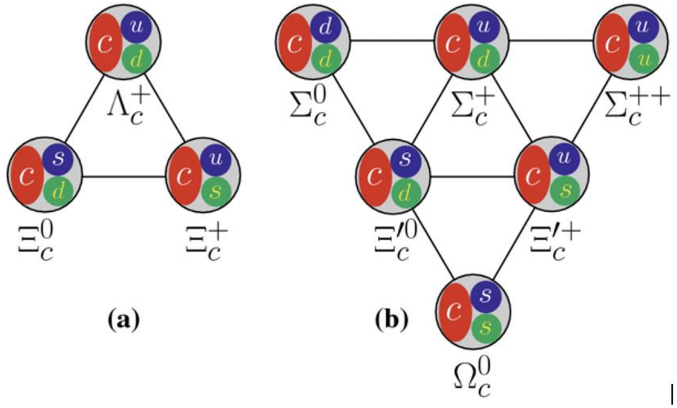

Recent experimental progress on Λ_c^+ decays

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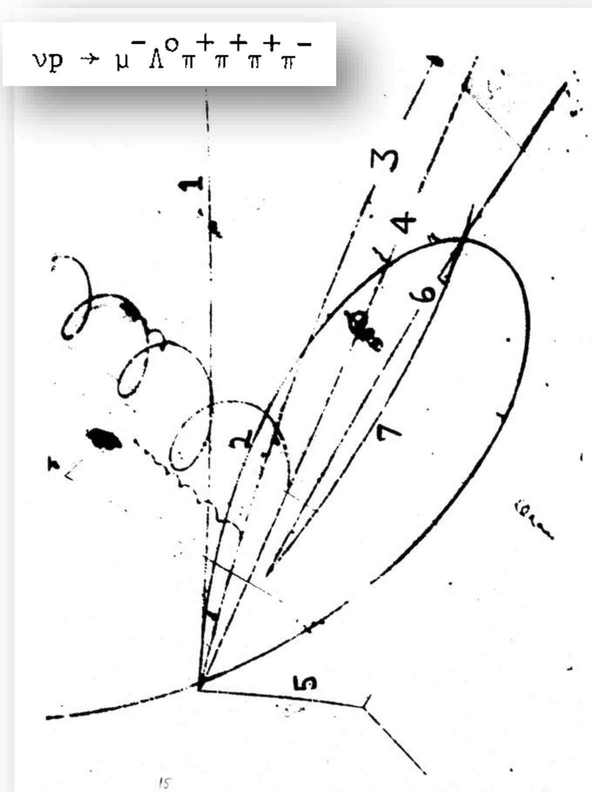
see review article: arXiv:2509.19141

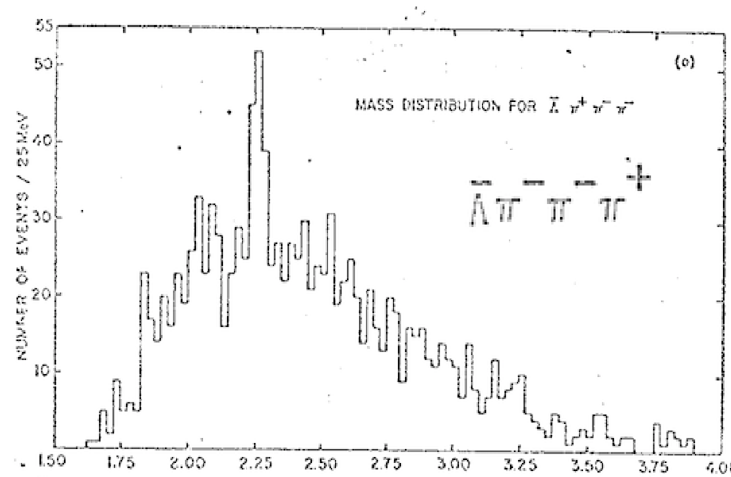
Outline

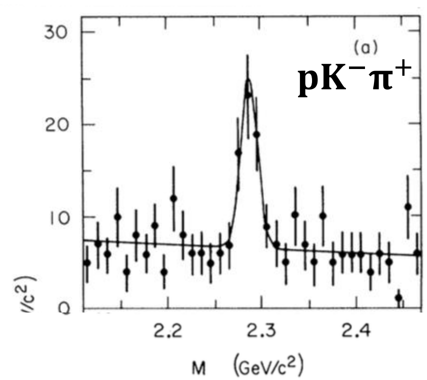
- Introduction to the charmed baryons
- Recent experimental progress in the Λ_c^+ decays
- Future
- Summary

Discovery of the charmed heavy baryon

- Not exclusively clear about the first observation
- A number of experiments which published evidence for the charmed baryons beginning in 1975
  - ✓ First hint of charmed baryon $\Sigma_c^{++} \rightarrow \Lambda_c^+ \pi^+$ in BNL PRL34, 1125 (1975)
  - ✓ First evidence of Λ_c^+ at Fermi Lab PRL37, 882 (1976)
- The first well established state is the Λ_c^+ at MarkII PRL44, 10 (1980)

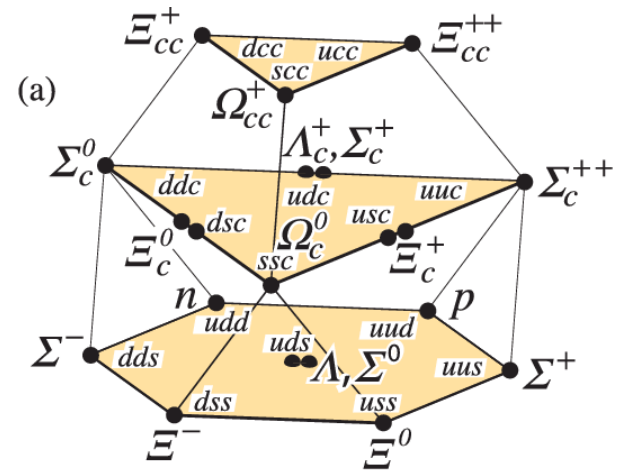






The charmed baryon family

- Singly charmed baryons
  - ✓ Established ground states:
    Λ_c^+, Σ_c , $\Xi_c^{(\prime)}$, Ω_c
  - ✓ Excited states are being explored
- Observation of other doubly charmed baryon Ξ_{cc}^{++}
- No observations of other doubly or triply charmed baryons

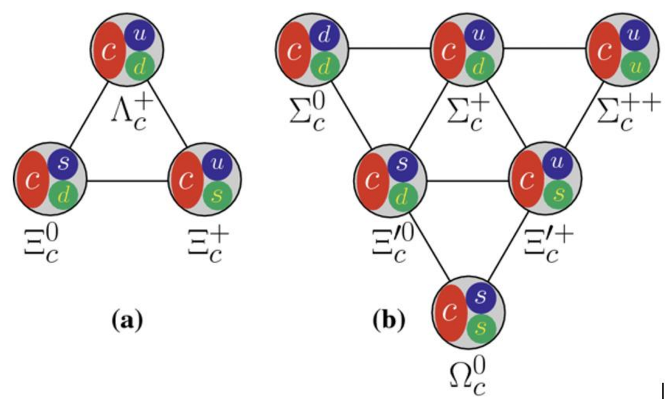


➢ Λ_c^+: decay only weakly, **many experimental progress since 2014**

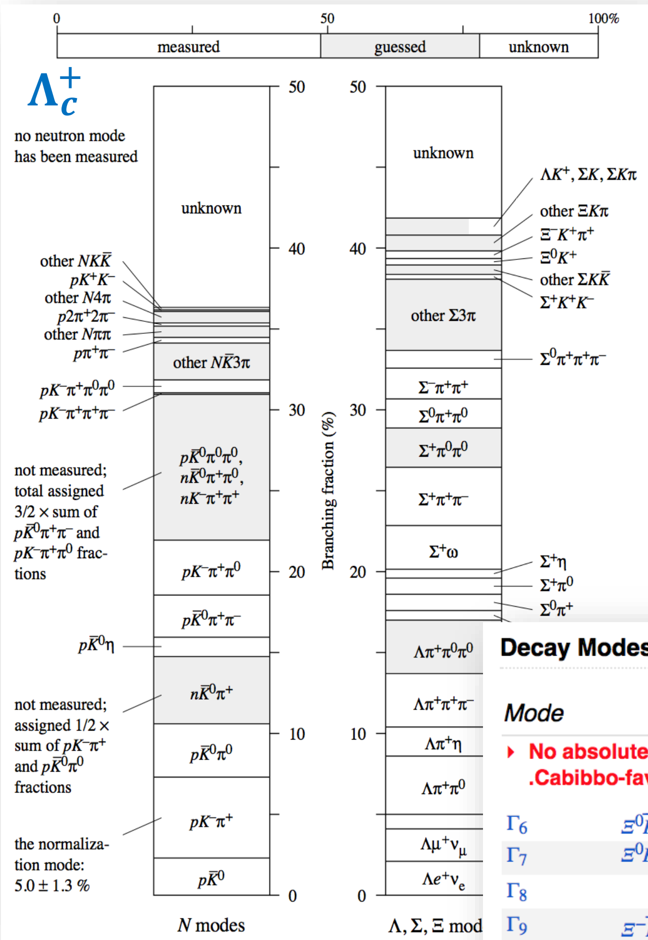
➢ Σ_c : $B(\Sigma_c \to \Lambda_c^+\pi)$~100%; $B(\Sigma_c \to \Lambda_c^+\gamma)$?

➢ Ξ_c : decay only weakly; absolute BF measured with poor precision

➢ Ω_c : decay only weakly; no absolute BF measured



Knowledge of charmed baryon decays before 2014



Ξ_c^+: relative to the decay of $\Xi^- 2\pi^+$

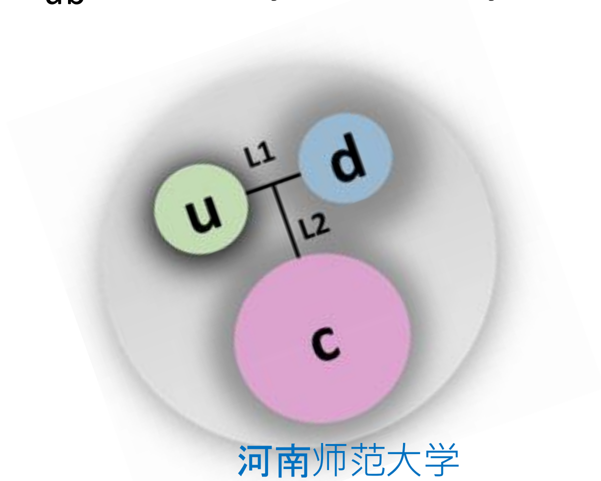
	Mode	Fraction (Γ_i/Γ)
	No absolute branching fractions have been measured.The following are branching to $\Xi^-\pi^+$ .Cabibbo-favored ($S = -2$) decays — relative to $\Xi^-\pi^+$	
Γ_1	$p2K_S^0$	0.087 ± 0.021
Γ_2	$\Lambda\bar{K}^0\pi^+$	
Γ_3	$\Sigma(1385)^+\bar{K}^0$	1.0 ± 0.5
Γ_4	$\Lambda K^-2\pi^+$	0.323 ± 0.033
Γ_5	$\Lambda\bar{K}^*(892)^0\pi^+$	< 0.16
Γ_6	$\Sigma(1385)^+K^-\pi^+$	< 0.23
Γ_7	$\Sigma^+K^-\pi^+$	0.94 ± 0.10
Γ_8	$\Sigma^+\bar{K}^*(892)^0$	0.81 ± 0.15
Γ_9	$\Sigma^0K^-2\pi^+$	0.27 ± 0.12
Γ_{10}	$\Xi^0\pi^+$	0.55 ± 0.16
Γ_{11}	$\Xi^-2\pi^+$	**DEFINEDAS1**
		< 0.10
		2.3 ± 0.7
		1.7 ± 0.5
		$2.3^{+0.7}_{-0.8}$
		0.07 ± 0.04
	…ative to $\Xi^-\pi^+$	
		0.21 ± 0.04
		0.116 ± 0.030
		0.48 ± 0.20
		0.18 ± 0.09
		0.15 ± 0.06

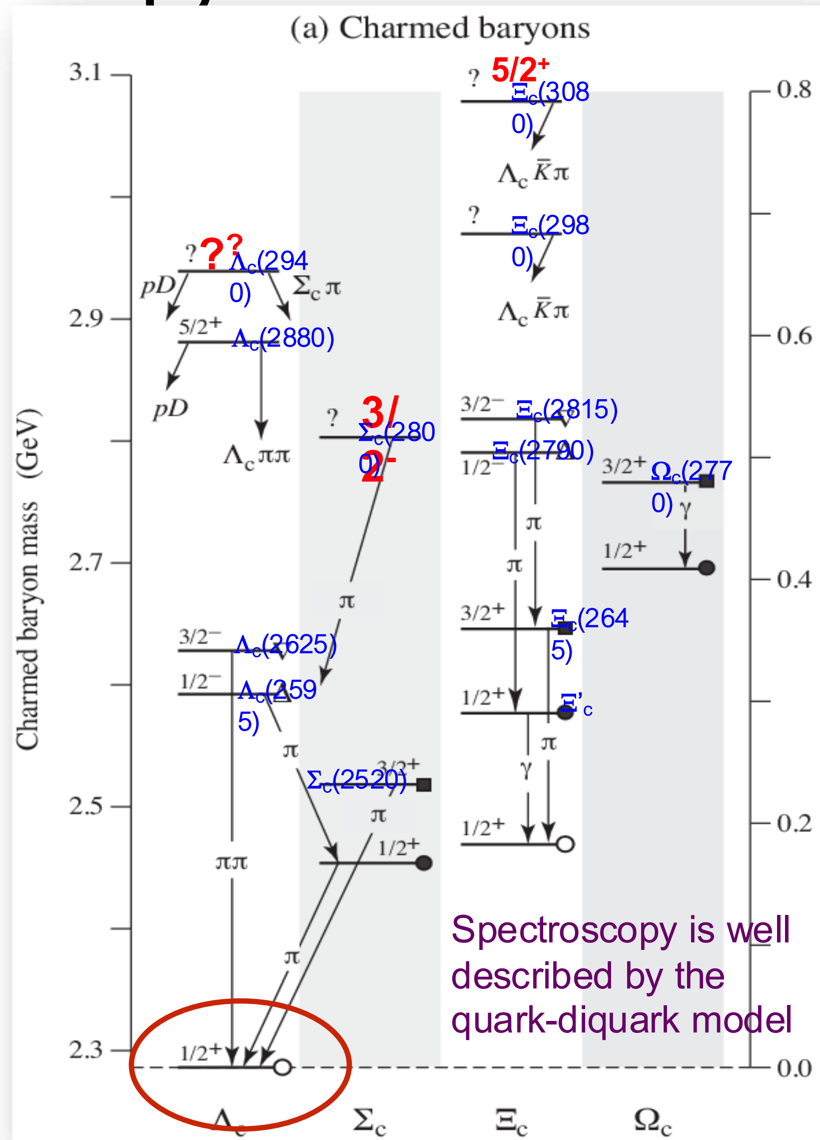
Decay Modes Ω_c^0

	Mode	Fraction (Γ_i/Γ)
	No absolute branching fractions have been measured.The following are branching ra .Cabibbo-favored ($S = -3$) decays – relative to $\Omega^-\pi^+$	
Γ_6	$\Xi^0\bar{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0K^-\pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0\bar{K}^{*0}$, $\bar{K}^{*0} \to K^-\pi^+$	0.68 ± 0.16
Γ_9	$\Xi^-\bar{K}^0\pi^+$	2.12 ± 0.28
Γ_{10}	$\Xi^-K^-2\pi^+$	0.63 ± 0.09
Γ_{11}	$\Xi(1530)^0K^-\pi^+$, $\Xi^{*0} \to \Xi^-\pi^+$	0.21 ± 0.06
Γ_{12}	$\Xi^-\bar{K}^{*0}\pi^+$	0.34 ± 0.11
Γ_{13}	$\Sigma^+K^-K^-\pi^+$	< 0.32
Γ_{14}	$\Lambda\bar{K}^0\bar{K}^0$	1.72 ± 0.35

Λ_c^+ : cornerstone of charmed baryon spectroscopy

- The lightest charmed baryon
- Most of the charmed baryons will eventually decay to Λc
- The Λc is one of important tagging hadrons in c-quark counting in the productions at high energy energies and Bottom baryon decays
- $B(\Lambda_c^+ \to pK^-\pi^+)$: dominant error for V_{ub} via baryon decay

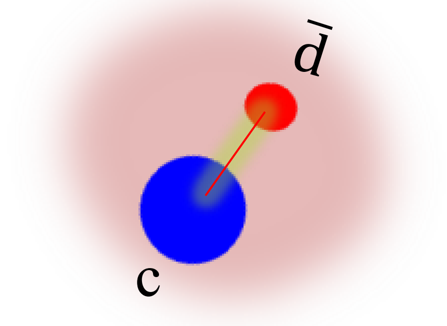


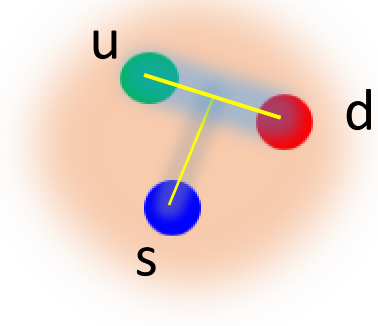


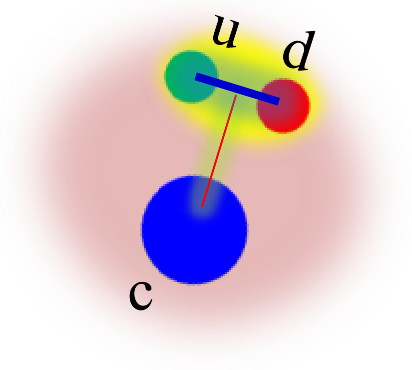
Quark model picture

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.*







→ Charmed meson ($D^+[c\bar{d}]$)

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

→ Strange baryons ($\Lambda[uds]$)

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

→ Charmed baryon ($\Lambda_c[udc]$)

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

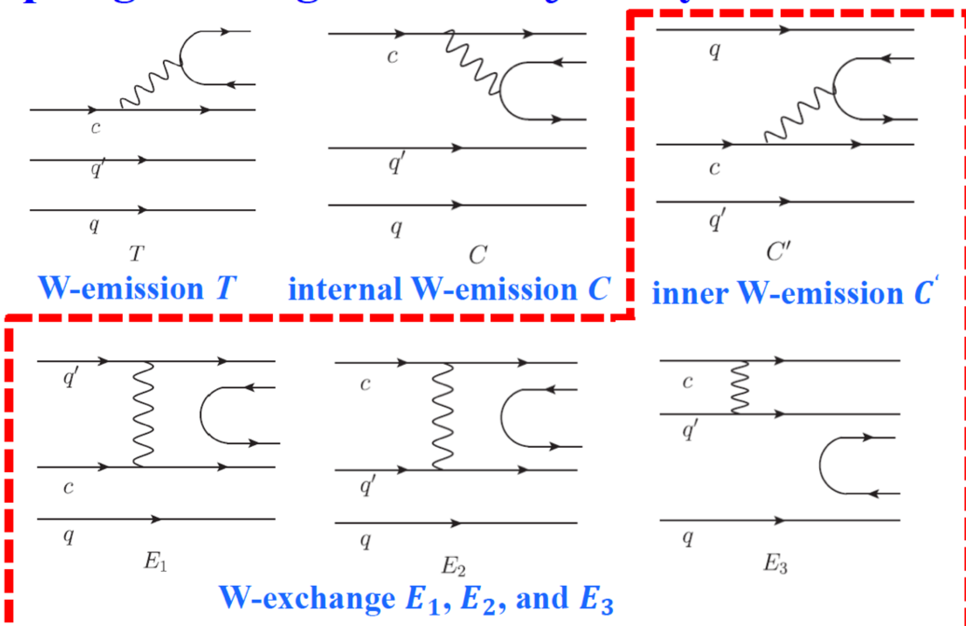
In some sense, more reliable prediction of heavy-light quark transition without dealing with light degrees of freedom that have net spin or isospin.

Λ_c^+ may provide complementary powerful test on internal dynamics to D/Ds does

Λ_c^+ weak decays

- Contrary to charmed meson, W-exchange contribution is important
- More information on the strong dynamics in the charm sector than those from the charmed meson decays

Topological Diagrams for Λ_c^+ decays:



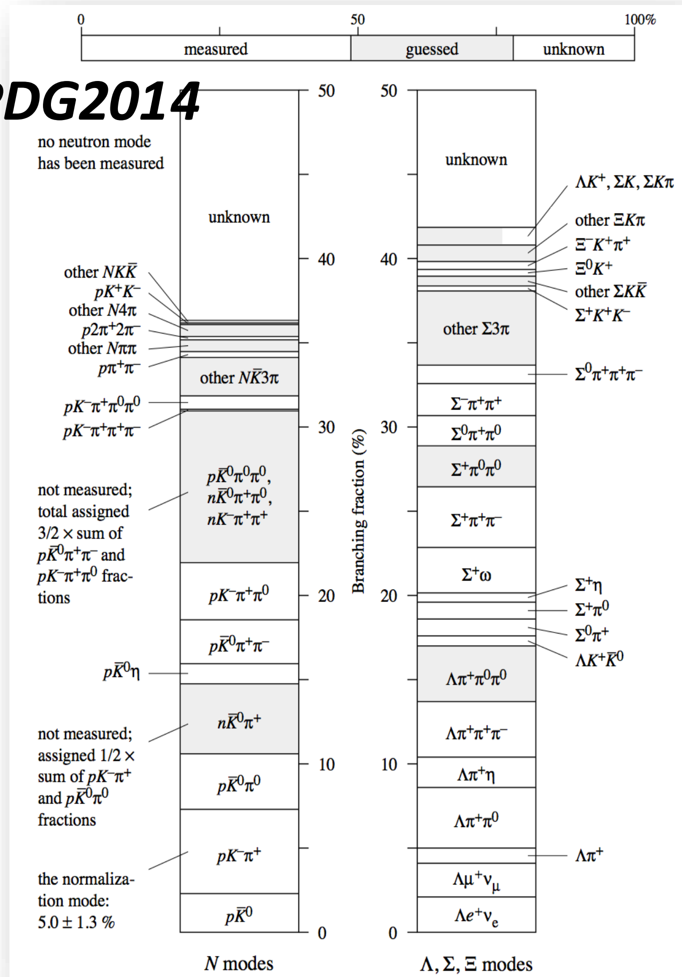
H.-Y. Cheng *et al.*, *Chinese Journal of Physics*, 78(2022) 324-362

Non-factorization amplitude
→ Calculation is not reliable,
need exp. input

The Λ_c^+ decays

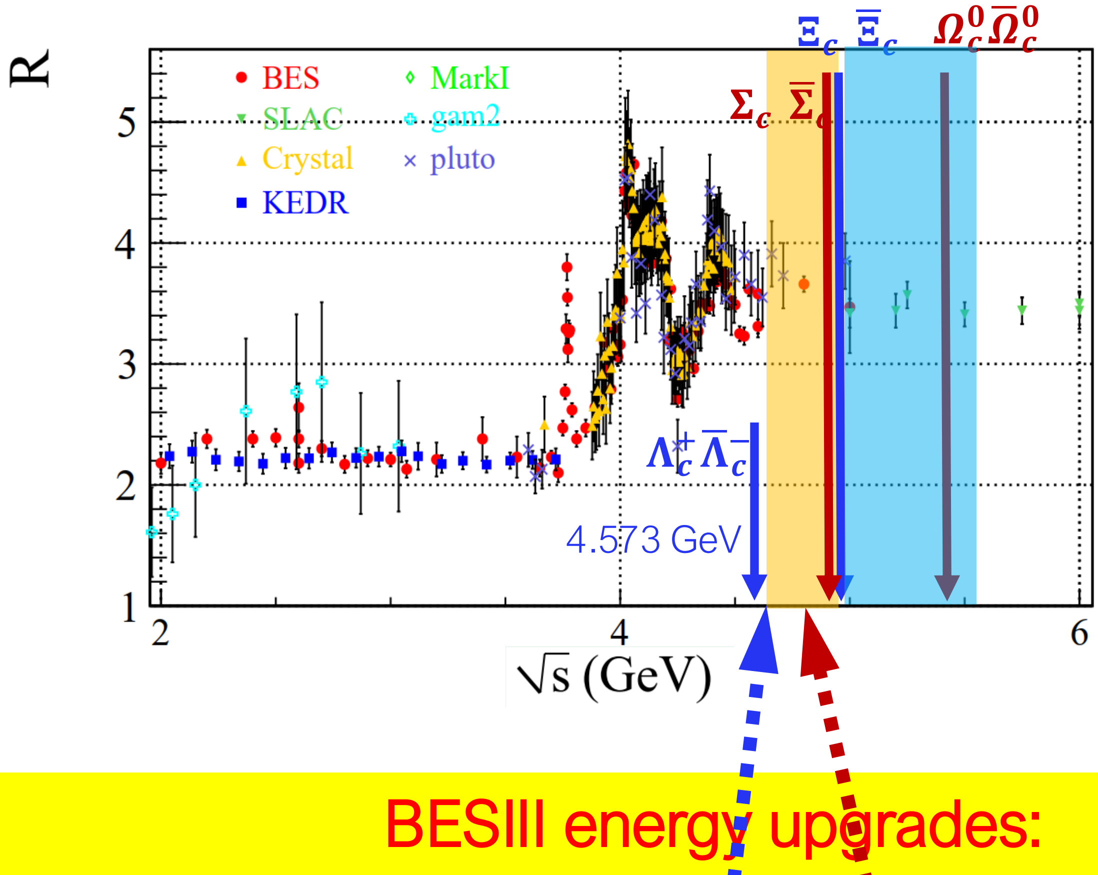
Since 1980's, the Λ_c^+ have been produced and studied at many experiments, notably fixed-target experiments (such as FOCUS and SELEX) and e^+e^- B-factories (ARGUS, CLEO, BABAR, and BELLE).

PDG2014



- Before 2014, absolute branching fractions (BF) of Λ_c^+ decays are still not well determined
  ➔ BFs of all measured decay modes are measured relative to $\Lambda_c^+ \to pK^-\pi^+$
- No completely model-independent measurements of $B(\Lambda_c^+ \to pK^-\pi^+)$: *uncertainties of BFs of Λ_c^+ decays are 25%~40% in PDG2014*
- The sum of measured BFs is only about 60%. Many missing channels, *esp.*, those leptonic or neutron-involved decays

Charmed baryon thresholds



BESIII energy upgrades:

4.6 GeV (Phase I, 2014)

→ 4.95 GeV(Phase II, 2021)

→ 5.6 GeV (Phase III, planned in 2026)

Specialties of current ongoing experiments

BESIII

- Threshold production & two body process
- Clean background
- Absolute meas. with many systematics cancel out
- Missing-mass technique: neutron, neutrino …
- Good photon resolution: Σ, Ξ, π^0, …

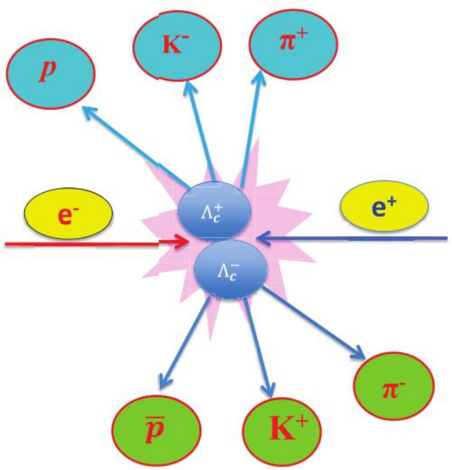
Belle (II) & LHCb

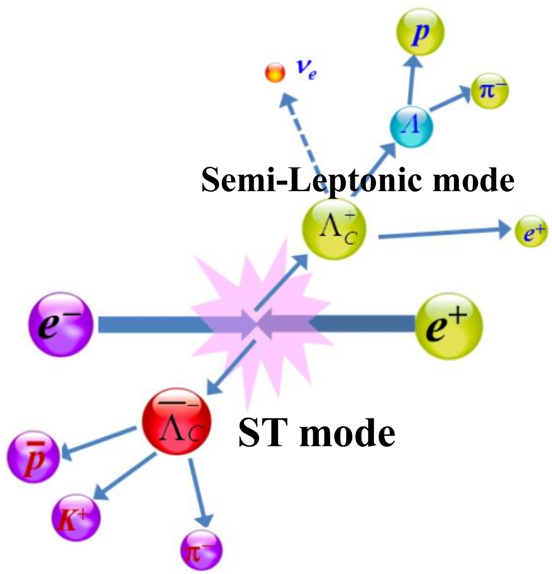
- Large statistics
- High background
- Good PID and vertexing
- Complex production environment
- Good hadron-ID and μ-ID
- Good photon resolution in electron machines

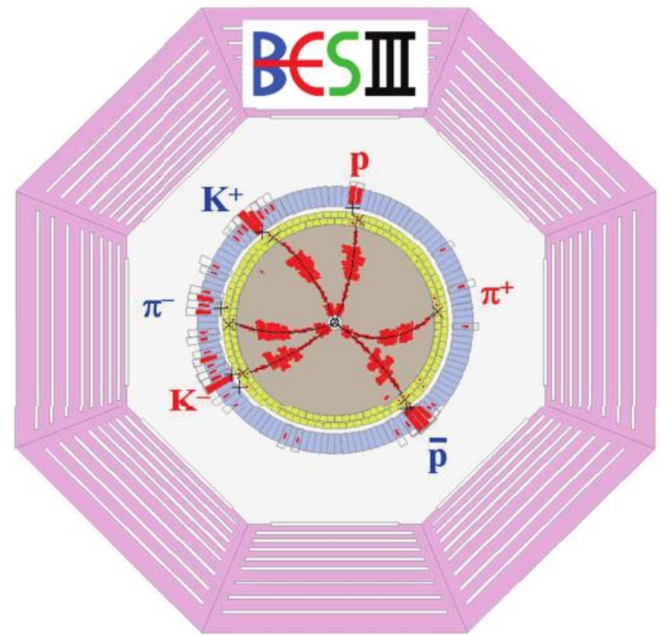
They are complementary!

Single Tag (ST) and Double Tag (DT) method at Threshold

The absolute BF can be obtained by the ratio of DT yields to ST yields.







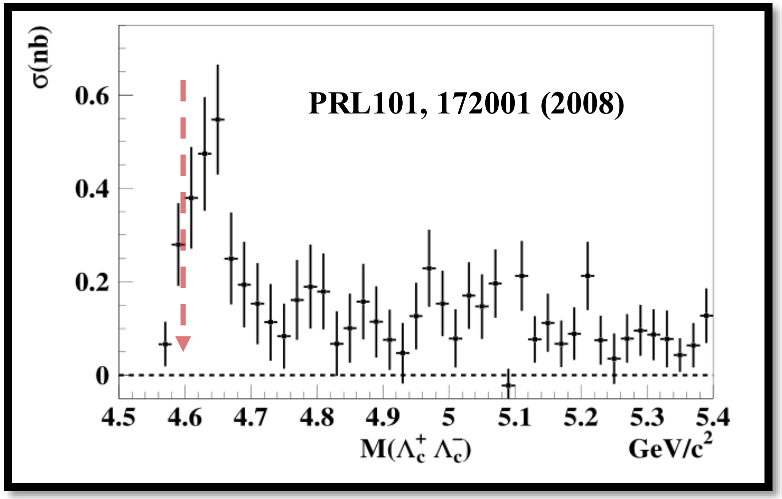
- High efficiency and clean background
- Absolute measurement with many systematics cancel out
- Missing-mass technique: K_L/neutron, neutrino, …
- Good photon resolution: Σ, Ξ, π^0, …

$$\mathcal{B}_i = \frac{N_{ij}^{\mathrm{DT}}}{N_j^{\mathrm{ST}}} \frac{\varepsilon_j}{\varepsilon_{ij}}$$

Near threshold production at BESIII

In 2014, BESIII took (only!) 35 days to run at 4.6GeV and collected ~500/pb data.

Energy(GeV)	lum.(1/pb)
4.575	47.67
4.580	8.54
4.590	8.16
4.600	566.93



Corresponds to 0.1M Λ_c pairs

Measurement using the threshold pair-productions via e^+e^- annihilations is unique: *the most simple and straightforward*

First time to systematically study charmed baryon at threshold!

Physics publications based on Phase I data

Published 17 papers

- A series of precise absolute BF measurements: hadronic, semi-leptonic and inclusive decays
- Observation of decays into neutron $\Lambda_c^+ \to nK_s\pi^+, \Sigma^-\pi^+\pi^+\pi^0$
- Threshold cross section and form factors of Λ_c^+ pairs
- Observation of Cabbibo-suppressed decay $\Lambda_c^+ \to p\pi^+\pi^-$
- First evidence of Cabbibo-suppressed decay $\Lambda_c^+ \to p\eta$
- First measurements of many decay asymmetries
- Determination of Λ_c^+ spin

Very productive for the data set taken in 35 days!

2014 : 0.567 fb^{-1} at 4.6 GeV

Hadronic decay

$\Lambda_c^+ \to pK^-\pi^+$ + 11 CF modes	**PRL 116, 052001 (2016)**
$\Lambda_c^+ \to pK^+K^-, p\pi^+\pi^-$	**PRL 117, 232002 (2016)**
$\Lambda_c^+ \to nK_s\pi^+$	**PRL 118, 12001 (2017)**
$\Lambda_c^+ \to p\eta, p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	PLB 772, 388 (2017)
$\Lambda_c^+ \to \Xi^{0(*)}K^+$	PLB 783, 200 (2018)
$\Lambda_c^+ \to \Lambda\eta\pi^+$	PRD 99, 032010 (2019)
$\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$	CPC 43, 083002 (2019)
$\Lambda_c^+ \to$ BP decay asymmetries	PRD 100, 072004 (2019)
$\Lambda_c^+ \to pK_s\eta$	PLB 817, 136327 (2021)
Λ_c^+ spin determination	PRD 103, L091101(2021)

Semi-leptonic decay

$\Lambda_c^+ \to \Lambda e^+\nu_e$	**PRL 115, 221805(2015)**
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$	PLB 767, 42 (2017)

Inclusive decay

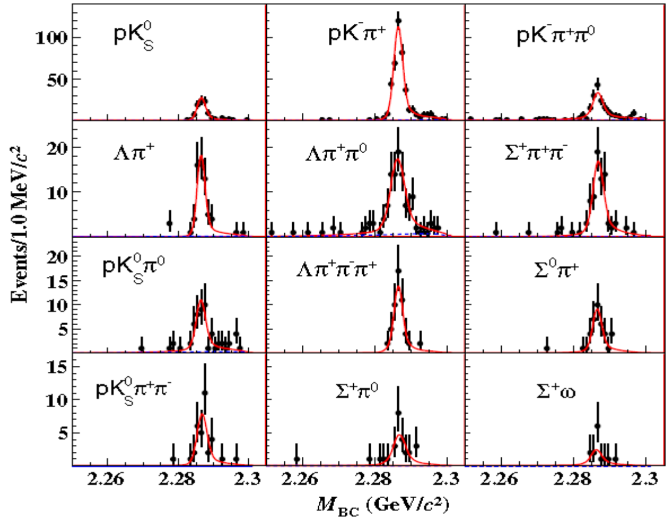
$\Lambda_c^+ \to \Lambda X$	**PRL121, 062003 (2018)**
$\Lambda_c^+ \to e^+X$	**PRL 121 251801(2018)**
$\Lambda_c^+ \to K_S^0X$	EPJC 80, 935 (2020)

Production

$\Lambda_c^+\bar{\Lambda}_c^-$ cross section	**PRL 120,132001(2018)**

Absolute BFs of Λ_c^+ hadronic decays

- Absolute BF of Λ_c^+ decays are still not well determined since its discovery 30 years ago. PDG2014: δB/B~26%; BELLE2014: δB/B~5.3%
- Double tag technique is applied to control systematics



- a global least square fit to 12 hadronic modes [Chin. Phys. C37(2013)106201]

PRL 116, 052001 (2016)

Mode	This work (%)	PDG (%)	BELLE $\mathcal{B}$
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

- ✓ **First direct measurement on Λc BFs at threshold**
- ✓ **$B(pK^-\pi^+)$: BESIII precision comparable with Belle's**
- ✓ **Improved precisions of the other 11 modes significantly**

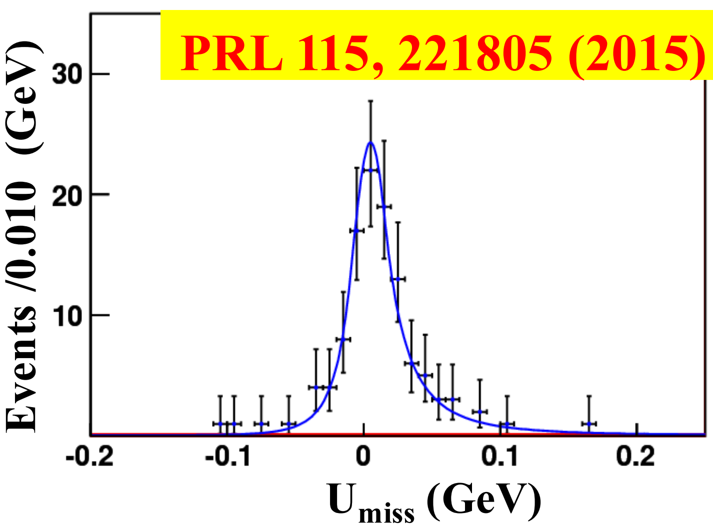
So far, the mostly cited BESIII charm paper

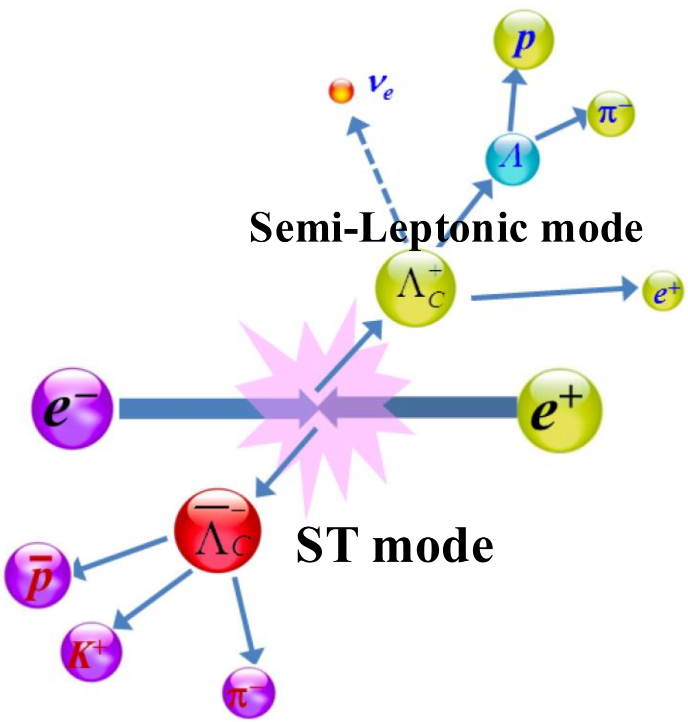
BF for $\Lambda_c^+ \to \Lambda e^+ \nu_e$

- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is a $c \to s l^+ \nu_l$ dominated process.
- Urgently needed for LQCD calculations.
- No direct absolute measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ available.

