Recent studies on Λ_c^+ at BESIII

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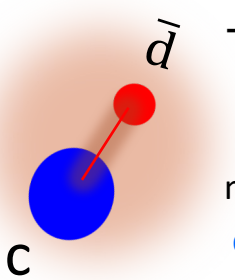
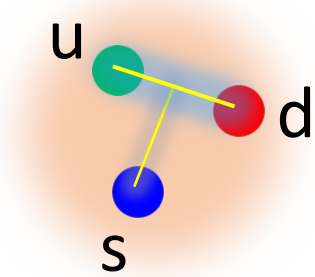
Λ_c^+: The lightest charmed baryon spectroscopy

- 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.
- Naïve quark model picture: a heavy quark (c) with an unexcited spin-zero diquark (u-d). Diquark correlation is enhanced by weak Color Magnetic Interaction with a heavy quark(HQET).
- Λ_c^+ may reveal more information of strong- and weak-interactions in charm region, complementary to D/Ds



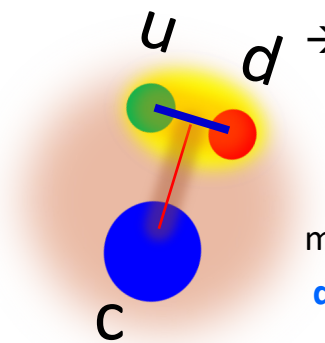
→ Charmed meson ($D^+[c\bar{d}]$)

$m_d << m_c$ →
quark + heavy quark
(q) (Q)



→ Strange baryons (Λ[uds])

m_u, $m_d \approx m_s$ →
(qqq) uniform

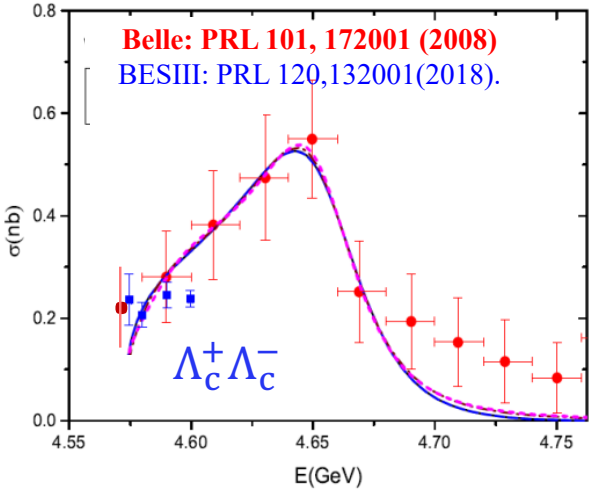


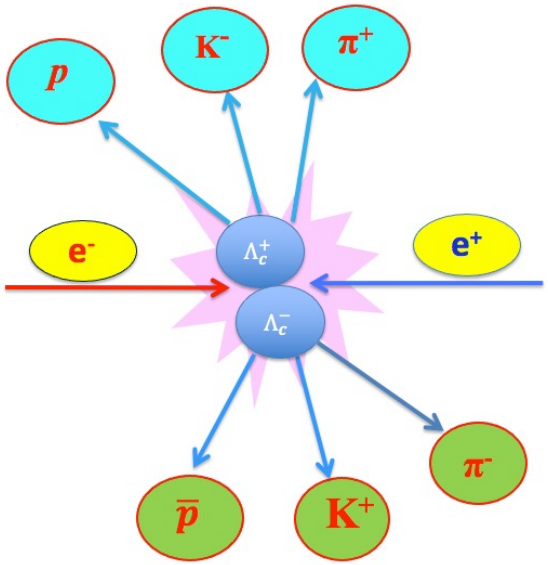
→ Charmed baryon (Λ_c[udc])

m_u, $m_d << m_c$ →
diquark + quark
(qq) (Q)

Production near threshold and tag technique

- E_{cms}-$2M_{\Lambda c}$=26MeV only!
- $\Lambda_c^+\Lambda_c^-$ produced in pairs with no additional accompany hadrons. $e^+e^-\to\gamma^*\to\Lambda_c^+\Lambda_c^-$
- Clean backgrounds and well constrained kinematics.
- Typically, two ways to study Λ_c^+ decays:
  - Single Tag(ST): detect only one of the $\Lambda_c^+\Lambda_c^-$.
    =>Relative higher backgrounds
    =>Higher efficiencies
    =>Full reconstruction only
  - Double Tag(DT): detect both of $\Lambda_c^+\Lambda_c^-$
    =>Lower backgrounds.
    =>Technique for missing particle.
    =>Systematic in tag side are mostly cancelled.

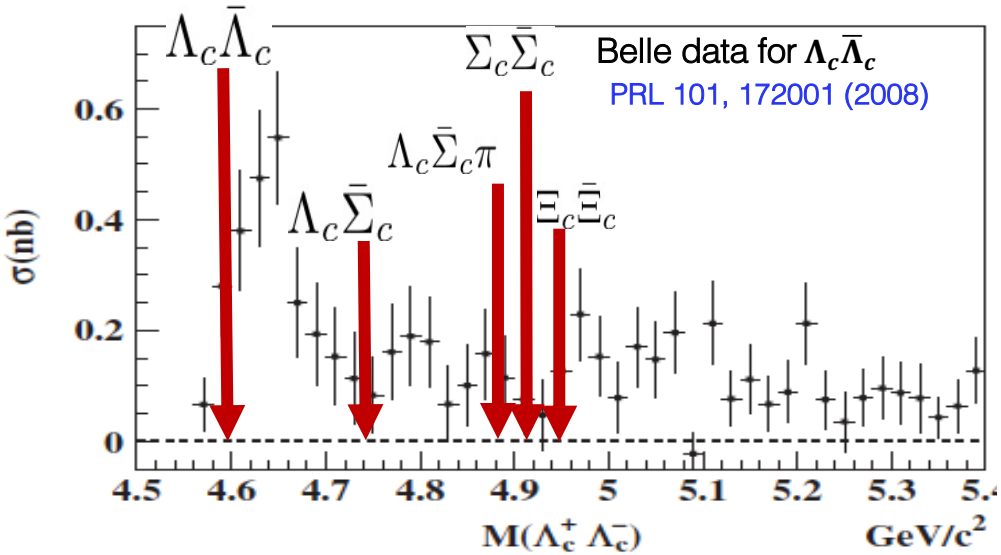




New data samples in 2020 and 2021

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

Studies on the Λ_c^+ measurments at BESIII

- Λ_c^+ leptonic decays
  - ☐FF of $\Lambda_c^+ \to \Lambda e^+ \nu_e$: PRL129.231803 (2022).
  - ☐BF of $\Lambda_c^+ \to pK^- e^+ \nu_e$: arXiv 2207.11483(PRD accepted).
  - ☐BF of $\Lambda_c^+ \to \mathrm{X} e^+ \nu_e$: arXiv 2212.03753 (PRD submitted).

