First measurements of absolute branching fractions of the Ξ_c^+ baryon at Belle

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We present the first measurements of the absolute branching fractions of Ξ_c^+ decays into $\Xi^-\pi^+\pi^+$ and $pK^-\pi^+$ final states. Our analysis is based on a data set of $(772 \pm 11) \times 10^6$ $B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector at the KEKB e^+e^- collider. We measure the absolute branching fraction of $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ with the Ξ_c^+ recoiling against $\bar{\Lambda}_c^-$ in $\bar{B}^0$ decays resulting in $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+) = [1.16 \pm 0.42(\text{stat.}) \pm 0.15(\text{syst.})] \times 10^{-3}$. We then measure the product branching fractions $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+)\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ and $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+)\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$. Dividing these product branching fractions by $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ yields $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = [2.86 \pm 1.21(\text{stat.}) \pm 0.38(\text{syst.})]\%$ and $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = [0.45 \pm 0.21(\text{stat.}) \pm 0.07(\text{syst.})]\%$. Our result for $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ can be combined with Ξ_c^+ branching fractions measured relative to $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ to set the absolute scale for many Ξ_c^+ branching fractions.

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In recent decades there has been significant experimental progress on the measurements of the weak decays of charmed baryons [1]. However, given the limited knowledge of the large nonperturbative effects of quantum chromodynamics, it is difficult to reliably calculate the decay amplitudes of charmed baryons from first principles. Furthermore, in exclusive charmed-baryon decays the heavy quark expansion does not work. Hence experimental data are needed to extract the nonperturbative quantities in the decay amplitudes [2–5] and to provide important information to constrain phenomenological models of such decays [6–13].

During the past few years, Belle and BESIII have measured absolute branching fractions of the Λ_c^+ and Ξ_c^0 charmed baryons [14–16]. However, the absolute branching fraction of the remaining member of the charmed-baryon SU(3) flavor antitriplet, the Ξ_c^+, has not been measured. Branching fractions of Ξ_c^+ decays have been measured relative to the $\Xi^-\pi^+\pi^+$ mode. A measurement of the absolute branching fraction $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ is needed to infer the absolute branching fractions of other Ξ_c^+ decays. The comparison of Ξ_c^+ decays with those of Λ_c^+ and Ξ_c^0 can also provide an important test of SU(3) flavor symmetry [17].

Along with the reference mode $\Xi_c^+ \to \Xi^-\pi^+\pi^+$, $\Xi_c^+ \to pK^-\pi^+$ is a particularly important decay mode as it is the one most often used to reconstruct Ξ_c^+ candidates at hadron collider experiments, such as LHCb. For example, the decay has been used to study the properties of Ξ_b and to search for higher excited Ξ_b states via $\Xi_b^0 \to \Xi_c^+\pi^-$ [18,19], to search for new Ω_c^* states in the $\Xi_c^+K^-$ mode [20], to measure the doubly charmed baryon via $\Xi_{cc}^{++} \to \Xi_c^+\pi^+$ [21], as well as to measure the ratio of fragmentation fractions of $b \to \Xi_b^0$ relative to $b \to \Lambda_b^0$ [22,23].

In experiments, the decay $\Xi_c^+ \to pK^-\pi^+$ has been observed by the FOCUS and SELEX collaborations and the branching fraction ratio is measured to be $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)/\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = 0.21 \pm 0.04$ [1,24–26]. A few models have been developed to predict the decay rates of Ξ_c^+. For example, the $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ has been predicted to be $(1.47 \pm 0.84)\%$ based on the SU(3) flavor symmetry [27]. Theory predicts $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ to be $(2.2 \pm 0.8)\%$ based on the measured ratio $\mathcal{B}(\Xi_c^+ \to p\bar{K}^{*0})/\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ and the U-spin symmetry that relates $\Xi_c^+ \to p\bar{K}^{*0}$ and $\Lambda_c^+ \to \Sigma^+K^{*0}$ [23,28]. The decay $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$, which proceeds via a $b \to c\bar{c}s$ transition, has been predicted to have a branching fraction of the order of 10^{-3} [29], but there has been no experimental measurement. The world average of the product branching fraction $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+)\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ is $(1.8 \pm 1.8) \times 10^{-5}$ with large uncertainty [1,30,31].

