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Charm hadronic physics at Belle

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We report an improved measurement of $\overline{B}^0 \to D_{sJ}^+ K^-$ decays using a data sample of 357 fb^{-1} and studies of $D_{s1}(2536)^+ \to D^+\pi^-K^+$, $D_{s1}(2536)^+ \to D^{*+}K_S^0$ and $D^0 \to K^-(\pi^-)l^+\nu$ decays using a data sample of 282 fb^{-1}. The data used in these analyses were collected by the Belle detector at the KEKB asymmetric energy e^+e^- collider. We measure $\mathscr{B}(\overline{B}^0 \to D_{sJ}^*(2317)^+K^-)\times \mathscr{B}(D_{sJ}^*(2317)^+ \to D_s^+\pi^0) = (4.4\pm0.8\pm0.6\pm1.1)\times10^{-5}$ and $\mathscr{B}(\overline{B}^0 \to D_{sJ}(2460)^+K^-)\times \mathscr{B}(D_{sJ}(2460)^+ \to D_s^+\gamma) = (0.53\pm0.20^{+0.16}_{-0.15})\times10^{-5}$. The decay $D_{s1}(2536)^+ \to D^+\pi^-K^+$ is observed for the first time. An angular analysis of the $D_{s1}(2536)^+ \to D^{*+}K_S^0$ decay is performed. Semileptonic D^0 decays are studied using a global reconstruction method that provides very good resolution in neutrino momentum and the momentum transfer q^2.

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1. Improved measurements of $\overline{B}^0 \to D_{sJ}^+ K^-$ decays

An updated study of the decays $\overline{B}^0 \to D_{sJ}^+ K^-$ [1] was performed with a data sample that is approximately 2.5 times larger than in the paper published recently by Belle [2] that first reported the $\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-$ decay mode. The $\overline{B}^0 \to D_{s(J)}^+ K^-$ decays can be described by a PQCD factorization W exchange process [3, 4] or, alternatively, by final state interactions [5, 6]. Assuming there is a four-quark component of the D_{sJ} mesons, the tree diagram with $s\bar{s}$ pair creation may also contribute [2].

In this analysis we applied the same selection criteria as in [2], where a detailed description of the criteria can be found. The $\Delta E = E_B^{CM} - E_{\rm beam}^{CM}$ and $\Delta M(D_{sJ}) = M(D_{sJ}^+) - M(D_s^+)$ distributions for the $D_{sJ}^+ K^-$ combinations are shown in Fig. 1 for the range $5.272\,\mathrm{GeV/c^2} < M_{\rm bc} < 5.288\,\mathrm{GeV/c^2}$, where E_B^{CM} and $E_{\rm beam}^{CM}$ are the B candidate and beam energies in the center-of-mass system. The ΔE distributions are modeled using a linear background function and a Gaussian signal shape (the Crystal Ball shape function [7] is used for the $D_{sJ}(2460)^+$) with zero mean and a fixed width determined from MC data. The $\Delta M(D_{sJ})$ distributions are described by the sum of a signal Gaussian and a linear background. The widths of the Gaussians are fixed from MC while the peak positions are allowed to float. A strong $\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-$ signal is observed and evidence of the $\overline{B}^0 \to D_{sJ}(2460)^+ K^-$ signal is also seen.

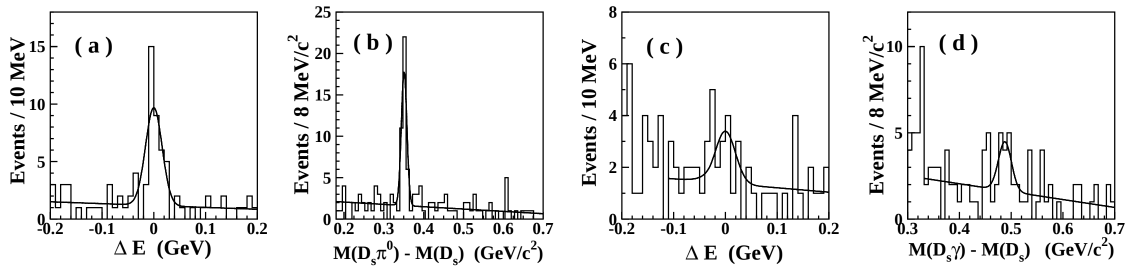

Figure 1: ΔE (a) and $\Delta M(D_{sJ})$ (b) distributions for the $\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-$ decay, and ΔE (c) and $\Delta M(D_{sJ})$ (d) distributions for the $\overline{B}^0 \to D_{sJ}(2460)^+ K^-$ decay.

