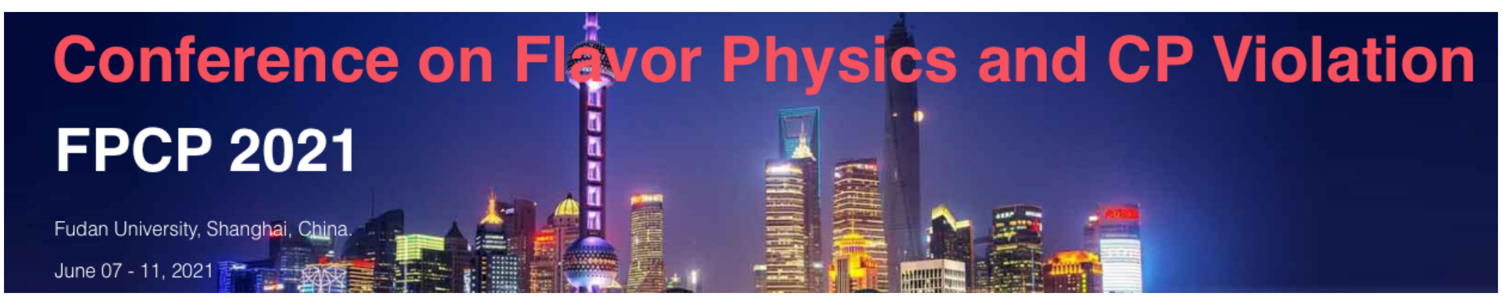
Results and prospects of charmed baryon physics at BESIII

Pei-Rong Li（李培荣）

Lanzhou University

On behalf of the BESIII Collaboration



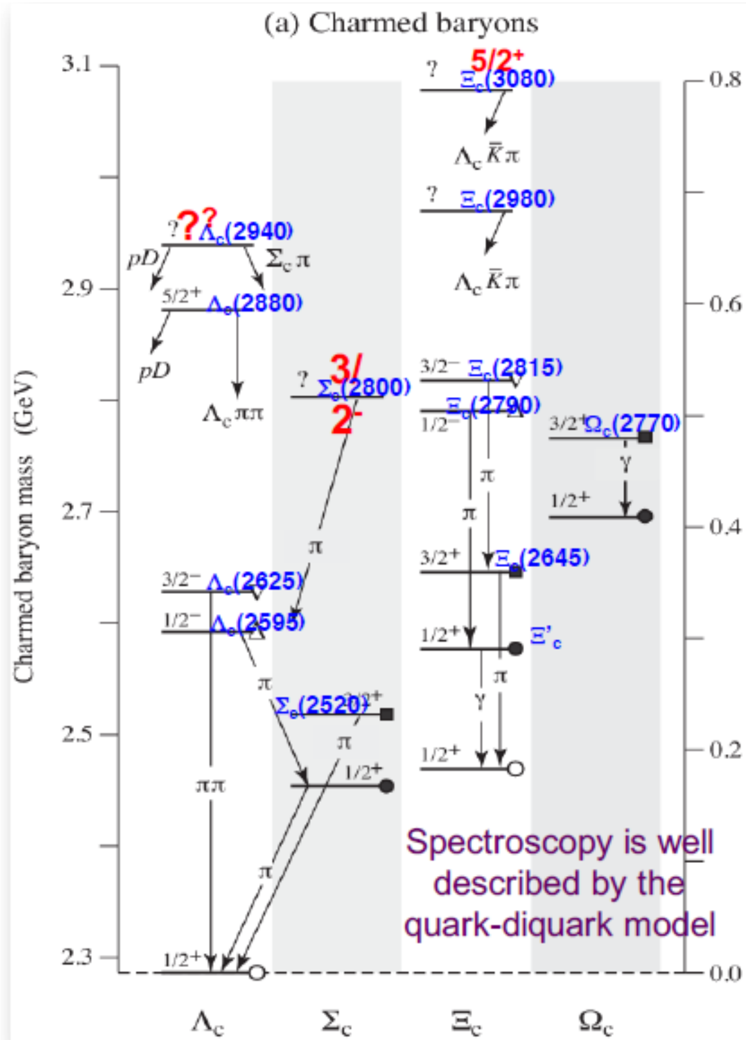
Outline

- Physics related to the charmed baryon
- Recent results on Λ_c^+ decays at BESIII
- Future prospects
- Summary

The charmed baryon family

- **Singly charmed baryons**
  - Established ground states:

    Λ_c^+, Σ_c, Ξ_c , Ω_c
  - Excited states are being explored
- **Doubly charmed baryons(Ξ_{cc}^{++}) observed by LHCb experiment.**
- **No observations of triply charmed baryons.**



✓ **Λ_c^+ decays only weakly, much recent experimental progress since 2014.**

✓ **Σ_c: B($\Sigma_c \to \Lambda_c^+\pi$)~100%, B($\Sigma_c \to \Lambda_c^+\gamma$)?**

✓ **Ξ_c : decays only weakly; no absolute BF measured, most relative to $\Xi^-\pi^+(\pi^+)$.**

✓ **Ω_c: decays only weakly; no absolute BF measured.**

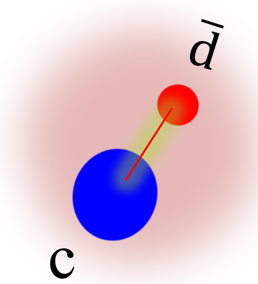
Λ_c^+: The lightest charmed baryon spectroscopy

- **Most of the charmed baryons will eventually decay to Λ_c^+.**

- **The Λ_c^+ is one of important tagging hadrons in c-quark counting in the productions at high energy experiment.**

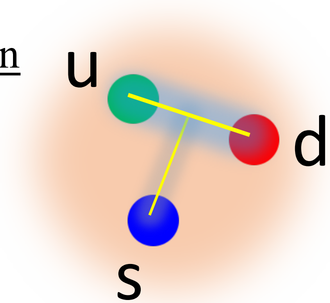
- **Naïve quark model picture: a heavy quark (*c*) with an unexcited spin-zero diquark (*u*-*d*). Diquark correlation is enhanced by weak Color Magnetic Interaction with a heavy quark(HQET).**

- **Λ_c^+ may reveal more information of strong- and weak-interactions in charm region, complementary to D/Ds**



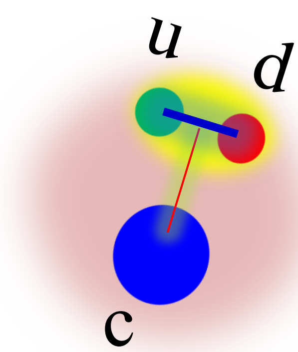
→ Charmed meson
(**$D^+[c\bar{d}]$**)

$m_d << m_c$ →
quark + heavy quark
(q) (Q)



→ Strange baryons
(Λ[uds])

m_u, $m_d \approx m_s$ →
(qqq) uniform



→ Charmed baryon
(Λ_c**[udc]**)

m_u, $m_d << m_c$ →
diquark + quark
(qq) (Q)

Production near threshold and tag technique

- E_{cms}-$2M_{\Lambda c}$=26MeV only!
- $\Lambda_c^+\Lambda_c^-$ produced in pairs with no additional accompany hadrons.
  - $e^+e^-\to\gamma^*\to\Lambda_c^+\Lambda_c^-$
- Clean backgrounds and well constrained kinematics.
- Typically, two ways to study Λ_c^+ decays:
  - Single Tag(ST): detect only one of the $\Lambda_c^+\Lambda_c^-$.

