Update on strong and radiative decays of the $D^*_{s0}(2317)$ and $D_{s1}(2460)$ and their bottom cousins

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Introduction

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The lightest positive-parity charm-strange mesons D^*_{s0} [1] and D_{s1} [2] are prominent candidates of hadronic molecules, with the dominant components residing in the isoscalar DK and D^*K channels. In hadronic molecular picture, the mass differences $M_{D^*}-M_D$ and $M_{D_{s1}}-M_{D^*_{s0}}$ is a natural consequence of heavy quark spin symmetry. The partial decay widths of these states play a unique role in discriminating various models. In particular, the isospin breaking hadronic decays $D^*_{s0}\to D_s\pi^0$ and $D_{s1}\to D^*_s\pi^0$ are expected to be much larger in the molecular approach than in other models, since in addition to the more conventional π^0-η mixing mechanism, also the mass differences of charged and neutral constituents contribute via loops. Heavy quark flavour symmetry (HQFS) allows one to estimate the masses of the bottom partners of the D^*_{s0} and D_{s1}, independent of the model assumptions for their internal structure. One finds

$$M_{B^*_{s0}} = \bar{M}_c + \Delta_{b-c} + (M_{D^*_{s0}} - \bar{M}_c)\frac{m_c}{m_b} \simeq 5.71 \text{ GeV},$$
$$M_{B_{s1}} = \bar{M}_c + \Delta_{b-c} + (M_{D_{s1}} - \bar{M}_c)\frac{m_c}{m_b} \simeq 5.76 \text{ GeV}, \quad (1)$$

where $\bar{M}_c = 2.42$ GeV is the spin-averaged mass of the charmed mesons, Δ_{b-c} is the difference between the bottom and charm quark mass scales, which may be estimated by $\bar{M}_{B_s} - \bar{M}_{D_s} \simeq 3.33$ GeV, with $\bar{M}_{B_s} = 5.40$ GeV and $\bar{M}_{D_s} = 2.08$ GeV the spin-averaged masses of the ground state pseudoscalar and vector $Q\bar{s}$ mesons. So far, neither of these two bottom-strange mesons has been observed, but they are currently searched for at the LHCb experiment. It is therefore important and timely to have reliable predictions of both radiative and isospin breaking hadronic decay widths of these mesons. The predictions in the hadronic molecular model have been made in Ref. [3]. However, the B^*_{s0} and B_{s1} masses used there, (5625 ± 45) MeV and (5671 ± 45) MeV, are too low to be consistent with the HQFS expectations derived from Eq. (1). Consequently, the partial decay widths computed therein need to be corrected.

Updated results on molecule states

The two-point loop integral can be regularized in different ways. One option is to use dimensional regularization with a subtraction constant $a(\mu)$. Alternatively, the ultraviolet divergence can be regularized by a hard cut-off, q_{max}, on the magnitude of the loop three-momentum. We denote the resulting two-point scalar loop functions by $G_{sub}(s, a(\mu))$ and $G_{CO}(s, q_{max})$.In the previous analysis [4],the method with a subtraction constant was used. However, the dependence of the subtraction constant on the heavy quark mass, m_Q, is not clearly. In order to take this into account, it was proposed in Ref. [5] to match G_{sub} and G_{CO} at the relevant charmed meson threshold to determine q_{max} from a given $a(\mu)$, and then use the same q_{max} in the bottom sector at a relevant bottom threshold to determine the value of $a(\mu)$ there.