$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (2.1 \pm 0.6)\% \qquad \text{PDG 2014}$$

11 hadronic single tag modes are used





$$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$

- First absolute measurement of the semi-leptonic decay
- Statistics limited
- Best precision to date: twofold improvement

First Lattice calculation on charmed baryon SL decays

PRL **118,** 082001 (2017) PHYSICAL REVIEW LETTERS week ending 24 FEBRUARY 2017

$\Lambda_c \to \Lambda l^+ \nu_l$ Form Factors and Decay Rates from Lattice QCD with Physical Quark Masses

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(Received 1 December 2016; published 21 February 2017)

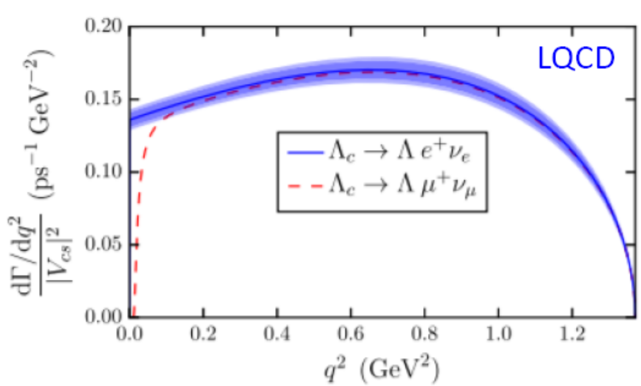
- Input the measured BFs from BESIII

Triggered by BESIII

$$\mathcal{B}(\Lambda_c \to \Lambda \ell^+ \nu_\ell) = \begin{cases} 0.0363(38)(20), & \ell = e, \\ 0.0349(46)(27), & \ell = \mu. \end{cases}$$

- The first LQCD calculations on BFs and form factors

$$\mathcal{B}(\Lambda_c \to \Lambda \ell^+ \nu_\ell) = \begin{cases} 0.0380(19)_{\rm LQCD}(11)_{\tau_{\Lambda_c}}, & \ell = e, \\ 0.0369(19)_{\rm LQCD}(11)_{\tau_{\Lambda_c}}, & \ell = \mu, \end{cases}$$



✓ The first determination of $|V_{cs}|$ based on BFs of $\Lambda_c^+ \to \Lambda l^+ \nu_l$ measured by BESIII

$$|V_{cs}| = \begin{cases} 0.951(24)_{\rm LQCD}(14)_{\tau_{\Lambda_c}}(56)_{\mathcal{B}}, & \ell = e, \\ 0.947(24)_{\rm LQCD}(14)_{\tau_{\Lambda_c}}(72)_{\mathcal{B}}, & \ell = \mu, \\ 0.949(24)_{\rm LQCD}(14)_{\tau_{\Lambda_c}}(49)_{\mathcal{B}}, & \ell = e, \mu, \end{cases}$$

✓ More data on Λ_c^+ will be collected at BESIII

PDG2015

Λ_c^+ DECAY MODES

	Mode		Fraction (Γ_i/Γ)	Sc Confi
	Hadronic modes with a p: $S=-1$ final states			
Γ_1	$p\overline{K}^0$		(3.21 ± 0.30) %	
Γ_2	$pK^-\pi^+$		$(6.84\,^{+\,0.32}_{-\,0.40})$ %	
Γ_3	$p\overline{K}^*(892)^0$	[a]	(2.13 ± 0.30) %	
Γ_4	$\Delta(1232)^{++}K^-$		(1.18 ± 0.27) %	
Γ_5	$\Lambda(1520)\pi^+$	[a]	(2.4 ± 0.6) %	
Γ_6	$pK^-\pi^+$ nonresonant		(3.8 ± 0.4) %	
Γ_7	$p\overline{K}^0\pi^0$		(4.5 ± 0.6) %	
Γ_8	$p\overline{K}^0\eta$		(1.7 ± 0.4) %	
Γ_9	$p\overline{K}^0\pi^+\pi^-$		(3.5 ± 0.4) %	
Γ_{10}	$pK^-\pi^+\pi^0$		(4.6 ± 0.8) %	
Γ_{11}	$pK^*(892)^-\pi^+$	[a]	(1.5 ± 0.5) %	
Γ_{12}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(5.0 ± 0.9) %	
Γ_{13}	$\Delta(1232)\overline{K}^*(892)$		seen	
Γ_{14}	$pK^-\pi^+\pi^+\pi^-$		$(1.5\pm1.0)\times10^{-3}$	
Γ_{15}	$pK^-\pi^+\pi^0\pi^0$		(1.1 ± 0.5) %	
Γ_{16}	$pK^-\pi^+3\pi^0$			
	Hadronic modes with a p: $S=0$ final states			
Γ_{17}	$p\pi^+\pi^-$		$(4.7\pm2.5)\times10^{-3}$	
Γ_{18}	$pf_0(980)$	[a]	$(3.8\pm2.5)\times10^{-3}$	
Γ_{19}	$p\pi^+\pi^+\pi^-\pi^-$		$(2.5\pm1.6)\times10^{-3}$	
Γ_{20}	pK^+K^-		$(1.1\pm0.4)\times10^{-3}$	
Γ_{21}	$p\phi$	[a]	$(1.12\pm0.23)\times10^{-3}$	
Γ_{22}	pK^+K^- non-ϕ		$(4.8\pm1.9)\times10^{-4}$	
	Hadronic modes with a hyperon: $S=-1$ final states			
Γ_{23}	$\Lambda\pi^+$		(1.46 ± 0.13) %	
Γ_{24}	$\Lambda\pi^+\pi^0$		(5.0 ± 1.3) %	
Γ_{25}	$\Lambda\rho^+$		<6 %	CL=95%
Γ_{26}	$\Lambda\pi^+\pi^+\pi^-$		(3.59 ± 0.28) %	
Γ_{27}	$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+}\to\Lambda\pi^+$		(1.0 ± 0.5) %	
Γ_{28}	$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-}\to\Lambda\pi^-$		$(7.5\pm1.4)\times10^{-3}$	
Γ_{29}	$\Lambda\pi^+\rho^0$		(1.4 ± 0.6) %	
Γ_{30}	$\Sigma(1385)^+\rho^0$, $\Sigma^{*+}\to\Lambda\pi^+$		$(5\pm4)\times10^{-3}$	
Γ_{31}	$\Lambda\pi^+\pi^+\pi^-$ nonresonant		<1.1 %	CL=90%
Γ_{32}	$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		(2.5 ± 0.9) %	
Γ_{33}	$\Lambda\pi^+\eta$	[a]	(2.4 ± 0.5) %	
Γ_{34}	$\Sigma(1385)^+\eta$	[a]	(1.16 ± 0.35) %	
Γ_{35}	$\Lambda\pi^+\omega$	[a]	(1.6 ± 0.6) %	
Γ_{36}	$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		$<9\times10^{-3}$	CL=90%
Γ_{37}	$\Lambda K^+\overline{K}^0$		$(6.4\pm1.3)\times10^{-3}$	S=1.6
Γ_{38}	$\Xi(1690)^0K^+$, $\Xi^{*0}\to\Lambda\overline{K}^0$		$(1.8\pm0.6)\times10^{-3}$	
Γ_{39}	$\Sigma^0\pi^+$		(1.43 ± 0.14) %	
Γ_{40}	$\Sigma^+\pi^0$		(1.37 ± 0.30) %	
Γ_{41}	$\Sigma^+\eta$		$(7.5\pm2.5)\times10^{-3}$	
Γ_{42}	$\Sigma^+\pi^+\pi^-$		(4.9 ± 0.5) %	
Γ_{43}	$\Sigma^+\rho^0$		<1.8 %	CL=95%
Γ_{44}	$\Sigma^-\pi^+\pi^+$		(2.3 ± 0.4) %	
Γ_{45}	$\Sigma^0\pi^+\pi^0$		(2.5 ± 0.9) %	
	Semileptonic modes			
Γ_{64}	$\Lambda\ell^+\nu_\ell$	[b]	(2.8 ± 0.4) %	
Γ_{65}	$\Lambda e^+\nu_e$		(2.9 ± 0.5) %	
Γ_{66}	$\Lambda\mu^+\nu_\mu$		(2.7 ± 0.6) %	

PDG2020

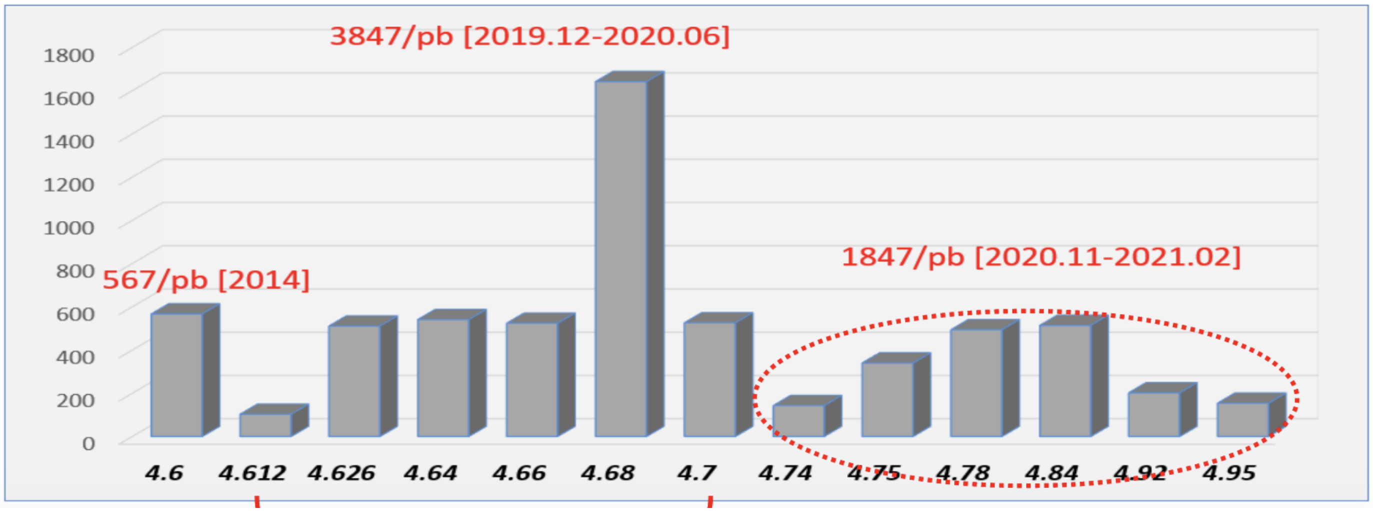
	Mode		Fraction	Change	S / CL
	Hadronic modes with a p or n: $S=-1$ final states				
Γ_1	pK^0_S		(1.59 ± 0.08) %	↓44%	S=1.1
Γ_2	$pK^-\pi^+$		(6.28 ± 0.32) %		S=1.4
Γ_3	$p\overline{K}^*(892)^0$	[a]	(1.96 ± 0.27) %		
Γ_4	$\Delta(1232)^{++}K^-$		(1.08 ± 0.25) %		
Γ_5	$\Lambda(1520)\pi^+$	[a]	(2.2 ± 0.5) %		
Γ_6	$pK^-\pi^+$ nonresonant		(3.5 ± 0.4) %		
Γ_7	$pK^0_S\pi^0$		(1.97 ± 0.13) %	↓50%	S=1.1
Γ_8	$nK^0_S\pi^+$		(1.82 ± 0.25) %	First	
Γ_9	$p\overline{K}^0\eta$		(1.6 ± 0.4) %		
Γ_{10}	$pK^0_S\pi^+\pi^-$		(1.60 ± 0.12) %	↓28%	S=1.1
Γ_{11}	$pK^-\pi^+\pi^0$		(4.46 ± 0.30) %	↓61%	S=1.5
Γ_{12}	$pK^*(892)^-\pi^+$	[a]	(1.4 ± 0.5) %		
Γ_{13}	$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(4.6 ± 0.8) %		
Γ_{14}	$\Delta(1232)\overline{K}^*(892)$		seen		
Γ_{15}	$pK^-2\pi^+\pi^-$		$(1.4\pm0.9)\times10^{-3}$		
Γ_{16}	$pK^-\pi^+2\pi^0$		(1.0 ± 0.5) %		
	Hadronic modes with a p: $S=0$ final states				
Γ_{17}	$p\pi^0$		$<2.7\times10^{-4}$		CL=90%
Γ_{18}	$p\eta$		$(1.24\pm0.30)\times10^{-3}$	First	
Γ_{19}	$p\omega(782)^0$		$(9\pm4)\times10^{-4}$		
Γ_{20}	$p\pi^+\pi^-$		$(4.61\pm0.28)\times10^{-3}$	First	
Γ_{21}	$pf_0(980)$	[a]	$(3.5\pm2.3)\times10^{-3}$		
Γ_{22}	$p2\pi^+2\pi^-$		$(2.3\pm1.4)\times10^{-3}$		
Γ_{23}	pK^+K^-		$(1.06\pm0.06)\times10^{-3}$		
Γ_{24}	$p\phi$	[a]	$(1.06\pm0.14)\times10^{-3}$	↓36%	
Γ_{25}	pK^+K^- non-ϕ		$(5.3\pm1.2)\times10^{-4}$		
Γ_{26}	$p\phi\pi^0$		$(10\pm4)\times10^{-5}$		
Γ_{27}	$pK^+K^-\pi^0$ nonresonant		$<6.3\times10^{-5}$		CL=90%
	Hadronic modes with a hyperon: $S=-1$ final states				
Γ_{28}	$\Lambda\pi^+$		(1.30 ± 0.07) %		S=1.1
Γ_{29}	$\Lambda\pi^+\pi^0$		(7.1 ± 0.4) %	↓78%	S=1.1
Γ_{30}	$\Lambda\rho^+$		<6 %		CL=95%
Γ_{31}	$\Lambda\pi^-2\pi^+$		(3.64 ± 0.29) %		S=1.4
Γ_{44}	$\Sigma^0\pi^+$		(1.29 ± 0.07) %	↓45%	S=1.1
Γ_{45}	$\Sigma^+\pi^0$		(1.25 ± 0.10) %	↓33%	
Γ_{46}	$\Sigma^+\eta$		$(4.4\pm2.0)\times10^{-3}$		
Γ_{47}	$\Sigma^+\eta'$		(1.5 ± 0.6) %		
Γ_{48}	$\Sigma^+\pi^+\pi^-$		(4.50 ± 0.25) %	↓46%	S=1.3
Γ_{49}	$\Sigma^+\rho^0$		<1.7 %		CL=95%
Γ_{50}	$\Sigma^-2\pi^+$		(1.87 ± 0.18) %		
Γ_{51}	$\Sigma^0\pi^+\pi^0$		(3.5 ± 0.4) %		
Γ_{52}	$\Sigma^+\pi^0\pi^0$		(1.55 ± 0.15) %		
Γ_{53}	$\Sigma^0\pi^-2\pi^+$		(1.11 ± 0.30) %		
	Semileptonic modes				
Γ_{72}	$\Lambda e^+\nu_e$		(3.6 ± 0.4) %	↓35%	
Γ_{73}	$\Lambda\mu^+\nu_\mu$		(3.5 ± 0.5) %		

Experimental precision reaches of the charmed hadrons

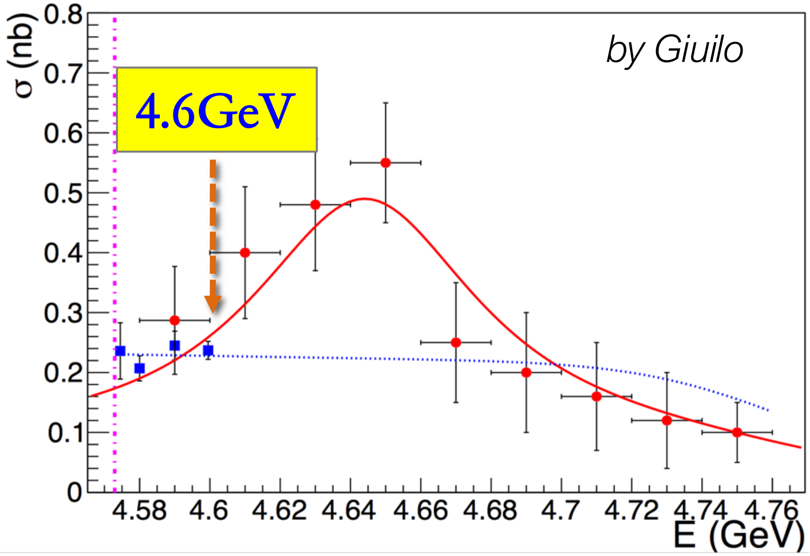
	Golden hadronic mode	δB/B	Golden SL mode	δB/B
D^0	B(Kπ)=(3.88±0.05)%	1.3%	B(Keν)=(3.55±0.05)%	1.4%
D^+	B(Kππ)=(9.13±0.19)%	2.1%	B(K^0eν)=(8.83±0.22)%	2.5%
D_s	B(KKpi)=(5.39±0.21)%	3.9%	B(ϕeν)=(2.49±0.14)%	5.6%
Λc	B(pKπ)=(5.0±1.3)%(PDG2014) =(6.8±0.36)% (BELLE) =(5.84±0.35)% (BESIII) =(6.46±0.24)% (HFLAV)	26% 5.3% 6.0% 3.7%	B(Λeν)=(2.1±0.6)%(PDG2014) =(3.63±0.43)% (BESIII) =(3.18±0.32)% (HFLAV)	29% 12% 10%

- The precisions of Λc decay rates reaches to the level of charmed mesons!
- However, search for more unknown modes, especially Cabbibo-suppressed mode, are important

More Λ_c^+ data at BESIII



in total, 6.4 fb^{-1} data above Λ_c^+ threshold (~8x times more Λ_c^+ statistics)



Based on Phase II data

Semi-leptonic decay

- ✓ Form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ and $\Lambda\mu^+\nu_\mu$ — ***PRL129, 231803 (2022);*** *PRD108, L031105 (2023)*
- ✓ $\Lambda_c^+ \to pK^- e^+ \nu_e$ — *PRD106, 112010 (2022)*
- ✓ Search for $\Lambda_c^+ \to \Lambda\pi^+\pi^- e^+\nu_e$ and $pK_s\pi^- e^+\nu_e$ — *PLB843, 137993 (2023)*
- ✓ $\Lambda_c^+ \to n e^+ \nu_e$ — ***Nature Commun. 16, 681 (2025)***

Neutron-involved decay

- ✓ $\Lambda_c^+ \to n\pi^+$ — ***PRL 128, 142001 (2022)***
- ✓ $\Lambda_c^+ \to n\pi^+\pi^0, n\pi^+\pi^+\pi^-,\ nK^-\pi^+\pi^+$ — *CPC 47, 023001 (2023) (Cover Story)*
- ✓ $\Lambda_c^+ \to nK_sK^+$ — *PRD 109, 072010 (2024)*
- ✓ $\Lambda_c^+ \to \Sigma^- K^+\pi^+$ — *PRD 109, L071103 (2024)*
- ✓ $\Lambda_c^+ \to nK_s\pi^+\pi^0$ — *PRD 109, 053005 (2024)*

Hadronic CS decays

- ✓ $\Lambda_c^+ \to p\pi^0, p\eta, p\omega$ — *JHEP11, 137 (2023); PRD09, L091101 (2024); PRD111, L051101 (2025)*
- ✓ $\Lambda_c^+ \to p\eta'$ — *PRD106, 072002 (2022)*
- ✓ $\Lambda_c^+ \to \Lambda K^+, \Lambda K^+\pi^0, \Lambda K_s\pi^+$ — *PRD106, L111101 (2022); PRD109, 032003 (2024); PRD111, 012014 (2025)*
- ✓ $\Lambda_c^+ \to \Sigma^+ K_s, \Sigma^0 K^+(\pi^0, \pi^+\pi^-), \Sigma^+K^+\pi^-$ — *PRD106, 052003 (2022); JHEP09, 125 (2023);arXiv:2502.11047*
- ✓ ***Hadronic CF decays***
- ✓ PWA of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ and $\Lambda\pi^+\eta$ — *JHEP 12, 033(2022);* ***PRL134, 021901 (2025)***
- ✓ W-exchange-only process $\Xi^0 K^+$ — ***PRL132, 031801 (2024)***
- ✓ $\Lambda_c^+ \to \Xi^0 K^+\pi^0$ — *PRD109, 052001 (2024)*
- ✓ $\Lambda_c^+ \to pK_L,\ pK_L\pi^0, pK_L\pi^+\pi^-$ — *JHEP09, 007 (2024)*

>35 papers are published

Inclusive decay

- ✓ Improved BF of $\Lambda_c^+ \to e^+ X$ — *PRD107, 052005 (2023)*
- ✓ First BF of $\bar{\Lambda}_c^- \to \bar{n} X$ — *PRD108, L031101 (2023)*
- ✓ First BF of $\bar{\Lambda}_c^- \to K_s^0 X$ — *arXiv:2502.20821*

Rare decay

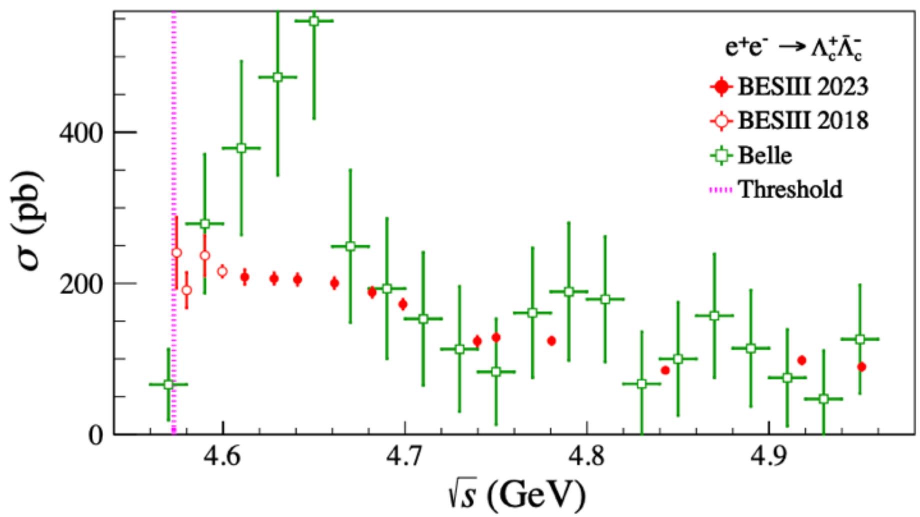
- ✓ $\Lambda_c^+ \to \gamma\Sigma^+$ — *PRD107, 052002 (2023)*

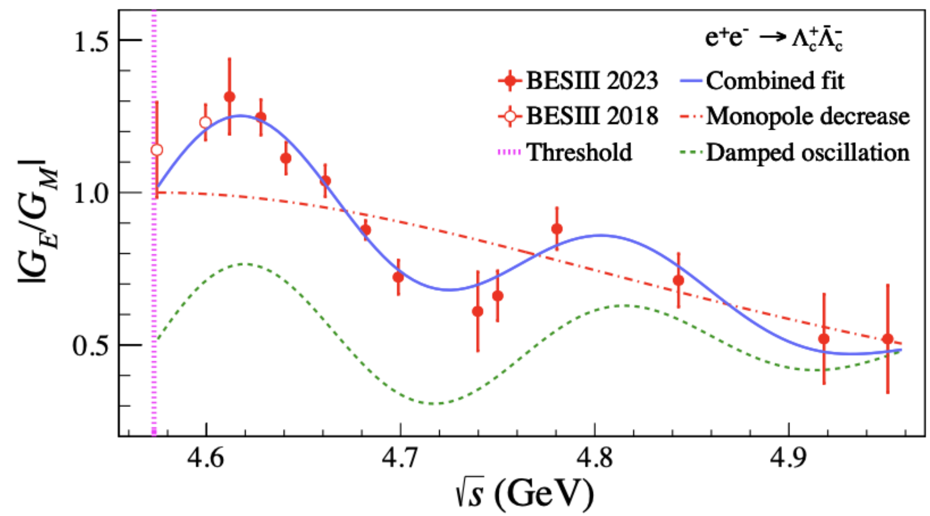
Production and excited Λ_c^+

- ✓ $\Lambda_c^+\bar{\Lambda}_c^-$ *lineshape and form factor* — ***PRL107, 052002 (2023)***
- ✓ $\Lambda_c(2595)^+$ *and* $\Lambda_c(2625)^+$ — *PRD109, L071104 (2024); PRD109, 112007 (2024); arXiv:2503.21413*

Cross sections of $e^+e^- \to \Lambda_c^+\Lambda_c^-$

PRL131, 191901 (2023)

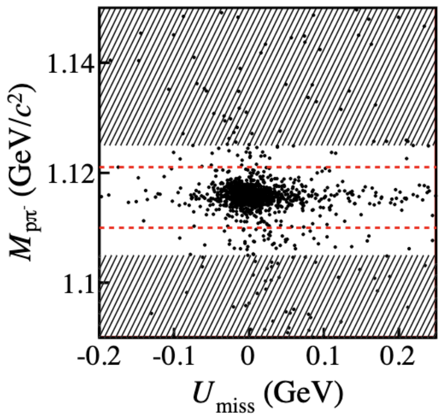


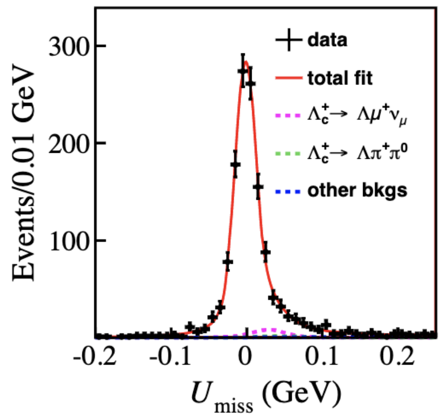


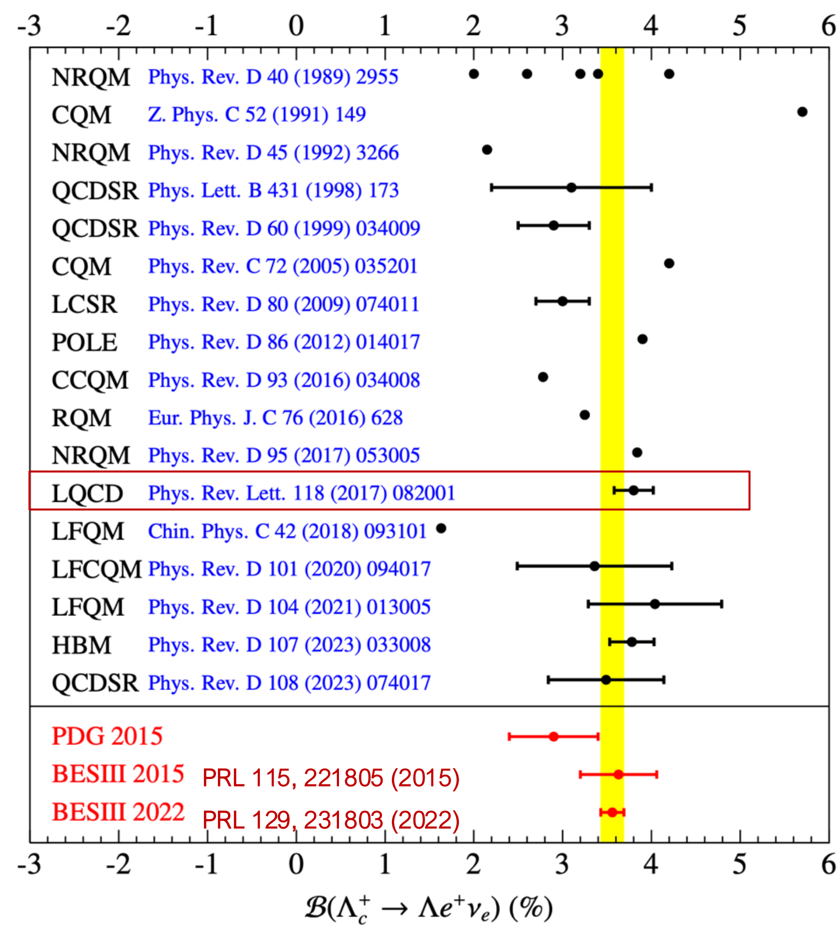
- Negate the $Y(4630)$ in decaying into $\Lambda_c^+\Lambda_c^-$ reported by BELLE
- Energy-dependence of $|G_E/G_M|$ reveals an oscillation feature, which may imply a non-trivial structure of the lightest charmed baryon.

Determination of absolute form factors of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

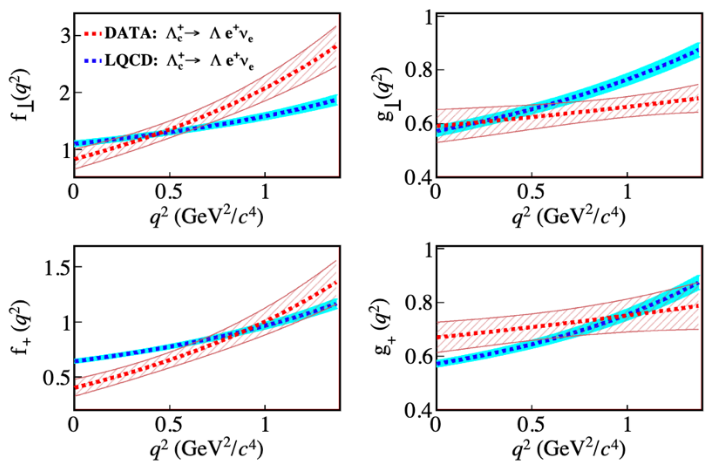
PRL129, 231803 (2022)







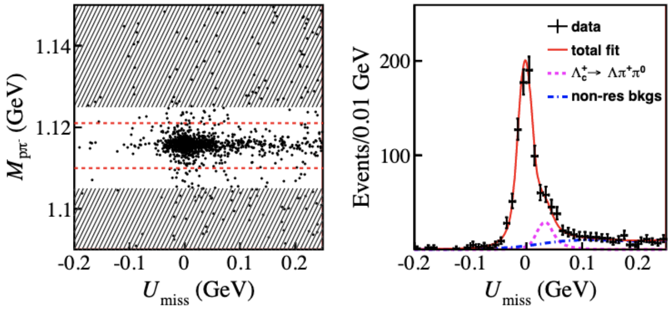
$B(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$

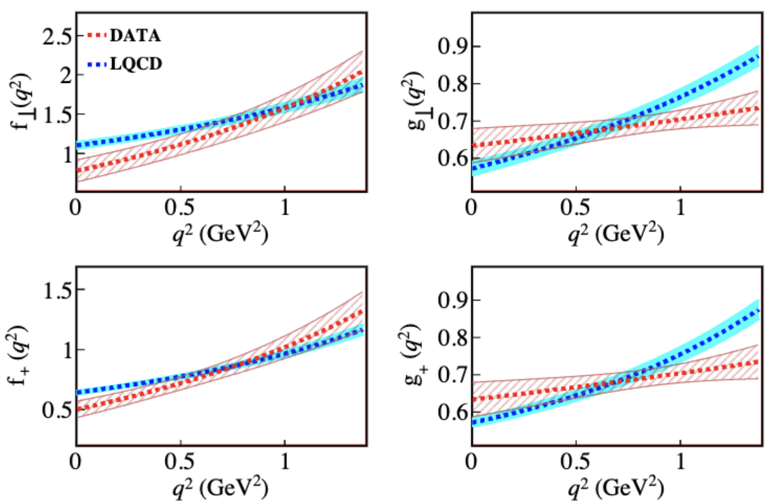


First direct comparisons on the differential decay rates and form factors with LQCD calculations

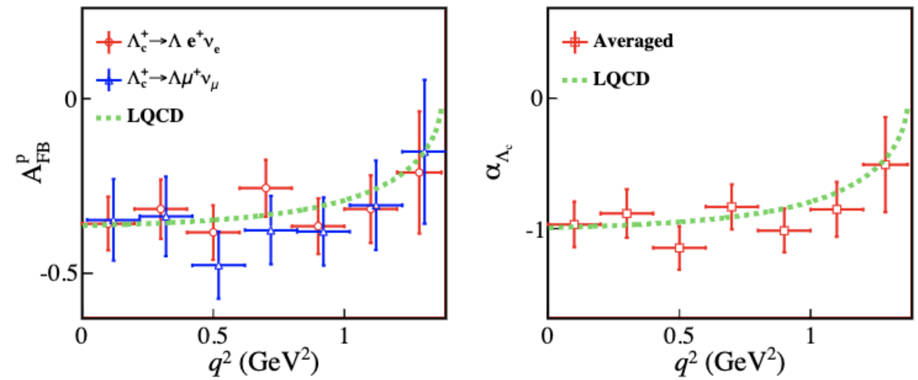
Combined form factor fits to $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$ and $\Lambda e^+\nu_e$

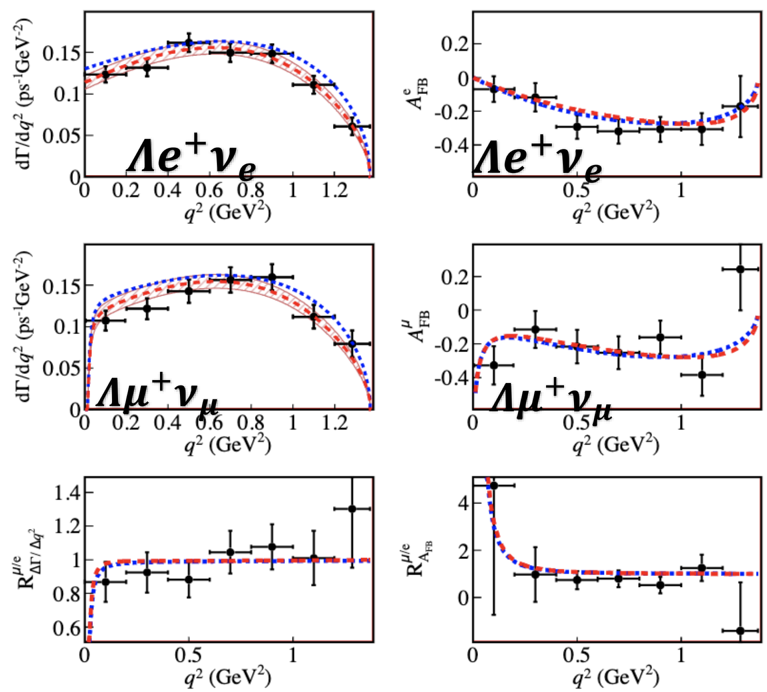
PRD 108, L031105 (2023)





$<\alpha_{\Lambda_c}>=-0.94 \pm 0.07 \pm 0.03$



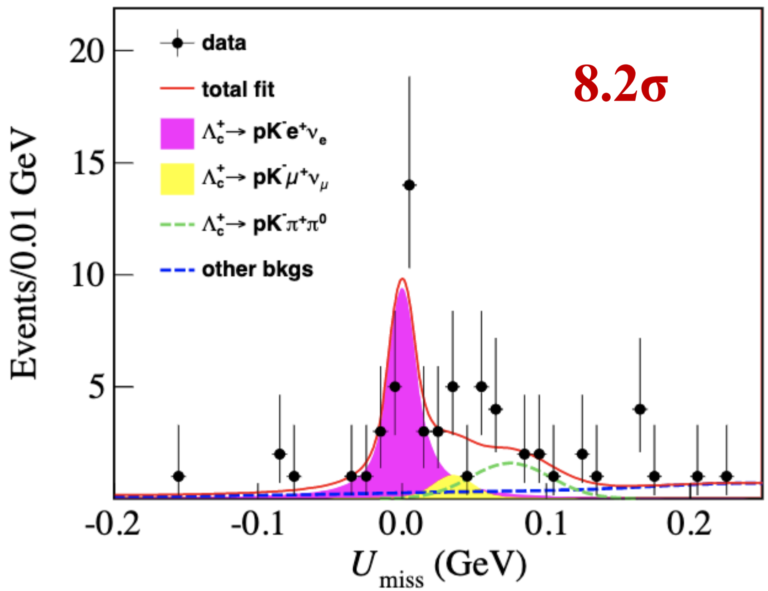


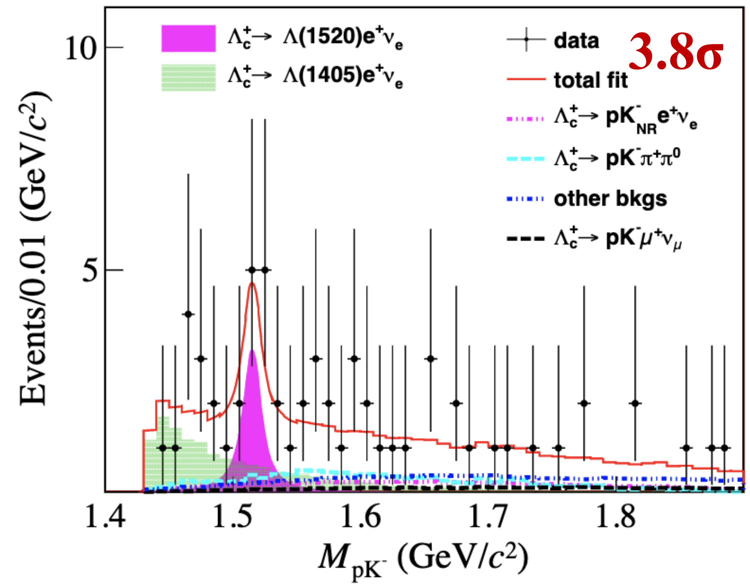
$B(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu) = (3.48 \pm 0.14 \pm 0.10)\%$

$B(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)/B(\Lambda_c^+ \to \Lambda e^+\nu_e) = 0.98 \pm 0.05 \pm 0.03$

Observation of $\Lambda_c^+ \to pK^-e^+\nu$

PRD106, 112010 (2022)

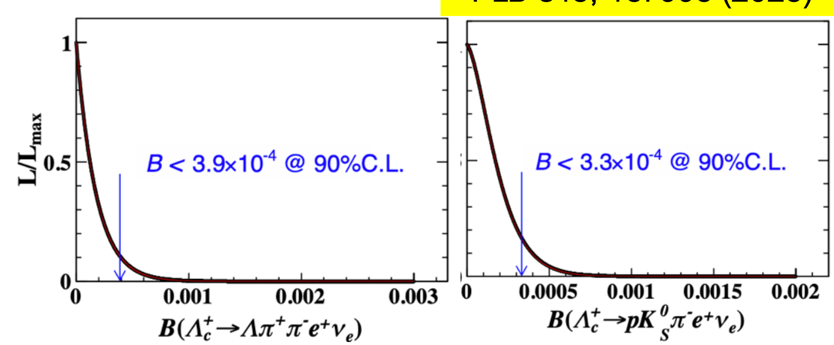




$B(\Lambda_c^+ \to pK^-e^+\nu_e) = (8.8 \pm 1.1 \pm 0.7) \times 10^{-4}$
$B(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e) = (10.2 \pm 5.2 \pm 1.1) \times 10^{-4}$

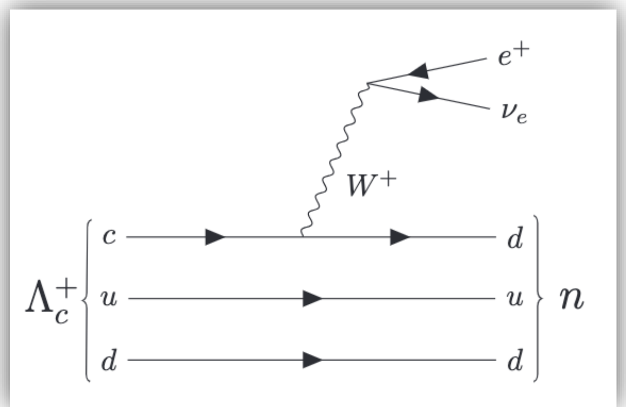
- Second leptonic decay of Λ_c^+ is observed!
- Good channel to study Λ excited states, such as Λ(1405) and Λ(1520)

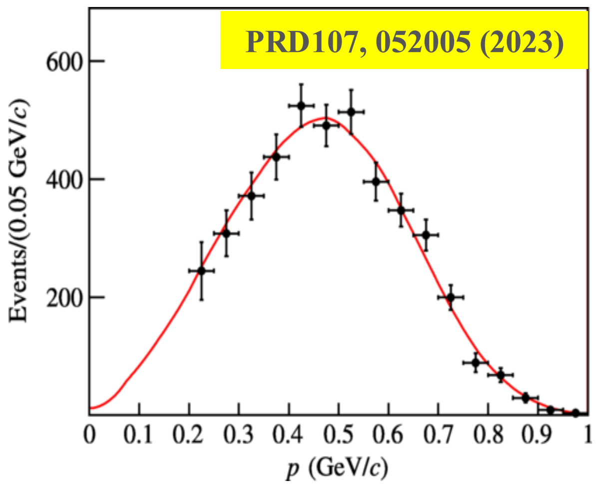
PLB 843, 137993 (2023)



Cabibbo-suppressed SL decays

- There is still room of 0.5% for un-seen SL decay of the Λ_c^+
- The Cabibbo-Suppressed SL decays have not been studied in experiment
- $\Lambda_c^+ \to n e^+ \nu_e$ is the most promising channel for the experimental observation



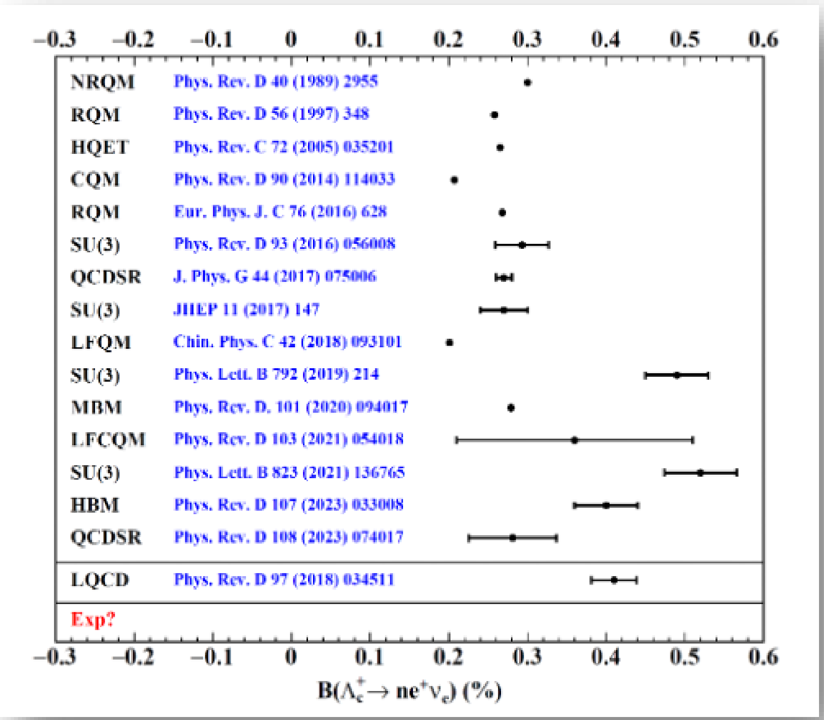


$\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e) = (4.06 \pm 0.10_{\rm stat} \pm 0.09_{\rm syst})\%.$

$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$

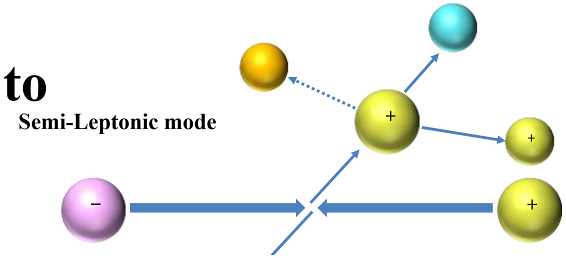
$B(\Lambda_c^+ \to p K^- e^+ \nu_e) = (8.8 \pm 1.1 \pm 0.7) \times 10^{-4}$

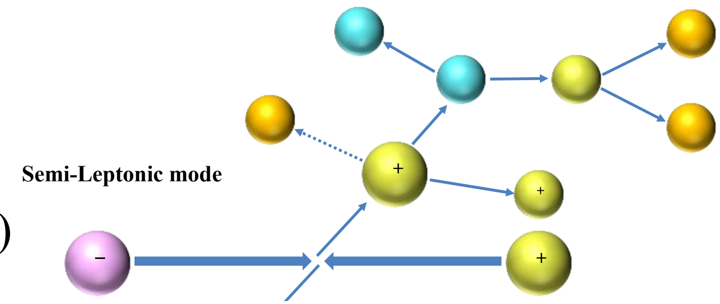
$B(\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e) = (10.2 \pm 5.2 \pm 1.1) \times 10^{-4}$



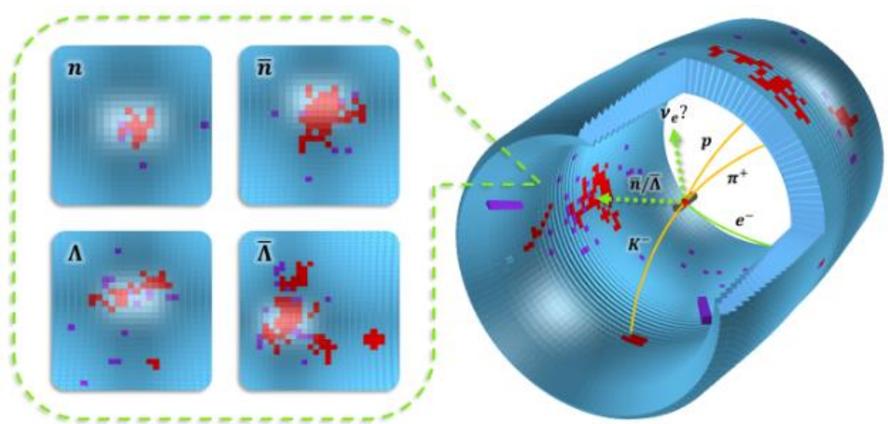
Hunting for $\Lambda_c^+ \to n e^+ \nu$

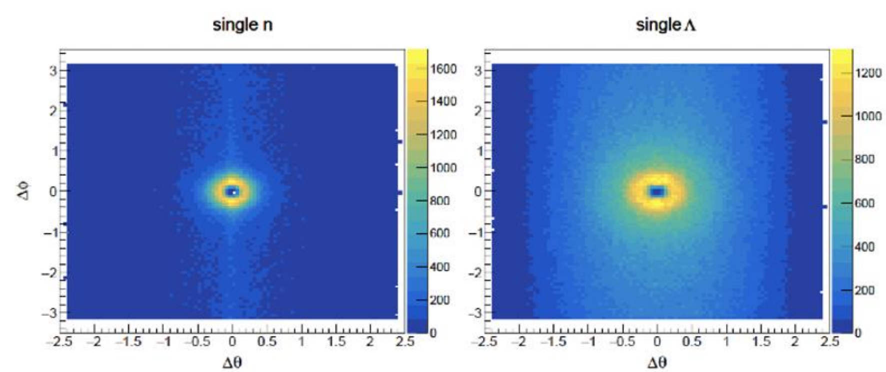
- **Important process of semi-leptonic Λ_c^+ decay to probe strong dynamics in charmed baryon**
- **Challenges:**
  - ✓ neutrino is missing in detection
  - ✓ dominant backgrounds from $\Lambda_c^+ \to \Lambda(\to n\pi^0)e^+\nu$, with ~10x yields than that of the pursuing signals
  - ✓ elusive neutron detection due to neutral charge and contaminations from the photon showers (& noises) in electro-magnetic calorimeter (EMC)





Need advanced Machine Learning tool to identify neutron showers in EMC

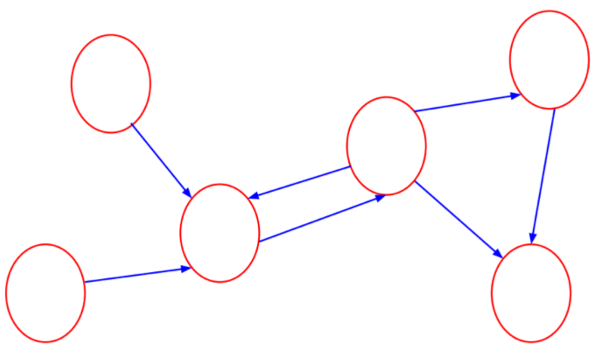


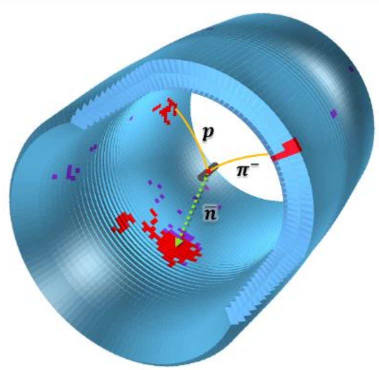


Why Graph Neural Networks (GNN)

Nature Comm. 16, 681 (2025)

- Many neural network architectures are specialized for sequential and image-like data such as RNNs, transformers and CNNs.
- GNN can model more arbitrary relations among data objects by treating them as edges between nodes in a graph.





