PROCEEDINGS OF SCIENCE

Rare $b \to c$ Decays at Belle

Simon Blyth[*†]
National Central University, Taiwan
E-mail: *blyth@hep1.phys.ntu.edu.tw*

This paper reports on improved measurements of $\overline{B}^0 \to D_s^- D^+$ decays and on a searches for $\overline{B}^0 \to D_s^+ D_s^-$ performed using a sample of 275×10^6 $B\overline{B}$ pairs collected by the Belle detector. We measure the branching fraction $\mathscr{B}(\overline{B}^0 \to D_s^- D^+) = (7.42 \pm 0.23(\text{stat.}) \pm 1.36(\text{syst.})) \times 10^{-3}$, with significantly improved precision compared to the existing measurements. We observe no statistically significant signal for the decay $\overline{B}^0 \to D_s^+ D_s^-$ and set the first upper limit on the branching fraction of $\mathscr{B}(\overline{B}^0 \to D_s^+ D_s^-) \leq 2.0 \times 10^{-4}$ at 90% C.L.

International Europhysics Conference on High Energy Physics
July 21st - 27th 2005
Lisboa, Portugal

*Speaker.
†on behalf of the Belle collaboration

1. Introduction

Recent measurements of rare decays involving a $b \to c$ transition at the B-factories have demonstrated the inadequacy of spectator descriptions of these decays and the need to account for final state interaction (FSI) effects. In particular, the recent observation of $\overline{B}^0 \to D_{sJ}(2317)^+K^-$ [1] at a rate comparable to that of $\overline{B}^0 \to D_s^+K^-$ [2] is in contrast to the corresponding rate for the decay $\overline{B}^0 \to D_{sJ}^*(2317)^+D^-$ which occurs at a rate an order of magnitude lower than $\overline{B}^0 \to D_s^-D^+$. These observations have stimulated experimental interest in improving the determinations of these rates and investigating decays that are expected to be described by similar mechanisms and have also caused theoretical interest in improving the descriptions of these processes using $W^\pm$ exchange or FSI approaches.

The decay of $\overline{B}^0 \to D_s^+D_s^-$ at the quark level can be described by annihilation mechanism $b\overline{d} \to c\overline{c}$, leading to the expectation of a vanishing amplitude. However non-factorizable contributions to the amplitude have led to a measurable branching fraction prediction as high as 2.5×10^{-4}[3]. The ratio of the rate of the Cabbibo allowed procees $\overline{B}^0 \to D_s^-D^+$ with that of $\overline{B}^0 \to D_s^-\pi^+$ can be related to the ratio of the CKM matrix elements $|Vub|/|Vcb|$[4] with a model dependent factor[5]. However, the world average uncertainty of $\mathscr{B}(\overline{B}^0 \to D_s^-D^+)$ is 38% [6], slightly worse than that of $\mathscr{B}(\overline{B}^0 \to D_s^-\pi^+)$ [2], motivating improvements on the precision of these rates.

This paper reports on improved measurements of $\overline{B}^0 \to D_s^-D^+$ decays and on a searches for $\overline{B}^0 \to D_s^+D_s^-$[1] decays with the Belle detector [8] at the KEKB asymmetric energy e^+e^- collider [9]. The results are based on a data sample, collected at the center-of-mass (CM) energy of the $\Upsilon(4S)$ resonance, which contains 275×10^6 produced $B\overline{B}$ pairs.

2. Improved measurement of $\overline{B}^0 \to D_s^-D^+$

The D_s^- mesons were reconstructed using the modes $D_s^- \to \phi\pi^-$, $K^{*0}K^-$, and $K_S^0K^-$ and D^+ mesons were reconstructed using the modes $D^+ \to K^+K^-\pi^+$, $K^-\pi^+\pi^+$, and $K_S^0\pi^+$. Combinations of oppositely charged kaons with $|M_\phi - M_{K^+K^-}| < 20$ MeV/c^2 were regarded as ϕ candidates and combinations of oppositely charged kaons and pions with $|M_{K^{*0}} - M_{K^+\pi^-}| < 85$ MeV/c^2 were retained as K^{*0} candidates. Neutral kaons (K_S^0) were reconstructed using pairs of oppositely charged tracks that have an invariant mass within 30 MeV$/c^2$ of the nominal K^0 mass, and have a displaced vertex from the interaction point. Charged tracked were identified as kaon(pion) candidates based on combined information from the CDC, TOF and ACC counters with simulated efficiencies of 92(96)%. Combinations of the $D_s^\pm$ and $D^\pm$ decay products with invariant masses within a 4 σ(4.5 σ) of the nominal masses were selected as candidate D mesons ($\sigma \approx 3.6 - 4.2$ MeV/c^2) and pairs of D_s^- and D^+ meson candidates are combined to form $\overline{B}^0$ meson candidates.

