Analysis of $\Lambda_c^+ \to \Lambda + X$

On behalf of BESIII Collaboration

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IHEP

全国第十四届重味物理和 CP 破坏研讨会
上海交通大学， 2016年11月3日

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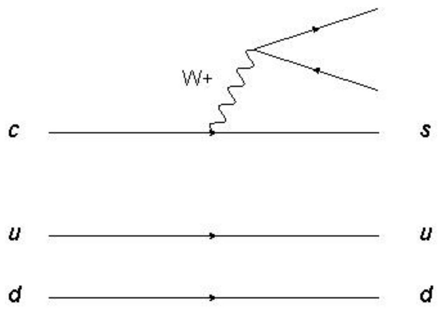
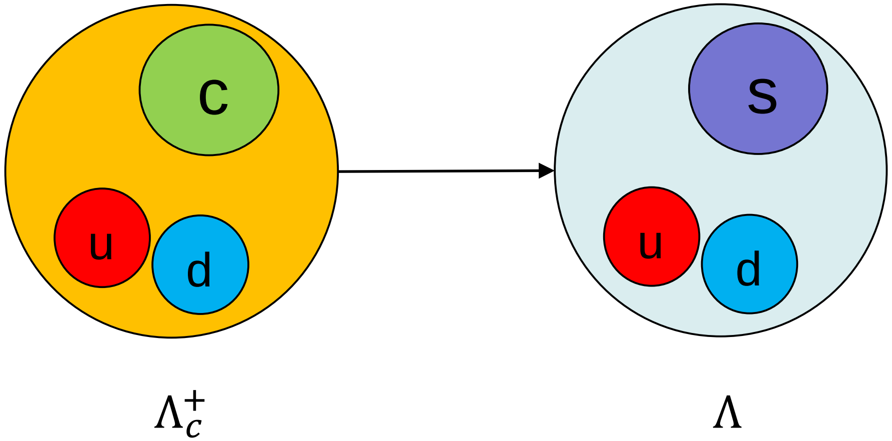
Motivation

Heavy Quark Effective Theory

Heavy quark physics plays an important role in testing the Standard Model and searching for new physics. This study is concerned on the measurement of inclusive branching fraction(BF) of $\Lambda_c^+ \to \Lambda + X$, which can be used to test the Heavy Quark Effective Theory (HQET).

Feynman Diagram





Motivation

PDG Results

The averaged BF in the latest PDG is $(35 \pm 11)\%$, of which the uncertainty is relatively large and the result is relative to the $\mathcal{B}(\Lambda_c^+ \to pK^-\pi^+)$.

The summary of the BFs of known decay modes of $\Lambda_c^+ \to \Lambda + X$ is not consistent with the inclusive measurement.

Decay modes	Branching fractions
$\Lambda_c^+ \to \Lambda\pi^+$	$(1.46 \pm 0.13)\%$
$\Lambda_c^+ \to \Lambda\pi^+\pi^0$	$(5.0 \pm 1.3)\%$
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-$	$(3.59 \pm 0.28)\%$
$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-\pi^0$	$(2.5 \pm 0.9)\%$
$\Lambda_c^+ \to \Lambda K^+\bar{K}^0$	$(6.4 \pm 1.3)\times10^{-3}$
$\Lambda_c^+ \to \Sigma^0\pi^+$, $\Sigma^0 \to \gamma\Lambda$	$(1.43 \pm 0.14)\%$
$\Lambda_c^+ \to \Sigma^0\pi^+\pi^0$, $\Sigma^0 \to \gamma\Lambda$	$(2.5 \pm 0.9)\%$
$\Lambda_c^+ \to \Sigma^0\pi^+\pi^+\pi^-$, $\Sigma^0 \to \gamma\Lambda$	$(1.13 \pm 0.31)\%$
$\Lambda_c^+ \to \Xi^0 K^+$, $\Xi^0 \to \Lambda\pi^0$	$(5.3 \pm 1.3)\times10^{-3}$
$\Lambda_c^+ \to \Xi^- K^+\pi^+$, $\Xi^- \to \Lambda\pi^-$	$(7.0 \pm 0.8)\times10^{-3}$
$\Lambda_c^+ \to \Lambda K^+$	$(6.9 \pm 1.4)\times10^{-4}$
$\Lambda_c^+ \to \Sigma^0 K^+$, $\Sigma^0 \to \gamma\Lambda$	$(5.7 \pm 1.0)\times10^{-4}$
$\Lambda_c^+ \to \Lambda l^+\nu_l$	$(2.8 \pm 0.4)\%$
Total	$(22.35 \pm 1.93)\%$
$\Lambda_c^+ \to \Sigma^0 K^+\pi^+\pi^-$, $\Sigma^0 \to \gamma\Lambda$	$< 2.9 \times 10^{-4}$
$\Lambda_c^+ \to \Lambda K^+\pi^+\pi^-$	$< 6 \times 10^{-4}$
$\Lambda_c^+ \to \Lambda\rho^+$	$< 6\%$

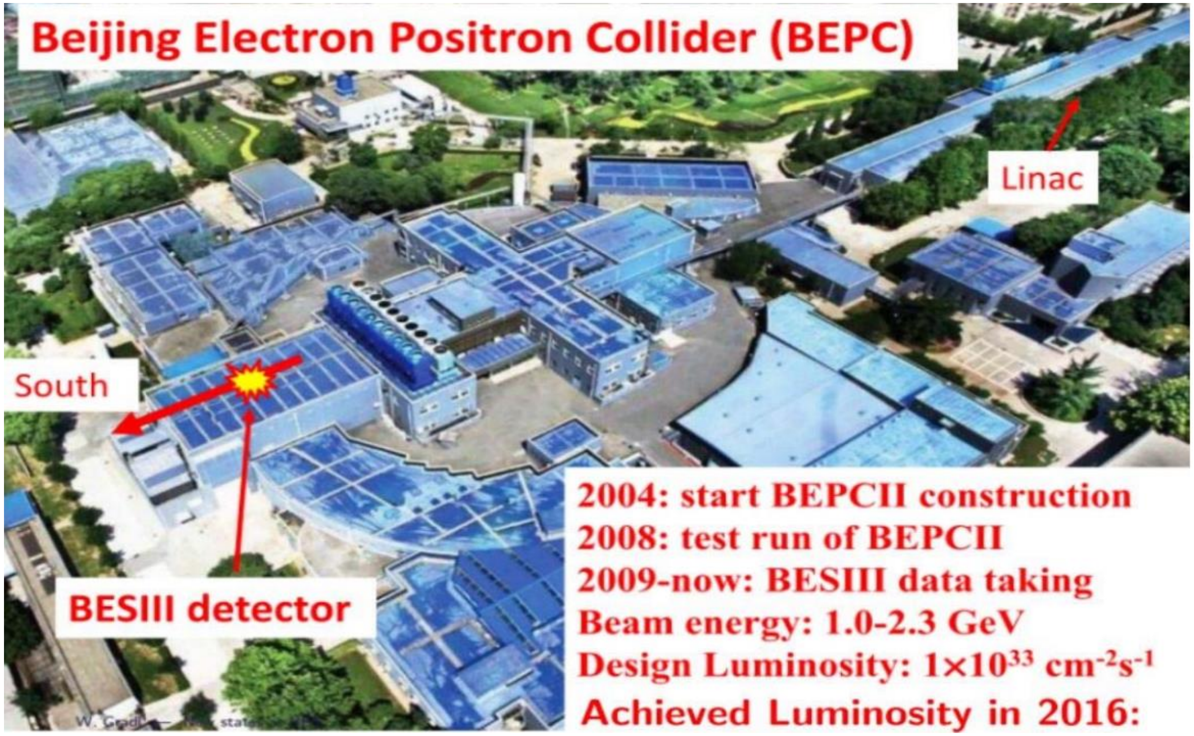
Table 1: Summary of the known decay modes of $\Lambda_c \to \Lambda + X$.

CP Violation

In c-quark sector, the contribution to CP violation from the CKM mechanism is small, which makes it an excellent place to look for new physics(NP). Precise measurement of the CP violation parameter in charm sector is important.

Apparatus and samples

BEPCII & BESIII



Samples

Data sample : $0.567 fb^{-1}$ at $\sqrt{s} = 4.5995$ GeV (2014).

MC sample : inclusive MC at $\sqrt{s} = 4.5995$ GeV.
(including the process of $\Lambda_c^+\Lambda_c^-, \tau^+\tau^-, D/D_s + X, q\bar{q}, ISR$)

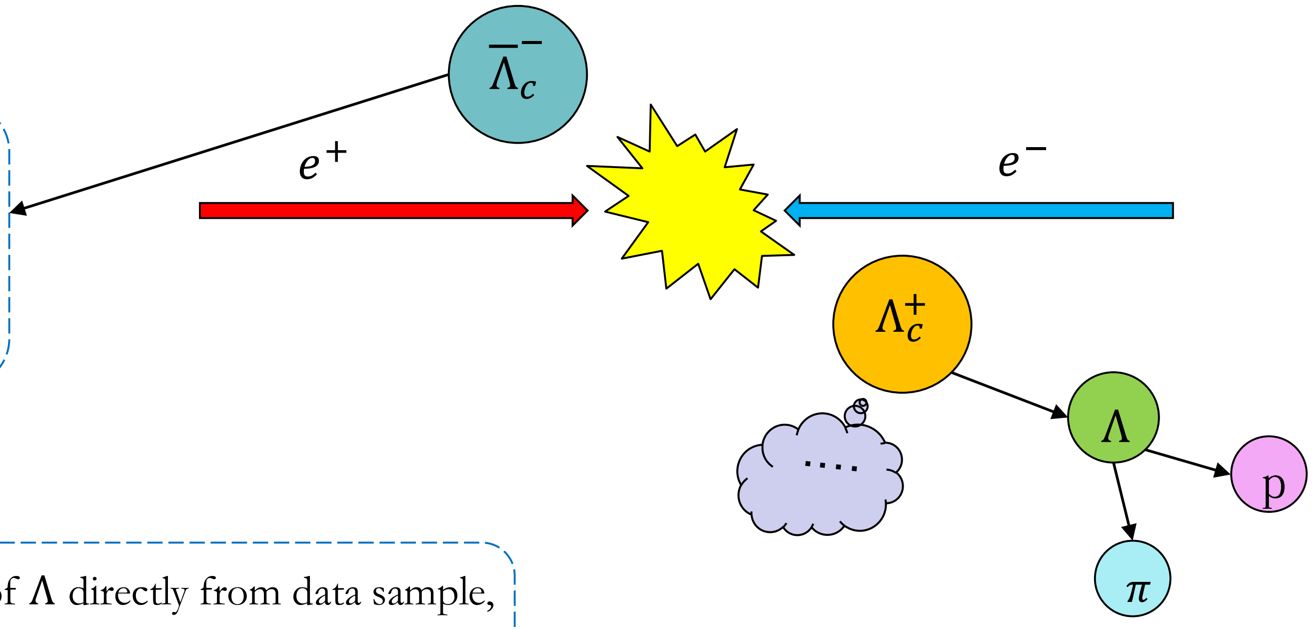
Method

Double tag

Two tag modes:

(1) $\overline{\Lambda}_c^- \to \overline{p} K_S^0$

(2) $\overline{\Lambda}_c^- \to \overline{p}\, K^+\, \pi^-$



Data driven

Obtain the efficiency of Λ directly from data sample, instead of from MC.
Control sample: $J/\psi \to \overline{p} K^+ \Lambda$ and c.c.

