Λ_c decays at BESIII

Yang Gao

On behalf of the BESIII Collaboration

University of Science and Technology of China

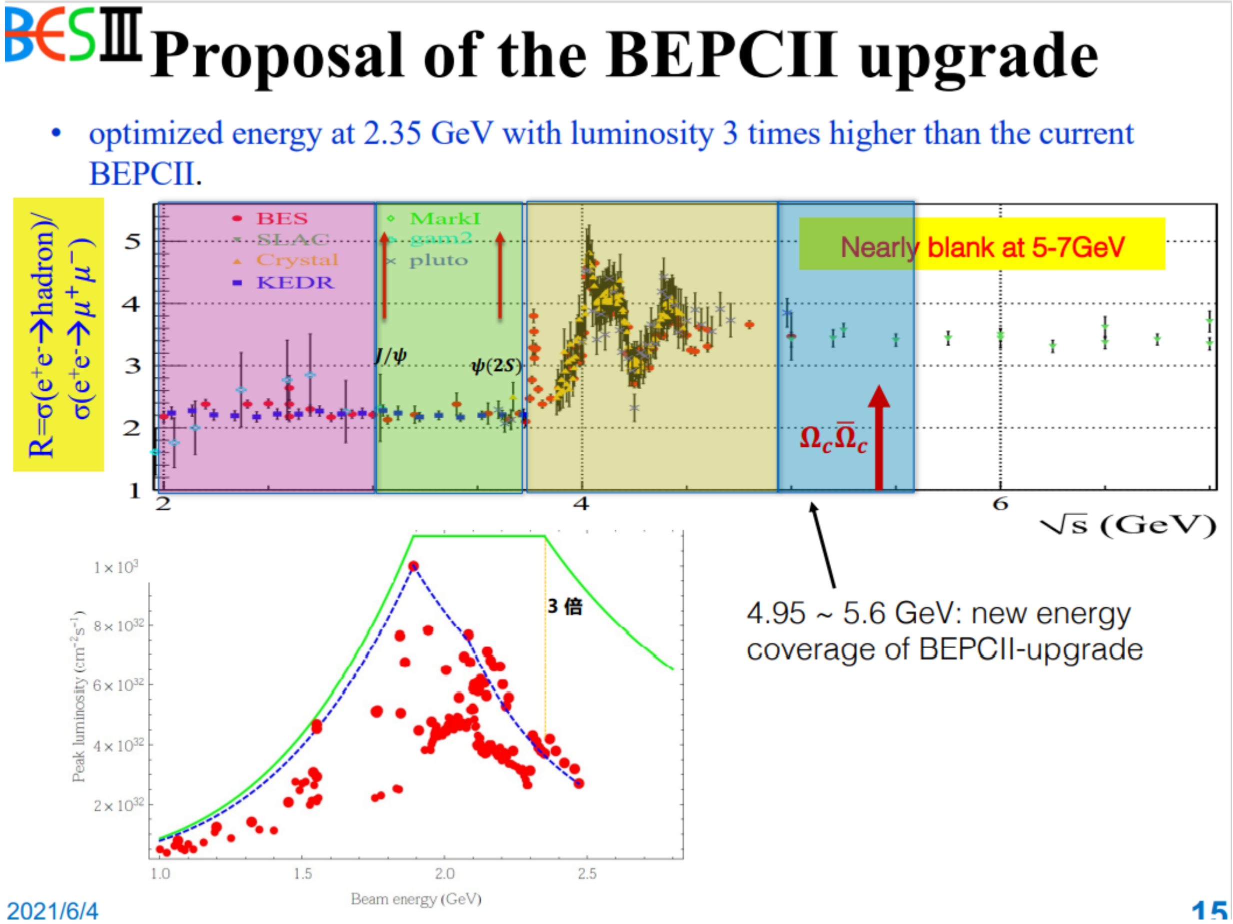
Outline

- Recap analysis of Λ_c^+ at BESIII
- BESIII experiment
- Introduction to $\Lambda_c^+ \to n\pi^+$
- Prediction of two-body decays of Λ_c^+
- $\Lambda_c^+ \to n\pi^+$ at BESIII
  - Double–tag method
  - Singly-tag yield
  - Distribution of $\Lambda_c^+ \to n\pi^+$
  - Results of $\Lambda_c^+ \to n\pi^+$
- The future
- Summary

