Nuclear Science Research Division
Few-body Systems in Physics Laboratory

1. Abstract

Unlike many-body systems, few-body systems can be described with microscopic theories that can be solved without approximations. To this end the laboratory uses numerical techniques to exactly solve the equations describing few-body quantum systems. In particular, an accurate calculation method called the 'Gaussian Expansion Method using infinitesimally shifted Gaussian lobe basis function' has been developed. This method makes calculations tractable up to five bodies even with complicated interactions. It has been applied to various three-, four- and five-body calculations in hypernuclei, light nuclear systems, as well as cold-atom systems. These calculations have provided new insights into these various fields of physics.

2. Major Research Subjects

(1) Structure of hypernuclei
(2) Neutron-rich nuclei
(3) Few-body universality in nuclear and atomic systems
(4) Structure of exotic hadron system

3. Summary of Research Activity

(1) Atomic system

A theoretical study of resonance lifetimes in a two-component three-body system, specifically examining the decay of three-body resonances into a deep dimer and an unbound particle is performed. Utilising the Gaussian expansion method together with the complex scaling method, we obtain the widths of these resonances from first principles. We focus on mass ratios in the typical range for mixtures of ultracold atoms and reveal an intriguing dependence of the resonance widths on the mass ratio: as the mass ratio increases, the widths exhibit oscillations on top of an overall decreasing trend.

(2) Few-nucleon system

The moments of the charge distributions obtained by the sum-of-Gaussians (SOG) analysis of electron-scattering data are examined in ^{3}H and ^{3}He, together with those obtained by the Fourier-Bessel (FB) analysis. The SOG and FB methods reproduce well the experimental form factors available at present, but provide different charge distributions from each other. As a result, they do not yield the same values of the moments of the charge distribution, although their analyses are called "model-independent." The moments are sensitive to the tail of the charge distribution. The present experimental data are not enough for SOG and FB analyses to determine with reasonable accuracy the shape of the tails, in a quantum mechanical point of view. New, accurate experimental data at small momentum transfer squared less than 0.1 fm-2 are desired.

Members

Director

Emiko HIYAMA

Senior Research Scientists

Takumi DOI
Yue MA
Pascal NAIDON

Senior Scientist

Makiko NIO

Contract Researcher

Nodoka YAMANAKA

Special Postdoctoral Researchers

Ahmad J. ARIFI
Lucas M.C. HAPP

Junior Research Associate

Shuhei OHNO (Yokohama City Univ. Graduate School)

Research Consultants

Tomokazu FUKUDA (Univ. of Electro-Commun.)
Toshio MOTOBA (Univ. of Electro-Commun.)
Tomofumi NAGAE (Kyoto Univ.)
Kazuma NAKAZAWA
Jean-Marc RICHARD (Lyon Univ.)
Thomas RIJKEN (Univ. of Nijmegen)
Shoji SHINMURA
Wolfram WEISE (TU Munich)
Yasuo YAMAMOTO (Tsuru Univ.)

Senior Visiting Scientists

Koji MIWA (Tohoku Univ.)
Makoto OKA (Tokyo Tech)

