PHYSICAL REVIEW D **66**, 091102(R) (2002)

Study of exclusive *B* decays to charmed baryons

N. Gabyshev,[8] H. Kichimi,[8] K. Abe,[8] K. Abe,[41] T. Abe,[42] I. Adachi,[8] H. Aihara,[43] M. Akatsu,[22] Y. Asano,[48] T. Aso,[47] V. Aulchenko,[1] T. Aushev,[12] A. M. Bakich,[38] Y. Ban,[52] E. Banas,[26] A. Bay,[18] P. K. Behera,[49] I. Bizjak,[13] A. Bondar,[1] A. Bozek,[26] M. Bračko,[20,13] J. Brodzicka,[26] T. E. Browder,[7] B. C. K. Casey,[7] P. Chang,[25] Y. Chao,[25] K.-F. Chen,[25] B. G. Cheon,[37] R. Chistov,[12] S.-K. Choi,[6] Y. Choi,[37] Y. K. Choi,[37] M. Danilov,[12] L. Y. Dong,[10] A. Drutskoy,[12] S. Eidelman,[1] V. Eiges,[12] Y. Enari,[22] F. Fang,[7] A. Garmash,[1,8] T. Gershon,[8] B. Golob,[19,13] J. Haba,[8] T. Hara,[30] H. Hayashii,[23] M. Hazumi,[8] E. M. Heenan,[21] T. Higuchi,[43] L. Hinz,[18] T. Hojo,[30] T. Hokuue,[22] Y. Hoshi,[41] W.-S. Hou,[25] H.-C. Huang,[25] T. Igaki,[22] Y. Igarashi,[8] T. Iijima,[22] K. Inami,[22] A. Ishikawa,[22] R. Itoh,[8] H. Iwasaki,[8] Y. Iwasaki,[8] H. K. Jang,[36] J. H. Kang,[51] J. S. Kang,[15] P. Kapusta,[26] N. Katayama,[8] H. Kawai,[2] Y. Kawakami,[22] T. Kawasaki,[28] D. W. Kim,[37] Heejong Kim,[51] H. J. Kim,[51] H. O. Kim,[37] Hyunwoo Kim,[15] S. K. Kim,[36] K. Kinoshita,[4] S. Kobayashi,[34] S. Korpar,[20,13] P. Križan,[19,13] P. Krokovny,[1] R. Kulasiri,[4] Y.-J. Kwon,[51] J. S. Lange,[5,33] G. Leder,[11] S. H. Lee,[36] J. Li,[35] D. Liventsev,[12] R.-S. Lu,[25] J. MacNaughton,[11] G. Majumder,[39] F. Mandl,[11] S. Matsumoto,[3] T. Matsumoto,[45] W. Mitaroff,[11] K. Miyabayashi,[23] H. Miyake,[30] H. Miyata,[28] G. R. Moloney,[21] T. Mori,[3] T. Nagamine,[42] Y. Nagasaka,[9] T. Nakadaira,[43] E. Nakano,[29] M. Nakao,[8] H. Nakazawa,[3] J. W. Nam,[37] Z. Natkaniec,[26] S. Nishida,[16] O. Nitoh,[46] S. Noguchi,[23] S. Ogawa,[40] T. Ohshima,[22] T. Okabe,[22] S. Okuno,[14] S. L. Olsen,[7] H. Ozaki,[8] P. Pakhlov,[12] H. Palka,[26] C. W. Park,[15] H. Park,[17] K. S. Park,[37] J.-P. Perroud,[18] M. Peters,[7] L. E. Piilonen,[50] F. J. Ronga,[18] N. Root,[1] K. Rybicki,[26] H. Sagawa,[8] S. Saitoh,[8] Y. Sakai,[8] H. Sakamoto,[16] M. Satapathy,[49] A. Satpathy,[8,4] O. Schneider,[18] C. Schwanda,[8,11] A. Schwartz,[4] S. Semenov,[12] K. Senyo,[22] R. Seuster,[7] M. E. Sevior,[21] H. Shibuya,[40] B. Shwartz,[1] V. Sidorov,[1] N. Soni,[31] S. Stanič,[48,*] M. Starič,[13] A. Sugi,[22] A. Sugiyama,[22] K. Sumisawa,[8] T. Sumiyoshi,[45] K. Suzuki,[8] T. Takahashi,[29] F. Takasaki,[8] N. Tamura,[28] J. Tanaka,[43] M. Tanaka,[8] G. N. Taylor,[21] Y. Teramoto,[29] S. Tokuda,[22] T. Tomura,[43] T. Tsuboyama,[8] T. Tsukamoto,[8] S. Uehara,[8] K. Ueno,[25] S. Uno,[8] Y. Ushiroda,[8] S. E. Vahsen,[32] G. Varner,[7] K. E. Varvell,[38] C. C. Wang,[25] C. H. Wang,[24] J. G. Wang,[50] M.-Z. Wang,[25] Y. Watanabe,[44] E. Won,[15] B. D. Yabsley,[50] Y. Yamada,[8] A. Yamaguchi,[42] Y. Yamashita,[27] H. Yanai,[28] J. Yashima,[8] Y. Yuan,[10] Y. Yusa,[42] C. C. Zhang,[10] Z. P. Zhang,[35] V. Zhilich,[1] and D. Žontar[48]

