Nuclear Science Research Division
Meson RIKEN ECL Research Team

1. Abstract

The Meson RIKEN ECL Research Team is investigating a new form of nucleus that contains a meson as a constituent particle. Presently, our focus lies in embedding an anti-kaon containing a strange quark, into nuclei using a high-intensity K^- beam provided by the J-PARC facility at Tokai, Japan. It is suggested that the density of kaonic nuclei increases, potentially revealing new aspects of nuclear matter. Our solenoid-based spectrometer, which is developed to study kaonic nuclei, is also employed in other experiments, such as a lifetime measurement of light hypernuclei.

In parallel, we are conducting interdisciplinary research using state-of-the-art superconducting X-ray detectors, known as TES detectors. We initially introduced these detectors to a kaonic atom experiment and are now applying them to muonic atoms in various fields of physics, including nuclear, atomic, molecular, and fundamental physics.

2. Major Research Subjects

(1) Search for nuclear-bound states containing a meson and study their properties.
(2) Study of basic property of few-body hypernuclei.
(3) Application of superconducting X-ray detectors
(4) Atomic, molecular, nuclear, and fundamental physics studies by precision X-ray measurements of muonic atoms

3. Summary of Research Activity

(1) Lifetime measurement of hypertriton

Hypertriton is the simplest hypernucleus composed of a proton, a neutron, and a Λ hyperon. It provides essential benchmarks for hypernuclear physics, like a deuteron for the standard nuclei. However, there has been an open issue, which is the so-called "hypertriton lifetime puzzle." Hypertriton is believed to be a loosely bound object, and thus the lifetimes are naively considered to be similar to that of Lambda in free space. In contrast, some heavy-ion-based experiments reported considerably shorter lifetimes. To pin down the situation, we are proceeding with a new experiment at J-PARC to measure the lifetimes of light hypernuclei using the (K^-, π^0) reaction. The spin-none-flip nature of the reaction and the direct time-domain measurement of the decay time make our experiment unique and complementary to heavy-ion-based experiments. We first performed a proof-of-principle experiment using a helium-4 target, for which we have already reported the lifetime of hyperhydrogen-4 [PLB845,138128(2023)].

In FY2024, we completed the data acquisition for measuring the hypertriton lifetime. The beamtime at the J-PARC hadron experimental facility was conducted in April–June 2024, and January–February 2025. During this period, which effectively corresponds to approximately one month, 65×10^9 K^-s were irradiated onto a ~15-cm thick liquid helium-3 target. We expect to reconstruct more than 1000 events of hypertriton two-body decays, which will enable us to evaluate the lifetime with an accuracy below 10%.

(2) Kaonic nuclei

Kaonic nuclei have been long searched for many years. Finally, we observed the simplest "K^-pp" state conclusively, by the exclusive measurement of Λpn final states in the in-flight K^- reaction on helium-3 [PLB789,620(2019)]. Using the same dataset, we further continued analysis on the other decay channels, such as "$K^-pp \to \pi\Sigma p, \pi\Lambda p$." Although these mesonic decay channels require a detection of the neutron, and our present solenoid spectrometer has limited capability in measuring neutrons, we succeeded in reconstructing these decay channels. The results were published [PRC110,14002(2024)], showing that the mesonic decay spectra are consistently understood with non-mesonic decay "$K^-pp \to \Lambda p$," and the much larger branching ratio for the mesonic modes as naively expected.

We also investigated a heaviear kaonic nuclear system, "K^-ppn." We had a chance to take data with a helium-4 target as controlled data for the hypertriton measurement. We reconstructed the Λdn events, similarly to the case of Λpn with a helium-3 target, and observed a hint of spectral structure below the kaon binding threshold.

In parallel, we are developing a new solenoid-based spectrometer system for the next-generation kaonic-nucleus experiment. The new spectrometer features a large solid angle covering almost 4π and an enhanced neutron detection capability on the barrel part of the solenoid. These will enable further systematic study of light kaonic nuclei including the size of the system and other internal properties. In 2024, we completed a superconducting solenoid magnet, started the commissioning of a 2.6-m-long cylindrical drift chamber, and tested 3-m-long neutron counters made of plastic scintillators. We plan to start the installation of the new detectors to the J-PARC K1.8BR beamline in FY2026.

(3) X-ray spectroscopy of exotic atoms using TES microcalorimeters

Transition-edge sensor (TES) microcalorimeters utilize the superconducting phenomena to achieve an excellent resolution for single-photon (X rays and γ rays) energy measurement. We have been leading the application of TES detectors to accelerator-based experiments, such as kaonic atom X rays for a strong-force study [PRL128,112503(2022)] and muonic atom X rays for strong-field QED validation [PRL130,173001(2023)] at J-PARC, as well as material sciences in a photon beamline at SPring-8. Previous experiments are based on a NIST-made TES system, applicable up to 20 keV, with a 5 eV FWHM resolution at 6 keV, which is 30 times better than conventional silicon detectors.

In 2024, we newly introduced the second TES system again from NIST. Two detector units are installed in the same new adiabatic demagnetization refrigerator, which are optimized for 50 keV and 100 keV, respectively. In the initial detector commissioning at the

J-PARC muon beam line MLF-D2, we demonstrated the operation of the new system with a reasonable degradation in spectroscopic performance, even under a harsh beam condition. A typical resolution achieved is 25 eV at 43 keV and 80 eV at 122 keV, which are one order of magnitude better compared to a typical germanium detector. After the beamtime, we brought back the TES system to the RIBF building, and continued basic studies, including further optimization of operational parameters and the energy calibration method. The next beam experiment is scheduled for April and May 2025 to validate the strong-field QED with muonic argon lines at 44 keV and 127 keV.

