SU(3) Chiral approach to meson and baryon dynamics

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We report on recent progress on the chiral unitary approach, which is shown to have a much larger convergence radius than ordinary chiral perturbation theory, allowing one to reproduce data for meson meson interaction up to 1.2 GeV and meson baryon interaction up to the first baryonic resonances. Applications to physical processes so far unsuited for a standard chiral perturbative approach are presented, concretely the $K^-p \to \Lambda(1405)\gamma$ reaction and the $N^*(1535)N^*(1535)\pi$ and η couplings.

1. CHIRAL UNITARY APPROACH

Chiral perturbation theory (χPT) has proved to be a very suitable instrument to implement the basic dynamics and symmetries of the meson meson and meson baryon interaction [1] at low energies. The essence of the perturbative technique, however, precludes the possibility of tackling problems where resonances appear, hence limiting tremendously the realm of applicability. The method that we expose leads naturally to low lying resonances and allows one to face many problems so far intractable within χPT.

The method incorporates new elements: 1) Unitarity is implemented exactly; 2) It can deal with the allowed coupled channels formed by pairs of particles from the octets of stable pseudoscalar mesons and $(\frac{1}{2}^+)$ baryons; 3) A chiral expansion in powers of the external four-momentum of the lightest pseudoscalars is done for Re T^{-1}, instead of the T matrix itself which is the case in standard χPT.

Within this scheme, and expanding $T_2 Re T^{-1} T_2$ up order $O(p^4)$, where T_2 is the $O(p^2)$ amplitude, one obtains the matrix relation in coupled channels

$$T = T_2[T_2 - T_4]^{-1}T_2, \tag{1}$$

where T_4 is the usual $O(p^4)$ amplitude in χPT.

Once this point is reached one has several options to proceed in decreasing order of complexity:

a) A full calculation of T_4 within the same renormalization scheme as in χPT can be done. The eight L_i coefficients from $L^{(4)}$ are then fitted to the existing meson meson data on phase shifts and inelasticities up to 1.2 GeV, where 4 meson states are still unimportant. This procedure has been carried out in [2,3] in the cases where the complete $O(p^4)$ amplitude has been calculated. The resulting L_i parameters are compatible with those used in χPT. At low energies the $O(p^4)$ expansion for T of eq. (1) is identical to that in χPT. However, at higher energies the nonperturbative structure of eq. (1), which implements unitarity exactly, allows one to extend the information contained in the chiral Lagrangians to much higher energy than in ordinary χ PT, which is up to about $\sqrt{s} \simeq 400$ MeV. Indeed it reproduces the resonances present in the L = 0, 1 partial waves.

b) A technically simpler and equally successful additional approximation is generated by ignoring the crossed channel loops and tadpoles and reabsorbing them in the L_i coefficients given the weak structure of these terms in the physical region. The fit to the data with the new $\hat{L}_i$ coefficients reproduces the whole meson meson sector, with the position, widths and partial decay widths of the $f_0(980)$, $a_0(980)$, $\kappa(900)$, $\rho(770)$, $K^*(900)$ resonances in good agreement with experiment [4]. A cut off regularization is used in [4] for the loops in the s-channel.

c) For the L = 0 sector (also in L = 0, S = -1 in the meson baryon interaction) a further technical simplification is possible. In these cases it is possible to choose the cut off such that, $\mathrm{Re}T_4 = T_2 \,\mathrm{Re}\, G\, T_2$ where G is the loop function of two meson propagators. This is possible in those cases because of the predominant role played by the unitarization of the lowest order χPT amplitude, which by itself leads to the low lying resonances, and because other genuine QCD resonances appear at higher energies.

In such a case and given the fact that $ImT_4 = T_2 ImG T_2$, eq. (1) becomes $T = T_2\,[T_2 - T_2\, G\, T_2]^{-1}\, T_2 = [1 - T_2\, G]^{-1}\, T_2 \rightarrow T = T_2 + T_2\, G\, T$, which is a Bethe-Salpeter equation with T_2 and T factorized on shell outside the loop integral, with T_2 playing the role of the potential. This option has proved to be successful in the L = 0 meson meson sector in [5] and in the L = 0, S = -1 meson baryon sector in [6].

In the meson baryon sector with S = 0, given the disparity of the masses in the coupled channels πN, ηN, $K\Sigma$, $K\Lambda$, the simple "one cut off approach" is not possible. In [7] higher order Lagrangians are introduced while in [8] different subtraction constants in G are incorporated in each of the former channels leading in both cases to acceptable solutions when compared with the data.

An alternative, related procedure to eq. (1), is developed in [9] using the N/D method and allowing the contribution of preexisting mesons which remain in the limit of large N_c. This procedure allows one to separate the physical mesons into preexisting ones, mostly $q\bar{q}$ pairs and the others which come as resonances of the meson meson scattering due to unitarization.

2. APPLICATION TO THE $K^- p \rightarrow \Lambda(1405)\gamma$ REACTION

Using the option c), a good description of interaction of the $K^- p$ is coupled channels interaction is obtained in terms of the lowest order Lagrangian and the Bethe Salpeter equation with a single cut off. One of the interesting features of the approach is the dynamical generation of the $\Lambda(1405)$ resonance just below the K^-p threshold. The threshold behavior of the K^-p amplitude is thus very much tied to the properties of this resonance. Modifications of these properties in a nuclear medium can substantially alter the K^-p and K^- nucleus interaction and experiments looking for these properties are most welcome.

