A new approach to chiral two-nucleon dynamics

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Chiral perturbation theory is a powerful tool for studying low-energy hadron dynamics. It is quite successful, for instance, in describing the $\pi\pi$ and πN scattering processes in the threshold region. On the other hand in the nucleon-nucleon sector a strictly perturbative treatment is impossible even close to threshold. Large S-wave scattering lengths and the deuteron bound state are obvious manifestations of this fact. One of the solutions of this problem within ChPT based on the ideas of Weinberg [1] is to implement a potential approach. In such a scheme, the scattering amplitude is generated by solving a dynamical equation in a non-perturbative manner with a potential calculated from the chiral Lagrangian [2].

We suggest an alternative approach [3] based on analytic properties of the scattering amplitude and the assumption that the interaction turns perturbative in some energy region below the two-nucleon threshold. The starting point of our approach is the nucleon-nucleon scattering amplitude calculated from the relativistic chiral Lagrangian using perturbation theory. We follow here the regular dimensional power counting that leads to the contributions up to the chiral order Q^3 as shown in Fig. 1.

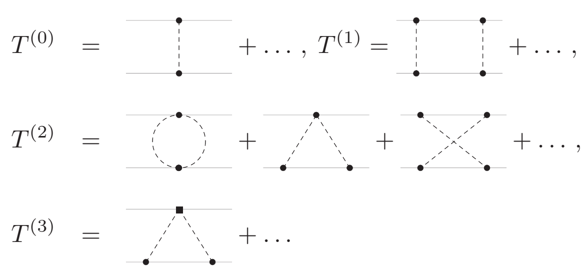

Figure 1: Feynman diagrams contributing to the NN scattering amplitude $T^{(i)}$ at order Q^i in the chiral expansion. While solid dots denote the lowest-order vertices from the chiral Lagrangian, the filled squares refer to subleading vertices. The ellipses denote diagrams leading to shorter-range contributions.

The next step consists in the analytic continuation of the subthreshold and perturbative partial-wave amplitudes into the physical and non-perturbative region taking into account the singularity structure of the amplitude in the complex s-plane. The partial-wave dispersion relation separates right- and left-hand singularities of the amplitude and reads

$$T(s) = U(s) + \int_{4m_N^2}^{\infty} \frac{ds'}{\pi} \frac{s-\mu_M^2}{s'-\mu_M^2} \frac{T(s)\,\rho(s')\,T^*(s')}{s'-s-i\epsilon}\,, \tag{1}$$

where μ_M is the matching point where perturbation theory is assumed to converge most rapidly. The generalized potential $U(s)$ possesses only left-hand cuts and is calculated from the chiral Lagrangian using conformal expansion techniques [4]. Finally, one restores the amplitude above threshold by solving Eq. (1) with $U(s)$ as an input.

The free parameters, which are related to the low-energy constants of the chiral Lagrangian, were adjusted to the empirical nucleon-nucleon phase shifts. The obtained fits are in a reasonable agreement with the data. As an example the results for the coupled partial waves, where at oder Q^3 there are only four unknown counter terms available for the fit, are shown in Fig. 2. Similar results are available for the uncoupled partial waves. The quality of the fit at order

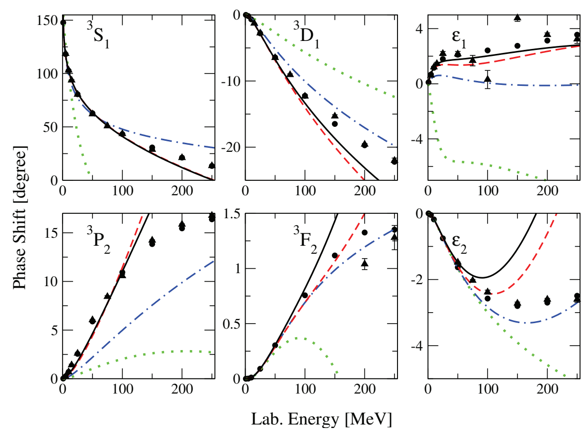

Figure 2: Phase shifts and mixing angles in the coupled $^3S_1$-$^3D_1$ and $^3P_2$-$^3F_2$ channels calculated at orders Q^0 (dotted lines), Q^1 (dash-dotted lines), Q^2 (dashed lines) and Q^3 (solid lines).

Q^3 is comparable with the one obtained in conventional approaches based on the chiral expansion of the NN potential. In all partial waves, the expansion for the phase shifts converges when going from the order Q^0 to Q^3. This supports our assumption of the validity of a perturbative expansion of the NN scattering amplitude in the subthreshold region.

References

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