Absolute Branching Fractions of Λ_c^+ Decays at BESIII

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Overview

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   - Analysis Technique
2. Hadronic decays
   - Measurement of Hadronic Λ_c^+ Branching Fractions
   - Measurement of Singly Cabbibo Suppressed Decays of $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$
   - Observation of $\Lambda_c^+ \to nK_S^0\pi^+$
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   - Evidence for the SCS Decay $\Lambda_c^+ \to p\eta$ and Search for $\Lambda_c^+ \to p\pi^0$
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4. Inclusive decays
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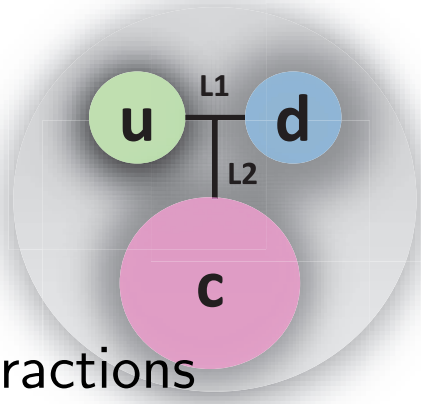
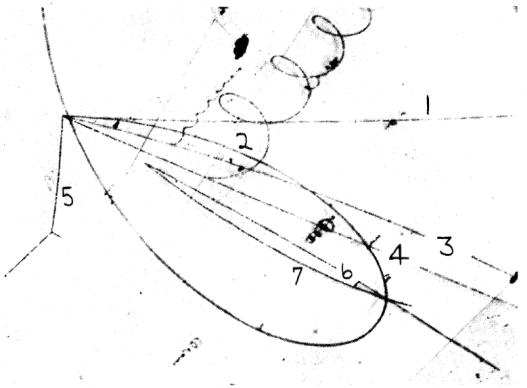
5. Summary



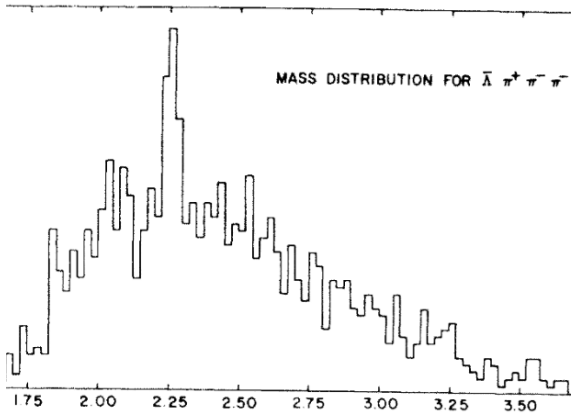
Discovery of the Λ_c^+ Baryon

BNL (hint)
$\nu p \to \mu \Lambda \pi^+ \pi^- \pi^+ \pi^+$



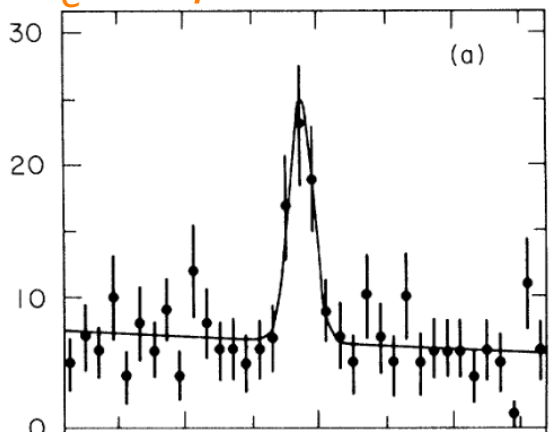
PRL 34, 1125 (1975)

Fermi Lab (evidence)



PRL 37, 882 (1975)

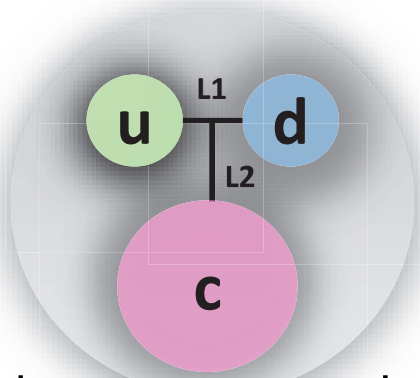
MARKII (observation)
$\Lambda_c^+ \to pK^-\pi^+$



