Comment on
“Study of $D_{sJ}$ decays to $D^*K$ in inclusive $e^+e^-$ interactions”

Eef van Beveren$^1$ and George Rupp$^2$

$^1$Centro de Física Computacional, Departamento de Física, Universidade de Coimbra, P-3004-516 Coimbra, Portugal eef@teor.fis.uc.pt

$^2$Centro de Física das Interacções Fundamentais, Instituto Superior Técnico, Technical University of Lisbon, Edifício Ciência, P-1049-001 Lisboa Codex, Portugal george@ist.utl.pt

PACS number(s): 14.40.Lb, 14.40.Ev, 13.25.Ft, 12.39.Pn

August 10, 2009

Abstract

We comment on the recent observation of the decay mode $D_{sJ}^*(2860)^+ \rightarrow D^*K$ by the BABAR Collaboration [B. Aubert et al. (BABAR Collaboration), arXiv:0908.0806], and contest their peremptory conclusion that the data exclude a $0^+$ assignment for the $D_{sJ}^*(2860)^+$. In particular, we argue that the observed branching fraction $\mathcal{B}(D_{sJ}^*(2860)^+ \rightarrow D^*K)/\mathcal{B}(D_{sJ}^*(2860)^+ \rightarrow DK) = 1.1 \pm 0.15 \pm 0.19$ supports the existence of two largely overlapping resonances at about 2.86 GeV, namely a pair of radially excited tensor ($2^+$) and scalar ($0^+$) $c\bar{s}$ states. This scenario is further justified by comparing with the corresponding excited charmonium states. Also other aspects of the charm-strange spectrum are discussed.

In a very recent study of decays of charm-strange mesons [1], the BABAR Collaboration for the first time observed the decay $D_{sJ}^*(2860)^+ \rightarrow D^*K$. When the $D_{sJ}^*(2860)$ meson was discovered by BABAR [2], only the $DK$ decay mode was detected, which made an assignment as a radially excited scalar $c\bar{s}$ meson plausible [3–5], though other configurations such as a $3^-$ state [5–7] could not be excluded. For a discussion of additional options, see Ref. [8]. The now observed $D^*K$ mode seems to exclude the $0^+$ scenario for the $D_{sJ}^*(2860)^+$, as concluded by BABAR. However, in the following we shall show that the true situation may be subtler, involving two overlapping resonances, one scalar ($J^P = 0^+$) and one tensor ($J^P = 2^+$) charm-strange meson.

The BABAR angular analysis of the $D_{sJ}^*(2860)^+ \rightarrow D^*K$ decays supports natural parity for the resonance, i.e., $J^P = 0^+, 1^-, 2^+, 3^-, \ldots$. Ruling out for the moment the scalar hypothesis, experiment also seems to eliminate the solution of Refs. [6, 7], viz. $3^-$ ($1^3D_3$). Namely, the
measured [1] branching ratio $\mathcal{B}(D_{sJ}^*(2860)^+ \to D^*K)/\mathcal{B}(D_{sJ}^*(2860)^+ \to DK) = 1.1 \pm 0.15 \pm 0.19$ is not compatible with the value 0.39 predicted for a $3^-$ state in Ref. [6, 7]. *A fortiori*, a $1^3D_1$ assignment can be excluded, too, as it would imply a branching ratio of only 0.06 in the latter model analysis. As for the other $1^-$ state ($2^3S_1$), the predicted [6, 7] branching ratio of 1.23 is in agreement with experiment (though see below). However, one expects this vector meson to have a considerably lower mass, close to 2.7 GeV, which makes the $D_{sJ}^*(2700)^+$ [9], now confirmed by BABAR and denoted $D_{sJ}^*(2710)^+$ [1], a much better candidate.

These results appear to suggest that the $2^+$ ($2^3P_2$) assignment for the $D_{sJ}^*(2860)^+$ is the most likely one. However, the inevitable mixing of the spectroscopic $2^3P_2$ and $1^3F_2$ states, resulting in two $2^+$ states, complicates the analysis of the tensor hypothesis. Similar complications arise in the vector case, with $2^3S_1$ and $1^3D_1$ mixing, and the axial-vector case, with $n^3P_1$ and $n^1P_1$ mixing, for any $n$, when dealing with $K_1, D_1, D_{s1}, \ldots$ mesons, which are not C-parity eigenstates. The latter mixing can be large [10, 11]. Moreover, in Ref. [11] it has been shown, that coupled channels naturally induce such an axial-vector mixing, and tend to give rise to one state that decouples to a large extent, while the other one is subject to a sizable coupled-channel mass shift, of the order of 80 MeV downwards. Since in our multichannel analysis of the $D_{sJ}^*(2860)^+$ [3] we found a very similar mass shift for the bare $2^3P_0$ state, we expect that a full coupled-channel calculation of the, in our model, degenerate bare $2^3P_2$ and $1^3F_2$ states will result in one physical $2^+ \ c\bar{s}$ resonance very close to the shifted $2^3P_0$ state, and so to the observed $D_{sJ}^*(2860)^+$, and another one at roughly 2.92 GeV.

