BESIII上Λ_c^+强子衰变的研究

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BESIII粲强子物理研讨会

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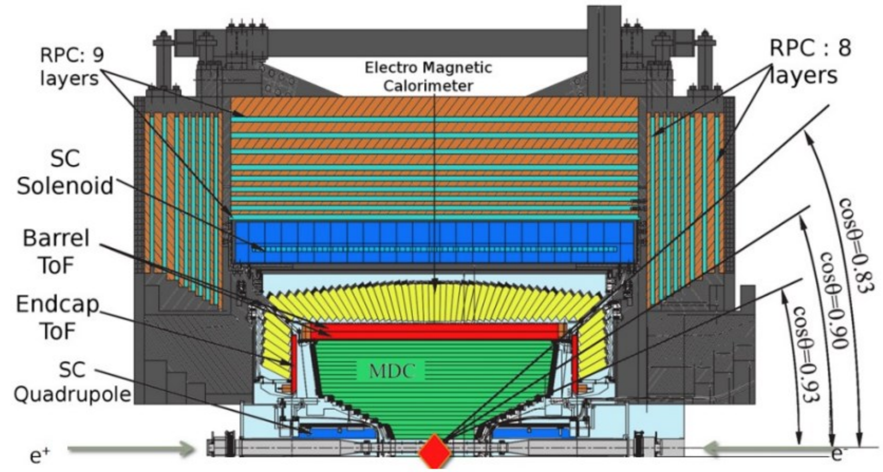
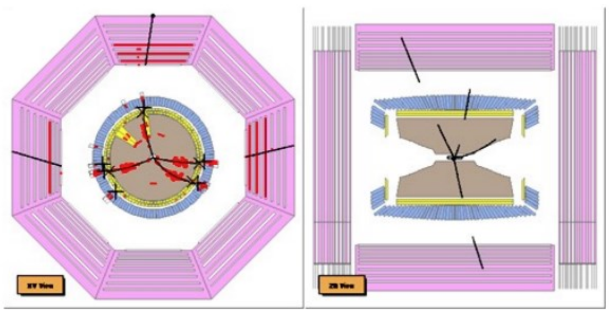
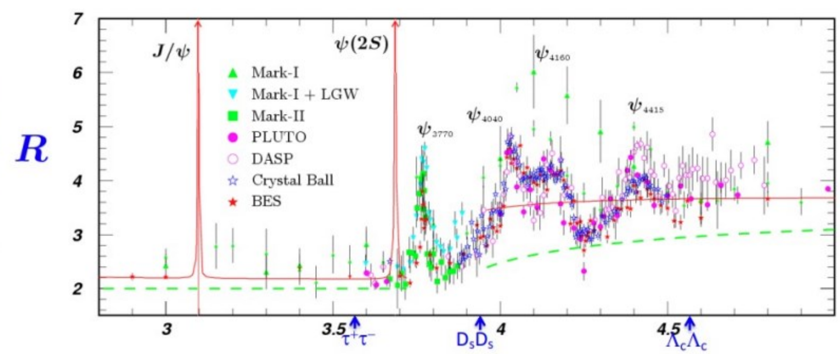
BEPCII & BESIII







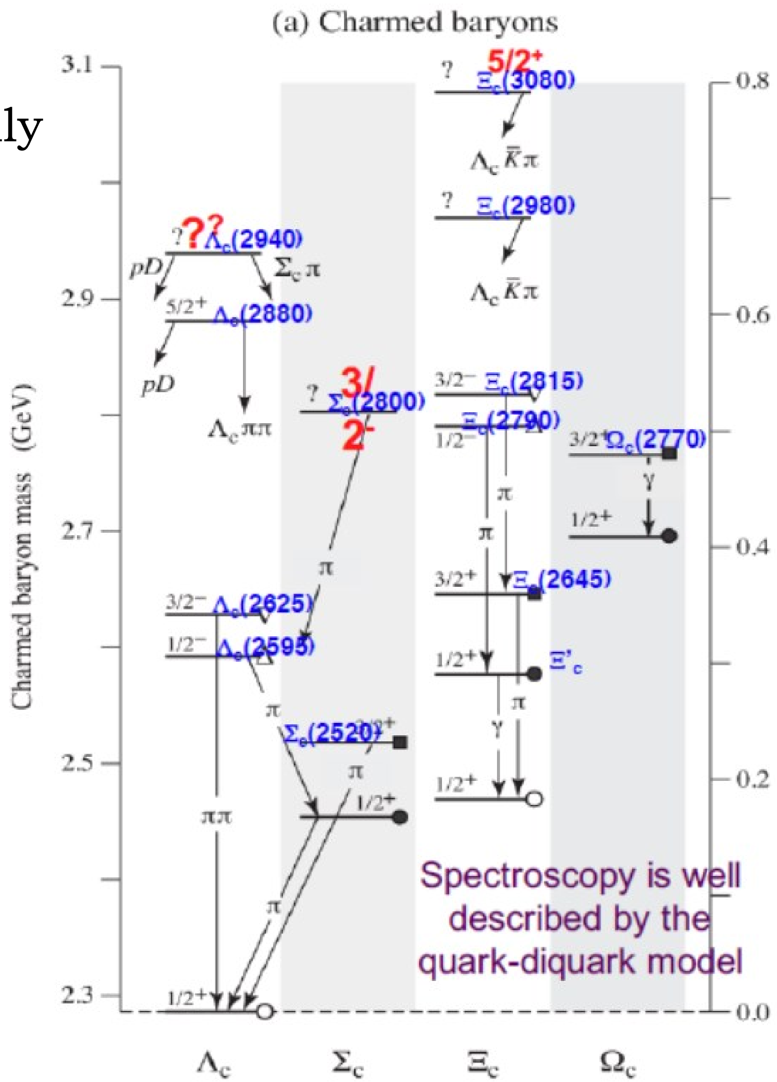
First HEP collider in China (1988)
c.m.s energy： 2 ~ 5 GeV
Max luminosity： $1\times10^{33}\mathrm{cm}^{-2}\mathrm{s}^{-1}$

Non-perturbative
$\tau - charm$ region
$\tau^{\pm}$ 、D/D_s、Λ_c^+…

J/ψ ： 2.97 fb^{-1}(10B)
$\psi(3686)$： 4.07 fb^{-1}(2.7B)
$\psi(3770)$： 20 fb^{-1}
4.6~4.95GeV： 6.4 fb^{-1}

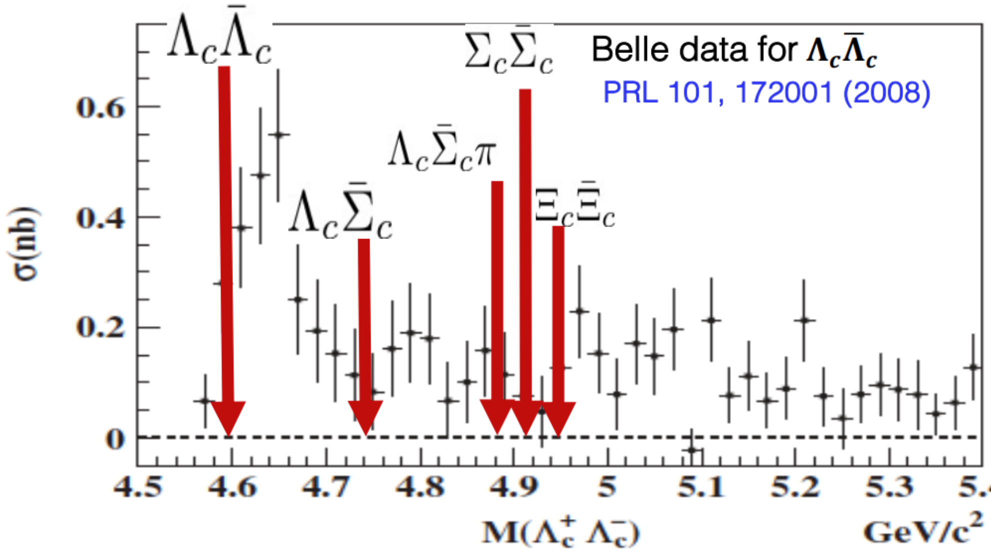
Λ_c^+: The lightest charmed baryon

- Most of the charmed baryons will eventually decay to Λ_c^+.
- The Λ_c^+ is one of important tagging hadrons in c-quark counting in the productions at high energy experiment.
- Λ_c^+ may reveal more information of strong- and weak-interactions in charm region, complementary to D/D_s.



