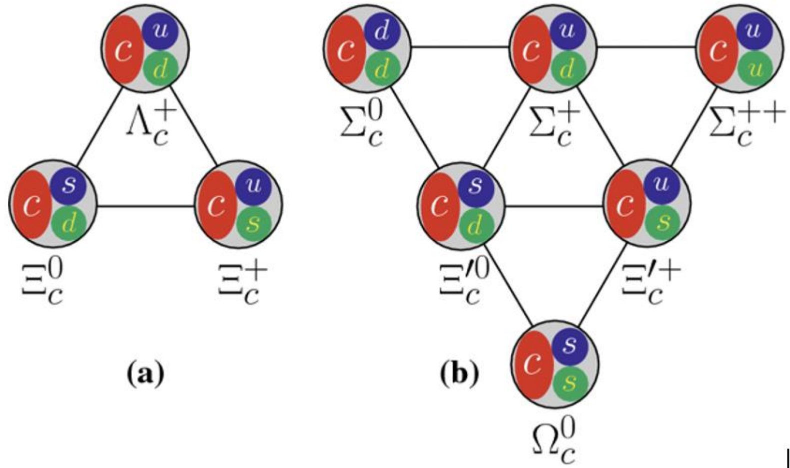


Study on the Charmed Baryons with Novel Technology in the BESIII Experiment

Xiao-Rui Lyu (吕晓睿)

(*xiaorui@ucas.ac.cn*)

University of Chinese Academy Sciences

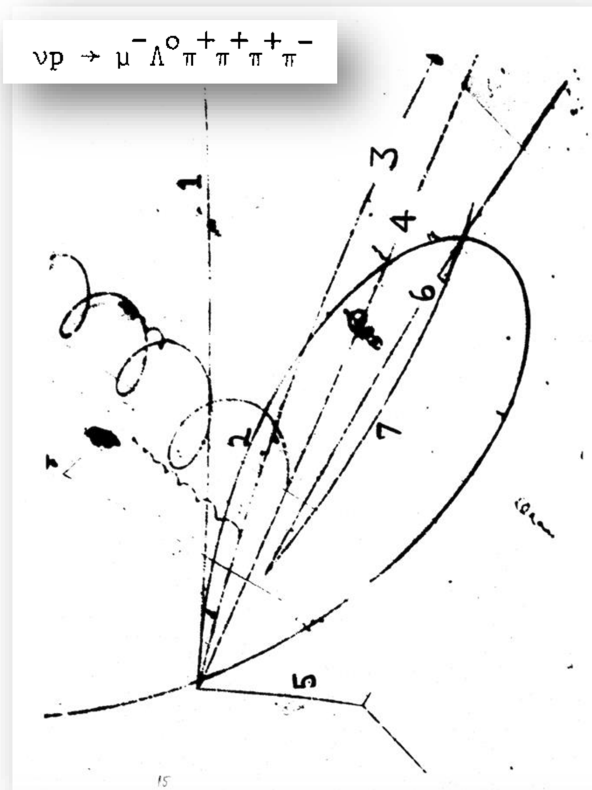
see review article:
P.-R. Li, **X.-R. Lyu**, Y. Zheng, Chin. Phys. C 50, 022002 (2026)

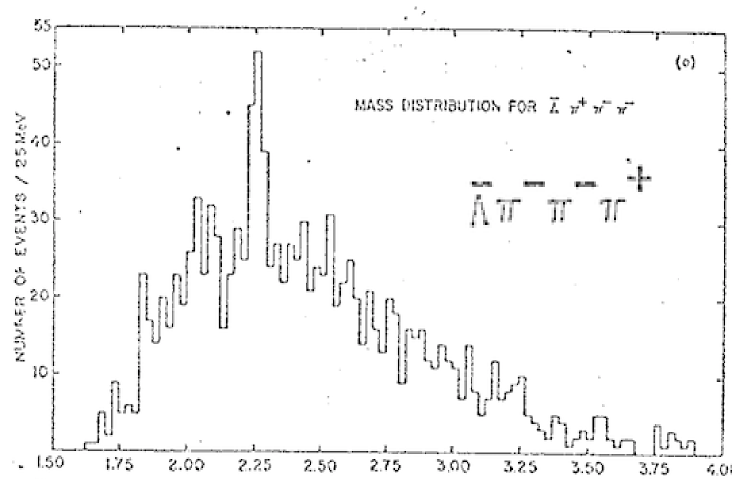
Outline

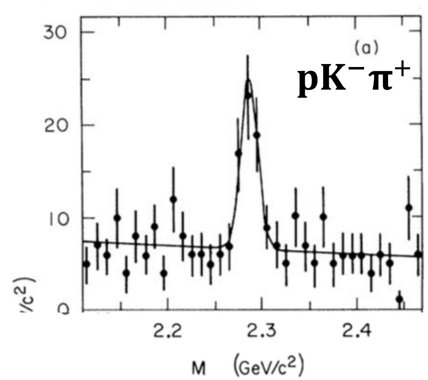
- **Introduction to the charmed baryons**
- **Recent progress at BESIII**
  - ✓ **Semi-Leptonic decays**
  - ✓ **Hadronic decay rates**
  - ✓ **Polarization and CP**
  - ✓ **Hyperon Spectroscopy**
- **Future**
- **Summary**

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 $\Sigma_c^{++} \to \Lambda_c^+ \pi^+$ 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)

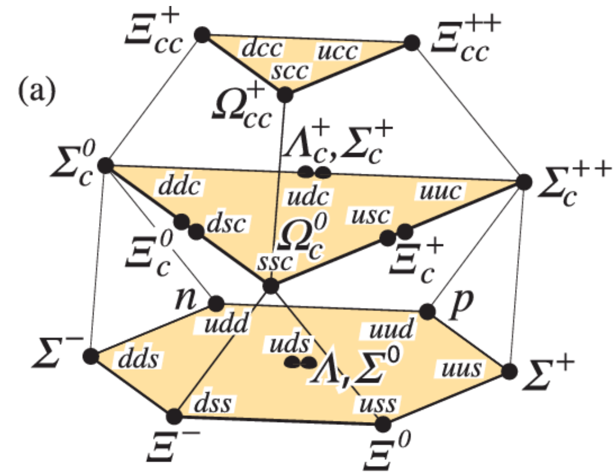




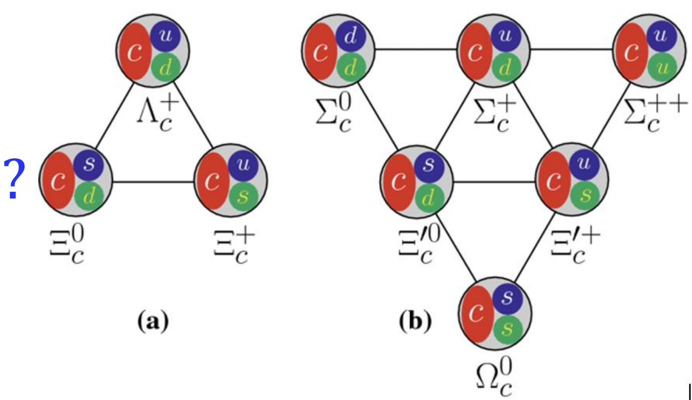


The charmed baryon family

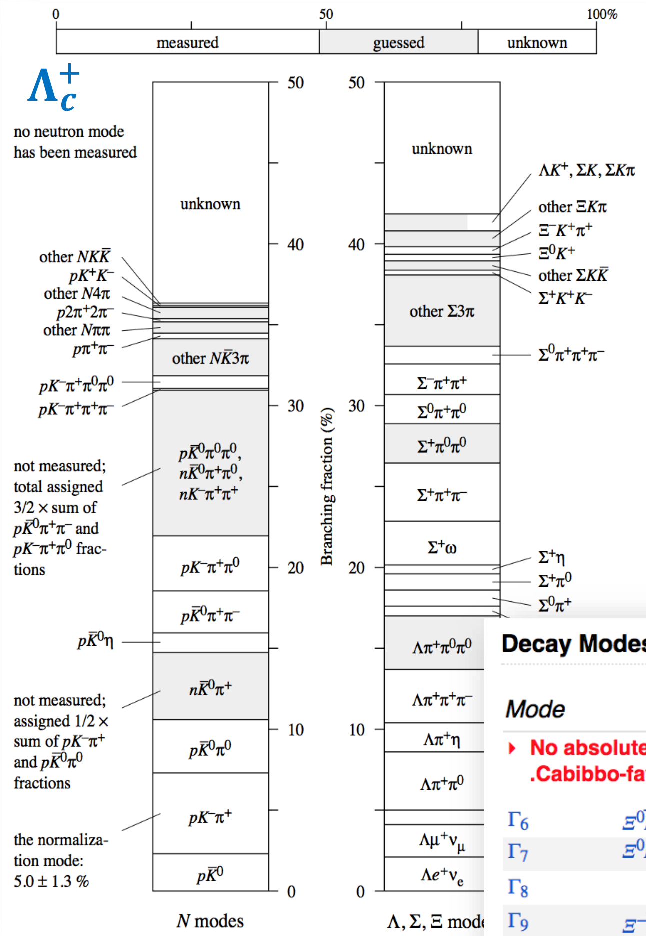
- **Singly charmed baryons**
  - ✓ Established ground states:
    Λ_c^+, Σ_c , $\Xi_c^{(\prime)}$, Ω_c
  - ✓ Excited states are being explored
- **Observation of other doubly charmed baryon Ξ_{cc}^{++} and Ξ_{cc}^{+}**
- **No observations of other doubly or triply charmed baryons**



- ➢ Λ_c^+: decay only weakly, **many experimental progress since 2014**
- ➢ Σ_c : $B(\Sigma_c \to \Lambda_c^+\pi)\sim100\%$; $B(\Sigma_c \to \Lambda_c^+\gamma)$?
- ➢ 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

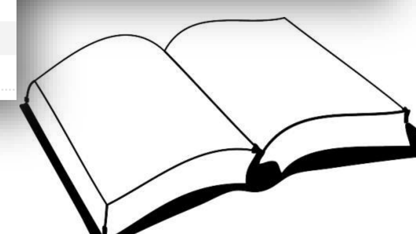


Ξ_c^+: relative to the decay of $\Xi^- 2\pi^+$

	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

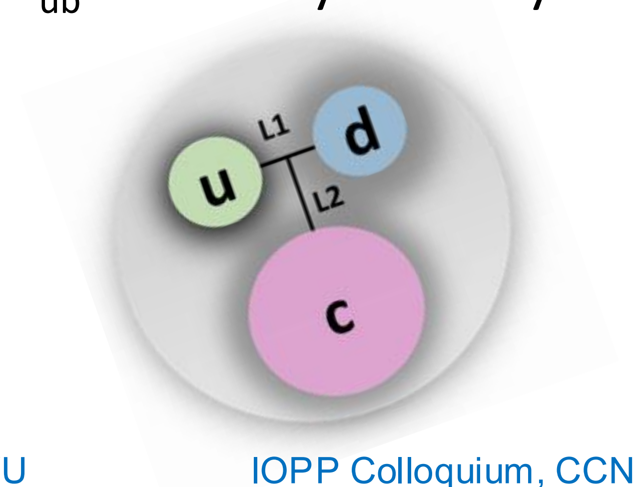
Decay Modes Ω_c^0

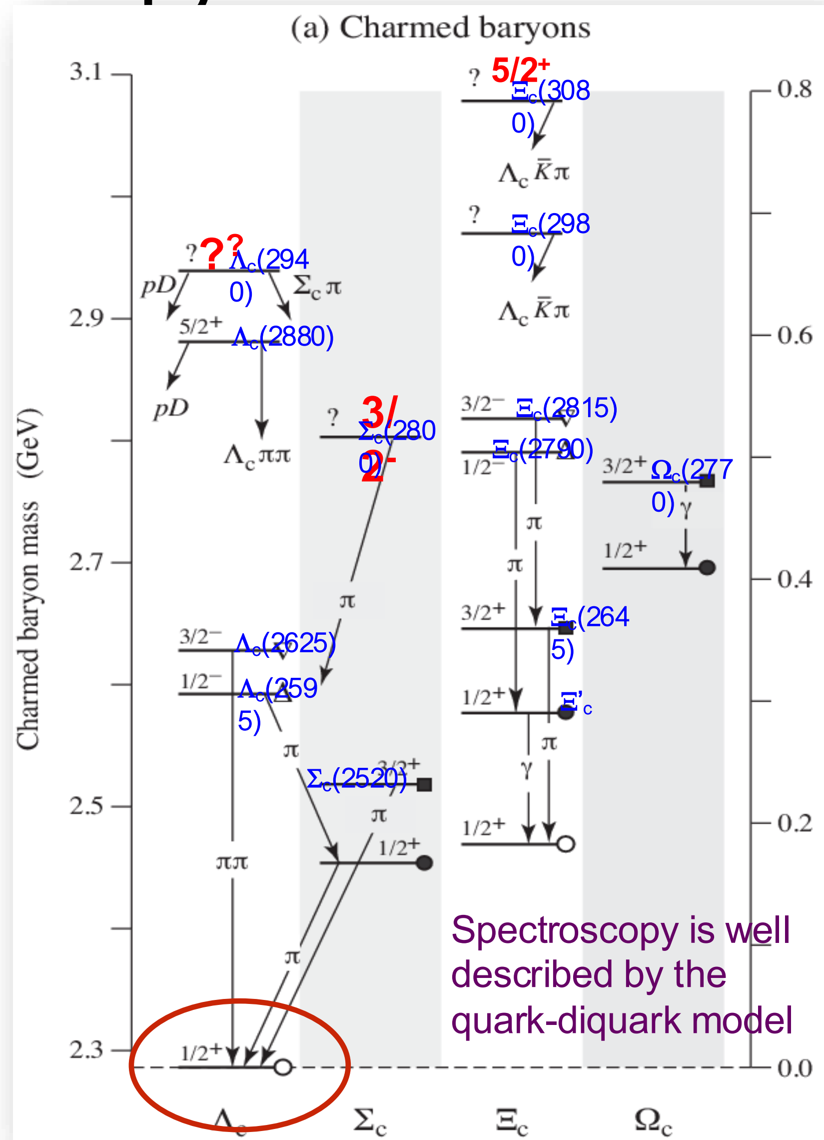
	Mode	*Fraction* (Γ_i/Γ)
No absolute branching fractions have been measured. The following are branching ra… .Cabibbo-favored ($S=-3$) decays – relative to $\Omega^-\pi^+$		
Γ_6	$\Xi^0\bar{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0K^-\pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0\bar{K}^{*0}$, $\bar{K}^{*0} \to K^-\pi^+$	0.68 ± 0.16
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
- $B(\Lambda_c^+ \to pK^-\pi^+)$: important input to V_{ub} via b-baryon decay

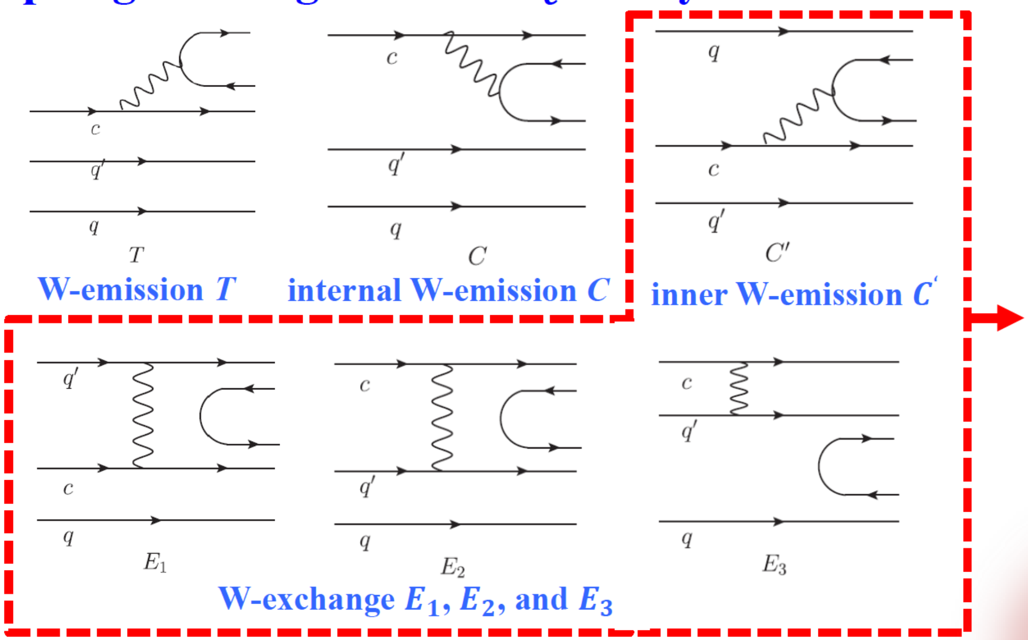




Λ_c^+ weak decays

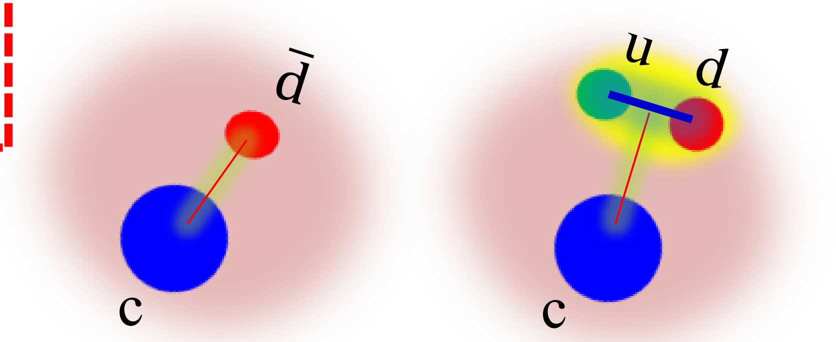
- Contrary to charmed meson, W-exchange contribution is important
- More information on the strong dynamics in the charm sector than those from the charmed meson decays

Topological Diagrams for Λ_c^+ decays:

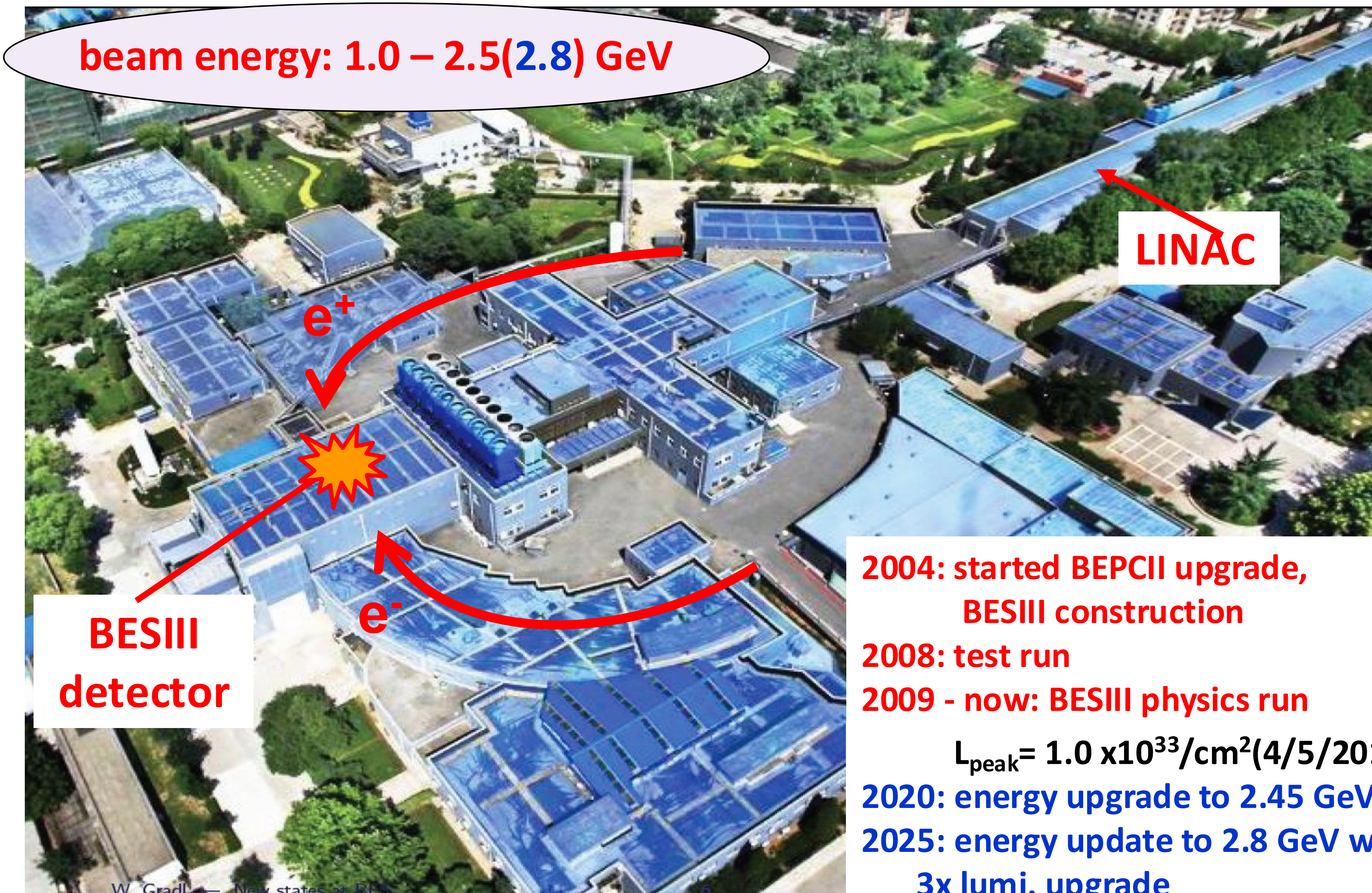


H.-Y. Cheng *et al.*, *Chinese Journal of Physics*, 78(2022) 324-362

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



Beijing Electron Positron Collider (BEPCII)



2004: started BEPCII upgrade,
BESIII construction

2008: test run

2009 - now: BESIII physics run

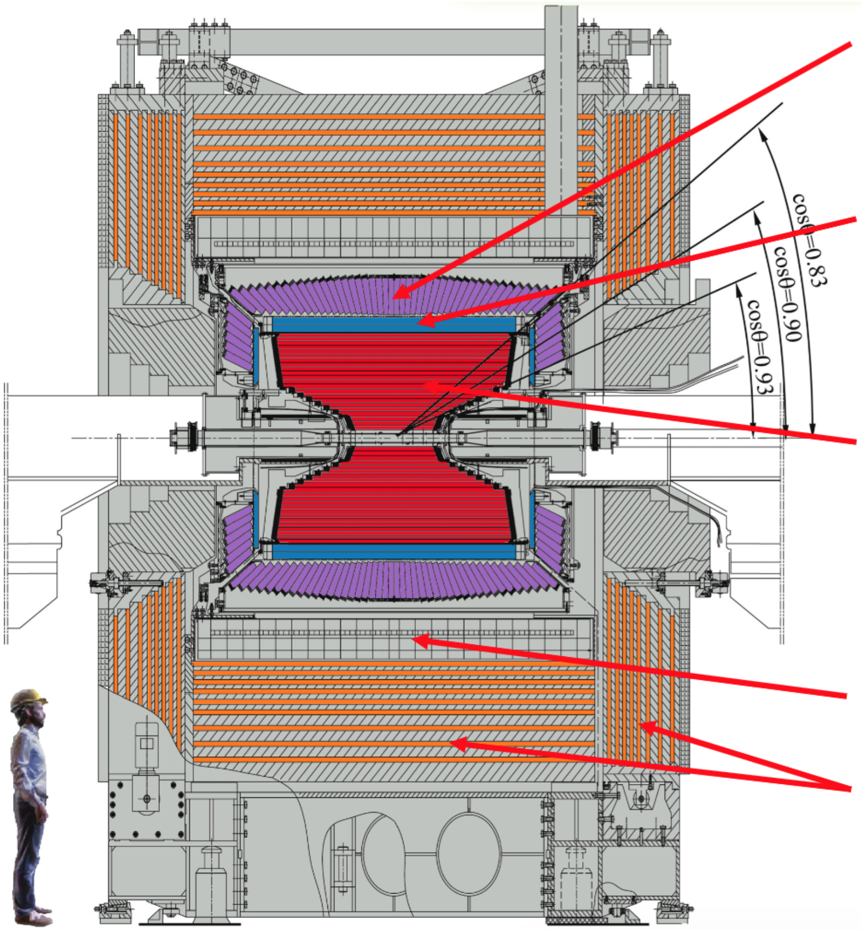
L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

2020: energy upgrade to 2.45 GeV

2025: energy update to 2.8 GeV with 3x lumi. upgrade

The BESIII detector

NIM A614, 345 (2010)



EMC: CsI crystals
$\Delta E/E$ = 2.5% @ 1 GeV - Barrel
$\Delta E/E$ = 5.0% @ 1 GeV - Endcaps

TOF:
σ_T = 80 ps Barrel
σ_T = 110 (60) ps Endcap

MDC: small cell & He gas
σ_{xy}= 130 μm
σ_p/p = 0.5% @1GeV
dE/dx = 6%

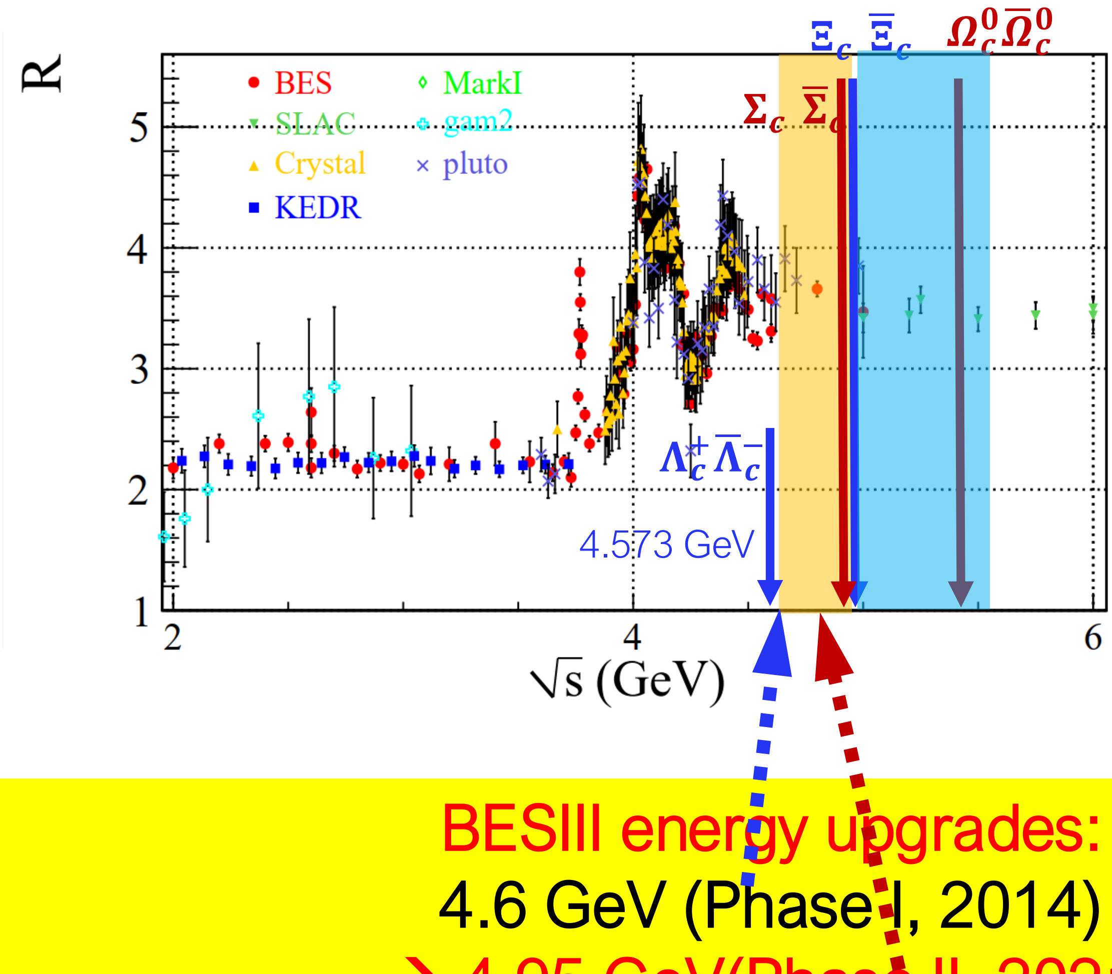
Magnet: 1T Super conducting

Muon ID: 9 layer RPC

Trigger: Tracks & Showers

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

Charmed baryon thresholds



BESIII energy upgrades:

4.6 GeV (Phase I, 2014)

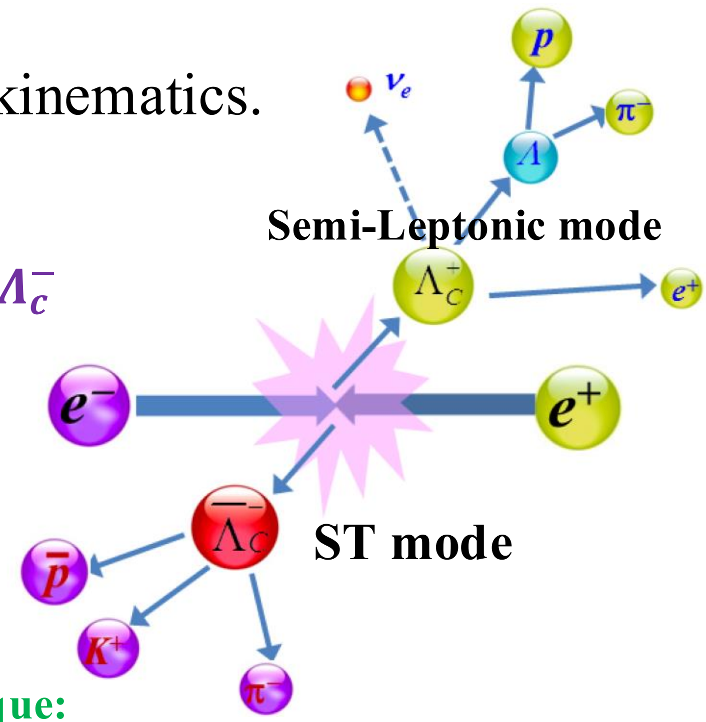
→ 4.95 GeV(Phase II, 2021)

