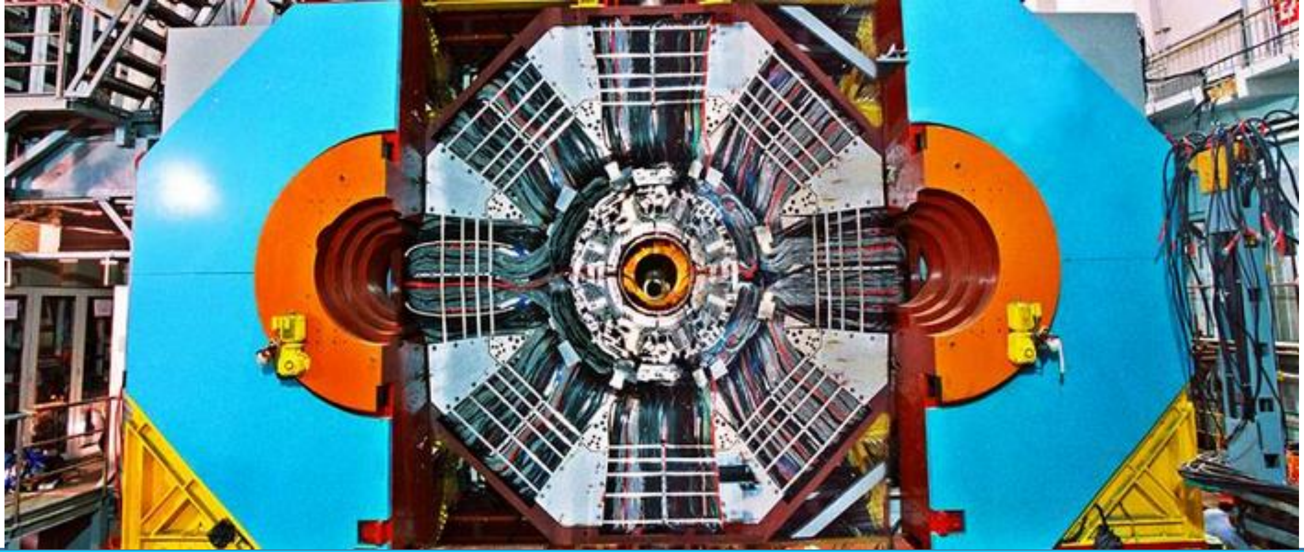

Measurement of absolute branching fractions of Charmed Baryon $\Lambda_c^{\pm}$ at BESIII

BESIII

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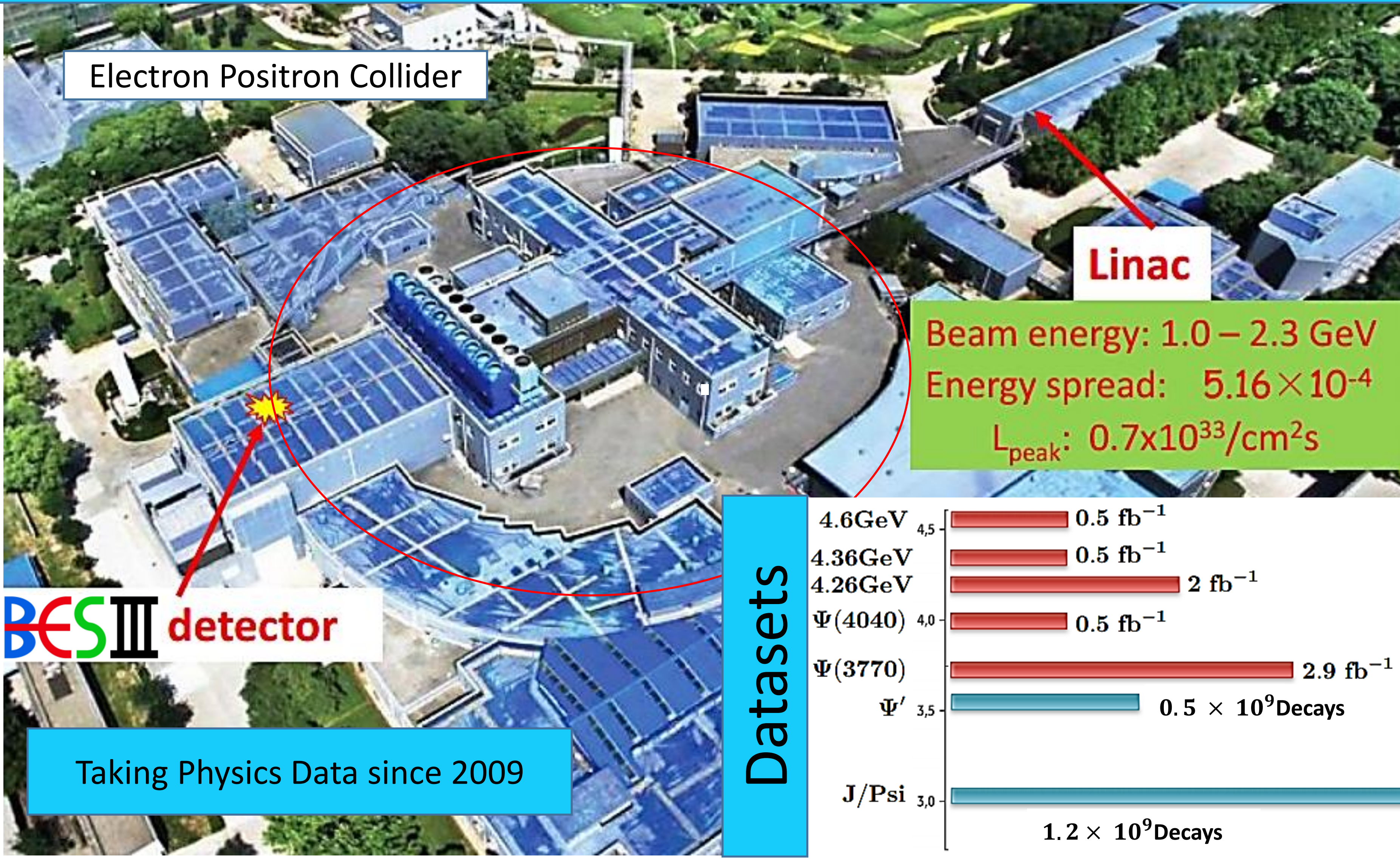
Overview

- BESIII experiment
- $\Lambda_c^{\pm}$ 12 Hadronic Branching Fractions
  - Motivation
  - Analysis
  - Global Fit of Branching Fractions
- $\Lambda_c^{\pm}$ Semi-leptonic $\mathcal{B}(\Lambda_c^{+} \to \Lambda e^{+} \nu_e)$
  - Motivation
  - Analysis
- Summary