New data samples in 2020 and 2021

Two major changes in BEPCII machine:
- **max beam energy: 2.30➔2.35(2020)➔ 2.48 GeV(2021)**
- **top-up injection:** data taking efficiency increased by 20~30%



CPC46.113003(2022)

Sample	E_{cms}/MeV	$\mathscr{L}_{Bhabha}$/pb^{-1}
4610	4611.86±0.12±0.30	103.65±0.05±0.55
4620	4628.00±0.06±0.32	521.53±0.11±2.76
4640	4640.91±0.06±0.38	551.65±0.12±2.92
4660	4661.24±0.06±0.29	529.43±0.12±2.81
4680	4681.92±0.08±0.29	1667.39±0.21±8.84
4700	4698.82±0.10±0.36	535.54±0.12±2.84
4740	4739.70±0.20±0.30	163.87±0.07±0.87
4750	4750.05±0.12±0.29	366.55±0.10±1.94
4780	4780.54±0.12±0.30	511.47±0.12±2.71
4840	4843.07±0.20±0.31	525.16±0.12±2.78
4920	4918.02±0.34±0.34	207.82±0.08±1.10
4950	4950.93±0.36±0.38	159.28±0.07±0.84

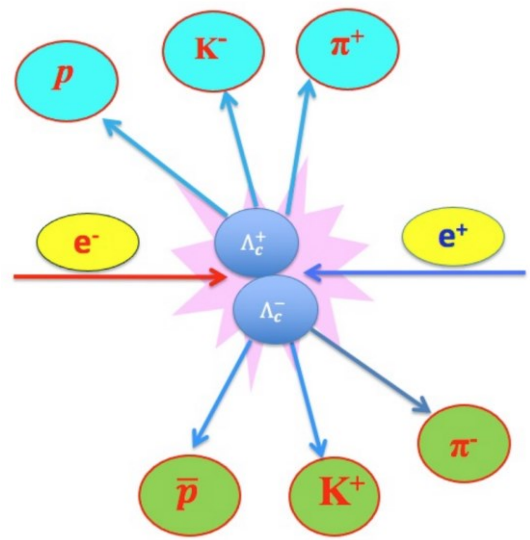
Available data for charmed baryons
- ✓ 0.567 fb^{-1} at 4.6 GeV (35 days in 2014)
- ✓ 3.9 fb^{-1} scan at 4.61, 4.63, 4.64, 4.66, 4.68, 4.7 GeV (186 days in 2020)
- ✓ 1.93 fb^{-1} scan at 4.74, 4.75, 4.78, 4.84, 4.92, 4.95 GeV (99 days in 2021)
- 8x Λ_c data that those at 4.6GeV.(~0.77M $\Lambda_c^+\bar{\Lambda}_c^-$)
- accessible to $\Sigma_c/\Xi_c/\Lambda_c^*$ prod. & decays

Production measurement near threshold

PhysRevLett.131.191901(2023)

- $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ cross section are measured at twelve energy points from 4.612-4.951 GeV.

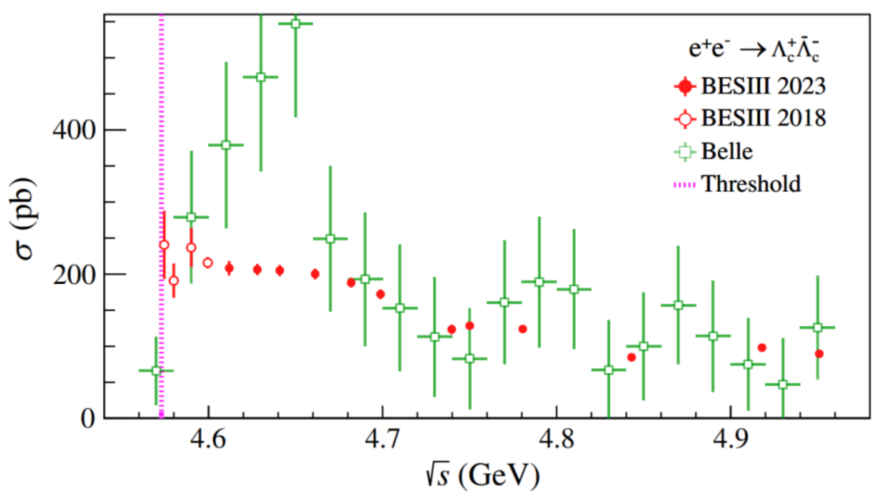
$$\sigma_{\pm} = \frac{N_{\mathrm{ST}}^{\pm}}{\varepsilon_{\mathrm{ST}}^{\pm} f_{\mathrm{ISR}} f_{\mathrm{VP}} \mathcal{L}_{\mathrm{int}} N_{\mathrm{DT}}} \sum_{n=1}^{9} \left(\frac{N_{\mathrm{ST}}^{\mp,n} \varepsilon_{\mathrm{DT}}^{n}}{\varepsilon_{\mathrm{ST}}^{\mp,n}} \right)$$

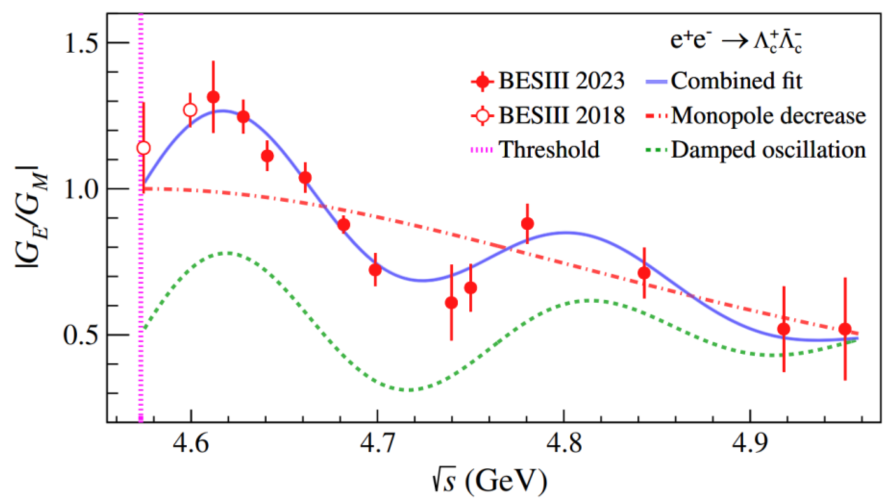


- Indicate no enhancement around Y(4630) resonance.
  => Conflict with Belle.

- $|G_E/G_M|$ ratio are derived by fitting to angular distribution.

- The oscillations on $|G_E/G_M|$ ratio is significantly observed with higher frequency than of the proton.





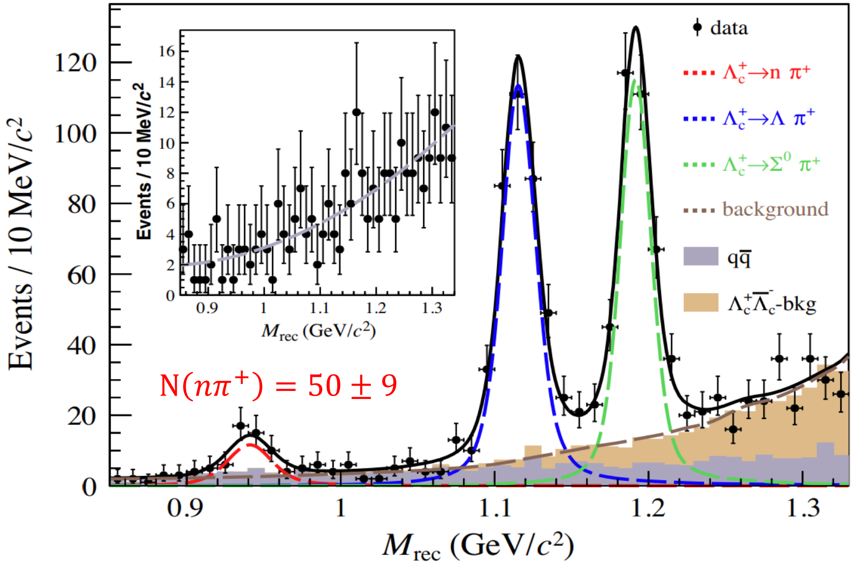
Studies on the Λ_c^+ hadronic measurements at BESIII using data 20/21

- Two-body decays
  - $\Lambda_c^+ \to n\pi^+$ ✓ : PRL 128.142001 (2022).
  - $\Lambda_c^+ \to \Sigma^0 K^+, \Sigma^+ K_S^0$: PRD 106.052003 (2022).
  - $\Lambda_c^+ \to p\pi^0$: arXiv 2311.06883.
  - $\Lambda_c^+ \to p\eta, p\omega$: JHEP 11.137 (2023).
  - $\Lambda_c^+ \to \Lambda K^+$: PRD 106.L111101 (2022).
  - $\Lambda_c^+ \to p\eta'$: PRD 106.072002 (2022).
  - $\Lambda_c^+ \to \Xi^0 K^+$ ✓ : PRL 132.031801 (2024).