- Sharing of parameters across node and edge updates in the graph
- Permutation invariance

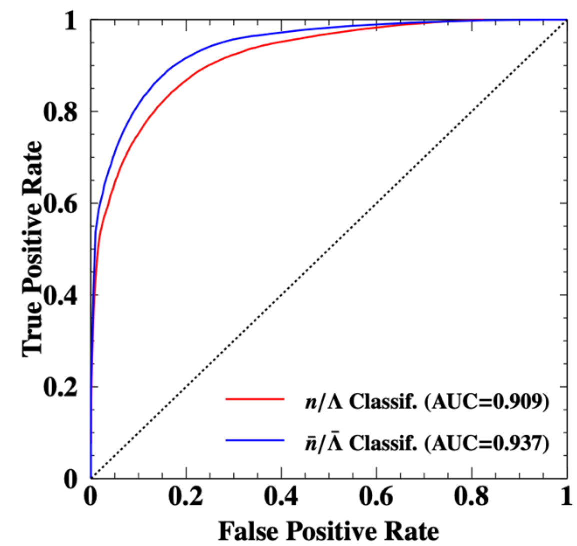
- Nearly unlimited labeled samples
- Structured data
- Clear training objectives

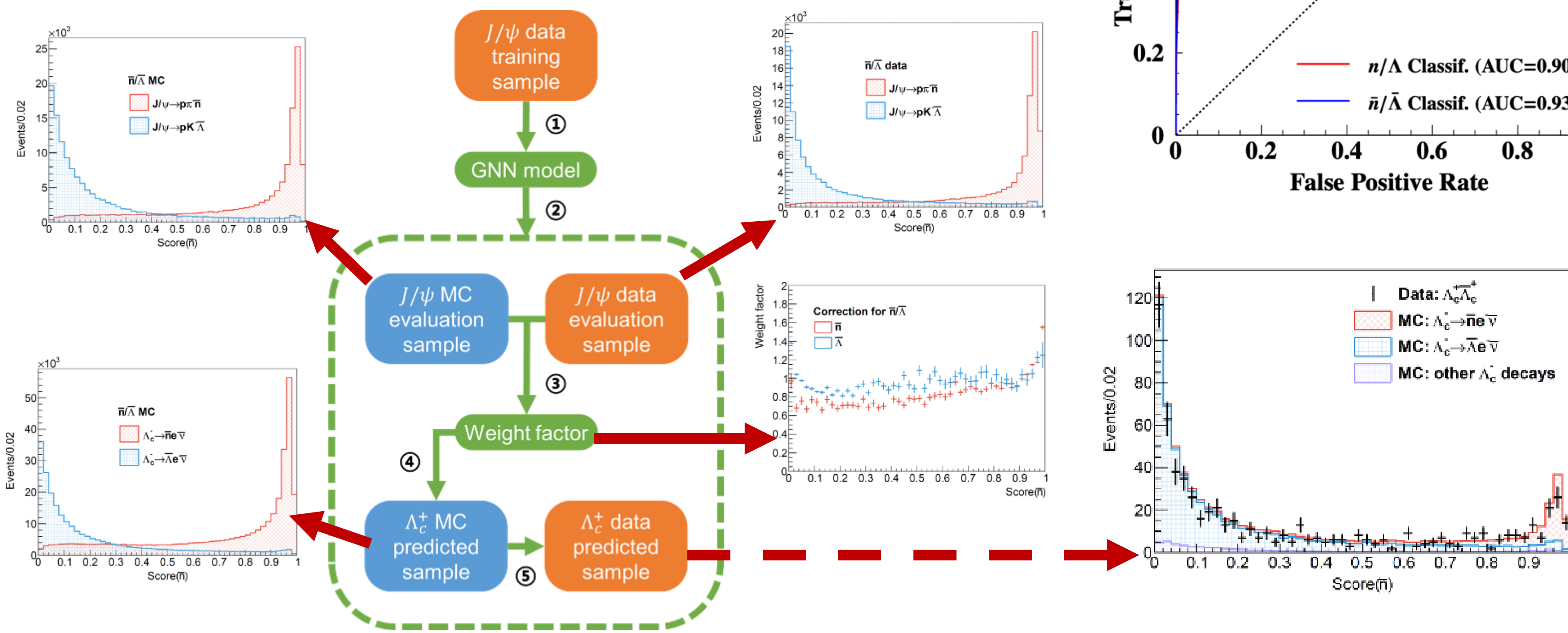
This fits well to the final state particles in physics collisions, where we deal with various objects like tracks/showers and their kinematic relations.

Analysis strategy

Nature Comm. 16, 681 (2025)

- Threshold Λ_c^+ production: clean environment and Λ_c^+ tagging
- Train GNN with **ParticleNet** using control data from $J/\psi \to \bar{p}n\pi^+, \bar{p}\Lambda K^+$ and c.c. modes based on 10B J/ψ decays

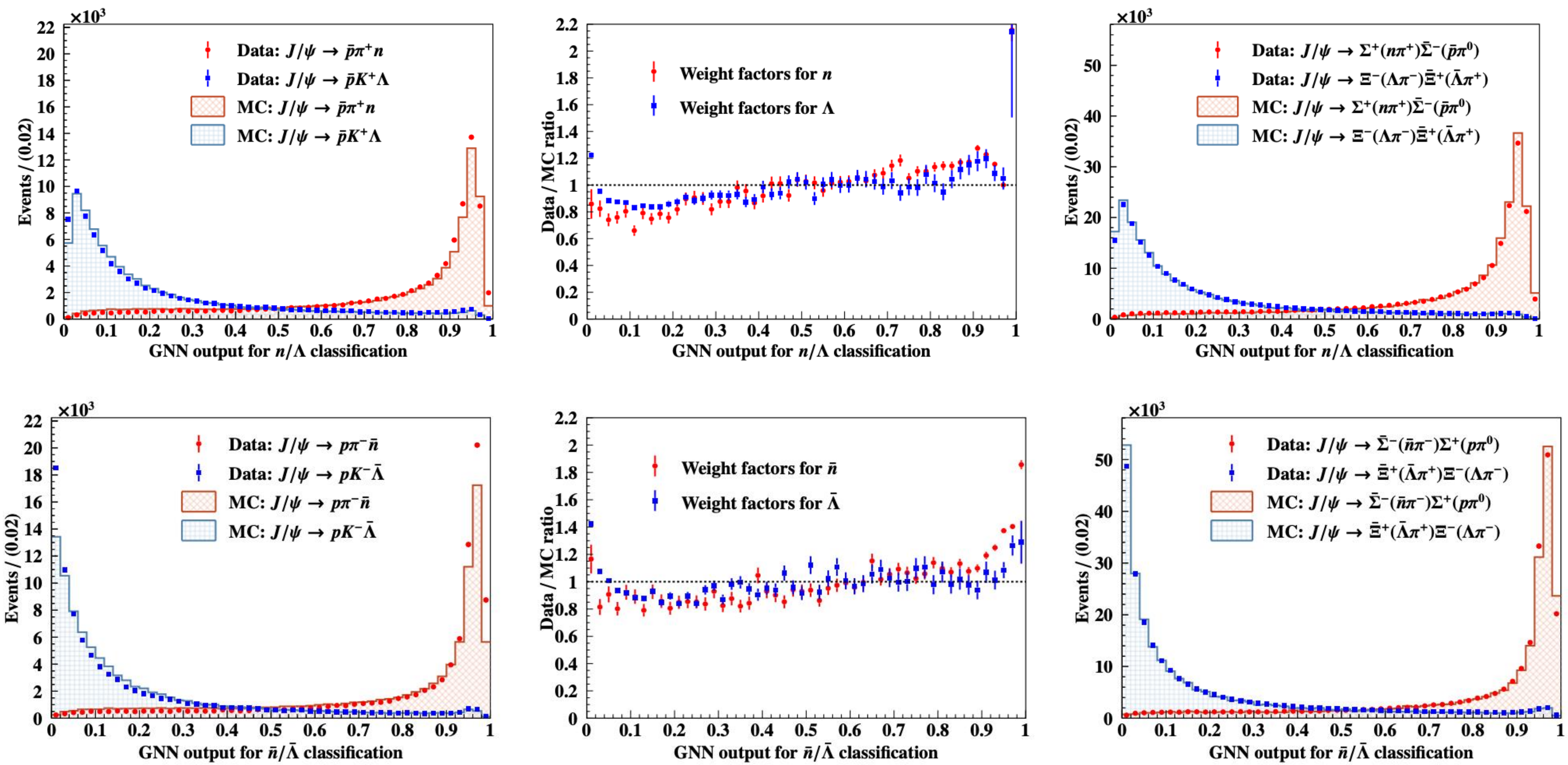




Method validation

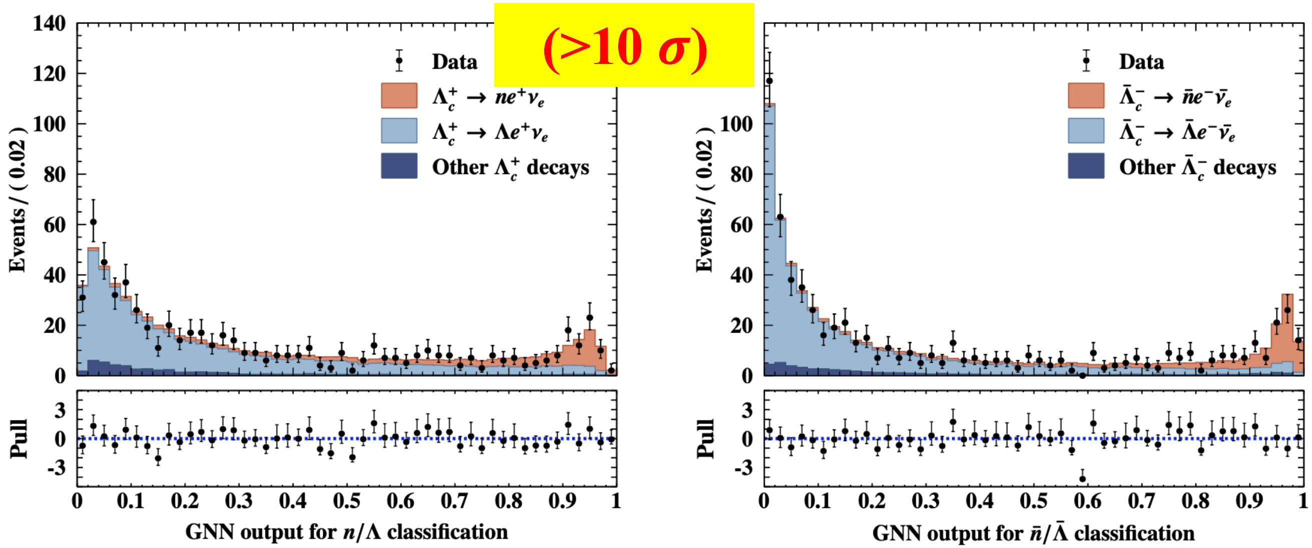
Nature Comm. 16, 681 (2025)

- Control channels of $J/\psi \to \Sigma^+(n\pi^+)\bar{\Sigma}^-(\bar{p}\pi^0)$ and $J/\psi \to \Xi^+(\Lambda\pi^+)\bar{\Xi}^-(\bar{\Lambda}\pi^-)$ based on 10B J/ψ decays



Observation of $\Lambda_c^+ \to n e^+ \nu$

Nature Comm. 16, 681 (2025)



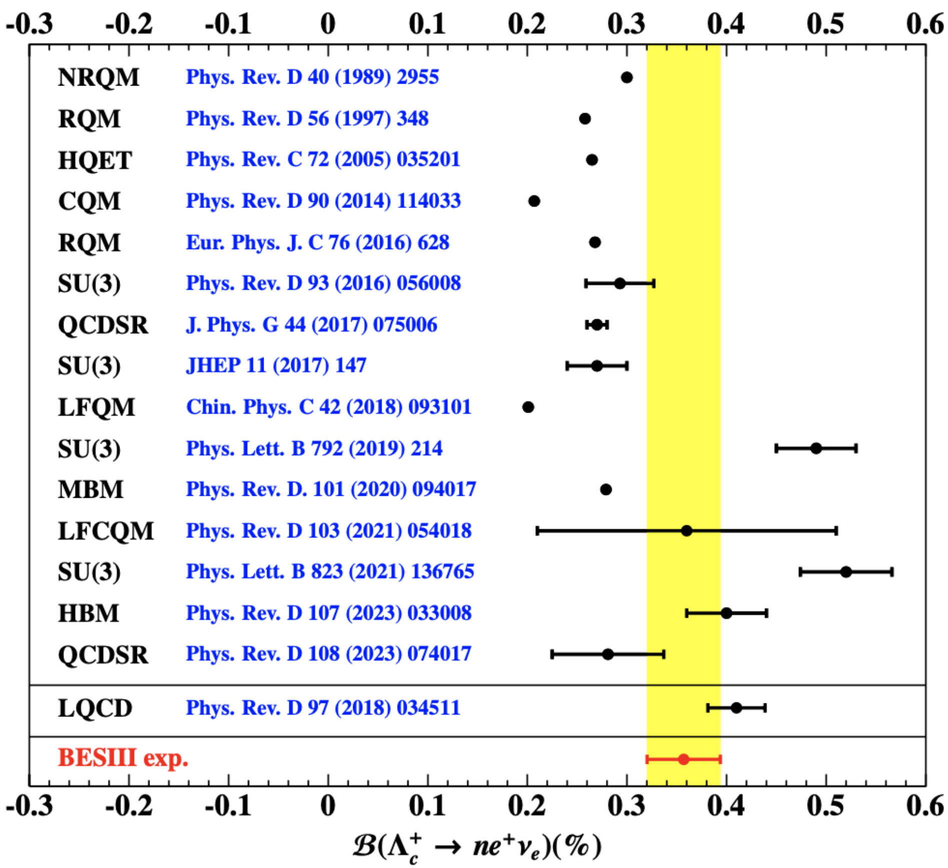
good control of systematics on GNN training

- **Model settings**: network weight initialization, batch processing sequence and dropout layer are randomly varied
- **Domain shift**: validation of independent control sample via $J/\psi \to \Sigma^+(n\pi^+)\overline{\Sigma}^-(\overline{p}\pi^0)$ and $J/\psi \to \Xi^-(\Lambda\pi^-)\overline{\Xi}^+(\overline{\Lambda}\pi^+)$

$$\mathcal{B}(\Lambda_c^+ \to n e^+ \nu_e) = (0.357 \pm 0.034_{\rm stat.} \pm 0.014_{\rm syst.})\%,$$

Results of BF for $\Lambda_c^+ \to n e^+ \nu$

Nature Comm. 16, 681 (2025)



Combing with the LQCD calculation of the Form Factors, we obtain $\Gamma(\Lambda_c^+ \to n e^+ \nu) = |V_{cd}|^2(0.405 \pm 0.016 \pm 0.020)\ \mathrm{ps}^{-1}$,

$|V_{\rm cd}| = 0.208 \pm 0.011_{\rm exp} \pm 0.005_{\rm LQCD} \pm 0.001_{\tau_{\Lambda_c}}$

first determination of $|V_{\rm cd}|$ in charmed baryon decays

Current status of the SL decays

Λ_c^+ Mode	BF($\times 10^{-3}$)	Experiment	Λ_c^+ Mode	BF($\times 10^{-3}$)	Experiment
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	23.7±5.1(37%)†	ARGUS(1991)[32]	$\Lambda_c^+ \to pK^- e^+ \nu_e$	0.88±0.18(20%)	BESIII(2022)[37]
	26.8±5.1(19%)†	CLEO(1994)[33]	$\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e$, $\Lambda(1405) \to pK^-$	0.42±0.19(45%)	BESIII(2022)[37]
	36.3±4.3(12%)	BESIII(2015)[38]			
	35.6±1.3(3.6%)	BESIII(2022)[39]	$\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e$	1.0±0.5(50%)	BESIII(2022)[37]
$\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$	34.9±5.3(15%)	BESIII(2017)[40]	$\Lambda_c^+ \to pK_S^0 \pi^- e^+ \nu_e$	<0.33	BESIII(2023)[41]
	34.8±1.7(4.9%)	BESIII(2023)[42]	$\Lambda_c^+ \to \Lambda \pi^+ \pi^- e^+ \nu_e$	<0.39	BESIII(2023)[41]
$\Lambda_c^+ \to e^+ X$	39.5±3.5(8.9%)	BESIII(2018)[43]	$\Lambda_c^+ \to n e^+ \nu_e$	3.57±0.37 (10%)	BESIII(2025)[44]
	40.6±1.3(3.2%)	BESIII(2023)[45]			

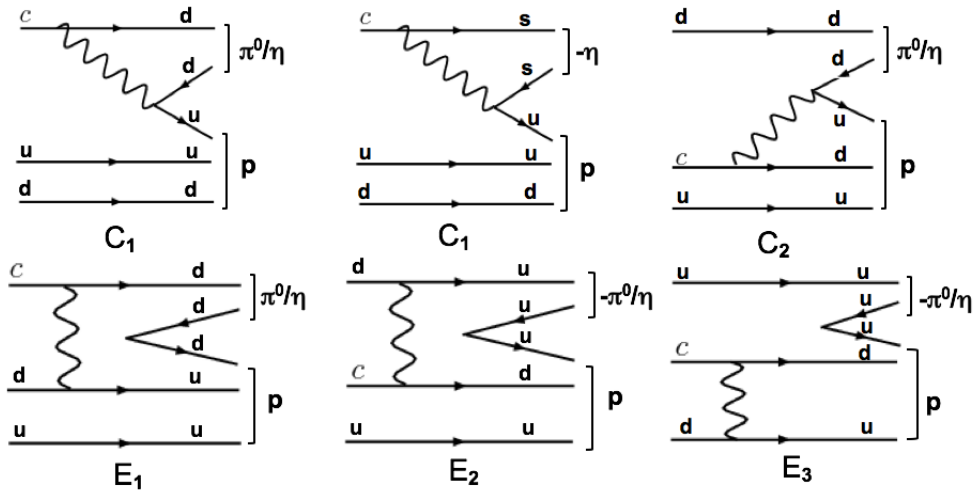
Ξ_c Mode	BF($\times 10^{-3}$)	Experiment	Ξ_c Mode	BF($\times 10^{-3}$)	Experiment
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	13.7±7.7(56%)†	ARGUS(1993)[34]	$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	10.1±2.1(21%)†	Belle(2021)[46]
	$44.3^{+16.6}_{-17.8}$(40%)†	CLEO(1995)[35]	$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	67±39(58%)†	CLEO(1995)[35]
	19.7±5.3(27%)†	ALICE(2021)[47]			
	10.4±2.1(20%)†	Belle(2021)[46]			

Ω_c^0 Mode	Ratio	Experiment	Ω_c^0 Mode	Ratio	Experiment
$\Omega_c^0 \to \Omega^- e^+ \nu_e$	2.4±1.1(47%)	CLEO(2002)[36]	$\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu$	1.94±0.21(11%)	Belle(2022)[48]
	1.98±0.15(7.7%)	Belle(2022)[48]			

Λ_c^+ hadronic decay

from HY Cheng

Singly Cabibbo-suppressed modes: $\Lambda_c^+ \to p\pi^0$, $p\eta$



$\pi^0 = (d\bar{d} - u\bar{u})/\sqrt{2}$, $\eta = (d\bar{d} + u\bar{u} - s\bar{s})/\sqrt{3}$ for $\eta - \eta'$ mixing angle = 19.5^0

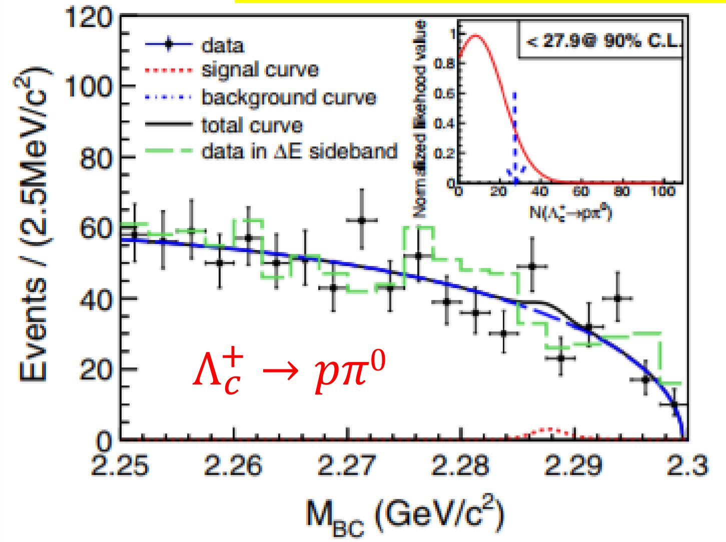
$A(\Lambda_c^+ \to p\pi^0) = (C_1 + C_2 + E_1 - E_2 - E_3)/\sqrt{2}$

$A(\Lambda_c^+ \to p\eta) = (2C_1 + C_2 + E_1 + E_2 + E_3)/\sqrt{3}$

It is most likely that

$\Gamma(\Lambda_c^+ \to p\eta) >> \Gamma(\Lambda_c^+ \to p\pi^0)$ 30

PRD95, 111102(R) (2017)



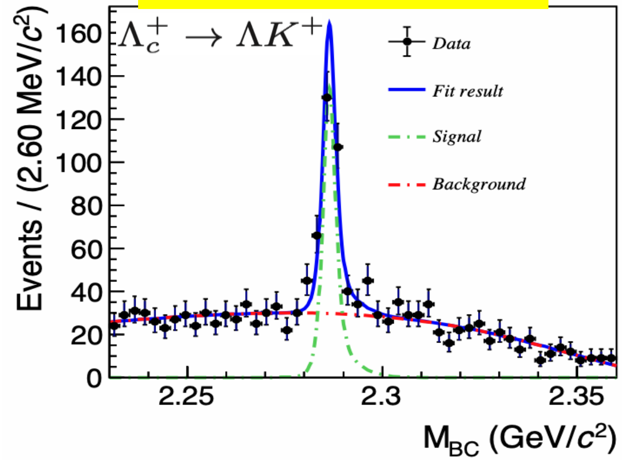
BESIII: BF<2.7×10^{-4}

$$M(\Lambda_c^+ \to n\pi^+) = \sqrt{2} M(\Lambda_c^+ \to p\pi^0),$$

More precise comparison of the two BFs are desired to explore the interference of different non-factorizable diagrams and BESIII result support the theoretic prediction. It is predicted that BF[$\Lambda_c^+ \to n\pi^+$]~3.5×BF[$\Lambda_c^+ \to p\pi^0$] [arXiv:1801.08625]

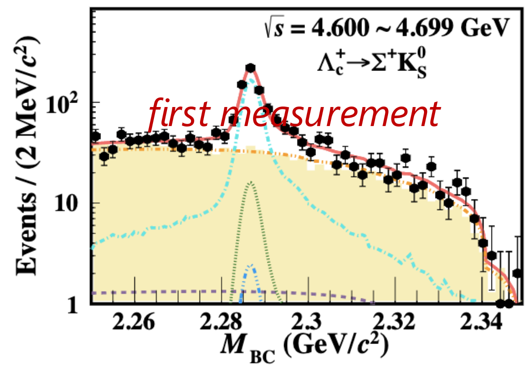
BESIII Some results on SCS hadronic decays

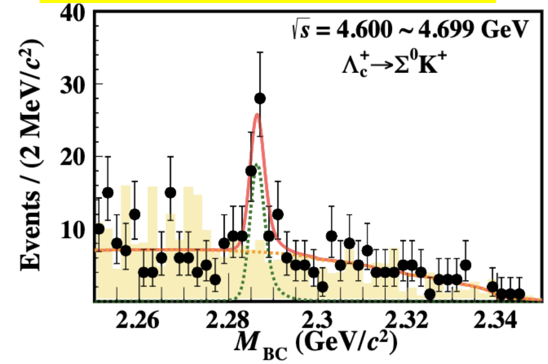
PRD106, 111101 (2022)



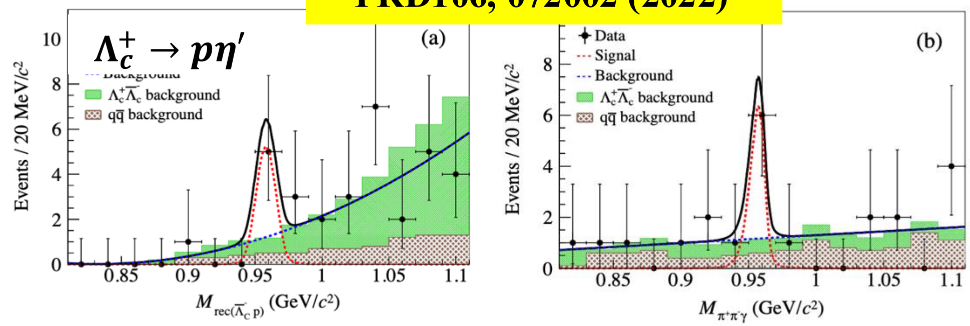
$\Lambda_c^+ \to \Sigma^+ K_S$ and $\Sigma^0 K^+$

PRD106, 052003 (2022)

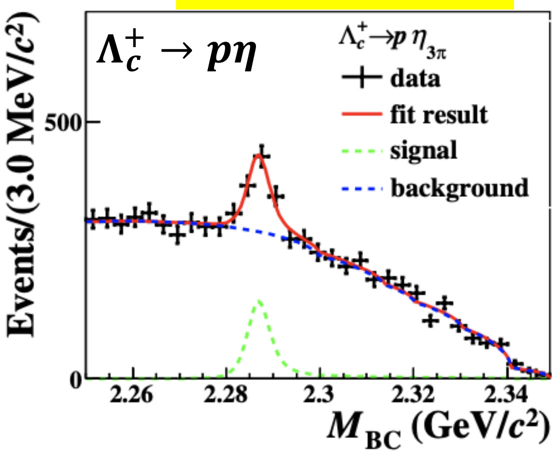




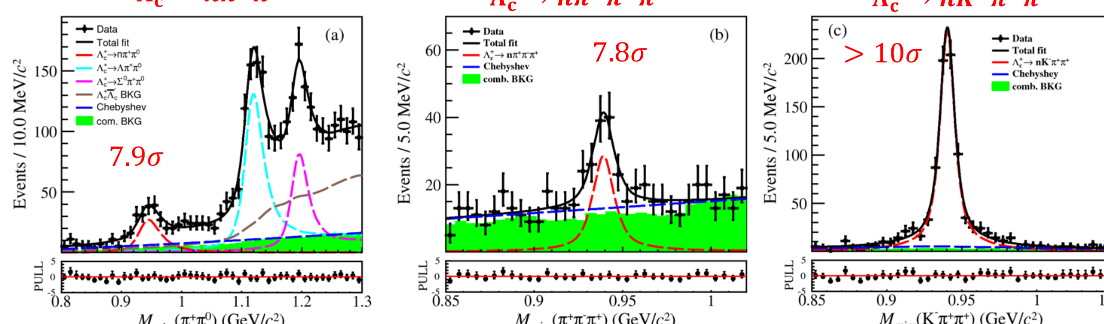
PRD106, 072002 (2022)



JHEP11, 137 (2023)



$\Lambda_c^+ \to n\pi^+\pi^0$ $\Lambda_c^+ \to n\pi^+\pi^-\pi^+$ $\Lambda_c^+ \to nK^-\pi^+\pi^+$



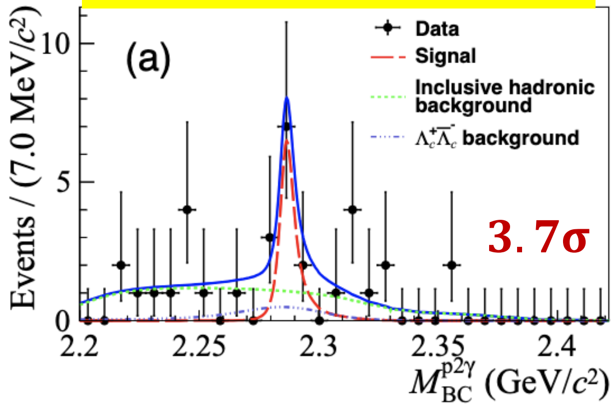
CPC47, 023001 (2023)

Many CS modes are being explored.

Singly Cabibbo-suppressed decays of $\Lambda_c^+ \to p\pi^0$ and $n\pi^+$

First evidence of $\Lambda_c^+ \to p\pi^0$

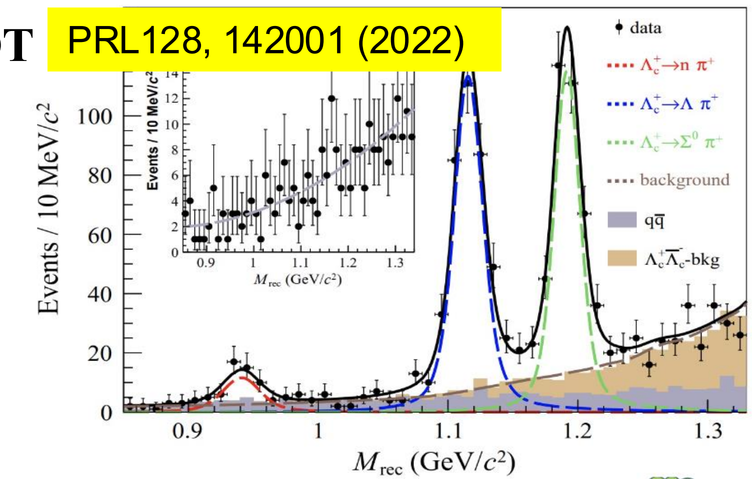
DT PRD109, L091101 (2024)



$\mathrm{BF} = (1.56^{+0.72}_{-0.58} \pm 0.20) \times 10^{-4}$

Observation of $\Lambda_c^+ \to n\pi^+$

DT PRL128, 142001 (2022)



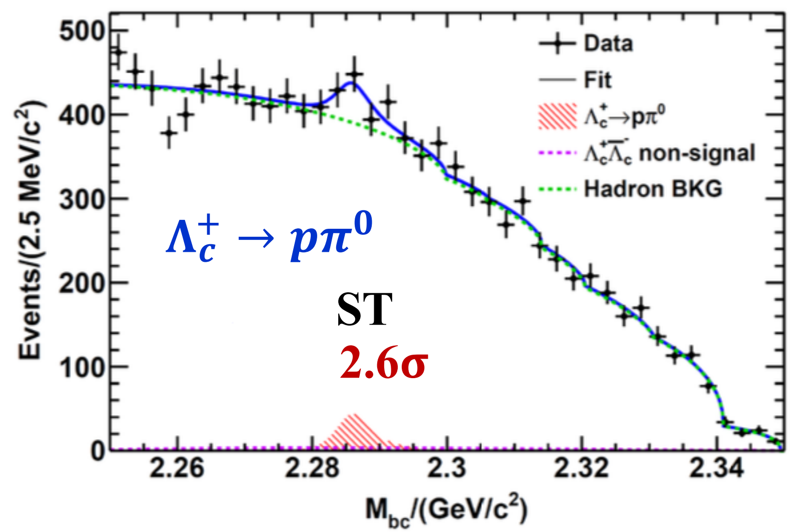
$\mathrm{BF} = (6.6 \pm 1.2 \pm 0.4) \times 10^{-4}$

$\Lambda_c^+ \to p\pi^0$:

- conflicts with BELLE (BF <8.0 $\times 10^{-5}$)
- need better precision to discriminate different theoretical calculations

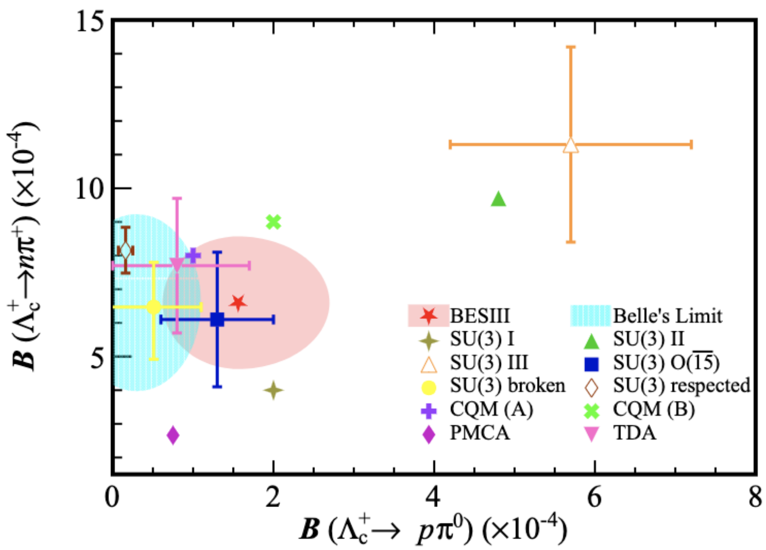
Experimental challenge

- neither ST nor DT can achieve sufficient signal sensitivity!



