

# First Measurement of the Decay Asymmetry of pure W-exchange Decay $\Lambda_c^+ \rightarrow \Xi^0 K^+$

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Based on  $4.4 \text{ fb}^{-1}$  of  $e^+e^-$  annihilation data collected at the center-of-mass energies between 4.60 and 4.70 GeV with the BESIII detector at the BEPCII collider, the pure  $W$ -exchange decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  is studied with a full angular analysis. The corresponding decay asymmetry is measured for the first time to be  $\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16(\text{stat.}) \pm 0.03(\text{syst.})$ . This result reflects the interference between the  $S$ - and  $P$ -wave amplitudes. The phase shift between  $S$ - and  $P$ -wave amplitudes is  $\delta_p - \delta_s = -1.55 \pm 0.25(\text{stat.}) \pm 0.05(\text{syst.}) \text{ rad}$ .

in the Standard Model (SM) of particle physics. The ground state of the singly-charmed baryons,  $\Lambda_c^+$ , was discovered in 1979 [1]. Many studies have since been made of the properties of charmed baryons, such as the decay branching fractions (BFs) and decay asymmetries. But experimental results of the decay asymmetries, which are sensitive to the different amplitudes in the decay dynamics, have been limited. Since 2014, there has been some progress on the weak hadronic decays of  $\Lambda_c^+$ ,  $\Xi_c^{+,0}$ , and  $\Omega_c^0$ , both experimentally and theoretically [2–4]. This provides crucial information about the properties of all the singly-charmed baryons and the searches for doubly-charmed baryons ( $\Xi_{cc}$  and  $\Omega_{cc}$ ) [5]. Nonetheless, the understanding of the decay dynamics of charmed baryons is still limited, due to the lack of precision experimental measurements and the difficulties in the theoretical treatment of strong interaction effects.

Compared to heavy meson decays, charmed baryon decays have a significant dependence on nonfactorizable contributions from  $W$ -exchange diagrams. However, these contributions cannot currently be calculated using theoretical approaches. Additionally, no experimental measurements exist for the decay asymmetries of  $W$ -exchange hadronic decays. An example of such a process is the decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ , which can only be produced via a  $W$ -exchange process as depicted in Fig. 1. Experimental measurements of the asymmetry parameters of the decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  can aid understanding of the internal dynamics and can also explore charge-parity ( $CP$ ) violation in baryons [6].

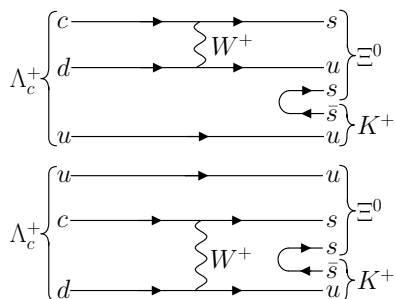


FIG. 1. Feynman diagrams for  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ .

Table I lists the theoretical calculations of the BF and asymmetry parameters of  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ , as well as the experimental measurements of the BF. Various predictions of the BFs based on the covariant confined quark model (CCQM), the pole model, and current algebra (CA) in the 1990s are all smaller than the experimental results [2]. This is explained as a strong cancellation in the  $S$ - and  $P$ -wave amplitudes. Moreover, the decay asymmetry parameter was predicted to be zero in these models owing to the vanishing  $S$ -wave amplitude [7–11]. This long-standing puzzle has recently experienced a renewed interest in the theoretical community [6, 12, 13], especially after the report of new

BF measured by BESIII in 2018 [14]. To reproduce the relatively large experimental branching fraction of this decay, Ref. [6] adopted a variant of the CA approach and obtained a larger  $\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+) \simeq 0.71\%$ . This modification introduces a large positive decay asymmetry of 0.90, which is quite close to the calculations based on SU(3) symmetry [12, 13]. However, regarding the significant enhancement of  $\alpha_{\Xi^0 K^+}$  from 0 to about 0.9, the authors of Ref. [15] pointed out that the particular construction of the  $S$ -wave amplitude in Ref. [6] is not well-justified. So experimental measurement of the asymmetry parameter of the decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  will be crucial to test these calculations and confirm the vanishing  $S$ -wave contribution [15].

In the SM, the amplitude for a spin-1/2 baryon decaying into a spin-1/2 baryon and a spin-0 meson can be written as  $M = i\bar{u}_f(A - B\gamma_5)u_i$ , where  $A$  and  $B$  are constants,  $u_i$  and  $\bar{u}_f$  are spinors describing the initial and final baryons [8]. For the decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ , the decay asymmetry is defined by  $\alpha_{\Xi^0 K^+} = 2\text{Re}(s^*p)/(|s|^2 + |p|^2)$ , where  $s = A$  and  $p = |\vec{p}_{\Xi^0}|B/(E_{\Xi^0} + m_{\Xi^0})$ ; here  $E_{\Xi^0}$  and  $\vec{p}_{\Xi^0}$  are the energy and momentum of the  $\Xi^0$  in the  $\Lambda_c^+$  rest frame [2]. The effect of the  $S$ - and  $P$ -wave phase shift difference,  $\delta_p - \delta_s$ , is not well accounted for in the theoretical calculations of decay asymmetries. It can be extracted from experiments combined with the BF cited from the Particle Data Group (PDG) [2] and provides an important experimental parameter for the theoretical prediction of  $CP$  violation [16].

