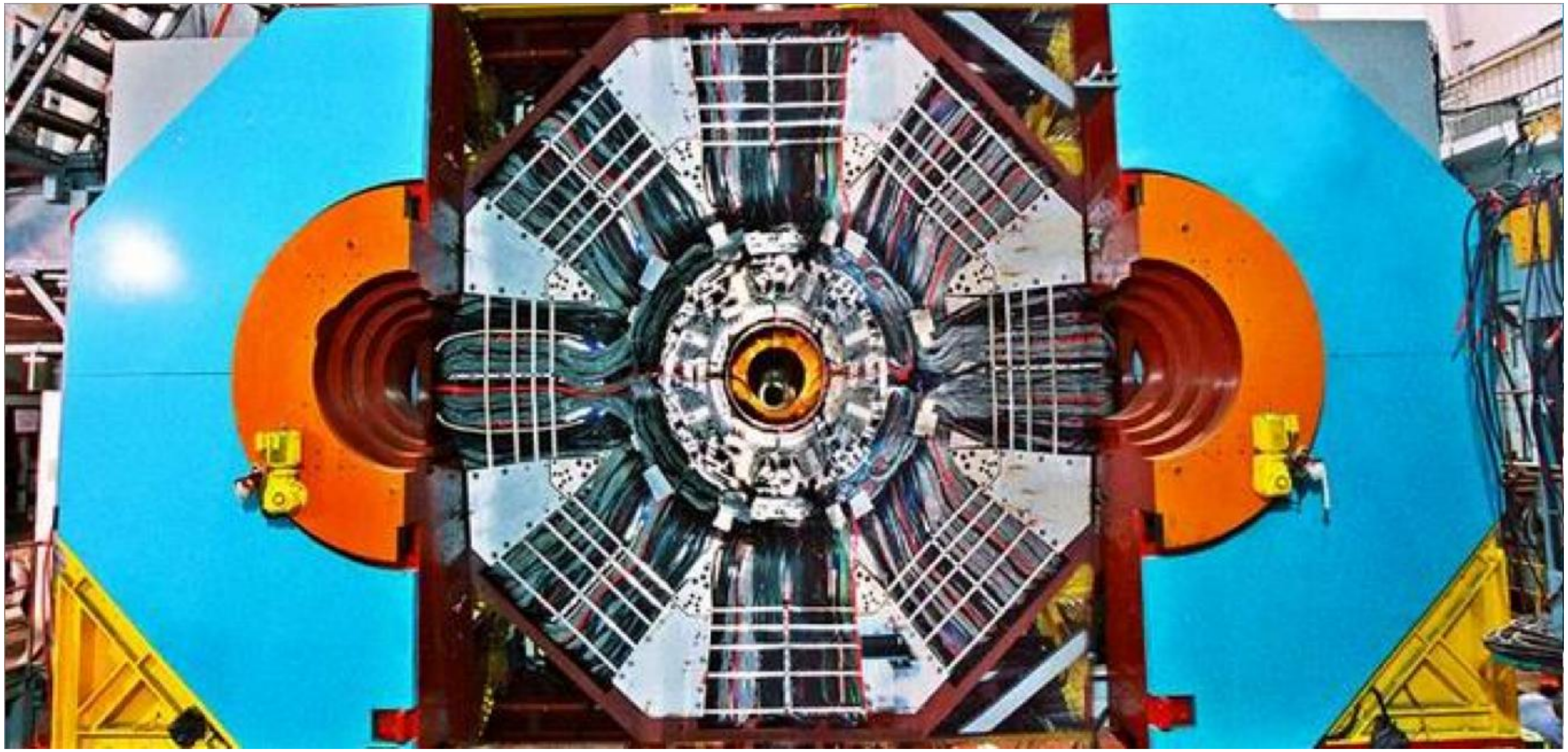

Λ_c decays at BESIII

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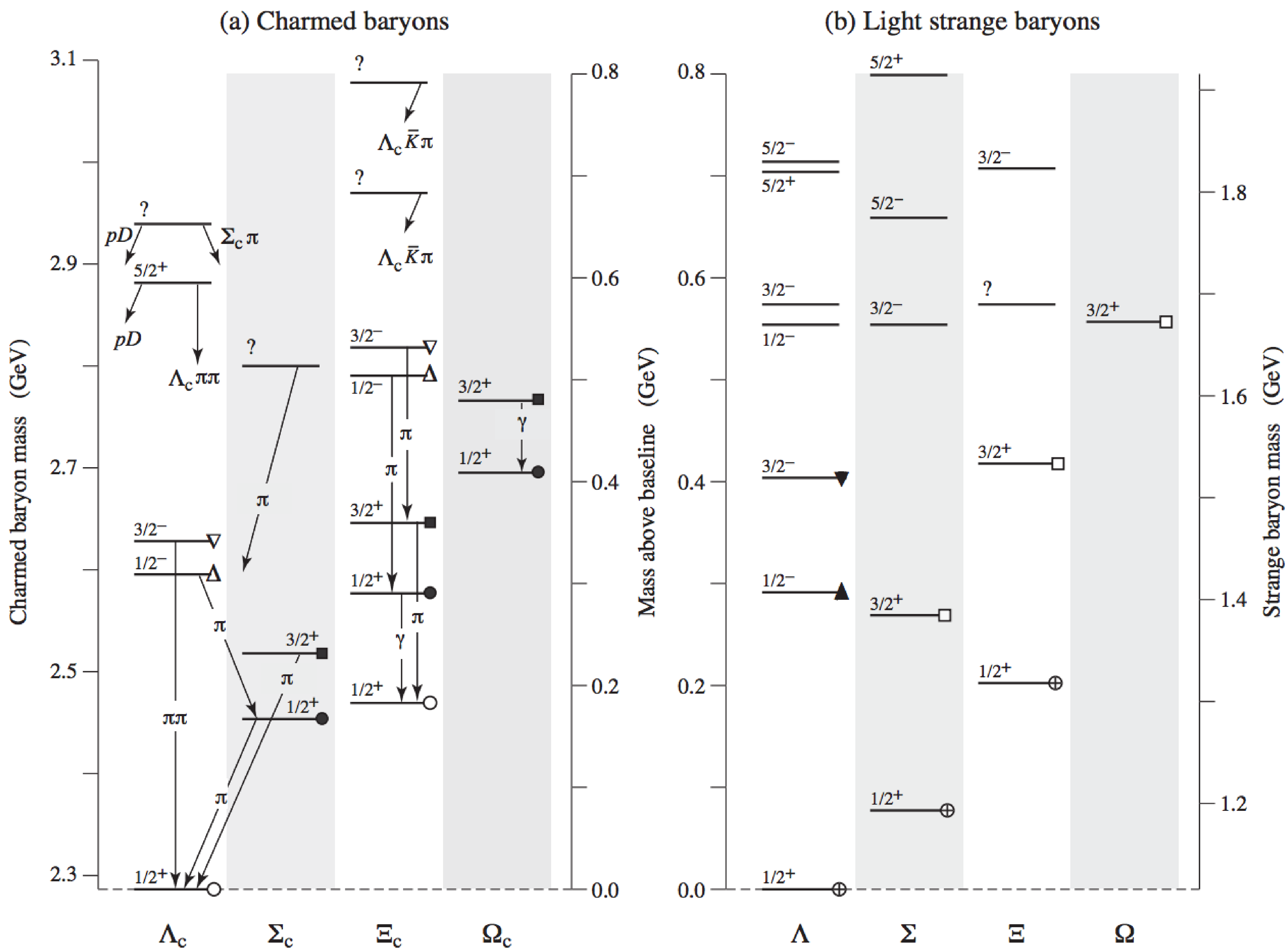
Charm 2015, WSU, USA

