Light hadrons from the Λ_c^+ decays

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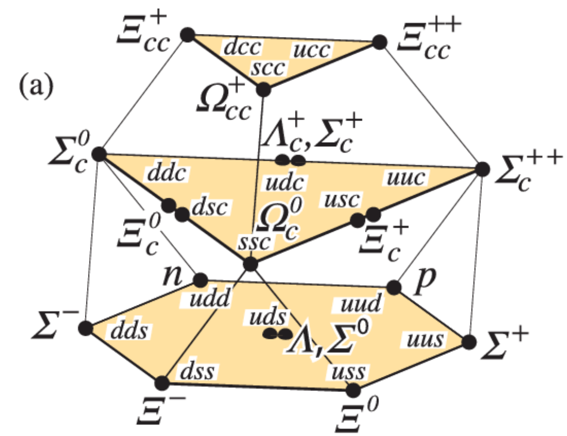
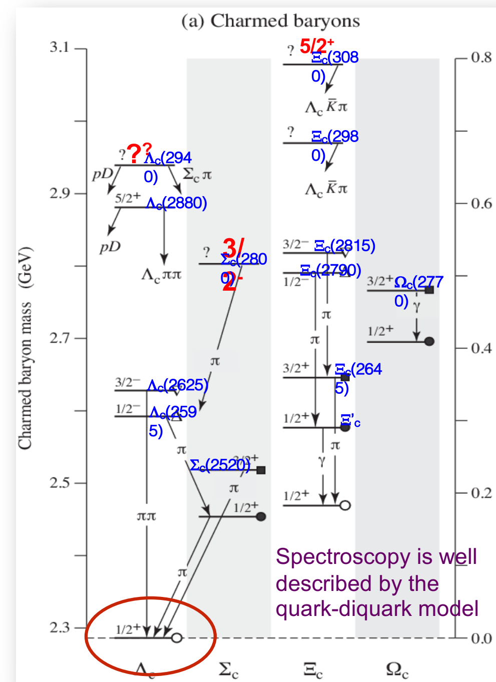
Outline

- Light hadrons from the charmed baryon decays
- Recent experimental progress
- Future dataset
- Summary

The charmed baryon family

- The ground-state singly charmed baryons mostly degenerate via weak process
- Light hadrons, esp. hyperons, are produced after charm quark weak decays in a charmed baryon
- Λ_c^+ is the lightest charmed baryon, which has been best studied in the experiments, such as BESIII, LHCb and Belle, in recent ten years
- Most of the charmed baryons will eventually decay to the Λ_c^+

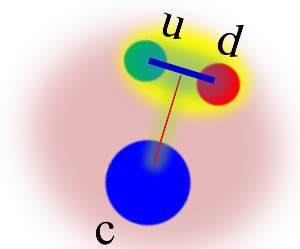




Light hadrons from Λ_c^+ weak decays

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.*

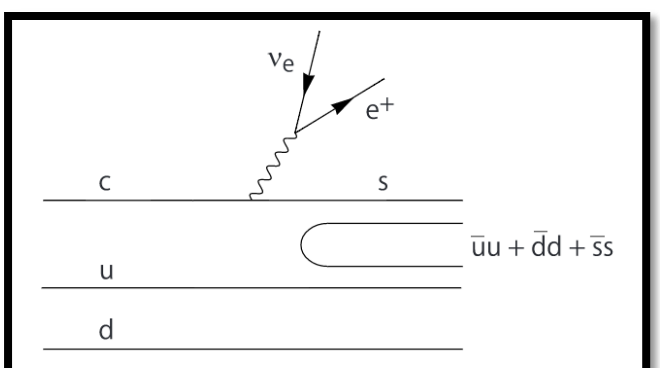


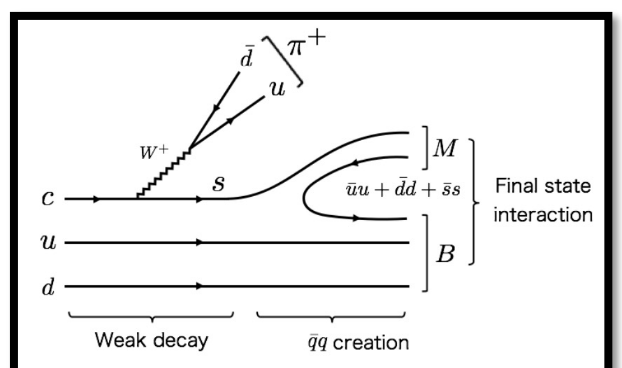
→ Charmed baryon (Λ_c[udc])
m_u, m_d << m_c → **diquark + quark**
(qq) (Q)

- 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)]





Accessible hyperon states

Particle	J^P	Overall status	Status as seen in — $N\overline{K}$	$\Sigma\pi$	Other channels
$\Lambda(1116)$	$1/2^+$	****			$N\pi$ (weak decay)
$\Lambda(1380)$	$1/2^-$	**	**	**	
$\Lambda(1405)$	$1/2^-$	****	****	****	
$\Lambda(1520)$	$3/2^-$	****	****	****	$\Lambda\pi\pi, \Lambda\gamma, \Sigma\pi\pi$
$\Lambda(1600)$	$1/2^+$	****	***	****	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1670)$	$1/2^-$	****	****	****	$\Lambda\eta$
$\Lambda(1690)$	$3/2^-$	****	****	***	$\Lambda\pi\pi, \Sigma(1385)\pi$
$\Lambda(1710)$	$1/2^+$	*	*	*	
$\Lambda(1800)$	$1/2^-$	***	***	**	$\Lambda\pi\pi, N\overline{K}^*$
$\Lambda(1810)$	$1/2^+$	***	**	**	$N\overline{K}^*$
$\Lambda(1820)$	$5/2^+$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1830)$	$5/2^-$	****	****	****	$\Sigma(1385)\pi$
$\Lambda(1890)$	$3/2^+$	****	****	**	$\Sigma(1385)\pi, N\overline{K}^*$
$\Lambda(2000)$	$1/2^-$	*	*	*	
$\Lambda(2050)$	$3/2^-$	*	*	*	
$\Lambda(2070)$	$3/2^+$	*	*	*	
$\Lambda(2080)$	$5/2^-$	*	*	*	
$\Lambda(2085)$	$7/2^+$	**	**	*	
$\Lambda(2100)$	$7/2^-$	****	****	**	$N\overline{K}^*$
$\Lambda(2110)$	$5/2^+$	***	**	**	$N\overline{K}^*$
$\Lambda(2325)$	$3/2^-$	*	*		
$\Lambda(2350)$	$9/2^+$	***	***	*	
$\Lambda(2585)$		*	*		

Particle	J^P	Overall status	Status as seen in — $N\overline{K}$	$\Lambda\pi$	$\Sigma\pi$	Other channels
$\Sigma(1193)$	$1/2^+$	****				$N\pi$ (weak decay)
$\Sigma(1385)$	$3/2^+$	****		****	****	$\Lambda\gamma$
$\Sigma(1580)$	$3/2^-$	*	*	*	*	
$\Sigma(1620)$	$1/2^-$	*	*	*	*	
$\Sigma(1660)$	$1/2^+$	***	***	***	***	
$\Sigma(1670)$	$3/2^-$	****	****	****	****	
$\Sigma(1750)$	$1/2^-$	***	***	**	***	$\Sigma\eta$
$\Sigma(1775)$	$5/2^-$	****	****	****	**	
$\Sigma(1780)$	$3/2^+$	*	*	*	*	
$\Sigma(1880)$	$1/2^+$	**	**	*		
$\Sigma(1900)$	$1/2^-$	**	**	*	**	
$\Sigma(1910)$	$3/2^-$	***	*	*	**	
$\Sigma(1915)$	$5/2^+$	****	***	***	***	
$\Sigma(1940)$	$3/2^+$	*	*		*	
$\Sigma(2010)$	$3/2^-$	*	*	*		
$\Sigma(2030)$	$7/2^+$	****	****	****	**	$\Delta(1232)\overline{K}, N\overline{K}^*, \Sigma(1385)\pi$
$\Sigma(2070)$	$5/2^+$	*	*		*	
$\Sigma(2080)$	$3/2^+$	*		*		
$\Sigma(2100)$	$7/2^-$	*	*	*	*	
$\Sigma(2110)$	$1/2^-$	*	*	*	*	
$\Sigma(2230)$	$3/2^+$	*	*	*	*	
$\Sigma(2250)$		**	**	*	*	
$\Sigma(2455)$		*	*			
$\Sigma(2620)$		*	*			