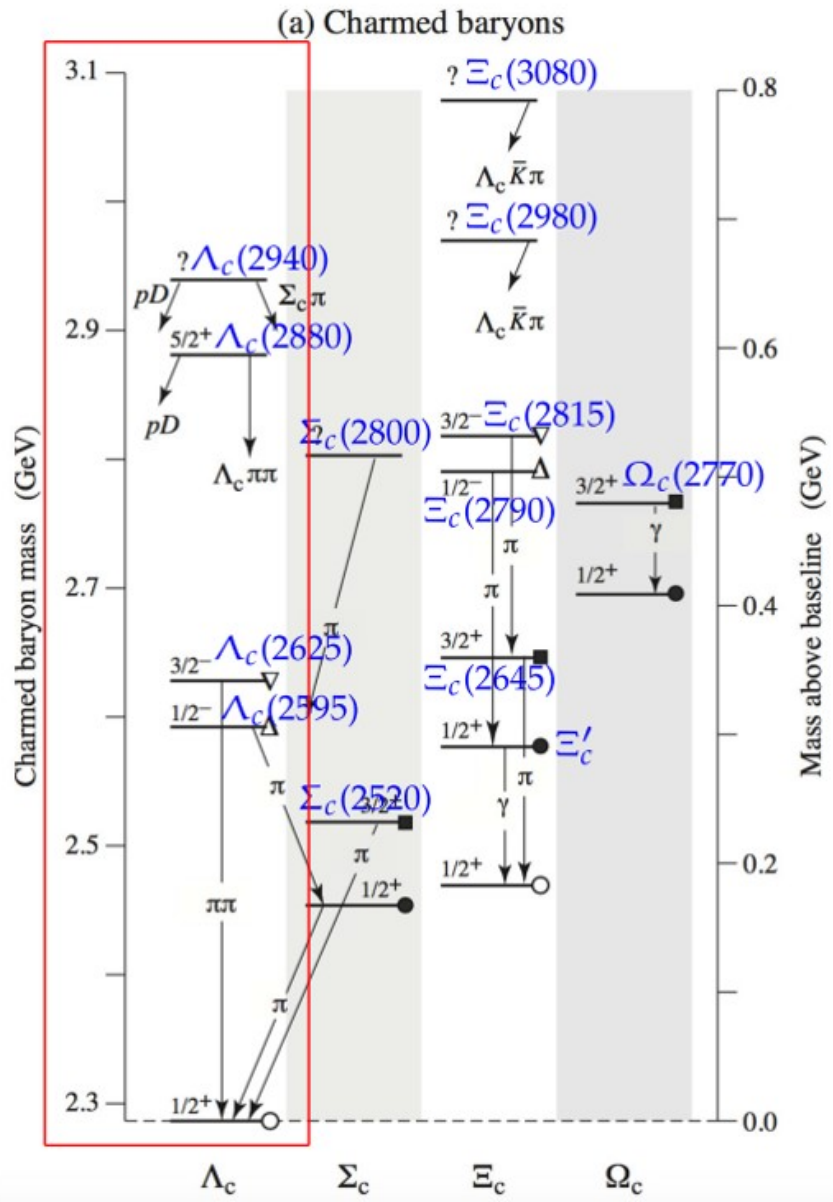
PRL 44, 10 (1980)

- Its decays are important to probe the quark structure when a "heavy" quark exists
- As a dominant final state particle in bottom decays, its decays are essential to test QCD in b-factories

