Λ_c decays at BESIII

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on behalf of BESIII Collaboration

Outline

1. Brief introduction

2. Hadronic decay of Λ_c

12 modes

$\Lambda_c^+ \to n K^S_0 \pi^+$

3. Semi-leptonic decay of Λ_c

$\Lambda_c \to \Lambda e \nu$

$\Lambda_c \to \Lambda \mu \nu$

4. Summary

A short introduction to Λ_c:

the lightest charmed baryon

Λ_c^+ $\qquad I(J^P) = 0(\frac{1}{2}^+)$

J is not well measured; $\frac{1}{2}$ is the quark-model prediction.

Mass $m = 2286.46 \pm 0.14$ MeV

Mean life $\tau = (200 \pm 6) \times 10^{-15}$ s $\quad$ (S = 1.6)

$c\tau = 59.9\ \mu$m

Mass and life time are well measured. Quantum numbers are not well measured, but no body doubt the current values.

Decay asymmetry parameters

$\Lambda\pi^+ \qquad \alpha = -0.91 \pm 0.15$

$\Sigma^+\pi^0 \qquad \alpha = -0.45 \pm 0.32$

$\Lambda\ell^+\nu_\ell \qquad \alpha = -0.86 \pm 0.04$

$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda\pi^+$, $\overline{\Lambda}_c^- \to \overline{\Lambda}\pi^- = -0.07 \pm 0.31$

$(\alpha + \overline{\alpha})/(\alpha - \overline{\alpha})$ in $\Lambda_c^+ \to \Lambda e^+\nu_e$, $\overline{\Lambda}_c^- \to \overline{\Lambda} e^-\overline{\nu}_e = 0.00 \pm 0.04$

Decay asymmetry parameters are measured in a few decay channels;
CP violation is searched, no hope to find (exclude) it with current data sample

$\Gamma(\Lambda_c^+ \to pK^-\pi^+)/\Gamma_{total}$	Γ_2/Γ
$\Gamma(\Lambda_c^+ \to p\overline{K}^*(892)^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_3/Γ_2
$\Gamma(\Lambda_c^+ \to \Delta(1232)^{++}K^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_4/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda(1520)\pi^+)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_5/Γ_2
$\Gamma(\Lambda_c^+ \to pK^-\pi^+$ nonresonant$)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_6/Γ_2
$\Gamma(\Lambda_c^+ \to p\overline{K}^0\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_7/Γ_2
$\Gamma(\Lambda_c^+ \to p\overline{K}^0\eta)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_8/Γ_2
$\Gamma(\Lambda_c^+ \to p\overline{K}^0\pi^+\pi^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_9/Γ_2
$\Gamma(\Lambda_c^+ \to pK^-\pi^+\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{10}/Γ_2
$\Gamma(\Lambda_c^+ \to p(K^-\pi^+)_{nonresonant}\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{12}/Γ_2
$\Gamma(\Lambda_c^+ \to pK^-\pi^+\pi^+\pi^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{14}/Γ_2
$\Gamma(\Lambda_c^+ \to pK^-\pi^+\pi^0\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{15}/Γ_2
$\Gamma(\Lambda_c^+ \to pK^-\pi^+3\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{16}/Γ_2
$\Gamma(\Lambda_c^+ \to p\pi^+\pi^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{17}/Γ_2
$\Gamma(\Lambda_c^+ \to pf_0(980))/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{18}/Γ_2
$\Gamma(\Lambda_c^+ \to p\pi^+\pi^+\pi^-\pi^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{19}/Γ_2
$\Gamma(\Lambda_c^+ \to pK^+K^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{20}/Γ_2
$\Gamma(\Lambda_c^+ \to p\phi)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{21}/Γ_2
$\Gamma(\Lambda_c^+ \to pK^+K^-$ non-$\phi)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{22}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{23}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{24}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\rho^+)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{25}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{26}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$ total$)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{32}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+\eta)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{33}/Γ_2
$\Gamma(\Lambda_c^+ \to \Sigma(1385)^+\eta)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{34}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+\omega)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{35}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$, no η or $\omega)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{36}/Γ_2
$\Gamma(\Lambda_c^+ \to \Lambda K^+\overline{K}^0)/\Gamma(\Lambda_c^+ \to pK^-\pi^+)$	Γ_{37}/Γ_2

No absolute branching fraction measurement until Belle's publication. Measurement with high precision is reachable with BESIII data sample.

Λ_c studies at BESIII

Pair production near the threshold, and no additional hadrons accompanying are produced:

CMS(GeV)	4.575	4.58	4.59	4.6
Lum.(pb^{-1})	48	9	8	568

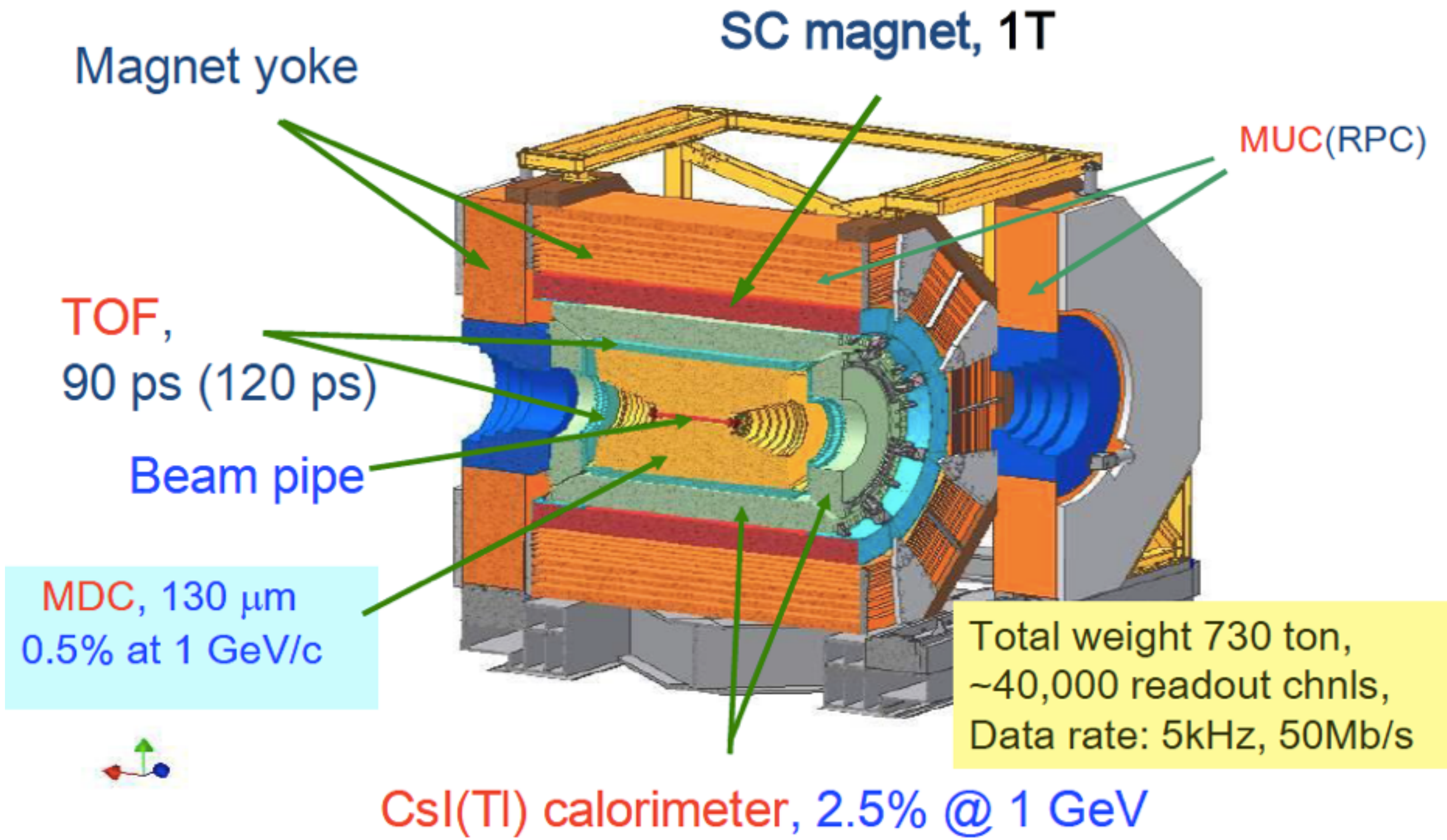
Cross section measurement near the production threshold: understand the strong interaction near threshold

Decay branching fraction measurement: processes with branching fraction at ~1% level or above can be reached; results are important to test the effective models based on QCD

Decay asymmetry parameters measurement: BESIII can improve the precision a little bit when comparing with current value

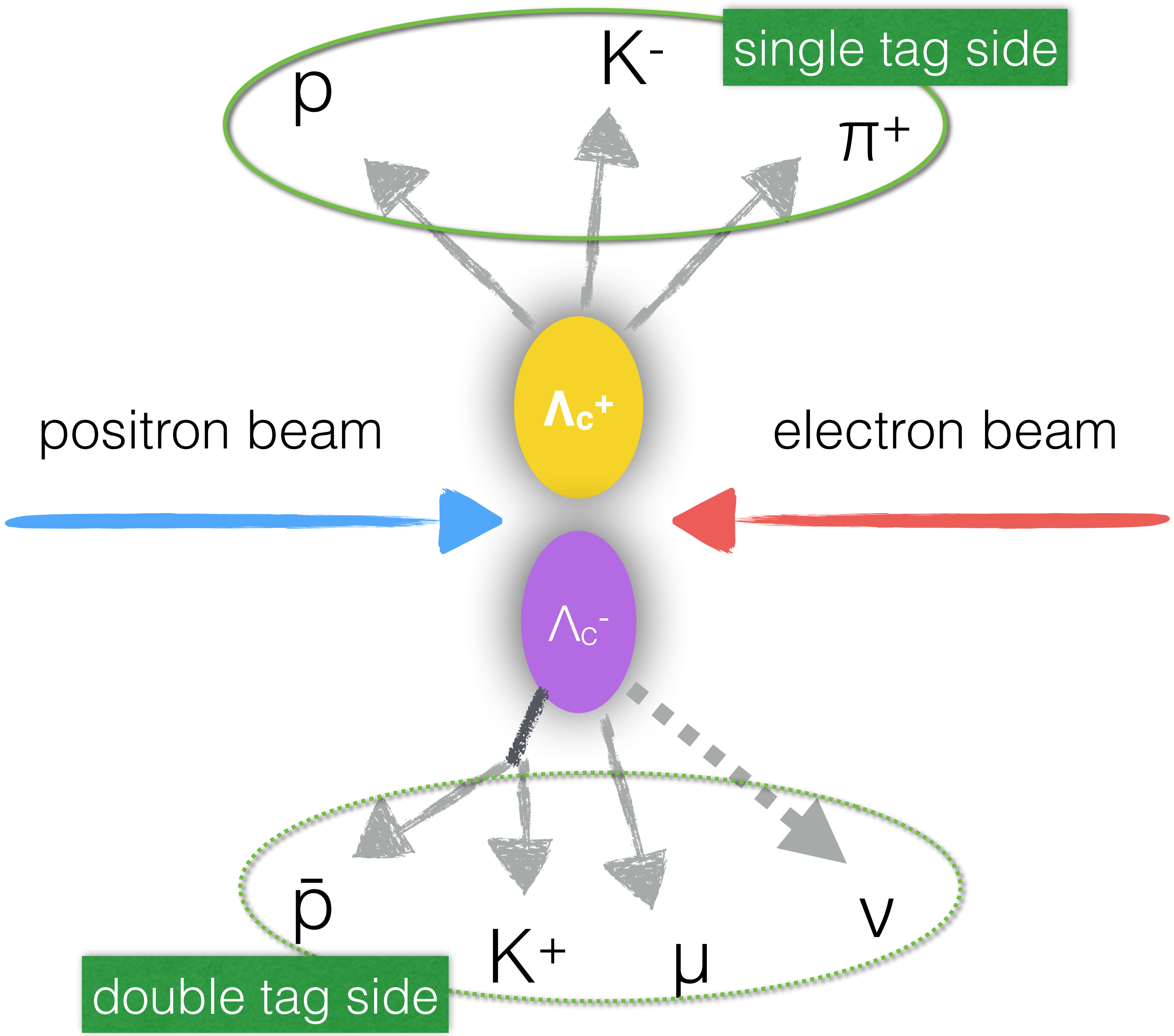
Spin and parity measurement: can pin them down with BESIII data