(Belle Collaboration)

[1]*Budker Institute of Nuclear Physics, Novosibirsk*
[2]*Chiba University, Chiba*
[3]*Chuo University, Tokyo*
[4]*University of Cincinnati, Cincinnati, Ohio*
[5]*University of Frankfurt, Frankfurt*
[6]*Gyeongsang National University, Chinju*
[7]*University of Hawaii, Honolulu, Hawaii*
[8]*High Energy Accelerator Research Organization (KEK), Tsukuba*
[9]*Hiroshima Institute of Technology, Hiroshima*
[10]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing*
[11]*Institute of High Energy Physics, Vienna*
[12]*Institute for Theoretical and Experimental Physics, Moscow*
[13]*J. Stefan Institute, Ljubljana*
[14]*Kanagawa University, Yokohama*
[15]*Korea University, Seoul*
[16]*Kyoto University, Kyoto*
[17]*Kyungpook National University, Taegu*
[18]*Institut de Physique des Hautes Énergies, Université de Lausanne, Lausanne*
[19]*University of Ljubljana, Ljubljana*
[20]*University of Maribor, Maribor*
[21]*University of Melbourne, Victoria*
[22]*Nagoya University, Nagoya*
[23]*Nara Women's University, Nara*
[24]*National Lien-Ho Institute of Technology, Miao Li*
[25]*National Taiwan University, Taipei*
[26]*H. Niewodniczanski Institute of Nuclear Physics, Krakow*
[27]*Nihon Dental College, Niigata*
[28]*Niigata University, Niigata*
[29]*Osaka City University, Osaka*
[30]*Osaka University, Osaka*
[31]*Panjab University, Chandigarh*
[32]*Princeton University, Princeton, New Jersey*

[33]*RIKEN BNL Research Center, Brookhaven, New York*
[34]*Saga University, Saga*
[35]*University of Science and Technology of China, Hefei*
[36]*Seoul National University, Seoul*
[37]*Sungkyunkwan University, Suwon*
[38]*University of Sydney, Sydney NSW*
[39]*Tata Institute of Fundamental Research, Bombay*
[40]*Toho University, Funabashi*
[41]*Tohoku Gakuin University, Tagajo*
[42]*Tohoku University, Sendai*
[43]*University of Tokyo, Tokyo*
[44]*Tokyo Institute of Technology, Tokyo*
[45]*Tokyo Metropolitan University, Tokyo*
[46]*Tokyo University of Agriculture and Technology, Tokyo*
[47]*Toyama National College of Maritime Technology, Toyama*
[48]*University of Tsukuba, Tsukuba*
[49]*Utkal University, Bhubaneswer*
[50]*Virginia Polytechnic Institute and State University, Blacksburg, Virginia*
[51]*Yonsei University, Seoul*
[52]*Peking University, Beijing*

(Received 25 August 2002; published 27 November 2002)