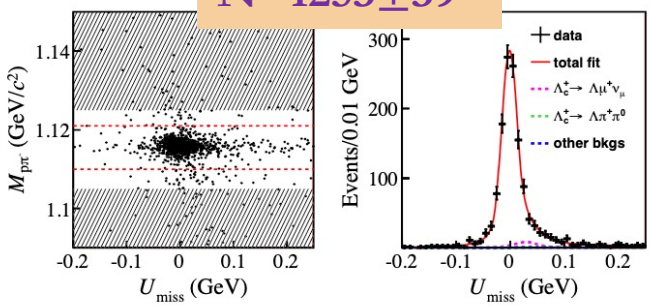
- Λ_c^+ hadronic decays

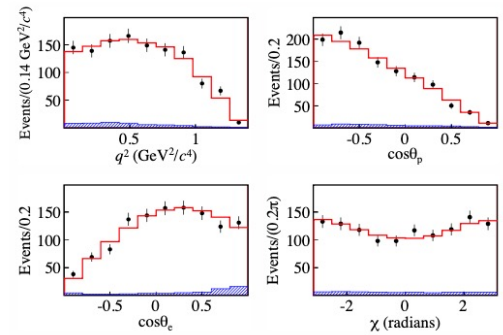
  - ☐BF($\Lambda_c^+ \to \mathrm{n}\pi^+$) : PRL 128.142001 (2022).
  - ☐BF($\Lambda_c^+ \to \Lambda K^+$) : PRD 106.L111101 (2022).
  - ☐BF($\Lambda_c^+ \to \Sigma^0 \mathrm{K}^+, \Sigma^+ K_S^0$) : PRD 106.052003 (2022).
  - ☐BF($\Lambda_c^+ \to p\eta'$) : PRD 106.072002 (2022).
  - ☐BF($\Lambda_c^+ \to n\pi^+\pi^0$、$n\pi^+\pi^-\pi^+$、$nK^-\pi^+\pi^+$) : CPC 47, 023001 (2023).
  - ☐BF($\bar{\Lambda}_c^- \to \bar{n}X$) : arXiv 2210.09561 (PRL submitted).
  - ☐PWA for $\Lambda_c^+ \to \Lambda\pi^+\pi^0$: arXiv 2209.08464 (JHEP accepted).

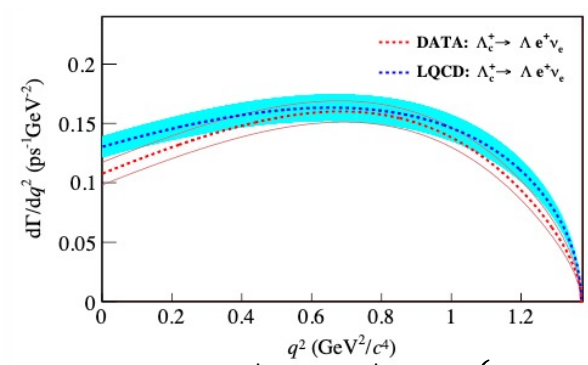
Form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

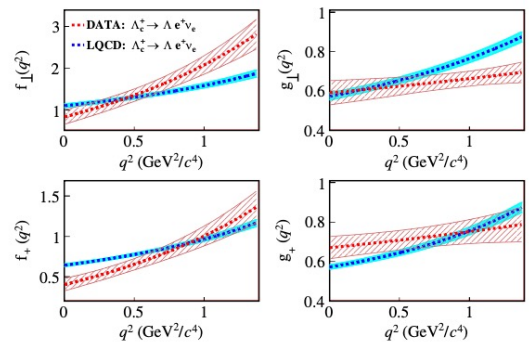
PRL 129,231803(2022)

N=1253±39









- BF is updated to be $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.56 \pm 0.11_{stat} \pm 0.07_{syst})\%$=>precision improved.
- Helicity amplitude deduced form factors can be extracted with 4D fitting to data.
- The differential decay rate is roughly consistent with LQCD calculation while discrepancies can be noticed on FFs show different kinematic behaviors.
- |Vcs| element from charmed baryons is measured to be $0.936 \pm 0.017_{\mathcal{B}} \pm 0.024_{\mathrm{LQCD}} \pm 0.007_{\tau_{\Lambda c}}$ which is consistent with the value obtained in charmed mesons decay.

BF Measurements of $\Lambda_c^+ \to pK^-e^+\nu_e$

arXiv 2207.11483(PRD accepted).

$N(pK^-e^+\nu_e)$=33.5±6.3

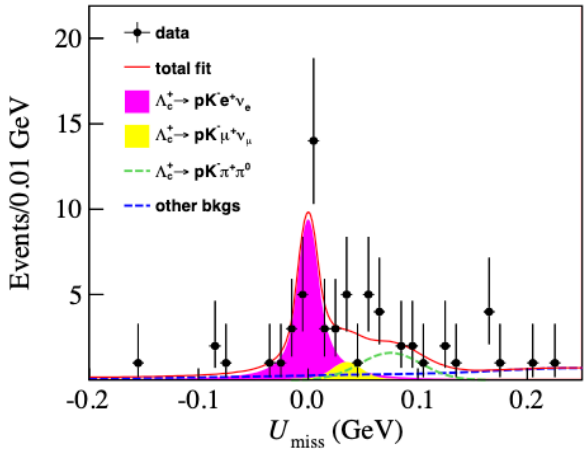


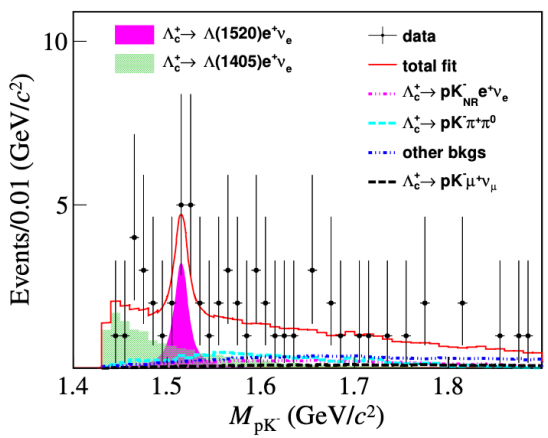
TABLE I. Comparison of $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)/\Lambda(1405)e^+\nu_e)$ [in $\times 10^{-3}$] between theoretical calculations and this measurement. The BF of $\Lambda(1405) \to pK^-$ is unknown.

	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e)$	$\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)e^+\nu_e)$
Constituent quark model [8]	1.01	3.04
Molecular state [9]	−−	0.02
Nonrelativistic quark model [10]	0.60	2.43
Lattice QCD [12, 13]	0.512 ± 0.082	−−
Measurement	$1.02 \pm 0.52 \pm 0.11$	$\frac{0.42\pm0.19\pm0.04}{B(\Lambda(1405)\to pK^-)}$

- $\Lambda_c^+ \to pK^-e^+\nu_e$ is firstly observed with significance of 8.2σ.

$N(\Lambda(1520)e^+\nu_e)$=8.4±4.3
$N(\Lambda(1405)e^+\nu_e)$=14.8±6.7

- Evidence of $\Lambda_c^+ \to \Lambda(1520)e^+\nu_e$ (3.3σ) and $\Lambda_c^+ \to \Lambda(1405)e^+\nu_e$ (3.2σ) are found.

