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Baryonic resonances from baryon decuplet-meson octet interaction

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Abstract

We study S-wave interactions of the baryon decuplet with the octet of pseudoscalar mesons using the lowest order chiral Lagrangian. In the $S = 1$ sector, we find an attractive interaction in the ΔK channel with $I = 1$ while it is repulsive for $I = 2$. The attractive interaction leads to a pole in the second Riemann sheet of the complex plane and is manifested as a large strength in the scattering amplitude close to the ΔK threshold, which is not the case for $I = 2$.

We use the unitarized coupled channel approach to also investigate all the other possible values of strangeness and isospin. We find two bound states in the $SU(3)$ limit corresponding to the octet and decuplet representations. These are found to split into eight different trajectories in the complex plane when the $SU(3)$ symmetry is broken gradually. Finally, we are able to provide a reasonable description for a good number of 4-star $\frac{3}{2}^-$ resonances listed by the Particle Data Group. In particular, the $\Xi(1820)$, the $\Lambda(1520)$ and the $\Sigma(1670)$ states are well reproduced. We predict a few other resonances and also evaluate the couplings of the observed resonances to the various channels from the residues at the poles of the scattering matrix from where partial decay widths into different channels can be evaluated.

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1. Introduction

The introduction of unitary techniques in a chiral dynamical treatment of the meson baryon interaction has been very successful. It has lead to good reproduction of meson baryon data with a minimum amount of free parameters, and has led to the dynamical generation of many low lying resonances which qualify as quasibound meson baryon states. These states would qualify as pentaquarks in the quark picture, although the molecular structure in terms of mesons and baryons is more appropriate from the practical point of view. At a time when evidence is piling up for a positive strangeness pentaquark state [1] (see [2] for a thorough list of related theoretical and experimental papers), it is also worth stating that claims for this multiquark nature of many non-exotic resonances, in the sense that they could be generated dynamically in a meson–baryon coupled channel approach, have been done before [3–7].

In this sense although the generation of the $\Lambda(1405)$ in a multichannel approach had been proved long ago [8], the combined use of chiral Lagrangians with the Lippmann Schwinger equation in coupled channels [9,10] leads to a successful generation of this resonance and a fair reproduction of the low energy K^-N data. The consideration of the full basis of $SU(3)$ allowed channels in [11] made it possible to reproduce all these data with the lowest order Lagrangian and just one cutoff to regularize the loops. Further work to make the chiral unitary approach more systematic was done in [12,14–16]. In particular, dimensional regularization was used in [12] which allowed one to make predictions at higher energies. In this way, other resonances, the $\Lambda(1670)$ and the $\Sigma(1620)$, were generated in the strangeness $S = -1$ sector [17], and the finding of another resonance in the $S = -2$ sector allowed one to associate it to the $\Xi(1620)$ and hence predict theoretically [18] the spin and parity of this resonance, so far unknown experimentally. In addition the $N^*(1535)$ has also been for long claimed to be another of these dynamically generated resonances [19–21]. Within similar chiral approaches, the same results concerning some of these resonances have been found in [22].

All these works led gradually to a more general result in which a detailed study of the $SU(3)$ breaking of the problem could show that there are actually two octets and one singlet of dynamically generated baryons with $J^P = 1/2^-$, coming from the interaction of the octet of pseudoscalar mesons of the pion and the octet of stable baryons of the proton [23,24].

The success of these findings motivated further searches and recently it was found that the interaction of the baryon decuplet of the Δ and the octet of mesons of the pion gives rise to a set of dynamically generated resonances [25], some of which could be easily identified with existing resonances and others were more difficult to identify. In addition some peaks of the speed plot in [25] appeared on top of thresholds of channels and deserve more thought as to their physical meaning.

In the present work we have taken over the work of [25] and conducted a systematic search of dynamically generated resonances by looking at poles in the complex plane. We have also calculated the residues at the poles, which allow us to determine partial decay widths into different channels and, hence, have more elements to associate the resonances found to known resonances or new ones so far unknown. In addition, we have done a systematic study of the evolution of the poles as we gradually break $SU(3)$ symmetry from