Using 29.1 fb^{-1} of data accumulated at the $\Upsilon(4S)$ with the Belle detector at KEKB, we have studied the decay modes $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$, $B^- \to \Lambda_c^+ \overline{p} \pi^-$, and $\overline{B}^0 \to \Lambda_c^+ \overline{p}$. We report branching fractions of exclusive B decays to charmed baryons with four-, three- and two-body final states, including intermediate Σ_c^{++} and Σ_c^0 states. We observed $\overline{B}^0 \to \Sigma_c(2455)^{++} \overline{p} \pi^-$ for the first time with a branching fraction of $(2.38^{+0.63}_{-0.55} \pm 0.41 \pm 0.62) \times 10^{-4}$ and observed evidence for the two-body decay $B^- \to \Sigma_c(2455)^0 \overline{p}$ with a branching fraction of $(0.45^{+0.26}_{-0.19} \pm 0.07 \pm 0.12) \times 10^{-4}$. We also set improved upper limits for the two-body decays $\overline{B}^0 \to \Lambda_c^+ \overline{p}$ and $B^- \to \Sigma_c(2520)^0 \overline{p}$.

DOI: 10.1103/PhysRevD.66.091102 PACS number(s): 13.25.Hw, 14.20.Lq

Baryon production in flavored meson decays is unique to the B meson system due to the heavy mass of the constituent b quark. Several studies of inclusive charmed baryon production in B meson decays [1] have been made and a large branching fraction for $\overline{B} \to \Lambda_c^+ X$ of $(6.4 \pm 1.1)\%$ has been reported. However, the mechanism is not well understood. The measured inclusive Λ_c^+ momentum spectra indicate that multibody final states are dominant in baryonic B decays. With a data sample of 2.39 fb^{-1}, CLEO [2] has studied exclusive charmed baryonic decay modes and measured the branching fractions for $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$ and $B^- \to \Lambda_c^+ \overline{p} \pi^-$. They found no evidence for $\overline{B}^0 \to \Lambda_c^+ \overline{p}$ and provided an upper limit. So far, no observations of two-body decays have been reported. On the other hand, there are theoretical predictions for branching fractions of two-body baryonic modes based on a pole model [3], a QCD sum rule [4], a diquark model [5], and a bag model [6]. The predictions of the different models vary by an order of magnitude, and experimental measurement can be used to discriminate among them. We have made a systematic study of exclusive charmed baryonic decays of $\overline{B}^0$ and B^- mesons into four-, three- and two-body final states including $\Sigma_c^{++/0}$ intermediate resonances, by analyzing the $\Lambda_c^+ \overline{p} \pi^+ \pi^-$, $\Lambda_c^+ \overline{p} \pi^-$ and $\Lambda_c^+ \overline{p}$ final states. Charge conjugate modes are included unless otherwise mentioned. This analysis is based on a data sample of 29.1 fb^{-1} corresponding to 3.17×10^7 $B\overline{B}$ pairs. The data were accumulated at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB asymmetric collider of 3.5 GeV e^+ and 8.0 GeV e^- [7].

The Belle detector is a large-solid-angle magnetic spectrometer that consists of a three-layer silicon vertex detector (SVD), a 50-layer cylindrical drift chamber (CDC), a mosaic of aerogel threshold Čerenkov counters (ACC), a barrel-like array of time-of-flight scintillation counters (TOF), and an array of CsI(Tl) crystals (ECL) located inside a superconducting solenoid coil that provides a 1.5 T magnetic field. An iron flux return located outside the coil is instrumented to detect muons and K_L mesons (KLM). The detector is described in detail elsewhere [8]. We use a GEANT based Monte Carlo (MC) simulation to model the response of the detector and determine the acceptance [9].

In searches for the decay modes $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$, $B^- \to \Lambda_c^+ \overline{p} \pi^-$, and $\overline{B}^0 \to \Lambda_c^+ \overline{p}$, the $\Lambda_c^+ \to p K^- \pi^+$ decay mode is used. Particle identification information from the CDC dE/dx, ACC and TOF is used to provide a mass assignment for each track. A likelihood ratio $LR(A,B) = L_A/(L_A + L_B) > 0.6$ is required to identify a particle as type A, where B is

*On leave from Nova Gorica Polytechnic, Nova Gorica.