Events with B meson candidates are identified by their CM energy difference, $\Delta E = E_B^{\rm CM} - E_{\rm beam}^{\rm CM}$, and beam constrained mass, $M_{\rm bc} = \sqrt{(E_{\rm beam}^{\rm CM})^2 - (p_B^{\rm CM})^2}$, where $E_{\rm beam}^{\rm CM} = \sqrt{s}/2$ is the CM beam energy and $E_B^{\rm CM}$ and $p_B^{\rm CM}$ are the reconstructed energy and momentum of the B meson candidate, respectively. We select events with $M_{\rm bc} > 5.2$ GeV$/c^2$ and $|\Delta E| < 0.2$ GeV.

The continuum background was suppressed by a selection based on the ratio of the second to zeroth Fox-Wolfram moments [10] $R_2 < 0.3$ and the thrust value $T < 0.8$. This retains more than

[1] See reference [7] hep-ex/0508040 for a more detailed description.

95% of $B\overline{B}$ events while rejecting about 55% of $c\overline{c}$ and 65% of uds events. The signal region is defined as $5.272\ \text{GeV}/c^2 \leq M_{\text{bc}} \leq 5.285\ \text{GeV}/c^2$ and $|\Delta E| \leq 0.025$ GeV.

A binned likelihood fit to the ΔE distribution for events within the M_{bc} signal region gives a signal yield of $N_{\text{data}} = 1372 \pm 42$ events. This however includes non-resonant $D_s^- \to K^+K^-\pi^-$ decays that result in the same final state, the fraction of this background was estimated from simulation to be $(3.46 \pm 0.74)\%$[2] The ΔE and M_{bc} distributions within the D and D_s mass sidebands are consistent with the backgrounds observed in the signal region. No peaking behaviour is observed in the D sideband but a clear signal is seen in the D_s sideband for the $D_s^- \to K^{*0}K^-$ decay mode, arising due to the three-body decay $\overline{B}^0 \to D^+K^{*0}K^-$[12]. As the $K^{*0}K^-$ invariant mass also populates the region under the D_s^- peak the fraction of this contribution to the signal is estimated by extrapolation from the sideband to be $(2.74 \pm 0.57)\%$[3]. After accounting for these backgrounds the number of signal $\overline{B}^0 \to D_s^- D^+$ in the sample is estimated to be 1287 ± 40, where the error is statistical only.

The overall selection efficiency including subdecay branching fractions was estimated from simulation to be : $\varepsilon(D_sD) = \sum_{i,j=1,3} \varepsilon_{i,j} \mathscr{B}(D_s i)\mathscr{B}(Dj) = (6.31 \pm 0.88) \times 10^{-4}$ where $\varepsilon_{i,j}$ represents the efficiency of reconstructing the event if the $D_s(D)$ meson decays through the $i(j)$-th mode. This accounts for the cross efficiencies between the reconstructed decay channels. The uncertainty is dominated ($\pm 13.9\%$) by uncertainties on the intermediate branching fractions [6, 11]. Alternatively, the efficiency can be expressed in terms of the subdecay branching fractions $\varepsilon(D_sD) = (3.18 \pm 0.25) \times 10^{-2} \cdot \mathscr{B}(D_s^+ \to \phi\pi^+)\mathscr{B}(\phi \to K^+K^-)$.

The measured branching fraction is thus[4]:

$$\mathscr{B}(\overline{B}^0 \to D_s^- D^+) = (7.42 \pm 0.23(\text{stat.}) \pm 1.36(\text{syst.})) \times 10^{-3},$$

where the total relative systematic uncertainty of $\pm 18.3\%$ includes $\pm 13.9\%$ from intermediate branching fractions, $\pm 7.1(6.4)\%$ from kaon(pion) identification, $\pm 6.0\%$ from track reconstruction as well as the background uncertainties already discussed. The same result can be expressed in terms of two of the subdecay branching fractions as $\mathscr{B}(\overline{B}^0 \to D_s^- D^+) \cdot \mathscr{B}(D_s^- \to \phi\pi^-)\mathscr{B}(\phi \to K^+K^-) = \left[1.47 \pm 0.05(\text{stat.}) \pm 0.21(\text{syst.})\right] \times 10^{-4}$, reducing the total uncertainty to $\pm 14\%$ (7.7% from intermediate $\mathscr{B}$'s). This determination represents almost a factor of two improvement in accuracy with respect to existing measurements[6].

