

# First measurement of the $\Lambda_c^+ \rightarrow p\eta'$ decay



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ABSTRACT: We present the first measurement of the branching fraction of the singly Cabibbo-suppressed (SCS) decay  $\Lambda_c^+ \rightarrow p\eta'$  with  $\eta' \rightarrow \eta\pi^+\pi^-$ , using a data sample corresponding to an integrated luminosity of  $981 \text{ fb}^{-1}$ , collected by the Belle detector at the KEKB  $e^+e^-$  asymmetric-energy collider. A significant  $\Lambda_c^+ \rightarrow p\eta'$  signal is observed for the first time with a signal significance of  $5.4\sigma$ . The relative branching fraction with respect to the normalization mode  $\Lambda_c^+ \rightarrow pK^-\pi^+$  is measured to be

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow p\eta')}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = (7.54 \pm 1.32 \pm 0.73) \times 10^{-3},$$

where the uncertainties are statistical and systematic, respectively. Using the world-average value of  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+) = (6.28 \pm 0.32) \times 10^{-2}$ , we obtain

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\eta') = (4.73 \pm 0.82 \pm 0.46 \pm 0.24) \times 10^{-4},$$

where the uncertainties are statistical, systematic, and from  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)$ , respectively.

KEYWORDS: Branching fraction,  $e^+e^-$  Experiments, Charm Physics, Particle and Resonance Production

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## 1 Introduction

Hadronic decays of charmed baryons provide an ideal laboratory to understand the interplay of weak and strong interactions in the charm system [1–3]. Decays of charmed baryons receive sizable nonfactorizable contributions from W-exchange diagrams, which are subject to color and helicity suppression [4–7]. Therefore, the study of nonfactorizable contributions is critical to understand the dynamics of charmed baryon decays. To avoid theoretical difficulties in the factorization approach [4], one can use the  $SU(3)_F$  flavor symmetry to relate the amplitudes among different decays [5, 8, 9]. Other theoretical approaches provide calculations based on dynamical models [10–12]. For the singly Cabibbo-suppressed (SCS) decay  $\Lambda_c^+ \rightarrow p\eta'$ , theoretical predictions on its branching fraction under different assumptions vary by more than an order of magnitude as listed in table 1. Currently, this decay has not yet been observed.

In this study, based on an  $e^+e^-$  annihilation data sample of  $981\text{ fb}^{-1}$  collected by the Belle experiment, we measure the branching fraction of the signal mode  $\Lambda_c^+ \rightarrow p\eta'$  with respect to the normalization mode  $\Lambda_c^+ \rightarrow pK^-\pi^+$ . Throughout this paper, charge-conjugate modes are implicitly included unless stated otherwise. The paper is organized as follows. Section 2 introduces the Belle detector and data sample. Section 3 discusses the event selection criteria. The signal and background estimations are presented in section 4. Sections 5 and 6 describe the systematic uncertainty and conclusion, respectively.

## 2 The Belle detector and data sample

This measurement is based on a data sample corresponding to an integrated luminosity of  $981\text{ fb}^{-1}$ , collected with the Belle detector at the KEKB asymmetric-energy  $e^+e^-$  collider [14, 15]. About 70% of the data were recorded at the  $\Upsilon(4S)$  resonance, and the rest

	SU(3) <sub>F</sub> symmetry [5]	SU(3) <sub>F</sub> symmetry [13]	Constituent quark model [3]
$\mathcal{B}(\Lambda_c^+ \rightarrow p\eta')$	0.4 – 0.6	$1.22^{+1.43}_{-0.87}$	0.04 – 0.2

**Table 1.** Comparison of different theoretical predictions for  $\mathcal{B}(\Lambda_c^+ \rightarrow p\eta')$  (in units of  $10^{-3}$ ).

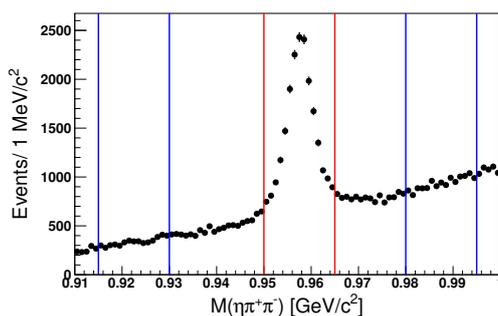
were collected at other  $\Upsilon(nS)$  ( $n = 1, 2, 3$ , or  $5$ ) states or at center-of-mass (CM) energies a few tens of MeV below the  $\Upsilon(4S)$  or the  $\Upsilon(nS)$  peaks.

