

Study of $B \rightarrow p\bar{r}\pi\pi$

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Using a data sample of 772×10^6 $B\bar{B}$ pairs collected on the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric energy e^+e^- collider, we report the observation of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and the first observation of $B^+ \rightarrow p\bar{p}\pi^+\pi^0$. We measure a decay branching fraction of $(0.83 \pm 0.17 \pm 0.17) \times 10^{-6}$ in $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ for $M_{\pi^+\pi^-} < 1.22$ GeV/ c^2 with a significance of 5.5 standard deviations. The contribution from $B^0 \rightarrow p\bar{p}K^0$ is excluded. We measure a decay branching fraction of $(4.58 \pm 1.17 \pm 0.67) \times 10^{-6}$ for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ with $M_{\pi^+\pi^0} < 1.3$ GeV/ c^2 with a significance of 5.4 standard deviations. We study the difference of the $M_{p\bar{p}}$ distributions in $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$.

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Charmless B decays offer a good opportunity to find sizable CP violation due to interference between the $b \rightarrow s$ penguin and $b \rightarrow u$ tree processes. Such decays can reveal new physics if measured results deviate from Standard Model expectations. In the B -factory era, both Belle and BABAR have discovered large direct CP violation in the $B \rightarrow K\pi$ system [1–3]. The LHCb Collaboration reported evidence of direct CP violation in $B^+ \rightarrow p\bar{p}K^+$ [4]. Here and throughout the text, the inclusion of the charge-conjugate mode is implied unless otherwise stated. This rare baryonic B decay presumably proceeds via the $b \rightarrow s$ penguin process with some non-negligible $b \rightarrow u$ contribution. It is intriguing that the invariant mass of the $p\bar{p}$ system peaks near threshold [5], and in the $p\bar{p}$ rest frame, K^+ is produced preferably in the \bar{p} direction [6]. Interestingly, this angular asymmetry is opposite to that observed in $B^+ \rightarrow p\bar{p}\pi^+$, which is presumably dominated by the $b \rightarrow u$ tree process [6]. Most of the baryonic B decays presumably proceed predominantly via the $b \rightarrow s$ process, except for $B^+ \rightarrow p\bar{p}\pi^+$ and $B^0 \rightarrow p\bar{p}\pi^0$ [7] decays. It is important to measure other $b \rightarrow u$ baryonic B decays to provide more information for theoretical investigation based on a generalized factorization approach [8]. $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ has been observed by LHCb [9], but there is still no observation for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$.

We report a study of both $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ including the $B \rightarrow p\bar{p}\rho$ mass region using the full $\Upsilon(4S)$ dataset collected by the Belle detector [10,11] at the asymmetric energy e^+ (3.5 GeV) e^- (8 GeV) KEKB collider [12,13]. The data sample used in this study corresponds to an integrated luminosity of 711 fb^{-1} , which contains 772×10^6 $B\bar{B}$ pairs produced on the $\Upsilon(4S)$

resonance. The Belle detector surrounds the interaction point of KEKB. It is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector, a 50-layer central drift chamber (CDC), an array of aerogel threshold Cherenkov counters (ACC), a barrel-like arrangement of time-of-flight scintillation counters (TOF), and an electromagnetic calorimeter (ECL) comprised of CsI(Tl) crystals located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux return located outside of the coil is instrumented to detect K_L^0 mesons and identify muons.

For the study of $B \rightarrow p\bar{p}\pi\pi$, samples simulated with the Monte Carlo technique (MC) are used to optimize the signal selection criteria and estimate the signal reconstruction efficiency. These samples are generated with EvtGen [14] and a GEANT-based software package [15] to model the detector response. We generate the signal MC sample by a phase space model reweighted with the $p\bar{p}$ mass distribution obtained by LHCb [9] on $B^0 \rightarrow p\bar{p}\pi^+\pi^-$. The background samples include the continuum events ($e^+e^- \rightarrow u\bar{u}, d\bar{d}, s\bar{s},$ and $c\bar{c}$), generic B decays ($b \rightarrow c$), and rare B decays ($b \rightarrow u, d, s$). These simulated background samples are 6 times larger than the integrated luminosity of the accumulated Belle data.

