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The nature of the orbitally excited charmed-strange mesons through nonleptonic $B \to D^{(*)}D_{sJ}^{(*)}$ decays

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Abstract. The Belle Collaboration has recently reported a study of the decays $B \to D_{s1}(2536)^+\bar{D}^{(*)}$ and has given also estimates of relevant ratios between branching fractions of decays $B \to D^{(*)}D_{sJ}^{(*)}$ providing important information to check the structure of the $D_{s0}^*(2317)$, $D_{s1}(2460)$ and $D_{s1}(2536)$ mesons. The disagreement between experimental data and Heavy Quark Symmetry has been used as an indication that $D_{s0}^*(2317)$ and $D_{s1}(2460)$ mesons could have a more complex structure than the canonical $c\bar{s}$ one. We analyze these ratios within the framework of a constituent quark model, which allows us to incorporate the effects given by finite c-quark mass corrections. Our findings are that while the $D_{s1}(2460)$ meson could have a sizable non-$q\bar{q}$ component, the $D_{s0}^*(2317)$ and $D_{s1}(2536)$ mesons seem to be well described by a pure $q\bar{q}$ structure.

1 Introduction

The most recent analysis of the production of $D_{s1}(2536)^+$ in double charmed B meson decays has been reported by the Belle Collaboration in Ref. [1]. Using the latest measurements of the $B \to D^{(*)}D_{sJ}^{(*)}$ branching fractions [2] they calculate the ratios

$$\begin{aligned}
R_{D0} &= \frac{\mathcal{B}(B \to DD_{s0}^*(2317))}{\mathcal{B}(B \to DD_s)} = 0.10 \pm 0.03, \qquad R_{D^*0} = \frac{\mathcal{B}(B \to D^*D_{s0}^*(2317))}{\mathcal{B}(B \to D^*D_s)} = 0.15 \pm 0.06, \\
R_{D1} &= \frac{\mathcal{B}(B \to DD_{s1}(2460))}{\mathcal{B}(B \to DD_s^*)} = 0.44 \pm 0.11, \qquad R_{D^*1} = \frac{\mathcal{B}(B \to D^*D_{s1}(2460))}{\mathcal{B}(B \to D^*D_s^*)} = 0.58 \pm 0.12. \quad (1)
\end{aligned}$$

In addition, the same ratios are calculated for $B \to D^{(*)}D_{s1}(2536)^+$ decays, using combined results by the BaBar [3] and Belle [1] Collaborations

$$R_{D1'} = \frac{\mathcal{B}(B \to DD_{s1}(2536))}{\mathcal{B}(B \to DD_s^*)} = 0.049 \pm 0.010, \qquad R_{D^*1'} = \frac{\mathcal{B}(B \to D^*D_{s1}(2536))}{\mathcal{B}(B \to D^*D_s^*)} = 0.044 \pm 0.010. \quad (2)$$

From a theoretical point of view, this kind of decays can be described using the factorization approximation. This amounts to evaluate the matrix element which describes the $B \to D^{(*)}D_{sJ}^{(*)}$ weak decay process as a product of two matrix elements, one for the B weak transition into the $D^{(*)}$ meson and the second one for the weak creation of the $c\bar{s}$ pair which makes the $D_{sJ}^{(*)}$ meson. The latter matrix element is proportional to the corresponding $D_{sJ}^{(*)}$ meson decay constant and therefore these processes can give information about the $D_{sJ}^{(*)}$ structure.

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According to Ref. [4], within the factorization approximation and in the heavy quark limit, the ratios R_{D0} and R_{D1} can be written as

$$R_{D0} = R_{D^*0} = \left| \frac{f_{D^*_{s0}(2317)}}{f_{D_s}} \right|^2, \qquad R_{D1} = R_{D^*1} = \left| \frac{f_{D_{s1}(2460)}}{f_{D^*_s}} \right|^2, \tag{3}$$

where the phase space effects are neglected because they are subleading in the heavy quark expansion. Now, in the heavy quark limit one has $f_{D^*_{s0}} = f_{D_{s1}}$ and $f_{D_s} = f_{D^*_s}$ and so one would predict $R_{D0} \approx R_{D1}$. Moreover, there are several estimates of the decay constants, always in the heavy quark limit, that predict for P-wave $j_q = 1/2$ states similar decay constants as for the ground state mesons (i.e. D_s and D^*_s), and very small decay constants for P-wave, $j_q = 3/2$ states.

