

Recent Λ_c^+ Results for BESIII

Haiping Peng (彭海平)

(On behalf BESIII Collaboration)

University of Science and Technology, China (USTC)

Excellence in Global Education



penghp@ustc.edu.cn

JAEA/ASRC Reimei(黎明) Workshop 2016, 24-26th October,

Inha University, Incheon, Republic of Korea

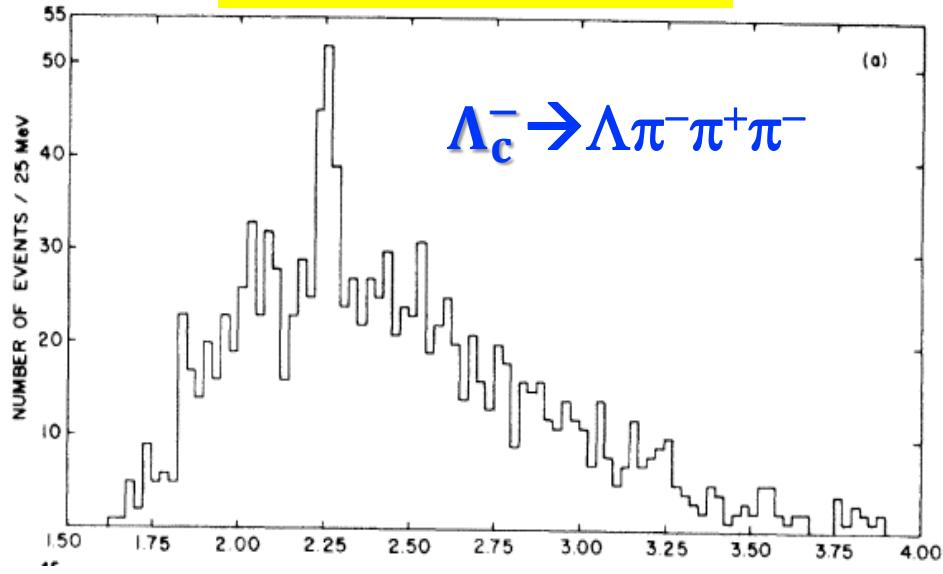
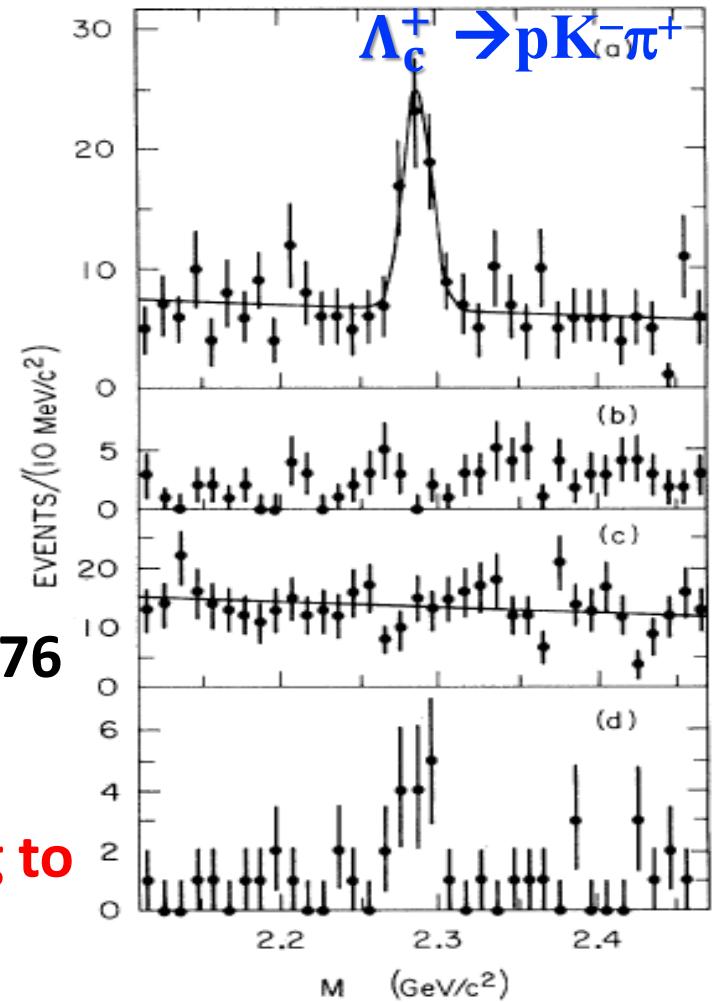
- Introduction
- BEPCII and BESIII

- Λ_c^+ Physics @ BESIII

- Λ_c^+ Semi-leptonic decay
- Λ_c^+ Hadronic decay
- Λ_c^+ inclusive decay

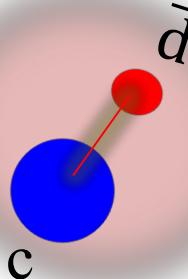
- Summary and Prospects

Introduction

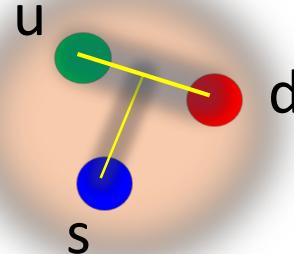
PRL 37 (1976) 882**PRL 44 (1980) 10**

- First observed at Fermi Lab in 1976
- Established at Mark II in 1980.
- Progress Relatively slow comparing to charmed mesons

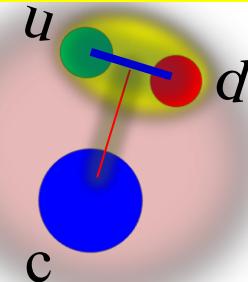
$\Lambda_c^+ : \text{a heavy quark (c) with a unexcited spin-zero diquark (u-d)}$



Charmed meson ($D^+[\bar{c}d]$)
 $m_d \ll m_c \rightarrow \text{quark + heavy quark}$
 $(q) \quad (Q)$



Strange baryons ($L[uds]$)
 $m_u, m_d \approx m_s \rightarrow (\text{qqq})$ uniform



Charmed baryon ($L_c[udc]$)
 $m_u, m_d \ll m_c \rightarrow \text{diquark + quark}$
 $(\bar{q}q) \quad (Q)$

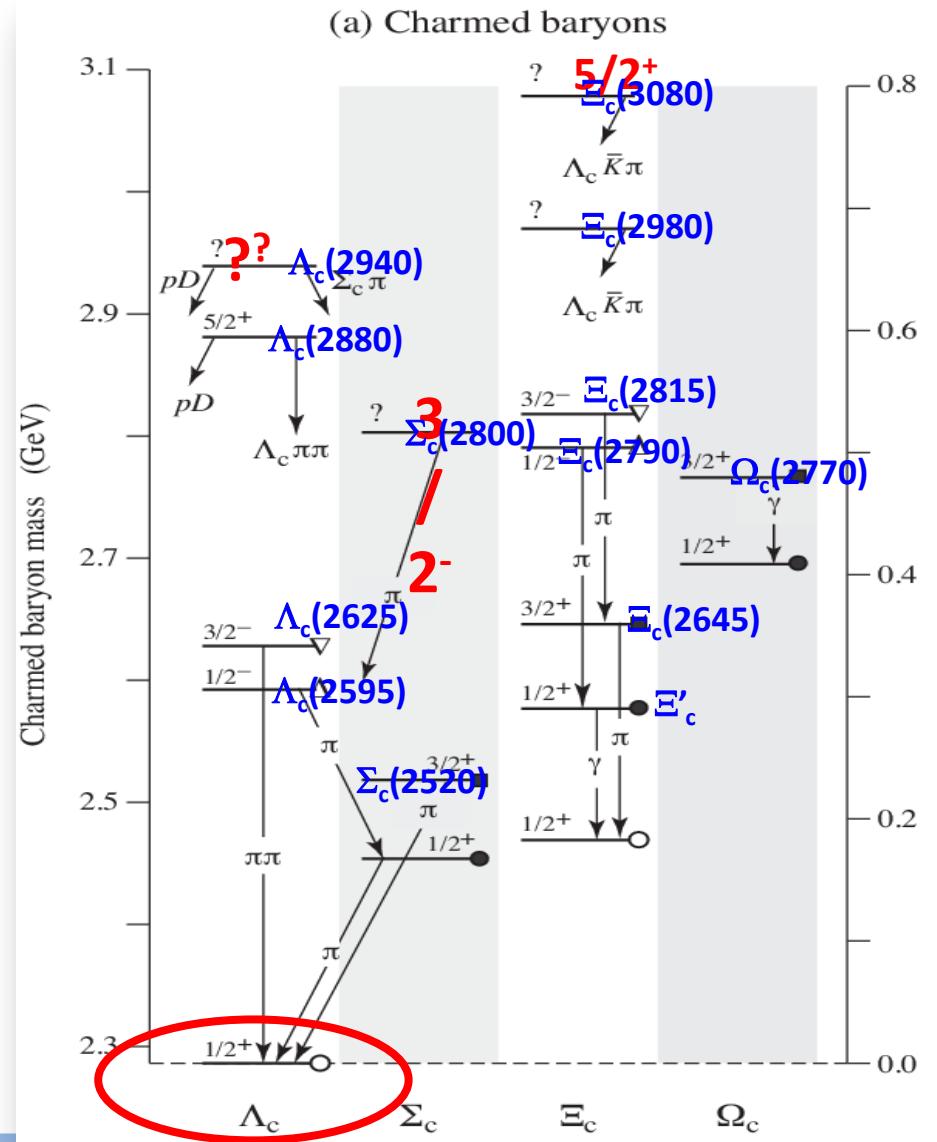
Heavy Quark Effective Theory :

- diquark correlation is enhanced by weak Color Magnetic Interaction with a heavy quark
- More reliable prediction of heavy-light quark transition without dealing with light degrees of freedom that have net spin or isospin.