→ 3x lumi. & 5.6 GeV (Phase III, during 2026- 2030)

Production near threshold and tag technique

E_{cms}=4600MeV

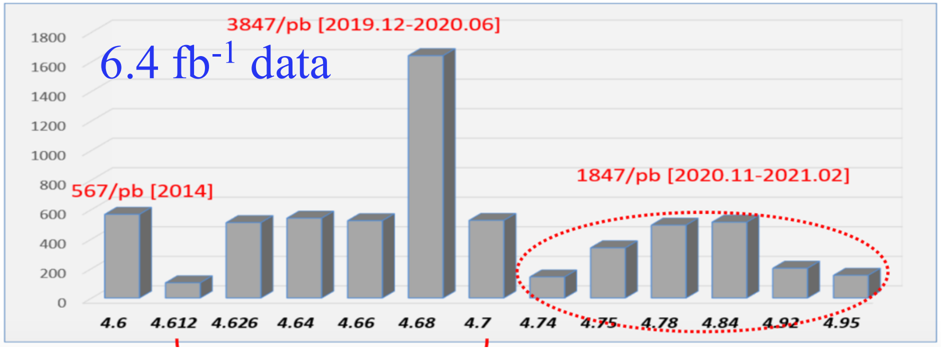
- E_{cms}-$2m_{\Lambda c}$=26 MeV only!
- $\Lambda_c^+\Lambda_c^-$ produced in pairs with no additional accompany hadrons.
  - $e^+e^-\rightarrow\gamma^*\rightarrow\Lambda_c^+\Lambda_c^-$
- Clean backgrounds and well constrained kinematics.
- Typically, two ways to study Λ_c^+ decays:
  - **Single Tag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

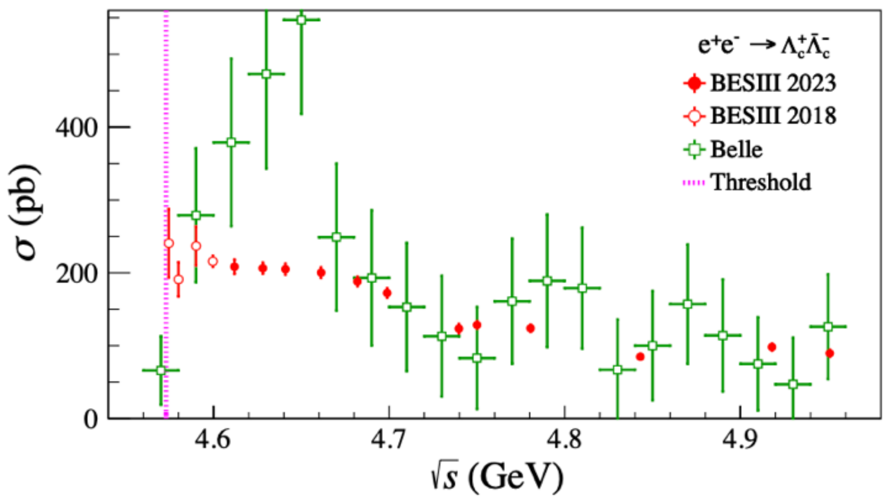


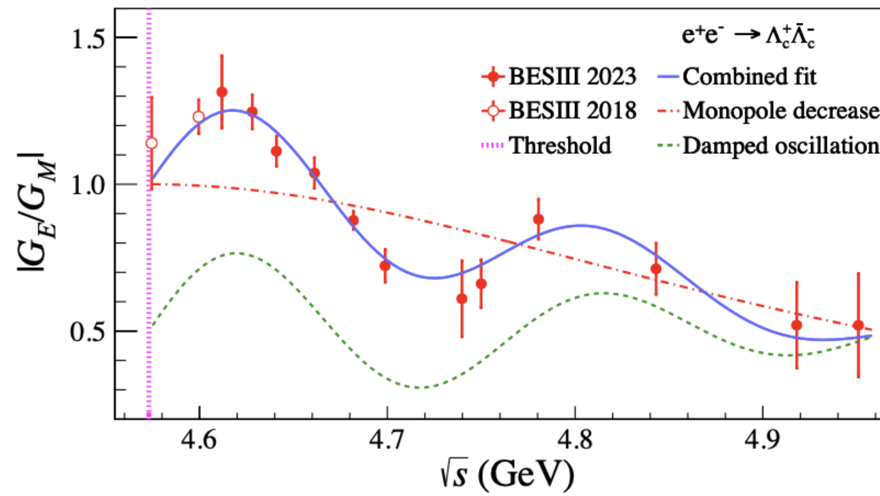
$$\mathcal{B}_i = \frac{N_{ij}^{\mathrm{DT}}}{N_j^{\mathrm{ST}}}\frac{\varepsilon_j}{\varepsilon_{ij}}$$

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

PRL131, 191901 (2023)





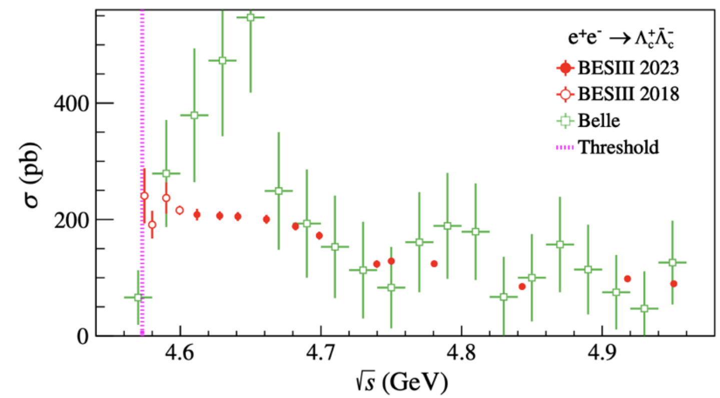


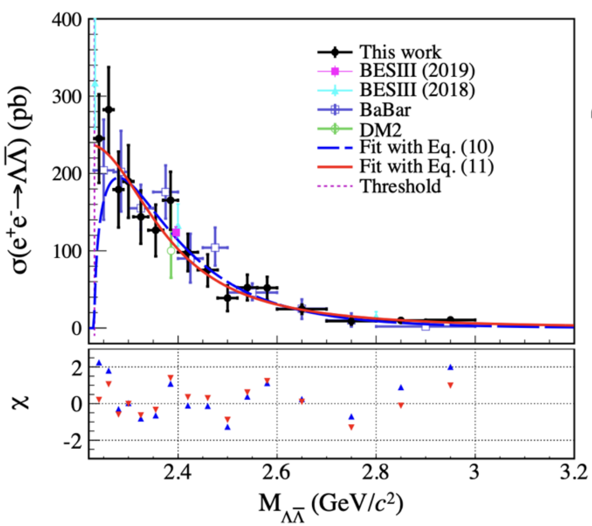
- Negate the $Y(4630)$ in decaying into $\Lambda_c^+\Lambda_c^-$ reported by BELLE
- Energy-dependence of $|G_E/G_M|$ reveals an oscillation feature, which may imply a non-trivial structure of the lightest charmed baryon.

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

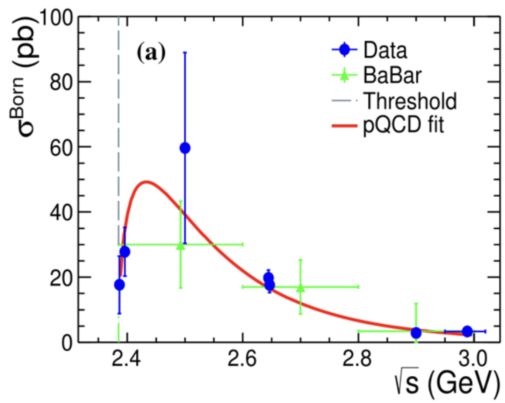
- $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$: an interesting isospin violating process to understand the QCD dynamics at charm sector
  - ✓ $\sigma(\Lambda_c^+\bar{\Sigma}_c^-)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$ v.s. $\sigma(\Lambda\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
    ➔ vaccum pol. to $c\bar{c}$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

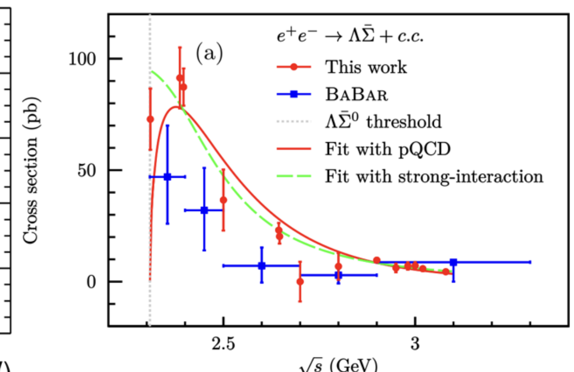




PRD107, 072005 (2023)



PLB 831, 137187 (2022)



PRD 109, 012002 (2024)

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

PRD 112, 092017 (2025)

no significant signals are observed

$\sigma(\Lambda_c^+\bar{\Sigma}_c^-)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$	$\sigma(\Lambda\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
<~1%	**~40%**
$\sigma(\Sigma_c\bar{\Sigma}_c)/\sigma(\Lambda_c^+\bar{\Lambda}_c^-)$	$\sigma(\Sigma\bar{\Sigma})/\sigma(\Lambda\bar{\Lambda})$
<~1%	**~20%**

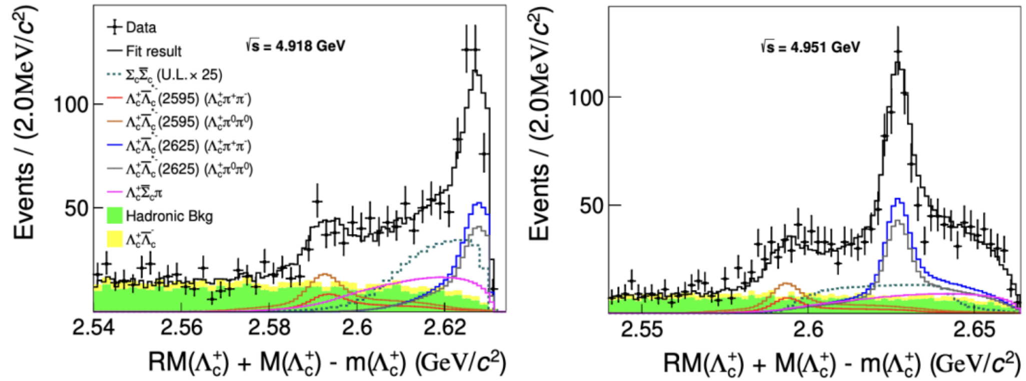


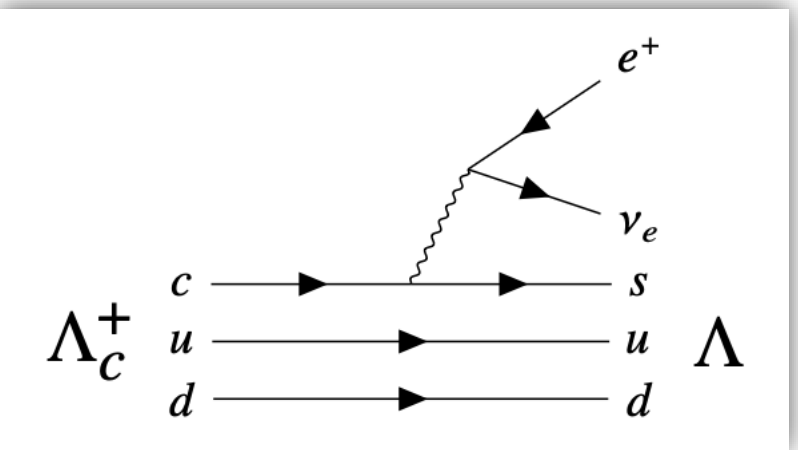
TABLE IV. Summary of the upper limits on Born cross sections of $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ at 90% C.L.. The results of $\sigma_{\rm Born}(e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-)$ are input from Ref. [20], where the first uncertainty represents statistical uncertainty and the second one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

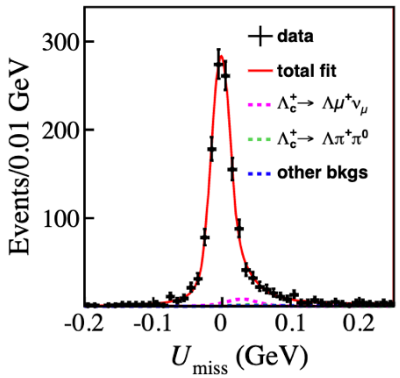
$\sqrt{s}$	f	baseline	Hypothesis 1	Hypothesis 2
4.918 GeV	$f_{\rm VP}$	1.06	1.06	1.06
	$f_{\rm ISR}$	0.96	0.68	0.58
	$\sigma_{\rm Born}$	< 0.55 pb	< 0.61 pb	< 0.83 pb
4.951 GeV	$f_{\rm VP}$	1.06	1.06	1.06
	$f_{\rm ISR}$	0.96	0.81	0.79
	$\sigma_{\rm Born}$	< 0.34 pb	< 0.39 pb	< 0.49 pb

Semi-Leptonic decays

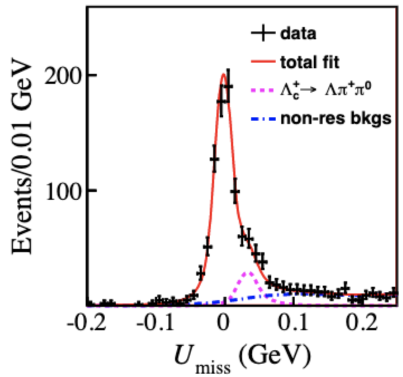


Decays of $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$ and $\Lambda e^+\nu_e$

PRL129, 231803 (2022)
PRD 108, L031105 (2023)

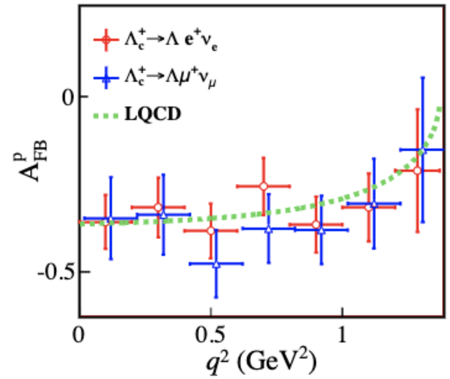


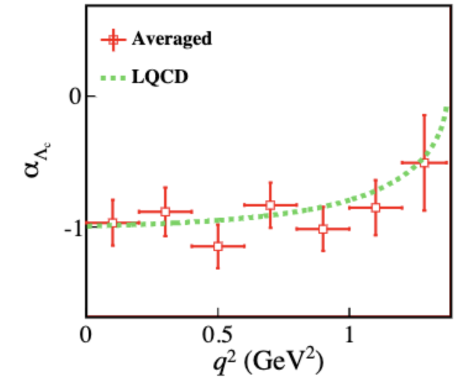
$\Lambda_c^+ \to \Lambda e^+\nu_e$

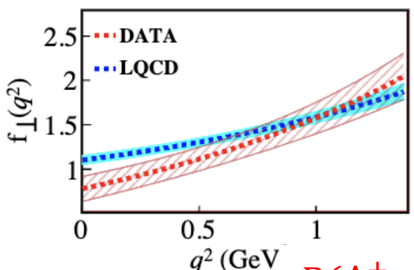


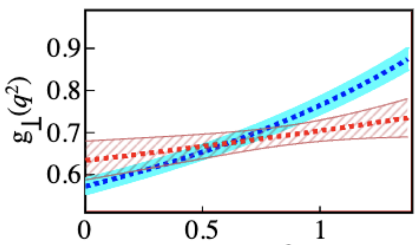
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$

$\langle\alpha_{\Lambda_c}\rangle = -0.94 \pm 0.07 \pm 0.03$

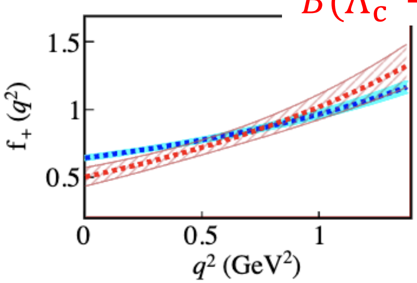


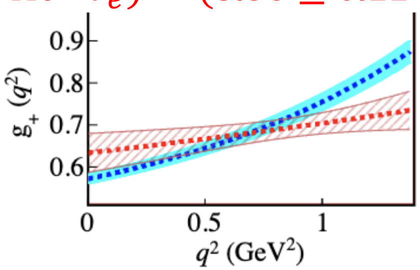


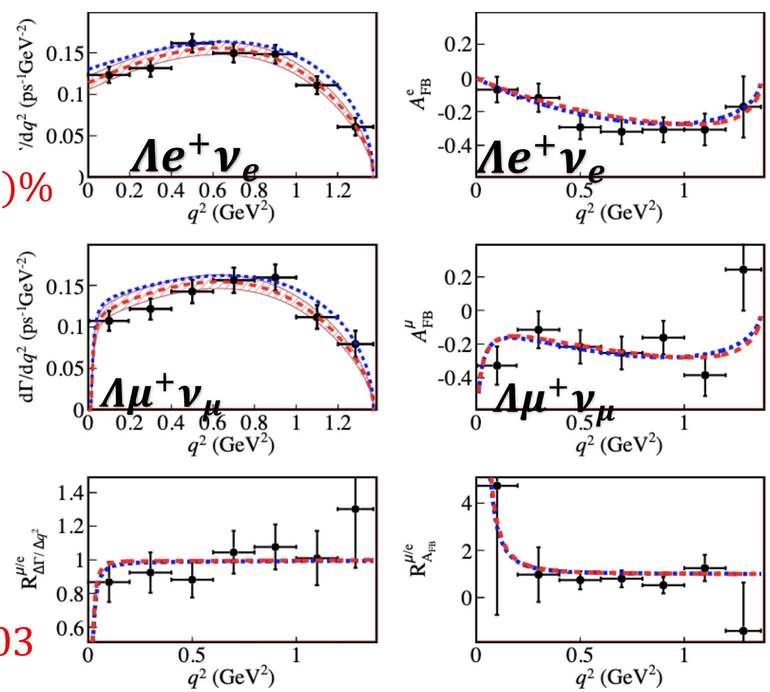




$B(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$







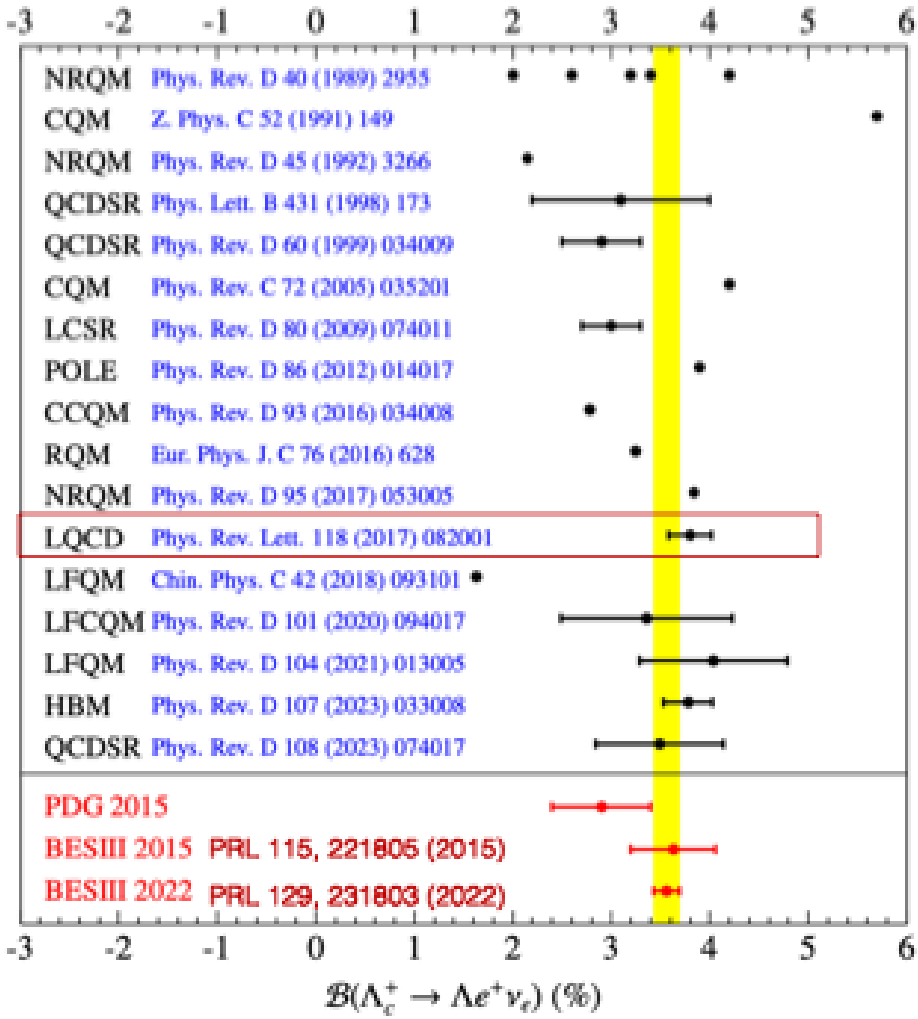
$B(\Lambda_c^+ \to \Lambda e^+\nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$

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

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

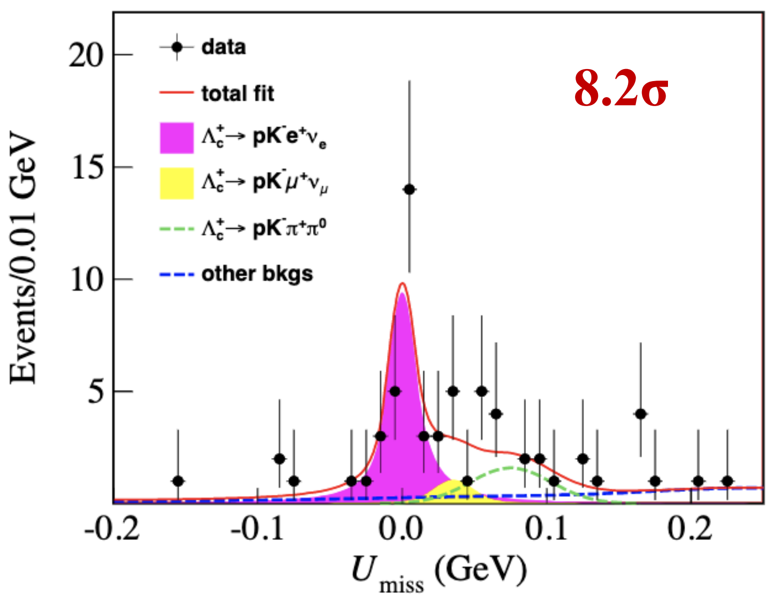
Branching fractions of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

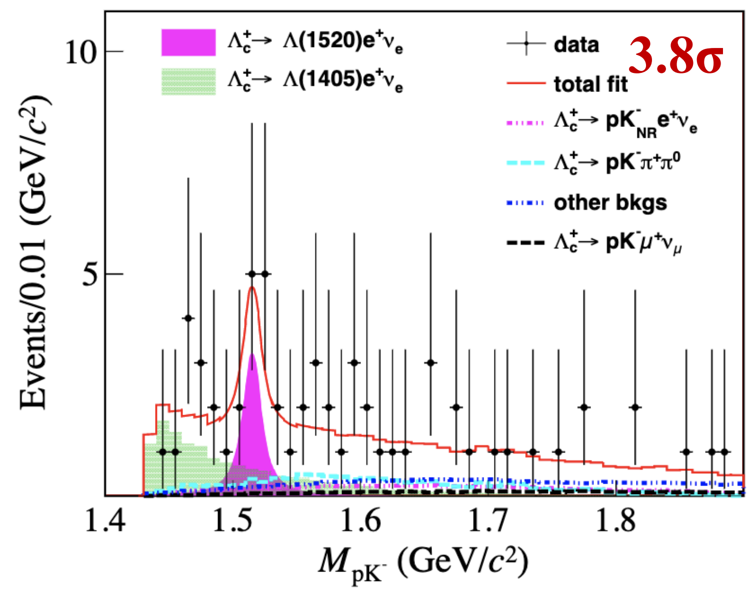
PRL129, 231803 (2022)



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

PRD106, 112010 (2022)

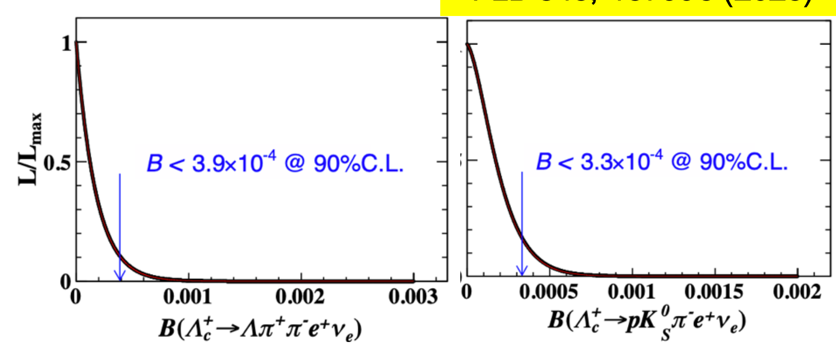




$B(\Lambda_c^+ \to pK^-e^+\nu_e) = (8.8 \pm 1.1 \pm 0.7) \times 10^{-4}$
$B(\Lambda_c^+ \to \Lambda(1520)e^+\nu_e) = (10.2 \pm 5.2 \pm 1.1) \times 10^{-4}$

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

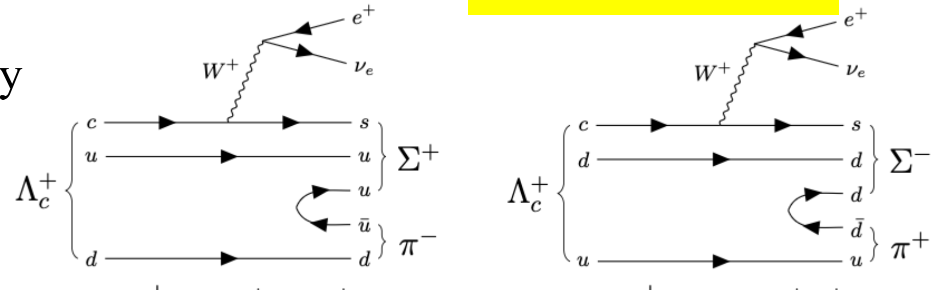
PLB 843, 137993 (2023)



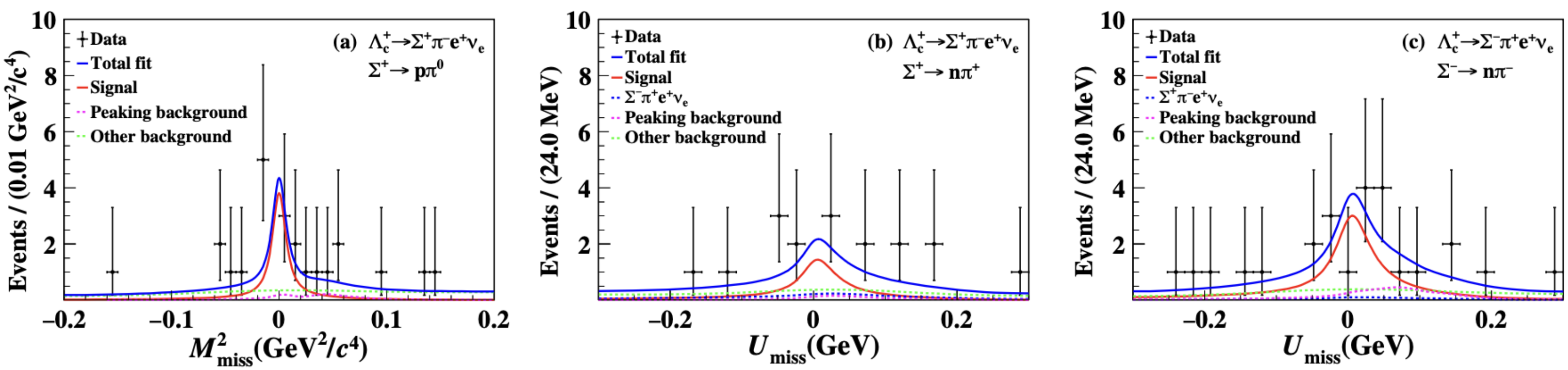
Evidence of $\Lambda_c^+ \to \Sigma^\pm \pi^\mp e^+ \nu$

arXiv:2512.05178

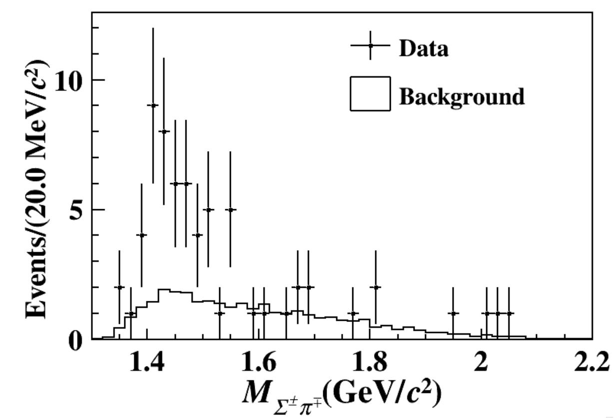
- $\Lambda_c^+ \to \Lambda^* e^+ \nu_e$ should have large decay rates into $\Lambda_c^+ \to \Sigma\pi e^+ \nu_e$
- Good way to study the state of $\Lambda(1405)$ via the SL decay