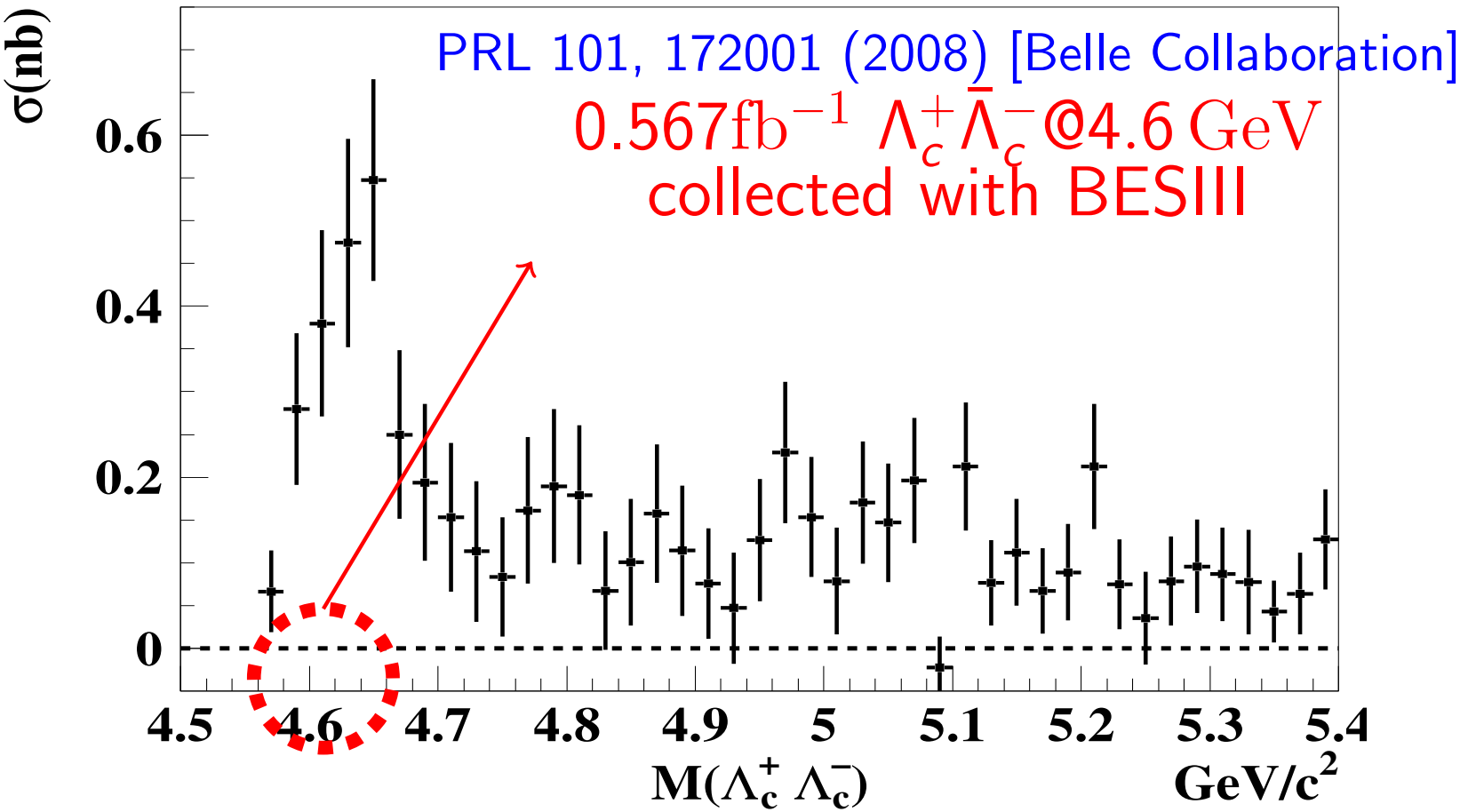
Singly Charmed Baryon Spectroscopy



- Quark structure: a heavy quark (c) with an ground state spin zero diquark (ud)
- The lightest charmed baryon ($m_{\Lambda_c^+} = 2286.48\,\mathrm{MeV}$), most of the charmed baryon would decay to it
- Only weak decays for Λ_c^+, but its total measured $\mathcal{B}$ is much less than 1 for PDG, so many channels are to be discovered



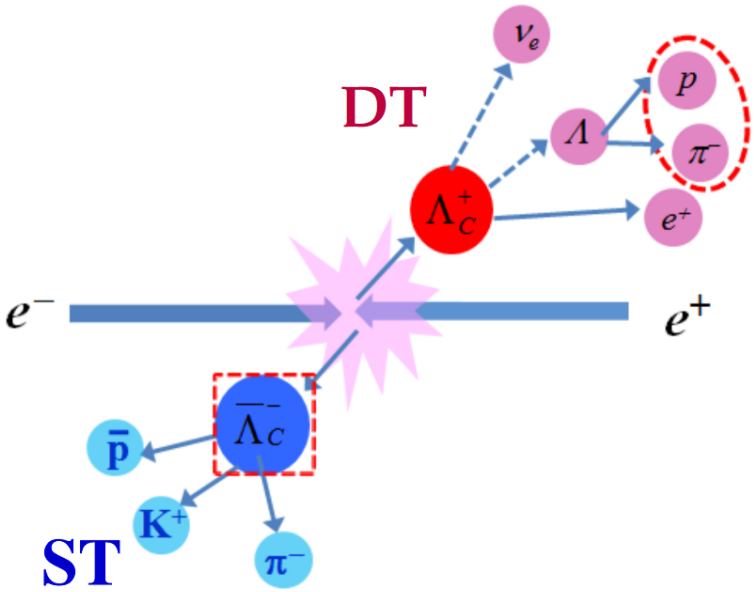
$\Lambda_c^+\bar{\Lambda}_c^-$ Production at 4.599 GeV



$\Lambda_c^+\bar{\Lambda}_c^-$ pair production

- provides a unique laboratory for precision measurements
- allows to determine the absolute branching fractions ($\mathcal{B}$)

Analysis Technique



1. Single Tag(ST)
   $$M_{BC} = \sqrt{E_{beam}^2/c^4 - |\mathbf{p}^2|/c^2}$$
2. Double Tag(DT)
   for semi-leptonic decays:
   $$U_{miss} = E_{miss} - c|\mathbf{p}_{miss}|$$
3. $$\mathcal{B} = \frac{N_{sig}}{N_{tag} \times \varepsilon_{sig}/\varepsilon_{tag,sig}}$$

Tag side:

Tag the $\bar{\Lambda}_c^-$ events via hadronic decays with large branching fractions, thus could suppress background effectively;

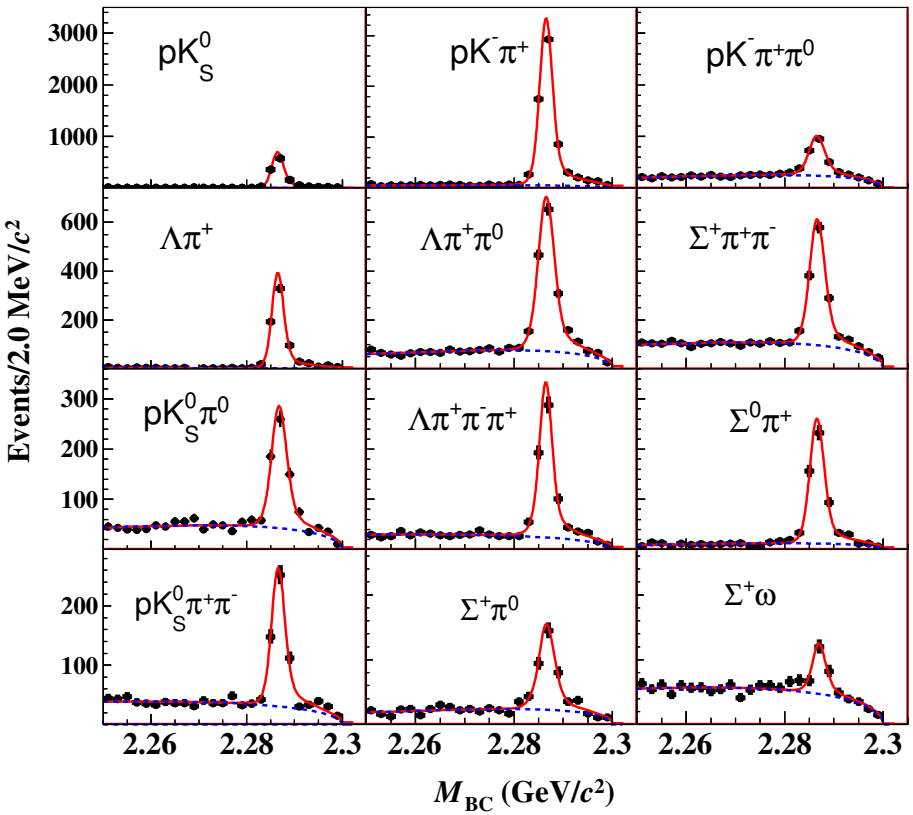
Signal side:

Hadronic decays (fully reconstructed); Semi-leptonic decays (neutrino missed) and Inclusive decays (partially reconstructed)

Measurement of Hadronic Λ_c^+ Branching Fractions

Single Tag Λ_c^+ Events

[PhysRevLett.116.052001]



Dominated by $pK^-\pi^+$

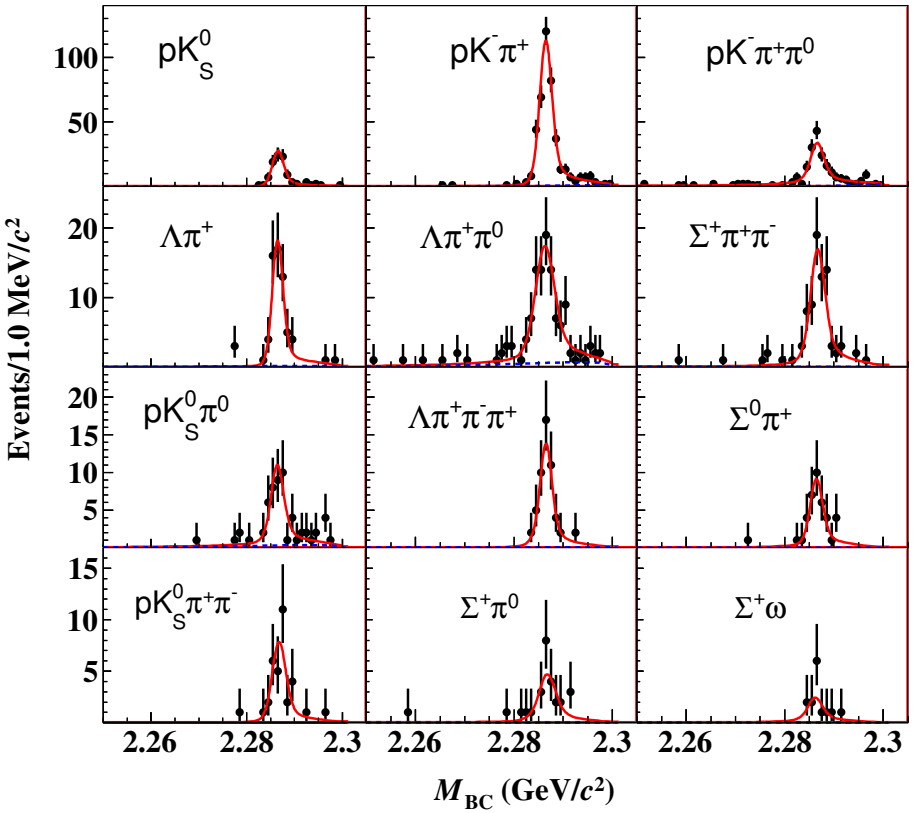
$\sim 1.5 \times 10^4$ single tag events

Mode	N^{ST}
pK^0_S	1243 ± 37
$pK^-\pi^+$	6308 ± 88
$pK^0_S\pi^0$	558 ± 33
$pK^0_S\pi^+\pi^-$	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

Measurement of Hadronic Λ_c^+ Branching Fractions

[PhysRevLett.116.052001]

Background free double tags



Mode	$N_{i-}^{\rm DT}$
pK_S^0	97 ± 10
$pK^-\pi^+$	420 ± 22
$pK_S^0\pi^0$	47 ± 8
$pK_S^0\pi^+\pi^-$	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 fitter:

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

simultaneous fit to all the tag modes, while constraining the total $\Lambda_c\bar{\Lambda}_c$ pair number, taking into account the correlations.

Measurement of Hadronic Λ_c^+ Branching Fractions

Cabbibo favored decays

[PhysRevLett.116.052001]

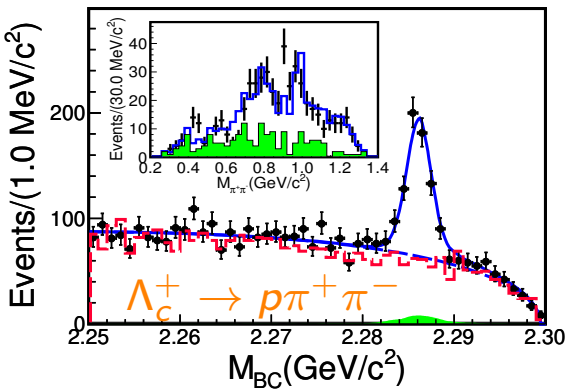
Mode	This work (%)	PDG (%)	BELLE (%)
pK_S^0	$1.52 \pm 0.08 \pm 0.03$	1.15 ± 0.30	
$pK^-\pi^+$	$5.84 \pm 0.27 \pm 0.23$	5.0 ± 1.3	$6.84 \pm 0.24^{+0.21}_{-0.27}$
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	1.65 ± 0.50	(PhysRevLett.113.042002)
$pK_S^0\pi^+\pi^-$	$1.53 \pm 0.11 \pm 0.09$	1.30 ± 0.35	
$pK^-\pi^+\pi^0$	$4.53 \pm 0.23 \pm 0.30$	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	

1. Absolute $\mathcal{B}$s are measured with improved precision;
2. The $\mathrm{V_{ub}}$ measurement suffers large uncertainty from $\mathcal{B}_{\Lambda_c^+ \to pK^-\pi^+}$.