Λ_c^+ may provide complementary powerful test on internal dynamics to charmed meson does

Cornerstone of charmed baryon Spectroscopy

- The **lightest charmed baryon**
- 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 energies and bottom baryon decays
- $B(\Lambda_c^+ \rightarrow p\bar{K}^-\pi^+)$: **dominant error** for V_{ub} via baryon decay



The Λ_c^+ Decays

Λ_c Measurements [PDG2015]

Λ_c^+ DECAY MODES	Fraction (Γ_i/Γ)	Scale factor/ Confidence level	P_{AB}	$\Delta B/B$	
Hadronic modes with a p: $S = -1$ final states					
$p\bar{K}^0$	(3.21 ± 0.30) %		9.3%		
$pK^-\pi^+$	(6.84 ± 0.32) %		5.8%		
$p\bar{K}^*(892)^0$	[q] (2.13 ± 0.30) %		14.1%		
$\Delta(1232)^{++}K^-$	(1.18 ± 0.27) %		22.9%		
$\Lambda(1520)\pi^+$	[q] (2.4 ± 0.6) %		25.0%		
$pK^-\pi^+$ nonresonant	(3.8 ± 0.4) %		10.5%		
$p\bar{K}^0\pi^0$	(4.5 ± 0.6) %		13.3%		
$p\bar{K}^0\eta$	(1.7 ± 0.4) %		23.5%		
$p\bar{K}^0\pi^+\pi^-$	(3.5 ± 0.4) %		11.4%		
$pK^-\pi^+\pi^0$	(4.6 ± 0.8) %		13.0%		
$pK^*(892)^-\pi^+$	[q] (1.5 ± 0.5) %		33.3%		
$p(K^-\pi^+)_\text{nonresonant}\pi^0$	(5.0 ± 0.9) %		18.0%		
$\Delta(1232)\bar{K}^*(892)$	seen				
$pK^-\pi^+\pi^+\pi^-$	(1.5 ± 1.0) $\times 10^{-3}$		66.7%		
$pK^-\pi^+\pi^0\pi^0$	(1.1 ± 0.5) %		45.4%		
Hadronic modes with a p: $S = 0$ final states					
$p\pi^+\pi^-$	(4.7 ± 2.5) $\times 10^{-3}$		45.4%		
$p f_0(980)$	[q] (3.8 ± 2.5) $\times 10^{-3}$		53.2%		
$p\pi^+\pi^+\pi^-\pi^-$	(2.5 ± 1.6) $\times 10^{-3}$		64.0%		
pK^+K^-	(1.1 ± 0.4) $\times 10^{-3}$		36.4%		
$p\phi$	[q] (1.12 ± 0.23) $\times 10^{-3}$				
pK^+K^- non- ϕ	(4.8 ± 1.9) $\times 10^{-4}$				
Hadronic modes with a hyperon: $S = -1$ final states					
$\Lambda\pi^+$	(1.46 ± 0.13) %		8.9%		
$\Lambda\pi^+\pi^0$	(5.0 ± 1.3) %		26.0%		
$\Lambda\rho^+$	< 6 %	CL=95%			
$\Lambda\pi^+\pi^+\pi^-$	(3.59 ± 0.28) %		7.8%		
$\Sigma(1385)^+\pi^+\pi^-, \Sigma^{*+} \rightarrow$	(1.0 ± 0.5) %		20.0%		
$\Lambda\pi^+$					
$\Sigma(1385)^-\pi^+\pi^+, \Sigma^{*-} \rightarrow$	(7.5 ± 1.4) $\times 10^{-3}$		18.7%		
$\Lambda\pi^-$					
Hadronic modes with a hyperon: $S = 0$ final states					
ΛK^+					
$\Lambda K^+\pi^-\pi^-$					
$\Sigma^0 K^+$					
$\Sigma^0 K^+\pi^+\pi^-$					
$\Sigma^+ K^-\pi^-$					
$\Sigma^+ K^*(892)^0$					
$\Sigma^- K^+\pi^+$					
$\Xi(1530)^0 K^+$					
Doubly Cabibbo-suppressed modes					
$pK^+\pi^-$					
$\Lambda e^+\nu_e$					
$\Lambda e^+\nu_e$					
Semileptonic modes					
$[r] (\mathbf{2.8 \pm 0.4}) \%$					17.2%
$(2.9 \pm 0.5) \%$					22.2%
$(2.7 \pm 0.6) \%$					

$\Delta B/B$
↓

42.8%
80.0%

36.0%

20.8%

30.2%

37.5%

20.3%

33.3%

10.0%

21.9%

33.3%

10.2%

17.4%

36.0%

27.4%

27.1%

15.8%

16.3%

26.2%

24.5%

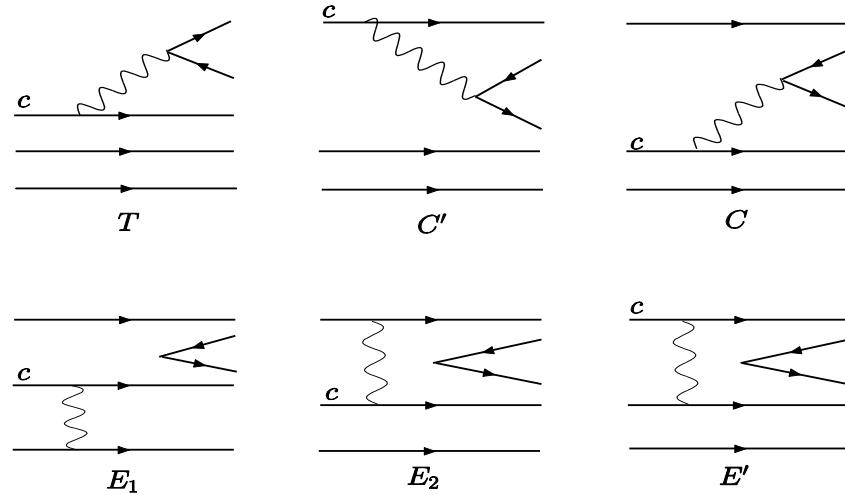
11.4%

28.6%

- Total branching fraction small than 65%.
- Lots of unknown decay channels
- Quite large uncertainties, most larger than 20%
- Most BFs are measured relative to $\Lambda_c^+ \rightarrow pK^-\pi^+$

- Contrary to charm meson, receive **sizable non-factorization W-exchange contribution**

Chau, HYC, Tseng 96



- Two distinct **internal W emission diagrams**, three different **W exchange diagrams**
- Need information of **decay asymmetry** to extract s-wave and p-wave amplitudes separately

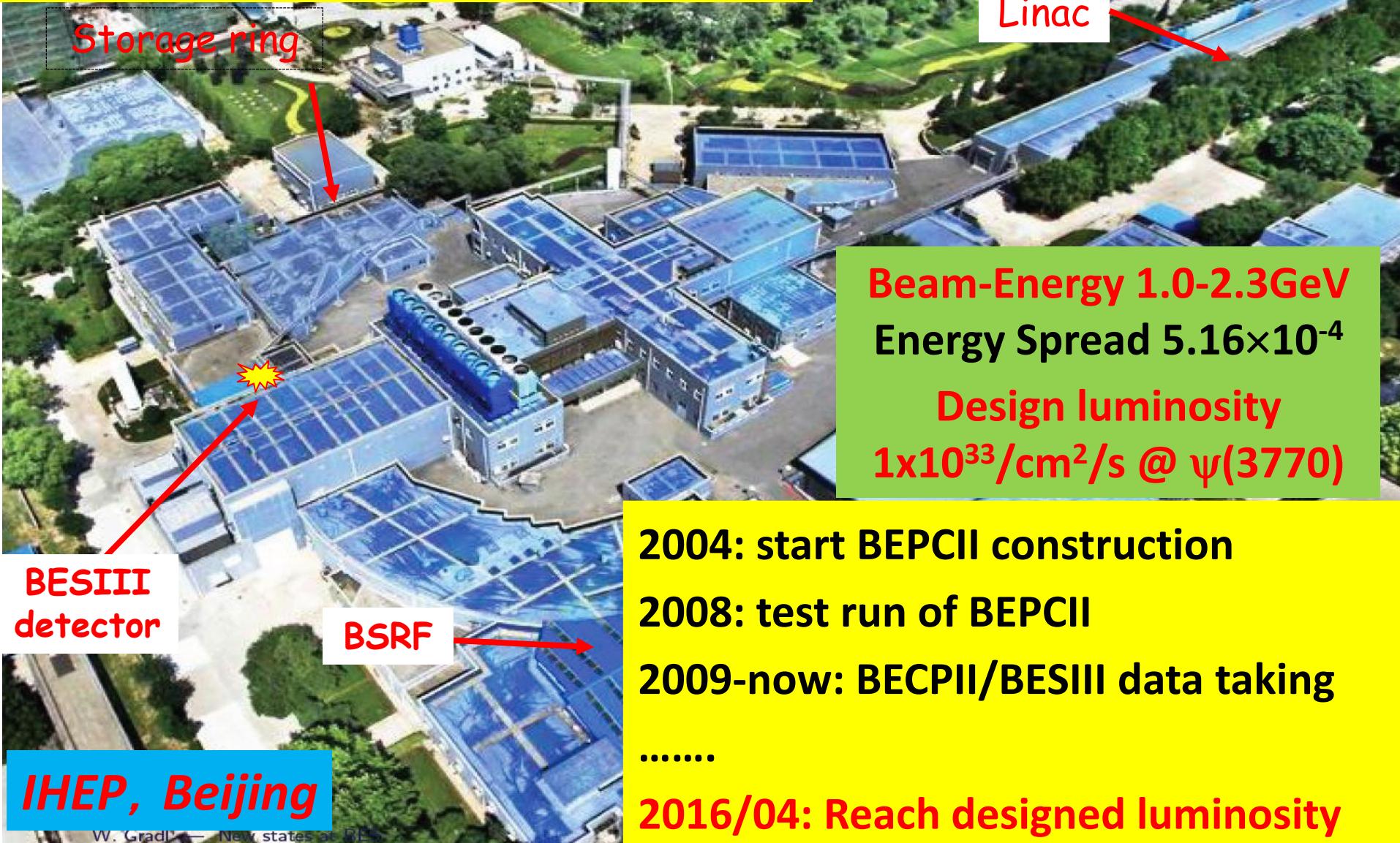
- Exotic search in $\Lambda_c^+ \rightarrow \phi p \pi^0$: an analog to P_c states in $\Lambda_b^0 \rightarrow J/\psi p K^-$

BEPCII and BESIII

Beijing Electron Positron Collider (BEPCII)



Double ring, Large Crossing angle



NIM A614, 345 (2010)