Recap analysis of Λ_c^+ at BESIII

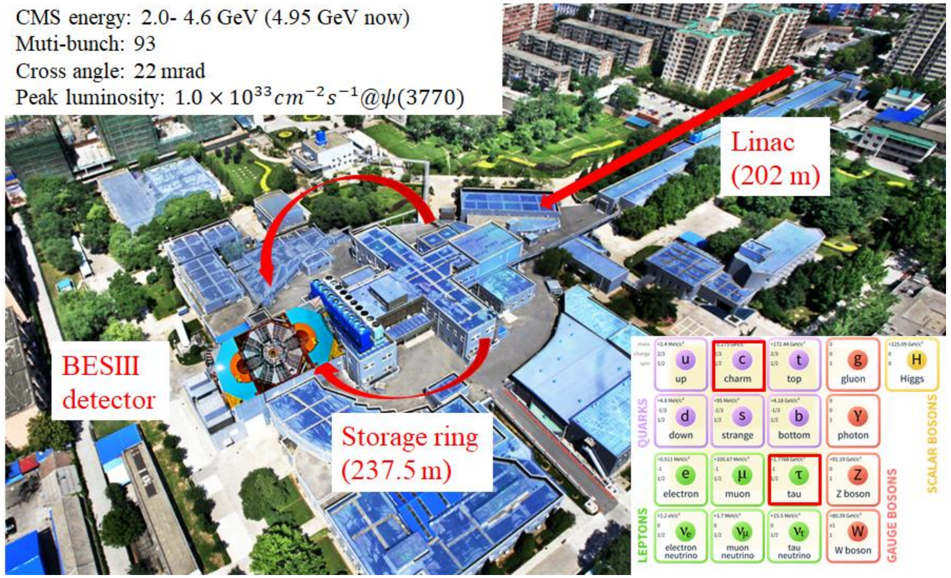
2014: 0.567 fb^{-1} at 4.6 GeV

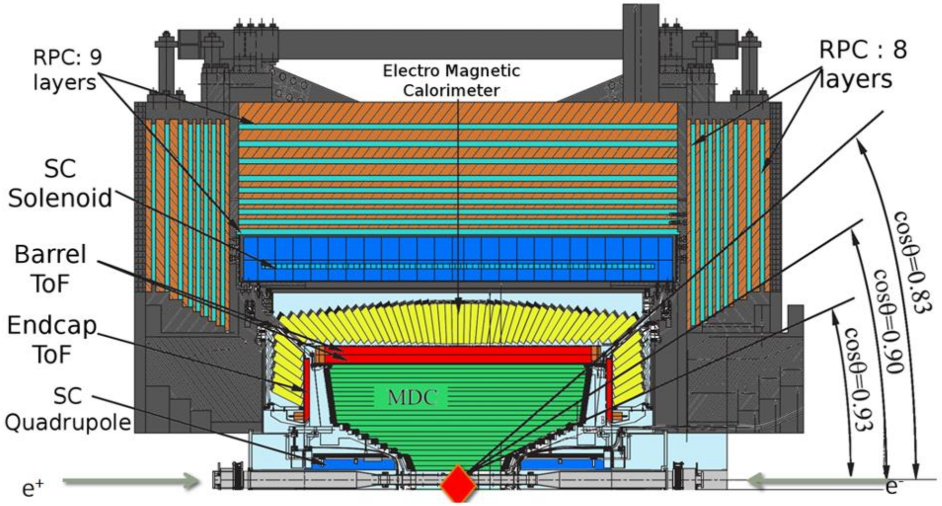
- Λ_c^+ hadronic decay
  - BF($\Lambda_c^+ \to pK^-\pi^+$) +11hadronic modes : PRL 116, 052001 (2016)
  - BF($\Lambda_c^+ \to pK^+K^-$, $p\pi^+\pi^-$) : PRL 117, 232002 (2016)
  - BF($\Lambda_c^+ \to nK_s\pi^+$) : PRL 118, 12001 (2017)
  - BF($\Lambda_c^+ \to p\eta$, $p\pi^0$) : PRD 95, 111102(R) (2017)
  - BF($\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$) : PLB 772, 388 (2017)
  - BF($\Lambda_c^+ \to \Xi^{(*)0}K^+$) : PLB 783,200 (2018)
  - BF($\Lambda_c^+ \to \Lambda\eta\pi^+$) : PRD99, 032010 (2019)
  - BF($\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$) : CPC43, 083002 (2019)
  - Λ_c^+ → BP decay asymmetries : PRD100, 072004 (2019)
  - BF($\Lambda_c^+ \to pK_s\eta$) : PLB 817, 136327 (2021)
  - Λ_c^+ spin determination : PRD 103, L091101 (2021)
- Λ_c^+ semi-leptonic decay
  - BF($\Lambda_c^+ \to \Lambda e^+\nu_e$) : PRL 115, 221805 (2015)
  - BF($\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$) : PLB 767, 42 (2017)
- Λ_c^+ inclusive decay $\Lambda_c^+ \to \Lambda+X$
  - BF($\Lambda_c^+ \to \Lambda X$) : PRL 121, 062003 (2018)
  - BF($\Lambda_c^+ \to eX$) : PRL 121 251801 (2018)
  - BF($\Lambda_c^+ \to K_S^0X$) : EPJC 80, 935 (2020)
- $\Lambda_c^+\bar{\Lambda}_c^-$ pair cross section : PRL 120,132001(2018).

