Λ_c^+ decays at BESIII

Cong GENG
Sun Yat-sen University
On behalf of BESIII Collaboration

ICHEP 2022 BOLOGNA

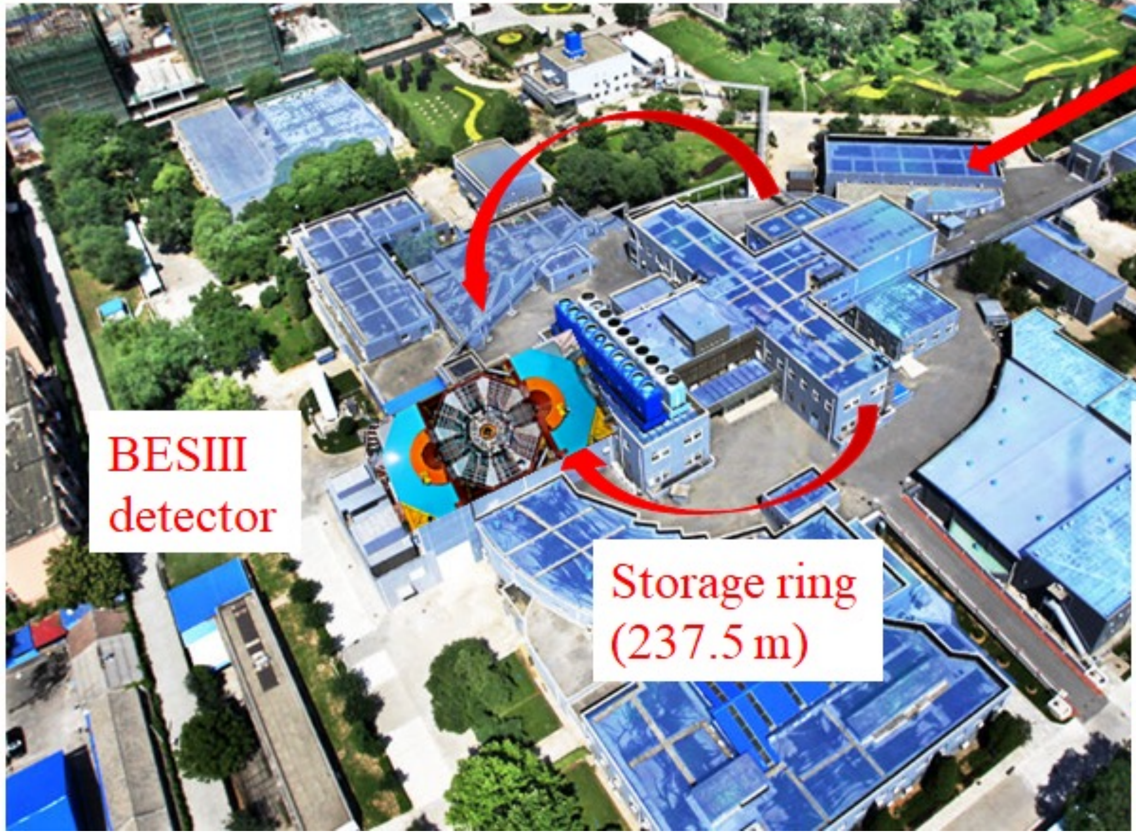
ICHEP 2022 XLI
International Conference on High Energy Physics
Bologna (Italy)
6 13 07 2022

