

Subnuclear System 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) Structure of Hypernuclei and neutron-rich nuclei from the view point of few-body problem
- (2) Structure of exotic hadron system
- (3) Quantum atomic systems and ultra-cold atomic systems
- (4) Equation of state for neutron star

3. Summary of Research Activity

Motivated by observation of Ξ hypernuclei, IBUKI, KINKA and IRRAWADDY events, to study Ξ N interaction, we study $^{14}\text{N}+\Xi$ hypernucleus within the framework of relativistic mean field theory. We found that the s -wave interaction deduced from the HAL QCD results is rather weak to obtain the energy difference between IRRAWADDY and KINKA events. The p -wave interaction is added and fitted to reproduce the energy difference. The resulting interaction together with the s -wave one gives a reasonable energy simultaneously for the IBUKI event as an excited Ξ p state.

- (1) We investigate the role of interaction in the p -wave channel in a mixture of two kinds of fermions. We find that three-body bound states of 2+1 fermions which were known to exist only when the two kinds of fermions have very different masses, can in fact exist for any mass of the fermions when their interaction is taken into account in the p -wave channel.
- (2) We predict a possible bound state of exotic titanium isotopes using the nuclear shell model based on the modern nuclear force. In addition, we study nucleon- Ξ interaction in nucleon- Ξ scattering and deuteron- Ξ scattering. For the former, we find that nucleon- Ξ interaction induces small coupling to deuteron continuum states, while, for the latter, the system shows small contribution of the coupling between nucleon- Ξ and Λ - Λ channels.

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List of Publications & Presentations

Publications

[Original Papers]

- Y. Tanimura, H. Sagawa, T. Sun, and E. Hiyama, “ Ξ hypernuclei (^{15}C and ^{12}Be , and the ΞN two-body interaction,” *Phys. Rev. C* **105**, 044324 (2022).
- Y. Zhang, H. Sagawa, and E. Hiyama, “Prediction of exotic hyperon halos in neutron-rich Zr hypernuclei,” *Prog. Theor. Exp. Phys.* **2022**, 023D01 (2022).
- Q. Meng, M. Harada, E. Hiyama, A. Hosaka, and M. Oka, “Doubly heavy tetraquark resonant states,” *Phys. Lett. B* **824**, 136800 (2022).
- M. Honda, E. Itou, Y. Kikuchi, and Y. Tanizaki, “Negative string tension of higher-charge Schwinger model via digital quantum simulation,” *PTEP* **2022**, 033B01 (2022).
- M. Honda, E. Itou, Y. Kikuchi, L. Nagano, and T. Okuda, “Classically emulated digital quantum simulation for screening and confinement in the Schwinger model with a topological term,” *Phys. Rev. D* **105**, 014504 (2022).
- T. Fukui, “Towards modeling cluster structure of ^8Be with chiral interaction,” *J. Phys. G* **49**, 055102 (2022).
- Y. Kamiya, K. Sasaki, T. Fukui, T. Hyodo, K. Morita, K. Ogata, A. Ohnishi, and T. Hatsuda, “Femtoscopic study of coupled-channel $N\Xi$ and $\Lambda\Lambda$ interactions,” *Phys. Rev. C* **105**, 014915 (2022).
- L. Coraggio, G. D. Gregorio, A. Gargano, N. Itaco, T. Fukui, Y. Z. Ma, and F. R. Xu, “Shell-model study of titanium isotopic chain with chiral two- and three-body forces,” *Phys. Rev. C* **104**, 054304 (2021).
- J. Singh, T. Matsumoto, T. Fukui, and K. Ogata, “Three-body description of ^9C : Role of low-lying resonances in breakup reactions,” *Phys. Rev. C* **104**, 034612 (2021).
- K. Ogata, T. Fukui, Y. Kamiya, and A. Ohnishi, “Effect of deuteron breakup on the deuteron- Ξ correlation function,” *Phys. Rev. C* **103**, 065205 (2021).
- M. Tokieda and S. Endo, “Equivalence of dissipative and dissipationless dynamics of interacting quantum systems with its application to the unitary Fermi gas,” *Front. Phys.* **9**, 730761 (2021).

[Proceedings]

- E. Itou and Y. Nagai, “QCD viscosity by combining the gradient flow and sparse modeling methods,” *Proc. Sci. LATTICE2021*, 214 (2021).
- K. Ishiguro, K. Iida, and E. Itou, “Flux tube profiles in two-color QCD at low temperature and high density,” *Proc. Sci. LATTICE2021*, 063 (2021).
- T. Fukui, L. Coraggio, G. D. Gregorio, A. Gargano, N. Itaco, Y. Z. Ma, and F. R. Xu, “Realistic shell model with chiral interaction and its application to drip-line predictions,” *Few-Body Syst.* **62**, 64 (2021).
- A. Ohnishi, Y. Kamiya, K. Sasaki, T. Fukui, T. Hatsuda, T. Hyodo, K. Morita, and K. Ogata, “Femtoscopic study of $N\Xi$ interaction and search for the H dibaryon state around the $N\Xi$ threshold,” *Few-Body Syst.* **62**, 42 (2021).