In this Letter, we present the first measurement of the decay asymmetry of  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  and its decay dynamic parameters ( $|A|$ ,  $|B|$ , and  $\delta_p - \delta_s$ ). A multidimensional angular analysis of the cascade-decay  $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ ,  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ ,  $\Xi^0 \rightarrow \Lambda \pi^0$ , and  $\Lambda \rightarrow p \pi^-$  is performed using a technique similar to that used to measure the asymmetry parameters of  $\Lambda_c^+ \rightarrow p K_S^0$ ,  $\Lambda \pi^+$ ,  $\Sigma^+ \pi^0$ , and  $\Sigma^0 \pi^+$  [17]. The data samples used in this analysis, with an integrated luminosity of  $4.4 \text{ fb}^{-1}$  [18], were collected at center-of-mass (CM) energies of 4.60, 4.63, 4.64, 4.66, 4.68, and 4.70 GeV with the BESIII detector at the BEPCII collider. Details about BEPCII as well as BESIII and its sub-detectors – a helium-based multilayer drift chamber (MDC), a plastic scintillator time-of-flight system (TOF), and a CsI(Tl) electromagnetic calorimeter (EMC) – can be found in Refs. [19–23]. Large data samples taken around the  $\Lambda_c^+ \bar{\Lambda}_c^-$  production threshold allow to measure decay asymmetry of low BF decays with the single-tag technique. The low-background environment is more favorable to measure  $\alpha_{\Xi^0 K^+}$  accurately. Charge-conjugate modes are always implied unless explicitly stated otherwise.

Simulated event samples produced with a GEANT4-based [24] Monte Carlo (MC) package, which provides the geometric description of the BESIII detector and the detector response, are used to determine detection efficiencies and to estimate backgrounds. The simulation

TABLE I. Theoretical calculations and experimental measurements of the BF,  $\alpha_{\Xi^0 K^+}$ ,  $|A|$ ,  $|B|$  and  $\delta_p - \delta_s$  of  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ .  $G_F$  is the Fermi constant. The superscript  $a$  denotes a model with SU(3) symmetry, while model  $b$  includes SU(3) symmetry-breaking effects. The PDG Fit BF also includes a CLEO result on  $\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+)/\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+)$  [2].

Theory or experiment	$\mathcal{B}(\Lambda_c^+ \rightarrow \Xi^0 K^+)$ ( $\times 10^{-3}$ )	$\alpha_{\Xi^0 K^+}$	$ A $ ( $\times 10^{-2} G_F \text{ GeV}^2$ )	$ B $ ( $\times 10^{-2} G_F \text{ GeV}^2$ )	$\delta_p - \delta_s$ (rad)
Körner (1992), CCQM [7]	2.6	0	-	-	-
Xu (1992), Pole [8]	1.0	0	0	7.94	-
Żencaykowski (1994), Pole [9]	3.6	0	-	-	-
Ivanov (1998), CCQM [10]	3.1	0	-	-	-
Sharma (1999), CA [11]	1.3	0	-	-	-
Geng (2019), SU(3) [12]	$5.7 \pm 0.9$	$0.94_{-0.11}^{+0.06}$	$2.7 \pm 0.6$	$16.1 \pm 2.6$	-
Zou (2020), CA [6]	7.1	0.90	4.48	12.10	-
Zhong (2022), SU(3) <sup>a</sup> [13]	$3.8_{-0.5}^{+0.4}$	$0.91_{-0.04}^{+0.03}$	$3.2 \pm 0.2$	$8.7_{-0.8}^{+0.6}$	-
Zhong (2022), SU(3) <sup>b</sup> [13]	$5.0_{-0.9}^{+0.6}$	$0.99 \pm 0.01$	$3.3_{-0.7}^{+0.5}$	$12.3_{-1.8}^{+1.2}$	-
BESIII (2018) [14]	$5.90 \pm 0.86 \pm 0.39$	-	-	-	-
PDG Fit (2022) [2]	$5.5 \pm 0.7$	-	-	-	-

models the beam energy spread and initial state radiation (ISR) in the  $e^+e^-$  annihilations with the generator KKMC [26, 27]. The inclusive MC sample includes the production of open charm processes, the ISR production of vector charmonium(-like) states, and the continuum processes incorporated in KKMC. All particle decays are modelled with EVTGEN [28, 29] using BFs either taken from the PDG [2], when available, or otherwise estimated with LUNDCHARM [30, 31]. Final state radiation from charged final state particles is incorporated using the PHOTOS package [32]. The phase space MC sample is generated uniformly over phase space, which is  $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$  followed by  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ ,  $\Xi^0 \rightarrow \Lambda(\rightarrow p\pi^-)\pi^0(\rightarrow \gamma\gamma)$  and  $\bar{\Lambda}_c^-$  decaying inclusively. For the signal MC sample, the signal process is generated by the helicity formalism using the decay asymmetry parameters measured in this work or cited from the PDG [2].