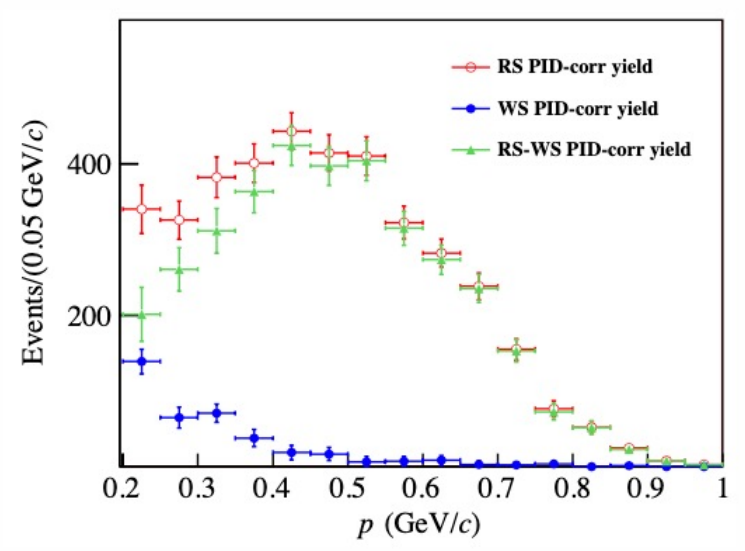


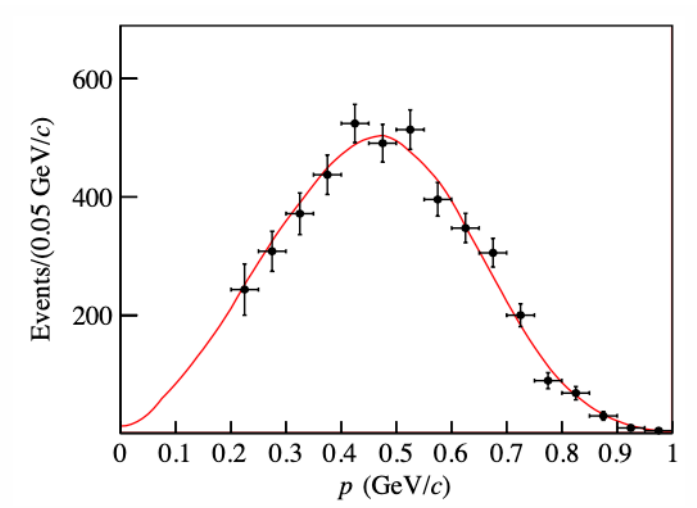
- BFs are measured to be :
  $\mathcal{B}(\Lambda_c^+ \to pK^-e^+\nu_e) = (0.88 \pm 0.17_{stat} \pm 0.07_{syst}) \times 10^{-3}$,
  $\mathcal{B}(\Lambda_c^+ \to \Lambda(1520)\, e^+\nu_e) = (1.36 \pm 0.56_{stat} \pm 0.11_{syst}) \times 10^{-3}$ and
  $\mathcal{B}(\Lambda_c^+ \to pK^-{}_{non-\Lambda(1520)}e^+\nu_e) = (0.53 \pm 0.15_{stat} \pm 0.06_{syst}) \times 10^{-3}$.

- $R = \frac{\mathcal{B}(\Lambda_c^+ \to pK^-e^+\nu_e)}{\mathcal{B}(\Lambda_c^+ \to Xe^+\nu_e)} = (2.1 \pm 0.4_{stat} \pm 0.1_{syst})\%$
  => the only observed SL channel beyond $\Lambda_c^+ \to \Lambda\, l^+\nu_l$

BF measurement of $\Lambda_c^+ \to X e^+ \nu_e$

arXiv 2212.03753 (PRD submitted)





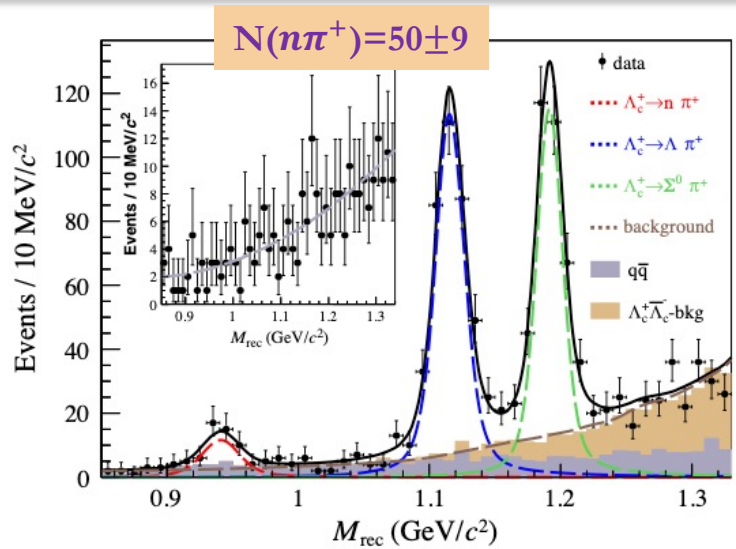
- WS technique is used to subtract charge symmetric backgrounds in each momentum bin.
- PID unfolding approach is performed to obtained the positron yields which is suffered from the contamination of other particle types(π^+、K^+、p).
- Extrapolation of positron momentum spectrum to whole phase space region.
- BF is measured to be $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e) = (4.06 \pm 0.10_{stat} \pm 0.09_{syst})\%$=>precision improved compared with PRL121,251801(2018).
- $\frac{\Gamma(\Lambda_c^+ \to X e^+ \nu_e)}{\Gamma(D \to X e^+ \nu_e)} = (1.28 \pm 0.05)\%$
  => improve the power to identify different predications.
  =>HQE(1.2), EQM(1.67)

PRD49,1310(1994)

PRD83,034025(2011)
PRD86,014017(2012)

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 asymmetry 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 asymmetry and dynamical calculation (2-4.7) while in consistent with SU(3) plus topological-diagram approach(9.6).

BF measurement of $\Lambda_c^+ \to \Lambda K^+$

PRD 106.L111101 (2022)

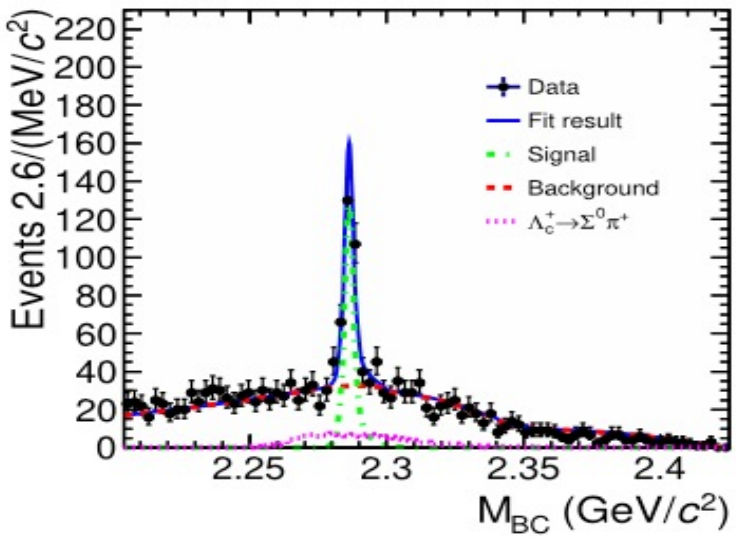


TABLE I. Theoretical predictions on the branching fraction of $\Lambda_c^+ \to \Lambda K^+$.

