Recent results of Λ_c^+ at BESIII

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On behalf of BESIII collaboration

第四届粒子物理天问论坛

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Outline

- BESIII experiment
- Λ_c^+ at BESIII
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  - The history of Λ_c^+ at BESIII
  - The recent result of Λ_c^+ at BESIII
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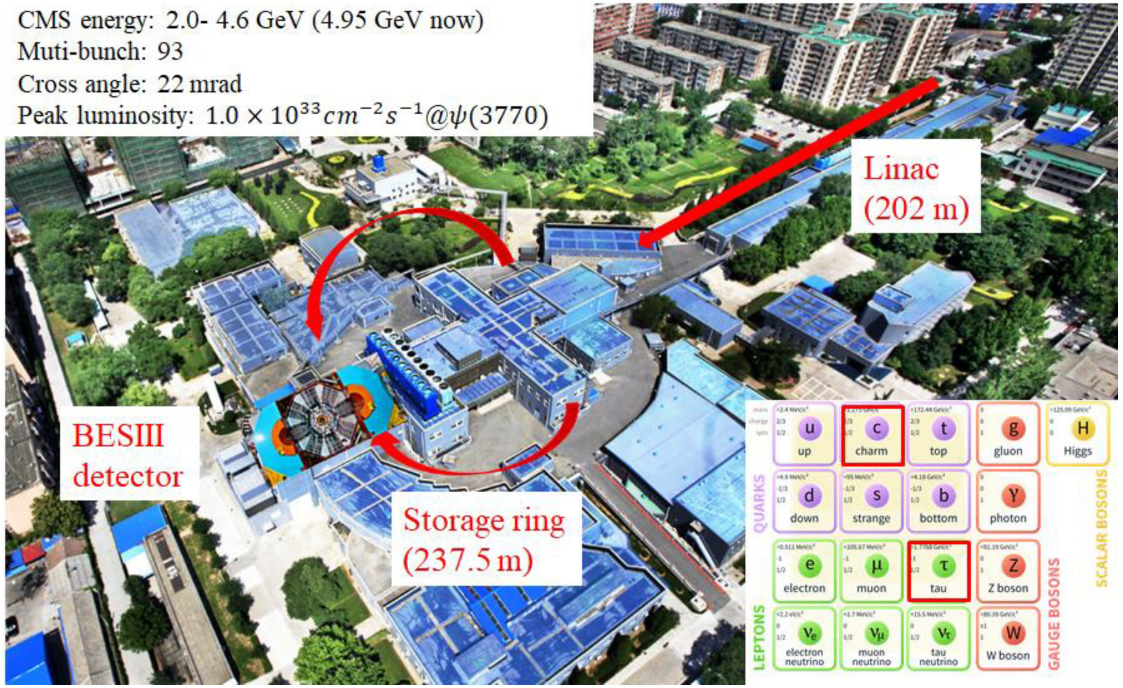
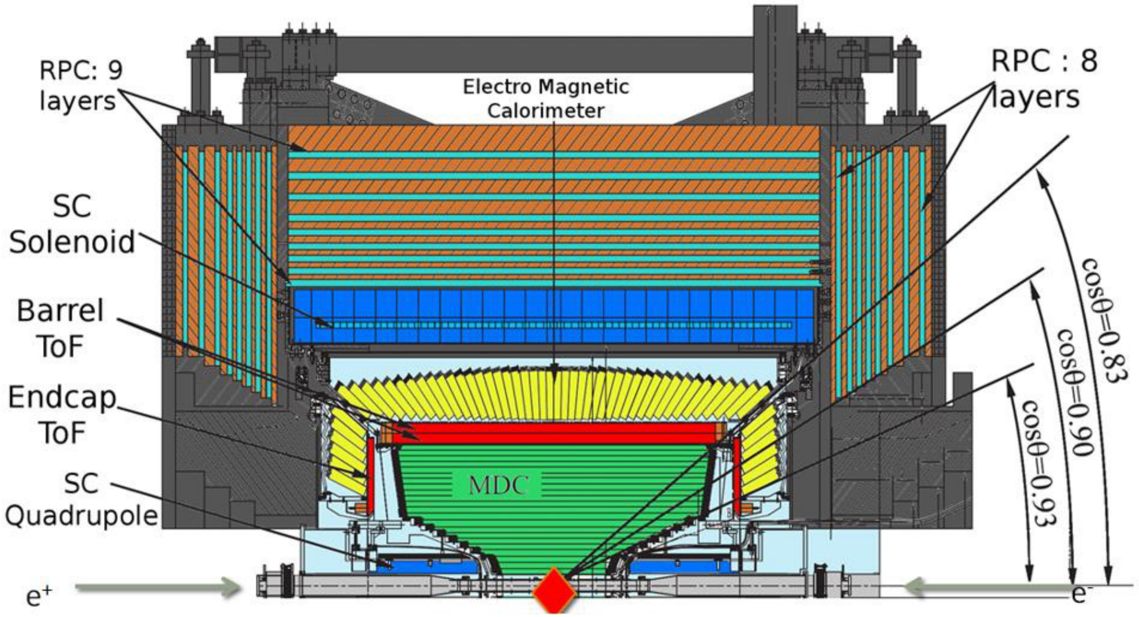
- Summary