We require charged particles to originate within a 2.0 cm region along the beam and from a 0.3 cm region on the transverse plane around the interaction region. To identify charged particles, we utilize the likelihood information determined for each particle type by the CDC, TOF, and ACC and apply the same selection criteria listed in Ref. [6] to select $p(\bar{p})$ and $\pi^+(\pi^-)$. The π^0 is reconstructed from two photons with a minimum energy in the laboratory frame of 0.05 GeV measured by the ECL. To reduce combinatoric background, the π^0 energy is required to be greater than 0.5 GeV, and the reconstructed mass is in the range $0.111 < M_{\gamma\gamma} < 0.151$ GeV/ c^2 , which corresponds to a ± 3.0 standard deviation (σ) window. We then perform a mass-constrained fit to the nominal π^0 mass [16] in order

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to improve the resolution of the reconstructed π^0 four-momentum. To reject $B \rightarrow p\bar{p}D^{(*)}$ events, we restrict the invariant $\pi\pi$ mass $M_{\pi\pi}$ to be less than $1.22 \text{ GeV}/c^2$ for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $1.3 \text{ GeV}/c^2$ for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ based on studies of the simulated background. We use $\Delta E = E_{\text{recon}}^* - E_{\text{beam}}^*$ and $M_{\text{bc}} = \sqrt{(E_{\text{beam}}^*/c^2)^2 - (P_{\text{recon}}^*/c)^2}$ to identify B decays. $E_{\text{recon}}^*/P_{\text{recon}}^*$ and E_{beam}^* are the reconstructed B energy/momentum and the beam energy measured in the $\Upsilon(4S)$ rest frame, respectively. For further investigation, we keep candidates with $5.24 < M_{\text{bc}} < 5.29 \text{ GeV}/c^2$ and $|\Delta E| < 0.2 \text{ GeV}$.

We have further applied a D veto to reject candidate events with a charged pion, assumed to be a charged kaon, satisfying $|M_{K\pi} - M_D| < 0.4 \text{ GeV}/c^2$. We require only one B candidate in each event. We choose the candidate with the smallest value of χ^2 in the B vertex fit. The fractions of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ MC events with multiple B candidates are 16.4% and 20.3%, respectively. This selection removes 5.6% of the $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and 8.7% of the $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ signal.

Based on the MC simulation, there are only a few events from generic or rare B decays in the candidate region ($5.24 < M_{\text{bc}} < 5.29 \text{ GeV}/c^2$ and $|\Delta E| < 0.2 \text{ GeV}$); thus, they are ignored. The continuum background is the dominant component in the candidate region. Variables describing event topology are used to distinguish spherical $B\bar{B}$ events from jetlike continuum events. We use a neural network package, NeuroBayes [17], to separate the B signal from the continuum background. There are 28 input parameters for the neural network training, of which 23 parameters are modified Fox-Wolfram moments of particles of the signal B candidate, and separately those of particles in the rest of the event [18,19]. The remaining five parameters are the separation between the B candidate vertex and the accompanying B vertex along the longitudinal direction, the angle between the B flight direction and the beam axis in the $\Upsilon(4S)$ rest frame, the angle between the B momentum and the thrust axis of the event in the $\Upsilon(4S)$ rest frame, the sphericity [20] of the event calculated in the $\Upsilon(4S)$ rest frame, and the B flavor tagging quality parameter [21].