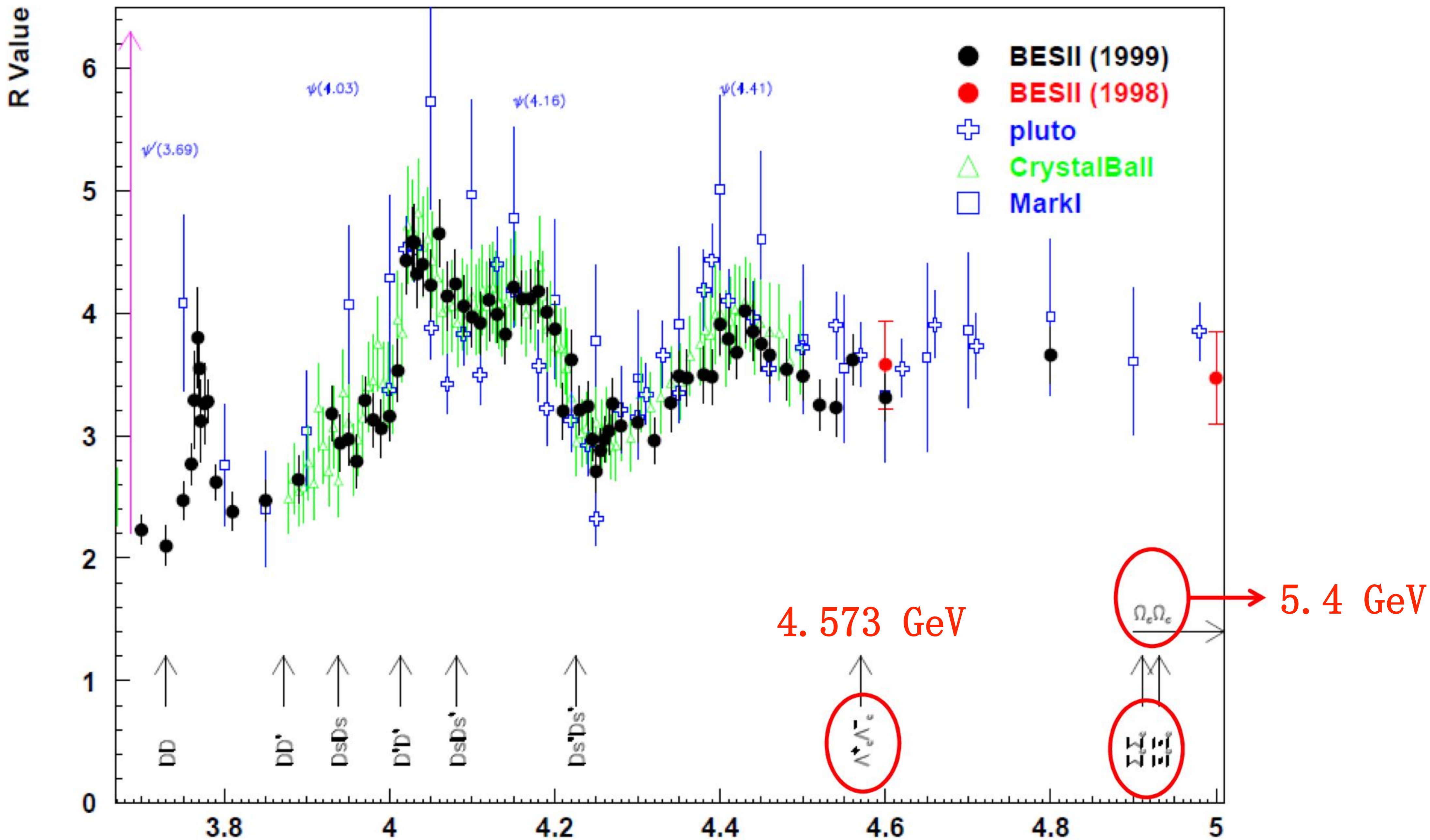
Outline

- **Introduction**
- **Measurements at BESIII (preliminary)**
  - ✓ **Λ_c^+ hadronic decays**
  - ✓ **Λ_c^+ semi-leptonic decays**
- **More potentials at BESIII**
- **Summary**

Charm baryon vs. strange baryon



Charmed baryon thresholds



BESIII data taken

In 2014, BESIII took data above Λ_c pair threshold and run machine at 4.6GeV with excellent performance!
This is a marvelous achievement of BES!

