Observation of $\Lambda_c^+ \to \Lambda a_0(980)^+$ and Evidence for $\Sigma(1380)^+$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$

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Based on 6.1 fb^{-1} of e^+e^- annihilation data collected at center-of-mass energies from 4.600 to 4.843 GeV with the BESIII detector at the BEPCII collider, a partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\eta$ is performed, and branching fractions and decay asymmetry parameters of intermediate processes are determined. The process $\Lambda_c^+ \to \Lambda a_0(980)^+$ is observed for the first time, and evidence for the pentaquark candidate $\Sigma(1380)^+$ decaying into $\Lambda\pi^+$ is found with statistical significance larger than 3σ with mass and width fixed to theoretical predictions. The branching fraction product $\mathcal{B}[\Lambda_c^+ \to \Lambda a_0(980)^+]\mathcal{B}[a_0(980)^+ \to \pi^+\eta]$ is determined to be $(1.05 \pm 0.16_{\rm stat} \pm 0.05_{\rm syst} \pm 0.07_{\rm ext})\%$, which is larger than theoretical calculations by 1–2 orders of magnitude. Here the third (external) systematic is from $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta)$. Finally, we precisely obtain the absolute branching fraction $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta) = (1.94 \pm 0.07_{\rm stat} \pm 0.11_{\rm syst})\%$.

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Apart from the traditional bound states like mesons and baryons, the quark model [1,2] allows for more complex structures such as tetraquarks, pentaquarks, hybrids, glueballs, and hadronic molecular states. For the studies of these exotic states, many important achievements have been made [3–9], especially in quarkonium, D meson, and B meson decays. Studies of baryon decays are relatively rare, except for studies of Λ_b^0 decays into P_c or $X(3872)$ states by the LHCb experiment [10–12]. Replacing the b quark with a c quark, the much lighter charm baryons lie at the boundary between perturbative and nonperturbative regions. Given the very interesting results already achieved in the first studies of heavy exotic states in bottom baryon decays, studies using charm baryon decays provide a new and exciting opportunity to probe lighter exotic states.

The exact nature of the scalar meson $a_0(980)^+$ remains elusive, with various interpretations proposed. These include a conventional $q\bar{q}$ meson [13,14], a compact tetraquark [15,16], a superposition of both [17], or a dynamically generated threshold effect [18–22]. Reference [23] adopted the compact tetraquark assumption to study the $\Lambda_c^+ \to \Lambda a_0(980)^+$ decay, as the $q\bar{q}$ picture failed to explain the measured $\mathcal{B}[\Lambda_c^+ \to p f_0(980)]$ [24], where the $f_0(980)$ is regarded as the scalar octet partner of $a_0(980)^+$ in the $q\bar{q}$ model. The $\Lambda_c^+ \to \Lambda a_0(980)^+$ branching fraction (BF) was calculated to be 1.9×10^{-4} based on factorization and the pole model, where the pole term was found to dominate over factorizable contributions. In a different perspective, Ref. [25] proposed a significant enhancement of the BF to $(1.7^{+2.8}_{-1.0} \pm 0.3) \times 10^{-3}$ by considering the process $\Lambda_c^+ \to \Sigma(1385)^+\eta$, followed by rescattering $\Sigma(1385)^+\eta \to \Lambda a_0(980)^+$. Here, the calculated $\mathcal{B}[\Lambda_c^+ \to \Sigma(1385)^+\eta]$ in the topological scheme [26] is employed as an input. Contributions from other processes, such as $\Lambda_c^+ \to \Lambda(1670)\pi^+ \to \Lambda a_0(980)^+$ and the triangle singularity enhanced $\Lambda_c^+ \to \Sigma^*\eta(N^*\bar{K}^0) \to \Lambda a_0(980)^+$, are estimated to be less than 1×10^{-3}. Moreover, due to the proximity of the $a_0(980)^+$ pole mass to the $K\bar{K}$ threshold, the $a_0(980)^+$ line shape exhibits a distinct cusp structure, a characteristic feature indicative of its molecular nature [27]. Therefore, the $\Lambda_c^+ \to \Lambda\pi^+\eta$ decay provides a good platform to study the internal structure of $a_0(980)^+$.