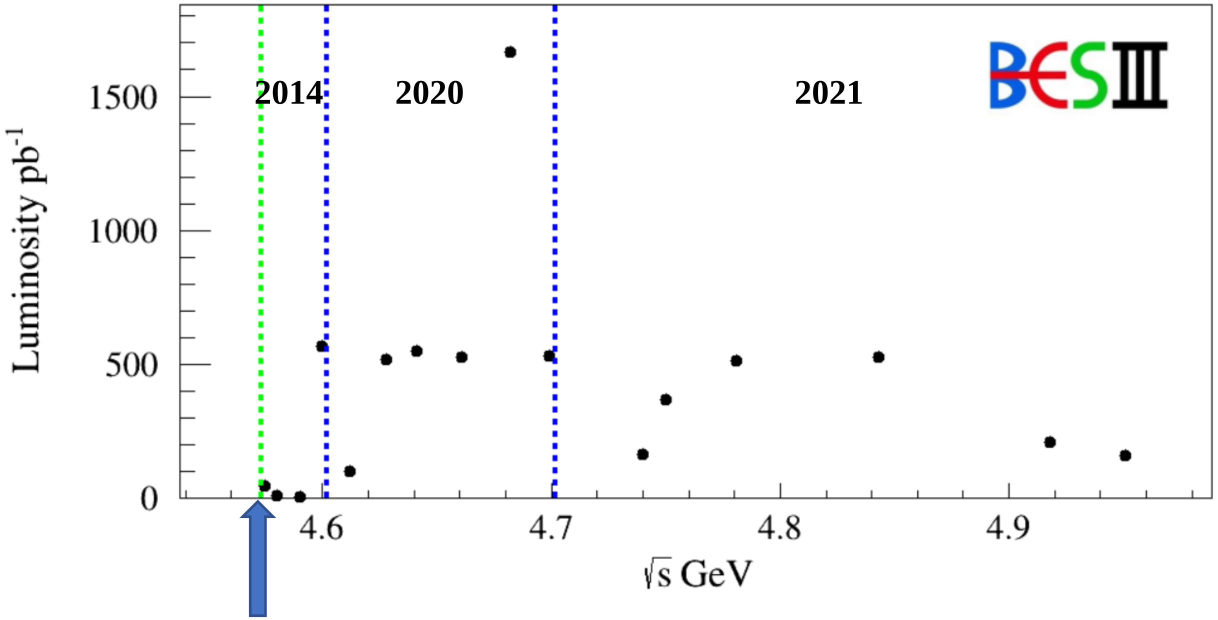


Reference: FPCP 2021: https://indico.ihep.ac.cn/event/12805/session/44/contribution/195/material/slides/0.pdf

BESIII experiment







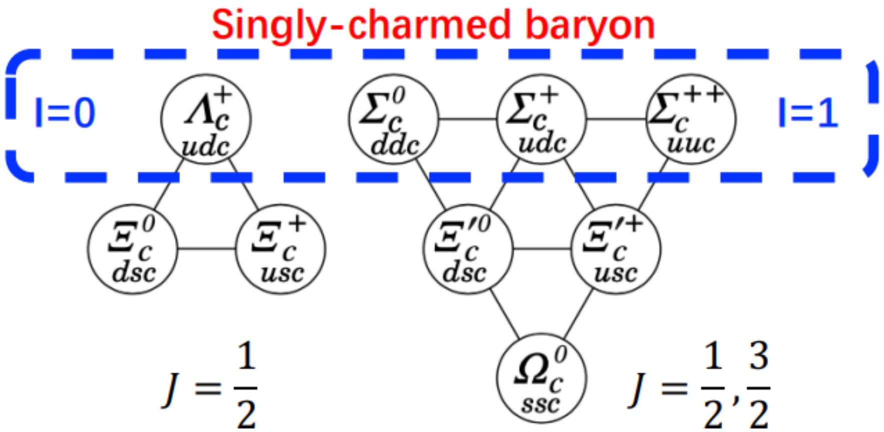
$\Lambda_c^+\bar{\Lambda}_c^-$ **production threshold**

arXiv:2205.04809

6.4 fb^{-1} collision data from 4.600 GeV to 4.951GeV

- The largest data samples collected near the $\Lambda_c^+\bar{\Lambda}_c^-$ production threshold