(a) $\Lambda_c^+ \to \Sigma^+\pi^- e^+\nu_e$ (b) $\Lambda_c^+ \to \Sigma^-\pi^+ e^+\nu_e$

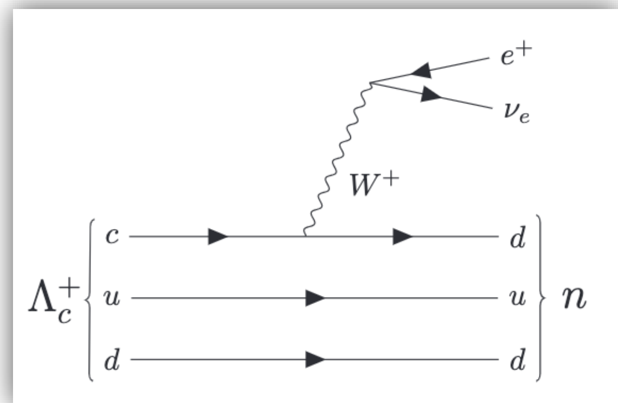


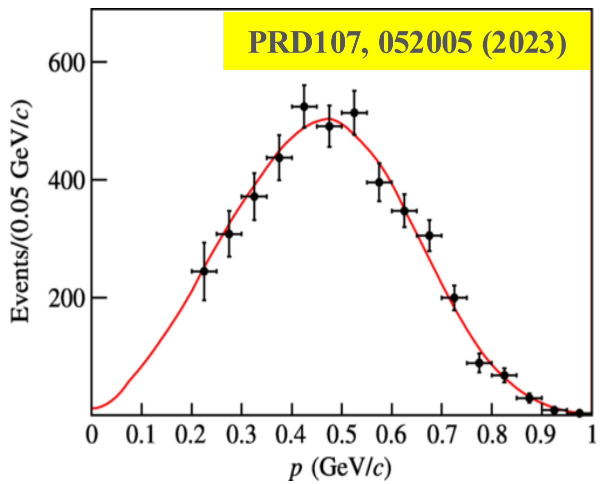
- Simultaneous fit to the three distributions assuming $B(\Lambda_c^+ \to \Sigma^+\pi^- e^+\nu) = B(\Lambda_c^+ \to \Sigma^-\pi^+ e^+\nu)$.
- BF is calculated to be $\left(7.7^{+2.5}_{-2.3} \pm 1.3\right) \times 10^{-4}$,with statistical significance is estimated to be 3.9 σ. This is consistent with the separate fit.
- Dominant contributions from the $\Lambda(1405)$ and $\Lambda(1520)$



Cabibbo-suppressed SL decays

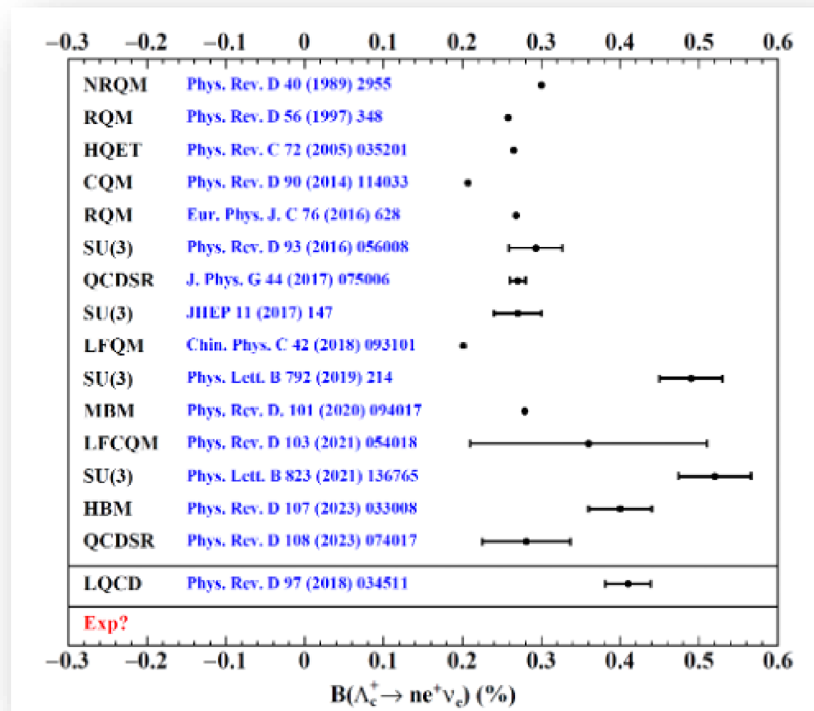
- There is still room of 0.5% for un-seen SL decay of the Λ_c^+
- The Cabibbo-Suppressed SL decays have not been studied in experiment
- $\Lambda_c^+ \to n e^+ \nu_e$ is the most promising channel for the experimental observation





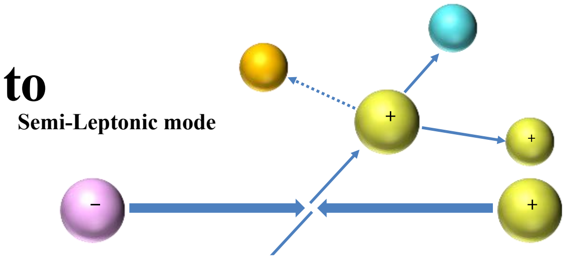
$\mathscr{B}(\Lambda_c^+ \to X e^+ \nu_e) = (4.06 \pm 0.10_{\rm stat} \pm 0.09_{\rm syst})\%.$

$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.56 \pm 0.11 \pm 0.07)\%$
$B(\Lambda_c^+ \to p K^- e^+ \nu_e) = (8.8 \pm 1.1 \pm 0.7) \times 10^{-4}$
$B(\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e) = (10.2 \pm 5.2 \pm 1.1) \times 10^{-4}$
$B(\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e) \sim 3 \times 10^{-3}$

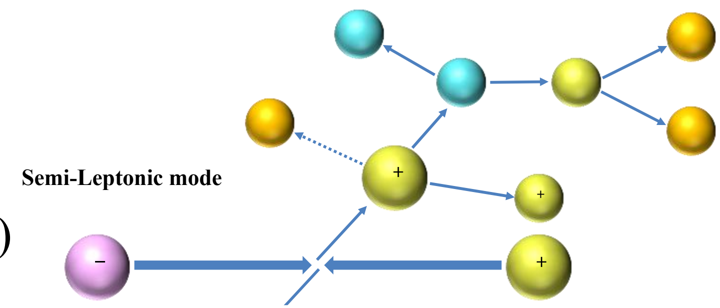


Hunting for $\Lambda_c^+ \to n e^+ \nu$

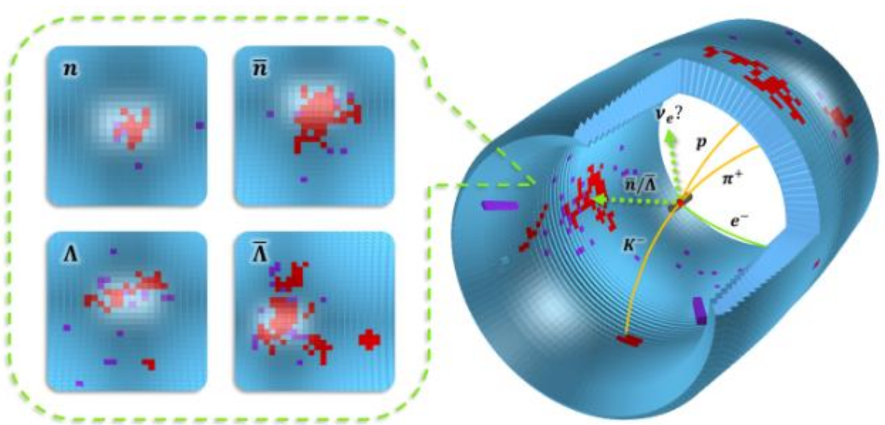
- **Important process of semi-leptonic Λ_c^+ decay to probe strong dynamics in charmed baryon**

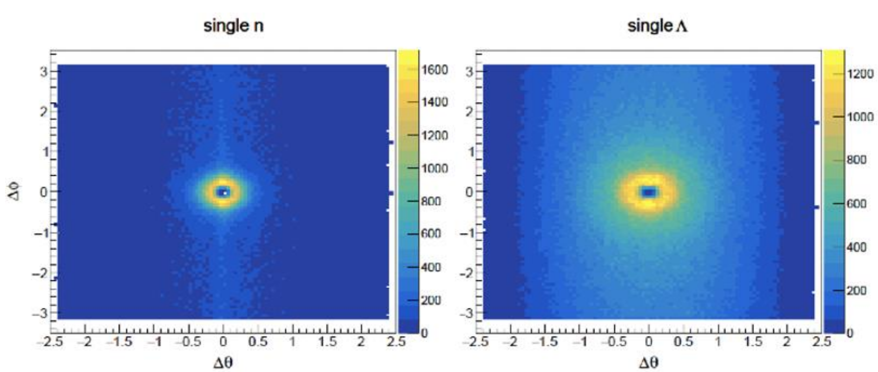


- **Challenges:**
  - ✓ neutrino is missing in detection
  - ✓ dominant backgrounds from $\Lambda_c^+ \to \Lambda(\to n\pi^0)e^+\nu$, with ~10x yields than that of the pursuing signals
  - ✓ elusive neutron detection due to neutral charge and contaminations from the photon showers (& noises) in electro-magnetic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



Need advanced Machine Learning tool to identify neutron showers in EMC

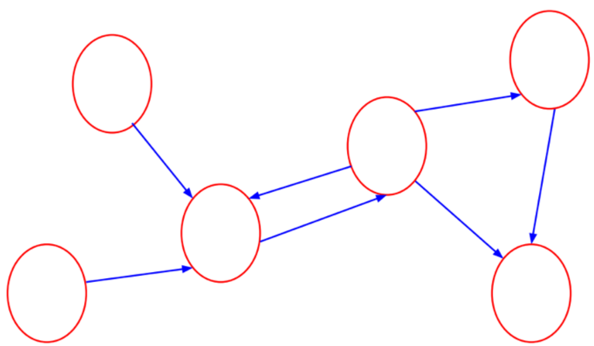


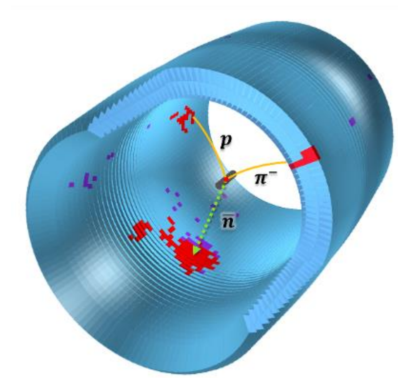


Why Graph Neural Networks (GNN)

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

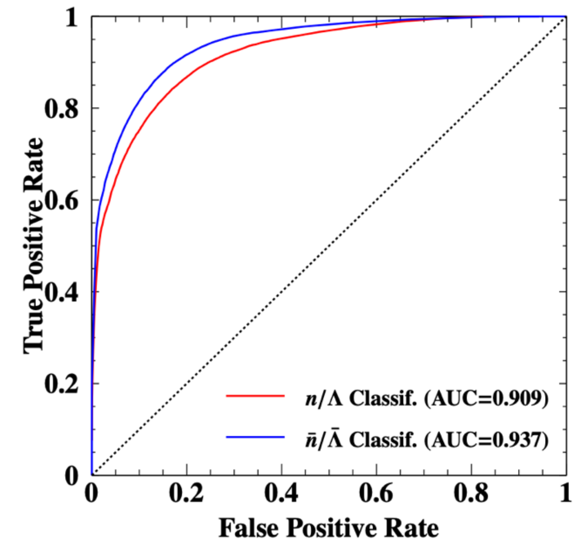
- Nearly unlimited labeled samples
- Structured data
- Clear training objectives

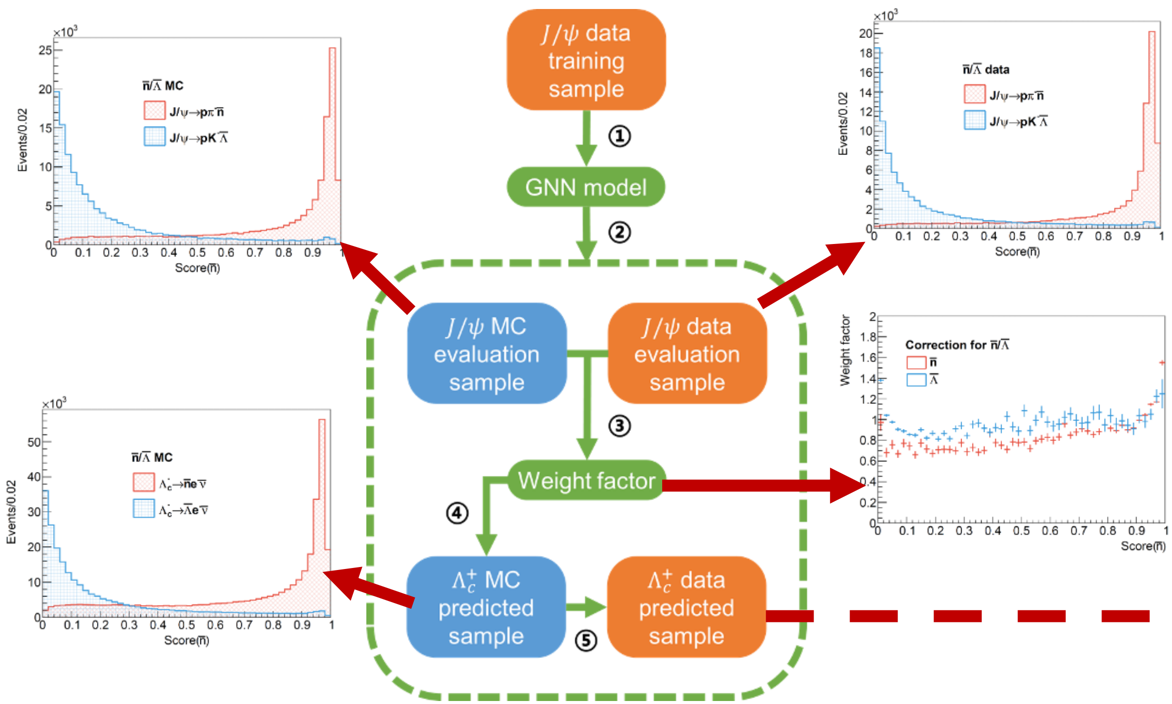
This fits well to the final state particles in physics collisions, where we deal with various objects like tracks/showers and their kinematic relations.

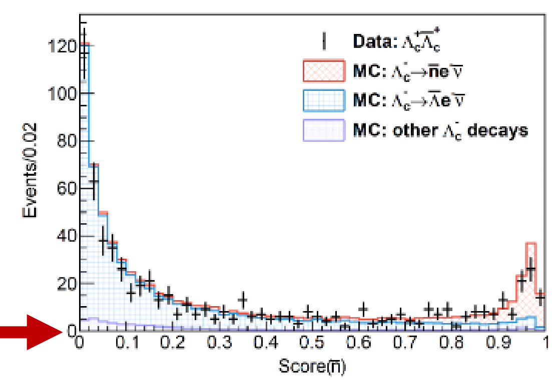
Analysis strategy

Nature Comm. 16, 681 (2025)

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



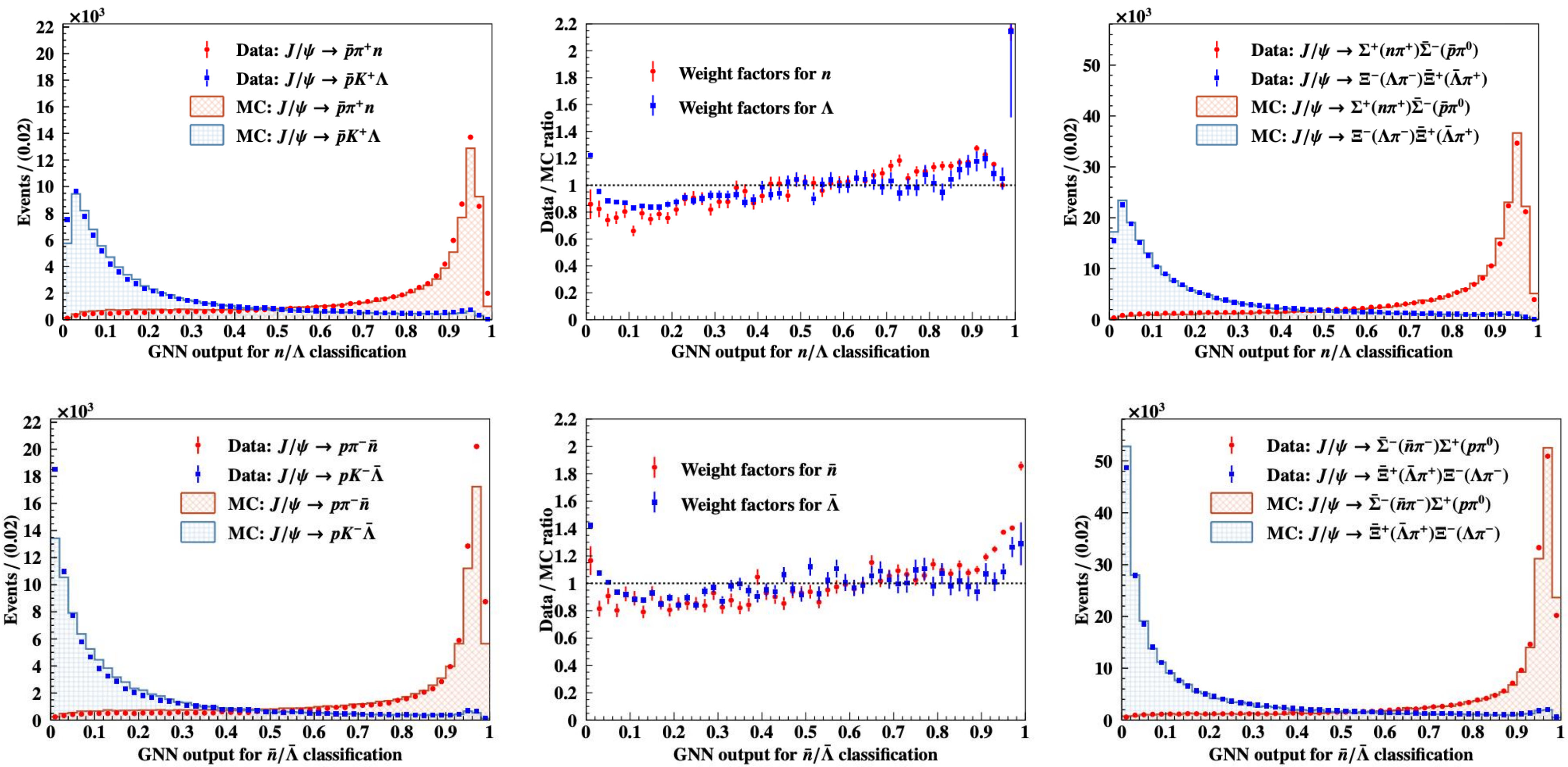




Method validation

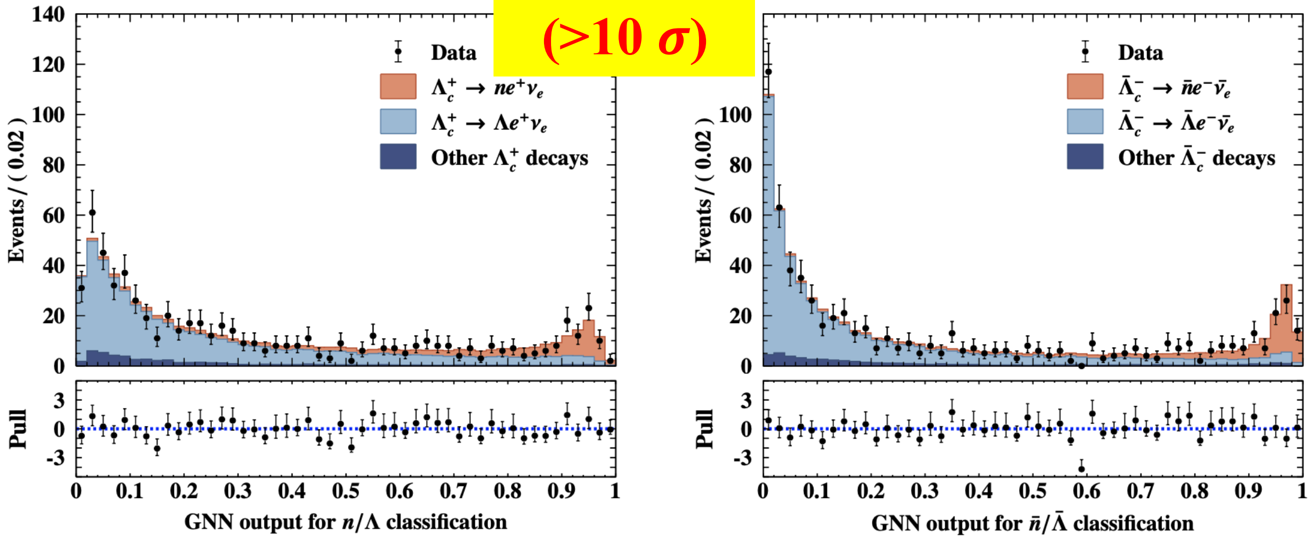
- Control channels of $J/\psi \to \Sigma^+(n\pi^+)\bar{\Sigma}^-(\bar{p}\pi^0)$ and $J/\psi \to \Xi^+(\Lambda\pi^+)\bar{\Xi}^-(\bar{\Lambda}\pi^-)$ based on 10B J/ψ decays

Nature Comm. 16, 681 (2025)



Observation of $\Lambda_c^+ \to ne^+\nu$

Nature Comm. 16, 681 (2025)



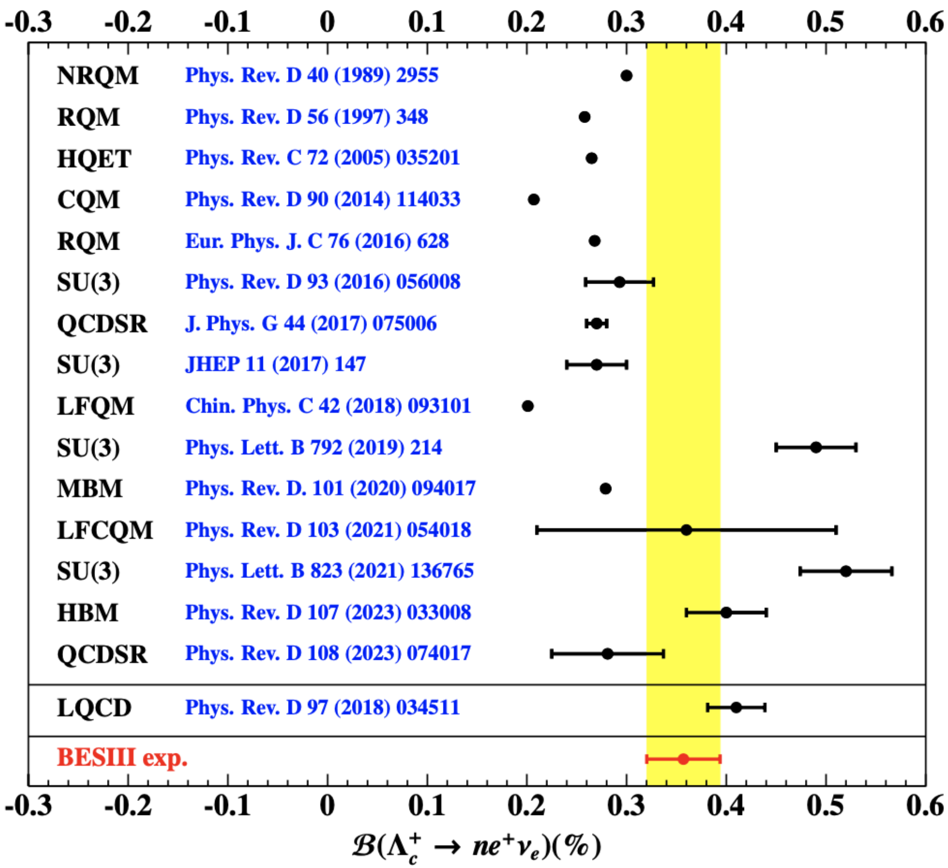
good control of systematics on GNN training

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

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

Results of BF for $\Lambda_c^+ \to ne^+\nu$

Nature Comm. 16, 681 (2025)



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

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

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

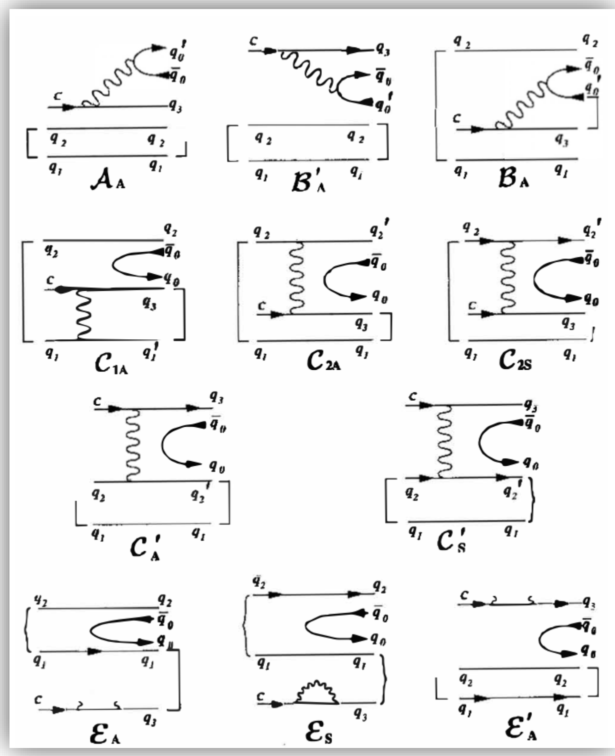
Current status of the SL decays

Chin. Phys. C 50, 022002 (2026)

Λ_c^+ Mode	BF($\times10^{-3}$)	Experiment
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	$23.7\pm5.1(37\%)^\dagger$	ARGUS(1991)[32]
	$26.8\pm5.1(19\%)^\dagger$	CLEO(1994)[33]
	$36.3\pm4.3(12\%)$	BESIII(2015)[38]
	$35.6\pm1.3(3.6\%)$	BESIII(2022)[39]
$\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$	$34.9\pm5.3(15\%)$	BESIII(2017)[40]
	$34.8\pm1.7(4.9\%)$	BESIII(2023)[42]
$\Lambda_c^+ \to e^+ X$	$39.5\pm3.5(8.9\%)$	BESIII(2018)[43]
	$40.6\pm1.3(3.2\%)$	BESIII(2023)[45]
$\Lambda_c^+ \to pK^- e^+ \nu_e$	$0.88\pm0.18(20\%)$	BESIII(2022)[37]
$\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e$, $\Lambda(1405) \to pK^-$	$0.42\pm0.19(45\%)$	BESIII(2022)[37]
$\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e$	$1.0\pm0.5(50\%)$	BESIII(2022)[37]
$\Lambda_c^+ \to pK_S^0 \pi^- e^+ \nu_e$	<0.33	BESIII(2023)[41]
$\Lambda_c^+ \to \Lambda \pi^+ \pi^- e^+ \nu_e$	<0.39	BESIII(2023)[41]
$\Lambda_c^+ \to n e^+ \nu_e$	$3.57\pm0.37\ (10\%)$	BESIII(2025)[44]

Ξ_c Mode	BF($\times10^{-3}$)	Experiment
$\Xi_c^0 \to \Xi^- e^+ \nu_e$	$13.7\pm7.7(56\%)^\dagger$	ARGUS(1993)[34]
	$44.3^{+16.6}_{-17.8}(40\%)^\dagger$	CLEO(1995)[35]
	$19.7\pm5.3(27\%)^\dagger$	ALICE(2021)[47]
	$10.4\pm2.1(20\%)^\dagger$	Belle(2021)[46]
$\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu$	$10.1\pm2.1(21\%)^\dagger$	Belle(2021)[46]
$\Xi_c^+ \to \Xi^0 e^+ \nu_e$	$67\pm39(58\%)^\dagger$	CLEO(1995)[35]
Ω_c^0 Mode	**Ratio**	**Experiment**
$\Omega_c^0 \to \Omega^- e^+ \nu_e$	$2.4\pm1.1(47\%)$	CLEO(2002)[36]
	$1.98\pm0.15(7.7\%)$	Belle(2022)[48]
$\Omega_c^0 \to \Omega^- \mu^+ \nu_\mu$	$1.94\pm0.21(11\%)$	Belle(2022)[48]

