PROCEEDINGS OF SCIENCE

Charmless B decay measurements at Belle

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In this report, we summarize the recent charmless B decay measurements at Belle. The studies are based on the Belle data sample of 711 fb^{-1} or 121 fb^{-1} collected at $\Upsilon(4S)$ or $\Upsilon(5S)$ resonance at the KEKB collider. Results of several decay modes are presented. In addition to their branching measurements, the structure in the two-body invariant mass are also investigated for some of the decay modes.

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1. Introduction

Charmless B decays are suppressed in Standard Model (SM), and are also sensitive to physics beyond the Standard Model (BSM) within the loop of penguin amplitude. Precise measurements on them could be a good sensitivity test against the prediction by SM. The main experimental challenge is the signal rate which is about 10^5 times smaller than the $e^+e^- \to q\bar{q}$ ($q = u, d, s, c$) continuum processes. Reduction of combinatorial background is hence critical. Using a Belle data sample of 711 fb^{-1} or 121 fb^{-1} collected at $\Upsilon(4S)$ or $\Upsilon(5S)$ resonance with the Belle detector [1] at the KEKB asymmetric-energy e^+e^- collider [2], we report the studies of the following B and B_s^0 decay modes: $B^0 \to p\bar{p}\pi^+\pi^-$, $B^+ \to p\bar{p}\pi^+\pi^0$ [3], $B^+ \to K^+K^-\pi^+$, $B^+ \to \pi^+\pi^0\pi^0$, $B_s^0 \to \eta' X_{s\bar{s}}$ [4], $B_s^0 \to \eta'\eta$ [5], and $B_s^0 \to \eta' K_S^0$[†] . Their signal yields ($N_{\rm sig}$) are measured by one or multi-dimensional extended unbinned likelihood fit on data with different variables, and branching fractions are estimated by $\mathcal{B} = \frac{N_{\rm sig}}{\epsilon \times N_B}$, where ϵ is the signal reconstruction efficiency and N_B is the number of B events (772M for B^+ or B^0, 16.6M for B_s^0).

2. $B^0 \to p\bar{p}\pi^+\pi^-$ and $B^+ \to p\bar{p}\pi^+\pi^0$

Baryonic B decays have various interesting features, such as the enhancement in the di-baryon low mass threshold [6], and the different angular distributions from different modes e.g. between $B^+ \to p\bar{p}K^+$ and $B^+ \to p\bar{p}\pi^+$ [7]. Signal B candidate is identified by the energy difference $\Delta E \equiv E_B - E_{\rm beam}$ and the beam-energy-constrained mass $M_{\rm bc} \equiv \sqrt{E^2_{\rm beam}/c^4 - |p_B/c|^2}$, where $E_{\rm beam}$ is the beam energy, and p_B and E_B are the momentum and energy of the reconstructed B meson, respectively. We use 2D fit with ΔE and $M_{\rm bc}$ to extract $N_{\rm sig}$, and obtain $\mathcal{B}(B^0 \to p\bar{p}\pi^+\pi^-) = (0.83 \pm 0.17(\text{stat.}) \pm 0.17(\text{syst.})) \times 10^{-6}$ and $\mathcal{B}(B^+ \to p\bar{p}\pi^+\pi^0) = (4.58 \pm 1.17(\text{stat.}) \pm 0.67(\text{syst.})) \times 10^{-6}$. The total measured $\mathcal{B}(B^+ \to p\bar{p}\pi^+\pi^0)$ is about a factor of 10 smaller than the predicted $\mathcal{B}(B^+ \to p\bar{p}\rho^+)$ from a theoretical calculation by generalized factorization method [8]. Figure 1 shows the $M_{\pi\pi}$ distribution. A χ^2 fit is perform on $M_{\pi^+\pi^0}$ and we obtain 86 ± 41 events for $B^+ \to p\bar{p}\rho^+$. Table 1 shows the signal yields in $M_{p\bar{p}}$ bins. Branching fraction of $B^0 \to p\bar{p}\pi^+\pi^-$ in the threshold enhancement region (the lowest bin) is estimated as $(0.35 \pm 0.13(\text{stat.}) \pm 0.07(\text{syst.})) \times 10^{-6}$, which is consistent with the LHCb result [9].

