Molecular Effects in Charmonium Spectrum

David R. Entem[1,a], Pablo G. Ortega[a], and Francisco Fernández[a]
[a]*Departamento de Física Fundamental and IUFFyM*
Universidad de Salamanca, E-37008 Salamanca, Spain

We study the influence of possible molecular structures in the charmonium spectrum. We focus on the 0^{++} and 1^{--} sectors. In the first one we coupled the 2^3P_0 $q\bar{q}$ pair with DD, $J/\psi\omega$, D_sD_s and $J/\psi\phi$ channels and we obtain two states compatibles with the $X(3945)$ and the $Y(3940)$. In the second one we include the 3^3S_1 and 2^3D_1 charmonium states coupled to DD, DD^*, D^*D^*, D_sD_s, $D_sD_s^*$ and $D_s^*D_s^*$. In this calculation we obtain a new molecular state that could be the $G(3900)$ or the controversial $Y(4008)$ and two $c\bar{c}$ states dressed by the molecular components assigned to the $\psi(4040)$ and the $\psi(4160)$. The two $c\bar{c}$ states show interesting properties and in particular they solve the strong disagreement of the decay branching ratios measured by BABAR.

1 Introduction

The discovery of the J/ψ meson in 1974 was the experimental confirmation of the existence of the charm quark introduced theoretically in 1970 by Glashow, Iliopoulus and Maiani to explain the cancellation of loop diagrams in K^0 weak decays. Consisting of a charm c quark and a $\bar{c}$ antiquark, the J/ψ particle became the starting point of a whole family of bound states called charmonium. A further milestone in the knowledge of the charmonium structure began in 2002 with the new data coming from high luminosity experiments at B factories. Since then, many new states have been observed. A summary of these states can be found in Ref. [1]. Most of them are difficult to understand in a quark-antiquark framework and meson-antimeson molecular states may represent an alternative explanation to these states.

Probably the most popular of these new states is the $X(3872)$ which lies very close to the DD^* threshold and is the most accepted candidate to be a meson-antimeson bound state. In Ref. [2] we have performed a calculation of the $X(3872)$ state as a DD^* molecule in the framework of a constituent quark model [3]. There also the coupling to $q\bar{q}$ states is included and only when we mix the DD^* channel and the $\chi_{c1}(2P)$ state the $X(3872)$ appears as a bound state. The original $\chi_{c1}(2P)$ $q\bar{q}$ state acquires a significant DD^* component and can be identified with the $X(3940)$.

[1]entem@usal.es

Following these ideas we have started a program to study the influence of possible molecular structures in the charmonium spectrum. We have generalized our formalism to study resonance above thresholds. In this contribution we focus on the results found in the 0^{++} and 1^{--} sectors.

2 Theoretical framework

We work in the framework of a coupled channel calculation following Ref. [4] generalized to include several meson-antimeson channels and several $q\bar{q}$ states. The T-matrix is decomposed in a non-resonant and a resonant contribution. We look for poles of the T-matrix in the second Riemann sheet looking for zeros of the dressed propagator. Then we solve an eigenvalue problem to obtained the $c\bar{c}$ amplitudes and with them and the dressed vertex we obtained the meson-antimeson wave functions. Finally we define the partial widths evaluating the residues of the pole.

The $q\bar{q}$ states are found solving the Schrödinger equation with the $q\bar{q}$ interaction of Ref. [3]. The meson-antimeson interaction is consistently obtained using the Resonating Group Method with these wave functions and interaction. Finally we couple the $q\bar{q}$ states with the $q\bar{q}q\bar{q}$ states using the microscopic $^3P_0$ model.

3 The 0^{++} sector

We study the 3900 MeV energy region and we include in the calculation the $\chi_{c0}(2P)$ $c\bar{c}$ state and the DD, $J/\psi\omega$, D_sD_s and $J/\psi\phi$ meson-antimeson states. We found two states corresponding to the first two lines in Table 1. For comparison we show the result of the updated Cornell model (C^3) of Ref. [5]. Our second state corresponds to the $\chi_{c0}(2P)$ dressed by the meson-antimeson states and is similar to the one found in the C^3 model. In addition our framework also allows to study resonances due to the binding of meson-antimeson channels and we found and additional state.

The experimental situation is not clear. Two states were found in these energy region, namely the $X(3945)$ [6] and the $Y(3940)$ [7] and they could be the two states we find, although recently these two states have been summarize in one, the $X(3915)$, due to compatible properties.