The study of low-lying excited baryons with $J^P = 1/2^-$ is crucial in hadron physics [28]. Historically, to address the reverse mass-order reverse of the $N(1535)$ and $\Lambda(1405)$ states, theorists proposed the pentaquark model [29–31] and the meson cloud and molecular model [32,33]. These models predict the lowest $\Sigma^*_{1/2^-}$ resonance around 1380 MeV$/c^2$ [34], close to the $N\bar{K}$ mass threshold [35]. Experimental and theoretical investigations on $\Sigma(1380)^+$ as well as other light pentaquark states containing strange quarks have been conducted in various processes [31,34,36–57]. However, establishing the lowest $\Sigma^*_{1/2^-}$ resonance remains a challenge. The $\Lambda_c^+ \to \Lambda\pi^+\eta$ decay has been highlighted as a golden channel [58,59]. The $\Lambda\pi^+$ mode, representing a pure $I = 1$ combination, excludes influences from Λ^* resonances as compared to the $\Sigma\pi$ and pK modes. Also, the influences from the $\Sigma(1385)^+$ and $\Lambda(1670)$ [60,61] on the $\Sigma(1380)^+$ can be

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distinguished. This is because $\Lambda(1670)$ predominantly affects the high end of the $M(\Lambda\pi^+)$ spectrum, while the $\Sigma(1385)^+$ exhibits a different spin-parity resulting in a distinct angular distribution.

In this Letter, the first partial wave analysis (PWA) of the $\Lambda_c^+ \to \Lambda\pi^+\eta$ decay is performed by using 11 datasets at center-of-mass (c.m.) energies from 4.600 to 4.843 GeV [62–66], where Λ_c^+ is dominantly produced via pair production $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$. There is no sufficient energy for producing additional hadrons below 4.7 GeV, and the process $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-\pi^0$ is highly suppressed between 4.7 and 4.843 GeV. The datasets used are accumulated with the BESIII detector at the BEPCII collider and correspond to an integrated luminosity of 6.1 fb^{-1}. Detailed information about BESIII and BEPCII can be found in Refs. [67–70]. The simulated "inclusive Monte Carlo (MC) sample" is described in Ref. [71]. In the "phase-space (PHSP) signal MC sample" and the "PWA signal MC sample," $\Lambda_c^+ \to \Lambda\pi^+\eta$ decays are simulated with a uniform PHSP distribution and our PWA result, respectively, while the $\bar{\Lambda}_c^-$ decays inclusively. Throughout this Letter, charge-conjugate modes are implied unless explicitly noted.

We use a single-tag (ST) method [72], where the Λ_c^+ is reconstructed via the cascade decays $\Lambda_c^+ \to \Lambda\pi^+\eta, \Lambda \to p\pi^-, \eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$, $\pi^0 \to \gamma\gamma$. The requirements for selecting charged tracks, photon showers, and particle identification (PID) for the proton and pion follow the previous BESIII analysis [71]. To reconstruct Λ candidates, the $p\pi^-$ pairs are constrained to originate from a common vertex by requiring the χ^2 of a vertex fit to be less than 100 and the $p\pi^-$ invariant mass to satisfy $1.08 < M_{p\pi^-} < 1.15\ \text{GeV}/c^2$. To reconstruct $\eta, \pi^0 \to \gamma\gamma$ candidates, the $\gamma\gamma$ invariant mass $M_{\gamma\gamma}$ is required to be within $[0.500, 0.600]\ \text{GeV}/c^2$ ($[0.105, 0.150]\ \text{GeV}/c^2$). To improve the momentum resolution, a one-constraint kinematic fit is performed by constraining $M_{\gamma\gamma}$ to the known η, π^0 masses [73], and the fit χ^2 must be less than 20 (200). The updated momenta are used in further analysis. To reconstruct $\eta \to \pi^+\pi^-\pi^0$ candidates, the $\pi^+\pi^-\pi^0$ invariant mass $M_{\pi^+\pi^-\pi^0}$ is required to be within $(0.500, 0.600)\ \text{GeV}/c^2$. If there are multiple Λ_c^+ combinations in an event, we choose the candidate with the minimum magnitude of the energy difference, defined as $\Delta E \equiv E_{\Lambda_c} - E_{\text{beam}}$, where E_{Λ_c} is the energy of the detected Λ_c^+ candidate in the e^+e^- rest frame, and E_{beam} is the beam energy. Furthermore, the requirement $-0.1 < \Delta E < 0.1$ GeV is imposed.