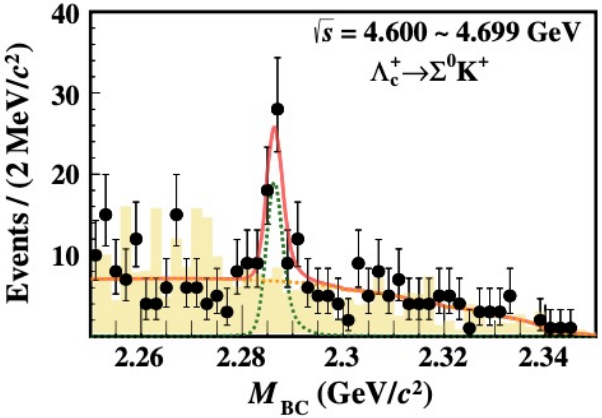
Theoretical predictions	$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)$ ($\times 10^{-3}$)
$SU(3)$ flavor symmetry [8]	1.4
Constituent quark model [14]	1.2
Current algebra [15]	1.06
Diquark picture [16]	0.18–0.39
$SU(3)$ flavor symmetry [17]	0.46 ± 0.09

- Singly Cabibbo-suppressed BF are measured relative to the CF process.
- $R = \frac{\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)}{\mathcal{B}(\Lambda_c^+ \to \Lambda \pi^+)} = (4.78 \pm 0.34_{stat} \pm 0.20_{syst})\%$
  =>Consistent with Belle $(7.4 \pm 1.0_{\mathrm{stat}} \pm 1.2_{\mathrm{syst}})\%$ and BaBar $(4.4 \pm 0.4_{\mathrm{stat}} \pm 0.3_{\mathrm{syst}})\%$
- $\mathcal{B}(\Lambda_c^+ \to \Lambda K^+) = (6.21 \pm 0.44_{stat} \pm 0.26_{syst} \pm 0.34_{ref}) \times 10^{-4}$
  =>significantly lower(~40%) than the prediction based on pure SU(3) flavor symmetry, constituent quark model and current algebra. =>nonfactorizable contribution are underestimated?

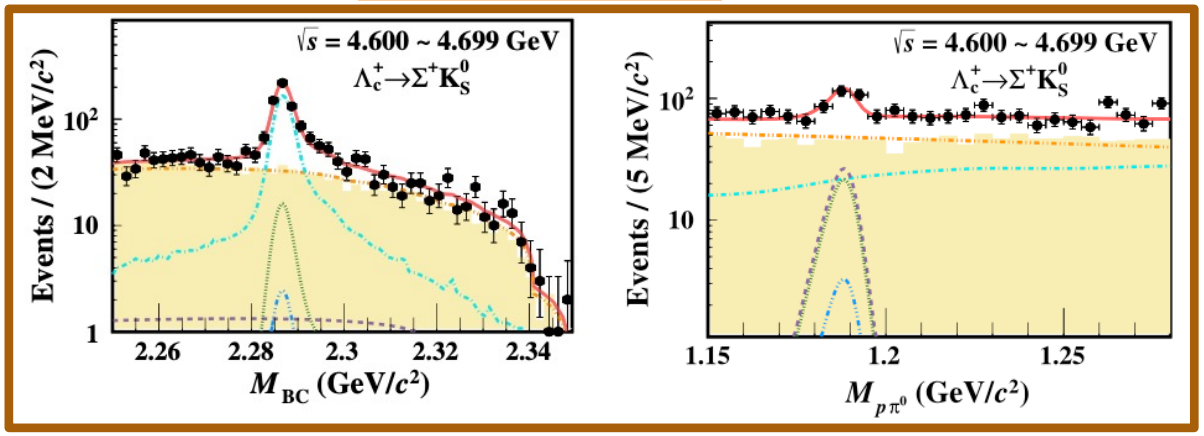
BF measurement of $\Lambda_c^+ \to \Sigma^0 K^+, \Sigma^+ K_S^0$

PRD 106.052003 (2022).

$N(\Sigma^0 K^+)=43.4\pm4.2$



$N(\Sigma^+ K_S^0)=43.6\pm6.0$



- Two singly Cabibbo-suppressed decays which only receive nonfactorizable contribution are observed.

- $R = \frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^0 \pi^+)} = 0.0361 \pm 0.0073_{stat} \pm 0.0005_{syst}$
  $R = \frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+ \pi^+ \pi^-)} = 0.0106 \pm 0.0031_{stat} \pm 0.0004_{syst}$

- $\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+) = (4.7 \pm 0.9_{stat} \pm 0.1_{syst} \pm 0.3_{ref}) \times 10^{-4}$
  $\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0) = (4.8 \pm 1.4_{stat} \pm 0.2_{syst} \pm 0.3_{ref}) \times 10^{-4}$
  First measurement for $\Lambda_c^+ \to \Sigma^+ K_S^0$.
  $\Lambda_c^+ \to \Sigma^0 K^+$ is consistent and comparable with Belle and BaBar.
  In consistent with SU(3) flavor symmetry.

- 2D fitting is performed for $\Lambda_c^+ \to \Sigma^+ K_S^0$ since the contamination of $\Lambda_c^+ \to p K_S^0 \pi^0$

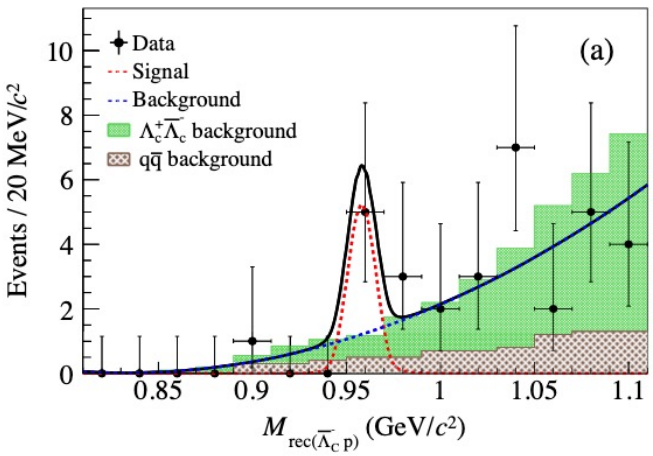
TABLE I. Comparison of various theoretical predictions and the experimental values for $\mathcal{B}(\Lambda_c^+ \to \Sigma K)$ (in unit of 10^{-4}). In Ref. [2], alternative assignments to QCD corrections give different predictions as shown in the parentheses. The theoretical uncertainties in Ref. [3] are estimated to be 25%, arising from a slight change of the MIT bag radius.

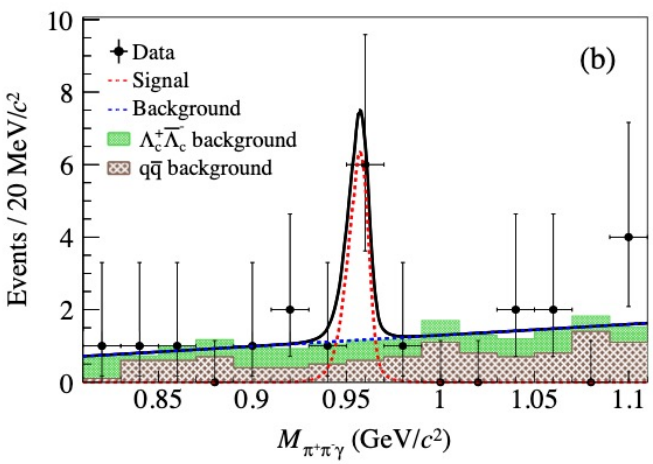
	$\mathcal{B}(\Lambda_c^+ \to \Sigma^0 K^+)$	$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0)$
QCD corrections [2]	2(8)	2(4)
MIT bag model [3]	7.2 ± 1.8	7.2 ± 1.8
Diagrammatic analysis [4]	5.5 ± 1.6	9.6 ± 2.4
$SU(3)_F$ flavor symmetry [5]	5.4 ± 0.7	5.4 ± 0.7
IRA method [6]	5.0 ± 0.6	1.0 ± 0.4
PDG 2020 [28]	5.2 ± 0.8	$\cdots$

First observation of $\Lambda_c^+ \to p\eta'$

PRD 106.072002 (2022).

