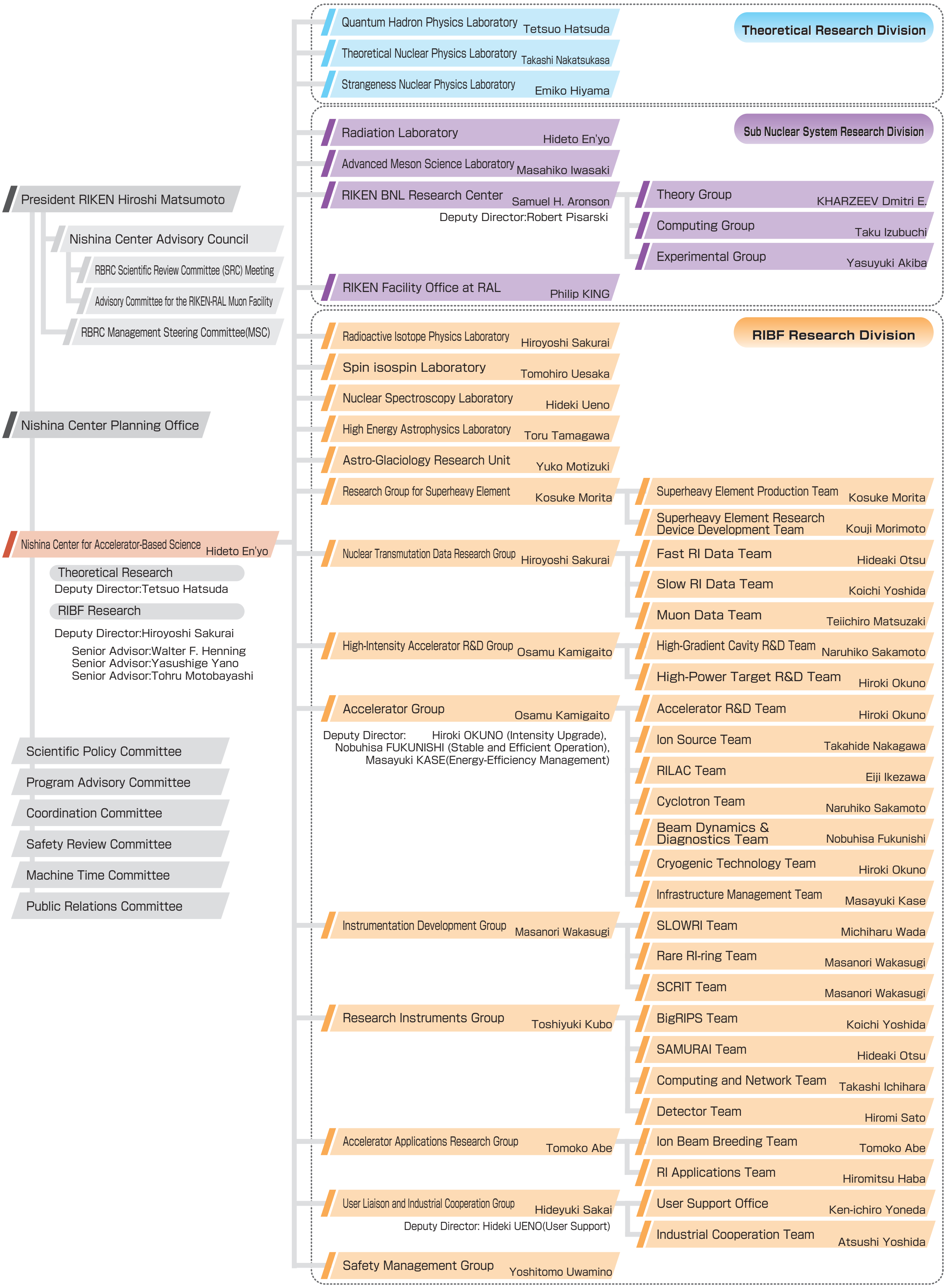
1. Organization

1.1 Organization Chart as of March 31, 2016



1.2 Topics in FY2015

In fiscal year 2015, 4.8 months operation was achieved along with the acquisition of fundamental nuclear transmutation data for the ImPACT (Impulsing Paradigm Change through Disruptive Technologies Program) project.

Accelerator system of RIBF has greatly improved with the upgrade of the beam intensity of the heavy ion in the RI beam generating system by threefold. This upgrading was accomplished two year ahead of schedule. RIBF has been highly available to the users even by the standard of research environment worldwide.

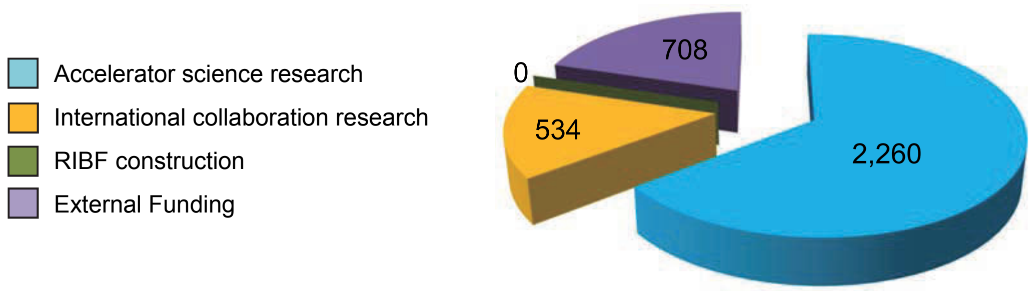
IUPAC recognized element 113 discovered as a new element by the research group led by Group Director Kosuke Morita (now Research Group for Superheavy Element), and gave the group the honor of naming and determining the two-letter symbol for the element. Element 113 will then become the first element to be named through the discovery made by an Asian research institution.

As a result of biological irradiation of the heavy ion in cooperation with public companies, the Ion Beam Breeding Team succeeded in the selective breeding of tear-free onion. Named ‘smile ball’, the new breed of onion is being marketed. Paid use of RI beams in the radiation resistance test of the semiconductor for use in space has been promoted for industrial application.

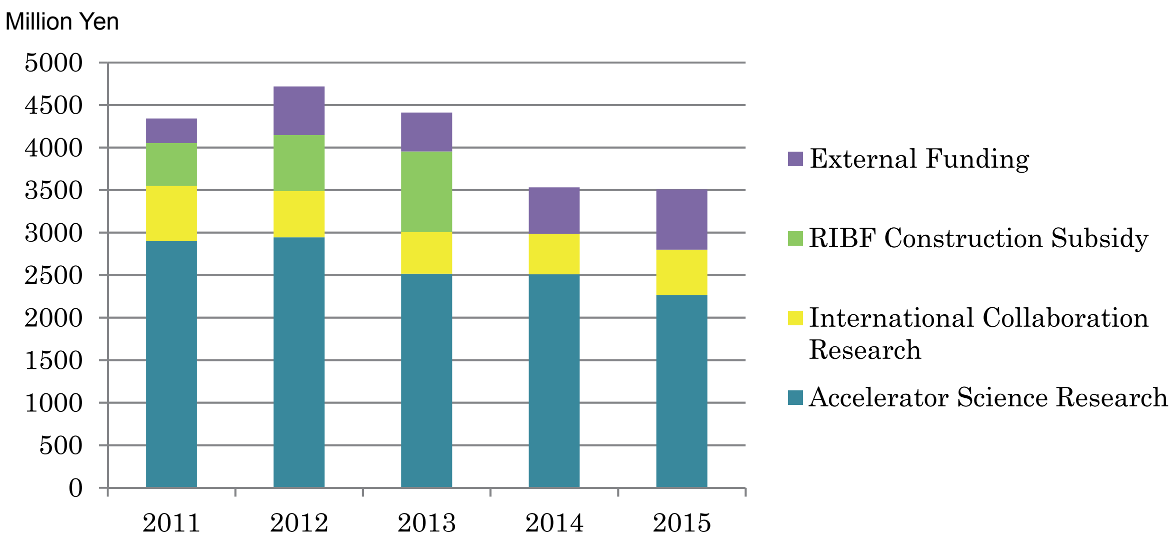
Year	Date	Topics in Management
2015	Sep. 1	Team Leader Michiharu WADA moves to the part-time position (Prof., Institute of Particle and Nuclear Studies, KEK)
	Nov. 1	New Appointment Group Leader of Theory Group: Dmitri E. KHARZEEV
2016	Jan. 12	Interim Review of the Chief Scientist, Osamu KAMIGAITO
	Mar. 8	Interim Review of Associate Chief Scientist, Toru TAMAGAWA
	Mar. 31	End of Theoretical Nuclear Physics Laboratory

2. Finances

As mentioned in “1.2 Administrative Topic in FY2015”, RNC executed approximately 4.8 months of RIBF operation. Breakdown expenses of the RNC FY2015 budget and a transition for the past five years are shown in following graphs.

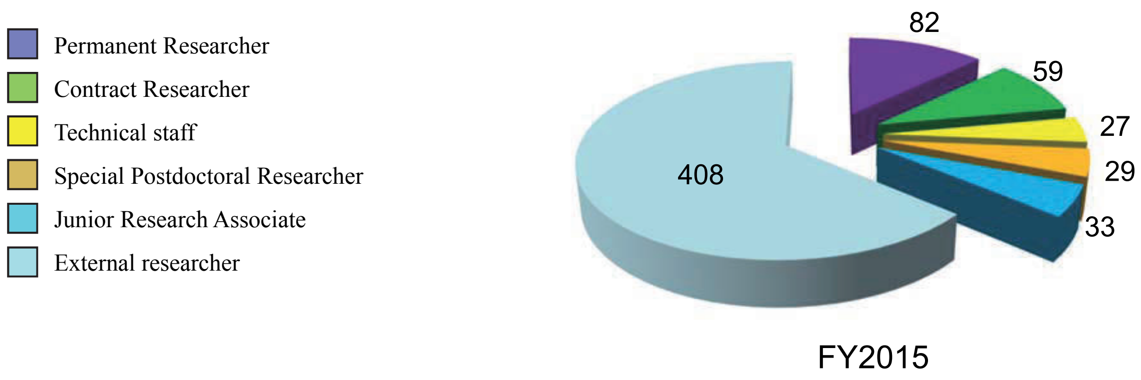


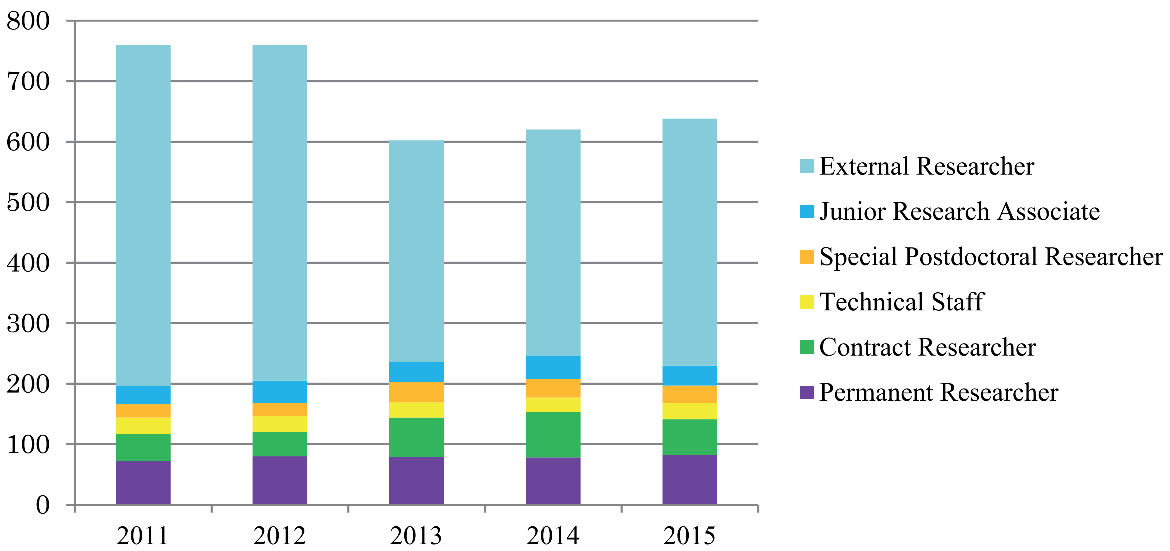
FY2014
Million Yen



3. Staffing

At the start of FY 2015, April 1 2015, there were 230 personnel affiliated with RNC and 408 researchers visiting RNC for research purpose. The following graphs show a breakdown of personnel into seven categories as of April 2015, and a transition of the number of each category.

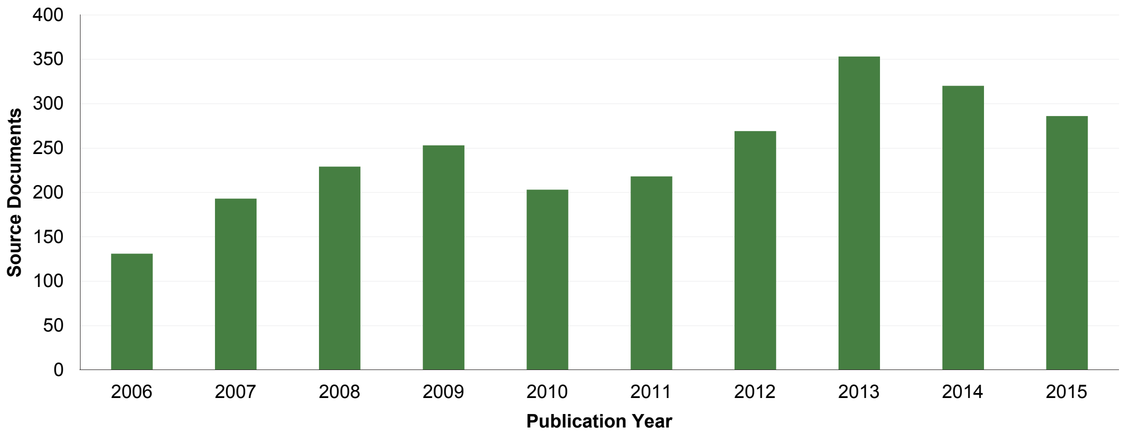




4. Research publication

Publication in the past 10 years

The number of papers published annually from RNC is shown graphically using the data of Thomson Reuiters' Web of Science Documents. The type of documents is “Article” and “Review”. Articles from 2013and before, however, include the proceedings of meetings.



Citation Analysis for past 3 years (2015 data is insufficient due to incomplete citation)

As of June 20, 2016

Indicators \ Year	2013	2014	2015
Total number of papers	353	320	286
Total number of citations	3039	1891	647
Number of papers in top 10%	47	47	37
Percentage of papers in top 10%	13.31	14.69	12.94
Number of papers in top 1%	8	3	2
Percentage of papers in top 1%	2.27	0.94	0.70

5. Management

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

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

as of the latter half of FY2015. 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
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, 2016)

Hideto EN'YO	Director RNC; Chief Scientist, Director of Radiation Laboratory
Tetsuo HATSUDA	Deputy Director (Theoretical Research), RNC; Chief Scientist, Director of Quantum Hadron Physics 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, 2016)

Hideto EN'YO	Director, RNC; Chief Scientist, Director of Radiation Laboratory
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Director of Radioactive Isotope Physics Laboratory; Group Director, Nuclear Transmutation Data Research Group
Tetsuo HATSUDA	Deputy Director, RNC; Chief Scientist, Director of Quantum Hadron Physics Laboratory
Walter F. HENNING	Senior Advisor
Yasushige YANO	Senior Advisor
Tohru MOTOBAYASHI	Senior Advisor
Masahiko IWASAKI	Chief Scientist, Director of Advanced Meson Science Laboratory
Tomohiro UESAKA	Chief Scientist, Director of Spin isospin Laboratory
Hideki UENO	Chief Scientist, Director of Nuclear Spectroscopy Laboratory; Deputy Group Director, User Liaison and Industrial Cooperation Group
Toru TAMAGAWA	Associate Chief Scientist, Director of High Energy Astrophysics Laboratory
Takashi NAKATSUKASA	Associate Chief Scientist, Director of Theoretical Nuclear Physics Laboratory
Emiko HIYAMA	Associate Chief Scientist, Director of 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, Radiation Biology 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
Naruhiko SAKAMOTO	Team Leader, Cyclotron Team; Team Leader, High-Gradient Cavity R&D Team
Hiromi SATO	Team Leader, Detector Team
Takahide NAKAGAWA	Team Leader, Ion Source Team
Hiromitsu HABA	Team Leader, RI Applications Team
Koji MORIMOTO	Team Leader, Superheavy Element Device Development Team
Atsushi YOSHIDA	Team Leader, Industrial Cooperation Team
Koichi YOSHIDA	Team Leader, BigRIPS Team; Team Leader, Slow RI Data Team
Ken-ichiro YONEDA	Team Leader, User Support Office
Michiharu WADA	Team Leader, SLOWRI Team
Hideaki OTSU	Team Leader, SAMURAI Team; Team Leader, Fast RI Data Team

Teiichiro MATSUZAKI	Team Leader, Muon Data Team
Yasuyuki AKIBA	Vice Chief Scientist; 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
Noriko SHIOMITSU	Director, Nishina Center Planning Office
Mitsuru KISHIMOTO	Deputy 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 ofbudget
Public relations activities

Members (as of March 31, 2016)

Noriko SHIOMITSU	Director, Head of Nishina Center Planning Office
Mitsuru KISHIMOTO	Deputy Director, Nishina Center Planning Office; Administration Manager, RBRC; Administration Manager, RIKEN Facility Office at RAL
Kazunori MABUCHI	Deputy Manager, Nishina Center Planning Office
Yasutaka AKAI	Administrative Officer of 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
Yukiko SATO	Task-Specific Employee
Kyoji YAMADA	Special Temporary Employee
Yoshio OKUIZUMI	Temporary Employee
Masatoshi MORIYAMA	Consultant for Advisory Committee, Research Review, etc.
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 FY2015.

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 16th NP-PAC was held on December 3-5, 2015 at RIBF.

Members (as of March 31, 2016)

Bradley. M.SHERRILL (Chair)	Prof., Director, National Superconducting Cyclotron Laboratory, Michigan State University
Andrei ANDREYEV	Prof., The University of York.
Angela BRACCO	Prof., Dipartiment di Fisica, The Istituto Nazionale di Fisica Nucleare
Piet Van Duppen	Prof., Instituut voor Kern- en Stralingsfysica, Departement Natuurkunde en Sterrenkunde, University of Leuven (K.U.Leuven)
Hironori Iwasaki	Associate Prof., National Superconducting Cyclotron Laboratory, Michigan State University
Walter D. LOVELAND	Prof., Department of Chemistry, Oregon State University, USA
Thomas NILSSON	Prof., Department of Fundamental Physics, Chalmers Univ. of Technology
Thomas Rauscher	Department of Physics, University of Basel
Haik Simon	GSI
Olivier Sorlin	GANIL(Grand Accélérateur National d'Ions Lourds)
Yuhu Zhang	Institute of Modern Physics, Chinese Academy of Sciences

Yutaka UTSUNO	Senior Scientist, Advanced Science Research Center, JAEA
Kazuyuki Ogata	Associate Prof., Theoretical Nuclear Physics, Research Center for Nuclear Physics, Osaka University
Atsushi TAMII	Associate Prof., Experimental Nuclear Physics Division, Research Center for Nuclear Physics, Osaka University, Japan
Satoshi N. Nakamura	Prof., Nuclear Experiment Group, Faculty of Science, Tohoku University
Ikuko Hamamoto	Prof. Emeritus, The Lund Univ., Senior Visiting Scientist, RNC

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

Members (as of March 31, 2016)

Adrian HILLIER (Chair)	ISIS, RAL
Philippe MENDELS	Prof., Laboratorie de Physique des Solides, Universite Paris-SUD
Shukri SULAIMAN	Prof. Universiti Sains Malaysia
Toshiyuki AZUMA	Chief Scientist, Atomic Molecular & Optical Physics Laboratory, RIKEN
Ryosuke KADONO	Prof., Division Head, Muon Science Laboratory, Institute of Materials Structure Science, KEK
Atsushi KAWAMOTO	Prof., Graduate School of Science, Hokkaido University
Kenya KUBO	Prof., Department of Material Science, International Christian University,
Norimichi KOJIMA	Full Time Research Fellow, Toyota Physical and Chemical Research Institute
Atsushi SHINOHARA	Prof., Graduate School of Science, Osaka University
Xu-Guang ZHENG	Prof., Department of Physics Faculty of Science and Engineering, Saga University
Hiroyuki YAMASE	Senior Researcher, National Institute for Materials Science
Shigeo YOSHIDA	Research Consultant, RIKEN Center for Sustainable Resource Science, RIKEN

Industrial Program Advisory Committee (In-PAC)

The 5th In-PAC was held on January 13, 2016 at RNC.

Members (as of March 31, 2016)

Akihiro IWASE (Chair)	Prof., Graduate School of Engineering, Osaka Prefecture University
Toshiyuki AZUMA	Chief Scientist, Atomic, Molecular & Optical Physics Laboratory, RIKEN
Kenya KUBO	Prof., The College of Liberal Arts, 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, Quantum Equipment Division, 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 RNC Director from the spokesperson of the approved experiment.

Safety Review Committee for Accelerator Experiments

Members (as of March 31, 2016)

Takashi KISHIDA (Chair)	Senior Research Scientist, Radioactive Isotope Physics Laboratory
Kouji MORIMOTO	Team Leader, Superheavy Element Device Development Team
Eiji IKEZAWA	Team Leader, RILAC Team
Hiromitsu 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
Hiromi SATO	Team Leader, Detector Team
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

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, 2016)

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
Hiromitsu 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, 2016)

Hideyuki SAKAI (Chair)	Group Director, User Liaison and Industrial Cooperation Group
Tomoko ABE	Group Director, Accelerator Applications Research Group
Nobuhisa FUKUNISHI	Deputy Group Director, Accelerator Group
Osamu KAMIGAITO	Group Director, Accelerator Group
Masayuki KASE	Deputy Group Director, Accelerator Group
Toshiyuki KUBO	Group Director, Research Instruments Group
Kouji MORIMOTO	Team Leader, Superheavy Element Research Device Development Team
Hiroki OKUNO	Deputy Group Director, Accelerator Group
Hiroyoshi SAKURAI	Chief Scientist, Radioactive Isotope Physics Laboratory
Hideki UENO	Chief Scientist, Nuclear Spectroscopy Laboratory
Tomohiro UESAKA	Chief Scientist, Spin isospin Laboratory
Yoshitomo UWAMINO	Group Director, Safety Management Group
Masanori WAKASUGI	Group Director, Instrumentation Development Group
Ken-ichiro YONEDA	Team Leader, User Support Office
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
Nobuaki IMAI	Chair, RIBF-UEC, Associate Prof. Center for Nuclear Study, University of Tokyo
Hiromitsu HABA	Team Leader, RI Applications Team
Kosuke MORITA	Group Director, Research Group for Superheavy Element
Tohru MOTOBAYASHI	RIBF Synergetic-Use Coordinator
Koichi YOSHIDA	Team Leader, BigRIPS Team; Team Leader, Slow RI Data Team
Kanenobu TANAKA	Deputy Group Director, Safety Management Group
Mitsuru KISHIMOTO	Deputy Director, Nishina Center Planning Office
Hideaki OTSU	Team Leader, Fast RI Data Team

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 theRNC
(2) Prioritization of the public relations activities for the RNC
(3) Other general and important matters concerning the public relations of RNC

Members (as of March 31, 2016)

Hiroshi TSUBOI	Executive Director; Director, Head of Nishina Center Planning Office
Hiroyoshi SAKURAI	Deputy Director, RNC; Chief Scientist, Radioactive Isotope Physics Laboratory
Tetsuo HATSUDA	Deputy Director, RNC; Chief Scientist, Quantum Hadron Physics Laboratory
Tohru MOTOBAYASHI	RIBF synergetic-use coordinator
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
Toru TAMAGAWA	Associate Chief Scientist, High Energy Astrophysics Laboratory
Takashi NAKATSUKASA	Associate Chief Scientist, Theoretical Nuclear Physics Laboratory
Emiko HIYAMA	Associate Chief Scientist, Strangeness Nuclear Physics Laboratory
Koji HASHIMOTO	Associate Chief Scientist, Mathematical Physics Laboratory
Kosuke MORITA	Group Director, Research Group for Superheavy Element
Osamu KAMIGAITO	Group Director, Accelerator 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 21st MSC was held on July 17, 2015 at RIBF.

Members (as of March 31, 2016)

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 2016 is the forth AC meeting since the establishment of the Nishina Center which promotes all of 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. Thr 3rd NCAC was held in July, 2014.

The mission of NCAC 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 of RIKEN, and to the Director of Nishina Center if necessary.

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

Members (as of March 31, 2016)

Sydney GALES (Chair)	Professor Dr., Director of Research IPN Orsay CNRS, Scientific Director, ELI-N
Robert V.F. JANSSENS	Division Director, Physics Division, Argonne National Laboratory (ANL)
Jochen WAMBACH	Professor, ECT* Director
Witold NAZAREWICZ	Professor, Michigan State University
Kinichi IMAI	Professor Emeritus, Kyoto University
Richard G. MILNER	Professor, Department of Physics, MIT
Angella BRACCO	Professor, Università degli Studi di Milano e INFN
Reiner KRÜCKEN	Dr. Deputy Director of TRIUMF
Hirokazu TAMURA	Professor, Department of Physics, Graduate School of Science, Tohoku University
Tokushi SHIBATA	Dr. Adviser, Chiyoda technol corporation Oarai Research Laboratory
Elvezio MORENYONI	Prof.Dr. Paul Scherrer Institut
Yoshitaka ITOW	Professor, Institute for Space-Earth Environmental Research, Nagoya University
Lia MERMINGA	Professor, Associate Lab Director, SLAC National Accelerator Laboratory
Akira YAMAMOTO	Head, Special Professor, HIGH ENERGY ACCELERATOR RESEARCH ORGANIZATION, KEK
Hidenori TAKAGI	Prof. Dr. Max-Planck Institute for Solid State Research

RBRC Scientific Review Committee (SRC)

Members (as of March 31, 2016)

Richard MILNER (Chair)	Prof., Director, Laboratory for Nuclear Science, MIT
Shinya AOKI	Prof., Yukawa Institute for Theoretical Physics, Kyoto University
Alfred MUELLER	Prof., Department of Physics, Columbia University
Albert De ROECK	Prof., LPC Fellow, LHC Physics Center, Fermilab
Xiandong JI	Prof., Department of Physics, University of Maryland
Julia VELKOVSKA	Prof., Department of Physics and Astronomy, Vanderbilt University

Advisory Committee for the RIKEN-RAL Muon Facility

Members (as of March 31, 2016)

Andrew D TAYLOR (Chair)	Executive Director, STFC National Laboratories, UK
Jean-Michel POUTISSOU	Senior research scientist Emeritus, TRIUMF, Canada
Klaus P. JUNGMANN	Prof., University of Groningen, Netherlands
Roberto De RENZI	Prof., Department of Physics and Earth Sciences, University of Parma, Italy
Yasuyuki MATSUDA	Assoc. Prof., Graduate School of Arts and Sciences, the University of Tokyo, Japan
Jun SUGIYAMA	Principal Research Scientist, Toyota Central R&D Labs., INC, Japan

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
Belgium	Katholieke Universiteit te Leuven	Framework	Michiharu WADA, Team Leader, SLOWRI Team
Canada	TRIUMF	Accelerator-based Science	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics 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
		Strategic cooperation (Nishina School)	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Shanghai Jiao Tong University	International Joint Graduate School Program	Takashi NAKATSUKASA, Associate chief scientist, Theoretical Nuclear Physics Laboratory
	ZHEJIANG University	International Joint Graduate School Program	Isao WATANABE, Advanced Meson Science Laboratoy
	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
EU	European Gamma-Ray Spectroscopy Pool Owners Committee	The use of Euroball ditector at RIKEN	Shunji NISHIMURA, Radioactive Isotope Physics Laboratory
	European Center for Theoretical Studies in Nuclear Physics and Related Areas (ECT*)	Theoretical physics	Tetsuo HATSUDA, Deputy Director, Chief Scientist, Quantum Hadron Physics Laboratory
	CERN	RD-51:R&D programme for micro-pattern gas detectors (MPGD)	Satoshi YOKKAICHI, Senior Research Scientist, Radiation Laboratory
		Collaboration in the ALICE Experiment as an Associate Member	Satoshi YOKKAICHI, Senior Research Scientist, Radiation Laboratory
		Collaboration in the ALICE Experiment	Satoshi YOKKAICHI, Senior Research Scientist, Radiation Laboratory
Finland	University of Jyvaskyla	Basic nuclear physics and related instrumentation	Michiharu WADA, Team Leader, SLOWRI Team
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
Germany	Technische Universität München	Nuclear physics, hadron physics, nuclear astrophysics	Emiko HIYAMA, Associate chief scientist, Strangeness Nuclear Physics Laboratory
	Max-Planck Gesellschaft	Comprehensive agreement	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	GSI	Physics of heavey 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
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 Laboratoy
	Universitas Hasanuddin	Agricultural science and related fields involving heavy-ion beam mutagenesis using Indonesian crops	Tomoko ABE, Group Director, Accelerator Applications Research Group

Country	Partner Institute	Objects	RNC contact person
Italy	National Institute of Nuclear Physics (INFN)	Physics of heavy ions	Tohru MOTOBAYASHI, RIBF synergetic-use coordinator
	Applied Physics Division, National Institute for New Technologies, Energy and Environment (ENEA)	Framework	Tohru MOTOBAYASHI, RIBF synergetic-use coordinator
Korea	Seoul National University	Nishina School	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
		International Joint Graduate School Program	Itaru NAKAGAWA, Radiation 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 Natural Sciences of Kyungpook National University	International Joint Graduate School Program	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	College of Science, Yonsei University	Framework	Tomohiro UESAKA, Chief Scientist, Spin Isospin Laboratory
	Department of Physics, Yonsei University	International Joint Graduate School Program	Yasuyuki AKIBA, Radiation 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 Laboratoy
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
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 Liverpool	International Joint Graduate School Program	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
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 for Nuclear Sciences and Technique	Nuclear Physics	Hiroyoshi Sakurai, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Hanoi University of Science	International Joint Graduate School Program	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory
	Institute of Physics, Vietnam Academy of Science and Technology	Framework	Hiroyoshi SAKURAI, Deputy Director, Chief Scientist, Radioactive Isotope Physics Laboratory

7. Awards

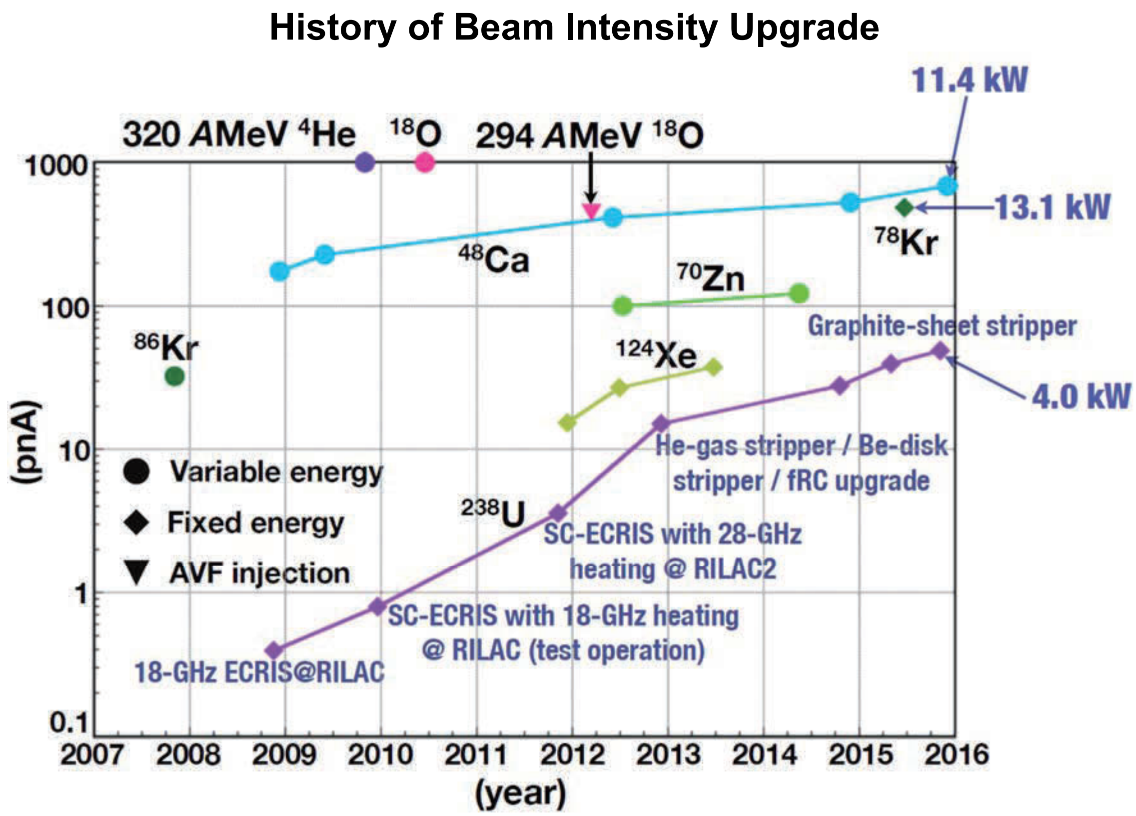
Awardee, Laboratory / Team	Award	Organization	Date
Larry McLerran, Theory Group, RBRC	Herman Feshbach Prize in Theoretical Nuclear Physics	American Physical Society	April
Takuya Maeyama, Special Postdoctoral Researcher, Beam Dynamics & Diagnostics Team	JSRC (Japanese Society of Radiation Chemistry) Young Scientist Award	Japanese Society of Radiation Chemistry	May 27
Takuya Maeyama, Special Postdoctoral Researcher, Beam Dynamics & Diagnostics Team	JSRC Young Investigators Travel Award (From ICRR 2015)	Japanese Society of Radiation Chemistry	May 29
Takuya Maeyama (Special Postdoctoral Researcher), Nobuhisa Fukunisi (Team Leader), Kenichi Ishikawa (visiting Scientsit) Beam Dynamics & Diagnostics Team	JRR(Journal of Radiation Research) Award at ICRR 20 15	Japanese Society of Radiation Chemistry	May 29
Tadashi Fujinawa (Research Consultant), Accelerator Group	Hoshino Prize	The Institute of Electrical Installation Engineers of Japan	Jun 5
Stefan Meinel, Computing Group, RBRC	Kenneth G. Wilson Award at the Lattice 2015 conference	RIKEN, Univ. of Tsukuba, Nagoya Univ. etc.	July
Takahide Nakagawa, Team Leader, Ion Source Team	The 11th PASJ Award for Technical Contributions	Particle Accelerator Society of Japan	Aug. 4
Masako Yamada, formerly affiliated with Radiation Laboratory	The 11th PASJ Award for Young Scientists	Particle Accelerator Society of Japan	Aug. 4
T. Motobayashi, Senior Advisor and H. Sakurai, Chief Scientist and Deputy Director of the Nishina Center	The Nishina Memorial Prize 2015	Nishina Memorial Foundation	Dec. 7
T. Motobayashi, Senior Advisor of the Nishina Cente	The Outstanding Referee	The Outstanding Referees Program instituted by APS	Jan. 8
Katsuhiko Ishida, Associate Chief Scientist of the Advanced Meson Science Laboratory and Tutomu Mibe, Visiting Scientist of the Advanced Meson Science Laboratory and the Radiation Laboratory	Nishikawa Prize	The Foundation For High Energy Accelerator Science	Feb. 15
Research Group for Superheavy Element	The certificate of appreciation	Wako-shi	Mar. 4
Yuma Kikuchi, Special Postdoctoral Researcher of the Spin isospin Laboratory	The 10th Young Scientist Award	Physical Society of Japan	Mar. 20
Kosuke Morita, Group Director, Research Group for Superheavey Element	The Japan Academy Prize	The Japan Academy	Apr. 20