BESIII Detector



Beam energy: 1-2.3 GeV, symmetric electron-positron collider.

Λ_c branching fraction measurement method at BESIII



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

Background is high.

Phys. Rev. Lett. **116**, 052001

Measurement of the absolute hadronic branching fractions of the Λ_c baryon

Analysis method:

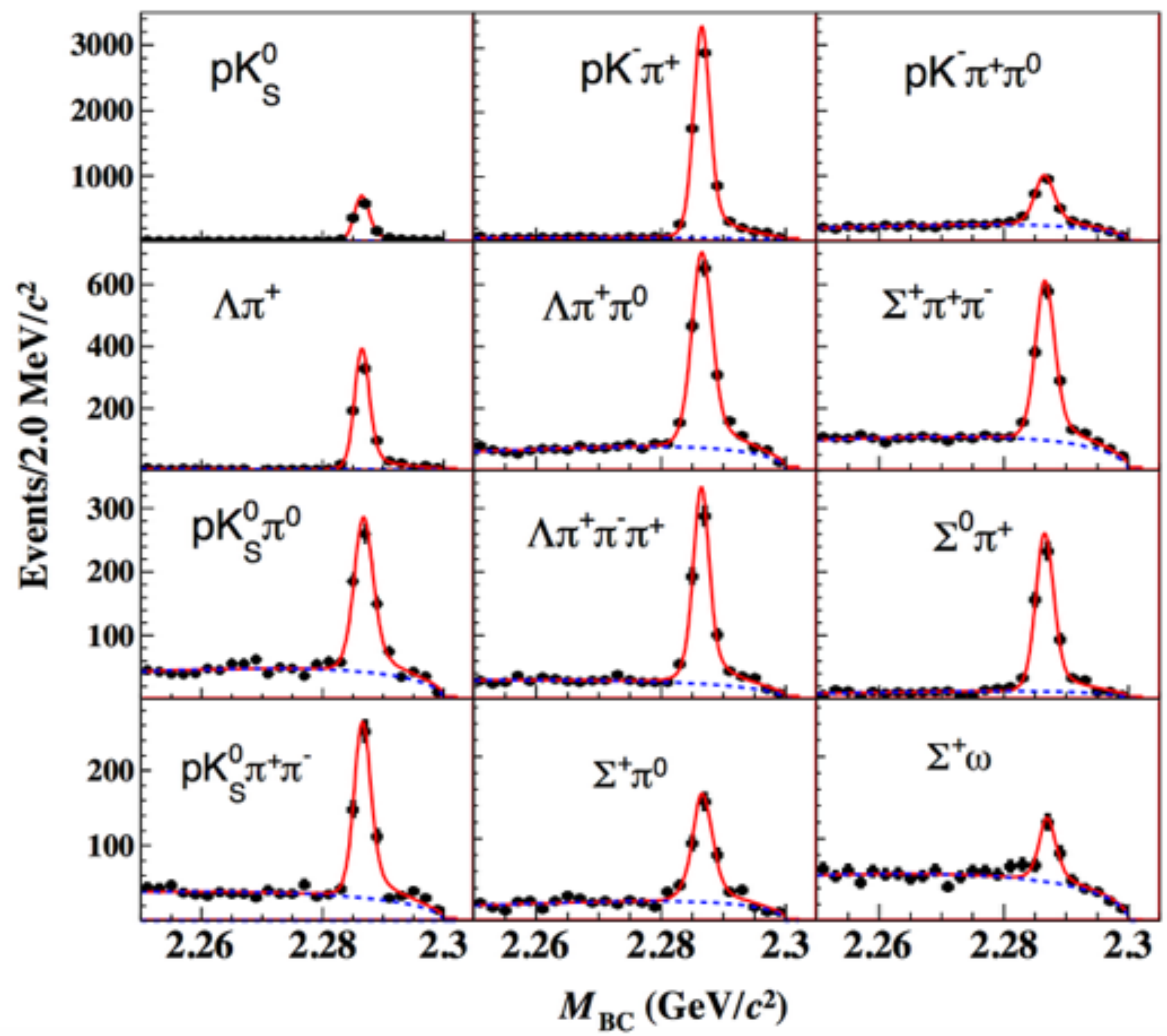
$$N_j^{\mathrm{ST}} = N_{\Lambda_c^+\overline{\Lambda}_c^-} \cdot \mathcal{B}_j \cdot \varepsilon_j$$

$$N_{ij}^{\mathrm{DT}} = N_{\Lambda_c^+\overline{\Lambda}_c^-} \cdot \mathcal{B}_i \cdot \mathcal{B}_j \cdot \varepsilon_{ij}$$

$$\mathcal{B}_i = \frac{N_{ij}^{\mathrm{DT}}}{N_j^{\mathrm{ST}}} \frac{\varepsilon_j}{\varepsilon_{ij}}$$