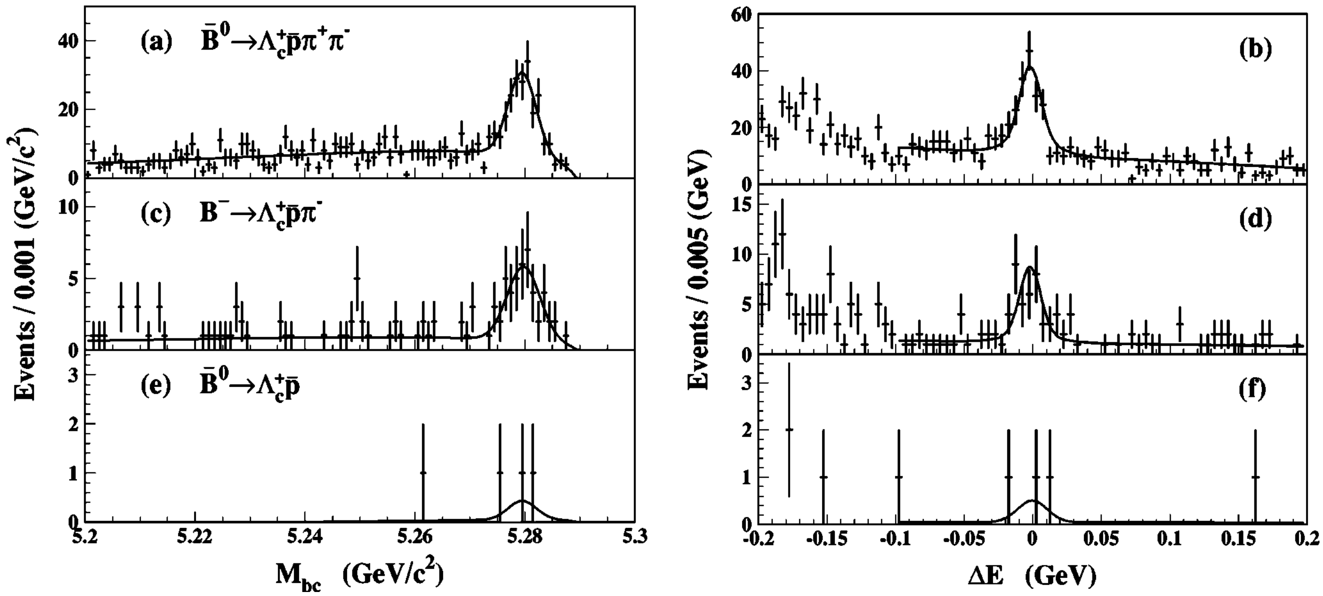

FIG. 1. $M_{\rm bc}$ distributions for $|\Delta E|<0.030$ GeV and ΔE distributions for $M_{\rm bc}>5.270$ GeV/c^2: (a) and (b) for $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$, (c) and (d) for $B^- \to \Lambda_c^+ \overline{p} \pi^-$, and (e) and (f) for $\overline{B}^0 \to \Lambda_c^+ \overline{p}$. Points with errors indicate the data and the curves indicate fits (see text for details).

the other possible assignment among $\pi^\pm$, $K^\pm$ and $p(\overline{p})$. Electron and muon candidate tracks are removed if their probabilities from the ECL, CDC dE/dx and KLM are greater than 95%. Candidate Λ_c^+'s are tagged if the invariant mass of the p, K^- and π^+ track combination is within 0.010 GeV/c^2 of the Λ_c^+ mass; tagged events are then examined for the three search modes by adding $\overline{p}$, π^-, and π^+ tracks. The width $\sigma_{\Lambda_c^+}$ is found to be 4.9 MeV/c^2, consistent with the MC simulation.

In order to select $\overline{B}$ meson candidates, we use the beam energy-constrained mass and energy difference, which are defined as $M_{\rm bc} = \sqrt{E_{\rm beam}^2 - (\Sigma \vec{p}_i)^2}$ and $\Delta E = \Sigma E_i - E_{\rm beam}$ in the center-of-mass (c.m.) frame of the e^+e^- collision. $E_{\rm beam}$ is the beam energy, and E_i and $\vec{p}_i$ are the energy and momentum vector for the i-th daughter particle of a B candidate. B candidates are selected with a loose cut to retain sideband events by requiring $M_{\rm bc}>5.2\,{\rm GeV}/c^2$ and $|\Delta E|<0.2$ GeV. A vertex-constrained fit for the three daughter tracks is carried out at the Λ_c^+ vertex. For each decay mode, the virtual Λ_c^+ track and additional tracks are required to form a good vertex. If there are multiple candidates for both Λ_c^+ and B, the candidate with the minimum $\chi^2 = \chi^2_{\Lambda_c^+} + \chi^2_B + (M_{\rm bc} - 5.279)^2/\sigma^2_{M_{\rm bc}}$ is selected. Here, $\chi^2_{\Lambda_c^+}$ and χ^2_B are the χ^2's from the fits for the Λ_c^+ and B vertices, respectively, and $\sigma_{M_{\rm bc}}$ is the MC value of the $M_{\rm bc}$ width (2.8 MeV/c^2). Loose cuts on $\chi^2_{\Lambda_c^+}$ and χ^2_B are applied to remove background from tracks arising from K_S^0 and Λ decays.