The output of NeuroBayes, C_{nb} , ranges from -1 to $+1$, where the value is close to $+1$ for $B\bar{B}$ -like and close to -1 for continuum-like events. We require the C_{nb} to be greater than 0.9 (0.87) for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ ($B^+ \rightarrow p\bar{p}\pi^+\pi^0$) with optimizations based on a figure of merit (FOM) defined as

$$\text{FOM} = \frac{N_s}{\sqrt{N_s + N_b}}, \quad (1)$$

where N_s is the expected signal yield, assuming the branching fraction measured by LHCb for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and the same value for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$, and N_b is the number of background events from the MC simulations. To extract

the $B \rightarrow p\bar{p}\pi\pi$ yield for events in the candidate region, we perform an extended unbinned likelihood fit to variables ΔE and M_{bc} . These variables are assumed to be uncorrelated. The fit function used is

$$\mathcal{L} = \frac{e^{-\sum_{j=1}^N (N_j)}}{N!} \prod_{i=1}^N \sum_j (N_j P_j(M_{\text{bc}}^i, \Delta E^i)), \quad (2)$$

where N is the number of total events, i denotes the event index, j stands for the component index (signal or background), and P represents the probability density function (PDF).

To model the signal distributions, we use double Gaussian functions for ΔE of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$, a Crystal Ball function [22] and a Gaussian function for ΔE of $B^+ \rightarrow p\bar{p}\pi^+\pi^0$, and a double Gaussian function for M_{bc} . For the background, we use a second-order Chebyshev polynomial function and an ARGUS function [23] to describe ΔE and M_{bc} , respectively. The signal distributions in ΔE and M_{bc} are calibrated with $B^0 \rightarrow p\bar{p}\bar{D}^0$ ($\bar{D}^0 \rightarrow K^+\pi^-$) and $B^0 \rightarrow \bar{D}^0\pi^0$ ($\bar{D}^0 \rightarrow K^+\pi^-$) by comparing the shape difference between the predictions of the MC and data. These modes have the same multiplicity in the final state as our signal, much larger statistics, and small backgrounds. We fix the calibrated signal shapes from MC simulation and allow the component yields and all other PDF shape parameters to float. The fit results are shown in Figs. 1 and 2.

We find the signal yields of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ to be $73.8_{-14.9}^{+15.8}$ and 151 ± 39 with fit significances of 5.5σ and 5.4σ , respectively. The significance is defined as $\sqrt{-2 \times \ln(\mathcal{L}_0/\mathcal{L}_s)}(\sigma)$, where \mathcal{L}_0 is the likelihood with zero signal yield and \mathcal{L}_s is the likelihood for the measured yield. In this calculation, we have used the likelihood function which is smeared by including the additive systematic uncertainties that affect the yield. With the large significance of both modes, we then measure the signal yields in different $M_{\pi\pi}$ bins with the same fit method. Table I and Fig. 3 show the yield and statistical significance in different $M_{\pi\pi}$ bins for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$; Table II and Fig. 4 show them for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$. For $B^0 \rightarrow p\bar{p}\pi^+\pi^-$, signal events in the bin $0.46 < M_{\pi\pi} < 0.53 \text{ GeV}/c^2$ are mostly from $B^0 \rightarrow p\bar{p}K_S^0$, and hence we exclude this range in the contribution shown in Table I and Fig. 3, and from the measurement of $\mathcal{B}(B^0 \rightarrow p\bar{p}\pi^+\pi^-)$. Assuming the $\Upsilon(4S)$ decays to charged and neutral $B\bar{B}$ pairs equally, we use the efficiency obtained from the MC simulation and fitted signal yield to calculate the branching fraction. After calculating overall efficiencies for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$, the branching fractions of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ for $M_{\pi^+\pi^-} < 1.22 \text{ GeV}/c^2$ and $M_{\pi^+\pi^0} < 1.3 \text{ GeV}/c^2$ are found to be $(0.83 \pm 0.17 \pm 0.17) \times 10^{-6}$ and $(4.58 \pm 1.17 \pm 0.67) \times 10^{-6}$; the signal efficiencies are 11.5% and 4.3%, respectively.