Introduction to $\Lambda_c^+ \to n\pi^+$

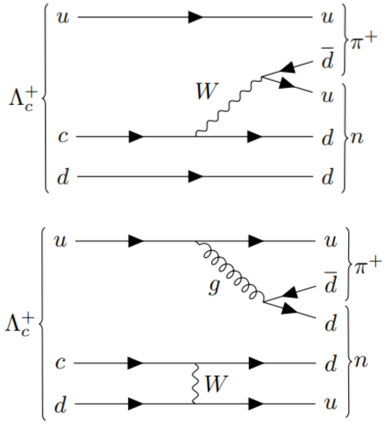


Most of the charmed baryons will eventually decay to Λ_c

Can't be ignored in charmed baryons

Λ_c hadronic decay amplitudes[1][2]

- Nonfactorizable components
- Factorizable components



$\mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0)$ → Sensitive in comparing different models.

[1]: L. L. Chau and H. Y. Cheng, Phys. Rev. Lett. 56, 1655 (1986).
[2]: K. Yoji, Phys. Rev. D. 44, 2799 (1991).

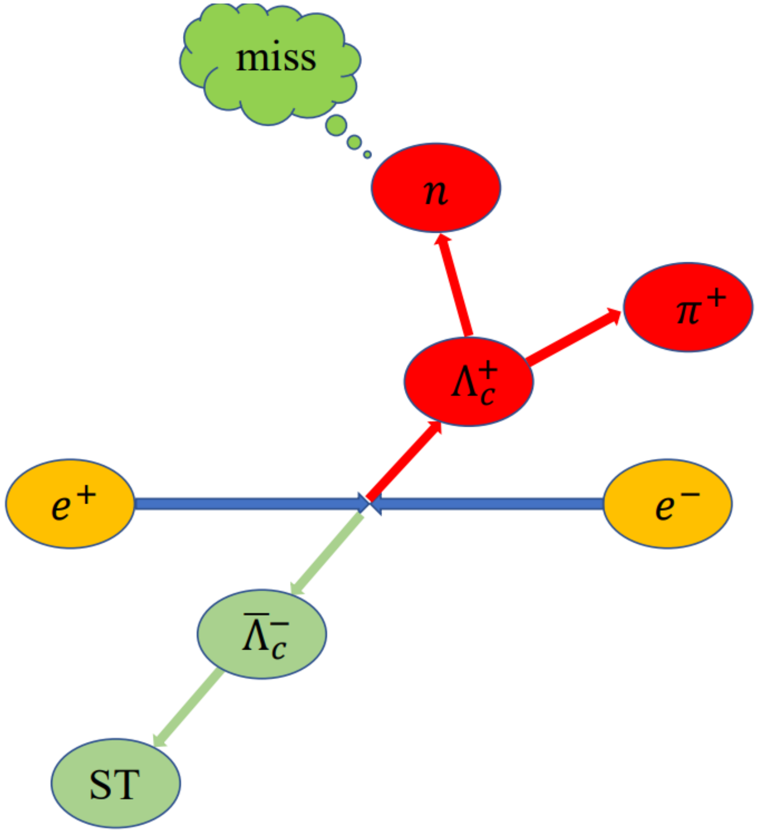
Prediction of two-body decays of Λ_c^+

Λ_c^+	$SU(3)_f$	Cheng et al.	Our work	Expt.
$10^4\mathcal{B}_{\Sigma^+K^0}$	10.5 ± 1.4	14.4	19.1 ± 4.8	
$10^4\mathcal{B}_{\Sigma^0K^+}$	5.2 ± 0.7	7.2	5.5 ± 1.6	5.2 ± 0.8
$10^4\mathcal{B}_{p\pi^0}$	$1.1^{+1.3}_{-1.1}$	1.3	$0.8^{+0.9}_{-0.8}$	0.8 ± 1.4
$10^4\mathcal{B}_{p\eta}$	11.2 ± 2.8	12.8	11.4 ± 3.5	12.4 ± 3.0
$10^4\mathcal{B}_{p\eta'}$	24.5 ± 14.6		7.1 ± 1.4	
$10^4\mathcal{B}_{n\pi^+}$	7.6 ± 1.1	0.9	7.7 ± 2.0	
$10^4\mathcal{B}_{\Lambda^0K^+}$	6.6 ± 0.9	10.7	5.9 ± 1.7	6.1 ± 1.2

Ref: J. High Energy Phys. 02 (2020) 165

- Challenge: Small branching fractions of 10^{-3} or below
- Provide more complete experimental inputs
- Input more precise results from experimental studies
- From $\mathcal{B}(\Lambda_c^+\to n\pi^+)/\mathcal{B}(\Lambda_c^+\to p\pi^0)$, test different models