Visiting Scientists

Shigeyoshi AOYAMA (KEK)
Masayuki ASAKAWA (Osaka Univ.)
Jaume CARBONELL (I'rene Joliot-Curie Lab.)
Akinobu DOTE (KEK)
Shimpei ENDO (Univ. of Electro-Commun.)
Tobias FREDERICO (Technological Inst. of Aeronautics)
Manami FUJITA (JAEA)
Yasuro FUNAKI (Kanto Gakuin Univ.)
Takenori FURUMOTO (Yokohama Nat'l Univ.)
Philipp GUBLER (JAEA)
Chengdong HAN (IMP, CAS)
Masashi HAYAKAWA (Nagoya Univ.)
Shuhei HAYAKAWA (Tohoku Univ.)
Satoru HIRENZAKI (Nara Women's Univ.)
Ryotaro HONDA (KEK)
Atsushi HOSAKA (Osaka Univ.)
Tomoaki HOTTA (Osaka Univ.)
Jinniu HU (Nankai Univ.)
Tetsuo HYODO (Tokyo Metropolitan Univ.)
Yudai ICHIKAWA (Tohoku Univ.)
Yoichi IKEDA (Osaka Univ.)
Masahiro ISAKA (Hosei Univ.)
Souichi ISHIKAWA (Hosei Univ.)
Naoyuki ITAGAKI (Osaka Metropolitan Univ.)
Daisuke JIDO (Tokyo Tech)
Masashi KANETA (Tohoku Univ.)
Hitoshi KATSURAGAWA (Osaka Univ.)
Hyun-Chul KIM (Inha Univ.)
Norihito MURAMATSU (Tohoku Univ.)
Takayuki MYO (Osaka Inst. of Tech.)
Sho NAGAO (Univ. of Tokyo)
Satoshi NAKAMURA (Univ. of Tokyo)
Takashi NAKANO (Osaka Univ.)
Shoichi SASAKI (Tohoku Univ.)
Hans-Josef SCHULZE (INFN)
Tingting SUN (Zhengzhou Univ.)
Masanori TACHIKAWA (Yokohama City Univ.)
Hiroyuki TAJIMA (Univ. of Tokyo)
Atsushi TOKIYASU (Tohoku Univ.)
Mifuyu UKAI (KEK)
Atsushi UMEYA (Nippon Inst. of Tech.)
Shin WATANABE (NIT, Gifu College)
Chengjun XIA (Yangzhou Univ.)
Ulugbek YAKHSHIEV (Inha Univ.)
Taiichi YAMADA (Kanto Gakuin Univ.)
Takeshi YAMAMOTO (JAEA)
Takuma YAMASHITA (Tohoku Univ.)
Ying ZHANG (Tianjin Univ.)
Xian-Rong ZHOU (East China Normal Univ.)

Student Trainees

Koki AMEMIYA (Tohoku Univ.)
Takeshi HARADA (Kyoto Univ.)
Akari HARATANI (Tohoku Univ.)
Yuning HONG (Tohoku Univ.)
Ryo IMAMOTO (Tohoku Univ.)
Rintaro KURATA (Tohoku Univ.)
Moemi MATSUMOTO (Tohoku Univ.)
Fumiya OURA (Tohoku Univ.)
Ryuta SAITO (Tohoku Univ.)
Ryusei SATO (Yokohama Nat'l Univ.)
Chesu SEONG (Tohoku Univ.)
Kaito SHIMAZAKI (Tohoku Univ.)
Zen TAKANO (Tohoku Univ.)
Shota TOYAMA (Tohoku Univ.)
Miyu YOSHIDA (Tohoku Univ.)

List of Publications & Presentations

Publications

[Original Papers]

L. Happ, P. Naidon, and E. Hiyama, "Mass ratio dependence of three-body resonance lifetimes in 1D and 3D," Few-Body Syst. **65(2)**, (2024).

S. Choi, E. Hiyama, C. Ho Hyun, and M. K. Cheoun, " Erratum to: Effects of many-body interactions in hypernuclei with Korea-IBS-Daegu-SKKU functionals," Eur. Phys. J. A **60(7)**, 152 (2024).

E. Hiyama, T. Suzuki, "Moments of the charge distribution observed through electron scattering in ^{3}H and ^{3}He," Prog. Theor. Exp. Phys. **2024(8)**, 083D02 (2024).

P. Froelich, T. Yamashita, Y. Kino, S. Jonsell, and E. Hiyama, "Formation of the positronium antihydride molecules (H^{-}Ps) in low energy, 5-body collisions of antihydrogen ion H^{-}+ with positronium atoms Ps," Few-Body Syst. **65(3)**, 82 (2024).

Y. Lyu, T. Doi, T. Hatsuda, and T. Sugiura, "Nucleon-charmonium interactions from lattice QCD," Phys. Lett. B **860**, 139178 (2025), arXiv:2410.22755 [hep-lat].

