Measurement of the Absolute Branching Fraction of the Inclusive Semileptonic Λ_c^+ Decay

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JC 95 report

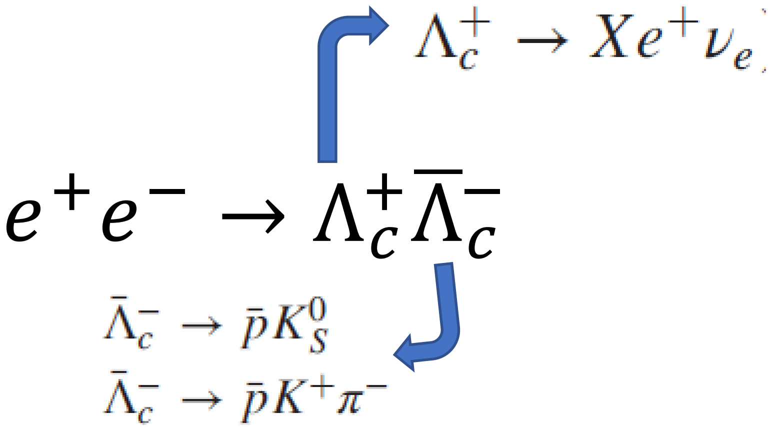
Introduction

- Information about semileptonic decays of the Λ_c^+ baryon is sparse.
- A comparison of $\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ **and** $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e)$, where X refers to any possible particle system, will guide searches for new semileptonic decay modes.
- Experimental data given $\boldsymbol{\Gamma(\Lambda_c^+ \to X e^+ \nu_e)/\bar{\Gamma}(D \to X e^+ \nu_e)}$=1.44$\pm$0.54. The ratio is predicted to be 1.67 using an effective-quark theory calculation and about 1.2 based on a calculation using the heavy-quark expansion. A more precise measurement of $\boldsymbol{\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e)}$ is desirable to test these theoretical predictions.
- We present the first absolute measurement of $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e)$, by employing a double-tag technique at $\sqrt{s}$=4.6 GeV. This technique takes advantage of a clean $\boldsymbol{\Lambda_c^+ \bar{\Lambda}_c^-}$ sample just above the threshold (4.573 GeV).

Event topology

Question from Amit

What is the double-tag technique? Please explain this with suitable and simple example.

