PROCEEDINGS OF SCIENCE

Hadronic b $\to$ c decays at Belle

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We report two studies of hadronic $b \to c$ decays based on data samples collected by the Belle detector at the KEK-B e^+e^- asymmetric collider. Exclusive B^+ meson decays to the $D_s^{(*)-}K^+\pi^+$ final state are analysed and respective branching fractions are measured. We also present measurements of $B^0 \to D_s^{*+}\pi^-$ and $B^0 \to D_s^{*-}K^+$ branching fractions. These studies are based on $657\times 10^6 B\overline{B}$ pairs collected at the $\Upsilon(4S)$ resonance.

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1. Introduction

The dominant process in the decays $B^+ \to D_s^{(*)-} K^+ \pi^+$ [1] is mediated by the $b \to c$ quark transition and includes the production of an additional $s\bar{s}$ pair. This process produces at least three final-state particles and can thus be distinguished from much more dominant decays, which include direct D_s production from the W boson vertex. These three-body decay modes were recently observed by BaBar [2] and need further confirmation. Studies of $B^+ \to D_s^{(*)-} K^+ \pi^+$ decays are also motivated by interest in the intermediate resonances that can be formed from the three final-state particles. These resonances would be visible as bands in the Dalitz plots for different two-body subsystems [3].

The measurement of $B^0 \to D_s^{*+} \pi^-$ and $B^0 \to D_s^{*-} K^+$ decay branching fractions is crucial in understanding the CP violation via the Cabibbo-Kobayashi-Maskawa (CKM) mechanism within the Standard Model. In particular, the time-dependent CP analysis of the $B^0(\overline{B}^0) \to D^{*\mp}\pi^{\pm}$ system provides a theoretically clean method for extracting $R_{D^*\pi} \sin(2\phi_1 + \phi_3)$, where ϕ_1 and ϕ_3 are the angles of the CKM Unitarity Triangle and the measurement of the ϕ_3 is experimentally challenged issue. $R_{D^*\pi}$, which is the ratio of the doubly Cabibbo suppressed decay (DCSD) amplitude to the Cabibbo favored decay (CFD) amplitude, must be measured independently in order to extract ϕ_3 and, assuming the SU(3) flavor symmetry, can be written as

$$R_{D^*\pi} = tan\theta_C \left(\frac{f_{D^*}}{f_{D_s^*}}\right) \sqrt{\frac{\mathscr{B}(B^0 \to D_s^{*+}\pi^-)}{\mathscr{B}(B^0 \to D^{*-}\pi^+)}}.$$

Here θ_C is the Cabibbo angle, f_{D^*} and $f_{D_s^*}$ are meson form factors, determined from Lattice QCD calculations, and the $\mathscr{B}'$ s represent the corresponding decay branching fractions.

The $B^0 \to D_s^{*-} K^+$ decay, which proceeds only via W-exchange, can be used to estimate W-exchange diagram contribution to $B^0 \to D^{*\mp}\pi^{\pm}$ which is neglected in the above correspondence between $D^{*+}\pi^-$ and $D_s^{*+}\pi^-$.

The D_s^+ candidates are reconstructed in three final states: $\phi(\to K^+K^-)\pi^+$, $\overline{K}^*(892)^0(\to K^-\pi^+)K^+$ and $K_S^0(\to \pi^+\pi^-)K^+$.

We exploit the event topology to discriminate between spherical $B\overline{B}$ events and the dominant background from jet-like continuum events, $e^+e^- \to q\overline{q}$ ($q = u, d, s, c$).

We accept K^+K^- ($K^-\pi^+$) pairs as ϕ ($\overline{K}^*(892)^0$) candidates if their invariant mass is within the specific range of the nominal ϕ ($\overline{K}^*(892)^0$) mass [4]. Candidate K_S^0 mesons are selected by combining oppositely charged pions with an invariant mass not differing by a few MeV/c^2 (depending on the channel) from the nominal K_S^0 mass. In addition, the vertices of these $\pi^+\pi^-$ pairs must be displaced from the interaction point by at least 1 mm. Photons used for $D_s^{*+} \to D_s^+\gamma$ reconstruction are accepted if their energies exceed 100 MeV in the laboratory frame.

