PROCEEDINGS OF SCIENCE

Observation of $B_s^0 \to D_s^{*-}\pi^+$, $B_s^0 \to D_s^{(*)-}\rho^+$ and $B_s^0 \to D_s^{(*)+}D_s^{(*)-}$ and Estimate of $\Delta\Gamma_{CP}$ at Belle

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The large data sample being recorded with the Belle detector at the $\Upsilon(5S)$ energy provides a unique opportunity to study the less-well-known B_s^0 meson decays. Following our recent measurement of $B_s^0 \to D_s^-\pi^+$ in a sample of 23.6 fb^{-1}, we extend the analysis to include decays with photons in the final state. Using the same sample, we report the first observation of three other dominant exclusive B_s^0 decays, in the modes $B_s^0 \to D_s^{*-}\pi^+$, $B_s^0 \to D_s^-\rho^+$ and $B_s^0 \to D_s^{*-}\rho^+$. We measure their respective branching fractions and, using helicity-angle distributions, the longitudinal polarization fraction of the $B_s^0 \to D_s^{*-}\rho^+$ decay.
We also present a measurement of the branching fractions for the decays $B_s^0 \to D_s^{(*)+}D_s^{(*)-}$. In the heavy quark limit, this branching fraction is directly related to the width difference between the B_s CP-even and CP-odd eigenstates.

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1. Introduction

Beginning in 2005, the Belle experiment running KEKB e^+e^- collider [1] has recorded several data sets at the center-of-mass energy corresponding to the $\Upsilon(5S)$ resonance. Belle has used this data sets to measure several B_s^0 properties and branching fractions. A total of 120 fb^{-1} at the $\Upsilon(5S)$ ($\sqrt{s}\approx$10.87 GeV) has been recorded. The results presented here correspond to the first 23.6 fb^{-1}.

The total $e^+e^- \to b\bar{b}$ cross section at the $\Upsilon(5S)$ energy was measured to be $\sigma_{b\bar{b}} = (302 \pm 14)$ pb [2, 3], with the fraction $f_s = \sigma(e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)})/\sigma_{b\bar{b}} = (19.3 \pm 2.9)\%$ [4]. The dominant B_s^0 production mode is $e^+e^- \to B_s^*\bar{B}_s^*$, with a fraction $f_{B_s^*\bar{B}_s^*} = (90.1^{+3.8}_{-4.0} \pm 0.2)\%$ of the $b\bar{b} \to B_s^{(*)}\bar{B}_s^{(*)}$ events [5]. Thus for 23.6 fb^{-1} the total number of $e^+e^- \to B_s^*\bar{B}_s^*$ events is $(1.24 \pm 0.2) \times 10^6$.

All signal B_s^0 decays are fully reconstructed from final-state particles using two quantities: the beam-energy-constrained mass $M_{bc} = \sqrt{E_b^2 - p_B^2}$, and the energy difference $\Delta E = E_B - E_b$, where p_B and E_B are the reconstructed momentum and energy of the B_s^0 candidate, and E_b is the beam energy. These quantities are evaluated in the e^+e^- center-of-mass frame. Although the B_s^* always decays to $B_s^0\gamma$, the γ is not reconstructed because of its extremely low momentum.

2. Observation of $B_s^0 \to D_s^{*-}\pi^+$ and $D_s^{(*)-}\rho^+$ Decays and Polarization Measurement of $B_s^0 \to D_s^{*-}\rho^+$

Three CKM-favored decays with relatively large branching fractions, $B_s^0 \to D_s^{*-}\pi^+$ and $D_s^{(*)-}\rho^+$, have been observed recently by Belle [6]. Three D_s^+ decay modes are considered: $\phi(\to K^+K^-)\pi^+$, $K_S(\to \pi^+\pi^-)K^+$ and $K^{*0}(\to K^+\pi^-)K^+$. Since only four charged tracks and up to one γ and π^0 are required, these final states have relatively large signals. The continuum events are removed using the ratio of the second to zeroth Fox-Wolfram moments [7]. This ratio differs for spherical B events and jet-like continuum events.

Only one B_s^0 candidate is allowed per event. This candidate is chosen based on the intermediate-particle reconstructed masses. The M_{bc} and ΔE distributions of the selected B_s^0 candidates are shown in Figure 1. For the $B_s^0 \to D_s^{*-}\rho^+$ candidates, the helicity angles $\theta_{D_s^{*-}}$ and θ_{ρ^-} are also reconstructed. These are defined as the angle between the D_s^- or π^+ and the opposite direction of the B_s^0 in the D_s^{*-} or ρ^- rest frame. The distributions of $\cos\theta_{D_s^{*-}}$ and $\cos\theta_{\rho^-}$ are fitted to determine the longitudinal polarization fraction f_L (see Table 1).