Branching fraction comparisons

Model	$\mathcal{B}(\Lambda_c^+ \to p\pi^0)\times 10^4$	$\mathcal{B}(\Lambda_c^+ \to p\eta)\times 10^4$	$\mathcal{B}(\Lambda_c^+ \to n\pi^+)\times 10^4$
Constituent quark model [7]	(1, 2)	3	(8, 9)
Heavy quark effective theory [8]	1.1 - 3.6	-	1.0 - 2.1
Dynamic calculation [9, 10]	(0.75, 1.3)	12.8	2.66
Topological diagram [11]	$0.8^{+0.9}_{-0.8}$	11.4 ± 3.5	7.7 ± 2.0
Topological diagram [12]	$(0.3^{+1.0}_{-0.3},\ 0.4^{+1.7}_{-0.4})$	$(14.2 \pm 2.3,\ 14.7 \pm 2.8)$	$(7.6 \pm 1.7,\ 8.3 \pm 2.6)$
SU(3) flavor symmetry [13]	2	-	4
SU(3) flavor symmetry [14]	4.8	-	9.7
SU(3) flavor symmetry [15]	5.7 ± 1.5	-	11.3 ± 2.9
SU(3) flavor symmetry [16]	1.3 ± 0.7	13.0 ± 1.0	6.1 ± 2.0
SU(3) flavor symmetry [17]	$1.1^{+1.3}_{-1.1}$	11.2 ± 2.8	7.6 ± 1.1
SU(3) flavor symmetry [18]	2.1 ± 1.0	14.1 ± 1.1	6.5 ± 2.3
BESIII experiment	< 2.7 [19] $1.57^{+0.74}_{-0.60}$ [23]	12.4 ± 3.0 [19] 15.8 ± 1.2 [20]	6.6 ± 1.3 [22]
Belle experiment	< 0.8 [21]	14.2 ± 1.2 [21]	-



ML-boosted observation of $\Lambda_c^+ \to p\pi^0$

PRD111, L051101 (2025)

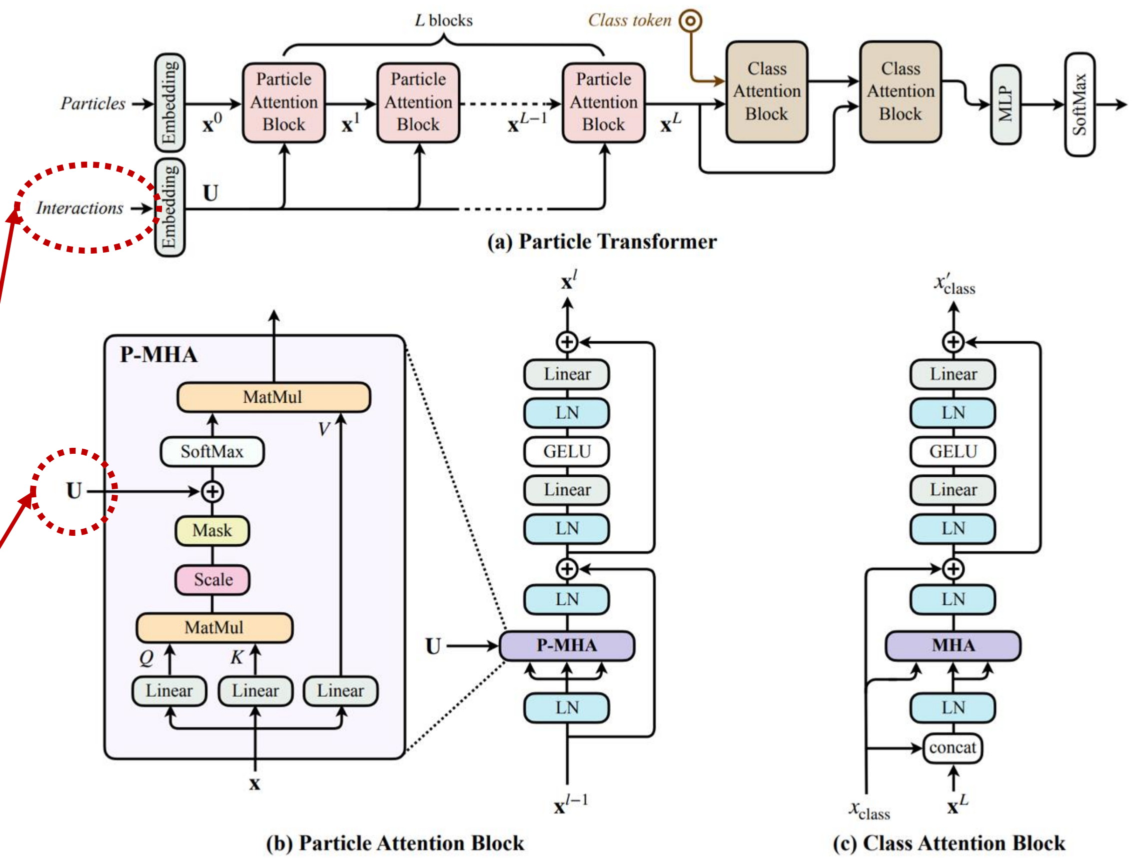
Model architecture – Transformer

- Foundation of Large Language Models like GPT
- Core concept: self-attention mechanism
- Particle Transformer: arXiv:2202.03772

✓ A transformer model tailored for particle physics

✓ Inject physics-inspired pairwise features as "bias" to the self-attention block

$$\Delta = \sqrt{(y_a - y_b)^2 + (\phi_a - \phi_b)^2},$$
$$k_T = \min(p_{T,a}, p_{T,b})\Delta,$$
$$z = \min(p_{T,a}, p_{T,b})/(p_{T,a} + p_{T,b}),$$
$$m^2 = (E_a + E_b)^2 - \|\mathbf{p}_a + \mathbf{p}_b\|^2.$$



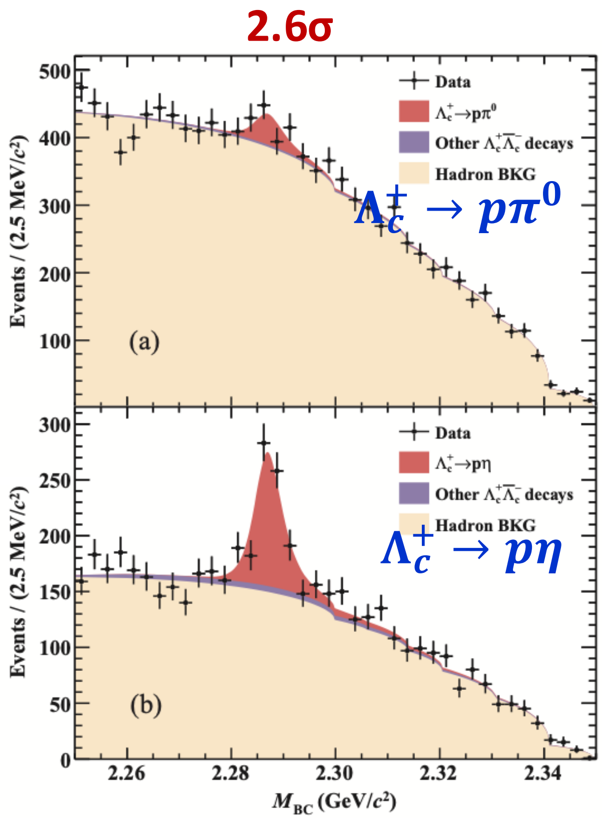
(a) Particle Transformer

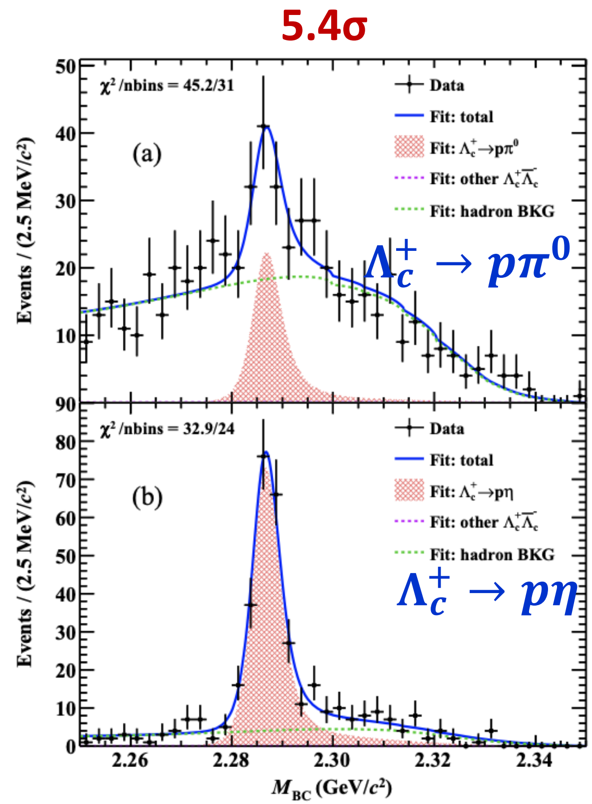
(b) Particle Attention Block

(c) Class Attention Block

ML-boosted observation of $\Lambda_c^+ \to p\pi^0$

PRD111, L051101 (2025)



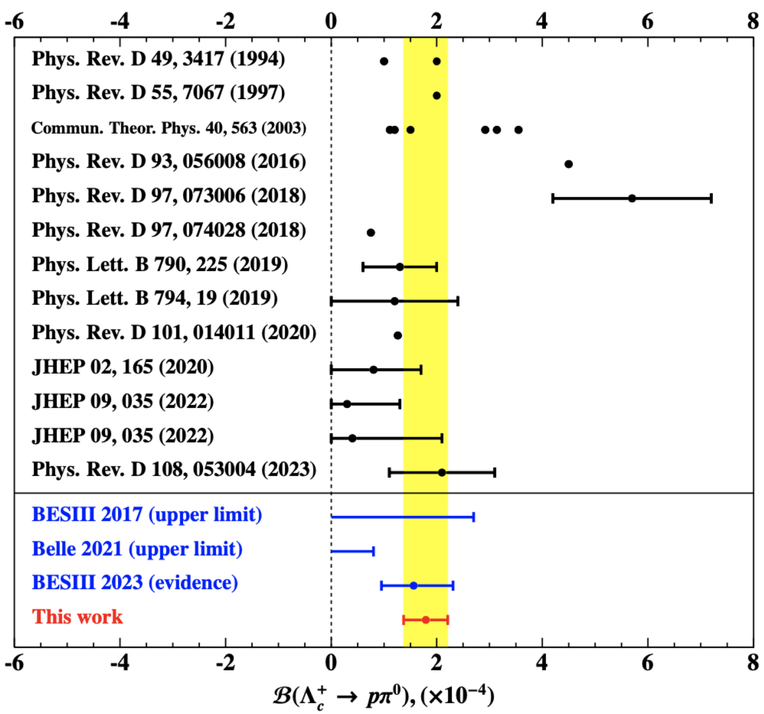


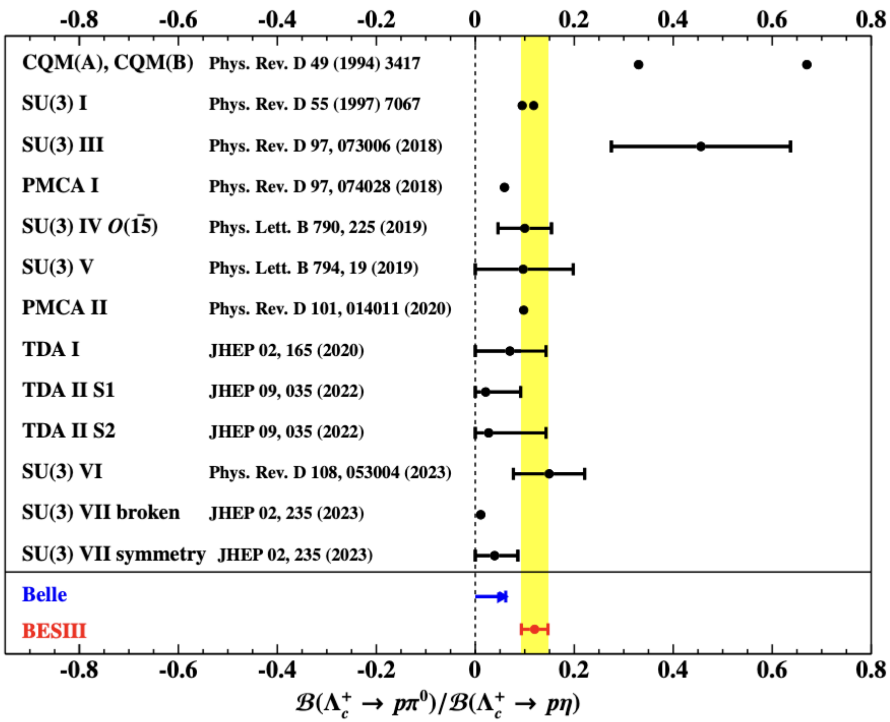
- **20 times of background suppression with 50% of signal efficiency**
- **validation samples of $\Lambda_c^+ \to pK_S\pi^0$ and $pK_S\eta$**

SCS decays of $\Lambda_c^+ \to p\pi^0$

PRD111, L051101 (2025)

- The ratio is directly measured to be $\frac{B(\Lambda_c^+ \to p\pi^0)}{B(\Lambda_c^+ \to p\eta)} = 0.120 \pm 0.026 \pm 0.007$
- The branching fraction is obtained to be $B(\Lambda_c^+ \to p\pi^0) = (1.79 \pm 0.39 \pm 0.11 \pm 0.08) \times 10^{-4}$, by adopting the average value of $B(\Lambda_c^+ \to p\eta)$ from BESIII and BELLE.
- Agree with previous BESIII measurements and exceeds the upper limit set by BELLE





Current status of hadronic decays

Table 2. Measurements of the BFs for the CF decays of the Λ_c^+ (in units of %).

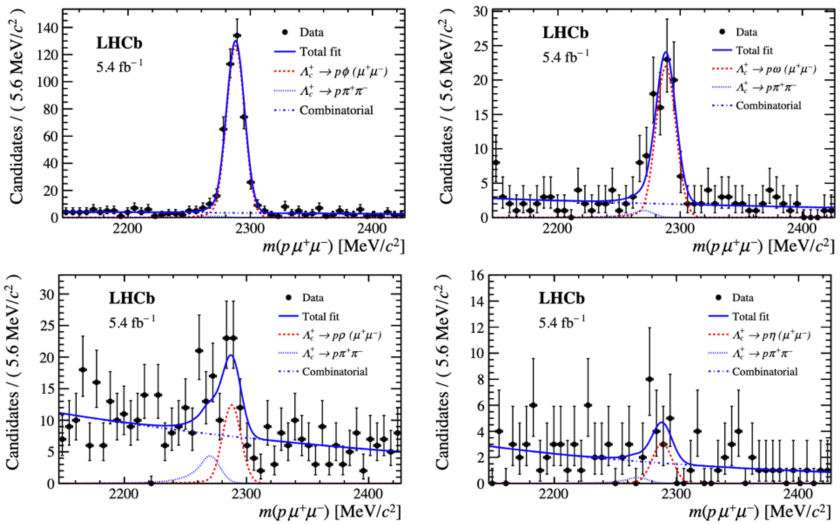
Mode	BF	Experiment	Mode	BF	Experiment
Nucleon-involved					
$\Lambda_c^+ \to pK_S^0$	1.52 ± 0.09	BESIII(2016)[80]	$\Lambda_c^+ \to nK_S^0\pi^+$	1.82 ± 0.25	BESIII(2017)[90]
$\Lambda_c^+ \to pK_L^0$	1.67 ± 0.07	BESIII(2024)[89]		1.86 ± 0.09	BESIII(2024)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(700)^0 \to pK^-\pi^+$	0.19 ± 0.06	LHCb(2023)[86]	$\Lambda_c^+ \to nK_S^0\pi^+\pi^0$	0.85 ± 0.13	BESIII(2024)[92]
$\Lambda_c^+ \to p\bar{K}_0^*(892)^0 \to pK^-\pi^+$	1.38 ± 0.08	LHCb(2023)[86]	$\Lambda_c^+ \to nK^-\pi^+\pi^+$	1.90 ± 0.12	BESIII(2023)[129]
$\Lambda_c^+ \to p\bar{K}_0^*(1430)^0 \to pK^-\pi^+$	0.92 ± 0.18	LHCb(2023)[86]	$\Lambda_c^+ \to pK_S^0\pi^0$	1.87 ± 0.14	BESIII(2016)[80]
$\Lambda_c^+ \to \Delta(1232)^{++}K^- \to p\pi^+K^-$	1.78 ± 0.05	LHCb(2023)[86]		2.12 ± 0.11	Belle(II)(2025)[144]
$\Lambda_c^+ \to \Delta(1600)^{++}K^- \to p\pi^+K^-$	0.28 ± 0.10	LHCb(2023)[86]	$\Lambda_c^+ \to pK_L^0\pi^0$	2.02 ± 0.14	BESIII(2024)[89]
$\Lambda_c^+ \to \Delta(1700)^{++}K^- \to p\pi^+K^-$	0.24 ± 0.06	LHCb(2023)[86]	$\Lambda_c^+ \to pK_S^0\eta$	0.41 ± 0.09	BESIII(2021)[145]
				0.44 ± 0.03	Belle(2023)[146]
			$\Lambda_c^+ \to pK_S^0\pi^+\pi^-$	1.53 ± 0.14	BESIII(2016)[80]
			$\Lambda_c^+ \to pK_L^0\pi^+\pi^-$	1.69 ± 0.11	BESIII(2024)[89]
			$\Lambda_c^+ \to pK^-\pi^+$	$6.84^{+0.32}_{-0.36}$	Belle(2014)[81]
				5.84 ± 0.35	BESIII(2016)[80]
			$\Lambda_c^+ \to pK^-\pi^+\pi^0$	4.53 ± 0.38	BESIII(2016)[80]
				4.42 ± 0.21	Belle(2017)[147]
Λ-involved					
$\Lambda_c^+ \to \Lambda\pi^+$	1.24 ± 0.08	BESIII(2016)[80]	$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	7.01 ± 0.42	BESIII(2016)[80]
	1.31 ± 0.09	BESIII(2023)[126]	$\Lambda_c^+ \to \Lambda\pi^+\eta$	1.84 ± 0.26	BESIII(2019)[94]
$\Lambda_c^+ \to \Lambda\rho(770)^+$	4.06 ± 0.52	BESIII(2022)[93]		1.84 ± 0.13	Belle(2021)[95]
$\Lambda_c^+ \to \Lambda a_0(980)^+$	1.23 ± 0.21	BESIII(2025)[94]		1.94 ± 0.13	BESIII(2025)[148]
$\Lambda_c^+ \to \Lambda(1405)\pi^+ \to pK^-\pi^+$	0.48 ± 0.19	LHCb(2023)[86]	$\Lambda_c^+ \to \Lambda\pi^+\pi^-\pi^+$	3.81 ± 0.30	BESIII(2016)[80]
$\Lambda_c^+ \to \Lambda(1520)\pi^+ \to pK^-\pi^+$	0.12 ± 0.02	LHCb(2023)[86]	$\Lambda_c^+ \to \Lambda K_S^0K^+$	0.30 ± 0.03	BESIII(2025)[134]
$\Lambda_c^+ \to \Lambda(1600)\pi^+ \to pK^-\pi^+$	0.32 ± 0.12	LHCb(2023)[86]		0.31 ± 0.05	BESIII(2025)[108]
$\Lambda_c^+ \to \Lambda(1670)\pi^+ \to pK^-\pi^+$	0.07 ± 0.02	LHCb(2023)[86]			
$\Lambda_c^+ \to \Lambda(1670)\pi^+ \to \Lambda\eta\pi^+$	0.27 ± 0.06	Belle(2021)[95]			
	0.27 ± 0.06	BESIII(2025)[148]			
$\Lambda_c^+ \to \Lambda(1690)\pi^+ \to pK^-\pi^+$	0.07 ± 0.02	LHCb(2023)[86]			
$\Lambda_c^+ \to \Lambda(2000)\pi^+ \to pK^-\pi^+$	0.60 ± 0.07	LHCb(2023)[86]			
Σ-involved					
$\Lambda_c^+ \to \Sigma^+\pi^0$	1.18 ± 0.10	BESIII(2016)[80]	$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$	4.25 ± 0.31	BESIII(2016)[80]
$\Lambda_c^+ \to \Sigma^+\eta$	0.41 ± 0.20	BESIII(2018)[96]		4.57 ± 0.28	Belle(2018)[149]
	0.31 ± 0.05	Belle(2023)[98]	$\Lambda_c^+ \to \Sigma^+\pi^0\pi^0$	1.57 ± 0.15	Belle(2018)[149]
	0.38 ± 0.06	BESIII(2025)[97]	$\Lambda_c^+ \to \Sigma^0\pi^+\pi^0$	3.65 ± 0.30	Belle(2018)[149]
$\Lambda_c^+ \to \Sigma^+\eta'$	1.34 ± 0.56	BESIII(2018)[96]	$\Lambda_c^+ \to \Sigma^0\pi^+\eta$	0.76 ± 0.08	Belle(2021)[95]
	0.42 ± 0.09	Belle(2023)[98]	$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$	1.81 ± 0.19	BESIII(2017)[105]
	0.57 ± 0.18	BESIII(2025)[97]	$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	2.11 ± 0.36	BESIII(2017)[105]
$\Lambda_c^+ \to \Sigma^+\omega$	1.56 ± 0.21	BESIII(2016)[80]	$\Lambda_c^+ \to \Sigma^+K^+K^-$	0.38 ± 0.05	BESIII(2023)[150]
$\Lambda_c^+ \to \Sigma^+\phi$	0.41 ± 0.09	BESIII(2023)[150]	$\Lambda_c^+ \to \Sigma^+K^+K^-_{\text{non-}\phi}$	0.20 ± 0.04	BESIII(2023)[150]
$\Lambda_c^+ \to \Sigma^0\pi^+$	1.27 ± 0.09	BESIII(2016)[80]	$\Lambda_c^+ \to \Sigma^0K_S^0K^+$	0.08 ± 0.03	BESIII(2025)[108]
	1.22 ± 0.11	BESIII(2023)[126]			
$\Lambda_c^+ \to \Sigma(1385)^+\pi^0$	0.59 ± 0.08	BESIII(2022)[93]			
$\Lambda_c^+ \to \Sigma(1385)^+\eta$	0.91 ± 0.20	BESIII(2019)[94]			
	1.21 ± 0.12	Belle(2021)[95]			
	0.68 ± 0.08	BESIII(2025)[148]			
$\Lambda_c^+ \to \Sigma(1385)^0\pi^+$	0.65 ± 0.10	BESIII(2022)[93]			
Ξ-involved					
$\Lambda_c^+ \to \Xi^0K^+$	0.59 ± 0.09	BESIII(2018)[106]	$\Lambda_c^+ \to \Xi^0K^+\pi^0$	0.78 ± 0.17	BESIII(2024)[107]
$\Lambda_c^+ \to \Xi(1530)^0K^+$	0.50 ± 0.10	BESIII(2018)[106]	$\Lambda_c^+ \to \Xi^0K_S^0\pi^+$	0.37 ± 0.06	BESIII(2025)[108]
	0.60 ± 0.11	BESIII(2024)[107]			

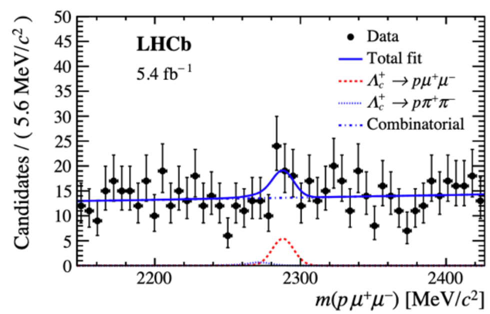
Table 3. The determined BFs for the CS decays of the Λ_c^+ (in units of 10^{-3}). Upper limits are set at 90% confidence level.

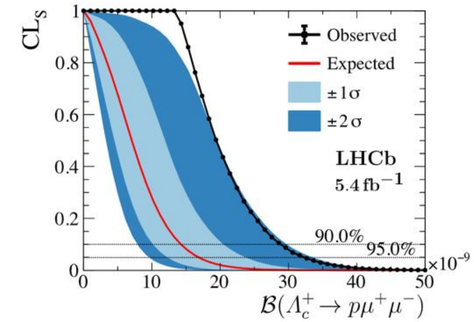
Mode	BF	Experiment	Mode	BF	Experiment
Nucleon-involved					
$\Lambda_c^+ \to n\pi^+$	0.66 ± 0.13	BESIII(2022)[126]	$\Lambda_c^+ \to nK^+\pi^0$	< 0.71	BESIII(2024)[107]
$\Lambda_c^+ \to p\pi^0$	< 0.27	BESIII(2017)[117]	$\Lambda_c^+ \to n\pi^+\pi^0$	0.64 ± 0.09	BESIII(2023)[129]
	< 0.08	Belle(2021)[109]	$\Lambda_c^+ \to nK_S^0K^+$	$0.39^{+0.17}_{-0.14}$	BESIII(2024)[91]
	$0.16^{+0.07}_{-0.06}$	BESIII(2024)[118]	$\Lambda_c^+ \to n\pi^+\pi^-\pi^+$	0.45 ± 0.08	BESIII(2023)[129]
	0.18 ± 0.04	BESIII(2025)[119]	$\Lambda_c^+ \to p\pi^+\pi^-$	3.91 ± 0.40	BESIII(2016)[127]
$\Lambda_c^+ \to p\eta$	1.24 ± 0.30	BESIII(2017)[117]		4.72 ± 0.28	LHCb(2018)[138]
	1.42 ± 0.12	Belle(2021)[109]	$\Lambda_c^+ \to pK^+K^-$	1.08 ± 0.07	LHCb(2018)[138]
	1.57 ± 0.12	BESIII(2023)[120]	$\Lambda_c^+ \to p(K^+K^-)_{\text{non-}\phi}$	0.55 ± 0.14	BESIII(2016)[127]
	1.63 ± 0.33	BESIII(2024)[118]	$\Lambda_c^+ \to pK_S^0K_S^0$	0.24 ± 0.02	Belle(2023)[146]
	1.67 ± 0.80	LHCb(2024)[121]	$\Lambda_c^+ \to p\phi\pi^0$	< 0.15	Belle(2017)[147]
$\Lambda_c^+ \to p\eta'$	$0.56^{+0.25}_{-0.21}$	BESIII(2022)[123]	$\Lambda_c^+ \to (pK^+K^-\pi^0)_{\text{NR}}$	< 0.06	Belle(2017)[147]
	0.47 ± 0.10	Belle(2022)[122]	$\Lambda_c^+ \to pK^+\pi^-$	0.16 ± 0.02	Belle(2016)[137]
$\Lambda_c^+ \to p\rho$	1.52 ± 0.44	LHCb(2024)[121]		0.10 ± 0.01	LHCb(2018)[138]
$\Lambda_c^+ \to p\omega$	0.94 ± 0.39	LHCb(2018)[124]			
	0.83 ± 0.11	Belle(2021)[125]			
	1.11 ± 0.21	BESIII(2023)[120]			
	0.98 ± 0.31	LHCb(2024)[121]			
$\Lambda_c^+ \to p\phi$	1.06 ± 0.22	BESIII(2016)[127]			
Λ-involved					
$\Lambda_c^+ \to \Lambda K^+$	0.62 ± 0.06	BESIII(2022)[131]	$\Lambda_c^+ \to \Lambda K^+\pi^0$	< 2.0	BESIII(2024)[107]
	0.66 ± 0.04	Belle(2023)[132]		1.49 ± 0.29	BESIII(2024)[135]
$\Lambda_c^+ \to \Lambda K^{*+}$	$2.40\pm0.59(\theta_0=0^\circ)$	BESIII(2025)[134]	$\Lambda_c^+ \to \Lambda K_S^0\pi^+$	1.73 ± 0.29	BESIII(2025)[134]
	$5.21\pm0.75(\theta_0=109^\circ)$	BESIII(2025)[134]	$\Lambda_c^+ \to \Lambda K^+\pi^+\pi^-$	0.41 ± 0.15	BESIII(2024)[135]
	$1.29\pm0.44(\theta_0=221^\circ)$	BESIII(2025)[134]			
Σ-involved					
$\Lambda_c^+ \to \Sigma^0K^+$	0.47 ± 0.10	BESIII(2022)[133]	$\Lambda_c^+ \to \Sigma^+K^+\pi^-$	2.00 ± 0.28	BESIII(2023)[150]
	0.36 ± 0.03	Belle(2023)[132]	$\Lambda_c^+ \to \Sigma^+K^+\pi^-\pi^0$	< 0.01	BESIII(2023)[150]
$\Lambda_c^+ \to \Sigma^+K_S^0$	0.48 ± 0.14	BESIII(2022)[133]	$\Lambda_c^+ \to \Sigma^0K^+\pi^0$	< 1.8	BESIII(2024)[107]
				< 0.50	BESIII(2024)[151]
			$\Lambda_c^+ \to \Sigma^0K^+\pi^+\pi^-$	< 0.65	BESIII(2024)[151]
			$\Lambda_c^+ \to \Sigma^-K^+\pi^+$	0.38 ± 0.12	BESIII(2024)[136]

CPV search and resonant contributions in $\Lambda_c^+ \to p\mu^+\mu^-$

PRD110, 052007 (2024)
arXiv:2502.04013



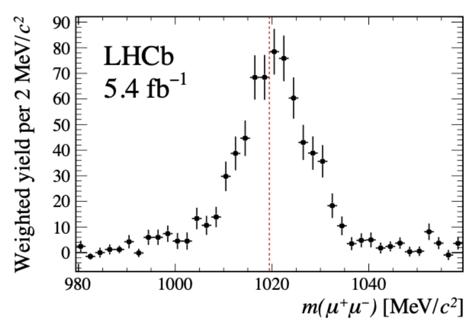


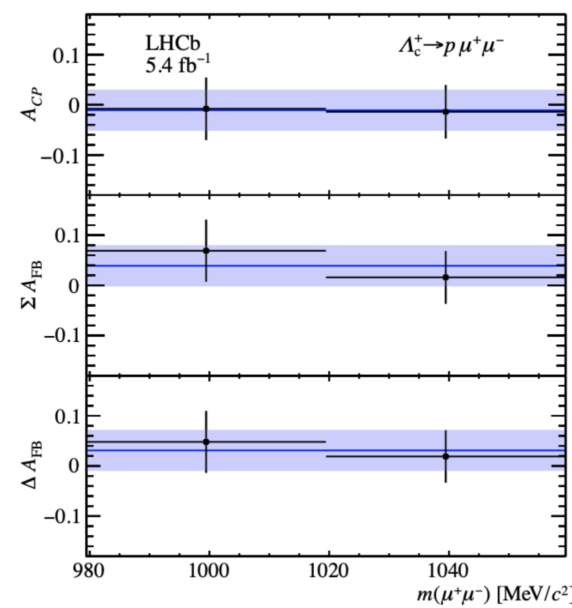


$$\mathcal{B}(\Lambda_c^+ \to p\mu^+\mu^-) < 2.9\ (3.2) \times 10^{-8} \text{ at } 90\%\ (95\%) \text{ CL.}$$

$$\mathcal{B}(\Lambda_c^+ \to p\omega) = (9.82 \pm 1.23\ (\text{stat.}) \pm 0.73\ (\text{syst.}) \pm 2.79\ (\text{ext.})) \times 10^{-4},$$
$$\mathcal{B}(\Lambda_c^+ \to p\rho) = (1.52 \pm 0.34\ (\text{stat.}) \pm 0.14\ (\text{syst.}) \pm 0.24\ (\text{ext.})) \times 10^{-3},$$
$$\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.67 \pm 0.69\ (\text{stat.}) \pm 0.23\ (\text{syst.}) \pm 0.34\ (\text{ext.})) \times 10^{-3},$$

Region	Range [MeV/c^2]
low-m	$211.32 < m_{\mu^+\mu^-} < 507.86$
high-m	$1059.46 < m_{\mu^+\mu^-} < 1348.13$
η	$507.86 < m_{\mu^+\mu^-} < 587.86$
ω	$742.65 < m_{\mu^+\mu^-} < 822.65$
ρ	$587.86 < m_{\mu^+\mu^-} < 742.65$
	or $822.65 < m_{\mu^+\mu^-} < 965.20$
ϕ	$979.46 < m_{\mu^+\mu^-} < 1059.46$



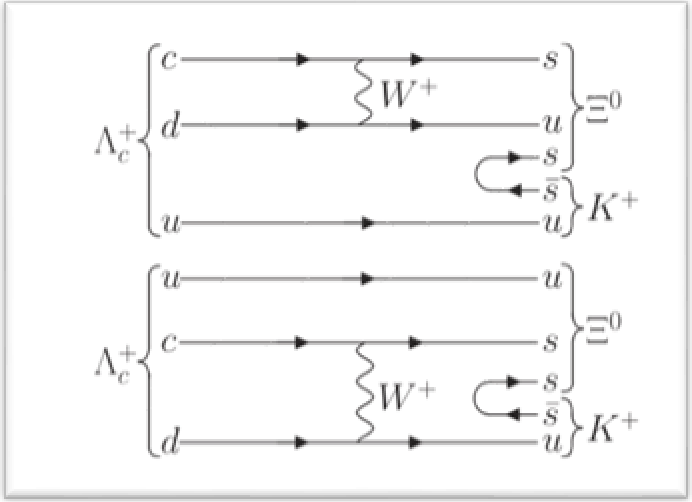


Decay asymmetry in W-exchange-only process $\Lambda_c^+ \to \Xi^0 K^+$

- Previous theoretical calculation on the BF lower than exp. measurement, which all predicted zero decay asymmetry
- BESIII confirmed the exp. result of BF in 2018 [PLB 783, 200 (2018)]
- In theory, BF is enhanced by enhancing the decay asymmetry close to 1

$$\alpha_{\Xi^0 K^+} = 2\mathrm{Re}(s^* p)/(|s|^2 + |p|^2),$$

$$\delta_p - \delta_s = \arctan(\sqrt{1-\alpha^2_{\Xi^0 K^+}} \sin \Delta_{\Xi^0 K^+}/\alpha_{\Xi^0 K^+})$$



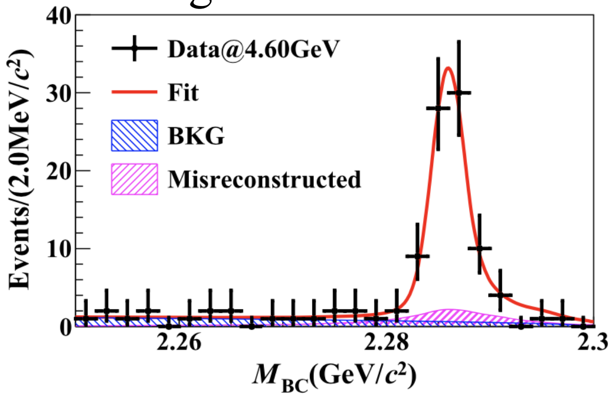
Theory or experiment	$\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ $(\times 10^{-3})$	$\alpha_{\Xi^0 K^+}$	$\lvert A\rvert$ $(\times 10^{-2} G_F\ \mathrm{GeV}^2)$	$\lvert B\rvert$ $(\times 10^{-2} G_F\ \mathrm{GeV}^2)$	$\delta_p - \delta_s$ (rad)
Körner (1992), CCQM [7]	2.6	0	...	...	...
Xu (1992), Pole [8]	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	...	...	...	...

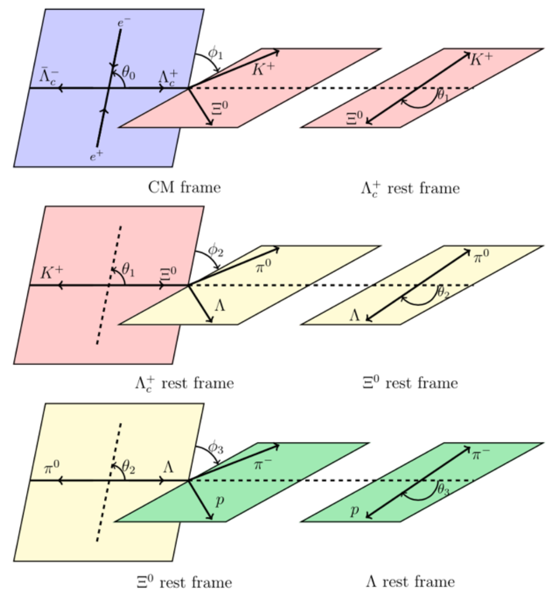
Decay asymmetry in W-exchange-only process $\Lambda_c^+ \to \Xi^0 K^+$

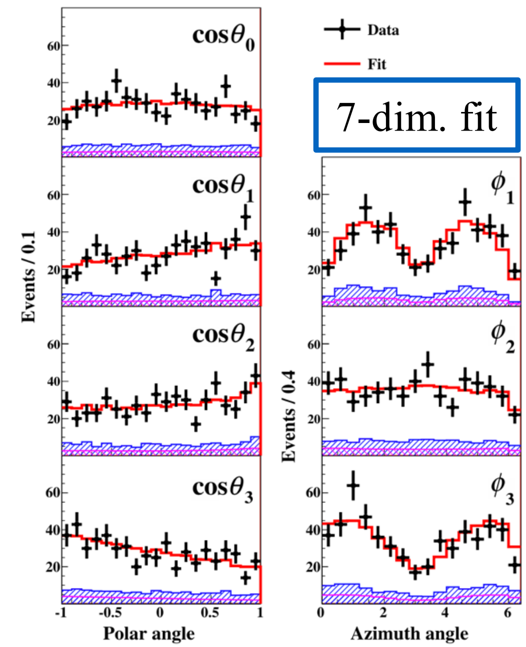
three-level cascade decay $\Lambda_c^+ \to \Xi^0 K^+$, $\Xi^0 \to \Lambda\pi^0$, $\Lambda \to p\pi^-$

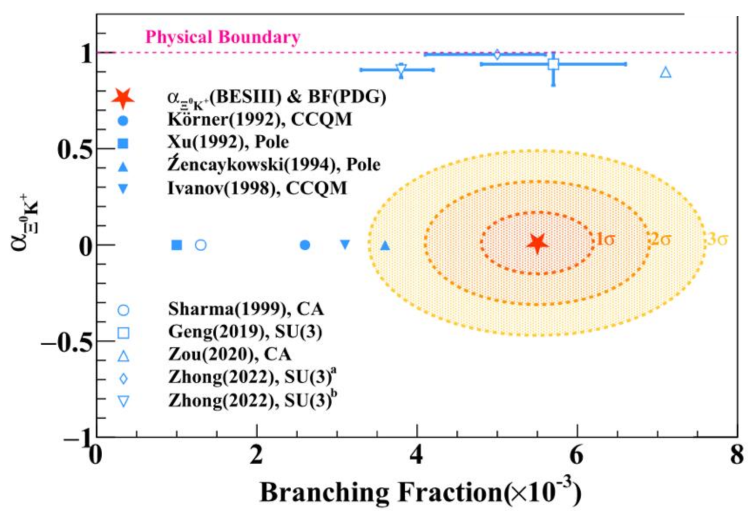
PRL132, 031801(2024)

~378 signals reconstructed









- First determination of decay asymmetry $\alpha_{\Xi^0K^+} = 0.01 \pm 0.16 \pm 0.03$, consistent with zero
- No theoretical model explains the current results
- First determination on phase difference $\delta_p - \delta_s$, with two solutions of $\pi/2$ and $-\pi/2$

Determination on the phase differences

- Based on the angular fit, the phase angle $\Delta_{\Xi^0 K^+} = (3.84 \pm 0.90 \pm 0.17)$ rad

$$\beta_{\Xi^0 K^+} = \sqrt{1-(\alpha_{\Xi^0 K^+})^2}\,\sin\Delta_{\Xi^0 K^+},$$

$$\gamma_{\Xi^0 K^+} = \sqrt{1-(\alpha_{\Xi^0 K^+})^2}\,\cos\Delta_{\Xi^0 K^+}.$$

$$\beta_{\Xi^0 K^+} = -0.64 \pm 0.69 \pm 0.13$$

$$\gamma_{\Xi^0 K^+} = -0.77 \pm 0.58 \pm 0.11$$

- First determination on phase difference $\delta_p - \delta_s$, with two solutions of $\pi/2$ and $-\pi/2$

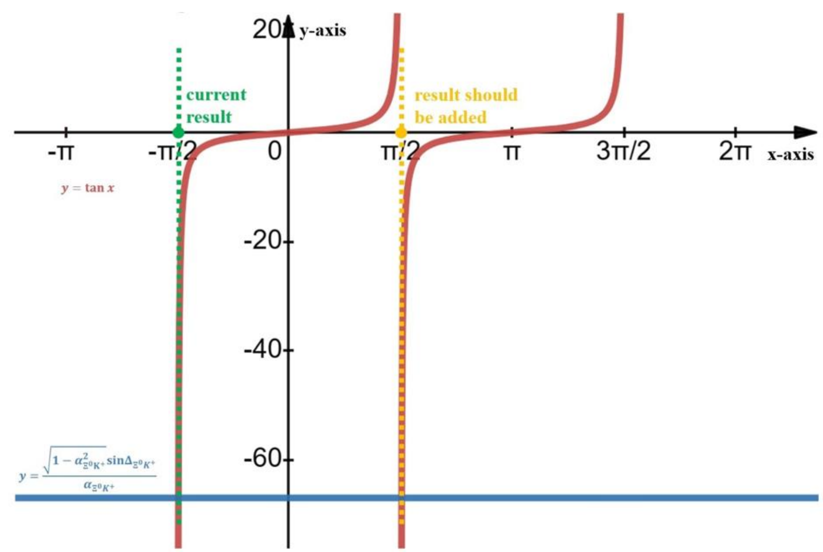
$$\Gamma_{\Xi^0 K^+} = \frac{\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)}{\tau_{\Lambda_c^+}} = \frac{|\vec{p}_c|}{8\pi}\left[\frac{(m_{\Lambda_c^+}+m_{\Xi^0})^2 - m_{K^+}^2}{m_{\Lambda_c^+}^2}|A|^2 + \frac{(m_{\Lambda_c^+}-m_{\Xi^0})^2 - m_{K^+}^2}{m_{\Lambda_c^+}^2}|B|^2\right],$$

$$\alpha_{\Xi^0 K^+} = \frac{2\kappa|A||B|\cos(\delta_p-\delta_s)}{|A|^2+\kappa^2|B|^2},$$

$$\Delta_{\Xi^0 K^+} = \arctan\frac{2\kappa|A||B|\sin(\delta_p-\delta_s)}{|A|^2-\kappa^2|B|^2}$$

$$\delta_p - \delta_s = \arctan\left(\sqrt{1-\alpha_{\Xi^0 K^+}^2}\,\sin\Delta_{\Xi^0 K^+}/\alpha_{\Xi^0 K^+}\right)$$

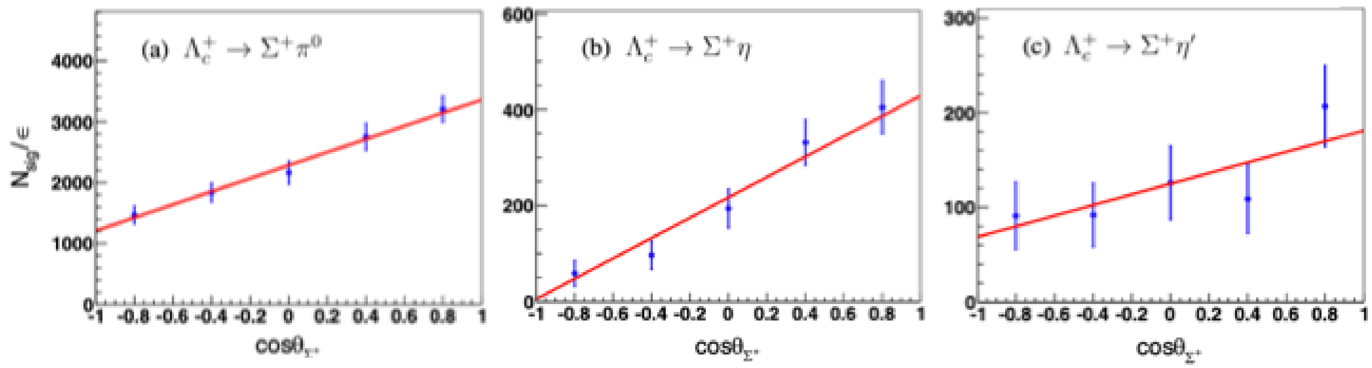
1st sol.: $(-1.55 \pm 0.25 \pm 0.05)$ rad
2nd sol.: $(1.59 \pm 0.25 \pm 0.05)$ rad



Decay asymmetries in two-body Λ_c^+ decays

PRD107, 032003 (2023)