available data set at BESIII

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

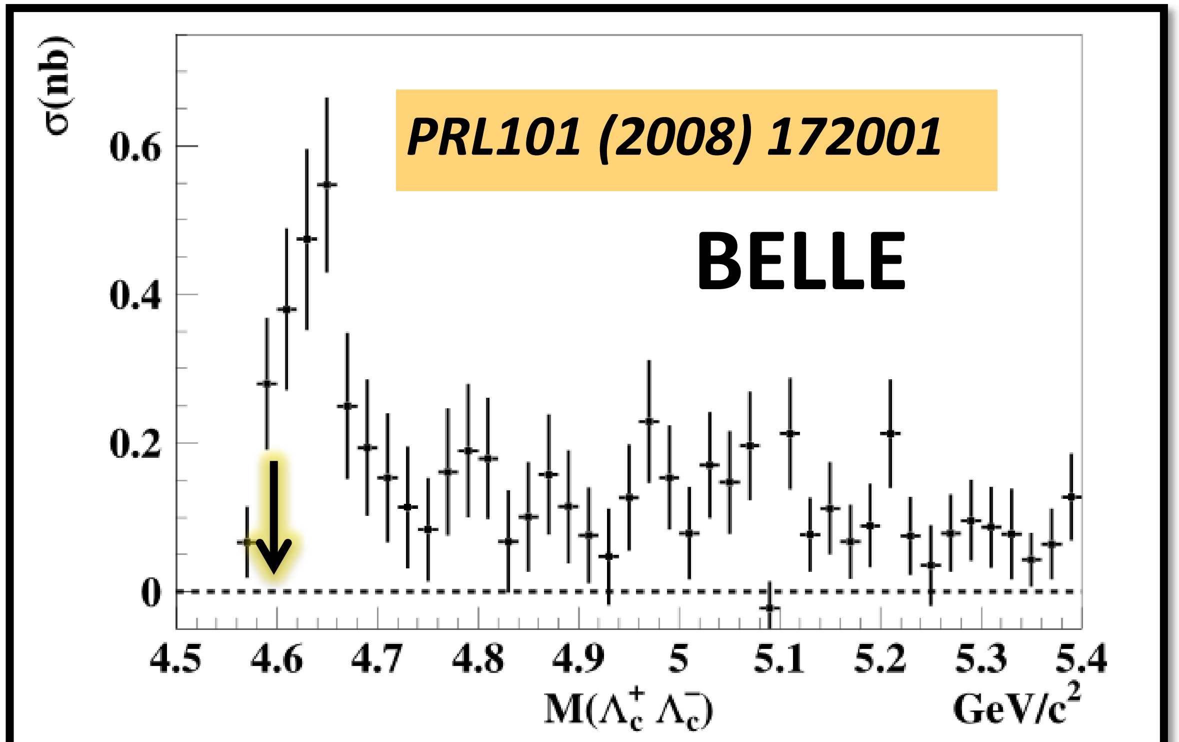


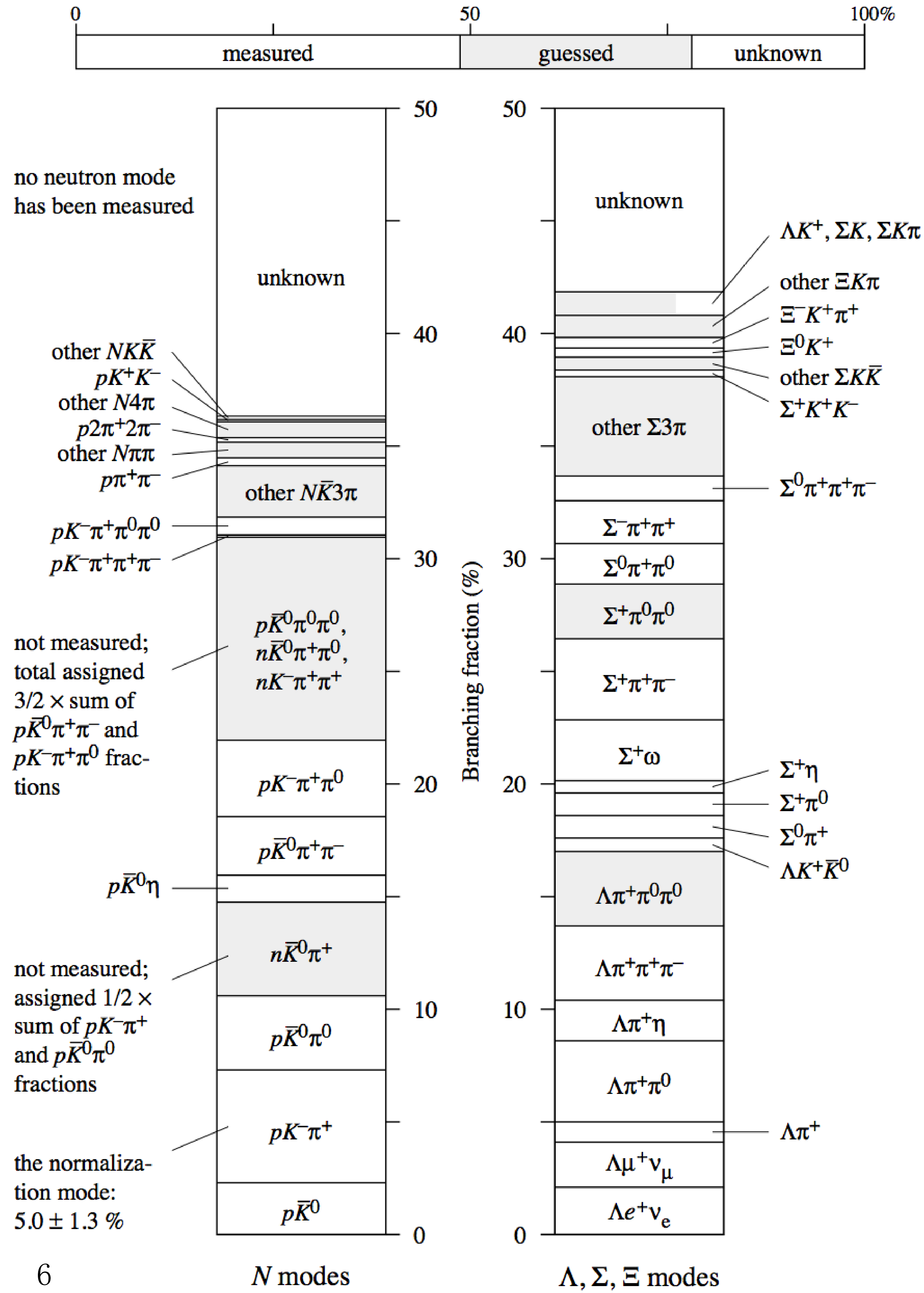
FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.

First time to systematically study charmed baryon at threshold!

Λ_c^+ decay rates

More reliable to be treated in HQET than mesons as it consists of a heavy quark and a spin and isospin zero light diquark

- absolute BF's has large uncertainties
- semi-leptonic decay modes have not been fully explored; The only measured $BF(\Lambda_c \rightarrow \Lambda l^+ \nu_l)$ has large uncertainties of $\delta B/B \sim 16\%$
- no neutron modes have been measured

