Recent Results on Λ_c^+ Hadronic Decay at BESIII

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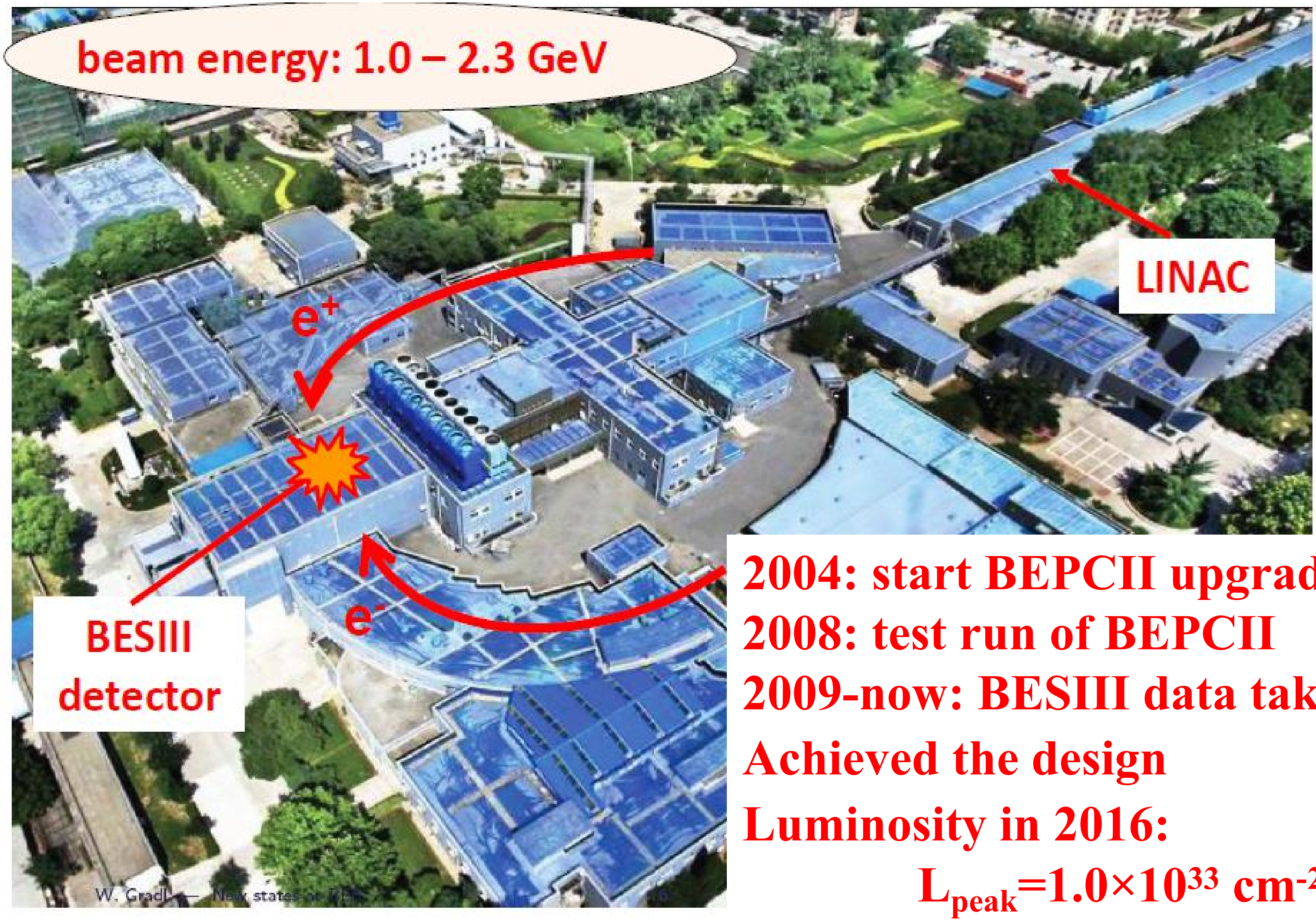
- Summary

Introduction

- Λ_c^+ is the lightest and most common charmed baryon.
- Provide an important normalization to the measurements of excited Λ_c and Σ_c and Λ_b.
- Only decay through the weak interaction.
- Many hadronic BFs have poor precision.

◆The high statistics Λ_c^+ data near the threshold therefore provide an excellent opportunity to perform precise measurements of Λ_c^+ decays.

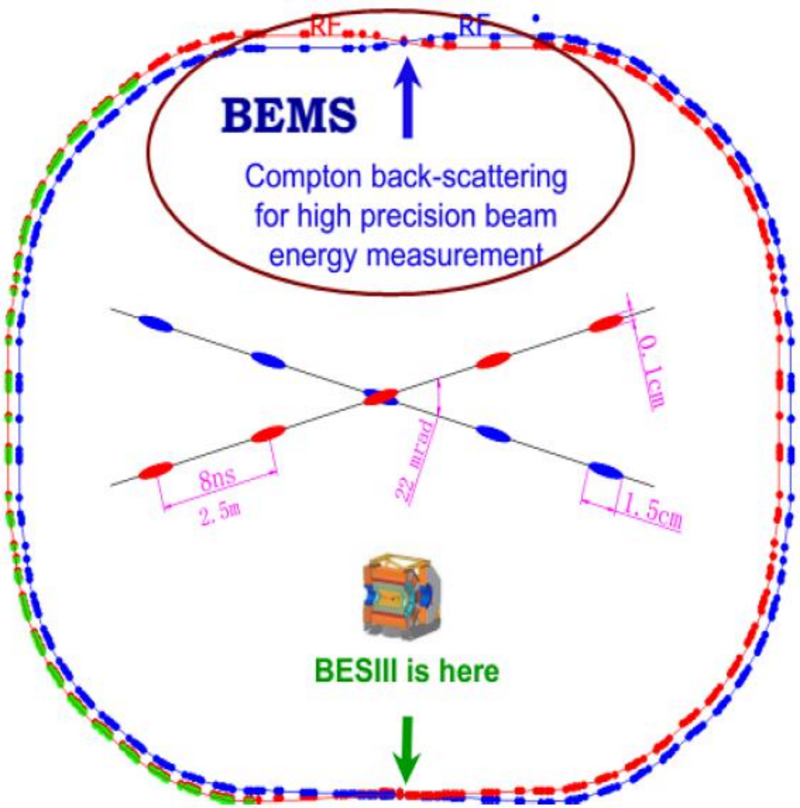
Beijing Electron Positron Collider (BEPCII)



