Charmed baryon decays at BESIII

Jiajia Qin(USC)

On behalf of the BESIII Collaboration

EPS-HEP 2025

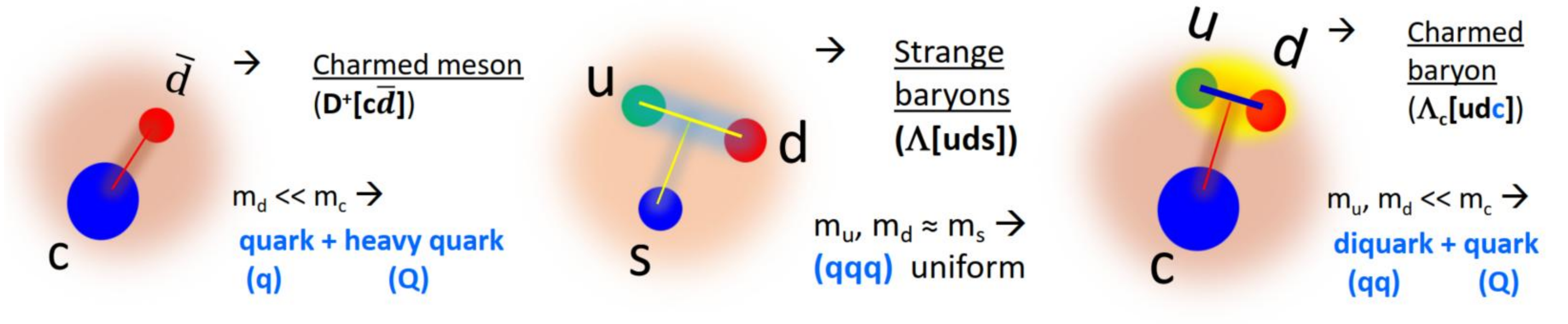
09th July 2025 @Marseille

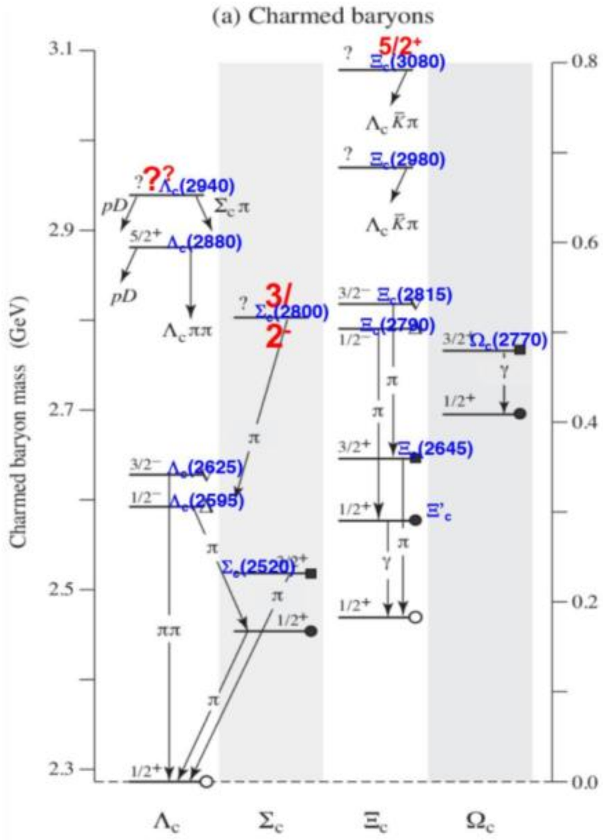
Outline

- Introduction
- BESIII experiment
- Λ_c^+ new results
  - Hadronic decays
  - Semi-leptonic decays
- Summary

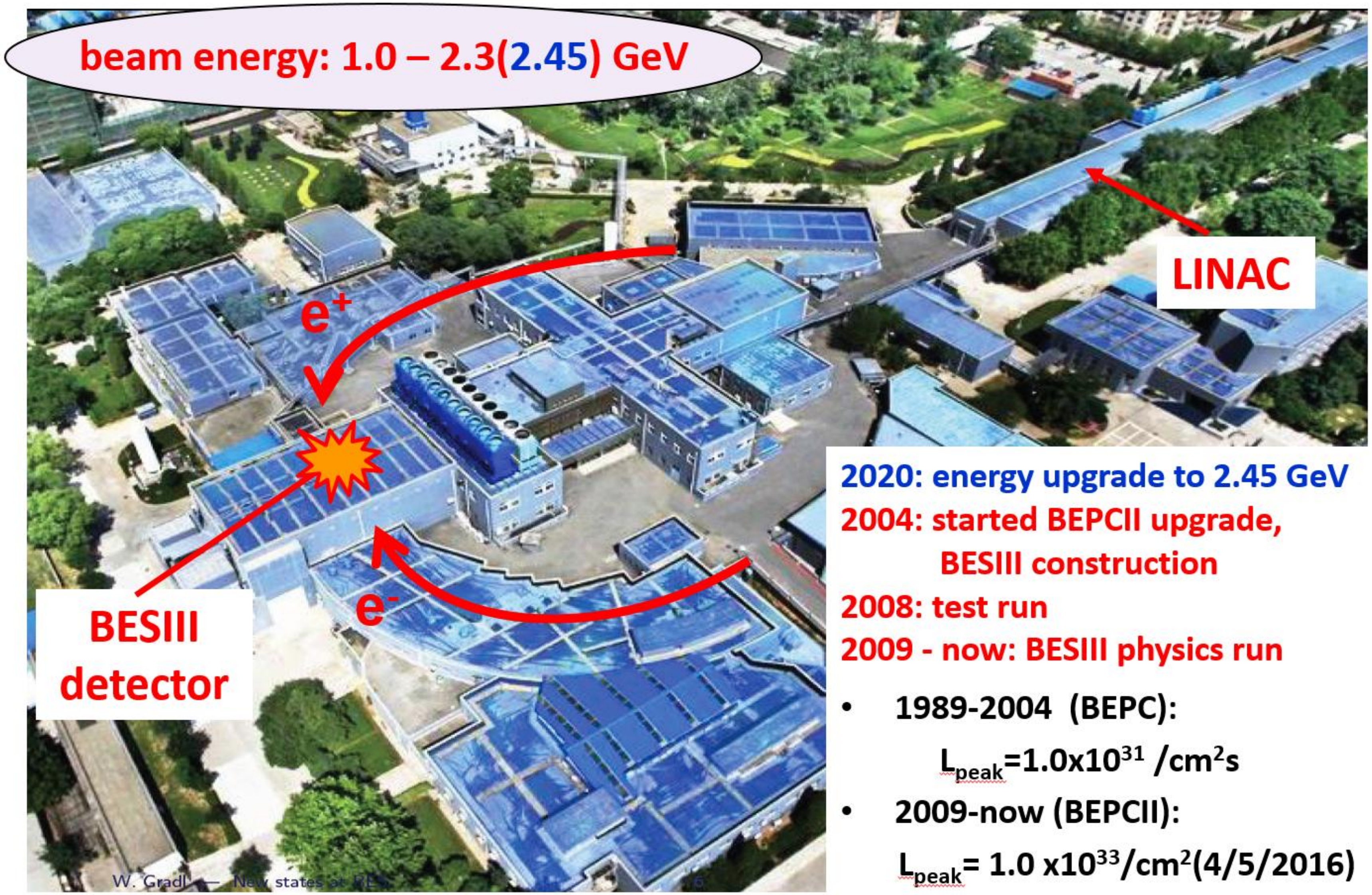
Introduction

- Λ_c^+ is the ground state charmed baryon, >40 years, characteristics still not very clear.
- Provides important information to understand strong and weak interactions.
- Most of the charmed baryons will eventually decay to Λ_c^+.
- Complementary to charmed mesons.
- Calculation is difficult, many phenomenology methods are developed, most need experimental results input.



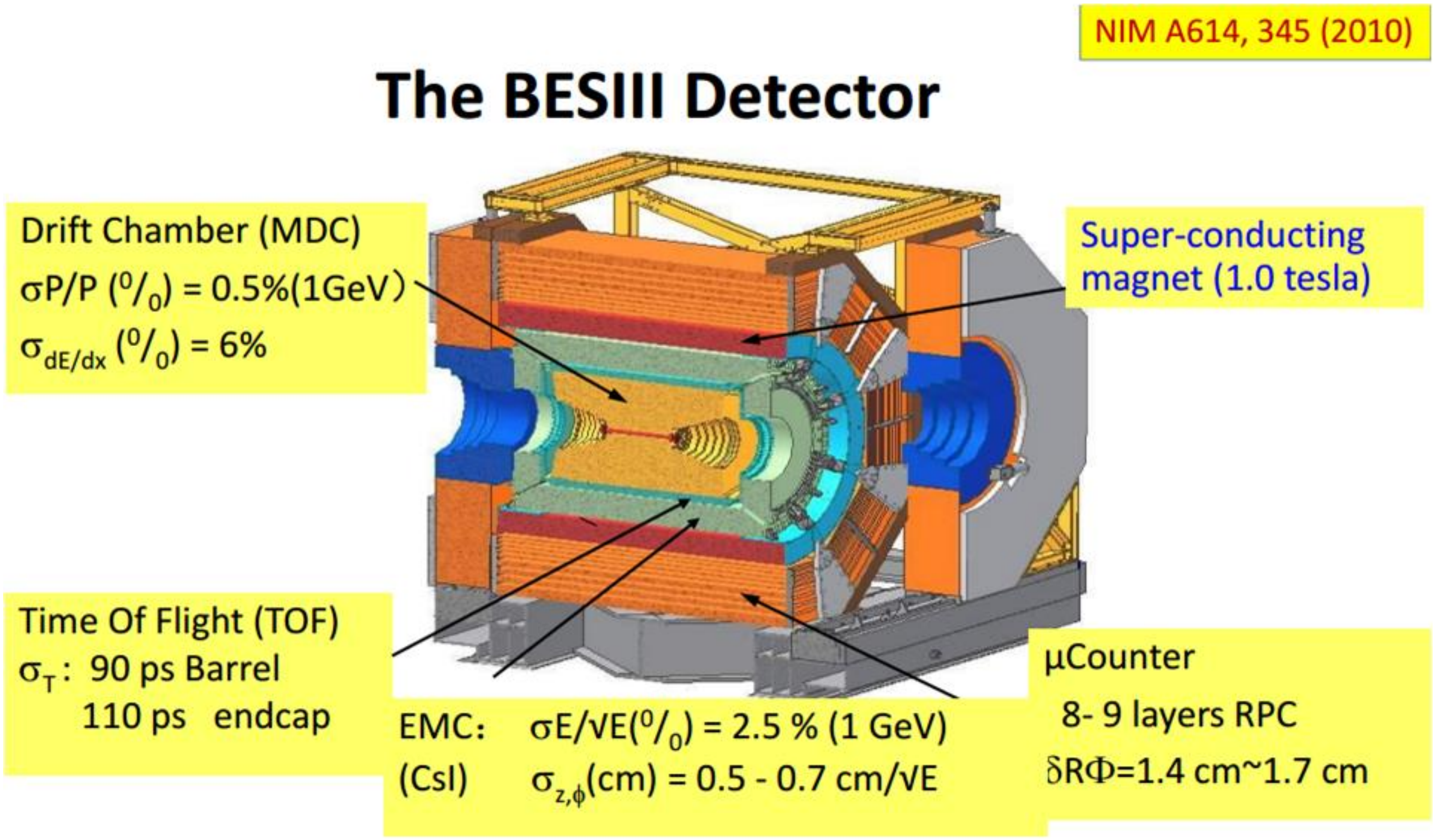


BEPCII



beam energy: 1.0 – 2.3(2.45) GeV
LINAC
e^+
e^-
BESIII detector
2020: energy upgrade to 2.45 GeV
2004: started BEPCII upgrade, BESIII construction
2008: test run
2009 - now: BESIII physics run
• 1989-2004 (BEPC):
L_{peak}=1.0x10^{31} /cm^{2}s
• 2009-now (BEPCII):
L_{peak}= 1.0 x10^{33}/cm^2(4/5/2016)