Studies on these hyperon states across different final states

Cross-channel studies

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

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

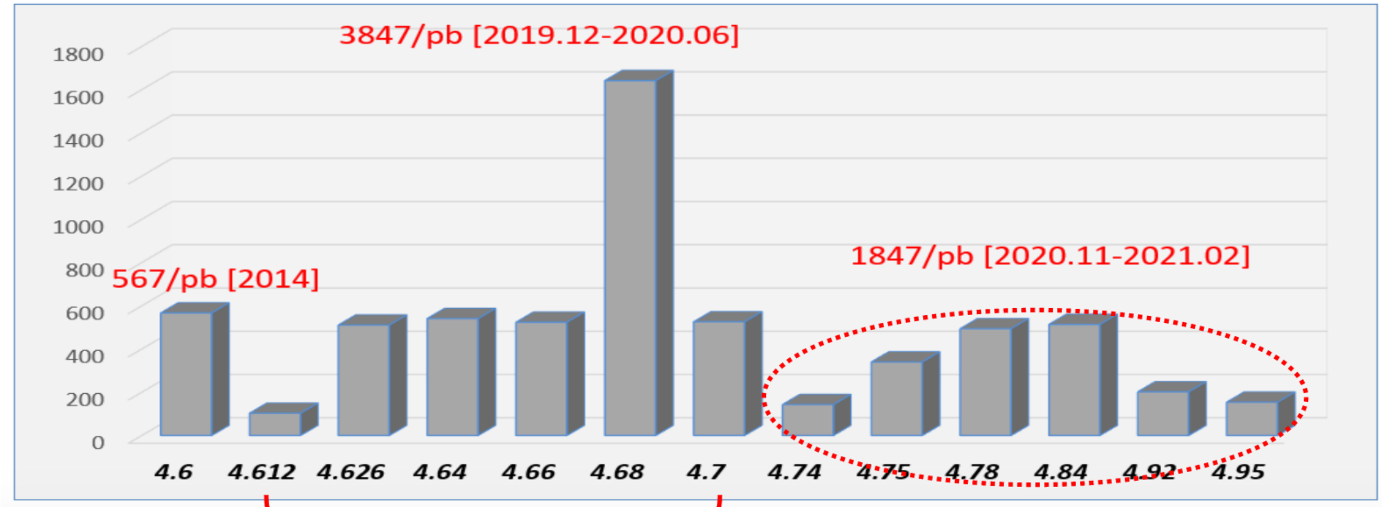
$\Lambda_c^+ \to \Sigma^{*+} \pi^0$

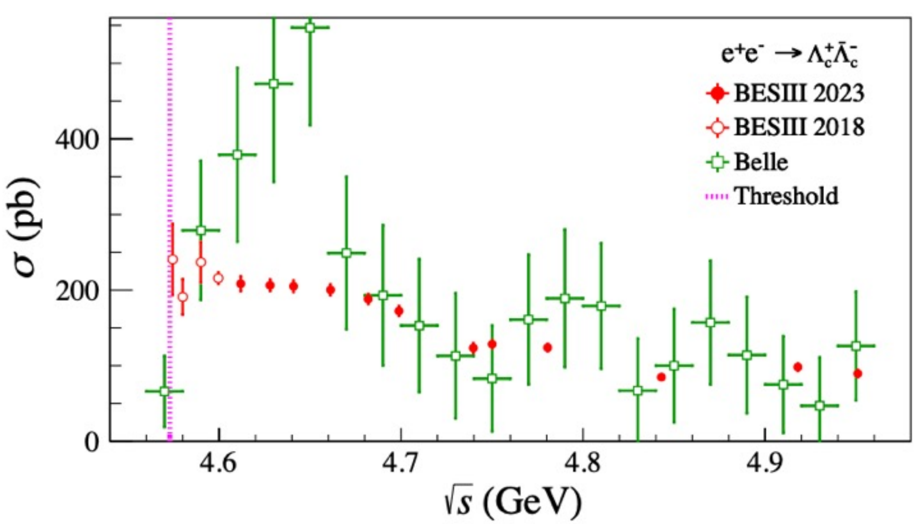
- $\Lambda_c^+ \to pK_S\pi^0$
- $\Lambda_c^+ \to \Lambda\pi^+\pi^0$
- $\Lambda_c^+ \to \Sigma^+\pi^0\pi^0$
- $\Lambda_c^+ \to \Sigma^0\pi^+\pi^0$
- $\Lambda_c^+ \to \Sigma^+\eta\pi^0$
- $\Xi_c^+ \to pK_S\pi^0$
- …

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

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

Λ_c^+ data samples at BESIII





BESIII, PRL131, 191901 (2023)

in total, 6.4 fb^{-1} data above Λ_c^+ threshold (~0.8M $\Lambda_c^+\bar{\Lambda}_c^-$ pairs)

Specialties of current ongoing experiments

BESIII

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

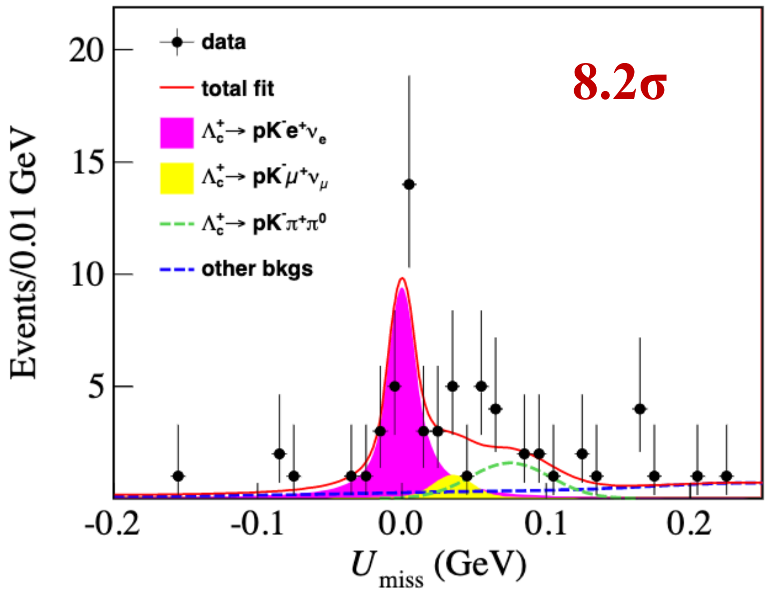
LHCb, Belle

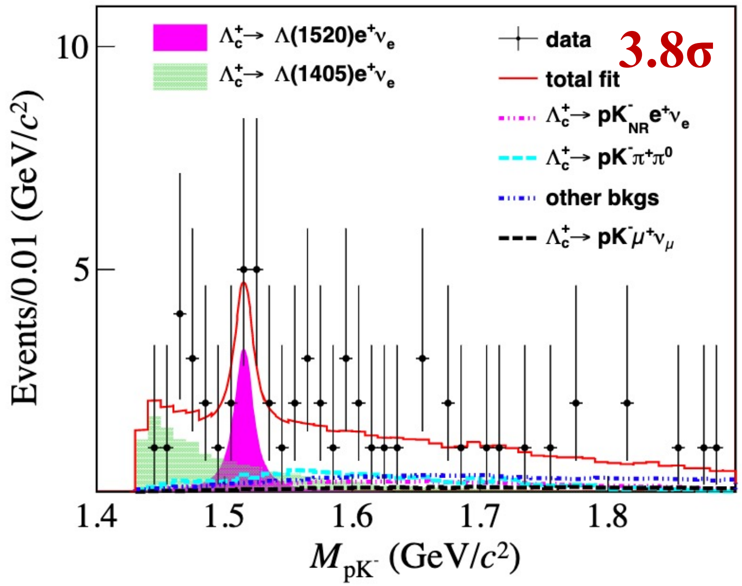
- Large statistics:
  LHCb XS ~100 μb; Belle XS ~1 nb
- High background
- Good PID and vertexing
- Complex production environment
- Good hadron-ID and μ-ID
- Good photon resolution in electron machines

They are complementary!

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

BESIII, PRD106, 112010 (2022)





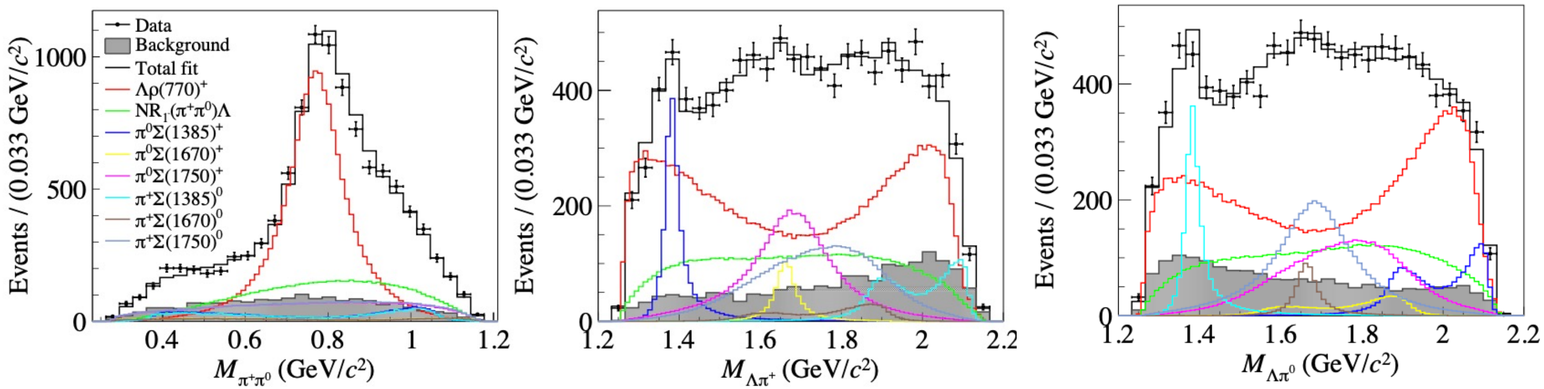
$$B(\Lambda_c^+ \to pK^- e^+ \nu_e) = (8.8 \pm 1.1 \pm 0.7)\times 10^{-4}$$
$$B(\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e) = (10.2 \pm 5.2 \pm 1.1)\times 10^{-4}$$

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

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

JHEP12, 033 (2022)

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



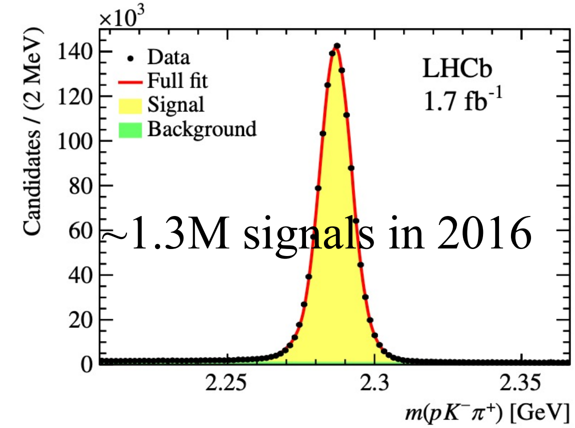
	Theoretical calculation		This work	PDG
$10^2 \times \mathcal{B}(\Lambda_c^+ \to \Lambda\rho(770)^+)$	4.81 ± 0.58 [13]	4.0 [14, 15]	4.06 ± 0.52	< 6
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^+\pi^0)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	5.86 ± 0.80	—
$10^3 \times \mathcal{B}(\Lambda_c^+ \to \Sigma(1385)^0\pi^+)$	2.8 ± 0.4 [16]	2.2 ± 0.4 [17]	6.47 ± 0.96	—
$\alpha_{\Lambda\rho(770)^+}$	-0.27 ± 0.04 [13]	-0.32 [14, 15]	-0.763 ± 0.066	—
$\alpha_{\Sigma(1385)^+\pi^0}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.917 ± 0.083	—
$\alpha_{\Sigma(1385)^0\pi^+}$	$-0.91^{+0.45}_{-0.10}$ [17]		-0.79 ± 0.11	—

Many first measurements of intermediate states!