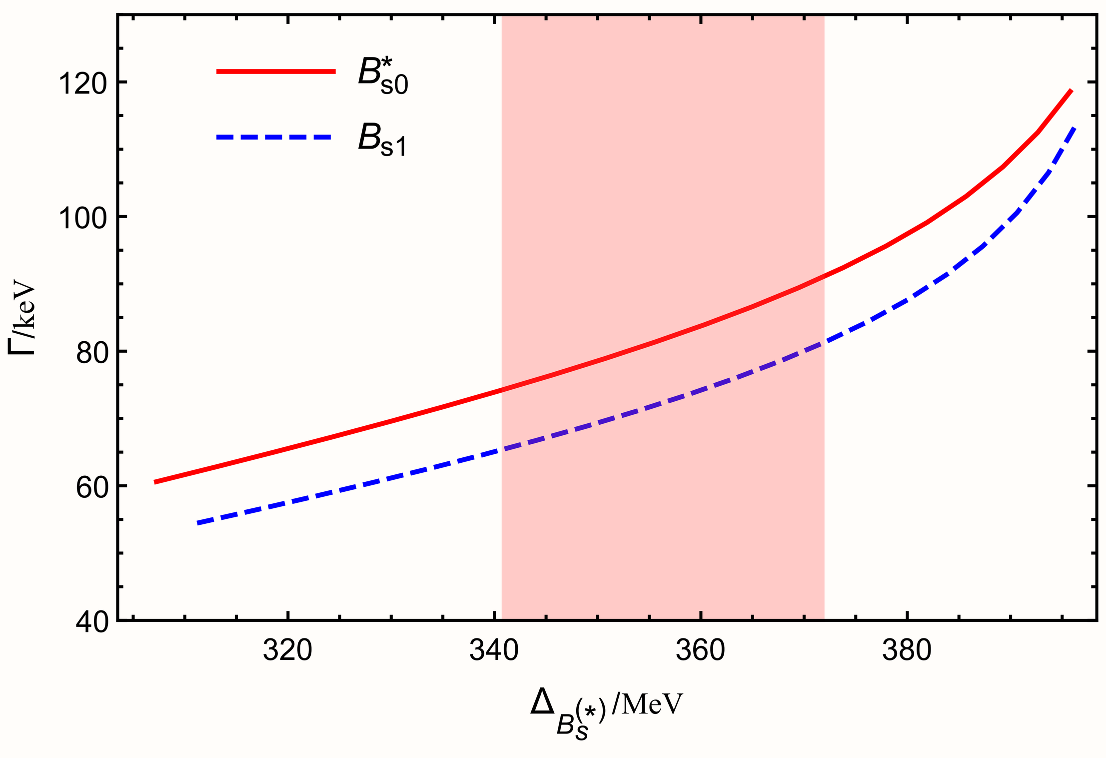

Figure 1: Dependence of the hadronic decay widths of the B^*_{s0} and B_{s1} on the mass differences $\Delta_{B_s} = M_{B^*_{s0}} - M_{B_s}$ and $\Delta_{B^*_s} = M_{B_{s1}} - M_{B^*_s}$

The matching requires

$$G_{sub}(M^2_{thr}, a(\mu)) = G_{CO}(M^2_{thr}, q_{max}) \ , \quad (2)$$

With this matching procedure, and considering the heavy-quark mass scaling of the low-energy constants (LECs), the B^*_{s0} and B_{s1} masses can be obtained in line with HQFS as listed in Table 1.

Table 1: Masses of the lowest positive-parity heavy-strange mesons given in units of MeV and GeV

Meson	Mass	g_1	g_2
D^*_{s0}	2318 (fixed)	9.4 ± 0.3	7.4 ± 0.1
D_{s1}	2458^{+15}_{-17}	$10.1^{+0.8}_{-0.9}$	7.9 ± 0.3
B^*_{s0}	5722 ± 14	$22.9^{+1.3}_{-1.5}$	$18.8^{+0.4}_{-0.5}$
B_{s1}	5774 ± 13	$22.5^{+1.3}_{-1.5}$	18.7 ± 0.5

Table 2: Hadronic partial decay widths of D^*_{s0}, D_{s1}, B^*_{s0} and B_{s1} as hadronic molecules (in units of keV)

Decay channel	Loops	π^0-η mixing	Full result
$D^*_{s0}\to D_s\pi^0$	50 ± 3	20 ± 2	132 ± 7
$D_{s1}\to D^*_s\pi^0$	37 ± 7	20 ± 3	111 ± 15
$B^*_{s0}\to B_s\pi^0$	15 ± 2	22 ± 3	75 ± 6
$B_{s1}\to B^*_s\pi^0$	16 ± 2	23 ± 3	76 ± 7

With the masses and the effective couplings, we can update the results in Ref. [3] of the partial decay widths of the D^*_{s0} and D_{s1} mesons and branching fractions and correct the results for the B^*_{s0} and B_{s1}.
The results for the isospin breaking hadronic partial decay widths are shown in Table 2, and those for the radiative partial decay widths are given in Table 3.
In Fig. 1, we show the dependence of the hadronic decay widths of the B^*_{s0} and B_{s1} on the mass differences $\Delta_{B_s} = M_{B^*_{s0}} - M_{B_s}$ and $\Delta_{B^*_s} = M_{B_{s1}} - M_{B^*_s}$, respectively. One clearly sees the quick increase of the results as the mass differences get larger.