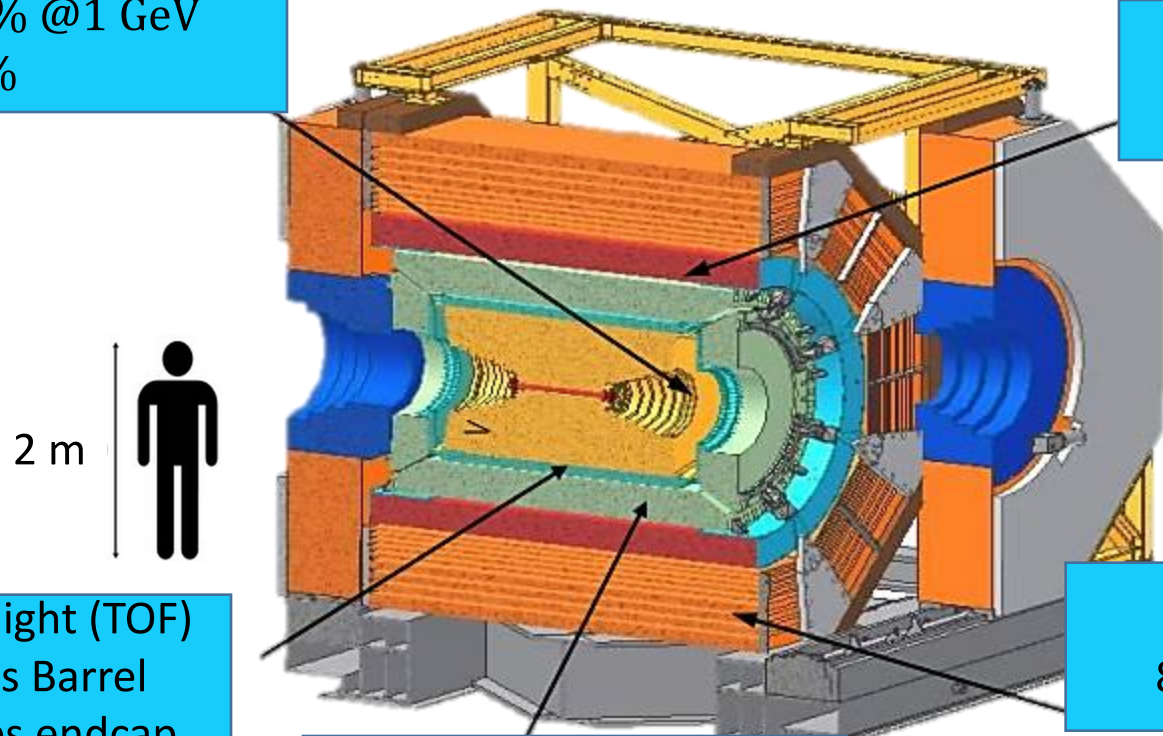
BEPCII and BESIII



BESIII Detector

Drift Chamber (MDC)
$\sigma_P/P = 0.5\%$ @1 GeV
$\sigma_{dE/dx} = 6\%$

Super-conducting magnet (1.0 tesla)



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

μ Counter
8- 9 layers RPC

EMC :
σ_E/E = 2.5%@1GeV
σ_Z = 0.6cm

M. Ablikim et al., (BESIII Collaboration), Nucl. Instrum. Meth. A 614, 345 (2010).

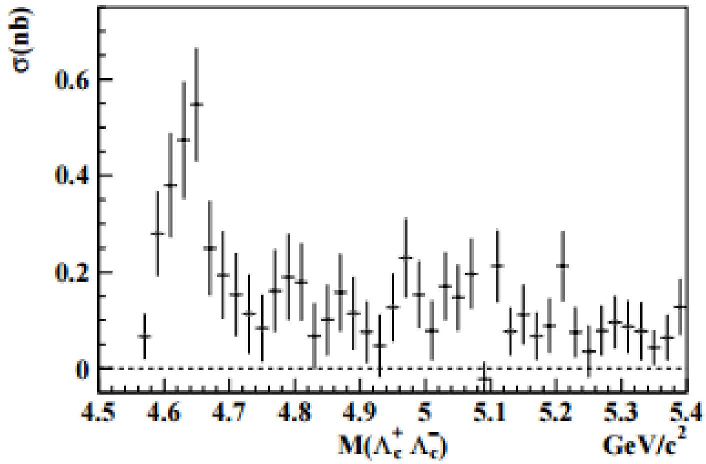
BESIII Collaboration

Motivation

- $\Lambda_C^{\pm}$, the first discovered charmed baryon, was discovered about 35 years ago.
- Most of branching fractions (BF) are measured relative to $\Lambda_C^{+} \to pK^{-}\pi^{+}$ which is determined on model assumption.
- Absolute branching fractions of $\Lambda_C^{\pm}$ decays was not well determined until BELLE's first "model-independent" measurement last year:
  - $\boldsymbol{B}$ ($\Lambda_C^{+} \to pK^{-}\pi^{+}$)=(6.84±0.24−0.27+0.21)% [arXiv:1312.7826]
    precision reaches to 4.7%
  - much higher than PDG value $\boldsymbol{B}$ ($\Lambda_C^{+} \to pK^{-}\pi^{+}$)=(5.0 ± 1.3)%
    precision at ~20-40%
- Another model-independent measurement of $\boldsymbol{B}$ ($\Lambda_C^{+} \to pK^{-}\pi^{+}$), along with the first model-independent measurements of many other modes is interesting.