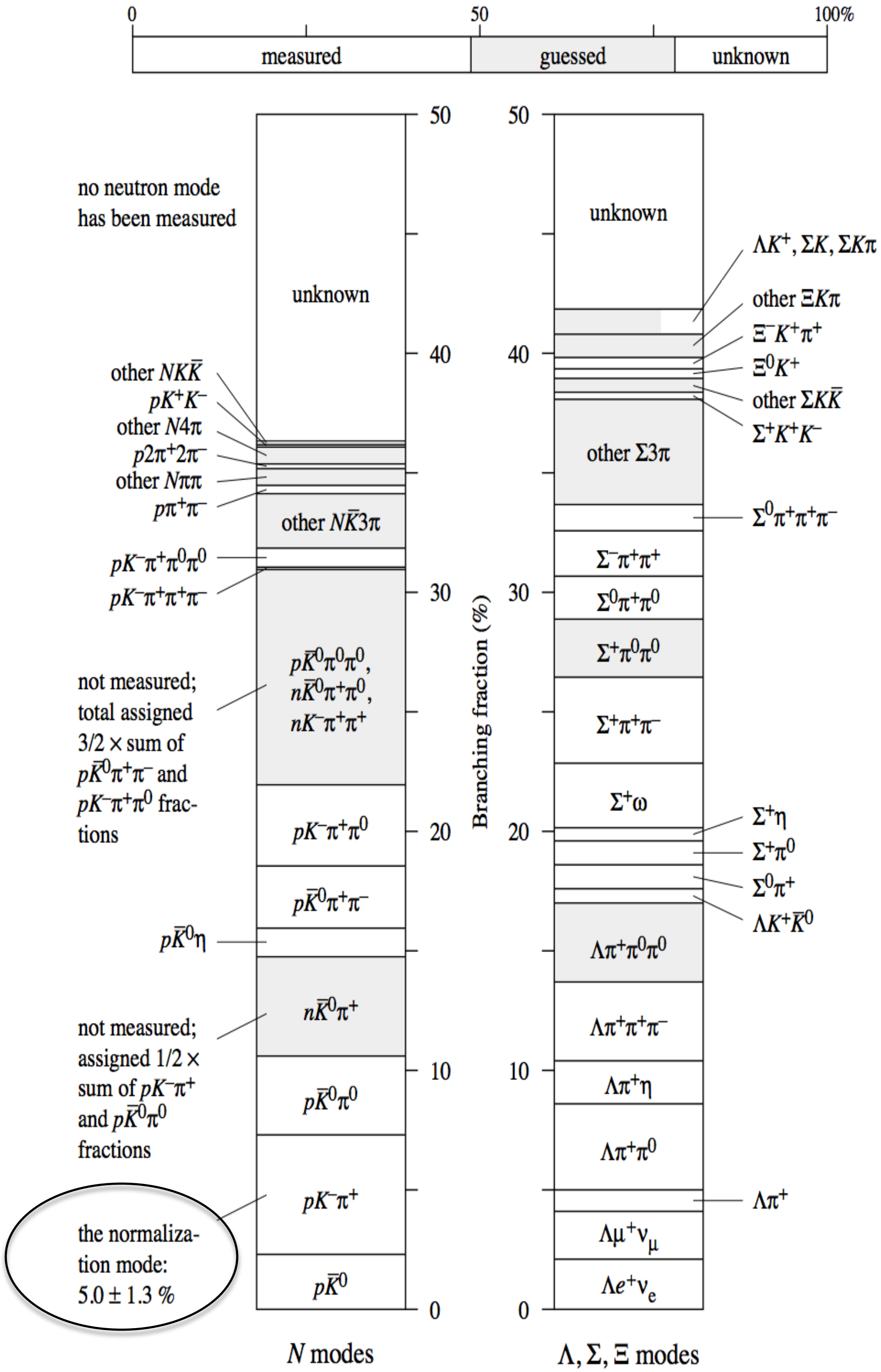


Absolute BF's of Λ_c^+ hadronic decays

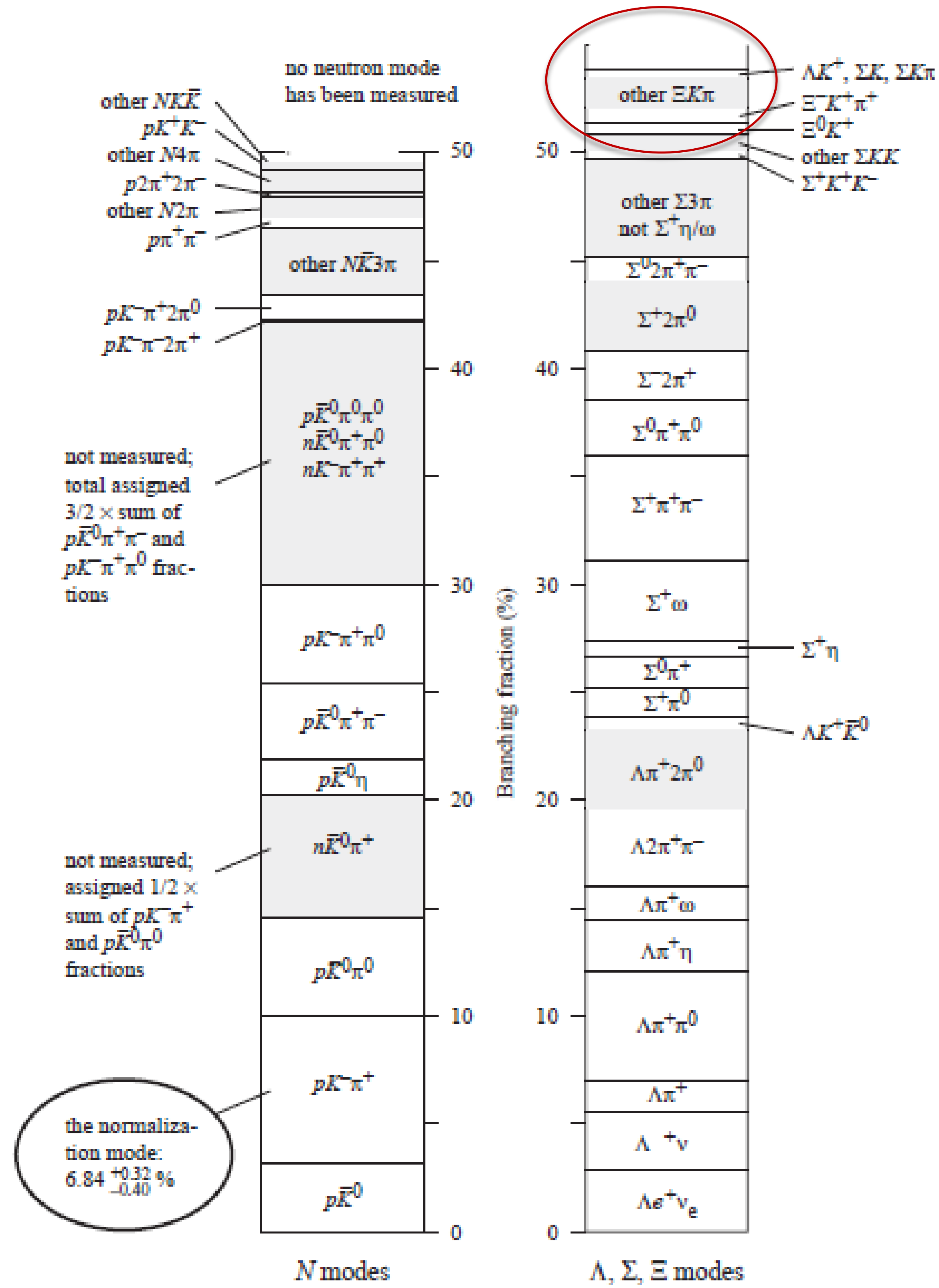
- Absolute branching fractions (BF) of Λ_c^+ decays are still not well determined since its discovery 30 years ago
  - BFs of all the decay modes (~85%) are measured relative to $\Lambda_c^+ \to pK^-\pi^+$
  - Charm counting ➔ test SM
  - However, no completely model-independent measurements of the absolute BF of $\Lambda_c^+ \to pK^-\pi^+$ (from Argus and CLEO very old results)
    uncertainties of BFs of Λ_c^+ decays are 25%~40% in PDG2014
- Until Belle's first "model-independent" measurement:
  $B(\Lambda_c^+ \to pK^-\pi^+) = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$
  precision reaches to 4.7%

  [PRL113(2014)042002]
- However, measurement using the threshold pair-productions via e^+e^- annihilations is unique:
  the most simple and straightforward

PDG2014



after adopting Belle's

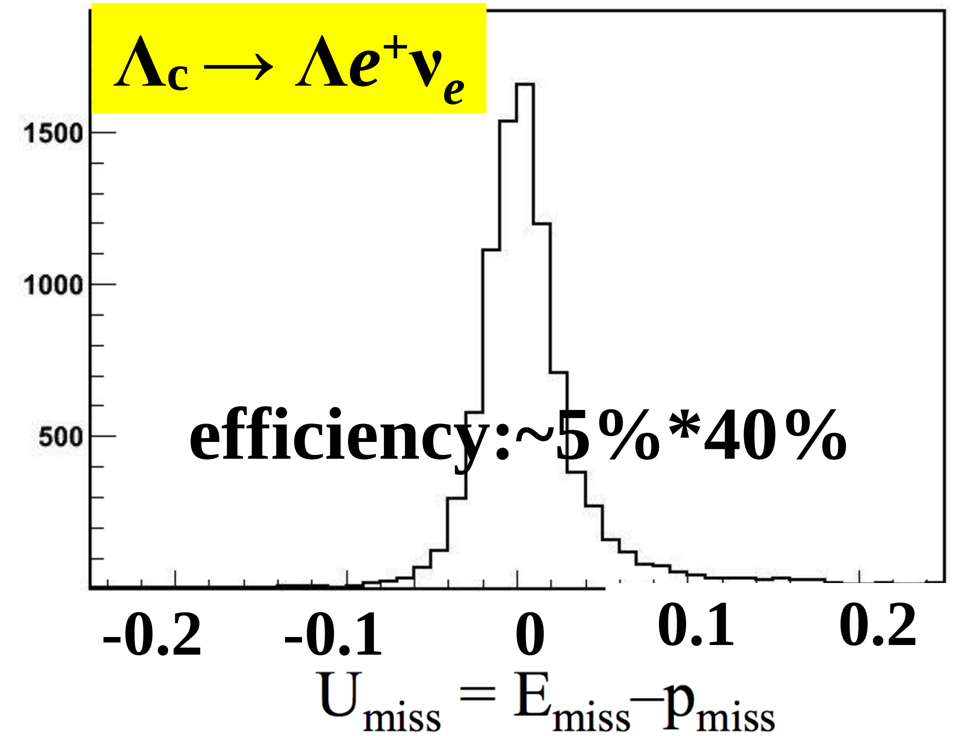


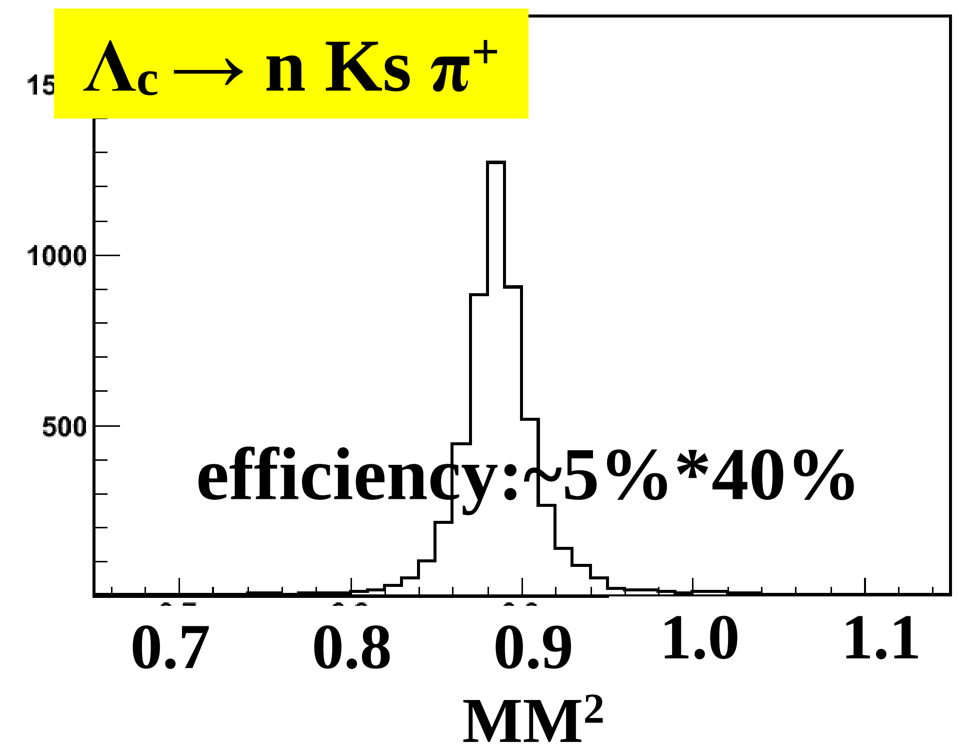
Measuring decay rate with missing particle

567/pb data @4.6GeV

Production at threshold has advantages on this type of decays!

- semi-leptonic decay rates BF($\Lambda_c \rightarrow \Lambda l^+ \nu_l$)
  - ✓ So far, large uncertainties of BF (δB/B~16%) mainly through partial reconstruction in inclusive productions at $\sqrt{s}$~10.4GeV at MARKII and CLEO
  - ✓ Systematic uncertainty (δB/B~14%) dominated due to the Λ_c SL modes
  - ✓ BESIII 567/pb data @4.6GeV will provide the measurement up to precision of **δB/B~10%** by using DT method
- no neutron modes has been measured
  - ✓ the first measurement of these modes up to the level of BF~0.5%.