To further suppress the backgrounds, a boosted decision tree with gradient boosting (BDTG) [74] based on the TMVA package [75] is used. The input variables are ΔE, $M_{p\pi^-}$, the ratio of the Λ decay length to its uncertainty L/σ_L, $M_{\gamma\gamma}$, $M_{\pi^+\pi^-\pi^0}$ (only for $\eta \to \pi^+\pi^-\pi^0$ channel), the cosine of the helicity angle of $\eta, \pi^0 \to \gamma\gamma$ decay, $\cos\theta_{\eta(\pi^0)}$, and the lateral moments of the showers with higher and lower energies $\text{Lat}(\gamma_{\text{High}})$ and $\text{Lat}(\gamma_{\text{Low}})$. The inclusive MC sample is input as the training set, in which the signal and nonsignal processes are tagged as signal and background, respectively. The resultant BDTG scores are required to be greater than 0.95 and 0.97 for the $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ channels, respectively, chosen by optimizing the figure-of-merit $\text{FOM} = (S/\sqrt{S+B})[S/(S+B)]$. Here, S (B) is the number of signal (background) events in the inclusive MC sample whose luminosity is normalized to the data.

An extended unbinned maximum likelihood fit is performed on the beam-constrained mass, $M_{\text{BC}} = \sqrt{E_{\text{beam}}^2 - |\vec{p}|^2}$, distribution [72] of each energy point to obtain the signal yields and purity in data, where $\vec{p}$ is the three-momentum of the ST Λ_c^+ candidate and E_{beam} is the beam energy, both evaluated in the e^+e^- center-of-mass system. The method is the same as Ref. [71], and 1312 ± 45 signal events are obtained with purity of about 80% in the signal regions, as shown in Supplemental Material [76]. The result of the fit to the M_{BC} distribution from the combined $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ channels at 4.682 GeV is shown in Fig. 1, and the results at other energy points are shown in Supplemental Material [76]. The event-by-event sWeight factor is calculated by the sPlot method [81], according to the fit results. The sPlot method is a statistical tool dedicated to the exploration of data samples populated by several sources of events, e.g., signal and background. The sWeight factor as a function of discriminating variable like M_{BC} is designed such that it is normal to signal distribution but orthogonal to background distribution. After applying the sWeight factor, background does not contribute to the extracted signal distribution. In order to improve the momentum resolution, an additional three-constraint kinematic fit is applied, in which the $\Lambda\pi^+\eta$ invariant mass and the recoiled $\bar{\Lambda}_c^-$ mass are constrained to the known Λ_c^+ mass, and the $p\pi^-$ invariant mass is constrained to the known Λ mass [73]. The recoiled $\bar{\Lambda}_c^-$

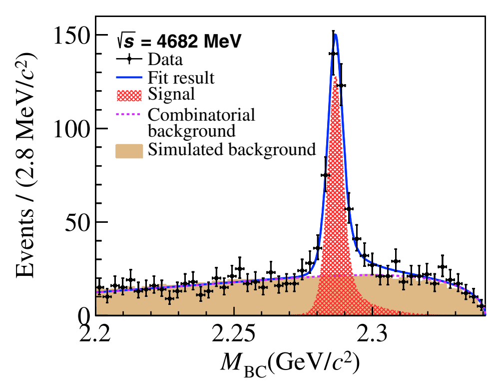

FIG. 1. The fit to the M_{BC} distribution combined from the $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ channels at 4.682 GeV. The points with error bars are data, the brown solid histogram is MC-simulated background, the red hatched histogram is signal, the violet dashed line is background shape, and the blue line is total fit.

momentum is calculated with the momentum of the initial e^+e^- system and $\Lambda\pi^+\eta$ momentum. The updated momenta of the signal candidates from the kinematic fit are used in the PWA.

