Λ_c decays at BESIII

Xiaozhong Huang
(on behalf of the BESIII collaboration)
Nanjing University

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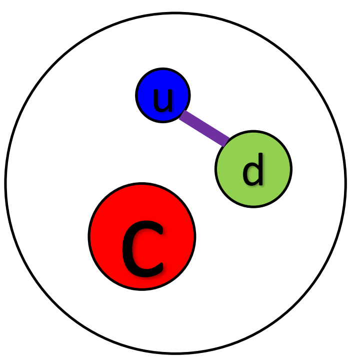
quark - lepton
Quy Nhon, Vietnam, September 13 - 17, 2016

Outline

- Introduction
- Λ_c decays
  - Semi-leptonic decays
    - $\Lambda_c^+ \to \Lambda e^+ \nu_e$
    - $\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu$
  - Hadronic decays
    - Absolute BFs of Λ_c hadronic decays
    - $\Lambda_c^+ \to n K_s^0 \pi^+$
    - ……
- Summary

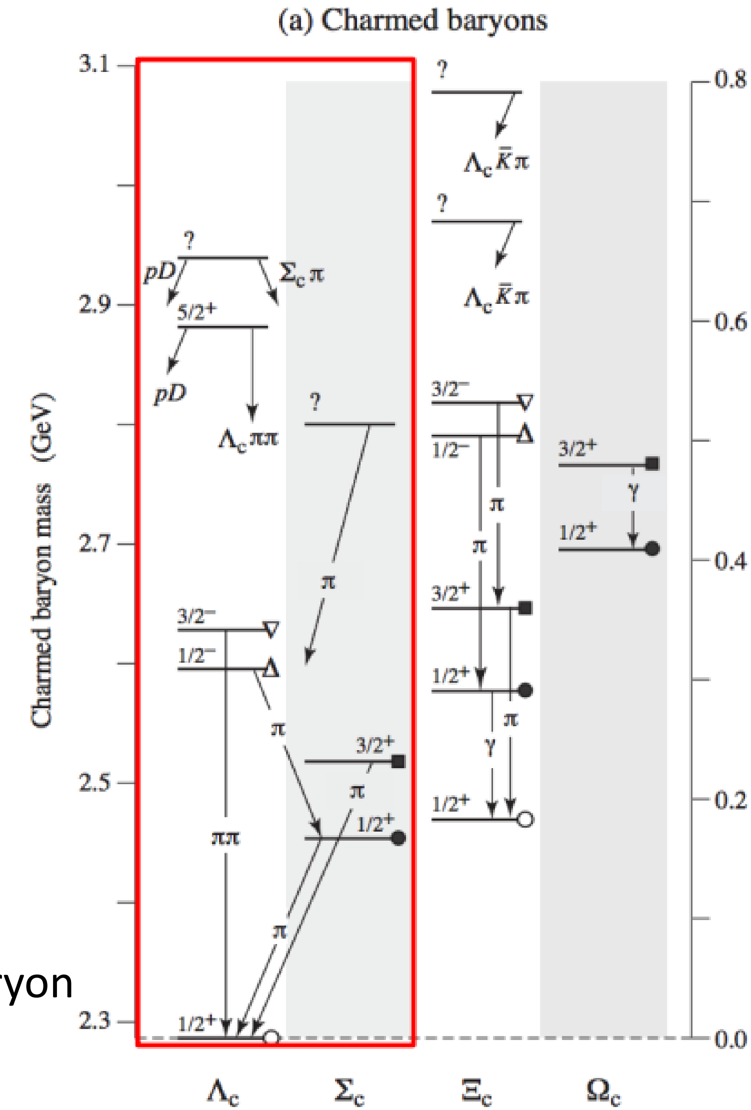
Introduction

- Most of the charmed baryons will eventually decay to Λ_c^+ baryon
- Cornerstone of charmed baryon spectroscopy
- Provide essential input for studying b-flavored baryon decays involving a Λ_c^+ baryon in the final state
- Help understand the weak interaction inside a baryon