Signal yields, efficiencies, branching fractions and significances for the studied decay channels are shown in Table 1. The signal yields are obtained from the fits of histograms shown in Fig. 1, where the three D_s^+ decay channels ($\phi\pi^+$, $K^{*0}K^+$ and $K_S^0 K^+$) are combined.

Results are in a good agreement with, and more sensitive than, the previous measurement [2]. The value of $\mathscr{B}(\overline{B}^0 \to D_{sJ}^*(2317)^+ K^-)$ is of the same order of magnitude as $\mathscr{B}(\overline{B}^0 \to D_s^+ K^-)$ and significantly larger than the $\overline{B}^0 \to D_{sJ}(2460)^+ K^-$ branching fraction. The experimental results disagree with the naïve expectation [8] that the ratio $\mathscr{B}(\overline{B}^0 \to D_s^+ h^-)/\mathscr{B}(\overline{B}^0 \to D_{sJ}^+ h^-)$ should be similar for $h^- = \pi^-, K^-$ or D^-.

2. Measurements of $D_{s1}(2536)^+ \to D^+\pi^-K^+$ and $D_{s1}(2536)^+ \to D^{*+}K_S^0$ decays

The $D_{s1}(2536)^+$ resonance was observed in two-body D^*K final states many years ago. In this analysis [9] the decay channel $D_{s1}(2536)^+ \to D^+\pi^-K^+$ is studied for the first time. Fig. 2 shows the mass spectra for $D^+\pi^-K^+$ (left top) and $D^{*+}K_S^0$ (left bottom) decay modes. Large

Decay mode	Yield $\Delta M(D_{sJ})$	Yield ΔE	Efficiency (10^{-4})	Product $\mathscr{B}(\overline{B}^0 \to D_{sJ}^+ K^-)\times$ $\mathscr{B}(D_{sJ} \to D_s \pi^0(\gamma))$ (10^{-5})	Signif. σ
$D_{sJ}^*(2317)^+K^-$	35.3 ± 6.4	34.1 ± 6.6	21.9 ± 0.6	$4.4 \pm 0.8 \pm 0.6 \pm 1.1$	9.2
$D_{sJ}(2460)^+K^-$	11.2 ± 5.4	10.2 ± 5.4	59.5 ± 1.4	$0.53 \pm 0.20^{+0.16}_{-0.15}$	3.1
				$< 0.86\,(90\%\,C.L.)$	

Table 1: Signal yields, efficiencies, product branching fractions, and significances for the $\overline{B}^0 \to D_{sJ}^+ K^-$ processes. The first error is the statistical uncertainty, the second is the systematic uncertainty. For the $\overline{B}^0 \to D_{sJ}^*(2317)^+K^-$ decay the uncertainty due to D_s^+ decay branching fractions is shown separately as the third error. Product branching fractions are obtained from simultaneous $\Delta M(D_{sJ})$ fits of three D_s decay modes as described in the text.

signals are seen in both modes. The ratio of branching fractions $\mathscr{B}(D_{s1}(2536)^+ \to D^+\pi^-K^+)/\mathscr{B}(D_{s1}(2536)^+ \to D^{*+}K_S^0)$ is measured to be $(2.8 \pm 0.2 \pm 0.4)\%$. The study of two-body invariant masses for the $D^+\pi^-K^+$ final state was performed and no clear resonant substructure is found.