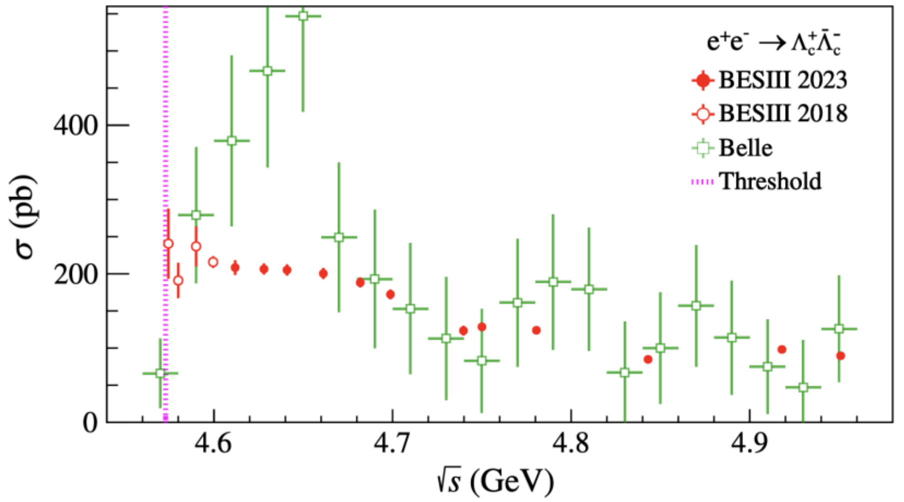
BESIII detector



Data samples

- Totally about 50 fb^{-1} from 2.0-4.95 GeV
- Data for charmed baryon studies
  - ✓ 0.567 fb^{-1} @4.6 GeV in 2014
  - ✓ 3.9 fb^{-1} 4.61-4.70 GeV scan data in 2020-2021
  - ✓ 1.9 fb^{-1} 4.74-4.95 GeV scan data 2021-2022
  - ✓ Totally ~6.4 fb^{-1} data from 13 energy points, ~1million pairs

PRL **131**, 191901 (2023)

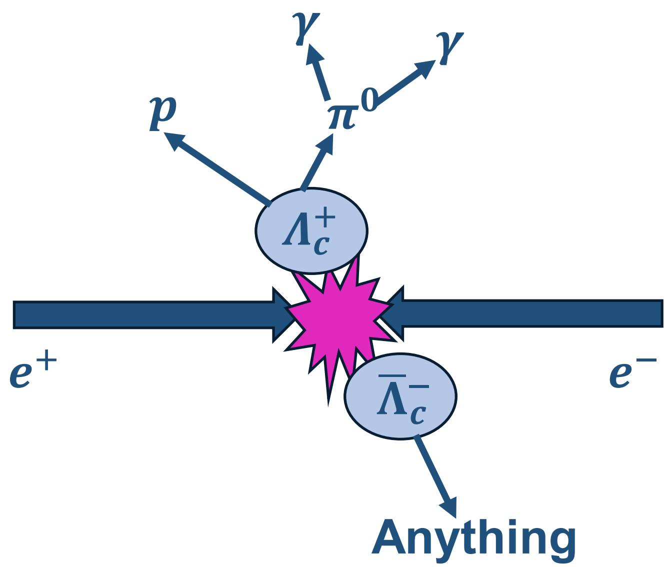


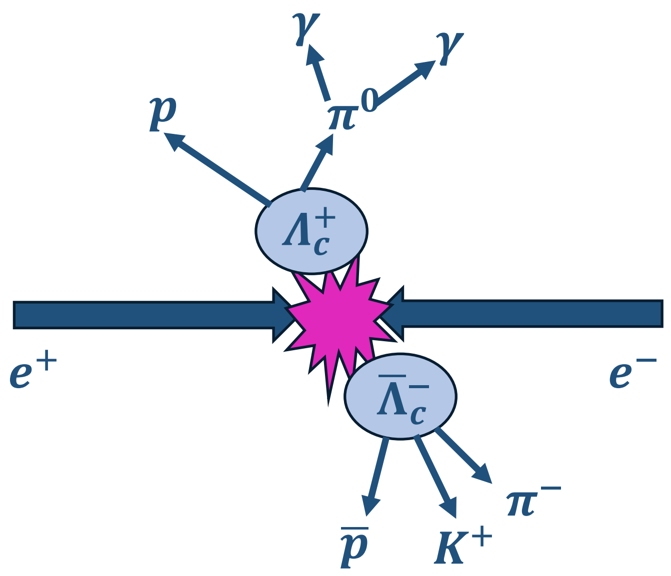
CPC **46**, 113003 (2022)

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

Unique abilities in Λ_c^+ decays

- Single-Tag method (ST)
  - ✓ High efficiency vs High background
- Double-Tag method (DT)
  - ✓ Low background vs low efficiency
  - ✓ Absolute BFs
  - ✓ Missing particles
- Deep learning method
  - ✓ Powerful vs validation
  - ✓ Event level topology
  - ✓ Two missing particles
  - ✓ …

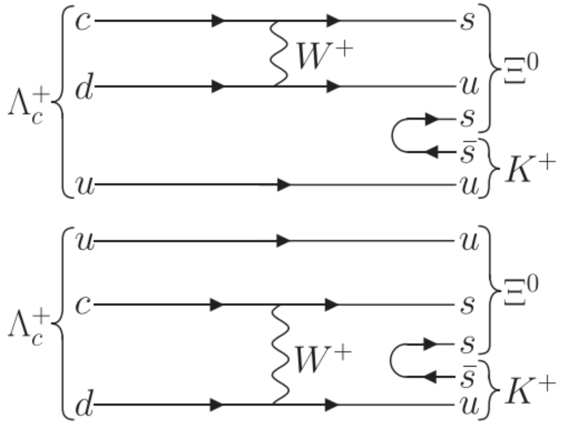


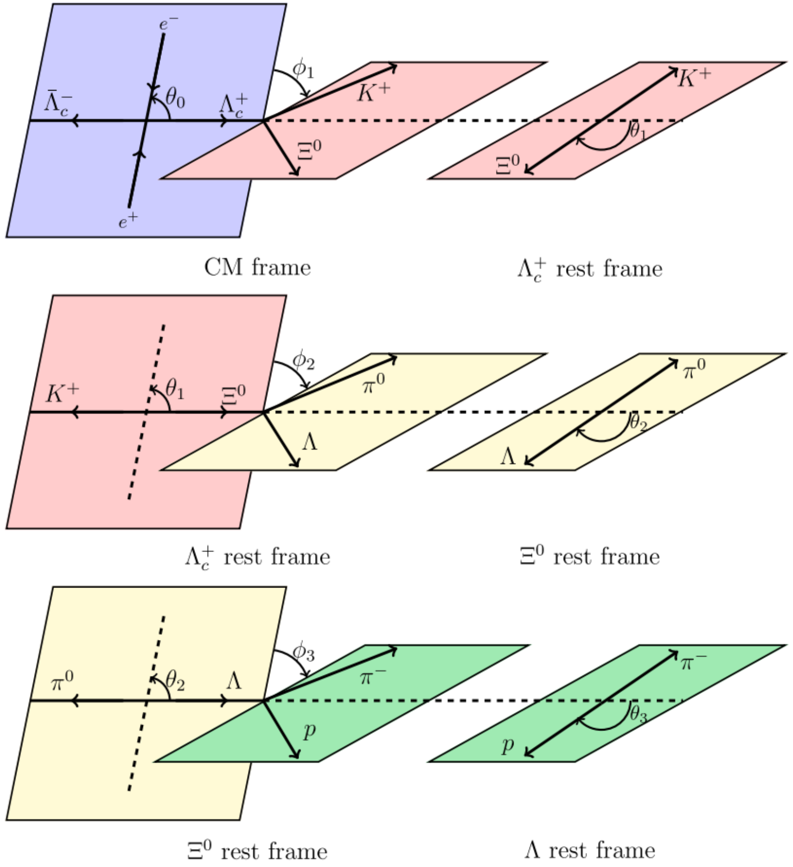


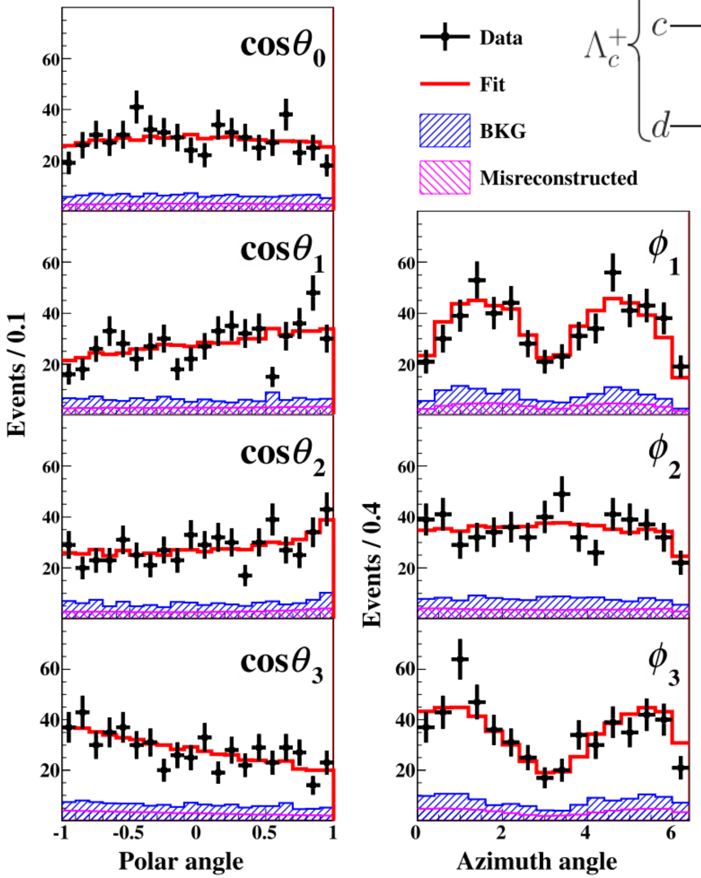
$\Lambda_c^+ \to \Xi^0 K^+$

Physical Review L 132,031801(2024)

- Pure W-exchange process
  - Only receives non-factorizable contribution
  - Longstanding puzzle on how large the S-wave amplitude
- Multidimensional angular fit using helicity basis