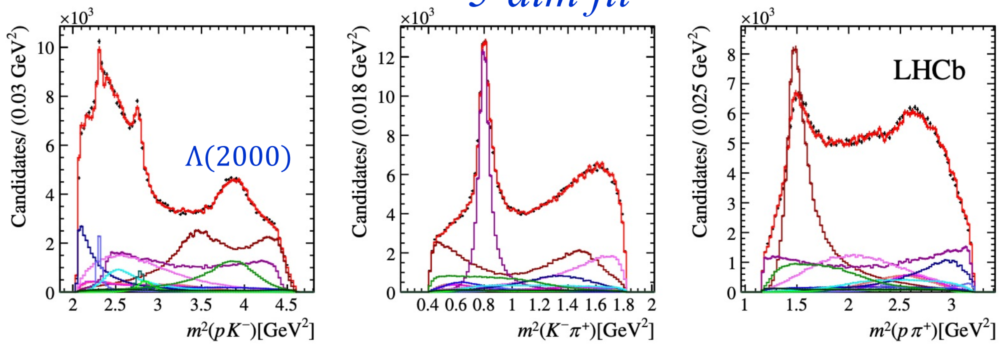
$\Lambda_c^+ \to pK^-\pi^+$ amplitude analysis

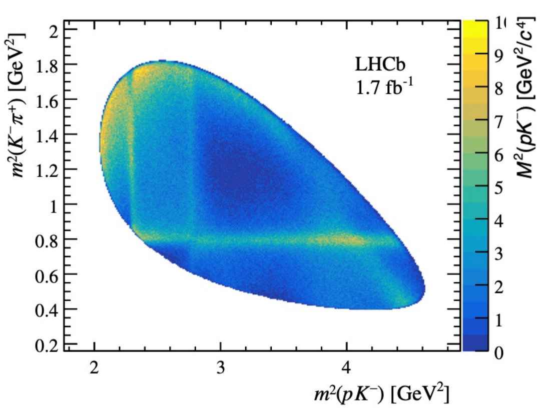
LHCb, PRD 108, 012023 (2023)

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

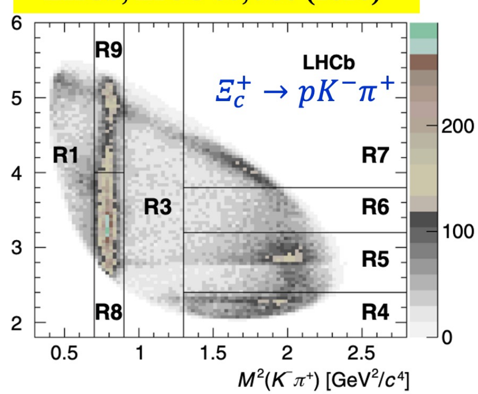


5-dim fit





LHCb, EPJC 80, 986 (2020)



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

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

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

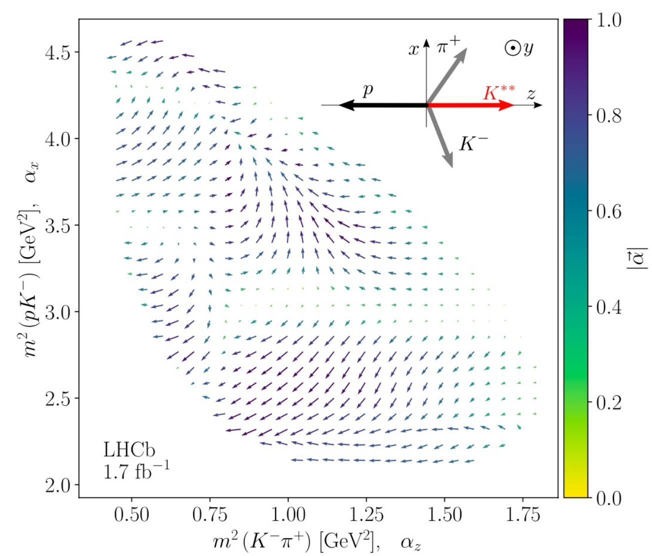
LHCb, PRD108, 012023 (2023)

LHCb, JHEP 07, 228 (2023)

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

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

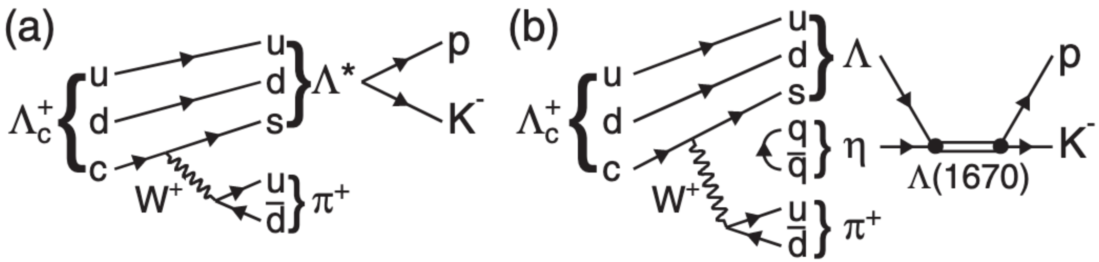
A large Λ_c^+ polarization is found in b semi-leptonic decays $\Lambda_b^0 \to \Lambda_c^+ \mu^- \nu$



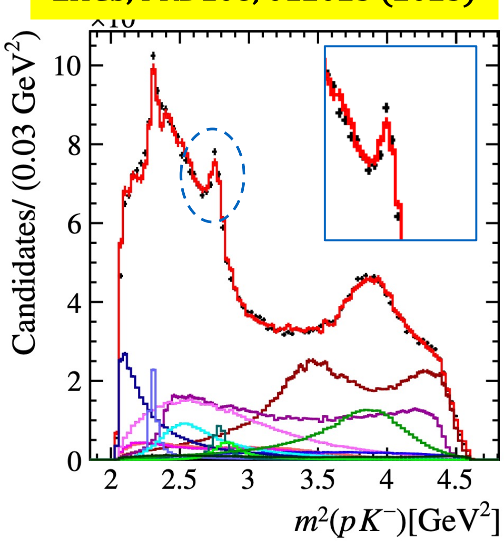
- The obtained representation can facilitate polarization measurements of the Λ_c^+ baryon and eases inclusion of the $\Lambda_c^+ \to pK^-\pi^+$ decay mode in hadronic amplitude analyses.
- At BESIII, the transverse polarization of Λ_c^+ can be obtained via $\Lambda_c^+ \to pK^-\pi^+$ polarimetry

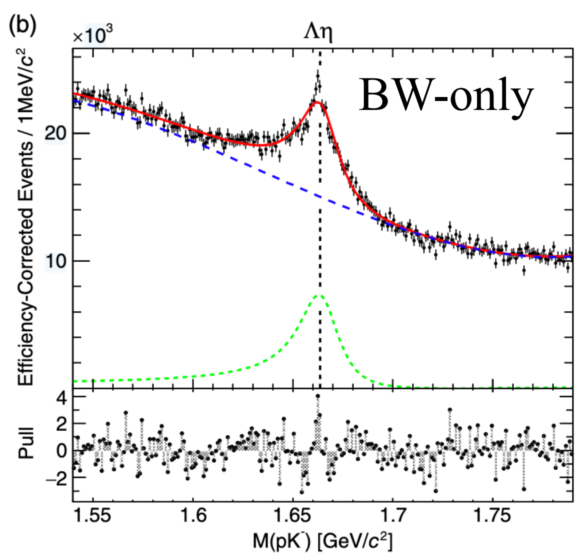
Threshold cusp at the $\Lambda\eta$ threshold in $\Lambda_c^+ \to pK^-\pi^+$

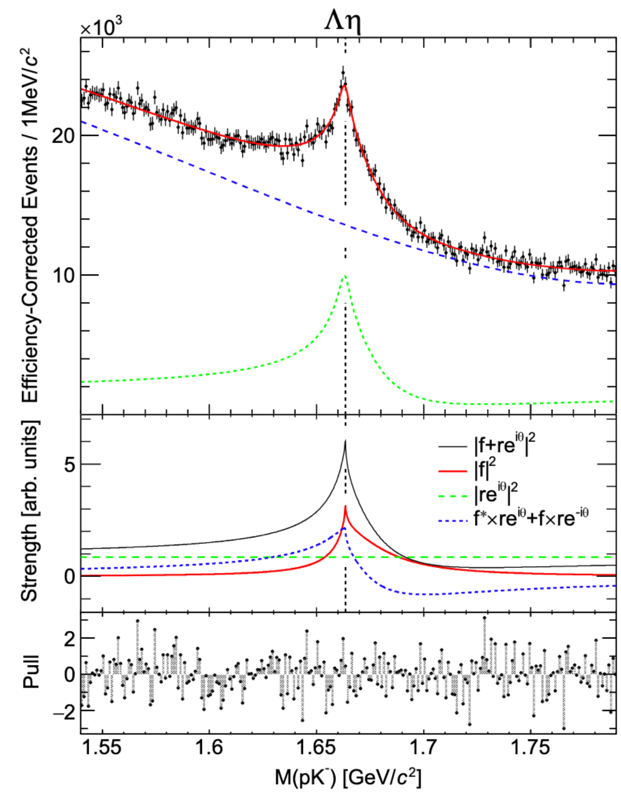
Belle, PRD108, L031104 (2023)



LHCb, PRD108, 012023 (2023)