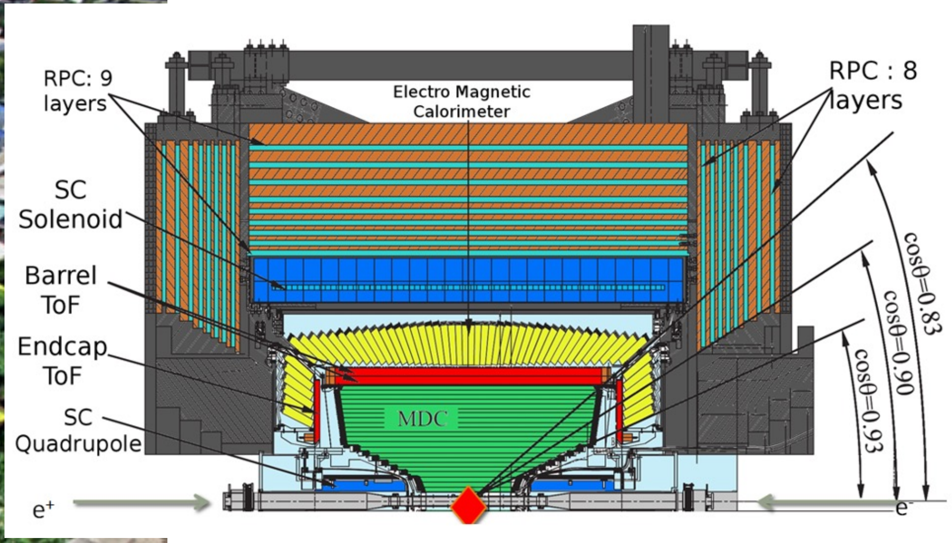
Outline

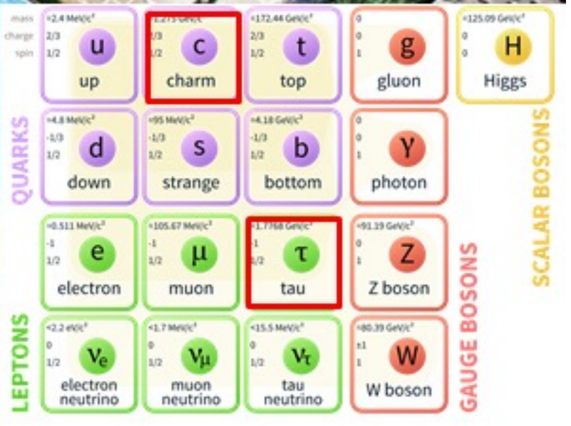
- BESIII experiment
- Λ_c^+ history at BESIII
- Interesting physics
- Advantage of Λ_c^+ study at BESIII
- Study of $\Lambda_c^+ \to n\pi^+$
- Prospect of Λ_c^+ at BESIII

BESIII Experiment

CMS energy: 2.0- 4.6 GeV (4.95 GeV now)
Muti-bunch: 93
Cross angle: 22 mrad
Peak luminosity: $1.0 \times 10^{33} cm^{-2} s^{-1} @\psi(3770)$



