Λ_c decays at BESIII

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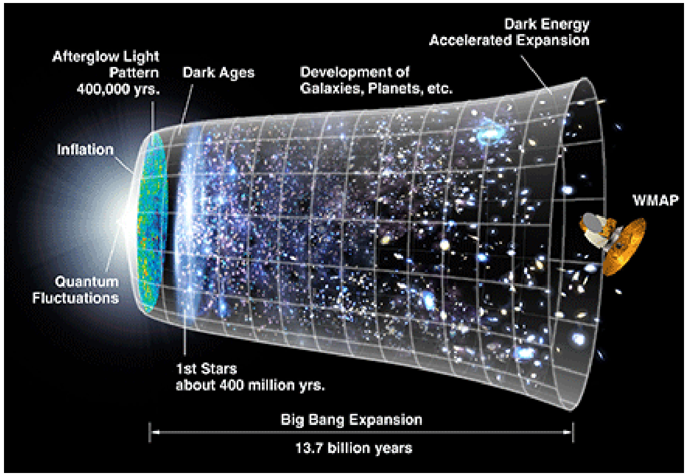
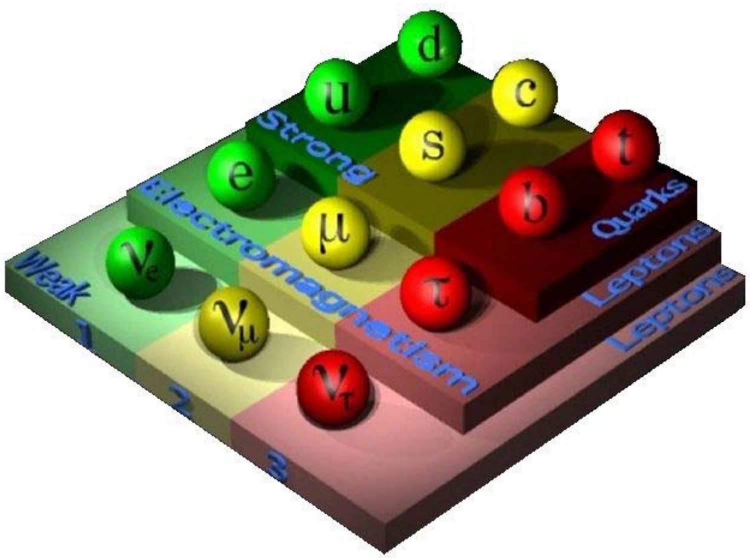
Baryons 2016, FSU, 2016.05

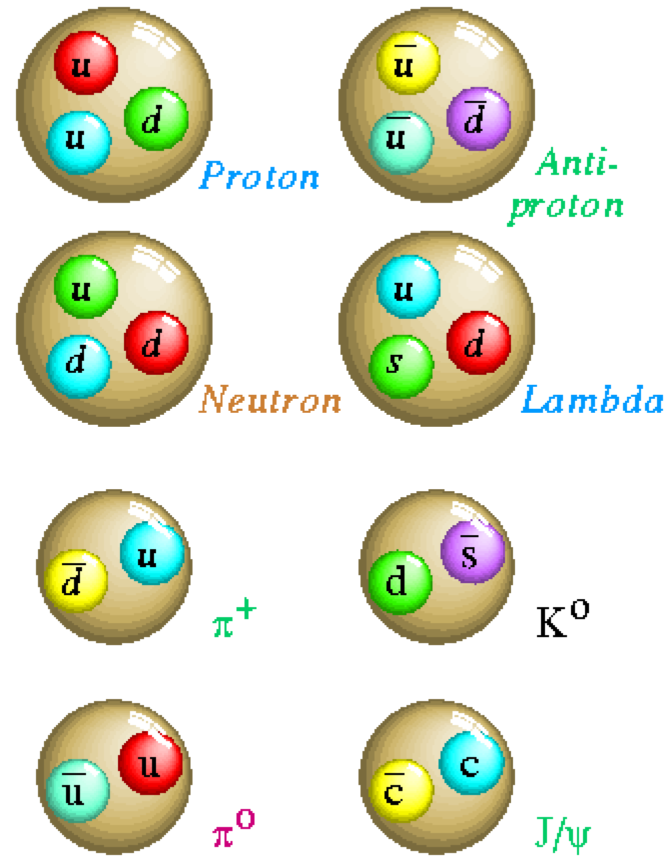
Overview

1. Introduction
   - Λ_c: the lightest charmed baryon
   - An overview of BESIII experiment
2. Λ_c decays at BESIII
   - Λ_c^+ hadronic decays
   - Λ_c^+ semi-leptonic decays
   - Λ_c^+ decays that involving the neutron
3. Prospects
4. Summary

The fundamental elements of our world

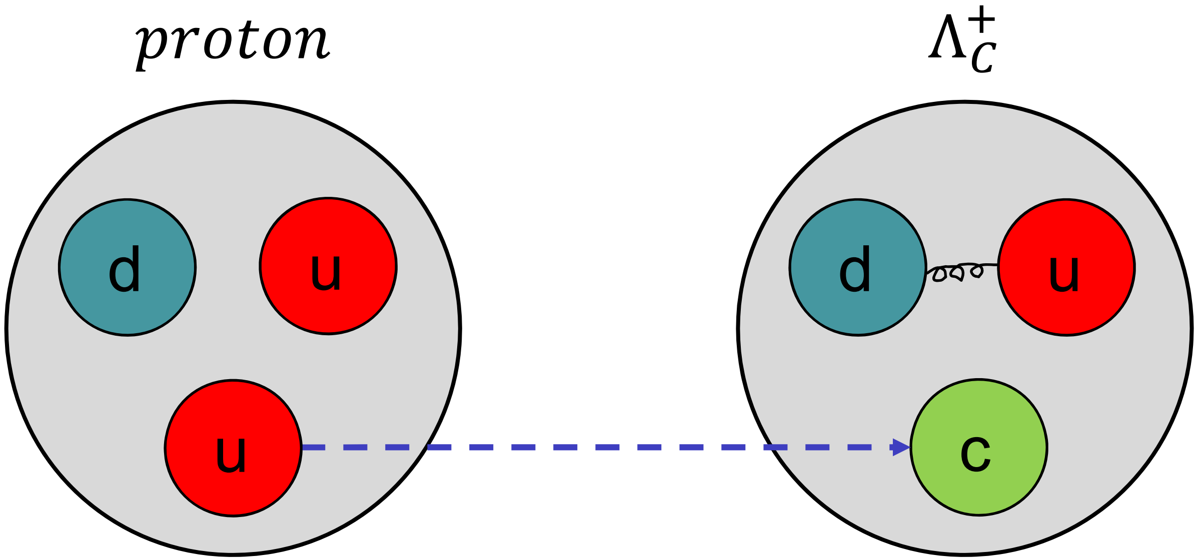






The quark model of Λ_c

The Λ_c baryon is composed of a heavy quark (c) and two light quarks (u & d).