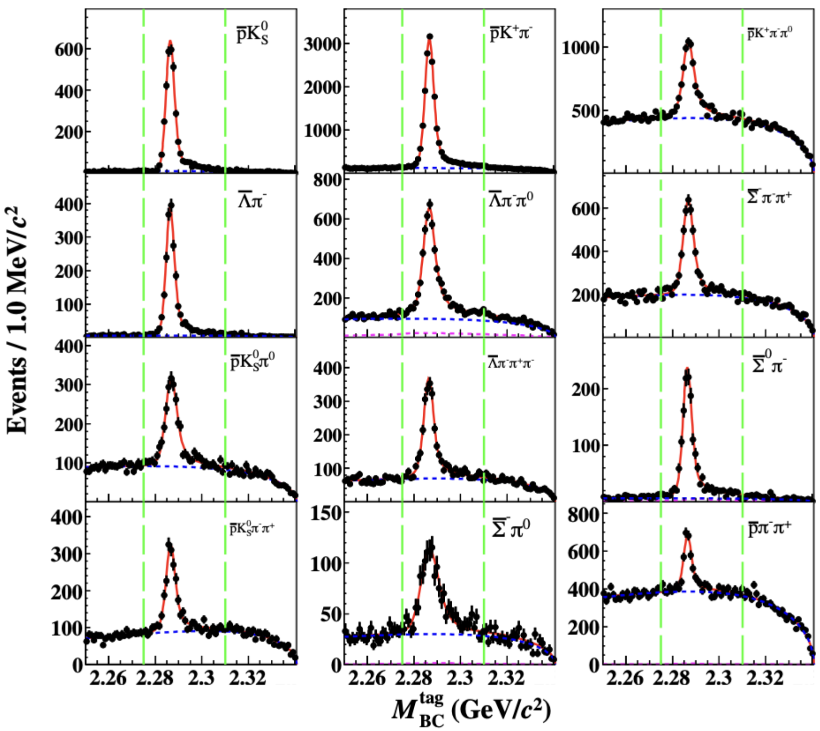
Hadronic decays

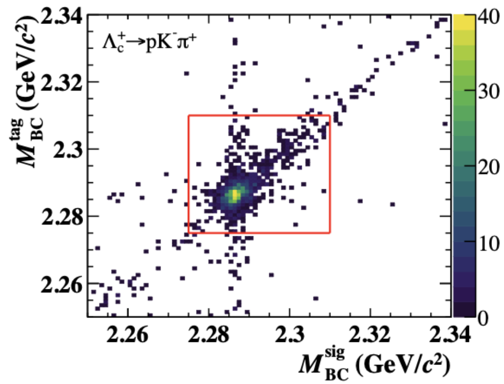


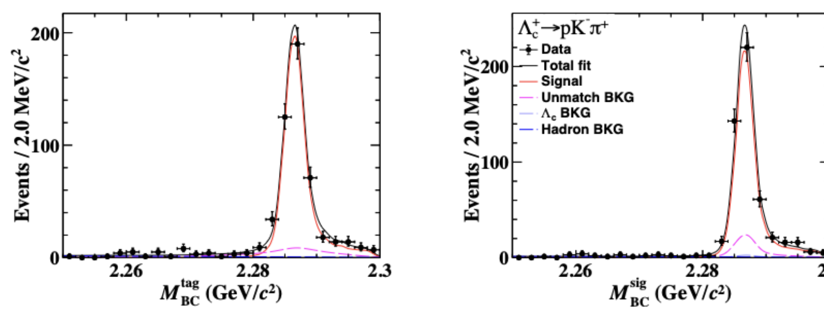
Absolute BFs of Λ_c^+ hadronic decays

arXiv:2601.01503

- Absolute BF of Λ_c^+ decays are important to validate QCD-derived models
- The precisions of the BF for the reference channel of $\Lambda_c^+ \to pK^-\pi^+$:
  PDG2014: δB/B~26%; BELLE2014: δB/B~5.3%; BESIII2015: δB/B~6.0%;
- Double tag technique is applied to control systematics







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

Absolute BFs of Λ_c^+ hadronic decays

unit: %

2024

arXiv:2601.01503

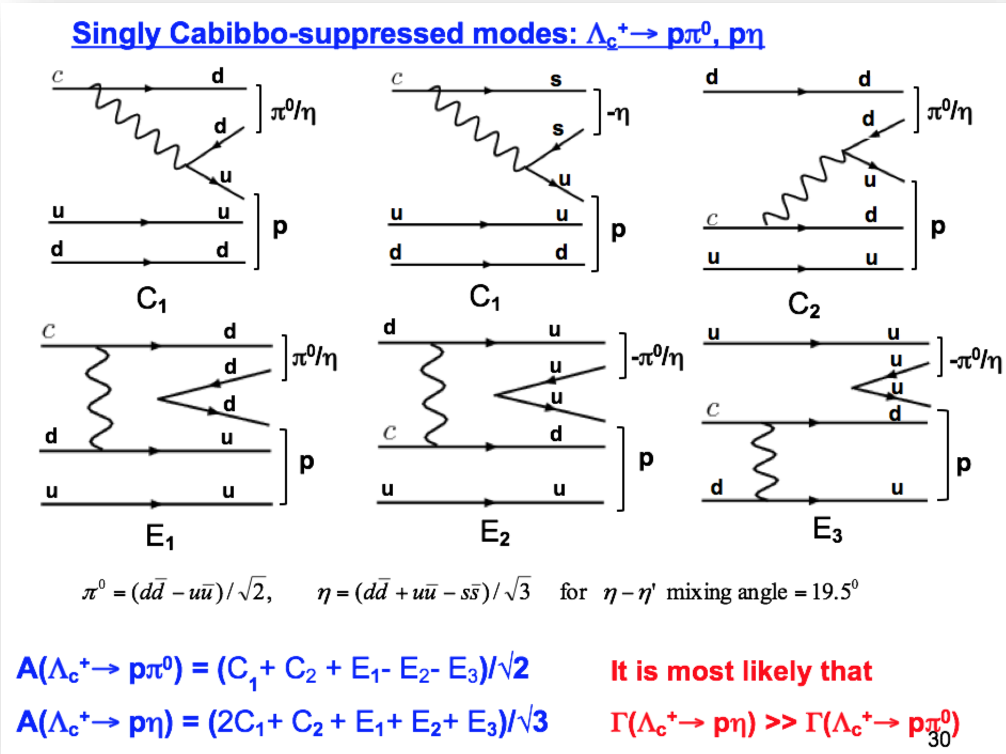
Signal mode	Global fit	PDG
pK_S^0	$1.70 \pm 0.03 \pm 0.05$	1.59 ± 0.07
$pK^-\pi^+$	$6.61 \pm 0.11 \pm 0.12$	6.24 ± 0.28
$pK_S^0\pi^0$	$2.19 \pm 0.06 \pm 0.05$	1.96 ± 0.12
$pK_S^0\pi^+\pi^-$	$1.88 \pm 0.04 \pm 0.07$	1.59 ± 0.11
$pK^-\pi^+\pi^0$	$4.89 \pm 0.10 \pm 0.11$	4.43 ± 0.28
$\Lambda\pi^+$	$1.32 \pm 0.03 \pm 0.03$	1.29 ± 0.05
$\Lambda\pi^+\pi^0$	$6.67 \pm 0.13 \pm 0.10$	7.02 ± 0.35
$\Lambda\pi^+\pi^-\pi^+$	$4.09 \pm 0.09 \pm 0.10$	3.61 ± 0.26
$\Sigma^0\pi^+$	$1.45 \pm 0.03 \pm 0.03$	1.27 ± 0.06
$\Sigma^+\pi^0$	$1.37 \pm 0.04 \pm 0.03$	1.24 ± 0.09
$\Sigma^+\pi^+\pi^-$	$4.58 \pm 0.10 \pm 0.10$	4.47 ± 0.22
$p\pi^+\pi^-$	$0.50 \pm 0.02 \pm 0.01$	0.46 ± 0.03

$\sqrt{s}$(MeV)	σ(pb)	$\lvert G_{\rm eff}\rvert(\times 10^{-2})$
4599.53	$213.1 \pm 3.9 \pm 1.9$	$53.8 \pm 0.5 \pm 0.2$
4611.86	$211.5 \pm 6.0 \pm 2.0$	$49.5 \pm 0.7 \pm 0.2$
4628.00	$207.6 \pm 3.7 \pm 1.8$	$45.6 \pm 0.4 \pm 0.2$
4640.91	$206.5 \pm 4.1 \pm 1.9$	$43.5 \pm 0.4 \pm 0.2$
4661.24	$206.2 \pm 3.9 \pm 2.0$	$41.2 \pm 0.4 \pm 0.2$
4681.92	$192.0 \pm 3.3 \pm 1.8$	$38.1 \pm 0.4 \pm 0.2$
4698.82	$172.0 \pm 3.5 \pm 2.2$	$35.0 \pm 0.4 \pm 0.2$

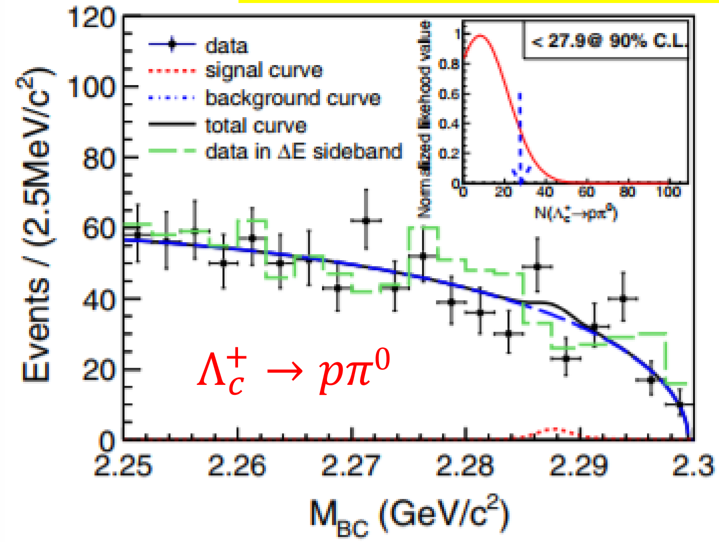
- ✓ $B(pK^-\pi^+)$: best precision and compatible with Belle's result $(6.84 \pm 0.24^{+0.21}_{-0.27})$%; Average value becomes (6.65 ± 0.15)%.
- ✓ Improved precisions of all the modes significantly
- ✓ Improved precisions on the cross sections and the effective form factors

Λ_c^+ two-body hadronic decay

from HY Cheng



PRD95, 111102(R) (2017)



BESIII: BF<2.7×10^-4

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

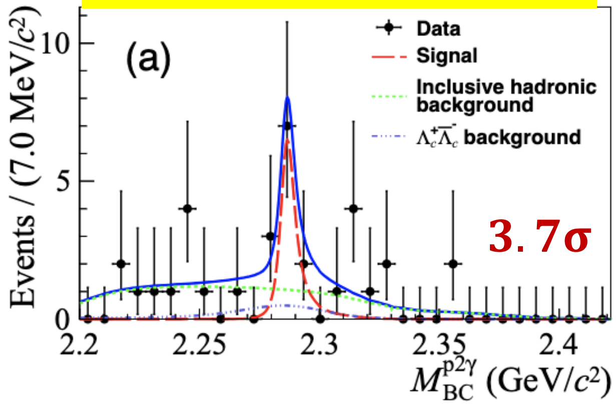
More precise comparison of the two BFs are desired to explore the interference of different non-factorizable diagrams and BESIII result support the theoretic prediction. It is predicted that

$B(\Lambda_c^+ \to n\pi^+) \sim 3.5 \times B(\Lambda_c^+ \to p\pi^0)$ [PRD 97, 074028 (2018)]

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

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

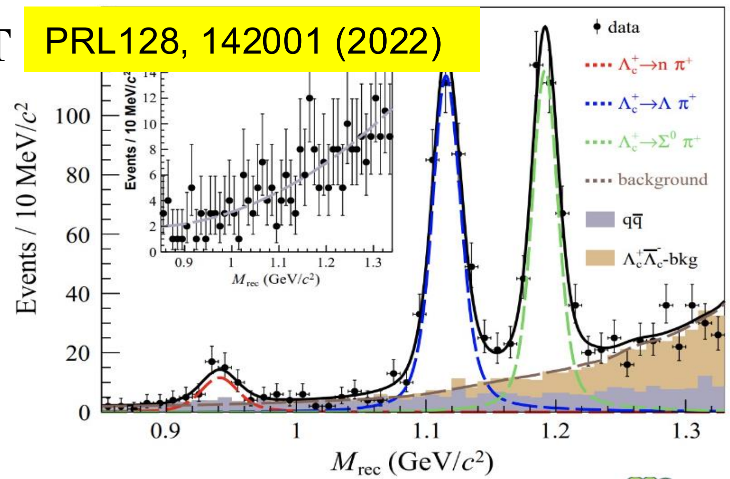
DT PRD109, L091101 (2024)



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

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

DT PRL128, 142001 (2022)



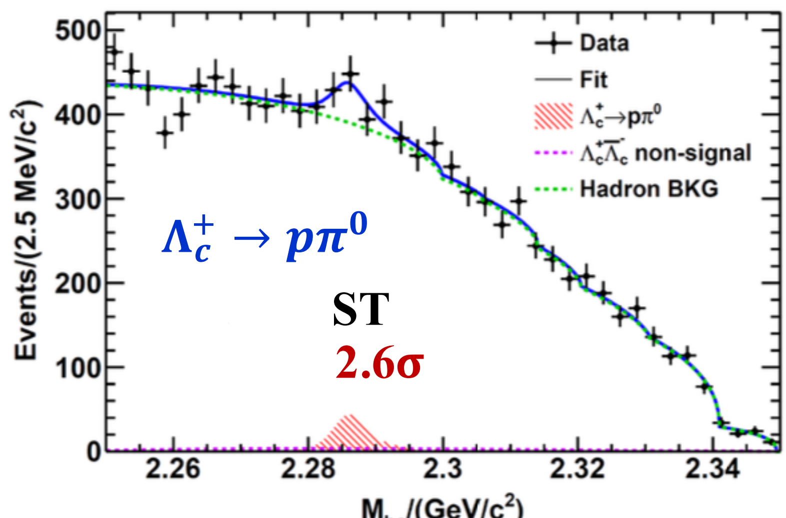
$\mathrm{BF} = (6.6 \pm 1.2 \pm 0.4) \times 10^{-4}$

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

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

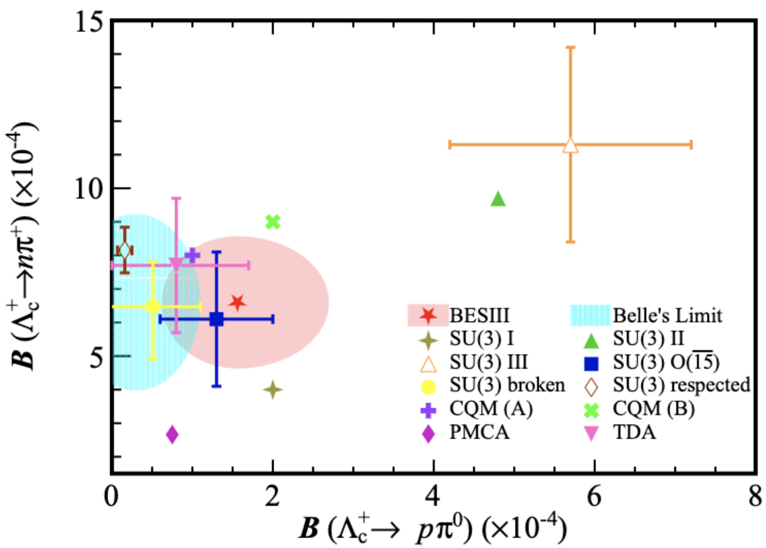
Experimental challenge

- 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)

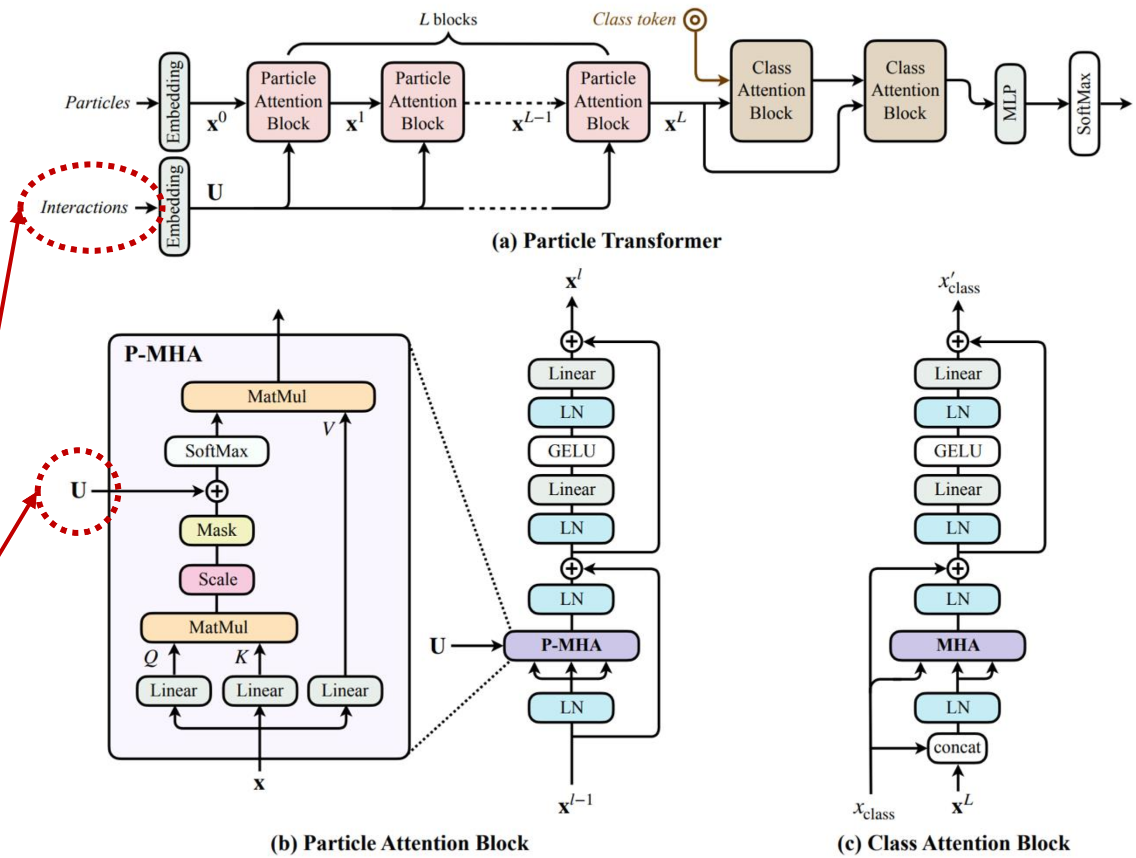
Model architecture – Transformer

- 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

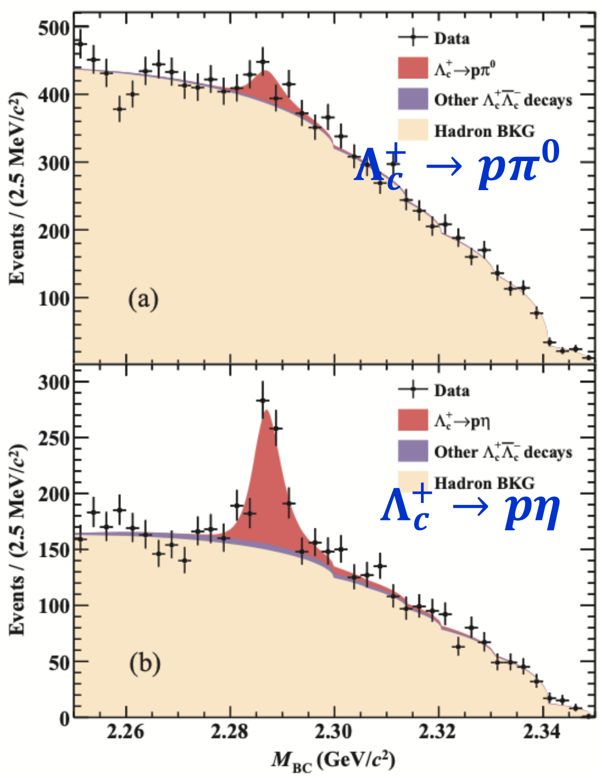
$$\Delta = \sqrt{(y_a - y_b)^2 + (\phi_a - \phi_b)^2},$$
$$k_T = \min(p_{T,a}, p_{T,b})\Delta,$$
$$z = \min(p_{T,a}, p_{T,b})/(p_{T,a} + p_{T,b}),$$
$$m^2 = (E_a + E_b)^2 - \|\mathbf{p}_a + \mathbf{p}_b\|^2.$$



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

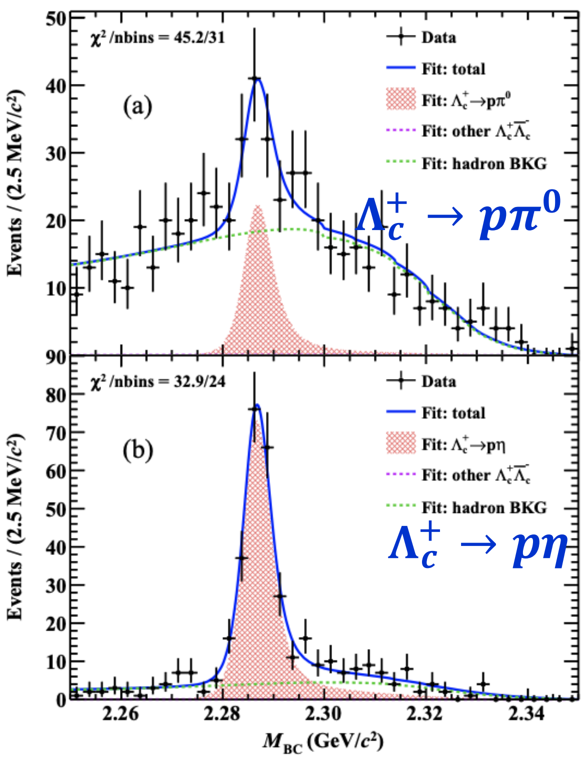
PRD111, L051101 (2025)

2.6σ



DNN training

5.4σ

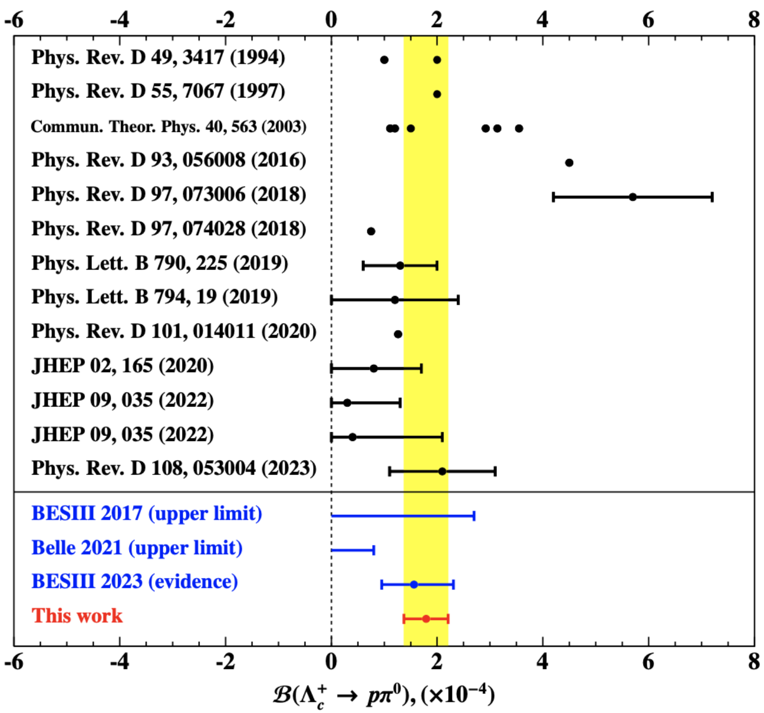


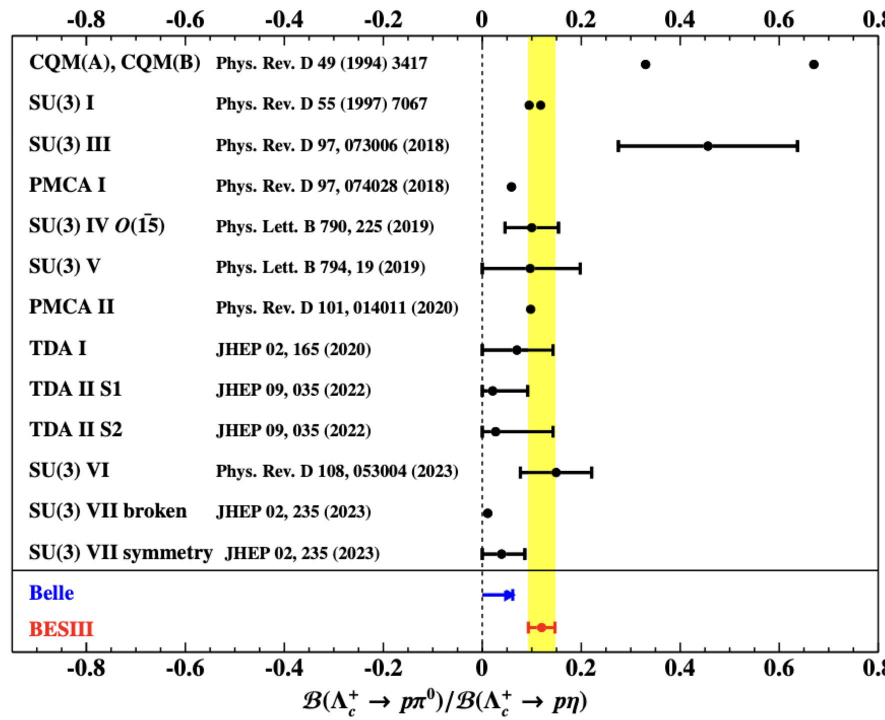
- 20 times of background suppression with 50% of signal efficiency
- validation samples of $\Lambda_c^+ \to pK_S\pi^0$ and $pK_S\eta$

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

PRD111, L051101 (2025)

- The ratio is directly measured to be $\frac{B(\Lambda_c^+ \to p\pi^0)}{B(\Lambda_c^+ \to p\eta)} = 0.120 \pm 0.026 \pm 0.007$
- We have $B(\Lambda_c^+ \to p\pi^0) = (1.79 \pm 0.39 \pm 0.11 \pm 0.08) \times 10^{-4}$ 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

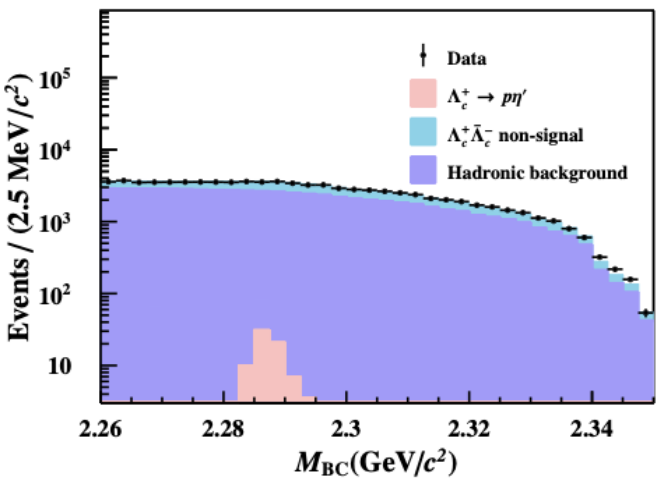




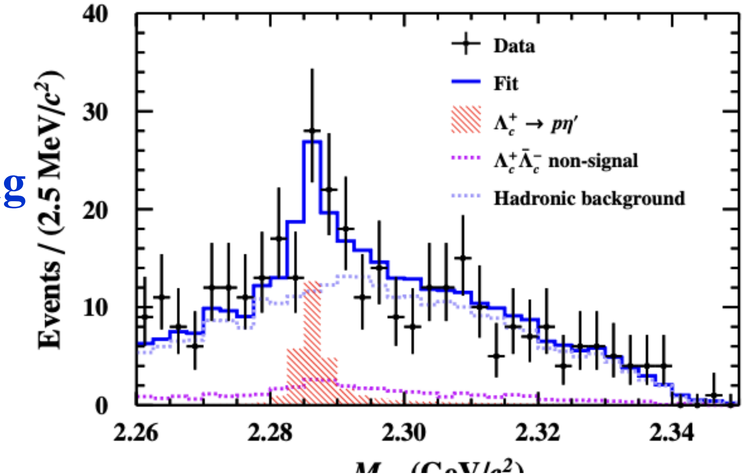
ML-boosted study of $\Lambda_c^+ \to p\eta'$

arXiv:2602.11974

- Single tag of $\Lambda_c^+ \to p\eta'$ via $\eta' \to \gamma\pi^+\pi^-$
- Expect more huge background ➔ DNN model based on Transformer

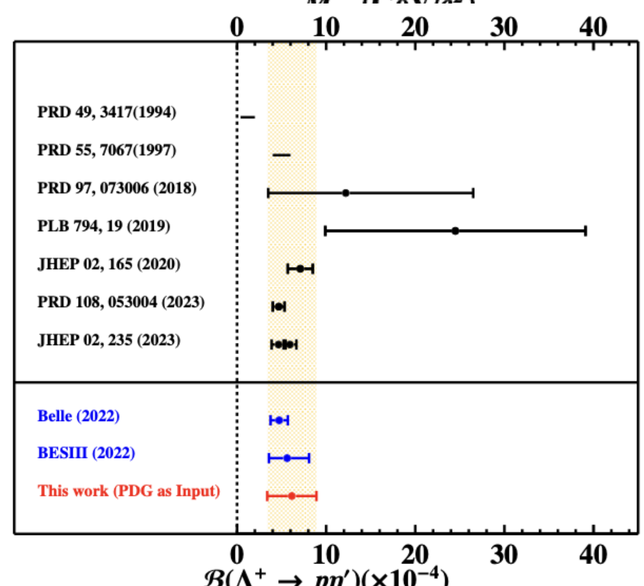


DNN training



Take $\Lambda_c^+ \to p\omega, \omega \to 3\pi$ as reference channel to control DNN systematics

$$\frac{B(\Lambda_c^+ \to p\eta')}{B(\Lambda_c^+ \to p\omega)} = 0.55 \pm 0.22 \pm 0.05$$



