A STUDY OF THE πN SCATTERING DATA WITH $J^P = 3/2^-$ AND A PROOF OF THE EXISTENCE OF THE $N^*(1700)^*$

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Using an interaction extracted from the local hidden gauge Lagrangians and the coupled channels ρN (s-wave), πN (d-wave), $\pi\Delta$ (s-wave) and $\pi\Delta$ (d-wave), we look in the region of $\sqrt{s} = 1400 - 1850$ MeV and we find two resonances dynamically generated which are naturally associated to the $N^*(1520)(3/2^-)$ and $N^*(1700)(3/2^-)$. The $N^*(1700)(3/2^-)$ appears neatly as a pole in the complex plane. The free parameters of the theory are chosen to fit the πN (d-wave) data. The unitary coupled channel approach followed here, in connection with the experimental data, leads automatically to a pole in the 1700 MeV region and makes this second $3/2^-$ resonance unavoidable.

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1. Introduction

The resonance $D_{13}(1520)(3/2^-)$ is catalogued as a four star resonance in the PDG.¹ The $D_{13}(1700)(3/2^-)$ is also catalogued as a three star resonance and has been advocated by many groups.²⁻⁴ However, the $D_{13}(1700)(3/2^-)$ is not “seen” in the GWU analysis of⁵ nor in former analyses of this group.⁶ In a recent unified Chew-Mandelstam SAID analysis of pion photoproduction data the resonance is

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not needed again,⁷ and it is also not included in the MAID analysis of photoproduction data⁸ where only four star resonances are considered, but it is one of the resonances included in the analysis of the Bonn-Gatchina group⁴ and shows more clearly in the analysis of the $(\gamma, \pi^0 \pi^0)$ data in.^{9,10} One common conclusion from^{2,9} is the strong coupling of the $D_{13}(1700)(3/2^-)$ state to the $\pi\Delta$ (d-wave) channel, something not intuitive nor expected from ordinary quark models. Furthermore other recent theoretical analysis^{11,12} also support the existence of $N^*(1700)$.

In view of the current discussion about these two resonances we have done a different analysis, purely theoretical, although paying attention to known data on the D_{13} channel. The work consist on taking four coupled channels, also considered in,^{2,6,5} the ρN (s-wave), πN (d-wave), $\pi\Delta$ (s-wave) and $\pi\Delta$ (d-wave). We look in the region of $\sqrt{s} = 1500 - 1750$ MeV and take the interaction between these channels from the local hidden gauge lagrangians, then solve the Bethe Salpeter equation in coupled channels and from this fully unitary approach we find two resonances dynamically generated by the interaction of these channels. The study provides the poles and the residues of the resonances and their coupling to the different channels, widths and partial decay widths. A fair agreement is obtained with phenomenology and the two resonances appear as poles in the complex plane. In particular a relatively strong coupling of the $N^*(1700)(3/2^-)$ to the $\pi\Delta$ (d-wave) suggested in^{2,9} is confirmed.

2. Formalism

We follow the formalism of the hidden gauge interaction of vector mesons.¹³ For the interaction of the vectors among themselves we have the three vector Lagrangian. For the transitions $VB \rightarrow PB$ we need the VPP Lagrangian and one of the two pseudoscalar mesons is exchanged between the external VP and the baryon. As shown in Ref.,¹⁴ the leading term of the $VB \rightarrow VB$ interaction involves the three vector vertex, with one vector meson exchanged, and the coupling of this exchanged vector to the baryon. These potentials has been used as the input of the Bethe-Salpeter equation to study the scattering matrix,

$$T = [1 - V G]^{-1} V \quad (1)$$

where G is the loop function of a vector meson and a baryon which is calculated in dimensional regularization, as shown in Ref.^{16,15}

The channels involved in our study are the ρN (s-wave), πN (d-wave), $\pi\Delta$ (s-wave) and $\pi\Delta$ (d-wave) all of them in isospin $I = 1/2$. To develop our calculation, we need the diagrams of the elastic interaction and the transitions diagrams as well. To include the $L = 2$ transitions, we use the same procedure as used in Ref.¹⁷ where the unknown potentials are introduced with a parameter γ and the momenta of the $L=2$ transition. In our case those channels are $\pi\Delta(d) \rightarrow \pi\Delta(d)$, $\pi\Delta(d) \rightarrow \pi N(d)$, $\pi N(d) \rightarrow \pi N(d)$.