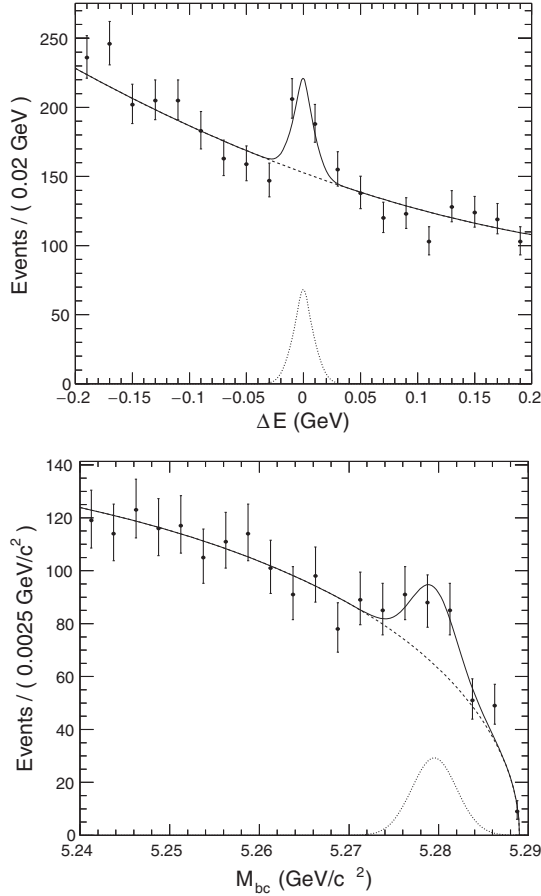


FIG. 1. Fit results of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ projected onto ΔE (with $5.27 < M_{bc} < 5.29 \text{ GeV}/c^2$) and M_{bc} (with $-0.03 < \Delta E < 0.03 \text{ GeV}$). The dashed line represents the background. The dotted line represents the signal. The solid line is the sum of all fit components.

We attempted to find the contribution of $B^+ \rightarrow p\bar{p}\rho^+$ by minimizing the χ^2 between the observed data and the assumed nonresonant $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ and $B^+ \rightarrow p\bar{p}\rho^+$ decays. To describe the $M_{\pi\pi}$ distribution, we use the phase space model for nonresonant $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ and a Breit-Wigner function convolved with a Gaussian function for $B^+ \rightarrow p\bar{p}\rho^+$. We set the Breit-Wigner function with its mean and width to the nominal values for the ρ^+ convolved with a Gaussian resolution function of $5 \text{ MeV}/c^2$ width. The result is shown in Fig. 4.

The fit gives a yield of 86 ± 41 events with a χ^2_{dof} of $17.0/11$ for $B^+ \rightarrow p\bar{p}\rho^+$. Our current data sample is not large enough to separate the contributions of $B^+ \rightarrow p\bar{p}\rho^+$ and nonresonant $B^+ \rightarrow p\bar{p}\pi^+\pi^0$. The measured $\mathcal{B}(B^+ \rightarrow p\bar{p}\pi^+\pi^0)$ with $B^+ \rightarrow p\bar{p}\rho^+$ included is almost a factor of 10 smaller than the predicted $\mathcal{B}(B^+ \rightarrow p\bar{p}\rho^+)$ [8].

There are modes sharing the same final-state particles as our signal, such as $B \rightarrow \bar{p}\Delta^{++}\pi$ or $B \rightarrow \bar{p}\Lambda^0\pi$. Examining the $M_{\Delta(p\pi^+)}$ and $M_{\Lambda(p\pi^-)}$ spectra, we find no obvious contribution from these modes.