    =>Relative higher backgrounds

    =>Higher efficiencies

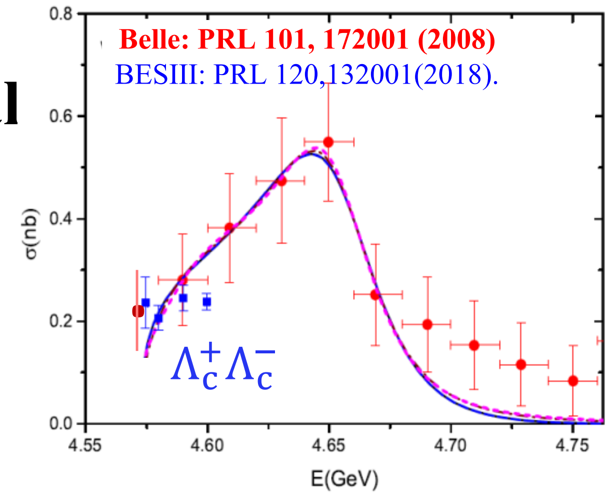
    =>Full reconstruction only
  - Double Tag(DT): detect both of $\Lambda_c^+\Lambda_c^-$

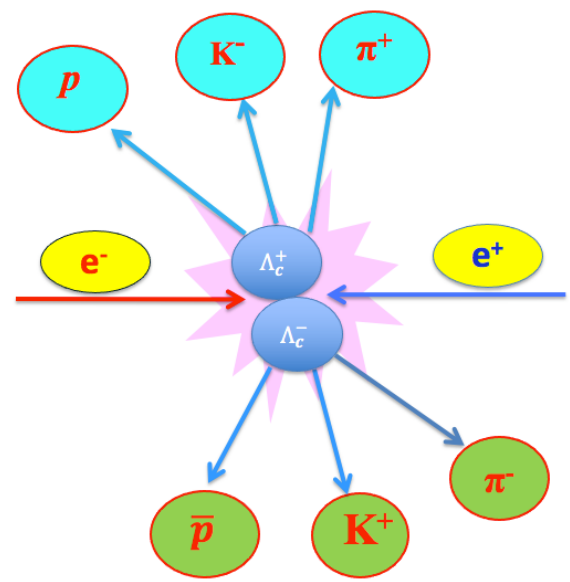
    =>Lower backgrounds.

    =>Technique for missing particle.

    =>Lower efficiencies.

    =>Systematic in tag side are mostly cancelled.





Studies on the Λ_c^+ measurments at BESIII

2014： 0.567 fb^{-1} at 4.6 GeV

- Λ_c^+ hadronic decay

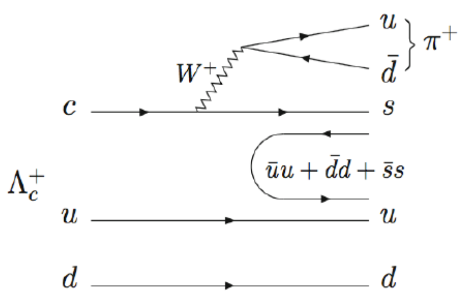
  - BF($\Lambda_c^+ \to \Lambda\eta\pi^+$) : PRD99, 032010 (2019)
  - BF($\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$) : CPC43, 083002 (2019)
  - BF($\Lambda_c^+ \to pK_s\eta$) : PLB 817, 136327 (2021)
  - BF($\Lambda_c^+ \to K_s^0 X$) : EPJC 80, 935 (2020)
  - $\Lambda_c^+ \to$ BP decay asymmetries : PRD100, 072004 (2019)
  - Λ_c^+ spin determination : PRD 103, L091101 (2021)

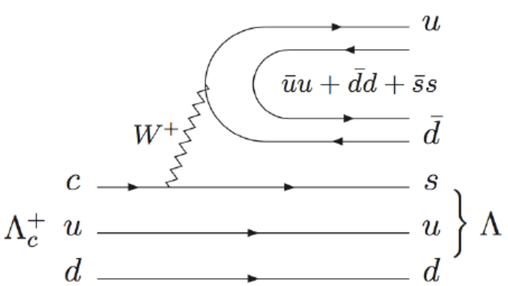
$\Lambda_c^+ \to \Lambda\eta\pi^+$

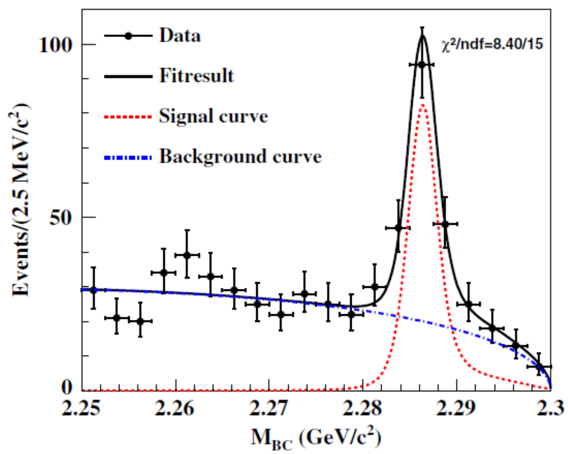
PRD 99, 032010,(2019)

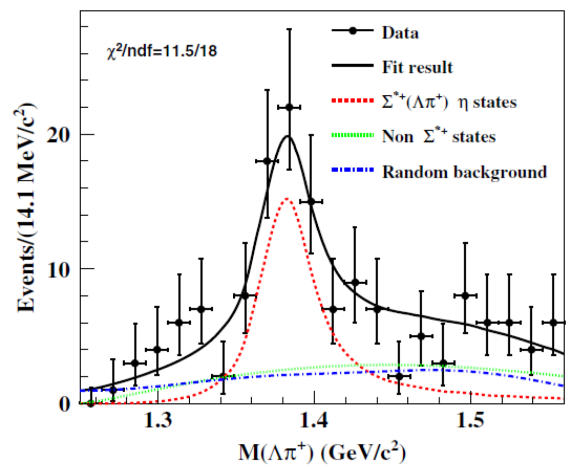
- Current world result has large uncertainty
- potential to study intermediate states, such as $a_0(980)$ and $\Lambda(1670)$

Decay	CLEO in 1995	CLEO in 2003	PDG average
$B(\Lambda_c^+ \to \Lambda\eta\pi^+)/B(\Lambda_c^+ \to pK^-\pi^+)$	$0.35 \pm 0.05 \pm 0.06$	$0.41 \pm 0.17 \pm 0.10$	0.36 ± 0.07
$B(\Lambda_c^+ \to \Lambda\eta\pi^+)$	----	----	$(2.3 \pm 0.5)\%$