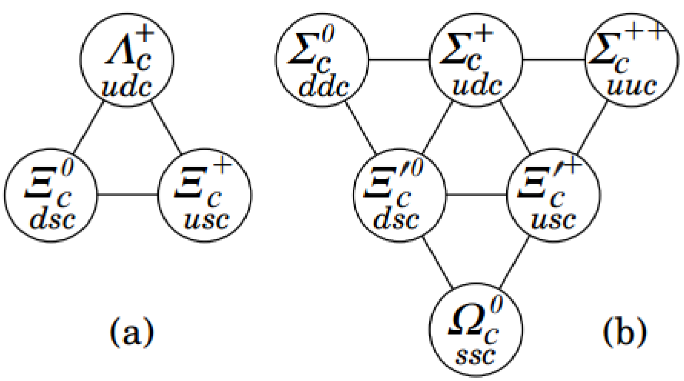
According to the HQET, the u-d quarks can be treated as a diquark that has zero spin and isospin, which indicates that:

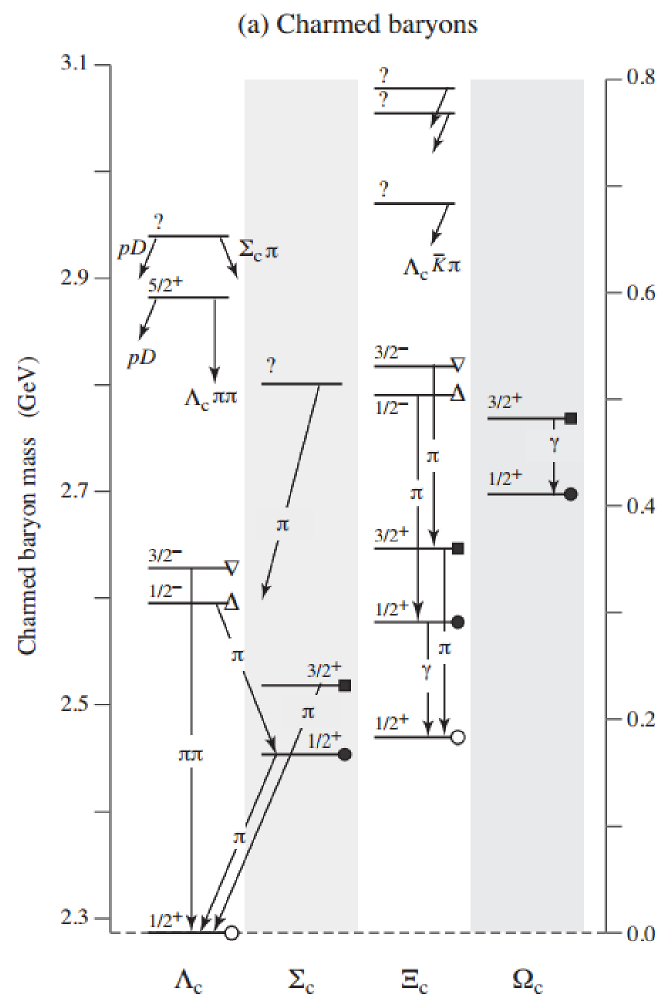
Λ_c can provide more powerful test on internal dynamics than mesons D/Ds.

The importance of of Λ_C

- Λ_C is the lightest charmed baryon, and most of the charmed baryons will eventually decay to Λ_C, which makes it the cornerstone of charmed baryons spectroscopy.

- Λ_C can also be used to tag the c-quark counting in the productions at higher energies.