The Belle detector is a large-solid-angle magnetic spectrometer that consists of a silicon vertex detector (SVD), 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 comprised 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 of the coil is instrumented to detect  $K_L^0$  mesons and to identify muons. The detector is described in detail elsewhere [16, 17]. The origin of the coordinate system is defined as the position of the nominal interaction point, and the axis aligning with the direction opposite the  $e^+$  beam is defined as the  $z$  axis. Monte Carlo (MC) simulated events are used to optimize the selection criteria, study backgrounds, and determine the signal reconstruction efficiency. Samples of simulated signal MC events are generated by EVTGEN [18] and propagated through a detector simulation based on GEANT3 [19]. The  $e^+e^- \rightarrow c\bar{c}$  events are simulated using PYTHIA [20]; the decays  $\Lambda_c^+ \rightarrow pK^-\pi^+$  and  $\eta' \rightarrow \eta\pi^+\pi^-$  are generated with a phase space model. We take into account the effect of final-state radiation from charged particles by using the PHOTOS package [22]. Simulated samples of  $\Upsilon(4S) \rightarrow B^+B^-/B^0\bar{B}^0$ ,  $\Upsilon(5S) \rightarrow B_s^{(*)}\bar{B}_s^{(*)}/B^{(*)}\bar{B}^{(*)}(\pi)/\Upsilon(4S)\gamma$ ,  $e^+e^- \rightarrow q\bar{q}$  ( $q = u, d, s, c$ ) at  $\sqrt{s} = 10.52, 10.58$ , and  $10.867$  GeV, and  $\Upsilon(1S, 2S, 3S)$  decays, normalized to the same integrated luminosity as real data, are used to develop the selection criteria and perform the background study [23].

### 3 Selection criteria

Selection criteria are optimized by maximizing a figure-of-merit  $\epsilon/(\frac{a}{2} + \sqrt{n_B})$  [24], where  $\epsilon$  is the signal efficiency;  $a$  is the target signal significance expressed in standard deviations in a one-sided Gaussian test, selected to be 5;  $n_B$  is the number of background events expected in a two-dimensional signal region of  $\eta'$  and  $\Lambda_c^+$  signals, which is defined as (0.95, 0.965) GeV/ $c^2$  in  $M(\eta\pi^+\pi^-)$  and (2.27, 2.31) GeV/ $c^2$  in  $M(p\eta')$ .

We reconstruct the decays  $\Lambda_c^+ \rightarrow p\eta'$  and  $\Lambda_c^+ \rightarrow pK^-\pi^+$ , with the  $\eta'$  decay reconstructed in the cascade  $\eta\pi^+\pi^-$ ,  $\eta \rightarrow \gamma\gamma$ . Final-state charged tracks are identified as  $p$ ,  $K$ , or  $\pi$  candidates using information from the charged-hadron identification systems (ACC, TOF, CDC) combined into a likelihood ratio,  $\mathcal{R}(h|h') = \mathcal{L}(h)/(\mathcal{L}(h) + \mathcal{L}(h'))$ , where  $h$  and  $h'$  are  $\pi$ ,  $K$ , or  $p$  as appropriate [25]. Tracks having  $\mathcal{R}(p|\pi) > 0.9$  and  $\mathcal{R}(p|K) > 0.9$  are identified as proton candidates; charged kaon candidates are required to have  $\mathcal{R}(K|p) > 0.4$  and  $\mathcal{R}(K|\pi) > 0.9$ ; and charged pion candidates to have  $\mathcal{R}(\pi|p) > 0.4$  and  $\mathcal{R}(\pi|K) > 0.4$ . A likelihood ratio for electron identification,  $\mathcal{R}(e)$ , is formed from ACC, CDC, and ECL information [26], and is required to be less than 0.9 for all charged tracks to suppress elec-



**Figure 1.** The invariant mass distribution of  $\eta\pi^+\pi^-$ . The region between two red lines is selected as the  $\eta'$  signal region, and the regions between two blue lines are the  $\eta'$  sidebands.