8. Brief overview of the RI Beam Factory

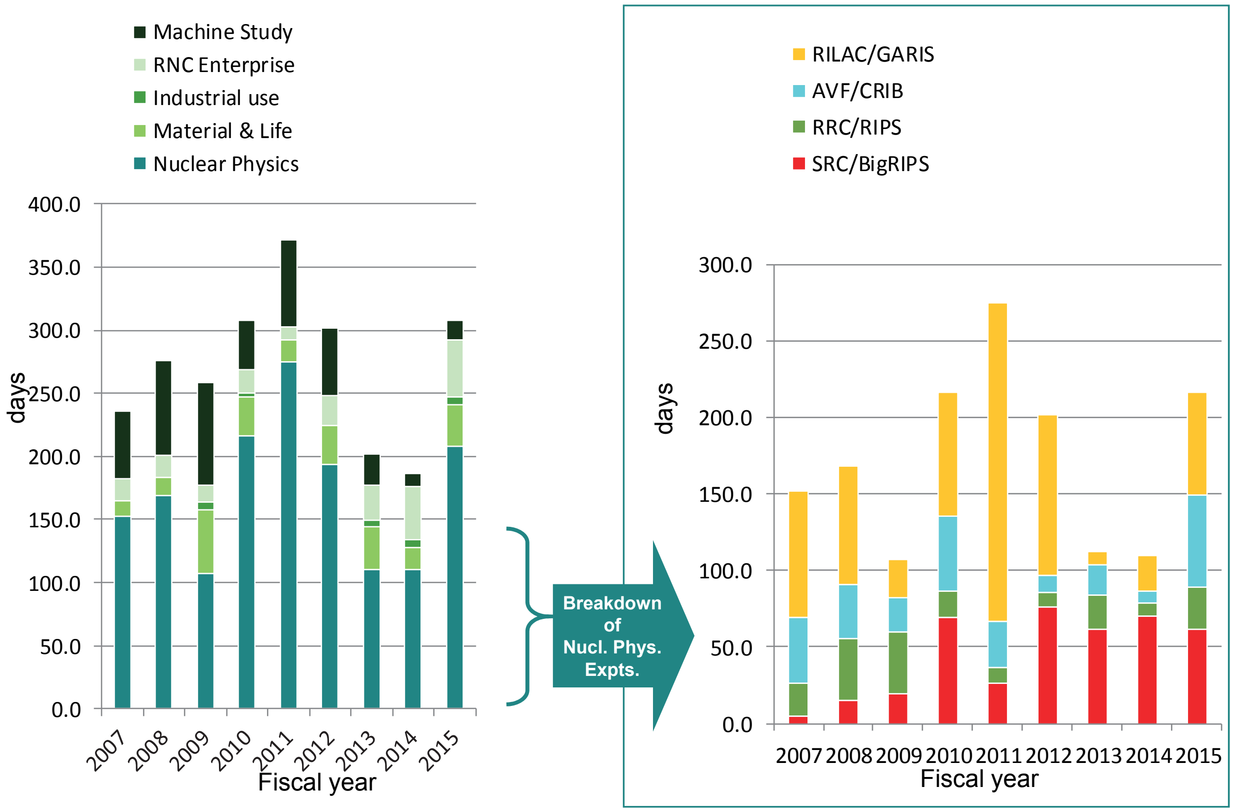
Intensity of Primary Beams

Achieved beam intensities (as of March 2016)

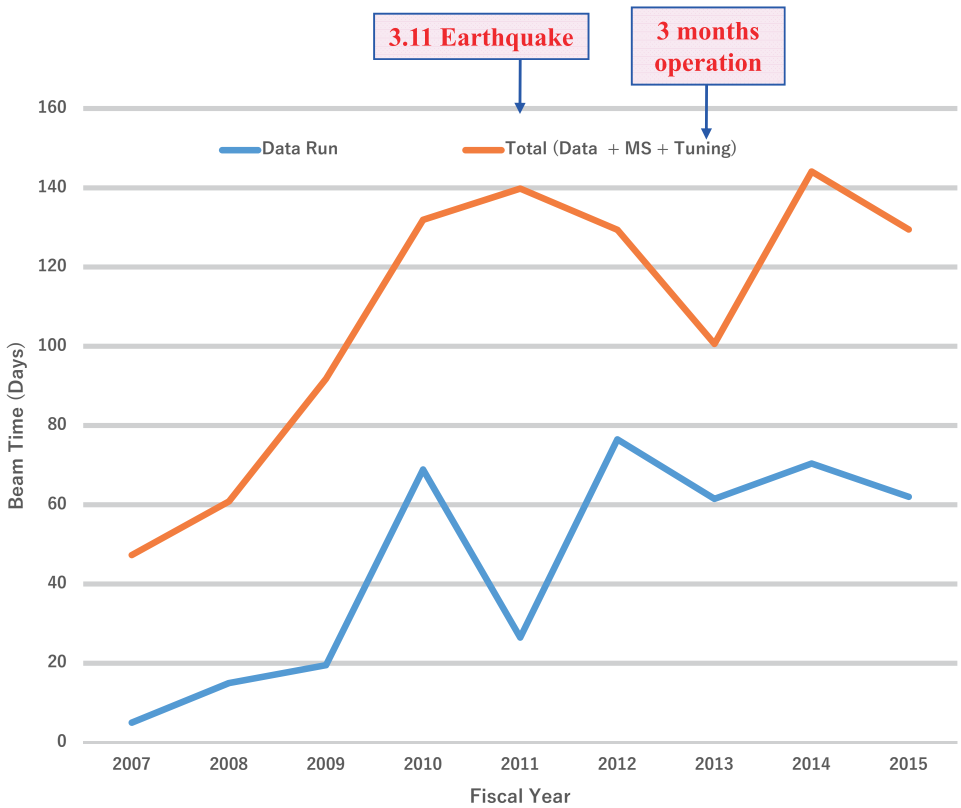
^{238}U	49 pnA	(345 MeV/u, Oct. 2015)
^{124}Xe	38 pnA	(345 MeV/u, Jun. 2013)
^{86}Kr	30 pnA	(345 MeV/u, Nov. 2007)
^{78}Kr	486 pnA	(345 MeV/u, May. 2015)
^{70}Zn	123 pnA	(345 MeV/u, Jun. 2014)
^{48}Ca	530 pnA	(345 MeV/u, Nov. 2014)
^{18}O	1,000 pnA	(345 MeV/u, Jun. 2010)
^{14}N	400 pnA	(250 MeV/u, Oct. 2010)
^{4}He	1,000 pnA	(250 MeV/u, Oct. 2009)
d	1,000 pnA	(250 MeV/u, Oct. 2010)
pol. d	120 pnA, P~80%	(250 MeV/u, May. 2015)



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 s the huge computational cost and is limited to small systems. For large systems, numerical simulation on discretized space-time with quantum Monte Carlo method is a powerful ab initio tool based on the importance sampling. In many quantum systems of nterest, however, it suffers from the so-called sign problem; large cancellation occurs between positive and negative quantities to physical signals, so that the computational time grows exponentially with the system size. So far, many attempts have been ed overcome the sign problem, which include the two promising candidates, the complex Langevin method and the etz-thimble method. In particular, the Lefschetz-thimble approach is a generalization of the steepest descent method for multiple ory integrals. In the past few years, we have studied extensively the mathematical basis of the Lefschetz-thimble method as well practical applications to quantum systems such as the real-time path integral for quantum tunneling, zero-dimensional bosonic mionic models, the one-site Hubbard model, and Polyakov-loop effective models for QCD. We have shown that the interference multiple Lefschetz thimbles is important to reproduce the general non-analytic behavior of the observables as a function of the l parameter. Such an interference is a key to understand the sign problem of finite-density QCD.

unctional 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 ~ 10^{19} T. In non-central heavy-ion collisions at RHIC and LHC, a magnetic field of the strength ~ 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 space-time

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 space-time where the field is situated. On the other hand, in our case, we first obtain quantum system and then the nature of space-time emerges. This is in accordance with the general ideas of emergent space-time 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 space-time symmetry breaking

We studied the effective field theory for space-time symmetry breaking from the local symmetry point of view. By gauging space-time 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 space-time symmetry breaking: Based on the relation between the Maurer-Cartan one-form and connections for space-time symmetries, we classified the physical meanings of the inverse Higgs constraints by the coordinate dimension of broken symmetries. Inverse Higgs constraints for space-time 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^{α}_{R} and Q^{α}_{A} : Q^{α}_{R} are symmetry generators of Hamiltonian systems, which are not generally conserved in dissipative systems. Q^{α}_{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^{α}_{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 (^{4}He, ^{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 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 (~ 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 space-time 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 ρ_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 ~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}Li-^{53}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

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Vice Chief Scientist
Tsukasa TADA

Research & Technical Scientists
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Yoshimasa HIDAKA (Senior Research Scientist)
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Haozhao LIANG (Research Scientist)

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Kazuhiko KAMIKADO (– Mar. 31, 2016)
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Takumi IRITANI (Kyoto Univ.)
Hiroshi TOKI (Osaka Univ.)
Tetsuo MATSUI (Univ. of Tokyo)
Makoto TAKIZAWA (Showa Pharm. Univ.)
Teiji KUNIHIRO (Kyoto Univ.)
Shoichi SASAKI (Tohoku Univ.)
Tatsumi AOYAMA (Nagoya Univ.)
Atsushi NAKAMURA (Hiroshima Univ.)
Takeo INAMI (Chuo Univ., National Taiwan University)
Koji HASHIMOTO (Osaka Univ.)
Minoru ETO (Yamagata Univ.)
Kanabu NAWA (Univ. of Tokyo)
Gergely FEJOS (Osaka Univ.)
Takashi SANO (AIST)
Shinsuke YOSHIDA (Niigata Univ., Central China Normal University)
Toshifumi NOUMI (The Hong Kong University of Science and Technology)
Shinya GONGYO (Kyoto Univ., CNRS)
Yoichi KAZAMA (Univ. of Tokyo)
Kazuo FUJIKAWA (Nihon Univ.)

Student Trainees
Yasuki TACHIBANA (Univ. of Tokyo)
Tomoya HAYATA (Univ. of Tokyo)
Koichi MURASE (Univ. of Tokyo)
Yuya TANIZAKI (Univ. of Tokyo)
Ryuichi KURITA (Univ. of Tokyo)
Kota MASUDA (Univ. of Tokyo)
Masanori YAMADA (Univ. of Tsukuba)
Terukazu ICHIHARA (Kyoto Univ.)
Yuta KIKUCHI (Kyoto Univ.)
Shoichiro TSUTSUI (Kyoto Univ.)
Takaya MIYAMOTO (Kyoto Univ.)
Shihang SHEN (Peking Univ.)

Part-time Workers
Yuki MINAMI (Oct. 1, 2014 – Mar. 31, 2015)
Yasuki TACHIBANA (– Sep. 18, 2015)
Tomoya HAYATA (– Apr. 30, 2015)
Koichi MURASE (– Oct. 3, 2015)
Kayo YAMAJI

List of Publications & Presentations

Publications

[Journal]
(Original Papers) *Subject to Peer Review

Yoichi Kazama, Shota Komatsu, and Takuya Nishimura, “On the singlet projector and the monodromy relation for psu(2, 2|4) spin chains and reduction to subsectors,” Journal of High Eenergy Physics 1509, 183 (2015).*
Yuya Tanizaki, Yoshimasa Hidaka, Tomoya Hayata, “Lefschetz-thimble analysis of the sign problem in one-site fermion model,” New Journal of Physics 18, 033002 (2016).*
Jean-Paul Blaizot, Yoshimasa Hidaka, Daisuke Satow, “Spectral properties of the Goldstino in supersymmetric Bose-Fermi mixtures,” Physical Review A92, 063629 (2015).*
Yuji Hirono, Yoshimasa Hidaka, “Jarzynski-type equalities in gambling: role of information in capital growth,” Journal of Statistical Physics, 161, 721 (2015).*
Yoshimasa Hidaka, Kazuhiko Kamikado, Takuya Kanazawa, Toshifumi Noumi, “Phonons, Pions and Quasi-Long-Range Order in Spatially Modulated Chiral Condensates,” Physical Review, D92, 034003 (2015).*
Yoshimasa Hidaka, Shu Lin, Robert D. Pisarski, Daisuke Satow, “Dilepton and photon production in the presence of a nontrivial Polyakov loop,” Journal of high energy physics, 10, 005 (2015).*

Tomoya Hayata, Yoshimasa Hidaka, Masaru Hongo, Toshifumi Noumi, “Relativistic hydrodynamics from quantum field theory on the basis of the generalized Gibbs ensemble method,” Physical Review D92, 065008 (2015).*

Yoshimasa Hidaka, Toshifumi Noumi, Gary Shiu, “Effective field theory for spacetime symmetry breaking,” Physical Review D92, 045020 (2015).

C. Gale, Y. Hidaka, S. Jeon, S. Lin, J. -F. Paquet, R.D. Pisarski, D. Satow, V.V. Skokov, G. Vujanovic, “Production and Elliptic Flow of Dileptons and Photons in the semi-Quark Gluon Plasma,” Physical Review Letters 114, 072301 (2015).*

Tomoya Hayata, and Yoshimasa Hidaka, “Dispersion relations of Nambu-Goldstone modes at finite temperature and density” Physical Review D 91, 056006 (2015).*

Ryoji Anzaki, Kenji Fukushima, Yoshimasa Hidaka, and Takashi Oka, “Restricted phase-space approximation in real-time stochastic quantization,” Annals of Physics. 353, 107 (2015).*

T. Kimura, “Linking loops in ABJM and refined theory,” Journal of High Energy Physics 07, 030 (2015).*

T. Kimura and M. Murata, “Transport Process in Multi-Junctions of Quantum Systems,” Journal of High Energy Physics 07, 072 (2015).*

Yuki Iimori and Shingo Torii, “Relation between the Reducibility Structures and between the Master Actions in the Witten Formulation and the Berkovits Formulation of Open Superstring Field Theory,” Journal of High Energy Physics 10 (2015) 127.*

Pascal Naidon, Shimpei Endo, and Antonio M García-García, “Scattering of universal fermionic clusters in the resonating group method,” Journal of Physics B: Atomic, Molecular, and Optical Physics, 49, 034002 (2015).*

Shimpei Endo, Antonio M. García-García, and Pascal Naidon, “Universal clusters as building blocks of stable quantum matter,” Physical Review A 93, 053611 (2015).*

K. Fujikawa, C.H. Oh, K. Umetsu, and Sixia Yu, “Separability criteria with angular and Hilbert-space averages,” Annals of Physics 368 (2016) 248.*

K. Fujikawa, “Yang-Mills theory and fermionic path integrals,” Modern Physics Letters A31 (2016) 1630004.*

K. Fujikawa, “ The gradient flow in λφ^{4} theory ,” Journal of High Energy Physics 03 (2016) 021.*

K. Fujikawa and A. Tureanu, “Neutrino-antineutrino Mass Splitting in the Standard Model: Neutrino Oscillation and Baryogenesis,” Modern Physics Letters A 30, 1530016 (2015).*

K. Fujikawa, Mo-Lin Ge, Yu-Long Liu and Qing Zhao, “Uncertainty principle, Shannon-Nyquist sampling and beyond,” Journal of Physical Society of Japan 84, (2015) 064801.*

K. Suzuki, P. Gubler and M. Oka, “D meson mass increase by restoration of chiral symmetry in in nuclear matter,” Physical Review C 93, 045209 (2016).*

P. Gubler, K. Hattori, S.-H. Lee, M. Oka, S. Ozaki and K. Suzuki, “D mesons in a magnetic field,” Physical Review D 93, 054026 (2016).*

K. Suzuki and T. Yoshida, “Cigar-shaped quarkonia under strong magnetic field,” Physical Review D 93, 051502(R) (2016).*

K. Masuda, T. Hatsuda and T. Takatsuka, “Hadron–quark crossover and hot neutron stars at birth,” Progress of Theoretical and Experimental Physics 2016, no. 2, 021D01 (2016).*

P. Gubler, N. Yamamoto, T. Hatsuda and Y. Nishida, “Single-particle spectral density of the unitary Fermi gas: Novel approach based on the operator product expansion, sum rules and the maximum entropy method,” Annals of Physics 356, 467 (2015).

G. Baym and T. Hatsuda, “Polarization of Direct Photons from Gluon Anisotropy in Ultrarelativistic Heavy Ion Collisions,” Progress of Theoretical and Experimental Physics 2015, no. 3, 031D01 (2015).*

F. Lenz, K. Ohta and K. Yazaki, “Revision of the brick wall method for calculating the blacl hole thermodynamic quantities,” Physical Review D 92, 064018 (2015)*.

G. Fejos, “Functional dependence of axial anomaly via mesonic fluctuations in the three flavor linear sigma model,” Physical Review D 92, 036011(2015).*

K. Fukushima, Y. Tanizaki, “Hamilton dynamics of the Lefschetz thimble integration akin to the complex Langevin method,” Progress of Theoretical and Experimental Physics (2015) 111A01.*

D. Mesterhazy, J. H. Stockemer, Y. Tanizaki, “From quantum to classical dynamics: The relativistic O(N) model in the framework of real-time functional renormalization group,” Physical Review D 92 (2015) 076001.*

Y. Tanizaki, H. Nishimura, K. Kashiwa, “Evading the sign problem in the mean-field approximation through Lefschetz-thimble path integral,” Physical Review D 91 (2015) 101701.*

Y. Tachibana and T. Hirano, “Interplay between Mach cone and radial expansion and its signal in gamma-jet events,” Physical Review C 93, 054907 (2016) .*

N. Ishibashi, T. Tada, “Infinite circumference limit of conformal field theory,” Journal of Physics A: Mathematical and Theoretical 48 (2015) 315402.*

K. Fukushima, K. Hattori, H.-U. Yee, and Y. Yin, “Heavy Quark Diffusion in Strong Magnetic Fields at Weak Coupling and Implication to Elliptic Flow,” Physical Review D 93 (2016) 074028. *

K. Hattori, T. Kojo, and N. Su, “Mesons in strong magnetic fields: (I) General analyses,” Nuclear Physics A951 (2016) 1-30. *

K. Hattori, K. Itakura, S. Ozaki, and S. Yasui, “QCD Kondo effect: quark matter with heavy-flavor impurities,” Physical Review D 92 (2015) 065003. *

S. Ozaki, T. Arai, K. Hattori, and K. Itakura, “Euler-Heisenberg-Weiss action for QCD+QED,” Physical. Review D 92 (2015) 1, 016002. *

S. Cho, K. Hattori, S. H. Lee, K. Morita, and S. Ozaki, “Charmonium Spectroscopy in Strong Magnetic Fields by QCD Sum Rules: S-Wave Ground States,” Physical Review D 91 (2015) 045025. *

Yoshitaka Hatta, Bo-Wen Xiao, and Di-Lun Yang, “Non-boost-invariant solution of relativistic hydrodynamics in 1+3 dimensions,” Physical Review D 93, 016012, (2016).*

Shi Pu and Di-Lun Yang, “Transverse flow induced by inhomogeneous magnetic fields in the Bjorken expansion,” Physical Review D 93, 054042, (2016).*

S. Ohnishi, Y. Ikeda, T. Hyodo and W. Weise, “Structure of the $\Lambda(1405)$ and the $K^-d\to\pi\Sigma n$ reaction,” Physical Review C 93, no. 2, 025207 (2016).*

K. Sasaki, S. Aoki, T. Doi, T. Hatsuda, Y. Ikeda, T. Inoue, N. Ishii and K. Murano (HAL QCD Collaboration), “Coupled channel approach to strangeness S = -2 baryon-baryon interactions in Lattice QCD,” Progress of Theoretical and Experimental Physics 2015, 113B01 (2015).*

M. Yamada, K. Sasaki, S. Aoki, T. Doi, T. Hatsuda, Y. Ikeda, T. Inoue, N. Ishii, K. Murano and H. Nemura (HAL QCD Collaboration), “Omega-Omega interaction from 2+1 flavor lattice QCD,” Progress of Theoretical and Experimental Physics 2015, 071B01 (2015).*

T. Inoue, S. Aoki, B. Charron, T. Doi, T. Hatsuda, Y. Ikeda, N. Ishii, K. Murano, H. Nemura and K. Sasaki (HAL QCD Collaboration), "Medium-Heavy Nuclei from Nucleon-Nucleon Interactions in Lattice QCD," Physical Review C 91, 011001(R) (2015).*

M. Deka, T. Doi, Y.-B. Yang, B. Chakraborty, S.-J. Dong, T. Draper, M. Glatzmaier, M. Gong, H.-W. Lin, K.-F. Liu, D. Mankame, N. Mathur and T. Streuer (chiQCD Collaboration), "Lattice Study of Quark and Glue Momenta and Angular Momenta in the Nucleon," Physical Review D 91,014505(2015).*

Yuki Nakaguchi, Noriaki Ogawa, Tomonori Ugajin,"Holographic Entanglement and Causal Shadow in Time-Dependent Janus Black Hole," Journal of High Energy Physics, 1507 (2015) 080.*

Koji Hashimoto, Noriaki Ogawa, Yasuhiro Nakaguchi, "Holographic Heavy Quark Symmetry," Journal of High Energy Physics, 1506 (2015) 040.*

Y. Tanimura, K. Hagino, and H.Z. Liang, "Three-dimensional mesh calculations for covariant density functional theory", Progress of Theoretical and Experimental Physics 2015, 073D01 (2015).*

D.-Y. Cheng, X. Liu, and T. Matsuki, "Prediction of charmoniumlike structures in the hidden-charm di-eta decays of higher charmonia," Journal of Physics G: Nuclear Particle Physics 42, 015002 (2015).*

D.-Y. Cheng, X. Liu, and T. Matsuki, "Hidden charm decays of *X*(3915) and *Z*(3930) as the P-wave charmonia, " Progress of Theoretical and Experimental Physiscs 2015 043B05 (2015).*

Qing-Tao Song, Dian-Yong Chen, Xiang Liu, and T. Matsuki, "*D*_{s1}^*(2860) and *D*_{s3}^*(2860): Candidates for *1D* charmed-strange mesons, " European Physical Journal *C* 75, 30 (2015).*

Bo Wang, Cheng-Qun Pang, Xiang Liu, and T. Matsuki, "Pseudotensor meson family," Physical Review D91,014025 (2015).*

D.-Y. Cheng, X. Liu, and T. Matsuki, "Observation of e^+e^- → χ_{c0}ω and missing higher charmonium ψ(4S), " Physical Review D91, 094023 (2015).*

Qin-Tao Song, Dian-Yong Chen, Xiang Liu, and T. Matsuki, "Charmed-strange mesons revisited: mass spectra and strong decays," Physical Review D 91, 054031 (2015).*

Kan Chen, Cheng-Qun Pang, Xiang Liu, and T. Matsuki, "Light axial vector mesons," Physical Review D 91, 074025 (2015).*

Qin-Tao Song, Dian-Yong Chen, Xiang Liu, and T. Matsuki, "Higher radial and orbital excitations in the charmed meson family," Physical Review D 92, 074011-1-16 (2015).*

Cheng-Qun Pang, Bo Wang, Xiang Liu, and T. Matsuki, "High-spin mesons below 3 GeV," Physical Review D 92, 014012-1-16 (2015).*

(Review)

Haozhao Liang, Jie Meng, Shan-Gui Zhou, "Hidden pseudospin and spin symmetries and their origins in atomic nuclei", Phys. Rept. 570 (2015)*

K. Masuda, T. Hatsuda and T. Takatsuka, "Hyperon Puzzle, Hadron-Quark Crossover and Massive Neutron Stars," European Physical Journal A52 (2016) 65 *

D. R. Chakrabarty , N. Dinh Dang, V. M. Datar, "Giant dipole resonance in hot rotating nuclei," The European Physical Journal A52 (2016) 143*

[Proceedings]

(Original Papers) *Subject to Peer Review

K. Suzuki, P. Gubler and M. Oka, "D meson properties in nuclear medium from QCD sum rules," to appear in Proceedings of 12th international conference on Hypernuclear and Strange Particle Physics(HYP2015), Tohoku University, Sendai, September 7-12, 2015.

Y. Tanizaki, H. Nishimura, K. Kashiwa, "Lefschetz-thimble path integral for solving the mean-field sign problem," Proceedings of Science (LATTICE 2015) 282 (2015), 33rd International Symposium on Lattice Field Theory (LATTICE 2015), July 14-18, 2015, Kobe International Conference Center, Kobe.

K. Hattori, L. McLerran, B. Schenke, "Geometrical scaling of jet fragmentation photons,," to appear in Nuclear Physics A, proceedings of 25th International conference on ultrarelativistic nucleus-nucleus collisions, Quark Matter 2015 (QM2015), Kobe Fashion Mart, Kobe, Japan, September 27-October 3, 2015.*

K. Hattori, K. Itakura, "Photon and dilepton spectra from nonlinear QED effects in supercritical magnetic fields induced by heavy-ion collisions," to appear in Nuclear Physics B Proceedings Supplement, proceedings of 7th International conference on Hard and Electromagnetic Probes of High-energy Nuclear Collisions (Hard Probes 2015), McGill University, Montreal, Canada, June 29-July3, 2015.*

M. Kitazawa, M. Asakawa, T. Hatsuda, T. Iritani, E. Itou and H. Suzuki, "Thermodynamics and reference scale of SU(3) gauge theory from gradient flow on fine lattices," 33rd International Symposium on Lattice Field Theory (Lattice 2015), Kobe, Japan, July 14-18, 2015.

T. Amagasa, S. Aoki, Y. Aoki, T. Aoyama, T. Doi, K. Fukumura, N. Ishii, K.-I. Ishikawa, H. Jitsumoto, H. Kamano, Y. Konno, H. Matsufuru, Y. Mikami, K. Miura, M. Sato, S. Takeda, O. Tatebe, H. Togawa, A. Ukawa, N. Ukita, Y. Watanabe, T. Yamazaki and T. Yoshie, "Sharing lattice QCD data over a widely distributed file system," 21st International Conference on Computing in High Energy and Nuclear Physics (CHEP2015) April 13–17, 2015, Okinawa, Japan, Journal of Physics: Conference Series, 664, 042058 (2015).*

Y. Tanimura, K. Hagino, and H.Z. Liang, "Three-dimensional mesh calculations for covariant density functional theory", in NUCLEAR STRUCTURE AND DYNAMICS '15 (Proceedings of NSD15, Portoroz, Slovenia, 14-19 June 2015), AIP Conference Proceedings 1681, 030008 (2015).*

T. Matsuki, Dian-Yong Chen, and Xiang Liu, "Charged charmonium-like structures and the initial single chiral particle emission mechanism, " AIP Conference Proceedings 1701, 050010 (2016), XIth Quark Confinement and the Hadron Spectrum held at St. Petersburg, Russia, September 8-12, 2014, arXiv:1502.03906.

T. Matsuki, D.-Y. Cheng, and X. Liu, "The Initial Single Chiral Particle Emission Mechanism and the Predictions of Charged Charmonium-like Structures," Acta Physica Polonica Supplement 8, 153-158 (2015).

[Book]

(Original Papers) *Subject to Peer Review

J.Y. Guo, H.Z. Liang, J. Meng, and S.G. Zhou, "Chapter 6: Relativistic symmetries in nuclear single-particle spectra", in Relativistic Density Functional for Nuclear Structure, edited by J. Meng (International Review of Nuclear Physics: Volume 10), World Scientific, 2016, pages 219-262.*

[Others]

風間洋一(訳), ヤン　チェン・ニン（著）「マックスウェル方程式とゲージ理論の概念的起源」,パリティ　2015 年 9 月号，30(9),13-21.

風間洋一，書評「超ひも理論をパパに習ってみた」,数理科学　2015 年 9 月号，53(9),60.
風間洋一，「弦理論は原理論か」,パリティ　2015 年 11 月号，30(11),6-13.
日高義将,「南部-ゴールドストンの定理の半世紀ぶりの一般化」，パリティ　2016 年 4 月号，31(4),19-25.
仁尾真紀子，「電磁気学と場の理論」，数理科学　2016 年 3 月号, 54(3), 14-19.

Oral Presentations

[International Conference etc.]

Yoichi Kazama, “Cognate structure at weak and strong coupling for three-point functions,” Invited lecture,エトヴェシ大学，ブダペスト，October 21, 2016.

Yoichi Kazama, “AdS/CFT and Integraibility: Cognate structure at weak and strong coupling for three-point functions,” Invited talk, NCTS(National Center for Theoretical Sciences) Annual theory meeting, National Tsing Hua University, Hsinchu, Taiwan, December 11, 2015.

K. Fujikawa, ”Quadratic divergences and naturalness,” invited talk, Conference on new physics at the Large Hadron Collider, March 4, 2016, Singapore.

K. Fujikawa, ”Lorentz invariant CPT breaking,” invited talk, Memorial meeting for Abdus Salam's 90th birthday, January 25, 2016, Singapore.

K. Fujikawa, ”Yang-Mills theory and path integrals,” invited talk, 60 years of Yang-Mills gauge field theories, May 27, 2015, Singapore.

Gergely Fejos, “Chiral symmetry restoration with functional renormalization group methods,” Theory Seminar, Wigner Research Centre, Budapest, Hungary, January 9, 2015.

Gergely Fejos, “Functional renormalization group method in quantum field theory and its applications in strongly coupled systems,” Theory Seminar, RCNP, Osaka University, Toyonaka, February 2, 2015.

Yoshimasa Hidaka, “Symmetry breaking and gapless excitations,” Topological Science Kick-off Symposium 2016, Keio University, 14-15 Mar. 2016.

Yoshimasa Hidaka, “Phonons, pions and quasi-long-range order in spatially modulated chiral condensates,” Molecule-type workshop on “Selected topics in the physics of the Quark-Gluon Plasma and Ultrarelativistic Heavy Ion Collisions,” YITP, September 14-26, 2015.

Yoshimasa Hidaka, “Magnetic Catalysis vs. Magnetic Inhibition,” QCD Chirality Workshop 2015, University of California, Los Angeles, USA, January 21-23, 2015.

K. Suzuki, P. Gubler and M. Oka, “*D* meson properties in nuclear medium from QCD sum rules,” 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Tohoku University, Sendai, September 7-12, 2015.

Pascal Naidon, “What determines the Efimov three-body parameter?” Invited talk, the International Workshop on Critical Stability in Few-Body Systems, RIKEN, Wako, January 26, 2015.

Pascal Naidon, “Scattering of universal fermionic clusters,” Selected Presentation at the 21st International Conference on Few-Body Problems in Physics, , Chicago, Illinois, USA, May 18, 2015.

Pascal Naidon, “Scattering of universal fermionic clusters,” Invited Presentation at the International Workshop on Critical Stability in Few-Body Systems, February 4, 2016, RIKEN, Wako, Japan.

Pascal Naidon, “Scattering of universal fermionic clusters,” Invited Presentation at the International Workshop on Critical Stability in Few-Body Systems, February 4, 2016, RIKEN, Wako, Japan.

Y. Tanizaki, Y. Hidaka, T. Hayata, “Lefschetz-thimble and complex Langevin approaches to Silver Blaze of one-site Hubbard model,” KEK Theory Workshop December 1-5, 2015, KEK, Tsukuba, Japan.

Y. Tanizaki, H. Nishimura, K. Kashiwa, “Lefschetz-thimble path integral for solving the mean-field sign problem,” 33rd International Symposium on Lattice Field Theory (LATTICE 2015), July 14-18, 2015, Kobe International Conference Center, Kobe, Japan.

Y. Tachibana, “Jet medium interactions,” invited talk, 6th Asian Triangle Heavy Ion Conference(ATHIC 2016), New Delhi, India, Feburary 19, 2016.*

Y. Tachibana and T. Hirano, “Interplay between Mach cone and radial expansion in jet events,” 25th International conference on ultrarelativistic nucleus-nucleus collisions, Quark Matter 2015 (QM 2015), Kobe Fashion Mart, Kobe, Japan, September 27-October 3, 2015.*

Y. Tachibana and T. Hirano, “Hydrodynamic excitation by jets in the expanding QGP,” Hard Probes 2015, McGill University, Montréal, June 30, 2015.*

Tsukasa Tada, “Dipolar quantization and the Hilbert space structure,” KEK Theory workshop 2015 December 1-5, 2015, KEK, Tsukuba, Japan.

T. Hatsuda, “Lattice QCD approach to nuclear physics,” invited lecture at ECT* doctoral training program on Computational Nuclear Physics - Hadrons, Nuclei and Dense Matter, Trento, Italy, April 13 - May 22 (2015).

T. Hatsuda, “QCD Spectral Functions,” invited talk, ECT* workshop on New perspectives on Photons and Dileptons in Ultrarelativistic Heavy-Ion Collisions at RHIC and LHC, Trento, Italy, Nov. 30 - Dec. 11 (2015).

Tatsumi Aoyama, “Numerical evaluation of QED contribution to lepton g-2,” plenary talk, 33rd International Symposium on Lattice Field Theory (LATTICE 2015), July 14-18, 2015, Kobe International Conference Center, Kobe, Japan.

K. Hattori, L. McLerran, B. Schenke, “Jet fragmentation photons in ultrarelativistic heavy-ion collisions,” 25th International conference on ultrarelativistic nucleus-nucleus collisions, Quark Matter 2015(QM2015), Kobe Fashion Mart, Kobe, Japan, September 27-October 3, 2015.*

K. Hattori, K. Itakura, “Photon and dilepton spectra from nonlinear QED effects in supercritical magnetic fields induced by heavy-ion collisions,” 7th International conference on Hard and Electromagnetic Probes of High-energy Nuclear Collisions (Hard Probes 2015), Montreal, Canada.*

K. Hattori, “Nonlinear QED effects on photon and dilepton spectra in supercritical magnetic fields,” New perspectives on Photons and Dileptons in Ultrarelativistic Heavy-Ion Collisions at RHIC and LHC, ECT*, Dec. 9, 2015.

K. Hattori, “Charmonium spectroscopy in strong magnetic fields by QCD sum rules,” Hadrons and Hadron Interactions in QCD -- Effective theories and Lattice --} (HHIQCD2015), YITP, Kyoto Univ., Mar. 10, 2015.

K. Hattori, “Photon propagation in strong magnetic fields,” QCD Chirality Workshop 2015, UCLA, Jan. 21-23, 2015.

Di-Lun Yang, “Two novel analytic solutions in relativistic hydrodynamics and magneto-hydrodynamics”, ITP seminar, Vienna University of technology, March 10, 2016, Vienna, Austria.

Di-Lun Yang, “Collective flow of photons in strongly coupled gauge theories”, Nuclear physics colloquium, ITP Goethe University Frankfurt am Main, March 3rd, 2016, Frankfurt, Germany.

K. Kamikado ,“Phase diagram of the U(2) x U(2) scalar model in three dimension” , 33rd International Symposium on Lattice Field Theory (LATTICE 2015), July 14-18, 2015, Kobe International Conference Center, Kobe, Japan.

T. Noumi, “Effective Field Theory for Spacetime Symmetry Breaking,” Gordon Research Conference “String Theory and Cosmology,” Hong Kong University of Science and Technology, Hong Kong, May 31- June 5 2015.

Y. Ikeda, “Status of Lattice QCD Simulations for Normal and Exotic Hadrons,'' Plenary invited talk, 12th International Conference on Low Energy Antiproton Physics(LEAP2016), March 6-11, 2016, Kanazawa-Kagekiza, Kanazawa, Japan.

Y. Ikeda, “Search for Tetraquarks from lattice QCD simulation,'' Invited talk, International Workshop on ``Critical Stability in Few-Body Systems,''

Feb. 1-5, 2016, RIKEN, Wako, Saitama, Japan.

Y. Ikeda, “Lattice QCD study of Z_c(3900),'' Plenary invited talk, the 31st Reimei WorkShop on Hadron Physics in Extreme Conditions at J-PARC,

Jan. 18-20, 2016, JAEA, Tokai, Ibaraki, Japan.

Y. Ikeda, “Structure of Z_c(3900) from coupled-channel scattering on the lattice,” Symposium on “Quarks to Universe in Computational Science (QUCS 2015),” November 4-8, 2015, Nara Kasugano International Forum, Nara, Japan.

Y. Ikeda, “Structure of Z_c(3900) from lattice QCD,'' Plenary invited talk, Frontiers in hadron and nuclear physics with strangeness and charm, October 19 - 23, 2015, ECT*, Trento, Italy.

Y. Ikeda, “Z_c(3900)$ from coupled-channel HAL QCD approach on the lattice,” Invited talk, 33rd International Symposium on Lattice Field Theory (Lattice2015), July 14-18, 2015, Kobe International Conference Center, Kobe, Japan.

Y. Ikeda, “On the structure of Z_c(3900) from lattice QCD,” Invited talk, 10th International Workshop on the Physics of Excited Nucleons (NSTAR2015), May 25-28, 2015, Osaka University, Suita, Japan.

M. Nio, “Status of QED contributions to lepton g-2,” g-2/EDM 10th collaboration meeting, J-PARC, Toukai, June 25, 2015.

T. Doi, for HAL QCD Collaboration, “Baryon Interactions from Lattice QCD with physical masses,” Invited talk, “The 31st Reimei Workshop on Hadron Physics in Extreme Conditions at J-PARC,” J-PARC, Tokai, Japan, Feb. 17-21, 2015.

T. Doi, for HAL QCD Collaboration, “Nuclear Physics from Lattice QCD,” Invited Talk, “Symposium on Quarks to Universe in Computational Science (QUCS 2015),” Nara Kasugano International Forum IRAKA, Nara, Japan, 4-8 Nov. 2015.

T. Doi, for chiQCD Collaboration, “A Lattice Study of Quark and Glue Momenta and Angular Momenta in the Nucleon,” Invited Talk, “The 10th Circum-Pan-Pacific Spin Symposium on High Energy Spin Physics (Pacific Spin 2015),”

Academia Sinica, Taipei, Taiwan, 5-8 October 2015.

T. Doi, for HAL QCD Collaboration, “Towards lattice QCD baryon forces at the physical point: First results,” “The 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015),” Tohoku University, Sendai, September 7-12, 2015.

T. Doi, for HAL QCD Collaboration, “First results of baryon interactions from lattice QCD with physical masses (1) -- General overview and two-nucleon forces --,” “The 33rd International Symposium on Lattice Field Theory (Lattice 2015),” Kobe, Japan, July 14-18, 2015.

T. Doi, for HAL QCD Collaboration, “Three-Nucleon Forces from Lattice QCD,” “Hadrons and Hadron Interactions in QCD – Effective theories and Lattice – (HHIQCD2015),” Yukawa Institute for Theoretical Physics (YITP), Kyoto, Japan, Feburary15-March 21 2015.

T. Doi, for HAL QCD Collaboration, “HAL QCD method for hadron interactions on the lattice,” Invited Talk, “Multi-Hadron and Nonlocal Matrix Elements in Lattice QCD (MNME 2015),” BNL, Upton, USA, February 5-6, 2015.

M. Hongo and Y. Hidaka, “Chiral-magnetohydorynamics from quantum field theory,” 13th international eXtreme QCD conference (eXtreme QCD 2015), Central China Normal University, Wuhan, September 21-23, 2015.