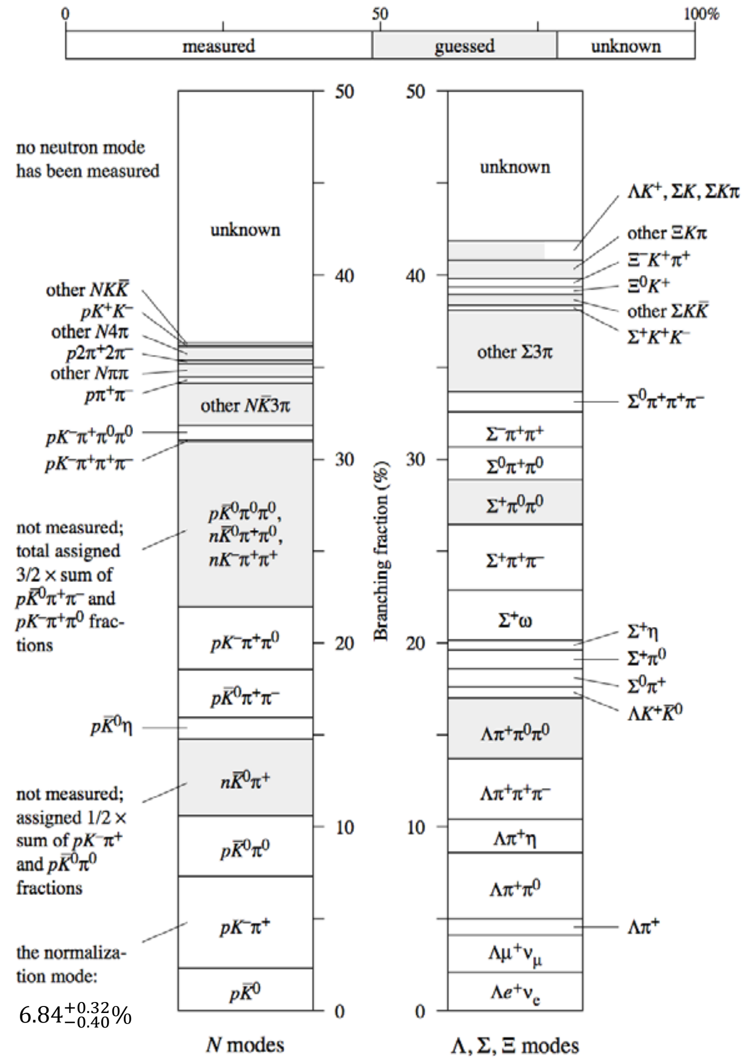




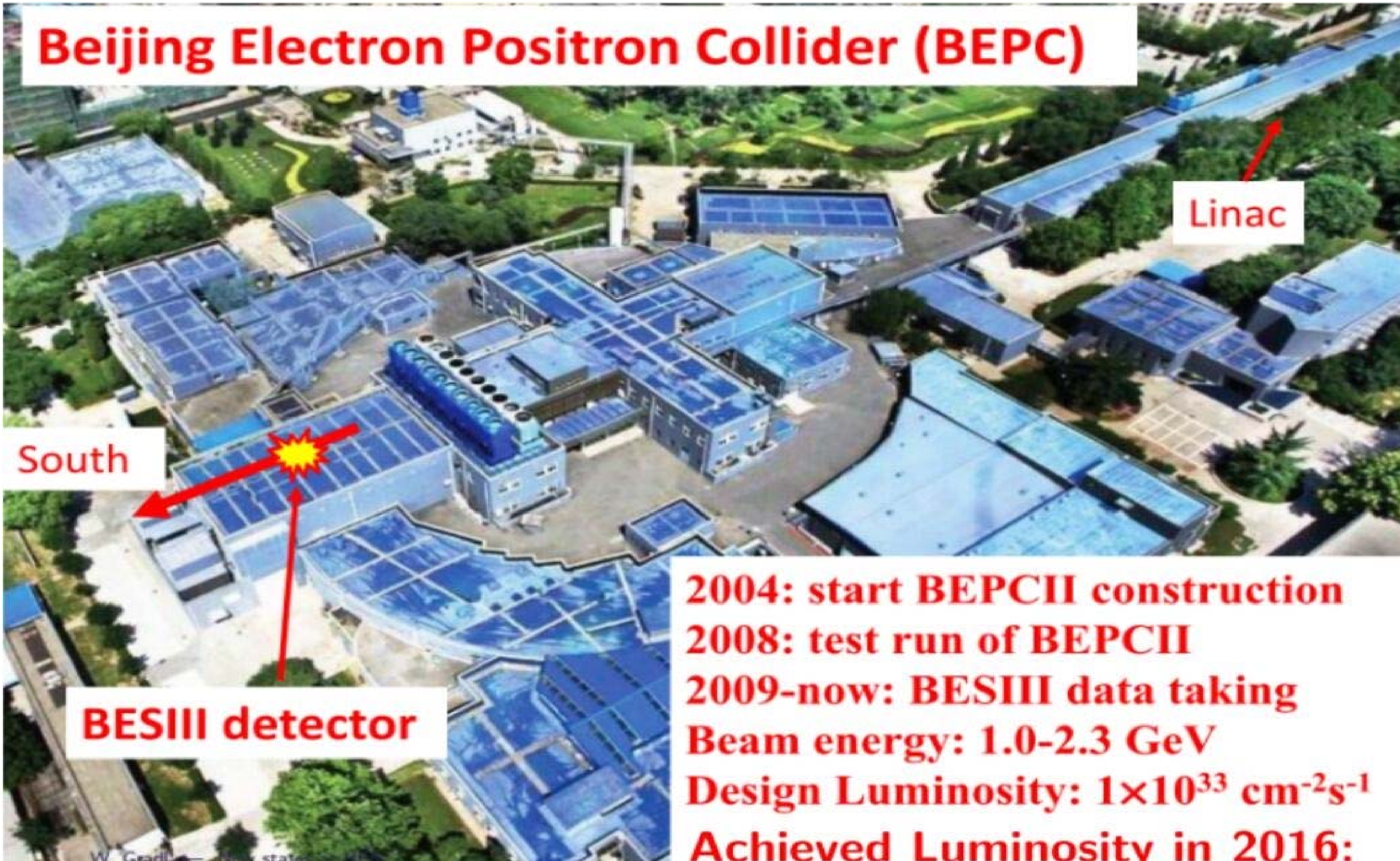
Known decays about Λ_C

From the PDG we can find that:

- Most of the BFs of Λ_C decays are based on the BF of $\Lambda_C^+ \to pK^-\pi^+$;
- Many hadronic modes have not been measured;
- No neutron mode has been measured yet.



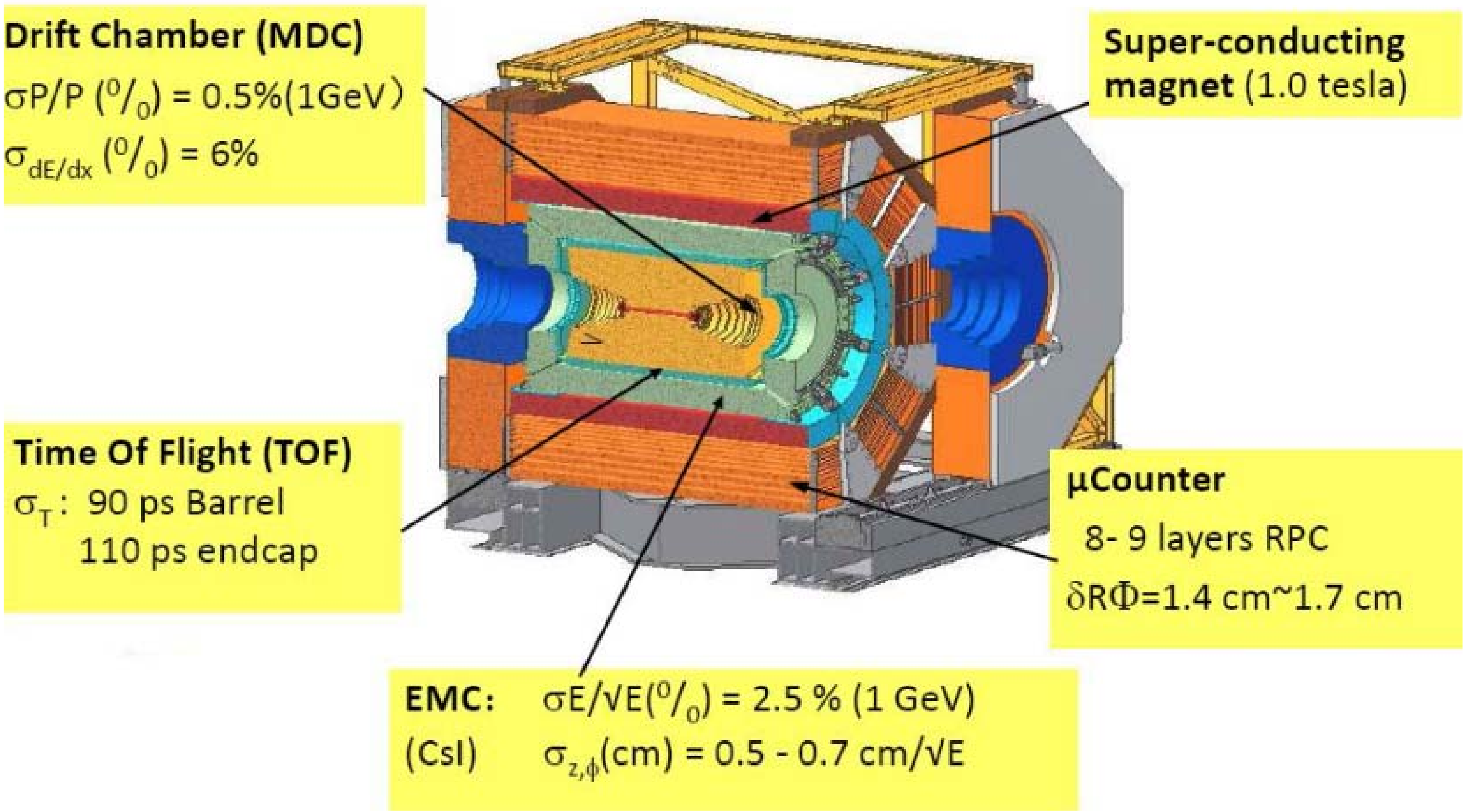
Beijing Electron Positron Collider (*BEPC-II*)



Achieved Luminosity in 2016:

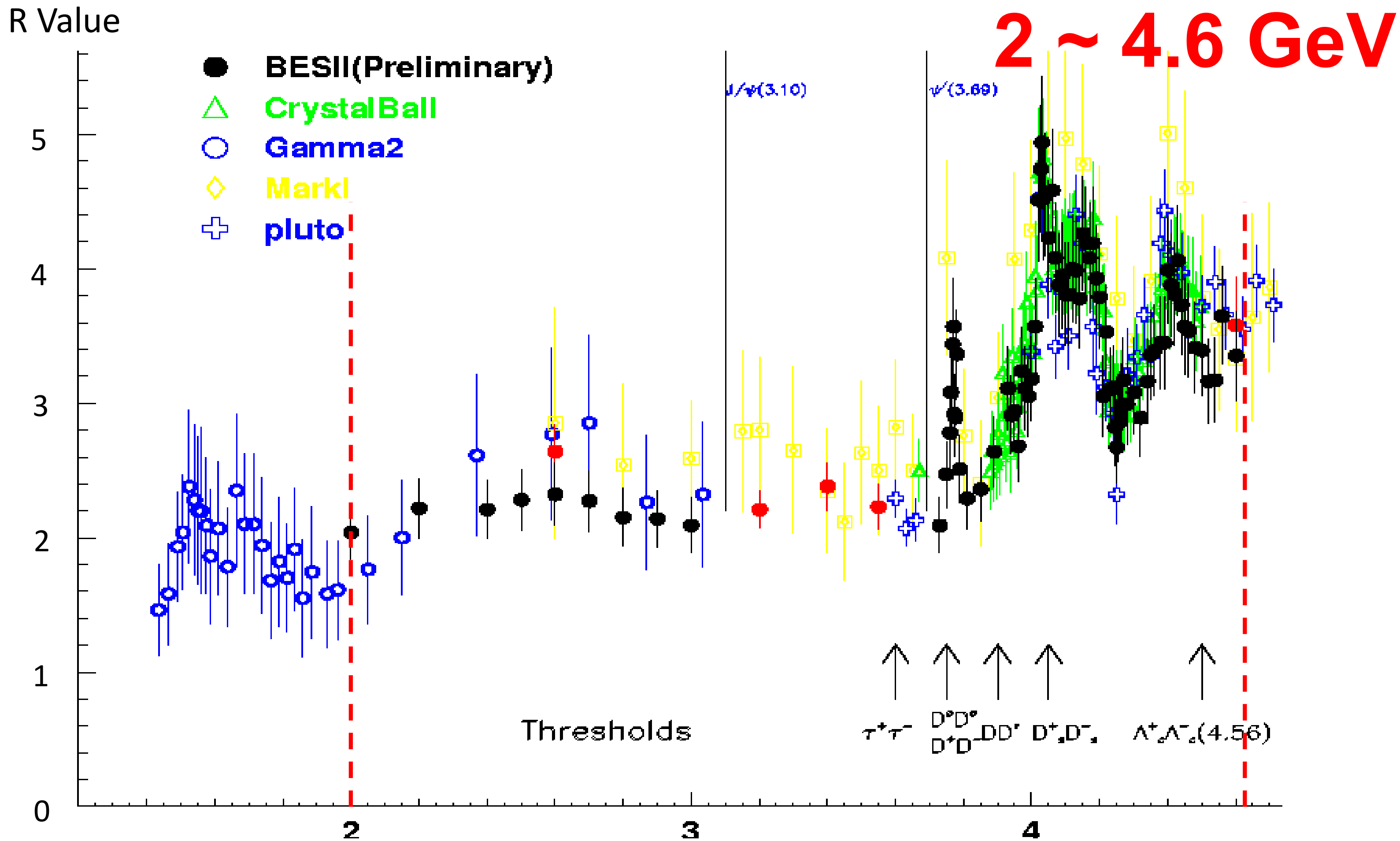
$$L_{peak} = 0.998 \times 10^{33} cm^{-2} s^{-1}$$

BESIII detector



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

BESIII data productions



BESIII is a unique place to study the hadron structure below 3 GeV.

BESIII data taken about Λ_c

In 2014, BESIII run the machine at 4.6 GeV with excellent performance and took data above the Λ_c pair threshold.

Energy (GeV)	Lum. (1/pb)
4.575	~ 48
4.580	~ 8.5
4.590	~ 8.1
4.599	~ 567

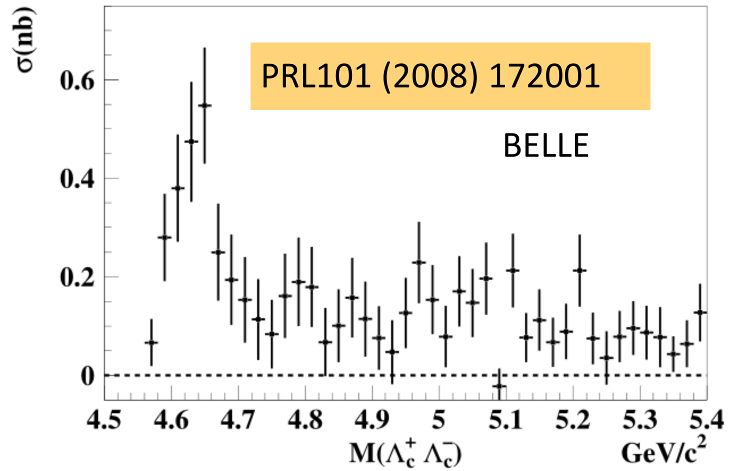
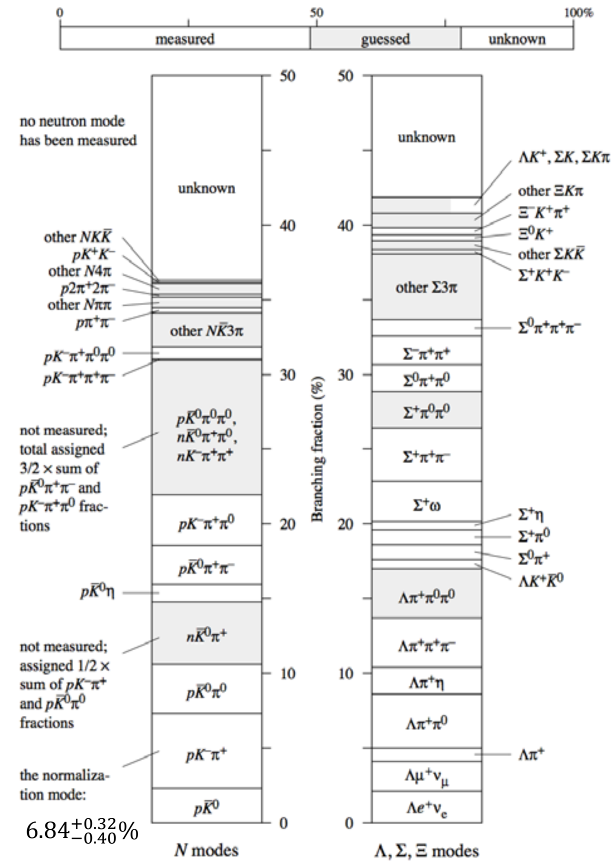


FIG. 4: The cross section for the exclusive process $e^+e^- \to \Lambda_c^+\Lambda_c^-$.

It is a great opportunity to study charmed baryon at threshold.

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.
- Most of the uncertainties of BF's of Λ_c^+ decays are relatively large(25%~40% in PDG 2014).
- BF's of all the known decay modes are measured relative to $\Lambda_c^+ \to pK^-\pi^+$.
- Belle's first model-independent measurement: $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (6.84 \pm 0.24^{+0.21}_{-0.27})\%$, the precision reaches 4.7%. -----[PRL 113(2014) 042002]