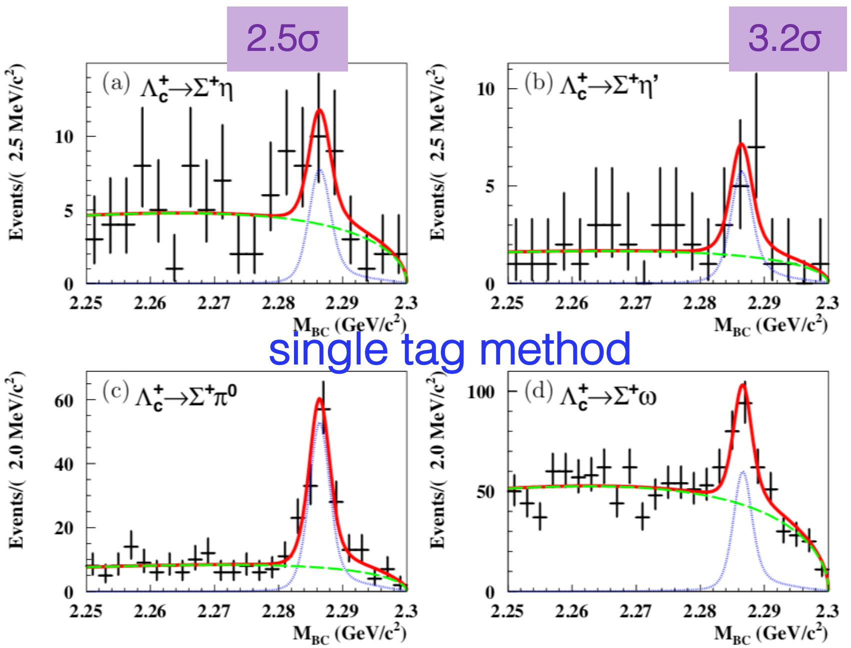


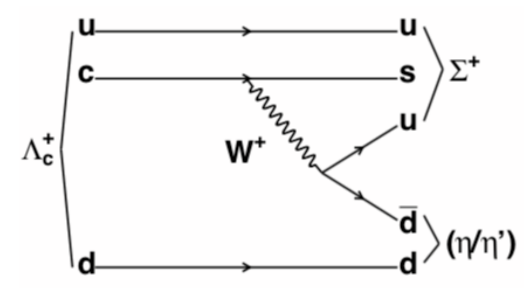
- branching fraction $B(\Lambda_c^+ \to \Lambda\eta\pi^+)$ measured to be $(1.84 \pm 0.21 \pm 0.15)\%$
  more precise than previous results
- $B(\Lambda_c^+ \to \Sigma^{*+}\eta)$ measured as $(0.91 \pm 0.08 \pm 0.09)\%$
  more precise than the previous result $(1.24 \pm 0.37)\%$

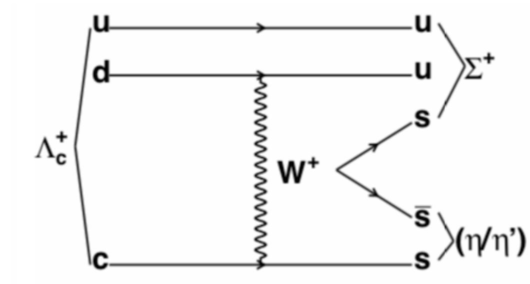
$\Lambda_c^+ \to \Sigma^+\eta, \Sigma^+\eta'$

CPC 43, 083002, (2019)

- Decay through internal W-emission and W-exchange.
- Both are non-factorable in theoretical calculation.







- $\Lambda_c^+ \to \Sigma^+\eta$ is smaller than CLEO but still compatible within uncertainty.
- $\Lambda_c^+ \to \Sigma^+\eta'$ is measured for first time.
- Our measurement contradict with most theoretical calculations.

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\pi^0)} = 0.35 \pm 0.16 \pm 0.03$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta')}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\omega)} = 0.86 \pm 0.34 \pm 0.07$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta')}{\mathcal{B}(\Lambda_c^+ \to \Sigma^+\eta)} = 3.5 \pm 2.1 \pm 0.4$$

Decay mode	Körner [5]	Sharma [3]	Zenczykowski [4]	Ivanov [6]	CLEO [12]	This work
$\Lambda_c^+ \to \Sigma^+\eta$	0.16	0.57	0.94	0.11	0.70±0.23	0.41±0.20 (<0.68)
$\Lambda_c^+ \to \Sigma^+\eta'$	1.28	0.10	0.12	0.12	-	1.34±0.57 (<1.9)

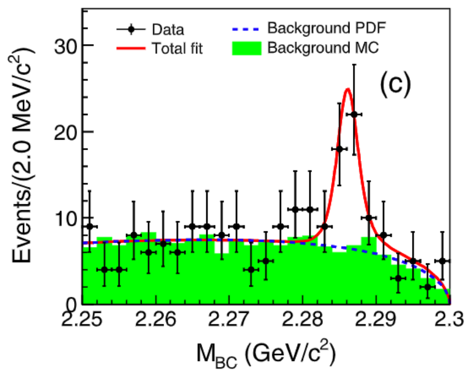
$\Lambda_c^+ \to pK_s\eta$

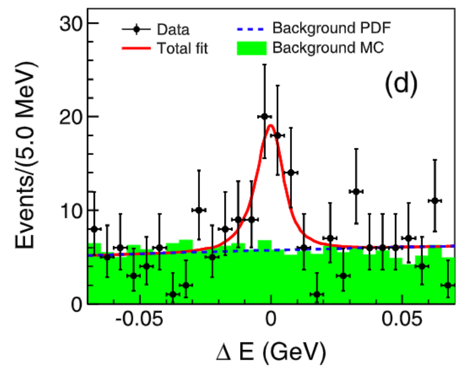
PLB 817, 136327 (2021)

- Previous CLEO result of $B(\Lambda_c^+ \to pK_s^0\eta) = (0.8 \pm 0.2)\%$, while theoretical calculations based on SU(3) symmetry give (0.35~0.45)%
- A potential channel to study a puzzling $N(1535)$ which has nontrivial decay rate of ηN and $K\Lambda$
- 2D fit to $M_{\rm BC}$ and ΔE distributions is implemented

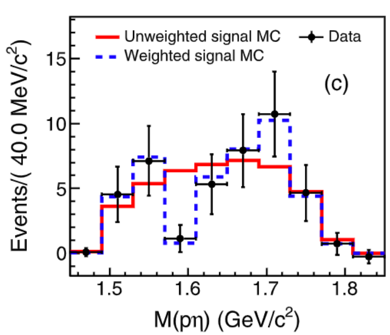
significance 5.3σ : first observation

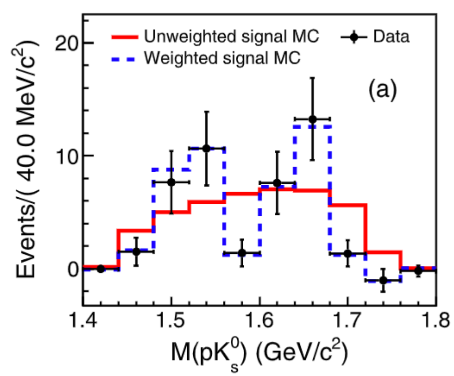
single tag method





42.0 ± 8.5 candidates





$$\mathcal{B}(\Lambda_c^+ \to pK_S^0\eta) = (0.414 \pm 0.084 \pm 0.028)\%$$

compatible with CLEO result within 1.5 σ

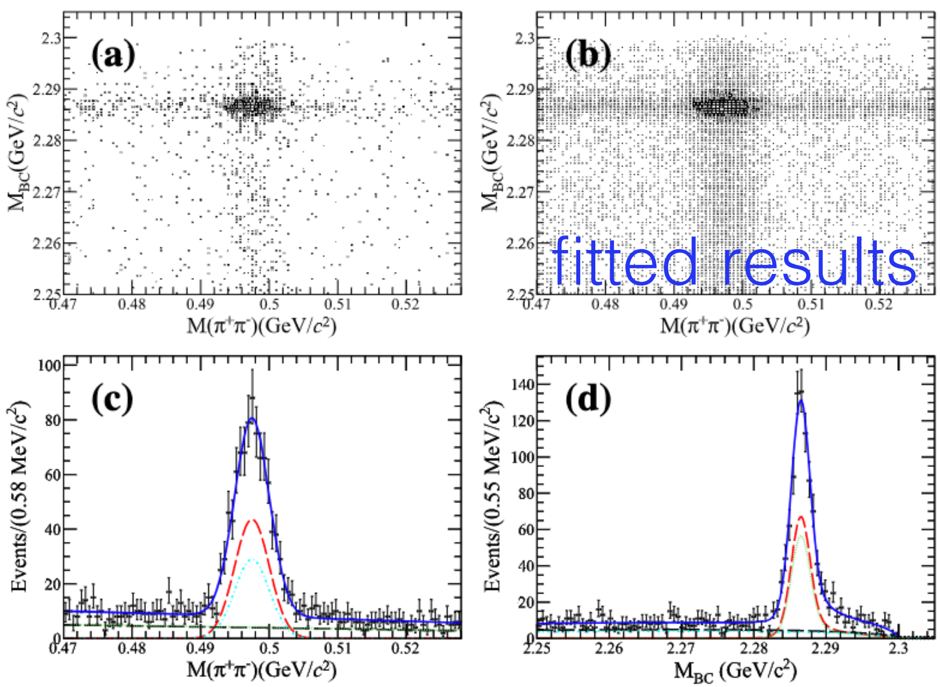
Inclusive decay $\Lambda_c^+ \to K_S^0 X$

