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Recent Belle results from $\Upsilon(5S)$ sample

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The large data sample recorded with the Belle detector at the $\Upsilon(5S)$ energy provides a unique opportunity to study the poorly-known B_s^0 meson. Two analyses, performed with a data sample representing an integrated luminosity of 121 fb^{-1}, are presented: the measurement of the $B_s^0 \to J/\psi\, f_0(980)$ and $B_s^0 \to J/\psi\, f_0(1370)$ branching fractions, and the 5σ observation of the decay $\bar{B}_s^0 \to \Lambda_c^+ \pi^- \bar{\Lambda}$ which is the first observation of a baryonic B_s^0 decay. In addition, we present new results of a measurement of the CKM angle $\phi_1(\beta)$ with $B\pi$ tagged events.

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Introduction

The Belle experiment [1], located at the interaction point of the KEKB asymmetric-energy e^+e^- collider, was designed for the study of B mesons[1] produced in e^+e^- annihilation at a center-of-mass (CM) energy corresponding to the mass of the $\Upsilon(4S)$ resonance ($\sqrt{s} \approx 10.58$ GeV). However, a data sample of integrated luminosity $L_{\rm int} = 121\,{\rm fb}^{-1}$ has been recorded and analyzed at the energy of the $\Upsilon(5S)$ resonance ($\sqrt{s} \approx 10.87$ GeV), above the $B_s^0\bar{B}_s^0$ threshold.

Apart from the $e^+e^- \to u\bar{u}, d\bar{d}, s\bar{s}, c\bar{c}$ continuum events, the $e^+e^- \to b\bar{b}$ process can produce different kinds of final states involving a pair of non-strange B mesons [2] ($B^*\bar{B}^*$, $B^*\bar{B}$, $B\bar{B}$, $B^*\bar{B}^*\pi$, $B^*\bar{B}\pi$, $B\bar{B}\pi$, $B\bar{B}\pi\pi$ and $B\bar{B}\gamma$), a pair of B_s^0 mesons ($B_s^*\bar{B}_s^*$, $B_s^*\bar{B}_s^0$ and $B_s^0\bar{B}_s^0$), or final states involving a light bottomonium resonance below the open-beauty threshold [3]. The B^* and B_s^* mesons always decay by emission of a photon. 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 [4] and the fraction of B_s^0 events to be $f_s = \sigma(e^+e^- \to B_s^{(*)}\bar{B}_s^{(*)})/\sigma_{b\bar{b}} = (19.3 \pm 2.9)\%$ [5]. The dominant B_s^0 production mode, $b\bar{b} \to B_s^*\bar{B}_s^*$, represents $f_{B_s^*\bar{B}_s^*} = \left(90.1^{+3.8}_{-4.0} \pm 0.2\right)\%$ of the $b\bar{b} \to B_s^{(*)}\bar{B}_s^{(*)}$ events, as measured with $B_s^0 \to D_s^-\pi^+$ events [6].

B_s^0 candidates are fully reconstructed from the final-state particles. From the reconstructed four-momentum in the e^+e^- center-of-mass, $(E^*_{B_s^0}, \boldsymbol{p}^*_{B_s^0})$, two observables are used to extract the signal yield: the energy difference $\Delta E = E^*_{B_s^0} - \sqrt{s}/2$ and the beam-constrained mass $M_{\rm bc} = \sqrt{s/4 - \boldsymbol{p}^{*2}_{B_s^0}}$. The corresponding branching fraction is then computed using the total efficiency (including sub-decay branching fractions) determined with Monte-Carlo (MC) simulations, $\sum \varepsilon \mathscr{B}$, and the number of B_s^0 mesons produced via the $e^+e^- \to B_s^*\bar{B}_s^*$ process, $N_{B_s^0} = 2 \times L_{\rm int} \times \sigma_{b\bar{b}} \times f_s \times f_{B_s^*\bar{B}_s^*}$.

1. Study of $\bar{B}_s^0 \to \Lambda_c^+\pi^-\bar{\Lambda}$

The $\bar{B}_s^0 \to \Lambda_c^+\pi^-\bar{\Lambda}$ decay is the counterpart if the already-observed $B^- \to \Lambda_c^+\pi^-\bar{p}$ decay. The study of $B_{(s)}$ baryonic decays is important as the latest observations [7] exhibit a baryon-antibaryon mass peak near the kinematic threshold and tend to have larger branching fractions than two-body decays.

