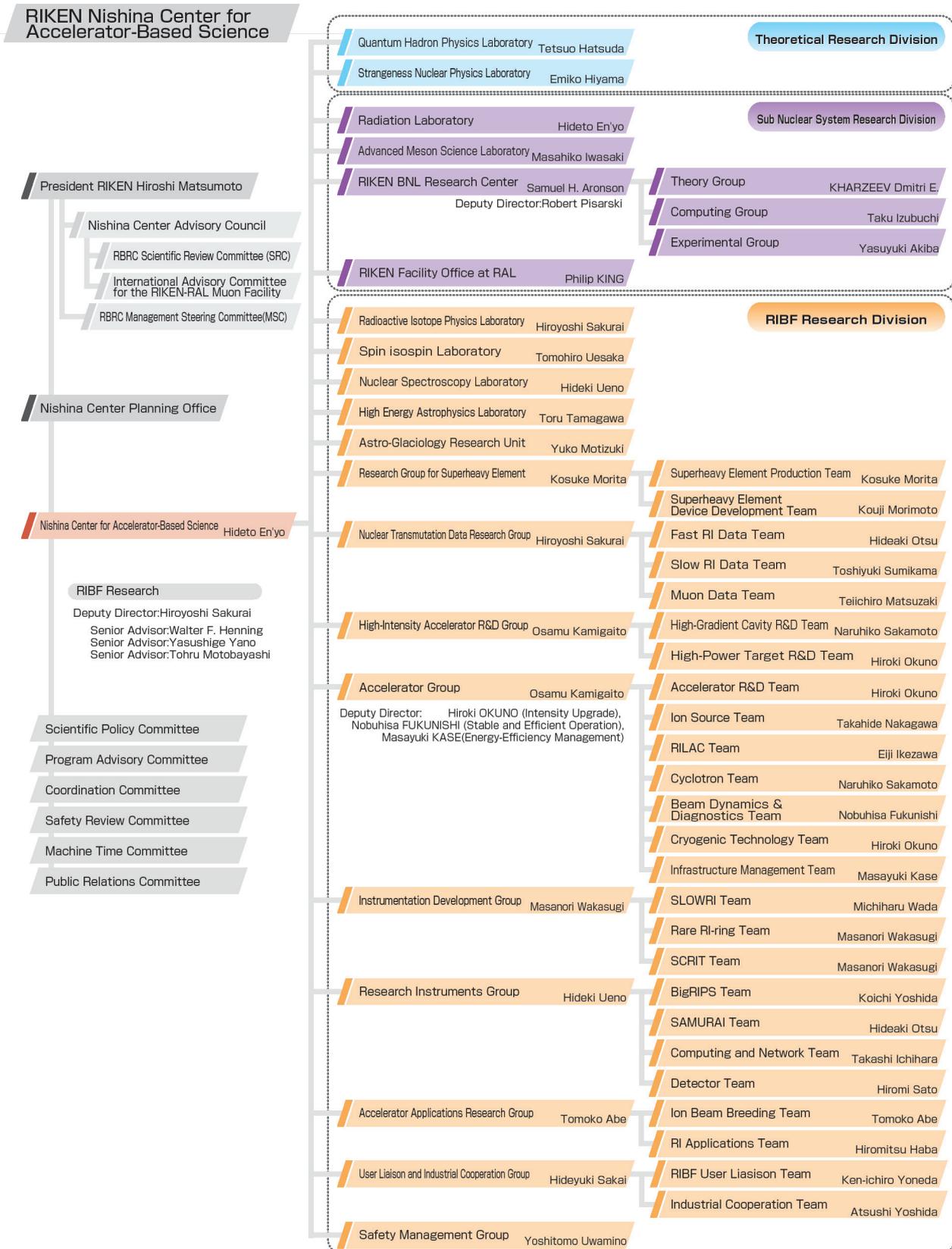


1. Organization

1.1 Organization Chart as of March 31, 2017 (End of FY2016)



1.2 Topics in FY2016

In fiscal year 2016, the International Union of Pure and Applied Chemistry (IUPAC) officially approved the name (nihonium) and chemical symbol (Nh) proposed earlier this year for element 113 by a research group led by Group Director Kosuke Morita, Research Group for Superheavy Element. A ceremony to commemorate the naming of element 113 as “nihonium” was held at the Japan Academy in Tokyo on March 14, 2017, with His Imperial Highness the Crown Prince in attendance.

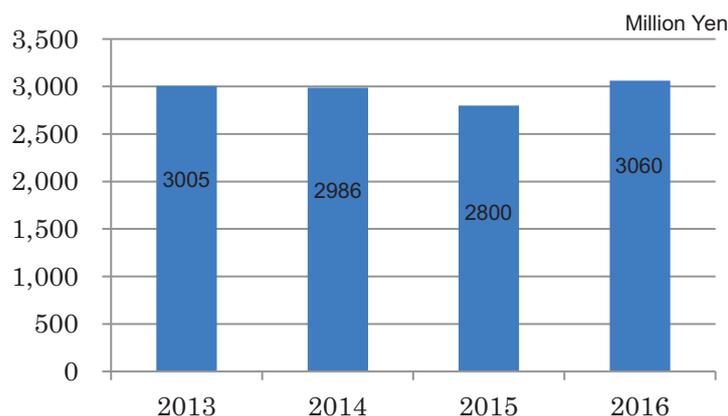
Five months operation was achieved as had been planned at the beginning of FY2016. The number of RIBF users from home and abroad was the highest ever. RIBF utilization rate exceeding 70% has been maintained.

A key development in accelerator technology was achieved by the Accelerator Group, whereby the use of new “graphene” carbon foils has enabled RIBF to reach an unprecedented, worldwide record in the intensity of 50 pA for a 238U beam.

Year	Date	Topics in Management
2016	Apr. 1	New appointment Director of Research Instruments Group: Hideki UENO
	Sep. 1	New appointment Team Leader of Slow RI Data Team: Toshiyuki SUMIKAMA
	Oct. 31	Step down from the position of Deputy Director of RNC: Tetsuo HATSUDA
	Dec. 5	Final Report of the former Associate Chief Scientist, Takashi NAKATSUKASA
2017	Jan. 30	Research Review of the Chief Scientist, Tetsuo HATSUDA

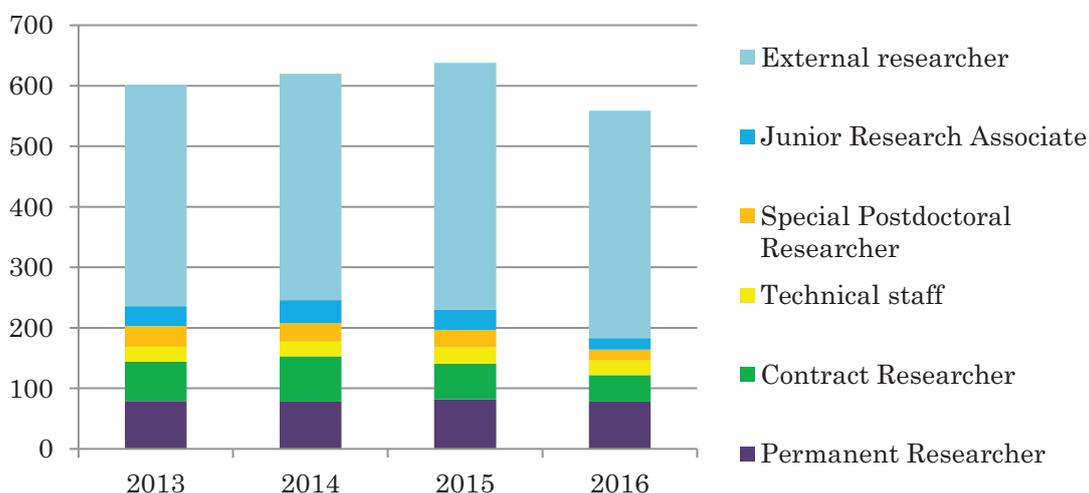
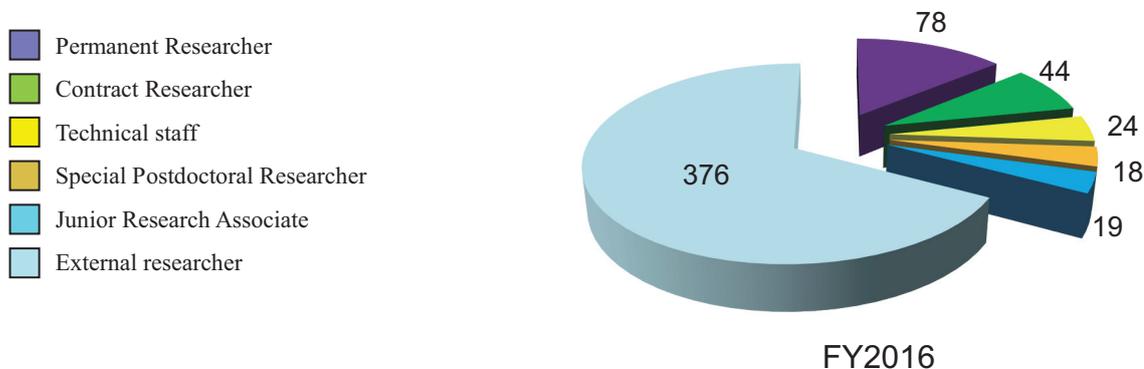
2. Finances

As mentioned in “1.2 Administrative Topic in FY2016”, RNC executed five months of RIBF operation. A transition of the RNC budget for the past four years is shown in following graph.



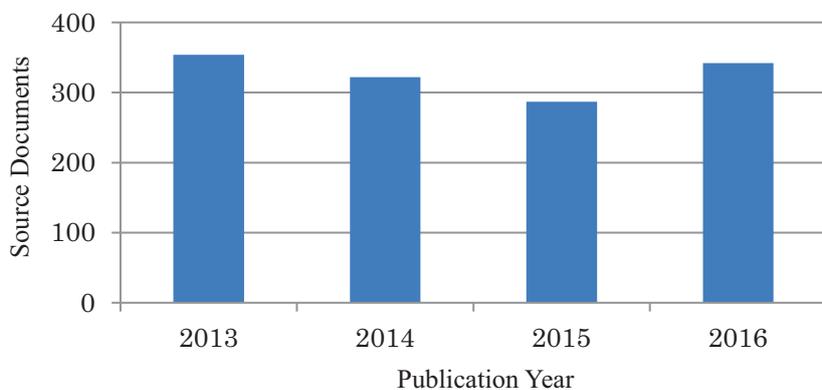
3. Staffing

At the start of FY 2016, there were 187 personnel affiliated with RNC and 376 researchers visiting RNC for research purpose. The following graphs show a breakdown of personnel into six categories as of April 1, 2016, and a transition of the number of each category.



4. Research publication

The number of papers published annually from RNC is shown graphically using the data obtained from Thomson Reuters' Web of Science Documents.



Citation analysis for the past four years

As of April 29, 2017

Indicators \ Year	2013	2014	2015	2016
Total number of papers	354	322	287	342
Total number of citations	4126	3190	1710	687
Number of papers in top 10%	59	62	50	40
Percentage of papers in top 10%	16.7	19.3	17.4	12.2
Number of papers in top 1%	8	5	3	3
Percentage of papers in top 1%	2.26	1.55	1.05	0.91

5. Management

Headed by the RNC Director Hideto En'yo, the RIKEN Nishina Center for Accelerator-Based Science (RNC) consists of:

- 8 Laboratories
- 1 Research unit
- 9 Groups with 25 Teams
- 2 overseas research center with 3 Groups

as of the latter half of FY2016. There are also three 'Partner Institutes' which conduct research in the laboratories set up in RNC.

RNC is managed by its Director who takes into consideration the majority decision of the RNC Coordination Committee. The Nishina Center Planning Office under the auspices of President of RIKEN is responsible for administrative matters of RNC.

The management of RNC is supported by the following committees:

- Scientific Policy Committee
- Program Advisory Committee
- Safety Review Committee
- RIBF Machine Time Committee
- Public Relations Committee

There are also committees to support the President of RIKEN and/or the Director of RNC such as:

- Nishina Center Advisory Council with two subcommittees
 - RBRC Scientific Review Committee (SRC) and
 - International Advisory Committee for the RIKEN-RAL Muon Facility
- RBRC Management Steering Committee (MSC)

Nishina Center for Accelerator-based Science

Executive Members (as of March 31, 2017)

Hideto EN'YO	Director RNC; Chief Scientist, Director of Radiation Laboratory
Hiroyoshi SAKURAI	Deputy Director (RIBF Research), RNC; Chief Scientist, Director of Radioactive Isotope Physics Laboratory; Group Director, Nuclear Transmutation Data Research Group
Walter F. HENNING	Senior Advisor
Yasushige YANO	Senior Advisor
Tohru MOTOBAYASHI	Senior Advisor
Minami IMANISHI	Assistant

RNC Coordination Committee

The following subjects relevant to the RNC management are deliberated under the chairmanship of the RNC Director:

- Establishment of the new organization or reorganization in RNC
- Personnel management of RNC researchers
- Research themes and research budget
- Approval of the Partner Institutes
- Evaluation of the management of RNC and the response to the recommendations by external evaluation

The RNC Coordination Committee is held monthly.

Members (as of March 31, 2017)

Hidetō EN'YO	Director, RNC; Chief Scientist, Radiation Laboratory
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Radioactive Isotope Physics Laboratory; Group Director, Nuclear Transmutation Data Research Group
Walter F. HENNING	Senior Advisor, RNC
Yasushige YANO	Senior Advisor, RNC
Tohru MOTOBAYASHI	Senior Advisor, RNC
Tetsuo HATSUDA	Chief Scientist, Quantum Hadron Physics Laboratory
Masahiko IWASAKI	Chief Scientist, Advanced Meson Science Laboratory
Tomohiro UESAKA	Chief Scientist, Spin isospin Laboratory
Hideki UENO	Chief Scientist, Nuclear Spectroscopy Laboratory; Group Director, Research Instruments Group
Toru TAMAGAWA	Associate Chief Scientist, High Energy Astrophysics Laboratory
Emiko HIYAMA	Associate Chief Scientist, Strangeness Nuclear Physics Laboratory
Kosuke MORITA	Group Director, Research Group for Superheavy Element; Team Leader, Superheavy Element Production Team
Osamu KAMIGAITO	Group Director, Accelerator Group; Group Director, High-Intensity Accelerator R&D Group
Hideyuki SAKAI	Group Director, User Liaison and Industrial Cooperation Group
Hiroki OKUNO	Deputy Group Director, Accelerator Group; Team Leader, Accelerator R&D Team; Team Leader, Cryogenic Technology Team; Team Leader, High-Power Target R&D Team
Nobuhisa FUKUNISHI	Deputy Group Director, Accelerator Group; Team Leader, Beam Dynamics & Diagnostics Team
Masayuki KASE	Deputy Group Director, Accelerator Group; Team Leader, Infrastructure Management Team
Tomoko ABE	Group Director, Accelerator Applications Research Group; Team Leader, Ion Beam Breeding Team
Yoshitomo UWAMINO	Group Director, Safety Management Group
Toshiyuki KUBO	Group Director, Research Instruments Group; Team Leader, Detector Team
Masanori WAKASUGI	Group Director, Instrumentation Development Group; Team Leader, Rare RI-ring Team; Team Leader, SCRIT Team
Eiji IKEZAWA	Team Leader, RILAC Team
Takashi ICHIHARA	Team Leader, Computing and Network Team; Vice Chief Scientist, Radioactive Isotope Physics Laboratory
Hideaki OTSU	Team Leader, SAMURAI Team; Team Leader, Fast RI Data Team
Naruhiko SAKAMOTO	Team Leader, Cyclotron Team; Team Leader, High-Gradient Cavity R&D Team
Hiromi SATO	Team Leader, Detector Team
Toshiyuki SUMIKAMA	Team Leader, Slow RI Data Team
Takahide NAKAGAWA	Team Leader, Ion Source Team
Hiromitsu HABA	Team Leader, RI Applications Team
Teiichiro MATSUZAKI	Team Leader, Muon Data Team
Koji MORIMOTO	Team Leader, Superheavy Element Device Development Team
Atsushi YOSHIDA	Team Leader, Industrial Cooperation Team
Koichi YOSHIDA	Team Leader, BigRIPS Team
Ken-ichiro YONEDA	Team Leader, RIBF User Liaison Team
Michiharu WADA	Team Leader, SLOWRI Team
Yasuyuki AKIBA	Vice Chief Scientist, Radiation Laboratory; Group Leader, Experimental Group, RIKEN BNL Research Center
Katsuhiko ISHIDA	Vice Chief Scientist, Advanced Meson Science Laboratory
Tsukasa TADA	Vice Chief Scientist, Quantum Hadron Physics Laboratory
Yuko MOTIZUKI	Research Unit Leader, Astro-Glaciology Research Unit
Kanenobu TANAKA	Deputy Group Director, Safety Management Group
Yasushi WATANABE	Deputy Team Leader, RIBF User Liaison Team
Noriko SHIOMITSU	Director, Nishina Center Planning Office

Nishina Center Planning Office

The Nishina Center Planning Office is responsible for the following issues:

- Planning and coordination of RNC's research program and system
- Planning and management of RNC's use of budget
- Public relations activities

Members (as of March 31, 2017)

Noriko SHIOMITSU	Director, Nishina Center Planning Office
Kazunori MABUCHI	Manager, Nishina Center Planning Office; Administration Manager, RBRC; Administration Manager, RIKEN Facility Office at RAL
Keiko IWANO	Deputy Manager, Nishina Center Planning Office
Yasutaka AKAI	Chief, Nishina Center Planning Office; Deputy Administration Manager, RBRC
Yukari ONISHI	Chief, Nishina Center Planning Office
Kumiko SUGITA	Special Administrative Employee
Yuko OKADA	Task-Specific Employee
Aiko KAWAMURA	Task-Specific Employee
Masatoshi MORIYAMA	Consultant
Rie KUWANA	Temporary Staff

Scientific Policy Committee

The Scientific Policy Committee deliberates on the following issues:

- Research measures and policies of RNC
- Administration of research facilities under RNC's management

The Committee members are selected among professionals within and outside RNC. The members were not chosen nor the Committee held in FY2016.

Program Advisory Committee

The Program Advisory Committee reviews experimental proposals submitted by researchers and reports the approval/disapproval of the proposals to the RNC Director. The Committee also reports to the RNC Director the available days of operation at RIBF or the Muon Facility at RAL allocated to researchers.

The Committee is divided into three categories according to the research field.

- (1) Nuclear Physics Experiments at RIBF (NP-PAC): academic research in nuclear physics
- (2) Materials and Life Science Researches at RNC (ML-PAC): academic research in materials science and life science
- (3) Industrial Program Advisory Committee (In-PAC): non-academic research

Program Advisory Committee for Nuclear Physics Experiments at RI Beam Factory (NP-PAC)

The 17th NP-PAC was held on December 1-3, 2016 at RIBF.

Members (as of March 31, 2017)

Bradley. M.SHERRILL (Chair)	Prof., Director, Michigan State University
Andrei ANDREYEV	Prof., The University of York
Angela BRACCO	Prof., The Istituto Nazionale di Fisica Nucleare
Ikuko Hamamoto	Prof. Emeritus, The Lund University, Senior Visiting Scientist, RNC
Hironori Iwasaki	Associate Prof., Michigan State University
Walter D. LOVELAND	Prof., Oregon State University
Satoshi Nakamura	Prof., Tohoku University
Thomas NILSSON	Prof., Chalmers University of Technology
Kazuyuki Ogata	Associate Prof., Osaka University
Thomas Rauscher	University of Basel
Haik Simon	GSI
Olivier Sorlin	GANIL(Grand Accélérateur National d'Ions Lourds)
Atsushi TAMII	Associate Prof., Osaka University
Yutaka UTSUNO	Senior Scientist, JAEA
Piet Van Duppen	Prof., University of Leuven (K.U.Leuven)
Yuhu Zhang	Institute of Modern Physics, Chinese Academy of Sciences

Program Advisory Committee for Materials and Life Science Researches at RIKEN Nishina Center (ML-PAC)

The 13th ML-PAC was held on January 19-20, 2017 at RIBF.

Members (as of March 31, 2017)

Adrian HILLIER (Chair)	ISIS, RAL
Toshiyuki AZUMA	Chief Scientist, RIKEN
Ryosuke KADONO	Prof., Institute of Materials Structure Science, KEK
Atsushi KAWAMOTO	Prof., Hokkaido University
Norimichi KOJIMA	Full Time Research Fellow, Toyota Physical and Chemical Research Institute
Kenya KUBO	Prof., International Christian University
Philippe MENDELS	Prof., Université Paris-SUD
Atsushi SHINOHARA	Prof., Osaka University
Shukri SULAIMAN	Prof., Universiti Sains Malaysia
Hiroyuki YAMASE	Senior Researcher, National Institute for Materials Science
Shigeo YOSHIDA	Research Consultant, RIKEN
Xu-Guang ZHENG	Prof., Saga University

Industrial Program Advisory Committee (In-PAC)

The 6th In-PAC was held on January 13, 2017 at RNC.

Members (as of March 31, 2017)

Akihiro IWASE (Chair)	Prof., Osaka Prefecture University
Toshiyuki AZUMA	Chief Scientist, RIKEN
Kenya KUBO	Prof., International Christian University
Hitoshi NAKAGAWA	Central Research Laboratory, Hamamatsu Photonics K.K.
Nobuhiko NISHIDA	Full Time Research fellow, Toyota Physical and Chemical Research Institute
Toshinori MITSUMOTO	Chief Engineer, Sumitomo Heavy Industries, Ltd

Safety Review Committee

The Safety Review Committee is composed of two sub committees, the Safety Review Committee for Accelerator Experiments and the Hot-Lab Safety Review Committee. These Committees review the safety regarding the usage of radiation generating equipment based on the proposal submitted to the RNC Director from the spokesperson of the approved experiment.

Safety Review Committee for Accelerator Experiments

Members (as of March 31, 2017)

Hiromi SATO (Chair)	Team Leader, Detector Team
Kouji MORIMOTO	Team Leader, Superheavy Element Device Development Team
Eiji IKEZAWA	Team Leader, RILAC Team
Hirimitsu HABA	Team Leader, RI Applications Team
Shinichiro MICHIMASA	Assistant Prof., Center for Nuclear Study, University of Tokyo
Hidetoshi YAMAGUCHI	Lecturer, Center for Nuclear Study, University of Tokyo
Hiroshi WATANABE	Lecturer, Radioactive Nuclear Beam Group, IPNS, KEK
Atsushi YOSHIDA	Team Leader, Industrial Cooperation Team
Koichi YOSHIDA	Team Leader, BigRIPS Team
Naoki FUKUDA	Nishina Center Research Scientist, BigRIPS Team
Naruhiko SAKAMOTO	Team Leader, Cyclotron Team
Daisuke SUZUKI	Research Scientist, Radioactive Isotope Physics Laboratory
Juzo ZENIHIRO	Research Scientist, Spin Isospin Laboratory
Yuichi ICHIKAWA	Research Scientist, Nuclear Spectroscopy Laboratory
Ex officio members	
Yoshitomo UWAMINO	Group Director, Safety Management Group
Kanenobu TANAKA	Deputy Group Director, Management Group
Hisao SAKAMOTO	Nishina Center Technical Scientist, Safety Management Group

Hot-Lab Safety Review Committee

Members (as of March 31, 2017)

Masako IZUMI (Chair)	Senior Research Scientist, Radiation Biology Team
Yoshitomo UWAMINO	Group Director, Safety Management Group
Hisao SAKAMOTO	Nishina Center Technical Scientist, Safety Management Group
Hiroki MUKAI	Assigned Employee, Safety Management Group
Kanenobu TANAKA	Deputy Group Director, Safety Management Group
Hirimitsu HABA	Team Leader, RI Applications Team

RIBF Machine Time Committee

Upon request of the RNC Director, the RIBF Machine Time Committee deliberates on the machine time schedule of RIBF, and reports the results to him.

Members (as of March 31, 2017)

Hideyuki SAKAI (Chair)	Group Director, User Liaison and Industrial Cooperation Group
Tomoko ABE	Group Director, Accelerator Applications Research Group; Team Leader, Ion Beam Breeding Team
Nobuhisa FUKUNISHI	Deputy Group Director, Accelerator Group; Team Leader, Beam Dynamics & Diagnostics Team
Osamu KAMIGAITO	Group Director, Accelerator Group; Group Director, High-Intensity Accelerator R&D Group
Masayuki KASE	Deputy Group Director, Accelerator Group
Kouji MORIMOTO	Team Leader, Superheavy Element Research Device Development Team
Hiroki OKUNO	Deputy Group Director, Accelerator Group; Team Leader, Accelerator R&D Team; Team Leader, Cryogenic Technology Team; Team Leader, High-Power Target R&D Team
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Radioactive Isotope Physics Laboratory; Group Director, Nuclear Transmutation Data Research Group
Hideki UENO	Chief Scientist, Nuclear Spectroscopy Laboratory; Group Director, Research Instruments Group
Tomohiro UESAKA	Chief Scientist, Spin Isospin Laboratory
Yoshitomo UWAMINO	Group Director, Safety Management Group
Masanori WAKASUGI	Group Director, Instrumentation Development Group; Team Leader, Rare RI-ring Team; Team Leader, SCRIT Team
Ken-ichiro YONEDA	Team Leader, RIBF User Liaison Team
External members	
Susumu SHIMOURA	Professor, Center for Nuclear Study, University of Tokyo
Hidetoshi YAMAGUCHI	Lecturer, Center for Nuclear Study, University of Tokyo
Hiroari MIYATAKE	Professor, Radioactive Nuclear Beam Group, IPNS, KEK

Observers

Hideto EN'YO	Director, RNC; Chief Scientist, Radiation Laboratory
Nobuaki IMAI	Chair, RIBF-UEC, Associate Prof. Center for Nuclear Study, University of Tokyo
Hiroimitsu HABA	Team Leader, RI Applications Team
Kosuke MORITA	Group Director, Research Group for Superheavy Element; Team Leader, Superheavy Element Production Team
Tohru MOTOBAYASHI	Senior Advisor, RNC
Koichi YOSHIDA	Team Leader, BigRIPS Team
Kanenobu TANAKA	Deputy Group Director, Safety Management Group
Hideaki OTSU	Team Leader, Fast RI Data Team
Kazunori MABUCHI	Manager, Nishina Center Planning Office

Public Relations Committee

Upon request of the RNC Director, the Public Relations Committee deliberates and coordinates the following matters:

- (1) Creating public relations system for RNC
- (2) Prioritization of the public relations activities for RNC
- (3) Other general and important matters concerning the public relations of RNC

Members (as of March 31, 2017)

Noriko SHIOMITSU (Chair)	Director, Nishina Center Planning Office
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Radioactive Isotope Physics Laboratory; Group Director, Nuclear Transmutation Data Research Group
Tetsuo HATSUDA	Deputy Director, RNC; Chief Scientist, Quantum Hadron Physics Laboratory
Tohru MOTOBAYASHI	Senior Advisor
Walter F. HENNING	Senior Advisor
Yasushige YANO	Senior Advisor
Masahiko IWASAKI	Chief Scientist, Advanced Meson Science Laboratory
Tomohiro UESAKA	Chief Scientist, Spin isospin Laboratory
Hideki UENO	Chief Scientist, Nuclear Spectroscopy Laboratory; Group Director, Research Instruments Group
Toru TAMAGAWA	Associate Chief Scientist, High Energy Astrophysics Laboratory
Emiko HIYAMA	Associate Chief Scientist, Strangeness Nuclear Physics Laboratory
Kosuke MORITA	Group Director, Research Group for Superheavy Element; Team Leader, Superheavy Element Production Team
Osamu KAMIGAITO	Group Director, Accelerator Group; Group Director, High-Intensity Accelerator R&D Group
Hideyuki SAKAI	Group Director, User Liaison and Industrial Cooperation Group

RBRC Management Steering Committee (MSC)

RBRC MSC is set up according to the Memorandum of Understanding between RIKEN and BNL concerning the collaboration on the Spin Physics Program at the Relativistic Heavy Ion Collider (RHIC). The 22nd MSC was held on June 3, 2016 at Brookhaven National Laboratory.

Members (as of March 31, 2017)

Yoichiro MATSUMOTO	Executive Director, RIKEN
Shoji NAGAMIYA	Science Advisor, RIKEN
Hideto EN'YO	Director, RNC
David LISSAUER	Deputy Chair, Physics Department, BNL
Berndt MUELLER	Associate Laboratory Director for Nuclear and Particle Physics, BNL
Satoshi OZAKI	Senior Advisor, BNL

Nishina Center Advisory Council (NCAC)

NCAC 2016 is the 4th AC meeting since the establishment of RNC which promotes RIKEN's accelerator based science including the RIKEN BNL Research Center and the RIKEN-RAL Muon Facility. NCAC has two sub-councils for the RBRC and the RAL Muon Facility respectively. The 1st NCAC was held in January, 2009. The 2nd NCAC was held in May, 2011. The 3rd NCAC was held in July, 2014.

The mission of NCAC 2016 is set by the Terms of Reference presented by President Matsumoto based on the Initiative for Scientific Excellence and the fundamental issues about research activities and research administration. NCAC submits its report to the President Matsumoto, and to the RNC Director if necessary.

The members of NCAC are recommended by the RNC Director to the President of RIKEN from among highly knowledgeable individuals and experts worldwide.

Members (as of March 31, 2017)

Sydney GALES (Chair)	Scientific Director, Research IPN Orsay CNRS, Scientific Director, ELI-N
Robert V.F. JANSSENS	Division Director, Argonne National Laboratory (ANL)
Jochen WAMBACH	Director, ECT*
Witold NAZAREWICZ	Prof., Michigan State University
Kinichi IMAI	Prof. Emeritus, Kyoto University
Richard G. MILNER	Prof., MIT
Angella BRACCO	Prof., The Istituto Nazionale di Fisica Nucleare
Reiner KRÜCKEN	Deputy Director, TRIUMF
Hirokazu TAMURA	Prof., Tohoku University
Tokushi SHIBATA	Adviser, Chiyoda Technol Corporation, Oarai Research Laboratory
Elvezio MORENYONI	Prof., Paul Scherrer Institut
Yoshitaka ITOW	Prof., Nagoya University
Lia MERMINGA	Accelerator Directorate, SLAC National Accelerator Laboratory
Akira YAMAMOTO	Prof. Emeritus, High Energy Accelerator Research Organization, KEK
Hidenori TAKAGI	Prof., Max-Planck Institute for Solid State Research

RBRC Scientific Review Committee (SRC)

Members (as of March 31, 2017)

Richard MILNER (Chair)	Prof., MIT
Shinya AOKI	Prof., Yukawa Institute for Theoretical Physics, Kyoto University
Alfred MUELLER	Prof., Columbia University
Albert De ROECK	Prof., CERN
Xiandong JI	Prof., University of Maryland
Julia VELKOVSKA	Prof., Vanderbilt University

International Advisory Committee for the RIKEN-RAL Muon Facility (RAL-IAC)

Members (as of March 31, 2017)

Andrew D TAYLOR (Chair)	Executive Director, STFC National Laboratories
Jean-Michel POUTISSOU	Senior research scientist Emeritus, TRIUMF
Klaus P. JUNGMANN	Prof., University of Groningen
Roberto De RENZI	Prof., University of Parma
Yasuyuki MATSUDA	Assoc. Prof., the University of Tokyo
Jun SUGIYAMA	Principal Research Scientist, Toyota Central R&D Labs., INC

6. International Collaboration

Country	Partner Institute	Objects	RNC contact person
Austria	Stefan Meyer Institute for Subatomic Physics	Experimental and theoretical hadron physics, especially in exotic hadronic atoms and meson and baryon nuclear bound states	Masahiko IWASAKI, Chief Scientist, Director of Advanced Meson Science Laboratory
China	China Nuclear Physics Society	Creation of the council for China -Japan research collaboration on nuclear physics	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Peking University	Nuclear Science	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Institute of Modern Physics, Chinese Academy of Science	Physics of heavy ions	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	School of Nuclear Science and Technology, Lanzhou University	Framework	Yue MA, Advanced Meson Science Laboratory
	School of Physics, Nanjing University	Framework	Emiko HIYAMA, Associate chief scientist, Strangeness Nuclear Physics Laboratory
	Department of Physics, Faculty of Science, The Univ. of Hong Kong	Experimental and educational research collaboration in the area of experimental nuclear physics	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	School of physics, Nankai University	Framework	
Finland	University of Jyväskylä	Basic nuclear physics and related instrumentation	Michiharu WADA, Team Leader, SLOWRI Team

Country	Partner Institute	Objects	RNC contact person
France	National Institute of Nuclear Physics and Particle Physics (IN2P3)	Physics of heavy ions	Tohru MOTOBAYASHI, RIBF synergetic-use coordinator
	CNRS, CEA, GANIL, Université Paris Sud, etc.	Creation of an International Associated Laboratory (LIA) French-Japanese International Associated Laboratory for Nuclear Structure Problems	Tohru MOTOBAYASHI, RIBF synergetic-use coordinator
	CEA-DSM	The use of MINOS device at RIKEN	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	SIMEM Graduate School, Department of Physics, Caen University	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	Centre National de la Recherche Scientifique (CSRS) Commissariat A L'Energie Atomique Et Aux Energies Alternatives (CEA)	Research Collaboration in EXPAND (Exploration Across the Neutron Dripline) project	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
Germany	Technische Universität München	Nuclear physics, hadron physics, nuclear astrophysics	Emiko HIYAMA, Associate chief scientist, Strangeness Nuclear Physics Laboratory
	GSI	Physics of heavy ions and accelerator	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	GSI and Reactions with Relativistic Radioactive Beam Collaboration (R3B)	The use of NeuLAND device at RIBF	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory
	Department of Physics, Technische Universität Darmstadt	Framework	Emiko Hiyama, Associate chief scientist, Strangeness Nuclear Physics Laboratory
	European Gamma-Ray Spectroscopy Pool Owners Committee	The use of Euroball detector at RIKEN	Shunji NISHIMURA, Radioactive Isotope Physics Laboratory
Hungary	The Institute of Nuclear Research of the Hungarian Academy of Sciences (ATOMKI)	Nuclear physics, Atomic Physics	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
Indonesia	ITB, UNPAD, ITS, UGM, UI	Material science using muons at the RIKEN-RAL muon facility	Isao WATANABE, Advanced Meson Science Laboratory
	Universitas Hasanuddin	Agricultural science and related fields involving heavy-ion beam mutagenesis using Indonesian crops	Tomoko ABE, Group Director, Accelerator Applications Research Group
Italy	Applied Physics Division, National Institute for New Technologies, Energy and Environment (ENEA)	Framework	Tohru MOTOBAYASHI, RIBF synergetic-use coordinator
	European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*)	Theoretical physics	Tetsuo HATSUDA, Deputy Director, Chief Scientist, Quantum Hadron Physics Laboratory
Korea	Seoul National University	Nishina School	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Institute of Basic Science, Rare Isotope Science Project	Rare ion accelerator and related fields	Hiroyoshi SAKURAI, Shunji NISHIMURA
	Department of Physics, Kyungpook National University	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	College of Science, Yonsei University	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	Department of Physics, Korea University	Framework	Yuji GOTO, Radiation Laboratory
	College of Natural Science, Ewha Women's University	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	College of Natural Sciences, INHA Univ.	Framework	Emiko Hiyama, Associate chief scientist, Strangeness Nuclear Physics Laboratory
Malaysia	Universiti Sains Malaysia	Muon Science	Isao WATANABE, Advanced Meson Science Laboratory
Poland	the Henryk Niewodniczanski Institute of Nuclear Physics, Polish Academy of Sciences (IFJ PAN)	Framework	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
Romania	"Horia Hulubei" National Institute of Physics and Nuclear Engineering Bucharest-Magurele, Romania	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
Russia	Joint Institute for Nuclear Research (JINR)	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	Russian Research Center "Kurchatov Institute"	Framework	Hiroyoshi SAKURAI, Tomohiro UESAKA, Osamu KAMIGAITO, Masanori WAKASUGI
Switzerland	Paul Scherrer Institute	Improve the performance and reliability of accelerator systems	Osamu KAMIGAITO, Director, Chief Scientist, Accelerator Group
	CERN	RD-51: R&D programme for micro-pattern gas detectors (MPGD)	Satoshi YOKKAICHI, Senior Research Scientist, Radiation Laboratory
	CERN	Collaboration in the ALICE Experiment as an Associate Member	Satoshi YOKKAICHI, Senior Research Scientist, Radiation Laboratory
UK	The Science and Technology Facilities Council	Muon science using the ISIS Facility at the Rutherford Appleton Laboratory	Philip KING, Director of RIKEN-RAL muon facility
	University of Surrey	Theoretical physics	Tetsuo HATSUDA, Deputy Director, Chief Scientist, Quantum Hadron Physics Laboratory

Country	Partner Institute	Objects	RNC contact person
USA	BNL	The Spin Physics Program at the Relativistic Heavy Ion Collider(RHIC)	Hideto EN'YO, Director of RNC
	Columbia University	The development of QCDCQ	Taku IZUBUCHI, Group Leader, Computing Group, RBRC
	Michigan State University	Comprehensive The use of TPC(Time Projection Chamber)	Tomohiro Uesaka, Chief Scientist, Spin Isospin Laboratory Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory & Tadaaki Isobe, Radioactive Isotope Physics Laboratory
Vietnam	Vietnam Atomic Energy Commission	Framework	Tohru MOTOBAYASHI, RIBF synergetic-use coordinator
	Institute of Physics, Vietnam Academy of Science and Technology	Framework	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory

7. Awards

Awardee, Laboratory / Team	Award	Organization	Date
Kosuke Morita, Group Director, Research Group for Superheavy Element	The Commendation for Science and Technology by the Minister of Education, Culture, Sports, Science and Technology for FY2016	Science and Technology by the Minister of Education, Culture, Sports, Science and Technology	Apr. 20
Kosuke Morita, Group Director, Research Group for Superheavy Element	The Japan Academy Prize	The Japan Academy	June 5
Tadashi Fujinawa, Research Consultant, Accelerator Group	The 12th PASJ Award for Significant Contributions	Particle Accelerator Society of Japan	Aug. 9
Yoshitaka Yamaguchi, Nishina Center Research Scientist, Rare RI-Ring Team	The 12th PASJ Award for Technical Contributions	Particle Accelerator Society of Japan	Aug. 9
Shinya Yanou, Technical Staff, RI Application Team	The Young Scientist Award	The Japan Society of Nuclear and Radiochemical Sciences	Sep. 12
Liang Haozhao, Research Scientist, Quantum Hadron Physics Laboratory	The International Union of Pure and Applied Physics (IUPAP) Young Scientist Prize 2016	International Union of Pure and Applied Physics (IUPAP)	Sep. 14
Kosuke Morita, Group Director, Research Group for Superheavy Element	The Oita Godo Shimbun Special Culture Award	The Oita Godo Shimbun	Nov. 13
Kosuke Morita, Group Director, Research Group for Superheavy Element	The Best Team of the Year 2016	The Best Team of the Year	Nov. 16
Yoshimasa Hidaka, Senior Research Scientist, Quantum Hadron Physics Laboratory	The 31st Nishinomiya-Yukawa Memorial Prize	Nishinomiya City	Dec. 3
Kosuke Morita, Group Director, Research Group for Superheavy Element	The 2016 Asahi Prize	The Asahi Shimbun Company	Jan. 30
Kosuke Morita, Group Director, Research Group for Superheavy Element	The Sai-no-Kuni Academic and Cultural Achievement Award	Saitama Prefecture	Jan. 31
Takahide Nakagawa, Team Leader, Ion Source Team	The 2016 Suwa Award	The Foundation for High Energy Accelerator Science	Feb. 14
Yuko Motizuki, Research Unit Leader, the Astro-Glaciology Research Unit	The 4th Toshiko Yuasa Prize	Ochanomizu University with the cooperation of the High Energy Accelerator Research Organization (KEK)	Feb. 24
Kosuke Morita, Group Director, Research Group for Superheavy Element	The Special Commendation for Outstanding Paper Award of the Physical Society of Japan	The Physical Society of Japan	Mar. 19

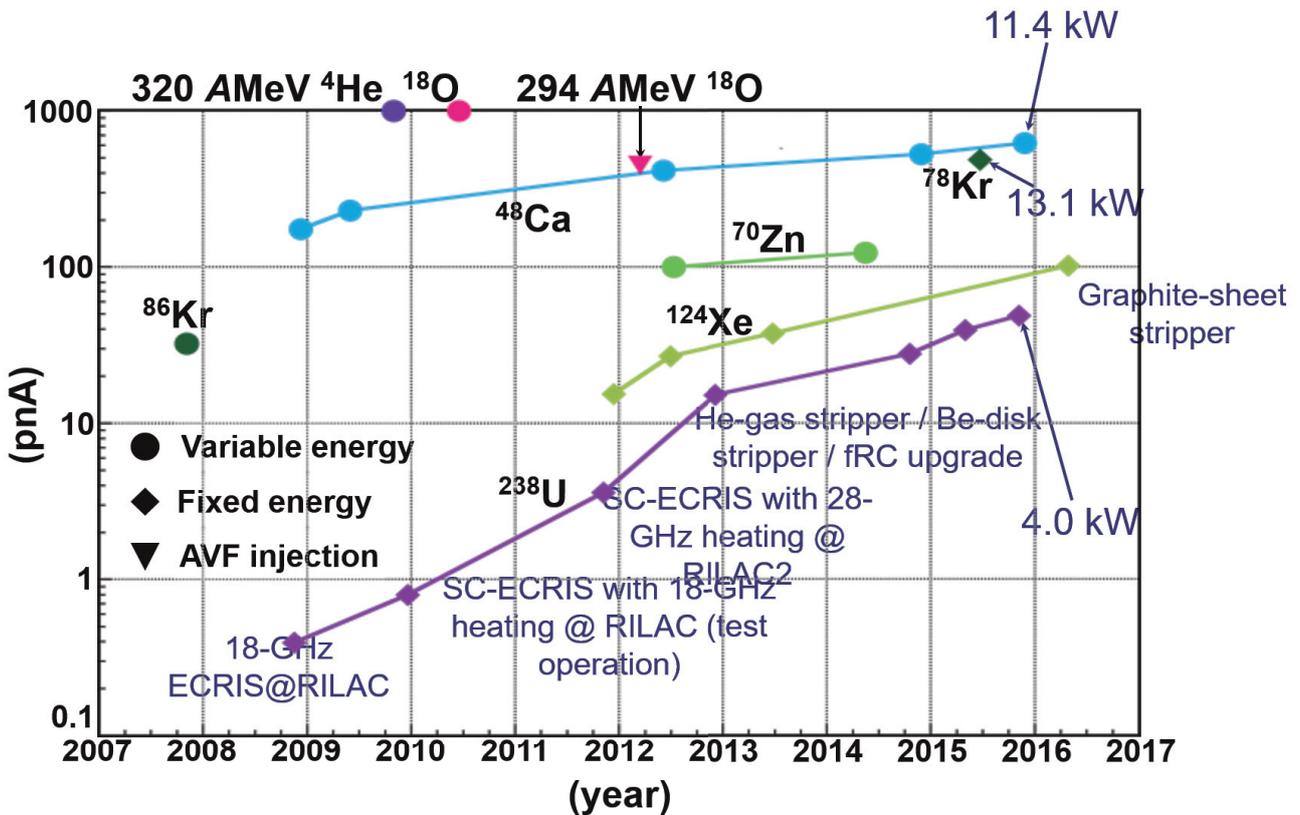
8. Brief overview of the RI Beam Factory

Intensity of Primary Beams

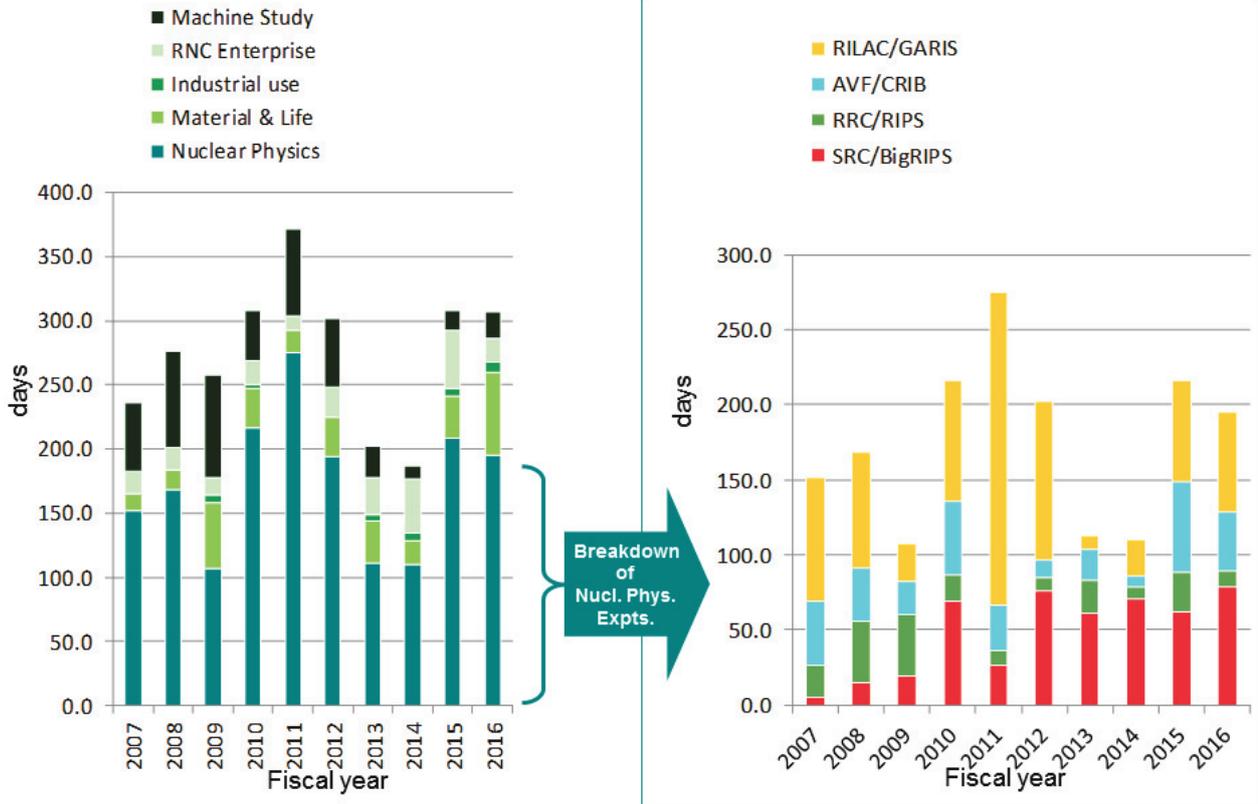
Achieved beam intensities (as of March 2017)

^{238}U	49 pnA (345 MeV/u, Oct. 2015)
^{124}Xe	102 pnA (345 MeV/u, Apr. 2016)
^{86}Kr	30 pnA (345 MeV/u, Nov. 2007)
^{78}Kr	486 pnA (345 MeV/u, May. 2015)
^{70}Zn	123 pnA (345 MeV/u, Jun. 2014)
^{48}Ca	730 pnA (345 MeV/u, Nov. 2016)
^{18}O	1000 pnA (345 MeV/u, Jun. 2010)
^{14}N	400 pnA (250 MeV/u, Oct. 2010)
^4He	1000 pnA (250 MeV/u, Oct. 2009)
d	1000 pnA (250 MeV/u, Oct. 2010)
pol. d	120 pnA, P~80% (250 MeV/u, May. 2015)

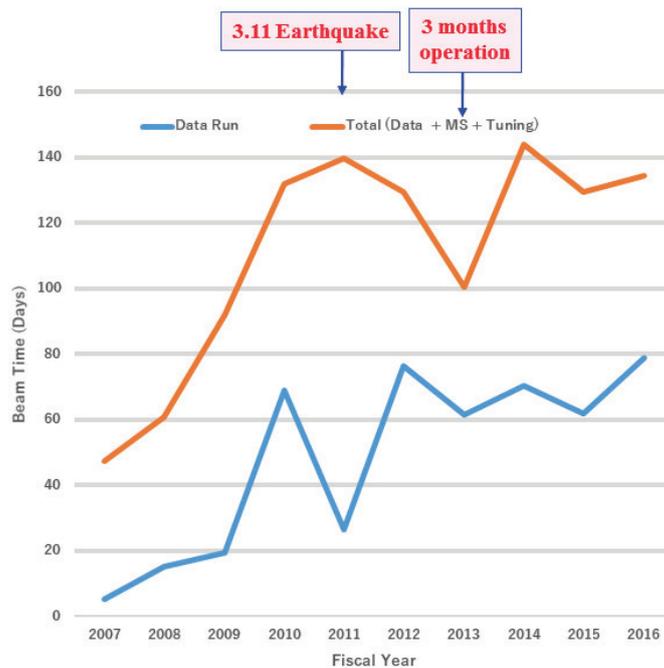
History of Beam Intensity Upgrade



Total beam time for experiments



Total beam time allocated to BigRIPS experiments



Theoretical Research Division Quantum Hadron Physics Laboratory

1. Abstract

Atomic nuclei are made of protons and neutrons bound by the exchange of pion and other mesons. Also, protons and neutrons are made of quarks bound by the exchange of gluons. These strong interactions are governed by the non-Abelian gauge theory called the quantum chromodynamics (QCD). On the basis of theoretical and numerical analyses of QCD, we study the interactions between the nucleons, properties of the dense quark matter realized at the center of neutron stars, and properties of the hot quark-gluon plasma realized in the early Universe. Strong correlations common in QCD and cold atoms are also studied theoretically to unravel the universal features of the strongly interacting many-body systems. Developing perturbative and non-perturbative techniques in quantum field theory and string theory are of great importance not only to solve gauge theories such as QED and QCD, but also to find the theories beyond the standard model of elementary particles. Various theoretical approaches along this line have been attempted.

2. Major Research Subjects

- (1) Perturbative and non-perturbative methods in quantum field theories
- (2) Theory of spontaneous symmetry breaking
- (3) Lattice gauge theory
- (4) QCD under extreme conditions
- (5) Nuclear and atomic many-body problems

3. Summary of Research Activity

(1) Perturbative and non-perturbative methods in quantum field theories

(1-1) 10th order QED calculation and the lepton anomalous magnetic moments

First preliminary value of the tenth-order QED contribution to the electron anomalous magnetic moment $a_e=(g-2)/2$ was reported by us in 2012. Since then, we have been improving and establishing its accuracy: We reevaluated the most difficult and large set of the Feynman diagrams by using advanced techniques of numerical calculation especially suitable to RIKEN's supercomputer. As a result, we have obtained precise values for the eighth- and tenth-order terms. Assuming the validity of the standard model, it leads to the world-best value of the fine-structure constant $\alpha^{-1}(a_e)=137.035\,999\,1570(29)(27)(18)(331)$, where uncertainties are from the eighth-order term, tenth-order term, hadronic and electroweak terms, and the experimental measurement of a_e . This is the most precise value of α available at present in the world and provides a stringent constraint on possible theories beyond the standard model.

(1-2) Picard–Lefschetz theory and the sign problem

Understanding strongly-correlated quantum field theories and many-body systems has been one of the ultimate goals in contemporary physics. Exact diagonalization of a Hamiltonian provides us with complete information on the system; however, it usually requires the huge computational cost and is limited to small systems. For large systems, numerical simulation on discretized spacetime lattice with quantum Monte Carlo method is a powerful ab initio tool based on the importance sampling. In many quantum systems of great interest, however, it suffers from the so-called sign problem; large cancellation occurs between positive and negative quantities to obtain physical signals, so that the computational time grows exponentially with the system size. So far, many attempts have been proposed overcome the sign problem, which include the two promising candidates, the complex Langevin method and the Lefschetz-thimble method. In particular, the Lefschetz-thimble approach is a generalization of the steepest descent method for multiple oscillatory integrals. In the past few years, we have studied extensively the mathematical basis of the Lefschetz-thimble method as well as its practical applications to quantum systems such as the real-time path integral for quantum tunneling, zero-dimensional bosonic and fermionic models, the one-site Hubbard model, and Polyakov-loop effective models for QCD. We have shown that the interference among multiple Lefschetz thimbles is important to reproduce the general non-analytic behavior of the observables as a function of the external parameter. Such an interference is a key to understand the sign problem of finite-density QCD.

(1-3) Functional renormalization group

- BEC-BCS crossover in cold fermionic atoms

We have developed a fermionic functional renormalization group (FRG) and applied this method to describe the superfluid phase transition of the two-component fermionic system with an attractive contact interaction. The connection between the fermionic FRG approach and the conventional Bardeen-Cooper-Schrieffer (BCS) theory with Gorkov and Melik-Barkhudarov (GMB) correction was clarified in the weak coupling region by using the renormalization group flow of the fermionic four-point vertex with particle-particle and particle-hole scatterings. To go beyond the BCS+GMB theory, coupled FRG flow equations of the fermion self-energy and the four-point vertex are studied under an Ansatz concerning their frequency/momentum dependence. We found that the fermion self-energy turns out to be substantial even in the weak coupling regime, and the frequency dependence of the four-point vertex is essential to obtain the correct asymptotic-ultraviolet behavior of the flow for the self-energy. The superfluid transition temperature and the associated chemical potential were evaluated in the region of negative scattering lengths.

- Tricritical point of the superconducting transition

The order of the phase transition in the Abelian Higgs model with complex scalar fields became of interest because of the analyses of the spontaneous symmetry breaking due to radiative corrections in 3+1 dimensions, and of a superconductor near the critical point with the dimensionally reduced Ginzburg-Landau theory. Indeed, the fluctuations of the gauge field were of great importance and may even turn the second-order transition to first-order at least for strongly type-I superconductors. We analyzed the order of the superconducting phase transition via the functional renormalization group approach: We derived for the first time fully analytic expressions for the β functions of the charge and the self-coupling in the Abelian Higgs model with N-component scalar field in $d = 3$ dimensions. The result supports the existence of two charged fixed-points: an infrared (IR) stable fixed point describing a second-order phase transition and a tricritical fixed

point controlling the region of the parameter space that is attracted by the former one. It was found that the region separating first and second-order transitions can be uniquely characterized by the critical Ginzburg-Landau parameter, $\kappa_c \approx 0.62/\sqrt{2}$ for $N=1$.

- **Chiral dynamics under strong magnetic field**

The magnetic field is not only interesting as a theoretical probe to the dynamics of QCD, but also important in cosmology and astrophysics: A class of neutron stars called magnetars has a strong surface magnetic field of order 10^{10} T while the primordial magnetic field in early Universe is estimated to be even as large as $\sim 10^{19}$ T. In non-central heavy-ion collisions at RHIC and LHC, a magnetic field of the strength $\sim 10^{15}$ T perpendicular to the reaction plane could be produced and can have impact on the thermodynamics and transport properties of the quark-gluon plasma. We investigated the quark-meson model in a magnetic field using the functional renormalization group equation beyond the local-potential approximation. We considered anisotropic wave function renormalization for mesons in the effective action, which allows us to investigate how the magnetic field distorts the propagation of neutral mesons. We found that the transverse velocity of mesons decreases with the magnetic field at all temperatures. Also, the constituent quark mass is found to increase with magnetic field, resulting in the crossover temperature that increases monotonically with the magnetic field.

(1-4) Emergent spacetime

In quantum field theories, symmetry plays an essential and exceptional role. Focusing on some proper symmetry and delving into its meaning have been proven to be one of the most fruitful strategies. A recent example is the $SO(2, 4)$ symmetry in AdS/CFT correspondence which leads to unexpected connection between gravity and gauge theory defined in different dimensions. We offer another example of quantum field theory where symmetry plays a central role and reveals interesting phenomena: Our focal point is the global conformal symmetry in two dimensional conformal field theory (2d CFT), which is homomorphic to $SL(2, R)$. We have shown that 2d CFT admits a novel quantization which we call dipolar quantization. Usually the study of the quantum field theory starts by defining the spacetime where the field is situated. On the other hand, in our case, we first obtain quantum system and then the nature of spacetime emerges. This is in accordance with the general ideas of emergent spacetime such as those discussed in matrix models.

(2) Theory of spontaneous symmetry breaking

(2-1) Dispersion relations of Nambu-Goldstone modes at finite temperature and density

We clarified the dispersion relations of Nambu-Goldstone (NG) modes associated with spontaneous breaking of internal symmetries at finite temperature and/or density. We showed that the dispersion relations of type-A and type-B NG modes are linear and quadratic in momentum, whose imaginary parts are quadratic and quartic, respectively. In both cases, the real parts of the dispersion relations are larger than the imaginary parts when the momentum is small, so that the NG modes can propagate for long distances. We derived the gap formula for NG modes in the presence of explicit symmetry breaking. We also discussed the gapped partners of type-B NG modes, when type-A and type-B NG modes coexist.

(2-2) Effective field theory for spacetime symmetry breaking

We studied the effective field theory for spacetime symmetry breaking from the local symmetry point of view. By gauging spacetime symmetries, the identification of Nambu-Goldstone (NG) fields and the construction of the effective action were performed based on the breaking pattern of diffeomorphism, local Lorentz, and isotropic Weyl symmetries as well as the internal symmetries including possible central extensions in nonrelativistic systems. Such a local picture provides a correct identification of the physical NG fields, while the standard coset construction based on global symmetry breaking does not. We also revisited the coset construction for spacetime symmetry breaking: Based on the relation between the Maurer-Cartan one-form and connections for spacetime symmetries, we classified the physical meanings of the inverse Higgs constraints by the coordinate dimension of broken symmetries. Inverse Higgs constraints for spacetime symmetries with a higher dimension remove the redundant NG fields, whereas those for dimensionless symmetries can be further classified by the local symmetry breaking pattern.

(2-3) Nambu-Goldstone modes in dissipative systems

Spontaneous symmetry breaking (SSB) in Hamiltonian systems is a universal and widely observed phenomena in nature, e.g., the electroweak and chiral symmetry breakings, superconductors, ferromagnets, solid crystals, and so on. It is also known that the SSB occurs even in dissipative systems such as reaction diffusion system and active matters. The translational symmetry in the reaction diffusion system is spontaneously broken by a spatial pattern formation such as the Turing pattern in biology. The rotational symmetry is spontaneously broken in the active hydrodynamics which describes collective motion of biological organisms. We found that there exist two types of NG modes in dissipative systems corresponding to type-A and type-B NG modes in Hamiltonian systems. By taking the $O(N)$ scalar model obeying a Fokker-Planck equation as an example, we have shown that the type-A NG modes in the dissipative system are diffusive modes, while they are propagating modes in Hamiltonian systems. We pointed out that this difference is caused by the existence of two types of Noether charges, Q^a_R and Q^a_A : Q^a_R are symmetry generators of Hamiltonian systems, which are not generally conserved in dissipative systems. Q^a_A are symmetry generators of dissipative systems described by the Fokker-Planck equation and are conserved. We found that the NG modes are propagating modes if Q^a_R are conserved, while those are diffusive modes if they are not conserved.

(3) Lattice gauge theory

(3-1) Hadron interactions from lattice QCD

One of the most important goals in nuclear physics is to determine baryon-baryon interactions directly from QCD. To achieve this goal, the HAL QCD Collaboration has been developing a novel lattice QCD formulation (HAL QCD method) and performing first-principles numerical simulations. We have calculated the spin-orbit forces for the first time from QCD by the HAL QCD method, and have observed the attraction in the 3P_2 channel related to the P-wave neutron superfluidity in neutron star cores. Our calculation of the N- Ω interaction shows that this system is bound in the 5S_2 channel. We have shown that the Ω - Ω interaction in the spin-singlet channel is in the unitary region where the scattering length becomes large. Three-nucleon forces have been calculated for several heavy quark masses. Our lattice calculations was extended to the heavy quark systems, e.g. the exotic tetraquark, T_{cc} and T_{cs} . Properties of the light and medium-heavy nuclei (^4He , ^{16}O , ^{40}Ca) have been calculated by combining the nuclear many-body techniques and the nuclear forces obtained from lattice QCD. Also, we have theoretically and numerically shown that the Luscher's method traditionally used in studying the hadron-hadron interactions does not lead to physical results for baryon-baryon interactions unless the lattice volume is unrealistically large, so that the HAL QCD method is the only reliable approach to link QCD to nuclear physics.

As a part of the High Performance Computing Infrastructure (HPCI) Project 5, we have completed the generation of (2+1)-flavor full QCD configurations with a large box, $V=(8 \text{ fm})^3$, and with nearly physical pion mass, 145MeV, on the 10Pflops super computer “K”. We are currently in the process of calculations of baryon-baryon interactions using these configurations.

(3-2) Momenta and Angular Momenta of Quarks and Gluons inside the Nucleon

Determining the quark and gluon contributions to the spin of the nucleon is one of the most challenging problems in QCD both experimentally and theoretically. Since the quark spin is found to be small ($\sim 25\%$ of the total proton spin) from the global analysis of deep inelastic scattering data, it is expected that the rest should come from the gluon spin and the orbital angular momenta of quarks and gluons. We made state-of-the-art calculations (with both connected and disconnected insertions) of the momenta and the angular momenta of quarks and gluons inside the proton. The u and d quark momentum/angular momentum fraction extrapolated to the physical point is found to be 0.64(5)/0.70(5), while the strange quark momentum/angular momentum fraction is 0.024(6)/0.023(7), and that of the gluon is 0.33(6)/0.28(8). This implies that the quark spin carries a fraction of 0.25(12) of the proton spin. Also, we found that the quark orbital angular momentum, which turned out to be dominated by the disconnected insertions, constitutes 0.47(13) of the proton spin.

(4) QCD under extreme conditions

(4-1) Production and Elliptic Flow of Dileptons and Photons in the semi-Quark Gluon Plasma

A notable property of peripheral heavy-ion collisions at RHIC and LHC is the elliptic flow which is a measure of the transfer of initial spatial anisotropy to momentum anisotropy. Both the PHENIX experiment at RHIC and the ALICE experiment at LHC have announced a puzzling observation; a large elliptic flow for photons, comparable to that of hadrons. We considered the thermal production of dileptons and photons at temperatures above the QCD critical temperature (T_c) on the basis of semi-QGP, a theoretical model for describing the quark-gluon plasma (QGP) near T_c . With realistic hydrodynamic simulations, we have shown that the strong suppression of photons in semi-QGP due to the inhibition of colored excitations tends to bias the elliptical flow of photons to that generated in the hadronic phase. This increases the total elliptic flow for thermal photons significantly towards the experimental data.

(4-2) Deriving relativistic hydrodynamics from quantum field theory

Hydrodynamics describes the spacetime evolution of conserved quantities, such the energy, the momentum, and the particle number. It does not depend on microscopic details of the system, so that it can be applied to many branches of physics from condensed matter to high-energy physics. One of the illuminating examples is the recent success of relativistic hydrodynamics in describing the evolution of QGP created in heavy-ion collisions. Inspired by the phenomenological success of relativistic hydrodynamics in describing QGP, theoretical derivations of the relativistic hydrodynamics have been attempted on the basis of the kinetic theory, the fluid/gravity correspondence, the non-equilibrium thermodynamics, and the projection operator method. In our study, a most microscopic and non-perturbative derivation of the relativistic hydrodynamics from quantum field theory was given on basis of the density operator with local Gibbs distribution at initial time. Performing the path-integral formulation of the local Gibbs distribution, we derived the generating functional for the non-dissipative hydrodynamics microscopically. Moreover, we formulated a procedure to evaluate dissipative corrections.

(4-3) Hadron-quark crossover in cold and hot neutron stars

We studied bulk properties of cold and hot neutron stars (NS) on the basis of the hadron-quark crossover picture where a smooth transition from the hadronic phase to the quark phase takes place at finite baryon density. By using a phenomenological equation of state (EOS) “CRover” which interpolates the two phases at around 3 times the nuclear matter density (ρ_0), it is found that the cold NSs with the gravitational mass larger than two solar mass can be sustained. This is in sharp contrast to the case of the first-order hadron-quark transition. The radii of the cold NSs with the CRover EOS are in the narrow range (12.5 ± 0.5) km which is insensitive to the NS masses. Due to the stiffening of the EOS induced by the hadron-quark crossover, the central density of the NSs is at most $4 \rho_0$ and the hyperon-mixing barely occurs inside the NS core. This constitutes a solution of the long-standing hyperon puzzle first pointed out by Takatsuka et al. The effect of color superconductivity (CSC) on the NS structures was also examined with the hadron-quark crossover picture. For the typical strength of the diquark attraction, a slight softening of the EOS due to two-flavor CSC takes place and the maximum mass is reduced by about 0.2 solar mass. The CRover EOS is generalized to the supernova matter at finite temperature to describe the hot NSs at birth. The hadron-quark crossover was found to decrease the central temperature of the hot NSs under isentropic condition. The gravitational energy release and the spin-up rate during the contraction from the hot NS to the cold NS were also estimated.

(5) Nuclear and atomic many-body problems

(5-1) Giant dipole resonance in hot nuclei

Over the last several decades, extensive experimental and theoretical works have been done on the giant dipole resonance (GDR) in excited nuclei covering a wide range of temperature (T), angular momentum (J) and nuclear mass. A reasonable stability of the GDR centroid energy and an increase of the GDR width with T (in the range $\sim 1-3$ MeV) and J are the two well-established results. Some experiments have indicated the saturation of the GDR width at high T : The gradual disappearance of the GDR vibration at much higher T has been observed. Experiments on the Jacobi transition and the GDR built on superdeformed shapes at high rotational frequencies have been reported in a few cases. We have demonstrated that thermal pairing included in the phonon damping model (PDM) is responsible for the nearly constant width of GDR at low temperature $T < 1$ MeV. We have also shown that the enhancement observed in the recent experimentally extracted nuclear level densities in ^{104}Pd at low excitation energy and various angular momenta is the first experimental evidence of the pairing reentrance in finite (hot rotating) nuclei. The results of calculations within the PDM were found in excellent agreement with the latest experimental data of GDR in the compound nucleus ^{88}Mo .

(5-2) Hidden pseudospin symmetries and their origins in atomic nuclei

The quasi-degeneracy between single-particle orbitals, $(n, l, j=l+1/2)$ and $(n-1, l+2, j=l+3/2)$, indicates a hidden symmetry in atomic nuclei, the so-called pseudospin symmetry (PSS). Since the introduction of the concept of PSS in atomic nuclei, there have been comprehensive efforts to understand its origin. Both splittings of spin doublets and pseudospin doublets play critical roles in the evolution of magic numbers in exotic nuclei discovered by modern spectroscopic studies with radioactive ion beam facilities. Since the PSS was recognized as a relativistic symmetry in 1990s, many special features, including the spin symmetry (SS) for anti-nucleon, and other new concepts have been introduced. We have published a comprehensive review article (Liang et al., Phys. Rept. 2015) on the PSS and SS in various systems, including extensions of the PSS study from stable to exotic nuclei, from non-confining to confining potentials, from local to non-local potentials, from central to tensor potentials, from bound to resonant states, from nucleon to anti-nucleon spectra, from nucleon to hyperon

spectra, and from spherical to deformed nuclei. We also summarized open issues in this field, including the perturbative nature, the supersymmetric representation with similarity renormalization group, and the puzzle of intruder states.

(5-3) Efimov Physics in cold atoms

For ultra-cold atoms and atomic nuclei, the pairwise interaction can be resonant. Then, universal few-body phenomena such as the Efimov effect may take place. We carried out an exploratory study suggesting that the Efimov effect can induce stable many-body ground states whose building blocks are universal clusters. We identified a range of parameters in a mass and density imbalanced two-species fermionic mixture for which the ground state is a gas of Efimov-related universal trimers. An explicit calculation of the trimer-trimer interaction reveals that the trimer phase is an SU(3) Fermi liquid stable against recombination losses. We proposed to experimentally observe this phase in a fermionic mixture of ${}^6\text{Li}$ - ${}^{53}\text{Cr}$ atoms. We have also written a comprehensive review article on theoretical and experimental advances in Efimov physics.

(5-4) Supersymmetric Bose-Fermi mixtures

Some special Bose-Fermi mixtures of cold atoms and molecules in optical lattices could be prepared in such a way as they exhibit approximate supersymmetry under the interchange of bosons and fermions. Since supersymmetry is broken at finite temperature and/or density, an analog of the Nambu-Goldstone excitation, dubbed the “Goldstino”, should appear. We evaluated the spectral properties of the Goldstino in a Bose-Fermi mixture of cold atoms and molecules. We derived model independent results from sum rules obeyed by the spectral function. Also, by carrying out specific calculations with random phase approximation, analytic formula for the dispersion relation of Goldstino at small momentum was obtained.

Members

Chief Scientist (Lab. Head)

Tetsuo HATSUDA

Vice Chief Scientist

Tsukasa TADA

Research & Technical Scientists

Takumi DOI (Senior Research Scientist)
Pascal Raphaël Gabriel NAIDON (Senior Research Scientist)

Yoshimasa HIDAKA (Senior Research Scientist)
Haozhao LIANG (Research Scientist)

Nishina Center Research Scientists

Makiko NIO

Dang NGUYEN DINH

Special Postdoctoral Researchers

Noriaki OGAWA
Kazuhiko KAMIKADO
Shinya GONGYO

Yuya TANIZAKI
Shingo TORII
Hiromichi NISHIMURA

Foreign Postdoctoral Researcher

Di-Lun YANG

Postdoctoral Researchers

Yoichi IKEDA
Takumi IRITANI

Koichi HATTORI

Junior Research Associate

Masaru HONGO (Univ. of Tokyo)

International Program Associate

Shihang SHEN (Peking University)

Zhaoxi LI (Beihang University)

Visiting Researchers

Kanako YAMAZAKI (JSPS Fellow)

Kei SUZUKI (JSPS Fellow)

Senior Visiting Scientist

Koichi YAZAKI (Univ. of Tokyo)

Visiting Scientists

Noriyoshi ISHII (Osaka Univ.)
Motoi TACHIBANA (Saga Univ.)
Toichiro KINOSHITA (Cornell Univ.)
Tatsumi AOYAMA (Nagoya Univ.)
Hiroshi SUZUKI (Kyushu Univ.)
Takeo INAMI (National Taiwan University)
Koji HASHIMOTO (Osaka Univ.)
Daisuke KADOH (Keio Univ.)
Yoichi IKEDA (Osaka Univ.)
Tatsuyuki TAKATSUKA (Iwate Univ.)

Kanabu NAWA (Univ. of Tokyo)
Tomoya HAYATA (Univ. of Tokyo)
Takashi SANO (AIST)
Keitaro NAGATA (Hiroshima Univ.)
Kazuyuki KANAYA (Univ. of Tsukuba)
Shinsuke YOSHIDA (Los Alamos National Laboratory)
Takayuki MATSUKI (Tokyo Kasei Univ.)
Takumi IRITANI (Stony Brook University)
Shinya GONGYO (Centre national de la recherche scientifique)

Hiroshi TOKI (Osaka Univ.)
Makoto TAKIZAWA (Showa Pharm. Univ.)
Shoichi SASAKI (Tohoku Univ.)

Yoshitaka HATTA (Univ. of Tsukuba)
Masashi HAYAKAWA (Nagoya Univ.)
Kenji SASAKI (Univ. of Tsukuba)
Shinya AOKI (Kyoto Univ.)
Atsushi NAKAMURA (Hiroshima Univ.)
Hung NGUYEN (Duy Tan University)
Keiko MURANO (Osaka Univ.)
Minoru ETO (Yamagata Univ.)
Norisuke SAKAI (Keio Univ.)
Arata YAMAMOTO (Univ. of Tokyo)

Student Trainees

Bruno CHARRON (Univ. of Tokyo)
Ryuichi KURITA (Univ. of Tokyo)
Terukazu ICHIHARA (Kyoto Univ.)
Takaya MIYAMOTO (Kyoto Univ.)
Tan Phuc LE (University of Science, Vietnam National University)

Part-time Workers

Koichi MURASE

Sho OZAKI (Yonsei University)
Gergely FEJOS (Osaka Univ.)
Takashi OKA (Univ. of Tokyo)
Takashi INOUE (Nihon Univ.)
Sachiko TAKEUCHI (Japan College of Social Work)
Toshifumi NOUMI (The Hong Kong University of Science and Technology)
Rhine Kumar Arayakkandi Keechirath (Tata Institute of Fundamental Research)
Yoichi KAZAMA (Univ. of Tokyo)
Tetsuo MATSUI (The Open Univ. of Japan)
Teiji KUNIHICO (Kyoto Univ.)
Kazuo FUJIKAWA (Nihon Univ.)

Yuya TANIZAKI (Univ. of Tokyo)
Kota MASUDA (Univ. of Tokyo)
Shoichiro TSUTSUI (Kyoto Univ.)
Min SHI (Anhui University)

Kayo YAMAJI

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- W. Bentz, A. Kotzinian, H.H. Matevosyan, Y. Ninomiya, A.W. Thomas and K. Yazaki, "Quark-Jet model for transverse momentum dependent fragmentation functions," *Physical Review D* 94 (2016) no.3, 034004.*
- N. Ishibashi, T. Tada, "Dipolar quantization and the infinite circumference limit of two-dimensional conformal field theories," *International Journal of Modern Physics A* 31, 1650170 (2016).*
- Y. Kazama, S. Komatsu, and T. Nishimura, "Classical Integrability for Three-point Functions: Cognate Structure at Weak and Strong Couplings," *Journal of High Energy Physics* 1610, 042 (2016).*
- Yoshimasa Hidaka, Shi Pu, Di-Lun Yang, "Relativistic Chiral Kinetic Theory from Quantum Field Theories," *Physical Review D* 95, 091901 (2017).*
- Ioannis Iatrakis, Elias Kiritsis, Chun Shen, Di-Lun Yang, "Holographic Photon Production in Heavy Ion Collisions," *Journal of High Energy Physics* 1704 (2017) 035.*
- Tomoya Hayata, Yoshimasa Hidaka, "Kinetic derivation of generalized phase space Chern-Simons theory," *Physical Review B* 95, 125137 (2017)*
- Kenji Fukushima, Yoshimasa Hidaka, "Magnetic shift of the chemical freezeout and electric charge fluctuations," *Physical Review Letters* 117, 102301 (2016).*
- Tomoya Hayata, Yoshimasa Hidaka, Yuya Tanizaki, "Complex saddle points and the sign problem in complex Langevin simulation," *Nuclear Physics B* 911, 94 (2016)*.
- T.Blum, N.Christ, M.Hayakawa, T.Izubuchi, L.Jin, C.Jung and C.Lehner, "Connected and Leading Disconnected Hadronic Light-by-Light Contribution to the Muon Anomalous Magnetic Moment with a Physical Pion Mass," *Physical Review Letters* 118, no. 2, 022005 (2017).*
- Y. Ikeda, S. Aoki, T. Doi, S. Gongyo, T. Hatsuda, T. Inoue, T. Iritani, N. Ishii, K. Murano, and K. Sasaki (HAL QCD Collaboration), "Fate of the Tetraquark Candidate $Z_c(3900)$ in Lattice QCD," *Physical Review Letters* 117, 242001 (2016).*
- T. Iritani, T. Doi, S. Aoki, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, N. Ishii, K. Murano, H. Nemura and K. Sasaki (HAL QCD Collaboration) "Mirage in Temporal Correlation functions for Baryon-Baryon Interactions in Lattice QCD," *Journal of High Energy Physics* 1610, 101 (2016).*
- F. Okiharu, T. Doi, H. Ichie, H. Iida, N. Ishii, M. Oka, H. Suganuma and T. T. Takahashi, "Tetraquark and Pentaquark Systems in Lattice QCD," *Journal of Modern Physics* 7 (2016) 774.*
- Masakiyo Kitazawa, Takumi Iritani, Masayuki Asakawa, Tetsuo Hatsuda, Hiroshi Suzuki, "Equation of State for SU(3) Gauge Theory via the Energy-Momentum Tensor under Gradient Flow," *Physical Review D* 94, 114512 (2016), arXiv:1610.07810 [hep-lat] (12 pages).*
- K. Fujikawa and A. Tureanu, "Naturalness in see-saw mechanism and Bogoliubov transformation", arXiv:1609.03309, *Physics Letters B* 767 (2017) 199-204. *
- K. Fujikawa and A. Tureanu, "Parity-doublet representation of Majorana fermions and neutron oscillation", *Physical Review D* 94 (2016) 115009.*
- K. Fujikawa, "Dimensional regularization is generic", *International Journal of Modern Physics A* 31 (2016) no.25, 1630042. *
- K. Fujikawa, "Nambu-Goldstone theorem and spin-statistics theorem", *International Journal of Modern Physics A* 31 (2016) no.13, 1630018. (Special article in memory of Yoichiro Nambu).
- K. Fujikawa, "BCS, Nambu-Jona-Lasinio, and Han-Nambu -- A sketch of Nambu's works in 1960-1965", *Progress of Theoretical and Experimental Physics* 2016 (2016) no.6, 06A101. *
- Norihiro Iizuka, Toshifumi Noumi and Noriaki Ogawa, "Entanglement entropy of de Sitter space α -vacua", *Nuclear Physics B* 910, 23 (2016).*
- N. Quang Hung, N. Dinh Dang, T. V. Nhan Hao, and L. Tan Phuc, *Physical Review C* 94, 064312 (2016).*

- N. Quang Hung, N. Dinh Dang, and L. T. Quynh Huong, *Physical Review C* 94, 024341 (2016).*
- N. Quang Hung, N. Dinh Dang, and L. T. Quynh Huong, *Physical Review Letters* 118, 022502 (2017).*
- D. Chakrabarty, N. Dinh Dang, and V.M. Datar, Giant dipole resonance in hot nuclei (invited review) *Eur. Phys. Jour. A* 52 (2016) : 143.*
- V. Vorobyev, et al. (Belle Collaboration), "Measurement of the CKM angle ϕ_1 in $B^0 \rightarrow D^{\pm} h^0$, $D^0 \rightarrow K_S^0 \pi^{\pm}$ decays with time-dependent binned Dalitz plot analysis," *Physical Review D* 94, 052004-1-15 (2016).*
- J. Yelton, et al. (Belle Collaboration), "Studies of excited Ξ_c states decaying into Ξ_c^0 and Ξ_c^+ baryons," *Physical Review D* 94, 052011-1-14 (2016).*
- R. Mizuk, et al. (Belle Collaboration), "Energy Scan of the $e^+e^- \rightarrow h_b(nP) \pi^+ \pi^-$ ($n=1,2$) Cross Sections and Evidence for $\Upsilon(11020)$ Decays into Charged Bottomoniumlike States," *Physical Review Letters* 117, 142001-1-7 (2016).*
- Y. Sato et al. (Belle Collaboration), "Measurement of the branching ratio of $B^0 \rightarrow D^{(*)} \tau^- \bar{\nu}_\tau$ relative to $B^0 \rightarrow D^{(*)} l^- \bar{\nu}_l$ decays with a semileptonic tagging method," *Physical Review D* 94, 072007-1-12 (2016).*
- E. Won, et al. (Belle Collaboration), "Search for a dark vector gauge boson decaying to $\pi^+ \pi^-$ using $\eta \rightarrow \pi^+ \pi^- \gamma$ decays," *Physical Review D* 94, 092006-1-6 (2016).*
- S. Takeuchi and M. Takizawa, "The hidden charm pentaquarks are the hidden color-octet uud baryons?" *Physics Letters B* 764, 254-259 (2017).*
- Y.-T. Lai, et al. (Belle Collaboration), "Search for the $0^{(-)}$ glueball in $Y(1S)$ and $Y(2S)$ decays," *Physical Review D* 95, 011102(R)-1-8 (2017).*
- S. Jia, et al. (Belle Collaboration), "Search for D^0 decays to invisible final states at Belle," *Physical Review D* 95, 012001-1-13 (2017).*
- T. Nanut, et al. (Belle Collaboration), "Observation of $D^0 \rightarrow \rho^0 \gamma$ and Search for CP Violation in Radiative Charm Decays," *Physical Review Letters* 118, 051801-1-8 (2017).*
- S. Wehle, et al. (Belle Collaboration), "Lepton-Flavor-Dependent Angular Analysis of $B \rightarrow K^* l^+ l^-$," *Physical Review Letters* 118, 111801-1-7 (2017).*
- S. Gongyo, Y. Kikuchi, T. Hyodo and T. Kunihiro, "Effective field theory and the scattering process for magnons in ferromagnets, antiferromagnets, and ferrimagnets," *Progress of Theoretical and Experimental Physics* 2016 (2016) no.8, 083B01.*
- M.N. Chernodub, S. Gongyo, "Interacting fermions in rotation: chiral symmetry restoration, moment of inertia and thermodynamics", *Journal of High Energy Physics* 1701 (2017) 136.*
- M.N. Chernodub, S. Gongyo, "Effects of rotation and boundaries on chiral symmetry breaking of relativistic fermions", *Physical Review D* 95 (2017) no.9, 096006.*
- Dian-Yong Chen, Xiang Liu, and Takayuki Matsuki, "Search for missing $\phi(4S) \phi(4S)$ in the $e^+e^- \rightarrow \pi^+ \pi^- \phi(2S)$ process", *Physical Review D* 93, 034028-1-10 (2016).*
- T. Matsuki, Qi-Fang L^u, Yubing Dong, and T. Morii, "Approximate degeneracy of heavy-light mesons with the same L", *Physics Letter B* 758, 274 (2016).*
- Hao Zu, Xiang Liu, Takayuki Matsuki, "Understanding $B \rightarrow X(3823)K^+$ via rescattering mechanism and predicting $B \rightarrow \eta_{(1D2)} \phi_{(3D3)K^+}$ ", *Physical Review D* 94, 034005 (2016).*
- Jun-Zhang Wang, Dian-Yong Chen, Qin-Tao Song, Xiang Liu, and Takayuki Matsuki, "Revealing the inner structure of the newly observed $D_{s2}^*(3000)$ ", *Phys. Rev. D* 94, 094044 (2016).*
- S.H. Shen, J.N. Hu, H.Z. Liang, J. Meng, P. Ring, and S.Q. Zhang, "Relativistic Brueckner-Hartree-Fock Theory for Finite Nuclei", *Chinese Physics Letter* 33, 102103 (2016).*
- N. Li, M. Shi, J.Y. Guo, Z.M. Niu, and H.Z. Liang, "Probing resonances of the Dirac equation with complex momentum representation", *Physical Review Letters* 117, 062502 (2016).*
- Z.M. Niu, B.H. Sun, H.Z. Liang, Y.F. Niu, and J.Y. Guo, "Improved radial basis function approach with odd-even corrections", *Physical Review C* 94, 054315 (2016).*
- Z. Fang, M. Shi, J.Y. Guo, Z.M. Niu, H.Z. Liang, and S.S. Zhang, "Probing the resonance in the Dirac equation with quadruple-deformed potentials by complex momentum representation method", *Physical Review C* 95, 024311 (2017).*
- M. Shi, X.X. Shi, Z.M. Niu, T.T. Sun and J.Y. Guo, "RMF-CGF method for resonances in deformed nuclei", *The European Physical Journal A* 53, 40 (2017).*

[Review]

- T. Doi and T. Inoue, "Baryon-Baryon Interactions from Lattice QCD: The Bridge from Quarks to Nuclei and Cosmos," *Nuclear Physics News* 27, 13 (2017).*
- Pascal Naidon, Shimpei Endo, "Efimov physics: a review" *Reports on Progress in Physics* 80 (2017) 056001.*
- H.Z. Liang, "Pseudospin symmetry in nuclear structure and its supersymmetric representation", *Physica Scripta* 91, 083005 (2016).*

[Proceedings]

(Original Papers) *Subject to Peer Review

- Ioannis Iatrakis, Elias Kiritsis, Chun Shen, Di-Lun Yang, Holographic Photon Production and Anisotropic Flow, to appear in *Nuclear and Particle Physics Proceedings* by Elsevier. [Contribution to the proceedings of Hard Probes 2016].*
- Ioannis Iatrakis, Elias Kiritsis, Chun Shen, Di-Lun Yang, Direct-Photon Spectra and Anisotropic Flow in Heavy Ion Collisions from Holography, to appear in *European Physical Journal Web of Conferences*. [Contribution to the proceedings of XII Quark Confinement and Hadron Spectrum].*
- Shi Pu, Di-Lun Yang, Analytic Solutions of Transverse Magneto-hydrodynamics under Bjorken Expansion, to appear in *European Physical Journal Web of Conferences*. [Contribution to the proceedings of XII Quark Confinement and Hadron Spectrum].*
- L. Jin, T. Blum, N. Christ, M. Hayakawa, T. Izubuchi, C. Jung and C. Lehner, "The connected and leading disconnected diagrams of the hadronic light-by-light contribution to muon $g-2$," *Proceedings of Science (LATTICE 2016)*, 181 (2016), 34rd International Symposium on Lattice Field Theory (LATTICE 2016), July 24-30, 2016, University of Southampton, Southampton, UK.
- T. Doi, S. Aoki, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, N. Ishii, T. Miyamoto, K. Murano, H. Nemura and K. Sasaki "Baryon interactions from lattice QCD with physical masses -- Overview and $S = 0, -4$ sectors --" *Proceeding of Science LATTICE2016*, 110 (2017).*

- N. Ishii, S. Aoki, T. Doi, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, T. Miyamoto, K. Murano, H. Nemura and K. Sasaki, "Baryon interactions from lattice QCD with physical masses -- $S = -3$ sector: χ Sigma and χ Lambda - χ Sigma --," Proceeding of Science LATTICE2016, 127 (2017).*
- K. Sasaki, S. Aoki, T. Doi, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, N. Ishii, T. Miyamoto and K. Murano "Baryon interactions from lattice QCD with physical masses -- $S = -2$ sector --" Proceeding of Science LATTICE2016, 116 (2017).*
- H. Nemura, S. Aoki, T. Doi, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, N. Ishii, T. Miyamoto, K. Murano and K. Sasaki "Lambda-Nucleon and Sigma-Nucleon interactions from lattice QCD with physical masses" Proceeding of Science LATTICE2016, 101 (2017).*
- S. Aoki, T. Doi and T. Iritani, for HAL QCD Collaboration "Luscher's finite volume test for two-baryon systems with attractive interactions" Proceeding of Science LATTICE2016, 109 (2016).*
- T. Doi, S. Aoki, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, N. Ishii, T. Miyamoto, K. Murano, H. Nemura and K. Sasaki "First results of baryon interactions from lattice QCD with physical masses (1) -- General overview and two-nucleon forces --" Proceeding of Science LATTICE2015, 086 (2016).*
- N. Ishii, S. Aoki, T. Doi, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, T. Miyamoto, K. Murano, H. Nemura and K. Sasaki "First results of baryon interactions from lattice QCD with physical masses (2) -- $S = -3$ and $S = -4$ sectors (χ Xi, χ Sigma, χ Lambda - χ Sigma channels)--" Proceeding of Science LATTICE2015, 087 (2016).*
- K. Sasaki, S. Aoki, T. Doi, S. Gongyo, T. Hatsuda, Y. Ikeda, T. Inoue, T. Iritani, N. Ishii, T. Miyamoto and K. Murano "First results of baryon interactions from lattice QCD with physical masses (3) -- Strangeness $S = -2$ two-baryon system" Proceeding of Science LATTICE2015, 088 (2016).*
- K. Fujikawa and A. Tureanu, "Lorentz invariant CPT violation in the Dirac equation", arXiv: 1607.01409. [Contribution to the Proceedings of the Memorial Meeting for Abdus Salam's 90th Birthday, Nanyang Technological University, Singapore].
- H.Z. Liang, "Microscopic studies on nuclear spin-isospin properties---a personal perspective on covariant density functional theory", (Proceedings of INPC2016, Adelaide, Australia, 11-16 September, 2016), PoS (INPC2016) 361.
- X. Roca-Maza, G. Colo, H.Z. Liang, J. Meng, P. Ring, H. Sagawa, and P. W. Zhao, "Towards the improvement of spin-isospin properties in nuclear energy density functionals", (Proceedings of the XXI International School on Nuclear Physics and Applications & International Symposium on Exotic Nuclei (ISEN-2015), Varna, Bulgaria, 6-12 September 2015), Journal of Physics: Conference Series 724, 012041 (2016).

[Book]

(Original Papers) *Subject to Peer Review

風間洋一、「宇宙の統一理論を求めて」(岩波現代文庫/学術 353、岩波書店).

[Others]

風間洋一、「物理にたずさわるすべての人が知っておくべき超弦理論の基礎」、(翻訳: Edward Witten, "What every physicist know about string theory") パリティ 2016年7月号、31(7)、4-12.

早川雅司、「ミューオンの異常磁気能率」、数理科学 2016年9月号 No.639.

T. Doi and editorial committee "20xx A Space Odyssey: from Quarks to Nuclei and Cosmos," The Physical Society of Japan Membership Journal Vol.71 No. 8, 522 (2016).

藤川和男、「ファインマン図, 反粒子, CPT の破れ」、数理科学 2016年7月号 34 ページ (サイエンス社) .

Oral Presentations

[International Conference etc.]

Tsukasa Tada, "Dipolar Quantization of conformal field theories," YITP Workshop String and Fields, August 10th, 2016.

Tsukasa Tada, "Dipolar quantization of conformal field theories," KEK Theory workshop 2016, December 6th, 2016.

Di-Lun Yang, "Side-Jumps and Collisions in Chiral Kinetic Theory from Quantum Field Theories", Chirality Workshop, UCLA, March 27, 2017, Los Angel, U.S.

Di-Lun Yang, "Holographic photon production and flow in strongly coupled quark gluon plasmas", Hard Probes 2016, East Lake International Conference Center, September 24th, 2016, Wuhan, China

Di-Lun Yang, "Holographic photon production in heavy ion collisions", XII Quark Confinement and Hadron Spectrum, Makedonia Palace, September 2nd, 2016, Thessaloniki, Greece.

Yoshimasa Hidaka, "Spatially modulated chiral condensates in quark matter," Quarkyonic matter, from theory to experiment, Oct 24-28, Central China Normal University, Wuhan, China.

Yoshimasa Hidaka, "The power of symmetry," Big Waves of Theoretical Science in Okinawa, July 8 (Fri.) - July 11 (Mon), 2016, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan.

Y. Tanizaki, Y. Hidaka, T. Hayata, "Lefschetz-thimble approach to the Silver Blaze problem of one-site fermion model", 34th International Symposium on Lattice Field Theory (Lattice2016), Southampton, UK, 24-30 July 2016.

M. Hayakawa, "Standard model prediction for the muon $g-2$: QCD and QED contributions", The 1st KEK-KIAS-NCTS Joint WorkShop on Particle Physics Phenomenology, May 26-29, 2016, National Center for Theoretical Physics, Taiwan.M. Hayakawa, "Hadronic light-by-light scattering contribution to the muon $g-2$ from lattice QCD" The 2nd Durham-KEK-KIPMU-KIAS Joint WorkShop, October 24-28, 2016, KIAS, Korea.M. Hayakawa, "Attempt to calculate hadronic light-by-light scattering contribution to the muon $g-2$ from lattice QCD," Towards high precision muon $g-2$ /EDM measurement at J-PARC, 28-29 November 2016, J-PARC, Tokai.

T. Doi, for HAL QCD Collaboration "Baryon-Baryon Interactions from Lattice QCD" Invited Talk given at KEK theory center workshop on "Hadron and Nuclear Physics in 2017", KEK, Tsukuba, Japan, 7-10 Jan. 2017.

T. Doi, for HAL QCD Collaboration "Baryon-Baryon Interactions from Lattice QCD" Invited Talk given at First Tsukuba-CCS-RIKEN joint workshop on "microscopic theories of nuclear structure and dynamics", RIKEN, Saitama, Japan, 12-16 Dec. 2016.

T. Doi, for HAL QCD Collaboration "Baryon-Baryon Interactions from Lattice QCD" Talk given at International Molecule-type Workshop "Realistic hadron interactions in QCD", YITP, Kyoto, Japan, 21, Nov. - 02 Dec. 2016.

- T. Doi, for HAL QCD Collaboration "Two- and Three-Baryon Forces from Lattice QCD" Invited Talk given at YIPQS long-term and Nishinomiya-Yukawa memorial workshop on "Nuclear Physics, Compact Stars, and Compact Star Mergers (NPCSM) 2016", YITP, Kyoto, Japan, 17 Oct. - 18 Nov. 2016.
- T. Doi, for HAL QCD Collaboration "Baryon interactions from lattice QCD with physical masses -- Overview and $S=0$, -4 sectors --" Talk given at "The 34th International Symposium on Lattice Field Theory (Lattice 2016)", Southampton, UK, 24-30 Jul. 2016.
- T. Doi, for HAL QCD Collaboration "Baryon Interactions from Lattice QCD with physical masses" Talk given at INT Program "Nuclear Physics from Lattice QCD", Institute for Nuclear Theory (INT), Seattle, USA, 17, Mar. - 27 May 2016.
- T. Iritani, Current status for two baryon-systems in lattice QCD II: HAL QCD potential method and diagnosis of the direct method, First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, December 12-13, 2016, RIKEN Nishina Center, 14-16, 2016, Center for Computational Science, University of Tsukuba, Japan.
- T. Iritani, "Lattice studies of Z_2 -symmetric QCD", ECT* Workshop "Gauge Topology: from Lattice to Colliders", November 7-11, 2016, ECT*, Trento, Italy.
- T. Iritani, "Baryon interactions in lattice QCD: the direct method vs. the HAL QCD potential method", The 34th International Symposium on Lattice Field Theory, July 24-30, 2016, Highfield Campus, University of Southampton, Southampton, UK.
- T. Iritani, "Baryon interactions from Luscher's finite volume method and HAL QCD method", INT-16-1 Nuclear Physics from Lattice QCD, April 18, 2016, Institute for Nuclear Theory, University of Washington, Seattle, USA.
- K. Fujikawa, "Higgs and neutrino masses in the Standard Model", Invited talk, YITP 50th Anniversary Symposium, Stony Brook University, Stony Brook, New York, USA, October 10-11, 2016.
- K. Fujikawa, "Chiral anomaly and Berry phase", Invited talk, International Symposium "Chiral Matter 2016", RIKEN, Wako, Japan, December 5-8, 2016.
- K. Fujikawa, "Path Integrals in Particle and Condensed Matter Physics: Quantum Anomalies and Related Topics", Invited talk, International Workshop "Path Integrals in Complex Systems", Lorentz Center, Leiden University, February 6-10, 2017.
- Pascal Naidon, "From the Yukawa to the Efimov attraction", Invited talk, Workshop on "Quantum Many-Body Problems in Particle, Nuclear, and Atomic Physics", Duy Tan University, Danang, Vietnam, March 8-11, 2017.
- Pascal Naidon, "Interacting Bose polarons: from the Yukawa to the Efimov attraction", Invited talk, Workshop on "Dynamics of highly unstable exotic light nuclei and few-body systems", CEA Saclay, France, January 30 - February 3, 2017.
- Pascal Naidon, "Universal clusters of mass-imbalanced fermions" Invited talk, "Few-body physics in cold-atomic gases", Beijing, China, Apr. 14-16, 2016.
- Noriaki Ogawa, "Physical Modeling of Growing Cellular Mosaic Patterns in Fish Retina", Workshop "Big Waves of Theoretical Science in Okinawa", Okinawa Institute for Science and Technology, 2016 July 9.
- N. Quang Hung, "Nuclear Theory Group at Duy Tan University", Oral talk, International Workshop on Quantum Many-Body Problems in Particle, Nuclear, and Atomic Physics, Danang city, Vietnam, Mar. 8-11, 2017.
- M. Takizawa, for Belle Collaboration, "New results on the XYZ states and B-decays from Belle," Invited talk, "Helmholts International Summer School - Dubna International Advanced School of Theoretical Physics", Dubna, Russia, July 18-30, 2016
- Takayuki Matsuki, "String point of view for heavy-light mesons", XIIth Quark Confinement and the Hadron Spectrum, Thessaloniki, Greece, Aug. 29-Sept. 3
- Shihang Shen, "Relativistic Brueckner-Hartree-Fock Theory for Finite Nuclei", Recent Progresses in Nuclear Structure Physics 2016 (NSP2016), Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan, December 5-23, 2016.
- Shihang Shen, "Relativistic Brueckner-Hartree-Fock Theory for Finite Nuclei", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Wako & Tsukuba, Japan, December 12-16, 2016.
- Min Shi, "Probing Resonances of the Dirac Equation with Complex Momentum Representation", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Wako & Tsukuba, Japan, December 12-16, 2016.
- Min Shi, "Probing Resonances of the Dirac Equation with RMF-CSM and RMF-CMR Method", Recent Progresses in Nuclear Structure Physics 2016 (NSP2016), Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan, December 5-23, 2016.
- Zhongming Niu, "High-precision nuclear physics inputs and their influences on the r-process simulations", Recent Progresses in Nuclear Structure Physics 2016 (NSP2016), Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan, December 5-23, 2016.
- Zhongming Niu, "Microscopic description of nuclear beta-decay half-lives", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Wako & Tsukuba, Japan, December 12-16, 2016.
- Haozhao Liang, "From Functional Renormalization Group to Density Functional Theory--- a case study of 0D anharmonic oscillator", Invited talk, ECT* Workshop: Unraveling the complexity of nuclear systems: single-particle and collective aspects through the looking glass, ECT*, Trento, Italy, February 6-10, 2017.
- Haozhao Liang, "From Functional Renormalization Group to Density Functional Theory--- a case study of 0D anharmonic oscillator", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Wako & Tsukuba, Japan, December 12-16, 2016.
- Haozhao Liang, "From Functional Renormalization Group to Density Functional Theory--- a case study of 0D anharmonic oscillator", Recent Progresses in Nuclear Structure Physics 2016 (NSP2016), Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto, Japan, December 5-23, 2016.
- Haozhao Liang, "Microscopic studies on nuclear spin-isospin properties---a personal perspective on covariant density functional theory", Invited talk, The 26th International Nuclear Physics Conference (INPC2016), Adelaide, Australia, September 11-16, 2016.
- Haozhao Liang, "Relativistic Brueckner-Hartree-Fock theory for finite nuclei", The 10th APCTP-BLTP/JINR-RCNP-RIKEN Joint Workshop on Nuclear and Hadronic Physics, RIKEN, Wako, Japan, August 17-21, 2016.
- M. Nio, "Higher-order QED contributions to muon $g-2$," invitead talk, international workshop on "Towards high precision muon $g-2$ /EDM measurement at J-PARC", J-PARC, Tokai, Japan, November 28-29, 2016.

[Domestic Conference]

日高義将, 南佑樹, "量子散逸系における南部・ゴールドストンの定理," 日本物理学会 第72回年次大会(2017年) (大阪大学) 3月17-20日.

日高義将, 福嶋健二, "Magnetic shift of the chemical freezeout and electric charge fluctuations," 日本物理学会 2016年秋季大会, 宮崎大学,

2016年9月21-24日.