The tracks of  $K^+$  candidates detected in the MDC are required to be within a polar angle ( $\theta$ ) range of  $|\cos\theta| < 0.93$ , where  $\theta$  is defined with respect to the  $z$  axis, which is the symmetry axis of the MDC. Besides, the distance of the closest approach to the interaction point (IP) must be less than 10 cm along the  $z$  axis,  $|V_z|$ , and less than 1 cm in the transverse plane,  $|V_{xy}|$ . The particle identification (PID) combining the  $dE/dx$  information from the MDC and the flight time from the TOF is implemented to evaluate the likelihoods  $\mathcal{L}(h)$  ( $h = \pi, K, p$ ) for different hadron hypotheses. Charged tracks satisfying  $\mathcal{L}(K) > \mathcal{L}(\pi)$ , and  $\mathcal{L}(K) > 0$  are assigned as kaon candidates.

The  $\pi^0$  candidates are formed by photon pairs with an invariant mass in the interval  $0.115 < M_{\gamma\gamma} < 0.150 \text{ GeV}/c^2$ . The  $\gamma$  candidates are reconstructed from showers in the EMC that are not associated with any charged track. The deposited energy must be larger than

25 MeV in the barrel region ( $|\cos\theta| < 0.80$ ) or 50 MeV in the end cap region ( $0.86 < |\cos\theta| < 0.92$ ). To suppress electronic noise and showers unrelated to the event, the difference between the EMC time and the event start time is required to be within  $[0, 700]$  ns. A mass-constrained fit to the known  $\pi^0$  mass [2] is applied to the photon pair and the resulting energy and momentum of the  $\pi^0$  is used for further analysis.

The  $\Lambda$  candidates are obtained from two oppositely charged tracks in the final states  $p\pi^-$ . Their distance of closest approaches to the IP must be within  $\pm 20$  cm along the beam direction. In order to improve signal purity, the proton PID is required to satisfy  $\mathcal{L}(p) > \mathcal{L}(K)$ ,  $\mathcal{L}(p) > \mathcal{L}(\pi)$  and  $\mathcal{L}(p) > 0$ . The two daughter tracks are constrained to originate from a common decay vertex by requiring the vertex fit  $\chi^2$  to be less than 20. The momentum of the  $\Lambda$  corrected by the vertex fit is used in subsequent analysis. Furthermore, the distance of the  $\Lambda$  decay vertex from the IP is required to be greater than twice the fitted vertex resolution. The  $p\pi^-$  invariant mass is required to lie in the  $\Lambda$  mass region (1.111, 1.121)  $\text{GeV}/c^2$ . The  $\Xi^0$  candidates are formed by  $\Lambda\pi^0$  combinations and the invariant mass  $M_{\Lambda\pi^0}$  must be within the mass region (1.30, 1.33)  $\text{GeV}/c^2$ . These mass regions are selected to be about three times the resolution.

Two kinematic variables, the energy difference  $\Delta E \equiv E_{\Lambda_c^+} - E_{\text{beam}}$  and the beam-constrained mass  $M_{\text{BC}} \equiv \sqrt{E_{\text{beam}}^2/c^4 - |\vec{p}_{\Lambda_c^+}|^2/c^2}$ , are defined to identify  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  candidates. Here,  $E_{\Lambda_c^+}$  and  $\vec{p}_{\Lambda_c^+}$  are the reconstructed energy and momentum of the  $\Lambda_c^+$  candidates calculated in the  $e^+e^-$  rest frame, and  $E_{\text{beam}}$  is the average energy of the  $e^+$  and  $e^-$  beams. All candidates are required to satisfy  $-0.05 < \Delta E < 0.05 \text{ GeV}$  and

$2.25 \text{ GeV}/c^2 < M_{\text{BC}} < E_{\text{beam}}$ . If more than one candidate satisfies the above requirements, the one with minimal  $|\Delta E|$  is kept. After applying these conditions, the  $M_{\text{BC}}$  distribution in data collected at 4.60 GeV is shown in the Fig. 2. In the fit to this data, the correctly and mis-reconstructed signal shapes are modeled with the MC-simulated shape convolved with a Gaussian function representing the resolution difference between data and MC simulation, and the background shape is described by an ARGUS function [33]. Finally,  $378 \pm 21$  signal events are obtained by combining the six energy points.