$\Lambda_c^+ \to \Xi^0 K^+$

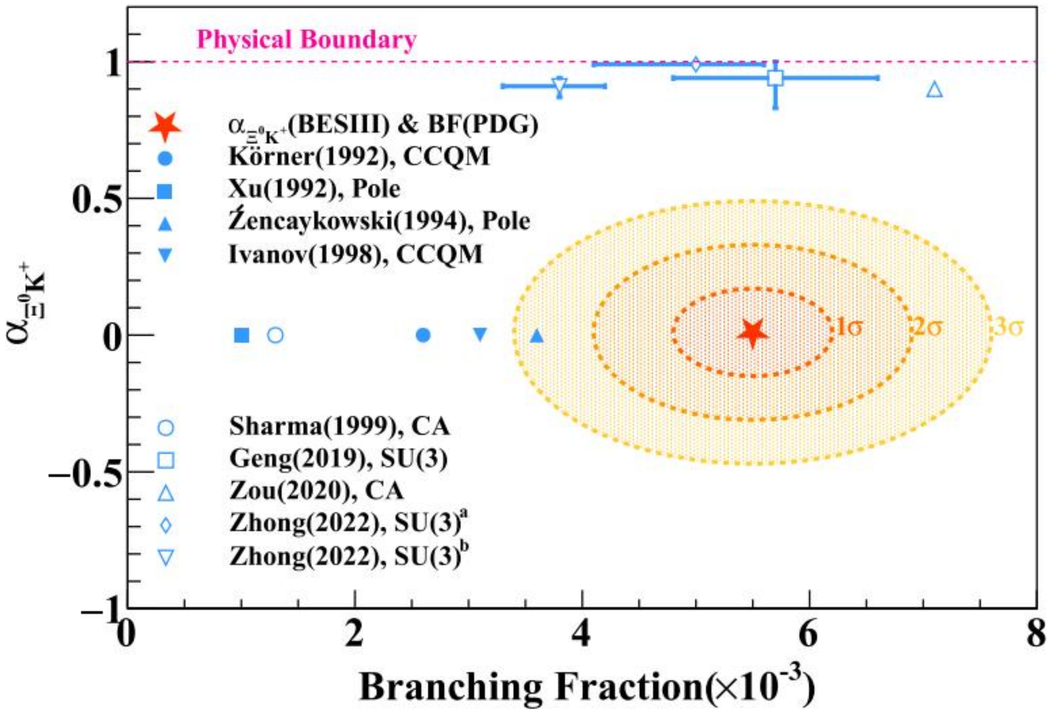
Physical Review L 132,031801(2024)

- Decay asymmetry results
  - ✓ $\alpha_{\Xi^0 K^+} = 0.01 \pm 0.16 \pm 0.03$
  - ✓ $\Delta_{\Xi^0 K^+} = 3.84 \pm 0.90 \pm 0.17$ rad
  - ✓ $\beta_{\Xi^0 K^+} = -0.64 \pm 0.69 \pm 0.13$
  - ✓ $\gamma_{\Xi^0 K^+} = -0.77 \pm 0.58 \pm 0.11$

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

$$\beta = \sqrt{1-\alpha^2} sin\Delta \qquad \gamma = \sqrt{1-\alpha^2} cos\Delta$$

- Phase difference between S and P-waves
  - ✓ Solution1: $\delta_p - \delta_S = -1.55 \pm 0.25 \pm 0.05$ rad
  - ✓ Solution2: $\delta_p - \delta_S = 1.59 \pm 0.25 \pm 0.05$ rad



- $\alpha_{\Xi^0 K^+}$ in good agreement with zero, providing strong identification for theoretical predictions
- $\cos(\delta_p - \delta_S)$ close to zero, which is not considered in previous literature
- Fill the long-standing puzzle on how to model $\alpha_{\Xi^0 K^+}$, and $\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$ simultaneously

$\Lambda_c^+ \to \Xi^0 K^+$

SU(3) include contributions from penguin diagrams:

Zhi-Peng Xing, Yu-ji Shi, Jin Sun and Ye Xing, Eur. Phys. J. C (2024) 84:1014

Prediction (Case I)		Prediction (Case II)			
Br(%)	α	Br(%)	α	β	γ
0.544(52)	−0.067(89)	0.455(39)	−0.05(16)	0.15(59)	0.988(87)

SU(3) consider two more form factors:

Jin Sun, Zhi-Peng Xing and Ruilin Zhu, Eur. Phys. J. C (2025) 85:262

Case I		Case II			
Br (%)	α	Br (%)	α	β	γ
0.423(29)	0.957(18)	0.555(70)	0.04(15)	0.37(88)	0.93(36)

Case II (complex form factors) seems better

$\Lambda_c^+ \to \Xi^0 K^+$

Light-cone sum rules:

Yu-ji Shi and Zhen-Xing Zhao, Phys. Rev. D 110, 096015 (2024)

$\alpha_{\Xi^0 K^+}$	$\mathcal{B}(\Lambda_c^+ \to \Xi^0 K^+)$
-0.09 ± 0.18	3.6 ± 1.0

All $\alpha_{\Xi^0 K^+}$ consistent with 0, but all with lower $\mathcal{B}$

SU(3) take both branching fractions and decay asymmetries as input data:

Chao-Qiang Geng, Xiao-Gang He, Xiang-nan Jin, Chai-Wei Liu and Chang Yang, Phys. Rev. D 109, L071302 (2024)

$\mathcal{B}_{exp}(\%)$	α_{exp}	$\mathcal{B}(\%)$	α	β	γ
**0.55(7)	0.01(16)	0.40(3)	−0.15(14)	−0.29(22)	0.94(7)

$\delta_p - \delta_s = -2.06 \pm 0.50$ rad

Hai-Yang Cheng, Fanrong Xu and Huiling Zhong, Phys. Rev. D 111, 034011 (2025) +LHCb new results

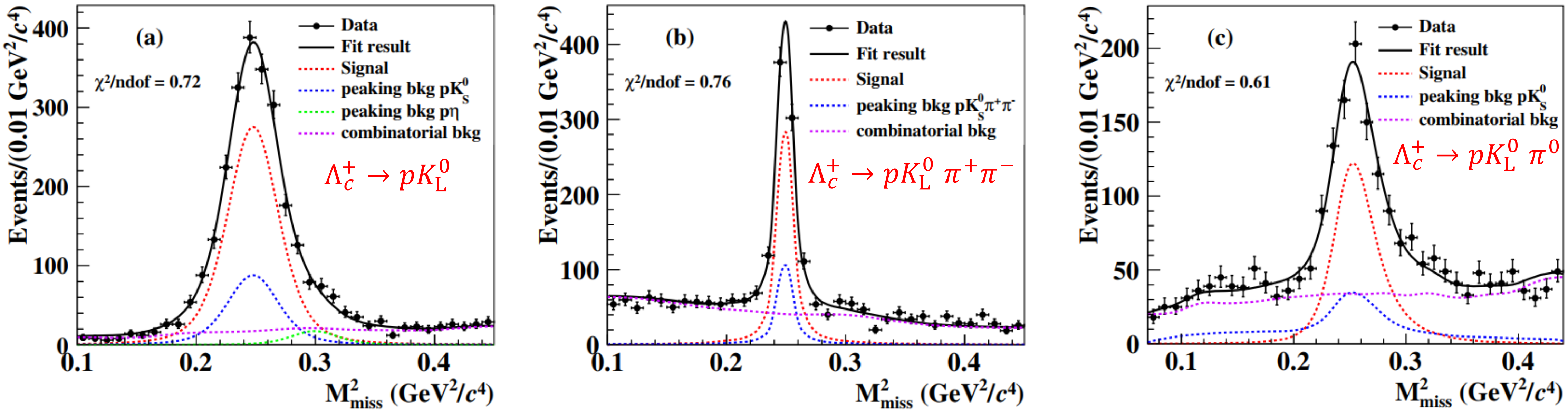
$10^2\mathcal{B}$	α	β	γ	$\lvert A\rvert$	$\lvert B\rvert$	$\delta_P - \delta_S$	$10^2\mathcal{B}_{exp}$	α_{exp}
0.34 ± 0.03	-0.04 ± 0.12	-0.98 ± 0.02	0.19 ± 0.09	2.76 ± 0.18	9.71 ± 0.47	-1.61 ± 0.12	0.55 ± 0.07	0.01 ± 0.16
0.34 ± 0.03	-0.06 ± 0.12	-0.98 ± 0.02	0.19 ± 0.09	2.77 ± 0.18	9.75 ± 0.46	-1.63 ± 0.12		
0.33 ± 0.03	-0.08 ± 0.12	-0.98 ± 0.02	0.18 ± 0.09	2.72 ± 0.18	9.69 ± 0.47	-1.65 ± 0.12	0.55 ± 0.07	0.01 ± 0.16
0.33 ± 0.03	-0.07 ± 0.11	-0.98 ± 0.02	0.18 ± 0.09	2.72 ± 0.18	9.69 ± 0.46	-1.64 ± 0.11		

All prefer solution1: $\delta_p - \delta_s = -1.55 \pm 0.25 \pm 0.05$ rad

$\Lambda_c^+ \to pK^0_{L,S}, pK^0_{L,S}\pi^+\pi^-$ and $pK^0_{L,S}\pi^0$

JHEP 09 (2024) 007

- $K_S^0 - K_L^0$ asymmetry offer possibility to DCS decays:
  - ✓ The ratio of amplitudes for CF and DCS is expected to be proportional to $|V_{ud}^* V_{cs} / V_{us}^* V_{cd}|$
  - ✓ DCS are rare to directly observe
  - ✓ $K_S^0 - K_L^0$ asymmetry arises from interference of CF and DCS, provide new way to indirect search for DCS
  - ✓ Non-zero asymmetry value indicates existence of DCS decays
- It has been studied in charmed mesons, but never in Λ_c^+



$\Lambda_c^+ \to pK^0_{L,S}, pK^0_{L,S}\pi^+\pi^-$ and $pK^0_{L,S}\pi^0$

JHEP 09 (2024) 007

$$R(\Lambda_c^+, K^0_{S,L}X) = \frac{\mathcal{B}(\Lambda_c^+ \to K^0_S X) - \mathcal{B}(\Lambda_c^+ \to K^0_L X)}{\mathcal{B}(\Lambda_c^+ \to K^0_S X) + \mathcal{B}(\Lambda_c^+ \to K^0_L X)}$$

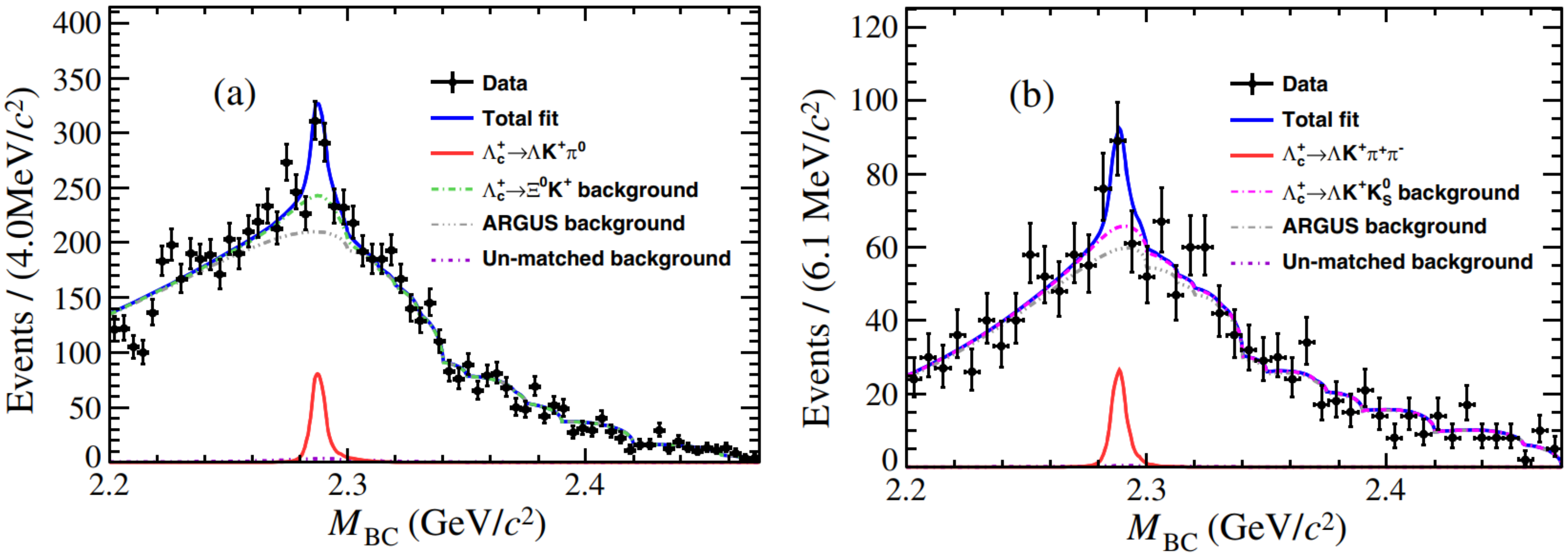
Mode	$\mathcal{B}(\Lambda_c^+ \to K^0_L X)$ (%)	$\mathcal{B}(\Lambda_c^+ \to K^0_S X)$ (%) [22]	$R(\Lambda_c^+, K^0_{L,S}X)$
$\Lambda_c^+ \to pK^0_{L,S}$	$1.67 \pm 0.06 \pm 0.04$	1.59 ± 0.07	-0.025 ± 0.031
$\Lambda_c^+ \to pK^0_{L,S}\pi^+\pi^-$	$1.69 \pm 0.10 \pm 0.05$	1.60 ± 0.11	-0.027 ± 0.048
$\Lambda_c^+ \to pK^0_{L,S}\pi^0$	$2.02 \pm 0.13 \pm 0.05$	1.96 ± 0.12	-0.015 ± 0.046

