

Nuclear Science Research Division

Nuclear Structure Research Group

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 (β -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. Furthermore, the group is also working on SLOWRI development to enable the use of high quality slowed RI beams. Anomalous nuclear structures and properties of far unstable nuclei are investigated from thus determined spin-related observables. The group also aims to apply RI and μ beams to interdisciplinary fields such as fundamental physics and materials science by exploiting nuclear probes.

2. Major Research Subjects

- (1) Nuclear spectroscopy utilizing spin-oriented fast RI beams
- (2) SLOWRI R&D
- (3) Nuclear/Atomic laser spectroscopy
- (4) Application of RI and μ probes to materials science
- (5) Fundamental physics: Study of symmetry

3. Summary of Research Activity

(1) Nuclear spectroscopy utilizing spin-oriented RI beams

Measurements of static electromagnetic nuclear moments over a substantial region of the nuclear chart have been conducted for structure studies on the nuclei far from the β -decay stability. Utilizing nuclear spin orientation phenomena of RIs created in the projectile-fragmentation reaction, ground- and excited-state electromagnetic nuclear moments 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. In particular, a new method 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, has been developed and employed making fully use of world's highest intensity rare RIBs delivered from BigRIPS for rare isotopes.

Since the development of a method applicable to RI ground states is an urgent issue, the group is also working on R&D of various method to produce spin-polarized RI beams in addition to the above methods.

(2) SLOWRI R&D

The SLOWRI system is one of the core experimental facilities of the RIBF facility, in which GeV-energy RI beams produced by BigRIPS are collected and stopped by He or Ar gas, and extracted as high quality low energy RI beams based on unique RF-ion guide technologies. The SLOWRI team, under the Nuclear Structure Research Group, is a team dedicated to this subject.

(3) Nuclear/Atomic laser spectroscopy

The group has been conducting system development for nuclear laser spectroscopy from the following two approaches in order to realize experiments for rare isotopes at RIBF. One is collinear laser spectroscopy for a large variety of elements using slowed-down RI beams produced via a projectile-fragmentation reaction, which can be achieved only by SLOWRI. This slowed-down RI-beam scheme enables to perform high-precision laser spectroscopy even with fast-fragmentation-based RIBs without the elemental limitation problematic in the ISOL-based RIBs.

The other approach is a new method utilizing superfluid helium (He II) as a stopping medium of energetic RI beams, in which the characteristic atomic properties of ions surrounded by superfluid helium enables us to perform unique nuclear laser spectroscopy. RI ions trapped in He II are known to exhibit a characteristic excitation spectrum significantly blue-shifted compared with the emission one. Consequently, the background derived from the excitation-laser stray light, which often causes serious problems in measurements, can be drastically reduced.

(4) Application of RI and μ probes to materials science

The application of RI, heavy-ion, and μ 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 and μ probes based on various spectroscopies utilizing RI probes such as β -NMR/NQR spectroscopy, Mössbauer spectroscopy, γ -ray time differential perturbed angular correlation (γ -TDPAC) spectroscopy, and μ SR spectroscopy.

(5) 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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List of Publications & Presentations

Publications

[Original Papers]

- S. Go, Y. Tsuzuki, H. Yoneda, Y. Ichikawa, T. Ikeda, N. Imai, K. Imamura, M. Niikura, D. Nishimura, R. Mizuno, S. Takeda, H. Ueno, S. Watanabe, T. Y. Saito, S. Shimoura, S. Sugawara, A. Takamine, and T. Takahashi, "Demonstration of nuclear gamma-ray polarimetry based on a multi-layer CdTe Compton camera," *Sci. Rep.* **14**, 2573-1-9 (2024). DOI: 10.1038/s41598-024-52692-2.
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- W. N. Zaharim, S. Sulaiman, A. Jamaludin, H. Rozak, and I. Watanabe, “Density functional theory investigation of electronic structure and muon hyperfine interaction in isolated adenine and thymine,” *Hyperfine Interact.* **245**, 47 (2024). DOI: 10.1007/s10751-024-01901-5.