Advantage: some systematic uncertainties canceled out

Single tag fit plots



MC⊗Gauss+Argus

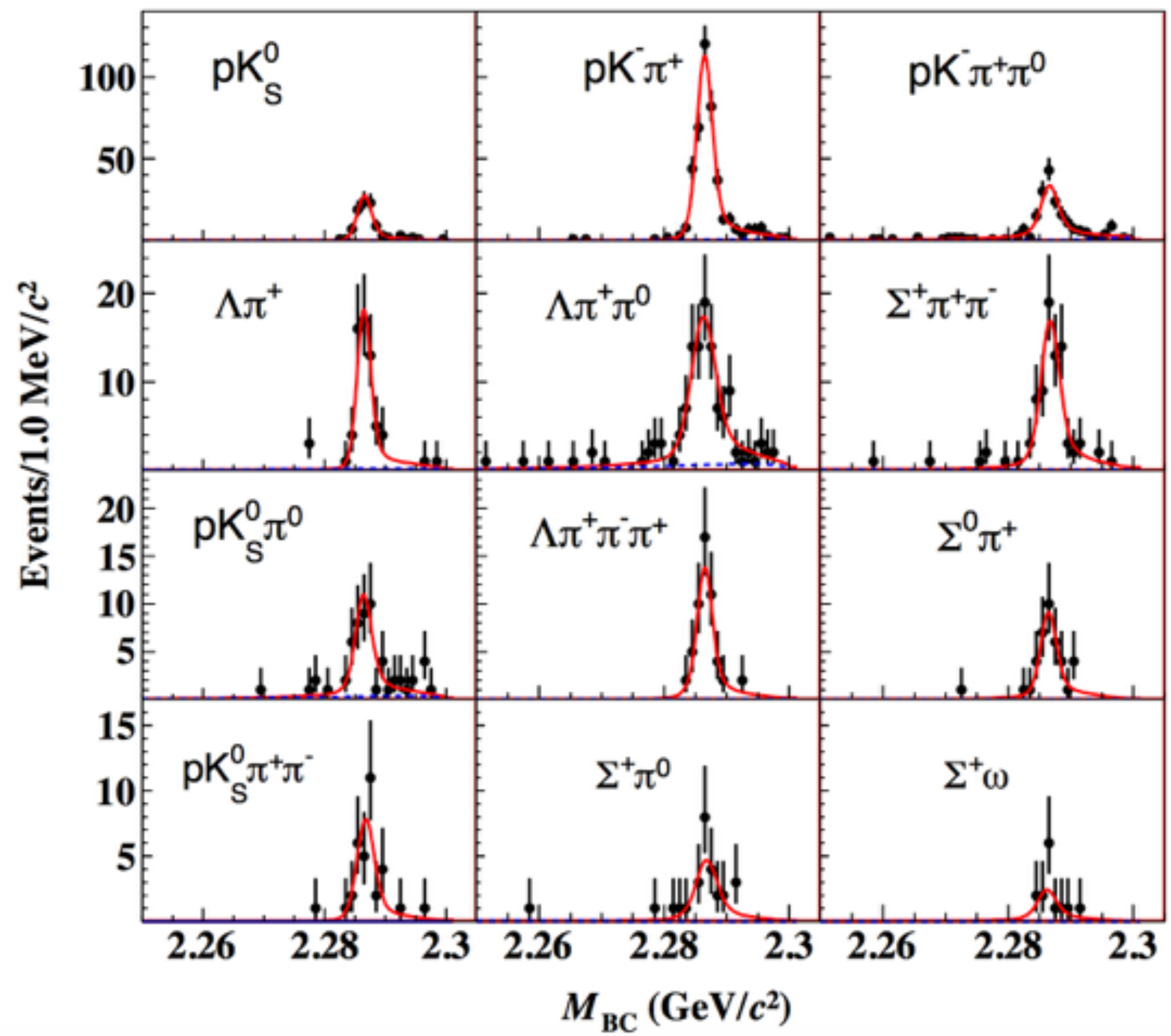
Number of events from fitting data and the efficiency from MC:

Mode	ΔE (MeV)	N_j^{ST}	$\varepsilon_j(\%)$	N_{i-}^{DT}	$\varepsilon_{i-}^{\mathrm{DT}}(\%)$
pK_S^0	$(-20, 20)$	1243 ± 37	55.9	97 ± 10	16.6
$pK^-\pi^+$	$(-20, 20)$	6308 ± 88	51.2	420 ± 22	14.1
$pK_S^0\pi^0$	$(-30, 20)$	558 ± 33	20.6	47 ± 8	6.8
$pK_S^0\pi^+\pi^-$	$(-20, 20)$	485 ± 29	21.4	34 ± 6	6.4
$pK^-\pi^+\pi^0$	$(-30, 20)$	1849 ± 71	19.6	176 ± 14	7.6
$\Lambda\pi^+$	$(-20, 20)$	706 ± 27	42.2	60 ± 8	12.7
$\Lambda\pi^+\pi^0$	$(-30, 20)$	1497 ± 52	15.7	101 ± 13	5.4
$\Lambda\pi^+\pi^-\pi^+$	$(-20, 20)$	609 ± 31	12.0	53 ± 7	3.6
$\Sigma^0\pi^+$	$(-20, 20)$	522 ± 27	29.9	38 ± 6	9.9
$\Sigma^+\pi^0$	$(-50, 30)$	309 ± 24	23.8	25 ± 5	8.0
$\Sigma^+\pi^+\pi^-$	$(-30, 20)$	1156 ± 49	24.2	80 ± 9	8.1
$\Sigma^+\omega$	$(-30, 20)$	157 ± 22	9.9	13 ± 3	3.8

$$\varepsilon_{i-}^{\mathrm{DT}} \equiv \frac{\sum_j (\mathcal{B}_j \cdot \varepsilon_{ij})}{\sum_j \mathcal{B}_j}$$

The ΔE requirement is set to less than about 3 times of the resolution.