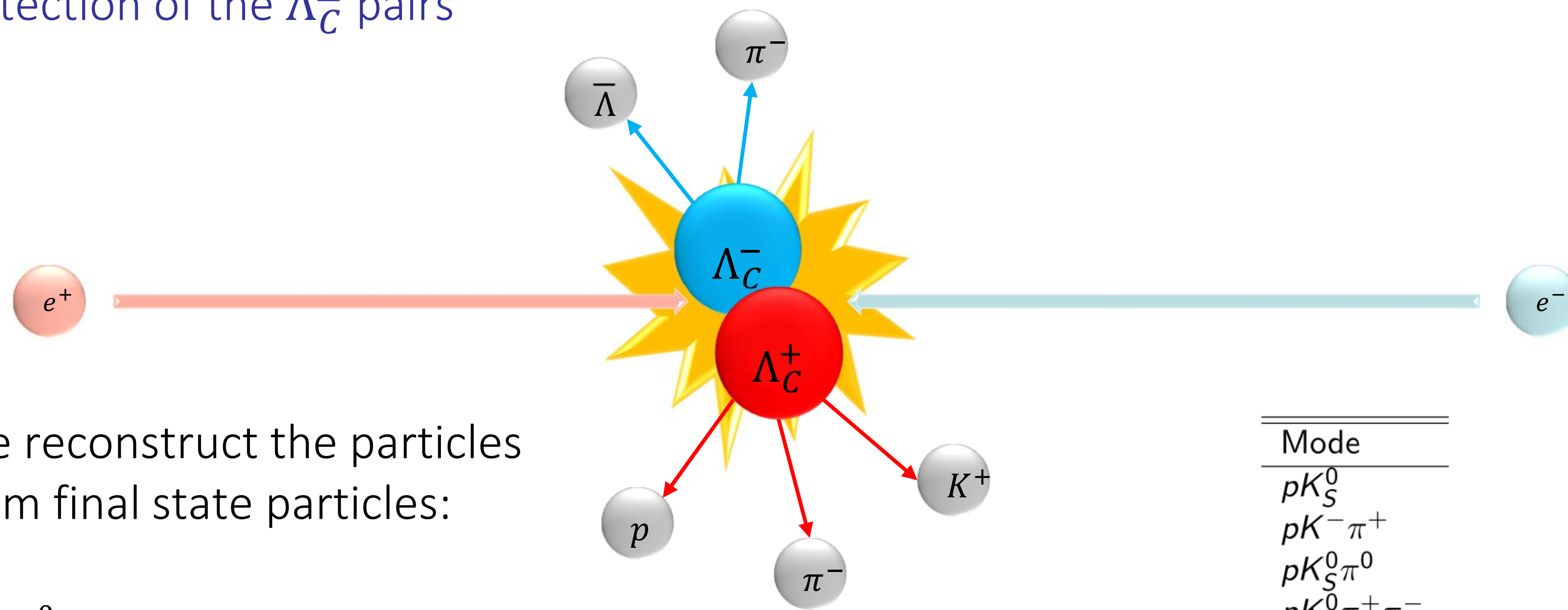


However, measurements using the threshold pair-productions via e^+e^- annihilations have the advantage:

Simple and straightforward!

Reconstruction of particles

Detection of the $\Lambda_c^\pm$ pairs



We reconstruct the particles from final state particles:

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

12 modes to reconstruct the Λ_c^+

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

Analysis techniques

Single Tag (ST):

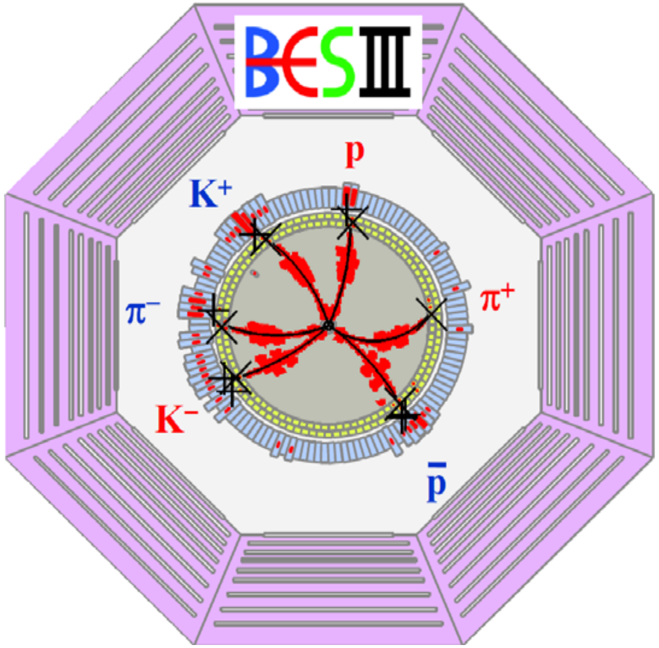
- $M_{bc} = \sqrt{E_{beam}^2/c^2 - |\boldsymbol{P}_{\Lambda_C}^2|}$

Double Tag (DT) method:

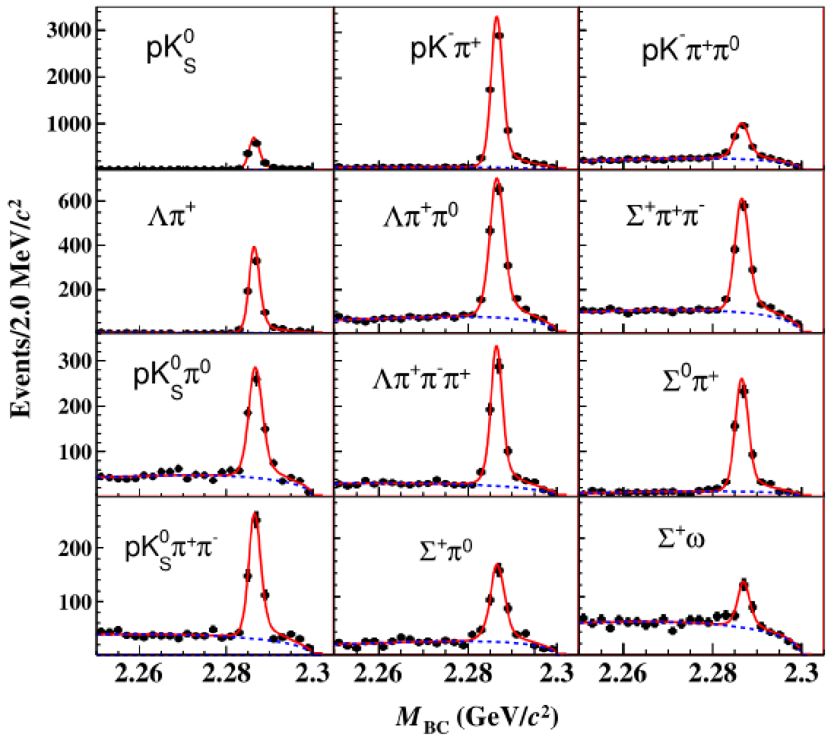
Reconstruction both Λ_C baryons.

Advantages:

- Events at threshold are clean;
- Some systematic uncertainties cancels while using DT method.