BESIII experiment

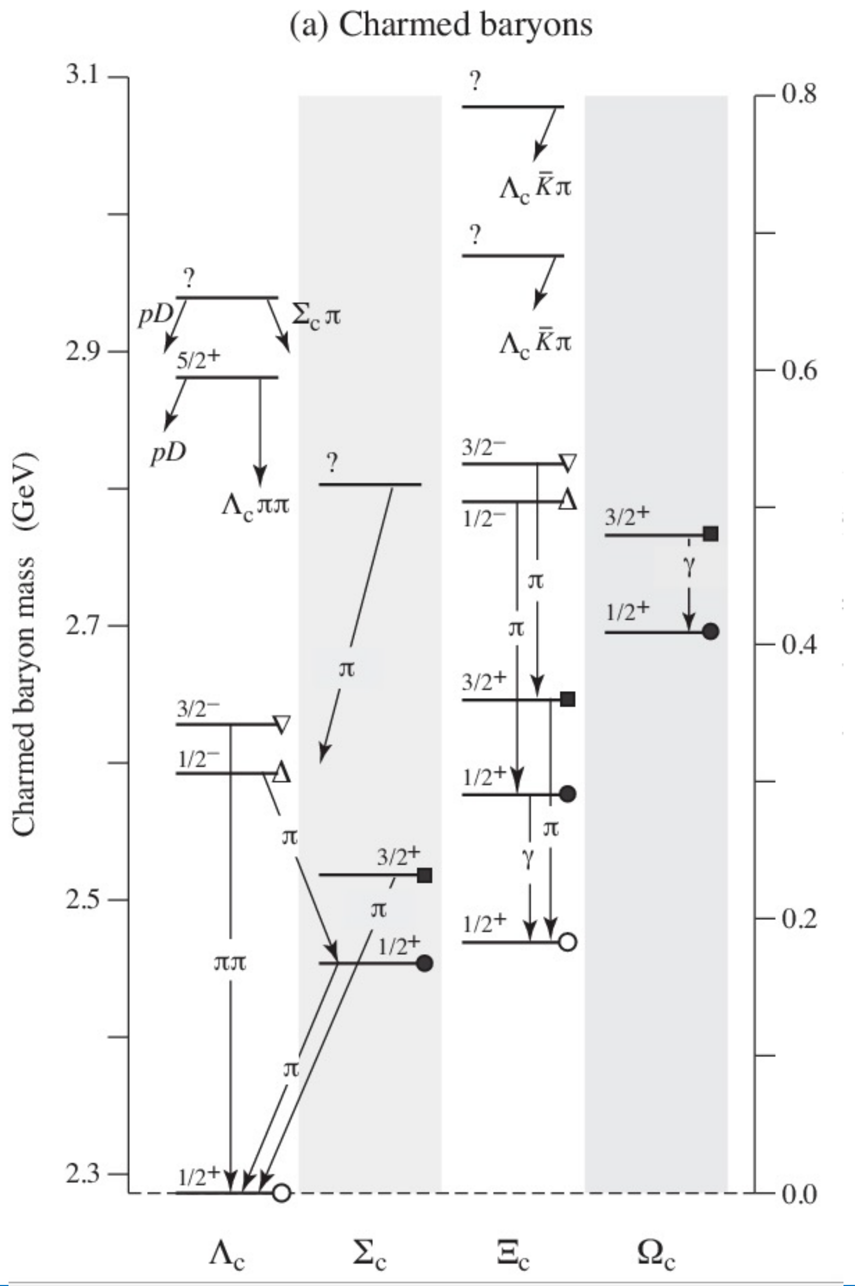




The interesting physics of Λ_c^+

- An important intermediates particle
  - Corner stone of charm baryon family
  - As bottom production

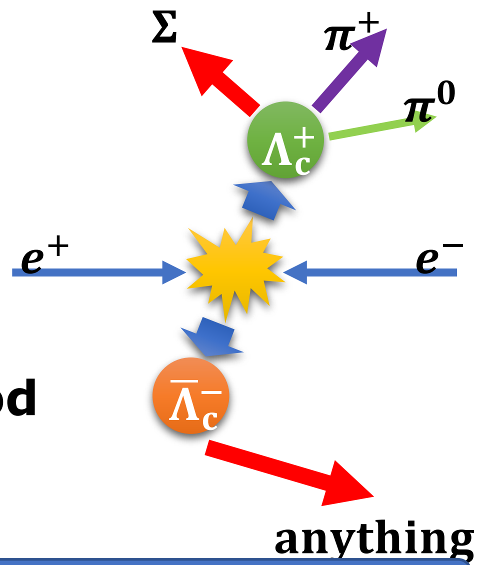
- Its decay reveal the information about weak and strong interaction in charm region, complementary to D/D_s



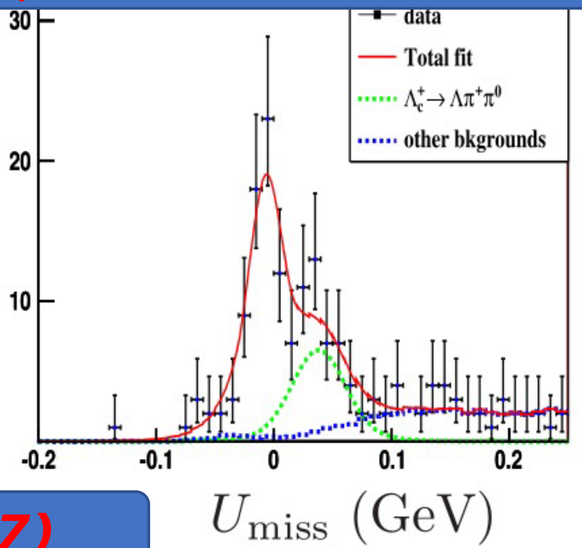
The advantage of Λ_c^+ at BESIII

- ➢ Threshold data
  - ✓ Pair production
  - ✓ Low background
  - ✓ Undetected particle
- ➢ Single-tag (ST) method
  - ✓ High efficiency
  - ✓ Higher background
- ✓ Double-tag (DT) method
  - ✓ Low efficiency
  - ✓ Lower background
  - ✓ Undetected particle