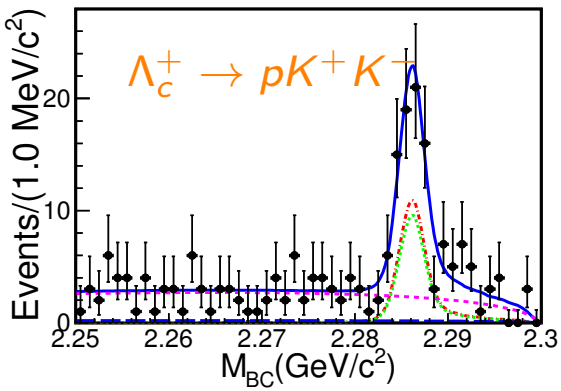
Measurement of Singly Cabbibo Suppressed Decays of $\Lambda_c^+ \to p\pi^+\pi^-$ and $\Lambda_c^+ \to pK^+K^-$ [PhysRevLett.117.232002]

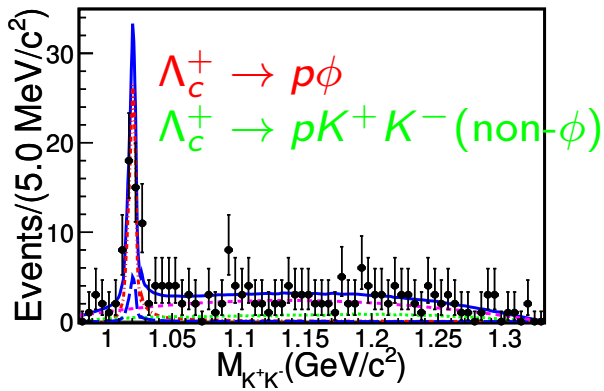
Single Tag method

- nonfactorizable contributions from W-exchange diagrams
- only internal W-emission diagram in $\Lambda_c^+ \to p\phi$



Reference mode: $\Lambda_c^+ \to pK^-\pi^+$





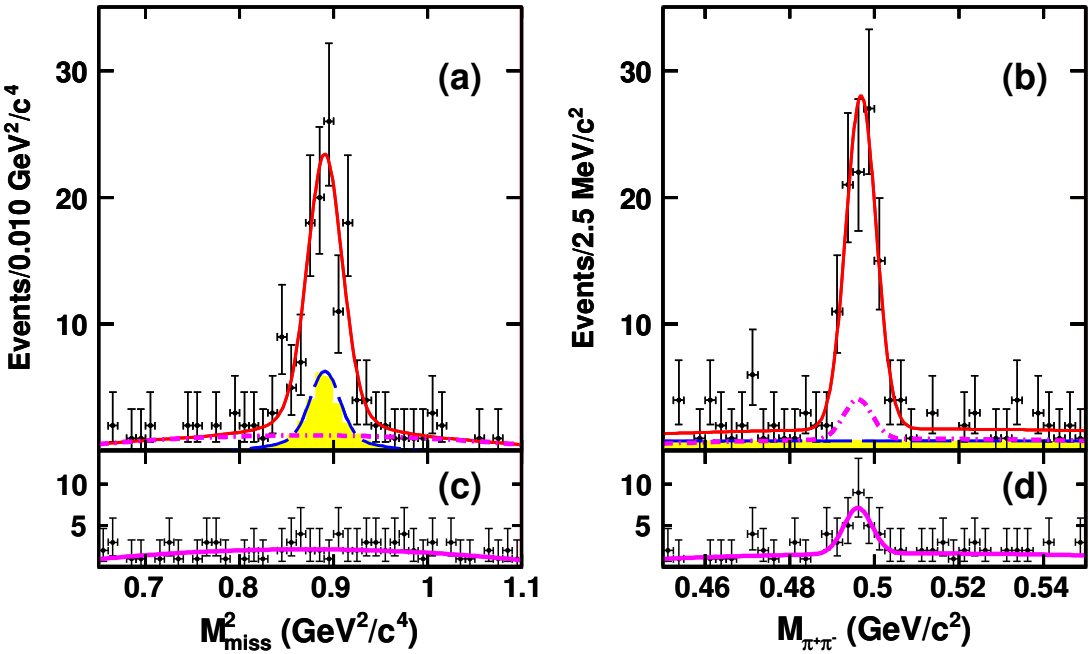
Decay modes	$\mathcal{B}$ (This work)	$\mathcal{B}$ (PDG average)
$\Lambda_c^+ \to p\pi^+\pi^-$	$(3.91 \pm 0.28 \pm 0.15 \pm 0.24) \times 10^{-3}$	$(3.5 \pm 2.0) \times 10^{-3}$
$\Lambda_c^+ \to p\phi$	$(1.06 \pm 0.19 \pm 0.08 \pm 0.06) \times 10^{-3}$	$(8.2 \pm 2.7) \times 10^{-4}$
$\Lambda_c^+ \to pK^+K^-$ (non-ϕ)	$(5.47 \pm 1.30 \pm 0.41 \pm 0.33) \times 10^{-4}$	$(3.5 \pm 1.7) \times 10^{-4}$