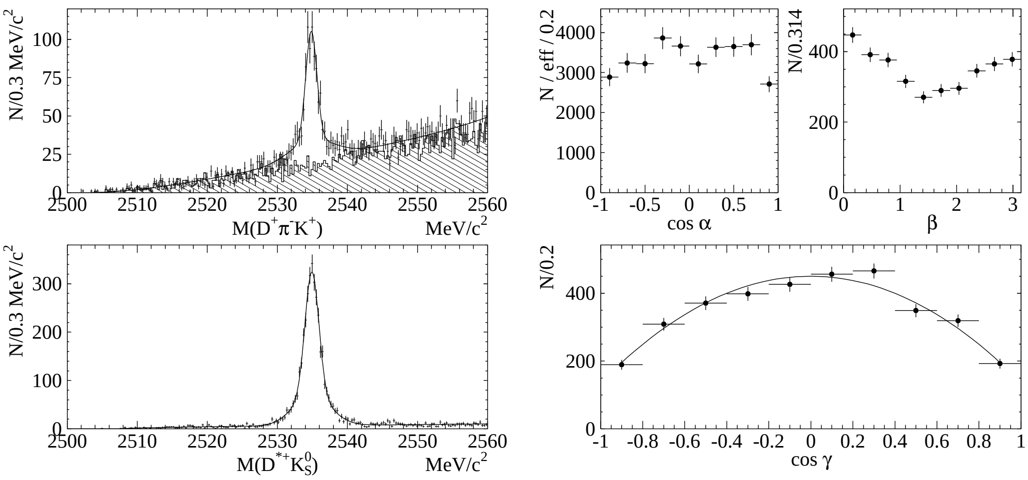

Figure 2: $D_{s1}(2536)^+$ mass spectra for $D^+\pi^-K^+$ (left top) and $D^{*+}K_S^0$ (left bottom) decay modes. The hatched histogram in the left top plot shows the corresponding spectrum of wrong sign $D^+\pi^+K^-$ combinations. The plots on the right side show angular distributions for the $D_{s1}(2536)^+ \to D^{*+}K_S^0$ decay. The definitions of angles and the fitting function are described in the text.

An angular analysis of the decay $D_{s1}(2536)^+ \to D^{*+}K_S^0$ is also performed using the method described in [10, 11]. The angles α and β are measured in the D_{s1}^+ rest frame with respect to the direction opposite to the e^+e^- center of mass momentum (boost direction). We define α as the angle between the boost direction and the K_S^0 momentum and β as the angle between the D_{s1}^+ decay plane and the plane formed by the K_S^0 and the boost direction. The third angle γ is defined in the D^{*+} rest frame between π^+ and K_S^0. The $D_{s1}(2536)^+ \to D^{*+}K_S^0$ decay angular distributions are shown in Fig. 2 (right). The cos γ distribution was fitted to the form $1 + A\cos^2\gamma$, and the fit yields the parameter $A = -0.70 \pm 0.03$. This measurement constrains the relative fraction $R = \Gamma_S/(\Gamma_S + \Gamma_D)$

of the S wave component to the range $0.277 < R < 0.955$, independently of the relative phase between S and D waves.

3. Measurements of $D^0 \to \pi^- l^+ \nu$ and $D^0 \to K^- l^+ \nu$ decays

A novel global reconstruction method is used to study the $D^0 \to \pi^- l^+ \nu$ and $D^0 \to K^- l^+ \nu$ decays [12]. Events are reconstructed assuming the process $e^+e^- \to D^{(*)}_{tag} D^*_{sig} X$, where X denotes additional π^0, $\pi^\pm$ and $K^\pm$ mesons. The tag-side $D^{\pm(0)}$ meson is fully reconstructed in $K^\pm n \pi^{\pm(0)}$ final states with $n = 1,2,3$. The signal side semileptonic decay $D^0 \to \pi^-(K^-)e^+(\mu^+)\nu$ is studied using a missing-mass method. This method enables a very good resolution in neutrino momentum and the momentum transfer $q^2 = (p_l + p_\nu)^2$, the accuracy $\sigma_{q^2} \approx 0.015$ GeV^2/c^4 can be achieved. This study provides an accurate information about the decay form factor $f_D(q^2)$. Additionally the decay channel $D^0 \to K^- l^+ \nu$ with a lower background and higher statistics was also investigated.

The relative branching fractions $\mathscr{B}(D^0 \to \pi^- e^+ \nu)/\ \mathscr{B}(D^0 \to K^- e^+ \nu) = 0.0809 \pm 0.0080 \pm 0.0032$ and $\mathscr{B}(D^0 \to \pi^- \mu^+ \nu)/\ \mathscr{B}(D^0 \to K^- \mu^+ \nu) = 0.0677 \pm 0.0078 \pm 0.0047$ are obtained in a good agreement with expectations. The normalized measured q^2 distribution was fitted to different models of form factors and some deviations from predictions of simple pole [13] and ISGW2 model [14] are observed.

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