

Search for charmless two-body baryonic decays of B mesons

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We report the results of a search for the rare baryonic decays $B^0 \rightarrow p\bar{p}$, $\Lambda\bar{\Lambda}$, and $B^+ \rightarrow p\bar{\Lambda}$. The analysis is based on a data set of 31.7×10^6 $B\bar{B}$ events collected by the Belle detector at the KEKB e^+e^- collider. No statistically significant signals are found, and we set branching fraction upper limits $\mathcal{B}(B^0 \rightarrow p\bar{p}) < 1.2 \times 10^{-6}$, $\mathcal{B}(B^0 \rightarrow \Lambda\bar{\Lambda}) < 1.0 \times 10^{-6}$, and $\mathcal{B}(B^+ \rightarrow p\bar{\Lambda}) < 2.2 \times 10^{-6}$ at the 90% confidence level.

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The Belle Collaboration recently reported the observation of the decay process $B^+ \rightarrow p\bar{p}K^+$ [1], which is the first known example of a B meson decay to a charmless final state containing baryons. In this paper we report the results of a search for the related two-body modes $B^0 \rightarrow p\bar{p}$, $\Lambda\bar{\Lambda}$ and $B^+ \rightarrow p\bar{\Lambda}$ [2]. In the standard model, these decays are expected to proceed via color-suppressed $b \rightarrow u$ tree diagrams [Figs. 1(a) and 1(c)] and $b \rightarrow s$, d penguin diagrams [Figs. 1(b) and 1(d)]. The search is based on a 29.4 fb^{-1} sample of e^+e^- data accumulated at the $\Upsilon(4S)$ resonance, which contains 31.7 million $B\bar{B}$ pairs. A previous search for these decays by the CLEO Collaboration using a 5.41 fb^{-1} sample of $\Upsilon(4S)$ data yielded 90% confidence-level (C.L.) upper limits [3].

Belle [4] is a general purpose detector operating at the KEKB asymmetric e^+e^- collider [5]. Tracking information is provided by a silicon vertex detector and a central drift chamber (CDC) in a 1.5 T magnetic field. Hadron identification (PID) for $\pi/K/p$ discrimination is obtained from CDC dE/dx measurements, aerogel Čerenkov counter pulse heights, and timing information from the time-of-flight system. Electron identification is based mainly on CsI(Tl) electromagnetic calorimeter and CDC dE/dx information. K_L and muons are identified by a system of resistive plate counters interleaved with the iron plates of the flux-return iron yoke.

The event selection criteria are based on tracking and PID requirements, and are optimized using Monte Carlo (MC) simulated event samples.

All primary charged tracks are required to satisfy the following track quality criteria based on the track impact parameters relative to the interaction point (IP), which is determined run by run. The z axis is defined by the positron beam line. The deviations from the IP position are required to be within ± 0.05 cm in the transverse (x - y) plane, and within ± 2 cm in the z direction. Tracks that satisfy the muon or electron identification requirements are rejected.

Primary proton candidates are selected based on $p/K/\pi$ likelihood functions obtained from the hadron identification

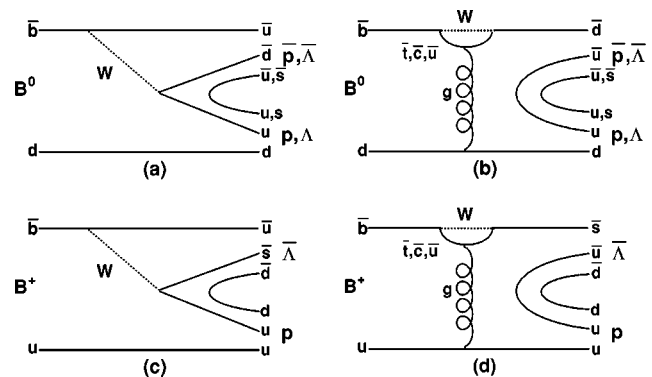


FIG. 1. Illustrative diagrams for B decays to charmless baryon pairs.