We fully reconstruct the decay via $\Lambda_c^+ \to pK^-\pi^+$ and $\bar{\Lambda} \to \bar{p}\pi^+$. After a fit of the two $\Lambda_{(c)}$ vertices, only $\bar{B}_s^0$ candidates for which the Λ_c^+ ($\bar{\Lambda}$) invariant mass lies within 100 MeV/c^2 (4 MeV/c^2) of the PDG value [5] are retained. The continuum is rejected with requirements on second-to-zeroth Fox-Wolfram moment ratio [8], $R_2 < 0.5$, and the cosine of thrust angle, $\cos\theta_{\rm th} < 0.85$.

A two-dimensional binned fit on $M_{\rm bc}$ and ΔE leads to a first 5.0σ-significant (including systematic effects) observation of 24 ± 7 events (Fig. 1). This is the first observation of a B_s^0 baryonic decay. The measured branching fraction,

$$\mathscr{B}(\bar{B}_s^0 \to \Lambda_c^+\pi^-\bar{\Lambda}) = (4.8 \pm 1.4({\rm stat.}) \pm 0.9({\rm syst.}) \pm 1.3(\Lambda_c^+)) \times 10^{-4},$$

where the uncertainty due to the Λ_c^+ branching fraction is quoted separately, is compatible with that of $B^- \to \Lambda_c^+\pi^-\bar{p}$ [5].

[1] The notation "B" refers either to a B^0 or a B^+. Moreover, charge-conjugated states are implied everywhere.

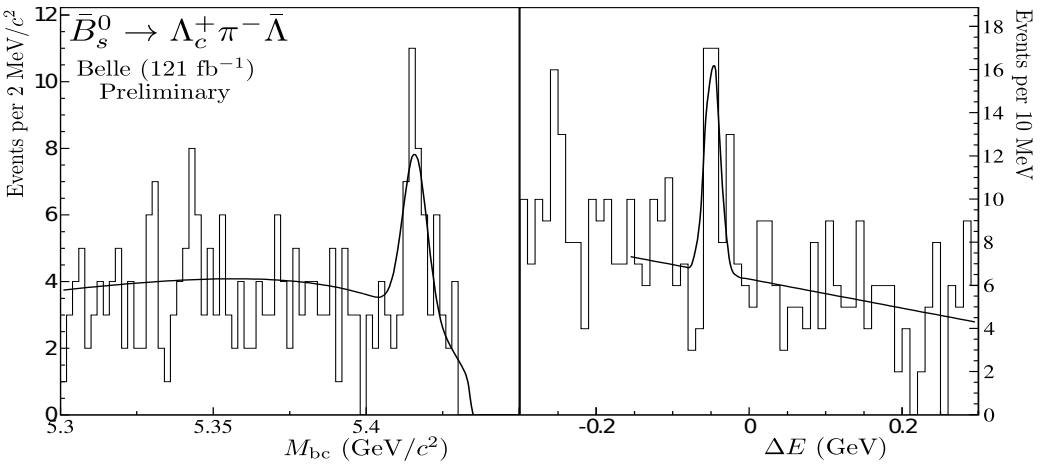

Figure 1: $M_{\rm bc}$ (left) and ΔE (right) distributions of the $\bar{B}^0_s \to \Lambda_c^+ \pi^- \bar{\Lambda}$ candidates (histogram) together with the fit result (solid curve). The dotted curve shows its background component.

2. Study of $B^0_s \to J/\psi f_0$

B^0_s decays to CP eigenstates are important for CP-violation measurements [9]. The $B^0_s \to J/\psi f_0$ mode is especially interesting for the hadron-collider experiments because it can be reconstructed from charged tracks only.

The J/ψ candidates are formed with oppositely-charged electron or muon pairs, while f_0 candidates are formed with $\pi^+\pi^-$ pairs. A mass and vertex constrained fit is then applied to the J/ψ candidates. If more than one candidate per event satisfies all the selection criteria, the one with the $M_{\rm bc}$ value the closest to the expected signal mean is selected. The main background is the continuum, which is reduced by requiring $R_2 < 0.4$. The $B^0_s \to J/\psi f_0$ signal is fitted using the energy difference, ΔE, and the f_0 mass, $M_{\pi^+\pi^-}$, distributions. Two f_0 resonances, $f_0(980)$ and $f_0(1370)$, are included in the fit.

We obtain a 8.4σ observation of 63^{+16}_{-10} $B^0_s \to J/\psi f_0(980)$ events and the first evidence for $B^0_s \to J/\psi f_0(1370)$ with 19^{+6}_{-8} events [10]. We extract the branching fractions $\mathscr{B}(B^0_s \to J/\psi f_0(980); f_0(980) \to \pi^+\pi^-) = [1.16^{+0.31}_{-0.19}(\text{stat.})^{+0.15}_{-0.17}(\text{syst.})^{+0.26}_{-0.18}(N(B^0_s))] \times 10^{-4}$ and $\mathscr{B}(B^0_s \to J/\psi f_0(1370); f_0(1370) \to \pi^+\pi^-) = [0.34^{+0.11}_{-0.14}(\text{stat.})^{+0.03}_{-0.02}(\text{syst.})^{+0.08}_{-0.05}(N(B^0_s))] \times 10^{-4}$, which are in agreement with other hadron-collider experiments [11].

