Consideration of nuclear force from viewpoint of renormalization group

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The nuclear force is one of the oldest problem in nuclear physics. A traditional approach to the nuclear force is to construct a phenomenological nuclear force (V_{ph}) with the following feature: The long-range mechanism is described by the one-pion-exchange potential (OPEP) while the short-range mechanism is given by a phenomenological model. So far, several high-precision NN-potentials have been constructed in this way. They are largely different from each other due to modeling the short-distance physics.

Meanwhile, it has been argued that one can derive a NN-potential (V_{EFT}) in a model-independent manner by working with effective field theory (EFT)[1]. In EFT, one starts with an effective Lagrangian which is the most general as far as a set of assumed symmetries is satisfied. From that Lagrangian, one derives V_{EFT} perturbatively. However, there remained some naive questions. In EFT, one describes the short-distance physics in terms of contact interactions which is much simpler compared to a model used in V_{ph}. Is the contact interaction really a good parameterization for the short-distance mechanism ? The other question was about the model-independence of EFT. Is V_{EFT} still one of many phase-shift equivalent potentials ? We would like to answer the questions to obtain a deeper understanding of EFT.

A key to answer the questions is the size of the model-space on which V_{ph} or V_{EFT} acts. The model-space means the nucleon state space where there is an upper cutoff (Λ) on the magnitude of the nucleon momentum. Typically, the model-space of V_{ph} is considerably larger than that of V_{EFT}. The use of a smaller model-space means a rougher view of a system, or equivalently an ignorance of *detail* of short-distance mechanism. Therefore, we can write the following scenario of a relation between V_{ph} and V_{EFT}. We start with a V_{ph} and reduce its model-space. As the model-space is reduced, information of *detail* of short-distance physics is gradually lost; it is expected that the simple contact interaction becomes to be a good parameterization of the short-distance part. Eventually, we obtain a low-momentum potential defined in the reduced model-space (V_M); V_M is free from the model-dependence found in the original V_{ph}. The identity of V_{EFT} is nothing more than a parameterization of V_M. This is a scenario of relating V_{EFT} with V_{ph}. If we show that this scenario is indeed realized, then we simultaneously answer the questions given in the previous paragraph.

What we have shown are [2]: (1) The model-space is appropriately reduced by the Wilsonian renormalization group (WRG) equation; (2) The above scenario is quantitatively well realized. This is shown in Figs. 1 and 2 where diagonal components of NN-potential in the momentum space are given. In Fig. 1, we show three V_{ph}'s for $\langle ^1S_0|V|^1S_0\rangle$ and the corresponding V_M's (Λ=200MeV). The model-dependence found in V_{ph}'s is not seen in V_M. In Fig. 2, V_M for $\langle ^3D_1|V|^3S_1\rangle$ is well simulated in terms of the OPEP plus a few contact interactions.

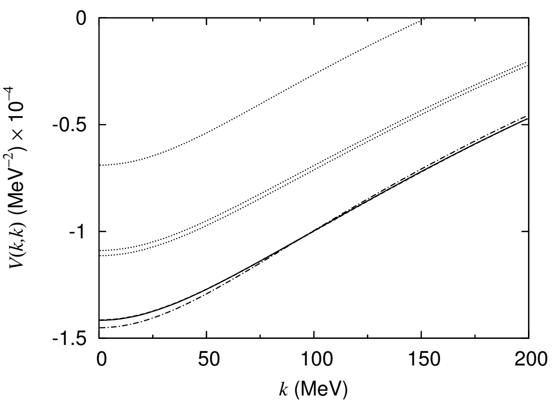

Figure 1: $\langle ^1S_0|V|^1S_0\rangle$ for the proton-neutron scattering. The upper three curves are bare V_{ph}'s. The lower three curves are V_M's obtained from the upper curves following the WRG equation.

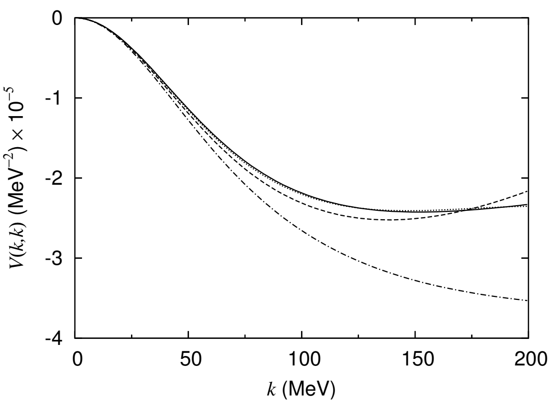

Figure 2: $\langle ^3D_1|V|^3S_1\rangle$ for the proton-neutron scattering. The solid curve is V_M and the dashed (dotted) curve is a simulation of V_M in terms of the OPEP plus one (two) contact interaction(s). The dash-dotted curve is the bare OPEP.

References

[1] S. Weinberg, Phys. Lett. **B251**, 288 (1990).
[2] S. X. Nakamura, nucl-th/0411108.