Event selection requirements are optimized using signal MC events and continuum background MC events consisting of $u\overline{u}$, $d\overline{d}$, $s\overline{s}$, and $c\overline{c}$ quark-antiquark pairs generated with the expected fractions. To suppress the continuum background, we use a Fisher discriminant constructed from 10 variables: 8 modified Fox Wolfram moments [10], $\cos\Theta_B$, and $\cos\Theta_{\Lambda_c^+}$. Here, $\cos\Theta_B$ is the cosine of the direction of the B meson with respect to the electron beam direction, and $\cos\Theta_{\Lambda_c^+}$ is the cosine of the direction of the daughter Λ_c^+ with respect to the thrust axis of the tracks not associated with the B candidates. Both quantities are defined in the c.m. system. A set of 10 coefficients for each mode is optimized to maximize separation of the signal from the continuum background. The probability density functions for the signals and for the continuum, $P_{\rm sig}$ and $P_{\rm con}$, respectively, are parametrized with Gaussian functions for the three search

TABLE I. Branching fractions for $\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$, $B^- \to \Lambda_c^+ \overline{p} \pi^-$, and $\overline{B}^0 \to \Lambda_c^+ \overline{p}$. The errors are statistical, systematic, and a common error due to the uncertainty in the value of $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$. The CLEO results are renormalized to $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.0 \pm 1.3)\%$ [12] for comparison.

Mode	Efficiency (%)	Yield	Significance	$\mathcal{B}$ ($\times 10^{-4}$)	CLEO ($\times 10^{-4}$)
$\overline{B}^0 \to \Lambda_c^+ \overline{p} \pi^+ \pi^-$	8.07	141^{+16}_{-15}	12.2	$11.0^{+1.2}_{-1.2} \pm 1.9 \pm 2.9$	$11.7^{+4.0}_{-3.7} \pm 2.7 \pm 3.0$
$B^- \to \Lambda_c^+ \overline{p} \pi^-$	10.2	$30.2^{+7.0}_{-6.4}$	6.0	$1.87^{+0.43}_{-0.40} \pm 0.28 \pm 0.49$	$5.5^{+2.0}_{-1.8} \pm 1.0 \pm 1.4$
$\overline{B}^0 \to \Lambda_c^+ \overline{p}$	12.9	$2.4^{+2.1}_{-1.5}$	1.9	$0.12^{+0.10}_{-0.07} \pm 0.02 \pm 0.03$	
		<6.1 (90% C.L.)		<0.31 (90% C.L.)	<1.85 (90% C.L.)