Single Tag method



$Br(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)$= $(3.49 \pm 0.46 \pm 0.26)\%$



PLB 767, 42 (2017)

The history of Λ_c^+ at BESIII

Hadronic decay

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

17paper
7PRL

$\Lambda_c^+ \to pK^-\pi^+$ + 11 CF modes	PRL 116, 052001 (2016)
$\Lambda_c^+ \to pK^+K^-, p\pi^+\pi^-$	PRL 117, 232002 (2016)
$\Lambda_c^+ \to nK_S\pi^+$	PRL 118, 12001 (2017)
$\Lambda_c^+ \to p\eta, p\pi^0$	PRD 95, 111102(R) (2017)
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$	PLB 772, 388 (2017)
$\Lambda_c^+ \to \Xi^{0(*)}K^+$	PLB783, 200 (2018)
$\Lambda_c^+ \to \Lambda\eta\pi^+$	PRD99, 032010 (2019)
$\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$	CPC43, 083002 (2019)
$\Lambda_c^+ \to$ BP decay asymmetries	PRD100, 072004 (2019)
$\Lambda_c^+ \to pK_S\eta$	PLB 817, 136327 (2021)
Λ_c^+ spin determination	PRD 103, L091101(2021)

Semi-leptonic decay

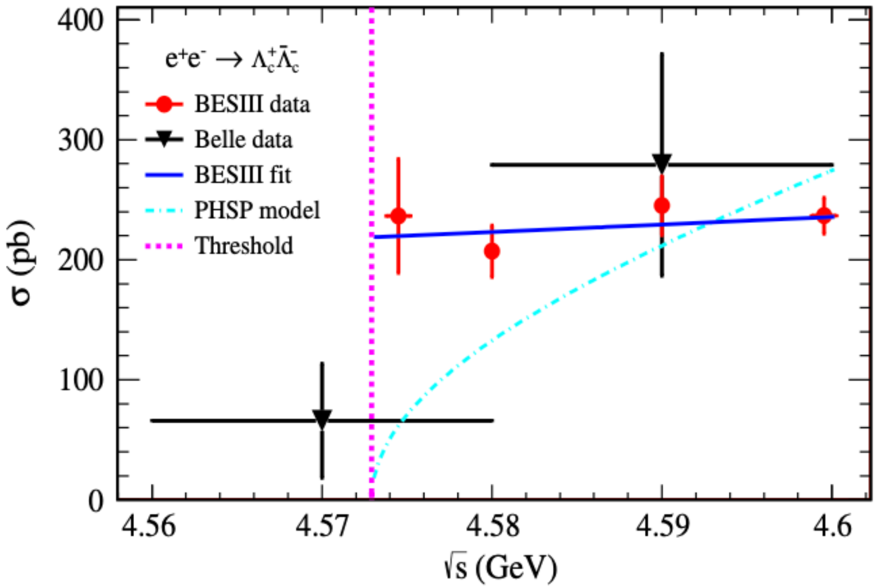
$\Lambda_c^+ \to \Lambda e^+\nu_e$	PRL 115, 221805(2015)
$\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$	PLB 767, 42 (2017)

Inclusive decay

$\Lambda_c^+ \to \Lambda X$	PRL121, 062003 (2018)
$\Lambda_c^+ \to e^+X$	PRL 121 251801(2018)
$\Lambda_c^+ \to K_S^0X$	EPJC 80, 935 (2020)

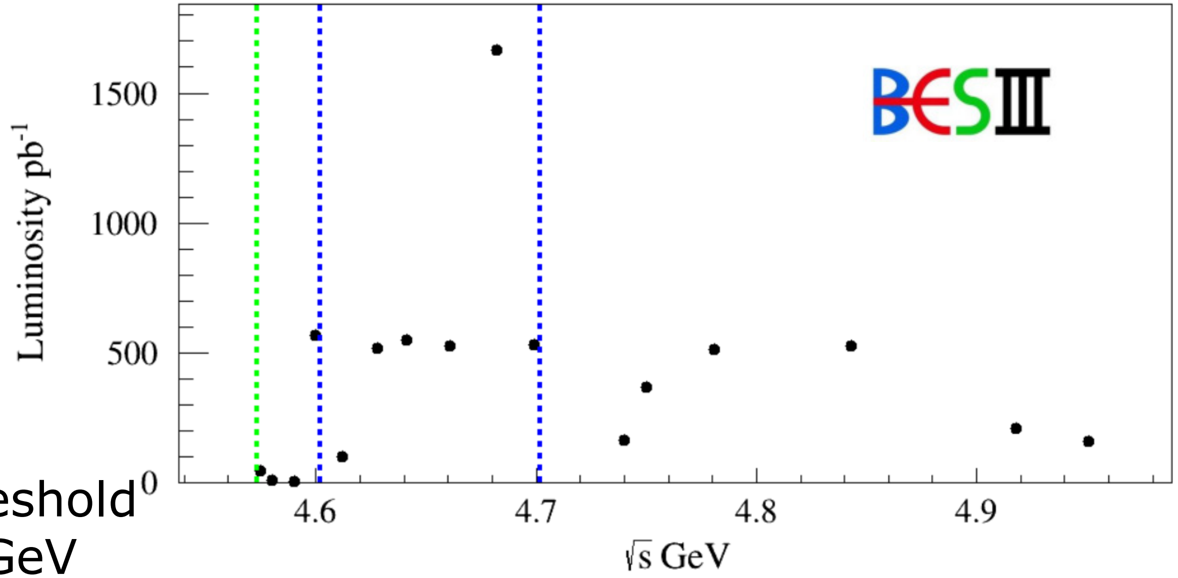
Production

$\Lambda_c^+\Lambda_c^-$ cross section	PRL 120,132001(2018)