Members

Team Leader

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List of Publications & Presentations

Publications

[Original Papers]

T. Yamaga *et al.*, "Measurement of the mesonic decay branch of the $\bar{K}NN$ quasi-bound state," Phys. Rev. C **110**, 14002 (2024) DOI: 10.1103/PhysRevC.110.014002 .

J. Yamagata-Sekihara *et al.*, "Investigation of kaonic atom optical potential by the high precision data of kaonic ^{3}He and ^{4}He atoms," Prog. Theor. Exp. Phys. **2025**, 013D02 (2025) DOI: 10.1093/ptep/ptae189 .

[Proceedings]

K. Itahashi *et al.*, "Chiral symmetry restoration in nuclear medium observed in pionic atoms," Il Nuovo Cimento **47C**, 229 (2024). DOI: 10.1393/ncc/i2024-24229-2 .

K. Itahashi *et al.*, "Chiral symmetry restoration in nucleus observed in pionic atoms," Acta Physica Polonica A **146**, 721 (2024) DOI: 10.12693/APhysPolA.146.721 .

F. Sakuma *et al.*, "Light kaonic nuclei at J-PARC," Proc. Sci. QNP2024, 211 (2025) DOI: 10.22323/1.465.0211 .

T. Y. Saito *et al.*, "Application of hard X-ray and gamma-ray TES microcalorimeter at accelerator facility," IEEE Trans. Appl. Supercond. **35**, 2100805 (2025) DOI: 10.1109/TASC.2024.3525445 .

G. Baptista *et al.*, "Towards precision spectroscopy of antiprotonic atoms for probing strong-field QED," Proc. Sci. EXA-LEAP2024, 085 (2025) DOI: 10.22323/1.480.0085 .

Presentations

[International Conferences/Workshops]

T. Hashimoto (invited), "Kaonic nuclei at J-PARC," J-PARC Hadron workshop 2024, Tokai, Japan, July 24, 2024.

T. Nanamura (oral), "Recent results of $\Sigma^+ p$ scattering experiment at J-PARC," 11th International Workshop on Chiral Dynamics (CD2024), Bochum, Germany, August 26–30, 2024.

T. Hashimoto (poster), "Lifetime measurement of light hypernuclei using K^- beam at J-PARC," International Conference on Exotic Atoms and Related Topics and conference on Low Energy Antiprotons (EXA/LEAP 2024), Vienna, Austria, August 26–30, 2024.

T. Hashimoto (invited), "Status of kaonic-atom experiments at J-PARC," KAMPAI—Kaonic, Antiprotonic, Muonic, Pionic and "onia" exotic Atoms: Interchanging knowledge and recent results, Trento, Italy, September 30–October 4, 2024.

T. Hashimoto (invited), "Exploring a new form of matter containing an anti-kaon," 4th J-PARC symposium (J-PARC2024), Mito, Japan, October 14–18, 2024.

T. Nanamura (poster), "Recent progress and prospect of $\Sigma^\pm p$ scattering experiments," 4th J-PARC symposium (J-PARC2024), Mito, Japan, October 14–18, 2024.

Y. Kimura (poster), "The development of the new Cylindrical Detector System for the systematic investigation of light kaonic nuclei," 4th J-PARC symposium (J-PARC2024), Mito, Japan, October 14–18, 2024.

T. Hashimoto (oral), "Muonic X-ray spectroscopy using TES microcalorimeters," FUture on Muon Elemental analysis (FUME), Tokai, Japan, October 19–20, 2024.

[Domestic Conferences/Workshops]

七村拓野 (口頭発表), 「控えめな “強い斥力” を示唆する $\Sigma^+ p$ 散乱実験の結果」, 軽井沢研究会「原子核多体問題の進展と展望２」, 軽井沢, 2024 年 7 月 5–6 日.

七村拓野 (口頭発表), 「大立体角スペクトロメータを用いた軽い反 K 中間子原子核の系統的研究の準備状況」, 日本物理学会 第 79 回年次大会, 札幌市 (北海道大学), 2024 年 9 月 17 日.

木村佑斗 (口頭発表), 「反 K 中間子束縛原子核探索のための円筒型ドリフトチェンバーの性能評価 (I)」, 日本物理学会 第 79 回年次大会, 札幌市 (北海道大学), 2024 年 9 月 19 日.

木村佑斗 (口頭発表), 「反 K 中間子束縛原子核探索のための円筒型ドリフトチェンバーの性能評価 (II)」, 日本物理学会 2025 年春季大会, オンライン, 2025 年 3 月 20 日.

佐々木舜世 (口頭発表), 「J-PARC での反 K 中間子原子核研究のための円筒形中性子検出器の性能評価」, 日本物理学会 2025 年春季大会, オンライン, 2025 年 3 月 20 日.

川崎海斗 (ポスター発表), 「γ 線標準線源を用いた超伝導転移端センサのエネルギー較正」, 日本物理学会 2025 年春季大会, オンライン, 2025 年 3 月 20 日.

Award

橋本直, 山田真也, 岡田信二, 奥村拓馬, 「極低温検出器を用いたエキゾチック原子 X 線精密分光の開拓」, 2024 年度高エネルギー加速器科学研究奨励会奨励賞（小柴賞）, 2025 年 2 月 7 日.