Efficiency bin by bin

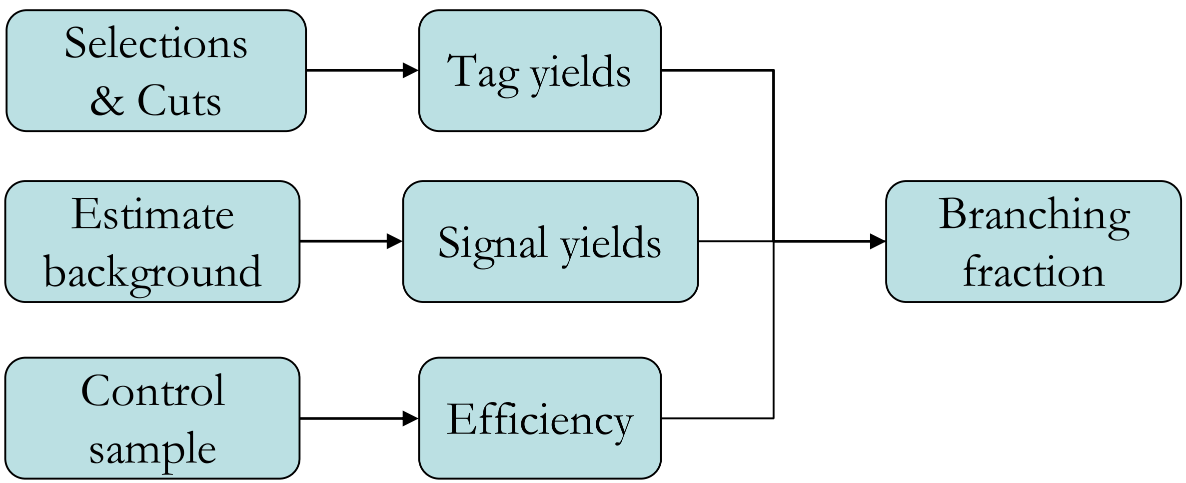
Divide the control sample into sample into 4×4 $p - |cos\theta|$ bins to obtain the efficiency.

Analysis procedure

Formula

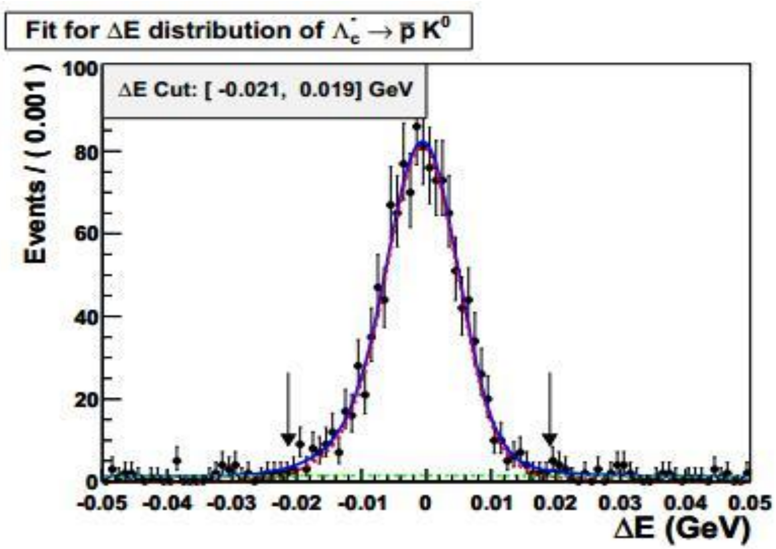
$$\mathcal{B}^{\text{sig}} = \frac{\sum_{ij} N_{ij}^{\text{sig}} / \varepsilon_j^{\text{sig}}}{\sum_i N_i^{\text{tag}}},$$

Work flow

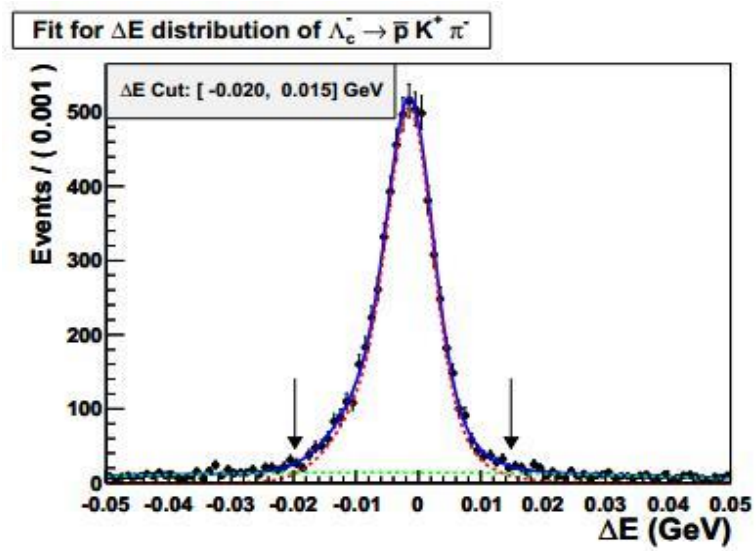


Reconstruction of $\Lambda_c^{\pm}$

ΔE cut



ΔE: $[-0.021GeV, 0.019GeV]$



ΔE: $[-0.020GeV, 0.015GeV]$

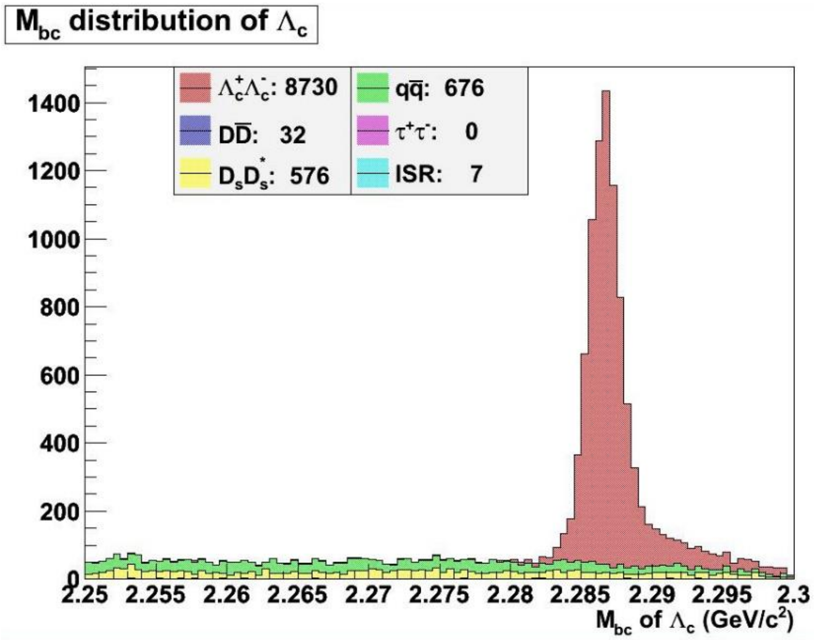
The signals are fitted by Crystal Ball function convoluted with a Gaussian function, while the backgrounds are described using polynomial function, 3σ cut criteria is taken.

Reconstruction of $\Lambda_c^{\pm}$

Background study

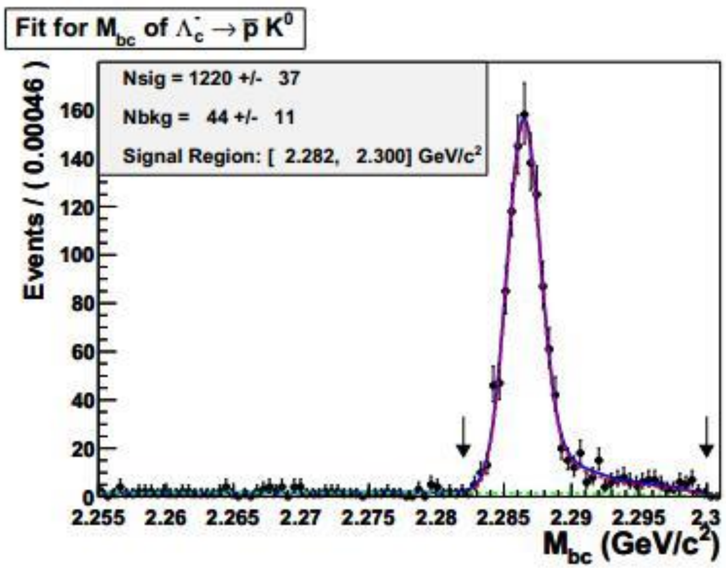
We generate fake data to study the origin of background. The fake data is produced by sampling from the inclusive Monte Carlo, each process has been scaled to be corresponding with the luminosity of data at $\sqrt{s} = 4.5995$ GeV.

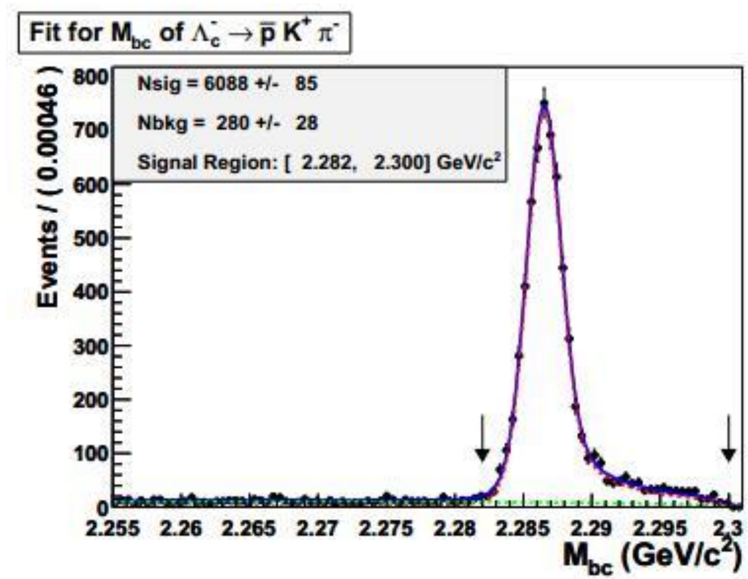
From the figure, we can see that there are no peaking background events in the M_{bc} distribution of tagged Λ_c. We can use Argus function to describe the background.