- 早川雅司, "Hadronic light-by-light scattering contribution to muon g-2 from lattice QCD: progress and challenges," New Physics Forum (Muon), January 19, 2016, KEK, Tsukuba.
- 早川雅司, "Is the theoretical prediction for the muon g-2 really correct?", PPP2016, 2016年9月5日~9日, 京都大学基礎物理学研究所, 京都.
- T. Doi, for HAL QCD Collaboration, "Baryon Forces from Lattice QCD," Invited Talk given at Workshop on "Advances of nuclear structure and reaction physics based on the realistic nuclear forces", Yukawa Institute of Theoretical Physics (YITP), Kyoto, Japan, 27-29 Mar. 2017.
- T. Doi, for HAL QCD Collaboration "Baryon forces from physical point lattice QCD [4] -- General overview and S=0, -4 sectors --" Talk given at JPS meeting, Osaka University, Osaka, Japan, 17-20 Mar. 2017.
- T. Doi, for HAL QCD Collaboration "Interactions between clusters on a lattice" Invited Talk given at Workshop on "Clusters connecting quarks, hadrons, nuclei and atoms", Osaka University, Osaka, Japan, 16, Mar. 2017.
- T. Doi, for HAL QCD Collaboration "Lattice QCD calculations for Three-Nucleon Forces" Talk given at JPS meeting, University of Miyazaki, Miyazaki, Japan, 21-24 Sep. 2016.
- T. Doi, for HAL QCD Collaboration, "Baryon forces from physical point lattice QCD [3] -- General overview and S=0, -4 sectors --" Talk given at JPS meeting, University of Miyazaki, Miyazaki, Japan, 21-24 Sep. 2016.
- T. Doi, for HAL QCD Collaboration, "Baryon Interactions from Lattice QCD" Invited Talk given at Symposium on "Forefront of researches with supercomputers HOKUSAI and Shoubu", RIKEN, Saitama, Japan, 08 Jun. 2016.
- T. Doi, "Baryon-Baryon Interactions from Lattice QCD" Seminar at Niigata University, Niigata, Japan, 6 Dec. 2016.
- T. Doi, "Hadron Interactions from Lattice QCD" Seminar at "QCD Club", RIKEN, Wako, Saitama, Japan, 28 Oct. 2016.
- T. Doi, "Baryon Interactions from Lattice QCD with physical masses" Seminar at Nagoya University, Nagoya, Japan, 17 May 2016.
- 入谷匠, "Current status for two baryon systems in lattice QCD II: HAL QCD potential method", 日本物理学会第72回年次大会、大阪大学豊中キャンパス、2017年3月17-20日.
- 入谷匠, "格子 QCD による核子 2 体計算の現状と展望"、素粒子・原子核・宇宙「京からポスト京に向けて」シンポジウム、筑波大学東京キャンパス、2017年2月16-17日
- Pascal Naidon, "From the Yukawa to the Efimov attraction", Japan Physical Society meeting, Osaka, March 17, 2017.
- Pascal Naidon, "Interacting Bose polarons", Cold-atom one-day workshop at RIKEN, Wako, August 25th 2016.
- 小川軌明, 初田哲男, 望月敦史, 立川正志, "Dynamical Pattern Selection of Growing Cellular Mosaic in Fish Retina", 日本物理学会年次大会, 大阪大学, 2017年3月17日.
- M. Takizawa, "Structure of $\Lambda(4260)$ by the quark model," Workshop on "Structures and Interactions of Heavy Quark Hadrons", KEK Tokai Campus, Tokai, Japan March 1-3, 2017.

Poster Presentations

[International Conference etc.]

- Di-Lun Yang, "Direct-Photon Spectra and Anisotropic Flow in Heavy Ion Collisions from Holography", Quark Matter 2017, Hyatt Regency, February 2, 2017, Chicago, U.S.
- Di-Lun Yang, "Transverse flow induced by inhomogeneous magnetic fields in the Bjorken expansion", XII Quark Confinement and Hadron Spectrum, Makedonia Palace, August 30, 2016, Thessaloniki, Greece.
- Pascal Naidon, "Two impurities in a Bose-Einstein condensate: from Yukawa to Efimov attracted polarons", 25th International Conference on Atomic Physics (ICAP2016), Seoul, South Korea, July 24-29, 2016.
- Noriaki Ogawa, Tetsuo Hatsuda, Atsushi Mochizuki, Masashi Tachikawa, "Dynamical Pattern Selection of Growing Cellular Mosaic in Fish Retina", Annual Conference of Japan Society of Mathematical Biology 2016, Kyushu University, 2016 Sep 7-8.
- Shihang Shen, "Relativistic Brueckner-Hartree-Fock Theory for Finite Nuclei", poster presentation at the NIC-XIV School 2016, June 15, 2016, Niigata University, Niigata, Japan.

[Domestic Conference]

- 小川軌明, 「魚類網膜錐体モザイク形成のモデル化と解析」、研究会「熱場の量子論」、理研和光, 2016年8月23日.
- 小川軌明, 初田哲男, 望月敦史, 立川正志, 「網膜錐体モザイク形成のモデル化と解析」、日本物理学会秋季大会, 金沢大学, 2016年9月16日.

Theoretical Research Division Strangeness Nuclear Physics Laboratory

1. Abstract

We proposed accurate calculation method called ‘Gaussian Expansion Method using infinitesimally shifted Gaussian lobe basis function’. When one proceeds to four-body systems, calculation of the Hamiltonian matrix elements becomes much laborious. In order to make the four-body calculation tractable even for complicated interactions, the infinitesimally-shifted Gaussian lobe basis function has been proposed. The GEM with the technique of infinitesimally-shifted Gaussians has been applied to various three-, four- and five-body calculations in hypernuclei, the four-nucleon systems, and cold-atom systems. As results, we succeeded in extracting new understandings in various fields.

2. Major Research Subjects

- (1) Hypernuclear structure from the view point of few-body problem
- (2) Structure of exotic hadron system
- (3) quantum atomic system and ultra cold atomic system
- (4) Equation of state for neutron star

3. Summary of Research Activity

- (1) Recently, at RIBF, they observed tetra neutron system to be bound or resonant state. Theoretically, it is requested to study this system theoretically. We performed four-body calculation using NN realistic force and a phenomenological three-body force. We found that we need unrealistically strong three-body force to describe $4n$ system.
- (2) We investigate the effects of the odd-state part of bare $\Lambda\Lambda$ interactions on the structure of neutron stars by constructing equations of state (EOSs) for uniform nuclear matter containing Λ and Σ hyperons with use of the cluster variational method. The EOS obtained for NS matter becomes stiffer as the odd-state $\Lambda\Lambda$ interaction becomes more repulsive, and correspondingly the maximum mass of NSs increases.
- (3) We calculate the universal spectrum of trimer and tetramer states in heteronuclear mixture of ultracold atoms with different masses in the vicinity of the heavy-light dimer threshold. We find that trimer and tetramer cross into the heavy-light dimer threshold at the same point and that as the mass ratio M/m decreases, the distance between the thresholds for trimer and tetramer states become smaller.

Members

Associate Chief Scientist (Lab. Head)

Emiko HIYAMA

Research Scientists

Hiroya SUNO (Research Scientist, concurrent: Strangeness
Nuclear Physics Laboratory, Main: Field Theory Research Team)

Contract Researchers

Yasuro FUNAKI

Hyun-Chul KIM

Special Postdoctoral Researchers

Masahiro ISAKA
Shin WATANABE

Hajime TOGASHI
Masahiro YAMAGUCHI

Postdoctoral Researchers

Hajime TOGASHI

Tingting SUN

Junior Research Associates

Saori MAEDA (Tokyo Tech.)
Jehee LEE (Inha University)

Tetsuya YOSHIDA (Tokyo Tech.)

International Program Associate

Christiane SCHMICKLER (TU Darmstadt)

Qian WU (Nanjing University)

Visiting Researcher

Naoyuki SAKUMICHI (JSPS Fellow)

Visiting Scientists

Masayuki ASAKAWA (Osaka Univ.)
Takayuki MYO (Osaka Inst. of Tech.)
Masakiyo KITAZAWA (Osaka Univ.)
Takenori FURUMOTO (Yokohama National Univ.)
Makoto OKA (Tokyo Tech.)

Yasuro FUNAKI (Beihang University)
Hidekatsu NEMURA (Univ. of Tsukuba)
Taiichi YAMADA (Kanto Gakuin Univ.)
Yasuo YAMAMOTO (Tsuru Univ.)
Atsushi UMEYA (Nihon Inst. of Tech.)

Tetsuo HYODO (Kyoto Univ.)
 Soichi ISHIKAWA (Hosei Univ.)
 Atsushi HOSAKA (Osaka Univ.)
 Akinobu DOTE (KEK)
 Ying ZHANG (Tianjin University)
 Jinniu HU (Nankai Univ.)
 Wolfram WEISE (TUM)
 Masahiro ISAKA (JSPS)
 Javier ROCAMAZA (Univ. of Milan)
 Xian-Rong ZHOU (East China Normal Univ.)
 Kei KOTAKE (Fukuoka Univ.)
 Hans-Josef SCHULZE (INFN)
 Tingting SUN (Zhengzhou University China)
 Jirina STONE (Univ. of Tennessee Knoxville)
 Chengjun XIA (Zhejiang University)
 Satoru HIRENZAKI (Nara Women's Univ.)
 Kiyomi IKEDA (Niigata Univ.)

Daisuke JIDO (Tokyo Met. Univ.)
 Thomas Adriaan RIJKEN (Radboud Univ. Nijmegen)
 Shoji SHINMURA (Gifu Univ.)
 Kazuma NAKAZAWA (Gifu Univ.)
 Toru SATO (Osaka Univ.)
 Philipp GUBLER (ECT*)
 Toshio MOTOBA (Osaka Elec.-Com. Univ.)
 Shuichi GOJUKI (SGI Japan Ltd.)
 Hyun-Chul KIM (Inha Univ.)
 Petr VESELY (Academy of Science of the Czech Republic Institute of the Nuclear Physics)
 Jean-Marc RICHARD (Lyon University)
 Ulugbek YAKHSHIEV (Inha University)
 Jiwei CUI (Xidian University)
 Satoshi NAKAMURA (Tohoku Univ.)
 Tomokazu FUKUDA (Osaka Elec.-Com. Univ.)

Student Trainees

Akira YOKOTA (Tokyo Tech.)
 Karl SALLMEN (TIT)

Christiane SCHMICKLER (TU Darmstadt)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- S. Maeda, M. Oka, A. Yokota, E. Hiyama and Y.-R. Liu, "A model of charmed baryon-nucleon potential and two- and three-body bound states with charmed baryon", *Progress of Theoretical and experimental Physics*, 2016, 023D02 (2016).*
- H. Togashi, E. Hiyama, Y. Yamamoto and M. Takano, "Equation of state for neutron stars with hyperons using a variational method", *Physical Review C*, 93, 035808 (2016).*
- E. Hiyama, R. Lazauskas, J. Carbonell and M. Kamimura, "Possibility of generating a 4-resonance with a $T=3/2$ isospin 3-neutron force", *Physical Review C* 93, 044004 (2016).*
- H. Togashi, K. Nakazato, Y. Takehara, S. Yamamuro, H. Suzuki and M. Takano, "Nuclear equation of state for core-collapse supernova simulations with realistic nuclear forces", *Nuclear Physics A*, 961, 78, (2017).*

Oral Presentations

[International Conference etc.]

- E. Hiyama, "Recent progress and future prospect of hypernuclear physics --from theory view point--", The 31st Reimei Workshop on Hadron Physics in Extreme Conditions at J-PARC, Tokai, Japan, January, 2016.
- E. Hiyama, "Clustering aspect of hypernuclei", International workshop on Clustering effects of nucleons in nuclei and quarks in multi-quark states, Beijing, China, April, 2016.
- H. Togashi, E. Hiyama and M. Takano, "Hyperon equation of state for supernovae and neutron stars with the variational method", 4th DTA Symposium on Compact stars and gravitational wave astronomy, Mitaka, Japan, May, 2016.
- H. Togashi, "Microscopic equation of state for core-collapse supernovae and neutron stars with realistic nuclear interactions", Key Laboratory Seminar in Institute of Theoretical Physics, Beijing, China, June, 2016.
- H. Togashi, E. Hiyama and M. Takano, "Variational study for the equation of state of hot nuclear matter with hyperons", J-PARC Workshop 2016: From Exotic hadrons to QGP, Incheon, Korea, June, 2016.
- H. Togashi, E. Hiyama and M. Takano, "Variational study of the supernova equation of state with hyperons", 14th Symposium on Nuclei in the Cosmos (NIC XIV), Niigata, Japan, June, 2016.
- H. Togashi, E. Hiyama and M. Takano, "Microscopic equation of state for hot dense matter in core-collapse supernovae", The 10th APCTP-BLTP/JINR-RCNP-RIKEN Joint Workshop on Nuclear and Hadron Physics, Wako, Japan, August, 2016.
- H. Togashi, E. Hiyama and M. Takano, "Variational study of hyperon effects on the nuclear equation of state at finite temperature", International Nuclear Physics Conference (INPC2016), Adelaide, Australia, September, 2016.
- H. Togashi, K. Nakazato, Y. Takehara, S. Yamamuro, H. Suzuki and M. Takano, "New nuclear equation of state for core-collapse supernovae with realistic nuclear forces", International conference on Compact stars and gravitational waves, Kyoto, Japan, October, 2016.
- H. Togashi, E. Hiyama and M. Takano, "Variational study of hyperon mixing in neutron stars and supernova cores", NSMAT 2016, Sendai, Japan, November, 2016.
- H. Togashi, K. Nakazato, Y. Takehara, S. Yamamuro, H. Suzuki and M. Takano, "New table of supernova equation of state using a variational method and its application to astrophysical compact objects", QCS2017, Kyoto, Japan, February, 2017.
- H. Togashi, "Nuclear equation of state with the variational method and the effect of Lambda hyperons in supernova cores", International Workshop on Quantum Many-Body Problems in Particle, Nuclear, and Atomic Physics, Danang, Vietnam, March, 2017.
- H. Togashi, E. Hiyama and M. Takano, "Hyperon stars at zero and finite temperatures with the variational method", SNP2017, Neyagawa, Japan, March, 2017.
- T. Oyamada, E. Hiyama and M. Tachikawa, "Three-Body Gaussian Expansion Method Calculations for He Atom", International Workshop on Quantum Many-Body Problems in Particle, Nuclear, and Atomic Physics, Danang, Vietnam, March, 2017.

- Y. Yamaguchi, A. Giachino, E. Santopinto and A. Hosaka, "Hidden-charm meson-baryon molecules with the five-quark bare field potential", Workshop on Structures and Interactions of Heavy Quark Hadrons, Tokai, Japan, March, 2017.
- Y. Yamaguchi and T. Hyodo, "Quark mass dependence of H-dibaryon in Lambda-Lambda scattering", SNP2017, Neyagawa, Japan, March, 2017.
- S. Watanabe, T. Matsumoto, K. Ogata, and M. Yahiro, "Four- and three-body breakup mechanism of ${}^6\text{Li}$ elastic scattering", 11th International Conference on Clustering Aspects of Nuclear Structure and Dynamics, Napoli, Italy, May, 2016.
- S. Watanabe, K. Minomo, M. Shimada, S. Tagami, M. Kimura, M. Takechi, M. Fukuda, D. Nishimura, T. Suzuki, T. Matsumoto, Y. R. Shimizu, and M. Yahiro, "Deformation and halo structure through reaction cross sections", Direct Reactions with Exotic Beams (DREB2016), Halifax, Canada, July, 2016.
- S. Watanabe, T. Matsumoto, K. Ogata, and M. Yahiro, "Four-body dynamics of ${}^6\text{Li}$ scattering", The 10th APCTP-BLTP/JINR-RCNP-RIKEN Joint Workshop on Nuclear and Hadron Physics, Wako, Japan, August, 2016.
- S. Watanabe, T. Matsumoto, K. Ogata, and M. Yahiro, "Four- and three-body dynamics in ${}^6\text{Li}$ scattering", International Nuclear Physics Conference (INPC2016), Adelaide, Australia, September, 2016.
- S. Watanabe, T. Matsumoto, K. Ogata, and M. Yahiro, "Four-body reaction mechanism of ${}^6\text{Li}$ scattering", Workshop on Nuclear Cluster Physics (WNCP2016), Yokohama, Japan, November, 2016.
- S. Watanabe, K. Ogata, T. Matsumoto, "Dynamic and static core excitation effects on deformed halo nuclei", International Workshop on Quantum Many-Body Problems in Particle, Nuclear, and Atomic Physics, Danang, Vietnam, March, 2017.

[Domestic Conference]

- 富樫甫, "Nuclear equation of state for neutron stars and core-collapse supernovae with the variational method", 筑波大学原子核理論研究室セミナー, 筑波, 6月, 2016.
- 富樫甫, 肥山詠美子, 鷹野正利, "変分法によるハイペロン混合を考慮した有限温度核物質状態方程式の研究", 日本物理学会 2016 年秋季大会, 宮崎, 9月, 2016.
- 富樫甫, 肥山詠美子, 鷹野正利, "変分法による有限温度ハイペロン物質状態方程式と原始中性子星への適用", 日本物理学会第72回年次大会, 大阪, 3月, 2017.
- 富樫甫, "変分法による核物質状態方程式 –Supernova EOS テーブル完成までの道のり–", 研究会「原子核のサイズと状態方程式の物理」, 福岡, 3月, 2017.
- 山口康宏, A. Giachino, 竹内幸子, 瀧澤誠, E. Santopinto, 保坂淳, "反 D 中間子とチャームバリオンによるハドロン分子状態の解析", 日本物理学会第72回年次大会, 大阪, 3月, 2017.
- 渡邊慎, " ${}^6\text{Li}$ 弾性散乱における動的性質", 法政大学セミナー, 東京, 4月, 2016.
- 渡邊慎, "CDCC calculations of ${}^6\text{Li}$ elastic scattering: Effects of four- and three-body breakup channels", 東京工業大学セミナー, 東京, 6月, 2016.
- 渡邊慎, "反応断面積で探る核構造研究の進展", 日本物理学会 2016 年秋季大会, 宮崎, 9月, 2016.
- 渡邊慎, "Reaction cross sections as a probe of deformation and shell structures", RIKEN RIBF Nuclear Physics Seminar, 埼玉, 12月, 2016.
- 渡邊慎, "変形や殻進化のプロープとしての反応断面積", 法政大学セミナー, 東京, 12月, 2016.
- 渡邊慎, 松本琢磨, 緒方一介, 八尋正信, "連続状態離散化チャネル結合法を用いた弱束縛原子核の記述", 研究会「クラスター・平均場 の両側面からみる原子核構造の多様性とそのダイナミクス」, 大阪, 1月, 2017.
- 渡邊慎, "変形ハロー核の動的背性質と静的性質", 九大原子核セミナー, 福岡, 3月, 2017.
- 渡邊慎, 緒方一介, 松本琢磨, "1 中性子ハロー核に対する芯核励起の効果", 日本物理学会第72回年次大会, 大阪, 3月, 2017.

Sub Nuclear System Research Division Radiation Laboratory

1. Abstract

Nucleons, such as protons and neutrons, are a bound state of constituent quarks glued together with gluons. The detail structure of nucleons, however, is not well understood yet. Especially the mechanism to build up the spin of proton, which is $1/2$, is a major problem in physics of the strong force. The research goal of Radiation Laboratory is to solve this fundamental question using the world first polarized-proton collider, realized at RHIC in Brookhaven National Laboratory (BNL) in USA. RHIC stands for Relativistic Heavy Ion Collider, aiming also to create Quark Gluon Plasma, the state of Universe just after the Big Bang, and study its property. RIKEN-BNL Research Center (RBRC) directed by S. Aronson carries our core team at BNL for those exciting researches using the PHENIX detector. We have observed that the proton spin carried by gluons is finite and indeed sizable. We also identified W bosons in the electron/positron decay channel and in the muon decay channel, with which we are about to conclude how much anti-quarks carry the proton spin. Other than the activities at RHIC we are preparing and starting new experiments at J-PARC and Fermilab to study the nature of hadron. We are also performing technical developments such as novel ion sources, fine-pitch silicon pixel detectors and high-performance trigger electronics.

2. Major Research Subjects

- 1) Spin physics with relativistic polarized-proton collisions at RHIC
- 2) Study of nuclear matter at high temperature and/or at high density
- 3) Technical developments on radiation detectors and accelerators

3. Summary of Research Activity

(1) Experimental study of spin structure of proton using RHIC polarized proton collider

[See also RIKEN-BNL Research Center Experimental Group for the activities at BNL]

The previously published central pion double spin asymmetries at the highest collision energies at RHIC of 510 GeV have been augmented with the publication of the first forward double spin asymmetries on J/Psi mesons in 2016 by PHENIX. The forward rapidities increase the probed gluon momentum fractions at RHIC down to regions not accessible until the planned electron-ion collider. While statistically limited, there is an indication of a positive gluon spin contribution also at such low momentum fractions and together with the previous measurements would indicate a rather dominant gluon contribution to the nucleon spin.

With the valence quark spin contribution already reasonably well known, the contributions from sea quarks and orbital angular momenta remain to be understood. PHENIX has collected data to access the sea quark polarizations via leptonic decays of W bosons. Preliminary results have been obtained using all the data taken so far. The central rapidity electron decay channel results have been published while the forward muon decay channel results are now finalized and will be published soon.

While orbital angular momentum cannot be directly accessed at RHIC, several transverse spin phenomena have been observed which relate to orbital angular momentum and the three-dimensional structure of the nucleon. These phenomena by themselves have become a major field of research as the dynamics of the strong interaction. During the 2015 RHIC operation, collisions of transversely polarized protons with Au and Al nuclei were provided for the first time. The observed asymmetries in very forward neutron production showed surprisingly strong nuclear-size dependence. It could be explained by a contribution of electromagnetic interactions which may be sizable for heavy nuclei. The results have been prepared for publication.

To further investigate these effects the PHENIX experiment proposes substantial detector upgrades to go along the expected accelerator improvements. The proposed upgrade replaces the present magnet with the Babar solenoid, and we are considering to build an open-geometry forward spectrometer which has both hadronic and electromagnetic calorimetry as well as tracking, designed with a focus on the measurement of charged tracks and fully reconstructed jets in p-p and p-A collisions. Key measurements of this upgrade are forward Drell-Yan di-electrons to study sea quarks in nuclei and transverse-spin asymmetries for forward inclusive jets to study spin-momentum correlations in the proton.

As a pilot measurement, some of us are participating in the Fermilab Sea Quest experiment which has been collecting muon pairs using a 120-GeV unpolarized proton at Fermilab. By measuring the unpolarized Drell-Yan process, we can study quark spin-orbit effects which supplement what can be learned in the polarized Drell-Yan process. For many jet related measurements fragmentation functions are necessary to gain spin and or flavor sensitivity. Those are currently extracted by some of us using the Belle data. In addition to using the fragmentation results with RHIC measurements, they will also provide the basis of several of the key measurements to be performed at the electron-ion collider.

(2) Experimental study of quark-gluon plasma using RHIC heavy ion collider

[See also RIKEN-BNL Research Center Experimental Group for the activities at BNL]

We have completed several key measurements in the study of quark-gluon plasma at RHIC. As the top of them, we lead the analysis of the first thermal photon measurement in heavy ion collisions. The measurement indicates that the initial temperature reached in the central Au+Au collision at 200 GeV is about 350 MeV, far above the expected transition temperature $T_c \sim 170$ MeV, from hadronic phase to quark-gluon plasma. This work was rewarded by Nishina Memorial Prize given to Y. Akiba in 2011. We also measured direct photons in d+Au and direct photon flow strength v_2 and v_3 in Au+Au.

We lead measurement of heavy quark (charm and bottom) using VTX, a 4 layer silicon vertex tracker which we jointly constructed with US DOE. The detector was installed in PHENIX in 2011. Analysis of heavy quark using the silicon vertex detector is ongoing. The final results of the 2011 run was published in Physical Review C (PRC93, 034904 (2016)). This is the

first publication from VTX. The result showed that the electrons from bottom quark decay is suppressed for $p_T > 4$ GeV/c, but the suppression factor is smaller than that of charm decay electrons for $3 < p_T < 4$ GeV/c. This is the first observation of bottom electron suppression in heavy ion collisions, and the first result that shows the bottom and charm suppression is different. PHENIX recorded approximately 10 times more data of Au+Au collisions in the 2014 run than the 2011 run. We report preliminary results of about 1/4 of the 2014 data in QM2017 conference, confirming the published results with 3 times of statistics. PHENIX recorded high statistics p+p and p+A data in 2015, and the doubled the Au+Au in 2016. PHENIX concluded its data taking in the 2016 run.

In Wako we are operating a cluster computer system (CCJ) specialized to analyze huge data sets taken with the PHENIX detector. It consists of 28 nodes (18 old nodes and 10 new nodes) each of which has two CPUs and 10 sets of local disk for data repository (old node: quad-core CPU, 1TB disk, new node: six-core CPU, 2TB disk). There are 264 CPU cores and 380 TB disks in total. This configuration ensures the fastest disk I/O when each job is assigned to the node where the required data sets are stored. It is also important that this scheme doesn't require an expensive RAID system and network. Through this development we have established a fast and cost-effective solution in analyzing massive data.

0.9 PB of data for the PHENIX experiment is stored in a hierarchical storage system which is a part of HOKUSAI GreatWave supercomputer system operated by the Advanced Center for Computing and Communication (ACCC). ACCC also provides 10 dedicated PC nodes for CCJ.

(3) Study of properties of mesons and exotic hadrons with domestic accelerators

Preparation of the experiment E16 at J-PARC 50-GeV PS is underway with several Grant-in-Aids. This experiment aims to perform a systematic study of the spectral modification of low-mass vector mesons in nuclei to explore the chiral symmetry breaking in dense nuclear matter, namely, the mechanism proposed by Nambu to generate the major part of hadron mass.

Gas Electron Multiplier (GEM) technology is adopted for the two key detectors, GEM Tracker (GTR) and Hadron-blind Cherenkov detector (HBD). With cooperation with Japanese industries, large GEM foils (30cm x 30cm, the world-largest size at that time) were newly developed. We have joined the CERN-RD51 collaboration for the joint-development of the GEM and its readout technology. For the electron ID, lead-glass calorimeter (LG) is also used. The lead-glass blocks are recycled from the TOPAZ experiment. The development phase of the detectors is over and we are in the production phase. The parts for six modules of GTR and two modules of HBD are delivered and some of their assemblies have started. The "Scalable Readout System" developed by RD51 is adopted and purchased for the readout electronics modules of GEM. For LG readout, a flush ADC module using DRS4 ASIC has been developed and the first batch of production was delivered. Trigger logic modules and the trigger preamp ASIC are still under the test.

Due to the budgetary limitation, we aim to install a part of detectors, eight modules of GTR/HBD/LG out of 26 modules in the full installation, at the beginning of experiment. The construction of the beam line will be completed in 2019, with a significant delay from the original plan which aimed for March 2016. The yield of phi mesons and sensitivity to the possible spectral modification with the eight-module configuration under the expected high-rate environment was evaluated by the Geant4 simulation including the achieved performance of each detector and by using a newly-developed GEM-signal simulator.

(4) Detector development for PHENIX experiment

The PHENIX experiment proposes substantial detector upgrades to go along the expected accelerator improvements, including the future electron-ion collider "eRHIC". The present PHENIX detector is repurposed to the sPHENIX (super PHENIX) detector replacing the present magnet with the Babar solenoid magnet at SLAC, and will be covered by the hadronic calorimeter which was absent in present RHIC experiment. The sPHENIX project is now funded by DOE, and RIKEN will participate in the construction of the inner silicon tracker.

We are considering to build an open-geometry forward spectrometer to be added to the sPHENIX detector. With this addition the fsPHENIX (sPHENIX with forward) detector will have both hadronic and electromagnetic calorimetry as well as tracking in the forward rapidity, which is suited to full reconstruction of p+A and p+p collisions. The fsPHENIX detector will further improved to the ePHENIX detector in the era of eRHIC.

(5) Development of beam source

Under the collaboration with Brookhaven National Laboratory, we are developing various techniques for a laser ion source (LIS) to provide high quality heavy-ion beams to the accelerators. In 2014, we installed a new LIS which provides various species of singly charged ions to the RHIC-AGS complex. Since the beam commissioning was very successful, the LIS was upgraded to provide high repetition rate Au beam to the RHIC in 2015. At the moment, all the ion beams except proton, neon and uranium are being supplied by the LIS and the capability of the fast switching species contributes enhanced versatility and uniqueness of the at the RHIC-AGS. Besides, we are studying the highly charged ionization and magnetic field confinement of laser ablation plasma, and testing a linear accelerator model which selectively accelerates charge states.

Members

Chief Scientist (Lab. Head)

Hideto EN'YO (Director, RNC)

Vice Chief Scientist

Yasuyuki AKIBA

Research & Technical Scientists

Yasushi WATANABE (Senior Research Scientist)
Yuji GOTO (Senior Research Scientist)
Itaru NAKAGAWA (Senior Research Scientist)
Satoshi YOKKAICHI (Senior Research Scientist)

Ralf SEIDL (Senior Research Scientist)
Hiroaki ONISHI (Senior Research Scientist, concurrent;
Advanced Meson Science Lab.)

Research Associates

Yusuke KOMATSU

Foreign Postdoctoral Researchers

Sanghwa PARK

Junior Research Associates

Yuko SEKIGUCHI (Univ. of Tokyo)
Koki KANNO (Univ. of Tokyo)
Wataru NAKAI (Univ. of Tokyo)
Tomoya HOSHINO (Hiroshima Univ.)
Shunsuke IKEDA (Tokyo Tech.)
Masafumi KUMAKI (Waseda Univ.)

Satoshi YANO (Hiroshima Univ.)
Daisuke WATANABE (Univ. of Tsukuba)
Kohei TERASAKI (Univ. of Tokyo)
Kazuya NAGASHIMA (Hiroshima Univ.)
Hikari MURAKAMI (Univ. of Tokyo)
Hiroshi NAKAGOMI (Univ. of Tsukuba)

International Program Associates

Inseok YOON (Seoul Nat'l Univ.)
Minjung KIM (Seoul Nat'l Univ.)
Minho KIM (Korea Univ.)

Taebong MOON (Yonsei Univ.)
Se Young HAN (Ewha Womans Univ.)
Jaehee YOO (Korea University)

Senior Visiting Scientists

Toshiaki SHIBATA (Tokyo Tech.)

Takashi NAKANO (Osaka Univ.)

Visiting Scientists

Kyoichiro OZAWA (KEK)
Susumu SATO (JAEA)
Megumi NARUKI (Kyoto Univ.)
Yoshinori FUKAO (KEK)
Michiko SEKIMOTO (KEK)
Kiyoshi TANIDA (JAEA)
Hirotugu KASHIWAGI (National Institute for
Quantum and Radiological Science and Technology)
Taku GUNJI (Univ. of Tokyo)
Junpei TAKANO (KEK)
Kazuya AOKI (KEK)
Masashi KANETA (Tohoku Univ.)
Munehisa OHTANI (Kyorin Univ.)
Yorito YAMAGUCHI (Univ. of Tokyo)
Youngil KWON (Yonsei Univ.)
Kenichi NAKANO (Tokyo Tech.)
Maya SHIMOMURA (Nara Women's Univ.)
Noriyosu HAYASHIZAKI (Tokyo Tech.)

Yuhei MORINO (KEK)
Kenji FUKUSHIMA (Univ. of Tokyo)
Ryo ICHIMIYA (KEK)
Tomohiro NISHITANI (Nagoya Univ.)
Tomonori TAKAHASHI (Osaka Univ.)
Tsutomu MIBE (KEK)
Makoto KUWAHARA (Nagoya Univ.)
Masahiro OKAMURA (BNL)
Shunzo KUMANO (KEK)
Bentz WOLFGANG (Tokai Univ.)
Alexander BAZILEVSKY (BNL)
Shin-ya SAWADA (KEK)
Ryotaro MUTO (KEK)
Masanori HIRAI (Tokyo Univ. of Sci.)
Kenta SHIGAKI (Hiroshima Univ.)
Sanghwa PARK (Stony Brook University)
Robert JAMESON (Goethe Universitat Frankfurt)
Takuya SUZUKI (Waseda Univ.)

Student Trainees

Shoichiro NISHIMURA (Univ. of Tokyo)
Yuki OBARA (Univ. of Tokyo)
Mana UENO (Nagoya Univ.)
Qidong Zhou (Nagoya Univ.)
Seiya MIYATA (Univ. of Tokyo)

Yosuke UEDA (Hiroshima Univ.)
Key NAGAI (Tokyo Tech.)
Koji IGARASHI (Tokyo Tech.)
Kenta SATO (Nagoya Univ.)
Kazuya NAGASHIMA (Hiroshima Univ.)

Interns

Junsang PARK (Seoul Nat'l Univ.)
Daisuke NEMOTO (Rikkyo Univ.)
Jaehee YOO (Korea University)
Hidekazu MASUDA (Rikkyo Univ.)

Naoki FUJIYAMA (Rikkyo Univ.)
Ryota KAWASHIMA (Rikkyo Univ.)
Minho KIM (Korea Univ.)

Part-time Workers

Toru NAGASHIMA (Rikkyo Univ.)
 Hidemitsu ASANO
 Wataru NAKAI (Univ. of Tokyo)
 Yusuke KOMATSU

Hidekazu MASUDA (Rikkyo Univ.)
 Koki KANNO (Univ. of Tokyo)
 Michiko SEKIMOTO

Assistant

Keiko SUZUKI

List of Publications & Presentations**Publications**

[Journal]

(Original Papers) *Subject to Peer Review

- Measurement of the Vector Meson Spectral Modification in the Nuclear Medium at J-PARC. By Yusuke Komatsu et al.. JPS Conf.Proc. 13 (2017) 020005.
- Angular decay coefficients of J/ψ mesons at forward rapidity from p+p collisions at $\sqrt{s}=510$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. D95 (2017) 092003.
- Measurement of the relative yields of $\psi(2S)$ to $\psi(1S)$ mesons produced at forward and backward rapidity in p+p, p+Al, p+Au, and $^3\text{He}+\text{Au}$ collisions at $\sqrt{s_{NN}}=200$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. C95 (2017) no.3, 034904.
- Nonperturbative-transverse-momentum effects and evolution in dihadron and direct photon-hadron angular correlations in p+p collisions at $\sqrt{s}=510$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. D95 (2017) no.7, 072002.
- Measurement of long-range angular correlations and azimuthal anisotropies in high-multiplicity p+Au collisions at $\sqrt{s_{NN}}=200$ GeV. By C. Aidala et al. Phys.Rev. C95 (2017) no.3, 034910.
- Measurements of double-helicity asymmetries in inclusive J/ψ production in longitudinally polarized p+p collisions at $\sqrt{s}=510$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. D94 (2016) no.11, 112008.
- Precision study of the $\eta \rightarrow \mu^+\mu^-\gamma$ and $\omega \rightarrow \mu^+\mu^-\pi^0$ electromagnetic transition form-factors and of the $\rho \rightarrow \mu^+\mu^-$ line shape in NA60. By NA60 Collaboration (R. Arnaldi et al.). Phys.Lett. B757 (2016) 437-444.
- Inclusive cross section and double-helicity asymmetry for π^0 production at midrapidity in p+p collisions at $\sqrt{s}=510$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. D93 (2016) no.1, 011501.
- Azimuthally anisotropic emission of low-momentum direct photons in Au+Au collisions at $\sqrt{s_{NN}}=200$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. C94 (2016) no.6, 064901.
- Scaling properties of fractional momentum loss of high- p_T hadrons in nucleus-nucleus collisions at $\sqrt{s_{NN}}$ from 62.4 GeV to 2.76 TeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. C93 (2016) no.2, 024911.
- Transverse energy production and charged-particle multiplicity at midrapidity in various systems from $\sqrt{s_{NN}}=7.7$ to 200 GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. C93 (2016) no.2, 024901.
- ϕ meson production in the forward/backward rapidity region in Cu+Au collisions at $\sqrt{s_{NN}}=200$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. C93 (2016) no.2, 024904.
- Centrality-dependent modification of jet-production rates in deuteron-gold collisions at $\sqrt{s_{NN}}=200$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev.Lett. 116 (2016) no.12, 122301.
- Measurement of higher cumulants of net-charge multiplicity distributions in Au+Au collisions at $\sqrt{s_{NN}}=7.7-200$ GeV. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. C93 (2016) no.1, 011901.
- Measurement of parity-violating spin asymmetries in W^{+-} production at midrapidity in longitudinally polarized p+p collisions. By PHENIX Collaboration (A. Adare et al.). Phys.Rev. D93 (2016) no.5, 051103.
- Performance of the Low Charge State Laser Ion Source in BNL. By Masahiro Okamura et al. 10.18429/JACoW-HIAT2015-THM1C03.
- Control of Laser Ablation Plasma by Pulsed Magnetic Field for Heavy Ion Beam Production. By Shunsuke Ikeda et al. 10.18429/JACoW-HIAT2015-WEPB28.
- Development of a hadron blind detector using a finely segmented pad readout. By Koki Kanno et al. Nuclear Instruments and Methods in Physics Research A, 819 (2016) 20-24.

[Proceedings]

(Original Papers) *Subject to Peer Review

- Polarized nucleon-structure physics at RHIC-PHENIX. By Yuji Goto (PHENIX Collaboration). Proceedings of Science (Hadron 2013) 155.
- Cross Section and Asymmetry Measurement of Very Forward Neutral Particle Production at RHIC. By Yuji Goto (RHICf collaboration). International Journal of Modern Physics, Conference Series 40, 1660110 (2016). Spin Physics. By Ralf Seidl, PoS DIS2016 (2016) 007
- Measurement of double helicity asymmetries (ALL) at mid- and forward rapidities in longitudinally polarized p+p collisions at $s^{\sqrt{}}=510$ GeV with PHENIX experiment. By Ralf Seidl and Taebong Moon, PoS DIS2016 (2016) 007

Oral Presentations

[International Conference etc.] [Domestic Conference]

- S. Yokkaichi (JPARC E16 collaboration), "Systematic study of the vector meson spectral modification in the nuclear medium at J-PARC" in MENU2016, July 27th, 2016 at Kyoto, Japan.
- S. Yokkaichi (JPARC E16 collaboration), "Measurements of spectral change of vector mesons in nuclear matter" in HINT2016, Dec 05th, 2016 at Tokai, Japan.
- Yuji Goto, "GPDs and TMDs at Electron-Ion Collider" in Hadron Tomography at J-PARC and KEKB, Jan. 6th, 2017 at Tsukuba, Japan.
- Ralf Seidl, "Spin Physics" in 24th International Workshop on Deep-Inelastic Scattering and Related Subjects, Apr. 11th, 2016, at Hamburg,

Germany.

Ralf Seidl, "Measurement of double helicity asymmetries (A_{LL}) in π^0 and π^+ production at mid-rapidity in longitudinally polarized p+p collisions at $\sqrt{s} = 510$ GeV with PHENIX experiment" in 24th International Workshop on Deep-Inelastic Scattering and Related Subjects, Apr. 13th, 2016, at Hamburg, Germany.

Ralf Seidl, "RHIC spin and Belle" in Workshop on hadron tomography, July 31st, 2016 at Kyoto, Japan.

Ralf Seidl, "The fragmentation function program at Belle" in 22th international spin symposium, Sep. 28th, 2016 at Urbana-Champaign, IL, USA.

Ralf Seidl, "The fragmentation function program at Belle" in 22th international spin symposium, Sep. 28th, 2016 at Urbana-Champaign, IL, USA.

Ralf Seidl, "Fragmentation function measurements in Belle" in KEK Hadron and nuclear physics workshop, Jan. 7th at Tsukuba, Japan.

[Domestic Conference]

Yuji Goto (RHICf collaboration), "RHICf experiment: Very forward measurement of particle production at RHIC" in Japan Physical Society Meeting, 20th March, 2016 at Sendai, Japan

Yuji Goto (PHENIX Collaboration), "Double-helicity asymmetry measurement of J/ψ production in $\sqrt{s} = 510$ GeV polarized p+p collisions at PHENIX" in Japan Physical Society Meeting, Sep. 23rd, 2016 at Miyazaki, Japan

Ralf Seidl, "Fragmentation function measurements in Belle" in JPS Fall Meeting, Sep. 23rd, 2016 at Miyazaki, Japan.

Sub Nuclear System Research Division Advanced Meson Science Laboratory

1. Abstract

Particles like muons, pions, and kaons have finite life times, so they do not exist in natural nuclei or matters. By implanting these particles into nuclei/matters, exotic phenomena in various objects can be studied from new point of view.

Kaon is the second lightest meson, which has strange quark as a constituent quark. It is expected that if one embed mesons into nuclei, the sizes of the nuclei become smaller and one can form a high-density object beyond the normal nuclear density. Study of this object could lead to better understanding of the origin of the mass of the matter, and may reveal the quark degree of freedom beyond the quark-confinement. The other example is the weak interaction in nuclear matter. It can only be studied by the weak decay of hypernuclei, which have Lambda particle in the nuclei.

Muon provides even wider scope of studies, covering condensed matter physics as well as nuclear and atomic physics, and we are trying to extend the application field further into chemical and biological studies. For instance, stopping positively charged muon in a material, we obtain information on the magnetic properties or the local field at the muon trapped site (μ SR). Injecting negatively charged muon to hydrogen gas, muonic hydrogen atom (μ p) is formed. We are planning to measure μ p hyperfine splitting energy to measure proton magnetic radius, which is complementary quantity to the proton charge radius and its puzzle lately attracts strong interest. We are also interested in precision measurement of muon property itself, such as muon anomalous magnetic moment ($g-2$).

In our research, we introduce different kind of impurities into nuclei / matters, and study new states of matter, new phenomena, or the object properties.

2. Major Research Subjects

- (1) Study of meson property and interaction in nuclei
- (2) Origin of matter mass / quark degree of freedom in nuclei
- (3) Condensed matter and material studies with muon
- (4) Nuclear and particle physics studies via muonic hydrogen
- (5) Development of ultra cold muon beam, and its application from material science to particle physics

3. Summary of Research Activity

(1) Hadron physics at J-PARC, RIKEN-RIBF, GSI and Spring-8

Kaon and pion will shed a new insight to the nuclear physics. The recent discovery of deeply bound pionic atom enables us to investigate the properties of mesons in nuclear matter. At RIKEN-RIBF, we are preparing precise experimental study of the pionic atom. We have also started next generation kaon experiments (E15 and E31) at J-PARC. In these experiments, we are aiming to determine the $K^{\text{bar}}N$ interaction precisely, clarify the nature of kaon in nuclei, and $\Lambda(1405)$ that could be $K^{\text{bar}}p$ bound state. At Spring-8 and at GSI, we are also aiming to study omega and eta' nuclei. By these experiments, we aim to be a world-leading scientific research group using these light meta-stable particles.

(1-A) Deeply bound kaonic nuclei

We have performed experimental exploration of theoretically predicted deeply bound kaonic nuclear states, such as the $\langle K^{\text{bar}}pp \rangle$ bound state. One of the most interesting features of the kaonic nucleus is the strong attraction of the $K^{\text{bar}}N$ interaction. Because of this strong attraction, the kaon in nucleus will attract surrounding nucleons resulting in extremely high-density object, which is several times larger than normal nuclear density. Measurement of the kaon properties at such high energy density will provide precious information on the origin of hadron masses and the chiral symmetry breaking and its partial restoration.

The experiment J-PARC E15 aims to identify the nature of the $\langle K^{\text{bar}}pp \rangle$ bound state by the in-flight ${}^3\text{He}(K^-, n)$ reaction, which allows us to investigate such state both in the formation via the missing-mass spectroscopy using the emitted neutron, and in its decay via the invariant-mass spectroscopy by detecting decay particles from $\langle K^{\text{bar}}pp \rangle$. For the experiment, we constructed a dedicated spectrometer system at the secondary beam-line, K1.8BR, in the hadron hall of J-PARC.

The first physics data-taking was carried out in March and May, 2013 with 6×10^9 kaons on ${}^3\text{He}$ target, corresponding to a $\sim 1\%$ of the approved proposal. We successfully obtained semi-inclusive ${}^3\text{He}(K^-, n)$ X missing-mass spectrum, and found a tail structure just below the mass threshold of $(K^- + p + p)$ which cannot be explained by well-known processes and backgrounds. We also demonstrated an exclusive analysis by reconstructing ${}^3\text{He}(K^-, \Lambda p) n$ events. To derive more information on the $K^{\text{bar}}N$ interaction by the exclusive measurement, we carried out the second physics data-taking in November-December, 2015 with 43×10^9 kaon on ${}^3\text{He}$ target, in which 7 times more data was accumulated. We have been analyzing the new data set focusing on the ${}^3\text{He}(K^-, \Lambda p)n$ channel, and a significant bump structure below the $(K^- + p + p)$ mass threshold has been observed in the Λp invariant-mass spectrum. To confirm whether or not the observed structure is the $\langle K^{\text{bar}}pp \rangle$ bound state, further analysis is currently in progress.

(1-B) Precision X-ray measurement of kaonic atom

Simultaneously with the above experiment (1-A), we have performed an X-ray spectroscopy of atomic $3d \rightarrow 2p$ transition of negatively charged K-mesons captured by helium atoms. However, the energy resolution of the conventional semiconductor spectrometers is insufficient to see the K^- - nucleus potential observed by atomic levels at zero energy. This is closely related to the problem on the existence of deeply bound kaonic states in nuclei, well below the atomic levels, and this is one of the biggest problems in strangeness nuclear physics. Aiming to provide a breakthrough from atomic level observation, we will perform high-resolution X-ray spectroscopy of kaonic atoms at a J-PARC hadron beam line using a novel cryogenic X-ray spectrometer: an array of superconducting transition-edge-sensor (TES) micro-calorimeters. The spectrometer offers unprecedented energy resolution, which is about two orders of magnitude better than that of

conventional semiconductor detectors. A spectrometer array of 240 pixels will have an effective area of about 20 mm². Very recently, we have performed a proof-of-principle experiment by measuring pionic-atom X rays with a TES array at the PiM1 beam line at the Paul Scherrer Institut (PSI), and successfully demonstrated the feasibility of TES-based exotic-atom x-ray spectroscopy in a hadron-beam environment. Based on the results, we are preparing for the kaonic-atom experiment at J-PARC.

Another important X-ray measurement of kaonic atom would be $2p \rightarrow 1s$ transition of kaonic deuteron. We have measured same transition of kaonic hydrogen, but the width and shift from electro-magnetic (EM) value reflect only isospin average of the $K^{\text{bar}}N$ interaction. We can resolve isospin dependence of the strong interaction by the measurement. We are presently preparing a proposal to J-PARC PAC to measure kaonic deuteron X-ray.

(1-C) Deeply bound pionic atoms and η' mesonic nuclei

We have been working on precision spectroscopy of pionic atoms systematically, that leads to understanding of hidden non-trivial structure of the vacuum and origin of hadron masses. The precision data set stringent constraints on the chiral condensate at nuclear medium. We are presently preparing for the systematic high precision measurement of pionic tin isotopes at RIBF. A pilot experiment was performed in 2010, and showed a very good performance of the system. A main experiment was performed in 2014 and we achieved unprecedented resolution with much reduced systematic errors. A new experiment is being prepared with a improved setup.

We are also working on spectroscopy of η' mesonic nuclei in GSI/FAIR. Theoretically, peculiarly large mass of η' is attributed to UA(1) symmetry and chiral symmetry breaking. As a result, large binding energy is expected for η' meson bound states in nuclei (η' -mesonic nuclei). First experiment was conducted in 2014 in GSI. We accumulated very high quality data in terms of the spectral resolution and the statistics and set constraints in the η' -nucleus interaction.

(1-D) Hadron physics at SPring-8/LEPS2

Photo production of meson in nuclei is known to be a powerful tool to investigate property of the hadron in nuclear media. For this study, we started a new experimental project named LEPS2 (Laser Electron Photon at SPring-8 II) in this RIKEN Mid-term. The experimental hutch for LEPS2 at SPring-8 was constructed in March 2011, lead by RIKEN. The Large solenoid spectrometer magnet (2.96 m inner diameter x 2.22 m length) was successfully transported from BNL (US) to SPring-8 and installed into LEPS2 hutch in 2011.

One of the first physics programs is photo-production of η' in nuclei. Especially (γ, p) is most important reaction channel, where we can perform missing mass spectroscopy by detecting forward going proton. One of the big advantages of photo-production reaction is that the initial reaction is expected to be much cleaner than the hadron channel.

Detector construction for the first physics program is in progress. The 4π Electro-Magnetic calorimeter has been constructed and proton counter to detect forward going proton produced via (γ, p) reaction was partially installed in November 2013. Engineering run for the first experiment was performed in December 2013 to confirm performance of our detector system. Detector construction have been completed and 1st physics data taking was starting since 2014. Based on data collected, detail analysis to extract signal of η' -mesic nucleus, photoproduction of η etc are in progress.

(2) Muon science at RIKEN-RAL branch

The research area ranges over particle physics, condensed matter studies, chemistry and life science. Our core activities are based on the RIKEN-RAL Muon Facility located at the Rutherford-Appleton Laboratory (UK), which provides intense pulsed-muon beams. We have variety of important research activities such as particle / nuclear physics studies with muon's spin and condensed matter physics by muon spin rotation / relaxation / resonance (μ SR).

(2-A) Condensed matter/materials studies with μ SR

Two μ SR spectrometer named CHRONUS and ARGUS are working together with ISIS standard data acquisition system, DAELI, with the front-end control system, SECI. Running a pulse-kicker system, we can perform two independent μ SR experiments in Port-2 and 4 at the same time, splitting double-pulse to share beam between the two.

Among our scientific activities on μ SR studies from year 2015 to 2017, following five subjects of material sciences are most important achievements at the RIKEN-RAL muon facility:

- 1) Novel superconducting state having partial nodal gaps in the two-dimensional organic superconductor λ -[BETS]₂GaCl₄.
- 2) Tiny magnetic moments and spin structures of Ir⁴⁺, Nd³⁺ in carrier doped pyrochlore iridates (Nd_{1-x}Ca_x)₂Ir₂O₇.
- 3) Magnetism and spin dynamics in superoxides CsO₂, NaO₂ and RbO₂.
- 4) Magnetic properties of the nano-cluster gold in the border of macro- and micro- scale
- 5) Effects of the spatial distributions of magnetic moments and muon positions estimated from density functional theory (DFT) and dipole-field calculations.

(2-B) Nuclear and particle physics studies via ultra cold muon beam and muonic atoms

If we can improve muon beam emittance, timing and energy dispersion (*so-called* "ultra-slow muon"), then the capability of μ SR study will be drastically improved. The ultra-slow muon beam can stop in thin foil, multi-layered materials and artificial lattices, so one can apply the μ SR techniques to surface and interface science. The development of ultra-slow muon beam is also very important as the source of ultra-cold (pencil-like small emittance) muon beam for muon g-2 measurement. Therefore, we have been working on R&D study.

We have been working on the "ultra-slow muon" generation by laser ionization of muonium atoms in vacuum (bound system of μ^+ and electron) emitted after stopping "surface muon beam" in a material. In this mid-term, we are developing two key components, namely, high efficiency muonium generator at room temperature and high intensity ionization laser. The study of muonium generator has been done in collaboration with TRIUMF and KEK. In 2013, we demonstrated at least 10 times increase of the muonium emission efficiency by fabricating fine laser drill-holes on the surface of silica aerogel. We also developed a high power Lyman- α laser in collaboration with laser group at RIKEN. In this laser development, we succeeded to synthesize novel laser crystal Nd:YAG, which has an ideal wavelength property for laser amplification to generate Lyman- α by four-wave mixing in Kr gas cell. We already achieved 10 times increase of

Lyman- α generation than before. We are working on the growth of large laser amplifying crystal so we can increase the Lyman- α by 10 times further. In order to fully apply these new developments to slow muon generation, we installed a new ultra-slow muon source chamber dedicated for silica aerogel in Port-3 with new features such as spin manipulation. We already demonstrated a method of maximizing the muon stopping in silica aerogel even under muon decay background from surrounding materials by using the spin rotation of muonium formed in aerogel.

Concerning the muonic atom, we are planning a new precise measurement of proton radius. A large discrepancy was found recently in the proton charge radius between the new precise value from muonic hydrogen atom at PSI and those from normal hydrogen spectroscopy and e-p scattering. We propose a precise measurement of Zemach radius (with charge and magnetic distributions combined) using the laser spectroscopy of hyperfine splitting energy in the muonic hydrogen atom. Preparation of the hydrogen target, mid-infrared laser and muon spin polarization detectors is in progress. We measured the delayed background in the detectors, which could overshadow the signal. We confirmed it is low enough if a coincidence detection is used. Port-1, previously used for muon catalysed fusion, is now being converted for the dedicated use by the proton radius measurement involving laser.

Members

Chief Scientist (Lab. Head)

Masahiko IWASAKI

Vice Chief Scientist

Katsuhiko ISHIDA

Research & Technical Scientists

Isao WATANABE (Senior Research Scientist)
Kenta ITAHASHI (Senior Research Scientist)
Haruhiko OUTA (Senior Research Scientist)

Hiroaki OHNISHI (Senior Research Scientist)
Fuminori SAKUMA (Senior Research Scientist)
Yue MA (Research Scientist)

Contract Researchers

Masaharu SATO

Special Postdoctoral Researchers

Tadashi HASHIMOTO
Sohtaro KANDA

Takahiro NISHI

Research Consultants

Yoshinori AKAISHI
Hironari MIYAZAWA

Masayasu KAMIMURA
Eiichi YAGI

Junior Research Associates

Kazuo TANAKA (Univ. of Tokyo)
Takuya SHIBUKAWA (Univ. of Tokyo)
Hirotomo HAMANO (Osaka Univ.)
Nam TRAN (Osaka Univ.)
Fahmi ASTUTI (Hokkaido Univ.)
Ryo KITAMURA (Univ. of Tokyo)

Dita PUSPITA SARI (Osaka Univ.)
Retno ASIH (Osaka Univ.)
Shu AIKAWA (Tokyo Tech.)
Shintaro TANAKA (Osaka Univ.)
Juila ANGEL (Hokkaido Univ.)

International Program Associates

Edi SUPRAYOGA (Bandung Inst. Tech.)
Zhang QI (Lanzhou Univ.)
Noraina ADAM (Universiti Sains Malaysia)

Sungwon YOON (Catholic Univ. of Korea)
Saidah Sakinah Mohd Tajudin (Universiti Sains Malaysia)

Senior Visiting Scientist

Kazuhiro TANAKA (KEK)

Visiting Scientists

Toshimitsu YAMAZAKI (Univ. of Tokyo)
Mototsugu MIHARA (Osaka Univ.)
Donald George FLEMING (Univ. of British Columbia/TRIUMF)
Yasuo NOZUE (Osaka Univ.)
Takehito NAKANO (Osaka Univ.)
Tadashi ADACHI (Sophia Univ.)
Zyun Francis EZAWA (Tohoku Univ.)
Yasuyuki ISHII (Shibaura Inst. of Tech.)
Johann ZMESKAL (SMI)
Risidiana (UNPAD)
Norimichi KOJIMA (Univ. of Tokyo)
Takao SUZUKI (Shibaura Inst. of Tech.)

Masami IIO (KEK)
Georg Peter BERG (Univ. of Notre Dame)
Takayuki GOTO (Sophia Univ.)
Masaya ENOMOTO (Tokyo Univ. of Sci.)
Hiroyuki FUJIOKA (Kyoto Univ.)
Takayuki KAWAMATA (Tohoku Univ.)
Lee CHOW (UCF)
Helmut WEICK (GSI)
Harry W. K. TOM (UC Riverside)
Agustinus NUGROHO (ITB)
Kawakami Kenji ROLAND (Univ. of California, Riverside)
Ichiro SHIRAKI (Univ. of Yamanashi)

Kensuke SUZUKI (Tohoku Univ.)
 Kyosuke ISODA (Kagawa Univ.)
 Ken SUZUKI (SMI)
 Irwan DHARMAWAN (UNPAD)
 Koji YOKOYAMA (Queen Mary Univ.)
 Catalina Oana Curceanu(INFN)
 Maryam Hassanvand(IUT)
 Kazuki UENO (KEK)
 Lusy SAFRIANI (UNPAD)
 Hiroyuki NOUMI (Osaka Univ.)
 Zhuan XU (Zhejiang Univ.)
 Hiroshi TANIDA (Hiroshima Univ.)
 Kenji KOJIMA (KEK)
 Atsushi OKAZAWA (Univ. of Tokyo)
 Tobat Parasian Irianto SARAGI (Univ. of Kassel)
 Hiroko ARIGA (Hokkaido Univ.)
 Yoshiki TANAKA(GSI)
 Katsuhiko NISHIMURA (Univ. of Toyama)
 Kenji MATSUDA (Univ. of Toyama)
 Hexi SHI (LNF)
 Mohamed Ismail MOHAMED IBRAHIM (USM)
 Shukri SULAIMAN (USM)
 Ayi BAHTIAR (UNPAD)
 Eberhard WIDMANN(SMI)
 Tsutomu MIBE (KEK)

Visiting Technicians

Kazuo OOOYAMA (JOHO com.)

Research Fellows

Yuta SADA (Osaka Univ.)
 Yuki NOZAWA (Osaka Univ.)

Student Trainees

Sohtaro KANDA (Univ. of Tokyo)
 Kentaro INOUE (Osaka Univ.)
 Yoshiki TANAKA (Univ. of Tokyo)
 Hiroyuki YAMADA (Univ. of Tokyo)
 Yuni WATANABE (Univ. of Tokyo)
 Xingliang Xu (Saga Univ.)
 Shingo KAWASAKI (Osaka Univ.)
 Ryo KITAMURA (Univ. of Tokyo)
 Kazuki MATSUI (Sophia Univ.)
 Ainul Fauzeeha Binti ROZLAN (Univ. Saints Malaysia)
 Saidah Sakinah Binti MOHD TAJUDIN (Univ. Saints Malaysia)
 Shu AIKAWA (Tokyo Tech.)
 Hiroshi HORII (Univ. of Tokyo)
 Kazuya KATAYAMA (Tokyo Tech.)

Part-time Workers

Makoto TOKUDA (Tokyo Tech.)
 Taehyung KIM (Tokyo Tech.)
 Yuki NOZAWA (Osaka Univ.)

Assistants

Tomoko IWANAMI
 Yoko FUJITA

Koichi ICHIMURA (Hokkaido Univ.)
 Youichi IGARASHI (KEK)
 Makoto YOKOYAMA (Ibaraki Univ.)
 KwangYong CHOI (Chung-Ang Univ.)
 Peklan TOH (Univ. Sains Malaysia)
 Emma HAETTNER (GSI)
 Andrea VACCHI (INFN)
 Seungwon LEE (Univ. of Toyama)
 Takahiro NAMIKI (Univ. of Toyama)
 Naohito SAITO (KEK)
 Kouichirou SHIMOMURA (KEK)
 Satoru HIRENZAKI (Nara Women's Univ.)
 Eiko TORIKAI (Univ. of Yamanashi)
 Ryoussuke KADONO (KEK)
 Wataru HIGEMOTO (JAEA)
 Yoji KOIKE (Tohoku Univ.)
 Kazuhiko SATOH (Saitama Univ.)
 Masaru YOSOI (Osaka Univ.)
 Dai TOMONO (Kyoto Univ.)
 Kazuki OHISHI (Comprehensive Res. Org. for Sci. and Soc.)
 Yasuhiro MIYAKE (KEK)
 Prasad Tara DAS (SUNY)
 Yu OISHI (KEK)
 Seiko KAWAMURA(JAEA)
 Hideyuki TATSUNO (Lund Univ.)

Natsuki HIROE (RCNP)

Koshi KURASHIMA (Tohoku Univ.)
 Tomotaka UEHARA (Saitama Univ.)
 Takuro FUJIMAKI (Yamanashi Univ.)
 Govinda KHANAL (Yamanashi Univ.)
 Akane SAKAUE (Kyoto Univ.)
 Isao YANAGIHARA (Kitasato Univ.)
 Muhamad UMAR (Hokkaido Univ.)
 Fahmi ASTUTI (Hokkaido Univ.)
 Edi SUPRAYOGA (Bandung Inst. Tech.)
 Taehyung KIM (Tokyo Tech.)
 Go MISHIMA (Univ. of Tokyo)
 Irwan RAMLI (Hokkaido Univ.)
 Harison Binti ROZAK (UTM)
 Juila ANGEL (Hokkaido Univ.)

Fahmi ASTUTI (Hokkaido Univ.)
 Takahiro NISHI (Univ. of Tokyo)
 Juila ANGEL (Hokkaido Univ.)

Mitsue YAMAMOTO

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- Y. Sada et al., "Structure near the $K+p+p$ threshold in the in-flight ${}^3\text{He}(K,\Lambda)p$ reaction", Prog. Theor. Exp. Phys., 051D01 (2016). DOI 10.1093/ptep/ptw040 *
- Y.K. Tanaka, K. Itahashi et al. (for eta-PRiME/Super-FRS collaboration), "Measurement of excitation spectra in the ${}^{12}\text{C}(p,d)$ reaction near the η' emission threshold", Physical Review Letters 117 (2016) 202501 *
- J. Äystö et al. (Super-FRS of NUSTAR@FAIR Collaboration), "Experimental program of the Super-FRS Collaboration at FAIR and developments of related instrumentation", Nucl. Instrum. Meth. B376 (2016) 111-115, DOI: 10.1016/j.nimb.2016.02.042 *
- N. Saito, Y. Oishi, K. Miyazaki, K. Okamura, J. Nakamura, M. Iwasaki, S. Wada, "Photoionization pathways and thresholds in generation of Lyman- α radiation by resonant four-wave mixing in Kr-Ar mixture", O. A. Louchev, AIP Advances 6, 095018/1-10 (2016). *
- Norihito Saito, Yu Oishi, Koji Miyazaki, Kotaro Okamura, Jumpei Nakamura, Oleg A. Louchev, Masahiko Iwasaki and Satoshi Wada, "High-efficiency generation of pulsed Lyman- α radiation by resonant laser wave mixing in low pressure Kr-Ar mixture", Optics Express 24, 7566 (2016); DOI:10.1364/OE.24.007566 *

[Proceedings]

(Original Papers) *Subject to Peer Review

- T. Yamaga et al., "Study of the elementary (K^-, n) reactions to search for the $K^{\text{bar}}\text{NN}$ bound state via the ${}^3\text{He}(K^-, n)$ reaction at J-PARC", Proceedings of XVI International Conference on Hadron Spectroscopy (Hadron2015), AIP Conf. Proc. 1735, 040007 (2016). *
- Yuni N. Watanabe et al., "Spectroscopy of Pionic Atoms Via $(p, 2\text{He})$ Reaction", JPS Conf.Proc. 13 (2017) 020015
- Kenta Itahashi et al. (η -PRiME/SuperFRS Collaboration), "Excitation Spectra of Carbon Nuclei near η' Emission Threshold", JPS Conf. Proc. 13 (2017) 020030, DOI: 10.7566/JPSCP.13.020030 *
- Kenta Itahashi et al., "Precision spectroscopy of pionic atoms and chiral symmetry in nuclei", EPJ Web Conf. 130 (2016) 01017, DOI: 10.1051/epjconf/201613001017 *
- Yoshiki K. Tanaka et al., "Search for η' mesic nuclei by missing-mass spectroscopy of the ${}^{12}\text{C}(p,d)$ reaction", EPJ Web Conf. 130 (2016) 02010 *
- Hiroyuki Fujioka, Tomokazu Fukuda, Toru Harada, Emiko Hiyama, Kenta Itahashi, Shunsuke Kanatsuki, Tomofumi Nagae, Takuya Nanamura, Takahiro Nishi, "Search for Tetraneutron by Pion Double Charge Exchange Reaction at J-PARC", JPS Conf.Proc. 13 (2017) 020058, DOI: 10.7566/JPSCP.13.020058 *

Oral Presentations

[International Conference etc.]

- F.Sakuma, "Experimental studies on the $K^{\text{bar}}\text{N}$ interaction", International Workshop on Strangeness Nuclear Physics 2017 (SNP2017), , Osaka, March 2017
- K.Inoue, "Analysis status of $d(K^-,n)\pi^0$ at J-PARC K1.8BR beam line", International Workshop on Strangeness Nuclear Physics 2017 (SNP2017), , Osaka, March 2017
- M.Iwasaki, "News about Latest Experiment at J-PARC", 55th International Winter Meeting on Nuclear Physics, Bormio, Italy, January 2017
- H.Outa, "Search for Deeply-bound K -pp States in ${}^3\text{He}(K^-, \Lambda)p$ Reaction - Recent Results from J-PARC E15 Experiment -", International Symposium on Neutron Star Matter (NSMAT2016), Sendai, November 2016
- T.Yamaga, "Improved ${}^3\text{He}(K^-, \Lambda)p$ Spectroscopy to Search for the $K^{\text{bar}}\text{NN}$ Bound State with J-PARC E15-2nd Data", The 26th International Nuclear Physics Conference (INPC2016), Adelaide, Australia, September 2016
- M.Iwasaki, "Kaonic nuclear state search by kaon reaction on ${}^3\text{He}$ target at 1GeV/c", Meson in Nucleus 2016 (MIN16), Kyoto, August 2016
- T.Yamaga, "Recent result of an exclusive measurement of ${}^3\text{He}(K^-, \Lambda)p$ reaction to search for $K^{\text{bar}}\text{NN}$ bound state at J-PARC", The 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2016), Kyoto, July 2016
- F.Sakuma, " $K^{\text{bar}}\text{NN}$ bound state search at J-PARC", The 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2016), Kyoto, July 2016
- S.Kawasaki, "Spectroscopic experiment of $\Lambda(1405)$ via in-flight $d(K^-,n)$ reaction at J-PARC K1.8BR", The 14th International Conference on Meson-Nucleon Physics and the Structure of the Nucleon (MENU2016), Kyoto, July 2016
- K.Itahashi, Transregio symposium, Bonn, 2016
- K. Itahashi, "Meson-nuclear bound states", The 71st Fujihara Seminar, Shimoda, July 2016
- K. Itahashi, "Precision spectroscopy of pionic atoms and chiral symmetry in nuclei", 14th International Workshop on Meson Production, Properties and Interaction (MESON 2016), Krakow, June 2016

[Domestic Conference]

- K. Itahashi, " π 中間子原子、 η' 中間子原子核分光実験", 日本物理学会第 71 回年次大会, 東北学院大学, 3 月(2016)
- Y.Ma, "Study of $K^{\text{bar}}\text{N}$ interaction at J-PARC K1.8BR beam line", ELPH 研究会「マルチフレイバーで探るエキゾチックハドロンとハドロン多体系の物理」, 東北大学, 仙台, 12 月(2016)
- 山我拓巳, "[シンポジウム:K 中間子クラスターと高密度物質への展開] $K^{\text{bar}}\text{pp}$ クラスター実験研究の最前線", 日本物理学会第 72 回年次大会, 大阪大学, 大阪, 3 月(2017)
- 川崎新吾, "J-PARC K1.8BR ビームラインにおける $d(K^-,n)$ 反応による $\Lambda(1405)$ 粒子の精密分光実験の $\pi^0\Sigma^0$ 終状態に関する解析状況", 日本物理学会第 72 回年次大会, 大阪大学, 大阪, 3 月(2017)

Sub Nuclear System Research Division RIKEN-BNL Research Center

1. Abstract

The RIKEN BNL Research Center was established in April 1997 at Brookhaven National Laboratory with Professor T. D. Lee of Columbia University as its initial Director. It is funded by the Rikagaku Kenkyusho (RIKEN, The Institute of Physical and Chemical Research) of Japan. The Center is dedicated to the study of strong interactions, including spin physics, lattice QCD and RHIC physics through the nurturing of a new generation of young physicists. Professor Lee was succeeded by BNL Distinguished Scientist, N. P. Samios, who served until 2013. The current director is Dr. S. H. Aronson. After strong and significant leadership for 4 years, S. Aronson steps down from Director in March 31st 2017. Hideto En'yo succeeds as an acting Director from JFY 2017. Support for RBRC was initially for five years and has been renewed three times, and presently extends to 2018. The Center is located in the BNL Physics Department. The RBRC Theory Group activities are closely and intimately related to those of the Nuclear Theory, High Energy Theory, and Lattice Gauge Theory Groups at BNL. The RBRC Experimental Group works closely with Radiation Laboratory at RIKEN, Wako, the RHIC Spin Group at BNL, the RHIC Spin Physics community, and the PHENIX collaboration. BNL provides office space, management, and administrative support. In addition, the Computational Science Center (CSC) and Information Technology Division (ITD) at BNL provide support for computing, particularly the operation and technical support for the RBRC 400 Teraflop QCDCQ (QCD Chiral Quark) lattice gauge theory computer. The Deputy Director of RBRC is R. Pisarski (BNL). D. Kharzeev (Stony Brook/BNL) is leader of the Theory Group. Y. Akiba (RIKEN) is Experimental Group leader with A. Deshpande (Stony Brook) deputy. T. Izubuchi (BNL) is Computing Group leader.

2. Major Research Subjects

Major research subjects of the theory group are

- (1) Heavy Ion Collision
- (2) Perturbative QCD
- (3) Phenomenological QCD

Major research subjects of the computing group are

- (1) Search for new law of physics through tests for Standard Model of particle and nuclear physics
- (2) Dynamics of QCD and related theories
- (3) Theoretical and algorithmic development for lattice field theories, QCD machine design

Major research subject of the experimental group are

- (1) Experimental Studies of the Spin Structure of the Nucleon
- (2) Study of Quark-Gluon Plasma at RHIC
- (3) sPHENIX detector construction as

3. Summary of Research Activity

Summary of Research Activities of the three groups of the Center are given in the sections of each group.

Members

Director

Samuel H. ARONSON

Deputy Director

Robert PISARSKI

Administrative Staff

Kazunori Mabuchi (Administration Manager, Nishina Center Planning Office)

Yasutaka AKAI (Deputy Administration Manager, Nishina Center Planning Office)

Colleen MICHAEL (Administrative Assistant)

Pamela ESPOSITO (Administrative Assistant)

Sub Nuclear System Research Division

RIKEN-BNL Research Center

Theory Group

1. Abstract

The efforts of the RBRC theory group are concentrated on the major topics of interest in High Energy Nuclear Physics. This includes: understanding of the Quark-Gluon Plasma; the nature of dense quark matter; the initial state in high energy collisions, the Color Glass Condensate; its evolution through a Glasma; spin physics, as is relevant for polarized hadronic collisions; physics relevant to electron-hadron collisions.

Theory Group hosted many joint tenure track positions with universities in U.S. and Japan.

2. Major Research Subjects

- (1) Heavy Ion Collision
- (2) Perturbative QCD
- (3) Phenomenological QCD

3. Summary of Research Activity

(1) Spin Physics

The experimental program at RBRC is strongly focused on determining the origin of spin in the proton and neutron. To extract the spin content of nucleon requires both precise data and precise computation. Dr. Jianwei Qiu of the Nuclear Theory group is one of the world's leading theorists in perturbative QCD, and leading the effort at BNL in spin physics. Their effort will continue to concentrate on computing perturbative QCD effects to sufficient precision that one can reliably extract information from the evolving experimental program. In addition they are developing ideas which might be tested in an electron-hadron collider, such as the one proposed to be built by adding an electron ring to RHIC.

(2) Matter at High Energy Density

The RHIC experimental heavy ion program is designed to study the properties of matter at energy densities much greater than that of atomic nuclei. This includes the initial state of nucleus-nucleus collisions, the Color Glass Condensate, the intermediate state to which it evolves, the Glasma, and lastly the thermal state to which it evolves, the Quark-Gluon Plasma. Theorists at the RBRC have made important contributions to all of these subjects.

Matter at high temperature has been studied by a variety of techniques involving both numerical and analytic methods. Much of the high precision work on numerical simulations of lattice QCD at nonzero temperature and density such matter have been done by members of the Lattice Gauge Theory Group at BNL, including Frithjof Karsch, Peter Petreczsky, Swagato Mukherjee, and postdoctoral assistants. These groups, along with collaborators at Columbia University, the University of Bielefeld, and other groups, have computed numerous properties of QCD in thermodynamic equilibrium. This includes the equation of state for physical quark masses, susceptibilities with respect to quark chemical potentials, and transport coefficients.

Phenomenological theories of the Quark-Gluon Plasma, based upon results from lattice simulations, have been developed by R. Pisarski of the Nuclear Theory Group, in collaboration with Dr. Y. Hidaka (previously of RBRC/BNL, and now a permanent member at RIKEN in Waco), Shu Lin, Daisuke Sato, and other postdoctoral research assistants at RBRC/BNL.

The theory of the Color Glass Condensate and Glasma was largely developed by RBRC scientists. This theory has been successfully applied to a wide variety of experimental results involving high energy collisions of hadrons, electrons and nuclei. There is recent data on heavy ion collisions that are naturally explained by such matter, including data on proton (or deuteron) nucleus collisions. Much of the effort here will be aimed towards excluding or verifying the Color Glass Condensate and Glasma hypothesis in RHIC and LHC experiments.

Thermal matter at high temperature and baryon density has been traditionally conjectured to be of two phases: confined and deconfined, with a direct correlation between deconfinement and the restoration of chiral symmetry. RBRC scientists have recently conjectured a third phase, of quarkyonic matter. This is baryonic matter at energy densities very high compared to the QCD scale. It has a pressure and energy density typical of quarks, yet it is confined. The name arises because it shares properties of confined baryonic matter with unconfined quark matter. This hypothesis is new and predicts new classes of phenomena that might be observed in collisions of nuclei of relatively low energy at RHIC. There are a number of first principle theoretical issues also to be understood.

Efforts on RHIC phenomenology proceed on a broad front. Recent efforts include improving hydrodynamic computations using state of the art equations of state derived from lattice gauge theory. Understanding the nature of matter at high baryon number density has generated the idea of Quarkyonic Matter, that may have implications for an upcoming low energy run at RHIC and eventual experiments in the future at FAIR and NICA. An issue being studied is the nature of mass generation and the breaking of translational invariance. A central focus of work at RBRC, the Color Glass Condensate and the Glasma, matter that controls the high energy limit of QCD, is being realized in experiments at RHIC. Much activity focuses on the relation between observations at LHC and the implications made at RHIC.

Members

Group Leader (Lab. Head)

Dmitri KHARZEEV

Deputy Group Leader

Robert PISARSKI (concurrent: Deputy Director, RBRC)

RBRC Researchers

Jinfeng LIAO (RHIC Physics Fellow)

Ho-Ung YEE (RHIC Physics Fellow)

Yuya TANIZAKI (Special Postdoctoral Researcher)

Hikomichi Nishimura (Special Postdoctoral Researcher)

Daniel PITONYAK (Research Associates)

Vladimir SKOKOV (Special Postdoctoral Researcher)

Ryutaro FUKUDA (Junior Research Associate)

Visiting Scientists

Koichi Hattori (Fudan Univ.)

Sub Nuclear System Research Division RIKEN-BNL Research Center Computing Group

1. Abstract

The computing group founded in 2011 as a part of the RIKEN BNL Research Center established at Brookhaven National Laboratory in New York, USA, and dedicated to conduct researches and developments for large-scale physics computations important for particle and nuclear physics. The group was forked from the RBRC Theory Group.

The main mission of the group is to provide important numerical information that is indispensable for theoretical interpretation of experimental data using the theories of particle and nuclear physics. Their primary area of research is lattice quantum chromodynamics (QCD), which describes the sub-atomic structures of hadrons, which allow us the ab-initio investigation for strongly interacting quantum field theories beyond perturbative analysis.

The RBRC group and its collaborators have emphasized the necessity and importance of precision calculations, which will precisely check the current understandings of nature, and will have a potential to find a physics beyond the current standard model of fundamental physics. We have therefore adopted techniques that aim to control and reduce any systematic errors. This approach has yielded many reliable results.

The areas of the major activities are R&D for high performance computers, developments for computing algorithms, and researches of particle, nuclear, and lattice theories. Since the inception of RBRC, many breakthroughs and pioneering works has carried out in computational forefronts. These are the use of the domain-wall fermions, which preserve chiral symmetry, a key symmetry for understanding nature of particle nuclear physics, the three generations of QCD devoted supercomputers, pioneering works for QCD calculation for Cabibbo-Kobayashi-Maskawa theory, QCD+QED simulation for isospin breaking, novel algorithm for error reduction in general lattice calculation. Now the chiral quark simulation is performed at the physical up, down quark mass, the precision for many basic quantities reached to accuracy of sub-percent, and the group is aiming for further important and challenging calculations, such as the full and complete calculation for $K \rightarrow \pi\pi$ decay, ε'/ε , or hadronic contributions to muon's anomalous magnetic moment, or Nucleon's shape and structures related to physics for future Electron Ion Collider (EIC).

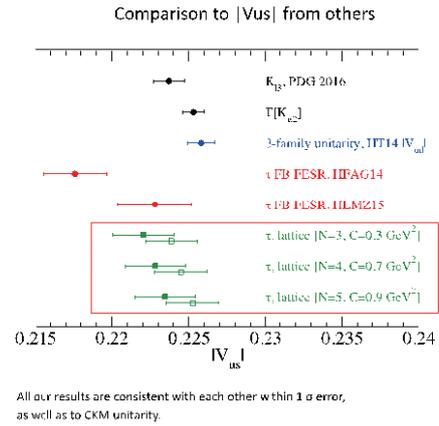
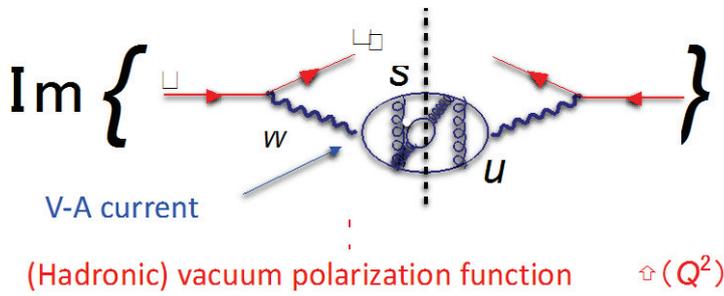
2. Major Research Subjects

- (1) Search for new law of physics through tests for Standard Model of particle and nuclear physics, especially in the framework of the Cabibbo-Kobayashi-Maskawa (CKM), hadronic contributions to the muon's anomalous magnetic moment ($g-2$).
- (2) Dynamics of QCD and related theories, including study for the structures of nucleons related to physics for Electron Ion Collider (EIC or eRHIC).
- (3) Theoretical and algorithmic development for lattice field theories, QCD machine design.

3. Summary of Research Activity

In 2011, QCD with Chiral Quarks (QCDCQ), a third-generation lattice QCD computer that is a pre-commercial version of IBM's Blue Gene/Q, was installed as an in-house computing resource at the RBRC. The computer was developed by collaboration among RBRC, Columbia University, the University of Edinburgh, and IBM. Two racks of QCDCQ having a peak computing power of 2×200 TFLOPS are in operation at the RBRC. In addition to the RBRC machine, one rack of QCDCQ is owned by BNL for wider use for scientific computing. In 2013, 1/2 rack of Blue Gene/Q is also installed by US-wide lattice QCD collaboration, USQCD. The group has also used the IBM Blue Gene supercomputers located at Argonne National Laboratory and BNL (NY Blue), and Hokusai and RICC, the super computers at RIKEN (Japan), Fermi National Accelerator Laboratory, the Jefferson Lab, and others. From 2016, the group started to use the institutional cluster both GPU and Intel KnightLanding (KNL) clusters installed at BNL extensively.

Such computing power enables the group to perform precise calculations using up, down, and strange quark flavors with proper handling of the important symmetry, called chiral symmetry, that quarks have. The group and its collaborators carried out the first calculation for the direct breaking of CP (Charge Parity) symmetry in the hadronic K meson decay ($K \rightarrow \pi\pi$) amplitudes, ε'/ε which provide a new information to CKM paradigm and its beyond. They also provide the hadronic contribution in muon's anomalous magnetic moment $(g-2)_\mu$. These calculation for ε'/ε hadronic light-by-light of $(g-2)_\mu$, are long waited calculation in theoretical physics delivered for the first time by the group. The $K \rightarrow \pi\pi$ result in terms of ε'/ε currently has a large error, and deviates from experimental results by 2.1σ . Hadronic Light-by-light contribution to $(g-2)_\mu$ is improved by more than two order of magnitudes compared to our previous results. Other projects including flavor physics in the framework of the CKM theory for kaons and B mesons that include the new calculation of b-baryon decay, $\Lambda_b \rightarrow p$; the electromagnetic properties of hadrons; the proton's and neutron's formfactors and structure function including electric dipole moments; proton decay; nucleon form factors, which are related to the proton spin problem; Neutron-antineutron oscillations; τ inclusive decay; nonperturbative studies for beyond standard model such composite Higgs or dark matter models from strong strongly interacting gauge theories; a few-body nuclear physics and their electromagnetic properties; and QCD thermodynamics in finite temperature/density systems such as those produced in heavy-ion collisions at the Relativistic Heavy Ion Collider.



Our result

Figure : Hadronic inclusive decay of tau lepton (left), the new results of CKM matrix element V_{us} (right).

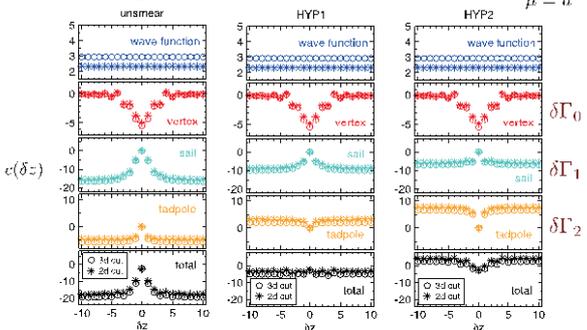
Theme	Significant Outcomes	Expected Impacts & Extensions
(a) DWF QCD ensemble generation and measurements of basic quantities.	hadron spectrum, f_π , f_K , K_B , B_K , and ChPT LECs, with smaller systematic errors	Basis of physical observables such as below
(b) Operator Renormalization	Precise matrix elements, bag parameters, quark masses, and coupling constants	Reduced systematic error in e.g. $K \rightarrow \pi\pi$ amplitudes
(c) Computational Algorithms, Software, and Machines	Fast and Cost-Effective Computing All-Mode Averaging (AMA) PhySyHCAI	Unprecedented precision and new physical quantities (see below)
(d) K physics	$K_B, \Delta I = 1/2, 3/2$, $K \rightarrow \pi\pi$ amplitudes, ϵ'/ϵ	New constraints e.g. on CKM from rare Kaon decay $K \rightarrow \pi\nu\bar{\nu}$
(e) B physics	Matrix elements for (semi-)leptonic decays and $B^0 - \bar{B}^0$ oscillations	CKM matrix, e.g., V_{ub} , V_{ts} , V_{td} .
(f) QED and Isospin breaking effects	Better determination of quark masses Proton-Neutron Mass Difference	A step towards sub-% precision groundwork for $(g-2)_\mu$
(g) Muon Anomalous Magnetic Moment $(g-2)_\mu$	Hadronic Vacuum Polarization contribution Light-by-Light contribution	$(g-2)_\mu$ experiments at BNL, FNAL, J-PARC
(h) Proton/Neutron Physics Electric Dipole Moments, ProtonDecay	Nucleon structure, Parton Distribution Functions (PDF) EM properties, Electric Dipole Moment (EDM)	Electron-Ion Collider (eRHIC) Spin Physics, Kamiokande Origin of matter in Universe

Table: Summary of current physics program and their impacts

One-loop matching coefficients: an example

- Naive fermion is used.
- Link smearing (HYP1, HYP2)

$$Z(\delta z) = 1 + \frac{g^2}{(4\pi)^2} C_P(\delta z) + O(g^4)$$



$\bar{q}(x)$ quasi-PDF ($F_L = 2$, $t_{\text{top}} = 4$)

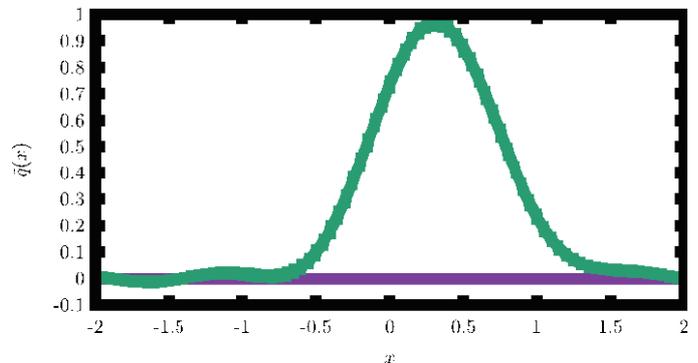


Figure: Renormalization of quasi Parton Distribution Function (PDF) operator (left), preliminary result of pion PDF (right)

The RBRC group and its collaborators have emphasized the necessity and importance of precision calculations, which will precisely check the current understandings of nature, and will have a potential to find physics beyond the current standard model of fundamental physics. We have therefore adopted techniques that aim to control and reduce any systematic errors. This approach has yielded many reliable results, many of basic quantities are now computed within sub-percent accuracies.

The group also delivers an algorithmic breakthrough, which speed up generic lattice gauge theory computation. In this novel technique called All Mode Averaging (AMA), the whole calculation is divided into frequent approximated calculations, and infrequent expensive and accurate calculation using lattice symmetries. Together with another formalism, zMöbius fermion, which approximate chiral lattice quark action efficiently, the typical calculation is now improved by a couple of orders of magnitudes compared to the traditional methods.

Members

Group Leader (Lab. Head)

Taku IZUBUCHI

RBRC Researcher

Tomomi ISHIKAWA (RIKEN BNL Fellow)
Yasumichi AOKI (RIKEN BNL Fellow, KEK)
Brian TIBURZI (RHIC Physics Fellow)
Ethan NEIL (RHIC Physics Fellow)

Stefan MEINEL (RHIC Physics Fellow)
Hiroshi OKI (Special Postdoctoral Researcher)
Sergey SYRITSYN (Special Postdoctoral Researcher)
Enrico RINALDI (Special Postdoctoral Researcher)

Visiting Scientists

Yasumichi AOKI (Nagoya Univ.)
Thomas BLUM (Univ. of Connecticut)
Chulwoo JUNG (BNL)
Christoph LEHNER (BNL)
Meifeng LIN (Yale Univ.)

Robert MAWHINNEY (Columbia)
Shigemi OHTA
Sergey SYRITSYN (Thomas Jefferson National Laboratory)
Tomomi ISHIKAWA (Shanghai Jiao-Tong Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) [* Currently subject to peer review]

- Thomas Blum, Norman Christ, Masashi Hayakawa, Taku Izubuchi, Luchang Jin, Chulwoo Jung, and Christoph Lehner
"Connected and Leading Disconnected Hadronic Light-by-Light Contribution to the Muon Anomalous Magnetic Moment with a Physical Pion Mass", Phys. Rev. Lett. 118, 022005 – Published 11 January 2017.
- T. Blum, P. A. Boyle, L. Del Debbio, R. J. Hudspeth, T. Izubuchi, A. Jüttner, C. Lehner, R. Lewis, K. Maltman, M. Krstić, Marinković, A. Portelli, M. Spraggs,
"Lattice calculation of the leading strange quark-connected contribution to the muon $g-2$ ", Published in JHEP 1604 (2016) 063,
Erratum: JHEP 1705 (2017) 034
- T. Blum, P. A. Boyle, T. Izubuchi, L. Jin, A. Jüttner, C. Lehner, K. Maltman, M. Marinkovic, A. Portelli, M. Spraggs, "Calculation of the hadronic vacuum polarization disconnected contribution to the muon anomalous magnetic moment", Published in Phys.Rev.Lett. 116 (2016) no.23, 232002
- Eigo Shintani, Thomas Blum, Taku Izubuchi, Amarjit Soni, "Neutron and proton electric dipole moments from $N_f=2+1$ domain-wall fermion lattice QCD", Phys.Rev. D93 (2016) no.9, 094503
- Michael G. Endres, Andrea Shindler, Brian C. Tiburzi, Andre Walker-Loud, "Massive photons: an infrared regularization scheme for lattice QCD + QED", Physical Review Letters, Volume 117, Article 072002, 2016/8/10*
- Matthew E. Matzelle, Brian C. Tiburzi, "Finite-volume corrections to electromagnetic masses for larger-than-physical electric charges", Physical Review D Volume 95, Article 094510 2017/5/30*
- Asumpta Parreño, Martin J. Savage, Brian C. Tiburzi, Johnas Wilhelm, Emmanuel Chang, William Detmold, Kostas Orginos (NPLQCD Collaboration), "Octet baryon magnetic moments from lattice QCD: Approaching experiment from a three-flavor symmetric point", Physical Review D, in press, 2017*
- Martin J. Savage, Phiala E. Shanahan, Brian C. Tiburzi, Michael L. Wagman, Frank Winter, Silas R. Beane, Emmanuel Chang, Zoreh Davoudi, William Detmold, Kostas Orginos (NPLQCD Collaboration), "Proton-proton fusion and tritium beta decay from lattice quantum chromodynamics", arXiv:1610.04545v1 [hep-lat] 2016/10/14
- T. DeGrand, M. Golterman, W. I. Jay, E. T. Neil, Y. Shamir and B. Svetitsky.
"Radiative contribution to the effective potential in composite Higgs models from lattice gauge theory." Phys. Rev. D94:5, 054501 (2016). arXiv:1606.02695.
- T. DeGrand, M. Golterman, E. T. Neil and Y. Shamir. "One-loop Chiral Perturbation Theory with two fermion representations", Phys. Rev. D94:2, 025020(2016). arXiv:1605.07738.
- G. D. Kribs and E. T. Neil. "Review of strongly-coupled composite dark matter models and lattice simulations", IJMPA 31:22, 1643004 (2016). arXiv:1604.04627.
- Jeremy Green, Nesreen Hasan, Stefan Meinel, Michael Engelhardt, Stefan Krieg, Jesse Laeuchli, John Negele, Kostas Orginos, Andrew Pochinsky, Sergey Syritsyn, "Up, down, and strange nucleon axial form factors from lattice QCD", Accepted by Phys. Rev. D arXiv:1703.06703 [hep-lat]
- A. Datta, S. Kamali, S. Meinel, A. Rashed. "Phenomenology of $\Lambda_b \rightarrow \Lambda_{ct} \tau \bar{\nu}$ using lattice QCD calculations", arXiv:1702.02243 [hep-ph] Submitted to JHEP RBRC-1228

- S. Meinel. " $\Lambda_c \rightarrow \Lambda l + \nu l$ form factors and decay rates from lattice QCD with physical quark masses", arXiv:1611.09696 [hep-lat] Phys. Rev. Lett. 118, no. 8, 082001 (2017) RBRC-1216
 T.Ishikawa, Y.Q.Ma, J.W.Qiu and S.Yoshida, "Practical quasi parton distribution functions," arXiv:1609.02018 [hep-lat] (* under peer review)
- Yasumichi Aoki, Tatsumi Aoyama, Ed Bennett, Masafumi Kurachi, Toshihide Maskawa, Kohtaroh Miura, Kei-ichi Nagai, Hiroshi Ohki, Enrico Rinaldi, Akihiro Shibata, Koichi Yamawaki, Takeshi Yamazaki (the LatKMI Collaboration), "Light flavor-singlet scalars and walking signals in $N_f=8$ QCD on the lattice"
- Y. Aoki et al. "Review of lattice results concerning low-energy particle physics ", Jul 1, 2016. 383 pp. Published in Eur.Phys.J. C77 (2017) no.2, 112

[Proceedings]

(Original Papers) *Subject to Peer Review

- Taku Izubuchi, Michael Abramczyk, Tom Blum, Hiroshi Ohki, Sergey Syritsyn, "Calculation of Nucleon Electric Dipole Moments Induced by Quark Chromo-Electric Dipole Moments", PoS LATTICE2016 (2017) 398
- Kim Maltman, Renwick Hudspith, Taku Izubuchi, Randy Lewis, Hiroshi Ohki, James Zanotti. "VusVus from inclusive determinations based on hadronic tau data", PoS LATTICE2016 (2017) 279
- Jonathan Flynn, Taku Izubuchi, Andreas Juttner, Taichi Kawanai, Christoph Lehner, Edwin Lizarazo, Amarjit Soni, Justus Tobias Tsang, Oliver Witzel. "Form factors for semi-leptonic BB decays", PoS LATTICE2016 (2016) 296.
- Matthew Spraggs, Peter A. Boyle, Luigi Del Debbio, Taku Izubuchi, Andreas Jüttner, Christoph Lehner, Kim Maltman, Marina Krstic Marinkovic, Antonin Portelli. "Computing the muon anomalous magnetic moment using the hybrid method with physical quark masses", PoS LATTICE2016 (2016) 184
- Luchang Jin, Thomas Blum, Norman Christ, Masashi Hayakawa, Taku Izubuchi, Chulwoo Jung, Christoph Lehner. "The connected and leading disconnected diagrams of the hadronic light-by-light contribution to muon $g-2$ ", PoS LATTICE2016 (2016) 181
- Kim Maltman, Renwick James Hudspith, Randy Lewis, Taku Izubuchi, Hiroshi Ohki, James M. Zanotti. "Determinations of Vuu using inclusive hadronic π decay data", Published in Mod.Phys.Lett. A31 (2016) no.29, 1630030
- Kim Maltman, Renwick J. Hudspith, Randy Lewis, Taku Izubuchi, Hiroshi Ohki, James Zanotti, "Determinations of VusVus from Hadronic τ Decay Data", PoS FPCP2016 (2017) 023
- Martin J. Savage, Phiala E. Shanahan, Brian C. Tiburzi, Michael L. Wagman, Frank Winter, Silas R. Beane, Emmanuel Chang, Zoreh Davoudi, William Detmold, Kostas Orginos, (NPLQCD Collaboration). "Axial-current matrix elements in light nuclei from lattice QCD", Proceedings of the 38th International Conference on High Energy Physics, PoS (ICHEP2016), 506
- Amy Nicholson, Evan Berkowitz, Chia Cheng Chang, M. A. Clark, Balint Joo, Thorsten Kurth, Enrico Rinaldi, Brian Tiburzi, Pavlos Vranas, Andre Walker-Loud, (CalLat Collaboration), "Neutrinoless double beta decay from lattice QCD" Proceedings of the 34th International Symposium on Lattice Field Theory, PoS (LATTICE2016), 017
- C. C. Chang et al. (Fermilab Lattice/MILC Collaborations). "D-Meson Mixing in 2+1-Flavor Lattice QCD." Proceedings of Science (LATTICE 2016).FERMILAB-CONF-17-017-T.
- J. Komijani et al. (Fermilab Lattice/MILC Collaborations). "Decay constants f_B and f_{B_s} and quark masses m_b and m_c from HISQ simulations." Proceedings of Science (LATTICE 2016). FERMILAB-CONF-16-545-T.
- E. Gamiz et al. (Fermilab Lattice/MILC Collaborations). "Kaon semileptonic decays with $N_f = 2 + 1 + 1$ HISQ fermions and physical light-quark masses." Proceedings of Science (LATTICE 2016). FERMILAB-CONF-16-544-T.
- T. A. DeGrand, D. Hackett, W. I. Jay, E. T. Neil, Y. Shamir, and B. Svetitsky. "Towards Partial Compositeness on the Lattice: Baryons with Fermions in Multiple Representations." Proceedings of Science (LATTICE 2016).
- N. Hasan, M. Engelhardt, J. Green, S. Krieg, S. Meinel, J. Negele, A. Pochinsky, S. Syritsyn, "Computing the nucleon Dirac radius directly at $Q^2 = 0$ " arXiv:1611.01383 [hep-lat] PoS LATTICE 2016, 147 (2016) RBRC-1216
- Luka Leskovec, Constantia Alexandrou, Giannis Koutsou, Stefan Meinel, John W. Negele, Srijit Paul, Marcus Petschlies, Andrew Pochinsky, Gumaro Rendon, Sergey Syritsyn. "A study of the radiative transition $\pi\pi\pi \rightarrow \pi\gamma^*$ with lattice QCD" arXiv:1611.00282 [hep-lat], PoS LATTICE 2016, 159 (2016)RBRC-1214
- A. Peters, P. Bicudo, L. Leskovec, S. Meinel, M. Wagner. "Lattice QCD study of heavy-heavy-light-light tetraquark candidates", arXiv:1609.00181 [hep-lat], PoS LATTICE 2016, 104 (2016), RBRC-1213
- S. Meinel, G. Rendon. "Lattice QCD calculation of form factors for $\Lambda_b \rightarrow \Lambda(1520)l^+l^-$ decays", arXiv:1608.08110 [hep-lat], PoS LATTICE, 2016, 299 (2016), RBRC-1203
- T. Ishikawa, Y. Q. Ma, J. W. Qiu and S. Yoshida, "Matching issue in quasi parton distribution approach", PoS LATTICE2016, 177 (2016).
- S. Syritsyn, A. Gambhir, B. Musch, K. Orginos, "Constructing Nucleon Operators on a Lattice for Form Factors with High Momentum Transfer", in proceedings of International Symposium LATTICE2016, Southampton, July 24-30; PoS LATTICE2016 (2017) 176.
- T. Izubuchi, M. Abramczyk, T. Blum, H. Ohki, S. Syritsyn, "Calculation of Nucleon Electric Dipole Moments Induced by Quark Chromo-Electric Dipole Moments", in proceedings of International Symposium LATTICE2016, Southampton, July 24-30; PoS LATTICE2016 (2017) 398; arXiv:1702.00052.
- L. Leskovec, C. Alexandrou, G. Koutsou, S. Meinel, J. W. Negele, S. Paul, M. Petschlies, A. Pochinsky, G. Rendon, S. Syritsyn, "A study of the radiative transition $\pi\pi \rightarrow \pi\gamma^*$ with lattice QCD", in proceedings of International Symposium LATTICE2016, Southampton, July 24-30; PoS LATTICE2016 (2017) 159 ; arXiv:1611.00282.

Oral Presentations**[International Conference etc.]**

- Taku Izubuchi. "Lattice calculation for the light-by-light hadronic contribution to muon $g-2$ ", 14th international workshop on Tau Lepton Physics, IHEP, Beijing, China, 19-23 September.
- Taku Izubuchi. "Search for beyond standard model and QCD", the 14th international conference on Meson-Nucleon Physics and Structure of the Nucleon MENU2016, Kyoto University, Japan July 25-30
- Taku Izubuchi. "Muon $g-2$ Light-by-light on Lattice and Related Topics" Precision for New discoveries, TRIUMF, Vancouver, Canada, June 8-10.

