PROCEEDINGS OF SCIENCE

Decay widths of Di-mesonic molecular states as candidates for Z_c and Z_b

Smruti Patel

Department of physics, Sardar Patel University, Vallabh Vidyanagar-388120
fizix.smriti@gmail.com

Manan Shah

Department of physics, Sardar Patel University, Vallabh Vidyanagar-388120
mnshah09@gmail.com

Kaushal Thakkar

Department of physics, Sardar Patel University, Vallabh Vidyanagar-388120
kaushal2physics@gmail.com

P. C. Vinodkumar*

Departmecnt of physics, Sardar Patel University, Vallabh Vidyanagar-388120
p.c.vinodkumar@gmail.com

Recently significant progress in experimental investigations of tetraquark states has been achieved in a series of exciting experiments BELLE, BES-III, CLEO etc. which provides challenge to theory due to puzzling internal structure of tetraquark states. It is argued that it would be possible to solve this puzzle by examining their decay rates and thereby knowing the working of strong force that confines quarks together inside the hadronic state. The exotic tetraquark states with charm and bottom flavor may open a new approach to study the finite density QCD matter because of the mass scales of charm and bottom hadrons. In this work, we compute the binding energy of the Di-mesons by considering a residual strong interaction of the Coulomb plus Woods-Saxon type. Further, we predict the two body strong decay widths, $Z_c \to \psi(\text{ns}) + \pi$, $Z_c \to \rho + \eta_c$ of Z_c^+ and $Z_b \to \Upsilon(\text{ns}) + \pi$ of Z_b^+ based on the phenomenological lagrangian field theory.

XV International Conference on Hadron Spectroscopy-Hadron 2013
4-8 November 2013
Nara, Japan

*Speaker.

PoS(Hadron 2013)189

1. Introduction

Many theoretical works have focused on the issue of resolving the status as tetraquarks or dimesonic molecular states of the the recently discovered $Z_c^+(3900)$ state by BES III [1] and BELLE Collabaration [2] and the Z_b (10610), $Z_{b'}$ (10650) resonances by BELLE [3, 4]. The interpretations of these new states have triggered considerable amount of theoretical work, especially due to the controversies related their internal structure. In this paper, we consider these exotic hadrons as $D^+\bar{D}^*$, $B\bar{B}^*$ and $B^*\bar{B}^*$ Di-mesonic molecular states.

2. Methodology

We use a Lagrangian approach by considering these newly found states as Di-mesonic molecules. To calculate hadron molecular binding energies (BE) of these states, we employ the interaction potential between two color singlet mesons of the Woods Saxon plus Coulomb form given by

$$V(r) = \frac{V_0}{1+\exp^{(\frac{r-R}{a})}} - \frac{B}{r} \tag{2.1}$$

The potential parameters employed here are as follows: $a = -0.0387$ fm; $V_0 = 0.03$ GeV; $B = 0.04$; $R = 0.8875$ fm. These parameters are fitted optimally to get minimum statistical deviations from the experimental binding energy results. The masses of the Di-mesonic molecular states $D^+\bar{D}^*$, $B\bar{B}^*$, $B^*\bar{B}^*$ are expressed in terms of the masses of the interacting mesons and the binding energy as

$$M_{D^+\bar{D}^*} = M_{D^+} + M_{\bar{D}^*} - BE, \;\; M_{B-\bar{B}^*} = M_B + M_{\bar{B}^*} - BE, \;\; M_{B^*-\bar{B}^*} = M_{B^*} + M_{\bar{B}^*} - BE, \tag{2.2}$$

The binding energy is obtained by solving the Schrödinger equation numerically with the molecular interaction potential defined in Eqn (2.1). The Di-mesonic molecular masses and binding energies thus computed are listed in Table 1 below.

Table 1: Binding energies and Di-mesonic molecular mass (in GeV).

System	BE	Di-mesonic mass
$D^+(1.869) - \bar{D}^*(2.007)$	0.02878	3.848
$B(5.279) - \bar{B}^*(5.325)$	0.01899	10.585
$B^*(5.325) - \bar{B}^*(5.325)$	0.01892	10.631

Our approach for computing the decay widths of these Di-mesons is based on an interaction Lagrangian described by the coupling of Z_c and Z_b to its constituents as shown in fig. 1 and 2 respectively.