2004: start BEPCII upgrade
2008: test run of BEPCII
2009-now: BESIII data taking
Achieved the design
Luminosity in 2016:
$$L_{peak}=1.0\times10^{33}\ \mathrm{cm}^{-2}\mathrm{s}^{-1}$$

Beijing Electron Positron Collider (BEPCII)

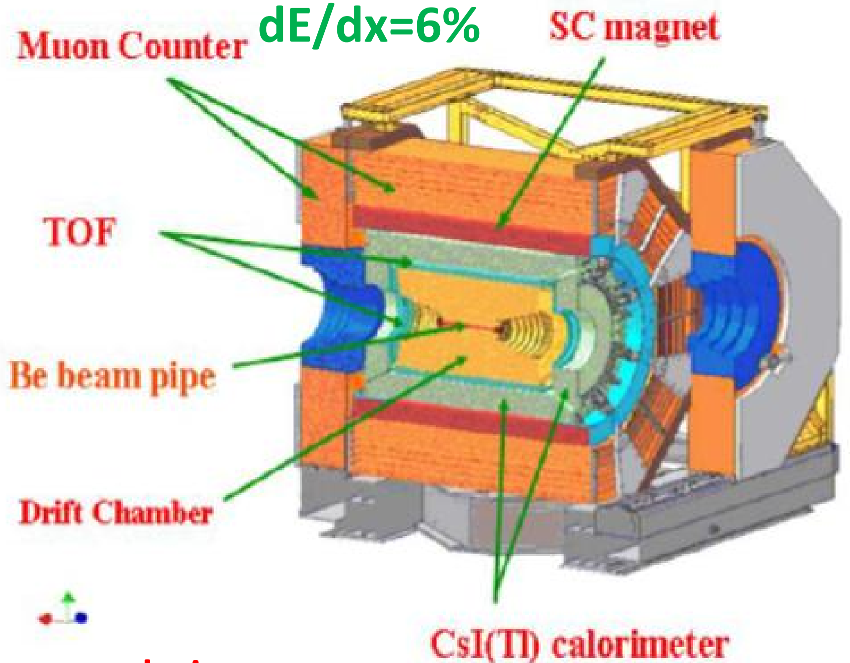
NIM A614, 345 (2010)



Excellent tracking:

σp/p=0.5%@1GeV

dE/dx=6%



Time resolution:

90ps@BTOF

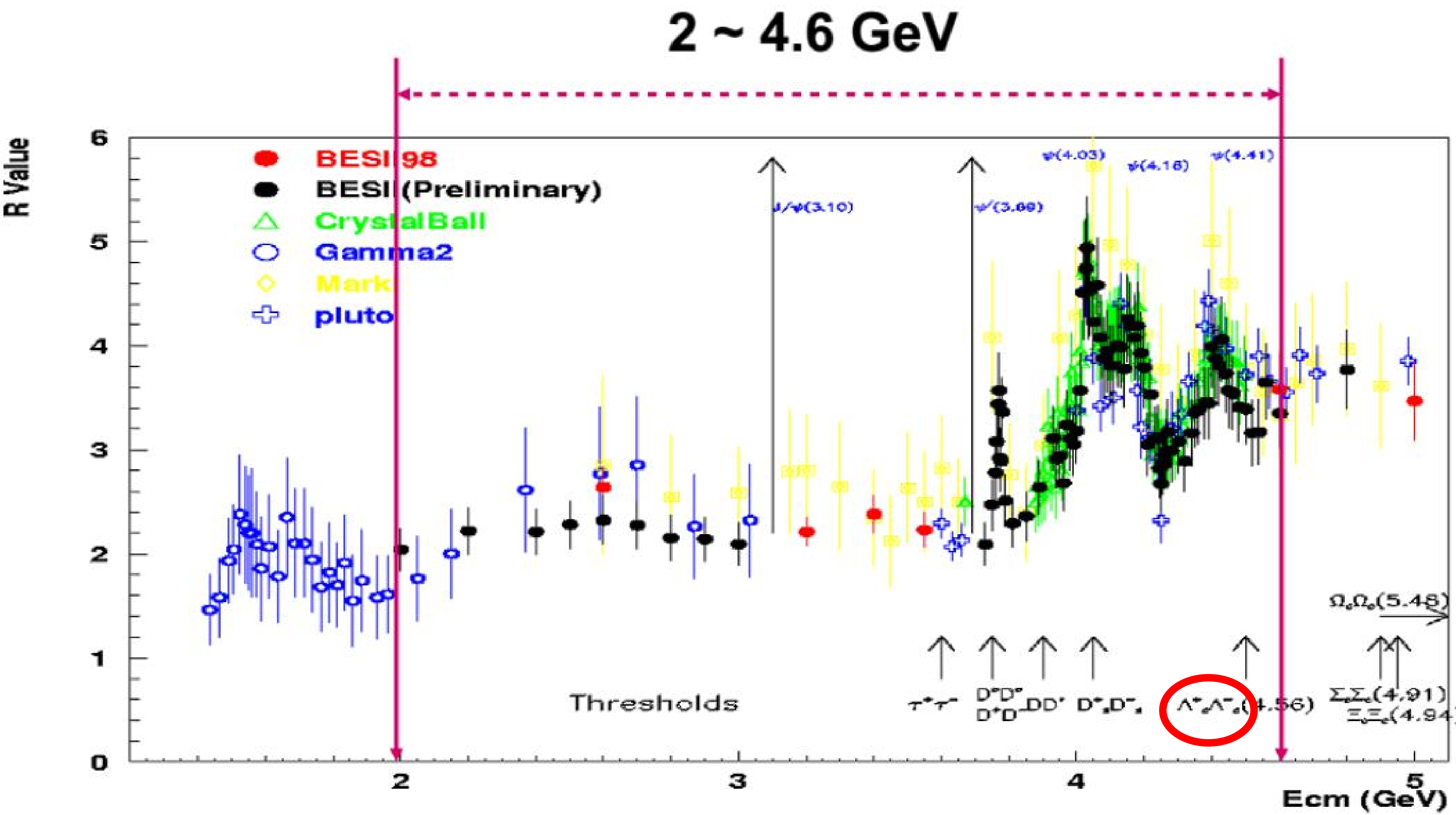
110ps@ETOF

Shower reconstruction:

σE/E=2.5%@1GeV

The new BESIII detector is hermetic for neutral and charged particle with excellent resolution, PID, and large coverage.