arXiv:2203.03133

arXiv:2205.04809

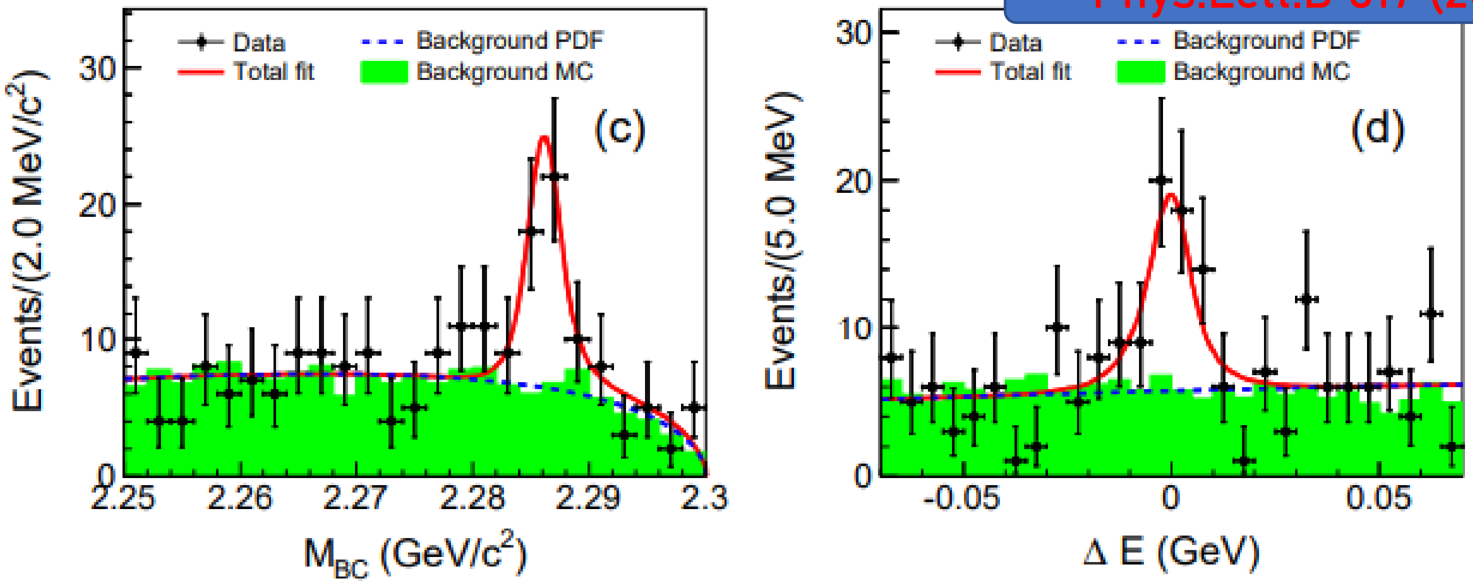


- The largest ee annihilation data near $\Lambda_c^+\bar{\Lambda}_c^-$ threshold

$4.5 fb^{-1}$ 4.600-4.699 GeV+$1.9\ fb^{-1}$ 4.740-4.951 GeV

$\Lambda_c^+ \to pK_s^0\eta$

Phys.Lett.B 817 (2021) 136327

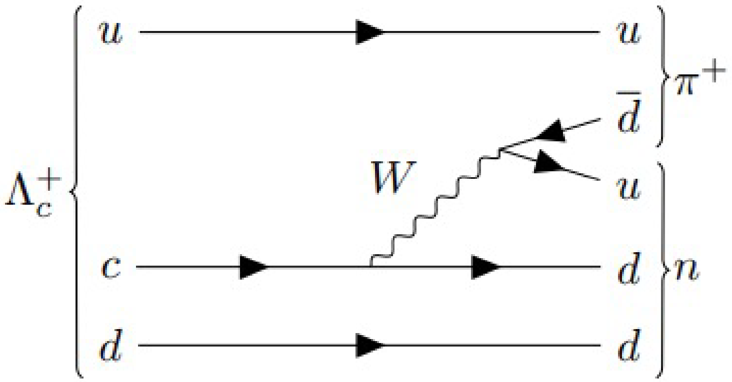


- Comparing with CLEO result $\frac{Br(\Lambda_c^+ \to pK_s^0\eta)}{Br(\Lambda_c^+ \to pK^-\pi^+)} = (0.8 \pm 0.2)\%$
- Theocratical prediction based on $SU(3)_f$ give $Br(\Lambda_c^+ \to pK_s^0\eta) = (0.35 - 0.45)\%$[1][2]
- This measure give $Br(\Lambda_c^+ \to pK_s^0\eta) = (0.414 \pm 0.084 \pm 0.028)\%$(only 4.6GeV)