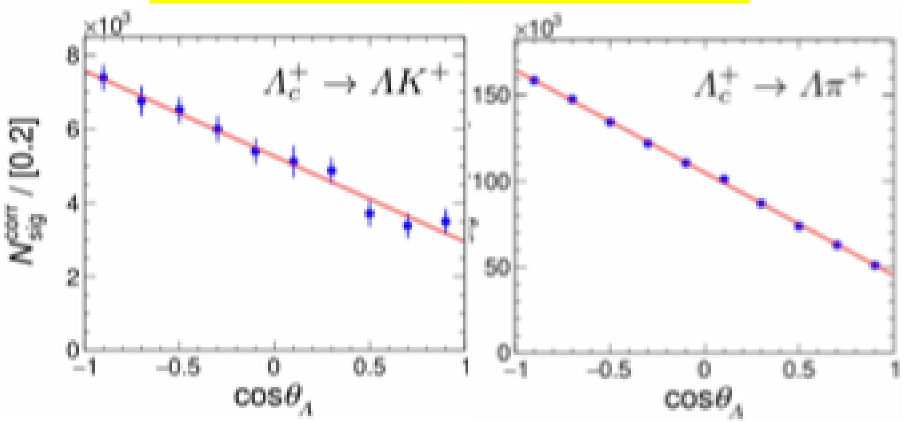
$$\frac{dN}{d\cos\theta_{\Sigma^+}} \propto 1 + \alpha_{\Sigma^+ h^0}\alpha_{p\pi^0}\cos\theta_{\Sigma^+}$$



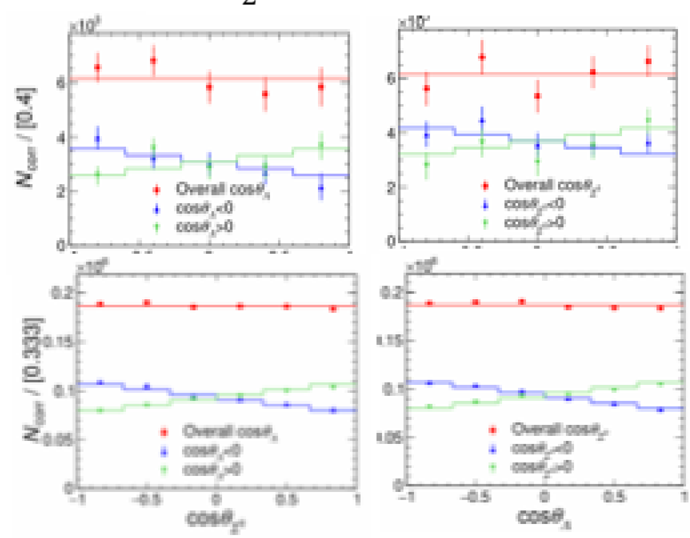
$\alpha_{\Sigma^+\pi^0} = -0.48 \pm 0.02 \pm 0.02$ $\alpha_{\Sigma^+\eta} = -0.99 \pm 0.03 \pm 0.05$ $\alpha_{\Sigma^+\eta'} = -0.46 \pm 0.06 \pm 0.03.$

Science Bulletin 68, 583 (2023)

$$\frac{dN}{d\cos\theta_{\Sigma^0}\, d\cos\theta_\Lambda} \propto 1 - \alpha_{\Lambda_c^+}\alpha_- \cos\theta_{\Sigma^0}\cos\theta_\Lambda$$



$$\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Lambda K^+) = -0.585 \pm 0.049 \pm 0.018,$$
$$\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Lambda\pi^+) = -0.755 \pm 0.005 \pm 0.003,$$



$$\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Sigma^0 K^+) = -0.54 \pm 0.18 \pm 0.09,$$
$$\alpha_{\Lambda_c^+}^{avg}(\Lambda_c^+ \to \Sigma^0\pi^+) = -0.463 \pm 0.016 \pm 0.008,$$

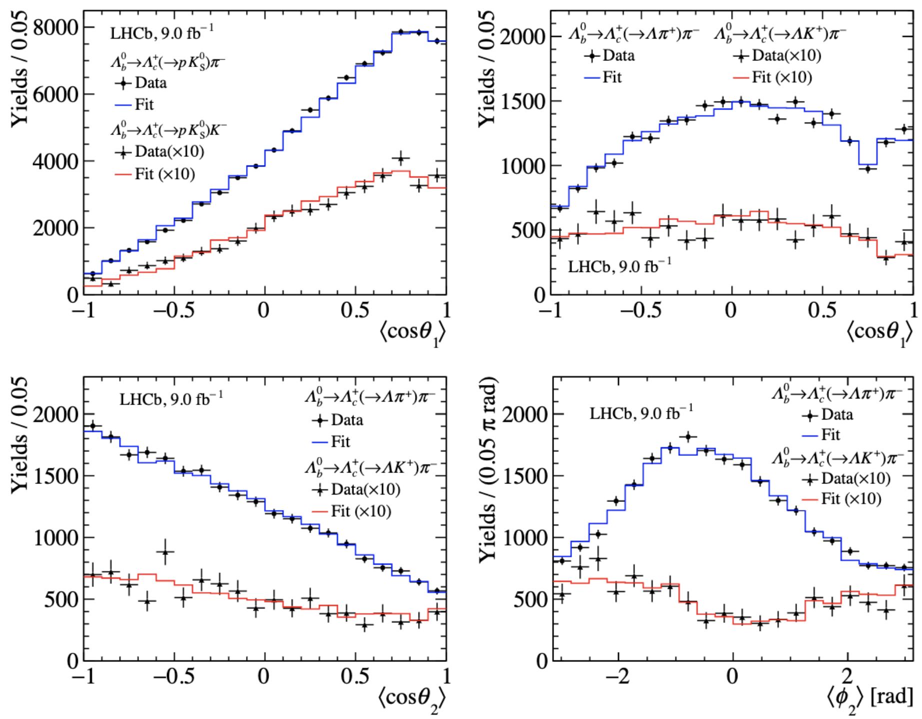
no CPV are seen in $\Lambda_c^+ \to \Lambda K^+$ and $\Sigma^0 K^+$

Decay asymmetries of Λ_c^+ via $\Lambda_b^0 \to \Lambda_c^+ h$

RUN1+2 data

PRL133 (2024) 26, 261804

Simultaneous fit to five decay modes: $\Lambda_b^0 \to$
$\Lambda_c^+(\to pK_S)\pi^-$, $\Lambda_c^+(\to pK_S)K^-$,
$\Lambda_c^+(\to \Lambda\pi^+)\pi^-$, $\Lambda_c^+(\to \Lambda\pi^+)K^-$,
$\Lambda_c^+(\to \Lambda K^+)\pi^-$



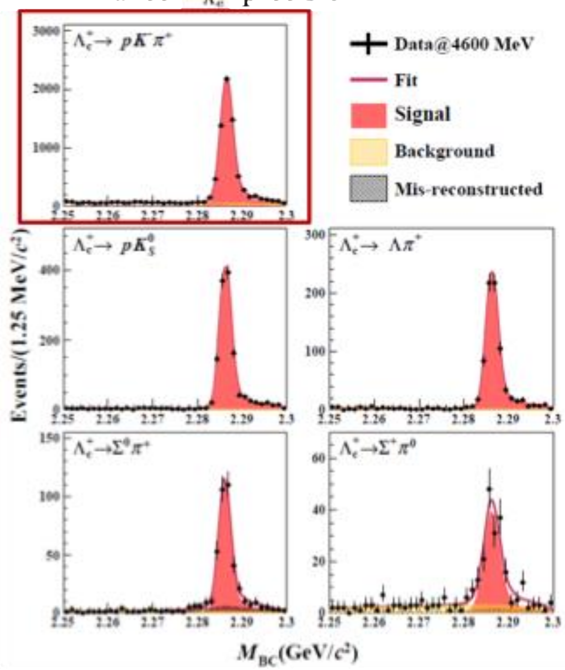
Decay	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Lambda K^+$
β	$0.368 \pm 0.019 \pm 0.008$	$0.35 \pm 0.12 \pm 0.04$
$\bar{\beta}$	$-0.387 \pm 0.018 \pm 0.010$	$-0.32 \pm 0.11 \pm 0.03$
γ	$0.502 \pm 0.016 \pm 0.006$	$-0.743 \pm 0.067 \pm 0.024$
$\bar{\gamma}$	$0.480 \pm 0.016 \pm 0.007$	$-0.828 \pm 0.049 \pm 0.013$
Δ (rad)	$0.633 \pm 0.036 \pm 0.013$	$2.70 \pm 0.17 \pm 0.04$
$\bar{\Delta}$ (rad)	$-0.678 \pm 0.035 \pm 0.013$	$-2.78 \pm 0.13 \pm 0.03$
R_β	$0.012 \pm 0.017 \pm 0.005$	$-0.04 \pm 0.15 \pm 0.02$
R'_β	$-0.481 \pm 0.019 \pm 0.009$	$-0.65 \pm 0.17 \pm 0.07$

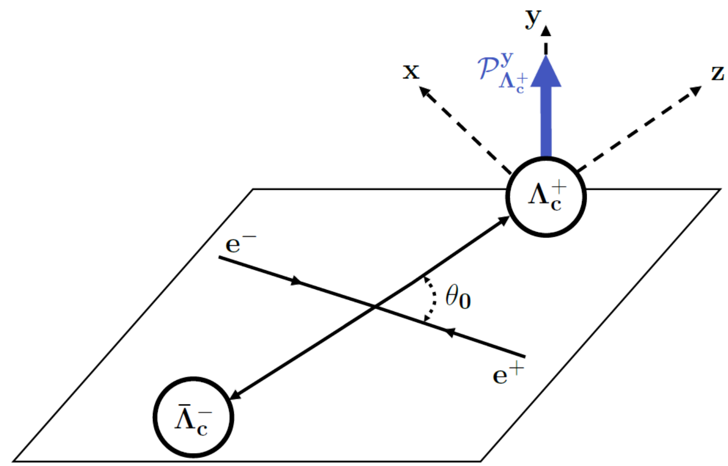
Decay	α	$\bar{\alpha}$	$\langle\alpha\rangle$	A_α
$\Lambda_b^0 \to \Lambda_c^+\pi^-$	$-1.010 \pm 0.011 \pm 0.003$	$0.996 \pm 0.011 \pm 0.003$	$-1.003 \pm 0.008 \pm 0.005$	$0.007 \pm 0.008 \pm 0.005$
$\Lambda_b^0 \to \Lambda_c^+ K^-$	$-0.933 \pm 0.042 \pm 0.014$	$0.995 \pm 0.036 \pm 0.013$	$-0.964 \pm 0.028 \pm 0.015$	$-0.032 \pm 0.029 \pm 0.006$
$\Lambda_c^+ \to \Lambda\pi^+$	$-0.782 \pm 0.009 \pm 0.004$	$0.787 \pm 0.009 \pm 0.003$	$-0.785 \pm 0.006 \pm 0.003$	$-0.003 \pm 0.008 \pm 0.002$
$\Lambda_c^+ \to \Lambda K^+$	$-0.569 \pm 0.059 \pm 0.028$	$0.464 \pm 0.058 \pm 0.017$	$-0.516 \pm 0.041 \pm 0.021$	$0.102 \pm 0.080 \pm 0.023$
$\Lambda_c^+ \to pK_S^0$	$-0.744 \pm 0.012 \pm 0.009$	$0.765 \pm 0.012 \pm 0.007$	$-0.754 \pm 0.008 \pm 0.006$	$-0.014 \pm 0.011 \pm 0.008$
$\Lambda \to p\pi^-$	$0.717 \pm 0.017 \pm 0.009$	$-0.748 \pm 0.016 \pm 0.007$	$0.733 \pm 0.012 \pm 0.006$	$-0.022 \pm 0.016 \pm 0.007$

Probe transverse polarization of the Λ_c^+

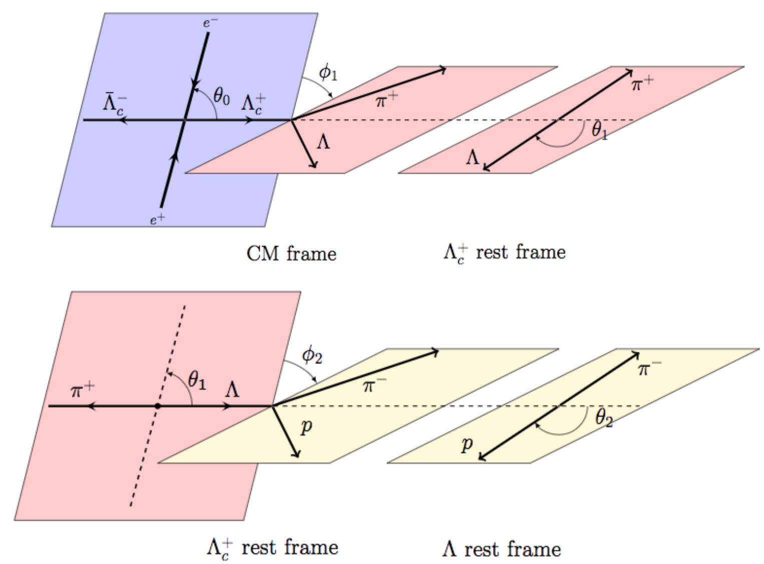
arXiv:2508.11400

- Evidence of transverse polarization using 587 fb^{-1} in 2018
- Using 6.4 fb^{-1} collected from 4.6-4.95 GeV, observe transverse polarization in multiple energy points
- Joint angular analyses of the cascade decays of $\Lambda_c \rightarrow pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ and amplitude analysis of $\Lambda_c \rightarrow pK^-\pi^+$
  - Enhance $\mathcal{P}^y_{\Lambda_c^+}$ precision





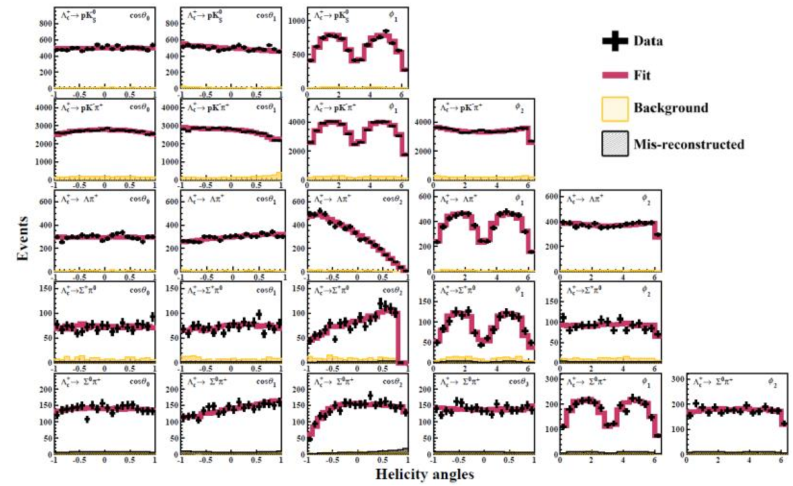
$$\mathcal{P}^y_{\Lambda_c^+}(\cos\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi$$

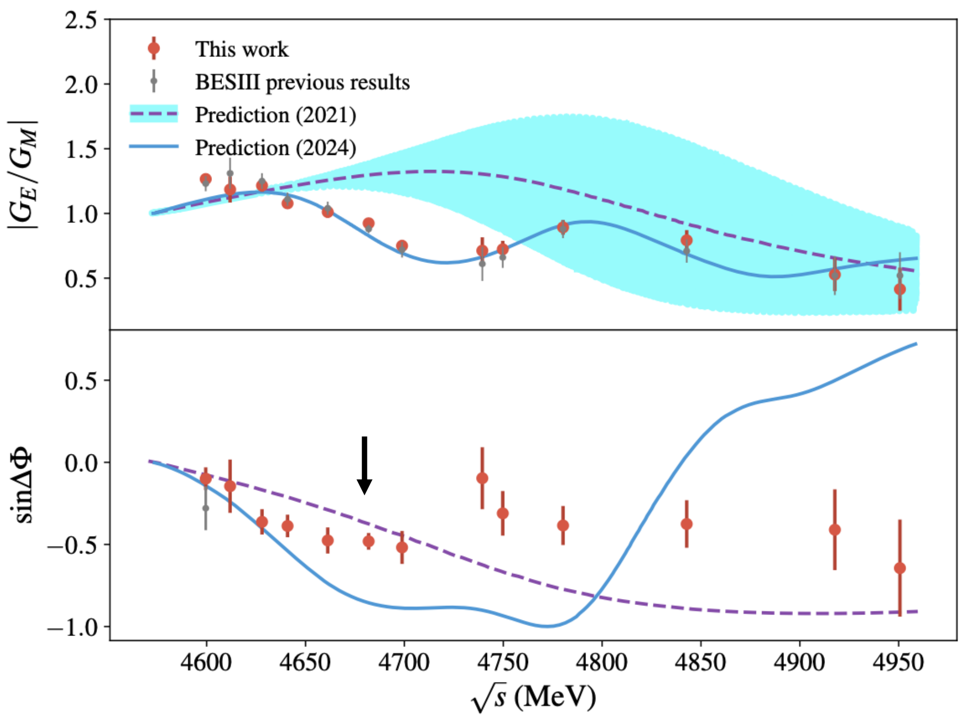


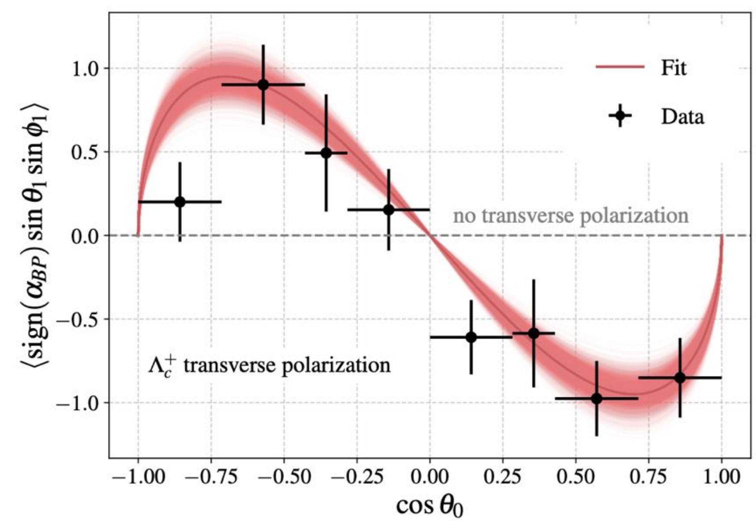
Observation of transverse polarization of the Λ_c^+

arXiv:2508.11400

- Simultaneous fits to 23 angles of 5 channels at 13 energy points
- Established a new method to enhance the precisions of the decay asymmetries $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$

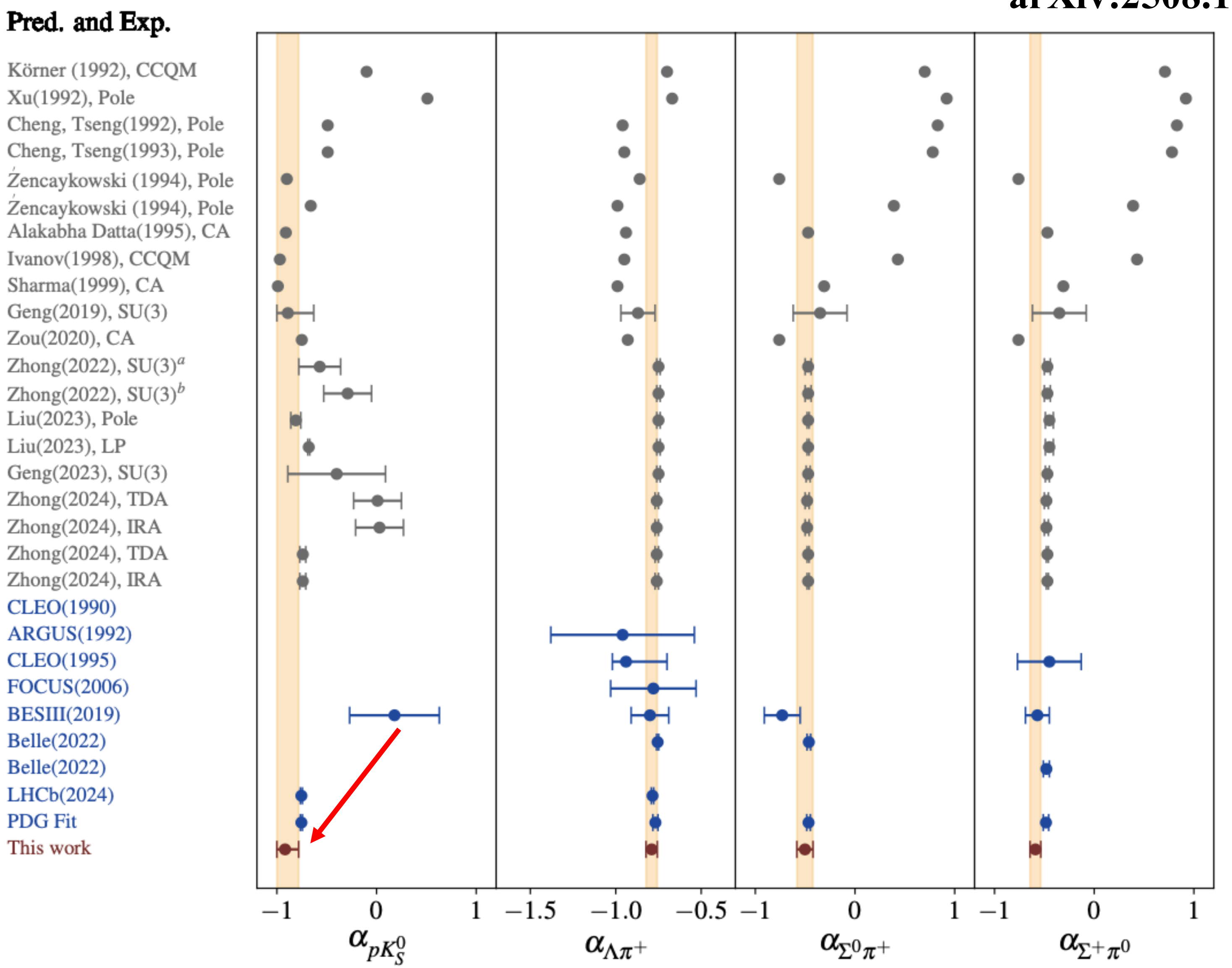






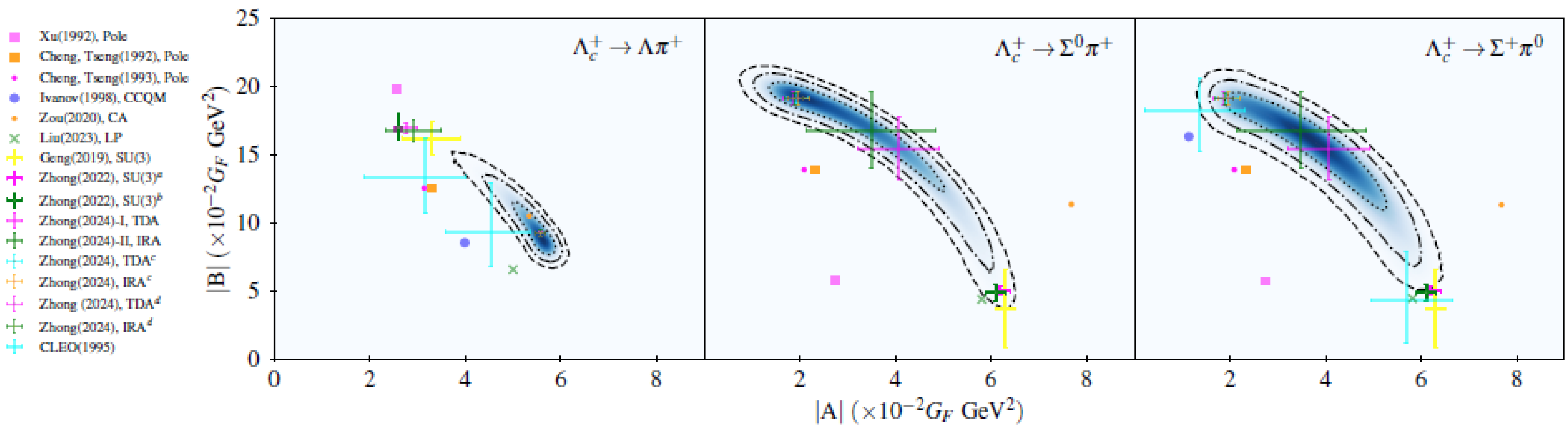
Improved Λ_c^+ decay asymmetries

arXiv:2508.11400



Λ_c^+ decay asymmetries

Parameter	$\Lambda_c^+ \to pK_S^0$	$\Lambda_c^+ \to \Lambda\pi^+$	$\Lambda_c^+ \to \Sigma^0\pi^+$	$\Lambda_c^+ \to \Sigma^+\pi^0$
$\langle\alpha_{BP}\rangle$	$-0.918^{+0.133}_{-0.082} \pm 0.031$	$-0.790 \pm 0.032 \pm 0.009$	$-0.502 \pm 0.080 \pm 0.009$	$-0.590 \pm 0.049 \pm 0.022$
$\langle\Delta_{BP}\rangle$	$\cdots$	$0.637 \pm 0.444 \pm 0.014$	$2.190 \pm 0.730 \pm 0.029$	$1.901 \pm 0.603 \pm 0.040$
$\langle\beta_{BP}\rangle$	$\cdots$	$0.365^{+0.173}_{-0.246} \pm 0.010$	$0.704^{+0.143}_{-0.480} \pm 0.015$	$0.764^{+0.051}_{-0.237} \pm 0.018$
$\langle\gamma_{BP}\rangle$	$\cdots$	$0.637^{+0.103}_{-0.202} \pm 0.011$	$-0.502^{+0.591}_{-0.303} \pm 0.021$	$-0.262^{+0.478}_{-0.383} \pm 0.031$
$\delta_p - \delta_s$	$\cdots$	$2.71^{+0.28}_{-0.17} \pm 0.02$	$2.19^{+0.49}_{-0.13} \pm 0.02$	$2.23^{+0.19}_{-0.06} \pm 0.03$
$A_{CP}^{\alpha BP}$	$0.079^{+0.115}_{-0.101} \pm 0.019$	$0.002 \pm 0.047 \pm 0.017$	$0.206^{+0.188}_{-0.156} \pm 0.028$	$-0.086 \pm 0.081 \pm 0.085$
$\tan\phi_{CP}$	$\cdots$	$0.232 \pm 0.242 \pm 0.025$	$0.393 \pm 0.651 \pm 0.042$	$-0.007 \pm 0.474 \pm 0.034$
$\tan\Delta_s$	$\cdots$	$-0.475 \pm 0.242 \pm 0.029$	$-1.411 \pm 0.672 \pm 0.062$	$-1.297 \pm 0.478 \pm 0.068$



Strong phase convention in baryon decays

ScienceBulletin 02.030(2025)

$$\alpha = \frac{2\,\mathrm{Re}(S^*P)}{|S|^2+|P|^2},\quad \beta = \frac{2\,\mathrm{Im}(S^*P)}{|S|^2+|P|^2},\quad \gamma = \frac{|S|^2-|P|^2}{|S|^2+|P|^2}$$

$$\delta_P - \delta_S = 2\arctan\frac{\beta\times sign}{\sqrt{\alpha^2+\beta^2}+\alpha\times sign},$$

$$\alpha_1 = \frac{2|S||P|\cos(\delta_P-\delta_S)}{|S|^2+|P|^2},\quad \beta_1 = \frac{2|S||P|\sin(\delta_P-\delta_S)}{|S|^2+|P|^2}.$$

$$S_1 = |S|e^{i\delta_S},\qquad P_1 = |P|e^{i\delta_P},$$

$$\alpha_2 = \frac{2\widetilde{S}\widetilde{P}\cos(\delta_P-\delta_S)}{|\widetilde{S}|^2+|\widetilde{P}|^2},\ \beta_2 = \frac{2\widetilde{S}\widetilde{P}\sin(\delta_P-\delta_S)}{|\widetilde{S}|^2+|\widetilde{P}|^2},$$

$$S_2 = \widetilde{S}e^{i\delta_S},\ P_2 = \widetilde{P}e^{i\delta_P},$$

$$\alpha_3 = \sin(2\zeta)\cos(\delta_P-\delta_S),\ \beta_3 = \sin(2\zeta)\sin(\delta_P-\delta_S).$$

$$S_3 = |\mathcal{A}|\sin\zeta\, e^{i\delta_S},\ P_3 = |\mathcal{A}|\cos\zeta\, e^{i\delta_P}.$$

Table 1

Summary of experimental data on the parameters α, β, and ϕ and the phase shift, $\delta_P-\delta_S$, in various two-body nonleptonic decays of the Λ and Ξ hyperons and singly charmed baryon Λ_c^+.

Experiment	Process	α or $\langle\alpha\rangle$	β or $\langle\beta\rangle$	ϕ or $\langle\phi\rangle$ (rad)	$\delta_P-\delta_S$ (rad)	Value of *sign*	$\delta_P-\delta_S$ (rad) Eq. (10) with *sign*=1	Eq. (10) with *sign*=−1
Λ from π^-p (1963) [14]	$\Lambda\to p\pi^-$	0.62 ± 0.07	-0.18 ± 0.24	...	-0.26 ± 0.35[a]	Unknown	-0.28 ± 0.36	2.86 ± 0.36
Λ from π^-p (1967) [15]		0.645 ± 0.017	-0.103 ± 0.065	-0.14 ± 0.10	-0.16 ± 0.10[a]	Unknown	-0.16 ± 0.10	2.98 ± 0.10
E756 (2003) [18]	$\Xi^-\to\Lambda\pi^-$	-0.458 ± 0.012	-0.03 ± 0.04	-0.03 ± 0.05	0.06 ± 0.09	$+1$	-3.08 ± 0.09	0.06 ± 0.09
HyperCP (2004) [19]		-0.458 ± 0.012	-0.037 ± 0.015	-0.041 ± 0.016	0.080 ± 0.032	Unknown	-3.062 ± 0.031	0.079 ± 0.031
BESIII (2022) [20]		-0.373 ± 0.006	Positive	0.016 ± 0.016	-0.040 ± 0.037	Unknown	3.102 ± 0.036	-0.040 ± 0.036
BESIII (2022) [21]		-0.350 ± 0.018	Positive	0.073 ± 0.052	-0.20 ± 0.13	Unknown	2.95 ± 0.13	-0.19 ± 0.13
BESIII (2024) [22]		-0.371 ± 0.004	Negative	-0.013 ± 0.008	0.033 ± 0.023	Unknown	-3.109 ± 0.025	0.033 ± 0.025
BESIII (2023) [23]	$\Xi^0\to\Lambda\pi^0$	-0.377 ± 0.003	Positive	0.005 ± 0.007	-0.013 ± 0.017	Unknown	3.129 ± 0.017	-0.012 ± 0.017
LHCb (2024) [24]	$\Lambda_c^+\to\Lambda\pi^+$	-0.785 ± 0.007	0.378 ± 0.015	0.656 ± 0.027	2.693 ± 0.017	Unknown	2.693 ± 0.015	-0.449 ± 0.015
LHCb (2024) [24]	$\Lambda_c^+\to\Lambda K^+$	-0.516 ± 0.046	0.33 ± 0.08	2.75 ± 0.11	2.57 ± 0.19	Unknown	2.58 ± 0.12	-0.56 ± 0.12
BESIII (2024) [13]	$\Lambda_c^+\to\Xi^0K^+$	0.01 ± 0.16	-0.64 ± 0.70	3.84 ± 0.90	$-1.55(1.59)\pm0.25$[b]	$+1$	$-1.55(1.59)\pm0.25$	$1.59(-1.55)\pm0.25$

Λ_c^+ decay asymmetries

Table 4. The determined polarization parameters of various Λ_c^+ decay modes.

Mode	α	Experiment	Mode	α	Experiment
Nucleon-involved			$\Lambda_c^+ \to \Lambda(1600)\pi^+$	0.2 ± 0.5	LHCb(2023)[86]
$\Lambda_c^+ \to pK_S^0$	0.18 ± 0.45	BESIII(2019)[153]	$\Lambda_c^+ \to \Lambda(1670)\pi^+$	0.82 ± 0.08	LHCb(2023)[86]
	-0.75 ± 0.10	LHCb(2024)[154]		0.21 ± 0.43	BESIII(2025)[148]
$\Lambda_c^+ \to p\bar{K}_0^*(700)^0$	-0.1 ± 0.7	LHCb(2023)[86]	$\Lambda_c^+ \to \Lambda(1690)\pi^+$	0.958 ± 0.034	LHCb(2023)[86]
$\Lambda_c^+ \to p\bar{K}_0^*(892)^0$	0.87 ± 0.03	LHCb(2023)[86]	$\Lambda_c^+ \to \Lambda(2000)\pi^+$	-0.57 ± 0.19	LHCb(2023)[86]
$\Lambda_c^+ \to p\bar{K}_0^*(1430)^0$	0.34 ± 0.14	LHCb(2023)[86]	**Σ-involved**		
$\Lambda_c^+ \to \Delta(1232)^{++}K^-$	0.55 ± 0.04	LHCb(2023)[86]	$\Lambda_c^+ \to \Sigma^+\pi^0$	-0.57 ± 0.12	BESIII(2019)[153]
$\Lambda_c^+ \to \Delta(1600)^{++}K^-$	-0.50 ± 0.18	LHCb(2023)[86]		-0.48 ± 0.03	Belle(2023)[98]
$\Lambda_c^+ \to \Delta(1700)^{++}K^-$	0.22 ± 0.08	LHCb(2023)[86]	$\Lambda_c^+ \to \Sigma^+\eta$	-0.99 ± 0.06	Belle(2023)[98]
Λ-involved			$\Lambda_c^+ \to \Sigma^+\eta'$	-0.46 ± 0.07	Belle(2023)[98]
$\Lambda_c^+ \to \Lambda\pi^+$	-0.80 ± 0.11	BESIII(2019)[153]	$\Lambda_c^+ \to \Sigma^0\pi^+$	-0.73 ± 0.18	BESIII(2019)[153]
	-0.755 ± 0.006	Belle(2023)[132]		-0.46 ± 0.02	Belle(2023)[132]
	-0.785 ± 0.007	LHCb(2024)[154]	$\Lambda_c^+ \to \Sigma(1385)^+\pi^0$	-0.917 ± 0.089	BESIII(2022)[93]
$\Lambda_c^+ \to \Lambda K^+$	-0.59 ± 0.05	Belle(2023)[132]	$\Lambda_c^+ \to \Sigma(1385)^+\eta$	-0.61 ± 0.16	BESIII(2025)[148]
	-0.52 ± 0.05	LHCb(2024)[154]	$\Lambda_c^+ \to \Sigma(1385)^0\pi^+$	-0.789 ± 0.113	BESIII(2022)[93]
$\Lambda_c^+ \to \Lambda\rho(770)^+$	-0.763 ± 0.070	BESIII(2022)[93]	$\Lambda_c^+ \to \Sigma^0 K^+$	-0.54 ± 0.20	Belle(2023)[132]
$\Lambda_c^+ \to \Lambda a(980)^+$	$-0.91^{+0.20}_{-0.12}$	BESIII(2025)[148]	**Ξ-involved**		
$\Lambda_c^+ \to \Lambda(1405)\pi^+$	0.58 ± 0.28	LHCb(2023)[86]	$\Lambda_c^+ \to \Xi^0 K^+$	0.01 ± 0.16	BESIII(2024)[155]
$\Lambda_c^+ \to \Lambda(1520)\pi^+$	0.93 ± 0.09	LHCb(2023)[86]			

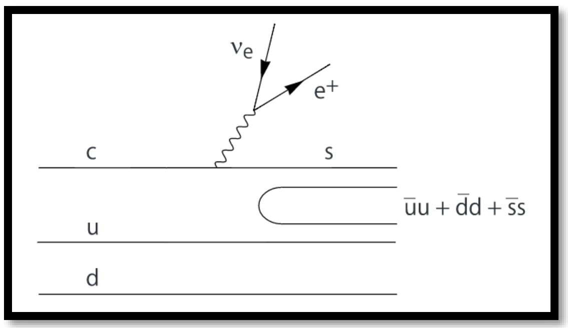
Mode	β	Experiment	Mode	γ	Experiment
$\Lambda_c^+ \to \Lambda\pi^+$	$0.06^{+0.58}_{-0.47}$	BESIII(2019)[153]	$\Lambda_c^+ \to \Lambda\pi^+$	$-0.60^{+0.97}_{-0.06}$	BESIII(2019)[153]
	0.378 ± 0.015	LHCb(2024)[154]		0.491 ± 0.012	LHCb(2024)[154]
$\Lambda_c^+ \to \Sigma^0\pi^+$	$0.48^{+0.36}_{-0.58}$	BESIII(2019)[153]	$\Lambda_c^+ \to \Sigma^0\pi^+$	$0.49^{+0.36}_{-0.57}$	BESIII(2019)[153]
$\Lambda_c^+ \to \Sigma^+\pi^0$	$-0.66^{+0.51}_{-0.25}$	BESIII(2019)[153]	$\Lambda_c^+ \to \Sigma^+\pi^0$	$-0.48^{+0.50}_{-0.42}$	BESIII(2019)[153]
$\Lambda_c^+ \to \Xi^0 K^+$	-0.64 ± 0.70	BESIII(2024)[155]	$\Lambda_c^+ \to \Xi^0 K^+$	-0.77 ± 0.59	BESIII(2024)[155]
$\Lambda_c^+ \to \Lambda K^+$	0.33 ± 0.08	LHCb(2024)[154]	$\Lambda_c^+ \to \Lambda K^+$	-0.799 ± 0.041	LHCb(2024)[154]

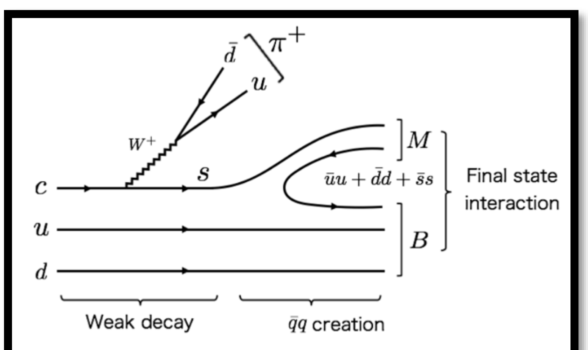
Hyperon spectroscopy in Λ_c^+ weak decays

- The Λ_c^+ weak decay acts as isospin filter

  e.g., Oset suggests to study the Λ(1405) through Λc→πΛ(1405) and Λ(1405) e *ν*, which filters isospin I=0 from contamination of the I=1

  [Phys. Rev. C 92, 055204 (2015), Phys. Rev. D 93. 014021 (2016)]





Particle	J^P	Overall status	Status a $N\overline{K}$	$\Sigma\pi$
$\Lambda(1116)$	$1/2^+$	****		
$\Lambda(1380)$	$1/2^-$	**	**	**
$\Lambda(1405)$	$1/2^-$	****	****	****
$\Lambda(1520)$	$3/2^-$	****	****	****
$\Lambda(1600)$	$1/2^+$	****	***	****
$\Lambda(1670)$	$1/2^-$	****	****	****
$\Lambda(1690)$	$3/2^-$	****	****	***
$\Lambda(1710)$	$1/2^+$	*	*	*
$\Lambda(1800)$	$1/2^-$	***	***	**
$\Lambda(1810)$	$1/2^+$	***	**	**
$\Lambda(1820)$	$5/2^+$	****	****	****
$\Lambda(1830)$	$5/2^-$	****	****	****
$\Lambda(1890)$	$3/2^+$	****	****	**
$\Lambda(2000)$	$1/2^-$	*	*	*
$\Lambda(2050)$	$3/2^-$	*	*	*
$\Lambda(2070)$	$3/2^+$	*	*	*
$\Lambda(2080)$	$5/2^-$	*	*	*
$\Lambda(2085)$	$7/2^+$	**	**	*
$\Lambda(2100)$	$7/2^-$	****	****	**
$\Lambda(2110)$	$5/2^+$	***	**	**
$\Lambda(2325)$	$3/2^-$	*	*	
$\Lambda(2350)$	$9/2^+$	***	***	*
$\Lambda(2585)$		*	*	

Particle	J^P	Overall status	Status as seen in — $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$
$\Sigma(1193)$	$1/2^+$	****			
$\Sigma(1385)$	$3/2^+$	****		****	****
$\Sigma(1580)$	$3/2^-$	*	*	*	*
$\Sigma(1620)$	$1/2^-$	*	*	*	*
$\Sigma(1660)$	$1/2^+$	***	***	***	***
$\Sigma(1670)$	$3/2^-$	****	****	****	****
$\Sigma(1750)$	$1/2^-$	***	***	**	***
$\Sigma(1775)$	$5/2^-$	****	****	****	**
$\Sigma(1780)$	$3/2^+$	*	*	*	*
$\Sigma(1880)$	$1/2^+$	**	**	*	
$\Sigma(1900)$	$1/2^-$	**	**	*	**
$\Sigma(1910)$	$3/2^-$	***	*	*	**
$\Sigma(1915)$	$5/2^+$	****	***	***	***
$\Sigma(1940)$	$3/2^+$	*	*		*
$\Sigma(2010)$	$3/2^-$	*	*	*	
$\Sigma(2030)$	$7/2^+$	****	****	****	**
$\Sigma(2070)$	$5/2^+$	*	*		*
$\Sigma(2080)$	$3/2^+$	*		*	
$\Sigma(2100)$	$7/2^-$	*	*	*	*
$\Sigma(2110)$	$1/2^-$	*	*	*	*
$\Sigma(2230)$	$3/2^+$	*	*	*	*
$\Sigma(2250)$		**	**	*	*
$\Sigma(2455)$		*	*		
$\Sigma(2620)$		*	*		

Cross-channel studies

$\Lambda_c^+ \to \Lambda^* \pi^+$

- $\Lambda_c^+ \to pK^-\pi^+$
- $\Lambda_c^+ \to nK_S\pi^+$
- $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$
- $\Lambda_c^+ \to \Sigma^0\pi^0\pi^+$
- $\Lambda_c^+ \to \Sigma^+\pi^-\pi^+$
- $\Lambda_c^+ \to \Lambda\eta\pi^+$
- …

$\Lambda_c^+ \to \Sigma^{*+} \pi^0$

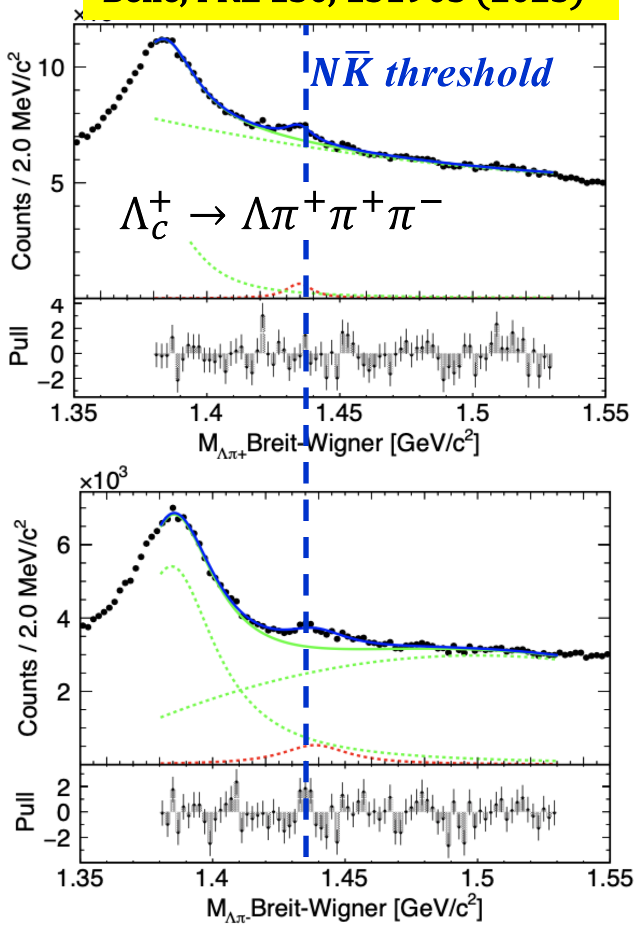
- $\Lambda_c^+ \to pK_S\pi^0$
- $\Lambda_c^+ \to \Lambda\pi^+\pi^0$
- $\Lambda_c^+ \to \Sigma^+\pi^0\pi^0$
- $\Lambda_c^+ \to \Sigma^0\pi^+\pi^0$
- $\Lambda_c^+ \to \Sigma^+\eta\pi^0$
- $\Xi_c^+ \to pK_S\pi^0$
- …

$\Lambda_c^+ \to \Sigma^{*0} \pi^+$

- $\Lambda_c^+ \to \Lambda\pi^0\pi^+$
- $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$
- $\Lambda_c^+ \to \Sigma^+\pi^-\pi^+$
- $\Xi_c^+ \to pK^-\pi^+$
- …

Hyperons from charmed baryon decays

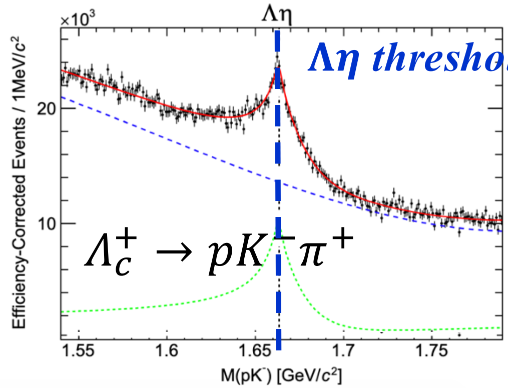
Belle, PRL 130, 151903 (2023)



Enhancement around 1.43 GeV

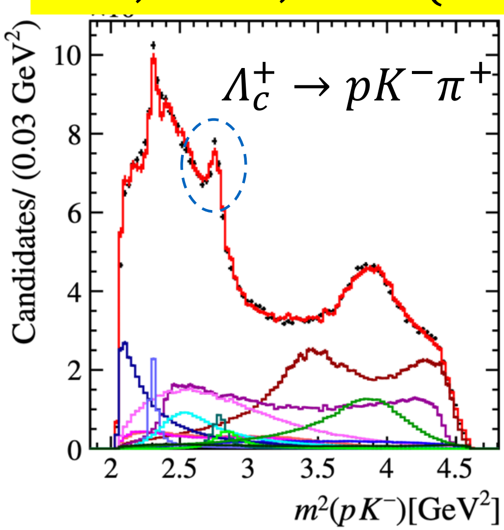
$\Sigma(1430)$ or $N\bar{K}$ threshold cusp?

