A new perspective on the $\Delta_{5/2^+}(2000)$ puzzle

Pedro González[a,b], Ju-Jun Xie[b,c], A. Martínez Torres[d], and E. Oset[a,b]
[a]Departamento de Física Teórica (Universidad de Valencia (UV)), Valencia, Spain
[b]Instituto de Física Corpuscular (IFIC), Centro Mixto CSIC-Universidad de Valencia, Institutos de Investigación de Paterna, Aptd. 22085, E-46071 Valencia, Spain
[c]Department of Physics, Zhengzhou University, Zhengzhou, Henan 450001, China
[d]Yukawa Institute for Theoretical Physics, Kyoto University, Kyoto 606-8502, Japan

We argue that $\Delta_{5/2^+}(2000)(**)$, cataloged as a resonance in the Particle Data Book Review (PDG), should be interpreted instead as two distinctive resonances, $\Delta_{5/2^+}(\sim 1740)$ and $\Delta_{5/2^+}(\sim 2200)$. Our argument is based on a solution of the $\pi\Delta\rho$ problem in a Fixed Center Approximation (FCA) to the Fadeev equations. $\Delta_{5/2^+}(\sim 1740)$ can then be interpreted as a $\pi - (\Delta\rho)_{N(1675)}$ bound state. As a corollary $\Delta_{1/2^+}(1750)(*)$ can be understood as a $\pi N_{1/2^-}(1650)$ bound state.

1 Introduction

In the PDG [1] there is only a well established $\Delta_{5/2^+}$ resonance, $\Delta(1905)$ F_{35} $(****)$, and fair evidence of the existence of another one, $\Delta(2000)$ F_{35} $(**)$. However, a careful look at this last resonance shows that its nominal mass is in fact estimated from $\Delta(1724 \pm 61)$, $\Delta(1752 \pm 32)$ and $\Delta(2200 \pm 125)$ respectively extracted from three independent analyses [2–4]. Moreover a recent new data analysis has reported a $\Delta_{5/2^+}$ with a pole position at 1738 MeV [5].

From a $3q$ description the $\Delta_{5/2^+}(1905)$ is naturally accommodated as the lowest $\Delta_{5/2^+}$ state in the second energy band [6]. Similarly, the reported $\Delta_{5/2^+}(2200)$ with a more uncertain mass (2200 ± 125 MeV) may be reasonably located in the fourth energy band. On the contrary $\Delta_{5/2^+}(1740)$ can not be accommodated as a $3q$ state without seriously spoiling the overall spectral description. The same kind of problem was tackled in [7] regarding the description of $\Delta_{5/2^-}(1930)$ with a mass much lower than the corresponding to the third energy band, the first available band for such a state. There the consideration of the $\rho\Delta$ channel, whose threshold (2002 MeV) lies close above the experimental mass of the resonance and far below the $3q$ mass ($\sim$ 2150 MeV), allowed for an explanation of $\Delta_{5/2^-}(1930)$ and its partners, $\Delta_{3/2^-}(1940)$ and $\Delta_{1/2^-}(1900)$, as $\rho\Delta$ bound states in the $I = 3/2$ sector. In addition $N_{1/2^-}(1650)$, $N_{3/2^-}(1700)$ and $N_{5/2^-}(1675)$ were also well described as $\rho\Delta$ bound states in the $I = 1/2$ sector although with a bigger sensitivity in this case to the cutoff (or subtraction constant) parameter employed in the chiral unitary approach.

For $\Delta_{5/2^+}(1740)$ one can easily identify a meson-baryon threshold, $\left[\pi N_{5/2^-}(1675)\right]_{threshold} =$ 1814 MeV, in between the $3q$ mass ($\sim$ 1910 MeV) and data. Then one can wonder about the possibility that the $\pi N_{5/2^-}(1675)$ system may give rise to a bound state which could provide theoretical support to the fair evidence of the existence of $\Delta_{5/2^+}(1740)$. Actually this bound state nature would provide an explanation to the extraction of this resonance in some data analyses and not in others. It turns out that only analyses reproducing the $\pi\pi N$ production cross section data extract it. Let us note that this would be a necessary condition to extract $\Delta_{5/2^+}(1740)$ if corresponding to a $\pi N_{5/2^-}(1675)$ state (let us recall that $N_{5/2^-}(1675)$ decays to πN and to $\pi\pi N$ with branching fractions of 40% and 55% respectively). To examine this possibility we have performed an analysis of the $\pi N_{5/2^-}(1675)$ system by assuming that $N_{5/2^-}(1675)$ is a $\rho\Delta$ bound state (we have fixed the subtraction constant $a_{\Delta\rho} = -2.28$ to get precisely the mass of $N(1675)$) [8].