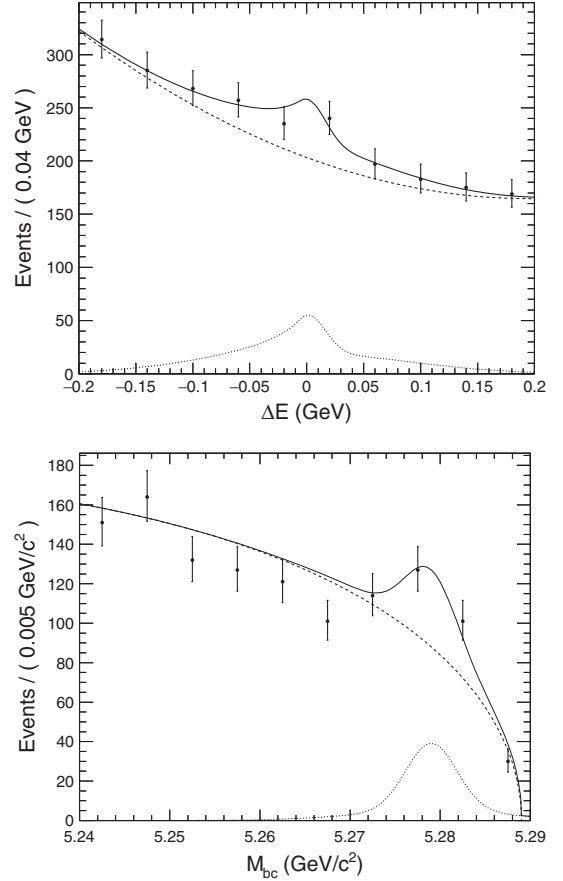
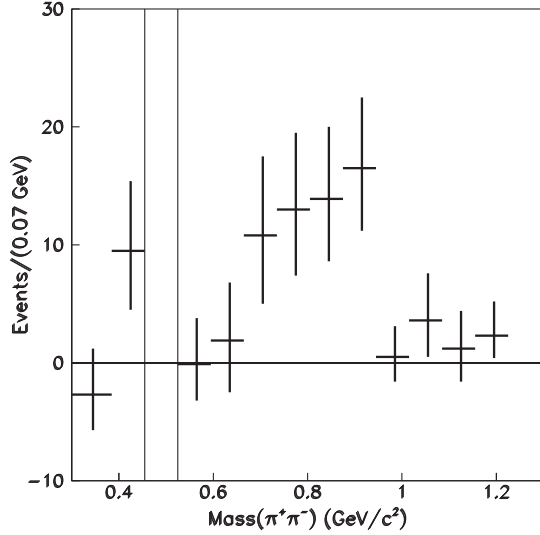


FIG. 2. Fit results of $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ projected onto ΔE (with $5.27 < M_{bc} < 5.29 \text{ GeV}/c^2$) and M_{bc} (with $-0.03 < \Delta E < 0.03 \text{ GeV}$). The dashed line represents the background. The dotted line represents the signal. The solid line is the sum of all fit components.

TABLE I. Yields, statistical significance, and efficiencies (ϵ_{eff}) in different $M_{\pi\pi}$ bins for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$.

$M_{\pi\pi}$ (GeV/ c^2)	N_s	σ	ϵ_{eff} (%)
$M_{\pi\pi} < 0.39$	$-2.7^{+3.9}_{-3.0}$	...	11.2
0.39–0.46	$9.5^{+5.9}_{-5.0}$	2.1	11.5
0.46–0.53	K_S^0 veto	...	...
0.53–0.6	$-0.1^{+3.9}_{-3.1}$	...	11.3
0.6–0.67	$1.9^{+4.9}_{-4.4}$	0.5	11.9
0.67–0.74	$10.8^{+6.7}_{-5.8}$	2.0	12.1
0.74–0.81	$13.0^{+6.5}_{-5.6}$	2.6	12.3
0.81–0.88	$13.9^{+6.1}_{-5.3}$	3.1	11.8
0.88–0.95	$16.5^{+6.0}_{-5.3}$	4.1	10.8
0.95–1.02	$0.5^{+2.6}_{-2.1}$	...	9.6
1.02–1.09	$3.6^{+4.0}_{-3.1}$	1.2	8.4
1.09–1.16	$1.2^{+3.2}_{-2.8}$	0.5	6.5
1.16–1.22	$2.3^{+2.9}_{-1.9}$	1.3	3.5

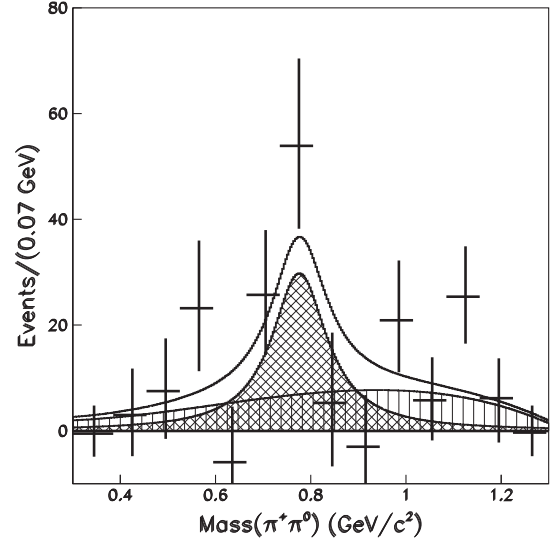
FIG. 3. The $M_{\pi\pi}$ signal distribution for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$.