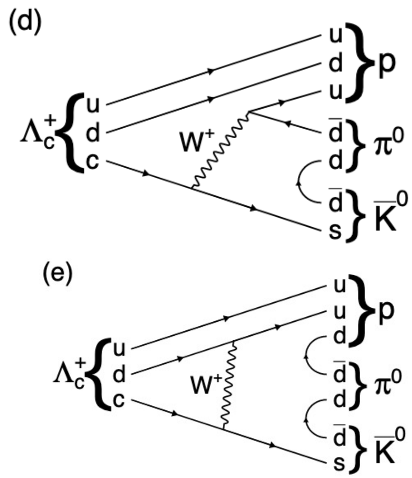
$$|f(m)|^2 = \left|\frac{1}{m - m_f + \frac{i}{2}(\Gamma' + \bar{g}_{\Lambda\eta}k)}\right|^2$$

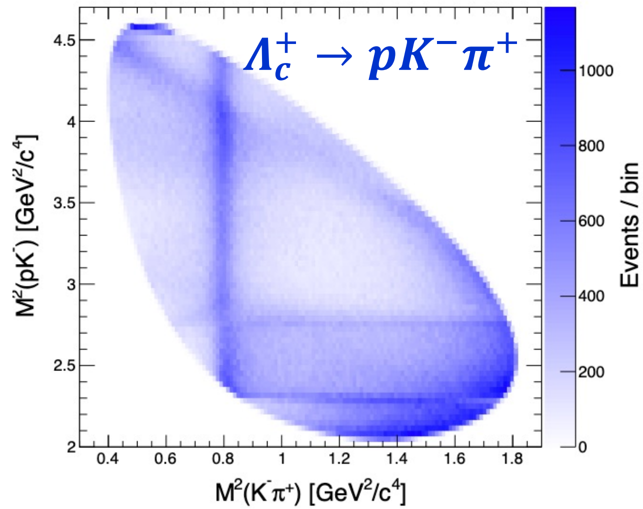
The peaking structure is explained better by a threshold cusp than to a new hadron resonance by more than 7σ

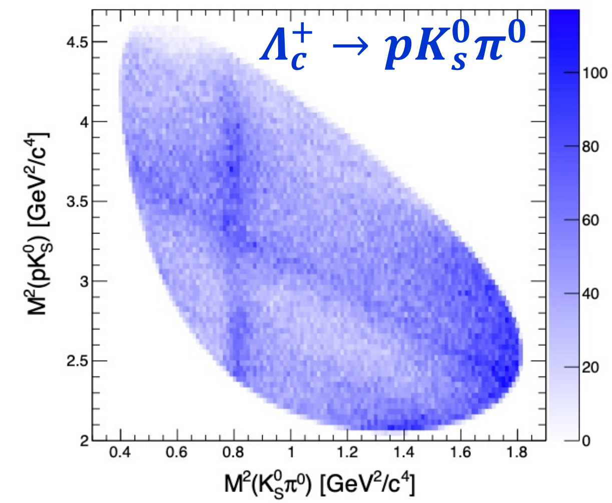
mass: $1674.3 \pm 0.8 \pm 4.9\ \mathrm{MeV}/c^2$
width: $50.3 \pm 2.9^{+5.5}_{-8.1}$ MeV
consistent with the Λ(1670)

Resonant structures in $\Lambda_c^+ \to pK_s^0\pi^0$

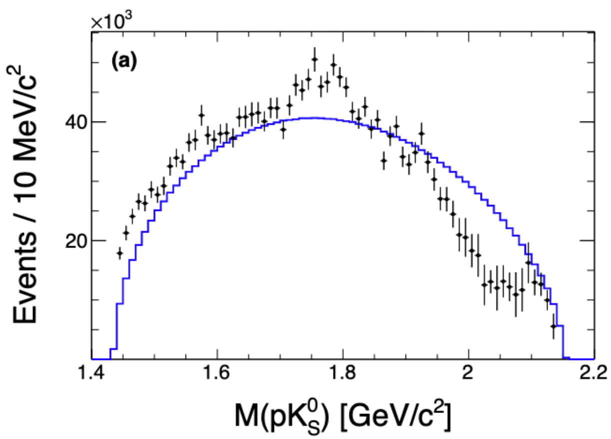
Belle, arXiv:2503.04371

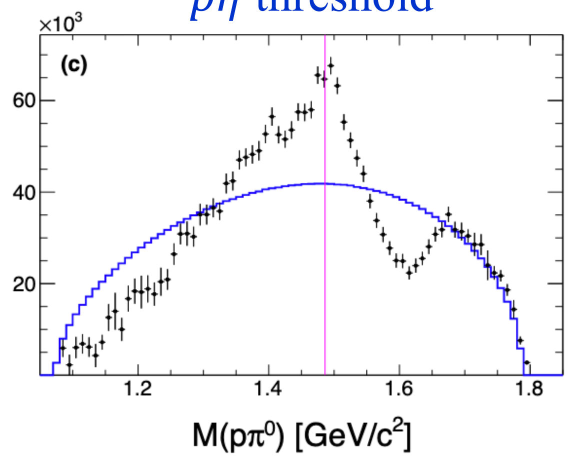


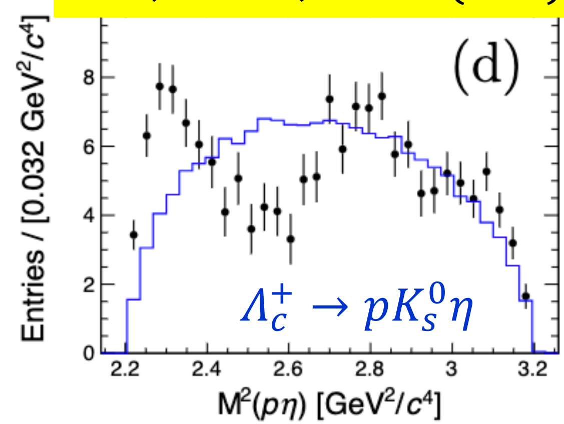




Belle, PRD107, 032004 (2023)







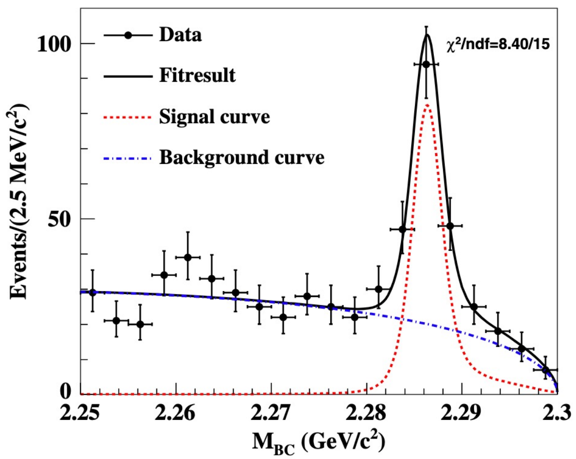
- no obvious structure in the pK_s^0 mass distribution
- clear peaking structure near the $p\eta$ mass threshold ($N^*(1535)$?)

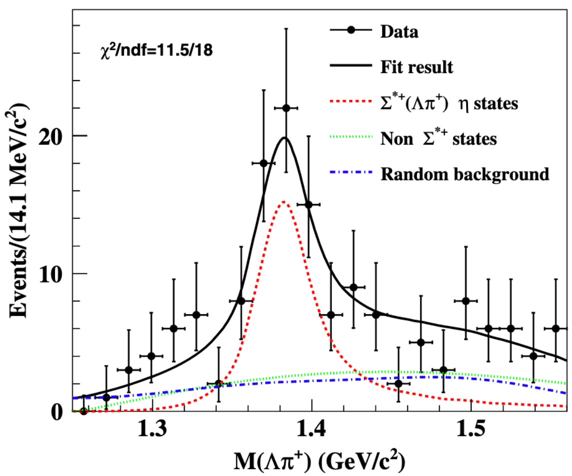
Intermediate states in $\Lambda_c^+ \to \Lambda\pi^+\eta$

- A good channel to investigate different types of hadron states, especially tetraquark or pentaquark candidates
- $\Lambda_c^+ \to \Lambda\pi^+\eta$ decay provides a good platform to study the internal structure of $a_0(980)^+$ whose exact nature remains elusive.
- The $\Lambda\pi^+$ mode, representing a pure I = 1 combination, excludes influences from Λ^* resonances as compared to the $\Sigma\pi$ and pK modes.
- Study of low-lying excited $\frac{1}{2}^-$ state, eg $\Sigma(1380)^+$, can be performed, along with the nearby state $\Sigma(1385)^+$ [Wang et al, CPL 41, 101401 (2024)]
- Explore the $\Lambda(1670)$ in $\Lambda_c^+ \to \Lambda\pi^+\eta$ and compare with that in $\Lambda_c^+ \to pK^-\pi^+$

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

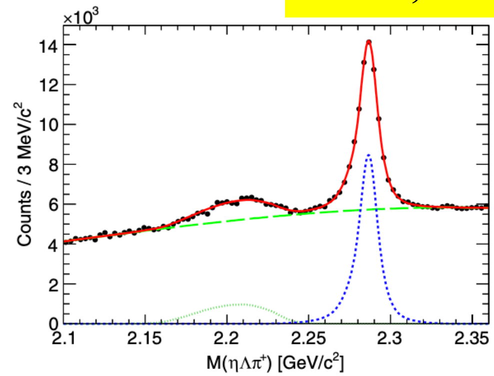
BESIII, PRD99, 032010 (2019)