Charge conjugate modes are implied in the following slides

Dataset $\sqrt{s} = 4.6$ GeV

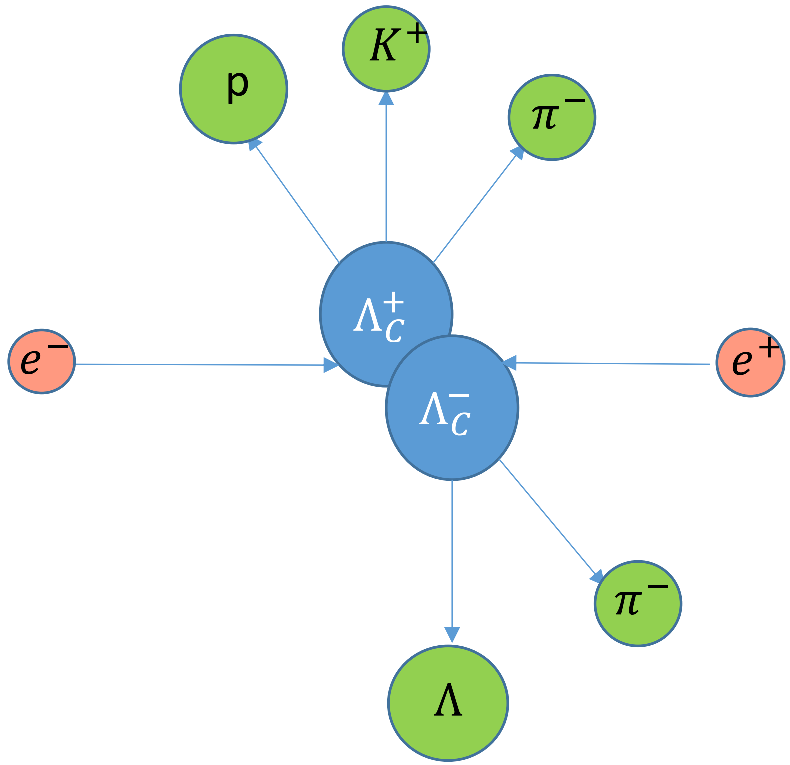


BELLE collaboration
Phys. Rev. Lett. 101 (2008) 172001

- 567 pb^{-1} Worlds first and only dataset at $\Lambda_C^+\Lambda_C^-$ threshold
- Creation of $\Lambda_C^+\Lambda_C^-$ pairs allows for a model independent double-tagging (DT) method

Λ_C selection

mode
$\Lambda_c \to pK_s$
$\Lambda_c \to pk^- \pi^+$
$\Lambda_c \to pK_S \pi^0$
$\Lambda_c \to pK_S \pi^+ \pi^-$
$\Lambda_c \to pk^- \pi^+ \pi^0$
$\Lambda_c \to \Lambda \pi^+$
$\Lambda_c \to \Lambda \pi^+ \pi^0$
$\Lambda_c \to \Lambda \pi^+ \pi^- \pi^+$
$\Lambda_c \to \Sigma^0 \pi^+$
$\Lambda_c \to \Sigma^+ \pi^0$
$\Lambda_c \to \Sigma^+ \pi^+ \pi^-$
$\Lambda_c \to \Sigma^+ \omega$



12 modes used in reconstruction of Λ_C covers ~1/3 of the total decays.

Constructing particles from final state particles:

- $K_S \to \pi^+\pi^-$
- $\pi^0 \to \gamma\gamma$
- $\Lambda \to p\pi^-$
- $\Sigma^0 \to \Lambda\gamma$
- $\Sigma^+ \to p\pi^0$
- $\omega \to \pi^+\pi^-\pi^0$

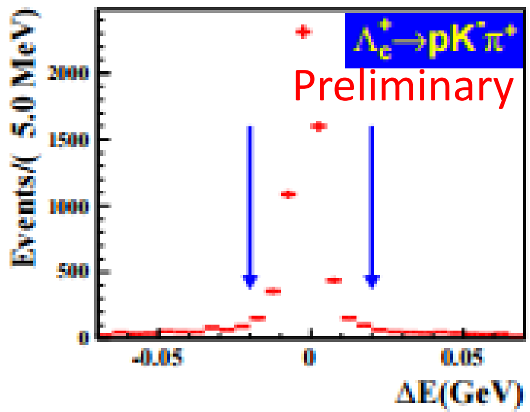
Tagging method

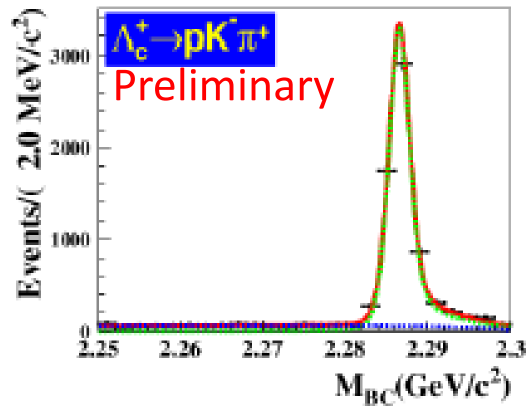
Single Tag (ST) $\Lambda_C^{\pm} \rightarrow i$

Reconstruct candidate particles for $\Lambda_C^{\pm}$ decay.

$$\Delta E = E_{\Lambda_C Rec} - E_{Beam}$$

$$M_{bc} = \sqrt{E_{beam}^2 - |\vec{P}_{\Lambda_C Rec}|^2}$$





Double Tag (DT) $\Lambda_C^{+} \rightarrow i,\ \Lambda_C^{-} \rightarrow j$

Reconstruct candidates particles for both Λ_C^{+} and Λ_C^{-} decays.

- Used to cancel out model dependence
- Background reduced
- Statistically suffer

Model independent through Double-tag method

Single Tags:

$$N_{\Lambda_c\overline{\Lambda}_c} \cdot Br_{i^+} \cdot \varepsilon_{i^+}^{ST} = N_{i^+}^{ST}$$

$$N_{\Lambda_c\overline{\Lambda}_c} \cdot Br_{i^-} \cdot \varepsilon_{i^-}^{ST} = N_{i^-}^{ST}$$

Double Tags:

$$N_{\Lambda_c\overline{\Lambda}_c} \cdot Br_{i^+} \cdot Br_{j^-} \cdot \varepsilon_{i^+j^-}^{DT} = N_{i^+j^-}^{DT}$$

$$N_{\Lambda_c\overline{\Lambda}_c} \cdot Br_{i^-} \cdot Br_{j^+} \cdot \varepsilon_{i^-j^+}^{DT} = N_{i^-j^+}^{DT}$$

Assuming CPV is negligible, $Br_{i+} = Br_{i-} = Br_i$
However detection efficiencies measured for both ±