Λ_c^+

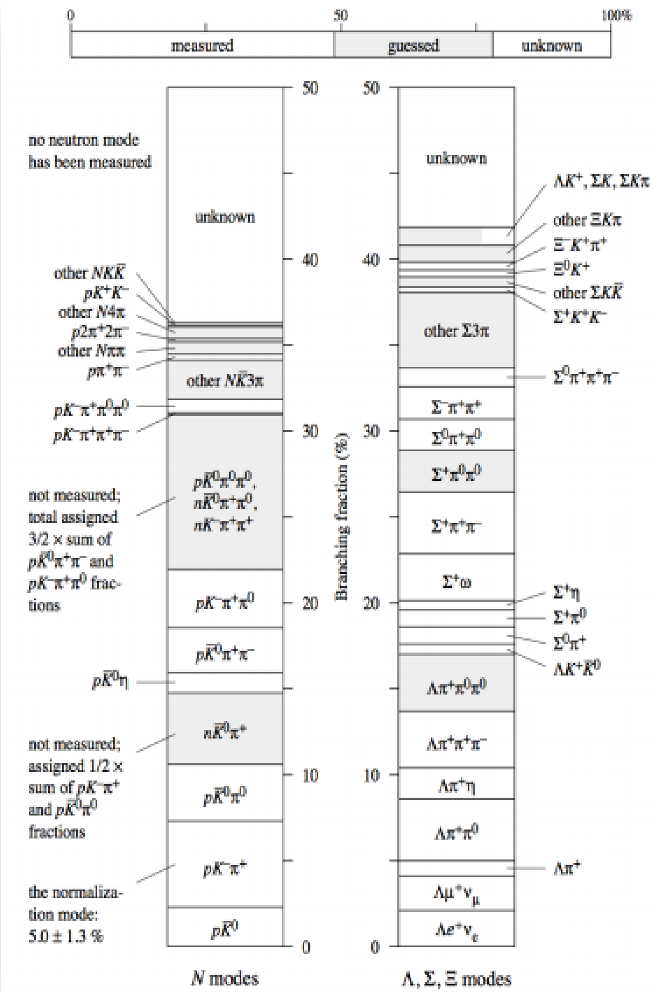
the lightest charmed baryon



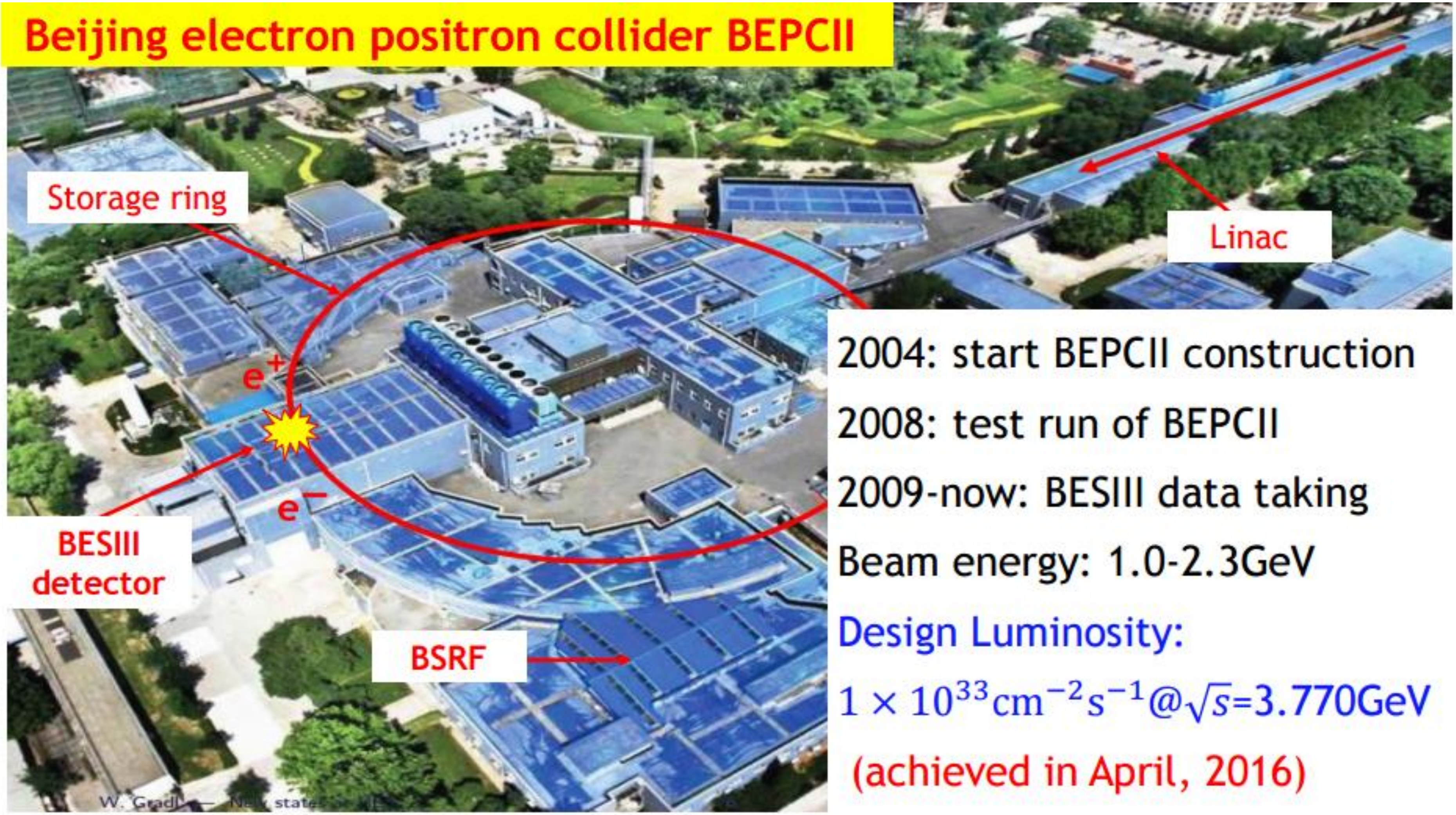
Status of Λ_c decays

Since the discovery of Λ_c^+ baryon in 1973, the progress of Λ_c decays is relatively slow compared to charmed meson.

- Total branching fraction: smaller than 65% (PDG2015)
- Many unobserved decay channels
- Large uncertainties (most larger than 20%)
- Most measurements of Λ_c decays are relative to the BF of $\Lambda_c^+ \to pK^-\pi^+$ channel, the absolute BFs are not well determined.



Beijing electron positron collider(BEPC)



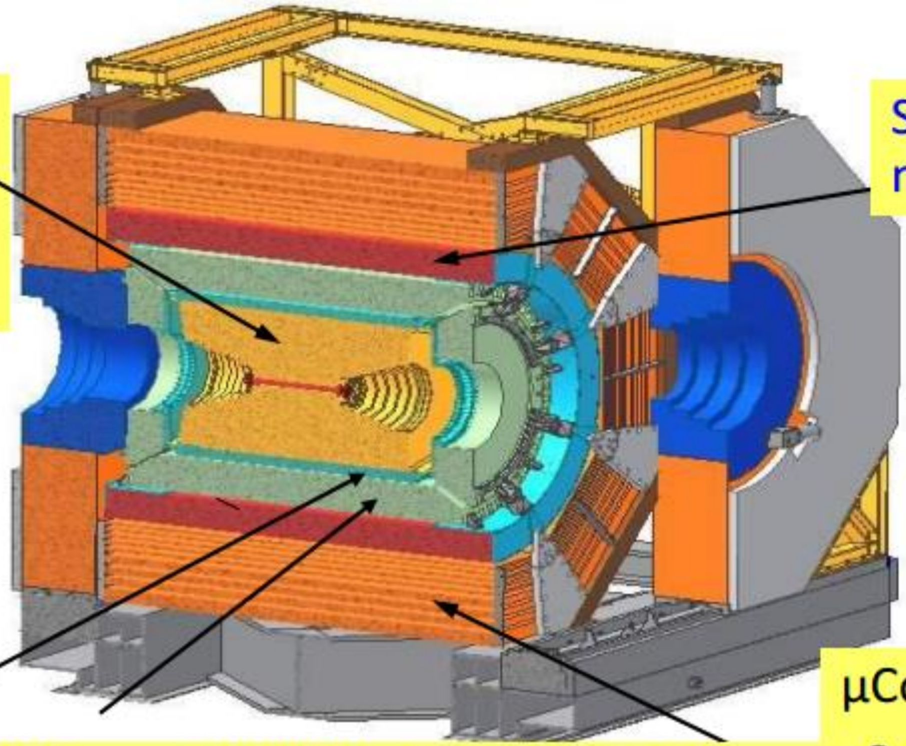
BESIII detector

NIM A614, 345 (2010)

The BESIII Detector

Drift Chamber (MDC)
$\sigma P/P\ (^0/_0) = 0.5\%(1\text{GeV})$
$\sigma_{dE/dx}\ (^0/_0) = 6\%$

Super-conducting magnet (1.0 tesla)



Time Of Flight (TOF)
σ_T: 90 ps Barrel
110 ps endcap

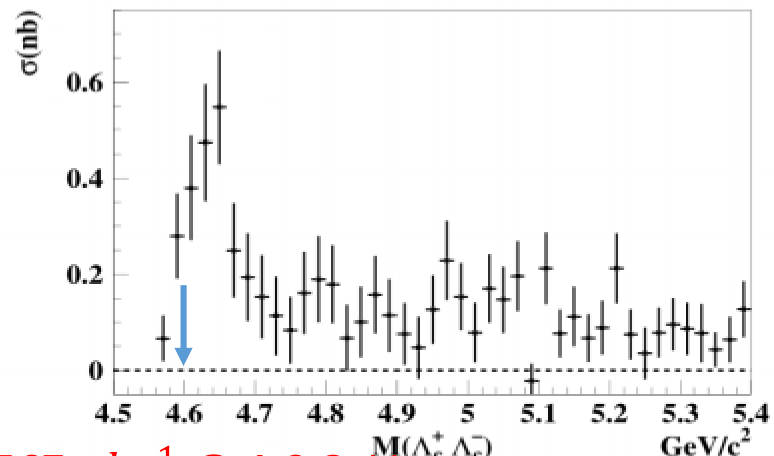
EMC: $\sigma E/\sqrt{E}(^0/_0) = 2.5\ \%\ (1\ \text{GeV})$
(CsI) $\sigma_{z,\phi}(\text{cm}) = 0.5 - 0.7\ \text{cm}/\sqrt{E}$

