Local representation of a realistic NN potential as derived in Δ-full chiral effective field theory

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Many areas of current frontier research in particle physics require accurate input from nuclear physics. The theoretical uncertainties that are introduced fall into two categories, one due to the unknown nuclear interaction and another one due to the difficulties in the treatment of many-body strongly interacting systems. The increasing popularity of so-called "chiral" nuclear interaction potentials, based on an effective field theory constrained by the (approximate) chiral symmetry of quantum chromodynamics, is also due to the possibility of quantifying the theoretical uncertainty, owing to the emergence of a well defined perturbative framework, valid in the low-energy domain. One of the short-comings of this approach is the fact that the ensuing interactions are non-local in coordinate space, which makes them little suited for exact numerical techniques, such as Quantum Monte Carlo (QMC) methods. Non-localities arise from the choice of the momentum-space regulator needed to obtain coordinate-space expressions, and from the contact interactions, which represent the low-momentum parametrization of unknown short-distance physics. The latter non-localities are unavoidable, if one proceeds at high orders of the low-energy expansion, as we showed in Ref. [1].

In Ref. [2] we provide a local version of the previously developed potential, derived up to the 4th order (N3LO) in the chiral effective theory including the Δ resonance, by performing constrained fits to nucleon-nucleon scattering observables up to 200 MeV laboratory energy and to the deuteron binding energy. We used a set of almost 3700 experimental points as provided by the Granada database [3].

The good quality of the fits (cfr. Fig. 2 can be taken as an indication that current data do not constrain the non-local structures that emerge at N3LO. The bands in the figures represent the variation with the short-distance cutoff. This is

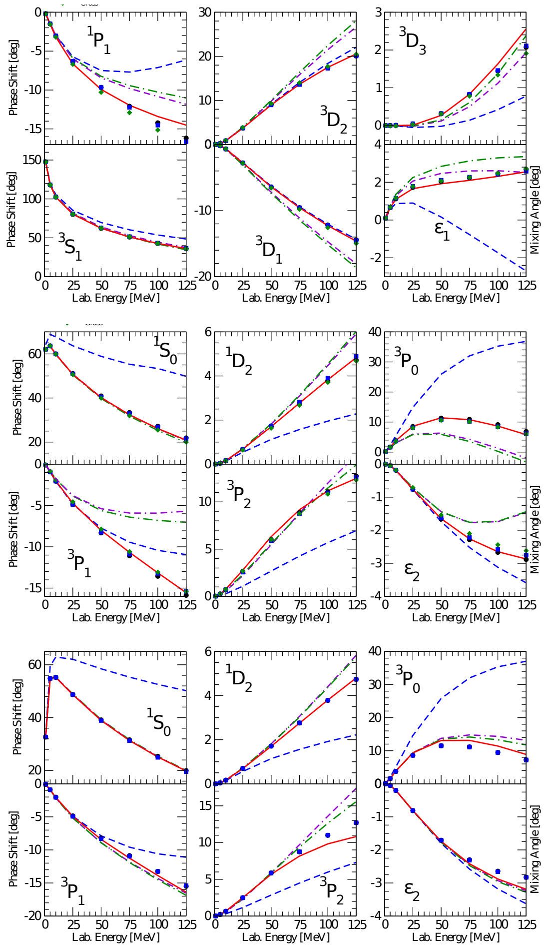

Figure 1. Chiral expansion of the neutron-proton (top two panels) and proton-proton (bottom panel) S-, P- and D-wave phaseshifts up to 125 MeV laboratory energy. The dots are the results of three different partial-wave analyses, from Nijmegen, Gross and Stadler, and Granada. Dashed (blue), dash-dotted (green), double-dash-dotted (magenta), and solid (red) lines correspond to LO, NLO, N2LO and N3LO respectively.