- Taku Izubuchi. "Muon g-2 theory status", Flavor Physics and CP violation 2016 (FPCP) 2016, at Caltech, Pasadena, CA, June 6-9.
- Taku Izubuchi, "Muon g-2 Hadronic Light by Light: Lattice QCD", Invited talk, Symposium on Effective Field Theories and Lattice Gauge Theory at Institute for Advanced Study, Technical University Munich, May 18-21.
- Brian C. Tiburzi. "Going to Extremes: Lattice QCD in External Fields", Invited talk, Maryland Center for Fundamental Physics, University of Maryland, 11/16/2016.
- Brian C. Tiburzi. "Going to Extremes: Lattice QCD in External Fields", Invited talk, Lawrence Berkeley National Laboratory, Berkeley, California, 11/8/2016.
- Brian C. Tiburzi. "New features of baryon magnetic moments uncovered from lattice QCD", Invited talk, TP Program "Frontiers in Nuclear Physics", Kavli Institute for Theoretical Physics, Santa Barbara, California, 9/16/2016.
- Brian C. Tiburzi. "Magnetic properties of light nuclei from lattice QCD", Invited talk, INT Program 16-1 "Nuclear Physics from Lattice QCD", Institute for Nuclear Theory, Seattle, Washington, 5/15/2016.
- Ethan Neil. "Lattice study of gauge theory with multiple fermion representations.", RIKEN Lunch Seminar, Brookhaven National Laboratory, Upton, NY. May 2017.
- Ethan Neil. "Lattice Insights for Composite BSM Models." High Energy/Cosmology Seminar, University of Wisconsin, Madison, WI. March 2017.
- Ethan Neil "Lattice Insights for Composite BSM Searches." Future Colliders Seminar series, Fermilab, Batavia, IL. December 2016.
- Stefan Meinel. "Heavy baryon decay form factors from lattice QCD," International Workshop on Hadronic Contributions to New Physics Searches, Puerto de la Cruz, Spain (invited talk) September 27, 2016.
- Stefan Meinel "Flavor physics with Λ_b baryons," 38th International Conference on High Energy Physics, Chicago, USA (invited talk) August 5 2016,
- Stefan Meinel "Lattice QCD calculation of form factors for $\Lambda_b \rightarrow \Lambda(1520)|I=1^-$ decays," 34th International Symposium on Lattice Field Theory, University of Southampton, UK, July 29, 2016,
- Stefan Meinel "Flavor physics with Λ_b baryons," Fermilab Theory Seminar, Batavia, USA (invited talk) June 2, 2016.
- Stefan Meinel "Heavy Baryons on the Lattice," International Conference on the Structure of Baryons, Florida State University, Tallahassee, USA (invited talk) May 18, 2016.
- Stefan Meinel "Lattice results and outlook," Prospects and challenges for semitauonic decays at LHCb, CERN, Geneva, Switzerland (invited talk, given remotely) April 28, 2016,
- T. Ishikawa. "Matching for quasi parton distribution functions", 22nd International Spin Symposium 2016, 25-30 September 2016, University of Illinois, Urbana-Champaign, USA.
- T. Ishikawa, "Matching issue in quasi parton distribution approach", The 34th International Symposium on Lattice Field Theory, 24-30 July 2016, University of Southampton, UK.
- S. Syritsyn, "Nucleon Form Factors at High Momentum Transfer", parallel presentation at the International Symposium LATTICE2016, Southampton, July 24-30.
- S. Syritsyn, "On Lattice Calculation of Nucleon Electric Dipole Moments", HET Lunch seminar, Brookhaven National Laboratory, March 2, 2017.
- S. Syritsyn, "On Lattice Calculation of Nucleon Electric Dipole Moments", Nuclear Theory seminar at Stony Brook University, March 2, 2017.
- Ohki Hiroshi. "Determination of $|\text{Vus}|$ from hadronic tau decays", The international workshop on future potential of high intensity accelerators for particle and nuclear physics (HINT2016), J-PARC, Tokai-village, Ibaraki, Japan, Dec. 6, 2016.
- Ohki Hiroshi. "Lattice calculation of Vus from inclusive strangeness changing tau decay", The 14th International Workshop on Tau Lepton Physics (Tau2016), IHEP, Beijing, September 19, 2016.
- Ohki Hiroshi "Vus from inclusive strange tau decay data and lattice HVP", The 34th International Symposium on Lattice Field Theory, Highfield Campus, University of Southampton, July 28, 2016.
- Ohki Hiroshi. "Many-flavor QCD dynamics on the lattice", Lattice for Beyond the Standard Model Physics 2016, Argonne National Laboratory, April 21, 2016.
- E. Rinaldi, "Lattice Gauge Theory insights on Dark Matter", at the Dark Interactions Workshop, BNL, Upton, NY, 10/06/2016
- E. Rinaldi, "Dark Interactions and the Lattice", at the Frontiers in Nuclear Physics Program, KITP, Santa Barbara, CA, 11/03/2016
- E. Rinaldi, "An overview of lattice field theory applications to dark matter searches", RIKEN lunch seminar, BNL, 11/10/2016
- E. Rinaldi, "Dark Interactions and Lattice Gauge Theories", at the Early Career Researcher Symposium, BNL, Upton, NY, 12/13/2016
- E. Rinaldi, "What lattice gauge theory can do for Dark Matter searches", at Università di Roma "La Sapienza", Rome, Italy, 02/23/2017
- E. Rinaldi, "Beyond the Standard Model Physics with Lattice Simulations", at Università di Roma "Tor Vergata", Rome, Italy, 03/01/2017

[Domestic Conference]

- Taku Izubuchi. "Lattice QCD computation for muon's anomalous magnetic moment", Talk at seminar, Yukawa Institute, Kyoto University, March 24.
- Taku Izubuchi. "Lattice QCD computation for muon's anomalous magnetic moment", Talk at seminar, Kanazawa University, March 21.
- Taku Izubuchi, "Lattice QCD computation for muon's anomalous magnetic moment" Invited talk, Japan Physics Society annual meeting, Osaka University, March 19.
- 青木 保道 "素粒子質量起源の理論探索 (Theoretical exploration of the origin of mass of elementary particles)", 第3回「京」を中心とする HPCI システム利用課題成果報告会, コクヨホール (東京都) 2016/10/21
- 青木 保道 "QCD の有限温度相転移とトポロジー", 素粒子・原子核・宇宙「京からポスト京に向けて」シンポジウム, 筑波大学東京キャンパス (東京都) 2017/2/17
- 青木 保道 "有限温度 2 フレーバー QCD のトポロジカル感受率 (Topological susceptibility of the finite-temperature two-flavor QCD)", 大阪大学 日本物理学会第 72 回年次大会 (JPS meeting 2017/3/18)
- 大木 洋. "物質優勢宇宙の謎解明のための核子構造精密計算", 2016 年度, 理研シンポジウム「スーパーコンピューター HOKUSAI と Shoubu, 研究開発の最前線」和光市理化学研究所, 2016 年 6 月 8 日.
- 大木 洋. "核子(chromo) EDM 演算子の格子計算", 日本物理学会第 72 回年次大会, 大阪大学, March 19, 2017.

Sub Nuclear System Research Division RIKEN-BNL Research Center Experimental Group

1. Abstract

RIKEN BNL Research Center (RBRC) Experimental Group studies the strong interactions (QCD) using RHIC accelerator at Brookhaven National Laboratory, the world first heavy ion collider and polarized p+p collider. We have three major activities: Spin Physics at RHIC, Heavy ion physics at RHIC, and detector upgrades of PHENIX experiment at RHIC.

We study the spin structure of the proton using the polarized proton-proton collisions at RHIC. This program has been promoted by RIKEN's leadership. The first focus of the research is to measure the gluon spin contribution to the proton spin. Recent results from PHENIX π^0 measurement and STAR jet measurement has shown that gluons in the proton carry about 30% of the proton spin. This is a major milestone of RHIC spin program. The second goal of the spin program is to measure the polarization of anti-quarks in the proton using $W \rightarrow e$ and $W \rightarrow \mu$ decays. The results of $W \rightarrow e$ measurement was published.

The aim of Heavy ion physics at RHIC is to re-create Quark Gluon Plasma (QGP), the state of Universe just after the Big Bang. Two important discoveries, jet quenching effect and strong elliptic flows, have established that new state of dense matter is indeed produced in heavy ion collisions at RHIC. We are now studying the property of the matter. Recently, we have measured direct photons in Au+Au collisions for $1 < p_T < 3$ GeV/c, where thermal radiation from hot QGP is expected to dominate. The comparison between the data and theory calculations indicates that the initial temperature of 300 MeV to 600 MeV is achieved. These values are well above the transition temperature to QGP, which is calculated to be approximately 160 MeV by lattice QCD calculations.

We had major roles in detector upgrades of PHENIX experiment, namely, the silicon vertex tracker (VTX) and muon trigger upgrades. Both of the upgrade is now complete. The VTX is the main device to measure heavy quark (charm and bottom) production and the muon trigger is essential for $W \rightarrow \mu$ measurement. The results from the first run with VTX detector in 2011 was published. The results show that electrons from bottom quark decay is strongly suppressed at high pT, but the suppression is weaker than that of charm decay electron for $3 < p_T < 4$ GeV/c. We have recorded 10 times as much Au+Au collisions data in each of the 2014 run and 2016 run. The large dataset will produce definitive results on heavy quark production at RHIC.

PHENIX completed its data taking in 2016. We are now working on R&D of intermediate silicon tracker INTT for sPHENIX, a new experiment at RHIC that will be installed in the PHENIX IR.

2. Major Research Subjects

- (1) Experimental Studies of the Spin Structure of the Nucleon
- (2) Study of Quark-Gluon Plasma at RHIC
- (3) PHENIX detector upgrades

3. Summary of Research Activity

We study the strong interactions (QCD) using the RHIC accelerator at Brookhaven National Laboratory, the world first heavy ion collider and polarized p+p collider. We have three major activities: Spin Physics at RHIC, Heavy ion physics at RHIC, and detector upgrades of PHENIX experiment.

(1) Experimental study of spin structure of proton using RHIC polarized proton collider

How is the spin of proton formed with 3 quarks and gluons? This is a very fundamental question in Quantum Chromodynamics (QCD), the theory of the strong nuclear forces. The RHIC Spin Project has been established as an international collaboration between RIKEN and Brookhaven National Laboratory (BNL) to solve this problem by colliding two polarized protons for the first time in history. This project also has extended the physics capabilities of RHIC.

The first goal of the Spin Physics program at RHIC is to determine the gluon contribution to proton spin. It is known that the spin of quark accounts for only 25% of proton spin. The remaining 75% should be carried either by the spin of gluons or the orbital angular momentum of quarks and gluons. One of the main goals of the RHIC spin program has been to determine the gluon spin contribution. Before the start of RHIC, there was little experimental constraint on the gluon polarization, ΔG .

PHENIX measures the double helicity asymmetry (A_{LL}) of π^0 production to determine the gluon polarization. Our most recent publication of π^0 ALL measurement at 510 GeV shows non-zero value of ALL, indicating that gluons in the proton is polarized. Global analysis shows that approximately 30% of proton spin is carried by gluons.

RHIC achieved polarized p+p collisions at 500 GeV in 2009. The collision energy increased to 510 GeV in 2012 and 2013. The main goal of these high energy p+p run is to measure anti-quark polarization via single spin asymmetry A_L of the W production. We upgraded the muon trigger system to measure $W \rightarrow \mu$ decays in the forward direction. With the measurement of $W \rightarrow e$ and $W \rightarrow \mu$, we can cover a wide kinematic range in anti-quark polarization measurement. The 2013 run is the main spin run at 510 GeV. PHENIX has recorded more than 150/pb of data in the run. The final results of the A_L measurement in $W \rightarrow e$ channel in combined data of 2011 to 2013 was published. The high statistics results give strong constraints on the polarization of anti-quarks in the proton. The analysis of $W \rightarrow \mu$ is in progress.

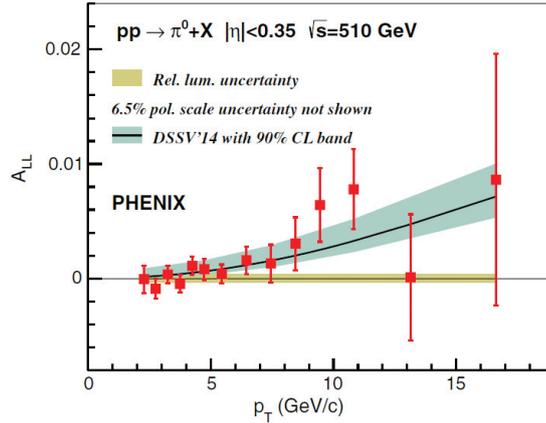


Figure 1 Double spin asymmetry A_{LL} in π^0 production as function of transverse momentum p_T . The non-zero A_{LL} indicates that gluons in the proton is polarized. Published in Physical Review D93,011501 (2016)

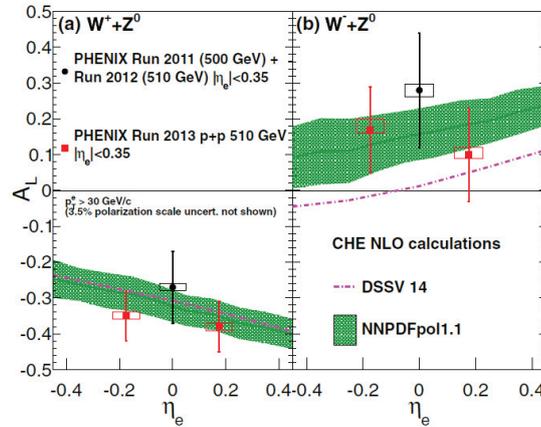


Figure 2 Single spin asymmetry A_L of electrons from W and Z decays. The A_L is sensitive to the polarization of anti-quarks in the proton. The curves and green shaded region show theoretical calculations based on various polarized parton distribution (PDF) sets. Published in Physical Review D93, 051103(R) (2016)

(2) Experimental study of Quark-Gluon Plasma using RHIC heavy-ion collider

The goal of high energy heavy ion physics at RHIC is study of QCD in extreme conditions i.e. at very high temperature and at very high energy density. Experimental results from RHIC have established that dense partonic matter is formed in Au+Au collisions at RHIC. The matter is very dense and opaque, and it has almost no viscosity and behaves like a perfect fluid. These conclusions are primarily based on the following two discoveries:

- Strong suppression of high transverse momentum hadrons in central Au+Au collisions (jet quenching)
- Strong elliptic flow

These results are summarized in PHENIX White paper, which has approximately 2400 citations to date.

The focus of the research in heavy ion physics at RHIC is now to investigate the properties of the matter. RBRC have played the leading roles in some of the most important results from PHENIX in the study of the matter properties. These include (1) measurements of heavy quark production from the single electrons from heavy flavor decay (2) measurements of J/Ψ production (3) measurements of di-electron continuum and (4) measurements of direct photons.

The most important recent result is the measurement of direct photons for $1 < p_T < 5$ GeV/c in p+p and Au+Au through their internal conversion to e^+e^- pairs. If the dense partonic matter formed at RHIC is thermalized, it should emit thermal photons. Observation of thermal photon is direct evidence of early thermalization, and we can determine the initial temperature of the matter. It is predicted that thermal photons from QGP phase is the dominant source of direct photons for $1 < p_T < 3$ GeV/c at the RHIC energy. We measured the direct photon in this p_T region from measurements of quasi-real virtual photons that decays into low-mass e^+e^- pairs. Strong enhancement of direct photon yield in Au+Au over the scaled p+p data has been observed. Several hydrodynamical models can reproduce the central Au+Au data within a factor of two. These models assume formation of a hot system with initial temperature of $T_{init} = 300$ MeV to 600 MeV. This is the first measurement of initial temperature of quark gluon plasma formed at RHIC. These results are recently published in Physical Review Letters. Y. Akiba is the leading person of the analysis and the main author of the paper. **He received 2011 Nishina memorial Prize mainly based on this work.**

(3) PHENIX detector upgrade

The group had major roles in several PHENIX detector upgrades, namely, the silicon vertex tracker (VTX) and muon trigger upgrades. VTX is a high precision charged particle tracker made of 4 layers of silicon detectors. It is jointly funded by RIKEN and the US DOE. The inner two layers are silicon pixel detectors and the outer two layers are silicon strip detectors. Y. Akiba is the project manager and A. Deshpande is the strip system manager. The VTX detector was completed in November 2010 and subsequently installed in PHENIX. The detector started taking data in the 2011 run. With the new detector, we measure heavy quark (charm and bottom) production in p+p, A+A collisions to study the properties of quark-gluon plasma. The final result of the 2011 run was published. The result show that single electrons from bottom quark decay is suppressed, but not as strong as that from charm decay in low p_T region ($3 < p_T < 4$ GeV/c). This is the first measurement of suppression of bottom decay electrons at RHIC and the first observation that bottom suppression is smaller than charm. We have recorded 10 times as much Au+Au collisions data in each of the 2014 run and 2016 run. The large dataset will produce definitive results on heavy quark production at RHIC.

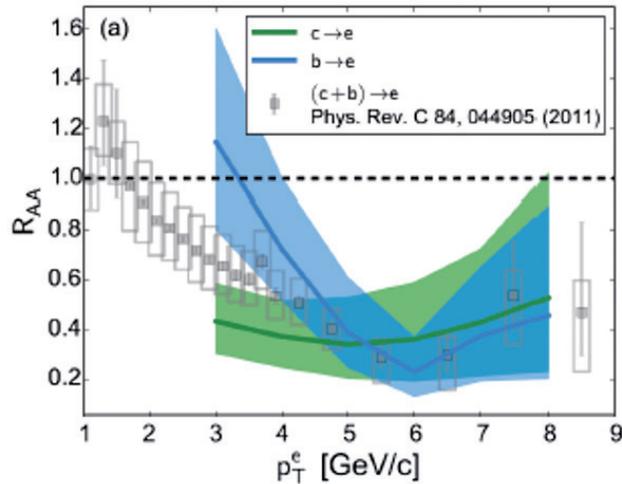


Figure 3. Nuclear modification factor R_{AA} for single electrons from charm (green band) and bottom (blue band) decays. Published in Physical Review C93, 034904 (2016)

PHENIX completed its data taking in 2016. We are now working on R&D of intermediate silicon tracker INTT for sPHENIX, a new experiment at RHIC that will be installed in the PHENIX IR.

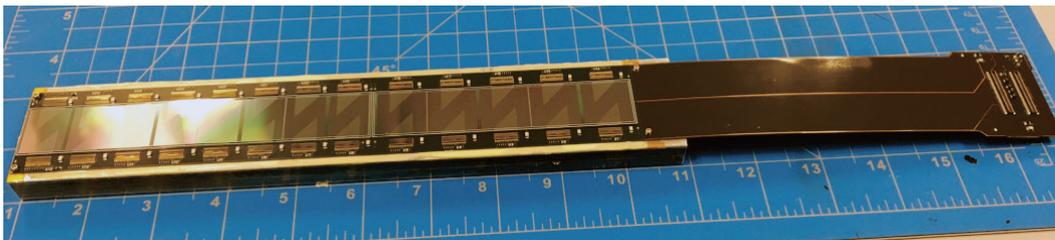


Figure 4. A prototype of sensor module of INTT silicon tracker for sPHENIX experiment

Members

Group Leader (Lab. Head)

Yasuyuki AKIBA (Deputy Chief Scientist)

Deputy Group Leader

Abhay DESHPANDE

RBRC Researcher

Xiaorong WANG (RHIC Physics Fellows)

Takashi HACHIYA

Yorito YAMAGUCHI

Gaku MITSUKA

Yasushi WATANABE (RIKEN Spin Program Researcher, concurrent: Radiation Lab.)

Yuji GOTO (RIKEN Spin Program Researcher, concurrent: Radiation Lab.)

Itaru NAKAGAWA (RIKEN Spin Program Researcher,
concurrent: Radiation Lab.)
Takashi ICHIHARA (RIKEN Spin Program Researcher,
concurrent: RI Physics Lab.)
Atsushi TAKETANI (RIKEN Spin Program Researcher,

concurrent: Neutron Beam Technology Team, Advanced
Photonics Technology development Group, RAP)
Satoshi YOKKAICHI (RIKEN Spin Program Researcher,
concurrent: Radiation Lab.)
Ralf SEIDL (RIKEN Spin Program Researcher, concurrent:
Radiation Lab.)

Visiting Scientists

Stefan BATHE (Baruch College University of New York)
Ady HERSHCOVITCH (RBRC Collaborating Scientist, BNL)
Akio OGAWA (BNL)

Rachid NOUCER (RBRC Collaborating Scientist)
Masahiro OKAMURA (concurrent: BNL)
Takao SAKAGUCHI (BNL)

List of Publications & Presentations

Publications

[Journal]

(Original Papers)

G Mitsuka "Recently measured large AN for forward neutron in pA collisions at $\sqrt{s}=200$ GeV explained through simulations of ultraperipheral collisions and hadronic interactions", Physical Review C95, 044908 (2017)

Oral Presentations

[International Conference etc.]

Takashi Hachiya, "Recent results on open and closed heavy flavor from PHENIX at RHIC", ICHEP2016

Takashi Hachiya, "Recent heavy flavor measurements from PHENIX at RHIC", ISMD2016

Takashi Hachiya, "Recent results on heavy flavor production at RHIC-PHENIX", INPC2016

Gaku Mitsuka, "Disentangling transverse single spin asymmetry for very forward neutrons in polarized pA collisions using ultra-peripheral collisions", 25th International Workshop of Deep Inelastic Scattering (DIS2017)

[Domestic Conference]

Gaku Mitsuka, "RHIC 単スピン非対称測定に対する ultra-peripheral collision の影響", 日本物理学会 第 72 回年次大会

Posters Presentations

[International Conference etc.]

Gaku Mitsuka "sPHENIX Intermediate silicon tracker INTT" Quark Matter 2017

Sub Nuclear System Research Division RIKEN Facility Office at RAL

1. Abstract

Our core activities are based on the RIKEN-RAL Muon Facility located at the Rutherford Appleton Laboratory (UK), which provides intense pulsed-muon beams. Muons have their own spins with 100% polarization, and can detect local magnetic fields and their fluctuations at muon stopping sites very precisely. The method to study characteristics of materials by observing time dependent changes of muon spin polarization is called “Muon Spin Rotation, Relaxation and Resonance (μ SR method), and is applied to study electro-magnetic properties of insulating, metallic, magnetic and superconducting systems. Muons reveal static and dynamic properties of the electronic state of materials in the zero-field condition, which is the ideal magnetic condition for research on magnetism. We have carried out μ SR investigations on frustrated pyrochlore systems, which have a variety of exotic ground states of magnetic spins, so the magnetism study of this system using muons is quite unique.

The ultra-slow muon beam can be stopped in thin foil, multi-layered materials and artificial lattices, which enables us to apply the μ SR techniques to surface and interface science. The development of an ultra-slow muon beam is also very important as a source of ultra-cold (pencil-like small emittance) muon beam for muon $g-2$ /EDM measurement. We have been developing muonium generators to create more muonium atoms in vacuum even at room temperature to improve beam quality compared with the conventional hot-tungsten muonium generator. We demonstrated a tremendous increase of the muonium emission efficiency by fabricating fine laser drill-holes on the surface of silica aerogel. We also developed a high power Lyman-alpha laser in collaboration with the Advanced Photonics group at RIKEN. The new laser will ionize muonium atoms 100 times more efficiently for slow muon beam generation.

2. Major Research Subjects

- (1) Materials science by muon-spin-relaxation method
- (2) Hyperfine interactions at muon sites studied by the computation science
- (3) Nuclear and particle physics studies via muonic atoms and ultra-cold muon beam

3. Summary of Research Activity

(1) Material Science at the RIKEN-RAL Muon Facility

Muons have their own spins with 100% polarization, and can detect local magnetic fields and their fluctuations at muon stopping sites very precisely. The μ SR method is applied to studies of newly fabricated materials. Muons enable us to conduct (1) material studies under external zero-field condition, (2) magnetism studies with samples without nuclear spins, and (3) measurements of muon spin relaxation changes over a wide temperature range with same detection sensitivity. The detection time range of local field fluctuations by μ SR is 10^{-6} to 10^{-11} second, which is an intermediate region between neutron scattering methods (10^{-10} - 10^{-12} second) and Nuclear Magnetic Resonance (NMR) (longer than 10^{-6} second). At Port-2 and 4 of the RIKEN-RAL Muon Facility, we have been performing μ SR research on strong correlated-electron systems, organic molecules and biological samples to study electron structures, superconductivity, magnetism, molecular structures and crystal structures.

In the period from 2015 to 2017, we have obtained excellent results, and the highlights are listed in the following,

- 1) The superconducting gap state of λ -[BETS] $_2$ GaCl $_4$ has both the *s*- and *d*-wave characters.
- 2) A static ordering in the Ca-doped pyrochlore iridate; (Nd $_{1-x}$ Ca $_x$) $_2$ Ir $_2$ O $_7$ is strongly suppressed by the carrier doping.
- 3) A long-range magnetic ordering is observed in alkali-metal superoxides of CsO $_2$ and RbO $_2$ but not in NaO $_2$.
- 4) Missing of a static ordering is confirmed in both Au $_{144}$ and Au $_{25}$ nano-clusters.
- 5) The quantum spatial distribution of the muon by the zero-point vibration energy is clarified by density functional theory calculations by using the RIKEN supercomputing system. HOKUSAI.

Result-1) One dimensional organic superconductor, λ -[BETS] $_2$ GaCl $_4$, has a unique Fermi-surface structure with the four-fold nodal points. The estimation of the superconducting gap from computational analysis of μ SR experimental data indicates a unique view of the superconducting gap to be a mixed state of the major *s*-wave component and the minor *d*-wave one. Result-2) Static orderings of both Nd and Ir magnetic spins are strongly suppressed by the carrier doping. A quantum critical change to the non-magnetic ground state is expected around $x=0.10$ being accompanied by changes in the transport properties. Result-3) The π electrons which are widely distributed on the O $_2$ dumbbell in superoxides CsO $_2$ and RbO $_2$ are found to form static long-range orderings. The magnetic moment is quantitatively estimated in conjunction with density functional theory calculations and confirmed to shrink to less than a half in the magnetically ordered state. Result-4) Ground states of nano-cluster of Au with 144 and 25 atoms are concluded to be still nonmagnetic down to 0.3 K from both the magnetic susceptibility and μ SR measurements although those systems have been argued to show some static magnetic states. Result-5) The muon trapped in materials is confirmed to be spatially distributed around the local minimum potential position by the zero-point vibration energy, which is due to the muon's physics character as a light particle. This quantum spatial distribution is now taken into account for the μ SR data analysis with the similar quantum spatial distribution of magnetic moments.

We are developing international collaborations on the muon science with Asian groups in order to organize new μ SR experimental research themes and to develop muon-site calculation activities using computational method. We renewed MOU's with Indonesian and Malaysian universities to enhance collaborative researches on the muon science at the RIKEN-RAL Muon Facility. We formed a new MOU with Universitas Indonesia (UI) as a new partner to work on the muon science and student education. We are developing new collaborations in μ SR experiments on strongly correlated systems with researchers from China, Taiwan and Korea including graduate students.

(2) Ultra Slow (low energy) Muon Beam Generation and Applications

A positive muon beam with thermal energy has been produced by laser ionization of muonium atoms (bound system of μ^+ and electron) emitted from hot tungsten surface with stopping surface muon beam at Port-3. The method generates a positive muon beam with acceleration energy from several 100 eV to several 10 keV, small beam size (a few mm) and good time resolution (less than 8 nsec). By stopping the ultra-slow muon beam in thin foil, multi-layered materials and artificial lattices, we can precisely measure local magnetic field in the materials, and apply the μ SR techniques to surface and interface science. Since there has been no appropriate probe to study magnetism at surface and interface, the ultra-slow muon beam will open a new area of these research fields. In addition, the development of ultra-slow muon beam is very important as the source of ultra-cold (pencil-like small emittance) muon beam for muon g-2/EDM measurement. It is essential to increase the slow muon beam production efficiency by 100 times for these applications. There are three key techniques in ultra-slow muon generation: production of thermal muonium, high intensity Lyman-alpha laser and the ultra-slow muon beam line.

In the period from 2011 to 2016, we developed a high power Lyman-alpha laser in collaboration with the Advanced Photonics group at RIKEN. The new laser will ionize muoniums 100 times more efficiently for slow muon beam generation. This development was funded mostly by the Grant-in-Aid for Scientific Research on Innovative Areas "Frontier in Materials, Life and Particle Science Explored by Ultra Slow Muon Microscope". This Grant-in-Aid research group is a complex of research institutions from universities together with J-PARC muon group and RIKEN. The new laser system was installed to J-PARC slow muon beam line and is being used for the generation of ultra-slow muons. In this development, we succeeded in synthesizing a novel ceramic-based Nd:YAG crystal. We already achieved 10 times increase in Lyman-alpha intensity and are waiting the growth of a large crystal to achieve the goal of 100 times increase. This crystal can also be applicable to the flash-lamp based Lyman-alpha laser system of RIKEN-RAL to realize substantial improvement of the laser power at a much reduced cost based on our experience so far.

We also aimed to realize drastic improvements on the ultra-slow muon source with much reduced emittance. We have been developing muonium generators to create more muoniums in vacuum even at room temperature. In 2013, we demonstrated at least 10 times increase of the muonium emission efficiency in one of the silica aerogel samples with fine holes fabricated on the surface. The measurement was carried out at TRIUMF in collaboration with J-PARC muon g-2/EDM group. In 2016 we studied the method of stable production of various laser drill-holes with Canadian collaborators so we can increase the muonium emission by systematic study of muonium emission under various target conditions.

We are planning to feed these new techniques to RIKEN-RAL ultra-slow muon beam line to realize further improvement of ultra-slow muon technology. The muonium production target section, which had been designed with hot tungsten, was completely redesigned and rebuilt to use advantages of the new room temperature silica aerogel target, such as no need of thermal shielding and spin control by applying weak magnetic field, etc. Also, we adopted an all-cylindrical beam-transport design, because of its simpler optics and better manufacture precision, which will contribute to the ultimate cold muon source required for muon g-2/EDM. In test experiments with the muon beam in 2016, we demonstrated a new powerful method of the muon stopping optimization in silica aerogel using muonium spin rotation.

(3) New Proposal for Fundamental Physics

We proposed the measurement of the proton radius by using the hyperfine splitting of the 1S states of muonic hydrogen. Recent measurement of the proton radius using muonic hydrogen at PSI revealed that the proton radius is surprisingly smaller than the radius so far measured using normal hydrogen spectroscopy and e-p scattering by more than 5 times their experimental precision. In contrast to the conventional measurement by means of electron, measurement with muonic hydrogen has larger sensitivity to the proton radius because the negative muon orbits closer to the proton, although there is no reason why these measurements can yield inconsistent results. The cause of the discrepancy is not understood yet, thus a new measurement with independent method is much anticipated.

There are two independent experimental proposals to RIKEN-RAL PAC to measure the hyperfine splitting energy of the 1S energy levels by laser excitation from singlet ground state to triplet state. This energy splitting is sensitive to the Zemach radius, which is a convolution of charge and magnetic distributions inside proton. Both commonly search resonant excitation from singlet 1S ($F=0$) to triplet 1S ($F=1$) using high intensity 6.7 μm excitation laser, but different schemes are proposed to detect the resonance. One is to detect muon transfer to the surrounding impurity atom by x-ray (European group), and the other is to detect the muon decay asymmetry recovery along the circularly polarized excitation laser, which selectively excites one of the $F=1$ states and regenerates the muon spin polarization (RIKEN group). RIKEN-RAL PAC accepted both proposals for feasibility studies.

RIKEN laser group made basic design of the laser system, based on their recent success on mid-infrared (6 μm) high-power pulse laser system. There is no direct way to produce 6.7 μm lasers, so we started to test the wavelength conversion efficiency of the laser key components. Other important progress is the background measurement. Since we need to stop muons in extremely low-density hydrogen target to substantially reduce the polarization quenching effect due to the atomic collision, all the muons stopped in the material other than the target can be a background source. Thus, we plan to use high Z materials for the target cell construction, so as all the muons stopping in surrounding materials quickly die out before the laser is introduced. We carried out the measurement of long-life background level, and confirmed that the background level can be made low enough by using coincidence detection method. The RIKEN-RAL Port 1 experimental area was refurbished for the proton radius experiments in 2016 and the muon beam was reestablished in March 2017.

(4) Other topics

New demand is emerging utilizing the muon beam for electronic chip radiation effect studies. Recent progress of semiconductor devices has produced electronic chips with very fine structure. It is anticipated that the single memory upset by the ionization effect of a single muon may result in malfunction or errors of advanced electronics. The muon is the main component of cosmic rays in our ordinary life and difficult to be removed. Measurements are being performed at RIKEN-RAL to measure such an error rate. Already several groups

carried out measurements on several different electronics. Although the sensitivity differs from chip to chip, in most cases, the error rate increases when the muon beam momentum is chosen so that the muon nearly stops in the chip itself (Bragg peak effect).

There were also demands for the use of negative muons for the non-destructive elements analysis using muonic x-rays. Especially its good depth sensitivity was clearly demonstrated. The applied objects so far are archaeological coins, sword, and oxygen concentration measurement in levers, movement of Li concentration in batteries, etc. The first paper on this work has recently been published ('Probing beneath the surface without a scratch — bulk non-destructive elemental analysis using negative muons', AD Hillier et al., *Microchemical Journal* 125 (2016) 203) which describes the technique's development and potential capabilities. A project has been initiated with STFC's Technology Department to develop detectors for this application and already demonstrated use of pixel detector for imaging.

Members

Director

Philip KING

Research & Technical Scientist

Isao WATANABE (concurrent: Advanced Meson Science Lab.)

Administration Manager

Mitsuru KISHIMOTO (concurrent: Nishina Center Planning Office)

Kazunori MABUCHI (concurrent: Nishina Center Planning Office)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

A. Adamczak et al., "Steps towards the hyperfine splitting measurement of the muonic hydrogen ground state: pulsed muon beam and detection system characterization", *Journal of Instrumentation*, 11, P05007 (2016); doi:10.1088/1748-0221/11/05/P05007 *

K.M. Suzuki, T. Adachi, H. Sato, I. Watanabe, and Y. Koike, "Successive Magnetic Transitions Relating to Itinerant Spins and Localized Cu Spins in $\text{La}_{2-x}\text{Sr}_x\text{Cu}_{1-y}\text{Fe}_y\text{O}_4$: Possible Existence of Stripe Correlations in the Overdoped Regime" *J. Phys. Soc. Jpn.* **85**, 124705-1-7 (2016).*

Xing-Liang Xu, Xu-Guang Zheng, and I. Watanabe, "Utilizing Muon-Spin-Relaxation to Probe Ferroelectric Transition in Hydroxyl Salt $\text{Co}_2(\text{OD})_3\text{Cl}$ " *Ferroelectrics* **505**, 1255131-1-6 (2016). *

T. Adachi, A. Takahashi, K.M. Suzuki, M.A. Baqiya, T. Konno, T. Takamatsu, M. Kato, I. Watanabe, A. Koda, M. Miyazaki, R. Kadono, and Y. Koike, "Strong Electron Correlation Behind the Superconductivity in Ce-Free and Ce-Underdoped High-Tc T'-Cuprates" *J. Phys. Soc. Jpn.* **85**, 124705-1-7 (2016). *

M. Enomoto, I. Watanabe, and N. Kojima, "Dynamical Behavior of the Charge Transfer Phase Transition in Dithiooxalato-Bridged Iron Mixed-Valence System", *Current Inorganic Chemistry* **6**, 49-60 (2016). *

Sunaryono, Ahmad Taufiq, Edy Giri Rahman Putra, A. Okazawa, I. Watanabe, N. Kojima, Supagorn Rugmai, Siriwat Soontaranon, Mohammad Zainuri, Triwikantoro, Suminar Pratapa, and Darminto, "Small-Angle X-Ray Scattering Study on PVA/ Fe_3O_4 Magnetic Hydrogels" *NANO* **11**, 1650027-1-12 (2016). *

I. Kawasaki, K. Fujimura, I. Watanabe, M. Avdeev, K. Tenya, and M. Yokoyama, "Muon Spin Relaxation and Neutron Diffraction Studies of Cluster-Glass State in $\text{Sr}_{1-x}\text{La}_x\text{RuO}_3$ " *J. Phys. Soc. Jpn.* **85**, 054701-1-8 (2016). *

T. Uehara, M. Ito, J. Angel, J. Shimada, N. Komakine, T. Tsuchiya, H. Taniguchi, K. Satoh, K. Triyana, Y. Ishii, and I. Watanabe, "Studies on Magnetism of the Layered Organic Antiferromagnet Bordered on a Superconducting Phase by Muon Spin Rotation and Magnetization Measurements", *J. Phys. Soc. Jpn.* **85**, 024710-1-6 (2016). *

[Proceedings]

(Original Papers) *Subject to Peer Review

M. Bagatin, S. Gerardin, A. Paccagnella, A. Visconti, S. Beltrami, M. Bertuccio, K. Ishida, C. D. Frost, A. Hillier, V. Ferlet-Cavrois
Reliability Physics Symposium (IRPS), 2016 IEEE International , 10.1109/IRPS.2016.7574552 *

Oral Presentations

[International Conference etc.]

K. Ishida, " Muon g-2/EDM at J-PARC " , Seventh Meeting on CPT and Lorentz Symmetry, Bloomington, USA, June 2016

K. Ishida, "Muon catalyzed d-t fusion ", The 6th Yamada Conference on Muonic X and Gamma ray Spectroscopy, Osaka, Sep 2016

[Domestic Conference]

北村遼他, " J-PARC ミューオン g-2/EDM 精密測定実験におけるミューオン加速実現に向けた低速ミューオン生成実験の結果報告と展望 "、日本物理学会年次大会、東北学院大学、3月(2016)

Posters Presentations

[International Conference etc.]

Alexandre Bossler, Viyas Gupta, Arto Javanainen, Georgios Tsiligiannis, Helmut Puchner, Frédéric Saigne, Frédéric Wrobel, Ari Virtanen , Luigi Dilillo, "Comparison of the Effects of Muon and Low-Energy Proton Irradiation on a 65 nm Low-Power SRAM", . RADECS: Radiation and Its Effects on Components and Systems, Sep 2016, Bremen, Germany.

RIBF Research Division Radioactive Isotope Physics Laboratory

1. Abstract

This Laboratory works as one of core research groups conducting programs at the world-premiere heavy-ion accelerator facility of RIKEN “RI Beam Factory (RIBF)”. The Laboratory explores exotic nuclear structures and dynamics in exotic nuclei that have never been investigated before, such as those with largely imbalanced proton and neutron numbers. Our aim is to develop new experimental techniques utilizing fast radioactive isotope (RI) beams at RIBF, to discover new phenomena and properties in exotic nuclei. The Laboratory is focusing three major subjects; shell evolution of very neutron-rich nuclei, the r-process path and equation-of-state in asymmetric nuclear matter. The Laboratory has initiated international collaborations for in-beam gamma spectroscopy, decay spectroscopy and heavy-ion induced reactions, and has formed a discussion forum for next generation gamma detectors.

2. Major Research Subjects

- (1) Study of structure and dynamics of exotic nuclei through developments of new tools in terms of reaction- and technique-based methodology
- (2) Research on EOS in asymmetric nuclear matter via heavy-ion induced reactions
- (3) Detector developments for spectroscopy and reaction studies

3. Summary of Research Activity

(1) In-beam gamma spectroscopy

In the medium and heavy mass region explored at RIBF, collective natures of nuclei are one of important subjects, which are obtained through production and observation of high excited and high spin states. To populate such states, heavy-ion induced reactions such as fragmentation, fission are useful. So far, we have developed two-step fragmentation method as an efficient method to identify and populate excited states, and lifetime measurements to deduce transition strength.

Devices utilized for the in-beam gamma spectroscopy are ZeroDegree Spectrometer (ZDS) and a NaI array DALI2. Since the end of 2008, the first spectroscopy on nuclei island-of-inversion region was performed, we have explored step-by-step new and unknown regions in the nuclear chart. The second campaign in 2009 was organized to study background components originating from atomic processes in a heavy target. Neutron-rich nuclei at $N=20$ to 28 were studied in 2010. In 2011-2013, we conducted experiment programs for Ca-54, Ni-78, neutron-rich nuclei at $N=82$ and neutron-deficient nuclei at $Z=50$.

A multitude of data obtained with inelastic, nucleon knock-out, fragmentation channels have been analyzed and published. In 2011-2013, collective natures of Mg-36, 38 and Si-42 were both published in PRL. Excited states firstly observed in Ca-54 were reported in Nature to demonstrate a new nuclear magic number of 34. Fragmentation reaction has been found efficient for nuclei with $A>100$ and low-lying excited state in Pd-126 has been successfully observed and reported in PRC.

To further strengthen the in-beam gamma spectroscopy at RIBF, we have proposed a new setup of MINOS + DALI2 to search for the 1st excited states in even-even neutron-rich nuclei with $Z\sim 20$ to 40. The program was submitted to the PAC 2013 as a new category “proposal for scientific program” and was S-ranked. A dedicated collaboration “SEASTAR” has been established as a subset of in-beam gamma collaboration “SUNFLOWER”. The two campaigns were organized in 2014 and 2015 to study very neutron-rich isotopes.

Concerning a next generation detector, a discussion forum has been established to write up a white paper on tracking germanium detectors and high-efficient crystal detectors such LaBr3 and GAGG.

(2) Decay spectroscopy

Beta- and isomer-spectroscopy is an efficient method for studying nuclear structure, especially for non-yrast levels. We had accumulated experimental techniques at the RIPS facility to investigate nuclear structure in light mass region via beta-gamma and beta-p coincidence. Concerning the medium and heavy mass region available at RIBF, we have developed two position-sensitive active-stoppers, strip-silicon detectors and a cylindrical active stopper called CAITEN, to achieve a low-background measurement by taking correlation between heavy ion stop position and beta-ray emission position. A site of decay-spectroscopy at the new facility of RIBF is the final focal plane of ZDS, where high precision of TOF in particle identification is obtained due to a long flight path from BigRIPS to ZDS.

At the end of 2009, the first decay spectroscopy was organized with a minimum setup of four clover gamma detectors and silicon strip detectors, to study neutron-rich nuclei with $A\sim 110$. The first campaign was found successful and efficient to publish four letter articles in 2011, two PRL's and two PLB's. One of the PRL papers is associated to the r-process path where half-lives for 18 neutron-rich nuclei were determined for the first time. The other PRL paper reported a finding of deformed magic number 64 in the Zr isotopes.

The success of the first decay-spectroscopy campaign stimulated to form a new large-scale collaboration “EURICA”, where a twelve Euroball cluster array is coupled with the silicon-strip detectors to enhance gamma efficiency by a factor of 10. A construction proposal of “EURICA” was approved in the PAC 2011, and the commissioning was successfully organized in spring 2012. Since then, physics runs have been conducted for programs approved to survey nuclei of interest as many as possible, such as Ni-78, Pd-128, Sn-100. So far, 34 papers including 11 PRL's and 8 PLB's were published. One of the highlights is discovery of a seniority isomer in Pd-128, of which cascade gamma decay gives the energy of 1st excited state and robustness of $N=82$ magic number, and the other is a half-life measurement for 110 neutron-rich nuclei across the $N=82$ shell gap, which shows implications for the mechanism and universality of the r-process path. The EURICA collaboration finished its physics programs in summer 2016.

Beta-delayed neutron emission probability of medium and heavy neutron-rich nuclei is important to understand nuclear structure and the r-process path. In 2013, a new collaboration “BRIKEN” has been established to form a He-3 detector array. A present design of the array has neutron efficiency as high as 70% up to 3 MeV. The array will be coupled with the AIDA silicon strip system. A construction

proposal was approved at the PAC 2013 and three physics proposals have been approved. The commissioning run was conducted in autumn 2016.

The CAITEN detector was successfully tested with fragments produced with a Ca-48 beam in 2010.

(3) Equation-of-state via heavy-ion central collisions

Equation-of-state in asymmetric nuclear matter is one of major subjects in physics of exotic nuclei. Pi-plus and pi-minus yields in central heavy ion collisions at the RIBF energy are considered as one of EOS sensitive observables at the RIBF energy. To observe charged pions, a TPC for the SAMURAI spectrometer is being constructed under an international collaboration "S π RIT". Construction proposal was submitted at the PAC 2012, and physics proposals were approved at the PAC 2012 and 2013. The physics runs were successfully conducted in spring 2016.

An international symposium "NuSYM" on nuclear symmetry energy was organized at RIKEN July 2010 to invite researchers in three sub-fields, nuclear structure, nuclear reaction and nuclear astrophysics, and to discuss nuclear symmetry energy together. Since then, the symposium series have been held every year and been useful to encourage theoretical works and to strengthen the collaboration.

(4) Nucleon correlation and cluster in nuclei

Nucleon correlation and cluster in nuclei are matters of central focus in a "beyond mean-field" picture. The relevant programs with in-beam gamma and missing-mass techniques are to depict nucleon condensations and correlations in nuclear media as a function of density as well as temperature. Neutron-halo and α -skin nuclei are objects to study dilute neutron matter at the surface. By changing excitation energies in neutron-rich nuclei, clustering phenomena and role of neutrons are to be investigated.

In 2013, two programs were conducted at the SAMURAI spectrometer. One is related to proton-neutron correlation in the C-12 nucleus via p-n knockout reaction with a carbon target. The other is to search for a cluster state in C-16, which was populated via inelastic alpha scattering. The data is being analyzed.

Members

Chief Scientist (Lab. Head)

Hiro Yoshi SAKURAI (Deputy Director, RNC)

Vice Chief Scientist

Takashi ICHIHARA

Research & Technical Scientists

Yoichi NAKAI (Senior Research Scientist)
Akihisa KOHAMA (Senior Research Scientist)
Takashi KISHIDA (Senior Research Scientist)
Shunji NISHIMURA (Senior Research Scientist)

Tadaaki ISOBE (Senior Research Scientist)
Pieter Christiaan DOORNENBAL (Research Scientist)
Daisuke SUZUKI (Research Scientist)

Contract Researchers

David STEPPENBECK

Mizuki NISHIMURA

Foreign Postdoctoral Researchers

Paer-Anders SOEDERSTROEM

He WANG

Research Consultants

Masayasu ISHIIHARA
Akitsu IKEDA

Hiro yuki MURAKAMI
Kenichi MATSUYANAGI

Junior Research Associate

Yoshiaki SHIGA (Rikkyo Univ.)
Noritsugu NAKATSUKA (Kyoto Univ.)

Keishi MATSUI (Univ. of Tokyo)
Masanori KANEKO (Kyoto Univ.)

International Program Associates

Ian MURRAY (Univ. Paris Sud)
Sidong CHEN (Peking Univ.)
Xiaohui SUN (Peking Univ.)

Phong VI (Hanoi University of Science,
Longchun TAO (Peking University)

Visiting Researchers

Gabor KISS (JSPS Fellow)
Martha Liliana CORTES SUA (JSPS Fellow)

David STEPPENBECK (JSPS Fellow)
Frank BROWNE (JSPS Fellow)

Senior Visiting Scientists

Kengo OGAWA (Chiba Univ.)
Koichiro ASAHII (TIT)

Shigeru KUBONO (Univ. of Tokyo)

Visiting Scientists

Hooi Jing ONG (RCNP)

Megumi NIIKURA (Univ. of Tokyo)

Silvio CHERUBINI (Univ. of Catania)
 Hyo Soon JUNG (Univ. of Notre Dame)
 Daiki NISHIMURA (Tokyo Univ. of Sci.)
 Takashi KISHIDA (Aoyama Univ.)
 Naohiko OTSUKA (Intl. Atomic Energy Agency, Austria)
 Giuseppe LORUSSO (National Physics Lab., UK)
 Hiu Ching LEE (Univ. of Hong Kong)
 Zhengyu XU (Univ. of Hong Kong)
 Indranil MAZUMDAR (GSI)
 Byungsik HONG (Korea Univ.)
 Prabhakar PALNI (MSU)
 Rebecca SHANE (MSU)
 Alan MCINTOSH (Texas A & M Univ.)
 Michael YOUNG (Texas A & M Univ.)
 Thomas DAVINSON (Univ. of Edinburgh)
 Yassid AYYAD (Osaka Univ.)
 Kathrin WIMMER (Univ. of Tokyo)
 Tetsuya MURAKAMI (Kyoto Univ.)

Kazuo IEKI (Rikkyo Univ.)
 Mitsunori FUKUDA (Osaka Univ.)
 Nori AOI (RCNP)
 Khiem Hong LE (Vietnam Academy of Sci. and Tech.)
 Evgueni NIKOLSKI (RRC Kurchatov Inst.)
 Alexey OGLOBLIN (RRC Kurchatov Inst.)
 Hiroshi WATANABE (Beihang Univ.)
 Akira ONO (Tohoku Univ.)
 Kazuhiro OYAMATSU (Aichi Shukutoku University)
 Clementine SANTAMARIA (Michigan State University)
 Kei IIDA (Kochi University)
 Natsumi IKENO (Tottori Univ.)
 Yont Jin KIM (Institute for Basic Science)
 Pawlowski PIOTR (Institute of Nuclear Physics PAN)
 Giordano CERIZZA (NSCL)
 Marisa GULINO (Universita di Enna Kore Italy)
 Satoshi TAKEUCHI (TIT)
 Hyo Sang LEE (Institute for Basic Science)

Visiting Technicians

Ivan KOJOUHAROV (GSI)

Student Trainees

Hiroki NISHIBATA (Osaka Univ.)
 Tetsuya YAMAMOTO (Osaka Univ.)
 Ayumi YAGI (Osaka Univ.)
 Ryo TANIUCHI (Univ. of Tokyo)
 Jin-hee CHANG (Korea University)
 Akira HOMMA (Niigata Univ.)
 Satoru MOMIYAMA (Univ. of Tokyo)
 Shintaro YAMAOKA (Osaka Univ.)
 Kouta WATANABE (Osaka Univ.)
 Justin ESTEE (Michigan State University)
 Masanori KANEKO (Kyoto Univ.)
 Suwat TANGWANCHAROEN (Michigan State University)
 JungWoo LEE (Korea University)
 Takashi ANDO (Univ. of Tokyo)
 Shunpei KOYAMA (Univ. of Tokyo)
 Hang DU (Osaka Univ.)
 Yuutaro TANAKA (Osaka Univ.)
 Jonathan BARNEY (Michigan State University)
 Hiroyuki OIKAWA (Tokyo Univ. of Science)
 Toshiki YOSHINOBU (Tokyo Univ. of Science)
 Yuki KANKE (Tokyo Univ. of Science)
 Junya NAGUMO (Tokyo Univ. of Science)
 Jiajian LIU (The University of Hong Kong)
 Shinnosuke KANAYA (Osaka Univ.)
 Hiroshi KANAOKA (Osaka Univ.)
 Yan ZHANG (Tsinghua University)
 Shunsuke NAGAMINE (Univ. of Tokyo)
 Takeshi SAITO (Univ. of Tokyo)
 Eri MIYATA (Niigata Univ.)
 Yuta KUNIMOTO (Rikkyo Univ.)
 Yohei TANAKA (Rikkyo Univ.)
 Sean SWEANY (Michigan State University)
 Shoichi YAGI (Osaka Univ.)
 Yuki TAKEI (Tokyo Univ. of Science)
 Pawel LASKO (Jagiellonian University)

Krzyszto PELCZAR (Jagiellonian University)
 Ryo HIGUCHI (Univ. of Tokyo)
 Riku TAMURA (Univ. of Tokyo)
 Masashi USAMI (Univ. of Tokyo)
 Kousuke ONISHI (Osaka Univ.)
 Takano SUGIHARA (Osaka Univ.)
 Juan MANFREDI (Michigan State University)
 Fredrik PARNEFJORD GUSTAFSSON (HKU)
 Chun Yuen TSANG (CUHK)
 Kosuke MAEDA (Rikkyo Univ.)
 Ryunosuke BANNAY (Rikkyo Univ.)
 Sakiko ASHIKAGA (Kyoto Univ.)
 Kento INABA (Kyoto Univ.)
 Shota MATSUMOTO (Kyoto Univ.)
 Ken WATANABE (Kyoto Univ.)
 Yu TAKAHASHI (Kyoto Univ.)
 Ami KOSHIKAWA (Kyoto Univ.)
 Andrea JEDEL (Texas A & M University)
 Taku KUMON (Univ. of Tokyo)
 Takuma KOIWA (Univ. of Tokyo)
 Yuma SHIMIZU (Univ. of Tokyo)
 SoomiCHA (Sungkyunkwan University)
 Taichi HORI (Osaka Univ.)
 Shoken NAKAMURA (Osaka Univ.)
 Rikuto YANAGIHARA (Osaka Univ.)
 Naoto KANDA (Niigata Univ.)
 Suharu HOSHINO (Niigata Univ.)
 Ryohei HOSODA (Niigata Univ.)
 Masaki SHIOTA (Niigata Univ.)
 Taro WADA (Niigata Univ.)
 Toshiki MOCHIZUKI (Univ. of Tokyo)
 Tomoaki KASUGA (Univ. of Tokyo)
 Ryohei ITO (Univ. of Tokyo)
 Herrera Wilmar RODRIGUEZ (Univ. Nacional de Colombia)
 Yusuke FUJINO (Rikkyo Univ.)

Interns

Dolachai BONIFACE (Univ. Paris SUD)

Part-time Workers

Yukiya SAITO (Univ. of Tokyo)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- G. Jhang, J. Barney, J. Estee, T. Isobe, M. Kaneko, M. Kurata-Nishimura, G. Cerizza, C. Santamaria, J.W. Lee, P. Lasko, J. Lukasik, W.G. Lynch, A.B. McIntosh, T. Murakami, P. Pawlowski, R. Shane, S. Tangwancharoen, M.B. Tsang, H. Baba, B. Hong, Y.J. Kim, H.S. Lee, H. Otsu, K. Pelczar, H. Sakurai, D. Suzuki, Z. Xiao, S.J. Yennello, Y. Zhang et. al., "Beam Commissioning of the SpiRIT Time Projection Chamber", *Journal of the Korean Physical Society*, Vol. 69, No. 2, 144 (2016) *
- J. W. Hwang, S. Kim, Y. Satou, N. A. Orr, Y. Kondo, T. Nakamura, J. Gibelin, N. L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, N. Inabe, T. Isobe, D. Kameda, D. Kanno, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F. M. Marques, R. Minakata, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, S. Ogoshi, H. Otsu, H. Sato, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, R. Tanaka, Y. Togano, A. G. Tuff, M. Vandebrouck, and K. Yoneda. 'Single-neutron knockout from ^{20}C and the structure of ^{19}C .' *Phys.Lett. B*, 769:503, 2017.
- H. N. Liu, J. Lee, P. Doornenbal, H. Scheit, S. Takeuchi, N. Aoi, K. A. Li, M. Matsushita, D. Steppenbeck, H. Wang, H. Baba, E. Ideguchi, N. Kobayashi, Y. Kondo, G. Lee, S. Michimasa, T. Motobayashi, A. Poves, H. Sakurai, M. Takechi, Y. Togano, J. A. Tostevin, and Y. Utsuno. 'Intruder configurations in the ground state of ^{30}Ne .' *Phys.Lett. B*, 767:58, 2017.
- N. Paul, A. Corsi, A. Obertelli, P. Doornenbal, G. Authélet, H. Baba, B. Bally, M. Bender, D. Calvet, F. Chateau, S. Chen, J. -P. Delaroche, A. Delbart, J. -M. Gheller, A. Giganon, A. Gillibert, M. Girod, P. -H. Heenen, Y. Lapoux, J. Libert, T. Motobayashi, M. Niikura, T. Otsuka, T. R. Rodriguez, J. -Y. Rousse, H. Sakurai, C. Santamaria, N. Shimizu, D. Steppenbeck, R. Taniuchi, T. Togashi, Y. Tsunoda, T. Uesaka, T. Ando, T. Arici, A. Blazhev, F. Browne, A. M. Bruce, R. Carroll, L. X. Chung, M. L. Cortes, M. Dewald, B. Ding, F. Flavigny, S. Franchoo, M. Gorska, A. Gottardo, A. Jungclaus, J. Lee, M. Lettmann, B. D. Linh, J. Liu, Z. Liu, C. Lizarazo, S. Momiyama, K. Moschner, S. Nagamine, N. Nakatsuka, C. Nita, C. R. Nobs, L. Olivier, Z. Patel, Z. Podolyak, M. Rudigier, T. Saito, C. Shand, P. -A. Soderstrom, I. Stefan, R. Orlandi, V. Vaquero, V. Werner, K. Wimmer, and Z. Xu. 'Are There Signatures of Harmonic Oscillator Shells Far from Stability? First Spectroscopy of ^{110}Zr .' *Phys.Rev.Lett.*, 118:032501, 2017.
- H. Wang, N. Aoi, S. Takeuchi, M. Matsushita, T. Motobayashi, D. Steppenbeck, K. Yoneda, H. Baba, Zs. Dombradi, K. Kobayashi, Y. Kondo, J. Lee, H. Liu, R. Minakata, D. Nishimura, H. Otsu, H. Sakurai, D. Sohler, Y. Sun, Z. Tian, R. Tanaka, Zs. Vajta, Z. Yang, T. Yamamoto, Y. Ye, and R. Yokoyama. 'First spectroscopic information from even-even nuclei in the region "southeast" of ^{132}Sn : Neutron-excitation dominance of the $2^+ 1$ state in ^{132}Cd .' *Phys.Rev. C*, 94:051301, 2016.
- D.Q. Fang, Y.G. Ma, X.Y. Sun, P. Zhou, Y. Togano, N. Aoi, H. Baba, X.Z. Cai, X.G. Cao, J.G. Chen, Y. Fu, W. Guo, Y. Hara, T. Honda, Z.G. Hu, K. Ieki, Y. Ishibashi, Y. Ito, N. Iwasa, S. Kanno, T. Kawabata, H. Kimura, Y. Kondo, K. Kurita, M. Kurokawa, T. Moriguchi, H. Murakami, H. Ooishi, K. Okada, S. Ota, A. Ozawa, H. Sakurai, S. Shimoura, R. Shioda, E. Takeshita, S. Takeuchi, W.D. Tian, H.W. Wang, J.S. Wang, M. Wang, K. Yamada, Y. Yamada, Y. Yasuda, K. Yoneda, G.Q. Zhang, T. Motobayashi: 'Proton-proton correlations in distinguishing the two-proton emission mechanism of ^{23}Al and ^{22}Mg ', *Phys. Rev. C* 94 (2016) 044621
- Y. Togano, T. Nakamura, Y. Kondo, J. A. Tostevin, A. T. Saito, J. Gibelin, N. A. Orr, N. L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, J. W. Hwang, N. Inabe, T. Isobe, D. Kameda, D. Kanno, S. Kim, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F. M. Marques, R. Minakata, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, S. Ogoshi, H. Otsu, H. Sato, Y. Satou, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, R. Tanaka, A. G. Tuff, M. Vandebrouck, and K. Yoneda. 'Interaction cross section study of the two-neutron halo nucleus ^{22}C .' *Phys.Lett. B*, 761:412, 2016.
- P. Doornenbal, H. Scheit, S. Takeuchi, N. Aoi, K. Li, M. Matsushita, D. Steppenbeck, H. Wang, H. Baba, E. Ideguchi, N. Kobayashi, Y. Kondo, J. Lee, S. Michimasa, T. Motobayashi, A. Poves, H. Sakurai, M. Takechi, Y. Togano, and K. Yoneda. 'Mapping the deformation in the "island of inversion": Inelastic scattering of ^{30}Ne and ^{36}Mg at intermediate energies.' *Phys.Rev. C*, 93:044306, 2016.
- H. Wang, H. Otsu, H. Sakurai, D.S. Ahn, M. Aikawa, T. Ando, S. Araki, S. Chen, N. Chiga, P. Doornenbal, N. Fukuda, T. Isobe, S. Kawakami, S. Kawase, T. Kin, Y. Kondo, S. Koyama, S. Kubono, Y. Maeda, A. Makinaga, M. Matsushita, T. Matsuzaki, S. Michimasa, S. Momiyama, S. Nagamine, T. Nakamura, K. Nakano, M. Niikura, T. Ozaki, A. Saito, T. Saito, Y. Shiga, M. Shikata, Y. Shimizu, S. Shimoura, T. Sumikama, P.-A. Söderström, H. Suzuki, H. Takeda, S. Takeuchi, R. Taniuchi, Y. Togano, J. Tsubota, M. Uesaka, Ya. Watanabe, Yu. Watanabe, K. Wimmer, T. Yamamoto, and K. Yoshida. 'Spallation reaction study for the long-lived fission product ^{107}Pd ', *Progress in Theory and Experiment Physics* 2017(2), 021D01 (2017).
- S. Hayakawa, S. Kubono, D. Kahl, H. Yamaguchi, D. N. Binh, T. Hashimoto, Y. Wakabayashi, J. J. He, N. Iwasa, S. Kato, T. Komatsubara, Y. K. Kwon, and T. Teranishi. "First direct measurement of the $^{11}\text{C}(\alpha, p)^{14}\text{N}$ stellar reaction by an extended thick-target method", : *Phys. Rev. C* 93 (2016) 065802 (8)
- W.P. Liu, Z.H. Li, J.J. He, X.D. Tang, G. Lian, Z. An, J.J. Chang, H. Chen, Q.H. Chen, X.J. Chen, Z.J. Chen, B.Q. Cui, X.C. Du, C.B. Fu, L. Gan, B. Guo, G.Z. He, A. Heger, S.Q. Hou, H.X. Huang, N. Huang, B.L. Jia, L.Y. Jiang, S. Kubono, J.M. Li, K.A. Li, T. Li, Y.J. Li, M. Lugaro, X.B. Luo, H.Y. Ma, S.B. Ma, D.M. Mei, Y.Z. Qian, J.C. Qin, J. Ren, Y.P. Shen, J. Su, L.T. Sun, W.P. Tan, I. Tanihata, S. Wang, P. Wang, Y.B. Wang, Q. Wu, S.W. Xu, S.Q. Yan, L.T. Yang, Y. Yang, X.Q. Yu, Q. Yue, S. Zeng, H.Y. Zhang, H. Zhang, L.Y. Zhang, N.T. Zhang, Q.W. Zhang, T. Zhang, X.P. Zhang, X.Z. Zhang, Z.M. Zhang, W. Zhao, Z. Zhao, and C. Zhou (JUNA Collaboration). "Progress of Jinping Underground laboratory for Nuclear Astrophysics (JUNA)", *SCIENCE CHINA - Physics, Mechanics & Astronomy* 59 (2016) 642001.
- X. Xu, P. Zhang, P. Shuai, R.J. Chen, X.L. Yan, Y.H. Zhang, M. Wang, Yu.A. Litvinov, H.S. Xu, T. Bao, X.C. Chen, H. Chen, C.Y. Fu, S. Kubono, Y.H. Lam, D.W. Liu, R.S. Mao, X.W. Ma, M.Z. Sun, X.L. Tu, Y.M. Xing, J.C. Yang, Y.J. Yuan, Q. Zeng, X. Zhou, X.H. Zhou, W.L. Zhan, S. Litvinov, K. Blaum, G. Audi, T. Uesaka, Y. Yamaguchi, T. Yamaguchi, A. Ozawa, B.H. Sun, Y. Sun, A. C. Dai, and F.R. Xu. "Identification of the Lowest $T=2, J_{\pi}=0^+$ Isobaric Analog State in ^{52}Co and Its Impact on the Understanding of β -Decay Properties of ^{52}Ni ", *Phys. Rev. Lett.* 117 (2016) 182503.
- P. Zhang, X. Xu, P. Shuai, R.J. Chen, X.L. Yan, Y.H. Zhang, M. Wang, Yu.A. Litvinov, K. Blaum, H.S. Xu, T. Bao, X.C. Chen, H. Chen, C.Y. Fua, J.J. He, S. Kubono, Y.H. Lam, D.W. Liua, R.S. Mao, X.W. Ma, M.Z. Suna, X.L. Tu, Y.M. Xing, J.C. Yang, Y.J. Yuan, Q. Zenga, X. Zhoua, X.H. Zhou, W.L. Zhan, S. Litvinov, G. Audi, T. Uesaka, Y. Yamaguchi, T. Yamaguchi, A. Ozawa, B.H. Sun, Y. Sun, F.R. Xu. "High-precision QEC values of super-allowed $0^+ \rightarrow 0^+$ β -emitters ^{46}Cr , ^{50}Fe and ^{54}Ni ", *Phys. Lett. B* 767 (2017) 20.
- T. Kawabata, T. Kawabata, Y. Fujikawa, T. Furuno, T. Goto, T. Hashimoto, M. Ichikawa, M. Itoh, N. Iwasa, Y. Kanada-En'yo, A. Koshikawa, S. Kubono, E. Miyawaki, M. Mizuno, K. Mizutani, T. Morimoto, M. Murata, T. Nanamura, S. Nishimura, S. Okamoto, Y. Sakaguchi, I. Sakata, A.

- Sakaue, R. Sawada, Y. Shikata, Y. Takahashi, D. Takechi, T. Takeda, C. Takimoto, M. Tsumura, K. Watanabe, and S. Yoshida. "Time-Reversal Measurement of the p-Wave Cross Sections of the ${}^7\text{Be}(n,\alpha){}^4\text{He}$ Reaction for the Cosmological Li Problem", *Phys. Rev. Lett.* 118 (2017) 052701.
- P. Russotto, S. Gannon, S. Kupny, P. Lasko, L. Acosta, M. Adamczyk, A. Al-Ajlan, M. Al-Garawi, S. Al-Homaidhi, F. Amorini, L. Auditore, T. Aumann, Y. Ayyad, Z. Basrak, J. Benlliure, M. Boisjoli, K. Boretzky, J. Brzychczyk, A. Budzanowski, C. Caesar, G. Cardella, P. Cammarata, Z. Chajecski, M. Chartier, A. Chbihi, M. Colonna, M.D. Cozma, B. Czech, E.De Filippo, M.Di Toro, M. Famiano, I. Gasparic, L. Grassi, C. Guazzoni, P. Guazzoni, M. Heil, L. Heilborn, R. Introzzi, T. Isobe, K. Kezzar, M. Kis, A. Krasznahorkay, N. Kurz, E. La Guidara, G. Lanzalone, A. Le Fevre, Y. Leifels, R.C. Lemmon, Q.F. Li, I. Lombardo, J. Lukasik, W.G. Lynch, P. Marini, Z. Matthews, L. May, T. Minniti, M. Mostazo, A. Pagano, E. V. Pagano, M. Papa, P. Pawlowski, S. Pirrone, G. Politi, F. Porto, W. Reviol, F. Riccio, F. Rizzo, E. Rosato, D. Rossi, S. Santoro, D.G. Sarantites, H. Simon, I. Skwirczynska, Z. Sosin, L. Stuhl, W. Trautmann, A. Trifiro, M. Trimarchi, M.B. Tsang, G. Verde, M. Veselsky, M. Vigilante, Y. Wang, A. Wieloch, P. Wigg, J. Winkelbauer, H.H. Wolter, P. Wu, S. Yennello, P. Zambon, L. Zetta, M. Zoric, "Results of the ASY-EOS experiment at GSI: The symmetry energy at suprasaturation density", *Physical Review C* 94 (2016) 034608.
- M.B. Tsang, J. Estee, H. Setiawan, W.G. Lynch, J. Barney, M.B. Chen, G. Cerizza, P. Danielewicz, J. Hong, P. Morfouace, R. Shane, S. Tangwancharoen, K. Zhu, T. Isobe, M. Kurata-Nishimura, J. Lukasik, T. Murakami, Z. Chajecski, "Pion Production in Rare Isotope Collisions", *Physical Review C* 95 (2016) 044614.
- S. Tangwancharoen, W.G. Lynch, J. Barney, J. Estee, R. Shane, M.B. Tsang, Y. Zhang, T. Isobe, M. Kurata-Nishimura, T. Murakami, Z.G. Xiao, Y.F. Zhang, the SpiRIT collaboration, "A gating grid driver for time projection chambers", *Nuclear Instruments and Methods A* 853 (2017) 44.
- P. Lasko, M. Adamczyk, J. Brzychczyk, P. Hirnyk, J. Lukasik, P. Pawlowski, K. Pelczar, A. Snoch, A. Sochocka, Z. Sosin, J. Barney, G. Cerizza, J. Estee, T. Isobe, G. Jhang, M. Kaneko, M. Kurata-Nishimura, W.G. Lynch, T. Murakami, C. Santamaria, M.B. Tsang, Y. Zhang, "KATANA – A charge-sensitive triggering system for the SpiRIT experiment", *Nuclear Instruments and Methods A* 856 (2017) 92.
- A. Tarifeno-Saldivia, J.L. Tain, Domingo-Pardo, F. Calvino, G. Cortes, V.H. Phong, A. Riego, J. Agramunt, A. Algora, N. Brewer, R. Caballero-Folch, P.J. Coleman-Smith, T. Davinson, I. Dillmann, A. Estrade, C.J. Griffin, R. Grzywacz, L.J. Harkness-Brennan, G.G. Kiss, M. Kogimtzis, M. Labiche, I.H. Lazarus, G. Lorusso, K. Matsui, K. Miernik, F. Montes, A.I. Morales, S. Nishimura, R.D. Page, Z.S. Podolyak, V.F.E. Pucknell, B.C. Rasco, P. Regan, B. Rubio, K.P. Rykaczewski, d Y. Saito, c;g H. Sakurai, c J. Simpson, k E. Sokol, t R. Surman, A. Svirikhin, S.L. Thomas, A. Tolosa and P. Woods "Conceptual design of a hybrid neutron-gamma detector for study of beta-delayed neutrons at the RIB facility of RIKEN" *Journal of Instrumentation* 12 (2016) P04006.
- T. Goigoux, P. Ascher, B. Blank, M. Gerbaux, J. Giovannazzo, S. Grevy, T. Kurtukian Nieto, C. Magron, P. Doornenbal, G. G. Kiss, S. Nishimura, P.-A. Söderström, V. H. Phong, J. Wu, D. S. Ahn, N. Fukuda, N. Inabe, T. Kubo, S. Kubono, H. Sakurai, Y. Shimizu, T. Sumikama, H. Suzuki, H. Takeda, J. Agramunt, A. Algora, V. Guadilla, A. Montaner-Piza, A. I. Morales, S. E. A. Orrigo, B. Rubio, Y. Fujita, M. Tanaka, W. Gelletly, P. Aguilera, F. Molina, F. Diel, D. Lubos, G. de Angelis, D. Napoli, C. Borcea, A. Boso, R. B. Cakirli, E. Ganioglu, J. Chiba, D. Nishimura, H. Oikawa, Y. Takei, S. Yagi, K. Wimmer, G. de France, S. Go, and B. A. Brown "Two-proton radioactivity of ${}^{67}\text{Kr}$ " *PHYSICAL REVIEW LETTERS* 117 (2016) 162501.
- B. Blank, T. Goigoux, P. Ascher, M. Gerbaux, J. Giovannazzo, S. Grevy, T. Kurtukian Nieto, C. Magron, J. Agramunt, A. Algora, V. Guadilla, A. Montaner-Piza, A. I. Morales, S. E. A. Orrigo, B. Rubio, D. S. Ahn, P. Doornenbal, N. Fukuda, N. Inabe, G. Kiss, T. Kubo, S. Kubono, S. Nishimura, V. H. Phong, H. Sakurai, Y. Shimizu, P.-A. Soderstrom, T. Sumikama, H. Suzuki, H. Takeda, J. Wu, Y. Fujita, M. Tanaka, W. Gelletly, P. Aguilera, F. Molina, F. Diel, D. Lubos, G. de Angelis, D. Napoli, C. Borcea, A. Boso, R. B. Cakirli, E. Ganioglu, J. Chiba, D. Nishimura, H. Oikawa, Y. Takei, S. Yagi, K. Wimmer, G. de France, and S. Go "New neutron-deficient isotopes from ${}^{78}\text{Kr}$ fragmentation" *PHYSICAL REVIEW C* 93 (2016) 061301(R)
- Y. Nakai, H. Hidaka, N. Watanabe, T. M. Kojima: "Stepwise formation of $\text{H}_3\text{O}^+(\text{H}_2\text{O})_n$ in an ion drift tube: empirical effective temperature of association/dissociation reaction equilibrium in an electric field", *Journal Chemical Physics* 144, (2016) 224306.
- P.J. Davies, H. Grawe, K. Moschner, A. Blazhev, R. Wadsworth, P. Boutachkov, F. Ameil, A. Yagi, H. Baba, T. Bäck, M. Dewald, P. Doornenbal, T. Faestermann, A. Gengelbach, J. Gerl, R. Gernhäuser, S. Go, M. Görski, E. Gregor, T. Isobe, D.G. Jenkins, H. Hotaka, J. Jolie, I. Kojouharov, N. Kurz, M. Lewitowicz, G. Lorusso, L. Maier, E. Merchan, F. Naqvi, H. Nishibata, D. Nishimura, S. Nishimura, F. Nowacki, N. Pietralla, H. Schaffner, P.-A. Söderström, H.S. Jung, K. Steiger, T. Sumikama, J. Taprogge, P. Thöle, N. Warr, H. Watanabe, V. Werner, Z.Y. Xu, K. Yoshinaga, Y. Zhu: "The role of core excitations in the structure and decay of the $16+$ spin-gap isomer in ${}^{96}\text{Cd}$ ", *Phys. Rev. Lett.* B 767 (2017) 474-479.
- J. Wu, S. Nishimura, G. Lorusso, P. Möller, E. Ideguchi, P.-H. Regan, G. S. Simpson, P.-A. Söderström, P. M. Walker, H. Watanabe, Z. Y. Xu, H. Baba, F. Browne, R. Daido, P. Doornenbal, Y. F. Fang, G. Gey, T. Isobe, P. S. Lee, J. J. Liu, Z. Li, Z. Korkulu, Z. Patel, V. Phong, S. Rice, H. Sakurai, L. Sinclair, T. Sumikama, M. Tanaka, A. Yagi, Y. L. Ye, R. Yokoyama, G. X. Zhang, T. Alharbi, N. Aoi, F. L. Bello Garrote, G. Benzoni, A. M. Bruce, R. J. Carroll, K. Y. Chae, Z. Dombradi, A. Estrade, A. Gottardo, C. J. Griffin, H. Kanaoka, I. Kojouharov, F. G. Kondev, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G. J. Lane, E. J. Lee, T. Lokotko, G. Lotay, C.-B. Moon, H. Nishibata, I. Nishizuka, C. R. Nita, A. Odahara, Zs. Podolyák, O. J. Roberts, H. Schaffner, C. Shand, J. Taprogge, S. Terashima, Z. Vajta, and S. Yoshida: "94 β -Decay Half-Lives of Neutron-Rich 55Cs to 67Ho: Experimental Feedback and Evaluation of the r-Process Rare-Earth Peak Formation", *Phys. Rev. Lett.* 118, 072701 (2017) 1-7.
- A.I. Morales, G. Benzoni, H. Watanabe, Y. Tsunoda, T. Otsuka, S. Nishimura, F. Browne, R. Daido, P. Doornenbal, Y. Fang, G. Lorusso, Z. Patel, S. Rice, L. Sinclair, P.-A. Söderström, T. Sumikama, J. Wu, Z.Y. Xu, A. Yagi, R. Yokoyama, H. Baba, R. Avigo, F.L. Bello Garrote, N. Blasi, A. Bracco, F. Camera, S. Ceruti, F.C.L. Crespi, G. de Angelis, M.-C. Delattre, Zs. Dombradi, A. Gottardo, T. Isobe, I. Kojouharov, N. Kurz, I. Kuti, K. Matsui, B. Melon, D. Mengoni, T. Miyazaki, V. Modamio-Hoybjor, S. Momiyama, D.R. Napoli, M. Niikura, R. Orlandi, H. Sakurai, E. Sahin, D. Sohier, H. Schaffner, R. Taniuchi, J. Taprogge, Zs. Vajta, J.J. Valiente-Dobón, O. Wieland, M. Yalcinkaya : Type II shell evolution in $A = 70$ isobars from the $N \geq 40$ island of inversion, *Phys. Lett. B* 765 (2017) 328-333.
- E. Ideguchi, G. S. Simpson, R. Yokoyama, M. Tanaka, S. Nishimura, P. Doornenbal, G. Lorusso, P.-A. Söderström, T. Sumikama, J. Wu, Z. Y. Xu, N. Aoi, H. Baba, F. L. Bello Garrote, G. Benzoni, F. Browne, R. Daido, Y. Fang, N. Fukuda, A. Gottardo, G. Gey, S. Go, N. Inabe, T. Isobe, D. Kameda, K. Kobayashi, M. Kobayashi, I. Kojouharov, T. Komatsubara, T. Kubo, N. Kurz, I. Kuti, Z. Li, M. Matsushita, S. Michimasa, C.-B. Moon, H. Nishibata, I. Nishizuka, A. Odahara, Z. Patel, S. Rice, E. Sahin, H. Sakurai, H. Schaffner, L. Sinclair, H. Suzuki, H. Takeda, J. Taprogge, Zs. Vajta, H. Watanabe, and A. Yagi : " μs isomers of ${}^{158,160}\text{Nd}$ ", *Phys Rev. C* 94, 064322 (2016) 1-5.
- J. Taprogge, A. Jungclauss, H. Grawe, I.N. Borzov, S. Nishimura, P. Doornenbal, G. Lorusso, G.S. Simpson, P.-A. Söderström, T. Sumikama, Z.Y. Xu, H. Baba, F. Browne, N. Fukuda, R. Gernhäuser, G. Gey, N. Inabe, T. Isobe, H.S. Jung, D. Kameda, G.D. Kim, Y.-K. Kim, I.

- Kojouharov, T. Kubo, N. Kurz, Y.K. Kwon, Z. Li, H. Sakurai, H. Schaffner, Y. Shimizu, K. Steiger, H. Suzuki, H. Takeda, Zs. Vajta, H. Watanabe, J. Wu, A. Yagi, K. Yoshinaga, G. Benzoni, S. Bo`nig, K.Y. Chae, L. Coraggio, J.-M. Daugas, F. Drouet, A. Gadea, A. Gargano, S. Ilieva, N. Itaco, F.G. Kondev, T. Kro`ll, G.J. Lane, A. Montaner-Piza´, K. Moschner³¹, D. Mu`cher, F. Naqvi, M. Niikura, H. Nishibata, A. Odahara, R. Orlandi, Z. Patel, Zs. Podolya´k, and A. Wendt : Proton-hole and core-excited states in the semi-magic nucleus $^{131}\text{In}_{82}$, *Eur. Phys. J. A* 52, 347 (2016) 1-10.
- P.-A. Söderström, P.M. Walker, J. Wu, H.L. Liu, P.H. Regan, H. Watanabe, P. Doornenbal, Z. Korkulu, P. Lee, J.J. Liu, G. Lorusso, S. Nishimura, V.H. Phong, T. Sumikama, F.R. Xu, A. Yagi, G.X. Zhang, D.S. Ahn, T. Alharbi, H. Baba, F. Browne, A.M. Bruce, R.J. Carroll, K.Y. Chae, Zs. Dombradi, A. Estrade, N. Fukuda, C.J. Griffin, E. Ideguchi, N. Inabe, T. Isobe, H. Kanaoka, S. Kanaya, I. Kojouharov, F.G. Kondev, T. Kubo, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G.J. Lane, E.J. Lee, C.S. Lee, G. Lotay, C.-B. Moon, I. Nishizuka, C.R. Nita, A. Odahar, Z. Patel, Zs. Podolyák, O.J. Roberts, H. Sakurai, H. Schaffner, C.M. Shand, H. Suzuki, H. Takeda, S. Terashima, Zs. Vajta, J.J. Valiente-Dòbon, Z.Y. Xu : "K-mixing in the doubly mid-shell nuclide ^{170}Dy and the role of vibrational degeneracy", *Phys. Lett. B* 762 (2016) 404-408.
- J. Lee, H. Liu, P. Doornenbal, M. Kimura, K. Minomo, K. Ogata, Y. Utsuno, N. Aoi, M. Matsushita, H. Scheit, D. Steppenbeck, S. Takeuchi, H. Wang, H. Baba, E. Ideguchi, N. Kobayashi, Y. Kondo, S. Michimasa, T. Motobayashi, H. Sakurai, M. Takechi, Y. Togano: "Asymmetry dependence of reduction factors from single-nucleon knockout of ^{30}Ne at similar to 230 MeV/nucleon", *Prog. Theo. and Exp Physics* 8 (2016) 083D01.
- A. Jungclaus, H. Grawe, S. Nishimura, P. Doornenbal, G. Lorusso, G. S. Simpson, P.-A. Söderström, T. Sumikama, J. Taprogge, Z. Y. Xu, H. Baba, F. Browne, N. Fukuda, R. Gernhäuser, G. Gey, N. Inabe, T. Isobe, H. S. Jung, D. Kameda, G. D. Kim, Y.-K. Kim, I. Kojouharov, T. Kubo, N. Kurz, Y. K. Kwon, Z. Li, H. Sakurai, H. Schaffner, Y. Shimizu, K. Steiger, H. Suzuki, H. Takeda, Zs. Vajta, H. Watanabe, J. Wu, A. Yagi, K. Yoshinaga, G. Benzoni, S. Bo`nig, K. Y. Chae, L. Coraggio, J.-M. Daugas, F. Drouet, A. Gadea, A. Gargano, S. Ilieva, N. Itaco, F. G. Kondev, T. Kro`ll, G. J. Lane, A. Montaner-Piza´, K. Moschner, D. Mu`cher, F. Naqvi, M. Niikura, H. Nishibata, A. Odahara, R. Orlandi, Z. Patel, Zs. Podolya´k, and A. Wendt: " β decay of semi-magic ^{130}Cd : Revision and extension of the level scheme of ^{130}In ", *Phys. Rev. C* 94, 024303 (2016) 1-8.
- H. Watanabe, G.X. Zhang, K. Yoshida, P.M. Walker, J.J. Liu, J. Wu, P.H. Regan, P.-A. Söderström, H. Kanaoka, Z. Korkulu, P.S. Lee, S. Nishimura, A. Yagi, D.S. Ahn, T. Alharbi, H. Baba, F. Browne, A.M. Bruce, R.J. Carroll, K.Y. Chae, Zs. Dombradi, P. Doornenbal, A. Estrade, N. Fukuda, C. Griffin, E. Ideguchi, N. Inabe, T. Isobe, S. Kanaya, I. Kojouharov, F.G. Kondev, T. Kubo, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G.J. Lane, C.S. Lee, E.J. Lee, G. Lorusso, G. Lotay, C.-B. Moon, I. Nishizuka, C.R. Nita, A. Odahara, Z. Patel, V.H. Phong, Zs. Podolyák, O.J. Roberts, H. Sakurai, H. Schaffner, C.M. Shand, Y. Shimizu, T. Sumikama, H. Suzuki, H. Takeda, S. Terashima, Zs. Vajta, J.J. Valiente-Dòbon, Z.Y. Xu : "Long-lived K isomer and enhanced γ vibration in the neutron-rich nucleus ^{172}Dy : Collectivity beyond double midshell", *Phys. Lett. B* 760 (2016) 641-646.
- H. Otsu, S. Koyama, N. Chiga, T. Isobe, T. Kobayashi, Y. Rondo, M. Kurokawa, W.G. Lynch, T. Motobayashi, T. Murakami, T. Nakamura, M. Kurata-Nishimura, V. Panin, H. Sato, Y. Shimizu, H. Sakurai, M.B. Tsang, K. Yoneda, H. Wang : "SAMURAI in its operation phase for RIBF users", *Nucl. Instrum and Methods B* 376 (2016) 175-179
- I. Čeliković, M. Lewitowicz, R. Gernhäuser, R. Krücken, S. Nishimura, H. Sakurai, D.S. Ahn, H. Baba, B. Blank, A. Blazhev, P. Boutachkov, F. Browne, G. de France, P. Doornenbal, T. Faestermann, Y. Fang, N. Fukuda, J. Giovinazzo, N. Goel, M. Górka, S. Ilieva, N. Inabe, T. Isobe, A. Jungclaus, D. Kameda, Y.-K. Kim, Y. K. Kwon, I. Kojouharov, T. Kubo, N. Kurz, G. Lorusso, D. Lubos, K. Moschner, D. Murai, I. Nishizuka, J. Park, Z. Patel, M. Rajabali, S. Rice, H. Schaffner, Y. Shimizu, L. Sinclair, P.-A. Söderström, K. Steiger, T. Sumikama, H. Suzuki, H. Takeda, Z. Wang, H. Watanabe, J. Wu, and Z. Xu : "New Isotopes and Proton Emitters—Crossing the Drip Line in the Vicinity of ^{100}Sn ", *Phys. Rev. Lett.* 116, 162501 (2016) 1-6.
- Y. L. Sun, J. Lee, Y. L. Ye, A. Obertelli, Z. H. Li, N. Aoi, H. J. Ong, Y. Ayyad, C. A. Bertulani, J. Chen, A. Corsi, F. Cappuzzello, M. Cavallaro, T. Furono, Y. C. Ge, T. Hashimoto, E. Ideguchi, T. Kawabata, J. L. Lou, Q. T. Li, G. Lorusso, F. Lu, H. N. Liu, S. Nishimura, H. Suzuki, J. Tanaka, M. Tanaka, D. T. Tran, M. B. Tsang, J. Wu, Z. Y. Xu, and T. Yamamoto : "Experimental study of the knockout reaction mechanism using ^{14}O at 60 MeV/nucleon", *Phys. Rev. C* 93, 044607 (2016) 1-8.
- A. Jungclaus, A. Gargano, H. Grawe, J. Taprogge, S. Nishimura, P. Doornenbal, G. Lorusso, Y. Shimizu, G. S. Simpson, P.-A. Söderström, T. Sumikama, Z. Y. Xu, H. Baba, F. Browne, N. Fukuda, R. Gernhäuser, G. Gey, N. Inabe, T. Isobe, H. S. Jung, D. Kameda, G. D. Kim, Y.-K. Kim, I. Kojouharov, T. Kubo, N. Kurz, Y. K. Kwon, Z. Li, H. Sakurai, H. Schaffner, K. Steiger, H. Suzuki, H. Takeda, Zs. Vajta, H. Watanabe, J. Wu, A. Yagi, K. Yoshinaga, S. Bo`nig, L. Coraggio, J.-M. Daugas, F. Drouet, A. Gadea, S. Ilieva, N. Itaco, T. Kro`ll, A. Montaner-Piza´, K. Moschner, D. Mu`cher, H. Nishibata, A. Odahara, R. Orlandi, and A. Wendt : "First observation of γ rays emitted from excited states south-east of ^{132}Sn : The $\pi g_{-1} \otimes \nu f_{7/2}$ multiplet of $^{132}\text{In}_{83}$ ", *Phys. Rev. C* 93, 041301(R) (2016) 1-6

[Proceedings]

(Original Papers) *Subject to Peer Review

- T. Isobe, *et al.*, "Constraint on Nuclear Symmetry Energy through Heavy RI Collision Experiment by Using SpiRIT Device at RIBF-SAMURAI", *JPS Conf. Proc.* 14, 010802 (2017) *
- H. Wang, "In-beam gamma-ray spectroscopy and cross section measurement strategy for long-lived fission products at RIBF", *Proceedings of the 2014 Symposium on Nuclear Data*, 69 (2016).
- D. Suzuki *et al.*, "Cluster structure of neutron-rich ^{10}Be and ^{14}C via resonant alpha scattering", *Il Nuovo Cimento C* 39, 372 (2016).
- P.-A. Söderström, P. M. Walker, J. Wu, H. L. Liu, P. H. Rega, H. Watanabe, P. Doornenbal, Z. Korkulu, P. Lee, J. J. Liu, G. Lorusso, S. Nishimura, V. H. Phong, T. Sumikama, F. R. Xu, A. Yagi, G. X. Zhang, D. S. Ahn, T. Alharbi, H. Baba, F. Browne, A. M. Bruce, R. J. Carroll, K. Y. Chae, Zs. Dombradi, A. Estrade, N. Fukuda, C. Griffin, E. Ideguchi, N. Inabe, T. Isobe, H. Kanaoka, S. Kanaya, I. Kojouharov, F. G. Kondev, T. Kubo, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G. J. Lane, E. J. Lee, C. S. Lee, G. Lotay, C.-B. Moon, I. Nishizuka, C. R. Nita, A. Odahara, Z. Patel, Zs. Podolyák, O. J. Roberts, H. Sakurai, H. Schaffner, C. M. Shand, H. Suzuki, H. Takeda, S. Terashima, Zs. Vajta, J. J. Valiente-Dòbon and Z. Y. Xu : "Collective And Single-particle Structures In The Neutron-rich Doubly Mid-shell Nucleus ^{170}Dy ", In *Proceedings of International Nuclear Physics Conference, PoS (INPC2016)*, page 072. Sissa, (2017).
- V. H. Phong, S. Nishimura, G. Lorusso and A. Algora, "Impact of the β -Delayed Neutron Emission Probabilities Around $A=100-125$ on the r-Process and the BRIKEN Project" In *Proceedings of the 14th International Symposium on Nuclei in the Cosmos (NIC2016)*, 020620 (2017).

[Others]

- The Proceedings of the 14th International Symposium on Nuclei in the Cosmos NIC2016 (Niigata, 19-24 June, 2016), JPS Conference Proceedings No. 14 (2017) edited by S. Kubono, T. Kajino, S. Nishimura, T. Isobe, S. Nagataki, T. Shima, and Y. Takeda
 櫻井博儀, “2重に魔法数をもったニッケル-78”、バリテイ 2016年12月号
 櫻井博儀, “百年の計”、Isotope News [特別号 No.1] 2017年1月号
 本林透、櫻井博儀, “魔法数の帰趨をめぐって”、原子核研究第61巻2号 1, 2017

Oral Presentations

[International Conference etc.]

- T. Isobe, “Constraint on Nuclear Symmetry Energy through Heavy RI Collision Experiment by Using SpiRIT Device at RIBF-SAMURAI”, 14th International Symposium on Nuclei in the Cosmos XIV, 19-24 Jun 2016, Toki-Messe, Niigata, Japan
 H. Wang, “Nuclear structure study for the neutron-rich nuclei beyond ¹³²Sn”, The international conference on Direct Reactions with Exotic Beams (DREB2016), July 11-15, 2016, Halifax, Canada
 H. Wang, “Spallation reaction study for fission products in nuclear waste: Cross section measurements for ¹³⁷Cs, ⁹⁰Sr and ¹⁰⁷Pd on proton and deuteron at different reaction energy”, International conference on nuclear data and technology (ND2016), September 11-16, 2016, Brugge, Belgium
 H. Wang, “Measurement of Spallation Cross Sections for ¹³⁷Cs, ⁹⁰Sr and ¹⁰⁷Pd on Proton and Deuteron Using the Inverse Kinematic Method”, Asian Nuclear Prospects 2016 (ANUP2016), October 24-27, 2016, Sendai, Japan
 H. Wang, “Spallation Reaction Study for the Long-Lived Fission Products in Nuclear Waste: Cross Section Measurement for ¹³⁷Cs, ⁹⁰Sr and ¹⁰⁷Pd Using the Inverse Kinematic Method”, The Fifth International Symposium on Innovative Nuclear Energy Systems (INES-5), October 31-November 2, 2016, Tokyo Institute of Technology, Tokyo, Japan
 D. Suzuki, “Second 0⁺ state of unbound ¹²O via the (p,t) reaction”, The international conference on Direct Reactions with Exotic Beams (DREB2016), July 11-15, 2016, Halifax, Canada
 D. Suzuki, “Tetra-proton cluster and mirror symmetry”, Third LISE/ICC workshop, December 12-14, 2016 GANIL, Caen, France
 D. Suzuki, “Gaseous detectors for radioactive beam experiment”, GDS Topical Meeting: GDS coupling to auxiliary detection systems, January 25-27, 2017 INFN Laboratori Nazionali di Legnaro, Italy
 S. Kubono, “Challenge to Explore the Mechanism of Evolution of the Universe and the Origin of Elements”: The 20th International Conference on Accelerators and Beam Utilizations, Nov. 2 - 4, 2016, Gyeongju, Korea, Nov, 2016
 S. Kubono, “Problems in BigBang nucleosynthesis; Heavy element synthesis and Li problem”, The 40th ASRC International Workshop on Experimental and Theoretical Advances in Fission and Heavy Nuclei, JAEA, Tokai, 12 – 13th December, 2016
 T. Isobe, “DAQ and computing infrastructure for high multiplicity tracking with SpiRIT”, Workshop on Software for Time Projection Chambers for Nuclear Physics Experiments, 8-10 Aug 2016, FRIB-MSU, East Lansing, Michigan, USA
 T. Isobe, “Experimental study of density dependent nuclear symmetry energy by using heavy RI collision at RIBF-SpiRIT”, KPS annual meeting, 19-21 Oct 2016, Kim-Daejeon Convension Center, Guanjin, Korea
 T. Isobe, “Experimental Study of Neutron Rich Matter EOS at RIKEN-RIBF”, APCC-AIP 2016 is the Asia Pacific Physics Conference and 22nd Australian Institute of Physics Congress, 4-8 Dec 2016, Brisbane Convention and Exhibition Centre, Brisbane, Australia
 T. Isobe, “Application of transport model to design experiment”, Transport 2017: International Workshop on Transport Simulations for Heavy Ion Collisions under Controlled Conditions, 27-31 Mar 2017, FRIB-MSU, East Lansing, Michigan, USA
 Y. Nakai, H. Hidaka, N. Watanabe, T.M. Kojima, “Equilibrium of association/dissociation reactions of a water molecule to/ from H₃O⁺(H₂O)_n cluster ions in an ion drift tube”, 12th Asian International Seminar on Atomic and Molecular Physics, 6-10 September 2016, Changchun, China
 G. G. Kiss, “Beta-delayed neutron emission probability measurements at RIKEN” Hungarian Wayfarer Meeting on Physics 2016, Aug. 24-27; Szeged, Hungary
 G. G. Kiss, “Introduction to the Briken project” 3rd EURICA collaboration workshop 2016, Sept. 7-8; Wako, Japan
 G. G. Kiss, “Beta delayed neutrons and the astrophysical r process” 3. Annual meeting of the Hungarian Nuclear Physics Community (2016, Dec. 7-9; Paks, Hungary
 S. Nishimura, “Experimental beta-decay rates of r-process nuclei”, Neutron star mergers: From gravitational waves to nucleosynthesis, (2017, January 15-21; Hirshegg, Austria
 S. Nishimura, “b-decay properties of neutron-rich nuclei: impact on r-process abundance”, The 14th International Symposium on Nuclei in the Cosmos (NIC-XIV), 2016, June 19-24; Niigata, Japan
 H. Sakurai, “Nuclear magic numbers”, The 71st Fujihara Seminar-Shimoda 2016, Shimoda, July 2016
 H. Sakurai, “RIB Experiments”, ICTP-IAEA workshop on Nuclear Structure and Decay Data: Experiment, Theory and Evaluation, Trieste, Aug. 2016
 H. Sakurai, “Decay studies of exotic nuclei at RIKEN”, The 2016 Zakopane Conference on Nuclear Physics “Extremes of the Nuclear Landscape”, Zakopane, Aug. 2016
 H. Sakurai, “Post RIBF project”, RIBF Users Meeting 2016, Wako, Sept. 2016
 H. Sakurai, “Long-lived Fission Product Transmutation”, 21st International Conference on Cyclotrons and their applications, Zurich, Sept. 2016
 H. Sakurai, “Recent highlights and future projects at RIBF”, Shapes and Symmetries in Nuclei: from Experiment to Theory, Orsay, Nov., 2016
 H. Sakurai, “Recent Activities and Plans at RIBF”, IBS-RIKEN Conference on Recent Developments in RI Physics, Daejeon, Nov. 2016
 H. Sakurai, “The status and future of RIBF”, ANPhA2916 Symposium, Sendai, Nov. 2016
 H. Sakurai, “New Magicity and Magicity Loss in Atomic Nuclei”, Joint 13th Asia Pacific Physics Conference and 22nd Australian Institute of Physics Congress, Brisbane, Dec. 2016

[Domestic Conference]

- 磯部忠昭, “高密度原子核物資の対称エネルギー”, 「熱場の量子論とその応用研究会」, 23-Aug-16, RIKEN
 H. Wang, “Reaction study for fission products in nuclear waste: Cross section measurements for the spallation of ¹³⁷Cs, ⁹⁰Sr and ¹⁰⁷Pd on proton and deuteron”, JPS meeting 2016 autumn, September 21-24, 2016, Miyazaki University

- D. Suzuki, "Missing mass spectroscopy with radioactive isotope beam", CNS Summer School 2016 (CNSSS2016), August 24 through 30, Riken Wako campus
- D. Suzuki, "Overview of the RIBF facility", CNS Summer School 2016 (CNSSS2016), August 24 through 30, Riken Wako campus
- 磯部忠昭, "中性子過剰核物質の状態方程式解明に向けた重 RI 衝突実験用タイムプロジェクションチェンバーの開発", 日本物理学会 2016 年秋季大会、21-24-Sep-16、宮崎大学
- 磯部忠昭, "世界最先端の研究と未来", 社会人講演会、細田学園高校、埼玉県志木市、2016 年 11 月
- 磯部忠昭, "中性子物質をさぐる時間射影型 3 次元飛跡検出器の開発", 「先端物理計測開発室 キックオフワークショップ」, 22-Dec-16, 東京工業大学
- 磯部忠昭, "科学者になるという事", SSH キャリア講演会、新潟県立長岡高校、新潟県長岡市、2017 年 2 月
- 磯部忠昭, "SpiRIT 検出器の読み出し回路系", 「新学術領域中性子星核物質 第二回検出器ワークショップ」, 4-Mar-17, 東京工業大学
- Y. Nakai, N. Watanabe, Y. Oba, "Hydrogenation of a thin foil C_{60} under low temperature condition", 72th Annual meeting of the physical society of Japan, March 2017, Osaka University
- 金子雅紀, "重イオン衝突を用いた高密度非対称核物質における対称エネルギー研究の解析状況", 日本物理学会 2016 年秋季大会, 21-24-Sep-16, 宮崎大学
- 櫻井博儀, "理研 RIBF における核物理研究", 東海・重イオン科学シンポジウムータンデム加速器成果報告会一、東海、2017 年 1 月
- 櫻井博儀, "親子一緒に"先端研究者から科学を学ぼう", 本郷、2016 年 7 月
- 櫻井博儀, "魔法数研究 RIPS から RIBF への展開と今後", 日本物理学会秋の分科会、宮崎大学、2016 年 9 月

Posters Presentations

[International Conference etc.]

- M. Kaneko, "Experimental Study on the Symmetry Energy of Nuclear Matter with SpiRIT-TPC", 14th International Symposium on Nuclei in the Cosmos XIV, 19-24 Jun 2016, Toki-Messe, Niigata, Japan

RIBF Research Division Spin isospin Laboratory

1. Abstract

The Spin Isospin Laboratory pursues research activities putting primary focus on interplay of spin and isospin in exotic nuclei. Understanding nucleosyntheses in the universe, especially those in *r*- and *rp*-processes is another big goal of our laboratory.

Investigations on isospin dependences of nuclear equation of state, spin-isospin responses of exotic nuclei, occurrence of various correlations at low-densities, evolution of spin-orbit coupling are main subjects along the line. We are leading a mass measurement project with the Rare RI Ring project, too. Through the experimental studies, we will be able to elucidate a variety of nuclear phenomena in terms of interplay of spin and isospin, which will in turn, lead us to better understanding of our universe.

2. Major Research Subjects

- (1) Direct reaction studies of neutron-matter equation of state
- (2) Study of spin-isospin responses with RI-beams
- (3) *R*-process nucleosynthesis study with heavy-ion storage ring
- (4) Application of spin-polarization technique to RI-beam experiments and other fields
- (5) Development of special targets for RI-beam experiments

3. Summary of Research Activity

(1) Direct reaction studies of neutron matter equation of state

Direct reactions induced by light-ions serve as powerful tools to investigate various aspects of nuclei. We are advancing experimental programs to explore equation of state of neutron matter, via light-ion induced reactions with RI-beams.

(1-a) Determination of a neutron skin thickness by proton elastic scattering

A neutron skin thickness is known to have strong relevance to asymmetry terms of nuclear equation of state, especially to a term proportional to density. The ESPRI project aims at determining density distributions in exotic nuclei precisely by proton elastic scattering at 200–300 MeV/nucleon. An experiment for ^{132}Sn that is a flagship in this project has been successfully performed in 2016.

(1-b) Asymmetry terms in nuclear incompressibility

Nuclear incompressibility represents stiffness of nuclear matter. Incompressibility of symmetric nuclear matter is determined to be 230 ± 20 MeV, but its isospin dependence still has a large uncertainty at present. A direct approach to the incompressibility of asymmetric nuclear matter is an experimental determination of energies of isoscalar giant monopole resonances (GMR) in heavy nuclei. We have developed, in close collaboration with Center for Nuclear Study (CNS) of University of Tokyo, an active gas target for deuteron inelastic scattering experiments to determine GMR energies. The active gas target has been already tested with oxygen and xenon beams at HIMAC and finally has been applied to a ^{132}Sn experiment in 2016.

(1-c) Multi-neutron and α -cluster correlations at low densities

Occurrences of multi-neutron and α -cluster correlations are other interesting aspects of nuclear matter and define its low-density behavior. The multi-neutron and α -cluster correlations can be investigated with the large-acceptance SAMURAI spectrometer. The SAMURAI has been already applied to experiments to explore light neutron-rich nuclei close to the dripline. We plan to reinforce experimental capabilities of the SAMURAI by introducing advanced devices such as MINOS (Saclay) and NeuLAND (GSI).

(1-d) Fission barrier heights in neutron-rich heavy nuclei

The symmetry energy has a strong influence on fission barrier heights in neutron-rich nuclei. Knowledge on the fission barrier heights, which is quite poor at present, is quite important for our proper understanding on termination of the *r*-process. We are planning to perform, in collaboration with the TU Munich group, (*p,2p*)-delayed fission experiments at the SAMURAI to determine the fission barrier heights in neutron-rich nuclei in Pb region.

(2) Study of spin-isospin responses with RI-beams

The study of spin-isospin responses in nuclei forms one of the important cores of nuclear physics. A variety of collective states, for example isovector giant dipole resonances, isobaric analogue states, Gamow-Teller resonances, have been extensively studied by use of electromagnetic and hadronic reactions from stable targets.

The research opportunities can be largely enhanced with light of availabilities of radioactive isotope (RI) beams and of physics of unstable nuclei. There are three possible directions to proceed. The first direction is studies of spin-isospin responses of unstable nuclei via inverse-kinematics charge exchange reactions. A neutron-detector array WINDS has been constructed, under a collaboration of CNS, Tokyo and RIKEN, for inverse kinematics (*p,n*) experiments at the RI Beam Factory. We have already applied WINDS to the (*p,n*) experiments for ^{12}Be , ^{132}Sn and plan to extend this kind of study to other exotic nuclei.