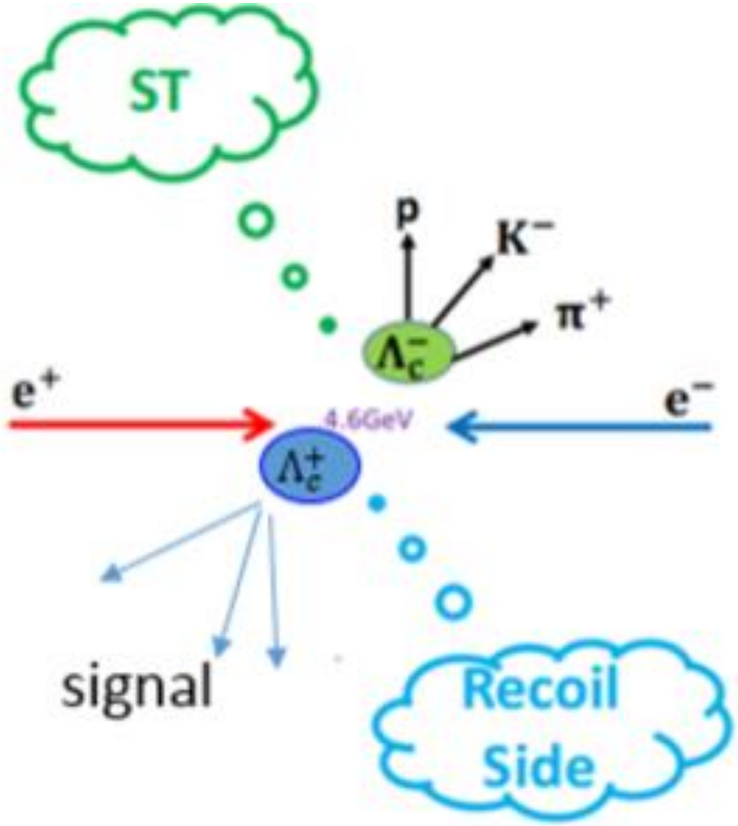


$\Lambda_c^+ \rightarrow X e^+ \nu_e$

$e^+e^- \rightarrow \Lambda_c^+ \overline{\Lambda}_c^-$

$\bar{\Lambda}_c^- \rightarrow \bar{p} K_S^0$

$\bar{\Lambda}_c^- \rightarrow \bar{p} K^+ \pi^-$



- A double-tag technique is employed.

1. we fully reconstruct one $\overline{\Lambda}_c^-$
2. search for candidates of the signal decay in the rest of the event that is recoiling against the tagged $\overline{\Lambda}_c^-$.

Calculate of Branching Fraction

$$N^{\mathrm{obs}}_{\mathrm{ST}} = 2N_{\Lambda_c^+\bar{\Lambda}_c^-}\mathcal{B}_{\mathrm{tag}}\epsilon_{\mathrm{tag}} \tag{1}$$

$$N^{\mathrm{obs}}_{\mathrm{DT}} = 2N_{\Lambda_c^+\bar{\Lambda}_c^-}\mathcal{B}_{\mathrm{tag}}\mathcal{B}_{\mathrm{sig}}\epsilon_{\mathrm{tag,sig}} \tag{2}$$

Then

$$\mathcal{B}_{\mathrm{sig}} = \frac{N^{\mathrm{obs}}_{\mathrm{DT}}}{N^{\mathrm{obs}}_{\mathrm{ST}}\frac{\epsilon_{\mathrm{tag,sig}}}{\epsilon_{\mathrm{tag}}}} = \frac{N^{\mathrm{obs}}_{\mathrm{DT}}}{N^{\mathrm{obs}}_{\mathrm{ST}}\epsilon} \tag{3}$$

Question from Xin

Hence, the absolute branching fraction of the inclusive semi-leptonic decay can be measured without knowing the total number of Λþc Λ ¯ −c pairs produced ··· why is that?

Question from Yuzhen

What does the double tag mean comparing to single tag? Why does it use double tag in this paper ?

Answer:

1, get more clean signals.

2, without knowing $N_{\Lambda_c^+\bar{\Lambda}_c^-}$

3, Can eliminate a lot of systematic uncertainties.

Determination of the tag yields

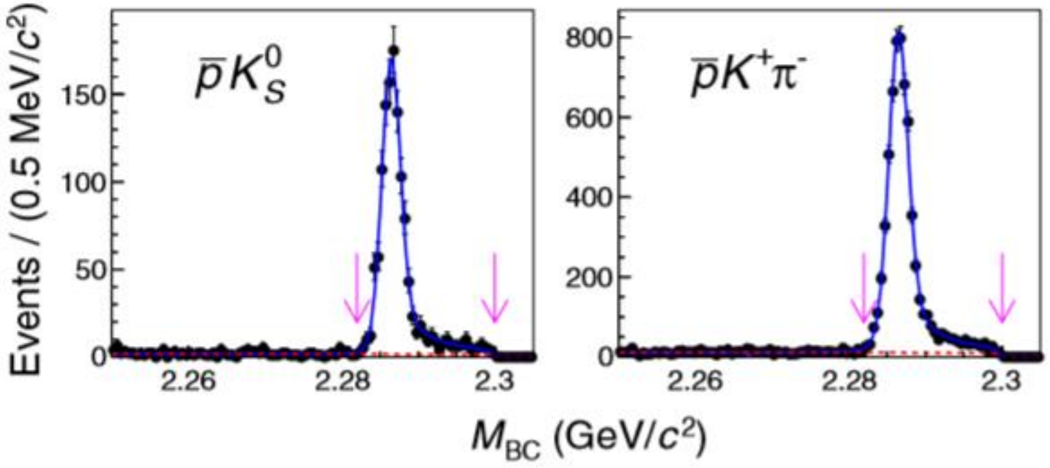
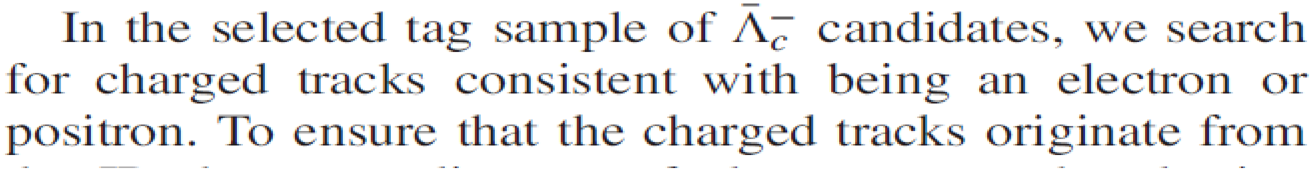


