PROCEEDINGS OF SCIENCE

Diquark-antidiquark states with hidden or open charm

PoS(HEP2005)105

Luciano Maiani
Università di Roma 'La Sapienza' and INFN Sezione di Roma, Italy
E-mail: `luciano.maiani@roma1.infn.it`

Fulvio Piccinini[*]
INFN Sezione di Pavia and Dipartimento di Fisica Nucleare e Teorica
v. A. Bassi 6, I-27100 Pavia, Italy
E-mail: `fulvio.piccinini@pv.infn.it`

Antonio D. Polosa
INFN Sezione di Roma and
Università di Roma 'La Sapienza', Roma, Italy
E-mail: `antonio.polosa@cern.ch`

Veronica Riquer
INFN Sezione di Roma and
Università di Roma 'La Sapienza', Roma, Italy
E-mail: `veronica.riquer@cern.ch`

Some features and predictions of a recently proposed model based on diquark-antidiquark bound states are illustrated. Its ability in accomodating newly discovered charmed resonances around 4 GeV is discussed.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

---

[*] Speaker.

http://pos.sissa.it/

1. Introduction

The recent discovery [1] of the $j_q = 1/2$ P-wave charm-strange resonance D_s^{**} with a mass significantly lower than expected has lead to new interest in charm spectroscopy. It was followed by the observation of some meson resonances with *no open* charm in e^+e^- annihilation with masses around 4 GeV starting with $X(3872)$ [2] and so far ending with $Y(4260)$ [3]. These states can be fitted with difficulties in the charmonium $c\bar{c}$ picture (see ref. [4] for a recent review of alternative interpretations). On the other hand, the evidence of low mass resonances (below 1 GeV) by the KLOE Collaboration in the $\pi\pi$ spectrum of the radiative decay $\phi \to \pi_0\pi_0\gamma$, $\sigma(450)$ [5], and by the E791 Collaboration in the $K\pi\pi$ spectrum from D decays, $\kappa(800)$ [6], reinforced the interpretation of the scalar nonet ($J^{PC} = 0^{++}$) components below 1 GeV, $f(980)$, $a(980)$, $\kappa(800)$ and $\sigma(450)$, as 4-quark bound states [7]. In particular such states can be thought of as being $S-$wave bound states of a diquark and an antidiquark, $[qq][\bar{q}\bar{q}]$, where the diquark is taken in the fully antisymmetric configuration $\mathbf{\bar{3}_c}$, $\mathbf{\bar{3}_f}$ and $\mathbf{1_s}$ of colour, spin and flavour respectively. The most convincing feature in favour of this interpretation is the inverted mass spectrum of the light scalar nonet, *i.e.* the lightest state has $I = 0$ and no strangeness, while the heaviest particles have $I = 1,0$ and like to decay in states containing strange quark pairs. In Ref. [8] we have shown that this interpretation can reasonably describe the OZI allowed strong decays of the light scalar mesons in terms of a single amplitude parameterizing the switch of a $q\bar{q}$ pair.

If the light scalar mesons are diquark-antidiquark composites, it is natural to consider analogous states with one or more heavy constituents [9, 10], *i.e.* of the form $[cq][\bar{c}\bar{q}']$, with $q,q' = u,d,s$. With respect to the light diquark case, two new elements come into the game: the near spin-independence of heavy quark forces (exact in the limit $m_c \to \infty$) and isospin breaking from light-quark masses. The first feature implies the presence of both spin zero and spin one diquarks, giving rise to a rich spectrum of states with $J = 0,1,2$, with both natural and unnatural J^{PC} quantum numbers. In the following we summarize the spectrum and decay properties of such four-quark states and their possible identification with recently discovered charmed resonances.

2. Spectrum of charmed diquark-antidiquark states

The mass spectrum of the systems $[cq][\bar{c}\bar{q}']$ with $q,q' = u,d$ can be described in terms of constituent diquark masses and spin-spin interactions, *i.e.* the Hamiltonian to be diagonalized is given by

$$\begin{aligned} H = 2m_{[cq]} &+ 2(\kappa_{cq})_{\bar{3}}[(S_c \cdot S_q) + (S_{\bar{c}}) \cdot (S_{\bar{q}'})] + 2(\kappa_{q\bar{q}})(S_q \cdot S_{\bar{q}'}) \\ &+ 2(\kappa_{c\bar{q}})[(S_c \cdot S_{\bar{q}'}) + (S_{\bar{c}} \cdot S_q)] + 2(\kappa_{c\bar{c}})(S_c \cdot S_{\bar{c}}) \end{aligned} \tag{2.1}$$

and analogously for the $[cs][\bar{c}\bar{q}']$ states. The Hamiltonian parameters can be obtained from known meson and baryon masses by resorting to the constituent quark model [11]

$$H = \sum_i m_i + \sum_{i<j} 2\kappa_{ij}(S_i \cdot S_j), \tag{2.2}$$

where the sum runs over the hadron constituents. The coefficients κ_{ij} depend on the flavour of the constituents i,j and on the particular colour state of the pair. For instance, applied to the $L = 0$