In the framework of the helicity amplitude formalism [82,83], a PWA is performed by using the open-source framework TF-PWA [84]. The fundamental concepts follow Ref. [71]. In this Letter, the amplitude is defined in the e^+e^- rest frame. The parameters describing the amplitude of the $\Lambda_c^+ \to \Lambda\pi^+\eta$ decay are shared for each energy point. Moreover, the parameters describing the amplitude of the $\bar{\Lambda}_c^-$ decay are related to those of Λ_c^+ via a parity transformation on the $\bar{\Lambda}_c^-$ candidates, under the assumption of CP conservation. The Λ_c^+ polarization components are fixed to $P_z = P_x = 0$, $P_y(\theta_{ee}, \alpha_0, \Delta_0) \propto \sqrt{1-\alpha_0^2}\sin\theta_{ee}\cos\theta_{ee}\sin\Delta_0$ [85]. Here, θ_{ee} is the polar angle of the Λ_c^+ with respect to the e^+ beam in the e^+e^- c.m. system, α_0 is fixed to the values from Refs. [86,87], and Δ_0 is fixed according to polarization results in data. The decay amplitudes of the Λ_c^+ decay are described with sequential helicity amplitudes for cascade quasi-two-body decay and the propagators of intermediate states. For decay chains with resonant intermediate states, the barrier factor term is included. For those with nonresonant (NR) intermediate states, the barrier factor term is omitted.

In the decay amplitude of $\Lambda_c^+ \to \Lambda a_0(980)^+$, $a_0(980)^+ \to \pi^+\eta$, the propagator of the $a_0(980)^+$ is described by the two coupled-channel Flatté model [88]. The nominal mass and coupling constants of the $a_0(980)^+$ decaying to the $\eta\pi$ and $K\bar{K}$ coupled channels are quoted from Ref. [89]. For the NR decay, the dynamical function is set to be unity. In the decay chains of $\Lambda_c^+ \to \Sigma(1385)^+\eta$, $\Sigma(1385)^+ \to \Lambda\pi^+$ and $\Lambda_c^+ \to \Lambda(1670)\pi^+$, $\Lambda(1670) \to \Lambda\eta$, the relativistic Breit-Wigner (RBW) formula [71] is used as the propagator of the $\Sigma(1385)^+$ and $\Lambda(1670)$. The nominal mass and width of the $\Sigma(1385)^+$ are fixed to the corresponding values from the Particle Data Group (PDG) [73], and those of $\Lambda(1670)$ are taken from a recent measurement [90]. The amplitude of $\Lambda \to p\pi^-$ is constrained according to the decay asymmetry α_Λ from the PDG [73]. The full amplitude is the coherent sum of amplitudes of all decay chains, and the alignment D functions are considered to align the helicities of the final state protons [60,91]. The construction of the signal probability density function and the derivations of fit fractions (FFs), interference, and corresponding statistical uncertainties follow the previous BESIII analysis [71]. The negative log-likelihood (NLL) is a sum over of all signal candidates considering the sWeight factor w_i of ith event, $-\ln L = -a\sum_{i\in\text{data}} w_i \ln P(p_i)$ with the normalization factor $a = \sum_{i\in\text{data}} w_i / \sum_{i\in\text{data}} w_i^2$ [92].