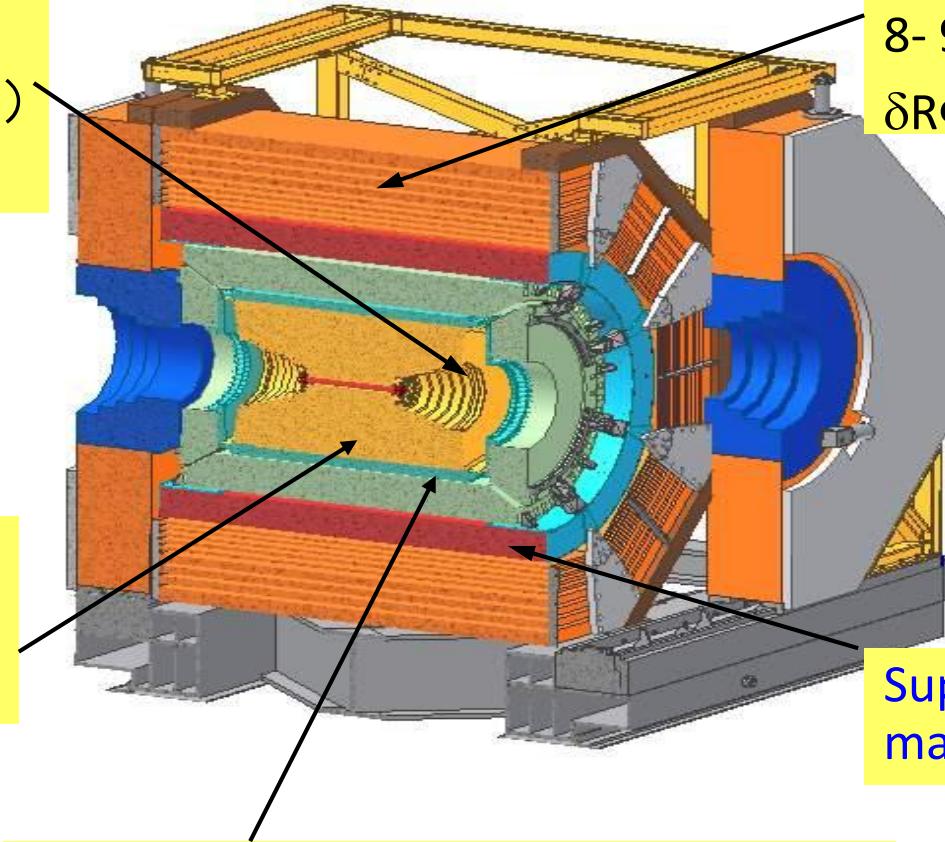
Drift Chamber (MDC)

$$\sigma P/P (\%) = 0.5\% (1 \text{ GeV})$$

$$\sigma_{dE/dx} (\%) = 6\%$$

Time Of Flight (TOF)

$$\sigma_T: 90 \text{ ps Barrel}$$
$$110 \text{ ps endcap}$$



μCounter

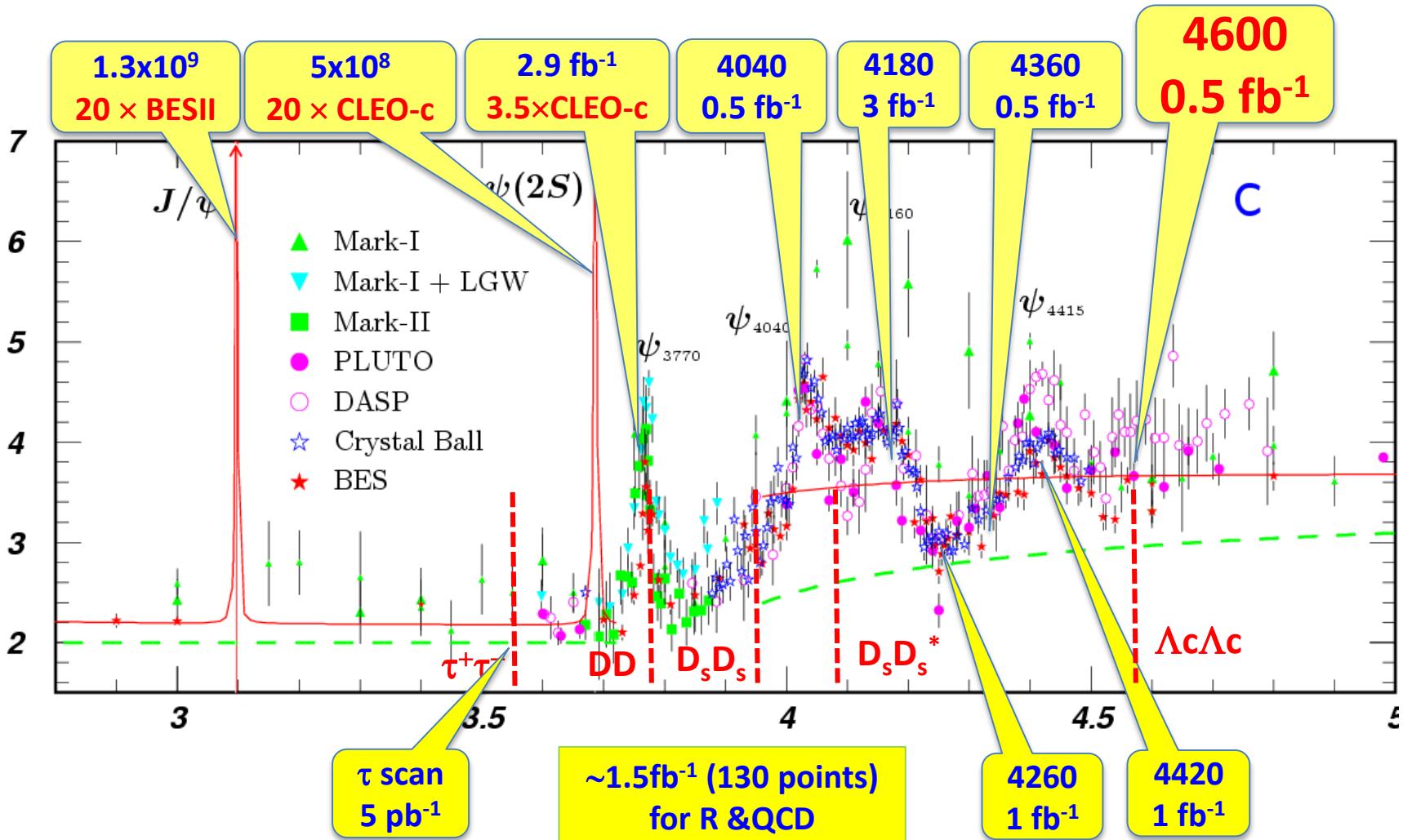
8- 9 layers RPC

$$\delta R\Phi = 1.4 \text{ cm} \sim 1.7 \text{ cm}$$

Super-conducting magnet (1.0 Tesla)

$$\text{EMC: } \sigma E/\sqrt{E} (\%) = 2.5 \% (1 \text{ GeV})$$

$$(\text{CsI}) \quad \sigma_{z,\phi} (\text{cm}) = 0.5 - 0.7 \text{ cm}/\sqrt{E}$$

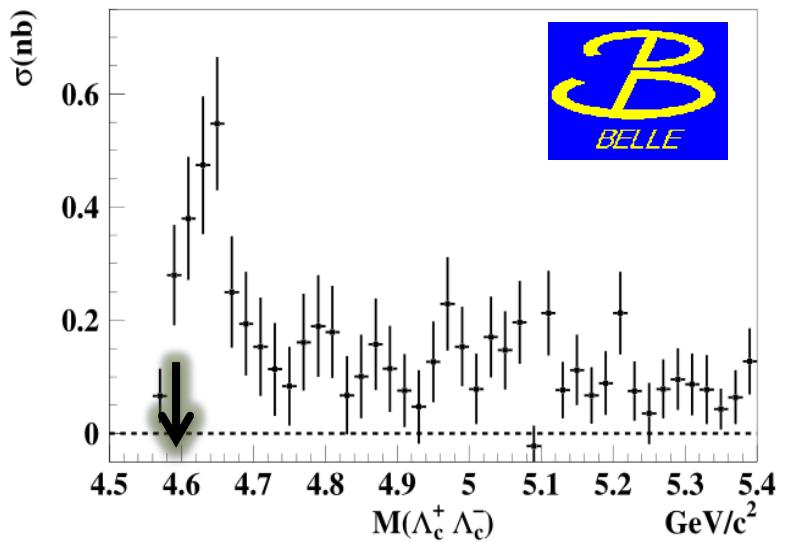


First time Run around 4.6 GeV in 2014, marvelous achievement of BEPCII

available data set at BESIII

Energy(GeV)	lum.(1/pb)
4.575	~48
4.580	~8.5
4.590	~8.1
4.600	~567

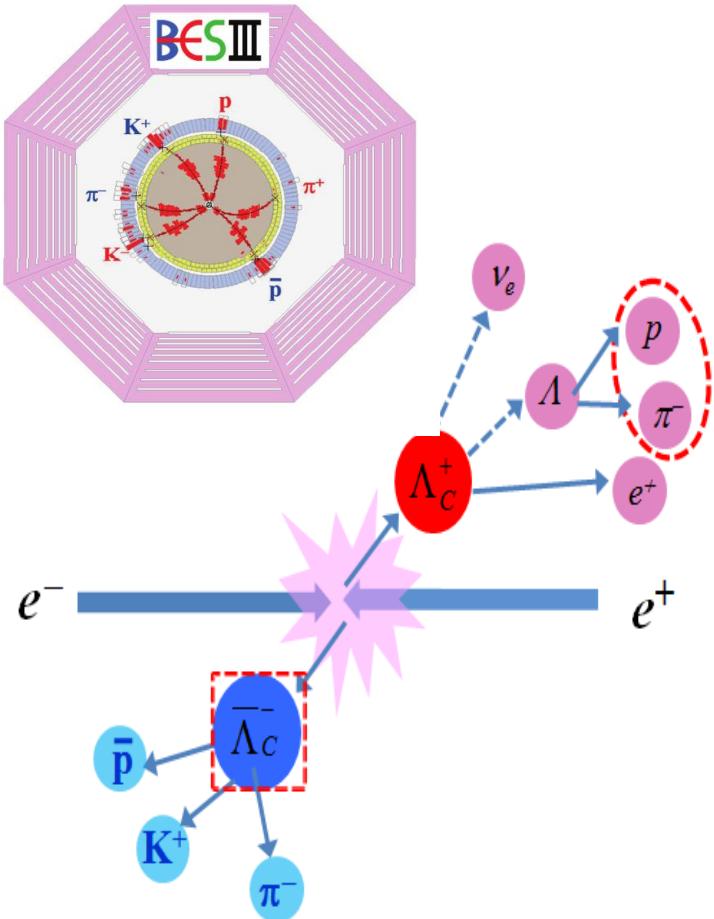
PRL 101 (2008) 172001



Λ_c^+ Measurement using the threshold pair-productions via e^+e^- annihilations is unique: *the most simple and straightforward*

First time to systematically study charmed baryon at threshold!