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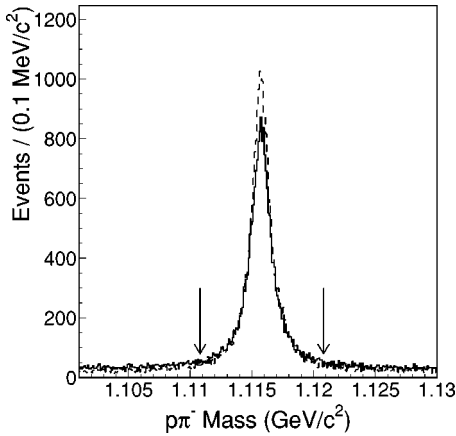


FIG. 2. The mass distribution of the selected $\Lambda \rightarrow p\pi^-$ candidates for a typical run period. The MC distribution is shown as a dashed histogram. The ± 5 MeV mass window is indicated by the vertical arrows.

system. The selection criteria are $L_p/(L_p+L_K) > 0.6$ and $L_p/(L_p+L_\pi) > 0.6$, where $L_{p/K/\pi}$ stands for the proton/kaon/pion likelihood.

Λ candidates are reconstructed via the $p\pi^-$ decay channel and are selected using cuts on four parameters: the angular difference between the Λ flight direction and the direction pointing from IP to the decay vertex in the transverse plane; the distance between each track and the IP in the transverse plane; the distance between the decay vertex and the IP in the transverse plane; and the displacement in z of the closest approach points of the two tracks to the beam axis. The secondary protons are required to have $L_p/(L_p+L_\pi) > 0.6$. The $p\pi^-$ mass spectrum after the application of the above selection criteria is shown in Fig. 2 for a typical run period. The peak position is consistent with the nominal Λ mass [6] and the mass resolution is about 0.9 MeV/ c^2 . Finally, we require the invariant mass of the Λ candidate to be within ± 5 MeV/ c^2 of the nominal Λ mass.

Due to the high momentum of the primary particles from these two-body decay modes, the background from generic B decays is negligible in the kinematic region (described below) for signal fitting. This is checked with MC samples of B^+B^- and $B^0\bar{B}^0$ pairs where the B -mesons decay dominantly via $b \rightarrow c$ processes. We also checked backgrounds using MC samples of charmless B meson decays that include low multiplicity B -decays into final states with π , K , K^* , ρ , ω , ϕ , η , and η' mesons. Only the $p\bar{p}$ mode is found to have any background contamination. However, the level of this contamination is negligible, corresponding to less than one event for the current data set.

The main background is from continuum $q\bar{q}$ processes. This is confirmed using an off-resonance data set [2.3 fb $^{-1}$ taken 60 MeV below the $Y(4S)$] and a MC sample of 65 million continuum events. These continuum events have a jetlike topology while $B\bar{B}$ events are more spherical in the $Y(4S)$ center of mass (c.m.) frame. For continuum event rejection we use $\cos\theta_T$, the cosine of the angle between the direction of one primary decay particle and the thrust axis [7]

of the noncandidate tracks and showers. This distribution is nearly flat for signal events and is strongly peaked at ± 1 for continuum background. We also use $\cos\theta_B$, the cosine of the angle between the B candidate flight direction and the positron beam direction. The signal has a $\sin^2\theta_B$ distribution while the background is uniformly distributed. We require the absolute values of $\cos\theta_T$ and $\cos\theta_B$ to be less than 0.9 for $\Lambda\bar{\Lambda}$ decays and less than 0.8 for the other modes. For the latter case, the background reduction factor is more than five, while $\sim 70\%$ of the signal is retained.

We use the following two kinematic variables to identify the reconstructed B meson candidates: the beam constrained mass, $m_{bc} = \sqrt{E_{\text{beam}}^2 - p_B^2}$, and the energy difference, $\Delta E = E_B - E_{\text{beam}}$, where E_{beam} , p_B and E_B are the beam energy, the momentum and energy of the reconstructed B meson in the $Y(4S)$ c.m. frame, respectively. We retain events with 5.20 GeV/ $c^2 < m_{bc} < 5.29$ GeV/ c^2 and -0.2 GeV $< \Delta E < 0.2$ GeV. The signal yield is extracted by maximizing the likelihood function

$$L = e^{-(s+b)} \prod_{i=1}^N [sP_s(m_{bc_i}, \Delta E_i) + bP_b(m_{bc_i}, \Delta E_i)],$$

where N is the total number of candidate events, $s(b)$ denotes the signal (background) yield and $P_{s(b)}$ denotes the signal (background) probability density function (pdf).