Reconstruction of $\Lambda_c^{\pm}$

Tag yields



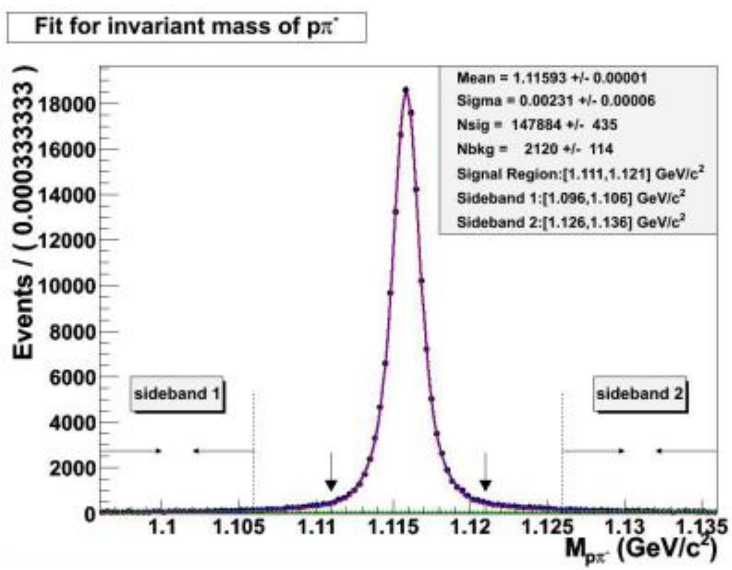


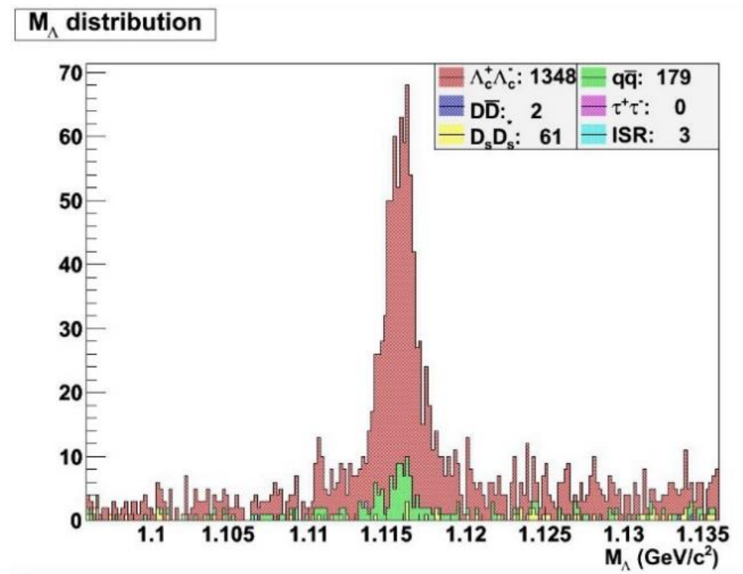
The signals of Λ_c are fitted by the shape obtained from signal Monte Carlo, while the backgrounds are described using Argus function.

Tag modes	ΔE(GeV)	$M_{\rm bc}$ (GeV/c^2)	Yields
$\bar{\Lambda}_c^- \to \bar{p} K_S^0$	[-0.021, 0.019]	[2.282, 2.300]	1220 ± 37
$\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$	[-0.020, 0.015]		6088 ± 85

Reconstruction of Λ

Background study

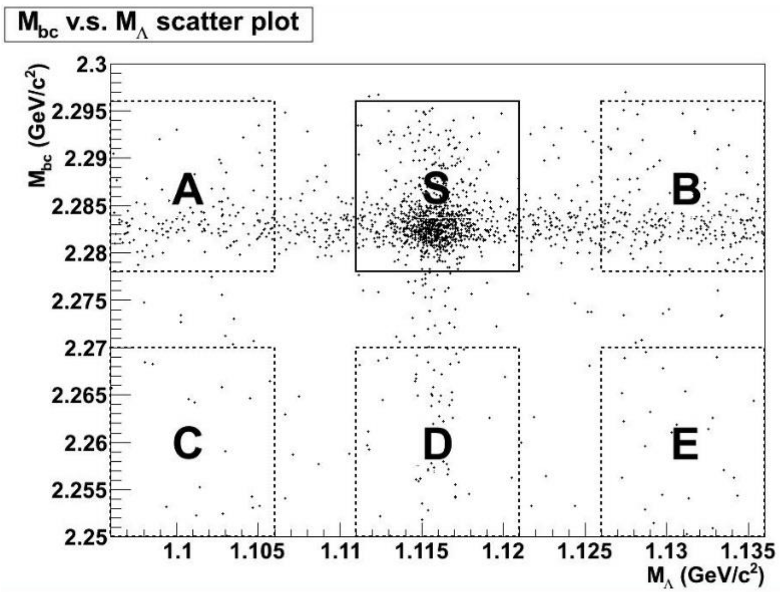


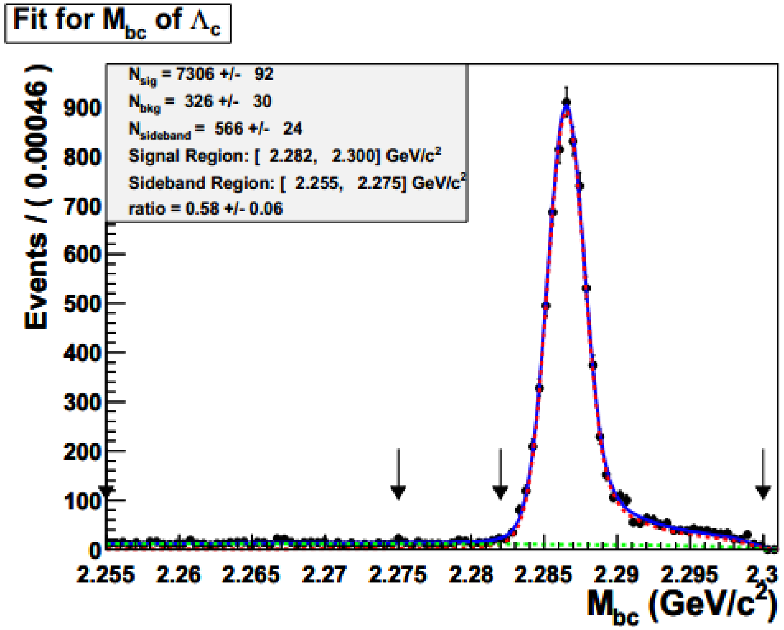


We take a look at the distribution of M_Λ in fake data and find that there are peaking background events in the signal region.

Reconstruction of Λ

Background study



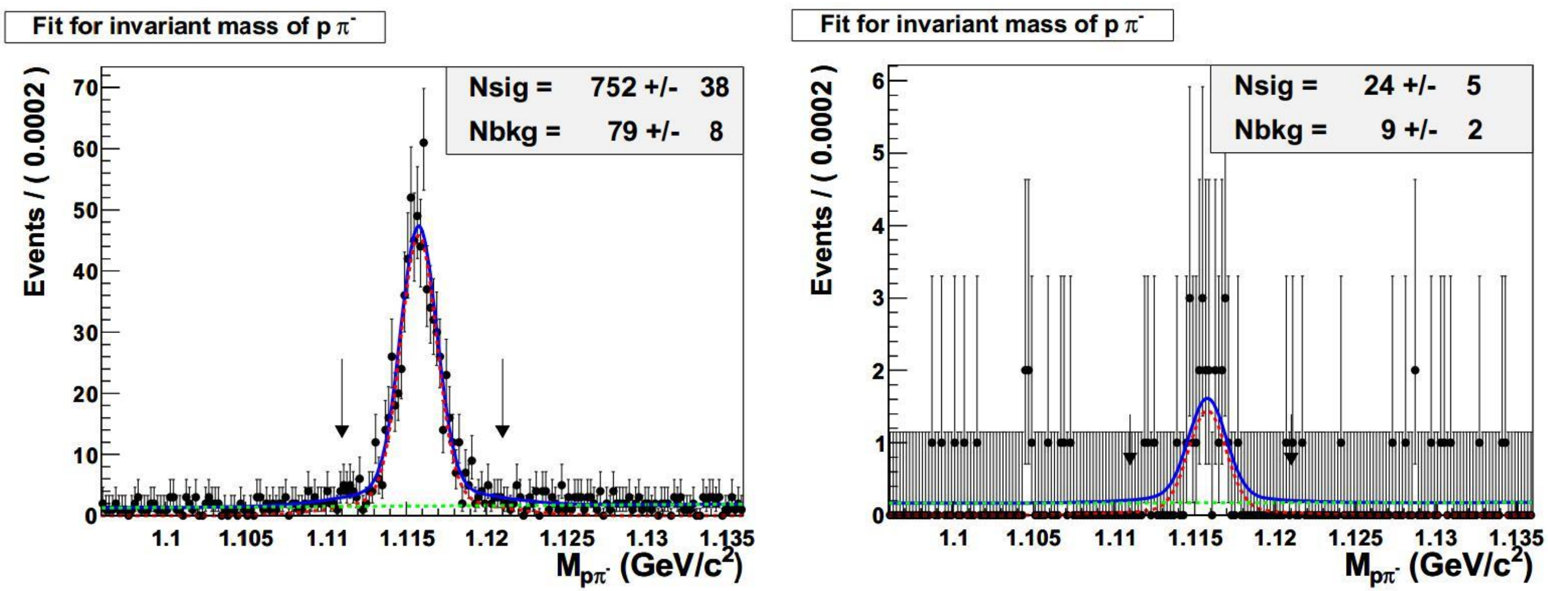


$$N_{sig} = N_S - (N_A + N_B)/2 - r \cdot N_D + r \cdot (N_C + N_E)/2$$

The normalization factor between the sideband region and signal region of M_{bc} is estimated to be 0.58 ± 0.06.

Reconstruction of Λ

Signal yields



(a) $2.282 \leqslant M_{\rm bc} \leqslant 2.300\,{\rm GeV}/c^2$. (b) $2.255 \leqslant M_{\rm bc} \leqslant 2.275\,{\rm GeV}/c^2$.

The signal yield is summed to be $N_{sig} = 706 \pm 29$, which is consistent with result obtained by directly fitting the invariant mass of $p\pi^-$, which is $N_{sig} = 738 \pm 38$.

