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Baryonic B decays at Belle

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Abstract. Recent results of baryonic B decays from Belle are reported. This study is done by a 78 fb^{-1} data sample, consisting of 85.0 ± 0.5 million $B\overline{B}$ pairs, collected by the Belle detector at the KEKB asymmetric energy e^+e^- (3.5 on 8 GeV) collider. The results reported here include the first observation of the two-body decay $B^0 \to p\overline{\Lambda}_c$, the first hyperonic decay $B^0 \to p\overline{\Lambda}\pi^-$, and first observations of $B^+ \to p\overline{p}\pi^+$, $B^0 \to p\overline{p}K^0$, and $B^0 \to p\overline{p}K^{*+}$.

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1 Introduction

The Belle collaboration recently reported the observation of $B^+ \to p\overline{p}K^{+1}$ [1], which is the first known example of B meson decay to charmless final states containing baryons. The three-body decay rate is larger than the rate for two-body decays (such as $B \to p\overline{p}$ [2]). We continue this study with a larger data set and search for other related baryonic decay modes. In the Standard Model, these decays proceed via $b \to u(c)$ tree and $b \to s(d)$ penguin diagrams. They may be used to search for direct CP violation and test our theoretical understanding of rare decay processes involving baryons [3,4,5,6,7].

Belle [8] is a general purpose detector operating at the KEKB asymmetric e^+e^- collider. Data sample used here consists of 85.0 ± 0.5 million $B\overline{B}$ pairs or ~78 fb^{-1} data set collected on the $\Upsilon(4S)$ resonance.

2 Analysis procedure

The biggest challenge of observing rare B decay processes is to fish out a few signal events from a huge sample of background events. For example, after the trigger and hadronic event pre-selection, there are about 170 million $e^+e^- \to q\overline{q}$ continuum events and 85 million $B\overline{B}$ events left for the 78 fb^{-1} data set. It is a tough job to reject all of the background. The following is a brief description of the procedure of a typical analysis.

2.1 Signal identification

Since the center-of-mass energy is set to match the $\Upsilon(4S)$ resonance and $\Upsilon(4S)$ decays into a $B\overline{B}$ pair, we can use the following two kinematic variables to identify the reconstructed B meson candidates: the beam-energy constraint mass, $M_{bc} = \sqrt{E_{beam}^2 - p_B^2}$, and the energy difference, $\Delta E = E_B - E_{beam}$, where E_{beam}, p_B and E_B are the beam energy, the momentum and energy of the reconstructed B meson in the rest frame of $\Upsilon(4S)$, respectively.

The resolution of M_{bc} is about 3 MeV/c^2 which is due to the spread of the beam energy. Typically, the resolution of ΔE is about 10 MeV for final states with charged particles only.

2.2 Background suppression

The generic B decay is mainly via the $b \to c$ transition which normally has more final state particles than those of the rare decay modes reported here, thus the background from generic B decays is much less than that from the continuum process. Similar B decay processes close to the target mode should be checked carefully one by one because they might feed into the signal region.

For the continuum events, they have quite different event topology (more back-to-back or jet-like) than that of $B\overline{B}$ events (more spherical) in the $\Upsilon(4S)$ frame. We can select some shape variables to form a Fisher discriminant in order to reject the continuum background.

The probability density functions (PDFs) of the Fisher discriminant and other uncorrelated kinematic variables (e.g. the angle between the B flight direction and the beam direction), are combined to form signal (background) likelihood $\mathcal{L}_{\mathrm{S(BG)}}$, and a cut is then applied on the likelihood ratio $\mathcal{LR} = \mathcal{L}_{\mathrm{S}}/(\mathcal{L}_{\mathrm{S}} + \mathcal{L}_{\mathrm{BG}})$ in order to fish out the signal.