We investigate the $M_{p\bar{p}}$ distribution of B signals in three regions: $M_{p\bar{p}} < 2.85$ GeV/c^2 for the threshold enhancement region, $2.85 < M_{p\bar{p}} < 3.128$ GeV/c^2 for the charmonium-enhanced region, and $3.128 < M_{p\bar{p}} < M_{p\bar{p}}$ for the phase-space-dominant region. We perform a 2D ($\Delta E, M_{bc}$) likelihood fit to extract the signal yields of the $B \rightarrow p\bar{p}\pi\pi$ decays in each region.

Tables III and IV show the fitted yields with statistical fit significances for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$, respectively. The charmonium-enhanced region, $2.85 < M_{p\bar{p}} < 3.128$ GeV/c^2 , includes other expected resonant modes such as $B \rightarrow J/\psi\rho$ [16]. We find that $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ events

TABLE II. Yields, statistical significance, and efficiencies (ϵ_{eff}) in different $M_{\pi\pi}$ bins for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$.

$M_{\pi\pi}$ (GeV/c^2)	N_s	σ	ϵ_{eff} (%)
$M_{\pi\pi} < 0.39$	$-0.5^{+5.3}_{-4.4}$	...	4.3
0.39–0.46	$3.0^{+8.8}_{-7.8}$	0.3	4.1
0.46–0.53	$7.5^{+10.0}_{-9.0}$	0.8	4.9
0.53–0.6	$23.2^{+12.8}_{-11.9}$	2.2	4.7
0.6–0.67	$-5.9^{+10.5}_{-9.2}$	...	4.8
0.67–0.74	$25.7^{+12.3}_{-11.4}$	1.8	5.0
0.74–0.81	$53.9^{+16.5}_{-15.7}$	3.7	5.1
0.81–0.88	$5.3^{+13.3}_{-12.0}$	0.4	4.8
0.88–0.95	$-3.0^{+9.8}_{-8.5}$	...	4.3
0.95–1.02	$20.9^{+11.3}_{-9.8}$	1.7	3.7
1.02–1.09	$5.8^{+8.1}_{-7.6}$	0.8	2.7
1.09–1.16	$25.4^{+9.5}_{-8.7}$	3.1	2.7
1.16–1.23	$6.2^{+7.5}_{-8.4}$	0.8	2.2
1.23–1.3	$-0.3^{+5.3}_{-4.5}$	...	0.8

FIG. 4. Fit results of $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ in different $M_{\pi\pi}$ bins. The cross-hatched region represents the $B^+ \rightarrow p\bar{p}\rho^+$ component, and the vertical-line-hatched region represents the $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ component.

are equally distributed in the bins below and above the charmonium-enhanced region, while $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ events are dominant in the bin below the charmonium-enhanced region. We also calculated the branching fraction of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ in the threshold enhancement region to be $(0.35 \pm 0.13 \pm 0.07) \times 10^{-6}$, which is consistent with the observed result from LHCb [9]. Sources of systematic uncertainties are summarized in Table V. The number of $B\bar{B}$ pairs is known to within 1.4%. By using the partially reconstructed $D^{*+} \rightarrow D^0\pi^+$ with $D^0 \rightarrow \pi^+\pi^-K_S^0$ events, the uncertainty due to the charged-track reconstruction

TABLE III. Yields, statistical significance, and efficiencies (ϵ_{eff}) in different $M_{p\bar{p}}$ bins for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ ($0.6 < M_{\pi\pi} < 1.22$ GeV/c^2).