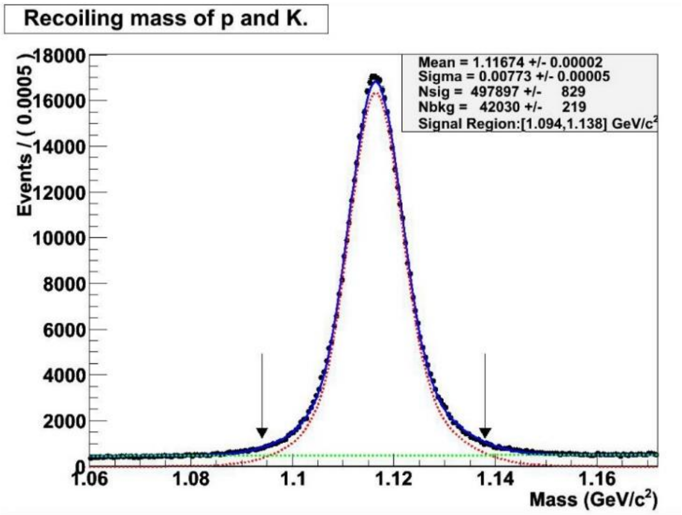
Efficiency of Λ

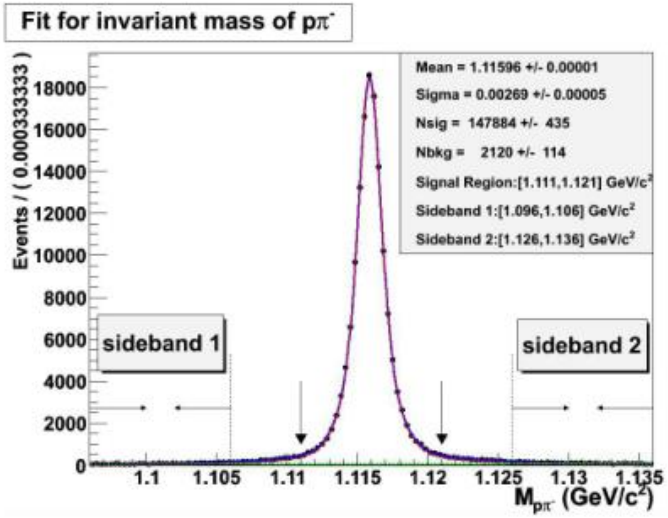
Control sample

$J/\psi \to \overline{p}K^{+}\Lambda$ and c.c.

The requirements to select out the control sample are:

Selection of control sample
- kaon PID: $\mathrm{prob(K)} > 0.01, \mathrm{prob(K)} > \mathrm{prob(\pi)}, \mathrm{prob(K)} > \mathrm{prob(p)}$
- proton PID: $\mathrm{prob(p)} > 0.01, \mathrm{prob(p)} > \mathrm{prob(\pi)}, \mathrm{prob(p)} > \mathrm{prob(K)}$
- Recoiling mass of pK^{-}: $M_{pK^{-}} \in [1.094, 1.138]\ GeV/c^2$

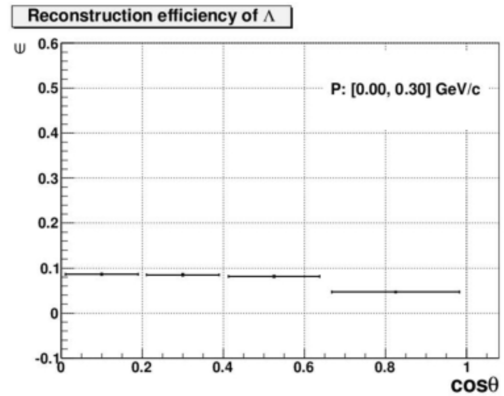




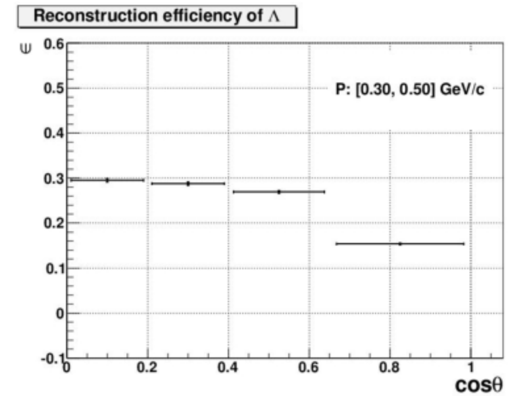
Efficiency of Λ

Efficiency

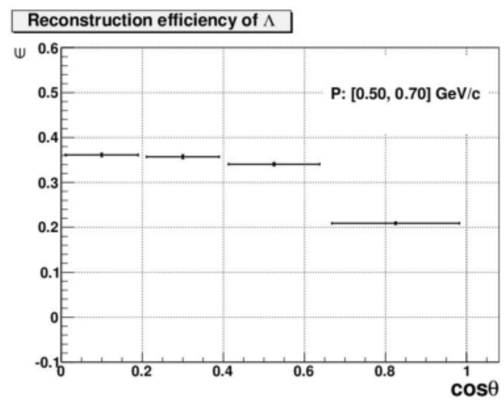
We also divide the control sample into 4×4 bins according to the recoiling momentum and $|cos\theta|$ of p and K, then fit the recoiling mass to obtain the number of control sample in each bin. The number of reconstructed Λ in each bin is obtained by subtracting the number of events in sideband region from those in signal region of M_{Λ}.



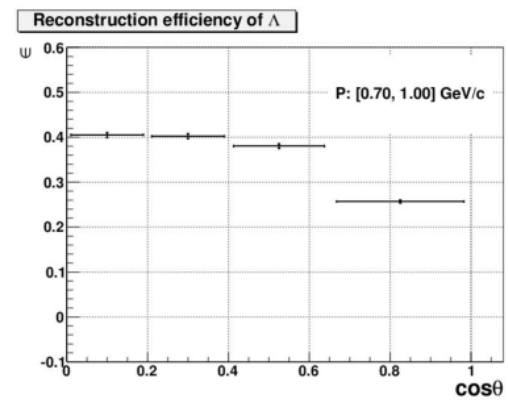
(a) $0.0 \leqslant p < 0.3$ GeV/c



(b) $0.3 \leqslant p < 0.5$ GeV/c



(c) $0.5 \leqslant p < 0.7$ GeV/c



(d) $0.7 \leqslant p < 1.0$ GeV/c

Efficiency of Λ

Efficiency

The distribution of momentum and polar angle of Λ in the control sample are different with those in the process of $\Lambda_C^+ \rightarrow \Lambda + X$, which may cause difference in the reconstruction efficiency. We **re-weight** the control sample to make sure that the distribution of $p{-}cos\theta$ are the same with those in the process of $\Lambda_C^+ \rightarrow \Lambda + X$, as shown in the backup slides.

$\epsilon_{data}(\%)$	P (GeV/c)			
$\lvert\cos\theta\rvert$	(0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	8.64 ± 0.23	29.52 ± 0.36	36.12 ± 0.39	40.52 ± 0.57
(0.20, 0.40)	8.50 ± 0.23	28.77 ± 0.36	35.71 ± 0.39	40.24 ± 0.56
(0.40, 0.65)	8.14 ± 0.20	26.92 ± 0.31	34.06 ± 0.35	38.05 ± 0.50
(0.65, 1.00)	4.69 ± 0.13	15.38 ± 0.19	20.90 ± 0.23	25.69 ± 0.36

Result

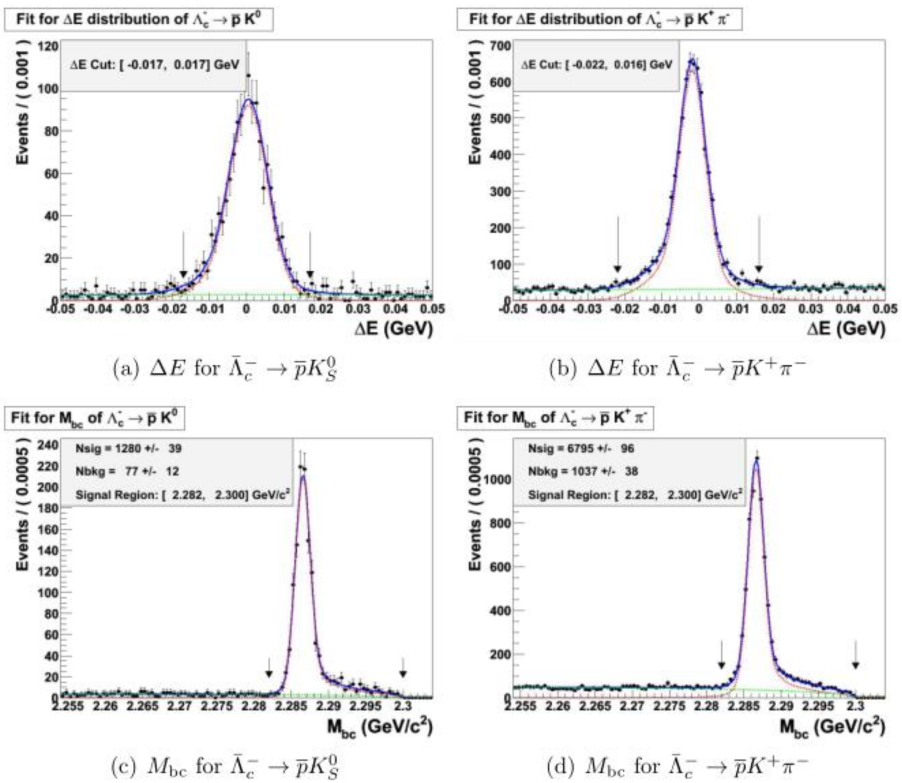
BF without systematic error

Then the branching fraction of $\Lambda_c^+ \to \Lambda + X$ is calculated to be:

$$\mathcal{B}(\Lambda_c^+ \to \Lambda + X) = (37.0 \pm 2.2)\%$$

Input-output check

Result from fake data



(a) ΔE for $\bar{\Lambda}_c^- \to \bar{p} K_S^0$

(b) ΔE for $\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$

(c) $M_{\rm bc}$ for $\bar{\Lambda}_c^- \to \bar{p} K_S^0$

(d) $M_{\rm bc}$ for $\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$

Tag modes	ΔE(GeV)	$M_{\rm bc}$ (GeV/c^2)	Yields
$\bar{\Lambda}_c^- \to \bar{p} K_S^0$	[-0.017, 0.017]	[2.282, 2.300]	1280 ± 39
$\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$	[-0.022, 0.016]		6795 ± 96