These approximations lead to ratios of order one for $D^*_{s0}(2317)$ and $D_{s1}(2460)$, in strong disagreement with experiment, and ratios very small for the $D_{s1}(2536)$ meson, which follows the expectations. This fact has motivated to argue that either those two states are not canonical $c\bar{s}$ mesons or that the factorization approximation does not hold for decays involving those particles.

Leaving aside that the factorization approximation has been recently analyzed finding that it works well in these kind of processes [5], we will concentrate in the influence of the effect of the finite c-quark mass in the theoretical predictions.

2 Constituent quark model

We work within the framework of the constituent quark model described in Ref. [6]. It has recently been applied to mesons containing heavy quarks in Refs. [7,8]. It has also been used successfully in the description of semileptonic $B \to D^{**}$ and $B_s \to D^{**}_s$ decays in Ref. [9], which provides us with confidence that the model describes well the weak decay transitions $B \to D^{(*)}$ which is one of the terms in the calculation of $B \to D^{(*)} D^{(*)}_{sJ}$ decays.

The model is not able to reproduce the spectrum of the P-wave charmed and charmed-strange mesons. The inconsistency with experiment is mainly due to the fact that the mass splittings between the $D^*_{s0}(2317)$, $D_{s1}(2460)$ and $D_{s1}(2536)$ mesons are not well reproduced. The same problem appears in other quark models but also in Lattice QCD calculations [10].

In order to improve these mass splittings we follow the proposal of Ref. [11] and include one-loop corrections to the OGE potential as derived by Gupta *et al.* [12]. This corrections shows a spin-dependent term which affects only mesons with different flavor quarks.

Table 1 shows the masses of well established charmed and charmed-strange mesons predicted by the constituent quark model and those including one-loop corrections to the OGE potential.

Table 1. Masses of well established charmed and charmed-strange mesons predicted by the constituent quark model (α_s) and those including one-loop corrections to the OGE potential (α_s^2).

	Charmed					
	$j_q^P = 1/2^-$		$j_q^P = 1/2^+$		$j_q^P = 3/2^+$	
	0^-	1^-	0^+	1^+	1^+	2^+
This work (α_s)	1896	2017	2516	2596	2466	2513
This work (α_s^2)	1896	2014	2362	2535	2499	2544
Exp.	1867.7 ± 0.3	2010.25 ± 0.14	2403 ± 38	2427 ± 36	2423.4 ± 3.1	2460.1 ± 4.4
	Charmed-strange					
	$j_q^P = 1/2^-$		$j_q^P = 1/2^+$		$j_q^P = 3/2^+$	
	0^-	1^-	0^+	1^+	1^+	2^+
This work (α_s)	1984	2110	2510	2593	2554	2591
This work (α_s^2)	1984	2104	2383	2570	2560	2609
Exp.	1969.0 ± 1.4	2112.3 ± 0.5	2318.0 ± 1.0	2459.6 ± 0.9	2535.12 ± 0.25	2572.6 ± 0.9

Table 2. Theoretical predictions of decay constants for pseudoscalar and vector charmed mesons. QL≡Quenched Lattice calculations.