Rather than relying upon the coupling constants used in Refs. [6, 7], since no information is available about the couplings of radially excited heavy-light mesons to low-lying states [6], we shall use the formalism based on harmonic-oscillator expansions developed in Ref. [12]. In this framework, all couplings of arbitrary excited states to all two-meson decay channels can be straightforwardly computed. Then, we get the couplings squared $(2^3P_2 \to D^*K) : (2^3P_2 \to DK) : (1^3F_2 \to D^*K) : (1^3F_2 \to DK) = 21 : 14 : 4 : 6$. If we neglect phase-space effects for a first rough estimate, we get the branching ratios $\mathcal{B}(2^3P_2 \to D^*K)/\mathcal{B}(2^3P_2 \to DK) \sim 1.5$, which is somewhat too large, and $\mathcal{B}(1^3F_2 \to D^*K)/\mathcal{B}(1^3F_2 \to DK) \sim 0.67$, which is somewhat too small. However, the situation changes dramatically for admixtures because of interference. When we assume an admixture of only 2% $1^3F_2$ and 98% $2^3P_2$, we find $\mathcal{B}(2^3P_2 \to D^*K)/\mathcal{B}(2^3P_2 \to DK) \sim 2.1$, whereas an admixture of 10%, respectively 90%, gives $\mathcal{B}(2^3P_2 \to D^*K)/\mathcal{B}(2^3P_2 \to DK) \sim 3.2$.

Of course, phase space may change those numbers considerably, by reducing the $D^*K$ rate, according to the usual formulae based on perturbation theory. However, also the predicted $DK$ rate may be considerably smaller, since channels that are wide open tend to fade out quite fast for further increasing momenta, as confirmed by open-charm decays of charmonium [13]. So if we take the branching ratios of 2–3 at face value, there also is a problem with the $2^+$ assignment. A possible way out is by supposing that there is a scalar ($2^3P_0$) $c\bar{s}$ resonance as well, largely overlapping with the $D_{sJ}^*(2860)^+$. Since the scalar does not decay into $D^*K$, a combination of tensor and scalar will have a smaller branching ratio $D^*K/DK$. In view of the above quoted result for this branching ratio of the BABAR Collaboration in Ref. [1], we thus need a large $2^3P_0$ contribution to the $D_{sJ}^*(2860)^+$ resonance, already for small to modest contributions of an unavoidable $c\bar{s} \ 1^3F_2$ component to the $c\bar{s} \ 2^+$ state at 2.860 GeV.

We can do an analogous analysis for the $2^3S_1$ state. Using the same scheme [12] as above, we get the couplings squared $(2^3S_1 \to D^*K) : (2^3S_1 \to DK) = 2 : 1$, resulting in a branching ratio of 2. So in this scenario we would also need a $2^3P_0$ contribution in order to agree with experiment. But more importantly, the $2^3S_1$ state is unlikely to overlap with the $2^3P_0$, as it should be significantly lighter.
Coming back to the $2^+/0^+$ scenario, how reasonable is it to assume that the $2^3P_2$ and $2^3P_0$ states overlap? From the point of view of possible spin-orbit forces, these are generally accepted to be small for radially excited states and less important than e.g. coupled-channel effects. On the other hand, browsing the PDG tables [9] we do not find any example of a clearly established pair of $2^3P_2$ and $2^3P_0$ states above threshold for OZI-allowed decay. However, charmonium may be an exception, comprising the $\chi_c(2P)$ with a mass of $3929 \pm 5 \pm 2$ MeV and a width of $29 \pm 10 \pm 2$ MeV, and the $X(3945)$ with a mass of $3916 \pm 6$ MeV and a width of $40^{+18}_{-13}$ MeV [9]. Although most quantum numbers of the latter resonance are undetermined so far, its positive $C$-parity [9] makes it a very good candidate for the $2^3P_0 c\bar{c}$ state (also see Ref. [14]). So we may have here a pair of $2^3P_2$ and $2^3P_0$ resonances with central masses (marginally) within each other’s error bars. Moreover, there may even be an indication of two different $D_{sJ}(2860)^+$ resonances in the very $BABAR$ data [1], as their $DK$ fit tends to peak at a slightly lower mass (2860 MeV) than the $DK + DK^*$ (2860–2866 MeV) and $DK^*$ ones (2865 MeV) (see Table II of Ref. [1]).