The B candidates, reconstructed by combining a $D_s^{(*)}$ candidate with an oppositely charged pion and/or kaon track, are identified by the energy difference, $\Delta E = \Sigma_i E_i - E_{\rm beam}$ between ± 200 MeV and the beam-energy constrained mass, $M_{\rm bc} = \sqrt{E_{\rm beam}^2 - (\Sigma_i \vec{p}_i)^2}$ between 5.2 GeV/c^2 and 5.3 GeV/c^2 for further analysis, where $E_{\rm beam}$ is the beam energy in the center of mass (CM) frame and $\vec{p}_i$ and E_i is the momentum and energy of the i-th daughter of the B meson in the CM frame.

2. Studies on $B^+ \to D_s^{(*)-} K^+ \pi^+$

The signal yields are extracted using unbinned extended maximum-likelihood fits to the events passing the selection criteria using three variables: $\Delta E, M_{\rm bc}, M(D_s^{(*)})$. Fig. 1 shows the fit results to all three variables for $B^+ \to D_s^- K^+ \pi^+$ and $B^+ \to D_s^{*-} K^+ \pi^+$, $D_s^- \to \phi\pi^-$.

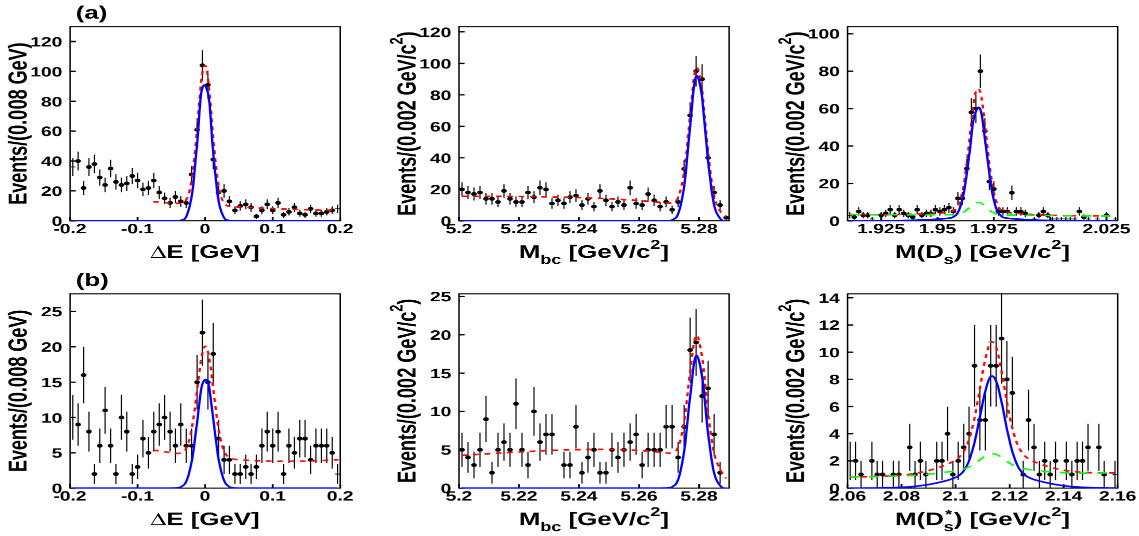

Figure 1: Distributions of ΔE, $M_{\rm bc}$ and $M(D_s^*)$ for **(a)** $B^+ \to D_s^-(\to \phi\pi^-)K^+\pi^+$ and **(b)** $B^+ \to D_s^{*-}(\to \phi\pi^-)K^+\pi^+$ decays. Projections in each variable – ΔE, $M_{\rm bc}$ and $M(D_s^*)$ – while chosing events in the signal region of the other two, are shown. The red dashed curves show the results of the overall fit, the blue solid curves correspond to the signal components and the green long-dashed curves indicate the fitted background for $M(D_s^{(*)})$.

The average branching fractions for the decays $B^+ \to D_s^- K^+ \pi^+$ and $B^+ \to D_s^{*-} K^+ \pi^+$ are obtained from a simultaneous fit to the data containing events from all three D_s decay modes.

In summary, the following branching fractions are determined:

$$\mathscr{B}(B^+ \to D_s^- K^+ \pi^+) = (1.71^{+0.08}_{-0.07}(\text{stat})\ ^{+0.20}_{-0.20}(\text{syst}) \pm 0.15(\mathscr{B}_{int})) \times 10^{-4}$$

$$\mathscr{B}(B^+ \to D_s^{*-} K^+ \pi^+) = (1.31^{+0.13}_{-0.12}(\text{stat})\ ^{+0.25}_{-0.25}(\text{syst}) \pm 0.12(\mathscr{B}_{int})) \times 10^{-4}.$$

Preliminary studies of two-body subsystems of $D_s^{(*)-} K^+ \pi^+$ do not confirm existence of any new resonance.