Presentations**[International Conferences/Workshops]**

- E. Hiyama (invited), “Recent progress of hypernuclear physics,” International Conference on Light Cone 2021—Physics of Hadron on the Light Front, Online, November 29–December 4, 2021.
- E. Hiyama (invited), “Few-body aspect of hypernuclear physics,” JPS Symposium on Intersection of Nuclear Physics in Japan and the United States, Online, September 17, 2021.
- E. Hiyama (invited), “Four-body structure of tetra-neutron system,” Workshop on Neutron Unbound Systems Around the dripline, Online, July 13–14, 2021.
- P. Naidon (invited), “Efimov physics and universality in few-body systems,” Lecture at the School on Critical Stability of Few-body Quantum Systems, São Paulo, ICTP-SAIFR Brazil, Online, October 4–8, 2021.
- E. Itou (oral), “Sparse modeling approach to obtaining the shear viscosity from smeared correlation functions,” The 38th International Symposium on Lattice Field Theory (LATTICE 2021), Online, July 26–30, 2021.
- E. Itou (invited), “Sparse modeling approach to obtaining the QCD shear viscosity from smeared correlation functions,” ECT* online workshop “Tackling The Real-Time Challenge In Strongly Correlated Systems: Spectral Properties From Euclidean Path Integrals,” Online, September 13–17, 2021.
- E. Itou (invited), “Digital quantum simulation for screening and confinement in gauge theory with a topological term,” RIKEN-Vancouver Joint Workshop on Quantum Computing, August 24–25, 2021.
- T. Fukui (oral), “Cluster-model calculations with chiral interaction,” Newcomers Seminar I, RIBF Nuclear Physics Seminar, Online, June 8, 2021.

[Domestic Conferences/Workshops]

- 肥山詠美子 (招待講演), 「ハイパー核の構造とハイペロン核子間相互作用」, ELPH 研究会 C031 「多彩なビーム実験と多様な理論的手法で迫るハドロン間相互作用」, オンライン, 2021 年 11 月 4–5 日.
- 伊藤悦子 (招待講演), 「量子計算の場の理論への応用」, 金沢大学研究会 「2022 計算物理学の発展」, オンライン, 2022 年 3 月 9 日.
- 伊藤悦子 (口頭発表), 「物理点におけるハドロン間力の計算に向けて—格子 QCD の配位生成」, 「富岳で加速する素粒子・原子核・宇宙・惑星」 シンポジウム, オンライン, 2022 年 1 月 17–18 日.
- 伊藤悦子 (口頭発表), 「2 カラー QCD の低温高密度相における状態方程式」, 日本物理学会 2021 年秋季大会, オンライン, 2021 年 9 月 14–17 日.
- 伊藤悦子 (口頭発表), 「量子計算でみる負のストリングテンションの出現」, 日本物理学会 2021 年秋季大会, オンライン, 2021 年 9 月 14–17 日.
- 福井徳朗 (口頭発表), L. Coraggio, G. D. Gregorio, A. Gargano, N. Itaco, Y. Z. Ma, F. R. Xu, 「現実的殻模型で探る Ca および Ti のドリップライン」, 日本物理学会第 77 回年次大会, オンライン, 2022 年 3 月 15–17 日.
- 福井徳朗 (招待講演), 「『日本物理学会若手奨励賞受賞記念講演』 3 体力の適正な取扱いに基づく第一原理殻模型計算の発展」, 日本物理学会第 77 回年次大会, オンライン, 2022 年 3 月 15–17 日.
- 福井徳朗 (口頭発表), 「カイラル相互作用に基づく現実的殻模型の進展」, 基研研究会 「核力に基づいた原子核の構造と反応」, 京都市, 2021 年 12 月 7–10 日.
- 福井徳朗 (招待講演), “Frontiers of many-body calculations with chiral interaction,” ELPH 研究会 C031 「多彩なビーム実験と多様な理論的手法で迫るハドロン間相互作用」, オンライン, 2021 年 11 月 4–5 日.
- 福井徳朗 (口頭発表), “Perspectives of many-body calculations with realistic nuclear force,” RCNP での次期計画検討会, オンライン, 2021 年 9 月 27–29 日.
- 猪谷太輔 (招待講演), 「量子計算を用いた (1+1) 次元 Schwinger 模型における実時間ダイナミクスの解析」, 国内モレキュール型研究会 「場の理論の量子計算 2022」, 京都市, 2022 年 2 月 24–25 日.

[Seminars]

- P. Naidon, “Physics of ultra-cold atoms,” Lecture at Tohoku University GPPU seminars, December 8, 2021.
- P. Naidon, “Prediction of a “mixed bubble,” quantum phase”, RIBF Nuclear Physics Seminar, Online, September 7, 2021.
- E. Itou, “Digital quantum simulation for screening and confinement in gauge theory with a topological term,” RCNP Nuclear Physics Theory Seminar, July 16, 2021.
- T. Fukui, 「現実的殻模型の進展—カイラル 3 体力と諸現象—」, Seminar at CNS, University of Tokyo, Online, Japan, February 4, 2022.

Awards

- E. Itou, “Editors’ Choice” of Progress of Theoretical and Experimental Physics **2022**, Issue 3, March 2022.
- 福井徳朗, 第 16 回 (2022 年) 日本物理学会若手奨励賞 理論核物理領域 (第 23 回核理論新人論文賞).

Press Release

- E. Itou, “Negative string tension of a higher-charge Schwinger model via digital quantum simulation,” RIKEN Interdisciplinary Theoretical and Mathematical Sciences Program, March 9, 2022. <https://ithems.riken.jp/ja/news/negative-string-tension-of-a-higher-charge-schwinger-model-via-digital-quantum-simulation>.