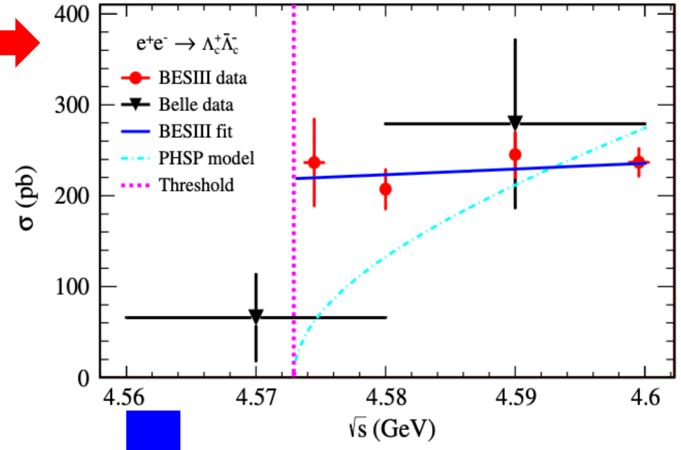




Λ_c^+ history at BESIII

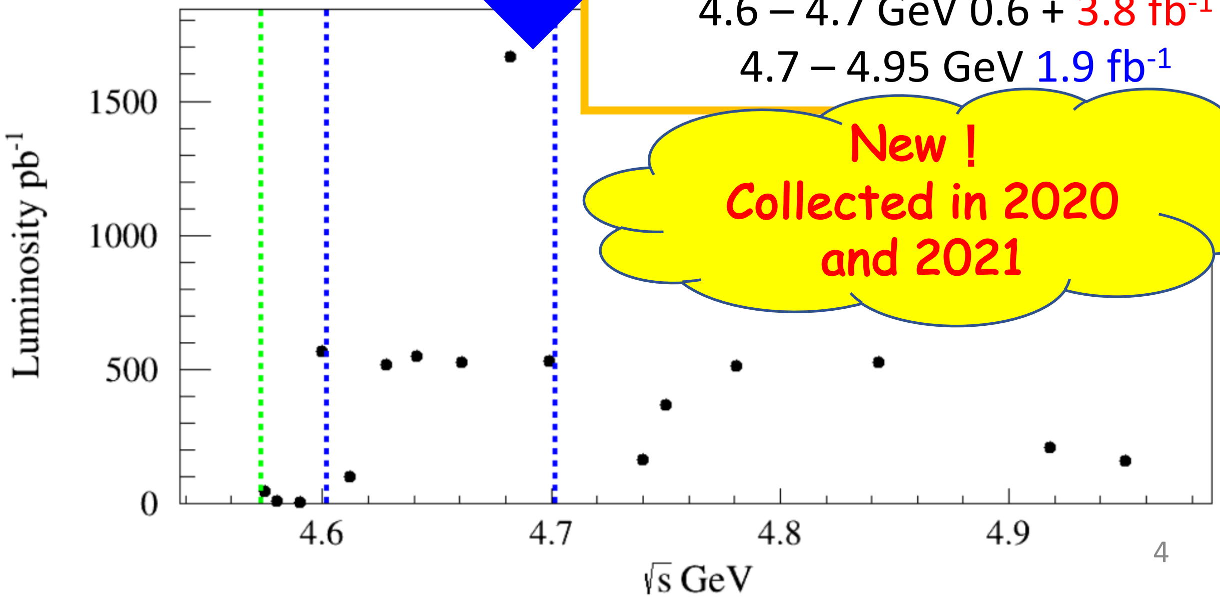
2014: 0.567 fb^{-1} at 4.6 GeV

- 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)
  - $\Lambda_c^+ \to$ 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($\Lambda_c^+ \to K_S^0 X$) : EPJC 80, 935 (2020)
- $\Lambda_c^+\bar{\Lambda}_c^-$ pair cross section : PRL 120,132001(2018).

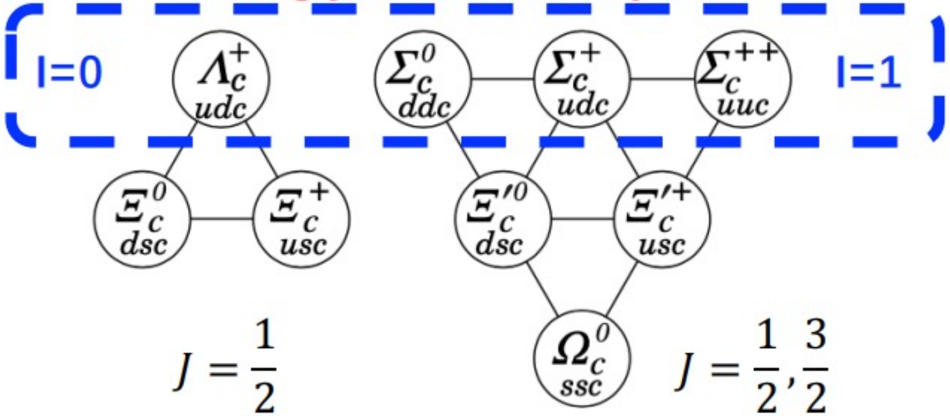


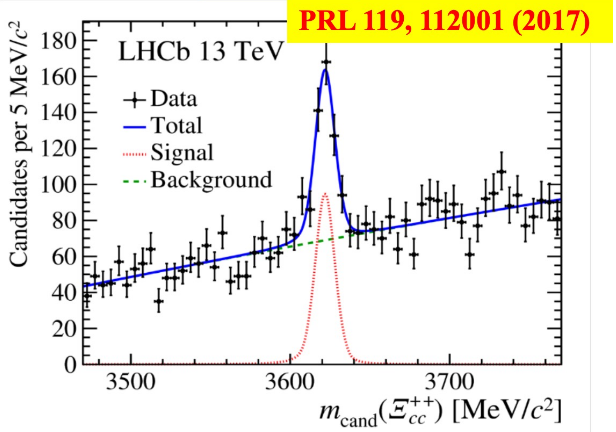
4.6 – 4.7 GeV 0.6 + 3.8 fb^{-1}
4.7 – 4.95 GeV 1.9 fb^{-1}