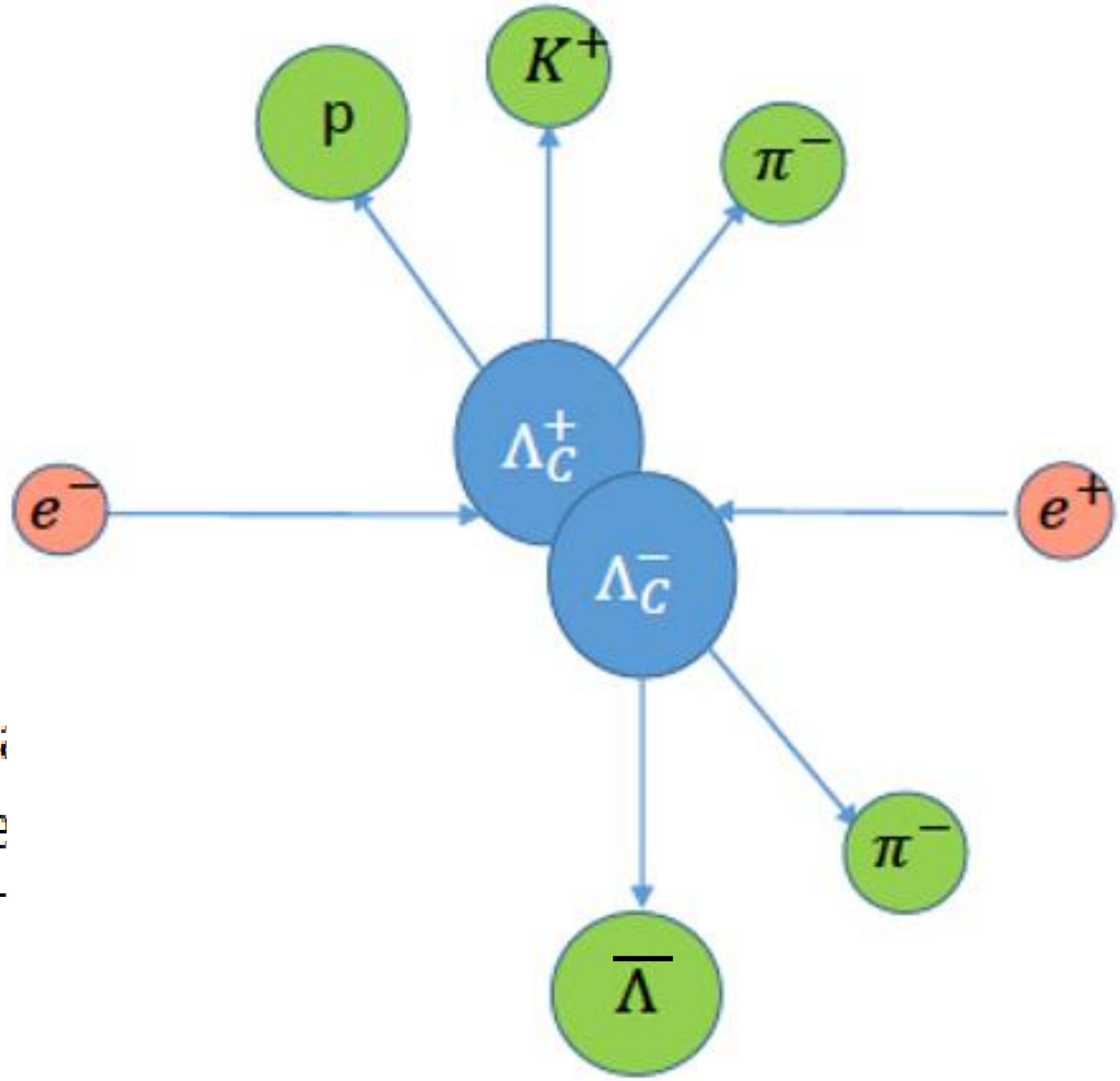


Measurements of hadronic BFs

- Produced in the pair production $e^+e^- \to \Lambda_c^+\Lambda_c^-$ at 4.6GeV ;
  - kinematics does not allow additional particle produced along with the $\Lambda_c^+\Lambda_c^-$ pair
  - fully reconstruct the pairs and take their yield ratios to measure the BFs:
    ratio of single tags (ST) and double tags (DT)
- 567/pb data consists of more than 100K $\Lambda_c^+\Lambda_c^-$ pairs
  - sensitivity of BF reaches to the level of 0.1%
- 12 hadronic modes are being measured at the same time based on a global fit *[Chinese Phys. C37(2013)106201]*

charge conjugate modes are implied in the following slides.

Detection of Λ_c pairs



12 modes

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

Constructing pa
from final state

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

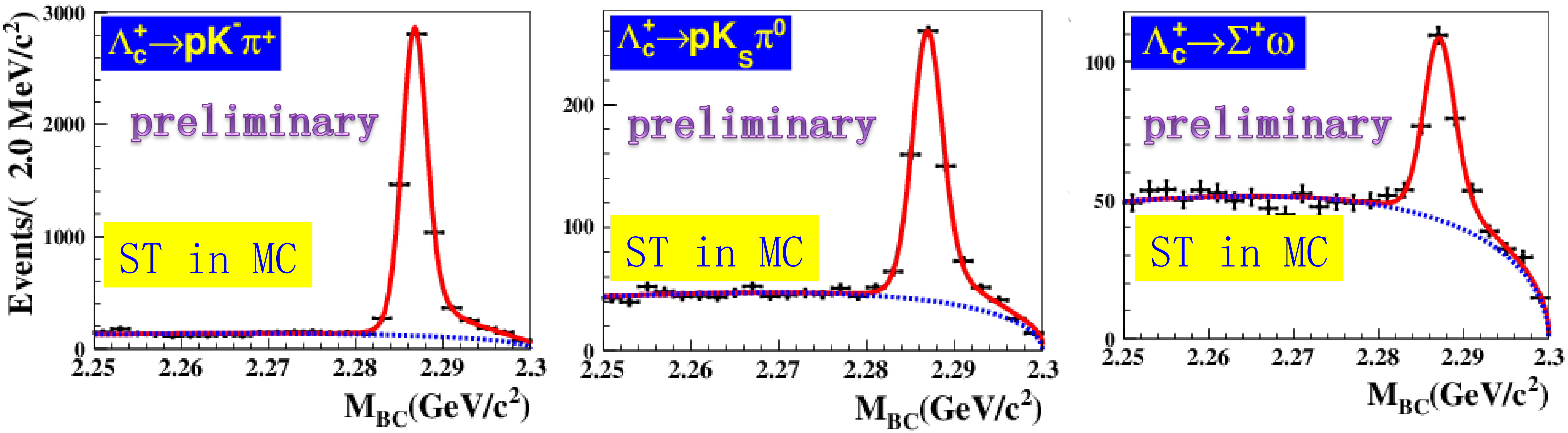
Estimation on the yields of the 12 modes

- Use energy difference (ΔE) to improve S/B
- Extract signal yields in the beam-constrained mass (M_{BC})

✓ ST yields $N_{i^+}^{ST} = N_{\Lambda_c^+\Lambda_c^-} \cdot \mathcal{B}_i \cdot \varepsilon_{i^+}^{ST}$