- Multi-body decays
  - $\Lambda_c^+ \to n K_S^0 \pi^+ \pi^0$: PRD 109.053005 (2024).
  - $\Lambda_c^+ \to n K_S^0 \pi^+, n K_S^0 K^+$: PRD 109.072010 (2024).
  - $\bar{\Lambda}_c^- \to \bar{n} X$: PRD 108.L031101 (2023).
  - $\Lambda_c^+ \to \Lambda K^+ \pi^0, \Lambda K^+ \pi^+ \pi^-$: PRD 109.032003 (2024).
  - $\Lambda_c^+ \to \Xi^0 K^+ \pi^0$ ✓ : PRD 109.052001 (2024).
  - $\Lambda_c^+ \to \Sigma^- K^+ \pi^+$ ✓ : PRD 109.L071103 (2024).
  - $\Lambda_c^+ \to \Sigma^+ K^+ K^-, \Sigma^+ \phi, \Sigma^+ K^+ \pi^- (\pi^0)$: JHEP 09.125 (2023).
  - $\Lambda_c^+ \to n\pi^+\pi^0, n\pi^+\pi^-\pi^+, nK^-\pi^+\pi^+$ ✓ : CPC 47.023001 (2023).
  - $\Lambda_c^+ \to \Lambda \pi^+ \pi^0$ ✓ : JHEP 12.033 (2022).

First observation of $\Lambda_c^+ \to n\pi^+$

PRL 128.142001 (2022)



- First singly Cabibbo-suppressed Λ_c^+ decay involved neutron was observed (7.3σ).
- Absolute BF is measured to be $\mathcal{B}(\Lambda_c^+ \to n\pi^+) = (6.6 \pm 1.2_{stat.} \pm 0.4_{syst.}) \times 10^{-4}$.
  =>Consistent with SU(3) flavor symmetry prediction. [PLB790,225 (2019)]

  =>Twice larger than the dynamical calculation based on Pole model and CA. [PRD97,074028 (2018)]

- $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+) = (1.31 \pm 0.08_{stat.} \pm 0.05_{syst.}) \times 10^{-2}$. => Consistent with previous BESIII results
- $\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+) = (1.22 \pm 0.08_{stat.} \pm 0.07_{syst.}) \times 10^{-2}$. => Consistent with previous BESIII results

- $R = \frac{\mathcal{B}(\Lambda_c^+ \to n\pi^+)}{\mathcal{B}(\Lambda_c^+ \to p\pi^0)} > 7.2$ @90% $C.L.$ ($\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 8.0 \times 10^{-5}$ @90% $C.L.$ From Belle)
  =>Disagrees with SU(3) flavor symmetry and dynamical calculation (2.0-4.7) while in consistent with SU(3) plus topological-diagram approach (9.6).

Decay Asymmetry of $\Lambda_c^+ \to \Xi^0 K^+$

PRL 132.031801 (2024)

- $\Lambda_c^+ \to \Xi^0 K^+$ is pure W-exchange process which have significant contributions in charmed baryon decay.
- Nonfactorizable W-exchange diagram cannot be calculated using theoretical approaches.
- Long-standing puzzle on how large the S-wave amplitude.

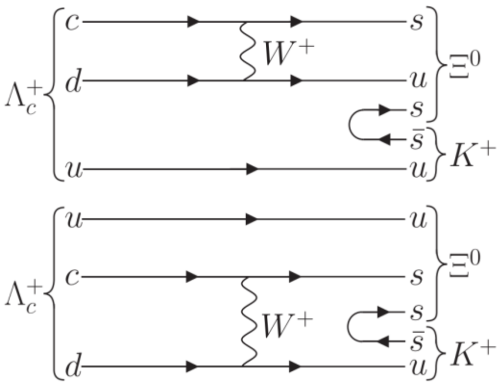


FIG. 1. Feynman diagrams for $\Lambda_c^+ \to \Xi^0 K^+$.

Theory or experiment	$\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ ($\times 10^{-3}$)	$\alpha_{\Xi^0 K^+}$	$\lvert A\rvert$ ($\times 10^{-2} G_F$ GeV^2)	$\lvert B\rvert$ ($\times 10^{-2} G_F$ GeV^2)	$\delta_p - \delta_s$ (rad)
Körner (1992), CCQM [7]	2.6	0	...	...	...
Xu (1992), Pole [8]	1.0	0	0	7.94	...
Źencaykowski (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 ± 0.9	$0.94^{+0.06}_{-0.11}$	2.7 ± 0.6	16.1 ± 2.6	...
Zou (2020), CA [6]	7.1	0.90	4.48	12.10	...
Zhong (2022), SU(3)^a [13]	$3.8^{+0.4}_{-0.5}$	$0.91^{+0.03}_{-0.04}$	3.2 ± 0.2	$8.7^{+0.6}_{-0.8}$	...
Zhong (2022), SU(3)^b [13]	$5.0^{+0.6}_{-0.9}$	0.99 ± 0.01	$3.3^{+0.5}_{-0.7}$	$12.3^{+1.2}_{-1.8}$	...
BESIII (2018) [14]	$5.90 \pm 0.86 \pm 0.39$	...	...	...	...
PDG fit (2022) [2]	5.5 ± 0.7	...	...	...	...

- Experimental measurement of decay asymmetry is crucial and urgent.

Decay Asymmetry of $\Lambda_c^+ \to \Xi^0 K^+$

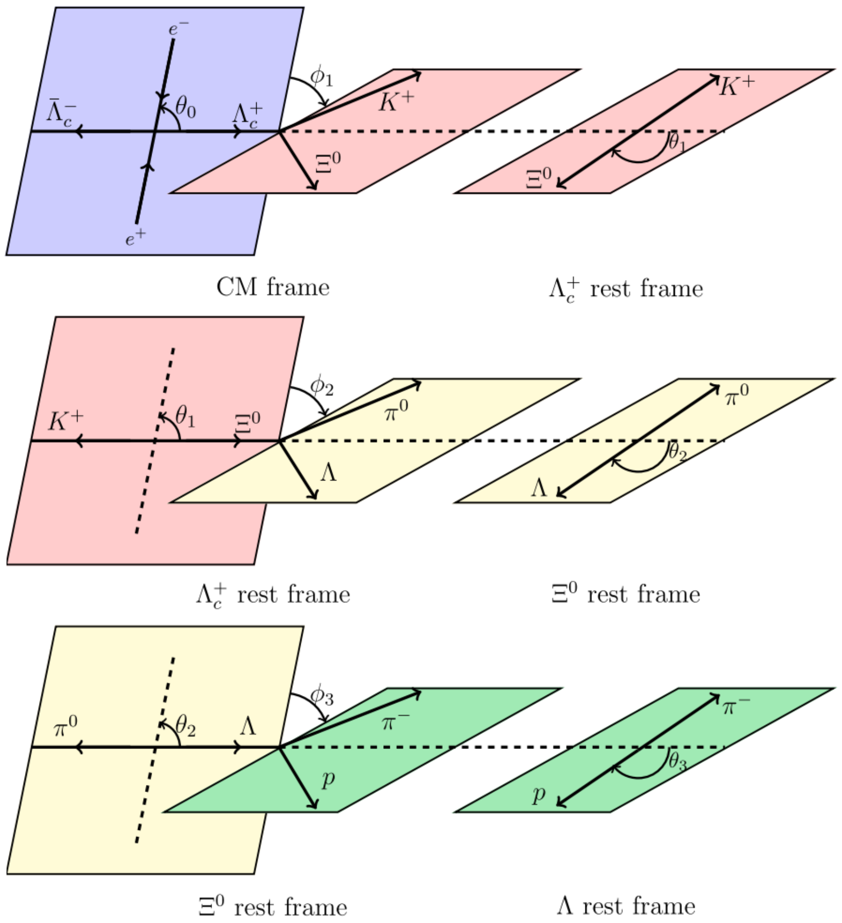
PRL 132.031801 (2024)

$$\alpha_{BP} = \frac{2\mathrm{Re}(s^* p)}{|s|^2 + |p|^2} \qquad \beta_{BP} = \frac{2\mathrm{Im}(s^* p)}{|s|^2 + |p|^2} \qquad \gamma_{BP} = \frac{|s|^2 - |p|^2}{|s|^2 + |p|^2}$$

$$\beta_{BP} = \sqrt{1-\alpha_{BP}^2}\sin\Delta_{BP} \qquad \gamma_{BP} = \sqrt{1-\alpha_{BP}^2}\cos\Delta_{BP}$$