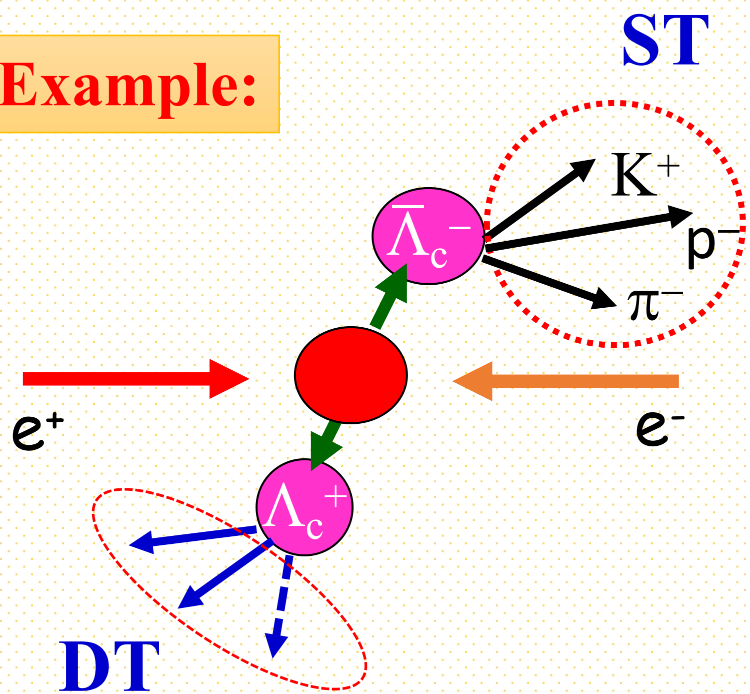
Data Sample in this talk



- 567 pb^{-1} data@4.6 GeV for $\Lambda_c^+\overline{\Lambda}_c^-$ production

Analysis Technique

Example:



ST: Find only one Λ_c

DT: Find both of them

$$\Delta E \equiv E_{\Lambda_c^+} - E_{beam}$$

$$M_{BC} \equiv \sqrt{E_{beam}^2/c^4 - \vec{p}^{\,2}_{\Lambda_c^+}/c^2}$$

$$M_{miss}^2 \equiv E_{miss}^2/c^4 - \vec{p}^{\,2}_{miss}/c^2$$

The advantage of data at threshold:

- **Charmed hadrons can be fully reconstructed by hadronic decays with large Branching Fractions(BF).**
- **Double Tag technique make one can access to absolute BFs and dynamics in the other side decays with clean background.**
- **Most systematic uncertainty in tag side are cancelled out.**

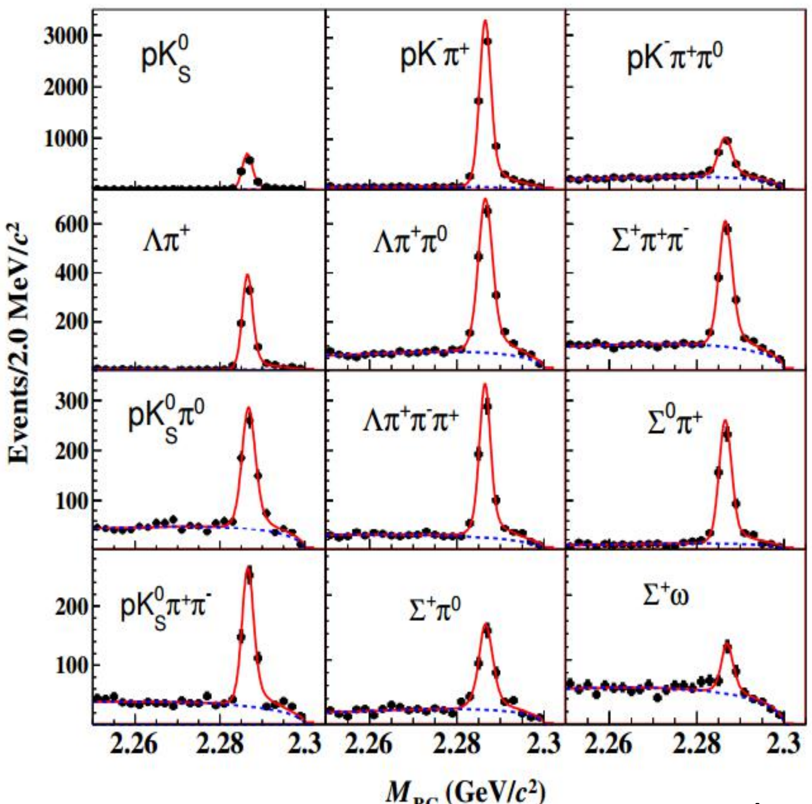
Absolute hadronic BFs of Λ_c^+ baryon decay (12 cabbibo-flavored channels) (1)

PRL116, 052001 (2016)