Compilation of Λ_c^+ hadronic decays

Chin. Phys. C 50, 022002 (2026)

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]			

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]

Status of Ξ_c and Ω_c hadronic decays

Chin. Phys. C 50, 022002 (2026)

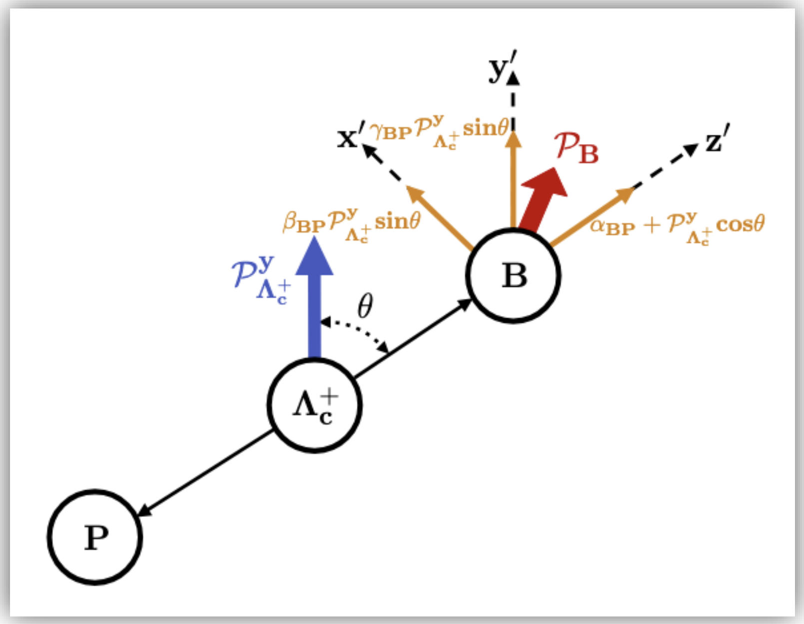
Ξ_c^0 mode	BF	Experiment	Ξ_c^+ mode	BF	Experiment
ΛK_S^0	0.33 ± 0.08	Belle(2022)[181]	$\Xi^-\pi^+\pi^+$	2.86 ± 1.27	Belle(2019)[179]
$\Lambda\bar{K}^{*0}$	0.33 ± 0.11	Belle(2021)[182]	$\Sigma^+K_S^0$	0.19 ± 0.09	Belle(II)(2025)[183]
Σ^+K^-	0.18 ± 0.04	Belle(2022)[181]	$\Xi^0\pi^+$	0.72 ± 0.32	Belle(II)(2025)[183]
Σ^+K^{*-}	0.61 ± 0.21	Belle(2021)[182]	pK_S^0	0.07 ± 0.03	Belle(II)(2025)[184]
$\Sigma^0\bar{K}^{*0}$	1.24 ± 0.37	Belle(2021)[182]	$\Lambda\pi^+$	0.05 ± 0.02	Belle(II)(2025)[184]
$\Sigma^0K_S^0$	0.05 ± 0.02	Belle(2022)[181]	$\Sigma^0\pi^+$	0.12 ± 0.06	Belle(II)(2025)[184]
$\Xi^0\pi^0$	0.69 ± 0.14	Belle(II)(2024)[185]	Ξ^0K^+	0.05 ± 0.02	Belle(II)(2025)[183]
$\Xi^0\eta$	0.16 ± 0.04	Belle(II)(2024)[185]	$pK^-\pi^+$	0.45 ± 0.22	Belle(2019)[179]
$\Xi^0\eta'$	0.12 ± 0.04	Belle(II)(2024)[185]		1.14 ± 0.39	LHCb(2020)[180]
$\Xi^-\pi^+$	1.80 ± 0.52	Belle(2019)[178]	$p\phi$	$0.012\pm0.006^\dagger$	LHCb(2019)[186]
$pK^-K^-\pi^+$	0.58 ± 0.24	Belle(2019)[178]			
$\Lambda K^-\pi^+$	1.17 ± 0.38	Belle(2019)[178]			
Ξ^-K^+	$0.04\pm0.01^\dagger$	Belle(2013)[187]			
$\Lambda\phi$ (CS)	$0.05\pm0.01^\dagger$	Belle(2013)[187]			
$\Lambda(K^+K^-)_{\text{non}-\phi}$	$0.04\pm0.01^\dagger$	Belle(2013)[187]			
$\Xi^0\phi$	$0.05\pm0.01^\dagger$	Belle(2021)[188]			
$\Xi^0(K^+K^-)_{\text{non}-\phi}$	$0.06\pm0.01^\dagger$	Belle(2021)[188]			
$\Lambda_c^+\pi^-$	0.55 ± 0.18	LHCb(2020)[180]			
	0.54 ± 0.14	Belle(2023)[189]			

Intermediate resonances obtained in PWA of $\Xi_c^+\to pK^-\pi^+$ at LHCb [190]

Resonance	Fit Fraction (%)	BF† ($\times10^{-4}$)	Resonance	Fit Fraction (%)	BF† ($\times10^{-4}$)
$\Lambda(1405)$	3.3±1.5	2.05 ± 0.94	$\Lambda(1520)$	2.64±0.14	1.637 ± 0.087
$\Lambda(1600)$	2.0±1.7	1.2 ± 1.1	$\Lambda(1670)$	3.03±0.21	1.88 ± 0.14
$\Lambda(1690)$	1.55±0.59	0.96 ± 0.37	$\Lambda(1710)$	2.3±1.9	1.4 ± 1.2
$\Lambda(1800)$	1.48±0.61	0.92 ± 0.38	$\Lambda(1810)$	1.3±1.0	0.83 ± 0.63
$\Lambda(1820)$	0.82±0.18	0.51 ± 0.11	$\Lambda(1830)$	0.20±0.12	0.124 ± 0.075
$\Lambda(1890)$	0.19±0.18	0.12 ± 0.11	$\Lambda(2000)$	7.4±1.4	4.59 ± 0.87
$\bar{K}_0^*(700)^0$	7.4±4.9	4.6 ± 3.0	$\bar{K}^*(892)^0$	28.6±1.2	17.74 ± 0.73
$\bar{K}_0^*(1430)^0$	15.6±7.4	9.7 ± 4.6	$\bar{K}_2^*(1430)^0$	3.3±2.8	2.1 ± 1.7
$\Delta(1232)^{++}$	17.2±1.4	10.66 ± 0.87	$\Delta(1600)^{++}$	4.3±1.3	2.67 ± 0.82
$\Delta(1620)^{++}$	3.3±1.0	2.04 ± 0.65	$\Delta(1700)^{++}$	2.01±0.49	1.25 ± 0.31

Mode	reltive BF	Experiment	Mode	reltive BF	Experiment
$\Omega_c^0\to\Xi^0\bar{K}^0$	1.64 ± 0.29	Belle(2018)[203]	$\Omega_c^0\to\Sigma^+K^-K^-\pi^+$	<0.32	Belle(2018)[203]
$\Omega_c^0\to\Xi^-\pi^+$	0.25 ± 0.06	Belle(2023)[205]	$\Omega_c^0\to\Lambda\bar{K}^0\bar{K}^0$	1.72 ± 0.35	Belle(2018)[203]
	0.16 ± 0.01	LHCb(2024)[206]	$\Omega_c^0\to\Xi^0K^-\pi^+$	1.20 ± 0.18	Belle(2018)[203]
$\Omega_c^0\to\Xi^-K^+$	<0.07	Belle(2023)[205]	$\Omega_c^0\to\Xi^-\bar{K}^0\pi^+$	2.12 ± 0.28	Belle(2018)[203]
$\Omega_c^0\to\Omega^-K^+$	<0.29	Belle(2023)[205]	$\Omega_c^0\to\Xi^-K^-\pi^+\pi^+$	0.68 ± 0.08	Belle(2018)[203]
	0.06 ± 0.01	LHCb(2024)[206]	$\Omega_c^0\to\Omega^-\pi^+\pi^0$	2.00 ± 0.20	Belle(2018)[203]
			$\Omega_c^0\to\Omega^-\pi^+\pi^-\pi^+$	0.32 ± 0.05	Belle(2018)[203]

Polarizations and CP

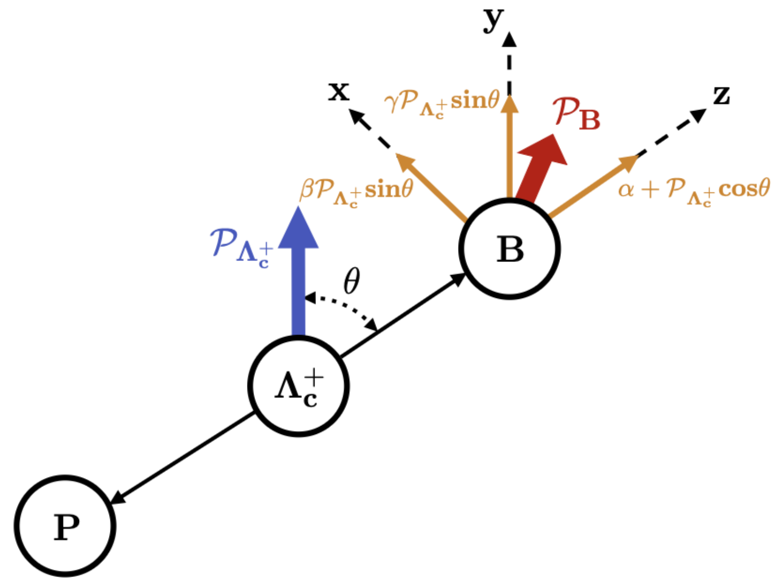


Polarization in baryon two-body decays

- Polarization and CP symmetry can be precisely tested in baryon weak decay by studying the polarization of the produced daughter particles.
- For simple case of Λ_c^+ decaying into $\frac{1}{2}^+$ baryon and a 0^- meson, decay asymmetries can be defined.

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

$$\beta = \frac{2\,\mathrm{Im}(S^* P)}{|S|^2 + |P|^2} \qquad \alpha^2 + \beta^2 + \gamma^2 = 1$$



CP asymmetry:

$$A = \frac{\alpha + \overline{\alpha}}{\alpha - \overline{\alpha}}, \quad B = \frac{\beta + \overline{\beta}}{\beta - \overline{\beta}}.$$

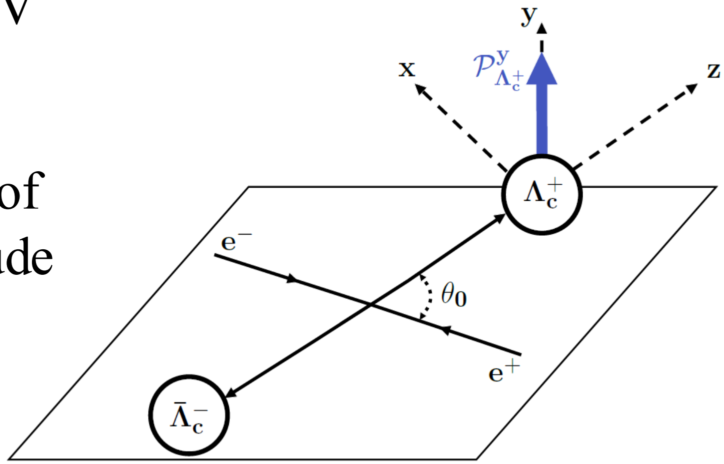
$$P_y(\cos\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi$$

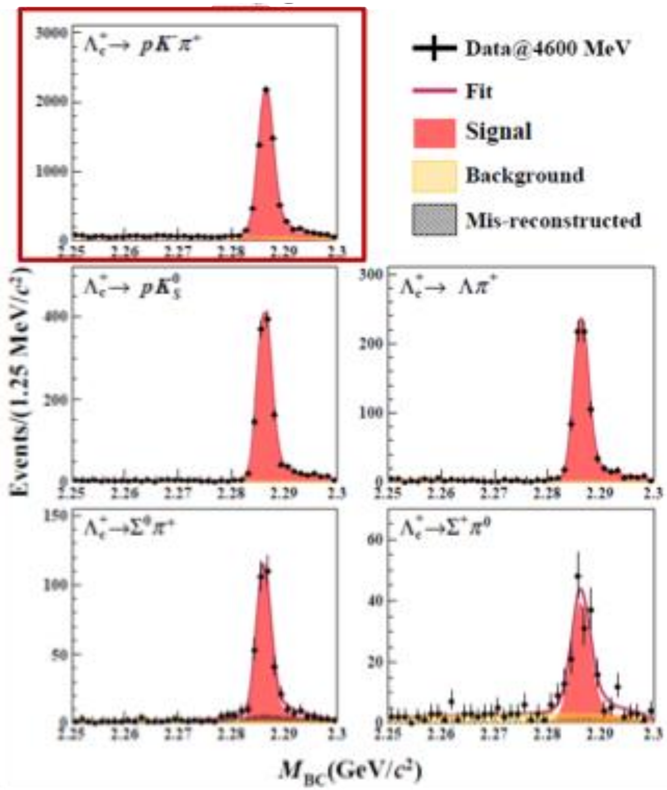
$\Delta\phi$ is the phase angle difference of G_E and G_M, can be explored via angular analysis of the spin-coherent hyperon-pair weak decays

Probe transverse polarization of the Λ_c^+

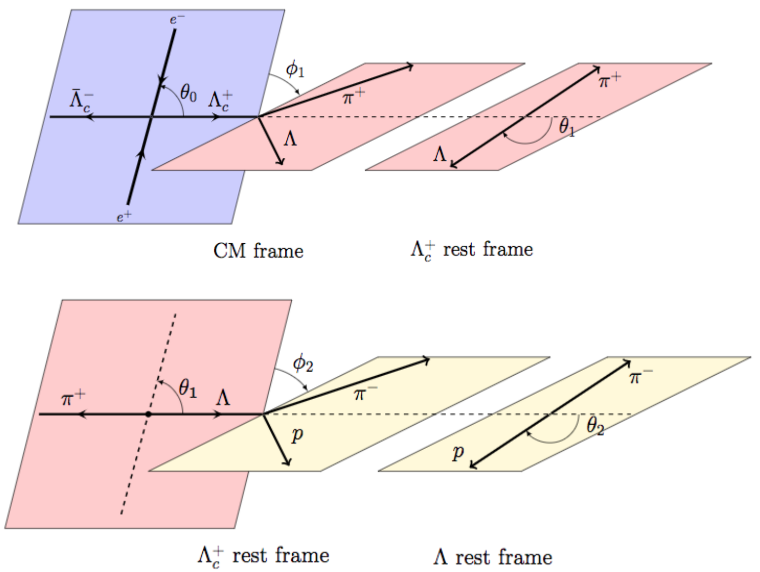
arXiv:2508.11400

- Evidence of transverse polarization at 4.6 GeV [BESIII, PRD 100, 072004 (2019)]
- More data collected from 4.6-4.95 GeV
- Joint angular analyses of the cascade decays of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ and amplitude analysis of $\Lambda_c \to pK^-\pi^+$





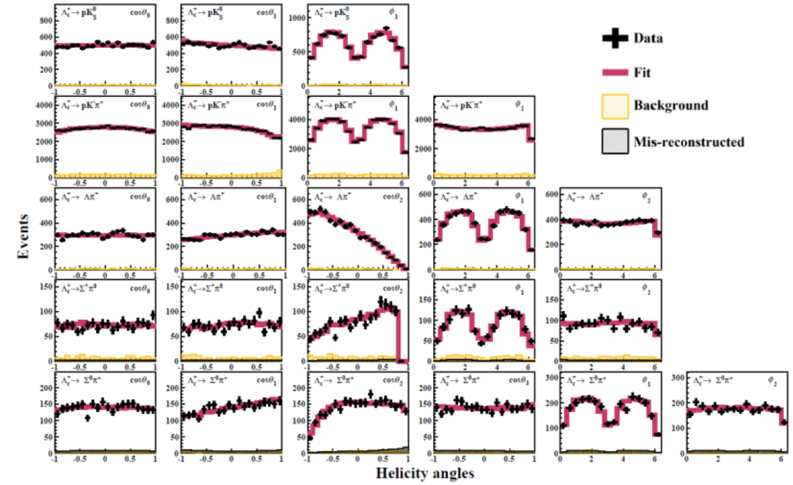
$$\mathcal{P}^y_{\Lambda_c^+}(\cos\theta_0) = \frac{3}{2(3+\alpha_0)}\sqrt{1-\alpha_0^2}\sin\theta_0\cos\theta_0\sin\Delta\Phi$$

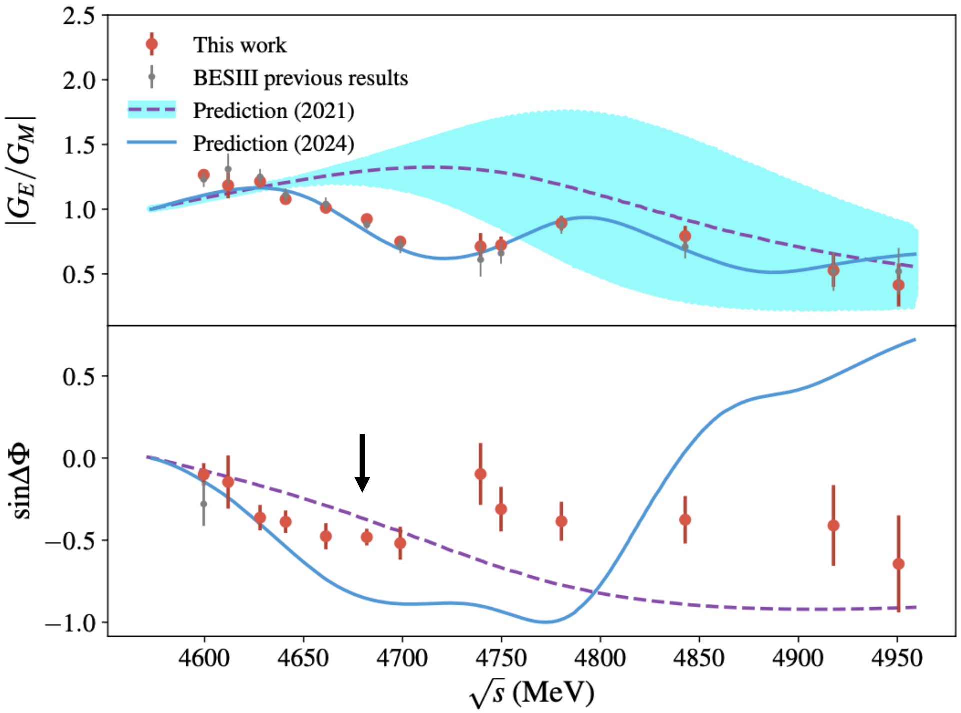


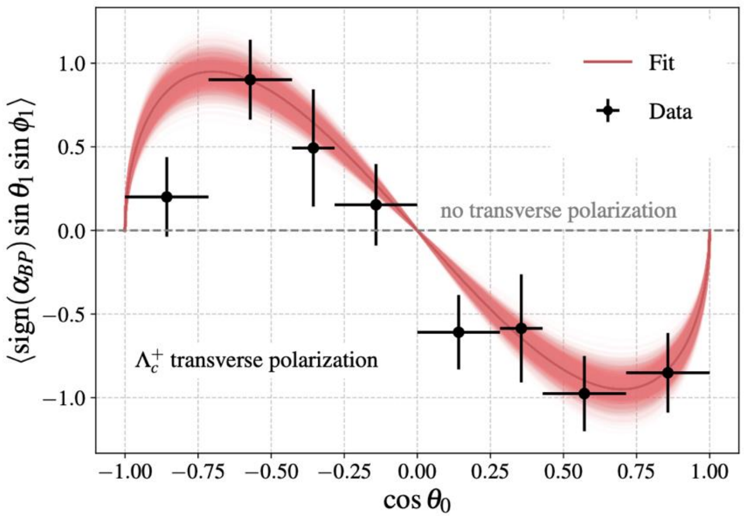
Observation of transverse polarization of the Λ_c^+

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 $\Sigma^0\pi^+$

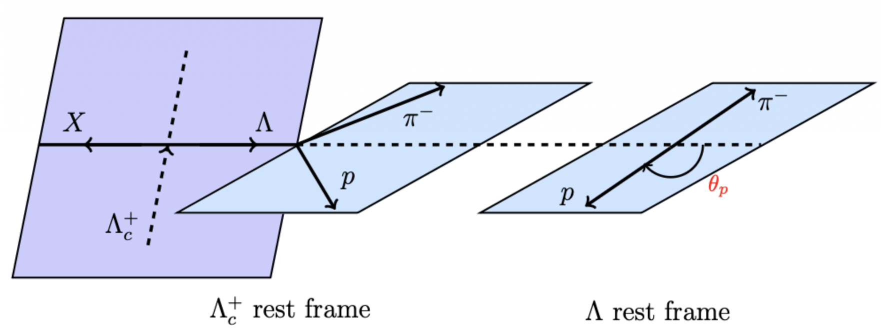




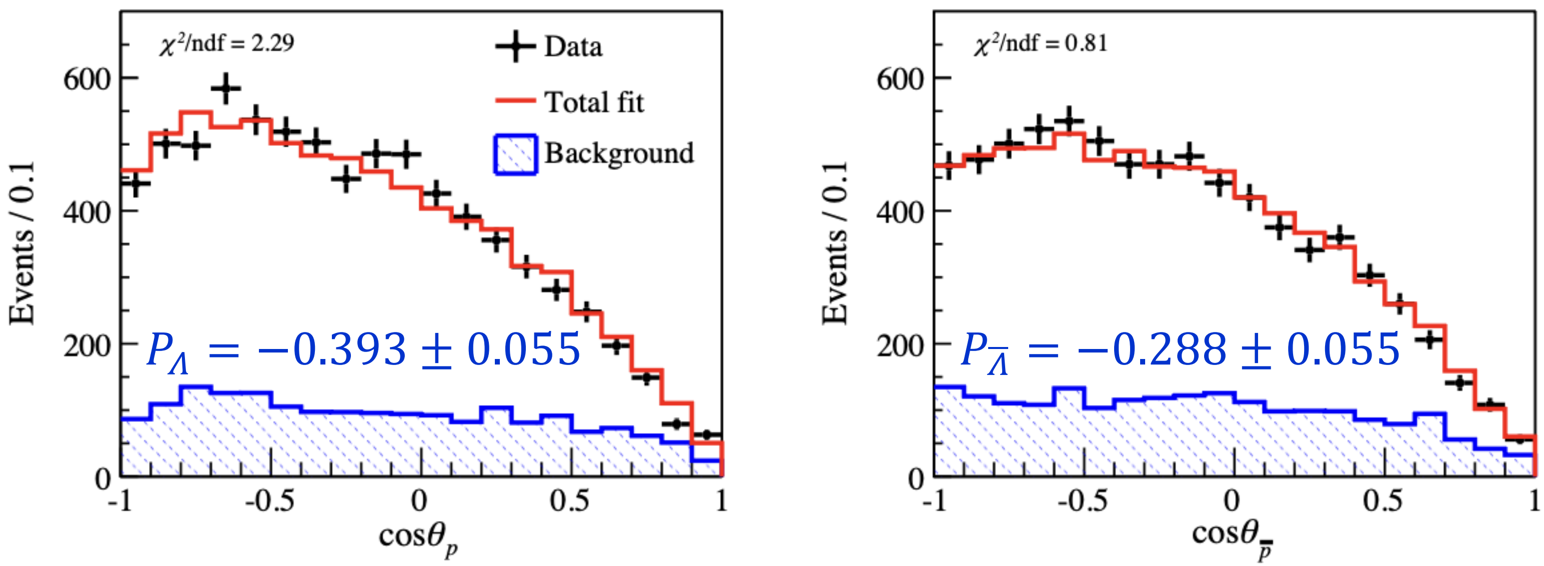


Decay Asymmetry in $\Lambda_c^+ \to \Lambda X$

arXiv:2602.24089



$$\frac{d\Gamma}{d\cos\theta_p} \propto 1 + \mathcal{P}_\Lambda \alpha_- \cos\theta_p,$$



$$B(\Lambda_c^+ \to \Lambda\, X) = (38.07 \pm 0.38 \pm 0.49)\%$$

Λ_c^+ decay asymmetries

Chin. Phys. C 50, 022002 (2026)

Mode	α	Experiment	Mode	α	Experiment
Nucleon-involved			$\Lambda_c^+ \to \Lambda(1600)\pi^+$	0.2 ± 0.5	LHCb(2023)[91]
$\Lambda_c^+ \to pK_S^0$	-0.75 ± 0.10	LHCb(2024)[161]	$\Lambda_c^+ \to \Lambda(1670)\pi^+$	0.82 ± 0.08	LHCb(2023)[91]
	$-0.92^{+0.14}_{-0.09}$	BESIII(2025)[160]		0.21 ± 0.43	BESIII(2025)[154]
$\Lambda_c^+ \to p\bar{K}_0^*(700)^0$	-0.1 ± 0.7	LHCb(2023)[91]	$\Lambda_c^+ \to \Lambda(1690)\pi^+$	0.958 ± 0.034	LHCb(2023)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(892)^0$	0.87 ± 0.03	LHCb(2023)[91]	$\Lambda_c^+ \to \Lambda(2000)\pi^+$	-0.57 ± 0.19	LHCb(2023)[91]
$\Lambda_c^+ \to p\bar{K}_0^*(1430)^0$	0.34 ± 0.14	LHCb(2023)[91]	**Σ-involved**		
$\Lambda_c^+ \to \Delta(1232)^{++}K^-$	0.55 ± 0.04	LHCb(2023)[91]	$\Lambda_c^+ \to \Sigma^+\pi^0$	-0.48 ± 0.03	Belle(2023)[103]
$\Lambda_c^+ \to \Delta(1600)^{++}K^-$	-0.50 ± 0.18	LHCb(2023)[91]		-0.59 ± 0.05	BESIII(2025)[160]
$\Lambda_c^+ \to \Delta(1700)^{++}K^-$	0.22 ± 0.08	LHCb(2023)[91]	$\Lambda_c^+ \to \Sigma^+\eta$	-0.99 ± 0.06	Belle(2023)[103]
Λ-involved			$\Lambda_c^+ \to \Sigma^+\eta'$	-0.46 ± 0.07	Belle(2023)[103]
$\Lambda_c^+ \to \Lambda\pi^+$	-0.785 ± 0.007	LHCb(2024)[161]	$\Lambda_c^+ \to \Sigma^0\pi^+$	-0.46 ± 0.02	Belle(2023)[138]
	-0.755 ± 0.006	Belle(2023)[138]		-0.50 ± 0.08	BESIII(2025)[160]
	-0.790 ± 0.033	BESIII(2025)[160]	$\Lambda_c^+ \to \Sigma(1385)^+\pi^0$	-0.917 ± 0.089	BESIII(2022)[98]
$\Lambda_c^+ \to \Lambda K^+$	-0.59 ± 0.05	Belle(2023)[138]	$\Lambda_c^+ \to \Sigma(1385)^+\eta$	-0.61 ± 0.16	BESIII(2025)[154]
	-0.52 ± 0.05	LHCb(2024)[161]	$\Lambda_c^+ \to \Sigma(1385)^0\pi^+$	-0.79 ± 0.11	BESIII(2022)[98]
$\Lambda_c^+ \to \Lambda\rho(770)^+$	-0.763 ± 0.070	BESIII(2022)[98]	$\Lambda_c^+ \to \Sigma^0 K^+$	-0.54 ± 0.20	Belle(2023)[138]
$\Lambda_c^+ \to \Lambda a(980)^+$	$-0.91^{+0.20}_{-0.12}$	BESIII(2025)[154]	**Ξ-involved**		
$\Lambda_c^+ \to \Lambda(1405)\pi^+$	0.58 ± 0.28	LHCb(2023)[91]	$\Lambda_c^+ \to \Xi^0 K^+$	0.01 ± 0.16	BESIII(2024)[162]
$\Lambda_c^+ \to \Lambda(1520)\pi^+$	0.93 ± 0.09	LHCb(2023)[91]			

Mode	β	Experiment	Mode	γ	Experiment
$\Lambda_c^+ \to \Lambda\pi^+$	0.378 ± 0.015	LHCb(2024)[161]	$\Lambda_c^+ \to \Lambda\pi^+$	0.491 ± 0.012	LHCb(2024)[161]
	$0.37^{+0.17}_{-0.25}$	BESIII(2025)[160]		$0.64^{+0.10}_{-0.20}$	BESIII(2025)[160]
$\Lambda_c^+ \to \Sigma^0\pi^+$	$0.70^{+0.14}_{-0.48}$	BESIII(2025)[160]	$\Lambda_c^+ \to \Sigma^0\pi^+$	$-0.50^{+0.59}_{-0.30}$	BESIII(2025)[160]
$\Lambda_c^+ \to \Sigma^+\pi^0$	$0.76^{+0.05}_{-0.24}$	BESIII(2025)[160]	$\Lambda_c^+ \to \Sigma^+\pi^0$	$-0.26^{+0.48}_{-0.38}$	BESIII(2025)[160]
$\Lambda_c^+ \to \Xi^0 K^+$	-0.64 ± 0.70	BESIII(2024)[162]	$\Lambda_c^+ \to \Xi^0 K^+$	-0.77 ± 0.59	BESIII(2024)[162]
$\Lambda_c^+ \to \Lambda K^+$	0.33 ± 0.08	LHCb(2024)[161]	$\Lambda_c^+ \to \Lambda K^+$	-0.799 ± 0.041	LHCb(2024)[161]