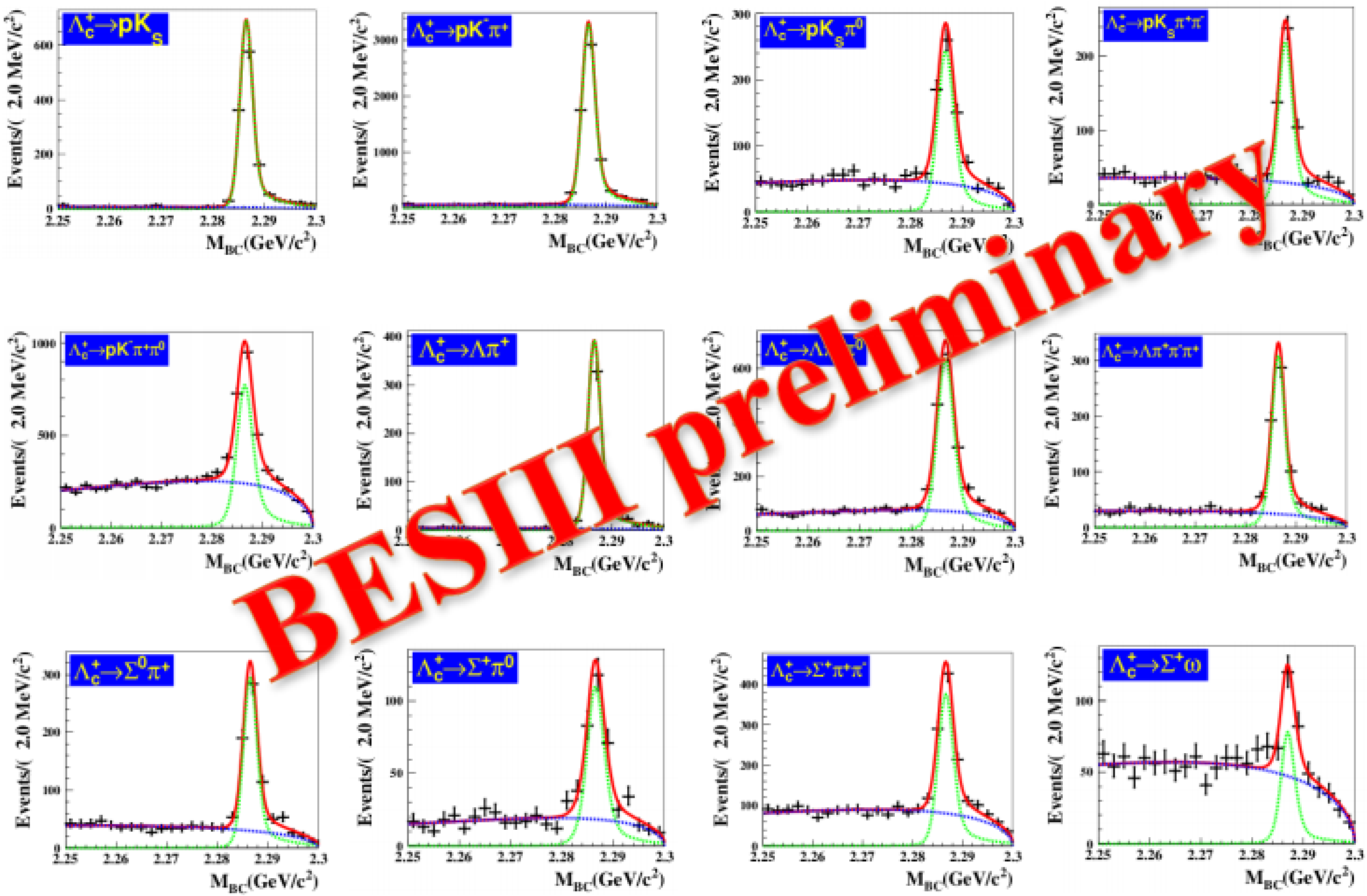
$$N_{-j}^{DT} = \sum_{i^+\neq j} N_{i^+j^-}^{DT} + \sum_{i^-\neq j} N_{i^-j^+}^{DT} + N_{jj}^{DT}$$

$$= \mathcal{B}_j \left(\sum_{i^+\neq j} \frac{N_{i^+}^{ST}}{\varepsilon_{i^+}^{ST}} \cdot \varepsilon_{i^+j^-}^{DT} + \sum_{i^-\neq j} \frac{N_{i^-}^{ST}}{\varepsilon_{i^-}^{ST}} \cdot \varepsilon_{i^-j^+}^{DT} + \frac{(N_{j^+}^{ST} + N_{j^-}^{ST})/2}{(\varepsilon_{j^+}^{ST} + \varepsilon_{j^-}^{ST})/2} \cdot \frac{\varepsilon_{j^-j^+}^{DT} + \varepsilon_{j^+j^-}^{DT}}{2}\right)$$

Ratio of DT yield to the ST yields provides absolute measurement of branching fraction

