Strange two-baryon interactions using chiral effective field theory

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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.

1 Introduction

The derivation of nuclear forces 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]. Recently the nucleon-nucleon ($NN$) interaction was described to a high precision in chiral EFT [3, 4].

As of today, the strangeness $S = -1$ hyperon-nucleon ($YN$) interaction ($Y = \Lambda, \Sigma$) was not investigated extensively using EFT [5]. 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 selected results for the recently constructed chiral EFT for the $S = -1, -2$ baryon-baryon ($BB$) channels [6, 7]. 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 [4]. 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.

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2 Formalism

We have constructed the chiral potentials for the \( S = -1, -2 \) sectors at LO using the Weinberg power counting, see [6]. 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 detail in [6]. The pertinent Lagrangians read

\[
\mathcal{L}^1 = C^1_i \langle \bar{B}_a B_b (\Gamma_i B)_b (\Gamma_i B)_a \rangle , \quad \mathcal{L}^2 = C^2_i \langle \bar{B}_a (\Gamma_i B)_a \bar{B}_b (\Gamma_i B)_b \rangle , \\
\mathcal{L}^3 = C^3_i \langle \bar{B}_a (\Gamma_i B)_a \rangle \langle \bar{B}_b (\Gamma_i B)_b \rangle .
\]  

(1)

As discussed in [6], in LO the Lagrangians give rise to six independent low-energy coefficients (LECs): \( C^1_S, C^1_T, C^2_S, C^2_T, C^3_S \) and \( C^3_T \), 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. [6]. 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, \( \exp \left[ -\frac{1}{2} \frac{p^A}{\Lambda^A} \right] \), 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 \( \Lambda = 550, \ldots, 700 \) MeV and for natural values of the LECs. The results are shown in Fig. 1. See [6] for more details. The \( YN \) interaction based on chiral EFT yields a correctly bound hypertriton, also reasonable \( \Lambda \) separation energies for \( \frac{3}{2} \) H have been predicted [6, 10].

![Figure 1](image)

**Figure 1.** \( YN \) integrated cross section \( \sigma \) as a function of \( p_{lab} \). The band is the chiral EFT for \( \Lambda = 550, \ldots, 700 \) MeV, the solid and dashed curves are the Jülich ’04 meson-exchange model [8] and Nijmegen NSC97I meson-exchange model [9] respectively.

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 as-
Figure 2. $YY$ and $\Xi N$ integrated cross section $\sigma$ as a function of $p_{lab}$. The band shows the chiral EFT for variations of the sixth LEC, as discussed in the text.

sume a moderate attraction and exclude bound states or near-threshold resonances. Based on these considerations the sixth LEC was varied in the range of $2.0, \ldots, -0.05$ times the natural value. Various cross sections for $\Lambda = 600$ MeV are shown in Fig. 2. See [7] for more details.

Our findings have shown that the chiral EFT scheme, successfully applied in [4] to the $NN$ interaction, also works well for the $S = -1, -2 BB$ interactions in LO. It will be interesting to perform a combined $NN$ and $YN$ study in chiral EFT, starting with a next-to-leading order (NLO) calculation. Work in this direction is in progress.

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