The corresponding Lagrangian is given by [5, 6]

$$\mathscr{L}_{Z_c}(x) = \frac{g_{Z_c}}{\sqrt{2}} Z_c^{\mu}(x) \int d^4y \;\; \Phi_{Z_c}(y^2) \left(D(x+\frac{y}{2})\, \bar{D}^*_{\mu}(x-\frac{y}{2}) + D^*_{\mu}(x+\frac{y}{2})\, \bar{D}(x-\frac{y}{2}) \right) \tag{2.3}$$

$$\mathscr{L}_{Z_b}(x) = \frac{g_{Z_b}}{\sqrt{2}} Z^{\mu} b(x) \int d^4y \;\; \Phi_{Z_b}(y^2) \left(B(x+\frac{y}{2})\, \bar{B}^*_{\mu}(x-\frac{y}{2}) + B^*_{\mu}(x+\frac{y}{2})\, \bar{B}(x-\frac{y}{2}) \right) \tag{2.4}$$

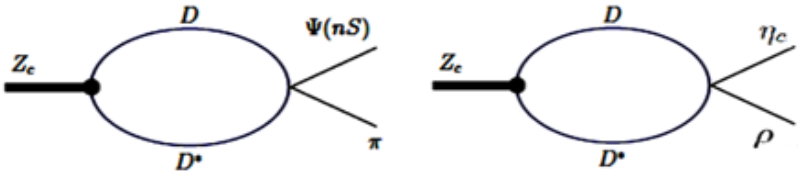

Figure 1: Two body decays of $Z_c^+ \to \psi(nS)\pi^+$, $Z_c^+ \to \eta_c\rho^+$

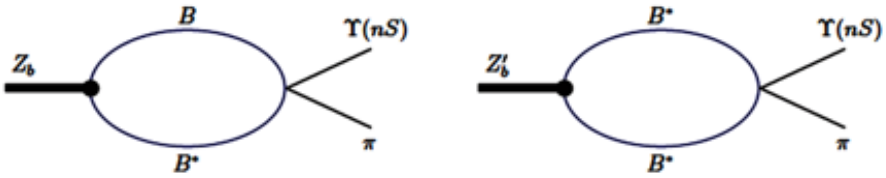

Figure 2: Two body decays of $Z_b^+ \to \Upsilon(nS)\pi^+$

$$\mathscr{L}_{Z_b'}(x) = \frac{g_{Z_b'}}{\sqrt{2}} i\varepsilon_{\mu\nu\alpha\beta}\partial^\mu Z_b'^\nu(x) \int d^4y \;\; \Phi_{Z_b'}(y^2)\, B^{*\alpha}(x+\frac{y}{2})\, \bar{B}^{*\beta}(x-\frac{y}{2}) \tag{2.5}$$

where y is a Jacobi coordinate, g_{Z_c}, g_{Z_b}, $g_{Z_b'}$ are the dimensionless coupling constants of Z_c, Z_b, Z_b' to the Di-mesonic molecules $D^+\bar{D}^*$, $B\bar{B}^*$, $B^*\bar{B}^*$, respectively. In this calculation, size parameter Λ characterizing the distribution of the two constituent mesons in the tetraquark systems is taken as Λ=0.5 GeV [5]. It leads to a regularization of the ultraviolet divergences in the feynman diagrams. In the present calculation, we have taken our results of binding energies (BE) as an input parameter as shown in Table 1, while in [5, 6] they have taken binding energy as variable quantity (5-20 MeV).

3. Numerical results

The decay widths of the two body decays $\Gamma(Z_c^+ \to \psi(nS)\pi^+)$, $\Gamma(Z_c^+ \to \eta_c\rho^+)$ are given by [5] and that for $\Gamma(Z_b^+ \to \Upsilon(nS)\pi)$ is given by [6].

$$\Gamma_{Z_c\to\psi(nS)\pi^+} = \frac{g_{Z_c\psi(nS)\pi^+}}{96\pi M_{Z_c}^3}\lambda^{3/2}(M_{Z_c}^2, M_{\psi(ns)}^2, M_\pi^2)\left(1+\frac{M_{\psi(ns)}^2}{2M_{Z_c}^2}\right) \tag{3.1}$$

$$\Gamma_{Z_c\to\eta_c\rho^+} = \frac{g_{Z_c\psi(nS)\pi^+}}{96\pi M_{Z_c}^3}\lambda^{3/2}(M_{Z_c}^2, M_{\eta_c}^2, M_\rho^2)\left(1+\frac{M_{\eta_c}^2}{2M_{Z_c}^2}\right) \tag{3.2}$$

$$\Gamma_{P\to\Upsilon(nS)\pi^+} = \frac{g_{P\Upsilon(nS)\pi^+}}{16\pi M_{Z_b}}\lambda(M_p^2, M_{\Upsilon(ns)}^2, M_\pi^2) \;\; where(P = Z_b,\;\; Z_b') \tag{3.3}$$

Here $\lambda(x,y,z) = x^2+y^2+z^2-2xy-2yz-2xz$, is the Källen function and the states (ns) are considered upto 2S only. The four coupling constants in eq. (3.1)-(3.3) are computed as per the descriptions given by [5, 6, 7, 8]. The Di-mesonic masses of Z_c, Z_b, Z_b' are taken as given in Table 1.