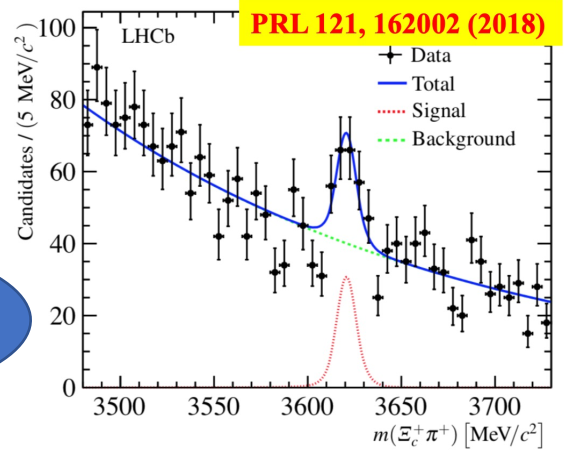
New !
Collected in 2020 and 2021



Charmed baryon Λ_c^+





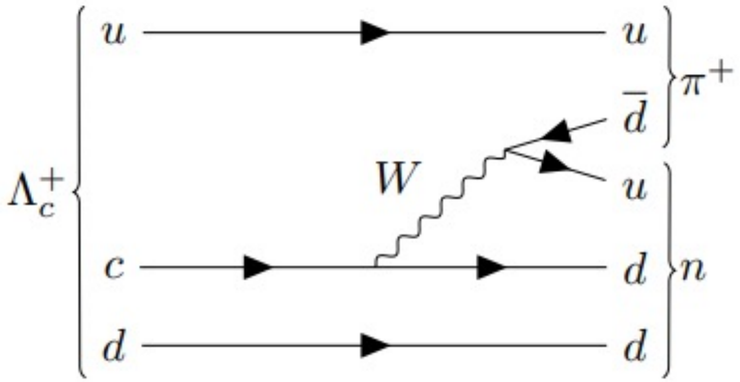


- LHCb observed doubly charm baryon Ξ_{cc}^{++} with $\Xi_{cc}^{++} \to \Lambda_c^+ K^- \pi^+ \pi^+$ and $\Xi_c^+ \pi^+$ decays.

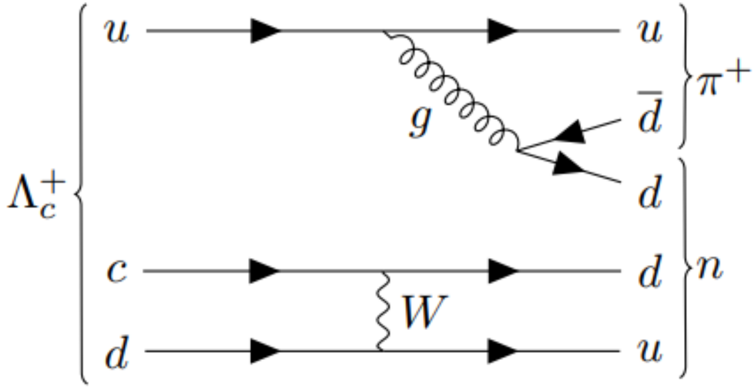
Λ_c^+ is lowest-lying charmed bayron: Important for the higher mass charmed baryon and bottomed baryon

Interesting Physics for $\Lambda_c^+ \to n\pi^+$

Internal W emission



W exchange



Difficult to calculate

Λ_c hadronic decay amplitudes[1][2]

- Nonfactorizable components
- Factorizable components

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

Importance of experimental results

Singly Cabibbo suppressed decays

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	
$10^4\mathcal{B}_{\Sigma^0 K^+}$	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	
$10^4\mathcal{B}_{\Lambda^0 K^+}$	6.6 ± 0.9	10.7	5.9 ± 1.7	6.1 ± 1.2