$N(p\eta', \pi^+\pi^-\eta) = 4.9^{+3.2}_{-2.6}$





$N(p\eta', \gamma\pi^+\pi^-) = 4.3^{+2.6}_{-2.2}$

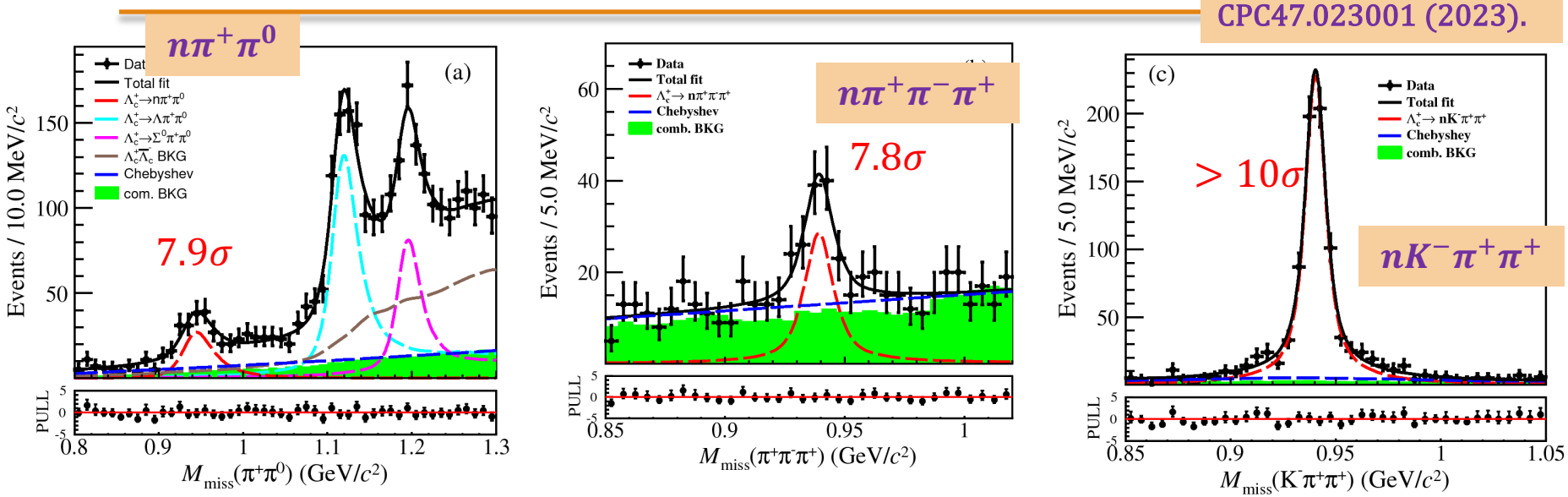
TABLE VI. Comparison of the measured branching fraction (in 10^{-4}) of $\Lambda_c^+ \to p\eta'$ to theoretical predictions and the Belle result.

	$\Lambda_c^+ \to p\eta'$
BESIII	$5.62^{+2.46}_{-2.04} \pm 0.26$
Belle [19]	4.73 ± 0.97
Sharma *et al.* [41]	4–6
Uppal *et al.* [42]	0.4–2
Geng *et al.* [17]	$12.2^{+14.3}_{-8.7}$

- An evidence of singly Cabibbo-suppressed $\Lambda_c^+ \to p\eta'$ decay was obtained(3.6σ).
- Absolute BF is measured to be $\mathcal{B}(\Lambda_c^+ \to p\eta') = (5.62^{+2.46}_{-2.04} \pm 0.26)\times 10^{-4}$.
  =>Consistent with Belle's relative measurement.
  => obviously higher than Constituent quark model
- The statistics of data is quite limited.

First observation of $\Lambda_c^+ \to n\pi^+\pi^0$、$n\pi^+\pi^-\pi^+$、$nK^-\pi^+\pi^+$

CPC47.023001 (2023).



- Two singly Cabibbo-suppressed $\Lambda_c^+ \to n\pi^+\pi^0$、$n\pi^+\pi^-\pi^+$ decays and one CF $\Lambda_c^+ \to nK^-\pi^+\pi^+$ was firstly observed.
- Absolute BFs are measured to be

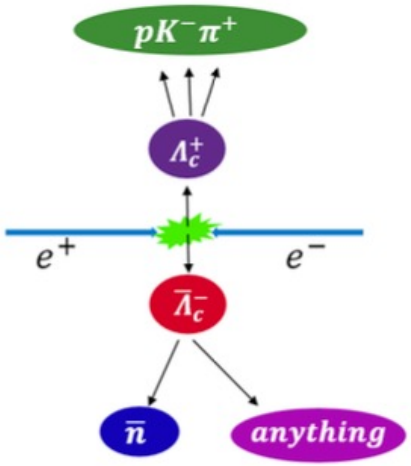
  $\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0) = (0.64 \pm 0.09_{stat} \pm 0.02_{syst})\%$

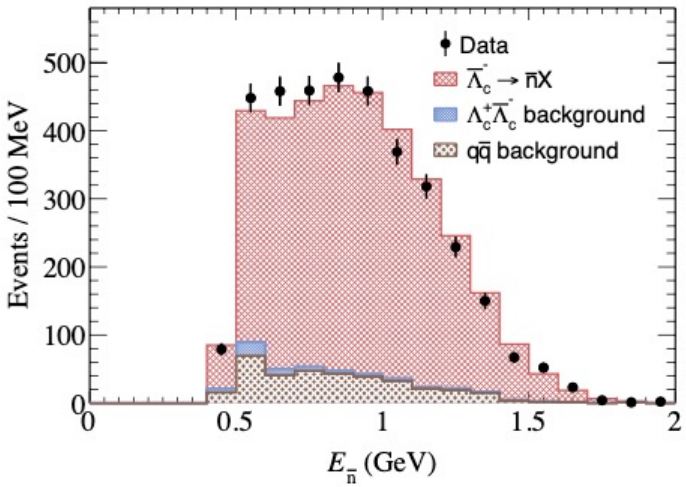
  $\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^-\pi^+) = (0.45 \pm 0.07_{stat} \pm 0.03_{syst})\%$

  $\mathcal{B}(\Lambda_c^+ \to nK^-\pi^+\pi^+) = (1.90 \pm 0.08_{stat} \pm 0.09_{syst})\%$
- $\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^+\pi^-)}{\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0)} = 0.72 \pm 0.11$ =>crucial inputs for SU(3) flavor symmetry.
- $\frac{\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^0)}{\mathcal{B}(\Lambda_c^+ \to n\pi^+)} = 9.7 \pm 2.4$ => intermediate resonances contributions needs to decouple.
- $\frac{\mathcal{B}(\Lambda_c^+ \to n\pi^+\pi^-\pi^+)}{\mathcal{B}(\Lambda_c^+ \to nK^-\pi^+\pi^+)} = 0.24 \pm 0.04$=>consistent with |Vcd|/|Vcs|= 0.224 ± 0.005.