Double-tag method



Reconstruct $\bar{\Lambda}_c^-$ from the tagged modes

↓

Extract the ST yields ($N_{i\,ST}$) from $M_{\rm BC}$ distribution

↓

Select the π^+ of Λ_c^+

↓

Extract the DT yields (N_{DT}) of neutron signal

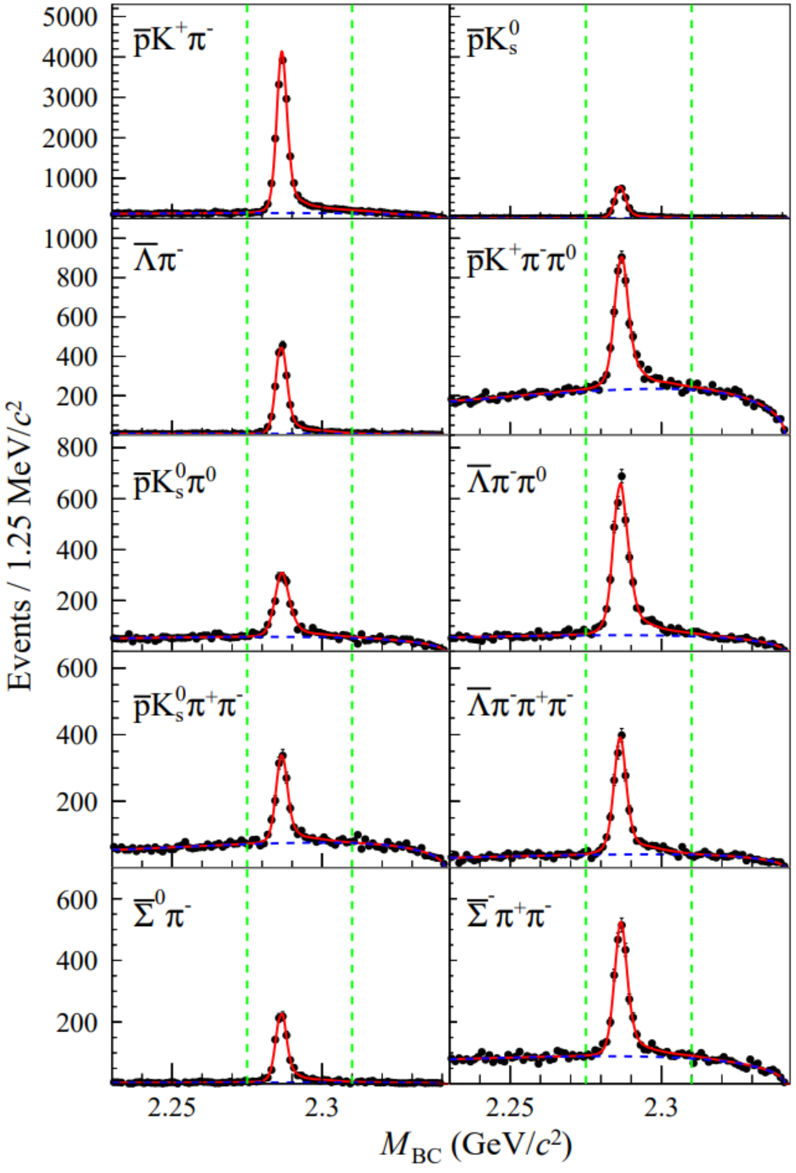
$$N_{i\,ST} = 2N_0 \times \mathcal{B}_i \times \varepsilon_{i\,ST}$$

$$N_{is\,DT} = 2N_0 \times \mathcal{B}_i \times \mathcal{B}_s \times \varepsilon_{is\,DT}$$

$$\mathcal{B}_s = \frac{\Sigma N_{is\,DT}}{\Sigma N_{i\,ST} \times \varepsilon_{is\,DT}/\varepsilon_{i\,ST}}$$

- $N_{i\,ST}$: The yields in the i singly tagged(ST) mode.
- $\varepsilon_{i\,ST}$: The efficiency in the i singly tagged(ST) mode.
- $N_{is\,DT}$: The signal yields in the i singly tagged(ST) mode.
- $\varepsilon_{is\,DT}$: The signal efficiency in the i singly tagged(ST) mode.
- N_0: The number of $\bar{\Lambda}_c^-\Lambda_c^+$ production.
- $\mathcal{B}_s$: The branching fraction of the signal decay.