Table 2: Decay width of $D^+\bar{D}^*$ di-mesonic molecular state (in MeV).

System	B.E.	Decay Mode	g_{Z_c}	J_1	λ(x,y,z)	$g_{Z_c\psi(ns)\pi}$	Decay width Γ (in MeV)				
	(GeV)				$(\text{GeV})^4$	$(\text{GeV})^{-1}$	Present	[5]	[9]	[10]	[11]
$D^+\bar{D}^*$	0.028	$Z_c \to \psi(1s)+\pi$	6.64	0.002458	25.94	1.084	12.00	10.43-23.89	3.67	29.1	29.0
		$Z_c \to \psi(2s)+\pi$			0.3928	6.83	0.9749	1.28-2.94	8.24	-	6.0
		$Z_c \to \rho+\eta_c$			7.03	0.241	0.0821	-	0.45	27.5	19.0

Table 3: Decay width of $B\bar{B}^*$ and $B^*\bar{B}^*$ di-mesonic molecular states (in MeV).

System	B.E.	Decay Mode	g_{Z_b}	J_1 or J_2	λ(x,y,z)	$g_{Z_b\Upsilon(ns)\pi}$	Decay width Γ (in MeV)		
	(GeV)				$(\text{GeV})^2$		Present	[6]	EXP. [3]
$B\bar{B}^*$	0.01899	$Z_b \to \Upsilon(1s)+\pi$	5.966	0.000759	22.48	0.2181	19.34	13.3-30.8	22.9±7.3
		$Z_b \to \Upsilon(2s)+\pi$			11.32	0.3322	23.54	15.4-35.7	21.1±4.0
$B^*\bar{B}^*$	0.01892	$Z_b' \to \Upsilon(1s)+\pi$	5.948	0.000755	23.38	0.2170	19.49	14.0-31.7	12±10±3
		$Z_b' \to \Upsilon(2s)+\pi$			12.24	0.3304	25.07	16.9-39.3	16.4±3.6

4. Conclusions

In this paper, we have presented the masses of the Di-mesonic molecular states of $D^+\bar{D}^*$, $B\bar{B}^*$, $B^*\bar{B}^*$. These molecular states are found to lie below their resonance threshold. The present partial decay widths of the dimesonic molecular states in the charm sector decaying to $(c\bar{c})ns+\pi$ and $\rho+\eta_c$ are presented in Table 2. While those in the beauty sector decaying to $\Upsilon(1s)+\pi$ are presented in Table 3. For Z_c^+ state, partial decay width of particular mode is not available experimentally, so we rely on theoretical data for the partial decay mode studied here. The decay mode $Z_c \to \psi(1s)+\pi$ is indeed one of the dominating mode than other decay modes.Present results in the charm sector are found to be in good agreement with results of [6] for Z_c^+. The results for Z_b partial decay widths are consistent with experimental data [3]. The contribution from the triangle diagrams [12] which are not included in the present study will be taken into account for a complete study of these molecular states. Finally, we conclude that more high precision experimental data for the partial width of these states [$Z_c^+(3900)$, $Z_b(10610)$ and $Z_b(10650)$], particularly in the case of Z_c^+ (3900) are required for resolving their status on firm footing.

5. Acknowledgements

The work is part of a Major research project NO. F.40-457/2011(SR) funded by UGC, INDIA. One of the our authors (SP) would like to thank to Prof. Yubing Dong for fruitful discussions.

References

[1] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett. **110**, 252001 (2013).

[2] Z. Q. Liu et al. (Belle Collaboration),Phys. Rev. Lett. **110**, 252002 (2013).

[3] I. Adachi et al. (Belle Collaboration), arXiv:hep-ex/1105.4583.

[4] A. Bondar et al. (Belle Collaboration), Phys. Rev. Lett. **108**, 122001 (2012).

[5] Y. Dong et al., Phys. Rev. D **88**, 014030 (2013).

[6] Y. Dong et al., J. Phys. G **40**, 015002 (2013).

[7] Z. W. Lin et al., Phys. Rev. C **62**, 034903 (2000).

[8] Lin Z W and Ko C M , Phys. Lett. B **503**,104 (2001); Oh Y S, Song T and Lee S H 2001 Phys. Rev. C 63, 034901.

[9] Hong-Wei Ke, Zheng-Tao Wei and Xue-Qian Li,arxiv:01307.2414(2013).

[10] J. M. Dias, F. S. Navarra, and M. Nielsen, Phys. Rev. D **80**, 016004 (2013).

[11] L Maiani et al., Phys. Rev. D **87**, 111102 (2013).

[12] S. Ohkoda, S. Yasui and A. Hosaka, arxiv:1310.3029 (2013).