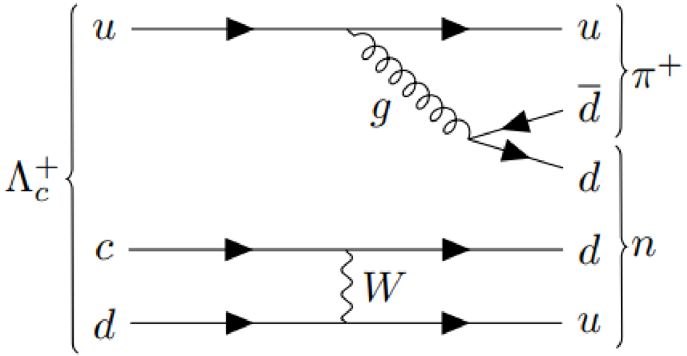
Consist with upon predictions.

[1]Eur.Phys.J.C 79 (2019) 11, 946
[2]Phys.Rev.D 99 (2019) 7, 073003

Internal W-emission



W-exchange



difficult to calculate

Λ_c^+ hadronic decay amplitude[1][2]

- Nonfactorizable components
- Factorizable components

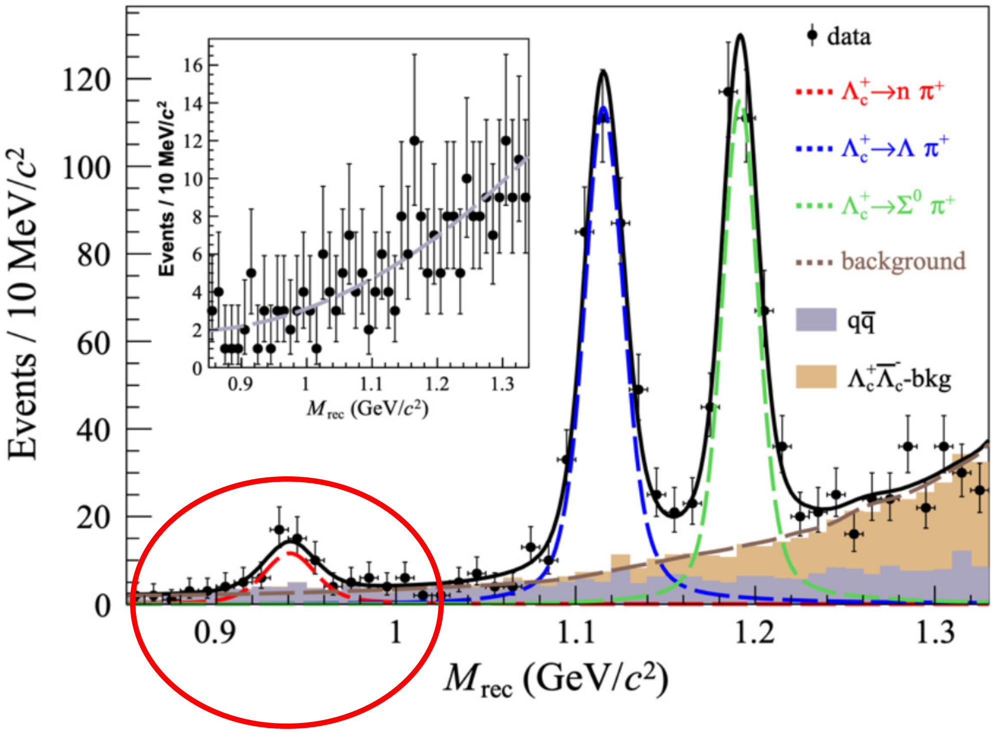
[1]L. L. Chau and H. Y. Cheng, Phys. Rev. Lett. 56, 1655 (1986).
[2]K. Yoji, Phys. Rev. D. 44, 2799 (1991).

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

Phys. Rev. Lett. 128 (2022) 142001

- First result with the newest 3.9 fb^{-1} data sets(4.612-4.699 GeV).
- First SCS decay with neutron using DT method.
- Non-factorization contributions are overestimated.

$$M_{rec} = \sqrt{(E_{beam} - E_{\pi^+})^2/c^4 - (\vec{p}_{rec-\Lambda_c^+} - \vec{p}_{\pi^+})/c^2}$$



Decay mode	Signal yield	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	$(1.22 \pm 0.08_{stat} \pm 0.07_{syst}) \times 10^{-2}$

7.3σ first discover!

Consist with PDG

Phys. Rev. D 103, 072004 (2021)

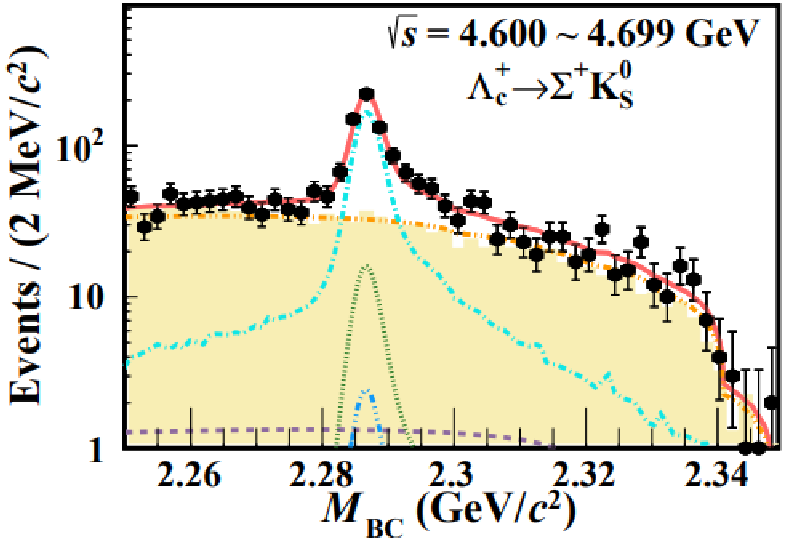
$$R=\frac{Br(\Lambda_c^+\to n\pi^+)}{Br(\Lambda_c^+\to p\pi^0)^{1}} > 7.2\ @\ 90\%\ \mathrm{C.L.}$$