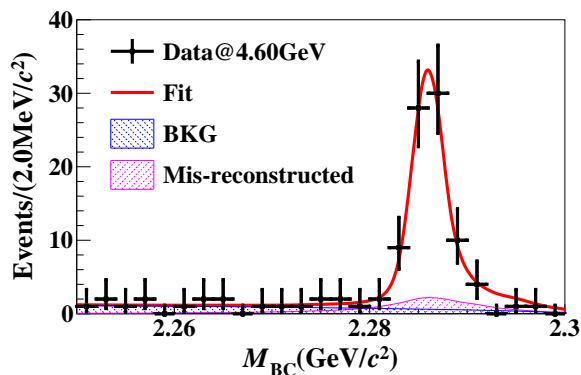


FIG. 2. Distribution of the  $M_{\text{BC}}$  fitting result at 4.60 GeV. Black points with error bars are data; the blue shaded region indicates the combinatorial background events and pink shaded region is the mis-reconstructed signal events.

The decay asymmetry parameters are determined by analyzing the multi-dimensional angular distributions, where the full cascade-decay chain is considered. The joint angular formula is obtained using helicity basis [34]. Figure 3 illustrates the definitions of the helicity angles for the three-level cascade decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ ,  $\Xi^0 \rightarrow \Lambda \pi^0$ , and  $\Lambda \rightarrow p \pi^-$  following the process of  $e^+ e^- \rightarrow \gamma^* \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ . In the helicity frame of the  $e^+ e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ ,  $\theta_0$  is the polar angle of the  $\Lambda_c^+$  with respect to the  $e^+$  beam axis in the  $e^+ e^-$  CM system. For the  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  decay,  $\phi_1$  is the angle between the  $e^+ \Lambda_c^+$  and  $\Xi^0 K^+$  planes, and  $\theta_1$  is the polar angle of the  $\Xi^0$  momentum in the  $\Lambda_c^+$  rest frame with respect to the  $\Lambda_c^+$  momentum in the CM frame. For the  $\Xi^0 \rightarrow \Lambda \pi^0$  decay,  $\phi_2$  is the angle between the  $\Xi^0 K^+$  and  $\Lambda \pi^0$  planes, and  $\theta_2$  is the polar angle of the  $\Lambda$  momentum with respect to the  $\Xi^0$  momentum in the rest frame of  $\Lambda_c^+$ . For the helicity angles describing the  $\Lambda \rightarrow p \pi^-$  decay,  $\phi_3$  is the angle between the  $\Lambda \pi^0$  and  $p \pi^-$  planes, and  $\theta_3$  is the polar angle of the proton with respect to the  $\Lambda$  momentum in the  $\Xi^0$  rest frame.

In Ref. [34],  $\Delta_0$  is defined as the phase shift between two individual helicity amplitudes,  $\mathcal{H}_{\lambda_1, \lambda_2}$ , for the  $\Lambda_c^+$  production process  $\gamma^* \rightarrow \Lambda_c^+(\lambda_1) \bar{\Lambda}_c^-(\lambda_2)$  with total helicities  $|\lambda_1 - \lambda_2| = 0$  and 1, respectively. In the case where one-photon exchange dominates the production process,  $\Delta_0$  is also the phase between the

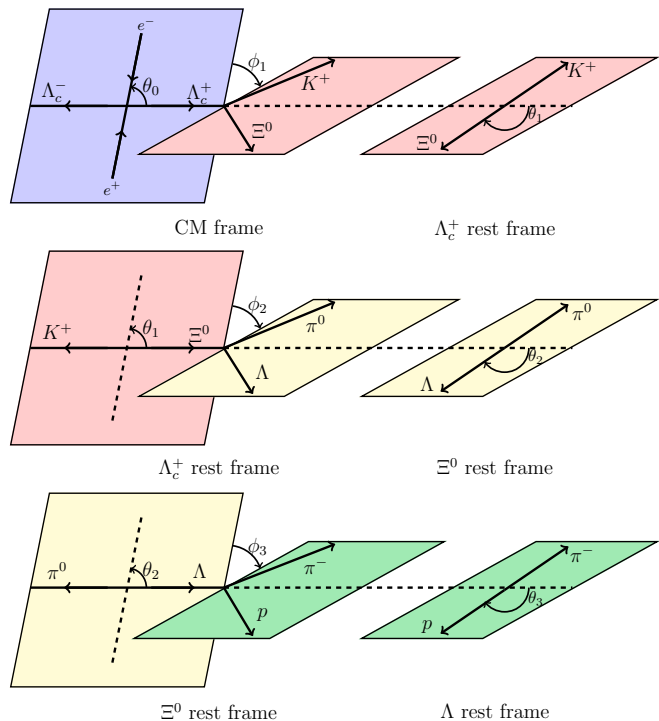


FIG. 3. Definitions of the helicity frames and related angles for  $e^+ e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$ ,  $\Lambda_c^+ \rightarrow \Xi^0 K^+$ ,  $\Xi^0 \rightarrow \Lambda \pi^0$ , and  $\Lambda \rightarrow p \pi^-$ .