Single Tag $\Lambda_c^{\pm}$ yields

Data

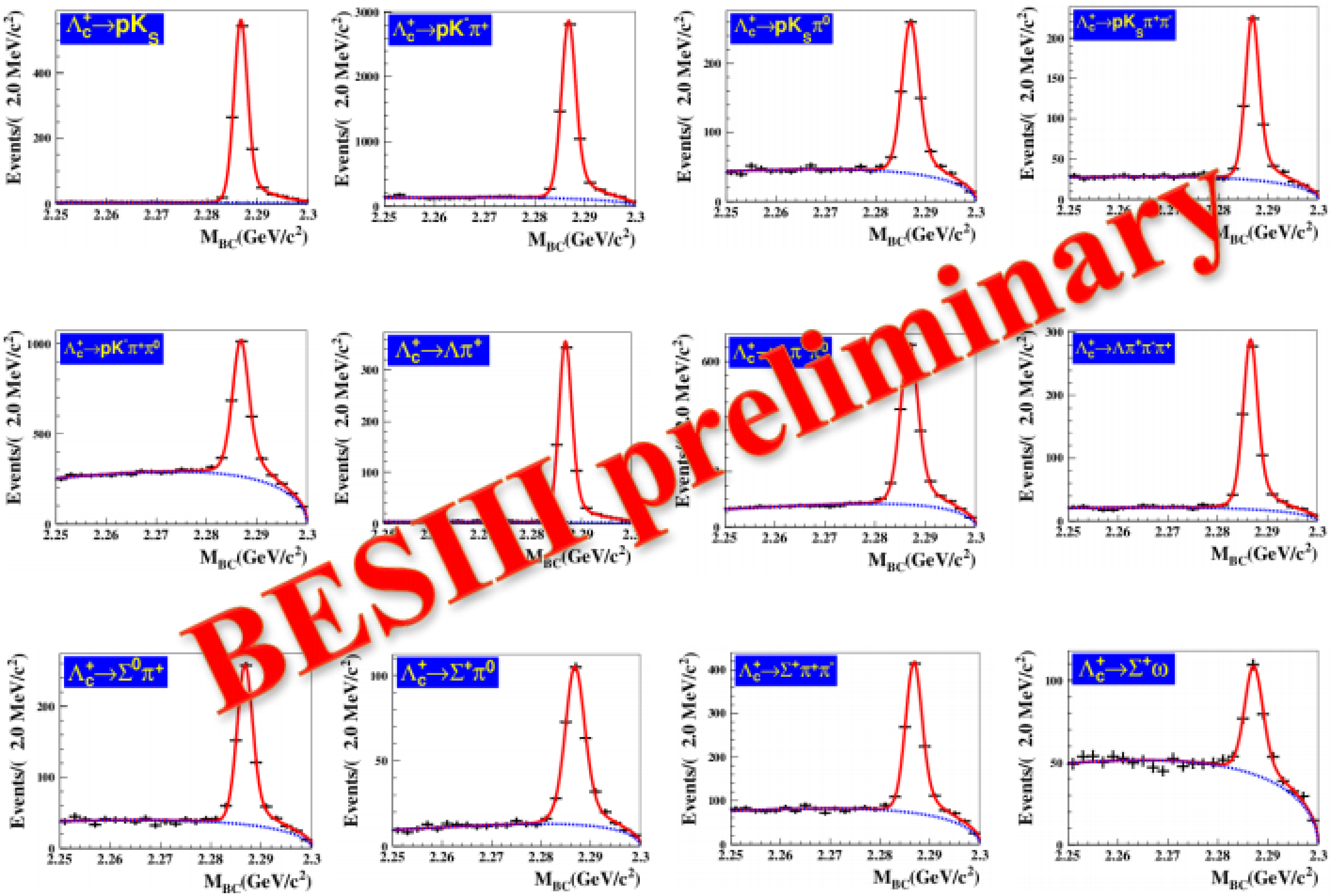


Fit with MC signal shape on an Argus background

modes	N_i^{ST}
pK_S	1243.0 ± 37.1
$pK^-\pi^+$	6307.7 ± 88.0
$pK_S\pi^0$	557.6 ± 32.8
$pK_S\pi^+\pi^-$	453.5 ± 28.2
$pK^-\pi^+\pi^0$	1848.5 ± 70.7
$\Lambda\pi^+$	706.1 ± 27.0
$\Lambda\pi^+\pi^0$	1496.9 ± 52.1
$\Lambda\pi^+\pi^-\pi^+$	608.5 ± 30.9
$\Sigma^0\pi^+$	585.7 ± 31.5
$\Sigma^+\pi^0$	270.7 ± 24.6
$\Sigma^+\pi^+\pi^-$	835.7 ± 43.0
$\Sigma^+\omega$	157.1 ± 21.8

Single Tag $\Lambda_c^{\pm}$ efficiencies

MC

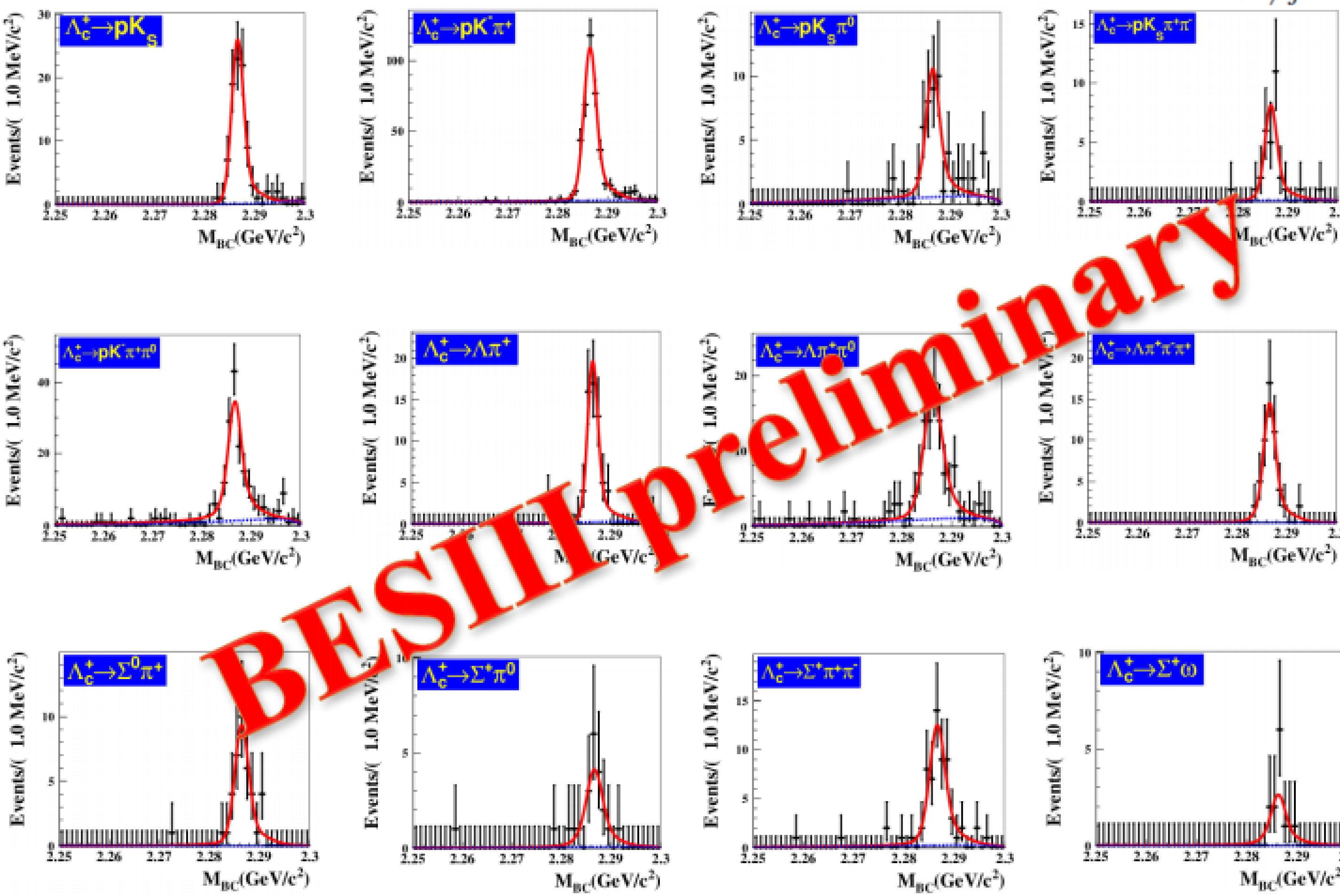


modes	ε_i^{ST} (%)
pK_S	56.9 ± 0.2
$pK^-\pi^+$	51.7 ± 0.2
$pK_S\pi^0$	21.4 ± 0.3
$pK_S\pi^+\pi^-$	21.2 ± 0.3
$pK^-\pi^+\pi^0$	20.4 ± 0.2
$\Lambda\pi^+$	43.2 ± 0.2
$\Lambda\pi^+\pi^0$	16.1 ± 0.1
$\Lambda\pi^+\pi^-\pi^+$	12.4 ± 0.1
$\Sigma^0\pi^+$	33.5 ± 0.6
$\Sigma^+\pi^0$	21.2 ± 0.4
$\Sigma^+\pi^+\pi^-$	20.8 ± 0.3
$\Sigma^+\omega$	10.8 ± 0.5