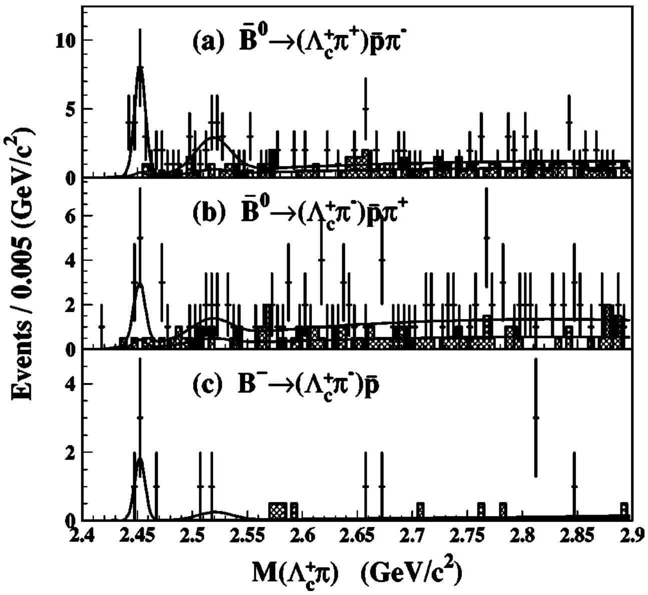

FIG. 2. Invariant mass distributions (a) $M(\Lambda_c^+\pi^+)$ and (b) $M(\Lambda_c^+\pi^-)$ for $\overline{B^0}\to\Lambda_c^+\overline{p}\pi^+\pi^-$, and (c) $M(\Lambda_c^+\pi^-)$ for $B^-\to\Lambda_c^+\overline{p}\pi^-$. Points with errors and shaded histograms indicate the distributions for the B signal and the sideband regions, respectively. The curves indicate fits (see text for details).

modes and for the continuum events. A cut on the likelihood ratio $R_{\rm sfw}=P_{\rm sig}/(P_{\rm sig}+P_{\rm con})>0.6$ is applied to all decay modes. In the MC simulation this cut removed 76% of the continuum background while retaining 86% of the signal for $\Lambda_c^+\overline{p}\pi^+\pi^-$.

Figure 1 shows the $M_{\rm bc}$ and ΔE distributions for the three decay modes, after a tight cut is made in the (ΔE, $M_{\rm bc}$) variable not plotted. The $M_{\rm bc}$ background distributions are parametrized by the ARGUS function [11], while a Gaussian is used for the signal. The ΔE distributions are fitted with a second-order polynomial for the background and a double Gaussian for the signal. Here, the width parameters are fixed to the values fitted to the signal MC events. The mean and width of $M_{\rm bc}$ in the data are found to be consistent with the MC values of 5.279 GeV/c^2 and 2.8 MeV/c^2, respectively. The width of ΔE is also consistent with the MC value (9.9 MeV) when fit to a single Gaussian. We obtain signal yields of 154^{+17}_{-16} and $38.8^{+7.6}_{-7.0}$ from the fits to the $M_{\rm bc}$ distributions (a) and (c), and 141^{+16}_{-15} and $30.2^{+7.0}_{-6.4}$ from the fits to the ΔE distributions (b) and (d), respectively. Here, we choose the asymmetric range of $-0.100<\Delta E<0.200$ GeV to exclude feed-down from higher multiplicity modes with extra pions; these produce the structure observed in the region $\Delta E<-0.150$ GeV. Since $M_{\rm bc}$ is used in the χ^2 calculation for the best candidate selection as described previously, we use the yields resulting from the fits to the ΔE distributions to calculate branching fractions.

We observe $\overline{B^0}\to\Lambda_c^+\overline{p}\pi^+\pi^-$ and $B^-\to\Lambda_c^+\overline{p}\pi^-$ signals. For $\overline{B^0}\to\Lambda_c^+\overline{p}$ we find a statistical significance of only 1.9σ from a fit to a Gaussian function for the signal with mean and width fixed to those from the signal MC simulation, and a linear background function. We thus set an upper limit of 6.1 events at the 90% confidence level based on the likelihood function, using the Bayesian method with a prior uniform in the branching fraction.

Table I summarizes the observed yields and branching fractions. Here, the detection efficiencies are calculated assuming nonresonant decays and do not include the branching fraction $\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)=(5.0\pm1.3)\%$ [12]. We assume the fractions of charged and neutral B mesons to be equal in the branching fraction calculations. We include a correlated systematic error of 2% per track for tracking and particle identification. Systematics due to the $\chi^2_{\Lambda_c^+}$, χ^2_B and $R_{\rm sfw}$ cuts are estimated by varying cut values. The signal shape systematic error is evaluated from the variation in fit results obtained with different-order polynomials used for the background and single and double Gaussians used for the signal. The resulting total systematic errors for $\Lambda_c^+\overline{p}\pi^+\pi^-$, $\Lambda_c^+\overline{p}\pi^-$ and $\Lambda_c^+\overline{p}$ are 17.2%, 14.8% and 13.3%, respectively. Table I shows the CLEO measurements renormalized to the same $\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)$ for comparison. Our branching fraction for $\overline{B^0}\to\Lambda_c^+\overline{p}\pi^+\pi^-$ is consistent with their measurement; however, our result for $B^-\to\Lambda_c^+\overline{p}\pi^-$ is somewhat lower (1.5σ). We also set a more restrictive upper limit on $\overline{B^0}\to\Lambda_c^+\overline{p}$.