The second direction is studies with RI-beam induced charge exchange reaction. RI-beam induced reactions have unique properties which are missing in stable-beam induced reactions and can be used to reach the yet-to-be-discovered states. We have constructed the SHARAQ spectrometer and the high-resolution beam-line at the RI Beam Factory to pursue the capabilities of RI-beam induced reactions as new probes to nuclei. One of the highlights is an observation of β^+ type isovector spin monopole resonances (IVSMR) in ^{208}Pb and ^{90}Zr

via the (t, ^3He) reaction at 300 MeV/nucleon.

The third direction is studies of neutron- and proton-rich nuclei via stable-beam induced charge exchange reactions, which is conducted under collaboration with Research Center for Nuclear Physics (RCNP), Osaka University. We have performed the double charge exchange $^{12}\text{C}(^{18}\text{O}, ^{18}\text{Ne})^{12}\text{Be}$ reaction at 80 MeV/nucleon to investigate structure of a neutron-rich ^{12}Be nucleus. Peaks corresponding to ground and excited levels in ^{12}Be have been clearly observed. Another double charge exchange reaction, ($^{12}\text{C}, ^{12}\text{Be}(0_2^+)$) are being used to search for double Gamow-Teller resonances.

(3) R-process nucleosynthesis study with heavy-ion storage ring

Most of the r-process nuclei become within reach of experimental studies for the first time at RI Beam Factory at RIKEN. The Rare RI Ring at RIBF is the unique facility with which we can perform mass measurements of r-process nuclei. Construction of the Rare RI Ring started in FY2012 in collaboration with Tsukuba and Saitama Universities. A major part of the ring has been completed and the commissioning run is planned in FY2014.

We are planning to start precise mass measurements of r-process nuclei soon. A series of experiments will start with nuclei in the A=80 region and will be extended to heavier region.

(4) Application of spin-polarization technique to RI-beam experiments and other fields

A technique to produce nuclear polarization by means of electron polarization in photo-excited triplet states of aromatic molecules can open new applications. The technique is called "Triplet-DNP". A distinguished feature of Triplet-DNP is that it works under a low magnetic field of 0.1–0.7 T and temperature higher than 100 K, which exhibits a striking contrast to standard dynamic nuclear polarization (DNP) techniques working in extreme conditions of several Tesla and sub-Kelvin.

We have constructed a polarized proton target system for use in RI-beam experiments. Recent experimental and theoretical studies have revealed that spin degrees of freedom play a vital role in exotic nuclei. Tensor force effects on the evolution of shell and possible occurrence of p-n pairing in the proton-rich region are good examples of manifestations of spin degrees of freedom. Experiments with the target system allow us to explore the spin effects in exotic nuclei. It should be noted that we have recently achieved a proton polarization of 40% at room temperature in a pentacene-d₁₄ doped p-terphenyl crystal.

Another interesting application of Triplet-DNP is sensitivity enhancement in NMR spectroscopy of biomolecules. We started a new project in 2016 to apply the Triplet-DNP technique to study protein-protein interaction via two-dimensional NMR spectroscopy, in close collaboration with biologists and chemists.

(5) Development of special targets for RI-beam experiments

For the research activities shown above, we are developing and hosting special targets for RI-beam experiments listed below:

- a) Polarized proton target (described in (4))
- b) Thin solid hydrogen target
- c) MINOS (developed at Saclay and hosted by the Spin Isospin Laboratory)

Members

Chief Scientist (Lab. Head)

Tomohiro UESAKA

Research & Technical Scientists

Ken-ichiro YONEDA (Senior Research Scientist,
concurrent ; Team Leader, User Support Office)
Masaki SASANO (Research Scientist)

Juzo ZENIHIRO (Research Scientist)
Sarah NAIMI (Research Scientist)

Contract Researcher

Daisuke NAGAE

Special Postdoctoral Researchers

Kenichiro TATEISHI
Yuki KUBOTA

Yuma KIKUCHI

Foreign Postdoctoral Researchers

Zaihong YANG

Postdoctoral Researchers

Valerii PANIN

Fumi SUZAKI

Research Associate

Masami SAKO
Takahiro NISHI
Kenichiro TATEISHI

Tsz Leung TANG

Junior Research Associates

CheongSoo LEE (Univ. of Tokyo)
Fumi SUZAKI (Saitama Univ.)

Shunichiro OMIKA (Saitama Univ.)
Yuki KUBOTA (Univ. of Tokyo)

International Program Associates

Sergey CHEBOTARYOV (Kyungpook Nat'l Univ.)
Evgeniy Vladimirovich MILMAN (Kyungpook Nat'l Univ.)

Zhuang GE (Institute of Modern Physics Chinese Academy of Sciences.)
Julian KAHLBOW (Technical University Darmstadt)

Research Consultant

Harutaka SAKAGUCHI

Kazuko TANABE

Visiting Researchers

Stuhl LASZLO (JSPS Fellow)

Keiichi KISAMORI (JSPS Fellow)

Senior Visiting Scientists

Hiroyuki SAGAWA (Aizu Univ.)

Visiting Scientists

Didier BEAUMEL (IPN)
Yasuyuki SUZUKI (Niigata Univ.)
Yosuke KONDO (Tokyo Tech.)
Zoltan ELEKES (ATOMKI)
Hidetoshi AKIMUNE (Konan Univ.)
Yohei MATSUDA (Osaka Univ.)
Yasuhiro TOGANO (Tokyo Tech.)
Satoshi SAKAGUCHI (Kyusyu Univ.)
Kenjiro MIKI (TU Darmstadt)
Valerie LAPOUX (CEA Saclay)
Alexandre OBERTELLI (CEA Saclay)
Alain GILLIBERT (CEA Saclay)
Emanuel POLLACCO (CEA Saclay)
Anna CORSI (CEA Saclay)
Dennis MUECHER (TUM)
Yuma KIKUCHI (Osaka City Univ.)
Yury LITVINOV (GSI)
Yuhu ZHANG (CAS)
Igor GASPARIĆ (Ruder Boskovic Inst. Zagreb Croatia)
Hans Toshihide TOERNQVIST (TU Darmstadt)
Christoph CAESAR (GSI)
Haik SIMON (GSI)
Matthias HOLL (TU Darmstadt)
Takayuki YAMAGUCHI (Saitama Univ.)
Takashi NAKAMURA (Tokyo Tech.)
Atsushi TAMII (Osaka Univ.)
Attila KRASZNAHORKAY (ATOMKI)

Takashi WAKUI (Tohoku Univ.)
Kimiko SEKIGUCHI (Tohoku Univ.)
Dorottya KUNNE SOHLER (Institute of Nuclear Research Hungarian Academy of Sciences (ATOMKI))
Satoru TERASHIMA (Beihang University)
Valdir GUIMARAES (Instituto de Fisica da Universidade de Sao Paulo)
Yasutaka TANIGUCHI (Nihon Institute of Medical Science)
Tetsuaki MORIGUCHI (Univ. of Tsukuba)
Kazuyuki OGATA (Osaka Univ.)
Shinji SUZUKI (Univ. of Tsukuba)
Zsolt VAJTA (Institute of Nuclear Research Hungarian Academy of Sciences (ATOMKI))
Istvan KUTI (Institute of Nuclear Research Hungarian Academy of Sciences (ATOMKI))
Makoto NEGORO (Osaka Univ.)
Konstanze BORETZKY (GSI)
Zsolt FULOP (Institute of Nuclear Research Hungarian Academy of Sciences (ATOMKI))
Zsolt DOMBRADI (Institute of Nuclear Research Hungarian Academy of Sciences (ATOMKI))
Akinori KAGAWA (Osaka Univ.)
Baohua SUN (Beihang Univ.)
Leyla ATAR (TU Darmstadt)
Zoltan HALASZ (ATOMKI)
Li-Gang CAO (North China Electric Power Univ.)
Kaori KAKI (Shizuoka Univ.)

Visiting Technicians

Tomomi KAWAHARA (Toho Univ.)
Gilles AUTHÉLET (CEA Saclay)
Jean-Marc GHELLER (CEA Saclay)
Cedric PERON (CEA Saclay)
Jean-Yves ROUSSE (CEA Saclay)
Denis CALVET (CEA Saclay)
Alan PEYAUD (CEA Saclay)

Alain DELBART (CEA Saclay)
Frederic CHATEAU (CEA Saclay)
Caroline LAHONDE-HAMDOUN (CEA Saclay)
Arnaud GIGANON (CEA Saclay)
Daniel KOERPER (GSI)
Clement HILAIRE (CEA Saclay)

Student Trainees

Yasunori WADA (Tohoku Univ.)
Tatsuya FURUNO (Kyoto Univ.)
Miho TSUMURA (Kyoto Univ.)
Jumpei YASUDA (Kyushu Univ.)
Mizuki SHIKATA (Tokyo Tech.)
Junichi TSUBOTA (Tokyo Tech.)
Yuuki TAKEUCHI (Saitama Univ.)
Syunichirou OHMIKA (Saitama Univ.)
Hiroshi MIURA (Saitama Univ.)
Takuma NISHIMURA (Saitama Univ.)
Motoki MURATA (Kyoto Univ.)
Syunsuke KAWAKAMI (Miyazaki Univ.)

Daijiro ETO (Tohoku Univ.)
Junki TANAKA (Osaka Univ.)
Sebastian Benedikt REICHERT (TU Munchen)
Tomoyuki OZAKI (Tokyo Tech.)
Atsumi SAITO (Tokyo Tech.)
Yusuke SHINDO (Kyushu Univ.)
Munemi TABATA (Kyushu Univ.)
Atomu WATANABE (Tohoku Univ.)
Ayaka OHKURA (Kyushu Univ.)
Yukina ICHIKAWA (Univ. of Tsukuba)
Kotaro YAMADA (Toho Univ.)
Tomoaki KANEKO (Toho Univ.)

Julian KAHLBOW (TU Darmstadt)
 Taras LOKOTKO (Univ. of Hong Kong)
 Dahee KIM (Ewha Womans Univ.)
 Natsuki TADANO (Saitama Univ.)
 Ikuma KATO (Saitama Univ.)
 Tomomi AKIEDA (Tohoku Univ.)
 Hiroshi KON (Tohoku Univ.)
 Tomoyuki MUKAI (Tohoku Univ.)
 Shinnosuke NAKAI (Tohoku Univ.)
 Takato TOMAI (Tokyo Tech.)
 Akihiro HIRAYAMA (Tokyo Tech.)
 Yoshiyuki TAJIRI (Univ. of Tsukuba)
 Kentaro HIRAIISHI (Univ. of Tsukuba)
 Simon LINDBERG (Chalmers University of Technology)
 Masamichi AMANO (Univ. of Tsukuba)
 Daisuke SAKAE (Kyushu Univ.)
 Yasuaki NORIMATSU (Kyushu Univ.)
 Takahiro FUKUTA (Kyushu Univ.)
 Youhei AKIYAMA (Kyushu Univ.)
 Kiyoshi WAKAYAMA (Saitama Univ.)
 Han Hagen MAYER (University of Cologne)
 Takahiro MORIMOTO (Kyoto Univ.)

Katsuyoshi HEGURI (Konan Univ.)
 Takuya MATSUMOTO (Univ. of Tsukuba)
 Tomoya HARADA (Toho Univ.)
 Kosei TANIUE (Univ. of Miyazaki)
 Masahiro YASUDA (Tokyo Tech.)
 Hiroki YAMADA (Tokyo Tech.)
 Jun OKAMOTO (Tohoku Univ.)
 Yu NASU (Tohoku Univ.)
 Shota MATSUMOTO (Kyoto Univ.)
 Simon GIRAUD (Université de Nantes)
 Yu ANDO (Kyungpook National Univ.)
 Sonja STORCK (TU Darmstadt)
 Ina Josephine SYNDIKUS (TU Darmstadt)
 Mayuko MATSUMOTO (Tokyo Tech.)
 Daiki KAMIOKA (Univ. of Tsukuba)
 Christopher LEHR (TU Darmstadt)
 Tomoya FUJII (Saitama Univ.)
 Kunimitsu NISHIMURO (Saitama Univ.)
 Ryo IGOSAWA (Saitama Univ.)
 Kumi INOMATA (Saitama Univ.)
 Hiroki ARAKAWA (Saitama Univ.)
 Jan Daniel STEINHAUSER (Tokyo Tech.)

Interns

Lily SIEGENBERG (Univ. of Surrey)
 Quentin Nathanael DESHAYES (Universite de Caen Normandie)

David HEGEDUES (Eotvos Lorand Univ.)

Part-time Worker

Kotaro YAMADA

Assistants

Emiko ISOGAI
 Yu NAYA

Yuri TSUBURAI
 Noriko KIYAMA

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- P. Moller, A.J. Sierk, T. Ichikawa, H. Sagawa, Nuclear ground-state masses and deformations: FRDM(2012), Atomic Data and Nuclear Data Tables, Volume 109, 1 (2016).
- J. Yasuda, M. Sasano, R.G.T. Zegers, H. Baba, W. Chao, M. Dozono, N. Fukuda, N. Inabe, T. Isobe, G. Jhang, D. Kameda, T. Kubo, M. Kurata-Nishimura, E. Milman, T. Motobayashi, H. Otsu, V. Panin, W. Powell, H. Sakai, M. Sako, H. Sato, Y. Shimizu, L. Stuhl, H. Suzuki, S. Tangwancharoen, H. Takeda, T. Uesaka, K. Yoneda, J. Zenihiro, T. Kobayashi, T. Sumikama, T. Tako, T. Nakamura, Y. Kondo, Y. Togano, M. Shikata, J. Tsubota, K. Yako, S. Shimoura, S. Ota, S. Kawase, Y. Kubota, M. Takaki, S. Michimasa, K. Kisamori, C.S. Lee, H. Tokieda, M. Kobayashi, S. Koyama, N. Kobayashi, T. Wakasa, S. Sakaguchi, A. Krasznahorkay, T. Murakami, N. Nakatsuka, M. Kaneko, Y. Matsuda, D. Mucher, S. Reichert, D. Bazin, J.W. Lee, Inverse kinematics reactions studies using the WINDS slow neutron detector and the SAMURAI spectrometer, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Volume 376, 393 (2016).
- E. Minaya Ramirez, P. Alfaut, M. Aouadi, P. Ascher, B. Blank, K. Blaum, J.-F. Cam, P. Chauveau, L. Daudin, P. Delahaye, F. Delaee, P. Dupre, S. El Abbeir, M. Gerbaux, S. Grevy, H. Guerin, D. Lunney, F. Metz, S. Naimi, L. Perrot, A. de Roubin, L. Serani, B. Thomas, J.-C. Thomas, Conception of PIPERADE: A high-capacity Penning-trap mass separator for high isobaric contamination at DESIR, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Volume 376, 298 (2016).
- H. Otsu, S. Koyama, N. Chiga, T. Isobe, T. Kobayashi, Y. Kondo, M. Kurokawa, W.G. Lynch, T. Motobayashi, T. Murakami, T. Nakamura, M. Kurata-Nishimura, V. Panin, H. Sato, Y. Shimizu, H. Sakurai, M.B. Tsang, K. Yoneda, H. Wang, SAMURAI in its operation phase for RIBF users, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, Volume 376, 175 (2016).
- Yusuke Tanimura and Hiroyuki Sagawa, Three-body model for an isoscalar spin-triplet neutron-proton pair in 102Sb, Physical Review C **93**, 064319 (2016)
- E. Ganioglu, H. Fujita, B. Rubio, Y. Fujita, T. Adachi, A. Algora, M. Csatlós, J. M. Deaven, E. Estevez-Aguado, C. J. Guess, J. Gulyás, K. Hatanaka, K. Hirota, M. Honma, D. Ishikawa, A. Krasznahorkay, H. Matsubara, R. Meharchand, F. Molina, H. Okamura, H. J. Ong, T. Otsuka, G. Perdikakis, C. Scholl, Y. Shimbara, G. Susoy, T. Suzuki, A. Tamii, J. H. Thies, R. G. T. Zegers, and J. Zenihiro, High-resolution study of Gamow-Teller transitions in the 48Ti(3He,t)48V reaction, Physical Review C **93**, 064326 (2016)
- J.W. Zhao, B.H. Sun, I. Tanihata, S. Terashima, L.H. Zhu, A. Enomoto, D. Nagae, T. Nishimura, S. Omika, A. Ozawa, Y. Takeuchi, T. Yamaguchi, Reaching time resolution of less than 10ps with plastic scintillation detectors, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment, Volume 823, 41 (2016).
- Y H Zhang, Yu A Litvinov, T Uesaka and H S Xu, Storage ring mass spectrometry for nuclear structure and astrophysics research, Physica

- Scripta **91**, 073002 (2016).
- H Sagawa, C L Bai and G Colò, Isovector spin-singlet ($T = 1$, $S = 0$) and isoscalar spin-triplet ($T = 0$, $S = 1$) pairing interactions and spin-isospin response, *Physica Scripta* **91**, 083011 (2016)
- Xian-Rong Zhou, E. Hiyama, and H. Sagawa, Exotic structure of medium-heavy hypernuclei in the Skyrme Hartree-Fock model, *Physical Review C* **94**, 024331 (2016)
- E Hiyama, Y Yamamoto and H Sagawa, The structure of hypernuclei and hyperon mixing in neutron-star matter, *Physica Scripta* **91**, 093001 (2016)
- M. Dozono, T. Uesaka, S. Michimasa, M. Takaki, M. Kobayashi, M. Matsushita, S. Ota, H. Tokieda, and S. Shimoura, Separated flow operation of the SHARAQ spectrometer for in-flight proton-decay experiments, *Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Volume 830, 233 (2016)
- Yuma Kikuchi, Kazuyuki Ogata, Yuki Kubota, Masaki Sasano, and Tomohiro Uesaka, Determination of a dineutron correlation in Borromean nuclei via a quasi-free knockout (p,pn) reaction, *Progress of Theoretical and Experimental Physics* **2016**, 103D03 (2016)
- X. Roca-Maza, Li-Gang Cao, G. Colò, and H. Sagawa, Fully self-consistent study of charge-exchange resonances and the impact on the symmetry energy parameters, *Physical Review C* **94**, 044313 (2016).
- Zhen-Yu Zhu, Ang Li, Jin-Niu Hu, and Hiroyuki Sagawa, $\Delta(1232)$ effects in density-dependent relativistic Hartree-Fock theory and neutron stars, *Physical Review C* **94**, 045803 (2016).
- H. Sagawa, T. Suzuki, and M. Sasano, Effect of isoscalar spin-triplet pairings on spin-isospin responses in sd-shell nuclei, *Physical Review C* **94**, 041303(R) (2016).
- X. Xu, P. Zhang, P. Shuai, R. J. Chen, X. L. Yan, Y. H. Zhang, M. Wang, Yu. A. Litvinov, H. S. Xu, T. Bao, X. C. Chen, H. Chen, C. Y. Fu, S. Kubono, Y. H. Lam, D. W. Liu, R. S. Mao, X. W. Ma, M. Z. Sun, X. L. Tu, Y. M. Xing, J. C. Yang, Y. J. Yuan, Q. Zeng, X. Zhou, X. H. Zhou, W. L. Zhan, S. Litvinov, K. Blaum, G. Audi, T. Uesaka, Y. Yamaguchi, T. Yamaguchi, A. Ozawa, B. H. Sun, Y. Sun, A. C. Dai, and F. R. Xu, Identification of the Lowest $T = 2$, $J\pi = 0^+$ Isobaric Analog State in ^{52}Co and Its Impact on the Understanding of β -Decay Properties of ^{52}Ni , *Physical Review Letters* **117**, 182503 (2016)
- T. Uesaka, Spins in exotic nuclei: RI beam experiments with polarized targets, *The European Physical Journal Plus* **131**, 403 (2016)
- D. T. Tran, H. J. Ong, T. T. Nguyen, I. Tanihata, N. Aoi, Y. Ayyad, P. Y. Chan, M. Fukuda, T. Hashimoto, T. H. Hoang, E. Ideguchi, A. Inoue, T. Kawabata, L. H. Khim, W. P. Lin, K. Matsuta, M. Mihara, S. Momota, D. Nagae, N. D. Nguyen, D. Nishimura, A. Ozawa, P. P. Ren, H. Sakaguchi, J. Tanaka, M. Takechi, S. Terashima, R. Wada, and T. Yamamoto, Charge-changing cross-section measurements of $^{12-16}\text{C}$ at around 45 A MeV and development of a Glauber model for incident energies 10 A–2100 A MeV, *Physical Review C* **94**, 064604 (2016)
- J.C. Zamora, T. Aumann, S. Bagchi, S. B̄rnig, M. Csatos, I. Dillmann, C. Dimopoulou, P. Egelhof, V. Eremin, T. Furuno, H. Geissel, R. Gerthaeuser, M.N. Harakeh, A.-L. Hartig, S. Ilieva, N. Kalantar-Nayestanaki, O. Kiselev, H. Kollmus, C. Kozhuharov, A. Krasznahorkay, Th. Kroll, M. Kuilman, S. Litvinov, Yu.A. Litvinov, M. Mahjour-Shafiei, M. Mutterer, D. Nagae, M.A. Najafi, C. Nociforo, F. Nolden, U. Popp, C. Rigollet, S. Roy, C. Scheidenberger, M. von Schmid, M. Steck, B. Streicher, L. Stuhl, M. Thurauf, T. Uesaka, H. Weick, J.S. Winfield, D. Winters, P.J. Woods, T. Yamaguchi, K. Yue, J. Zenihiro, First measurement of isoscalar giant resonances in a stored-beam experiment, *Physics Letters B*, Volume 763, 16 (2016).
- T. T. Sun, E. Hiyama, H. Sagawa, H.-J. Schulze, and J. Meng, Mean-field approaches for Ξ -hypernuclei and current experimental data, *Physical Review C* **94**, 064319 (2016)
- H. Sagawa and T. Uesaka, Sum rule study for double Gamow-Teller states, *Physical Review C* **94**, 064325 (2016).
- Y. F. Niu, G. Colò, E. Vigezzi, C. L. Bai, and H. Sagawa, Quasiparticle random-phase approximation with quasiparticle-vibration coupling: Application to the Gamow-Teller response of the superfluid nucleus ^{120}Sn , *Physical Review C* **94**, 064328 (2016).
- N. Paul, A. Corsi, A. Obertelli, P. Doornenbal, G. Authalet, H. Baba, B. Bally, M. Bender, D. Calvet, F. Ch̄teau, S. Chen, J.-P. Delaroche, A. Delbart, J.-M. Gheller, A. Giganon, A. Gillibert, M. Girod, P.-H. Heenen, V. Lapoux, J. Libert, T. Motobayashi, M. Niikura, T. Otsuka, T. R. Rodríguez, J.-Y. Roussé, H. Sakurai, C. Santamaria, N. Shimizu, D. Steppenbeck, R. Taniuchi, T. Togashi, Y. Tsunoda, T. Uesaka, T. Ando, T. Arici, A. Blazhev, F. Browne, A. M. Bruce, R. Carroll, L. X. Chung, M. L. Cortés, M. Dewald, B. Ding, F. Flavigny, S. Franchoo, M. Górska, A. Gottardo, A. Jungclaus, J. Lee, M. Lettmann, B. D. Linh, J. Liu, Z. Liu, C. Lizarazo, S. Momiyama, K. Moschner, S. Nagamine, N. Nakatsuka, C. Nita, C. R. Nobs, L. Olivier, Z. Patel, Zs. Podolyák, M. Rudigier, T. Saito, C. Shand, P.-A. Söderström, I. Stefan, R. Orlandi, V. Vaquero, V. Werner, K. Wimmer, and Z. Xu, Are There Signatures of Harmonic Oscillator Shells Far from Stability? First Spectroscopy of ^{110}Zr , *Physical Review Letters* **118**, 032501 (2017).
- K. Hagino and H. Sagawa, New concept for the pairing anti-halo effect as a localized wave packet of quasiparticles, *Physical Review C* **95**, 024304 (2017).
- P. Zhang, X. Xu, P. Shuai, R.J. Chen, X.L. Yan, Y.H. Zhang, M. Wang, Yu.A. Litvinov, K. Blaum, H.S. Xu, T. Bao, X.C. Chen, H. Chen, C.Y. Fu, J.J. He, S. Kubono, Y.H. Lam, D.W. Liu, R.S. Mao, X.W. Ma, M.Z. Sun, X.L. Tu, Y.M. Xing, J.C. Yang, Y.J. Yuan, Q. Zeng, X. Zhou, X.H. Zhou, W.L. Zhan, S. Litvinov, G. Audi, T. Uesaka, Y. Yamaguchi, T. Yamaguchi, A. Ozawa, B.H. Sun, Y. Sun, and F.R. Xu, High-precision QEC values of superallowed $0^+ \rightarrow 0^+$ β -emitters ^{46}Cr , ^{50}Fe and ^{54}Ni , *Physics Letters B*, Volume 767, 20 (2017).
- S. Chen, P. Doornenbal, A. Obertelli, T. R. Rodríguez, G. Authalet, H. Baba, D. Calvet, F. Ch̄teau, A. Corsi, A. Delbart, J.-M. Gheller, A. Giganon, A. Gillibert, V. Lapoux, T. Motobayashi, M. Niikura, N. Paul, J.-Y. Roussé, H. Sakurai, C. Santamaria, D. Steppenbeck, R. Taniuchi, T. Uesaka, T. Ando, T. Arici, A. Blazhev, F. Browne, A. M. Bruce, R. Carroll, L. X. Chung, M. L. Cortés, M. Dewald, B. Ding, F. Flavigny, S. Franchoo, M. Górska, A. Gottardo, A. Jungclaus, J. Lee, M. Lettmann, B. D. Linh, J. Liu, Z. Liu, C. Lizarazo, S. Momiyama, K. Moschner, S. Nagamine, N. Nakatsuka, C. R. Nita, C. Nobs, L. Olivier, R. Orlandi, Z. Patel, Zs. Podolyak, M. Rudigier, T. Saito, C. Shand, P.-A. Söderström, I. Stefan, V. Vaquero, V. Werner, K. Wimmer, and Z. Xu, Low-lying structure and shape evolution in neutron-rich Se isotopes, *Physical Review C* **95**, 041302(R) (2017).
- M. Scott, R. G. T. Zegers, R. Almus, Sam M. Austin, D. Bazin, B. A. Brown, C. Campbell, A. Gade, M. Bowry, S. Galès, U. Garg, M. N. Harakeh, E. Kwan, C. Langer, C. Loelius, S. Lipschutz, E. Litvinova, E. Lunderberg, C. Morse, S. Noji, G. Perdikakis, T. Redpath, C. Robin, H. Sakai, Y. Sasamoto, M. Sasano, C. Sullivan, J. A. Tostevin, T. Uesaka, and D. Weisshaar, Observation of the Isovector Giant Monopole Resonance via the $^{28}\text{Si}(^{10}\text{Be}, ^{10}\text{B}^* [1.74 \text{ MeV}])$ Reaction at 100 A MeV, *Physical Review Letters* **118**, 172501 (2017).
- N. Nakatsuka, H. Baba, T. Aumann, R. Avigo, S.R. Banerjee, A. Bracco, C. Caesar, F. Camera, S. Ceruti, S. Chen, V. Derya, P. Doornenbal, A. Giaz, A. Horvat, K. Ieki, T. Inakura, N. Imai, T. Kawabata, N. Kobayashi, Y. Kondo, S. Koyama, M. Kurata-Nishimura, S. Masuoka, M. Matsushita, S. Michimasa, B. Million, T. Motobayashi, T. Murakami, T. Nakamura, T. Ohnishi, H.J. Ong, S. Ota, H. Otsu, T. Ozaki, A. Saito, H. Sakurai, H. Scheit, F. Schindler, P. Schrock, Y. Shiga, M. Shikata, S. Shimoura, D. Steppenbeck, T. Sumikama, I. Syndikus, H. Takeda, S.

- Takeuchi, A. Tamii, R. Taniuchi, Y. Togano, J. Tschuschner, J. Tsubota, H. Wang, O. Wieland, K. Wimmer, Y. Yamaguchi, K. Yoneda, and J. Zenihiro, Observation of isoscalar and isovector dipole excitations in neutron-rich ^{20}O , *Physics Letters B*, Volume 768, 387 (2017).
- K. Sawahata, A. Ozawa, Y. Saito, Y. Abe, Y. Ichikawa, N. Inaba, Y. Ishibashi, A. Kitagawa, S. Matsunaga, T. Moriguchi, D. Nagae, S. Okada, S. Sato, S. Suzuki, T. Suzuki, Y. Takeuchi, T. Yamaguchi, J. Zenihiro, Investigations of charge-changing processes for light proton-rich nuclei on carbon and solid-hydrogen targets, *Nuclear Physics A*, Volume 961, 142 (2017).
- J. Li, Y. L. Ye, Z. H. Li, C. J. Lin, Q. T. Li, Y. C. Ge, J. L. Lou, Z. Y. Tian, W. Jiang, Z. H. Yang, J. Feng, P. J. Li, J. Chen, Q. Liu, H. L. Zang, B. Yang, Y. Zhang, Z. Q. Chen, Y. Liu, X. H. Sun, J. Ma, H. M. Jia, X. X. Xu, L. Yang, N. R. Ma and L. J. Sun, Selective decay from a candidate of the σ -bond linear-chain state in ^{14}C , *Physical Review C* **95**, 021303(R) (2017).
- G. Audi, F.G. Kondev, Meng Wang, W.J. Huang, and S. Naimi, The NUBASE2016 evaluation of nuclear properties, *Chinese Physics C* **41**, 030001 (2017).
- W.J. Huang, G. Audi, Meng Wang, F.G. Kondev, S. Naimi, and Xing Xu, The AME2016 atomic mass evaluation (I). Evaluation of input data; and adjustment procedures, *Chinese Physics C* **41**, 030002 (2017).
- Meng Wang, G. Audi, F.G. Kondev, W.J. Huang, S. Naimi, and Xing Xu, The AME2016 atomic mass evaluation (II). Tables, graphs and references, *Chinese Physics* **41**, 030003 (2017).

[Proceedings]

(Original Papers) *Subject to Peer Review

- J. Yasuda, T. Wakasa, M. Dozono, T. Fukunaga, S. Gotanda, K. Hatanaka, Y. Kanaya, Y. Maeda, K. Miki, Y. Nishio, T. Noro, K. Ohnaka, S. Sakaguchi, Y. Sakemi, K. Sekiguchi, A. Tamii, T. Taguchi, Y. Wada, Development of Neutron Polarization Measurement System for Studying NN interaction in Nuclear Medium, *International Journal of Modern Physics: Conference Series* **40**, 1660073 (2016).
- Satoshi Sakaguchi, Tomohiro Uesaka, Takashi Wakui, Sergey Chebotaryov, Tomomi Kawahara, Shoichiro Kawase, Evgeniy Milman, Tsz Leung Tang, Kenichiro Tateishi, and Takashi Teranishi, Studies of Unstable Nuclei with Spin-Polarized Proton Target, *International Journal of Modern Physics: Conference Series* **40**, 1660071 (2016).
- K. Sekiguchi, Y. Wada, A. Watanabe, D. Eto, T. Akieda, H. Kon, K. Miki, N. Sakamoto, H. Sakai, M. Sasano, Y. Shimizu, H. Suzuki, T. Uesaka, Y. Yanagisawa, M. Dozono, S. Kawase, Y. Kubota, C. S. Lee, K. Yako, Y. Maeda, S. Kawakami, T. Yamamoto, S. Sakaguchi, T. Wakasa, J. Yasuda, A. Ohkura, Y. Shindo, M. Tabata, E. Milman, S. Chebotaryov, H. Okamura, and T. L. Tang, Deuteron Analyzing Powers for dp Elastic Scattering at Intermediate Energies and Three-Nucleon Forces, *The 23rd European Conference on Few-Body Problems in Physics*, 48 (2017).

Oral Presentations

[International Conference etc.]

- T. Uesaka, "R-process studies at RIBF", ICNT Workshop "The r-process nucleosynthesis: connecting FRIB with the cosmos", East Lansing, USA, 6—10 June, 2016
- T. Uesaka, "RIBF's challenge to the r-process nucleosynthesis", 14th International Symposium on Nuclei in the Cosmos (NIC-XIV), Niigata, Japan, 19—24 June 2016.
- T. Uesaka, "(d,p) and Knockout reactions with high momentum transfer", ECT* Workshop "Three-body systems in reactions with rare isotopes", Trento, Italy, 3—7 October, 2016
- T. Uesaka, "Studies of neutron-rich nuclei at RIBF – from tetra-neutron to fission", 6th International Conference on Fission and properties of neutron-rich nuclei, Florida, USA, 6—12 November 2016.
- T. Uesaka, Y. Yamazaki, H. Katori, S. Ulmer, "Extreme precision to Explore fundamental physics with Exotic particles", Symposium for exploring prospective research "Pioneering New Fields: Forefront of RIKEN's Science and Beyond", Saitama, Japan, 21—22 November 2016
- T. Uesaka, "Looking Through Double Charge Exchange Reactions", ISOLDE Workshop and Users meeting 2016, Zurich, 7—9 December 2016.
- H. Sagawa and P. Moller, "New mass model FRDM2012 and symmetry energy", 14th International Symposium on Nuclei in the Cosmos (NIC-XIV), Niigata, Japan, 19—24 June 2016.
- H. Sagawa, "Three-body model for exotic nuclei", XXIII Nuclear Physics Workshop, Kazimeirz, Poland, 17 Sept.—1 Oct. 2016.
- H. Sagawa, "Pairing and di-neutron correlations in Exotic Nuclei", RAON/RISP workshop, Deajone, Korea, 28 Oct., 2016.
- H. Sagawa, "Nuclear models and Hyperons", invited seminar, Soongsil University, Seoul, Korea, 31 Oct., 2016.
- H. Sagawa, "Isoscalar pairing and spin-isospin response", 1st RIKEN-Tsukuba-CNS workshop, Japan, 12—15 December 2016.
- H. Sagawa, "Three-body model for nuclei near and beyond drip line", Recent Progresses in Nuclear Structure Physics 2016 (NSP2016), Kyoto, Japan, 21 December 2016.
- H. Sagawa, "Isoscalar pairing and spin-isospin response", Workshop on spin-isospin excitations and related nuclear structure problems, Milano, Italy, 13—14 March 2017.
- M. Sasano, "Study Of Gamow-Teller Transitions from ^{132}Sn Via The Inverse Kinematics (p,n) Reaction", INPC2016, Adelaide, Australia, 11—16 Spetember 2016.
- M. Sasano, "Status report on studies of GT transitions via the (p,n) reaction and (p,2p) fission at SAMURAI", SAMURAI international workshop 2016, Kyushu, Japan, 5—6 September 2016.
- M. Sasano, "Fission study project in RIKEN RIBF: towards the "complete" measurement of fission observables", 6th Workshop on Nuclear Fission and Spectroscopy of Neutron-Rich Nuclei, Chamrousse, France, 20—24 March 2017.
- L. Stuhl, "A New Low-energy Plastic Scintillation Neutron Detector For Real Time Pulse Shape Discrimination", INPC2016, Adelaide, Australia, 11—16 Spetember 2016.
- Y. Kubota, "Study of neutron-neutron correlation in Borromean nucleus ^{11}Li via the (p,pn) reaction", DREB2016, Halifax, Canada, 11—15 July 2016
- Y. Kubota, "Study On Neutron-neutron Correlation In Borromean Nucleus ^{11}Li Via The Quasi-free (p,pn) Reaction", INPC2016, Adelaide, Australia, 11—16 Spetember 2016.
- Y. Kubota, "Probing neutron-neutron correlation in Borromean nuclei via the quasi-free (p,pn) reaction", SAMURAI international workshop 2016, Kyushu, Japan, 5—6 September 2016.

- J. Zenihiro, "Proton elastic scattering and nucleon density distributions", International Symposium on Neutron Star Matter (NSMAT2016), Sendai, Japan, 21—24 November 2016.
- D. Nagae, "The rare-RI ring at RIKEN RI beam factory", International Symposium on Neutron Star Matter (NSMAT2016), Sendai, Japan, 21—24 November 2016.
- V. Panin, "Heavy-ion-proton experiments at SAMURAI: challenges and perspectives", SAMURAI international workshop 2016, Kyushu, Japan, 5—6 September 2016.
- J. Yasuda, "Study of Gamow Teller strength from ^{132}Sn via the inverse kinematics (p,n) reaction", DREB2016, Halifax, Canada, 11—15 July 2016
- T. Tang, "Quasi-free proton knockout of $^{23,25}\text{F}$ ", DREB2016, Halifax, Canada, 11—15 July 2016
- Y. Zaihong, "Study on the Dineutron Decay in ^8He ", Workshop on Nuclear Clustering, Beijing, China, 2—3 July 2016.
- Y. Zaihong, "Study on the cluster structure in nuclei using direct reactions", Cluster16, Napoli, Italy, 23—27 May 2016.
- Y. Zaihong, "Status and Results of SAMURAI018", 5th Sunflower workshop, Hongkong, China, 18—20 September 2016.
- Y. Zaihong, "Study of cluster structure in light nuclei by using neutron-rich Carbon isotope beams", SAMURAI international workshop 2016, Kyushu, Japan, 5—6 September 2016.
- T. Lokotko, "Spectroscopy of $^{69,71,73}\text{Co}$ isotopes", 5th Sunflower workshop, Hongkong, China, 18—20 September 2016.
- M. Tsumura, "Search for the rare g-decay mode in ^{12}C ", Cluster16, Napoli, Italy, 23—27 May 2016.
- T. Furuno, "An active target MAIKo to investigate cluster structures in unstable nuclei", Cluster16, Napoli, Italy, 23—27 May 2016.
- S. Sakaguchi, "Polarized proton target at SAMURAI: elastic scattering of ^6He from polarized proton", SAMURAI international workshop 2016, Kyushu, Japan, 5—6 September 2016.

[Domestic Conference]

- M. Sasano, "Study of nuclear fission via the (p,2p) reaction at RIBF", 第8回 停止・低速RIビームを用いた核分光研究会(SSRI), Wako, Japan, 4—5 March 2016
- 上坂友洋, "トリプレットDNP法の最近の進展と生物学研究への応用", 日本物理学会 2016年秋季大会, 宮崎, 日本, 2016年9月21日-9月24日.
- 上坂友洋、立石健一郎、"トリプレットDNP ~新たな核偏極法の可能性~", 第18回CROSSroads Workshop 「偏極ターゲットと偏極中性子技術開発」, 東海村, 日本, 2016年6月15日
- 上坂友洋、立石健一郎、"トリプレットDNP ~高温・低磁場での核偏極生成とタンパク質研究における展望~", 新世代研究所2016年度水和ナノ構造・バイオ単分子合同研究会, 東京, 日本, 2017年3月27日
- S. Chebotaryov, "Experiment on elastic scattering of polarized protons from neutronrich ^6He isotopes at 200 MeV/nucleon", 日本物理学会 2016年秋季大会, 宮崎, 日本, 2016年9月21日—9月24日.
- E. Milman, "Search for low-lying resonances in ^{10}N structure via $^9\text{C} + p$ resonant scattering", 日本物理学会 2016年秋季大会, 宮崎, 日本, 2016年9月21日—9月24日.
- 津村美保, " ^{12}C 原子核における稀 γ 崩壊モード探索のためのテスト実験", 日本物理学会 2016年秋季大会, 宮崎, 日本, 2016年9月21日-9月24日.
- 佐川弘幸, "スピニアイソスピン応答から探る対相関とテンソル力", 日本物理学会 (シンポジウム講演) 2016年秋季大会, 宮崎, 日本, 2016年9月21日—9月24日
- Y. Zaihong, "Two-neutron decay of ^8He excited states", Workshop on Cluster Physics 2016 (WNCP2016), Yokohama, Japan, 14—17 November 2016.
- 大甕舜一郎, "稀少RIリングのための粒子周回モニターの開発", 日本物理学会 2017年春季大会, 豊中, 日本, 2017年3月17日—3月20日.
- Zhuang GE, "Development of Large area position sensitive MCP detector at Rare RI Ring", 日本物理学会 2017年春季大会, 豊中, 日本, 2017年3月17日—3月20日.
- 那須裕, "崩壊 α 粒子測定による炭素13の α クラスターガス状態の探索", 日本物理学会 2017年春季大会, 豊中, 日本, 2017年3月17日-3月20日.
- 古野達也, "MAIKoアクティブ標的を用いた ^{10}C の質量欠損分光", 日本物理学会 2017年春季大会, 豊中, 日本, 2017年3月17日-3月20日.
- S. Chebotaryov, "Status of data analysis from experiment on p- ^6He elastic scattering at 200 MeV/nucleon", 日本物理学会 2017年春季大会, 豊中, 日本, 2017年3月17日—3月20日.
- 立石健一郎, "信号増大比660倍を超える光励起三重項電子を用いたDNP" (招待講演) 第44回 日本磁気共鳴医学会大会スタディグループ (超偏極による他核MRSIの高感度計測), 大宮ソニックシティ 2016年9月10日.
- 立石健一郎, "光励起三重項電子スピンを用いた動的核偏極による室温での ^1H スピン偏極率40%の達成" 日本物理学会 2016年秋季大会, 金沢大学 2016年9月16日.
- 立石健一郎, "光励起三重項電子を用いた動的核偏極 -660倍を超える偏極増大", 日本物理学会 (シンポジウム講演) 2017年春季大会, 豊中, 日本, 2017年3月17日-3月20日.
- 上坂友洋, "トリプレットDNP ~新たな核偏極法の可能性~", 北海道大学原子核理論グループセミナー, 札幌, 日本, 2016年10月26日
- 上坂友洋、立石健一郎、"トリプレットDNP ~高温・低磁場での核偏極が拓く世界~", 山形大学クォーク核物理学研究室セミナー, 山形, 日本, 2017年1月12日
- 佐川弘幸, "原子核の対相関", 平成28年度第19回先導原子力研コロキウム, 東京, 日本, 2016年10月13日.

Posters Presentations

[International Conference etc.]

- M. Tsumura, "Search for the rare gamma-decay mode in ^{12}C ", 14th International Symposium on Nuclei in the Cosmos (NIC-XIV), Niigata, Japan, 19—24 June 2016.
- M. Murata, "The measurement of ^4He photodisintegration with MAIKo active target", 14th International Symposium on Nuclei in the Cosmos (NIC-XIV), Niigata, Japan, 19—24 June 2016.

RIBF Research Division Nuclear Spectroscopy Laboratory

1. Abstract

The research group has conducted nuclear-physics studies utilizing stopped/slowed-down radioactive-isotope (RI) beams mainly at the RIBF facility. These studies are based on the technique of nuclear spectroscopy such as β -ray-detected NMR, γ -PAD (Perturbed Angular Distribution), laser, and Mössbauer among other methods that takes advantage of intrinsic nuclear properties such as nuclear spins, electromagnetic moments, and decay modes. In particular, techniques and devices for the production of spin-controlled RI beams have been developed and combined to the spectroscopic studies, which enable high-sensitivity measurements of spin precessions/resonances through a change in the angular distribution of radiations. Anomalous nuclear structures and properties of far unstable nuclei are investigated from thus determined spin-related observables. The group also aims to apply such techniques to interdisciplinary fields such as fundamental physics and materials science by exploiting nuclear probes.

2. Major Research Subjects

- (1) Nuclear spectroscopy with spin-oriented RI beams
- (2) R&D studies for laser spectroscopy of stopped/slowed-down RI beams
- (3) Application of RI probes
- (4) Fundamental physics: Study of symmetry

3. Summary of Research Activity

(1) Nuclear spectroscopy with spin-oriented RI beams

Measurements of static electromagnetic nuclear moments over a substantial region of the nuclear chart have been conducted for structure studies on the nuclei far from the β -decay stability. Utilizing nuclear spin orientation phenomena of RIs created in the projectile-fragmentation reaction, ground- and excited-state nuclear moments of nuclei far from the stability have been determined by means of the β -ray-detected nuclear magnetic resonance (β -NMR) and the γ -ray time differential perturbed angular distribution (γ -TDPAD) methods. To extend these observations to extremely rare RIs, development of a new apparatus to produce highly spin-polarized RI beams will be conducted by extending the atomic beam resonance method to fragmentation-based RI beams.

(2) R&D studies for laser spectroscopy of stopped/slowed-down RI beams

For the measurement of electromagnetic nuclear properties such as spin, isotope shift, and electromagnetic nuclear moments at RIBF, we have been conducting R&D studies on nuclear laser spectroscopy. One is development of a new laser-spectroscopy system utilizing superfluid helium (He II) as a stopping medium of energetic RI beams, where characteristic atomic properties of ions surrounded by liquid helium enable us to perform unique nuclear laser spectroscopy. The other is a system for collinear laser spectroscopy for a large variety of elements using slowed-down RI beams produced via projectile-fragmentation reaction at RIBF, which can be achieved only by a universal low-energy RI-beam delivery system SLOWRI.

(3) Application of RI probes

The application of RI and heavy ion beams as a probe for condensed matter studies is also conducted by the group. The microscopic material dynamics and properties have been investigated through the deduced internal local fields and the spin relaxation of RI probes based on various spectroscopies utilizing RI probes such as the β -NMR/nuclear quadrupole resonance (NQR) methods, in-beam Mössbauer spectroscopy and the γ -ray time differential perturbed angular correlation (γ -TDPAC) spectroscopy.

(4) Fundamental physics: Study of symmetry

The nuclear spins of stable and unstable isotopes sometimes play important roles in fundamental physics research. New experimental methods and devices have been developed for studies of the violation of time reversal symmetry (T-violation) using spin-polarized nuclei. These experiments aim to detect the small frequency shift in the spin precession arising from new mechanisms beyond the Standard Model.

Members

Chief Scientist (Lab. Head)

Hideki UENO

Research & Technical Scientists

Hiroki YAMAZAKI (Senior Research Scientist)
Aiko TAKAMINE (Research Scientist)

Yuichi ICHIKAWA (Research Scientist)

Research Consultant

Takuya OKADA

Special Postdoctoral Researcher

Tomoya SATO

Junior Research Associates

Kei IMAMURA (Meiji Univ.)

Tomomi FUJITA (Osaka Univ.)

International Program Associates

Ian MURRAY (Univ. Paris Sud)

Aleksy GLADKOV (Kyungpook National Univ.)

Part-time Worker

Yoko ISHIBASHI (Univ. of Tsukuba)

Senior Visiting Scientist

Yukari MATSUO (Hosei Univ.)

Visiting Researcher

Hiroki NISHIBATA (JSPS Fellow)

Visiting Scientists

Wataru SATO (Kanazawa Univ.)
 Kensaku MATSUTA (Osaka Univ.)
 Jin NAKAMURA (Univ. of Elec.-Com.)
 Atsushi HATAKEYAMA (Tokyo Univ. of Agric. and Tech.)
 Takeshi FURUKAWA (Tokyo Met. Univ.)
 Satoshi TSUTSUI (JASRI)
 Takamasa MOMOSE (Univ. of British Columbia)
 Jean-Michel DAUGAS (CEA)
 Yoshio KOBAYASHI (Univ. of Elec.-Com.)
 Jiro MURATA (Rikkyo Univ.)

Jun MIYAZAKI (Hokuriku Univ.)
 Yasuhiro YAMADA (Tokyo Univ. of Sci.)
 Kenya KUBO (ICU)
 Akihiro YOSHIMI (Okayama Univ.)
 Dimiter Loukanov BALABANSKI (IHIN)
 Naoki NISHIDA (Tokyo Univ. of Science)
 Boulay FLORENT (CNRS GANIL)
 Yasuaki EINAGA (Keio Univ.)
 Kei IMAMURA (Meiji Univ.)
 Takashi ABE (Univ. Of Tokyo)

Student Trainees

Yoko ISHIBASHI (Univ. of Tsukuba)
 Masaomi TANAKA (Osaka Univ.)
 Ryosuke KANBE (Osaka Univ.)
 Yukiko SATO (Univ. of Elec.-Com.)
 Shotaro TANIGAWA (Univ. of Elec.-Com.)
 Daiki NATORI (Univ. of Elec.-Com.)
 Kenichi TANABE (Tokyo Univ. of Sci.)
 Miho SATO (Tokyo Univ. of Sci.)
 Takafumi TABATA (Tokyo Univ. of Sci.)
 Tomoya SATO (Tokyo Tech.)
 Daiki TOMINAGA (Hosei Univ.)
 Ippei KUBONO (Tokyo Univ. of Sci.)
 Shota AMAGASA (Tokyo Univ. of Sci.)
 Tsuyoshi EGAMI (Hosei Univ.)

Takafumi KAWAGUCHI (Hosei Univ.)
 Yuka KOBAYASHI (Tokyo Univ. of Science)
 Masanari SEKI (Tokyo Univ. of Science)
 Takaya KOIZUMI (Univ. of Elec.-Com.)
 Kenya TAKAHASHI (Univ. of Elec.-Com.)
 Yuki MINATO (Univ. of Elec.-Com.)
 Ryouhei KOZU (Univ. of Elec.-Com.)
 Takayuki KAWAMURA (Osaka Univ.)
 Makoto SANJO (Hosei Univ.)
 Wataru KOBAYASHI (Hosei Univ.)
 Masato SUZUKI (Univ. of Elec.-Com.)
 Taishi NISHIZAKA (Hosei Univ.)
 Shuichiro KOJIMA (Tokyo Tech.)
 Chikako FUNAYAMA (Tokyo Tech.)

Interns

Yig JIANG (Peking University)
 Cheng CHEN (Peking University)
 Xudong LYU (Peking University)
 Chenguang WU (Peking University)
 Bo DAI (Peking University)
 Yunxiang WANG (Peking University)
 Younsik KIM (Seoul National University)
 Young Ju CHO (Seoul National University)
 Yun Gi JEONG (Seoul National University)
 Seugho HAN (Seoul National University)

Jung Hwan LEE (Seoul National University)
 Taekeun YOON (Seoul National University)
 Alfred AMRUTH (University of Hong Kong)
 CALVIN (University of Hong Kong)
 Sen Yu CHANG (University of Hong Kong)
 Frederik O. A. PARNEFJORD GUSTAFSSON (University of Hong Kong)
 Xinzhi TENG (University of Hong Kong)
 Jia-Shian WANG (University of Hong Kong)

Assistant

Yuri TSUBURAI

List of Publications & Presentations**Publications**

[Journal]

(Original Papers) *Subject to Peer Review

- A. Kusoglu, G. Georgiev, C. Sotty, D. L. Balabanski, A. Goasduff, Y. Ishii, Y. Abe, K. Asahi, M. Bostan, R. Chevrier, M. Chikamori, J. M. Daugas, T. Furukawa, H. Nishibata, Y. Ichikawa, Y. Ishibashi, R. Lozeva, H. Miyatake, D. Nagae, T. Nanao, M. Niikura, T. Niwa, S. Okada, A. Ozawa, Y. Saito, H. Shirai, H. Ueno, D. T. Jordanov, N. Yoshida, "Magnetic moment of the $13/2^+$ isomeric state in ^{69}Cu : Spin alignment in the one-nucleon removal reaction", Phys. Rev. C 93, 054313 (2016).*
- A. Takamine, M. Wada, K. Okada, Y. Ito, P. Schury, F. Arai, I. Katayama, K. Imamura, Y. Ichikawa, H. Ueno, H. Wollnik, H. A. Shuessler, "Towards high precision measurements of nuclear g-factors for the Be isotopes", Nucl. Instr. Meth. Phys. Res. B 376, 307 (2016).*

- T. Inoue, T. Furukawa, A. Yoshimi, T. Nanao, M. Chikamori, K. Suzuki, H. Hayashi, H. Miyatake, Y. Ichikawa, M. Tsuchiya, N. Hatakeyama, S. Kagami, M. Uchida, H. Ueno, Y. Matsuo, T. Fukuyama, K. Asahi, "Frequency characteristics of nuclear spin oscillator with an artificial feedback toward search for ^{129}Xe atomic electric dipole moment", *Eur. Phys. J. D* 70, 129 (2016).*
- H. Heylen, M. De Rydt, G. Neyens, M. L. Bissell, L. Caceres, R. Chevrier, J. M. Daugas, Y. Ichikawa, Y. Ishibashi, O. Kamalou, T. J. Mertzimekis, P. Morel, J. Papuga, A. Poves, M. M. Rajabali, C. Stodel, J. C. Thomas, H. Ueno, Y. Utsuno, N. Yoshida, and A. Yoshimi, "High-precision quadrupole moment reveals significant intruder component in ^{33}Al ground state", *Phys. Rev. C* 94, 034312 (2016).*
- H. Ishiyama, S. C. Jeong, Y. X. Watanabe, Y. Hirayama, N. Imai, H. Miyatake, M. Oyaizu, I. Katayama, A. Osa, Y. Otokawa, M. Matsuda, K. Nishio, H. Makii, T. Sato, N. Kuwata, J. Kawamura, A. Nakao, H. Ueno, Y. H. Kim, S. Kimura, and M. Mukai, "Direct measurement of nanoscale lithium diffusion in solid battery materials using radioactive tracer of ^6Li ", *Nucl. Instr. Meth. Phys. Res. B* 376, 307-310 (2016)
- K. Asahi, T. Sato, and Y. Ichikawa, "EDMS of Closed-shell Atoms: An Example of Xe Atom", *Asian Journal of Physics* 25, 1403-1412 (2016).*

(Review)

[Proceedings]

(Original Papers) *Subject to Peer Review

Oral Presentations

[International Conference etc.]

- H. Ueno, "Nuclear moment measurements using radioactive ion beams", International Conference on Hyperfine Interactions and their Applications (HYPERFINE2016), Leuven, Belgium, July 3–8, 2016.
- A. Takamine, "Determination of the hyperfine anomaly for the one-neutron halo nucleus ^{11}Be ", 2016 SSRI-PNS collaboration meeting, Wako, Japan, September 2-3, 2016.
- A. Takamine, "Collinear laser spectroscopy at SLOWRI", 2016 SSRI-PNS collaboration meeting, Wako, Japan, September 2-3, 2016.
- A. Takamine, "Measurements of nuclear moments by using RI atomic beam (RIAB)", 2016 SSRI-PNS collaboration meeting, Wako, Japan, September 2-3, 2016.
- Y. Ichikawa, "Magnetic moment measurement using spin-aligned beam at RIBF", RIBF Users Meeting, Wako, Japan, September 8-9, 2016.
- Y. Ichikawa, A. Takamine, H. Nishibata, K. Imamura, T. Fujita, T. Sato, S. Momiyama, Y. Shimizu, D. S. Ahn, K. Asahi, H. Baba, D. L. Balabanski, F. Boulay, J. M. Daugas, T. Egami, N. Fukuda, C. Funayama, T. Furukawa, G. Georgiev, A. Gladkov, N. Inabe, Y. Ishibashi, Y. Kobayashi, S. Kojima, A. Kusoglu, T. Kawaguchi, T. Kawamura, I. Mukul, M. Niikura, T. Nishizaka, A. Odahara, Y. Ohtomo, D. Ralet, T. Shimoda, G. S. Simpson, T. Sumikama, H. Suzuki, H. Takeda, L. C. Tao, Y. Togano, D. Tomonaga, H. Ueno, H. Yamazaki and X. F. Yang, "Magnetic moment of isomeric state of ^{75}Cu measured with highly spin-aligned beam", International Nuclear Physics Conference (INPC) 2016, Adelaide, Australia, September 11-16, 2016.
- T. Sato, Y. Ichikawa, S. Kojima, C. Funayama, S. Tanaka, Y. Sakamoto, Y. Ohtomo, C. Hirao, M. Chikamori, E. Hikota, T. Furukawa, A. Yoshimi, C. P. Bidinosti, T. Ino, H. Ueno, Y. Matsuo, T. Fukuyama, K. Asahi, "Development of ^{131}Xe comagnetometry for Xe atomic EDM search", International Nuclear Physics Conference (INPC) 2016, Adelaide, Australia, September 11-16, 2016.
- K. Imamura, T. Fujita, T. Egami, T. Nishizaka, D. Tominaga, T. Kawaguchi, A. Takamine, T. Furukawa, Y. Ichikawa, T. Wakui, H. Odashima, H. Ueno, Y. Matsuo, "Development of laser spectroscopy technique using superfluid helium for the study of low-yield nuclei", International Nuclear Physics Conference (INPC) 2016, Adelaide, Australia, September 11-16, 2016.
- H. Nishibata, "Various structures of the neutron-rich nucleus ^{31}Mg investigated by beta-gamma spectroscopy of spin-polarized ^{31}Na ", 22nd International Spin Symposium (SPIN2016), Illinois, USA, September 25-30, 2016.
- H. Ueno, "Nuclear moments and their applications", 2016 IBS Annual Meeting - IBS-RIKEN Conference on Recent Developments in RI Physics, Daejeon, Korea, November 17-18, 2016.
- H. Ueno, "Nuclear-moment measurements at RIBF utilizing spin-oriented RI beams", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Wako & Tsukuba, Japan, December 12-16, 2016.
- T. Sato, Y. Ichikawa, T. Inoue, A. Uchiyama, A. Gladkov, A. Takamine, S. Kojima, C. Funayama, S. Tanaka, Y. Sakamoto, Y. Ohtomo, C. Hirao, M. Chikamori, E. Hikota, T. Furukawa, A. Yoshimi, C. P. Bidinosti, T. Ino, H. Ueno, Y. Matsuo, T. Fukuyama, N. Yoshinaga, Y. Sakemi, K. Asahi, "Search for Xe atomic EDM using nuclear spin masers of xenon-129 and -131", 9th International Workshop on "Fundamental Physics Using Atoms" (FPUA 2017), Kyoto, Japan, January 9-10, 2017.
- K. Imamura, T. Egami, T. Nishizaka, A. Takamine, D. Tominaga, T. Kawaguchi, W. Kobayashi, M. Sanjo, T. Furukawa, Y. Ichikawa, T. Sato, H. Nishibata, A. Gladkov, L. C. Tao, T. Wakui, H. Odashima, H. Ueno, Y. Matsuo, "Development of laser spectroscopy technique of atoms in superfluid helium for the study of low production yield nuclei", 9th International Workshop on "Fundamental Physics Using Atoms" (FPUA 2017), Kyoto, Japan, January 9-10, 2017.
- A. Takamine, "Laser Spectroscopy at the SLOWRI facility in RIKEN", CSNSM/IPN seminar, Orsay, France, March 28, 2017.

[Domestic Conference]

- 上野秀樹, 「核電磁モーメントで探る原子核構造研究」, 「分子システム研究」第5回春季研究会, 熱海, 2016年5月13-16日
- 北村徳隆, 今井伸明, 下浦享, K. Wimmer, 道正新一郎, 大田晋輔, O. Beliuskina, P. Schrock, 小林幹, 清川裕, 山口勇貴, 増岡翔一郎, 上野秀樹, 米田健一郎, 市川雄一, 寺西高, 清水則孝, 宇都野穰, 「陽子共鳴散乱を用いた ^{35}Si の核構造の研究」, 日本物理学会 2016年秋季大会, 宮崎, 2016年9月21-24日
- Evgeniy Milman, Takashi Teranishi, Satoshi Sakaguchi, Sergey Chebotaryov, B. Tomohiro Uesaka, Kenichiro Tateishi, Yuichi Ichikawa, Masaki Sasano, Wooyoung Kim, Reii Kaku, Yasuaki Norimatsu, Youhei Akiyama, Takahiro Fukuta, Daisuke Sakae, Nobuaki Imai, Hidetoshi Yamaguchi, Seiya Hayakawa, Daid Miles Kahl, Yuji Sakaguchi, Keijiro Abe, Noritaka Kitamura, Tomoaki Kaneko, Kotaro Yamada, Sanghoon Hwang, Dahee Kim, G. Alfredo Galindo-Uribarri, Elisa Romero-Romero, Didier Beaumel, "Search for low-lying resonances in ^{10}N structure via $^9\text{C} + p$ resonant scattering", 日本物理学会 2016年秋季大会, 宮崎, 2016年9月21-24日
- 金原慎二, NP1406 RRC-32-02 collaborators, 「ハイパー核の核種同定における荷電粒子識別法の開発」, 日本物理学会 2016年秋季大会, 宮崎, 2016年9月21-24日
- 村井李奈, 吉田純也, Myint Kyaw Soe, Aye Moh Moh Theint, 金原慎二, 大橋正樹, 長瀬雄一, 仲澤和馬, NP1406-RRC32 Collaborators, 「原

- 子核乾板中のハイパー核同定のための娘粒子の識別(角度依存性)], 日本物理学会 2016 年秋季大会, 宮崎, 2016 年 9 月 21-24 日
 長瀬雄一, 金原慎二, 村井李奈, 仲澤和馬, 他理研 NP1406-RR32 Collaborators, 「原子核乾板中飛跡の核種同定(特に ${}^6\text{He}$ について)」, 日本物理学会 2016 年秋季大会, 宮崎, 2016 年 9 月 21-24 日
 今村慧, 藤田朋美, 江上魁, 西坂太志, 高峰愛子, 富永大樹, 川口貴史, 小林航, 三條真, 古川武, 市川雄一, 佐藤智哉, 西畑洗希, A. Gladkov, L. C. Tao, 涌井崇, 小田島仁司, 上野秀樹, 松尾由賀利, 「超流動ヘリウム環境を用いた原子分光と核構造研究手法(OROCHI)の開発」, 第 9 回停止・低速不安定核ビームを用いた核分光研究, 東海, 2017 年 3 月 5-6 日
 高峰愛子, 「インフライト核反応生成 RI を対象としたコリニアレーザー分光 (Collinear laser spectroscopy for the nuclides provided from an in-flight RI beam separator)」, 第 9 回停止・低速不安定核ビームを用いた核分光研究, 東海, 2017 年 3 月 5-6 日
 江上魁, 今村慧, 高峰愛子, 小林航, 藤田朋美, 富永大樹, 三條真, 中村祐太郎, 涌井崇志, 古川武, 上野秀樹, 松尾由賀利, 「超流動ヘリウム中に打ち込まれた低収量核原子の超微細構造間隔測定に向けた光学クライオスタットの開発」, 日本物理学会第 72 回年次大会, 大阪, 2017 年 3 月 17-20 日
 佐藤智哉, 市川雄一, 井上壯志, 内山愛子, 高峰愛子, 小島修一郎, 舟山智歌子, 田中俊也, 坂本雄, 大友祐一, 平尾千佳, 近森正敏, 彦田絵里, 古川武, 吉見彰洋, C.P. Bidinosti, 猪野隆, 上野秀樹, 松尾由賀利, 福山武志, 吉永尚孝, 酒見泰寛, 旭耕一郎, 「能動帰還型核スピナーにおける帰還磁場印加方式と周波数安定性」, 日本物理学会第 72 回年次大会, 大阪, 2017 年 3 月 17-20 日
 伊藤由太, 和田道治, P. Schury, 加治大哉, 森本幸司, 羽場宏光, I. Murray, M. Rosenbusch, 木村創大, 高峰愛子, 宮武宇也, 山木さやか, 新井郁也, H. Wollnik, 「MRTOF 質量分析器による八重極変形核 ${}^{223,224}\text{Th}$ の精密原子質量測定」, 日本物理学会第 72 回年次大会, 大阪, 2017 年 3 月 17-20 日

Posters Presentations

[International Conference etc.]

- Y. Ichikawa, A. Takamine, H. Nishibata, K. Imamura, T. Fujita, T. Sato, S. Momiyama, Y. Shimizu, D. S. Ahn, K. Asahi, H. Baba, D. L. Balabanski, F. Boulay, J. M. Daugas, T. Egami, N. Fukuda, C. Funayama, T. Furukawa, G. Georgiev, A. Gladkov, N. Inabe, Y. Ishibashi, Y. Kobayashi, S. Kojima, A. Kusoglu, T. Kawaguchi, T. Kawamura, I. Mukul, M. Niikura, T. Nishizaka, A. Odahara, Y. Ohtomo, D. Ralet, T. Shimoda, G. S. Simpson, T. Sumikama, H. Suzuki, H. Takeda, L. C. Tao, Y. Togano, D. Tomonaga, H. Ueno, H. Yamazaki and X. F. Yang, "Magnetic moment of ${}^{75m}\text{Cu}$ and collectivity around ${}^{78}\text{Ni}$ ", 14th International Symposium on Nuclei in the Cosmos XIV, Niigata, Japan, June 19-24, 2016.
 A. Takamine, M. Wada, K. Okada, Y. Ito, P. Schury, I. Katayama, K. Imamura, Y. Ichikawa, H. Ueno, H. Wollnik, H. A. Schuessler, "Precision laser spectroscopy for laser-cooled radioactive beryllium isotopes" International Nuclear Physics Conference (INPC) 2016, Adelaide, Australia, September 11-16, 2016

[Domestic Conference]

- 今村慧, 早坂美希, 藤田朋美, 小林徹, 古川武, 上野秀樹, 松尾由賀利, 「パルス Ti:Sa レーザーによる超流動ヘリウム環境中原子のスピン偏極生成」, 原子・分子・光 (AMO) 科学討論会, 和光, 2016 年 6 月 3-4 日.
 江上魁, 今村慧, 藤田朋美, 西坂太志, 富永大樹, 川口高史, 高峰愛子, 古川武, 上野秀樹, 松尾由賀利, 「低収量原子核の核構造研究に向けた超流動ヘリウム環境におけるレーザー核分光法の開発」, 原子・分子・光 (AMO) 科学討論会, 和光, 2016 年 6 月 3-4 日.
 富永大樹, 今村慧, 藤田朋美, 高峰愛子, 小林徹, 上野秀樹, 松尾由賀利, 「超流動ヘリウム中レーザーアブレーション法による Ba^+ イオンの発生と蛍光観測」, イオンビーム工学研究所シンポジウム, 東京, 2016 年 12 月 7 日.
 小林航, 今村慧, 江上魁, 西坂太志, 三條真, 藤田朋美, 富永大樹, 中村祐太郎, 高峰愛子, 涌井崇志, 古川武, 上野秀樹, 松尾由賀利, 「低収量原子核の核構造研究に向けた超流動ヘリウム中原子のレーザー誘起蛍光検出系の高度化」, 日本物理学会第 72 回年次大会, 大阪, 2017 年 3 月 17-20 日.

RIBF Research Division High Energy Astrophysics Laboratory

1. Abstract

Immediately after the Big Bang, the beginning of our universe, only hydrogen and helium existed. However, nuclear fusion in the interior of stars and the explosion of supernovae in the universe over the course of 13.8 billion years led to the evolution of a world brimming with the many different elements we have today. By using man-made satellites to observe X-rays and gamma-rays emitted from celestial objects, we are observing the synthesis of the elements at their actual source. Our goal is to comprehensively elucidate the scenarios for the formation of the elements in the universe, together with our research on sub-atomic physics through the use of an accelerator.

2. Major Research Subjects

- (1) Connect missing links of nucleosynthesis in our universe
- (2) Reveal the particle acceleration mechanism in astronomical objects, planets and inter-planetary space
- (3) Discover new physics in extremely strong magnetic and gravitational environment
- (4) Research and development of innovative X-ray and gamma-ray detectors

3. Summary of Research Activity

High Energy Astrophysics Laboratory started in April 2010. The goal of our research is to reveal the mechanism of nucleosynthesis and the evolution of elements in our universe, to study the particle acceleration mechanisms by shockwaves or electrical potential, and to observe/discover exotic physical phenomena in extremely strong magnetic and/or gravitational fields. We have observed supernova remnants, strongly magnetized neutron stars, pulsars, black holes, galaxies, and planets of the solar system with UV, X-ray, and gamma-ray astronomical satellites and/or ground-based telescopes. In FY2016, we have following achievements.

(1) Ultra high-resolution spectroscopy

The microcalorimeter, Soft X-ray Spectrometer (SXS), onboard the Hitomi (ASTRO-H) X-ray satellite was launched in February 2016. Our laboratory contributed to the mission, in particular to the development of the SXS. The SXS consisted of a semiconductor sensor cooled down around 50 mK, and measuring X-ray energy with a very sensitive thermometer. Soon after the Hitomi launch, SXS achieved the operation temperature and observed the Perseus galaxy cluster and some other celestial objects for verifying the detector system. Although the Hitomi satellite was lost in March 2016 due to a tragic accident, the data obtained in the verification phase was analyzed and published to Nature. This analysis demonstrated the excellent capability of the microcalorimeter in spectroscopy: A recovery mission is planned for the launch in 2021.

(2) X-ray polarimeter development

X-ray polarimeter is one of our key devices developing for more than 12 years. We have evaluated the basic performance of the X-ray polarimeter for Relativistic Astrophysical X-ray Sources (PRAXyS) small explorer. PRAXyS is the NASA's mission designed to probe the space-time geometry in strong gravitational field and strong magnetic field of high-energy astronomical objects in the universe, such as black holes and neutron stars, via X-ray polarimetry in the energy band of 2-10 keV. An engineering model of the polarimeter was tested at the Brookhaven National Laboratory and NASA's Goddard Space Flight Center. We measured its modulation factor, the most important indicator of polarimetry, and successfully verified that the measured values were consistent with the ones obtained with simulations, which well meets the mission requirement.

(3) Observations of Jupiter's aurora

We made an international observing campaign for Jupiter's space environment by using the Hisaki satellite, Hubble Space Telescope (HST), and Juno explorer in mid-2016. Continuous monitoring of Jupiter's aurora with Hisaki indicated an explosive auroral brightening within a few hours, of which structure was found expanding in longitude and latitude in the HST high-resolution imaging. During the auroral explosion, Juno detected a forward shock in the solar wind plasma propagating to Jupiter. We interpret the observations as a release of electromagnetic energy stored at <100 Jovian radii from Jupiter, followed by Jupiter-ward transport of the released energy as the hot plasma population, which finally excites the auroral explosion. This rapid energy release and transport could universally take place at other magnetized rotating bodies, e.g., exoplanets, neutron stars, and white dwarfs.

(4) Observations of neutron stars

We have analyzed the X-ray data of the Neutron Star Low-Mass X-ray Binary (NS-LMXB) Aquila X-1 obtained by the Japanese X-ray satellite Suzaku. The spectrum was represented by an optically thick disk emission (multi-color blackbody) and a Comptonized emission by a corona around the neutron star as shown in the previous studies, but we discovered small hump structure around 30 keV for the spectrum obtained in the hard state, in which the Comptonized emission is dominant. The structure was well represented by a single Gaussian model or a recombination edge emission mode. One of the possible interpretations of the hump is the fluorescence line or K-edge recombination of the heavy element that is produced in a rapid proton capture process (rp-process) in Type-I X-ray bursts or superbursts occurred on the neutron star surface of Aql X-1.

(5) Observations of supernova remnants

We have performed a systematic X-ray study of nine evolved supernova remnants in the Magellanic Clouds, DEM L238, DEM L249, 0534-69.9, 0548-70.4, B0532-71.0, B0532-67.5, 0103-72.6, 0049-73.6, and 0104-72.3, using archival data of the Suzaku satellite. Although Suzaku does not spatially resolve the SN ejecta from the swept-up ISM due to the limited angular resolution, its excellent energy resolution has enabled clear separation of emission lines in the soft X-ray band. The Fe/Ne mass ratios clearly divide the observed SNRs into the Type Ia and core-collapse groups, confirming some previous typing made by Chandra observations that had utilized its extremely

high angular resolution. This demonstrates that spatially integrated X-ray spectra of old SNRs can also be used to discriminate their progenitor type.

(6) Development of a new analysis method for gravitational weak lensing

We developed a new weak gravitational lensing shear analysis method which can correct pixel noise effect. The gravitational lensing analysis is a great tool to direct measurement of mass information, and it can be applied to constrain the cosmological parameters by measuring cosmic shear, it is distortion by the large scale structure. Because the mass concentration of the structure is very weak, so the lensing effect is also very weak, so precise shear analysis method is needed for stronger constraining. The pixel noise effect is shear measurement error from random counts on galaxy images from Poisson noises of sky count. We studied pixel noise correction method with an analytical approach, and the new method has 10 times high precision about pixel noise effect.

Members

Associate Chief Scientist (Lab. Head)

Toru TAMAGAWA

Contract Researchers

Yuki OKURA

Asami HAYATO

Special Postdoctoral Researchers

Kumi ISHIKAWA

Hirofumi NODA

Takayuki YUASA

Tomoki KIMURA

Toshio NAKANO

Part-time Workers

Megu KUBOTA

Kazuki NISHIDA

Naoto MURATA

Sonoe ODA

Yuanhui ZHOU

Tatsuya YOSHIDA

Visiting Researcher

Wataru IWAKIRI (JSPS Fellow)

Visiting Scientists

Yukikatsu TERADA (Saitama Univ.)

Yujin NAKAGAWA (JAXA)

Masaki WAKABAYASHI (Jakulin Commercial Company LC)

Aya BAMBABA (Aoyama Gakuin Univ.)

Naohisa INADA (National Institute of Tech., Nara College)

Rohta TAKAHASHI (Tomakomai Nat'l College of Tech.)

Toru MISAWA (Shinshu Univ.)

Hiroya YAMAGUCHI (Harvard Univ.)

Satoru KATSUDA (JAXA)

Shin'ya YAMADA (Tokyo Met. Univ.)

Takao KITAGUCHI (Hiroshima Univ.)

Teruaki ENOTO (Kyoto Univ.)

Hirofumi NODA (Tohoku Univ.)

Yuzuru Tawara (Nagoya Univ.)

Ikuyuki Mitsuishi (Nagoya Univ.)

Harufumi TSUCHIYA (JAEA)

Teruaki ENOTO (Kyoto Univ.)

Yuzuru TAWARA (Nagoya Univ.)

Student Trainees

Yoko TAKEUCHI (Tokyo Univ. of Sci.)

Megu KUBOTA (Tokyo Univ. of Sci.)

Kazuki NISHIDA (Tokyo Univ. of Sci.)

Sonoe ODA (Tokyo Univ. of Sci.)

Ryouta MICHIGAMI (Nagasaki Institute of Applied Science)

Naoto MURATA (Tokyo Univ. of Sci.)

Yuanhui ZHOU (Tokyo Univ. of Sci.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

The Hitomi collaboration; "The quiescent intracluster medium in the core of the Perseus cluster", *Nature*, 535, 117-121 (2016).*

The Hitomi collaboration; "Hitomi Constraints on the 3.5 keV Line in the Perseus Galaxy Cluster", *The Astrophysical Journal Letters*, 837, L15, (2017).*

Takeuchi, Yoko; Yamaguchi, Hiroya; Tamagawa, Toru; "A systematic study of evolved supernova remnants in the large and small Magellanic Clouds with Suzaku", *Publications of the Astronomical Society of Japan*, 68, S9 (2016).*

Iwakiri, W. B.; Black, J. K.; Cole, R.; Enoto, T.; Hayato, A.; Hill, J. E.; Jahoda, K.; Kaaret, P.; Kitaguchi, T.; Kubota, M.; Marlowe, H.; McCurdy, R.; Takeuchi, Y.; Tamagawa, T.: "Performance of the PRAXyS X-ray polarimeter", *Nuclear Inst. and Methods in Physics Research*, A, 838, 89 (2016). *

Terada, Y.; Maeda, K.; Fukazawa, Y.; Bamba, A.; Ueda, Y.; Katsuda, S.; Enoto, T.; Takahashi, T.; Tamagawa, T.; Röpke, F. K.; Summa, A.; Diehl, R.; "Measurements of the Soft Gamma-Ray Emission from SN2014J with Suzaku", *The Astrophysical Journal*, 823, 43, (2016).*

Okura, Yuki; Futamase, Toshifumi: "The Systematic Error Test for PSF Correction in Weak Gravitational Lensing Shear Measurement By the ERA Method By Idealizing PSF" *The Astrophysical Journal*, 827, 138 (2016). *

- Okura, Yuki; Petri, Andrea; May, Morgan; Plazas, Andrs A.; Tamagawa, Toru: "Consequences of CCD Imperfections for Cosmology Determined by Weak Lensing Surveys: From Laboratory Measurements to Cosmological Parameter Bias" *The Astrophysical Journal*, 825, 61 (2016). *
- Furusawa, Hisanori; Kashikawa, Nobunari; Kobayashi, Masakazu A. R.; Dunlop, James S.; Shimasaku, Kazuhiro; Takata, Tadafumi; Sekiguchi, Kazuhiro; Naito, Yoshiaki; Furusawa, Junko; Ouchi, Masami; Nakata, Fumiaki; Yasuda, Naoki; Okura, Yuki; Taniguchi, Yoshiaki; Yamada, Toru; Kajisawa, Masaru; Fynbo, Johan P. U.; Le Fvre, Olivier: "A New Constraint on the Ly α Fraction of UV Very Bright Galaxies at Redshift 7" *The Astrophysical Journal*, 822, 46 (2016). *
- Tao, Chihiro; Kimura, Tomoki; Badman, Sarah V; Murakami, Go; Yoshioka, Kazuo; Tsuchiya, Fuminori; Andre, Nicolas; Yoshikawa, Ichiro; Yamazaki, Atsushi; Shiota, Daikou; "Variation of Jupiter's aurora observed by Hisaki/EXCEED: 1. Observed characteristics of the auroral electron energies compared with observations performed using HST/STIS", *Journal of Geophysical Research: Space Physics*, 121, 4041-4054, (2016). *
- Kita, Hajime; Kimura, Tomoki; Tao, Chihiro; Tsuchiya, Fuminori; Misawa, Hiroaki; Sakanoi, Takeshi; Kasaba, Yasumasa; Murakami, Go; Yoshioka, Kazuo; Yamazaki, Atsushi; "Characteristics of solar wind control on Jovian UV auroral activity deciphered by long-term Hisaki EXCEED observations: Evidence of preconditioning of the magnetosphere?", *Geophysical Research Letters*, 43, 6790-6798, (2016). *
- Gray, RL; Badman, Sarah Victoria; Bonfond, Bertrand; Kimura, Tomoki; Misawa, H; Nichols, JD; Vogt, MF; Ray, LC; "Auroral evidence of radial transport at Jupiter during January 2014", *Journal of Geophysical Research: Space Physics*, 121, 9972-9984, (2016). *
- Yoshikawa, Ichiro; Yoshioka, Kazuo; Murakami, Go; Suzuki, Fumiharu; Hikida, Reina; Yamazaki, Atsushi; Kimura, Tomoki; Tsuchiya, Fuminori; Kagitani, Masato; Sakanoi, Takeshi; "Properties of hot electrons in the Jovian inner magnetosphere deduced from extended observations of the Io Plasma Torus", *Geophysical Research Letters*, 43, 11,552{11,557, (2016). *
- Yoshioka, K; Tsuchiya, F; Kimura, T; Kagitani, M; Murakami, G; Yamazaki, A; Kuwabara, M; Suzuki, F; Hikida, R; Yoshikawa, I; "Radial variation of sulfur and oxygen ions in the Io plasma torus as deduced from remote observations by Hisaki", *Journal of Geophysical Research: Space Physics*, 122, 2999-3012, (2017). *
- Kuwabara, Masaki; Yoshioka, Kazuo; Murakami, Go; Tsuchiya, Fuminori; Kimura, Tomoki; Yamazaki, Atsushi; Yoshikawa, Ichiro; "The geocoronal responses to the geomagnetic disturbances", *Journal of Geophysical Research: Space Physics*, 122, 1269-1276, (2017). *
- 笠羽康正; 三澤浩昭; 土屋史紀; 笠原禎也; 井町智彦; 木村智樹; 加藤雄人; 熊本篤志; 小嶋浩嗣; 八木谷聡; 尾崎光紀; 石坂圭吾; 埜千尋; 三好由純; 阿部琢美; 諸岡倫子, 「みんなでふたたび木星へ, そして氷衛星へその 4 電波・プラズマ波動観測器 RPWI の飛翔へ」, *日本惑星科学会誌遊星人*, 25, 96-107, (2016). *
- Serino, Motoko; Iwakiri, Wataru; Tamagawa, Toru; Sakamoto, Takanori; Nakahira, Satoshi; Matsuoka, Masaru; Yamaoka, Kazutaka; Negro, Hitoshi; "MAXI observations of long X-ray bursts", *Publications of the Astronomical Society of Japan*, 68, 95 (2016). *
- Nakano, Toshio; Murakami, Hiroaki; Furuta, Yoshihiro; Enoto, Teruaki; Masuyama, Miyu; Shigeyama, Toshikazu; Makishima, Kazuo; "Study of the progenitor of the magnetar 1E 2259+586 through Suzaku observations of the associated supernova remnant CTB 109", *Publications of the Astronomical Society of Japan*, 69, 40 (2017).*
- Makishima, Kazuo; Enoto, Teruaki; Murakami, Hiroaki; Furuta, Yoshihiro; Nakano, Toshio; Sasano, Makoto; Nakazawa, Kazuhiro; "Evidence for a 36 ks phase modulation in the hard X-ray pulses from the magnetar 1E 1547.0-5408", *Publications of the Astronomical Society of Japan*, 68, S12 (2016).*

[Proceedings]

(Original Papers) *Subject to Peer Review

- Fujimoto, Ryuichi; Takei, Yoh; Mitsuda, Kazuhisa; Yamasaki, Noriko Y.; Tsujimoto, Masahiro; Koyama, Shu; Ishikawa, Kumi; Sugita, Hiroyuki; Sato, Yoichi; Shinozaki, Keisuke; Okamoto, Atsushi; Kitamoto, Shunji; Hoshino, Akio; Sato, Kosuke; Ezoe, Yuichiro; Ishisaki, Yoshitaka; Yamada, Shinya; Seta, Hiromi; Ohashi, Takaya; Tamagawa, Toru; Noda, Hirofumi; Sawada, Makoto; Tashiro, Makoto; Yatsu, Yoichi; Mitsuishi, Ikuyuki; Kanao, Kenichi; Yoshida, Seiji; Miyaoka, Mikio; Tsunematsu, Shoji; Otsuka, Kiyomi; Narasaki, Katsuhiko; DiPirro, Michael J.; Shirron, Peter J.; Sneiderman, Gary A.; Kilbourne, Caroline A.; Porter, F. Scott; Chiao, Meng P.; Eckart, Megan E.; Kelley, Richard L.; "Performance of the helium dewar and cryocoolers of ASTRO-H SXS", *Proceedings of the SPIE*, 9905, 99053S (2016).
- Hill, J. E.; Black, J. K.; Jahoda, K.; Tamagawa, T.; Iwakiri, W.; Kitaguchi, T.; Kubota, M.; Kaaret, P.; McCurdy, R.; Miles, D. M.; Okajima, T.; Soong, Y.; Olsen, L.; Sparr, L.; Mosely, S. J.; Nolan, D.; "The x-ray polarimeter instrument on board the Polarimeter for Relativistic Astrophysical X-ray Sources (PRAXyS) mission", *Proceedings of the SPIE*, 9905, 99051B (2016).
- Jahoda, Keith; Kallman, Timothy R.; Kouveliotou, Chryssa; Angelini, Lorella; Black, J. Kevin; Hill, Joanne E.; Jaeger, Theodore; Kaaret, Philip E.; Markwardt, Craig B.; Okajima, Takashi; Petre, Robert; Schnittman, Jeremy; Soong, Yang; Strohmayer, Tod E.; Tamagawa, Toru; Tawara, Yuzuru; "The Polarimeter for Relativistic Astrophysical X-ray Sources", *Proceedings of the SPIE*, 9905, 990516 (2016).
- Tsujimoto, Masahiro; Mitsuda, Kazuhisa; Kelley, Richard L.; den Herder, Jan-Willem A.; Akamatsu, Hiroki; Bialas, Thomas G.; Boyce, Kevin R.; Brown, Gregory V.; Chiao, Meng P.; Costantini, Elisa; de Vries, Cor P.; DiPirro, Michael J.; Eckart, Megan E.; Ezoe, Yuichiro; Fujimoto, Ryuichi; Haas, Daniel; Hoshino, Akio; Ishikawa, Kumi; Ishisaki, Yoshitaka; Iyomoto, Naoko; Kilbourne, Caroline A.; Kitamoto, Shunji; Koyama, Shu; Leutenegger, Maurice A.; McCammon, Dan; Mitsuishi, Ikuyuki; Murakami, Hiroshi; Murakami, Masahide; Noda, Hirofumi; Ogawa, Mina; Ota, Naomi; Paltani, Stéphane; Porter, Frederick S.; Sato, Kosuke; Sato, Yoichi; Sawada, Makoto; Seta, Hiromi; Shinozaki, Keisuke; Shirron, Peter J.; Sneiderman, Gary A.; Sugita, Hiroyuki; Szymkowiak, Andrew E.; Takei, Yoh; Tamagawa, Toru; Tashiro, Makoto S.; Terada, Yukikatsu; Yamada, Shinya; Yamasaki, Noriko Y.; Yatsu, Yoichi; "In-orbit operation of the ASTRO-H SXS", *Proceedings of the SPIE*, 9905, 99050Y (2016).
- Kelley, Richard L.; Akamatsu, Hiroki; Azzarello, Philipp; Bialas, Tom; Boyce, Kevin R.; Brown, Gregory V.; Canavan, Edgar; Chiao, Meng P.; Costantini, Elisa; DiPirro, Michael J.; Eckart, Megan E.; Ezoe, Yuichiro; Fujimoto, Ryuichi; Haas, Daniel; den Herder, Jan-Willem; Hoshino, Akio; Ishikawa, Kumi; Ishisaki, Yoshitaka; Iyomoto, Naoko; Kilbourne, Caroline A.; Kimball, Mark O.; Kitamoto, Shunji; Konami, Saori; Koyama, Shu; Leutenegger, Maurice A.; McCammon, Dan; Mitsuda, Kazuhisa; Mitsuishi, Ikuyuki; Moseley, Harvey; Murakami, Hiroshi; Murakami, Masahide; Noda, Hirofumi; Ogawa, Mina; Ohashi, Takaya; Okamoto, Atsushi; Ota, Naomi; Paltani, Stéphane; Porter, F. S.; Sakai, Kazuhiro; Sato, Kosuke; Sato, Yohichi; Sawada, Makoto; Seta, Hiromi; Shinozaki, Keisuke; Shirron, Peter J.; Sneiderman, Gary A.; Sugita, Hiroyuki; Szymkowiak, Andrew E.; Takei, Yoh; Tamagawa, Toru; Tashiro, Makoto; Terada, Yukikatsu; Tsujimoto, Masahiro; de Vries, Cor P.; Yamada, Shinya; Yamasaki, Noriko Y.; Yatsu, Yoichi; "The Astro-H high resolution soft x-ray spectrometer", *Proceedings of the SPIE*, 9905, 99050V (2016).
- The Hitomi Collaboration, "The ASTRO-H (Hitomi) x-ray astronomy satellite", *Proceedings of the SPIE*, 9905, 99050U (2016).

Watanabe, Shin; Tajima, Hiroyasu; Fukazawa, Yasushi; Blandford, Roger; Enoto, Teruaki; Goldwurm, Andrea; Hagino, Kouichi; Hayashi, Katsuhiro; Ichinohe, Yuto; Kataoka, Jun; Katsuta, Junichiro; Kitaguchi, Takao; Kokubun, Motohide; Laurent, Philippe; Lebrun, François; Limousin, Olivier; Madejski, Grzegorz M.; Makishima, Kazuo; Mizuno, Tsunefumi; Mori, Kunishiro; Nakamori, Takeshi; Nakano, Toshio; Nakazawa, Kazuhiro; Noda, Hirofumi; Odaka, Hirokazu; Ohno, Masanori; Ohta, Masayuki; Saito, Shinya; Sato, Goro; Sato, Rie; Takeda, Shin'ichiro; Takahashi, Hiromitsu; Takahashi, Tadayuki; Tanaka, Takaaki; Tanaka, Yasuyuki; Terada, Yukikatsu; Uchiyama, Hideki; Uchiyama, Yasunobu; Yamaoka, Kazutaka; Yatsu, Yoichi; Yonetoku, Daisuke; Yuasa, Takayuki; " The soft gamma-ray detector (SGD) onboard ASTRO-H", Proceedings of the SPIE, 9905, 990513 (2016).

Nakazawa, Kazuhiro; Sato, Goro; Kokubun, Motohide; Enoto, Teruaki; Fukazawa, Yasushi; Hagino, Kouichi; Harayama, Atsushi; Hayashi, Katsuhiro; Kataoka, Jun; Katsuta, Junichiro; Laurent, Philippe; Lebrun, François; Limousin, Olivier; Makishima, Kazuo; Mizuno, Tsunefumi; Mori, Kunishiro; Nakamori, Takeshi; Nakano, Toshio; Noda, Hirofumi; Odaka, Hirokazu; Ohno, Masanori; Ohta, Masayuki; Saito, Shinya; Sato, Rie; Tajima, Hiroyasu; Takahashi, Hiromitsu; Takahashi, Tadayuki; Takeda, Shin'ichiro; Terada, Yukikatsu; Uchiyama, Hideki; Uchiyama, Yasunobu; Watanabe, Shin; Yamaoka, Kazutaka; Yatsu, Yoichi; Yuasa, Takayuki; " The hard x-ray imager (HXI) onboard ASTRO-H", Proceedings of the SPIE, 9905, 990511 (2016).

Oral Presentations

[International Conference etc.]

Tomoki Kimura, Kazuo Yoshioka, Fuminori Tsuchiya, Yasutaka Hiraki, Chihiro Tao, Go Murakami, Atsushi Yamazaki, Masaki Fujimoto, Sarah Victoria Badman, Peter A Delamere, Fran Bagenal, "Response of tail reconnection and energetic event to plasma mass loading monitored by Hisaki", NASA Participating Scientist Program meeting for Hisaki/EXCEED, Boulder, USA, January (2017).

Tomoki Kimura, Go Murakami, Atsushi Yamazaki, Fuminori Tsuchiya, Kazuo Yoshioka, Chihiro Tao, Hajime Kita, Sarah V Badman, Masaki Fujimoto, Hisaki Science Team, "Continuous Monitoring of Jupiter's Aurora and Io Plasma Torus with the Hisaki Satellite: Recent Results and Future Coordination with JUNO" 8th International Workshop on Planetary, Solar and Heliospheric Radio Emissions (PRE VIII), Graz, Austria, October (2017).

Tomoki KIMURA, "Substorm like events seen as auroras and their responses to the plasma mass loading from Io", The influence of Io on Jupiter's Magnetosphere, International Space Science Institute Meeting, Zurich, Switzerland, September (2016).

Tomoki Kimura, Kazuo Yoshioka, Go Murakami, Atsushi Yamazaki, Fuminori Tsuchiya, Chihiro Tao, Masaki Fujimoto, "Hisaki Science team, Synergetic Multi-Wavelength Observation of Jupiter's Magnetosphere Driven by Hisaki: Recent Results and Plans for JUNO Mission", Japan Geoscience Union Meeting 2016, Makuhari, Japan, May (2016).

Yuki Okura; "Ellipticity of Re-smearred Articial image (ERA) Method", HSC collaboration meeting 2016 August, IPMU, Japan, August (2016).

Yuki Okura; "Current Status of ERA method and Pixel Noise Study", HSC WLWG f2f meeting at Princeton, IPMU, Japan, August (2016).

Toru Tamagawa, "X-ray polarimetry mission PRAXyS", 7 years of MAXI : monitoring X-ray transients conference, RIKEN, Japan, December (2016).

Toru Tamagawa, "A Modulated X-ray Generator for Possible Industrial Applications", IEEE NSS/MIC conference 2016, Strasbourg, France, November (2016).

[Domestic Conference]

玉川徹, 早藤麻美, 岩切渉, 中野俊男, 深沢泰司, 水野恒史, 北口貴雄, 田中慎之, 戸田皓陽, 榎戸輝揚, 窪田恵, 西田和樹, 田原譲, 三石郁之, 菅沼亮紀, 幅良統, 林田清, 井上翔太, Keith Jahoda, Joanne Hill-Kittle, ほか PRAXyS 衛星チーム, 「X線偏光観測衛星 PRAXyS の進捗(4)」 日本天文学会 2017 年春季年会, 九州大学, 3 月(2017).

三石郁之, 菅沼亮紀, 二村泰介, 松本浩典, 田原譲, 立花一志, 大西崇文, 立花健二, 中野俊男, 玉川徹, 岡島崇, William Chang, Keith Jahoda, 「X線偏光観測衛星 PRAXyS 搭載 X線望遠鏡用サーマルシールドの開発」 日本天文学会 2017 年春季年会, 九州大学, 3 月(2017).

北口貴雄, 深沢泰司, 水野恒史, 玉川徹, 早藤麻美, 岩切渉, 中野俊男, 窪田恵, 榎戸輝揚, 他 PRAXyS チーム, 「PRAXyS 衛星に搭載する光電子追跡型 X線偏光計の偏光角再構成法」 日本天文学会 2017 年春季年会, 九州大学, 3 月(2017).

中野俊男, 玉川徹, 早藤麻美, 岩切渉, 窪田恵, 北口貴雄, 田中慎之, 戸田皓陽, 深沢泰司, 水野恒史, 三石郁之, 田原譲, 井上翔太, 林田清, 榎戸輝揚, Keith Jahoda, Joanne Hill-Kittle, ほか PRAXyS 衛星チーム, 「PRAXyS 衛星搭載の X線ミラーと偏光計のビームラインによる性能評価」 日本天文学会 2017 年春季年会, 九州大学, 3 月(2017).

菅沼亮紀, 二村泰介, 田原譲, 松本浩典, 三石郁之, 立花一志, 大西崇文, 立花健二, 中野俊男, 玉川徹, 「PRAXyS 衛星搭載 X線望遠鏡サーマルシールド用ポリイミドフィルムの特性評価」 日本天文学会 2017 年春季年会, 九州大学, 3 月(2017).

窪田めぐ, 玉川徹, 牧島一夫, 芹野素子, 岩切渉, 杉崎睦, 中野俊男, 小野光, 「中性子星大気中における Z=52 付近の重元素の存在」 日本天文学会 2017 年春季年会, 九州大学, 3 月(2017).

玉川徹, 岩切渉, 中野俊男, 早藤麻美, 北口貴雄, 水野恒史, 深沢泰司, 榎戸輝揚, 窪田恵, 西田和樹, 田原譲, 三石郁之, 幅良統, 林田清, Keith Jahoda, Joanne Hill, ほか PRAXyS 衛星チーム, 「X線偏光観測衛星 PRAXyS の進捗状況」 日本天文学会 2016 年秋季年会, 愛媛大学, 9 月(2016).

田原譲, 二村泰介, 菅沼亮紀, 三石郁之, 松本浩典, 玉川徹, 岡島崇, 「PRAXyS 搭載用 X線望遠鏡のためのサーマルシールドの開発」 日本天文学会 2016 年秋季年会, 愛媛大学, 9 月(2016).

玉川徹, 早藤麻美, 岩切渉, 中野俊男, 窪田恵, 西田和樹, 田原譲, 三石郁之, 菅沼亮紀, 深沢泰司, 水野恒史, 北口貴雄, 田中慎之, 戸田皓陽, 榎戸輝揚, 林田清, 井上翔太, 渡辺伸, PRAXyS team, 「X線偏光観測衛星 PRAXyS」 第 17 回宇宙科学シンポジウム, 宇宙科学研究所, 1 月(2017).

木村智樹, 「Dynamics of Jupiter's aurora unveiled by the Hisaki-JUNO-Hubble collaboration: initial results」, Symposium on Planetary Science 2017, 東北大学, 2 月(2017).

木村智樹, 吉岡和夫, 土屋史紀, 平木康隆, 埜千尋, 北元, 村上豪, 山崎敦, 藤本正樹, 「ひさき衛星によるオーロラとプラズマ供給率の連続監視で明らかにする木星サブストームライクイベントの動力学」, 地球電磁気・地球惑星圏学会第 138 回総会・講演会, 九州大学, 11 月(2016).

中野俊男: 「長周期 CCO を伴う SNR RCW103 とマグネター SNR CTB109 の比較」 山形県蔵王アストリアホテル 9 月(2016)

RIBF Research Division Astro-Glaciology Research Unit

Summary of Research Activities

Our Astro-Glaciology Research Unit promotes both experimental and theoretical studies to open up the new interdisciplinary research field of astro-glaciology, which combines astrophysics and glaciology.

On the experimental side, we analyze ice cores drilled at the Dome Fuji station, in Antarctica, in collaboration with the National Institute of Polar Research (NIPR, Tokyo). These ice cores are time capsules. In particular, the ice cores obtained at Dome Fuji are known to be unique because they contain much more information on conditions in the stratosphere than any other ice cores recovered from other locations in either hemisphere. This means that there are significant advantages in using Dome Fuji ice cores if we wish to study astronomical phenomena of the past. Since gamma-rays and high-energy protons that are emitted in certain astronomical processes affect the chemical and isotopic compositions in the stratosphere but not those in the troposphere, we have been measuring:

- (1) Variations in the nitrate ion (NO_3^-) concentrations in the ice cores, in an effort to establish a new proxy for supernova explosions in our own galaxy as well as past solar activity.
- (2) Variations in the water isotopes (^{18}O and ^2H) in the ice cores, in order to construct in more detail records of past changes in the temperature of the surface of the earth; and
- (3) Variations in the nitrogen isotope (^{15}N) in the nitrates contained in the ice cores, in order to investigate the possibility of utilizing ^{15}N as a new and more stable proxy for galactic supernovae explosions and past solar activity.

In the case of items (1), (2), and (3), our analyses of Dome Fuji ice cores cover the most recent 2000 years. The temporal resolution of the results of our research is currently 12 months. We intend to compare the results obtained in item (1) with those in item (2), in order to understand better the relationships between solar activity and long-term changes in the temperature of the earth. The underlying assumptions in item (2) are already well accepted in glaciology. Item (3) refers to one of the very first measurements of ^{15}N concentrations in ice cores.

On the theoretical side, we are simulating numerically:

- (4) Changes in the chemical composition of the stratosphere induced by gamma-rays and/or high-energy particles emitted from explosive astronomical phenomena, such as galactic supernovae and solar proton events; and
- (5) The explosive nucleosynthesis (including the r-process, the rapid neutron capture process, which creates elements heavier than iron) that arises in the environment of core-collapse supernova explosions.

Items (4) and (5) in our list, the chemical composition of the stratosphere and explosive nucleosynthesis, are very important in solar-terrestrial research and nuclear astrophysics; furthermore, these simulations provide a theoretical support when considering the characteristics of supernova explosions and solar activity, as seen in our ice core data. These studies are also important because it is necessary to discount the effects of the meteorological noise.

It is noteworthy that the as yet not fully understood frequency of supernova explosions in our galaxy is crucial to an understanding of the r-process nucleosynthesis. The results obtained from items (1) and (3) are expected to reveal the average rate of supernova explosions in our galaxy during the past million years of ice deposition.

Members

Research Unit Leader (Lab. Head)

Yuko MOTIZUKI

Research & Technical Scientists

Kazuya TAKAHASHI (Concurrent: RI Application Team, Senior Research Scientist)

Yoichi NAKAI (Concurrent: RI Physics Lab., Senior Research Scientist)

Part-time Workers

Manami MARUYAMA
Yuma HASEBE
Satomi NEGISHI

Sachiko MIYAZAKI
Yoko HOSHINO
Emi NISHIZAWA

Visiting Scientists

Yasushi YANO (Concurrent)
Akira HORI (Kitami Inst. of Tech.)

Hideharu AKIYOSHI (Nat'l Inst. for Environ. Studies)
Hideki MADOKORO (Mitsubishi Heavy Ind., Ltd.)