BF measurement of $\bar{\Lambda}_c^- \to \bar{n}X$

arXiv 2210.09561 (PRL submitted)

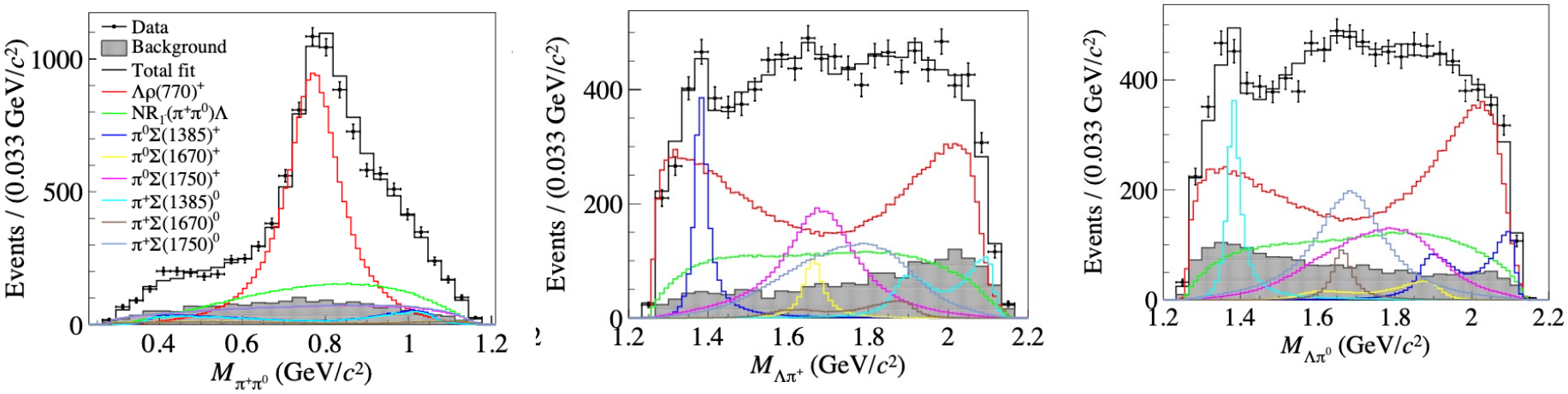




- The deposited energy in EMC is used to identify $\bar{n}$.
- Data-driven technique to model $\bar{n}$ behavior in the detector.
- Absolute BFs are measured to be
  $\mathcal{B}(\bar{\Lambda}_c^- \to \bar{n}X) = (33.5 \pm 0.7_{stat} \pm 1.2_{syst})\%$, precision up to 4%.
- All known exclusive process with neutron in final state is about 25%=>more space to be explored.
- Asymmetry between $\mathcal{B}(\Lambda_c^+ \to nX)$ and $\mathcal{B}(\Lambda_c^+ \to pX)$ is observed.

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

arXiv 2209.08464 (JHEP accepted).



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 between $\Lambda\rho(770)$ and $\Sigma(1385)^{0/+}\pi^{+/0}$.

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

arXiv 2209.08464 (JHEP accepted).

$\frac{1}{2}^+(\Lambda_c^+) \to \frac{3}{2}^+(\Sigma(1385)^+) + 0^-(\pi^0)$			$\frac{1}{2}^+(\Lambda_c^+) \to \frac{3}{2}^+(\Sigma(1385)^0) + 0^-(\pi^+)$		
Amplitude	Magnitude	Phase ϕ (rad)	Amplitude	Magnitude	Phase ϕ (rad)
$g^{\Sigma(1385)^+}_{1,\frac{3}{2}}$	1.0 (fixed)	0.0 (fixed)	$g^{\Sigma(1385)^0}_{1,\frac{3}{2}}$	1.0 (fixed)	0.0 (fixed)
$g^{\Sigma(1385)^+}_{2,\frac{3}{2}}$	1.29 ± 0.25	2.82 ± 0.18	$g^{\Sigma(1385)^0}_{2,\frac{3}{2}}$	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)
$g^{\Sigma(1670)^+}_{1,\frac{3}{2}}$	1.0 (fixed)	0.0 (fixed)	$g^{\Sigma(1670)^0}_{1,\frac{3}{2}}$	1.0 (fixed)	0.0 (fixed)
$g^{\Sigma(1670)^+}_{2,\frac{3}{2}}$	1.39 ± 0.42	0.85 ± 0.26	$g^{\Sigma(1670)^0}_{2,\frac{3}{2}}$	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)
$g^{\Sigma(1750)^+}_{0,\frac{1}{2}}$	1.0 (fixed)	0.0 (fixed)	$g^{\Sigma(1750)^0}_{0,\frac{1}{2}}$	1.0 (fixed)	0.0 (fixed)
$g^{\Sigma(1750)^+}_{1,\frac{1}{2}}$	0.45 ± 0.10	-2.28 ± 0.22	$g^{\Sigma(1750)^0}_{1,\frac{1}{2}}$	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)
$g^{\rho}_{0,\frac{1}{2}}$	1.0 (fixed)	0.0 (fixed)	$g^{NR}_{0,\frac{1}{2}}$	1.0 (fixed)	0.0 (fixed)
$g^{\rho}_{1,\frac{1}{2}}$	0.48 ± 0.12	-1.69 ± 0.12	$g^{NR}_{1,\frac{1}{2}}$	0.94 ± 0.12	-0.49 ± 0.16
$g^{\rho}_{1,\frac{3}{2}}$	0.90 ± 0.10	0.48 ± 0.13	$g^{NR}_{1,\frac{3}{2}}$	0.21 ± 0.09	-2.84 ± 0.53
$g^{\rho}_{2,\frac{3}{2}}$	0.55 ± 0.08	-0.04 ± 0.18	$g^{NR}_{2,\frac{3}{2}}$	0.33 ± 0.14	-1.92 ± 0.30
$\frac{1}{2}^+(\Lambda) \to \frac{1}{2}^+(p) + 0^-(\pi^-)$					
Amplitude	Magnitude	Phase ϕ (rad)			
$g^{\Lambda}_{0,\frac{1}{2}}$	1.0 (fixed)	0.0 (fixed)			
$g^{\Lambda}_{1,\frac{1}{2}}$	0.435376 (fixed)	0.0 (fixed)			

$$\alpha_{\Lambda\rho(770)^+} = \frac{|H^{\rho}_{\frac{1}{2},1}|^2 - |H^{\rho}_{-\frac{1}{2},-1}|^2 + |H^{\rho}_{\frac{1}{2},0}|^2 - |H^{\rho}_{-\frac{1}{2},0}|^2}{|H^{\rho}_{\frac{1}{2},1}|^2 + |H^{\rho}_{-\frac{1}{2},-1}|^2 + |H^{\rho}_{\frac{1}{2},0}|^2 + |H^{\rho}_{-\frac{1}{2},0}|^2}$$
$$= \frac{\sqrt{\frac{1}{9}} \cdot 2 \cdot \Re\left(g^{\rho}_{0,\frac{1}{2}} \cdot \bar{g}^{\rho}_{1,\frac{1}{2}} - g^{\rho}_{1,\frac{3}{2}} \cdot \bar{g}^{\rho}_{2,\frac{3}{2}}\right) - \sqrt{\frac{8}{9}} \cdot 2 \cdot \Re\left(g^{\rho}_{0,\frac{1}{2}} \cdot \bar{g}^{\rho}_{1,\frac{3}{2}} + g^{\rho}_{1,\frac{1}{2}} \cdot \bar{g}^{\rho}_{2,\frac{3}{2}}\right)}{|g^{\rho}_{0,\frac{1}{2}}|^2 + |g^{\rho}_{1,\frac{1}{2}}|^2 + |g^{\rho}_{1,\frac{3}{2}}|^2 + |g^{\rho}_{2,\frac{3}{2}}|^2}. \quad (4.28)$$

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

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

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

arXiv 2209.08464 (JHEP accepted).