In the coupled-channel calculation for $J^P = 0^+$ of Ref. [3] we definitely obtain a resonance at 2.847 GeV with a width of about 50 MeV (see Fig. 1). A calculation for $J^P = 2^+$ has not been performed yet. But, since the bare states of $2^+$ and $0^+$ are degenerate in our coupled-channel model and come at 2.925 GeV, we expect to find a resonance for $2^+$ very near the $0^+$ resonance and with a comparable width.

In conclusion, we would like to stress the importance of the experimental effort to further complete the $c\bar{s}$ spectrum, which has been receiving an enormous boost by $BABAR$ in recent years. However, it is crucial that the $D_{sJ}(2860)^+$ and the newly discovered $D_{sJ}(3040)^+$ get confirmed and their quantum numbers pinned down by other collaborations. In particular, a possible experimental disentangling of the $D_{sJ}(2860)^+$ structure in a scalar and a tensor part as suggested here would be an enormous step forward in meson spectroscopy.

We are indebted to Prof. Xiang Liu of Lanzhou University for drawing our attention to

![Figure 1: The experimental line shape of $DK$ in the invariant–mass interval $2.77 – 2.94$ GeV from data published by the BABAR Collaboration in Ref. [2] (in size adjusted to the theoretical curve) and the result ( ) of our coupled-channel model for inelastic $DK$ scattering.](image-url)
the new BABAR data. This work was supported by the Fundação para a Ciência e a Tecnologia of the Ministério da Ciência, Tecnologia e Ensino Superior of Portugal, under contract CERN/FP/83502/2008.

References

[1] B. Aubert [BaBar Collaboration], *Study of $D_{sJ}$ decays to $D^*K$ in inclusive $e^+e^-$ interactions*, arXiv:0908.0806 [hep-ex].

[2] B. Aubert [BABAR Collaboration], *Observation of a new $D_s$ meson decaying to $DK$ at a mass of 2.86-GeV/c^2*, Phys. Rev. Lett. 97, 222001 (2006) arXiv:hep-ex/0607082.

[3] E. van Beveren and G. Rupp, *New BABAR state $D_{sJ}(2860)$ as the first radial excitation of the $D_{s0}(2317)$*, Phys. Rev. Lett. 97, 202001 (2006) arXiv:hep-ph/0606110.

[4] F. E. Close, C. E. Thomas, O. Lakhina, and E. S. Swanson, *Canonical Interpretation of the $D_{sJ}(2860)$ and $D_{sJ}(2690)$*, Phys. Lett. B 647, 159 (2007) arXiv:hep-ph/0608139.

[5] B. Zhang, X. Liu, W. Z. Deng, and S. L. Zhu, *$D_{sJ}(2860)$ and $D_{sJ}(2715)$*, Eur. Phys. J. C 50, 617 (2007) arXiv:hep-ph/0609013.

[6] P. Colangelo, F. De Fazio and S. Nicotri, *$D_{sJ}(2860)$ resonance and the $s_\ell^P = \frac{5}{2}^- c\bar{s}$ ($c\bar{q}$) doublet*, Phys. Lett. B 642, 48 (2006) arXiv:hep-ph/0607245.

[7] F. De Fazio, *Investigating quantum numbers of new $c\bar{s}$ states*, Nucl. Phys. Proc. Suppl. 186, 363 (2009) arXiv:0810.3549 [hep-ph].

[8] A. Zhang, *Implications to $c\bar{s}$ assignments of $D_{s1}(2700)\pm$ and $D_{sJ}(2860)$*, arXiv:0904.2453 [hep-ph].

[9] C. Amsler *et al.* [Particle Data Group Collaboration], *Review of Particle Physics*, Phys. Lett. B 667, 1 (2008).

[10] S. Godfrey and Richard Kokoski, *The Properties Of P Wave Mesons With One Heavy Quark*, Phys. Rev. D 43, 1679 (1991).

[11] E. van Beveren and G. Rupp, *Continuum bound states K-long, $D_1(2420)$, $D_{s1}(2536)$ and their partners K-short, $D_1(2400)$, $D_{sJ}^*(2463)$*, Eur. Phys. J. C 32, 493 (2004) arXiv:hep-ph/0306051.

[12] E. van Beveren, *Recoupling matrix elements and decay*, Z. Phys. C 17, 135 (1983) arXiv:hep-ph/0602248.

[13] E. van Beveren and G. Rupp, *Production of hadron pairs in $e^+e^-$ annihilation near the $K^+K^-$, $DD$, $BB$ and $\Lambda_c^+\Lambda_c^-$ thresholds*, arXiv:0908.0242 [hep-ph].

[14] E. van Beveren, J. E. G. Costa, F. Kleefeld and G. Rupp, *From the Kappa via the $D_{s0}^*(2317)$ to the $\chi_{c0}$: connecting light and heavy scalar mesons*, Phys. Rev. D 74, 037501 (2006) arXiv:hep-ph/0509351.