3. Studies on $B^0 \to D_s^{*+} \pi^-$ and $B^0 \to D_s^{*-} K^+$

We determine the branching fractions performing an unbinned extended maximum likelihood fit on the ΔE variable simultaneously in the three D_s^+ decay modes of each signal mode. To account for the cross-feeds between the signal modes due to the mis-identification of the prompt track, the $B^0 \to D_s^{*+}\pi^-$ and $B^0 \to D_s^{*-}K^+$ modes are fitted simultaneously, where each mode contributes to the fit of the other only via its cross-feed contribution to the overall background for that mode.

Some of the other rare B decays involving a true $D_s^{(*)+}$ show prominent peaking structures in the fit region: the $B^0 \to D_s^+\pi^-$ ($B^0 \to D_s K^+$) events populate around +150 MeV due to the extra

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photon added, making a $B^0 \to D_s^{*+}\pi^-$ ($B^0 \to D_s^{*}K^+$) event, whereas the $B^0 \to D_s^{(*)+}\rho^-(B^+ \to D_s^{(*)-}K^+\pi^+)$ events gather around -150 MeV, losing the π^0 (π^+). The shape and normalization of these backgrounds are determined from the large MC samples. Fig. 2 shows the simultaneous fit results for the $D_s^+ \to \phi\pi^+$ mode for both studied channels.

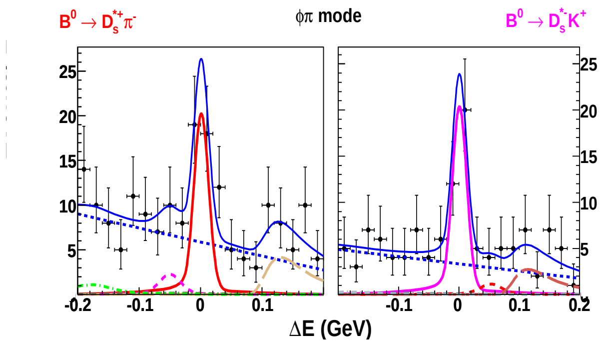

Figure 2: The results of simultaneous fit for $B^0 \to D_s^{*+}\pi^-$ (left) and for $B^0 \to D_s^{*-}K^+$ (right) in the $D_s \to \phi\pi$ mode. The solid red and pink curves show the signal peak for the respective channels, the solid blue curves represent the overall fit, dashed lines (red/pink) represent the cross-feed contributions from the opposite signal mode. The dot-dashed green line shows $B^0 \to D_s^{(*)+}\rho^-$ and the long-dashed light brown (dark red) curves show the respective $B^0 \to D_s^+\pi^-(B^0 \to D_s^-K^+)$ peaking components.

Finally, we obtain:

$$\mathscr{B}(B^0 \to D_s^{*+}\pi^-) = (1.75 \pm 0.33(stat) \pm 0.17(syst) \pm 0.10(\mathscr{B}_{int})) \times 10^{-5}$$
$$\mathscr{B}(B^0 \to D_s^{*-}K^+) = (2.02 \pm 0.32(stat) \pm 0.18(syst) \pm 0.14(\mathscr{B}_{int})) \times 10^{-5}$$

with statistical significance of 6.6 σ and 8.6 σ respectively.

Using the measured value for the $B^0 \to D_s^{*+}\pi^-$ branching fraction observation with the latest values for $\mathscr{B}(B^0 \to D^{*-}\pi^+) = (2.76 \pm 0.13) \times 10^{-3}$ [4] and the Cabibbo angle, $\tan\theta_C = 0.2314 \pm 0.0021$ as well as the calculation for the $f_{D_s^{*+}} / f_{D^{*+}} = 1.10 \pm 0.02$ [5], one can obtain

$$R_{D^*\pi} = (1.63 \pm 0.16(stat) \pm 0.10(syst) \pm 0.03(th))\%,$$

which is the most precise measurement of $R_{D^*\pi}$ so far.

From the observed value for the $B^0 \to D_s^{*-}K^+$ branching fraction one can conclude that the effect of the W- exchange processes in $B \to D^{*\mp}\pi^\pm$ is small and can be neglected in $R_{D^*\pi}$ (without introducing significant error).

References

[1] Throughout this report, the inclusion of the charge-conjugate decay mode is implied unless otherwise stated.

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