4 The 1^{--} sector

We study the 4100 MeV energy region and we include the 3^3S_1 and 2^3D_1 $c\bar{c}$ states and the DD, DD^*, D^*D^*, D_sD_s, $D_sD_s^*$ and $D_s^*D_s^*$ meson-antimeson channels. Our results are summarized in Tables 2 and 3. We find two states corresponding to the dressing of

Mass(MeV)	2^3P_0	DD	$J/\psi\omega$	D_sD_s	$J/\psi\phi$	Γ_{DD}	$\Gamma_{J/\psi\omega}$	$\Gamma_{D_sD_s}$
$3896.05 - i2.10$	34.22	46.67	9.41	9.67	0.03	3.37	0.83	–
$3970.07 - i94.67$	57.27	35.32	0.15	5.72	1.54	38.69	2.89	147.76
$3881.4 - i\,30.75$	49	34.22	–	4.41	–			

Table 1: Pole position, probabilities and partial widths for the two states (in the first two lines) obtained in the 0^{++} sector. For comparison we show in the last line the result of the updated Cornell model (C^3) of Ref. [5] for the only state found in the 3900 MeV energy region.

$M\,(MeV)$	3^3S_1	2^3D_1	DD	DD^*	D^*D^*	D_sD_s	$D_sD_s^*$	$D_s^*D_s^*$
$3994.6 - i\,11.60$	31.56	3.00	2.49	36.44	17.75	7.53	0.52	0.71
$4048.4 - i\,7.54$	0.92	36.15	2.99	23.49	25.81	8.86	0.92	0.85
$4123.9 - i\,71.11$	59.01	0.98	2.13	6.84	19.19	0.75	3.37	7.73
$4038 - i\,37$	44.89	0.16	2.87	20.36	23.10	0.98	1.58	1.08
$(4160) - i\,24.6$	0.09	47.61	8.37	4.24	8.87	0.55	0.96	1.31

Table 2: Pole position and probabilities for the three states (in the first three lines) obtained in the 1^{--} sector. For comparison we show in the last line the result of the updated Cornell model (C^3) of Ref. [5] for the two states found in the 4100 MeV energy region.

the original $c\bar{c}$ states corresponding to the well established $\psi(4040)$ and $\psi(4160)$ and one additional state that could be the $G(3900)$ or the controversial $Y(4008)$.

The dressed states shows a peculiar feature. Although originally the 3^3S_1 state is below the 2^3D_1, when coupled to the meson-antimeson channels, the lowest state is predominantly 2^3D_1 and the highest 3^3S_1. This is due to the additional state which has a stronger coupling with the 3^3S_1 and push the dress state to higher energies. In order to test this new assignment we have calculated the branching ratios measured by BABAR [8]. We show the results for the original bare $q\bar{q}$ states and the states obtained in the coupled channel calculation in Table 4. There is a strong disagreement with the experimental data for the bare states, while the results for the coupled channel calculation are within three standard deviations.

M	Γ	$\Gamma(DD)$	$\Gamma(DD^*)$	$\Gamma(D^*D^*)$	$\Gamma(D_sD_s)$	$\Gamma(D_sD_s^*)$
3994.6	23.37	0.12	19.09	–	4.16	–
4048.4	15.09	0.51	7.24	4.42	2.92	–
4123.9	142.23	4.73	7.51	100.03	3.82	26.15

Table 3: Partial widths for the three states obtained in the 1^{--} sector.

Ratio	Experimental value	$q\bar{q}$ with $^3P_0$	Coupled channel
$\frac{\mathcal{B}(\psi(4040)\to D\overline{D})}{\mathcal{B}(\psi(4040)\to D\overline{D}^*)}$	$0.24 \pm 0.05 \pm 0.12$	0.21	0.07
$\frac{\mathcal{B}(\psi(4040)\to D^*\overline{D}^*)}{\mathcal{B}(\psi(4040)\to D\overline{D}^*)}$	$0.18 \pm 0.14 \pm 0.03$	3.7	0.61
$\frac{\mathcal{B}(\psi(4160)\to D\overline{D})}{\mathcal{B}(\psi(4160)\to D^*\overline{D}^*)}$	$0.02 \pm 0.03 \pm 0.02$	0.27	0.05
$\frac{\mathcal{B}(\psi(4160)\to D\overline{D}^*)}{\mathcal{B}(\psi(4160)\to D^*\overline{D}^*)}$	$0.34 \pm 0.14 \pm 0.05$	0.027	0.08

Table 4: Branching ratios measured by BABAR [8] for the $\psi(4040)$ and the $\psi(4160)$ (second column). The third column shows the result for the bare $c\bar{c}$ states and the fourth the results of the states of Table 2.

Acknowledgments

This work has been partially funded by Ministerio de Ciencia y Tecnología under Contract No. FPA2010-21750-C02-02, by the European Community-Research Infrastructure Integrating Activity 'Study of Strongly Interacting Matter' (HadronPhysics2 Grant No. 227431) and by the Spanish Ingenio-Consolider 2010 Program CPAN (CSD2007-00042).

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