Approach	f_D (MeV)	f_{D_s} (MeV)	f_{D_s}/f_D
Ours	$297.019^{(\dagger)}$	$416.827^{(\dagger)}$	$1.40^{(\dagger)}$
	$214.613^{(\ddagger)}$	$286.382^{(\ddagger)}$	$1.33^{(\ddagger)}$
Experiment	206.7 ± 8.9	257.5 ± 6.1	1.25 ± 0.06
Approach	f_{D^*} (MeV)	$f_{D_s^*}$ (MeV)	$f_{D_s^*}/f_{D^*}$
Ours	$247.865^{(\dagger)}$	$329.441^{(\dagger)}$	$1.33^{(\dagger)}$
QL (Italy)	234	254	$1.04 \pm 0.01^{+2}_{-4}$
QL (UKQCD)	$245 \pm 20^{+0}_{-2}$	$272 \pm 16^{+0}_{-20}$	1.11 ± 0.03

The charmed and charmed-strange 0^+ states are sensitive to the one-loop corrections of the OGE potential which bring their masses closer to experiment. However, the spin dependent corrections to the OGE potential, are not enough to solve the puzzle in the 1^+ sector. In Ref. [8] the 1^+ $c\bar{s}$ states were coupled to a $c\bar{s}n\bar{n}$ tetraquark structure. We found that the $J^P = 1^+$ $D_{s1}(2460)$ has an important non-$q\bar{q}$ contribution whereas the $J^P = 1^+$ $D_{s1}(2536)$ is almost a pure $q\bar{q}$ state.

3 Nonleptonic $B \to D^{(*)} D_{sJ}^{(*)}$ decays

In this section we present our results for the ratios in Eqs. (1) and (2). Using experimental masses we obtain the ratios

$$R_{D0} = 0.9008 \times \left|\frac{f_{D_{s0}^*(2317)}}{f_{D_s}}\right|^2, \qquad R_{D^*0} = 0.7166 \times \left|\frac{f_{D_{s0}^*(2317)}}{f_{D_s}}\right|^2,$$
$$R_{D1} = 0.7040 \times \left|\frac{f_{D_{s1}(2460)}}{f_{D_s^*}}\right|^2, \qquad R_{D^*1} = 1.0039 \times \left|\frac{f_{D_{s1}(2460)}}{f_{D_s^*}}\right|^2,$$
$$R_{D1'} = 0.6370 \times \left|\frac{f_{D_{s1}(2536)}}{f_{D_s^*}}\right|^2, \qquad R_{D^*1'} = 0.9923 \times \left|\frac{f_{D_{s1}(2536)}}{f_{D_s^*}}\right|^2, \tag{4}$$

where the numerical factors, assumed to be one in the heavy quark limit, are determined by weak matrix elements and the corresponding phase space integrals. As we can see, one cannot ignore phase space and weak matrix element corrections.

The ratios can be written as functions of decay constants. The decay constants of pseudoscalar and vector mesons in charmed and charmed-strange sectors are given in Table 2. We compare our results with the experimental data and those predicted by different approaches. Our original values are those with the symbol (†). The decay constants of vector mesons agree with other approaches. In the case of the pseudoscalar mesons, the decay constants are simply too large.

The reason for that is the following: Our CQM presents an OGE potential which has a spin-spin contact hyperfine interaction. It is conveniently regularized to determine the hyperfine splittings in the different flavor sectors, achieving a good agreement in all of them. While most of the physical observables are insensitive to the regularization of this delta term, those related with annihilation processes are affected. The effect is very small for the different partial waves except for the $^1S_0$ channel in which the delta term is attractive.

One should expect the wave functions of the 1^1S_0 and 1^3S_1 states to be very similar except for the very short range. The values with the symbol (‡) in Table 2 are referred to the pseudoscalar decay constants which have been calculated using the wave function of the corresponding $^3S_1$ state. We recover the agreement with the experiment.

Table 3. Decay constants calculated within the CQM including 1-loop QCD corrections to the OGE potential and non-$q\bar{q}$ structure in channel 1^+.

Meson	f_D (MeV)	$\sqrt{M_D} f_D$ (GeV$^{3/2}$)
$D_{s0}^*(2317)$	118.706	0.181
$D_{s1}(2460)$	165.097	0.259
$D_{s1}(2536)$	59.176	0.094

Table 4. Ratios of branching fractions for nonleptonic decays $B \to D^{(*)} D_{sJ}^{(*)}$.