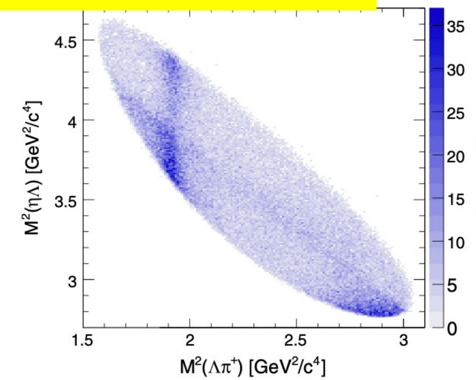


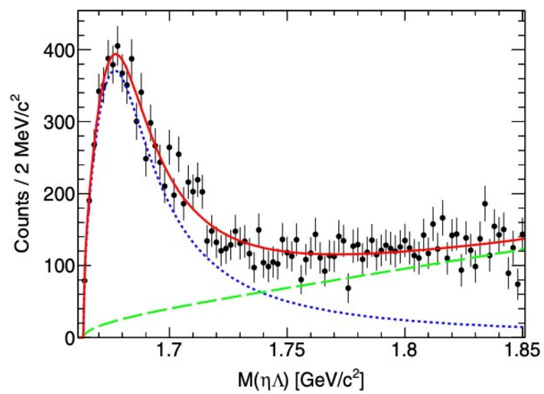


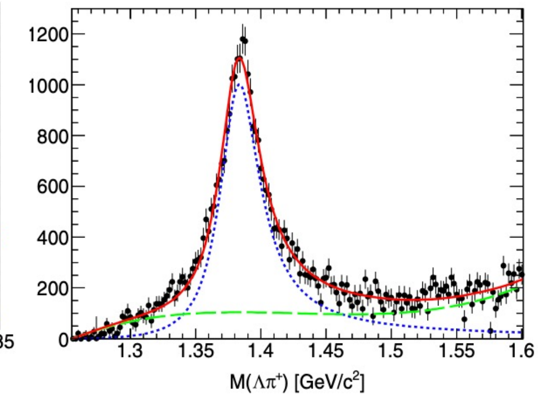
$$\mathcal{B}(\Lambda_c^+ \to \Sigma^{*+}\eta) = (0.91 \pm 0.18 \pm 0.09)\%.$$

Belle, PRD103, 052005 (2021)









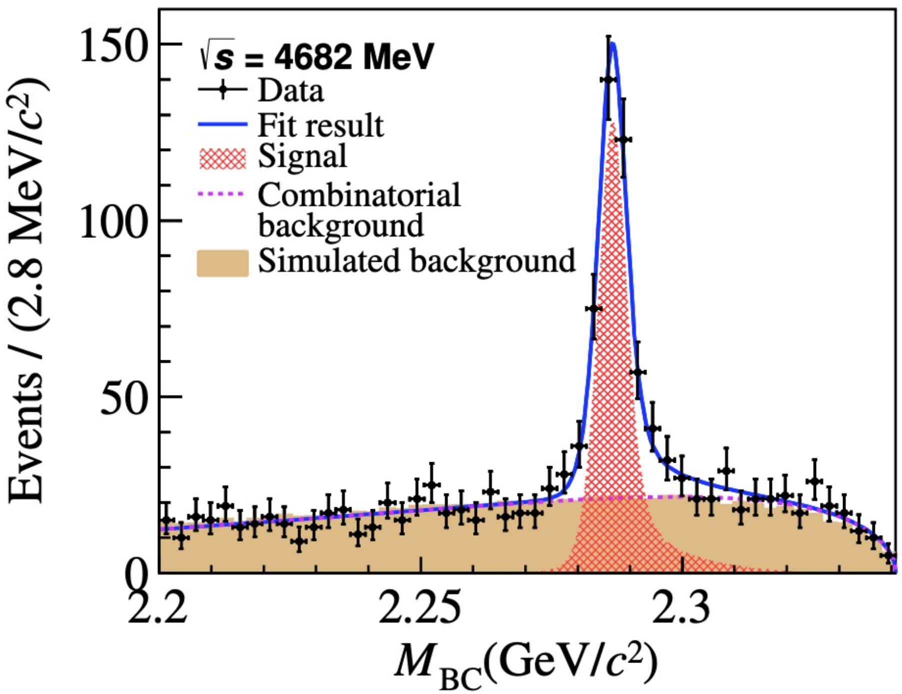
Resonances	Mass $[\mathrm{MeV}/c^2]$	Width [MeV]
$\Lambda(1670)$	$1674.3 \pm 0.8 \pm 4.9$	$36.1 \pm 2.4 \pm 4.8$
$\Sigma(1385)^+$	$1384.8 \pm 0.3 \pm 1.4$	$38.1 \pm 1.5 \pm 2.1$

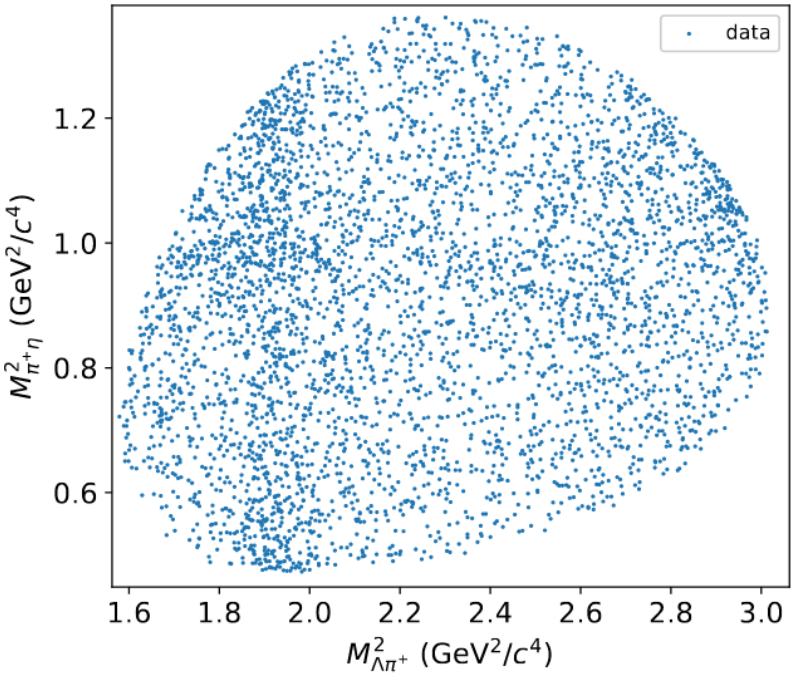
Decay modes	$\mathcal{B}(\text{Decay mode})/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$
$\Lambda_c^+ \to \Lambda(1670)\pi^+$; $\Lambda(1670) \to \eta\Lambda$	$(5.54 \pm 0.29 \pm 0.73) \times 10^{-2}$
$\Lambda_c^+ \to \eta\Sigma(1385)^+$	$0.192 \pm 0.006 \pm 0.016$

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

PRL134, 021901 (2025)

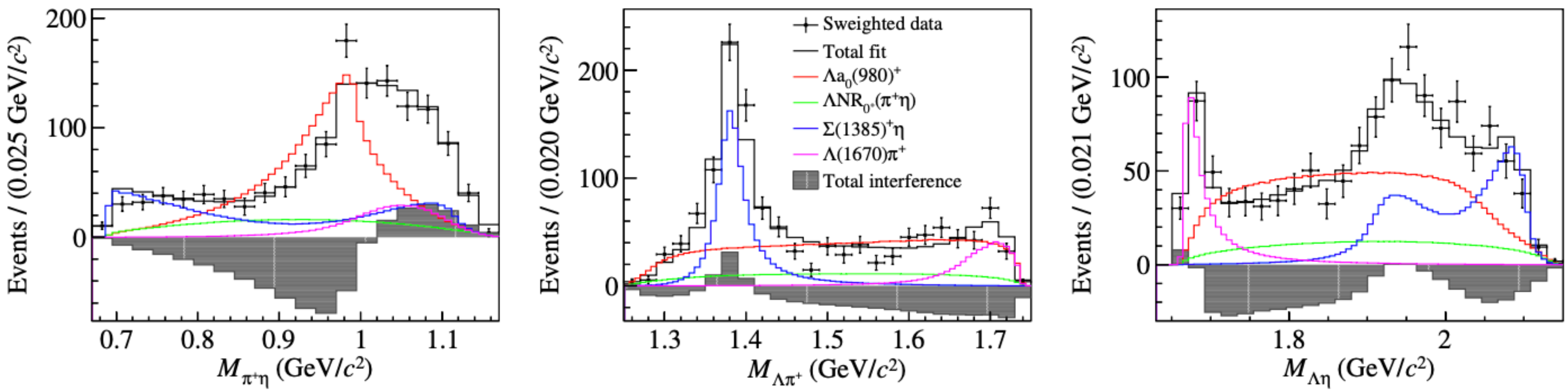
- 8x Λ_c^+ samples are used with combination of $\eta \to \gamma\gamma$ and $\pi^+\pi^-\pi^0$
- BDTG trained sample with about 1312 signals with purity of about 80%
- Based on TF-PWA package: *https://gitlab.com/jiangyi15/tf-pwa*

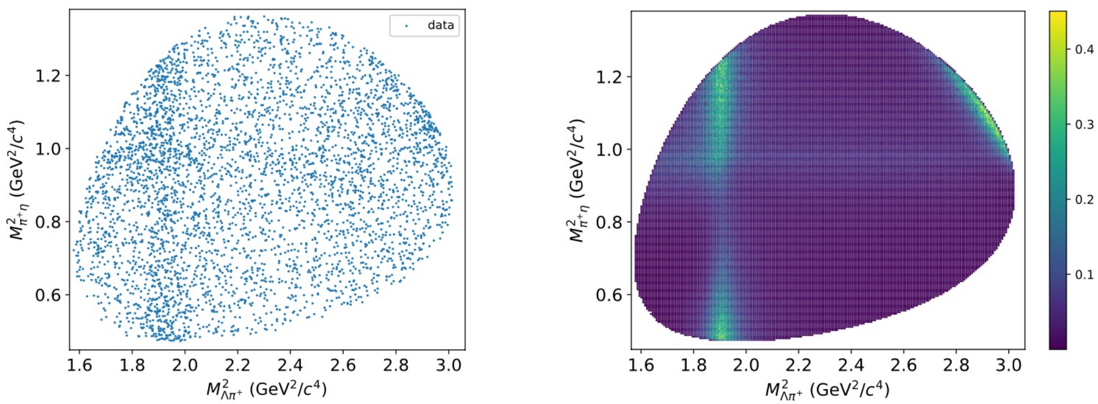




Baseline model of $\Lambda_c^+ \to \Lambda\pi^+\eta$

PRL134, 021901 (2025)