Noriaki Ogawa, “Physical Approach to Fish Retinal Cone Mosaic,” RIKEN-NCBS Joint Meeting for Theoretical Biology, RIKEN, Wako, April 7-10, 2015.

Noriaki Ogawa, “Physical Modeling for Development of Fish Retinal Patterns,” YITP Long-Term Workshop on Non-equilibrium Physics, Yukawa Institute for Theoretical Physics(YITP), Kyoto, July 24, 2015.

Noriaki Ogawa, Tetsuo Hatsuda, Atsushi Mochizuki, Masashi Tachikawa, “Theoretical Analysis of Fish Retinal Cone Mosaic Formation,” 5th China-Japan-Korea Colloquium on Mathematical Biology & 25th Annual Meeting of Japan Society of Mathematical Biology, Doshisha University, Kyoto, August 26-29, 2015.

Noriaki Ogawa, “Nambu and Living World: Symmetry Breaking and Pattern Selection in Cellular Mosaic Formation,” Osaka CTSR - Kavli IPMU - RKEN iTHES International Workshop “Nambu and Science Frontier,” Osaka University, Toyonaka, November 17, 2015.

Di-Lun Yang,“Collective flow of photons in strongly coupled gauge theories”, YITP Nuclear Theory seminar, Kyoto University, November 19, 2015, Kyoto, Japan.

Di-Lun Yang, “Two novel analytic solutions in relativistic hydrodynamics and magneto-hydrodynamics”, H-ken colloquium, Nagoya University, March 28, 2016, Nagoya, Japan.

H.Z. Liang, Lecture: “Relativistic symmetries in atomic nuclei”, Lectures on Covariant Density Functional Theory in Nuclear Physics, Jan 21-25, 2016, Changchun, China.

H.Z. Liang, Invited talk: “Towards the self-consistent and relativistic study of spin-isospin excitations in deformed nuclei”, SKLTP-BLTP Joint Workshop on Physics of Strong Interaction, Oct 29-Nov 3, 2015, Guilin, China.

H.Z. Liang, “Localized form of Fock terms in nuclear covariant density functional theory”, YITP long-term workshop: Computational Advances in Nuclear and Hadron Physics, Sep 21-Oct 30, 2015, Kyoto, Japan.

H.Z. Liang, Invited talk: “Towards the self-consistent and relativistic study of spin-isospin excitations in deformed nuclei”, The 5th Conference: Collective Motion in Nuclei under Extreme Conditions, Sep 14-18, 2015, Krakow, Poland.

H.Z. Liang, Invited lecture: “Covariant density functional theory and nuclear spin-isospin excitations”, The 14th CNS International Summer School, Aug 26-Sep 1, 2015, Wako, Japan.

H.Z. Liang, Invited talk: “Hidden pseudospin and spin symmetries in nuclei”, NORDITA Workshop “Chiral Bands in Nuclei”, Apr 20-22, 2015, Stockholm, Sweden.

[Domestic Conference]

日高義将,「自発的対称性と南部ゴールドストーンモード」, 理研研究会『これからの弦理論橋本研 closing 研究会～』, 大河内ホール, 理研, 和光, 2015 年 2 月 21-22 日.

服部恒一，板倉数記，「高強度磁場がひきおこす光子の分裂」，日本物理学会第 70 回年次大会，早稲田大学，東京, 2015 年 3 月 21-24 日.

日高義将，早田智也，本郷優，南佑樹，野海俊文,「相対論的流体の有効ラグランジアンと自発的対称性の破れ」,日本物理学会第 70 回年次大会，早稲田大学，東京, 2015 年 3 月 21-24 日.

日高義将，「QGP の基礎的性質概観（粘性など）」 チュートリアル研究会「重イオン衝突の物理：基礎から最先端まで」，理研，和光, 2015 年 3 月 25-27 日.

日高義将，「自発的対称性の破れと南部ゴールドストーンモード」，第 43 回北陸信越地区素粒子論グループ合宿研究会，国立妙高青少年自然の家，2015 年 5 月 15-17 日.

日高義将，集中講義「有限温度・有限密度の場の量子論：基礎から最近の話題まで」 千葉大学, 2016 年 3 月 8-9 日.

日高義将，集中講義「平衡系，非平衡系における場の量子論」，中央大学, 2016 年 1 月 6-8 日.

日高義将，「有限温度・有限密度の場の量子論: 基礎から応用まで」，三者若手夏の学校，ホテルたつき，蒲郡，2015 年 8 月 17 日-22 日.

日高義将，「南部ゴールドストンの定理とその発展」，シンポジウム講演，日本物理学会 第 71 回年次大会，東北学院大学，仙台，2016 年 3 月 19-22 日.

板倉数記，服部恒一，「強磁場中の光子が示す複屈折に対する媒質効果」，日本物理学会第 70 回年次大会，早稲田大学，東京，2015 年 3 月 21-24 日.

安井繁宏，服部恒一，板倉数記，尾崎翔，「低温高密度クォーク物質における近藤効果」，日本物理学会第 70 回年次大会，早稲田大学，東京, 2015 年 3 月 21-24 日.

上門和彦，“First and second order phase transitions in the U(2)xU(2) chiral model,” 三者若手夏の学校，ホテルたつき，蒲郡，2015 年 8 月 17 日-22 日.

上門和彦, “Phonons, Pions and Quasi-Long-Range Order in Spatially Modulated Chiral Condensates,”研究会「熱場の量子論とその応用」，京都大学基礎物理学研究所，京都市，2015 年 8 月 31 日−9 月 2 日.

Theoretical Research Division
Theoretical Nuclear Physics Laboratory

1. Abstract

Nuclei are finite many-particle systems composed of protons and neutrons. They are self-bound in femto-scale (10^{-15}m) by the strong interaction (nuclear force) whose study was pioneered by Hideki Yukawa. Uncommon properties of the nuclear force (repulsive core, spin-isospin dependence, tensor force, etc.) prevent complete microscopic studies of nuclear structure. There exist number of unsolved problems even at present. In addition, radioactive beam facilities reveal novel aspects of unstable nuclei. We are tackling these old problems and new issues in theoretical nuclear physics, developing new models and pursuing large-scale calculations of quantum many-body systems. We are also strongly involved in research on other quantum many-body systems, to resolve mysteries in the quantum physics.

2. Major Research Subjects

(1) Nuclear structure and quantum reaction theories
(2) First-principle calculations with the density functional theory for many Fermion systems
(3) Computational nuclear physics

3. Summary of Research Activity

(1) Microscopic determination of nuclear reaction path and inertial mass

Nuclear reaction at low energy is described by the quantum scattering theory. However, when many nucleons are involved in the reaction processes, the full treatment becomes impractical. In this case, it is very useful to find the optimal collective coordinate to describe the reaction. Based on the time-dependent density-functional theory, we can achieve this by solving a set of equations, the moving mean-field equation and the moving RPA equation, which we derived previously using a theory of large amplitude collective motion. This requires complicated coding and large computational resources. We have developed a computer program based on the three-dimensional real-space representation and applied this to reaction of light nuclei, such as ^{8}Be and ^{16}O. We have succeeded to derive the fission path of ^{8}Be into two alpha particles. At the same time, the inertial mass parameter for this reaction is microscopically determined. It turns out that the collective inertial mass is equal to the reduced mass in a asymptotic region and increases near the touching region of two alpha's.

(2) Energy density functional approaches to superheavy nuclei

We have performed a systematic calculation for superheavy nuclei using the energy density functional methods. A purpose of this study is to quantify the theoretical uncertainty of the energy density functional methods. Comparing the results with known experimental data, we have found nice agreement. However, in unknown territories of the superheavy nuclei, we do not know the predictive power of the method. To quantify the uncertainty, we use many different kinds of modern energy density functionals and compare the results to each other. Surprisingly, the results agree with each other in open-shell region where the nuclei are well deformed. On the other hand, in the semi-magic and the transitional regions, the predicted values are scattered. Most probably, this is associated with missing correlations, such as shape fluctuation effects, and indicates necessity of further extension of the model.

(3) Energy and mass number dependence of total reaction cross sections of nuclei

We have systematically analyzed nuclear reaction data that are sensitive to nuclear size, namely, proton-nucleus total reaction cross sections and differential elastic cross sections, using a phenomenological black-sphere approximation of nuclei that we are developing. In this framework, the radius of the black sphere is found to be a useful length scale that simultaneously accounts for the observed proton-nucleus total reaction cross section and first diffraction peak in the proton elastic differential cross section. This framework is expected to be applicable to any kind of projectile that is strongly attenuated in the nucleus. On the basis of a cross-section formula constructed within this framework, we find that a less familiar $A^{1/6}$ dependence plays a crucial role in describing the energy dependence of proton-nucleus total reaction cross sections

(4) Deformed nuclei in the black-sphere approximation of nuclei

In order to access the information of nuclear equation of state, such as the value of L, we have studied total reaction cross sections by focusing on the empirical data of the interaction cross section measured at ~900 MeV per nucleon, as a first step. Since the data of Ne and Mg isotopes have already been obtained with the energy of ~240 MeV per nucleon at the RI Beam Factory of RIKEN, systematic analyses are indispensable. For the analyses, we adopt the black-sphere approximation of nuclei. Since we have to face the nuclear deformation in this region of nuclei, we change the black sphere into a spheroid of the same volume in order to take into account nuclear deformation. So far, we have obtained the results showing rather small effect from nuclear deformation. This study is now in progress.

(5) Giant Dipole Resonance built on hot rotating nuclei produced during evaporation of light particles from Mo-88 compound nucleus

We succeeded to show that the phonon damping model (PDM by Dang & Arima 1998), which was extended to finite angular momentum in 2012, describes very well the most recent data of the giant dipole resonance (GDR) built on hot rotating nuclei produced during evaporation of light particles from ^{88}Mo compound nucleus by the experimentalists in Krakow and Milano.

(6) Reentrance phenomenon of superfluid pairing in hot rotating nuclei

We applied the FTBCS1 theory (proposed and developed by Dang and Hung in 2008) at finite temperature and angular momentum to study the pairing phenomenon and level density in ^{104}Pd, of which an enhancement of level density at low excitation energy and high angular momentum has been experimentally observed by the experimentalists at BARC (Mumbai). The quantitative agreement between experiment and theory suggests that this enhancement is indeed the first experimental evidence of the reentrance of superfluid pairing in a finite nucleus.

(7) Effects of thermal shape fluctuations and pairing fluctuations on the giant dipole resonance in warm nuclei

We presented the complete formalism based on the microscopic - macroscopic approach for determining the deformation energies and a macroscopic approach which links the deformation to GDR observables. We discussed our results for the nuclei ^{97}Tc, ^{120}Sn, ^{179}Au, and ^{208}Pb, and corroborate with the experimental data available. We showed that the thermal-shape fluctuation model could explain the data successfully at low temperature only with a proper treatment of pairing and its fluctuations.

(8) Experimental investigation on the temperature dependence of the nuclear level density parameter

In collaboration with the experimentalists at the VECC (Kolkata), who studied the effect of temperature T and angular momentum J on the inverse level density parameter k by populating the compound nucleus ^{97}Tc in the reaction ^{4}He + ^{93}Nb at four incident beam energies of 28, 35, 42, and 50 MeV, we compared the T dependence of k for two angular momentum windows with different theoretical predictions as well as with the results of calculations within the FTBCS1. We found that the experimental data are in good agreement with the theoretical calculations at higher J but deviate from all the calculations at lower J.

(9) Review of three-decay study of giant dipole vibration in hot rotating nuclei

In collaboration with D. Chakrabarty and V. Datar, we have written and submitted to The European Physical Journal A – Hadrons and Nuclei an invited review article, entitled “Giant dipole vibration in hot rotating nuclei". The review has been accepted for publication and is now in production.

(10) Gauge symmetry in the large-amplitude collective motion of superfluid nuclei

The adiabatic self-consistent collective coordinate (ASCC) method is a practical method for describing the large-amplitude collective motion in atomic nuclei with superfluidity and an advanced version of the adiabatic time-dependent Hartree-Fock-Bogoliubov theory. We investigate the gauge symmetry in the ASCC method on the basis of the Dirac-Bergmann theory of constrained systems. We have shown that the gauge symmetry in the ASCC method originates from the constraint on the particle number in the collective Hamiltonian, and that it is partially broken by the adiabatic expansion. The validity of the adiabatic expansion under the general gauge transformation is also confirmed.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

S. Yoon, F. Dalfovo, T. Nakatsukasa, and G. Watanabe, "Multiple period states of the superfluid Fermi gas in an optical lattice", New J. Phys.18 (2016) 023011 (10 pages).

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K. Sato, “Gauge symmetry in the large-amplitude collective motion of superfluid nuclei”, Progress of Theoretical and Experimental Physics (2015) 123D01.

(Review)

K. Matsuyanagi, M. Matsuo, T. Nakatsukasa, K. Yoshida, N. Hinohara, and K. Sato, "Microscopic derivation of the quadrupole collective Hamiltonian for shape coexistence/mixing dynamics", Journal of Physics G: Nuclear and Particle Physics 43, 024006 (2016).

[Proceedings]

(Original Papers) *Subject to Peer Review

S. Ebata and T. Nakatsukasa, "Repulsive aspects of pairing correlation in nuclear fusion reaction", JPS Conf. Proc. 6 (2015) 020056 (6 pages).

W. Horiuchi, T. Inakura, T. Nakatsukasa, and Y. Suzuki, "Systematic analysis of total reaction cross sections of unstable nuclei with Glauber theory", JPS Conf. Proc. 6 (2015) 030079 (4 pages).

K. Sato, J. Dobaczewski, T. Nakatsukasa, W. Satula,"Mean-Field Calculation Based on Proton-Neutron Mixed Energy Density Functionals", Proceedings of the Conference on Advances in Radioactive Isotope Science (ARIS2014), Tokyo, Jun. 1-6, 2014, JPS Conference Proceedings 6, 020051 (2015).*

A. Makinaga, S. Ebata, M. Aikawa, N. Furutachi, D. Ichinkholoo, K. Kato, M. Odsuren, V. Devi, N. Otuka, A. Kohama, H. Otsu, and H. Sakurai, “Compilation of Nuclear Reaction Data from RIBF”, Proceedings of the Conference on Advances in Radioactive Isotope Science (ARIS2014), Tokyo, Jun. 1-6, 2014, JPS Conference Proceedings 6, 030135 (2015).

[Book]

(Original Papers) *Subject to Peer Review

海老原充、他多数（中務孝）、朝倉書店、放射化学の事典、2015.

Oral Presentations

[International Conference etc.]

T. Nakatsukasa, "Recent activities in the time-dependent density-fucntional theory", 9th Japan-China Joint Nuclear Physics Symposium (JCNP2015)", November 7-12, 2015, RCNP（大阪府茨木市）.

T. Nakatsukasa, "Isospin invariant energy density functional and its applications", 2015 SKLTP-BLTP Joing Workshop on Physics of Strong Interaction, October 29-November 3, 2015, Guilin, China.

T. Nakatsukasa, "TDDFT studies of nuclear quantum dynamics in small and large amplitudes", XXII Nuclear Physics Workshop “Marie & Pierre Curie”, September 22-27, 2015, Kazimierz-Dolny, Poland.

T. Nakatsukasa, "Problems associated with the symmetry breaking", Progress in and beyond Theoretical Nuclear Physics Laboratory, RIKEN Wako Campus, Wako, Saitama, March 28th, 2016.

A. Kohama, "Systematic studies of total reaction cross sections", Progress in and beyond Theoretical Nuclear Physics Laboratory, RIKEN Wako Campus, Wako, Saitama, March 28th, 2016.

N. Dinh Dang, *Pairing reentrance in hot rotating nuclei*, invited lecture at the XXII Nuclear Physics Workshop “Marie & Pierre Curie”, September 22 – 27, 2015, Kazimierz Dolny, Poland.

N. Dinh Dang, *Effect of thermal fluctuations in the pairing field on the width of giant dipole resonance*, invited lecture at the 5th International conference on “*Collective Motion in Nuclei Under Extreme Conditions*” (COMEX5), September 14 – 18, 2015, Krakow, Poland.

K. Sato, "Proton-neutron mixed density functional calculation with isospin breaking interaction", 2nd International Workshop & 12th RIBF Discussion on Neutron-Proton Correlations. The University of Hong Kong, Jul. 6-9, 2015.

[Domestic Conference]

中務孝、「原子核構造における自発的対称性の破れ」、日本物理学会年会シンポジウム、2016.3.19-22、東北学院大学（宮城県仙台市）.
Kai Wen, 中務孝、「8Be の崩壊経路と集団質量」、日本物理学会年会、2016.3.19-22、東北学院大学（宮城県仙台市）.
佐藤弘一,「超流動原子核の大振幅集団運動におけるゲージ対称性」『日本物理学会第 71 回年次大会』、東北学院大学、2016 年 3 月
佐藤弘一, 「Gauge symmetry in the large-amplitude collective motion of superfluid nuclei」『理研セミナー』、理化学研究所初田量子ハドロン物理学研究室、2016 年 2 月.
佐藤弘一, Jacek Dobaczewski、中務孝、Wojciech Satula,「Isospin breaking term を入れた陽子-中性子混合密度汎関数計算 II」『日本物理学会 2015 年秋季大会』、大阪市立大学、2015 年 9 月.
Koichi Sato, “Gauge symmetry in the large-amplitude collective motion of superfluid nuclei”,『Workshop on many-body correlations in microscopic nuclear model』 尖閣荘(新潟県佐渡市), 2015 年 8 月.

Posters Presentations

[Domestic Conference]

佐藤俊輔, 飯田圭, 小濱洋央, 親松和浩、「反応断面積から探る核構造の質量数依存性」『日本物理学会第 71 回年次大会』学部学生ポスターセッション（合同）、東北学院大学、2016 年 3 月.

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) Baryon-baryon interaction based on lattice QCD
(4) Structure of three- and four-body ^{4}He atom systems

3. Summary of Research Activity

(1) Recently, we observed of neutron-rich system nnΛ as a bound state. To investigate this system, we performed nnΛ+NnΣ three-body coupled channel calculation. Using YN interaction to reproduce observed binding energies for 4_ΛH, 4_ΛHe, and 3_ΛH, we do not find any bound state for nnΛ system which is inconsistent with the data. Now, we propose the experimentalists to perform a search experiment of nnΛ system again.
(2) It is interesting to study the structure of Ar isotope, since we have some superdeformed states (SD) in this Isotope. Within the framework of AMD method, we investigate the structure of SD states. In addition, we study the structure of Ar Λ hypernuclei. Then, we found that Λ-separation energy was dependent on the degree of deformation of core nuclei.
(3) Using several realistic 4He atomic potential, we calculate Efimov spectra of trimer and tetramer systems of 4He. Our result shows an extension of the universality in Efimov trimers that the appearance of the repulsive barrier at the three-body hyperradius $R_3 \approx 2\ W_{rvd}$ makes the critical scattering lengths independent of the short-range details of the interactions as reported in the literature and also in the present work for the 4He trimer with the realistic potentials.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

E. Hiyama, M. Isaka, M. Kimura, T. Myo., T. Motoba, "Resonant states of the neutron-rich Λhypernucleus $^{7}{}_{\Lambda}$He ", Physical Review C, 91, 054316 (2015).*

M. Isaka, M. Kimura, "Impurity effects of the Λ particle on the 2α cluster states of ^{9}Be and ^{10}Be", Physical Review C, 92, 044326 (2015).*

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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]

In 2015 the final neutral pion double spin asymmetry results at central rapidity and the highest collisions energies of 510 GeV have been successfully published for the PHENIX experiment. They very strongly confirm earlier global fits that the gluon spin contribution to the proton spin is substantial and likely the dominating contribution. The increased collision energy extends the accessed gluon momentum fraction down to previously inaccessible regions. Ongoing measurements of more forward hadrons will extend it to the lowest values accessible before an eventual electron-ion collider. 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 being prepared for publication.

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 overall three-dimensional structure of the nucleon. These phenomena in itself have become a major field of research as the dynamics of the strong interaction is being probed. One recent surprise was the behavior of very forward neutron asymmetries when colliding transversely polarized protons with protons, Al and Au ions as happened during the 2015 RHIC running period.

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 can measure hadrons, photons, electrons, muons and jets. Especially forward jet and Drell-Yan (quark-antiquark annihilation into lepton pairs) transverse single spin asymmetries are the main goal of these upgrades. 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.

(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 350MeV, far above the expected transition temperature Tc~170MeV, 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 v2 and v3. Using the same "virtual photon" method used in the thermal photon measurement, measurement of direct photons in Cu+Cu collision is on-going by a JRA student.

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 pT>4 GeV/c, but the suppression factor is smaller than that of charm decay electrons for 3<pT<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. The analysis of this large dataset is on-going.

In Wako we are operating a cluster computer system 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.

The 1.7 PB of data produced by the PHENIX experiment was reduced to 0.9PB and relocated to the new Hierarchical Storage system (HSM) which is a part of HOKUSAI-GreateWave supercomputer system operated by the Advanced Center for Computing and Communication (ACCC).

(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 a cooperation with Japanese industries, large GEM foils (30cm x 30cm, the world-largest size at that time) were newly developed. Through the beam tests at ELPH, J-PARC, LEPS, and RIKEN RIBF, the followings are achieved and proven; 1) required position resolution of 0.1 mm, and 2) stable operation under the hadron-background environment, typically 30 times higher rate than that expected in the J-PARC experimental area. The design parameters of the GTR and HBD were finalized and the mass-production of GEM is started. A beam-test result on the small-pad readout of HBD, which brings higher pion-rejection performance, is published. For the electron ID, lead-glass calorimeter (LG) is also used. The lead-glass blocks are recycled from the TOPAZ experiment.

For the readout electronics of GEM, a preamp using the APV25 ASIC chip is developed, tested, and mass production is performed. For the digitization and the data transfer, the SRS system developed by CERN is also tested and adopted. Another preamp-ASIC for the trigger signal from GEM foils is also developed in cooperation with the KEK e-sys group, and test is still on-going. Trigger logic boards, which are developed by Belle II collaboration, are tested with the firmware customized for this experiment. We have joined the CERN-RD51 collaboration for the joint-development of the GEM & readout technology.

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 ready to construction. For the readout/trigger electronics modules, the mass production will start after some remained tests. Due to the budgetary limitation, we aim to install a part of detectors, eight modules of GTR/HBD/LG out of 26 modules in full installation, at the beginning of experiment. The construction of the beam line is finally funded in KEK and started at J-PARC in 2013. However, original completion date (March 2016) has been extended. Only the spectrometer magnet is re-assembled and located at the proper position in the planned beam line in October 2015, which uses new pole pieces and some additional parts fabricated in 2011-12 using a Grant-in-Aid.

(4) Detector development for PHENIX experiment

After 7 years of hard work, we installed the silicon vertex tracker (VTX) into the PHENIX detector at RHIC in December 2010. VTX is a 4-layer silicon tracker to measure heavy quark (charm and bottom) production in p+p and heavy ion collisions at RHIC. The detector was funded by RIKEN and the US DOE. We and RIKEN BNL Research Center were responsible for construction and operation of the inner two pixel detectors.

Sea quark polarization measurement via W-boson production is one of the highlight of PHENIX spin program. In order to detect high momentum muons from W-decay, we developed the momentum-sensitive trigger system for the PHENIX forward muon arms with collaborators from KEK, Kyoto and Rikkyo University. Together with new hadron absorber, W-boson measurement was successfully carried out using the new high momentum trigger. We accumulated high-integrated luminosity of about $250pb^{-1}$ in Run13 and almost achieved our goal. The intensive analysis is underway towards the publication. Preliminary results were released in October 2014 and the analysis is at the final stage towards the publication. Besides W detection, the trigger system has been also operated for heavy flavor meson detection in conjunction with a forward vertex (FVTX) detector.

A silicon strip tracker R&D project for sPHENIX was launched in 2014. The high momentum resolution tracker system is the essential component of the temperature measurements using upsilon 3 states. This is one of 3 physics high-lighted goals of sPHENIX. Prototyping silicon sensors and their readout high-density integrated circuits are currently ongoing. The readout chip is to be employed FPHX chip, which was developed for PHENIX-FVTX detector. The low power consumption of the chip, i.e. 1/5th of SVX4 chip used for pixel detector is the advantage so that the cooling system can be designed rather simple to reduce the material budget. The major technical challenge of the silicon strip tracker is to minimize the material budget in order to achieve the good momentum resolution.

(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 at present or in the future. In 2014, we installed a new LIS which provides various species of singly charged ions to the RHIC-AGS complex. The commissioning was very successful and we have delivered C, Al, Ti, Si, Ta and Au ions. We also demonstrated fast switching of ion species within one second. Last year we upgraded this LIS to provide gold beam and other lighter ion beams simultaneously by installing another laser system. 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.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

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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 (μSR). Injecting negatively charged muon to hydrogen gas, muonic hydrogen atom (μp) is formed. We are planning to measure μp 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 $K^{bar}N$ interaction precisely, clarify the nature of kaon in nuclei, and Λ(1405) that could be K^-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 $\langle K^-pp\rangle$ bound state. One of the most interesting features of the kaonic nucleus is the strong attraction of the $K^{bar}N$ 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 $\langle K^-pp\rangle$ bound state by the in-flight ^{3}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 $\langle K^-pp\rangle$. 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 $6x10^9$ kaons on ^{3}He target, corresponding to a ~1% of the approved proposal. We successfully obtained semi-inclusive ^{3}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}He(K^-, Λp) n events. To derive more information on the $K^{bar}N$ interaction by the exclusive measurement, we carried out the second physics data-taking in November-December, 2015 with $43x10^9$ kaon ^{3}He target, in which 7 times more data was accumulated. We have been analyzing the new data set, especially focusing on the ^{3}He(K^-, Λp)n channel. This analysis would give us the new insight of the $K^{bar}N$ interaction below the mass threshold.

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

Simultaneously with the above experiment (1), 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 mm^2. 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 $K^{bar}N$ 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 the origin of hadron mass. The precision data set stringent constraints on the chiral condensate at nuclear medium. We are presently preparing for the precision measurement at RIBF. The first measurement is aiming at ^{121}Sn as the first step for the systematic spectroscopy. A pilot experiment was performed in 2010, and showed a very good performance of the system. We have been analyzing the data to improve experimental setup of the pionic atom spectroscopy at the RIBF in RIKEN. We expect to achieve better experimental resolution with much reduced systematic errors.

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). From this measurement, we can access information about partial restoration of chiral symmetry in nuclear media via the binding energy and decay width of η'-nuclear bound state.

(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 (μSR).

(2-A) Condensed matter/materials studies with μSR

We have opened the new μSR spectrometer named CHRONUS to collaborative experiments from the May-June cycle in 2014. To have higher affinity on μSR studies with the ISIS muon facility, common data acquisition (DAQ) system with the ISIS standard DAQ (DAEII) and the front-end control system (SECI) have been installed and optimized along with other equipment in Port-4. The same DAQ and control systems will be installed in Port-2 as well. Thus, we can perform two independent μSR experiments in Port-2 and 4 at the same time, switching double-pulse to share beam between the two.

Among our scientific activities on μSR studies from year 2014 to 2016, following six subjects of material sciences are most important achievements at the RIKEN-RAL muon facility:

1) Novel superconducting state having partial nodal gaps in the one-dimensional organic superconductor λ-$[BETS]_2GaCl_4$.
2) Tiny magnetic moments and spin structures of Ir^{4+}, Nd^{3+} and Sm^{3+} in pyrochlore iridates $Nd_2Ir_2O_7$ and $Sm_2Ir_2O_7$.
3) Magnetism and spin structure in superoxide CsO_2 and NaO_2.
4) Magnetic properties of the nano-cluster gold in the border of macro- and micro- scale
5) Coexistence of short-range ordered state and superconductive state in high-T_C superconducting cuprate with the T' structure.
6) 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 μSR 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 μSR 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 had been working on the "ultra-slow muon" generation based on the following technique, namely, positive muon beam with thermal energy has been produced by laser ionization of muoniums in vacuum (bound system of μ^+ and electron) emitted from the hot tungsten surface by stopping "surface muon beam" at Port-3. However, the muon yield and obtained emittance was far from satisfactory, and remained to be far from any kind of realistic application.

Therefore, in this mid-term, we are developing two key components first, 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. 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:YGAG, which has an ideal wavelength property for laser amplification to generate Lyman-α by four-wave mixing in Kr gas cell. We already achieved 5 times increase of Lyman-α generation than before. Once the large-size crystal for the main amplifier is completed, the new laser will ionize muoniums 100 times more efficiently for slow muon beam generation. In order to fully apply these new developments to slow muon generation, we designed and manufactured a new ultra-slow muon source chamber dedicated for silica aerogel with new features such as spin manipulation. The beam test started on Sep 2015.

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. Port-1, previously used for muon catalysed fusion, is now being converted for the dedicated use by the proton radius measurement involving laser.

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Taehyung KIM (Tokyo Tech.)
Yuki NOZAWA (Kyoto Univ.)
Saidah Sakinah MOHD TAJUDIN (Universiti Sains Malaysia)
Fahmi ASTUTI (Hokkaido Univ.)

Assistants

Yoko FUJITA
Mitsue YAMAMOTO (May 1, 2014 –)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

A.D. Hillier, D.McK. Paul, K. Ishida, “Probing beneath the surface without a scratch — Bulk non-destructive elemental analysis using negative muons”, Microchemical Journal, 125, 203-207 (2016). *

P. Bakule, O. Sukhorukov, K. Ishida, F.L. Pratt, D. Fleming, T. Momose, Y. Matsuda, and E. Torikai, "First Accurate Experimental Study of Mu Reactivity from a State-Selected Reactant in the Gas Phase: the Mu + H2{1} Reaction Rate at 300 K", J. Phys. B (At. Mol. Opt.) 48, 045204 (2015). *

T. Matsuzaki, K. Ishida, M. Iwasaki, “High-pressure solid hydrogen target for muon catalyzed fusion”, Journal of Radioanalytical and Nuclear Chemistry, DOI 10.1007/s10967-015-4080-y *

Rakesh Mohan Das, Souvik Chatterjee, Masahiko Iwasaki, and Takashi Nakajima, “Ionization efficiencies of Doppler-broadened atoms by transform-limited and broadband nanosecond pulses: one-photon resonant two-photon ionization of muoniums”, J. Opt. Soc. Am. B 32, 1237-1244 (2015). *

T.Hashimoto et al., “Search for the deeply bound K-pp state from the semi-inclusive forward-neutron spectrum in the in-flight K- reaction on helium-3”, Prog. Theor. Exp. Phys., 061D01 (2015). DOI 10.1093/ptep/ptv076 *

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Masaharu Sato, Katsuhiko Ishida, Masahiko Iwasaki, Sohtaro Kanda, Yue Ma, Yasuyuki Matsuda, Teiichiro Matsuzaki, Katsumi Midorikawa, Yu Oishi, Shinji Okada, Norihito Saito, Kazuo Tanaka and Satoshi Wada, “Laser Spectroscopy of Ground State Hyperfine Splitting Energy of Muonic Hydrogen”,Proc. 2nd Int. Symp. Science at J-PARC, JPS Conf. Proc.8 , 025005 (2015). *

R.Kitamura, G.Beer, K.Ishida, M.Iwasaki, S.Kanda, H.Kawai, N.Kawamura, W.Lee, S.Lee, G.M.Marshall, Y.Matsuda, T.Mibe, Y.Miyake, S.Nishimura, Y.Oishi, S.Okada, A.Olin, M.Otani, N.Saito, K.Shimomura, P.Strasser, M.Tabata, D.Tomono, K.Ueno, E.Won and J-PARC muon g-2/EDM collaboration, “Studies on Muonium Production from Silica Aerogel with Substructure for the Muon g-2/EDM Experiment”, Proc. 2nd Int. Symp. Science at J-PARC, JPS Conf. Proc. 8, 025016 (2015).*

H. A. Torii, M. Aoki, Y. Fukao, Y. Higashi, T. Higuchi, H. Iinuma, Y. Ikedo, K. Ishida, M. Iwasaki, R. Kadono, O. Kamigaito. S. Kanda, D. Kawall, N. Kawamura, A. Koda, K. M. Kojima, K. Kubo, Y. Matsuda, T. Mibe, Y. Miyake, T. Mizutani, K. Nagamine, K. Nishiyama, T. Ogitsu, R. Okubo, N. Saito, K. Sasaki, K. Shimomura, P. Strasser, M. Sugano, M. Tajima, K. S. Tanaka, D. Tomono, “Precise Measurement of Muonium HFS at J-PARC MUSE”, Proc. 2nd Int. Symp. Science at J-PARC, JPS Conf. Proc. 8, 025018 (2015).*

K. Ninomiya, M. K. Kubo, P. Strasser, T. Nagatomo, Y. Kobayashi, K. Ishida, W. Higemoto, N. Kawamura, K. Shimomura, Y. Miyake, T. Suzuki, A. Shinohara, T. Saito, “Elemental Analysis of Bronze Artifacts by Muonic X-ray Spectroscopy”, Proc. 2nd Int. Symp. Science at J-PARC, JPS Conf. Proc., 8, 033005 (2015).*

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[International Conference etc.]

K. Ishida, "Development of ultra-slow muon source based on room temperature muonium production target and its application to muon g-2/EDM measurement", International USMM & CMSI Workshop: Fronties of Materials and Correlated Electron Science - from Bulk to Thin Films and Interface, Tokyo, Jan 2016.

Y.Sada (J-PARC E15 collaboration), “Exclusive Analysis of the in-flight 3He(K-, Λp)n_missing reaction to search for the KbarNN bound state”, 21st International Conference on Few-Body Problems in Physics (FB21), Chicago, Illinois, USA, May 2015.

F.Sakuma (J-PARC E15 collaboration), “Recent results of the KbarNN search via the in-flight 3He(K-,n) reaction at J-PARC”, The 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sendai, Japan, Sep 2015

T.Hashimoto (J-PARC E15 collaboration), “Kaonic nuclei searchvia the in-flight (K-, n) reaction on helium-3”, ELPH workshop C013, Meson Production and Meson-Baryon Interaction (MPMBI), Sendai, Sep 2015

H.Ohnishi (J-PARC E15 collaboration), “Recent results of the experiment to search for KbarNN bound state via the in-fight 3He(K-,N) reactions at J-PARC”, ECT*, Frontiers in hadron and nuclear physics with strangeness and charm, Oct 2015

F.Sakuma (J-PARC E15 collaboration), “Experimental Investigations of the KbarN Interaction at J-PARC K1.8BR”, The 31st Reimei WorkShop on Hadron Physics in Extreme Conditions at J-PARC, Tokai, Jan 2016

T.Yamaga (J-PARC E15 collaboration), “Recent result of an exclusive 3He(K-,Lp)n analysis to search for KbarNN bound state”, International workshop on "Progress on J-PARC hadron physics in 2016", Mar 2016

S.Okada (HEATES and J-PARC E17 collaborations), “High-resolution Exotic-Atom x-ray spectroscopy with Transition-Edge-Sensor microcalorimeters”, Jagiellonian Symposium on Fundamental and Applied Subatomic Physics, June 2015

S.Okada (HEATES collaboration), “Hadronic-atom X-ray spectroscopy with cryogenic detectors”, ECT*, Frontiers in hadron and nuclear physics with strangeness and charm, Oct 2015

S.Okada, “Kaonic atom factory at J-PARC”, International workshop on physics at the extended hadron experimental facility of J-PARC, Mar 2016

T.Hashimoto (HEATES and J-PARC E62 collaborations), “Kaonic atom x-ray spectroscopy with superconducting microcalorimeters”, The 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sendai, Japan, Sep 2015

[Domestic Conference]

北村遼，深尾祥紀，石田勝彦，河村成肇，近藤恭弘，三部勉，三宅康博，大谷将士，Patrick Strasser，齊藤直人，下村浩一郎 他 J-PARC muon g-2/EDM コラボレーション: ″J-PARC ミューオン g-2/EDM 精密測定実験のためのミューオン再加速試験に向けた低速ミューオン源開発の準備状況″，日本物理学会第 70 回年次大会、早稲田大学、東京、3 月(2015)

山我拓巳(J-PARC E15 collaboration)，”3He(in-flight K-,n)反応を用いた反 K 中間子束縛状態探索のための水素・重水素標的を用いた素過程解析”，日本物理学会秋季大会，大阪市立大学，大阪 9 月(2015)

山我拓巳(J-PARC E15 collaboration)，”J-PARC K1.8BR ビームラインに於ける 3He(K-,n)反応を用いた KbarNN 縛状態の探索”，日本物理学会第 71 回年次大会，東北学院大学，3 月(2016)

橋本直(HEATES and J-PARC E62 collaboration), ”超伝導遷移端マイクロカロリメータを用いた K 中間子原子 X 線精密分光実験 (2)”, 日本物理学会秋季大会, 大阪市立大学, 大阪 9 月(2015)

橋本直(J-PARC E15/E62 collaboration), “J-PARC K1.8BR における K-ビームを用いた KbarN 相互作用の研究”, 滞在型研究会＠JPARC「原子核媒質中のハドロン研究 III」, J-PARC, 10 月(2015)

Posters Presentations

[International Conference etc.]