Level	Decay	Helicity angle	Helicity amplitude
0	$e^+e^- \to \Lambda_c^+(\lambda_1)\,\bar{\Lambda}_c^-(\lambda_2)$	(θ_0)	$\mathcal{A}_{\lambda_1,\lambda_2}$
1	$\Lambda_c^+ \to \Xi^0(\lambda_3)\,K^+$	(θ_1,ϕ_1)	$\mathcal{B}_{\lambda_3}$
2	$\Xi^0 \to \Lambda(\lambda_4)\,\pi^0$	(θ_2,ϕ_2)	$\mathcal{C}_{\lambda_4}$
3	$\Lambda \to p(\lambda_5)\,\pi^-$	(θ_3,ϕ_3)	$\mathcal{D}_{\lambda_5}$

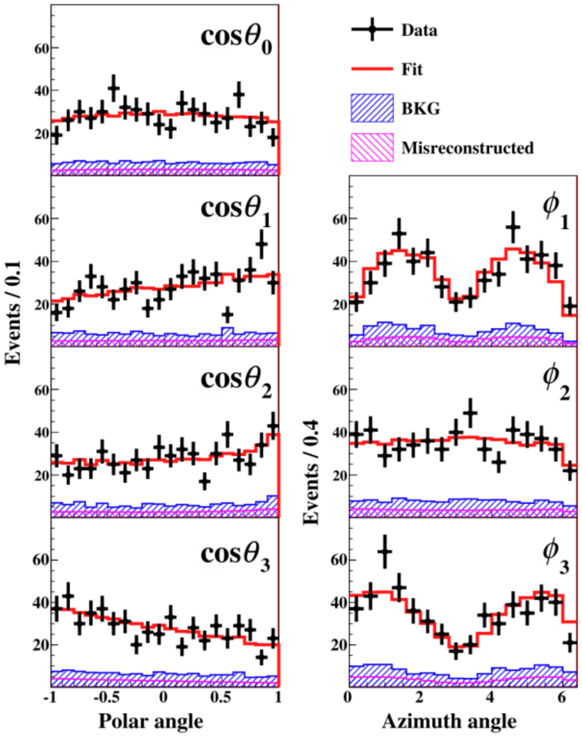
$$\begin{aligned}
&\frac{d\Gamma}{d\cos\theta_0\ d\cos\theta_1\ d\cos\theta_2\ d\cos\theta_3\ d\phi_1\ d\phi_2\ d\phi_3}\\
&\propto 1+\alpha_0\cos^2\theta_0\\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\alpha_{\Lambda\pi^0}\cos\theta_2\\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\alpha_{p\pi^-}\cos\theta_2\cos\theta_3\\
&+(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Lambda\pi^0}\alpha_{p\pi^-}\cos\theta_3\\
&-(1+\alpha_0\cos^2\theta_0)\ \alpha_{\Xi^0K^+}\sqrt{1-\alpha_{\Lambda\pi^0}^2}\ \alpha_{p\pi^-}\sin\theta_2\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Xi^0K^+}\sin\theta_1\sin\phi_1\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Lambda\pi^0}\sin\theta_1\sin\phi_1\cos\theta_2\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{\Xi^0K^+}\alpha_{\Lambda\pi^0}\alpha_{p\pi^-}\sin\theta_1\sin\phi_1\cos\theta_3\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\alpha_{p\pi^-}\sin\theta_1\sin\phi_1\cos\theta_2\cos\theta_3\\
&-\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Lambda\pi^0}^2}\ \alpha_{p\pi^-}\sin\theta_1\sin\phi_1\sin\theta_2\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\ \alpha_{\Lambda\pi^0}\cos\phi_1\sin\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\ \alpha_{\Lambda\pi^0}\cos\theta_1\sin\phi_1\sin\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\sin\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\cos\theta_3\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\ \alpha_{p\pi^-}\cos\phi_1\sin\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\cos\theta_3\\
&-\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\sqrt{1-\alpha_{\Lambda\pi^0}^2}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\sin(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\sin(\Delta_{\Lambda\pi^0}+\phi_3)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\ \sqrt{1-\alpha_{\Lambda\pi^0}^2}\ \alpha_{p\pi^-}\cos\theta_1\sin\phi_1\cos\theta_2\cos(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\sqrt{1-\alpha_{\Lambda\pi^0}^2}\ \alpha_{p\pi^-}\cos\phi_1\cos(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\sin(\Delta_{\Lambda\pi^0}+\phi_3)\\
&+\sqrt{1-\alpha_0^2}\ \sin\Delta_0\sin\theta_0\cos\theta_0\sqrt{1-\alpha_{\Xi^0K^+}^2}\sqrt{1-\alpha_{\Lambda\pi^0}^2}\ \alpha_{p\pi^-}\cos\phi_1\cos\theta_2\sin(\Delta_{\Xi^0K^+}+\phi_2)\sin\theta_3\cos(\Delta_{\Lambda\pi^0}+\phi_3)
\end{aligned}$$

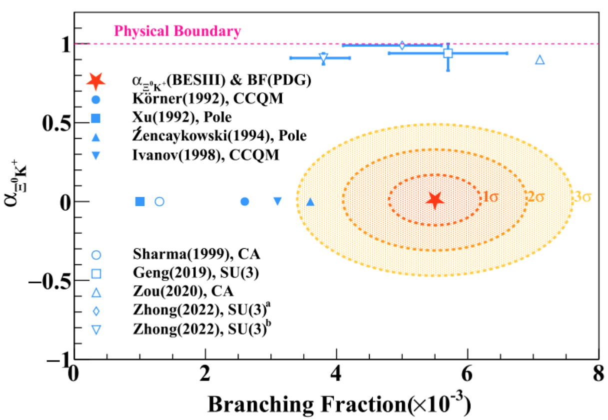


- The joint angular distribution for $\Lambda_c^+ \to \Xi^0 K^+$ is derived based on helicity amplitude.

Decay Asymmetry of $\Lambda_c^+ \to \Xi^0 K^+$

PRL 132.031801 (2024)





- From the fit, we obtain

$$\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16_{stat.} \pm 0.03_{syst.},$$
$$\Delta_{\Xi^0 K^+} = 3.84 \pm 0.90_{stat.} \pm 0.17_{syst.}.$$

- $\alpha_{\Xi^0 K^+}$ is in good agreement with zero.
  => strong identification for theoretical predictions.

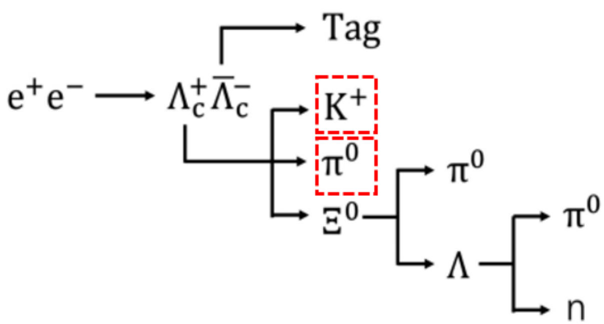
$$\Gamma_{\Xi^0 K^+} = \frac{\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)}{\tau_{\Lambda_c^+}} = \frac{|\vec{p}_c|}{8\pi}\left[\frac{(m_{\Lambda_c^+}+m_{\Xi^0})^2 - m_{K^+}^2}{m_{\Lambda_c^+}^2}|A|^2 + \frac{(m_{\Lambda_c^+}-m_{\Xi^0})^2 - m_{K^+}^2}{m_{\Lambda_c^+}^2}|B|^2\right]$$
$$\alpha_{\Xi^0 K^+} = \frac{2\kappa|A||B|\cos(\delta_p-\delta_s)}{|A|^2+\kappa^2|B|^2}$$
$$\Delta_{\Xi^0 K^+} = \arctan\frac{2\kappa|A||B|\sin(\delta_p-\delta_s)}{|A|^2-\kappa^2|B|^2}$$

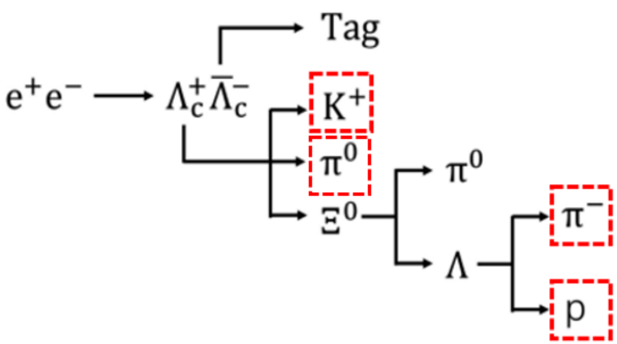
- Especially, $\cos(\delta_p - \delta_s)$ is measured to close to zero. => Not considered in previous literature.
- Fills the long-standing puzzle on how to model $\alpha_{\Xi^0 K^+}$ and $\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ simultaneously.
- After considered the phase shift, some calculations