In this paper, we perform an analysis of $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ with $\bar{\Lambda}_c^-$ reconstructed via its $\bar{p}K^+\pi^-$ decay, and Ξ_c^+ reconstructed both inclusively and exclusively via the decay modes $\Xi^-\pi^+\pi^+$ and $pK^-\pi^+$ [32]. We present first a measurement of the absolute branching fraction for $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ using a missing-mass technique, which is explained below. For this analysis we fully reconstruct the tag-side B^0 decay. We subsequently measure the product branching fractions $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+)\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ and $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+)\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ without reconstructing the recoiling B^0 decay in the event as the signal decays are fully reconstructed. Dividing these product branching fractions by the result for $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+)$ yields the $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ and $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$.

This analysis is based on the full data sample of 711 fb^{-1} collected at the $\Upsilon(4S)$ resonance by the Belle detector [33] at the KEKB asymmetric-energy e^+e^- collider [34]. To determine detection efficiency and optimize signal event selections, B meson decay events are generated using EVTGEN [35] and Ξ_c^+ inclusive decays are generated using PYTHIA [36]. The events are then processed by a detector simulation based on GEANT3 [37]. Monte Carlo (MC) simulated samples of $\Upsilon(4S) \to B\bar{B}$ events with $B = B^+$ or B^0, and $e^+e^- \to q\bar{q}$ events with $q = u, d, s, c$ at a center-of-mass energy of $\sqrt{s} = 10.58$ GeV are used to examine possible peaking backgrounds.

Selection of signal and $\Lambda \to p\pi^-$ candidates uses well reconstructed tracks and particle identification as described in Ref. [38]. For the inclusive analysis of the Ξ_c^+ decay, the tag-side B^0 meson candidate, B^0_{tag}, is reconstructed using a neural network based on a full hadron-reconstruction algorithm [39]. Each B^0_{tag} candidate has an associated output value O_{NN} from the multivariate analysis, which ranges from 0 to 1. A candidate with larger O_{NN} is more likely to be a true B^0 meson. If multiple B^0_{tag} candidates are found in an event, the candidate with the largest O_{NN} value is selected. To improve the purity of the B^0_{tag} sample, we require $O_{\mathrm{NN}} > 0.005$, $M_{\mathrm{bc}}^{\mathrm{tag}} > 5.27\ \mathrm{GeV}/c^2$, and $|\Delta E^{\mathrm{tag}}| < 0.04$ GeV, where the latter two intervals correspond to approximately 3 standard deviations, 3σ. $M_{\mathrm{bc}}^{\mathrm{tag}}$ and ΔE^{tag} are defined as $M_{\mathrm{bc}}^{\mathrm{tag}} \equiv \sqrt{E^2_{\mathrm{beam}} - (\sum_i \vec{p}_i^{\,\mathrm{tag}})^2}$ and $\Delta E^{\mathrm{tag}} \equiv \sum_i E_i^{\mathrm{tag}} - E_{\mathrm{beam}}$, where $E_{\mathrm{beam}} \equiv \sqrt{s}/2$ is the beam energy, $(E_i^{\mathrm{tag}}, \vec{p}_i^{\,\mathrm{tag}})$ is the four-momentum of the B^0_{tag} daughter i in the e^+e^- center-of-mass system (c.m.s.). $\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$ candidates are selected using the same method as in Ref. [16]. A 3σ $\bar{\Lambda}_c^-$ signal region is defined by $|M_{\bar{\Lambda}_c^-} - m_{\bar{\Lambda}_c^-}| < 10\ \mathrm{MeV}/c^2$. Here and throughout the text, M_i represents a measured invariant mass and m_i denotes the nominal mass of the particle i [1].

The mass recoiling against the $\bar{\Lambda}_c^-$ in $\bar{B}^0 \to \bar{\Lambda}_c^- + X$ is calculated using $M^{\mathrm{recoil}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-} = \sqrt{(P_{\mathrm{c.m.s.}} - P_{B^0_{\mathrm{tag}}} - P_{\bar{\Lambda}_c^-})^2}$. To improve the recoil-mass resolution we use $M^{\mathrm{rec}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-} \equiv M^{\mathrm{recoil}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-} + M_{B^0_{\mathrm{tag}}} - m_{B^0} + M_{\bar{\Lambda}_c^-} - m_{\bar{\Lambda}_c^-}$. Here, $P_{\mathrm{c.m.s.}}$, $P_{B^0_{\mathrm{tag}}}$, and $P_{\bar{\Lambda}_c^-}$ are four-momenta of the initial e^+e^- system, the tagged B^0 meson, and the reconstructed $\bar{\Lambda}_c^-$ baryon, respectively.