Research Consultant

Kenji Tanabe

Student Trainees

Yuma HASEBE (Saitama Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- Y. Motizuki, H. Motoyama, Y. Nakai, K. Suzuki, Y. Iizuka and K. Takahashi: "Overview of the chemical composition and characteristics of Na⁺ and Cl⁻ distributions in shallow samples from Antarctic ice core DF01 (Dome Fuji) drilled in 2001", *Geochemical J.*, 51, 3, 293-298, 2017, doi:10.2343/geochemj.2.0458 (Open Access article)*
- Shuji Fujita, Kumiko Goto-Azuma, Motohiro Hirabayashi, Akira Hori, Yoshinori Iizuka, Yuko Motizuki, Hideaki Motoyama, Kazuya Takahashi: "Densification of layered firm of the ice sheet at Dome Fuji, Antarctica", *Journal of Glaciology*, 21 pages, 2016, doi:10.1017/jog.2016.16 (Open Access article)*
- Y. Nakai, Y. Motizuki, M. Maruyama, Y. Hasebe, H. Akiyoshi, T. Imamura: "Box-model simulation for influence of solar proton events on the middle atmosphere", *RIKEN Accel. Prog. Rep.* 50, in press*
- Y. Motizuki, H. Motoyama, Y. Nakai, K. Suzuki, Y. Iizuka and K. Takahashi: "Characteristics of Na⁺ and Cl⁻ distributions in shallow samples from an Antarctic ice core DF01 (Dome Fuji) drilled in 2001: Result of strong atmospheric high-pressure blocking events?", *RIKEN Accel. Prog. Rep.* 50, in press*
- Y. Motizuki, K. Takahashi, Y. Nakai, Y. Iizuka, K. Suzuki, H. Motoyama: "Overview of the chemical composition and characteristics of Na⁺ and Cl⁻ distributions in samples from Antarctic ice core DF01 (Dome Fuji) drilled in 2001", *RIKEN Accel. Prog. Rep.* 49, 133, 2017*
- Y. Nakai, Y. Motizuki, M. Maruyama, H. Akiyoshi, T. Imamura: "Box-model simulation for variation of atmospheric chemical composition caused by solar energetic particles", *RIKEN Accel. Prog. Rep.* 49, 132, 2017*
- Y. Hasebe, Y. Motizuki, Y. Nakai, K. Takahashi: "Diagnose oscillation properties observed in an annual ice-core oxygen isotope record obtained from Dronning Maud Land, Antarctica", *RIKEN Accel. Prog. Rep.* 49, 131, 2017*

[Book]

(Original Papers) *Subject to Peer Review

- 望月優子、佐藤勝彦：『人類の住む宇宙 第2版』（シリーズ現代の天文学 第1巻）、pp. 99-144（「第3章 元素の起源」）、岡村定矩他編、日本評論社、2017年3月*
- 望月優子：「ナイスステップな研究者から見た変化の新潮流」、文部科学省機関紙STI Horizon、2017年第3巻1号、pp. 17-20*

Oral Presentations

[International Conference etc.]

- (Invited talk) Yuko Motizuki: "Solar signatures in ice cores", The 10th East Asian Meeting on Astronomy, Seoul, Korea, Sep. 26-30, 2016.
- (Invited talk) Yuko Motizuki: "Women astronomers in Japan", The 10th East Asian Meeting on Astronomy, Seoul, Korea, Sep. 26-30, 2016.
- (Invited talk) Yuko Motizuki: "Astronomical signatures embedded in ice cores", Baymfest in Tokyo -Exploring Extreme Forms of Matter-, Tokyo, Japan, Mar. 14, 2016.
- H. Akiyoshi, Y. Nakai, Y. Motizuki, T. Imamura, Y. Yamashita: "A preliminary result of NO_x and ozone change simulation for a solar proton event using a nudged CCM and box chemistry model", Int. Workshop on Solar Cycle Activity and Impact on Climate for The 2nd PSTEP International symposium (PSTEP-2), Kyoto, March 22, 2017.
- Shuji Fujita, Kumiko Goto-Azuma, Hiroyuki Enomoto, Kotaro Fukui, Motohiro Hirabayashi, Akira Hori, Yu Hoshina, Yoshinori Iizuka, Yuko Motizuki, Hideaki Motoyama, Fumio Nakazawa, Shin Sugiyama, Sylviane Surdyk, Kazuya Takahashi: "Metamorphism of layered firm at Dome Fuji, Antarctica: Evolution of relations between Near-infrared reflectivity and the other textural/chemical properties", The 7th Symposium on Polar Science, Tachikawa, Nov. 29 - Dec. 2, 2016.
- Shuji Fujita, Kumiko Goto-Azuma, Hiroyuki Enomoto, Kotaro Fukui, Motohiro Hirabayashi, Akira Hori, Yu Hoshina, Yoshinori Iizuka, Yuko Motizuki, Hideaki Motoyama, Fumio Nakazawa, Shin Sugiyama, Sylviane Surdyk, Kazuya Takahashi: "Metamorphism of layered firm at Dome Fuji, Antarctica: Evolution of relations between Near-infrared reflectivity and the other textural/chemical properties", XXXIV SCAR(Scientific Committee on Antarctic Research) Open Science Conference, Kuala Lumpur, Malaysia, Aug. 20-30, 2016.

[Domestic Conference]

- 望月優子、中井陽一、高橋和也、ほかドームふじ氷床コア解析チーム：「南極氷床コアに刻まれた超新星カシオペアAの爆発年代」、日本天文学会春季年会、福岡、2017年3月17日。
- (招待講演) 望月優子：埼玉大学理学部物理量子力学特別講義「アイスコアからさぐる天文・宇宙のサイエンス -過去の超新星爆発と太陽活動、地球への影響-」、さいたま、2017年1月23日。
- (招待講演) 中井陽一：第36回北海道大学低温科学研究所セミナー「太陽プロトン現象に誘起される地球中層大気の微量成分濃度変化 -ボックスモデルシミュレーションによるイオン化学反応の影響の研究-」、札幌、2017年1月19日。
- (招待講演) 中井陽一、望月優子、丸山真美、秋吉英治、今村隆史：「太陽プロトン現象が引き起こす中層大気でのイオン化学反応の影響：ボックスモデルシミュレーションによる研究」、平成28年度「MTI研究集会」「宇宙空間からの地球超高層大気観測に関する研究会」合同研究会、小金井、2016年8月29日。
- 高橋和也、望月優子、中井陽一、本山秀明：「南極ドームふじ基地で掘削されたアイスコアの氷同位体比分析に基づく過去2000年の高時間分解能気温変動」、「The isotopic measurements of oxygen and hydrogen in Dome-Fuji (Antarctica) ice core: Annually-resolved temperature reconstructions of the past 2000 years」、日本地球惑星科学連合2016年連合大会、千葉、2016年5月22-26日。
- 中井陽一、望月優子、丸山真美、秋吉英治、今村隆史：「太陽高エネルギー粒子の大気への影響に関するボックスモデルシミュレーション：中層大気での微量化学種の変動」、「Box-model simulation for atmospheric effect of solar energetic particles: variation of trace chemical species in the middle atmosphere」、日本地球惑星科学連合2016年連合大会、千葉、2016年5月22-26日。
- Shuji Fujita, Kumiko Goto-Azuma, Hiroyuki Enomoto, Kotaro Fukui, Motohiro Hirabayashi, Akira Hori, Yu Hoshina, Yoshinori Iizuka, Yuko Motizuki, Hideaki Motoyama, Fumio Nakazawa, Shin Sugiyama, Sylviane Surdyk, Kazuya Takahashi: "Metamorphism of layered firm at Dome Fuji, Antarctica: Evolution of relations between Near-infrared reflectivity and the other textural and chemical properties"、日本地球惑星科学連合2016年連合大会、千葉、2016年5月22-26日。

三宅 美沙、増田 公明、堀内 一穂、本山 秀明、松崎 浩之、望月 優子、高橋 和也、中井 陽一：「ドームふじアイスコアの¹⁰Be分析による単年宇宙線イベントの調査」、日本地球惑星科学連合2016年連合大会、千葉、2016年5月22-26日。

Posters Presentations

[International Conference etc.]

Yuko Motizuki, Kazuya Takahashi, Yoichi Nakai, and Hideaki Motoyama: "Annually-resolved temperature reconstructions of the past 2000 years from Dome-Fuji, East Antarctica" (A poster paper), EGU General Assembly 2016, Vienna, Austria, Apr. 17-22, 2016.

[Domestic Conference]

長谷部 憂磨、望月 優子、中井 陽一、高橋 和也：「南極および北極アイスコアの酸素同位体比から得られる気温変動周期」(ポスター発表)、「Diagnose oscillation properties of $\delta 18\text{O}$ embeded in ice cores from Antarctica and Greenland」、日本地球惑星科学連合2016年連合大会、千葉、2016年5月22-26日。

RIBF Research Division Research Group for Superheavy Element

1. Abstract

The elements with their atomic number $Z > 103$ are called as trans-actinide or superheavy elements. The chemical properties of those elements have not yet been studied in detail. Those elements do not exist in nature. Therefore, they must be produced by artificially for the scientific study of those elements. In our laboratory, we have been studying the physical and chemical properties of the superheavy elements utilizing the accelerators in RIKEN and various methods of efficient production of the superheavy elements.

2. Major Research Subjects

- (1) Search for new superheavy elements
- (2) Decay spectroscopy of the heaviest nuclei
- (3) Study of the chemical properties of the heaviest elements
- (4) Study of the reaction mechanism of the fusion process (theory)

3. Summary of Research Activity

(1) Searching for new elements

To expand the periodic table of elements and the nuclear chart, we will search for new elements.

(2) Spectroscopic study of the nucleus of heavy elements

Using the high sensitivity system for detecting the heaviest element, we plan to perform a spectroscopic study of nuclei of the heavy elements.

(3) Chemistry of superheavy elements

Study of chemistry of the trans-actinide (superheavy element) has just started world-wide, making it a new frontier in the field of chemistry. Relativistic effects in chemical property are predicted by many theoretical studies. We will try to develop this new field.

(4) Study of a reaction mechanism for fusion process

Superheavy elements have been produced by complete fusion reaction of two heavy nuclei. However, the reaction mechanism of the fusion process is still not well understood theoretically. When we design an experiment to synthesize nuclei of the superheavy elements, we need to determine a beam-target combination and the most appropriate reaction energy. This is when the theory becomes important. We will try to develop a reaction theory useful in designing an experiment by collaborating with the theorists.

(5) Research Highlight

The discovery of a new element is one of the exciting topics both for nuclear physicists and nuclear chemists. The elements with their atomic number $Z > 103$ are called as trans-actinides or superheavy elements. The chemical properties of those elements have not yet been studied in detail. Since those elements do not exist in nature, they must be produced by artificially, by using nuclear reactions for the study of those elements. Because the production rate of atoms of those elements is extremely small, an efficient production and collection are key issues of the superheavy research. In our laboratory, we have been trying to produce new elements, studying the physical and chemical properties of the superheavy elements utilizing the accelerators in RIKEN.

Although the Research Group for Superheavy element has started at April 2013, the Group is a renewal of the Superheavy Element Laboratory started at April 2006, based on a research group which belonged to the RIKEN accelerator research facility (RARF), and had studied the productions of the heaviest elements. The main experimental apparatus is a gas-filled recoil ion separator GARIS. The heaviest elements with their atomic numbers, 107 (Bohrium), 108 (Hassium), 109 (Meitnerium), 110 (Darmstadtium), 111 (Roentogenium), and 112 (Copernicium) were discovered as new elements at Helmholtzzentrum für Schwerionenforschung GmbH (GSI), Germany by using ^{208}Pb or ^{209}Bi based complete fusion reactions, so called "cold fusion" reactions. We have made independent confirmations of the productions of isotopes of 108^{th} , 110^{th} , 111^{th} , and 112^{th} elements by using the same reactions performed at GSI. After these work, we observed an isotope of the 113^{th} element, $^{278}113$, in July 2004, in April, 2005, and in August 2012. The isotope, $^{278}113$, has both the largest atomic number, ($Z = 113$) and atomic mass number ($A = 278$) which have determined experimentally among the isotopes which have been produced by cold fusion reactions. We could show the world highest sensitivity for production and detection of the superheavy elements by these observations. Our results that related to $^{278}113$ has been recognized as a discovery of new element by a Joint Working Party of the International Union of Pure and Applied Chemistry (IUPAC) and International Union of Pure and Applied Physics (IUPAP). Finally, we named the 113^{th} element as "Nihonium".

We decided to make one more recoil separator GARIS-II, which has an acceptance twice as large as existing GARIS, in order to realize higher sensitivity. The design of GARIS-II has finished in 2008. All fabrication of the separator will be finished at the end of fiscal year 2008. It has been ready for operation after some commissioning works.

Preparatory work for the study of the chemical properties of the superheavy elements has started by using the gas-jet transport system coupled to GARIS. The experiment was quite successful. The background radioactivity of unwanted reaction products has been highly suppressed. Without using the recoil separator upstream the gas-jet transport system, large amount of unwanted radioactivity strongly prevents the unique identification of the event of our interest. This new technique makes clean and clear studies of chemistry of the heaviest elements promising.

The spectroscopic study of the heaviest elements has started by using alpha spectrometry. New isotope, ^{263}Hs ($Z=108$), which has the smallest atomic mass number ever observed among the Hassium isotopes, had discovered in the study. New spectroscopic information for ^{264}Hs and its daughters have obtained also. The spectroscopic study of Rutherfordium isotope ^{261}Rf ($Z=104$) has done and 1.9-s isomeric state has directly produced for the first time.

Preparatory works for the study of the new superheavy elements with atomic number 119 and 120 have started in 2013. We measured the reaction products of the ^{248}Cm (^{48}Ca , xn) $^{296-x}\text{Lv}$ ($Z=116$) previously studied by Frelow Laboratory of Nuclear Reaction, Russia, and GSI. We observed 5 isotopes in total which tentatively assigned to ^{293}Lv , and ^{292}Lv .

Members

Group Director

Kosuke MORITA

Visiting Scientist

Kunihiro FUJITA (Kyushu Univ.)

Student Trainees

Taiki TANAKA (Kyushu Univ.)

Yuki YAMANO (Kyushu Univ.)

Kenyu WATANABE (Kyushu Univ.)

Publications

[Journal]

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K. Morimoto, T. Tanaka, "理研における超重元素研究の今後", RIBF ミニ・ワークショップ「超重核生成反応の理論的理解に向けて」, RIKEN Japan, August 31 2016

T. Tanaka, "RIBF ミニ・ワークショップ「超重核生成反応の理論的理解に向けて」の報告", 日本物理学会 2016 秋季大会 SSRI インフォーマルミーティング, Miyazaki University Japan, September 22 2016

T. Tanaka, "新元素合成のための核融合反応における入射核依存性", 東海・重イオン科学シンポジウム —タンデム加速器成果報告会—, JAEA Japan, January 6 2017

T. Niwase, K. Morita, K. Fujita, Y. Yamano, K. Watanabe, S. Mitsuoka, T. Hirano, D. Kaji, K. Morimoto, H. Haba, B. J. P. Gall, Z. Asfari "Measurement of barrier distribution for 208Pb (51V , xn) $259-x\text{Db}$ reaction", JPS 72th Annual Meeting (2017), Osaka University Japan, March 20 2017

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森本幸司 理研における超重元素合成実験の現状と計画 "Status and future plan of Superheavy element research at RIKEN" 「第9回停止・低速 RI ビームを用いた核分光研究会」 & 「2017 超重元素の科学研究会」 合同研究会

原子力機構・先端基礎研究センター 茨城県東海村・原子力科学研究所 2017年3月6日

K. Morimoto "Status and future plan of Superheavy element research at RIKEN" RIBF Users Meeting 2016, September 8, 2016, RIKEN JAPAN

森本幸司「113番元素の合成と確認」AMO 討論会、理研、和光 2016年6月3日

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[その他]

森本幸司「日本初、新元素“ニホニウム”の発見」IUPAC 賛助会員委員会 2016年11月2日東京、明治大学紫紺館

森本幸司「113番新元素の生成と確認」真空シンポジウム(VACUUM2016)2016年9月9日、神奈川、パシフィコ横浜

森本幸司「日本初、原子番号113"ニホニウム"の発見と、新元素がもたらす未来の産業創造への展望」JST フェア 2016, 東京ビッグサイト、2016/8/26 基調講演

森本幸司「113番新元素の発見」アトムサイエンスフェア講演会 2016、京都、熊取交流センター、2016年10月22日

森本幸司「113番新元素ニホニウムの発見」平成28年度 大学等における放射線安全管理研修会、東京大学 農学部 弥生講堂 一条ホール、2016年8月30日

森本幸司「ニホニウム発見物語」東北大学大学院理学研究科公開サイエンス講座東北大学川内キャンパス、仙台、2016年12月10日

RIBF Research Division

Research Group for Superheavy Element

Superheavy Element Production Team

1. Abstract

The elements with their atomic number $Z > 103$ are called as trans-actinide or superheavy elements. The chemical properties of those elements have not yet been studied in detail. Those elements do not exist in nature. Therefore, they must be produced by artificially for the scientific study of those elements. In our laboratory, we have been studying the physical and chemical properties of the superheavy elements utilizing the accelerators in RIKEN and various methods of efficient production of the superheavy elements.

2. Major Research Subjects

- (1) Search for new superheavy elements
- (2) Decay spectroscopy of the heaviest nuclei
- (3) Study of the chemical properties of the heaviest elements
- (4) Study of the reaction mechanism of the fusion process (theory)

Summary of Research Activity

(1) Searching for new elements

To expand the periodic table of elements and the nuclear chart, we will search for new elements.

(2) Spectroscopic study of the nucleus of heavy elements

Using the high sensitivity system for detecting the heaviest element, we plan to perform a spectroscopic study of nuclei of the heavy elements.

(3) Chemistry of superheavy elements

Study of chemistry of the trans-actinide (superheavy element) has just started world-wide, making it a new frontier in the field of chemistry. Relativistic effects in chemical property are predicted by many theoretical studies. We will try to develop this new field.

(4) Study of a reaction mechanism for fusion process

Superheavy elements have been produced by complete fusion reaction of two heavy nuclei. However, the reaction mechanism of the fusion process is still not well understood theoretically. When we design an experiment to synthesize nuclei of the superheavy elements, we need to determine a beam-target combination and the most appropriate reaction energy. This is when the theory becomes important. We will try to develop a reaction theory useful in designing an experiment by collaborating with the theorists.

Members

Team Leader

Kosuke MORITA (concurrent; Group Director, Research Group for Superheavy Element)

Research & Technical Scientist

Kouji MORIMOTO (Senior Research Scientist, concurrent; Team Leader, Superheavy Element Device Development Team)

Nishina Center Research Scientist

Daiya KAJI (concurrent; Superheavy Element Device Development Team)

Nishina Center Technical Scientist-Consultant

Akira YONEDA

Research Consultant

Kenji KATORI

Junior Research Associate

Taiki TANAKA (Kyushu Univ.)

Visiting Scientists

Hiroyuki KOURA (JAEA)
Benoit Jean-Paul GALL (Strasbourg Univ.)

Marc ASFARI (Institut Pluridisciplinaire Hubert Curien)
Mirei TAKEYAMA (Yamagata Univ.)

Student Trainees

Toshitaka NIWASE (Kyushu Univ.)
Takeshi HIRANO (Kyushu Univ.)
Shun MITSUOKA (Kyushu Univ.)
Pierre BRIONNET (Strasbourg University)

Publications

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森本幸司「新元素“ニホニウム”の発見」*真空ジャーナル* p. 20-21, 159, 2017年1月

森本幸司「新元素発見までの道のり」*兵庫教育* 3月号 No.793, p. 17-19

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RIBF Research Division

Research Group for Superheavy Element

Superheavy Element Device Development Team

1. Abstract

A gas-filled recoil ion separator has been used as a main experimental device for the study of superheavy elements. This team is in charge of maintain, improve, develop and operate the separators and related devices. There are two gas-filled recoil ion separators installed at RILAC experimental hall. One is GARIS that is designed for symmetric reaction such as cold-fusion reaction, and the other is newly developed GARIS-II that is designed for an asymmetric reaction such as hot-fusion reaction. New elements $^{278}113$ were produced by $^{70}\text{Zn} + ^{209}\text{Bi}$ reaction using GARIS. Further the new element search $Z > 118$ are preparing by using GARIS-II.

2. Major Research Subjects

- (1) Maintenance of GARIS and development of new gas-filled recoil ion separator GARIS-II.
- (2) Maintenance and development of detector and DAQ system for GARIS and GARIS-II.
- (3) Maintenance and development of target system for GARIS and GARIS-II.

3. Summary of Research Activity

The GARIS-II is newly developed which has an acceptance twice as large as existing GARIS, in order to realize higher sensitivity for asymmetric reaction such as a hot fusion reaction. After some commissioning works, the GARIS-II has been ready for new element research. We will also offer user-support if a researcher wishes to use the devices for his/her own research program.

Members

Team Leader

Kouji MORIMOTO

Nishina Center Research Scientist

Daiya KAJI

Junior Research Associate

Sayaka YAMAKI (Saitama Univ.)

Visiting Scientists

Fuyuki TOKANAI (Yamagata Univ.)

Student Trainee

Satoshi ISHIZAWA (Yamagata Univ.)

Ryutaro ITO (Yamagata Univ.)

Yuichiro INOMATA (Yamagata Univ.)

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- K. Morita, "Discovery of Element 113 and Future Research Direction at RIKEN", Nobel Symposia, NS160: Chemistry and Physics of Heavy and Superheavy Elements, Scania Sweden, May 29 to June 3, 2016
- K. Morita, "The Discovery of Super-Heavy Element of Atomic Number $Z=113$ and Beyond", *Nuclei in the Cosmos XIV(NIC XIV)*, TokiMesse, Niigata Japan, June 22, 2016
- T. Tanaka, Y. Narikiyo, K. Morita, K. Fujita, D. Kaji, K. Morimoto, S. Yamaki, Y. Wakabayashi, K. Tanaka, M. Takeyama, A. Yoneyama, H. Haba, Y. Komori, S. Yanou, B. J. P. Gall, Z. Asfari, H. Faure, H. Hasebe, M. Huang, J. Kanaya, M. Murakami, A. Yoshida, T. Yamaguchi, T. Tokanai, T. Yoshida, Z. Gan, L. Ma, H. Geissel, S. Hofmann, Y. Maurer, S. Yamamoto, Y. Yamano, K. Watanabe, S. Ishizawa, M. Asai, R. Aono, S. Goto, K. Katori "Study of barrier distribution in heavy reaction system at the RIKEN-GARIS", *Fusion17*, Hobart Australia, February 23 2017
- K. Morimoto "The discovery of element 113 at RIKEN" 26th International Nuclear Physics Conference (INPC2016) Sep. 11-16, 2016, Adelaide Convention Center, Australia (Plenary talk)
- T. Tanaka, "Study of barrier distribution in heavy reaction system at the RIKEN-GARIS", 40th ASRC International Workshop 'Experimental

and Theoretical Advances in Fission and Heavy Nuclei', Tokai Japan, December 13 2016

[Domestic Conference]

- K. Morita, "Journey to the Discovery of Element 113", 64th General Meeting of Japanese Society of Chemistry, Kobe Japan, June 9, 2016
- K. Morita, "Discovery of Element 113", JAIF General Meeting(2016), Tokyo Japan, June 21, 2016
- K. Watanabe, D. Kaji, T. Niwase, T. Hirano, K. Fujita, Y. Yamano, S. Mitsuoka, K. Morimoto, K. Morita "Search for barrier distributions of Ti+Cm and V+Cm reaction", 122th Annual Meeting of Kyushu Branch of JPS, Fukuoka University Japan, December 10 2016
- Y. Yamano, K. Morita, K. Fujita, K. Watanabe, T. Niwase, T. Hirano, S. Mitsuoka, K. Morimoto, D. Kaji, H. Haba, "Barrier distributions of 50Ti + 248Cm and 51V+ 248Cm reactions", JPS 72th Annual Meeting(2017), Osaka University Japan, March 20 2017
- K. Fujita, "Present Status and Future Prospects of GARIS", JPS 72th Annual Meeting(2017), Osaka University Japan, March 17 2017
- K. Morimoto, T. Tanaka, "理研における超重元素研究の今後", RIBF ミニ・ワークショップ「超重核生成反応の理論的理解に向けて」, RIKEN Japan, August 31 2016
- T. Tanaka, "RIBF ミニ・ワークショップ「超重核生成反応の理論的理解に向けて」の報告", 日本物理学会 2016 秋季大会 SSRI インフォーマルミーティング, Miyazaki University Japan, September 22 2016
- T. Tanaka, "新元素合成のための核融合反応における入射核依存性", 東海・重イオン科学シンポジウム —タンデム加速器成果報告会—, JAEA Japan, January 6 2017
- T. Niwase, K. Morita, K. Fujita, Y. Yamano, K. Watanabe, S. Mitsuoka, T. Hirano, D. Kaji, K. Morimoto, H. Haba, B. J. P. Gall, Z. Asfari "Measurement of barrier distribution for 208Pb(51V,xn)259-xDb reaction", JPS 72th Annual Meeting (2017), Osaka University Japan, March 20 2017
- D. Kaji, K. Morita, K. Morimoto, H. Haba "Frontline in superheavy element study using a gas-filled recoil separator GARIS" 第 60 回放射化学討論会, Tohoku University Japan, September 10-12 2016 (invited)
- D. Kaji, K. Morimoto, H. Haba, Y. Wakabayashi, M. Takeyama, S. Yamaki, Y. Komori, S. Yano, S. Goto "Study on hot fusion reaction of 48Ca+238U→286Cn* using GARIS-II" 第 60 回放射化学討論会, Tohoku University Japan, September 10-12 2016
- 森本幸司 理研における超重元素合成実験の現状と計画 "Status and future plan of Superheavy element research at RIKEN" 「第 9 回停止・低速 RI ビームを用いた核分光研究会」 & 「2017 超重元素の科学研究会」 合同研究会
原子力機構・先端基礎研究センター 茨城県東海村・原子力科学研究所 2017 年 3 月 6 日
- K. Morimoto "Status and future plan of Superheavy element research at RIKEN" RIBF Users Meeting 2016, September 8, 2016, RIKEN JAPAN
- 森本幸司 「113 番元素の合成と確認」 AMO 討論会、理研、和光 2016 年 6 月 3 日

Posters Presentations

[International Conference etc.]

- S. Ishizawa, K. Morimoto, D. Kaji, F. Tokanai "Development of time-of-flight detector for studying on superheavy nuclei", The 77th JSAP Autumn Meeting(2016), TOKI MESSE (Niigata Convention Center), Japan, September 13 2016
- S. Ishizawa, K. Morimoto, D. Kaji, F. Tokanai "Development of time-of-flight detector for studying on superheavy nuclei II", The 64th JSAP Spring Meeting(2017), PACIFICO Yokohama, Japan, March 15 2017

[その他]

- 森本幸司 「日本初、新元素“ニホニウム”の発見」 IUPAC 賛助会員委員会 2016 年 11 月 2 日東京、明治大学紫紺館
- 森本幸司 「113 番新元素の生成と確認」真空シンポジウム(VACUUM2016)2016 年 9 月 9 日、神奈川、パシフィコ横浜
- 森本幸司 「日本初、原子番号 113 “ニホニウム”の発見と、新元素がもたらす未来の産業創造への展望」JST フェア 2016, 東京ビッグサイト、2016/8/26 基調講演
- 森本幸司 「113 番新元素の発見」アトムサイエンスフェア講演会 2016、京都、熊取交流センター、2016 年 10 月 22 日
- 森本幸司 「113 番新元素ニホニウムの発見」平成 28 年度 大学等における放射線安全管理研修会、東京大学 農学部 弥生講堂 一条ホール、2016 年 8 月 30 日
- 森本幸司 「ニホニウム発見物語」東北大学大学院理学研究科公開サイエンス講座東北大学川内キャンパス、仙台、2016 年 12 月 10 日

RIBF Research Division Nuclear Transmutation Data Research Group

1. Abstract

The disposal of high-level radioactive wastes from nuclear power plants is a problem considered to be one of the most important issues at both national and international levels. As a fundamental solution to the problem, the establishment of nuclear transmutation technology where long-lived nuclides can be changed to short-lived or stable ones will be vital. Progress in R & D in the transmutation of long-lived fission products (LLFP) in the nuclear wastes however, has been slow. Our group aims to obtain reaction data of LLFP at RIBF and other facilities which may lead to a new discovery and invention for peaceful use of nuclear power and the welfare of humanity.

2. Major Research Subjects

The Group is formed by three research teams. The first two Teams, “Fast RI Data Team” and “Slow RI Data Team”, are in charge of proton- and deuteron-induced reaction data for LLFP in inverse kinematics at RIBF. The third Team “Muon Data Team” is to obtain muon capture data of LLFP at muon facilities. All the teams are focusing to obtain high-quality data which are essentially necessary to establish reliable reaction models. Each team has its own subjects and promotes LLFP reaction programs based on their large experiences, techniques and skills.

3. Summary of Research Activity

In 2014, all the teams polished up experimental strategies, formed collaboration and prepared experiments. Physics runs for spallation reaction and Coulomb breakup reaction with the beams at 100-200 MeV/u were successfully organized by using the ZeroDegree and SAMURAI spectrometers at RIBF in 2015-2016. In 2017, a physics run with an energy-decelerated radioactive beam will be conducted under collaboration with CNS, Univ. of Tokyo. The muon program started at J-PARC and RCNP (Osaka University) in spring 2016. A neutron detection array was newly developed to measure evaporation neutrons after muon capture process, and was utilized at an experiment at RCNP in February 2017. In 2017 and 2018, experiments will be organized at both RAL and RCNP to have complete sets of the muon data for a specific LLFP nuclide.

Members

Group Director

Hiroyoshi SAKURAI (concurrent: Chief Scientist, RI Physics Lab.)

Assitant

Izumi YOSHIDA (Apr. 1, 2015 –)
Asako TAKAHASHI (Apr. 1, 2015 –)

RIBF Research Division

Nuclear Transmutation Data Research Group

Fast RI Data Team

1. Abstract

Fast RI team aims at obtaining and accumulating the cross section data for long lived fission products (LLFPs) in order to explore the possibility of using accelerator for nuclear transmutation.

LLFPs as nuclear waste have been generated continuously in nuclear power plants for wealth for human lives, while people noticed the way of disposal has not necessarily been established, especially after the Fukushima Daiichi power plant disaster. One of the ways to reduce the amount of LLFP or to recover them as recycled resources is nuclear transmutation technique.

RIBF facility has a property to generate such LLFP as a secondary beam and the beam species are identified by event by event. Utilizing the property, absolute values of the cross section of various reactions on LLFPs are measured and accumulated as database.

2. Major Research Subjects

- 1) Measurement of reaction products by the interaction of LLFPs with proton, deuteron, and photon to explore candidate reactions for transmutation of LLFPs.
- 2) Evaluation of the cross section data for the neutron induced reactions from the obtained data.

3. Summary of Research Activity

- 1) Acting as collaboration hub on many groups which plan to take data using fast RI beam in RIBF facility.
- 2) Concentrating on take data for proton and deuteron induced spallation reactions with inverse kinematics.
- 3) Accumulating the cross section data and evaluating them as evaluated nuclear data.
- 4) Evaluating cross section of neutron induced reaction on LLFP by collaborating with the nuclear model calculation and evaluation group.

Members

Team Leader

Hideaki OTSU (Concurrent: Team Leader, SAMURAI Team)

Technical Staff I

Nobuyuki CHIGA

Student Trainees

Shouhei ARAKI (Kyushu Univ.)
 Tatsuya YAMAMOTO (Miyazaki Univ.)
 Keita NAKANO (Kyushu Univ.)
 Ayaka IKEDA (Niigata Univ.)
 Kazuya CHIKAATO (Niigata Univ.)
 Hiroki TAKAHASHI (Niigata Univ.)
 Yoshiki SUDO (Miyazaki Univ.)

Kenji NISHIZUKA (Niigata Univ.)
 Junki SUWA (Kyushu Univ.)
 Masamichi AMANO (Rikkyo Univ.)
 Junki AMANO (Rikkyo Univ.)
 Akira HOMMA (Niigata Univ.)
 Naoto KANDA (Niigata Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers)

H. Wang, H. Otsu, H. Sakurai, D. Ahn, M. Aikawa, T. Ando, S. Araki, S. Chen, N. Chiga, P. Doornenbal, N. Fukuda, T. Isobe, S. Kawakami, S. Kawase, T. Kin, Y. Kondo, S. Koyama, S. Kubono, Y. Maeda, A. Makinaga, M. Matsushita, T. Matsuzaki, S. Michimasa, S. Momiyama, S. Nagamine, T. Nakamura, K. Nakano, M. Niikura, T. Ozaki, A. Saito, T. Saito, Y. Shiga, M. Shikata, Y. Shimizu, S. Shimoura, T. Sumikama, P.A. Söderström, H. Suzuki, H. Takeda, S. Takeuchi, R. Taniuchi, Y. Togano, J. Tsubota, M. Uesaka, Y. Watanabe, Y. Watanabe, K. Wimmer, T. Yamamoto, K. Yoshida, "Spallation reaction study for the long-lived fission product ^{107}Pd ", *Prog Theor Exp Phys* (2017) 2017 (2): 021D01.

H. Wang, H. Otsu, H. Sakurai, D.S. Ahn, M. Aikawa, P. Doornenbal, N. Fukuda, T. Isobe, S. Kawakami, S. Koyama, T. Kubo, S. Kubono, G. Lorusso, Y. Maeda, A. Makinaga, S. Momiyama, K. Nakano, M. Niikura, Y. Shiga, P.-A. Söderström, H. Suzuki, H. Takeda, S. Takeuchi, R. Taniuchi, Ya. Watanabe, Yu. Watanabe, H. Yamasaki, K. Yoshida, "Spallation reaction study for fission products in nuclear waste: Cross section measurements for ^{137}Cs and ^{90}Sr on proton and deuteron", *Phys. Lett. B* 754 (2016), 104-108.

(Proceedings)

H. Wang, H. Otsu, H. Sakurai et al., Spallation reaction study for fission products in nuclear waste: Cross section measurements for ^{137}Cs , ^{90}Sr and ^{107}Pd on proton and deuteron, accepted, the Proceeding of ND2016, October, 2016

H. Wang, H. Otsu, H. Sakurai et al., Spallation reaction study for the long-lived fission products in nuclear waste: Cross section measurements for ^{137}Cs , ^{90}Sr and ^{107}Pd using inverse kinematics method, accepted, the Proceeding of INES-5, January 2017

S. Kawase et al., "Cross section measurement of residues produced in proton- and deuteron-induced spallation reactions on ^{93}Zr at 100MeV/u using the inverse kinematics method", Proceedings of ND2016 International Conference on NUCLEAR DATA FOR SCIENCE

AND TECHNOLOGY

K. Nakano et al., "Cross sections for nuclide production in proton- and deuteron-induced reactions on niobium-93 measured using the inverse kinematics method", Proceedings of ND2016 International Conference on NUCLEAR DATA FOR SCIENCE AND TECHNOLOGY

Oral Presentations

[International Conference]

- H. Wang, Spallation reaction study for fission products in nuclear waste: Cross section measurements for ^{137}Cs , ^{90}Sr and ^{107}Pd on proton and deuteron at different reaction energy, International conference on nuclear data and technology (ND2016), September 11-16, 2016, Brugge, Belgium
- H. Wang, Measurement of Spallation Cross Sections for ^{137}Cs , ^{90}Sr and ^{107}Pd on Proton and Deuteron Using the Inverse Kinematic Method, Asian Nuclear Prospects 2016 (ANUP2016), October 24-27, 2016, Sendai, Japan
- H. Wang, Spallation Reaction Study for the Long-Lived Fission Products in Nuclear Waste: Cross Section Measurement for ^{137}Cs , ^{90}Sr and ^{107}Pd Using the Inverse Kinematic Method, The Fifth International Symposium on Innovative Nuclear Energy Systems (INES-5), October 31-November 2, 2016, Tokyo Institute of Technology, Tokyo, Japan
- S. Takeuchi, "Status report of ImpACT experiments", SAMURAI International Collaboration Workshop 2016, Kyushu
- S. Kawase et al., "Cross section measurement of residues produced in proton- and deuteron-induced spallation reactions on ^{93}Zr at 100MeV/u using the inverse kinematics method", ND2016: International Conference on Nuclear Data for Science and Technology, Bruges, Belgium, Sep. 2016
- S. Kawase et al., "Measurement of Isotopic Production Cross Sections through Proton- and Deuteron-Induced Spallation Reactions on ^{93}Zr and ^{93}Nb using the Inverse Kinematics Method", The Fifth International Symposium on Innovative Nuclear Energy Systems (INES5), Tokyo, Japan, Nov. 2016

[Domestic Conference]

- H. Wang, Reaction study for fission products in nuclear waste: Cross section measurements for the spallation of ^{137}Cs , ^{90}Sr and ^{107}Pd on proton and deuteron, JPS meeting 2016 autumn, September 21-24, 2016, Miyazaki, Japan
- 平山晃大, ^{79}Se , ^{80}Se のクーロン分解反応, 2017年3月 日本物理学会年次大会, 大阪
- 武内聡, クーロン分解反応による $^{107,108}\text{Pd}$ および $^{93,94}\text{Zr}$ の光吸収断面積, 2016年3月 日本物理学会年次大会, 仙台
- 尾崎友志, ^{238}U の飛行核分裂によって生成される ^{107}Pd , ^{79}Se のアイソマー比 2016年3月 日本物理学会年次大会, 仙台
- 川瀬頌一郎, 他 11名, "陽子・重陽子に対する 100 MeV/u ^{93}Zr 入射核破砕反応による同位体生成断面積の測定", 日本物理学会 2015年秋季大会, 大阪市, 2015年9月
- 中野敬太, 他 9名, ImpACT-RIBF Collaboration, "水素・重水素に対する 100 MeV/u ^{93}Zr 及び ^{93}Nb 入射核破砕反応の残留核生成断面積測定", 日本原子力学会九州支部第 34 回研究発表講演会, O-02, 福岡市, 2015年12月
- 川瀬頌一郎, 他 9名, ImpACT-RIBF Collaboration, "逆運動学的手法を用いた陽子・重陽子による核破砕反応の残留核生成断面積測定 (2) 100 MeV/u ^{93}Zr 入射反応", 日本原子力学会 2016年春の年会, 2J12, 仙台市, 2016年3月
- 中野敬太, 他 9名, ImpACT-RIBF Collaboration, "逆運動学的手法を用いた陽子・重陽子による核破砕反応の残留核生成断面積測定 (3) 100 MeV/u ^{93}Nb 入射反応", 日本原子力学会 2016年春の年会, 2J13, 仙台市, 2016年3月
- 中野敬太, 他 9名, ImpACT-RIBF Collaboration, " ^{93}Zr 及び ^{93}Nb に対する陽子・重陽子入射核破砕反応の同位体生成に関する研究", 日本原子力学会九州支部第 35 回研究発表講演会, O-05, 春日市, 2016年12月
- 諏訪純貴, 他 3名, ImpACT-RIBF Collaboration, "陽子・重陽子に対する 91Y 核破砕反応の同位体生成断面積測定" 日本原子力学会 2017年春の年会, 平塚市, 2017年3月
- 千賀信幸, 相関陽子検出器の開発, 平成 27 年度高エネルギー加速器研究機構技術研究会, KEK つくばキャンパス, 平成 28 年 3 月 17 日
- 渡辺幸信, 逆運動学的手法を用いた陽子・重陽子による核破砕反応の残留核生成断面積測定 (1) 実験目的と概要, 日本原子力学会春の大会, 東北大学, 2016年3月
- 川瀬頌一郎, 逆運動学的手法を用いた陽子・重陽子による核破砕反応の残留核生成断面積測定 (2) 100 MeV/u ^{93}Zr 射反応, 日本原子力学会春の大会, 東北大学, 2016年3月
- 中野敬太, 逆運動学的手法を用いた陽子・重陽子による核破砕反応の残留核生成断面積測定 (3) 100 MeV/u ^{93}Nb 入射反応, 日本原子力学会春の大会, 東北大学, 2016年3月
- 武内聡, クーロン分解反応による $^{107,108}\text{Pd}$ および $^{93,94}\text{Zr}$ の光吸収断面積, 日本物理学会年次大会, 東北学院大学, 2016年3月
- 尾崎友志, ^{238}U の飛行核分裂によって生成される ^{107}Pd , ^{79}Se のアイソマー比, 日本物理学会年次大会, 東北学院大学, 2016年3月

Posters Presentations

[Domestic Conference]

- 平山晃大 不安定核の分解反応のための荷電フラグメント用ホドスコープの開発 2016年3月 日本物理学会年次大会, 仙台
- 中野敬太, 逆運動学的手法を用いた陽子・重陽子による核破砕反応の残留核生成断面積測定, 日本原子力学会春の大会, 東北大学, 2016年3月
- 尾崎友志, ^{238}U の飛行核分裂によって生成される ^{107}Pd , ^{79}Se のアイソマー比, 2016年8月 第62回原子核三者若手夏の学校
- 平山晃大, 不安定核分解反応のための荷電フラグメント粒子識別用ホドスコープの開発, 2016年8月 第62回原子核三者若手夏の学校

修士論文

- 四方瑞紀 $^{93,94}\text{Zr}$ のクーロン分解反応による光吸収断面積の測定, 東京工業大学
- 中野敬太, "Cross section measurement of isotope production in proton- and deuteron-induced reactions on ^{93}Nb using the inverse kinematics method" 九州大学大学院総合理工学府先端エネルギー理工学専攻

卒業論文

- 平山晃大 学士論文: 荷電フラグメントの粒子識別用ホドスコープの開発, 東京工業大学
- 諏訪純貴, "陽子・重陽子に対する ^{93}Zr 入射核破砕反応による核種生成実験データの予備解析" 九州大学工学部エネルギー科学科 卒業論文, 2016年2月

RIBF Research Division

Nuclear Transmutation Data Research Group

Slow RI Data Team

1. Abstract

This team is in charge of the development of low-energy RI beams of long-lived fission fragments (LLFP) from the ^{238}U by means of degrading the energy of beams produced by the BigRIPS fragment separator.

2. Major Research Subjects

Studies of the slowing down and purification of RI beams are the main subjects of the team. Developments of devices used for the slowing down of RI beams are also an important subject.

3. Summary of Research Activity

- 1) Study and development of the slowed-down methods for LLFP.
- 2) Development of the devices used for the slowing down.
- 3) Operation of the BigRIPS separator and supply the low energy LLFP beam to the experiment in which the cross sections of LLFP are measured at the low energy.

Members

Team Leader

Koichi YOSHIDA (– Aug. 31, 2016, concurrent: BigRIPS Team)

Toshiyuki SUMIKAMA (Sep. 1, 2016 –)

List of Publications & Presentations

Publications

[Proceedings]

(Original Papers)

T. Sumikama, D.S. Ahn, N. Fukuda, N. Inabe, T. Kubo, Y. Shimizu, H. Suzuki, H. Takeda, N. Aoi, D. Beaumel, K. Hasegawa, E. Ideguchi, N. Imai, T. Kobayashi, M. Matsushita, S. Michimasa, H. Otsu, S. Shimoura, T. Teranishi, "First test experiment to produce the slowed-down RI beam with the momentum-compression mode at RIBF", Nuclear Instruments and Methods in Physics Research B 367, 180-184, (2016).

Oral Presentations

[International Conference etc.]

T. Sumikama, "Slowed-down RI beam produced from fast projectile fragment at RIBF", Fragment separator expert meeting, Grand Rapids, Michigan, USA, August 30 – September 1, 2016.

T. Sumikama, "Spectroscopy of neutron-rich isotope around ^{108}Zr ", EURICA collaboration meeting, RIKEN, Wako, Saitama, Japan, September 6-7, 2016.

T. Sumikama et al., "Shape evolution of neutron-rich nuclei in the vicinity of ^{110}Zr ", the 26th International Nuclear Physics Conference (INPC 2016), Adelaide, Australia, September 11-16, 2016.

[Domestic Conference]

炭竈聡之 他, "中性子過剰 Mo 同位体の崩壊核分光", 日本物理学会第 72 回年次大会, 大阪大学, 大阪, 2017 年 3 月 17 日-20 日。

RIBF Research Division

Nuclear Transmutation Data Research Group

Muon Data Team

1. Abstract

Dr. Yoshio Nishina observed muons in the cosmic rays in 1937. The muon is an elementary particle belonging to the lepton group. The muon has positive or negative electric charge, and the lifetime is 2.2 μsec . The negative muon is 207 times heavier than the electron, and behaves as a “heavy electron” in materials. The negative muon is caught by a nucleus (atomic number: Z) in materials to form a muonic atom, and is then captured by the nucleus. The muon is combined with a proton in the nucleus to convert to a neutron and a neutrino. The muon rest-mass energy is transferred to the nucleus with $Z-1$ to create the excited nuclear states. Emissions of neutrons and γ -rays are followed to produce several isotopic nuclei with $Z-1$. From a viewpoint of the nuclear physics, the nuclear reaction is very unique and interesting. High energy is suddenly introduced in the nuclei associated with the conversion process of proton to the neutron and the neutrino. Many experiments have been so far reported, but the reaction mechanism is not yet well clarified. The research team aims at obtaining the experimental data to understand the reaction mechanism of muon nuclear capture as well as at establishing the nuclear reaction theory.

2. Major Research Subjects

- (1) Experimental clarification on the reaction mechanism of nuclear muon capture
- (2) Establishment of the reaction theory on nuclear muon capture
- (3) Interdisciplinary application of the nuclear muon capture reaction

3. Summary of Research Activity

There are two experimental methods to study the reaction mechanism of muon nuclear capture. The first one is “muon in-beam method”. The neutron and γ -ray emissions from the excited states of nucleus with $Z-1$ are prompt events, and are observed by the “muon in-beam method” employing DC muon beam. The DC muon beam in Japan is obtained at the MuSIC (Muon Science Innovative Channel) muon facility constructed at Research Center for Nuclear Physics (RCNP) at Osaka University. The second one is “muon activation method” employing the pulsed muon beam. The unstable nuclei with $Z-1$ produced in the muon nuclear capture reaction make $\beta^{+/-}$ decay to stable nuclei. The γ -rays associated with the $\beta^{+/-}$ decay from the unstable nuclei are observed, and the γ -ray build-up (at beam-on) and decay (at beam-off) curves are measured. Since the half-lives and the absolute decay branches of $\beta^{+/-}$ - γ decays are known, the production ratio of the isotopic $Z-1$ nuclei is extracted from the curves. The pulsed muon beam is obtained at the RIKEN-RAL Muon Facility in the UK and J-PARC MLF MUSE muon facility in Japan.

3.1 Test experiment at the MuSIC in early 2016

We made a test experiment of γ -ray observation associated with the muon nuclear capture reaction on isotope enriched Pd targets ($^{104,105,106,108,110}\text{Pd}$) at the MuSIC muon facility in the Osaka University. The DC muon beam is appropriate to observe the prompt neutron and γ -ray emissions. The primary proton beam intensity was 20 nA, and the capture solenoid magnets of the MuSIC were not fully energized because of the quench problem. The stopping muon number at Pd targets was 8 $\mu\text{/second}$. Under such a severe experimental condition, we successfully observed the prompt γ -rays from $^A\text{Pd}(\mu^-, \nu)^{A-x}\text{Rh}$ reactions and the muonic K, L, M and N X-rays from muonic Pd atoms.

3.2 Experiment at the MuSIC in late 2016

At the MuSIC muon facility, the radiation shield structure was improved around the production target, and the primary proton beam intensity to the MuSIC was raised up to 1 μA from 20 nA. The muon intensity is expected to be increased by 50 times, and the experimental data with good quality is obtained. In addition, we have installed a radiation shield wall at the end of the MuSIC beam line to reduce the background to the detection system. The wall consists of 30cm thick concrete block with 5 mm thick lead plate at the downstream side.

We performed the experiment concentrated to $^{108}\text{Pd}(\mu^-, \nu)^{108-x}\text{Rh}$ reactions. Employing a newly built neutron spectrometer, the prompt neutron and γ -ray were measured to obtain the reaction branching ratios of $^{108}\text{Pd}(\mu^-, \nu)^{108-x}\text{Rh}$ reactions.

For the neutron and γ -ray measurement, we have constructed a neutron spectrometer named “Seamine”: Scintillator Enclosure Array for Muon Induced Neutron Emission. The spectrometer consists of 21 liquid scintillation counters, 2 Ge γ -ray detectors, 7 BaF₂ counters. The Pd target assembly including the muon beam counters and degraders is located at the center of the spectrometer. The neutron counter is a BC-501A liquid scintillation counter with 20cm diameter and 5cm depth, and is connected to a 5” photo multiplication tube (H4144-01). The total neutron detection efficiency is estimated 5%, where the distance is 4 cm between the neutron counter and the target. The Ge γ -ray detectors are placed at 10 cm from the target, and the typical detection efficiency is 0.5% for 200 keV γ -ray. The BaF₂ counters are located beneath the target to obtain fast γ -ray signals associated with muon nuclear capture reaction, which give the time spectrum of γ -rays emitted from the compound nucleus.

Signals from the liquid scintillation counters for neutron detection are processed in a CAEN V1730B waveform digitizer (16channel, 14bit, 500M samplings/sec.). The neutron- γ discrimination is performed on-line during the experiment, and the detailed analysis is conducted off-line after the experiment. The neutron energy spectrum is also constructed simultaneously. Signals from Ge γ -ray detectors are also processed in the CAEN V1730B waveform digitizer to obtain the energy and the time spectrum of γ -rays associated with muon

nuclear capture reaction. Signals from the BaF₂ counters and muon beam counters are sent to the CAEN V1730B waveform digitizer to make fast timing signals. The accumulated data is about 6.6 TB in the experiment, and the detailed off-line analysis is now in progress.

3.3 Test experiment at J-PARC MLF MUSE

We made a test experiment for a few hours at D2 beam line in the J-APRC MLF MUSE muon facility. The ¹⁰⁸Pd target was placed at the center of the vacuum chamber designed for muonic X-ray observation experiment. In spite of the long distance between the target and Ge γ -ray detectors, we successfully observed some γ -rays originated from the β^- decays of unstable Rh nuclei produced by ¹⁰⁸Pd (μ^- , $xn \nu$) ¹⁰⁸Rh reactions. The γ -ray yield build-up curve at beam-on and the decay curve at beam-off were obtained by the off-line data analysis. The experimental technique for the muon activation method was established by the test experiment.

The experiments employing the muon activation method are scheduled in late 2017 at the RIKEN-RAL Muon Facility and J-PARC MLF MUSE muon facility.

3.4 Comparison with theory

The muon activation method gives the reaction branching ratios. The muon in-beam method gives the neutron multiplicity distribution (reaction branching ratio) and the neutron energy spectrum. We will compare the experimental results with theoretical calculations of the statistical compound nuclear model for the first step.

Members

Team Leader
Teiichiro MATSUZAKI

List of Publications & Presentations

Publications

[解説、和文]

松崎禎市郎 “原子力分野への負ミュオンの応用；負ミュオンによる核変換・核融合・核分裂”、日本原子力学会誌 Vol. 58 No.10 (2016) P.612

Oral Presentations

[International Conference etc.]

松崎禎市郎、“Nuclear Transmutation by Muon Nuclear Capture Reaction” Muonic X and Gamma ray Spectroscopy (MXG16)、茨木市、2016年9月27日

斎藤岳志、松崎禎市郎、櫻井博儀、新倉潤、他、“Muon Nuclear Capture Reaction on Pd Isotopes” Muonic X and Gamma ray Spectroscopy (MXG16)、茨木市、2016年9月27日

[Domestic Conference]

松崎禎市郎、“負ミュオンによる原子核変換”、負ミュオン研究会、東海村、2016年7月11日

松崎禎市郎、“原子力分野へのミュオン応用：原子核変換と触媒核融合”、日本原子力学会 2016年春の年会、仙台市、2016年3月28日

斎藤岳志、“松崎禎市郎、櫻井博儀、新倉潤、他、RCNP MuSIC における安定 Pd 同位体の μ^- 捕獲現象の研究”、日本物理学会第72回年次大会 (2017年)、2017年3月17日

特許出願

特許の名称：「ミュオン照射による放射性物質の製造方法およびその製造物質」

発明者：松崎禎市郎、櫻井博儀

出願人：理化学研究所

出願番号：JP2017/003226

出願年月日：2017年1月30日

出願国：国際出願

共同出願人：なし

RIBF Research Division High-Intensity Accelerator R&D Group

1. Abstract

The R&D group, consisting of two teams, develops elemental technology of high-power accelerators and high-power targets, aiming at future applications to nuclear transmutations of long-lived fission product into short-lived nuclides. The research subjects are superconducting rf cavities for low-velocity ions, design of high-power accelerators, high-power target systems and related technologies.

2. Major Research Subjects

(1) R&D of elemental technology of high-power accelerators and high-power targets

3. Summary of Research Activity

(1) Based on the discussion with other research groups, R&D study of various accelerator components and elements is under progress.

Members

Group Director

Osamu KAMIGAITO (concurrent: Chief Scientist, Group Director,
Accelerator Gr.)

List of Publications & Presentations

Oral Presentations

[Domestic Conference]

上垣外修一、他、加速器システムの要素技術開発、日本物理学会秋季大会、宮崎大学、木花キャンパス、2016年9月22日

RIBF Research Division High-Intensity Accelerator R&D Group High-Gradient Cavity R&D Team

Abstract

We develop new components for accelerators dedicated for low-beta-ions with very high intensity. Specifically, we are designing and constructing a cryomodule for superconducting linac efficient for acceleration of low-beta-ions. In parallel, we try to optimize an rf acceleration system by making computer simulations for acceleration of very high intensity beams.

Major Research Subjects

- Development of high-gradient cavities for low beta ions
- Development of power saving cryomodules

Summary of Research Activity

Development of highly efficient superconducting accelerator modules

Members

Team Leader

Naruhiko SAKAMOTO (concurrent: Cyclotron Team)

Research & Technical Scientists

Kazunari YAMADA (concurrent: Senior Technical Scientist, Beam Dynamics & Diagnostics Team)

Kazutaka OZEKI (concurrent: Technical Scientist, Cyclotron Team)

Yutaka WATANABE (concurrent: Senior Technical Scientist, RILAC team)

Nishina Center Research Scientist

Kenji SUDA (concurrent: Cyclotron Team)

Postdoctoral Researchers

Xingguang LIU

List of Publications & Presentations

Oral Presentations

[International Conference etc.]

Naruhiko Sakamoto, et al., Reduction and Resource Recycling of High-level Radioactive Wastes through Nuclear Transmutation-Development of Superconducting Quarter-Wave Resonators and their Cryomodules for Accelerator of Intense Low- β Ion-Beams, The 5th International Conference on Asian Nuclear Prospects (ANUP2016), Sendai, Japan, October 26 2016.

Kazutaka Ozeki, et al., Design and fabrication status of RIKEN SC-Linac cryomodule, 2017 TESLA Technology Collaboration meeting, East Lansing, USA, February 21 2017

Kazutaka Ozeki et al., Cavity fabrication, processing and VT result of RIKEN QWR, 2017 TESLA Technology Collaboration meeting, East Lansing, USA, February 22 2017

Posters Presentations

[International Conference etc.]

Kazutaka Ozeki, et al., Cryomodule and power coupler for RIKEN Superconducting QWR, 28th Linear Accelerator Conference, East Lansing, USA, September 27 2016

Kazunari Yamada et al., First Vertical Test of Superconducting QWR Prototype at RIKEN, 28th Linear Accelerator Conference, East Lansing, USA, September 29 2016

RIBF Research Division
High-Intensity Accelerator R&D Group
High-Power Target R&D Team

1. Abstract

The subjects of this team cover R&D studies with respect to target technology for the transmutation of the LLFPs.

2. Major Research Subjects

- (1) Liquid lithium target for production of neutron or muon
- (2) Beam window without solid structure

3. Summary of Research Activity

- (1) Liquid lithium target for production of neutron or muon
(H. Okuno, N. Ikoma)
- (2) Beam window with solid structure
(H. Imao, N. Ikoma)

Members

Team Leader

Hiroki OKUNO (concurrent: Deputy Group Director, Accelerator Gr.)

Research and Technical Scientist

Kanenobu TANAKA (concurrent: Deputy Group Director, Safety Management Group)
Hiroshi IMAO (concurrent: Senior Research Scientist, Accelerator R&D Team)
Takashi NAGATOMO (concurrent: Technical Scientist, Ion Source Team)

Part-time Worker

Naoya IKOMA

RIBF Research Division Accelerator Group

1. Abstract

The accelerator group, consisting of seven teams, pursues various upgrade programs of the world-leading heavy-ion accelerator facility, RI-Beam Factory (RIBF), to enhance the accelerator performance and operation efficiency. The programs include the R&D of superconducting ECR ion source, charge stripping systems, beam diagnostic devices, radiofrequency systems, control systems, and beam simulation studies. We are also maintaining the large infrastructure to realize effective operation of the RIBF, and are actively promoting the applications of the facility to a variety of research fields.

Our primary mission is to supply intense, stable heavy-ion beams for the users through effective operation, maintenance, and upgrade of the RIBF accelerators and related infrastructure. The director members shown below govern the development programs that are not dealt with by a single group, such as intensity upgrade and effective operation. We also promote the future plans of the RIBF accelerators along with other laboratories belonging to the RIBF research division.

2. Major Research Subjects

- (1) Intensity upgrade of RIBF accelerators (Okuno)
- (2) Effective and stable operation of RIBF accelerators (Fukunishi)
- (3) Operation and maintenance of infrastructures for RIBF (Kase)
- (4) Promotion of the future plan (Kamigaito, Fukunishi, Okuno)

3. Summary of Activity

- (1) The maximum intensity of the calcium beam reached 738 pnA at 345 MeV/u, which corresponds to 12.2 kW.
- (2) The maximum intensity of the xenon beams reached 102 pnA at 345 MeV/u.
- (3) The overall beam availability for the RIBF experiments has been kept above 90 % since 2014.
- (4) The large infrastructure was properly maintained based on a well-organized cooperation among the related sections.
- (5) An intensity-upgrade plan of the RIBF has been further investigated in cooperation with the experimental groups.

Members

Group Director

Osamu KAMIGAITO

Deputy Group Directors

Hiroki OKUNO (Intensity upgrade)
Nobuhisa FUKUNISHI (Stable and efficient operation)
Masayuki KASE (Energy-efficiency management)

Research Consultant

Tadashi FUJINAWA

Visiting Researchers

Akira GOTO (Yamagata Univ.)
Toshiyuki HATTORI (TIT)
Kensei UMEMORI (KEK)

Hirohisa NAKAI (KEK)
Eiji KAKO (KEK)

Assistant

Karen SAKUMA

RIBF Research Division Accelerator Group Accelerator R&D Team

1. Abstract

We are developing the key hardware in upgrading the RIBF accelerator complex. Our primary focus and research is charge stripper which plays an essential role in the RIBF accelerator complex. Charge strippers remove many electrons in ions and realize efficient acceleration of heavy ions by greatly enhancing charge state. The intensity of uranium beams is limited by the lifetime of the carbon foil stripper conventionally installed in the acceleration chain. The improvement of stripper lifetimes is essential to increase beam power towards the final goal of RIBF in the future. We are developing the low-Z gas stripper. In general gas stripper is free from the lifetime related problems but gives low equilibrium charge state because of the lack of density effect. Low-Z gas stripper, however, can give as high equilibrium charge state as that in carbon foil because of the suppression of the electron capture process. Another our focus is the upgrade of the world's first superconducting ring cyclotron.

2. Major Research Subjects

- (1) Development of charge strippers for high power beams (foil, low-Z gas)
- (2) Upgrade of the superconducting ring cyclotron
- (3) Maintenance and R&D of the electrostatic deflection/inflexion channels for the beam extraction/injection

3. Summary of Research Activity

(1) Development of charge strippers for high power beams (foil, low-Z gas)

(Hasebe, H., Imao, H. Okuno., H.)

We are developing the charge strippers for high intensity heavy ion beams. We are focusing on the developments on carbon or beryllium foils and gas strippers including He gas stripper.

(2) Upgrade of the superconducting ring cyclotron

(Ohnishi, J., Okuno, H.)

We are focusing on the upgrade of the superconducting ring cyclotron.

(3) Maintenance and R&D of the electrostatic deflection/inflexion channels for the beam extraction/injection

(Ohnishi, J., Okuno, H.)

We are developing high-performance electrostatic channels for high power beam injection and extraction.

Members

Team Leader

Hiroki OKUNO (concurrent: Deputy Group Director, Accelerator Gr.)

Research & Technical Scientists

Hiroshi IMAO (Senior Research Scientist)

Jun-ichi OHNISHI (Senior Technical Scientist)

Nishina Center Technical Scientist

Hiroo HASEBE

Visiting Scientists

Andreas ADELMANN (PSI)

Hironori KUBOKI (KEK)

Noriyosu HAYASHIZAKI (TIT.)

Junior Research Associate

Naoya IKOMA (Nagaoka Univ. of Technology)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

H. Hasebe, H. Okuno, H. Kuboki, H. Imao, N. Fukunishi, M. Kase, O. Kamigaito, "Development of rotating beryllium disk stripper", Journal of Radioanalytical and Nuclear Chemistry, 305, 825 (2015).

[Proceedings]

(Original Papers) *Subject to Peer Review

H. Hasebe, H. Okuno, H. Kuboki, H. Imao, N. Fukunishi, M. Kase, O. Kamigaito, "History of Solid Disk Improvement for Rotating Charge Stripper", Proceeding of HIAT2015, Yokohama, Japan (2015) MOA1C01.

Oral Presentations

[International Conference etc.]

H. Hasebe, H. Okuno, H. Kuboki, H. Imao, N. Fukunishi, M. Kase, O. Kamigaito, "History of Solid Disk Improvement for Rotating Charge Stripper", HIAT2015, Yokohama, Japan (2015) MOA1C01.

Posters Presentations

[International Conference etc.]

H. Imao, H. Kuboki, H. Hasebe, O. Kamigaito, M. Kase, H. Okuno, "Operation of Gas Strippers at RIBF ; Thining Effect of High-Intensity Very Heavy Ion Beams" , HIAT2015, Yokohama, Japan (2015) MOPA32.

RIBF Research Division

Accelerator Group

Ion Source Team

1. Abstract

Our aim is to operate and develop the ECR ion sources for the accelerator-complex system of the RI Beam Factory. We focus on further upgrading the performance of the RI Beam Factory through the design and fabrication of a superconducting ECR ion source for production of high-intensity heavy ions.

2. Major Research Subjects

- (1) Operation and development of the ECR ion sources
- (2) Development of a superconducting ECR heavy-ion source for production of high-intensity heavy ion beams

3. Summary of Research Activity

(1) Operation and development of ECR ion sources

(T. Nakagawa, M. Kidera, Y. Higurashi, T. Nagatomo, and H. Haba)

We routinely produce and supply various kinds of heavy ions such as zinc and calcium ions for the super-heavy element search experiment as well as uranium ions for RIBF experiments. We also perform R&D's to meet the requirements for stable supply of high-intensity heavy ion beams.

(2) Development of a superconducting ECR ion source for use in production of a high-intensity heavy ion beam

(T. Nakagawa, J. Ohnishi, M. Kidera, Y. Higurashi, and T. Nagatomo)

The RIBF is required to supply heavy ion beams with very high intensity so as to produce RI's and for super-heavy element search experiment. We have designed and are fabricating an ECR ion source with high magnetic field and high microwave- frequency, since the existing ECR ion sources have their limits in beam intensity. The coils of this ion source are designed to be superconducting for the production of high magnetic field. We are also designing the low-energy beam transport line of the superconducting ECR ion source.

Members

Team Leader

Takahide NAKAGAWA

Research & Technical Scientist

Takashi NAGATOMO (Technical Scientist)

Nishina Center Research Scientists

Masanori KIDERA, Yoshihide HIGURASHI

Special Postdoctoral Researcher

Tatsuya URABE (Apr. 1, 2014 –)

List of Publications & Presentations

Publications

[Proceedings]

(Original Papers) *Subject to Peer Review

A.Uchiyama, K. Ozeki, Y. Higurashi, M. Kidera, M. Komiyama, and T. Nakagawa, 'Control system renewal for efficient operation in RIKEN 18 GHz electron cyclotron resonance ion source', Rev. Sci. Instrum. 87(2016)02A722*

J. Ohnishi, Y. Higurashi, T. Nakagawa, 'Progress in high-temperature oven development for 28 GHz electron cyclotron resonance ion source', Rev. Sci. Instrum. 87(2016)02A709*

Oral Presentations

[International Conference etc.]

T. Nakagawa, 'Optimization of Magnetic Field Distribution of RIKEN 28 GHz SC-ECRIS for Intense Beam Production', ECRIS2016, Aug.28–Sept 2, 2016, Busan, Korea

Y. Higurashi, 'Recent development of RIKEN 28GHz ECRIS', ECRIS2016, Aug.28–Sept 2, 2016, Busan, Korea

Posters Presentations

[International Conference etc.]

T. Nagatomo, 'Transverse Four-Dimension Phase-Space Distribution Measured by the Pepper-Pot Type Emittance Meter', ECRIS2016, Aug.28–Sept. 2, 2016, Busan, Korea

RIBF Research Division
Accelerator Group
RILAC Team

1. Abstract

The operation and maintenance of the RIKEN Heavy-ion Linac (RILAC) have been carried out. There are two operation modes: one is the stand-alone mode operation and the other is the injection mode operation. The RILAC has been used especially as an injector for the RIKEN RI-Beam Factory accelerator complex. The RILAC is composed of the ECR ion source, the frequency-variable RFQ linac, six frequency-variable main linac cavities, and six energy booster cavities (CSM).

2. Major Research Subjects

- (1) The long term high stability of the RILAC operation.
- (2) Improvement of high efficiency of the RILAC operation.

3. Summary of Research Activity

The RILAC was started to supply ion beams for experiments in 1981. Thousands hours are spent in a year for delivering many kinds of heavy-ion beams to various experiments.

The RILAC has two operation modes: one is the stand-alone mode operation delivering low-energy beams directly to experiments and the other is the injection mode operation injecting beams into the RRC. In the first mode, the RILAC supplies a very important beam to the nuclear physics experiment of “the research of super heavy elements”. In the second mode, the RILAC plays a very important role as upstream end of the RIBF accelerator complex.

The maintenance of these devices is extremely important in order to keep the long-term high stability and high efficiency of the RILAC beams. Therefore, improvements are always carried out for the purpose of more stable and more efficient operation.

Members

Team Leader

Eiji IKEZAWA

Research & Technical Scientist

Yutaka WATANABE (Senior Technical Scientist)

Research Consultants

Masatake HEMMI

Toshiya CHIBA

RIBF Research Division Accelerator Group Cyclotron Team

1. Abstract

Together with other teams of Nishina Center accelerator division, maintaining and improving the RIBF cyclotron complex. The accelerator provides high intensity heavy ions. Our mission is to have stable operation of cyclotrons for high power beam operation. Recently stabilization of the rf system is a key issue to provide 10 kW heavy ion beam.

2. Major Research Subjects

- (1) RF technology for Cyclotrons
- (2) Operation of RIBF cyclotron complex
- (3) Maintenance and improvement of RIBF cyclotrons
- (4) Single turn operation for polarized deuteron beams
- (5) Development of superconducting cavity

3. Summary of Research Activity

- Development of the rf system for a reliable operation
- Development of highly stabilized low level rf system
- Development of superconducting rebuncher cavity
- Development of the intermediate-energy polarized deuteron beams.

Members

Team Leader

Naruhiko SAKAMOTO

Research & Technical Scientist

Kazutaka OZEKI (Technical Scientist)

Nishina Center Research Scientist

Kenji SUDA

List of Publications & Presentations

Publications

[Proceedings]

- K. Yadomi, S. Fukuzawa, M. Hamanaka, S. Ishikawa, K. Kobayashi, R. Koyama, T. Nakamura, M. Nishida, M. Nishimura, J. Shibata, N. Tsukiori, K. Suda, T. Dantsuka, M. Fujimaki, T. Fujinawa, N. Fukunishi, H. Hasebe, Y. Higurashi, E. Ikezawa, H. Imao, M. Kase, O. Kamigaito, M. Kidera, M. Komiyama, K. Kumagai, T. Maie, M. Nagase, T. Nagatomo, T. Nakagawa, M. Nakamura, J. Ohnishi, H. Okuno, K. Ozeki, N. Sakamoto, A. Uchiyama, S. Watanabe, T. Watanabe, Y. Watanabe, K. Yamada, H. Yamasawa, "Status report of the operation of the RIBF ring cyclotrons", Proceedings of the 13th annual meeting of Particle Accelerator Society of Japan, Chiba (2016) p1339.
- S. Ishikawa, K. Kobayashi, R. Koyama, J. Shibata, N. Tsukiori, T. Nakamura, M. Nishida, M. Nishimura, M. Hamanaka, S. Fukuzawa, K. Yadomi, A. Uchiyama, K. Ozeki, J. Ohnishi, H. Okuno, M. Kase, O. Kamigaito, K. Kumagai, M. Komiyama, N. Sakamoto, K. Suda, T. Nakagawa, M. Nagase, T. Nagatomo, N. Fukunishi, M. Fujimaki, T. Maie, K. Yamada, T. Watanabe, Y. Watanabe, Y. Ohshiro, Y. Kotaka, S. Yamaka, "Status report on operation of RIKEN AVF cyclotron", Proceedings of the 13th annual meeting of Particle Accelerator Society of Japan, Chiba (2016) p1344.

Posters Presentations

[Domestic Conference]

- K. Yadomi, S. Fukuzawa, M. Hamanaka, S. Ishikawa, K. Kobayashi, R. Koyama, T. Nakamura, M. Nishida, M. Nishimura, J. Shibata, N. Tsukiori, K. Suda, T. Dantsuka, M. Fujimaki, T. Fujinawa, N. Fukunishi, H. Hasebe, Y. Higurashi, E. Ikezawa, H. Imao, M. Kase, O. Kamigaito, M. Kidera, M. Komiyama, K. Kumagai, T. Maie, M. Nagase, T. Nagatomo, T. Nakagawa, M. Nakamura, J. Ohnishi, H. Okuno, K. Ozeki, N. Sakamoto, A. Uchiyama, S. Watanabe, T. Watanabe, Y. Watanabe, K. Yamada, H. Yamasawa, "Status report of the operation of the RIBF ring cyclotrons", Proceedings of the 13th annual meeting of Particle Accelerator Society of Japan, Chiba (2016) FSP008.
- S. Ishikawa, K. Kobayashi, R. Koyama, J. Shibata, N. Tsukiori, T. Nakamura, M. Nishida, M. Nishimura, M. Hamanaka, S. Fukuzawa, K. Yadomi, A. Uchiyama, K. Ozeki, J. Ohnishi, H. Okuno, M. Kase, O. Kamigaito, K. Kumagai, M. Komiyama, N. Sakamoto, K. Suda, T. Nakagawa, M. Nagase, T. Nagatomo, N. Fukunishi, M. Fujimaki, T. Maie, K. Yamada, T. Watanabe, Y. Watanabe, Y. Ohshiro, Y. Kotaka, S. Yamaka, "Status report on operation of RIKEN AVF cyclotron", Proceedings of the 13th annual meeting of Particle Accelerator Society of Japan, Chiba (2016) FSP009.

RIBF Research Division

Accelerator Group

Beam Dynamics & Diagnostics Team

1. Abstract

The cascaded cyclotron system at RIKEN RI Beam Factory (RIBF) requires not only strict matching of operation parameters but also high stability of all the accelerator components in order to establish stable operation of the world's most intense heavy-ion beams. Beam Dynamics and Diagnostics Team is responsible for power supplies, beam instrumentation, computer control and beam dynamic of the RIBF accelerator complex and strongly contributes to the performance upgrade of the RIBF.

2. Major Research Subjects

- (1) Extracting the best performance of the RIBF accelerator complex based on the precise beam dynamics study.
- (2) Maintenance and developments of the beam instrumentation, especially non-destructive monitors.
- (3) Upgrade of the computer control system of the RIBF accelerator complex.
- (4) Maintenance and improvements of the magnets and power supplies.
- (5) Upgrade of the existing beam interlock system for higher intensity beams.

3. Summary of Research Activity

- (1) High-intensity heavy-ion beams including 55-pnA uranium, 102-pnA xenon, 486-pnA krypton, and 740-pnA calcium beams have been obtained.
- (2) The world-first high-Tc SQUID beam current monitor has been developed.
- (3) The bending power of the fixed-frequency Ring Cyclotron has been upgraded to 700 MeV. It enables us to accelerate $^{238}\text{U}^{64+}$ ions obtained by the helium gas stripper.
- (4) An EPICS-based control system and a homemade beam interlock system have been stably operated. Replacements of the existing legacy control system used in the old half of our facility is ongoing. Construction of the new control system for the new injector RILAC2 was successfully completed, where the embedded EPICS system running on F3RP61-2L CPU module, developed by KEK and RIKEN control group, was used.
- (5) We replaced some dated power supplies of RIKEN Ring Cyclotron by new ones, which have better long-term stability than the old ones. The other existing power supplies (~900) are stably operated owing to elaborate maintenance work.
- (6) We have contributed to RILAC2 construction, especially in its beam diagnosis, control system, magnet power supplies, vacuum system, high-energy beam transport system etc.

Members

Team Leader

Nobuhisa FUKUNISHI (concurrent; Deputy Group Director,
Accelerator Gr.)

Research & Technical Scientists

Masaki FUJIMAKI (Senior Technical Scientist)
Keiko KUMAGAI (Senior Technical Scientist)

Tamaki WATANABE (Senior Technical Scientist)
Kazunari YAMADA (Senior Technical Scientist)

Nishina Center Technical Scientists

Misaki KOMIYAMA

Akito UCHIYAMA

Special Postdoctoral Researcher

Part-time Workers

Makoto NAGASE

Visiting Scientists

Kenichi ISHIKAWA (Univ. of Tokyo)
Shin-ichiro HAYASHI (Hiroshima Int'l Univ.)

Hiromichi RYUTO (Kyoto Univ.)
Takuya MAEYAMA (Kitasato Univ.)

Visiting Technician

Jun-ichi ODAGIRI (KEK)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

Maeyama T., Fukunishi N., Ishikawa K.L., Furuta T., Fukasaku K., and Fukuda S., "Radiological properties of nanocomposite Fricke gel dosimeters for heavy ion beams", *Journal of Radiation Research* **57**, pp.318–324 (2016)*.

Uchiyama A., Ozeki K., Higurashi Y., Kidera M., Komiyama M., and Nakagawa T., "Control System Renewal for Efficient Operation in RIKEN 18 GHz Electron Cyclotron Resonance Ion Source", *Rev. Sci. Instrum.* **87**, 02A722 (2016)*.

Posters Presentations

[International Conference etc.]

Komiyama M., Fukunishi N., Uchiyama A., "Recent Improvements to the RI Beam Factory Control System", The 11th International Workshop on Personal Computers and Particle Accelerator Controls (PCaPAC2016), Campinas, Brazil, October 2016, WEPOPRPO11 (2016).

Uchiyama A., Komiyama M., Fujimaki M., Fukunishi N., "Integration of Standalone Control Systems into EPICS-based System at RIKEN RIBF", The 11th International Workshop on Personal Computers and Particle Accelerator Controls (PCaPAC2016), Campinas, Brazil, October 2016, WEPOPRPO12 (2016).

[Domestic Conference]

Watanabe T., Fukunishi N., Inamori S., Kon K., "Sensitivity Improvement and Miniaturization of HTc-SQUID Beam Current Monitor", 13th Annual Meeting of Particle Accelerator Society of Japan, August 2016, Chiba, Japan, pp. 1127-1133 (2016).

Uchiyama A., Komiyama M., "An Attempt to Implement the Alive Monitoring System for Reliable EPICS-based Control System", 13th Annual Meeting of Particle Accelerator Society of Japan, August 2016, Chiba, Japan, pp. 664-667 (2016).

Nishimura M., Uchiyama A., Ohshiro Y., "Upgrade of HyperECR Ion Source Control System for System Integration at RIBF", 13th Annual Meeting of Particle Accelerator Society of Japan, August 2016, Chiba, Japan, pp. 660-663 (2016).

RIBF Research Division
Accelerator Group
Cryogenic Technology Team

1. Abstract

We are operating the cryogenic system for the superconducting ring cyclotron in RIBF. We are operating the helium cryogenic system in the south area of RIKEN Wako campus and delivering the liquid helium to users in RIKEN. We are trying to collect efficiently gas helium after usage of liquid helium.

2. Major Research Subjects

- (1) Operation of the cryogenic system for the superconducting ring cyclotron in RIBF
- (2) Operation of the helium cryogenic plant in the south area of Wako campus and delivering the liquid helium to users in Wako campus.

3. Summary of Research Activity

- (1) Operation of the cryogenic system for the superconducting ring cyclotron in RIBF
(Okuno, H., Dantsuka, T., Nakamura, M., Maie, T.)
- (2) Operation of the helium cryogenic plant in the south area of Wako campus and delivering the liquid helium to users in Wako campus.
(Dantsuka, T., Tsuruma, S., Okuno, H.).

Members

Team Leader

Hiroki OKUNO (concurrent: Deputy Group Director, Accelerator Gr.)

Research & Technical Scientist

Masato NAKAMURA (Senior Technical Scientist)

Nishina Center Technical Scientist

Takeshi MAIE

Technical Staff I

Tomoyuki DANTSUKA

Part-time Worker

Shizuho TSURUMA

RIBF Research Division
Accelerator Group
Infrastructure Management Team

1. Abstract

The RIBF facility is consisting of many accelerators and its infrastructure is very important in order to make an efficient operation of RIBF project. We are maintaining the infrastructure of the whole system and to support the accelerator operation with high performance. We are also concerning the contracts of gas- and electricity-supply companies according to the annual operation plan. The contracts should be reasonable and also flexible against a possible change of operations. And we are searching the sources of inefficiency in the operation and trying to solve them for the high-stable machine operation.

2. Major Research Subjects

- (1) Operation and maintenance of infrastructure for RIBF accelerators.
- (2) Renewal of the old equipment for the efficient operation.
- (3) Support of accelerator operations.

Members

Team Leader

Masayuki KASE (concurrent; Deputy Group Director,
Accelerator Gr.)

Research & Technical Scientists

Shu WATANABE (Senior Technical Scientist)

Research Consultant

Hideyuki YAMASAWA

Visiting Scientist

Hideshi MUTO (Tokyo Univ. of Sci. Suwa)

RIBF Research Division Instrumentation Development Group

1. Abstract

This group develops core experimental installations at the RI Beam factory. They are a slow-RI beam facility (SLOWRI), and highly program specific facilities of SCRIT and Rare-RI Ring (R3). All were designed to maximize the research potential of the world's most intense RI beams, made possible by the exclusive equipment available at the RI Beam Factory. While SLOWRI is under preparation for commissioning, physics experiments conducted in storage rings have been just started at SCRIT and R3 facilities. Beam manipulation techniques, such as a beam accumulation and a beam cooling, will be able to provide opportunities of new experimental challenges and the foundation for future developments of RIBF.

2. Major Research Subjects

- (1) SCRIT Project
- (2) SLOWRI Project
- (3) Rear RI Ring Project

3. Summary of Research Activity

We are developing beam manipulation technology in carrying out above listed project. They are the high-quality slow RI beam production (SCRIT and SLOWRI), the beam cooling and stopping (SCRIT and SLOWRI), and the beam accumulation technology (SCRIT and R3). The technological knowhow accumulated in our projects will play a significant role in the next generation RIBF. Status and future plan for each project is described in subsections. SCRIT is now under test experimental phase in which the angular distribution of scattered electrons from ^{132}Xe isotopes has been successfully measured and the nuclear charge density distribution has been obtained. Electron scattering off unstable nuclei is now under preparation for the first experiment in 2017. Rare RI Ring was commissioned in three-times machine-study experiments, and we have demonstrated that the ring has an ability for precision mass measurement with the accuracy of the order of 10 ppm. We will be able to try to measure masses of nuclei $^{74-78}\text{Ni}$ in 2017-2018 and continuously make improvement in the accuracy. Construction of the SLOWRI system has been almost completed in 2014. PALIS device was commissioned in 2015 and 2016, and basic functions such as the RI-beam stopping in argon gas cell and the extraction with the gas flow were confirmed. Other devices are now under setting up for the first commissioning.

Members

Group Director

Masanori WAKASUGI

Visiting Scientist

Akira OZAWA (Univ. of Tsukuba)

Student Trainees

Mitsuki HORI (Rikkyo Univ.)

Nobuaki UCHIDA (Rikkyo Univ.)

Shin-nosuke SASAMURA (Rikkyo Univ.)

List of Publications & Presentations

Publications and presentations for each project team are listed in subsections.

RIBF Research Division Instrumentation Development Group SLOWRI Team

1. Abstract

SLOWRI is a universal low-energy RI-beam facility at RIBF that provides a wide variety of short-lived nuclei as high-purity and low-emittance ion beams or stored ions in a trap, including a parasitic operation mode. The SLOWRI team develops and manages the facility and performs high-precision spectroscopy experiments. The construction of the SLOWRI facility began in FY2013 and commissioning work has been ongoing. Two major online prototype setups have been successfully tested. The first was a large room-temperature gas cell with RF-carpet structure. With this setup, the hyperfine structure constants of all odd Be isotopes were precisely measured by laser-microwave double resonance spectroscopy of trapped Be ions, followed by the first online mass measurement with a multi-reflection time-of-flight mass spectrograph (MRTOF) performed on $^8\text{Li}^+$ ions. The second prototype is a medium-sized cryogenic RF-carpet gas cell for the SHE-Mass project that aims to measure masses of trans-uranium elements at the GARIS-II facility. This prototype showed that a traveling-wave RF-carpet works fine and the cryogenic gas cell dominantly provides doubly charged ions even for Fr isotopes.

2. Major Research Subjects

- (1) Construction of stopped and low-energy RI-beam facility, SLOWRI.
- (2) Laser spectroscopy of trapped radioactive beryllium isotopes.
- (3) Development of a multi-reflection time-of-flight mass spectrograph for precision mass measurements of short-lived nuclei.
- (4) Development of collinear laser spectroscopy apparatus.
- (5) Development of parasitic slow RI-beam production method using resonance laser ionization.

3. Summary of Research Activity

(1) Construction of stopped and low-energy RI-beam facility (SLOWRI)

Installation of SLOWRI began in FY2013. It consists of two gas catchers (RF Carpet gas cell and PALIS gas cell), magnetic mass separators, a 50-m beam transport line, a beam cooler-buncher, an isobar separator, and a laser system. The RF Carpet gas cell will be installed at the exit of the D5 dipole magnet of BigRIPS. This gas catcher comprises a large cryogenic He gas cell with a large traveling wave rf-carpet. It will convert main beams of BigRIPS to low-energy, low-emittance beams without any restrictions from the chemical properties of the elements. The PALIS gas cell will be installed in the vicinity of the second focal plane slit of BigRIPS. It will provide parasitic RI-beams from the ions normally lost in the slits during other experiments. In this gas catcher, thermalized RI quickly become neutralized and will be selectively re-ionized by resonant laser radiations. These gas catchers have been tested off-line. The 50 m beam transport line consists of four dipole magnets (SD1 to SD4), two focal plane chambers, 62 electrostatic quadrupole singlets, 11 electrostatic quadrupole quartets (EQQ1 to EQQ11) and 7 beam profile monitors (BPM). SD1 and SD2, located right after the gas catchers, will be used for isotope separation. After eliminating contaminant ions at the focal plane chamber, the low energy beam will be transported by a FODO lattice structure with phase space matching using EQQs. The EQQs have multipole elements made of 16 rods on which various potentials can be applied to produce 6-pole and 8-pole fields simultaneously, to compensate ion optical aberrations. This multipole element can also produce dipole fields for steering and scanning the beam. The BPM have a classical cross-wire beam monitor as well as a channel electron multiplier with a pinhole collimator. Combining the scanning capability of the EQQs and the pinhole detector, we can observe a beam profile even for a very low-intensity RI-beams. Off- and on-line commissioning is underway.

Based on test experiments with the prototype setups, the large RF-carpet gas cell contains a three stage rf-carpet structure: a gutter rf carpet for collection of thermal ions in the cell into a small slit, a narrow (≈ 10 mm) traveling-wave rf-carpet for collection of ions from the gutter carpet and for transporting the ions toward the exit, and a small rf carpet for extraction from the gas cell. An offline test of the gutter structure has shown a high collection efficiency of ions in the gas cell.

(2) Laser spectroscopy of trapped radioactive beryllium isotope ions

As a first application of the prototype SLOWRI setup, we applied hyperfine structure spectroscopy to the beryllium isotopes to determine, in particular, the anomalous radius of the valence neutron of the neutron halo nucleus ^{11}Be , and to determine the charge radii of these beryllium isotopes through laser-laser double resonance spectroscopy of laser-cooled ions. Laser cooling is an essential prerequisite for these planned experiments. The first laser spectroscopy experiments for beryllium isotopes were performed to measure the resonance frequencies of the $2s\ ^2S_{1/2} - 2p\ ^2P_{3/2}$ transition in $^7\text{Be}^+$, $^9\text{Be}^+$, $^{10}\text{Be}^+$ and $^{10}\text{Be}^+$ ions and the nuclear charge radii of these isotopes were determined. The hyperfine structures of $^{11}\text{Be}^+$ and $^7\text{Be}^+$ ions were also performed using the laser-microwave double resonance spectroscopy and the magnetic hyperfine constants of $^7\text{Be}^+$ and $^{11}\text{Be}^+$ ions were determined with accuracies of better than 10^{-7} . A new combined-trap setup for high-precision determination of nuclear g-factors of the odd Be isotopes using a superconducting Helmholtz magnet is under preparation at the SLOWRI experimental area in collaboration with Ueno nuclear spectroscopy laboratory.

(3) Development of a multi-reflection TOF mass spectrograph for short-lived nuclei

The atomic mass is one of the most important quantities of a nucleus and has been studied by various methods since the early days of modern physics. From among many methods we have chosen a multi-reflection time-of-flight (MR-TOF) mass spectrometer. Slow RI beams extracted from the RF ion-guide are bunched and injected into the spectrometer with a repetition rate of ~ 100 Hz. The spectrometer consists of two electrostatic mirrors between which the ions travel back and forth repeatedly. These mirrors are designed such that energy-isochronicity in the flight time is guaranteed during the multiple reflections while the flight time varies with the masses of ions. A

mass-resolving power of 170,000 has been obtained within a 2 ms flight time for the $^{40}\text{K}^+$ and $^{40}\text{Ca}^+$ isobaric doublet. This mass-resolving power should allow determination of ion masses with an accuracy of $\leq 10^{-7}$. An online mass measurement for the radioactive isotope ^8Li has been carried out at the prototype SLOWRI setup.

The MR-TOF mass spectrograph has been placed under the GARIS-II separator with the goal of direct mass measurements of trans-uranium elements. A cryogenic gas catcher cell was placed at the focal plane box of GARIS-II and bunched low-energy heavy ion beams were transported to the trap of MR-TOF. In online commissioning experiments using No isotopes, more than 30% extraction efficiency from the cryogenic gas cell was achieved. In FY2016, mass measurements of more than 80 nuclides, including short-lived ($T_{1/2} = 10$ ms) isotopes of Ra and several isotopes of the trans-uranium elements Fm, Es, No and Md were performed at GARIS-II in collaboration with the KEK Wako Nuclear Science Center and the Super Heavy Element Synthesis team of RIKEN. The highest precisions, achieved for Ga isotopes, reached a level of 0.03 ppm. For most of the well-known nuclides, agreement with the literature mass values was found. However, discrepancies were found in some literature values derived from pre-1980 indirect measurements. This suggests that such indirect measurements must be revised with comprehensive direct mass measurements. The masses of four isotopes of Es and Md were measured for the first time, allowing for confirmation of the $N = 152$ shell closure in Md. Using these new mass data as anchor-points, the masses of seven isotopes of super-heavy elements up to Mt were indirectly determined and comparisons with various nuclear mass models were performed.

(4) Development of collinear fast beam apparatus for nuclear charge radii measurements

The root-mean-square charge radii of unstable nuclei have been determined exclusively by isotope shift measurements of the optical transitions of singly-charged ions or neutral atoms by laser spectroscopy. Many isotopes of alkali, alkali-earth, and noble-gas elements in addition to several other elements have been measured by collinear laser spectroscopy since these ions all have good optical transitions and are available at conventional ISOL facilities. However, isotopes of other elements, especially refractory and short-lived ones, have not been investigated so far.

In SLOWRI, isotopes of all atomic elements will be provided as well collimated, mono-energetic ion beams. This should expand the range of nuclides available for laser spectroscopy. In the first years of the RIBF project, elements in the vicinity of Ni, such as Ni, Co, Fe, Cr, Cu, Ga, and Ge are planned to be investigated. They all have possible optical transitions in the ground states of neutral atoms with presently available laser systems. Some of them have so called recycling transitions, which enhance the detection probabilities noticeably. Also, the multistep resonance ionization (RIS) method can be applied to the isotopes of Ni as well as those of some other elements. The required minimum intensity for this method can be as low as 10 atoms per second.

An off-line mass separator and a collinear fast beam apparatus with a large solid-angle fluorescence detector was built previously. A 617 nm transition of the metastable Ar^+ ion at 20 keV was measured with both collinear and anti-collinear geometry that allowed determination of the absolute resonant frequency of the transition at rest with a relative accuracy of more than 10^{-8} . A new setup is under preparation at the SLOWRI experiment area in collaboration with the Ueno nuclear spectroscopy laboratory.

(5) Development of parasitic slow RI-beam production scheme using resonance laser ionization

More than 99.9% of RI ions produced in projectile fission or fragmentation are simply dumped in the first dipole magnet and the slits. A new scheme, named PALIS, meant to rescue such precious RI using a compact gas catcher cell and resonance laser ionization, was proposed as a part of SLOWRI. The thermalized RI ions in a gas cell filled with Ar gas can be quickly neutralized and transported to the exit of the cell by gas flow. Irradiation of resonance lasers at the exit ionizes neutral RI atoms efficiently and selectively. The ionized RI ions can be further selected by a magnetic mass separator and transported to the SLOWRI experimental area for various experiments. The resonance ionization scheme itself can also be a useful method to perform hyperfine structure spectroscopy of RI of many elements.

A prototype setup has been used to test resonance ionization schemes of several elements, extraction from the cell, and transport to a high-vacuum chamber. An online setup was fabricated in FY2013 and the first online commissioning took place in FY2015. It was confirmed that the PALIS gas cell is not deleterious for BigRIPS experiments, and a reasonable amount of radioactive Cu isotopes were extracted from the cell by gas flow. Mechanical problems discovered in the commissioning have been solved by modification of the gas cell, bellows structure, and laser path. Next online commissioning is scheduled in October 2017.

Members

Team Leader

Michiharu WADA

Research & Technical Scientist

Takao KOJIMA (Senior Research Scientist)

Aiko TAKAMINE (concurrent; UENO laboratory)

Nishina Center Research Scientists

Tetsu SONODA

Kensuke KUSAKA (concurrent; BigRIPS Team)

Nishina Center Technical Scientist

Takeshi MAIE (concurrent; Cryogenic Technology Team)

Special Postdoctoral Researcher

Yuta ITO

Part-time Workers

Shigeaki ARAI

Sota KIMURA

Ichiro KATAYAMA

Visiting Researcher

Mikael REPONEN (JSPS)

Visiting Scientists

Hans A SCHUESSLER (Texas A&M Univ.)
 Hermann WOLLNIK (Univ. of Giessen)
 Hideki IIMURA (JAEA)
 Hideki TOMITA (Nagoya Univ.)

Klaus WENDT (Johannes Gutenberg Univ. Mainz)
 Kunihiro OKADA (Sophia Univ.)
 Volker SONNENSCHNEIN (Nagoya Univ.)

Student Trainees

Naoki KIMURA (Sophia Univ.)
 Takuma NOTO (Nagoya Univ.)
 Yoshitaka ADACHI (Nagoya Univ.)

Takahide TAKAMATSU (Nagoya Univ.)
 Daiki MATSUI (Nagoya Univ.)

List of Publications & Presentations**Publications**

[Journal]

(Original Papers) *Subject to Peer Review

- P. Schury, M. Wada, Y. Ito, D. Kaji, F. Arai, M. MacCormick, I. Murray, H. Haba, S. Jeong, S. Kimura, H. Koura, H. Miyatake, K. Morimoto, K. Morita, A. Ozawa, M. Rosenbusch, M. Reponen, P.-A. Söderström, A. Takamine, T. Tanaka, H. Wollnik, "First online multireflection time-of-flight mass measurements of isomer chains produced by fusion-evaporation reactions: Toward identification of superheavy elements via mass spectroscopy", *Physical Review C* 95, 011305(R) (2017)*
- T. Sonoda, T. Tsubota, M. Wada, I. Katayama, T.M. Kojima, M. Reponen, « A gas circulation and purification system for gas-cell-based low-energy RI-beam production », *Review of Scientific Instruments*, 87 (2016) 065104.*
- A Hamaker, M. Brodeur, J.M. Kelly, J. Long, C. Nicoloff, S. Syan, B.E. Schult, P. Schury, M. Wada, « Experimental investigation of the repelling force from RF carpets », *International Journal Mass Spectrometry*, 404 (2016) 14-19.*

[Proceedings]

(Original Papers) *Subject to Peer Review

- A. Takamine, M. Wada, K. Okada, Y. Ito, P. Schury, F. Arai, I. Katayama, K. Imamura, Y. Ichikawa, H. Ueno, H. Wollnik, H.A. Schuessler, « Towards high precision measurements of nuclear g-factors for the Be isotopes », *Nucl. Inst. Meth. B376* (2016) 307-310.*
- Y. Hirayama, Y.X. Watanabe, N. Imai, H. Ishiyama, S.C. Jeong, H.S. Jung, H. Miyatake, M. Oyaizu, S. Kimura, M. Mukai, Y.H. Kim, T. Sonoda, M. Wada, M. Huyse, Yu. Kudryavtsev, P. van Duppen, « On-line experimental results of an argon gas cell-based laser ion source (KEK Isotope Separation System) », *Nucl. Inst. Meth. B376* (2016) 52-56.*
- M. Mukai, Y. Hirayama, H. Ishiyama, H.S. Jung, H. Miyatake, M. Oyaizu, Y.X. Watanabe, S. Kimura, A. Ozawa, S.C. Jeong, T. Sonoda, « Search for efficient laser resonance ionization schemes of tantalum using a newly developed time-of-flight mass spectrometer in KISS », *Nucl. Inst. Meth B376* (2016) 73-76.*
- S. Kimura, H. Ishiyama, H. Miyatake, Y. Hirayama, Y.X. Watanabe, H.S. Jung, M. Oyaizu, M. Mukai, S.C. Jeong, A. Ozawa, « Development of the detector system for image-decay spectroscopy at the KEK Isotope Separator System », *Nucl. Inst. Meth. B376* (2016) 338-340.*
- Y. Hirayama, H. Miyatake, Y.X. Watanabe, N. Imai, H. Ishiyama, S.C. Jeong, H.S. Jung, M. Oyaizu, M. Mukai, S. Kimura, T. Sonoda, M. Wada, Y.H. Kim, M. Huyse, Yu. Kudryavtsev, P. van Duppen, « Beta-decay spectroscopy of r-process nuclei around N=126 », *EPJ Web Conf.* 109 (2016) 08001, 1-6.*

Oral Presentations

[International Conference etc.]

- Y. Ito et al., « First online mass measurements of isobar chains via MRTOF-MS : Toward direct identification of SHE », *International Nuclear Physics Conference*, Sept. 11-16, 2016, Adelaide, Australia.
- P. Schury et al., « Gas Catcher Systems Status: SLOWRI/PALIS, SlowSHE, and KISS », *Fragment Separator Expert Meeting*, Aug. 30 – Sept. 2, 2016, Grand Rapids, Michigan, USA.
- T. Sonoda et al., "Parasitic low-energy RI-beam production using gas catcher and resonance ionization", *Stopping and Manipulation of Ions and related topics (SMI-2016)*, June 8-10, 2016, IMP, Lanzhou, China.

[Domestic Conference]

- M. Wada, « Possibility of comprehensive mass measurements of heavy elements », *Symposium on Perspective of super heavy element science*, Mar. 17-20, Osaka, Japan.
- M. Wada et al., "High precision nuclear spectroscopy with trapped radioactive ions", *The 2nd Cicily East Asia Workshop on Low-energy Nuclear Physics*, June 26-28, 2016, RIKEN, Japan.

RIBF Research Division Instrumentation Development Group Rare RI-ring Team

1. Abstract

Mass measurement is one of the most important contributions to a nuclear property research especially for short-lived unstable nuclei far from the beta-stability line. In particular, a high-precision mass measurement for nuclei located around the r-process pass (rare-RI) is required in nucleosynthesis point of view. We chose a method of isochronous mass spectrometry (IMS) to make a measurement time shorter than 1 ms. Heavy-ion storage ring named "Rare-RI Ring (R3)" has been constructed until end of 2014 and commissioning experiments were successfully performed in 2015. Our target performance in the mass determination is to achieve accuracy of the order of 1 ppm (~ 100 keV) even if we get only one event. Since an isochronism in R3 is established over a wide range of the momentum, rare-RI with a large momentum spread, $\Delta p/p = \pm 0.5\%$, are acceptable. Another significant feature of the R3 system is an individual injection scheme in which a produced rare-RI itself triggers the injection kicker. In the first commissioning experiment using primary ^{78}Kr beam, we demonstrated a high ability of R3 as a storage ring and succeed in establishing the individual injection scheme for the first time. In the second experiment using secondary beams of ^{36}Ar and ^{35}Cl , we successfully demonstrated mass determination by measuring revolution time for both isotopes with the accuracy of ~ 20 ppm. In last year, we performed the third experiment using isotopes around ^{78}Ge . We successfully extracted several kinds of isotopes, ^{79}As , ^{77}Ga , ^{76}Zn , and ^{75}Cu from the R3 in the same setting and established the mass measurement method. We are going to try to measure masses for isotopes around ^{78}Ni region in near future.

2. Major Research Subjects

- (1) Developments of heavy-ion storage ring
- (2) Precision mass measurement for rarely produced isotopes related to r-process.

3. Summary of Research Activity

Since the lattice design of R3 is based on the cyclotron motion, it can provide an isochronism in a wide range of the momentum. We expect a great improvement in mass resolution in IMS as long as the isochronous field is precisely formed in R3. Therefore, IMS using R3 is capable of both a high-precision measurement and a fast measurement. All the devices in R3 was designed under the assumption that an incoming beam has an energy of less than 200 MeV/u and a charge to mass ratio, m/q , of less than 3. The ring structure was designed with a similar concept of a separate-sector ring cyclotron. It consists of six sectors and 4.02-m straight sections, and each sector consists of four rectangular bending magnets. A radially homogeneous magnetic field is produced in the magnet, and a magnetic rigidity is 6.5 Tm at maximum, for instance, ^{78}Ni with the magnetic rigidity of 5.96 Tm. Two magnets at both ends of each sector are additionally equipped with ten trim coils to form a precise isochronous magnetic field. For $\Delta p=0$ particle, the circumference is 60.35 m and the betatron tunes are $\nu_x=1.21$ and $\nu_y=0.84$ in horizontal and vertical directions, respectively. The momentum acceptance is $\Delta p/p = \pm 0.5\%$, and the transverse acceptances are 20π mmmrad and 10π mmmrad in horizontal and vertical directions, respectively.

Another performance required for R3 is to efficiently seize hold of an opportunity of the measurement for rare-RI produced unpredictably. We adopted an individual injection scheme in which the produced rare-RI itself triggers the injection kicker magnets. Full activation of the kicker magnetic field has to be completed within the flight time of the rare-RI from an originating point (F3 focal point in BigRIPS) of the trigger signal to the kicker position in R3. We successfully developed an ultra-fast response kicker system working with the repetition rate of 100 Hz.

Since R3 accumulates, in principle, only single ion, we need high-sensitive beam diagnostic devices in the ring, and they should be applicable even for a single particle circulation. One of them is a cavity type of Schottky pick-up installed for tuning of isochronous field. A resonance frequency is 171 MHz, a measured quality factor is about 1945, and shunt impedance is 190 k Ω . Another is a timing monitor, which detects secondary electrons emitted from thin carbon foil placed on the accumulation orbit. The thickness of the foil will be 50 $\mu\text{g}/\text{cm}^2$. The rare-RI with the energy of 200 MeV/u survives only for first 100 turns because of an energy loss at the foil.