$\Lambda_c^+ \bar{\Lambda}_c^-$ pair production at e^+e^- collision at mass threshold,
no additional hadron in final states



□ Tagging method :

- Single tag (ST) : reconstruct one Λ_c^+
- Double tag (DT) : fully reconstruct $\Lambda_c^+ \bar{\Lambda}_c^-$ pair

□ Two important variables:

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

$$\Delta E = E - E_{\text{beam}}$$

□ Advantages:

- Clean environment
- Straightforward and model independent absolute BRs measurement
- Some systematic uncertainties canceled in DT method

Λ_c^+ Physics @ BESIII

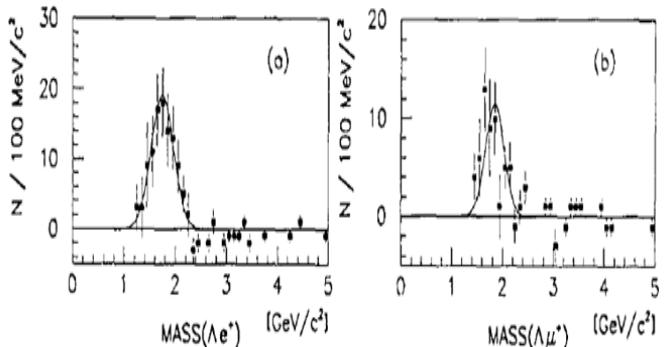
Semi-Leptonic decay $\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l$

□ ARGUS first measurement :

Phys. Lett. B 269, 234 (1991).

$$\sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \rightarrow \Lambda e^+ X) = 4.20 \pm 1.28 \pm 0.71 \text{ pb}$$

$$\sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \rightarrow \Lambda \mu^+ X) = 3.91 \pm 2.02 \pm 0.90 \text{ pb}$$

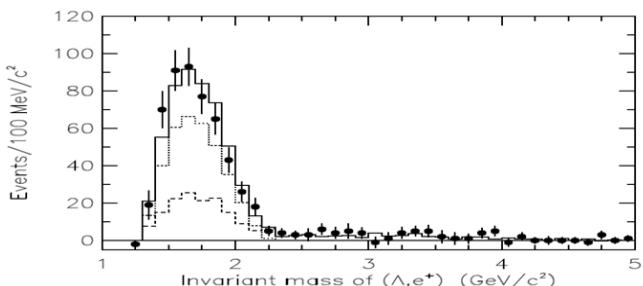


□ CLEO improved measurement :

Phys. Lett. B 323, 219 (1994).

$$\sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \rightarrow \Lambda e^+ X) = 4.87 \pm 0.28 \pm 0.69 \text{ pb}$$

$$\sigma(e^+e^- \rightarrow \Lambda_c^+ X) \cdot BR(\Lambda_c^+ \rightarrow \Lambda \mu^+ X) = 4.43 \pm 0.51 \pm 0.64 \text{ pb}$$



□ Combined with the $\tau(\Lambda_c^+)$ and the assumption of form factors

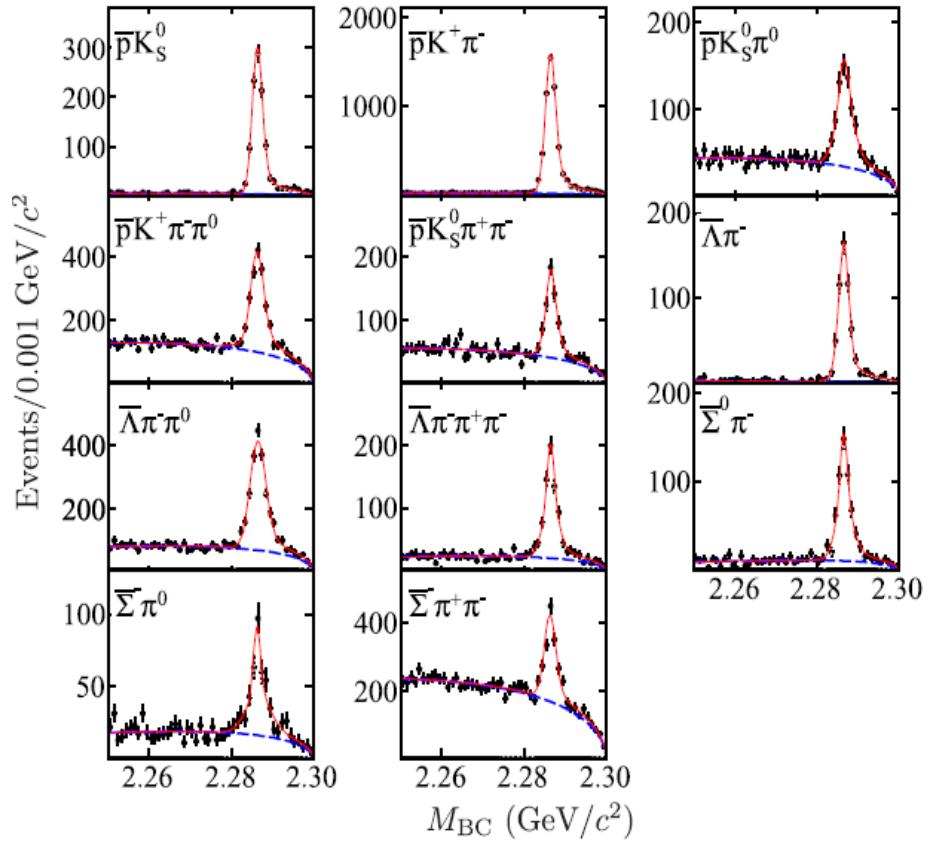
$\Lambda l^+ \nu_l$	PDG 2015
$\Lambda e^+ \nu_e$	[r] (2.8 ± 0.4) %
$\Lambda \mu^+ \nu_\mu$	(2.9 ± 0.5) %
	(2.7 ± 0.6) %

Not a direct measurement!

Theoretical calculations on the BF ranges from 1.4% to 9.2%

Double tag method
11 tag modes :

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

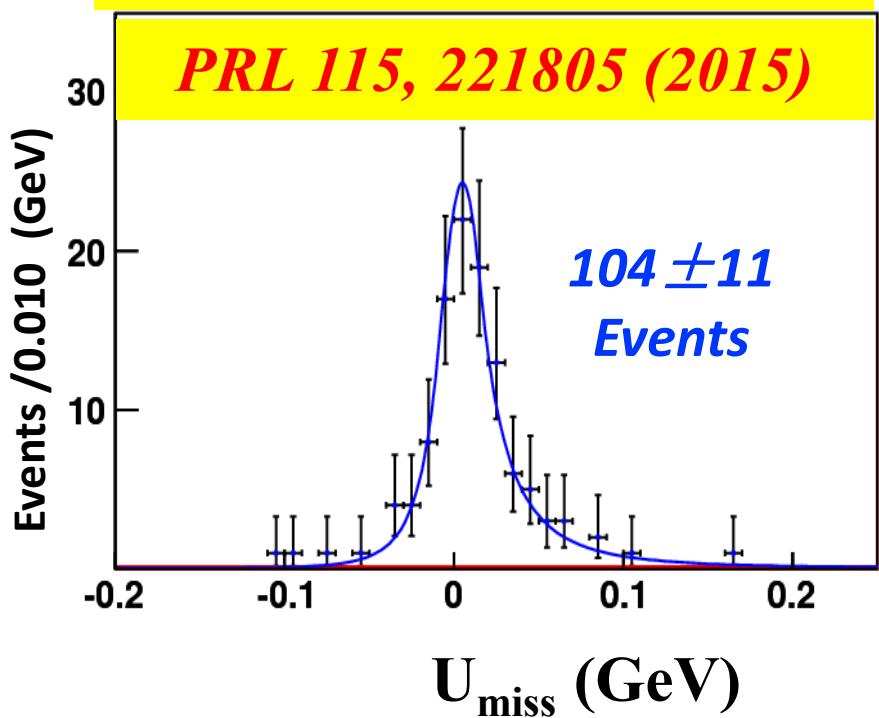


Mode	ΔE (GeV)	$N_{\bar{\Lambda}_c^-}$
$\bar{p}K_S^0$	$[-0.025, 0.028]$	1066 ± 33
$\bar{p}K^+\pi^-$	$[-0.019, 0.023]$	5692 ± 88
$\bar{p}K_S^0\pi^0$	$[-0.035, 0.049]$	593 ± 41
$\bar{p}K^+\pi^-\pi^0$	$[-0.044, 0.052]$	1547 ± 61
$\bar{p}K_S^0\pi^+\pi^-$	$[-0.029, 0.032]$	516 ± 34
$\bar{\Lambda}\pi^-$	$[-0.033, 0.035]$	593 ± 25
$\bar{\Lambda}\pi^-\pi^0$	$[-0.037, 0.052]$	1864 ± 56
$\bar{\Lambda}\pi^-\pi^+\pi^-$	$[-0.028, 0.030]$	674 ± 36
$\bar{\Sigma}^0\pi^-$	$[-0.029, 0.032]$	532 ± 30
$\bar{\Sigma}^-\pi^0$	$[-0.038, 0.062]$	329 ± 28
$\bar{\Sigma}^-\pi^+\pi^-$	$[-0.049, 0.054]$	1009 ± 57

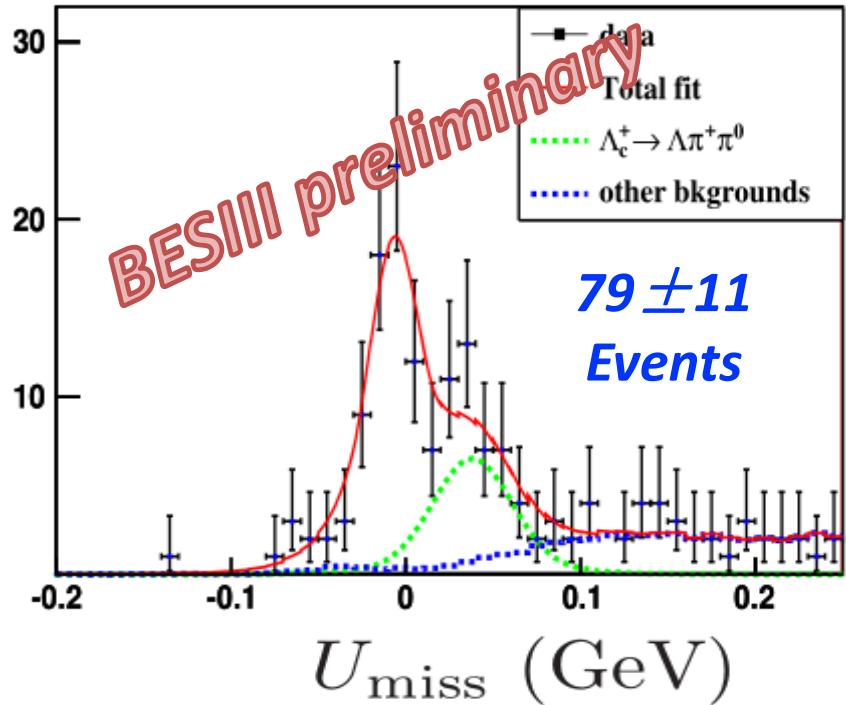
ST yields: 14415 ± 159 events with 11 ST modes

