

Partner Institution

Wako Nuclear Science Center, IPNS (Institute of Particle and Nuclear Studies)
KEK (High Energy Accelerator Research Organization)

1. Abstract

The Wako Nuclear Science Center (WNSC) of KEK aims to promote low-energy nuclear physics, nuclear astrophysics research, and interdisciplinary studies using short-lived radioactive nuclides. WNSC operates the KEK Isotope Separation System (KISS), an electromagnetic isotope separator featuring elemental selectivity from resonance laser ionization in a gas catcher. The KISS facility uniquely provides various neutron-rich isotopes of refractory elements and the nuclei in the vicinity of the neutron magic numbers $N = 126$ and $N = 152$ via multinucleon transfer reactions to users from universities. Optical and β - γ spectroscopy and mass spectrometry have been applied to these neutron-rich nuclear beams for nuclear structure and nuclear astrophysical studies. WNSC leads comprehensive mass measurements of all nuclides available at RIBF using multi-reflection time of flight mass spectrographs (MRTOF-MS). Three MRTOF setups were placed at the GARIS-II, the beam dump of the ZeroDegree spectrometer, and KISS—the masses of more than 400 nuclides, including dozens of first masses, were measured. An upgrade plan, KISS-1.5, has been proposed to study the origin of uranium for the first time.

2. Major Research Subjects

- (1) Production and manipulation of radioactive isotope beams for nuclear experiments
- (2) Explosive nucleosynthesis (r - and rp -process)
- (3) Heavy ion reaction mechanism for producing heavy neutron-rich nuclei
- (4) Development of MRTOF mass spectrographs for short-lived nuclei
- (5) Comprehensive mass measurements of short-lived nuclei, including superheavy elements
- (6) Development of upgrade facility, KISS-1.5

3. Summary of Research Activity

The Wako Nuclear Science Center (WNSC) provides low-energy, short-lived radioactive ion beams of neutron-rich refractory elements to university researchers using the KEK isotope separation system (KISS). Laser spectroscopy of neutron-rich refractory elements, including long-lived isotopes, is uniquely performed using the resonant laser ionization scheme of KISS and the MRTOF device's capability of isobaric separation. In FY2023, four experiments were performed at KISS: the isomeric states search in the hafnium isotopes and the isotope shift measurements at the tungsten and rhenium isotopes were successfully carried out. The commissioning experiment of a large-volume argon gas cell was also done to improve the capability of the KISS.

The WNSC team leads comprehensive mass measurements of all nuclides available at RIKEN RIBF using three MRTOF mass spectrographs: GARIS-II MRTOF, ZeroDegree MRTOF, and KISS MRTOF. We have continued the mass measurement study of the superheavy nuclei with the GARIS-II MRTOF and established a new method for the excitation function measurement with the MRTOF. The commissioning of the new experimental setup based on the GARIS-II MRTOF, aiming at the future new isotope search, was done successfully.

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List of Publications & Presentations

Publications

[Original Papers]