3. Observation of $B_s \to D_s^{(*)-}D_s^{(*)+}$ Decays and a Determination of the $\Delta\Gamma_s$

Decays of $B_s \to D_s^{(*)-}D_s^{(*)+}$ are interesting due to their large CP-even fraction. The pure CP-even $D_s^-D_s^+$ state and predominantly CP-even $D_s^*D_s^{(*)}$ states are Cabibbo-favored and expected to dominate the width difference of the $B_s^0 - \bar{B}_s^0$ system. In the heavy quark limit, assuming negligible CP violation, the relative width difference is $\Delta\Gamma_s^{CP}/\Gamma_s = 2\mathscr{B}/(1-\mathscr{B})$, where $\mathscr{B}$ is the total branching fraction of $B_s \to D_s^{(*)-}D_s^{(*)+}$ decays [8].

For this study [9], D_s^+ candidates are reconstructed in six modes, $\phi\pi^+$, K_SK^+, $K^{*0}K^+$, $\phi\rho^+$, $K^{*+}K_S$ and $K^{*+}K^{*0}$. B_s^0 candidates are reconstructed from two oppositely charged $D_s^{(*)}$ mesons. As the daughter photon of the D_s^* has very low momentum, more than half of the events yield more than one B_s^0 candidate sharing the same D_s pair. Only one candidate per event is selected

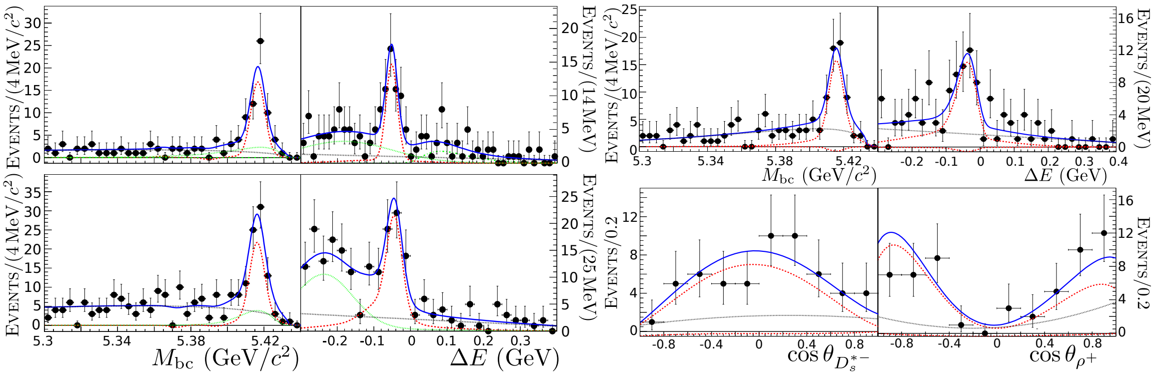

Figure 1: Projections of $B_s^*\bar{B}_s^*$ signal region in M_{bc} and ΔE for fits of B_s^0 to $D_s^{*-}\pi^+$(top-left), $D_s^-\rho^+$ (bottom-left), and $D_s^{*-}\rho^+$ (top-right). The bottom-right figure shows the helicity distributions for $D_s^{*-}\rho^+$ mode. The solid-blue line represents the total fit, while the red-dashed(black-dotted) curve is the signal(background).

using a selection criteria based on M_{D_s} and $M_{D_s^*} - M_{D_s}$ information. After rejecting continuum events using a Fisher discriminant based on a set of modified Fox-Wolfram moments [7, 10], the remaining background events are largely $B_{(s)} \to D_s^{(*)}X$ decays, where X is an accidental particle combination with a reconstructed mass within the D_s mass window. The $B_s^0 \to D_s^- D_s^+$, $D_s^{*-}D_s^+$, and $D_s^{*-}D_s^{*+}$ modes are fitted simultaneously; the fit projections are shown in Figure 2.