[Book]

- Y. Tsunoda and T. Otsuka, “Configuration interaction approach to atomic nuclei: the shell model,” *Configuration Interaction Approach to Atomic Nuclei: The Shell Model*. In: I. Tanihata, H. Toki, and T. Kajino (eds), *Handbook of Nuclear Physics* (Springer, Singapore, 2023). DOI: 10.1007/978-981-19-6345-2_17.

Presentations

[International Conferences/Workshops]

- M. Rosenbusch (invited), M. Wada, S. Chen, A. Takamine, S. Iimura, D. Hou, W. Xian, S. Yan, P. Schury, Y. Hirayama, Y. Ito, H. Ishiyama, S. Kimura, T. M. Kojima, J. Lee, J. Liu, S. Michimasa, H. Miyatake, J. Y. Moon, M. Mukai, S. Naimi, S. Nishimura, T. Niwase, T. Sonoda, Y. X. Watanabe, and H. Wollnik, “A first review of the SLOWRI/MRTOF-MS project at BigRIPS/ZeroDegree,” *International Conference on Stopping and Manipulation of Ions and Related Topics (SMI-2023)*, Giessen, Germany, May 8–11, 2023.
- A. Takamine (invited), S. Iimura, D. Hou, J. M. Yap, M. Rosenbusch, M. Wada, H. Ishiyama, P. Schury, W. Xian, S. Chen, T. Gao, S. Nishimura, T. Niwase, S. Kimura, Y. Hirayama, Y. Ito, T. Kojima, H. Miyatake, J. Y. Moon, M. Mukai, T. Sonoda, H. Ueno, P. Vi, and Y. X. Watanabe, “RF gas catcher for the BigRIPS beams,” *International Conference on Stopping and Manipulation of Ions and Related Topics (SMI-2023)*, Giessen, Germany, May 8–11, 2023.
- M. Rosenbusch (oral), “Recent highlights from high-precision atomic mass measurements using MRTOF-MS at RIKEN/RIBF,” *The 4th International Conference on Advances in Radioactive Isotope Science (ARIS2023)*, Avignon, France, June 4–9, 2023.
- T. Otsuka (invited), “Prevailing triaxial shapes in exotic and heavy nuclei,” *The 4th International Conference on Advances in Radioactive Isotope Science (ARIS2023)*, Avignon, France, June 4–9, 2023.
- A. Takamine (invited), “Recent progress of the laser spectroscopy activities for the study of exotic nuclei,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- Y. Komiyama (oral), S. Onishi, H. Kuwahara, H. Kuroe, K. Kurashima, T. Kawamata, Y. Koike, Dita P. Sari, I. Watanabe, and T. Adachi, “Muon spin relaxation study of the Fe-substitution effects on spin fluctuations in the heavily overdoped Bi-2201 cuprates,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- Y. Matsuo (poster), K. Imamura, A. Takamine, K. Kikuchi, R. Mitsuyasu, S. Akimoto, M. Ito, K. Tsubura, A. Gladkov, M. Tajima, S. Go, M. Mukai, M. Doi, M. Nishimura, T. Yamamoto, H. Endo, Y. Fukuzawa, S. Sasamori, S. Takahashi, M. Hase, K. Kawata, H. Nishibata, Y. Ichikawa, A. Kitagawa, T. Wakui, and H. Ueno, “Injection of high energetic ion beams to superfluid helium as a host matrix of laser spectroscopic study of radioisotope atoms,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- S. Takahashi (poster), K. Imamura, A. Takamine, H. Endo, T. Yamamoto, H. Ueno, and Y. Matsuo, “Laser spectroscopic measurement of the hyperfine structure splitting of silver atoms in superfluid helium,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- M. A. Syakur (poster), A. E. Putri, A. Rostika Noviyanti, U. Widayiswari, T. Saragi, Risdiana, D. P. Sari, and I. Watanabe, “Magnetic moments and ordered states on $\text{Sm}_2\text{Ru}_2\text{O}_7$ studied by muons,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- P. Jaikaew (poster), S. Rimjaem, C. Thongbai, T. Adachi, K. Shimomura, A. Koda, and I. Watanabe, “Optimization trials of the muon beam transportation at the J-PARC muon facility,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- I. Watanabe (poster), W. N. Zaharim, S. Sulaiman, A. Jamaluddin, and H. Rozak, “Density functional theory investigation of the electronic structure and muon hyperfine interaction in isolated adenine and thymine,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- M. Rosenbusch (poster), A. Takamine, J. M. Yap for the KEK-RIKEN MRTOF Collaboration, and the RICO Collaboration, “About general challenges for high-resolution MRTOF mass separation with subsequent C-CLS measurements,” *International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023)*, Nara, Japan, November 13–17, 2023.
- H. Endo (poster), K. Ishii, K. Imamura, A. Takamine, Y. Matsuo, T. Tahara, and H. Ueno, “Towards the measurement of relaxation times of Rb atomic bubbles in superfluid helium using picosecond time-resolved detection,” *International Conference on Hyperfine*

