$\Delta\rho\pi$ interaction leading to $N^*$ and $\Delta^*$ resonances *

Ju-Jun Xie · A. Martínez Torres · E. Oset · P. González.

Abstract We have performed a calculation for the three body $\Delta\rho\pi$ system by using the fixed center approximation to Faddeev equations, taking the interaction between $\Delta$ and $\rho$, $\Delta$ and $\pi$, and $\rho$ and $\pi$ from the chiral unitary approach. We find several peaks in the modulus squared of the three-body scattering amplitude, indicating the existence of resonances, which can be associated to known $I = 1/2, 3/2$ and $J^P = 1/2^+, 3/2^+$ and $5/2^+$ baryon states.

Keywords Fixed center approximation · Three body system · Chiral unitary model

1 Introduction

Our knowledge on the baryon resonances mainly comes from $\pi N$ experiments and is still under debate [1,3,4]. The information extracted from photon nucleon reactions have helped in making progress in this field, reconforming many known resonances and claiming evidence for new ones [5,6,7,8,9,10,11]. The fact that some known resonances are explained in terms of three body systems of two mesons and one baryon [12,13] should certainly stimulate work looking for resonances in three body final states of reactions. In this sense a suggestion is made in [14] to look for a predicted state of $N\bar{K}K$ [15,16] in the $\gamma p \rightarrow K^+K^-p$ reaction close to threshold.

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Ju-Jun Xie
Instituto de Física Corpuscular (IFIC), Centro Mixto CSIC-Universidad de Valencia, Institutos de Investigación de Paterna, Aptd. 22085, E-46071 Valencia, Spain
Department of Physics, Zhengzhou University, Zhengzhou, Henan 450001, China
E-mail: xiejjun@ific.uv.es

A. Martínez Torres
Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

E. Oset and P. González
Departamento de Física Teórica and Instituto de Física Corpuscular (IFIC), Centro Mixto CSIC-Universidad de Valencia, Institutos de Investigación de Paterna, Aptd. 22085, E-46071 Valencia, Spain
The main aim of the present work is to investigate the three-body $\Delta\rho\pi$ system considering the interaction of the three components among themselves keeping in mind the expected strong correlations of the $\Delta\rho$ system which generate the $N^*$ and/or $\Delta^*$ bound states. For this purpose, we have solved the Faddeev equations by using the fixed center approximation (FCA) in terms of two body $\Delta\pi$ and $\rho\pi$ scattering amplitudes.

The FCA to the Faddeev equations is a tool which has proved to be efficient and accurate to study the interaction of particles with bound states of a pair of particles at very low energies, or below threshold $[17,18,19,20]$. Recently, this approach was used in Ref. $[21]$ to describe the $f_2(1270), \rho_3(1690), f_4(2050), \rho_5(2350)$ and $f_6(2510)$ resonances as multi-$\rho$ states, and in Ref. $[22]$ to study the $K^*_2(1430), K^*_3(1780), K^*_4(2045), K^*_5(2380)$, and a not yet discovered $K^*_6$ resonances as $K^*-\text{multi-}\rho$ states. The success of these works encourages us to extend the method to study the present $\Delta\rho\pi$ system.

2 Formalism and results

For the three body $\Delta\rho\pi$ system, we consider $\Delta\rho$ as a bound state of $N^*(I_{\Delta\rho} = 1/2)$ resonance or $\Delta^*(I_{\Delta\rho} = 3/2)$ resonance, which allows us to use the FCA to solve the Faddeev equations. The external $\pi$ meson interacts successively with the $\Delta$ baryon and the $\rho$ meson which form the $\Delta\rho$ cluster. In terms of two partition functions $T_1$ and $T_2$, the FCA equations are

\begin{align*}
T_1 &= t_1 + t_1 G_0 T_2, \quad (1) \\
T_2 &= t_2 + t_2 G_0 T_1, \quad (2) \\
T &= T_1 + T_2, \quad (3)
\end{align*}

where $T$ is the total three-body scattering amplitude and $T_i (i = 1, 2)$ accounts for the diagrams starting with the interaction of the external particle with the particle $i$ of the compound system and $t_i$ represents the two body $\Delta\pi$ and $\rho\pi$ unitarized scattering amplitudes.

Next, we will show the results obtained from the scattering amplitude of the $\Delta\rho\pi$ system. We evaluate the scattering amplitude $T$ matrix of Eq. 3 and associate the peaks of $|T|^2$ to resonances. In table 1 we show a summary of the findings obtained from our model and the tentative association to known states $[1]$.

3 Discussions and Conclusions

We have performed a Faddeev calculation for the three body $\Delta\rho\pi$ system by using the fixed center approximation, taking the interaction between $\Delta$ and $\rho$, $\Delta$ and $\pi$, and $\rho$ and $\pi$ from the chiral unitary approach. The $\Delta\rho$ interaction within the framework of the hidden-gauge formalism in $I = 1/2$ sector describes the $N^*(1675), JP = 5/2^-$ as a $\Delta\rho$ bound state, then we write the three-body interaction in terms of two-body ($\Delta\pi$ and $\rho\pi$) $s$-wave scattering amplitudes based on the chiral Lagrangians. The three body states found are degenerated in $JP = 1/2^+, 3/2^+, 5/2^+$. We found candidates in the PDG book which can be associated to the states obtained, but one of them, with isospin 3/2 and mass around 2000 MeV, is missing. It is very interesting to observe
Table 1 The properties of the generated resonances with our model and their possible PDG counterparts.

| $I, \Delta \rho$ | Mass of our model (MeV) | PDG data name | $J^P$ | mass (MeV) | status |
|----------------|-------------------------|---------------|-------|------------|--------|
| $\frac{1}{2}^-, \frac{3}{2}^+$ | $\sim 1850$ | $N^*(1900)$ | $3/2^+$ | 1900 | ** |
| $\frac{1}{2}^-, \frac{3}{2}^+$ | $\sim 1800$ | $\Delta^*(1750)$ | $1/2^+$ | 1750 | * |
| | | $\Delta^*(2000)$ 1/2 | $5/2^+$ | 1724 ± 61 | Ref. 23 |
| | | $\Delta^*(2000)$ 3/2 | $5/2^+$ | 1752 ± 32 | Ref. 24 |
| | $\sim 1900$ | $\Delta^*(1905)$ | $3/2^+$ | 1900 − 1970 | **** |
| | $\sim 2200$ | $\Delta^*(2000)$ 5/2 | $5/2^+$ | 2200 ± 125 | Ref. 25 |
| $\frac{1}{2}^-, \frac{3}{2}^+$ | $\sim 2000$ | $N^*(2000)$ | $5/2^+$ | 2000 | ** |
| $\frac{1}{2}^-, \frac{3}{2}^+$ | $\sim 2000$ | ? | ? | ? | ? |

that, even if the $\Delta \rho \pi$ system allows for $I = 5/2$, the dynamics of the system precludes the formation of these exotic states.

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