μCounter
8- 9 layers RPC
$\delta R\Phi = 1.4\ \text{cm} \sim 1.7\ \text{cm}$

Data Samples

In 2014, BESIII collected 567 pb^{-1} data just above the threshold of $\Lambda_c^+\overline{\Lambda}_c^-$ pairs ($\mathrm{E_{cms}} = 4.600$ GeV)

Energy (GeV)	Luminosity (pb^{-1})
4.575	47.67
4.580	8.545
4.590	8.162
4.600	566.93



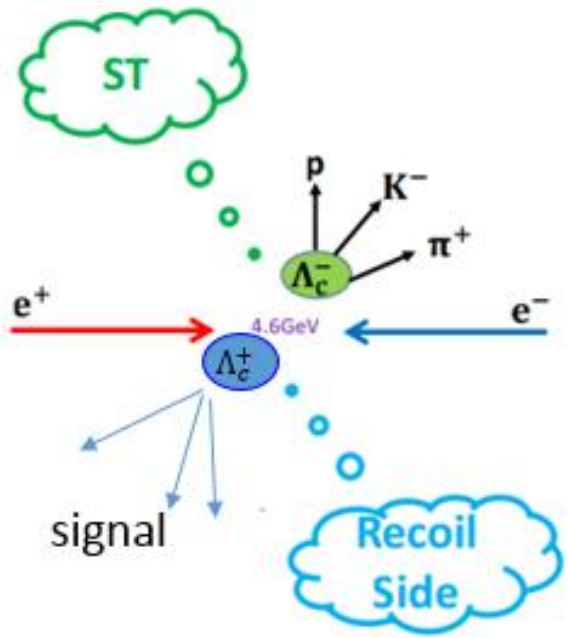
567 pb^{-1} @ 4.6 GeV

FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.

This dataset is unique in the world

- Expected to perform precise measurement and search for new decay modes
- absolute BF measurement(just above threshold, Double tag)

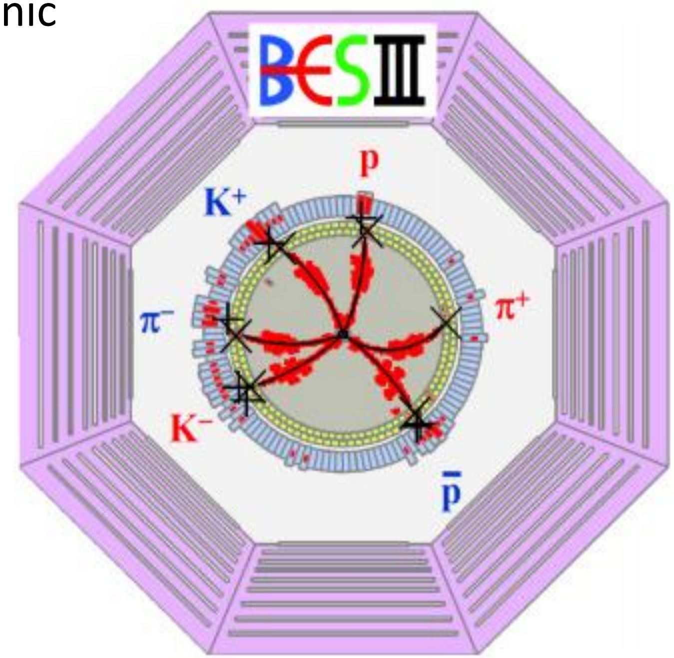
Double tag technique



① Single tag (ST)side :
reconstruct one $\overline{\Lambda}_c^-$ anti-baryon via hadronic decays (large branching fractions and low background)

- Beam-constraint mass: $M_{BC} \equiv \sqrt{E_{beam}^2 - |\vec{p}_{\Lambda_c^+}|}$
- Energy difference: $\Delta E = E_{\Lambda_c^+} - E_{beam}$
- Charge conjugation is always implied in the work

② Recoil side(DT):
semi-leptonic
hadronic



Advantages:

- ☐ Obtain the absolute branching fractions with lower background
- ☐ Most systematic uncertainty in the ST side are cancelled out

Absolute branching fraction of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

PRL. 115, 221805

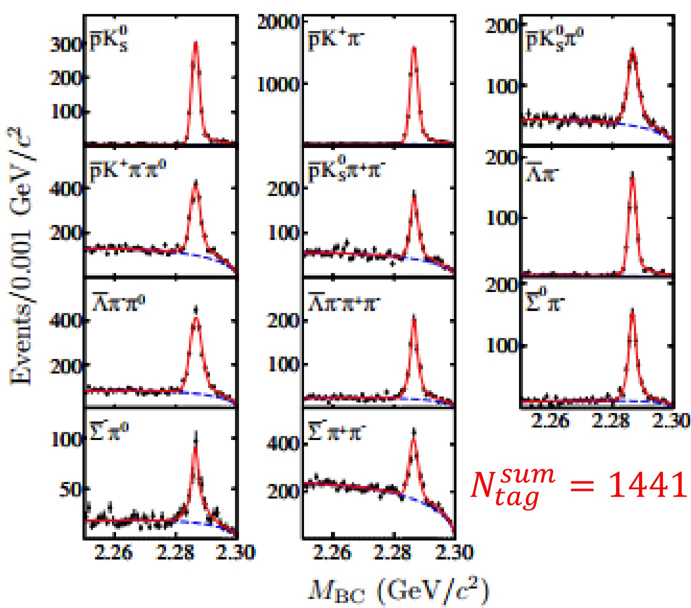
Motivation:

- Theoretical predictions: 1.4% - 9.2%
- PDG2015: $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (2.9 \pm 0.5)\%$
- Not direct measurement

$$U_{\rm miss} = E_{\rm miss} - c|\vec{p}_{\rm miss}|$$
$$E_{\rm miss} = E_{\rm beam} - E_{\Lambda} - E_{e^+}$$
$$\vec{p}_{\rm miss} = \vec{p}_{\Lambda_c^+} - \vec{p}_{\Lambda} - \vec{p}_{e^+}$$
$$\vec{p}_{\Lambda_c^+} = -\hat{p}_{\rm tag}\sqrt{E_{\rm beam}^2 - m_{\Lambda_c^-}^2}$$