- No obvious asymmetry is observed in any of the three decays
- $R(\Lambda_c^+, K^0_{S,L}X)$ in $\Lambda_c^+ \to pK^0_{L,S}$ is compatible with SU(3) prediction of (-0.010,0.087)

$\Lambda_c^+ \to \Lambda/\Sigma K^+\pi^0$ & $\Lambda_c^+ \to \Lambda/\Sigma K^+\pi^+\pi^-$

Physical Review D 109, 032003 (2024)
Chinese Physics C Vol. 49, No. 8 (2025)

- Singly Cabibbo-suppressed decays with $10^{-4} - 10^{-3}$ branching fraction
- All involve internal W-emission and W-exchange contributions
- ST method used
  - ✓ First observation of $\Lambda_c^+ \to \Lambda K^+\pi^0 (5.7\sigma)$ and evidence of $\Lambda_c^+ \to \Lambda K^+\pi^+\pi^- (3.1\sigma)$



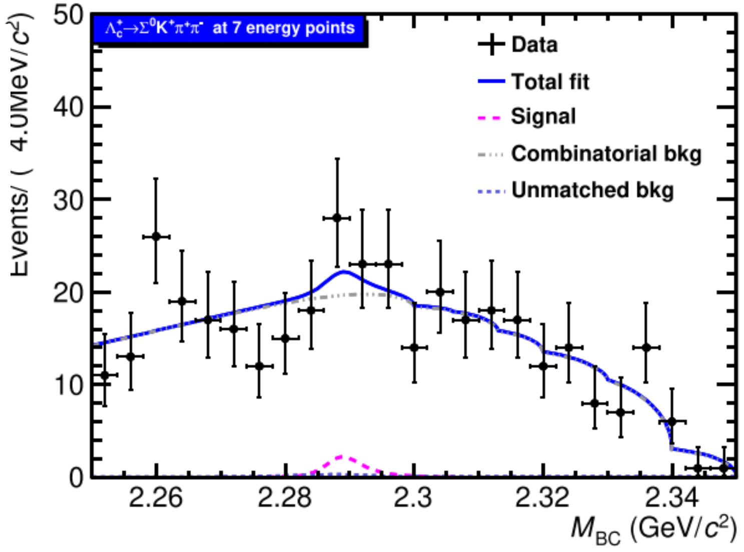
- $\mathcal{B}(\Lambda_c^+ \to \Lambda K^+\pi^0) = (1.49 \pm 0.27 \pm 0.05 \pm 0.08) \times 10^{-3}$, deviates from SU(3) predictions $(4.5 \pm 0.8) \times 10^{-3}$ and $(3.5 \pm 0.6) \times 10^{-3}$ by 3.5σ and 3.0σ.
- $\mathcal{B}(\Lambda_c^+ \to \Lambda K^+\pi^+\pi^-) = (4.13 \pm 1.48 \pm 0.20 \pm 0.33) \times 10^{-4}$, consistent with BaBar's result.

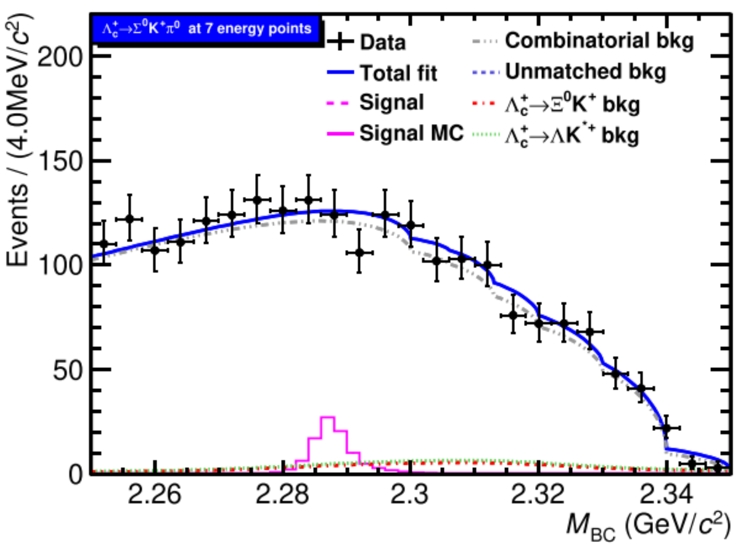
$\Lambda_c^+ \to \Lambda/\Sigma K^+\pi^0$ & $\Lambda_c^+ \to \Lambda/\Sigma K^+\pi^+\pi^-$

Physical Review D 109, 032003 (2024)
Chinese Physics C Vol. 49, No. 8 (2025)

- Singly Cabibbo-suppressed decays with $10^{-4} - 10^{-3}$ branching fraction
- All involve internal W-emission and W-exchange contributions
- ST method used
  - ✓ First observation of $\Lambda_c^+ \to \Lambda K^+\pi^0 (5.7\sigma)$ and evidence of $\Lambda_c^+ \to \Lambda K^+\pi^+\pi^- (3.1\sigma)$
  - ✓ Upper limit of $\Lambda_c^+ \to \Sigma K^+\pi^0$ and $\Sigma K^+\pi^+\pi^-$

Decay mode	$\Lambda_c^+ \to \Sigma^0 K^+\pi^0$	$\Lambda_c^+ \to \Sigma^0 K^+\pi^+\pi^-$
M.Gronau *et al.* [10]	$(2.1\pm0.6)\times10^{-3}$	-
C.Q.Geng *et al.* [7]	$(1.2\pm0.3)\times10^{-3}$	-
J.Y.Cen *et al.* [8]	$(7.8\pm2.3)\times10^{-4}$	-
C.Q.Geng *et al.* [9]	$(8.2\pm1.4)\times10^{-4}$	-
BESIII (double-tag) [11]	$<1.8\times10^{-3}$	-
BaBar experiment [12]	-	$<2.5\times10^{-4}$
BESIII (single-tag)	$<5.0\times10^{-4}$	$<6.5\times10^{-4}$



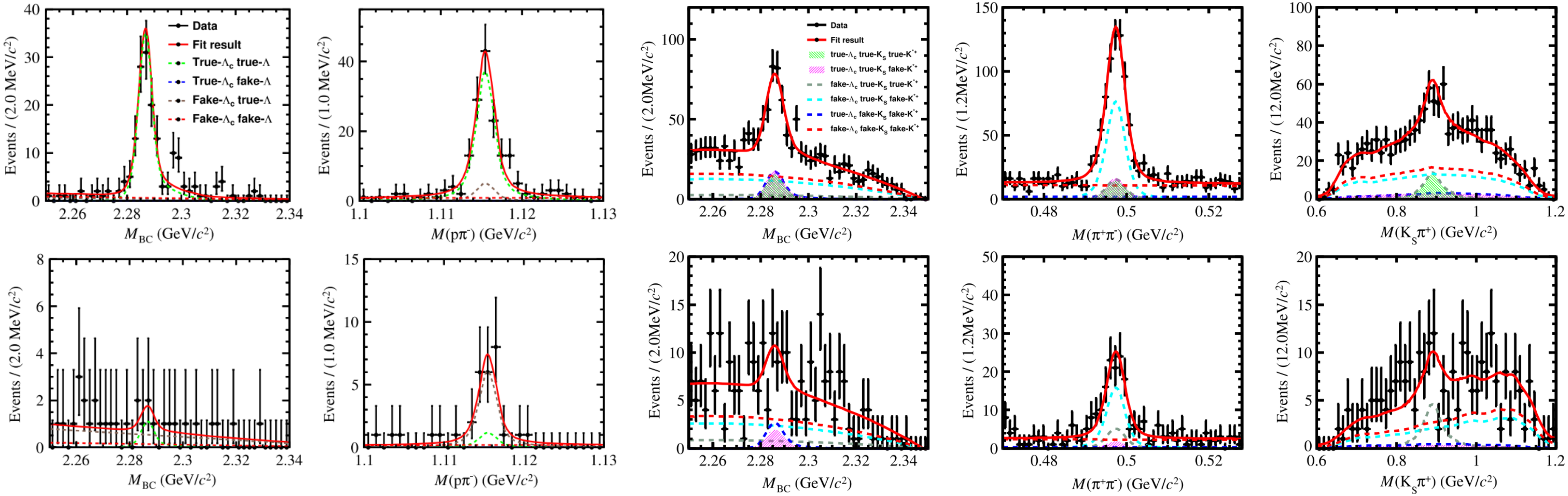


- $\mathcal{B}(\Lambda_c^+ \to \Sigma K^+\pi^0)$ lower than SU(3) by ~2σ and than statistical isospin model by ~3σ
- $\mathcal{B}(\Lambda_c^+ \to \Sigma K^+\pi^+\pi^-)$ less stringent than BaBar's result

$\Lambda_c^+ \to \Lambda K_S^0 K^+ / \Lambda K_S^0 \pi^+ / \Lambda K^{*+}$

Physical Review D 111, 012014 (2025)

- Inclusive $\mathcal{B}(\Lambda_c^+ \to \Lambda X) = (38.2^{+2.8}_{-2.2} \pm 0.9)\%$ vs known exclusive $(30.4 \pm 1.3)\%$
- Inclusive $\mathcal{B}(\Lambda_c^+ \to K_S^0 X) = (9.9 \pm 0.6 \pm 0.4)\%$ vs known exclusive $(8.1 \pm 0.4)\%$
- All involve internal W-emission and W-exchange contributions
- 2-D fit of $M_{\rm BC}, M(p\pi^-)$ for $\Lambda_c^+ \to \Lambda K_S^0 K^+$
- 3-D fit of $M_{\rm BC}, M(\pi^+\pi^-)$ and $M(K_S^0\pi^+)$ for $\Lambda_c^+ \to \Lambda K_S^0 \pi^+$, under three assumptions of interference between the NR and ΛK^{*+}



$\Lambda_c^+ \to \Lambda K_S^0 K^+ / \Lambda K_S^0 \pi^+ / \Lambda K^{*+}$

Physical Review D 111, 012014 (2025)