- T. Niwase, M. Wada, P. Schury, M. Rosenbusch, D. Kaji, K. Morimoto, S. Kimura, and W. Xian, “Decay-correlated mass measurement technique via multi-reflection time-of-flight mass spectrograph with the α/β -TOF detector,” *Nucl. Instrum. Methods Phys. Res. B* **541**, 197–199 (2023).
- M. Tajima, A. Takamine, H. Iimura, M. Wada, S. Kimura, T. Niwase, P. Schury, H. A. Schuessler, J. Lassen, and H. Ueno, “Offline development for collinear laser spectroscopy at the SLOWRI facility,” *Nucl. Instrum. Methods Phys. Res. B* **541**, 272–274 (2023).
- Y. Cho, Y. H. Kim, S. Choi, J. Park, S. Bae, K. I. Hahn, Y. Son, A. Navin, A. Lemasson, M. Rejmund, D. Ramos, D. Ackermann, A. Utepov, C. Fourgeres, J. C. Thomas, J. Goupil, G. Fremont, G. de France, Y. X. Watanabe, Y. Hirayama, S. Jeong, T. Niwase, H. Miyatake, P. Schury, M. Rosenbusch, K. Chae, C. Kim, S. Kim, G. M. Gu M. J. Kim, P. John, A. N. Andreyev, W. Korten, F. Recchia, G. de Angelis, R. Perez Vidal, K. Rezykina, J. Ha, F. Didierjean, P. Marini, D. Treasa, I. Tsekhanovich, J. Dudouet, S. Bhattacharyya, G. Mukherjee, R. Banik, S. Bhattacharya, and M. Mukai, “Particle identification at VAMOS++ with machine learning techniques,” *Nucl. Instrum. Methods Phys. Res. B* **541**, 240–242 (2023).
- P. Brionnet, R. K. Grzywacz, D. Kaji, T. T. King, T. Niwase, K. Morimoto, K. P. Rykaczewski, and H. Sakai, “Development of digital electronics for the search of SHE nuclei using GARIS-II/III at RIKEN,” *Nucl. Instrum. Methods Phys. Res. A* **1049**, 168068 (2023).
- Y. Hirayama, M. Mukai, P. Schury, Y. X. Watanabe, S. Iimura, H. Ishiyama, S. C. Jeong, H. Miyatake, T. Niwase, M. Rosenbusch, A. Takamine, A. Taniguchi, and M. Wada, “Helium gas cell with RF wire carpets for KEK isotope separation system,” *Nucl. Instrum. Methods Phys. Res. A* **1058**, 168838 (2024).
- D. S. Hou, A. Takamine, M. Rosenbusch, W. D. Xian, S. Iimura, S. D. Chen, M. Wada, H. Ishiyama, P. Schury, Z. M. Niu, H. Z. Liang, S. X. Yan, P. Doornenbal, Y. Hirayama, Y. Ito, S. Kimura, T. M. Kojima, W. Korten, J. Lee, J. J. Liu, Z. Liu, S. Michimasa, H. Miyatake, J. Y. Moon, S. Naimi, S. Nishimura, T. Niwase, T. Sonoda, D. Suzuki, Y. X. Watanabe, K. Wimmer, and H. Wollnik, “First direct mass measurement for neutron-rich ^{112}Mo with the new ZD-MRTOF mass spectrograph system,” *Phys. Rev. C* **108**, 054312 (2023).
- J. W. Zhao, D. Amanbayev, T. Dickel, I. Miskun, W. R. Plaß, N. Tortorelli, S. Ayet San Andrés, S. Beck, J. Bergmann, Z. Brencic, P. Constantin, H. Geissel, F. Greiner, L. Gröf, C. Hornung, N. Kuzminchuk, G. Kripkó-Koncz, I. Mardor, I. Pohjalainen, C. Scheidenberger, P. G. Thirolf, S. Bagchi k, E. Haettner, E. Kazantseva, D. Kostyleva, A. Oberstedt, S. Pietri, M. P. Reiter, Y. K. Tanaka, M. Wada, D. L. Balabanski, D. Benyamin, M. N. Harakeh, N. Hubbard, N. Kalantar-Nayestanaki, A. Mollaebrahimi, I. Mukha, M. Narang, T. Niwase, Z. Patyk, S. Purushothaman, A. Rotaru, A. Spataru, G. Stanic, M. Vencelj, H. Weick, and J. Yu, the Super-FRS Experiment Collaboration, “Increasing the rate capability for the cryogenic stopping cell of the FRS Ion Catcher,” *Nucl. Instrum. Methods Phys. Res. B* **547**, 165175 (2024).
- T. Chillery, J. Hwang, M. Dozono, N. Imai, S. Michimasa, T. Sumikama, N. Chiga, S. Ota, S. Nakayama, D. S. Ahn, O. Beliuskina, K. Chikaato, N. Fukuda, S. Hayakawa, E. Ideguchi, K. Iribe, C. Iwamoto, S. Kawase, K. Kawata, N. Kitamura, K. Kusaka, S. Masuoka, H. Miki, H. Miyatake, D. Nagae, R. Nakajima, K. Nakano, M. Ohtake, S. Omika, H. J. Ong, H. Otsu, H. Sakurai, P. Schrock, H. Shimizu, Y. Shimizu, X. Sun, D. Suzuki, H. Suzuki, M. Takaki, M. Takechi, H. Takeda, S. Takeuchi, T. Teranishi, R. Tsunoda, H. Wang, Y. Watanabe, Y. X. Watanabe, K. Wimmer, K. Yako, H. Yamada, K. Yamada, H. Yamaguchi, L. Yang, R. Yanagihara, Y. Yanagisawa, H. Yoshida, K. Yoshida, and S. Shimoura, “Studying the impact of deuteron non-elastic breakup on $^{93}\text{Zr} + d$ reaction cross sections measured at 28 MeV/nucleon,” *Prog. Theor. Exp. Phys.* **2023**, 121D01 (2023).
- W. Xian, S. Chen, S. Nikas, M. Rosenbusch, M. Wada, H. Ishiyama, D. Hou, S. Iimura, S. Nishimura, P. Schury, A. Takamine, S. Yan, F. Browne, P. Doornenbal, F. Flavigny, Y. Hirayama, Y. Ito, S. Kimura, T. M. Kojima, J. Lee, J. Liu, H. Miyatake, S. Michimasa, J. Y. Moon, S. Naimi, T. Niwase, T. Sonoda, D. Suzuki, Y. X. Watanabe, V. Werner, K. Wimmer, and H. Wollnik, “Mass measurements of neutron-rich $A \approx 90$ nuclei constrain element abundances,” *Phys. Rev. C* **109**, 035804 (2024).