Interactions and their Applications (HYPERFINE2023), Nara, Japan, November 13–17, 2023.

- Y. Fukuzawa (poster), K. Imamura, A. Takamine, A. Gladkov, T. Kato, K. Shimizu, M. Rosenbusch, S. Go, Y. Ito, M. Tajima, Y. Matuo, and H. Ueno, “Development of a neutralizer to produce thermalized RI atoms,” International Conference on Hyperfine Interactions and their Applications (HYPERFINE2023), Nara, Japan, November 13–17, 2023.
- A. Takamine (invited), “Recent development of the helium-gas-filled ion catcher at BigRIPS at RIKEN RIBF,” The 2023 Fall Meeting (6th Joint Meeting) of the Division of Nuclear Physics of American Physical Society and the Physical Society of Japan (HAWAII2023), Waikoloa, Hawaii, USA, November 26–December 1, 2023.
- M. Rosenbusch (invited), A. N. Andreyev, S. Chen, Y. Hirayama, D. Hou, H. Ishiyama, S. Kimura, M. Mukai, S. Nikas, T. Niwase, P. Schury, A. Takamine, M. Wada, Y. X. Watanabe, and W. Xian, “Recent high-precision atomic mass measurements from medium-mass to heavy isotopes using MRTOF-MS at RIKEN/RIBF,” The 2023 Fall Meeting (6th Joint Meeting) of the Division of Nuclear Physics of American Physical Society and the Physical Society of Japan (HAWAII2023), Waikoloa, Hawaii, USA, November 26–December 1, 2023.
- S. Go (invited), “Nuclear spectroscopy in mass 40 region,” The 2023 Fall Meeting (6th Joint Meeting) of the Division of Nuclear Physics of American Physical Society and the Physical Society of Japan (HAWAII2023), Waikoloa, Hawaii, USA, November 26–December 1, 2023.
- H. Nagahama (oral), K. Nakamura, M. Sato, S. Nagase, T. Nakashita, M. Fukase, S. Kumahara, K. Abe, T. Aoki, H. Haba, A. Takamine, and Y. Sakemi, “Electron EDM search with laser-cooled heavy elements,” The 2023 Fall Meeting (6th Joint Meeting) of the Division of Nuclear Physics of American Physical Society and the Physical Society of Japan (HAWAII2023), Waikoloa, Hawaii, USA, November 26–December 1, 2023.
- M. A. Syakuur, A. E. Putri, A. R. Noviyanti, U. Widayiswari, T. Saragi, Risdiana, D. P. Sari, and I. Watanabe, “ μ SR study on the magnetic properties of $\text{Sm}_2\text{Ru}_2\text{O}_7$,” The 3rd Advanced Mater. Grand Meeting (MRM2023/IUMRS-ICA2023), Kyoto, Japan, December 11–16, 2023.
- Y. Komiyama (oral), S. Onishi, H. Kuwahara, M. Harada, H. Kuwahara, H. Kuroe, K. Kurashima, T. Kawamata, Y. Koike, Dita Puspita Sari, I. Watanabe, Y. Ikeda, T. Taniguchi, M. Matsuda, T. Masuda, M. Fujita, and T. Adachi, “Antiferromagnetic/Ferromagnetic spin fluctuations in non-superconducting heavily overdoped Bi-2201 cuprates,” The 3rd Advanced Mater. Grand Meeting (MRM2023/IUMRS-ICA2023), Kyoto, Japan, December 11–16, 2023.
- H. Ueno (invited seminar), “Scientific opportunities at the RIKEN RIBF facility,” Maejo University, Chiang Mai, Thailand, December 12, 2023.
- H. Ueno (invited), “Scientific opportunities at the RIKEN RIBF facility,” The 5th International Conference on Radiation and Emission in Mater. (ICREM2023), Chiang Mai, Thailand, December 13–15, 2023.
- S. Go (invited), “Nuclear spectroscopy towards a deeper understanding,” Advancing physics at next RIBF (ADRI24), Wako, Japan, January 23–24, 2024.
- M. Rosenbusch (invited), “Future perspectives for high-precision atomic mass measurements from medium-mass to heavy isotopes using MRTOF-MS at RIBF,” Advancing physics at next RIBF (ADRI24), Wako, Japan, January 23–24, 2024.
- A. Takamine (invited), “Atomic precision spectroscopy for the RI beams at RIKEN RIBF,” 3rd RIKEN-IBS Joint Conference on Nuclear Physics, Wako, Japan, January 25–26, 2024.
- I. Watanabe (invited), Wan Nurfaadhilah Zaharim, Dita Puspita Sari, Y. Komiyama, T. Goto, and T. Adachi, “Developments of μ SR data analysis techniques by using Machine Learning and DFT,” The First Conference of Accelerator-Based Sciences and Technology (CAST 2024), Serpong, Indonesia, February 19–22, 2024.
- H. Ueno (keynote), “RIBF Research Activities,” The First Conference of Accelerator-Based Sciences and Technology (CAST2024), Serpong, Indonesia, February 19–22, 2024.
- M. A. Syakuur (oral), A. E. Putri, A. R. Noviyanti, U. Widayiswari, T. Saragi, Risdiana, D. Puspita Sari, and I. Watanabe, “Magnetic properties of $\text{Sm}_2\text{Ru}_2\text{O}_7$ studied by muons,” The First Conference of Accelerator-Based Sciences and Technology (CAST2024), Serpong, Indonesia, February 19–22, 2024.
- P. Jaikaew (oral), “Surface muon production at J-PARC muon facility,” The First Conference of Accelerator-Based Sciences and Technology (CAST 2024), Serpong, Indonesia, February 19–22, 2024.
- H. Ueno (invited seminar), “Nuclear spectroscopy utilizing stop/slowed-down RI beams,” The First Conference of Accelerator-Based Sciences and Technology (CAST 2024), Serpong, Indonesia, February 19–22, 2024.
- M. Rosenbusch (plenary), “High-precision mass measurements at RIBF,” NUSTAR Annual Meeting 2024, Darmstadt, Germany, February 26–March 1, 2024.
- S. Go (oral), “Gamma-ray polarimetry based on a multi-layer CdTe Compton camera,” A3F-Workshop on Frontier Nuclear Studies with Gamma-ray Spectrometer Arrays (gamma24), Osaka, Japan, March 26–28, 2024.