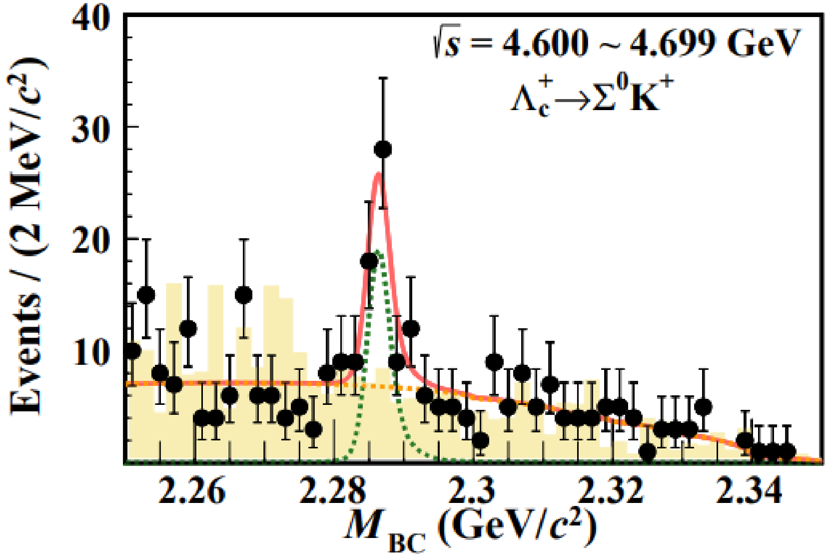
Use Br($\Lambda_c^+ \to p\pi^0$)$<8.0 \times 10^{-5}$ (90% C.L.) of Belle

Br($\Lambda_c^+ \to n\pi^+$)$\times 10^4$	**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

- Both Br and R is contradictory
- Br is consisted with us but R not
- Both Br and R is consisted with but large uncertainty with $\Lambda_c^+ \to p\pi^0$