The m_{bc} and ΔE signal pdf's are determined by MC simulation. We use a Gaussian function as the signal pdf for the m_{bc} distribution and a sum of two Gaussians for the ΔE distribution. The Gaussian parameters (mean and σ) are determined separately for each mode. Background shapes are determined from events in sideband regions of ΔE and m_{bc} separately. We adopt an empirical function [8] to model the m_{bc} background shape (for events with 0.1 GeV $< |\Delta E| < 0.2$ GeV) and a first-order polynomial for the ΔE background shape (for events with 5.20 GeV/ $c^2 < m_{bc} < 5.26$ GeV/ c^2).

Table I summarizes the results. The efficiencies for the $\Lambda\bar{\Lambda}$ and $p\bar{\Lambda}$ modes include the $\Lambda \rightarrow p\pi^-$ branching fraction (64%). The efficiencies are determined from a signal MC sample with the identical event selection and fitting procedure as for the data. Figures 3 and 4 show the m_{bc} (with $|\Delta E| < 0.05$ GeV) and ΔE (with 5.27 GeV/ $c^2 < m_{bc} < 5.29$ GeV/ c^2) projections for these three modes, respectively. Projections of the fits are shown as smooth curves. No statistically significant signals are found and we determine 90% C.L. upper limits on the signal yields by integrating the likelihood function. We also compute limits using a counting method [9]. We define a signal region by 5.27 GeV/ $c^2 < m_{bc} < 5.29$ GeV/ c^2 and $|\Delta E| < 0.05$ GeV, and treat the number of background events from the maximum likelihood fit as a prediction for the background in this region. We then count the number of events actually observed, and apply the method of [9] to obtain 90% C.L. intervals.

To estimate the possible influence of fluctuations on the determination of the upper limits, we vary the parameters of the pdf's by one standard deviation and change the form of the ΔE signal pdf to a single Gaussian. The relative change

TABLE I. Results of the search for the exclusive baryon modes. The signal yields, Y , and errors are determined from maximum likelihood fits. The 90% C.L. upper limits from the fits and from the counting method are listed together. We quote the higher values as our conservative estimates for upper limits. The efficiencies, ε , are obtained from MC simulation. The 90% C.L. upper limits for the branching fractions, \mathcal{B} , determined by this experiment are shown along with previous CLEO results. Some theoretical predictions from Ref. [10] are quoted for comparison.

Mode	Y	UL (fitting/counting)	ε (%)	$\mathcal{B}(10^{-6})$	CLEO $\mathcal{B}(10^{-6})$	Theory $\mathcal{B}(10^{-6})$
$p\bar{p}$	$0.6_{-0.6}^{+2.7}$	7.0/9.7	27.5 ± 2.0	< 1.2	< 7.0	0.1–7.0
$\Lambda\bar{\Lambda}$	$0.0_{-0.0}^{+0.5}$	3.0/3.2	10.8 ± 1.1	< 1.0	< 3.9	0.0–0.2
$p\bar{\Lambda}$	$1.0_{-1.0}^{+2.5}$	7.0/10.4	16.2 ± 1.4	< 2.2	< 2.6	0.2–3.0

of the upper limit is 25%, which is mainly due to the changes in the background shape. The upper limit determination by the counting method is checked by redefining the signal region (varying the ΔE range from 2σ to 4σ) and comparing the outcomes. The upper limits from both methods listed in column 3 of Table I include these fluctuations. We quote the values from the counting method as the most conservative upper limits. Fit projections with the signal yield fixed at the upper limit for each mode are shown as the superimposed dashed curves in Figs. 3 and 4 for comparison.

The systematic error due to the efficiency of the proton identification (p - K and p - π) criteria is studied using Λ samples. We vary the likelihood ratio requirement for protons and compare the ratio of reconstructed Λ yields in data and MC calculation. The overall error is about 3%. We include a 2% error per track to account for the uncertainty in tracking efficiency. The Λ reconstruction efficiency is checked by comparing the flight distance distributions of data and MC calculation. They agree very well and no additional error is assigned. The correlated parts of the errors are added linearly to obtain the overall uncertainty in the tracking efficiency and the uncertainty in the PID efficiencies (for

p and \bar{p}), then the resulting errors are combined in quadrature. When determining the upper limit for the branching fraction, the efficiency was reduced by one standard deviation. The efficiencies and upper limits for all three decay modes are listed in Table I.