First direct measurement, optimized variables : $U_{\text{miss}} = E_{\text{miss}} - c|\vec{p}_{\text{miss}}|$

$$B(\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$$



$$B[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$$

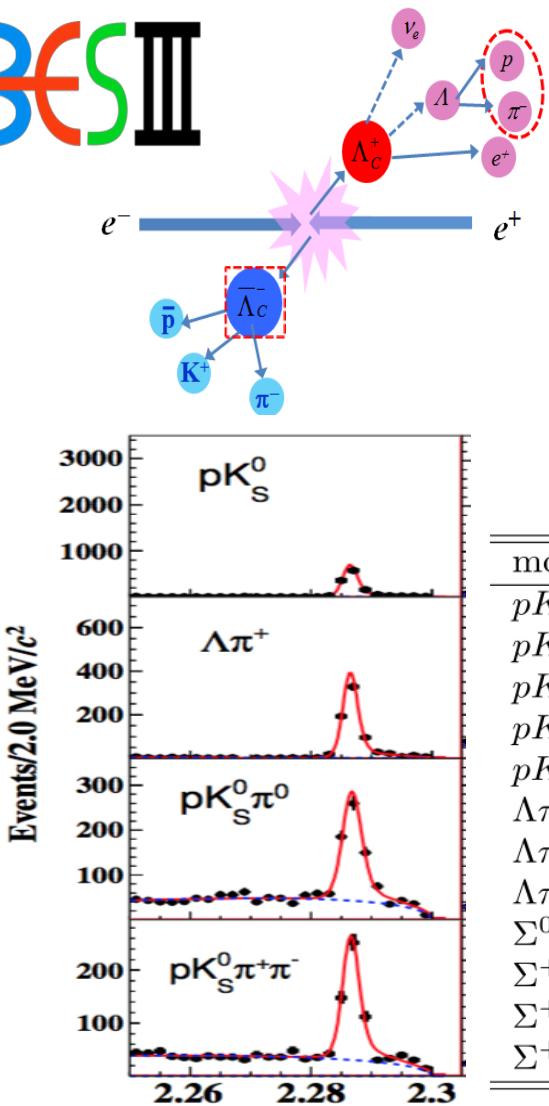


$$\Gamma[\Lambda_c^+ \rightarrow \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$$

Important for test and calibrate the LQCD and lepton universality.

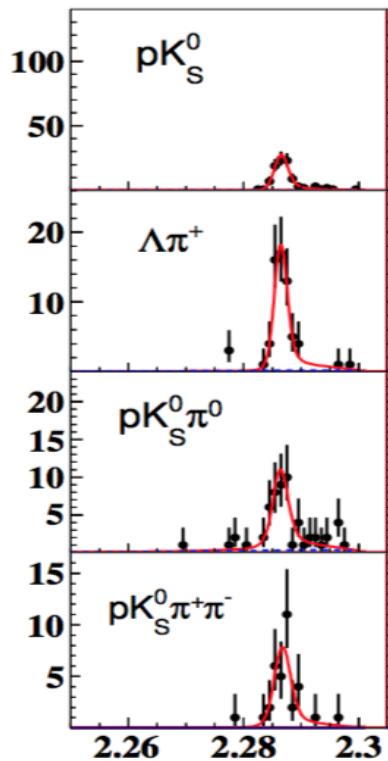
Absolute BFs for 12 Λ_c^+ CF Hadronic decays

BES II



PRL 116, 052001 (2016)

Signal Tag Variable : $M_{BC} = \sqrt{E_{\text{beam}}^2 - |\vec{p}_{\bar{\Lambda}_c^-}|^2}$



ST yields

modes	N_i^{ST}
$p\bar{K}_S$	1243 ± 37
$p\bar{K}^-\pi^+$	6308 ± 88
$p\bar{K}_S\pi^0$	558 ± 33
$p\bar{K}_S\pi^+\pi^-$	454 ± 28
$p\bar{K}^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	586 ± 32
$\Sigma^+\pi^0$	271 ± 25
$\Sigma^+\pi^+\pi^-$	836 ± 43
$\Sigma^+\omega$	157 ± 22

DT yields

Decay modes	N_{-j}^{DT}
$p\bar{K}_S$	89 ± 10
$p\bar{K}^-\pi^+$	390 ± 21
$p\bar{K}_S\pi^0$	40 ± 7
$p\bar{K}_S\pi^+\pi^-$	29 ± 6
$p\bar{K}^-\pi^+\pi^0$	148 ± 14
$\Lambda\pi^+$	59 ± 8
$\Lambda\pi^+\pi^0$	89 ± 11
$\Lambda\pi^+\pi^-\pi^+$	53 ± 7
$\Sigma^0\pi^+$	39 ± 6
$\Sigma^+\pi^0$	20 ± 5
$\Sigma^+\pi^+\pi^-$	56 ± 8
$\Sigma^+\omega$	13 ± 3

Very clean backgrounds!!!

- Straightforward and model independent

PRL 116, 052001 (2016)

- A least square global simultaneous fit :

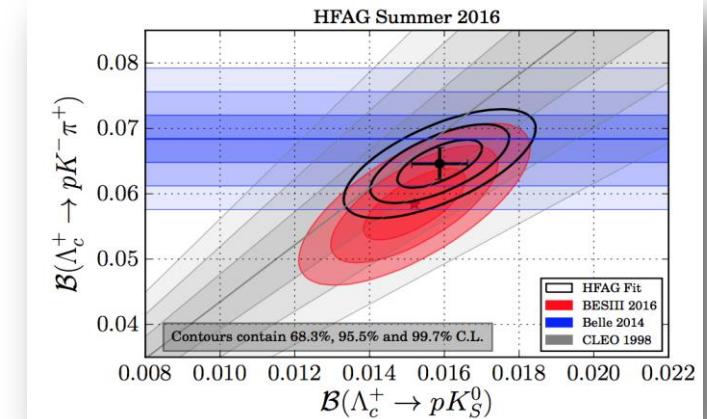
[CPC 37, 106201 (2013)]

Mode	This work (%)	PDG (%)	BELLE \mathcal{B}
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^- \pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0 \pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0 \pi^+ \pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^- \pi^+ \pi^0$	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda \pi^+$	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda \pi^+ \pi^0$	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda \pi^+ \pi^- \pi^+$	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0 \pi^+$	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+ \pi^0$	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+ \pi^+ \pi^-$	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+ \omega$	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	

- $B(\Lambda_c^+ \rightarrow p K^- \pi^+)$: BESIII precision **comparable** with Belle's
- BESIII $B(\Lambda_c^+ \rightarrow p K^- \pi^+)$ is compatible with BELLE's with 2σ
- Improved precisions of the other 11 modes significantly

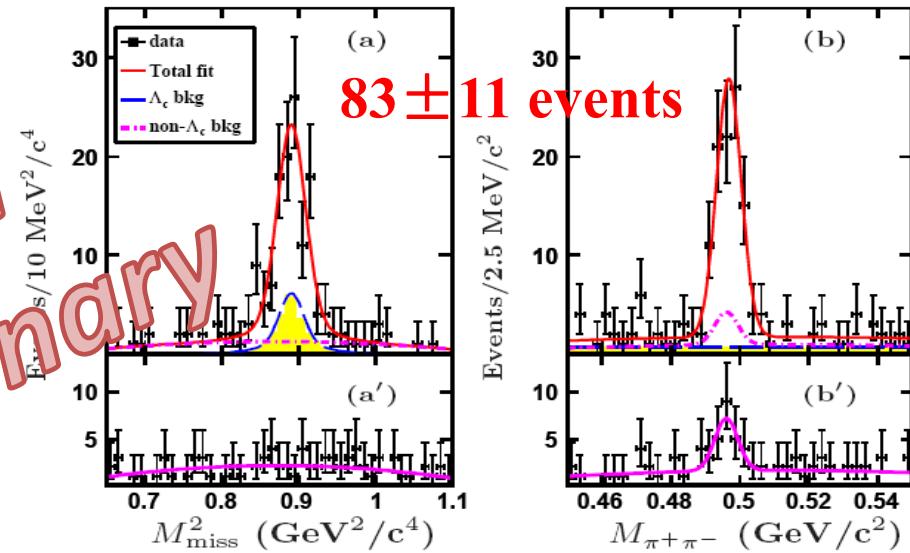
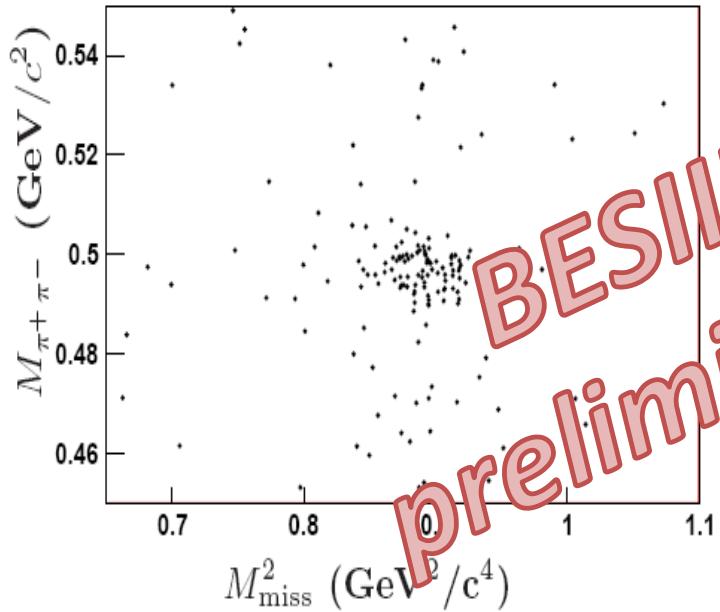
- A fitter to constrain the 12 hadronic BFs and 1 SL BF, based on all the existing experimental data, overall $\chi^2/\text{ndf}=30.0/23=1.3$
- Correlated systematics are fully taken into account

Mode	HFAG 2016 (%)	BESIII (%)	PDG 2014 (%)	BELLE (%)
pK_S^0	1.59 ± 0.07	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^- \pi^+$	6.46 ± 0.24	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	
$pK_S^0 \pi^0$	2.03 ± 0.12	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	
$pK_S^0 \pi^+ \pi^-$	1.69 ± 0.11	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^- \pi^+ \pi^0$	5.05 ± 0.29	$4.53 \pm 0.23 \pm 0.30$	3.4 ± 1.0	
$\Lambda \pi^+$	1.28 ± 0.06	$1.24 \pm 0.07 \pm 0.03$	1.07 ± 0.28	
$\Lambda \pi^+ \pi^0$	7.09 ± 0.36	$7.01 \pm 0.37 \pm 0.19$	3.6 ± 1.3	
$\Lambda \pi^+ \pi^- \pi^+$	3.73 ± 0.21	$3.81 \pm 0.24 \pm 0.18$	2.6 ± 0.7	
$\Sigma^0 \pi^+$	1.31 ± 0.07	$1.27 \pm 0.08 \pm 0.03$	1.05 ± 0.28	
$\Sigma^+ \pi^0$	1.25 ± 0.09	$1.18 \pm 0.10 \pm 0.03$	1.00 ± 0.34	
$\Sigma^+ \pi^+ \pi^-$	4.64 ± 0.24	$4.25 \pm 0.24 \pm 0.20$	3.6 ± 1.0	
$\Sigma^+ \omega$	1.77 ± 0.21	$1.56 \pm 0.20 \pm 0.07$	2.7 ± 1.0	
$\Lambda e^+ \nu_e$	3.18 ± 0.32	$3.63 \pm 0.38 \pm 0.20$	2.1 ± 0.6	



Precise $B(pK^- \pi^+)$ is useful for V_{ub} measurement via baryonic mode

First observation of Λ_c^+ decays involving the neutron in final states.