Double tag fit plots



MC⊗Gauss+Argus

Systematic uncertainties from tracking, PID, intermediate resonances tagging efficiency are estimated by control sample; reweighing factors for the 12 modes are changed within statistical uncertainty to estimate the signal model uncertainty;

Source	Tracking	PID	K_S^0	Λ	π^0	Signal model	MC stat.	Quoted BFs	Total
pK_S^0	1.3	0.3	1.2			0.2	0.4	0.1	2.0
$pK^-\pi^+$	2.5	3.2					0.2		3.9
$pK_S^0\pi^0$	1.1	1.6	1.2		1.0	1.0	0.5	0.1	2.7
$pK_S^0\pi^+\pi^-$	2.8	5.4	1.2			0.5	0.5	0.1	5.9
$pK^-\pi^+\pi^0$	3.3	5.8			1.0	2.0	0.5		6.6
$\Lambda\pi^+$	1.0	1.0		2.5		0.5	0.5	0.8	2.4
$\Lambda\pi^+\pi^0$	1.0	1.0		2.5	1.0	0.6	0.6	0.8	2.7
$\Lambda\pi^+\pi^-\pi^+$	3.0	3.0		2.5		0.8	0.8	0.8	4.7
$\Sigma^0\pi^+$	1.0	1.0		2.5		1.7	0.7	0.8	2.4
$\Sigma^+\pi^0$	1.3	0.3			2.0	1.7	0.8	0.1	2.5
$\Sigma^+\pi^+\pi^-$	3.0	3.7			1.0	0.8	0.4	0.1	4.7
$\Sigma^+\omega$	3.0	3.2			2.0	7.1	1.0	0.8	4.5

A least-squares fitter, which considers the statistical and systematic correlations among the different hadronic modes, is used to obtain the branching fraction results:

Mode	This work (%)	PDG (%)
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
$pK_S^0\pi^0$	$1.87 \pm 0.13 \pm 0.05$	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

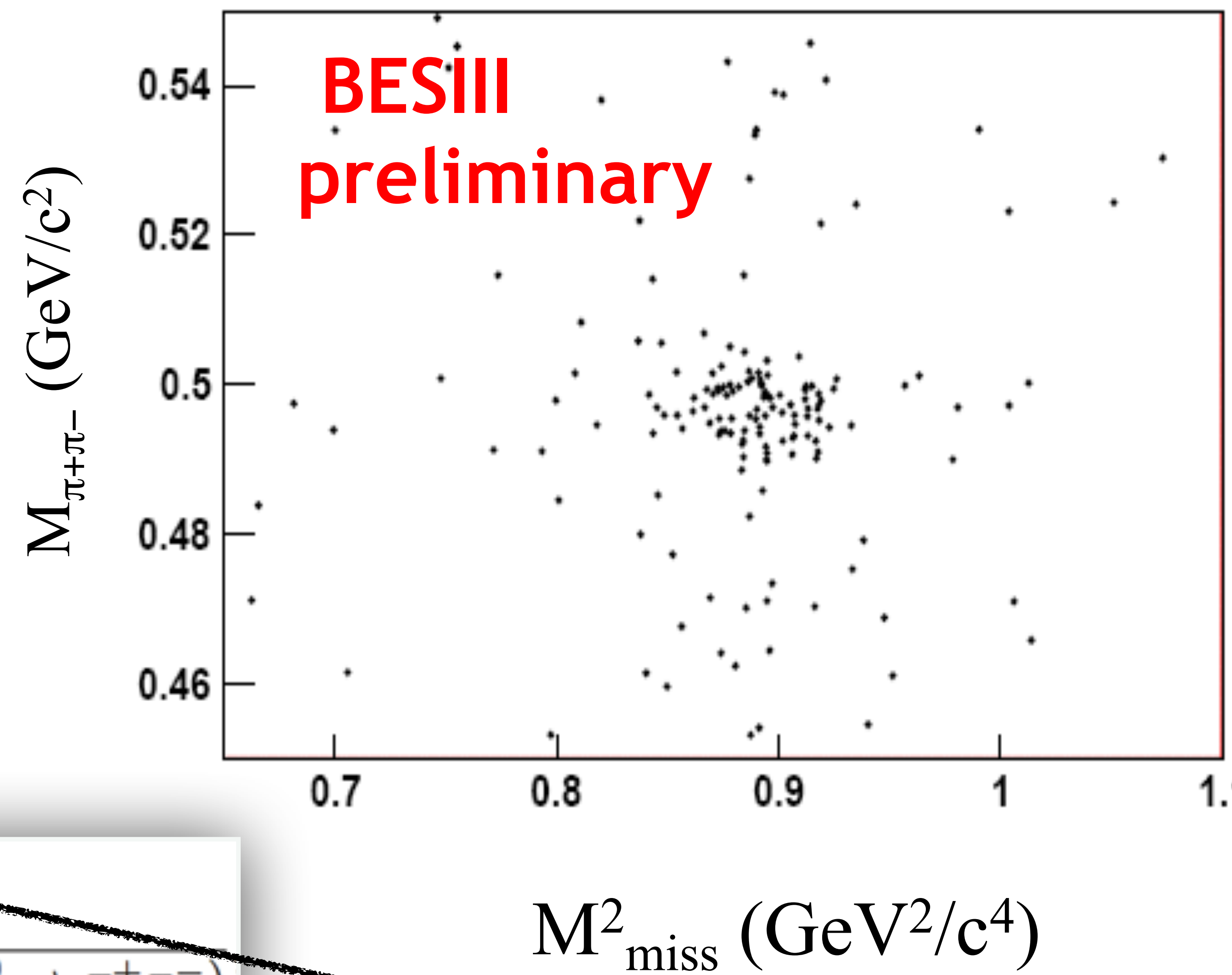
Short summary:

12 Cabibbo-favored decays rates are measured; for the pKπ mode, BESIII result is lower than the Belle result with a significance of about 2 σ; for the others modes, the precisions are improved by factors of 3-6 compared to the world averaged values.