electric and magnetic form factors of  $\Lambda_c^+$  [35, 36], and  $\alpha_0$  is the angular distribution parameter of  $\Lambda_c^+$  defined by the helicity amplitude  $\alpha_0 = (|\mathcal{H}_{1/2, -1/2}|^2 - 2|\mathcal{H}_{1/2, 1/2}|^2) / (|\mathcal{H}_{1/2, -1/2}|^2 + 2|\mathcal{H}_{1/2, 1/2}|^2)$ . Similarly, the  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  decay is described by two parameters,  $\alpha_{\Xi^0 K^+}$  and  $\Delta_{\Xi^0 K^+}$ , where the latter one is the phase shift between the two helicity amplitudes. The Lee-Yang parameters [34, 37] can be obtained with the relations

$$\begin{aligned} \beta_{\Xi^0 K^+} &= \sqrt{1 - (\alpha_{\Xi^0 K^+})^2} \sin \Delta_{\Xi^0 K^+}, \\ \gamma_{\Xi^0 K^+} &= \sqrt{1 - (\alpha_{\Xi^0 K^+})^2} \cos \Delta_{\Xi^0 K^+}. \end{aligned} \quad (1)$$

In this analysis, the common free parameters ( $\alpha_{\Xi^0 K^+}$  and  $\Delta_{\Xi^0 K^+}$ ) describing the angular distributions for the six data sets are determined by a simultaneous unbinned maximum likelihood fit. The likelihood function is constructed from the joint probability density function (PDF) by

$$\mathcal{L}_{\text{total}} = \sum_{\text{energy}} \mathcal{L}_{\text{data}} = \prod_{i=1}^{N_{\text{data}}} f_s(\vec{\xi}_i). \quad (2)$$

Here,  $f_s(\vec{\xi}_i)$  is the PDF of the signal process,  $N_{\text{data}}$  is the number of events in data and  $i$  is the event index. The

signal PDF  $f_s(\vec{\xi}_i)$  is formulated as

$$f_s(\vec{\xi}_i) = \frac{\epsilon(\vec{\xi}_i)|M(\vec{\xi}_i; \vec{\eta})|^2}{\int \epsilon(\vec{\xi}_i)|M(\vec{\xi}_i; \vec{\eta})|^2 d\vec{\xi}_i}, \quad (3)$$

where  $\vec{\xi}_i$  denotes the kinematic angular observables ( $\theta_{0,1,2,3}$  and  $\phi_{1,2,3}$ ) and  $\vec{\eta}$  denotes the free parameters ( $\alpha_{\Xi^0 K^+}$  and  $\Delta_{\Xi^0 K^+}$ ) to be determined. The  $M(\vec{\xi}_i; \vec{\eta})$  is the total decay amplitude [34] and  $\epsilon(\vec{\xi}_i)$  is the detection efficiency parameterized in terms of the kinematic variables  $\xi_i$ . The background contribution to the joint likelihood is subtracted according to the calculated likelihoods for the combinatorial background based on the inclusive MC simulation and for the mis-reconstructed signal events based on the signal MC simulation. The integration of the normalization factor is calculated with a large phase space MC sample as

$$\int \epsilon(\vec{\xi}_i)|M(\vec{\xi}_i; \vec{\eta})|^2 d\vec{\xi}_i = \frac{1}{N_{\text{gen}}} \sum_{k_{\text{MC}}}^{N_{\text{MC}}} |M(\vec{\xi}_{k_{\text{MC}}}; \vec{\eta})|^2, \quad (4)$$

where  $N_{\text{gen}}$  is the total number of the simulated phase space MC events,  $N_{\text{MC}}$  is the number of the phase space MC events surviving all selection criteria and  $k_{\text{MC}}$  is the event index.