[Thesis]

- W. Xian, “Precision mass measurement of neutron-rich nuclei around $A = 90$ ($Z = 32\text{--}34$) and towards ^{78}Ni via multi-reflection time-of-flight mass spectrograph at ZeroDegree spectrometer,” PhD Thesis, The University of Hong Kong, October 2023.

Presentations

[International Conferences/Workshops]

- T. Niwase (oral), “High-precision direct mass measurement of (super) heavy nuclides with MRTOF via GARIS-II and KISS setups,” TASC23, 20th Workshop on Recoil Separator for Superheavy Element Chemistry & Physics, Hybrid (Darmstadt, Germany and Online), April 25–27, 2023.
- Y. Hirayama (invited), “Cryogenic He gas catcher with an RF curtain structure for upgraded KISS facility,” 14th International Conference on Stopping and Manipulation of Ions and Related Topics (SMI-2023), Gießen, Germany, May 8–11, 2023.
- M. Rosenbusch (invited), “A first review of the SLOWRI/MRTOF-MS project at BigRIPS/ZeroDegree,” 14th International Conference on Stopping and Manipulation of Ions and Related Topics (SMI-2023), Gießen, Germany, May 8–11, 2023.
- T. Niwase (oral), “High-precision mass measurement of the actinide nuclides via MRTOF-MS of the KEK isotope separation system,” 14th International Conference on Stopping and Manipulation of Ions and Related Topics (SMI-2023), Gießen, Germany, May 8–11, 2023.
- M. Wada (invited), “Precision mass measurements of superheavy and other exotic nuclides,” 7th International Conference on the Chemistry and Physics of the Transactinide Elements (TAN23), Huizhou, China, November 12–17, 2023.
- Y. Hirayama (oral), “In-gas-cell laser ionization spectroscopy at KISS,” International Conference on Hyperfine Interactions and their

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

- Y. X. Watanabe (invited), “Spectroscopy of neutron-rich nuclei produced by multinucleon transfer reactions at KISS,” International Conference on Heavy-Ion Collisions at near-barrier energies (FUSION23), Shimizu, Japan, November 19–24, 2023.
- Y. Hirayama (invited), “KISS gas cell system for the nuclear spectroscopy of multinucleon transfer reaction products,” 6th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Hawaii, USA, November 26–December 1, 2023.
- Y. X. Watanabe (invited), “Decay spectroscopy of neutron-rich nuclei produced in multinucleon transfer reactions at KISS,” 6th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Hawaii, USA, November 26–December 1, 2023.
- M. Rosenbusch (invited), “Recent high-precision atomic mass measurements from medium-mass to heavy isotopes using MRTOF-MS at RIKEN/RIBF,” 6th Joint Meeting of the APS Division of Nuclear Physics and the Physical Society of Japan, Hawaii, USA, November 26–December 1, 2023.
- Y. X. Watanabe, RIKEN RNC-IBS Collaboration Workshop, Wako, Japan, January 25–26, 2024.
- S. Kimura (invited), NAPS2024, Tokai, Japan, February 20–22, 2024.
- Y. X. Watanabe (invited), The workshop on frontier nuclear studies with gamma-ray spectrometer arrays (gamma24), Minoh, Japan, March 26–28, 2024.
- M. Mukai (oral), “Recent results of nuclear spectroscopy for neutron-rich isotopes at KISS,” LISA Conference, Leuven, Belgium, May 22–26, 2023.
- M. Mukai (oral), “Mass and isotope shift measurements of neutron-rich tungsten isotopes at KISS,” Resonance ionization mass spectrometry instruments workshop, Fukushima, Japan, March 25–30, 2024.