Ξ_c decay asymmetries

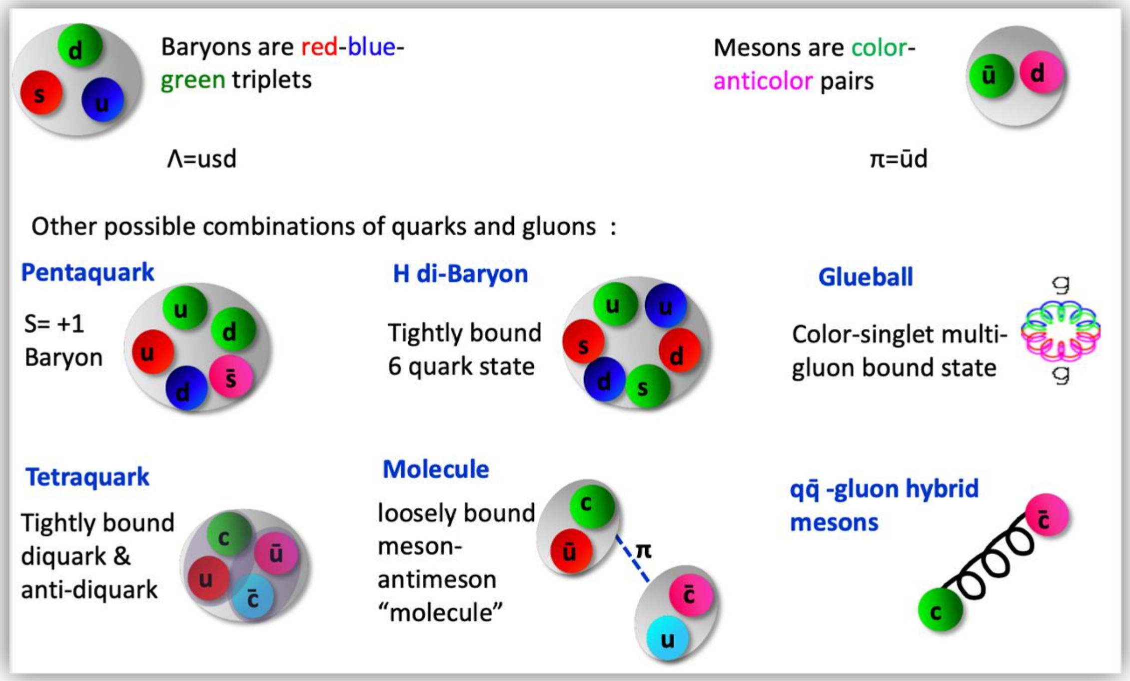
Chin. Phys. C 50, 022002 (2026)

Mode	polarization α	Experiment	Mode	polarization α	Experiment
$\Xi_c^0 \to \Xi^- \pi^+$	-0.63 ± 0.03	Belle(2021)[46]	$\Xi_c^0 \to \Lambda \bar{K}^*(892)^0$	0.15 ± 0.22	Belle(2021)[182]
$\Xi_c^0 \to \Xi^0 \pi^0$	-0.90 ± 0.27	Belle(II)(2024)[185]	$\Xi_c^0 \to \Sigma^+ K^*(892)^-$	-0.52 ± 0.30	Belle(2021)[182]

Polarization parameter α in Ξ_c^+ decays from PWA of $\Xi_c^+ \to pK^-\pi^+$ at LHCb [190]

Decay	polarization α	Decay	polarization α	Decay	polarization α
$p\bar{K}^*(892)^0$	0.613 ± 0.065	$p\bar{K}_2^*(1430)^0$	0.36 ± 0.17	$p\bar{K}_0^*(700)^0$	0.60 ± 0.12
$p\bar{K}_0^*(1430)^0$	-0.76 ± 0.10	$\Lambda(1405)\pi^+$	-0.75 ± 0.30	$\Lambda(1520)\pi^+$	-0.77 ± 0.13
$\Lambda(1600)\pi^+$	-0.06 ± 0.41	$\Lambda(1670)\pi^+$	-0.66 ± 0.19	$\Lambda(1690)\pi^+$	-0.58 ± 0.16
$\Lambda(1710)\pi^+$	-0.86 ± 0.36	$\Lambda(1800)\pi^+$	-0.5 ± 1.2	$\Lambda(1810)\pi^+$	0.96 ± 0.43
$\Lambda(1820)\pi^+$	0.64 ± 0.33	$\Lambda(1830)\pi^+$	0.30 ± 1.02	$\Lambda(1890)\pi^+$	-0.19 ± 0.58
$\Lambda(2000)\pi^+$	0.53 ± 0.15	$\Delta(1232)^{++}K^-$	-0.774 ± 0.071	$\Delta(1600)^{++}K^-$	0.35 ± 0.28
$\Delta(1620)^{++}K^-$	0.26 ± 0.39	$\Delta(1700)^{++}K^-$	0.15 ± 0.30		

Spectroscopy

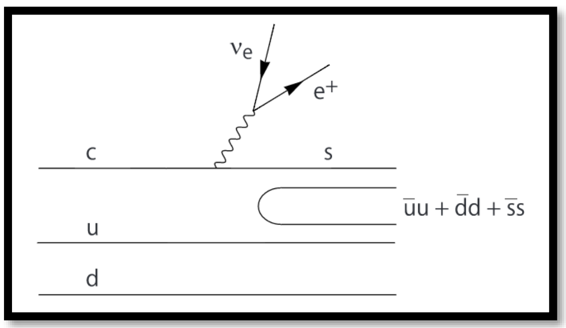


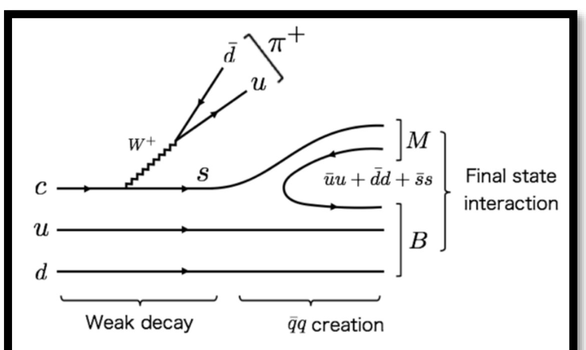
Hyperon spectroscopy in Λ_c^+ weak decays

- 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

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

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

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

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

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

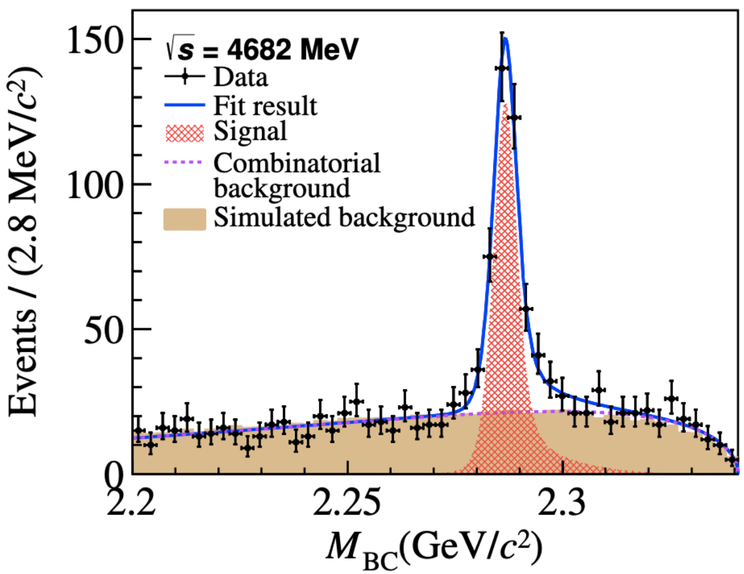
- $\Lambda_c^+ \to \Lambda\pi^0\pi^+$
- $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$
- $\Lambda_c^+ \to \Sigma^+\pi^-\pi^+$
- $\Xi_c^+ \to pK^-\pi^+$
- …

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

PRL134, 021901 (2025)

- $\Lambda_c^+ \to \Lambda\pi^+\eta$ 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)]

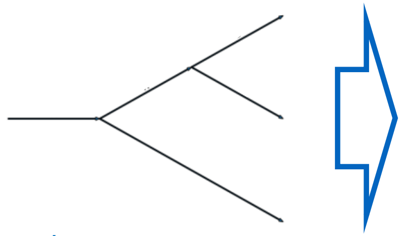
- Based on TF-PWA package: *https://gitlab.com/jiangyi15/tf-pwa*
- BDTG trained sample with about 1312 signals with purity of about 80%



TF-PWA: Partial Wave Analysis with TensorFlow

- Fast
  - GPU based
  - Vectorized calculation
  - Automatic differentiation
    Quasi-Newton Method: scipy.optimize
- General
  - Model customization support
- Easy to use
  - Simple configuration file (example provided)
  - Most processing is automatic
  - All necessary functions implemented
  - Rich function support
- Open access
  https://github.com/jiangyi15/tf-pwa

TF-PWA: amplitude factorization



$$A^{R}_{\lambda_A,\lambda_B',\lambda_C',\lambda_D'}$$

$$\sum_{\lambda} H_{\lambda_R\lambda_B} D^{j_A\star}_{\lambda_A,\lambda_R-\lambda_B}(\varphi_1,\theta_1,0) R(M) H_{\lambda_C,\lambda_D} D^{j_R\star}_{\lambda_R,\lambda_C-\lambda_D}(\varphi_2,\theta_2,0)$$

$$D^{j_B\star}_{\lambda_B,\lambda_B'}(\alpha_B,\beta_B,\gamma_B) D^{j_C\star}_{\lambda_C,\lambda_C'}(\alpha_C,\beta_C,\gamma_C) D^{j_D\star}_{\lambda_D,\lambda_D'}(\alpha_D,\beta_D,\gamma_D)$$

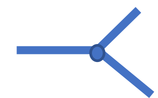
$$\frac{d\sigma}{d\Phi} \propto \sum_{\lambda_A} \sum_{\lambda_B,\lambda_C,\lambda_D} \left| \sum_{R} A^{R}_{\lambda_A,\lambda_B,\lambda_C,\lambda_D} \right|^2$$

Automatically calculated from decay structure

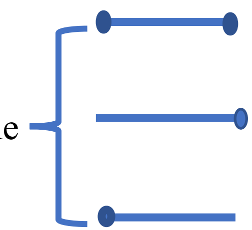
- automatic factorization of amplitude, as combination of summation and production
- automatic differentiation in likelihood minimization and error propagation
- optional optimization for better performances
  - amplitude caching (eg, resonance lineshape, …)
  - mixed likelihood for simultaneous fit

Feynman rules

Decay



Particle



user defined

$$A^{0\to 1+2} = H_{\lambda_1,\lambda_2} D^{j_0\star}_{\lambda_0,\lambda_1-\lambda_2}(\varphi,\theta,0)$$

Wigner-D matrix

$$R(M) = \frac{1}{m_0^2 - M^2 - i m_0 \Gamma}, \cdots$$

1 or $\rho = 1 + \vec{p}\cdot\vec{\sigma}$

$D^{j_1\star}_{\lambda_1,\lambda_1'}(\alpha,\beta,\gamma)$ alignment

probability: $|\mathcal{A}|^2$

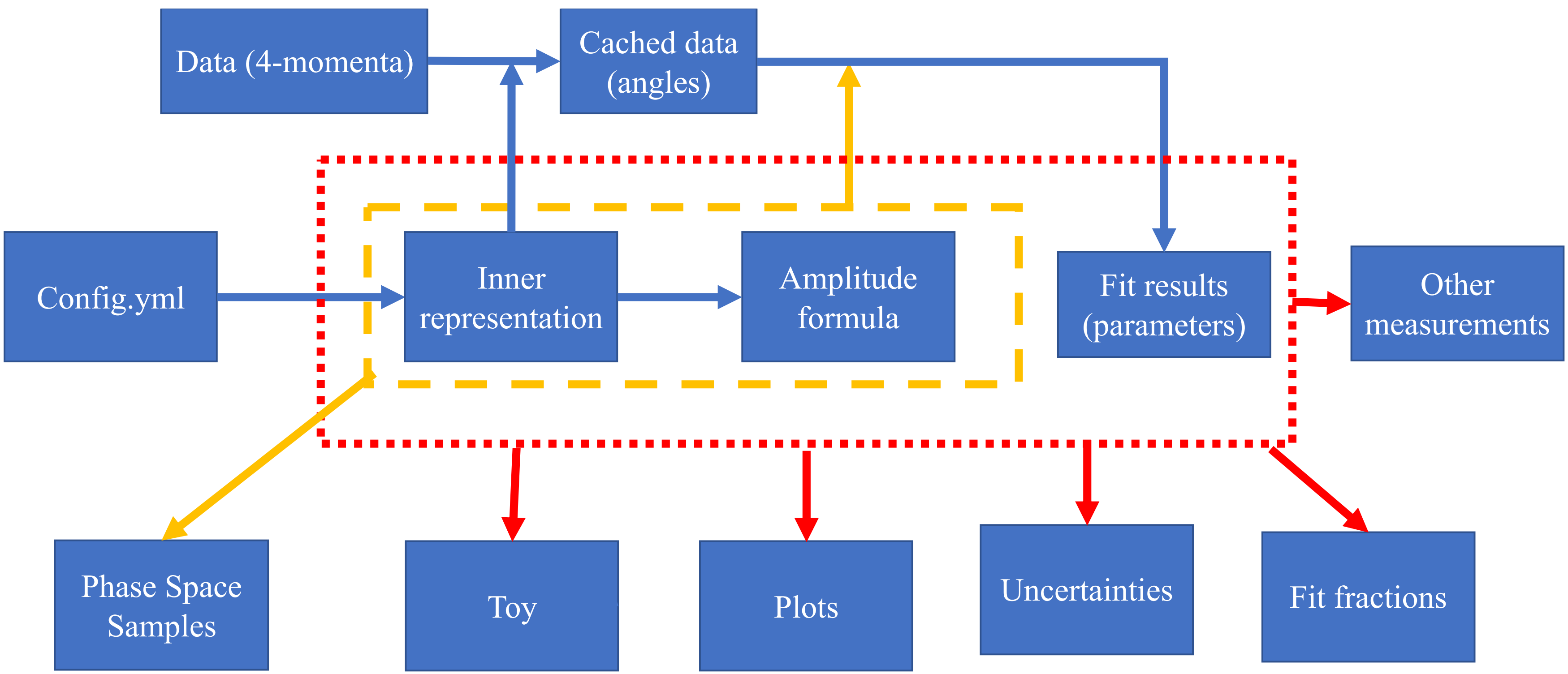
Decay Group: $\mathcal{A} = \tilde{A}_1 + \tilde{A}_2 + \cdots$

Decay Chain: $\tilde{A} = A_1 R A_2 \cdots$

Decay: Wigner D-matrix, $A = HD^{*J}(\phi,\theta,0)$

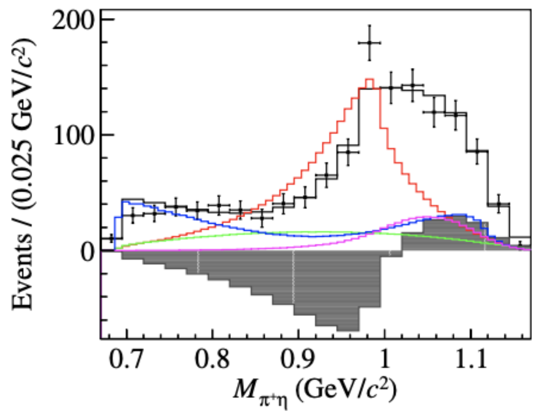
Particle: Breit-Wigner: $R(m)$, user defined

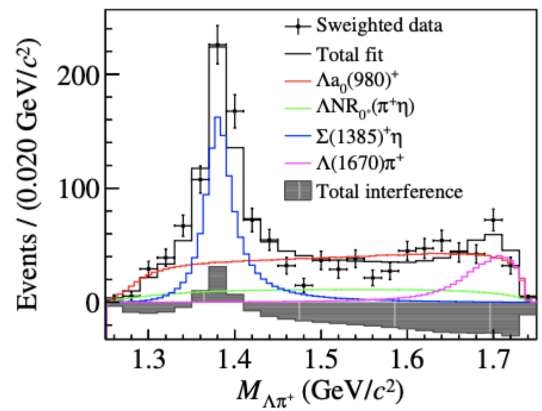
TF-PWA architecture

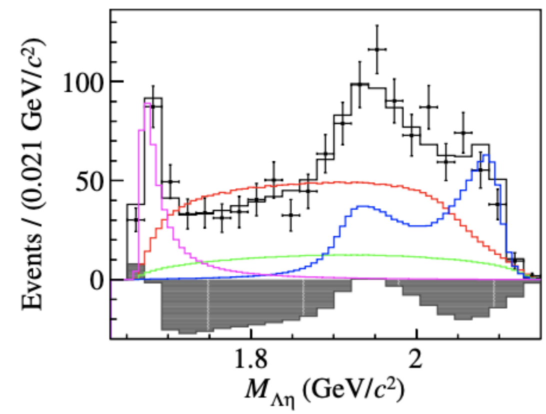


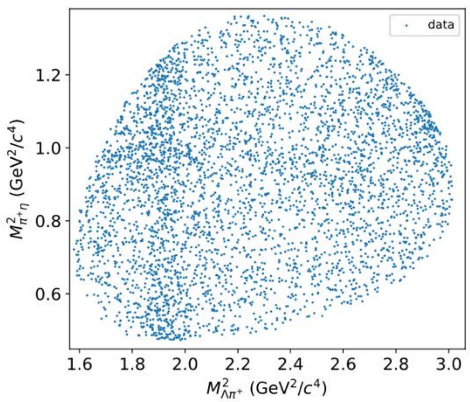
Baseline model of $\Lambda_c^+ \to \Lambda\pi^+\eta$

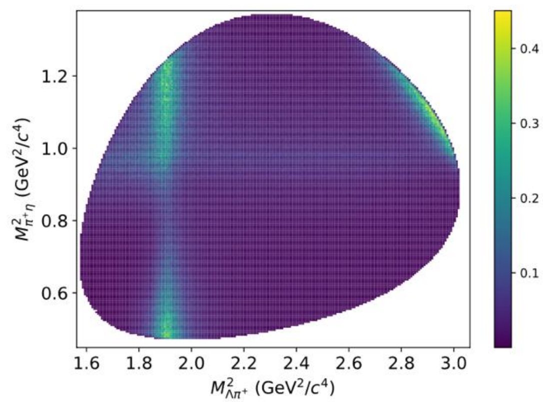
PRL134, 021901 (2025)











- **$\Lambda_c^+ \to \Lambda a_0(980)^+$ 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	...

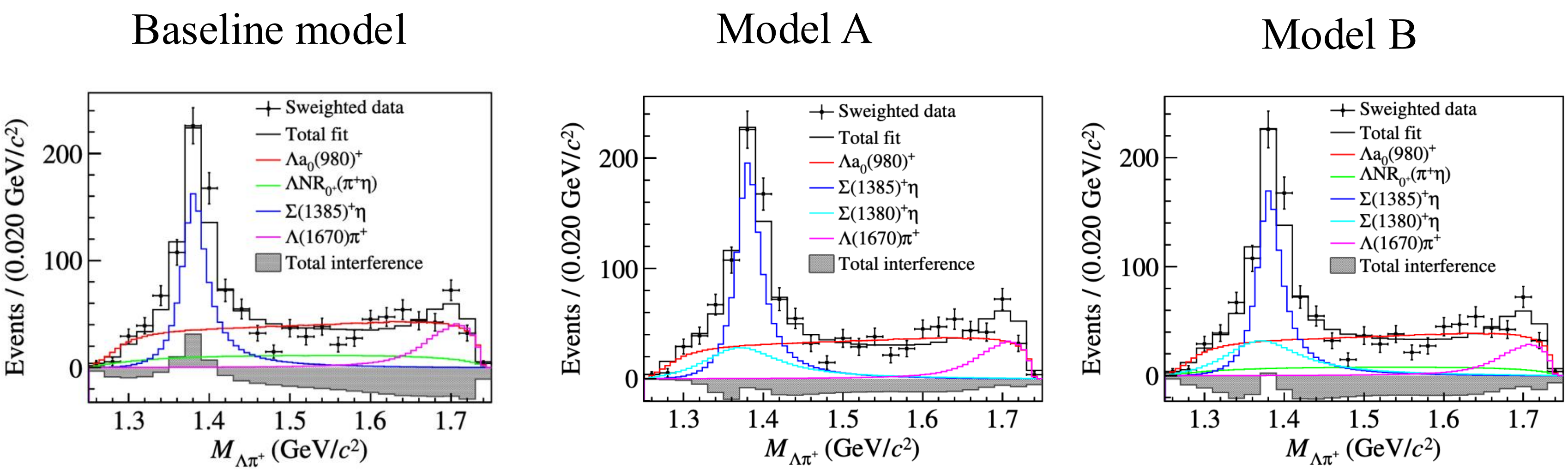
$$\alpha_{\Lambda a_0(980)^+} = \frac{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Lambda a_0(980)^+}_{-\frac{1}{2},0}\right|^2}$$

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

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

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

PRL134, 021901 (2025)



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

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	$2.1 \pm 1.1/1.4 \pm 1.0$	$6.2 \pm 0.5\,(3.1 \pm 0.6)$	$5.3 \pm 0.8\,(7.3 \pm 1.5)$

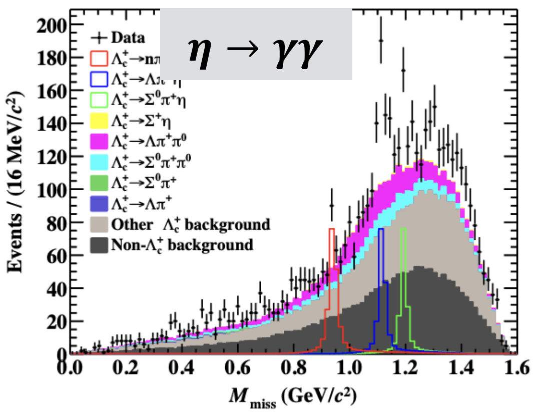
Decay Mode	Ref. [26]	Ref. [27]
$\Lambda_c^+ \to \Lambda a_0(980)^+$	1.9×10^{-4}	$(1.7^{+2.8}_{-1.0} \pm 0.3) \times 10^{-3}$

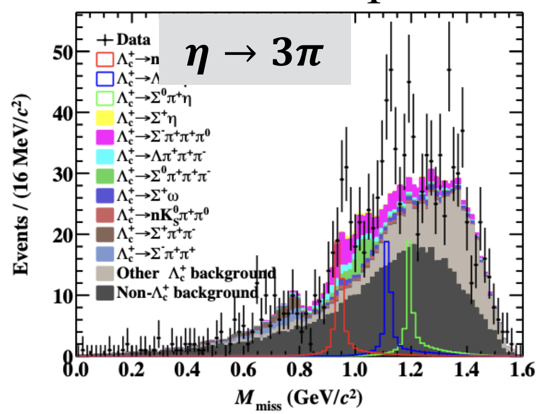
- If taking $\mathcal{B}(a_0(980)^+ \to \pi^+\eta) = (85.3 \pm 1.4)\%$, $\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+) = (1.23 \pm 0.21)\%$, which differs significantly larger than theoretical prediction by 1-2 orders of magnitude.
- Large decay asymmetry in $\Lambda_c^+ \to \Lambda a_0(980)^+$

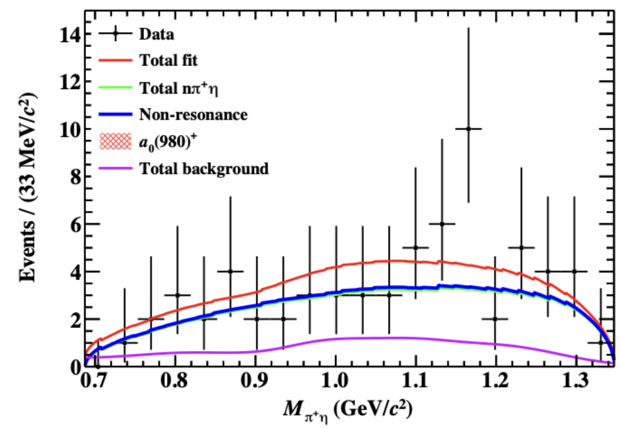
ML-boosted study of $\Lambda_c^+ \to n\pi^+\eta$

arXiv:2603.28232

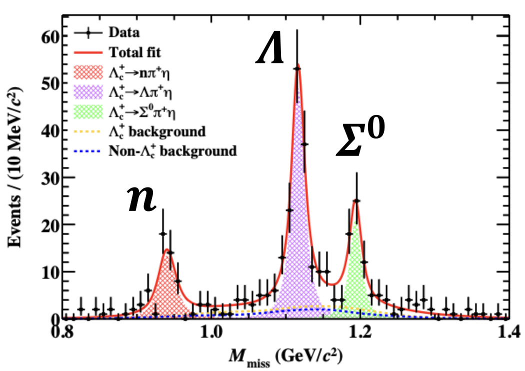
- As $\Lambda_c^+ \to \Lambda a_0(980)^+$ is observed with BF of $(1.23 \pm 0.21)\%$, it is natural to search for the SCS mode of $\Lambda_c^+ \to n a_0(980)^+$ in $\Lambda_c^+ \to n\pi^+\eta$
- However, more challenging due to the suppressed decay rate and the un-detectable neutron ➔ DT method is implemented to missing the neutron

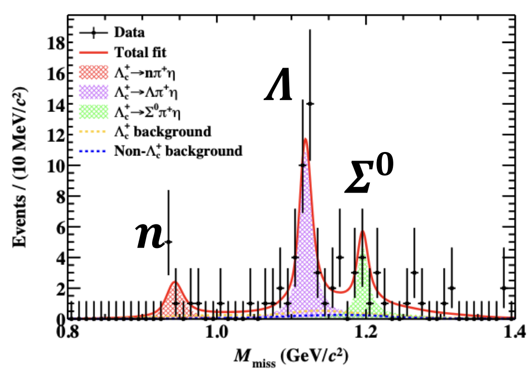






DNN





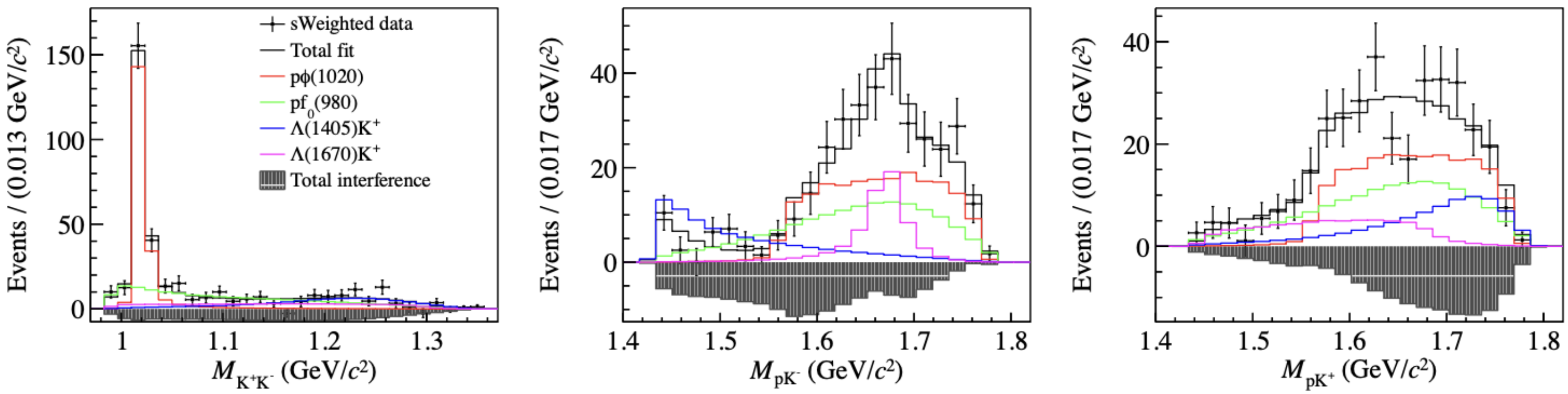
- $\Lambda_c^+ \to n\pi^+\eta$ is observed
- $\frac{B(\Lambda_c^+\to n\pi^+\eta)}{B(\Lambda_c^+\to\Lambda\pi^+\eta)} = 0.155 \pm 0.031 \pm 0.012$
- $a_0(980)^+$ is not seen

BESIII

Partial wave analysis of $\Lambda_c^+ \to pK^+K^-$

arXiv:2603.08469

- A clean SCS mode to explore the intermediate states
- About 526 signals used to carry out the partial wave analysis based on TF-PWA package
- Very clean ϕ component



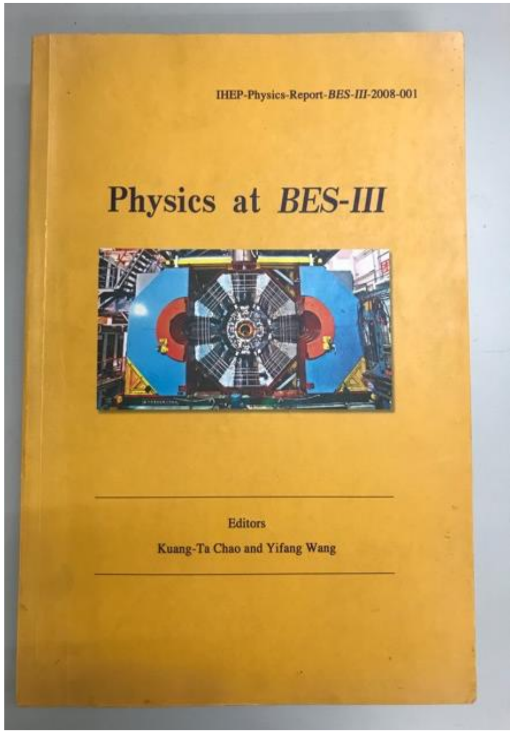
Process	FF (%)	$\mathcal{S}$
$p\phi(1020)$	$57 \pm 5 \pm 2$	16.6σ
$pf_0(980)$	$40 \pm 16 \pm 15$	3.6σ
$\Lambda(1405)K^+$	$21 \pm 9 \pm 6$	4.6σ
$\Lambda(1670)K^+$	$12 \pm 10 \pm 8$	5.0σ