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

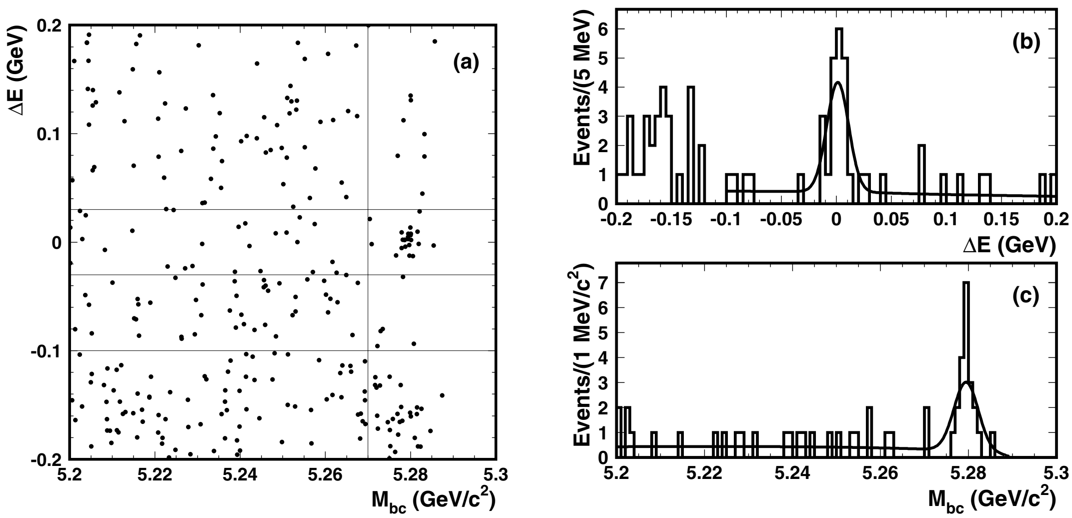

Fig. 1. Candidate $B^0 \to p\overline{\Lambda}_c$ events: **a** scatter plot of ΔE versus M_{bc}, **b** ΔE distribution for $M_{bc} > 5.27\text{GeV}/c^2$, and **c** M_{bc} distribution for $|\Delta E| < 0.03$ GeV. Solid curves indicate the fit results

2.3 Yield determination

After the optimization of selection cuts, events in the candidate $M_{bc} - \Delta E$ region are used for yield determination. This can be done either by un-binned likelihood fit or binned fit. The signal PDFs are normally a Gaussian function for M_{bc} and a double Gaussian for ΔE with parameters determined by MC simulation. The background PDFs are Argus function for M_{bc} and a straight line for ΔE with parameters determined by sideband events or by continuum MC simulation. If there is no evidence of signal events, one can use the fit results to estimate the expected background, and compare this with the observed number of events in the signal region in order to set the upper limit on the yield at the 90% confidence level [9].

2.4 Systematic check

If one is lucky to observe a new decay mode, the comparison between signal MC simulation and data is necessary. However, most of the systematic studies are limited by the small statistics of the signal events. Therefore, control samples with large statistics and relevant to the study are checked in order to determine the systematic errors. For example, the systematic error due to the efficiency error of the proton identification requirements is studied with the $\Lambda \to p\pi^-$ sample; the kaon identification is studied with the $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\pi^+$ sample; the tracking efficiency is studied with the $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ sample, etc..

3 Recent results

3.1 Results of $B^0 \to p\overline{\Lambda}_c$

Although the four- and three-body baryonic B decays of $B^0 \to p\overline{\Lambda}_c\pi^+\pi^-$ and $B^+ \to p\overline{\Lambda}_c\pi^+$ are experimentally well observed [10], there has no two-body mode being found. An effort is made to search for $B^0 \to p\overline{\Lambda}_c$ with $\overline{\Lambda}_c \to \overline{p}K^+\pi^-$. Figure 1 shows the results. The measured branching fraction is $\mathcal{B}(B^0 \to p\overline{\Lambda}_c) = (2.19^{+0.56}_{-0.49} \pm 0.32 \pm 0.57) \times 10^{-5}$, where the first and the second errors are statistical and systematic, respectively. The last error is due to the uncertainty in the branching fraction $\mathcal{B}(\overline{\Lambda}_c \to \overline{p}K^+\pi^-)$ [11]. This is the first ever observation of a two-body baryonic B decays. One interesting feature is that this two-body decay rate is about factor of 10 smaller than that of the related three-body decay. In contrast, the two- and three-body mesonic B decays are comparable.