FIG. 1. $M_{\rm BC}$ distributions for the different tag modes in data. The solid blue line is the total fit, the dashed red line is the background component, and the pink arrows denote the $M_{\rm BC}$ signal region.

In the fits, the signal shape is modeled by the shape derived from MC simulation convolved with a Gaussian function that describes the resolution difference between data and MC simulation; the combinatorial background is described by an ARGUS function [24]. We obtain the tag yields by subtracting the integral of the background function in the signal region $2.282 < M_{\rm BC} < 2.300$ GeV$/c^2$ from the total number of events in the same region. The tails of the $M_{\rm BC}$

$$M_{\rm BC} \equiv \sqrt{E^2_{\rm beam}/c^4 - |\vec{p}_{\bar{\Lambda}_c^-}|^2/c^2},$$

Select the right e^+


In the selected tag sample of $\bar{\Lambda}_c^-$ candidates, we search for charged tracks consistent with being an electron or positron. To ensure that the charged tracks originate from

1, PID under (e, pi, K, P), Misidentification

$$\begin{pmatrix} N_e^{\text{obs}} \\ N_\pi^{\text{obs}} \\ N_K^{\text{obs}} \\ N_p^{\text{obs}} \end{pmatrix} = \begin{pmatrix} P_{e\to e} & P_{\pi\to e} & P_{K\to e} & P_{p\to e} \\ P_{e\to\pi} & P_{\pi\to\pi} & P_{K\to\pi} & P_{p\to\pi} \\ P_{e\to K} & P_{\pi\to K} & P_{K\to K} & P_{p\to K} \\ P_{e\to p} & P_{\pi\to p} & P_{K\to p} & P_{p\to p} \end{pmatrix} \begin{pmatrix} N_e^{\text{true}} \\ N_\pi^{\text{true}} \\ N_K^{\text{true}} \\ N_p^{\text{true}} \end{pmatrix},$$

2, non Λ_c^+ decays in the signal region, estimate by its sideband

3, secondary positrons, evaluated from the wrong-sign positron sample

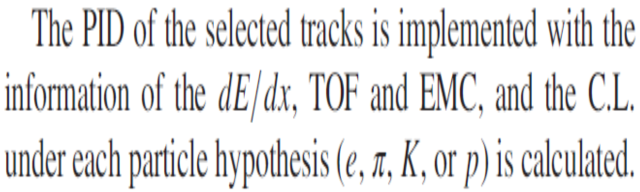
4, track reconstruction efficiency, selection efficiency, and resolution effects, corrected by