[Domestic Conferences/Workshops]

- 宮武宇也, 「(私が見てきた) 短寿命核ビームの科学+ α 」, 短寿命核ビームの科学, 千代田区 (学士会館), 2023 年 4 月 7 日.
- 木村創大 (口頭発表), 「イオンの荷電変換反応における核スピン効果の初観測?」, 第 12 回停止・低速 RI ビームを用いた核分光研究会 (12th SSRI), 豊島区 (立教大学), 2023 年 9 月 4–5 日.
- 向井もも (口頭発表), 「Isotope shift measurement of neutron-rich tungsten isotopes」, 第 12 回停止・低速 RI ビームを用いた核分光研究会 (12th SSRI), 豊島区 (立教大学), 2023 年 9 月 4–5 日.
- 平山賀一 (口頭発表), 「Collinear laser ionization spectroscopy with helium gas cell at KISS」, 第 12 回停止・低速 RI ビームを用いた核分光研究会 (12th SSRI), 豊島区 (立教大学), 2023 年 9 月 4–5 日.
- 庭瀬暁隆 (口頭発表), 「MRTOF を用いた質量測定と核反応研究」, 第 12 回停止・低速 RI ビームを用いた核分光研究会 (12th SSRI), 豊島区 (立教大学), 2023 年 9 月 4–5 日.
- S. Iimura (oral), “Development of RF carpet type He gas cell and high-precision mass measurement of neutron-rich nuclei at around $A = 50$ –60 with MRTOF,” RIBF Users Meeting 2023, Wako (RIKEN), Japan & Online, September 6–7, 2023.
- Y. Hirayama (oral), “Present status and future plan of KISS,” RIBF Users Meeting 2023, Wako (RIKEN), Japan & Online, September 6–7, 2023.
- T. Niwase (oral), “Recent progress of superheavy element research,” RIBF Users Meeting 2023, Wako (RIKEN), Japan & Online, September 6–7, 2023.
- 渡邊裕 (招待講演), 「KISS での多核子移行反応を用いた RI 生成と核分光」, 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 (原子力機構原子力科学研究所), 2024 年 1 月 10–11 日.
- 和田道治, 「質量測定の現状と今後」, 研究会「精密 N 体問題の解が拓く物理」, 仙台市, 2024 年 1 月 15–16 日.
- 渡邊裕 (招待講演), 「KEK 元素選択型質量分離装置 (KISS) の紹介: 多核子移行反応による RI 合成と核分光実験」, 第 38 回研究会「放射線検出器とその応用」, つくば市 (高エネルギー加速器研究機構), 2024 年 1 月 22–24 日.

[Seminars]

- 渡邊裕, 「不安定核ビームで探る元素の起源 (The use of unstable nuclear beams to elucidate the origins of chemical elements)」, 総研大高エネルギー加速器研究機構加速器科学セミナー, つくば市, 2023 年 7 月 26 日.
- 渡邊裕, 「和光原子核科学センターでの KISS 実験と将来計画」, KEK 放射線科学センターセミナー, つくば市, 2023 年 8 月 10 日.
- Y. Hirayama (invited), “Nuclear spectroscopy at KISS and upgrade plan of the facility,” JSPS alumni seminar: Probing the ground state and decay properties of exotic nuclei at KEK-WNSC and JYFL-ACCLAB, Jyväskylä, Finland, October 27, 2023.
- M. Mukai, “The progress of in-gas-cell laser ionization spectroscopy of neutron-rich tungsten nuclei,” JSPS alumni seminar: Probing the ground state and decay properties of exotic nuclei at KEK-WNSC and JYFL-ACCLAB, Jyväskylä, Finland, October 27, 2023.
- 和田道治, 「短寿命原子核の精密原子分光法による研究」, 新潟大学コロキウム, 新潟市, 2024 年 1 月 23 日.

Awards

- Shun Iimura, “Development of RF carpet type He gas cell and high-precision mass measurement of neutron-rich nuclei at around $A = 50$ –60 with MRTOF,” RIBF Users Group Thesis Awards 2023.
- 向井もも, 第 18 回 (2024 年) 日本物理学会実験核物理領域: 若手奨励賞 (Young Scientist Award of the Physical Society of Japan), 第 30 回原子核談話会新人賞.