A UNIFIED CHIRAL APPROACH TO MESON-NUCLEON INTERACTION

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A combined chiral and $1/N_c$ expansion of the Bethe-Salpeter interaction kernel leads to a good description of the kaon-nucleon, antikaon-nucleon and pion-nucleon scattering data typically up to laboratory momenta of $p_{\rm lab} \simeq 500$ MeV. The covariant on-shell reduced coupled channel Bethe-Salpeter equation with the interaction kernel truncated to chiral order Q^3 and to the leading order in the $1/N_c$ expansion is evaluated.

We review the recent application of the chiral SU(3) Lagrangian to meson-baryon scattering[1]. The acronym 'χ-BS(3)' is used as to indicate that the Bethe-Salpeter scattering equation is applied and properly furnished with an interaction kernel constrained by the chiral SU(3) symmetry. In addition we consider the number of colors (N_c) in QCD as a large parameter relying on a systematic expansion of the interaction kernel in powers of $1/N_c$. Since the baryon octet and decuplet states are degenerate in the large-N_c limit of QCD the latter are included as explicit degrees of freedom in our scheme. The coupled-channel Bethe-Salpeter kernel is evaluated in a combined chiral and $1/N_c$ expansion including terms of chiral order Q^3.

In contrast to previous coupled channel approaches[2,3] that are based on the chiral Lagrangian, particular emphasis is put on the interplay of the regularization and renormalization of the scattering kernel and scattering amplitude. The use of phenomenological form factors or cutoff parameters is avoided. An important ingredient of the χ-BS(3) scheme is a systematic and covariant on-shell reduction of the Bethe-Salpeter equation. This is required as to avoid an unphysical and uncontrolled dependence of the scattering amplitudes on the choice of chiral coordinates or the choice of interpolating fields. Given any scheme the on-shell scattering amplitude should not change if a different representation of the chiral Lagrangian is used. In the χ-BS(3) scheme the on-shell reduction is implied unambiguously by the existence of a unique and covariant projector algebra which solves the Bethe-Salpeter equation for any choice of quasi-local interaction terms. The covariant projector algebra permits the application of dimensional regularization. In the language of the N/D method introduced by Chew and Mandelstam[4] this leads to a strong correlation of the many subtraction constants, which arise when imposing a

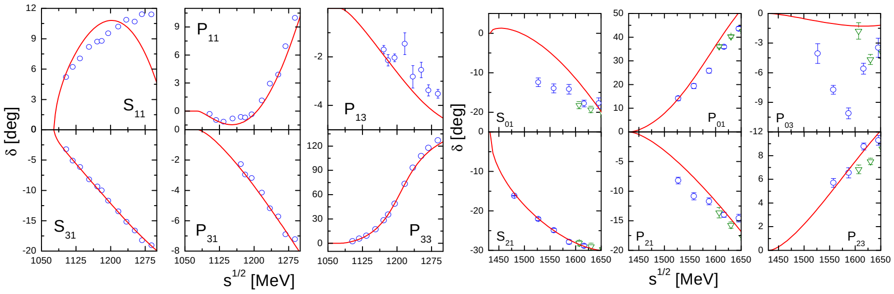

Figure 1. Left panel: S- and p-wave pion-nucleon phase shifts. The single energy phase shifts are taken from[7]. Right panel: S- and p-wave K^+-nucleon phase shifts. The solid lines represent the results of the χ-BS(3) approach. The open circles are from the Hyslop analysis[8] and the open triangles from the Hashimoto analysis[9]

dispersion-integral representation for the unitarity loop function of a given partial wave. As compared to the scheme proposed recently by Oller and Meißner[5], which applies the N/D method, a significant parameter reduction is achieved in particular when higher partial wave amplitudes are considered. Approximate crossing symmetry of the amplitudes is guaranteed in the χ-BS(3) scheme by a renormalization program which leads to the matching of subthreshold amplitudes. For instance, the kaon- and antikaon-nucleon scattering amplitudes are shown to agree below threshold within their respective applicability domains.

At subleading order Q^2 the chiral SU(3) Lagrangian predicts the relevance of 12 basically unknown parameters, which all need to be adjusted to the empirical scattering data. It is important to realize that chiral symmetry is largely predictive in the SU(3) sector in the sense that it reduces the number of parameters beyond the static SU(3) symmetry. For example one should compare the six tensors which result from decomposing $8 \otimes 8 = 1 \oplus 8_S \oplus 8_A \oplus 10 \oplus \overline{10} \oplus 27$ into its irreducible components with the subset of SU(3) structures selected by chiral symmetry in a given partial wave. Thus, static SU(3) symmetry alone would predict 18 independent terms for the s-wave and two p-wave channels rather than the 12 chiral Q^2 background parameters. The number of parameters was reduced further by insisting on large-N_c sum rules for the symmetry conserving quasi-local two body interaction terms. All together there remain 5 parameters only, all of which are found to have natural size.