2 Formalism

The interaction of a particle with a bound state of a pair of particles at very low energies or below threshold can be efficiently and accurately studied by means of the FCA to the Faddeev equations for the three-particle system [9]. For the Δ-ρ-π system the π is assumed to scatter one by one the fixed centers ρ and Δ. Then the total three-body scattering amplitude T is given in terms of two partition functions T_1 and T_2 accounting for the diagrams starting with the interaction of the π with particle i of the compound system:

$$T = T_1 + T_2, \tag{1}$$

$$T_1 = t_1 + t_1 G_0 T_2, \tag{2}$$

$$T_2 = t_2 + t_2 G_0 T_1 \tag{3}$$

where t_i represent the $\Delta\pi$ and $\rho\pi$ unitarized scattering amplitudes, see Refs. [10,11] for details. G_0 is the loop function for the π meson propagating inside the $N_{5/2^-}(1675)$ resonance (see Ref. [8] for details).

3 Results and discussion

The dynamic generation of resonances from our formalism depends on two subtraction constants, $a_{\Delta\pi}$ and $a_{\rho\pi}$, respectively associated to the Δ-π and ρ-π unitarized $s-$wave interactions entering in our calculation. We assume that they are effective parameters, their values implicitly taking into account the effects of the $3q$ component of $N_{5/2^-}(1675)$. Therefore they could differ significantly from the values used in Refs. [10,11].

Examples of results giving rise to a $\pi - N(1675)$ bound state are graphically shown in Fig. 1. The three peaks in the figures may be unambiguously assigned to $\Delta_{5/2^+}(1740)$, $\Delta_{5/2^+}(1905)$ and $\Delta_{5/2^+}(2200)$. Note that the location of the first peak varies from 1770 MeV to 1800 MeV, a little bit higher than the masses of the existing candidates in [1]. Indeed we could force $a_{\Delta\pi} = -4.3$ to get an average mass of 1740 MeV. Therefore these results should mainly be interpreted as a fit to fix the parameters in our formalism. In order to gain confidence about the possible existence of $\Delta_{5/2^+}(1740)$ it becomes essential that further predictions from our formalism (with no free parameters) are successful in the interpretation of data. Let us examine some of these predictions in the $I = 3/2$ sector.

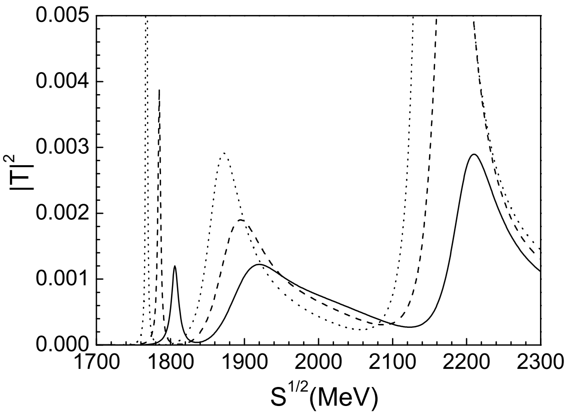

Figure 1: Modulus squared of the three-body scattering amplitude for $I = 3/2$. Results obtained with $a_{\rho\pi} = -2.0$ and $a_{\Delta\pi} = -2.6$ (solid line), -3.0 (dash line), -3.4 (dotted line).