- the first observation of the SCS decay $\Lambda_c^+ \to p\pi^+\pi^-$

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

A test to the isospin symmetry

[PhysRevLett.118.112001]



$$M^2_{miss} = E^2_{miss}/c^4 - |\vec{p}_{miss}|^2/c^2$$

Peaking backgrounds:

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

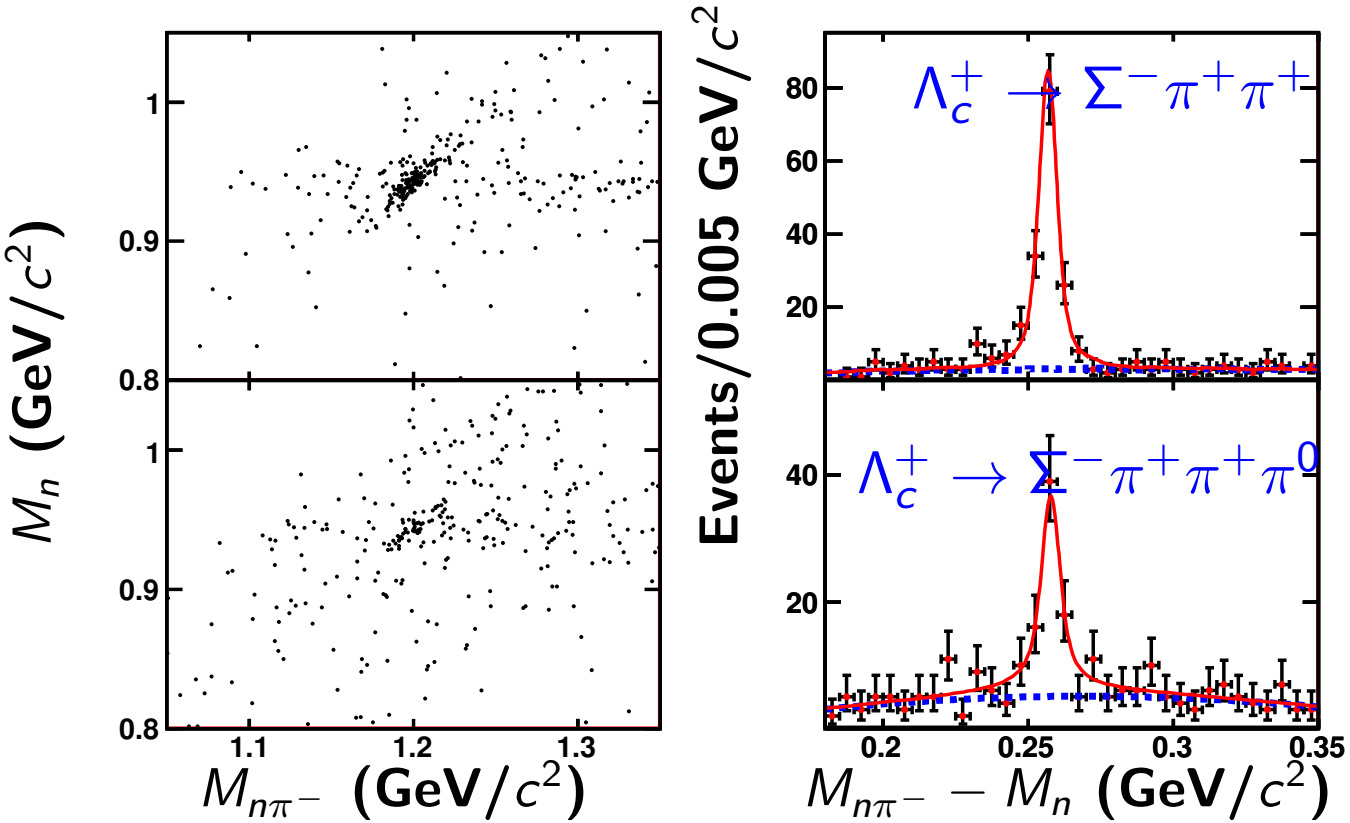
$\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$

$(\Sigma^\pm \to n\pi^\pm)$

- $\mathcal{B}(\Lambda_c^+ \to nK_S^0\pi^+) = (1.82 \pm 0.23 \pm 0.11)\%$
- $\mathcal{B}(\Lambda_c^+ \to n\bar{K}^0\pi^+)/\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+) = (0.62 \pm 0.09)\%$
- $\mathcal{B}(\Lambda_c^+ \to n\bar{K}^0\pi^+)/\mathcal{B}(\Lambda_c^+ \to p\bar{K}^0\pi^0) = (0.97 \pm 0.16)\%$
- confirms the isospin symmetry and helps to understand the final state interactions