Decay mode (10^{-3})		This work	PDG [6]	Theory
$\Lambda K_S^0 K^+$		$3.04 \pm 0.30 \pm 0.16$	2.85 ± 0.55	2.8 ± 0.6 [7]
				2.7 ± 0.5 [9]
$\Lambda K_S^0 \pi^+$		$1.73 \pm 0.26 \pm 0.10$	$\cdots$	4.4 ± 0.7 [7]
				2.0 ± 0.4 [9]
ΛK^{*+}	(No interference)	$2.40 \pm 0.58 \pm 0.11$	$\cdots$	3.4 ± 0.4 [10]
	$(\theta_0 = 109°)$	$5.21 \pm 0.71 \pm 0.25$		1.97 [8]
	$(\theta_0 = 221°)$	$1.29 \pm 0.44 \pm 0.06$		$4.71^{+0.48}_{-0.20}$ [11]

- $\mathcal{B}(\Lambda_c^+ \to \Lambda K_S^0 K^+)$ consistent with PDG but with improved precision
- First observation of $\Lambda_c^+ \to \Lambda K_S^0 \pi^+$, lower than SU(3) by ~$4\sigma$
- Evidence of $\Lambda_c^+ \to \Lambda K^{*+}$, studied for the first time(4.71σ)

Brief summary of Λ_c^+ decay with a hyperon

Reference list

Channel	BESIII	Predictions	Predictions	Comparison
$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)(10^{-4})$	$6.21 \pm 0.44 \pm 0.26 \pm 0.34$	SU(3) 1997[1]: 14 SU(3) 2018[2]: 4.6 ± 0.9	Constituent quark model[3]: 12 Current algebra[4]:10.6 Diquark picture[5]: 1.8-3.9	Significantly overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Sigma K^+)(10^{-4})$	$4.7 \pm 0.9 \pm 0.1 \pm 0.3$	SU(3) 2019[6]: 5.4 ± 0.7	MIT bag model[7]: 7.2 ± 1.8 Diagrammatic analysis[8]: 5.5 ± 1.6 IRA method[9]: 5.0 ± 0.6 Constituent quark model[3]: 2(8)	Consistent and generally overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0)(10^{-4})$	$4.8 \pm 1.4 \pm 0.2 \pm 0.3$	SU(3) 2019[6]: 5.4 ± 0.7	MIT bag model[7]: 7.2 ± 1.8 Diagrammatic analysis[8]: 9.6 ± 2.4 IRA method[9]: 1.0 ± 0.4 (2.5σ) Constituent quark model[3]: 2(4)	Consistent and generally overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+ \pi^0)(10^{-3})$	$1.49 \pm 0.27 \pm 0.05 \pm 0.08$	SU(3) 2019[10]: $4.5 \pm 0.8(3.5\sigma)$ SU(3) 2019[11]: $3.5 \pm 0.6(3.0\sigma)$ SU(3) 2024[12]: 1.36 ± 0.25	-	Overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K_S^0 \pi^+)(10^{-3})$	$1.73 \pm 0.26 \pm 0.10$	SU(3) 2019[10]: $4.4 \pm 0.7(4.0\sigma)$ SU(3) 2024[12]: 2.0 ± 0.4	-	Overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K_S^0 K^+)(10^{-3})$	$3.04 \pm 0.30 \pm 0.16$	SU(3) 2019[10]: 2.8 ± 0.6 SU(3) 2024[12]: 2.7 ± 0.5	-	Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K^{*+})(10^{-3})$	$2.4 \pm 0.58 \pm 0.11$(no interference) $5.21 \pm 0.71 \pm 0.25(\theta_0 = 109^\circ)$ $1.29 \pm 0.44 \pm 0.06(\theta_0 = 221^\circ)$	SU(3) 2020[13]: 3.4 ± 0.4	light-front approach[14]: 1.97 Final-state re-scattering[15]: $4.71^{+0.48}_{-0.20}$	-
$\mathcal{B}(\Lambda_c^+ \to \Sigma K^+ \pi^0)(10^{-4})$	$< 5.0 \times 10^{-4}$	SU(3) 2019[10]: $12 \pm 3(2.4\sigma)$ SU(3) 2019[11]: $7.8 \pm 2.3(1.7\sigma)$ SU(3) 2024[12]: $8.2 \pm 1.4(2.0\sigma)$	Statistical isospin model[16]: $21 \pm 6(2.9\sigma)$	Overestimate

Brief summary of Λ_c^+ decay with a hyperon

Reference list

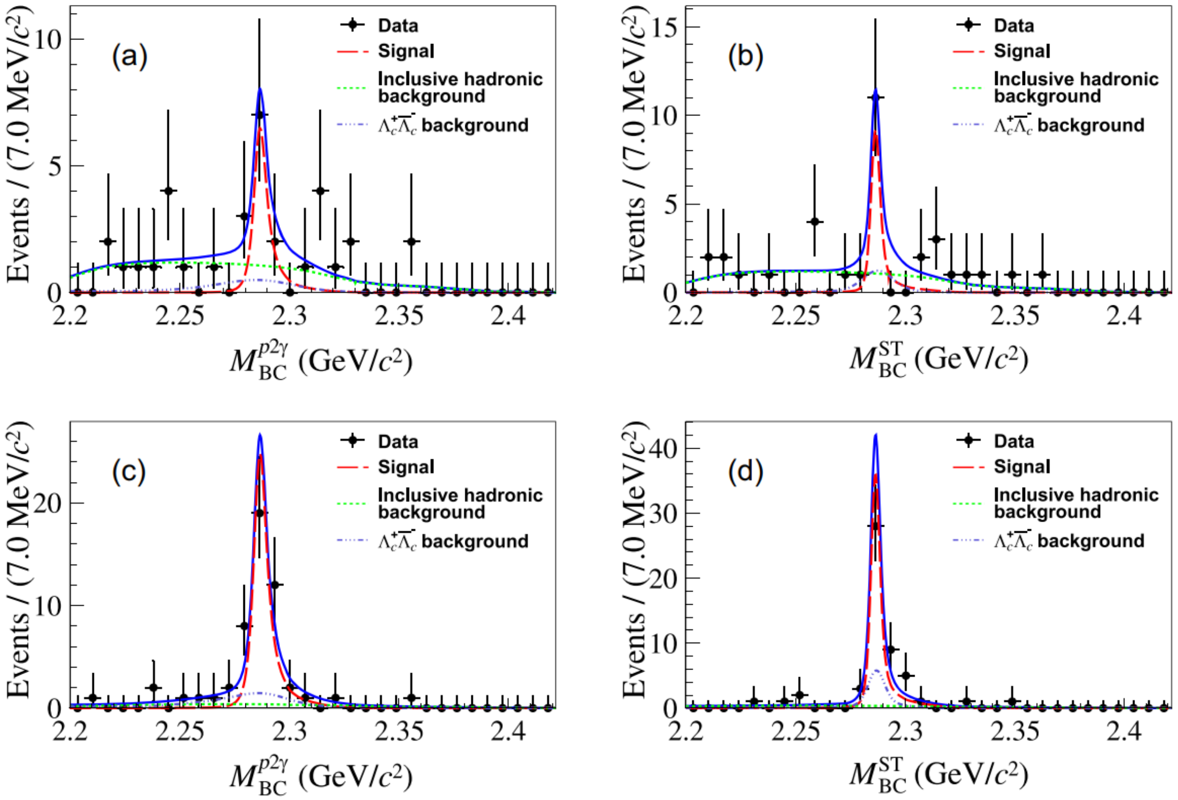
Channel	BESIII	Predictions	Predictions	Comparison
$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+)(10^{-4})$	$6.21 \pm 0.44 \pm 0.26 \pm 0.34$	SU(3) 1997[1]: 14 SU(3) 2018[2]: 4.6 ± 0.9	Constituent quark model[3]: 12 Current algebra[4]:10.6 Diquark picture[5]: 1.8-3.9	Significantly overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Sigma K^+)(10^{-4})$	$4.7 \pm 0.9 \pm 0.1 \pm 0.3$	SU(3) 2019[6]: 5.4 ± 0.7	MIT bag model[7]: 7.2 ± 1.8 Diagrammatic analysis[8]: 5.5 ± 1.6 IRA method[9]: 5.0 ± 0.6 Constituent quark model[3]: 2(8)	Consistent and generally overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Sigma^+ K_S^0)(10^{-4})$	$4.8 \pm 1.4 \pm 0.2 \pm 0.3$	SU(3) 2019[6]: 5.4 ± 0.7	MIT bag model[7]: 7.2 ± 1.8 Diagrammatic analysis[8]: 9.6 ± 2.4 IRA method[9]: 1.0 ± 0.4 (2.5σ) Constituent quark model[3]: 2(4)	Consistent and generally overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K^+ \pi^0)(10^{-3})$	$1.49 \pm 0.27 \pm 0.05 \pm 0.08$	SU(3) 2019[10]: $4.5 \pm 0.8 (3.5\sigma)$ SU(3) 2019[11]: $3.5 \pm 0.6 (3.0\sigma)$ SU(3) 2024[12]: 1.36 ± 0.25	-	Overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K_S^0 \pi^+)(10^{-3})$	$1.73 \pm 0.26 \pm 0.10$	SU(3) 2019[10]: $4.4 \pm 0.7 (4.0\sigma)$ SU(3) 2024[12]: 2.0 ± 0.4	-	Overestimate Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K_S^0 K^+)(10^{-3})$	$3.04 \pm 0.30 \pm 0.16$	SU(3) 2019[10]: 2.8 ± 0.6 SU(3) 2024[12]: 2.7 ± 0.5	-	Consistent
$\mathcal{B}(\Lambda_c^+ \to \Lambda K^{*+})(10^{-3})$	$2.4 \pm 0.58 \pm 0.11$(no interference) $5.21 \pm 0.71 \pm 0.25(\theta_0 = 109^\circ)$ $1.29 \pm 0.44 \pm 0.06(\theta_0 = 221^\circ)$	SU(3) 2020[13]: 3.4 ± 0.4	light-front approach[14]: 1.97 Final-state re-scattering[15]: $4.71^{+0.48}_{-0.20}$	-
$\mathcal{B}(\Lambda_c^+ \to \Sigma K^+ \pi^0)(10^{-4})$	$< 5.0 \times 10^{-4}$	SU(3) 2019[10]: $12 \pm 3 (2.4\sigma)$ SU(3) 2019[11]: $7.8 \pm 2.3 (1.7\sigma)$ SU(3) 2024[12]: $8.2 \pm 1.4 (2.0\sigma)$	Statistical isospin model[16]: $21 \pm 6 (2.9\sigma)$	Overestimate

More intensive investigations are needed

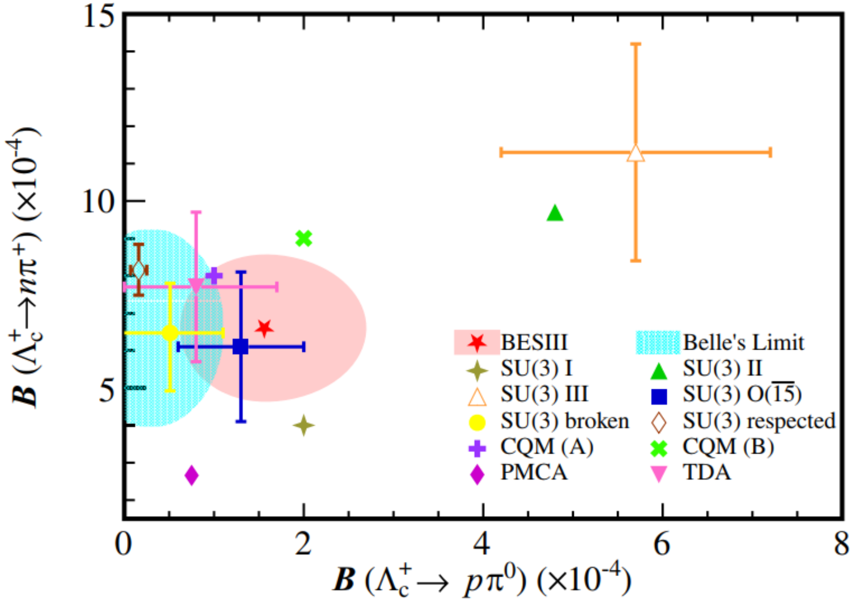
$\Lambda_c^+ \to p\pi^0$

Physical Review D 109, L091101 (2024)
Physical Review D 111, L051101 (2025)

- Two-body SCS decay with much interest.
- A long-standing contradiction between experimental results and SU(3) predictions.
- Previous experimental results show inconsistency:
  - BESIII 2017 with ST: $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$@90%C.L.
  - Belle 2021: $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 0.8 \times 10^{-4}$@90%C.L.