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

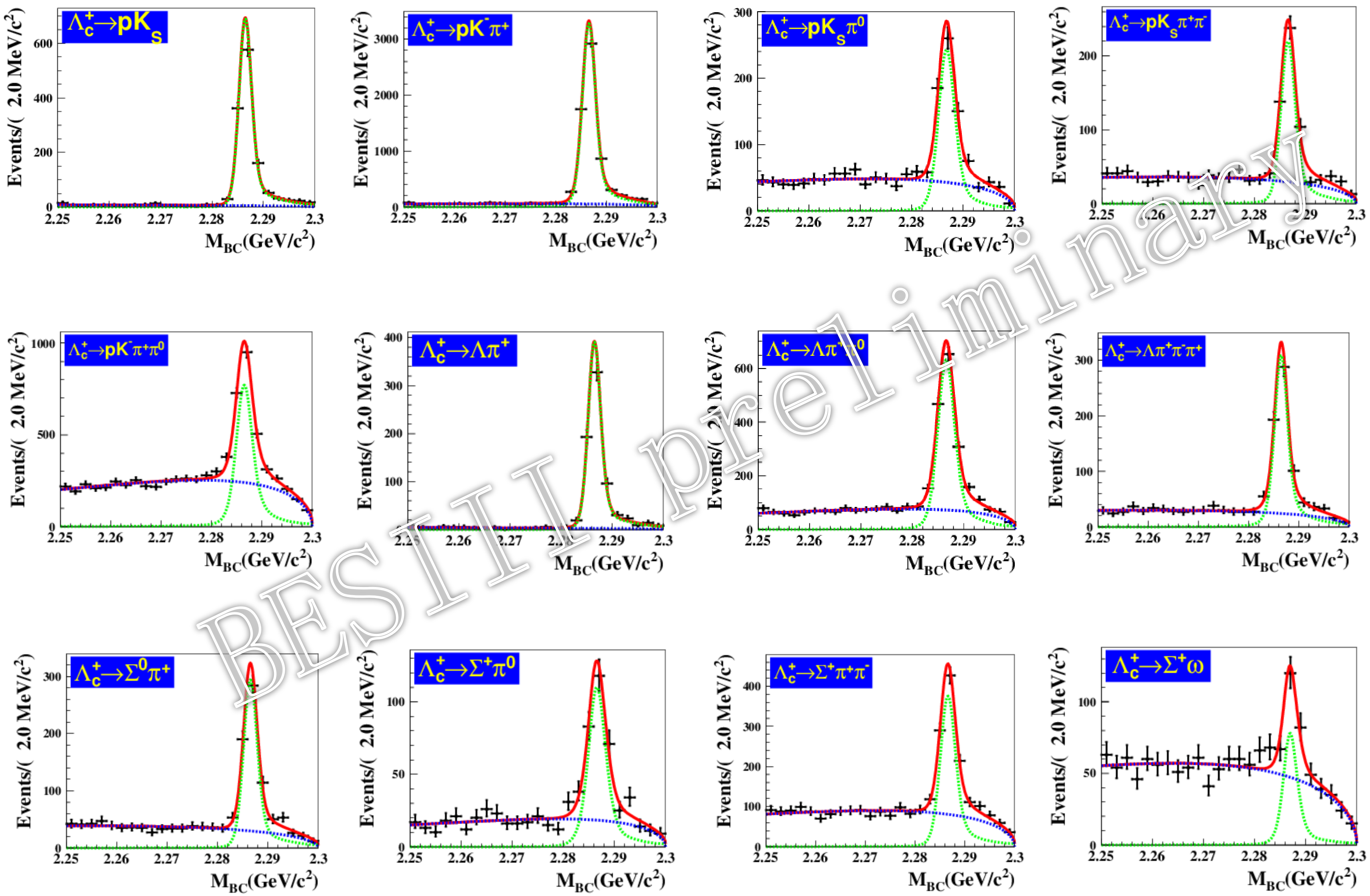
✓ DT yields $N_{i^+j^-}^{DT} = N_{\Lambda_c^+\Lambda_c^-} \cdot \mathcal{B}_i \cdot \mathcal{B}_j \cdot \varepsilon_{i^+j^-}^{DT}$



We tune ST MC simulations according to the decay pattern in data to better control of systematics.

BESIII

ST $\Lambda_c^{\pm}$ yields in data



data

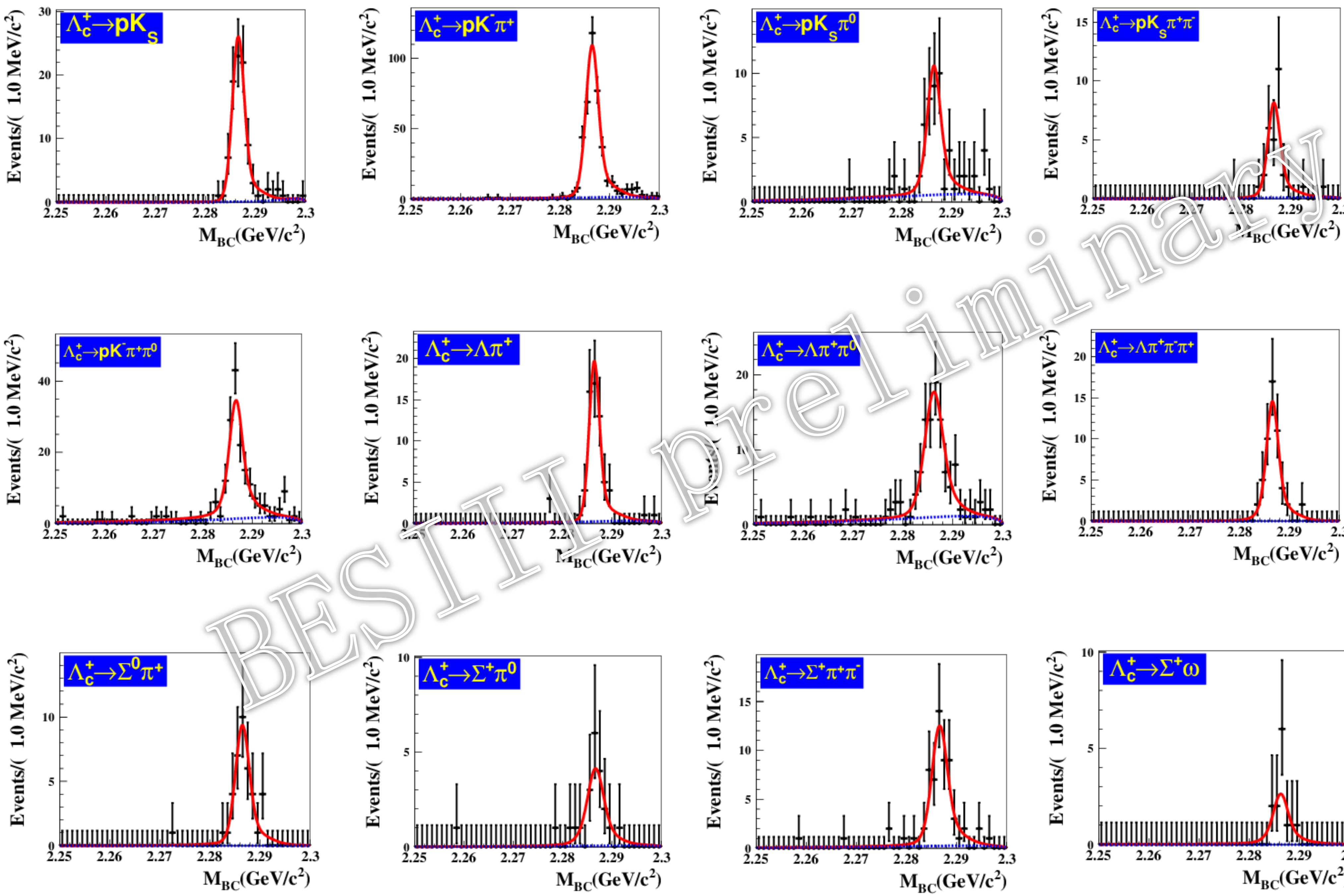
modes	N_i^{ST}
pK_S	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK_S\pi^0$	558 ± 33
$pK_S\pi^+\pi^-$	454 ± 28
$pK^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	586 ± 32
$\Sigma^+\pi^0$	271 ± 25
$\Sigma^+\pi^+\pi^-$	836 ± 43
$\Sigma^+\omega$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

ST sum:~15K

Very clean backgrounds

DT yields

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



data

Decay modes	N_{-j}^{DT}
pK_S	89 ± 10
$pK^-\pi^+$	390 ± 21
$pK_S\pi^0$	40 ± 7
$pK_S\pi^+\pi^-$	29 ± 6
$pK^-\pi^+\pi^0$	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

Hadronic branching fraction results

- a least square global fitter: simultaneous fit to the all tag modes while constraining the total Λ_c pair number, taking into account the correlations

Chinese Phys. C 37 , 106201 (2013)

BESIII prel.

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	

<u>only stat. errors</u>

- ✓ **$B(pK^-\pi^+)$: BESIII precision comparable with Belle's result**
- ✓ **BESIII rate $B(pK^-\pi^+)$ is smaller**
- ✓ **Improved precisions of the other 11 modes significantly**

BF of $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is a $c \to s l^+ \nu_l$ dominated process.
- Urgently needed for LQCD calculations.
- No direct absolute measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ available.

$$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (2.1 \pm 0.6)\% \qquad \text{PDG 2014}$$

scaling to (2.9±0.5)%, when taking the BELLE's B($pK^-\pi^+$)

However, this is not a direct measurement.