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

first observation of $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$ [PLB.772 (2017) 388-393]



$$E_n^2 = (E_{beam} - E_{3\pi s(\pi^0)})^2$$

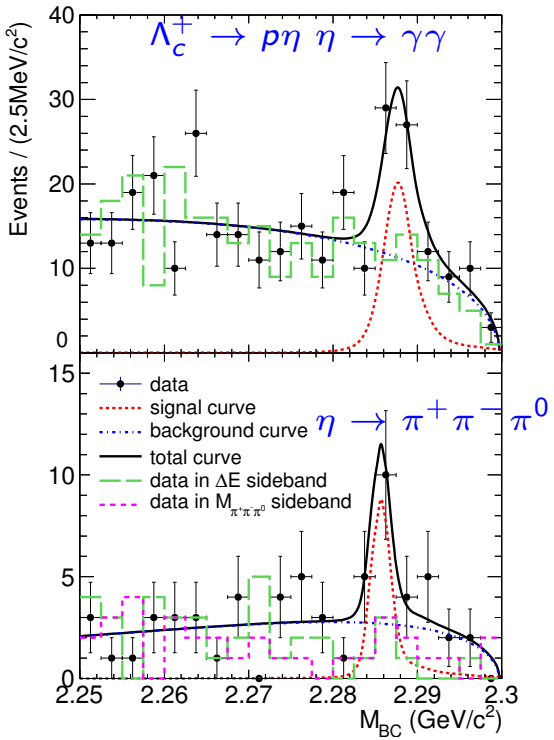
$$|\vec{p}_n|^2 = |\vec{p}_{\Lambda_c^+} - \vec{p}_{3\pi s(\pi^0)}|^2$$

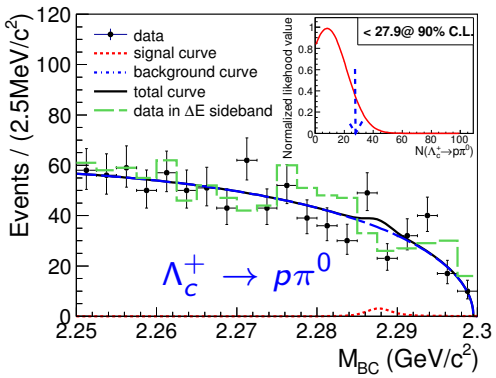
$$M_n = \sqrt{E_n^2 - |\vec{p}_n|^2}$$

- $\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+) = (1.81 \pm 0.17 \pm 0.09)\%$
- $\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0) = (2.11 \pm 0.33 \pm 0.14)\%$
- the first observation of $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+\pi^0$ and improvement on the $\mathcal{B}(\Lambda_c^+ \to \Sigma^-\pi^+\pi^+)$

Evidence for the SCS Decay $\Lambda_c^+ \to p\eta$ and Search for $\Lambda_c^+ \to p\pi^0$

[PhysRevD.95.111102]





- set constraint on the theoretical calculations
- test SU(3) flavor symmetry and understand the underlying dynamics

	$\Lambda_c^+ \to p\eta$	$\Lambda_c^+ \to p\pi^0$	$\frac{\mathcal{B}_{\Lambda_c^+ \to p\pi^0}}{\mathcal{B}_{\Lambda_c^+ \to p\eta}}$
This work	$1.24 \pm 0.28 \pm 0.10$	< 0.27	< 0.24
Sharma *et al*[1]	$0.2^a(1.7^b)$	0.2	$1.0^a(0.1^b)$
Uppal *et al*[2]	0.3	0.1-0.2	0.3-0.7
S. L. Chen *et al*[3]	...	0.11-0.36	...
Cai-Dian Lü *et al*[4]	...	0.45	...

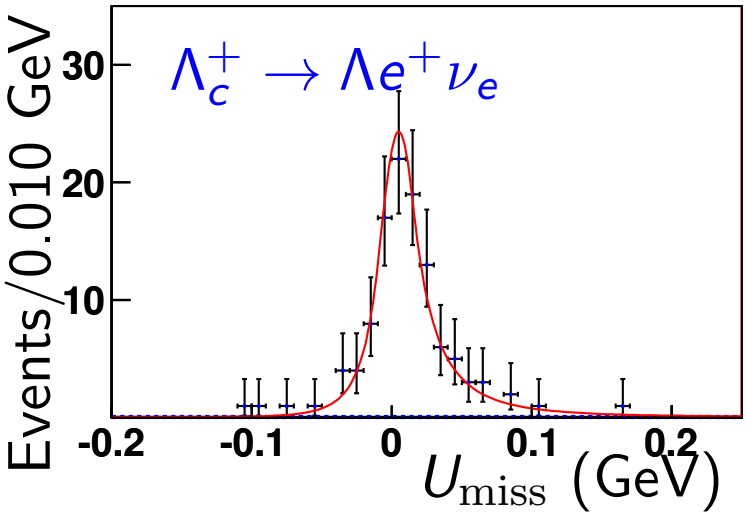
assume positive$^{(a)}$ and negative sign$^{(b)}$ of p-wave amplitude of $\Lambda_c^+ \to \Xi^0 K^+$
[1]PRD 55,7067 [2]PRD 49,3417 [3]Commun. Theor. Phys. 40, 563
[4]PRD 93, 056008

- $\mathcal{B}_{\Lambda_c^+ \to p\eta}$ is consistent with one theoretical expectation[3] within 2σ, but much higher than the other
- Upper limit on $\mathcal{B}_{\Lambda_c^+ \to p\pi^0}$ is compatible with expected values