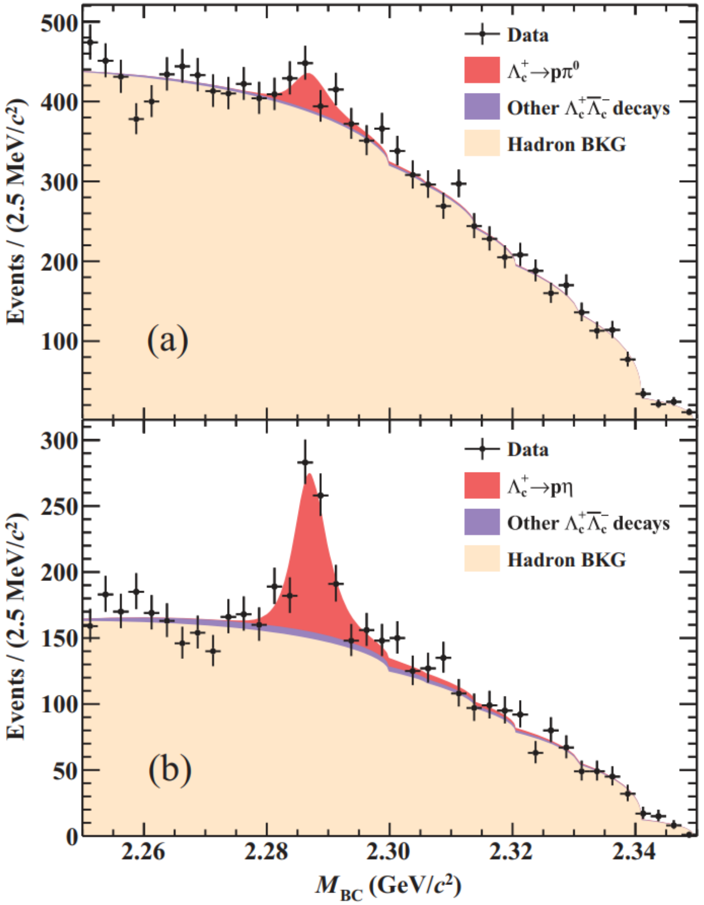
- BESIII 2024 with DT:
  $\mathcal{B}(\Lambda_c^+ \to p\pi^0) = (1.56^{+0.72}_{-0.58} \pm 0.20) \times 10^{-4}$ with 3.7σ



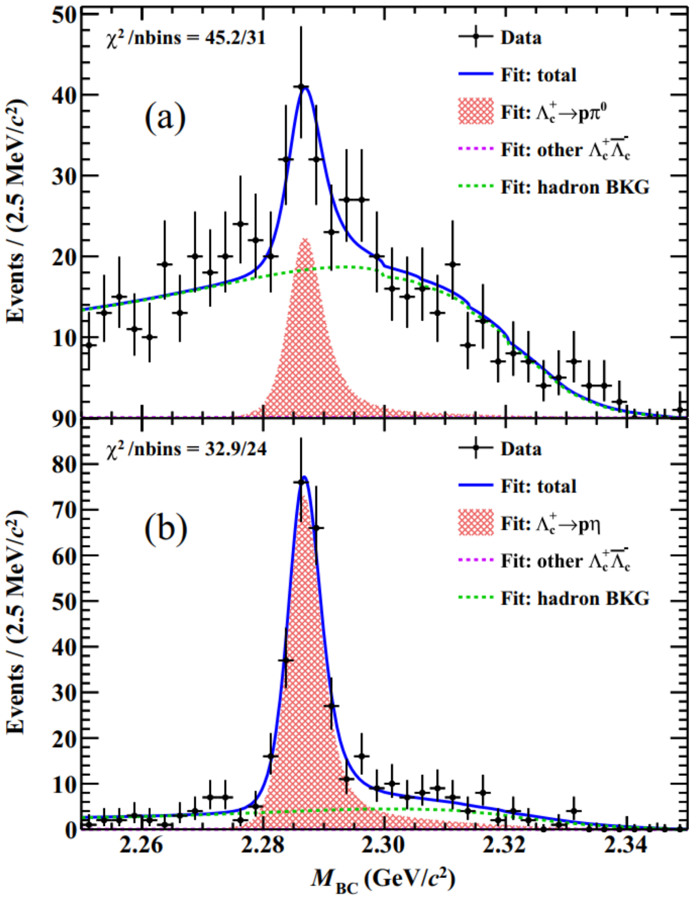
$\Lambda_c^+ \to p\pi^0$

Physical Review D 109, L091101 (2024)
Physical Review D 111, L051101 (2025)

- Difficulty to the observation:
  - ST with high hadron background
  - DT with low signal efficiency

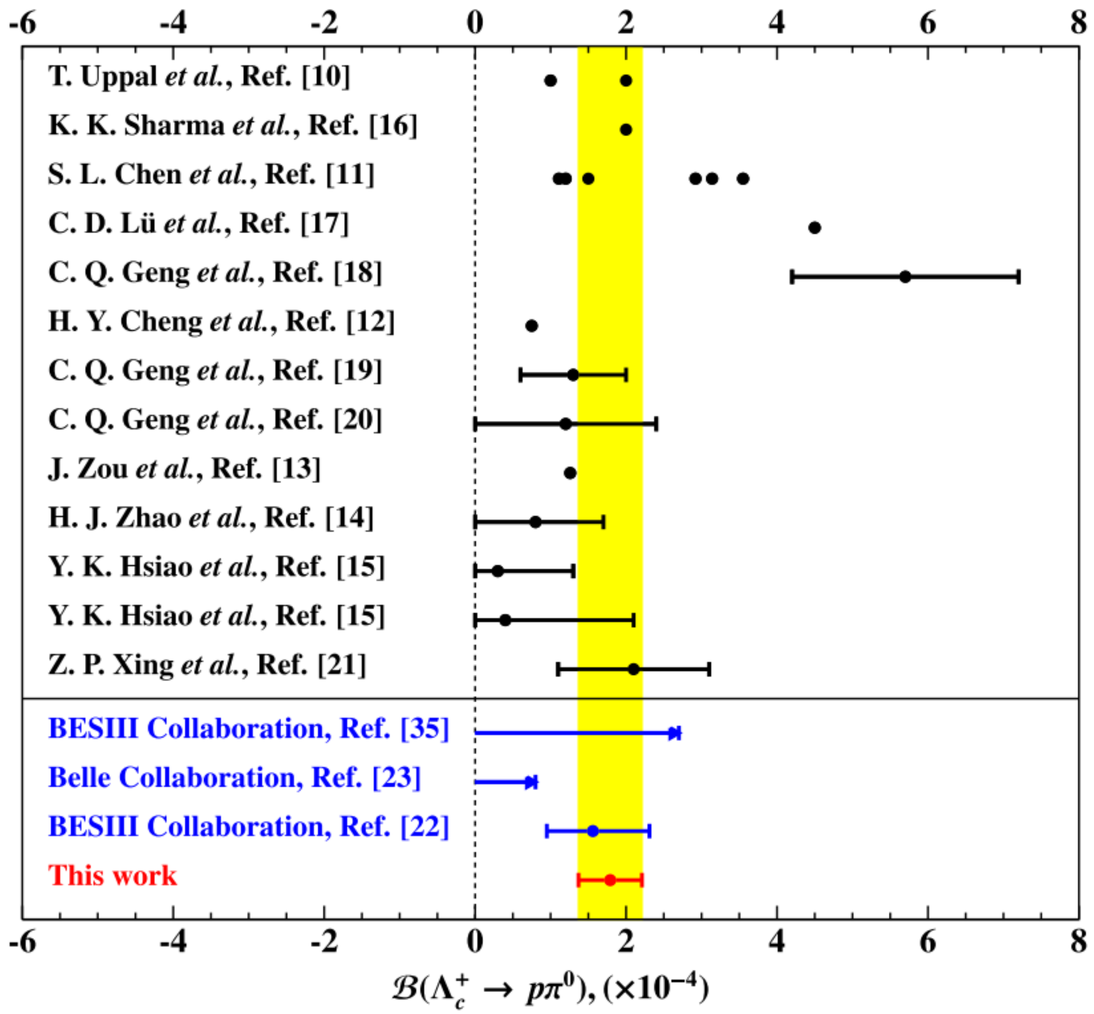


- Observation achieved recently with a novel deep learning method
  - Use Transformer-based deep neural network (DNN) to classify signal and background decay topologies
  - $\Lambda_c^+ \to p\eta$ as reference channel



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

Physical Review D 109, L091101 (2024)
Physical Review D 111, L051101 (2025)

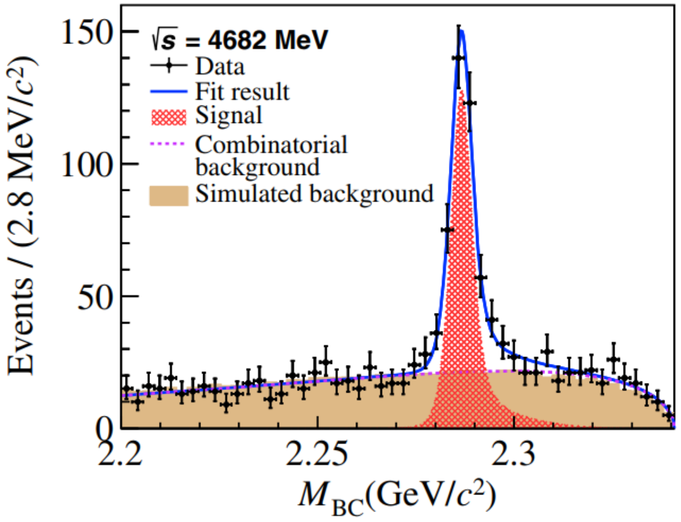


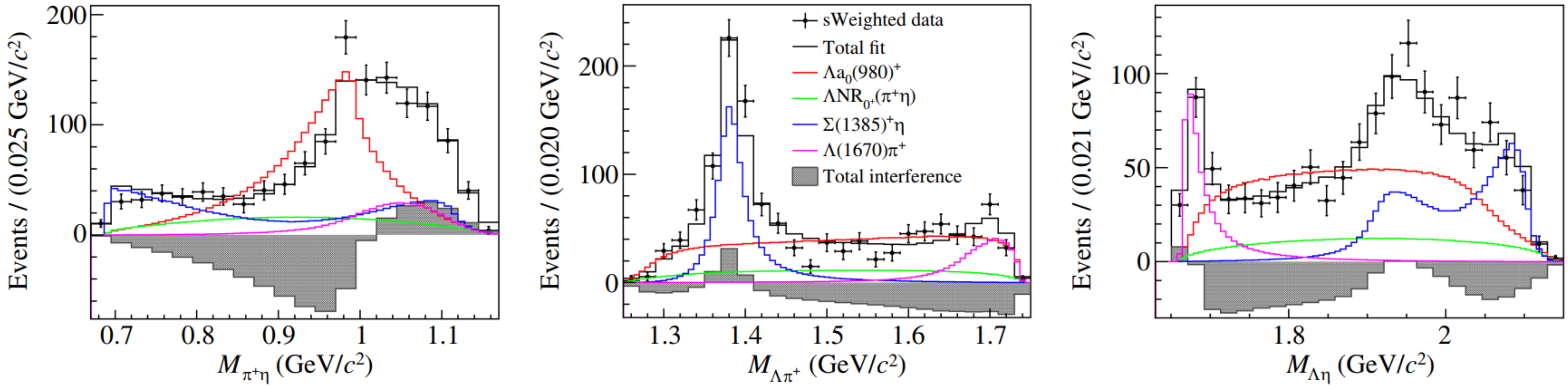
- ✓ $\frac{\mathcal{B}(\Lambda_c^+ \to p\pi^0)}{\mathcal{B}(\Lambda_c^+ \to p\eta)} = 0.120 \pm 0.026 \pm 0.007$ with 5.4σ
- ✓ $\mathcal{B}(\Lambda_c^+ \to p\pi^0) = (1.79 \pm 0.39 \pm 0.11 \pm 0.08) \times 10^{-4}$, consistent with previous BESIII evidence, yet exceeds the upper limit set by Belle
- ✓ The deep learning approach could be directly applicable to many other studies…