To determine the baseline solution of PWA, significant resonances $\Sigma(1385)^+$, $\Lambda(1670)$, and $a_0(980)^+$ are added in the first trial. In the second iteration, other possible components are added one by one. The $\mathcal{S}$ wave $\pi^+\eta$ NR component NR_{0^+} with highest significance is chosen. In the third iteration, the statistical significances of these amplitudes are all greater than 5σ, as shown in Table I, and no other resonant component exceeds this threshold. The statistical significance is calculated from the change of the NLL values with and without including the component, taking into account the change of the number of degrees of freedom (d.o.f.). The fit results projected on different mass spectra are shown in Fig. 2. The fit results for the FFs and decay asymmetry parameters are listed in Table I, where the decay asymmetry parameter arises from the interference between partial wave amplitudes. Using fits to samples from pseudo-experiments, each matched to the data statistics, the pull distribution of each parameter is obtained. We correct the central value and scale the statistical uncertainty for a parameter if its pull distribution deviates significantly from the normal distribution. Since the fitted $\alpha_{\Lambda a_0(980)^+}$ value is very close to its physical limit, an asymmetric statistical uncertainty is derived by scanning the NLL.

Adopting the Breit-Wigner mass and width values of $1380\ \text{MeV}/c^2$ and 120 MeV, respectively, as predicted in Refs. [34,58], the potential pentaquark state $\Sigma(1380)^+$ is investigated in the signal process. In the construction of the baseline solution NR_{0^+} is introduced to better describe data with statistical significance of 6.7σ, while that of the $\Sigma(1380)^+$ is slightly lower. To investigate the statistical significance of $\Sigma(1380)^+$, we construct "model A" [$\Lambda a_0(980)^+$, $\Sigma(1385)^+\eta$, $\Lambda(1670)\pi^+$, $\Sigma(1380)^+\eta$] and "model B" [$\Lambda a_0(980)^+$, $\Sigma(1385)^+\eta$, $\Lambda(1670)\pi^+$, $\Sigma(1380)^+\eta$, ΛNR_{0^+}]. Comparing model A (model B) with and without $\Sigma(1380)^+$, the statistical significance is determined to be 6.1σ (3.3σ) under model assumption of mass and width fixed to Refs. [34,58]. The change in NLL is 24.1 and 9.2 for model A and model B, respectively, while number of d.o.f. changes are both 4. Projections onto the $M_{\Lambda\pi^+}$ spectrum for models A and B are illustrated in Fig. 3 left and middle, while the corresponding results for the FFs are detailed in Table II. Despite the overall significance of NR_{0^+} being higher than that of $\Sigma(1380)^+$, a subtle preference for $\Sigma(1380)^+$ over NR_{0^+} is discerned from the Σ^{*+} helicity angle distribution in the $a_0(980)^+$ signal region, $M_{\Lambda\pi^+} > 1.44$ and $M_{\Lambda\eta} > 1.72\ \text{GeV}/c^2$. The comparison plot is shown in Fig. 3 right, and more details can

TABLE I. Fit fractions, statistical significances $\mathcal{S}$, and decay asymmetry parameters α for different components in the baseline solution. The total FF is 113.9%. The first uncertainty is statistical, and the second is systematic.

Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$-0.91^{+0.18}_{-0.09} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	22.5σ	$-0.61 \pm 0.15 \pm 0.04$
$\Lambda(1670)\pi^+$	$14.1 \pm 2.8 \pm 1.2$	11.7σ	$0.21 \pm 0.27 \pm 0.33$
ΛNR_{0^+}	15.4 ± 5.3	6.7σ	$\cdots$