3. Results

In order to determine the unknown parameters γ_{ij} we make a fit of the D_{13} partial wave amplitude of πN scattering extracted from experimental data in Ref.⁵ In our case we fit both the real and imaginary parts in an energy range of 1400 to 1800 MeV using the gradient fit method of χ^2 . Using the potentials for the transitions of the previous section, we construct the scattering t-matrix using the Bethe-Salpeter equation. In the analysis of the t-matrix we found two poles that can be associated to the resonances $N^*(1520)$ and $N^*(1700)$ respectively. The poles are found in the second Riemann sheet and the couplings are obtained through the residues of the poles. Using the couplings one can determine the partial decay widths of the states to each channel. In Tables 1 and 2 we show these results for the central values, and compare them with the experimental results of the PDG.¹ As the PDG average has big uncertainties, we consider appropriate to include also some single results of the experiments and analysis.^{2,18,20,10}

Table 1. Results of the partial decay widths for the $N^*(1520)$ resonance.

$N^*(1520)D_{13}$							
Pole	Briet-Wigner		Branching ratio ($\Gamma_i/\Gamma(\%)$)				
	Mass (MeV)	Γ (MeV)	$\rho N_{(s)}$	$\pi \Delta_{(s)}$	$\pi \Delta_{(d)}$	$\pi N_{(d)}$	
This work	(1467,83)		5.09	18.37	8.25	65.38	
PDG ¹	(1510,55)	1515–1525	100–125	15–25	10–20	10–15	55–65
Manley92 ²		1524±4	124±8	21±4	5±3	15±4	59±3
Manley12 ¹⁹	(1501,56)	1512.6±0.5	117±1	20.9±0.7	9.3±0.7	6.3±0.5	62.7±0.5
Cutkosky79 ¹⁸	(1510,57)	1525±15	125±25				58±3
Vrana00 ²⁰	(1504,56)	1518±3	125±4	9±1	15±2	11±2	63±2
Toma08 ¹⁰	(1509,57)	1520±10	125±15	13±5	12±4	14±5	58±8
Anisovich12 ⁴	(1507,56)	1517±3	114±4		19±4	9±2	62±3
Ardnt06 ⁵	(1515,57)	1514.5±0.2	103.6±0.4				63.2±0.1

Table 2. Results of the partial decay widths for the $N^*(1700)$ resonance.

$N^*(1700)D_{13}$							
Pole	Briet-Wigner		Branching ratio ($\Gamma_i/\Gamma(\%)$)				
	Mass (MeV)	Γ (MeV)	$\rho N_{(s)}$	$\pi \Delta_{(s)}$	$\pi \Delta_{(d)}$	$\pi N_{(d)}$	
This work	(1665,78)		8.02	4.51	13.36	28.54	
PDG ¹	(1700,75)	1650–1750	100–250	<35	10–90	<20	12±5
Manley92 ²		1737±44	249±218	13±17	5±10	80±19	1±2
Manley12 ¹⁹	(1662,55)	1665±3	56±8	38±6	31±9	3±2	2.8±0.5
Cutkosky79 ¹⁸	(1660,38)	1670±25	80±40				11±5
Vrana00 ²⁰	(1704,78)	1736±33	175±133	7±1	11±1	79±56	4±1
Toma08 ¹⁰	(1710,78)	1740±20	180±30	20±15	10±5	20±11	8 ⁺⁸ ₋₄
Anisovich12 ⁴	(1770,210)	1790±40	390±140		72±23	≤10	12±5

4. Conclusions

We have done a theoretical study for the meson-baryon scattering in the region of $\sqrt{s} = 1400 - 1800 \text{ MeV}$ with $J^P = 3/2^-$. We considered the standard coupled channels used in the most complete experimental analyses, ρN (s-wave), $\pi\Delta$ (s-wave), $\pi\Delta$ (d-wave) and πN (d-wave). The interaction of these channels was taken from the local hidden gauge approach and the loops were regularized using dimensional regularization with subtraction constant of natural size. These constants were varied within a moderate range to obtain a good fit to the πN (d-wave) data. After this, the rest are predictions of the theory.

The first important theoretical finding is that the model obtained, after fitting exclusively the πN (d-wave) extracted from data, produces two poles: one around 1480 MeV that we associate to the $N^*(1520)(3/2^-)$ and another around 1670 MeV that we associate to the $N^*(1700)(3/2^-)$. It is worth noting that the presence of the two poles is rather solid, since they remain by making changes in the parameters that do not spoil massively the agreement with the πN (d-wave) experimental data.

With the model obtained we determined partial decay widths to all the channels. We found an excellent agreement with experiments for the data on the $N^*(1520)(3/2^-)$ and rough to fair for the $N^*(1700)(3/2^-)$. Yet, we noticed the large dispersions of experimental data for the $N^*(1700)(3/2^-)$. The study done here gives a boost to the existence of the $N^*(1700)$ which has been questioned in some recent experimental analyses. In view of this extra support for the $N^*(1700)$ and the large dispersion of the data, further experimental studies concentrating in this energy region for the quantum numbers $(3/2^-)$ of this resonance should be encouraged.

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