TABLE II. Efficiencies, yields, significances and branching fractions for decay modes with $\Sigma_c^{++/0}$ resonances. The errors are statistical, systematic, and a common error due to the uncertainty in the value of $\mathcal{B}(\Lambda_c^+\to pK^-\pi^+)$.

Mode	Efficiency (%)	Yield	Significance	$\mathcal{B}$ ($\times10^{-4}$)
$\overline{B^0}\to\Sigma_c(2455)^{++}\overline{p}\pi^-$	4.93	$18.6^{+4.9}_{-4.3}$	5.3	$2.38^{+0.63}_{-0.55}\pm0.41\pm0.62$
$\overline{B^0}\to\Sigma_c(2520)^{++}\overline{p}\pi^-$	6.38	$16.5^{+5.8}_{-5.2}$	3.5	$1.63^{+0.57}_{-0.51}\pm0.28\pm0.42$
$\overline{B^0}\to\Sigma_c(2455)^0\overline{p}\pi^+$	4.80	$6.4^{+3.2}_{-2.7}$	2.6	$0.84^{+0.42}_{-0.35}\pm0.14\pm0.22$
		<11.6 (90% C.L.)		<1.59 (90% C.L.)
$\overline{B^0}\to\Sigma_c(2520)^0\overline{p}\pi^+$	6.35	$4.8^{+4.5}_{-4.0}$	1.2	$0.48^{+0.45}_{-0.40}\pm0.08\pm0.12$
		<11.7 (90% C.L.)		<1.21 (90% C.L.)
$B^-\to\Sigma_c(2455)^0\overline{p}$	6.00	$4.3^{+2.5}_{-1.8}$	3.0	$0.45^{+0.26}_{-0.19}\pm0.07\pm0.12$
		<8.5 (90% C.L.)		<0.93 (90% C.L.)
$B^-\to\Sigma_c(2520)^0\overline{p}$	7.47	$1.7^{+1.8}_{-1.1}$	1.8	$0.14^{+0.15}_{-0.09}\pm0.02\pm0.04$
		<5.2 (90% C.L.)		<0.46 (90% C.L.)

Figure 2 shows the $\Lambda_c^+\pi^\pm$ invariant mass distributions in the B signal region, $|\Delta E|<0.030$ GeV and $M_{\rm bc}>5.270$ GeV/c^2. Significant signals are observed for the $\Sigma_c(2455)$ and $\Sigma_c(2520)$. The shaded histograms are the distributions for events in the sideband region $0.040<|\Delta E|<0.100$ GeV, normalized to the signal region $|\Delta E|<0.030$ GeV; these account for continuum Σ_c background. The two curves indicate the results of separate fits to the distributions for the B signal and the sideband regions, with Σ_c masses and widths fixed to fit values for the signal MC events generated with Particle Data Group (PDG) values for masses and widths [12]. The background shapes are taken from a nonresonant signal MC. To extract the Σ_c yields, we performed a simultaneous likelihood fit to the distributions for the B signal and sideband regions. We express the expected number N_{Σ_c} of B events as $N_{\Sigma_c}=N_{Bb}-r\cdot N_{sb}$, where N_{Bb} is the yield in the B signal region, N_{sb} is the yield in the sideband region, and $r=0.5$ is the normalization factor due to the ratio of their ΔE ranges, assuming a linear background shape.

Table II summarizes the observed signal yields and branching fractions. We observe the $\overline{B}^0\to\Sigma_c(2455)^{++}\overline{p}\pi^-$ decay for the first time with a statistical significance of 5.3σ. We also see 3.5σ evidence for $\overline{B}^0\to\Sigma_c(2520)^{++}\overline{p}\pi^-$, $2.6\,\sigma$ evidence for $\overline{B}^0\to\Sigma_c(2455)^0\overline{p}\pi^+$, and less evidence for $\overline{B}^0\to\Sigma_c(2520)^0\overline{p}\pi^+$. We see $3.0\,\sigma$ evidence for the two-body decay $B^-\to\Sigma_c(2455)^0\overline{p}$, and less evidence for $B^-\to\Sigma_c(2520)^0\overline{p}$. For those modes with a significance of three sigmas or less, we set upper limits on their branching fractions.