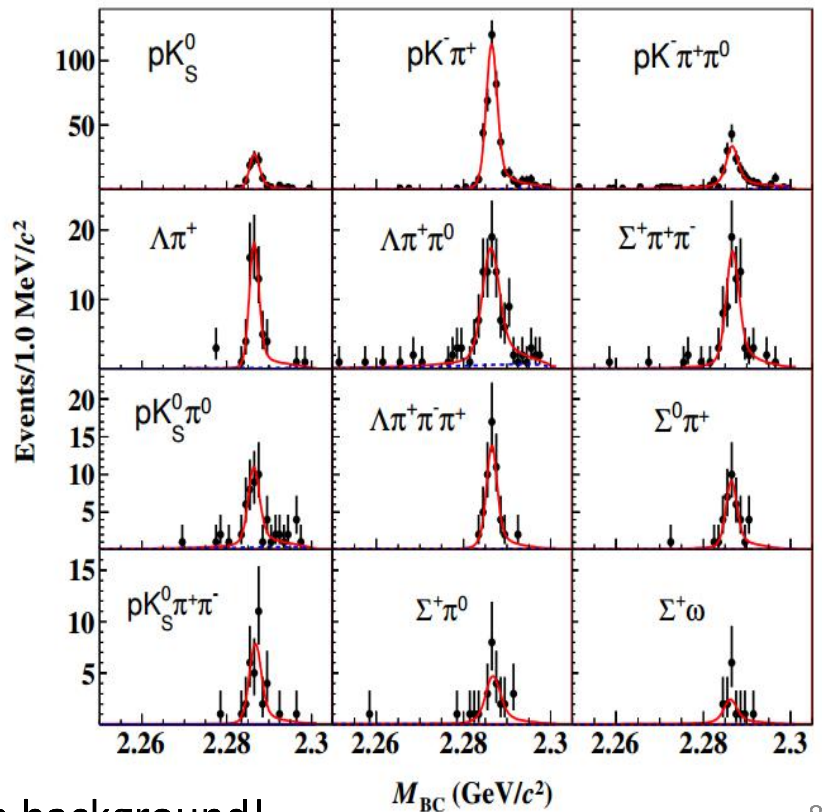
Measurement using the threshold pair-productions via e^+e^- annihilations is unique:

- ✓ kinematics do not allow additional particle produced along with the $\Lambda_c^+\Lambda_c^+$ pair
- ✓ the most simple and straight forward

ST



DT



Very clean background!

Absolute hadronic BFs of Λ_c^+ baryon decay (12 cabbibo-flavored channels) (2)

PRL116, 052001 (2016)

$$N_i^{\mathrm{ST}} = N_{\Lambda_c^+\bar{\Lambda}_c^-} \cdot \mathcal{B}_i \cdot \varepsilon_i^{\mathrm{ST}},$$

$$N_{-j}^{\mathrm{DT}} = \sum_i N_{ij}^{\mathrm{DT}} = \mathcal{B}_j \cdot \sum_i \left(\frac{N_i^{\mathrm{ST}}}{\varepsilon_i^{\mathrm{ST}}} \cdot \varepsilon_{ij}^{\mathrm{DT}}\right)$$

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	

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

- **A global least-square fitter: simultaneous fit to all the modes and constrain to the total number of $N_{\Lambda c+\Lambda c-}$ to improve the measured precision for 12 Λ_c^+ hadronic decay channels.**

- **BESIII BF for $\Lambda_c^+ \rightarrow pK^-\pi^+$ is comparable in precision and compatible with BELLE's with 2σ.**

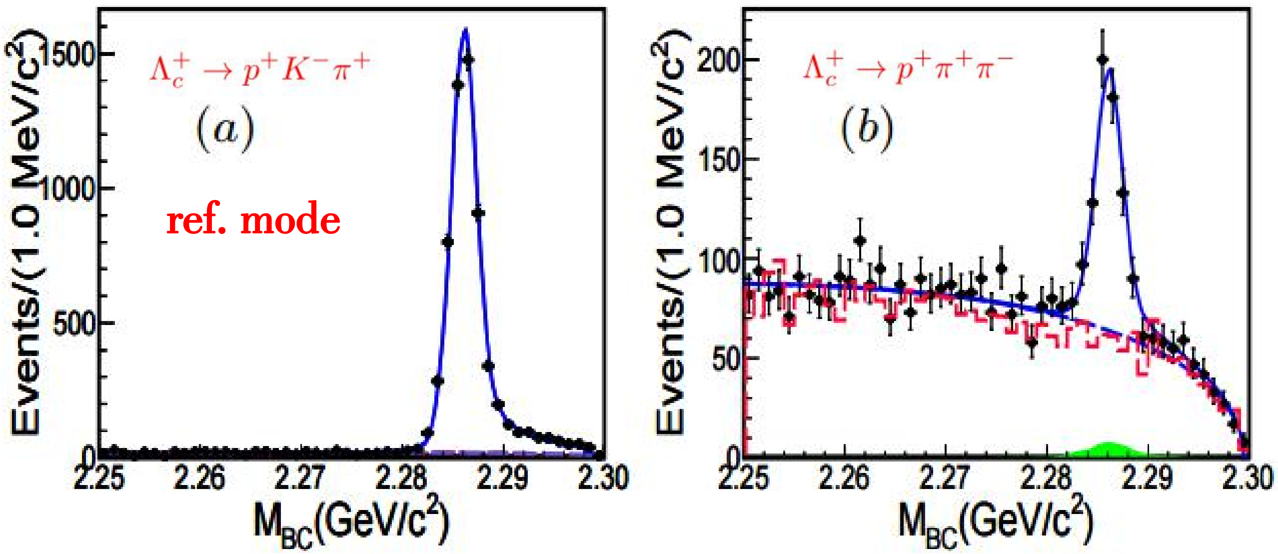
◆ **The precision of absolute BFs of 12 modes are improved significantly.**

Singly Cabibbo-Suppressed Decay $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$

$\Lambda_c^+ \to pK^-\pi^+$ and $\Lambda_c^+ \to p\pi^+\pi^-$

submitted to PRL arXiv:1608.00407

- Sensitive to nonfactorzable contributions from W-exchange diagrams.
- First observation of the singly cabibbo-suppressed decays $\Lambda_c^+ \to p\pi^+\pi^-$ and improved (comparable) mesurements of the $\Lambda_c^+ \to p\phi$ and $\Lambda_c^+ \to pK^+K^-_{non\text{-}\phi}$ BFs comparing to Belle's results.