S. Okada, P. Bakule, G. Beer, J. Brewer, Y. Fujiwara, K. Ishida, M. Iwasaki, S. Kanda, H. Kawai, N. Kawamura, R. Kitamura, W. Lee, Y. Ma, G. Marshall, Y. Matsuda, T. Mibe, Y. Miyake, S. Nishimura, Y. Oishi, A. Olin, M. Otani, N. Saito, M. Sato, K. Shimomura, P. Strasser, M. Tabata, D. Tomono, K. Ueno, E. Won, K. Yokoyama, "Ultra-slow muon production with room-temperature thermal-muonium-emitting material", The international workshop on future potential of high intensity proton accelerator for particle and nuclear physics (HINT2015), Oct 2015

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. 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 the DOE RHIC Spin Group, the RIKEN Spin Group at BNL, and the PHENIX heavy ion groups. 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) PHENIX detector upgrades

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

Mituru KISHIMOTO (Administration Manager, Nishina Center Planning Office)
Yasutaka AKAI (Deputy Administration Manager, Nishina Center Planning Office, Jan. 1, 2015 –)
Colleen MICHAEL (Administrative Assistant)
Pamela ESPOSITO (Administrative Assistant)
Taeko ITO (Administrative Assistant, – Apr.30, 2015)
Tammy STEIN (Sep. 8, 2015 – Jan. 31, 2016)

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, susceptibilies 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)
Larry McLERRAN (– Oct. 30, 2015)
Dmitri KHARZEEV (Nov. 1, 2015 –)

Deputy Group Leader
Robert PISARSKI (concurrent：Deputy Director, RBRC)

RBRC Researchers
Jinfeng LIAO (RHIC Physics Fellow)
Fedor BEZRUKOV ((RHIC Physics Fellow, – Dec. 31, 2015)
Ho-Ung YEE (RHIC Physics Fellow)
Akihiko MONNAI (Special Postdoctoral Researcher)
Lin SHU (Foreign Postdoctoral Researcher, – Aug. 28, 2015)
Sergey SYRITSYN (Foreign Postdoctoral Researchers, - Aug. 28, 2015)
Daniel PITONYAK (Research Associates)
Vladimir SKOKOV

Visiting Scientists
Thomas BLUM (Univ. of Connecticut)
Taku IZUBUCHI (concurrent; Computing Gr.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

Yoshitaka Hatta, Akihiko Monnai, Bo-Wen Xiaoc ”Elliptic flow difference of charged pions in heavy-ion collisions” Nuclear Physics A Volume 947, March 2016, Pages 155–160*
Y. Koike, D. Pitonyak, Y. Takagi, S. Yoshida ” Twist-3 fragmentation effects for ALT in light hadron production from proton–proton collisions” Physics Letters B, Volume 752, 10 January 2016, Pages 95–101*
Larry McLerran, Vladimir V. Skokov ”The Eccentric Collective BFKL Pomeron” arXiv:1407.2651 *
A Monnai, B Schenke ”Pseudorapicity correlations in heavy ion collisions from viscous fluid dynamics”- Physics Letters B, Volume 752, 10 January 2016, Pages 317–321 *
K Fukushima, K Hattori, HU Yee, Y Yin ”Heavy Quark Diffusion in Strong Magnetic Fields at Weak Coupling and Implication to Elliptic Flow” arXiv:1512.03689v2 [hep-ph] 20 Apr 2016
KA Mamo, HU Yee ”Spin Polarized Photons from Axially Charged Plasma at Weak Coupling: Complete Leading Order ” arXiv:1512.01316v3 [hep-ph] 11 Apr 2016
Yuri V. Kovchegov, Daniel Pitonyak, Matthew D. Sievert ”Helicity Evolution at Small-x” arXiv:1511.06737v2 [hep-ph] 12 Jan 2016
Philipp Gubler, Koichi Hattori, Su Houng Lee, Makoto Oka, Sho Ozaki, Kei Suzuki ”D mesons in a magnetic field”arXiv:1512.08864v2 [hep-ph] 28 Mar 2016
Koichi Kanazawa, Yuji Koike, Andreas Metz, Daniel Pitonyak, Marc Schlegel ”Operator constraints for twist-3 functions and Lorentz invariance properties of twist-3 observables” arXiv: 1512.07233v2 [hep-ph] 16 Mar 2016
A Bzdak, V Skokov ”Multi-particle eccentricities in collisions dominated by fluctuations” Nuclear Physics A Volume 943, November 2015, Pages 1–8*
Dmitri E. Kharzeev ”Topology, magnetic field, and strongly interacting matter” arXiv:1501.01336v1 [hep-ph] 6 Jan 2015
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Gustavo M. Monteiro, Alexander G. Abanov, and Dmitri E. Kharzeev ”Magneto transport in Dirac metals: chiral magnetic effect and quantum oscillations” Phys. Rev. B 92, 165109 – Published 8 October 2015*
Robert D. Pisarski, Vladimir V. Skokov ”A chiral matrix model of the semi-Quark Gluon Plasma in QCD” arXiv:1604.00022v1 [hep-ph] 31 Mar 2016
Fedor Bezrukov, Dmitry Gorbunov “On the applicability of approximations used in calculation of spectrum of Dark Matter particles produced in particle decays” arXiv:1412.1341v2 [hep-ph] 6 Dec 2015
Xu, Jiechen; Liao, Jinfeng; Gyulassy, Miklos ”Bridging soft-hard transport properties of quark-gluon plasmas with CUJET3.0”Journal of High Energy Physics, Volume 2016, article id.169, 50 pp.*
L McLerran, VV Skokov ”Finite numbers of sources, particle correlations and the Color Glass Condensate” Nuclear Physics A Volume 947, March 2016, Pages 142–154*
Larry McLerran, Vladimir V. Skokov ”The MV Model of the Color Glass Condensate for a Finite Number of Sources Including Coulomb Interactions”arXiv:1604.05286v1 [hep-ph] 18 Apr 2016
Shiyong Li, Kiminad A. Mamo, Ho-Ung Yee ”Jet quenching parameter of quark-gluon plasma in strong magnetic field: perturbative AdS/CFT correspondence”arXiv:1605.00188v2 [hep-ph] 31 May 2016
É. Aubourg and others "Cosmological implications of baryon acoustic oscillation measurements" Phys. Rev. D92, 123516 (2015).
F. Bezrukov and M. Shaposhnikov "Why should we care about the top quark Yukawa coupling?" J. Exp. Theor. Phys. 120, 335-343 (2015).
F. Bezrukov and M. Shaposhnikov "Inflation, LHC and the Higgs boson" Int. J. Mod. Phys. A30, 1545001 (2015).
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C. Gale, Y. Hidaka, S. Jeon, S. Lin, J.-F. Paquet, R. D. Pisarski, D. Satow, V. V. Skokov and G. Vujanovic "Production and Elliptic Flow of Dileptons and Photons in a Matrix Model of the Quark-Gluon Plasma" Phys. Rev. Lett. 114, 072301 (2015).

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K. Kanazawa, Y. Koike, A. Metz and D. Pitonyak "Transverse single-spin asymmetries in p^↑ p to γ X from quark-gluon-quark correlations in the proton" Phys. Rev. D91, 014013 (2015).
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D. E. Kharzeev, R. D. Pisarski and H.-U. Yee "Universality of plasmon excitations in Dirac semimetals" Phys. Rev. Lett. 115, 236402 (2015).
K. A. Mamo and H.-U. Yee "Gradient Correction to Photon Emission Rate at Strong Coupling" Phys. Rev. D91, 086011 (2015).
K. A. Mamo and H.-U. Yee "Thermalization of Quark-Gluon Plasma in Magnetic Field at Strong Coupling" Phys. Rev. D92, 105005 (2015).
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L. McLerran "Lessons learned and ideas formed from early studies of pA collisions" Annals Phys. 352, 52-58 (2015).
A. Monnai "Effective distributions of quasiparticles for thermal photons" Phys. Rev. C92, 014905 (2015).
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J.-P. Blaizot, Y. Jiang and J. Liao "Gluon transport equation with effective mass and dynamical onset of Bose–Einstein condensation" Nucl. Phys. A949, 48-70 (2016).
J.-P. Blaizot and J. Liao "Gluon Transport Equations with Condensate in the Small Angle Approximation" Nucl. Phys. A949, 35-47 (2016).
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K. Hattori, T. Kojo and N. Su "Mesons in strong magnetic fields: (I) General analyses" Nucl. Phys. A951, 1-30 (2016).
I. Iatrakis and D. E. Kharzeev "Holographic entropy and real-time dynamics of quarkonium dissociation in non-Abelian plasma" Phys. Rev. D93, 086009 (2016).
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M. A. Stephanov and H.-U. Yee "No-Drag Frame for Anomalous Chiral Fluid" Phys. Rev. Lett. 116, 122302 (2016).
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(Review)

Larry McLerran, Vladimir V. Skokov ”The Eccentric Collective BFKL Pomeron” arXiv:1407.2651
Adrian Dumitru, Tuomas Lappi, and Vladimir Skokov ”Distribution of Linearly Polarized Gluons and Elliptic Azimuthal Anisotropy in Deep Inelastic Scattering Dijet Production at High Energy” Phys. Rev. Lett. 115, 252301 – Published 17 December 2015
Fedor Bezrukov, Javier Rubio, and Mikhail Shaposhnikov ”Living beyond the edge: Higgs inflation and vacuum metastability” Phys. Rev. D 92, 083512 – Published 13 October 2015
Dmitri E. Kharzeev and Eugene M. Levin ”Color Confinement and Screening in the θ Vacuum of QCD”Phys. Rev. Lett. 114, 242001 – Published 16 June 2015

[Proceedings]

(Original Papers) *Subject to Peer Review

Koichi Kanazawa, Yuji Koike, Andreas Metz, Daniel Pitonyak ”New Collinear Twist-3 Analysis of Transverse SSA: Toward a Solution for the Sign-Mismatch Problem” Few-Body Systems September 2015, Volume 56, Issue 6, pp 343–348 *
Andreas Metz, Daniel Pitonyak, Andreas Schäfer, Marc Schlegel, Werner Vogelsang ,Jian Zhou ”Transverse Single-Spin Asymmetries: Challenges and Recent Progress” Few-Body Systems September 2015, Volume 56, Issue 6, pp 331-336 *
DE Kharzeev, J Liao, SA Voloshin, G Wang ”Chiral magnetic and vortical effects in high-energy nuclear collisions-A status report”Progress in Particle and Nuclear Physics Volume 88, May 2016, Pages 1–28
D Pitonyak, K Kanazawa, Y Koike, A Metz ”AN in single-inclusive particle production from proton-proton collisions”QCD Evolution Workshop Newport News, VA May 26, 2015
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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 pertrubative 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 calaution for $K\rightarrow\pi\pi$ decay, ε'/ε, or hadronic contributions go 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.

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 $(g\text{-}2)_\mu$. These calculation for ε'/ε, hadronic light-by-light of (g-2), 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 2.1 σ. Hadronic Light-by-light contribution to $(g\text{-}2)_\mu$ 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; 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.

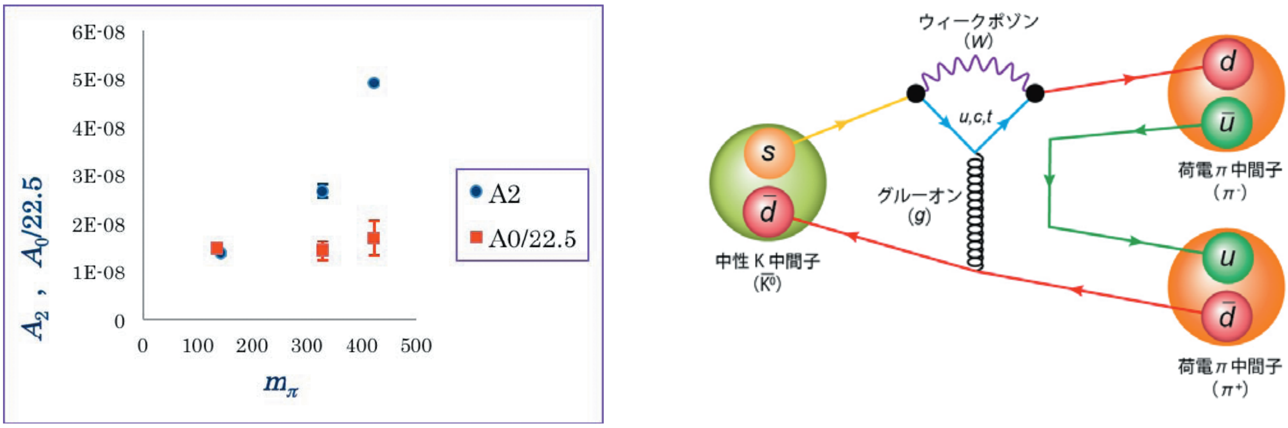

Figure : Computed results of K→ $\pi\pi$ decay amplitudes, isospin two, A_2, and isospin zero A_0 divided by 22.5 (left), the schematic diagram of the decay (left).

Theme	Significant Outcomes	Expected Impacts & Extensions
(a) DWF QCD ensemble generation and measurements of basic quantities.	hadron spectrum, f_π, f_K, K_{l3}, 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.* $K \to \pi\pi$ amplitudes
(c) Computational Algorithms, Software, and Machines	Fast and Cost-Effective Computing All-Mode Averaging (AMA) PhySyHCAl	Unprecedented precision and new physical quantities (see below)
(d) K physics	K_{l3}, $\Delta I = 1/2, 3/2$, $K \to \pi\pi$ amplitudes, ϵ'/ϵ $K_L - K_S$ Mass Difference	New constraints *e.g.* on CKM from rare Kaon decay $K \to \pi\nu\bar{\nu}$
(e) B physics	Matrix elements for (semi-)leptonic decays and $B^0 - \overline{B^0}$ 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: Summery of current physics program and their impacts

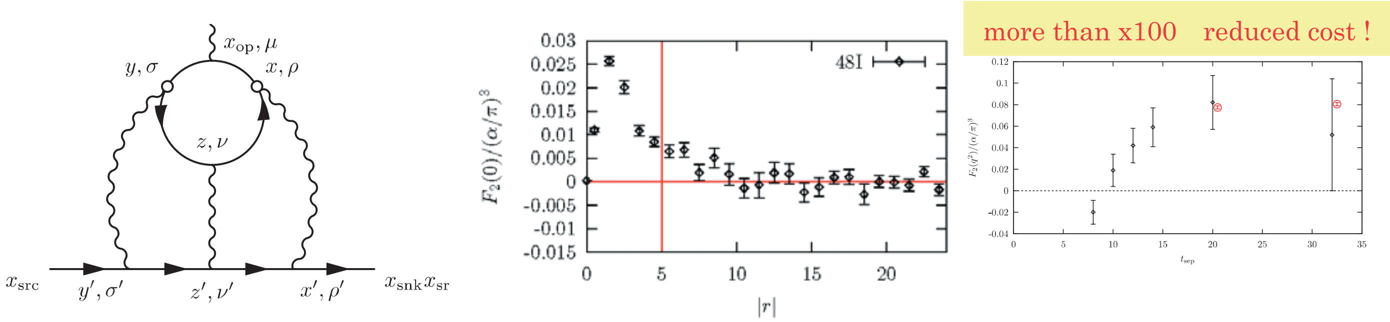

Figure: Hadronic Light-by-light contribution to muon's anomalous moment, diagram, integrand, results, which is improved by more than two order of magnitudes compared to previous calculation.

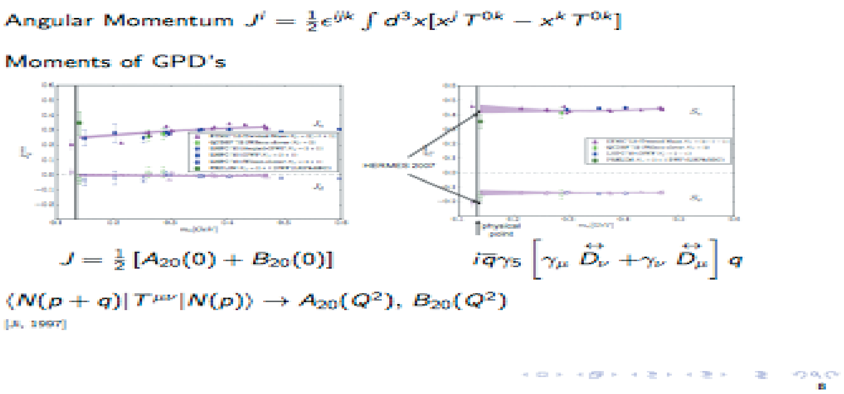

Figure: Preliminary results for Nucleon's Angular momentum (Moments of Generalized Parton Distributions)

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, zMobius 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.

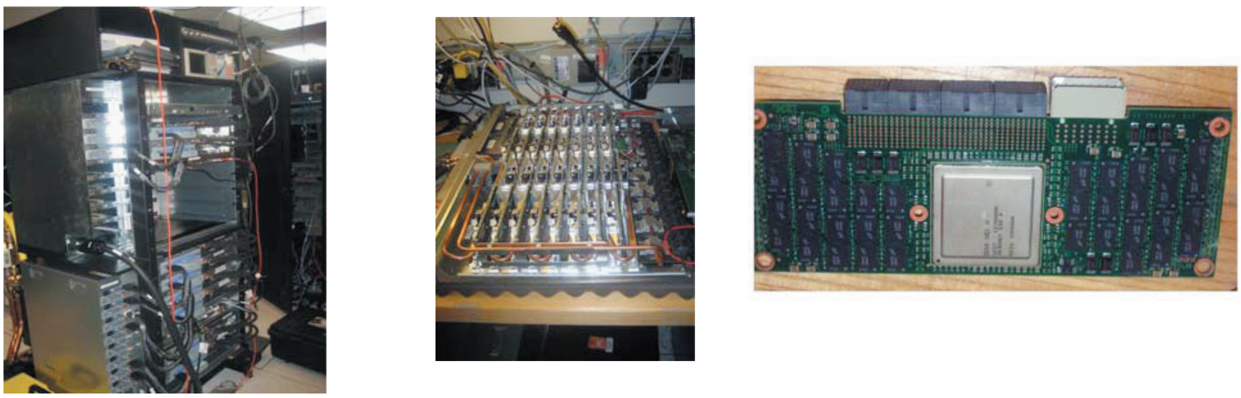

Fig. The rack, motherboard, and chip of QCDCQ

Members

Group Leader (Lab. Head)
Taku IZUBUCHI

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Thomas BLUM (Univ. of Connecticut)
Chulwoo JUNG (BNL)
Christoph LEHNER (BNL)
Meifeng LIN (Yale Univ.)
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Shigemi OHTA
Eigo SHINTANI (concurrent, Jul. 1, 2015 -, RIKEN AICS)
Sergey SYRITSYN (Thomas Jefferson National Laboratory)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

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Shigemi Ohta "Some nucleon isovector observables from 2+1-flavor domain-wall QCD at the physical pion mass" The 33rd International Symposium on Lattice Field Theory 14 -18 July 2015 Kobe International Conference Center, Kobe, Japan

Sergey Syritsyn "Nucleon Structure on a Lattice at the Physical Point" Journal of Physics: Conference Series, Volume 640, conference 1

[Book]

(Original Papers) *Subject to Peer Review

Brian C. Tiburzi "Chiral Perturbation Theory", Lattice QCD for Nuclear Physics, Volume 889 of the series Lecture Notes in Physics pp 107-152, 2014/9/18

Oral Presentations

[International Conference etc.]

T. Blum "Progress on the muon anomalous magnetic momen from lattice QCD" Plenary talk (ChiralDynamics15)

T. Blum "Precision EW calculations for future experiments" Invited talk (Aspen Winter Conference on Particle Physics 2016)

T. Blum "hadronic contributions to the muon g-2" Invited talk (DPF-APS April Meeting 2016)

N. Christ, "Lattice QCD calculation of direct CP violation and long distance effects in kaon mixing and rare decays" Plenary talk (Flavor Physics & CP Violation, Nagoya, May 2015)

N. Christ, "Using high performance computing to relate asymmetries in particle decays and Physics at the highest energies", Invited talk, (Higgs Symposium, Edinburgh, Jan 2015)

T. Izubuchi, "Recent results of Lattice QCD using chiral quarks" Invited talk, Symposium on Quarks to Universe in Computational Science (QUCS 2015) November 4 -8 (talk November 4) 2015 , Nara, Japan

T. Izubuchi, "Inclusive tau decay and Lattice QCD" Invited talk, Kavli Institute for Theoretical Physics, "Lattice Gauge Theory for the LHC and Beyond" September 7 - 27 (talk on Sep 23), 2015

T. Izubuchi, "Anomalous magnetic moment of the muon" Plenary talk, Mainz Institute for Theoretical Physics workshop "Fundamental Parameters from Lattice QCD" August 29 - September 5 (talk on Sep 1), 2015

T. Izubuchi, "g-2 LbL" Invited talk, Benasque workshop "High Precision QCD at low energy" August 2-12 (talk on Aug 5), 2015

T. Izubuchi, "Latice QCD moments - g-2 and nEDM-" Plenary talk, The 33rd International Symposium on Lattice Field Theory, Kobe, Japan July 14-18, 2015 (talk on July 14)

T. Izubuchi, "Nucleon Structures using Lattice QCD" Invited talk, April 8-10 (talk on April 9), 2015, The 6th workshop of topical group on hadronic physics, APS, Baltimore, MD

T. Izubuchi, "Introduction to forefront research topics at zero temperature Lattice Gauge Theory" Six 1.5-hours-long invited lectures Mar 16-20, 2015, The 4th Huada QCD school on Lattice QCD

1. General Introduction
2. Chiral Fermion 1
3. Chiral Fermion 2
4. Chiral Fermion 3
5. Algorithm
6. Particle Physics applications

T. Izubuchi, "All-mode averaging, zMobius, and their possible applications including DWF measurements on GPU" Invited talk, CCS-BNL LGT2015 workshop, Mar 12-13, 2015, Tsukuba Univ, Tsukuba, Japan

T. Izubuchi, "Nucleon's Electric Dipole Moment from quark's chromo EDM operator" Invited talk, May 1-2 (talk on May 1), 2015, USQCD All hands meeting, FNAL, IL

E. Neil, "New Ideas for the Composition of Dark Matter" Plenary, KITP Blackboard Talk (Lattice Gauge Theory for LHC and Beyond), August 2015

S. Meinel, "Lattice progress for semileptonic b decays", Invited talk (Implications of LHCb measurements and future prospects, CERN, 2015)

S. Meinel, "Hints for physics beyond the Standard Model in decays of beauty quarks", Colloquium (University of Utah, 2015)

S. Meinel, "Determination of $|V_{ub}/V_{cb}|$ using baryonic decays", Invited talk (Brookhaven Forum 2015)

S. Meinel, "Rare b decays", Invited talk (LHP V, 2015)

S. Meinel, "Determination of $|V_{ub}/V_{cb}|$ using baryonic decays", Plenary talk (Lattice 2015)

S. Meinel, "Rare b decays and lattice QCD", Invited talk (CIPANP 2015)

S. Meinel, "Lattice QCD and the search for new physics using beauty quarks", Invited talk (APS Four Corners Meeting, 2014)

C. Kelly, "Kaon decays on the lattice", Plenary talk (5th KEK Flavor Factory Workshop [KEK-FF2015]", Tokyo, Japan 10/2015)

C. Kelly, "CP violation in the kaon sector on the lattice", Plenary talk (MITP workshop: Fundamental Parameters in Lattice QCD", Johannes Gutenberg University Mainz, Germany 09/2015)

C. Kelly, "Standard model prediction for direct CP-violation in $K\to\pi\pi$ decay", Plenary talk (Lattice 2015, Kobe, Japan 07/2015)

H. Ohki, (Invited talk) "Composite Scalar Spectrum in many-flavor QCD", KITP Program: Lattice Gauge Theory for the LHC and Beyond, The Kavli Institute for Theoretical Physics, University of California, Santa Barbara, USA, September 18, 2015.

S. Syritsyn " Nucleon structure results from LQCD using Wilson fermions ", April 8-10 (talk on April 9), 2015, The 6th workshop of topical group on hadronic physics, APS, Baltimore, MD

C. Kelly, "Standard model prediction for direct CP-violation in $K\to\pi\pi$ decay", Seminar (Los Alamos National Laboratory, USA 12/2015)

C. Kelly, "Standard model prediction for direct CP-violation in $K\to\pi\pi$ decay", Seminar (High Energy Accelerator Research Organization [KEK], Tsukuba, Japan 10/2015)

C. Kelly, "Lattice measurement of the $\Delta I = 1/2$ contribution to Standard Model direct CP-violation in $K¥to¥pi¥pi$ decays at physical kinematics", Seminar (University of Edinburgh, UK 09/2014)

Meifeng Lin, Eric Papenhausen, M. Harper Langston, Benoit Meister, Muthu Baskaran, Taku Izubuchi, Chulwoo Jung "Optimizing the domain wall fermion Dirac operator using the R-Stream source-to-source compiler", Proceedings of the 33rd International Symposium on

Lattice Field Theory.

Hiroshi Ohki, “Walking and conformal dynamics in many-flavor QCD” Proceedings of the 33rd International Symposium on Lattice Field Theory

Hiroshi Ohki, “Lattice Study of Walking Dynamics in Many-flavor QCD”, Brookhaven Forum 2015: Great Expectations, a New Chapter, Brookhaven National Laboratory, October 7, 2015.

Shigemi Ohta ”Some nucleon isovector observables from 2+1-flavor domain-wall QCD at the physical pion mass” The 33rd International Symposium on Lattice Field Theory 14 -18 July 2015 Kobe International Conference Center, Kobe, Japan

[Domestic Conference]

Hiroshi Ohki, Lattice study of the scalar and baryon spectra in many-flav” Contribution to Sakata Memorial KMI Workshop on "Origin of Mass and Strong Coupling Gauge Theories (SCGT15)", 3-6 March 2015, Nagoya University,

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 pi0 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→e and W→μ decays. The results of W->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 have 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→μ 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<pT<4 GeV/c. This is the first observation of bottom decay electron suppression as well as the first observation that energy loss of bottom quark is different from that of 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.

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 pi0 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→m decays in the forward direction. With the measurement of W→ e and W→μ, 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→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→μ is in progress.

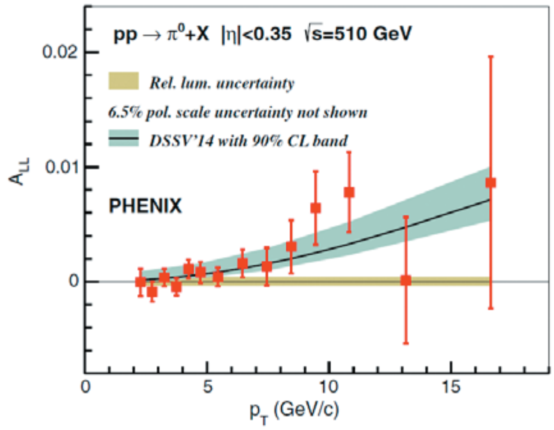

Figure 1 Double spin asymmetry ALL in π^0 production as function of transverse momentum pT. The non-zero ALL indicates that gluons in the proton is polarized. Published in Physical Review D93,011501 (2016)

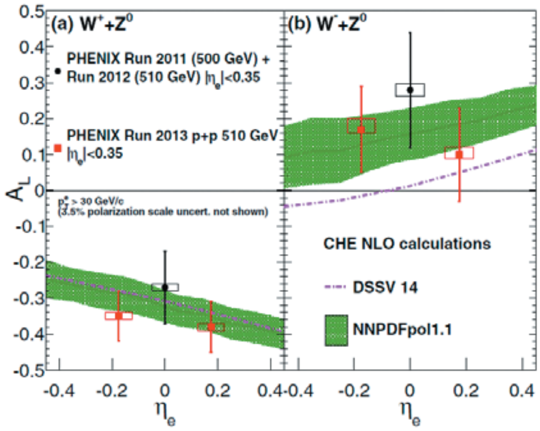

Figure 2 Single spin asymmetry A_L of electrons from W and Z decays. The A_L is sensitive to the polarization of anti-quarks in the proton. The curves and green shaded region show theoretical calculations based on various polarized parton distribution (PDF) sets. Published in Physical Review D93, 051103(R) (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 2200 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/Psi 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+A data within a factor of two. These models assume formation of a hot system with initial temperature of Tinit = 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 has 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 pT region (3<pT<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.

Muon trigger upgrades are needed for W→μ measurement at 500 GeV. New trigger electronics (Muon Trigger FEE) and new Muon trigger detectors using RPC technology were installed in PHENIX muon arms. Additional hadron absorbers were installed in front of the muon arms to reduce the background. These upgrades were essential for the high statistic W→μ measurement in 2013 run. Over 150/pb of data was recorded in the run.

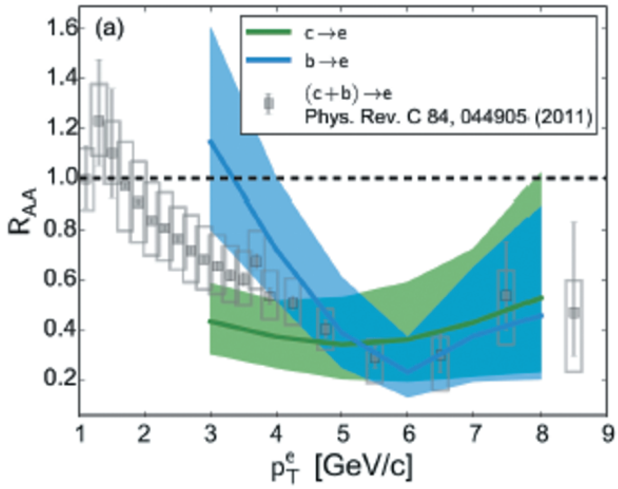

Figure 3. Nuclear modification factor RAA for single electrons from charm (green band) and bottom (blue band) decays. Published in Physical Review C93, 034904 (2016)

Members

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Stefan BATHE ((RHIC Physics Fellows – Jan. 31, 2015)

List of Publications & Presentations

Publications

[Journal]

(Original Papers)

G Mitsuka ”Forward hadron production in ultra-peripheral proton–heavy-ion collisions at the LHC and RHIC” The European Physical Journal C, 2015*

Oral Presentations

[International Conference etc.]

Takashi Hachiya, ”Non-prompt "J"/ψ measurement with the PHENIX VTX detector at RHIC” , 32nd Winter Workshop of Nuclear Dynamics - WWND2016

[Domestic Conference]

Takashi Hachiya, ”Non-prompt "J"/ψ measurement with the PHENIX VTX detector at RHIC” , 日本物理学会　第７１回年次大会

Posters Presentations

[International Conference etc.]

Takashi Hachiya, ”Non-prompt "J"/ψ measurement with the PHENIX VTX detector at RHIC” , Quark Matter 2015

Gaku Mitsuka　”Silicon strip detector R&D for the sPHENIX tracker”　Quark Matter 2015

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 characteristic of materials by observing time dependent changes of muon spin polarization is called "Muon Spin Rotation, Relaxation and Resonance (μSR method), and is applied to study electro-magnetic properties of insulating, metallic, magnetic, superconducting systems. Muons reveal static and dynamic properties of electronic state of materials in the zero-field condition, which is the ideal magnetic condition for researches on the magnetism. We have carried out μSR investigations on frustrated pyrochlore systems, which have variety of exotic ground state of magnetic spins, so the magnetism study of this system using muon 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 μSR techniques to surface and interface science. The development of 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 muoniums in vacuum even at room temperature to improve beam quality than the conventional hot-tungsten muonium generator. Very recently, we demonstrated 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 muoniums 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 μSR 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 at wide temperature range with same detection sensitivity. The detection time range of local field fluctuations by μSR is 10^{-6} to 10^{-11} second, which is an intermediate region between neutron scattering method (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 μSR researches 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 2012 to 2015, we have obtained excellent results, and the highlights are listed in the following,

1) A static ordering of small Ir moments in the pyrochlore iridate; $Nd_2Ir_2O_7$ is close to a quantum critical point.
2) A static ordering of Yb moment on the corner of the pyrochlore structure of $Yb_2Ti_2O_7$ can be explained by the Higgs mechanism.
3) Spontaneous small static internal fields in the superconducting state of URu_2Si_2 is an evidence of the appearance of an exotic superconducting state.
4) Universality class of the Mott transition is confirmed in $EtMe_3P[Pd(dmit)_2]_2$.
5) Finding new muon sites in La_2CuO_4 which can be explained taking into account an effect of the spatial distribution of Cu spin.
6) A novel coexisting state between Fe spin-glass and Cu stripe ordered states in the overdoped regime of $La_{2-x}Sr_xCu_{1-y}Fe_yO_4$.

Result-1 and 2) Solid observations of a statically magnetic-ordered state of corner-shared magnetic moments on pyrochlore systems gave us new interpretations to understand exotic phenomena, like the quantum criticality of magnetic moments and a quasi-magnetic monopole state. Result-3) We measured an increase of static internal fields at the muon site in the zero-field condition just below the superconducting transition temperature of URu_2Si_2. This could shed a light on the mechanism of the superconductivity, which has been a long-standing problem of this system. Result-4) We have been developing gas-pressurized high-pressure apparatus, which can be used not only for μSR but also for other purposes. We have applied this pressure system to $EtMe_3P[Pd(dmit)_2]_2$, and have found that pressure dependent resistivity and thermoelectric coefficient measurements have shown that the Mott transition belongs to the Ising universality class even in two-dimensional states. Result-5) Well known and deeply investigated La_2CuO_4 has opened a new scheme of the Cu spin. Taking into account the effect of the spatial distribution of Cu spin, we have succeeded to explain newly found muon sites and hyperfine fields at those sites. Result-6) Fe spins form a spin glass state through the RKKY interaction in the over-doped regime in $La_{2-x}Sr_xCu_{1-y}Fe_yO_4$. This spin glass state is expected to co-exist with the stripe ordered state at lower temperatures.

We have been developing muon activities in Asian countries. We enhanced international collaborations to organize new μSR experimental groups and to develop muon-site calculation groups using computational method. We have formed MOU with Universiti Sains Malaysia (USM) in order to develop activities on the muon-site calculation. We have newly started collaboration in μSR experiments on strongly correlated systems with researchers from Taiwan and Korea including graduate student.

As for the facility upgrade, we start operating new μSR spectrometer "Chronus", multi-segmented counter arrays of 608 channels, in Port-4, in parallel with ARGUS in Port-2. Software system, for data acquisition and experimental condition control, is unified to the ISIS standard system (DAE with SECI), which can handle muon signals more than 100 million events per hour, in both Port-2 and 4.

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

Positive muon beam with thermal energy has been produced by laser ionization of muoniums (bound system of μ^+ and electron) emitted from hot tungsten surface with stopping surface muon beam at Port-3. The method generates 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 μSR 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 2015, 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 to synthesize novel ceramic-based Nd:YGAG crystal, and 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 the experiences.

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 by fabricating fine laser drill-holes on the surface of silica aerogel. The measurement was carried out at TRIUMF in collaboration with J-PARC muon g-2/EDM group. We believe that the better efficiency and beam quality can be achieved in ultra-slow muon generation by using this new muonium source.

We are planning to feed these new techniques to RIKEN-RAL ultra-slow muon beam line to realize further development of ultra-slow muon technology. The muonium production target section, which had been designed with hot tungsten, was completely redesigned and rebuilt to use advantage 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. The test experiment with the muon beam started in Sep 2015.

(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 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, PSI experiment utilized muonic hydrogen atom, and measured two different allowed transitions from one of the 2S levels to one of the 2P levels. The muonic atom 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 if there exists no exotic physics or unidentified phenomenon behind. 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 are common to search resonant excitation from singlet 1S (F=0) to triplet 1S (F=1) using high intensity 6.7 μm excitation laser, but different scheme 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 their feasibility studies.

RIKEN laser group made basic design of the laser system, based on their recent success on mid-infared (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 have started the measurement of long-life background level, and got a reasonably small value. A further study is planned. Refurbishment of the RIKEN-RAL Port 1 experimental area, following removal of muon catalyzed fusion equipment, is in progress for the proton radius experiment.

(4) Other topics

Muon catalyzed fusion has been one of the main subject of studies since the start of the RIKEN-RAL Muon Facility. It has produced many new results by using the advantage of the high-intensity pulsed muon beam and the advanced tritium handling facility as was reported in previous RIKEN-RAL IACs. Even though, huge increase of the catalysis rate that is enough for energy production is yet difficult to achieve. Considering the limited budget and human resources maintaining the tritium facility, we decided the safe closure of the tritium facility. The safe removal of the tritium handling facility was completed in March 2015 – the tritium handling system was transferred to the UK Atomic Energy Authority, a nice partnership activity between RIKEN, STFC and UKAEA.

New demand is emerging utilizing the muon beam for electronic chip radiation effect studies. Recent progress of semiconductor devices has produced electronics chips with very fine structure. It is anticipated that the single memory upset by the ionization effect of single muon may result in malfunction or errors of advanced electronics. Muon is the main component of the cosmic ray in our ordinal 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 chips to chips, 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, 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.