Observation of $\Lambda_c^+ \to nK^S_0\pi^+$

Analysis method:

Same as previous analysis, except for the neutron reconstruction is not required, but using the missing mass information to select the signal process. The reason is that the neutron reconstruction is very hard.



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

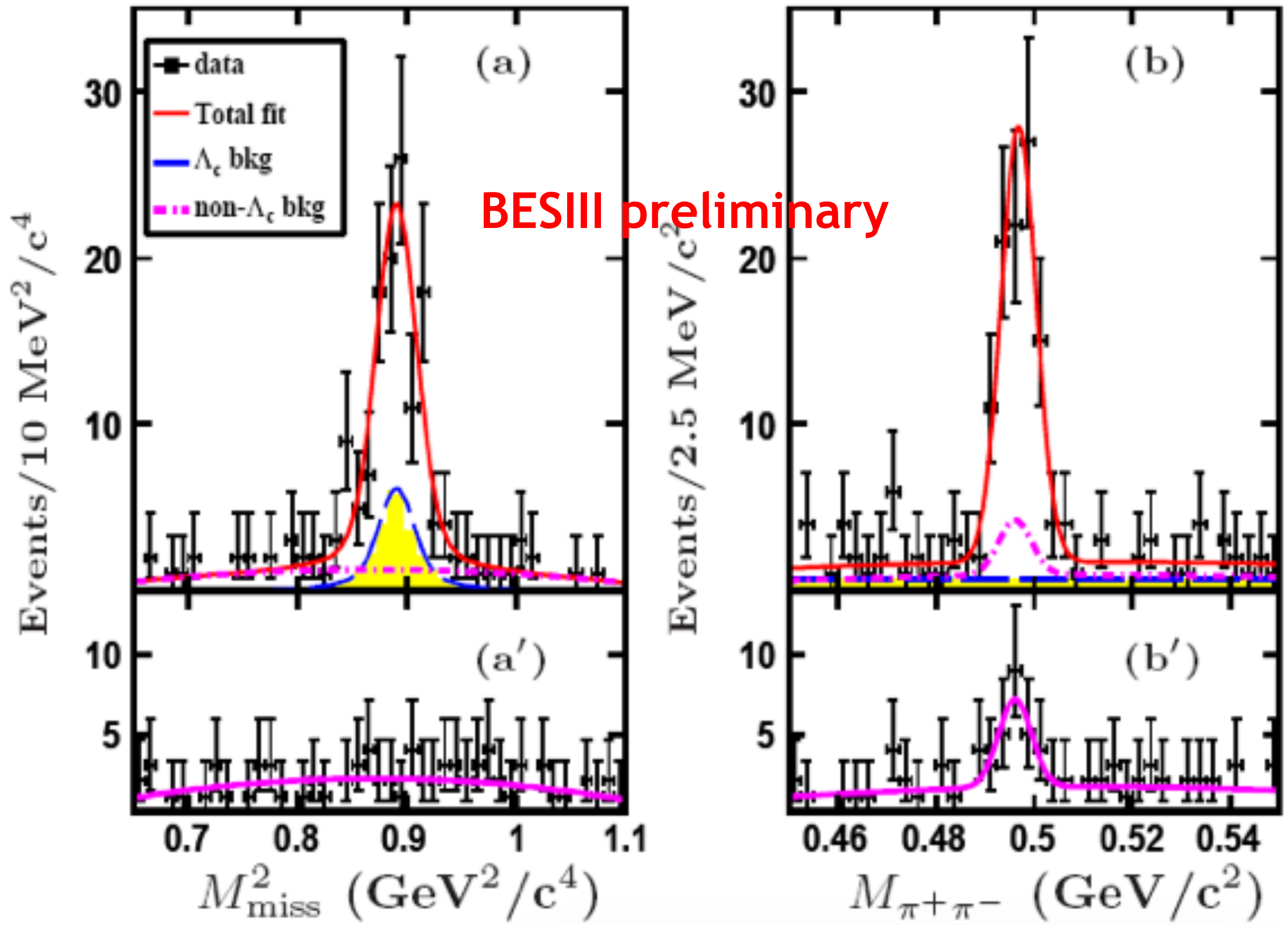
single tag fit: 14415+/-159

MC simulation: (58.88+/-0.28)%

Double tag fit: next slide

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

Double tag fit plots



Signal: double Gaussian with parameters fixed to MC simulation;
The Λ_c background: constant function in $M_{\pi+\pi-}$ and double Gaussian in M^2_{miss};
The non-Λ_c decay background: 2nd order polynomial in M^2_{miss} and Gaussian + 2nd order polynomial in $M_{\pi+\pi-}$.

Λc bkg: $\Lambda_c^+ \to \Sigma^-\pi^+\pi^+$ $\Lambda_c^+ \to \Sigma^+\pi^+\pi^-$ $\Sigma^\pm \to n\pi^\pm$

Short summary:

First observation of Λ_C^+ decays to final states involved with neutron.