Double Tag $\Lambda_c^{\pm}$ yields

Data

$$N_{-j}^{DT} = \sum_{i^+ \neq j} N_{i^+j^-}^{DT} + \sum_{i^- \neq j} N_{i^-j^+}^{DT} + N_{jj}^{DT}$$



Decay modes	N_{-j}^{DT}
pK_S	89.1 ± 9.7
$pK^-\pi^+$	390.2 ± 20.8
$pK_S\pi^0$	40.1 ± 7.4
$pK_S\pi^+\pi^-$	28.9 ± 5.6
$pK^-\pi^+\pi^0$	148.2 ± 14.1
$\Lambda\pi^+$	58.6 ± 7.9
$\Lambda\pi^+\pi^0$	88.6 ± 11.2
$\Lambda\pi^+\pi^-\pi^+$	52.9 ± 7.3
$\Sigma^0\pi^+$	38.6 ± 6.2
$\Sigma^+\pi^0$	20.1 ± 4.9
$\Sigma^+\pi^+\pi^-$	56.0 ± 8.2
$\Sigma^+\omega$	12.5 ± 3.4

DT efficiency

DT modes	$p^- K_S$	$p^- K^+ \pi^-$	$p^- K_S \pi^0$	$p^- K_S \pi^- \pi^+$	$p^- K^+ \pi^- \pi^0$	$\Lambda \pi^-$
pK_S	31.7 ± 0.2	29.2 ± 0.1	12.8 ± 0.1	11.7 ± 0.1	13.5 ± 0.1	24.5 ± 0.2
$pK^- \pi^+$	29.2 ± 0.1	26.7 ± 0.1	11.8 ± 0.1	10.8 ± 0.1	12.7 ± 0.1	21.8 ± 0.2
$pK_S \pi^0$	12.8 ± 0.1	11.8 ± 0.1	5.1 ± 0.1	4.4 ± 0.1	5.5 ± 0.1	10.1 ± 0.1
$pK_S \pi^+ \pi^-$	11.7 ± 0.1	10.8 ± 0.1	4.4 ± 0.1	4.8 ± 0.1	4.9 ± 0.1	8.6 ± 0.1
$pK^- \pi^+ \pi^0$	13.5 ± 0.1	12.7 ± 0.1	5.5 ± 0.1	4.9 ± 0.1	6.8 ± 0.1	10.1 ± 0.1
$\Lambda \pi^+$	24.6 ± 0.2	21.9 ± 0.2	10.1 ± 0.1	8.6 ± 0.1	10.1 ± 0.1	18.2 ± 0.3
$\Lambda \pi^+ \pi^0$	9.9 ± 0.1	8.9 ± 0.0	3.9 ± 0.0	3.3 ± 0.0	4.4 ± 0.0	7.5 ± 0.1
$\Lambda \pi^+ \pi^- \pi^+$	6.6 ± 0.1	6.1 ± 0.1	2.6 ± 0.0	2.4 ± 0.0	2.8 ± 0.0	4.9 ± 0.1
$\Sigma^0 \pi^+$	18.4 ± 0.2	17.2 ± 0.1	7.6 ± 0.1	6.2 ± 0.1	8.2 ± 0.1	13.8 ± 0.3
$\Sigma^+ \pi^0$	12.9 ± 0.2	11.7 ± 0.1	5.0 ± 0.1	4.5 ± 0.1	5.1 ± 0.1	10.1 ± 0.2
$\Sigma^+ \pi^+ \pi^-$	12.3 ± 0.1	11.4 ± 0.1	4.8 ± 0.1	4.3 ± 0.1	5.3 ± 0.1	9.3 ± 0.1
$\Sigma^+ \omega$	7.0 ± 0.1	6.4 ± 0.1	2.6 ± 0.1	2.2 ± 0.1	3.1 ± 0.1	5.3 ± 0.2
DT modes	$\Lambda \pi^- \pi^0$	$\Lambda \pi^- \pi^+ \pi^-$	$\Sigma^0 \pi^-$	$\Sigma^- \pi^0$	$\Sigma^- \pi^- \pi^+$	$\Sigma^- \omega$
pK_S	9.9 ± 0.1	6.6 ± 0.1	18.5 ± 0.2	12.9 ± 0.2	12.3 ± 0.1	6.9 ± 0.1
$pK^- \pi^+$	8.9 ± 0.0	6.1 ± 0.1	17.1 ± 0.1	11.7 ± 0.1	11.4 ± 0.1	6.4 ± 0.1
$pK_S \pi^0$	3.9 ± 0.0	2.6 ± 0.0	7.6 ± 0.1	5.0 ± 0.1	4.7 ± 0.1	2.6 ± 0.1
$pK_S \pi^+ \pi^-$	3.3 ± 0.0	2.4 ± 0.0	6.2 ± 0.1	4.6 ± 0.1	4.4 ± 0.1	2.2 ± 0.1
$pK^- \pi^+ \pi^0$	4.4 ± 0.0	2.8 ± 0.0	8.2 ± 0.1	5.1 ± 0.1	5.3 ± 0.1	3.1 ± 0.1
$\Lambda \pi^+$	7.5 ± 0.1	4.9 ± 0.1	13.8 ± 0.3	10.2 ± 0.2	9.2 ± 0.1	5.3 ± 0.2
$\Lambda \pi^+ \pi^0$	3.0 ± 0.0	1.8 ± 0.0	5.8 ± 0.1	4.0 ± 0.1	3.8 ± 0.0	2.1 ± 0.0
$\Lambda \pi^+ \pi^- \pi^+$	1.8 ± 0.0	1.3 ± 0.0	3.8 ± 0.1	2.7 ± 0.1	2.6 ± 0.0	1.4 ± 0.0
$\Sigma^0 \pi^+$	5.8 ± 0.1	3.8 ± 0.1	11.3 ± 0.3	8.0 ± 0.2	7.3 ± 0.1	4.2 ± 0.1
$\Sigma^+ \pi^0$	4.0 ± 0.1	2.7 ± 0.1	8.0 ± 0.2	4.8 ± 0.2	4.8 ± 0.1	2.7 ± 0.1
$\Sigma^+ \pi^+ \pi^-$	3.8 ± 0.0	2.6 ± 0.0	7.3 ± 0.1	4.8 ± 0.1	4.8 ± 0.1	2.6 ± 0.1
$\Sigma^+ \omega$	2.1 ± 0.0	1.4 ± 0.0	4.1 ± 0.1	2.7 ± 0.1	2.6 ± 0.1	1.4 ± 0.1

Table 7: DT efficiencies in percentage.

