Low-energy constants in relativistic chiral nucleon-nucleon potential

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Abstract. In this work we focus on the possibility of extract low energy constants via fits from phase shifts of nucleon-nucleon scattering, pointing out the differences between the relativistic and heavy baryon formulations of chiral perturbation theory. Preliminary results indicate that these two formulations give slightly different predictions for phase shifts, affecting the extraction of the low energy constants.

INTRODUCTION

After more than fifty years of intense research it became well established that this basic theory, QCD, can be represented by means of chiral perturbation theory (ChPT) in the low-energy region. In the phase diagram of QCD this corresponds to small values of temperature and density, where QCD is non-perturbative. Even though it covers only a limited area of the phase diagram, ChPT can be used as a good guide for extrapolations to intermediate energies still inaccessible by perturbative QCD. The chiral lagrangian is described in terms of low energy constants (LECs). In processes involving baryons, they are often determined through pion-nucleon processes, but the existing values come with large uncertainties [1]. They are also present in the nucleon-nucleon (NN) [3, 4, 5] and few nucleon [6] systems constructed via ChPT, with reasonable description of scattering observables given as predictions. With the large amount of NN scattering data available [7] it is interesting to, conversely, use of them to fix some of these LECs. This idea was first proposed by the Nijmegen group [8], who claims to have extracted three of them with an accuracy of 2-5%. Apart from the fact that their procedure might not be reliable (see [9] for instance) there is also the discussion about whether the heavy baryon formalism employed is appropriate for these purposes. In the following sections we bring this latter question into consideration, showing how they can possibly interfere the determination of LECs.

RELATIVISTIC VERSUS HEAVY BARYON

Contrary to what happens in ChPT in the mesonic sector, with baryons the theory gets more complicated. The first and widely used solution is to apply a sort of non-relativistic expansion, the so called heavy baryon expansion. Even though most of the chiral NN potentials are based on these ideas, there are problems regarding the validity of such an

FIGURE 1. Ratios of the heavy baryon expansion for the triangle diagram by its relativistic version.

expansion, as pointed out by Becher and Leutwyler [10]. Relativistic approaches which avoid these problems were proposed [10] and applied to the NN system [4, 5]. An important result was shown in [5], that the heavy baryon formalism fails to describe the asymptotic behavior of the NN potential. This is illustrated in fig.1, where a basic relativistic loop integral that describes the potential (the “triangle” diagram, denoted by S_t) is expanded in powers of $1/M$, where M is the baryon mass. In the heavy baryon potential up to $O(q^4)$ this integral contributes up to next-to-leading order (NLO), but in some cases (for instance, where this integral is multiplied by m_π^3) only the first term is kept. Clearly this is a crude approximation, and seems to diverge for large distances.

LECS AND PHASE SHIFTS

As mentioned before, the LECs are present not only in pion-nucleon, but also in few-body nuclear physics, the most important being c_1 , c_3 and c_4 . The accepted values for them lie in the following range [6],

$$c_1 = -0.81 \cdots -1.53, \quad c_3 = -4.70 \cdots -6.19, \quad c_4 = 3.25 \cdots 4.12.$$

Such values allow variations of almost two times the strength of the central isoscalar potential (by far, the most important component for the NN phenomenology) in the region between 1.4 and 5 fm. The Nijmegen values, designated here as set 1, are $c_1 = -0.76(7)$, $c_3 = -4.78(10)$, and $c_4 = 3.96(22)$. In order to see the variation of phase shifts on these parameters, we use the values from Büttiker and Meißner [1] (set 2): $c_1 = -0.81$, $c_3 = -4.7$, and $c_4 = 3.25$.

In fig.2 we show the dependence of the 3F_3 phase shift on the values of the LECs used, as well as the formalism used to obtain the potential. This clearly illustrates that the values for the LECs extracted from phase shifts depends on which formalism one is working with. Due to the odds of the heavy baryon framework to describe the long

FIGURE 2. 3F_3 phase shift, as a function of energy. The black (gray) curves correspond to the relativistic (heavy baryon) potential, calculated using the LECs from Refs. [8] (set 1) and [1] (set 2).

distance properties of the NN interaction, we argue here that, for a determination of LECs from phase shifts with a well grounded theoretical basis is necessary to use the relativistic potential.

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