- Sum BF for exclusive channels with K^0 or $\bar{K}^0$ is evaluated to be $(22.4 \pm 0.9)\%$ with inclusion of guessed modes
- Its difference from the inclusive rate $B(\Lambda_c^+ \to K^0/\bar{K}^0 X)$ will help in identifying unknown modes
- Eleven hadronic tag modes are used

EPJC 80, 935 (2020)

Mode	Value (%)	Mode	Value (%)
Observed BF		Extrapolated BF	
$p\bar{K}^0$	3.18±0.16	$n\bar{K}^0\pi^+\pi^0$	3.07±0.16
$p\bar{K}^0\pi^0$	3.94±0.26	$p\bar{K}^0\pi^0\pi^0$	1.36±0.07
$p\bar{K}^0\pi^+\pi^-$	3.20±0.24	$n\bar{K}^0\pi^+\pi^+\pi^-$	0.14±0.09
$n\bar{K}^0\pi^+$	3.64±0.50	$p\bar{K}^0\pi^+\pi^-\pi^0$	0.22±0.14
$p\bar{K}^0\eta$	1.60±0.40	$n\bar{K}^0\pi^+\pi^0\pi^0$	0.10±0.06
$\Lambda K^+\bar{K}^0$	0.57±0.11	$p\bar{K}^0\pi^0\pi^0\pi^0$	0.03±0.02
		$(\Sigma K)^+\bar{K}^0$	0.68±0.34
		$\Xi^0 K^0\pi^+$	0.62±0.06
Total	16.1 ± 0.8	Total	6.3 ± 0.4
Total	22.4±0.9		

in statistical isospin model
PRD97, 116015 (2018)



fitted results

$$B(\Lambda_c^+ \to K_S^0 X) = (9.9 \pm 0.6 \pm 0.4)\%$$

$$B(\Lambda_c^+ \to K^0/\bar{K}^0 X) = (19.8 \pm 1.2 \pm 0.8 \pm 1.0)\%$$

- 2D fit
- Signal yields: 478 ± 27

- third error due to isospin breaking for Λ_c^+ decaying to Ks or K_L in final states
- compatible with the estimated exclusive rate

Λ_c^+ decay asymmetries

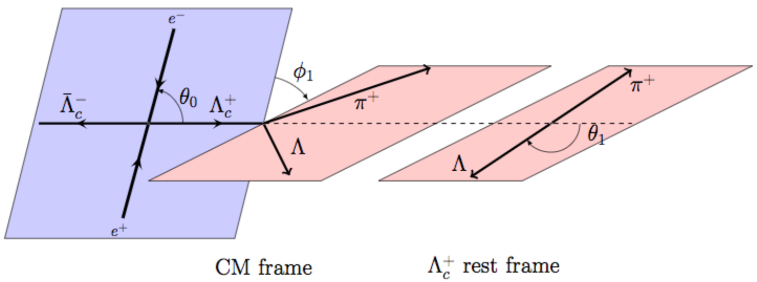
PRD100, 072004 (2019)

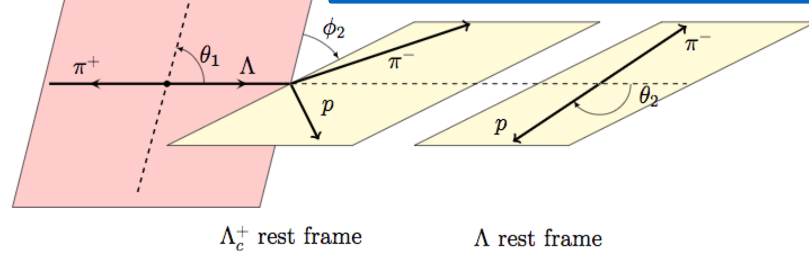
single tag method

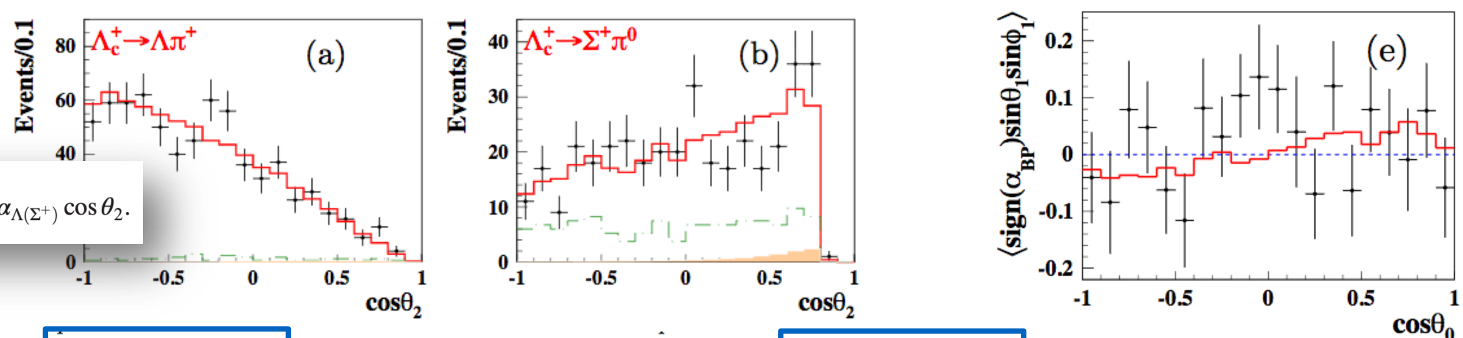
4(6)-fold angular analysis of the cascade decays of $\Lambda_c^+ \to pK_S, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$

$$\mathcal{W} \propto 1 + \alpha_0 \cos^2\theta_0 + \mathcal{P}_T \alpha_{BP}^+ \sin\theta_1 \sin\phi_1$$

$$\mathcal{P}_T(\cos\theta_0) \equiv \sqrt{1-\alpha_0^2}\cos\theta_0 \sin\theta_0 \sin\Delta_0$$







$$\frac{dN}{d\cos\theta_2} \propto 1 + \alpha^+_{\Lambda\pi^+(\Sigma^+\pi^0)}\alpha_{\Lambda(\Sigma^+)}\cos\theta_2.$$

$\Lambda_c^+ \to$		pK_S^0	$\Lambda\pi^+$	$\Sigma^+\pi^0$	$\Sigma^0\pi^+$
$\alpha_{BP} = \frac{2\mathrm{Re}(s^*p)}{\lvert s\rvert^2+\lvert p\rvert^2}$	Predicted	−1.0 [16], 0.51 [11]	−0.70 [16], −0.67 [11]	0.71 [16], 0.92 [11]	0.70 [16], 0.92 [11]
		−0.49 [10], −0.90 [10]	−0.95 [10], −0.99 [10]	0.79 [10] −0.49 [10]	0.78 [10], −0.49 [10]
		−0.49 [17], −0.97 [18]	−0.96 [17], −0.95 [18]	0.83 [17], 0.43 [18]	0.83 [17], 0.43 [18]
		−0.66 [19], −0.90 [30]	−0.99 [19], −0.86 [30]	0.39 [19], −0.76 [30]	0.39 [19], −0.76 [30]
		−0.99 [20], −0.91 [31]	−0.99 [20], −0.94 [31]	−0.31 [20], −0.47 [31]	−0.31 [20], −0.47 [31]
	PDG [2]		-0.91 ± 0.15	-0.45 ± 0.32	
	This work	$0.18 \pm 0.43 \pm 0.14$	$-0.80 \pm 0.11 \pm 0.02$	$-0.57 \pm 0.10 \pm 0.07$	$-0.73 \pm 0.17 \pm 0.07$