arXiv:2207.10906

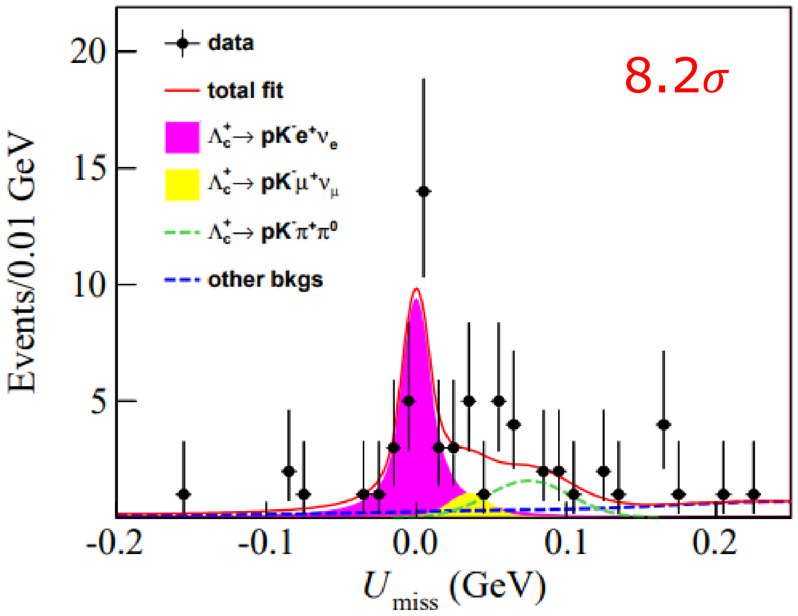


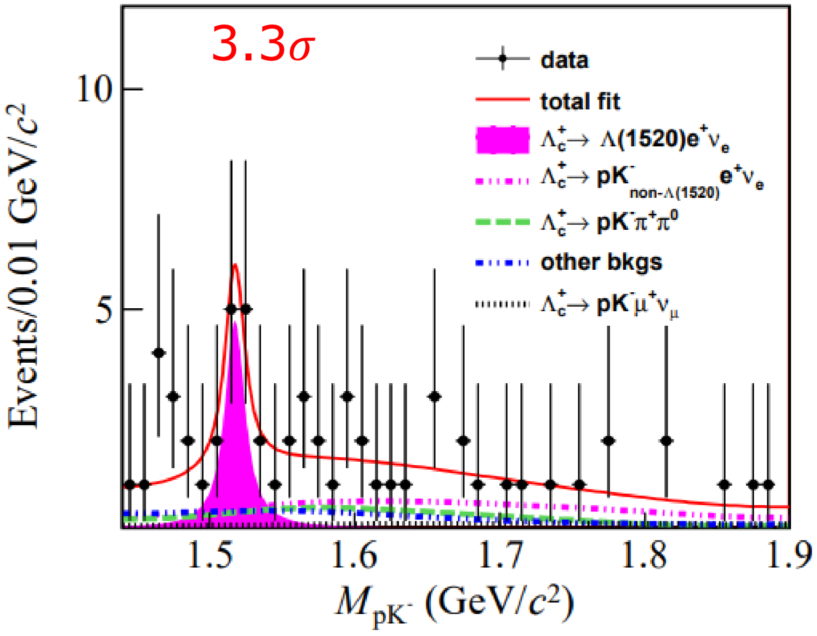


- First measurement for $\Lambda_c^+ \to \Sigma^+ K_s^0$ mode.
- $Br(\Lambda_c^+ \to \Sigma^+ K_s^0)$=$(4.8 \pm 1.4_{stat.} \pm 0.2_{syst.} \pm 0.3_{ref.}) \times 10^{-4}$ different from prediction[1] 2.5σ
- $Br(\Lambda_c^+ \to \Sigma^0 K^+)$=$(4.7 \pm 0.9_{stat.} \pm 0.1_{syst.} \pm 0.3_{ref.}) \times 10^{-4}$ consist with previous result.

[1]JHEP03(2022)143

arXiv:2207.11483

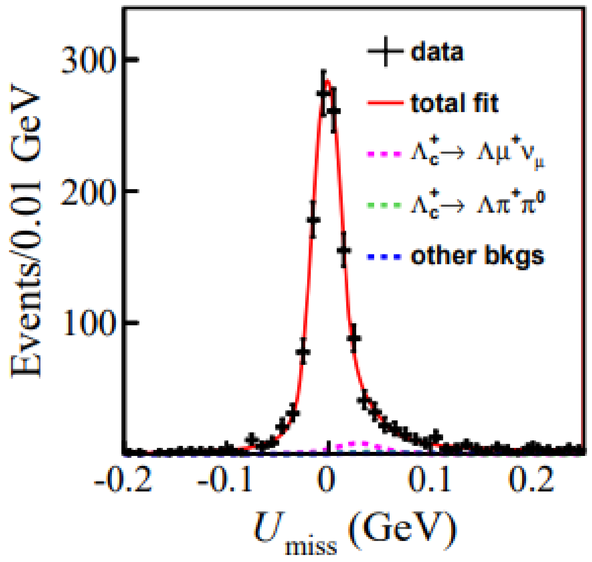


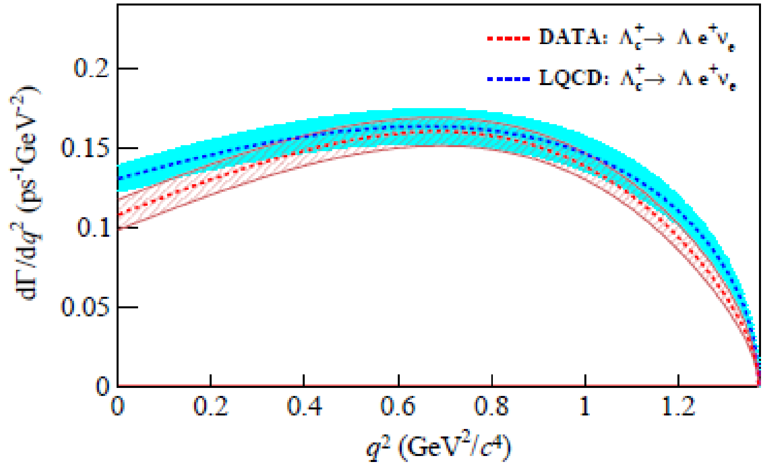


- $4.5 fb^{-1}$ for 4.6-4.699 GeV
- Br($\Lambda_c^+ \to pK^- e^+ \nu_e$)=$(0.82 \pm 0.15_{stat.} \pm 0.05_{syst.}) \times 10^{-3}$
- Br($\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e$)=$(1.36 \pm 0.56_{stat.} \pm 0.14_{syst.}) \times 10^{-3}$
- More $\Lambda_c^+ \to X e^+ \nu_e$ exsit?

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

arXiv:2207.14149





- Br($\Lambda_c^+ \to \Lambda e^+ \nu_e$)=$(3.56 \pm 0.11 \pm 0.07)$% (improve the precision more than threefold[1])
- First directly compare with LQCD calculation
- Determine $|V_{cs}| = 0.936 \pm 0.017_B \pm 0.024_{LQCD} \pm 0.007_{\tau\Lambda_c}$(Consist with $D \to K l \nu_l$ with 1σ[2])

[1]Phys. Rev. Lett. 115,221805 (2015).
[2] Prog. Theor. Exp. Phys.2020, 083C01 (2020) and 2021 update.

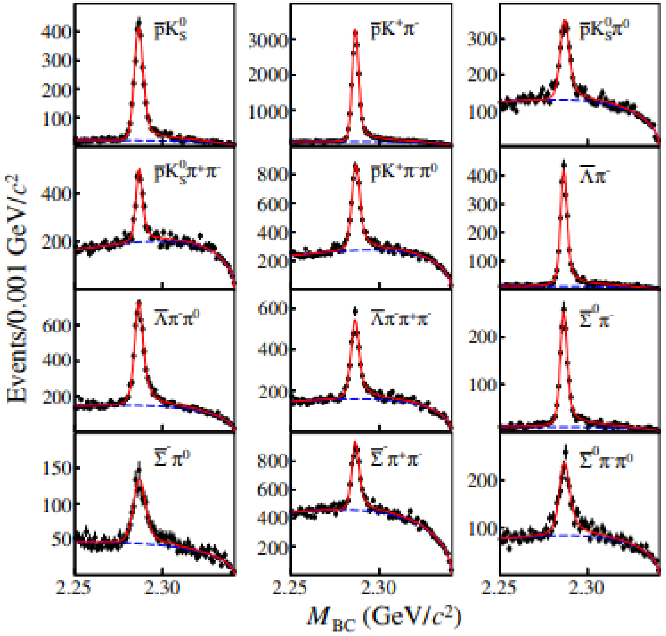
- Disfavor the prediction [8-12] with 95% C.L.