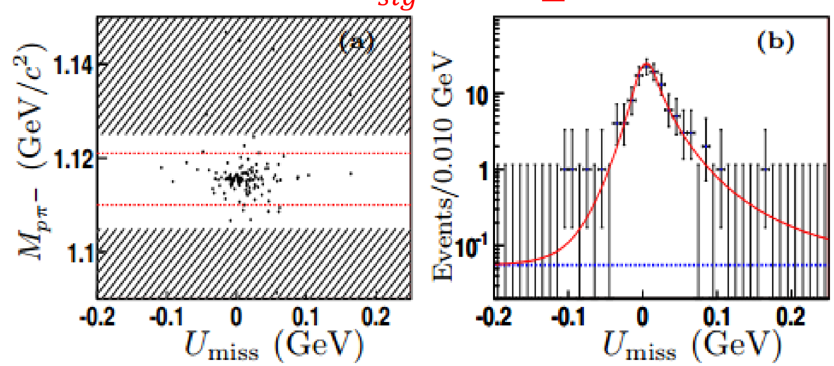
Technique:

- Double tag technique (11 tag modes)



$N_{tag}^{sum} = 14415 \pm 159$

$N_{sig} = 104 \pm 11$



Result:

$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.20)\%$

- ✓ The first absolute measurement
- ✓ The precision is improved significantly

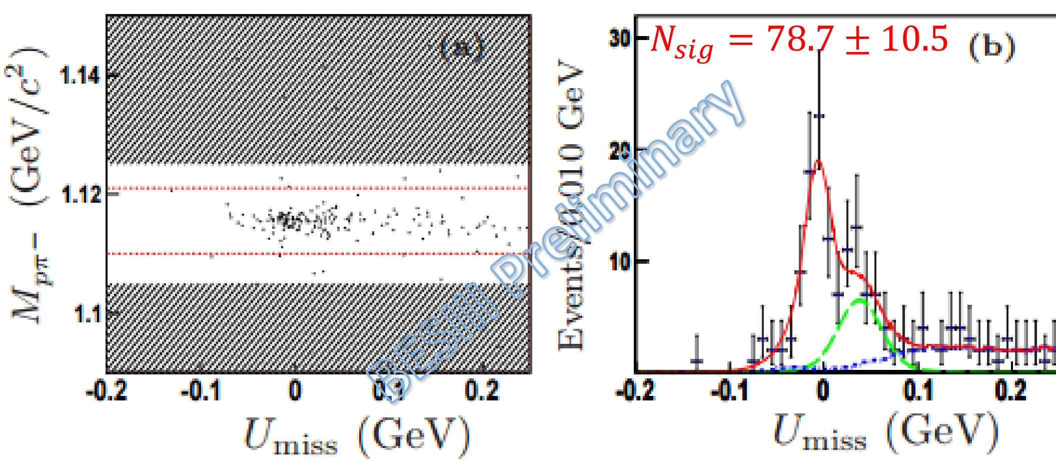
Absolute branching fraction of $\Lambda_c^+ \to \Lambda\mu^+\nu_\mu$

Motivation:

- Theoretical predictions: 1.4% - 9.2%
- PDG2015: $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e) = (2.7 \pm 0.6)\%$
- not direct measurement

Technique:

- Double tag technique (11 tag modes)



Preliminary Result:

$$\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu) = (3.49 \pm 0.46 \pm 0.27)\%$$

$$\frac{\mathcal{B}(\Lambda_c^+ \to \Lambda\mu^+\nu_\mu)}{\mathcal{B}(\Lambda_c^+ \to \Lambda e^+\nu_e)} = 0.96 \pm 0.16 \pm 0.04$$

- ✓ The first absolute measurement
- ✓ The precision is improved a lot

Absolute BFs of Λ_c hadronic decays (CF)

PRL. 116, 052001

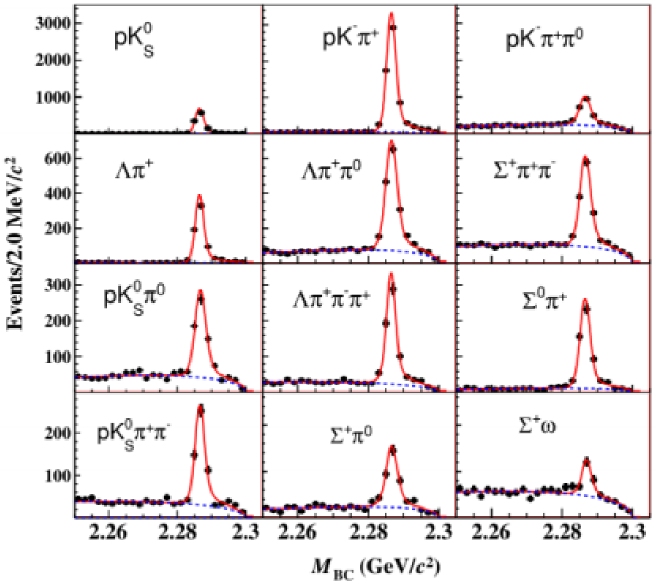
Motivation:

- Most relative to the $pK^-\pi^+$ channel
- No direct measurement on the BF of $pK^-\pi^+$ channel

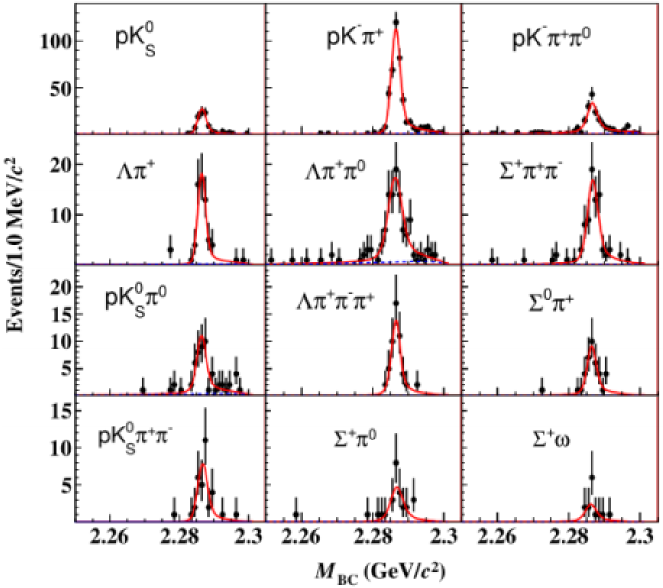
Technique:

- Double tag method: straight and simple

Single tag(ST): ~15000



Double tag(DT): ~1000



Absolute BFs of Λ_c hadronic decays (CF)