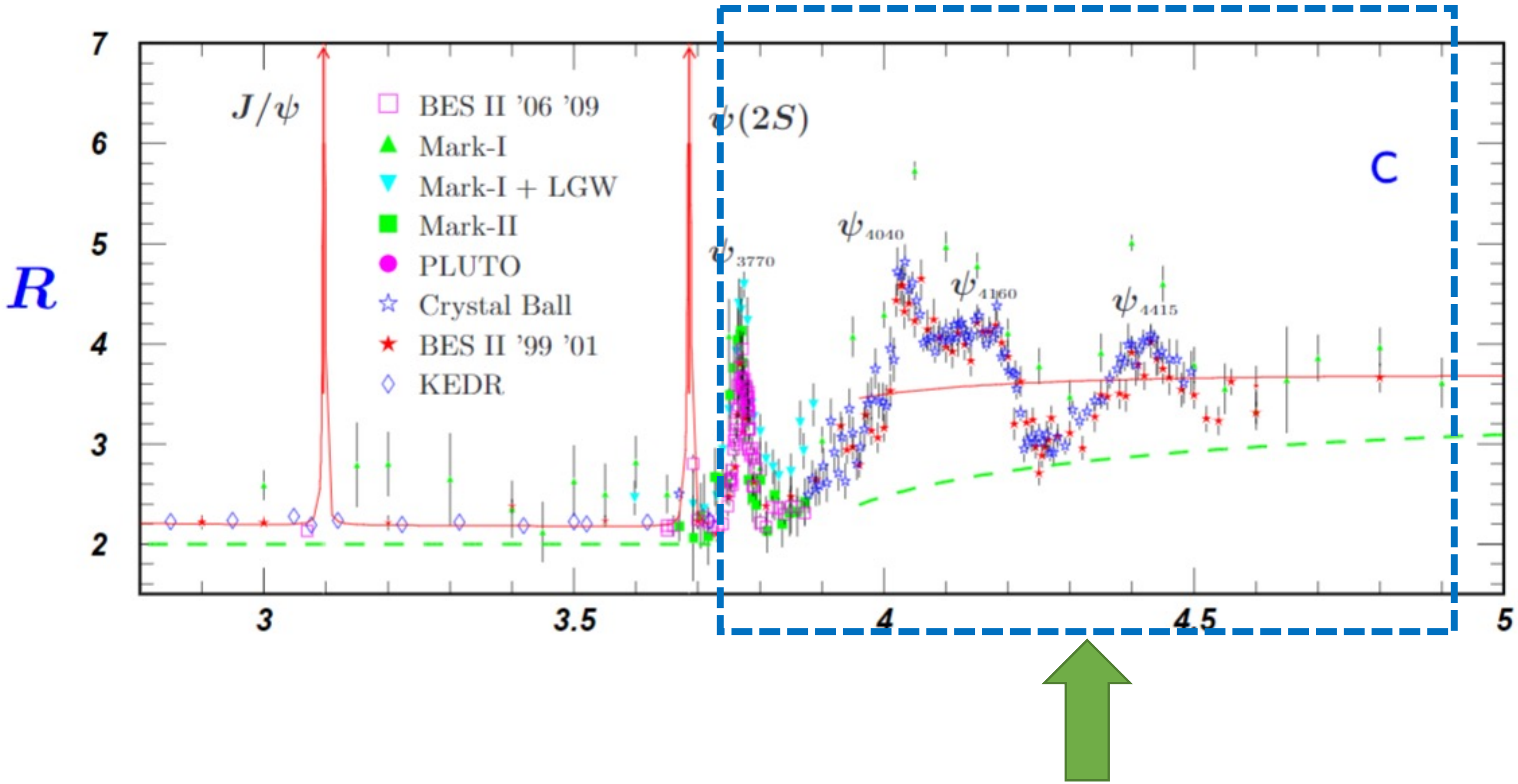
Ref: J. High Energy Phys. 02 (2020) 165

Latest experimental results

Lack of observation

- Challenge: Small branching fractions of 10^{-3} or below
- Input more precise results from experimental studies
- $\mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0)$, test different models:
  SU(3) flavor symmetry, pole model and current-algebra, topological-diagram approach, etc