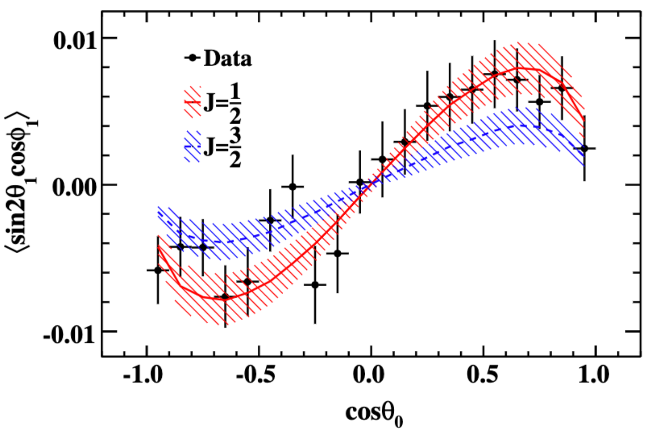
$\sin\Delta_0 = -0.28 \pm 0.13 \pm 0.03$

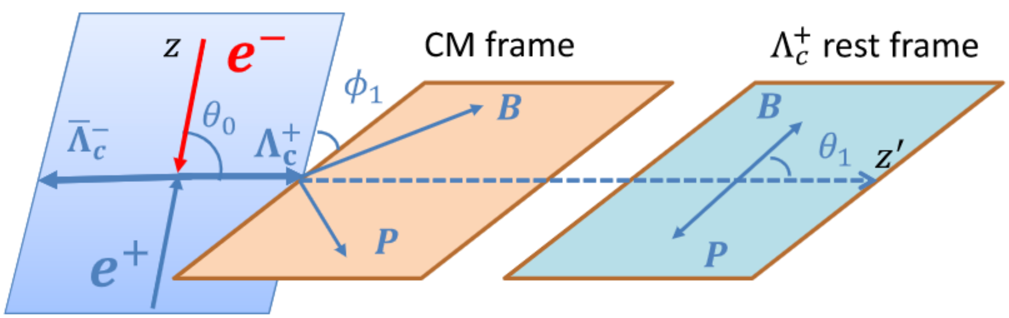
- Best precisions on the hadronic weak decay asymmetries
- No theoretical models fully describe the new BESIII results
- The transverse polarization is firstly studied and found to be non-zero with 2.1σ

Λ_c^+ spin determination

PRD103, L091101(2021)

- No spin-determination of the Λ_c since first discovery more than 30 years ago
- Currently, the spin half of the Λ_c is inferred to be from the naive quark model
- It would be crucial to test this spin assignment in experiment, to test the quark model hadron classification
- Multi-dimensional angular analysis on the ST samples of $\Lambda_c \to pK_s, \Lambda\pi^+, \Sigma^+\pi^0$ and $\Sigma^0\pi^+$ are carried out to test both hypotheses of J=1/2 and 3/2

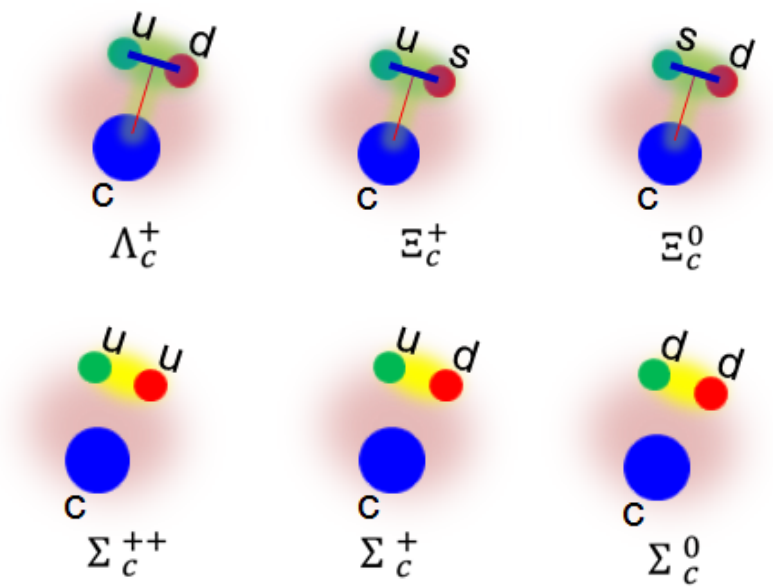


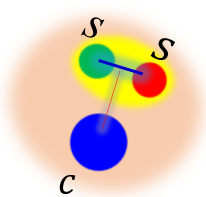


J=1/2 is preferred over J=3/2 with a significance of 6σ

- consistent with the expectation of the naive quark model.
- a cornerstone in the extraction of the properties of heavier charmed and beauty baryons

Heavier charmed baryons





Ω_c^+

	Structure	J^P	Mass, MeV	Width,MeV	Decay
Λ_c^+	udc	$(1/2)^+$	2286.46 ± 0.14	(200 ± 6) fs	weak
Ξ_c^+	usc	$(1/2)^+$	$2467.8^{+0.4}_{-0.6}$	(442 ± 26) fs	weak
Ξ_c^0	dsc	$(1/2)^+$	$2470.88^{+0.34}_{-0.8}$	112^{+13}_{-10} fs	weak
Σ_c^{++}	uuc	$(1/2)^+$	2454.02 ± 0.18	2.23 ± 0.30	$\Lambda_c^+\pi^+$
Σ_c^{+}	udc	$(1/2)^+$	2452.9 ± 0.4	< 4.6	$\Lambda_c^+\pi^0$
Σ_c^{0}	ddc	$(1/2)^+$	2453.76 ± 0.18	2.2 ± 0.4	$\Lambda_c^+\pi^-$
$\Xi_c^{\prime +}$	usc	$(1/2)^+$	2575.6 ± 3.1	—	$\Xi_c^+\gamma$
$\Xi_c^{\prime 0}$	dsc	$(1/2)^+$	2577.9 ± 2.9	—	$\Xi_c^0\gamma$
Ω_c^0	ssc	$(1/2)^+$	2695.2 ± 1.7	(69 ± 12) fs	weak
Σ_c^{*++}	uuc	$(3/2)^+$	2518.4 ± 0.6	14.9 ± 1.9	$\Lambda_c^+\pi^+$
Σ_c^{*+}	udc	$(3/2)^+$	2517.5 ± 2.3	< 17	$\Lambda_c^+\pi^0$
Σ_c^{*0}	ddc	$(3/2)^+$	2518.0 ± 0.5	16.1 ± 2.1	$\Lambda_c^+\pi^-$
Ξ_c^{*+}	usc	$(3/2)^+$	$2645.9^{+0.5}_{-0.6}$	< 3.1	$\Xi_c\pi$
Ξ_c^{*0}	dsc	$(3/2)^+$	2645.9 ± 0.5	< 5.5	$\Xi_c\pi$
Ω_c^{*0}	ssc	$(3/2)^+$	2765.9 ± 2.0	—	$\Omega_c^0\gamma$