Distribution of MBC for the decays:

Blue dashed lines: combinatorial bkg shapes;

red dashed histograms: data from the ΔE sideband region;

green shaded histogram: the peaking background from $\Lambda_c^+ \to pK_s^0$ and $\Lambda_c^+ \to \Lambda\pi^+$.

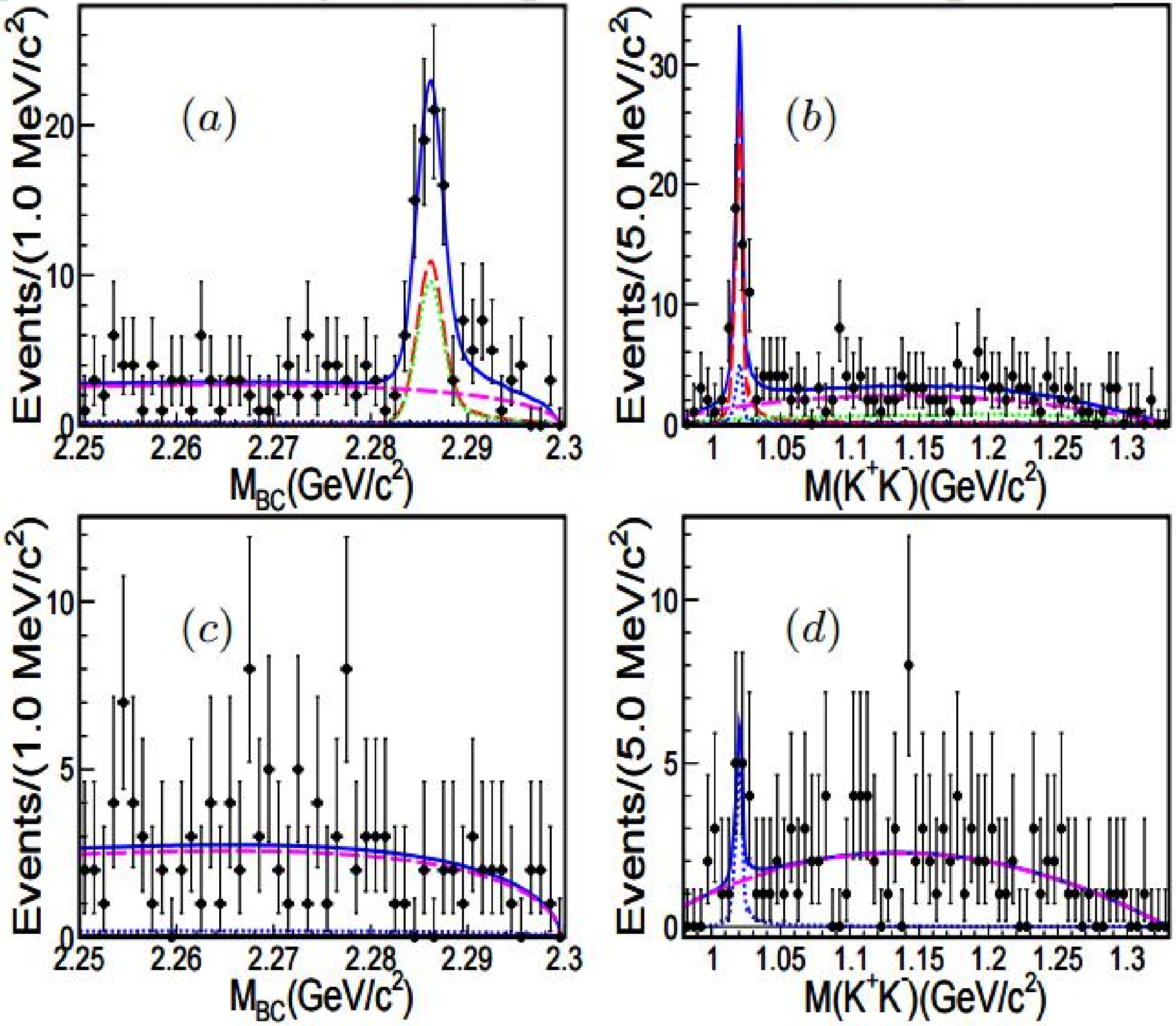
Fit the data with signal shape and argus function.

Decay modes	N_{sig}	ε(%)
$\Lambda_c^+ \to pK^-\pi^+$	5940±85	48.0±0.1
$\Lambda_c^+ \to p\pi^+\pi^-$	495±35	59.7±0.1

Singly Cabibbo-Suppressed Decay $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$

$\Lambda_c^+ \to p^+ K^+ K^-$

- ΔE signal region (upper):
  - 4 components:
    - $\Lambda_c^+ \to p\phi(\phi \to K^+K^-)$
    - $\Lambda_c^+ \to pK^+K^-$ non-ϕ
    - ϕ background
    - non-ϕ background
- ΔE sideband region (bottom)
  - 2 components:
    - ϕ background
    - non-ϕ background



Fit to M_{BC} and M_{K+K-} spectra in ΔE signal area (a,b) and ΔE sideband area(c,d) simultaneously.