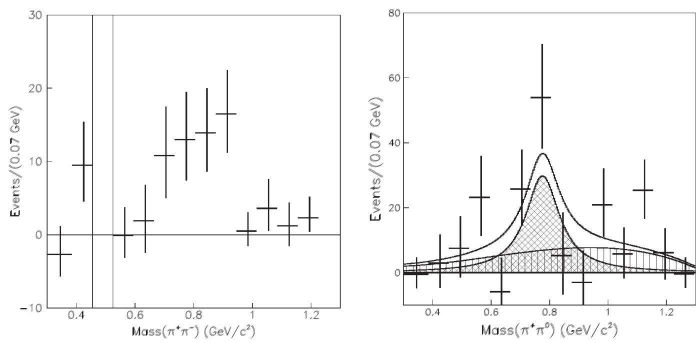

Figure 1: $M_{\pi^+\pi^-}$ (left) and $M_{\pi^+\pi^0}$ (right) distributions of $B^0 \to p\bar{p}\pi^+\pi^-$ and $B^+ \to p\bar{p}\pi^+\pi^0$, respectively.

[†]Throughout this paper, inclusion of charge-conjugate decay modes is always implied.

Table 1: Fitted yields of $B^0 \to p\bar{p}\pi^+\pi^-$ (0.6 GeV/c^2 < $M_{\pi^+\pi^-}$ < 1.22 GeV/c^2) and $B^+ \to p\bar{p}\pi^+\pi^0$ ($M_{\pi^+\pi^0}$ < 1.3 GeV/c^2) in $M_{p\bar{p}}$ bins.

$M_{p\bar{p}}$ (GeV/c^2)	Yield of $B^0 \to p\bar{p}\pi^+\pi^-$	Yield of $B^+ \to p\bar{p}\pi^+\pi^0$
$M_{p\bar{p}} < 2.85$	$26.1^{+10.0}_{-9.1}$	$133.5^{+26.6}_{-25.2}$
$2.85 < M_{p\bar{p}} < 3.128$	$19.6^{+10.2}_{-9.3}$	$12.3^{+10.3}_{-9.7}$
$3.128 < M_{p\bar{p}}$	$29.1^{+16.2}_{-13.1}$	$-3.8^{+15.1}_{-13.8}$

3. $B^+ \to K^+K^-\pi^+$

Compared to previous measurement by Belle [10], $B^+ \to K^+K^-\pi^+$ result is updated with a re-optimized binning to study the property of the structure and localized $\mathcal{A}_{CP}$ at low $M_{K^+K^-}$ region which were also observed in BaBar [11] and LHCb [12–14]. Signal yields and $\mathcal{A}_{CP}$ are extracted by using 2D fit with ΔE and $M_{\rm bc}$ within each $M_{K^+K^-}$ bins, and Figure 2 shows the results. The structure at $M_{K^+K^-}$ < 1.1 GeV/c^2 has an $\mathcal{A}_{CP}$ of $-0.90\pm0.17(\text{stat.})\pm0.03(\text{syst.})$ with a significance of 4.8σ. Helicity angle ($\theta_{\rm hel}$, defined as the angle between B^+ and K^+ in the K^+K^- rest frame) for signal events within $M_{K^+K^-}$ < 1.1 GeV/c^2 is shown in Figure 3. The distribution is consistent with a coherent sum of spin-0 and spin-1 the most.

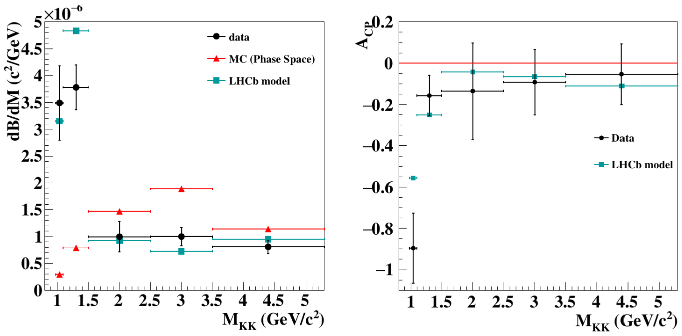

Figure 2: Differential branching fraction (left) and $\mathcal{A}_{CP}$ (right) distributions as a function of $M_{K^+K^-}$ for $B^+ \to K^+K^-\pi^+$.