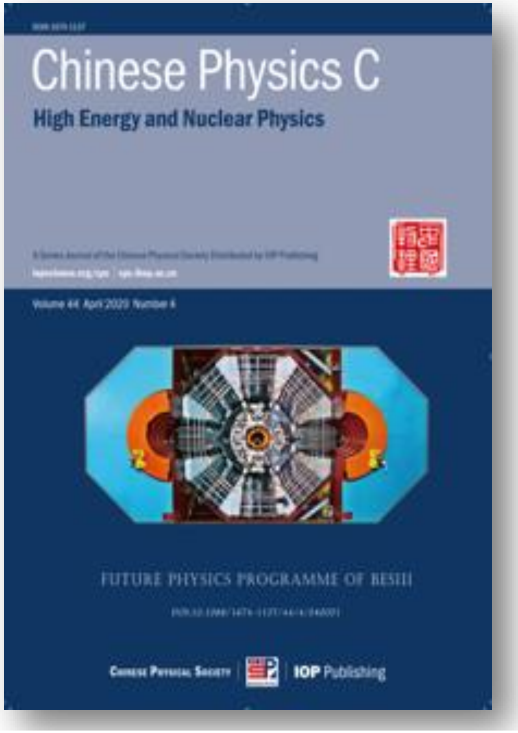
$$B(\Lambda_c^+ \to pK^+K^-) = (9.94 \pm 0.65 \pm 0.50) \times 10^{-4}$$

$$\mathcal{B}(\Lambda_c^+ \to \Lambda(1405)K^+, \Lambda(1405) \to pK^-) = (0.23 \pm 0.10 \pm 0.06 \pm 0.01) \times 10^{-3},$$
$$\mathcal{B}(\Lambda_c^+ \to \Lambda(1670)K^+, \Lambda(1670) \to pK^-) = (0.13 \pm 0.11 \pm 0.09 \pm 0.01) \times 10^{-3},$$
$$\mathcal{B}(\Lambda_c^+ \to pf_0(980), f_0(980) \to K^+K^-) = (0.43 \pm 0.17 \pm 0.16 \pm 0.02) \times 10^{-3},$$
$$\mathcal{B}(\Lambda_c^+ \to p\phi(1020), \phi(1020) \to K^+K^-) = (0.62 \pm 0.05 \pm 0.02 \pm 0.03) \times 10^{-3}.$$

$$B(\Lambda_c^+ \to p\phi) = (1.21 \pm 0.11 \pm 0.08 \pm 0.01) \times 10^{-3}$$

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 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

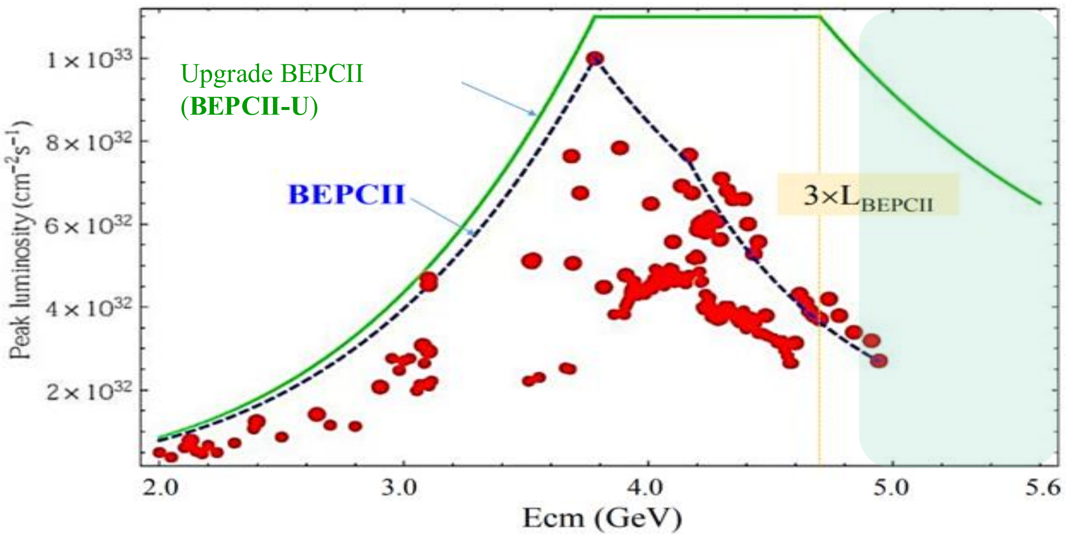
in 2020-2021, 5.8 fb^{-1} is taken

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

Proposal of the upgrade BEPCII

An upgrade of BEPCII (**BEPCII-U**) has been completed in 2025

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

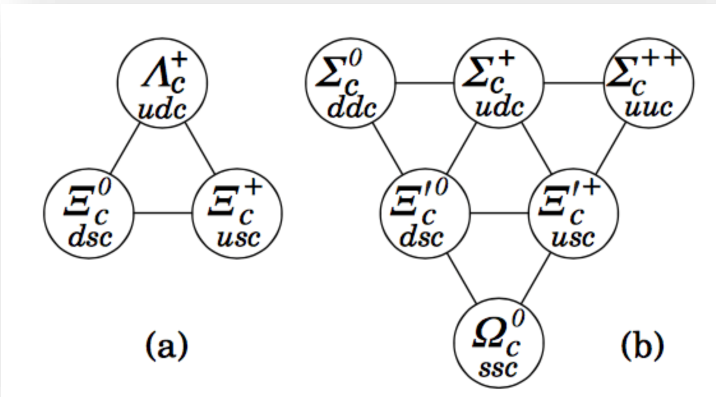


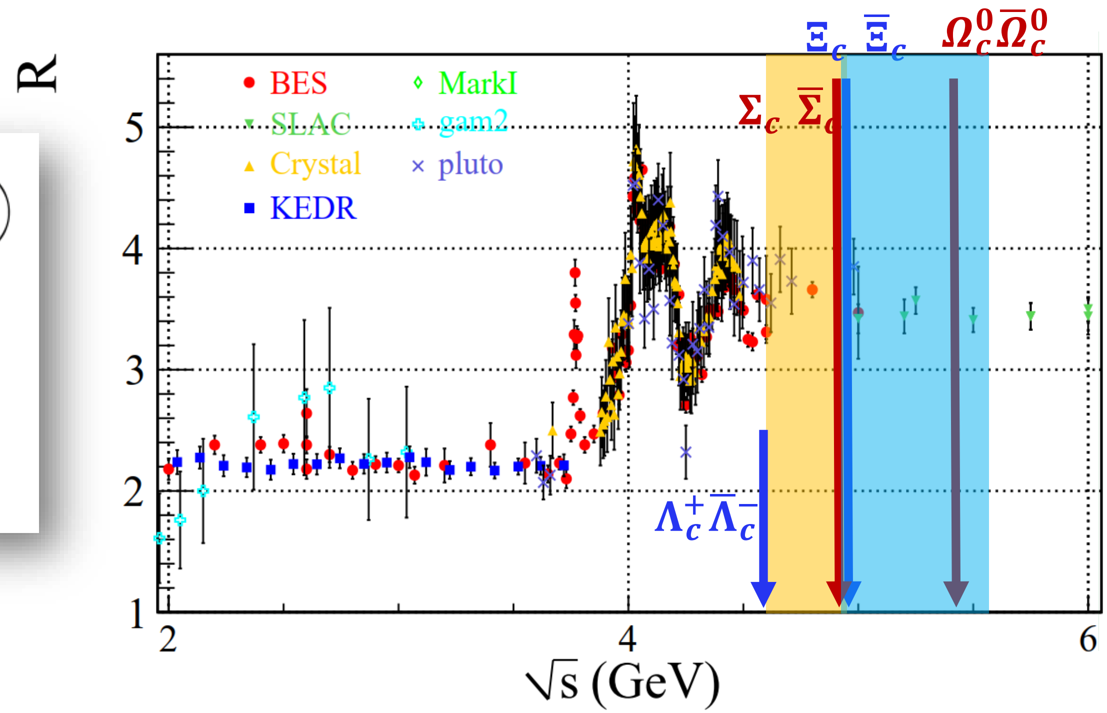
Capable of finishing the proposed luminosity of Λ_c^+ data in shorter time

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



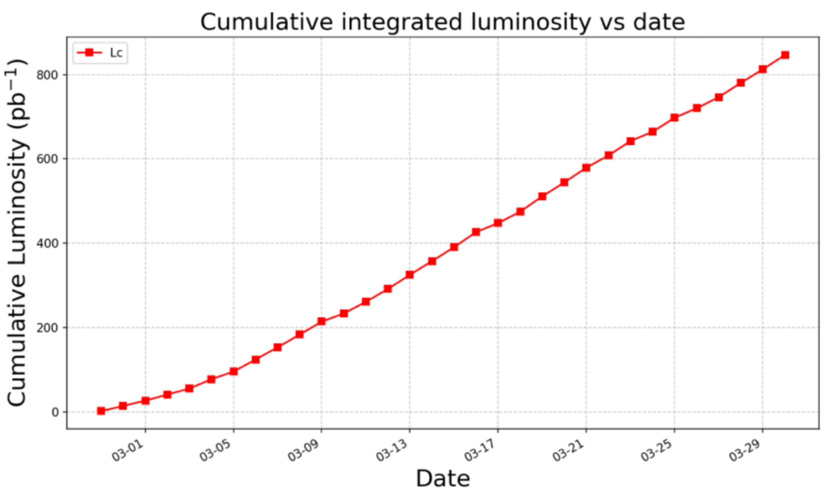


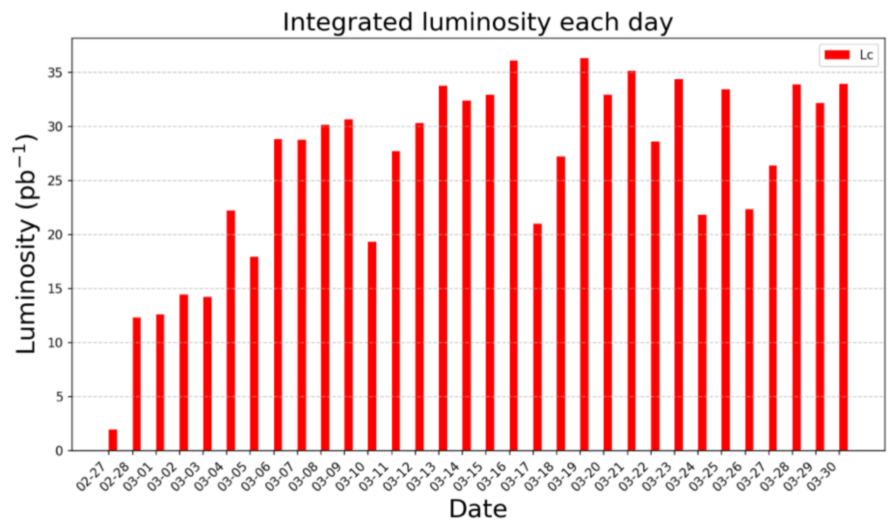
- Energy thresholds
  - ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
  - ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c\ \pi$ 4.88 GeV
  - ✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV
  - ✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$ 4.94 GeV
  - ✓ $e^+e^- \to \Omega_c^0\bar{\Omega}_c^0$ 5.40 GeV

- 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

Λ_c^+ data taking with BEPCII-U

- Began a new round of Λ_c^+ data taking at 4.68 GeV on Feb.27 2026
- Very smooth data taking





- Integrated luminosity: 0.85 fb^{-1}
- The highest daily integrated luminosity reached 36 pb^{-1} (~7k $\Lambda_c^+\bar{\Lambda}_c^-$ pairs)

Summary

- In recent years, experimental activities on charmed baryons are reviving, esp. at BESIII
- 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
  - ✓ Additional >160 M Λ_c^+ samples are collecting now
  - ✓ More efforts on hadronic decays with $n/\Sigma/\Xi$ particles & semi-leptonic decays
- Opportunity in other charmed baryons:

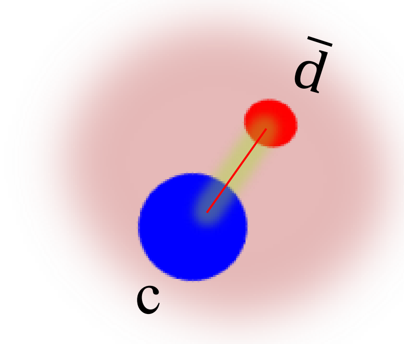
  Plan to take data up to 5.6 GeV to cover all the ground-state charmed baryons

Backup

Quark model picture

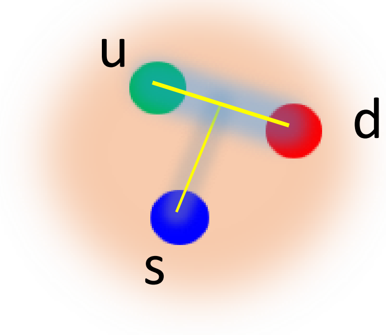
a heavy quark (*c*) with an unexcited spin-zero diquark (*u*-*d*)

➔ *diquark correlation is enhanced by weak Color Magnetic Interaction with a heavy quark.*



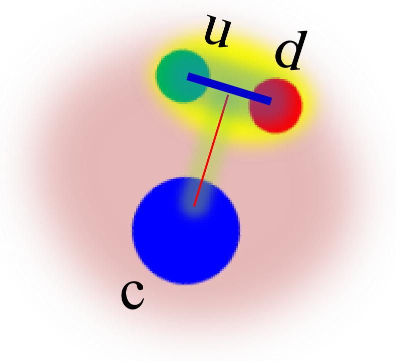
→ Charmed meson (D[+][c$\bar{d}$])

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



→ Strange baryons (Λ[uds])

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



→ Charmed baryon (Λ_c[udc])

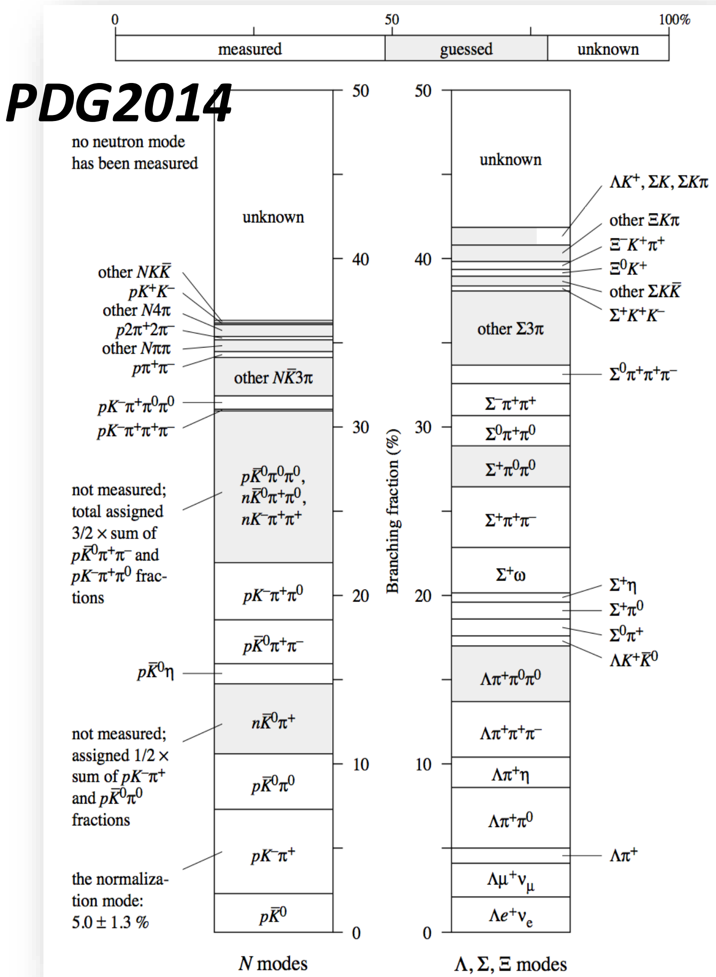
$m_u, m_d \ll m_c$ → **diquark + quark**
(qq) **(Q)**

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

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).

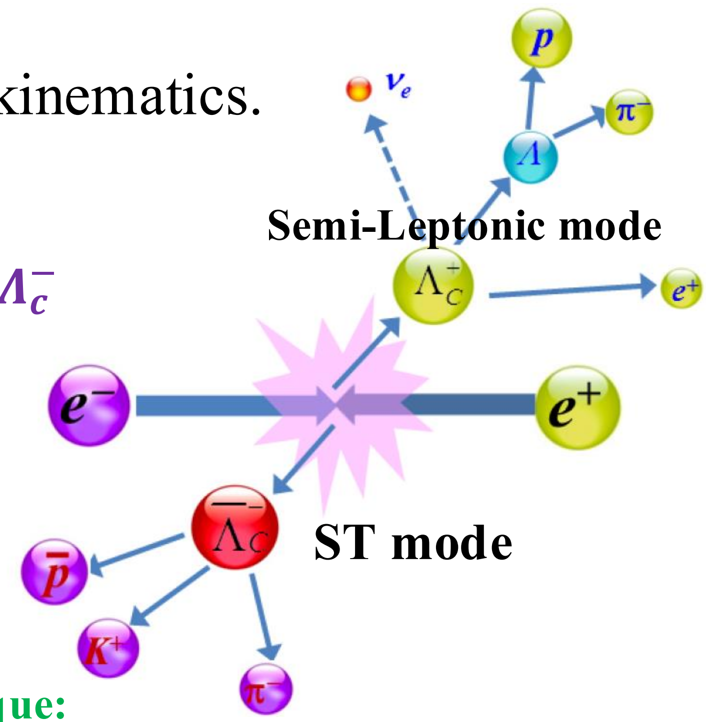


- Before 2014, absolute branching fractions (BF) of Λ_c^+ decays are still not well determined
  ➔ BFs of all measured decay modes are measured relative to $\Lambda_c^+ \to pK^-\pi^+$
- No completely model-independent measurements of $B(\Lambda_c^+ \to pK^-\pi^+)$: *uncertainties of BFs of Λ_c^+ decays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

Production near threshold and tag technique

E_{cms}=4600MeV

- E_{cms}-2$m_{\Lambda c}$=26 MeV 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 $\Lambda_c^+\Lambda_c^-$**
    - ✓ **Clean backgrounds**
    - ✓ **Missing mass technique: missing-mass technique: K_L/neutron, neutrino, …**
    - ✓ **Lower efficiencies**
    - ✓ **Systematic in tag side are mostly cancelled**



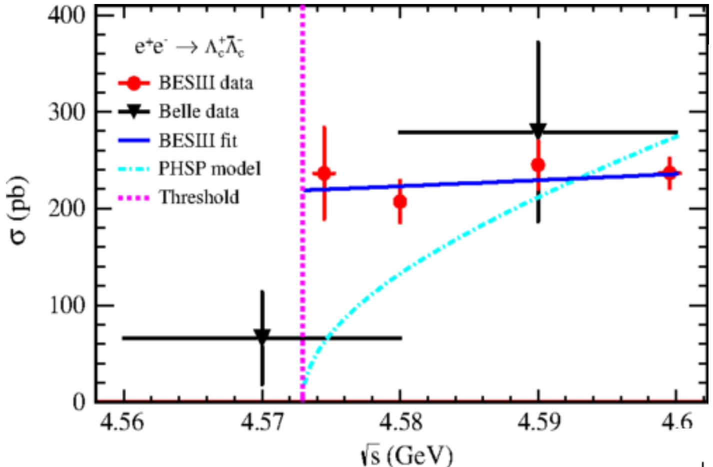
$$\mathcal{B}_i=\frac{N_{ij}^{\rm DT}}{N_j^{\rm ST}}\frac{\varepsilon_j}{\varepsilon_{ij}}$$

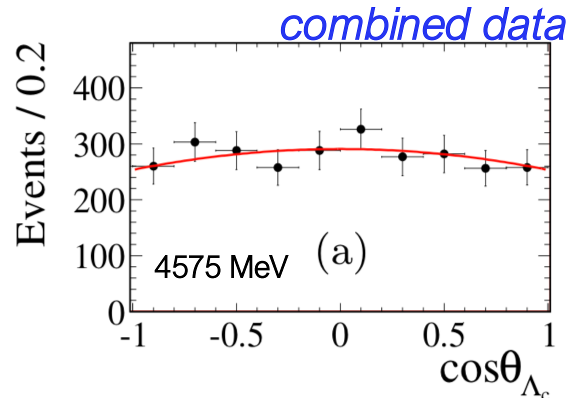
Charmed Baryons

	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	—	$\Omega_c^0\gamma$

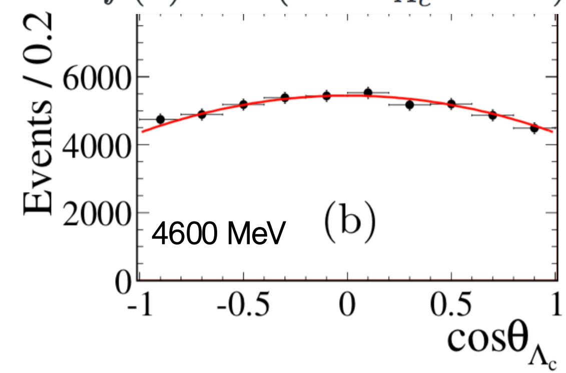
Angular dependence analysis of $e^+e^- \to \Lambda_c^+ \bar{\Lambda}_c^-$ near threshold

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^+

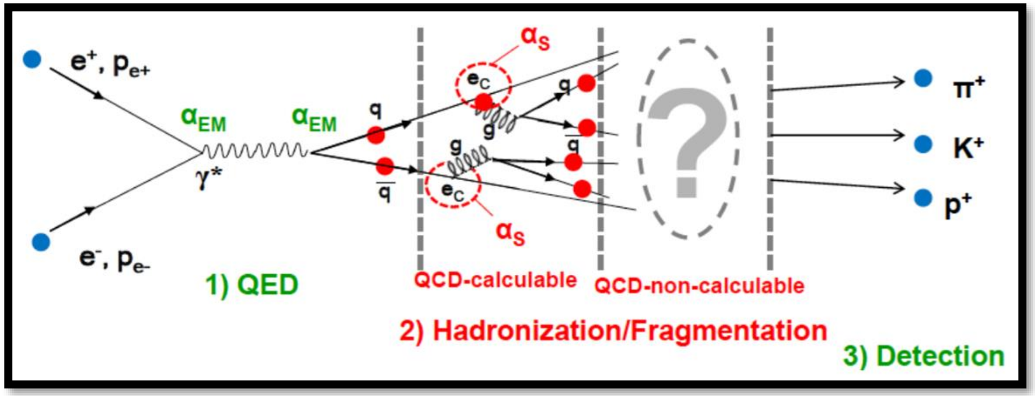
Important Input for b physics

- 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
Γ_{sl}	2.0
Lifetime ratio	2.6
PID efficiency	2.5
Subtotal	6.3
$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$	26.0
Total	26.8



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

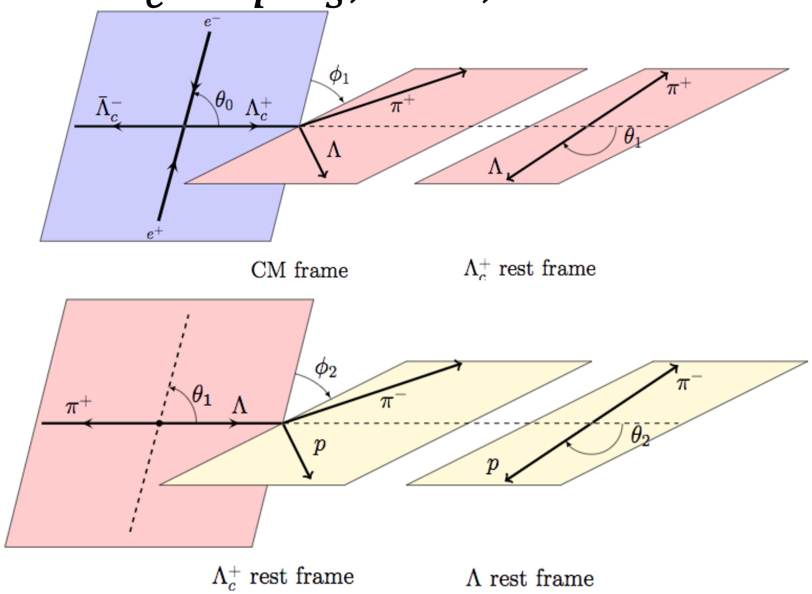
First Measurements of absolute BFs for Ξ_c

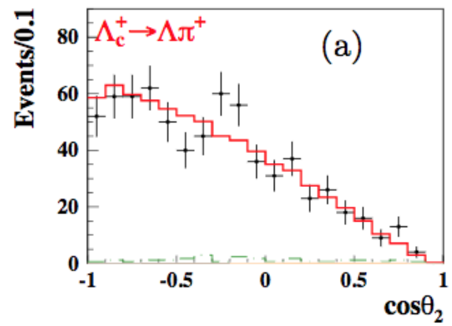
$$\mathcal{B}(\Xi_c^0 \to \Xi^-\pi^+) = (1.80 \pm 0.50 \pm 0.14)\%,$$
$$\mathcal{B}(\Xi_c^0 \to \Lambda K^-\pi^+) = (1.17 \pm 0.37 \pm 0.09)\%,$$
$$\mathcal{B}(\Xi_c^0 \to pK^-K^-\pi^+) = (0.58 \pm 0.23 \pm 0.05)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^-\pi^+\pi^+) = (2.86 \pm 1.21 \pm 0.38)\%,$$
$$\mathcal{B}(\Xi_c^+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

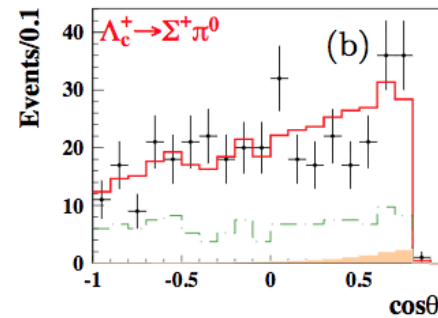
- Large errors
- Belle II will improve these to ~10%
- BESIII has potential to improve these to be <5%

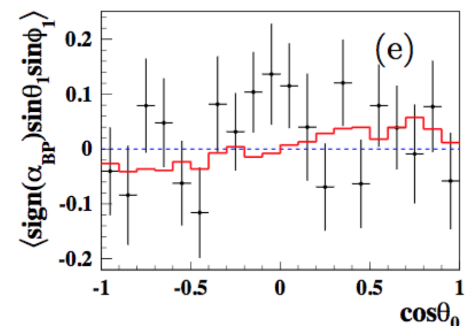
Λ_c decay asymmetries

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)**







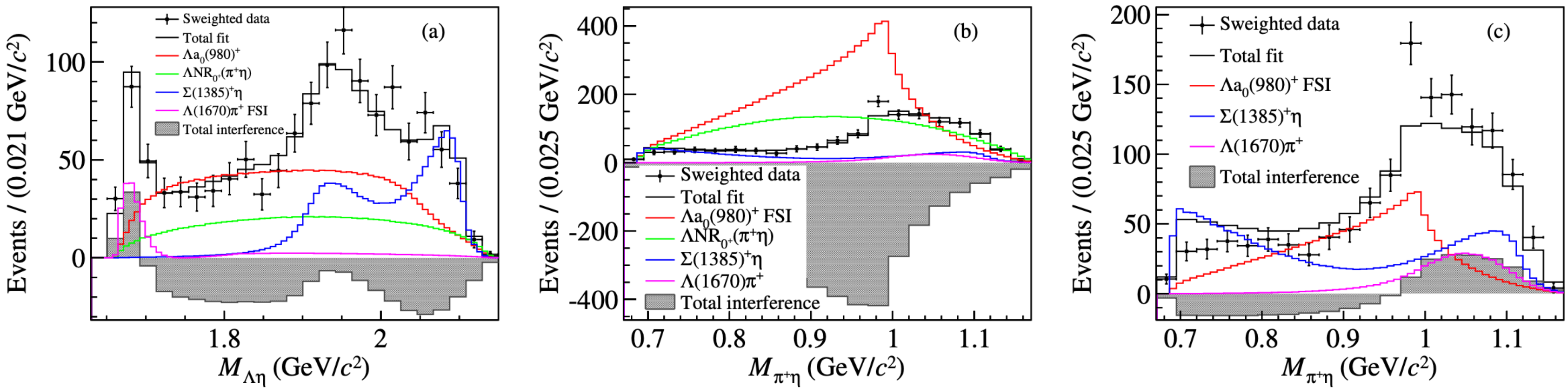


$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP}^{\Lambda_c^+}$	Predicted	−1.0 [16], 0.51 [11] −0.49 [10], −0.90 [10] −0.49 [17], −0.97 [18] −0.66 [19], −0.90 [30] −0.99 [20], −0.91 [31]	−0.70 [16], −0.67 [11] −0.95 [10], −0.99 [10] −0.96 [17], −0.95 [18] −0.99 [19], −0.86 [30] −0.99 [20], −0.94 [31]	0.71 [16], 0.92 [11] 0.79 [10] −0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], −0.76 [30] −0.31 [20], −0.47 [31]	0.70 [16], 0.92 [11] 0.78 [10], −0.49 [10] 0.83 [17], 0.43 [18] 0.39 [19], −0.76 [30] −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

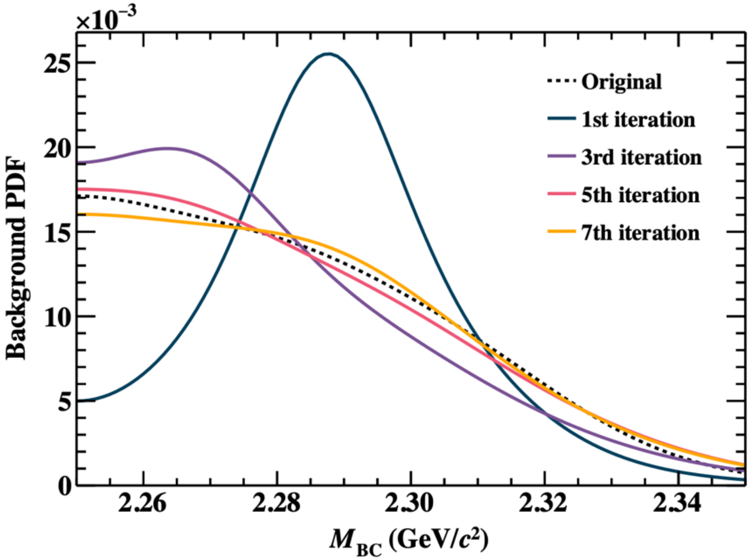
ML-boosted observation of $\Lambda_c^+ \to p\pi^0$

PRD111, L051101 (2025)

- Use Deep Neural Network (DNN) to identify $\Lambda_c^+(\to p\pi^0)\bar{\Lambda}_c^-(\to anything)$ **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

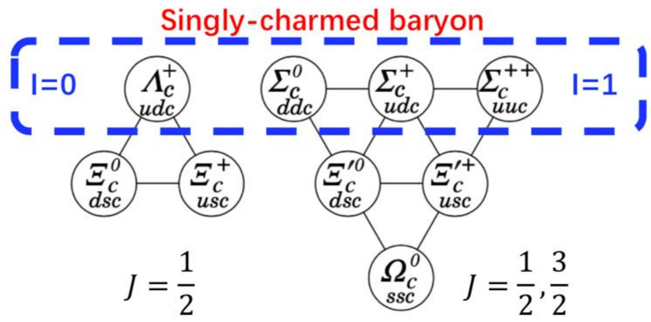
- Data augmentation
  - ✓ train $\Lambda_c^+ \to p\pi^0$ and $\Lambda_c^+ \to p\eta$ in one uniform model
  - ✓ maximum systematic cancellation
- Mass decorrelation to ease the model decoration on the signal discriminator
  - ✓ an iterative method is implemented on beam-constrained mass in background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

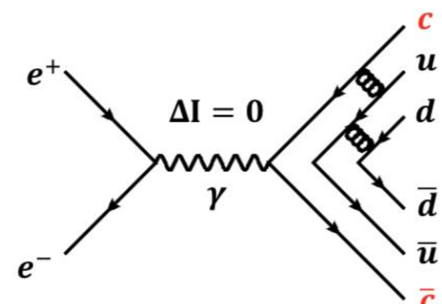
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74~4.87 GeV
- ✓ $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-(2595)(\bar{\Sigma}_c\ \pi)$ 4.88 GeV
- ✓ $e^+e^- \to \Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV
- ✓ $e^+e^- \to \Xi_c\ \bar{\Xi}_c$ 4.95 GeV



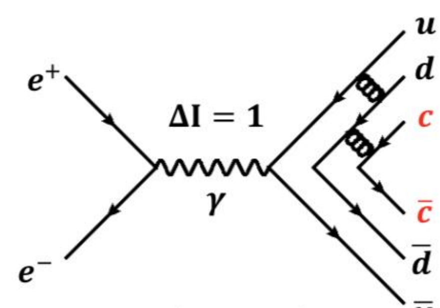
The Born cross-section **ratios** between $\Lambda_c^+\Lambda_c^- + c.c.$ and $\Lambda_c^-\Sigma_c^+ + c.c.$ at different energy points can provide more information about the production of $c\bar{c}$ or $q\bar{q}$ from vacuum.