Each number is the average of the two efficiencies ε^{DT}_{j+i-} and ε^{DT}_{j-i+}

Branching Fraction Results

A least square global fitter: simultaneous fit to the all tag modes while constraining the total $\Lambda_c^+ \Lambda_c^-$ pair number, taking into account the correlations.

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only stat. errors are included.

Decay modes	global fit $\mathcal{B}$	PDG $\mathcal{B}$	Belle $\mathcal{B}$
pK_S	1.48 ± 0.08	1.15 ± 0.30	
$pK^-\pi^+$	5.77 ± 0.27	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S\pi^0$	1.77 ± 0.12	1.65 ± 0.50	
$pK_S\pi^+\pi^-$	1.43 ± 0.10	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	4.25 ± 0.22	3.4 ± 1.0	
$\Lambda\pi^+$	1.20 ± 0.07	1.07 ± 0.28	
$\Lambda\pi^+\pi^0$	6.70 ± 0.35	3.6 ± 1.3	
$\Lambda\pi^+\pi^-\pi^+$	3.67 ± 0.23	2.6 ± 0.7	
$\Sigma^0\pi^+$	1.28 ± 0.08	1.05 ± 0.28	
$\Sigma^+\pi^0$	1.18 ± 0.11	1.00 ± 0.34	
$\Sigma^+\pi^+\pi^-$	3.58 ± 0.22	3.6 ± 1.0	
$\Sigma^+\omega$	1.47 ± 0.18	2.7 ± 1.0	

Semi-leptonic Motivation

- $\Lambda_c^+ \to \Lambda e^+ \upsilon_e$ is a $c \to s l^+ \upsilon$ dominated process
- No direct absolute measurement of $B(\Lambda_c^+ \to \Lambda e^+ \upsilon_e)$ available.

Direct measurement eagerly awaited for LQCD calculations.

From indirect measurements

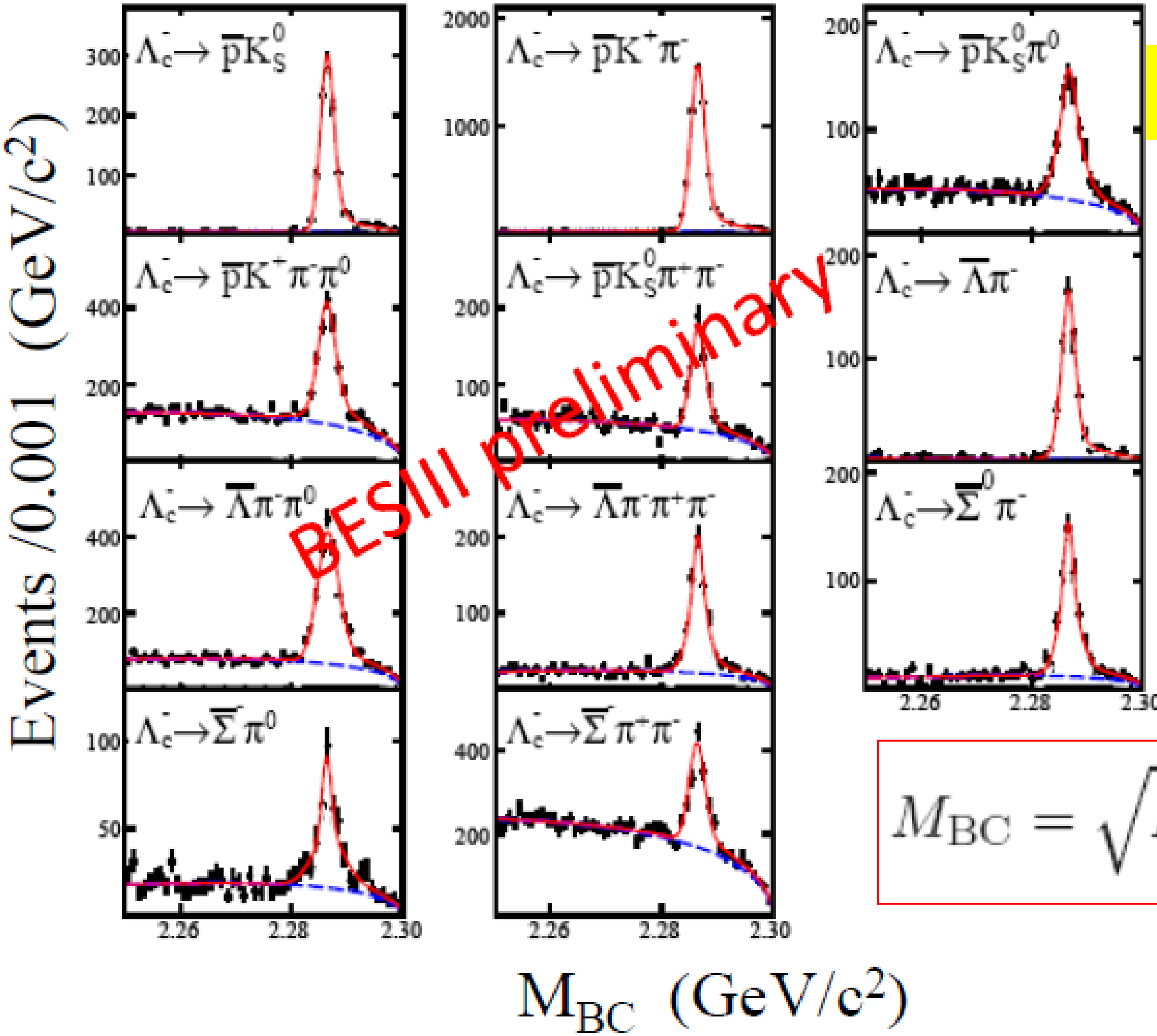
$B(\Lambda_c^+ \to \Lambda e^+ \upsilon_e) = (2.1 \pm 0.6)\%$ PDG 2014

Using recent BELLE measurement of $\boldsymbol{B}$ ($\Lambda_C^+ \to$p$K^- \pi^+$), we get $(2.9 \pm 0.5)\%$

- Theoretical predictions for branching fraction of $\Lambda_c^+ \to \Lambda e^+ \upsilon_e$ ranges from 1.4% to 9.2%.
- Thus, measuring $B(\Lambda_c^+ \to \Lambda e^+ \upsilon_e)$ will provide very important experimental information for
    1) Testing the theoretical predictions for $B(\Lambda_c^+ \to \Lambda e^+ \upsilon_e)$.
    2) Calibrating the LQCD calculations.
    3) Additionally can help in determining CKM elements.