Using the MINUIT package [38], we minimize the negative logarithmic likelihood with background subtraction over the six data samples. Here,  $\alpha_0$ ,  $\Delta_0$ ,  $\alpha_{\Lambda\pi^0}$ ,  $\alpha_{\bar{\Lambda}\pi^0}$ ,  $\Delta_{\Lambda\pi^0}$ , and  $\Delta_{\bar{\Lambda}\pi^0}$  are fixed to individual values measured by BESIII [39, 40],  $\alpha_{p\pi^-}$  and  $\alpha_{\bar{p}\pi^+}$  are fixed to the values from the PDG [2]. In the fit,  $\alpha_{\Xi^0 K^+}$  and  $\Delta_{\Xi^0 K^+}$  are free parameters, and  $\alpha_{\Xi^0 K^+} = -\alpha_{\bar{\Xi}^0 K^-}$  and  $\Delta_{\Xi^0 K^+} = -\Delta_{\bar{\Xi}^0 K^-}$  as required under the  $CP$  invariance assumption. The projections of the best fit onto several variables are shown in Fig. 4. The data are compared with the MC events weighted by the nominal fitting result. From this fit, we obtain  $\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16$  and  $\Delta_{\Xi^0 K^+} = 3.84 \pm 0.90$  rad. Hence, the other two Lee-Yang parameters are calculated to be  $\beta_{\Xi^0 K^+} = -0.64 \pm 0.69$  and  $\gamma_{\Xi^0 K^+} = -0.77 \pm 0.58$ , where the uncertainties are statistical only.

The systematic uncertainties arise mainly from the reconstruction of final state particles, which is studied with  $J/\psi \rightarrow K_s^0 K^\pm \pi^\mp$  for kaon,  $\Lambda_c^+ \rightarrow \Lambda X$  for  $\Lambda$ ,  $\psi(3686) \rightarrow J/\psi \pi^0 \pi^0$  and  $e^+e^- \rightarrow \omega \pi^0$  for  $\pi^0$ . For  $\Delta E$  requirement and  $M_{\text{BC}}$  signal regions, which are estimated by smearing the phase space MC samples using resolution parameters. For the background subtraction, which is taking into account the background shape and size. The uncertainties from the quoted values of  $\alpha_0$ ,  $\Delta_0$ ,  $\alpha_{\Lambda\pi^0}$ ,  $\alpha_{\bar{\Lambda}\pi^0}$ ,  $\Delta_{\Lambda\pi^0}$ ,  $\Delta_{\bar{\Lambda}\pi^0}$ ,  $\alpha_{p\pi^-}$  and  $\alpha_{\bar{p}\pi^+}$  are estimated by Gaussian sampling considered their uncertainties and refit the angular distribution, and take the values in one time uncertainty of Gaussian fit as the uncertainties of this part. The fit bias, which is

the difference before and after the correction from pull distribution check. Systematic uncertainties from all sources are combined in quadrature to calculate the total systematic uncertainties. All systematic uncertainties are summarized in Table II and the relevant details can be found in Ref. [34].

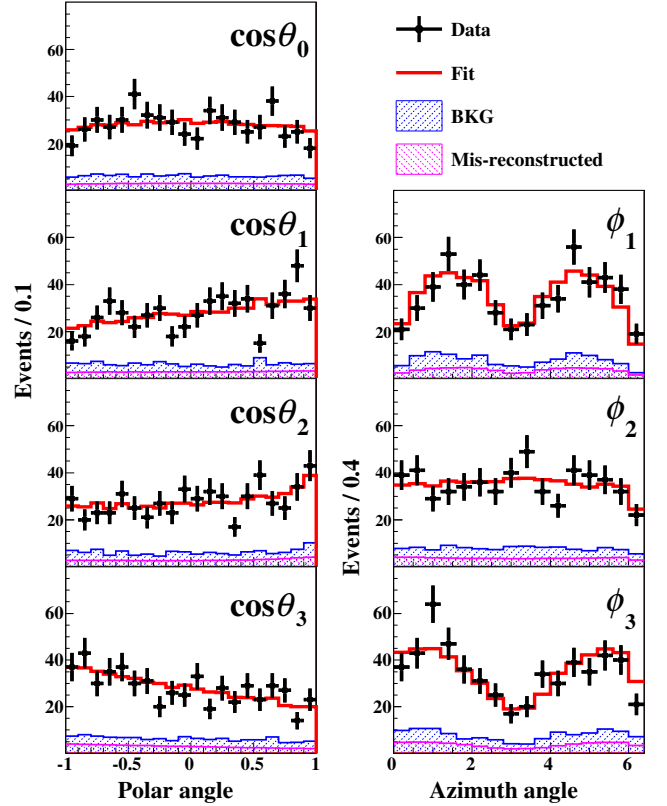


FIG. 4. Projections of the best fit onto various variables. Black points with error bars are data; red solid lines are phase space MC events re-weighted by angular distribution formula, and represent the fitting result; the blue shaded region denotes the combinatorial background events and the pink shaded region is the mis-reconstructed signal events.

TABLE II. Systematic uncertainties in  $\alpha_{\Xi^0 K^+}$  and  $\Delta_{\Xi^0 K^+}$ .