Our results provide stringent constraints upon theoretical predictions [3–6]. The predictions for $\overline{B}^0\to\Lambda_c^+\overline{p}$ in [3–5] were already much larger than the CLEO experimental upper limit [2]; here we set an even more restrictive upper limit. A recent study based on a bag model [6] gives predictions of branching fractions of $\leqslant(0.1\sim0.3)\times10^{-4}$ for $\overline{B}^0\to\Lambda_c^+\overline{p}$ and $(4.3\sim15.1)\times10^{-4}$ for $B^-\to\Lambda_c^+\overline{p}\pi^-$. Our upper limit for $\overline{B}^0\to\Lambda_c^+\overline{p}$ does not contradict this model, while our measured result for $B^-\to\Lambda_c^+\overline{p}\pi^-$ is much smaller than its predicted value.

In summary, we have observed the exclusive three-body decay $\overline{B}^0\to\Sigma_c(2455)^{++}\overline{p}\pi^-$ for the first time and observed evidence for the exclusive two-body decay $B^-\to\Sigma_c(2455)^0\overline{p}$. We make improved measurements of the branching fractions for $\overline{B}^0\to\Lambda_c^+\overline{p}\pi^+\pi^-$ and $B^-\to\Lambda_c^+\overline{p}\pi^-$, and also set a more restrictive upper limit on $\overline{B}^0\to\Lambda_c^+\overline{p}$.

ACKNOWLEDGMENTS

We wish to thank the KEKB accelerator group for the excellent operation of the KEKB accelerator. We acknowledge support from the Ministry of Education, Culture, Sports, Science, and Technology of Japan and the Japan Society for the Promotion of Science; the Australian Research Council and the Australian Department of Industry, Science and Resources; the National Science Foundation of China under Contract No. 10175071; the Department of Science and Technology of India; the BK21 program of the Ministry of Education of Korea and the CHEP SRC program of the Korea Science and Engineering Foundation; the Polish State Committee for Scientific Research under contract No. 2P03B 17017; the Ministry of Science and Technology of the Russian Federation; the Ministry of Education, Science and Sport of Slovenia; the National Science Council and the Ministry of Education of Taiwan; and the U.S. Department of Energy.

[1] ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **210**, 263 (1988); CLEO Collaboration, G. Crawford *et al.*, Phys. Rev. D **45**, 752 (1992); CLEO Collaboration, M. Procario *et al.*, Phys. Rev. Lett. **73**, 1472 (1994).
[2] CLEO Collaboration, X. Fu *et al.*, Phys. Rev. Lett. **79**, 3125 (1997).
[3] M. Jarfi *et al.*, Phys. Lett. B **237**, 513 (1990); M. Jarfi *et al.*, Phys. Rev. D **43**, 1599 (1991); N. Deshpande, J. Trampetic, and A. Soni, Mod. Phys. Lett. A **3**, 749 (1988).
[4] V. Chernyak and I. Zhitnitsky, Nucl. Phys. **B345**, 137 (1990).
[5] P. Ball and H.G. Dosch, Z. Phys. C **51**, 445 (1991).
[6] H. Cheng and K. Yang, Phys. Rev. D **65**, 054028 (2002).
[7] KEK report 2001-157, edited by E. Kikutani, 2001.
[8] Belle Collaboration, A. Abashian *et al.*, Nucl. Instrum. Methods Phys. Res. A **479**, 117 (2002).
[9] Events are generated with the CLEO QQ program (http://www.lns.cornell.edu/public/CLEO/soft/QQ). The detector response is simulated using GEANT, R. Brun *et al.*, GEANT 3.21, CERN Report DD/EE/84-1 1984.
[10] The Fox-Wolfram moments are introduced in G.C. Fox and S. Wolfram, Phys. Rev. Lett. **41**, 1581 (1978); The Fisher discriminant used by Belle is described in Belle Collaboration, K. Abe *et al.*, *ibid.* **87**, 101801 (2001); Belle Collaboration, K. Abe *et al.*, Phys. Lett. B **511**, 151 (2001).
[11] ARGUS Collaboration, H. Albrecht *et al.*, Phys. Lett. B **229**, 304 (1989).
[12] Particle Data Group, D.E. Groom *et al.*, Eur. Phys. J. C **15**, 636 (2000).