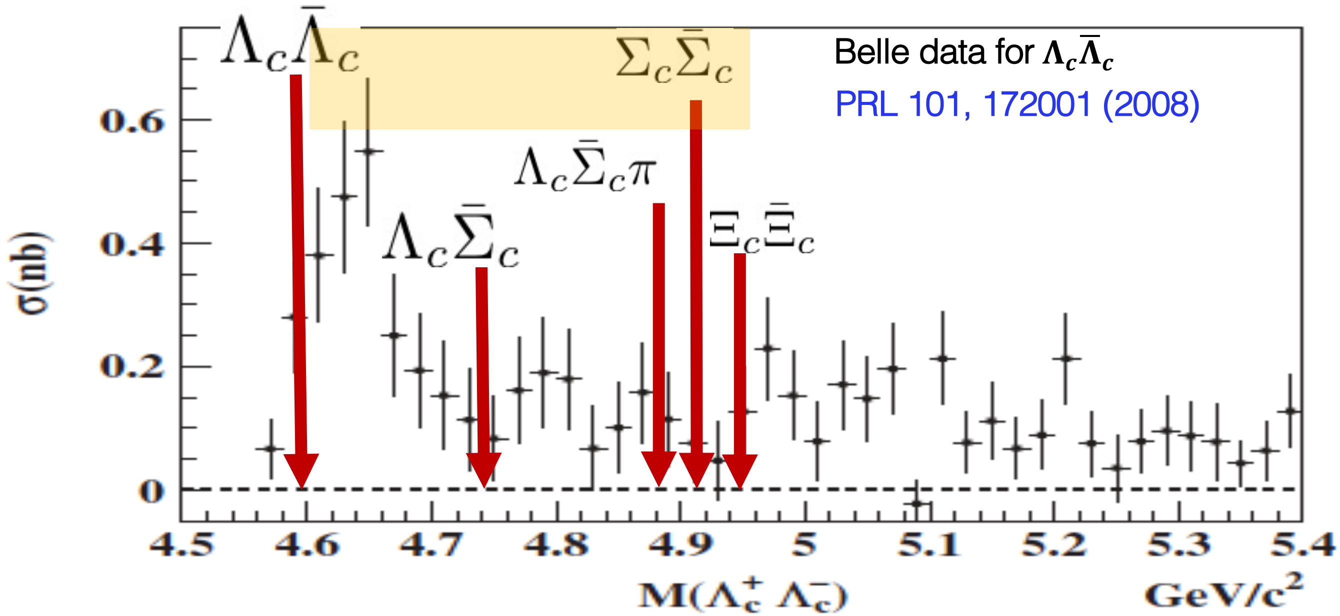
Energy thresholds

- ✓ $\Lambda_c^+\bar{\Sigma}_c^-$ 4.74 GeV
- ✓ $\Lambda_c^+\bar{\Sigma}_c\ \pi$ 4.88 GeV
- ✓ $\Sigma_c\ \bar{\Sigma}_c$ 4.91 GeV
- ✓ $\Xi_c\ \bar{\Xi}_c$ 4.95 GeV
- ✓ $\Omega_c^0\bar{\Omega}_c^0$ 5.4 GeV

New data samples in 2020 and 2021

Two major changes in BEPCII machine:

- **max beam energy: 2.30➔2.35(2018)➔ 2.48 GeV(2020)**
- **top-up injection:** data taking efficiency increased by 20~30%

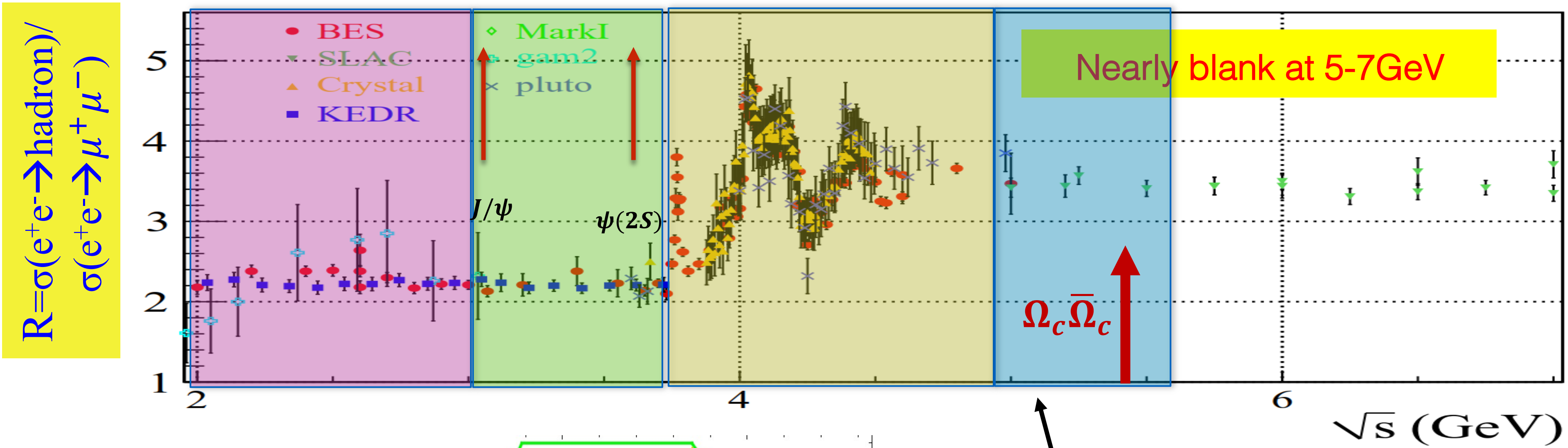


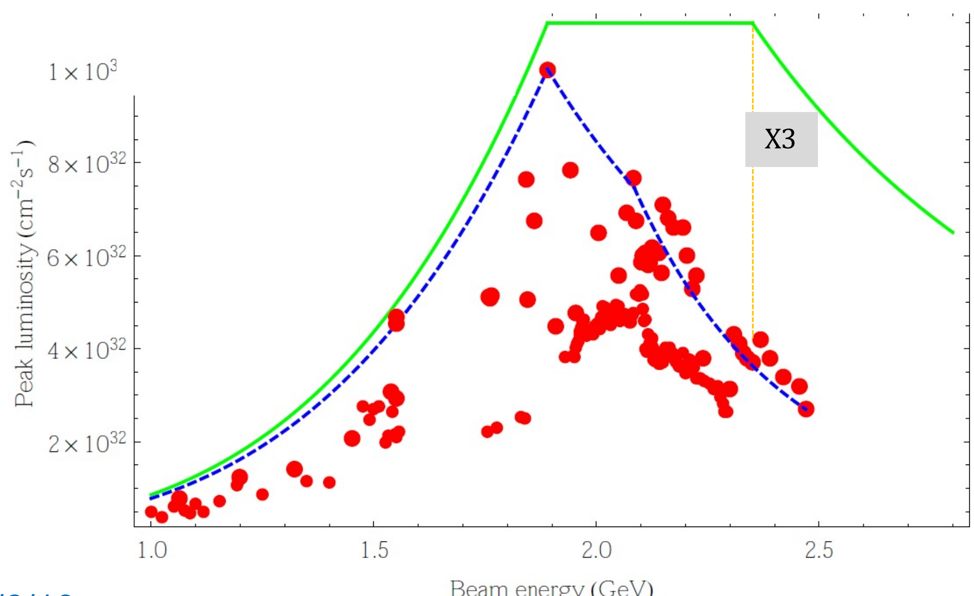
Available data for charmed baryons

- ✓ 0.567 fb^{-1} at 4.6 GeV (35 days in 2014)
- ✓ 3.8 fb^{-1} scan at 4.61, 4.63, 4.64, 4.66, 4.68, 4.7 GeV (186 days in 2020)
- ✓ 2 fb^{-1} scan at 4.74, 4.78, 4.84, 4.91, 4.95 GeV (99 days in 2021)
- 10x Λ_c data that those at 4.6GeV.
- accessible to Σ_c/Ξ_c prod. & decays

Proposal of the BEPCII upgrade

- optimized energy at 2.35 GeV with luminosity 3 times higher than the current BEPCII.