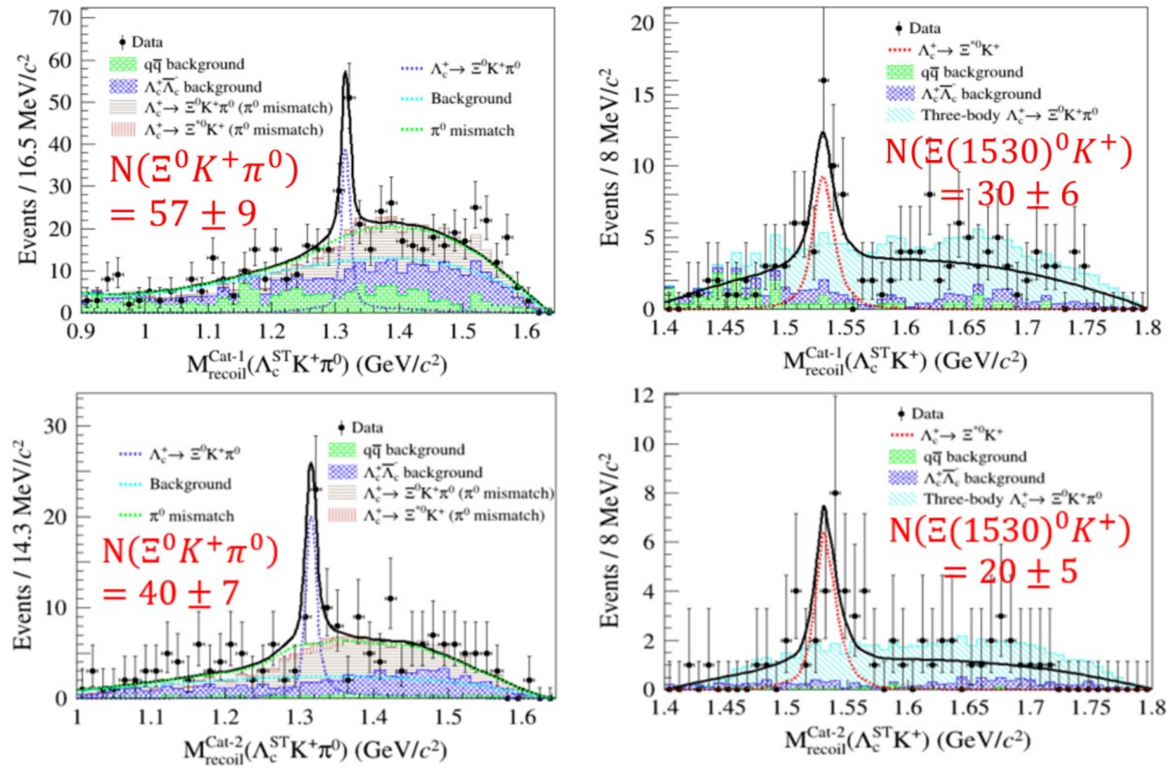
✓	Geng (2023), SU(3)	-0.15 ± 0.14	: PRD 109.L071302 (2024).
✓	Zhong (2024), TDA	-0.16 ± 0.13	: arXiv 2401.15926.
✓	Zhong (2024), IRA	-0.19 ± 0.12	: arXiv 2401.15926.

BF measurement of $\Lambda_c^+ \to \Xi^0 K^+ \pi^0$

PRD 109.052001 (2024)





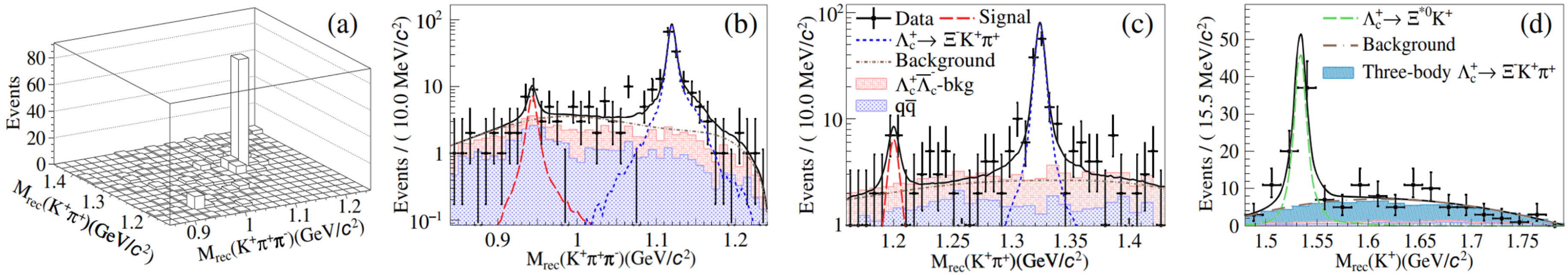


	$\Lambda_c^+ \to \Xi(1530)^0 K^+$	$\Lambda_c^+ \to \Xi^0 K^+ \pi^0$	$\Lambda_c^+ \to \Sigma^0 K^+ \pi^0$	$\Lambda_c^+ \to \Lambda K^+ \pi^0$	$\Lambda_c^+ \to n K^+ \pi^0$
This measurement	$5.99 \pm 1.04 \pm 0.32$	$7.79 \pm 1.46 \pm 0.95$	< 1.8	< 2.0	< 0.71
K. K. Sharma *et al.* [23]	...	45 ± 8	1.2 ± 0.3	4.5 ± 0.8	0.05 ± 0.005
Jian-Yong Cen *et al.* [24]	...	32 ± 6	0.7 ± 0.2	3.5 ± 0.6	0.05 ± 0.006
$\mathcal{B}$(previous results) [48]	$5.02 \pm 0.99 \pm 0.31$	...	...	...	...

- ✓ $\mathcal{B}(\Lambda_c^+ \to \Xi(1530)^0 K^+)$ => Consistent with previous BESIII results.
- ✓ $\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+ \pi^0)$ => Lower than prediction based on SU(3) symmetry.

Observation of SCS decay $\Lambda_c^+ \to \Sigma^- K^+ \pi^+$

PRD 109.L071103 (2024)



- Singly Cabibbo-suppressed decay $\Lambda_c^+ \to \Sigma^- K^+ \pi^+$ was observed for the first time (5.4σ).
- Absolute BF is measured to be $\mathcal{B}(\Lambda_c^+ \to \Sigma^- K^+ \pi^+) = (3.8 \pm 1.2_{stat.} \pm 0.2_{syst.}) \times 10^{-4}$.

  =>Consistent with SU(3) flavor symmetry prediction $(3.3 \pm 2.3) \times 10^{-4}$. [PRD99, 073003 (2019)]

- $\mathcal{B}(\Lambda_c^+ \to \Xi^- K^+ \pi^+) = (7.74 \pm 0.76_{stat.} \pm 0.54_{syst.}) \times 10^{-3}$. => Consistent with PDG Fit
- $\mathcal{B}(\Lambda_c^+ \to \Xi(1530)^0 K^+) = (5.03 \pm 0.77_{stat.} \pm 0.20_{syst.}) \times 10^{-3}$. => Consistent with previous BESIII results [PLB783, 200-206 (2018)]

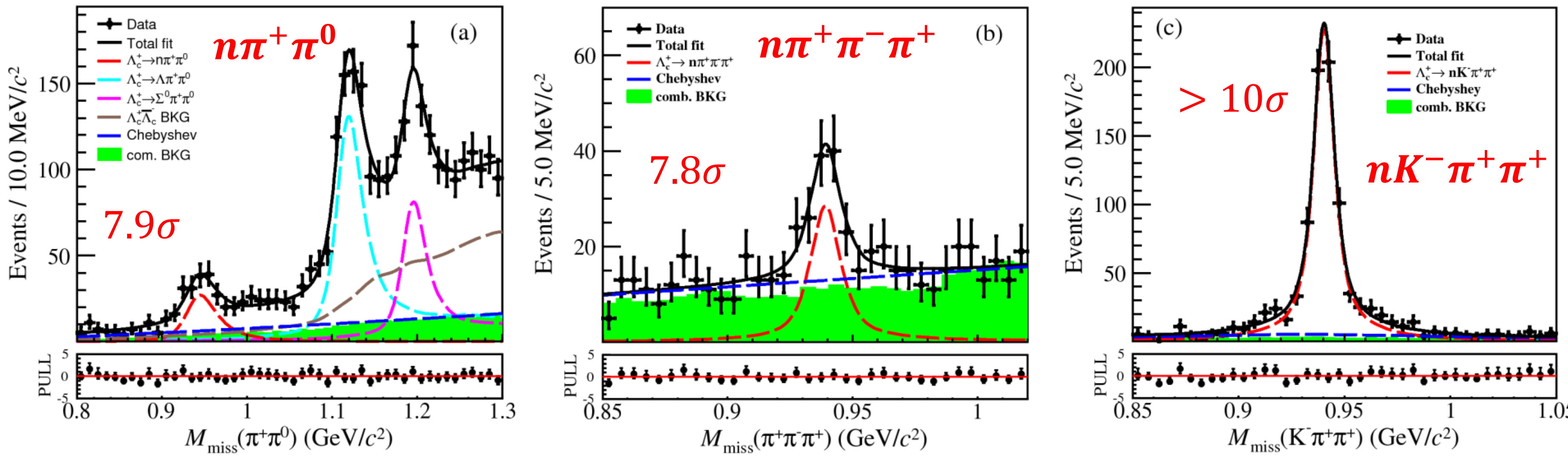
- $\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^- K^+ \pi^+)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^- \pi^+ \pi^+)} = (2.03 \pm 0.73)\% \simeq (0.4 \pm 0.1)s_c^2$ $(s_c^2 \equiv sin\theta_c = 0.2248)$

  =>Close to $\frac{\mathcal{B}(\Xi_c^0 \to \Xi^- K^+)}{\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+)}$ and deviates significantly from $1.0 s_c^2$.