3.2 Results of $B^0 \to p\overline{\Lambda}\pi^-$

We observe a clear signal for $B^0 \to p\overline{\Lambda}\pi^-$, which is the first hyperonic B decay being found. Since the decay is not uniform in phase space, we fit the ΔE signal yield in bins of $M_{p\overline{\Lambda}}$, and correct for the MC-determined detection efficiency for each bin. This reduces the model dependence of the branching fraction determination. The signal yield as a function of $p\overline{\Lambda}$ mass is shown in Fig. 2. This threshold peaking behavior is similar to that of $B^0 \to p\overline{p}K^+$ [1]. The measured branching fraction is $\mathcal{B}(B^0 \to p\overline{\Lambda}\pi^-) = (3.97^{+1.00}_{-0.80}(stat.) \pm 0.56(syst.)) \times 10^{-6}$. Searches for $B^0 \to p\overline{\Lambda}K^-$ and $p\overline{\Sigma}^0\pi^-$ yield no significant signals and we set 90% confidence-level upper limits of $\mathcal{B}(B^0 \to p\overline{\Lambda}K^-) < 8.2 \times 10^{-7}$ and $\mathcal{B}(B^0 \to p\overline{\Sigma}^0\pi^-) < 3.8 \times 10^{-6}$.

3.3 Results of $B \to p\overline{p}h^{(*)}$

$B^+ \to p\overline{p}K^+$ and $B^0 \to p\overline{\Lambda}\pi^-$ are the first examples of B meson decays to charmless three-body final states containing baryons, and are candidates for $b \to s$ penguin transitions. Our observation of these modes has stimulated much theoretical interest. An interesting feature of these

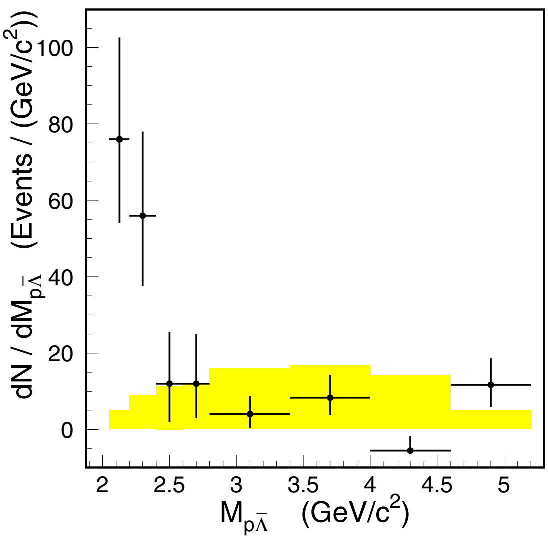

Fig. 2. The fitted yield divided by the bin size for $B^0 \to p\overline{\Lambda}\pi^-$ as a function of $M_{p\overline{\Lambda}}$. The shaded distribution is from a phase-space MC simulation with area normalized to signal yield