Source	$\alpha_{\Xi^0 K^+}$	$\Delta_{\Xi^0 K^+}$ [rad]
Tracking and PID efficiencies	negligible	negligible
$\pi^0$ reconstruction	negligible	negligible
$\Lambda$ reconstruction	0.01	0.01
$\Delta E$ and $M_{\text{BC}}$ signal regions	negligible	negligible
Background subtraction	0.03	0.08
Input parameters	0.01	0.14
Fit bias	negligible	0.05
Total	0.03	0.17

The  $\delta_p - \delta_s$  can be expressed by  $\delta_p - \delta_s =$

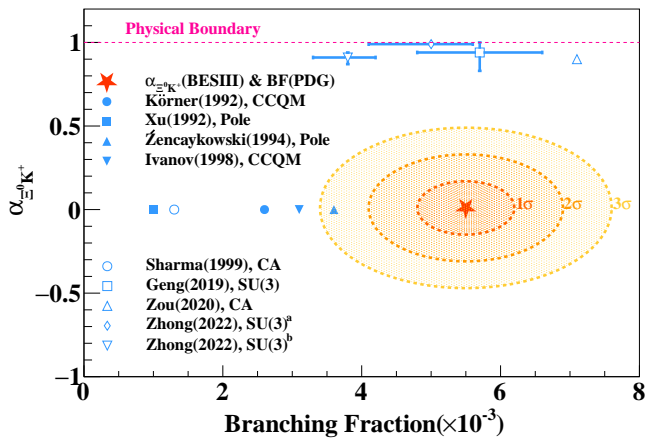


FIG. 5. The comparison between this work and theoretical predictions, where the branching fraction is taken from PDG (2022) [2]. The blue symbols are theoretical predictions and the red star is result from this work. The definitions of the superscripts *a* and *b* can be found in Table I and the theory acronyms are explained in the text.

$\arctan(\sqrt{1 - \alpha_{\Xi^0 K^+}^2} \sin \Delta_{\Xi^0 K^+} / \alpha_{\Xi^0 K^+})$  and the derivation of  $|A|$  and  $|B|$  can be found in Ref. [34]. The study has uncovered two distinct physical solutions, with one group characterized by  $|A| = 1.6_{-1.6}^{+1.9}(\text{stat.}) \pm 0.4(\text{syst.})$  and  $|B| = 18.3 \pm 2.8(\text{stat.}) \pm 0.7(\text{syst.})$ , and the other by  $|A| = 4.3 \pm 0.7(\text{stat.}) \pm 0.2(\text{syst.})$  and  $|B| = 6.7_{-6.7}^{+8.3}(\text{stat.}) \pm 1.6(\text{syst.})$ .

In summary, by analyzing  $4.4 \text{ fb}^{-1}$  of  $e^+e^-$  annihilation data collected at the CM energies between 4.60 and 4.70 GeV with the BESIII detector, the pure  $W$ -exchange decay  $\Lambda_c^+ \rightarrow \Xi^0 K^+$  from the  $e^+e^- \rightarrow \Lambda_c^+ \bar{\Lambda}_c^-$  production has been studied. The decay asymmetry parameters are measured for the first time as  $\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16(\text{stat.}) \pm 0.03(\text{syst.})$  and  $\Delta_{\Xi^0 K^+} = 3.84 \pm 0.90(\text{stat.}) \pm 0.17(\text{syst.})$  rad. The other two Lee-Yang parameters are calculated to be  $\beta_{\Xi^0 K^+} = -0.64 \pm 0.69(\text{stat.}) \pm 0.13(\text{syst.})$  and  $\gamma_{\Xi^0 K^+} = -0.77 \pm 0.58(\text{stat.}) \pm 0.11(\text{syst.})$ . The comparison between this work and theoretical predictions is shown in Fig. 5. Our measurement of  $\alpha_{\Xi^0 K^+}$  is in good agreement with zero, which is consistent with the theoretical predictions from the 1990s. The decay dynamics parameters  $|A|$ ,  $|B|$ , and  $\delta_p - \delta_s$  are derived. The value of  $\delta_p - \delta_s$  is observed to be  $-1.55 \pm 0.25(\text{stat.}) \pm 0.05(\text{syst.})$ . This is of great significance for decay asymmetries, as  $\cos(\delta_p - \delta_s)$  measured in this study is close to zero, an effect that had not been anticipated in previous literature. This measurement fills the long-standing puzzle and deepens our understanding of the strong dynamics in charmed baryon sector.