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

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

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

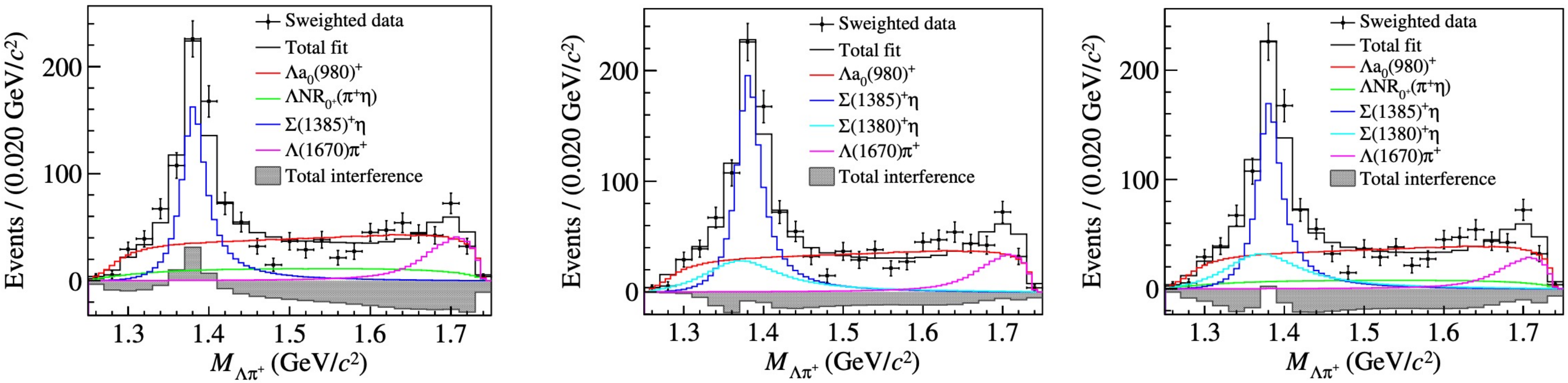
$$\alpha_{\Sigma(1385)^+\eta} = \frac{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 - \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2}{\left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{\frac{1}{2},0}\right|^2 + \left|H^{\Lambda_c^+\to\Sigma(1385)^+\eta}_{-\frac{1}{2},0}\right|^2}$$

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

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

PRL134, 021901 (2025)

Baseline model | Model A | Model B

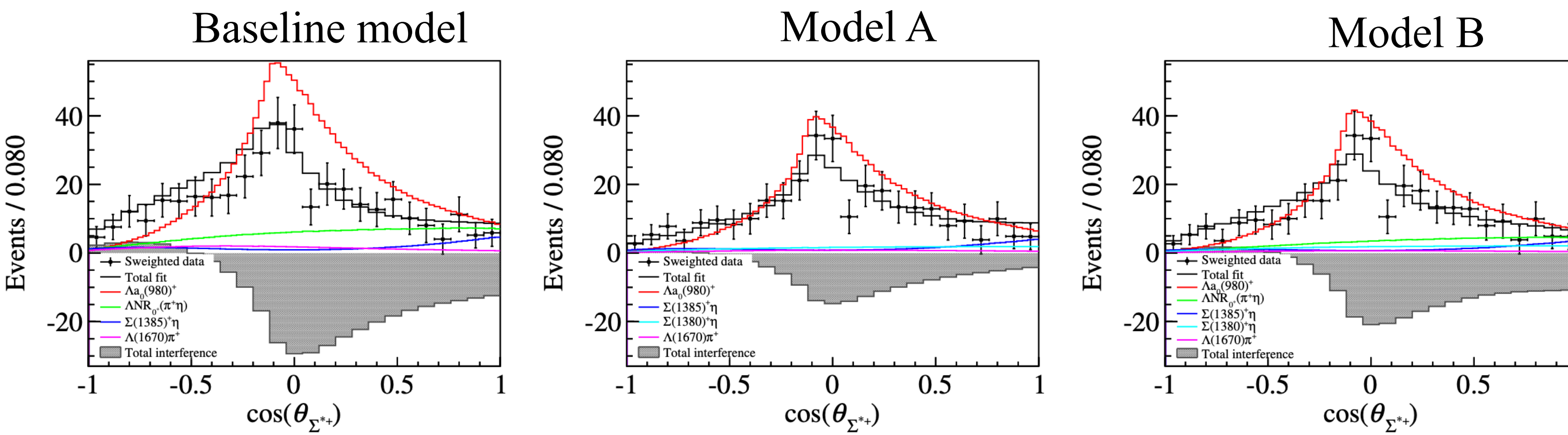


Process	Model A	Model B
$\Lambda a_0(980)^+$	$52.9 \pm 4.5\,(13.4\sigma)$	$50.6 \pm 8.0\,(11.1\sigma)$
$\Sigma(1385)^+\eta$	$36.6 \pm 2.6\,(15.8\sigma)$	$31.3 \pm 3.0\,(14.6\sigma)$
$\Lambda(1670)\pi^+$	$10.7 \pm 1.4\,(15.0\sigma)$	$9.0 \pm 1.6\,(11.9\sigma)$
$\Sigma(1380)^+\eta$	$15.5 \pm 4.4\,(6.1\sigma)$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

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

Comparison of Σ^{*+} helicity angles

PRL134, 021901 (2025)

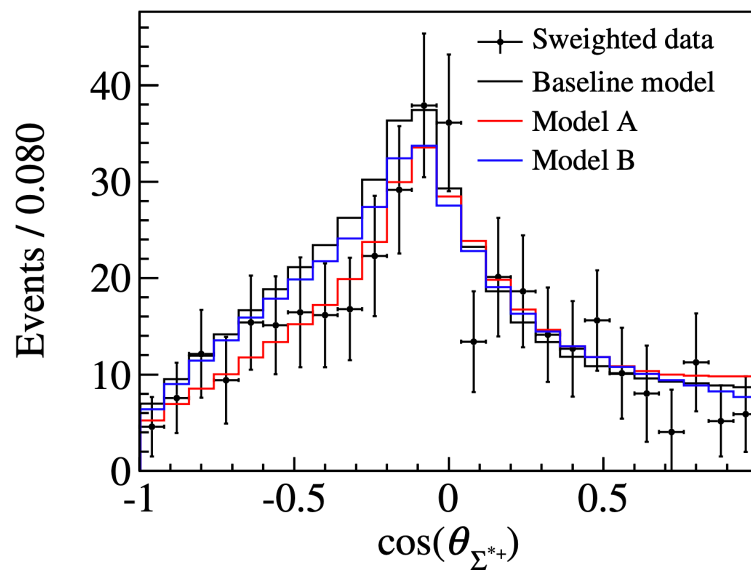


Kinematic region:

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

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

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



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

PRL134, 021901 (2025)

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

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

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

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

$\Lambda(1670)$ decay rates

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

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

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

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

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

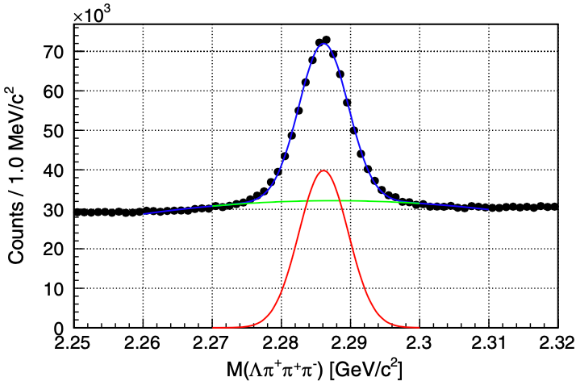
$\Lambda(1670)$ **DECAY MODES**

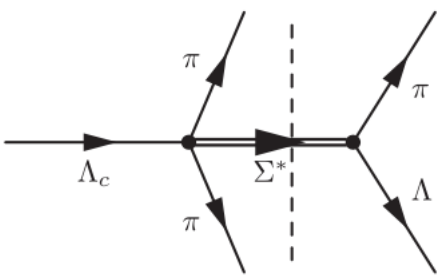
Mode		Fraction (Γ_i / Γ)
Γ_1	$N\overline{K}$	20–30%
Γ_2	$\Sigma\pi$	25–55%
Γ_3	$\Lambda\eta$	10–25%

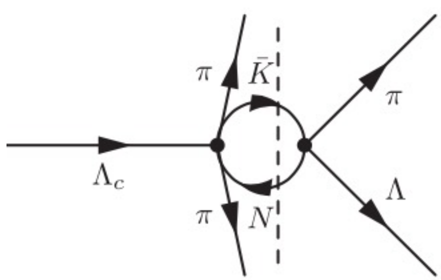
The rate of $N\overline{K}$ from the previous measurement seems too large!