PRL. 116, 052001

A global least-square fitter is utilized to improve the measured precision for 12 Λ_c hadronic decay channels

$$N_{i+}^{ST} = N_{\Lambda_c^+\bar{\Lambda}_c^-} B_i \varepsilon_{i+}^{ST}$$

$$N_{i+}^{DT} = N_{\Lambda_c^+\bar{\Lambda}_c^-} B_i B_j \varepsilon_{i+j-}^{DT}$$

$$B = \frac{N_{sig}}{N_{tag} \times \varepsilon_{sig}/\varepsilon_{tag,sig}}$$

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	

$$N_{\Lambda_c^+\bar{\Lambda}_c^-} = (105.9 \pm 4.8 \pm 0.5) \times 10^3$$

Result:

- The precision of the absolute BFs are improved significantly
- BF for $pK^-\pi^+$ is consistent with PDG value, but lower than Belle's value with a significance of 2σ.
- Improved absolute BF of $pK^-\pi^+$ are key to calibrate other decays

Observation of $\Lambda_c^+ \to nK_s^0\pi^+$

Motivation:

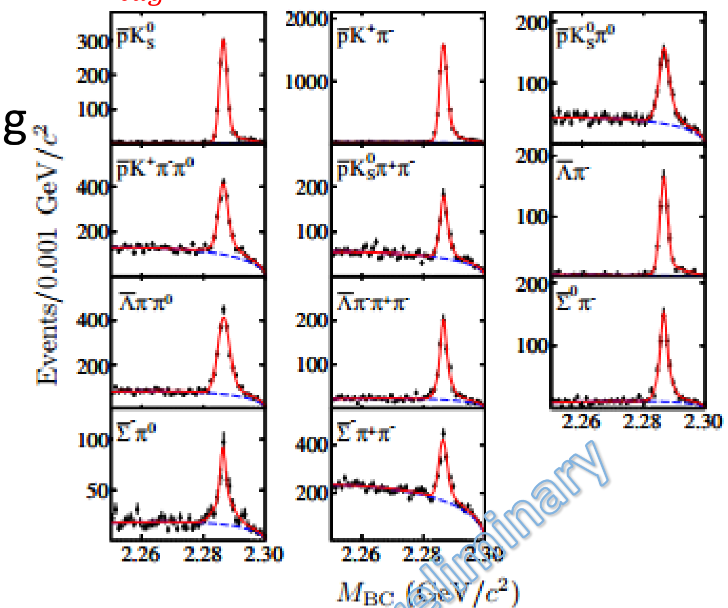
- No decay channels with final states containing neutron
- The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry for Λ_c^+ decays.

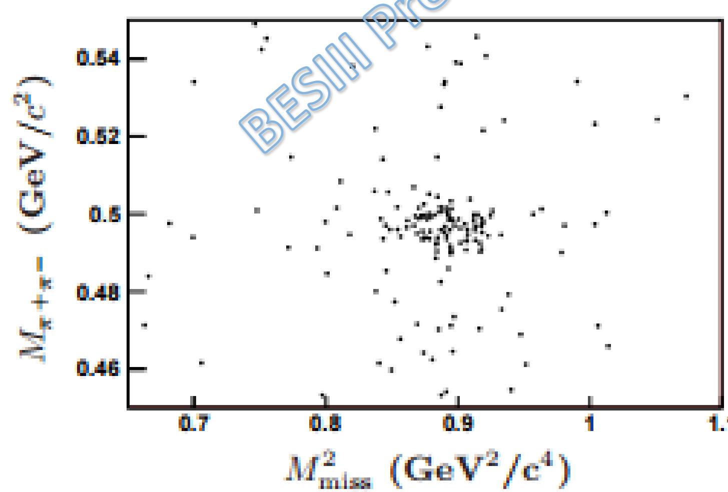
Technique:

- Double tag technique (11 tag modes)
- The missing neutron is detected by:

$$M_{miss}^2 = \left(p_{\Lambda_c^+} - p_{K_S^0} - p_{\pi^+}\right)^2$$
$$= E_{miss}^2 - c^2|\vec{p}_{miss}|^2$$

$N_{tag}^{sum} = 14415 \pm 159$





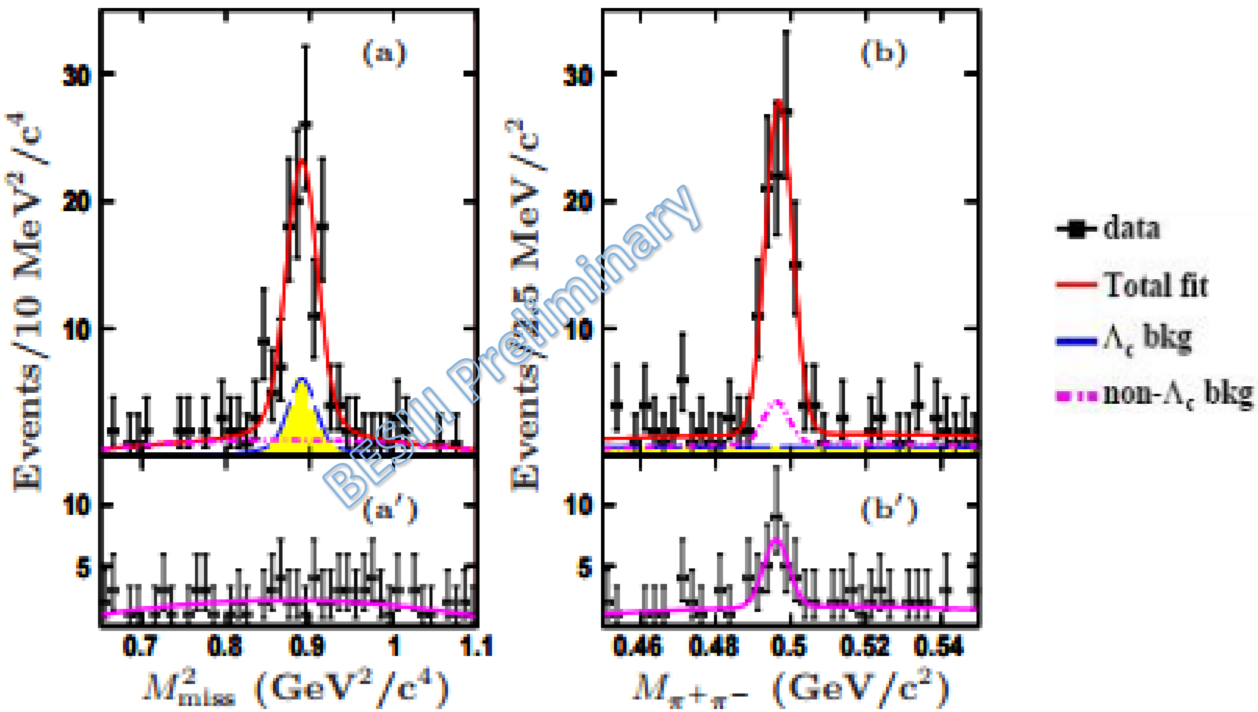
Observation of $\Lambda_c^+ \to n K_s^0 \pi^+$

Fit to M^2_{miss} and $M_{\pi^+\pi^-}$ spectra in (a,b) Λ_c^+ signal region and (a',b') Λ_c^+ sideband region simultaneously.

