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Properties of the D_{sJ} states

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Abstract. Recent measurements involving the newly discovered D_{sJ} particles are reported. The results of D_{sJ} production and decay branching fraction measurements are shown. Possible spin-parity and quark content assignments of D_{sJ} mesons are discussed. The results are based on a large data sample recorded by the Belle detector at the KEKB e^+e^- collider.

1. Introduction

A narrow $D^*_{sJ}(2317)^+$ resonance decaying to the $D_s\pi^0$ final state has been observed by the BaBar collaboration [1] in e^+e^- continuum interactions. Later the CLEO collaboration observed a nearby narrow $D_{sJ}(2460)^+$ resonance decaying to the $D^*_s\pi^0$ final state [2]. The Belle experiment has confirmed the existence of these two resonances [3, 4]. Comparing the measured D_{sJ} decay branching fractions and upper limits, the quantum numbers have been classified tentatively as $J^P = 0^+$ for $D^*_{sJ}(2317)^+$ and $J^P = 1^+$ for $D_{sJ}(2460)^+$. However, the measured masses of these resonances are significantly lower than the values predicted within potential models for 0^+ and 1^+ states [5]. There has been a significant effort to explain the surprising D_{sJ} masses [5], and some authors have discussed the possibility of four-quark content in the D_{sJ} states. To clarify the behaviors of the D_{sJ} states the Belle collaboration has searched for B decays to two-body final states involving the combination of a D^+_{sJ} meson and a D, D^*, kaon or pion.

2. $B \to \bar{D}^{(*)} D_{sJ}$ decays

With a data sample of 253 fb^{-1} collected with the Belle detector, the $B \to \bar{D} D_{sJ}$ decay modes are measured with improved accuracy (Belle previously published the observation of these decays with 140 fb^{-1} of data [4]) and new decay modes $B \to \bar{D}^* D_{sJ}$ are observed. These processes are described by conventional tree diagrams, similar to the $B \to \bar{D}^{(*)} D_s$ decays. D_{sJ} candidates are reconstructed in the modes $D_s^{(*)}\pi^0$, $D_s^{(*)}\gamma$ and $D_s^{(*)}\pi^+\pi^-$.

The results of the combined data fit (isospin invariance is assumed to combine decay channels) are listed in Table 1. From these measurements we obtain the branching fraction ratio: $\mathcal{B}(D_{sJ}(2460)^+ \to D_s^+\gamma)/\mathcal{B}(D_{sJ}(2460)^+ \to D_s^{*+}\pi^0) = 0.43 \pm 0.08 \pm 0.04$.

The efficiency-corrected helicity angle [4] distributions are consistent with expectations for the $J = 0$ hypothesis for $D^*_{sJ}(2317) \to D_s\pi^0$ decay (Fig. 1, left) and with expectations for the $J = 1$ hypothesis for $D_{sJ}(2460) \to D_s\gamma$ decay (Fig. 1, right).

Table 1. Branching fractions and signal significances for the combined fit results.

Decay channel	$\mathcal{B}$, 10^{-4}	Significance
$B \to \bar{D} D^*_{sJ}(2317)$ $[D_s\pi^0]$	$10.1 \pm 1.5 \pm 3.0$	9.5σ
$B \to \bar{D} D^*_{sJ}(2317)$ $[D^*_s\gamma]$	$4.0^{+1.5}_{-1.4} (< 8.4)$	3.5σ
$B \to \bar{D} D_{sJ}(2460)$ $[D^*_s\pi^0]$	$14.8^{+2.8}_{-2.5} \pm 4.4$	8.6σ
$B \to \bar{D} D_{sJ}(2460)$ $[D_s\gamma]$	$6.4 \pm 0.8 \pm 1.9$	11σ
$B \to \bar{D} D_{sJ}(2460)$ $[D^*_s\gamma]$	$2.6^{+1.1}_{-1.0} (< 5.7)$	3.0σ
$B \to \bar{D} D_{sJ}(2460)$ $[D_s\pi^+\pi^-]$	$1.0^{+0.5}_{-0.4} (< 2.3)$	2.6σ
$B \to \bar{D} D_{sJ}(2460)$ $[D_s\pi^0]$	$0.2^{+0.7}_{-0.5} (< 1.7)$	-
$B \to \bar{D}^* D^*_{sJ}(2317)$ $[D_s\pi^0]$	$3.1^{+2.1}_{-1.7} (< 8.5)$	2.0σ
$B \to \bar{D}^* D_{sJ}(2460)$ $[D^*_s\pi^0]$	$28.7^{+7.4}_{-6.4} \pm 8.6$	6.9σ
$B \to \bar{D}^* D_{sJ}(2460)$ $[D_s\gamma]$	$12.7^{+2.2}_{-2.0} \pm 3.8$	10σ