$M_{p\bar{p}}$ (GeV/c^2)	N_s	σ	ϵ_{eff} (%)
$M_{p\bar{p}} < 2.85$	$26.1^{+10.0}_{-9.1}$	4.0	9.8
$2.85 < M_{p\bar{p}} < 3.128$	$19.6^{+10.2}_{-9.3}$	2.9	9.9
$3.128 < M_{p\bar{p}}$	$29.1^{+16.2}_{-13.1}$	3.5	9.4

TABLE IV. Yields, statistical significance, and efficiencies (ϵ_{eff}) in different $M_{p\bar{p}}$ bins for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ ($M_{\pi\pi} < 1.3$ GeV/c^2).

$M_{p\bar{p}}$ (GeV/c^2)	N_s	σ	ϵ_{eff} (%)
$M_{p\bar{p}} < 2.85$	$133.5^{+26.6}_{-25.2}$	5.1	4.8
$2.85 < M_{p\bar{p}} < 3.128$	$12.3^{+10.3}_{-9.7}$	1.4	4.0
$3.128 < M_{p\bar{p}}$	$-3.8^{+15.1}_{-13.8}$	...	3.4

TABLE V. Table of systematic uncertainties (%) for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$.

Uncertainties	$B^0 \rightarrow p\bar{p}\pi^+\pi^-$	$B^+ \rightarrow p\bar{p}\pi^+\pi^0$
$N_{B\bar{B}}$	1.4	1.4
Tracking	1.4	1.1
p/π identification	3.3	2.4
π^0 reconstruction	...	2.8
Continuum suppression	4.7	4.3
Decay model	14.3	8.6
ΔE , M_{bc} shape	12.4	10.4
Summary	19.9	14.6

efficiency is estimated to be 0.35% per track. We use a $\Lambda \rightarrow p\pi^-$ ($D^{*+} \rightarrow D^0\pi^+$, $D^0 \rightarrow K^-\pi^+$) sample to calibrate the MC p (π^+) identification efficiency and assign uncertainties of 3.3% and 2.4% for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ decays, respectively. For π^0 reconstruction, we determine its uncertainty by using a $\tau^- \rightarrow \pi^-\pi^0\nu$ data sample [24]. To estimate the systematic error due to continuum suppression, we use the $B^0 \rightarrow p\bar{p}\bar{D}^0$ and $B^0 \rightarrow \bar{D}^0\pi^0$ data/MC samples, where $\bar{D}^0 \rightarrow K^+\pi^-$. We choose the efficiency of the phase space model for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and the efficiency of the reweighted phase space model for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$, and we estimate the efficiency uncertainty as a difference of signal efficiencies for $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ in the reweighted phase space model and $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ in the phase space model. The uncertainty associated with the parameters of the ΔE and M_{bc} PDFs is examined by repeating the fit with each parameter varied by 1 standard deviation from its nominal value. The assumption of no correlation between ΔE and M_{bc} is examined by replacing the PDF of B signal events with the corresponding 2D histogram function.

In summary, we report the observation of $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ and the first observation of $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ with branching fractions of $(0.83 \pm 0.17 \pm 0.17) \times 10^{-6}$ and $(4.58 \pm 1.17 \pm 0.67) \times 10^{-6}$ for $M_{\pi^+\pi^-} < 1.22 \text{ GeV}/c^2$ and $M_{\pi^+\pi^0} < 1.3 \text{ GeV}/c^2$, respectively. In contrast to the theoretical prediction [8], the measured \mathcal{B} for $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ in the ρ -enhanced region is an order of magnitude smaller than the theoretical expectation. Similar deviation from the theoretical expectation has also been found in $B^+ \rightarrow p\bar{p}\mu^+\nu_\mu$ by LHCb [25] and Belle [26]. We find that the $B^+ \rightarrow p\bar{p}\pi^+\pi^0$ decay should be dominated by the lower $M_{p\bar{p}}$ bin, which is not the case in the $B^0 \rightarrow p\bar{p}\pi^+\pi^-$ decay. These findings are useful for future theoretical investigation.

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