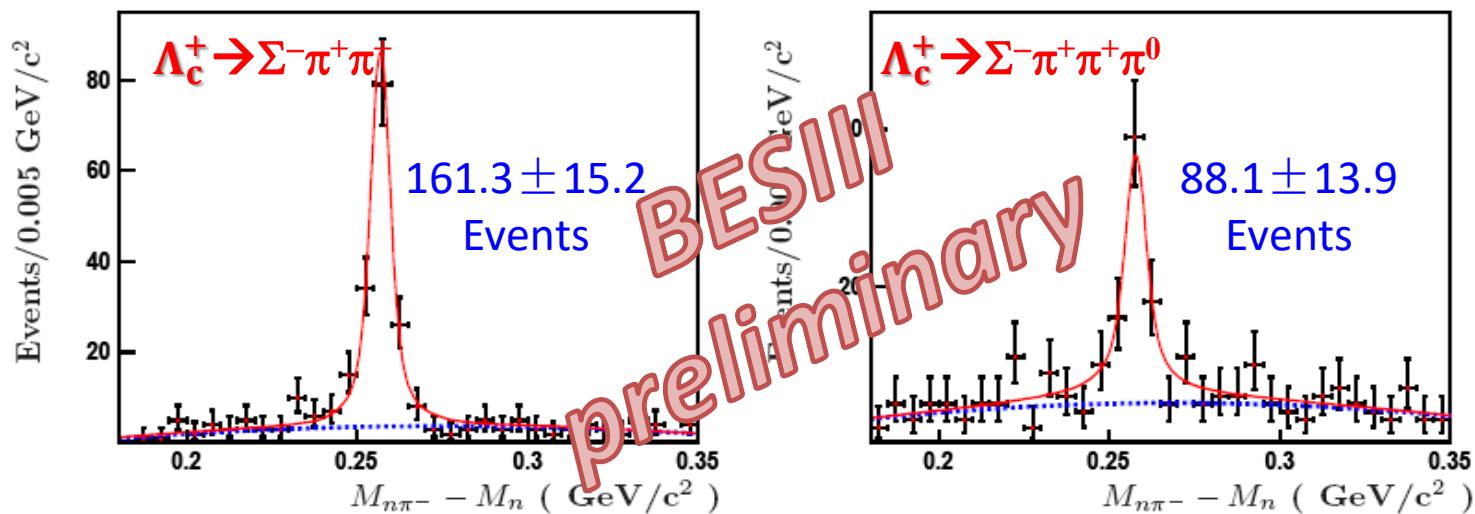


- The missing neutron is detected by:
$$M_{\text{miss}}^2 = (p_{\Lambda_c^+} - p_{K_S^0} - p_{\pi^+})^2 = E_{\text{miss}}^2 - c^2 |\vec{p}_{\text{miss}}|^2$$
- Simultaneous fit to M_{miss}^2 and $M_{\pi^+ \pi^-}$ spectra
- Preliminary results : $B[\Lambda_c^+ \rightarrow n K_S^0 \pi^+] = (1.82 \pm 0.23 \pm 0.11)\%$

The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry and extract the strong phases of different final states.

- The total measured Λ_c^+ decay BFs is $\sim 65\%$, searching for more decay modes are important
- Only one Λ_c^+ decay involved Σ^- is observed, $B(\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+) = (2.3 \pm 0.4)\%$, where Σ^- dominantly decay to $n\pi^-$

11 ST modes, 11415 ± 159 Λ_c^+ tagged candidates

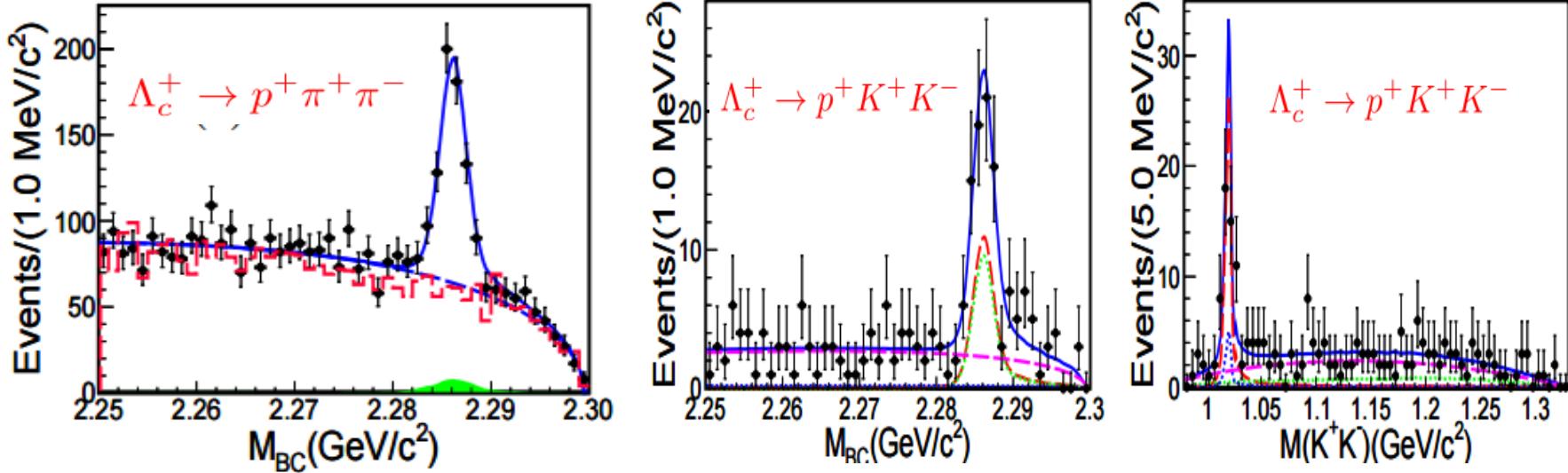


$$B[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+] = (1.81 \pm 0.17)\% \quad [\text{Improved precision}]$$

$$B[\Lambda_c^+ \rightarrow \Sigma^- \pi^+ \pi^+ \pi^0] = (2.11 \pm 0.33)\% \quad [\text{first observation}]$$

Statistical only,
 totally uncertainty <5%

Sensitive to non-factorizable contributions from W-exchanged process

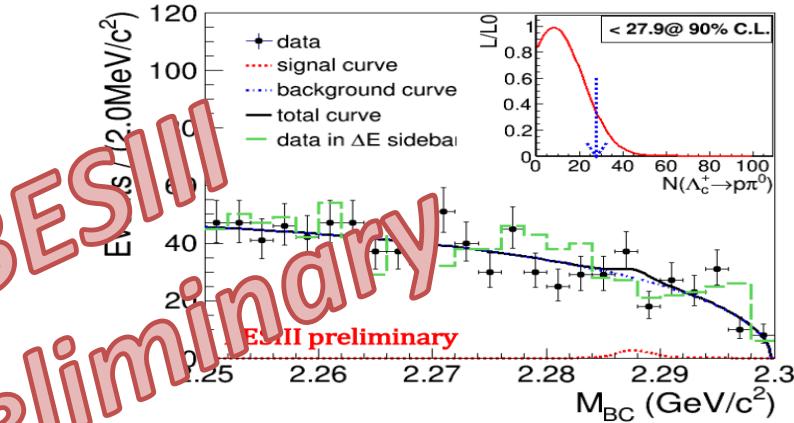
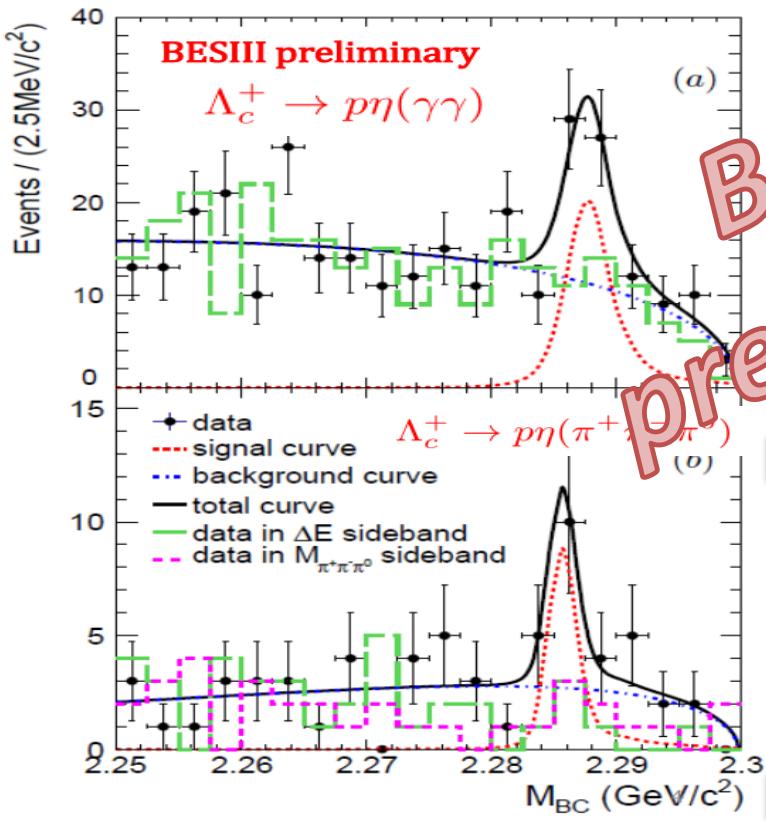


Decay modes	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref.}}$ (this work)	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref.}}$ ([28])
$\Lambda_c^+ \rightarrow p\pi^+\pi^-$	$(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$	—
$\Lambda_c^+ \rightarrow p\phi$	$(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$	$0.015 \pm 0.002 \pm 0.002$
$\Lambda_c^+ \rightarrow pK^+K^-$ (non- ϕ)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$0.007 \pm 0.002 \pm 0.002$
—	$\mathcal{B}_{\text{mode}}$	$\mathcal{B}(\text{PDG})$
$\Lambda_c^+ \rightarrow p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \rightarrow p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \rightarrow pK^+K^-$ (non- ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

Submitted to PRL
arXiv:1608.00407

→ **first observation**
 } **improved precision**

- $B(\Lambda_c^+ \rightarrow p\eta) >> B(\Lambda_c^+ \rightarrow p\pi^0)$ in the SU(3) flavor symmetry generated by u,d and s.
- Their relative size is essential to understand the interference of different non-factorizable diagrams



