Implementation of chiral two-nucleon forces to nuclear many-body methods with Gaussian-wave packets†

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Clustering is a key feature of nuclear systems, and several efforts have aimed to understand the cluster structure in light of nuclear forces. To this end, many-body methods employing Gaussian-wave packets have been widely used to describe the spatial distribution of nucleons. However, the chiral effective field theory,[3–5] a state-of-the-art theory of nuclear forces, has yet to be applied to the many-body methods such as fermionic molecular dynamics[1] and antisymmetrized molecular dynamics.[2]

To combine such many-body methods with chiral forces we derived the two-body matrix elements (MEs) of the chiral two-nucleon force at next-to-next-to-next-to-leading order using the local Gaussian basis functions in this work.

Additionally, we visualize the two-body MEs of the chiral forces at leading order (LO) and next-to-leading order (NLO) in Figs. 1(a) and (b), respectively. To obtain these two-body MEs, a spin-up neutron is located at the origin and another spin-up proton moves on the x-z plane, where the spin direction is set to the z-axis. Our adopted parameters associated with the regulator cutoff $\Lambda = 500$ MeV are given in Ref. 7).

In Fig. 1(a), the two-body MEs of the LO potential designed to describe nucleon-nucleon scattering at very low momenta show maximal attraction for the spin-aligned neutron-proton pair at $(x, z) = (0, 0)$. This is consistent with low-momentum nucleon-nucleon scattering, where the neutron-proton interaction of the triplet-s state is attractive.[6]

In contrast to the LO ME, the NLO MEs displayed in Fig. 1(b) are repulsive at the origin. This repulsion originates from the high-momentum nucleon-nucleon scattering induced by the NLO potential, which depends on the square of the momentum. Moreover, the repulsive MEs at NLO mirrors the neutron-proton interaction switching from attraction to repulsion at ∼400 MeV/c relative momentum, as seen in the scattering phase shift of the triplet-s state.[6]

Figure 1 shows the asymmetry of the MEs with respect to the $z = x$ line. This asymmetry stems from the tensor forces, specifically, the one-pion-exchange term at LO, as well as the two-pion-exchange and contact terms at NLO. The role played by the tensor forces are discussed in detail in the original paper.

In conclusion, this study serves as a foundation for an *ab initio* exploration of diverse cluster phenomena based on the modern nuclear force.

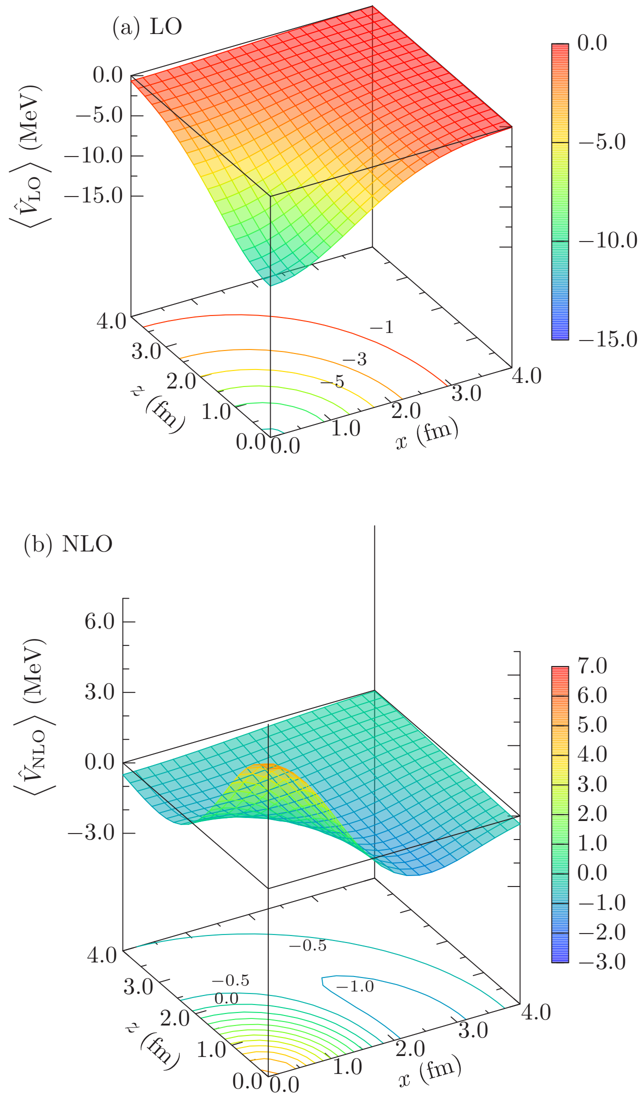

Fig. 1. The two-body MEs of the chiral two-nucleon force at (a) LO and (b) NLO computed with the local Gaussian basis functions.

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