[Domestic Conferences/Workshops]

- 高橋翔輝 (ポスター), 今村慧, 山本匠, 上野秀樹, 松尾由賀利, 高峰愛子, 「超流動ヘリウム中 Ag 原子の超微細構造間隔測定へ向けた DPSS レーザーのレーザーパワー最適化」, 第 19 回 原子・分子・光科学 (AMO) 討論会, 仙台市 (東北大学青葉山キャンパス), 2023 年 6 月 2–3 日.
- 笹森慎也, 高峰愛子, 今村慧, 遠藤宏紀, 高橋翔輝, 上野秀樹, 松尾由賀利, 「超流動ヘリウム中 Rb 原子の超微細構造異常測定に向けたマイクロ波掃引の検証」, 第 19 回 原子・分子・光科学 (AMO) 討論会, 仙台市 (東北大学青葉山キャンパス), 2023 年 6 月 2–3 日.
- 福澤悠亮, 今村慧, 高峰愛子, GLADKOV Aleksey, 加藤大河, 郷慎太郎, 田島美典, 松尾由賀利, ROSENBUSCH Marco, 上野秀樹, 「低速・高偏極 RI ビーム生成に向けた中性化装置開発における $^{88}\text{Sr}^+$ イオンの冷却実験」, 第 19 回 原子・分子・光科学 (AMO) 討論会, 仙台市 (東北大学青葉山キャンパス), 2023 年 6 月 2–3 日.