BELLE, PRD108, L031104 (2023)

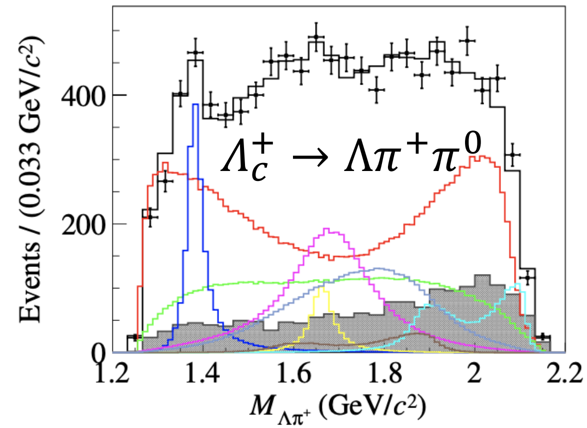


Λη threshold cusp enhanced due to $\Lambda(1670)$

LHCb, PRD108, 012023 (2023)

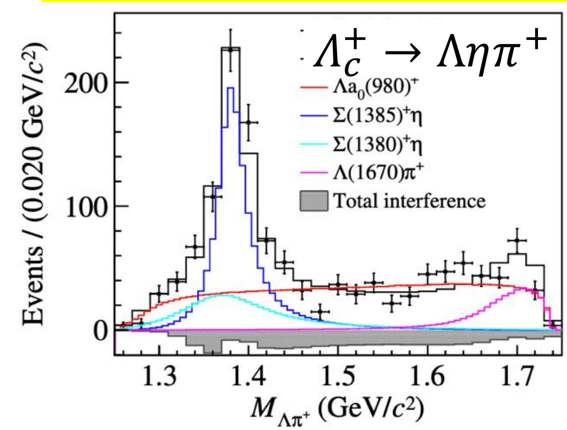


BESIII, JHEP12(2022)033



Many Σ^* contributions

BESIII, PRL134, 021901 (2025)

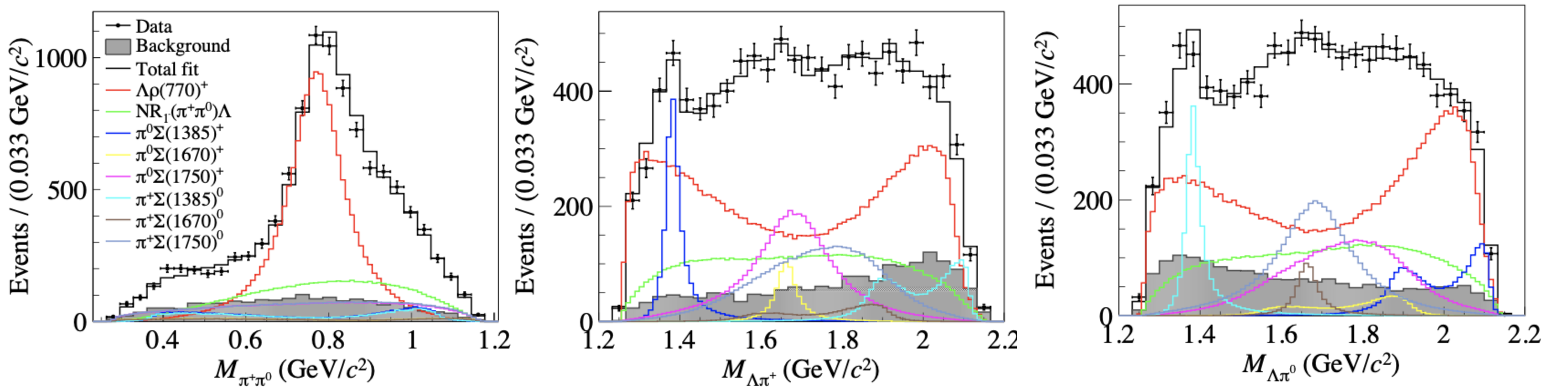


Evidence for $\Sigma(1380)^+$

BESIII Amplitude analysis of $\Lambda_c^+ \to \Lambda\pi^+\pi^0$

JHEP12, 033 (2022)

- First amplitude analysis of charmed baryon multi-hadronic decays
- Based on TF-PWA package: ***https://gitlab.com/jiangyi15/tf-pwa***



	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	—

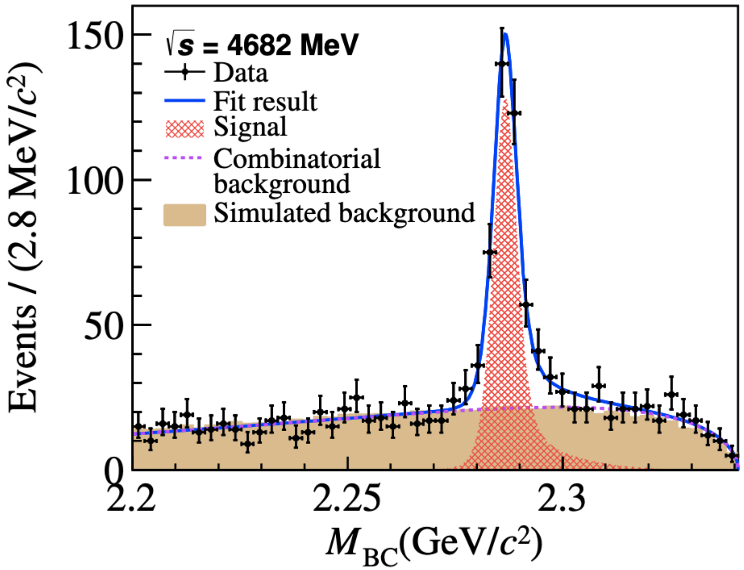
Many first measurements of intermediate states!

Partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\eta$

PRL134, 021901 (2025)

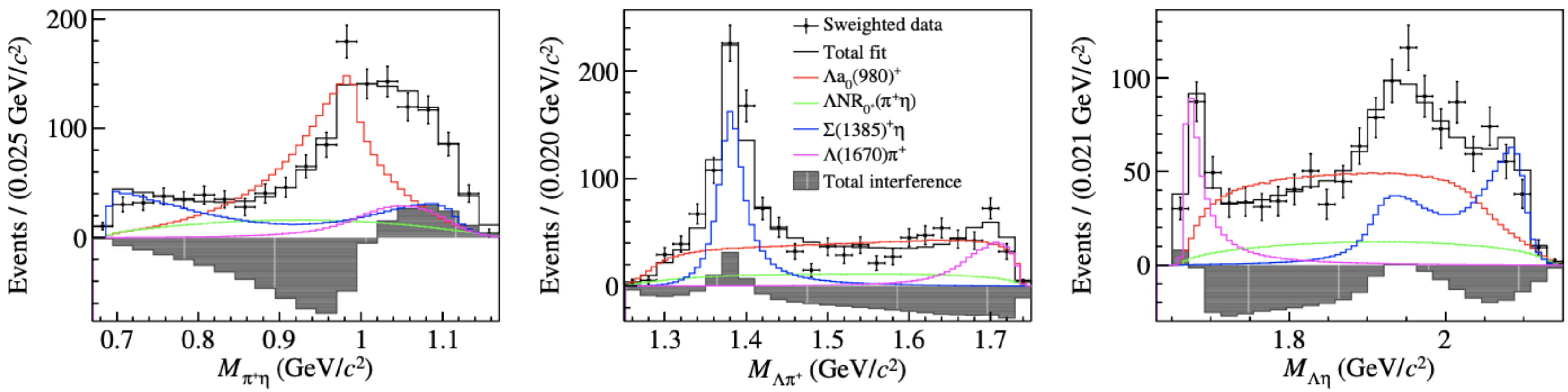
- A good channel to investigate different types of hadron states, especially tetraquark or pentaquark candidates
- $\Lambda_c^+ \to \Lambda\pi^+\eta$ decay provides a good platform to study the internal structure of $a_0(980)^+$ whose exact nature remains elusive.
- The $\Lambda\pi^+$ mode, representing a pure I = 1 combination, excludes influences from Λ^* resonances as compared to the $\Sigma\pi$ and pK modes.
- Study of low-lying excited $\frac{1}{2}^-$ state, eg $\Sigma(1380)^+$, can be performed, along with the nearby state $\Sigma(1385)^+$ [Wang et al, CPL 41, 101401 (2024)]

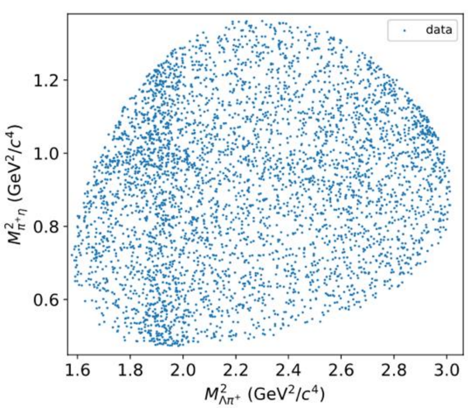
- Based on TF-PWA package: *https://gitlab.com/jiangyi15/tf-pwa*
- BDTG trained sample with about 1312 signals with purity of about 80%

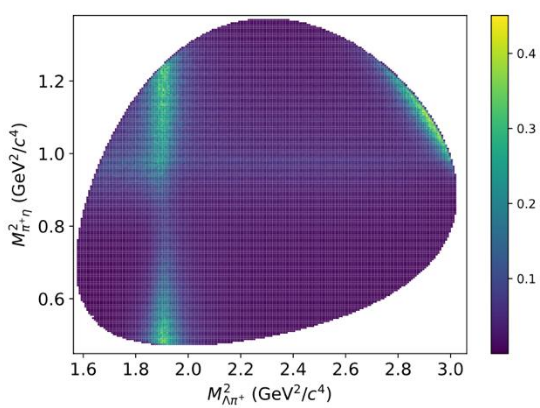


Baseline model of $\Lambda_c^+ \to \Lambda\pi^+\eta$

PRL134, 021901 (2025)







- **$\Lambda_c^+ \to \Lambda a_0(980)^+$ firstly observed**
- **Decay asymmetries obtained based on PWA amplitudes**

Process	FF (%)	$\mathcal{S}$	α
$\Lambda a_0(980)^+$	$54.0 \pm 8.4 \pm 2.6$	13.1σ	$0.91^{+0.09}_{-0.18} \pm 0.08$
$\Sigma(1385)^+\eta$	$30.4 \pm 2.6 \pm 0.7$	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	...

$$\alpha_{\Lambda a_0(980)^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2}$$

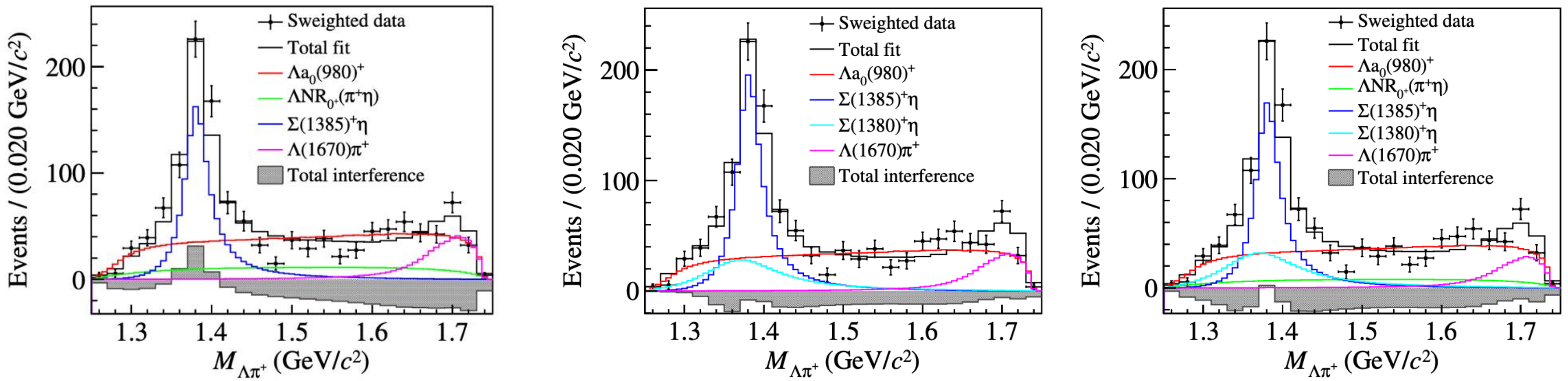
$$\alpha_{\Sigma(1385)^+\eta} = \frac{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2}$$

$$\alpha_{\Lambda(1670)\pi^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda(1670)\pi^+}_{-\frac{1}{2},0}\right|^2}$$

Test of $\Sigma(1380)^+$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$

PRL134, 021901 (2025)

Baseline model | Model A | Model B



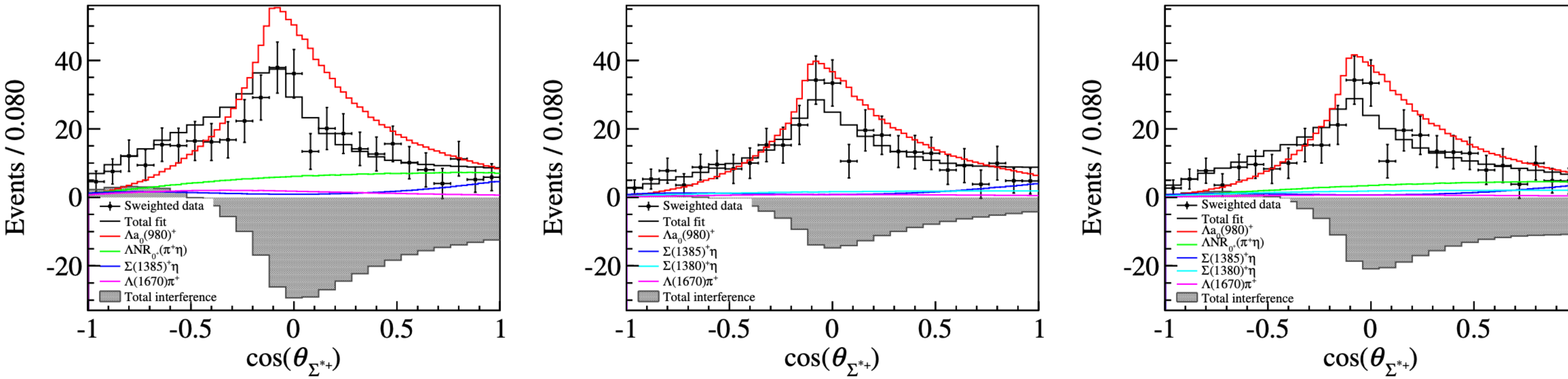
Process	Model A	Model B
$\Lambda a_0(980)^+$	$52.9 \pm 4.5\,(13.4\sigma)$	$50.6 \pm 8.0\,(11.1\sigma)$
$\Sigma(1385)^+\eta$	$36.6 \pm 2.6\,(15.8\sigma)$	$31.3 \pm 3.0\,(14.6\sigma)$
$\Lambda(1670)\pi^+$	$10.7 \pm 1.4\,(15.0\sigma)$	$9.0 \pm 1.6\,(11.9\sigma)$
$\Sigma(1380)^+\eta$	$15.5 \pm 4.4\,(6.1\sigma)$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

- An evidence of $\Sigma(1380)^+$ is found with significance larger than 3σ

Comparison of Σ^{*+} helicity angles

PRL134, 021901 (2025)

Baseline model | Model A | Model B

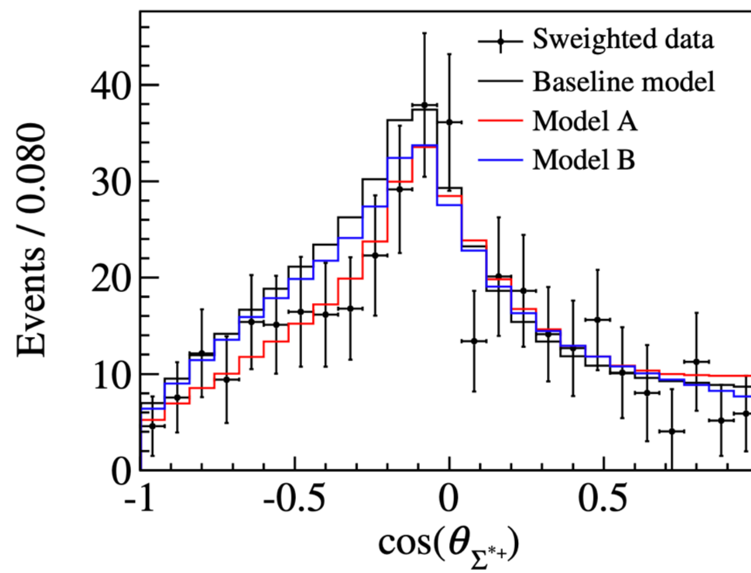


Kinematic region:

$M_{\Lambda\pi^+} > 1.44\ \mathrm{GeV/c^2}$

$M_{\Lambda\eta} > 1.72\ \mathrm{GeV/c^2}$

Better description of Σ^{*+} helicity angle distribution with inclusion of $\Sigma(1380)$



Partial wave analysis of $\Lambda_c^+ \to \Lambda\pi^+\eta$

PRL134, 021901 (2025)

	This work	BESIII previous	Belle
$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta)(\%)$	1.94 ± 0.13	1.84 ± 0.26	1.84 ± 0.13
$\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+) \cdot \mathcal{B}(a_0(980)^+ \to \pi^+\eta)(\%)$	1.05 ± 0.18	—	—
$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\eta)(\times 10^{-3})$	6.78 ± 0.76	9.1 ± 2.0	12.1 ± 1.5
$\mathcal{B}(\Lambda_c^+ \to \Lambda(1670)^0\pi^+) \cdot \mathcal{B}(\Lambda(1670)^0 \to \Lambda\eta)(\times 10^{-3})$	2.74 ± 0.62	—	3.48 ± 0.53
$\alpha_{\Lambda a_0(980)^+}$	$0.91^{+0.09}_{-0.18} \pm 0.08$	—	—
$\alpha_{\Sigma(1385)^+\eta}$	-0.61 ± 0.15	—	—
$\alpha_{\Lambda(1670)^0\pi^+}$	0.21 ± 0.43	—	—

Decay Mode	Ref. [19]	Ref. [20]	Ref. [21]	Ref. [14]
$\Lambda_c^+ \to \Sigma(1385)^+\eta\,(\times 10^{-3})$	10.4	$2.1 \pm 1.1/1.4 \pm 1.0$	$6.2 \pm 0.5\,(3.1 \pm 0.6)$	$5.3 \pm 0.8\,(7.3 \pm 1.5)$

Decay Mode	Ref. [26]	Ref. [27]
$\Lambda_c^+ \to \Lambda a_0(980)^+$	1.9×10^{-4}	$(1.7^{+2.8}_{-1.0} \pm 0.3) \times 10^{-3}$

- If taking $\mathcal{B}(a_0(980)^+ \to \pi^+\eta) = (85.3 \pm 1.4)\%$, $\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+) = (1.23 \pm 0.21)\%$, which differs significantly larger than theoretical prediction by 1-2 orders of magnitude.
- Large decay asymmetry in $\Lambda_c^+ \to \Lambda a_0(980)^+$

$\Lambda(1670)$ decay rates

Comparing the fraction of the $\Lambda(1670)$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$ and that in $\Lambda_c^+ \to pK^-\pi^+$:

$$\mathcal{B}(\Lambda_c^+ \to \Lambda(1670)\pi^+, \Lambda(1670) \to \Lambda\eta) = (2.74 \pm 0.62) \times 10^{-3} \text{ [BESIII2025]}$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda(1670)\pi^+,\ \Lambda(1670) \to pK^-)}{\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)} = (1.18 \pm 0.33)\% \text{ [LHCb 2023]}$$

$$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.24 \pm 0.28)\% \text{ [PDG2024]}$$

We have $$\frac{\mathcal{B}(\Lambda(1670) \to pK^-)}{\mathcal{B}(\Lambda(1670) \to \Lambda\eta)} = (26.9 \pm 9.7)\%$$

$\Lambda(1670)$ DECAY MODES

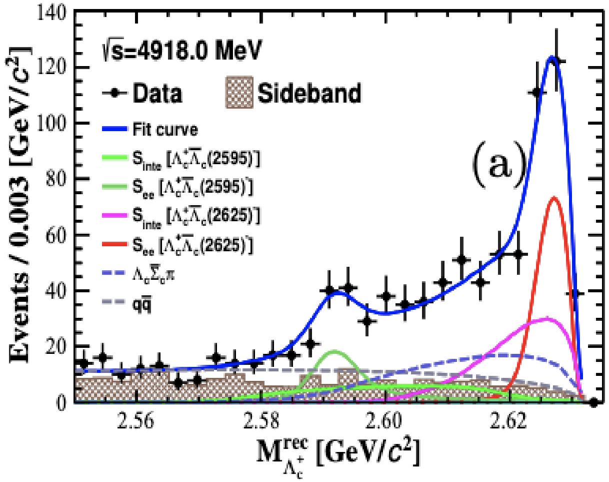
Mode		Fraction (Γ_i/Γ)
Γ_1	$N\overline{K}$	20–30%
Γ_2	$\Sigma\pi$	25–55%
Γ_3	$\Lambda\eta$	10–25%

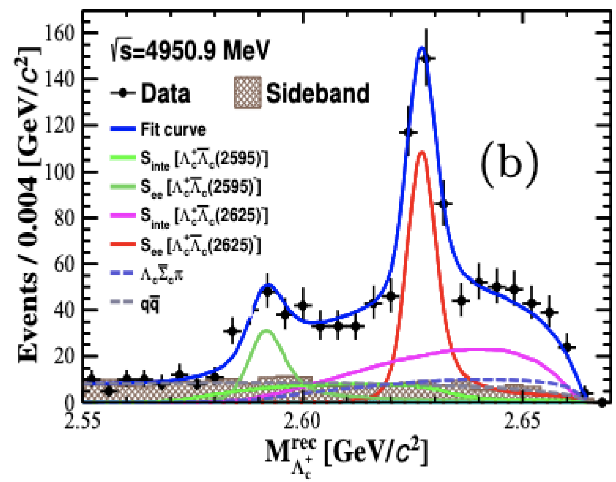
The rate of $N\overline{K}$ from the previous measurement seems too large!

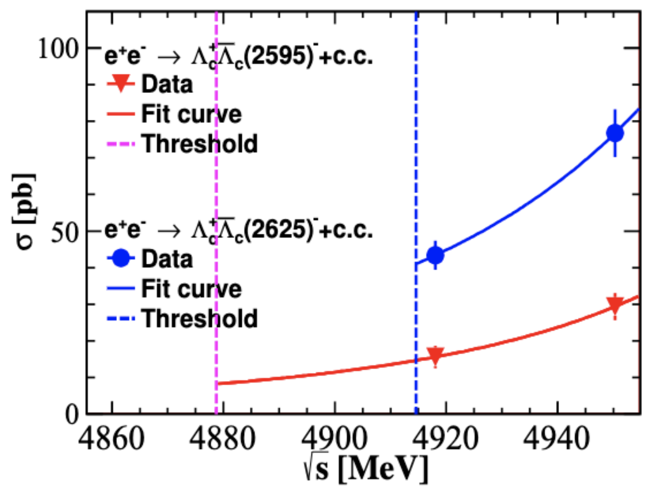
Observation of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c(2595)^-$ and $\Lambda_c^+\bar{\Lambda}_c(2625)^-$

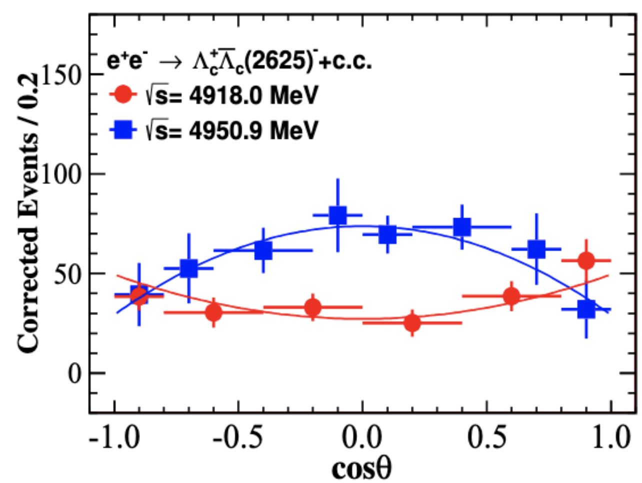
PRD 109, L071104 (2024)

Datasets of 208/pb at 4.92 GeV and 159/pb at 4.95 GeV







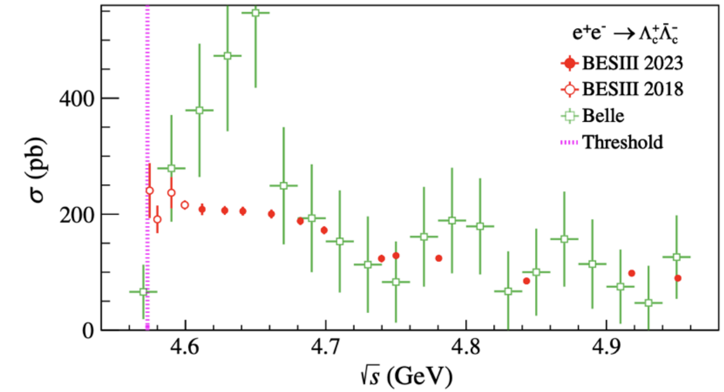


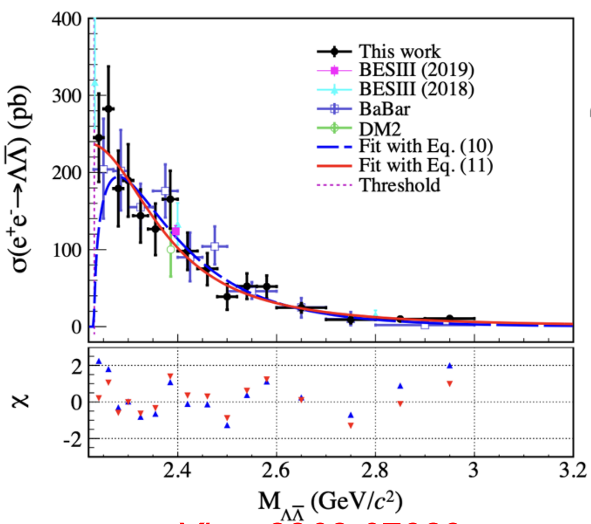
$$\frac{d\sigma}{d\cos\theta} \propto (1+\cos^2\theta)(|G_E|^2+3|G_M|^2)+\frac{1}{\tau}|G_C|^2\sin^2\theta$$

Search for $e^+e^- \to \Sigma_c\bar{\Sigma}_c$ and $\Lambda_c^+\bar{\Sigma}_c^-$

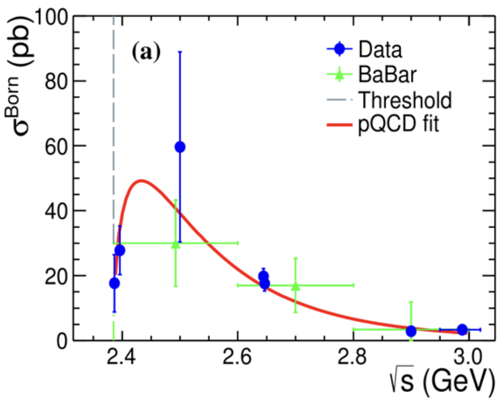
- $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$: an interesting isospin violating process to understand the QCD dynamics at charm sector
  - ✓ $\sigma(\Lambda_c^+\bar{\Sigma}_c^-)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$ v.s. $\sigma(\Lambda\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
    ➔ vaccum pol. to $c\bar{c}$ v.s. $s\bar{s}$
- $e^+e^- \to \Sigma_c\,\bar{\Sigma}_c$:
  - ✓ Comparison to $\sigma(e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-)$
    ➔ good diquark v.s. bad diquark

Phys. Rev. Lett. 131, 191901 (2023)

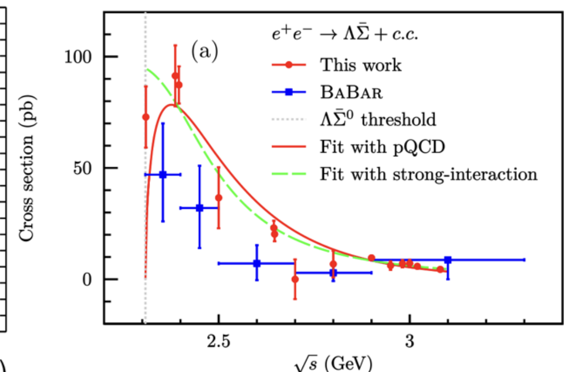




arXiv：2303.07629



Phys. Lett. B 831, 137187 (2022)



Phys. Rev. D 109, 012002 (2024)

Cross sections for $e^+e^- \to \Sigma_c\bar{\Sigma}_c$ and $\Lambda_c^+\bar{\Sigma}_c^-$

arXiv:2508.16871

no significant signals are observed

$\sigma(\Lambda_c^+\bar{\Sigma}_c^-)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$	$\sigma(\Lambda\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
<~0.01	~0.4
$\sigma(\Sigma_c\ \bar{\Sigma}_c\ )/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$	$\sigma(\Sigma\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
<~0.01	~0.2

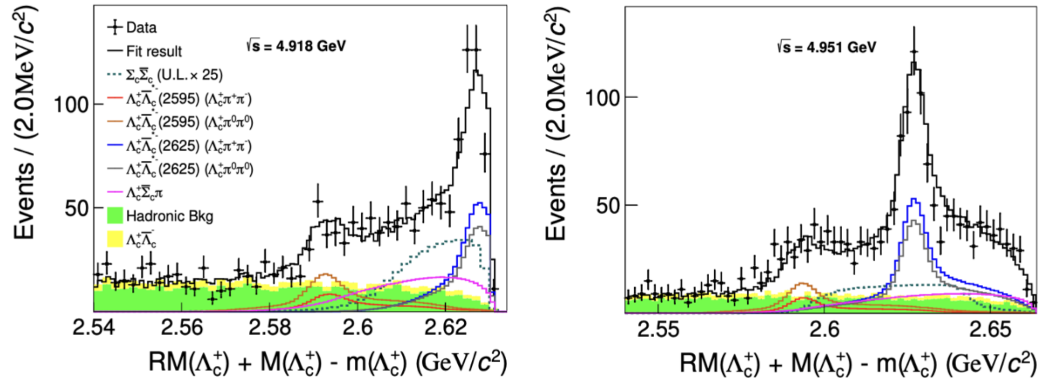


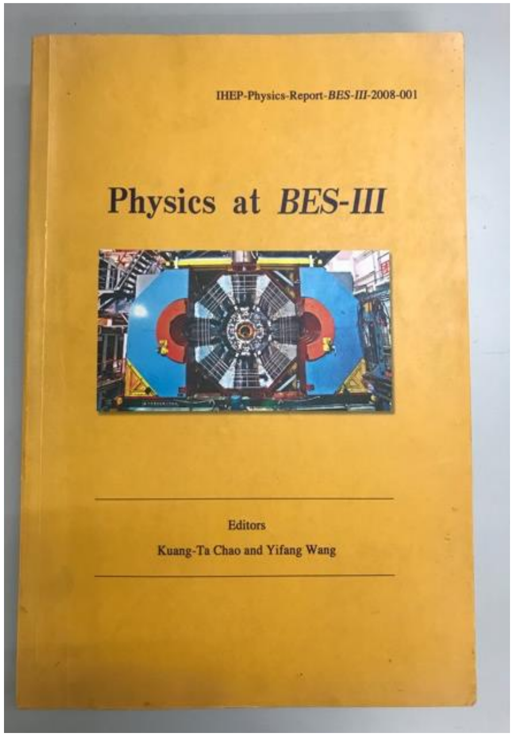
TABLE IV. Summary of the upper limits on Born cross sections of $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ at 90% C.L.. The results of $\sigma_{\rm Born}(e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-)$ are input from Ref. [20], where the first uncertainty represents statistical uncertainty and the second one represents systematic uncertainty.

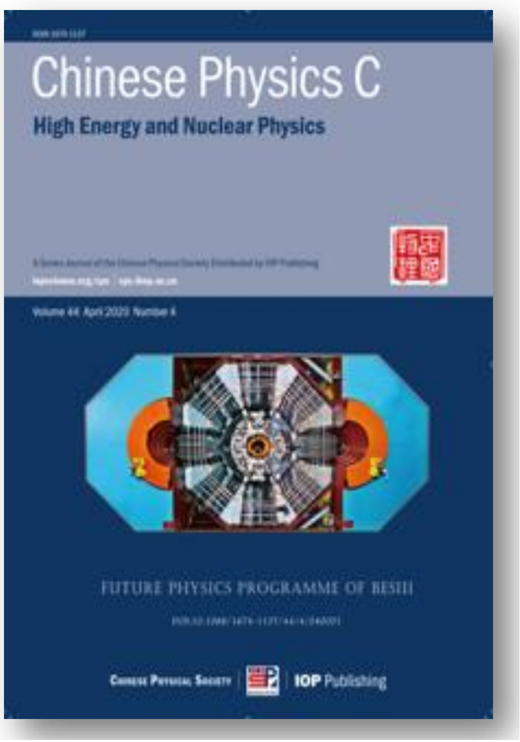
$\sqrt{s}$	4.750 GeV	4.781 GeV	4.843 GeV	4.918 GeV	4.951 GeV
$R(\sigma)$ (%)	< 1.1	< 0.6	< 1.5	< 3.4	< 1.6
$\sigma_{\rm Born}(e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-)$ (pb)	$134 \pm 3 \pm 4$	$127 \pm 2 \pm 4$	$83 \pm 2 \pm 3$	$96 \pm 3 \pm 4$	$88 \pm 4 \pm 3$
$\sigma_{\rm Born}(e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-)$ (pb)	< 1.52	< 0.76	< 1.26	< 3.26	< 1.38

TABLE III. Summary of $f_{\rm VP}$, $f_{\rm ISR}$ and $\sigma_{\rm Born}(e^+e^- \to \Sigma_c\bar{\Sigma}_c)$, based on different assumptions of line shapes: 1. baseline model adopting $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ measurements from Ref. [20]; 2. threshold-enhanced hypothesis (Hypothesis 1); 3. non-enhanced scenario (Hypothesis 2). All upper limits are set at the 90% C.L., and do not include the systematic uncertainties.

$\sqrt{s}$	f	baseline	Hypothesis 1	Hypothesis 2
4.918 GeV	$f_{\rm VP}$	1.06	1.06	1.06
	$f_{\rm ISR}$	0.96	0.68	0.58
	$\sigma_{\rm Born}$	< 0.55 pb	< 0.61 pb	< 0.83 pb
4.951 GeV	$f_{\rm VP}$	1.06	1.06	1.06
	$f_{\rm ISR}$	0.96	0.81	0.79
	$\sigma_{\rm Born}$	< 0.34 pb	< 0.39 pb	< 0.49 pb

BESIII Physics White Paper





Int. J. Mod. Phys. A 24, S1-794 (2009)
[arXiv:0809.1869 [hep-ex]].

Chin. Phys. C 44, 040001 (2020)
doi:10.1088/1674-1137/44/4/040001
[arXiv:1912.05983 [hep-ex]].