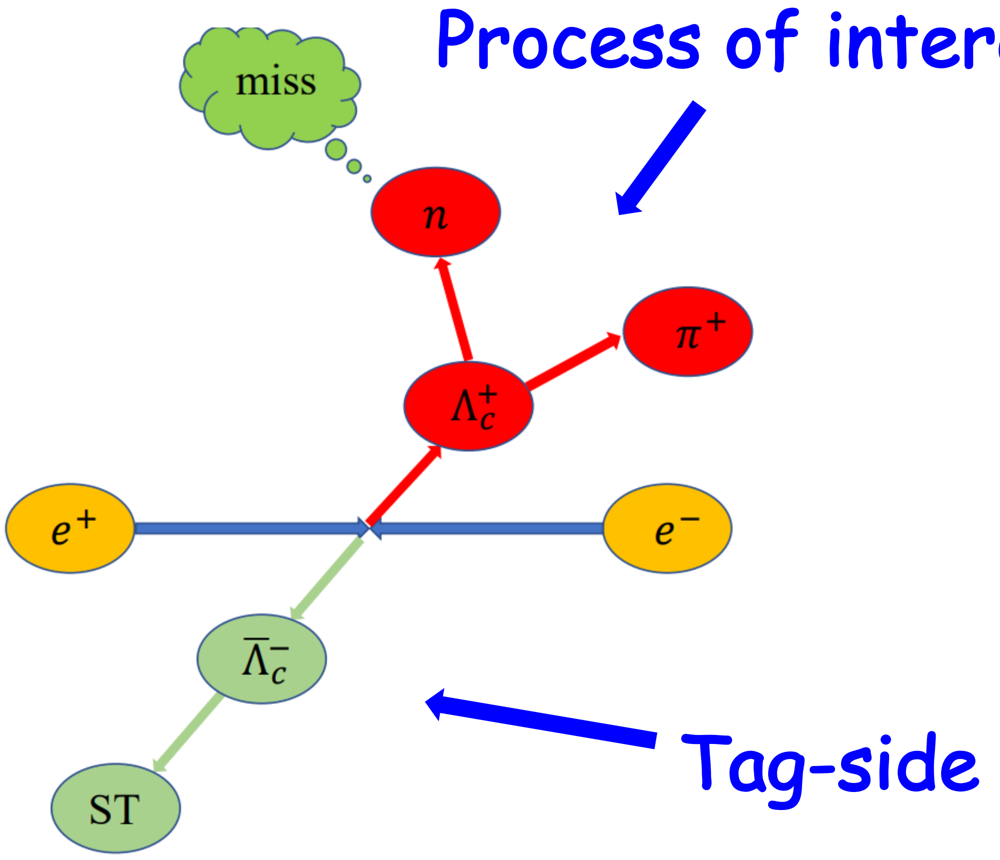
Advantage of Λ_c^+ study at BESIII



Threshold effect: pair production of charmed mesons/baryons !

$$e^+e^- \to D\bar{D}, D\bar{D}^*, D^*\bar{D}^*, \Lambda_c^+\bar{\Lambda}_c^-$$

Double-tag approach



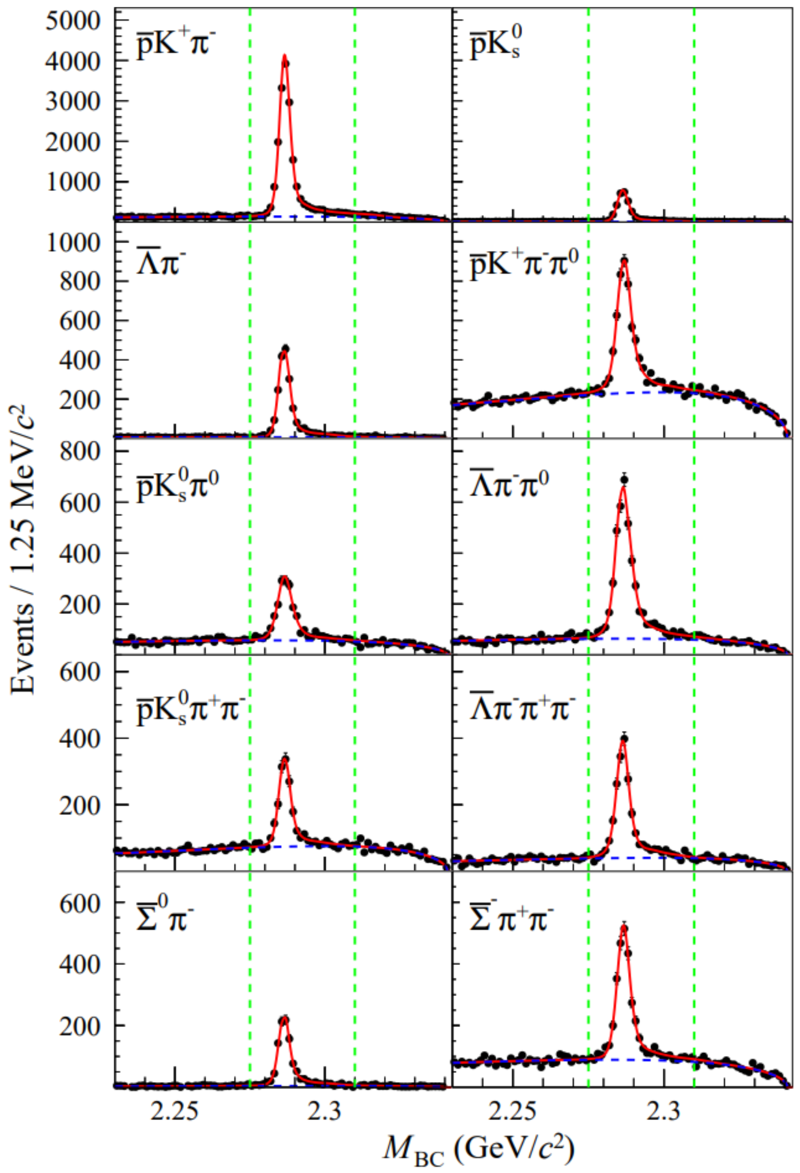
$$N_{i\ ST} = 2N_0 \times \mathcal{B}_i \times \varepsilon_{i\ ST}$$

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

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

- $N_{i\ ST}$: 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.