4. $B^+ \to \pi^+\pi^0\pi^0$

The major challenge in the $B^+ \to \pi^+\pi^0\pi^0$ measurement is the shower leakage [15] due to two π^0 in the reconstruction, and the correlation between energy and other variables. e.g. between ΔE and $M_{\pi\pi}$. To handle those effects, we require the momentum to be greater 0.5 GeV/c^2 for all π^0 candidates. By a 3D fit with ΔE, $M_{\rm bc}$, and a Neural-Network [16] output discriminant for continuum suppression [17], we obtain inclusive $\mathcal{B}(B^+ \to \pi^+\pi^0\pi^0) = (19.0 \pm 1.5(\text{stat.}) \pm 1.4(\text{syst.})) \times 10^{-6}$ and $\mathcal{A}_{CP} = (9.2 \pm 6.8(\text{stat.}) \pm 0.5(\text{syst.}))\%$. We use the ${}_s\mathcal{P}lot$ technique [18] to isolate signal on $M_{\pi\pi}$ distribution, and perform a 2D binned fit on the histogram to extract the signal model composition as shown in Figure 4. In addition to the $B^+ \to \rho(770)^+\pi^0$ structure at low $M_{\pi^+\pi^0,\rm min}$

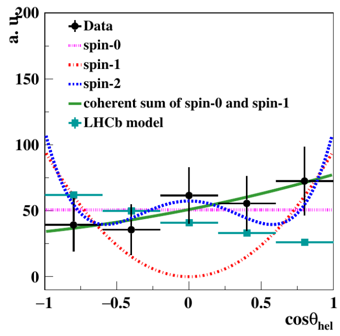

Figure 3: The helicity angle distribution with applying efficiency correction and comparisons to different models, where the LHCb model is from Ref. [13].

region† , and we also observe a new structure at $M_{\pi^0\pi^0}$ region, which is modeled by an incoherent sum of $f_0(980)$, $f_2(1270)$, and $f_0(500)$. A combined branching fraction for this $\pi^0\pi^0$ structure is measured as $(6.9 \pm 0.9(\mathrm{stat.}) \pm 0.6(\mathrm{syst.})) \times 10^{-6}$, which has a significance of 9.2σ. A large $\mathcal{A}_{CP}$ is seen at $M_{\pi^0\pi^0} \sim 1.4$ GeV/c^2 as shown in Figure 5.

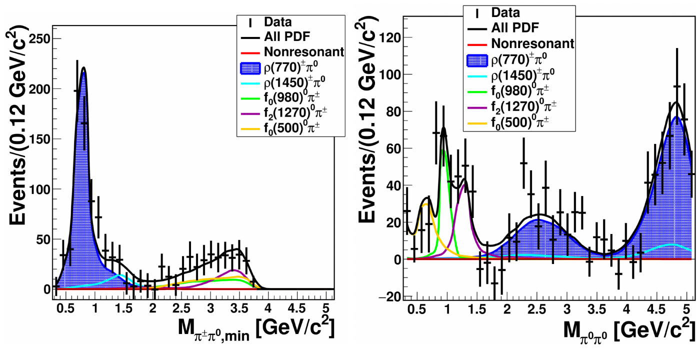

Figure 4: Projection of the fit result to $_s\mathcal{W}eights$ $M_{\pi^+\pi^0,\mathrm{min}}$-vs-$M_{\pi^0\pi^0}$ histogram.

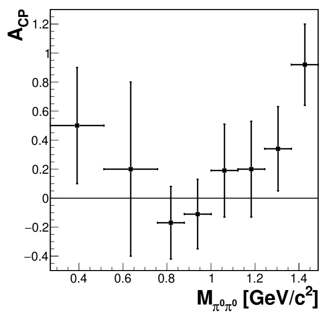

Figure 5: $_s\mathcal{W}eights$ $\mathcal{A}_{CP}$ as a function of $M_{\pi^0\pi^0}$ for $M_{\pi^+\pi^0,\mathrm{min}} > 1.9$ GeV/c^2. The first few bins are combined due to low number of events.