郷慎太郎 (口頭), 今村慧, 高峰愛子, 遠藤宏紀, 山本匠, 上野秀樹, 松尾由賀利, 「多層半導体コンプトンカメラによる核分光研究」, 第 12 回 停止・低速 RI ビームを用いた核分光研究会, 東京, 2023 年 9 月 4-5 日.

高橋翔輝 (ポスター), 今村慧, 高峰愛子, 遠藤宏紀, 山本匠, 上野秀樹, 松尾由賀利, 「超流動ヘリウム中 Ag 原子の超微細構造間隔測定へ向けて」, 第 12 回 停止・低速 RI ビームを用いた核分光研究会, 東京, 2023 年 9 月 4-5 日.

上野秀樹 (依頼講演), 「計画研究 B03 班 高偏極 RI ビームの生成と核・物質科学研究への応用」, 新学術領域研究「宇宙観測検出器と量子ビームの出会い. 新たな応用の架け橋.」領域研究会 (第 5 回領域全体会議), オンライン, 2023 年 10 月 27-28 日.

郷慎太郎 (依頼講演), 「多層半導体検出器を用いた原子核研究」, 新学術領域研究「宇宙観測検出器と量子ビームの出会い. 新たな応用の架け橋.」領域研究会 (第 5 回領域全体会議), オンライン, 2023 年 10 月 27-28 日.

高峰愛子 (ポスター), 今村慧, 菊地快, 光安陸大, 秋元彩, 伊藤愛美, 螺良健太, 上野秀樹, 松尾由賀利, 「HIMAC 施設 2 次不安定核ビームを利用した超流動ヘリウム中不安定核原子の超微細構造精密測定手法開発」, 第 3 回日本量子医科学会学術大会, 和光市 (理化学研究所), 2023 年 12 月 8-9 日.

郷慎太郎 (口頭), 「アイソマースコープ法を用いたアクチノイド核の核分光研究」, 東海・重イオン科学シンポジウム—タンデム加速器成果報告会—, 東海村, 2024 年 1 月 10-11 日.

伊藤尚輝 (口頭), 外山裕一, 東俊行, 池田時浩, 長澤俊作, 岡田信二, 高橋忠幸, 高峰愛子, 上野秀樹, 「ペレトロン加速器からの陽子線マイクロビームを使った TimePix3 読み出しチップ搭載型 Si ピクセル検出器の陽子イオン検出性能の評価」, 日本物理学会 2024 年春季大会, オンライン, 2024 年 3 月 18-21 日.

望月真生, 高峰愛子, 今村慧, 菊地快, 光安陸大, 大岩彩良, 上野秀樹, 松尾由賀利, 「超流動ヘリウム中 Rb 不安定核原子のレーザー分光観測のためのビーム診断真空チェンバー内での光電子増倍管の動作検証」, 日本物理学会 2024 年春季大会, オンライン, 2024 年 3 月 18-21 日.

妹尾仁嗣, 圓谷貴夫, 大島勇吾, 渡邊功雄, 加藤礼三, 宮崎剛, 「量子スピン液体物質 Pd(dmit)_2 塩の磁氣的相互作用の異方性に対する多軌道性の効果」, 日本物理学会 2024 年春季大会, オンライン, 2024 年 3 月 18-21 日.

Press Releases

「40 年ぶりに中性子過剰なウラン同位体を新発見」, 高エネルギー加速器研究機構, 理化学研究所共同プレスリリース, 2023 年 4 月 3 日, https://www.riken.jp/press/2023/20230403_1/index.html.

「最先端宇宙観測技術で見る原子核の姿—原子核からの『偏光』を捉える高感度カメラ」, 理化学研究所, 東京大学 Kavli IPMU, 九州大学, 東京都市大学共同プレスリリース, 2024 年 2 月 9 日, https://www.riken.jp/press/2024/20240209_2/index.html.

Award

T. Abe and T. Otsuka, “*Ab-initio* calculations of the Hoyle state of the carbon-12 nucleus,” FY2022 RIKEN Baiho Award, March 22, 2023.