$\sqrt{s} = 4.682$ GeV as an example



Λ_c^+ tagging

Phys. Rev. Lett. 128 (2022) 142001

✓ 10 singly tagged modes at BESIII

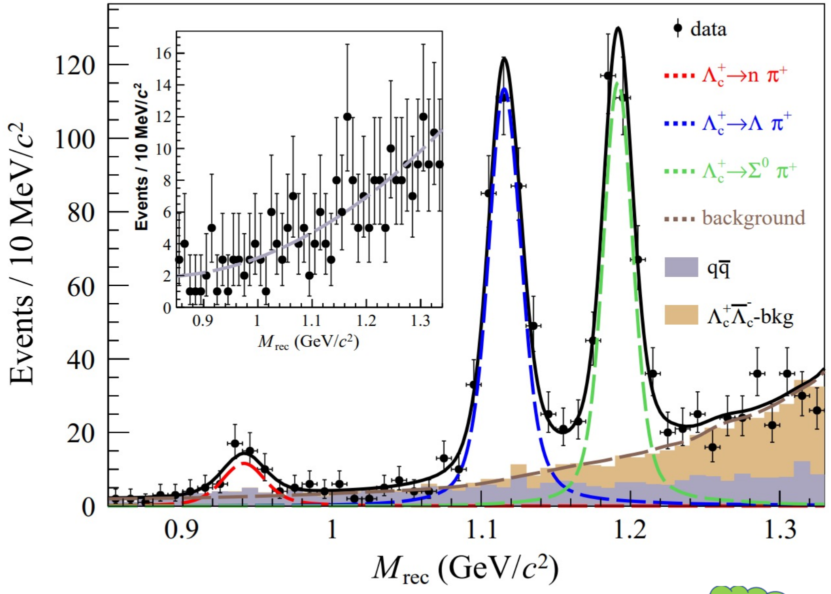
✓ $N_{ST} = 90692 \pm 359$ with 10 tags @ 4.612-4.699 GeV

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

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

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

Phys. Rev. Lett. 128 (2022) 142001

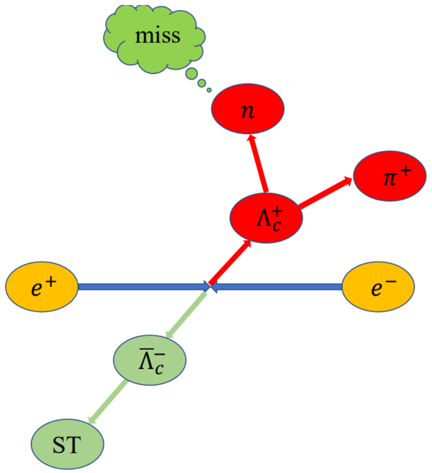


$$M_{\rm rec}^2 = (E_{\rm beam} - E_{\pi^+})^2/c^4 - |\rho \cdot \vec{p}_0 - \vec{p}_{\pi^+}|^2/c^2$$

- E_{π^+} and $\vec{p}_{\pi^+}$ are the energy and momentum of π^+ candidate
- $\rho = \sqrt{E_{\rm beam}^2/c^2 - m_{\Lambda_c^+}^2 c^2}$
- $\vec{p}_0 = -\vec{p}_{\bar{\Lambda}_c^-}/|\vec{p}_{\bar{\Lambda}_c^-}|$ is the unit direction opposite to the ST $\bar{\Lambda}_c^-$

Energy-momentum conservation !

- 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 $\Lambda_c^+ \to \Lambda\pi^0\pi^+$……)