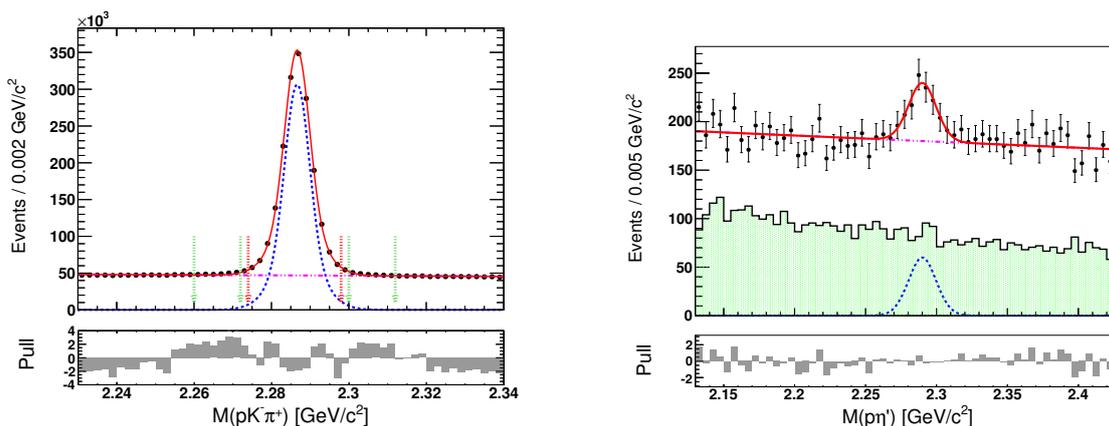
trons. The identification efficiencies of  $p$ ,  $K$ , and  $\pi$  are 82%, 70%, and 97%, respectively. The probabilities of misidentifying  $h$  as  $h'$ ,  $P(h \rightarrow h')$ , are estimated to be 3% [ $P(p \rightarrow \pi)$ ], 7% [ $P(p \rightarrow K)$ ], 10% [ $P(K \rightarrow \pi)$ ], 2% [ $P(K \rightarrow p)$ ], 5% [ $P(\pi \rightarrow K)$ ], and 1% [ $P(\pi \rightarrow p)$ ]. For each charged track, the distance of the closest approach with respect to the interaction point along the  $z$  axis and in the transverse  $x - y$  plane is required to be less than 2.0 cm and 0.1 cm, respectively. Each track must have at least one SVD hit in both the  $z$  direction and the  $x - y$  plane.

Photon candidates are selected from ECL clusters not associated with any charged tracks. The photon energy is required to be greater than 90 MeV in the barrel region ( $-0.63 < \cos\theta < 0.85$ ) and greater than 120 MeV in the endcap regions ( $-0.91 < \cos\theta < -0.63$  or  $0.85 < \cos\theta < 0.98$ ) of the ECL, where  $\theta$  is the polar angle relative to the positive  $z$  axis. To reject neutral hadrons, the ratio of the energy deposited in the central  $3 \times 3$  array of ECL crystals to the total energy deposited in the enclosing  $5 \times 5$  array of crystals is required to be at least 0.9 for each photon candidate.

The  $\eta$  candidates are reconstructed via their decay to two photons. The  $\gamma\gamma$  invariant mass is required to satisfy  $0.45 < M(\gamma\gamma) < 0.65 \text{ GeV}/c^2$ , and then a mass-constrained fit is performed for  $\eta$  candidates to improve the momentum resolution. The corresponding  $\chi^2$  value of the mass-constrained fit on  $\eta$  ( $\chi_\eta^2$ ) is required to be less than 10. To further suppress background events, we remove  $\eta$  candidates in which either of the daughter photons can be combined with other photons in the event to form  $\pi^0 \rightarrow \gamma\gamma$  candidates satisfying  $|M(\gamma\gamma) - m_{\pi^0}| < 12 \text{ MeV}/c^2$ , where  $m_{\pi^0}$  is the nominal  $\pi^0$  mass [21]. With this veto, we reject 42% of the background, while retaining 83% of the signal.