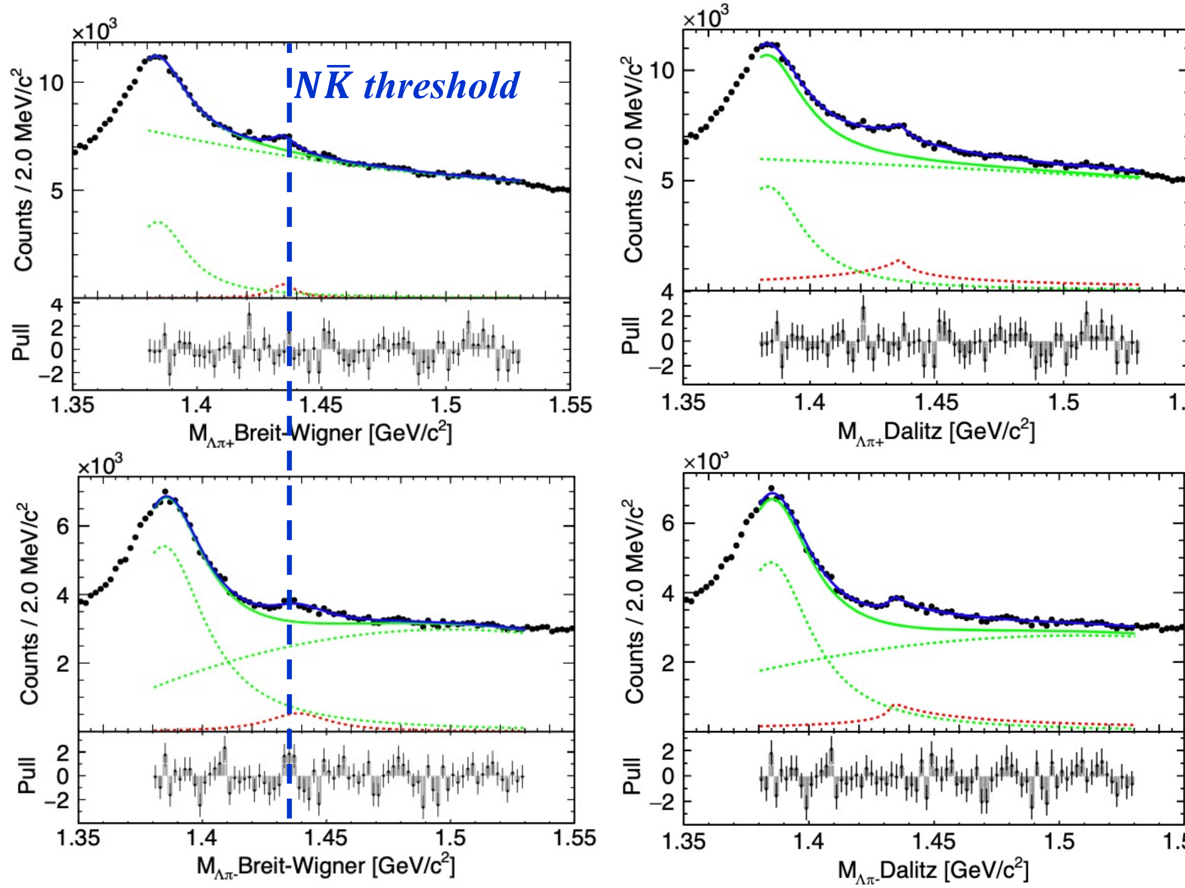
Structures near $N\bar{K}$ threshold in $\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$

Belle, PRL 130, 151903 (2023)









Enhancement around 1.43 GeV/c^2:

- significances are larger than 6.2 σ
- the current statistics can not distinguish the hypothesis of the $\Sigma(1430)$ or $N\bar{K}$ threshold cusp.

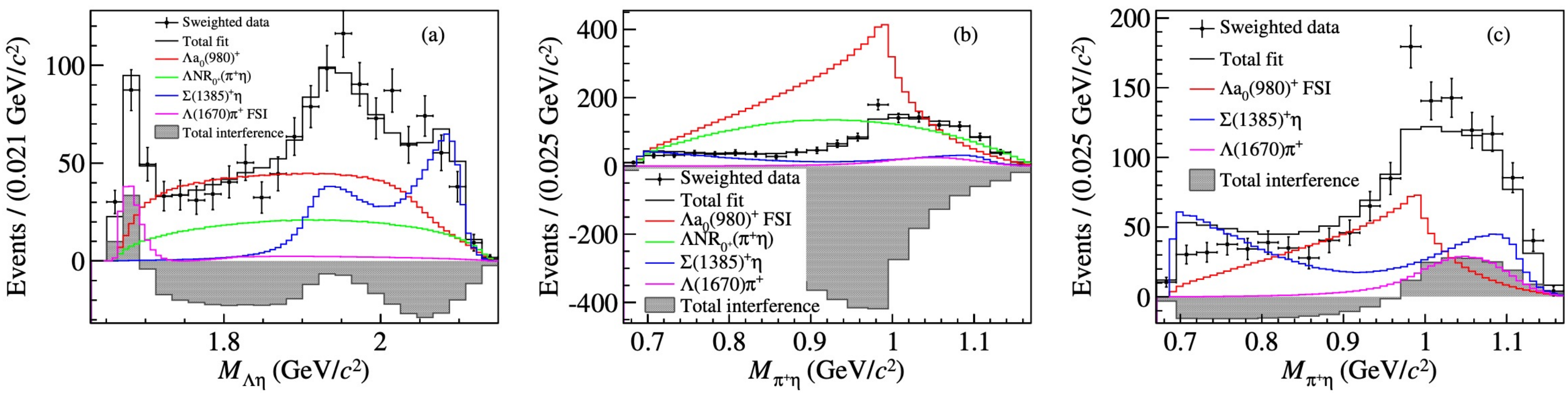
Summary

- Charmed baryon multi-body weak decays provide a unique laboratory to study the light hadron spectroscopy
- In recent years, experimental activities are mostly on the Λ_c^+ decays, esp. at BESIII, LHCb and Belle
- Amplitude analysis is a necessary to disentangle the interferences of different intermediate states
  - ✓ $\Lambda_c^+ \to pK^-\pi^+$ at LHCb
  - ✓ $\Lambda_c^+ \to \Lambda\pi^+\pi^0$ and $\Lambda\pi^+\eta$ at BESIII
- More studies are expected not only on Λ_c^+ decays, but also on $\Xi_c^{+/0}$ and Ω_c^0 decays. For example:
  - ✓ Amplitude analysis on $\Lambda_c^+ \to \Lambda 3\pi$ to understand the $\Lambda\pi$ structure as a $\Sigma(1430)$ or $N\bar{K}$ threshold cusp
  - ✓ Cross-channel studies via $\Lambda_c^+ \to pK_S\pi^0, pKK, p\pi\pi, pK^+\pi^-$ and $pK\pi\pi$; $\Lambda_c^+ \to \Sigma\pi\pi$; $\Xi_c \to \Xi hh', \Sigma hh', \Lambda hh', p3h/p2h$; $\Omega_c \to \Omega^-\pi^+\pi^0, \Xi\bar{K}\pi^+$
  - ✓ Semi-leptonic decays of $\Lambda_c^+ \to pK^-\mu^+\nu$

Thank you!

Backup

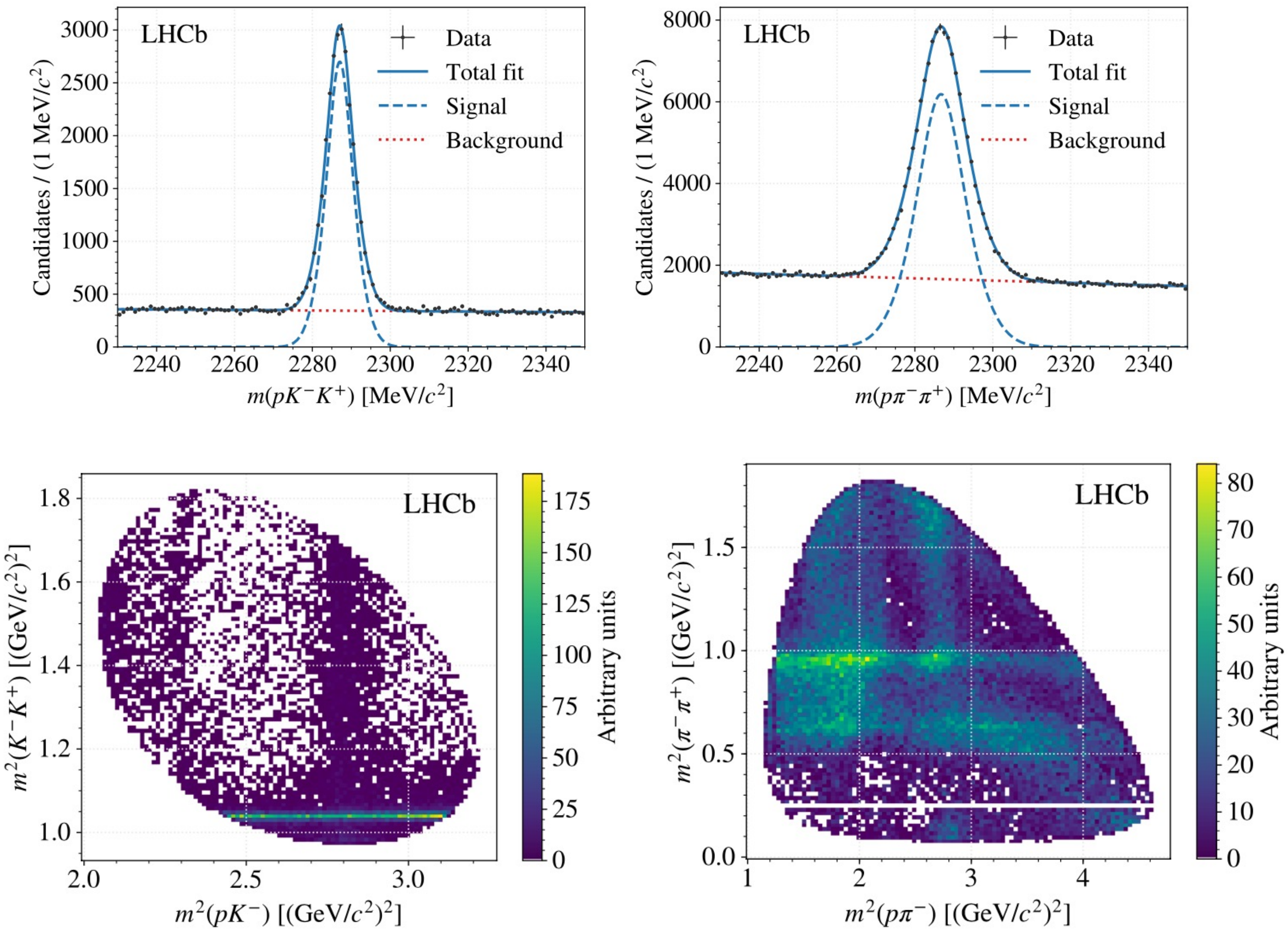
Test FSI model of $a_0(980)^+$ and $\Lambda(1670)$



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

Structures in $\Lambda_c^+ \to pK^-K^+$ and $\Lambda_c^+ \to p\pi^-\pi^+$

LHCb, JHEP03,182(2018)