Decay modes	N_{sig}	ε(%)
$\Lambda_c^+ \to pK^+K^-$(via ϕ)	44±8	40.2±0.1
$\Lambda_c^+ \to pK^+K^-$non-ϕ	38±9	32.7±0.1

Singly Cabibbo-Suppressed Decay $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$

Results

Decay modes	N_{sig}	$\varepsilon(\%)$
$\Lambda_c^+ \to pK^-\pi^+$ **(ref.)**	5940±85	48.0±0.1
$\Lambda_c^+ \to p\pi^+\pi^-$	495±35	59.7±0.1
$\Lambda_c^+ \to p\phi$(via ϕ)	44±8	40.2±0.1
$\Lambda_c^+ \to pK^+K^-$(non-ϕ)	38±9	32.7±0.1

Decay modes	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref.}}$ (This work)	$\mathcal{B}_{\text{mode}}/\mathcal{B}_{\text{ref.}}$ (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)	$(9.36 \pm 2.22 \pm 0.71) \times 10^{-3}$	$0.007 \pm 0.002 \pm 0.002$	
–	$\mathcal{B}_{\text{mode}}$ (This work)	$\mathcal{B}_{\text{mode}}$ (PDG average)	
$\Lambda_c^+ \to p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$	first observation
$\Lambda_c^+ \to p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$	improved preision
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$	

- Uncertainties are statistical, systematic, and reference mode uncertainty.
- For the relative branching fractions, the reference mode uncertainty is absent.
- The results provide important data to understand the dynamics of Λ_c^+ decays.
- They especially help to distinguish predictions from different theoretical models and understand contributions from factorizable effects.

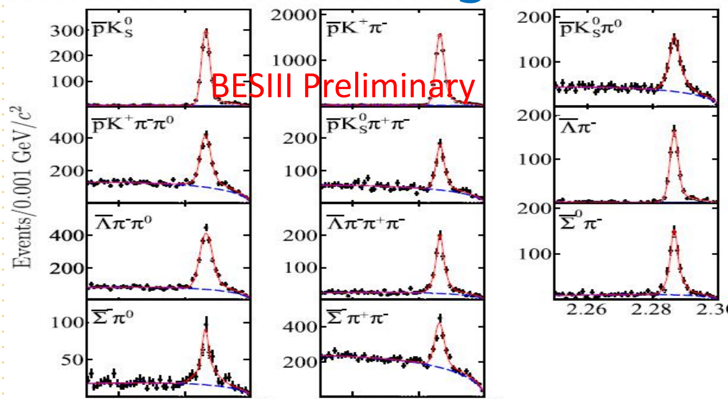
Observation of $\Lambda_c^+ \to n K_S^0 \pi^+$ (1)

BESIII Preliminary

- Comparing BFs for $\Lambda_c^+ \to p(K\pi)^0$ and $\Lambda_c^+ \to n K_S^0 \pi^+$ provides an excellent opportunity to test final state interactions and isospin asymmetry in the charmed baryon sector [Phys. Rev. D 93(2016) 056008]
- First observation of Λ_c^+ decays to final states involving the neutron.

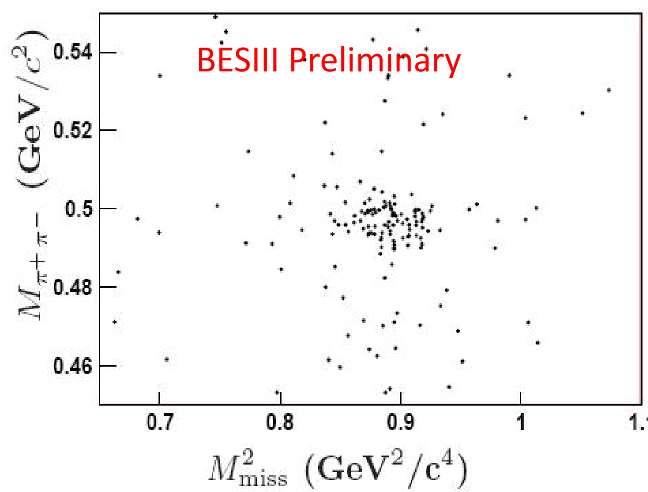
■ 11 single tag modes:

- $\Lambda_c^- \to \bar{p}K_S^0$, $\Lambda_c^- \to \bar{p}K^+\pi^-$
- $\Lambda_c^- \to \bar{p}K_S^0\pi^0$, $\Lambda_c^- \to \bar{p}K^+\pi^-\pi^0$,
- $\Lambda_c^- \to \bar{p}K_S^0\pi^+\pi^-$, $\Lambda_c^- \to \bar{\Lambda}\pi^-$,
- $\Lambda_c^- \to \bar{\Lambda}\pi^-\pi^0$, $\Lambda_c^- \to \bar{\Lambda}\pi^-\pi^+\pi^-$,
- $\Lambda_c^- \to \bar{\Sigma}^0\pi^-$, $\Lambda_c^- \to \bar{\Sigma}^-\pi^0$ and $\Lambda_c^- \to \bar{\Sigma}^-\pi^+\pi^-$,



The missing neutron is detected by:

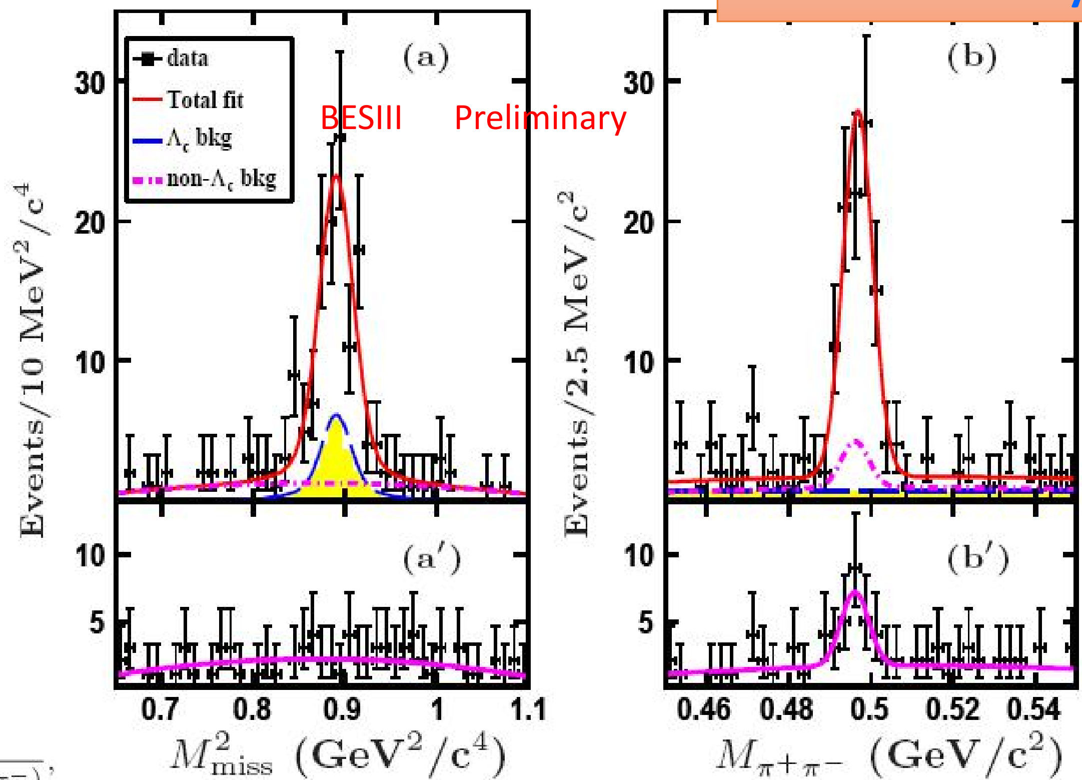
$$M_{miss}^2 \equiv E_{miss}^2/c^4 - \vec{p}_{miss}^{\,2}/c^2$$