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 $\Sigma_c^+\bar{\Sigma}_c^-$



➢ $e^+e^- \to \Lambda_c^+\Lambda_c^-$

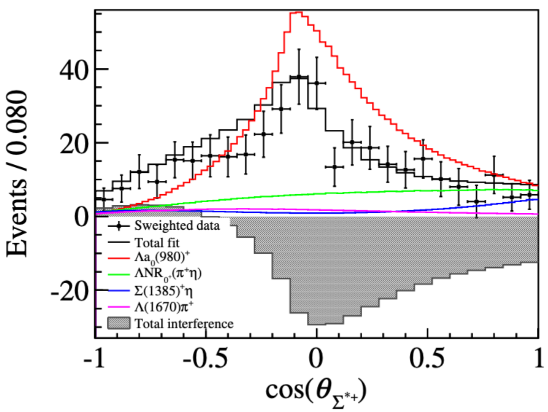


➢ $e^+e^- \to \Lambda_c^+\Sigma_c^-$

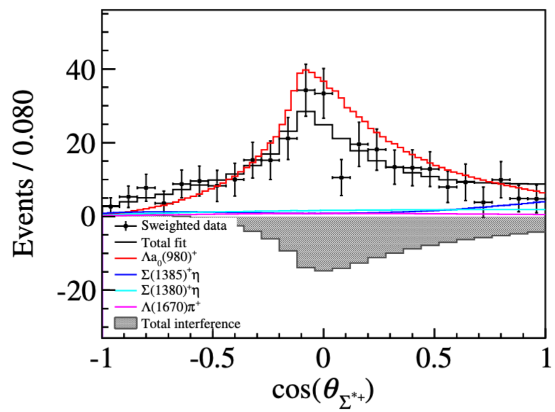
Comparison of Σ^{*+} helicity angles

PRL134, 021901 (2025)

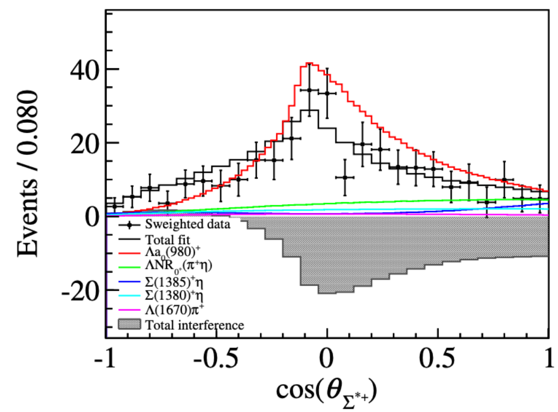
Baseline model



Model A



Model B

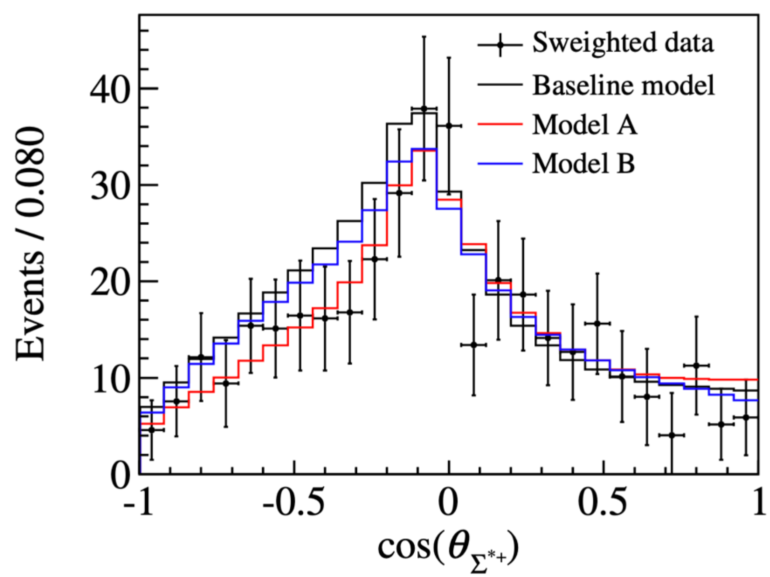


Kinematic region:

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

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

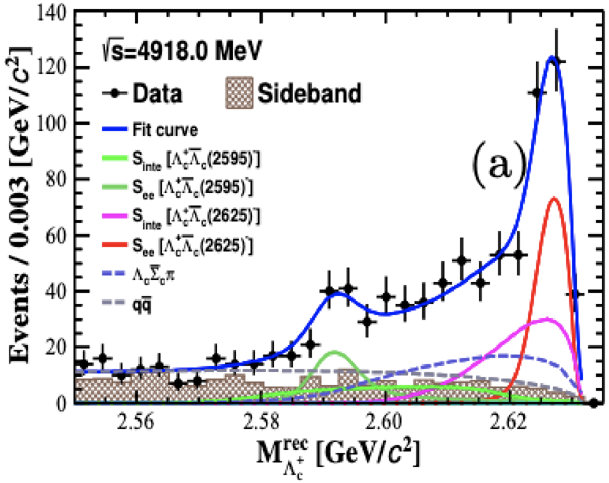
Better description of Σ^{*+} helicity angle distribution with inclusion of $\Sigma(1380)$

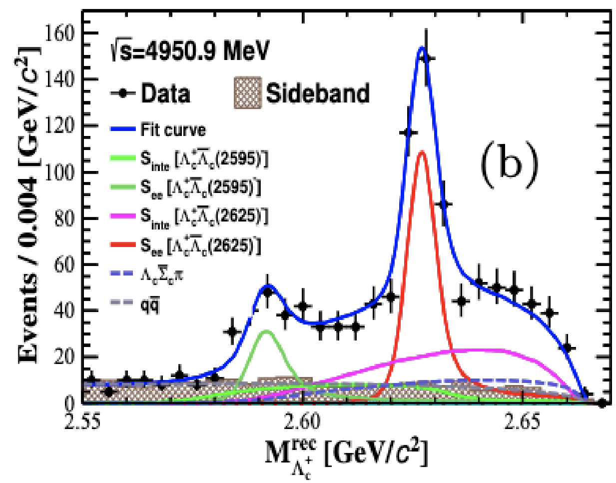


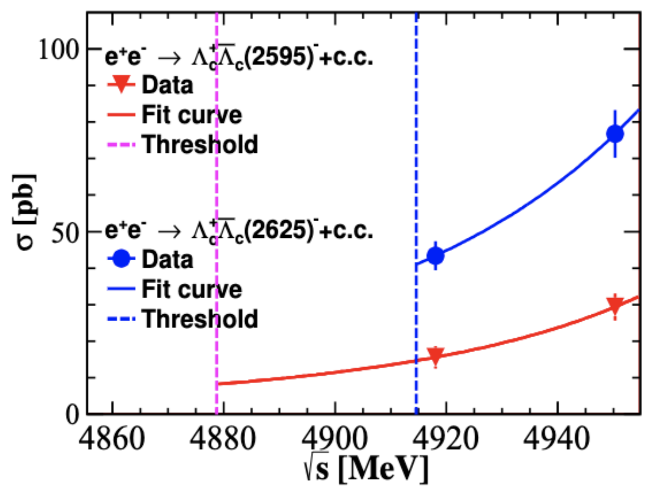
Observation of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c(2595)^-$ and $\Lambda_c^+\bar{\Lambda}_c(2625)^-$

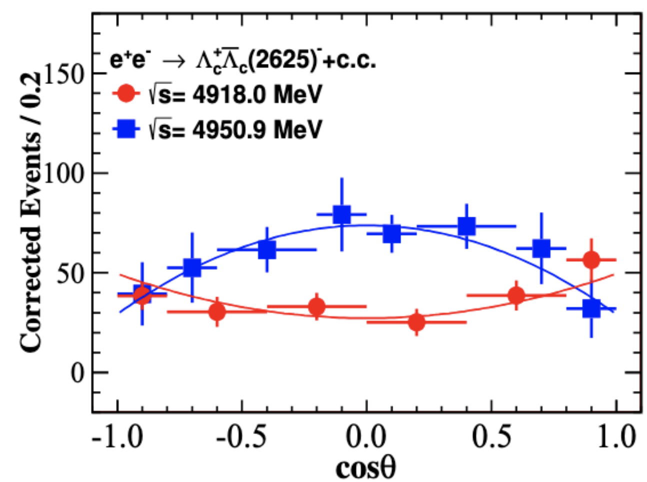
PRD 109, L071104 (2024)

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









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

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

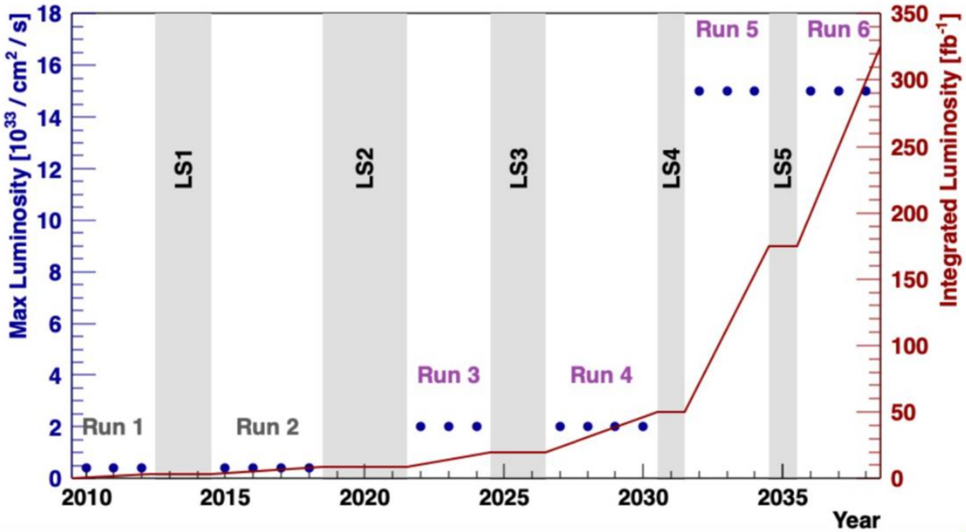
	Mode	Fraction (Γ_i/Γ)
	Cabibbo-favored ($S=-3$) decays — relative to $\Omega^-\pi^+$	
Γ_6	$\Xi^0\overline{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0K^-\pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0\overline{K}^{*0}$, $\overline{K}^{*0}\to K^-\pi^+$	0.68 ± 0.16
Γ_9	$\Omega(2012)^-\pi^+$, $\Omega(2012)^-\to\Xi^0K^-$	0.12 ± 0.05
Γ_{10}	$\Xi^-\overline{K}^0\pi^+$	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

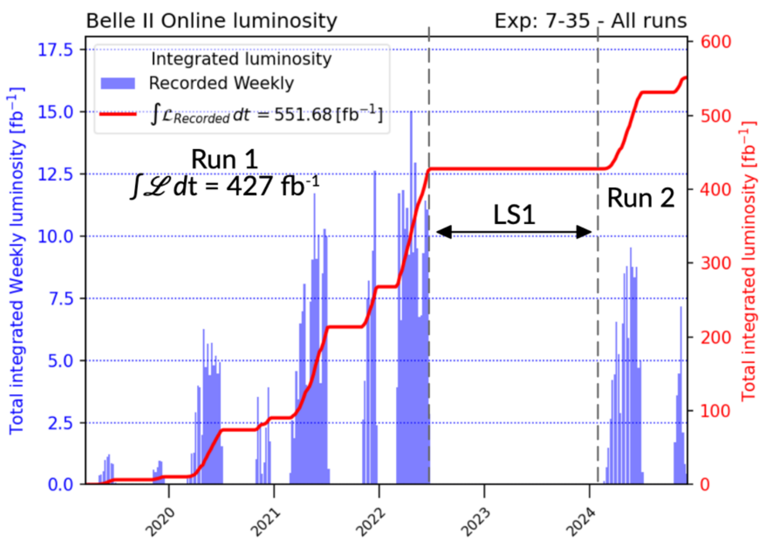
Ω_c^0 PDG2023

Future opportunity at LHCb and Belle II

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

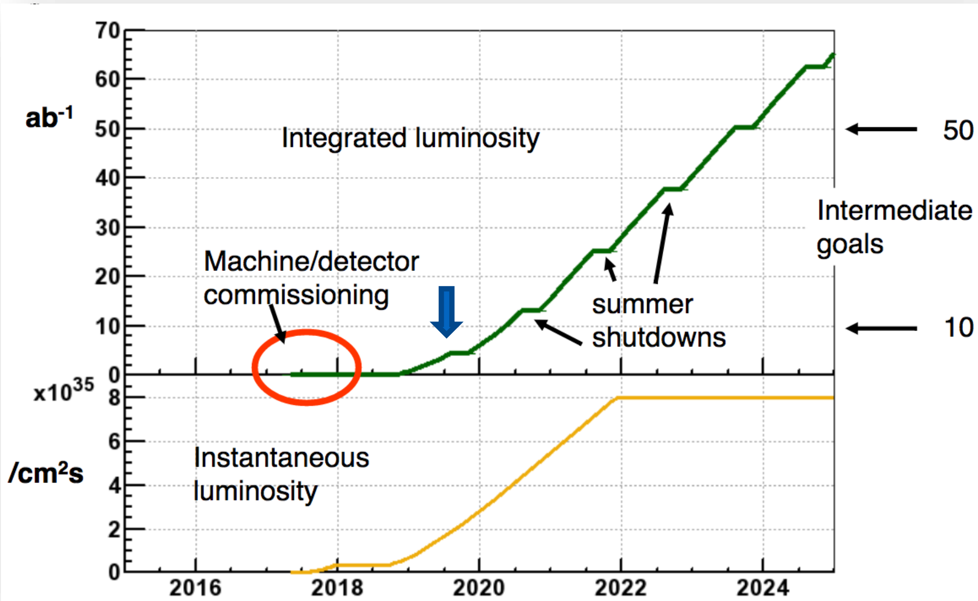
➔ x10 more statistics



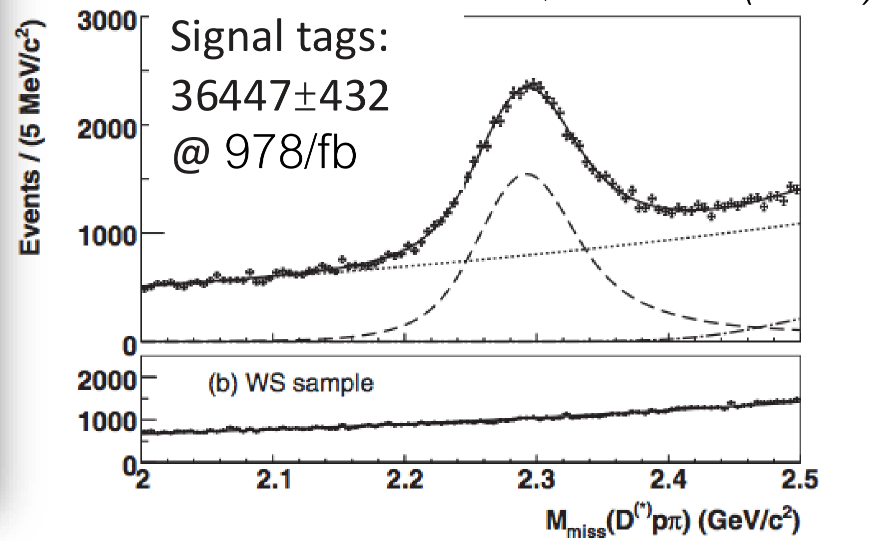


- Belle: 1 ab^{-1}
- Belle II: >0.55 ab^{-1}
- Future Belle II: 50 ab^{-1}

Competition from Belle & Belle II



Belle. PRL113, 042002 (2014)



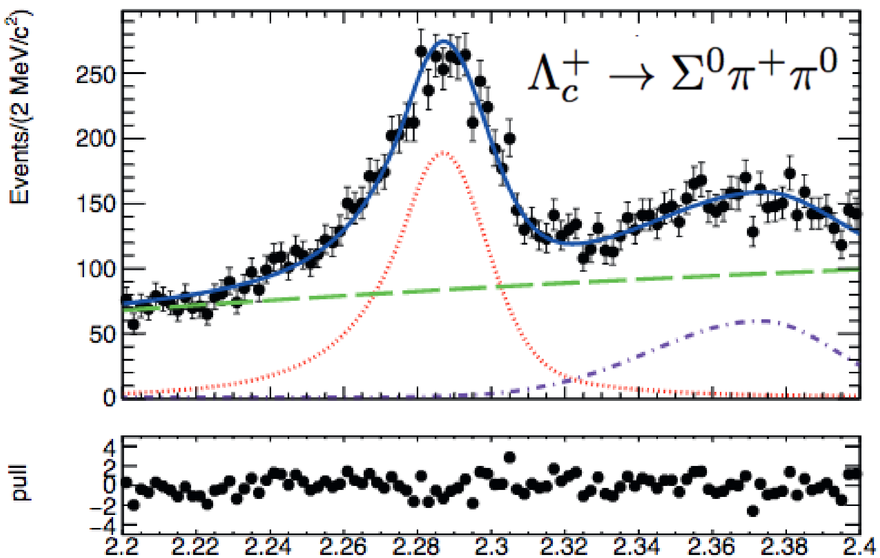
- Belle tags ~36K Λ_c^+, while BESIII now tags 15K Λ_c^+ (567/pb@4.6GeV)
- By middle of 2019, BELLEII will have 5/ab data, 5x of BELLE data;
  ➔ 180K tagged Λ_c^+;
- We will have 150K tagged Λ_c^+, however, BESIII is very clean
- Many precise measurements at BESIII will reach to the level of systematic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

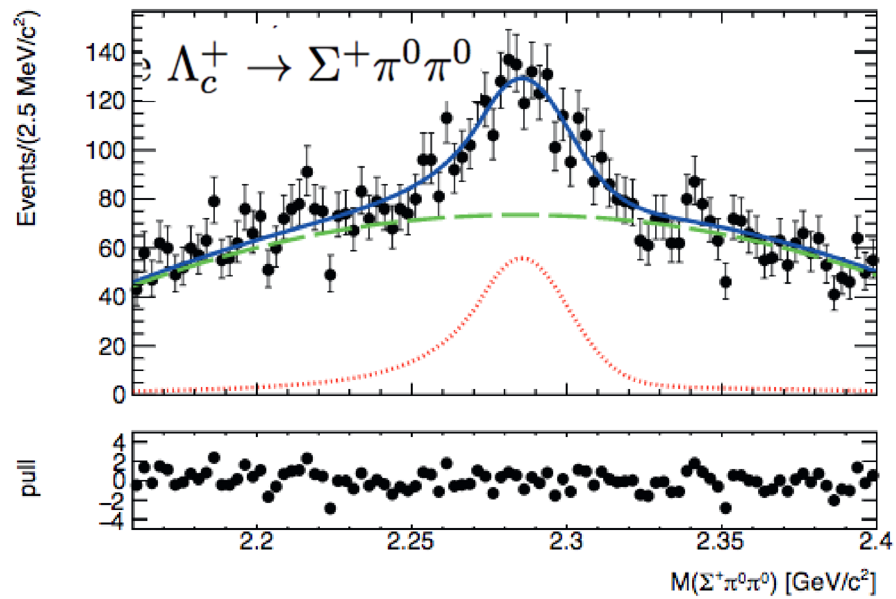
World campaign on the Λ_c^+

	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.

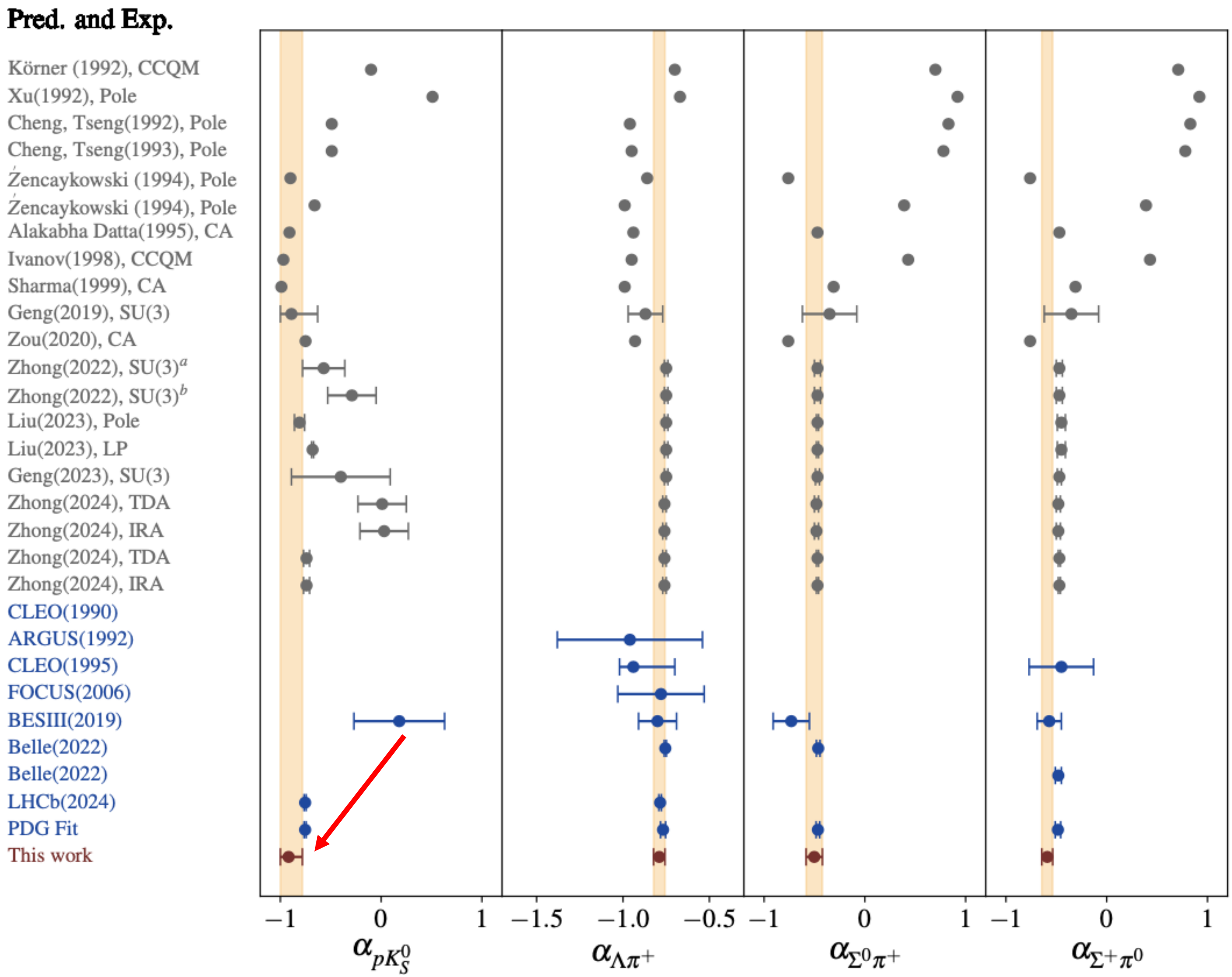
Measurement of the Decays $\Lambda_c \to \Sigma\pi\pi$ at Belle





Improved Λ_c^+ decay asymmetries

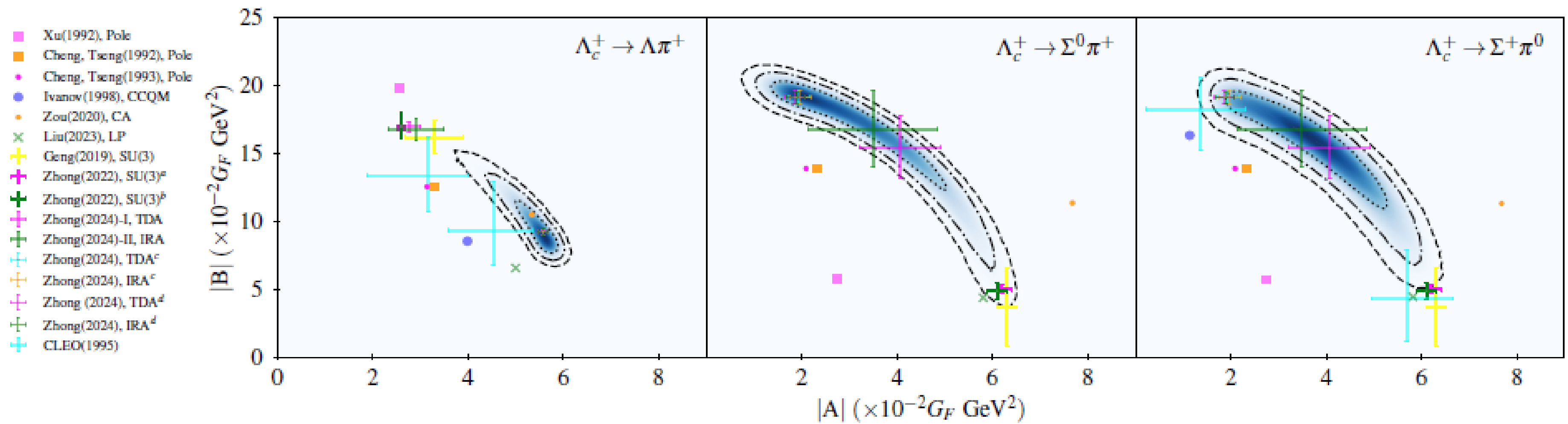
arXiv:2508.11400



Λ_c^+ decay asymmetries

arXiv:2508.11400

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)

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

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

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

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

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

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

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

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

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 $\pi^- p$ (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 $\pi^- p$ (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]	$\Lambda_c^+ \to \Xi^0 K^+$	0.01 ± 0.16	-0.64 ± 0.70	3.84 ± 0.90	$-1.55(1.59) \pm 0.25$[b]	+1	$-1.55(1.59) \pm 0.25$	$1.59(-1.55) \pm 0.25$