In 2015, we had two times of commissioning experiments. In the first experiment, we use primary $^{78}\text{Kr}^{36+}$ beam with the energy of 168 MeV/u. We succeeded in beam injection particle by particle in individual injection scheme, beam extraction after 700- μs accumulation (~ 1860 turns), and measurements of the TOF from the injection to the extraction. It was demonstrated that R3 works well as a storage ring and a single particle is certainly manipulated in this storage ring system. The individual injection scheme was established for the first time in the world. In addition, the Schottky pick-up monitored a single $^{78}\text{Kr}^{36+}$ particle circulation with the measuring time of less than 10 ms. That demonstrated that our pick-up is world most sensitive non-destructive monitor. In this experiment, we could tune completely the first order isochronism, but higher order components were remained, consequently, the 10-ppm accuracy of the isochronism was obtained. More precise tuning is possible with reference the Schottky data. In the second experiment, we injected two isotopes, ^{36}Ar and ^{35}Cl , selected in the secondary beams into the ring, in which the isochronism is tuned for ^{36}Ar . It was obviously demonstrated that the mass of ^{35}Cl relative to ^{36}Ar is determined by comparing the TOF values for both isotopes, and the accuracy was ~ 20 ppm, which is one-order less than our target value of a few ppm. We found that the imperfection of isochronism significantly contributes to the time resolution of measured TOF values.

In 2016, we performed the third commissioning experiment using unstable nuclei. In this experiment, the 5-ppm accuracy of isochronism was obtained for the reference isotope ^{78}Ge by adjusting the isochronism up to second order. In addition, we derived the masses of ^{79}As , ^{77}Ga , ^{76}Zn , and ^{75}Cu relative to ^{78}Ge by determining its revolution time with beta correction. We found that not only the imperfection of isochronism but also the insufficient resolution of beta measurement significantly contributes to the mass resolution.

Detailed analysis is ongoing. In next time, we will try to improve the accuracy of isochronism and the beta measurement resolution. We plan to try mass measurements for isotopes related r-process pass around ^{78}Ni region after conducting the forth commissioning experiment.

Members

Team Leader

Masanori WAKASUGI (concurrent; Group Director,
Instrumentations Development Gr.)

Nishina Center Research Scientists

Yoshitaka YAMAGUCHI

Nishina Center Technical Scientists

Takeshi MAIE (concurrent; Cryogenic Technology Team)

Contract Researcher

Daisuke NAGAE (Spin-Isospin Lab.)

Special Postdoctoral Researcher

Yasushi ABE

Postdoctoral Researcher

Fumi SUZAKI (Spin-Isospin Lab.)

Research Consultant

Akira NODA

List of Publications & Presentations

Publications

[Journal]

(Review)

Y. Yamaguchi, M. Wakasugi, Y. Abe, F. Suzaki, D. Nagae, S. Omika, H. Miura, S. Naimi, Z. Ge, T. Yamaguchi, A. Ozawa, T. Uesaka, J. Ohnishi, T. Kikuchi, M. Komiyama, K. Kumagai, A. Tokuchi, T. Fujinawa, T. Maie, H. Yamasawa, Y. Yanagisawa, T. Watanabe, Y. Watanabe, and Y. Yano, "Construction of the rare-RI ring at RIKEN RI Beam", *Journal of Particle Accelerator of Japan*, Vol.12, No.3, 132-141 (2015).

[Proceedings]

(Original Papers) *Subject to Peer Review

S. Suzuki, A. Ozawa, T. Moriguchi, Y. Ichikawa, M. Amano, D. Kamioka, Y. Tajiri, K. Hiraishi, T. Matsumoto, D. Nagae, Y. Abe, S. Naimi, T. Yamaguchi, S. Omika, Z. Ge, N. Tadano, K. Wakayama, A. Kitagawa, S. Sato, "Development of secondary electron time detector for ion beams", *Proceedings of Science, INPC2016* (2016) 111. *

F. Suzaki, J. Zenihiro, Y. Abe, A. Ozawa, T. Suzuki, T. Uesaka, M. Wakasugi, K. Yamada, T. Yamaguchi, and Y. Yamaguchi, "Performance of a resonant Schottky pick-up for the Rare-RI Ring project", *JPS Conference Proceedings Vol.6* (2015) 030119.*

T. Yamaguchi, "Present status of Rare-RI Ring facility at RIBF", *Physica Scripta T166* (2015) 014039.*

Y. Abe, Y. Yamaguchi, M. Wakasugi, T. Uesaka, A. Ozawa, F. Suzaki, D. Nagae, H. Miura, and T. Yamaguchi, "Isochronous field study of the Rare-RI Ring", *Physica Scripta T166* (2015) 014039.*

F. Suzaki, J. Zenihiro, A. Ozawa, T. Suzuki, T. Uesaka, M. Wakasugi, K. Yamada, T. Yamaguchi, Y. Abe, and Y. Yamaguchi, "A resonant Schottky pick-up for Rare-RI Ring at RIKEN", *Physica Scripta T166* (2015) 014059.*

Y. Yamaguchi, H. Miura, M. Wakasugi, Y. Abe, A. Ozawa, F. Suzaki, A. Tokuchi, T. Uesaka, T. Yamaguchi, and Y. Yano, "Fast-kicker system for rare-RI ring" *Physica Scripta T166* (2015) 014056.*

H. Miura, Y. Abe, Z. Ge, K. Hiraishi, Y. Ishikawa, I. Kato, T. Moriguchi, D. Nagae, S. Naimi, T. Nishimura, S. Omika, A. Ozawa, F. Suzaki, S. Suzuki, "Performance of a fast kicker magnet for rare-RI ring", *Proceedings of the HIAT2015* (2015) 95-97.

F. Suzaki, Y. Abe, Z. Ge, D. Nagae, S. Naimi, T. Uesaka, T. Watanabe, M. Wakasugi, K. Yamada, Y. Yamaguchi, J. Zenihiro, Y. Yano, I. Kato, H. Miura, T. Nishimura, S. Omika, T. Suzuki, N. Tadano, Y. Takeuchi, T. Yamaguchi, K. Hiraishi, Y. Ichikawa, T. Moriguchi, A. Ozawa, S. Suzuki, and Y. Tajiri, "Performance of a resonant Schottky pick-up in the commissioning of rare-RI ring", *Proceedings of the HIAT2015* (2015) 98-100.

Y. Yamaguchi, Y. Abe, and rare-RI ring collaborators, "The rare-RI ring at RIKEN RI Beam Factory", *Proceedings of the HIAT2015* (2015) 121-123.

T. Yamaguchi, T. Izumikawa, S. Miyazawa, T. Suzuki, F. Tokanai, H. Furuki, N. Ichihashi, C. Ichikawa, A. Kitagawa, T. Kuboki, S. Momota, D. Nagae, M. Nagashima, Y. Nakamura, R. Nishikiori, T. Ohtsubo, A. Ozawa, K. Sato, S. Sato, and S. Suzuki, "Performance of high-resolution position-sensitive detectors developed for storage-ring decay experiments", *Nuclear Instruments and Methods in Physics Research Section B* 317 (2013) 697-700.*

F. Suzaki, J. Zenihiro, T. Yamaguchi, A. Ozawa, T. Uesaka, M. Wakasugi, K. Yamada, Y. Yamaguchi, and rare-RI ring collaboration, "Design

- study of a resonant Schottky pick-up for the Rare-RI Ring project", Nuclear Instruments and Methods in Physics Research Section B317 (2013) 636-639.*
- D. Nagae, S. Okada, A. Ozawa, T. Yamaguchi, H. Suzuki, T. Moriguchi, Y. Ishibashi, S. Fukuoka, R. Nishikiori, T. Niwa, T. Suzuki, K. Sato, H. Furuki, N. Ichihashi, S. Miyazawa, Y. Yamaguchi, T. Uesaka, and M. Wakasugi, "Time-of-flight detector applied to mass measurements in Rare-RI Ring", Nuclear Instruments and Methods in Physics Research Section B 317 (2013) 640-643.*
- Y. Yamaguchi, M. Wakasugi, T. Uesaka, A. Ozawa, Y. Abe, T. Fujinawa, M. Kase, M. Komiyama, T. Kubo, K. Kumagai, T. Maie, D. Nagae, J. Ohnishi, F. Suzaki, A. Tokuchi, Y. Watanabe, K. Yoshida, K. Yamada, T. Yamaguchi, H. Yamasawa, Y. Yanagisawa, J. Zenihiro, and Y. Yano, "Construction of rare-RI ring at RIKEN RI Beam Factory", Nuclear Instruments and Methods in Physics Research Section B 317 (2013) 629-635.*
- Yu.A. Litvinov, S. Bishop, K. Blaum, F. Bosch, C. Brandau, L.X. Chen, I. Dillmann, P. Egelhof, H. Geissel, R.E. Grisenti, S. Hagmann, M. Heil, A. Heinz, N. Kalantar-Nayestanaki, R. Knoebel, C. Kozhuharov, M. Lestinsky, X.W. Ma, T. Nilsson, F. Nolden, A. Ozawa, R. Raabe, M.W. Reed, R. Reifarth, M.S. Sanjari, D. Schneider, H. Simon, M. Steck, T. Stoehlker, B.H. Sun, X.L. Tu, T. Uesaka, P.M. Walker, M. Wakasugi, H. Weick, N. Winckler, P.J. Woods, H.S. Xu, T. Yamaguchi, Y. Yamaguchi, and Y.H. Zhang, "Nuclear physics experiments with ion storage rings", Nuclear Instruments and Methods in Physics Research Section B 317 (2013) 603-616.*
- T. Yamaguchi, Y. Yamaguchi, and A. Ozawa "The challenge of precision mass measurements of short-lived exotic nuclei: Development of a new storage-ring mass spectrometry", Journal of Mass Spectrometry 349-350 (2013) 240-246.*
- M. Wakasugi, and rare-RI ring collaborators, "Construction of the rare-RI ring at the RIKEN RI beam factory", Proceedings of Cyclotron2013 (2013) 477-481.
- Y. Abe, D. Nagae, and rare-RI ring collaboration, "Developments of time-of-flight detectors for Rare-RI Ring", Proceedings of the 12th Asia Pacific Physics Conference 1 (2013) 013059.*
- F. Suzaki, T. Yamaguchi, and rare-RI ring collaboration, "Storage-ring mass spectrometry in Japan", Proceedings of the 12th Asia Pacific Physics Conference 1 (2013) 013058.*
- M. Komiyama, A. Uchiyama, N. Fukunishi, M. Wakasugi, M. Hamanaka, and M. Nishimura, "Status of the RIKE RI Beam Factory Control System", Proceedings of ICALEPCS2013 (2013) 348-351.

Oral Presentations

[International Conference etc.]

- Y. Yamaguchi, M. Wakasugi, Y. Abe, D. Nagae, F. Suzaki, A. Ozawa, T. Uesaka, T. Yamaguchi, S. Naimi, and rare-RI ring collaborators, "The rare-RI ring at RIKEN RI beam factory", International Nuclear Physics Conference (INPC2016), Adelaide, Australia, September (2016).
- S. Suzuki, A. Ozawa, T. Moriguchi, Y. Ichikawa, M. Amano, D. Kamioka, Y. Tajiri, K. Hiraishi, T. Matsumoto, D. Nagae, Y. Abe, S. Naimi, T. Yamaguchi, S. Omika, Z. Ge, N. Tadano, K. Wakayama, A. Kitagawa, S. Sato, "Development of secondary electron time detector for ion beams", International Nuclear Physics Conference (INPC2016), Adelaide, Australia, September (2016).
- D. Nagae, S. Omika, F. Suzaki, Y. Abe, Y. Yamaguchi, S. Naimi, T. Yamaguchi, A. Ozawa, T. Uesaka, M. Wakasugi, and rare-RI ring collaborators, "The rare-RI ring at RIKEN RI beam factory", International Symposium on Neutron Star Matter (NSMAT2016), Sendai, Japan, November (2016).
- T. Yamaguchi, "RI beam experiments with storage rings -present and future-", International Symposium on Interplay between Hadronic, Nuclear and Atomic Physics, Shimoda, Japan, July (2016).
- T. Yamaguchi, "Rare-RI Ring at RIKEN present status", NUSTAR annual meeting, Darmstadt, Germany, February (2017).
- Y. Yamaguchi, "The Rare RI Ring at RI Beam Factory", 13th International Conference on Heavy Ion Accelerator Technology, Yokohama, Japan, September (2015).
- Y. Yamaguchi, "Commissioning of the Rare-RI Ring at RI Beam Factory", International Workshop on Beam Cooling and Related Topics, Newport News, USA, October (2015).
- Y. Yamaguchi, "Commissioning of the Rare-RI Ring at RI Beam Factory", The 9th Japan-China Joint Nuclear Physics Symposium, Osaka, Japan, November (2015).
- Ozawa, and rare-RI ring collaboration, "Mass measurement with Rare-RI Ring at RIKEN", SKLTP-BLTP Joint Workshop on Physics of Strong Interaction, Guangxi, China, November (2015).
- Y. Yamaguchi, and rare-RI ring collaboration, "Present status of Rare-RI Ring", RIBF Users Meeting 2015, Wako, Japan, September (2015).
- M. Wakasugi, and rare-RI ring collaboration, "The Rare-RI Ring Facility at RIKEN RI Beam Factory", 2nd Conference on Advances in Radioactive Isotope Science, Tokyo, Japan, June (2014).
- Y. Yamaguchi, and rare-RI ring collaboration, "Rare-RI Ring at RIKEN RI Beam Factory", The 6th International Conference on Trapped Charged Particles and Fundamental Physics, Takamatsu, Japan, December (2014).
- Y. Abe, Y. Yamaguchi, M. Wakasugi, T. Uesaka, A. Ozawa, F. Suzaki, H. Miura, T. Yamaguchi, and Y. Yano, "Isochronous study of the Rare-RI Ring", 9th International Conference on Nuclear Physics at Storage Rings, St. Goar, Germany, September (2014).
- Ozawa, "Mass measurement with Rare-RI Ring", Science and Next Generation Experiments at FRIB and RIBF, Hawaii, USA, October (2014).
- Y. Abe, "Mass measurement of RI with Rare-RI Ring at RIKEN", Post-TCP PMM Workshop, Wako, Japan, December (2014).
- M. Wakasugi, and rare-RI ring collaborators, "Construction of the Rare RI Ring (R3) at the RIKEN RI Beam Factory", The 20th International Conference on Cyclotrons and Their Applications, Vancouver, Canada, September (2013).
- T. Yamaguchi, "Rare-RI Ring project in RIKEN", Sino-German Symposium on (High precision experiments with stored exotic and stable nuclei), Lanzhou, China, November (2013).
- Y. Yamaguchi, and rare-RI ring collaboration, "Construction status of the Rare-RI Ring", RIBF Users Meeting 2013, Wako, Japan, June (2013).
- Ozawa, and rare-RI ring collaboration, "Rare-RI Ring for Mass measurements at RIBF", The 12th International Symposium on Origin of Matter and Evolution of Galaxies, Tsukuba, Japan, November (2013).

[Domestic Conference]

- 若山清志、阿部康志、天野将道、上岡大起、北川敦志、長江大輔、大甕舜一朗、小沢顕、佐藤眞二、鈴木伸司、鈴木健、只野奈津生、山口貴之、「ファイバーシンチレータと MPPC による簡易な重イオンビーム位置検出器の開発」日本物理学会第 72 回年次大会、大阪市、3 月 (2017).
- 大甕舜一朗、山口貴之、只野奈津生、鈴木健、若山清志、阿部康志、上坂友洋、Naimi Sarah、Ge Zhuang、洲寄ふみ、長江大輔、山口由高、若杉昌徳、天野将道、小沢顕、上岡大起、鈴木伸司、森口哲朗、北川敦志、佐藤眞二、「稀少 RI リングのための粒子周回モニターの開発」日本物理学会第 72 回年次大会、大阪市、3 月 (2017).
- Ge Zhuang、Naimi Sarah、長江大輔、阿部康志、大甕舜一朗、上坂友洋、洲寄ふみ、山口由高、若杉昌徳、若山清志、山口貴之、小沢顕、鈴木伸司、森口哲朗、矢野安重、「Development of a large area position sensitive (TOF) detector at the Rare RI Ring at RIBF」日本物理学会第 72 回年次大会、大阪市、3 月 (2017).
- 大甕舜一朗、山口貴之、若杉昌徳、山口由高、阿部康志、上坂友洋、小沢顕、洲寄ふみ、鈴木健、長江大輔、三浦宙、柳澤善行、「稀少 RI リング個別入射方式のための同軸管の開発」日本物理学会 2015 年秋季大会、大阪市、9 月 (2015).
- 鈴木伸司、市川ゆきな、長江大輔、小沢顕、阿部康志、森口哲朗、岡田俊祐、石橋陽子、松本拓也、田尻芳之、斎藤祐多、稲葉成紀、沢畑克樹、山口貴之、鈴木健、河野準平、山木さやか、松本達、榎本彩乃、大甕舜一朗、竹内勇貴、加藤郁磨、只野奈津生、西村拓真、北川敦志、佐藤眞二、「RI ビーム飛行時間検出器の開発」日本物理学会 2015 年秋季大会、大阪市、9 月 (2015).
- 阿部康志、山口由高、上坂友洋、小沢顕、洲寄ふみ、山口貴之、若杉昌徳、稀少 RI リングコラボレーション、「稀少 RI リングの性能評価」日本物理学会第 71 回年次大会、仙台市、3 月 (2016).
- 洲寄ふみ、阿部康志、Ge Zhuang、平石健太郎、市川ゆきな、加藤郁磨、三浦宙、森口哲朗、長江大輔、Naimi Sarah、西村拓真、大甕舜一朗、小沢顕、鈴木伸司、鈴木健、只野奈津生、田尻芳之、竹内勇貴、上坂友洋、若杉昌徳、渡邊環、山田一成、山口貴之、山口由高、銭廣十三、矢野安重、「稀少 RI リングのための共鳴ショットキーピックアップのオンライン性能評価」日本物理学会第 71 回年次大会、仙台市、3 月 (2016).
- 鈴木伸司、小沢顕、市川ゆきな、森口哲朗、田尻芳之、平石健太郎、松本拓也、長江大輔、阿部康志、Naimi Sarah、Ge Zhuang、山口貴之、松本達、鈴木健、大甕舜一朗、竹内勇貴、加藤郁磨、只野奈津生、西村拓真、北川敦志、佐藤眞二、「質量測定用飛行時間検出器の開発」日本物理学会第 71 回年次大会、仙台市、3 月 (2016).
- 小沢顕、「Present status of Rare-RI Ring project at RIBF」実験と観測で解き明かす中性子星の核物質 第 4 回研究会、葉山、9 月 (2015).
- 山口貴之、「稀少 RI リングによる r プロセス核の測定計画」宇宙核物理連絡協議会 研究会、三鷹市、2 月 (2016).
- Naimi Sarah、「Mass measurement in connection to the nuclear astrophysics」宇宙核物理連絡協議会 研究会、三鷹市、2 月 (2016).
- 洲寄ふみ、阿部康志、Naimi Sarah、三浦宙、小沢顕、鈴木健、上坂友洋、若杉昌徳、山田一成、山口貴之、山口由高、銭廣十三、Chen Xiangcheng、「稀少 RI リングの共鳴ショットキーピックアップのオフライン性能試験」日本物理学会第 70 回年次大会、東京、3 月 (2015).
- 三浦宙、山口由高、若杉昌徳、阿部康志、小沢顕、洲寄ふみ、徳地明、上坂友洋、山口貴之、長江大輔、柳澤善行、鈴木健、「稀少 RI リングのためのキッカーマグネットの開発」日本物理学会第 70 回年次大会、東京、3 月 (2015).
- 阿部康志、長江大輔、岡田俊祐、小沢顕、山口貴之、石橋陽子、斎藤祐多、沢畑克樹、鈴木健、河野準平、山木さやか、山口由高、上坂友洋、若杉昌徳、「稀少 RI リングのビームモニターの開発」日本物理学会 2013 年秋季大会、高知市、9 月 (2013).
- 洲寄ふみ、銭廣十三、小沢顕、鈴木健、上坂友洋、若杉昌徳、山田一成、山口貴之、山口由高、「稀少 RI リングの共鳴ショットキーピックアップ設計のための電磁場シミュレーション」日本物理学会 2013 年秋季大会、高知市、9 月 (2013).
- 洲寄ふみ、銭廣十三、小沢顕、鈴木健、上坂友洋、若杉昌徳、山田一成、山口貴之、山口由高、「稀少 RI リングの共鳴ショットキーピックアップの性能試験」日本物理学会第 69 回年次大会、平塚市、3 月 (2014).

Posters Presentations

[International Conference etc.]

- S. Suzuki, A. Ozawa, Y. Ichikawa, T. Moriguchi, Y. Tajiri, K. Hiraiishi, T. Matsumoto, D. Nagae, Y. Abe, S. Naimi, T. Yamaguchi, T. Suzuki, S. Omika, Z. Ge, Y. Takeuchi, N. Tadano, I. Kato, T. Nishimura, A. Kitagawa, S. Sato, "Development of time-of-flight detector for mass measurements of short-lived nuclei with the rare-RI ring", International Symposium on Neutron Star Matter (NSMAT2016), Sendai, Japan, November (2016).
- H. Miura and rare-RI ring collaborators, "Development of a Fast Kicker System for Rare-RI Ring", 13th International Conference on Heavy Ion Accelerator Technology, Yokohama, Japan, September (2015).
- F. Suzaki and rare-RI ring collaborators, "Performance of a resonant Schottky pick-up in the commissioning of Rare-RI Ring", 13th International Conference on Heavy Ion Accelerator Technology, Yokohama, Japan, September (2015).
- Z. Ge and rare-RI ring collaborators, "Rare-RI Ring at RIKEN", The 13th International Symposium on Origin of Matter and Evolution of Galaxies, Beijing, China, June (2015).
- Y. Yamaguchi, H. Miura, M. Wakasugi, Y. Abe, A. Ozawa, F. Suzaki, A. Tokuchi, T. Uesaka, T. Yamaguchi, and Y. Yano, "Fast-kicker system for Rare-RI Ring", 9th International Conference on Nuclear Physics at Storage Rings, St. Goar, Germany, September (2014).
- F. Suzaki, J. Zenihiro, A. Ozawa, T. Suzuki, T. Uesaka, M. Wakasugi, K. Yamada, T. Yamaguchi, Y. Abe, and Y. Yamaguchi, "A resonant Schottky pick-up for Rare-RI Ring at RIKEN", 9th International Conference on Nuclear Physics at Storage Rings, St. Goar, Germany, September (2014).
- F. Suzaki, J. Zenihiro, A. Ozawa, T. Suzuki, T. Uesaka, M. Wakasugi, K. Yamada, T. Yamaguchi, Y. Abe, and Y. Yamaguchi, "Performance of a resonant Schottky pick-up for Rare-RI Ring project", 2nd Conference on Advances in Radioactive Isotope Science, Tokyo, Japan, June (2014).
- Y. Abe, and D. Nagae, "Developments of time-of-flight detectors for Rare-RI Ring", The 12th Asia Pacific Physics Conference, Chiba, Japan, July (2013).
- T. Yamaguchi, F. Suzaki, and rare-RI ring collaborators, "Storage-ring mass spectrometry in Japan", The 12th Asia Pacific Physics Conference, Chiba, Japan, July (2013).
- T. Yamaguchi, "Cherenkov light detection as a velocity selector for uranium fission products at intermediate energies", 8th International workshop on Ring imaging Cherenkov Detectors, Hayama, Japan, December (2013).

[Domestic Conference]

- 山口由高、若杉昌徳、阿部康志、洲寄ふみ、藤縄雅、加瀬昌之、込山美咲、熊谷桂子、眞家武士、長江大輔、大西純一、小沢顕、上坂友洋、渡邊裕、山口貴之、山澤秀行、柳澤善行、銭廣十三、矢野安重、「理研 RIBF における稀少 RI リングの現状」第 11 回日本加速器学会年会、青森市、8 月 (2014).

RIBF Research Division Instrumentation Development Group SCRIT Team

1. Abstract

The SCRIT Electron Scattering Facility has been constructed at RIKEN RIBF. This aims at investigation of internal nuclear structure for short-lived unstable nuclei by means of electron scattering. SCRIT (Self-Confining RI Ion Target) is a novel method to form internal targets in an electron storage ring. This is a unique method for making electron scattering experiments for unstable nuclei possible. Construction of the facility has been started in 2009. This facility consists of an electron accelerator (RTM), a SCRIT-equipped electron storage ring (SR2), an electron-beam-driven RI separator (ERIS), and a detector system consisting of a high-resolution magnetic spectrometer, drift chambers and trigger scintillators. Installation of all components in the facility was completed in 2015, and it is now under comprehensive test experiment phase. In the test experiments, the luminosity was reached to 3×10^{27} /(cm²s) with the number of injected ions of 3×10^8 . In 2016, we successfully completed a measurement of diffraction of scattered electrons from ¹³²Xe nuclei and determined the charge density distribution for the first time. The facility is now under setting up to move the first experiment for unstable nuclei.

2. Major Research Subjects

Development of SCRIT electron scattering technique and measurement of the nuclear charge density distributions of unstable nuclei.

3. Summary of Research Activity

SCRIT is a novel technique to form internal target in an electron storage ring. Positive ions are three dimensionally confined in the electron beam axis by transverse focusing force given by the circulating electron beam and applied electrostatic longitudinal mirror potential. The created ion cloud composed of RI ions injected from outside works as a target for electron scattering. Construction of the SCRIT electron scattering facility has been started in 2009. The electron accelerators RTM and the storage ring SR2 were successfully commissioned in 2010. Typical accumulation current in SR2 is 250-300 mA at the energy range of 100-300 MeV that is required energy range in electron scattering experiment. The SCRIT device was inserted in the straight section of SR2 and connected to an ISOL named ERIS (Electron-beam-driven RI separator for SCRIT) by 20-m long low energy ion transport line. A buncher system based on RFQ linear trap was inserted in the transport line to convert the continuous beam from ERIS to pulsed beam, which is acceptable for SCRIT. A detector system consisting of a high-resolution magnetic spectrometer, drift chambers and trigger schintillators was constructed, and this has a solid angle of 100 msr, energy resolution of 10^{-3} , and the scattering angle coverage of 25-55 degrees. A wide range of momentum transfer, 80-300 MeV/c, is covered by changing the electron beam energy from 150 to 300 MeV. Installation of all the components in the facility has been completed in last year, and we are now under comprehensive test experiments.

We successfully measured a diffraction pattern in the angular distribution of scattered electron from ¹³²Xe isotope at the electron beam energy of 150MeV, 200MeV, and 300MeV, and derived the nuclear charge distribution by assuming two-parameters Fermi model for the first time. At this time, luminosity was reached to 3×10^{27} /(cm²s) at maximum and the averaged value was 1.2×10^{27} /(cm²s) with the number of injected target ions of 3×10^8 .

We are now under preparation for going to the experiments for unstable nuclei. There are some key issues for that. They are increasing the intensity of the RI beams from ERIS, efficient DC-to-pulse conversion at the buncher, and effective suppression of the background in measurement of scattered electrons. RI beam intensity will be improved by upgrading the electron beam power from 10W to 60W, increasing the contained amount of U in the target ion source, and some modifications in mechanical structure in the ion source. For efficient DC-to-pulse conversion, we will innovate two-step bunching method, which is time compression at the buncher in combination with pre-bunching at the ion source using grid action, and was already demonstrated in off-line test. Since one of significant contribution to the background for scattered electron is scattering from massive structural objects around the trapping region originated from halo components of the electron beam, we will remodel the SCRIT electrodes. Luminosity for radioactive Xe isotopes is expected to be more than 10^{26} /(cm²s) after these improvements. Then, we will be able to start experiments for unstable nuclei. When further upgrading in the RTM power planed to be 3kW will be achieved, we can extend the measurements to more exotic nuclei.

Members

Team Leader

Masanori WAKASUGI (concurrent; Group Director, Instrumentations Development Gr.)

Research & Technical Scientists

Masamitsu WATANABE (Senior Research Scientist)

Tetsuya OHNISHI (Senior Technical Scientist)

Nishina Center Research Scientist

Akitomo ENOKIZONO

Research Consultants

Tadaaki TAMAE
Shin-ichi ICHIKAWA

Masahiro HARA
Takashi EMOTO

Senior Visiting Scientist

Toshitada HORI (Hiroshima University)

Visiting Scientists

Shuo WANG (Shandong University)
Yuki HONDA (Tohoku University)
Kyo TSUKADA (Tohoku University)

Toshimi SUDA (Tohoku University)
Kazuyoshi KURITA (Rikkyo University)

Research Fellow

Mamoru TOGASAKI (Rikkyo University)

Student Trainees

Keita KASAMA (Tohoku University)
Kazuki NAMBA (Tohoku University)

Mitsuki HORI (Rikkyo University)
Nobuaki UCHIDA (Rikkyo University)

List of Publications & Presentations**Publications**

[Journals]

- K. Tsukada, A. Enokizono, T. Ohnishi, K. Adachi, T. Fujita, M. Hara, M. Hori, T. Hori, S. Ichikawa, K. Kurita, K. Matsuda, T. Suda, T. Tamae, M. Togasaki, M. Wakasugi, M. Watanabe, and K. Yamada, "First Elastic Electron Scattering from ^{132}Xe at the SCRIT Facility", *Physical Review Letters* **118**, 262501, 27 June (2017)
T. Suda and Haik Simon, "Prospects for electron scattering on unstable, exotic nuclei", *Progress in Particle and Nuclear Physics*, in press (2017)

[Proceedings]

(Original Papers) *Subject to Peer Review

- M. Togasaki, K. Kurita, K. Yamada, R. Toba, M. Hara, T. Ohnishi, and M. Wakasugi, "Development of a buffer-gas-free buncher for low energy RI ion beam", *HIAT2015 proceedings*, 253 (2015).
T. Ohnishi, S. Ichikawa, and M. Wakasugi, "Electron-beam-driven RI separator for SCRIT at RIKEN RI Beam Factory", *HIAT2015 proceedings*, 194 (2015).
T. Ohnishi, A. Enokizono, M. Hara, T. Hori, S. Ichikawa, K. Kurita, S. Matsuo, T. Suda, T. Tamae, M. Togasaki, K. Tsukada, T. Tsuru, S. Wang, S. Yoneyama, and M. Wakasugi, "The SCRIT electron scattering facility project at RI Beam Factory", *Physca Scripta*, T166 , 014071 (2015).*
T. Suda, A. Enokizono, M. Hara, Y. Haraguchi, S. Ichikawa, K. Kurita, S. Matsuo, T. Ohnishi, T. Tamae, M. Togasaki, K. Tsukada, T. Tsuru, S. Wang, S. Yoneyama, and M. Wakasugi, "SCRIT Electron Scattering Facility", *JPS Conf. Proc.* 6, 030100 (2015).*

Oral Presentations

[International Conference etc.]

- A. Enokizono, K. Adachi, T. Fujita, M. Hara, M. Hori, T. Hori, S. Ichikawa, K. Kasama, K. Kurita, K. Namba, T. Ohnishi, S. Sasamura, T. Suda, T. Tamae, K. Tsukada, M. Togasaki, N. Uchida, M. Wakasugi, S. Wang, M. Watanabe, K. Yamada, "Results of the first physics experiment with ^{132}Xe and ^{208}Pb targets at the SCRIT facility", *ARIS2017, Keystone, Colorado*, May 30th, (2017)
A. Enokizono, K. Adachi, T. Fujita, M. Hara, M. Hori, T. Hori, S. Ichikawa, K. Kasama, K. Kurita, K. Nam
T. Suda, T. Tamae, K. Tsukada, M. Togasaki, N. Uchida, M. Wakasugi, M. Watanabe, K. Yamada, "The Performance Of The Scrit Detectors For Electron-RI Scattering Experiment", *International Nuclear Physics Conference (INPC2016), Adelaide Convention Centre, Australia*, Data: September 11-16, (2016).
T. Ohnishi, M. Hara, T. Hori, S. Ichikawa, M. Watanabe, M. Wakasugi, K. Adachi, A. Enokizono, T. Fujita, M. Hori, S. Sasamura, M. Togasaki, N. Uchida, K. Yamada, K. Kurita, K. Kasama, K. Namba, K. Tsukada, T. Tamae, T. Suda, S. Wang, T. Kikuchi, "The SCRIT Electron Scattering Facility at the Riken RI Beam Factory", *International Nuclear Physics Conference (INPC2016), Adelaide Convention Centre, Australia*, Data: September 11-16, (2016).
K. Tsukada, K. Kasama, K. Namba, T. Suda, T. Tamae, M. Hara, T. Hori, S. Ichikawa, T. Ohnishi, M. Wakasugi, M. Watanabe, K. Adachi, A. Enokizono, T. Fujita, M. Hori, K. Kurita, S. Sasamura, M. Togasaki, N. Uchida, K. Yamada, "First result from SCRIT electron scattering facility: Charge density distribution of ^{132}Xe ", *International Nuclear Physics Conference, Adelaide Convention Centre, Australia*, September 11-16, (2016).
K. Kurita, "How SCRIT came into reality", *International Symposium on Modern technique and its Outlook in Heavy Ion Science (MOTO16)*, Rikkyo University, Tokyo, Japan, June (2016).
T. Suda, "SCRIT electron scattering facility : present status and future perspectives", *Neutron Skin of Nuclei*, Mainz, Germany, May 17 – 27, (2016).
T. Suda, "Electron scattering off short-lived nuclei at SCRIT facility", *Seminar at GANIL, CAEN, France*. April 29, 2016.
K. Tsukada, "Physics program with SCRIT", *Electron-radioactive ion collisions : theoretical and experimental challenges*, Saclay, France, April 25 – 27, (2016).
T. Suda, "Future perspectives of the SCRIT facility", *Electron-radioactive ion collisions : theoretical and experimental challenges*, Saclay, France, April 25 – 27, (2016).
M. Wakasugi, "The SCRIT Facility at RIKEN", *Int. Workshop on Electron Radioactive Collision*, Apr. 25-27, CEA Saclay, France (2016).
M. Wakasugi, T. Ohnishi, M. Watanabe, S. Ichikawa, M. Hara, T. Hori, M. Togasaki, K. Yamada, T. Fujita, K. Adachi, M. Hori, A. Enokizono,

K. Kurita, K. Tsukada, T. Tamae, and T. Suda, "Current status of electron-RI collision project at RIKEN", Int. Workshop on Beam Cooling and Related Topics COOL15, Sep.28-Oct.2, JLab Newport News, Virginia, USA (2015).

T. Ohnishi, A. Enokizono, M. Hara, T. Hori, S. Ichikawa, K. Kurita, S. Matsuo, T. Suda, T. Tamae, M. Togasaki, K. Tsukada, T. Tsuru, S. Wang, S. Yoneyama, and M. Wakasugi, "The SCRIT electron scattering facility project at RI Beam Factory", 9th Int. Conf. on Nuclear Physics at Storage Ring, Sep.28-Oct.2, Schloss Rheinfels, St. Goar, Germany (2015).

[Domestic Conference]

- 山田耕平, 大西哲哉, 栗田和好, 戸ヶ崎衛, 鳥羽僚太, 原雅弘, 渡邊正満, 若杉昌徳 "SCRIT 実験のためのイオンビームバンチャーの開発", 日本物理学会, 3月, 大阪大学, 大阪(2017).
- 藤田峻広, 足立江介, 市川進一, 内田信昭, 榎園昭智, 大西哲哉, 笠間桂太, 栗田和好, 笹村新之介, 須田利美, 玉江忠明, 塚田暁, 戸ヶ崎衛, 南波和希, 原雅弘, 堀利匡, 堀充希, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "電子蓄積リングにおける電子散乱実験の制動輻射を用いたルミノシティ測定", 日本物理学会, 3月, 大阪大学, 大阪(2017).
- 塚田暁, 足立江介, 市川進一, 榎園昭智, 大西哲哉, 笠間桂太, 栗田和好, 笹村新之介, 須田利美, 玉江忠明, 戸ヶ崎衛, 南波和希, 原雅弘, 藤田峻広, 堀利匡, 堀充希, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "SCRIT法を用いた¹³²Xeの電荷分布測定", 日本物理学会, 9月, 宮崎大学, 宮崎(2016).
- 藤田峻広, 足立江介, 市川進一, 榎園昭智, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 塚田暁, 戸ヶ崎衛, 原雅弘, 堀利匡, 堀充希, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "SCRIT 法を用いた Xe 同位体標的・電子散乱実験における ルミノシティ測定", 日本物理学会, 9月, 宮崎大学, 宮崎(2016).
- 塚田暁, 足立江介, 市川進一, 榎園昭智, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 水流輝明, 戸ヶ崎衛, 原雅弘, 藤田峻広, 堀利匡, 堀充希, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "SCRIT法を用いたXe同位体標的における電子散乱の角度分布測定", 日本物理学会, 3月, 東北学院大, 仙台(2016).
- 榎園昭智, 足立江介, 市川進一, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 塚田暁, 水流輝明, 戸ヶ崎衛, 原雅弘, 藤田峻広, 堀利匡, 堀充希, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "SCRIT法を用いた電子・不安定Xe核散乱実験におけるルミノシティの測定", 日本物理学会, 3月, 東北学院大, 仙台(2016).
- 塚田暁, 市川進一, 榎園昭智, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 水流輝明, 戸ヶ崎衛, 原雅弘, 藤田峻広, 堀利匡, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "SCRIT 法を用いた電子・不安定核散乱実験に向けた電子スペクトロメータのアクセプタンス評価", 日本物理学会, 9月, 大阪市立大, 大阪(2015).
- 榎園昭智, 足立江介, 市川進一, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 塚田暁, 水流輝明, 戸ヶ崎衛, 原雅弘, 藤田峻広, 堀利匡, 松田一衛, 山田耕平, 若杉昌徳, 渡邊正満, "SCRIT 法を用いた電子・不安定核散乱実験に向けたルミノシティ決定精度の評価", 日本物理学会, 9月, 大阪市立大, 大阪(2015).
- 戸ヶ崎衛, 大西哲哉, 栗田和好, 鳥羽僚太, 原雅弘, 山田耕平, 若杉昌徳, "イオンビームクーラー・バンチャーの開発", 日本物理学会, 9月, 大阪市立大, 大阪(2015).
- 塚田暁, 市川進一, 榎園昭智, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 水流輝明, 戸ヶ崎衛, 堀利匡, 原雅弘, 松尾咲希, 松田一衛, 森谷洋祐, 米山俊平, 若杉昌徳, "SCRIT 電子スペクトロメータの運動量分解能とアクセプタンス評価", 日本物理学会, 3月, 早稲田大, 東京(2015).
- 米山俊平, 榎園昭智, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 塚田暁, 水流輝明, 戸ヶ崎衛, 松尾咲希, 松田一衛, 森谷洋祐, 若杉昌徳, "SCRIT 実験用ルミノシティモニター", 日本物理学会, 3月, 早稲田大, 東京(2015).
- 松尾咲希, 市川進一, 榎園昭智, 大西哲哉, 栗田和好, 須田利美, 玉江忠明, 塚田暁, 水流輝明, 戸ヶ崎衛, 原雅弘, 堀利匡, 松田一衛, 森谷洋祐, 米山俊平, 若杉昌徳, "SCRIT 実験における散乱電子スペクトロメータの開発", 日本物理学会, 3月, 早稲田大, 東京(2015).

Posters Presentations

[International Conference etc.]

- M. Togasaki, K. Kurita, K. Yamada, R. Toba, M. Hara, T. Ohnishi, and M. Wakasugi, "Development of a buffer-gas-free buncher for low energy RI ion beam", 13th Int. Conf. on Heavy Ion Accelerator Technology HIAT2015, Sep. 7-11, Yokohama, Japan (2015).
- T. Ohnishi, S. Ichikawa, and M. Wakasugi, "Electron-beam-driven RI separator for SCRIT at RIKEN RI Beam Factory", 13th Int. Conf. on Heavy Ion Accelerator Technology HIAT2015, Sep. 7-11, Yokohama, Japan (2015).

RIBF Research Division Research Instruments Group

1. Abstract

The Research Instruments Group is the driving force at RI Beam Factory (RIBF) for continuous enhancement of activities and competitiveness of experimental research. Consisting of four teams, we are in charge of the operation, maintenance, and improvement of the core research instruments at RIBF, such as the BigRIPS in-flight RI separator, ZeroDegree spectrometer and SAMURAI spectrometer, and the related infrastructure and equipment. We are also in charge of the production and delivery of RI beams using the BigRIPS separator. The group also conducts related experimental research as well as R&D studies on the research instruments.

2. Major Research Subjects

Design, construction, operation, maintenance, and improvement of the core research instruments at RIBF and related R&D studies. Experimental studies on exotic nuclei.

3. Summary of Research Activity

The current research subjects are summarized as follows:

- (1) Production and delivery of RI beams and related research
- (2) Design, construction, operation, maintenance, and improvement of the core research instruments at RIBF and their related infrastructure and equipment
- (3) R&D studies on the core research instruments and their related equipment at RIBF
- (4) Experimental research on exotic nuclei using the core research instruments at RIBF

Members

Group Directors

Toshiyuki KUBO (– Mar. 31, 2016)
Hideki UENO (Apr. 1, 2016 –)

Junior Research Associates

Daichi MURAI (Rikkyo Univ.)

Momo MUKAI (Tsukuba Univ.)

Special Temporary Employee

Toshiyuki KUBO

Senior Visiting Scientists

Toshio KOBAYASHI (Tohoku Univ.)

Jerry NOLEN (Argonne National Lab.)

Visiting Scientist

Toshiyuki KUBO (Michigan State Univ.)

Student Trainee

Katrina Elizabeth KOEHLER (West Michigan University)

RIBF Research Division

Research Instruments Group

BigRIPS Team

1. Abstract

This team is in charge of design, construction, development and operation of BigRIPS in-flight separator and its related research instruments at RI beam factory (RIBF). They are employed not only for the production of RI beams but also the experimental studies using RI beams.

2. Major Research Subjects

Design, construction, development and operation of BigRIPS in-flight separator, RI-beam transport lines, and their related research instruments

3. Summary of Research Activity

This team is in charge of design, construction, development and operation of BigRIPS in-flight separator, RI-beam transport lines, and their related research instruments such as ZeroDegree spectrometer at RI beam factory (RIBF). They are employed not only for the production of RI beams but also various kinds of experimental studies using RI beams.

The research subjects may be summarized as follows:

- (1) General studies on RI-beam production using in-flight scheme.
- (2) Studies on ion-optics of in-flight separators, including particle identification of RI beams
- (3) Simulation and optimization of RI-beam production.
- (4) Development of beam-line detectors and their data acquisition system.
- (5) Experimental studies on production reactions and unstable nuclei.
- (6) Experimental studies of the limits of nuclear binding.
- (7) Development of superconducting magnets and their helium cryogenic systems.
- (8) Development of a high-power production target system.
- (9) Development of a high-power beam dump system.
- (10) Development of a remote maintenance and remote handling systems.
- (11) Operation, maintenance and improvement of BigRIPS separator system, RI-beam transport lines, and their related research instruments such as ZeroDegree spectrometer and so on.
- (12) Experimental research using RI beams.

Members

Team Leader

Koichi YOSHIDA

Research & Technical Scientists

Yoshiyuki YANAGISAWA (Senior Research Scientist)
Naohito INABE (Senior Technical Scientist)

Masao OHTAKE (Senior Technical Scientist)

Nishina Center Research Scientists

Hiroyuki TAKEDA
Kensuke KUSAKA

Naoki FUKUDA

Contract Researchers

Toshiyuki SUMIKAMA
Hiroshi SUZUKI

Yohei SHIMIZU

Postdoctoral Researchers

Deuk Soon AHN

Zeren KORKULU

Research Consultant

Hidekazu KUMAGAI

Part-time Worker

Tetsuro Komatsubara

Senior Visiting Scientist

Jerry NOLEN (Argonne National Lab.)

Visiting Scientists

Daisuke KAMEDA (TOSHIBA Corp.)
 Michael A. FAMIANO (Western Michigan Univ.)
 Daniel Pierre BAZIN (NSCL, MSU)
 Oleg Borisovich TARASOV (NSCL, MSU)
 Hans GEISSEL (GSI)
 David Joseph MORRISSEY (NSCL, MSU)
 Bradley Marc SHERRILL (NSCL, MSU)
 Martin Alfred WINKLER (GSI)

Mauricio PORTILLO (NSCL, MSU)
 Alan Matthew AMTHOR (Bucknell Univ.)
 Tuomas Arne Santeri GRAHN (Univ. of Jyväskylä)
 Alfredo ESTRADA VAZ (Central Michigan Univ.)
 Yutaka MIZOI (Osaka Elec.-Com. Univ.)
 Naohito IWASA (Tohoku Univ.)
 Sadao MOMOTA (Kochi Univ. of Tech.)
 Kazuo IEKI (Rikkyo Univ.)

Student Trainees

Daichi MURAI (Rikkyo Univ.)
 Ha JEONGSU (Seoul National Univ.)
 Kousei ASADA (Tohoku Univ.)

Junki AMANO (Rikkyo Univ.)
 Takahiro SAKAKIBARA (Tohoku Univ.)
 Shunki ISHIKAWA (Tohoku Univ.)

List of Publications & Presentations**Publications**

[Journal]

(Original Papers) *Subject to Peer Review

- B. Blank, T. Goigoux, P. Ascher, M. Gerbaux, J. Giovinozzo, S. Grévy, T. Kurtukian Nieto, C. Magron, J. Agramunt, A. Algora, V. Guadilla, A. Montaner-Piza, A. I. Morales, S. E. A. Orrigo, B. Rubio, D. S. Ahn, P. Doornenbal, N. Fukuda, N. Inabe, G. Kiss, T. Kubo, S. Kubono, S. Nishimura, V. H. Phong, H. Sakurai, Y. Shimizu, P.-A. Söderström, T. Sumikama, H. Suzuki, H. Takeda, J. Wu, Y. Fujita, M. Tanaka, W. Gelletly, P. Aguilera, F. Molina, F. Diel, D. Lubos, G. de Angelis, D. Napoli, C. Borcea, A. Boso, R. B. Cakirli, E. Ganioglu, J. Chiba, D. Nishimura, H. Oikawa, Y. Takei, S. Yagi, K. Wimmer, G. de France, and S. Go, "New neutron-deficient isotopes from ^{78}Kr fragmentation", *Physical Review C* 93, 061301(R), (2016).*
- A. Jungclaus, A. Gargano, H. Grawe, J. Taprogge, S. Nishimura, P. Doornenbal, G. Lorusso, Y. Shimizu, G. S. Simpson, P.-A. Söderström, T. Sumikama, Z. Y. Xu, H. Baba, F. Browne, N. Fukuda, R. Gernhäuser, G. Gey, N. Inabe, T. Isobe, H. S. Jung, D. Kameda, G. D. Kim, Y.-K. Kim, I. Kojouharov, T. Kubo, N. Kurz, Y. K. Kwon, Z. Li, H. Sakurai, H. Schaffner, K. Steiger, H. Suzuki, H. Takeda, Zs. Vajta, H. Watanabe, J. Wu, A. Yagi, K. Yoshinaga, S. Bönig, L. Coraggio, J.-M. Daugas, F. Drouet, A. Gadea, S. Ilieva, N. Itaco, T. Kröll, A. Montaner-Pizá, K. Moschner, D. Mücher, H. Nishibata, A. Odahara, R. Orlandi, and A. Wendt, "First observation of γ rays emitted from excited states south-east of ^{132}Sn : The $\pi g_{7/2}^{-1} \otimes \nu f_{7/2}$ multiplet of $^{132}\text{In}_{83}$ ", *Physical Review C* 93, 041301(R), (2016).*
- R. Lozeva, H. Naïdja, F. Nowacki, J. Dudek, A. Odahara, C.-B. Moon, S. Nishimura, P. Doornenbal, J.-M. Daugas, P.-A. Söderström, T. Sumikama, G. Lorusso, J. Wu, Z. Y. Xu, H. Baba, F. Browne, R. Daido, Y. Fang, T. Isobe, I. Kojouharov, N. Kurz, Z. Patel, S. Rice, H. Sakurai, H. Schaffner, L. Sinclair, H. Watanabe, A. Yagi, R. Yokoyama, T. Kubo, N. Inabe, H. Suzuki, N. Fukuda, D. Kameda, H. Takeda, D. S. Ahn, D. Murai, F. L. Bello Garrote, F. Didierjean, E. Ideguchi, T. Ishigaki, H. S. Jung, T. Komatsubara, Y. K. Kwon, P. Lee, C. S. Lee, S. Morimoto, M. Niikura, H. Nishibata, and I. Nishizuka, "New isomer found in $^{140}_{51}\text{Sb}_{89}$: Sphericity and shell evolution between $N=82$ and $N=90$ ", *Physical Review C* 93, 014316, (2016).*
- N. Kobayashi, T. Nakamura, Y. Kondo, J. A. Tostevin, N. Aoi, H. Baba, R. Barthelemy, M. A. Famiano, N. Fukuda, N. Inabe, M. Ishihara, R. Kanungo, S. Kim, T. Kubo, G. S. Lee, H. S. Lee, M. Matsushita, T. Motobayashi, T. Ohnishi, N. A. Orr, H. Otsu, T. Sako, H. Sakurai, Y. Satou, T. Sumikama, H. Takeda, S. Takeuchi, R. Tanaka, Y. Togano, and K. Yoneda, "One-neutron removal from ^{29}Ne : Defining the lower limits of the island of inversion", *Physical Review C* 93, 014613, (2016).*
- A. Jungclaus, H. Grawe, S. Nishimura, P. Doornenbal, G. Lorusso, G. S. Simpson, P.-A. Söderström, T. Sumikama, J. Taprogge, Z. Y. Xu, H. Baba, F. Browne, N. Fukuda, R. Gernhäuser, G. Gey, N. Inabe, T. Isobe, H. S. Jung, D. Kameda, G. D. Kim, Y.-K. Kim, I. Kojouharov, T. Kubo, N. Kurz, Y. K. Kwon, Z. Li, H. Sakurai, H. Schaffner, Y. Shimizu, K. Steiger, H. Suzuki, H. Takeda, Zs. Vajta, H. Watanabe, J. Wu, A. Yagi, K. Yoshinaga, G. Benzoni, S. Bönig, K. Y. Chae, L. Coraggio, J.-M. Daugas, F. Drouet, A. Gadea, A. Gargano, S. Ilieva, N. Itaco, F. G. Kondev, T. Kröll, G. J. Lane, A. Montaner-Pizá, K. Moschner, D. Mücher, F. Naqvi, M. Niikura, H. Nishibata, A. Odahara, R. Orlandi, Z. Patel, Zs. Podolyák, and A. Wendt, " β decay of semi-magic ^{130}Cd : Revision and extension of the level scheme of ^{130}In ", *Physical Review C* 94, 024303, (2016).*
- I. Čeliković, M. Lewitowicz, R. Gernhäuser, R. Krücken, S. Nishimura, H. Sakurai, D.S. Ahn, H. Baba, B. Blank, A. Blazhev, P. Boutachkov, F. Browne, G. de France, P. Doornenbal, T. Faestermann, Y. Fang, N. Fukuda, J. Giovinozzo, N. Goel, M. Górská, S. Ilieva, N. Inabe, T. Isobe, A. Jungclaus, D. Kameda, Y.-K. Kim, Y. K. Kwon, I. Kojouharov, T. Kubo, N. Kurz, G. Lorusso, D. Lubos, K. Moschner, D. Murai, I. Nishizuka, J. Park, Z. Patel, M. Rajabali, S. Rice, H. Schaffner, Y. Shimizu, L. Sinclair, P.-A. Söderström, K. Steiger, T. Sumikama, H. Suzuki, H. Takeda, Z. Wang, H. Watanabe, J. Wu, and Z. Xu, "New Isotopes and Proton Emitters—Crossing the Drip Line in the Vicinity of ^{100}Sn ", *Physical Review Letters* 116, 162501, (2016).*
- Y. Kondo, T. Nakamura, R. Tanaka, R. Minakata, S. Ogoshi, N. A. Orr, N. L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, J. Gibelin, J. W. Hwang, N. Inabe, T. Isobe, D. Kameda, D. Kanno, S. Kim, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F. M. Marqués, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, H. Otsu, H. Sato, Y. Satou, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, Y. Togano, A. G. Tuff, M. Vandebrouck, and K. Yoneda, "Nucleus ^{26}O : A Barely Unbound System beyond the Drip Line", *Physical Review Letters* 116, 102503, (2016).*
- K. Kisamori, S. Shimoura, H. Miya, S. Michimasa, S. Ota, M. Assie, H. Baba, T. Baba, D. Beaumel, M. Dozono, T. Fujii, N. Fukuda, S. Go, F. Hammache, E. Ideguchi, N. Inabe, M. Itoh, D. Kameda, S. Kawase, T. Kawabata, M. Kobayashi, Y. Kondo, T. Kubo, Y. Kubota, M. Kurata-Nishimura, C. S. Lee, Y. Maeda, H. Matsubara, K. Miki, T. Nishi, S. Noji, S. Sakaguchi, H. Sakai, Y. Sasamoto, M. Sasano, H. Sato, Y. Shimizu, A. Stolz, H. Suzuki, M. Takaki, H. Takeda, S. Takeuchi, A. Tamii, L. Tang, H. Tokieda, M. Tsumura, T. Uesaka, K. Yako, Y. Yanagisawa, R. Yokoyama, and K. Yoshida, "Candidate Resonant Tetraneutron State Populated by the $^4\text{He}(\text{He}, \text{Be})$ Reaction", *Physical Review Letters* 116, 052501, (2016).*
- T. Goigoux, P. Ascher, B. Blank, M. Gerbaux, J. Giovinozzo, S. Grévy, T. Kurtukian Nieto, C. Magron, P. Doornenbal, G. G. Kiss, S. Nishimura,

- P.-A. Söderström, V. H. Phong, J. Wu, D. S. Ahn, N. Fukuda, N. Inabe, T. Kubo, S. Kubono, H. Sakurai, Y. Shimizu, T. Sumikama, H. Suzuki, H. Takeda, J. Agramunt, A. Algora, V. Guadilla, A. Montaner-Piza, A. I. Morales, S. E. A. Orrigo, B. Rubio, Y. Fujita, M. Tanaka, W. Gelletly, P. Aguilera, F. Molina, F. Diel, D. Lubos, G. de Angelis, D. Napoli, C. Borcea, A. Boso, R. B. Cakirli, E. Ganioglu, J. Chiba, D. Nishimura, H. Oikawa, Y. Takei, S. Yagi, K. Wimmer, G. de France, S. Go, and B. A. Brown, "Two-Proton Radioactivity of ^{67}Kr ", *Physical Review Letters* 117, 162501, (2016).*
- Z. Patel, Zs. Podolyák, P.M. Walker, P.H. Regan, P.-A. Söderström, H. Watanabe, E. Ideguchi, G.S. Simpson, S. Nishimura, F. Browne, P. Doornenbal, G. Lorusso, S. Rice, L. Sinclair, T. Sumikama, J. Wu, Z.Y. Xu, N. Aoi, H. Baba, F.L. Bello Garrote, G. Benzoni, R. Daido, Zs. Dombrádi, Y. Fang, N. Fukuda, G. Gey, S. Go, A. Gottardo, N. Inabe, T. Isobe, D. Kameda, K. Kobayashi, M. Kobayashi, T. Komatsubara, I. Kojouharov, T. Kubo, N. Kurz, I. Kuti, Z. Li, H.L. Liu, M. Matsushita, S. Michimasa, C.-B. Moon, H. Nishibata, I. Nishizuka, A. Odahara, E. Şahin, H. Sakurai, H. Schaffner, H. Suzuki, H. Takeda, M. Tanaka, J. Taprogge, Zs. Vajta, F.R. Xu, A. Yagi, R. Yokoyama, "Decay spectroscopy of ^{160}Sm : The lightest four-quasiparticle K isomer", *Physics Letter B* 753, 182, (2016).*
- H. Wang, H. Otsu, H. Sakurai, D.S. Ahn, M. Aikawa, P. Doornenbal, N. Fukuda, T. Isobe, S. Kawakami, S. Koyama, T. Kubo, S. Kubono, G. Lorusso, Y. Maeda, A. Makinaga, S. Momiyama, K. Nakano, M. Niikura, Y. Shiga, P.-A. Söderström, H. Suzuki, H. Takeda, S. Takeuchi, R. Taniuchi, Ya. Watanabe, Yu. Watanabe, H. Yamasaki, K. Yoshida, "Spallation reaction study for fission products in nuclear waste: Cross section measurements for ^{137}Cs and ^{90}Sr on proton and deuteron", *Physics. Letter B* 754, 104, (2016).*
- H. Watanabe, G.X. Zhang, K. Yoshida, P.M. Walker, J.J. Liu, J. Wu, P.H. Regan, P.-A. Söderström, H. Kanaoka, Z. Korkulu, P.S. Lee, S. Nishimura, A. Yagi, D.S. Ahn, T. Alharbi, H. Baba, F. Browne, A.M. Bruce, R.J. Carroll, K.Y. Chae, Zs. Dombradi, P. Doornenbal, A. Estrade, N. Fukuda, C. Griffin, E. Ideguchi, N. Inabe, T. Isobe, S. Kanaya, I. Kojouharov, F.G. Kondev, T. Kubo, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G.J. Lane, C.S. Lee, E.J. Lee, G. Lorusso, G. Lotay, C.-B. Moon, I. Nishizuka, C.R. Nita, A. Odahara, Z. Patel, V.H. Phong, Zs. Podolyák, O.J. Roberts, H. Sakurai, H. Schaffne, C.M. Shand, Y. Shimizu, T. Sumikama, H. Suzuki, H. Takeda, S. Terashima, Zs. Vajta, J.J. Valiente-Dóbon, Z.Y. Xu, "Long-lived K isomer and enhanced γ vibration in the neutron-rich nucleus ^{172}Dy : Collectivity beyond double midshell", *Physics Letter B* 760, 641, (2016).*
- Y. Togano, T. Nakamura, Y. Kondo, J.A. Tostevin, A.T. Saito, J. Gibelin, N.A. Orr, N.L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, J.W. Hwang, N. Inabe, T. Isobe, D. Kameda, D. Kanno, S. Kim, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F.M. Marqués, R. Minakata, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, S. Ogoshi, H. Otsu, H. Sato, Y. Satou, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, R. Tanaka, A.G. Tuff, M. Vandebrouck, K. Yoneda, "Interaction cross section study of the two-neutron halo nucleus ^{22}C ", *Physics Letter B* 761, 412, (2016).*
- P.-A. Söderström, P.M. Walker, J. Wu, H.L. Liu, P.H. Regan, H. Watanabe, P. Doornenbal, Z. Korkulu, P. Lee, J.J. Liu, G. Lorusso, S. Nishimura, V.H. Phong, T. Sumikama, F.R. Xu, A. Yagi, G.X. Zhang, D.S. Ahn, T. Alharbi, H. Baba, F. Browne, A.M. Bruce, R.J. Carroll, K.Y. Chae, Zs. Dombradi, A. Estrade, N. Fukuda, C.J. Griffin, E. Ideguchi, N. Inabe, T. Isobe, H. Kanaoka, S. Kanaya, I. Kojouharov, F.G. Kondev, T. Kubo, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G.J. Lane, E.J. Lee, C.S. Lee, G. Lotay, C.-B. Moon, I. Nishizuka, C.R. Niță, A. Odahara, Z. Patel, Zs. Podolyák, O.J. Roberts, H. Sakurai, H. Schaffner, C.M. Shand, H. Suzuki, H. Takeda, S. Terashima, Zs. Vajta, J.J. Valiente-Dóbon, Z.Y. Xu, " K -mixing in the doubly mid-shell nuclide ^{170}Dy and the role of vibrational degeneracy", *Physics Letter. B* 762, 404, (2016).*
- J. Taprogge, A. Jungclauss, H. Grawe, I. N. Borzov, S. Nishimura, P. Doornenbal, G. Lorusso, G. S. Simpson, P.-A. Söderström, T. Sumikama, Z. Y. Xu, H. Baba, F. Browne, N. Fukuda, R. Gernhäuser, G. Gey, N. Inabe, T. Isobe, H. S. Jung, D. Kameda, G. D. Kim, Y. -K. Kim, I. Kojouharov, T. Kubo, N. Kurz, Y. K. Kwon, Z. Li, H. Sakurai, H. Schaffner, Y. Shimizu, K. Steiger, H. Suzuki, H. Takeda, Zs. Vajta, H. Watanabe, J. Wu, A. Yagi, K. Yoshinaga, G. Benzoni, S. Bönig, K. Y. Chae, L. Coraggio, J. -M. Daugas, F. Drouet, A. Gadea, A. Gargano, S. Ilieva, N. Itaco, F. G. Kondev, T. Kröll, G. J. Lane, A. Montaner-Pizá, K. Moschner, D. Mücher, F. Naqvi, M. Niikura, H. Nishibata, A. Odahara, R. Orlandi, Z. Patel, Zs. Podolyák, and A. Wendt, "Proton-hole and core-excited states in the semi-magic nucleus $^{131}\text{In}_{\pi 2}$ ", *European Physics Journal A* 52, 347, (2016).*

[Proceedings]

(Original Papers) *Subject to Peer Review

- T. Kubo, "Recent progress of in-flight separators and rare isotope beam production", *Nuclear Instruments & Methods B* 376, 102 (2016).*
- T. Sumikama, D.S. Ahn, N. Fukuda, N. Inabe, T. Kubo, Y. Shimizu, H. Suzuki, H. Takeda, N. Aoi, D. Beaumel, K. Hasegawa, E. Ideguchi, N. Imai, T. Kobayashi, M. Matsushita, S. Michimasa, H. Otsu, S. Shimoura, T. Teranishi, "First test experiment to produce the slowed-down RI beam with the momentum-compression mode at RIBF", *Nuclear Instruments & Methods B* 376, 180 (2016).*

Oral Presentations

[International Conference etc.]

- K. Yoshida, "Preset Status of the target and beam dump system at BigRIPS fragment separator", The 6th High Power targetry Workshop, Oxford, UK, April 11 – 15, 2016.
- Z. Korkulu, "ANSYS code calculations of the beam spot temperature at BigRIPS separator", The 6th High Power targetry Workshop, Oxford, UK, April 11 – 15, 2016.
- N. Fukuda, "Operational Experiences with BigRIPS", 6th Fragment Separator Expert Meeting, Grand Rapids, MI, USA, August 30 – September 1, 2016.
- H. Suzuki, "Ion optics development-1 (high resolution PID mode)", 6th Fragment Separator Expert Meeting, Grand Rapids, MI, USA, August 30 – September 1, 2016.
- H. Takeda, "Ion optical developments at BigRIPS -Additive and Subtractive Modes", 6th Fragment Separator Expert Meeting, Grand Rapids, MI, USA, August 30 – September 1, 2016.
- K. Yoshida, "High-power Issues: Status and Simulations", 6th Fragment Separator Expert Meeting, Grand Rapids, MI, USA, August 30 – September 1, 2016.
- Y. Shimizu, "Production yields and cross sections at the BigRIPS separator", 6th Fragment Separator Expert Meeting, Grand Rapids, MI, USA, August 30 – September 1, 2016.
- Y. Shimizu, "New isotope search in the EURICA campaign at RIKEN RIBF", EURICA Celebration and Collaboration Meeting, RIKEN, Wako, Saitama, Japan, September 6, 2016.

[Domestic Conference]

- 小山俊平, 大津秀暁, 清水陽平, 米田健一郎, 佐藤広海, 本林透, 西村美月, 銭廣十三, 櫻井博儀, 武内聡, 磯部忠昭, 馬場秀忠, 日下健祐, 大西純一, 笹野匡紀, P. Doornenbal, 福田直樹, 小林俊雄, 炭竈聡之, 松田洋平, 佐藤義輝, J. Hwang, 近藤洋介, 中村隆司, 梅野泰宏, 南方亮吾, 生越駿, 村上哲也, 中塚徳継, J. Gibelin, L. Sylvain, 新倉潤, 小林信之, H. Liu, J. Lee, E. Nikolskii, 坂口聡志, D. Beaumel, 「不変質量法を用いた ^{16}C のクラスター状態の研究」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 市川雄一, 高峰愛子, 西畑洗希, 今村慧, 藤田朋美, 佐藤智哉, 靱山悟至, 清水陽平, D.S.Ahn, 旭耕一郎, 馬場秀忠, D.L.Balabanski, F.Boulay, J.M.Daugas, 江上魁, 福田直樹, 舟山智歌子, 古川武, G.Georgiev, A.Gladkov, 稲辺尚人, 石橋陽子, 小林義男, 小島修一郎, A.Kusoglu, 川口高史, 河村嵩之, I.Mukul, 新倉潤, 西坂太志, 小田原厚子, 大友祐一, D.Ralet, 下田正, G.S.Simpson, 炭竈聡之, 鈴木宏, 竹田浩之, L.C.Tao, 梅野泰宏, 富永大樹, 上野秀樹, 山崎展樹, X.F.Yang, 「中性子過剰核 ^{75}Cu のアイソマー状態の核磁気モーメント」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 武内聡, 四方瑞紀, 中村隆司, 梅野泰宏, 近藤洋介, 坪田潤一, 尾崎友志, 齊藤敦美, 大津秀暁, Wang He, 渡辺幸信, 川瀬頌一郎, ImpACT-RIBF コラボレーション, 「クローン分解反応による $^{107,108}\text{Pd}$ および $^{93,94}\text{Zr}$ の光吸収断面積」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 阿部康志, 山口由高, 上坂友洋, 小沢顕, 洲崎ふみ, 山口貴之, 若杉昌徳, 稀少 RI リングコラボレーション, 「稀少 RI リングの性能評価」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- T. L. Tang, S. Kawase, T. Uesaka, D. Beaumel, M. Dozono, T. Fujii, N. Fukada, T. Fukunaga, A. Galinda-Urbarri, S. H. Hwang, N. Inabe, D. Kameda, T. Kawahara, W. Y. Kim, K. Kismori, M. Kobayashi, T. Kubo, Y. Kubota, K. Kusaka, C. S. Lee, Y. Maeda, H. Matsubara, S. Michimasa, H. Miya, T. Noro, A. Obertelli, S. Ota, E. Padilla-Rodal, S. Sakaguchi, H. Sakai, M. Sasano, S. Shimoura, S. S. Stepanyan, H. Suzuki, M. Takaki, H. Takeda, H. Tokieda, T. Wakasa, T. Wakui, K. Yako, Y. Yanagisawa, J. Yasuda, R. Yokoyama, K. Yoshia, and J. Zenihiro, "Quasi-free proton knockout of $^{23,25}\text{F}$ ", 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 村井大地, 家城和夫, 久保敏幸, 稲辺尚人, 福田直樹, 竹田浩之, 鈴木宏, 安得順, 清水陽平, 佐藤広海, 佐藤優樹, 日下健祐, 柳澤善行, 大竹政雄, 吉田光一, 大津秀暁, 岩佐直仁, 中村隆司, Oleg B. Tarasov, Brad M. Sherrill, Dave J. Morrissey, Hans Geissel, 「大強度 ^{48}Ca ビームを用いた中性子ドリップライン探索 II」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 清川裕, 道正新一郎, 小林幹, 西村太樹, 横山輪, 小林和馬, 水上淳, 笈川浩之, 馬場秀忠, G.P.A. Berg, 堂園昌伯, 福田直樹, 古野達也, 井手口栄治, 稲辺尚人, 川畑貴裕, 川瀬頌一郎, 木佐森慶一, 久保敏幸, 久保田悠樹, 李清秀, 松下昌史, 宮裕之, 永倉弘康, 大田晋輔, 酒井英行, 下浦享, A. Stolz, 鈴木宏, 高木基伸, 竹田浩之, 武内聡, 時枝紘史, 上坂友洋, 矢向謙太郎, 山口勇貴, 柳澤善行, 吉田光一, 「SHARAQ における中性子過剰 ^{90}Se 近傍核の核異性体 γ 線分光」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 安田淳平, 笹野匡紀, R.G.T. Zegars, 馬場秀明, W. Chao, 福田直樹, 稲辺尚人, 磯部忠明, G. Jhang, 亀田大輔, 久保敏幸, 西村美月, E. Milman, 本林透, 大津秀暁, V. Panin, W. Powell, 酒井英行, 酒向正巳, 佐藤広海, 清水陽平, L. Stuhl, 鈴木宏, S. Tangwancharoen, 竹田浩之, 上坂友洋, 米田健一郎, 銭廣十三, 小林俊雄, 炭竈聡之, 田高義, 中村隆司, 近藤洋介, 梅野泰宏, 四方瑞紀, 坪田潤一, 矢向謙太郎, 下浦享, 大田晋輔, 川瀬頌一郎, 久保田悠樹, 高木基伸, 道正新一郎, 木佐森慶一, 李清秀, 時枝紘史, 堂園昌伯, 小林幹, 小山俊平, 小林信之, 若狭智嗣, 坂口聡, A. Krasznahorkay, 村上哲也, 中塚徳継, 金子雅紀, 松田洋平, D. Mucher, S. Reichert, D. Bazin, J.W. Lee, 「 $^{132}\text{Sn}(p,n)$ 反応によるガモフテラー遷移の研究」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 尾崎友志, 中村隆司, 武内聡, 近藤洋介, 梅野泰宏, 四方瑞紀, 坪田潤一, 齊藤敦美, 大津秀暁^A, 王赫^A, 渡辺幸信^B, 他 ImpACT-RIBF コラボレーション, 「 ^{238}U の飛行核分裂によって生成される ^{107}Pd , ^{79}Se のアイソマー比」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 秋枝智美, 関口仁子, 和田泰敬, 江藤大二郎, 渡邊跡武, 今紘史, 坂本成彦, 酒井英行, 上坂友洋, 鈴木宏, 柳澤善行, 堂園昌伯, 久保田悠樹, 若狭智嗣, 坂口聡志, 安田淳平, 進藤佑輔, 田端心海, 大倉綾華, 前田幸重, 川上駿介, 山本達也, Evgeniy Milman, Sergey Chebotaryov, 「186.6 MeV/nucleon 重陽子-陽子弾性散乱における重陽子偏極分解能測定と三体力」, 日本物理学会 第 71 回年次大会(2016), 東北学院大学、宮城県、3/19 – 22, 2016.
- 小林幹, 道正新一郎, 清川裕, 馬場秀忠^A, G.P.A. Berg^B, 堂園昌伯, 福田直樹^A, 古野達也^C, 井手口栄治^D, 稲辺尚人^A, 川畑貴裕^C, 川瀬頌一郎, 木佐森慶一, 小林和馬^E, 久保敏幸^A, 久保田悠樹, 李清秀, 松下昌史, 宮裕之, 水上淳^F, 永倉弘康^E, 西村太樹^F, 笈川浩之^F, 大田晋輔, 酒井英行^A, 下浦享, A. Stolz^G, 鈴木宏^A, 高木基伸, 竹田浩之^A, 武内聡^A, 時枝紘史, 上坂友洋^A, 矢向謙太郎, 山口勇貴^E, 柳澤善行^A, 横山輪, 吉田光一, 「飛行時間法を用いた中性子数 34 近傍 Ca 同位体の質量測定」, 日本物理学会 2016 年秋季大会, 宮崎大学、宮崎県、9/21 – 24, 2016.
- 横山輪, 井手口栄治, G. Simpson, 田中まな, 西村俊二, P. Doornenbal, P-A Söderström, G. Lorusso, Z. Y. Xu, J. Wu, 炭竈聡之, 青井考, 馬場秀忠, F. Bello, F. Browne, 大道理恵, Y. Fang, 福田直樹, G. Gey, 郷慎太郎, 稲辺尚人, 磯部忠昭, 亀田大輔, 小林和馬, 小林幹, 小松原哲郎, 久保敏幸, I. Kuti, Z. Li, 松下昌史, 道正新一郎, C.-B. Moon, 西畑洗希, 西塚一平, 小田原厚子, Z. Patel, S. Rice, Sahin, L. Sinclair, 鈴木宏, 竹田浩之, J. Taprogge, E. Z. Vajta, 渡邊寛, 八木彩祐未, 「中性子過剰 Nd 同位体の変形進化における十六重極変形の効果」, 日本物理学会 2016 年秋季大会, 宮崎大学、宮崎県、9/21 – 24, 2016.

RIBF Research Division

Research Instruments Group

SAMURAI Team

1. Abstract

In collaboration with research groups in and outside RIKEN, the team designs, develops and constructs the SAMURAI spectrometer and relevant equipment that are and will be used for reaction experiments using RI beams at RI Beam Factory. The SAMURAI spectrometer consists of a large superconducting dipole magnet and a variety of detectors to measure charged particles and neutrons. After the commissioning experiment in March 2012, the team prepared and conducted, in collaboration with researchers in individual experimental groups, the first series of experiments with SAMURAI in May 2012. Then, several numbers of experiments were well performed until now utilizing the property of SAMURAI. The team also provides basis for research activities by, for example, organizing collaboration workshops by researchers who are interested in studies or plan to perform experiments with the SAMURAI spectrometer.

2. Major Research Subjects

Design, operation, maintenance and improvement of the SAMURAI spectrometer and its related research instruments. Support and management for SAMURAI-based research programs.

3. Summary of Research Activity

The current research subjects are summarized as follows:

- (1) Operation, maintenance and improvement of a large superconducting dipole magnet that is the main component of the SAMURAI spectrometer
- (2) Design, development and construction of various detectors that are used for nuclear reaction experiments using the SAMURAI spectrometer.
- (3) Preparation for planning experiments using SAMURAI spectrometer.
- (4) Maintenance and improvement of the SAMURAI beam line.
- (5) Formation of a collaboration platform called "SAMURAI collaboration"

Members

Team Leader

Hideaki OTSU

List of Publications & Presentations

Publications

[Journal]

(Original Papers)

- J.W. Hwang, S. Kim, Y. Satou, N.A. Orr, Y. Kondo, T. Nakamura, J. Gibelin, N.L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, N. Inabe, T. Isobe, D. Kameda, D. Kanno, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F.M. Marqués, R. Minakata, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, S. Ogoshi, H. Otsu, H. Sato, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, R. Tanaka, Y. Togano, A.G. Tuff, M. Vandebrouck, K. Yoneda, "Single-neutron knockout from ^{20}C and the structure of ^{19}C ", *Phys. Lett. B* 769, 503 (2017).
- Y. Togano, T. Nakamura, Y. Kondo, J.A. Tostevin, A.T. Saito, J. Gibelin, N.A. Orr, N.L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, J.W. Hwang, N. Inabe, T. Isobe, D. Kameda, D. Kanno, S. Kim, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F.M. Marqués, R. Minakata, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, S. Ogoshi, H. Otsu, H. Sato, Y. Satou, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, R. Tanaka, A.G. Tuff, M. Vandebrouck, K. Yoneda, "Interaction cross section study of the two-neutron halo nucleus ^{22}C ", *Phys. Lett. B* 761, 412 (2016).
- Y. Kondo, T. Nakamura, R. Tanaka, R. Minakata, S. Ogoshi, N.A. Orr, N.L. Achouri, T. Aumann, H. Baba, F. Delaunay, P. Doornenbal, N. Fukuda, J. Gibelin, J.W. Hwang, N. Inabe, T. Isobe, D. Kameda, D. Kanno, S. Kim, N. Kobayashi, T. Kobayashi, T. Kubo, S. Leblond, J. Lee, F.M. Marqués, T. Motobayashi, D. Murai, T. Murakami, K. Muto, T. Nakashima, N. Nakatsuka, A. Navin, S. Nishi, H. Otsu, H. Sato, Y. Satou, Y. Shimizu, H. Suzuki, K. Takahashi, H. Takeda, S. Takeuchi, Y. Togano, A.G. Tuff, M. Vandebrouck, K. Yoneda, "Nucleus ^{26}O : A Barely Unbound System beyond the Drip Line", *Phys. Rev. Lett.* 116, 102503 (6pages) (2016).
- H. Otsu, S. Koyama, N. Chiga, T. Isobe, T. Kobayashi, Y. Kondo, M. Kurokawa, W.G. Lynch, T. Motobayashi, T. Murakami, T. Nakamura, M. Kurata-Nishimura, V. Panin, H. Sato, Y. Shimizu, H. Sakurai, M.B. Tsang, K. Yoneda, H. Wang, "SAMURAI in its operation phase for RIBF", *NIMB* 376, (2016), 175-179.
- J. Yasuda, M. Sasano, R.G.T. Zegers, H. Baba, W. Chao, M. Dozono, N. Fukuda, N. Inabe, T. Isobe, G. Jhang, D. Kameda, T. Kubo, M. Kurata-Nishimura, E. Milman, T. Motobayashi, H. Otsu, V. Panin, W. Powell, H. Sakai, M. Sako, H. Sato, et al., "Inverse kinematics (p,n) reactions studies using the WINDS slow neutron detector and the SAMURAI spectrometer", *NIMB* 376 (2016), 393-396.
- T. Nakamura, Y. Kondo, "Large acceptance spectrometers for invariant mass spectroscopy of exotic nuclei and future developments", *NIMB* 376 (2016), 156-161.

(Review)

- T. Motobayashi, "Study of weakly bound nuclei at RIKEN RIBF", *Few-Body Systems* 57, 337-341 (2016).
(Proceedings)
- S. Sakaguchi, T. Uesaka, T. Wakui, S. Chebotaryov, T. Kawahara, S. Kawase, E. Milman, T. L. Tang, K. Tateishi and T. Teranishi, "Studies of Unstable Nuclei with Spin-Polarized Proton Target", *International Journal of Modern Physics* 40, 1660071 (2016).
- L. Stuhl et al., A New Low-energy Plastic Scintillation Neutron Detector For Real Time Pulse Shape Discrimination, *PoS Proceeding of Science (INPC2016)* 085 (2017).

Oral Presentations

[International Conference etc.]

- T. Nakamura, (Invited) "Weakly bound and unbound nuclei near the neutron drip line", INPC2016, 11-16, Sep, 2016, Adelaide, Australia
- T. Nakamura, (Invited) "Recent Experiments and Perspectives of SAMURAI", RIBF Users Meeting 2016, 8-9, Sep, 2016, Wako, Saitama
- T. Nakamura, (Invited) "Spectroscopy of weakly bound and unbound nuclei", *Physics beyond the limits of stability: exploring the continuum*, 17-21, Oct., 2016, ECT*, Trento, Italy
- T. Nakamura, (Invited) "Nuclear structure near and beyond the neutron drip line", 1st Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, 12-16, Dec., 2016, Wako, Saitama
- T. Nakamura, (Invited) "Neutron-star matter and related physics studied by neutron-rich nuclei", *International Symposium on Neutron Star Matter (NSMAT2016)*, 21-23, Nov., 2016, Sendai
- T. Nakamura, (Invited) "Structure of neutron drip-line nuclei probed by breakup reactions", APCC-APC 4-8, Dec., 2016, Brisbane, Australia
- T. Nakamura, (Invited) "Structure of nuclei along and beyond the neutron drip line", *ESNT Workshop on Dynamics of highly unstable exotic light nuclei and few-body systems* 30, Jan-3, Feb, 2017, ESNT, Saclay, France
- Y. Kondo, (Invited) "Experimental study of 25-28O with SAMURAI", *Direct Reactions with Exotic Beams (DREB2016)* 11-15, Jul., 2016, Halifax, Canada
- M. Sasano et al., (Invited) "Study of Gamow-Teller transitions from 132Sn via the (p,n) reaction", *ECT* workshop "Unraveling the complexity of nuclear systems: single-particle and collective aspects through the looking glass"*, Trento Italy, February 10 to 17, 2017.
- M. Sasano et al., (Invited) "Gamow-Teller giant resonances in 132Sn", *Advances in Radioactive Isotope Science (ARIS) 2017*, Keystone CO US, May 28 to June 2, 2017.
- Y. Kubota, (Invited) "Two-neutron correlation in Borromean nuclei via the quasi-free (p,pn) reaction", in *ESNT Workshop, Dynamics of highly unstable exotic light nuclei and few-body systems (Saclay, France, 2017)*
- Y. Kondo, "Recent experimental studies using SAMURAI at RIBF", *Current Activities and Future Prospects on Unstable Nuclei: Japan-Korea Exchange Program (JPS meeting)*, Tohoku gakuin University, 21, March, 2016
- Y. Kondo, "Experimental study of unbound oxygen isotopes beyond the drip line", *International Workshop on "Critical Stability in Few-Body Systems"*, RIKEN, 4 Feb, 2016
- Y. Kubota, "Study on neutron-neutron correlation in Borromean nucleus 11Li via the quasi-free (p,pn) reaction", in *International Nuclear Physics Conference (INPC2016) (Adelaide, Australia, 2016)*.
- Y. Kubota, "Probing neutron-neutron correlation in Borromean nuclei via the quasi-free (p,pn) reaction", in *SAMURAI International Collaboration Workshop 2016 (Fukuoka, Japan, 2016)*.
- Y. Kubota, "Study of neutron-neutron correlation in Borromean nucleus 11Li via the (p,pn) reaction", in *Direct Reactions with Exotic Beams (DREB2016) (Halifax, Canada, 2016)*.
- Y. Kubota, "Direct measurement of two neutron correlation in 11Li via the (p,pn) reaction", in *International Workshop on "Critical Stability in Few-Body Systems" (Saitama, Japan, 2016)*.
- S. Chebotaryov, S. Sakaguchi, et al., "Elastic scattering of neutron-rich 6He nuclei from polarized protons at 200 A MeV", *22nd International Spin Symposium, University of Illinois, 27 September 2016*.
- S. Sakaguchi, S. Chebotaryov, et al., "Polarized proton target at SAMURAI: Elastic scattering of 6He from polarized proton", *SAMURAI International Collaboration Workshop 2016, Kyushu University, 5 September 2016*.
- M. Sasano et al., "Study of Gamow-Teller transitions from 132Sn via the inverse kinematics (p,n) reaction", *The 26th International Nuclear Physics Conference (INPC2016) Adelaide, Australia, 2016*.
- L. Stuhl et al., A new low-energy plastic scintillation neutron detector for real time pulse shape discrimination, *The 26th International Nuclear Physics Conference (INPC2016) Adelaide, Australia, 2016*.
- Yasuhiro Togano, 'Reaction cross section of the two-neutron halo nucleus 22C at 235 MeV/nucleon', *INPC2016, September 2016, Adelaide, Australia*
- S. Koyama, H. Otsu, et al., "Cluster structure on neutron rich nuclei 16C", *11th international Conference on Clustering Aspects of Nuclear Structure and Dynamics, 23rd May 2016, Naples, Italy*
- S. Koyama, H. Otsu, et al., "Study of cluster structure in 16C via α inelastic scattering", *Direct Reactions with Exotic Beams, 15th July 2016, Halifax, Canada*
- M. Kurata-Nishimura, "SpRIT-TPC experiments at RIKEN 2016", *Transport 2017, 2017/3/27 -30, MSU/FRIB, USA*
- M. Kurata-Nishimura, "First Experiments with The SpRIT-TPC at SAMURAI in RIKEN-RIBF", *新学術領域「中性子星核物質」第5回ウィンタースクール・研究会「中性子星の核物質」, 2017/2/16-18, Fukushima, Japan*
- M. Kurata-Nishimura, "First Experiment with the SPiRIT-TPC", *The 26th International Nuclear Physics Conference, 2016/9/11-16, Adelaide, Australia*
- M. Kurata-Nishimura, "Preliminary results of SPiRIT-TPC experiment at RIBF-SAMURAI", *The 14th International Symposium on Nuclei in the Cosmos XIV, 2016/6/19 - 24, Niigata, Japan*
- Z. Yang, "Status and Results of SAMURAI018", *5th Sunflower workshop, Hongkong China 2016, Sep.18-20*
- Z. Yang, "Study on the cluster structure in nuclei using direct reactions", *Cluster 2016, Napoli Italy 2016, May 23-27*

[Domestic Conference]

- 梅野泰宏, “ γ -ray detector CATANA and E1 response of n-rich Ca isotopes”, 梅野泰宏, 宇宙核物理連絡協議会 研究会, 2016年2月 国立天文台
- 梅野泰宏, “新 γ 線検出器 CATANA”, 日本物理学会第71回年次大会, 2016年3月 東北学院大学
- Y. Togano, “Study of nuclear astrophysics by Coulomb dissociation”, MOTO16, June 2016, Rikkyo Univ.
- 梅野泰宏, “ ^{22}C 反応断面積の高統計測定”, 日本物理学会 2016年秋季大会, 2016年9月 宮崎大学
- 梅野泰宏, “中性子過剰核の E1 応答と新 γ 線検出器 CATANA”, 新学術領域「中性子星核物質」第5回ウィンタースクール, 2017年2月, 福島
- Y. Kubota, (Invited), “Two-neutron correlation in Borromean nuclei via the quasi-free (p,pn) reaction”, 日本物理学会第72回年次大会シンポジウム New aspects of direct reactions in probing exotic nuclei, 2017年2月大阪大学豊中キャンパス
- 久保田悠樹, “ボロミアン核(p,pn)反応を用いた二中性子運動量相関の研究”, 日本物理学会第71回年次大会 東北学院大学 泉キャンパス, 2016年3月 東北学院大学泉キャンパス
- 小山俊平, 大津秀暁, 他, “不変質量法を用いた ^{16}C のクラスター状態の研究”, 日本物理学会年次大会春季, 2016年3月20日, 仙台
- 小山俊平, 大津秀暁, 他, “ ^{16}C のクラスター構造”, 日本物理学会年次大会春季, 2017年3月18日, 大阪
- 齋藤岳志, 千賀信幸, 田村陸, 宇佐見正志, 樋口諒, 大津秀暁, “SAMURAI 実験における陽子検出器 NINJA の開発状況”, 日本物理学会年次大会, 2016年3月21日 仙台
- 齋藤敦美, 中村隆司, 近藤洋介他, “反跳陽子のトラッキングを用いた高分解能中性子検出器の開発”, 日本物理学会 第72回年次大会 2017年3月17日-20日, 大阪府豊中市 大阪大学
- 平山晃大, 中村隆司, 武内聡他 “ $^{79}\text{Se}, ^{80}\text{Se}$ のクーロン分解反応” 日本物理学会 第72回年次大会 2017年3月17日-21日, 大阪府豊中市 大阪大学
- 斗米貴人, 中村隆司, 梅野泰宏他, “分解反応を用いた ^{31}Ne の核分光”, 日本物理学会 第72回年次大会 2017年3月17日-22日, 大阪府豊中市 大阪大学
- 山田啓貴, 中村隆司, 梅野泰宏, 近藤洋介他 “不安定核反応実験のための γ 線検出器アレー-CATANA の性能評価”, 日本物理学会 第73回年次大会 2017年3月17日-23日, 大阪府豊中市 大阪大学
- 安田昌弘, 近藤洋介, 中村隆司他, “中性子ドリップライン近傍のフッ素・ネオン同位体のインビームガンマ線核分光”, 日本物理学会 第74回年次大会, 2017年3月17日-24日, 大阪府豊中市 大阪大学
- 近藤洋介 “中性子ドリップラインを超えた領域での酸素同位体の不変質量核分光”, 基研研究会「核力に基づく核構造、核反応物理の展開」, 2017年3月27日-29日, 京都府京都市 京都大学

Posters Presentations

[International Conference etc.]

- L. Stuhl et al., “PANDORA, a large volume low-energy neutron detector with real-time neutron-gamma discrimination”, Advances in Radioactive Isotope Science (ARIS) 2017, Keystone CO US, May 28 to June 2, 2017.

Doctoral Dissertation

- J. Yasuda, “Study of Gamow-Teller transitions from ^{132}Sn via the (p,n) reaction in inverse kinematics”, PhD thesis, Kyushu University, March 2017.
- Y. Kubota, “Neutron-neutron correlation in Borromean nucleus ^{11}Li via the (p,pn) reaction”, PhD thesis, University of Tokyo, March 2017.

Master Thesis

- S. Koyama, “不変質量法を用いた ^{16}C のクラスター状態の研究 Study for cluster states in ^{16}C via invariant mass method, 2016”, 東京大学
- 坪田 潤一 ^{26}F の不変質量核分光, 東京工業大学
- 尾崎友志 三中性子非束縛系 ^{27}O の核分光, 東京工業大学
- 齋藤敦美 ダイニュートロン相関探索に向けた高分解能中性子検出器 HIME の開発, 東京工業大学

Bachelor Thesis

- 斗米 貴人 不安定核反応実験のための大立体角中性子検出器の性能評価, 東京工業大学
- 平山 晃大 荷電フラグメントの粒子識別用ホドスコープの開発, 東京工業大学
- 安田昌弘 中性子ドリップライン近傍のフッ素・ネオン核の線核分光, 東京工業大学
- 山田啓貴 不安定核反応実験のための γ 線検出器アレー-CATANA の性能評価, 東京工業大学

RIBF Research Division

Research Instruments Group

Computing and Network Team

1. Abstract

This team is in charge of development, management and operation of the computing and network environment, mail and information servers and data acquisition system and management of the information security of the RIKEN Nishina Center.

2. Major Research Subjects

- (1) Development, management and operation of the general computing servers
- (2) Development, management and operation of the mail and information servers
- (3) Development, management and operation of the data acquisition system
- (4) Development, management and operation of the network environment
- (5) Management of the information security

3. Summary of Research Activity

This team is in charge of development, management and operation of the computing and network environment, mail and information servers and data acquisition system and management of the information security. The details are described elsewhere in this progress report.

(1) Development, management and operation of the general computing servers

We are operating Linux/Unix NIS/NFS cluster system for the data analysis of the experiments and general computing. This cluster system consists of eight computing servers with 64 CPU cores and totally 200 TB RAID of highly-reliable Fibre-channel interconnection. Approximately 700 user accounts are registered on this cluster system. We are adopting the latest version of the Scientific Linux (X86_64) as the primary operating system, which is widely used in the accelerator research facilities, nuclear physics and high-energy physics communities in the world.

(2) Development, management and operation of the mail and information servers

We are operating RIBF.RIKEN.JP server as a mail/NFS/NIS server. This server is a core server of RIBF Linux cluster system. Postfix has been used for mail transport software and dovecot has been used for imap and pop services. These software packages enable secure and reliable mail delivery. Because six years have passed since the installation of this server, we are preparing to replace the server and RAID file system. Sophos Email Security and Control (PMX) installed on the mail front-end servers which tags spam mails and isolates virus-infected mails. The probability to identify the spam is approximately 95-99%. We noticed that virus-infected mails were occasionally not detected by PMX in the case of new types of virus. Therefore, we added a new rule to PMX to isolate and remove executable image files attached in mail because they are often aimed at virus infection. As a result, most of the viruses in mails are successfully blocked by PMX. We are operating several information servers such as Web servers, Integrated Digital Conference (INDICO) server, Wiki servers, Groupware servers, Wowza streaming servers. An anonymous ftp server, FTP.RIKEN.JP, is managed and operated at the RNC. Major Linux distributions, including Scientific Linux, Ubuntu and CentOS, are mirrored daily for the convenience of their users and for facilitating high-speed access. An HP ProLiant DL-380G6 server was installed in 2009, and it is scheduled to be replaced by DL-380G9 in June 2017. Simultaneously, the OS will be upgraded from SL 5.11 to SL 7.3. We have been operating approximately 70 units of wireless LAN access points in RNC. Almost the entire radiation-controlled area of the East Area of RIKEN Wako campus is covered by wireless LAN for the convenience of experiments and daily work. Since the devices used for the Wireless LAN access points became obsolete, all of them were replaced by WAPM-1166D or WAPS-APG-600H in 2016, which supports the protocols of 802.11b, 11g, 11a, 11n, and 11ac.

(3) Development, management and operation of the data acquisition system

We have developed the standard data-acquisition system named as RIBFDAQ. This system can process up to 40 MB/s data. By using parallel readout from front-end systems, the dead time could be small. To synchronize the independent DAQ systems, the time stamping system has been developed. The resolution and depth of the time stamp are 10 ns and 48 bit, respectively. This time stamping system is very useful for beta decay experiments such as EURICA and BRIKEN projects. The current main task is the DAQ coupling, because detector systems with dedicated DAQ systems are transported to RIBF from foreign facilities. In case of SAMURAI Silicon (NSCL/TUM/WUSTL), the readout system is integrated into RIBFDAQ. The projects of MUST2 (GANIL), MINOS (CEA Saclay), NeuLAND (GSI) and TRB3 (TUM) cases, data taken by their DAQ systems are transferred to RIBFDAQ. For SPIRIT (RIKEN/GANIL/CEA Saclay/NSCL), RIBFDAQ is controlled from the NARVAL-GET system that is a large-scale signal processing system for the time projection chamber. EURICA (GSI), BRIKEN (GSI/Univ. Liverpool/IFIC) and VANDLE (UTK) projects, we adopt the time stamping system to use individual trigger for each detector system. In this case, data are merged in offline. In addition to the development DAQ system, we are developing intelligent circuits based on FPGA. Mountable Controller (MOCO) is a very fast readout controller for VME modules. General Trigger Operator (GTO) is an intelligent triggering NIM module. Functions of "common trigger management", "gate and delay generator", "scaler" are successfully implemented on GTO.

(4) Development, management and operation of the network environment

We have been managing the network environment collaborating with Advanced Center for Computing and Communications (ACCC). All the Ethernet ports of the information wall sockets are capable of the Gigabit Ethernet connection (10/100/1000BT). In addition, a 10 Gbps network port has been introduced to the RIBF Experimental area in for the high speed data transfer of RIBF experiment to ACCC in near future. Approximately 60 units of wireless LAN access points have been installed to cover the almost entire area of Nishina Center.

(5) Management of the information security

It is essential to take proper information security measures for information assets.
We are managing the information security of Nishina Center collaborating with ACCC.

Members**Team Leader**

Takashi ICHIHARA (concurrent; Vice Chief Scientist, RI Physics Lab.)

Research & Technical Scientist

Yasushi WATANABE (concurrent; Senior Research Scientist, Radiation Lab.)

Nishina Center Research Scientist

Hidetada BABA

List of Publications & Presentations**Publications**

[Journal]

(Original Papers) *Subject to Peer Review

Inclusive cross section and double helicity asymmetry for π^0 production in p+p collisions at $\sqrt{s} = 510$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. D 93 (2016), 011501(R)

e+e- pair production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. By Adare *et al.* By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 014904

Measurement of higher cumulants of net-charge multiplicity distributions in Au+Au collisions at $\sqrt{s_{NN}} = 7.7$ to 200 GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 011901(R)

Charged particle multiplicity and transverse energy production in heavy ion collisions spanning $\sqrt{s_{NN}} = 7.7$ GeV to 200 GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 024901

Nuclear matter effects on ϕ meson production in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 024904

System dependence of fractional momentum loss of high pT hadrons in relativistic heavy ion collisions. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 024911

System size dependence of the forward J/psi production in PHENIX. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 034903

Single electron yields from semileptonic charm and bottom hadron decays in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 034904

Measurement of parity violating spin asymmetries in W^{\pm} production at mid-rapidity in longitudinally polarized p+p collisions at $\sqrt{s} = 510$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. D 93 (2016), 051103(R)

Jet Production in d+Au Collisions at $\sqrt{s_{NN}} = 200$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. Lett. 116 (2016), 122301

Measurements of identified particle higher harmonic flow in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 93 (2016), 051902(R)

Measurement of 1st, 2nd and 3rd azimuthal anisotropy in Cu+Au collisions. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 94 (2016), 054910

Elliptical and triangular flow of soft direct photons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. C 94 (2016), 064901

J/psi longitudinal double spin asymmetry measurement at forward rapidity in p+p collisions at $\sqrt{s} = 510$ GeV. By PHENIX Collaboration (A. Adare *et al.*). Phys. Rev. D 94 (2016), 112008

Oral Presentations

[International Conference etc.]

H. Baba, "Isospin character of low-energy dipole strength in 200", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Saitama/Ibaraki, Japan, 12-16th December, 2016 (Invited)

H. Baba, "Status of experiments RIBF56 and RIBF64", 5th SUNFLOWER Workshop, 18-20th September, 2016, Hong Kong, China, 2016

Posters Presentations

[International Conference etc.]

H. Baba, T. Ichihara, T. Ohnishi, K. Yoshida, Y. Watanabe, S. Ota, S. Shimoura, R. Yokoyama, S. Takeuchi, D. Nishimura and A. Tokiyasu, "Complete Parallel Readout VME DAQ System", IEEE 20th Real Time Conference, 5-10th June, 2016

RIBF Research Division

Research Instruments Group

Detector Team

1. Abstract

This team is in charge of development, fabrication, and operation of various detectors used for nuclear physics experiments at RIBF. Our current main mission is maintenance and improvement of detectors which are used at BigRIPS separator and its succeeding beam lines for beam diagnosis and particle identification of RI beams. We are also engaged in R&D of new detectors that can be used for higher-intensity RI beams. In addition, we are doing the R&D which uses the pelletron accelerator together with other groups.

2. Major Research Subjects

Development, fabrication, and operation of various detectors for nuclear physics experiments, including beam-line detectors which are used for the production and delivery of RI beams (beam diagnosis and particle identification). R&D which uses the pelletron accelerator.

3. Summary of Research Activity

The current research subjects are summarized as follows:

- (1) Maintenance and improvement of the beam-line detectors which are used at BigRIPS separator and its succeeding beam lines.
- (2) Development of new beam-line detectors with radiation hardness and tolerance for higher counting rates
- (3) Management of the pelletron accelerator and R&D which uses the pelletron

Members

Team Leader

Hiroimi SATO

Research and Technical Scientist

Tokihiro IKEDA (Senior Research Scientist)

Special Temporary Employee

Manabu HAMAGAKI

Visiting Scientist

Takeshi KOIKE (Tohoku Univ.)

Student Trainee

Itaru HAKAMADA (Tokyo Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- R. Yokoyama, S. Go, D. Kameda, T. Kubo, N. Inabe, N. Fukuda, H. Takeda, H. Suzuki, K. Yoshida, K. Kusaka, K. Tanaka, Y. Yanagisawa, M. Ohtake, H. Sato, Y. Shimizu, H. Baba, M. Kurokawa, D. Nishimura, T. Ohnishi, N. Iwasa, A. Chiba, T. Yamada, E. Ideguchi, T. Fujii, H. Nishibata, K. Ieki, D. Murai, S. Momota, Y. Sato, J.W. Hwang, S. Kim, O.B. Tarasov, D.J. Morrissey, B.M. Sherrill, G. Simpson, C.R. Praharaj, "New K isomers in the neutron-rich N=100 isotones Sm-162, Eu-163, and Gd-164", *Physical Review C* 95, 034313 (2017). *
- T. Ikeda, T.M. Kojima, Y. Natsume, J. Kimura, and T. Abe, "Stable transmission of slow highly charged ions through tapered glass capillary with active discharging method for sub-micron sized beams", *Applied Physics Letters* 109, 133501 (2016). *
- Y. Kazama, K. Ishii, W. Aonuma, T. Ikeda, H. Kawamoto, A. Koizumi, D. Filatov, M. Chibalina, R. Bergero, D. Charlesworth, T. Abe, and S. Kawano, "A new physical mapping approach refines the sex-determining gene positions on the *Silene latifolia* Y-chromosome", *Scientific Reports* 6, 18917 (2016). *
- S.J. Wickramarachchi, T. Ikeda, B.S. Dassanayake, D. Keerthisinghe, and J. A. Tanis, "Incident energy and charge deposition dependences of electron transmission through a microsized tapered glass capillary", *Nuclear Instruments and Methods in Physics Research Section B* 82, 60 (2016). *
- K. Ishii, Y. Kazama, R. Morita, T. Hirano, T. Ikeda, S. Usuda, Y. Hayashi, S. Ohbu, R. Motoyama, Y. Nagamura, and T. Abe, "Linear Energy Transfer-dependent Change in Rice Gene Expression Profile after Heavy-ion Beam Irradiation", *PLOS ONE* 11 (7): e0160061 (2016).*
- S.J. Wickramarachchi, T. Ikeda, B. S. Dassanayake, D. Keerthisinghe, and J. A. Tanis, "Electron-beam transmission through a micrometer-sized tapered-glass capillary: Dependence on incident energy and angular tilt angle", *Physical Review A* 94, 022701 (2016). *

Oral Presentations

[International Conference etc.]

H. Sato : "Status of PID detectors at BigRIPS", Fragment Separator Expert Meeting 2016, (Amway Grand Plaza Hotel), Grand Rapids, USA, August (2016).