$B[\Lambda_c^+ \to nK_S^0\pi^+]=(1.82\pm0.23\pm0.11)\%$

Phys. Rev. Lett. **115**, 221805

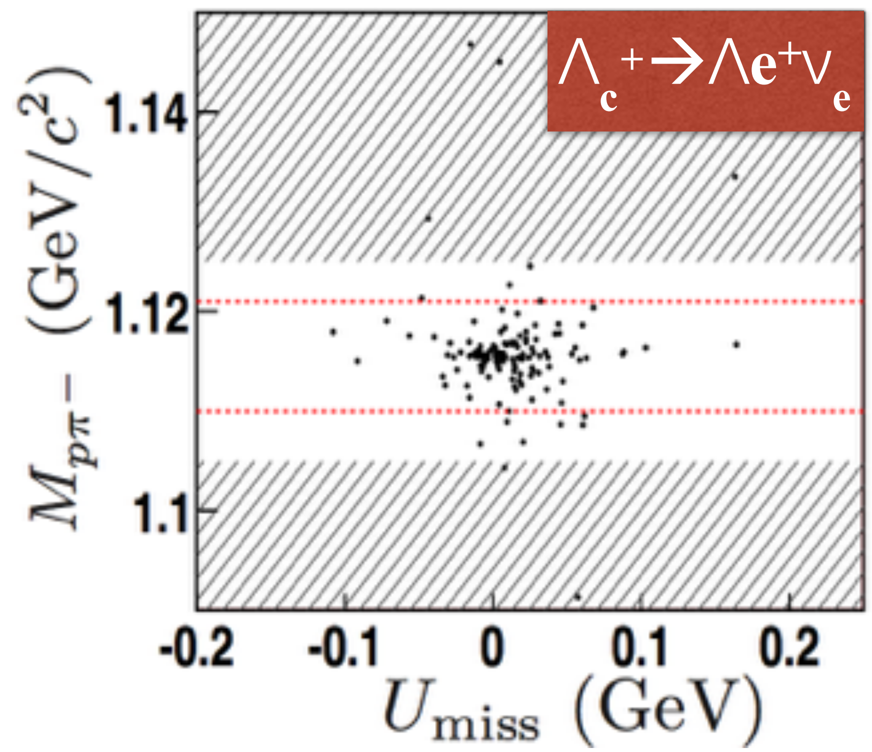
Measurement of the absolute branching fraction for $\Lambda_c^+ \to \Lambda l^+ \nu$

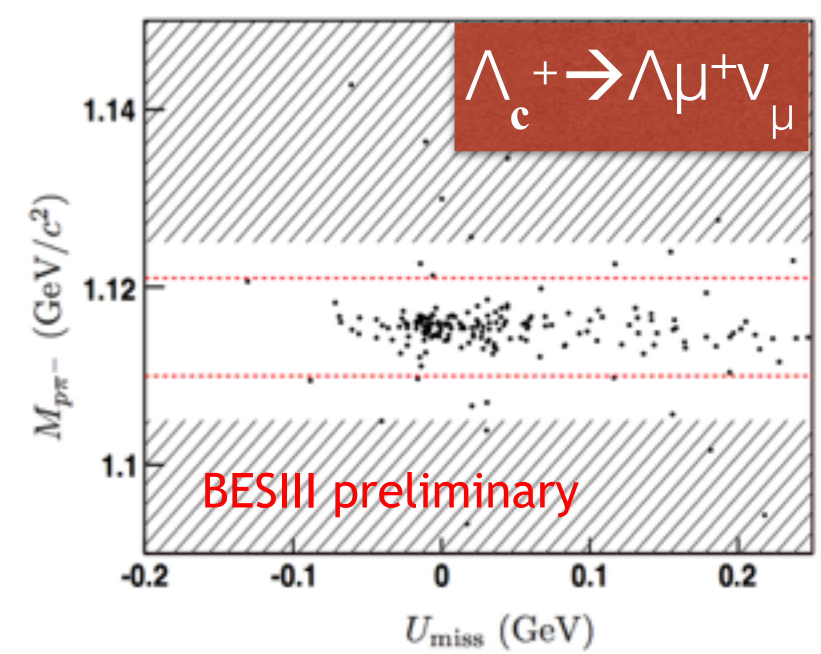
Analysis method:

Same as previous analysis, except U_{miss} is used rather that missing mass, as the neutrino is almost massless:

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

The background component is different between electron mode and muon mode, as a pion is easier to fake as a muon than as an electron. The background is estimated based on MC simulation.





Signal function: a Gaussian to model the core of U_{miss} and two power law tails to account for the ISR and FSR effect:

$$f(U_{\rm miss}) = \begin{cases} p_1(\frac{n_1}{\alpha_1} - \alpha_1 + t)^{-n_1}, & t > \alpha_1 \\ e^{-t^2/2}, & -\alpha_2 < t < \alpha_1 \\ p_2(\frac{n_2}{\alpha_2} - \alpha_2 - t)^{-n_2}, & t < -\alpha_2 \end{cases} \quad (1)$$

where $t = (U_{\rm miss} - U_{\rm mean})/\sigma_{U_{\rm miss}}$, $U_{\rm mean}$ and $\sigma_{U_{\rm miss}}$ are the mean value and resolution of the Gaussian function, respectively, $p_1 \equiv (n_1/\alpha_1)^{n_1} e^{-\alpha_1^2/2}$ and $p_2 \equiv (n_2/\alpha_2)^{n_2} e^{-\alpha_2^2/2}$. The parameters α_1, α_2, n_1 and n_2 are fixed to the values obtained in the signal MC simulations. From the fit, we obtain the number of SL signals to be 109.4 ± 10.9.