□ BESIII preliminary results:

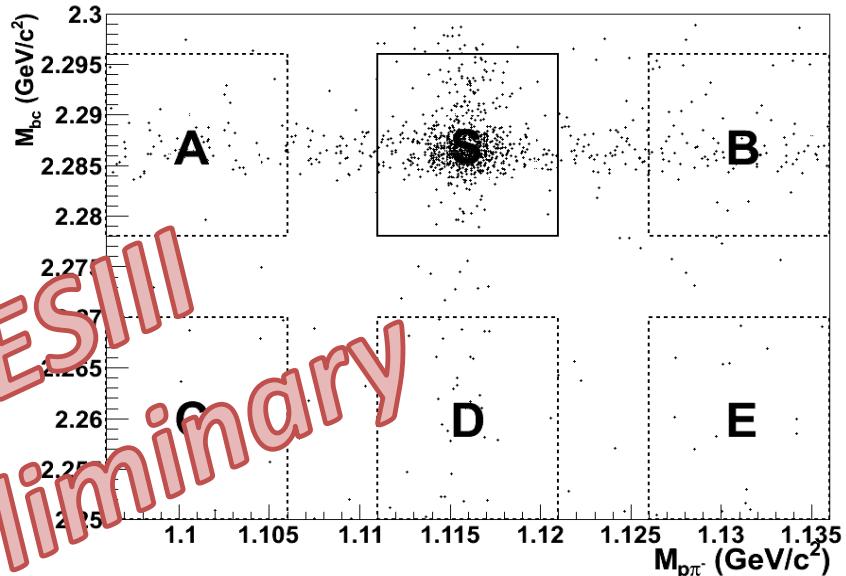
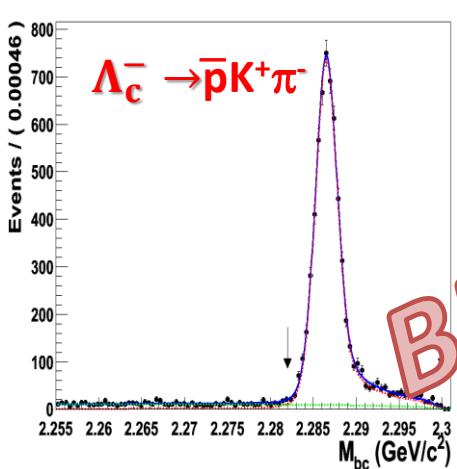
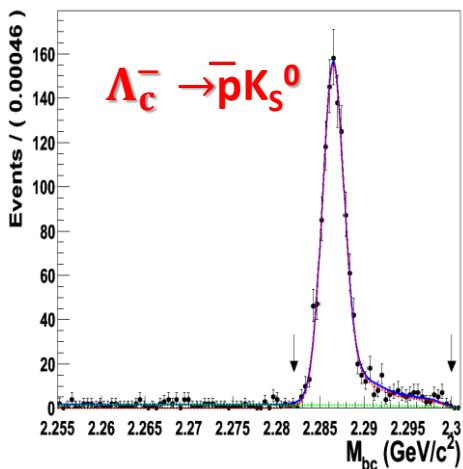
$$B(\Lambda_c^+ \rightarrow p\eta) = (1.24 \pm 0.28 \pm 0.10) \times 10^{-3};$$

$$B(\Lambda_c^+ \rightarrow p\pi^0) < 2.7 \times 10^{-4};$$

$$B(\Lambda_c^+ \rightarrow p\pi^0)/B(\Lambda_c^+ \rightarrow p\eta) < 0.24$$

□ First evidence for $\Lambda_c^+ \rightarrow p\eta$ with 4.2σ

- The measurement is useful to test of HQET
- PDG2016 $B(\Lambda_c^+ \rightarrow \Lambda + X) = 35 \pm 11\%$



BESIII
preliminary

Tag modes	$\Delta E(\text{GeV})$	Yields
$\bar{\Lambda}_c^- \rightarrow \bar{p} K_S^0$	[-0.021, 0.019]	1220 ± 37
$\bar{\Lambda}_c^- \rightarrow \bar{p} K^+ \pi^-$	[-0.020, 0.015]	6088 ± 85

$$\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) = (36.98 \pm 2.18)\%$$

$$\mathcal{A}_{\text{CP}} = \frac{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) - \mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X)}{\mathcal{B}(\Lambda_c^+ \rightarrow \Lambda + X) + \mathcal{B}(\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X)}.$$

Decay mode	Branching fraction(%)	\mathcal{A}_{CP}
$\Lambda_c^+ \rightarrow \Lambda + X$	$38.02 \pm 3.24 \pm 0.61$	$0.02 \pm 0.06 \pm 0.01$
$\bar{\Lambda}_c^- \rightarrow \bar{\Lambda} + X$	$36.70 \pm 3.04 \pm 0.59$	

Conclusion and Prospects

	Golden hadronic mode	$\Delta B/B$	Golden SL mode	$\Delta B/B$
D ⁰	$B(K\pi)=(3.88 \pm 0.05)\%$	1.3%	$B(K\bar{e}v)=(3.55 \pm 0.05)\%$	1.4%
D ⁺	$B(K\pi\pi)=(9.13 \pm 0.19)\%$	2.1%	$B(K^0\bar{e}v)=(8.83 \pm 0.22)\%$	2.5%
D _s	$B(KK\bar{p}i)=(5.39 \pm 0.21)\%$	3.9%	$B(\phi\bar{e}v)=(2.49 \pm 0.14)\%$	5.6%
Λ_c	$B(pK\pi)=(5.0 \pm 1.3)\% \text{ (PDG2014)}$ $= (6.8 \pm 0.36)\% \text{ (BELLE)}$ $= (5.84 \pm 0.35)\% \text{ (BESII)}$ $= (6.46 \pm 0.24)\% \text{ (HFAG)}$	26% 5.3% 6.0% 3.7%	$B(\Lambda\bar{e}v)=(2.1 \pm 0.6)\% \text{ (PDG2014)}$ $= (3.63 \pm 0.43)\% \text{ (BESIII)}$ $= (3.18 \pm 0.32)\% \text{ (HFAG)}$	29% 12% 10%

- The **precisions** of Λ_c^+ decay rates is **reaching** to the level of charmed mesons!
- LHCb data will further constrain the HFAG fit
- BESIII data is **unique**, especially for the decay with **neutral** objects involved.
 However, BESIII data sample is small, and beam energy is not large sufficiently

□ Replace one cavity in summer of 2017

(~3 months for the replacement, takes time for ramping up).

□ Mini-workshop with machine people for the possible upgrade

◆ Top up plan ?

◆ Increase the beam energy ?

- currently: 2.30 GeV
- Phase I: 2.35 GeV, to increase Λ_c^+ pair production x-sec
(hardware replacement,)
- Phase II: 2.35 GeV < E < 2.45 GeV, for others charmed baryons
bottleneck: ISPB, new magnet and power supply
- Phase III: > 2.45 GeV, for more charmed baryons
bottleneck: ISPB and SCQ

◆ Increase the luminosity?

Crab Waist technology, Dr. Anton Bogomygkov's talk at tau2016

<http://indico.ihep.ac.cn/event/5221/session/7/contribution/29/material/slides/0.pdf>

- MDC: Malter effect found in inner chamber in 2012,
add water vapor to the chamber to cure the aging
problem.
 - New inner chamber, built by IHEP, is ready now.
 - CGEM as the inner chamber ongoing : Italy group in
collaboration with other groups.
- New ETOF (built by USTC & IHEP) was installed last year
to improve the time resolution.
- Other possible upgrade plan is under discussion

- BEPCII/BESIII reach a **new territory** to study the charmed baryons
- BESIII is **unique** to study charmed baryons, and is **complementary** to others experiments
- A lots of Λ_c^+ **measurements** at BESIII are done or ongoing....
- Upgrades on machine and detector are on discussion

Thanks !

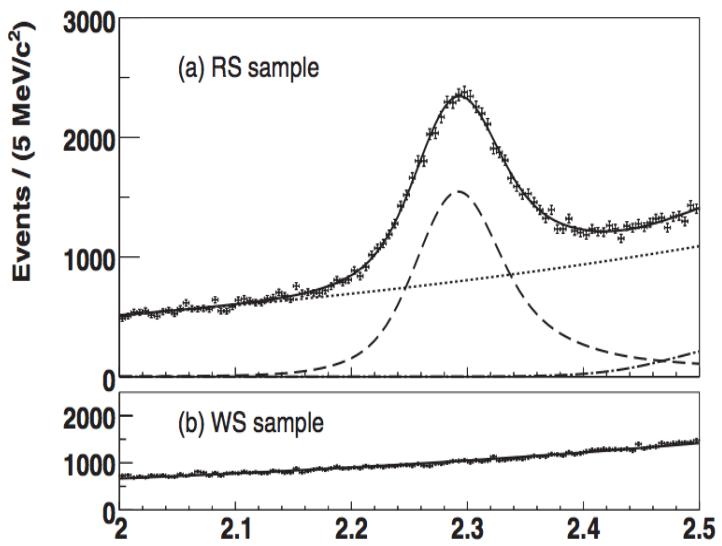
BACKUP

$$B(\Lambda_c^+ \rightarrow p K^- \pi^+)$$

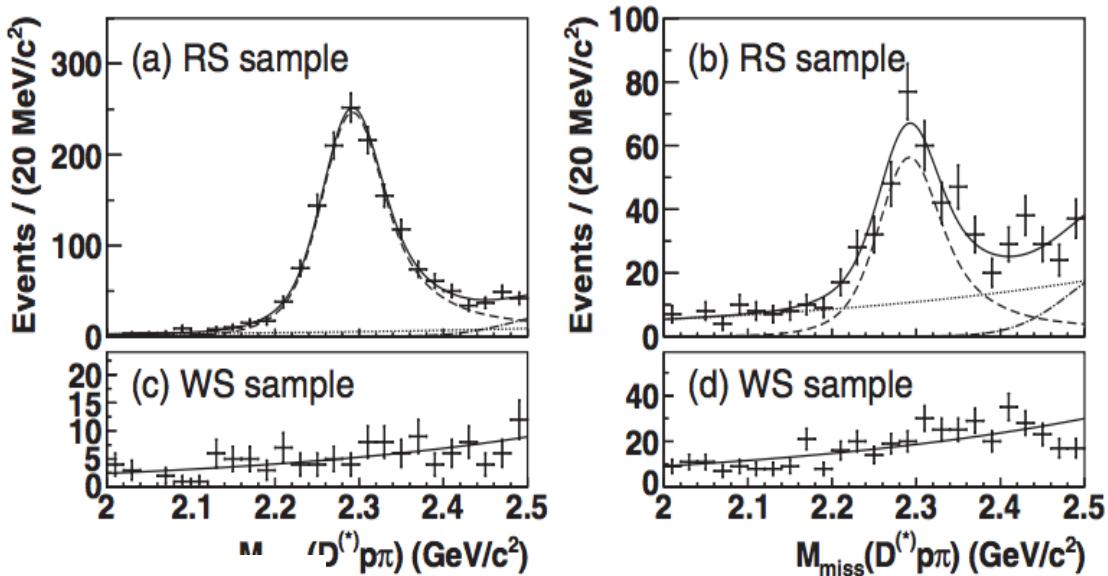
decay process: $e^+e^- \rightarrow D^{(*)-}\bar{p}\pi^+\Lambda_c^+$