4.95 ~ 5.6 GeV: new energy coverage of BEPCII-upgrade

More details about the upgrade please check the talk from Zhang Yuan

BESIII Ξ_c (*usc/dsc*): decay information is limited

- No absolute BFs have been measured/calculated until 2019
- Belle measured abs. BFs in 2019, but uncertainties are large: δB~30%

Ξ_c^+: relative to the decay of $\Xi^- 2\pi^+$

	Mode	Fraction (Γ_i /Γ)
No absolute branching fractions have been measured.The following are branching to $\Xi^-\pi^+$ .Cabibbo-favored ($S = -2$) decays — relative to $\Xi^-\pi^+$		
Γ_1	$p2K_S^0$	0.087 ± 0.021
Γ_2	$\Lambda\overline{K}^0\pi^+$	
Γ_3	$\Sigma(1385)^+\overline{K}^0$	1.0 ± 0.5
Γ_4	$\Lambda K^- 2\pi^+$	0.323 ± 0.033
Γ_5	$\Lambda\overline{K}^*(892)^0\pi^+$	< 0.16
Γ_6	$\Sigma(1385)^+K^-\pi^+$	< 0.23
Γ_7	$\Sigma^+K^-\pi^+$	0.94 ± 0.10
Γ_8	$\Sigma^+\overline{K}^*(892)^0$	0.81 ± 0.15
Γ_9	$\Sigma^0 K^- 2\pi^+$	0.27 ± 0.12
Γ_{10}	$\Xi^0\pi^+$	0.55 ± 0.16
Γ_{11}	$\Xi^- 2\pi^+$	**DEFINEDAS1**
Γ_{12}	$\Xi(1530)^0\pi^+$	< 0.10
Γ_{13}	$\Xi^0\pi^+\pi^0$	2.3 ± 0.7
Γ_{14}	$\Xi^0\pi^- 2\pi^+$	1.7 ± 0.5
Γ_{15}	$\Xi^0 e^+\nu_e$	$2.3^{+0.7}_{-0.8}$
Γ_{16}	$\Omega^- K^+\pi^+$	0.07 ± 0.04
Cabibbo-s		
Γ_{17}		
Γ_{18}		
Γ_{19}		
Γ_{20}		
Γ_{21}	$\Sigma^+K^+K^-$	0.15 ± 0.06

Decay Modes Ξ_c^0

	Mode	Fraction (Γ_i /Γ)
Cabibbo-favored (S = −2) decays		
Γ_1	$pK^-K^-\pi^+$	$(4.8 \pm 1.2) \times 10^{-3}$
Γ_2	$pK^-\overline{K}^*(892)^0$, $\overline{K}^{*0} \to K^-\pi^+$	$(2.0 \pm 0.6) \times 10^{-3}$
Γ_3	$pK^-K^-\pi^+$ (no $\overline{K}^{*0}$)	$(3.0 \pm 0.9) \times 10^{-3}$
Γ_4	ΛK_S^0	$(3.0 \pm 0.8) \times 10^{-3}$
Γ_5	$\Lambda K^-\pi^+$	$(1.45 \pm 0.33)\%$
Γ_6	$\Lambda\overline{K}^0\pi^+\pi^-$	seen
Γ_7	$\Lambda K^-\pi^+\pi^+\pi^-$	seen
Γ_8	$\boxed{\Xi^-\pi^+}$	$(1.43 \pm 0.32)\%$
Γ_9	$\Xi^-\pi^+\pi^+\pi^-$	$(4.8 \pm 2.3)\%$
Γ_{10}	$\Omega^- K^+$	$(4.2 \pm 1.0) \times 10^{-3}$
Γ_{11}	$\Xi^- e^+\nu_e$	$(1.8 \pm 1.2)\%$
Cabibbo-suppressed decays		
Γ_{12}	$\Xi^- K^+$	$(3.9 \pm 1.2) \times 10^{-4}$
Γ_{13}	ΛK^+K^- (no ϕ)	$(4.1 \pm 1.4) \times 10^{-4}$
Γ_{14}	$\Lambda\phi$	$(4.9 \pm 1.5) \times 10^{-4}$

Very limited knowledge on their decays
We have opportunity to systematically study more decays

Studies on the Ω_c^0

Mode		Fraction (Γ_i /Γ)

No absolute branching fractions have been measured. The following are branching *ratios* relative to $\Omega^-\pi^+$.
Cabibbo-favored (S = -3) decays – relative to $\Omega^-\pi^+$

Γ_1	$\Omega^-\pi^+$	**DEFINED AS 1**
Γ_2	$\Omega^-\pi^+\pi^0$	1.80 ± 0.33
Γ_3	$\Omega^-\rho^+$	> 1.3
Γ_4	$\Omega^-\pi^-2\pi^+$	0.31 ± 0.05
Γ_5	$\Omega^- e^+\nu_e$	2.4 ± 1.2
Γ_6	$\Xi^0\overline{K}^0$	1.64 ± 0.29
Γ_7	$\Xi^0 K^-\pi^+$	1.20 ± 0.18
Γ_8	$\Xi^0\overline{K}^{*0}$, $\overline{K}^{*0} \to K^-\pi^+$	0.68 ± 0.16
Γ_9	$\Xi^-\overline{K}^0\pi^+$	2.12 ± 0.28
Γ_{10}	$\Xi^- K^- 2\pi^+$	0.63 ± 0.09
Γ_{11}	$\Xi(1530)^0 K^-\pi^+$, $\Xi^{*0} \to \Xi^-\pi^+$	0.21 ± 0.06
Γ_{12}	$\Xi^-\overline{K}^{*0}\pi^+$	0.34 ± 0.11
Γ_{13}	$\Sigma^+ K^- K^-\pi^+$	< 0.32
Γ_{14}	$\Lambda\overline{K}^0\overline{K}^0$	1.72 ± 0.35

Studies on most of the Ξ_c / Ω_c weak decays are missing in experiment (I)

BFs of CF decays

(in units of %)

Decay	RQM Körner, Krämer ('92)	Pole Xu, Kamal ('92)	Pole Cheng, Tseng ('93)	RQM Ivanov et al. ('98)	Pole Żenczykowski ('94)	Pole Sharma, Verma ('99)	Expt.
$\Xi_c^+ \to \Sigma^+ \bar{K}^0$	6.45	0.44	0.84	3.08	1.56	0.04	
$\Xi_c^+ \to \Xi^0 \pi^+$	3.54	3.36	3.93	4.40	1.59	0.53	0.55 ± 0.16^a
$\Xi_c^0 \to \Lambda \bar{K}^0$	0.12	0.37	0.27	0.42	0.35	0.54	seen
$\Xi_c^0 \to \Sigma^0 \bar{K}^0$	1.18	0.11	0.13	0.20	0.11	0.07	
$\Xi_c^0 \to \Sigma^+ K^-$	0.12	0.12		0.27	0.36	0.12	
$\Xi_c^0 \to \Xi^0 \pi^0$	0.03	0.56	0.28	0.04	0.69	0.87	
$\Xi_c^0 \to \Xi^0 \eta$	0.24			0.28	0.01	0.22	
$\Xi_c^0 \to \Xi^0 \eta'$	0.85			0.31	0.09	0.06	
$\Xi_c^0 \to \Xi^- \pi^+$	1.04	1.74	1.25	1.22	0.61	2.46	seen
$\Omega_c^0 \to \Xi^0 \bar{K}^0$	1.21		0.09	0.02			

Studies on most of the Ξ_c / Ω_c^0 weak decays are missing in experiment (II)