The  $\eta'$  candidates are reconstructed by combining two opposite-charge  $\pi$  tracks with an  $\eta$  candidate. The invariant mass distribution of  $\eta\pi^+\pi^-$  from data is shown in figure 1. Candidates  $\eta'$  are retained if  $0.950 < M(\eta\pi^+\pi^-) < 0.965 \text{ GeV}/c^2$ , corresponding to an efficiency of 96%. The  $\eta'$  sidebands are defined as 0.915 to 0.930  $\text{GeV}/c^2$  and 0.980 to 0.995  $\text{GeV}/c^2$ , which are the regions between two blue lines in the  $M(\eta\pi^+\pi^-)$  distribution.

Candidates for  $\Lambda_c^+ \rightarrow pK^-\pi^+$  and  $\Lambda_c^+ \rightarrow p\eta'$  decays are reconstructed by combining  $p$ ,  $K^-$ ,  $\pi^+$  candidates, and  $p$ ,  $\eta'$  candidates, respectively. A vertex fit is performed with the three charged tracks to suppress combinatorial background events. The resulting fit



**Figure 2.** Fits to the invariant mass distributions of the  $pK^-\pi^+$  (Left) and  $p\eta'$  combinations (Right). Black dots with error bars represent the data; red solid lines represent the total fitted result; blue dashed lines represent the signal shape; magenta dot-dashed lines represent the background shape; and the green histogram is from normalized  $\eta'$  sidebands.

quality is labeled  $\chi_{\text{vtx}}^2$ . For  $\Lambda_c^+ \rightarrow pK^-\pi^+$ , the  $\chi_{\text{vtx}}^2$  is required to be less than 40, while for  $\Lambda_c^+ \rightarrow p\eta'$ ,  $\chi_{\text{vtx}}^2 < 15$  is required. For both  $\chi_{\text{vtx}}^2$  requirements, the efficiency is larger than 98%. A scaled momentum of  $x_p > 0.53$  is required to suppress background, especially from  $B$ -meson decays, where  $x_p = p^* / \sqrt{E_{\text{cm}}^2 / 4c^2 - M^2 c^2}$ ,  $E_{\text{cm}}$  is the CM energy, and  $p^*$  and  $M$  are the momentum and invariant mass, respectively, of the  $\Lambda_c^+$  candidates in the CM frame.

After the preliminary selection, about 0.8% of the  $\Lambda_c^+ \rightarrow pK^-\pi^+$  events and 13.3% of the  $\Lambda_c^+ \rightarrow p\eta'$  events have two or more  $\Lambda_c^+$  candidates. We choose the best  $\eta$  candidate according to the smallest value of  $\chi_{\eta}^2$ ; the rate of events having multiple  $\Lambda_c^+ \rightarrow p\eta'$  candidates with this criterion is 1.6%. For such multi-candidate events, we choose a single  $\Lambda_c^+$  candidate randomly. This best-candidate selection, based on the MC simulation, identifies the correct candidate 65% of the time. The  $p\eta'$  mass distribution for wrong-combination simulated signal events is found to be smooth. We keep all candidates of  $\Lambda_c^+ \rightarrow pK^-\pi^+$  in multiple-candidate events as the multiplicity is negligible.

## 4 Signal and background estimation

With the above selection criteria applied, the invariant mass distributions of normalization and signal modes are shown in figure 2. From a study of generic MC samples [23], no known peaking background processes contribute to mass distributions in the  $\Lambda_c^+$  signal region.

To extract the number of signal events, we perform an unbinned maximum-likelihood fit to the  $M(pK^-\pi^+)$  or  $M(p\eta')$  distribution. The likelihood function is defined in terms of a signal PDF ( $F_S$ ) and a background PDF ( $F_B$ ) as

$$\mathcal{L} = \frac{e^{-(n_S+n_B)}}{N!} \prod_i^N [n_S F_S(M_i) + n_B F_B(M_i)], \quad (4.1)$$

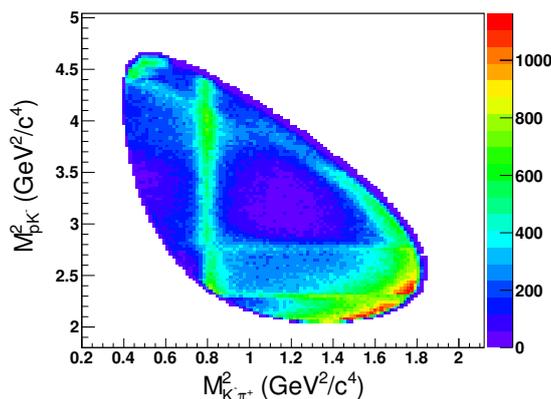
where  $N$  is the total number of observed events;  $n_S$  and  $n_B$  are the numbers of signal events and background events, respectively;  $M$  is  $pK^-\pi^+$  or  $p\eta'$  invariant mass; and  $i$  denotes the

event index. The fit is performed to candidate events surviving the selection criteria;  $n_S$  and  $n_B$  are free parameters in the fit.

