The χ-BS(3) approach

M.F.M. Lutz[1,2] and E.E. Kolomeitsev[3]
[1]GSI, [2]TU-Darmstadt, [3]ECT*

We report on our recent non-perturbative application of the chiral $SU(3)$ Lagrangian to meson-nucleon scattering [1]. The most striking phenomena arise in the strangeness sector. At leading chiral order the kaon- and antikaon-nucleon interactions are supposedly described by the Weinberg-Tomozawa term,

$$\mathcal{L}_{WT} = \frac{i}{8\,f^2}(\bar{N}\,\gamma_\mu\,N)\big((\partial^\mu\,K)^\dagger\,K - K^\dagger(\partial^\mu\,K)\big) + \frac{3\,i}{8\,f^2}(\bar{N}\,\gamma_\mu\,\vec{\tau}\,N)\big((\partial^\mu\,K)^\dagger\,\vec{\tau}\,K - K^\dagger\vec{\tau}\,(\partial^\mu\,K)\big)\,,$$

where the parameter $f \simeq f_\pi \simeq 92.4$ MeV is known from the decay process of charged pions. In contrast to the successful application of the chiral Lagrangian in the flavor $SU(2)$ sector, its application to the strange sector of QCD is flawed by a number of subtleties if the machinery of chiral perturbation theory is applied. The leading interaction term fails miserably in describing the s-wave scattering lengths of both kaons and antikaons off a nucleon. Most stunning is the failure of reproducing the repulsive K^-p scattering length [2]. The chiral Lagrangian predicts an attractive scattering length at leading order instead. This is closely linked to the presence of the $\Lambda(1405)$ resonance in the K^-p scattering amplitude just below the K^-p threshold. Considerable theoretical progress has been made over the last few years by incorporating the dynamics of that $\Lambda(1405)$ resonance into the chiral dynamics [3, 4]. These early works consider s-wave interactions to leading [4] and subleading [3] chiral order only. The key point is to change approximation strategy and expand the interaction kernel rather than the scattering amplitude directly. That amounts to solving some type of coupled-channel scattering equation like the Lippmann-Schwinger or the Bethe-Salpeter equation. As a consequence the $\Lambda(1405)$ resonance is generated dynamically by coupled channel effects. The advantage of the chiral approach over previous phenomenological K-matrix analyses (see e.g. [5]), which also lead to a dynamic generation of the $\Lambda(1405)$ resonance, is the systematic parameter reduction implied by the chiral SU(3) symmetry of QCD.

A realistic description of the antikaon-nucleon scattering process requires the inclusion of all SU(3) channels $\bar{K}N, \pi\Lambda, \pi\Sigma, \eta\Sigma, \eta\Lambda$ and $K\Xi$ together with correction terms predicted by the chiral $SU(3)$ Lagrangian. In the χ-BS(3) approach [1], which considers s- p- and d-wave interactions to subsubleading order, the number of free parameters controlling the chiral correction terms is significantly reduced by insisting on sum rule relations as they arise from QCD in the large-N_c limit. It is demonstrated for the first time that the chiral $SU(3)$ Lagrangian does describe all low-energy pion-, kaon- and antikaon-nucleon scattering data fairly well, once chiral perturbation theory is applied to the covariant scattering kernel of the Bethe-Salpeter scattering equation.

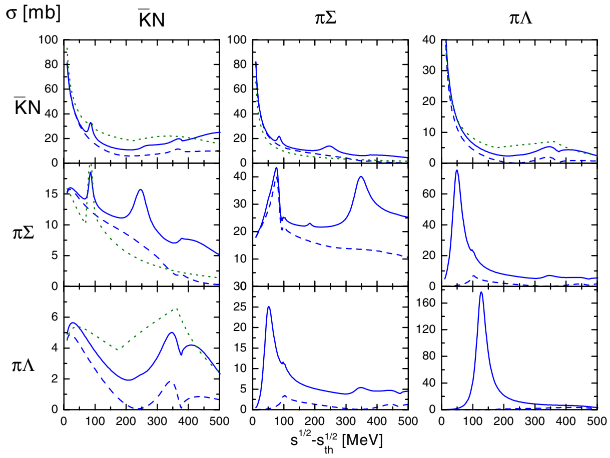

Figure 1: Total isospin averaged cross sections $\bar{K}N \to \bar{K}N$, $\bar{K}N \to \pi\Sigma$, $\bar{K}N \to \pi\Lambda$ etc compared to the parameterization of [6]. The solid and dashed lines give the results of the χ-BS(3) approach with and without p- and d-wave contributions respectively.

Crossing symmetry relates the $\bar{K}N$ and KN scattering amplitudes at subthreshold energies. A problem arises because the kaon- and antikaon-nucleon scattering processes are described by two distinct Bethe-Salpeter equations. That would lead to a violation of crossing symmetry unless an appropriate mechanism is devised to protect that symmetry. It is important to face this problem since for instance the in-medium antikaon spectral function tests the subthreshold $\bar{K}N$ amplitudes. This problem was not addressed in [3, 4] but is solved in the χ-BS(3) approach by supplementing the Bethe-Salpeter equation with an appropriate renormalization program that leads to the matching of the subthreshold KN and $\bar{K}N$ amplitudes.

In Fig. 1 we confront the isospin averaged cross sections of the channels $\bar{K}N, \pi\Sigma$ and $\pi\Lambda$ with typical parameterizations used in transport model calculations. We find most interesting the sizeable cross section of about 30 mb for the $\pi\Sigma \to \pi\Sigma$ reaction. We believe that the χ-BS(3) approach is particularly well suited to determine cross sections like those for the $\pi\Sigma \to \pi\Sigma, \pi\Lambda$ reactions not directly accessible in scattering experiments and so far not considered in transport model simulations of heavy ion reactions.

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