Singly-tag yield

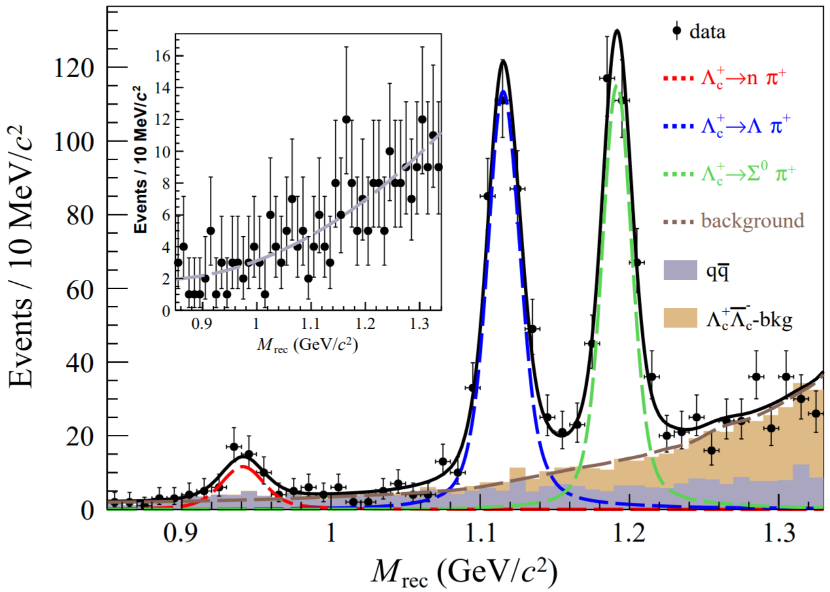


- ✓ Data sample: data @ 4.612-4.699 GeV
- ✓ 10 singly tagged modes at BESIII
- ✓ $N_{ST} = 90692 \pm 359$ with 10 tags @ 4.612-4.699 GeV
- ✓ Left figure: $\sqrt{s} = 4.682$ GeV as example

$$M_{\rm BC} = \sqrt{E_{\rm beam}^2/c^4 - |\vec{p}_{\bar{\Lambda}_c^-}|^2/c^2}$$

- $E_{\rm beam}$ is the beam energy.
- $\vec{p}_{\bar{\Lambda}_c^-}$ is the momentum of the $\bar{\Lambda}_c^-$ candidate.

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



$$M_{\rm rec}^2 = (E_{\rm beam} - E_{\pi^+})^2/c^4 - |\rho \cdot \vec{p}_0 - \vec{p}_{\pi^+}|^2/c^2$$

- E_{π^+} and $\vec{p}_{\pi^+}$ are the energy and momentum of π^+ candidate
- $\rho = \sqrt{E_{\rm beam}^2/c^2 - m_{\Lambda_c^+}^2 c^2}$

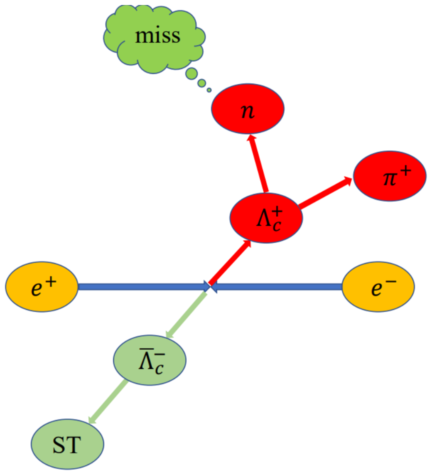
Phys. Rev. Lett. 128 (2022) 142001

- $\vec{p}_0 = -\vec{p}_{\bar{\Lambda}_c^-}/|\vec{p}_{\bar{\Lambda}_c^-}|$ is the unit direction opposite to the ST $\bar{\Lambda}_c^-$

- Red peak: $\Lambda_c^+ \to n\pi^+$
- Blue peak: $\Lambda_c^+ \to \Lambda\pi^+$
- Green peak: $\Lambda_c^+ \to \Sigma^0\pi^+$

- The background from continuum processes $e^+e^- \to q\bar{q}(q = u, d, s)$
- The background from the other decays of $\Lambda_c^+\bar{\Lambda}_c^-$ (like $\Lambda_c^+ \to \Lambda\pi^0\pi^+$……)