Members

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

A.D. Hillier, D.McK. Paul, K. Ishida, "Probing beneath the surface without a scratch — Bulk non-destructive elemental analysis using negative muons", Microchemical Journal, 125, 203-207 (2016). *

P. Bakule, O. Sukhorukov, K. Ishida, F.L. Pratt, D. Fleming, T. Momose, Y. Matsuda, and E. Torikai, "First Accurate Experimental Study of Mu Reactivity from a State-Selected Reactant in the Gas Phase: the Mu + $H_{2\{1\}}$ Reaction Rate at 300 K", Journal of Physics B (At. Mol. Opt.) 48, 045204 (2015). *

T. Matsuzaki, K. Ishida, M. Iwasaki, "High-pressure solid hydrogen target for muon catalyzed fusion", Journal of Radioanalytical and Nuclear Chemistry, DOI 10.1007/s10967-015-4080-y *

Rakesh Mohan Das, Souvik Chatterjee, Masahiko Iwasaki, and Takashi Nakajima, "Ionization efficiencies of Doppler-broadened atoms by transform-limited and broadband nanosecond pulses: one-photon resonant two-photon ionization of muoniums", Journal of Optical Society of America B 32, 1237-1244 (2015). *

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RIBF Research Division
Radioactive Isotope Physics Laboratory

1. Abstract

This 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 RI beams to discover new phenomena and properties in exotic nuclei. Another important subject is the equation-of-state in asymmetric nuclear matter, and its association with the origin of elements and with neutron stars. For instance, we are making attempts to the better understand underlying mechanism for exotic stability-enhancements of very neutron-rich fluorine isotopes, the large deformation of the nucleus Mg-34 with N=22 in spite of its vicinity to the N=20 magic neutron number and anomalous collectivity in C-16. We are further extending these studies to medium- and heavy-mass regions by developing facilities, detectors and unique methods at RIBF, thereby leading on the challenging task to find new exotic phenomena. We also perform numerical simulations of nucleosynthesis under the environment of core-collapse supernovae, and moreover quest for footprints of supernovae and solar activities in the past, embedded in Antarctic ice core.

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~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 construction proposal of a LaBr3 array "SHOGUN", was submitted to the PAC 2009, and an international workshop was organized in Feb. 2011 to form the SHOGUN collaboration. An international collaboration is being formed to construct the SHOGUN array.

(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~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, 21 papers including 8 PRL's and 4 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.

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 and physics run will start 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 "SπRIT". 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 –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.

(5) Nuclear data for nuclear waste of long-lived fission products

The nuclear waste problem is an inevitable subject in nuclear physics and nuclear engineering communities. Since the Chicago Pile was established in 1942, nuclear energy has become one of major sources of energy. However, nowadays the nuclear waste produced at nuclear power plants has caused social problems. Minor actinide components of the waste have been studied well as a fuel in fast breeder reactors or ADS. Long-lived fission products in waste, on the other hand, have not been studied extensively. A deep geological disposal has been a policy of several governments, but it is difficult to find out location of the disposal station in terms of security, sociology and politics. To solve the social problem, a scientific effort is necessary for nuclear physics community to find out efficient methods for reduction of nuclear waste radioactivity.

In 2013, we have started up a new project to take nuclear data for transmutation of long-lived fission products to obtain cross section data needed for designing a nuclear waste treatment system. In 2014, we made the first attempt to obtain fragmentation reaction data with Cs-137 and Sr-90 beams at 200A MeV and published the data at PLB in 2016.

Since 2014, this activity has been intensively organized as one of the ImPACT projects by the Nuclear Transmutation Data Research Group.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

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D. Suzuki, "Study of the proton drip-line nuclei using (p,t) reactions", 2nd LISE Workshop from December 16 through 18 at GANIL, Caen, France

D. Suzuki, “Revisit of unbound 12O via the (p, t) reaction”, MUST2 workshop 2015 from June 4 through 6 at CEA-Saclay, Orme des Merisiers, France

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Y. Nakai, H. Hidaka, N. Watanabe, T. M. Kojima, “Measurements of reaction equilibrium distribution for $H^+(H_2O)_n$ generated in an ion drift tube”, 4th meeting of Ion Mobility Research (Invited talk), Sendai, April 2015.

N. Watanabe, Y. Nakai, T. Hama, H. Hidaka, “Ion-induced nucleation experiment III: Approach to reaction kinetics”, Japan Geoscience Union Meeting 2015, Chiba, May 2015.

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Y. Nakai, H. Hidaka, N. Watanabe, T. M. Kojima, “Reaction equilibrium for stepwise attachment/detachment of a water molecule to/from $H_3O^+(H_2O)_n$ in electric field of an ion drift tube”, 31st Symposium on Chemical Kinetics and Dynamics, Sapporo, June 2015.

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K. Takahashi, Y. Motizuki, Y. Nakai, K. Suzuki, Y. Iizuka, and H. Motoyama, “Overview of chemical composition and the characteristics of the distributions of Na+ and Cl- in shallow ice core samples from DF01 core (Antarctica) drilled in 2001”, The 6th Symposium on Polar Science, Tachikawa, Japan, November 2015. *

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”, The 6th Symposium on Polar Science, Tachikawa, Japan, November 2015.

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 is planned to be performed in 2015. Prior to the ^{132}Sn experiment, we have applied the ESPRI setup that consists of a solid hydrogen target and recoil proton detectors to ^{16}C in 2012.

(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 will be applied to a ^{132}Sn experiment in 2015.

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

Occurrences of multi-neutron andα-cluster correlations are other interesting aspects of nuclear matter and define its low-density behavior. The multi-neutron andα-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, ^{3}He) 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}C(^{18}O, ^{18}Ne)^{12}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}C, ^{12}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 in 2015. 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 “Tripletd-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-d_{14} doped p-terphenyl crystal.

Another interesting application of Triplet-DNP is sensitivity enhancement in NMR spectroscopy of biomolecules. We will start 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)

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List of Publications & Presentations

Publications

[Journal]

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Oral Presentations

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T. Uesaka, ``Double Gamow-Teller Resonances – the other side of ββ-decay'', Neutrino and Dark Matter in Nuclear Physics 2015, Jyvaskyla, Finland, 1—5 June 2015. (invited)

T. Uesaka, ``Rare RI Ring at RIBF – Yet Another Storage Device in RIKEN --'', 6th Intereneational Workshop on Electrostatic Storage Devices,

Tokyo, Japan, 8—11 June 2015. (invited)
T. Uesaka, ``New Aspects of Nuclear Spin-Isospin Responses probed with Heavy-Ion Charge Exchange Reactions'', 12th International Coference on Nucleaus-Nucleus Collisions, Catania, Italy, 21—26 June 2015. (invited)
T. Uesaka, ``Probing two-neutron correlations via knockout-delayed particle emission'', 2nd International Wrokshop on Neutron-Proton Correlations, Hong Kong, China, 6—9 July 2015. (invited)
T. Uesaka, ``Experimental methods and measured observables with polarized proton targets : Understanding Spin-Orbit'', Rewriting Nuclear Physics textbooks - 30 years with Radioactive Ion Beam Physics -, Pisa, Italy, 20—24 July 2015. (invited lecture)
T. Uesaka, ``Research Programs at RI Beam Factory'', 9th International Physics Conference of the Balkan Physical Union, Istanbul, Turkey, 24—27 August 2015. (invited)
T. Uesaka, ``Nuclear Astrophysics at RIBF'', 8th European Summer School on Experimental Nuclear Astrophysics, Catania, Italy, 13—20 September 2015. (invited lecture)
T. Uesaka, ``Physics with exotic nuclei at RIKEN and in Asia'', 19th Colloque GANIL, Anglet, France, 11—16 October 2015. (invited)
T. Uesaka, ``New Aspects of Nuclear Spin-Isospin Responses probed with Heavy-Ion Charge Exchange Reactions'', High Resolution Spectrometer Workshop, Darmstadt, Germany, 4—6 November 2015. (invited)
T. Uesaka, ``New Aspects of Nuclear Spin-Isospin Responses probed with Heavy-Ion Charge Exchange Reactions'', International Symposium on High-Resolution Spectroscopy and Tensor Interactions, Osaka, Japan, 16—19 November 2015. (invi1ted)
T. Uesaka, ``Mass Measurements at RIBF'', NUSTAR Annual Meeting 2016, Darmstadt, Germany, 29 February—4 March 2016. (invi1ted)
V. Panin, "New generation of the experiments for the investigation of the stellar (p,γ) reaction rates using SAMURAI", Fifth International Conference on Proton-emitting Nuclei (PROCON2015), Lanzhou, China, 6-10 July 2015.
V. Panin, "Progress report on Heavy-Ion-Proton project", SAMURAI International Collaboration Workshop 2015, Wako, Saitama, 7-8 September 2015.
Z. Yang, "Study on the cluster structure of light neutron-rich nuclei", SINAP-CUSTIPEN Workshop on Clusters and Correlations in Nuclei, Nuclear Reactions and Neutron Stars, Shanghai China, 14-18 Dec (2015).
Z. Yang, "Cluster structure in light neutron-rich nuclei", International Mini-Workshop on alpha-condensates and monopole excitations, Osaka Japan, 2-3 Sep (2015).
M. Sasano, "Study of Gamow-Teller transitions in 132Sn", International Conference, Nuclear Structure and Related Topics, Dubna, Russia, 14-18th July (2015). (invited).
M. Sasano, "Gamow-Teller transitions from 132Sn", Collective motion in nuclei under extreme conditions, Krakow, Poland, 14-18th September (2015). (invited).
M. Sasano, "Status of fission experiments at RIKEN RIBF", 27th ASRC International Workshop " Nuclear Fission and Exotic Nuclei ", Ibraraki Quantum Beam Research Center, Tokai, Japan, 1-2nd.December (2015). (invited).
M. Sasano, ``Gamow-Teller transitions from ^{56}Ni'', International Symposium on High-Resolution Spectroscopy and Tensor Interactions, Osaka, Japan, 16—19 November 2015. (invited)
L. Stuhl, "Investigation of spin-isospin collectivity in asymmetric nuclear matter", 14th CNS International Summer School (CNSS15), Wako, Saitama, Japan, 26th August – 1st September (2015).
J. Yasuda, "Slow neutron detector WINDS for (p,n) reaction in inverse kinematics with SAMURAI spectrometer", International Conference on Electromagnetic Isotope Separator and Related Topics (EMIS 2015), Grand Raipids, MI, US, 11-15th May (2015).
J. Zenihiro, ``Proton elastic scattering and neutron density distributions'', International Symposium on High-Resolution Spectroscopy and Tensor Interactions, Osaka, Japan, 16—19 November 2015. (invited)
Y. Kubota, "Probing multi-neutron correlation via knockout reaction", Critical Stability in Few-Body Systems, Saitama, Japan, 26–30th January (2015).
S. Reichert, "Study of fission barriers in neutron-rich nuclei using the (p,2p) reaction: Status of SAMURAI Experiment NP1306 SAMURAI14" at DPG Fruehjahrstagung, March 23-27, Heidelberg
S. Reichert, "Fission barrier in n-rich nuclei: Status of SAMURAI Experiment NP1306 SAMURAI14" at RA G Science Day at Max Planck Institute for Extraterrestic Physics, July 9, Munich
H. Sagawa, "Three-body model for exotic nuclei", Gordon conference of nuclear chemistry, New Hampshire, USA, May 31-June 5th, (2015).
H. Sagawa, "Isoscalar spin-triplet pairing interaction and Spin-Isospin excitations", International workshop on Nucleon-nucleon interaction in 2015, Catania, Italy June 18-20 (2015).
H. Sagawa, "Three-body model for unbound nucleus ^{26}O", Nucleus-nucleus collision 2015, Catania, Italy, June 22-26 (2015).
H. Sagawa, "Does monopole pigmy resonance exist in ^{68}Ni?" Nucleus-nucleus collision 2015, Catania, Italy, June 22-26 (2015).
H. Sagawa, "Isoscalar spin-triplet pairing correlations and Spin-Isospin response", 2nd International workshop on neutron-proton correlations, HongKong, China, July 6-9 (2015).
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[Domestic Conference]
V. Panin, "Investigation of key nuclear reactions in the astrophysical rp-process using SAMURAI", 70th JPS Annual meeting, Tokyo, Japan, 21-24 March 2015.
Z. Yang, "Strong Monopole Transition and Clustering in ^{12}Be", アイソスカラー型単極遷移で探る原子核の励起状態とクラスター構造, Osaka Japan, 16-17 July (2015).
笹野　匡紀, 「ノックアウト(p,2p)反応を用いた核分裂閾値エネルギーの測定」、日本物理学会2015年秋季大会、シンポジウム「重イオン深部非弾性散乱の基礎と応用」、大阪市立大学、2015年9月25日 (招待・シンポジウム講演)
L. Stuhl, "Around the Nucleus", JSPS Science Dialogue, Tochigi Prefectural Utsunomiya Girl's Senior High School, Utsunomiya, Japan, 2nd October (2015).
Y. Kubota, "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", 70th JPS meeting, Tokyo, Japan, 25-–28th March (2015).
洲崎ふみ, "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フライン性能試験", 第 70 回日本物理学会 年次大会, 早稲田大学, 20150321-0324

E. Milman “Experimental Plan for Resonant Scattering of 9C off Polarized Proton at 5.6 MeV/A”, JPS 70th Annual Meeting（2015）， Mar. 21-24，2015.

T. Uesaka, ``We are at the epoch !'', Workshop on ``Nuclear Physics with Triplet-DNP technique and its application'', Fukuoka, Japan, 8th January (2016).

K. Tateishi, ``What is the important parameter for Triplet-DNP and chemical/medical applications'', Workshop on ``Nuclear Physics with Triplet-DNP technique and its application'', Fukuoka, Japan, 8th January (2016).

S. Chebotaryov, ``Experiments on Elastic Scattering of Polarized Protons from $^{6}$He'', Workshop on ``Nuclear Physics with Triplet-DNP technique and its application'', Fukuoka, Japan, 8th January (2016).

E. Milman, `` Search for $^{10}$N resonances with $^{9}$C + p resonant scattering'', Workshop on ``Nuclear Physics with Triplet-DNP technique and its application'', Fukuoka, Japan, 8th January (2016).

T. Kaneko, `` Polarization transfer from electron to $^{13}$C via $^{1}$H spins'', Workshop on ``Nuclear Physics with Triplet-DNP technique and its application'', Fukuoka, Japan, 8th January (2016).

K. Yamada, ``Hyperpolarization of flowing water with Overhauser DNP'', Workshop on ``Nuclear Physics with Triplet-DNP technique and its application'', Fukuoka, Japan, 8th January (2016).

上坂友洋, “サイクロトロン型蓄積リングによる稀少不安定核の質量測定”, 第 71 回日本物理学会年次大会シンポジウム「イオン蓄積リングが切り拓く多彩な物理」, 仙台, 日本, 2016 年 3 月 19—22 日

Posters Presentations

[International Conference etc.]

L. Stuhl, “A new low-energy neutron detector for (p,n) experiments with pulse shape discrimination properties”, Collective motion in nuclei under extreme conditions, Krakow, Poland, 14-18th September (2015).

Z. Ge, “Rare RI Ring at RIKEN -Isochronous Mass Spectrometry for the r-process nuclei”, The 13th international symposium on Origin of Matter and Evolution of Galaxies (OMEG2015), Beijing, China, June 24-27 (2015).

F. Suzaki, “Performance of a resonant Schottky pick-up in the commissioning of Rare-RI Ring”, 13th International Conference on Heavy Ion Accelerator Technology (HIAT2015), Yokohama, Japan, 201509

RIBF Research Division
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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 stopped/slowed-down RI beams
(2) R&D studies on the production of spin-oriented RI beam
(3) Application of RI probes
(4) Fundamental physics: Study of symmetry

3. Summary of Research Activity

(1) Nuclear spectroscopy with stopped/slowed-down 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, a new method has been developed based on the laser spectroscopy which makes use of characteristic atomic properties of RIs surrounded by liquid helium.

(2) R&D studies on the production of spin-oriented RI beams

A new method has been developed for controlling spin in a system of rare RIs, taking advantage of the mechanism of the two-step projectile fragmentation reaction combined with the momentum-dispersion matching technique. This success allows us to utilize spin-controlled world's highest intensity rare RIBs delivered from BigRIPS for researches on the nuclear structure of species situated outside the traditional region of the nuclear chart. In parallel with this work, the 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.

(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.

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Deokhwa HONG (Seoul National University)
Han Sol SONG (Seoul National University)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

T. Sato, Y. Ichikawa, Y. Ohtomo, Y. Sakamoto, S. Kojima, C. Funayama, T. Suzuki, M. Chikamori, E. Hikota, M. Tsuchiya, T. Furukawa, A. Yoshimi, C. P. Bidinosti, T. Ino, H. Ueno, Y. Matsuo, T. Fukuyama, K. Asahi, "EDM measurement in ^{129}Xe atom using dual active feedback nuclear spin maser", Hyperfine Interactions 230, 147-153 (2015).*

Y. Sakamoto, C. P. Bidinosti, Y. Ichikawa, T. Sato, Y. Ohtomo, S. Kojima, C. Funayama, T. Suzuki, M. Tsuchiya, T. Furukawa, A. Yoshimi, T. Ino, H. Ueno, Y. Matsuo, T. Fukuyama, K. Asahi, "Development of high-homogeneity magnetic field coil for ^{129}Xe EDM experiment", Hyperfine Interactions 230, 141-146 (2015).*

K. Imamura, T. Furukawa, X. F. Yang, Y. Mitsuya, T. Fujita, M. Hayasaka, T. Kobayashi, A. Hatakeyama, H. Ueno, H. Odashima, Y. Matsuo, "Measurement of hyperfine splitting of ^{133}Cs atoms in superfluid helium", Hyperfine Interactions 230, 73-77 (2015).*

T. Fujita, T. Furukawa, K. Imamura, X. F. Yang, T. Wakui, Y. Mitsuya, M. Hayasaka, Y. Ichikawa, Y. Ishibashi, H. Shirai, T. Suzuki, T. Sato, Y. Ohtomo, S. Kojima, Y. Ebara, S. Kishi, T. Sagayama, A. Hatakeyama, T. Kobayashi, H. Ueno, K. Asahi, T. Shimoda, Y. Matsuo, "Laser spectroscopy of atoms in superfluid helium for the measurement of nuclear spins and electromagnetic moments of radioisotope atoms", Hyperfine Interact. 236, 95-100 (2015).*

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(Review)

H. Ueno and Y. Ichikawa, “Spin-Aligned Radioactive Isotope Beams via Two-Step Fragmentation Reaction”, Nuclear Physics News International, Volume 25, Issue 2, 12-16 (2015).*

[Proceedings]

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Y. Ichikawa, H. Ueno, Y. Ishii, T. Furukawa, A. Yoshimi, D. Kameda, H. Watanabe, N. Aoi, K. Asahi, D. L. Balabanski, R. Chevrier, J. M. Daugas, N. Fukuda, G. Georgiev, H. Hayashi, H. Iijima, N. Inabe, M. Ishihara, T. Inoue, T. Kubo, T. Nanao, T. Ohnishi, M. M. Rajabali, K. Suzuki, H. Takeda, M. Tsuchiya, "Spin-aligned RI beams and g-factor measurements", JPS Conference Proceedings 6, 030004 (2015).*

T. Sato, Y. Ichikawa, Y. Ohtomo, Y. Sakamoto, S. Kojima, T. Suzuki, H. Shirai, M. Chikamori, E. Hikota, H. Miyatake, T. Nanao, K. Suzuki, M. Tsuchiya, T. Inoue, T. Furukawa, A. Yoshimi, C. P. Bidinosti, T. Ino, H. Ueno, Y. Mastuo, T. Fukuyama, K. Asahi, “^{129}Xe EDM Search Experiment Using Active Nuclear Spin Maser”, JPS Conference Proceedings 6, 020031 (2015).*

Y. Ohtomo, Y. Ichikawa, T. Sato, Y. Sakamoto, S. Kojima, T. Suzuki, H. Shirai, M. Chikamori, E. Hikota, H. Miyatake, T. Nanao, K. Suzuki, M. Tsuchiya, T. Inoue, T. Furukawa, A. Yoshimi, C. P. Bidinosti, T. Ino, H. Ueno, Y. Mastuo, T. Fukuyama, K. Asahi, “Double-cell geometry for ^{129}Xe/^{3}He co-magnetometery”, JPS Conference Proceedings 6, 030067 (2015).*

H. Ueno, “Nuclear Moments and Structure of Unstable Nuclei”, JPS Conference Proceedings 6, 010009 (2015).*

K. Imamura, T. Furukawa, T. Wakui, X. F. Yang, Y. Mitsuya, T. Fujita, Y. Ebara, M. Hayasaka, Y. Ichikawa, H. Shirai, T. Suzuki, T. Sato, Y. Ohtomo, S. Kojima, A. Hatakeyama, H. Odashima, T. Kobayashi, H. Ueno, K. Asahi, Y. Matsuo, “Measurement of hyperfine splitting of alkali atoms in superfluid helium for a laser spectroscopy of atoms with unstable nuclei”, JPS Conference Proceedings 6, 030115 (2015).

T. Fujita, T. Furukawa, K. Imamura, X. F. Yang, Y. Mitsuya, M. Hayasaka, T. Sagayama, S. Kishi, T. Kobayashi, T. Shimoda, Y. Matsuo, “Measurement of hyperfine structure of Au atom in superfluid helium”, JPS Conference Proceedings 6, 030116 (2015).*

M. Mihara, Y. Ishibashi, Y. Abe, Y. Kamisho, Y. Morita, J. Ohno, M. Tanaka, S. Shinozaki, R. Kanbe, M. Fukuda, K. Matsuta, A. Ozawa, D. Nagae, S. Inaba, S. Okada, Y. Saito, H. Ueno, K. Yamada, T. Izumikawa, T. Ohtsubo, S. Momota, D. Nishimura, T. Suzuki, T. Yamaguchi, Y. Kobayashi, K. Imamura, X.F. Yang, T. Nagatomo, T. Minamisono, M. Takechi, M. Ogura, K. Matsukawa, K. Shirai, T. Fujimura, “Production of Spin Polarized ^{58}Cu and its Magnetic Moment”, JPS Conference Proceedings 6, 030114 (2015).*

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[International Conference etc.]

S. Kinbara, K. Nakazawa, H. Ueno, Y. Ichikawa, J. Yoshida, K. T. Tint, M. K. Soe, A. M. M. Theint, H. Itoh, H. Kobaayashi, S. Hwang, H. Ekawa, S. Hayakawa, “Development of PIS method in nuclear emulsion”, The 12th International Conference on Hypernuclear and Strange Particle Physics (HYP2015), Sendai, Japan, September 7-11, 2015.

A. Takamine, “Super-deformation in the ground states of N=Z nuclei”, 2015 SSRI-PNS collaboration meeting, Wako, Saitama, September 3-4, 2015.

H. Ueno, “Spin-polarized RI beams utilizing the OEDO-SHARAQ system”, OEDO-SHARAQ International Collaboration Workshop, Wako, Saitama, Japan, September 8-19, 2015.

H. Ueno, “Research programs at RIKEN RIBF”, The 9th Japan-China Nuclear Physics Symposium (JCNP2015), Suita, Osaka, Japan, November 7-12, 2015.

K. Asahi, “Isotope differential measurement of Xe atomic EDM with a double-species spin maser”, 8th International Workshop on “Fundamental Physics Using Atoms” (FPUA2015) –Towards better understanding of our matter universe-, Wako, Saitama, November 30 – December 1, 2015.

H. Ueno, “g-factor measurement with polarized beam”, Physics with Fragment Separators – 25th Anniversary of RIKEN-Projectile Fragment Separator (RIPS25)”, Hayama, Kanagawa, Japan, December 6-7, 2015.

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[Domestic Conference]

金原慎二，仲澤和馬，上野秀樹，市川雄一，吉田純也, Khin Than Tint, Myint Kyaw Soe, Aye Moh Moh Thient, 伊藤宏紀，小林秀隆，中島大輔，村井李奈，江川弘行，早川修平, Sanghoon Hwang,「原子核乾板中の電離損失による粒子識別法の確立」，日本物理学会 2015 年秋季大会，大阪, 2015 年 9 月 25-28 日

佐藤智哉，市川雄一，小島修一郎，舟山智歌子，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，旭耕一郎，「^{129}Xe/^{3}He 二核種スピンメーザーを用いた周波数精密測定における周波数不定性」，日本物理学会 2015 年秋季大会，大阪, 2015 年 9 月 25-28 日

相川脩，石田勝彦，岩崎雅彦，上野秀樹，大石裕，岡田信二，斎藤徳人，佐藤将春，高峰愛子，馬越，松崎禎市郎，緑川克美，湯本正樹，和田智之，神田聡太郎，田中香津生，松田恭幸，「ミュオン水素原子超微細構造エネルギー測定のための中赤外レーザーの開発(I)」，日本物理学会 2015 年秋季大会，大阪, 2015 年 9 月 25-28 日

佐藤将春，石田勝彦，岩崎雅彦，上野秀樹，大石裕，岡田信二，斎藤徳人，高峰愛子，松崎禎市郎，馬越，緑川克美，湯本正樹，和田智之，相川脩，神田聡太郎，田中香津生，松田恭幸，「ミュオン水素原子超微細構造レーザー分光による陽子半径の測定実験」，日本物理学会 2015 年秋季大会，大阪, 2015 年 9 月 25-28 日

山崎展樹，「The film characterization using RI – What I want to do」，第 8 回停止・低速 RI ビームを用いた核分光研究会(SSRI)，埼玉県和光市, 2016 年 3 月 4-5 日

市川雄一，高峰愛子，西畑洸希，今村慧，藤田朋美，佐藤智哉，籾山悟至，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，炭竃聡之，鈴木宏，竹田浩之, L. C. Tao，栂野泰宏，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，仙台, 2016 年 3 月 19-22 日

石橋陽子，市川雄一，高峰愛子，今村慧，藤田朋美，佐藤智哉，旭耕一郎，江上魁，舟山智歌子，川口高史，小島修一郎，西坂太志，大友祐一，小沢顕，富永大樹，山崎展樹，吉見彰洋，上野秀樹，「中性子過剰核 ^{39}S の核磁気モーメント」，日本物理学会第 71 回年次大会，仙台, 2016 年 3 月 19-22 日

E. Milman, T. Teranishi, S. Sakaguchi, S. Chebotaryov, T. Uesaka, K. Tateishi, Y. Ichikawa, M. Sasano, W. Kim, R. Kaku, Y. Norimatsu, Y. Akiyama, T. Fukuta, D. Sakae, N. Imai, H. Yamaguchi, S. Hayakawa, D. M. Kahl, Y. Sakaguchi, K. Abe, N. Kitamura, T. Kaneko, K. Yamada, S. H. Hwang, D. H. Kim, Al.Galindo-Uribarri, E. Romero-Romero, D. Beaumel, "Search for ^{10}N resonances with ^{9}C + p resonant scattering", 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

早坂美希, 今村慧, 富田英生, 高松峻英, 山口康広, 藤田朋美, 小林徹, 植松晴子, 古川武, 上野秀樹, 松尾由賀利, 「パルス Ti:S レーザーによる超流動ヘリウム中原子のスピン偏極生成」, 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

藤田朋美, 今村慧, 富永大樹, 川口高史, 江上魁, 西坂太志, 小林徹, 高峰愛子, 古川武, 上野秀樹, 下田正, 松尾由賀利,「超流動ヘリウム環境下における 11 族原子の超微細構造間遷移」, 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

江上魁, 今村慧, 西坂太志, 高峰愛子, 藤田朋美, 富永大樹, 川口高史, 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へ向けたレーザー・MW 二重共鳴信号の強度評価」, 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

舟山智歌子, 佐藤智哉, 市川雄一, 小島修一郎, 田中俊也, 坂本雄, 大友祐一, 平尾千佳, 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, 旭耕一郎,「異核種共存セルにおけるスピン偏極生成･緩和機構」, 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

小島修一郎, 佐藤智哉, 市川雄一, 田中俊也, 舟山智歌子, 坂本雄, 大友祐一, 平尾千佳, 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, 旭耕一郎, 「^{129}Xe/^{131}Xe 共存核スピンメーザーの周波数特性」, 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

佐藤智哉, 市川雄一, 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, 旭耕一郎, 「異核種共存核スピンメーザーを用いた EDM 測定実験」, 日本物理学会第 71 回年次大会, 仙台, 2016 年 3 月 19-22 日

Posters Presentations

[International Conference etc.]

A. Takamine, M. Wada, Y. Ito, F. Arai, P. Schury, I. Katayama, K. Imamura, Y. Ichikawa, H. Ueno, H. Wollnik, H. A. Schuessler, "Towards high precision measurements of nulear g-factors for Be isotopes", The 17th International Conference on Electromagnetic Isotope Separators and Related Topics (EMIS2015)

A. Takamine, M. Wada, Y. Ito, F. Arai, P. Schury, I. Katayama, K. Imamura, Y. Ichikawa, H. Ueno, H. Wollnik, H. A. Schuessler, "Towards a hyperfine anomaly measurement of the one-neutron halo nucleus ^{11}Be", Physics with Fragment Separators -25th Anniversary of RIKEN-Projectile Fragment Separator (RIPS25), Hayama, Kanagawa, Japan, December 5-7, 2015

A. Takamine, R. Shiozuka, H. Maeda, "Population redistribution of cold Rydberg atoms", 12th International Conference on Low Energy Physics (LEAP2016)

[Domestic Conference]

藤田朋美, 「OROCHI: 超流動ヘリウム中原子のレーザー分光 –低収量 RI の核構造研究に向けて-」, 国際光年シンポジウム, 東京, 2015 年 4 月 21 日

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RIBF Research Division
High Energy Astrophysics Laboratory

1. Abstract

In the immediate aftermath of 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) Nucleosynthesis in Stars and Supernovae
(2) Particle Acceleration Mechanism in Astronomical Objects
(3) Physics in Extremely Strong Magnetism and Gravity
(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 the universe, 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 and galaxies with X-ray astronomical satellites and/or ground-based telescopes.

We are running an X-ray polarimetry satellite mission PRAXyS (Polarimeter for Relativistic Astrophysical X-ray Sources) in collaboration with NASA Goddard Space Flight Center. This is the heritage mission of the canceled GEMS. The mission proposal was submitted to NASA in December 2014, and selected for Phase A (conceptual design) study in July 2015. We are now in step forward to Phase B (flight design) and the expected launch in August 2020. For the PRAXyS project, we have developed gas electron multiplier foils for flights and analyzed calibration data of semi-flight polarimeter to evaluate the systematic uncertainty of the detectors.

We contributed to the 6th Japanese X-ray astronomical satellite ASTRO-H which was launched on February 17, 2016 from JAXA's Tanegashima Space Center (TNSC) by the H-IIA launch vehicle F-30. The JAXA's ASTRO-H mission is constructed by all the Japanese institutes related to the X-ray astrophysics including RIKEN in collaboration with US and Europe. The total mass of the satellite is 2.7 ton and the length is 14 m after deploying the optical boom. ASTRO-H carries four X-ray and gamma-ray detectors covering the 0.3-600 keV energy range. We, in collaboration with JAXA, Tokyo Metropolitan University, Kanazawa University, Saitama University, NASA/GSFC etc., is contributing to the soft X-ray spectrometer (SXS), which achieves unprecedented energy resolution (< 7 eV) in the 0.3-12 keV energy band with a low temperature micro calorimeter. Although ASTRO-H was successfully launched in Low Earth Orbit, the satellite was unfortunately lost by an accident. We are analyzing a small amount of scientific data taken just before the accident, and preparing to publish calibration and scientific papers.

Besides the missions described above, we are partially contributing to the following missions.

- Hisaki: A Japanese small satellite dedicated for planetary science, observing EUV photons. (Contributors: Tomoki Kimura)
- NuSTAR: A NASA's small explorer mission for hard X-ray imaging in the 5–80 keV band. World first imaging capability in hard X-ray band opened a new field in observation: nuclear astrophysics. (Contributors: Takao Kitaguchi)
- NICER and MAXI: Both are the detectors onboard International Space Station (ISS). NICER is a mission of NASA/GSFC for exploring the interior of neutron stars which will be launch in fall 2016. MAXI is the RIKEN-led all sky X-ray monitor mission. (Contributors: Teruaki Enoto, Wataru Iwakiri, Toru Tamagawa)
- Large Synoptic Survey Telescope (LSST): All sky survey telescope in the optical band being constructed by US community. The telescope surveys all sky of the southern hemisphere with ~24 mag sensitivity every three days. It is under construction and expected first light in 2019. This telescope has good synergy with all sky X-ray monitor mission such as MAXI in astrophysics. (Contributors: Yuki Okura, Toru Tamagawa through RIKEN Brookhaven Research Center)
- Future X-ray spectrometry missions, DIOS and Athena: DIOS is a Japanese small satellite exploring the missing baryon in the universe in 2020's, and Athena is the ESA's large class mission for observing the evolution of galaxies/clusters in late 2020's. (Contributors: Noda Hirofumi, Toru Tamagawa)

Members

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Asami HAYATO (Dec. 1, 2015 –)

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Kumi ISHIKAWA (– Mar. 31, 2016)
Hirofumi NODA (– Mar. 31, 2016)
Takayuki YUASA (– Mar. 31, 2016)
Tomoki KIMURA (Apr. 1, 2015 –)

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Megu KUBOTA (Aug. 17, 2015 – Feb. 29, 2016)
Kazuki NISHIDA (Aug. 17, 2015 – Feb. 29, 2016)
Sonoe ODA (Sep. 14, 2015 – Feb. 29, 2016)
Tatsuya YOSHIDA (Jan. 7, 2016 – Jan. 28, 2016)

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Teruaki ENOTO (JSPS Fellow, Stanford Univ. – Mar. 31, 2015)

Visiting Scientists
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Masaki WAKABAYASHI (Jakulin Commercial Company LC)
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Naohisa INADA (National Institute of Tech., Nara College)
Rohta TAKAHASHI (Tomakomai Nat'l College of Tech.)
Toru MISAWA (Shinshu Univ.)
Hiroya YAMAGUCHI (Harvard Univ.)
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Shin'ya YAMADA (Tokyo Met. Univ.)
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List of Publications & Presentations

Publications
[Journal]
(Original Papers) *Subject to Peer Review

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Posters Presentations

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Kubota, Megu: “Measurement of the GEM gain uniformity for the PRAXyS mission” 4th International Micro Pattern Gaseouse Detector Conference, Trieste, Italy, October (2015).

Kitaguchi, Takao: “Development of the GEM-TPC X-ray Polarimeter with the Scalable Readout System” 4th International Micro Pattern Gaseouse Detector Conference, Trieste, Italy, October (2015).

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 ^{2}H) 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)
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Yoichi NAKAI (Concurrent: RI Physics Lab., Senior Research Scientist)

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Yuma HASEBE (Saitama Univ., Nov. 1, 2014 –)
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Yoko HOSHINO (Jan. 5, 2016 - Mar. 31, 2016)

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

Shuji Fujita, Kumiko Goto-Azuma, Motohiro Hirabayashi, Akira Hori, Yoshinori Iizuka, Yuko Motizuki, Hideaki Motoyama, Kazuya Takahashi: "Densification of layered firn of the ice sheet at Dome Fuji, Antarctica", Journal of Glaciology (2016), 21 pages, Available on CJO2016 doi:10.1017/jog.2016.16*

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Y. Nakai, Y. Motizuki, M. Maruyama, H. Akiyoshi, T. Imamura : "Variation of chemical composition induced by solar energetic particle events in the middle atmosphere", RIKEN Accel. Prog. Rep. 48, 168, 2015.*

Y. Motizuki, S. Okamoto, K. Takahashi, Y. Nakai, A. Makabe, K. Koba, H. Motoyama : "Measurements of nitrogen isotope ratios in samples with very low nitrate concentrations from the Dome Fuji ice core (Antarctica) drilled in 2010", RIKEN Accel. Prog. Rep. 48, 169, 2015.*

M. Sigl, J. McConnell, M. Toohey, M. Curran, S. Das, R. Edwards, E. Isaksson, K. Kawamura, S. Kipfstuhl, K. Krüger, L. Layman, O. Maselli, Y. Motizuki, H. Motoyama, D. Pasteris, M. Severi: "Insights from Antarctica on volcanic forcing during the Common Era", RIKEN Accel. Prog. Rep. 48, 167, 2015.*

[Book]

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望月優子：『放射化学の事典』（共同執筆）、日本放射化学会編、pp. 274-277(「軽い元素の原子核合成」「重い元素の原子核合成」)、朝倉書店、2015.＊

Oral Presentations

[International Conference etc.]

(Invited talk) Yuko Motizuki: "Astronomical signatures embedded in ice cores", Baymfest in Tokyo -Exploring Extreme Forms of Matter-, Tokyo, Japan, Mar. 14, 2016.

Kenji Tanabe and Yuko Motiziuki: "Possible geologial records of symbiotic binary R Aquarii's historical outbursts", XXIX IAU General Assembly, Honolulu, USA, Aug. 3-14, 2015.

Y. Nakai, Y. Motizuki, M. Maruyama, H. Akiyoshi, T. Imamura: "Variation of trace chemical species induced by solar energetic particles in the middle atmosphere: ozone and nitric acid", Japan Geoscience Union Meeting, Chiba, May 24-28, 2015.

[Domestic Conference]

（招待講演）望月優子：「アイスコアからさぐる天文・宇宙のサイエンスー過去の超新星の爆発から宇宙のリズムまでー」、大阪大学理学部講義「理学への招待」、豊中、2015年11月30日.

（招待講演）望月優子：「浅層コア詳細化学解析ーこれまでのまとめと第9期の研究提案、IPICS 2kへの貢献を見据えてー」極地研研究集会「南極雪氷科学の展開による新たな古環境復元とメカニズム理解にむけて」、立川、2015年9月24-25日.

長谷部憂磨、望月優子：「南極ドローニングモードランドアイスコアの酸素同位体比からわかる気温変動と太陽活動周期との関係」、日本天文学会2015年秋季年会、神戸、2015年9月9-11日.

（招待講演）望月優子：「宇宙と生命とのつながりー生命と元素、星、宇宙のリズムー」、平成２７年度スーパーサイエンスハイスクール生徒研究発表会研究者ミニライブ、大阪、2015年8月6日.