  =>Ratio of isospin partner modes $\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K^+ \pi^-)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)}$ consistent with $1.0 s_c^2$.

Observation of multi-body SCS/CF decay involved neutron

CPC 47.023001 (2023)



- Absolute BF is measured to be

$$\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0) = (0.64 \pm 0.09 \pm 0.02)\%,$$
$$\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^-\pi^+) = (0.45 \pm 0.07 \pm 0.03)\%,$$
$$\mathcal{B}(\Lambda_c^+ \to nK^-\pi^+\pi^+) = (1.90 \pm 0.08 \pm 0.09)\%.$$

- $\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0)} = 0.72 \pm 0.11$ → Provides key SU(3) symmetry constraint
- $\frac{\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0)}{\mathcal{B}(\Lambda_c^+ \to n\pi^+)} = 9.2 \pm 2.4$ → Rich intermediate resonance states
- $\frac{\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \to nK^-\pi^+\pi^+)} = 0.24 \pm 0.04$ → Consistent with $1.0s_c^2$

PWA for $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

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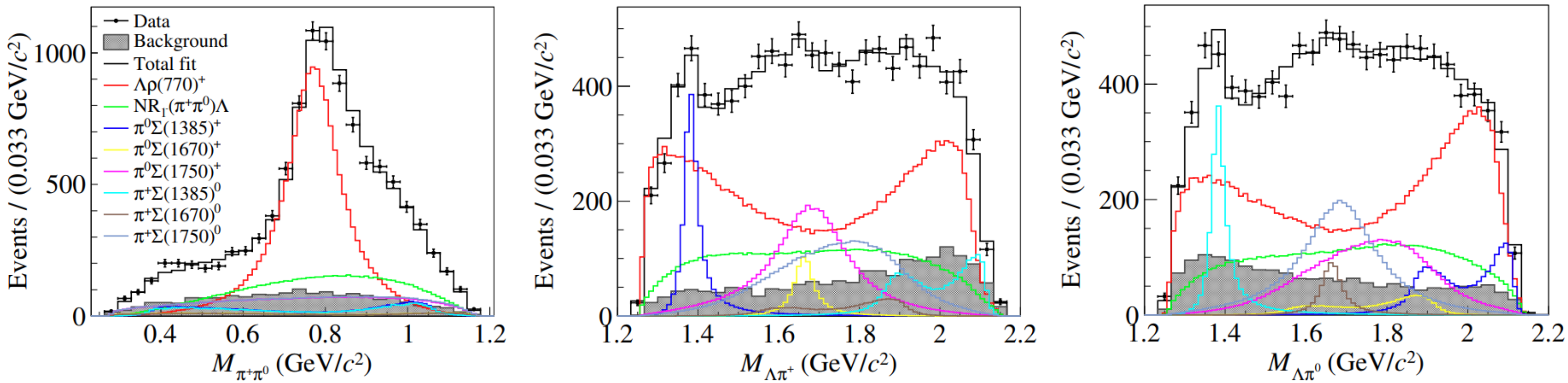

Process	Magnitude	Phase ϕ (rad)	FF (%)	Significance
$\Lambda\rho(770)^+$	1.0 (fixed)	0.0 (fixed)	57.2 ± 4.2	$36.9\,\sigma$
$\Sigma(1385)^+\pi^0$	0.43 ± 0.06	-0.23 ± 0.18	7.18 ± 0.60	$14.8\,\sigma$
$\Sigma(1385)^0\pi^+$	0.37 ± 0.07	2.84 ± 0.23	7.92 ± 0.72	$16.0\,\sigma$
$\Sigma(1670)^+\pi^0$	0.31 ± 0.08	-0.77 ± 0.23	2.90 ± 0.63	$5.1\,\sigma$
$\Sigma(1670)^0\pi^+$	0.41 ± 0.07	2.77 ± 0.20	2.65 ± 0.58	$5.2\,\sigma$
$\Sigma(1750)^+\pi^0$	1.75 ± 0.21	-1.73 ± 0.11	16.6 ± 2.2	$10.1\,\sigma$
$\Sigma(1750)^0\pi^+$	1.83 ± 0.21	1.34 ± 0.11	17.5 ± 2.3	$10.2\,\sigma$
$\Lambda + NR_{1^-}$	4.05 ± 0.47	2.16 ± 0.13	29.7 ± 4.5	$10.5\,\sigma$

- About 10K events survived which purity is larger than 80%.
- PWA based on helicity amplitude is performed.
- Interference mostly exist $\Lambda\rho(770)$ and $\Sigma(1385)^{0/+}\pi^{+/0}$.

PWA for $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

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$\frac{1}{2}^+(\Lambda_c^+) \to \frac{3}{2}^+(\Sigma(1385)^+) + 0^-(\pi^0)$			$\frac{1}{2}^+(\Lambda_c^+) \to \frac{3}{2}^+(\Sigma(1385)^0) + 0^-(\pi^+)$		
Amplitude	Magnitude	Phase ϕ (rad)	Amplitude	Magnitude	Phase ϕ (rad)
$g_{1,\frac{3}{2}}^{\Sigma(1385)^+}$	1.0 (fixed)	0.0 (fixed)	$g_{1,\frac{3}{2}}^{\Sigma(1385)^0}$	1.0 (fixed)	0.0 (fixed)
$g_{2,\frac{3}{2}}^{\Sigma(1385)^+}$	1.29 ± 0.25	2.82 ± 0.18	$g_{2,\frac{3}{2}}^{\Sigma(1385)^0}$	1.70 ± 0.38	2.70 ± 0.22

$\frac{1}{2}^+(\Lambda_c^+) \to \frac{3}{2}^-(\Sigma(1670)^+) + 0^-(\pi^0)$			$\frac{1}{2}^+(\Lambda_c^+) \to \frac{3}{2}^-(\Sigma(1670)^0) + 0^-(\pi^+)$		
Amplitude	Magnitude	Phase ϕ (rad)	Amplitude	Magnitude	Phase ϕ (rad)
$g_{1,\frac{3}{2}}^{\Sigma(1670)^+}$	1.0 (fixed)	0.0 (fixed)	$g_{1,\frac{3}{2}}^{\Sigma(1670)^0}$	1.0 (fixed)	0.0 (fixed)
$g_{2,\frac{3}{2}}^{\Sigma(1670)^+}$	1.39 ± 0.42	0.85 ± 0.26	$g_{2,\frac{3}{2}}^{\Sigma(1670)^0}$	0.74 ± 0.18	0.29 ± 0.24

$\frac{1}{2}^+(\Lambda_c^+) \to \frac{1}{2}^-(\Sigma(1750)^+) + 0^-(\pi^0)$			$\frac{1}{2}^+(\Lambda_c^+) \to \frac{1}{2}^-(\Sigma(1750)^0) + 0^-(\pi^+)$		
Amplitude	Magnitude	Phase ϕ (rad)	Amplitude	Magnitude	Phase ϕ (rad)
$g_{0,\frac{1}{2}}^{\Sigma(1750)^+}$	1.0 (fixed)	0.0 (fixed)	$g_{0,\frac{1}{2}}^{\Sigma(1750)^0}$	1.0 (fixed)	0.0 (fixed)
$g_{1,\frac{1}{2}}^{\Sigma(1750)^+}$	0.45 ± 0.10	-2.28 ± 0.22	$g_{1,\frac{1}{2}}^{\Sigma(1750)^0}$	0.38 ± 0.10	-2.03 ± 0.20