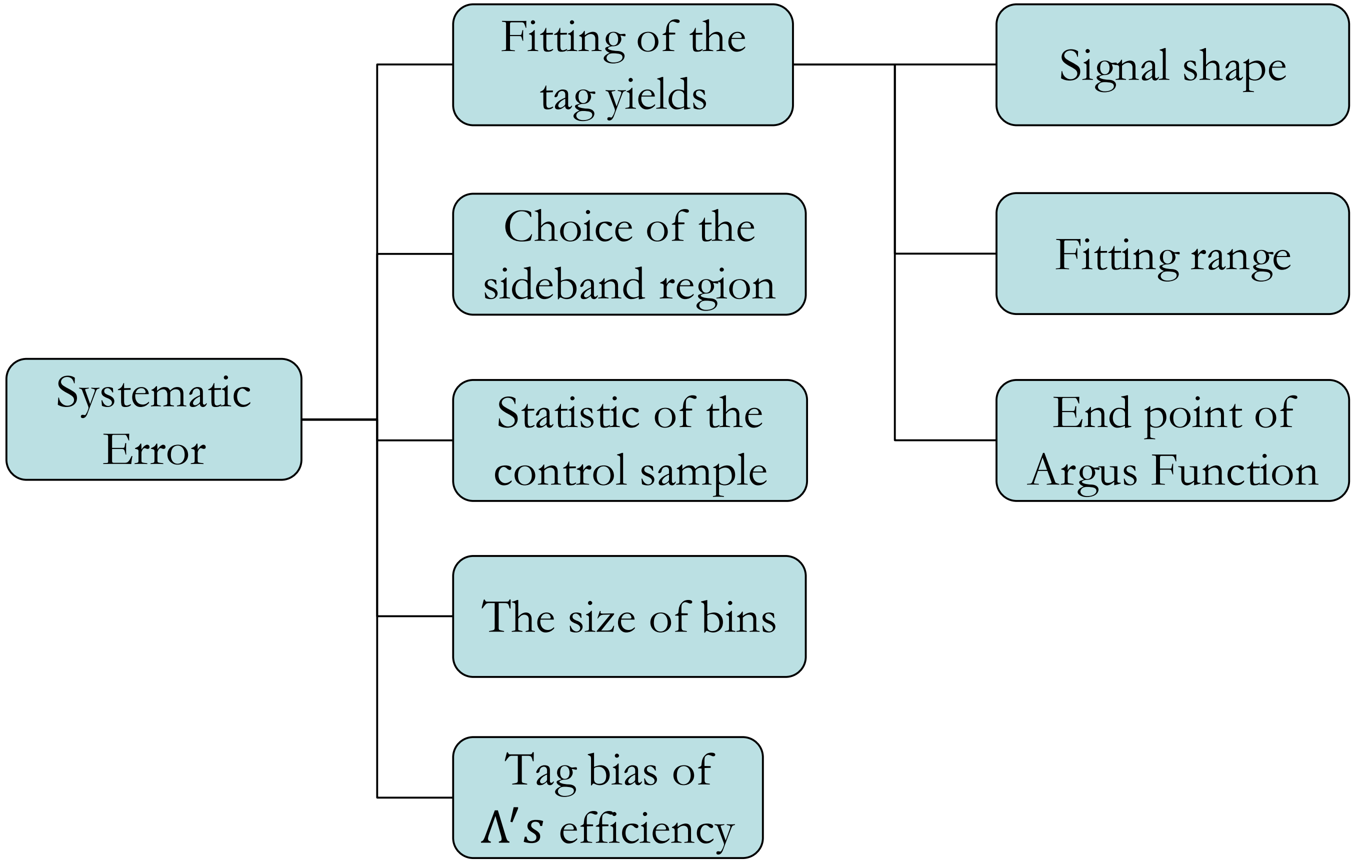
|cosθ|	ϵ_{data}(%)			
	P (GeV/c)			
	(0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	7.73 ± 0.16	27.23 ± 0.26	34.43 ± 0.29	38.16 ± 0.40
(0.20, 0.40)	7.19 ± 0.16	26.65 ± 0.26	33.48 ± 0.28	37.53 ± 0.39
(0.40, 0.65)	6.84 ± 0.14	24.56 ± 0.22	31.50 ± 0.25	35.08 ± 0.34
(0.65, 1.00)	3.71 ± 0.09	13.38 ± 0.13	18.36 ± 0.15	21.92 ± 0.22
|cosθ|	N_{signal}			
	P (GeV/c)			
	(0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	7.8 ± 4.8	40.2 ± 8.7	56.8 ± 9.6	37.6 ± 8.9
(0.20, 0.40)	5.4 ± 4.4	30.7 ± 7.9	56.2 ± 8.9	63.8 ± 9.6
(0.40, 0.65)	8.7 ± 4.7	57.1 ± 9.8	75.6 ± 10.5	46.7 ± 8.9
(0.65, 1.00)	-1.1 ± 3.9	34.7 ± 8.1	56.5 ± 9.1	36.8 ± 8.8

$$\mathcal{B}_{input} = 33.2\%$$

$$\mathcal{B}_{output} = (30.7 \pm 2.5)\%$$

Systematic Error

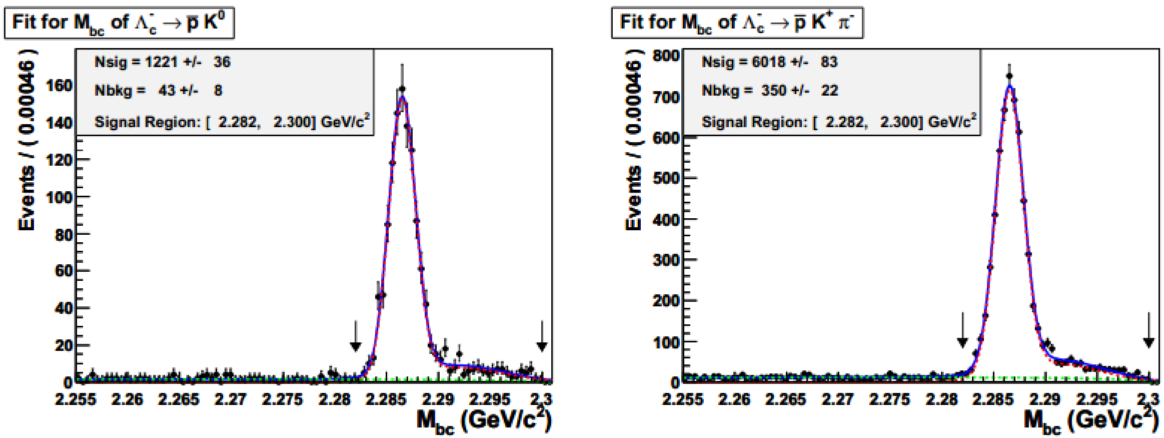
Outline



Systematic Error

Fitting of tag yields: signal shape

The signal shape we used to fit the M_{bc} of $\overline{\Lambda}_C^-$ is obtained from signal Monte Carlo. To estimate the uncertainty due to the choice of the shape, we change the signal shape used in the fitting procedure and regain the tag yields.



(a) $\bar{\Lambda}_c^- \to \overline{p} K_S^0$ (b) $\bar{\Lambda}_c^- \to \overline{p} K^+ \pi^-$

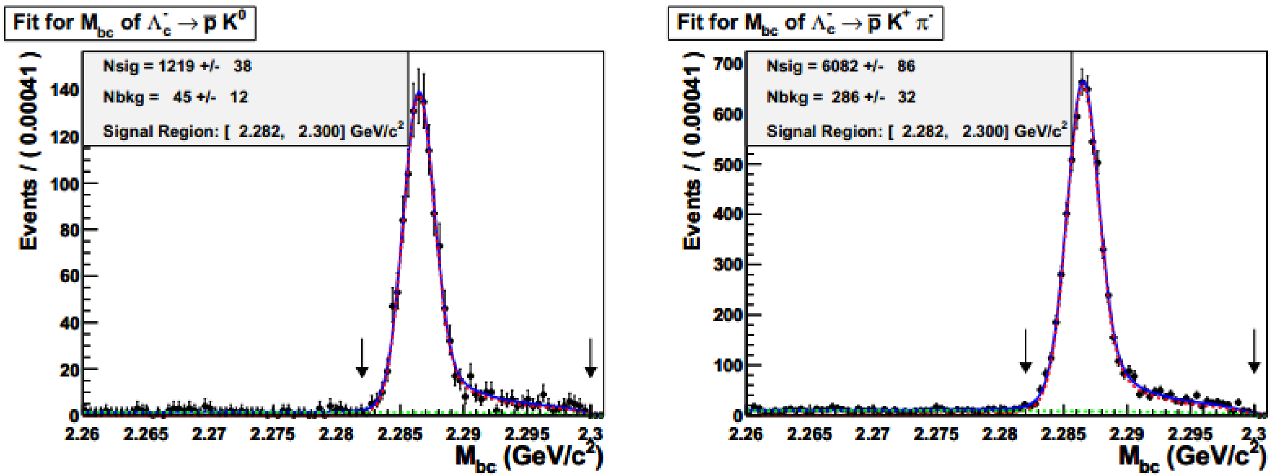
Signal shape	Yield($\bar{\Lambda}_c^- \to \overline{p} K_S^0$)	Yield($\bar{\Lambda}_c^- \to \overline{p} K^+ \pi^-$)	Total yields
signal MC	1220 ± 37	6088 ± 85	7308 ± 93
CB + Gauss	1221 ± 36	6018 ± 83	7239 ± 90

The systematic uncertainty due to this is 0.94% relatively.

Systematic Error

Fitting of tag yields: fitting range

We also try different fitting range to see if there are any changes of the tag yields. The range of M_{bc} is changed to [2.255,2.300] GeV/c^2 and the fits are redone.



(a) $\bar{\Lambda}_c^- \to \bar{p} K_S^0$

(b) $\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$

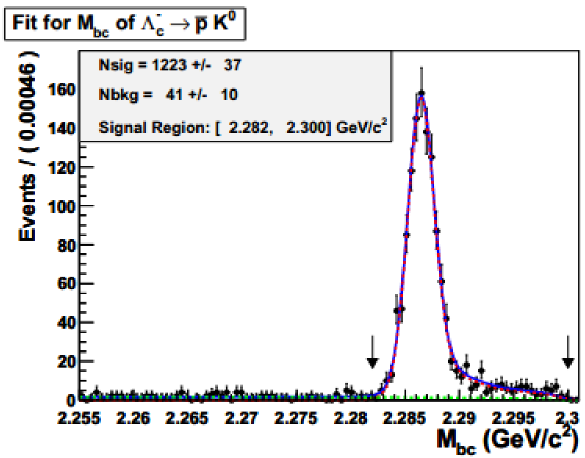
Fitting range(GeV/c^2)	Yield($\bar{\Lambda}_c^- \to \bar{p} K_S^0$)	Yield($\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$)	Total yields
$[2.255, 2.300]$	1220 ± 37	6088 ± 85	7308 ± 93
$[2.260, 2.300]$	1219 ± 38	6082 ± 86	7301 ± 94

The systematic uncertainty due to this is 0.10% relatively.

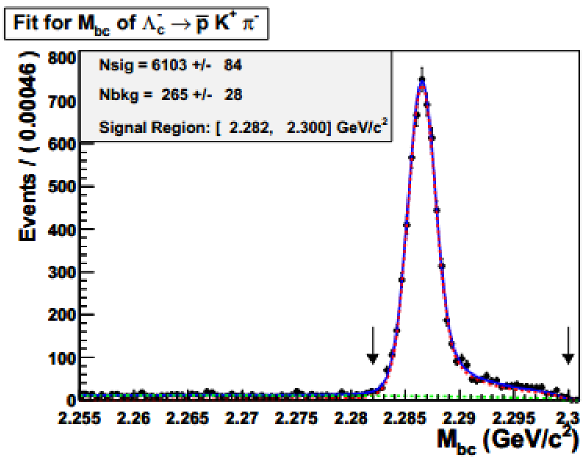
Systematic Error

Fitting of tag yields: endpoint of Argus function

The endpoint of the Argus function is set floated now, we fix it to the beam energy 2.2995 GeV/c^2 and redo the fit to see the influence on the tag yields.