The obtained branching fraction can be used to improve the value of the $|V_{ub}|$ CKM element within the prediction of [5]. Using $\mathscr{B}(\overline{B}^0 \to D_s^- \pi^+)$ from [2] we obtain $\frac{|V_{ub}|}{|V_{cb}|} = (7.4 \pm 1.2) \times 10^{-2}$.

3. Search for $\overline{B}^0 \to D_s^+ D_s^-$ decays

The same D_s selection outlined in the previous section was used to search for $\overline{B}^0 \to D_s^+ D_s^-$ decays. In this mode a cross-feed from $\overline{B}^0 \to D_s^- D^+$ decays, where the D^+ decays into a $K^-\pi^+\pi^+$ or $\overline{K}^0\pi^+$ final state and one of the pions is misidentified as a kaon occurs. Although shifted from zero in the ΔE distribution, this background makes observation of a small possible signal difficult.

[2] $(3.46 \pm 1.70)\%$ including the uncertainty on the non-resonant $D_s^- \to K^+K^-\pi^-$ branching fraction[6].

[3] $(2.74 \pm 1.24)\%$ including the uncertainty from assumption of equal contributions to D_s sideband and signal regions.

[4] assuming equal production of $B^0\overline{B^0}$ and B^+B^- pairs

This background is reduced by applying a veto against $D_s^{\pm}$ candidates decaying into $K^+K^-\pi^{\pm}$ or $K_S^0K^{\pm}$ which are within 20 MeV$/c^2$ of the $D^{\pm}$ mass after substituting the $\pi^{\pm}$ mass with the $K^{\pm}$ mass.

A binned likelihood fit to the $\Delta E(M_{\mathrm{bc}})$ distribution gives $N_{\mathrm{D_sD_s}} = 3.2 \pm 2.3$ (4.7 ± 2.6) signal events , where the errors are statistical only. We observe no statistically significant signal in the $\overline{B}^0 \to D_s^+D_s^-$ decay mode. The selection efficiency is estimated from simulation to be $\varepsilon(D_sD_s) = \sum_{i,j=1,3} \varepsilon_{i,j}\mathscr{B}(D_s i)\mathscr{B}(D_s j) = (1.63 \pm 0.39) \times 10^{-4}$, using the same approach used for $D_s^-D^+$.

We derive $\mathscr{B}(\overline{B}^0 \to D_s^+D_s^-) = (7.1 \pm 5.1) \times 10^{-5}$, with a statistical error only. The total relative systematic uncertainty of $\pm 28.4\%$ includes $\pm 23.1\%$ from intermediate branching fractions of D_s, $\pm 8.5(5.2)\%$ from kaon(pion) identification and $\pm 6.0\%$ from track reconstruction. An uncertainty of $\pm 9.5\%$ from the fitting model was estimated by comparing the fitted and true number of simulated signal events. Using the Feldman-Cousins [13] upper limit estimation method we find $\mathscr{B}(\overline{B}^0 \to D_s^+D_s^-) \leq 1.6 \times 10^{-4}$ at 90% C.L. . We inflate this upper limit by the overall systematic error to derive:

$$\mathscr{B}(\overline{B}^0 \to D_s^+D_s^-) \leq 2.0 \times 10^{-4} \text{ at 90\% C.L.}$$

This value represents the first existing limit on this decay mode and reaches the sensitivity to test the prediction of [3].

References

[1] A. Drutskoy *et al.*, Belle Collaboration, Phys. Rev. Lett. **94**, 061802 (2005).

[2] K. Abe *et al.*, Belle Collaboration, hep-ex/0408109.

[3] J. O. Eeg, S. Fajfer, A. Prapotnik, hep-ph/0501031.

[4] M. Kobayashi and T. Maskawa, Prog. Theor. Phys. **49**, 652 (1973);
N. Cabibbo, Phys. Rev. Lett. **10**, 531 (1963).

[5] C. S. Kim *et al.*, Phys. Rev. **D63**, 094506 (2001).

[6] S. Eidelman *et al.*, Phys. Lett. **B592**, 1 (2004).

[7] K. Abe *et al.*, Belle Collaboration, hep-ex/0508040.

[8] A. Abashian *et al.*, Belle Collaboration, Nucl. Instr. Meth. **A479**, 117 (2002).

[9] S. Kurokawa and E. Kikutani, Nucl. Instr. Meth. **A499**, 1 (2003), and other papers included in this Volume.

[10] G. C. Fox, S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978).

[11] B. Aubert *et al.*, BaBar Collaboration, hep-ex/0502041.

[12] A. Drutskoy *et al.*, Belle Collaboration, Phys. Lett. **B542**, 171 (2002).

[13] G. J. Feldman, R. D. Cousins, Phys. Rev. **D57**, 3873 (1998).