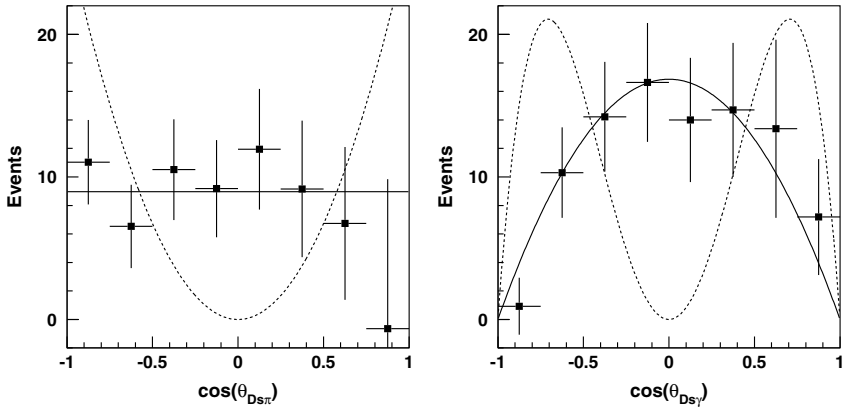

Figure 1. The efficiency-corrected $\cos\theta_{\rm hel}$ distributions for $D_{sJ}(2317) \to D_s\pi^0$ (left) and $D_{sJ}(2460) \to D_s\gamma$ (right) decays. Solid and dashed curves are predictions: for the $J = 0$ and $J = 1$ hypotheses of $D^*_{sJ}(2317)$; $J = 1$ and $J = 2$ hypotheses of $D_{sJ}(2460)$, respectively.

3. $\bar{B}^0 \to D^+_{sJ}K^-$ and $\bar{B}^0 \to D^-_{sJ}\pi^+$ decays

The decays $\bar{B}^0 \to D^+_{sJ}K^-$ and $\bar{B}^0 \to D^-_{sJ}\pi^+$ are studied by the Belle collaboration for the first time with 140 fb^{-1} of data. The $\Delta M(D_{sJ}) \equiv M(D^+_s\pi^0(/\gamma)) - M(D^+_s)$ distributions for the various $D^+_{sJ}K^-$ and $D^-_{sJ}\pi^+$ combinations are shown in Fig. 2 for candidates from the B signal region. A clear $\bar{B}^0 \to D^*_{sJ}(2317)^+K^-$ signal is observed; no significant signals are observed in the remaining modes. The branching fractions, upper limits and significances for these decay channels are listed in Table 2.

The $\bar{B}^0 \to D^+_{sJ}K^-$ decay is generally described by the W exchange diagram (Fig. 3a) or, alternatively, the tree diagram with final state interaction (Fig. 3b). If the D_{sJ} mesons have a four-quark component, then the tree diagram with $s\bar{s}$ pair creation (shown in Fig. 3c) may also contribute.

Assuming the approximate values of D_{sJ} decay branching fractions ($\mathcal{B}(D^*_{sJ}(2317)^+ \to D^+_s\pi^0) \sim 100\%$, $\mathcal{B}(D_{sJ}(2460)^+ \to D^+_s\gamma) \sim 30\%$), we conclude that $\mathcal{B}(\bar{B}^0 \to D^*_{sJ}(2317)^+K^-)$ is of the same order of magnitude as $\mathcal{B}(\bar{B}^0 \to D^+_sK^-)$ but at least a factor of two larger than $\mathcal{B}(\bar{B}^0 \to D_{sJ}(2460)^+K^-)$.