(a) $\bar{\Lambda}_c^- \to \bar{p} K_S^0$



(b) $\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$

Argus function	Yield($\bar{\Lambda}_c^- \to \bar{p} K_S^0$)	Yield($\bar{\Lambda}_c^- \to \bar{p} K^+ \pi^-$)	Total yields
floated endpoint	1220 ± 37	6088 ± 85	7308 ± 93
fixed endpoint	1223 ± 37	6103 ± 84	7326 ± 93

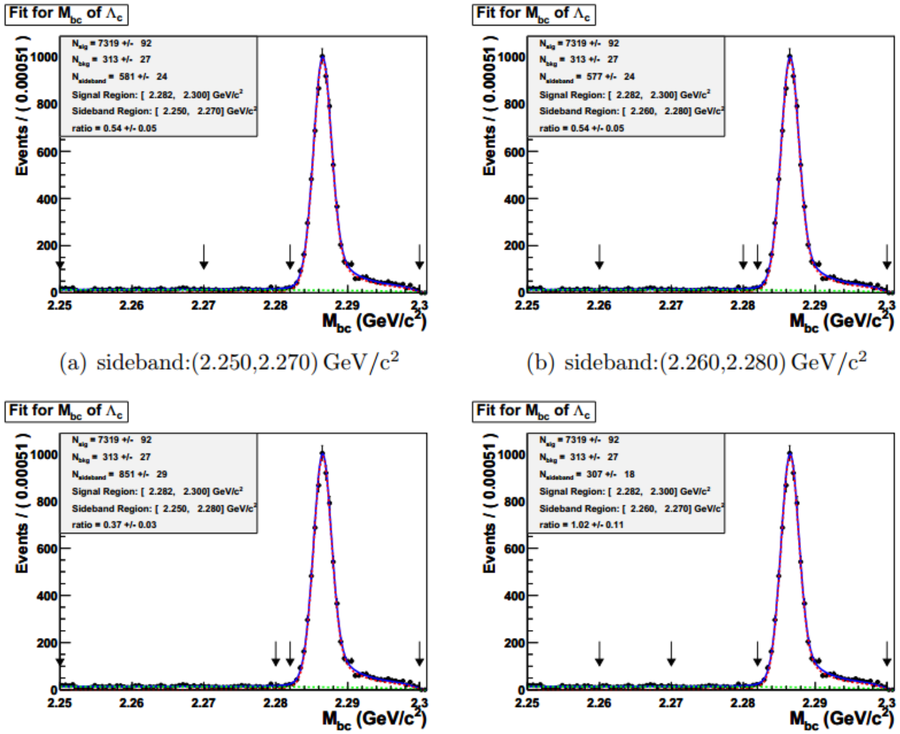
The systematic uncertainty due to this is 0.98% relatively.

Systematic Error

Choice of the sideband region

The choice of sideband region may influence the estimation of the peaking background. We try to estimate the systematic error due to this by varying the sideband region and recalculating the branching fraction.

The uncertainty due to the choice of sideband region is estimated to be 0.10%, which is negligible.



(a) sideband:(2.250,2.270) GeV/c^2 (b) sideband:(2.260,2.280) GeV/c^2

(c) sideband:(2.250,2.280) GeV/c^2 (d) sideband:(2.260,2.270) GeV/c^2

Sideband region (GeV/c^2)	*ratio*	$\mathcal{B}(\Lambda_c^+ \to \Lambda + X)(\%)$
(2.250,2.270)	0.54 ± 0.05	37.26 ± 2.17
(2.260,2.280)	0.54 ± 0.05	36.81 ± 2.17
(2.250,2.280)	0.37 ± 0.03	37.07 ± 2.17
(2.260,2.270)	1.02 ± 0.11	36.94 ± 2.18
Averaged		37.02 ± 1.09

Systematic Error

Statistic of the control sample

The limited statistic of the control sample $J/\psi \to \overline{p}K^{+}\Lambda$ may bring systematic uncertainty into the reconstruction efficiency of Λ, which can be calculated out from the table of efficiency using the following equation.

P(GeV/c)	$\lvert\cos\theta\rvert$	N_{S}	N_{A}	N_{B}	N_{C}	N_{D}	N_{E}	N_{signal}
(0.0, 0.3)	(0.00, 0.20)	12.0 ± 3.5	8.0 ± 2.8	9.0 ± 3.0	0.0 ± 0.0	0.0 ± 0.0	1.0 ± 1.0	3.9 ± 4.0
	(0.20, 0.40)	17.0 ± 4.1	3.0 ± 1.7	7.0 ± 2.6	3.0 ± 1.7	3.0 ± 1.7	0.0 ± 0.0	10.9 ± 4.6
	(0.40, 0.65)	14.0 ± 3.7	5.0 ± 2.2	7.0 ± 2.6	0.0 ± 0.0	2.0 ± 1.4	0.0 ± 0.0	6.5 ± 4.3
	(0.65, 1.00)	12.0 ± 3.5	6.0 ± 2.4	8.0 ± 2.8	1.0 ± 1.0	1.0 ± 1.0	3.0 ± 1.7	5.7 ± 4.1
(0.3, 0.5)	(0.00, 0.20)	77.0 ± 8.8	15.0 ± 3.9	15.0 ± 3.9	4.0 ± 2.0	4.0 ± 2.0	2.0 ± 1.4	61.3 ± 9.4
	(0.20, 0.40)	61.0 ± 7.8	14.0 ± 3.7	21.0 ± 4.6	1.0 ± 1.0	4.0 ± 2.0	6.0 ± 2.4	43.1 ± 8.5
	(0.40, 0.65)	89.0 ± 9.4	13.0 ± 3.6	22.0 ± 4.7	1.0 ± 1.0	4.0 ± 2.0	1.0 ± 1.0	69.3 ± 10.0
	(0.65, 1.00)	47.0 ± 6.9	18.0 ± 4.2	17.0 ± 4.1	1.0 ± 1.0	4.0 ± 2.0	2.0 ± 1.4	27.6 ± 7.6
(0.5, 0.7)	(0.00, 0.20)	97.0 ± 9.8	5.0 ± 2.2	5.0 ± 2.2	0.0 ± 0.0	4.0 ± 2.0	0.0 ± 0.0	89.0 ± 10.1
	(0.20, 0.40)	87.0 ± 9.3	8.0 ± 2.8	14.0 ± 3.7	0.0 ± 0.0	3.0 ± 1.7	1.0 ± 1.0	74.2 ± 9.7
	(0.40, 0.65)	81.0 ± 9.0	3.0 ± 1.7	9.0 ± 3.0	1.0 ± 1.0	8.0 ± 2.8	0.0 ± 0.0	69.5 ± 9.4
	(0.65, 1.00)	65.0 ± 8.1	5.0 ± 2.2	13.0 ± 3.6	1.0 ± 1.0	7.0 ± 2.6	3.0 ± 1.7	52.3 ± 8.6
(0.7, 1.0)	(0.00, 0.20)	68.0 ± 8.2	9.0 ± 3.0	21.0 ± 4.6	0.0 ± 0.0	4.0 ± 2.0	1.0 ± 1.0	50.4 ± 8.8
	(0.20, 0.40)	59.0 ± 7.7	7.0 ± 2.6	12.0 ± 3.5	1.0 ± 1.0	6.0 ± 2.4	0.0 ± 0.0	45.4 ± 8.2
	(0.40, 0.65)	71.0 ± 8.4	7.0 ± 2.6	17.0 ± 4.1	1.0 ± 1.0	2.0 ± 1.4	2.0 ± 1.4	58.6 ± 8.9
	(0.65, 1.00)	57.0 ± 7.5	6.0 ± 2.4	16.0 ± 4.0	0.0 ± 0.0	3.0 ± 1.7	2.0 ± 1.4	44.5 ± 8.0

$$\delta\varepsilon^{\mathrm{sig}} = \frac{\sqrt{\sum_{ij}(\delta\varepsilon_j^{\mathrm{sig}} \cdot N_{ij}^{\mathrm{sig}}/(\varepsilon_j^{\mathrm{sig}})^2)^2}}{\sum_{ij}(N_{ij}^{\mathrm{sig}}/\varepsilon_j^{\mathrm{sig}})},$$

$\epsilon_{data}(\%)$	P (GeV/c)			
$\lvert\cos\theta\rvert$	(0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	8.64 ± 0.23	29.52 ± 0.36	36.12 ± 0.39	40.52 ± 0.57
(0.20, 0.40)	8.50 ± 0.23	28.77 ± 0.36	35.71 ± 0.39	40.24 ± 0.56
(0.40, 0.65)	8.14 ± 0.20	26.92 ± 0.31	34.06 ± 0.35	38.05 ± 0.50
(0.65, 1.00)	4.69 ± 0.13	15.38 ± 0.19	20.90 ± 0.23	25.69 ± 0.36

The systematic uncertainty due to this is 0.36% relatively.

Systematic Error

Size of the bins

To study the systematic error due to binning , we change the number of bins and see how the branching fraction will change with it.

We divide the control sample of $J/\psi \to \overline{p}K^+\Lambda$ into 3×4, 4×3, 4×5 and 5×4 p−$|cos\theta|$ bins to obtain the corresponding efficiency, then divide the data sample to get the signal yields.

Bin number of p	Bin number of $\|\cos\theta\|$	$\mathcal{B}(\Lambda_c^+ \to \Lambda + X)(\%)$
3	4	37.34 ± 1.95
4	3	37.24 ± 2.16
4	5	37.02 ± 2.18
5	4	37.05 ± 2.18
Averaged		37.16 ± 1.06

The systematic uncertainty due to this is 0.49% relatively.

Systematic Error

The bias of efficiency in different tag modes

We assume that the reconstruction efficiency of Λ is independent of the tag modes, which may cause systematic error. We use the inclusive Monte Carlo of $\Lambda_c^+\Lambda_c^-$ to obtain the signal efficiency in different tag modes.

Tag modes	Efficiency(%)
$\bar{\Lambda}_c^- \to \bar{p}K_S^0$	29.9 ± 0.6
$\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$	30.3 ± 0.2
Averaged	30.2 ± 0.5

The systematic error due to this is estimated to be 1.10% relatively.

Systematic Error

Summary of the systematic error

Categories	Systematic Uncertainties(%)
Statistics of the control sample	0.36
Tag bias of Λ's efficiency	1.10
Fitting of the tag yields	0.98
The size of the bins	0.49
Choice of the sideband region	0.1
Total	1.60

Thus the systematic uncertainty is $37.0\% \times 1.6\% = 0.6\%$.