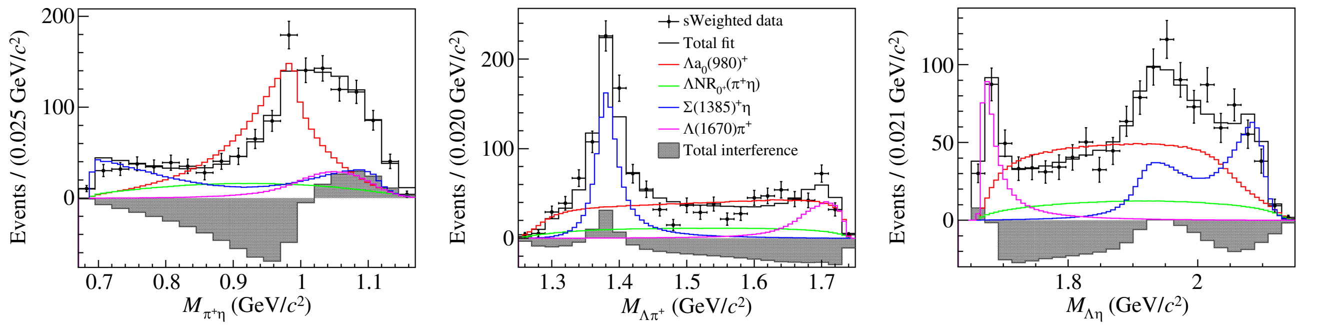

FIG. 2. Projections of the fit results in the $M_{\pi^+\eta}$, $M_{\Lambda\pi^+}$, and $M_{\Lambda\eta}$ spectra. Points with error bars are sWeighted data at all energy points. The curves in different colors are different components.

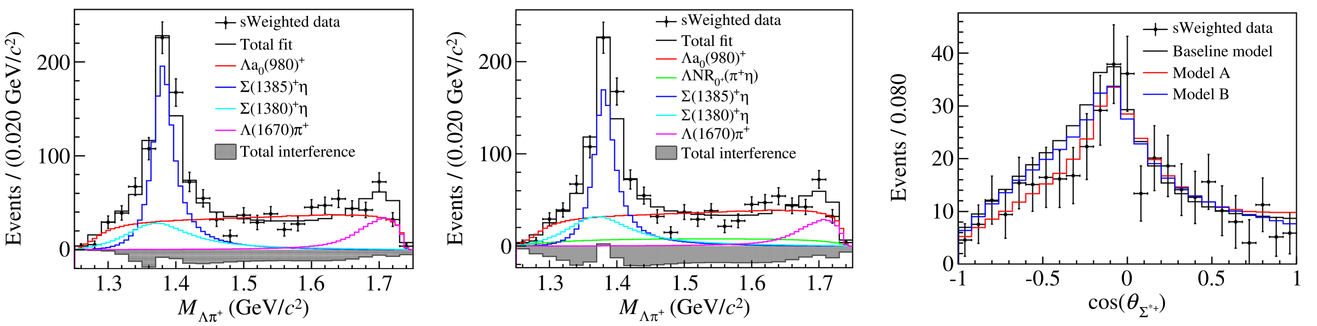

FIG. 3. Left/middle: projections of models A and B on the $M_{\Lambda\pi^+}$ spectrum, respectively, where points with error bars are sWeighted data, and the curves in different colors are different components. Right: projections of the baseline model, models A and B on the Σ^{*+} helicity angle, $\cos\theta_{\Sigma^{*+}}$, with the curve indicating the total fit.

be found in Supplemental Material [76]. Additionally, various models are tested by replacing NR_{0^+} with other excited states such as Σ^{*+}, Λ^*, a_0^+, and a_2^+, while considering systematic uncertainties arising from fixed mass and width parameters, by varying them within $\pm1\sigma$ [34], or float mass and width parameters. In all cases, the calculated statistical significances exceed 3σ. Consequently, this study presents the first evidence for the $\Sigma(1380)^+$.

The line shapes of the $a_0(980)^+$ and $\Lambda(1670)$ are also tested with the final-state-interaction (FSI) model [27], and alternative PWA fits are performed. No significant differences are observed in the results of the RBW and FSI models, but the interference between $a_0(980)^+$ and NR_{0^+} is very large if the Flatté model is replaced by the FSI model. However, if we remove NR_{0^+} and refit the data, there is an obvious discrepancy between data and fit. Details can be found in Supplemental Material [76].

TABLE II. Fit results of FFs and statistical significances for different components in alternative models including $\Sigma(1380)^+$. The total FFs are 115.8% and 119.8% for models A and B, respectively. The uncertainties are statistical only.

