Physics Letters B 665 (2008) 157–163

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

Hadronic-loop induced mass shifts in scalar heavy–light mesons

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ARTICLE INFO

Article history:
Received 15 January 2008
Received in revised form 25 April 2008
Accepted 3 June 2008
Available online 12 June 2008
Editor: J.-P. Blaizot

PACS:
12.39.-x
12.40.Yx
14.40.Lb

ABSTRACT

We calculate the mass shifts of heavy–light scalar mesons due to hadronic loops under the assumption that these vanish for the groundstate heavy–light mesons. The results show that the masses calculated in quark models can be reduced significantly. We stress that the mass alone is not a signal for a molecular interpretation. Both the resulting mass and the width suggest the observed D_0^* state could be a dressed $c\bar{q}$ state. We give further predictions for the bottom scalar mesons which can be used to test the dressing mechanism.

1. Introduction

The constituent quark model has been very successful in describing hadron spectroscopy. In recent years, some newly observed hadrons attracted much interest from both the experimental and theoretical community since these hadrons do not fit to the quark model predictions [1]. For instance, the mass of the observed charm-strange scalar meson D_{s0}^* [2] is 2317.8 ± 0.6 MeV [3], while the predictions from most quark models spread from 2400 MeV to 2500 MeV [4,5]. The high mass predicted in constituent quark models is obtained through an orbital angular momentum excitation. The result from QCD sum rules in heavy quark effective theory gives a mass range 2.42 ± 0.13 GeV for the D_{s0}^* $(c\bar{s})$ state which is consistent with, but the central value is 100 MeV higher than, the experimental value [6]. Due to the fact that the mass of the $D_{s0}^*(2317)$ is just below the DK threshold at 2.36 GeV, a DK molecular interpretation was proposed by Barnes et al. [7] and some others [8]. We want to remark that a DK bound state can be dynamically generated with a mass consistent with the observed mass of the $D_{s0}^*(2317)$ in the framework of the heavy chiral unitary approach [9,10]. Other exotic explanations were also proposed, such as tetraquark state [11], and $D\pi$ atom [12]. Besides these exotic explanations, some authors tried to modify the quark model predictions. In [13], one loop corrections to the spin-dependent one-gluon exchange potential was considered, and the predicted mass of the D_{s0}^* is higher than the experimental value by only about 20 MeV. Another kind of modification is the mixing of the $c\bar{s}$ with the $cq\bar{s}\bar{q}$ tetraquark [14], or considering the coupling of the $c\bar{s}$ to hadronic channels, such as DK [15]. The prediction for the D_{s0}^* from the QCD sum rules can also be lowered to 2.331 ± 0.016 GeV considering the DK continuum explicitly [16]. Note that it is possible to distinguish a hadronic bound state from elementary hadrons, as done for the deuteron [17] and for the light scalars $a_0(980)$ and $f_0(980)$ [18]. All the results from Refs. [15,16] indicate the importance of the strongly coupled hadronic channels on determining the mass of a hadron. For the charm-non-strange sector, both the Belle and FOCUS collaborations reported a scalar meson with a large width [19,20]. Although the reported masses by different collaborations are not consistent with each other, the measurements are considered as the same charm scalar meson by the Particle Data Group (PDG), and the PDG average value of the mass is 2352 ± 50 MeV. The structure of this state has not been clear yet. In this Letter, we revisit the mass shifts of the heavy scalar mesons induced by the strongly coupled hadronic loops. For instance, the D_{s0}^{*+}, the 1^3P_0 $c\bar{s}$ state in quark model, can couple to the D^+K^0, D^0K^+ and $D_s\eta$ loops, see Fig. 1. The coupling constants of the D_{s0}^{*+} to the three channels can be related by SU(3) symmetry. We shall use three different coupling types to study the mass shifts, called Models I, II and III in the following. In Model I, the coupling of the scalar heavy meson (S) to the heavy pseudoscalar meson (P) and the Goldstone boson (ϕ) is assumed to be a constant. In Model II, the coupling is derived in the framework of heavy meson chiral perturbation theory (HMχPT) which combines the chiral expansion with the heavy quark expansion [21,22] (for a review, see Ref. [23]). In Model III, a chiral effective coupling is constructed disregarding the heavy quark expansion. Of course, such corrections

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0370-2693
doi:10.1016/j.physletb.2008.06.008

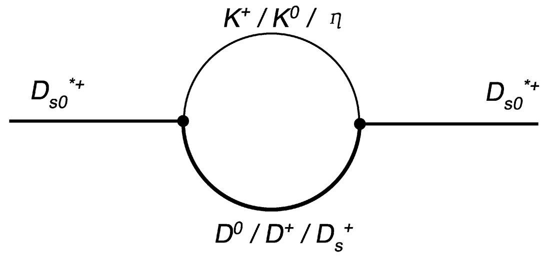

Fig. 1. The relevant hadronic loops coupled to the D_{s0}^*.

due to hadronic loops are always model-dependent and are, in general, difficult to quantify, for a recent discussion see [24] (for further discussion of incorporating hadronic loops in the quark model, see [25]). This is why we consider three different models and also need to assume that for the ground state meson $Q\bar{q}$ (with $Q=c,b$ and $q=u,d,s$), the shift due to the hadronic loops vanishes as it was done, e.g., in the calculation of the mass shifts of charmonia in Ref. [26].