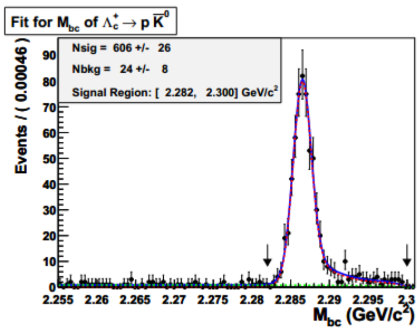
BF with systematic error

$$\mathcal{B}(\Lambda_C^+ \to \Lambda + X) = (37.0 \pm 2.2 \pm 0.6)\%$$

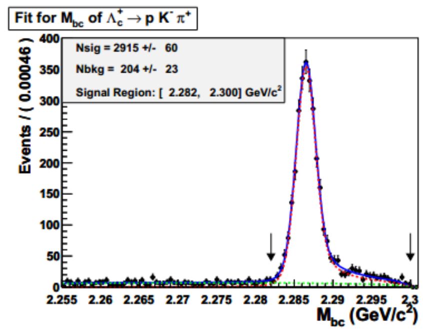
CP violation in Λ_C decay

Definition

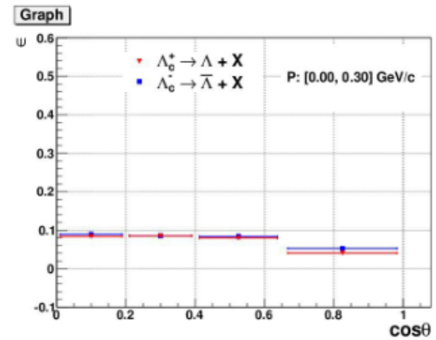
$$\mathcal{A}_{\rm CP} = \frac{\mathcal{B}(\Lambda_c^+ \to \Lambda + X) - \mathcal{B}(\bar{\Lambda}_c^- \to \bar{\Lambda} + X)}{\mathcal{B}(\Lambda_c^+ \to \Lambda + X) + \mathcal{B}(\bar{\Lambda}_c^- \to \bar{\Lambda} + X)}.$$



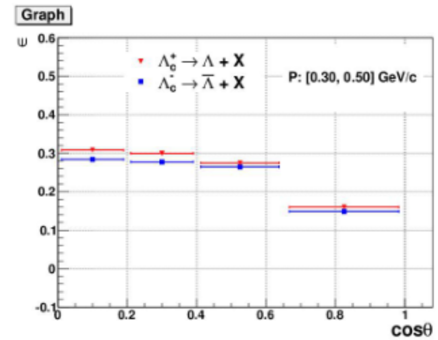
(a) $\Lambda_c^+ \to pK_S^0$



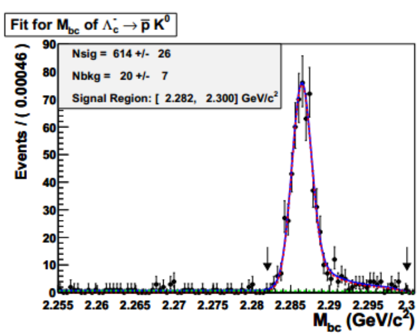
(b) $\Lambda_c^+ \to pK^-\pi^+$



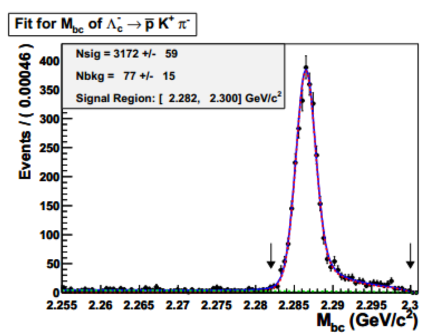
(a) $0.0 \leqslant p < 0.3$ GeV/c



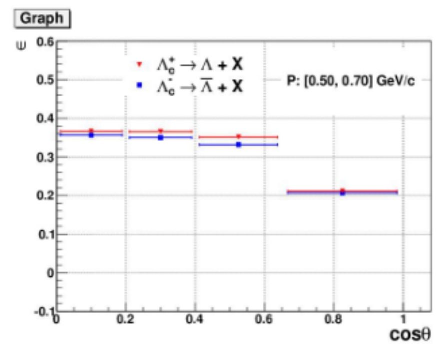
(b) $0.3 \leqslant p < 0.5$ GeV/c



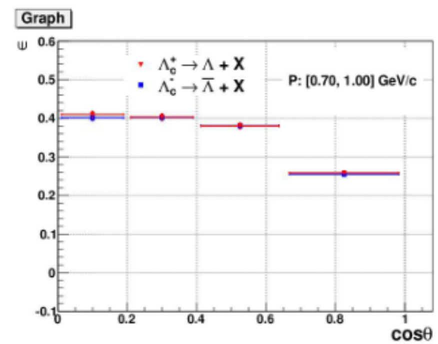
(c) $\bar{\Lambda}_c^- \to \bar{p}K_S^0$



(d) $\bar{\Lambda}_c^- \to \bar{p}K^+\pi^-$



(c) $0.5 \leqslant p < 0.7$ GeV/c



(d) $0.7 \leqslant p < 1.0$ GeV/c

CP violation in Λ_c decay

The tag yields, signal yields and efficiencies are reobtained separately.

$\|\cos\theta\|$	$\epsilon_\Lambda(\%)$ P (GeV/c) (0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	8.35 ± 0.33	30.80 ± 0.54	36.68 ± 0.59	41.00 ± 0.86
(0.20, 0.40)	8.47 ± 0.32	29.97 ± 0.53	36.56 ± 0.58	40.30 ± 0.85
(0.40, 0.65)	7.91 ± 0.28	27.44 ± 0.45	35.10 ± 0.52	38.00 ± 0.73
(0.65, 1.00)	4.04 ± 0.17	15.97 ± 0.29	21.17 ± 0.33	25.87 ± 0.51
$\|\cos\theta\|$	N_Λ P (GeV/c) (0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	2.5 ± 2.5	27.9 ± 6.5	47.5 ± 7.3	25.0 ± 6.2
(0.20, 0.40)	4.6 ± 3.2	20.5 ± 5.6	36.5 ± 6.5	22.0 ± 5.8
(0.40, 0.65)	5.8 ± 3.1	44.6 ± 7.4	25.6 ± 6.3	32.6 ± 6.3
(0.65, 1.00)	7.2 ± 3.2	10.0 ± 4.8	28.4 ± 6.3	20.5 ± 5.8

$\|\cos\theta\|$	$\epsilon_{\bar\Lambda}(\%)$ P (GeV/c) (0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	8.91 ± 0.33	28.38 ± 0.48	35.64 ± 0.53	40.14 ± 0.76
(0.20, 0.40)	8.53 ± 0.31	27.71 ± 0.48	34.98 ± 0.53	40.20 ± 0.75
(0.40, 0.65)	8.35 ± 0.28	26.45 ± 0.42	33.18 ± 0.46	38.08 ± 0.68
(0.65, 1.00)	5.27 ± 0.19	14.84 ± 0.26	20.67 ± 0.31	25.52 ± 0.50
$\|\cos\theta\|$	$N_{\bar\Lambda}$ P (GeV/c) (0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.20)	1.4 ± 3.2	33.4 ± 6.7	41.5 ± 7.0	25.4 ± 6.2
(0.20, 0.40)	6.3 ± 3.4	22.6 ± 6.5	37.6 ± 7.2	23.4 ± 5.8
(0.40, 0.65)	0.8 ± 3.0	24.6 ± 6.7	43.9 ± 7.0	26.0 ± 6.2
(0.65, 1.00)	-1.5 ± 2.5	17.6 ± 6.0	23.9 ± 5.9	24.0 ± 5.6

Tag mode	Tag yield
$\Lambda_c^+ \to pK_S^0$	606 ± 26
$\Lambda_c^+ \to pK^-\pi^+$	2915 ± 60
$\bar\Lambda_c^- \to \bar{p}K_S^0$	614 ± 26
$\bar\Lambda_c^- \to \bar{p}K^+\pi^-$	3172 ± 59

Result

Decay mode	Branching fraction(%)	$\mathcal{A}_{CP}$
$\Lambda_c^+ \to \Lambda + X$	$38.02 \pm 3.24 \pm 0.61$	$0.02 \pm 0.06 \pm 0.01$
$\bar\Lambda_c^- \to \bar\Lambda + X$	$36.70 \pm 3.04 \pm 0.59$	

Summary

- Using double tag method and the technique of data driven, we have measured the branching fraction of $\Lambda_c^+ \to \Lambda + X$ to be $(37.0 \pm 2.2 \pm 0.6)\%$, which is more precise than the latest PDG value, which is $(35 \pm 11)\%$.
- We also study the CP violation in the decay $\Lambda_c^+ \to \Lambda + X$, the CP violation parameter $\mathcal{A}_{CP}$ is measured to be $0.02 \pm 0.06 \pm 0.01$.
- The reconstruction efficiency of Λ has been studied detailedly. The table for the systematic error of Λ's reconstruction efficiency is available.

Thanks for your attention !

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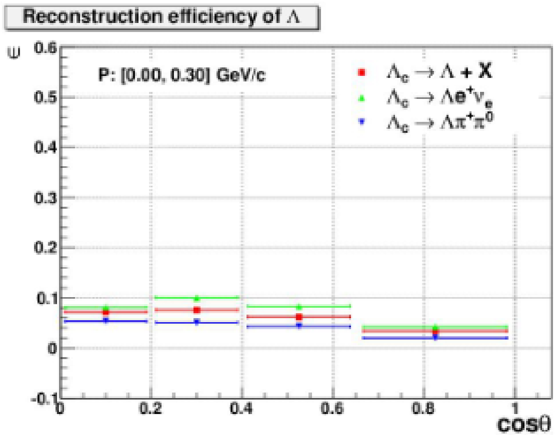
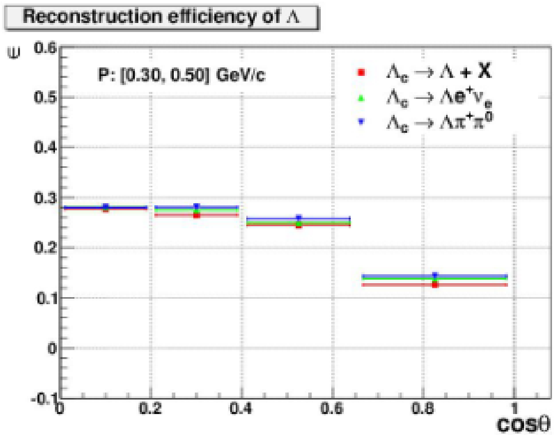
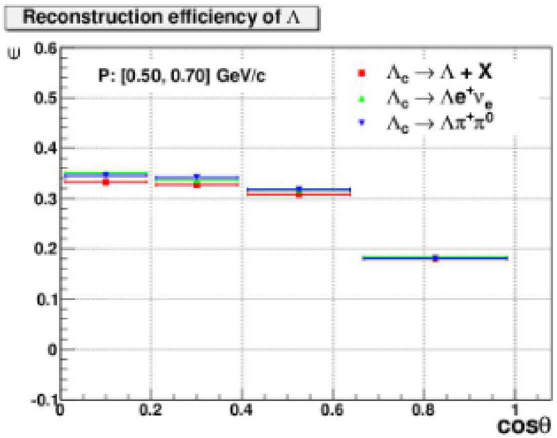
Backup: Λ's efficiency in different MC samples