$\frac{1}{2}^+(\Lambda_c^+) \to \frac{1}{2}^+(\Lambda) + 1^-(\rho(770)^+)$			$\frac{1}{2}^+(\Lambda_c^+) \to \frac{1}{2}^+(\Lambda) + 1^-(NR_{1^-})$		
Amplitude	Magnitude	Phase ϕ (rad)	Amplitude	Magnitude	Phase ϕ (rad)
$g_{0,\frac{1}{2}}^{\rho}$	1.0 (fixed)	0.0 (fixed)	$g_{0,\frac{1}{2}}^{NR}$	1.0 (fixed)	0.0 (fixed)
$g_{1,\frac{1}{2}}^{\rho}$	0.48 ± 0.12	-1.69 ± 0.12	$g_{1,\frac{1}{2}}^{NR}$	0.94 ± 0.12	-0.49 ± 0.16
$g_{1,\frac{3}{2}}^{\rho}$	0.90 ± 0.10	0.48 ± 0.13	$g_{1,\frac{3}{2}}^{NR}$	0.21 ± 0.09	-2.84 ± 0.53
$g_{2,\frac{3}{2}}^{\rho}$	0.55 ± 0.08	-0.04 ± 0.18	$g_{2,\frac{3}{2}}^{NR}$	0.33 ± 0.14	-1.92 ± 0.30

$\frac{1}{2}^+(\Lambda) \to \frac{1}{2}^+(p) + 0^-(\pi^-)$		
Amplitude	Magnitude	Phase ϕ (rad)
$g_{0,\frac{1}{2}}^{\Lambda}$	1.0 (fixed)	0.0 (fixed)
$g_{1,\frac{1}{2}}^{\Lambda}$	0.435376 (fixed)	0.0 (fixed)

$$\alpha_{\Lambda\rho(770)^+} = \frac{|H^{\rho}_{\frac{1}{2},1}|^2 - |H^{\rho}_{-\frac{1}{2},-1}|^2 + |H^{\rho}_{\frac{1}{2},0}|^2 - |H^{\rho}_{-\frac{1}{2},0}|^2}{|H^{\rho}_{\frac{1}{2},1}|^2 + |H^{\rho}_{-\frac{1}{2},-1}|^2 + |H^{\rho}_{\frac{1}{2},0}|^2 + |H^{\rho}_{-\frac{1}{2},0}|^2}$$
$$= \frac{\sqrt{\frac{1}{9}} \cdot 2 \cdot \Re\left(g^{\rho}_{0,\frac{1}{2}} \cdot \bar{g}^{\rho}_{1,\frac{1}{2}} - g^{\rho}_{1,\frac{3}{2}} \cdot \bar{g}^{\rho}_{2,\frac{3}{2}}\right) - \sqrt{\frac{8}{9}} \cdot 2 \cdot \Re\left(g^{\rho}_{0,\frac{1}{2}} \cdot \bar{g}^{\rho}_{1,\frac{3}{2}} + g^{\rho}_{1,\frac{1}{2}} \cdot \bar{g}^{\rho}_{2,\frac{3}{2}}\right)}{|g^{\rho}_{0,\frac{1}{2}}|^2 + |g^{\rho}_{1,\frac{1}{2}}|^2 + |g^{\rho}_{1,\frac{3}{2}}|^2 + |g^{\rho}_{2,\frac{3}{2}}|^2}.$$

$$\alpha_{\Sigma(1385)\pi} = \frac{|H^{\Sigma(1385)}_{0,\frac{1}{2}}|^2 - |H^{\Sigma(1385)}_{0,-\frac{1}{2}}|^2}{|H^{\Sigma(1385)}_{0,\frac{1}{2}}|^2 + |H^{\Sigma(1385)}_{0,-\frac{1}{2}}|^2} = \frac{2\Re\left(g^{\Sigma(1385)}_{1,\frac{3}{2}} \cdot \bar{g}^{\Sigma(1385)}_{2,\frac{3}{2}}\right)}{|g^{\Sigma(1385)}_{1,\frac{3}{2}}|^2 + |g^{\Sigma(1385)}_{2,\frac{3}{2}}|^2}.$$

- Decay asymmetry parameters can be obtained by the fit results of the partial wave amplitudes.

PWA for $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

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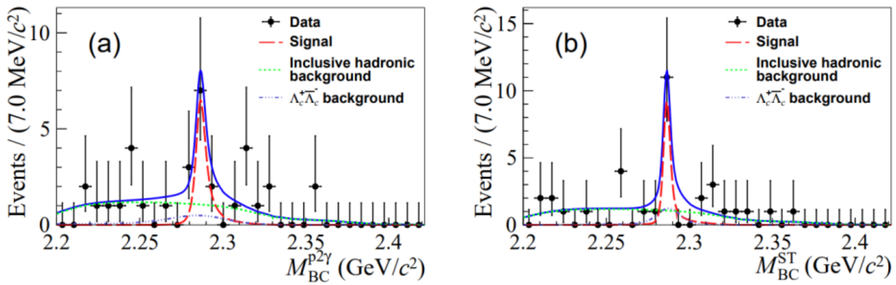
Table 9. The comparison among this work, various theoretical calculations and PDG results. Here, the uncertainties of this work are the combined uncertainties. "—" means unavailable.

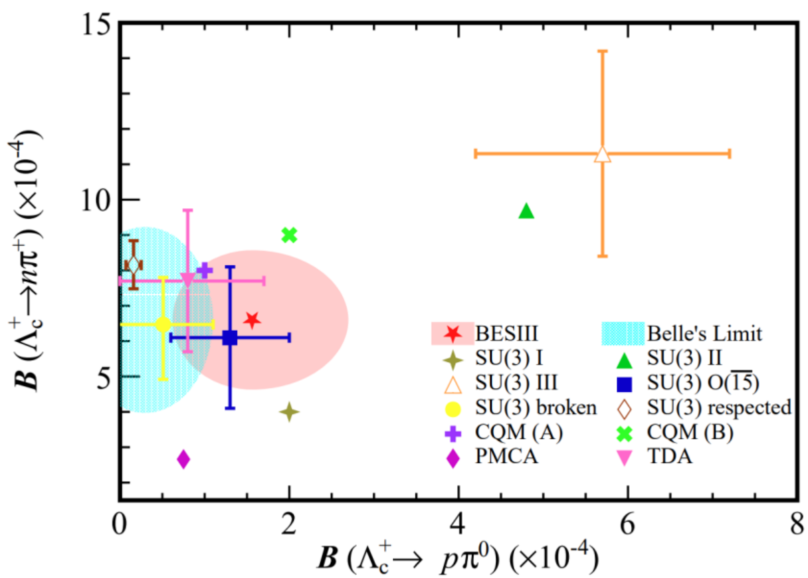
	Theoretical calculation		This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52	< 6
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80	—
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	6.47 ± 0.96	—
$\alpha_{\Lambda\rho(770)^+}$	-0.27 ± 0.04 [13]	-0.32 [14, 15]	-0.763 ± 0.070	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.089	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.79 ± 0.11	—

- No theoretical models is able to explain both BFs and decay asymmetries simultaneously.
- Fruitful results are extracted which provide crucial input to extend the understanding of dynamics of charmed baryon hadronic decays.

Some new results

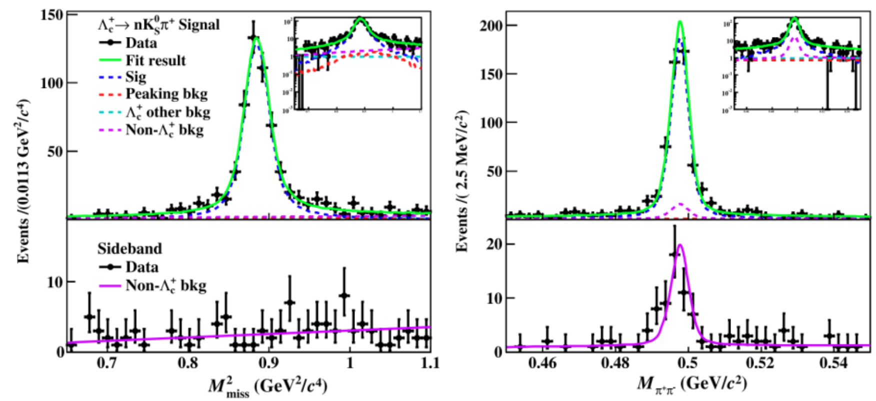
$\Lambda_c^+ \to p\pi^0$ **arXiv 2311.06883**



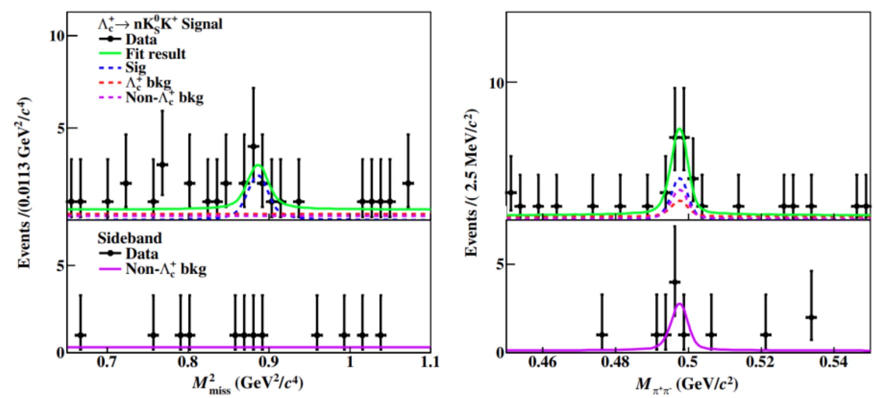


- ✓ $\mathcal{B}(\Lambda_c^+ \to p\pi^0) = (1.56^{+0.72}_{-0.58} \pm 0.20) \times 10^{-4}$
- ✓ $\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^0)}{\mathcal{B}(\Lambda_c^+ \to n\pi^+)} = 3.2^{+2.2}_{-1.2}$
- ✓ $\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.63 \pm 0.31 \pm 0.20) \times 10^{-3}$

$\Lambda_c^+ \to nK_S^0\pi^+, nK_S^0K^+$ **PRD 109.072010 (2024)**



(a) Projections of the 2D simultaneous fits to $\Lambda_c^+ \to nK_S^0\pi^+$.