81 ± 11

Signal region:

Sideband region:



Preliminary result (Absolute branching fraction):

$\mathcal{B}(\Lambda_c^+ \to n K_s^0 \pi^+) = (1.82 \pm 0.23 \pm 0.11)\%$

First observation of Λ_c^+ decays involving neutron.

$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ and $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$

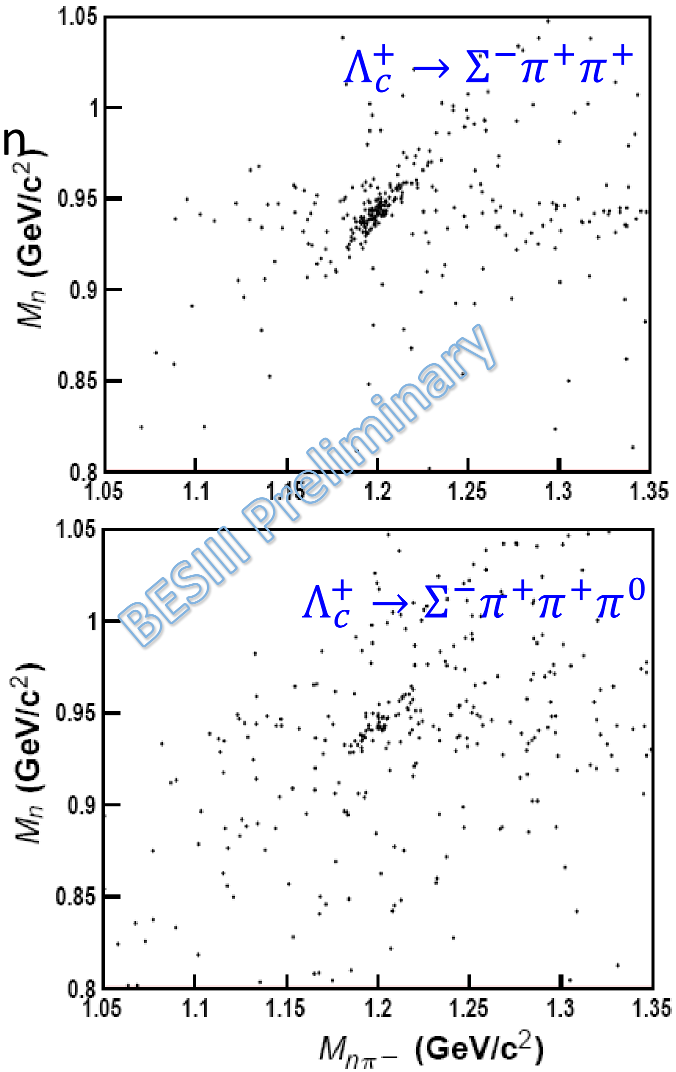
Motivation:

- Only one Λ_c^+ decay channel with Σ^- hyperon is measured.
  PDG2015
  $\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) = (2.3 \pm 0.4)\%$
- Search for new decay modes

Technique:

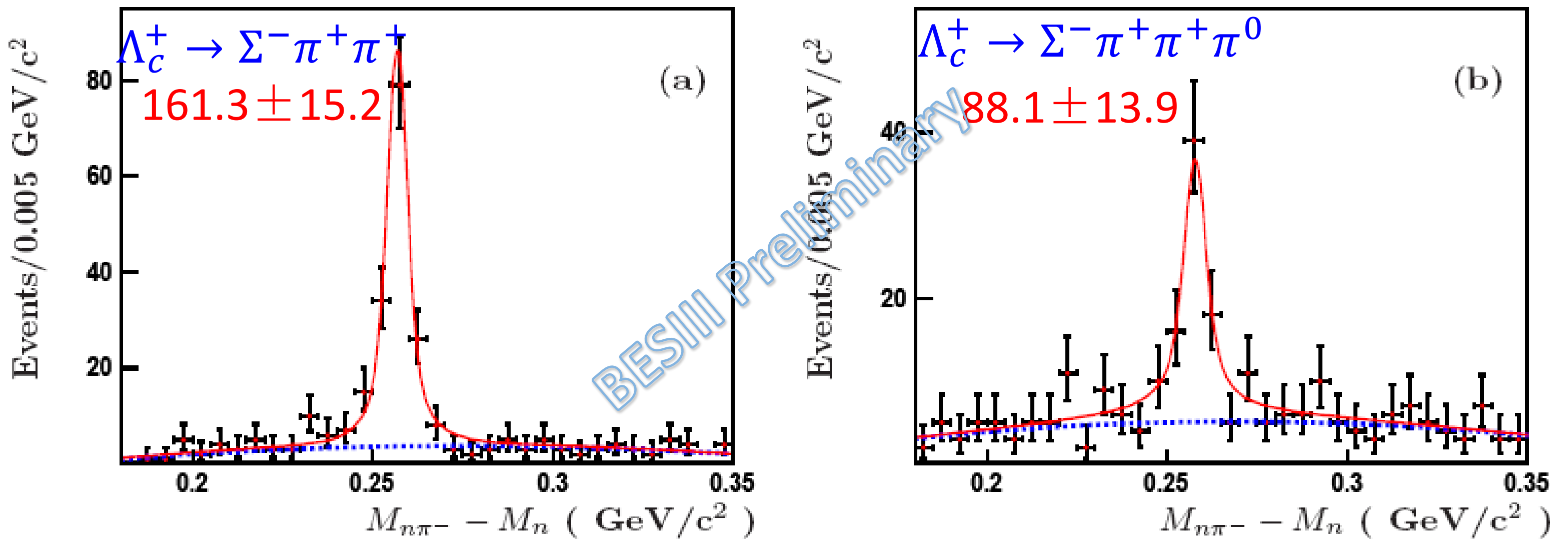
- Double tag technique (11 tag modes)
- Σ^- is reconstructed by: $\Sigma^- \to n\pi^-$
  The missing neutron is detected by:

$$M_n^2 = M_{miss}^2 = \left(p_{\Lambda_c^+} - p_{K_S^0} - p_{\pi^+}\right)^2$$
$$= E_{miss}^2 - c^2|\vec{p}_{miss}|^2$$



$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ and $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$

Fit to the mass difference of $M_{n\pi^-}$ and M_n



Preliminary results (Absolute Branching fraction):

$\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) = (1.81 \pm 0.17)\%$ (PDG2015: $(2.3 \pm 0.4)\%$)

$\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0) = (2.11 \pm 0.33)\%$ (First observation)