At chiral order Q^3 the number of parameters increases significantly unless further constraints from QCD are imposed. A systematic expansion of the in-

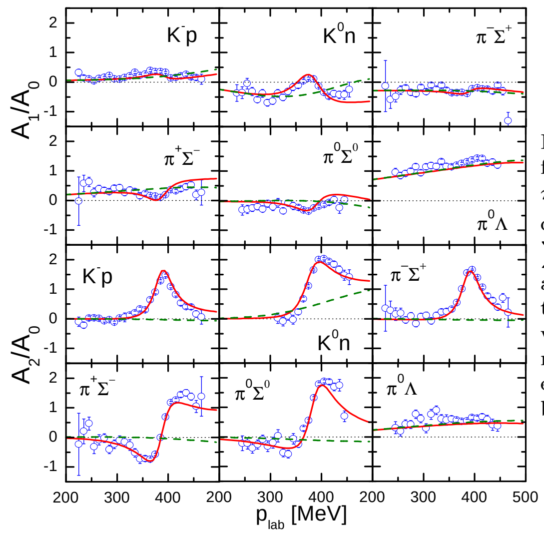

Figure 2. Coefficients A_1 and A_2 for the $K^-p \to \pi^0\Lambda$, $K^-p \to \pi^\mp\Sigma^\pm$ and $K^-p \to \pi^0\Sigma$ differential cross sections, where $\frac{d\sigma(\sqrt{s},\cos\theta)}{d\cos\theta} = \sum_{n=0}^{\infty} A_n(\sqrt{s}\,)\,P_n(\cos\theta)$. The data are taken from [10]. The solid lines are the result of the χ-BS(3) approach with inclusion of the d-wave resonances. The dashed lines show the effect of switching off d-wave contributions.

teraction kernel in powers of $1/N_c$ leads to a much reduced parameter set. For example the $1/N_c$ expansion leads to only four further parameters describing the refined symmetry-conserving two-body interaction vertices. This is to be compared with the ten parameters found to be relevant at order Q^3 if large-N_c sum rules are not imposed. At order Q^3 there are no symmetry-breaking 2-body interaction vertices. To that order the only symmetry-breaking effects result from the refined 3-point vertices. A particularly rich picture emerges. At order Q^3 there are 23 parameters describing symmetry-breaking effects in the 3-point meson-baryon vertices. For instance, to that order the baryon-octet states may couple to the pseudo-scalar mesons also via pseudo-scalar vertices rather than only via the leading axial-vector vertices. Out of those 23 parameters 16 contribute at the same time to matrix elements of the axial-vector current. Thus, in order to control the symmetry breaking effects, it is mandatory to include constraints from the weak decay widths of the baryon octet states also. A detailed analysis of the 3-point vertices in the $1/N_c$ expansion of QCD reveals that in fact only ten parameters, rather than the 23 parameters, are needed at leading order in that expansion. Since the leading parameters together with the symmetry-breaking parameters describe at the same time the weak decay widths of the baryon octet and decuplet ground states, the number of free parameters does not increase significantly at the Q^3 level if the large-N_c limit is applied.

In the left panel of Fig. 1 we confront the result of our global fit with the empirical πN phase shifts. All s- and p-wave phase shifts are well reproduced up to $\sqrt{s} \simeq 1300$ MeV with the exception of the S_{11} phase for which our result agrees with the partial-wave analysis less accurately. One should not expect quantitative agreement for $\sqrt{s} > m_N + 2\,m_\pi \simeq 1215$ MeV where the inelastic pion production process, not included in this work, starts. The missing higher order range terms in the S_{11} phase are expected to be induced by additional inelastic channels or by the nucleon resonances $N(1520)$ and $N(1650)$. In the right panel of Fig. 1 we confront the s- and p-wave K^+-nucleon phase shifts with the most recent analyses by Hyslop et al.[8] and Hashimoto[9]. The phase shifts are reasonably close to these single energy phase shifts except the P_{03} phase for which we obtain much smaller strength. Note however, that at higher energies the single energy phase shifts of Hashimoto[9] are reached smoothly.

In Fig. 2 we compare the empirical ratios A_1/A_0 and A_2/A_0 of the elastic and inelastic K^-p scattering with the results of the χ-BS(3) approach. For $p_{\rm lab} < 300$ MeV the empirical ratios with $n \geq 3$ are compatible with zero within their given errors. A large A_1/A_0 ratio is found only in the $K^-p \to \pi^0\Lambda$ channel demonstrating the importance of p-wave effects in the isospin one channel. The dashed lines of Fig. 2, which are obtained when switching off d-wave contributions, confirm the importance of the $\Lambda(1520)$ resonance for the angular distributions in the isospin zero channel. The latter resonance is included in the χ-BS(3) approach as part of a baryon nonet resonance field. For details we refer to[1].

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