3. Measurement of $\sin 2\phi_1$ with $B\pi$ tagging

Because the $\Upsilon(5S)$ mass is above the $B^*\bar{B}^*\pi$ threshold, a significant number of $\Upsilon(5S) \to B^{(*)}\bar{B}^{(*)}\pi^\pm$ events are present in the data sample [2]. The sign of the pion indicates whether the event contains a $B^{(*)0}$ ($e^+e^- \to B^{(*)0}B^{(*)-}\pi^+$) or a $\bar{B}^{(*)0}$ ($e^+e^- \to \bar{B}^{(*)0}B^{(*)+}\pi^-$). With B^0 decaying to a CP eigenstate, the asymmetry, $A_{BB\pi} = (N(BB\pi^-) - N(BB\pi^+))/(N(BB\pi^-) + N(BB\pi^+))$, the CKM angle ϕ_1 can be determined via the relation [12]: $\sin 2\phi_1 = -\eta_{CP} A_{BB\pi}(1+x^2)/x$, where $x = \Delta m/\Gamma$.

From a clean sample of 75.9 ± 9.5 fully reconstructed $B^0 \to J/\psi(\to l^+l^-)K^0_S(\to \pi^+\pi^-)$ events, we simultaneously fit the missing masses of the $B^0\pi^-$ and $B^0\pi^+$ candidates by adding a charged

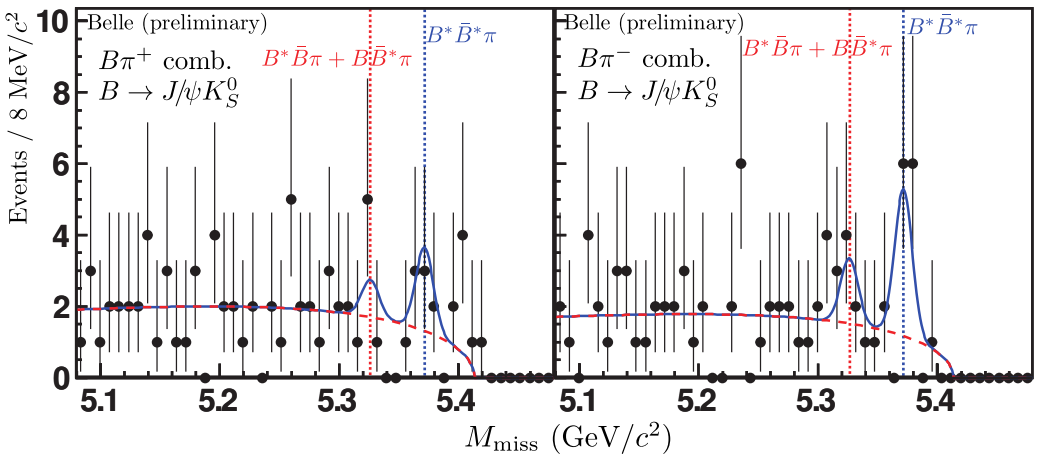

Figure 2: $B^0\pi^+$ (left) and $B^0\pi^-$ (right) missing mass distributions for selected $B^0 \to J/\psi K^0_S$ candidates (data points) together with the fit result (solid curve) and its background component (dashed curve).

pion. The fit involves three signal components for the $B^*\bar{B}^*\pi$, $B^*\bar{B}\pi$ (+c.c.) and $B\bar{B}\pi$ classes of events. A total signal of 21.5 ± 6.8 $B^0\pi^\pm$ events is obtained together with the asymmetry $A_{BB\pi} = 0.28 \pm 0.28$(stat.). While this analysis clearly suffers from lack of statistics, it nevertheless demonstrates that ϕ_1 can be measured by this alternative method.

Conclusion

We presented new results on B^0_s decays obtained from 121 fb^{-1} of $\Upsilon(5S)$ data recorded by the Belle detector. While modes with large statistics can provide precise measurements of branching fractions and $B^{(*)}_s$ properties, first observations of several CP-eigenstate B^0_s decays are a confirmation of the large potential of our 120 fb^{-1} $e^+e^- \to \Upsilon(5S)$ data sample and advocate an ambitious B^0_s program at super-B factories.

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