Observation of $\Lambda_c^+ \to nK_S^0\pi^+$ (2)

BESIII Preliminary

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



BESIII Preliminary results:

83±11 net signal events

$$\mathcal{B}(\Lambda_c^+ \to nK_S^0\pi^+) = \frac{N^{obs}_{nK_S^0\pi^+}}{N^{tot}_{\Lambda_c^-} \times \varepsilon_{nK_S^0\pi^+} \times \mathcal{B}(K_S^0 \to \pi^+\pi^-)},$$

$B[\Lambda_c^+ \to nK_S^0\pi^+] = (1.82 \pm 0.23 \pm 0.11)\%$ [first observation]

$B[\Lambda_c^+ \to n\overline{K}^0\pi^+]/B[\Lambda_c^+ \to pK^-\pi^+] = 0.62 \pm 0.09$

$B[\Lambda_c^+ \to n\overline{K}^0\pi^+]/B[\Lambda_c^+ \to p\overline{K}^0\pi^0] = 0.97 \pm 0.16$

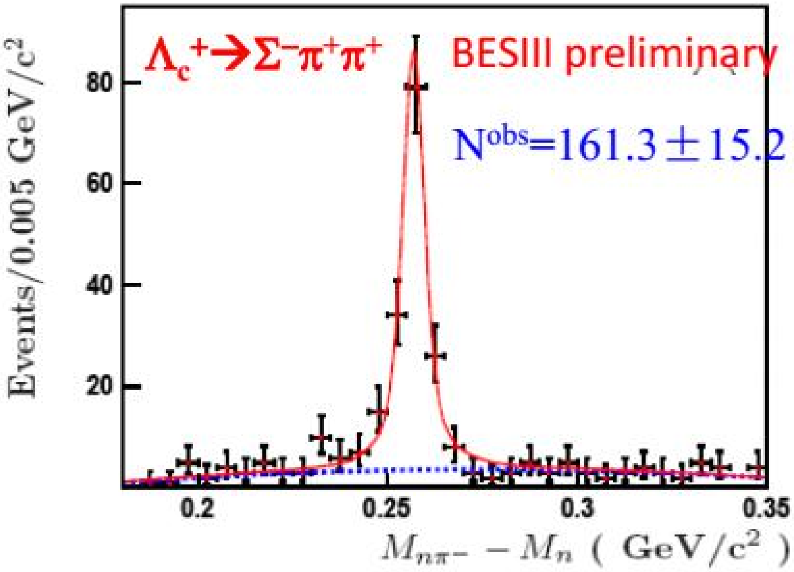
The relative BF of neutron-involved mode to proton-involved mode is essential to test the isospin symmetry for Λ_c^+ decays.

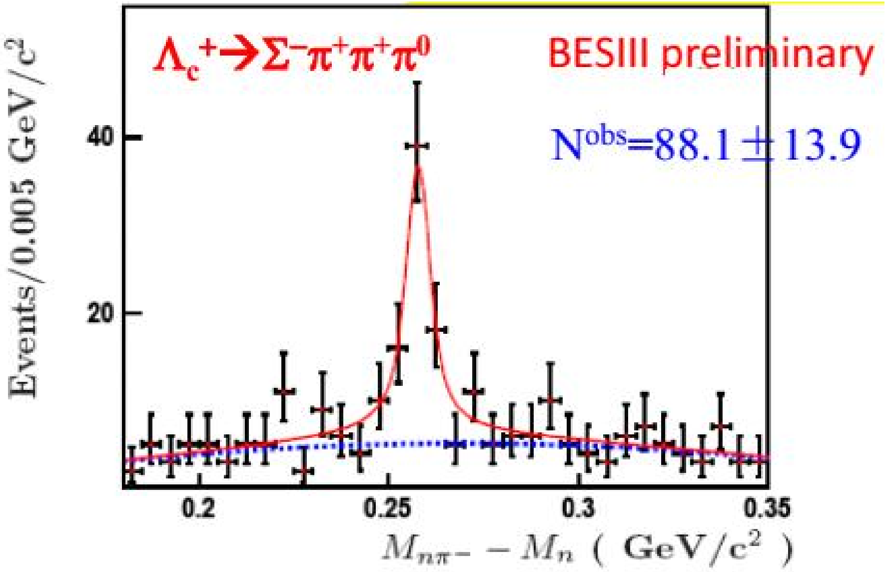
Absolute BFs for $\Lambda_c^+ \to \Sigma^- \pi^+\pi^+$ and $\Lambda_c^+ \to \Sigma^- \pi^+\pi^+\pi^0$

BESIII Preliminary

- Only one Λ_c^+ decay mode with Σ^- is measured with quite large error: $B(\Lambda_c \to \Sigma^- \pi^+\pi^+) = 2.3 \pm 0.4\%$.
- BESIII can precisely study the Λ_c^+ decay involving neutron or Σ^- by using double tag method.