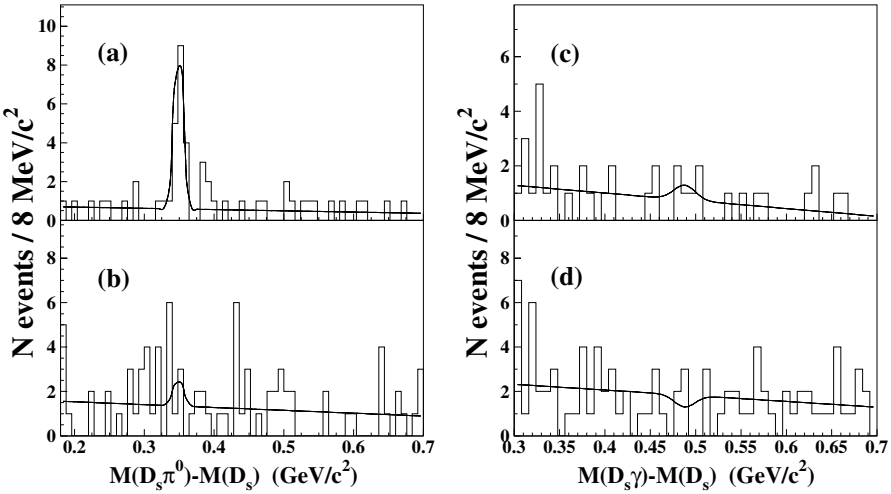

Figure 2. $\Delta M(D_{sJ})$ distributions for $\bar{B}^0$ decays to (a) $D^*_{sJ}(2317)^+K^-$, (b) $D^*_{sJ}(2317)^-\pi^+$, (c) $D_{sJ}(2460)^+K^-$ and (d) $D_{sJ}(2460)^-\pi^+$.

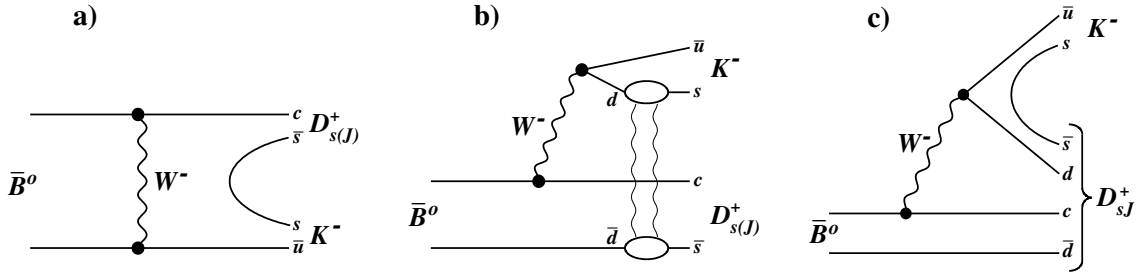

Figure 3. Diagrams describing $\bar{B}^0 \to D^+_{sJ}K^-$ decay.

Table 2. Branching fractions and signal significances for the B decays to $D^+_{sJ}K^-$ and $D^-_{sJ}\pi^+$ final states.

Decay channel	$\mathcal{B}$, 10^{-5}	Significance
$\bar{B}^0 \to D^*_{sJ}(2317)^+K^-$ $[D_s\pi^0]$	$5.3^{+1.5}_{-1.3} \pm 0.7 \pm 1.4$	6.8σ
$\bar{B}^0 \to D^*_{sJ}(2317)^-\pi^+$ $[D_s\pi^0]$	< 2.5 (90% C.L.)	-
$\bar{B}^0 \to D_{sJ}(2460)^+K^-$ $[D_s\gamma]$	< 0.94 (90% C.L.)	-
$\bar{B}^0 \to D_{sJ}(2460)^-\pi^+$ $[D_s\gamma]$	< 0.40 (90% C.L.)	-

4. Quantum numbers of D_{sJ} resonances

To determine the D_{sJ} quantum numbers, the following experimental results are considered:

- The decay mode $D^*_{sJ}(2317)^+ \to D^+_s\pi^0$ is dominant. No significant signals are observed for the $D^*_{sJ}(2317)^+ \to D^+_s\gamma$ and $D^*_{sJ}(2317)^+ \to D^{*+}_s\pi^0$ decays.
- Significant signals are observed in the decay modes $D_{sJ}(2460)^+ \to D^+_s\gamma$ and $D_{sJ}(2460)^+ \to D^{*+}_s\pi^0$. No significant signal is observed for the $D_{sJ}(2460)^+ \to D^+_s\pi^0$ decay.
- The helicity angular distributions in the $B \to \bar{D}^{(*)}D_{sJ}$ decays favor the $J = 0$ hypothesis for $D^*_{sJ}(2317)^+$ and $J = 1$ for $D_{sJ}(2460)^+$.
- The helicity angular distribution in the $\bar{B}^0 \to D^+_{sJ}K^-$ decay favors the $J = 0$ hypothesis for $D^*_{sJ}(2317)^+$.

Taking into account this information, the 0^+ quantum numbers for the $D^*_{sJ}(2317)^+$ and 1^+ for the $D_{sJ}(2460)^+$ are now established with high confidence.

5. Quark content of D_{sJ} resonances

In recent theoretical papers many authors indicate that there are no substantial reasons to assume a four-quark content (or significant admixture) for the D_{sJ} mesons. However, there are some experimental results, which can not be explained clearly within a two-quark picture:

1) The branching fraction ratio measured by the Belle collaboration in continuum: $\mathcal{B}(D^*_{sJ}(2317)^+ \to D^{*+}_s\gamma)/\mathcal{B}((D^*_{sJ}(2317)^+ \to D^+_s\pi^0) < 0.18$ $(at\ 90\%\ C.L.)$.

2) The branching fraction ratio $\mathcal{B}(D_{sJ}(2460)^+ \to D^+_s\pi^+\pi^-)/\mathcal{B}((D_{sJ}(2460)^+ \to D^{*+}_s\pi^0)$ is measured by the Belle collaboration to be $0.14 \pm 0.04 \pm 0.02$ in continuum and < 0.13 $(at\ 90\%\ C.L.)$ in B meson decays.

3) The branching fractions for $B \to \bar{D}^{(*)}D_{sJ}$ measured by Belle are an order of magnitude smaller than those for $B \to \bar{D}^{(*)}D_s$.

4) The branching fraction for $\bar{B}^0 \to D^*_{sJ}(2317)^+K^-$ measured by Belle is of the same order of magnitude as that for $\bar{B}^0 \to D^+_sK^-$.

In case of a conventional two-quark interpretation, the D_{sJ} decays with π^0 in the final state must be suppressed due to isospin violation, and the ratios 1) and 2) are expected to be somewhat larger than the obtained values [6]. However, these values are readily explained within a four-quark D_{sJ} interpretation [6]. The order-of-magnitude difference in the $B \to \bar{D}^{(*)}D_{sJ}$ and $B \to \bar{D}^{(*)}D_s$ decay branching fractions indicated in 3) can be also explained as the effect of an additional quark pair creation in a four-quark interpretation [7]. (It has to be mentioned that, due to vector current conservation, B decay tree diagrams with a 0^+ meson produced from the virtual W boson are expected to be suppressed [8]; this problem was not discussed in [7].) In contrast to 3), the branching fractions indicated in 4) are of the same order, but it may be explained by the contribution from the diagram shown in Fig. 3c. Further theoretical analysis of the two- and four-quark interpretation opportunities will be required to understand the nature of the D_{sJ} mesons.

References

[1] BaBar Collaboration, Aubert B *et al.* 2003 *Phys. Rev. Lett.* **90** 242001
[2] CLEO Collaboration, Besson D *et al.* 2003 *Phys. Rev.* D **68** 032002
[3] Belle Collaboration, Mikami Y *et al.* 2004 *Phys. Rev. Lett.* **92** 012002
[4] Belle Collaboration, Krokovny P *et al.* 2003 *Phys. Rev. Lett.* **91** 262002
[5] Colangelo P, De Fazio F and Ferrandes R 2004 *Preprint* BARI-TH/04-486 (hep-ph/0407137)
[6] Hayashigaki A, Terasaki K 2004 *Preprint* YITP-04-63 (hep-ph/0410393)
[7] Chen C-H, Li H-n 2004 *Phys. Rev.* D **69** 054002
[8] Laplace S, Shelkov V 2001 *Eur. Phys. Jour.* C **22** 431