ΛN and ΣN interactions from $2+1$ lattice QCD with almost physical masses †

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Description of the nuclear force from a fundamental perspective is a challenging problem in physics. Characterization of an atomic nucleus as a nucleonic many body system provides successful results although a nucleon is not a true rudimentary constituent of atomic nucleus but a composition of quarks and gluons defined in quantum chromodynamics (QCD). Especially, precise determination of the nucleon-nucleon (NN), hyperon-nucleon (YN), and hyperon-hyperon (YY) interactions has a large impact on the studies of both hypernuclei and hyperonic matter inside neutron stars since phenomenological descriptions of YN and YY interactions are not well constrained from experimental data because of the short life time of hyperons.

In the recent few years, 2+1 flavor lattice QCD calculations have been widely performed. This is an opportune moment to investigate beyond the baryon-baryon (BB) potentials at the flavor $SU(3)$ point since exploring breakdown of the flavor symmetry is not only an intriguing subject but also a major concern of the phenomenological YN and YY interaction models. Therefore, it is beneficial to take account of a large number of BB channels. We have proposed an approach for the efficient calculation of a large number of four-point correlation functions for various BB channels, and implemented a hybrid parallel C++ program at the very beginning (the first quarter of 2013) for calculating such a large number (e.g., 52 channels) for the BB interactions from NN to $\Xi\Xi$.[1)]

Based on those works, an extremely large scale lattice QCD calculation is now being performed to unveil the nature of nuclear forces with strangeness $S = 0$ (NN) to -4 ($\Xi\Xi$) and almost physical quark masses corresponding to $(m_\pi, m_K) \approx (146, 525)$ MeV and large volume $(La)^4 = (96a)^4 \approx (8.1\ \mathrm{fm})^4$ with lattice spacing $a \approx 0.085$ fm.

Figure 1 shows preliminary result of $\Lambda N \to \Sigma N$ tensor potential in the ${}^3S_1 - {}^3D_1$ channel (top), ΣN central potential in the $I = 1/2$, ${}^1S_0$ channel (middle), and ΣN central potential in the $I = 3/2$, ${}^3S_1 - {}^3D_1$ channel (bottom). In the figure, the potentials are obtained at imaginary time ($t - t_0 = 5 - 12$) in the lattice QCD, which might be slightly smaller than the region where the excited state contamination above pion production is suppressed because the statistics is not large enough at this moment. See Ref. 2 for detail. Calculation is underway to improve both the signal/noise ratio and the systematic uncertainty. Nevertheless, the present results show remarkable behaviors. For example, the top figure shows a sizable strength of $\Lambda N \to \Sigma N$ tensor interaction, which is expected to play an important role to have a light hypernucleus bounded. The lower two figures show that these two ΣN interaction channels are repulsive, which is consistent with the quark model's prediction. Hence, lattice QCD would be a promising approach to clarify the origin of repulsive nature of the ΣN interaction.

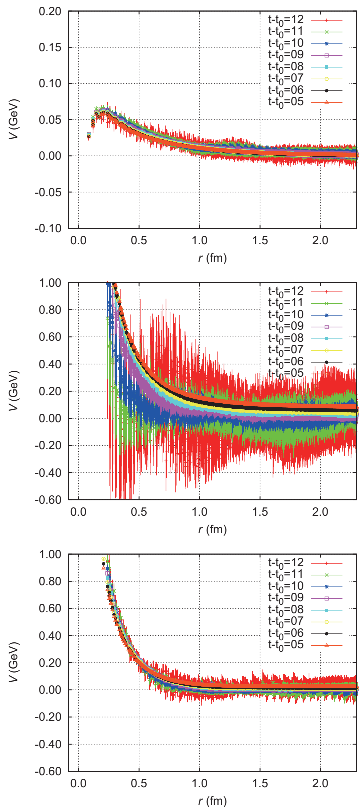

Fig. 1. Top: $\Lambda N - \Sigma N$ tensor potential in the ${}^3S_1 - {}^3D_1$ channel obtained with nearly physical point lattice QCD calculation on a volume $(96a)^4 \approx (8.1\ \mathrm{fm})^4$ with lattice spacing $a \approx 0.085$ fm and $(m_\pi, m_K) \approx (146, 525)$ MeV. Middle: ΣN central potential in the $I = 1/2$, ${}^1S_0$ channel. Bottom: ΣN central potential in the $I = 3/2$, ${}^3S_1 -{}^3D_1$ channel.

References

1) H. Nemura, Comput. Phys. Commun. **207**, 91 (2016) [arXiv:1510.00903 [hep-lat]].
2) H. Nemura *et al.*, arXiv:1702.00734 [hep-lat].

† Condensed from Ref. 1

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