[Domestic Conference]

八木彩祐未, 小田原厚子, R. Lozeva, C. Moon, 方一帆, 大道理恵, 西畑洗希, 金岡裕志, P. Lee, 下田正, 西村俊二, P. Doornenbal, G. Lorusso, 炭竈聡之, 渡辺寛, P.S. derstrm, J. Wu, F. Brown, Z.Y. Xu, 横山輪, 磯部忠昭, 馬場秀忠, 櫻井博儀, 鈴木宏, 稲辺尚人, 亀田大輔, 福田直樹, 竹田浩之, 安得順, 清水陽平, 佐藤広海, 久保敏幸, 石垣知樹, 森本翔太, 井手口栄治, 小松原哲郎, 新倉潤, 西塚一平, C.S. Lee, and the EURICA collaborators: "中性子過剰な Xe 同位体における集団運動状態の系統的变化", 日本物理学会第 72 回年次大会, (大阪大学), 大阪, 3 月 (2017).

小山俊平, 大津秀暁, 清水陽平, 米田健一郎, 佐藤広海, 本林透, 西村美月, 銭廣十三, 櫻井博儀, 武内聡, 磯部忠昭, 馬場秀忠, 日下健祐, 大西純一, 笹野匡紀, P. Doornenbal, 福田直樹, 小林俊雄, 炭竈聡之, 松田洋平, 佐藤義輝, J. Hwang, 近藤洋介, 中村隆司, 梅野泰宏, 南方亮吾, 生越駿, 村上哲也, 中塚徳継, J. Gibelin, L. Sylvain, 新倉潤, 小林信之, H. Liu, J. Lee, E. Nikolskii, 坂口聡志, D. Beaumel: "16C のクラスター構造", 日本物理学会第 72 回年次大会, (大阪大学), 大阪, 3 月 (2017).

池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: "電極付きガラスキャピラリー光学系による低速マイクロイオンビーム安定供給のためのアクティブ放電法", ビーム物理研究会 2016, (SPring-8), 佐用郡佐用町, 11 月 (2016).

池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: "Active discharging method for stable transmission of ion beams through tapered glass capillary optics", 第 17 回「イオンビームによる表面・界面解析」特別研究会, (京都府立大学), 京都市, 12 月 (2016).

池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: "ガラスキャピラリーによる低速多価イオンビームのサブミクロン化と安定供給のためのアクティブガイディング", 原子衝突学会第 41 回年会, (富山大学), 富山市, 12 月 (2016).

池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: "高機能ガラスキャピラリー光学系による低速多価イオンマイクロビームの安定供給", 日本物理学会第 72 回年次大会, (大阪大学), 豊中市, 3 月 (2017).

池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: "招待講演: キャピラリーマイクロイオンビームの放射線生物学応用", 平成 28 年度弥生研究会「量子ビームの技術と利用」, (東京大学), 東海村, 3 月 (2017).

RIBF Research Division Accelerator Applications Research Group

1. Abstract

This group promotes various applications of ion beams from RI Beam Factory (RIBF). Radiation Biology Team studies various biological effects of fast heavy ions and develops new technology to breed plants and microbes by heavy-ion irradiations. RI Applications Team studies production and application of radioisotopes for various research fields, development of trace element analysis and its application, and development of chemical materials for ECR ion sources of RIBF accelerators.

2. Major Research Subjects

Research and development in biology, chemistry and materials science utilizing heavy-ion beams from RI Beam Factory.

3. Summary of Research Activity

- (1) Biological effects of fast heavy ions.
- (2) Research and development of heavy-ion breeding.
- (3) RI application researches
- (4) Research and development of RI production technology at RIBF.
- (5) Developments of trace elements analyses.
- (6) Development of chemical materials for ECR ion sources of RIBF accelerators.

Members

Group Director

Tomoko ABE

RIBF Research Division
Accelerator Applications Research Group
Ion Beam Breeding Team

1. Abstract

Ion beam breeding team studies various biological effects of fast heavy ions. It also develops new technique to breed plants and microbes by heavy-ion irradiations. Fast heavy ions can produce dense and localized ionizations in matters along their tracks, in contrast to photons (X rays and gamma rays) which produce randomly distributed isolated ionizations. These localized and dense ionization can cause double-strand breaks of DNA which are not easily repaired and result in mutation more effectively than single-strand breaks. A unique feature of our experimental facility at the RIKEN Ring Cyclotron (RRC) is that we can irradiate living tissues in atmosphere since the delivered heavy-ion beams have energies high enough to penetrate deep in matter. This team utilizes a dedicated beam line (E5B) of the RRC to irradiate microbes, plants and animals with beams ranging from carbon to iron. Its research subjects cover physiological study of DNA repair, genome analyses of mutation, and development of mutation breeding of plants by heavy-ion irradiation. Some new cultivars have already been brought to the market.

2. Major Research Subjects

- (1) Study on the biological effects by heavy-ion irradiation
- (2) Study on the molecular nature of DNA alterations induced by heavy-ion irradiation
- (3) Innovative applications of heavy-ion beams

3. Summary of Research Activity

We study biological effects of fast heavy ions from the RRC using 135A MeV C, N, Ne ions, 95A MeV Ar ions, 90A MeV Fe ions and from the IRC using 160A MeV Ar ions. We also develop breeding technology of microbes and plants. Main subjects are:

(1) Study on the biological effects by heavy-ion irradiation

Heavy-ion beam deposits a concentrated amount of dose at just before stop with severely changing the linear energy transfer (LET). The peak of LET is achieved at the stopping point and known as the Bragg peak (BP). It is well known to be good for cancer therapy to adjust the BP to target malignant cells. On the other hand, a uniform dose distribution is a key to the systematic study for heavy-ion mutagenesis, and thus to the improvement of the mutation efficiency. Therefore plants and microbes are treated using ions with stable LET. We investigated the effect of LET ranging from 23 to 640 keV/μm, on mutation induction using dry seeds of the model plants *Arabidopsis thaliana*. The most effective LET (LET_{max}) was 30 keV/μm. LET_{max} irradiations showed the same mutation rate as that by chemical mutagens, which typically cause high mutation rate. The LET_{max} of imbibed rice (*Oryza sativa* L.) seeds, dry rice seeds and dry wheat (*Triticum monococcum*) seeds were shown to be 50-63 keV/μm, 23-30 keV/μm and 50 keV/μm, respectively. In the case of microbe (*Mesorhizobium lotii*), the results showed a higher incidence of deletion mutations for Fe ions at 640 KeV/μm than for C ions at 23-40 keV/μm. Thus, the LET is an important factor to be considered in heavy-ion mutagenesis.

(2) Study on the molecular nature of DNA alterations induced by heavy-ion irradiation

Detailed analyses on the molecular nature of DNA alterations have been reported as an LET-dependent effect for induced mutation. The most mutations were deletions ranging from a few to several tens of base pairs (bp) in the *Arabidopsis thaliana* mutants induced by irradiation with C ions at 30 keV/μm and rice mutants induced by irradiation with C ions at 50 keV/μm or Ne ions at 63 keV/μm. LET_{max} is effective for breeding because of its very high mutation frequency. Since most mutations are small deletions, these are sufficient to disrupt a single gene. Thus, irradiation can efficiently generate knockout mutants of a target gene, and can be applied to reverse genetics. On the other hand, irradiation with Ar ions at 290 keV/μm showed a mutation spectrum different from that at LET_{max}: the proportion of small deletions (<1 kbp) was low, while that of large deletions ranging from several to several tens of kbp, and rearrangements was high. Many genes in the genome (> 10%) are composed of tandem duplicated genes that share functions. For knockout of the tandem duplicated genes, large deletions are required, and the appropriate deletion size is estimated to be around 5-10 kbp and 10-20 kbp based on the gene density in *Arabidopsis* and rice, respectively. No method is currently available to efficiently generate deletion mutants of this size. As such, higher LET irradiation is promising as a new mutagen suitable for the functional analysis of tandem duplicated genes.

(3) Innovative application of heavy-ion beams

We have formed a consortium for ion-beam breeding. It consisted of 24 groups in 1999, in 2016, it consisted of 173 groups from Japan and 10 from overseas. Breeding was performed previously using mainly flowers and ornamental plants. We have recently put a new Japanese barnyard millet cultivar with low amylose content and short culm, 'Nebarikko No. 2' on the market. Beneficial variants have been grown for various plant species, such as high yield rice, semi-dwarf early rice, semi-dwarf buckwheat, semi-dwarf barley, hypoallergenic peanut, spineless oranges, non-flowering Eucalyptus and lipids-hyperaccumulating unicellular alga. We collaborate with Miyagi prefecture and Tohoku University to breed salt-resistant lines in the more delicious commercial rice varieties, 'Hitomebore' and 'Manamumume'. Imbibed seeds were irradiated with the LET_{max} (C-ions) on 16 April, 2011. We isolated 73 candidate lines of salt-resistant mutants from 719 M₂ progenies grown in the saline paddy field in Tohoku University in 2012. From these, we selected 12 salt-resistant M₃ lines in 2013, 4 M₄ lines in 2014 and one M₅ line in 2015. The target of heavy-ion breeding is extended from flowers to crops like grains so that it will contribute to solve the global problems of food and environment.

Members

Team Leader

Tomoko ABE (concurrent: Group Director, Accelerator Applications Research Gr.)

Research & Technical Scientist

Kazuhide TSUNEIZUMI (Senior Research Scientist)
Masako IZUMI (Senior Research Scientist)
Teruyo TSUKADA (Senior Research Scientist)
Tokihiko IKEDA (concurrent)

Katsunori ICHINOSE (Senior Technical Scientist)
Hiroshi ABE (Senior Technical Scientist)
Ryouhei MORITA (Technical Scientist)

Contract Researchers

Hiroyuki ICHIDA

Yusuke KAZAMA

Postdoctoral Researcher

Kotaro ISHII

Technical Staff I

Yoriko HAYASHI

Yuki SHIRAKAWA

Technical Staff II

Sumie OHBU

Research Consultants

Masahiro MII

Part-time Workers

Hideo TOKAIRIN
Sachiko KOGURE
Taeko WAKANA

Mieko YAMADA
Haruka WATANABE (Aug.15 – Sep. 12, 2016)
Hitomi TAMURA (Aug.15 – Sep. 12, 2016)

Visiting Scientist

Makoto FUJIWARA (Univ. of Tokyo)
Masao WATANABE (Tohoku Univ.)
Hisashi TSUJIMOTO (Tottori Univ.)
Yutaka MIYAZAWA (Tohoku Univ.)
Toshinari GODO (Flower & Garden Bank)
Masanori TOMITA (CRIEPI)
Toshikazu MORISHITA (Nat'l. Inst. Agric. Res.)
Koji MURAI (Fukui Pref. Univ.)
Hinako TAKEHISA (Nat'l. Inst. Agric. Sci.)
Akiko HOKURA (Tokyo Denki Univ.)
Norihiro OHTSUBO (Kyoto Pref. Univ.)

Eitaro FUKATSU (Forestry and Forest Products Res. Inst.)
Tomonari HIRANO (Univ. of Miyazaki)
Yoichi SATO (Riken Food Co., Ltd.)
Ali FERJANI (Tokyo Gakugei Univ.)
Katsutomo SASAKI (Nat'l. Agric. and Food Res. Org.)
Kunio SUZUKI (Technoflora, Co., Ltd.)
Kazumitsu MIYOSHI (Chiba. Univ.)
Makoto UBUKATA (Hokkaido Univ.)
Tadashi SATO (Tohoku Univ.)
Takeshi YAMAKI (Riken Vitamin Co., Ltd.)

Visiting Technicians

Takuji YOSHIDA (Takii Seed Co., Ltd.)
Daisuke SAITO (Riken Food Co., Ltd.)

Keiji IKEDA (KK SeaAct)

Research Fellows

Naoji WAKITA (Wadomari Cho Agr. Exp. Station)
Tadahito OOTUBO (Wadomari Cho Agr. Exp. Station)
Shunsuke IMANISHI (Nat'l. Inst. Veg. and Tea Sci.)
Tomihiko TAKESHITA (Wadomari Cho)

Yoshiharu TAKE (Wadomari Cho)
Hiroshi ASATO (Wadomari Cho)
Kenji OYOYOSHI (Wadomari Cho)
Hironari UCHIDA (Saitama Pref. Res. Inst.)

Student Trainees

Yu IMAMURA (Tokyo Denki Univ.)
Kazuki TAKANASHI (Tokyo Denki Univ.)
Yoshihiro TAKAHASHI (Kitazato Univ.)
Takuya NISHINOBO (Tokyo Denki Univ.)

Koichi NAMBU (Tokyo Denki Univ.)
Naoko HIROSE (Tokyo Denki Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- 遠藤幸子, 齋藤裕太郎, 阿部篤智, 野口協一, 新野清, 西村幸一, 酒井友幸, 高橋由信, 阿部知子: “ショクヨウギク新品種 ‘山園 K4 号’ の育成”, 山形県農業研究報告 **8**, 93-102 (2016). *
- Kato M., Masamura N., Shono J., Okamoto D., Abe T., Imai S.: “Production and characterization of tearless and non-pungent onion”, SCIENTIFIC REPORTS **6**, Article No. 23779 (2016). *
- Yamada K., Kazama Y., Mitra S., Marukawa Y., Arashida R., Abe T., Ishikawa T., Suzuki K.: “Production of a thermal stress resistant mutant *Euglena gracilis* strain using Fe-ion beam irradiation”, Bioscience, Biotechnology, and Biochemistry **80**, 1650-1656 (2016). *
- Sato Y., Hirano T., Niwa K., Suzuki T., Fukunishi N., Abe T., Kawano S.: “Phenotypic differentiation in the morphology and nutrient uptake kinetics among *Undaria pinnatifida* cultivated at six sites in Japan”, Journal of Applied Phycology **28**, 3447-3458 (2016). *
- Yamada K., Suzuki H., Takeuchi T., Kazama Y., Mitra S., Abe T., Goda K., Suzuki K., Iwata O.: “Efficient selective breeding of live oil-rich *Euglena gracilis* with fluorescence-activated cell sorting”, SCIENTIFIC REPORTS **6**, Article No. 26327 (2016). *
- Ishii K., Kazama Y., Hirano T., Hamada M., Ono Y., Yamada M., Abe T.: “AMAP: A pipeline for whole-genome mutation detection in *Arabidopsis thaliana*”, Genes & Genetics Systems **91**, 229-233(2016).*
- Ishii K., Kazama Y., Morita R., Hirano T., Ikeda T., Usuda S., Hayashi Y., Ohbu S., Ikeda R., Nakamura Y., Abe T.: “Linear Energy Transfer-Dependent Change in Rice Gene Expression Profile after Heavy-Ion Beam Irradiation”, PLOS ONE **11**, e0160061 (2016). *
- Ikeda T., Kojima T., Natsume Y., Kimura J., Abe T.: “Stable transmission of slow highly charged ions through tapered glass capillary with active discharging method for sub-micron sized beams”, Applied Physics Letters **109**, Article No. 133501 (2016). *
- Morita R., Nakagawa M., Takehisa H., Hayashi Y., Ichida H., Usuda S., Ichinose K., Abe H., Shirakawa Y., Sato T., Fujiwara T. M., Itoh D.R., Abe T.: “Heavy-ion beam mutagenesis identified an essential gene for chloroplast development under cold stress conditions during both early growth and tillering stages in rice”, Bioscience, Biotechnology, and Biochemistry **81**, 271-282 (2016). *
- Grasso R., Abe T., Cirrone A.P. G., Cuttone G., Gulino M., Musumeci F., Romeno F., Ryuto H., Scordino A.: “Effects of Ion Irradiation on Seedlings Growth Monitored by Ultraweak Delayed Luminescence”, PLOS ONE **11**, Article No. e0167998 (2016). *
- 澤田倫平, 平野智也, 飯傘禮和彦, 阿部知子, 尾崎行生: “レタス(*Lactuca sativa* L.)プロトプラストへのイオンビーム照射によって出現した低ポリフェノールオキシターゼ活性を示す突然変異体”, 園芸学研究 **15**, 347-353 (2016). *
- Ueno Y., Aikawa S., Niwa K., Abe T., Murakami A., Kondo A., Akimoto S.: “Variety in excitation energy transfer processes from phycobilisomes to photosystems I and II”, Photosynthesis Research, doi: 10. 1007/s11120-017-0345-3 (2017). *

(Review)

- 阿部知子, 林依子: “重イオンビームを用いた品種改良技術の開発とサクラ新品種の育成”, FB News **469**, 2-6(2016).
- 阿部知子: “古典園芸植物の復活を目指して”, エネルギーレビュー **36**, 25 (2016).
- 風間裕介, 石井公太郎, 阿部知子: “植物巨大 Y 染色体の遺伝子地図作成に成功—Y 染色体は進化の過程で大きな逆位を起こしていた”, 生物の科学 遺伝 **70**, 394-397 (2016)
- 風間裕介, 平野智也, 大田修平, 佐藤陽一, 村井耕二, 河野重行, 小野克徳, 阿部知子: “重イオンビーム育種によるグリーンイノベーションの創出”, 作物研究 **61**, 73-79 (2016)
- 阿部知子: “植物に出されたパズルに挑戦し、新たな花を創る”, NL だより **469**, 1(2017).
- 佐藤陽一, 阿部知子, 福西暢尚: “三陸ワカメ養殖における品種改良と複数回養殖に関する技術開発”, 水産学シリーズ **184** 新技術開発による東日本大震災からの復興・再生, 53-66 (2017).

[Others]

- 福西暢尚, 佐藤陽一, 市田裕之, 阿部知子, 平野智也: “三陸における特産海藻類の品種改良技術開発と新品種育成に関する拠点形成”, 日本水産学会誌, **82**, 160 (2016). *

Oral Presentations

(Domestic Conference)

- 久村麻子, 峯大樹, 阿部知子, 林依子, 平野智也: “奇形花の発生が少ない夏秋輪ギク「白涼」の育成”, イオンビーム育種研究会第 11 回大会, 福井, 5 月 (2016).
- 阿部知子: “未来をつくる七つ道具 イオンビームってなあに?”, イオンビーム育種研究会第 11 回大会, 福井, 5 月 (2016).
- 高城啓一, 如下昌範, 平野智也, 風間裕介, 林依子, 塚田晃代, 阿部知子: “植物組織におけるイオンビーム照射後の γ -H2AX の分布と消長”, イオンビーム育種研究会第 11 回大会, 福井, 5 月 (2016).
- 石井公太郎, 平野智也, 風間裕介, 浜田道昭, 小野幸輝, 白川侑希, 大部澄江, 阿部知子: “重イオンビーム照射由来シロイヌナズナ変異体の全変異解析”, イオンビーム育種研究会第 11 回大会, 福井, 5 月 (2016).
- 佐藤陽一, 小野克徳, 平野智也, 市田裕之, 林依子, 福西暢尚, 阿部知子: “三陸産ワカメの品種改良と実用化”, イオンビーム育種研究会第 11 回大会, 福井, 5 月 (2016).
- 二羽恭介, 阿部知子: “養殖ノリの突然変異育種における効率的な選抜手法と高水温耐性株作出の試み”, 平成 28 年度日本水産学会秋季大会, 奈良, 9 月 (2016).
- 市田裕之, 森田竜平, 白川侑希, 林依子, 阿部知子: “イネゲノム/エキソーム解析による変異遺伝子の迅速同定と重イオンビーム誘発変異の解析”, 日本育種学会第 130 回講演会, 鳥取, 9 月 (2016).
- 阿部知子, 風間裕介, 市田裕之: “重イオンビーム品種改良技術の開発と変異体を用いた原因遺伝子解析”, 日本放射線影響学会 第 59 回大会, 広島, 10 月 (2016).
- 阿部知子, 市田裕之, 福西暢尚, 佐藤陽一, 平野智也: “重イオンビーム照射による三陸ワカメの品種改良”, DNA 鑑定学会第 9 回大会, 東京, 11 月 (2016).
- 池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: “電極付きガラスキャピラリー光学系による低速マイクロイオンビーム安定供給のためのアクティブ放電法”, ビーム物理研究会 2016, 兵庫, 11 月 (2016).
- Ikeda T., Kojima T., Natsume Y., Kimura J., Abe T.: “Active discharging method for stable transmission of ion beams through tapered glass capillary optics”, 第 17 回「イオンビームによる表面・界面解析」特別研究会, 京都, 12 月 (2016).
- 阿部知子: “加速器を利用した放射線育種による地域農業への貢献の展望”, 文部科学省主催アジア原子力協力フォーラム(FNCA)「持続可能な

- 農業のための放射線技術・放射線育種の応用に関する公開セミナー」, 福井, 12月 (2016).
- 池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: “高機能ガラスキャピラリー光学系による低速多価イオンマイクロビームの安定供給”, 日本物理学会第 72 回年次大会, 豊中, 3月 (2017).
- 石川浩樹, 佐々木駿, 平野智也, 風間裕介, 阿部知子, 伊藤竜一, 藤原誠: “シロイヌナズナ葉緑体分裂異常変異体を用いた花粉発生過程における色素体増殖の解析”, 日本農芸化学会 2017 年度(平成 29 年度)大会, 京都, 3月 (2017).
- 田中朋之, Rehenuma T., 阿部知子: “イネ突然変異系統 13-45 における白未熟粒発生機構の解析 第 3 報: 温度応答性の定量的比較”, 第 243 回日本作物学会講演会, 東京, 3月 (2017).
- 李鋒, 丹羽紗也佳, 西村宣之, 市田裕之, 森田竜平, 阿部知子, 加藤浩: “イネエキソーム解析によるガンマ線誘発突然変異の探索および原因遺伝子の迅速同定”, 日本育種学会第 131 回講演会, 名古屋, 3月 (2017).
- 山谷浩史, 上妻馨梨, 中野道治, 林依子, 高見常明, 門田有希, 奥本裕, 坂本亘, 阿部知子, 草場信: “イネ stay-green 遺伝子 DCD1 の単離と機能解析”, 日本育種学会第 131 回講演会, 名古屋, 3月 (2017).

Posters Presentations (Domestic Conference)

- 石井公太郎, 風間裕介, 平野智也, 白川侑希, 大部澄江, 山田美恵子, 若菜妙子, 阿部知子: “重イオンビーム照射で作出したシロイヌナズナ巨大欠失変異体集団の形態と欠失領域の同定”, 日本植物形態学会第 28 回総会・大会, 沖縄, 9月 (2016).
- 浅野円花, 大田修平, 山崎誠和, 石井公太郎, 風間裕介, 阿部知子, 河野重行: “微細藻類の核型解析: クロレラゲノムの倍数化と重イオンビーム照射による染色体分断”, 日本植物形態学会第 28 回総会・大会, 沖縄, 9月 (2016).
- 鈴木絢子, 清河ひかる, 郡司玄, 高橋和希, 浅岡真理子, 平野智也, 風間裕介, 阿部知子, 塚谷裕一, Ferjani A.: “det3-1 の矮小化は過剰なリグニン蓄積に起因するののか?”, 日本植物形態学会第 28 回総会・大会, 沖縄, 9月 (2016).
- 風間裕介, 池田啓二, 彼谷邦光, 坂倉良男, 阿部知子: “放射線照射によるボトリオコッカスの浮揚現象”, 日本植物形態学会第 28 回総会・大会, 沖縄, 9月 (2016).
- 風間裕介, 平野智也, 石井公太郎, 白川侑希, 大部澄江, 山田美恵子, 若菜妙子, 阿部知子: “シロイヌナズナの重イオンビーム欠失変異体集団を用いた必須染色体領域のマッピング”, 日本植物学会第 80 回大会, 沖縄, 9月 (2016).
- 平野智也, 風間裕介, 石井公太郎, Vuong N. Q., 大部澄江, 國武久登, 阿部知子: “重イオンビーム照射由来シロイヌナズナ大輪変異体の全ゲノム変異解析”, 日本植物学会第 80 回大会, 沖縄, 9月 (2016).
- Suzuki J., Kiyokawa H., Gunji S., Takahashi K., Asaoka M., Hirano T., Kazama Y., Abe T., Tsukaya H., Ferjani A.: “The Whys and the Hows of flowering stem cracking: Evidenced by histological and genetic approaches”, 日本植物学会第 80 回大会, 沖縄, 9月 (2016).
- 石井公太郎, 風間裕介, 平野智也, 山田美恵子, 大部澄江, 浜田道昭, 小野幸輝, 阿部知子: “変異検出パイプライン AMAP の開発と重イオンビームの全ゲノム変異スペクトラム解析”, 日本植物学会第 80 回大会, 沖縄, 9月 (2016).
- 浅野円花, 大田修平, 山崎誠和, 石井公太郎, 風間裕介, 阿部知子, 河野重行: “クロレラゲノムの倍数化と重イオンビーム照射による染色体分断化と再構成”, 日本植物学会第 80 回大会, 沖縄, 9月 (2016).
- 山谷浩史, 上妻馨梨, 中野道治, 林依子, 高見常明, 加藤裕介, 門田有希, 熊丸敏博, 奥本裕, 坂本亘, 阿部知子, 草場信: “イネ stay-green 突然変異体 dcd1 の分子遺伝学的解析”, 日本育種学会第 130 回講演会, 鳥取, 9月 (2016).
- 林依子, 森田竜平, 一瀬勝紀, 白田祥子, 白川侑希, 東海林英夫, 佐藤雅志, 阿部知子: “イネの種子含水率による重イオンビーム変異誘発の最適化”, 日本育種学会第 130 回講演会, 鳥取, 9月 (2016).
- 森田竜平, 市田裕之, 白川侑希, 林依子, 白田祥子, 一瀬勝紀, 東海林英夫, 佐藤雅志, 阿部知子: “イネ変異解析パイプラインによる重イオンビーム誘発突然変異の同定”, 日本育種学会第 130 回講演会, 鳥取, 9月 (2016).
- 池田時浩, 小島隆夫, 夏目好夫, 木村純, 阿部知子: “ガラスキャピラリーによる低速多価イオンビームのサブミクロン化と安定供給のためのアクティブガイディング”, 原子衝突学会第 41 回年会, 富山, 12月 (2016).
- 東條宏史, 中村あき, フェルジャニ アリ, 風間裕介, 阿部知子, 飯田秀利: “根の貫入が不可能な硬さの培地の表面で生き残れるシロイヌナズナ突然変異株のスクリーニング”, 第 58 回日本植物生理学会年会, 鹿児島, 3月 (2017).
- 石井公太郎, 風間裕介, 森田竜平, 平野智也, 池田時浩, 白田祥子, 林依子, 大部澄江, 本山立子, 長村吉晃, 阿部知子: “LET 依存的に変動するイネの遺伝子発現プロファイル”, 日本育種学会第 131 回講演会, 名古屋, 3月 (2017).
- 森田竜平, 中川蘭, 竹久妃奈子, 林依子, 市田裕之, 白田祥子, 一瀬勝紀, 安部弘, 白川侑希, 東海林英夫, 佐藤雅志, 藤原誠, 伊藤竜一, 阿部知子: “重イオンビームで誘発したイネ温度感受性 virescent 変異体 csv1 の原因遺伝子同定と特性解析”, 日本育種学会第 131 回講演会, 名古屋, 3月 (2017).

RIBF Research Division

Accelerator Applications Research Group

RI Applications Team

1. Abstract

The RI Applications Team develops production technologies of radioisotopes (RIs) at RIKEN RI Beam Factory (RIBF) for application studies in the fields of physics, chemistry, biology, engineering, medicine, pharmaceutical and environmental sciences. We use the RIs mainly for nuclear and radiochemical studies such as RI production and superheavy element chemistry. The purified RIs such as ^{65}Zn and ^{109}Cd are delivered to universities and institutes through Japan Radioisotope Association. We also develop new technologies of mass spectrometry for the trace-element analyses using accelerator technology and apply them to the research fields such as cosmochemistry, environmental science, archaeology and so on. We also develop chemical materials for ECR ion sources of heavy-ion accelerators in RIBF.

2. Major Research Subjects

- (1) Research and development of RI production technology at RIBF
- (2) RI application researches
- (3) Development of trace element and isotope analyses and their applications to geoscience and environmental science
- (4) Development of chemical materials for ECR ion sources of heavy-ion accelerators in RIBF

3. Summary of Research Activity

(1) Research and development of RI production technology at RIBF and RI application studies

Due to its high sensitivity, the radioactive tracer technique has been successfully applied for investigations of the behavior of elements in the fields of chemistry, biology, engineering, medicine, pharmaceutical and environmental sciences. We have been developing production technologies of useful radiotracers at RIBF and conducting their application studies in collaboration with many researchers in various fields. With 14-MeV proton, 24-MeV deuteron, and 50-MeV alpha beams from the AVF cyclotron, we presently produce about 40 radiotracers from ^7Be to ^{211}At . Among them, ^{65}Zn , ^{85}Sr , ^{88}Y , and ^{109}Cd are delivered to Japan Radioisotope Association for fee-based distribution to the general public in Japan. Our RIs are also distributed to researchers under the Supply Platform of Short-lived Radioisotopes for Fundamental Research, supported by the Ministry of Education, Culture, Sports, Science and Technology, Grant-in-Aid for Scientific Research on Innovative Areas. On the other hand, radionuclides of a large number of elements are simultaneously produced from metallic targets such as ^{nat}Ti , ^{nat}Ag , ^{nat}Hf , and ^{197}Au irradiated with a 135-MeV $\text{nucl.}^{-1}^{14}\text{N}$ beam from the RIKEN Ring Cyclotron. These multitracers are also supplied to universities and institutes as collaborative researches.

In 2016, we developed production technologies of radioisotopes such as ^{28}Mg , $^{44\text{m}}\text{Sc}$, ^{44}Ti , ^{48}Cr , ^{67}Cu , ^{75}Se , ^{88}Y , $^{121\text{m}}\text{Te}$, $^{135\text{m}}\text{Ba}$, and ^{211}At which were strongly demanded but lack supply sources in Japan. We also investigated the excitation functions for the $^{nat}\text{Ti}(\alpha,x)$, $^{nat}\text{Zn}(d,x)$, $^{nat}\text{Zn}(\alpha,x)$, $^{nat}\text{Pd}(d,x)$, $^{169}\text{Tm}(d,x)$, $^{nat}\text{Lu}(p,x)$, $^{nat}\text{Lu}(d,x)$, $^{nat}\text{Ta}(p,x)$, and $^{nat}\text{Ta}(d,x)$ reactions to quantitatively produce useful RIs. We used radiotracers of ^{61}Cu , ^{66}Ga , $^{69\text{m}}\text{Zn}$, ^{88}Y , ^{99}Rh , and ^{139}Ce for application studies in chemistry, ^{67}Cu and ^{211}At in nuclear medicine, $^{88,89}\text{Zr}$, ^{175}Hf , and ^{177}Ta in geochemistry, and ^{88}Zr and $^{121\text{m}}\text{Te}$ in environmental science. We also produced ^{65}Zn , ^{85}Sr , ^{88}Y , and ^{109}Cd for our scientific researches on a regular schedule and supplied the surpluses through Japan Radioisotope Association to the general public. In 2016, we accepted 5 orders of ^{65}Zn with a total activity of 24 MBq, 1 order of ^{85}Sr with 1 MBq, 2 orders of ^{88}Y with 2 MBq, and 2 orders of ^{109}Cd with 12 MBq. We also distributed $^{44\text{m}}\text{Sc}$ (3 MBq \times 1), ^{67}Cu (10 MBq \times 1), ^{88}Zr (2 MBq \times 3), ^{95}Nb (2 MBq \times 1), $^{121\text{m}}\text{Te}$ (2 MBq \times 1), ^{175}Hf (2 MBq \times 2), ^{179}Ta (2 MBq \times 1), and ^{211}At (20 MBq \times 1) under the the Supply Platform of Short-lived Radioisotopes for Fundamental Research.

(2) Superheavy element chemistry

Chemical characterization of newly-discovered superheavy elements (SHEs, atomic numbers $Z \geq 104$) is an extremely interesting and challenging subject in modern nuclear and radiochemistry. We are developing SHE production systems as well as rapid single-atom chemistry apparatuses at RIBF. Using heavy-ion beams from RILAC and AVF, ^{261}Rf ($Z = 104$), ^{262}Db ($Z = 105$), and ^{265}Sg ($Z = 106$) are produced in the $^{248}\text{Cm}(^{18}\text{O},5n)^{261}\text{Rf}$, $^{248}\text{Cm}(^{19}\text{F},5n)^{262}\text{Db}$, and $^{248}\text{Cm}(^{22}\text{Ne},5n)^{265}\text{Sg}$ reactions, respectively, and their chemical properties are investigated.

We installed a gas-jet transport system to the focal plane of the gas-filled recoil ion separator GARIS at RILAC. This system is a promising approach for exploring new frontiers in SHE chemistry: the background radiation from unwanted products are strongly suppressed, the intense primary heavy-ion beam is absent in the gas-jet chamber, and hence the high gas-jet extraction yield is attained. Furthermore, the beam-free conditions make it possible to investigate new chemical systems. In 2016, the isotope of element 107 ^{266}Bh was produced in the $^{248}\text{Cm}(^{23}\text{Na},5n)^{266}\text{Bh}$ reaction, and its decay properties were investigated with the rotating wheel apparatus MANON for α /SF spectrometry. Using ^{265}Sg atoms pre-separated by GARIS, the stability of the metal carbon bond in $\text{Sg}(\text{CO})_6$ was investigated with a thermal decomposition setup under a large international collaboration led by Paul Scherrer Institute. To realize aqueous chemistry studies of Sg and Bh, we have been developing a continuous and rapid solvent extraction apparatus which consists of a continuous dissolution apparatus Membrane DeGasser (MDG), a Flow Solvent Extractor (FSE), and a liquid scintillation detector for α /SF-spectrometry. The performance of MDG and FSE were investigated using $^{170,174}\text{Re}$ and ^{176}Re produced in the $^{nat}\text{Gd}(^{23}\text{Na},xn)$ and $^{152}\text{Gd}(^{23}\text{Na},5n)$ reactions, respectively at GARIS.

At AVF, the distribution ratios (D) of ^{261}Rf in the Aliquat 336/HCl system were measured with the flow-type liquid-liquid extraction apparatus called as "flow Injection Solvent Extraction apparatus (ISE)" in collaboration with Osaka Univ. The reversed-phase extraction chromatography of ^{262}Db in the Aliquat 336/HF system were also conducted with Automated Rapid Chemistry Apparatus of JAEA in

collaboration with Niigata Univ. and JAEA. We also used radiotracers of ^{88}Zr , $^{90,95}\text{Nb}$, $^{93\text{m}}\text{Mo}$, $^{95\text{m}}\text{Tc}$, ^{175}Hf , $^{178\text{a},179}\text{Ta}$, $^{177,179\text{m},181}\text{W}$, and $^{183,184\text{m},184\text{g}}\text{Re}$ for model experiments of SHEs.

(3) Development of trace element and isotope analyses and their applications to geoscience and environmental science

We have been developing the ECR Ion Source Mass Spectrometer (ECRIS-MS) for trace element analyses. In 2016, we renovated the detection system of ECRIS-MS and evaluated sensitivity and mass resolution power. We equipped a laser-ablation system with an ion source and a pre-concentration system to achieve high-resolution analyses for noble gases such as Kr and Xe. This technique is expected to monitor the atmosphere around nuclear power plants.

Using the conventional ICP-MS, TIMS, IRMS and so on, we analyzed sediments such as a ferro-manganese nodule in the Pacific ocean to elucidate its growth history concerning the environmental changes in the ocean. We also studied lead and sulfur isotope ratios on cinnabar and asphalt samples from ancient ruins in Japan to elucidate the distribution of goods in the archaic society and to reveal the establishment of the Yamato dynasty in the period from Jomon to Tumulus. We also studied a feasibility to improve the sensitivity for the sulfur isotope ratios with the “trapping and focusing” techniques using a cryo-system.

(4) Development of chemical materials for ECR ion sources of RIBF

In 2016, we prepared metallic ^{238}U rods and $^{238}\text{UO}_2$ on a regular schedule for ^{238}U -ion accelerations with the 28-GHz ECR of RILAC II.

Members

Team Leader

Hiromitsu HABA

Research & Technical Scientist

Kazuya TAKAHASHI (Senior Research Scientist)

Postdoctoral Researcher

Yukiko KOMORI

Technical Staff I

Shinya YANO

Research Consultant

Seiichi SHIBATA

Part-time Workers

Michiko KITAGAWA

Yu Vin SAHOO

Nozomi SATO

Keiko WATANABE

Visiting Scientists

Masayuki AIKAWA (Hokkaido Univ.)

Mayeen Uddin KHANDAKER (Univ. Malaya)

Takumi KUBOTA (Kyoto Univ.)

Aya SAKAGUCHI (Univ. of Tsukuba)

Miho TAKAHASHI (Tokyo Univ. Marine Sci. and Tech.)

Atsushi TOYOSHIMA (JAEA)

Takahiro YAMADA (Japan Rad. Assoc.)

Kazuhiko AKIYAMA (Tokyo Met. Univ.)

Hidetoshi KIKUNAGA (Tohoku Univ.)

Kazuhiro OOE (Niigata Univ.)

Hiroshi SHIMIZU (Rissho Univ.)

Masayoshi TODA (Tokyo Univ. Marine Sci. and Tech.)

Naoyuki UKON (Hokkaido Univ.)

Akihiko YOKOYAMA (Kanazawa Univ.)

Visiting Technicians

Yuichiro WAKITANI (Japan Rad. Assoc.)

Student Trainees

Ryuji AONO (Niigata Univ.)

Yuki HATTORI (Tokyo Univ. Marine Sci. and Tech.)

Junichi HIRATA (Tokyo Univ. Marine Sci. and Tech.)

Junpei INAGAKI (Univ. of Tsukuba)

Narumi KONDO (Osaka Univ.)

Takuya MORIYAMA (Niigata Univ.)

Tetuya NAGAOKA (Niigata Univ.)

Yu NAMBA (Niigata Univ.)

Kouki OUCHI (Osaka Univ.)

Yoshiki FUKUDA (Kanazawa Univ.)

Kazunori HAYASHI (Kanazawa Univ.)

Takumi IKEDA (Osaka Univ.)

Akimitsu KANDA (Osaka Univ.)

Kouki MORIYA (Kanazawa Univ.)

Risa MOTOYAMA (Niigata Univ.)

Masahiro NAGASE (Osaka Univ.)

Shuta OE (Kanazawa Univ.)

Moemi SAITOH (Hokkaido Univ.)

Daisuke SATO (Niigata Univ.)

Kaori SHIRAI (Niigata Univ.)

Shota TSUCHIYA (Niigata Univ.)

Ryohei YAMADA (Niigata Univ.)

Yukari YATSU (Kanazawa Univ.)

Yudai SHIGEKAWA (Osaka Univ.)

Tomohiro TOMITSUKA (Niigata Univ.)

Rufai Ahmed USMAN (Univ. Malaya)

Yuki YASUDA (Osaka Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- A. R. Usman, M. U. Khandaker, H. Haba, M. Murakami, and N. Otuka, "Measurements of deuteron-induced reaction cross-sections on natural nickel up to 24 MeV", *Nuclear Instruments and Methods in Physics Research Section B* **368**, 112–119 (2016).*
- D. Kaji, K. Morimoto, H. Haba, E. Ideguchi, H. Koura, and K. Morita, "Decay properties of new isotopes ^{234}Bk and ^{230}Am , and even–even Nuclides ^{234}Cm and ^{230}Pu ", *Journal of the Physical Society of Japan* **85**, 015002-1–2 (2016).*
- S. Cao, Y. Wang, Z. Qin, F. Fan, H. Haba, Y. Komori, X. Wu, C. Tan, and X. Zhang, "Gas-phase chemistry of ruthenium and rhodium carbonyl complexes", *Physical Chemistry Chemical Physics* **18**, 119–125 (2016).*
- S. Takács, M. P. Takács, F. Ditrói, M. Aikawa, H. Haba, and Y. Komori, "Activation cross sections of longer-lived radionuclides produced in germanium by alpha particle irradiation", *Nuclear Instruments and Methods in Physics Research Section B* **383**, 213–226 (2016).*
- F. Ditrói, S. Takács, H. Haba, Y. Komori, M. Aikawa, Z. Szűcs, and M. Saito, "Excitation function of the alpha particle induced nuclear reactions on enriched ^{116}Cd , production of the theranostic isotope $^{117\text{m}}\text{Sn}$ ", *Nuclear Instruments and Methods in Physics Research Section B* **385**, 1–8 (2016).*
- A. R. Usman, M. U. Khandaker, H. Haba, N. Otuka, M. Murakami, and Y. Komori, "Production cross-sections of radionuclides from α -induced reactions on natural copper up to 50 MeV", *Applied Radiation and Isotopes* **114**, 104–113 (2016).*
- Y. Kasamatsu, T. Yokokita, K. Toyomura, Y. Shigekawa, H. Haba, J. Kanaya, M. Huang, Y. Ezaki, T. Yoshimura, K. Morita, and A. Shinohara, "Coprecipitation experiment with Sm hydroxide using a multitracer produced by nuclear spallation reaction: A tool for chemical studies with superheavy elements", *Applied Radiation and Isotopes* **118**, 105–116 (2016).*
- T. Yokokita, Y. Kasamatsu, A. Kino, H. Haba, Y. Shigekawa, Y. Yasuda, K. Nakamura, K. Toyomura, Y. Komori, M. Murakami, T. Yoshimura, N. Takahashi, K. Morita, and A. Shinohara, "Observation of the chemical reaction equilibria of element 104, rutherfordium: Solid-liquid extraction of Rf, Zr, Hf and Th with Aliquat 336 resin from HCl", *Dalton Transactions* **45**, 18827–18831 (2016).*
- J. Hirata, K. Takahashi, Yu Vin Sahoo, and M. Tanaka, "Laser ablation inductively coupled plasma mass spectrometry for quantitative imaging of elements in ferromanganese nodule", *Chemical Geology* **427**, 65–72 (2016).*
- S. Sekimoto, T. Kobayashi, K. Takamiya, M. Ebihara, and S. Shibata, "Origin of spherule samples recovered from Antarctic ice sheet – Terrestrial or extraterrestrial?", *Nuclear Engineering and Technology* **48**, 293–298 (2016).*
- S. Fujita, K. Goto-Azuma, M. Hirabayashi, A. Hori, Y. Iizuka, Y. Motizuki, H. Motoyama, and K. Takahashi, "Densification of layered firm in the ice sheet at Dome Fuji, Antarctica", *Journal of Glaciology* **62**, 103–123 (2016).*

[Proceeding]

(Original Paper) *Subject to Peer Review

- H. Haba, "Superheavy element chemistry at GARIS", *EPJ Web of Conferences* **131**, 07006-1–6 (2016).*

[Book]

(Original Paper)

- K. Takahashi, "Frequently used evaluations for aerial and solid pollution" in *Corrosion control and surface finishing* edited by H. Kanematsu and D. M. Barry, pp. 141–151, Springer (2016).
羽場宏光, "理科年表 国立天文台編 平成 29 年 第 90 冊", p. 582, 丸善出版, 2016 年 11 月 30 日.

Oral Presentations

[International Conference etc.]

- H. Haba, "Superheavy element chemistry behind GARIS at RIKEN", Nobel Symposia, NS160: Chemistry and Physics of Heavy and Superheavy Elements, Scania, Sweden, May–June (2016).
- H. Haba, "SHE nuclear chemistry at RIKEN", Seminar für Kern- und Radiochemie, Institut für Kernchemie, Johannes Gutenberg-Universität, Mainz, Germany, June (2016).
- K. Takahashi, Y. Obi, and M. Tanaka, "The lead isotopes of aeolian dust observed at Saitama area (Japan) and their genetic implications", International Conference Series on Environmental and Food Monitoring (ISEAC-39), Hamburg, Germany, July (2016).
- R. Eichler, M. Asai, H. Brand, N. M. Chiera, A. Di Nitto, R. Dressler, Ch. E. Düllmann, J. Even, R. Eichler, F. Fangli, M. Goetz, H. Haba, W. Hartmann, E. Jäger, D. Kaji, J. Kanaya, Y. Kaneya, J. Khuyagbaatar, B. Kindler, Y. Komori, B. Kraus, J. V. Kratz, J. Krier, Y. Kudou, N. Kurz, S. Miyashita, K. Morimoto, K. Morita, M. Murakami, Y. Nagame, K. Ooe, D. Piquet, N. Sato, T. K. Sato, J. Steiner, P. Steinegger, T. Sumita, M. Takeyama, K. Tanaka, T. Tomitsuka, A. Toyoshima, K. Tsukada, A. Türler, I. Usoltsev, Y. Wakabayashi, Y. Wang, N. Wiehl, A. Yakushev, S. Yamaki, S. Yano, S. Yamaki, and Z. Qin, "Experimentally assessing the metal-carbon bond stability in $\text{Sg}(\text{CO})_6$ ", 9th International Conference on Nuclear and Radiochemistry (NRC9), Helsinki, Finland, Aug.–Sep. (2016).
- T. Fukuchi, H. Haba, S. Yamamoto, Y. Watanabe, and S. Enomoto, "Dual isotope imaging of small animal by a positron emission tomography with additional γ -ray detectors", World Molecular Imaging Congress 2016, New York, USA, Sept. (2016).
- A. R. Usman, M. U. Khandaker, H. Haba, and N. Karpuz, "Experimental and calculated excitation functions of ^{56}Mn from deuteron-induced nuclear reactions on nickel", 3rd International Conference on Computational and Experimental Science and Engineering (ICCESEN-2016), Antalya, Turkey, Oct. (2016).
- T. Fukuchi, H. Haba, S. Yamamoto, Y. Watanabe, and S. Enomoto, "Positron emission tomography with additional γ -ray detectors for multiple probe imaging", 2016 IEEE NSS/MIC, Strasbourg, France, Oct.–Nov. (2016).
- M. Aikawa, M. Saito, Y. Komori, H. Haba, S. Takács, F. Ditrói, and Z. Szűcs, "Activation cross sections of alpha-induced reactions on natural palladium for ^{103}Ag production", The 7th Asian Nuclear Reaction Database Development Workshop (AASPP 2016), Beijing, China, Nov. (2016).
- H. Haba, "Forefront of superheavy element researches at RIKEN", Symposium for exploring prospective research –Pioneering new fields:

Forefront of RIKEN's science and beyond-, Wako, Japan, Nov. (2016).

[Domestic Conference]

- 羽場宏光, “理研 RI ビームファクトリーにおける RI 製造応用”, 日本放射性医薬品協会賀詞交歓会, 千代田区, 1 月 (2016).
- 羽場宏光, “理研における RI 製造”, 東北大学電子光学研究センター研究会 「放射性同位元素 (RI) 製造計画と多分野における RI 利用の現状”, 仙台市, 2 月 (2016).
- 羽場宏光, “理研 RI ビームファクトリーにおけるアルファ放射体利用”, 第 7 回アルファ放射体実験室利用研究会, 仙台市, 2 月 (2016).
- 田中泰貴, 成清義博, 森田浩介, 藤田訓裕, 加治大哉, 森本幸司, 山木さやか, 若林泰生, 田中謙伍, 武山美麗, 米田晃, 羽場宏光, 小森有希子, 矢納慎也, B. J. P. Gall, Z. Asfari, H. Faure, 長谷部裕雄, M. Huang, 金谷淳平, 村上昌史, 吉田敦, 山口貴之, 門叶冬樹, 吉田友美, Z. Gan, L. Ma, H. Geissel, S. Hofmann, Y. Maurer, 山本翔也, 山野裕貴, 渡辺健友, 石澤倫, 浅井雅人, 青野竜士, 後藤真一, 鹿取謙二, “RIKEN-GARIS を用いた, 超重元素領域での融合障壁分布の研究”, 日本物理学会第 71 回年次大会, 仙台市, 3 月 (2016).
- 羽場宏光, “加速器を用いた応用研究用ラジオアイソトープの製造”, 日本物理学会第 71 回年次大会, 仙台市, 3 月 (2016).
- 羽場宏光, “理研 RI ビームファクトリーにおける RI 製造応用”, 第 11 回 Eichrom Technologies 社製品ユーザーズセミナー, 千代田区, 4 月 (2016).
- 佐藤望, 矢納慎也, 羽場宏光, 小森有希子, 柴田誠一, 渡邊慶子, 加治大哉, 豊嶋厚史, 松本幹雄, “理研における At-211 製造”, 第 53 回アイソトープ・放射線研究発表会, 文京区, 7 月 (2016).
- 矢納慎也, 羽場宏光, 柴田誠一, 小森有希子, 高橋和也, 佐藤望, 渡邊慶子, 脇谷雄一郎, 山田崇裕, 松本幹雄, “理研における頒布用精製 ^{67}Cu の製造開発”, 第 53 回アイソトープ・放射線研究発表会, 文京区, 7 月 (2016).
- 羽場宏光, “短寿命 RI 供給プラットフォームについて”, 2016 核化学夏の学校, 徳島市, 8 月 (2016).
- 齋藤萌美, 合川正幸, 羽場宏光, 小森有希子, サンドールタカーチ, “ ^{169}Tm への重陽子入射における ^{169}Yb の生成断面積について”, 日本原子力学会 2016 年秋の大会, 久留米市, 9 月 (2016).
- 菊永英寿, 高宮幸一, 大槻勲, 羽場宏光, “ ^{48}Cr の半減期精密測定”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 矢納慎也, 羽場宏光, 柴田誠一, 小森有希子, 高橋和也, 渡邊慶子, 脇谷雄一郎, 山田崇裕, 松本幹雄, “ $^{70}\text{Zn}(d,an)^{67}\text{Cu}$ 反応による頒布用精製 ^{67}Cu の製造”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 加治大哉, 森本幸司, 羽場宏光, 若林泰生, 武山美麗, 山木さやか, 小森有希子, 矢納慎也, 後藤真一, “GARIS-II を用いたホットフュージョン反応 $^{46}\text{Ca}+^{238}\text{U}\rightarrow^{286}\text{Cn}^*$ に関する研究”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 海老原充, 大浦泰嗣, 白井直樹, 鶴田治雄, 森口祐一, 永川榮泰, 櫻井昇, 羽場宏光, 松崎浩之, 山形武靖, 永井尚生, 関本俊, “東電福島原発事故直後に採取された大気浮遊塵試料中の $^{129}\text{I}/^{131}\text{I}$ 比”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 大浦泰嗣, 海老原充, 白井直樹, 鶴田治雄, 中島映至, 森口祐一, 大原利真, 永川榮泰, 櫻井昇, 羽場宏光, 松崎浩之, “東電福島原発事故直後に採取された大気浮遊塵試料のオートラジオグラフと $^{129}\text{I}/^{137}\text{Cs}$ 比”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 小森有希子, 羽場宏光, 大江一弘, 豊嶋厚史, 水飼秋葉, 佐藤大輔, 本山李沙, 矢納慎也, 渡邊慶子, 佐藤望, 山下さやか, 田中泰貴, 加治大哉, 森本幸司, 坂口綾, 稲垣純平, 菊永英寿, 重河優大, 笠松良崇, Jon Petter Omtvedt, “107 番元素ボーリウムの溶液化学研究に向けた GARIS ガスジェット装置による Re 同位体の製造とフロー溶媒抽出器を用いた Re のオンライン抽出”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 田中康介, 秋山和彦, 羽場宏光, “化学的還元反応を用いた金属内包フラーレン分離の条件検討”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 佐藤望, 矢納慎也, 羽場宏光, 小森有希子, 柴田誠一, 渡邊慶子, 加治大哉, 豊嶋厚史, 高橋和也, 松本幹雄, “理研における At-211 製造”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 森田浩介, 森本幸司, 加治大哉, 羽場宏光, “GARIS を用いた超重元素研究の最前線—新元素認定までの道のり、周期表の拡張を目指した挑戦—”, 2016 日本放射化学学会年会・第 60 回放射化学討論会, 新潟市, 9 月 (2016).
- 羽場宏光, “理研 GARIS を用いた Sg と Bh の揮発性研究”, 2016 「超重元素の科学」研究会, 新潟市, 9 月 (2016).
- 小森有希子, “GARIS を用いた Sg と Bh の溶液化学研究”, 2016 「超重元素の科学」研究会, 新潟市, 9 月 (2016).
- 羽場宏光, “超重元素合成に関する理研の将来計画”, 2016 「超重元素の科学」研究会, 新潟市, 9 月 (2016).
- 高橋和也, 南武志, 上條信彦, 北川路子, Yu-Vin Sahoo, “硫黄同位体比分析による、北日本に産出する原油/アスファルトの識別の試み”, 日本分析化学学会年会・第 65 年会, 札幌市, 9 月 (2016).
- 岡部駿也, 田中美穂, 有我洋香, 高梨聖, 高橋和也, “シリカスケールの生成機構の鍵”, 日本分析化学学会年会・第 65 年会, 札幌市, 9 月 (2016).
- 羽場宏光, “理研 RIBF における応用研究用 RI の製造”, 東京大学大学院工学系研究科原子力国際専攻高橋研究室セミナー, 文京区, 10 月 (2016).
- 羽場宏光, “理研 RIBF における医療用 RI 製造の現状と展望”, 第 56 回日本核医学会学術総会・第 36 回日本核医学技術学会総会学術大会, 名古屋, 11 月 (2016).
- M. Aikawa, M. Saito, S. Ebata, Y. Komori, and H. Haba, “Activation cross sections of alpha-induced reactions on natural zinc for ^{68}Ge production”, 2016 年度核データ研究会, つくば市, 11 月 (2016).
- 宗兼将之, 本村信治, 神野伸一郎, 上田真史, 羽場宏光, 吉川豊, 安井裕之, 榎本秀一, “抗糖尿病作用を有する亜鉛錯体の体内動態と化学形態の同時解析”, 第 55 回日本薬学会・日本薬剤師会・日本病院薬剤師会中国四国支部学術大会, 岡山市, 11 月 (2016).
- 羽場宏光, “いかにして人工元素は合成されたか”, 2016 年度 (第 62 回) 仁科記念講演会, 文京区, 12 月 (2016).

Posters Presentations

[International Conference etc.]

- J. Inagaki, A. Sakaguchi, M. Inoue, A. Usui, H. Haba, T. Kashiwabara, S. Yamasaki, K. Sueki, and Y. Takahashi, “Fractionation of zirconium-hafnium in ferromanganese crusts”, 26th Goldschmidt Conference, Yokohama, Japan, June (2016).
- F. Ditrói, S. Takács, H. Haba, Y. Komori, M. Aikawa, Z. Szucs, and M. Saito, “Measurements of alpha particle induced reaction cross sections on ^{nat}Cd and ^{116}Cd for practical applications up to 50 MeV”, 12th European Conference on Accelerators in Applied Research and Technology, Jyväskylä, Finland, July (2016).
- H. Haba, F. Fan, D. Kaji, Y. Kasamatsu, H. Kikunaga, Y. Komori, N. Kondo, H. Kudo, K. Morimoto, K. Morita, M. Murakami, K. Nishio, K. Ooe, Z. Qin, N. Sato, A. Shinohara, M. Takeyama, T. Tanaka, A. Toyoshima, K. Tsukada, Y. Wakabayashi, Y. Wang, S. Yamaki, S. Yano, Y. Yasuda, T. Yokokita, and A. Yoneda, “Production and decay studies of ^{261}Rf , ^{262}Db , ^{265}Sg , and ^{266}Bh for superheavy element chemistry”, 9th International Conference on Nuclear and Radiochemistry (NRC9), Helsinki, Finland, Aug.–Sep. (2016).

- Y. Komori, H. Haba, K. Ooe, A. Toyoshima, A. Mitsukai, M. Murakami, D. Sato, R. Motoyama, S. Yano, K. Watanabe, A. Sakaguchi, J. Inagaki, H. Kikunaga, S. Wulff, and J. P. Omtvedt, "Development of a rapid solvent extraction apparatus for aqueous chemistry of the heaviest elements", 9th International Conference on Nuclear and Radiochemistry (NRC9), Helsinki, Finland, Aug.–Sep. (2016).
- L. Lens, A. Yakushev, Ch. E. Düllmann, M. Asai, M. Block, H. M. David, J. Despotopoulos, A. Di Nitto, K. Eberhardt, M. Götz, S. Götz, H. Haba, L. Harkness-Brennan, F. P. Heßberger, R.-D. Herzberg, D. Hinde, J. Hoffmann, A. Hübner, E. Jäger, D. Judson, J. Khuyagbaatar, B. Kindler, Y. Komori, J. Konki, J. V. Kratz, J. Krier, N. Kurz, M. Laatiaoui, S. Lahiri, B. Lommel, M. Maiti, A. K. Mistry, C. Mokry, K. Moody, Y. Nagame, J. P. Omtvedt, P. Papadakis, V. Pershina, D. Rudolph, J. Runke, M. Schädel, P. Scharrer, T. Sato, D. Shaughnessy, B. Schausten, J. Steiner, P. Thörle-Pospiech, N. Trautmann, K. Tsukada, J. Uusitalo, A. Ward, M. Wegrzecki, E. Williams, N. Wiehl, and V. Yakusheva, "Single-atom flerovium chemistry at TASCA", 9th International Conference on Nuclear and Radiochemistry (NRC9), Helsinki, Finland, Aug.–Sep. (2016).
- A. Yokoyama, Y. Kitayama, Y. Fukuda, H. Kikunaga, M. Murakami, Y. Komori, S. Yano, H. Haba, K. Tsukada, and A. Toyoshima, "Extraction behavior of rutherfordium as a cationic fluoride complex with a TTA chelate extractant from HF/HNO₃ acidic solutions", 9th International Conference on Nuclear and Radiochemistry (NRC9), Helsinki, Finland, Aug.–Sep. (2016).
- Y. Komori, M. Murakami, and H. Haba, "Measurement of production cross sections of Tc isotopes in deuteron-induced reactions on ^{nat}Mo up to 24 MeV", 9th International Conference on Nuclear and Radiochemistry (NRC9), Helsinki, Finland, Aug.–Sep. (2016).

[Domestic Conference]

- 山田亮平, 大江一弘, 後藤真一, 工藤久昭, 羽場宏光, 小森有希子, "フローインジェクション分析法を利用した4族元素 Zr, Hf のキレート抽出", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).
- 大江一弘, 山田亮平, 後藤真一, 工藤久昭, 羽場宏光, 小森有希子, "Rf の同族元素 Zr, Hf の4-イソプロピルトロポロンを用いた溶媒抽出挙動", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).
- 佐藤大輔, 村上昌史, 大江一弘, 本山李沙, 羽場宏光, 小森有希子, 豊嶋厚史, 水飼秋菜, 菊永英寿, 後藤真一, 工藤久昭, "5族元素 Nb, Ta のフッ化水素酸からの Aliquat 336 樹脂への抽出: 分配係数の抽出剤濃度依存性の検討", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).
- 本山李沙, 大江一弘, 村上昌史, 羽場宏光, 後藤真一, 工藤久昭, "5族元素 Nb, Ta の塩酸溶液からのトリイソオクチルアミンによる溶媒抽出—Ta トレーサー調製法の影響—", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).
- 水飼秋菜, 豊嶋厚史, 小森有希子, 羽場宏光, 浅井雅人, 塚田和明, 佐藤哲也, 永目論一郎, "フロー抽出装置を用いたフッ化水素酸—Aliquat336系におけるタングステンの溶媒抽出", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).
- 豊嶋厚史, 神田晃充, 池田卓海, 吉村崇, 篠原厚, 矢納慎也, 小森有希子, 羽場宏光, "アスタチンの酸化還元と溶媒抽出挙動", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).
- 神原正, 吉田敦, 羽場宏光, "陽電子放出核種による回転体検査法の開発", 2016 日本放射化学会年会・第60回放射化学討論会, 新潟市, 9月 (2016).

RIBF Research Division

User Liaison and Industrial Cooperation Group

1. Abstract

The essential mission of the “User Liaison and Industrial Cooperation (ULIC) Group” is to maximize the research activities of RIBF by attracting users in various fields with a wide scope.

The ULIC Group consists of two teams.

The RIBF User Liaison Team provides various supports to visiting RIBF users through the User’s Office. The Industrial Cooperation Team supports potential users in industries who use the beams for application purposes or for accelerator related technologies other than basic research. Production of various radioisotopes by the AVF cyclotron is also one of the important mission. The produced radioisotopes are distributed to researchers in Japan for a charge through the Japan Radioisotope Association.

In addition the ULIC Group takes care of laboratory tours for RIBF visitors from public. The numbers of visitors amounts to 2,300 per year.

Members

Group Director

Hideyuki SAKAI

Special Temporary Employee

Tadashi KAMBARA

Senior Visiting Scientists

Ikuko HAMAMOTO (Lund Univ.)

Munetake ICHIMURA (Univ. of Tokyo)

Assistants

Katsura IWAI

Tomoko IWANAMI

Noriko KIYAMA

Tomomi OKAYASU

Yoko FUJITA

Yu NAYA

RIBF Research Division

User Liaison and Industrial Cooperation Group

RIBF User Liaison Team (User Support Office)

1. Abstract

To enhance synergetic common use of the world-class accelerator facility, the Radioisotope Beam Factory (RIBF), it is necessary to promote a broad range of applications and to maximize the facility's importance. The facilitation and promotion of the RIBF are important missions charged to the team. Important operational activities of the team include: i) the organization of international Program Advisory Committee (PAC) meetings to review experimental proposals submitted by RIBF users, ii) RIBF beam-time operation management, and iii) promotion of facility use by hosting outside users through the RIBF Independent Users program, which is a new-user registration program begun in FY2010 at the RIKEN Nishina Center (RNC) to enhance the synergetic common use of the RIBF. The team opened the RIBF Users Office in the RIBF building in 2010, which is the main point of contact for Independent Users and provides a wide range of services and information.

2. Major Research Subjects

- (1) Facilitation of the use of the RIBF
- (2) Promotion of the RIBF to interested researchers

3. Summary of Research Activity

(1) Facilitation of the use of the RIBF

The RIBF Users Office, formed by the team in 2010, is a point of contact for user registration through the RIBF Independent User program. This activity includes:

- registration of users as RIBF Independent Users,
- registration of radiation workers at the RIKEN Wako Institute,
- provision of an RIBF User Card (a regular entry permit) and an optically stimulated luminescence dosimeter for each RIBF Independent User, and
- provision of safety training for new registrants regarding working around radiation, accelerator use at the RIBF facility, and information security, which must be completed before they begin RIBF research.

The RIBF Users Office is also a point of contact for users regarding RIBF beam-time-related paperwork, which includes:

- contact for beam-time scheduling and safety review of experiments by the In-House Safety Committee,
- preparation of annual Accelerator Progress Reports, and
- maintaining the above information in a beam-time record database.

In addition, the RIBF Users Office assists RIBF Independent Users with matters related to their visit, such as invitation procedures, visa applications, and the reservation of on-campus accommodation.

(2) Promotion of the RIBF to interested researchers

- The team has organized an international PAC for RIBF experiments; it consists of leading scientists worldwide and reviews proposals in the field of nuclear physics (NP) purely on the basis of their scientific merit and feasibility. The team also assists another PAC meeting for material and life sciences (ML) organized by the RNC Advanced Meson Laboratory. The NP and ML PAC meetings are organized twice a year.
- The team coordinates beam times for PAC-approved experiments and other development activities. It manages the operating schedule of the RIBF accelerator complex according to the decisions arrived at by the RIBF Machine Time Committee.
- To promote research activities at RIBF, proposals for User Liaison and Industrial Cooperation Group symposia/mini-workshops are solicited broadly both inside and outside of the RNC. The RIBF Users Office assists in the related paperwork.
- The team is the point of contact for the RIBF users' association. It arranges meetings at RNC headquarters for the RIBF User Executive Committee of the users' association.
- The Team conducts publicity activities, such as arranging for RIBF tours, development and improvement of the RNC official web site, and delivery of RNC news via email and the web.

Members

Team Leader

Ken-ichiro YONEDA

Deputy Team Leader

Yasushi WATANABE (concurrent: Senior Research Scientist, Radiation Lab.)

Technical Staff I

Narumasa MIYAUCHI

RIBF Research Division

User Liaison and Industrial Cooperation Group

Industrial Cooperation Team

1. Abstract

Industrial cooperation team handles non-academic activities at RIBF corresponding to industries and to general public.

2. Major Research Subjects

- (1) Fee-based distribution of radioisotopes produced at RIKEN AVF Cyclotron
- (2) Support of industrial application using the RIBF accelerator beam and its related technologies including novel industrial applications.
- (3) Development of real-time wear diagnostics of industrial material using RI beams

3. Summary of Research Activity

(1) Fee-based distribution of radioisotopes

This team has been handling fee-based distribution of radioisotopes since 2007. Radionuclides of Zn-65, Sr-85, Y-88 and Cd-109, which are produced by the RI application team at the AVF cyclotron, are distributed to nonaffiliated users under a Material Transfer Agreement (MTA) between Japan Radioisotope Association and RIKEN. In 2016, we delivered 2 shipments of Cd-109 with a total activity of 12 MBq, 5 shipments of Zn-65 with a total activity of 24 MBq, 2 shipments of Y-88 with an activity of 2 MBq and one shipment of Sr-85 with an activity of 1 MBq. The final recipients of the RIs were seven universities and one hospital.

(2) Support of Industrial application using RIBF

RNC promotes facility-sharing program "Promotion of applications of high-energy heavy ions and RI beams". In this program, RNC opens the old part of the RIBF facility, which includes the AVF cyclotron, RILAC, RIKEN Ring Cyclotron and experimental instruments, to non-academic proposals from users including private companies. The proposals are reviewed by a program advisory committee, industrial PAC (InPAC). The proposals which have been approved by the InPAC are allocated with beam times and the users pay RIKEN the beam time fee. The intellectual properties obtained by the use of RIBF belong to the users. In order to encourage the use of RIBF by those who are not familiar with utilization of ion beams, the first two beam times of each proposal can be assigned to trial uses which are free of beam time fee.

The sixth InPAC meeting held in January 2017 reviewed two fee-based proposals from private companies and approved them. Until now, five proposals of fee-based utilization from three private companies have been performed. Private companies used heavy-ion beams of Ar-40 (95 MeV/A) and Kr-84 (70 MeV/A) at the E5A beamline for an irradiation test of space-use semi-conductors in the atmosphere. For future users, we have developed higher LET beams of Xe-136 (39 MeV/A) and Au-197 (18.4 MeV/A) at the same beamline.

(3) Development of real-time wear diagnostics using RI beams

We are developing a method to determine the spatial distribution of gamma-ray emitting RIs on periodically-moving objects, named "GIRO" (Gamma-ray Inspection of Rotating Object), that is based on the same principle as the medical PET imaging but is simpler and less expensive. This method can be used for real-time inspection of a closed system in a running machine. In 2016, the scintillation detectors were replaced by new ones and the gamma-ray collimators were modified on the test bench. We also tried single-photon emission computer tomography (SPECT) mode measurement.

Members

Team Leader

Atsushi YOSHIDA

Contract Researcher

Tadashi KAMBARA

Technical Staff I

Shinya YANO (concurrent: RI Application Team)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

A.Yoshida, T.Kambara, A.Nakao, R.Uemoto, H.Uno, A.Nagano, H.Yamaguchi, T.Nakao, D.Kahl, Y.Yanagisawa, D.Kameda, T.Ohnishi, N.Fukuda, T.Kubo, "Wear diagnostics of industrial material using RI beams of ^7Be and ^{22}Na ", Nuclear Instruments and Methods in Physics Research Section B 317, 785-788 (2013) *

T. Kambara, A. Yoshida, H. Takeichi, "Gamma-ray inspection of rotating object", Nuclear Instruments and Methods in Physics Research A 797, 1-7 (2015) *.

T. Kambara, "Gamma-Ray Inspection of Rotating Object (GIRO)", Nuclear Physics News Vol. 26, No.4, 26-29 (2016).

[Proceedings]

(Original Papers) *Subject to Peer Review

T. Kambara, A. Yoshida, Y. Yanagisawa, D. Kameda, N. Fukuda, T. Ohnishi, T. Kubo, R. Uemoto, A. Nagano, and H. Uno, "Industrial Application of Radioactive Ion Beams at the RIKEN RI Beam Factory", AIP Conference Proceedings 1412 (2011), American Institute of Physics *

[Book]

(Original Papers) *Subject to Peer Review

A. Yoshida, T. Kambara, R. Uemoto, "RI ビーム打込み法を用いた摩耗検査法の開発", 月刊トライボロジー2014-08 No324 pg.16-18,新樹社 (2014)

A. Yoshida, T. Kambara, "研究室紹介 No.43 理化学研究所仁科加速器研究センター産業連携チーム", 月刊トライボロジー2015-02 No330 pg.66,新樹社(2014)

T. Kambara, "RI ビーム照射を用いた摩耗試験", 加速器 Vol. 12, No. 4(2015)

Oral Presentations

[International Conference etc.]

T. Kambara, et al., "Industrial Application of Radioactive Ion Beams at the RIKEN RI Beam Factory", 11th International Conference on Applications of Nuclear Techniques, Crete, Greece, Jun (2011)

A. Yoshida, et al., "Wear diagnostics of industrial material using RI beams of ^7Be and ^{22}Na ", 16th International Conference on Electromagnetic Iso-tope Separators and Techniques Related to their Applications (EMIS2012), Matsue, Dec.(2012)

[Domestic Conference]

A. Yoshida, "RI ビームの工業応用ー 表面摩耗量検査法開発", 理研シンポジウム第 16 回「トライボコーティングの現状と将来」, (トライボコーティング技術研究会主催), 和光, 2 月 (2014).

A. Yoshida, "理研 RI ビームパラエティ (産業利用まで)", 第 54 回放射線科学研究会(エキゾチックビームシリーズ<12>), 大阪ニュークリアサイエンス協会, 大阪, 7 月(2014).

T. Kambara, "イオン照射による材料改質と摩耗試験", 日本物理学会 年次大会, 東北学院大学 仙台, 03/19-22 (2016)

Posters Presentations

[Domestic Conference]

A. Yoshida, T. Kambara, "R I ビームでオンライン精密摩耗量測定～摩耗のイメージング～", nano tech 2016 第 15 回国際ナノテクノロジー総合展・技術会議, 01/27-29, 東京ビッグサイト, (2016)

T. Kambara, A. Yoshida, H. Haba, "陽電子放出核種による回転体検査法の開発", 2016 日本放射化学会年会・第 60 回放射化学討論会, 新潟大学, 09/10-12,(2016)

RIBF Research Division Safety Management Group

1. Abstract

The RIKEN Nishina Center for Accelerator-Based Science possesses one of the largest accelerator facilities in the world, which consists of two heavy-ion linear accelerators and five cyclotrons. This is the only site in Japan where uranium ions are accelerated. The center also has electron accelerators of microtron and synchrotron storage ring. Our function is to keep the radiation level in and around the facility below the allowable limit and to keep the exposure of workers as low as reasonably achievable. We are also involved in the safety management of the Radioisotope Center, where many types of experiments are performed with sealed and unsealed radioisotopes.

2. Major Research Subjects

- (1) Safety management at radiation facilities of Nishina Center for Accelerator-Based Science
- (2) Safety management at Radioisotope Center
- (3) Radiation shielding design and development of accelerator safety systems

3. Summary of Research Activity

Our most important task is to keep the personnel exposure as low as reasonably achievable, and to prevent an accident. Therefore, we daily patrol the facility, measure the ambient dose rates, maintain the survey meters, shield doors and facilities of exhaust air and wastewater, replenish the protective supplies, and manage the radioactive waste. Advice, supervision and assistance at major accelerator maintenance works are also our task.

The radioactive argon gas in the RIBF experimental rooms was reduced by a partition. The argon gas was generated at around the target and beam dump, and it diffuses to experimental rooms slightly by air circulation. We installed an air partition tentatively. The air flow and the radioactive gas was successfully restricted.

We measured the radiation level and shielding power in the RILAC irradiation room. The RILAC accelerator will be upgraded and additional shield be required. The amount of the shield was estimated by this evaluation.

Minor improvements of the radiation safety systems were also done, for example, part of the radiation control system at RIBF building was renewed because it was developed by old programming language. The radiation monitors at the Nishina building has been replaced annually from 2015 because they get older, which were installed in 1986.

Members

Group Director

Yoshitomo UWAMINO

Deputy Group Director

Kanenobu TANAKA

Nishina Center Technical Scientists

Rieko HIGURASHI

Hisao SAKAMOTO

Takeshi MAIE (concurrent; Cryogenic Technology Team)

Technical Staff I

Atsuko AKASHIO

Tomoyuki DANTSUKA (concurrent; Cryogenic Technology Team)

Research Consultant

Masaharu OKANO (Japan Radiation Res. Soc.)

Visiting Scientists

Hee Seock LEE (POSTECH)

Joo-Hee OH (POSTECH)

Nam-Suk JUNG (POSTECH)

Takashi NAKAMURA (Shimizu Corp.)

Noriaki NAKAO (Shimizu Corp.)

Koji OHISHI (Shimizu Corp.)

Arim LEE (Pohang Accelerator Laboratory POSTECH)

Nobuhiro SHIGYO (Kyushu Univ.)

Student Trainees

Kentaro SUGIHARA

Assigned Employee

Hiroki MUKAI

Temporary Staffing

Ryuji SUZUKI

Part-time Workers

Hiroshi KATO
 Satomi IIZUKA
 Kimie IGARASHI
 Hiroko AISO

Naoko USUDATE
 Shin FUJITA
 Yukiko SHIODA

Assistant

Tomomi OKAYASU (concurrent: User Liaison and Industrial
 Cooperation Group)

List of Publications & Presentations**Oral Presentations**

[International Conference etc.]

Akashio, A., Tanaka, K., Imao, H., and Uwamino Y.: "Activation measurement by ^{238}U beam irradiation around 11A MeV on He gas", 13th International Conference on Radiation Shielding & 19th Topical Meeting of the Radiation Protection & Shielding Division of the American Nuclear Society 2016 (ICRS13-RPSD2016), Paris, France, October (2016).

Oh, J., Jung, N., Lee, H., Oranj, L., Nakao, N., Uwamino, Y. and Ko S.: "Neutron Production from thin Be target irradiated by 50 MeV/u ^{238}U beam.", 13th International Conference on Radiation Shielding & 19th Topical Meeting of the Radiation Protection & Shielding Division of the American Nuclear Society 2016 (ICRS13-RPSD2016), Paris, France, October (2016).

[Domestic Conference]

田中鐘信: "理化学研究所 RI ビームファクトリー加速器施設の緊急時対応", 第4回加速器施設安全シンポジウム, 東海村, 1月,(2017).

赤塩敦子, 田中鐘信, 今尾 浩士: "RIBF 加速器におけるヘリウムガスへのウランビーム 11MeV/u 照射による放射化評価", 日本原子力学会 2017年春の年会, 湘南, 3月 (2016).

田中鐘信: "PHITS を用いた RI ビームファクトリー重イオン加速器施設の放射線影響評価", PHITS 研究会, 熱海, 9月 (2016).

Partner Institutions

The Nishina Center established the “Research Partnership System” in 2008. This system permits an external institute to develop its own projects at the RIKEN Wako campus in equal partnership with the Nishina Center. At present, three institutes, Center for Nuclear Study, the University of Tokyo (CNS); Institute of Particle and Nuclear Studies, KEK (KEK); and the Institute of Science and Technology, Niigata University (Niigata) are conducting research activities under the Research Partnership System.

CNS and the Nishina Center signed the partnership agreement in 2008. Until then, CNS had collaborated in joint programs with RIKEN under the “Research Collaboration Agreement on Heavy Ion Physics” (collaboration agreement) signed in 1998. The partnership agreement redefines procedures related to the joint programs while keeping the spirit of the collaboration agreement. The joint programs include experimental nuclear physics activities using CRIB, SHARAQ, and GRAPE at RIBF, theoretical nuclear physics activities with ALPHLEET, accelerator development, and activities at RHIC PHENIX.

The partnership agreement with the Niigata University was signed in 2010. The activity includes theoretical and experimental nuclear physics, and nuclear chemistry.

KEK started low-energy nuclear physics activity at RIBF in 2011 under the Research Partnership System. The joint experimental programs are based on KISS (KEK Isotope Separator). After the R&D studies on KISS, it became available for users from 2015. In this year, a new KEK branch, Wako Nuclear Science Center (WNSC) has been launched at the Wako campus to enhance the scientific activities of KISS.

The experimental proposals that request the use of the above-noted devices of CNS and KEK together with the other RIBF key devices are screened by the Program Advisory Committee (PAC). The PAC meetings are co-hosted by CNS and KEK.

The activities of CNS, Niigata, and KEK are reported in the following pages.

Partner Institution
Center for Nuclear Study, Graduate School of Science
The University of Tokyo

1. Abstract

The Center for Nuclear Study (CNS) aims to elucidate the nature of nuclear system by producing the characteristic states where the Isospin, Spin and Quark degrees of freedom play central roles. These researches in CNS lead to the understanding of the matter based on common natures of many-body systems in various phases. We also aim at elucidating the explosion phenomena and the evolution of the universe by the direct measurements simulating nuclear reactions in the universe. In order to advance the nuclear science with heavy-ion reactions, we develop AVF upgrade, CRIB and SHARAQ facilities in the large-scale accelerators laboratories RIBF. We started a new project OEDO for a new energy-degrading scheme, where a RF deflector system is introduced to obtain a good quality of low-energy beam. In 2016, a new group for fundamental symmetry has been added. We promote collaboration programs at RIBF as well as RHIC-PHENIX and ALICE-LHC with scientists in the world, and host international meetings and conferences. We also provide educational opportunities to young scientists in the heavy-ion science through the graduate course as a member of the department of physics in the University of Tokyo and through hosting the international summer school.

2. Major Research Subjects

- (1) Accelerator Physics
- (2) Nuclear Astrophysics
- (3) Nuclear spectroscopy of exotic nuclei
- (4) Quark physics
- (5) Nuclear Theory
- (6) OEDO/SHARAQ project
- (7) Exotic Nuclear Reaction
- (8) Low Energy Nuclear Reaction Group
- (9) Active Target Development
- (10) Fundamental Physics

3. Summary of Research Activity

(1) Accelerator Physics

One of the major tasks of the accelerator group is the AVF upgrade project that includes development of ion sources, upgrading the AVF cyclotron of RIKEN and the beam line to CRIB. Development of ECR heavy ion source is to provide new HI beams, higher and stable beams of metallic ions, and to improve the control system. The Hyper ECR and the Super ECR sources provide all the beams for the AVF cyclotron and support not only CRIB experiments but also a large number of RIBF experiments. Injection beam monitoring and control are being developed and studied in order to measure four-dimensional emittance. Detailed studies of the optics from the ion sources in consideration of the space charge effect are expected to improve transmission and qualities of beams for the RIBF facility. In 2016, The beam intensities of some light ions accelerated by AVF cyclotron have been doubled by improving the extraction system of the Hyper ECR.

(2) Nuclear Astrophysics

The nuclear astrophysics group in CNS is working for experimental studies with the low-energy RI beam separator CRIB. In FY2016, experiments on the alpha-cluster structure in the ^{22}Mg nucleus, $^7\text{Be}(n, \alpha)/(n, p)$ astrophysical reactions using the Trojan Horse method, production of ^7Be -implanted target, and the proton resonant scattering experiment with ^{26}Al isomeric beam were performed at CRIB under international collaborations including Korean, Italian, UK, and Chinese groups. The isomeric ^{26}Al beam production at CRIB was for the first time, and a high isomeric purity of over 30% was achieved. A strong indication of an exotic linear-chain cluster structure in ^{14}C nucleus was presented based on the $^{10}\text{Be}+\alpha$ resonant scattering experiment previously performed at CRIB.

(3) Nuclear structure of exotic nuclei

The NUSPEQ (NUclear SPectroscopy for Extreme Quantum system) group studies exotic structures in high-isospin and/or high-spin states in nuclei. The CNS GRAPE (Gamma-Ray detector Array with Position and Energy sensitivity) is a major apparatus for high-resolution in-beam gamma-ray spectroscopy. Missing mass spectroscopy using the SHARAQ is used for another approach on exotic nuclei. In 2016, the following progress has been made.

Experimental data taken in 2013 under the EURICA collaboration has been analyzed for studying octupole deformation in neutron-rich Ba isotopes and preparing publication. Exochemic charge exchange reaction ($^8\text{He}, ^8\text{Li}^*(1+)$) on ^4He has been analyzed for studying spin-dipole response of few-body system on the photon line. A new experiment measuring the $^4\text{He}(^8\text{He}, ^8\text{Be})4n$ reaction was performed for better statistics and better accuracy in order to verify a candidate of the ground state of the tetra neutrons just above the $4n$ threshold, which is under analysis.

A DAQ system for the CNS GRAPE was upgraded, where event building system is included for several digitizing modules based on sampling ADCs and FPGAs on boards.

(4) Quark Physics

Main goal of the quark physics group is to understand the properties of hot and dense nuclear matter created by colliding heavy nuclei at relativistic energies. The group has been involved in the PHENIX experiment at Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory, and the ALICE experiment at Large Hadron Collider (LHC) at CERN. As for ALICE, the group has involved in the data analyses, which include the measurement of low-mass lepton pairs in Pb-Pb and p-Pb collisions, heavy flavor baryon measurements in pp and p-Pb collisions, particle correlations with large rapidity gap in p-Pb collisions, and searches for dibaryons in Pb-Pb collisions. The group has involved in the ALICE-TPC upgrade using a Gas Electron Multiplier (GEM). New readout chip of the TPC upgrade, called as SAMPA, was tested and development of the new data readout system for the TPC upgrade, which aims online data processing by utilizing FPGA and GPU, has begun in 2016.

(5) Nuclear Theory

The nuclear theory group participate a project, "Priority Issue 9 to be tackled by using the Post-K Computer" and promotes computational nuclear physics utilizing supercomputers. In 2016, we revealed the quantum phase transition of nuclear shape in neutron-rich Zr isotopes by the Monte Carlo shell model. In parallel, we have been promoting the CNS-RIKEN collaboration project on large-scale nuclear structure calculations and performed shell-model calculations under various collaborations with many experimentalists for investigating the exotic structure of neutron-rich nuclei, such as $^{38,40}\text{P}$, ^{48}Ca , ^{55}Ca , ^{128}Cd , and ^{132}Sn .

(6) OEDO/SHARAQ project

The OEDO/SHARAQ group pursues experimental studies of RI beams by using the high-resolution beamline and the SHARAQ spectrometer. A mass measurement by TOF-Brho technique for very neutron-rich calcium isotopes around $N=34$ was successfully performed. The parity-transfer charge exchange (^{16}O , ^{16}F) was studied, since the reaction is expected to probe the 0^- strength in nuclei. The result of the study was recently published. The OEDO project, which is a major upgrade of the high-resolution beamline for RI beams with energies lower than 100 MeV/u, is ongoing. The beam line has been constructed in March 2017. The commissioning of the energy degrading scheme is scheduled in June 2017.

(7) Exotic Nuclear Reaction

The Exotic Nuclear Reaction group studies various exotic reactions induced by beams of unstable nuclei. One subject is inverse-kinematics (p,n) reaction. In 2016 a set of neutron counters PANDORA was developed and an in-beam test was performed. Candidate nuclei to study is high spin isomers such as $^{52}\text{Fe}(12^+)$. Development of isomer beam was carried out at HIMAC.

(8) Low Energy Nuclear Reaction Group

A new measurement of the isobaric analog resonances of RRC31 was analyzed. Due to the low production yield of ^{34}Si beam from ^{48}Ca at 64 MeV/nucleon which was 1 orders magnitudes smaller than the estimation of EPAX-2.15, we couldn't improve the excitation function though the experimental result was observed to be consistent with the previous measurement.

For the development of the exotic targets, the feasibility study of $\text{Ti-}^3\text{H}$ was carried out by making a thin $\text{Ti-}^2\text{H}$ target. The ^2H in the $\text{Ti-}^2\text{H}$ target will desorb when the target is heated upto above 300 degrees in Celsius. As far as the target temperature is kept below 100 degrees, erosion of ^3H from $\text{Ti-}^3\text{H}$ will be 0. Activity measurement after ^{20}Ne beam of 8.2 MeV/nucleon on the $\text{Ti-}^2\text{H}$ target, any strong activity was not measured, meaning that Toyama Univ can decommission the target after the campaign of the experiments. A thin and higher concentration ratio of the target have been also under testing.

Single-crystal (sc) diamond detector is considered as a next-generation semiconductor detector. We found that the pulse height defect for fission fragments of ^{252}Cf was almost saturated with the electric field of 2 V/ μm .

(9) Active Target Development

Two types of gaseous active target TPCs called GEM-MSTPC and CATs are developed and used for the missing mass spectroscopy. A new resonance in ^{30}S has been observed via the study of alpha inelastic scattering using GEM-MSTPC. The data analysis of astrophysical reaction (α , p) on ^{18}Ne and ^{22}Mg and the β -decay of ^{16}Ne followed by α emission. The study of Equation of State of nuclear matter using CATs is ongoing. The data analysis of deuteron inelastic scattering on $^{15,16}\text{O}$ and ^{132}Xe measured at HIMAC by using CAT-S is in progress. The measurement of giant monopole resonance in ^{132}Sn by using CAT-S has been done at RIBF in April, 2016. Larger volume active target CAT-M is being developed aiming at 10-times larger yield.

(10) Fundamental Physics

To investigate the matter-antimatter asymmetry (CP violation) in the universe, and to understand the CP violating components in the fundamental interactions, the experimental project to search for the electric dipole moment (EDM) of the ^{210}Fr is going on. The thermal ionizer to produce the ^{210}Fr with fusion reaction, an optical lattice to accumulate the cooled atoms, and an atomic interferometer to measure the frequency of the spin precession of ^{210}Fr are ready now. The yield of the Fr ions with 10^6 Fr $^+$ /s has been achieved, and the improvement of the trapping efficiency to get the high intensity cooled Fr atoms will be done by upgrading the laser optics.

Members

Director

Susumu SHIMOURA

Scientific Staff

Susumu SHIMOURA (Professor)
Yasuhiro SAKEMI (Professor)
Kentaro YAKO (Associate Professor)
Nobuaki IMAI (Associate Professor)
Noritaka SHIMIZU (Project Associate Professor)

Hidetoshi YAMAGUCHI (Lecturer)
Shin'ichiro MICHIMASA (Assistant Professor)
Taku GUNJI (Assistant Professor)
Shinsuke OTA (Assistant Professor)

Guest Scientists

Yutaka UTSUNO (Guest Associate Professor)

Yutaka MIZOI (Guest Associate Professor)

Technical Staff

Yasuteru KOTAKA

Technical Assistants

Yukimitsu OHSHIRO
Mamoru KATAYANAGI
Reiko KOJIMA

Kazuyuki YOSHIMURA
Hiroshi KUREI

Project Research Associates

Tooru YOSHIDA
Olga BELIUSKINA

Post Doctoral Associates

Yosuke WATANABE
Philipp SCHROCK
Laszlo STUHL
Masanori DOZONO

Seiya HAYAKAWA
Chihiro IWAMOTO
Lei YANG
Rin YOKOYAMA

Graduate Students

Hiroshi TOKIEDA
Yuko SEKIGUCHI
Yuki YAMAGUCHI
Ryo NAKAJIMA
Keita KAWATA
Noritaka KITAMURA
Hideki SHIMIZU

Motonobu TAKAKI
Motoki KOBAYASHI
Soichiro MASUOKA
Shinichi HAYASHI
Kohei TERASAKI
Keijiro ABE

Administration Staff

Mikio OKI
Takako ENDO
Yuko SOMA

Ikuko YAMAMOTO
Yukino KISHI

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- S. Hayakawa, S. Kubono, D. Kahl, H. Yamaguchi, D.N. Binh, T. Hashimoto, Y. Wakabayashi, J.J. He, N. Iwasa, S. Kato, T. Komatsubara, Y.K. Kwon, T. Teranishi, "First direct measurement of the $^{11}\text{C}(\alpha, p)^{14}\text{N}$ stellar reaction by an extended thick-target method", *Physical Review C* 93, 065802 (2016). *
- H. Yamaguchi, D. Kahl, S. Hayakawa, Y. Sakaguchi, K. Abe, T. Nakao, T. Suhara, N. Iwasa, A. Kim, D.H. Kim, S.M. Cha, M.S. Kwag, J.H. Lee, E.J. Lee, K.Y. Chae, Y. Wakabayashi, N. Imai, N. Kitamura, P. Lee, J.Y. Moon, K.B. Lee, C. Akers, H.S. Jung, N.N. Duy, L.H. Khiem, and C.S. Lee, "Experimental investigation of linear-chain structured nucleus in ^{14}C ", *Physics Letters B* 766, 11 (2017). *
- L. Yang, C.J. Lin, H.M. Jia, D.X. Wang, L.J. Sun, N.R. Ma, F. Yang, Z.D. Wu, X.X. Xu, H.Q. Zhang, Z.H. Liu, and P.F. Bao, "Optical model potentials for $^6\text{He}+^{64}\text{Zn}$ from $^{63}\text{Cu}(^7\text{Li}, ^6\text{He})^{64}\text{Zn}$ reactions", *Physical Review C* 95, 034616 (2017). *
- R. G. Pizzone, G. D'Agata, M. La Cognata, I. Indelicato, C. Spitaleri, S. Blagus, S. Cherubini, P. Figuera, L. Grassi, G. L. Guardo, M. Gulino, S. Hayakawa, R. Kshetri, L. Lamia, M. Lattuada, T. Mijatovic, M. Milin, D.H. Miljanic D., L. Prepolec, G. G. Rapisarda, S. Romano, M. L. Sergi, N. Skukan, N. Soic, V. Tokic, A. Tumino, and M. Uroic, "First Measurement of the $^{19}\text{F}(\alpha, p)^{22}\text{Ne}$ Reaction at Energies of Astrophysical Relevance", *Astrophysical Journal*, 836, 57 (2017). *
- O. Beliuskina, A.O. Strekalovsky, A.A. Aleksandrov, I.A. Aleksandrova, H.M. Devaraja, C. Heinz, S. Heinz, S. Hofmann, S. Ilich, N. Imai, D.V. Kamanin, M. Kis, G.N. Knyazheva, C. Kozhuharov, E.A. Kuznetsova, J. Maurer, G.V. Mishinsky, M. Pomorski, Yu.V. Pyatkov, O.V. Strekalovsky, M. Träger and V.E. Zhuchko, "Pulse-height defect in single-crystal CVD diamond detectors", *Eur. Phys. J. A* 53, 32 (2017)*.
- M. Klintefjord, K. Hadynska-Klek, A. Gorgen, C. Bauer, F.L. Bello Garrote, S. Bonig, B. Bounthong, A. Damyanova, J.P. Delaroche, V.

- Fedosseev, D.A. Fink, F. Giacoppo, M. Girod, P. Hoff, N. Imai, W. Korten, A.C. Larsen, J. Libert, R. Lutter, B.A. Marsh, P.L. Molkanov, H. Naidja, P. Napiorkowski, F. Nowacki, J. Pakarinen, E. Rapisarda, P. Reiter, T. Renstrom, S. Rothe, M.D. Seliverstov, B. Siebeck, S. Siem, J. Srebny, T. Stora, P. Thole, T.G. Tornyi, G.M. Tveten, P. Van Duppen, M.J. Vermeulen, D. Voulot, N. Warr, F. Wenander, H.De Witte, M. Zielinska: "Structure of low-lying states in ^{140}Sm studied by Coulomb excitation", *Phys.Rev. C* 93, 054303 (2016)*.
- J. Lee, H. Liu, P. Doornenbal, M. Kimura, K. Minomo, K. Ogata, Y. Utsuno, N. Aoi, K. Li, M. Matsushita, H. Scheit, D. Steppenbeck, S. Takeuchi, H. Wang, H. Baba, E. Ideguchi, N. Kobayashi, Y. Kondo, S. Michimasa, T. Motobayashi, H. Sakurai, M. Takechi, and Y. Togano, "Asymmetry dependence of reduction factors from single-nucleon knockout of ^{30}Ne at ~ 230 MeV/nucleon", *Progress of Theoretical and Experimental Physics* 2016, 083D01 (2016)*
- C. Babcock, H. Heylen, M. L. Bissell, K. Blaum, P. Campbell, B. Cheal, D. Fedorov, R. F. Garcia Ruiz, W. Geithner, W. Gins, T. Day Goodacre, L.K. Grob, M. Kowalska, S. M. Lenzi, B. Maass, S. Malbrunot-Ettenauer, B. Marsh, R. Neugart, G. Neyens, W. Nörtershäuser, T. Otsuka, R. Rossel, S. Rothe, R. Sánchez, Y. Tsunoda, C. Wraith, L. Xie, and X. F. Yang, "Quadrupole moments of odd-A $^{53-63}\text{Mn}$: Onset of collectivity towards $N=40$ ", *Physics Letters B* 760, 387 (2016)*
- H. Heylen, M. De Rydt, G. Neyens, M. L. Bissell, L. Caceres, R. Chevrier, J. M. Daugas, Y. Ichikawa, Y. Ishibashi, O. Kamalou, T. J. Mertzimekis, P. Morel, J. Papuga, A. Poves, M. M. Rajabali, C. Stödel, J. C. Thomas, H. Ueno, Y. Utsuno, N. Yoshida, and A. Yoshimi, "High-precision quadrupole moment reveals significant intruder component in $^{33}\text{Al}_{20}$ ground state", *Physical Review C* 94, 034312 (2016)*
- T. Togashi, Y. Tsunoda, T. Otsuka, and N. Shimizu, "Quantum Phase Transition in the Shape of Zr isotopes", *Physical Review Letters* 117, 172502 (2016)*
- C. Kremer, S. Aslanidou, S. Bassauer, M. Hilcker, A. Krugmann, P. von Neumann-Cosel, T. Otsuka, N. Pietralla, V. Yu. Ponomarev, N. Shimizu, M. Singer, G. Steinhilber, T. Togashi, Y. Tsunoda, V. Werner, and M. Zweidinger, "First Measurement of Collectivity of Coexisting Shapes Based on Type II Shell Evolution: The Case of ^{96}Zr ", *Physical Review Letters* 117, 172503 (2016)*
- H. Heylen, C. Babcock, R. Beerwerth, J. Billowes, M. L. Bissell, K. Blaum, J. Bonnard, P. Campbell, B. Cheal, T. Day Goodacre, D. Fedorov, S. Fritzsche, R. F. Garcia Ruiz, W. Geithner, Ch. Geppert, W. Gins, L. K. Grob, M. Kowalska, K. Kreim, S. M. Lenzi, I. D. Moore, B. Maass, S. Malbrunot-Ettenauer, B. Marsh, R. Neugart, G. Neyens, W. Nörtershäuser, T. Otsuka, J. Papuga, R. Rossel, S. Rothe, R. Sánchez, Y. Tsunoda, C. Wraith, L. Xie, X. F. Yang, and D. T. Yordanov, "Changes in nuclear structure along the Mn isotopic chain studied via charge radii", *Physical Review C* 94, 054321 (2016)*
- A. I. Morales, G. Benzoni, H. Watanabe, Y. Tsunoda, T. Otsuka, S. Nishimura, F. Browne, R. Daido, P. Doornenbal, Y. Fang, G. Lorusso, Z. Patel, S. Rice, L. Sinclair, P.-A. Söderström, T. Sumikama, J. Wu, Z. Y. Xu, A. Yagi, R. Yokoyama, H. Baba, R. Avigo, F. L. Bello Garrote, N. Blasi, A. Bracco, F. Camera, S. Ceruti, F. C. L. Crespi, G. de Angelis, M.-C. Delattre, Zs. Dombradi, A. Gottardo, T. Isobe, I. Kojouharov, N. Kurz, I. Kuti, K. Matsui, B. Melon, D. Mengoni, T. Miyazaki, V. Modamio-Hoybjor, S. Momiyama, D.R. Napoli, M. Niikura, R. Orlandi, H. Sakurai, E. Sahin, D. Sohler, H. Schaffner, R. Taniuchi, J. Taprogge, Zs. Vajta, J. J. Valiente-Dobón, O. Wieland, and M. Yalcinkaya, "Type II shell evolution in $A=70$ isobars from the $N\geq 40$ island of inversion", *Physics Letters B* 765, 328 (2017)*
- N. Paul, A. Corsi, A. Obertelli, P. Doornenbal, G. Authalet, H. Baba, B. Bally, M. Bender, D. Calvet, F. Château, S. Chen, J.-P. Delaroche, A. Delbart, J.-M. Gheller, A. Giganon, A. Gillibert, M. Girod, P.-H. Heenen, V. Lapoux, J. Libert, T. Motobayashi, M. Niikura, T. Otsuka, T. R. Rodríguez, J.-Y. Roussé, H. Sakurai, C. Santamaria, N. Shimizu, D. Steppenbeck, R. Taniuchi, T. Togashi, Y. Tsunoda, T. Uesaka, T. Ando, T. Arici, A. Blazhev, F. Browne, A. M. Bruce, R. Caroll, L. X. Chung, M.L. Cortés, M. Dewald, B. Ding, F. Flavigny, S. Franchoo, M. Gorska, A. Gottardo, A. Jungclaus, J. Lee, M. Lettmann, B. D. Linh, J. Liu, Z. Liu, C. Lizarazo, S. Momiyama, K. Moschner, S. Nagamine, N. Nakatsuka, C. Nita, C. R. Nobs, L. Olivier, Z. Patel, Z. Podolyák, M. Rudigier, T. Saito, C. Shand, P.-A. Söderström, I. Stefan, R. Orlandi, V. Vaquero, V. Werner, K. Wimmer, and Z. Xu, "Are There Signatures of Harmonic Oscillator Shells Far from Stability? First Spectroscopy of ^{110}Zr ", *Physical Review Letters* 118, 032501 (2017)*
- N. Tsunoda, T. Otsuka, N. Shimizu, M. Hjorth-Jensen, K. Takayanagi, and T. Suzuki, "Exotic neutron-rich medium-mass nuclei with realistic nuclear forces", *Physical Review C* 95, 021304(R) (2017)*
- V. Tripathi, R. S. Lubna, B. Abromeit, H. L. Crawford, S. N. Liddick, Y. Utsuno, P. C. Bender, B. P. Crider, R. Dungan, P. Fallon, K. Kravvaris, N. Larson, A. O. Macchiavelli, T. Otsuka, C. J. Prokop, A. L. Richard, N. Shimizu, S. L. Tabor, A. Volya, and S. Yoshida, " β decay of $^{38,40}\text{Si}$ ($T_z=+5,+6$) to low-lying core excited states in odd-odd $^{38,40}\text{P}$ isotopes", *Physical Review C* 95, 024308 (2017)*
- H.N. Liu, J. Lee, P. Doornenbal, H. Scheit, S. Takeuchi, N. Aoi, K.A. Li, M. Matsushita, D. Steppenbeck, H. Wang, H. Baba, E. Ideguchi, N. Kobayashi, Y. Kondo, G. Lee, S. Michimasa, T. Motobayashi, A. Poves, H. Sakurai, M. Takechi, Y. Togano, J.A. Tostevin, and Y. Utsuno, "Intruder configurations in the ground state of ^{30}Ne ", *Physics Letters B* 767, 58 (2017)*
- He Wang, Hideaki Otsu, Hiroyoshi Sakurai, DeukSoon Ahn, Masayuki Aikawa, Takashi Ando, Shouhei Araki, Sidong Chen, Nobuyuki Chiga, Pieter Doornenbal, Naoki Fukuda, Tadaaki Isobe, Shunsuke Kawakami, Shoichiro Kawase, Tadahiro Kin, Yosuke Kondo, Shunpei Koyama, Shigeru Kubono, Yukie Maeda, Ayano Makinaga, Masafumi Matsushita, Teiichiro Matsuzaki, Shin'ichiro Michimasa, Satoru Momiyama, Shunsuke Nagamine, Takashi Nakamura, Keita Nakano, Megumi Niikura, Tomoyuki Ozaki, Atsumi Saito, Takeshi Saito, Yoshiaki Shiga, Mizuki Shikata, Yohei Shimizu, Susumu Shimoura, Toshiyuki Sumikama, Par-Anders Soderstrom, Hiroshi Suzuki, Hiroyuki Takeda, Satoshi Takeuchi, Ryo Taniuchi, Yasuhiro Togano, Junichi Tsubota, Meiko Uesaka, Yasushi Watanabe, Yukinobu Watanabe, Kathrin Wimmer, Tatsuya Yamamoto, Koichi Yoshida: "Spallation reaction study for the long-lived fission product ^{107}Pd ", *Prog. Theor. Exp. Phys.* 2017, 021D01 (2017)*
- P. Doornenbal, H. Scheit, S. Takeuchi, N. Aoi, K. Li, M. Matsushita, D. Steppenbeck, H. Wang, H. Baba, E. Ideguchi, N. Kobayashi, Y. Kondo, J. Lee, S. Michimasa, T. Motobayashi, A. Poves, H. Sakurai, M. Takechi, Y. Togano, K. Yoneda: "Mapping the deformation in the island of inversion: Inelastic scattering of ^{30}Ne and ^{36}Mg at intermediate energies", *Phys. Rev. C* 93, 044306 (2016)*
- D.Q. Fang, Y.G. Ma, X.Y. Sun, P. Zhou, Y. Togano, N. Aoi, H. Baba, X.Z. Cai, X.G. Cao, J.G. Chen, Y. Fu, W. Guo, Y. Hara, T. Honda, Z.G. Hu, K. Ieki, Y. Ishibashi, Y. Ito, N. Iwasa, S. Kanno, T. Kawabata, H. Kimura, Y. Kondo, K. Kurita, M. Kurokawa, T. Moriguchi, H. Murakami, H. Oishi, K. Okada, S. Ota, A. Ozawa, H. Sakurai, S. Shimoura, R. Shioda, E. Takeshita, S. Takeuchi, W.D. Tian, H.W. Wang, J.S. Wang, M. Wang, K. Yamada, Y. Yamada, Y. Yasuda, K. Yoneda, G.Q. Zhang, T. Motobayashi: "Proton-proton correlations in distinguishing the two-proton emission mechanism of ^{23}Al and ^{22}Mg ", *Phys. Rev. C* 94, 044621 (2016)*
- H. Wang, N. Aoi, S. Takeuchi, M. Matsushita, T. Motobayashi, D. Steppenbeck, K. Yoneda, H. Baba, Zs. Dombradi, K. Kobayashi, Y. Kondo, J. Lee, H. Liu, R. Minakata, D. Nishimura, H. Otsu, H. Sakurai, D. Sohler, Y. Sun, Z. Tian, R. Tanaka, Zs. Vajta, Z. Yang, T. Yamamoto, Y. Ye, R. Yokoyama: "First spectroscopic information from even-even nuclei in the region "southeast" of ^{132}Sn : Neutron-excitation dominance of the 2^+ state in ^{132}Cd ", *Phys. Rev. C* 94, 051301 (2016)*
- E. Ideguchi, G.S. Simpson, R. Yokoyama, Mn. Tanaka, S. Nishimura, P. Doornenbal, G. Lorusso, P. Aoderstrom, T. Sumikama, J. Wu, Z. Y.