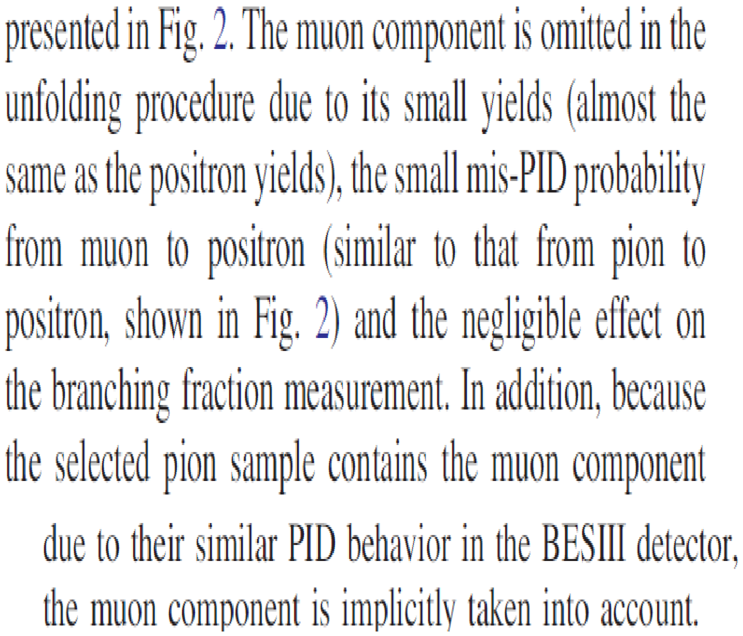
$$N_i^{\text{true}} = \sum_j T(i|j) N_j^{\text{pro}},$$

Question from Kai

on page5. for the PID, why the hyperthesis of muon is not considered in this paper?

Answer:


The PID of the selected tracks is implemented with the information of the dE/dx, TOF and EMC, and the C.L. under each particle hypothesis (e, π, K, or p) is calculated.


presented in Fig. 2. The muon component is omitted in the unfolding procedure due to its small yields (almost the same as the positron yields), the small mis-PID probability from muon to positron (similar to that from pion to positron, shown in Fig. 2) and the negligible effect on the branching fraction measurement. In addition, because the selected pion sample contains the muon component due to their similar PID behavior in the BESIII detector, the muon component is implicitly taken into account.

Positron yields

Question from Yuhang

What's sideband subtraction in table II ?

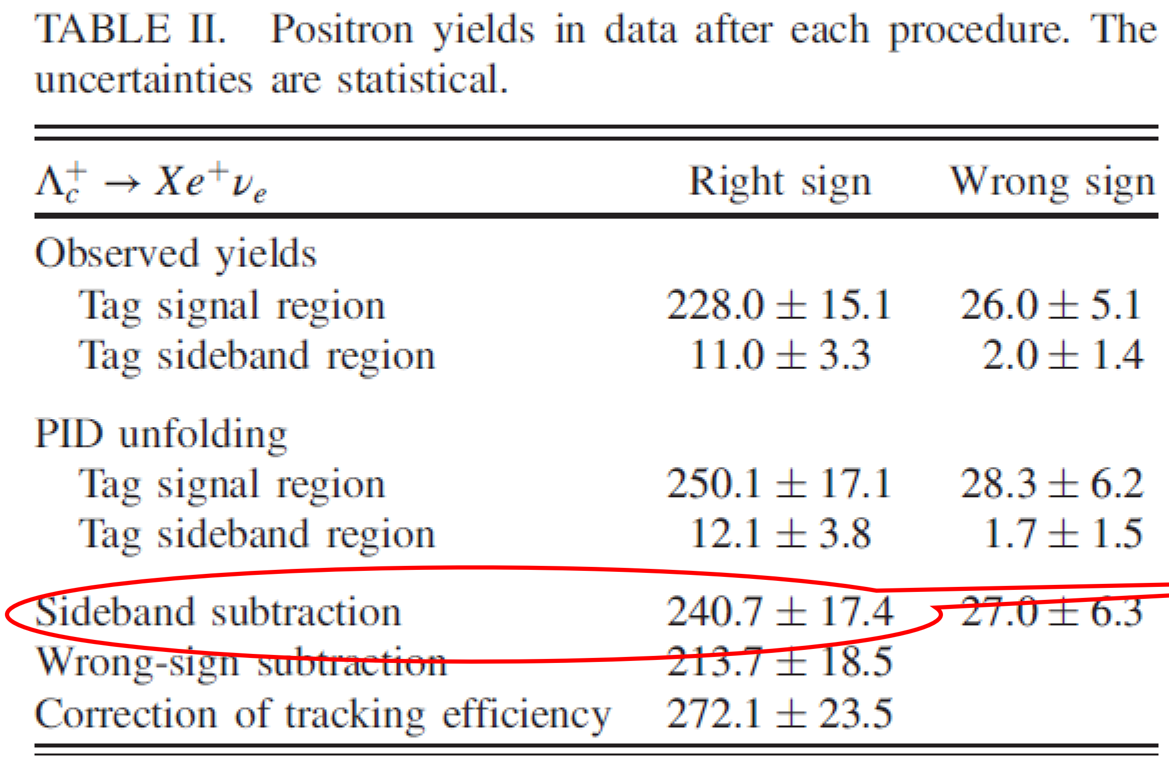
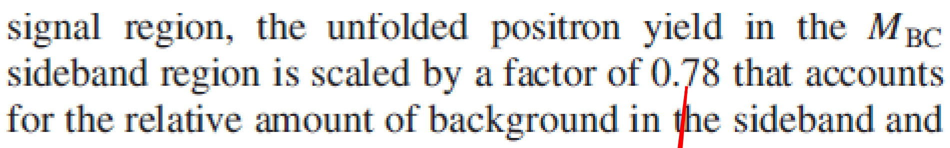