Fits to the ST M_{bc} distributions in data

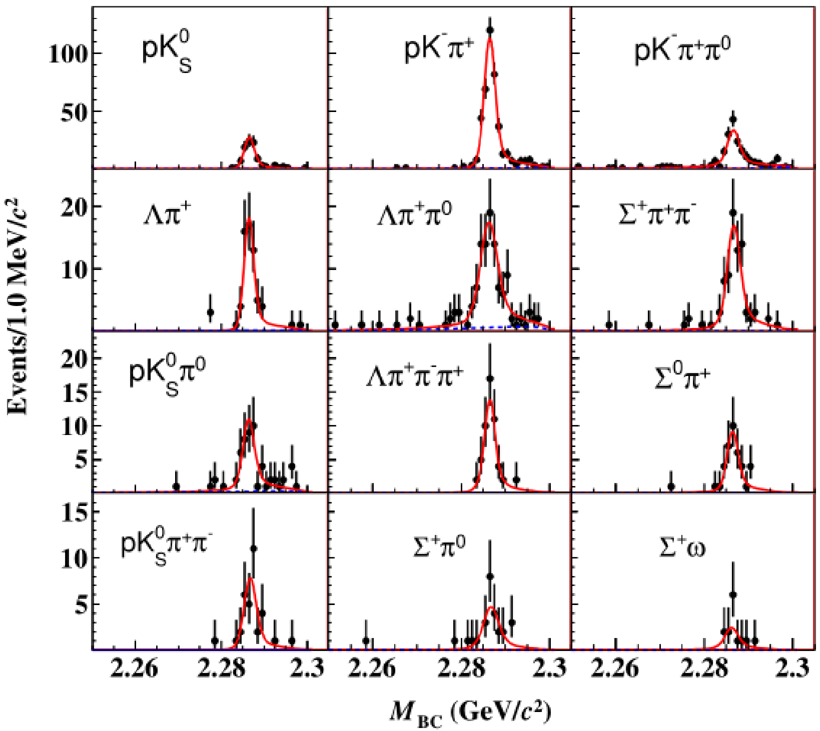


Mode	N^{ST}
pK_S^0	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK_S^0\pi^0$	558 ± 33
$pK_S^0\pi^+\pi^-$	485 ± 29
$pK^-\pi^+\pi^0$	1849 ± 71
$\Lambda\pi^+$	706 ± 27
$\Lambda\pi^+\pi^0$	1497 ± 52
$\Lambda\pi^+\pi^-\pi^+$	609 ± 31
$\Sigma^0\pi^+$	522 ± 27
$\Sigma^+\pi^0$	309 ± 24
$\Sigma^+\pi^+\pi^-$	1156 ± 49
$\Sigma^+\omega$	157 ± 22

Dominated by $pK^-\pi^+$

$$N_{i^+}^{ST} = N_{\Lambda_c^+\Lambda_c^-}\mathcal{B}_i\epsilon_{i^+}^{ST}$$

Fits to the DT M_{bc} distributions in data



Mode	N^{DT}_{i-}
pK^0_S	97 ± 10
$pK^-\pi^+$	420 ± 22
$pK^0_S\pi^0$	47 ± 8
$pK^0_S\pi^+\pi^-$	34 ± 6
$pK^-\pi^+\pi^0$	176 ± 14
$\Lambda\pi^+$	60 ± 8
$\Lambda\pi^+\pi^0$	101 ± 13
$\Lambda\pi^+\pi^-\pi^+$	53 ± 7
$\Sigma^0\pi^+$	38 ± 6
$\Sigma^+\pi^0$	25 ± 5
$\Sigma^+\pi^+\pi^-$	80 ± 9
$\Sigma^+\omega$	13 ± 3

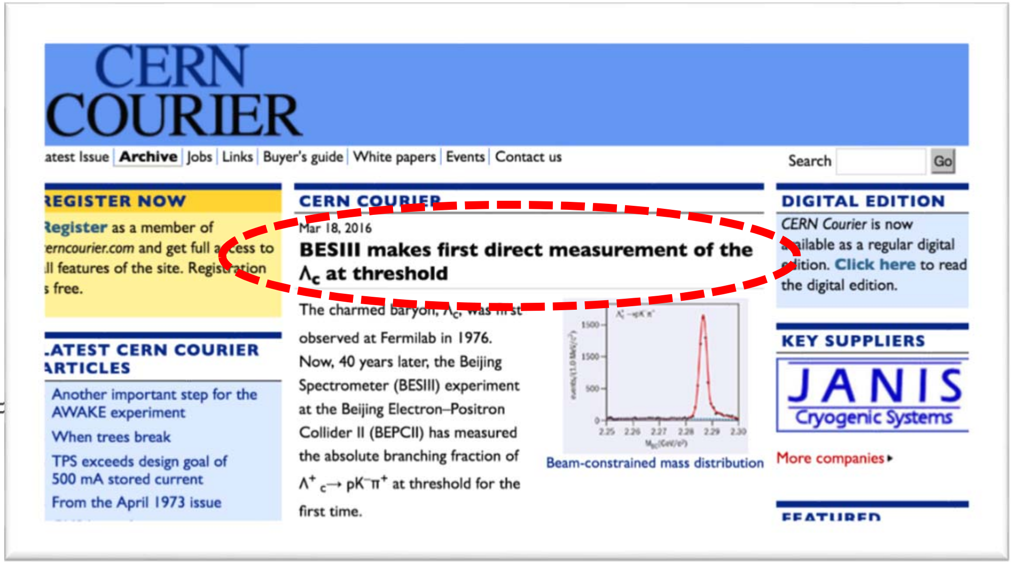
A least square global fit:

Simultaneous fit to all the tag modes, while constraining the total $\Lambda_c^+\overline{\Lambda}_c^-$ pair number, taking into account the correlations.

$$N^{DT}_{i^+j^-} = N_{\Lambda_c^+\Lambda_c^-}\mathcal{B}_i\mathcal{B}_j\epsilon^{DT}_{i^+j^-}$$

Results of the absolute BF's of Λ_c^+ hadronic decays

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	



- Branching fraction for $pK^-\pi^+$ is consistent with that of BELLE $\mathcal{B}$;
- The BF's improve the precision of PDG value significantly.

PhysRevLett.116.052001

Absolute BF of the $\Lambda_c^+ \to \Lambda e^+ \nu_e$

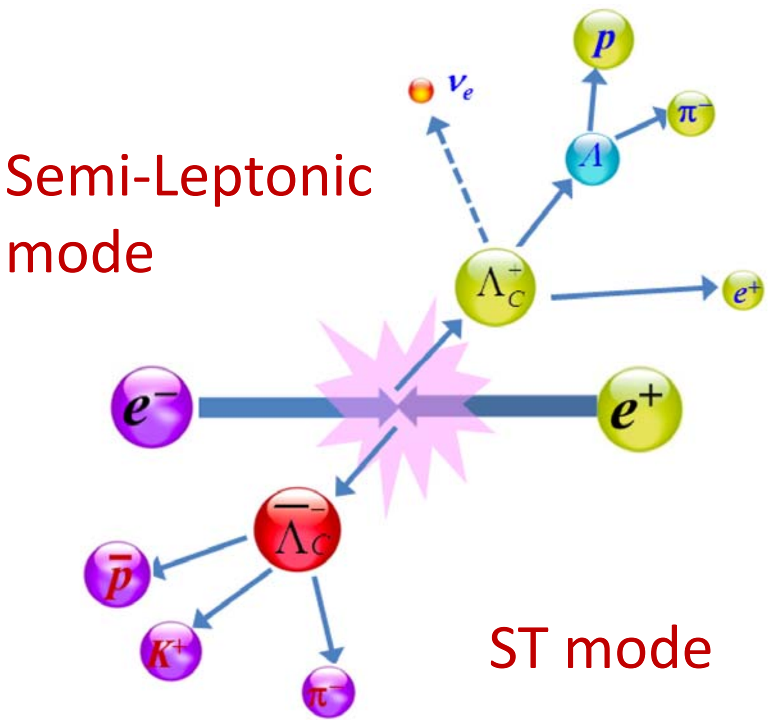
- $\Lambda_c^+ \to \Lambda e^+ \nu_e$ is a $c \to s l^+ \nu_l$ dominated process.
- Theoretical predications for BF of $\Lambda_c^+ \to \Lambda e^+ \nu_e$ ranges from 1.4% to 9.2%.
- Urgently need for LQCD calculations.
- No direct absolute measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ yet.