T. Aoyama, T. M. Doi, T. Doi, E. Itou, Y. Lyu, K. Murakami, and T. Sugiura (HAL QCD Collaboration), "Scale setting and hadronic properties in the light quark sector with (2 + 1)-flavor Wilson fermions at the physical point," Phys. Rev. D **110**, 094502 (2024), arXiv:2406.16665 [hep-lat].

S. Endo, E. Epelbaum, P. Naidon, Y. Nishida, K. Sekiguchi, and Y. Takahashi, "Three-body forces and Efimov physics in nuclei and atoms," Eur. Phys. J. A **61**, 9 (2025).

P. Naidon, "Inequivalence of stochastic and Bohmian arrival times in time-of-flight experiments," Phys. Rev. A **109**, 063312 (2024).

K. Oi, P. Naidon, and S. Endo, "Universality of Efimov states in highly mass-imbalanced cold-atom mixtures with van der Waals and dipole interactions," Phys. Rev. A **110**, 033305 (2024).

P. Naidon, "Closed-channel parameters of Feshbach resonances," SciPost Phys. **18**, 036 (2025).

T. Aoyama, M. Hayakawa, A. Hirayama, and M. Nio, "Verification of the tenth-order QED contribution to the anomalous magnetic moment of the electron from diagrams without fermion loops," Phys. Rev. D **111**, L031902 (2025).

N. Yamanaka, "Sketch of the resolution of the axial U(1) problem without chiral anomaly," arXiv: 2411.02792 [hep-ph].

N. Ponkhuha, A. J. Arifi, and D. Samart, Two-pion emission decays of negative parity singly heavy baryons, Phys. Rev. D **110**, 114046 (2024).

Self-consistent M1 radiative transitions of excited Bc and heavy quarkonia with different polarizations in the light-front quark model, M. Ridwan, A. J. Arifi, and T. Mart, Phys. Rev. D **111**, 016011 (2025).

A. J. Arifi, P. T. P. Parada, and K. Tsushima, In-medium electromagnetic form factors of pseudoscalar mesons from the quark model, Phys. Rev. **111**, 074004 (2025).

A. J. Arifi, L. Happ, S. Ohno, and M. Oka, "Structure of heavy mesons in the light-front quark model," Phys. Rev. D **110**, 014020 (2024).

T. Schnurrenberger, L. Happ, and M. Efremov, Borromean states in a one-dimensional three-body system, Phys. Rev. Res. **7**, 013090 (2025).

R. Kim, M. Oka, and K. Suzuki, "Chiral effective theory of scalar and vector diquarks revisited," Phys. Rev. D **111**, 034014 (2025).

Q. Meng, G. -J. Wang, and M. Oka, "Mass spectra of full-heavy and double-heavy tetraquark states in the conventional quark model," Phys. Rev. D **111**, 014018 (2025).

G. -J. Wang, Z. Yang, J. -J. Wu, M. Oka, and S. -L. Zhu, "New insight into the exotic states strongly coupled with $D\overline{D}^*$ from T_{cc}^+," Sci. Bull. **69**, 3036 (2024).

[Proceedings]

Y. Lyu, T. Doi, T. Hatsuda, and T. Sugiura, "NJ/ψ and $N\eta c$ interactions from lattice QCD," PoS LATTICE2024, 103 (2025), arXiv:2502.00054 [hep-lat].

S. Aoki, T. Doi, and Y. Lyu, "Left-hand cut and the HAL QCD method," PoS LATTICE2024, 089 (2025), arXiv:2501.16804 [hep-lat].

L. Wang, T. Doi, T. Hatsuda, and Y. Lyu, "Building hadron potentials from lattice QCD with deep neural networks," PoS LATTICE2024, 076 (2025), arXiv:2410.03082 [hep-lat].