In summary, we have performed a search for the rare baryonic decays $B^0 \rightarrow p\bar{p}$, $\Lambda\bar{\Lambda}$, and $B^+ \rightarrow p\bar{\Lambda}$ with 31.7 million $B\bar{B}$ events collected by the Belle detector at the KEKB e^+e^- collider. No statistically significant signals are found for these modes, and we set upper limits on their branching fractions at the 90% C.L. The upper limits are

$$\mathcal{B}(B^0 \rightarrow p\bar{p}) < 1.2 \times 10^{-6},$$

$$\mathcal{B}(B^0 \rightarrow \Lambda\bar{\Lambda}) < 1.0 \times 10^{-6},$$

$$\mathcal{B}(B^+ \rightarrow p\bar{\Lambda}) < 2.2 \times 10^{-6}.$$

These are currently the most stringent limits for these decays. The limit on $B^0 \rightarrow p\bar{p}$ has been improved by a factor of six compared to the existing bound [3]. These limits are con-

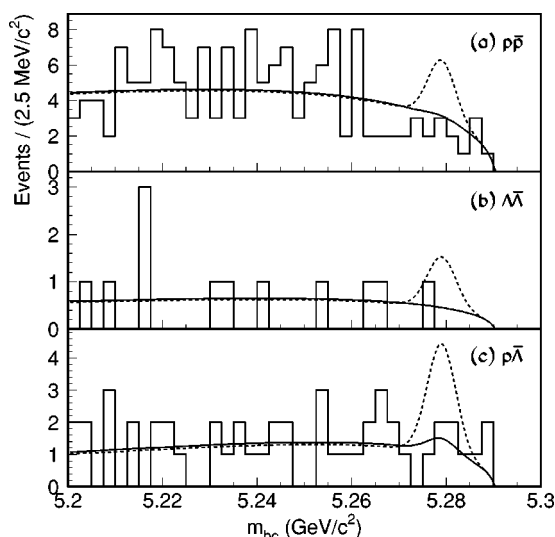


FIG. 3. The distributions of m_{bc} for (a) $B^0 \rightarrow p\bar{p}$, (b) $B^0 \rightarrow \Lambda\bar{\Lambda}$ and (c) $B^+ \rightarrow p\bar{\Lambda}$ candidates. The solid curve is the projection of the maximum likelihood fit. The dashed curve shows the fit with the signal yield fixed at the 90% C.L. upper limit.

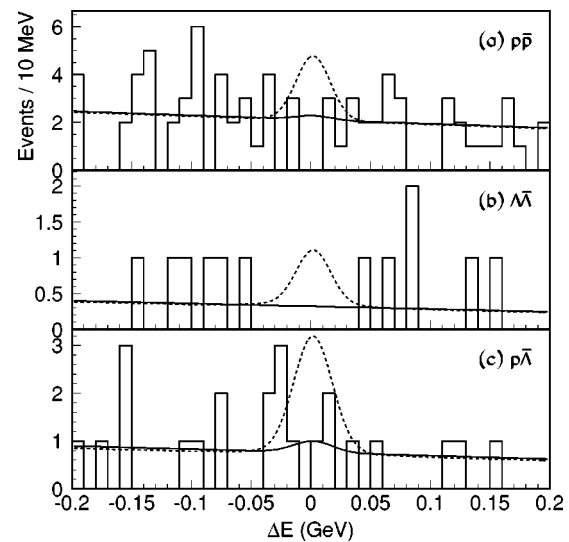


FIG. 4. The distributions of ΔE for (a) $B^0 \rightarrow p\bar{p}$, (b) $B^0 \rightarrow \Lambda\bar{\Lambda}$ and (c) $B^+ \rightarrow p\bar{\Lambda}$ candidates. The solid curve is the projection of the maximum likelihood fit. The dashed curve shows the fit with the signal yield fixed at the 90% C.L. upper limit.

siderably below corresponding charmless mesonic branching fractions which are typically at the level of 10^{-5} . In contrast, the recent Belle measurement of $B^+ \rightarrow p\bar{p}K^+$ [1] indicates a relatively large branching fraction of 4.3×10^{-6} . The underlying physics [10] is now being probed with rapidly accumulating data and new experimental results.

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