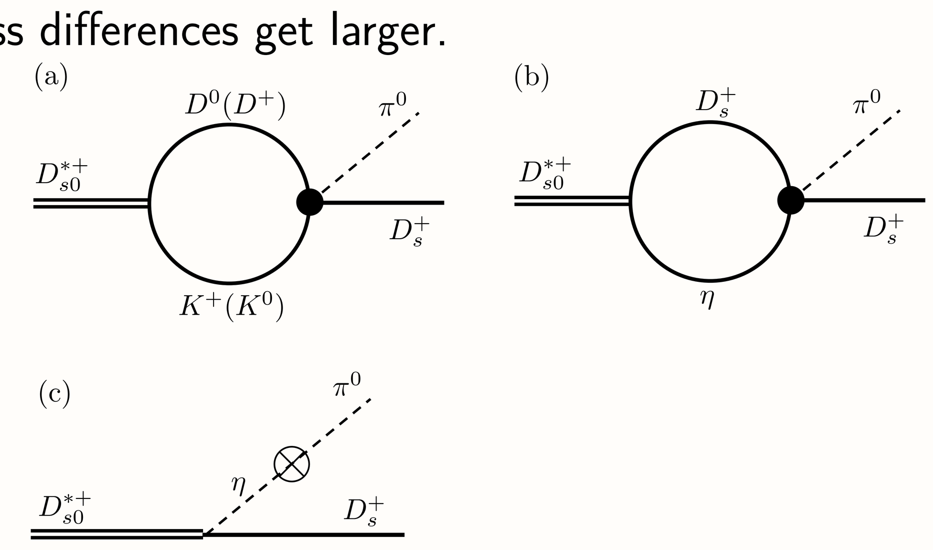

Figure 2: The diagrams for the hadronic decay mode $D^*_{s0}\to D^+_s\pi^0$. (a), with isospin conserving $D^{+(0)}K^{0(+)}\to D^+_s\pi^0$ four-point vertices, and (c) were considered in Ref. [3]. Here we consider all these three diagrams and four-point vertices with isospin breaking effects.

Table 3: Radiative partial decay widths of D^*_{s0}, D_{s1}, B^*_{s0} and B_{s1} as hadronic molecules (in units of keV).

Decay channel	EC	MM	CT	Full result
$D^*_{s0}\to D^*_s\gamma$	3.5 ± 0.3	0.06 ± 0.02	0.04	3.7 ± 0.3
$D_{s1}\to D_s\gamma$	13 ± 1	6.5 ± 0.6	0.1	42 ± 4
$D_{s1}\to D^*_s\gamma$	12 ± 2	0.8 ± 0.1	0.1	13 ± 2
$D_{s1}\to D^*_{s0}\gamma$	–	3.0 ± 0.6	?	?
$B^*_{s0}\to B^*_s\gamma$	58 ± 8	2.1 ± 0.3	0.02	59 ± 8
$B_{s1}\to B_s\gamma$	70 ± 10	41 ± 6	0.02	220 ± 31
$B_{s1}\to B^*_s\gamma$	110 ± 15	0.19 ± 0.02	0.03	100 ± 15
$B_{s1}\to B^*_{s0}\gamma$	–	0.03 ± 0.01	?	?

In Ref. [3], the hadronic decay widths are split into that from the π^0–η mixing, and that from DK loops due to the mass differences between the charged and neutral D and K mesons. The hadronic width obtained in that way for the $D^*_{s0}(2317)$ is (95±5) keV [3]. The width may also be related to the imaginary part of the pole in the complex energy plane. In Table 4 we give the poles obtained by considering isospin breaking in the T-matrix in the particle basis. One sees that the result Ref. [3] is smaller than that in Table 4. The main reason for the difference is that in the transition vertex $D^+K^0(D^0K^+)\to D_s\pi^0$ denoted by the solid circle in (a), there is also a subleading isospin breaking contribution. Here, we keep these isospin breaking terms in the four-point transition vertices as derived from the next-to-leading order chiral Lagrangian [6], and consider further Fig. 2 (b) for self-consistency.

Table 4: Masses and hadronic partial decay widths of D^*_{s0}, D_{s1}, B^*_{s0} and B_{s1} computed from searching for poles in the complex energy plane of the T-matrices in the particle basis.

Meson	Mass [MeV]	Hadronic width (pole) [keV]
D^*_{s0}	2318 (fixed)	120^{+18}_{-4}
D_{s1}	2458^{+15}_{-17}	102^{+27}_{-11}
B^*_{s0}	5722 ± 14	75^{+24}_{-9}
B_{s1}	5774 ± 13	74^{+23}_{-8}

Summary and conclusions

To summarize, we update the results reported in Ref. [3] for the widths of the lightest scalar heavy light mesons in the molecular approach. The results presented here should be useful for the search of the lowest positive-parity bottom-strange mesons, with the $B_s\pi^0$ and $B_s\gamma$ being the preferred searching channels for B^*_{s0} and B_{s1}, respectively, and revealing the internal structure of the charmed ones.

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