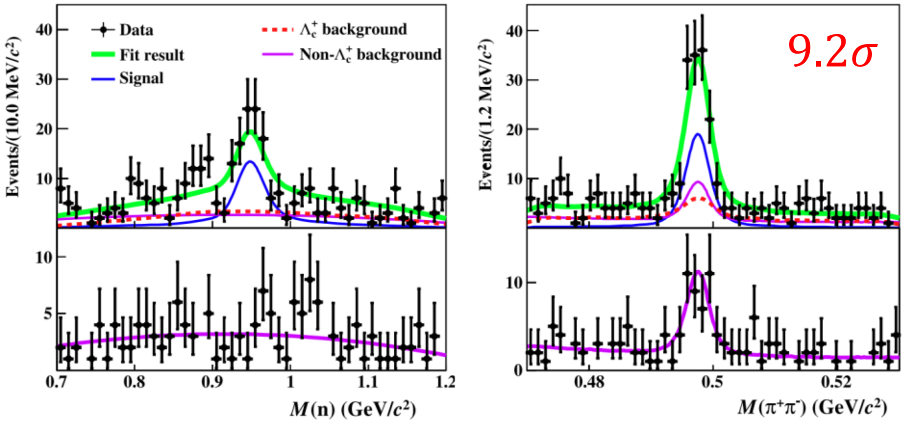
(b) Projections of the 2D simultaneous fits to $\Lambda_c^+ \to nK_S^0K^+$.

- ✓ $\mathcal{B}(\Lambda_c^+ \to nK_S^0\pi^+) = (1.86 \pm 0.08 \pm 0.04) \times 10^{-2}$
- ✓ $\mathcal{B}(\Lambda_c^+ \to nK_S^0K^+) = (3.9^{+1.7}_{-1.4} \pm 0.3) \times 10^{-4}$ **=> Lower than prediction**

$$\cos\delta = \frac{\mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(pK^-\pi^+)}{2\sqrt{\mathcal{B}(p\bar{K}^0\pi^0)(\mathcal{B}(pK^-\pi^+) + \mathcal{B}(n\bar{K}^0\pi^+) - \mathcal{B}(p\bar{K}^0\pi^0))}} = \boxed{-0.26 \pm 0.03}$$

Some new results

$\Lambda_c^+ \to nK_S^0\pi^+\pi^0$ **PRD 109.053005 (2024)**



✓$\mathcal{B}(\Lambda_c^+ \to nK_S^0\pi^+\pi^0) = (0.85 \pm 0.13 \pm 0.03)\%$

✓Differ from theoretical prediction based on isospin by 4.4σ.

$\Lambda_c^+ \to \Lambda K^+\pi^0, \Lambda K^+\pi^+\pi^-$ **PRD 109.032003 (2024)**

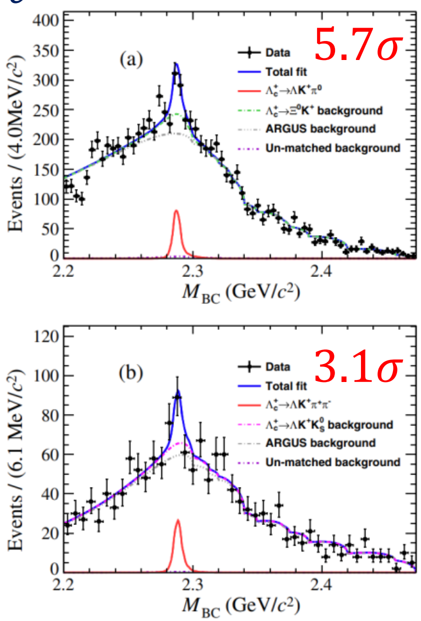


FIG. 3. Combined simultaneous fit results to the distributions of M_{BC} for (a) $\Lambda_c^+ \to \Lambda K^+\pi^0$ and (b) $\Lambda_c^+ \to \Lambda K^+\pi^+\pi^-$ at 13 energy points.

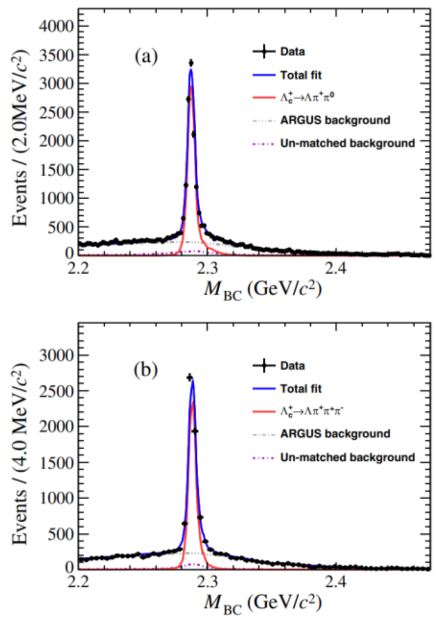


FIG. 4. Combined simultaneous fit results to the distributions of M_{BC} for (a) $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ and (b) $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$ at 13 energy points.

✓ $\frac{\mathcal{B}(\Lambda_c^+\to\Lambda K^+\pi^0)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^0)} = (2.09 \pm 0.39 \pm 0.07) \times 10^{-2}$

✓ $\frac{\mathcal{B}(\Lambda_c^+\to\Lambda K^+\pi^+\pi^-)}{\mathcal{B}(\Lambda_c^+\to\Lambda\pi^+\pi^+\pi^-)} = (1.13 \pm 0.41 \pm 0.06) \times 10^{-2}$

✓ $\mathcal{B}(\Lambda_c^+ \to \Lambda K^+\pi^0) =$
$(1.49 \pm 0.27 \pm 0.05 \pm 0.08_{\text{ref.}}) \times 10^{-3}$
=> Lower than prediction based on SU(3)

✓$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+\pi^+\pi^-) =$
$(4.13 \pm 1.48 \pm 0.20 \pm 0.33_{\text{ref.}}) \times 10^{-4}$
=> Consistent with BaBar experiment

Summary

- BESIII have collected the largest data samples with 6.4fb^{-1} integrated luminosity from 4.60 to 4.95 GeV near the $\Lambda_c^+\bar{\Lambda}_c^-$ production threshold.
- Many singly Cabibbo-suppressed Λ_c^+ decay involved neutron were observed for the first time.
- The polarization of pure W-exchange process $\Lambda_c^+ \to \Xi^0 K^+$ was measured for the first time, which fills the long-standing puzzle on how to model $\alpha_{\Xi^0 K^+}$ and $\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ simultaneously.
- The process $\Lambda_c^+ \to \Lambda K^+ \pi^0$ was observed and BF of $\Lambda_c^+ \to \Xi^0 K^+ \pi^0$ was updated, which are both lower than prediction based on SU(3) symmetry.
- The SCS decay $\Lambda_c^+ \to \Sigma^- K^+ \pi^+$ was observed for the first time and consistent with SU(3) flavor symmetry prediction $(3.3 \pm 2.3) \times 10^{-4}$.
- The polarization of two-body intermediate channels in the three-body decay $\Lambda_c^+ \to \Lambda \pi^+ \pi^0$ was measured, and more similar analyses are ongoing.
  - ✓ $\Lambda_c^+ \to pK^-\pi^+$ ✓ $\Lambda_c^+ \to pK_S^0\pi^0$ ✓ $\Lambda_c^+ \to \Lambda^0\pi^+\eta$ ✓ $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$
  - ✓ $\Lambda_c^+ \to pK^-\pi^+\pi^0$ ✓ $\Lambda_c^+ \to nK_S^0\pi^+$ ✓ $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ ✓ ...
- More polarization information about $\Lambda_c^+ \to pK_S^0/\Lambda^0\pi^+/\Sigma^0\pi^+/\Sigma^+\pi^0$ will be released soon.

Thanks!