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

Physical Review L 134, 021901 (2025)

- Partial wave analysis:
  - ✓ Opportunity to probe lighter exotic states
  - ✓ Nature of scalar meson $a_0(980)^+$ remains elusive
  - ✓ Golden channel to study low-lying exited baryons like $\Sigma^*_{1/2^-}$
- ST with $6.1\ \mathrm{fb}^{-1}$ data from 4.6-4.843 GeV

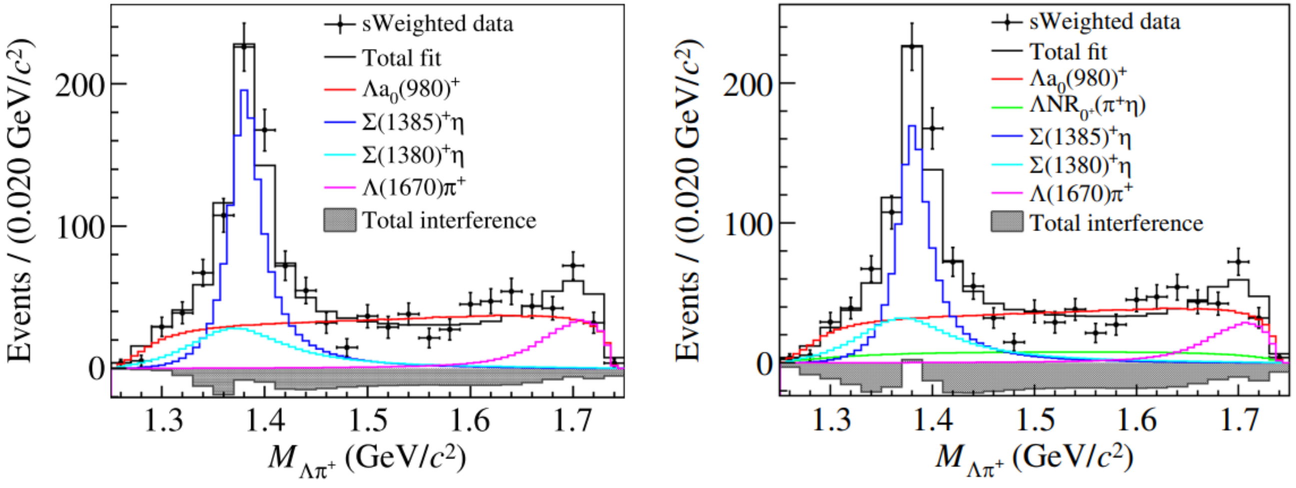




$\Lambda_c^+ \to \Lambda\pi^+\eta$

Physical Review L 134, 021901 (2025)

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



- ✓ $\Lambda_c^+ \to \Lambda a_0(980)^+$ is first observed with 13.1σ
- ✓ Evidence for potential pentaquark state $\Sigma(1380)^+$
  - Statistical significance 6.1σ (3.3σ) without (with) $\pi^+\eta$ non-resonant contribution
- ✓ First determined the decay asymmetry parameters of the three intermediate processes
  - $\alpha(\Lambda_c^+ \to \Sigma(1385)^+\eta)$ consistent with $-0.97^{+0.43}_{-0.03}$ in SU(3) [6]
  - $\alpha(\Lambda_c^+ \to \Lambda a_0(980)^+)$ contradicts with the small value(~0) in Triangle re-scattering [2]

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

Physical Review L 134, 021901 (2025)

	BESIII	Belle	This work	Predictions
$\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta)(\%)$	1.84 ± 0.26	1.84 ± 0.13	$1.94 \pm 0.07 \pm 0.01$	[1] 1.93 ± 0.27
$\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+) \times \mathcal{B}(a_0(980)^+ \to \pi^+\eta)(\%)$	-	-	$1.05 \pm 0.16 \pm 0.05 \pm 0.07$	[2] $0.17^{+0.28}_{-0.1} \pm 0.3$ [3] 0.019
$\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\eta)(10^{-3})$	9.1 ± 2.0	12.1 ± 1.2	$6.78 \pm 0.58 \pm 0.16 \pm 0.47$	[4] 10.4 [5] $2.1 \pm 1.1(1.4 \pm 1.0)$ [6] $6.2 \pm 0.5(3.1 \pm 0.6)$ [7] $5.3 \pm 0.8(7.3 \pm 1.5)$
$\mathcal{B}(\Lambda_c^+ \to \Lambda(1670)\pi^+) \times \mathcal{B}(\Lambda(1670) \to \Lambda\eta)(10^{-3})$	-	3.48 ± 0.53	$2.74 \pm 0.54 \pm 0.24 \pm 0.18$	-

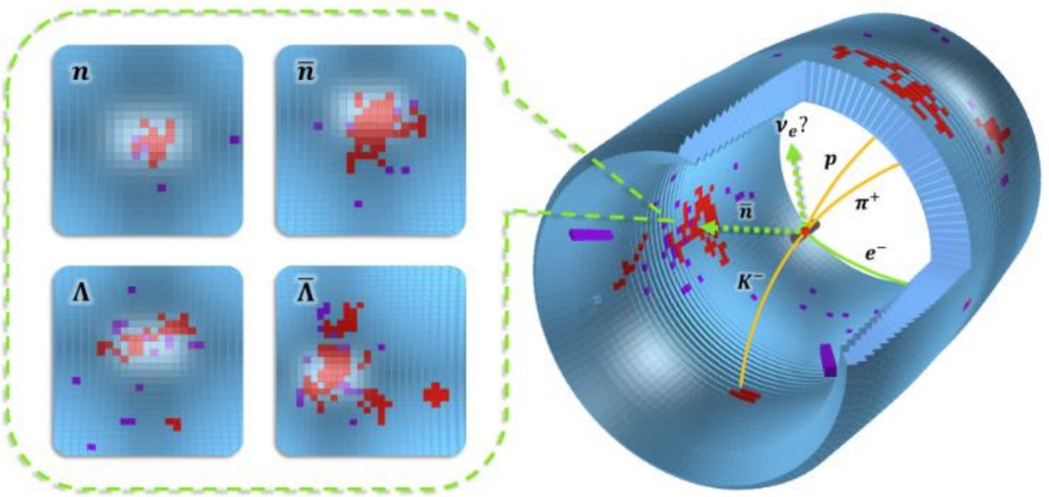
- $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+\eta)$ consistent with the previous results of BESIII and Belle
- $\mathcal{B}(\Lambda_c^+ \to \Lambda a_0(980)^+) \times \mathcal{B}(a_0(980)^+ \to \pi^+\eta)$, larger than theoretical calculations by 1-2 orders of magnitude
- $\mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\eta)$ differs with Belle, [4] and [5] over 3σ
- Crucial to calibrate nonfactorizable contribution in theory

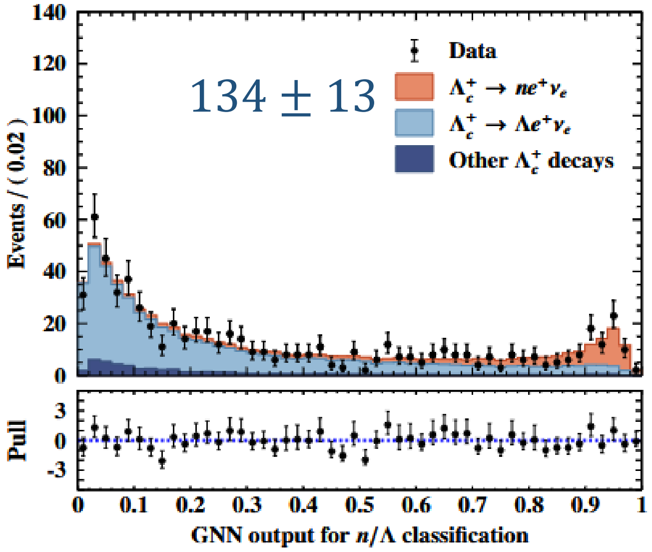
[1] SU(3): Phys. Rev. D 109 (2024) 093002
[2] Triangle re-scattering: J. Phys. G. 36.075005 (2009)
[3] Tetraquark state: Phys. Lett. B.820.136586 (2021)
[4] Current algebra: Z. Phys. C 55 (1992) 659-670
[5] SU(3) $\eta - \eta'$ mixing: Phys. Rev. D.55 (1997) 7067-7074
[6] SU(3) effective Hamiltonian: Phys. Rev. D.99 (2019) 114022
[7] SU(3) quark-diagram scheme: Eur. Phys. J. C.80.1067

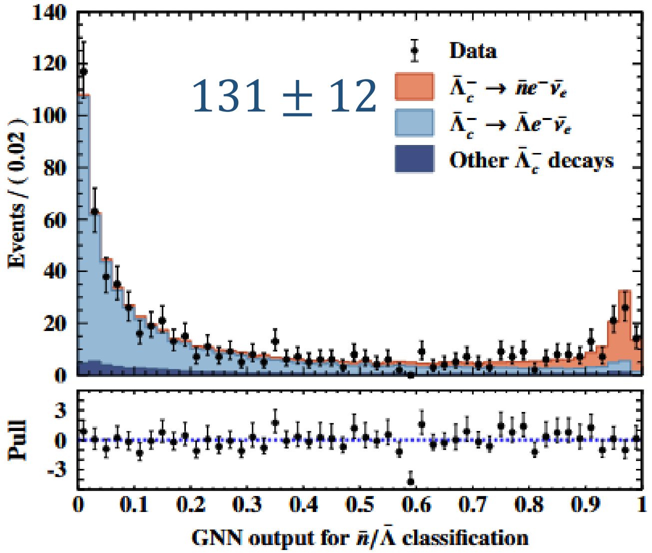
$\Lambda_c^+ \to ne^+\nu$

Nat. Comm. 16, 681 (2025)