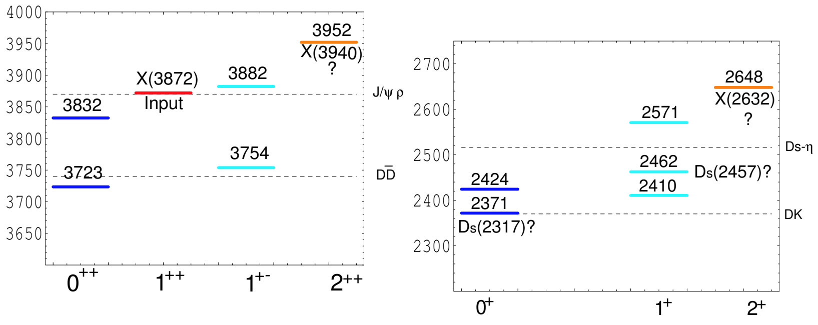

Figure 1: The predicted spectrum of X particles with hidden charm (left) and with open charm and strangeness (right). Indicated mass values are in MeV. Dashed lines show the decay thresholds.

mesons K and K^*, Eq. (2.2) gives the relation $M = m_q + m_s + \kappa_{s\bar{q}}[J(J+1) - 3/2]$. Similar equations can be written for the meson pairs π-ρ, D-D^* and D_s-D_s^*. Spin-spin interaction coefficients in antitriplet colour state can be estimated from baryon masses. For the quark-antiquark interactions to which we don't have yet experimental access we rely on estimates based on one-gluon exchange. The obtained results for the diquark masses are: $m_{[ud]} = 395$ MeV, $m_{[ud]} = 590$ MeV, $m_{[cq]} = 1933$ MeV. The explcit values for the spin-spin couplings κ_{ij} are listed in Tab. II and III of Ref. [9]. By diagonalization of the Hamiltonian of Eq. (2.1), on the basis of the states with definite diquark spin S_{cq}, antidiquark spin $S_{\bar{c}\bar{q}'}$ and total angular momentum J, we obtain six states corresponding to the following J^{PC} assignments: $2 \times 0^{++}$, 1^{++}, $2 \times 1^{+-}$, 2^{++}. The state 1^{++}, with the symmetric spin distribution $[cq]_{S=1}[\bar{c}\bar{q}]_{S=0}$+$[cq]_{S=0}[\bar{c}\bar{q}]_{S=1}$, is a good candidate to explain the properties of the $X(3872)$: it is expected to be narrow, like all diquark-antidiquark systems under baryon-antibaryon threshold; the unnatural spin-parity forbids the decay in D-$\bar{D}$, which is not seen; it can decay into both channels $J/\Psi\rho$ and $J/\Psi\omega$, as observed experimentally, due to isospin breaking in its wave function. By identification of the 1^{++} state with the observed $X(3872)$, the resulting mass spectrum is depicted in Fig. 1 (left). The analogous six eigenvectors of the Hamiltonian for the $[cq][\bar{s}\bar{q}']$ are not invariant under C-conjugation and we have the following J^P quantum numbers and multiplicities: $2 \times 0^+$, $3 \times 1^+$, 2^+. The resulting spectrum is shown in Fig. 1 (right). Of the two states 0^{++}, one can decay in $\eta_c\pi$, $\eta_c\eta$ or multihadron states, the other one should decay into $D\bar{D}$. Up to now none of them has been seen experimentally. The same holds for the 1^{+-} states, which could decay in $J/\Psi + \pi(\eta)$, $\eta_c + \rho(\omega)$. The predicted mass of the 2^{++} state is, instead, in the right place of the $X(3940)$ seen by Belle in the channel $J/\Psi\omega$. In the discussed framework, however, it could also decay into $D^*\bar{D}^*$ and $D\bar{D}$ in D-wave. Of the states with strangeness, the lowest lying 0^+ and one of the 1^+ could be assigned to the $D_s(2317)$ and $D_s(2457)$ [1], respectively, in agreement with the observed decays $D_s(2317) \to D_s\pi^0$, $D_s(2457) \to D_s\gamma\pi^0$; $(D_s)^*\pi^0$. The state 2^+ could fit naturally the particle claimed be the SELEX Collaboration [12].