Δ resonances generated from $\pi N_{3/2^-}(1700)$ and $\pi N_{1/2^-}(1650)$ are of particular interest since $N_{3/2^-}(1700)$ and $N_{1/2^-}(1650)$ are dynamically generated from $\Delta\rho$ as degenerate states to $N_{5/2^-}(1675)$. Hence we predict $I = 3/2$, $J^P = 1/2^+, 3/2^+$ states almost degenerate to $\Delta_{5/2^+}(1740)$. For $J^P = 1/2^+$ the state may be assigned to $\Delta_{1/2^+}(1750)(*)$, a resonance that can not be described by quark models [6]. It should be remarked that only analyses reproducing the $\pi\pi N$ production cross section data extract it as it was the case for $\Delta_{5/2^+}(1740)$. Therefore the mere existence of $\Delta_{1/2^+}(1750)(*)$ could be considered within our calculation framework as an argument in favor of the existence of $\Delta_{5/2^+}(1740)$. In what respects to $\Delta_{3/2^+}(\sim 1740)$ it is assigned to $\Delta_{3/2^+}(1600)$ which is also overpredicted by $3q$ models as the first radial excitation of the $\Delta(1232)$. However, other channels as $\sigma\Delta(1232)$ and $\pi N_{3/2^-}(1520)$ could be playing a more important role in the generation of this resonance [12].

Additional analyses have been done in the $I = 3/2, 1/2$ sectors [8]. The consistency of the whole scheme and the good agreement with data makes us confident that the approximations followed draw the essential dynamics. From our results we may conclude that there is a sound theoretical basis to support the data analyses extracting two distinctive resonances, $\Delta_{5/2^+}(1740)$ and $\Delta_{5/2^+}(2200)$, cataloged altogether as $\Delta_{5/2^+}(2000)$ in the PDG.

Acknowledgments

This work is partly supported by DGICYT Contract No. FIS2006-03438, the Generalitat Valenciana in the project PROMETEO and the EU Integrated Infrastructure Initiative Hadron Physics Project under contract RII3-CT-2004-506078. J.-J.X. acknowledges Ministerio de Educación Grant SAB2009-0116. The work of A.M.T. is supported by the Grant-in-Aid for the Global COE Program "The Next Generation of Physics, Spun from Universality and Emergence" from the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan. P.G. benefits from the funding by the Spanish Ministerio de Ciencia y Tecnología and UE FEDER under Contract No. FPA2007-65748, by the Spanish Consolider Ingenio 2010 Program CPAN (CSD2007-00042) and by the Prometeo Program (2009/129) of the Generalitat Valenciana. Partial funding is also provided by HadronPhisics2, a FP7-Integrating Activities and Infrastructure Program of the EU under Grant 227431.

References

[1] K. Nakamura *et al.* (Particle Data Group), J. Phys. G **37**, 075021 (2010).

[2] T. P. Vrana, S. A. Dytman and T.-S. H. Lee, Phys. Rep. **328**, 181 (2000).

[3] D.M. Manley and E.M. Saleski, Phys. Rev. D **45**, 4002 (1992).

[4] R.E. Cutkosky, C.P. Forsyth, J.B. Babcock, R.L. Kelly, and R.E. Hendrick, Proceedings of the IV International Conference on Baryon Resonances (Baryon 1980), edited by N. Isgur, Toronto 1980.

[5] N. Suzuki *et al.* (EBAC), Phys. Rev. Lett. **104**, 042302 (2010).

[6] S. Capstick and N. Isgur, Phys. Rev. D **34**, 2809 (1986); S. Capstick and W. Roberts, Prog. Part. Nucl. Phys. **45** S241 (2000).

[7] P. González, E. Oset and J. Vijande, Phys. Rev. C **79**, 025209 (2009).

[8] Ju-Jun Xie, A. Martínez Torres, E. Oset and P. González, Phys. Rev. C **83**, 055204 (2011).

[9] R. Chand and R. H. Dalitz, Annals Phys. **20**, 1 (1962); R. C. Barrett and A. Deloff, Phys. Rev. C **60**, 025201 (1999); R. C. Barrett and A. Deloff, Phys. Rev. C **60**, 025201 (1999); S. S. Kamalov, E. Oset and A. Ramos, Nucl. Phys. A **690**, 494 (2001).

[10] Sourav Sarkar, E. Oset, and M. J. Vicente Vacas, Nucl. Phys. A **750**, 294 (2005), Erratum-ibid. A **780**, 90 (2006), and references therein.

[11] L. Roca, E. Oset, and J. Singh, Phys. Rev. D **72**, 014002 (2005) and references therein.

[12] P. González, J. Vijande and A. Valcarce, Phys. Rev. C **77**, 065213 (2008).