For the  $\Lambda_c^+ \rightarrow pK^-\pi^+$  channel, we extract the  $\Lambda_c^+$  signal yields by fitting the  $M(pK^-\pi^+)$  distribution. The signal PDF is a sum of two Gaussian functions with a common mean, and the background PDF is a second-order polynomial. All parameters of  $F_S$  and  $F_B$  are floated. The fit result is shown in figure 2 (Left), along with the pull distribution. The fitted signal yield is  $N_{\text{norm}} = 1472190 \pm 5726$ , where the uncertainty is statistical. From the MC simulation, the mass resolution for  $\Lambda_c^+ \rightarrow pK^-\pi^+$  is  $8 \text{ MeV}/c^2$ .

For the  $\Lambda_c^+ \rightarrow p\eta'$  channel, we first check the  $M(p\pi^+\pi^-\eta)$  distribution from normalized  $\eta'$  sidebands, as shown in figure 2 (Right). The distribution from the normalized  $\eta'$  sidebands is smoothly falling, indicating a negligible contribution from  $\Lambda_c^+ \rightarrow p\pi^+\pi^-\eta$  decays. We subsequently fit the  $M(p\eta')$  distribution to extract the  $\Lambda_c^+$  signal yield. A sum of a Gaussian function and a Crystal Ball (CB) function [27] is used as the signal PDF, and a second-order polynomial as the background PDF. The Gaussian and CB functions are fixed to have a common mean. All other parameters are floated in the fit. The fit result, along with the pull distribution, is shown in figure 2 (Right). A clear  $\Lambda_c^+$  signal is observed in the  $M(p\eta')$  distribution. The fitted signal yield is  $N_{\text{sig}} = 294 \pm 52$ , where the uncertainty is statistical. The mass resolution for  $\Lambda_c^+ \rightarrow p\eta'$  is  $13 \text{ MeV}/c^2$  from the MC simulation, which is the half-width at half maximum. The statistical significance of the  $\Lambda_c^+$  signal is  $6.3\sigma$ , calculated from the difference of the logarithmic likelihoods,  $-2\ln(\mathcal{L}_0/\mathcal{L}_{\text{max}}) = 59.2$ , where  $\mathcal{L}_0$  and  $\mathcal{L}_{\text{max}}$  are the maximized likelihoods without and with a signal component, respectively [28]. The significance takes into account the difference in the number of degrees of freedom in the two fits ( $\Delta ndf=7$ ). Since the largest systematic uncertainty is due to the fit, as described in section 5, alternative fits to the  $M(p\eta')$  spectrum under different fit conditions are performed and the  $\Lambda_c^+$  signal significance is larger than  $5.4\sigma$  in all cases.

To measure the branching fraction, we must divide these extracted signal yields by their reconstruction efficiencies. Since  $\Lambda_c^+ \rightarrow p\eta'$  is a two-body decay and  $\eta' \rightarrow \eta\pi^+\pi^-$  is well modeled by the phase space [29], we estimate the reconstruction efficiency directly from the simulated events by the ratio  $n_{\text{sel}}/n_{\text{gen}}$ , where  $n_{\text{sel}}$  and  $n_{\text{gen}}$  are the numbers of true signal events surviving the selection criteria and generated events, respectively. The signal mode reconstruction efficiency is determined to be  $\epsilon_{\text{sig}} = (2.22 \pm 0.02)\%$ . However, the reconstruction efficiency for the decay  $\Lambda_c^+ \rightarrow pK^-\pi^+$  can vary across the three-body phase space, as visualized in a Dalitz plot [30] with polarization neglected. To take this into account, we correct the reconstruction efficiency according to the Dalitz plot from data as follows. Figure 3 shows the Dalitz distribution of  $M^2(pK^-)$  versus  $M^2(K^-\pi^+)$  in the  $\Lambda_c^+ \rightarrow pK^-\pi^+$  signal region from data which is defined as  $2.274 < M(pK^-\pi^+) < 2.298 \text{ GeV}/c^2$ . The number of background events has been subtracted using the normalized  $\Lambda_c^+$  sidebands defined as  $(2.260, 2.272) \text{ GeV}/c^2$  and  $(2.300, 2.312) \text{ GeV}/c^2$ . The effect of the variation of the kinematic boundaries with  $M(pK^-\pi^+)$  is neglected. We divide the Dalitz plot for the data into  $120 \times 120$  bins, with a bin size of  $0.027 \text{ GeV}^2/c^4$  for  $M^2(pK^-)$  and  $0.016 \text{ GeV}^2/c^4$  for  $M^2(K^-\pi^+)$ . The corrected reconstruction efficiency is determined