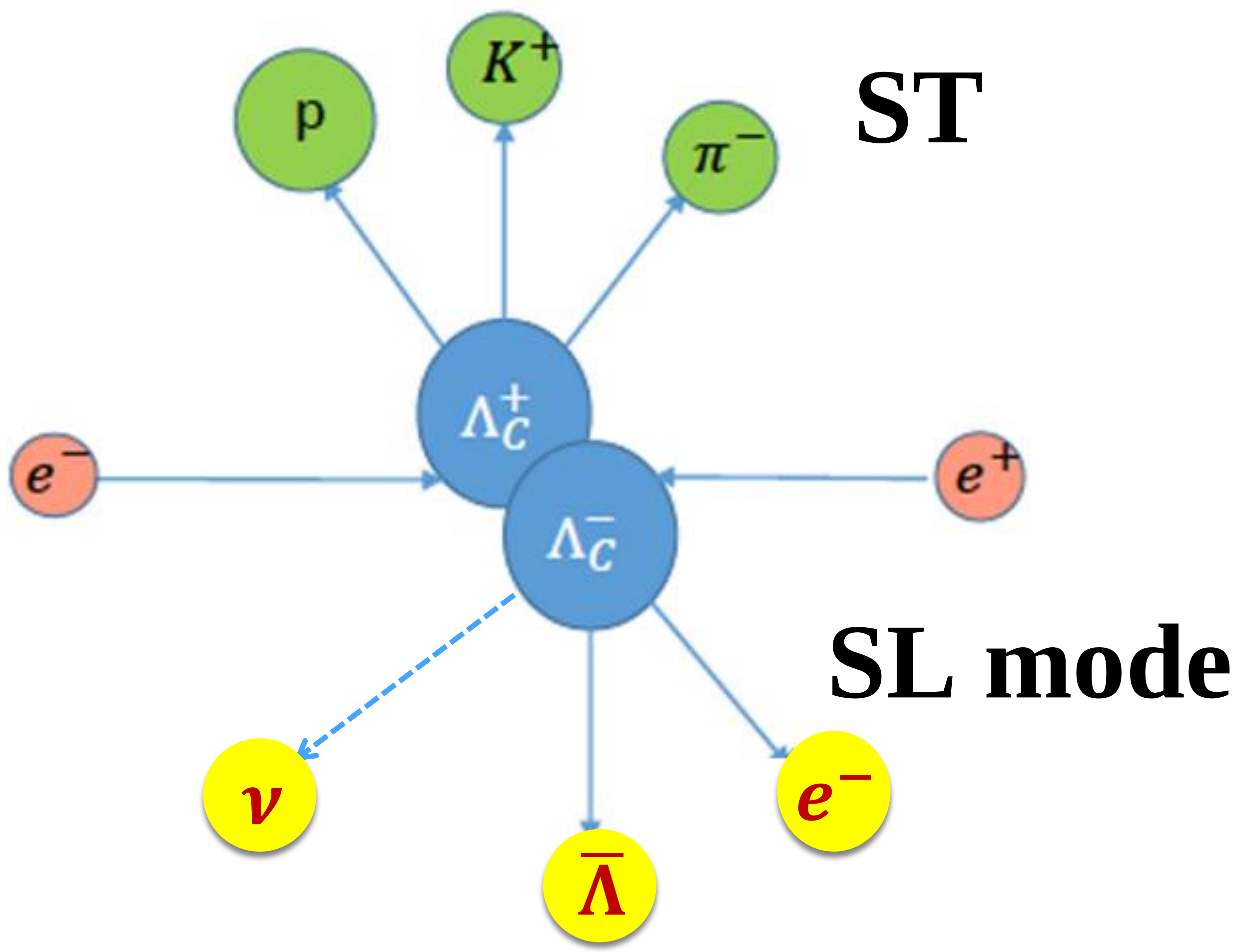
- Theoretical predications for branching fraction of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ ranges from 1.4% to 9.2%.
- Thus, measuring $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ will provide very important experimental information for
  1) testing the theoretical predications for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$.
  2) calibrating the LQCD calculations.
  3) addition information for determining CKM elements.

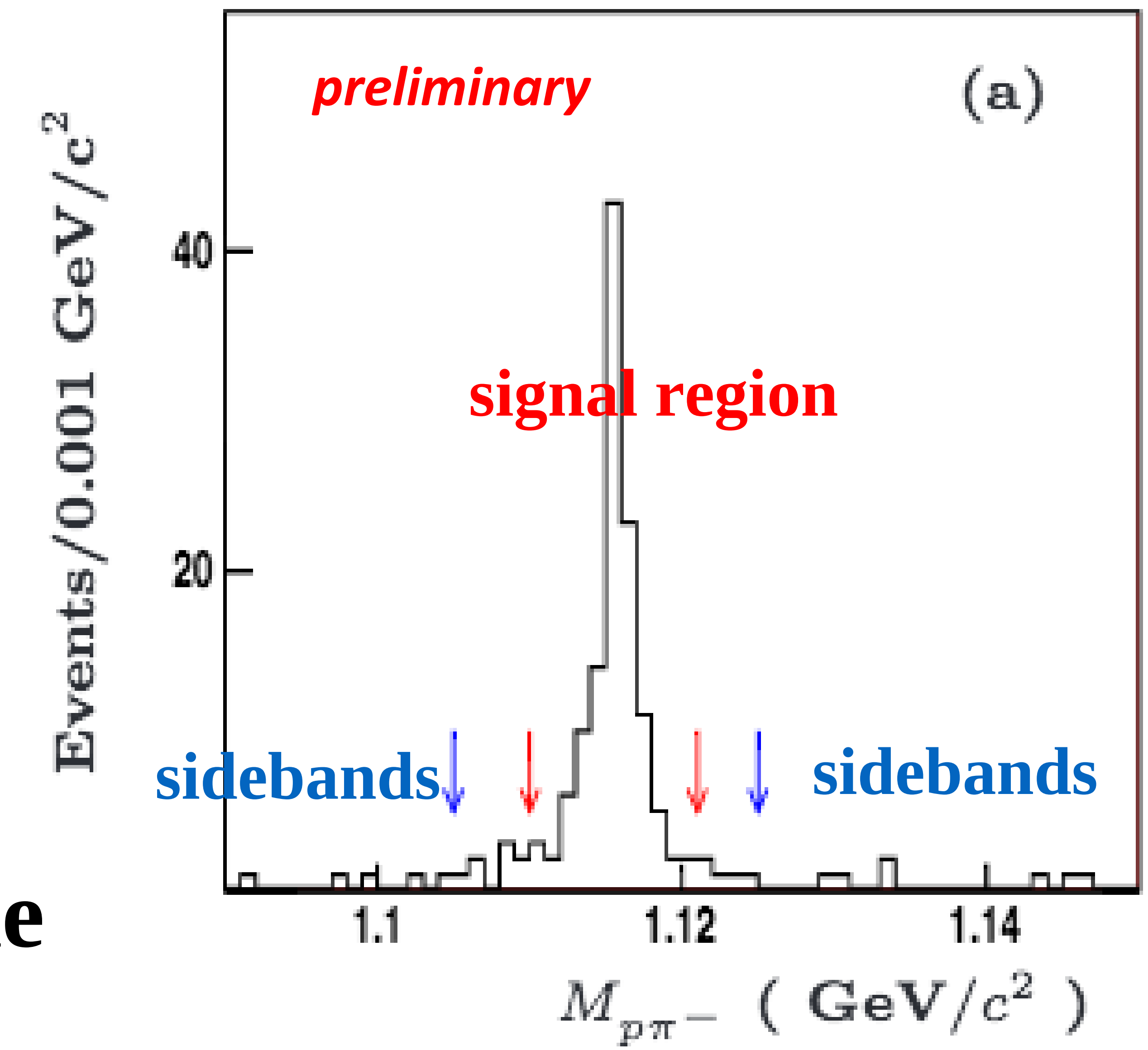
Candidate events for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