Result:

$B[\Lambda_c^+ \to \Lambda e^+ \nu_e] = (3.63 \pm 0.38 \pm 0.20)\%$

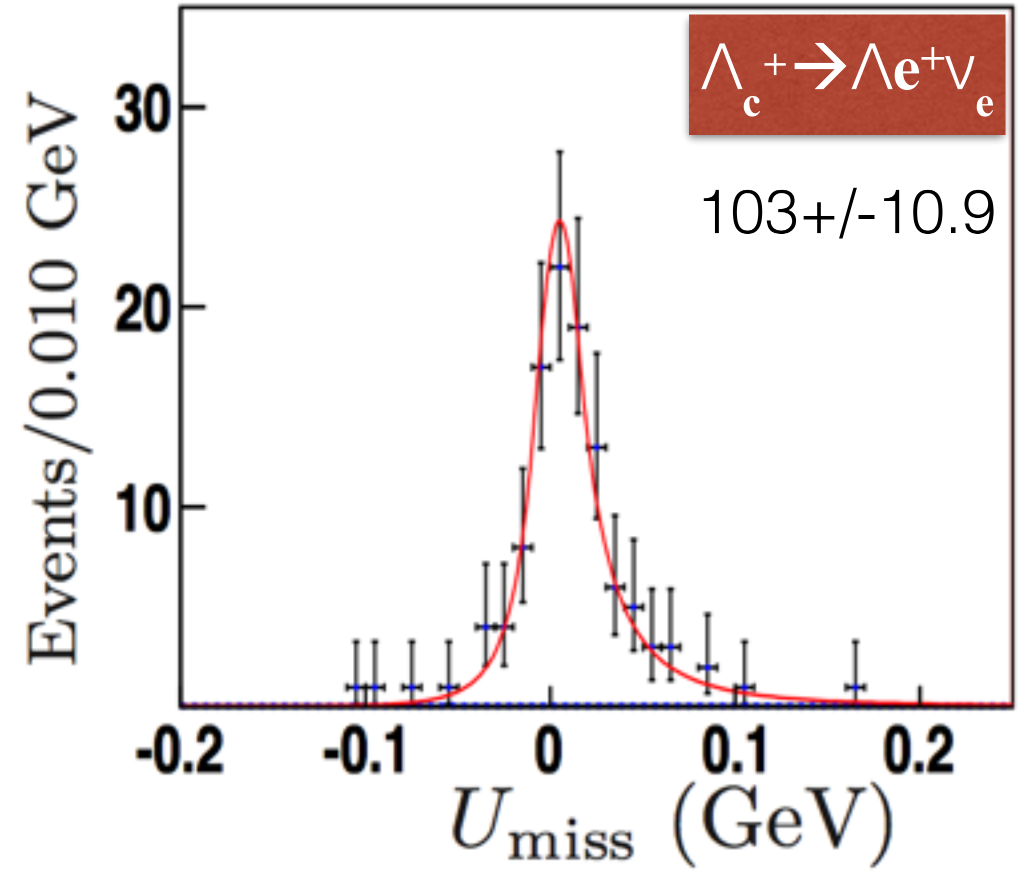
$B[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu] = (3.49 \pm 0.46 \pm 0.26)\%$

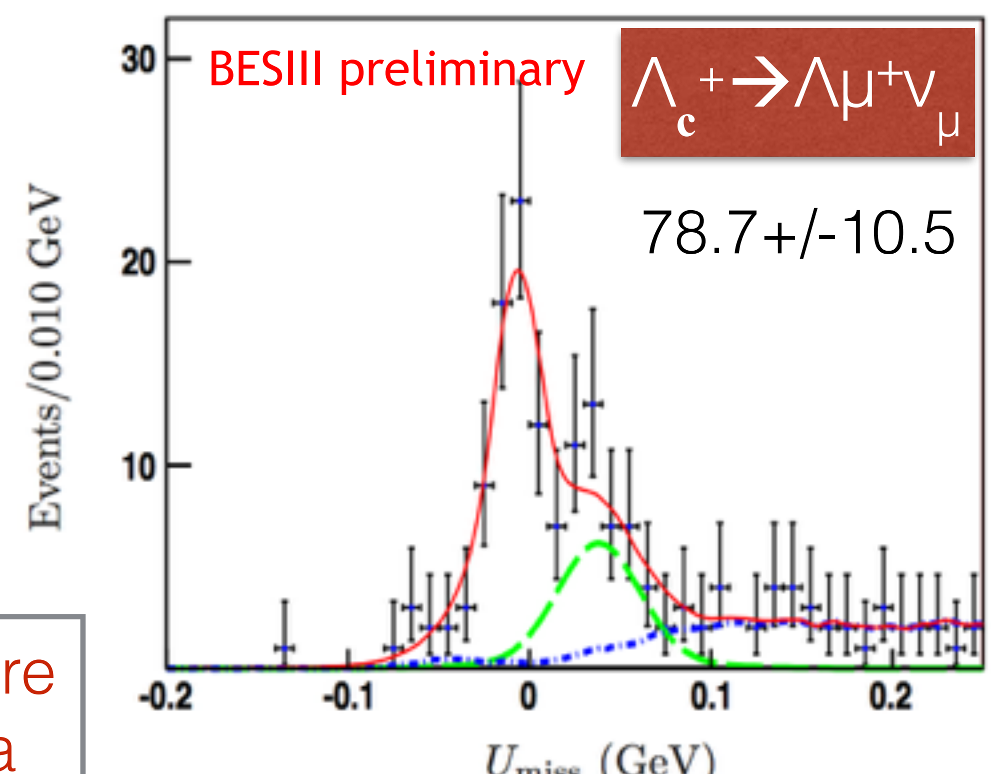
$\Gamma[\Lambda_c^+ \to \Lambda \mu^+ \nu_\mu]/\Gamma[\Lambda_c^+ \to \Lambda e^+ \nu_e] = 0.96 \pm 0.16 \pm 0.04$

Short summary:

The branching ratios of two semi-leptonic decays are measured in the highest precision with BESIII data

Double tag fit plots





Obvious background from $\Lambda_c^+ \to \Lambda \pi^+ \pi^0$

Summary

The branching fractions of Λ_c for the main hadronic, and semi-leptonic decay modes have been measured with high precision at BESIII;

More results about searching for decay modes with smaller branching fraction, cross section measurement, decay asymmetry parameters measurement and spin-parity are still under collaboration review.

THANK YOU !