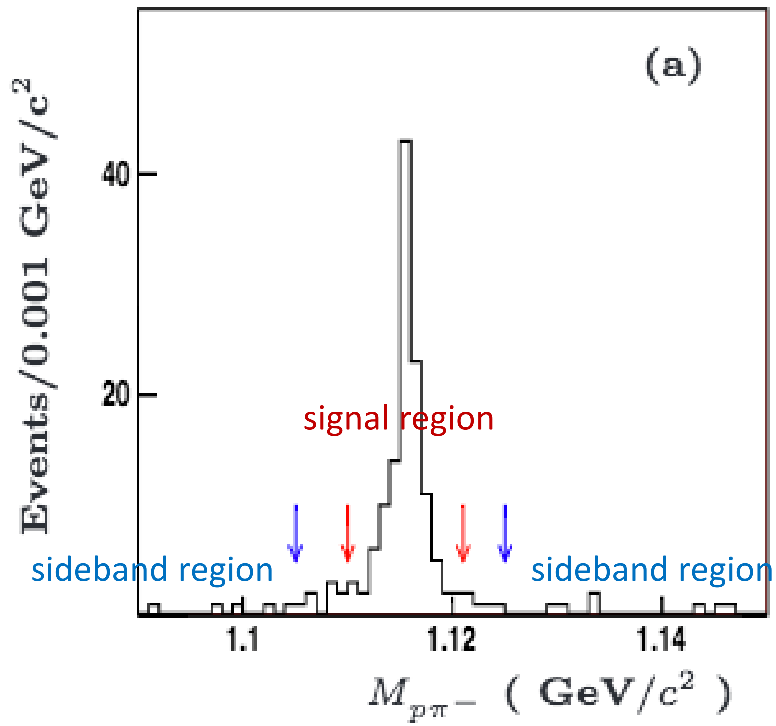
- So the measurement for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ can provide important experiment information for:

a) testing the theoretical predications for $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$.
b) calibrating the LQCD calculations.
c) additional information for determining CKM elements.

Reconstruction of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

- 11 ST modes are used.
- We find a p, π^- and e^+ from the remaining tracks of the ST mode, and require that the p and π^- are from a Λ.





The Λ's peak is very clean.

Results of the BF of $\Lambda_c^+ \to \Lambda e^+ \nu_e$

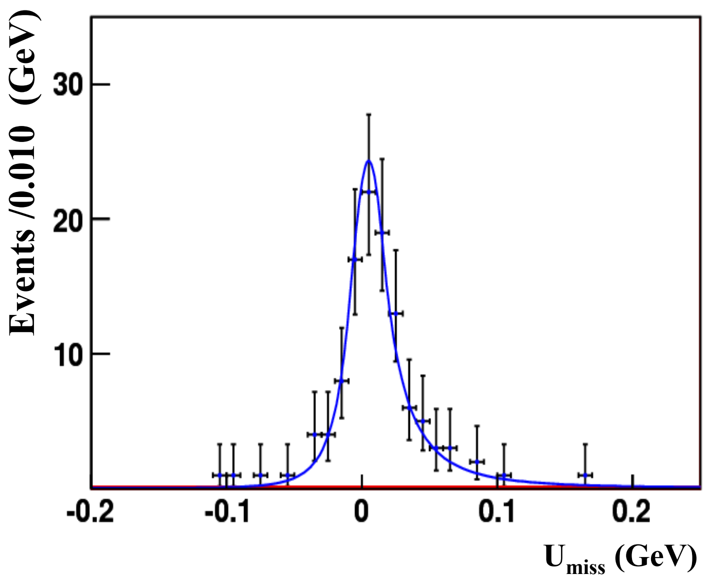
We fit the U_{miss} to obtain the signal yieds.

$$U_{\rm miss} = E_{\rm miss} - c|\vec{p}_{\rm miss}|$$

$$E_{\rm miss} = E_{\rm beam} - E_{\Lambda} - E_{e^+},$$

$$\vec{p}_{\rm miss} = \vec{p}_{\Lambda_c^+} - \vec{p}_{\Lambda} - \vec{p}_{e^+},$$

$$\vec{p}_{\Lambda_c^+} = -\hat{p}_{\rm tag}\sqrt{E_{\rm beam}^2 - m_{\Lambda_c^+}^2},$$



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

This is the first absolute measurement!

And the precision is better than previous PDG results.

Phys.Rev.Lett. 115 (2015) 221805

Comparison with theoretical predictions and PDG

Theoretical Models	predicated branching fraction for $\Lambda_c^+ \to \Lambda e^+ \nu_e$
MBM [1]	1.9%
NRQM [1]	2.6%
SU(4)-symmetry limit [2]	9.2%
RSQM [3]	4.4%
QCM [4]	5.62%
SQM [5]	1.96%
NRQM2 [6]	2.15%
NRQM3 [7]	1.42%
QCD SR1 [8]	$(3.0 \pm 0.9)\%$
QCD SR2 [9]	$(2.6 \pm 0.4)\%$
QCD SR3 [9]	$(5.8 \pm 1.5)\%$
STSR [10]	2.22% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
STNR [10]	1.58% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HOSR [10]	4.72% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
HONR [10]	4.2% for $\Lambda_c^+ \to \Lambda l^+ \nu_l$
LCSRs [11]	$(3.0 \pm 0.3)\%$ for $\Lambda_c^+ \to \Lambda l^+ \nu_l$ (CZ-type)
PDG 2014 [14]	$(2.1 \pm 0.6)\%$
BESIII	$(3.62 \pm 0.38 \pm 0.20)\%$

Semileptonic Λ_c^+ decay

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

$\Gamma(\Lambda_c^+ \to \Lambda e^+ \nu_e) = (18.2 \pm 2.1) \times 10^{10} s^{-1}$

$\Gamma(\Lambda_c^+ \to X e^+ \nu) = (22.5 \pm 8.5) \times 10^{10} s^{-1}$

$\Gamma(D^0 \to X e^+ \nu) = (15.84 \pm 0.27) \times 10^{10} s^{-1}$ PDG2014

$\Gamma(D^+ \to X e^+ \nu) = (15.45 \pm 0.29) \times 10^{10} s^{-1}$

Experiment: $\frac{\Gamma(\Lambda_c^+ \to \Lambda e^+ \nu)}{\Gamma(D \to X e^+ \nu)} = 1.16 \pm 0.13$ $\frac{\Gamma(\Lambda_c^+ \to X e^+ \nu)}{\Gamma(D \to X e^+ \nu)} = 1.44 \pm 0.54$

Prediction: $\frac{\Gamma(\Lambda_c^+ \to X e^+ \nu)}{\Gamma(D \to X e^+ \nu)} = 1.20 \sim 1.67$