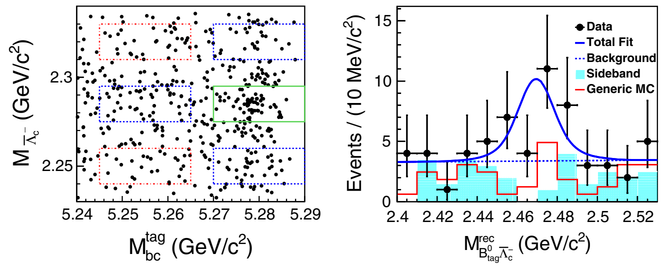

FIG. 1. The distribution of $M_{\mathrm{bc}}^{\mathrm{tag}}$ of the B^0_{tag} versus $M_{\bar{\Lambda}_c^-}$ for selected $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ candidates with $\Xi_c^+ \to$ anything and $\bar{\Lambda}_c^- \to \bar{p}K^-\pi^+$ (left) and the fit to the $M^{\mathrm{rec}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-}$ distribution (right). The solid box shows the selected signal region. The blue dashed and red dash-dotted boxes define the $M_{\mathrm{bc}}^{\mathrm{tag}}$ and $M_{\bar{\Lambda}_c^-}$ sidebands described in the text. The points with error bars are the data in the signal box, the solid blue curve is the best fit, the dashed curve is the fitted background, the cyan shaded histogram is the normalized $M_{\mathrm{bc}}^{\mathrm{tag}}$ and $M_{\bar{\Lambda}_c^-}$ sidebands, the red open histogram is the sum of the MC-simulated contributions for $e^+e^- \to q\bar{q}$, and $\Upsilon(4S) \to B\bar{B}$ generic-decay backgrounds with the number of events normalized to the number of events from the normalized $M_{\mathrm{bc}}^{\mathrm{tag}}$ and $M_{\bar{\Lambda}_c^-}$ sidebands.

Figure 1 (left) shows the distribution of $M_{\mathrm{bc}}^{\mathrm{tag}}$ of the B^0_{tag} candidates versus $M_{\bar{\Lambda}_c^-}$ of the selected $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ signal candidates after all selection requirements in the studied Ξ_c^+ mass region of $2.4 < M^{\mathrm{rec}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-} < 2.53\ \mathrm{GeV}/c^2$. Candidates $\bar{B}^0 \to \bar{\Lambda}_c^-\Xi_c^+$ are observed in the signal region defined by the solid box. To check possible peaking backgrounds, we define $M_{\mathrm{bc}}^{\mathrm{tag}}$ and $M_{\bar{\Lambda}_c^-}$ sidebands, which are represented by the dashed and dash-dotted boxes. The normalized contribution of the $M_{\mathrm{bc}}^{\mathrm{tag}}$ and $M_{\bar{\Lambda}_c^-}$ sidebands is estimated as being half the number of events in the blue dashed boxes minus one fourth the number of events in the red dash-dotted boxes. The $M^{\mathrm{rec}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-}$ distribution in the signal and the sideband boxes is shown in Fig. 1 (right).

To extract the Ξ_c^+ signal yields we perform an unbinned maximum likelihood fit to the $M^{\mathrm{rec}}_{B^0_{\mathrm{tag}}\bar{\Lambda}_c^-}$ distribution. A double-Gaussian function with its parameters fixed to those from a fit to the MC-simulated signal distribution is used to model the Ξ_c^+ signal shape and a first-order polynomial is used for the background shape since we find no peaking background in the $M_{\mathrm{bc}}^{\mathrm{tag}}$ and $M_{\bar{\Lambda}_c^-}$ sideband events. For all the fits described in this paper, the signal and background yields, and the parameters of the background shape are left free. The fit results are shown in Fig. 1 (right).