Statistical only

Systematic: ~5%

SCS decays: $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$

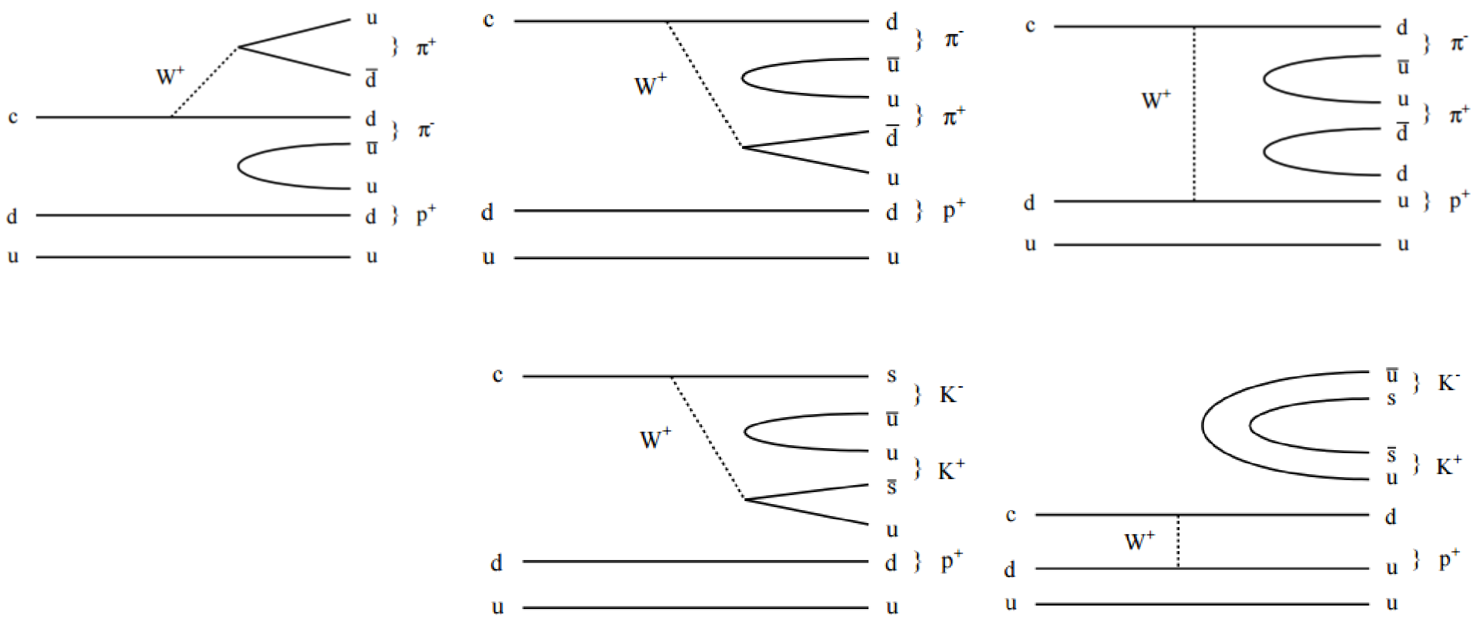
Submitted to PRL arXiv:1608.00407

Motivation:

- Shed light on dynamics of Λ_c^+ decays
- $\Lambda_c^+ \to p\phi$ is of particular interest since it proceeds internal W-emission only.

$p\pi^+\pi^-$

pK^+K^-

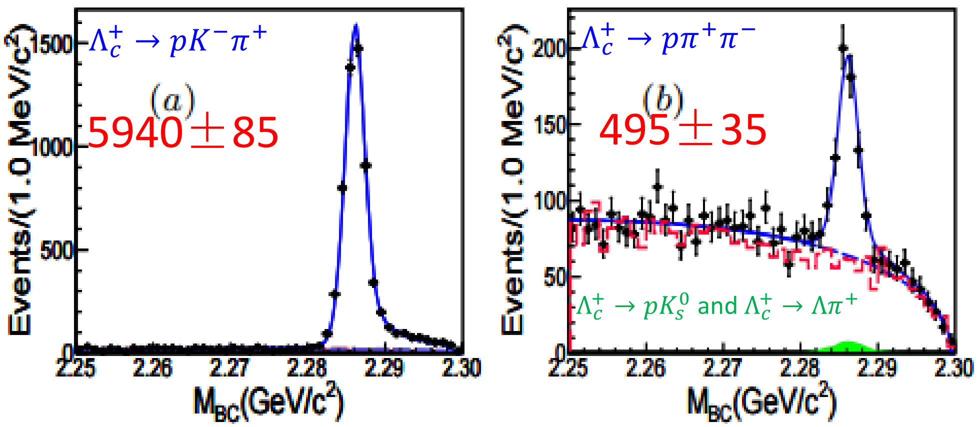


external W-emission   internal W-emission   W-exchange

SCS decays: $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$

Submitted to PRL arXiv:1608.00407

Fit to the M_{BC} distribution

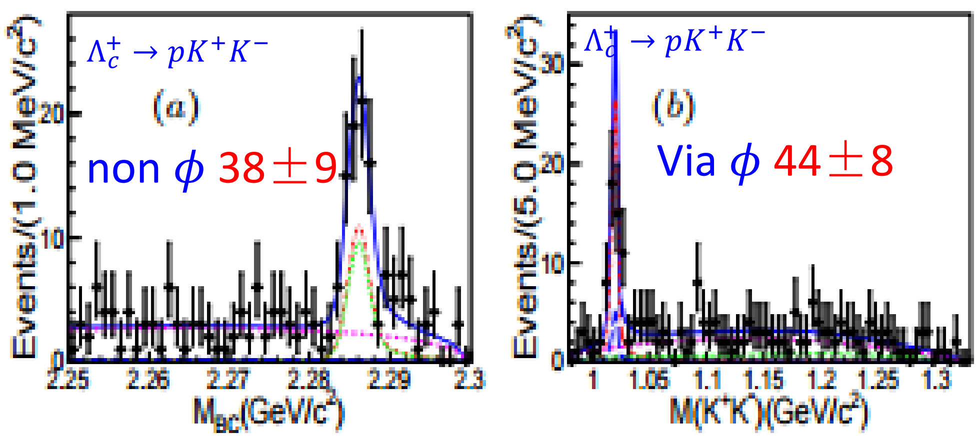


Technique:

- Relative to $pK^-\pi^+$
- Input BESIII measurement:

$\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (5.84 \pm 0.27 \pm 0.23)\%$

two-dimensional unbinned maximum likelihood fit



Result:

Decay modes	$\mathcal{B}_{mode}/\mathcal{B}_{ref.}$ (This work)	$\mathcal{B}_{mode}/\mathcal{B}_{ref.}$ (PDG average)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(6.70 \pm 0.48 \pm 0.25) \times 10^{-2}$	0.069 ± 0.036
$\Lambda_c^+ \to p\phi$	$(1.81 \pm 0.33 \pm 0.13) \times 10^{-2}$	0.0164 ± 0.0032
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$0.007 \pm 0.002 \pm 0.002$
-	$\mathcal{B}_{mode}$ (This work)	$\mathcal{B}_{mode}$ (PDG average)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

Uncertainty in the second column: statistical + systematic + reference mode

SCS decays: $\Lambda_c^+ \to p\eta$ and $\Lambda_c^+ \to p\pi^0$

Motivation:

- Not measured yet
- In the SU(3) flavor symmetry
  $\mathcal{B}(\Lambda_c^+ \to p\eta) >> \mathcal{B}(\Lambda_c^+ \to p\pi^0)$

Simultaneous fit to the M_{BC} distribution

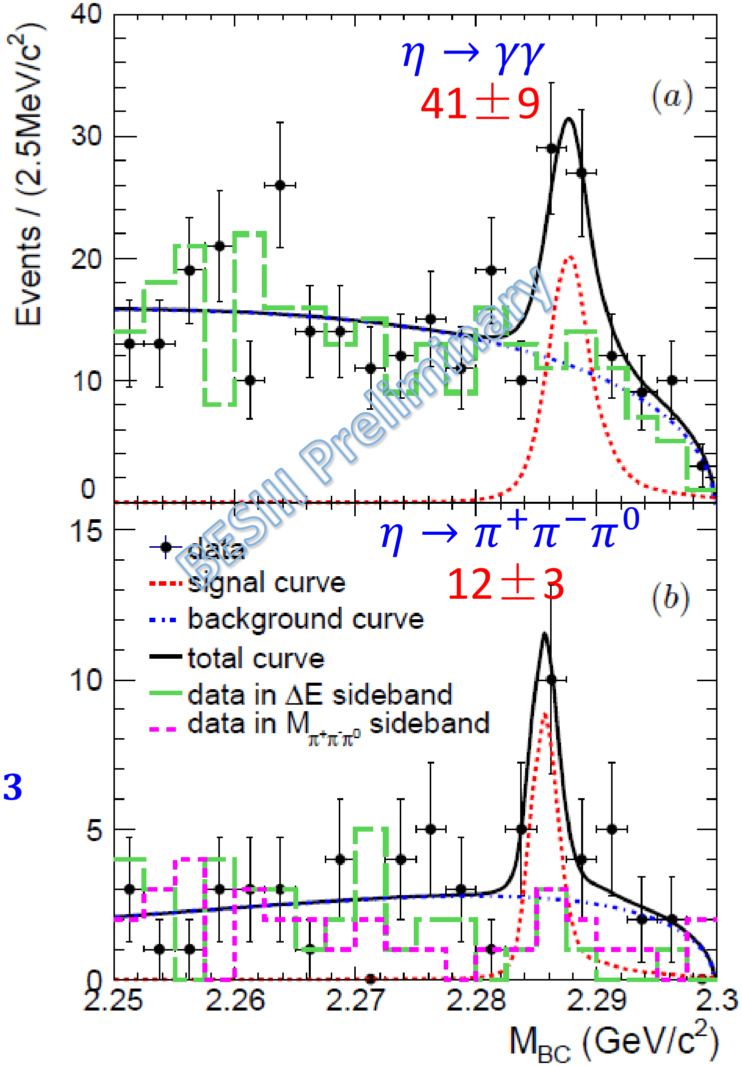
a) $\eta \to \gamma\gamma$

b) $\eta \to \pi^+\pi^-\pi^0$

Preliminary result:

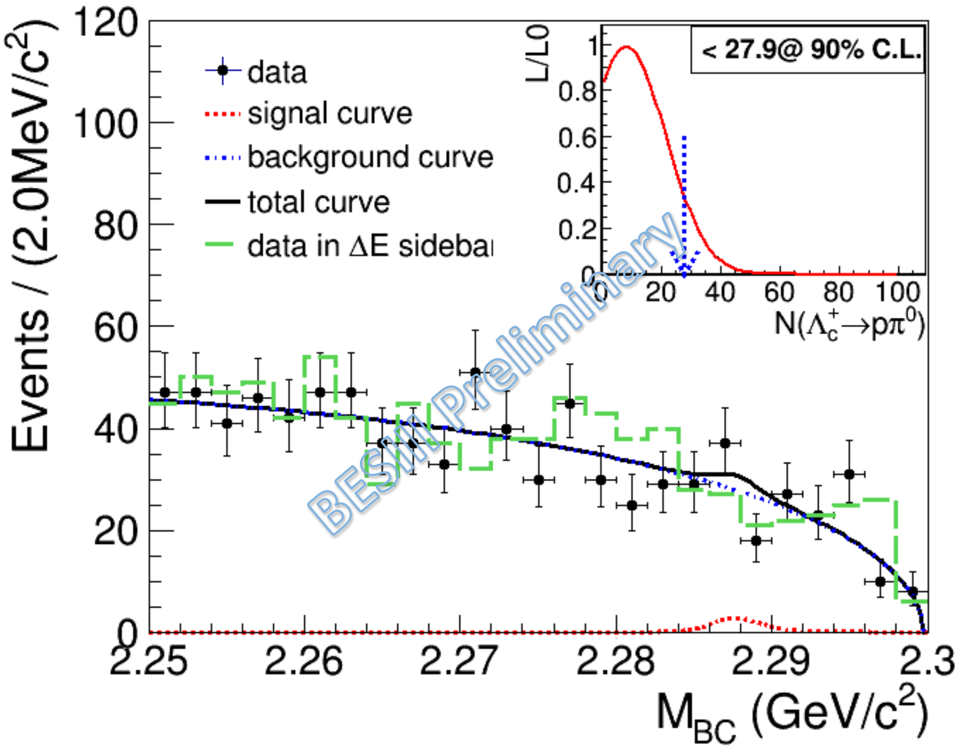
$\mathcal{B}(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.28 \pm 0.1) \times 10^{-3}$

First evidence for $\Lambda_c^+ \to p\eta$ (4.2σ)



SCS decays: $\Lambda_c^+ \to p\eta$ and $\Lambda_c^+ \to p\pi^0$

$\Lambda_c^+ \to p\pi^0$: no obvious signal



Fit to the M_{BC} distribution

Upper limit:

$\mathcal{B}(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$ **(@90% C.L.)**

Compared with $\mathcal{B}(\Lambda_c^+ \to p\eta)$:

$\mathcal{B}(\Lambda_c^+ \to p\pi^0)/\mathcal{B}(\Lambda_c^+ \to p\eta)$**<0.24**

Summary

Based on the 567 pb^{-1} data taken just above the threshold of $\Lambda_c^+\overline{\Lambda}_c^-$ pairs, BESIII presents

- Improved measurements of many hadronic and semi-leptonic decays
  - ✓ $\Lambda_c^+ \to pK^-\pi^+$
  - ✓ $\Lambda_c^+ \to \Lambda l^+\nu_l$
  - ✓ ....
- Evidence/Observation of other decay modes for the first time
  - ✓ $\Lambda_c^+ \to p\eta$ (evidence)
  - ✓ $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$ (observation)
  - ✓ $\Lambda_c^+ \to nK_s^0\pi^+$(observation)
  - ✓ $\Lambda_c^+ \to p\pi^+\pi^-$(observation)

They are important to our understanding of the Λ_c^+ baryon.

More results are coming !

THANK YOU

FOR

YOUR ATTENTION !