（招待講演）望月優子：「南極アイスコアから探る環境変動」、文部科学省科学技術・学術政策研究所主催「近未来への招待状〜ナイスステップな研究者2014からのメッセージ」、東京、2015年7月27日.

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Kazuya Takahashi, Yuko Motizuki, Yoichi Nakai, Keisuke Suzuki, Yoshinori Iizuka, and Hideaki Motoyama: "Overview of chemical composition and the characteristics of the distributions of Na^+ and Cl^- in shallow ice core samples from DF01 core (Antarctica) drilled in 2001" (A poster paper), The 6th Symposium on Polar Science, Tachikawa, Japan, Nov. 16-19, 2015.

Yuma Hasebe, Yuko Motizuki, Yoichi Nakai, Kazuya Takahashi: "Diagnose oscillation properties observed in an annual ice-core oxygen isotope record obtained from Dronning Maud Land, Antarctica" (A poster paper), The 6th Symposium on Polar Science, Tachikawa, Japan, Nov. 16-19, 2015.

[Domestic Conference]

（招待講演）望月優子：「地球規模の気候に影響を与えた火山噴火に関する南極アイスコア科学の推進」（パネル発表）、第56回（2015年度）文部科学省科学技術週間展示、東京、2015年4月13日-19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 Superheay 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 (not yet named) 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 108th, 110th, 111th, and 112th elements by using the same reactions performed at GSI. After these work, we observed an isotope of the 113th 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. Finally, 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).

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 will be ready for operation in fiscal year 2009 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)$^{296\text{-}x}$Lv(Z=116) previously studied by Frelov Laboratory of Nuclear Reaction, Russia, and GSI. We observed 5 isotopes in total which tentatively assigned to ^{293}Lv, and ^{292}Lv.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

D. Kaji, K. Morimoto, H. Haba, E. Ideguchi, H. Koura, K. Morita "Decay Properties of New Isotopes 234Bk and 230Am, and Even–Even Nuclides 234Cm and 230Pu", Journal of the Physical Society of Japan, 85, 015002 (2016) *

D. Kaji, K. Morimoto, Double-layered target and identification method of individual target correlated with evaporation residues, Nuclear Instruments & Methods in Physics Research A792 (2015) 11-14*

[解説、和文]

K. Morimoto 113 番新元素の合成 "Synthesis of 113th new element", 放射化学 The Japan Society of Nuclear and Radiochemical Sciences, Vol.33, pp. 10-16

Oral Presentations

[International Conference etc.]

D. Kaji, K. Morimoto, Y. Wakabayashi, M. Takeyama, S. Yamaki, K. Tanaka, K. Morita, H. Haba, M. Murakami, S. Goto, H. Kikunaga, and M. Asai "GARIS-II: New Gas-filled Recoil Ion Separator at RIKEN", 超アクチノイド元素の化学と物理国際会議 2015（TAN15）, Aizu Fukushima Japan, May 29 2015"

S. Wakabayashi, K. Morita, K. Morimoto, D. Kaji, H. Haba, M. Takeyama, S. Yamaki, K. Tanaka, T. Tanaka, M. Murakami, Y. Komori, K. Nishio, H. Koura, M. Asai, Y. Aritomo, A. Yoneda "Production of new isotopes, ^{215}U and ^{216}U close to N = 126", The 5th International Conference on the Chemistry and Physics of the Transactinide Elements (TAN15), Aizu Fukushima Japan, May 29 2015

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K. Morita, "SHE research at RIKEN/GARIS", TAN15 Fukushima Japan, May 25-29 2015

K. Morita, "Research of superheavy element at RIKEN", LEAP2016, Kanazawa Japan, March 6-11 2016

[Domestic Conference]

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R. Aono, S. Goto, D. Kaji, K. Morimoto, H. Haba, M. Murakami, K. Ooe, H. Kudo "Production of neutron-deficient rutherfordium isotopes in the Pb-208 + Ti-48,50 reactions", 2015 日本放射化学会年会・第 59 回放射化学討論会, Tohoku Univercity Japan, Septmeber 26 2015

Posters Presentations

[International Conference etc.]

M. Takeyama, D. Kaji, K. Morimoto, Y. Wakabayashi, F. Tokanai, K. Morita "Detector calibration to spontaneous fission for the study of superheavy elements using gas-filled recoil ion separator", International Symposium on Radiation Detectors and Their Uses (ISRD2016), Tsukuba Japan December 19 2015

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 supreheavy 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
Akira YONEDA

Contract Researcher
Yasuo WAKABAYASHI (Apr. 1, 2015 – June 30, 2015)

Special Postdoctoral Researcher
Yasuo WAKABAYASHI (Apr. 2012 – Mar. 31, 2015)

Research Consultant
Kenji KATORI

Junior Research Associate
Mirei TAKEYAMA (Yamagata Univ., – Mar. 31, 2015)

Part-time Worker
Kengo TANAKA (Tokyo Univ. of Sci., – Mar. 31, 2015)

Visiting Scientists

Hiroyuki KOURA (JAEA)
Marc ASFARI (Institut Pluridisciplinaire Hubert Curien)
Benoit Jean-Paul GALL (Strasbourg Univ.)
Mirei TAKEYAMA (Yamagata Univ.)

Student Trainees

Takuya YOKOKITA (Osaka Univ.)
Christian Stefan BERNER (Technische Universitat Munchen)
Kengo TANAKA (Tokyo Univ. of Sci.)
Hugo FAURE (Strasbourg University)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

D. Kaji, K. Morimoto, H. Haba, E. Ideguchi, H. Koura, K. Morita "Decay Properties of New Isotopes 234Bk and 230Am, and Even–Even Nuclides 234Cm and 230Pu", Journal of the Physical Society of Japan, 85, 015002 (2016) *

(Review)

[解説、和文]

K. Morimoto 113 番新元素の合成 "Synthesis of 113th new element", 放射化学 The Japan Society of Nuclear and Radiochemical Sciences, Vol.33, pp. 10-16

Oral Presentations

[International Conference etc.]

D. Kaji, K. Morimoto, Y. Wakabayashi, M. Takeyama, S. Yamaki, K. Tanaka, K. Morita, H. Haba, M. Murakami, S. Goto, H. Kikunaga, and M. Asai "GARIS-II: New Gas-filled Recoil Ion Separator at RIKEN"", 超アクチノイド元素の化学と物理国際会議 2015（TAN15）, Aizu Fukushima Japan, May 29 2015"

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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}Zn + ^{209}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. It will be ready for operation in fiscal year 2014 after some commissioning works. 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

Nishina Center Technical Scientist
Akira YONEDA (concurrent: Superheavy Element Production Team)

Junior Research Associate
Sayaka YAMAKI (Saitama Univ., Apr. 1, 2014 –)

Part-time Worker
Sayaka YAMAKI (– Mar. 31, 2014)

Visiting Scientists
Fuyuki TOKANAI (Yamagata Univ.)

Student Trainee
Satoshi ISHIZAWA (Yamagata Univ.)

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Publications

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D. Kaji, K. Morimoto, Double-layered target and identification method of individual target correlated with evaporation residues, Nuclear Instruments & Methods in Physics Research A792 (2015) 11-14*
(Review)
[解説、和文]
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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 of LLFP in inverse kinematics at RIBF. The third Team "Muon Data Team" is to obtain muon capture data of LLFP at muon facilities. All of 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 were successfully organized at RIBF in 2015. The muon program started at J-PARC and RCNP, Osaka University in spring 2016.

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 (Oct. 1, 2014–, concurrent: Team Leader, SAMURAI Team)

Technical Staff I
Nobuyuki CHIGA (Jan. 1, 2015–)

Part-time Worker
Meiko Kurokara UESAKA (Apr. 1, 2015 – Jul. 26, 2015)

Student Trainees
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Tatsuya YAMAMOTO (Miyazaki Univ.)
Keita NAKANO (Kyushu Univ.)
Ayaka IKEDA (Niigata Univ.)
Kazuya CHIKAATO (Niigata Univ.)
Hiroki TAKAHASHI (Niigata Univ.)
Kenji NISHIZUKA (Niigata Univ.)
Junki SUWA (Kyushu Univ.)
Masamichi AMANO (Rikkyo Univ.)
Junki AMANO (Rikkyo Univ.)

List of Publications & Presentations

Publications
[Journal]
(Original Papers)

H. Wang[a, ,], H. Otsu[a], H. Sakurai[a], D.S. Ahn[a], M. Aikawa[b], P. Doornenbal[a], N. Fukuda[a], T. Isobe[a], S. Kawakami[c], S. Koyama[d], T. Kubo[a], S. Kubono[a], G. Lorusso[a], Y. Maeda[c], A. Makinaga[e], S. Momiyama[d], K. Nakano[f], M. Niikura[d], Y. Shiga[g, a], P.-A. Söderström[a], H. Suzuki[a], H. Takeda[a], S. Takeuchi[a], R. Taniuchi[d, a], Ya. Watanabe[a], Yu. Watanabe[f], H. Yamasaki[d], K. Yoshida[a], “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.

Oral Presentations
[Domestic Conference]

川瀬頌一郎、陽子・重陽子に対する 100MeV/u ^{93}Zr 入射核破砕反応による同位体生成断面積の測定、日本物理学会秋季大会、大阪市立大学、2015 年 9 月 28 日
武内聡、107,108Pd のクーロン分解反応による光吸収断面積の測定、日本物理学会秋季大会、大阪市立大学、2015 年 9 月 28 日
四方瑞紀、93,94Zr のクーロン分解反応による光吸収断面積の測定、日本物理学会秋季大会、大阪市立大学、2015 年 9 月 28 日
尾崎友志、飛行核分裂によって生成された 107Pd のアイソマー比の測定、日本物理学会秋季大会、大阪市立大学、2015 年 9 月 28 日
川上駿介，前田幸重，王赫，大津秀暁，櫻井博義　他 22 名、"90Sr 近傍核種における荷電交換反応測定"、日本物理学会 2015 年秋季大会、

大阪市立大学、2015 年 9 月 28 日
中野敬太、水素・重水素に対する 100MeV/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研究発表会、九州大学、2015 年 12 月 5 日
川上駿介，前田幸重，王赫，大津秀暁，櫻井博義　他 22 名、"90Sr 近傍の核分裂生成核種ビームによる荷電交換反応測定"、日本物理学会 2015 年九州支部例会、九州工業大学、2015 年 12 月 5 日
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 27 日
川瀬頌一郎、逆運動学手法を用いた陽子・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、日本原子力学会春の大会、東北大学、2016 年 3 月 27 日
中野敬太、逆運動学手法を用いた陽子・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 27 日
武内聡、クーロン分解反応による 107,108Pd および 93,94Zr 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 19 日
尾崎友志、238U の飛行核分裂によって生成される 107Pd,79Se 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 20 日

Posters Presentations

[Domestic Conference]

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 27 日

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 energy degradation and purification of RI beams are the main subjects of the team. Developments of devices used for the energy degradation of RI beams are also an important subject.

3. Summary of Research Activity

1) Study and development of the energy degradation methods for LLFP.
2) Development of the devices used for the energy degradation.
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 (concurrent: BigRIPS Team)

RIBF Research Division
Nuclear Transmutation Data Research Group
Muon Data Team

1. Abstract

Dr. Yoshio Nishina observed muons in cosmic rays in 1937. The muon is an elementary particle belonging to electron group, and is 207 times as heavy as electron. The muon has positive or negative electric charge, and the lifetime is 2.2 μsec. 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 negative muon is combined with a proton to form a neutron and a neutrino to create an excited state of the nucleus with the atomic number of Z-1, followed by emissions of neutrons and gamma rays. The muon nuclear capture reaction produces the isotopes of the (Z-1) nucleus. However, the reaction mechanism is not yet well clarified. The research team aims at obtaining the experimental data to understand the mechanism of muon nuclear capture reactions as well as at establishing the reaction theory.

2. Major Research Subjects

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

3. Summary of Research Activity

Clarification of muon nuclear capture reaction and the application

Members

Team Leader
Teiichiro MATSUZAKI

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.)

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 cavites 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 OHZEKI (concurrent: Technical Scientist, Cyclotron Team)
Yutaka WATANABE (concurrent: Senior Technical Scientist, RILAC team)

Nishina Center Research Scientist

Kenji SUDA (concurrent: Cyclotron Team)

List of Publications & Presentations

Publications

[Proceedings]

Naruhiko Sakamoto et al., Design Studies for Quarter-Wave Resonators and Cryomodules for the RIKEN SC-LINAC, Proceedings of the 17th International Conference on RF Superconductivity, Whistler, September 16 2015.

Kazutaka Ozeki et al., Design of Input Coupler for RIKEN Superconducting Quarter-Wave Resonator, Proceedings of the 17th International Conference on RF Superconductivity, Whistler, September 16 2015.

Kazutaka Ozeki et al., Heat flow estimation of the cryomodule for superconducting quarter-wavelength resonator, Proceedings of the 12th Annual Meeting of Particle Accelerator Society of Japan, Suruga, 6 August 2015.

Oral Presentations

[International Conference etc.]

Naruhiko Sakamoto et al., Design Studies for Quarter-Wave Resonators and Cryomodules for the RIKEN SC-LINAC, 17th International Conference on RF Superconductivity, Whistler, September 16 2015.

Kazutaka Ozeki et al., Design of Input Coupler for RIKEN Superconducting Quarter-Wave Resonator , TESLA Technology Collaboration Meeting, Menlo Park, USA, December 2, 2015.

Posters Presentations

[International Conference etc.]

Kazutaka Ozeki et al., Design of Input Coupler for RIKEN Superconducting Quarter-Wave Resonator, 17th International Conference on RF Superconductivity, Whistler, September 16 2015.

[Domestic Conference]

Kazutaka Ozeki et al., Heat flow estimation of the cryomodule for superconducting quarter-wavelength resonator, 12th Annual Meeting of Particle Accelerator Society of Japan, Suruga, 6 August 2015.

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
Noya IKOMA (Sep. 1, 2015 -)

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 689 pnA at 345 MeV/u, which corresponds to 10.4 kW. That of the krypton beam reached 486 pnA, corresponding to 13.4 kW.
(2) The maximum intensities of the uranium and xenon beams reached 49 and 102 pnA, respectively, at 345 MeV/u.
(3) The overall beam availability for the RIBF experiments in 2015 reached 92 %. It 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, mainly on the design of a new superconducting linac.

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

International Program Associate
Vasileios TZOGANIS (Univ. of Liverpool, – Jan. 15, 2016)

Visiting Researchers
Akira GOTO (Yamagata Univ.)
Toshiyuki HATTORI (TIT)
Kensei UMEMORI (KEK)
Hirotaka 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/inflection 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 berrilium 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/inflection 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.)

Student Trainee

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 uranium 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 uranium 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 uranium ion beam

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

The RIBF is required to supply uranium ion beams with very high intensity so as to produce RI's. 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 –)

Research Consultant
Tadashi KAGEYAMA (Apr. 1, 2014 – Mar. 31, 2015)

Part-time Worker
Yumi KURAMITSU (–Jun. 30, 2015)

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

K. Ozeki, Y. Higurashi, M. Kidera and T. Nakagawa, 'Effect of hot liner in producing ^{40,48}Ca beam from RIKEN 18-GHz electron cyclotron resonance ion source', Rev. Sci. Instrum. 86(2015)016114*

[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, 'Recent developments of RIKEN 28GHz SC-ECRIS', 21st Int. Workshop on ECR ion sources, August 24-28, 2014, Nizhny Novgorod, Russia

Y. Higurashi, 'Emittance measurement for RIKEN 28 GHz SC-ECRIS', 21st Int. Workshop on ECR ion sources, August 24-28, 2014, Nizhny Novgorod, Russia

T. Nakagawa, 'Further improvement of RIKEN 28GHz SC-ECRIS for production of intense U beam', ICIS2015, Aug. 23-28, 2015, New York, USA

Y. Higurashi, 'Emittance measurement for RIKEN 28GHz SC-ECRIS' ICIS2015, Aug. 23-28, 2015, New York, USA

[Domestic Conference]

T. Nakagawa, 'Development of ECR ion sources for production of the intense beam of highly charged heavy ions', 12th Annual Meeting of PASJ, Aug. 5-8, 2015, Tsuruga,

Posters Presentations

[International Conference etc.]

T. Nagatomo, 'Development of an in-situ emittance meter installed in LEBT following 18-GHz Superconducting ECR Ion Source', 21st Int. Workshop on ECR ion sources, August 24-28, 2014, Nizhny Novgorod, Russia

[Domestic Conference]

K. Ozeki, 'Installation of new 18-GHz ECR ion source for the RIKEN RILAC', 11th Annual Meeting of PASJ, Aug. 9-11, 2014, Aomori,

T. Nagatomo, 'Development of the on-line beam monitor based on the pepper-pot method for high-brightness low-energy multi-charged ion beams extracted from ECR ion source', 12th Annual Meeting of PASJ, Aug. 5-8, 2015, Tsuruga,

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 log-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 OHZEKI (Technical Scientist)

Nishina Center Research Scientist
Kenji SUDA

List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

R. Koyama, N. Sakamoto, M. Fujimaki, N. Fukunishi, A. Goto, M. Hemmi, M. Kase, K. Suda, T. Watanabe, K. Yamada, O. Kamigaito, "Online monitoring of beam phase and intensity using lock-in amplifiers", Nuclear Instruments and Methods A729(2013)p788-799.

K. Suda, N. Sakamoto, K. Yamada, S. Arai, Y. Chiba, M. Kase, H. Okuno, Y. Watanabe, O. Kamigaito, "Design and construction of drift tube linac cavities for RIKEN RI-Beam Factory", Nuclear Instruments and Methods A722(2013)p55-64.

K. Sekiguchi, H. Okamura, N. Sakamoto, H. Suzuki, M. Dozono, Y. Maeda, T. Saito, S. Sakaguchi, H. Sakai, M. Sasano, Y. Shimizu, T. Wakasa, K. Yako, H. Witala, W. Glockle, J. Golak, H. Kamada, and A. Nogga, "Three Nucleon Force Effects in Intermediate Energy Deuteron Analyzing Powers for dp Elastic Scattering", Physical Review C **83**, 061001(R) (2011).

[Proceedings]

(Original Papers) *Subject to Peer Review

N. Sakamoto, O. Kamigaito, H. Okuno, K. Ozeki, K. Suda, Y. Watanabe, K. Yamada, H. Hara, K.Okihira, K. Sennyu, T. Yanagisawa, E. Kako, H. Nakai, K. Umemori, "Design Studies for Quarter-Wave Resonators and Cryomodules for the RIKEN SC-LINAC", Proceedings of the 17th International Conference on RF Superconductivity, Whistler(2015)p976, WEBA06.

K. Suda, M. Nishida, S. Fukuzawa, M. Hamanaka, S. Ishikawa, K. Kobayashi, R. Koyama, T. Nakamura, M. Nishimura, J. Shibata, N. Tsukiori, K. Yadomi, Y. Kotaka, T. Dantsuka, M. Fujimaki, N. Fukunishi, T. Fujinawa, H. Hasebe, Y. Higurashi, E. Ikezawa, H. Imao, M. Kase, T. Kageyama, O. Kamigaito, M. Kidera, K. Kumagai, M. Komiyama, T. Maie, M. Nagase, T. Nakagawa, M. Nakamura, J. Ohnishi, H. Okuno, K. Ozeki, N. Sakamoto, A. Uchiyama, T. Watanabe, Y. Watanabe, S. Watanabe, K. Yamada, H. Yamasawa, "Status Report of the Operation of the RIKEN Ring Cyclotrons", Proceedings of the 13th International Conference on Heavy Ion Accelerator Technology, Yokohama(2015)p65, MOPA12.

K. Ozeki, T. Nakamura, S. Ishikawa, K. Kobayashi, R. Koyama, J. Shibata, N. Tsukiori, M. Nishida, M. Nishimura, M. Hamanaka, S. Fukuzawa, K. Yadomi, K. Suda, A. Uchiyama, H. Okuno, T. Kageyama, M. Kase, O. Kamigaito, K. Kumagai, M. Komiyama, N. Sakamoto, T. Nakagawa, M. Nagase, T. Nagatomo, N. Fukunishi, M. Fujimaki, T. Maie, K. Yamada, T. Watanabe, Y. Watanabe, S. Yamaka, Y. Ohshiro, and Y. Kotaka, "Status Report of the Operation of RIKEN AVF Cyclotron", Proceedings of the 13th International Conference on Heavy Ion Accelerator Technology, Yokohama(2015)p191, WEPB01.

M. Nishida, S. Fukuzawa, M. Hamanaka, S. Ishikawa, K. Kobayashi, R. Koyama, T. Nakamura, M. Nishimura, J. Shibata, N. Tsukiori, K. Yadomi, Y. Kotaka, T. Dantsuka, M. Fujimaki, N. Fukunishi, T. Fujinawa, H. Hasebe, Y. Higurashi, E. Ikezawa, H. Imao, M. Kase, T. Kageyama, O. Kamigaito, M. Kidera, K. Kumagai, M. Komiyama, T. Maie, M. Nagase, T. Nakagawa, M. Nakamura, J. Ohnishi, H. Okuno, K. Ozeki, N. Sakamoto, K. Suda, A. Uchiyama, T. Watanabe, Y. Watanabe, S. Watanabe, K. Yamada, H. Yamasawa, "Status Report of the Operation of the RIKEN Ring Cyclotrons", Proceedings of the 12th annual meeting of Particle Accelerator Society of Japan, Suruga(2015)p276, FSP003.

K. Suda, E. Ikezawa, O. Kamigaito, N. Sakamoto, K. Yamada, Y. Touchi, "Construction of the New Amplifieres for the RIKEN-LINAC", Proceedings of the 27th International Linear Accelerator Conference, Geneva(2014)p339, MOPP122.

N. Sakamoto, M. Fujimaki, N. Fukunishi, Y. Higurashi, O. Kamigaito, H. Okuno, K. Suda, T. Watanabe, Y. Watanabe, K. Yamada, R. Koyama, "Performance of New Injector RILAC2 for RIKEN RI-Beam Factory", Proceedings of the 27th International Linear Accelerator Conference, Geneva(2014)p1123, THPP116.

T. Nakamura, S. Ishikawa, K. Kobayashi, R. Koyama, J. Shibata, N. Tsukiori, M. Nishida, M. Nishimura, M. Hamanaka, S. Fukuzawa, K. Yadomi, K. Suda, A. Uchiyama, K. Ozeki, H. Okuno, T. Kageyama, M. Kase, O. Kamigaito, K. Kumagai, M. Komiyama, N. Sakamoto, T. Nakagawa, M. Nagase, T. Nagatomo, N. Fukunishi, M. Fujimaki, T. Maie, K. Yamada, T. Watanabe, Y. Watanabe, S. Yamaka, Y. Ohshiro, and Y. Kotaka, "Status Report of the Operation of RIKEN AVF Cyclotron", Proceedings of the 12th annual meeting of Particle Accelerator Society of Japan, Suruga(2015)p305, FSP011.

L. Lu, O. Kamigaito, N. Sakamoto, K. Suda, and K. Yamada, "Design of a Triple-Spoke Cavity as a Rebuncher for RIKEN RI-Beam Factory", Proc the 16th International Conference on RF Superconductivity, Paris (2013).

N. Sakamoto, M. Fujimaki, H. Hasebe, Y. Higurashi, O. Kamigaito, H. Okuno, K. Suda, T. Watanabe, and K. Yamada, "Commissioning of a New Injector for the RIKEN RI-Beam Factory", the XXVI Linear Accelerator Conference, Tel-Aviv(2012)p125-129.

N. Sakamoto, T. Dantsuka, T. Fujinawa, N. Fukunishik H. Hasebe, Y. Higurashi, K. Ikegami, E. Ikezawa, H. Imao, T. Kageyama, O. Kamigaito, M. Kase, M. Kidera, M. Komiyama, H. Kuboki, K. Kumagai, T. Maie, M. Nagase, T. Nakagawa, M. Nakamura, H. Okuno, J. Ohnishi, K. Suda, H. Watanabe, T. Watanabe, Y. Watanabe, K. Yamada, L. Lu, H. Yamasawa, K. Ozeki, "High intensity heavy-ion-beam operation of RIKEN RIBF", Proc. the 9th Annual Meeting of Particle Accelerator Society Japan, Toyonaka (2012)p7-11.

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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 49-pnA uranium, 102-pnA xenon, 486-pnA krypton, and 689-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 $^{238}U^{64+}$ 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
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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

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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
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Research & Technical Scientist
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Takeshi MAIE

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Tomoyuki DANTSUKA

Research Consultant
Kumio IKEGAMI (Apr. 1, 2014 –)

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
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Hideyuki YAMASAWA (Manager)

Visiting Scientist
Hideshi MUTO (Tokyo Univ. of Sci. Suwa)

List of Publications & Presentations

Posters Presentations

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Tomonori Ohki, Eiji Ikezawa, Hiromoto Yamauchi, Kazuyuki Oyamada, Masashi Tamura, Akira Yusa, Kenta Kaneko, Yutaka Watanabe, Uchiyama Akito, Masayuki Kase, Osamu Kamigaito. "PRESENT STATUS OF RILAC", Proceedings of the 12th Annual Meeting of Particle Accelerator Society of Japan, August 5-7, 2015, Tsuruga, Japan pp309-311.

RIBF Research Division
Instrumentation Development Group

1. Abstract

This group develops core experimental installations at the RI Beam factory. Experimental installations currently under testing include common elements enabling multiple-use (SLOWRI), as well as others that are highly program specific (SCRIT and Rare-RI Ring). 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. 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 (Rare RI Ring). 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 2016. Rare RI Ring construction has been commissioned in two-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 around ^{78}Ni region and continuously make improvement in the accuracy in 2016. Construction of the SLOWRI system has been completed in 2014. PALIS device was commissioned in 2015, and basic functions such as the RI-beam stopping in Ar gas cell and the extraction with the gas flow were confirmed. Other devices are now under setting up for the first commissioning.

Members

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Takahiro FUJITA (Rikkyo Univ.)
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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

Construction of a next-generation stopped and low-energy radioactive ion beam facility (SLOWRI) which will provide low-energy, high-purity and small emittance ion beams of all elements has been started in FY2013 as one of the principal facilities at the RIKEN RI-beam factory (RIBF). High-energy radioactive ion beams from the projectile fragment separator BigRIPS are thermalized in a large He gas catcher cell (RFC cell) or in a small Ar gas catcher cell (PALIS cell). In the RFC cell, thermalized ions in buffer gas are guided and extracted to a vacuum environment by a combination of dc electric fields and inhomogeneous rf fields (rf carpet ion guide). The PALIS cell will be placed in the vicinity of the second focal plane slits of BigRIPS and can be used continuously during other experiments. From these gas cells, the low-energy ion beams will be delivered via mass separators and switchyards to various devices: such as an ion trap, a collinear fast beam apparatus, and a multi-reflection time of flight mass spectrograph. In the R&D works at the present ring cyclotron facility, an extraction efficiency of 33% for a 100A MeV ^{8}Li ion beam from the projectile fragment separator RIPS was achieved and the dependence of the efficiency on the ion beam intensity was investigated.

First spectroscopy experiment at the prototype SLOWI was performed on Be isotopes. Energetic ions of ^{7,10,11}Be from the RIPS were trapped and laser cooled in a linear rf trap and precision spectroscopy was performed. The evaluated ion temperature of <10 mK demonstrates that a reduction of more than 15 orders of magnitude for the kinetic energy of radioactive Be was achieved online. The ground state hyperfine constants of all Be isotopes have been measured precisely by laser and microwave. These precision measurements will be used to confirm the anomalous mean radius of the valence neutron of the so called neutron halo nucleus. Other laser spectroscopy experiments using the slow RI-beams are also under progress in off-line setups.

A multi-reflection time-of-flight mass spectrograph (MRTOF) has been developed and tested online for radioactive lithium isotope, ^{8}Li at RIPS. A high mass resolving power of 170,000 has been obtained for an isobaric doublet of ^{40}K and ^{40}Ca with a very short flight time of 2 ms. This performance allowed accurate mass determination of $<10^{-7}$ accuracy by a single isobaric reference. Two mass measurement projects using MRTOF mass spectrographs have been started: one is for trans uranium elements at the GARIS facility and the other is for r-process nuclides at SLOWRI facility. At GARIS-II, we performed mass measurements of ^{206}Fr, ^{205}Fr, ^{201}At and their isobars simultaneously.

Resonance ionization spectroscopy has been tested during the offline development of PALIS gas cell. Stable isotopes of Co, Cu, Fe, Ni, Ti, Nb, Sn, In, and Pd were resonantly ionized by excimer pumped dye lasers or Nd:YAG laser pumped Ti:Sapphire lasers with the prototype gas cell setup. The resonance spectra are in many cases sufficient to resolve the hyperfine structures. Nuclear spins and magnetic moments will be determined for various isotopes obtained during other experiments. An online commissioning experiment of parasitic low-energy production facility (PALIS) was performed and confirmed that the PALIS setup can coexist with other BigRIPS experiments and obtained radioactive Cu isotopes from the gas cell.

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)

(WADA, Michiharu, SONODA, Tetsu, KATAYAMA, Ichiro, KOJIMA, Takao, SCHURY, Peter, ITO, Yuta, ARAI, Fumiya, ARAI, Shigeaki, KUBO, Toshiyuki, KUSAKA, Kensuke, FUJINAWA Tadashi, MAIE Takeshi, YAMASAWA Hideyuki, WOLLNIK, Hermann,)

Installation of SLOWRI has been started in FY2013. It consists of two gas catchers (RF Carpet gas cell and PALIS gas cell), mass separators a 50-m beam transport line, a beam cooler-buncher, an isobar separator, and a laser system. The RFCarpet gas cell will be installed at the exit of the D5 dipole magnet of BigRIPS. The gas catcher contains 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 on 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 those ions lost in the slits during other experiments. In this gas catcher, thermalized RI ions quickly become neutral and will be re-ionized by resonant laser radiations. These gas catchers will be tested off-line in FY2014. 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 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, for compensation of 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 are underway.

(2) Laser spectroscopy of trapped radioactive beryllium isotope ions

(WADA, Michiharu, TAKAMINE, Aiko, SCHURY Peter, SONODA Tetsu, OKADA, Kunihiro, KANAI, Yasuyuki, YOSHIDA, Atsushi, KUBO, Toshiyuki, WOLLNIK, Hermann, SCHUESSLER, Hans, KATAYAMA Ichiro)

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 2s $^2S_{1/2}$ - 2p $^2P_{3/2}$ transition of $^7Be+$, $^9Be+$, $^{10}Be^+$ and $^{10}Be+$ ions and the nuclear charge radii of these isotopes were determined. The hyperfine structures of $^{11}Be^+$ and $^7Be^+$ ions using the laser-microwave double resonance spectroscopy were also performed and the magnetic hyperfine constants of $^7Be^+$ and $^{11}Be^+$ ions were determined with accuracies of better than10^{-7}.

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

(WADA, Michiharu, SCHURY Peter, ITO, Yuta, ARAI, Fumiya, MUARRY, Ian, SONODA Tetsu, WOLLNIK, Hermann, MORIMOTO, Koji, KAJI, Daiya, HABA, Hiromitsu, KOURA, Hiroyuki)

The atomic mass is one of the most important quantities of a nucleus and has been studied in various methods since the early days of physics. Among many methods we chose a multi-reflection time-of-flight (MR-TOF) mass spectrometer. Slow RI beams extracted from the RF ion-guide are bunch 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-isochrononicity 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 with a 2 ms flight time for 40K and 40Ca isobaric doublet. This mass-resolving power should allow us to determine ion masses with an accuracy of 10^{-7}. An online mass measurement for radioactive lithium isotope has been carried out at the prototype SLOWRI setup.

The MR-TOF mass spectrograph has been placed under the GARIS-II separator aiming at direct mass measurements of trans-uranium elements. A small cryogenic gas catcher cell was placed at the focal plane box of GARIS-II and a bunched low-energy heavy ion beam were transported to the trap of MR-TOF. In online commissioning experiments, we achieved more than 30% of extraction efficiency from the cryogenic gas cell. We measured masses of ^{206}Fr, ^{205}Fr, ^{201}At and some of their isobars simultaneously. Further measurements towards trans-uranium isotopes is planned in FY2016.

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

(WADA, Michiharu, SCHUESSLER, Hans, IIMURA, Hideki, SONODA, Tetsu, SCHURY, Peter, TAKAMINE, Aiko, OKADA, Kunihiro, WOLLNIK, Hermann)

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 alkaline, alkaline-earth, noble-gases and several other elements have been measured by collinear laser spectroscopy since these ions have all 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 beams. This should expand the range of applicable nuclides of laser spectroscopy. In the first years of the RIBF project, Ni and its vicinities, such as Ni, Co, Fe, Cr, Cu, Ga, 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 recycle 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.

We have built an off-line mass separator and a collinear fast beam apparatus with a large solid-angle fluorescence detector. A 617 nm transition of the metastable Ar+ ion at 20 keV was measured with both collinear and anti-collinear geometry that allowed us to determine the absolute resonant frequency of the transition at rest with more than 10^{-8} accuracy. Such high accuracy measurements for Ti and Ni isotopes are in progress.

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

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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, to rescue such dumped 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 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 SLOWRI experimental area for various experiment. 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 tested for resonance ionization scheme of several elements, extraction from the cell, and transport to a high vacuum chamber. An online setup, has been fabricated in FY2013 and the first online commissioning took place in Fy2015. We confirmed that the PALIS gas cell doesn't harm BigRIPS experiment, and a reasonable amount of radioactive Cu isotopes were extracted from the cell by gas flow. A second online commissioning is scheduled in FY2016 and we are going to provide parasitic low-energy RI-beams for various experiments at the SLOWRI experimental area.

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M. Wada et al., « SHE-mass project at RIKEN RIBF », May 25-29, 2015, TAN2015, Urabandai, Fukushima, Japan
T. Sonoda et al., « Development of the parasitic production of low-energy RI-beam and gas-ject nuclear spectroscopy at RIKEN BigRIPS « , June 7-10, 2015, LAP2015, Michigan State Univ. East Lancing, MI, USA
M. Wada, « Laser spectroscopy and mass measurements at RIKEN SLOWRI », Aug. 24-27, ECT* Workshop, TRENTO, Italy
M. Wada et al, « Towards high precision nuclear spectroscopy at SLOWRI, RIKEN RIBF », Nov. 07-12, JCNP2015, RCNP, Osaka, Japan.

Posters Presentations

[International Conference etc.]

Y. Ito et al., « Development of a gas cell system for SHE-mass project at RIKEN », May 25-29, 2015, TAN2015, Urabandai, Fukushima, Japan
M. Reponen, et al., « Resonance ionization spectroscopy data-analysis software for PALIS-facility », June 7-10, 2015, LAP2015, Michigan State Univ., East Lancing, MI, USA

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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 2013 and commissioning experiments were successfully performed in last year. 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-RIs 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 could 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 ^{25}Cl, we successfully demonstrated mass determination by measuring revolution time for both isotopes with the accuracy of ~20 ppm. We are going to try to measure masses for isotopes around ^{78}Ni region in 2016.

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-RIs 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 kΩ. 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 $\mu g/cm^2$. 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 last year, we had two times of commissioning experiments. In the first experiment, we use primary $^{78}Kr^{36+}$ 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 $^{78}Kr^{36+}$ 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 was remained, consequently, the 10-ppm accuracy of the isochronism was obtained. More precise tuning is possible with reference the Schottky data. In the second commissioning 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 and the magnetic field fluctuation (less than 10 ppm) is also considerable. These inexpediencies will be improved in next time. In this year, we will be able to try mass measurements for isotopes related r-process pass around ^{78}Ni region.

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List of Publications & Presentations

Publications
[Journal]
(Review)
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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} /(cm^{2}s) with the number of injected ions of 3×10^8, and we successfully measured a diffraction pattern in the angular distribution of scattered electrons from ^{132}Xe isotope 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 ^{132}Xe 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}/(cm^{2}s) at maximum and the averaged value was 1.2×10^{27}/(cm^{2}s) 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}/(cm^{2}s) 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.

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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 construction, operation and improvement of the core research instruments at RIBF, such as BigRIPS in-flight 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 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 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 Director

Toshiyuki KUBO

Junior Research Associates

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Momo MUKAI (Tsukuba Univ.)