The fitted number of Ξ_c^+ signal events is $N_{\Xi_c^+} = 18.8 \pm 6.8$. This corresponds to a statistical significance of 3.2σ estimated using $\sqrt{-2\ln(\mathcal{L}_0/\mathcal{L}_{\mathrm{max}})}$, where $\mathcal{L}_0$ and $\mathcal{L}_{\mathrm{max}}$ are the maximum likelihood values of the fits

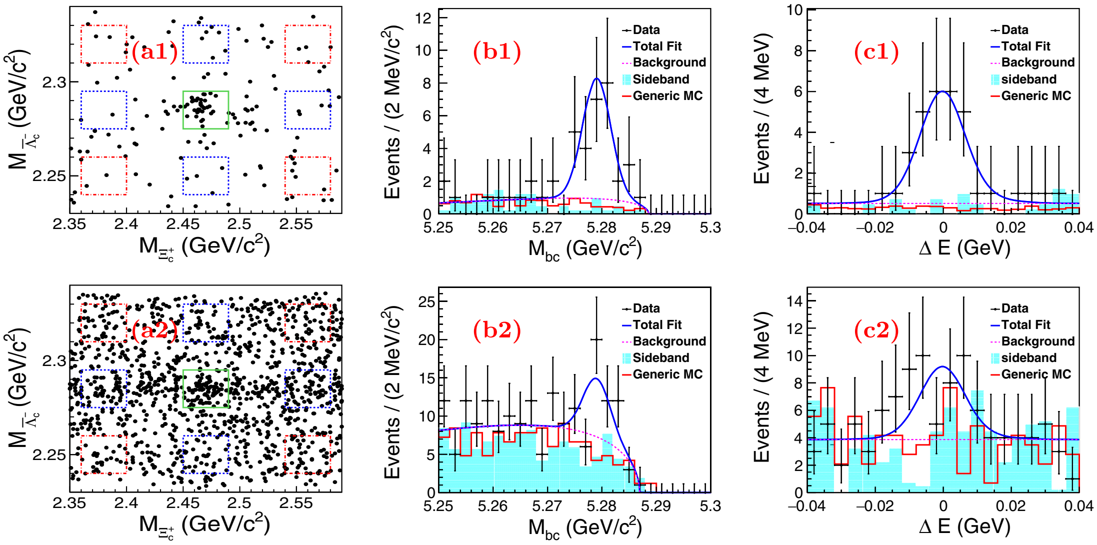

FIG. 2. The distributions of (a) $M_{\Xi_c^+}$ versus $M_{\bar{\Lambda}_c^-}$, and the fits to the (b) $M_{\rm bc}$ and (c) ΔE distributions of the selected $\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+$ candidates for (b1-c1) the $\Xi_c^+ \to \Xi^- \pi^+ \pi^+$ and (b2-c2) the $\Xi_c^+ \to pK^- \pi^+$ decay modes. In plots (a1-a2), the central solid boxes are the signal regions, and the red dash-dotted and blue dashed boxes show the $M_{\Xi_c^+}$ and $M_{\bar{\Lambda}_c^-}$ sidebands used to estimate of the backgrounds (see text). The dots with error bars are the data, the blue solid curves represent the best fits, and the dashed curves represent the fit background contributions. The shaded histograms are the normalized as in the text $M_{\Xi_c^+}$ and $M_{\bar{\Lambda}_c^-}$ sidebands, the red open histograms represent the generic background described in the caption of Fig. 1.

without and with a signal component, respectively. The signal significance becomes 3.1σ once we convolve the likelihood with a Gaussian function whose width equals the total systematic uncertainty. The signal significance found using alternative fits to the $M^{\rm rec}_{B^0_{\rm tag}\bar{\Lambda}_c^-}$ distribution as described in the section on systematic uncertainties, is greater than 3.0σ in all cases. The branching fraction is

$$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+) = N_{\Xi_c^+}/[2N_{\bar{B}^0}\varepsilon_{\rm inc}\mathcal{B}(\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-)] = [1.16 \pm 0.42({\rm stat.})] \times 10^{-3},$$

where $N_{\bar{B}^0} = N_{\Upsilon(4S)}\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$, $N_{\Upsilon(4S)}$ is the number of $\Upsilon(4S)$ events, and $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0) = 0.486$ [1]. The reconstruction efficiency, $\varepsilon_{\rm inc}$, is obtained from the MC simulation. The $\mathcal{B}(\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-)$ is taken from Ref. [1].