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- [1] G. S. Abrams, M. S. Alam, C. A. Blocker, A. Boyarski, M. Breidenbach, D. L. Burke, W. C. Carithers, W. Chinowsky, M. W. Coles and S. Cooper, *et al. Phys. Rev. Lett.* **44**, 10 (1980).
  - [2] R. L. Workman *et al.* (Particle Data Group), *PTEP* **2022**, 083C01 (2022).
  - [3] H. Y. Cheng, *Chin. J. Phys.* **78**, 324 (2022).
  - [4] H. Y. Cheng, *Sci. Bull.* **67**, 445 (2022).
  - [5] F. S. Yu, H. Y. Jiang, R. H. Li, C. D. Lü, W. Wang and Z. X. Zhao, *Chin. Phys. C* **42**, 051001 (2018).
  - [6] J. Zou, F. Xu, G. Meng and H. Y. Cheng, *Phys. Rev. D* **101**, 014011 (2020).
  - [7] J. G. Körner and M. Kramer, *Z. Phys. C* **55**, 659 (1992).
  - [8] Q. P. Xu and A. N. Kamal, *Phys. Rev. D* **46**, 270 (1992).
  - [9] P. Zenczykowski, *Phys. Rev. D* **50**, 5787 (1994).
  - [10] M. A. Ivanov, J. G. Körner, V. E. Lyubovitskij and A. G. Rusetsky, *Phys. Rev. D* **57**, 5632 (1998).



- [11] K. K. Sharma and R. C. Verma, *Eur. Phys. J. C* **7**, 217 (1999).
- [12] C. Q. Geng, C. W. Liu and T. H. Tsai, *Phys. Lett. B* **794**, 19 (2019).
- [13] H. Zhong, F. Xu, Q. Wen and Y. Gu, *JHEP* **02**, 235 (2023).
- [14] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Lett. B* **783**, 200 (2018).
- [15] S. Groote and J. G. Körner, *Eur. Phys. J. C* **82**, 297 (2022).
- [16] J. P. Wang and F. S. Yu, [arXiv:2208.01589 \[hep-ph\]](https://arxiv.org/abs/2208.01589)
- [17] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **100**, 072004 (2019).
- [18] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **46**, no.11, 113003 (2022).
- [19] M. Ablikim *et al.* (BESIII Collaboration), *Nucl. Instrum. Meth. A* **614**, 345 (2010).
- [20] C. H. Yu *et al.*, *Proceedings of IPAC2016, Busan, Korea, 2016*.
- [21] M. Ablikim *et al.* (BESIII Collaboration), *Chin. Phys. C* **44**, 040001 (2020).
- [22] J. W. Zhang, L. H. Wu, S. S. Sun, J. H. Zou, C. X. Liu, Z. Y. Deng, Q. M. Ma, S. P. Wen, G. F. Cao and B. L. Zhang, *et al. Rad. Det. Tech. Meth.* **6**, no.3, 289-293 (2022).
- [23] X. Li *et al.*, *Rad. Det. Tech. Meth.* **1**, 13 (2017); Y. X. Guo *et al.*, *Rad. Det. Tech. Meth.* **1**, 15 (2017); P. Cao *et al.*, *Nucl. Instrum. Meth. A* **953**, 163053 (2020).
- [24] S. Agostinelli *et al.* (GEANT4 Collaboration), *Nucl. Instrum. Meth. A* **506**, 250 (2003).
- [25] K. X. Huang, Z. J. Li, Z. Qian, J. Zhu, H. Y. Li, Y. M. Zhang, S. S. Sun and Z. Y. You, *Nucl. Sci. Tech.* **33**, 142 (2022).
- [26] S. Jadach, B. F. L. Ward and Z. Was, *Phys. Rev. D* **63**, 113009 (2001).
- [27] S. Jadach, B. F. L. Ward and Z. Was, *Comput. Phys. Commun.* **130**, 260 (2000).
- [28] D. J. Lange, *Nucl. Instrum. Meth. A* **462**, 152 (2001).
- [29] R. G. Ping, *Chin. Phys. C* **32**, 599 (2008).
- [30] J. C. Chen, G. S. Huang, X. R. Qi, D. H. Zhang and Y. S. Zhu, *Phys. Rev. D* **62**, 034003 (2000).
- [31] R. L. Yang, R. G. Ping and H. Chen, *Chin. Phys. Lett.* **31**, 061301 (2014).
- [32] E. Richter-Was, *Phys. Lett. B* **303**, 163 (1993).
- [33] H. Albrecht *et al.* [ARGUS], *Phys. Lett. B* **241**, 278-282 (1990).
- [34] See Supplemental Material at <http://link.aps.org/supplemental/10.11xx/PhysRev.1xx.0xxxxx> for the Lee-Yang parameters, joint angular distribution formula, details of the systematic uncertainties, and the relation with weak decay amplitude.
- [35] G. Fäldt, *Phys. Rev. D* **97**, 053002 (2018).
- [36] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. Lett.* **120**, 132001 (2018).
- [37] T. D. Lee and C. N. Yang, *Phys. Rev.* **108**, 1645 (1957).
- [38] F. James and M. Roos, *Comput. Phys. Commun.* **10**, 343 (1975).
- [39] M. Ablikim *et al.* (BESIII Collaboration), [arXiv:2307.07316 \[hep-ex\]](https://arxiv.org/abs/2307.07316)
- [40] M. Ablikim *et al.* (BESIII Collaboration), *Phys. Rev. D* **108**, no.3, L031106 (2023)