Planned future data set

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 most right column shows the number of required data taking days in current (T_C) or 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

18 fb^{-1} Λ_c^+ data

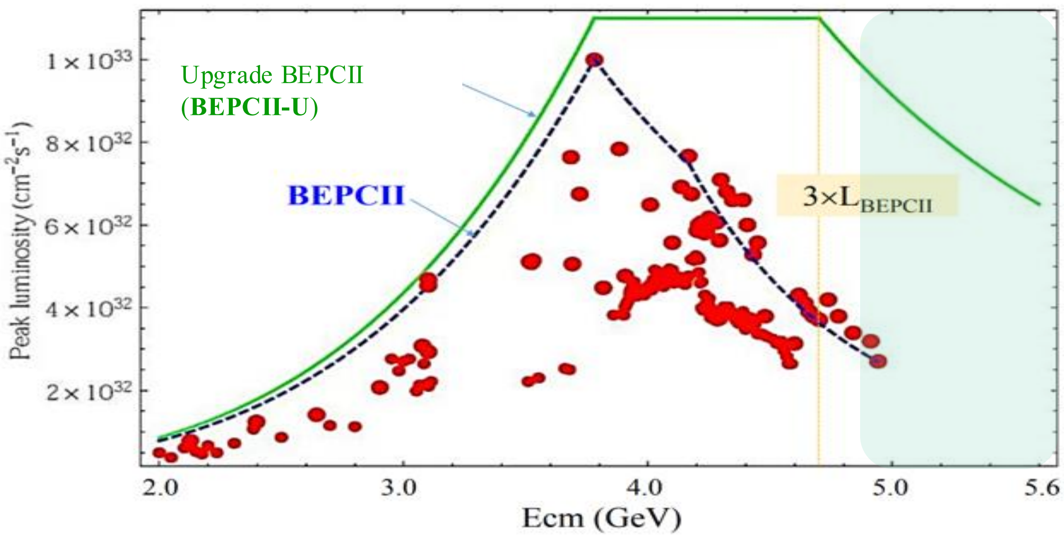
in 2020-2021, 5.8 fb^{-1} is taken

[Chin. Phys. C 46, 113003 (2022)]

Proposal of the upgrade BEPCII

An upgrade of BEPCII (**BEPCII-U**) has been approved in July 2021 and planned to be completed by the end of 2024

- ✓ **Improve luminosity by 3 times higher than current BEPCII at 4.7 GeV**
- ✓ **Extend the maximum energy to 5.6 GeV**

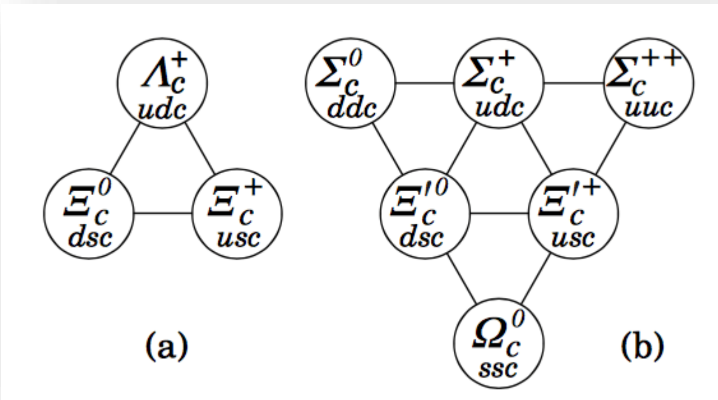


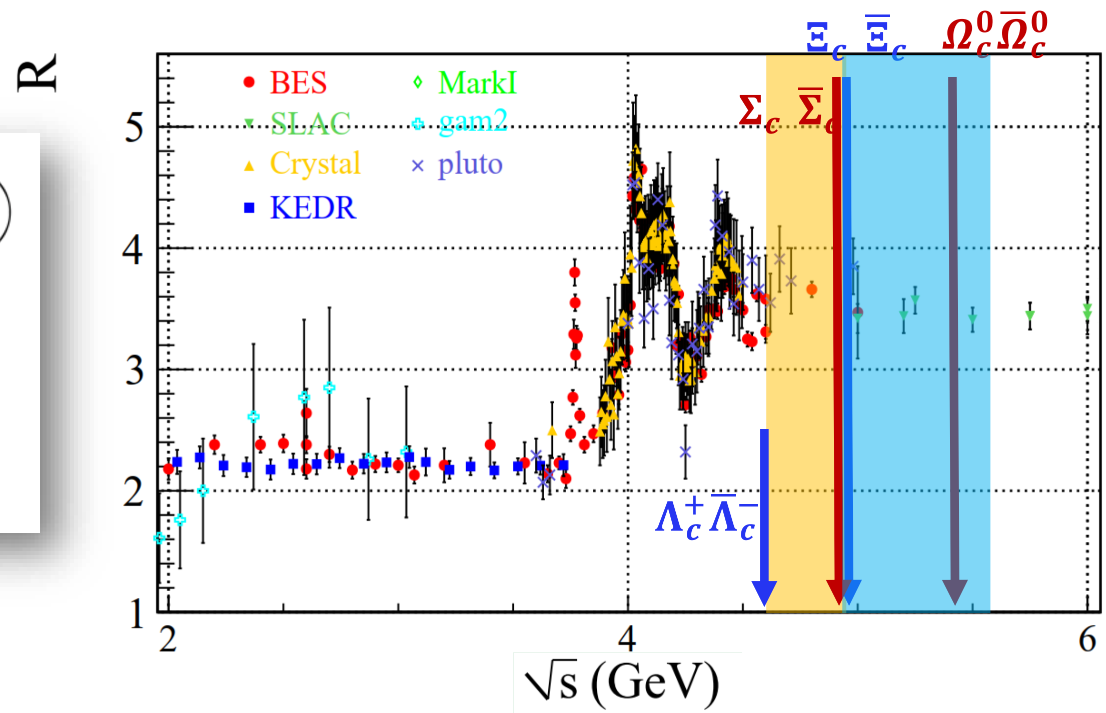
Capable of finishing the proposed luminosity of Λ_c^+ data in shorter time

1490 → 600 days

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
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

Heavier charmed baryons





- Energy thresholds
  - ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
  - ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c\ \pi$ 4.88 GeV
  - ✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV
  - ✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$ 4.94 GeV
  - ✓ $e^+e^- \to \Omega_c^0\bar{\Omega}_c^0$ 5.40 GeV

- Cover all the ground-state charmed baryons: studies on their production & decays, CPV search, to help developing more reliable QCD-derived models in charm sector
- Studies on the production and decays of excited charmed baryons

Yet-to-be-Explored $\Xi_c^{+,0}$/ Ω_c^0 Decays

- We (will) have precise Λ_c^+ data after BESIII efforts
- However, $\Xi_c^{+,0}$/ Ω_c^0 has insufficient data
- A new territory for BESIII!

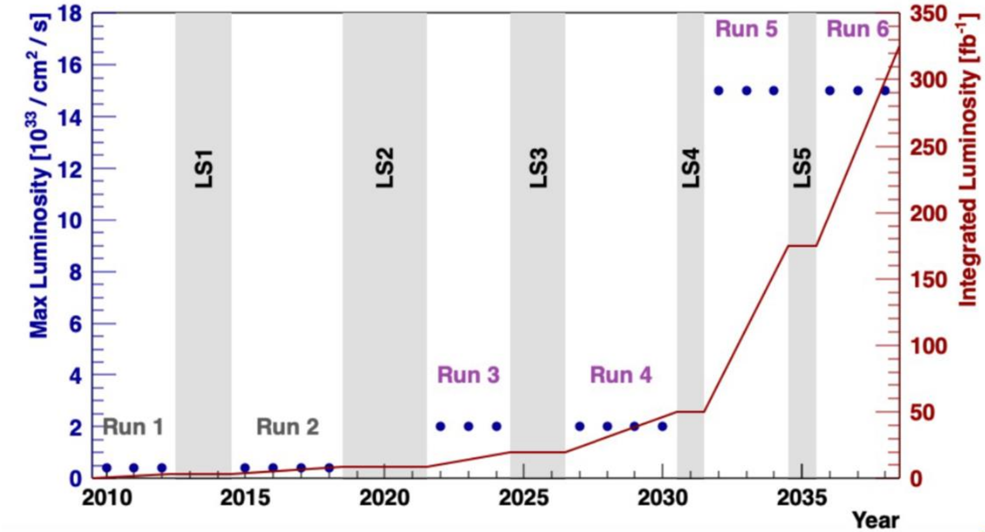
	Mode		Fraction (Γ_i/Γ)
	Cabibbo-favored ($S=-2$) decays		
Γ_1	$p2K_S^0$		$(2.5\pm1.3)\times10^{-3}$
Γ_2	$\Lambda\overline{K}^0\pi^+$		
Γ_3	$\Sigma(1385)^+\overline{K}^0$	[1]	$(2.9\pm2.0)\%$
Γ_4	$\Lambda K^-2\pi^+$		$(9\pm4)\times10^{-3}$
Γ_5	$\Lambda\overline{K}^*(892)^0\pi^+$	[1]	$<5\times10^{-3}$
Γ_6	$\Sigma(1385)^+K^-\pi^+$	[1]	$<6\times10^{-3}$
Γ_7	$\Sigma^+K^-\pi^+$		$(2.7\pm1.2)\%$
Γ_8	$\Sigma^+\overline{K}^*(892)^0$	[1]	$(2.3\pm1.1)\%$
Γ_9	$\Sigma^0K^-2\pi^+$		$(8\pm5)\times10^{-3}$
Γ_{10}	$\Xi^0\pi^+$		$(1.6\pm0.8)\%$
Γ_{11}	$\Xi^-2\pi^+$		$(2.9\pm1.3)\%$
Γ_{12}	$\Xi(1530)^0\pi^+$	[1]	$<2.9\times10^{-3}$
Γ_{13}	$\Xi(1620)^0\pi^+$		seen
Γ_{14}	$\Xi(1690)^0\pi^+$		seen
Γ_{15}	$\Xi^0\pi^+\pi^0$		$(6.7\pm3.5)\%$
Γ_{16}	$\Xi^0\pi^-2\pi^+$		$(5.0\pm2.6)\%$
Γ_{17}	$\Xi^0e^+\nu_e$		$(7\pm4)\%$
Γ_{18}	$\Omega^-K^+\pi^+$		$(2.0\pm1.5)\times10^{-3}$

Ξ_c^+ PDG2023

	Mode	Fraction (Γ_i/Γ)
	Cabibbo-favored ($S=-3$) decays — relative to $\Omega^-\pi^+$	
Γ_6	$\Xi^0\overline{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0K^-\pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0\overline{K}^{*0}$, $\overline{K}^{*0}\to K^-\pi^+$	0.68 ± 0.16
Γ_9	$\Omega(2012)^-\pi^+$, $\Omega(2012)^-\to\Xi^0K^-$	0.12 ± 0.05
Γ_{10}	$\Xi^-\overline{K}^0\pi^+$	2.12 ± 0.28
Γ_{11}	$\Omega(2012)^-\pi^+$, $\Omega(2012)^-\to\Xi^-\overline{K}^0$	0.12 ± 0.06
Γ_{12}	$\Xi^-K^-2\pi^+$	0.63 ± 0.09
Γ_{13}	$\Xi(1530)^0K^-\pi^+$, $\Xi^{*0}\to\Xi^-\pi^+$	0.21 ± 0.06
Γ_{14}	$\Xi^-\overline{K}^{*0}\pi^+$	0.34 ± 0.11
Γ_{15}	$pK^-K^-\pi^+$	seen
Γ_{16}	$\Sigma^+K^-K^-\pi^+$	<0.32
Γ_{17}	$\Lambda\overline{K}^0\overline{K}^0$	1.72 ± 0.35

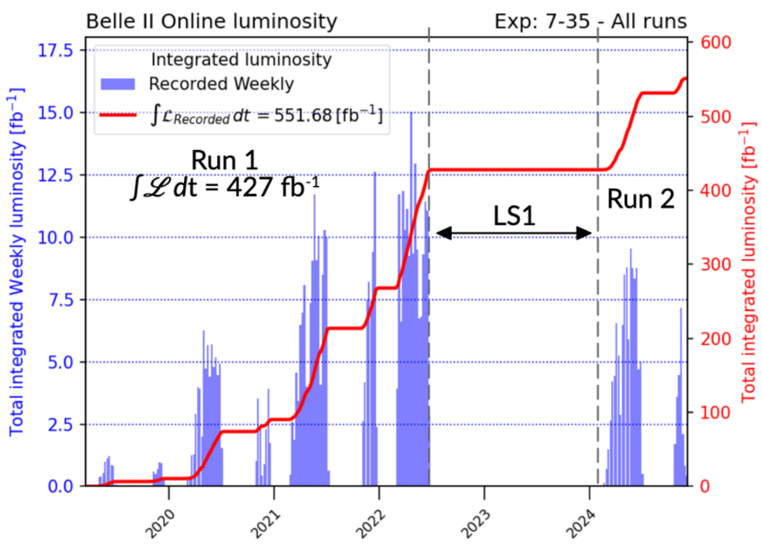
Ω_c^0 PDG2023

Future opportunity at LHCb and Belle II



- RUN1&2: 9 fb^{-1}
- RUN3&4: 50 fb^{-1}

➔ x10 more statistics



- Belle: 1 ab^{-1}
- Belle II: >0.55 ab^{-1}
- Future Belle II: 50 ab^{-1}

Summary

- In recent years, experimental activities on charmed baryons are reviving, esp. at BESIII, LHCb and Belle (II)
- Threshold data at BESIII opens a new door to direct measurements of the decays ➔comprehensive and systematic studies of charmed baryon decays
  - ✓ BESIII has published several world-leading results based on ~80 M Λ_c^+ samples
  - ✓ More efforts on hadronic decays with $n/\Sigma/\Xi$ particles & semi-leptonic decays
  - ✓ Plan to take data up to 5.6 GeV to cover all the ground-state charmed baryons
- LHCb/Belle (II) has largest charmed baryon yields ➔ large potential of best precisions
  - Search for more semi-leptonic decays
  - Precise determination of decay rate and amplitude analysis
  - Decay asymmetry and CPV test
  - Rare decays: LFV, FCNC, …
- They will be complementary in charmed baryon decays

Backup

Production near threshold and tag technique

E_{cms}=4600MeV

- 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

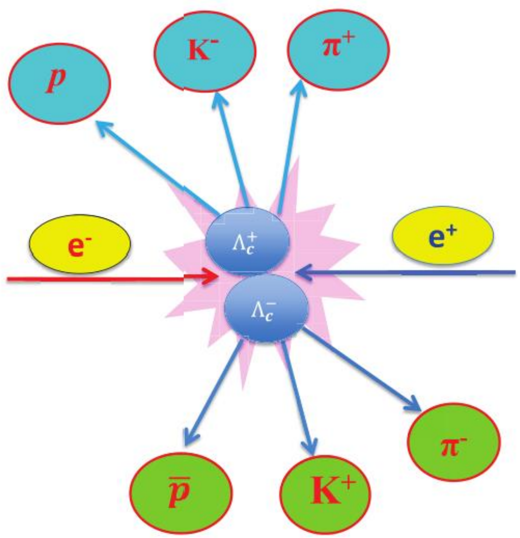
    => Full reconstruction
  - **Double Tag (DT): detect both of $\Lambda_c^+\Lambda_c^-$**

    => Smaller backgrounds

    => Missing mass technique

    => Lower efficiencies

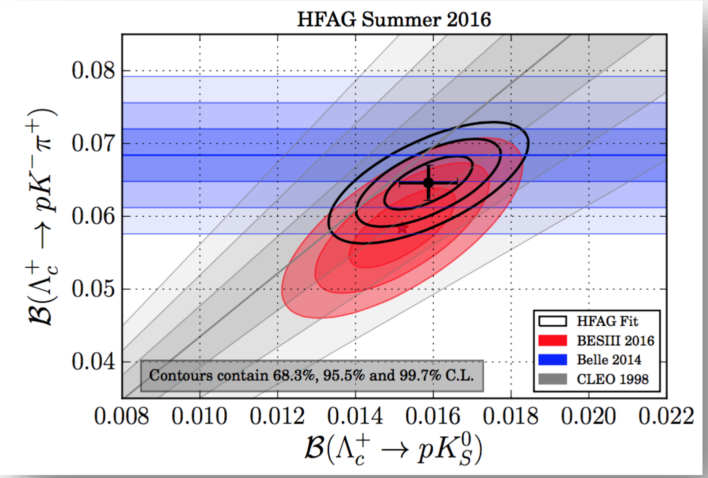
    => Systematic in tag side are mostly cancelled



HFLAV Fit to world BF data

- A fitter to constrain the 12 hadronic BFs and 1 SL BF, based on all the existing experimental data
- Correlated systematics are fully taken into account

Mode	HFAG 2016 (%)	BESIII (%)	PDG 2014 (%)	BELLE (%)
pK_S^0	1.59 ± 0.07	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	6.46 ± 0.24	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	2.03 ± 0.12	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0\pi^+\pi^-$	1.69 ± 0.11	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	5.05 ± 0.29	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda\pi^+$	1.28 ± 0.06	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	7.09 ± 0.36	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.73 ± 0.21	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.31 ± 0.07	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.25 ± 0.09	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	4.64 ± 0.24	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+\omega$	1.77 ± 0.21	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	
$\Lambda e^+\nu_e$	3.18 ± 0.32	$3.63 \pm 0.38 \pm 0.20$	2.1 ± 0.6	



The least overall χ^2/ndf=30.0/23=1.3

Precise $B(pK^-\pi^+)$ is useful for constrain V_{ub} determined via baryonic mode

Contribution to PDG

PDG2014

$\Gamma(p\overline{K}^0\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_7/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.66±0.05±0.07	774	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(p\overline{K}^0\eta)/\Gamma(pK^-\pi^+)$ — Γ_8/Γ_2

Unseen decay modes of the η are included.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.25±0.04±0.04	57	AMMAR	95	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(p\overline{K}^0\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ — Γ_9/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.51±0.06 OUR AVERAGE					
0.52±0.04±0.05	985	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$
0.43±0.12±0.04	83	AVERY	91	CLEO	e^+e^- 10.5 GeV
0.98±0.36±0.08	12	BARLAG	90D	NA32	π^- 230 GeV

$\Gamma(pK^-\pi^+\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{10}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.67±0.04±0.11	2606	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(pK^*(892)^-\pi^+)/\Gamma(p\overline{K}^0\pi^+\pi^-)$ — Γ_{11}/Γ_9

Unseen decay modes of the $K^*(892)^-$ are included.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.44±0.14	17	ALEEV	94	BIS2	nN 20–70 GeV

$\Gamma(p(K^-\pi^+)_{\text{nonresonant}}\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{12}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.73±0.12±0.05	67	BOZEK	93	NA32	π^- Cu 230 GeV

PDG2019

$\Gamma(pK^0_S\pi^0)/\Gamma_{\text{total}}$ — Γ_7/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.96±0.13 OUR FIT	Error includes scale factor of 1.1.				
1.87±0.13±0.05	558	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

$\Gamma(pK^0_S\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_7/Γ_2

Measurements given as a $\overline{K}^0$ ratio have been divided by 2 to convert to a K^0_S ratio.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.314±0.018 OUR FIT					
0.33 ±0.03 ±0.04	774	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(nK^0_S\pi^+)/\Gamma_{\text{total}}$ — Γ_8/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.82±0.23±0.11	83	ABLIKIM	17H	BES3	e^+e^- at 4.6 GeV

$\Gamma(p\overline{K}^0\eta)/\Gamma(pK^-\pi^+)$ — Γ_9/Γ_2

Unseen decay modes of the η are included.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.25±0.04±0.04	57	AMMAR	95	CLE2	$e^+e^- \approx \Upsilon(4S)$

$\Gamma(pK^0_S\pi^+\pi^-)/\Gamma_{\text{total}}$ — Γ_{10}/Γ

VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
1.59±0.12 OUR FIT	Error includes scale factor of 1.2.				
1.53±0.11±0.09	485	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

$\Gamma(pK^0_S\pi^+\pi^-)/\Gamma(pK^-\pi^+)$ — Γ_{10}/Γ_2

Measurements given as a $\overline{K}^0$ ratio have been divided by 2 to convert to a K^0_S ratio.

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT
0.255±0.015 OUR FIT	Error includes scale factor of 1.1.				
0.257±0.031 OUR AVERAGE					
0.26 ±0.02 ±0.03	985	ALAM	98	CLE2	$e^+e^- \approx \Upsilon(4S)$
0.22 ±0.06 ±0.02	83	AVERY	91	CLEO	e^+e^- 10.5 GeV
0.49 ±0.18 ±0.04	12	BARLAG	90D	NA32	π^- 230 GeV

$\Gamma(pK^-\pi^+\pi^0)/\Gamma_{\text{total}}$ — Γ_{11}/Γ

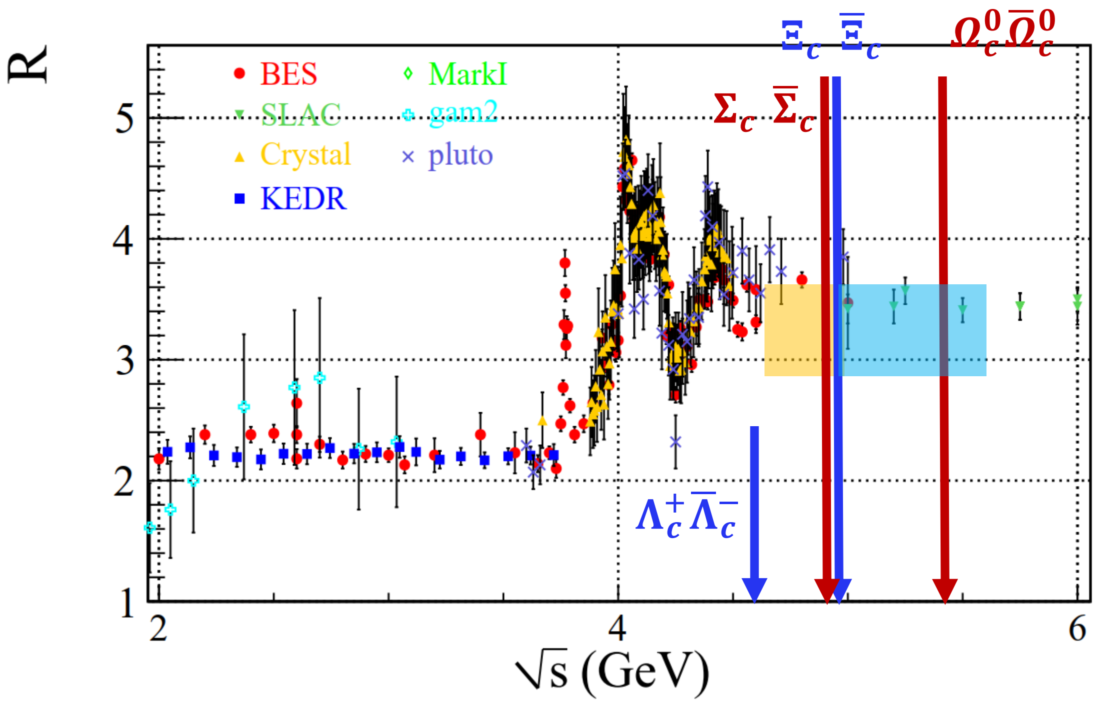
VALUE (%)	EVTS	DOCUMENT ID		TECN	COMMENT
4.42±0.31 OUR FIT	Error includes scale factor of 1.5.				
4.53±0.23±0.30	1849	ABLIKIM	16	BES3	$e^+e^- \to \Lambda_c\overline{\Lambda}_c$, 4.599 GeV

$\Gamma(pK^-\pi^+\pi^0)/\Gamma(pK^-\pi^+)$ — Γ_{11}/Γ_2

VALUE	EVTS	DOCUMENT ID		TECN	COMMENT

- ✦BESIII的贡献使得多数分支比结果由相对测量改为绝对测量。
- ✦BESIII对黄金道$\Lambda_c^+ \to pK\pi$的测量 ⇒ “模型依赖”变为“模型无关”。
- ✦BESIII贡献发现了更多以前没发现的衰变道(比如含中子末态的衰变)。

- Energy thresholds
  - ✓ $e^+e^- \to \Lambda_c^+ \bar{\Sigma}_c^-$ 4.74 GeV
  - ✓ $e^+e^- \to \Lambda_c^+ \bar{\Sigma}_c\ \pi$ 4.88 GeV
  - ✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV
  - ✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$ 4.94 GeV
  - ✓ $e^+e^- \to \Omega_c^0 \bar{\Omega}_c^0$ 5.40 GeV

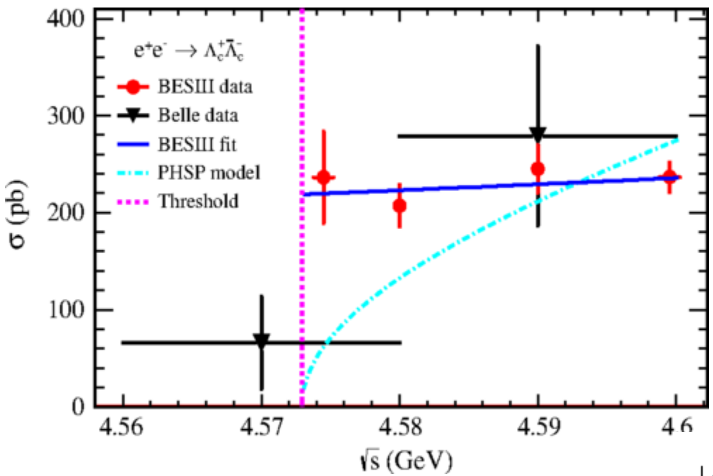


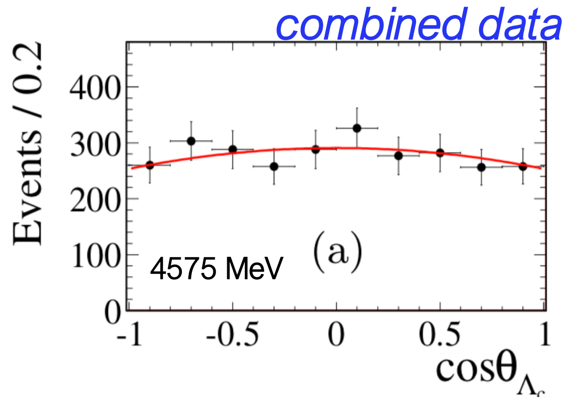
Charmed Baryons

	Structure	J^P	Mass, MeV	Width,MeV	Decay
Λ_c^+	udc	$(1/2)^+$	2286.46 ± 0.14	(200 ± 6) fs	weak
Ξ_c^+	usc	$(1/2)^+$	$2467.8^{+0.4}_{-0.6}$	(442 ± 26) fs	weak
Ξ_c^0	dsc	$(1/2)^+$	$2470.88^{+0.34}_{-0.8}$	112^{+13}_{-10} fs	weak
Σ_c^{++}	uuc	$(1/2)^+$	2454.02 ± 0.18	2.23 ± 0.30	$\Lambda_c^+\pi^+$
Σ_c^+	udc	$(1/2)^+$	2452.9 ± 0.4	< 4.6	$\Lambda_c^+\pi^0$
Σ_c^0	ddc	$(1/2)^+$	2453.76 ± 0.18	2.2 ± 0.4	$\Lambda_c^+\pi^-$
$\Xi_c^{\prime +}$	usc	$(1/2)^+$	2575.6 ± 3.1	—	$\Xi_c^+\gamma$
$\Xi_c^{\prime 0}$	dsc	$(1/2)^+$	2577.9 ± 2.9	—	$\Xi_c^0\gamma$
Ω_c^0	ssc	$(1/2)^+$	2695.2 ± 1.7	(69 ± 12) fs	weak
Σ_c^{*++}	uuc	$(3/2)^+$	2518.4 ± 0.6	14.9 ± 1.9	$\Lambda_c^+\pi^+$
Σ_c^{*+}	udc	$(3/2)^+$	2517.5 ± 2.3	< 17	$\Lambda_c^+\pi^0$
Σ_c^{*0}	ddc	$(3/2)^+$	2518.0 ± 0.5	16.1 ± 2.1	$\Lambda_c^+\pi^-$
Ξ_c^{*+}	usc	$(3/2)^+$	$2645.9^{+0.5}_{-0.6}$	< 3.1	$\Xi_c\pi$
Ξ_c^{*0}	dsc	$(3/2)^+$	2645.9 ± 0.5	< 5.5	$\Xi_c\pi$
Ω_c^{*0}	ssc	$(3/2)^+$	2765.9 ± 2.0	—	$\Omega_c^0\gamma$

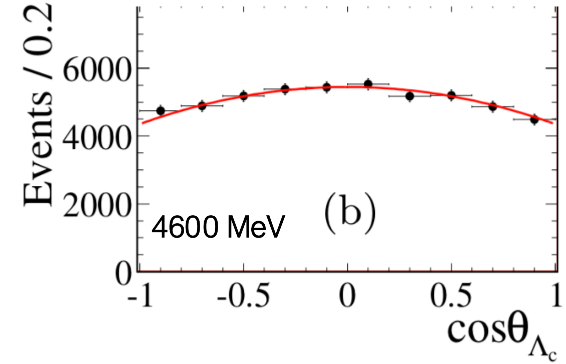
Angular dependence analysis of $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$ near threshold

PRL 120, 132001 (2018)





$f(\theta) \propto (1 + \alpha_{\Lambda_c} \cos^2\theta)$



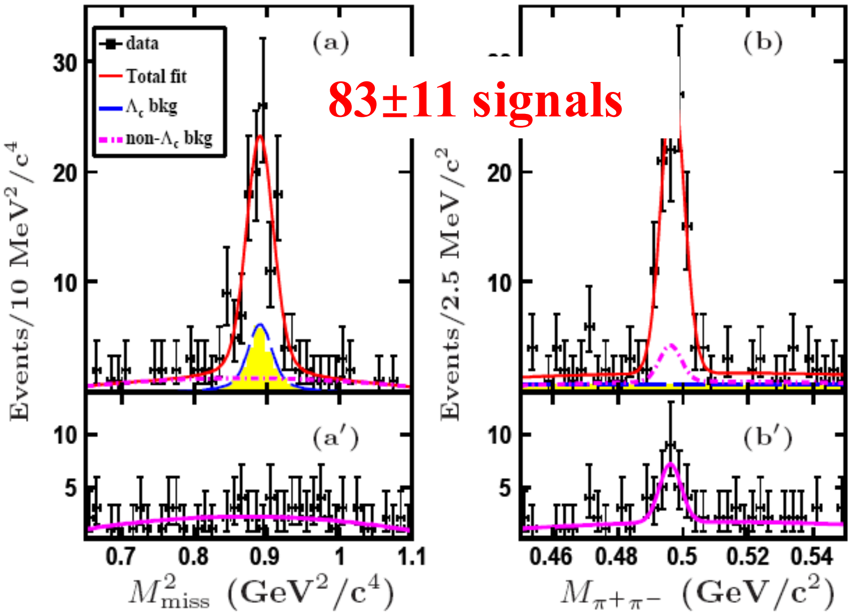
$$|G_E/G_M|^2(1-\beta^2) = (1-\alpha_{\Lambda_c})/(1+\alpha_{\Lambda_c}).$$

$\sqrt{s}$ (MeV)	α_{Λ_c}	$\lvert G_E/G_M \rvert$
4574.5	$-0.13 \pm 0.12 \pm 0.08$	$1.14 \pm 0.14 \pm 0.07$
4599.5	$-0.20 \pm 0.04 \pm 0.02$	$1.23 \pm 0.05 \pm 0.03$

- One of the most basic observables that intimately related to the internal structure of the nucleon.
- One of the most challenging questions in contemporary physics is why and how quarks are confined into hadrons.
- The electromagnetic form factors (EMFFs) have been a powerful tool in understanding the structure of nucleons.
- First measurements of the EMFFs of the Λ_c^+

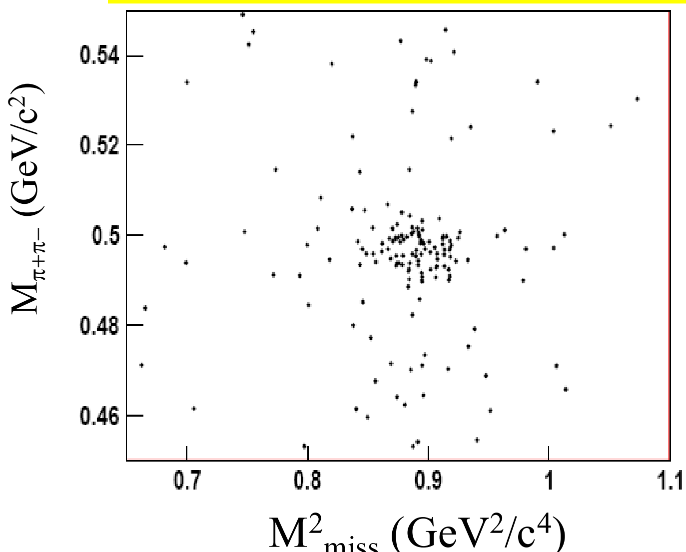
Observation of $\Lambda_c^+ \rightarrow nK_S\pi^+$

- ✓ No measurements for Λ_c^+ decay into a neutron yet.
- ✓ To confer the missing neutron, we define the variable M^2_{miss} , which considers the beam energy constrain to improve resolution



two-dimensional fit

567/pb data @ 4.6 GeV

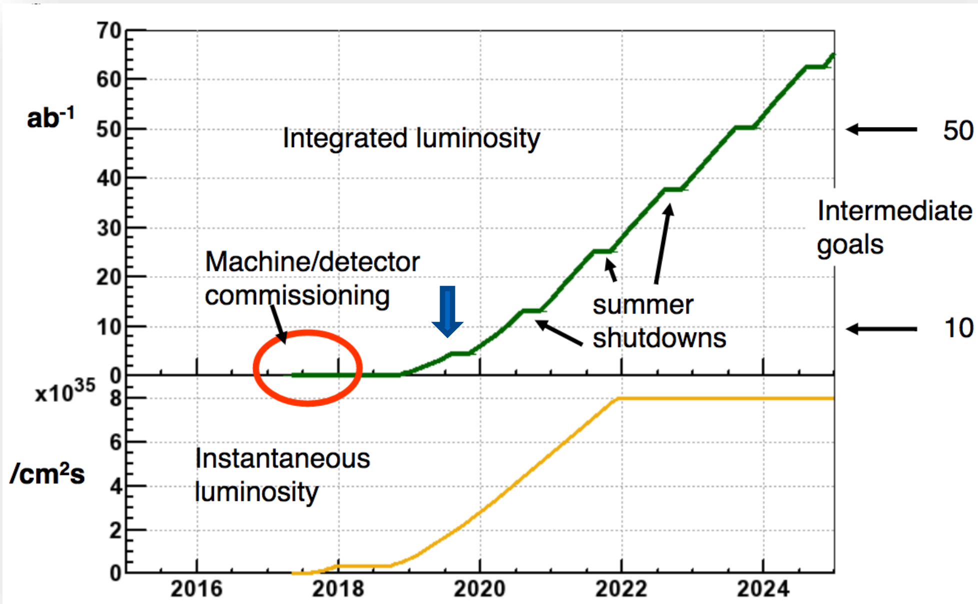


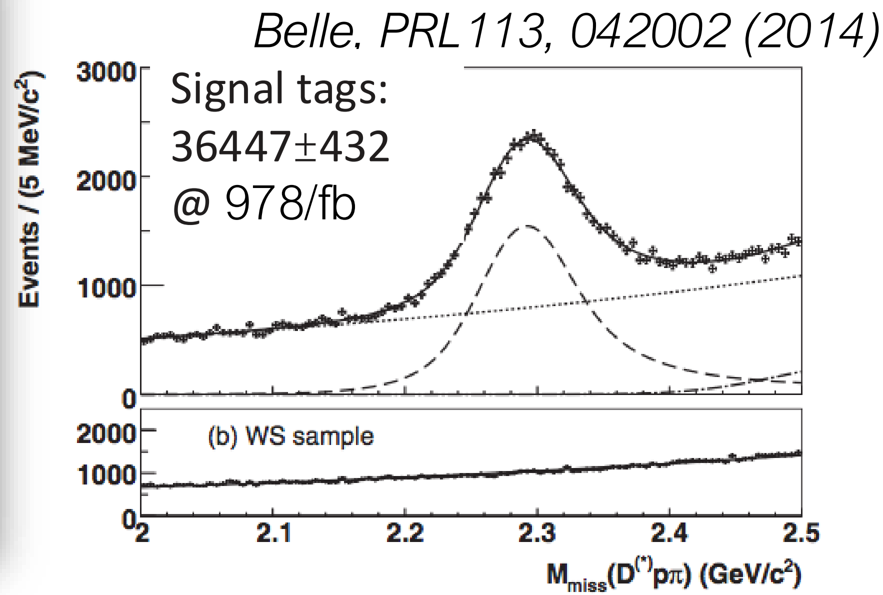
scatter plots $M_{\pi+\pi-}$ versus M^2_{miss}

BESIII Preliminary results: $B[\Lambda_c^+ \rightarrow nK_S\pi^+]=(1.82\pm0.23\pm0.11)\%$

First observation of Λ_C^+ decays to final states involving the neutron

Competition from Belle & BelleII





- Belle tags ~36K Λ_c^+, while BESIII now tags 15K Λ_c^+ (567/pb@4.6GeV)
- By middle of 2019, BELLEII will have 5/ab data, 5x of BELLE data;
  ➔ 180K tagged Λ_c^+;
- We will have 150K tagged Λ_c^+, however, BESIII is very clean
- Many precise measurements at BESIII will reach to the level of systematic dominated
  ➔ BESIII has advantages on backgrounds and systematics

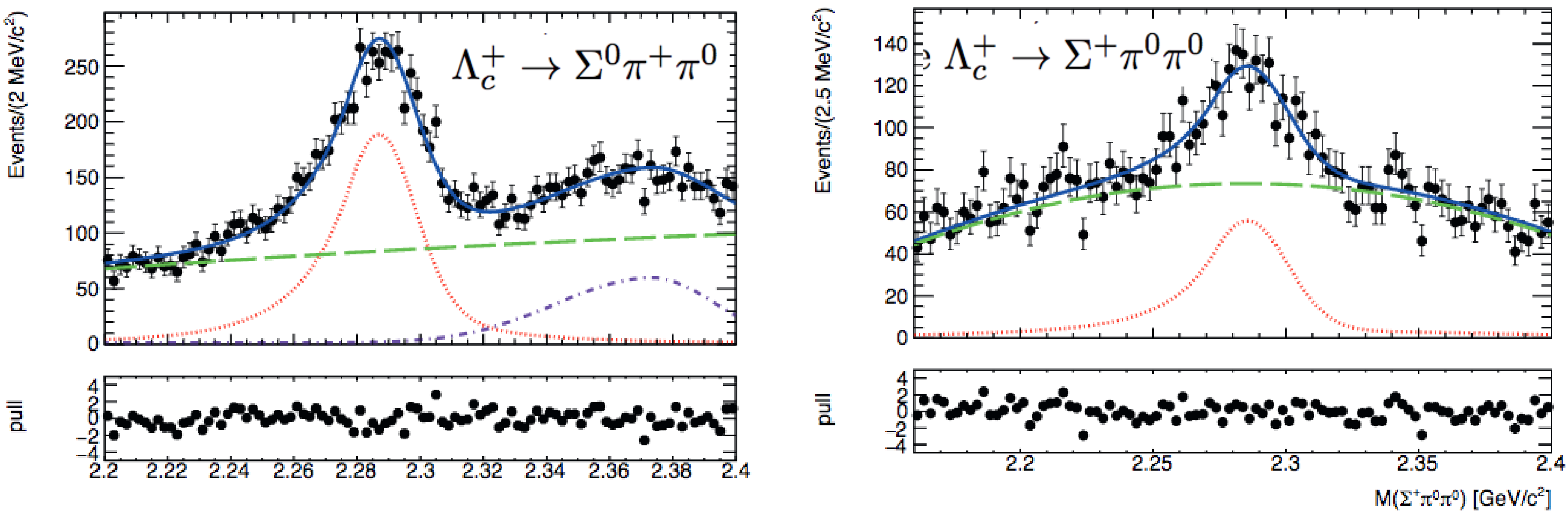
World campaign on the Λ_c^+

	BESIII	Belle(-II)	LHCb
Λ_c^+ total yields	⋆ ⋆ ⋆	⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆ ⋆ ⋆
S/B ratio	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆	⋆ ⋆
Systematic error	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆	⋆ ⋆
Systematic research	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆	⋆
Semi-leptonic mode	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆	⋆
n/K_L-involved mode	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆	☆
Photon final state	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆ ⋆	☆
Absolute measurement	⋆ ⋆ ⋆ ⋆ ⋆	⋆ ⋆ ⋆	☆

- The threshold data at BESIII have systematic advantage over Belle(-II) and LHCb in the Λ_c^+ studies.
- This proposal holds an optimal time window to maximize the visibility of BESIII physics.

Phys. Rev. D 98, 112006 (2018)

Measurement of the Decays $\Lambda_c \to \Sigma\pi\pi$ at Belle



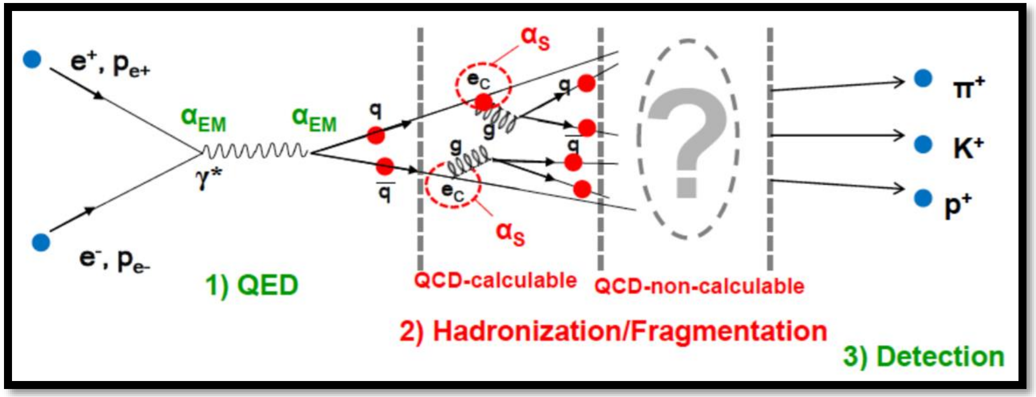
Important Input for b physics

- stringent Fragmentation Function of b/c quark to baryon
  - [Eur. Phys. J. C12, 225 (2000); Eur. Phys. J. C 16, 597 (2000); Phys. Rev. D 85, 032008 (2012), Phys. Rev.D 66, 091101 (2002).]
  - Fragmentation Function (FF) is an important probe in experiment to test and calibrate QCD theory.

PhysRevD.85.032008

TABLE IV. Systematic uncertainties on the absolute scale of $f_{\Lambda_b}/(f_u + f_d)$.