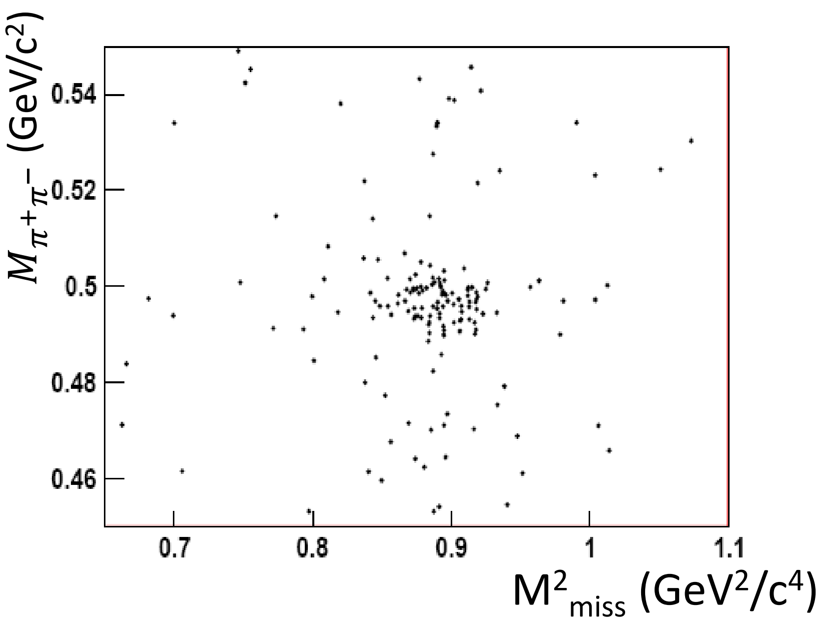
J. Rosner (2012)
Manohar, Wise(1994)
Gronau and Rosner(2011)

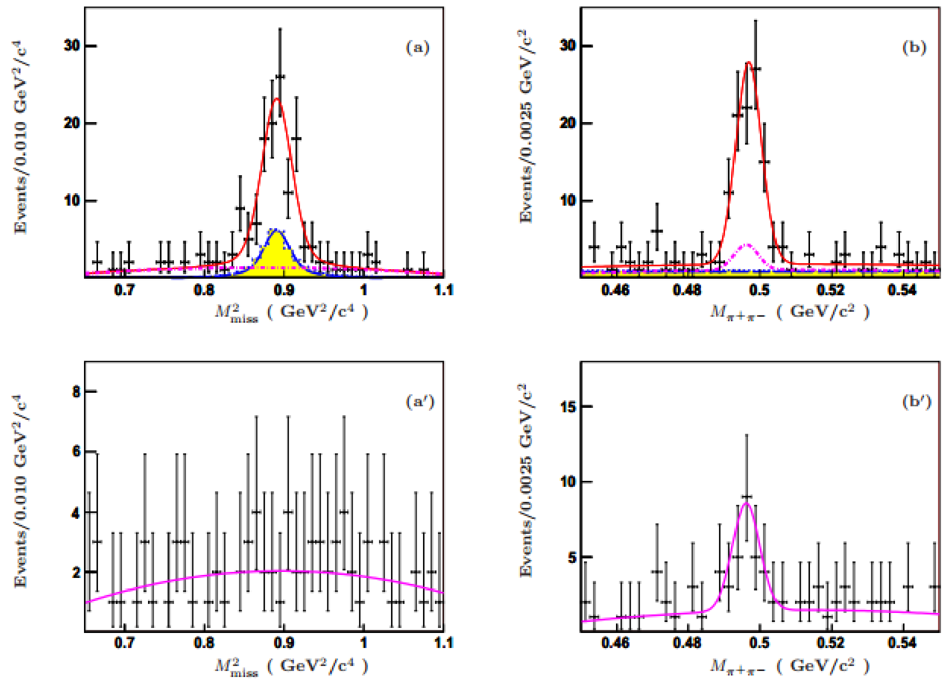
Indications:

- The inclusive Λ_c^+ semileptonic decay rate close to the $\Lambda_c^+ \to \Lambda l^+ \nu_l$ rate.
- No evidence for semileptonic decay in the final states without a Λ.
- Precise measurement of the inclusive Λ_c^+ semileptonic decay is important.
- Search for other semileptonic decay mode is important.

Observation of $\Lambda_C^+ \to n K_S^0 \pi^+$

- 11 ST modes are used.
- Two-dimensional unbined simultaneous fit to M^2_{miss} and $M_{\pi^+\pi^-}$ is performed.





$$\mathcal{B}(\Lambda_C^+ \to \Lambda e^+ \nu_e) = (1.82 \pm 0.23 \pm 0.10)\%$$

First observation of Λ_C^+ decays to final states involving the neutron.

More Λ_c^+ data set?

A combined data taking proposal of studying Λ_c^+

Proposal of precise study of the charmed baryon Λ_c^+ decays

Hai-Bo Li, Peirong Li, Lei Li, Xiao-Rui Lyu, Haiping Peng, Yangheng Zheng

Analyticity Violation in $e^+e^- \rightarrow \Lambda_c \bar{\Lambda}_c$?
A request for additional integrated luminosity at threshold

Rinaldo Baldini, Marco Maggiora, Guangshun Huang, RongGang Ping, Weimin Song, Weiping Wang, Liang Yan, Zhengguo Zhao, Xiaorong Zhou, Kai Zhu, and the BESIII Italian Collaboration Team

BESIII collaboration meeting at SJTU 2015.6.14

We propose one year dedicated data taking at Λ_c threshold

Prospect of precision

Push the precisions to the level of those of D/Ds mesons.

If more 0.5 M $\Lambda_C^{\pm}$ pairs

Hadronic decays :

- PWA analysis of Cabbio-favored hadronic decays: light hadrons;
- Studies of the modes involving neutron particles.

Semi-Leptonic decays :

- So far, only mode $\Lambda_C^+ \to \Lambda e^+ \nu_e$ is measured, how about $\Lambda_C^+ \to pK^- e^+ \nu_e$?
- Many more semi-leptonic modes can be established at BESIII!

	golden mode	δB/B	SL	δB/B
D0	B(Kpi)=(3.88±0.05)%	1.3%	B(K e ν)=(3.55±0.05)%	1.4%
D+	B(Kpipi)=(9.13±0.19)%	2.1%	B(K0 e ν)=(8.83±0.22)%	2.5%
Ds	B(Kkpi)=(5.39±0.21)%	3.9%	B(phi e ν)=(2.49±0.14)%	5.6%
Λc	B(pKpi)=(5.0±1.3)% (PDG2014) =(6.8±0.36)% (BELLE) =(5.84±0.35)% (BESIII) =(5.84±0.18)% (new BESIII)	26% 5.3% 6.0% 3.0%	B(Λeν)=(2.1±0.6)%(PDG2014) =(3.63±0.43)% (BESIII) =(3.63±0.20)% (new BESIII)	29% 12% 5.4%

Other relevant studies

Λ_c^+ hadronic weak decays:

- Two-body hadronic decays of Λ_c^+ are of great interest;
- Decay asymmetry parameters in Λ_c^+ two-body hadronic weak decays, such as $\Lambda_c^+ \to BP$ and $\Lambda_c^+ \to BV$.

Search for Λ_c^+ low rate decays and rare decays:

- Weak radiative decay $\Lambda_c^+ \to \gamma\Sigma^+$; predictions of BF are 10^{-4} ~10^{-5}
  Sensitivity with 0.5 M Λ_c^+ pairs gets to ~10^{-4}
- FCNC, lepton number/family violation, baryon family violation.
  Sensitivity with 0.5 M Λ_c^+ pairs reaches to ~10^{-5}

Summary

Achievements:

- BESIII took a data set of 567/pb and published several world-best results;
- For the first time, BESIII is able to precisely study its decays at threshold.

More potentials

- A larger data set
  A golden opportunity to thoroughly improve our knowledge on Λ_C^+ decays;

- Hadronic decays
  PWA analysis of Cabbio-favored hadronic decays and studies of the modes involving the neutron;

- Semi-Leptonic decays
  Many more semi-leptonic modes, like $\Lambda_C^+ \to pK^- e^+ \nu_e$, can be studied at BESIII!

Thank you !