$\Lambda_c^+ \to pK^-K^+$ $\Lambda_c^+ \to p\pi^-\pi^+$

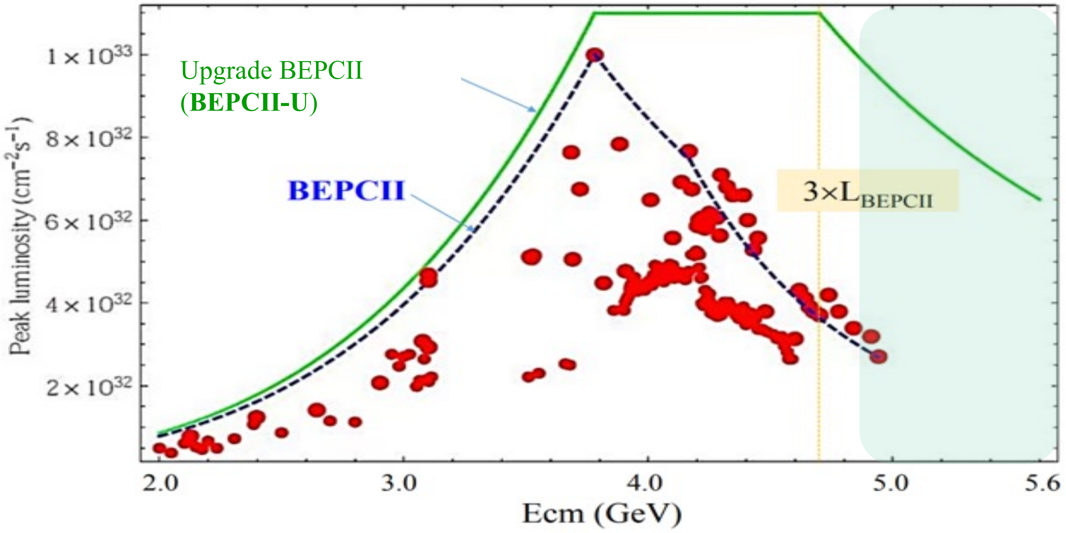
Future prospects

Proposal of the upgrade BEPCII

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

✓ **Improve luminosity by 3 times higher than current BEPCII at 4.7 GeV**

✓ **Extend the maximum energy to 5.6 GeV**

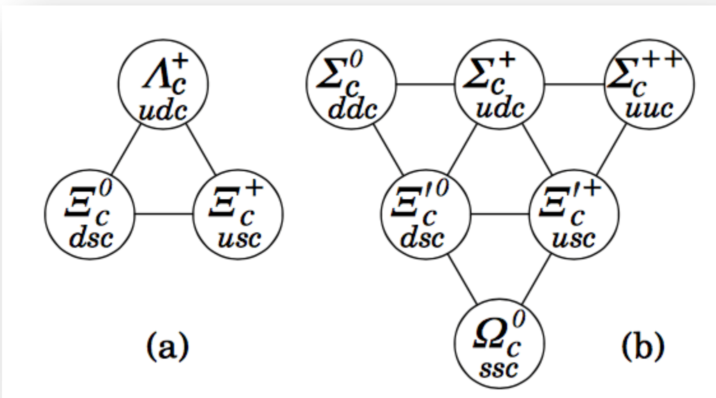


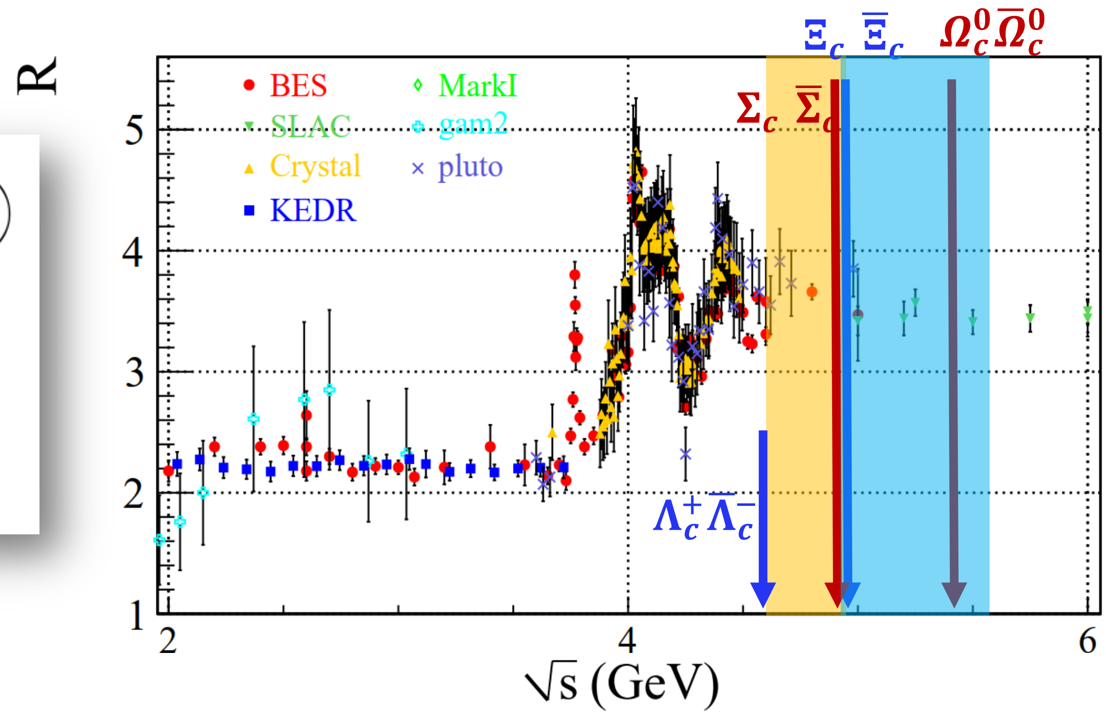
Capable of finishing the proposed luminosity of Λ_c^+ data in shorter time

1490 ➔ 600 days

Energy	Physics motivations	Current data	Expected final data	T_C / T_U
4.6 - 4.9 GeV	Charmed baryon/XYZ cross-sections	0.56 fb^{-1} at 4.6 GeV	15 fb^{-1} at different $\sqrt{s}$	1490/600 days
4.74 GeV	$\Sigma_c^+\bar{\Lambda}_c^-$ cross-section	N/A	1.0 fb^{-1}	100/40 days
4.91 GeV	$\Sigma_c\bar{\Sigma}_c$ cross-section	N/A	1.0 fb^{-1}	120/50 days
4.95 GeV	Ξ_c decays	N/A	1.0 fb^{-1}	130/50 days

Heavier charmed baryons





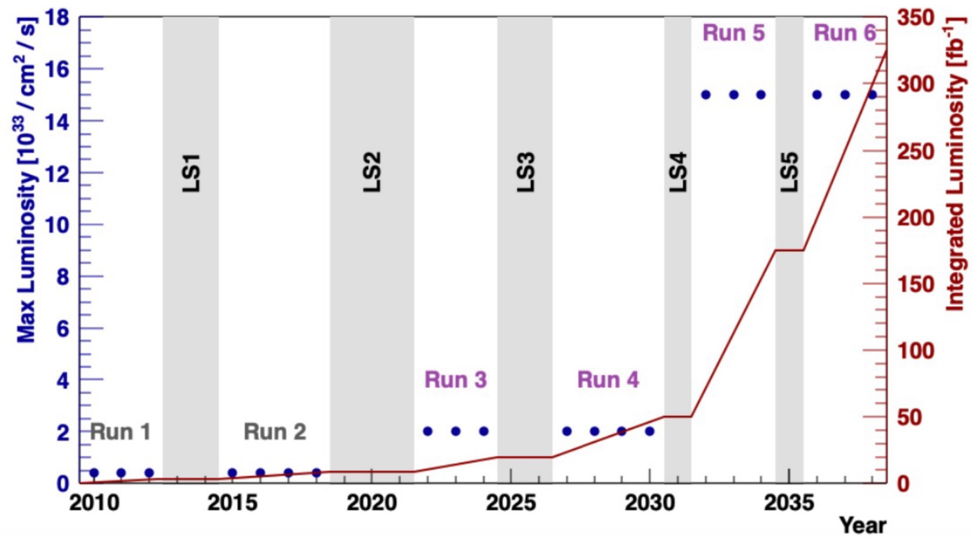
- Energy thresholds
  - ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
  - ✓ $e^+e^- \to \Lambda_c^+\bar{\Sigma}_c\,\pi$ 4.88 GeV
  - ✓ $e^+e^- \to \Sigma_c\,\bar{\Sigma}_c$ 4.91 GeV
  - ✓ $e^+e^- \to \Xi_c\,\bar{\Xi}_c$ 4.94 GeV
  - ✓ $e^+e^- \to \Omega_c^0\bar{\Omega}_c^0$ 5.40 GeV

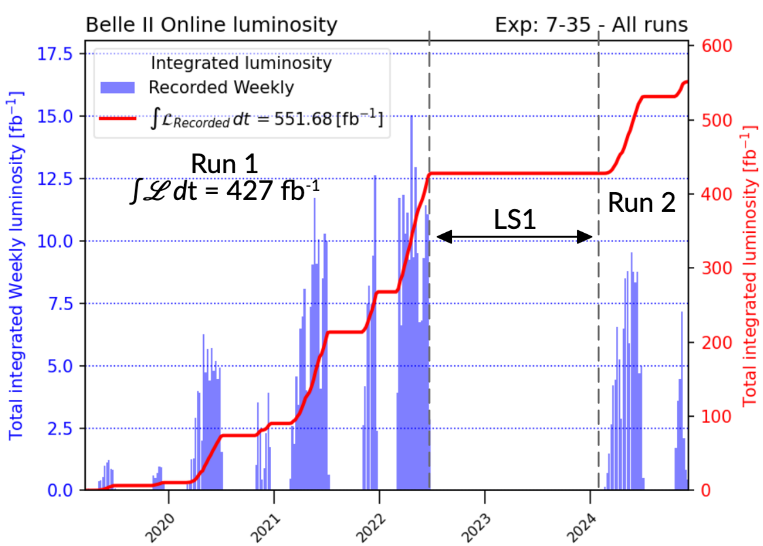
- Cover all the ground-state charmed baryons: studies on their production & decays, CPV search, to help developing more reliable QCD-derived models in charm sector
- Studies on the production and decays of excited charmed baryons

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}