11 single tag modes: same with $\Lambda_c^+ \to nK_S^0\pi^+$. Use $M_{n\pi-}$ - M_n to improve the resolution.





BESIII Preliminary

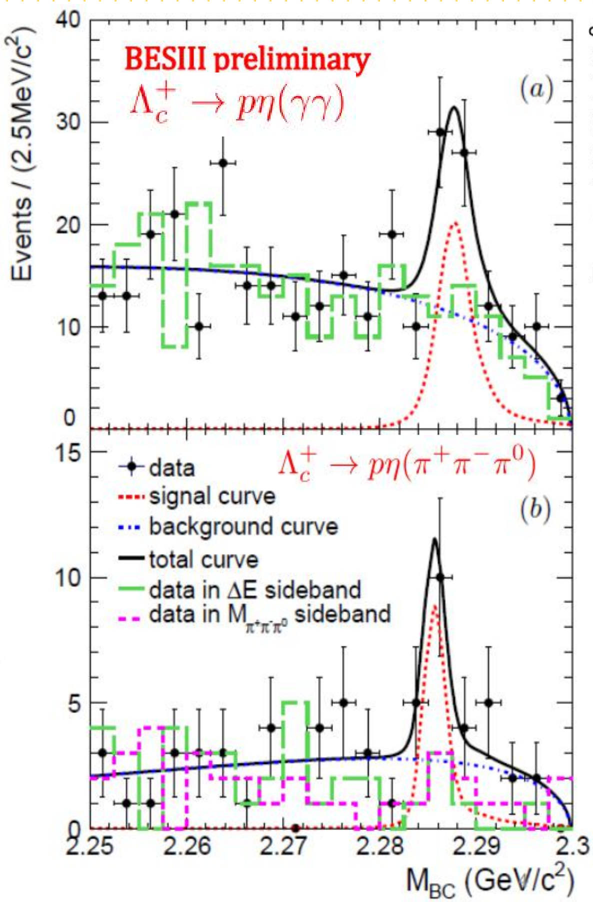
$B(\Lambda_c \to \Sigma^- \pi^+\pi^+) = (1.81 \pm 0.17)\%$, [consistend with and more precise than PDG2015 (2.3±0.4)%]

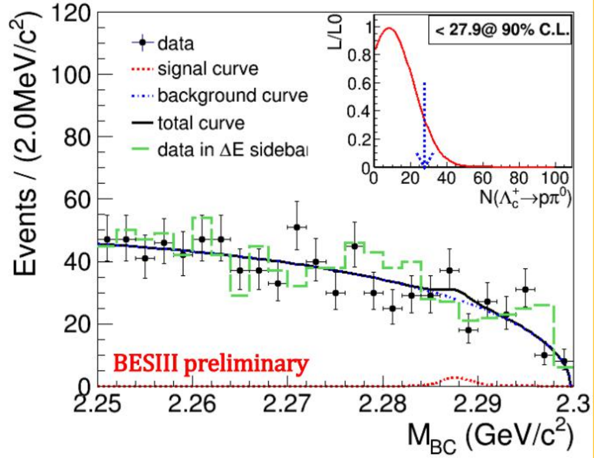
$B(\Lambda_c \to \Sigma^- \pi^+\pi^+\pi^0) = (2.11 \pm 0.33)\%$ [First observation for large BF decay involving neutron]

Singly Cabbibo-Suppressed decay of $\Lambda_c^+ \to p\eta$ and $\Lambda_c^+ \to p\pi^0$

BESIII Preliminary

- Searching for new decay mode to understand Λ_c^+ decay (sum of measured BF only about 63%).
- BF of $\Lambda_c^+ \to p\eta >> \Lambda_c^+ \to p\pi^0$ in the SU(3) flavor symmetry generated by u,d and s.
- Their relative size essential to understand the interference of different non-factorizable diagrams





1. ST method and un-binned maximum likelihood fit on the MBC for $\Lambda_c^+ \to p\eta$, simutaneously fitting $\eta(\gamma\gamma)$ $\eta(\pi^+\pi^-\pi^0)$ mode, the total number of $N_{\Lambda c+\Lambda c-}$ from PRL116, 052001 (2016)
2. an upper limit at 90% confidence level is given for $\Lambda_c^+ \to p\pi^0$

BESIII Preliminary

- $B(\Lambda_c^+ \to p\eta) = (1.24 \pm 0.28(stat.) \pm 0.10(syst.)) \times 10^{-3}$; $B(\Lambda_c^+ \to p\pi^0) < 2.7 \times 10^{-4}$.
- First evidence for $\Lambda_c^+ \to p\eta$ with 4.2σ significance.
- The ratio of BFs $B(\Lambda_c^+ \to p\pi^0)/B(\Lambda_c^+ \to p\eta) < 0.24$.

Summary

- **With 567pb^{-1} data taken at 4.6GeV, BesIII has released many new Λ_c^+ hadronic results.**
- **Open a door to study the lowest charmed baryon state Λ_c^+ .**
  - low backgrounds and high detection efficiency.
- **Several physic potentials have been and are being explored.**
  - The absolute BFs for "the golden reference mode" $\Lambda_c^+ \to pK^-\pi^+$ are improved, as well as other 11 cabbibo-favored decay channels.
  - Hadronic decay involving a neutron in the final state $\Lambda_c^+ \to nK_S^0\pi^+$(first), and Singly Cabbibo-Suppressed decay $\Lambda_c^+ \to p\pi^+\pi^-$(first) and $\Lambda_c^+ \to pK^+K^-$ are measured.
  - new decay mode are being found and more precise measurements are being made ($\Lambda_c^+ \to \Sigma^- \pi^+\pi^+$, $\Lambda_c^+ \to \Sigma^- \pi^+\pi^+\pi^0$(first), $\Lambda_c^+ \to p\eta$(first) and $\Lambda_c^+ \to p\pi^0$(first)).
- **More fruitful results will come out.**

Thanks