For the analysis of the exclusive Ξ_c^+ decays, we reconstruct Ξ_c^+ from $\Xi^-\pi^+\pi^+$ with $\Xi^- \to \Lambda\pi^-(\Lambda \to p\pi^-)$ and $\Xi^- \to pK^-\pi^+$ modes, with no $B^0_{\rm tag}$. The daughters of the $\bar{B}^0$, Ξ_c^+, and Ξ^- candidates are fit to common vertices. If there is more than one $\bar{B}^0$ candidate in an event, the one with the smallest $\chi^2_{\rm vertex}/{\rm n.d.f.}$ from the $\bar{B}^0$ vertex fit is selected. The requirements of $\chi^2_{\rm vertex}/{\rm n.d.f.} < 50$, 15, and 15 are applied to reconstructed $\bar{B}^0$, Ξ_c^+, and Ξ^- candidates, respectively, with selection efficiencies above 96%, 95%, and 95%. Ξ^- and Ξ_c^+ signals are defined as $|M_{\Xi^-} - m_{\Xi^-}| < 10$ MeV/c^2 and $|M_{\Xi_c^+} - m_{\Xi_c^+}| < 20$ MeV/c^2 corresponding to about 3σ. The $\bar{\Lambda}_c^-$ signal interval is the same as in the inclusive analysis of Ξ_c^+ decays. $\bar{B}^0$ signal candidates are identified using the beam-constrained mass $M_{\rm bc}$ and the energy difference ΔE. Here, $M_{\rm bc}$ and ΔE are defined as $M^{\rm tag}_{\rm bc}$ and $\Delta E^{\rm tag}$ above, but calculated using the momenta of the signal candidate tracks directly.

After the event selections, the distributions of $M_{\Xi_c^+}$ versus $M_{\bar{\Lambda}_c^-}$ in the $\bar{B}^0$ signal region defined by $|\Delta E| < 0.03$ GeV and $M_{\rm bc} > 5.27$ GeV/c^2 corresponding to about 3σ are shown in Figs. 2(a1) and 2(a2). The central solid boxes are the Ξ_c^+ and $\bar{\Lambda}_c^-$ signal regions. The backgrounds from non-Ξ_c^+ and non-$\bar{\Lambda}_c^-$ events are estimated with the $M_{\Xi_c^+}$ and $M_{\bar{\Lambda}_c^-}$ sidebands, represented by the dashed and dash-dotted boxes in Figs. 2(a1) and 2(a2). The normalized contributions from the $M_{\Xi_c^+}$ and $M_{\bar{\Lambda}_c^-}$ sidebands are estimated using half the number of events in the blue dashed boxes minus one fourth the number of events in the red dash-dotted boxes. Figure 2 shows the $M_{\rm bc}$ and ΔE distributions in the Ξ_c^+ and $\bar{\Lambda}_c^-$ signal regions from the selected $\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+$ candidates with $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ (b1-c1) and $\Xi_c^+ \to pK^-\pi^+$ (b2-c2) decay modes.

We perform a two-dimensional (2D) maximum likelihood fit to the $M_{\rm bc}$ and ΔE distributions to extract the number of $\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+$ signal events with $\Xi_c^+ \to \Xi^-\pi^+\pi^+/pK^-\pi^+$. For the $M_{\rm bc}$ distribution, the signal shape is modeled using a Gaussian function and the background is described using an ARGUS function [40]. For the ΔE distribution, the signal shape is a double Gaussian and the background is a first-order polynomial. All shape parameters of the signal functions are fixed to the

TABLE I. Summary of the measured Ξ_c^+ branching fractions and ratio (last column), and the corresponding systematic uncertainties in %. For the branching fractions and ratio, the first uncertainties are statistical and the second are systematic.

Observable	Efficiency	Fit	Λ_c decays	$B_{\rm tag}$	$N_{\bar{B}^0}$	Sum	Measured value
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)$	3.66	10.3	5.3	4.5	1.82	13.1	$(1.16 \pm 0.42 \pm 0.15) \times 10^{-3}$
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	6.24	5.61	5.3	···	1.82	10.1	$(3.32 \pm 0.74 \pm 0.33) \times 10^{-5}$
$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$	7.32	9.53	5.3	···	1.82	13.3	$(5.27 \pm 1.51 \pm 0.69) \times 10^{-6}$
$\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	4.23	11.7	···	4.5	···	13.2	$(2.86 \pm 1.21 \pm 0.38)\%$
$\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$	3.66	14.0	···	4.5	···	15.2	$(0.45 \pm 0.21 \pm 0.07)\%$
$\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)/\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$	4.90	11.0	···	···	···	12.0	$0.16 \pm 0.06 \pm 0.02$

values obtained from the fits to the MC simulated signal distributions. The fit results are shown in Fig. 2.