**Figure 3.** Dalitz plot of the selected  $\Lambda_c^+ \rightarrow pK^-\pi^+$  candidates.

via the formula

$$\epsilon_{\text{norm}}^{\text{corr}} = \frac{\sum_i s_i}{\sum_j (s_j / \epsilon_j)}, \quad (4.2)$$

where  $i$  and  $j$  run over all bins;  $\sum_i s_i$  is the number of signal candidates in data;  $s_j$  and  $\epsilon_j$  are the number of signal candidates in data and the reconstruction efficiency from MC simulation events for each bin, respectively. The reconstruction efficiency for each bin is obtained by dividing the number of signal events after applying the selection criteria by the number of generated events. The corrected reconstruction efficiency is  $\epsilon_{\text{norm}}^{\text{corr}} = (14.06 \pm 0.01)\%$ .

The branching fraction of the signal mode relative to that of the normalization mode is determined via

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow p\eta')}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = \frac{N_{\text{sig}}/\epsilon_{\text{sig}}}{N_{\text{norm}}/\epsilon_{\text{norm}}^{\text{corr}}} \times \frac{1}{\mathcal{B}'}, \quad (4.3)$$

where  $\mathcal{B}' = \mathcal{B}(\eta' \rightarrow \eta\pi^+\pi^-) \times \mathcal{B}(\eta \rightarrow \gamma\gamma)$  [21]. Inserting all extracted signal yields and reconstruction efficiencies into eq. (4.3) gives the branching fraction ratio

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow p\eta')}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = (7.54 \pm 1.32 \pm 0.73) \times 10^{-3}, \quad (4.4)$$

where the first error is statistical and the second is systematic, as evaluated in section 5. Multiplying both sides of eq. (4.4) by the world average value  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+) = (6.28 \pm 0.32) \times 10^{-2}$  [21] gives

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\eta') = (4.73 \pm 0.82 \pm 0.46 \pm 0.24) \times 10^{-4}, \quad (4.5)$$

where the third uncertainty is from the uncertainty in  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)$ .

## 5 Systematic uncertainties

Table 2 summarizes the sources of systematic uncertainties in measuring the ratio of branching fractions. These uncertainties are assessed as follows.

Source	Systematic uncertainties (%)
PID efficiency	3.5
Photon efficiency	4.0
$\eta'$ mass window	0.8
Best-candidate selection	1.2
Normalization mode fit	1.8
Signal mode fit	7.6
$\mathcal{B}'$	1.3
Signal MC sample size	0.7
Total	9.7

**Table 2.** The sources of the relative systematic uncertainties (%) in the measurement of the ratio of branching fractions.

- The momentum and angular distributions of protons from  $\Lambda_c^+ \rightarrow pK^-\pi^+$  and  $\Lambda_c^+ \rightarrow p\eta'$  are similar. Based on the study of inclusive  $\Lambda$  decay  $\Lambda \rightarrow p\eta'$ , the uncertainty from PID efficiency of the proton is below 0.1% and is therefore neglected. For the pion with the same charge in the numerator and denominator of eq. (4.4), the uncertainties in PID efficiencies only partially cancel because of differences in momentum distributions; Using a control sample of  $D^{*+} \rightarrow D^0\pi^+$  with  $D^0 \rightarrow K^-\pi^+$  decay, we assign an uncertainty of 0.7%. Uncertainties of 1.6% and 1.2% are assigned for the  $K$  and remaining  $\pi$  identification efficiencies, respectively. The total systematic uncertainty from PID is 3.5%, adding individual PID uncertainties linearly as they are highly correlated.
- Based on a study of radiative Bhabha events, a systematic uncertainty of 2.0% is assigned to the photon efficiency for each photon, and the total systematic uncertainty from photon reconstruction is thus 4.0%.
- The efficiency of the requirement on  $M(\eta\pi^+\pi^-)$  is 96.3% for data and 97.1% for MC simulation, with a ratio of 99.2%. We take the relative difference on efficiencies between data and MC simulation as the uncertainty due to the  $\eta'$  mass window, which is 0.8%.
- The uncertainty from the best-candidate selection is estimated by turning off the multiple candidate rejection and the difference in branching fraction ratio without best-candidate selection relative to the nominal one is taken as the uncertainty, which is 1.2%.
- Uncertainties from the fits are estimated by modifying the forms of  $F_S$  and  $F_B$ , and enlarging the fit range.