	$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ [%]
Constituent quark model (HONR) [8]	4.25
Light-front approach [9]	1.63
Covariant quark model [10]	2.78
Relativistic quark model [11]	3.25
Non-relativistic quark model [12]	3.84
Light-cone sum rule [13]	3.0 ± 0.3
Lattice QCD [14]	3.80 ± 0.22
$SU(3)$ [15]	3.6 ± 0.4
Light-front constituent quark model [16]	3.36 ± 0.87
MIT bag model [16]	3.48
Light-front quark model [17]	4.04 ± 0.75
This work	$3.56 \pm 0.11 \pm 0.07$

Prospect for the future

For hadronic mode

- With $4.5 fb^{-1}$ data near the threshold of Λ_c^+, lots of SCS and DCS modes could be updated/measured.(especially for the neutron even the ant-neutron).
- To understand nonfactorizable diagrams and test the theoretical prediction $(SU(3)_F)$.
- $\Lambda_c^+ \to p\pi^0,\ p\eta,\ p\eta',\ nK^+, \Lambda K^+, nK^+\pi^0\ etc.$
- PWA result for three-body, decay asymmetry for two-body.



Prospect for the future

Semi-leptonic mode

- Inspired by new result of $\Lambda_c^+ \to pK^- e^+ \nu_e$ and evidence for $\Lambda_c^+ \to \Lambda(1520) e^+ \nu_e$ more semi-leptonic mode is unclear, precise result of $\Lambda_c^+ \to \mathrm{X} \mathrm{e}^+ \nu_e$ is need.

Inclusive mode

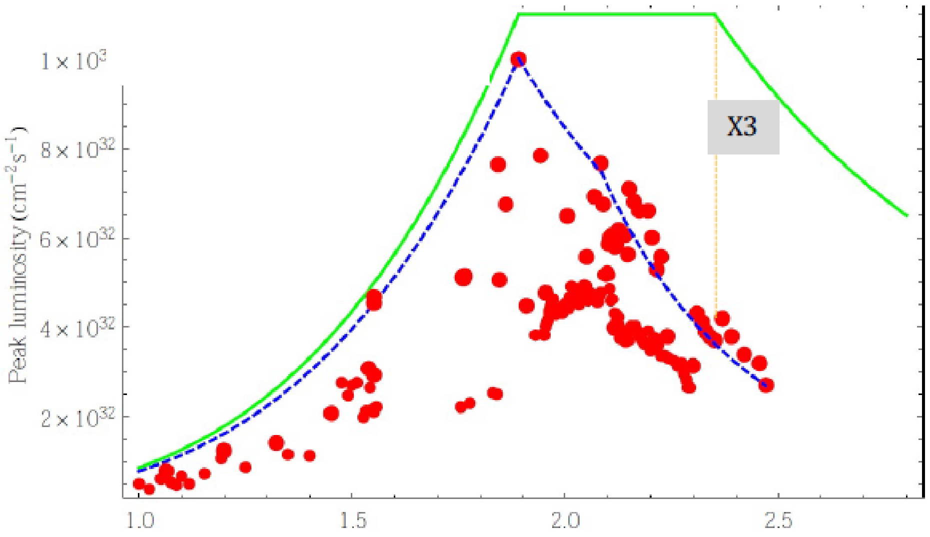
- $\Lambda_c^+ \to X e^+ \nu_e$

Studied by MC simulation, the uncertainty is improved to~4%

- $\overline{\Lambda}_c^- \to \bar{n} X$

Studied by MC simulation, thousand of events was observed with low background.

Prospect for the future



- Will upgrade at future with higher luminosity and beam energy(4.95-5.6GeV)

4.60 GeV	Λ_c/XYZ	0.56 fb^{-1}	1.0 fb^{-1}
4.64 GeV	Λ_c/XYZ	N/A	5.0 fb^{-1}
4.65 GeV	Λ_c/XYZ	N/A	0.2 fb^{-1}
4.70 GeV	Λ_c/XYZ	N/A	0.65 fb^{-1}
4.80 GeV	Λ_c/XYZ	N/A	1.0 fb^{-1}
4.90 GeV	Λ_c/XYZ	N/A	1.3 fb^{-1}
$\Sigma_c^+\bar{\Lambda}_c^-$ 4.74 GeV	Charm Baryons	N/A	1.0 fb^{-1}
$\Sigma_c\bar{\Sigma}_c$ 4.91 GeV	Charm Baryons	N/A	1.0 fb^{-1}
$\Xi_c\bar{\Xi}_c$ 4.95 GeV	Charm Baryons	N/A	1.0 fb^{-1}

BESIII white paper

- New data gives the strongly support for the study of Λ_c^+, lots of SCS and DCS will be measured.
- More precisely result will coming out and help us understand the charm baryon.

Thank you for your attention!