11 ST modes are used, except $\Sigma^+\omega$

567/pb @ 4.6 GeV

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



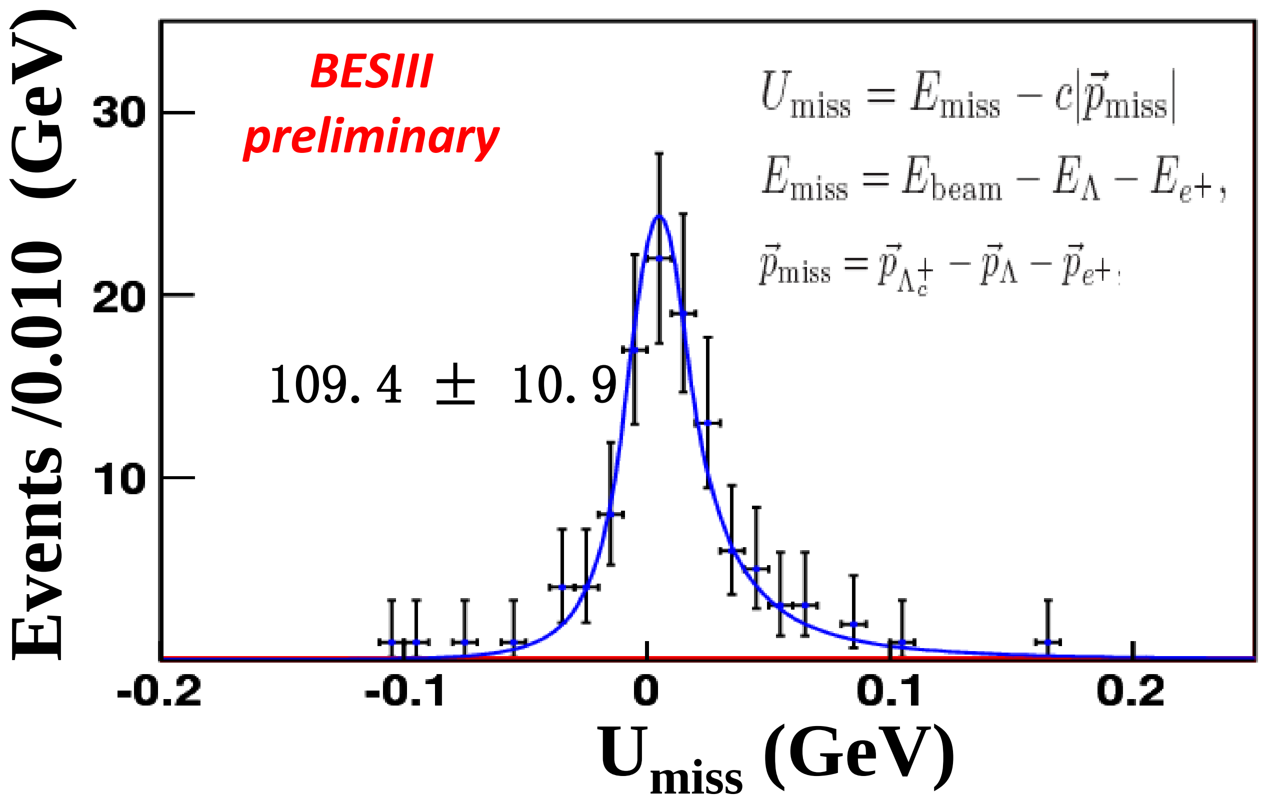


clean Λ peak

Candidate Events for $\Lambda_c^+ \rightarrow \Lambda e^+ \nu_e$

✓ Fitting function:

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



subtraction of backgrounds:

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

➔ **signal yields: 103.5 ± 10.9**

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

scaled PDG
(2.9±0.5)%

- Statistics limited measurement.
  ➔ systematic error smaller than statistical
- Best precision to date: twofold improvement

What is more potentials at BESIII

- Is 4.6GeV the BEPCII's ultimate?
- How about to go to the XS peak @4635MeV
  - ✓ Belle's ISR data has large uncertainties of ~25%
  - ✓ reduce uncertainties of the XS line shapes
- Prospects of increased threshold data set (naively say x10 statistics)
  - ✓ the intermediate structures in three-body decays via dedicated PWA analysis
  - ✓ more SL modes: $nl\nu$, $\Lambda^* l\nu$, $\Sigma X l\nu\ldots$
  - ✓ decay asymmetry parameters in Λ_c^+ hadronic weak decays, such as $\Lambda_c^+ \to BP$ and $\Lambda_c^+ \to BV$
  - ✓ searching for Λ_c^+ low rate decays and rare decays, such as weak radiative decay $\Lambda_c^+ \to \gamma\Sigma^+$, FCNC $\Lambda_c^+ \to pl^+l^-$, LNV
  - ✓ the spin-parity of Λ_c^-

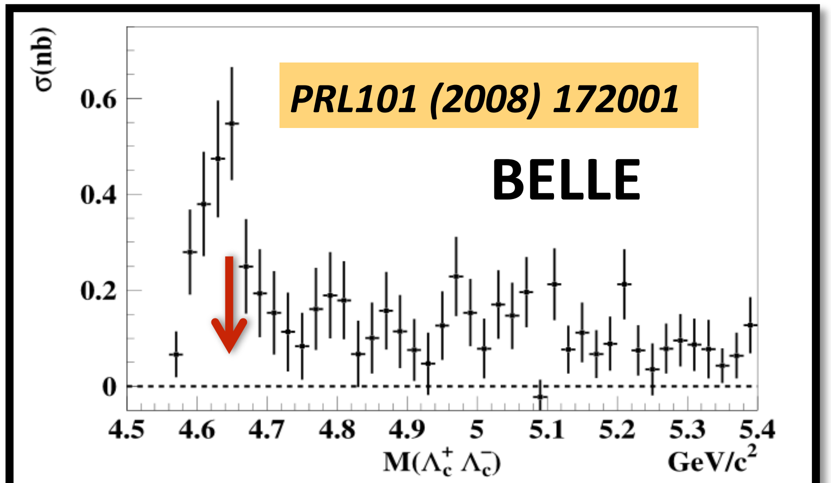
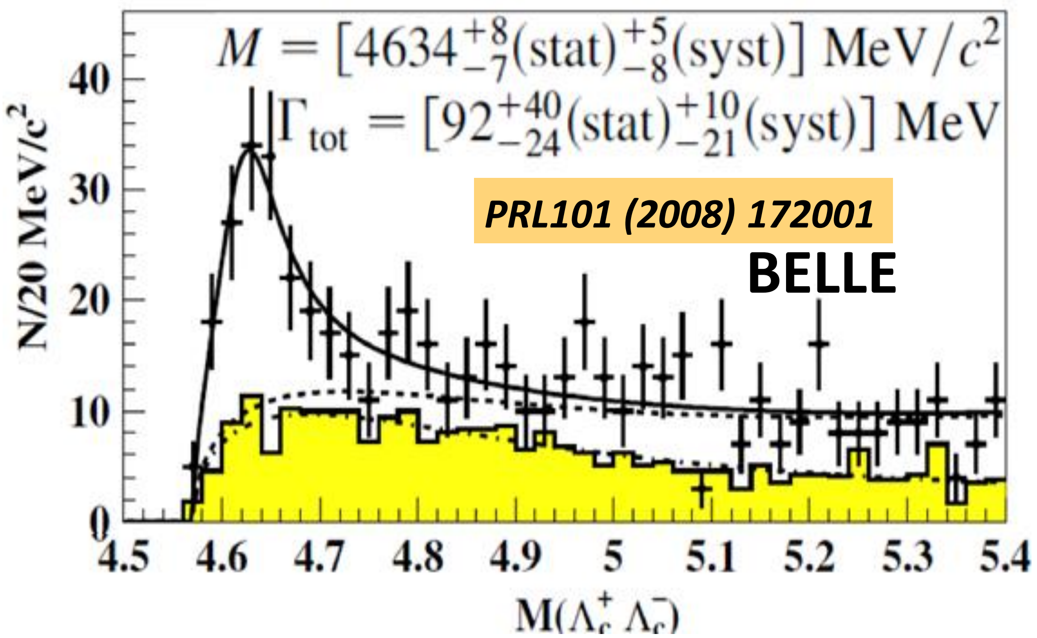


FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.



Summary

- BEPCII/BESIII accumulated ~567/pb data set @4.6GeV
- Opens a door to study the lowest charmed baryon state Λ_c^+
  - ➔ low backgrounds and high detection efficiency
- Several physics potentials has been and is being explored
  - ➔ absolute BFs of hadronic decays model-independently
  - ➔ Λ_c SL decays
  - ➔ …
- More threshold data set will be good/necessary to complete knowledge on the Λ_c decay dynamics.

Thank you!

谢谢！