PRL 113, 042002 (2014)

Missing Λ_c^+



Tagging $\Lambda_c^+ \rightarrow p K^- \pi^+$



$$\mathcal{B}(\Lambda_c^+ \rightarrow p K^- \pi^+) = \frac{N(\Lambda_c^+ \rightarrow p K^- \pi^+)}{N_{\text{inc}}^{\Lambda_c} f_{\text{bias}} \epsilon(\Lambda_c^+ \rightarrow p K^- \pi^+)} = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$$

precision ~4.7%: significant improvement from world average (~25%)

Model &Experiment	$Br^{\text{exp}} [\%]$	References
SU(4) symmetry limit	9.2	M. Avila-Aoki et al [PRD40, 2944 (1989)]
Non-relativistic quark model	2.6	Perez-Marcial et al [PRD40, 2955 (1989)]
MIT bag model [MBM]	1.9	Perez-Marcial et al [PRD40, 2955 (1989)]
Relativistic spectator Model	4.4	F. Hussain et al [ZPC51, 607 (1991)]
Spectator quark model	1.96	Robert Singleton, Jr. [PRD43, 2939(1991)]
Quark confinement Model	5.62	G. V. Efimov et al [ZPC52, 149 (1991)]
Non-relativistic quark model	2.15	A. Garcia et al [PRD45, 3266 (1992)]
Non-relativistic quark model	1.42	H. Y. Cheng et al [PRD53, 1457 (1995)]
QCD Sum Rule	3.0 ± 0.9	H. G. Dosch et al [PLB431, 173 (1998)]
QCD Sum Rule	2.6 ± 0.4	R. S. Marques de Carvalho et al [PRD60, 034009 (1999)]
QCD Sum Rule	5.8 ± 1.5	
HOSR	4.72	M. Pervin et al [PRC72, 035201 (2005)]
HONR	4.2	
STSR	2.22	
STNR	1.58	
LCSR	3.0 ± 0.3 (CZ-type) 2.0 ± 0.3 (Ioffe-type)	Y. L. Liu, M.Q. Huang and D. W. Wang [PRD80, 074011 (2009)]
Convariant confined quark model	2.78	Thomas Gutsche et al [PRD93, 034008(2016)]
24-26/10/2016 H.P. Peng	Inha University (Republic Korea)	
RESULE	2.62 ± 0.42	PRD 115, 031905 (2015)



$$I(J^P) = 0(\frac{1}{2}^+)$$

J is not well measured; $\frac{1}{2}$ is the quark-model prediction.

Mass $m = 2286.46 \pm 0.14$ MeV

Mean life $\tau = (200 \pm 6) \times 10^{-15}$ s ($S = 1.6$)

$$c\tau = 59.9 \mu\text{m}$$

□ If Λ_c^+ is J=1/2, it favors the decay $\Lambda_c^+ \rightarrow \Lambda^* l^+ \nu_l$ is favors, $B[\Lambda_c^+ \rightarrow \Lambda^* l^+ \nu_l] \ll B[\Lambda_c^+ \rightarrow \Lambda l^+ \nu_l]$?

□ Searching for $\Lambda_c^+ \rightarrow \Lambda^* l^+ \nu_l$ is quite important. ($\Lambda^* \rightarrow pK^-/\Sigma\pi$)

$\Lambda(1405) 1/2^-$

$$I(J^P) = 0(\frac{1}{2}^-)$$

Mass $m = 1405.1 \pm 1.3$ MeV
Full width $\Gamma = 50.5 \pm 2.0$ MeV
Below $\bar{K}N$ threshold

$\Lambda(1405)$ DECAY MODES

$$\text{Fraction } (\Gamma_j/\Gamma)$$

$$\frac{\Lambda^* \pi}{\Sigma \pi} = 100\%$$

$\Lambda(1600) 1/2^+$

$$I(J^P) = 0(\frac{1}{2}^+)$$

Mass $m = 1560$ to 1700 (≈ 1600) MeV
Full width $\Gamma = 50$ to 250 (≈ 150) MeV
 $p_{beam} = 0.58 \text{ GeV}/c$ $4\pi\chi^2 = 41.6 \text{ mb}$

$\Lambda(1600)$ DECAY MODES

$$\text{Fraction } (\Gamma_j/\Gamma)$$

$$\frac{N\bar{K}}{\Sigma\pi} = 15\text{--}30\%$$

$$\frac{\Lambda^*\pi}{\Sigma\pi} = 10\text{--}60\%$$

$$\rho \text{ (MeV}/c)$$

$$343$$

$$339$$

$\Lambda(1520) 3/2^-$

$$I(J^P) = 0(\frac{3}{2}^-)$$

Mass $m = 1519.5 \pm 1.0$ MeV [a]
Full width $\Gamma = 15.6 \pm 1.0$ MeV [a]

$\Lambda(1520)$ DECAY MODES

$$\text{Fraction } (\Gamma_j/\Gamma)$$

$$\frac{N\bar{K}}{\Sigma\pi} = (45 \pm 1) \text{ \%}$$

$$\frac{\Lambda\pi\pi}{\Sigma\pi\pi} = (42 \pm 1) \text{ \%}$$

$$\frac{\Lambda\gamma}{\Sigma\gamma} = (10 \pm 1) \text{ \%}$$

$$\frac{\Lambda\pi\pi}{\Sigma\pi\pi} = (0.9 \pm 0.1) \text{ \%}$$

$$\frac{\Lambda\gamma}{\Sigma\gamma} = (0.85 \pm 0.15) \text{ \%}$$

$\Lambda(1670) 1/2^-$

$$I(J^P) = 0(\frac{1}{2}^-)$$

Mass $m = 1660$ to 1680 (≈ 1670) MeV
Full width $\Gamma = 25$ to 50 (≈ 35) MeV
 $p_{beam} = 0.74 \text{ GeV}/c$ $4\pi\chi^2 = 28.5 \text{ mb}$

$\Lambda(1670)$ DECAY MODES

$$\text{Fraction } (\Gamma_j/\Gamma)$$

$$\frac{N\bar{K}}{\Sigma\pi} = 20\text{--}30\%$$

$$\frac{\Lambda\eta\eta}{\Sigma\eta\eta} = 25\text{--}55\%$$

$$\frac{\Lambda\eta\eta}{\Sigma\eta\eta} = 10\text{--}25\%$$

$$\frac{1\pi N\bar{K}^*(892), S=3/2, D\text{-wave}}{3\pi} = (5 \pm 4)\%$$

$$\rho \text{ (MeV}/c)$$

$$414$$

$$394$$

$$59$$

$$†$$

channel

N. Ikeno et al.
[PRD93, 14021]

M. Pervin et al.
[PRC72, 035201]

$\Lambda_c^+ \rightarrow \Lambda(1405) e^+ \nu_e$

$$2 \times 10^{-5}$$

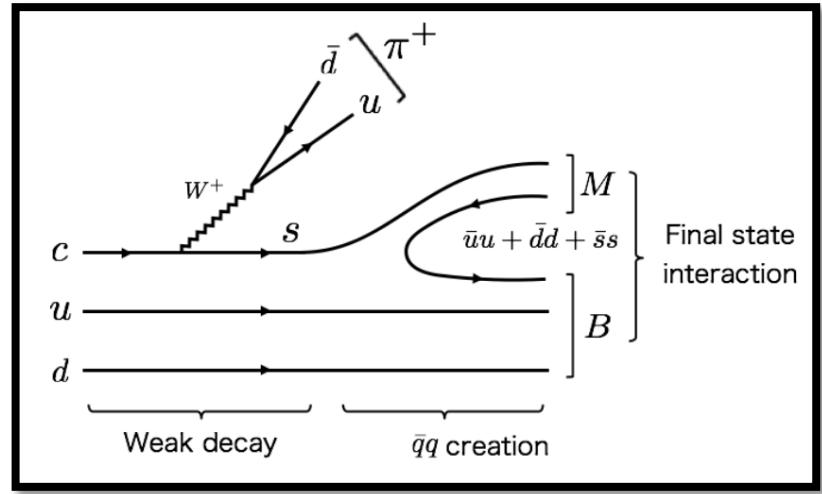
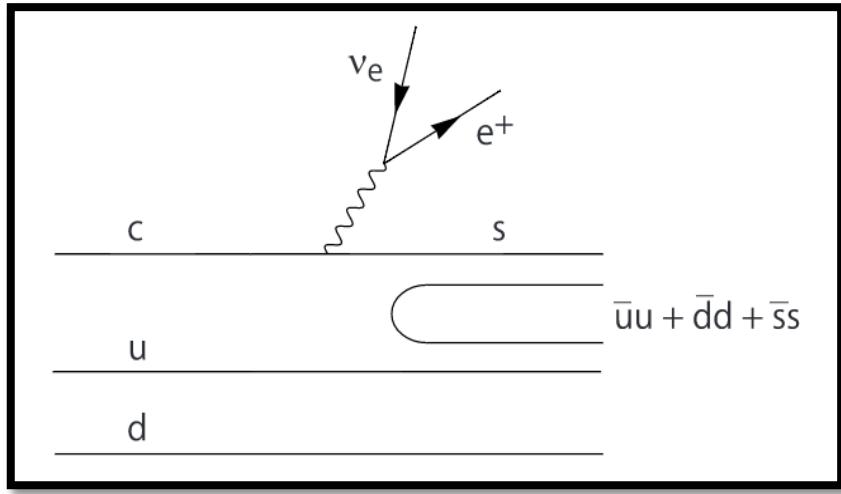
$$0.6\%$$

$\Lambda_c^+ \rightarrow \Lambda(1520) e^+ \nu_e$

--

$$0.1\%$$

Some theories suggested that the weak decay processes are important to clarify the existence and the nature of $\Lambda(1405)$.



- **acts as isospin filter:** suggests to study the $\Lambda(1405)$ through $\Lambda_c \rightarrow \pi \Lambda(1405)$ and $\Lambda(1405) e \nu$, which filters isospin $I=0$ from contamination of the $I=1$

Phys. Rev. C 92, 055204 (2015),
Phys. Rev. D 93, 014021 (2016)