- Λ_c^+ CS transition $c \to dl^+\nu$ beta decay never been observed
- Big challenge due to two missing particles n and ν, extensive bkg. from $\Lambda_c^+ \to \Lambda(n\pi^0)e^+\nu$
- DT with Graph Neural Network(GNN) is used for 3-D classification
- Validated with control samples of $J/\psi \to \bar{p}\pi^+n$, $J/\psi \to \bar{p}K^+\Lambda$ and c.c.
- Further cross check on $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu)$

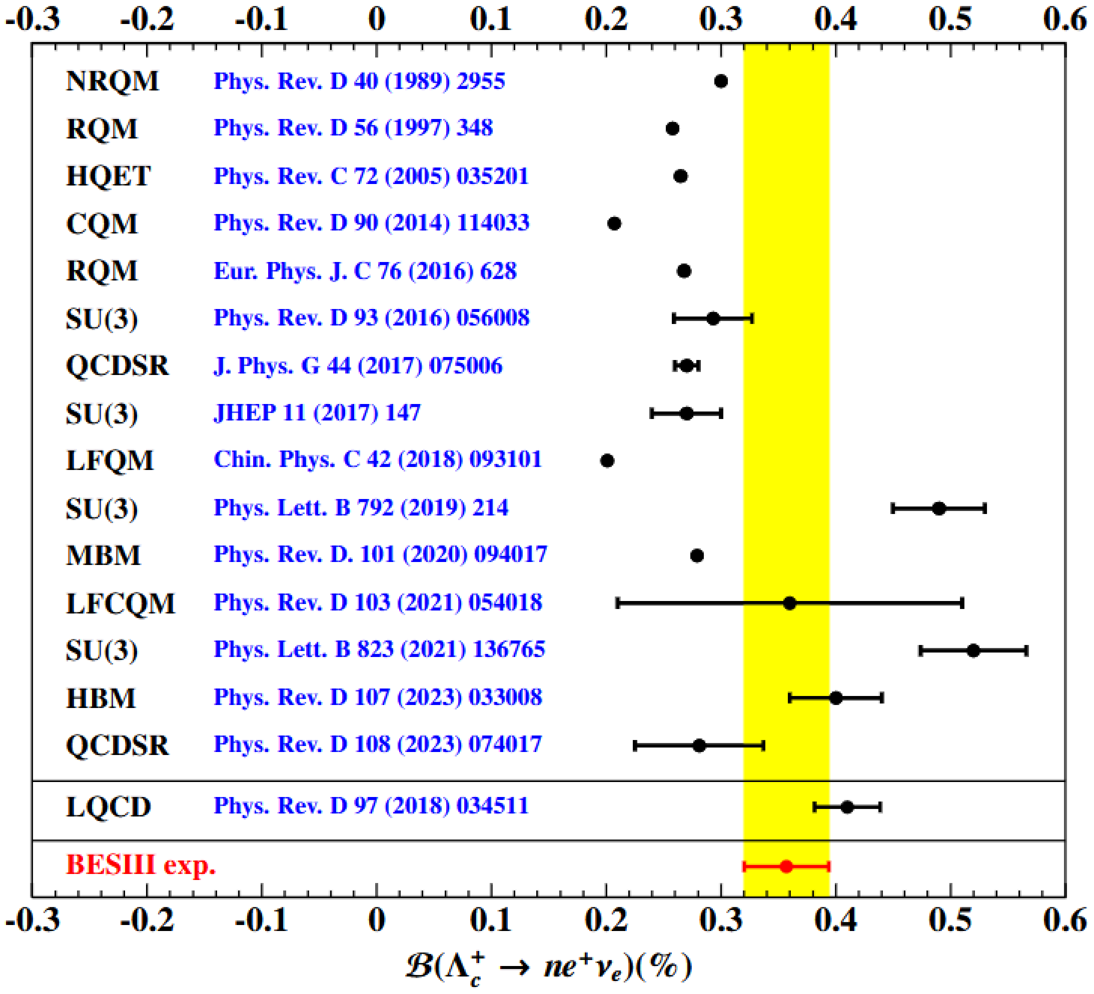






$\Lambda_c^+ \to n e^+ \nu$

Nat. Comm. 16, 681 (2025)

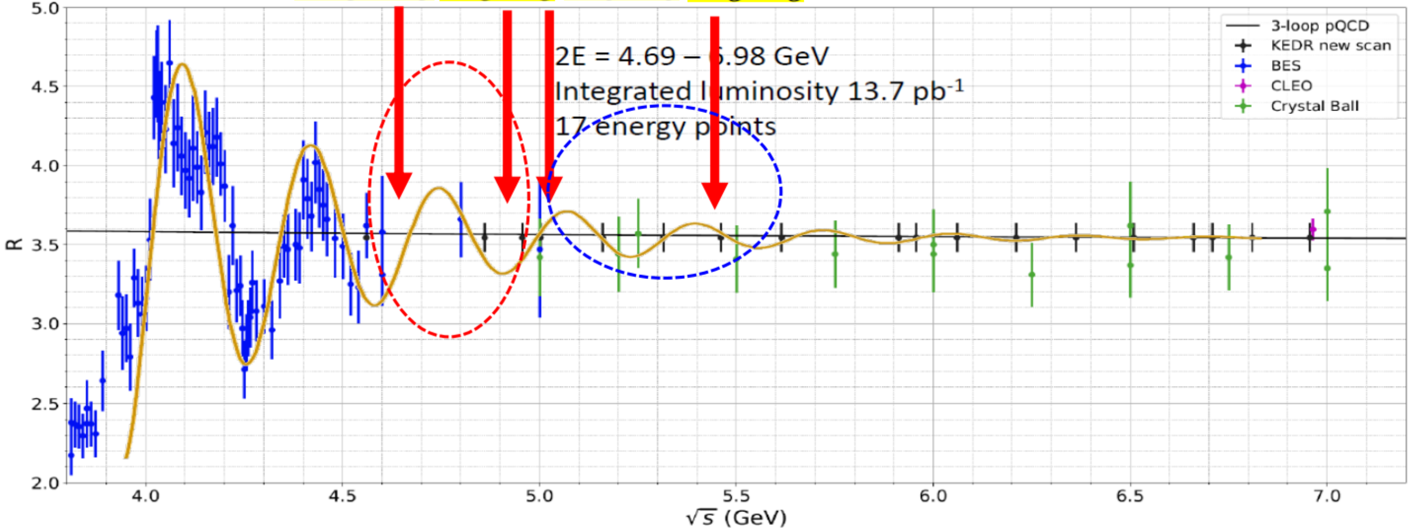


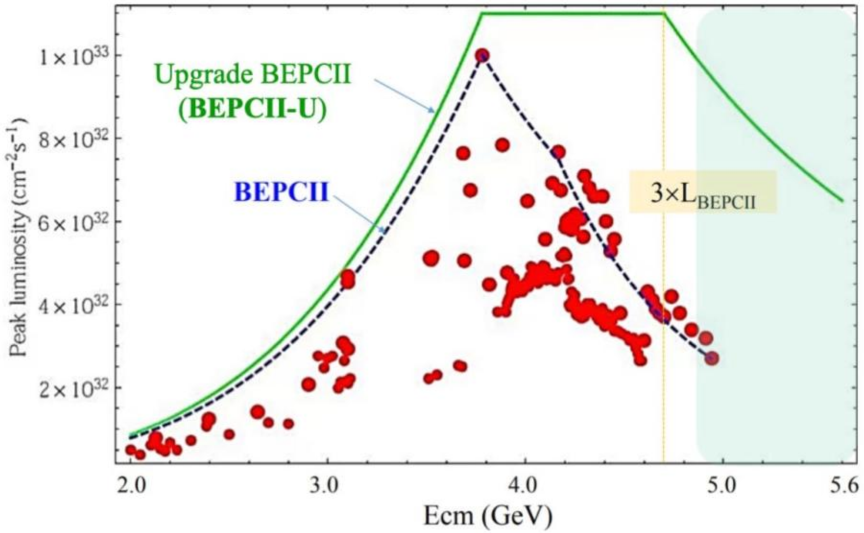
- ✓ $\mathcal{B}(\Lambda_c^+ \to n e^+ \nu) = (3.57 \pm 0.34_{stat.} \pm 0.14_{syst.}) \times 10^{-3}$, consistent and precision comparable to LQCD.
- ✓ $|V_{cd}| = 0.208 \pm 0.011 \pm 0.007 \pm 0.001$, first from charmed baryon decay and consistent with the world average value (0.221 ± 0.004).
- ✓ Test various theoretical models.
- ✓ Power of modern machine learning techniques.

Prospect

- BEPCII(-U) and BESIII is currently under a major machine upgrade
  - Triple the luminosity @4.7 GeV
  - Center-of-mass energy up to 5.6 GeV
  - Replace inner MDC with CGEM

$\Lambda_c\bar{\Lambda}_c\ \Sigma_c\bar{\Sigma}_c\ \Xi_c\bar{\Xi}_c\ \Omega_c\bar{\Omega}_c$





- $9\ \text{fb}^{-1}$ more 4.68 GeV Λ_c^+ data has been planned in 2025-2026
- >5 GeV data will start in 2028

Summary

- The world's largest threshold data makes BESIII **dominant Λ_c^+ measurments.**
- **Fruitful results released recently**
  - Hadronic decays
  - Semi-leptonic decays

- Long-standing search channel $\Lambda_c^+ \to p\pi^0$ and milestone channel $\Lambda_c^+ \to ne^+\nu$ **were firstly observed and studied with deep learning method**, which provide opportunity to many analyses of BESIII.
- 2025/26 BEPCII-U will be more efficient and **9 fb^{-1} more will be obtained @ 4.68 GeV.**
- **Charm is charming**, more will come...

Thanks for your attention!

BACK UP

Brief summary of Λ_c^+ decay with a hyperon

[1] K. K. Sharma and R. C. Verma, Phys. Rev. D 55, 7067 (1997)
[2] C. Q. Geng, Y. K. Hsiao, and Y. H. Lin, Phys. Lett. B 776, 265 (2018)
[3] T. Uppal, R. C. Verma, and M. P. Khanna, Phys. Rev. D 49, 3417 (1994)
[4] H. Y. Cheng, X. W. Kang, and F. R. Xu, Phys. Rev. D 97, 074028 (2018)
[5] S. L. Chen, X. H. Guo, X. Q. Li, and G. L. Wang, Commun. Theor. Phys. 40, 563 (2003)
[6] C. Geng, C. W. Liu, and T. H. Tsai, Phys. Lett. B 794, 19 (2019)
[7] J. Zou, F. Xu, G. Meng, and H. Y. Cheng, Phys. Rev. D 101, 014011 (2020)
[8] H. J. Zhao, Y. L. Wang, Y. K. Hsiao, and Y. Yu, J. High Energy Phys. 02 (2020) 165
[9] F. Huang, Z. P. Xing, and X. G. He, J. High Energy Phys. 03 (2022) 143
[10] C. Q. Geng, Y. K. Hsiao, C. W. Liu, and T. H. Tsai, Phys. Rev. D 99, 073003 (2019)
[11] J. Y. Cen, C. Q. Geng, C. W. Liu, and T. H. Tsai, Eur. Phys. J. C 79, 946 (2019)
[12] C. Q. Geng, C. W. Liu, and S. L. L, Phys. Rev. D 109, 093002 (2024)
[13] C. Q. Geng, C. W. Liu, and T. H. Tsai, Phys. Rev. D 101, 053002 (2020)
[14] Z. X. Zhao, Chin. Phys. C 42, 093101 (2018)
[15] C. P. Jia, H. Y. Jiang, J. P. Wang, and F. S. Yu, J. High Energy Phys. 11 (2024) 072
[16] M. Gronau, J. L. Rosner, and C. G. Wohl, Phys. Rev. D 98, 073003(A) (2018)