Y. Aoki, E. Bennett, R. Bignell, K. U. Can, T. Doi, S. Gottlieb, R. Gupta, G. von Hippel, I. Kanamori, A. Kotov, G. Koutsou, A. Patella, G. Pederiva, C. Schmidt, T. Yamazaki, and Y. -B. Yang, "Lattice gauge ensembles and data management," PoS LATTICE2024, 412 (2025), arXiv:2502.08303 [hep-lat].

Presentations

[International Conferences/Workshops]

E. Hiyama (invited), "Structure of light hypernuclei," ECT* Workshop SPICE: Strange hadrons as a Precision tool for strongly InteraCting systEms, Trento, Italy, May 13–17, 2024.

E. Hiyama (invited), "Structure of light neutron- rich nuclei," HaloWeek'24, Gothenburg, Sweden, June 10–14, 2024.

E. Hiyama (invited), "Structure of Ξ hypernuclei," 5th Jagiellonian Symposium on Advances in Particle Physics and Medicine (JS:2024), Kraków, Poland, June 29–July 7, 2024.

E. Hiyama (invited), "Structure of light hypernuclei from view point of few-body problem," QNP2024—The 10th International Conference on Quarks and Nuclear Physics, Barcelona, Spain, July 8–12, 2024.

E. Hiyama (invited), "Hypernuclear physics from view point of few-body problem," International School of Nuclear Physics 45th Course, Erice-Sicily, Italy, September 16–22, 2024.

E. Hiyama (invited), "Structure of multi-neutron systems," The 23rd International Conference on Few-Body Problems in Physics (FB23), Beijing, China, September 22–27, 2024.

E. Hiyama (invited), "Structure of light hypernuclei from view point of few-body problem," STAR eTOF and BES-II Workshop near-final agenda, Remote, December 3–6, 2024.

T. Doi for HAL QCD Collaboration, "Lattice QCD studies of Hadron interactions from the HAL QCD method," Invited Talk given at YITP long-term workshop on "Hadrons and Hadron In-teractions in QCD (HHIQCD2024)," Yukawa Institute of Theoretical Physics (YITP), Kyoto, Japan, October 14–November 15, 2024.

T. Doi for HAL QCD Collaboration, "N-ϕ interaction from Lattice QCD," Invited Talk given at "E16 workshop," Academia Sinica, Taiwan, September 9–10, 2024.

T. Doi, Y. Lyu, K. Murakami, and L. Zhang, for HAL QCD Collaboration, "Lattice QCD study of Ξ cc −Ξ cc interactions on the physical point," Talk given at "The 41st International Symposium on Lattice Field Theory (Lattice 2024)," Liverpool, UK, July 28–August 3, 2024.

T. Doi, for HAL QCD Collaboration, "Recent Lattice QCD results of hadron interactions from the HAL QCD method," Invited Talk given at the Reimei Workshop on "Hadron interactions with strangeness and charm," Jeju Island, Korea, June 26–28, 2024.

P. Naidon, "Renormalised quantum defect theory of Feshbach resonances," Ultracold Atoms Japan 2024, Okinawa, Japan, April 9–12, 2024.

P. Naidon (invited), "Borromean three-body Halo universality," Universality of Strongly Correlated Few-body and Many-body Quantum Systems, Tokyo Electron House of Creativity, Tohoku University, Sendai, Japan, August 27, 2024.

P. Naidon (invited), "Closed-channel parameters of Feshbach resonances," Conference "Universality of Quantum Systems: from Cold Atoms, Nuclei, to Hadron Physics," Tohoku University, Sendai, Japan, September 4–5, 2024.

P. Naidon (invited), "Universal trimers of fermions," Universality of Strongly Correlated Few-body and Many-body Quantum Systems, Tokyo Electron House of Creativity, Tohoku University, Sendai, Japan, September 26, 2024.

P. Naidon (invited), "Cold atomic systems as a laboratory for nuclear physics," Lecture at the GPPU School in Tohoku University, Sendai, Japan, September 24, 2024.