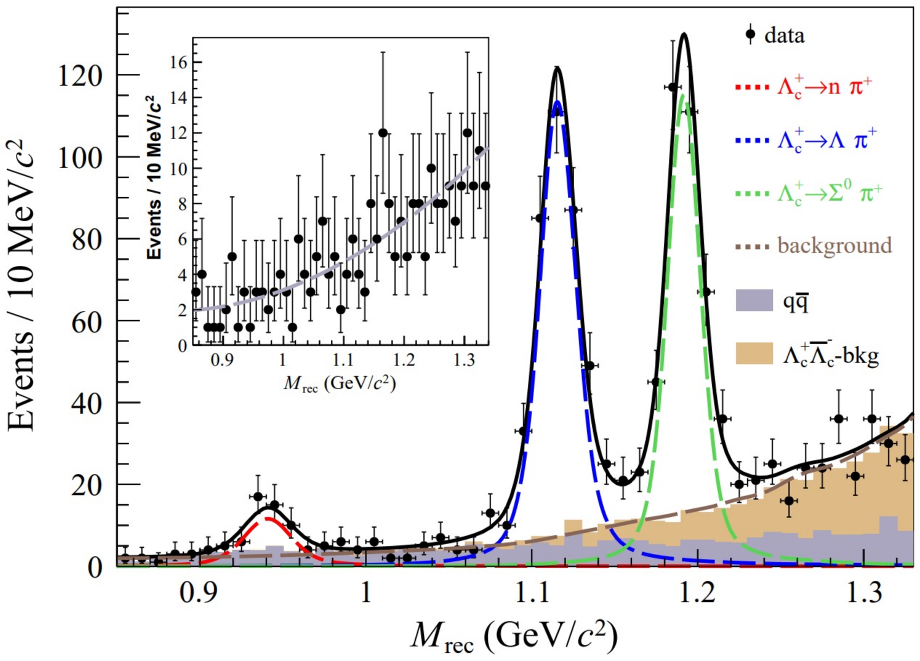


✓ Select the signal pion after reconstructing the ST $\bar{\Lambda}_c^-$.

✓ Require no charged tracks from the missing part.

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

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



Decay	Yields	Branching fraction
$\Lambda_c^+ \to n\pi^+$	50 ± 9	$(6.6 \pm 1.2_{stat} \pm 0.4_{syst})\times10^{-4}$
$\Lambda_c^+ \to \Lambda\pi^+$	376 ± 22	$(1.31 \pm 0.08_{stat} \pm 0.05_{syst})\times10^{-2}$
$\Lambda_c^+ \to \Sigma^0\pi^+$	343 ± 22	$(1.22 \pm 0.08_{stat} \pm 0.07_{syst})\times10^{-2}$

- ✓ 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

$\mathbf{R} = \mathcal{B}(\Lambda_c^+ \to n\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\pi^0)$

✓ Use $\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 8.0\times10^{-5}$ at 90% C.L. of Belle from Phys. Rev. D 103, 072004 (2021)

R	**> 7.2 at 90% C.L.**

Comparison to theory

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%.

Prospect: hadronic decays

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

DT Method

Sensitive in different models like $SU(3)_F$

- $\Lambda_c^+ \to p\pi^0$ ~5 events, input Br $= 1\times10^{-4}$
- With MC simulation ~3σ 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
  $\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.28_{stat.} \pm 0.10_{syst.})\times10^{-3}$
- Expect $\sigma_{stat.}$: $0.28 \Rightarrow \sim 0.1$

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

DT Method

……

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

Prospect: semi-leptonic decays

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

Use DT method.

- With studies of MC simulation, 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
- 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%

……

Prospect: inclusive decays

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^0_S 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 MC simulation

- Challenge: consistency between data and MC for $\bar{n}$.

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

Use DT method.

- Improve the precision

……

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

Summary

✓ In 2022, $\Lambda_c^+ \to n\pi^+$ is measured for the first time at BESIII with 3.8 fb^{-1} data between $\sqrt{s} = 4.6$ and 4.7 GeV:

Phys. Rev. Lett. 128 (2022) 142001

- $\mathcal{B}(\Lambda_c^+ \to n\pi^+) = (6.6 \pm 1.2_{\text{stat}} \pm 0.4_{\text{syst}})\times 10^{-4}$ 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.

✓ The results disagree with most of the predictions.

✓ More results of Λ_c will come very soon.

Thanks for your attention!

Backup

Data collected at BESIII

Data sets collected so far include,

- **10×10^9 J/ψ events**
- 0.5×10^9 ψ' events
- Scan data [2.0, 3.08] GeV; [3.735, 4.600] GeV

  130 energy points, about 2.0 fb^{-1}
- Large data sets for XYZ study above 4.0 GeV

  about 20 fb^{-1}

Unique data sets at open charm thresholds

$$3.77\,\mathrm{GeV}\quad 2.93\,\mathrm{fb}^{-1}\quad D\bar{D}$$

$$4.008\,\mathrm{GeV}\quad 0.48\,\mathrm{fb}^{-1}\quad D_s^+D_s^-$$

$$4.18\,\mathrm{GeV}\quad 3.2\,\mathrm{fb}^{-1}\quad D_sD_s^*$$

$$4.6-4.7\,\mathrm{GeV}\quad 0.6+3.8\,\mathrm{fb}^{-1}\quad \Lambda_c^+\bar{\Lambda}_c^-$$

Totally about 33 fb^{-1} in 10 year running