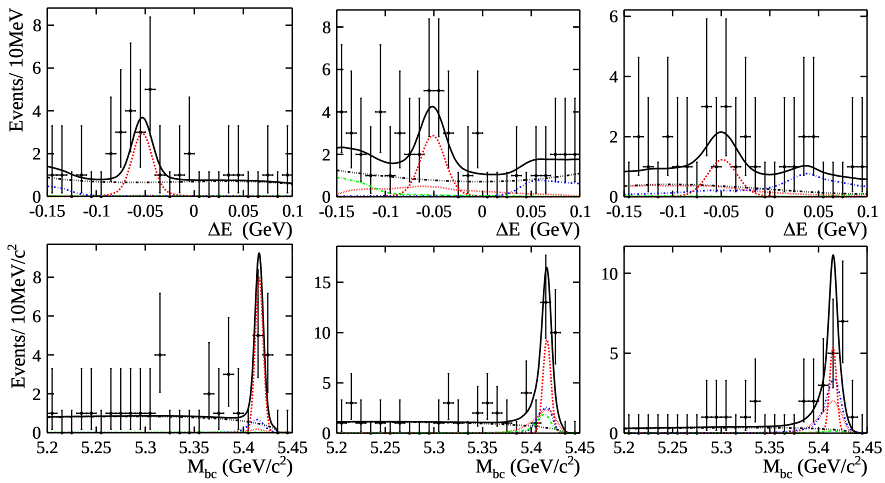

Figure 2: ΔE (top) and M_{bc}(bottom) distributions for $D_s^- D_s^+$, $D_s^- D_s^+$ and $D_s^- D_s^+$, from left to right respectively. The red-dashed curve represents correctly reconstructed signal events, the black curve is the total fit.

The signal yields, branching fractions, and resulting value of $\Delta\Gamma/\Gamma_{CP}$ are listed in Table 1. Various systematic uncertainties are studied, and the resulting systematic errors are listed after the statistical errors. The second systematic error is due to uncertainty of f_s for $B_s^0 \to D_s^{*-}\pi^+$, $D_s^{(*)-}\rho^+$ modes. For $B_s^0 \to D_s^{(*)-}D_s^{(*)+}$ modes, it also includes uncertainties of D_s branching fractions, $\sigma_{\Upsilon(5S)}$, and $f_{B_s^*\bar{B}_s^*}$. Our results are in good agreement with the theoretical predictions [11, 12] and existing measurements[13].

Mode	$N_{B_s^*\bar{B}_s^*}$	S	ε	$\mathscr{B}(\%)$	*World Average*
$B_s^0 \to D_s^{*-}\pi^+$	$53.4^{+10.3}_{-9.4}$	7.1	9.13×10^{-2}	$0.24^{+0.05}_{-0.04}\pm0.03\pm0.04$	1^{st} Measurement
$B_s^0 \to D_s^{-}\rho^+$	$92.2^{+14.2}_{-13.2}$	8.2	4.40×10^{-2}	$0.85^{+0.13}_{-0.12}\pm0.11\pm0.13$	1^{st} Measurement
$B_s^0 \to D_s^{*-}\rho^+$	$77.8^{+14.5}_{-13.4}$	7.4	2.67×10^{-2}	$1.19^{+0.22}_{-0.20}\pm0.17\pm0.18$	1^{st} Measurement
$f_L(B_s^0 \to D_s^{*-}\rho^+)$	$1.05^{+0.08+0.03}_{-0.10-0.04}$				1^{st} Measurement
$B_s^0 \to D_s^{-}D_s^+$	$8.5^{+3.2}_{-2.6}$	6.2	3.31×10^{-4}	$1.03^{+0.39}_{-0.32}{}^{+0.15}_{-0.13}\pm0.21$	$(1.04\pm0.35)\%$
$B_s^0 \to D_s^{*-}D_s^+$	$9.2^{+2.8}_{-2.4}$	6.6	1.35×10^{-4}	$2.75^{+0.83}_{-0.71}\pm0.40\pm0.56$	1^{st} Observation
$B_s^0 \to D_s^{*-}D_s^{*+}$	$4.9^{+1.9}_{-1.7}$	3.1	0.643×10^{-4}	$3.08^{+1.22}_{-1.04}{}^{+0.57}_{-0.58}\pm0.63$	1^{st} Evidence
$B_s^0 \to D_s^{(*)-}D_s^{(*)+}$	$22.6^{+4.7}_{-3.9}$			$6.85^{+1.53}_{-1.30}\pm1.11^{+1.40}_{-1.41}$	$(4.0\pm1.5)\%$
$\Delta\Gamma_s/\Delta\Gamma$	$0.147^{+0.036+0.042}_{-0.030-0.041}$				0.080 ± 0.030

Table 1: Summary of the results. Signal yields in the $B_s^*\bar{B}_s^*$ production mode, $N_{B_s^*\bar{B}_s^*}$; significances, S (including systematics); total signal efficiencies, ε (including all sub-decay branching fractions); and branching fractions, $\mathscr{B}$. The first error is statistical, while the latter two are systematic and arise from internal and external sources. The significance $S = \sqrt{(-2\ln(L_0/L_{max}))}$, where $L_0(L_{max})$ are likelihood values when the signal yield is fixed to zero (floated).

4. Conclusion

We presented recent branching fraction measurements of B_s^0 decays obtained from 23.6 fb^{-1} of $\Upsilon(5S)$ data recorded by the Belle experiment. Also, the longitudinal polarization fraction is measured for the $B_s^0 \to D_s^{*-}\rho^+$ mode and $\Delta\Gamma_s^{CP}/\Gamma_s$ is estimated using $D_s^{(*)-}D_s^{(*)+}$ modes.

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