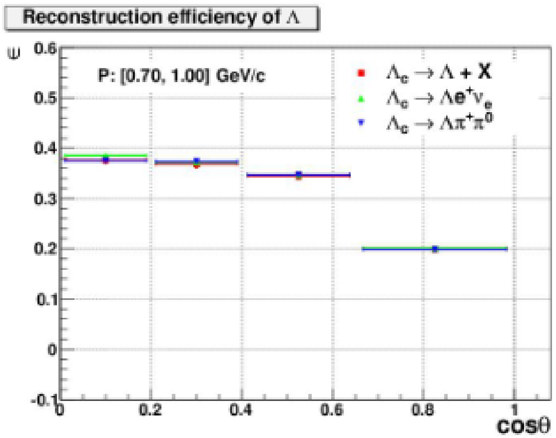
(a) $0.0 \leqslant p < 0.3$ GeV/c



(b) $0.3 \leqslant p < 0.5$ GeV/c

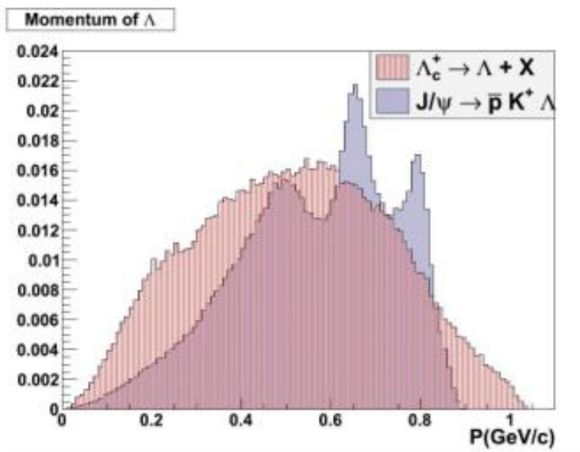


(c) $0.5 \leqslant p < 0.7$ GeV/c

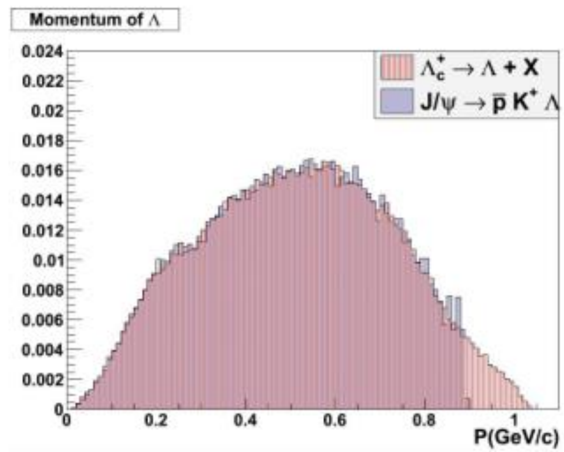


(d) $0.7 \leqslant p < 1.0$ GeV/c

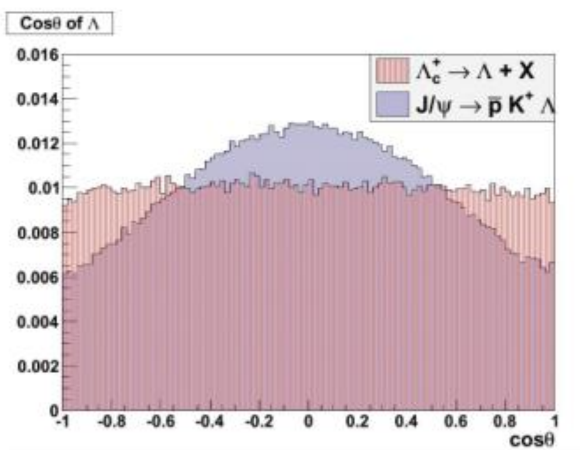
Backup: Re-weight of the control sample



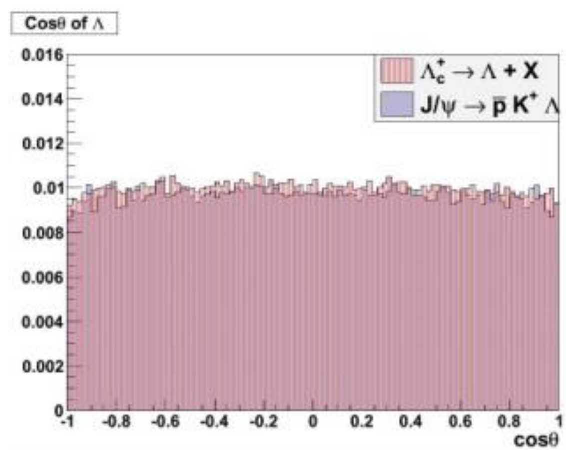
(a) Momentum of Λ before re-weight



(b) Momentum of Λ after re-weight

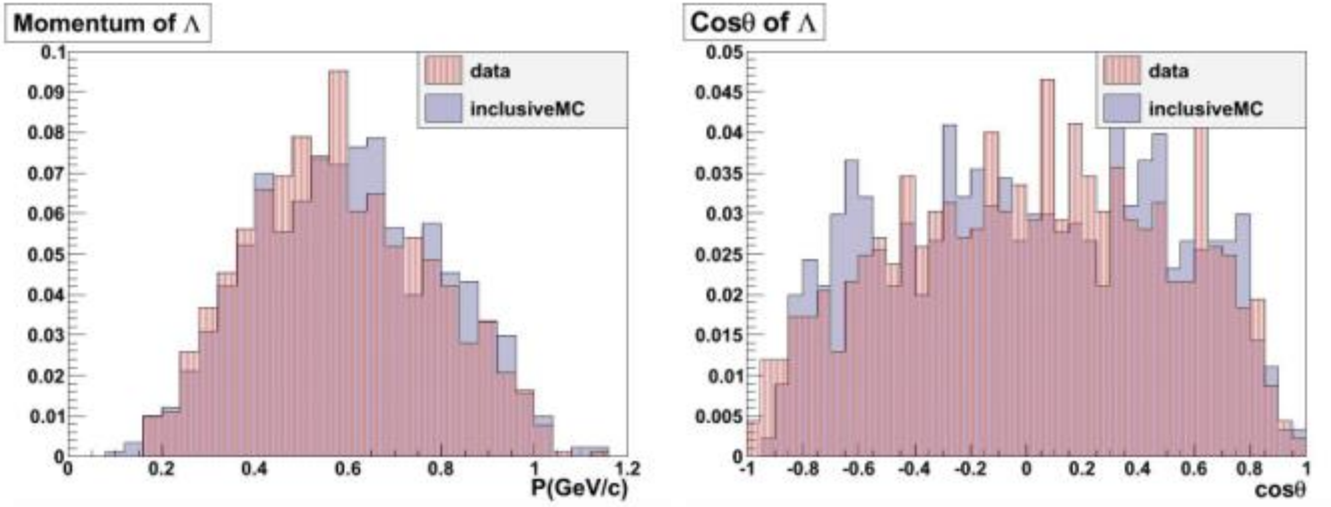


(c) $\cos\theta$ of Λ before re-weight



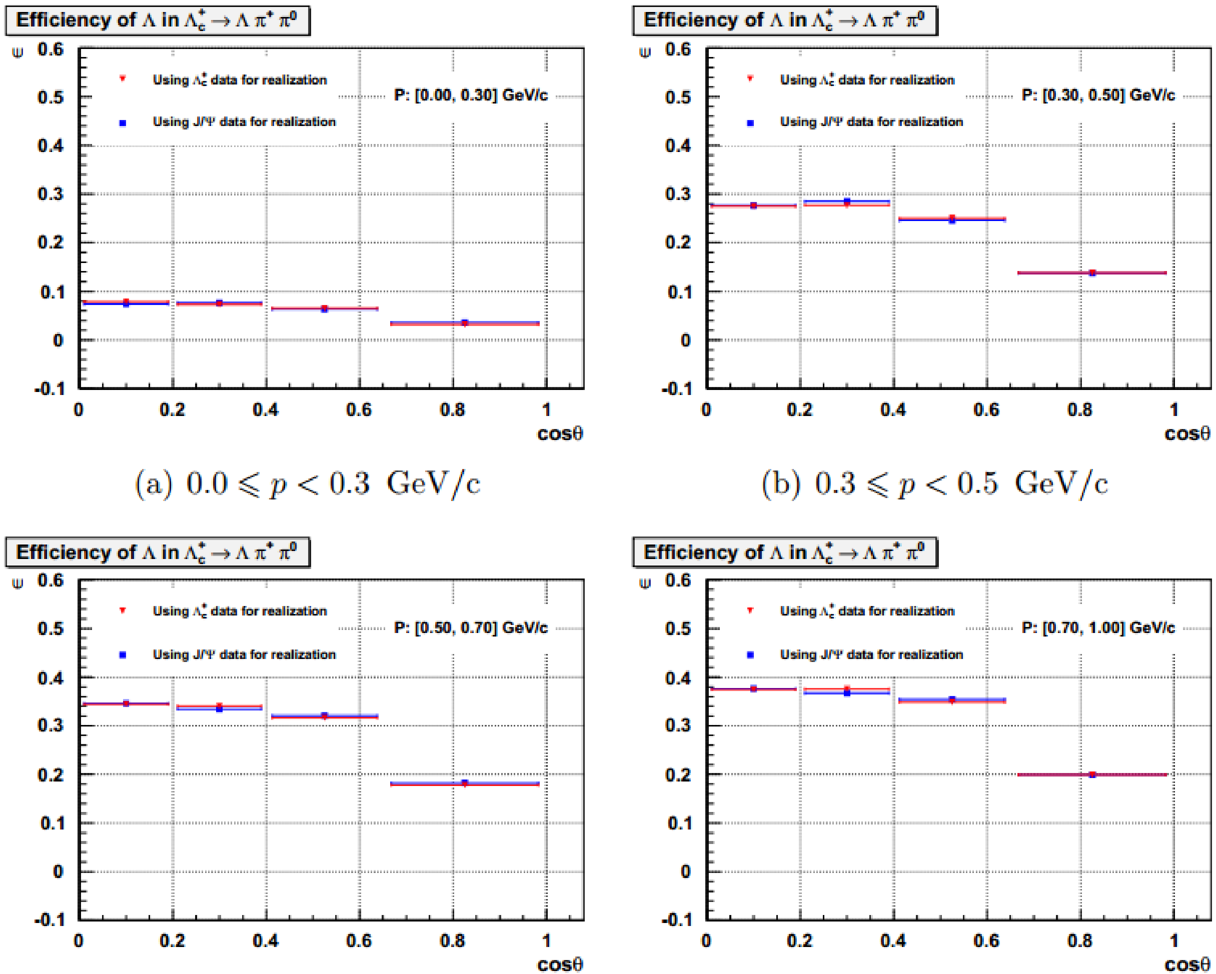
(d) $\cos\theta$ of Λ after re-weight

Backup: Distribution of Λ's momentum and $cos\theta$



(a) Momentum of Λ (b) $\cos\theta$ of Λ

Backup: Efficiency of Λ with different data for realization



(a) $0.0 \leqslant p < 0.3$ GeV/c

(b) $0.3 \leqslant p < 0.5$ GeV/c

(c) $0.5 \leqslant p < 0.7$ GeV/c

(d) $0.7 \leqslant p < 1.0$ GeV/c