Abstract

We have constructed the leading order strangeness $S = -1, -2$ baryon-baryon potential in a chiral effective field theory approach. The chiral potential consists of one-pseudoscalar-meson exchanges and non-derivative four-baryon contact terms. The potential, derived using SU(3)$_f$ symmetry constraints, contains six independent low-energy coefficients. We have solved a regularized Lippmann-Schwinger equation and achieved a good description of the available scattering data. Furthermore a correctly bound hypertriton has been obtained.

Key words: Hyperon-nucleon interaction, Hyperon-hyperon interaction, Chiral effective field theory

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1. Introduction

The derivation of the nuclear force from chiral effective field theory (EFT) has been discussed extensively in the literature since the work of Weinberg [1]. An underlying power counting allows to improve calculations systematically by going to higher orders in a perturbative expansion. In addition, it is possible to derive two- and corresponding three-nucleon forces as well as external current operators in a consistent way. For reviews we refer the reader to [2,3]. Recently the nucleon-nucleon ($NN$) interaction has been described to a high precision using chiral EFT [4,5].

As of today, the strangeness $S = -1$ hyperon-nucleon ($YN$) interaction ($Y = \Lambda, \Sigma$) was not investigated extensively using EFT [6]. The strangeness $S = -2$ hyperon-hyperon ($YY$) and cascade-nucleon ($\Xi N$) interactions had not been investigated using chiral EFT so far. In this contribution we show the results for the recently constructed chiral EFT for the $S = -1, -2$ baryon-baryon ($BB$) channels [7,8]. At leading order (LO) in the power
counting, the $YN$, $YY$ and $\Xi N$ potentials consist of four-baryon contact terms without derivatives and of one-pseudoscalar-meson exchanges, analogous to the $NN$ potential of [5]. The potentials are derived using SU(3) constraints. We solve a coupled channels Lippmann-Schwinger (LS) equation for the LO potential and fit to the low-energy $YN$ scattering data. Furthermore results for various $YY$ and $\Xi N$ cross sections are given.

2. Formalism

We have constructed the chiral potentials for the $S = -1, -2$ sectors at LO using the Weinberg power counting, see [7]. The LO potential consists of four-baryon contact terms without derivatives and of one-pseudoscalar-meson exchanges. The LO SU(3)$_f$ invariant contact terms for the octet baryon-baryon interactions that are Hermitian and invariant under Lorentz transformations were discussed in [7]. The pertinent Lagrangians read

\begin{align}
\mathcal{L}^1 &= C^1_i \langle \bar{B}_a B_b \left( \Gamma, B \right)_a \left( \Gamma, B \right)_b \rangle, \\
\mathcal{L}^2 &= C^2_i \langle \bar{B}_a \left( \Gamma, B \right)_a \bar{B}_b \left( \Gamma, B \right)_b \rangle, \\
\mathcal{L}^3 &= C^3_i \langle \bar{B}_a \left( \Gamma, B \right)_a \rangle \langle \bar{B}_b \left( \Gamma, B \right)_b \rangle.
\end{align}

(1)

Here, the labels $a$ and $b$ are the Dirac indices of the particles, the label $i$ denotes the five elements of the Clifford algebra, $B$ is the usual irreducible octet representation of SU(3)$_f$ (a $3 \times 3$-matrix). The Clifford algebra elements are here actually diagonal $3 \times 3$-matrices in flavor space. The brackets denote taking the trace in flavor space. In LO the Lagrangians give rise to six independent low-energy coefficients (LECs): $C^1_S$, $C^2_T$, $C^3_S$, $C^4_T$, $C^5_S$ and $C^6_T$, where $S$ and $T$ refer to the central and spin-spin parts of the potential respectively.

The contribution of one-pseudoscalar-meson exchanges is discussed extensively in the literature. We do not discuss it here, instead we refer the reader to e.g. [7].

We solve the LS equation for the $YN$, $YY$ and $\Xi N$ systems. The potentials in the LS equation are cut off with a regulator function, $\exp \left[ - \left( p'^4 + p^4 \right) / \Lambda^4 \right]$, in order to remove high-energy components of the baryon and pseudoscalar meson fields.

3. Results and discussion

Because of SU(3)$_f$ symmetry, only five of the LECs can be determined in a fit to the $YN$ scattering data. A good description of the 35 low-energy $YN$ scattering data has been obtained for cut-off values $\Lambda = 550, ..., 700$ MeV and for natural values of the LECs. The results are shown in Fig. 1. See [7] for more details. In Fig. 1 the shaded band represents the results of the chiral EFT in the considered cut-off region. For comparison also results for the Jülich '04 meson-exchange model [9] and the Nijmegen NSC97f meson-exchange model [10] are shown. The $YN$ interaction based on chiral EFT yields a correctly bound hypertriton, also reasonable $\Lambda$ separation energies for $^4\Lambda$H have been predicted [7,11].

The sixth LEC is only present in the isospin zero $S = -2$ channels. There is scarce experimental knowledge in these channels. In the $\Lambda\Lambda$ system, we assume a moderate attraction and exclude bound states or near-threshold resonances. Based on these considerations the sixth LEC was varied in the range of 2.0, ..., $-0.05$ times the natural value. Various cross sections for $\Lambda = 600$ MeV are shown in Fig. 2. See [8] for more details.

Our findings have shown that the chiral EFT scheme, successfully applied in [5] to the $NN$ interaction, also works well for the $S = -1, -2 BB$ interactions in LO. It will be
interesting to perform a combined \( N N \) and \( Y N \) study in chiral EFT, starting with a next-to-leading order (NLO) calculation. Work in this direction is in progress.

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