Process	Model A	Model B
$\Lambda a_0(980)^+$	$52.9 \pm 4.5(13.4\sigma)$	$50.6 \pm 8.0(11.1\sigma)$
$\Sigma(1385)^+\eta$	$36.6 \pm 2.6(15.8\sigma)$	$31.3 \pm 3.0(14.6\sigma)$
$\Lambda(1670)\pi^+$	$10.7 \pm 1.4(15.0\sigma)$	$9.0 \pm 1.6(11.9\sigma)$
$\Sigma(1380)^+\eta$	$15.5 \pm 4.4(6.1\sigma)$	$17.7 \pm 5.7(3.3\sigma)$
$\Lambda\mathrm{NR}_{0^+}$	$\cdots$	$11.3 \pm 4.4(4.2\sigma)$

In the measurement of the absolute BF of $\Lambda_c^+ \to \Lambda\pi^+\eta$, the selection criteria are almost the same as those used to select the PWA sample except for the requirements of BDTG scores. The requirements of BDTG scores are optimized to be greater than 0.93 and 0.94 for the $\eta \to \gamma\gamma$ and $\eta \to \pi^+\pi^-\pi^0$ channels, respectively, by using an alternative FOM, $S/\sqrt{S+B}$. Extended unbinned maximum likelihood fits are performed to the M_{BC} distribution, simultaneously at each energy point. In the fit, four components are considered, including signal, mismatched background, Λ_c^+ decay backgrounds, which are derived from MC simulation, and combinatorial background modeled with an ARGUS function [93]. A truth-match method [94] is employed to separate signals and mismatched backgrounds. The yield ratios of signals and mismatched backgrounds and Λ_c^+ decay backgrounds are fixed according to MC simulation. The total signal yield is given by $N_{\mathrm{sig}} = 2 \times N_{\Lambda_c^+\bar{\Lambda}_c^-} \times \mathcal{B} \times \mathcal{B}_{\mathrm{inter}} \times \varepsilon$. Here, $N_{\Lambda_c^+\bar{\Lambda}_c^-}$ is the number of $\Lambda_c^+\bar{\Lambda}_c^-$ pairs calculated from the luminosities and cross sections [64,65,86,87], and $\mathcal{B}$ is the BF of the signal decay shared for all c.m. energy points, $\mathcal{B}_{\mathrm{inter}} = \mathcal{B}(\Lambda \to p\pi^-) \cdot \mathcal{B}(\eta \to \gamma\gamma)$ and $\mathcal{B}(\Lambda \to p\pi^-) \cdot \mathcal{B}(\eta \to \pi^+\pi^-\pi^0) \cdot \mathcal{B}(\pi^0 \to \gamma\gamma)$ is the BF of intermediate decays quoted from the PDG [73]. Finally, ε is the average detection efficiency based on PWA signal MC samples in which Λ_c^+ decays follow decay amplitudes with parameters fixed by PWA results: $(13.73 \pm 0.02)\%$ and $(4.83 \pm 0.01)\%$ for the $\eta \to \gamma\gamma$, and $\eta \to \pi^+\pi^-\pi^0$ channels, respectively. The uncertainties are statistical only. The BF is determined to be $(1.94 \pm 0.07)\%$ which is consistent with the previous measurements [60,61,73]. The fit plots can be found in Supplemental Material [76].

The systematic uncertainties on the measurement of the FFs and decay asymmetry parameters include the fixed parameters, barrier radius, additional resonant components, Λ_c^+ polarization, fit method, differences between data and MC simulation, and background descriptions. The total systematic uncertainty on the BF measurement is evaluated to be 5.7% including tracking (0.9%), PID (0.3%), Λ reconstruction (2.6%), η reconstruction (1.0%), BDTG score requirements (1.1%), signal model (2.7%), fit model (0.9%), $\mathcal{B}_{\rm inter}$ (0.9%), $N_{\Lambda_c^+\bar{\Lambda}_c^-}$ (3.9%), and MC statistics (0.4%). Details for both the PWA and BF results can be found in Supplemental Material [76].