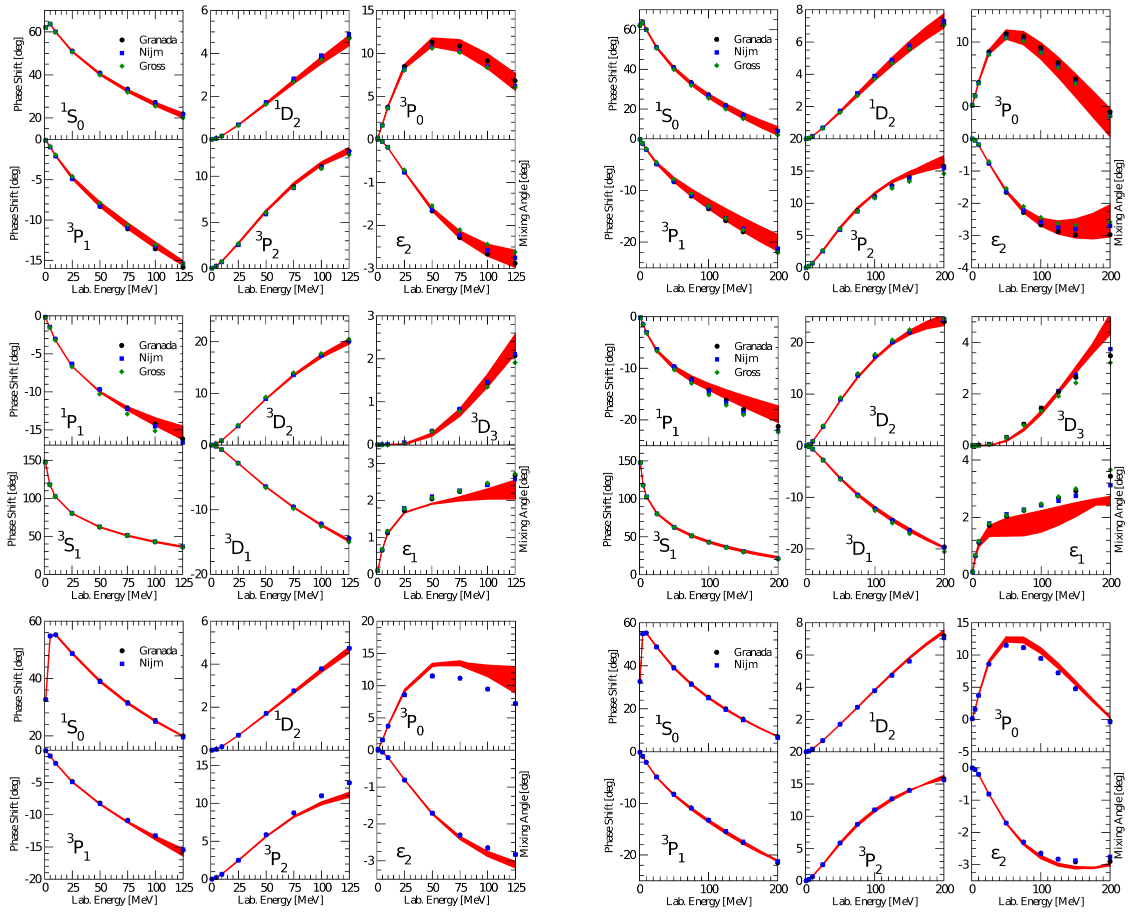

Figure 2. S-, P- and D-wave phaseshifts for neutron-proton in isospin 0 and 1 channels (top two panels) and proton-proton (bottom panel). as predicted in our models (bands) and in the Nijmegen, Gross and Stadler, and Granada partial wave analyses.

a defining parameter of the effective field theory, representing the scale at which new physics (not explicitly considered in the effective field theory) comes into play. It may be considered as a tool to estimate the truncation error of the low-momentum expansion, and thus the theoretical uncertainty of the calculation: an all-order calculation would be unaffected by such variation. The resulting χ^2 is of the same quality as modern "realistic" nuclear potential, such as the widely used phenomenological AV18 [4]. In Fig. 1 we show the order-by-order convergence of the NN phaseshifts, for one given choice of the cutoff. It is seen that, while there is a definite improvement passing from leading order (LO, dashed-blue) to NLO (dashed-dotted, green), the N2LO results (double-dashed-dotted, magenta) are slightly worse than at NLO, while only at N3LO (solid, red) a satisfactory description is reached. We notice that no new fitting parameter enters in passing from NLO to N2LO, since the additional terms are fixed by low-energy pion-nucleon scattering. This makes the convergence pattern not entirely satisfactory and may call for a combined consideration of the NN and πN systems, In Ref. [2] we also used the so-derived NN interaction to calculate the ground and excited states of ^{3}H, ^{3}He, ^{4}He, ^{6}He and ^{6}Li nuclei, with the hyperspherical harmonics and QMC methods, thus demonstrating its suitability in these domains.

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