TABLE II. Positron yields in data after each procedure. The uncertainties are statistical.

$\Lambda_c^+ \to X e^+ \nu_e$	Right sign	Wrong sign
Observed yields		
Tag signal region	228.0 ± 15.1	26.0 ± 5.1
Tag sideband region	11.0 ± 3.3	2.0 ± 1.4
PID unfolding		
Tag signal region	250.1 ± 17.1	28.3 ± 6.2
Tag sideband region	12.1 ± 3.8	1.7 ± 1.5
Sideband subtraction	240.7 ± 17.4	27.0 ± 6.3
Wrong-sign subtraction	213.7 ± 18.5	
Correction of tracking efficiency	272.1 ± 23.5	



signal region, the unfolded positron yield in the M_{BC} sideband region is scaled by a factor of 0.78 that accounts for the relative amount of background in the sideband and

Ntrue= Nobserved – Nsideband

240.7= 250.1-0.78×12.1

Result

$$\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e) = \frac{N^{\rm pro}(p_e > 200~{\rm MeV}/c)}{N_{\rm tag}[1 - f(p_e < 200~{\rm MeV}/c)]}, \qquad (2)$$

where $N^{\rm pro}(p_e > 200~{\rm MeV}/c)$ is the yield of positrons with momentum p_e above 200 MeV/c after the correction of the tracking efficiency, $N_{\rm tag}$ is the tag yield, and $f(p_e < 200~{\rm MeV}/c)$ is the fraction of positrons below 200 MeV/c. Finally, we obtain $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e) = (3.95 \pm 0.34)\%$, where the uncertainty is statistical only.