The signal yields are $N_{\Xi^-\pi^+\pi^+} = 24.2 \pm 5.4$ (6.9σ significance and 6.8σ with systematic uncertainties included) and $N_{pK^-\pi^+} = 24.0 \pm 6.9$ (4.5σ significance and 4.4σ with systematic uncertainties included). We use the efficiencies from MC simulations to measure $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ and $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ as $[3.32 \pm 0.74(\text{stat.})] \times 10^{-5}$ and $[5.27 \pm 1.51(\text{stat.})] \times 10^{-6}$, respectively.

We divide the above product branching fractions by the value of $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)$ and for the first time measure $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$, $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$, and the ratio between them. These are listed in Table I.

There are several sources of systematic uncertainties in the branching fraction measurements. The uncertainties related to reconstruction efficiency include those for tracking efficiency (0.35% per track), particle identification efficiency (0.9% per kaon, 0.9% per pion, and 3.3% per proton), as well as Λ reconstruction efficiency (3.0% per Λ [41]). We assume these reconstruction-efficiency-related uncertainties are independent and sum them in quadrature. We estimate the systematic uncertainties associated with the fitting procedures by changing the order of the background polynomial, the range of the fit, and by enlarging the mass resolution by 10%. The observed deviations from the nominal fit results are taken as systematic uncertainties. The uncertainty on $\mathcal{B}(\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-)$ is taken from Ref. [1]. The uncertainty due to the B^0 tagging efficiency is 4.5% [42]. A relative systematic uncertainty on $\mathcal{B}(\Upsilon(4S) \to B^0\bar{B}^0)$ is 1.23% [1]. The systematic uncertainty on $N_{\Upsilon(4S)}$ is 1.37% [43]. For the Ξ_c^+ branching fractions and the corresponding ratio, some common systematic uncertainties, including tracking, particle identification, $\bar{\Lambda}_c^-$ decay branching fraction, Λ selection, and the total number of $B\bar{B}$ pairs, cancel. We summarize the sources of systematic uncertainties in Table I, assume them to be independent, and add them in quadrature to obtain the total systematic uncertainties.

We report the first measurements of the absolute branching fractions:

$$\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.86 \pm 1.21 \pm 0.38)\%,$$
$$\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = (0.45 \pm 0.21 \pm 0.07)\%,$$

where the first uncertainties are statistical and the second systematic. The measured $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ value is consistent with the theoretical prediction within uncertainties [27]. The measured central value of $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$ is smaller than that of the theoretical predictions [23,28], perhaps indicating a large U-spin symmetry breaking effect in the singly-Cabibbo-suppressed charmed-baryon decays. The branching fraction $\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)$ is measured for the first time to be $[1.16 \pm 0.42(\text{stat.}) \pm 0.15(\text{syst.})] \times 10^{-3}$ and agrees well with that of $B^- \to \bar{\Lambda}_c^- \Xi_c^0$ [16] which is consistent with the expectation from isospin symmetry. The product branching fractions are

$$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (3.32 \pm 0.74 \pm 0.33) \times 10^{-5},$$
$$\mathcal{B}(\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+)\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = (5.27 \pm 1.51 \pm 0.69) \times 10^{-6}.$$

The first of these branching fraction measurements is consistent with previous measurements, with improved precision, and supersedes the Belle measurement [30]. The ratio $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)/\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ is measured to be $0.16 \pm 0.06(\text{stat.}) \pm 0.02(\text{syst.})$, which is consistent with world-average value of 0.21 ± 0.04 [1] within uncertainties. Our measured Ξ_c^+ branching fractions, e.g., for $\Xi_c^+ \to \Xi^-\pi^+\pi^+$, can be combined with Ξ_c^+ branching fractions measured relative to $\Xi_c^+ \to \Xi^-\pi^+\pi^+$ to yield other absolute Ξ_c^+ branching fractions.

In summary, based on $(772 \pm 11) \times 10^6$ $B\bar{B}$ pairs collected at the $\Upsilon(4S)$ resonance with the Belle detector, we perform an analysis of $\bar{B}^0 \to \bar{\Lambda}_c^- \Xi_c^+$ inclusively using a hadronic B-tagging method based on a full reconstruction algorithm [39], and exclusively with Ξ_c^+ decays into $\Xi^-\pi^+\pi^+$ and $pK^-\pi^+$ final states. These are the first measurements of the absolute branching fractions $\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+)$ and $\mathcal{B}(\Xi_c^+ \to pK^-\pi^+)$.

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