Background

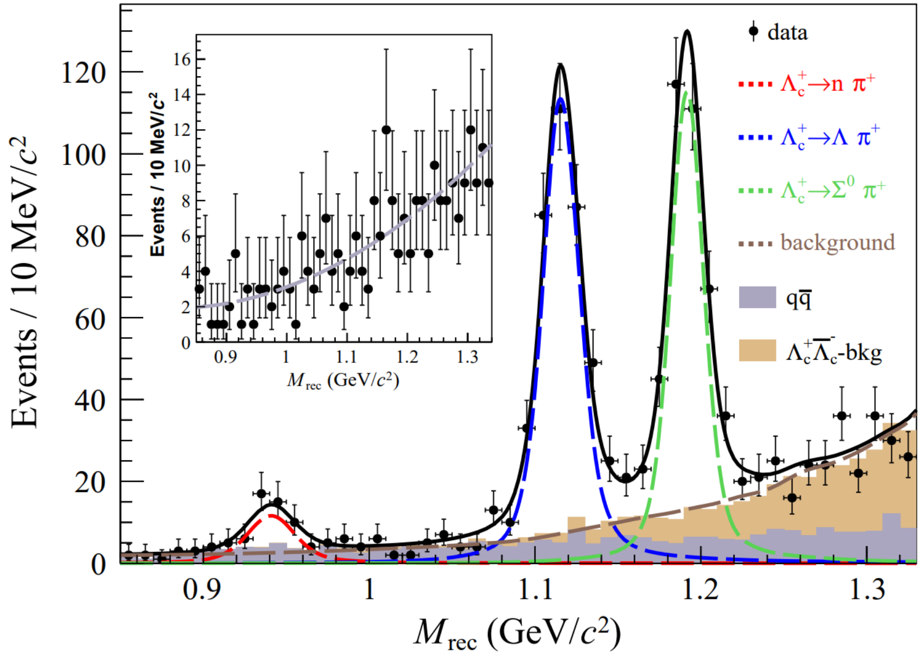


✓ Select the signal pion after reconstructing the ST $\bar{\Lambda}_c^-$.

✓ Require no charged tracks from the missing part.

✓ Extract the yields from the invariant mass of the missing part.

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



Decay	Yields	Branching fraction
$\Lambda_c^+ \to n\pi^+$	50 ± 9	$(6.6 \pm 1.2_{stat} \pm 0.4_{syst}) \times 10^{-4}$
$\Lambda_c^+ \to \Lambda\pi^+$	376 ± 22	$(1.31 \pm 0.08_{stat} \pm 0.05_{syst}) \times 10^{-2}$
$\Lambda_c^+ \to \Sigma^0\pi^+$	343 ± 22	$(1.22 \pm 0.08_{stat} \pm 0.07_{syst}) \times 10^{-2}$

- ✓ Define $R = \mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0)$
- ✓ Use $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 8.0 \times 10^{-5}$ at 90% C.L. of Belle from Phys. Rev. D 103, 072004 (2021)

R	> 7.2 at 90% C.L.

- ✓ Red peak: $\Lambda_c^+ \to n\pi^+$ 7.3σ
- ✓ Blue peak: $\Lambda_c^+ \to \Lambda\pi^+$
- ✓ Green peak: $\Lambda_c^+ \to \Sigma^0\pi^+$

} Consistent with results from PDG

Phys. Rev. Lett. 128 (2022) 142001

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

Decay	Yields	Branching fraction this work
$\Lambda_c^+ \to n\pi^+$	50 ± 9	$(6.6 \pm 1.2_{\text{stat}} \pm 0.4_{\text{syst}}) \times 10^{-4}$
R	> 7.2 at 90% C.L.	

$\mathcal{B}(\Lambda_c^+ \to n\pi^+) \times 10^{-4}$	R	Reference
4	2	PRD 55, 7067 (1997)
9	2	PRD 93, 056008 (2016)
11.3 ± 2.9	2	PRD 97, 073006 (2018)
8 or 9	4.5 or 8.0	PRD 49, 3417 (1994)
2.66	3.5	PRD 97, 074028 (2018)
6.1 ± 2.0	4.7	PLB 790, 225 (2019)
7.7 ± 2.0	9.6	JHEP 02 (2020) 165

- ✓ For the branching fraction of $\Lambda_c^+ \to n\pi^+$ and the ratio, it is contradictory between our measurement and these references.
- ✓ The branching fraction is consistent with our result but the ratio is contradictory with it.
- ✓ The branching fraction and ratio are consistent with our results, but the uncertainty of $\mathcal{B}(\Lambda_c^+ \to p\pi^0)$ is about 100%.

The future: hadronic decays

Sensitivity of $\Lambda_c^+ \to p\pi^0$, $\Lambda_c^+ \to p\eta$ and $\Lambda_c^+ \to p\eta'$……

For the hint of $\Lambda_c^+ \to p\pi^0$

DT Method

Sensitive in different models

- $\Lambda_c^+ \to p\pi^0$ ~5 events, input Br $= 1 \times 10^{-4}$
- With MC simulation $\sim 3\sigma$ significance
- Provide new results about $R = \mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0)$

Measurement of $\Lambda_c^+ \to p\eta$

ST Method

More precise input.