Decay asymmetry α for CF decays

Longitudinal pol. of daughter baryon from unpol. parent baryon

⇒ information on the relative sign between s- and p-waves

Decay	Körner, Krämer ('92)	Xu, Kamal ('92)	Cheng, Tseng ('93)	Ivanov et al. ('98)	Żenczykowski ('94)	Sharma, Verma ('99)	Expt.
$\Xi_c^+ \to \Sigma^+ \bar{K}^0$	-1.0	0.24	-0.09	-0.99	1.00	0.54	
$\Xi_c^+ \to \Xi^0 \pi^+$	-0.78	-0.81	-0.77	-1.0	1.00	-0.27	
$\Xi_c^0 \to \Lambda \bar{K}^0$	-0.76	1.0	-0.73	-0.75	-0.29	-0.79	
$\Xi_c^0 \to \Sigma^0 \bar{K}^0$	-0.96	-0.99	-0.59	-0.55	-0.50	0.48	
$\Xi_c^0 \to \Sigma^+ K^-$	0	0		0	0	0	
$\Xi_c^0 \to \Xi^0 \pi^0$	0.92	0.92	-0.54	0.94	0.21	-0.80	
$\Xi_c^0 \to \Xi^0 \eta$	-0.92			-1.0	-0.04	0.21	
$\Xi_c^0 \to \Xi^0 \eta'$	-0.38			-0.32	-1.00	0.80	
$\Xi_c^0 \to \Xi^- \pi^+$	-0.38	-0.38	-0.99	-0.84	-0.79	-0.97	-0.6 ± 0.4
$\Omega_c^0 \to \Xi^0 \bar{K}^0$	0.51		-0.93	-0.81			

Studies on most of the Ξ_c / Ω_c^0 weak decays are missing in experiment (III)

Charm-flavor-conserving weak decays

- Light quarks undergo weak transitions, while c quark behaves as a "spectator" e.g. $\Xi_c \to \Lambda_c\pi$ ($s \to W^- u$). Can be studied using HHChPT.

Br($\Xi_c^0 \to \Lambda_c^+\pi^-$)=2.9×10^{-4}

Br($\Xi_c^+ \to \Lambda_c^+\pi^0$)=6.7×10^{-4}

Cheng, Cheung, Lin, Lin, Yan, Yu ('92)

Br($\Xi_c^0 \to \Lambda_c^+\pi^-$)= $(0.55 \pm 0.02 \pm 0.18)\%$

[LHCb, PRD 102, 071101 (2020)]

Larger than theoretical predictions

These can be further tested at BESIII

Semileptonic decays

|→ NRQM ←| RQM LFQM QSR QSR

Process	Pérez-Marcial et al. [85]	Singleton [86]	Cheng, Tseng [81]	Ivanov et al. [87]	Luo [88]	Marques de Carvalho et al. [89]	Huang, Wang [90]	Expt. [3]
$\Xi_c^0 \to \Xi^- e^+\nu_e$	18.1 (12.5)	8.5	7.4	8.16	9.7			seen
$\Xi_c^+ \to \Xi^0 e^+\nu_e$	18.4 (12.7)	8.5	7.4	8.16	9.7			seen

in units of 10^{10} s^{-1}

$$\mathcal{B}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = (1.72 \pm 0.10 \pm 0.12 \pm 0.50)\%$$
$$\mathcal{B}(\Xi_c^0 \to \Xi^- \mu^+ \nu_\mu) = (1.71 \pm 0.17 \pm 0.13 \pm 0.50)\%$$

[Belle, arXiv:2103.06496]

$$\mathcal{B}_{\rm exp}(\Xi_c^0 \to \Xi^- e^+ \nu_e) = 2.43(0.25)(0.35)(0.72)\%$$

[ALICE, PoS ICHEP 2020, 524(2021)]

Summary

- BESIII has been playing significant role in studying Λ_c decays
- Many new results of Λ_c decays have been published
- BEPCII energy upgrade during 2020-2021 has improved the BESIII capability in Λ_c physics by accumulating more statistics at different energy points and pose opportunity to study Σ_c/Ξ_c physics
- Proposal of BEPCII upgrade (3x luminosity and energy up to 5.6 GeV) will greatly extend the physics opportunities in c-baryon sector

Thanks

Studies on the Λ_c^+ decays 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)
- $\Lambda_c^+\Lambda_c^-$ pair cross section : PRL 120,132001(2018).

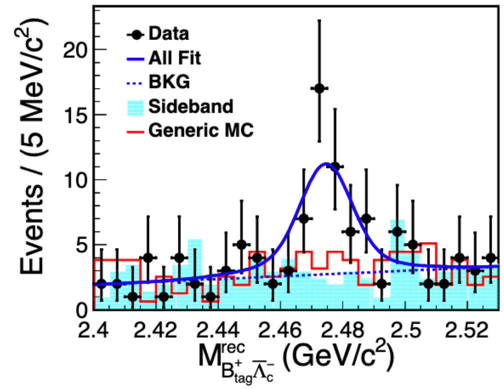
Prospect Charm Baryons data sample at BESIII

Energy	physics highlight	Current data # of events or integrated luminosity	Expected final data # of events or integrated luminosity
1.8 - 2.0 GeV	R values cross-sections	N/A	Scan: 3 energy points
2.0 - 3.1 GeV	R values cross-sections	Scan: 20 energy points	No requirement
J/ψ peak	Light Hadron & Glueball Charmonium decay	5.0 billion	10.0 billion
$\psi(3686)$ peak	Light hadron& Glueball Charmonium decay	0.5 billion	3.0 billion
$\psi(3770)$ peak	$D^0/D^{\pm}$ decays Form-factor/CKM decay constant	2.9 fb^{-1}	20.0 fb^{-1}
3.8 - 4.6 GeV	R value XYZ/Open charm	Scan: 105 energy points	No requirement
4.180 GeV	D_s decay XYZ/Open charm	3.1 fb^{-1}	6.0 fb^{-1}
4.0 - 4.6 GeV	XYZ/Open charm Higher charmonia cross-sections	Scan: 12.0 fb^{-1}	Scan: 30.0 fb^{-1} 10 MeV step/0.5 fb^{-1}/point 30 energy points
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}

First Measurements of absolute BFs for Ξ_c at Belle

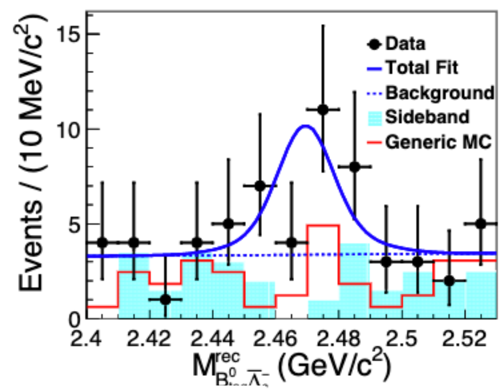
Belle, Phys.Rev.Lett. 122, 082001 (2019)
Belle, Phys. Rev. D 100, 031101 (2019)

$$\mathcal{B}(\Xi_c^0 \to \Xi^- \pi^+) = (1.80 \pm 0.50 \pm 0.14)\%,$$
$$\mathcal{B}(\Xi_c^0 \to \Lambda K^- \pi^+) = (1.17 \pm 0.37 \pm 0.09)\%,$$
$$\mathcal{B}(\Xi_c^0 \to p K^- K^- \pi^+) = (0.58 \pm 0.23 \pm 0.05)\%,$$
$$\mathcal{B}(\Xi_c^+ \to \Xi^- \pi^+ \pi^+) = (2.86 \pm 1.21 \pm 0.38)\%,$$
$$\mathcal{B}(\Xi_c^+ \to p K^- \pi^+) = (0.45 \pm 0.21 \pm 0.07)\%.$$



$$N_{\Xi_c^0} = 40.9 \pm 9.0$$

- Large errors
- Belle II will improve these to ~10%
- BESIII has potential to improve them



$$N_{\Xi_c^+} = 18.8 \pm 6.8.$$