In a recent paper [10] we propose the $K^-p \to \Lambda(1405)\gamma$ reaction as a means to study the resonance, together with the $K^-A \to \Lambda(1405)\gamma A'$ reaction to see the modification of its properties in nuclei. The $\Lambda(1405)$ is seen in its decay products in the $\pi\Sigma$ channel, but as shown in [10] the sum of the cross sections for $\pi^0\Sigma^0$, $\pi^+\Sigma^-$, $\pi^-\Sigma^+$ production has the shape of the resonance $\Lambda(1405)$ in the I = 0 channel. Hence, the detection of the γ in the elementary reaction, looking at $d\sigma/dM_I$ (M_I being the invariant mass of the meson baryon system which can be obtained from the γ momentum), is sufficient to get a clear $\Lambda(1045)$ signal. In fig. 1 we show the cross sections predicted for the $K^-p \to \Lambda(1405)\gamma$ reaction looking at $\gamma\pi^0\Sigma^0$, γ *all* and $\gamma\Lambda(1405)$ (alone). All of them have approximately the same shape and strength given the fact that the I = 1 contribution is rather small. The momentum chosen for the K^- is 500 MeV/c which makes it suitable of experimentation at KEK and others facilities.

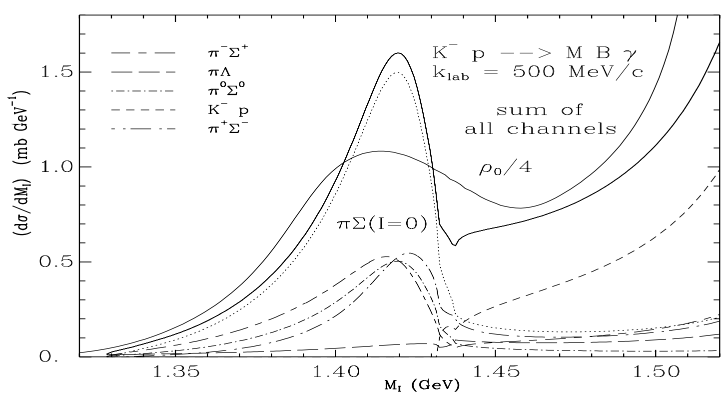

Figure 1. Mass distribution for the different channels, as a function of the invariant mass M_I of the final meson baryon system.

3. $N^*(1535)N^*(1535)\pi, \eta$ COUPLINGS

Since the $N^*(1535)$ resonance is also obtained via the Bethe-Salpeter equation (see fig. 2) in the meson baryon $S = 0$ sector with the channels πN, ηN, $K\Sigma$, $K\Lambda$, one can automatically generate the series implicit in fig. 3 which provides the coupling of a π or an η to the resonance, the latter being generated at both sides of the external mesonic vertex. All vertices needed for the calculation can be obtained from standard chiral Lagrangians. The results which we obtain are [11] $\frac{g_{\pi^0 N^* N^*}}{g_{\pi^0 NN}} = 1.3$; $\frac{g_{\eta N^* N^*}}{g_{\eta NN}} = 2.2$ The result for the π coupling rule out the mirror assignment in chiral models where the nucleon and the $N^*(1535)$ form a parity doublet [11,12] in analogy with the linear σ model.

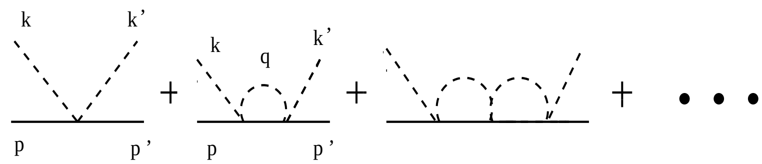

Figure 2. Diagrammatic representation of the Bethe Salpeter equation

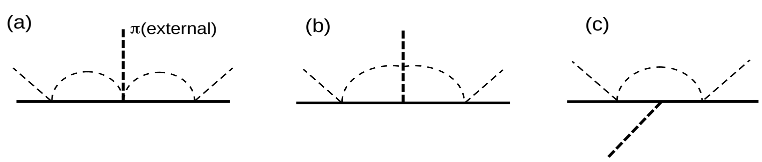

Figure 3. Diagrammatic representation of the $\pi N^* N^*$ coupling

4. SUMMARY

We have reported on the unitary approach to meson meson and meson baryon interactions using chiral Lagrangians, which has proved to be an efficient method to extend the information on chiral symmetry breaking to higher energies where χPT cannot be used. This new approach has opened the doors to the investigation of many new problems so far intractable with χPT and a few examples have been reported here. We have applied these techniques to the $K^- p \to \Lambda(1405)\gamma$ reaction and the evaluation of the $N^* N^* \pi, \eta$ couplings. The experimental implementation of the former reaction and others on photoproduction of scalar mesons and of the $\Lambda(1405)$, reported elsewhere [13], will provide new tests of these emerging pictures implementing chiral symmetry and unitarity. Similarly, the techniques used to evaluate the $N^* N^* \pi, \eta$ couplings can be easily extended to evaluate electromagnetic properties of low lying resonances which are generated within the unitary scheme.

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