Part-time Worker

Meiko UESAKA (– Mar. 31, 2015)

Senior Visiting Scientist

Toshio KOBAYASHI (Tohoku 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
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Research & Technical Scientists
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Naohito INABE (Senior Technical Scientist)
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Yohei SHIMIZU (Jan. 1, 2015 –)

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Ha JEONGSU (Seoul National University, Apr. 1, 2015 – Aug. 30, 2015)

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David Joseph MORRISSEY (NSCL, MSU)
Bradley Marc SHERRILL (NSCL, MSU)
Martin Alfred WINKLER (GSI)
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Yutaka MIZOI (Osaka Elec.-Com. Univ.)
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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

G. Lorusso, S. Nishimura, Z. Y. Xu, A. Jungclaus, Y. Shimizu, G. S. Simpson, P.-A. Söderström, H. Watanabe, F. Browne, P. Doornenbal, G. Gey, H. S. Jung, B. Meyer, T. Sumikama, J. Taprogge, Zs. Vajta, J. Wu,H. Baba, G. Benzoni, K. Y. Chae, F. C. L. Crespi, N. Fukuda, R. Gernhäuser, N. Inabe, T. Isobe, T. Kajino, D. Kameda, G. D. Kim, Y.-K. Kim, I. Kojouharov, F. G. Kondev, T. Kubo, N. Kurz,Y. K. Kwon, G. J. Lane, Z. Li, A. Montaner-Pizá, K. Moschner, F. Naqvi, M. Niikura, H. Nishibata, A. Odahara, R. Orlandi, Z. Patel, Zs. Podolyák, H. Sakurai, H. Schaffner, P. Schury, S. Shibagaki, K. Steiger,H. Suzuki, H. Takeda, A. Wendt, A. Yagi, and K. Yoshinaga, "β-Decay Half-Lives of 110 Neutron-Rich Nuclei across the N = 82 Shell Gap: Implications for the Mechanism and Universality of the Astrophysical r Process", Physical Review Letter 114, 192501, (2015).*

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栂野泰宏，南方亮吾，生越駿，中村隆司，磯部忠昭，稲辺尚人，大津秀暁，亀田大輔，簡野大輝，久保敏幸，小林俊雄，小林信之，近藤洋介，佐藤広海，佐藤義輝，清水陽平，鈴木宏，高橋賢人，武内聡，竹田浩之，田中隆己，中嶋丈嘉，中塚徳継，西征爾郎，福田直樹，馬場秀忠，武藤琴美，村井大地，村上哲也，本林透，米田健一郎，N. L. Achouri，A. G. Tuff，T. Aumann，F. Delaunay，J. Gibelin，J. Hwang，S. Kim，J. Lee，M. Marques，A.Navin，N. A. Orr，P. Doornenbal，S. Leblond，M. Vandebrouck，**「^{19,20,22}C の反応断面積」，日本物理学会　第 70 回年次大会(2015)，早稲田大学、東京都、3/21 – 24, 2015.**

小林幹，道正新一郎，清川裕，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，小林和馬，久保敏幸，久保田悠樹，李清秀，松下昌史，宮裕之，水上淳，永倉弘康，西村太樹，笈川浩之，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，横山輪，吉田光一，**「中性子数 34 近傍カルシウム同位体の直接質量測定」，**日本物理学会　2015 年秋季大会、大阪市立大学、大阪市、9/25 - 28, 2015

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 F 中性子ドリップラインの探索」，**日本物理学会　2015 年秋季大会、大阪市立大学、大阪市、9/25 - 28, 2015

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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 におけるアイソマー同定システムの開発」，**日本物理学会　2015 年秋季大会、大阪市立大学、大阪市、9/25 - 28, 2015

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園田哲，和田道治，飯村秀紀，片山一郎，Reponen.M，小島隆夫，Sonnenschein.V，富田英生，久保敏幸，吉田光一，稲辺尚人，福田直樹，竹田浩之，鈴木宏，日下健祐，若杉昌徳，新井重昭，新井郁也，Schury.P，伊藤由太，宮武宇也，石山博恒，今井伸明，平山賀一，渡辺裕，岡田邦宏，「RIBF におけるパラサイト低速 RI ビーム生成とガスジェットレーザー核分光の開発」，日本物理学会　2015 年秋季大会、大阪市立大学、大阪市、9/25 - 28, 2015

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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. Help 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

Visiting Scientist

Bertis Charles RASCO (Louisiana State Univ.)

List of Publications & Presentations

Publications

[Journal]

(Original Papers)

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.Marques, 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 26O: A Barely Unbound System beyond the Drip Line", Phys. Rev. Lett 116, 102503 (6pages) (2016).

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V. Panin, “Progress report on Heavy-Ion-Proton project”, SAMURAI International Collaboration Workshop 2015, Wako, Saitama, 7-8 September 2015.

S. Koyama, “Study of cluster degree of freedom in neutron-rich sd-shell nuclei via alpha inelastic scattering”, SAMURAI International Collaboration Workshop 2015, Wako, Saitama, 7-8 September 2015.

H. Otsu, “Report on Day-two experiments”, SAMURAI International Collaboration Workshop 2015, Wako, Saitama, 7-8 September 2015.

M. Sasano, “Study of Gamow-Teller transitions in 132Sn”, International Conference, Nuclear Structure and Related Topics, Dubna, Russia, 14-18th July (2015). An invited talk.

M. Sasano, “Gamow-Teller transitions from 132Sn”, Collective motion in nuclei under extreme conditions, Krakow, Poland, 14-18th September (2015). An invited talk.

H. Otsu, “SAMURAI in its operation phase for RIBF”, International Conference on Electromagnetic Isotope Separator and Related Topics (EMIS 2015), Grand Raipids, MI, US, 11-15th May (2015).

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Y. Kubota, “Probing multi-neutron correlation via knockout reaction”, Critical Stability in Few-Body Systems, Saitama, Japan, 26–30th January (2015).

Y. Kubota, “Direct measurement of two neutron correlation in 11Li via the (p,pn) reaction”, Critical Stability in Few-Body Systems, Saitama, Japan, 1–5th February (2016).

S. Reichert, "Study of fission barriers in neutron-rich nuclei using the (p,2p) reaction: Status of SAMURAI Experiment NP1306 SAMURAI14" at DPG Fruehjahrstagung, March 23-27, Heidelberg

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L. Stuhl, “Investigation of spin-isospin collectivity in asymmetric nuclear matter”, 14th CNS International Summer School (CNSS15), Wako, Saitama, Japan, 26th August – 1st September (2015).

[Domestic Conference]

大津　秀暁､”Particle/Gamma detectors in RIBF”, ELPH 研究会 C10､｢素粒子･原子核実験における全吸収型カロリメーターの実例と応用｣､東北大学 ELPH、2015 年 3 月 10 日

V. Panin, “Investigation of key nuclear reactions in the astrophysical rp-process using SAMURAI”, 70th JPS Annual meeting, Tokyo, Japan, 21-24 March 2015.

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 (Invited)

笹野　匡紀，「ノックアウト(p,2p)反応を用いた核分裂閾値エネルギーの測定」、日本物理学会 2015 年秋季大会、シンポジウム「重イオン深部非弾性散乱の基礎と応用」、大阪市立大学、2015 年 9 月 25 日 (招待・シンポジウム講演)

大津　秀暁, “Unbound states in neutron rich nuclei studied at SAMURAI”, 日本物理学会 2015 年秋季大会、シンポジウム「ドリップライン近傍のハイパー核と不安定核」、大阪市立大学、2015 年 9 月 27 日 (シンポジウム講演)

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 (Invited)

Y. Kondo, “Invariant spectroscopy at RIPS and RIBF”, Physics with Fragment Separators - 25th Anniversary of RIKEN-Projectile Fragment Separator (RIPS25), Shonan Village center, December 6-7, 2015 (Invited)

近藤洋介, “Island of Inversion の南側”, 九大研究会　-中性子過剰領域における弱束縛系の物理- , 九州大学箱崎キャンパス, 2015 年 3 月 9, 10 日 (招待講演)

L. Stuhl, “Around the Nucleus”, JSPS Science Dialogue, Tochigi Prefectural Utsunomiya Girl’s Senior High School, Utsunomiya, Japan, 2nd October (2015).

Y. Kubota, "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", 70th JPS meeting, Tokyo, Japan, 25 - 28th March (2015).

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Y. Kondo, “Experimental study of unbound oxygen isotopes”, 「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, 湘南国際村センター, 17-18, September, 2015

Y. Kondo, “Report on Day one experiments”, SAMURAI International Collaboration Workshop 2015, RIKEN, 7-8, September, 2015

近藤洋介, 中村隆司, Nadia Lynda Achouri, Thomas Aumann, 馬場秀忠, Franck Delaunay, Pieter Doornenbal, 福田直樹, Julien Gibelin, Jongwon Hwang, 稲辺尚人, 磯部忠昭, 亀田大輔, 簡野大輝, Sunji Kim, 小林信之, 小林俊雄, 久保敏幸, Sylvain Leblond, Jenny Lee, Miguel Marques, 南方亮吾, 本林透, 村井大地, 村上哲也, 武藤琴美, 中嶋丈嘉, 中塚徳継, Alahari Navin, 西征爾郎, 生越駿, Nigel Andrew Orr, 大津秀暁, 佐藤広海, 佐藤義輝, 清水陽平, 鈴木宏, 高橋賢人, 竹田浩之, 武内聡, 田中隆己, 栂野泰宏, Adam Garry Tuff, Marine Vandebrouck, 米田健一郎, “非束縛酸素同位体 26O の不変質量核分光”, 日本物理学会 2015 年秋季大会 大阪市立大学杉本キャンパス, 9 月 25 日- 29 日, 2015

Posters Presentations

[International Conference etc.]

L. Stuhl, “A new low-energy neutron detector for (p,n) experiments with pulse shape discrimination properties”, Collective motion in nuclei under extreme conditions, Krakow, Poland, 14-18th September (2015).

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 600 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. We have added a 52 TB RAID for the data analysis in the autumn of 2014 and replaced the ssh login server (RIBF00) in the winter of 2015.

(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. Sophos Email Security and Control (PMX) installed on the mail front-end servers tags spam mails and isolates virus-infected mails. The probability to identify the spam is approximately 95-99%. We are operating several information servers such as Web servers, Integrated Digital Conference (INDICO) server, Wiki servers, Groupware servers, Wowza streaming servers, and an anonymous FTP server (FTP.RIKEN.JP). A new Web server has been installed in April 2014 as an official Web server of RNC to replace the old Web server installed in 2005. A new 72 TB RAID was installed to replace the old RAID to the anonymous FTP server in August 2014. A research record server (RIBFDBOX) was installed, and is started operation in April 2015. This server consists of an HP DL-320e server, a 52 TB SAS RAID6 system, and Proself 4 software.

(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), and NeuLAND (GSI) 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) and BRIKEN (GSI/Univ. Liverpool/IFIC) 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

Junior Research Associate
Ryousuke TANUMA (Rikkyo Univ.)

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
Hiromi SATO (Apr. 1, 2014 –)

Research and Technical Scientist
Tokihiro IKEDA (Senior Research Scientist, Oct. 1, 2015 –)

Special Postdoctoral Researcher
Yuki SATO (– Jun. 30, 2015)

Research Consultant
Hiroyuki MURAKAMI

Visiting Scientist
Kohei FUJIWARA (Tokyo Met. Ind. Tech. Res. Inst.)

List of Publications & Presentations

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[Journal]

(Original Papers) *Subject to Peer Review

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Y. Sato, T. Shimaoka, J.H. Kaneko, H. Murakami, M. Isobe, M. Osakabe, M. Tsubota, K. Ochiai, A. Chayahara, H. Umezawa, S. Shikata, “Radiation hardness of a single crystal CVD diamond detector for MeV energy protons”, Nuclear Instruments and Methods in Physics Research Section A, 784, 147 (2015). *

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 He-4 (He-8, Be-8) Reaction”, Physical Review Letters 116, 052501 (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 O^{26}: A Barely Unbound System beyond the Drip Line”, Physical Review Letters 116, 102503 (2016). *

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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) Research and development of RI production technology at RIBF.
(4) Developments of trace elements analyses.
(5) 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 RIKEN Ring Cyclotron using 135A MeV C, N, Ne ions, 95A MeV Ar ions and 90A MeV Fe 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 at 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 (LETmax) was 30 keV/μm. LETmax irradiations showed the same mutation rate as that by chemical mutagens, which typically cause high mutation rate. The LETmax of imbibed rice (*Oryza sativa* L.) seeds and dry wheat (*Triticum monococcum*) seeds were shown to be 50-63 keV/μm and 50 keV/μm, respectively. In the case of microbe (*Mesorhizobium lothi*), 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 *Arabidpsis* 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. LETmax 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 LETmax: 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 *Arabidpsis* 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 2015, it consisted of 158 groups from Japan and 8 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 'Manamusume'. Imbibed seeds were irradiated with the LETmax (C-ions) on 16 April, 2011. We isolated 73 candidate lines of salt-resistant mutants from 719 M_2 progenies grown in the saline paddy field in Tohoku University in 2012. From these, we selected 12 salt-resistant M_3 lines in 2013 and 4 M_4 lines in 2014. 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.

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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 using accelerator techniques and its 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 conducted 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 30 radiotracers from ^{7}Be 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. 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 nucl.$^{-1}$ ^{14}N beam from the RIKEN Ring Cyclotron. These multitracers are also supplied to universities and institutes as collaborative researches.

In 2014–2015, we developed production technologies of radioisotopes such as ^{28}Mg, ^{48,51}Cr, ^{44}Ti, ^{67}Cu, ^{75}Se, ^{95m}Tc, ^{121m}Te, ^{181}W, ^{182}Ta, ^{183,184m,184g}Re, ^{191}Pt, and ^{211}At which were strongly demanded but lack supply sources in Japan. We also investigated the excitation functions for the ^{27}Al(α,x), ^{nat}Ti(α,x), ^{nat}Cu(α,x), ^{nat}Ge(α,x), ^{nat}Zr(α,x), ^{nat}Mo(d,x), ^{nat}Cd(α,x), ^{116}Cd(α,x), ^{nat}Pd(α,x), ^{nat}Ce(d,x), ^{nat}Sm(d,x), ^{159}Tb(d,x), ^{nat}Ho(α,x), ^{169}Tm(d,x), ^{nat}Lu(p,x), ^{nat}Lu(d,x), ^{nat}Ta(p,x), ^{nat}Ta(d,x), ^{nat}W(d,x), and ^{nat}Pt(d,x) reactions to quantitatively produce useful RIs. We used radiotracers of ^{139}Ce for application studies in chemistry, ^{65}Zn, ^{67}Cu, ^{88}Y, ^{191}Pt, and ^{211}At in nuclear medicine, ^{88,89}Zr, ^{95}Nb, ^{175}Hf, and ^{177}Ta in geochemistry, and ^{85}Sr and ^{121m}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 2014–2015, we have accepted 10 orders of ^{65}Zn with a total activity of 59 MBq, 1 order of ^{85}Sr with 1 MBq, 2 orders of ^{88}Y with 2 MBq, and 6 orders of ^{109}Cd with 26 MBq.

(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}Cm(^{18}O,5n)^{261}Rf, ^{248}Cm(^{19}F,5n)^{262}Db, and ^{248}Cm(^{22}Ne,5n)^{265}Sg reactions, respectively, and their chemical properties are investigated.

We have been developing a gas-jet transport system at 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: (i) the background radioactivities of unwanted reaction products are strongly suppressed, (ii) the intense beam is absent in the gas-jet chamber and hence high gas-jet efficiency is achieved, and (iii) the beam-free condition also allows for investigations of new chemical systems. In 2014–2015, the isotope of element 107 ^{266}Bh was produced in the ^{248}Cm(^{23}Na,5n)^{266}Bh reaction, and its decay properties were investigated using the rotating wheel apparatus MANON for α/SF spectrometry. Toward the SHE chemistry behind GARIS, we developed a gas-chromatograph apparatus directly coupled to GARIS, which enabled in-situ complexation and gas-chromatographic separation of a large variety of volatile compounds of SHEs. Toward aqueous chemistry of the heaviest elements such as Sg and Bh, we have started to develop a new rapid chemistry apparatus which consists of a continuous dissolution apparatus Membrane DeGasser (MDG), a Flow Solvent Extractor (FSE), and a flow liquid scintillation detector for α/SF-spectrometry. The performance of MDG and FSE were investigated using ^{92,94m}Tc and ^{181}Re produced in the ^{nat}Mo(d,xn) and ^{nat}W(d,xn) reactions, respectively, at AVF.

At AVF, the distribution coefficients (K_d) of ^{261}Rf on the Aliquat 336 resin were measured in HCl with the AutoMated Batch-type solid-liquid Extraction apparatus for Repetitive experiments of transactinides (AMBER) in collaboration with Osaka Univ. The extraction behavior of ^{89m}Zr and ^{173}Hf in the Aliquat 336/HCl system was investigated for Rf chemistry with the flow-type liquid-liquid extraction apparatus. The reversed-phase TTA extraction chromatography of ^{261}Rf and its homologues ^{85}Zr and ^{169}Hf was conducted in HF/HNO_3 using the Automated Rapid Chemistry Apparatus (ARCA) in collaboration with Niigata Univ. and JAEA. The reversed-phase extraction chromatography of ^{90g}Nb and ^{178a}Ta in Aliquat 336/HF and the anion-exchange chromatography of ^{90g}Nb and ^{178a}Ta in HF/HNO_3 were also conducted with ARCA for chemical studies of Db. We also used radiotracers of ^{88,89m}Zr, ^{95}Nb, ^{93m}Mo, ^{95m}Tc, ^{173,175}Hf, ^{178a,179}Ta, ^{177,179m,181}W, and ^{183}Re for model experiments of SHEs.

(3) Development of trace element analysis using accelerator techniques and its application to geoscience and archaeological research fields

We developed a new mass spectrometry technology for trace element analyses as an application of accelerator technology to various fields such as cosmochemistry, environmental science, and archaeology. ECRIS-AMS is a new type of accelerator mass spectrometry at RILAC equipped with an ECR ion source. This system is available for measuring trace elements (10^{-14}–10^{-15} level) and is expected to be especially effective for measurements of low-electron-affinity elements such as ^{26}Al, ^{41}Ca, and ^{53}Mn. In 2014–2015, we have renovated the detection system and examined the sensitivity and mass resolution power. We also attempted to develop another technology by customizing a mass spectrometer equipped with a stand-alone ECR ion source for analyses of elemental and isotopic abundances. Especially, we equipped a laser-ablation system with an ion source to achieve high-resolution analysis.

Using the conventional ICP-MS, TIMS, IRMS and so on, we also examined the origin of burials from ancient tombs and ruins. We are challenging two issues. One is the analyses of sulfur and lead isotope ratios for cinnabar samples from ancient tombs in Japan to elucidate the establishment of Yamato dynasty around 3rd and 4th centuries. We showed that the lead isotopes in cinnabar ore exhibited clear local characteristics and the origin of the cinnabar ore could be distinguished from the lead isotope compositions. The other issue is to elucidate the market of oil and asphalt in Jomon Period in the North Japan based on the sulfur isotopes. We started a feasibility study to analyze the sulfur isotope ratios to distinguish the origin of oil samples.

(4) Development of chemical materials for ECR ion sources of RIBF

In 2014–2015, we developed a chemical procedure to recover an enriched $^{48}CaCO_3$ from the ^{48}CaO/Al mixture used in the 18-GHz ECR ion source of RILAC. We prepared metallic ^{238}U rods and $^{238}UO_2$ on a regular schedule for ^{238}U-ion accelerations with the 28-GHz ECR of RILAC II.

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Shingo UENO (Kanazawa Univ.)
Kazunori HAYASHI (Kanazawa Univ.)
Takumi TANIGUCHI (Kanazawa Univ.)
Naoya GOTO (Niigata Univ.)
Takumi KOYAMA (Niigata Univ.)

Shohei TSUTO (Niigata Univ.)
Ryuji AONO (Niigata Univ.)
Daisuke SATO (Niigata Univ.)
Akira TANAKA (Niigata Univ.)
Tetuya NAGAOKA (Niigata Univ.)
Iori CHIYONISHIO (Kanazawa Univ.)
Ahmed USMAN (Univ. of Malaya)
Kento MURAKAMI (Kanazawa Univ.)
Teruyoshi FUJISAWA (Kanazawa Univ.)
Yukari YATSU (Kanazawa Univ.)
Yuki YASUDA (Osaka Univ.)
Yoshihiko HAYASHI (Osaka Univ.)
Risa MOTOYAMA (Niigata Univ.)
Tomihiro TOMITSUKA (Niigata Univ.)
Kaori SHIRAI (Niigata Univ.)
Yu NAMBA (Niigata Univ.)
Kouki MORIYA (Kanazawa Univ.)
Shuta OE (Kanazawa Univ.)
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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

A. Toyoshima, K. Ooe, S. Miyashita, M. Asai, M. F. Attallah, N. Goto, N. S. Gupta, H. Haba, M. Huang, J. Kanaya, Y. Kaneya, Y. Kasamatsu, Y. Kitatsuji, Y. Kitayama, K. Koga, Y. Komori, T. Koyama, J. V. Kratz, H. V. Lerum, Y. Oshimi, V. Pershina, D. Sato, T. K. Sato, Y. Shigekawa, A. Shinohara, A. Tanaka, K. Tsukada, S. Tsuto, T. Yokokita, A. Yokoyama, J. P. Omtvedt, Y. Nagame, and M. Schädel, "Chemical studies of Mo and W in preparation of a seaborgium (Sg) reduction experiment using MDG, FEC, and SISAK", Journal of Radioanalytical and Nuclear Chemistry **303**, 1169–1172 (2015).*

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H. Yashima, S. Sekimoto, K. Ninomiya, Y. Kasamatsu, T. Shima, N. Takahashi, A. Shinohara, H. Matsumura, D. Satoh Y. Iwamoto, M. Hagiwara, K. Nishiizumi, M. W. Caffee, and S. Shibata, "Measurements of the neutron activation cross sections for Bi and Co at 134 MeV", Tenth International Conference on Methods and Applications of Radioanalytical Chemistry (MARC X), (Los Alamos National Laboratory), Kailua-Kona, USA, Apr. (2015).

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A. Toyoshima, K. Ooe, M. Asai, M.F. Attallah, N. Goto, N.S. Gupta, H. Haba, M. Kaneko, Y. Kaneya, Y. Kasamatsu, Y. Kitatsuji, Y. Kitayama, K. Koga, Y. Komori, T. Koyama, J.V. Kratz, H.V. Lerum, A. Mitsukai, S. Miyashita, Y. Oshimi, V. Pershina, D. Sato, T.K. Sato, Y. Shigekawa, A. Shinohara, A. Tanaka, K. Tsukada, S. Tsuto, A. Vascon, T. Yokokita, A. Yokoyama, J. P. Omtvedt, Y. Nagame, and M. Schädel, "Developments towards aqueous phase chemistry of transactinide elements", 5th International Conference on the Chemistry and Physics of the Transactinide Elements (TAN15), (Advanced Science Research Center, Japan Atomic Energy Agency; Nishina Center for Accelerator-Based Science, RIKEN), Urabandai, Japan, May (2015).

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[Domestic Conference]

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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.

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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.

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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 handles fee-based distribution of radioisotopes Zn-65, Y-88 and Cd-109 from 2007, which are produced by the RI application team at the AVF cyclotron, to nonaffiliated users under a Material Transfer Agreement (MTA) between Japan Radioisotope Association and RIKEN. In 2015, the MTA was amended to newly list Sr-85. We delivered 3 shipments of Cd-109 with a total activity of 4 MBq, 2 shipments of Zn-65 with a total activity of 10 MBq and one shipment of Y-88 with an activity of 1 MBq. The final recipients of the RIs were five universities and one hospital.

(2) Support of Industrial application using RIBF

In 2009, RNC started a new project "Promotion of applications of high-energy heavy ions and RI beams" as a grant-in-aid program of MEXT "Sharing Advanced Facilities for Common Use Program". In this project, RNC opens the old part of the RIBF facility, which includes the AVF cyclotron, RILAC, RIKEN Ring Cyclotron and experimental instruments like RIPS, to non-academic proposals from users including private companies. This MEXT program was terminated in 2010, but RNC succeed and promote this facility-sharing program after that. 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 fifth InPAC meeting held in January 2016 reviewed two fee-based proposals from private companies and approved them. Until now, three proposals of fee-based utilization 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.

(3) Development of real-time wear diagnostics using RI beams

We are promoting a method for real-time wear diagnostics of industrial materials using RI beams as tracers. For that purpose, very intense RI beams of Be-7 ($T_{1/2}$=52 days) at 4.1 MeV/A and Na-22 ($T_{1/2}$=2.6 years) at 3.7 MeV/A were produced via the (p,n) reaction at the CRIB separator using beams from the AVF cyclotron. As we can provide RI beams of different nuclides and control the implantation depth, we have developed a novel method of wear diagnostics.

In 2014, under a collaborative research agreement between RIKEN, University of Tokyo and two private companies, we had two beam-times to produce RI beams of Be-7 and Na-22 and implanted them near surface of metallic machine parts, whose wear-loss rate was evaluated through measurements of the radio-activities. Until now, one proposal of fee-based utilization using Be-7 beam have been accepted, but it is not completed yet.

We are also developing a new method to determine the spatial distribution of positron-emitting RIs on periodically-moving objects in a closed system, named "GIRO" (Gamma-ray Inspection of Rotating Object). This is based on the same principle as the medical PET systems but is simpler and less expensive. We have constructed a test bench and performed measurements with Na-22 sources to verify the principle and evaluate the resolution. In future this method can be used for real-time evaluation of wear loss in a running machine.

Members

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List of Publications & Presentations

Publications

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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.

Training is very important for safety, and we started annual retraining to all the RIBF users by using an e-learning system. The users can take the training anywhere in the world. Unless the users finish it, their entry is refused at the gate of radiation area.

The radiation monitor system at the Nishina building were installed in 1986. While the central control unit was replaced about 10 years ago, repair of the detector heads became difficult recently, and their replacement was started in 2015.

According to the change of guideline issued by Nuclear Regulation Authority, we must measure the radionuclides concentrations of exhaust air from all the facilities where nuclear fuel materials are used. The exhaust lines of the linac building and the Nishina building were modified, and we could meet the requirement without increase the online concentration monitors which were very expensive.

Minor improvements of the radiation safety systems were also done, for example, the warning sirens of irradiation rooms in the RIBF building were replaced by voice alarms, which made clear what place became dangerous.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers)

Mikami, S., Maeyama, T., Hoshide, Y., Sakamoto, R., Sato, S., Okuda, N., Demongeot, S., Gurriaran, R., Uwamino, Y., Kato, H., Fujiwara, M., Sato, T., Takemiya, H. and Saito, K.: “Spatial distributions of radionuclides deposited onto ground soil around the Fukushima Dai-ichi Nuclear Power Plant and their temporal change until December 2012”, Journal of Environmental Radioactivity, 139, 320-343 (2015). *

[Book]

遮蔽ハンドブック研究専門委員会編: “放射線遮蔽ハンドブックー基礎編ー”, 日本原子力学会 (2015).

Oral Presentations

[International Conference etc.]

Oh, J., Jung, N., Lee, H., Oranj, L., Nakao, N., Uwamino, Y. and Ko S.: “Measurements of secondary neutrons spectra from 50 MeV/u 238U beams with the beryllium stripper”, 8th International Symposium on Radiation Safety and Detection Technology (ISORD-8), Jeju, Korea, July (2015).

[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放射線安全", 第 3 回加速器施設安全シンポジウム, 東海村, 1 月,(2016).

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 2016 年春の年会, 仙台, 3 月 (2016).

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Partner Institution

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 of the University of Tokyo (CNS), Institute of Particle and Nuclear Studies of KEK (KEK), and Department of Physics, 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, 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 newly constructed isotope separator KISS will be available for the users in near future.

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. 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

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 sources 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. Detailed study of the optics from the ion sources are expected to improve transmission and qualities of beams for the RIBF facility.

(2) Nuclear Astrophysics

The nuclear astrophysics group in CNS is working for experimental researches using the low-energy RI beam separator CRIB. In 2015, experiments on the alpha-cluster structure in ^{14}C and ^{19}Ne nuclei, ^{18}F(p, α) astrophysical reaction using the Trojan Horse method with a improved precision, and the ^{17}F+Ni scattering near the Coulomb barrier were performed at CRIB under international collaborations including Korean, Italian, and Chinese groups. The call for CRIB proposals at the NP-PAC has been resumed in 2014, and 3 new proposals were approved in 2015.

(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 2015, 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. Exothemic charge exchange reaction (^{8}He,^{8}Li*(1+)) on ^{4}He has been analyzed for studying spin-dipole response of few-body system on the photon line. The tetra-neutron studied by the ^{4}He(^{8}He,^{8}Be)4n reaction, showing a candidate of the ground state of the tetra neutrons just above the 4n threshold as well as continuum at higher excitation energy, has been published. We plan to measure the reaction with better statistics and more accuracy in missing mass.

The readout system of 14 detectors of the CNS GRAPE was upgraded, where digital pulse data taken by sampling ADCs are analyzed by 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 PHENIX, the group has been concentrating on the physics analysis involving dielectron measurement in Au+Au collisions. 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). Performance evaluation of the MicroMegas + GEM systems for the upgrade has been performed. R&D of GEM and related techniques has been continuing. Development of Teflon GEM has been progressing in collaboration with the Tamagawa group of RIKEN.

(5) Nuclear Theory

The nuclear theory group has 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 ^{37,38}Si, ^{50}Ar and ^{80,82}Zn. We also participated in activities of HPCI Strategic Programs, which was finished at the end of FY2015. Since FY2015, we joined a new project "Priority Issue 9 to be tackled by using the Post-K Computer" and promotes computational nuclear physics utilizing supercomputers.

(6) OEDO/SHARAQ project

The OEDO/SHARAQ group promotes high-resolution experimental studies of RI beams by using the high-resolution beamline and SHARAQ spectrometer. A mass measurement by TOF-Bρ technique was performed for very neutron-rich calcium isotopes around N=34. For the experiment, we introduced new detector devices. A set of diamond detectors, developed as timing counters with excellent resolution, were installed as time-of- flight counters at the first and final foci of the beam line. Clover-type Ge detectors were installed at the final focal plane of the SHARAQ spectrometer for the first time, enabling particle identification of RI beams by probing delayed gamma rays from known isomeric states of specific nuclei. The OEDO project, which is a major upgrade of the high-resolution beamline for high-quality RI beams with energies lower than 100 MeV/u, is ongoing. The basic magnet arrangement and ion optics was fixed. We will finish the construction of the new beamline before March, 2017.

(7) Exotic Nuclear Reaction

The Exotic Nuclear Reaction group studies various exotic reactions induced by beams of unstable nuclei. In 2015, analyses of experiments performed in 2014 showed progress: (1) parity transfer probe of the (^{16}O, ^{16} F(g.s)) reaction on ^{12}C gave an enhancement on 0 - states in ^{12}B near zero degrees demonstrating the effectiveness of this reaction, (2) the spectrum of two-neutron relative momentum in knockout reactions from Borromean nucleus ^{11}Li was successfully decomposed into each angular momentum and a candidate of a d-wave resonance was found.

(8) Low Energy Nuclear Reaction Group

We measured the proton resonance elastic scattering with the energy degraded ^{34}Si beam at RIPS facility. This experiment aims to get the excitation function with higher statistics and better energy resolution than the previous experiment. Though the beam intensity was less than expected, we successfully observed the excitation function.

We're also developing two types of the exotic targets, Ti-3H and high-spin isomeric state of ^{178m2}Hf. For the first target, we tested vulnerability with Ti-D which has an atomic ratio of 1:0.2 as the first step. We're going to test the uniformity and impurity in the target with ^{20}Ne beam of 8.2 MeV/u. For the second target, we measured the production cross section of natYb(a,2n) reaction and conducted the chemical separation. Although the activities of other short-lived isotopes are around 10MBq, we successfully identified the cascade decay from ^{178m2}Hf of about 100 Bq by employing EURICA. We obtained the condition for mass production of ^{178m2}Hf at RIBF.

(9) Active Target Development

Two types of gaseous active target TPCs called GEM-MSTPC and CAT are developed and used for the missing mass spectroscopy in inverse kinematics. The common remarkable features of these detectors are the capabilities of the high intensity beam injection and the low energy recoil measurement. The astrophysical reactions of (α,p) on ^{18}Ne, ^{22}Mg and ^{30}S were measured by using the GEM-MSTPC. The alpha emission following the beta decay of ^{16}N was measured with the GEM-MSTPC in combination with the gating grid. The present topic of the CAT is the monopole transition strength distribution in nuclei extracted via deuteron inelastic scattering.

We measured the deuteron scattering off ^{132}Xe and ^{16}O to study the equation of state of nuclear matter and the cluster structure, respectively, at the HIMAC in Chiba. The measurement of deuteron inelastic scattering off ^{132}Sn will be performed in RIBF soon.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

A. Pakou, N. Keeley, D. Pierroutsakou, M. Mazzocco, L. Acosta, X. Aslanoglou, A. Boiano, C. Boiano, D. Carbone, M. Cavallaro, J.Grebosz, M. La Commara, C. Manea, G. Marquinez-Duran, I. Martel, C. Parascandolo, K. Rusek, A.M. Sanchez-Benitez, O. Sgouros, C. Signorini, F. Soramel,V.Soukeras, E. Stiliaris, E. Strano, D. Torresi, A. Trzcinska, Y.X. Watanabe, and H. Yamaguchi:``Total reaction cross sections for ^{8}Li+^{90}Zr at near barrier energies'',Eur. Phys. J. A 51, 55 (2015)*

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S. Ota, H. Tokieda, C.S. Lee, Y.N. Watanabe: "CNS active target (CAT) for missing mass spectroscopy with intense beams'', Proceedings of the 27th world conference of the international nuclear target, J. Radioanalytical and Nuclear Chemistry,

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[Others]

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Oral Presentations

[International Conference etc.]

H. Yamaguchi for the CRIB collaboration (oral, invited): ``Nuclear astophysics projects with low-energy RI beams at CRIB'': Pioneering Symposium: ``Nuclear physics at the RIB facilities'' in Korean Physical Society Meeting, Apr 22--24, 2015, Daejeon Convention Center, Daejeon, Korea.

H. Yamaguchi (oral, invited): ``Studying astrophysical reactions with low-energy RI beams at CRIB'', The 12th International Conference on Nucleus-Nucleus Collisions (NN2015), June 21--26 2015, Department of Physics and Astronomy, Catania University.

H. Yamaguchi (oral): ``Experimental study on astrophysical reactions with low-energy RI beams'', The 13th Russbach School on Nuclear

Astrophysics, Mar. 6--11, 2016, Russbach am Pass Gschutt, Austria.
S. Hayakawa (oral): ``Trojan horse method at CRIB for RI+n reactions'', The 8th Japan-Italy symposium, Mar. 7--10 2016, RIKEN, Saitama, Japan.
T. Gunji for the ALICE Collaboration (oral): ``Overview of Recent ALICE Results'', XXV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (QM2015), Sept. 19 - Oct. 3, 2015, Kobe, Japan
T. Gunji (oral, invited): ``Quarkonia and heavy flavour production in heavy-ion collisions - an experimental overview'', 6th Asian Triangle Heavy-Ion Conference, Feb. 15-19, India International Center, New Delhi, India
T. Gunji (oral, invited): ``Dark photon search in heavy ion experiments at RHIC and LHC'', International workshop on Light Dark Matter at Accelerator, June 24 - 26, 2015, Camogli, Italy
Y. Watanabe (oral, invited): ``Experimental overview on EM observables'', XXV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (QM2015), Sept. 19 - Oct. 3, 2015, Kobe, Japan
Y. Watanabe (oral, invited): ``Dilepton production in heavy ion collisions'', 6th Asian Triangle Heavy-Ion Conference, Feb. 15-19, India International Center, New Delhi, India
Y. Watanabe for the PHENIX Collaboration (oral): ``Dielectron measurements by PHENIX'', ECT* workshop on New perspectives on Photons and Dileptons in Ultrarelativistic Heavy-Ion Collisions at RHIC and LHC, Nov. 30 - Dec. 11, Trento, Italy
Y. Watanabe (oral, invited): ``Charmed and exotic hadron measurements with ALICE at the LHC'', ExHIC2016 workshop, Mar. 24, 2016, Kyoto, Japan
S. Hayashi on behalf of the ALICE Collaboration (oral): ``Dielectron measurement in pp, p-Pb, and Pb-Pb collisions with the ALICE detector'', Hard Probes 2015, June 29 -July 3, 2015, McGill University, Montreal, Canada
Y.Sekiguchi for the ALICE collaboration (oral): ``Two particle correlations in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with the ALICE detector'', 6th Asian Triangle Heavy-Ion Conference, Feb. 15-19, India International Center, New Delhi, India
M. Matsushita (Oral): ``New energy-degrading scheme for low-energy reaction measurements of rare isotope beams'', Advances in Nuclear Structure at Extreme Conditions, Feb. 19--22, 2014, Bormio, Italy.
S. Shimoura (invited): ``Nucleon-nucleon correlation in neutron-rich nuclei'', International Workshop & the 12th RIBF Discussion on Neutron-Proton Correlations, July 6--9, 2015, Hong Kong.
S. Ota (invited):"On pn-pair transfer/pick-up reactions'', International Workshop & the 12th RIBF Discussion on Neutron-Proton Correlations, July 6--9, 2015, Hong Kong.
S. Ota (invited): ``Using TPC to study ISGMR/ISGDR'', Science with SpRIT TPC Workshop, June, 5--6, 2015, RIKEN, Japan.
S. Ota (invited): ``Active Target Development in Japan'', Workshop on Active Targets and Time Projection Chambers for Nuclear Physics Experiments, May 18--20, 2015, MSU
S. Michimasa (Oral): ``Construction of OEDO beamline'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
M. Matsushita (Oral): ``Simulation of OEDO beam line'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
S. Shimoura (Oral): ``Present status of GRAPE'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
K. Yako (Oral): ``Spin-isospin studies at SHARAQ'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
M. Kobayashi (Oral): ``Direct mass measurements of neutron-rich Ca isotopes beyond N=34", OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
M. Dozono (Oral): ``The parity-transfer (^{16}O,^{16}F) reaction for studies of the spin-dipole 0^- mode'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
M. Takaki (Oral): ``Investigation of Double Gamow-Teller Giant Resonances via heavy-ion double charge exchange reactions'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
S. Ota (Oral): ``Transfer Reaction and Active Target'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
N. Imai (Oral): ``Two experimental proposals using the energy-degraded beams'', OEDO-SHARAQ International Collaboration Workshop, September 8--9, 2015, CNS Wako, Saitama, Japan
M. Dozono (Oral): ``Parity-transfer reaction for study of spin-dipole 0^- mode'', 5th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX5), September 14--18, 2015, Krakow, Poland
S. Ota (Oral): ``Towards the first observation of isoscalar giant monopole resonance in unstable Tin isotopes with CNS active target'', 5th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX5), September 14--18, 2015, Krakow, Poland
M. Takaki (Oral): ``Search for double Gamow-Teller resonance via heavy-ion double charge exchange reaction'', 5th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX5), September 14--18, 2015, Krakow, Poland
R. Yokoyama (Oral): ``Investigation of the octupole correlation of neutron-rich Z 56 isotopes by beta-gamma spectroscopy'', 5th International Conference on Collective Motion in Nuclei under Extreme Conditions (COMEX5), September 14--18, 2015, Krakow, Poland
S. Shimoura (invited): ``OEDO project -- New energy degraded beam line at RIBF'', International symposium on the Frontier of γ-ray spectroscopy (Gamma15), October 1--3, 2015, Osaka University, Japan
R. Yokoyama (Oral): ``Investigation of the octupole correlation of neutron-rich Z ~ 56 isotopes by beta-gamma spectroscopy'', International symposium on the Frontier γ-ray spectroscopy (Gamma15), October 1--3, 2015, Osaka University, Japan
S. Michimasa (invited): ``Dispersion-matching of RI-beams and its applications to nuclear structure studies'', HRS-Workshop on high-resolution magnetic spectrometers and experiments with them, November 4--6, 2015, GSI, Darmstadt, Germany.
S. Shimoura (invited): ``OEDO Project: EXTENDED dispersion-matching technique for production of low-energy RI beams'', HRS-Workshop on high-resolution magnetic spectrometers and experiments with them, November 4--6, 2015, GSI, Darmstadt, Germany.
M. Takaki (invited): ``Challenges with heavy-ion double charge exchange reactions at RCNP and RIBF'', NUMEN2015 workshop, December 1--2, 2015, Catania, Italy
S. Shimoura (invited): ``Tetraneutron at SHARAQ'', International Workshop on Critical Stability in Few-Body Systems, Feb. 1--5 2016, RIKEN, Wako, Japan

M. Takaki (invited): ``Recent Activities with Heavy-Ion Double Charge Exchange Reactions at RCNP and RIBF'', 8th Japan-Italy symposium on Nuclear Physics, March 7--10, 2016, RIKEN, Japan

Y. Utsuno(Oral, Invited): ``Shell and shape evolution in exotic nuclei'', Korean Physical Society (KPS) Spring Meeting 2015, Apr. 22-24, 2015, Daejeon, Korea.