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)}{\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0)} = (57.2 \pm 4.2 \pm 4.9)\%,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0) \cdot \mathcal{B}(\Sigma(1385)^+ \to \Lambda\pi^+)}{\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0)} = (7.18 \pm 0.60 \pm 0.64)\%,$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+) \cdot \mathcal{B}(\Sigma(1385)^0 \to \Lambda\pi^0)}{\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\pi^0)} = (7.92 \pm 0.72 \pm 0.80)\%.$$

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+) = (4.06 \pm 0.30 \pm 0.35 \pm 0.23)\%,$$

$$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0) = (5.86 \pm 0.49 \pm 0.52 \pm 0.35) \times 10^{-3},$$

$$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+) = (6.47 \pm 0.59 \pm 0.66 \pm 0.38) \times 10^{-3},$$

$$\alpha_{\Lambda\rho(770)^+} = -0.763 \pm 0.053 \pm 0.039,$$

$$\alpha_{\Sigma(1385)^+\pi^0} = -0.917 \pm 0.069 \pm 0.046,$$

$$\alpha_{\Sigma(1385)^0\pi^+} = -0.789 \pm 0.098 \pm 0.056.$$

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 ± 0.066	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.083	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [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.

Coming soon stay tunned

- $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$ for lepton flavor universality and also the FF will also be accessed.
- $\Lambda_c^+ \to ne^+\nu_e$
- $\Lambda_c^+ \to \Lambda\pi^+\pi^-e^+\nu_e(\Lambda(1520)\Lambda(1600)/e^+\nu_e)$、$pK_s^0\pi^-e^+\nu_e$
- $\Lambda_c^+ \to \Sigma^+\pi^-e^+\nu_e$、 $\Sigma^-\pi^+e^+\nu_e$
- $\Lambda_c^+ \to p\pi^-e^+\nu_e$
- $\Lambda_c^+ \to nK_s^0e^+\nu_e$

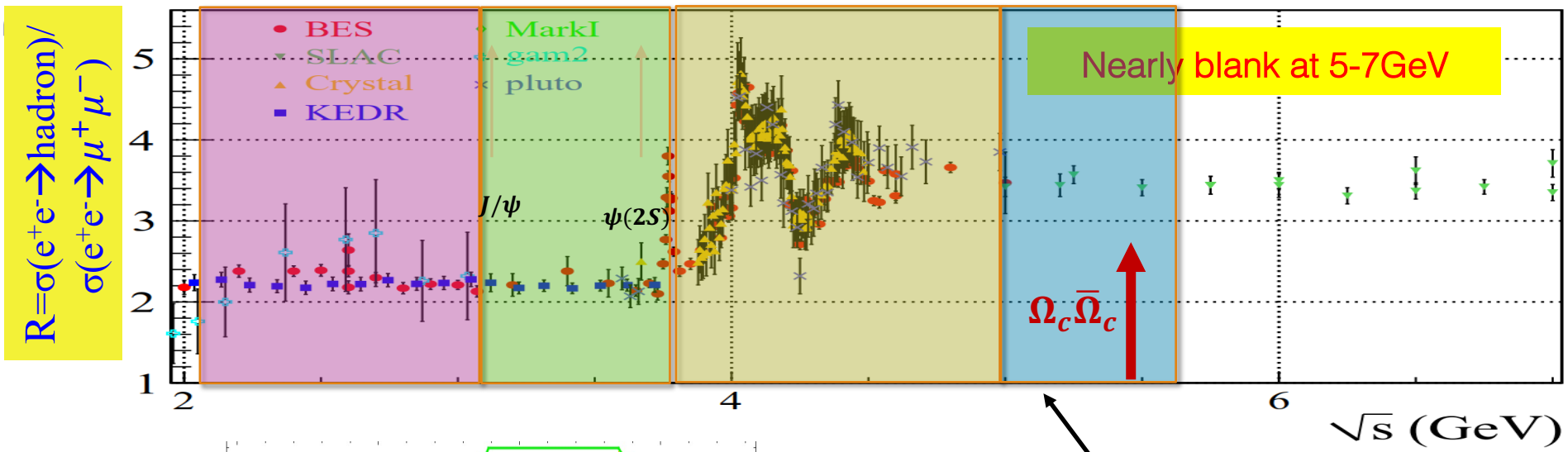
- $\Lambda_c^+ \to p\eta$、 $p\omega$、 $p\pi^0$
- $\Lambda_c^+ \to pK_L^0$、 $pK_L^0\pi^0$、 $pK_L^0\pi^+\pi^-$
- $\Lambda_c^+ \to \Sigma^+\eta$、 $\Sigma^+\eta'$

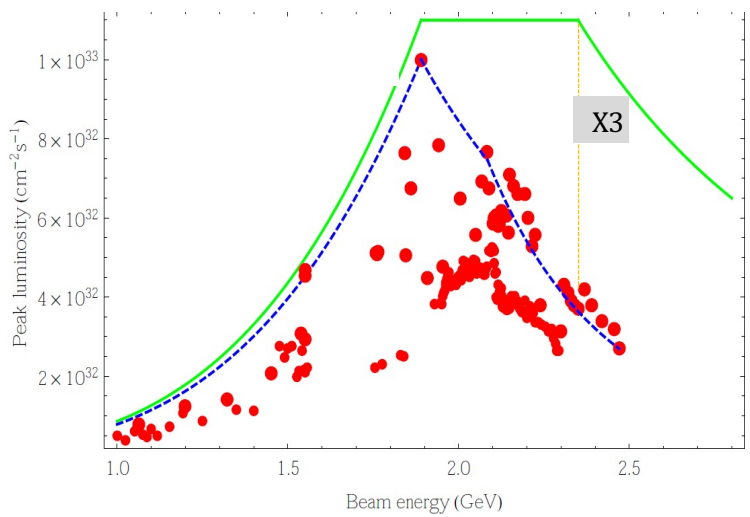
- 12 tag modes including $\Lambda_c^+ \to p\mathrm{K}^-\pi^+$
- $\Lambda_c^+ \to \Sigma^+\mathrm{K}^+\mathrm{K}^+\ (\phi)$、 $\Sigma^+\mathrm{K}^+\pi^-(\pi^0)$
- $\Lambda_c^+ \to \Sigma^-\mathrm{K}^+\pi^+$、 $\Xi^-\mathrm{K}^+\pi^+$
- $\Lambda_c^+ \to n\mathrm{K}^+\pi^0$、$\Lambda\mathrm{K}^+\pi^0$、$\Sigma^0\mathrm{K}^+\pi^0$、 $\Xi^0\mathrm{K}^+\pi^0$
- $\Lambda_c^+ \to nK_s^0\pi^+$、 $nK_s^0\mathrm{K}^+$
- $\Lambda_c^+ \to \Lambda K_s^0\mathrm{K}^+$、$\Lambda K_s^0\pi^+(\Lambda\mathrm{K}^{*+})$
- $\Lambda_c^+ \to \Lambda K_s^0\mathrm{K}^+$、 $\Sigma^0K_s^0\mathrm{K}^+$、 $\Xi^0K_s^0\mathrm{K}^+$
- $\Lambda_c^+ \to \Lambda\mathrm{K}^+\pi^0$、 $\Lambda\mathrm{K}^+\pi^+\pi^-$

- Weak radiative decay $\Lambda_c^+ \to \gamma\Sigma^+$
- Decay asymmetry for $\Lambda_c^+ \to \Xi^0\mathrm{K}^+$、$p\phi$
- Decay asymmetry and polarization study for $\Lambda_c^+ \to pK_s^0$、 $\Lambda\pi^+$、 $\Sigma^0\pi^+$、$\Sigma^+\pi^0$
- Inclusive BF of $\Lambda_c^+ \to \Lambda X$、$K_s^0X$、$pX$
- Cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$、$\Lambda_c^+\bar{\Lambda}_c^{*-}$

Proposal of the BEPCII upgrade

- optimized energy at 2.35 GeV with luminosity 3 times higher than the current BEPCII.