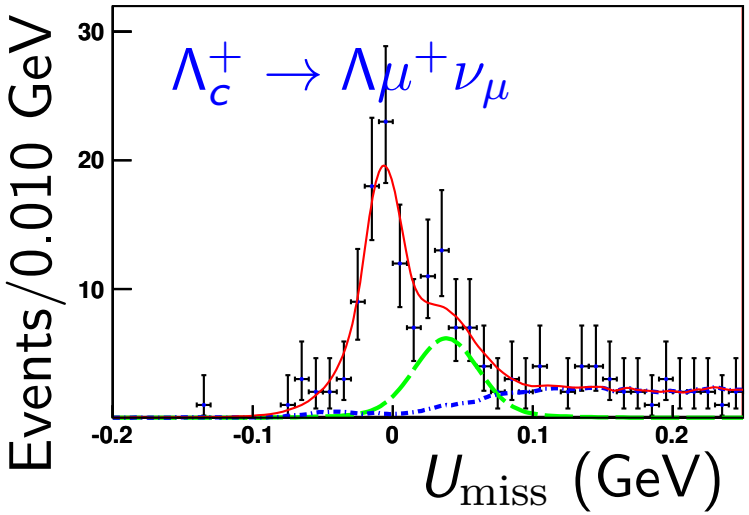
$\mathcal{B}$ of $\Lambda_c^+ \to \Lambda \ell^+ \nu_\ell$ $(\ell = e, \mu)$

[PRL.115.221805 and PLB.767 42-47]

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



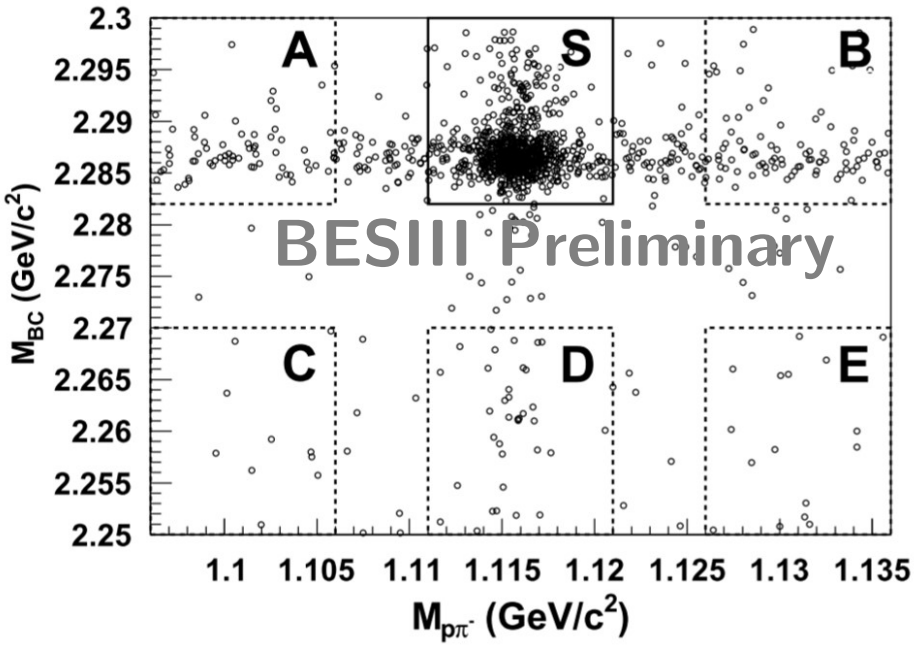
background: $\Lambda_c^+ \to \Lambda \pi^+ \pi^0$



1. the first absolute measurement, with
   $\mathcal{B}_{\Lambda_c^+ \to \Lambda e^+ \nu_e} = (3.63 \pm 0.38 \pm 0.20)\%$ and
   $\mathcal{B}_{\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu} = (3.49 \pm 0.46 \pm 0.27)\%$
2. a good test to non-perturbative models and LQCD calculations

$\mathcal{B}$ of $\Lambda_c^+ \to \Lambda X$

- proceed via $c \to s$ and dominates the rates of Λ_c^+ decay
- help to understand the Λ_c^+ quark structure and decay dynamics
- essential input for Λ_b decays



Two tag modes: $\bar{\Lambda}_c^- \to \bar{p}K_S^0$, $\bar{p}K^+\pi^-$

$$N^{sig} = N^S - \frac{N^A+N^B}{2} - f \cdot (N^D - \frac{N^C+N^E}{2})$$

$$\mathcal{B}_{\Lambda_c^+ \to \Lambda X} = (38.2^{+2.8}_{-2.2} \pm 0.6)\%$$

$$\mathcal{A}_{CP} = (2.1^{+7.0}_{-6.6} \pm 1.1)\%$$

- The total known $\mathcal{B}$ involving Λ is $(24.5 \pm 2.1)\%$, indicates many unknown decay channels from this measurement
- No CP asymmetry effect is observed in current precision

Summary

1. $\Lambda_c^+\bar{\Lambda}_c^-$ pair production at BESIII allows to determine the absolute $\mathcal{B}$s of Λ_c^+ decays;
2. The semileptonic decays improve the understanding of non-perturbative QCD, and provide good test to theoretical calculations;
3. The hadronic and inclusive decays are good channels to understand the decay dynamics and quark structure;
4. Λ_c^+ decays serve as essential inputs in Λ_b precision measurement and $\mathrm{V_{ub}}$ determination;
5. More data is expected at BESIII in the near future to explore more channels and improve the existing results.

The End