- To evaluate the uncertainty from the fit of the normalization mode, the signal PDF used is a sum of three Gaussian functions with a common mean, and the background PDF used is a first-order polynomial. The fit range is enlarged to be (2.15, 2.42) GeV/c<sup>2</sup>. The difference in signal yields is taken as the uncertainty. We sum these contributions in quadrature to obtain a 1.8% uncertainty.
- To evaluate the uncertainty from the fit of the signal mode, the signal PDF is changed to a sum of two CB functions, and the background PDF is changed to a third-order polynomial. We also enlarge the fit range. Moreover, we perform a simultaneous fit to the  $M(p\pi^+\pi^-\eta)$  distributions from the selected events in the  $\eta'$  signal region and the normalized  $\eta'$  sidebands to estimate the contribution from a possible  $\Lambda_c^+ \rightarrow p\pi^+\pi^-\eta$  non-resonant component. The difference in signal yields from each change is taken as the uncertainty. We sum these contributions in quadrature to obtain a 7.6% uncertainty.
- The uncertainty on the product of the branching fractions of the decays  $\eta' \rightarrow \eta\pi^+\pi^-$  and  $\eta \rightarrow \gamma\gamma$  is 1.3% [21].
- Uncertainty from the finite statistics of the signal MC samples is 0.7%.
- Since there are three charged tracks in the final states both for normalization mode and signal mode, the uncertainty due to the tracking efficiency largely cancels in the ratio. For the normalization mode, the reconstruction efficiency is corrected by the Dalitz plot of the data; the uncertainty from the generator model is therefore negligible. For the signal mode, since the signal efficiency does not depend on the angular distribution of the proton in the  $\Lambda_c^+$  rest frame, the model-dependent uncertainty has a negligible effect on the efficiency. For the decay  $\eta' \rightarrow \eta\pi^+\pi^-$ , the internal dynamics is very similar to the phase space [29], thus the systematic uncertainty from the generator model of  $\eta' \rightarrow \eta\pi^+\pi^-$  is ignored.

The total systematic uncertainty is obtained by adding in quadrature all the above contributions. The results are listed in table 2.

## 6 Conclusions

In summary, using the full Belle data set corresponding to an integrated luminosity of 981 fb<sup>-1</sup>, we present the first measurement of the branching fraction of  $\Lambda_c^+ \rightarrow p\eta'$  relative to that of  $\Lambda_c^+ \rightarrow pK^-\pi^+$ . The decay  $\Lambda_c^+ \rightarrow p\eta'$  is observed with a significance of 5.4 $\sigma$ . Our result is

$$\frac{\mathcal{B}(\Lambda_c^+ \rightarrow p\eta')}{\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)} = (7.54 \pm 1.32(\text{stat}) \pm 0.73(\text{syst})) \times 10^{-3}.$$

Inserting the world average value  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+) = (6.28 \pm 0.32) \times 10^{-2}$  [21] gives the absolute branching fraction

$$\mathcal{B}(\Lambda_c^+ \rightarrow p\eta') = (4.73 \pm 0.82(\text{stat}) \pm 0.46(\text{syst}) \pm 0.24(\text{ref})) \times 10^{-4},$$

where the uncertainties are statistical, systematic, and from  $\mathcal{B}(\Lambda_c^+ \rightarrow pK^-\pi^+)$ , respectively. Our result is consistent with theoretical calculations based on  $SU(3)_F$  symmetry [5, 13], while not consistent with a constituent quark model prediction [3].

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