P. Naidon (invited), "A review of Efimov physis," Mathematical Challenges in Quantum Mechanics, L'Aquila, Italy, February 10–14, 2025.

P. Naidon, "Quantum measurements of time," Seminar at Laboratoire Charles Fabry, Palaiseau, France, February 17, 2025.

P. Naidon (invited), "Closed-channel parameters of Feshbach resonances," Seminar at Collège de France, Paris, France, February 27, 2025.

M. Nio (invited), "Update on QED contributions," Seventh Plenary Workshop of the Muon g-2 Theory Initiative, KEK, Tsukuba, September 9–13, 2024.

M. Nio (invited), "Memory of Toichiro Kinoshita," Seventh Plenary Workshop of the Muon g-2 Theory Initiative, KEK, Tsukuba, September 9–13, 2024.

N. Yamanaka, "Resolutions of the strong CP problem and the U(1) problem," 4th Franco-Japanese workshop on Few-body: from Atoms to Quarks, Caen, France, March 3–7, 2025.

N. Yamanaka, "Ab initio calculation of nuclear electric dipole moment and three-nucleon force," Workshop on Tomoe Project, Sendai, Japan, January 6–10, 2025.

N. Yamanaka (invited), "Irrelevance of anomalous breaking of axial U(1) symmetry and the U(1) problem," International Workshop on Quark Structure of Hadrons 2024, Wako, Japan, August 9–10, 2024.

N. Yamanaka, "Irrelevance of anomalous breaking of axial U(1) symmetry and the U(1) problem," International Workshop on J-PARC Hadron Physics 2024 (J-PARC Hadron 2024), Tokai, Japan, July 23–25, 2024.

N. Yamanaka (invited), "CP violation and electric dipole moment," Invited Lecture at IBS-CTPU, Daejeon, Korea, May 21–23, 2024.

A. J. Arifi (oral), "Heavy quarkonia in light-front quark model," The 21st International Conference on Hadron Spectroscopy and Structure, Osaka University, Japan, March 27–31, 2025.

A. J. Arifi (oral), "Two-pion emission decays of singly heavy baryons," East Asian Workshop on Exotic Hadrons 2024, Nanjing, China, December 8–11, 2024.

A. J. Arifi (invited), "Recent developments in hadron structure using the light-front quark model," International Conference for Particles and Radiation (ICPR 2024), UST, Manila, Philippines, October 17–19, 2024.

A. J. Arifi (oral), "Self-consistent light-front quark model analyis of meson structure," The 23rd International Conference on Few-Body Problems in Physics (FB23), Beijing, China, September 22–27, 2024.

L. Happ, "Dependence of three-body resonance lifetimes on the mass ratio and dimensionality," Ultracold Atoms Japan 2024, Onna Japan, April 09–12, 2024.

L. Happ, "Mass ratio dependence of three-body resonance lifetimes in 1D and 3D," APS DAMOP Meeting 2024, Fort Worth USA, June 03–07, 2024.

L. Happ, "Lifetimes of three-body resonances," UQS-Tohoku-2024, Sendai Japan, August 26–September 27, 2024.

L. Happ, "Lifetimes of three-body resonances: dimensionality and mass ratio," UQS-Tohoku-2024 Conference, Sendai Japan, September 04–05, 2024.

L. Happ, "Lifetimes of three-body resonances: dimensionality and mass ratio," International School of Nuclear Physics, Erice Italy, September 16–22, 2024.

L. Happ, "Lifetimes of three-body resonances: dimensionality and mass ratio," International Conference on Few-body Problems in Physics FB23, Beijing China 2024, September 22–27, 2024.

L. Happ, "Stabilization of three-body resonances to bound states in a continuum," 4th Franco-Japanese workshop on Few-body Problems in Physics from Atoms to Quarks, Caen France, March 03–07, 2025.

M. Oka (invited), "Quark structure of hadrons," International Workshop on Quark Structure of Hadrons, RIKEN, Japan, August 9, 2024.