3. Isospin breaking

Due to asymptotic freedom, at the large momentum scale implied by the heavy quark, the strength of the self-energy annihilation diagrams decreases. As a consequence, particle masses should be approximately diagonal with quark masses, even for up and down quarks [10, 13]. In this limit the neutral mass eigenstate coincide with $X_u = [cu][\bar{c}\bar{u}]$ and $X_u = [cd][\bar{c}\bar{d}]$. Non-negligible gluon annihilation diagrams mix X_u and X_d giving rise to different eigenvalues separated by $\Delta M = 2(m_d - m_u)/\cos(2\theta) = (7\pm2)/\cos(2\theta)$ MeV. Thus the $X(3872)$ should consist, to a closer inspection, of two separate states. The mixing angle θ could be determined from ΔM, as well from the ratio of the decay rates in $J/\Psi+\rho$ and $J/\Psi+\omega$, which are both allowed due to isospin breaking. From the measured ratio $\Gamma(J/\Psi\pi^+\pi^-)/\Gamma(J/\Psi\pi^+\pi^-\pi^0)$ by Belle we derive $\theta \simeq 20^\circ$, giving $\Delta M = 8\pm3$ MeV.

4. Orbital excitations

One of the distinctive features of the model based on diquark-antidiquark bound states is the presence of orbital angular momentum excitations, since the basic objects are coloured diquarks in a rising confining potential. Actually, the recently discovered state by BABAR $Y(4260)$ [3], with $J^{PC} = 1^{--}$, could be one of such orbital excitations. It is seen in the channel $J/\Psi\pi^+\pi^-$, with $M(\pi^+\pi^-)$ around 1 GeV, consistently with the decay $J/\Psi f_0(980)$. Given these features, the state can be interpreted as a bound state $[cs][\bar{c}\bar{s}]$ with both diquarks in spin zero and with a unit of relative orbital angular momentum. In Ref. [14] we have shown that this picture predicts a mass of 4330 ± 70 MeV, in nice agreement with the experimental value. A crucial prediction of the model is also the decay channel $D_s\bar{D}_s$, which still awaits for experimental observation.

Acknowledgements: F.P. would like to thank the conveners for their invitation.

References

[1] B. Aubert et al. Phys. Rev. Lett. **90**, (2003) 242001.

[2] S.K. Choi et al. Phys. Rev. Lett. 91, (2003) 262001; D. Acosta et al., Phys. Rev. Lett. **93**, (2004) 072001; V.M. Abazov et al., Phys. Rev. Lett. **93**, (2004) 162002; B. Aubert et al., Phys. Rev. **D71** (2005) 07103.

[3] B. Aubert et al., Phys. Rev. Lett. **95**, (2005) 142001.

[4] C. Quigg, these proceedings, [arXiv:hep-ph/0509332].

[5] A. Aloisio et al., Phys. Lett. **B537** (2002) 21; E.M. Aitala et al., Phys. Rev. Lett. **86** (2001) 770.

[6] E.M. Aitala et al., Phys. Rev. Lett. **89** (2002) 121801.

[7] R.L. Jaffe, Phys. Rev. **D15** (1977) 281; Phys. Rep. **409** (2005) 1 and references therein.

[8] L. Maiani, F. Piccinini, A.D. Polosa and V. Riquer, Phys. Rev. Lett. **93** (2004) 212002.

[9] L. Maiani, F. Piccinini, A.D. Polosa and V. Riquer, Phys. Rev. **D71** (2005) 014028.

[10] L. Maiani, F. Piccinini, A.D. Polosa and V. Riquer, Phys. Rev. **D70** (2004) 054009.

[11] A. De Rujula, H. Georgi and S.L. Glashow, Phys. Rev. **D12** (1975) 147; Phys. Rev. Lett. **38** (1977) 317.

[12] A.V. Evdokimov et al., [arXiv:hep-ex/0406045].

[13] G.C. Rossi and G. Veneziano, Phys. Lett. **B70** (1977) 255; *ibid.* **B597** (2004) 338.

[14] L. Maiani, F. Piccinini, A.D. Polosa and V. Riquer, Phys. Rev. **D72** (2005) 031502.