‡ $M_{\pi^+\pi^0,\mathrm{min}}$ refers to the smaller of two $M_{\pi^+\pi^0}$ values in a reconstructed B candidate.

5. $B_s^0 \to \eta' X_{s\bar{s}}$, $B_s^0 \to \eta'\eta$, and $B_s^0 \to \eta' K_S^0$

As B decays with η' in the final state have been observed firstly by CLEO [19, 20], we have found some special properties in this particle and decays involving it. η' mass is higher than the expectation from symmetry considerations [21]. Measurements of $\mathcal{B}(B \to \eta' X_s)$ [23–25] also show unexpected enhancement compared with SM prediction [22]. Any new observation on decays with η' could provide further information to understand its property.

We report the first measurement on $B_s^0 \to \eta' X_{s\bar{s}}$ based on a semi-inclusive method [4]. Simulation of $X_{s\bar{s}}$ fragmentation is performed with PYTHIA 6 [26] with a flat mass distribution. $X_{s\bar{s}}$ candidates are reconstructed with two kaons (K^+K^- or $K^\pm K_S^0$ with $K_S^0 \to \pi^+\pi^-$) and up to four pions with at most one π^0. η' candidates are reconstructed with $\pi^+\pi^-\eta$ and $\eta \to \gamma\gamma$. $N_{\rm sig}$ is extracted by a 1D fit on $M_{\rm bc}$ with -0.12 GeV $< \Delta E <$ 0.05 GeV in $M_{X_{s\bar{s}}}$ bins. As none of the bins shows significant yield, we set an upper limit on $\mathcal{B}(B_s^0 \to \eta' X_{s\bar{s}})$ as 1.4×10^{-3} at 90% confidence level (C.L.).

Branching fraction and CP asymmetry of $B_s^0 \to \eta'\eta$ decay could be affected by various BSM scenarios [28]. Along with the results of other $B_{d,s}^0 \to \eta\eta, \eta'\eta, \eta'\eta'$ modes, measurement on $B_s^0 \to \eta'\eta$ is helpful to extract CP-violating parameters from SU(3)/U(3) symmetry [29]. $N_{\rm sig}$ of $B_s^0 \to \eta'\eta$ is extracted by 3D fit with ΔE, $M_{\rm bc}$, and $M_{\eta'}$. We obtain 2.7 ± 2.5 events and set upper limits of $f_s \times \mathcal{B}(B_s^0 \to \eta'\eta)$ and $\mathcal{B}(B_s^0 \to \eta'\eta)$ as 1.3×10^{-5} and 6.5×10^{-5} at 90% C.L., respectively, where f_s is the fraction of $B_s^{(*)0}\bar{B}_s^{(*)0}$ in $b\bar{b}$ events and its world average is 0.201 ± 0.031 [27].

$B_s^0 \to \eta' K_S^0$ decay contains contributions from gluonic and electroweak penguin amplitudes, such that it is sensitive to BSM physics [28] which can affect both decay rate and CP asymmetries. $N_{\rm sig}$ of $B_s^0 \to \eta' K_S^0$ is extracted by 3D fit with ΔE, $M_{\rm bc}$, and $M_{\eta'}$. We obtain -3.21 ± 1.85 events and set upper limits of $f_s \times \mathcal{B}(B_s^0 \to \eta' K_S^0)$ and $\mathcal{B}(B_s^0 \to \eta' K_S^0)$ as 1.64×10^{-5} and 8.16×10^{-5} at 90% C.L., respectively.

6. Summary

We report the results of several charmless B decays using Belle data collected at $\Upsilon(4S)$ or $\Upsilon(5S)$ resonance. In addition to branching fraction measurement, we also look into the distribution of two-body invariant mass of $B^0 \to p\bar{p}\pi^+\pi^-$, $B^+ \to p\bar{p}\pi^+\pi^0$, $B^+ \to K^+K^-\pi^+$, and $B^+ \to \pi^+\pi^0\pi^0$ to study their decay structure. We do not observe significant signal yield for $B_s^0 \to \eta' X_{s\bar{s}}$, $B_s^0 \to \eta'\eta$, and $B_s^0 \to \eta' K_S^0$, and upper limits on branching fraction are estimated at 90% C.L.. In near future, larger data set from Belle II [30] can further improve the measurement on these decay modes.

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