- Xu, N. Aoi, H. Baba, F. L. Bello Garrote, G. Benzoni, F. Browne, R. Daido, Y. Fang, N. Fukuda, A. Gottardo, G. Gey, S. Go, N. Inabe, T. Isobe, D. Kameda, K. Kobayashi, M. Kobayashi, I. Kojouharov, T. Komatsubara, T. Kubo, N. Kurz, I. Kuti, Z. Li, M. Matsushita, S. Michimasa, C.B. Moon, H. Nishibata, I. Nishizuka, A. Odahara, Z. Patel, S. Rice, E. Sahin, H. Sakurai, H. Schaffner, L. Sinclair, H. Suzuki, H. Takeda, J. Taprogge, Zs. Vajta, H. Watanabe, A. Yagi: `` μ s isomers of $^{158,160}\text{Nd}$ ”, *Phys. Rev. C* **94**, 064322 (2016) *
- M. Dozono, T. Uesaka, S. Michimasa, M. Takaki, M. Kobayashi, M. Matsushita, S. Ota, H. Tokieda, S. Shimoura: "Separated flow operation of the SHARAQ spectrometer for in-flight proton-decay experiments", *Nucl. Instr. Meth. Phys. Res. A* **830**, 233–242 (2016) *
- R. Yokoyama, S. Go, D. Kameda, T. Kubo, N. Inabe, N. Fukuda, H. Takeda, H. Suzuki, K. Yoshida, K. Kusaka, K. Tanaka, Y. Yanagisawa, M. Ohtake, H. Sato, Y. Shimizu, H. Baba, M. Kurokawa, D. Nishimura, T. Ohnishi, N. Iwasa, A. Chiba, T. Yamada, E. Ideguchi, T. Fujii, H. Nishibata, K. Ieki, D. Murai, S. Momota, Y. Sato, J.W. Hwang, S. Kim, O.B. Tarasov, D.J. Morrissey, B.M. Sherrill, G. Simpson, C.R. Praharaj: ``New K isomers in the neutron-rich N=100 isotones ^{162}Sm , ^{163}Eu , and ^{164}Gd ”, *Phys. Rev. C* **95**, 034313 (2017) *
- J. Wu, S. Nishimura, G. Lorusso, P. Moller, E. Ideguchi, P.H. Regan, G.S. Simpson, P. A. Soderstrom, P.M. Walker, H. Watanabe, Z.Y. Xu, H. Baba, F. Browne, R. Daido, P. Doornenbal, Y.F. Fang, G. Gey, T. Isobe, P.S. Lee, J.J. Liu, Z. Li, Z. Korkulu, Z. Patel, V. Phong, S. Rice, H. Sakurai, L. Sinclair, T. Sumikama, M. Tanaka, A. Yagi, Y.L. Ye, R. Yokoyama, G.X. Zhang, T. Alharbi, N. Aoi, F.L. Bello Garrote, G. Benzoni, A.M. Bruce, R.J. Carroll, K.Y. Chae, Z. Dombradi, A. Estrade, A. Gottardo, C.J. Griffin, H. Kanaoka, I. Kojouharov, F.G. Kondev, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G.J. Lane, E.J. Lee, T. Lokotko, G. Lotay, C. B. Moon, H. Nishibata, I. Nishizuka, C.R. Nita, A. Odahara, Zs. Podolyak, O.J. Roberts, H. Schaffner, C. Shand, J. Taprogge, S. Terashima, Z. Vajta, S. Yoshida: ``94 β -Decay Half-Lives of Neutron-Rich ^{55}Cs to ^{67}Ho : Experimental Feedback and Evaluation of the r-Process Rare-Earth Peak Formation”, *Phys. Rev. Lett.* **118**, 0722701 (2017) *
- A.I. Morales, G. Benzoni, H. Watanabe, Y. Tsunoda, T. Otsuka, S. Nishimura, F. Browne, R. Daido, P. Doornenbal, Y. Fang, G. Lorusso, Z. Patel, S. Rice, L. Sinclair, P.A. Soderstrom, T. Sumikama, J. Wu, Z.Y. Xu, A. Yagi, R. Yokoyama, H. Baba, R. Avigo, F.L. Bello Garrote, N. Blasi, A. Bracco, F. Camera, S. Ceruti, F.C.L. Crespi, G. de Angelis, M.C. Delattre, Zs. Dombradi, A. Gottardo, T. Isobe, I. Kojouharov, N. Kurz, I. Kuti, K. Matsui, B. Melon, D. Mengoni, T. Miyazaki, V. Modamio-Hoybjor, S. Momiyama, D.R. Napoli, M. Niikura, R.Orlandi, H.Sakurai, E.Sahin, D.Sohler, H.Schaffner, R.Taniuchi, J.Taprogge, Zs. Vajta, J.J. Valiente-Dobon, O. Wieland, M. Yalcinkaya: ``Type II shell evolution in A=70 isobars from the N> 40 island of inversion”, *Phys.-Lett.-B* **765**, 328 (2017) *
- A. Adare et al. [PHENIX Collaboration], ``Angular decay coefficients of J/ψ mesons at forward rapidity from p+p collisions at $\sqrt{s} = 510$ GeV,” *Phys. Rev. D* **95**, 092003 (2017) *
- J. Adam et al. [ALICE Collaboration], ``W and Z boson production in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV,” *JHEP* **1702**, 077 (2017) *
- J. Adam et al. [ALICE Collaboration], ``Determination of the event collision time with the ALICE detector at the LHC,” *Eur. Phys. J. Plus* **132**, no. 2, 99 (2017) *
- A. Adare et al. [PHENIX Collaboration], ``Measurement of the relative yields of $\psi(2S)$ to $\psi(1S)$ mesons produced at forward and backward rapidity in pp, p+Al, p+Au, and $^3\text{He}+\text{Au}$ collisions at $\sqrt{s_{NN}}=200$ GeV,” *Phys. Rev. C* **95**, no. 3, 034904 (2017) *
- A. Adare et al. [PHENIX Collaboration], ``Nonperturbative-transverse-momentum effects and evolution in dihadron and direct photon-hadron angular correlations in pp collisions at $\sqrt{s} = 510$ GeV,” *Phys. Rev. D* **95**, no. 7, 072002 (2017) *
- J. Adam et al. [ALICE Collaboration], ``Jet-like correlations with neutral pion triggers in pp and central Pb–Pb collisions at 2.76 TeV,” *Phys. Lett. B* **763**, 238 (2016) *
- J. Adam et al. [ALICE Collaboration], `` J/ψ suppression at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV”, *Phys. Lett. B* **766**, 212 (2017) *
- J. Adam et al. [ALICE Collaboration], ``Enhanced production of multi-strange hadrons in high-multiplicity proton-proton collisions,” *Nature Phys.* **13**, 535 (2017) *
- J. Adam et al. [ALICE Collaboration], ``Higher harmonic flow coefficients of identified hadrons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV,” *JHEP* **1609**, 164 (2016) *
- A. Adare et al. [PHENIX Collaboration], ``Measurements of double-helicity asymmetries in inclusive J/ψ production in longitudinally polarized p+p collisions at $\sqrt{s}=510$ GeV,” *Phys. Rev. D* **94**, no. 11, 112008 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Elliptic flow of electrons from heavy-flavour hadron decays at mid-rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV,” *JHEP* **1609**, 028 (2016) *
- J. Adam et al. [ALICE Collaboration], ``D-meson production in p-Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV and in pp collisions at $\sqrt{s}=7$ TeV,” *Phys. Rev. C* **94**, no. 5, 054908 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Measurement of azimuthal correlations of D mesons and charged particles in pp collisions at $\sqrt{s}=7$ TeV and p-Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV,” *Eur. Phys. J. C* **77**, no. 4, 245 (2017) *
- J. Adam et al. [ALICE Collaboration], ``Pseudorapidity dependence of the anisotropic flow of charged particles in Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$ TeV,” *Phys. Lett. B* **762**, 376 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Correlated event-by-event fluctuations of flow harmonics in Pb-Pb collisions at $\sqrt{s_{NN}}=2.76$ TeV,” *Phys. Rev. Lett.* **117**, 182301 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Measurement of transverse energy at midrapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV,” *Phys. Rev. C* **94**, no. 3, 034903 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Centrality dependence of charged jet production in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV,” *Eur. Phys. J. C* **76**, no. 5, 271 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Centrality dependence of $\psi(2S)$ suppression in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV,” *JHEP* **1606**, 050 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Measurement of D-meson production versus multiplicity in p-Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV,” *JHEP* **1608**, 078 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Particle identification in ALICE: a Bayesian approach,” *Eur. Phys. J. Plus* **131**, no. 5, 168 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Anisotropic flow of charged particles in Pb-Pb collisions at $\sqrt{s_{NN}}=5.02$ TeV,” *Phys. Rev. Lett.* **116**, no. 13, 132302 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Production of $K^*(892)^0$ and $\phi(1020)$ in p–Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV,” *Eur. Phys. J. C* **76**, no. 5, 245 (2016) *
- J. Adam et al. [ALICE Collaboration], ``Multiplicity dependence of charged pion, kaon, and (anti)proton production at large transverse momentum in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV,” *Phys. Lett. B* **760**, 720 (2016) *

- J. Adam et al. [ALICE Collaboration], "Multipion Bose-Einstein correlations in pp, p-Pb, and Pb-Pb collisions at energies available at the CERN Large Hadron Collider," *Phys. Rev. C* **93**, no. 5, 054908 (2016) *
- J. Adam et al. [ALICE Collaboration], "Multi-strange baryon production in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV," *Phys. Lett. B* **758**, 389 (2016) *
- J. Adam et al. [ALICE Collaboration], "Centrality dependence of the charged-particle multiplicity density at midrapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV," *Phys. Rev. Lett.* **116**, no. 22, 222302 (2016) *
- J. Adam et al. [ALICE Collaboration], "Measurement of an excess in the yield of J/ψ at very low p_T in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Rev. Lett.* **116**, no. 22, 222301 (2016) *
- J. Adam et al. [ALICE Collaboration], "Pseudorapidity and transverse-momentum distributions of charged particles in proton-proton collisions at $\sqrt{s} = 13$ TeV," *Phys. Lett. B* **753**, 319 (2016) *
- J. Adam et al. [ALICE Collaboration], "Inclusive quarkonium production at forward rapidity in pp collisions at $\sqrt{s} = 8$ TeV," *Eur. Phys. J. C* **76**, no. 4, 184 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Measurements of directed, elliptic, and triangular flow in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. C* **94**, no. 5, 054910 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Azimuthally anisotropic emission of low-momentum direct photons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. C* **94**, no. 6, 064901 (2016) *
- J. Adam et al. [ALICE Collaboration], "Measurement of electrons from heavy-flavour hadron decays in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV," *Phys. Lett. B* **754**, 81 (2016) *
- J. Adam et al. [ALICE Collaboration], "Azimuthal anisotropy of charged jet production in $\sqrt{s_{NN}} = 2.76$ TeV Pb-Pb collisions," *Phys. Lett. B* **753**, 511 (2016) *
- J. Adam et al. [ALICE Collaboration], "Direct photon production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Lett. B* **754**, 235 (2016) *
- J. Adam et al. [ALICE Collaboration], "Centrality evolution of the charged-particle pseudorapidity density over a broad pseudorapidity range in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Lett. B* **754**, 373 (2016) *
- J. Adam et al. [ALICE Collaboration], "Measurement of D_s^+ production and nuclear modification factor in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *JHEP* **1603**, 082 (2016) *
- J. Adam et al. [ALICE Collaboration], "Multiplicity and transverse momentum evolution of charge-dependent correlations in pp, p-Pb, and Pb-Pb collisions at the LHC," *Eur. Phys. J. C* **76**, no. 2, 86 (2016) *
- J. Adam et al. [ALICE Collaboration], "Transverse momentum dependence of D-meson production in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *JHEP* **1603**, 081 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Scaling properties of fractional momentum loss of high- p_T hadrons in nucleus-nucleus collisions at $\sqrt{s_{NN}}$ from 62.4 GeV to 2.76 TeV," *Phys. Rev. C* **93**, no. 2, 024911 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Transverse energy production and charged-particle multiplicity at midrapidity in various systems from $\sqrt{s_{NN}} = 7.7$ to 200 GeV," *Phys. Rev. C* **93**, no. 2, 024901 (2016) *
- A. Adare et al. [PHENIX Collaboration], " ϕ meson production in the forward/backward rapidity region in Cu+Au collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. C* **93**, no. 2, 024904 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Forward J/ψ production in U+U collisions at $\sqrt{s_{NN}} = 193$ GeV," *Phys. Rev. C* **93**, no. 3, 034903 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Dielectron production in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. C* **93**, no. 1, 014904 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Single electron yields from semileptonic charm and bottom hadron decays in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. C* **93**, no. 3, 034904 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Centrality-dependent modification of jet-production rates in deuteron-gold collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. Lett.* **116**, no. 12, 122301 (2016) *
- J. Adam et al. [ALICE Collaboration], "Study of cosmic ray events with high muon multiplicity using the ALICE detector at the CERN Large Hadron Collider," *JCAP* **1601**, no. 01, 032 (2016) *
- J. Adam et al. [ALICE Collaboration], "Centrality dependence of pion freeze-out radii in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Rev. C* **93**, no. 2, 024905 (2016) *
- J. Adam et al. [ALICE Collaboration], "Event shape engineering for inclusive spectra and elliptic flow in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Rev. C* **93**, no. 3, 034916 (2016) *
- J. Adam et al. [ALICE Collaboration], "Elliptic flow of muons from heavy-flavour hadron decays at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Lett. B* **753**, 41 (2016) *
- J. Adam et al. [ALICE Collaboration], "Production of light nuclei and anti-nuclei in pp and Pb-Pb collisions at energies available at the CERN Large Hadron Collider," *Phys. Rev. C* **93**, no. 2, 024917 (2016) *
- J. Adam et al. [ALICE Collaboration], "Differential studies of inclusive J/ψ and $\psi(2S)$ production at forward rapidity in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *JHEP* **1605**, 179 (2016) *
- J. Adam et al. [ALICE Collaboration], "Forward-central two-particle correlations in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV," *Phys. Lett. B* **753**, 126 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Measurement of higher cumulants of net-charge multiplicity distributions in Au+Au collisions at $\sqrt{s_{NN}} = 7.7-200$ GeV," *Phys. Rev. C* **93**, no. 1, 011901 (2016) *
- J. Adam et al. [ALICE Collaboration], "Centrality dependence of the nuclear modification factor of charged pions, kaons, and protons in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV," *Phys. Rev. C* **93**, no. 3, 034913 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Measurement of parity-violating spin asymmetries in W^+ production at midrapidity in longitudinally polarized p+p collisions," *Phys. Rev. D* **93**, no. 5, 051103 (2016) *
- A. Adare et al. [PHENIX Collaboration], "Measurement of the higher-order anisotropic flow coefficients for identified hadrons in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV," *Phys. Rev. C* **93**, no. 5, 051902 (2016) *
- B. Abelev et al. [ALICE Collaboration], "Measurement of electrons from beauty hadron decays in pp collisions at $\sqrt{s} = 7$ TeV," *Phys. Lett. B* **721**, 13 (2013) Erratum: [*Phys. Lett. B* **763**, 507 (2016)] *
- J. Yasuda et al.: "Inverse kinematics (p,n) reactions studies using the WINDS slow neutron detector and the SAMURAI spectrometer", *Nucl.*

Instr. and Meth. In Phys. Res. B 376, 393 (2016)*

- A. Krasznahorkay et al.: "Observation of anomalous internal pair creation in ^8Be : A possible indication of a light, neutral boson", Phys. Rev. Lett. 042501 (2016)*
- J.C. Zamora et al.: "First measurement of isoscalar giant resonances in a stored-beam experiment", Phys. Lett. B 763, 16 (2016)*
- P. Russotto et al.: "Results of the ASY-EOS experiment at GSI: The symmetry energy at supra-saturation density", Phys. Rev. C 94 034608 (2016)*

[Proceedings]

(Original Papers) *Subject to Peer Review

- D. Kahl, A. A. Chen, S. Kubono, H. Yamaguchi, D. N. Binh, J. Chen, S. Cherubini, N.N. Duy, T. Hashimoto, S. Hayakawa, N. Iwasa, H.S. Jung, S. Kato, Y.K. Kwon, S. Nishimura, S. Ota, K. Setoodehnia, T. Teranishi, H. Tokieda, T. Yamada, C.C. Yun and L.Y. Zhang: "Experimental investigation of the $^{30}\text{S}(\alpha, p)$ thermonuclear reaction in x-ray bursts", EPJ Web of Conferences **109**, 04005 (2016).
- Y.B. Wang, S.J. Jin, L. Jing, Z.Y. Han, X.X. Bai, B. Guo, Y.J. Li, Z.H. Li, G. Lian, J. Su, L.J. Sun, S.Q. Yan, S. Zeng, W.P. Liu, H. Yamaguchi, S. Kubono, J. Hu, D. Kahl, J.J. He, J.S. Wang, X.D. Tang, S.W. Xu, P. Ma, N.T. Zhang, Z. Bai, M.R. Huang, B.L. Jia, S.L. Jin, J.B. Ma, S.B. Ma, W.H. Ma, Y.Y. Yang, L.Y. Zhang, H.S. Jung, J.Y. Moon, C.S. Lee, T. Teranishi, H.W. Wang, H. Ishiyama, N. Iwasa, T. Komatsubara and B.A. Brown: "Two measurements of the $^{22}\text{Na}+p$ resonant scattering via thick-target inverse-kinematics method", EPJ Web of Conferences **109**, 04010 (2016).
- S. Kubono, H. Yamaguchi, S. Hayakawa, S.Q. Hou and J.J. He, "Explosive Nuclear Burning in the pp-Chain Region and the Breakout Processes", EPJ Web of Conferences **109** 01001 (2016).
- S. Hayakawa, C. Spitaleri, N. Burtebayev, A. Aimaganbetov, P. Figuera, M. Fisichella, G.L. Guardo, S. Igamov, I. Indelicato, G. Kiss, S. Kliczewski, M. La Cognata, L. Lamia, M. Lattuada, E. Piasecki, G. G. Rapisarda, S. Romano, S. B. Sakuta, R. Siudak, A. Trzcinska, A. Tumino and A. Urkinbayev: "Indirect Study of the $^{16}\text{O} + ^{16}\text{O}$ Fusion Reaction Toward Stellar Energies by the Trojan Horse Method", Nucleus Nucleus 2015 (NN2015), Catania, Italy, EPJ Web of Conferences **109**, 09013 (2016).
- H. Yamaguchi, D. Kahl, S. Hayakawa, Y. Sakaguchi, Y. Wakabayashi, T. Hashimoto, S. Cherubini, M. Gulino, C. Spitaleri, G.G. Rapisarda, M. La Cognata, L. Lamia, S. Romano, S. Kubono, N. Iwasa, T. Teranishi, T. Kawabata, Y.K. Kwon, D.N. Binh, L.H. Khiem, N.N. Duy, S. Kato, T. Komatsubara, A.Coc, N. de Sereville, F.Hammache, G. Kiss and S. Bishop: "Studying astrophysical reactions with low-energy RI beams at CRIB", EPJ Web of Conferences **117**, 09005 (2016).
- G. D'Agata, C. Spitaleri, R.G. Pizzone, S. Blagus, P. Figuera, L. Grassi, G.L. Guardo, M. Gulino, S. Hayakawa, I. Indelicato, R. Kshetri, M. La Cognata, L. Lamia, M. Lattuada, T. Mijatović, M. Milin, D. Miljanic, L. Prepolec, M.L. Sergi, N. Skukan, N. Soic, V. Tokic, A. Tumino and M. Uroic: "First evidences for $^{19}\text{F}(\alpha, p)^{22}\text{Ne}$ at astrophysical energies", 8th European Summer School on Experimental Nuclear Astrophysics, S. Tecla, Italy, J. of Phys.: Conf. Series, **703**, 012016 (2016).
- M. Mazzocco, A. Boiano, C. Boiano, M. La Commara, C. Manea, C. Parascandolo, D. Pierroutsakou, C. Signorini, E. Strano, D. Torresi, H. Yamaguchi, D. Kahl, L. Acosta, P. Di Meo, J.P. Fernandez-Garcia, T. Glodariu, J. Grebosz, A. Guglielmetti, N. Imai, Y. Hirayama, H. Ishiyama, N. Iwasa, S.C. Jeong, H.M. Jia, N. Keeley, Y.H. Kim, S. Kimura, S. Kubono, J.A. Lay, C.J. Lin, G. Marquez-Duran, I. Martel, H. Miyatake, M. Mukai, T. Nakao, M. Nicoletto, A. Pakou, K. Rusek, Y. Sakaguchi, A.M. Sanchez-Benitez, T. Sava, O. Sgouros, C. Stefanini, F. Soramel, V. Soukeras, E. Stiliaris, L. Stroe, T. Teranishi, N. Toniolo, Y. Wakabayashi, Y.X. Watanabe, L. Yang and Y.Y. Yang, " ^7Be - and ^8B -reaction dynamics at Coulomb barrier energies", EPJ Web of Conferences **117**, 060006 (2016).
- H. Yamaguchi, D. Kahl, S. Hayakawa, L. Yang, Y. Sakaguchi, K. Abe, H. Shimizu, and CRIB Collaboration, "Overview of the activities at the low-energy beam separator CRIB", Il Nuovo Cimento **39C**, 358 (2016).
- D. Kahl, H. Yamaguchi, H. Shimizu, K. Abe, O. Beliuskina, S. M. Cha, K.Y. Chae, Z. Ge, S. Hayakawa, M.S. Kwag, D. H. Kim, J. Y. Moon, S.Y. Park, L. Yang: "Explosive destruction of ^{26}Al ", Il Nuovo Cimento **39C**, 362 (2016).
- S. Hayakawa: "Trials for the cosmological ^7Li problem with ^7Be beams at CRIB and collaborating studies", Il Nuovo Cimento **39C** 370 (2016).
- S.M. Cha, K.Y. Chae, K. Abe, S.H. Bae, S.H. Choi, D.N. Binh, N.N. Duy, K.I. Hahn, S. Hayakawa, B. Hong, H.S. Jung, D. Kahl, L.H. Khiem, A. Kim, D.H. Kim, E.J. Kim, G.W. Kim, M.J. Kim, K.J. Kwag, M.S. Kwag, Y.K. Kwon, C.S. Lee, E.J. Lee, S.I. Lim, B. Moon, J.Y. Moon, T. Nakao, S.Y. Park, H. Shimizu, H. Yamaguchi, L. Yang, and G. Zhuang, "Study of alpha cluster structure in ^{22}Mg ", Il Nuovo Cimento **39C**, 371 (2016).
- S. Hayakawa, C. Spitaleri, N. Burtebayev, A. Aimaganbetov, S.V. Artemov, P. Figuera, M. Fisichella, G.L. Guardo, S. Igamov, I. Indelicato, G.G. Kiss, S. Kubono, M. La Cognata, L. Lamia, M. Lattuada, M. Nassurlla, E. Piasecki, G.G. Rapisarda, S. Romano, S.B. Sakuta, A. Trzcinska, A. Tumino, A. Urkinbayev, and T. Zholdybayev, "Trojan Horse Method for the Oxygen-Burning Process Reactions", JPS Conf. Proc. **14**, 020406 (2017).
- H. Yamaguchi, D. Kahl, S. Hayakawa, Y. Sakaguchi, K. Abe, H. Shimizu, Y. Wakabayashi, T. Hashimoto, S. Cherubini, M. Gulino, C. Spitaleri, G. G. Rapisarda, M. La Cognata, L. Lamia, S. Romano, S. Kubono, N. Iwasa, T. Teranishi, T. Kawabata, Y. K. Kwon, D. N. Binh, L. H. Khiem, N. N. Duy, S. Kato, T. Komatsubara, A. Coc, N. de Sereville, F. Hammache, G. Kiss, and S. Bishop, "Experimental Studies of Light-Ion Nuclear Reactions Using Low-Energy RI Beams", JPS Conf. Proc. **14**, 010503 (2017).
- D. Kahl, A. A. Chen, S. Kubono, H. Yamaguchi, D. N. Binh, J. Chen, S. Cherubini, N. N. Duy, T. Hashimoto, S. Hayakawa, N. Iwasa, H. S. Jung, S. Kato, Y. K. Kwon, S. Nishimura, S. Ota, K. Setoodehnia, T. Teranishi, H. Tokieda, T. Yamada, C. C. Yun, and L. Y. Zhang, " $^{30}\text{S}(\alpha, p)$ Thermonuclear Reaction Rate from Experimental Level Structure of ^{34}Ar ", JPS Conf. Proc. **14**, 020510 (2017).
- K. Abe, S. Hayakawa, H. Yamaguchi, and L. Lamia, "Feasibility Study for the $^7\text{Be}+n$ Reaction Measurements by Trojan Horse Method at CRIB", JPS Conf. Proc. **14**, 020507 (2017).
- Marisa Gulino, Silvio Cherubini, Claudio Spitaleri, Giuseppe Gabriele Rapisarda, Marco La Cognata, Livio Lamia, Rosario Gianluca Pizzone, Stefano Romano, Shigeru Kubono, Hidetoshi Yamaguchi, Seya Hayakawa, Yasuo Wakabayashi, Naohito Iwasa, Seigo Kato, Tetsuro Komatsubara, Takashi Teranishi, Alain Coc, Nicolas de Sereville, Fairouz Hammache, Gabor Kiss, Shawn Bishop, and Dam Nguyen Binh: "The $^{18}\text{F}(n, \alpha)$ Reaction: First Study of n-Induced Reaction on a Radioactive Nucleus Using the Trojan Horse Method", JPS Conf. Proc. **14**, 021104 (2017).
- N. Shimizu, Y. Utsuno, Y. Futamura, T. Sakurai, T. Mizusaki, T. Otsuka, "Stochastic estimation of level density in nuclear shell-model calculations", EPJ Web of Conferences **122**, 02003 (2016)*

- T. Sumikama, D.S. Ahn, N. Fukuda, N. Inabe, T. Kubo, Y. Shimizu, H. Suzuki, H. Takeda, N. Aoi, D. Beaumel, K. Hasegawa, E. Ideguchi, N. Imai, T. Kobayashi, M. Matsushita, S. Michimasa, H. Otsu, S. Shimoura, T. Teranishi: "First test experiment to produce the slowed-down RI beam with the momentum-compression mode at RIBF", Proceedings of 17th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS2015), Nucl. Instr. Meth. Phys. Res. B 376, 180–184 (2016)
- J. Yasuda, M. Sasano, R.G.T. Zegers, H. Baba, W. Chao, M. Dozono, N. Fukuda, N. Inabe, T. Isobe, G. Jhang, D. Kameda, T. Kubo, M. Kurata-Nishimura, E. Milman, T. Motobayashi, H. Otsu, V. Panin, W. Powell, H. Sakai, M. Sako, H. Sato, Y. Shimizu, L. Stuhl, H. Suzuki, S. Tangwancharoen, H. Takeda, T. Uesaka, K. Yoneda, J. Zenihiro, T. Kobayashi, T. Sumikama, T. Tako, T. Nakamura, Y. Kondo, Y. Togano, M. Shikata, J. Tsubota, K. Yako, S. Shimoura, S. Ota, S. Kawase, Y. Kubota, M. Takaki, S. Michimasa, K. Kisamori, C.S. Lee, H. Tokieda, M. Kobayashi, S. Koyama, N. Kobayashi, T. Wakasa, S. Sakaguchi, A. Krasznahorkay, T. Murakami, N. Nakatsuka, M. Kaneko, Y. Matsuda, D. Mucher, S. Reichert, D. Bazin, J.W. Lee: "Inverse kinematics (p,n) reactions studies using the WINDS slow neutron detector and the SAMURAI spectrometer", Proceedings of 17th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS2015), Nucl. Instr. Meth. Phys. Res. B 376, 393–396 (2016).
- H. Sako et al. [J-PARC Heavy-Ion Collaboration], "Studies of high density baryon matter with high intensity heavy-ion beams at J-PARC," Nucl. Phys. A **956**, 850 (2016).
- T. Gunji [ALICE Collaboration], "Overview of recent ALICE results," Nucl. Phys. A **956**, 11 (2016)
- C. Zhao, T. Gunji et al., "First performance results of the ALICE TPC Readout Control Unit 2," JINST **11**, no. 01, C01024 (2016).
- K. Itahashi et al., "Precision spectroscopy of pionic atoms and chiral symmetry in nuclei", MESON 2016 14th International Workshop on meson production, properties and interaction, EPJ Web Conf. 130 (2016) 01017
- M.L. Cortes et al., "Inelastic scattering of ^{72}Ni , ^{74}Ni off a proton target", XXI INTERNATIONAL SCHOOL ON NUCLEAR PHYSICS, NEUTRON PHYSICS AND APPLICATIONS & INTERNATIONAL SYMPOSIUM ON EXOTIC NUCLEI (ISEN-2015), J. of Phys. Conf. 724, (2016) 012008
- L. Stuhl et al.: "A newly developed wrapping method for scintillator detectors", J. of Phys. Conf. Ser. 665, 012050 (2016).
- T. Kröll et al.: "Nuclear reactions in the storage ring ESR with EXL", J. of Phys. Conf. Ser. 724, 012026 (2016).
- M. Sasano et al.: "Study of Gamow-Teller transitions from ^{132}Sn via the (p,n) reaction at 220 MeV/u in inverse kinematics", Eur. Phys. J. Conf. 107, 06003 (2016).
- R. Reifarth et al.: "Nuclear astrophysics with radioactive ions at FAIR", J. of Phys. Conf. Ser. 665, 012044 (2016).

[Book]

(Original Papers) *Subject to Peer Review

[Others]

- 下浦 享: "テトラ中性子の探査", ISOTOPE NEWS, 749, 7–9 (2017)
- 下浦 享: "RIビームを用いたテトラ中性子研究", 原子核研究, 61, 70–77 (2017)

Oral Presentations

[International Conference etc.]

- H. Yamaguchi (oral): "Study on alpha-cluster levels in non-4n nuclei using low-energy RI beams", 11th International Conference on Clustering Aspects of Nuclear Structure and Dynamics, May 23–27, 2016, Conference Center of the Università di Napoli Federico II, Napoli, Italy.
- H. Shimizu (oral): "Searching for the origin of galactic Al-26 with an experiment using isomeric Al-26 beam", NIC-XIV School, June 13–16, 2016, Niigata University, Niigata, Japan.
- H. Yamaguchi (oral, invited): "Experimental studies of light-ion nuclear reactions using low-energy RI beams", the 14th International Symposium on Nuclei in the Cosmos (NIC-XIV), June 19–24, 2016, Toki Messe, Niigata, Japan.
- H. Yamaguchi (oral): "Overview of CRIB projects", the Second Sicily-East Asia Workshop on Low Energy Nuclear Physics (SEA2016), June 26–28, 2016, CNS, the University of Tokyo, Wako, Saitama, Japan.
- S. Hayakawa (oral): "Trials for the cosmological ^7Li problem with ^7Be beams at CRIB and collaborating studies", the Second Sicily-East Asia Workshop on Low-energy Nuclear Physics (SEA2016), June 26–28, 2016, CNS, the University of Tokyo, Wako, Saitama, Japan.
- H. Yamaguchi (oral): "Recent activities at the low-energy RI beam separator CRIB", RIBF users meeting 2016, Sep. 8–9, 2016, RIKEN, Wako, Saitama, Japan.
- H. Yamaguchi (oral): "Overview of recent experiments at CRIB", SKKU mini workshop, Oct. 11, 2016, Sungkyunkwan University, Suwon, Korea.
- S. Hayakawa (oral): "Upcoming CRIB experiment: $^7\text{Be} + n$ reaction measurements by the Trojan horse method", SKKU mini Workshop, Oct. 11, 2016, Suwon, Korea.
- H. Yamaguchi (oral): "Introduction of the low-energy RI beam facility CRIB and recent research activities at CRIB", Nuclear Physics Seminar, Oct. 25, 2016, Beihang University, Beijing, China.
- N. Imai, "OEDO and proton resonance elastic scattering" (invited) HIAS2016 2016/9/18–20, Canberra, Australia
- N. Imai, "Physics program with low-energy RI beams" (invited) 2016/11/16–18 Daejeong, Korea, RNC-RISP RIB physics workshop
- N. Shimizu, "Shape phase transition and shell evolution in large-scale shell-model calculations", 8th Workshop on Quantum Phase Transitions in Nuclei and Many-Body Systems, Jun. 6–9, 2016, Prague, Czech Republic.
- Y. Utsuno (invited), N. Shimizu, T. Otsuka, "Shell-model applications to gamma-ray strength function and level density", NUSPIN 2016 Workshop of the Nuclear Spectroscopy Instrumentation Network and AGATA Physics Workshop, Jun. 27–Jul. 1, 2016, Venice, Italy.
- N. Tsunoda, "Island of Inversion by microscopically derived shell-model Hamiltonian", Direct Reactions with Exotic Beams (DREB) 2016, Jul. 11–15, 2016, Halifax, Canada.

- Y. Tsunoda, "Monte Carlo shell model calculations for structure of nuclei around $Z=28$ ", The 15th CNS International Summer School, Aug. 24-30, 2016, Wako, Japan.
- N. Shimizu, "Large-scale shell-model studies for exotic nuclei and nuclear level densities", International Conference Nuclear Theory in the Supercomputing Era - 2016, Sep. 19-23, 2016, Khabarovsk, Russia.
- N. Shimizu, "Clustering structure in no-core Monte Carlo shell model", Workshop on Nuclear Cluster Physics (WNCP2016), Nov. 14-17, 2016, Yokohama, Japan.
- J. Menéndez, "Towards double-beta decay matrix elements with theoretical uncertainties", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Dec. 12-16, 2016, Tsukuba, Japan.
- N. Shimizu, "Nuclear shell-model calculations in HPC", First Tsukuba-CCS-RIKEN joint workshop on microscopic theories of nuclear structure and dynamics, Dec. 12-16, 2016, Tsukuba, Japan.
- Y. Utsuno, S. Yoshida, N. Shimizu, T. Otsuka, T. Togashi, T. Suzuki, M. Honma, "Shell-model study of Gamow-Teller and first-forbidden β decay in the $N=28$ region", 6th Workshop on Nuclear Fission and Spectroscopy of Neutron-Rich Nuclei, Mar. 20-24, 2017, Chamrousse, France.
- S. Shimoura (invited): "Tetraneutron states populated via ${}^4\text{He}({}^8\text{He}, {}^8\text{Be})$ reaction", The 11th International Conference on Clustering Aspects of Nuclear Structure and Dynamics (Cluster16), May. 23--27, 2016, Naples, Italy.
- S. Shimoura (Oral): "Tetra-neutron states populated by ${}^4\text{He}({}^8\text{He}, {}^8\text{Be})$ reaction", The 9th International Conference on Direct Reactions with Exotic Beams (DREB2016), July 11--15, 2016, Halifax, Canada.
- S. Shimoura (invited): "Interplay between reaction and structure in nuclear physics", International Symposium on Modern Technique and its Outlook in Heavy ion Science (MOTO16), June 26--27, 2016, Rikkyo University, Tokyo, Japan.
- M. Dozono (Oral): "Separated flow operation of the SHARAQ spectrometer for in-flight proton-decay experiments", International Symposium on Modern Technique and its Outlook in Heavy ion Science (MOTO16), June 26--27, 2016, Rikkyo University, Tokyo, Japan.
- S. Michimasa (Invited): "New Beamline with Optimized Energy-degrading Optics of RI beams", The Second Sicily-East Asia Workshop on Low Energy Nuclear Physics (SEA2), June 26--28, 2016, Nishina Hall, RIKEN, Wako, Saitama, Japan.
- S. Shimoura: "Experimental studies of the tetra-neutron system by using RI-beam", RIBF Discussion on the tetra-neutron system, August 3, 2016, Tohoku University, Sendai, Japan
- S. Shimoura (invited): "Experimental studies of the tetra-neutron system by using RI-beam", The 23rd European Conference on Few-Body Problems in Physics, Aug. 8--12, 2016, Aarhus, Denmark.
- S. Michimasa (Invited): "Recent Achievement of OEDO/SHARAQ system", RIBF Users Meeting 2016, September 8--9, 2016, RIBF Conference Hall, RIKEN, Wako, Saitama, Japan.
- S. Shimoura (invited): "Charge Exchange Reaction of RI Beam to Populate Exotic States", International Nuclear Physics Conference (INPC2016), Sep. 11--16, 2016, Adelaide, Australia.
- S. Michimasa (Oral): "Sharaq Spectrometer: High-resolution Spectroscopy Using Exotic Beams And Reactions", International Nuclear Physics Conference (INPC2016), Sep. 11--16, 2016, Adelaide, Australia.
- S. Michimasa (Oral): "OEDO Beamline: New Energy-degrading Ion Optics of RI Beams", International Nuclear Physics Conference (INPC2016), Sep. 11--16, 2016, Adelaide, Australia.
- R. Yokoyama (Oral): "Role Of Hexadecupole Deformation In The Shape Evolution Of Neutron-rich Nd Isotopes", International Nuclear Physics Conference (INPC2016), Sep. 11--16, 2016, Adelaide, Australia.
- M. Kobayashi (Oral): "Time-of-flight Mass Measurements Of Neutron-rich Calcium Isotopes Beyond $N=34$ ", International Nuclear Physics Conference (INPC2016), Sep. 11--16, 2016, Adelaide, Australia.
- M. Takaki (Oral): "Search for Double Gamow-Teller Resonance via Heavy-ion Double Charge Exchange Reaction", International Nuclear Physics Conference (INPC2016), Sep. 11--16, 2016, Adelaide, Australia.
- S. Shimoura (invited): "Tetra-neutron system populated by exothermic double-charge exchange reaction ${}^4\text{He}({}^8\text{He}, {}^8\text{Be})$ at 190 MeV/u", The 22nd International Spin Symposium, Sep. 25--30, 2016, Champaign, IL, USA.
- S. Shimoura (invited): "Tetra-neutron system studied by ${}^4\text{He}({}^8\text{He}, {}^8\text{Be})$ ", ECT* Workshop on Physics beyond the limits of stability: exploring the continuum, Oct. 17--21, 2016, Trento, Italy
- S. Michimasa (Invited): "New energy-degraded beam project at RIBF -- OEDO project --", KPS 2016 Fall Meeting, October 19--21, 2016, Kimdaejung Convention Center, Gwangju, Korea.
- S. Shimoura (invited): "Tetra-neutron system studied by ${}^4\text{He}({}^8\text{He}, {}^8\text{Be})$ ", Workshop on Nuclear Cluster Physics (WNCP2016), Oct. 17--21, 2016, Kanto-Gakuin University, Yokohama, Japan
- S. Shimoura (invited): "Tetra-neutron system studied by using RI beam", International Symposium on Neutron Star Matter (NSMAT2016), Recent Progress in Observations, Experiments and Theories, Oct. 21--24, 2016, Tohoku University, Sendai, Japan
- S. Shimoura (invited): "Tetra-neutron system populated by reaction of exotic beam", ESNT Workshop on Dynamics of highly unstable exotic light nuclei and few-body systems, January 30--February 3, 2017, Saclay, France
- T. Gunji (Oral) for the ALICE Collaboration: "Low mass dielectron measurements in pp, p-Pb, and Pb-Pb collisions with ALICE at the LHC", The 8th International Conference on Hard and Electromagnetic Probes of High-energy Nuclear Collisions (Hard Probes 2016), 9/23-27, 2016, Wuhan, China
- T. Gunji (Oral) for the ALICE Collaboration: "Physics with heavy-ions and Dark Photon Searches at the LHC-ALICE experiment", Aspen workshop on Particle Physics in 2017 : From the LHC to Dark Matter and Beyond, 3/20-25, 2017, Aspen, Colorado, USA, 3/20-3/25
- Y. Watanabe (Oral) ; "Experimental overview on hadronic resonance production in high-energy nuclear collisions", The 16th International Conference on Strangeness in Quark Matter (Strangeness in Quark Matter 2016), 6/26-7/1, 2016, Berkeley, USA
- Y. Watanabe (Oral) for the ALICE Collaboration, "ALICE Overview", 33rd Winter Workshop on Nuclear Dynamics, 1/8-14, 2017, Salt Lake City, USA
- S. Ota (invited), "CNS Active Target (CAT) for high-intensity beam experiment and the first experiment at RIBF", Workshop on Software for Time Projection Chamber for Nuclear Physics Experiments, Aug. 8-10, 2016, MSU, US
- H. Tokieda (invited), "Event Search Algorithm for CAT", Workshop on Software for Time Projection Chamber for Nuclear Physics Experiments, Aug. 8-10, 2016, MSU, US
- C. Iwamoto (invited), "Simulation for high-intensity heavy-ion beam injection in CAT", Workshop on Software for Time Projection Chamber for Nuclear Physics Experiments, Aug. 8-10, 2016, MSU, US

L. Stuhl et al. (oral): "A new low-energy plastic scintillation neutron detector for real time pulse shape discrimination": The 26th International Nuclear Physics Conference (INPC2016), Sep 11—16, 2016, Adelaide, Australia.

[Domestic Conference]

- 早川勢也 (oral): "トロイの木馬法による ${}^7\text{Be}+n$ ビッグバン元素合成反応の測定 (Measurement of the ${}^7\text{Be}+n$ Big-Bang nucleosynthesis reactions by the Trojan horse method)", 日本物理学会 第 72 回年次大会, 3 月 17 日~20 日, 大阪大学
- 清水英樹 (oral): "CRIB における ${}^{26}\text{Al}$ 異性核反応の宇宙 γ 線観測への寄与の研究 (Study on e contribution of isomeric aluminum-26 reaction to cosmic gamma-ray observation with CRIB)", 日本物理学会 第 72 回年次大会, 3 月 17 日~20 日, 大阪大学
- N. Kitamura et al., "Shell structure of ${}^{35}\text{Si}$ studied by proton resonance scattering", JPS 2016 fall meeting
- O. Beliuskina et al., "Pulse height defect in CVD Diamond Detectors", JPS 2016 fall meeting
- N. Imai, "Single particle structure studies with the transfer reaction and the resonance elastic reaction" (invited) JPS meeting 2017, symposium for New aspects of direct reactions in probing exotic nuclei
- 角田佑介、大塚孝治、清水則孝、本間道雄、宇都野穰、"大規模殻模型計算による $Z=28$ 近傍の核構造の研究", 日本物理学会 2016 年秋季大会, Sep. 21-24, 2016、宮崎大学木花キャンパス、宮崎
- 富樫智章、角田佑介、大塚孝治、清水則孝、"Zr 同位体における形の量子相転移のモンテカルロ殻模型による研究", 日本物理学会 2016 年秋季大会, Sep. 21-24, 2016、宮崎大学木花キャンパス、宮崎
- 吉田亨、清水則孝、阿部喬、大塚孝治、"Be, C 同位体の intrinsic 状態のモンテカルロ殻模型による研究", 日本物理学会 2016 年秋季大会, Sep. 21-24, 2016、宮崎大学木花キャンパス、宮崎
- 富樫智章、角田佑介、大塚孝治、清水則孝、"Zr 同位体における形の量子相転移のモンテカルロ殻模型による研究", 研究会「クラスター・平均場の両側面から見る原子核構造の多様性とそのダイナミクス」、Jan. 19-20, 2017、大阪市立大学、大阪
- 市川隆敏、清水則孝、宇都野穰、大塚孝治、"大規模殻模型計算による質量数 $A=40$ 領域における $4p-4h$ 変形状態の系統的探索", 日本物理学会第 72 回年次大会, Mar. 17-20, 2017、大阪大学豊中キャンパス、大阪
- 宇都野穰、藤田佳孝、"二核子配位のガモフテラー遷移と陽子中性子対相関", 日本物理学会第 72 回年次大会, Mar. 17-20, 2017、大阪大学豊中キャンパス、大阪
- 清水則孝、富樫智章、大塚孝治、宇都野穰、吉田聡太、"ベイズ統計による殻模型計算解析", 日本物理学会第 72 回年次大会, Mar. 17-20, 2017、大阪大学豊中キャンパス、大阪
- 角田直文、大塚孝治、鈴木俊夫、高柳和雄、清水則孝、Morten Hjorth-Jensen、"核力に依拠した有効相互作用による殻模型計算でみる「逆転の島」の新しい様相", 日本物理学会第 72 回年次大会, Mar. 17-20, 2017、大阪大学豊中キャンパス、大阪
- 角田佑介 (受賞講演)、"Ni 同位体における新奇な変形共存現象と核子配位に依存した殻進化の研究", 日本物理学会第 72 回年次大会, Mar. 17-20, 2017、大阪大学豊中キャンパス、大阪
- 富樫智章、角田佑介、大塚孝治、清水則孝、"Zr 同位体とその近傍核における形の量子相転移のモンテカルロ殻模型による研究", 日本物理学会第 72 回年次大会, Mar. 17-20, 2017、大阪大学豊中キャンパス、大阪
- 角田直文、"Medium-mass nuclei from nuclear force", 基研研究会「核力に基づく核構造、核反応物理の展開」、Mar. 27-29, 2017、京都大学基礎物理学研究所、京都
- 下浦 享 (invited): "イオンビームを用いた原子核研究と放射線計測技術の現状と課題", 放射線科学とその応用第 186 委員会 第 19 回研究会, 2016年5月19日, 東京大学山上会館, 東京
- 下浦 享 (invited): "RIビームを用いた原子核物理学研究と放射線測定技術", 第62回放射線計測研究会, 2016年10月15日, 三菱総合研究所, 東京
- S. Shimoura (invited): "Tetra-neutron system populated by exothermic double-charge exchange reaction", 基研研究会「核力に基づく核構造、核反応物理の展開」, 2017年3月27-29日, 京都大学, 京都.
- S. Masuoka 他: "複数中性子識別のための反跳陽子飛跡検出器の開発II", JPS Fall meeting, September 21--24, 2016, Miyazaki University, Miyazaki, Japan
- Y. Yamaguchi, 他: "DSPを用いた多重ガンマ線検出用Ge検出器アレイのデータ収集系の開発2", JPS Fall meeting, September 21--24, 2016, Miyazaki University, Miyazaki, Japan
- M. Kobayashi 他: "飛行時間法を用いた中性子数34近傍Ca同位体の質量測定", JPS Fall meeting, September 21--24, 2016, Miyazaki University, Miyazaki, Japan
- R. Yokoyama, 他: "中性子過剰Nd同位体の変形進化における十六重極変形の効果", JPS Fall meeting, September 21--24, 2016, Miyazaki University, Miyazaki, Japan
- S. Shimoura (invited): "New energy degraded beam line at RIBF -- OEDO", 「超重元素の新展開」シンポジウム, JPS Spring meeting, March 17--20, 2017, Osaka University, Osaka, Japan
- 小高康照(oral): "4次元エミッタンスデータによる AVF 入射軌道解析", 第 13 回 AVF 合同打合せ, 2016 年 10 月 27-28 日, 東北大学 CYRI
- 大城幸光(oral): "CNS イオン源の現状", 第 13 回 AVF 合同打合せ, 2016 年 10 月 27-28 日, 東北大学 CYRIC
- S. Hayashi for the ALICE Collaboration, "Dielectron production from Heavy Quarks in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with the ALICE detector", JPS 2016 Autumn Meeting, Sep. 21-24, University of Miyazaki, Miyazaki, Japan
- K. Terasaki for the ALICE Collaboration, "Search for exotic dibaryons and study of baryon-baryon correlations at LHC-ALICE", JPS 2016 Autumn Meeting, Sep. 21-24, University of Miyazaki, Miyazaki, Japan
- Y. Sekiguchi for the ALICE Collaboration, "Study of two particle correlations in p-Pb collisions at $\sqrt{s_{NN}} = 5.02$ TeV with ALICE", JPS 2016 Autumn Meeting, Sep. 21-24, University of Miyazaki, Miyazaki, Japan
- 大田晋輔、"重水素アクティブ標的を用いた錫領域不安定核の巨大共鳴の測定"日本物理学会第 72 回年次大会、2017 年 3 月 17 日~2017 年 3 月 20 日、大阪大学
- 大田晋輔(invited)、"CNS Active Target"、新学術領域『中性子星核物質』第二回検出器ワークショップ

Posters Presentations

[International Conference etc.]

- S. Hayakawa, C. Spitaleri, N. Burtebayev, A. Aimaganbetov, S.V. Artemov, P. Figuera, M. Fisichella, G.L. Guardo, S. Igamov, I. Indelicato, G.G. Kiss, S. Kubono, M. La Cognata, L. Lamia, M. Lattuada, M. Nassurlla, E. Piasecki, G.G. Rapisarda, S. Romano, S.B. Sakuta, A. Trzcinska, A. Tumino, A. Urkinbayev, and T. Zhodybayev (poster): "Trojan Horse Method for the Oxygen-Burning Process Reactions", The 14th International Symposium on Nuclei in the Cosmos (NIC2016), Jun. 19-24, Niigata, Japan

- K. Abe, S. Hayakawa, H. Yamaguchi, and L. Lamia (poster) : ``Feasibility Study for the ${}^7\text{Be}+n$ Reaction Measurements by Trojan Horse Method at CRIB'', The 14th International Symposium on Nuclei in the Cosmos (NIC2016), Jun. 19-24, Niigata, Japan
- T. Togashi, "E1 strength function in Monte Carlo shell model", The 15th CNS International Summer School, Aug. 24-30, 2016, Wako, Japan.
- T. Yoshida, "Structure of Be and C isotopes with large-scale shell model calculations", The 15th CNS International Summer School, Aug. 24-30, 2016, Wako, Japan
- H. Murakami for the ALICE Collaboration, "Measurements of neutral mesons in pp collisions at $\sqrt{s} = 5.02\text{TeV}$ via conversion method with ALICE", Quark Matter 2017, Feb. 5-11, 2017, Chicago, USA

[Domestic Conference]

- 小高康熙 : 「ペーパーポット型エミッタンス測定器を用いた理研 AVF サイクロトロン入射系の解析」, 第 13 回日本加速器学会年会, 2016 年 8 月 8-10 日, 幕張メッセ国際会議場

Partner Institution
 Center for Radioactive Ion Beam Sciences
 Institute of Natural Science and Technology, Niigata University

1. Abstract

The Center for Radioactive Ion Beam Sciences, Niigata University, aims at uncovering the properties of atomic nuclei and heavy elements and their roles in the synthesis of elements, with use of the advanced techniques of heavy ion and radioactive ion beam experiments as well as the theoretical methods. Main research subjects include the measurements of various reaction cross sections and moments of neutron- or proton-rich nuclei, synthesis of super-heavy elements and radio-chemical studies of heavy nuclei, and theoretical studies of exotic nuclei based on quantum many-body methods and various nuclear models. In addition, we promote interdisciplinary researches related to the radioactive ion beam sciences, such as applications of radioactive isotopes and radiation techniques to material sciences, nuclear engineering and medicine. Many of them are performed in collaboration with RIKEN Nishina Center and with use of the RIBF facilities. The center emphasizes also its function of graduate education in corporation with the Graduate School of Science and Technology, Niigata University, which invites three researchers in RIKEN Nishina Center as visiting professors.

2. Major Research Subjects

- (1) Reaction cross section and radii of neutron-rich nuclei
- (2) Production of superheavy nuclei and radiochemistry of heavy elements
- (3) Nuclear theory

3. Summary of Research Activity

- (1) Measurements of matter and charge radii of exotic nuclei

The experimental nuclear physics group has studied the nuclear structures of exotic nuclei through the measurements of nuclear matter radii. The nuclear matter radii can be determined from interaction cross sections with the use of nuclear reaction model. At RIBF, RIKEN, we have performed experiments to measure interaction cross sections of F, Ne, Na, Mg, and Al isotopes and clarified the halo structure of ^{31}Ne , and also the development of strong deformation in those isotopes, $^{28-32}\text{Ne}$, $^{32-38}\text{Mg}$, which are located around and beyond the “island of inversion” region. Recently our new project to explore the equation of state (EOS) of nuclear matter has been started. For the understanding of the EOS of asymmetric nuclear matter, either highly proton deficient or neutron deficient, the investigation of the development of neutron skin thickness in the exotic nuclei give the crucial information. We have measured interaction cross sections and charge changing cross sections for $^{58-78}\text{Ni}$ using BigRIPS fragments separator at RIBF in FY2016. While nuclear matter radii can be determined from interaction cross sections, the proton distribution radii will be determined from charge-changing cross sections, thus neutron skin thickness will be obtained. The data analysis are in progress.

- (2) Production of superheavy nuclei and radiochemistry of heavy elements

The nuclear chemistry group has been investigating decay properties of super-heavy nuclei, measured the excitation functions of rutherfordium isotopes, and clarified the ambiguity of the assignment of a few-second spontaneously fissioning isotope of ^{261}Rf . The new equipment designed for measurement of short-lived alpha emitters is under development.

For the chemistry research of super-heavy elements, preparatory experiments, such as solvent extraction for the group 4, 5, and 6th elements and gaseous phase chemistry for group-4 elements, have been performed using radioisotopes of corresponding homolog elements.

- (4) Nuclear theory

One of the main activities of the nuclear theory group concerns with developments of the nuclear density functional theory and exploration of novel correlations and excitations in exotic nuclei. A fully selfconsistent scheme of the quasiparticle random phase approximation (QRPA) on top of the Skyrme-Hartree-Fock-Bogoliubov mean-field for deformed nuclei has been developed in the group. The versatility of this method to describe the deformation splitting of the giant resonances associated with the onset of deformation has been demonstrated for the first time by the intensive numerical calculation performed for the light nuclei such as ^{28}Si and the comparison with the recent experimental data. For the medium-heavy nuclei, softening of the gamma vibration in the neutron-rich Dy isotopes observed by the EURICA experiment was successfully described, and the microscopic mechanism was made clear. The QRPA in the density functional framework has been developed in various directions. The continuum QRPA, which describes not only collective correlations but also coupling to unbound continuum states of nucleons, has been applied to describe the direct neutron capture reaction in the r-process nucleosynthesis. The QRPA is recently applied to describe collective excitation in inner crust of neutron stars. The continuum quasiparticle states are also analyzed to study possible pairing effects on low-lying p-wave resonances and s-wave scattering states in unbound odd-N nuclei. Cluster structure and the ab initio studies of light nuclei are also important research subjects of the theory group.

Members

Director

Masayuki MATSUO (Professor)

Scientific Staff

Hisaaki KUDO (Professor)
 Takashi OHTSUBO (Associate Professor)
 Shin-ichi GOTO (Associate Professor)
 Shigeyoshi AOYAMA (Associate Professor)
 Takuji IZUMIKAWA (Associate Professor)

Kenichi YOSHIDA (Assistant Professor)
 Kazuhiro OOE (Assistant Professor)
 Jun GOTO (Assistant Professor)
 Maya TAKECHI (Assistant Professor)

Post Doctoral Associates

Tsunenori INAKURA

Graduate Students

Yoshihiko KOBAYASHI

List of Publications & Presentations**Publications**

[Journal]

(Original Papers) *Subject to Peer Review

- T. Peach, U. Garg, Y. K. Gupta, J. Hoffman, J. T. Matta, D. Patel, P. V. Madhusudhana Rao, K. Yoshida, M. Itoh, M. Fujiwara, K. Hara, H. Hashimoto, K. Nakanishi, M. Yosoi, H. Sakaguchi, S. Terashima, S. Kishi, T. Murakami, M. Uchida, Y. Yasuda, H. Akimune, T. Kawabata, M. N. Harakeh, and G. Colò, "Effect of ground-state deformation on isoscalar giant resonances in ^{28}Si ", *Physical Review C* **93**, 064325 (2016).*
- H. Watanabe, G. X. Zhang, K. Yoshida, P. M. Walker, J. J. Liu, J. Wu, P. H. Regan, P.-A. Soderstrom, H. Kanaoka, Z. Korkulu, P. S. Lee, S. Nishimura, A. Yagi, D. S. Ahn, T. Alharbi, H. Baba, F. Browne, A. M. Bruce, R. J. Carroll, K. Y. Chae, Zs. Dombradi, P. Doornenbal, A. Estrade, N. Fukuda, C. Griffin, E. Ideguchi, N. Inabe, T. Isobe, S. Kanaya, I. Kojouharov, F. G. Kondev, T. Kubo, S. Kubono, N. Kurz, I. Kuti, S. Lalkovski, G. J. Lane, C. S. Lee, E. J. Lee, G. Lorusso, G. Lotay, C.-B. Moon, I. Nishizuka, C. R. Nita, A. Odahara, Z. Patel, V. H. Phong, Zs. Podolyak, O. J. Roberts, H. Sakurai, H. Schaffner, "Long-lived K isomer and enhanced γ vibration in the neutron-rich nucleus ^{172}Dy : Collectivity beyond double midshell", *Physics Letters B* **760**, 641 (2016).*
- K. Yoshida and H. Watanabe, "Enhanced collectivity of γ vibration in neutron-rich Dy isotopes with $N=108-110$ ", *Progress of Theoretical and Experimental Physics* **2016**, 123D02 (2016).*
- Y. Kobayashi, M. Matsuo, "Effects of pairing correlation on the low-lying quasiparticle resonance in neutron drip-line nuclei", *Progress of Theoretical and Experimental Physics*, **2016**, 013D01 (1-14) (2016).*
- N. Nakatsuka, H. Baba, T. Aumann, R. Avigo, S.R. Banerjee, A. Bracco, C. Caesar, F. Camera, S. Ceruti, S. Chen, V. Derya, P. Doornenbal, A. Giaz, A. Horvat, K. Ieki, T. Inakura, N. Imai, T. Kawabata, N. Kobayashi, Y. Kondo, S. Koyama, M. Kurata-Nishimura, S. Masuoka, M. Matsushita, S. Michimasa, B. Million, T. Motobayashi, T. Murakami, T. Nakamura, T. Ohnishi, H.J. Ong, S. Ota, H. Otsu, T. Ozaki, A. Saito, H. Sakurai, H. Scheit, F. Schindler, P. Schrock, Y. Shiga, M. Shikata, S. Shimoura, D. Steppenbeck, T. Sumikama, I. Syndikus, H. Takeda, S. Takeuchi, A. Tamii, R. Taniuchi, Y. Togano, J. Tscheuschner, J. Tsubota, H. Wang, O. Wieland, K. Wimmer, Y. Yamaguchi, K. Yoneda, J. Zenihiro, "Observation of isoscalar and isovector dipole excitations in neutron-rich ^{20}O ", *Physical Letter B* **768** (2017) 387-392*
- D. T. Tran *et al.*, "Charge-changing cross-section measurements of $^{12-16}\text{C}$ at around 45A MeV and development of a Glauber model for incident energies 10A–2100A MeV", *Phys. Rev. C* **94**, (2016) 064604
- Y. K. Tanaka *et al.*, "Measurement of Excitation Spectra in the $^{12}\text{C}(p, d)$ Reaction near the η' Emission Threshold", *Phys. Rev. Lett.* **117**, (2016) 202501
- R. Kanungo *et al.*, "Proton Distribution Radii of $^{12-19}\text{C}$ Illuminate Features of Neutron Halos", *Phys. Rev. Lett.* **117**, (2016) 102501
- J. Lee *et al.*, "First Measurement of Several β -Delayed Neutron Emitting Isotopes Beyond $N = 126$ ", *Prog Theor Exp Phys* (2016) 2016 (8)
- R. Caballero-Folch *et al.*, "Asymmetry dependence of reduction factors from single-nucleon knockout of ^{30}Ne at ~ 230 MeV/nucleon", *Phys. Rev. Lett.* **117**, (2016) 012501
- P. Doornenbal *et al.*, "Mapping the deformation in the "island of inversion": Inelastic scattering of ^{30}Ne and ^{36}Mg at intermediate energies", *Phys. Rev. C* **93**, (2016) 044306
- I. Tanihata *et al.*, "Observation of large enhancements of charge exchange cross sections with neutron-rich carbon isotopes", *Prog Theor Exp Phys* (2016) 2016 (4)
- M. P. Reiter *et al.*, "Rate capability of a cryogenic stopping cell for uranium projectile fragments produced at 1000 MeV/u", *NIM B* **376** (2016) 240
- Y. Kawano, A. Munaim, J. Goto, Y. Shobugawa and M. Naito, "Sensing Space: Augmenting Scientific Data with Spatial Ethnography", *GeoHumanities* **2**, 485 (2016).*(Review)
- 吉田賢市, 伊藤正俊, "変形原子核の巨大単極共鳴", *日本物理学会誌* **72**, 45 (2017).

[Proceedings]

(Original Papers) *Subject to Peer Review

- A. Homma *et al.*, "Measurements of Interaction Cross Sections for $^{19-27}\text{F}$ Isotopes", *JPS Conf. Proc.* **14**, 021010 (2017)
- K. Nishizuka *et al.*, "Measurements of Reaction Cross Sections for ^{9-11}C ", *JPS Conf. Proc.* **14**, 021015 (2017)
- E. Miyata *et al.*, "Development of High Resolution TOF Detector for RI Beams Using Cherenkov Radiation", *J Acta Phys.Polon.* **B48** (2017) 409
- M. Tanaka *et al.*, "Reaction Cross Sections for $^{13-15}\text{B}$ and One-neutron Halo in ^{14}B ", *J Acta Phys.Polon.* **B48** (2017) 461
- J. Goto, Y. Shobugawa, Y. Kawano, Y. Amaya, T. Izumikawa, Y. Katsuragi, T. Shiya, T. Suzuki, TA. Takahashi, TO Takahashi, H. Yoshida, and M. Naito, "Development of a Portable Gamma-ray Survey System for the Measurement of Air Dose Rates", *JPS Conference Proceedings* **11**, 070007 (2016).*

[Book]

(Original Papers) *Subject to Peer Review

内藤眞, 青木萩子, 野中昌法, 後藤淳, 菖蒲川由郷, 高橋俊博, 吉田秀義, 天谷吉宏, Y. Kawano, 岩佐有華, 齋藤智子, 西方真弓, 吉川夏樹, 原田直樹, 山城秀昭, 高橋剛, "BISHAMON の軌跡-II ~福島支援 5年間の記録~, 新潟日報事業社(2016)

[Others]

吉田賢市, 伊藤正俊, "変形原子核の巨大単極共鳴", 日本物理学会誌 **72**, 45 (2017).

Oral Presentations

[International Conference etc.]

- K. Yoshida and H. Watanabe, "Enhanced Collectivity of Gamma Vibration in Neutron-rich Dy Isotopes with $N=108-110$ ", The Nuclear Structure 2016 Conference, Knoxville, USA, July 24-29, 2016.
- K. Yoshida, "Spin-isospin Responses of Deformed Neutron-rich Nuclei", The 26th International Nuclear Physics Conference, Adelaide, Australia, September 11-16, 2016.
- K. Yoshida, "Low-lying excitations in neutron-rich nuclei: Effects of deformation and pairing", The first Tsukuba-CCS-RIKEN joint workshop on Microscopic Theories of nuclear structure and dynamics, RIKEN, Wako, Saitama, December 12-16, 2016.
- K. Yoshida, "Roles of neutron excess and deformation on charge-exchange collective modes of excitation", Recent Progresses in Nuclear Structure Physics 2016", YITP, Kyoto, December 19-23, 2016.
- Y. Kobayashi, M. Matsuo, "Effects of pairing correlation on low-energy p- and s-wave scattering in neutron-rich nuclei" ECT* Workshop "Physics beyond the limits of stability: exploring the continuum", European Center for Theoretical Studies in Nuclear Physics and Related Areas, Trento, October 20, 2016.
- Y. Kobayashi, M. Matsuo, "Effects of pairing correlation on the low-lying quasiparticle resonance in neutron drip-line nuclei", International Nuclear Physics Conference 2016, Adelaide Convention Center, Adelaide, September 13, 2016.
- Y. Kobayashi, M. Matsuo, "Single-neutron resonance and pairing correlation in neutron-rich nuclei", Resonance and non-Hermitian Quantum Mechanics 2016, 2016年08月04日, Research Center for Nuclear Physics, August 4, 2016.
- T. Inakura, H. Nakada, "Constraining the slope parameter of symmetry energy from nuclear structure", International symposium on Neutron Star Matter, Tohoku University, Sendai, Miyagi, November 21-24, 2016.
- T. Inakura, M. Matsuo, "Calculation of collective excitation of inner crust using density functional theory", The first Tsukuba-CCS-RIKEN joint workshop on Microscopic Theories of nuclear structure and dynamics, Center for Computational Science, University of Tsukuba, Tsukuba, Ibaraki, December 19-23, 2016.
- M. Takechi, E. Miyata, *et al.* "Development of High Resolution TOF detector for RI Beams using Cherenkov Radiation", ZAKOPANE Conference on Nuclear Physics, Zakopane, Poland, 28, August - 4, September, 2016.
- A. Homma *et al.*, "Measurements of Reaction Cross Section for $^{19-27}\text{F}$ Isotopes", ZAKOPANE Conference on Nuclear Physics, Zakopane, Poland, 28, August - 4, September, 2016.
- M. Tanaka *et al.*, "Reaction Cross Sections for $^{13-15}\text{B}$ and One-neutron Halo in ^{14}B ", ZAKOPANE Conference on Nuclear Physics, Zakopane, Poland, 28, August - 4, September, 2016.

[Domestic Conference]

- 吉田賢市, "Deformation effect on giant resonances in ^{24}Mg and ^{28}Si ", 日本物理学会 2016年秋季大会, 宮崎大学, 9月(2016).
- 吉田賢市, "Variety of excitation modes associated with nuclear deformation and superfluidity", クラスタ・平均場の両側面から見る原子核構造の多様性とそのダイナミクス, 大阪市立大学, 1月(2017).
- 吉田賢市, "Charge-exchange dipole excitations in deformed nuclei", 日本物理学会第72回年次大会, 大阪大学豊中キャンパス, 3月(2017).
- 小林良彦, 松尾正之, "低エネルギーS波散乱が受ける対相関効果のS行列による分析", 日本物理学会第72回年次大会, 大阪大学豊中キャンパス, 2017年3月
- 小林良彦, 松尾正之, "中性子過剰核におけるS波散乱が受ける対相関効果", 日本物理学会 2016年秋季大会, 宮崎大学, 2016年9月
- 稲倉恒法, 松尾正之, "中性子星内殻における超流動中性子・原子核系の集団運動", 日本物理学会 2016年秋季大会, 宮崎大学, 2016年9月
- 稲倉恒法, 松尾正之, "中性子星内殻における超流動中性子・原子核系の集団運動", クラスタ・平均場の両側面から見る原子核構造の多様性とそのダイナミクス, 大阪市立大学, 2017年1月
- 稲倉恒法, "中性子星内殻における超流動中性子と原子核の集団運動", 実験と観測で解き明かす中性子星の核物質 第5回ウィンタースクール・研究会, 飯坂温泉, 福島 2017年2月
- 稲倉恒法, 松尾正之, "密度汎関数理論による中性子内殻の集団励起モード", 日本物理学会第72回年次大会, 大阪大学豊中キャンパス, 2017年3月
- 福田光順, 田中悠太郎, 田中聖臣, 西村太樹, 武智麻耶 ほか 29名 $^{6,8}\text{He}$ の中性子剥離断面積と荷電変化断面積", 日本物理学会 2016年秋季大会 宮崎大学 2016年9月21-24日
- 田中悠太郎, 福田光順, 西村太樹, 武智麻耶, 田中聖臣, ほか 33名 "反応断面積測定による $^{6,8}\text{He}$ の核構造" 日本物理学会 2016年秋季大会 宮崎大学 2016年9月21-24日
- 杜航, 福田光順, 西村太樹, 武智麻耶, 安部敬治郎 ほか 36名 $^{15,16}\text{C}$ の反応断面積と核構造", 日本物理学会 2016年秋季大会 宮崎大学 2016年9月21-24日
- 大西康介, 福田光順, 西村太樹, 武智麻耶, 青木一矢 ほか 34名, "中間エネルギー領域における ^{12}N の反応断面積と核構造" 日本物理学会 2016年秋季大会 宮崎大学 2016年9月21-24日
- 本間彰 ほか 67名 "中性子過剰側 Ni 同位体の相互作用断面積測定", 日本物理学会 2017年々次大会 大阪大学 2017年3月17-20日
- 中村翔健, 武智麻耶 ほか 67名 "Ni 領域中重核の陽子標的相互作用断面積測定", 日本物理学会 2017年々次大会 大阪大学 2017年3月17-20日

- 中村翔健, 武智麻耶 ほか 67 名 "Ni 領域中重核の陽子標的相互作用断面積測定", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 田中聖臣, ほか 67 名 "Ca, Ni 同位体の荷電変化断面積測定", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 八木翔一, ほか 25 名 "中間エネルギー領域における ^{10}Be の 反応断面積と核構造", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 田中悠太郎, ほか 67 名 "Ca 同位体の相互作用断面積と核構造", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 大西康介, ほか 33 名 "中間エネルギー領域における ^{12}N の 1 陽子剥離断面積", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 西塚賢治, ほか 49 名 "陽子過剰側 C 同位体の陽子、中性子密度分布", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 柳原陸斗, ほか 67 名 "Ni 領域中性子過剰核における核子剥離反応の系統的研究", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 宮田恵理, ほか 43 名 "チェレンコフ放射を利用した不安定核ビーム時間分解能検出器の研究 III", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- 町田聖寛 ほか 31 名 "重イオン用 Ring-Imaging Cherenkov Counter の開発と性能評価", 日本物理学会 2017 年年次大会 大阪大学 2017 年 3 月 17 - 20 日
- J. Goto, T. Takahashi, R. Endo, Y. Amaya, Y. Shobugawa, H. Yoshida, and M. Naito, "自動車走行サーベイシステム ASURA を用いた道路上の放射性セシウム沈着量調査", 日本原子力学会 2017 年春の年会, 東海大学湘南キャンパス, 3 月 (2017).
- J. Goto, T. Takahashi, R. Endo, Y. Amaya, Y. Shobugawa, H. Yoshida, and M. Naito, "ASURA を用いた放射性セシウム沈着量調査", 第 4 回「原発事故被災地域における放射線量マッピングシステムの技術開発・運用とデータ解析に関する研究会」, 京都大学原子炉実験所, 1 月 (2017).
- R. Endo, T. Takahashi, T. Kanbayashi, J. Goto, and M. Naito, "自動車走行サーベイシステム ASURA によるホットスポットの位置推定", 第 4 回「原発事故被災地域における放射線量マッピングシステムの技術開発・運用とデータ解析に関する研究会」, 京都大学原子炉実験所, 1 月 (2017).
- K. Shirai, Y. Oshimi, S. Goto, K. Ooe and H. Kudo, "Rf 同族元素 Zr, Hf の塩化物に対する等温ガスクロマトグラフィ", 第 60 回放射化学討論会, 新潟大学五十嵐キャンパス, 9 月 (2016).
- S. Goto, "新潟大における Zr, Hf および Rf 塩化物の気相化学研究および今後の計画", 2016「超重元素の科学」研究会, 新潟大学駅南キャンパス「ときめいと」, 9 月 (2016).
- K. Ooe, "固液、液液抽出法による Db のフッ化物錯形成と Rf のキレート錯形成の研究", 2016「超重元素の科学」研究会, 新潟大学駅南キャンパス「ときめいと」, 9 月 (2016).
- D. Sato, "105 番元素 Db の aliquot 336 樹脂を用いたフッ化水素酸からの抽出", 2017 超重元素の科学研究会, 日本原子力研究開発機構 先端基礎研究センター, 3 月 (2017).

Posters Presentations

[International Conference etc.]

- Y. Kobayashi, M. Matsuo, "Effects of pairing correlation on p-wave resonance and s-wave scattering in neutron-rich nuclei", RIBF Users Meeting 2016, RIKEN Nishina Center, September 8, 2016.
- Y. Kobayashi, M. Matsuo, "Pairing correlation effects on width of quasiparticle resonance in neutron dripline nuclei", NIC-XIV School, Niigata University, June 15, 2016.
- T. Inakura, M. Matsuo, "Systematic calculation of collective excitation of inner crust using density functional theory", International symposium on Neutron Star Matter, Tohoku University, Sendai, Miyagi, November 21-24, 2016.
- K. Nishizuka, M. Takechi, T. Ohtsubo et al., "Measurement of reaction cross sections for ^{9-12}C isotopes", ZAKOPANE Conference on Nuclear Physics, Zakopane, Poland 28, August - 4, September, 2016.
- A. Homma, M. Takechi, T. Ohtsubo et al., "Measurements of reaction cross sections for $^{19-27}\text{F}$ isotopes", Nuclei in the Cosmos XIV, Niigata, Japan 22-28, May, 2016.
- K. Nishizuka, M. Takechi, T. Ohtsubo et al., "Measurement of Reaction Cross Sections for ^{9-12}C Isotopes", Nuclei in the Cosmos XIV, Niigata, Japan 22-28, May, 2016.

[Domestic Conference]

- R. Yamada, K. Ooe, S. Goto and H. Kudo, H. Haba, Y. Komori, "フローインジェクション分析法を利用した 4 族元素 Zr, Hf のキレート抽出", 第 60 回放射化学討論会, 新潟大学五十嵐キャンパス, 9 月 (2016).
- K. Ooe, R. Yamada, S. Goto and H. Kudo, H. Haba, Y. Komori, "Rf の同族元素 Zr, Hf の 4-イソプロピルトロポロンを用いた溶媒抽出挙動", 第 60 回放射化学討論会, 新潟大学五十嵐キャンパス, 9 月 (2016).
- D. Sato, M. Murakami, K. Ooe, R. Motoyama, H. Haba, Y. Komori, A. Toyoshima, A. Mitsukai, H. Kikunaga, S. Goto and H. Kudo, "5 族元素 Nb, Ta のフッ化水素酸からの Aliquat 336 樹脂への抽出: 分配係数の抽出剤濃度依存性の検討", 第 60 回放射化学討論会, 新潟大学五十嵐キャンパス, 9 月 (2016).
- R. Motoyama, K. Ooe, M. Murakami, H. Haba, S. Goto and H. Kudo, "5 族元素 Nb, Ta の塩酸溶液からのトリイソオクチルアミンによる溶媒抽出—Ta トレーサー調製法の影響—", 第 60 回放射化学討論会, 新潟大学五十嵐キャンパス, 9 月 (2016).

Partner Institution

Wako Nuclear Science Center, IPNS (Institute for Particle and Nuclear Studies)
KEK (High Energy Accelerator Research Organization)

1. Abstract

The KEK Isotope Separation System (KISS) has been constructed to experimentally study the β -decay properties of unknown neutron-rich nuclei near neutron magic number $N = 126$, which are of astrophysical interest. A new rotating target system was introduced and higher yields and more stable operational conditions were achieved. Resonance ionization spectroscopy for the hyperfine structure of ^{199}Pt was performed at KISS. An international collaboration with IBS (Institute of Basic Science), Korea, has been organized. As part of this collaboration, an array of super-clover germanium detectors was installed. A new project for comprehensive mass measurements with MRTOF mass spectrograph at KISS and other devices has started in collaboration with the RIKEN SLOWRI team.

2. Major Research Subjects

- (1) Radioactive isotope beam production and manipulation for nuclear experiments.
- (2) Explosive nucleosynthesis (r- and rp-process).
- (3) Heavy ion reaction mechanism for producing heavy neutron-rich nuclei.
- (4) Development of MRTOF mass spectrograph for short-lived heavy nuclei.
- (5) Development of RNB probes for materials science applications.

3. Summary of Research Activity

KISS is an element-selective isotope separator, combining use of a magnetic mass separator with in-gas-cell resonant laser ionization. The gas cell, filled with argon gas of 75 kPa, a central component of KISS, from which only the element of interest are extracted as an ion beam for subsequent mass separation. In the cell, nuclei primarily produced by low-energy heavy-ion reactions are stopped (thermalization and neutralization), transported by buffer gas (gas-flow of ~ 75 kPa argon in the present case), and then re-ionized by laser irradiation just before the exit. The gas cell was fabricated to efficiently collect the reaction products produced by multi-nucleon transfer (MNT) reactions in the $^{136}\text{Xe} + ^{198}\text{Pt}$ system. For the first extraction of the reaction products, the ^{136}Xe beam energy and ^{198}Pt target thickness were set at 10.8 MeV/u and 6 mg/cm², respectively. In FY2014, the half-life of ^{199}Pt was measured with β -ray telescopes and a tape transport system located at the focal point of KISS. The β -ray telescopes were composed of three double-layered thin plastic scintillators; thickness of the first and second layers was 0.5 mm and 1 mm, respectively. In order to reduce the background, low-activity lead blocks and a veto counter system consisting of plastic scintillator bars surrounded the telescopes. The background rate of these β -ray telescopes was measured to be 0.7 counts per second. For further reduction of the background rate, as low as 0.1 counts per hour, a gas counter based beta-ray telescope system was installed in FY2016. An array of germanium detectors consisting of four super-clover germanium crystals was also brought into operation in FY2016.

For higher primary beam intensities and higher extraction efficiency, a doughnut-shaped gas cell with a rotating target wheel setup has been developed for KISS. Using this setup, resonance ionization spectroscopy of the ground state hyperfine structure of Pt and Ir were performed. The nuclear g -factor and charge radius of the ground state and an isomeric state of ^{199}Pt were deduced from the experimental results.

Cross-section measurements were performed at GANIL in 2012 to investigate the feasibility of using MNT in the reaction system of ^{136}Xe on ^{198}Pt to produce heavy neutron-rich isotopes around mass number of 200 with the neutron magic number of 126; the analysis of the data has been completed. The cross sections of target-like fragments around $N = 126$ were comparable to those estimated using the GRAZING code, and they appear to be mainly contributed by the reactions with low total energy loss with weak N/Z equilibration and particle evaporation. This suggests use of the MNT reactions with a heavy projectile at energies above the Coulomb barrier could be a promising means for production of neutron-rich isotopes around $N = 126$.

The multi-reflection time-of-flight mass spectrograph (MRTOF-MS) has been developed for direct mass measurements of short-lived heavy nuclei at KISS and other facilities. In FY2016, mass measurements of more than 80 nuclides, including short-lived ($T_{1/2} = 10$ ms) isotopes of Ra and several isotopes of the trans-uranium elements Es and Md were performed at GARIS-II in collaboration with the SLOWRI team and the Super Heavy Element Synthesis team of RIKEN. The highest precisions, achieved for Ga isotopes, reached a level of 0.03 ppm. For most of the well-known nuclides, agreement with the literature mass values was found. However, discrepancies were found in some literature values derived from pre-1980 indirect measurements. This suggests that such indirect measurements must be revised with comprehensive direct mass measurements. The masses of four isotopes of Es and Md were measured for the first time, allowing for confirmation of the $N = 152$ shell closure in Md. Using these new mass data as anchor-points, the masses of seven isotopes of super-heavy elements up to Mt were indirectly determined and comparisons with various nuclear mass models were performed.

The diffusion coefficient of lithium in solid materials used in secondary Li-ion batteries is one of the key parameters that determine how fast a battery can be charged. The reported Li diffusion coefficients in solid battery materials scatter over several order of magnitude. An in-situ nanoscale diffusion measurement method, using α -emitting radioactive ^8Li as a tracer, has been developed. In this method, while implanting a pulsed 8 keV beam of ^8Li , the α -particles emitted at small angles ($\theta = 10 \pm 1^\circ$) relative to the sample surface were detected as a function of time. The Li diffusion coefficient could then be determined from the time dependent yields of the α -particles, whose energy loss can be converted to nanometer-scale position information of diffused ^8Li . The method has been successfully applied to measure the lithium diffusion coefficients for an amorphous $\text{Li}_4\text{SiO}_4 - \text{Li}_3\text{VO}_4$ (LVSO) which was used as a solid electrolyte in a solid-state Li thin film battery, well-demonstrating that the present method has a sensitivity to the diffusion coefficients down to the level of 10^{-12} cm²/s, corresponding with nanoscale Li diffusion. In FY2016, this method was used to determine Li diffusion coefficients in a spinel type Li compound of LiMn_2O_4 (LMO), which is used as the anode of a Li battery in an electric vehicle. A significant change in the time dependent yields of the α particles was

observed at the sample temperature of around 623 K and the measurements will be continued in order to obtain the temperature dependence of Li diffusion coefficients in LMO.

Members

Group Leader

Hiroari MIYATAKE

Researchers

Michiharu WADA

Yutaka WATANABE

Yoshikazu HIRAYAMA

Peter SCHURY

Technical Staff

Yutaka KAKIGUCHI

Michihiro OYAIZU

Visiting Researchers

Jun-young Moon (IBS)

Jin-hyung Park (IBS)

Student Trainees

Momo MUKAI (PhD. Student, Tsukuba Univ.)

Sota KIMURA (PhD. Student, Tsukuba Univ.)

Murad AHMED MD (PhD. Student, Tsukuba Univ.)

Assistant

Machiko IZAWA

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

- H. Kawamura, T. Akiyama, M. Hata, Y. Hirayama, M. Ikeda, Y. Ikeda, T. Ishii, D. Kameda, S. Mitsuoka, H. Miyatake, D. Nagae, Y. Nakaya, K. Ninomiya, M. Niita, N. Ogawa, J. Onishi, E. Seitaibashi, S. Tanaka, R. Tanuma, Y. Totsuka, T. Toyoda, Y.X. Watanabe, J. Murata, « A new measurement of electron transverse polarization in polarized nuclear beta-decay », *Modern Physics Letter A* 32, 1750058 (2017).*
- E. Strano, D. Torresi, M. Mazzocco, N. Keeley, A. Boiano, C. Boiano, P. Di Meo, A. Guglielmetti, M. La Commara, P. Molini, C. Manea, C. Parascandolo, D. Pierroutsakou, C. Signorini, F. Soramel, D. Filipescu, A. Gheorghe, T. Glodariu, J. Grebosz, S. Jeong, Y.H. Kim, J.A. Lay, H. Miyatake, M. Nicoletto, A. Pakou, K. Rusek, O. Sgouros, V. Soukeras, L. Stroe, N. Toniolo, A. Vitturi, Y. Watanabe, K. Zerva, « Discrimination of processes and optical model analysis in the $^{17}\text{O}+^{58}\text{Ni}$ collision around the coulomb barrier », *Acta Physics Polon. B48* (2017) 615 *.
- S.K. Das, T. Fukuda, Y. Mizoi, H. Ishiyama, H. Miyatake, Y.X. Watanabe, Y. Hirayama, S.C. Jeong, H. Ikezoe, M. Matsuda, K. Nishio, T. Hashimoto, « New measurement of the $8\text{Li}(\alpha, n)^{11}\text{B}$ reaction in a lower-energy region below the Coulomb barrier », *Physical Review C* 95, 055805 (2017) *
- P. Schury, M. Wada, Y. Ito, D. Kaji, F. Arai, M. MacCormick, I. Murray, H. Haba, S. Jeong, S. Kimura, H. Koura, H. Miyatake, K. Morimoto, K. Morita, A. Ozawa, M. Rosenbusch, M. Reponen, P.-A. Söderström, A. Takamine, T. Tanaka, H. Wollnik, "First online multireflection time-of-flight mass measurements of isomer chains produced by fusion-evaporation reactions: Toward identification of superheavy elements via mass spectroscopy", *Physical Review C* 95, 011305(R) (2017) *
- E. Strano, D. Torresi, M. Mazzocco, N. Keeley, A. Boiano, C. Boiano, P. Di Meo, A. Guglielmetti, M. La Commara, P. Molini, C. Manea, C. Parascandolo, D. Pierroutsakou, C. Signorini, F. Soramel, D. Filipescu, A. Gheorghe, T. Glodariu, J. Grebosz, S. Jeong, Y. H. Kim, J. A. Lay, H. Miyatake, M. Nicoletto, A. Pakou, K. Rusek, O. Sgouros, V. Soukeras, L. Stroe, N. Toniolo, A. Vitturi, Y. Watanabe, K. Zerva, « $^{17}\text{O}+^{58}\text{Ni}$ scattering and reaction dynamics around the Coulomb barrier », *Physical Review C* 94, 024622 (2016) *
- T. Sonoda, T. Tsubota, M. Wada, I. Katayama, T.M. Kojima, M. Reponen, « A gas circulation and purification system for gas-cell-based low-energy RI-beam production », *Review of Scientific Instruments*, 87 (2016) 065104. *
- A Hamaker, M. Brodeur, J.M. Kelly, J. Long, C. Nicoloff, S. Syan, B.E. Schult, P. Schury, M. Wada, «Experimental investigation of the repelling force from RF carpets », *International Journal Mass Spectrometry*, 404 (2016) 14-19. *

[Proceedings]

(Original Papers) *Subject to Peer Review

- Torresi, E. Strano, M. Mazzocco, A. Boiano, C. Boiano, P. Di Meo, M. La Commara, C. Manea, M. Nicoletto, J. Grebosz, A. Guglielmetti, P. Molini, C. Parascandolo, D. Pierroutsakou, C. Signorini, F. Soramel, N. Toniolo, D. Filipescu, A. Gheorghe, T. Glodariu, S. Jeong, Y.H. Kim, J.A. Lay, H. Miyatake, A. Pakou, O. Sgouros, V. Soukeras, L. Stroe, A. Vitturi, Y. Watanabe, K. Zerva, «Elastic scattering of $^{17}\text{O}+^{208}\text{Pb}$ at energies near the Coulomb barrier », *EPJ Web of Conferences* 117, 08027 (2016) *
- P. Schury, M. Wada, Y. Ito, F. Arai, D. Kaji, S. Kimura, K. Morimoto, H. Haba, S. Jeong, H. Miyatake, H. Koura, K. Morita, M. Reponen, A. Ozawa, T. Sonoda, A. Takamine, H. Wollnik, «Status of the low-energy super-heavy element facility at RIKEN », *Nucl. Inst. Meth. B376* (2016) 52-56 *
- Y. Hirayama, Y.X. Watanabe, N. Imai, H. Ishiyama, S.C. Jeong, H.S. Jung, H. Miyatake, M. Oyaizu, S. Kimura, M. Mukai, Y.H. Kim, T. Sonoda, M. Wada, M. Huyse, Yu. Kudryavtsev, P. van Duppen, « On-line experimental results of an argon gas cell-based laser ion source (KEK Isotope Separation System) », *Nucl. Inst. Meth. B376* (2016) 52-56.*

- M. Mukai, Y. Hirayama, H. Ishiyama, H.S. Jung, H. Miyatake, M. Oyaizu, Y.X. Watanabe, S. Kimura, A. Ozawa, S.C. Jeong, T. Sonoda, « Search for efficient laser resonance ionization schemes of tantalum using a newly developed time-of-flight mass spectrometer in KISS », Nucl. Inst. Meth B376 (2016) 73-76.*
- S. Kimura, H. Ishiyama, H. Miyatake, Y. Hirayama, Y.X. Watanabe, H.S. Jung, M. Oyaizu, M. Mukai, S.C. Jeong, A. Ozawa, « Development of the detector system for image-decay spectroscopy at the KEK Isotope Separator System », Nucl. Inst. Meth. B376 (2016) 338-340.*
- H. Ishiyama, S.C. Jeong, Y.X. Watanabe, Y. Hirayama, N. Imai, H.S. Jung, H. Miyatake, M. Oyaizu, A. Osa, Y. Otokawa, M. Matsuda, K. Nishio, H. Makii, T.K. Sato, N. Kuwata, J. Kawamura, H. Ueno, Y.H. Kim, S. Kimura, M. Mukai, « Direct measurement of nanoscale lithium diffusion in solid battery materials using radioactive tracer of ^8Li », Nucl. Instrum. Meth. B 376 (2016) 379-381. *
- Y. Hirayama, Y. X. Watanabe, H. Miyatake, P. Schury, M. Wada, M. Oyaizu, Y. Kakiguchi, M. Mukai, S. Kimura, M. Ahmed, S. C. Jeong, J. Y. Moon, J. H. Park, "Nuclear spectroscopy of r-process nuclei around $N = 126$ using KISS", NUOVO CIMENTO, 39 C (2016) 359 *
- M. Mazzocco, A. Boiano, C. Boiano, M. La Commara, C. Manea, C. Parascandolo, D. Pierroutsakou, C. Signorini, E. Strano, D. Torresi, H. Yamaguchi, D. Kahl, L. Acosta, P. Di Meo, J.P. Fernandez-Garcia, T. Glodariu, J. Grebosz, A. Guglielmetti, N. Imai, Y. Hirayama, H. Ishiyama, N. Iwasa, S.C. Jeong, H.M. Jia, N. Keeley, Y.H. Kim, S. Kimura, S. Kubono, J.A. Lay, C.J Lin, G. Marquinez-Duran, I. Martel, H. Miyatake, M. Mukai, T. Nakao, M. Nicoletto, A. Pakou, K. Rusek, Y. Sakaguchi, A.M. Sánchez-Benítez, T. Sava, O. Sgouros, C. Stefanini, F. Soramel, V. Soukeras, E. Stiliaris, L. Stroe, T. Teranishi, N. Toniolo, Y. Wakabayashi, Y.X. Watanabe, L. Yang, Y.Y. Yang, "7Be- and 8B-reaction dynamics at Coulomb barrier energies", EPJ Web of Conferences, 117, 06006 (2016) *
- Y. Hirayama, H. Miyatake, Y.X. Watanabe, N. Imai, H. Ishiyama, S.C. Jeong, H.S. Jung, M. Oyaizu, M. Mukai, S. Kimura, T. Sonoda, M. Wada, Y.H. Kim, M. Huyse, Yu Kudryavtsev, P. van Duppen, "Beta-decay spectroscopy of r-process nuclei around $N=126$ ", EPJ Web Conf. 109 08001, 1-6 (2016)

Oral Presentations

[International Conference etc.]

- P. Schury, « Technical Issues in Achieving Long-Term Stability of MRTOF », RISP Workshop on MRTOF, Nov. 18, 2016, Daejeon, Korea.
- P. Schury, « Mass measurements with MRTOF », RNC-RIPS Meeting, Nov. 17-19, 2016, Daejeon, Korea.
- Y.X. Watanabe, « Production of $N=126$ nuclei and beyond using deep inelastic transfer products at KISS », the 6th international conference on Fission and Properties of Neutron-rich Nuclei, Nov. 6-12, 2016, Florida, USA.
- Y. Hirayama, « Recent spectroscopic activities using multi-nucleon transfer reaction products at KISS », LA3NET Laser Ion Source Workshop, Oct. 24-25, 2016, Paris, France.
- P. Schury, « Nuclear Physics with Slow and Stopped Beam at RIBF », KPS meeting, Oct. 19-21, 2016, Gwangju, Korea.
- P. Schury, « Gas Catcher Systems Status: SLOWRI/PALIS, SlowSHE, and KISS », Fragment Separator Expert Meeting, Aug. 30 – Sept. 2, 2016, Grand Rapids, Michigan, USA.
- P. Schury, "Mass Measurements of r-process Nuclei at KISS and SLOWRI", The 14th International Symposium on Nuclei in the Cosmos (NIC), June 19-24, 2016, Niigata, Japan.
- Y.X. Watanabe, "Production of radioactive nuclei relevant to r-process by multinucleon transfer reaction for KISS", The 14th International Symposium on Nuclei in the Cosmos (NIC), June 19-24, 2016, Niigata, Japan.
- H. Soon, "Beta-decay half-lives of neutron rich nuclei and its impact on production of r-process elements", The 14th International Symposium on Nuclei in the Cosmos (NIC), June 19-24, 2016, Niigata, Japan.
- Y. Hirayama, "Spectroscopy of multi-nucleon transfer reaction products using KISS", Stopping and Manipulation of Ions and related topics (SMI-2016), June 8-10, 2016, IMP, Lanzhou, China.

[Domestic Conference]

- M. Wada, « Possibility of comprehensive mass measurements of heavy elements », Symposium on Perspective of super heavy element science, Mar. 17-20, Osaka, Japan.
- Y.X. Watanabe, « Production of radioactive nuclei relevant to r-process by multinucleon transfer reactions for KISS », SSRI Workshop, Mar. 5-6, JAEA, Tokai, Japan.
- Y. Hirayama, « Present status of KISS », SSRI Workshop, Mar. 5-6, JAEA, Tokai, Japan.
- M. Mukai, « Development of low-background gas-counter for the beta spectroscopy at KISS », SSRI Workshop, Mar. 5-6, 2016, JAEA, Tokai, Japan.
- P. Schury, « Observation of doubly-charged ions of Pb through Pu extracted from cryogenic gas cell and mass analyzed by MRTOF-MS », SSRI Workshop, Mar. 5-6, 2016, JAEA, Tokai, Japan.
- S. Kimura, « Precision mass measurements of proton-rich nuclei in $A=60-80$ region with the multireflection time-of-flight mass spectrometer », SSRI Workshop, Mar. 5-6, 2016, JAEA, Tokai, Japan.
- H. Miyatake, « KISS, SLOWRI 施設での低エネルギー核分光研究 », KUR 専門研究会, Dec. 20-21, 2016, 京大原子炉、京都
- H. Miyatake, "Recent Progress of the KISS project at KEK-WNSC", 40th ASRC Int. Workshop on Experimental and Theoretical Advances in Fission and Heavy Nuclei, Dec. 12-13, 2016, JAEA 東海, Japan.,
- M. Wada, "High precision nuclear spectroscopy with trapped radioactive ions", The 2nd Cicily East Asia Workshop on Low-energy Nuclear Physics", June 26-28, RIKEN, Japan.
- Y. Hirayama, "Nuclear spectroscopy of r-process nuclei around $N=126$ using KISS", The 2nd Cicily East Asia Workshop on Low-energy Nuclear Physics", June 26-28, RIKEN, Japan.

Events (April 2016 — March 2017)

RNC

Apr. 6–8	RBRC Scientific Review Committee (SRC)
Apr. 23	Wako Open campus
May 30–31	The 5th International Advisory Committee for the RIKEN-RAL Muon Facility (RAL-IAC)
July 21–23	The 4th Nishina Center Advisory Council (NCAC)
June 3	The 22nd RBRC Management Steering Committee (MSC)
Aug. 1–12	Nishina School
Dec. 1–3	The 17th Program Advisory Committee for Nuclear Physics Experiments at RI Beam Factory (NP-PAC)
Dec. 5	Final Report of the former Associate Chief Scientist, Takashi Nakatsukasa
Dec. 14–16	The 10th RIKEN Advisory Council (RAC)
Jan. 13	The 6th Industrial Program Advisory Committee (In-PAC)
Jan. 19–20	The 13th Program Advisory Committee for Materials and Life Science Researches at RIKEN Nishina Center (ML-PAC)
Jan. 30	Research Review of the Chief Scientist, Tetsuo Hatsuda

CNS

Jul. 25	坂井光夫先生追悼講演会 http://indico.cns.s.u-tokyo.ac.jp/conferenceDisplay.py?confId=302
Aug. 24–30	The 15th CNS International Summer School(CNSSS16) http://indico.cns.s.u-tokyo.ac.jp/conferenceDisplay.py?confId=288

Niigata Univ.

	not held in FY2016
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KEK

Aug. 18–26	KEK Summer Challenge 2016 http://www2.kek.jp/ksc/10th_2016/index.html
Sept. 2–3	SSRI-pns Collaboration Meeting 2016 http://research.kek.jp/group/wnc/ssri-pns-jp/
Sept. 4	KEK Open Campus 2016 https://www2.kek.jp/openhouse/

Press Releases (April 2016 - March 2017)

RNC		
Sep. 27	Stable transmission of slow highly charged ions through tapered glass capillary with active discharging method for sub-micron sized beams	Tomoko Abe and Tokihiro Ikeda; Ion Beam Breeding Team, Takao Kojima; SLOWRI team
Sep. 30	First Vertical Test of Superconducting QWR Prototype at RIKEN	Naruhiko Sakamoto, Kazunari Yamada, Yutaka Watanabe, Kenji Suda, Kazutaka Ozeki; High Gradient Cavity R&D Team, Osamu Kamigaito; High-Intensity Accelerator R&D Group
Dec. 14	Fate of the Tetraquark Candidate $Z_c(3900)$ from Lattice QCD	Yoichi Ikeda, Takumi Doi, Tetsuo Hatsuda; Quantum Hadron Physics Laboratory
Feb. 13	Spallation reaction study for the long-lived fission product ^{107}Pd	He Wang; Radioactive Isotope Physics Laboratory, Hiroyoshi Sakurai; Nuclear Transmutation Data Research Group, Hideaki Otsu; Fast RI Data Team
Feb.17	94 β -Decay Half-Lives of Neutron-Rich ^{55}Cs to ^{67}Ho : Experimental Feedback and Evaluation of the r-Process Rare-Earth Peak Formation	Jin Wu, Shunji Nishimura, Hiroyoshi Sakurai; Radioactive Isotope Physics Laboratory
Feb. 21	Are There Signatures of Harmonic Oscillator Shells Far from Stability? First Spectroscopy of ^{110}Zr	Pieter Doornenbal, Hiroyoshi Sakurai; Radioactive Isotope Physics Laboratory, Alexandre Obertelli, Tomohiro Uesaka; Spin Isospin Laboratory
Mar. 1	Study of the Reaction $^{48}\text{Ca} + ^{248}\text{Cm} \rightarrow ^{296}\text{Lv}$ at RIKEN-GARIS	Daiya Kaji, Kouji Morimoto; Superheavy Element Device Development Team, Kosuke Morita; Research Group for Superheavy Element, Hiromitsu Haba; RI Applications Team
Mar. 6	Overview of the chemical composition and characteristics of Na^+ and Cl^- distributions in shallow samples from Antarctic ice core DF01 (Dome Fuji) drilled in 2001	Kazuya Takahashi, Yuko Motizuki, Yoichi Nakai; Astro-Glaciology Research Unit
CNS		
Oct. 18	Quantum phase transition in the shape of nuclei and simulations using K computer	T. Otsuka, T. Togashi, Y. Tsunoda, N. Shimizu