4.95 ~ 5.6 GeV: new energy coverage of BEPCII-upgrade

Energy thresholds

✓	$\Lambda_c^+\bar{\Sigma}_c^-$	4.74 GeV
✓	$\Lambda_c^+\bar{\Sigma}_c\ \pi$	4.88 GeV
✓	$\Sigma_c\ \bar{\Sigma}_c$	4.91 GeV
✓	$\Xi_c\ \bar{\Xi}_c$	4.95 GeV
✓	$\Omega_c^0\bar{\Omega}_c^0$	5.4 GeV

Prospect Charm Baryons data sample at BESIII

Table 7.1. List of data samples collected by BESIII/BEPCII up to 2019, and the proposed samples for the remainder of the physics program. The right-most column shows the number of required data taking days with the current (T_C) and upgraded (T_U) machine. The machine upgrades include top-up implementation and beam current increase.

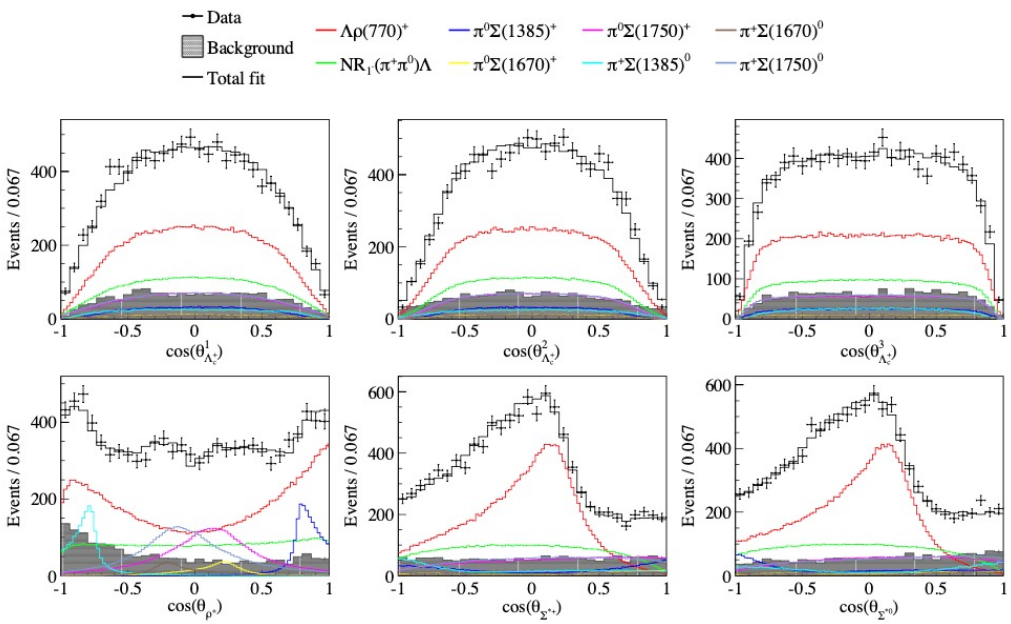
Energy	Physics motivations	Current data	Expected final data	T_C / T_U
1.8 - 2.0 GeV	R values Nucleon cross-sections	N/A	0.1 fb^{-1} (fine scan)	60/50 days
2.0 - 3.1 GeV	R values Cross-sections	Fine scan (20 energy points)	Complete scan (additional points)	250/180 days
J/ψ peak	Light hadron & Glueball J/ψ decays	3.2 fb^{-1} (10 billion)	3.2 fb^{-1} (10 billion)	N/A
$\psi(3686)$ peak	Light hadron & Glueball Charmonium decays	0.67 fb^{-1} (0.45 billion)	4.5 fb^{-1} (3.0 billion)	150/90 days
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays	2.9 fb^{-1}	20.0 fb^{-1}	610/360 days
3.8 - 4.6 GeV	R values XYZ/Open charm	Fine scan (105 energy points)	No requirement	N/A
4.180 GeV	D_s decay XYZ/Open charm	3.2 fb^{-1}	6 fb^{-1}	140/50 days
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	16.0 fb^{-1} at different $\sqrt{s}$	30 fb^{-1} at different $\sqrt{s}$	770/310 days
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

Summary

- BEPCII energy upgrade during 2020-2021 has improved the BESIII capability in Λ_c physics by accumulating more statistics at different energy points and pose opportunity to study $\Sigma_c/\Xi_c/\Lambda_c^*$ related physics
- BESIII has been playing significant role in studying Λ_c decays
- Many new results of Λ_c decays have been published in 2022.
- Proposal of BEPCII upgrade (3x luminosity and energy up to 5.6 GeV) will greatly extend the physics opportunities in c-baryon sector

Thanks

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



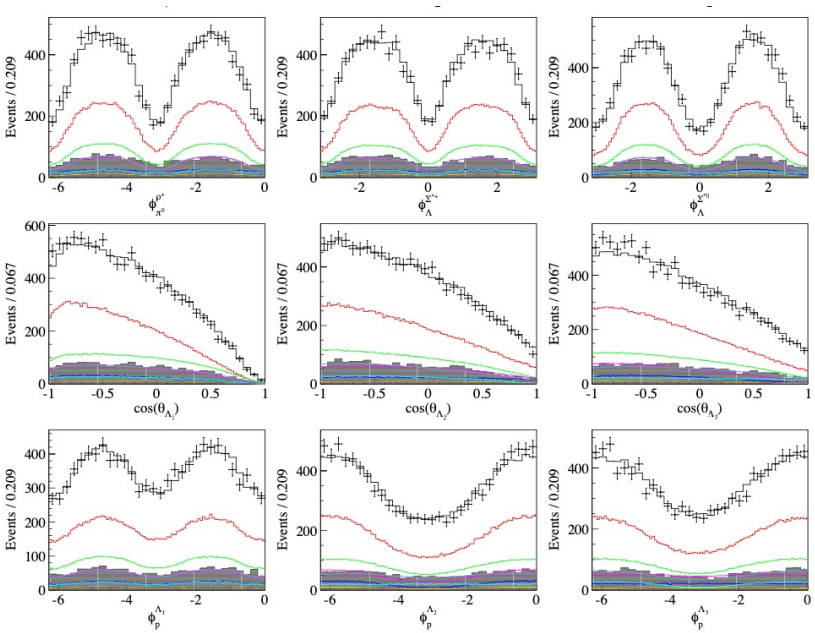


Figure 6. Projections of the fit results in the distributions of helicity angles.