	$X \equiv D_{s0}^*(2317)$		$X \equiv D_{s1}(2460)$		$X \equiv D_{s1}(2536)$	
	The.	Exp.	The.	Exp.	The.	Exp.
$\mathcal{B}(B \to DX)/\mathcal{B}(B \to DD_s)$	$0.19^{(*)}$	0.10 ± 0.03	-	-	-	-
$\mathcal{B}(B \to D^*X)/\mathcal{B}(B \to D^*D_s)$	$0.15^{(*)}$	0.15 ± 0.06	-	-	-	-
$\mathcal{B}(B \to DX)/\mathcal{B}(B \to DD_s^*)$	-	-	0.177	0.44 ± 0.11	0.021	0.049 ± 0.010
$\mathcal{B}(B \to D^*X)/\mathcal{B}(B \to D^*D_s^*)$	-	-	0.252	0.58 ± 0.12	0.032	0.044 ± 0.010

Table 3 summarizes the remaining decay constants needed for the calculation we are interested in. Our results for the decay constants clearly deviate from the ones obtained in the infinite heavy quark mass limit. That was already noticed in Ref. [4], where the authors, using the experimental ratios, estimated that $f_{D_{s0}^*(2317)} \sim \frac{1}{3} f_{D_s}$ and $f_{D_{s0}^*(2317)} \sim f_{D_{s1}(2460)}$ instead. We obtain $f_{D_{s0}^*(2317)}/f_{D_s} = 0.36$ and $f_{D_{s0}^*(2317)} \sim 0.72 f_{D_{s1}(2460)}$.

Finally, we show in Table 4 our results for the ratios. The symbol $(*)$ indicates that the ratios have been calculated using the experimental pseudoscalar decay constant in Table 2. We get results close to or within the experimental error bars for the $D_{s0}^*(2317)$ meson, which to us is an indication that this meson could be a canonical $c\bar{s}$ state.

The incorporation of the non-$q\bar{q}$ degrees of freedom in the $J^P = 1^+$ channel, enhances the $j_q = 3/2$ component of the $D_{s1}(2536)$ meson and it gives rise to ratios in better agreement with experiment. Note that this state is still an almost pure $q\bar{q}$ state in our description [8].

The $D_{s1}(2460)$ has a sizable non-$q\bar{q}$ component which contributes to the decays under study. We have computed the ratios considering only the contribution coming from the $q\bar{q}$ structure of the $D_{s1}(2460)$ meson. The ratios are a factor 2 below the experimental ones.

References

1. T. Aushev *et al.*, Phys. Rev. D **83**, (2011) 051102.
2. K. Nakamura *et al.*, J. Phys. G: Nucl. Part. Phys. **37**, (2010) 075021.
3. B. Aubert *et al.*, Phys. Rev. D **77**, (2008) 011102.
4. Alakabha Datta and P.J. O'Donnell, Phys. Lett. B **572**, (2003) 164-170.
5. Zumin Luo and Jonathan L. Rosner, Phys. Rev. D **64**, 094001 (2001).
6. J. Vijande, F. Fernández and A. Valcarce, J. Phys. G: Nucl. Part. Phys. **31**, (2005) 481.
7. J. Segovia, A.M. Yasser, D.R. Entem and F. Fernández, Phys. Rev. D **78**, (2008) 114033.
8. J. Segovia, A.M. Yasser, D.R. Entem and F. Fernández, Phys. Rev. D **80**, (2009) 054017.
9. J. Segovia, C. Albertus, D.R. Entem, F. Fernández, E. Hernández and M.A. Pérez-García, Phys. Rev. D **84**, (2011) 094029.
10. D. Mohler and R.M. Woloshyn, Phys. Rev. D **84**, (2011) 054505.
11. Olga Lakhina and Eric S. Swanson, Phys. Lett. B **650**, (2007) 159-165.
12. Suraj N. Gupta and Stanley F. Radford, Phys. Rev. D **24**, (1981) 2309.