The fraction of positrons below 200 MeV/c is obtained by fitting the efficiency-corrected positron momentum spectrum with the sum of the spectra of the exclusive decay channels (Table III), as shown in Fig. 3. In the fit, the

Decay channel	$\mathcal{B}$ (%)	Model
$\Lambda_c^+ \to \Lambda e^+ \nu_e$	3.63 ± 0.43 [5]	$F_1^V(q^2)$ $= 2.52/5.09 - q^2$ [28]
$\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e$	0.38 ± 0.38 [30]	PYTHIA [29]
$\Lambda_c^+ \to n e^+ \nu_e$	0.27 ± 0.27 [31]	PYTHIA [29]

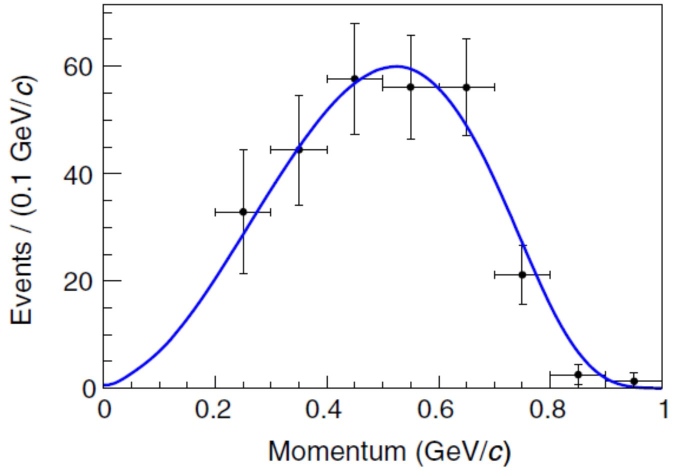


FIG. 3. Extrapolation of the positron momentum spectrum in the laboratory frame obtained from data, shown as points with error bars. The blue curve shows the extrapolated spectrum.

- Question from Suyu
- What is heavy-quark expansion?

- Answer :

Λ_c^+ ->ud**c**

• Question from Ryuta

- In table III, the semi-leptonic decay modes to extrapolate the positron momentum spectrum are listed, but the latter two are unobserved ones. Is there strong motivation to include those ?
- (I mean , we could introduce any hypothetical decays to adjust calculation, such as lepton violating modes etc. in the extreme example)

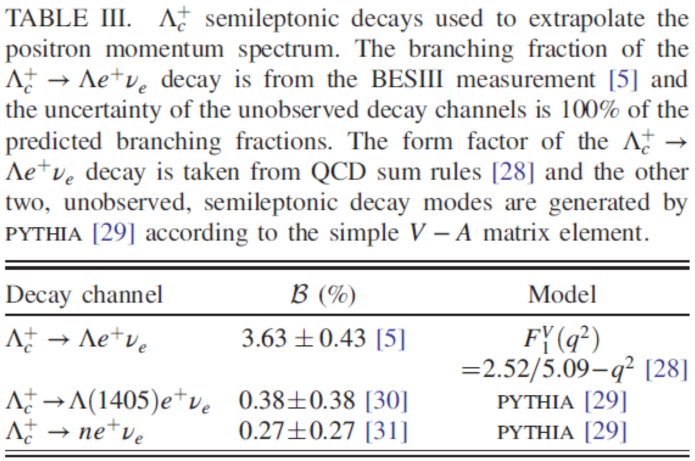


TABLE III. Λ_c^+ semileptonic decays used to extrapolate the positron momentum spectrum. The branching fraction of the $\Lambda_c^+ \to \Lambda e^+ \nu_e$ decay is from the BESIII measurement [5] and the uncertainty of the unobserved decay channels is 100% of the predicted branching fractions. The form factor of the $\Lambda_c^+ \to \Lambda e^+ \nu_e$ decay is taken from QCD sum rules [28] and the other two, unobserved, semileptonic decay modes are generated by PYTHIA [29] according to the simple $V - A$ matrix element.

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• Answer:

1,$\mathcal{B}(\Lambda_c^+ \to \Lambda e^+ \nu_e)$ / $\mathcal{B}(\Lambda_c^+ \to X e^+ \nu_e) = (80.7 \pm 31.9)\%$

adding this two decays $\Lambda_c^+ \to \Lambda(1405) e^+ \nu_e$ and $\Lambda_c^+ \to n e^+ \nu_e$, these three processes account for 90% of the total.

2, The total of others is about 10%, considering the statistics of the data, this three mode is enough .