2. Choices of coupling

2.1. Model I

First, the coupling of S to P,ϕ is taken as a constant. The loop integral that enters the dressed propagator is

$$G^{\mathrm{I}}(s)=i\int\frac{d^4q}{(2\pi)^4}\frac{1}{(q^2-m_1^2+i\epsilon)[(p-q)^2-m_2^2+i\epsilon]},\tag{1}$$

where $s=p^2$. The analytic expression is given by [27,28]

$$G^{\mathrm{I}}(s)=\frac{1}{16\pi^2}\Bigg\{R-1+\ln\frac{m_2^2}{\mu^2}+\frac{m_1^2-m_2^2+s}{2s}\ln\frac{m_1^2}{m_2^2}+\frac{\sigma}{2s}\big[\ln\big(s-m_1^2+m_2^2+\sigma\big)$$
$$-\ln\big(-s+m_1^2-m_2^2+\sigma\big)+\ln\big(s+m_1^2-m_2^2+\sigma\big)-\ln\big(-s-m_1^2+m_2^2+\sigma\big)\big]\Bigg\},\tag{2}$$

where $R=-[2/(4-d)-\gamma_E+\ln(4\pi)+1]$ will be set to zero in the calculations and γ_E is Euler's constant, μ is the scale of dimensional regularization, and $\sigma=\sqrt{[s-(m_1+m_2)^2][s-(m_1-m_2)^2]}$. Taking into account the D^0K^+, D^+K^0 and $D_s^+\eta$ channels, the shifted mass of the D_{s0}^{*+} is given by the solution of the equation

$$s-(\mathring{M}_{D_{s0}^*})^2-g^2\,\mathrm{Re}\left[2G^{\mathrm{I}}_{DK}(s)+\frac{2}{3}G^{\mathrm{I}}_{D_s\eta}(s)\right]=0,\tag{3}$$

where $\mathring{M}_{D_{s0}^*}$ denotes the bare mass of the D_{s0}^*. Note that we only consider the lowest possible intermediate states. In principle, all states with quantum numbers allowed by conservation laws can contribute [25]. For instance, besides the channels considered here, the D^*K^*, $D_s\eta'$ and $D_s^*\rho$ can contribute either. But their threshold are at least 500 MeV higher than that of the DK, thus their contributions are expected to be suppressed. The corresponding equation for the non-strange charm meson D_0^{*+} is

$$s-(\mathring{M}_{D_0^*})^2-g^2\,\mathrm{Re}\left[\frac{3}{2}G^{\mathrm{I}}_{D\pi}(s)+\frac{1}{6}G^{\mathrm{I}}_{D\eta}(s)+G^{\mathrm{I}}_{D_sK}(s)\right]=0,\tag{4}$$

where four channels, $D^+\pi^0$, $D^0\pi^+$, $D^+\eta$ and $D_s^+K^0$, are taken into account. The coupling constant g has been calculated by using light-cone QCD sum rules in [29], $g=6.3\pm1.2$ GeV in the charm sector, $g=21\pm7$ GeV in the bottom sector. A more recent analysis considering the $D_{s0}^*(2317)$ state as a conventional $c\bar{s}$ meson gives the coupling constant for D_{s0}^*DK as $5.9^{+1.7}_{-1.6}$ GeV [30], which is consistent with that given in Ref. [29]. In this Letter, we study the mass shifts of bare $c\bar{q}$ (and $b\bar{q}$) mesons induced by hadronic loops. The values of coupling constants given in Ref. [29] will be taken because the masses of the scalar heavy mesons used therein are consistent with the quark-model expectation (no fitting to the mass of the $D_{s0}^*(2317)$ was performed since the state had not been discovered yet) and hence correspond to the bare masses.

2.2. Model II

In the HMχPT, the Lagrangian for the coupling of S to P and ϕ to leading order is [22,23]

$$\mathcal{L}=ih\langle S_b\gamma_\mu\gamma_5A^\mu_{ba}\bar{H}_a\rangle+\text{h.c.}=\frac{i\sqrt{2}h}{f_\pi}\big(D_{0b}v^\mu\partial_\mu\Phi_{ba}P_a^\dagger-D_{1b}^\nu v^\mu\partial_\mu\Phi_{ba}P_{a\nu}^{*\dagger}\big)+\cdots,\tag{5}$$

where the axial field

$$A^\mu_{ba}=\frac{i}{2}\big(\xi^\dagger\partial^\mu\xi-\xi\partial^\mu\xi^\dagger\big)_{ba}=-\frac{\partial^\mu\Phi_{ba}}{\sqrt{2}f_\pi}+\cdots\tag{6}$$

contains the Goldstone bosons