In summary, based on 6.1 fb^{-1} of e^+e^- annihilation data collected at the c.m. energy region between 4.600 and 4.843 GeV with the BESIII detector, the first PWA of $\Lambda_c^+ \to \Lambda\pi^+\eta$ is performed. The $\Lambda_c^+ \to \Lambda a_0(980)^+$ decay is observed for the first time, with a statistical significance of 13.1σ, and evidence for the potential pentaquark state $\Sigma(1380)^+$ is found in the $\Lambda\pi^+$ system via a PWA, with a statistical significance larger than 3σ. The BF of $\Lambda_c^+ \to \Lambda\pi^+\eta$ is measured to be $(1.94 \pm 0.07_{\rm stat} \pm 0.01_{\rm syst})\%$, which is consistent with the previous results of BESIII [60] and Belle [61]. The product BF of $\Lambda_c^+ \to \Lambda a_0(980)^+$ and $a_0(980)^+ \to \pi^+\eta$ is calculated to be $(1.05 \pm 0.16 \pm 0.05 \pm 0.07)\%$, where the first and second uncertainties are quoted from those of FF value, while the third is due to $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta)$. Taking $\mathcal{B}[a_0(980)^+ \to \pi^+\eta] = 0.853 \pm 0.014$ [95], the BF of $\Lambda_c^+ \to \Lambda a_0(980)^+$ is determined to be $(1.23 \pm 0.21)\%$, which differs significantly from the theoretical predictions evaluated in Refs. [23,25] by 1–2 orders of magnitude. A comparable scenario has been seen in $D_s^+ \to a_0(980)^{+(0)}\pi^{0(+)}$ decay [96]. Nevertheless, that puzzle can be resolved by accounting for a long-distance contribution [97,98]. However, the BF and line shape evaluated from this long-distance effect fail to adequately describe the experimental data of $\Lambda_c^+ \to \Lambda a_0(980)^+$ decay. Such a large difference between theory and experiment suggests some unknown decay mechanisms. In addition, this large BF implies that Λ_c^+ decays may offer a new window to study the light scalar meson $a_0(980)^+$.

Furthermore, we determine $\mathcal{B}[\Lambda_c^+ \to \Sigma(1385)^+\eta] = (6.78 \pm 0.58 \pm 0.16 \pm 0.47) \times 10^{-3}$ and $\mathcal{B}[\Lambda_c^+ \to \Lambda(1670)\pi^+] \cdot \mathcal{B}[\Lambda(1670) \to \Lambda\eta] = (2.74 \pm 0.54 \pm 0.24 \pm 0.18) \times 10^{-3}$, where the third uncertainty of $\mathcal{B}[\Lambda_c^+ \to \Sigma(1385)^+\eta]$ also includes the uncertainty from $\mathcal{B}[\Sigma(1385)^+ \to \Lambda\pi^+] = (87.5 \pm 1.5)\%$ [73]. The obtained product $\mathcal{B}[\Lambda_c^+ \to \Sigma(1385)^+\eta]$ is consistent with the previous BESIII result [60] within 2σ but differs from the Belle result [61] by over 3σ. The obtained $\mathcal{B}[\Lambda_c^+ \to \Lambda(1670)\pi^+] \cdot \mathcal{B}[\Lambda(1670) \to \Lambda\eta]$ is consistent with the Belle result within 1σ. The $\mathcal{B}[\Lambda_c^+ \to \Sigma(1385)^+\eta]$ measured in this work is in good agreement with recent calculations [26,99], while it differs from the early calculations [100,101] by over 3σ. There is a pure nonfactorizable contribution in $\Lambda_c^+ \to \Sigma(1385)^+\eta$ [26] that is difficult to calculate; our measurement is crucial to calibrate theoretical treatments of this nonfactorizable contribution. Based on the PWA results, the decay asymmetry parameters of these three intermediate processes are determined for the first time. The measured decay asymmetry parameter of $\Lambda_c^+ \to \Sigma(1385)^+\eta$, $-0.61 \pm 0.15 \pm 0.04$, is consistent with $-0.97^{+0.43}_{-0.03}$ evaluated in Ref. [99]. However, that of $\Lambda_c^+ \to \Lambda a_0(980)^+$ is close to -1, which contradicts the small asymmetry estimated in Ref. [23]. This discrepancy might indicate issues in the consideration of $a_0(980)^+$ decay constant or parity-violating transition amplitudes. Our results are essential to improve the current understanding of the dynamics of the hadronic Λ_c^+ decays.

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