Y. Utsuno(Oral, Invited), T. Otsuka, N. Shimizu, and T. Togashi: ``Probing shell evolution with large-scale shell-model calculation'', International Collaborations in Nuclear Theory: Theory for open-shell nuclei near the limits of stability, May 11-29, 2015, East Lansing, Michigan, USA.

N. Tsunoda: ``Neutron-rich nuclei from the nuclear force'', International Collaborations in Nuclear Theory (ICNT) workshop, May 24-30, 2015, Michigan State University, Michigan, USA.

Y. Tsunoda(Oral, Invited):``Structure of Exotic Ni and Neighboring Nuclei'', The 2015 Gordon Research Conference on Nuclear Chemistry, June 2, 2015, Colby-Sawyer College, New Hampshire, USA.

Y. Iwata, N. Shimizu, T. Otsuka, Y. Utsuno, J. Menendez, M. Honma, and T. Abe: `` Large-scale shell model calculation project for neutrinoless double-beta decay of Ca48'', June 1-5, 2015, Neutrinos and Dark Matter in Nuclear Physics 2015 (NDM15), Jyvaskyla, Finland.

T. Otsuka: ``Dual quantum liquid picture of nuclei and its implication to reflection asymmetry'', ``Reflections on the atomic nucleus'', July 30, 2015, University of Liverpool, U.K.

Y. Tsunoda: ``Large-scale shell model calculations for structure of nuclei around Z=28'', The 14th CNS International Summer School (CNSSS15), Aug. 28, 2015, RIKEN, Wako, Saitama, Japan.

N. Tsunoda: ``Construction of Effective interaction for shell model calculation and its appli- cation to island of inversion", The 14th CNS International Summer School (CNSSS15), Aug. 26- Sep. 1, 2015, RIKEN, Wako, Saitama, Japan.

N. Shimizu(Oral, Invited): ``Large-scale shell model calculations on E1 spectra in medium-heavy nuclei'', The 5th international conference on ``Collective Motion in Nuclei under Extreme Conditions (COMEX5)'', Sep. 15, 2015, Krakow, Poland.

Y. Tsunoda(Oral, Invited): ``Monte Carlo shell model calculations for structure of Ni isotope'', the international symposium on the ``Frontier of γ-ray spectroscopy'' (Gamma15), Oct. 1, 2015, Osaka University, Toyonaka campus, Osaka, Japan.

T. Otsuka(Oral, Invited): ``Dual quantum liquid picture of atomic nuclei'', the international symposium on the ``Frontier of γ-ray spectroscopy'' (Gamma15), Oct. 1-3, 2015, Osaka University, Toyonaka campus, Osaka, Japan.

T. Otsuka: ``Quantum chaos and symmetry'', YIPQS Long-term workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 30, 2015, Yukawa Institute, Kyoto University, Kyoto, Japan.

N. Shimizu: ``Shell model study of nuclei around N=80'', YIPQS Long-term workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Oct. 2, 2015, Yukawa Institute, Kyoto University, Kyoto, Japan.

Y. Tsunoda: ``Monte Carlo shell model calculations for structure of nuclei around Z=28'', YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 29, 2015, Kyoto, Japan.

T. Togashi, N. Shimizu, Y. Utsuno, T. Otsuka, and M. Honma: ``Electric dipole transitions in medium-heavy nuclei described with Monte Carlo shell model'', YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Oct. 2, 2015, Kyoto, Japan.

Y. Utsuno, N. Shimizu, T. Otsuka, M. Honma, S. Yoshida, and S. Ebata: ``Shell-model study of strength function in the sd-pf shell region'', YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 28-Oct. 2, 2015, Kyoto, Japan.

Y. Iwata:``Two-neutrino and neutrinoless double beta decay of Ca48'', YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 28-Oct. 2, 2015, Kyoto, Japan.

Y. Iwata: ``Heavy Neutrino-Exchange Potential for the Large-Scale Shell Model Calculations of Double-Beta Decay'', YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 28-Oct. 2, 2015, Kyoto, Japan.

T. Yoshida, N. Shimizu, T. Abe, and T. Otsuka: ``Study of shell and cluster configurations of 12Be based on Monte Carlo shell model'', YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 28-Oct. 2, 2015, Kyoto, Japan.

N. Tsunoda: ``Construction of Effective interaction for shell model calculation and its appli- cation to island of inversion", YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Sep. 21-Oct. 30, 2015, Kyoto, Japan.

T. Otsuka, K. Tsukiyama and R. Fujimoto: ``Feshbash's doorway-state resonances, heavy-ion induced nucleon transfer reactions and exotic nuclei", YIPQS Long-term workshop Computational Advances in Nuclear and Hadron Physics (CANHP 2015), Oct. 28, 2015, Yukawa Institute, Kyoto University, Kyoto, Japan.

T. Togashi(Oral, Invited), N. Shimizu, Y. Utsuno, T. Otsuka, and M. Honma: ``Photoabsorption cross sections in medium-heavy nuclei calculated with Monte Carlo shell model'', The 5th International Workshop on Compound-Nuclear Reactions and Related Topics (CNR*15), Oct. 19, 2015, Tokyo, Japan.

N. Shimizu: ``Stochastic estimation of level density in nuclear shell-model calculations'', The 5th International Workshop on Compound-Nuclear Reactions and Related Topics (CNR*15),Oct. 20, 2015, Tokyo Institute of Techinology, Ookayama, Tokyo, Japan.

Y. Utsuno(Poster), N. Shimizu, and T. Otsuka: ``Large-scale shell-model calculation for γ-ray strength function'', The 5th International Workshop on Compound-Nuclear Reactions and Related Topics, Oct. 19-23, 2015, Tokyo, Japan.

T. Otsuka: ``Report on Large-scale Quantum Many-body Calculation on Nuclear Properties and its Applications'', International symposium on ``Quarks to Universe in Computational Science (QUCS 2015)'', Nov. 4, 2015, Nara Kasugano International Forum IRAKA, Nara, Japan.

N. Tsunoda (Oral, Invited): ``Nuclear force to Neutron-rich nuclei'', ``Quark to Universe in Computational Science 2015 (QUCS2015)'', Nov. 4-8, 2015, Nara Kasugano International Forum IRAKA, Nara, Japan.

N. Shimizu (Oral, Invited): ``Nuclear structure and excitations clarified by Monte Carlo Shell Model calculation on K computer'', International symposium on ``Quarks to Universe in Computational Science (QUCS 2015)'', Nov. 4-8, 2015, Nara Kasugano International Forum IRAKA, Nara, Japan.

Y. Tsunoda: ``Monte Carlo shell model calculations for structure of nuclei around Z=28'', International symposium on ``Quarks to Universe in Computational Science (QUCS 2015)'', Nov. 4-8, 2015, Nara Kasugano International Forum IRAKA, Nara, Japan.

T. Togashi, N. Shimizu, Y. Utsuno, T. Otsuka, and M. Honma: ``Monte Carlo shell model for electric dipole strength distribution in medium-heavy nuclei'', Nov. 5, 2015, Symposium on Quarks to Universe in Computational Science (QUCS 2015), Nara, Japan.
Y. Iwata:``The nuclear matrix element of double beta decay'', Nov. 4-8, 2015. Symposium on Quarks to Universe in Computational Science (QUCS 2015), Nara, Japan.
Y. Utsuno (Oral, Invited), S. Yoshida, N. Shimizu, and T. Otsuka: ``Shell model calculations for Gamow-Teller strength function in the neutron-rich sd-pf shell region'', Dec. 1-2, 2015, 27th ASRC International Workshop ``Nuclear Fission and Exotic Nuclei", Tokai, Japan.
[Domestic Conference]
坂口裕司 (oral): ``CRIB による 14C の linear-chain cluster states の探索'', RCNP 研究会「アイソスカラー型単極遷移で探る原子核の励起状態とクラスター構造」, 2015 年 7 月 16--17 日，阪大 RCNP
S. Ota (invited): ``アクティブ標的を用いた錫１３２近傍原子核の巨大単極共鳴測定'', RCNP 研究会「アイソスカラー型単極遷移で探る原子核の励起状態とクラスター構造」, 2015 年 7 月 16–17 日，阪大 RCNP
H. Yamaguchi (oral): ``Recent activities at the low-energy RI beam separator CRIB'', RIBF Users Meeting 2015, Sep. 10--11, 2015, RIKEN Nishina Center, Wako, Saitama, Japan.
早川勢也(oral):「CRIB における Trojan horse method の応用による Big Bang 元素合成反応の測定計画」，宇宙核物理連絡協議会研究会 2016 年 2 月 22-24 日，国立天文台 三鷹キャンパス
T. Gunji (invited),``高エネルギー重イオン衝突実験の面白さと今後の課題'', QCD Club, Dec. 18, 2015, the University of Tokyo, Hongo, Japan
T. Gunji (invited),``高エネルギー重イオン衝突実験の今後の展望'', 高密度核物質に挑む実験の将来－施設装置の観点から，Dec. 5, 2015, RIKEN, Japan
K. Terasaki, T. Gunji, H. Hamagaki (oral): ``LHC-ALICE 実験 TPC 高度化の為の研究開発と量産準備状況'', 第 12 回 MPDG 研究会, Dec.4-5, Hiroshima University, Higashi-hiroshima, Japan
S. Ota (invited): ``GMR で探る状態方程式'', 宇宙核物理連絡協議会研究会, February 22--24, 2016, Mitaka campus, National Astronomical Observatory of Japan.
岩田順敬: ``ニュートリノレス二重ベータ崩壊の核行列要素の大規模殻模型計算'', 新学術領域 「宇宙の歴史をひもとく地下素粒子原子核研究」2015 年領域研究会、 2015 年 5 月 15 日、神戸大学百年記念館、神戸市.
Y. Iwata: ``TDDFT による超重核合成反応の計算'', 2015 年 8 月, SI 研究会，近畿大学，大阪.
T. Otsuka: ``Shell-model perspectives for quantities of astrophysical interests in medium and heavy nuclei'', Numazu Workshop 2015: ``Challenges of modeling supernovae with nuclear data'', Sep. 2, 2015, Mishima, Numazu, Japan.
Y. Utsuno (Oral, Invited), N. Shimizu, and T. Otsuka: ``Current frontiers and perspectives in large-scale shell-model study'', RIBF Users Meeting 2015, Sep. 10-11, 2015, Wako, Japan.
岩田順敬: ``ニュートリノレス二重ベータ崩壊の核行列要素の成分分析'', 第 7 回「学際計算科学による新たな知の発見・統合・創出」シンポジウム，筑波大学，つくば市 2015 年 10 月.
Y. Utsuno (Oral, Invited), N. Shimizu, T. Otsuka, M. Honma, S. Ebata, T. Mizusaki, Y. Futamura, and T. Sakurai: ``Large-scale shell-model study of E1 strength function and level density'', Nov. 16-19, 2015, "High-resolution Spectroscopy and Tensor interactions" (HST15), Osaka, Japan.
Y. Tsunoda:``「モンテカルロ殻模型計算による Z=28 近傍の核構造の研究」'', KEK 理論センター研究会「原子核・ハドロン物理の課題と将来」、2015 年 11 月 25 日、高エネルギー加速器研究機構研究本館、つくば市.
Y. Watanabe for the ALICE Collaboration, ``LHC-ALICE 実験におけるチャームバリオン生成の測定'', 71th JPS annual meeting, Mar.19-22, Tohoku Gakuin University, Sendai, Japan
Y. Sekiguchi for the ALICE collaboration, ``Long-range correlations in p-Pb collisions at $\sqrt{s_{NN}}$ = 5.02 TeV with the ALICE detector'', 71th JPS annual meeting, Mar.19-22, Tohoku Gakuin University, Sendai, Japan
K. Terasaki for the ALICE Collaboration, ``Search for exotic strange dibaryon at LHC-ALICE'', 71th JPS annual meeting, Mar.19-22, Tohoku Gakuin University, Sendai, Japan
H. Murakami for the ALICE collaboration, ``Status of direct photon measurements via external conversions in high multiplicity pp collisions at 13 TeV with ALICE'', 71th JPS annual meeting, Mar.19-22, Tohoku Gakuin University, Sendai, Japan
S. Shimoura (invited): ``Experimental studies of the tetra-neutron system by using RI-beam'',「ドリップライン近傍のハイパー核と不安定核」シンポジウム, JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
K. Yako (invited): ``荷電交換反応による新モード探索'' 「スピン・アイソスピン応答研究の新たな地平」シンポジウム, JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
S. Ota et al.: ``理研 RIBF BigRIPS における大強度不安定核ビームの粒子識別の開発'', JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
M. Takaki et al.: ``重イオン二重荷電交換反応による ^{48}Ti の二重ガモフテラー共鳴探索'', JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
R. Yokoyama et al.: ``β-γ核分光を用いた中性子過剰 La 同位体の変形'', JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
M. Kobayashi et al.: ``中性子数 34 近傍カルシウム同位体の直接質量測定'', JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
Y. Kiyokawa et al.:``SHARAQ におけるアイソマー同定システムの開発'', JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
M. Dozono et al.: ``パリティ移行核反応による原子核の 0^-状態の研究 II'', JPS Fall meeting, September 25--28, 2015, Osaka City University, Osaka, Japan
S. Michimasa, M. Kobayashi, Y. Kiyokawa, M. Takaki, M. Dozono, S. Go, H. Baba, E. Ideguchi, K. Kisamori, T. Matsubara, M. Matsushita, H. Miya, S. Ota, H. Sakai, S. Shimoura, A. Stolz, T.L. Tang, H. Tokieda, T. Uesaka, R.G.T. Zegers: ``多結晶ダイヤモンド検出器の開発'', JPS Spring meeting, March 19--22, 2016, Tohoku Gakuin Unversity, Sendai, Japan
Y. Kubota et al.: ``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'', JPS Spring meeting, March 19--22, 2016, Tohoku Gakuin Unversity, Sendai, Japan
Y. Kiyokawa et al.:``SHARAQ における中性子過剰 Sc 近傍核の核異性体γ線分光'',JPS Spring meeting, March 19--22, 2016, Tohoku Gakuin Unversity, Sendai, Japan
S. Masuoka, S. Shimoura, K. Kobayashi, Y. Kunimoto: ``複数中性子識別のための反跳陽子飛跡検出器の開発'', JPS Spring meeting, March

19--22, 2016, Tohoku Gakuin Unversity, Sendai, Japan

Y. Yamaguchi, S. Shimoura, N. Imai, K. Wimmer, T. Kitamura: ``DSP を用いた多重ガンマ線検出用 Ge 検出器アレイの為のデータ収集系の開発'', JPS Spring meeting, March 19--22, 2016, Tohoku Gakuin Unversity, Sendai, Japan

T. Kitamura, N. Imai, Y. Yamaguchi, H. Haba: ``高スピンアイソマー^{178m2}Hf 標的開発のためのアイソマー生成および純化手法の検討'', JPS Spring meeting, March 19--22, 2016, Tohoku Gakuin Unversity, Sendai, Japan

Y. Iwata(Oral, Invited): ``TDHF で見た fission'', the JPS Autumn Meeting, Sep. 25-28, 2015, Osaka City University, Osaka, Japan.

N. Shimizu, Y. Futamura, T. Sakurai, T. Mizusaki, Y. Utsuno, and T. Otsuka:``殻模型計算における確率論的な準位密度計算法'', the JPS Autumn Meeting, Sep. 27, 2015, Osaka City University, Osaka, Japan.

Y. Utsuno, N. Shimizu, T. Togashi, T. Otsuka, T. Suzuki, and M. Honma: ``第一禁止ベータ崩壊データによる中性子過剰カルシウム同位体の殻進化の解析'', the JPS Autumn Meeting, Sep. 25-28, 2015, Osaka City University, Osaka, Japan.

Y. Iwata, N. Shimizu, T. Otsuka, Y. Utsuno, J. Menendez, M. Honma, and T. Abe:``48Ca の二重ベータ崩壊の 殻模型計算による記述 III'', the JPS Autumn Meeting, Sep. 25-28, 2015, Osaka City University, Osaka, Japan.

T. Togashi, T. Otsuka, N. Shimizu, and Y. Utsuno: ``モンテカルロ殻模型によるセレン 79 の光吸収断面積の計算'', the JPS Autumn Meeting, Sep. 25-28, 2015, Osaka City University, Osaka, Japan.

T. Yoshida, N. Shimizu, T. Abe, and T. Otsuka:``12Be における殻構造と クラスター構造のモンテカルロ殻模型による研究'', the JPS Autumn Meeting, Sep. 26, 2015, Osaka City University, Osaka, Japan.

N. Tsunoda:``核力に基づいた中性子過剰 Ca 同位体の構造'', the JPS Autumn Meeting, Sep. 25-28, 2015, Osaka City University, Osaka, Japan.

Y. Tsunoda:``大規模殻模型計算による Z=28 近傍の核構造の研究'', the JPS Autumn Meeting, Sep. 27, 2015, Osaka City University, Osaka, Japan.

Y. Utsuno(Oral, Invited):``中性子過剰な原子核の物理'', the JPS Spring Meeting, Mar. 19-22, 2016, Tohoku Gakuin University, Sendai, Japan.

Y. Tsunoda:``大規模殻模型計算による Z=28 近傍の核構造の研究'', the JPS Spring Meeting, Mar. 22, 2016, Tohoku Gakuin University, Sendai, Japan.

T. Yoshida, N. Shimizu, T. Abe, and T. Otsuka: ``Be 同位体における intrinsic 状態の研究'', the JPS Spring Meeting, Mar. 19, 2016, Tohoku Gakuin University, Sendai, Japan.

T. Togashi, T. Otsuka, N. Shimizu, and Y. Utsuno:``モンテカルロ殻模型による 79Se,90Sr,93Zr の光吸収断面積の計算'', the JPS Spring Meeting, Mar. 22, 2016, Tohoku Gakuin University, Sendai, Japan.

Y. Iwata, N. Shimizu, T. Otsuka, J. Menendez, Y. Utsuno, M. Honma, and T. Abe: `` Ca48 のニュートリノレス二重ベータ 崩壊に対するステライル・ニュートリノの影響'', the JPS Spring Meeting, Mar. 19-22, 2016, Tohoku Gakuin University, Sendai, Japan.

N. Tsunoda: ``核力に基づいた pf-shell 原子核の構造'', the JPS Spring Meeting, Mar. 19-22, 2016, Tohoku Gakuin University, Sendai, Japan.

Posters Presentations

[International Conference etc.]

S. Hayashi on behalf of the ALICE Collaboration (poster): ``Dielectron measurement from charm and bottom quark decays in p-Pb collisions with the ALICE detector'', XXV International Conference on Ultrarelativistic Nucleus-Nucleus Collisions (QM2015), Sept. 27 - Oct. 3, Kobe, Japan

M. Dozono (poster): ``The parity-transfer (^{16}O,^{16}F) reaction for studies of the spin-dipole 0^- mode'', International symposium on Physics with Fragment Separators --25th Anniversary of RIKEN-Projectile Fragment Separator (RIPS25), December 6--7, 2015, Hayama, Kanagawa, Japan

M. Kobayashi (poster):``Time-of-flight mass measurements of neutron-rich Ca isotopes beyond N = 34'', International symposium on Physics with Fragment Separators --25th Anniversary of RIKEN-Projectile Fragment Separator (RIPS25), December 6--7, 2015, Hayama, Kanagawa, Japan

S. Michimasa (poster): ``OEDO beamline for high-quality slow-down RI beams'', International symposium on Physics with Fragment Separators --25th Anniversary of RIKEN-Projectile Fragment Separator (RIPS25), December 6--7, 2015, Hayama, Kanagawa, Japan

Y. Kotaka, Y. Ohshiro, S. Watanabe, H. Yamaguchi, N. Imai, S. Shimoura, M. Kase, S. Kubono, K. Hatanaka, A. Goto, H. Muto (poster): ``Development of low-energy heavy-ion beams by the Riken AVF cyclotron and Hyper ECR ion source of CNS'', 13th International Conference on Heavy Ion Accelerator Technology (HIAT2015), September 7-11, 2015, Yokohama, Japan

H. Muto, Y. Oshiro, Y. Kotaka, S. Yamaka, S. Watanabe, H. Yamaguchi, S. Shimoura, M. Kase, S. Kubono, K. Kobayashi, M. Nishimura, M. Oyaizu, T. Hattori (poster): ``Observation of sublimation effect of Mg and Ti ions at the Hyper-electron cyclotron resonance ion source'', 13th International Conference on Heavy Ion Accelerator Technology (HIAT2015), September 7-11, 2015, Yokohama, Japan

N. Tsunoda(Poster): ``Neutron-rich nuclei from the nuclear force'', Gordon Research Conference, May 31- June 5, 2015, Colby-Sawyer college, NH, USA.

T. Yoshida(Poster), N. Shimizu, T. Abe, and T. Otsuka:``Alpha-cluster structure for Be isotopes appeared in the wave function of Monte Carlo shell model'', Nov. 4-8, 2015, Symposium on Quarks to Universe in Computational Science (QUCS 2015), Nara, Japan.

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) Reaction cross section and radii of neutron-rich nuclei

The experimental nuclear physics group has studied nuclear structure with the RI beam. One of our main interests is the interaction/reaction cross section measurements. They are good probes to investigate nuclear matter radii and nuclear matter distributions including halo or skin structure. Recently we have measured the interaction sections of Ne, Na, Mg and Al isotopes from stable region to neutron drip line with BigRIPS in RIBF. We found a large enhancement of cross section at ^{31}Ne. It suggests that ^{31}Ne nucleus has a neutron halo. It is consistent with the soft E1 excitation measurement. We also found an enhancement at ^{37}Mg. For odd-Z nuclei, Na and Al, we did not find such a large enhancement from neighbor isotopes. The systematics of observed interaction/reaction cross sections shows the changing of nuclear structure from stable region to neutron drip line via island of inversion.

(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 ^{24}Mg and ^{28}Si. The same method is further extended to describe the spin-isospin modes of excitation. A successful description of the Gamow-Teller transition strengths in ^{42}Ca is achieved with this method, which implies an important role of proton-neutron pair correlation in the $N = Z$ nucleus ^{42}Sc. Another correlation of interest in neutron-rich nuclei is the neutron-pair correlation, for which the spatial di-neutron correlation has been a key topic. Applying the continuum QRPA to the pairing modes of excitation in neutron-rich Sn isotopes, we predict the emergence of an anomalous pair vibration for isotopes with $A > 132$. Furthermore the new mode is predicted to exhibits the di-neutron character. In addition to these studies, the di-neutron correlation in the asymptotic tail in drip-line nuclei, the quasiparticle resonances in unbound odd-N nuclei are under way. As an application of the continuum QRPA, a microscopic theory of the direct neutron capture reaction has been developed recently. Cluster structure and the ab initio studies of light nuclei are also important research subjects of the theory group.

Members

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List of Publications & Presentations

Publications

[Journal]

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K. Yoshida, Proton-neutron pairing vibrations, 2nd International Workshop & 12th RIBF Discussion on Neutron-Proton Correlation, University of Hong Kong, China, July 6–9, 2015.
K. Yoshida, Pairing in spin-isospin responses, YIPQS Long-term and Nishinomiya-Yukawa Memorial International workshop ‘Computational Advances in Nuclear and Hadron Physics’, YITP, Kyoto University, September 21–October 30, 2015.
K. Yoshida, Skyrme energy-density-functional method for large-scale linear-response calculations, Symposium on ‘Quarks to Universe in Computational Science’, Nara Kasugano International Forum IRAKA, Nara, November 4–8, 2015.
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R. Aono, S. Goto, D. Kaji, K. Morimoto, H. Haba, M. Murakami, K. Ooe and H. Kudo, “^{208}Pb + ^{48,50}Ti 反応における中性子欠損 Rf 同位体の合成”, 第 59 回放射化学討論会，東北大学川内キャンパス, 9 月 (2015).
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Partner Institution
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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 with around neutron magic numbers N = 126 for astrophysical interest. In FY2015, a new rotational target system was introduced and higher yields and more stable operational conditions were achieved. Resonance ionization spectroscopy for the hyperfine structure of ^{199}Pt has been performed at KISS. An international collaboration with IBS (Institute of Basic Science), Korea has been organized for development of an array of super-clover germanium detectors and an MRTOF mass spectrograph.

2. Major Research Subjects
(1) Radioactive isotope beam production and manipulation for nuclear experiments.
(2) Explosive nucleosyhnthesis (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
The KISS is an element-selective isotope separator using a magnetic mass separator combined with in-gas-cell resonant laser ionization. The gas cell filled with argon gas of 50 kPa is a central component of the KISS for extracting only the element of interest as ion beam for subsequent mass separation. In the cell, the element primarily produced by low-energy heavy ion reactions is stopped (thermalization and neutralization), transported by buffer gas (argon gas-flow of ~50 kPa in the present case), and then re-ionized by laser irradiation just before the exit. The gas cell was fabricated to efficiently correct the reaction products produced by the multi-nucleon transfer reaction of ^{136}Xe +^{198}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/cm^2, respectively. In FY2014, half-lives of 199Pt were measured with β-ray telescopes and a tape transport system were installed at the focal point of KISS. The β-ray telescopes were composed of three double-layered thin plastic scintillators; thickness of the first layer and second one were 0.5 and 1 mm, respectively. In order to reduce the background, they were surrounded with low-activity lead blocks and a veto counter system consisting of plastic scintillator bars. The background rate of the present β-ray telescopes was measured to be 0.7 counts per second. In order to drastically reduce the background rate, lower than a few counts per hour, a gas counter based beta-ray telescope is under development in FY2015.

For higher primary beam intensities and higher extraction efficiency, we developed a doughnut-shaped gas cell and a rotating target wheel setup for KISS. With this new setup, resonance ionization spectroscopy of the ground state hyperfine structure of ^{198}Pt was performed. The nuclear g-factor and the charge radius of ^{199}Pt can be deduced from the experimental results.

As a continuing effort for search for effective laser ionization scheme of elements of our interest (Z<82), a reference cell was fabricated, and is currently being used to search for auto ionizing states in Ta, W, and etc…

In order to investigate the feasibility of the multi-nucleon transfer (MNT) in the reaction system of ^{136}Xe on ^{198}Pt for producing heavy neutron-rich isotopes around the mass number of 200 with the neutron magic number of 126, We performed the cross section measurement at GANIL in 2012 and 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 the weak N/Z equilibration and particle evaporation. This suggests the promising use of the MNT reactions with a heavy projectile at the energies above the Coulomb barrier for production of the neutron-rich isotopes around N = 126.

Aiming at direct mass measurements of short-lived heavy nuclei at KISS and other facilities, we worked on a development of a multi-reflection time-of-flight mass spectrograph (MRTOF-MS). In FY2015, we demonstrated mass measurements of Fr and At isotopes at GARIS-II with a collaboration with the SLOWRI team and the Super Heavy Element Synthesis team of RIKEN.

The diffusion coefficient of lithium in solid materials used in secondary Li-ion batteries is one of key parameters that determine how fast a battery can be charged. The reported Li diffusion coefficients in solid battery materials are largely scattered over several order of magnitudes. We have developed an in-situ nanoscale diffusion measurement method using α-emitting radioactive ^{8}Li tracer. In the method, while implanting a pulsed ^{8}Li beam of 8 keV, the alpha particles emitted at a small angle ($\theta = 10 \pm 1^\circ$) relative to a sample surface were detected as a function of time. We can obtain Li diffusion coefficient from the time dependent yields of the α particles, whose energy loss can be converted to nanometer-scale position information of diffusing ^{8}Li. The method has been successfully applied to measure the lithium diffusion coefficients for an amorphous Li_4SiO_4 - Li_3VO_4 (LVSO) which was used as a solid electrotype in a solid-state Li thin film battery, well demonstrating that the present method has the sensitivity to the diffusion coefficients down to a value of 10^{-12} cm^2/s, corresponding with nanoscale Li diffusion. In FY2015, we continued measuring Li diffusion coefficients in a spinel type Li compound of $LiMn_2O_4$ (LMO), which is used as a positive electrode of a Li battery in an electric vehicle. We have observed a significant change on the time dependent yields of the α particles at the sample temperature of around 623 K and will continue the measurements to obtain temperature dependency of Li diffusion coefficients in LMO.

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List of Publications & Presentations

Publications

[Journal]

(Original Papers) *Subject to Peer Review

Y.X. Watanabe, Y.H. Kim, S.C. Jeong, Y. Hirayama, N. Imai, H. Ishiyama, H.S. Jung, H. Miyatake, S. Choi, J.S. Song, E. Clement, G. de France, A. Navin, M. Rejmund, C. Schmitt, G. Polarolo, L. Corradi, E. Fioretto, D. Montanari, M. Niikura, D. Suzuki, H. Nishibata, J. Takatsu, « Pathway for the production of neutron-rich isotopes around N=126 shell closure », Phys. Rev. Lett. 115 (2015) 172503, 1-5.*

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Y. Hirayama, Y.X. Watanabe, N. Imai, H. Ishiyama, S.C. Jeong, H. Miyatake, M. Oyaizu, S. Kimura, M. Mukai, Y.H. Kim, T. Sonoda, M. Wada, M. Huyse, Yu. Kudryavtsev, P. van Duppen, « Laser ion source for multi-nucleon transfer products », Nucl. Inst. Meth B353 (2015) 4-15.*

K. Okada, M. Ichikawa, M. Wada, « Characterization of ion crystals for fundamental science », Hyp. Int. DOI 10.1007/s10751-015-1188-y, 2015*

Oral Presentations

[International Conference etc.]

H. Miyatake, « Beta-decay spectroscopy of r-process nuclei around N=126 », OMEG2015, June 24-27, Beijing, China.

Y. Hirayama, « Online experimental results of an argon gas cell based laser ion source (KEK Isotope Separation System), May 11-15, EMIS2015, Grand Rapids, MI, USA.

M. Wada, « Towards high precision nuclear spectroscopy at SLOWRI, RIKEN RIBF », Nov. 07-12, JCNP2015, RCNP, Osaka, Japan.

[Domestic Conference]

Y. Hirayama, « Nuclear spectroscopy of the waiting point nuclides around the third peak in r-process (KISS project) », Feb. 22-24, NAOJ, Mitaka, Japan.

Posters Presentations

[International Conference etc.]

M. Mukai, « Search for efficient laser resonance ionization schemes of tantalum using a newly developed time-of-flight mass spectrometer in KISS », May 11-15, EMIS2015, Grand Rapids, MI, USA.

S. Kimura, « Development of the detector system for image-decay spectroscopy at the KEK Isotope Sepaator System », May 11-15, EMIS2015, Grand Rapids, MI, USA.

[Domestic Conference]

S. Kimura, « Mass measurements of N=Z-2 nuclei in the vicinity of proton drip line », Feb. 22-24, NAOJ, Mitaka, Japan.

M. Mukai, « Development of low background gas-counter for KISS », Feb. 22-24, NAOJ, Mitaka, Japan.

Events (April 2015 - March 2016)

RNC

Apr. 23	Wako Open campus
Jun. 27 - 28	The 14th NP-PAC
Jul. 27 – Aug. 7	Nishina School
Aug. 11	Safety Review Committee for Accelerator Experiments
Sep. 10-11	RIBF Users Meeting 2015
Sep. 18	Effect of MOU between RNC and The University of Hong Kong
Oct. 30	Effect of MOU between RNC and Technishe Universität Darmstadt
Dec. 3-5	The 16th NP-PAC
Dec. 6-7	Physics with Fragment Separators - 25th Anniversary of RIKEN-Projectile Fragment Separator [RIPS25]
Jan. 12	Interim Review of the Chief Scientist, Osamu KAMIGAITO
Jan. 13	The 5th In PAC
Feb. 16-17	The 12th ML-PAC
Mar. 8	Hot-Lab Safety Review Committee Interim Review of Associate Chief Scientist, Toru TAMAGAWA
Mar. 31	End of Theoretical Nuclear Physics Laboratory led by associate chief scientist Takashi Nakatsukasa

CNS

Aug. 26 - Sep. 1	The 14th CNS international Summer School (CNSSS15) http://indico.cns.s.u-tokyo.ac.jp/conferenceDisplay.py?confId=231

Niigata Univ.

	not held in FY2015

KEK

	not held in FY2015

Press Releases (April 2015 - March 2016)

RNC

May 12	For the violent r-process, the devil's in the details. Success in precise measurements of the half-lives of 110 nuclei which hold the key to the synthesis of heavy elements -A major step forward toward providing an experimental ground for models of the mysterious astrophysical "r-process"-	Giuseppe Lorusso, Shunji Nishimura, Hiroyoshi Sakurai; Radioactive Isotope Physics Laboratory, EURICA collaboration
Nov. 4	Supercomputing the Strange Difference between Matter and Antimatter -The first calculation of direct "CP" symmetry violation—how the behavior of subatomic particles (in this case, the decay of kaons) differs when matter is swapped out for antimatter-	Taku Izubuchi, Christopher Kelly,; Computing Group, RBRC
Dec. 22	Discovery of a tetraneutron resonance nucleus—exploring the highway of the study for neutron matter	Susumu Shimoura (CNS),; Joint PR: Released from the Univ. of Tokyo
Dec. 31	It's official! Element 113 was discovered at RIKEN —Element 113 has become the first element on the periodic table found in Asia—	Kosuke Morita, Research Group for Superheavy Element
Jan. 8	Construction of plant Y-chromosome gene map -Application of heavy-ion induced mutants revealing large inversion of Y-chromosome during its evolution-	Tomoko Abe, Yusuke Kazama, Koutaro Ishii; Ion Beam Breeding Team, Univ. of Tokyo, Univ. of Oxford, Univ. of Edinburgh
Jan. 8	Precise measurement of the orientation of gluons in the proton -A major step in solving the puzzle of the proton spin-	Yasuyuki Akiba, Yuji Goto, Yoon Inseok; Experimental Group, RBRC
Feb. 19	The first attempt in the history of nuclear physics to solve the problem of the LLFP transmutation and has triggered the reaction studies for other long-lived fission products. -Spallation reaction study for fission products in nuclear waste: Cross section measurements for 137Cs and 90Sr on proton and deuteron-	He Wong, Hiroyoshi Sakurai, Hideaki Otsu; Radioactive Isotope Physics Laboratory, SAMURAI Team
Mar. 10	"Two neutrons barely unbound to a nucleus – a picture of a nucleus at the limit, depicted by mass measurement for a heavy Oxygen isotope"	SAMURAI Team, Radioactive Isotope Physics Laboratory ; Joint PR: Released from TIT
Mar. 23	Solar Wind Induces Jupiter's X-ray Aurora	High Energy Astrophysics Laboratory; Joint PR: Released from JAXA

CNS

Dec. 22	Candidate Resonant Tetraneutron State Populated by the ^{4}He(^{8}He, ^{8}Be) Reaction	K. Kisamori, S. Shimoura, T. Uesaka et al.
Mar. 17	Large-scale shell-model analysis of the neutorinoless $\beta\beta$ decay of ^{48}Ca	Y. Iwata, N. Shimizu, T. Otsuka, Y. Utsuno, J. Menendez, M. Honma, T. Abe