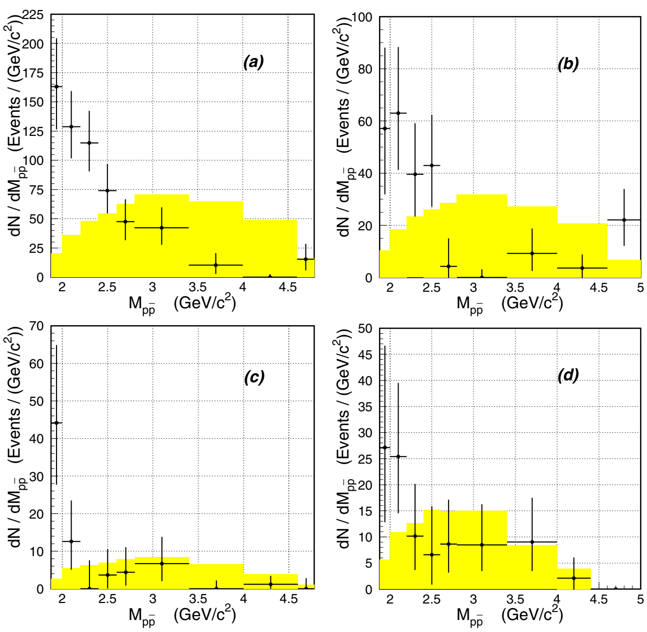

Fig. 3. Fitted signal yield divided by the bin size for **a** $p\overline{p}K^+$, **b** $p\overline{p}\pi^+$, **c** $p\overline{p}K^0$, and **d** *ppst* modes in bins of $M_{p\overline{p}}$. The shaded distribution is from the phase-space MC simulation with area normalized to signal yield

modes is that the baryon pair mass spectra seem to peak toward threshold as originally conjectured [3,7]. With the larger data sample, we have studied the related three-body decays and made the first observation of $B^+ \to p\overline{p}\pi^+$, which is dominated by the $b \to u$ tree diagram. We also observe significant signals of $B^0 \to p\overline{p}K^0$ and $B^+ \to p\overline{p}K^{\star +}$ decays, and improve the measurement of $B^+ \to p\overline{p}K^+$. A search for the $B^0 \to p\overline{p}K^{\star 0}$ mode yields only an upper limit.

Table 1. Summary of $p\overline{p}h^*$ results

	$\mathcal{B}(\times 10^{-6})$	$M_{p\overline{p}} < 2.85$ GeV/c^2	Sig.
$p\overline{p}K^+$	$5.66^{+0.67}_{-0.57} \pm 0.62$	$4.89\,^{+0.50}_{-0.55} \pm 0.54$	15.3σ
$p\overline{p}\pi^+$	$3.06^{+0.73}_{-0.62} \pm 0.37$	$1.76\,^{+0.42}_{-0.37} \pm 0.21$	6.7σ
$p\overline{p}K^0$	$1.88^{+0.77}_{-0.60} \pm 0.23$	$1.56\,^{+0.52}_{-0.40} \pm 0.19$	5.1σ
$p\overline{p}K^{\star +}$	$10.31^{+3.52}_{-2.77} \pm 1.55$	$6.7\,^{+2.4}_{-2.0}\,^{+0.9}_{-1.1}$	6.0σ
$p\overline{p}K^{\star 0}$	$< 7.6 \times 10^{-6}$		

These modes are of interest as they may be used to search for direct CP violation and test our theoretical understanding of rare decay processes involving baryons. Table 1 summarizes the measured branching fractions of these decays. The present results offer valuable information for understanding the mechanism of charmless baryonic B decay. In particular, the threshold peaking behavior is now firmly established as shown in Fig. 3. The $B^+ \to p\overline{p}K^+$ data can be used to constrain the production of narrow glueball states that decay to $p\overline{p}$ [12]. It should be noted that the observed $B^+ \to p\overline{p}\pi^+$ rate is less than $B^+ \to p\overline{p}K^+$, which is consistent with what is observed in $B \to K\pi$, $\pi\pi$ modes. The $B^0 \to p\overline{p}K^0$ rate is considerably lower than that of the $B^+ \to p\overline{p}K^+$ mode, indicating that $p\overline{p}$ may have more than one isospin component, which should be contrasted with $B^{0,+} \to \pi^0 K^{0,+}$ modes. These modes are of interest for direct CP violation searches. For the $B^{\mp} \to p\overline{p}K^{\mp}$ and $p\overline{p}\pi^{\mp}$ modes that have larger statistics, we find the charge asymmetry to be -0.05 ± 0.11 and -0.16 ± 0.22 respectively. The listed errors are statistical errors only and the measured asymmetries are consistent with zero.

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