- Use ~0.5 fb^{-1} data in 2014

$\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.28_{\text{stat.}} \pm 0.10_{\text{syst.}}) \times 10^{-3}$

- With inclusive MC, expect $\sigma_{\text{stat.}}$: $0.28 \Rightarrow \sim 0.1$

For the hint of $\Lambda_c^+ \to p\eta'$

DT Method

……

- Dominant decay modes, $\eta' \to \pi^+\pi^-\eta$ and the neutral modes of η as missing in the selections
- With MC simulation $\sim 4\sigma$ significance

The future: semi-leptonic decays

Sensitivity of semi-leptonic decays: $\Lambda_c^+ \to pK^-e^+\nu_e$ $\Lambda_c^+ \to \Lambda e^+\nu_e$ ……

Find the hint of $\Lambda_c^+ \to pK^-e^+\nu_e$

Use DT method.

- With studies of inclusive MC, expect $> 5\sigma$ significance
- Clean signal peak.

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

Use DT method.

- $\Gamma_s = \frac{d\Gamma}{dq^2 d\cos\theta_\Lambda d\cos\theta_W d\chi} \sim F(f_1, f_2)$

  f_1, f_2 is form factor
- MC simulation, 6 times MC of data at 4600 GeV, $f_2/f_1 = -0.31 \pm 0.08(25\%)$, input -0.31;
- with 16 times MC of data at 4600 GeV, the precision for f_2/f_1 will be ~15%
- If combining electron and muon channels, the precision of f_2/f_1 will be expected to reach ~12%

……

The future: inclusive decays

Sensitivity of inclusive decays: $\bar{\Lambda}_c^- \to \bar{n} + X$ ……

Inclusive modes

Γ_{74}	e^+ anything	(3.95 ± 0.35) %
Γ_{75}	p anything	(50 ±16) %
Γ_{76}	n anything	(50 ±16) %
Γ_{77}	Λ anything	$(38.2\ ^{+2.9}_{-2.4})$ %
Γ_{78}	K_S^0 anything	(9.9 ± 0.7) %
Γ_{79}	3prongs	(24 ± 8) %

➢ From PDG, in the inclusive modes, the precision ~32% for $p +$ anything and $n +$ anything and ~9% for $e^+ +$ anything.

Measurement of $\bar{\Lambda}_c^- \to \bar{n} + X$

Use DT method.

Thousands of candidates from inclusive MC simulation

- Challenge: adjust the MC of anti-neutron to be consistent with data.

Measurement of $\Lambda_c^+ \to X + e^+\nu_e$

Use DT method.

- Thousands of candidates from inclusive MC simulation

……

More information: Future Physics Programme of BESIII (Chinese Physics C Vol. 44, No. 4 (2020) 040001)

Summary

- ✓ In 2022, we have new results about $\Lambda_c^+ \to n\pi^+$ which are measured firstly:
  - ➢ $\mathcal{B}(\Lambda_c^+ \to n\pi^+) = (6.6 \pm 1.2_{\text{stat}} \pm 0.4_{\text{syst}}) \times 10^{-4}$ with a statistical significance of 7.3 σ.
  - ➢ $R(\Lambda_c^+ \to n\pi^+/\Lambda_c^+ \to p\pi^0) > 7.2$ at 90% C.L.

Phys. Rev. Lett. 128 (2022) 142001

- ✓ We have results about $\Lambda_c^+ \to \Lambda\pi^+$ and $\Lambda_c^+ \to \Sigma^0\pi^+$ which are consistent with PDG:
  - ➢ $\mathcal{B}(\Lambda_c^+ \to \Lambda\pi^+) = (1.31 \pm 0.08_{\text{stat}} \pm 0.05_{\text{syst}}) \times 10^{-2}$
  - ➢ $\mathcal{B}(\Lambda_c^+ \to \Sigma^0\pi^+) = (1.22 \pm 0.08_{\text{stat}} \pm 0.07_{\text{syst}}) \times 10^{-2}$

- ✓ The results of branching fraction of $\Lambda_c^+ \to n\pi^+$ and the ratio between the branching fractions of $\Lambda_c^+ \to n\pi^+$ and $\Lambda_c^+ \to p\pi^0$ disagree with the most predictions of models.

- ✓ To obtain an improved understanding of Λ_c, it is desirable to preform improved studies of these decays, in particular concerning the $\Lambda_c^+ \to p\pi^0$ branching fraction in the future using the data from 4.600 to 4.951 GeV.

- ✓ More results of Λ_c will be published very soon.

Thanks for your attention!