Singly Tagged Λ_c^- baryons

✓ Fitting function: Signal Shape⇨double-Gaussian plus Argus



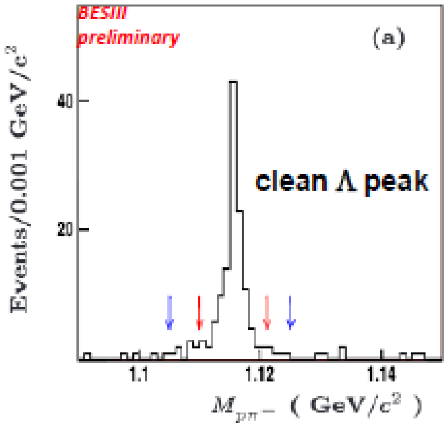
567pb⁻¹ @ 4.6 GeV

11 single tag modes are used to reconstruct singly tagged Λ_c^- baryons.

$$M_{\rm BC} = \sqrt{E_{\rm beam}^2 - |\vec{p}_{\Lambda_c^-}|^2}$$

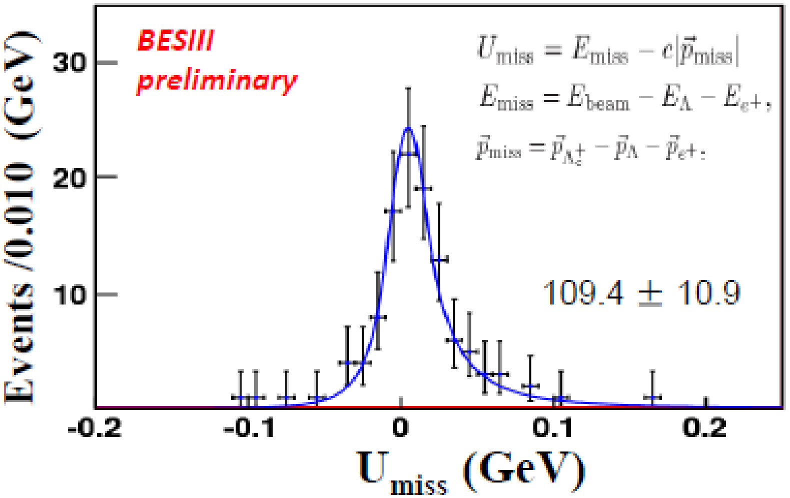
Candidate Events and Results

We detect a p, π^- and e^+ among the remaining tracks from the ST Λ_c^- and require p and π^- are from Λ.



✓ Fitting function:

- ➢ signals: Gaussian with two power law tails
- ➢ backgrounds: 1st order polynomial



After subtraction of the following backgrounds:

- non-ST events: negligible
- Λ sidebands: 1.4 ± 0.8
- $\Lambda\mu^+\nu + \Lambda\pi^+\pi^0 + \Lambda\pi^+ = 4.5 \pm 0.5$

we obtain signal yields: 103.5 ± 10.9

Then $$B(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (3.63 \pm 0.38 \pm 0.??)\%$$

Statistics limited measurement. Systematic error is smaller than statistical error.

Summary

- Based on the 567 pb^{-1} of e^{+} e^{-} collision data at center-of-mass energy of 4.6 GeV collected with the BESIII detector at BEPCII, we have a unique opportunity to measure Λ_C decay BFs at $\Lambda_C^+\Lambda_C^-$ pair threshold.
- BFs of 12 hadronic Λ_C decay modes are measured with DT method and a global fit to improve precision.
- BF of semi-leptonic $\Lambda_c^+ \rightarrow \Lambda e^+ \upsilon_e$ decay is measured with a DT method.
- 12 of 13 modes are the first model-independent measurements of the absolute branching fraction of Λ_C decays.
- Significant statistical improvement over current PDG measurements

Thank you

Λ_c selection criteria

mode
$\Lambda_c \to pK_S$
$\Lambda_c \to pK^-\pi^+$
$\Lambda_c \to pK_S\pi^0$
$\Lambda_c \to pK_S\pi^+\pi^-$
$\Lambda_c \to pK^-\pi^+\pi^0$
$\Lambda_c \to \Lambda\pi^+$
$\Lambda_c \to \Lambda\pi^+\pi^0$
$\Lambda_c \to \Lambda\pi^+\pi^-\pi^+$
$\Lambda_c \to \Sigma^0\pi^+$
$\Lambda_c \to \Sigma^+\pi^0$
$\Lambda_c \to \Sigma^+\pi^+\pi^-$
$\Lambda_c \to \Sigma^+\omega$

- **charged track**
  - $|Vr|<1.0$cm, $|Vz|<10.0$cm; $|\cos\theta|<0.93$
- **PID (use SimplePIDSvc-06)**
  - K : prob(K)>0 && prob(K)>prob(π)
  - π : prob(π)>0 && prob(π)>prob(K)
  - p : prob(p)>0 && prob(p)>prob(K) && prob(p)>prob(π)
- **K_S (Λ)**
  - π^+ and π^- (p and π^-) with $|Vz|<20.0$ cm , $|\cos\theta|<0.93$, and no PID
  - Primary vertex fit, $\chi^2<100$
  - Second vertex fit, $L/\sigma>2$
  - $0.487 < M(\pi^+\pi^-) < 0.511$ GeV/c^2 ($1.111 < M(p\pi^-) < 1.121$ GeV/c^2)
- **π^0**
  - $E_{barrel}>0.025$ GeV, ($|\cos\theta|<0.8$) $E_{endcap}>0.05$ GeV ($0.84<\cos\theta<0.92$)
  - $0\leq$ TDC ≤ 14
  - $0.115 < M(\gamma\gamma) < 0.150$ GeV/c^2
  - 1C kinematic fit, $\chi^2<200$
- **Σ^0**
  - $E_{barrel}>0.025$ GeV, ($|\cos\theta|<0.8$) $E_{endcap}>0.05$ GeV ($0.84<\cos\theta<0.92$)
  - $0\leq$ TDC ≤ 14
  - $1.179 < M(\Lambda\gamma) < 1.203$GeV/$c^2$
- **Σ^+**
  - $1.176 < M(p\pi^0) < 1.200$ GeV/c^2
- **ω**
  - $0.76 < M(\pi^+\pi^-\pi^0) < 0.80$ GeV/c^2

Global fit

Matrix of efficiency-corrected yields (c):

$$c = E^{-1}n$$

E is the signal efficiencies matrix (24x24)

n is the yields contain ST and DT (24x1)

Least squares fitter constrains all BF simultaneously:

$$\chi^2 \equiv (c - \tilde{c})^T V_c^{-1}(c - \tilde{c}) + 2\lambda_\alpha^T g(\tilde{c}, m)$$

Where m indicates unknown parameters(12 BF and $N_{\Lambda_c \overline{\Lambda_c}}$, 13x1)

λ are the vectors of Lagrange multipliers

Minimizing χ^2 optimizes the value of m

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