Source	Error (%)
Bin-dependent errors	2.2
$\mathcal{B}(\Lambda_b^0 \to D^0 p X \mu^- \bar{\nu})$	2.0
Monte Carlo modelling	1.0
Backgrounds	3.0
Tracking efficiency	2.0
$\Gamma_{\rm sl}$	2.0
Lifetime ratio	2.6
PID efficiency	2.5
Subtotal	6.3
$\mathcal{B}(\Lambda_c^+ \to p K^- \pi^+)$	26.0
Total	26.8



- Now B($pK^-\pi^+$) are still dominated (6%)
- 20x data=> small than 2%

First Measurements of absolute BFs for Ξ_c

$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (1.80 \pm 0.50 \pm 0.14)\%,$$
$$\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+) = (1.17 \pm 0.37 \pm 0.09)\%,$$
$$\mathcal{B}(\Xi_c^0 \to pK^-K^-\pi^+) = (0.58 \pm 0.23 \pm 0.05)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.86 \pm 1.21 \pm 0.38)\%,$$
$$\mathcal{B}(\Xi_c^+ \to pK^-\pi^+) = (0.45 \pm 0.21 \pm 0.07)\%.$$

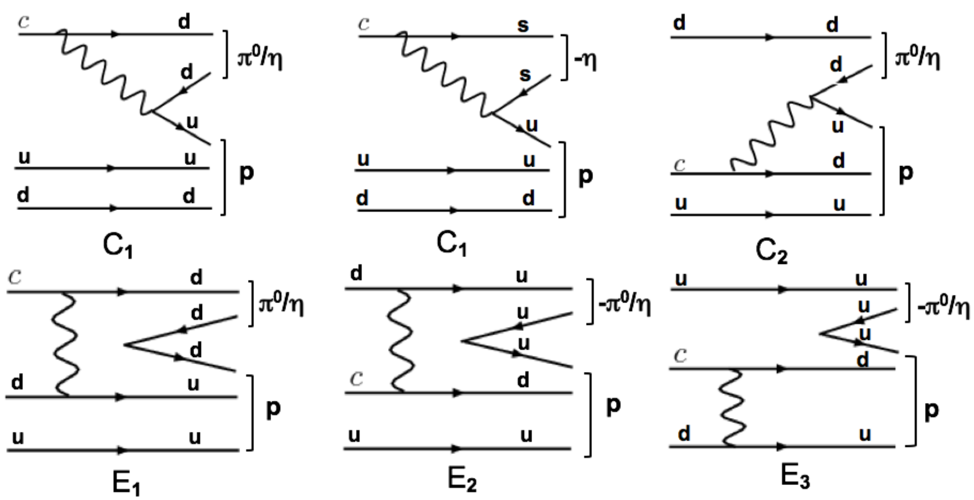
- Large errors
- Belle II will improve these to ~10%
- BESIII has potential to improve these to be <5%

Λ_c^+ hadronic decay

- Study of SCS channels: $\Lambda_c^+ \rightarrow \Lambda K^+, p\pi^0, p\eta, n\pi^+, \Sigma^0 K^+, \Sigma^+ K^0$ etc.

From Prof. Hai-Yang Cheng's report.

Singly Cabibbo-suppressed modes: $\Lambda_c^+ \rightarrow p\pi^0, p\eta$



$\pi^0 = (d\bar{d} - u\bar{u})/\sqrt{2}$, $\eta = (d\bar{d} + u\bar{u} - s\bar{s})/\sqrt{3}$ for $\eta - \eta'$ mixing angle = 19.5^0

$A(\Lambda_c^+ \rightarrow p\pi^0) = (C_1 + C_2 + E_1 - E_2 - E_3)/\sqrt{2}$

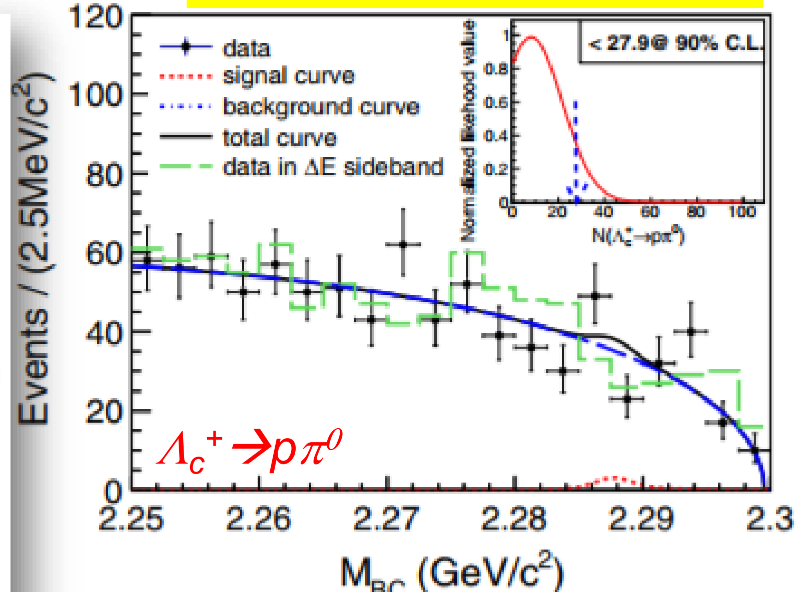
$A(\Lambda_c^+ \rightarrow p\eta) = (2C_1 + C_2 + E_1 + E_2 + E_3)/\sqrt{3}$

It is most likely that

$\Gamma(\Lambda_c^+ \rightarrow p\eta) >> \Gamma(\Lambda_c^+ \rightarrow p\pi^0)$

30

PRD95(2017)111102(R)



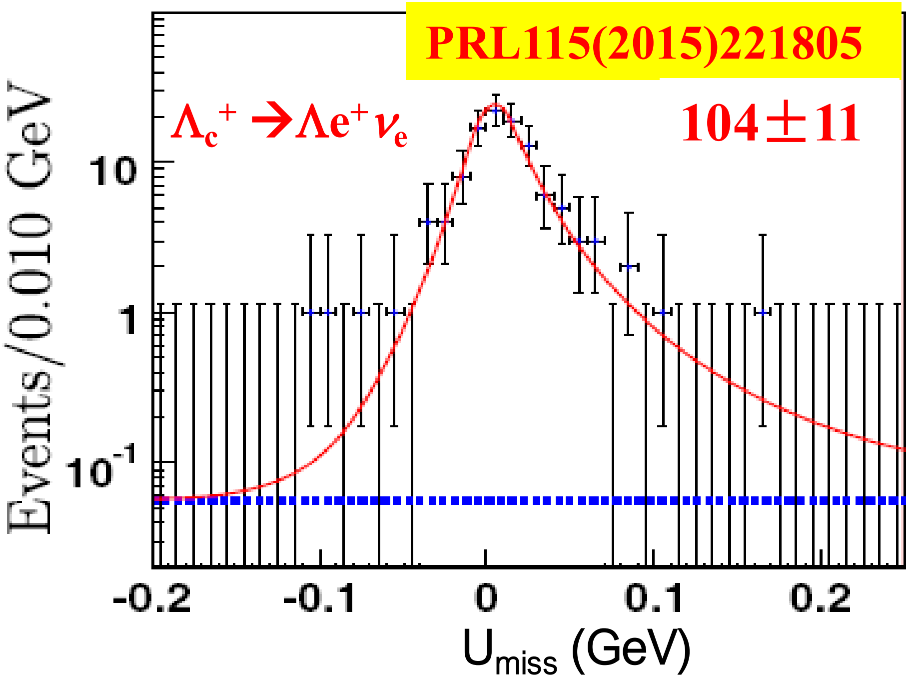
BESIII: $B[\Lambda_c^+ \rightarrow p\pi^0] < 2.7 \times 10^{-4}$

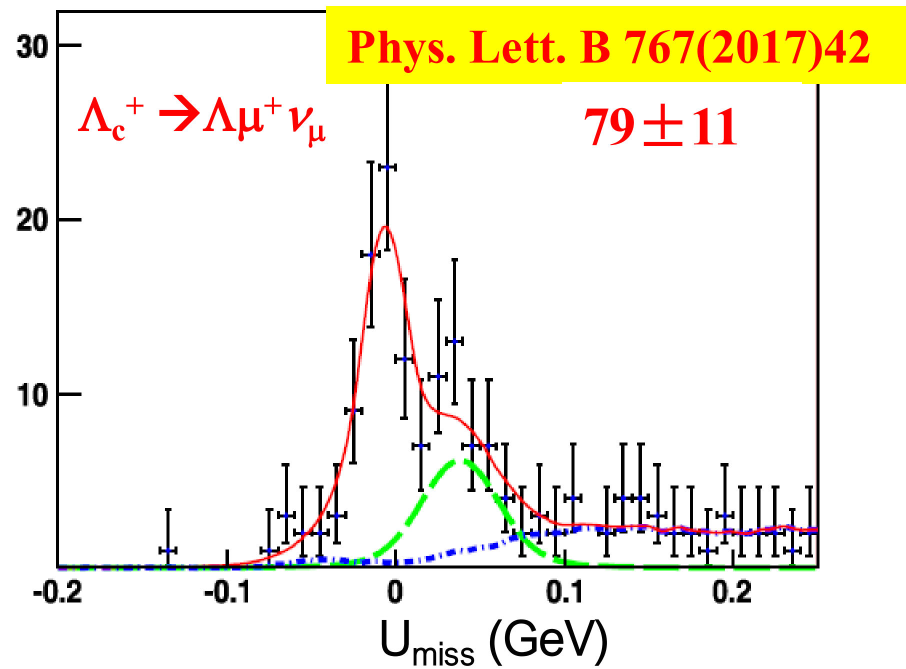
$$M(\Lambda_c^+ \rightarrow n\pi^+) = \sqrt{2} M(\Lambda_c^+ \rightarrow p\pi^0),$$

- More precise comparison of the two BFs are desired to explore the interference of different non-factorizable diagrams and BESIII result support the theoretic prediction. It is predicted that $Br[\Lambda_c^+ \rightarrow n\pi^+] \sim 3.5 \times Br[\Lambda_c^+ \rightarrow p\pi^0]$ [Hai-Yang Cheng, arXiv: 1801.08625]

$\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$ decays

- Theoretical calculations on the BF ranges from 1.4% to 9.2%
- BESIII performed the first absolute BF measurements.
- The BFs provide complementary information on determining





$B[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = (3.63 \pm 0.38 \pm 0.20)\%$

$B[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

$\Gamma[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] / \Gamma[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

Provides important input for calibrating the LQCD calculations.

Λ_c^+ data in PDG2015

Λ_c^+ DECAY MODES		Fraction (Γ_i/Γ)	Scale factor/ Confidence level	p (MeV/c)	
Hadronic modes with a p: $S = -1$ final states					
$p\overline{K}^0$		(3.21 ± 0.30) %			
$pK^-\pi^+$		($6.84^{+0.32}_{-0.40}$) %			
$p\overline{K}^*(892)^0$	[q]	(2.13 ± 0.30) %			
$\Delta(1232)^{++}K^-$		(1.18 ± 0.27) %			22.9%
$\Lambda(1520)\pi^+$	[q]	(2.4 ± 0.6) %			25.0%
$pK^-\pi^+$ nonresonant		(3.8 ± 0.4) %			10.5%
$p\overline{K}^0\pi^0$		(4.5 ± 0.6) %			13.3%
$p\overline{K}^0\eta$		(1.7 ± 0.4) %			23.5%
$p\overline{K}^0\pi^+\pi^-$		(3.5 ± 0.4) %			11.4%
$pK^-\pi^+\pi^0$		(4.6 ± 0.8) %			13.0%
$pK^*(892)^-\pi^+$	[q]	(1.5 ± 0.5) %			33.3%
$p(K^-\pi^+)_{\text{nonresonant}}\pi^0$		(5.0 ± 0.9) %			18.0%
$\Delta(1232)\overline{K}^*(892)$		seen			
$pK^-\pi^+\pi^+\pi^-$		(1.5 ± 1.0) $\times 10^{-3}$			66.7%
$pK^-\pi^+\pi^0\pi^0$		(1.1 ± 0.5) %			45.4%
Hadronic modes with a p: $S = 0$ final states					
$p\pi^+\pi^-$		(4.7 ± 2.5) $\times 10^{-3}$			45.4%
$pf_0(980)$	[q]	(3.8 ± 2.5) $\times 10^{-3}$			53.2%
$p\pi^+\pi^+\pi^-\pi^-$		(2.5 ± 1.6) $\times 10^{-3}$			64.0%
pK^+K^-		(1.1 ± 0.4) $\times 10^{-3}$			36.4%
$p\phi$	[q]	(1.12 ± 0.23) $\times 10^{-3}$			
pK^+K^- non-ϕ		(4.8 ± 1.9) $\times 10^{-4}$			
Hadronic modes with a hyperon: $S = -1$ final states					
$\Lambda\pi^+$		(1.46 ± 0.13) %			8.9%
$\Lambda\pi^+\pi^0$		(5.0 ± 1.3) %			26.0%
$\Lambda\rho^+$		< 6 %	CL=95%		
$\Lambda\pi^+\pi^+\pi^-$		(3.59 ± 0.28) %			7.8%
$\Sigma(1385)^+\pi^+\pi^-$, $\Sigma^{*+} \to \Lambda\pi^+$		(1.0 ± 0.5) %			20.0%
$\Sigma(1385)^-\pi^+\pi^+$, $\Sigma^{*-} \to \Lambda\pi^-$		(7.5 ± 1.4) $\times 10^{-3}$			18.7%

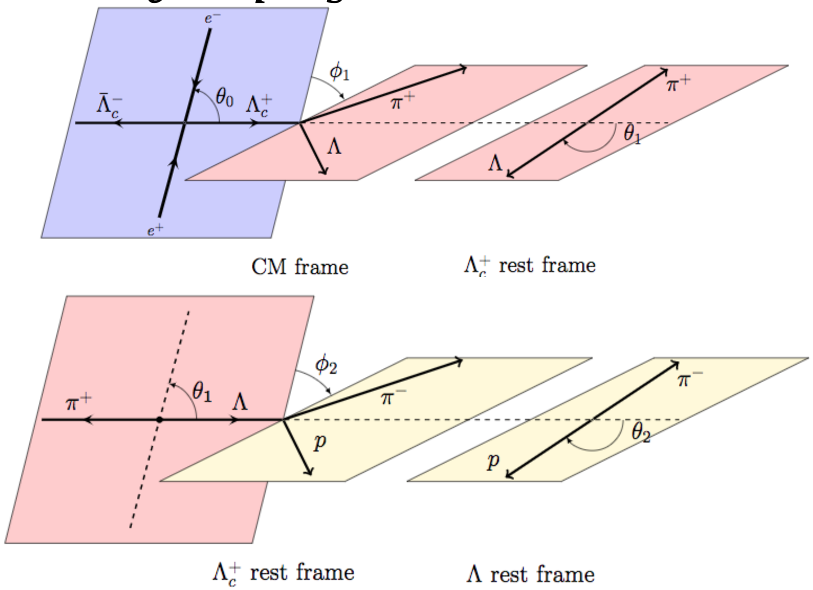
HTTP://PDG.LBL.GOV Page 32 Created: 10/6/2015 12

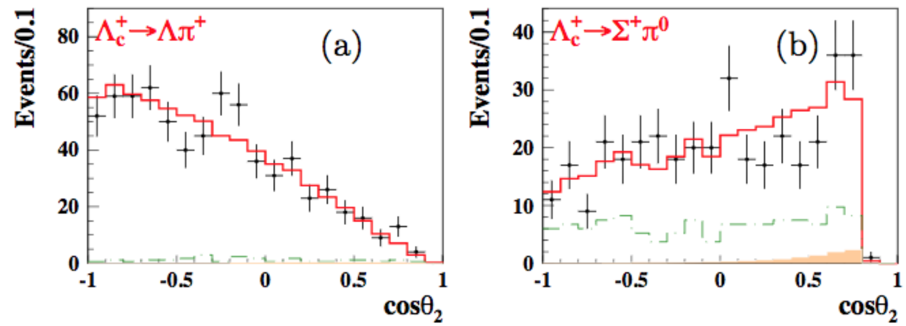
$\Lambda\pi^+\rho^0$		(1.4 ± 0.6) %		42.8%
$\Sigma(1385)^+\rho^0$, $\Sigma^{*+} \to \Lambda\pi^+$		(5 ± 4) $\times 10^{-3}$		80.0%
$\Lambda\pi^+\pi^+\pi^-$ nonresonant		< 1.1 %	CL=90%	
$\Lambda\pi^+\pi^+\pi^-\pi^0$ total		(2.5 ± 0.9) %		36.0%
$\Lambda\pi^+\eta$	[q]	(2.4 ± 0.5) %		20.8%
$\Sigma(1385)^+\eta$	[q]	(1.16 ± 0.35) %		30.2%
$\Lambda\pi^+\omega$	[q]	(1.6 ± 0.6) %		37.5%
$\Lambda\pi^+\pi^+\pi^-\pi^0$, no η or ω		< 9 $\times 10^{-3}$	CL=90%	
$\Lambda K^+\overline{K}^0$		(6.4 ± 1.3) $\times 10^{-3}$	S=1.6	20.3%
$\Xi(1690)^0K^+$, $\Xi^{*0} \to \Lambda\overline{K}^0$		(1.8 ± 0.6) $\times 10^{-3}$		33.3%
$\Sigma^0\pi^+$		(1.43 ± 0.14) %		10.0%
$\Sigma^+\pi^0$		(1.37 ± 0.30) %		21.9%
$\Sigma^+\eta$		(7.5 ± 2.5) $\times 10^{-3}$		33.3%
$\Sigma^+\pi^+\pi^-$		(4.9 ± 0.5) %		10.2%
$\Sigma^+\rho^0$		< 1.8 %	CL=95%	
$\Sigma^-\pi^+\pi^+$		(2.3 ± 0.4) %		17.4%
$\Sigma^0\pi^+\pi^0$		(2.5 ± 0.9) %		36.0%
$\Sigma^0\pi^+\pi^+\pi^-$		(1.13 ± 0.31) %		27.4%
$\Sigma^+\pi^+\pi^-\pi^0$		—		
$\Sigma^+\omega$	[q]	(3.7 ± 1.0) %		27.1%
$\Sigma^+K^+K^-$		(3.8 ± 0.6) $\times 10^{-3}$		15.8%
$\Sigma^+\phi$	[q]	(4.3 ± 0.7) $\times 10^{-3}$		16.3%
$\Xi(1690)^0K^+$, $\Xi^{*0} \to \Sigma^+K^-$		(1.11 ± 0.29) $\times 10^{-3}$		26.2%
$\Sigma^+K^+K^-$ nonresonant		< 9 $\times 10^{-4}$	CL=90%	
Ξ^0K^+		(5.3 ± 1.3) $\times 10^{-3}$		24.5%
$\Xi^-K^+\pi^+$		(7.0 ± 0.8) $\times 10^{-3}$	S=1.1	11.4%
$\Xi(1530)^0K^+$	[q]	(3.5 ± 1.0) $\times 10^{-3}$		28.6%
Hadronic modes with a hyperon: $S = 0$ final states				
ΛK^+		(6.9 ± 1.4) $\times 10^{-4}$		20.3%
$\Lambda K^+\pi^+\pi^-$		< 6 $\times 10^{-4}$	CL=90%	
Σ^0K^+		(5.7 ± 1.0) $\times 10^{-4}$		17.5%
$\Sigma^0K^+\pi^+\pi^-$		< 2.9 $\times 10^{-4}$	CL=90%	
$\Sigma^+K^+\pi^-$		(2.3 ± 0.7) $\times 10^{-3}$		30.4%
$\Sigma^+K^*(892)^0$	[q]	(3.8 ± 1.2) $\times 10^{-3}$		31.6%
$\Sigma^-K^+\pi^+$		< 1.3 $\times 10^{-3}$	CL=90%	
Doubly Cabibbo-suppressed modes				
$pK^+\pi^-$		< 3.1 $\times 10^{-4}$	CL=90%	
Semileptonic modes				
$\Lambda\ell^+\nu_\ell$	[r]	(2.8 ± 0.4) %		
$\Lambda e^+\nu_e$		(2.9 ± 0.5) %		17.2%
$\Lambda\mu^+\nu_\mu$		(2.7 ± 0.6) %		22.2%

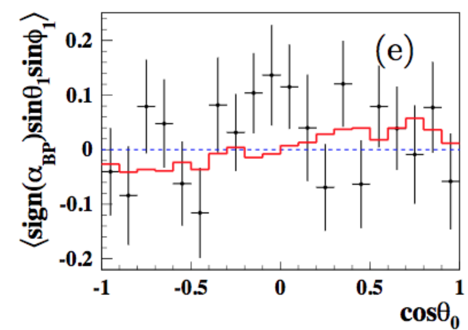
- ✓ Total branching fraction ~60%
- ✓ Lots of unknown decay channels
- ✓ Quite large uncertainties(>20%)
- ✓ Most BFs are measured relative to $\Lambda_c^+ \to pK^-\pi^+$

Λ_c decay asymmetries

4(6)-fold angular analysis of the cascade decays of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ PRD 100, 072004 (2019)





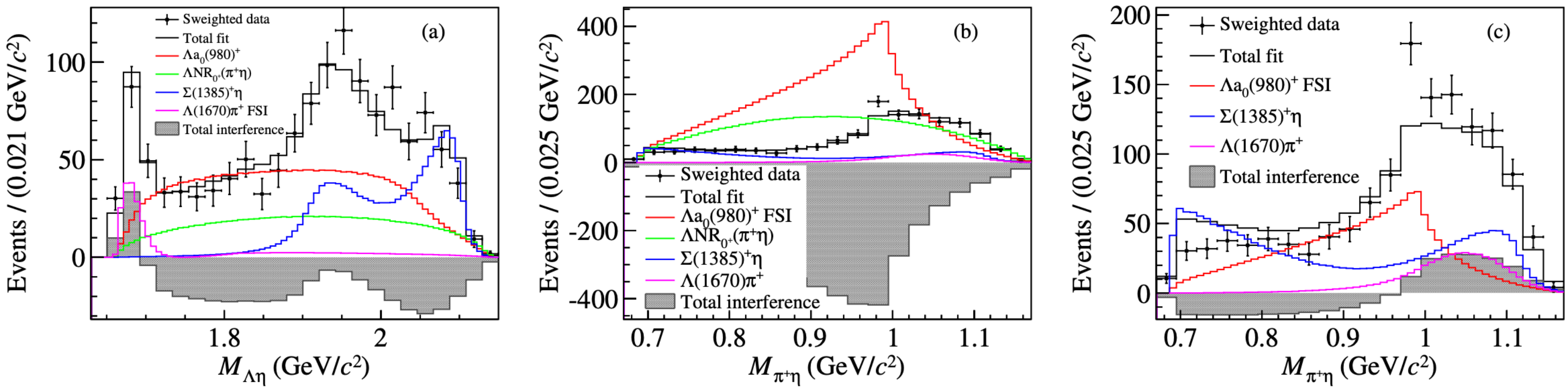


$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	−1.0 [16], 0.51 [11]	−0.70 [16], −0.67 [11]	0.71 [16], 0.92 [11]	0.70 [16], 0.92 [11]
		−0.49 [10], −0.90 [10]	−0.95 [10], −0.99 [10]	0.79 [10], −0.49 [10]	0.78 [10], −0.49 [10]
		−0.49 [17], −0.97 [18]	−0.96 [17], −0.95 [18]	0.83 [17], 0.43 [18]	0.83 [17], 0.43 [18]
		−0.66 [19], −0.90 [30]	−0.99 [19], −0.86 [30]	0.39 [19], −0.76 [30]	0.39 [19], −0.76 [30]
		−0.99 [20], −0.91 [31]	−0.99 [20], −0.94 [31]	−0.31 [20], −0.47 [31]	−0.31 [20], −0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$

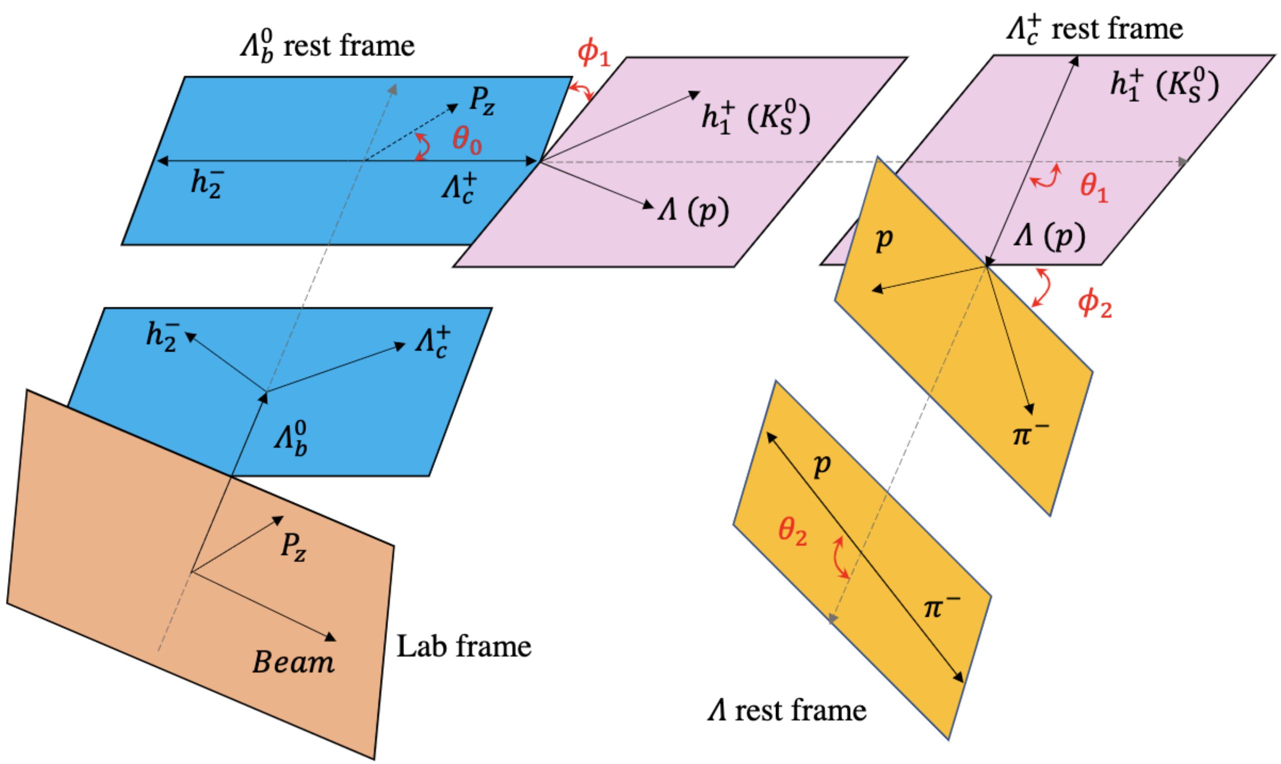
$\sin\Delta_0 = -0.28 \pm 0.13 \pm 0.03$

- Best precisions on the hadronic weak decay asymmetries
- The transverse polarization is firstly studied and found to be non-zero with 2.1σ

Test FSI model of $a_0(980)^+$ and $\Lambda(1670)$



Large interference between $a_0(980)^+$ FSI with NR



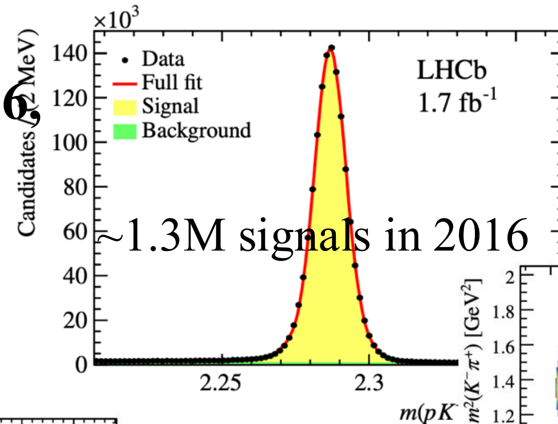
$$\frac{\mathrm{d}^3\Gamma}{\mathrm{d}\cos\theta_1\mathrm{d}\cos\theta_2\mathrm{d}\phi_2} \propto (1 + \alpha_{\Lambda_b^0}\alpha_{\Lambda_c^+}\cos\theta_1 + \alpha_{\Lambda_c^+}\alpha_{\Lambda}\cos\theta_2 + \alpha_{\Lambda_b^0}\alpha_{\Lambda}\cos\theta_1\cos\theta_2$$
$$- \alpha_{\Lambda_b^0}\gamma_{\Lambda_c^+}\alpha_{\Lambda}\sin\theta_1\sin\theta_2\cos\phi_2 + \alpha_{\Lambda_b^0}\beta_{\Lambda_c^+}\alpha_{\Lambda}\sin\theta_1\sin\theta_2\sin\phi_2),$$

$$\frac{\mathrm{d}\Gamma}{\mathrm{d}\cos\theta_1} \propto 1 + \alpha_{\Lambda_b^0}\alpha_{\Lambda_c^+}\cos\theta_1,$$

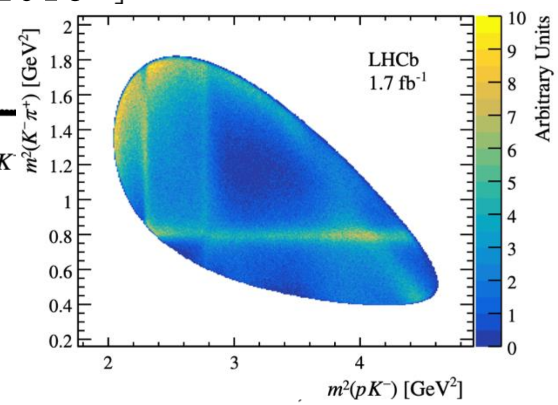
$\Lambda_c^+ \to pK^-\pi^+$ amplitude analysis

Phys. Rev. D 108, 012023 (2023)

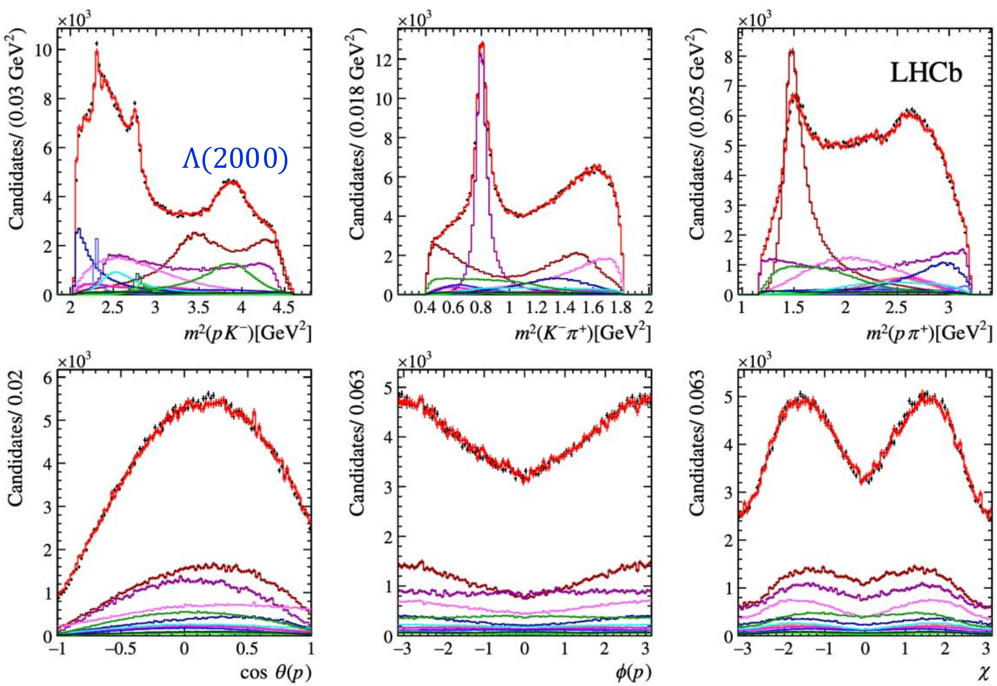
Λ_c^+ signals are selected via $\Lambda_b^0 \to \Lambda_c^+ \mu^- \nu$ from dataset taken in 2016, where only a subset of 0.4 M signals are employed



~1.3M signals in 2016



5-dim fit



Resonance	Fit fraction (%)
$\Lambda(1405)$	7.7
$\Lambda(1520)$	1.86
$\Lambda(1600)$	5.2
$\Lambda(1670)$	1.18
$\Lambda(1690)$	1.19
$\Lambda(2000)$	9.58
$\Delta(1232)^{++}$	28.60
$\Delta(1600)^{++}$	4.5
$\Delta(1700)^{++}$	3.90
$K_0^*(700)$	3.02
$K^*(892)$	22.14
$K_0^*(1430)$	14.7

Resonance	α
Model $\sqrt{3}S$	0.662
$K^*(892)$ $\sqrt{3}S$	0.873
$\Lambda(1405)$	−0.58
$\Lambda(1520)$	−0.925
$\Lambda(1600)$	−0.20
$\Lambda(1670)$	−0.817
$\Lambda(1690)$	−0.958
$\Lambda(2000)$	−0.57
$\Delta(1232)^{++}$	−0.548
$\Delta(1600)^{++}$	−0.50
$\Delta(1700)^{++}$	−0.216
$K_0^*(700)$	−0.06
$K_0^*(1430)$	−0.34

Λ_c^+ polarization and $\Lambda_c^+ \to pK^-\pi^+$ polarimetry

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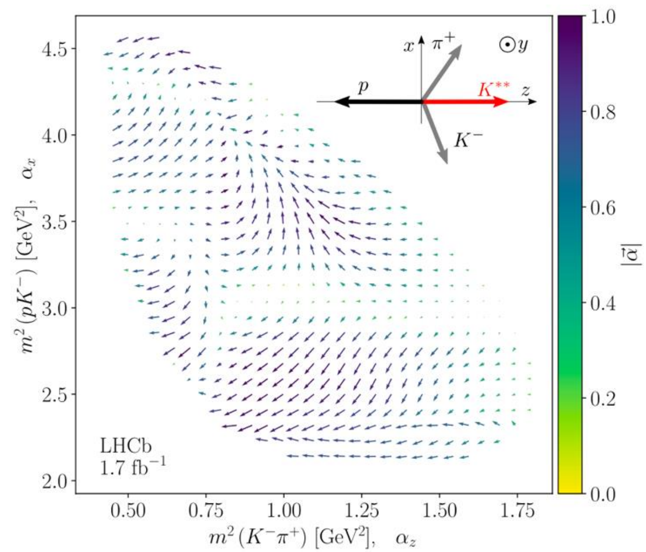
JHEP 07, 228 (2023)

Component	Value (%)
P_x (lab)	$60.32 \pm 0.68 \pm 0.98 \pm 0.21$
P_y (lab)	$-0.41 \pm 0.61 \pm 0.16 \pm 0.07$
P_z (lab)	$-24.7 \pm 0.6 \pm 0.3 \pm 1.1$
P_x ($\tilde{B}$)	$21.65 \pm 0.68 \pm 0.36 \pm 0.15$
P_y ($\tilde{B}$)	$1.08 \pm 0.61 \pm 0.09 \pm 0.08$
P_z ($\tilde{B}$)	$-66.5 \pm 0.6 \pm 1.1 \pm 0.1$

The amplitude model is used to produce the distribution of the kinematic-dependent polarimeter vector in the space of Mandelstam variables to express the polarized decay rate in a model-independent way.

A large Λ_c^+ polarization is found in *b* semi-leptonic decays $\Lambda_b^0 \to \Lambda_c^+ \mu^- \nu$



- The obtained representation can facilitate polarization measurements of the Λ_c^+ baryon and eases inclusion of the $\Lambda_c^+ \to pK^-\pi^+$ decay mode in hadronic amplitude analyses.
- At BESIII, the transverse polarization of Λ_c^+ can be obtained via $\Lambda_c^+ \to pK^-\pi^+$ polarimetry

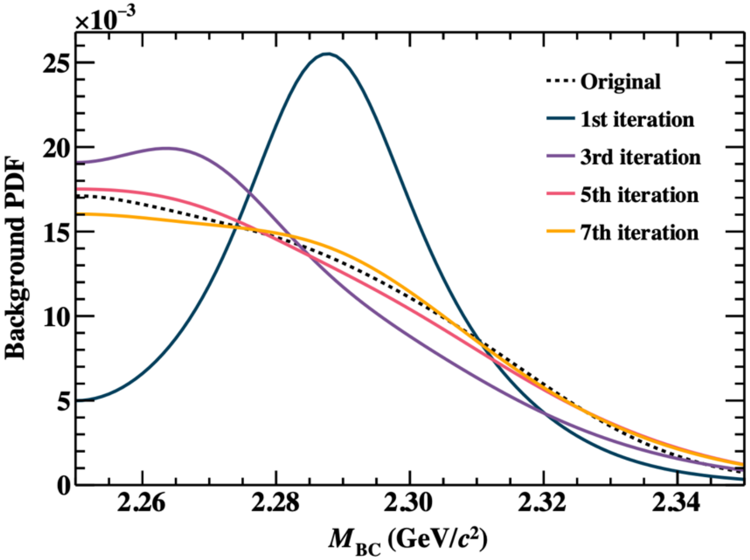
ML-boosted observation of $\Lambda_c^+ \to p\pi^0$

PRD111, L051101 (2025)

- Use Deep Neural Network (DNN) to identify $\boldsymbol{\Lambda_c^+(\to p\pi^0)\bar{\Lambda}_c^-(\to anything)}$ **after ST selections**
  - ✓ Form point clouds with all recorded tracks & showers
  - ✓ Train Transformer model with MC samples covering all $\bar{\Lambda}_c^-$ final states
  - ✓ Randomly shuffle signal & background MC samples with equal statistics
- Take $\Lambda_c^+ \to p\eta, \eta \to \gamma\gamma$ as reference channel

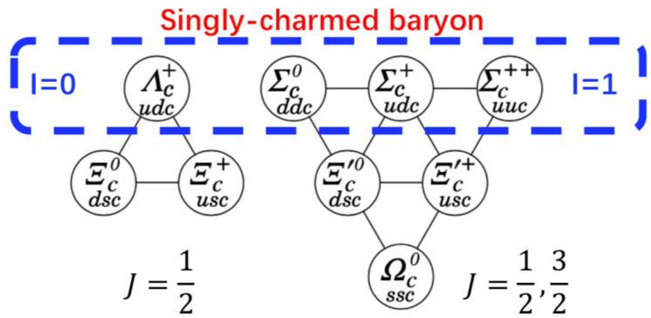
- Data augmentation
  - ✓ train $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ in one uniform model
  - ✓ maximum systematic cancellation
- Mass decorrelation to ease the model decoration on the signal discriminator
  - ✓ an iterative method is implemented on beam-constrained mass in background events in loss function

$$\omega_0(M_{BC}) = 1, \omega_i(M_{BC}) = \omega_{i-1}(M_{BC}) \cdot \frac{p_{i-1}^{BKG}(M_{BC})}{p_{orig}^{BKG}(M_{BC})}$$



Energy thresholds

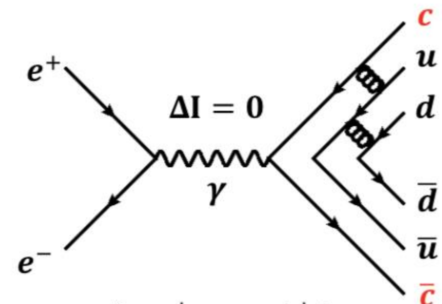
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74~4.87 GeV
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-(2595)(\bar{\Sigma}_c\,\pi)$ 4.88 GeV
- ✓ $e^+e^- \to \Sigma_c\,\bar{\Sigma}_c$ 4.91 GeV
- ✓ $e^+e^- \to \Xi_c\,\bar{\Xi}_c$ 4.95 GeV



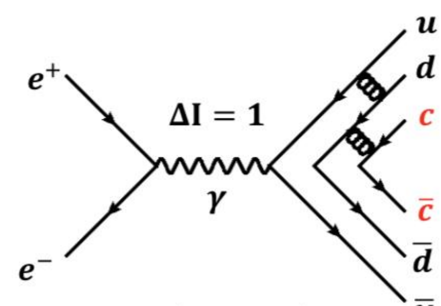
The Born cross-section **ratios** between $\Lambda_c^+\Lambda_c^- + c.c.$ and $\Lambda_c^-\Sigma_c^+ + c.c.$ at different energy points can provide more information about the production of $c\bar{c}$ or $q\bar{q}$ from vacuum.

BESIII Cross sections for $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ and $\Sigma_c\,\bar{\Sigma}_c$

- $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ **above 4.74 GeV:** An interesting isospin violating process to understand the QCD dynamics at charm sector
  - ✓ A cross section scan slightly above 4.74 GeV will be useful for comparison with that of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ and $\Lambda_c^+\bar{\Sigma}_c^-$
  - ✓ $\sigma(\Lambda_c^+\bar{\Sigma}_c^-)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$ v.s. $\sigma(\Lambda\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
    ➔ vaccum pol. to $c\bar{c}$ v.s. $s\bar{s}$
  - ✓ If observed, study the polarizations and form factors
- $e^+e^- \to \Sigma_c\,\bar{\Sigma}_c$ **around 4.91 GeV:**
  - ✓ Cross section comparison with that of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$
    ➔ good diquark v.s. bad diquark
  - ✓ Study the polarizations and form factors in $e^+e^- \to \Sigma_c^0\bar{\Sigma}_c^0$ and $\Sigma_c^+\bar{\Sigma}_c^-$



➢ $e^+e^- \to \Lambda_c^+\Lambda_c^-$



➢ $e^+e^- \to \Lambda_c^+\Sigma_c^-$