M. Oka (invited), "Quark confinement for exotic hadrons in the quark model," The 16th Quark Confinement and the Hadron Spectrum, Cairns, Australia, August 19, 2024.

M. Oka (invited), "Heavy hadron spectroscopy and quark confinement in the quark model," Compact stars in the QCD Phase Diagram, Kyoto, Japan, October 10, 2024.

M. Oka, "Quark, diquark and baryon in chiral symmetry," The 21st International Conference on Hadron Spectroscopy and Structure, Osaka, Japan, March 28, 2025.

A. Tomiya (poster) and S. Ohno, "Benchmarking neural network wave functions in positronium," The 13th International Workshop on Positron and Positronium Chemistry (PPC13), Kanazawa, Japan, October 29–November 1, 2024.

[Domestic Conferences/Workshops]

T. Doi, Y. Lyu, and L. Zhang for HAL QCD Collaboration, "Charmed hadron interactions from physical point lattice QCD simulations," Talk Given at JPS Meeting, Hokkaido University, Sapporo, Japan, September 16–19, 2024.

T. Doi, "From quarks to nuclear physics using lattice QCD," Invited Talk given at "QNSI kickoff workshop," Quark Nuclear Science Institute (QNSI), the University of Tokyo, Tokyo, Japan, August 29, 2024.

山中長閑, 「Irrelevance of anomalous breaking of axial U(1) symmetry and the U(1) problem」, 日本物理学会 2025 春期大会, オンライン, 2025 年 3 月 18–21 日.

A. J. Arifi (口頭発表), "M1 radiative decays in the light-front quark model," Research Center for Accelerator and Radioisotope Science (RARIS) Workshop. Tohoku University, Japan, November 20–21, 2024.

A. J. Arifi (口頭発表), "Light-front quark model analysis of hadron structure," Workshop on Universality of Strongly Correlated Few-body and Many-body Quantum Systems, Tohoku University, Japan, September 3–6, 2024.

A. J. Arifi (口頭発表), "Structure and properties of mesons in the light-front quark model," International Workshop on J-PARC Hadron Physics 2024, Tokai-mura, Japan, July 23–25, 2024.

岡真（招待講演), 「クォークの閉じ込めと高密度物質」, 京都ミーティング, 東海（KEK), 2024 年 12 月 14 日.

富谷昭夫 (口頭発表), 大野周平, 「ニューラルネットワーク波動関数による変分法の実装と二体問題への応用」, 第 16 回陽電子科学研究交流会, 金沢市 (金沢市文化ホール), 2024 年 11 月 2 日.

大野周平 (口頭発表), 「Julia ではじめる変分法」, Julia in Physics 2024, 文京区 (東京大学), 2024 年 12 月 14 日.

大野周平 (ポスター発表), 「Google Colab で Julia をはじめよう！」, 計算物理春の学校 2025, 那覇市 (沖縄県市町村自治会館), 2025 年 3 月 10–15 日.

[Seminars]

N. Yamanaka, "Resolutions of the strong CP problem and the U(1) problem," Seminar at Laboratoire Irene Joliot-Curie, Orsay, France, February 28, 2025.

N. Yamanaka, "Resolutions of the strong CP problem and the U(1) problem," Seminar at Osaka University RCNP, Osaka, Japan, December 6, 2024.

A. J. Arifi (invited), "Application of gaussian-expansion method in the light-front quark model," North Carolina State University Physics Seminar, United States, April 26, 2024.

Award

T. Aoyama, M. Hayakawa, and M. Nio, 24th Particle Physics Medal, Japan Particle and Nuclear Theory Forum, for "High-precision theoretical calculation of the lepton anomalous magnetic moments," September 18, 2024.

Outreach Activities

A. J. Arifi (Organizer), International workshop on quark structure of hadrons, Wako, Japan, August 9–10, 2024.

S. Ohno (Open-Source Software), "TwoBody.jl: A Julia package for quantum mechanical two-body problems," `https://github.com/ohno/TwoBody.jl`, (2024).