Research of the production behavior of $\Lambda_c^+\bar{\Lambda}_c^-$ near the threshold at BESIII

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Outline

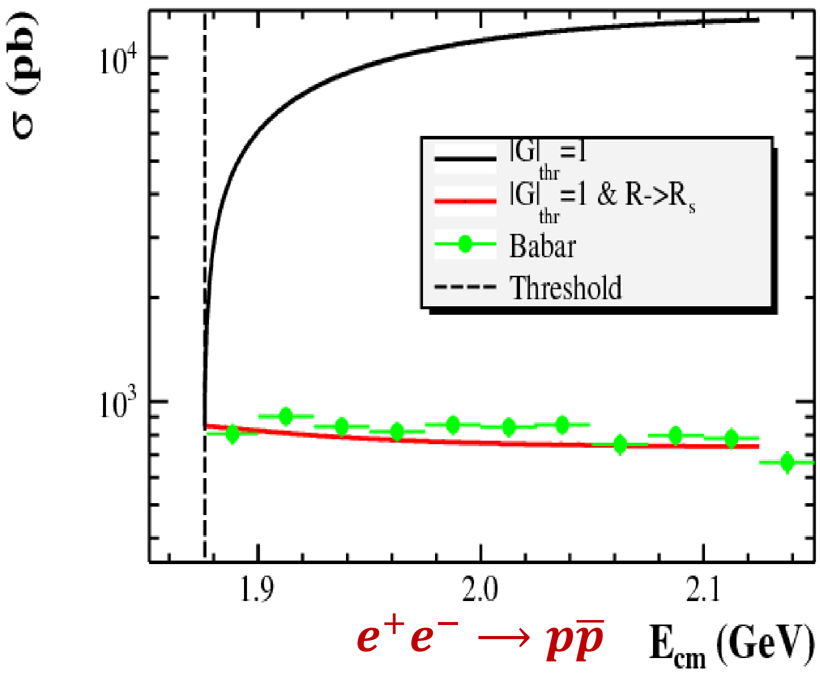
- Motivation
- Event selection
- Fit results
- Systematical uncertainty
- Calculations of cross section
- Summary

Why the cross section near threshold?

Briefly , we want to know how much does the Coulomb interaction and strong interaction affect the production behavior of $\Lambda_c^+ \bar{\Lambda}_c^-$ from the annihilation of electron and positron pair.

Why the cross section near threshold?

Study for production near threshold of $p\bar{p}$:



The cross section of $e^+e^- \longrightarrow p\bar{p}$ near threshold is about 850 pb.

Why the cross section near threshold?

Study for production near threshold of $p\bar{p}$:

$$\sigma_{p\bar{p}} = \frac{4\pi\alpha^2\beta C}{3q^2}\left[\,\left|G_M^p(q^2)\right|^2 + \frac{2m_p^2}{q^2}\left|G_E^p(q^2)\right|^2\,\right]$$

$$C = \frac{\pi\alpha}{\beta} \times R = \frac{\pi\alpha}{\beta}\frac{\sqrt{1-\beta^2}}{1-\exp(-\pi\alpha/\beta)} \qquad \text{(a)}$$

or

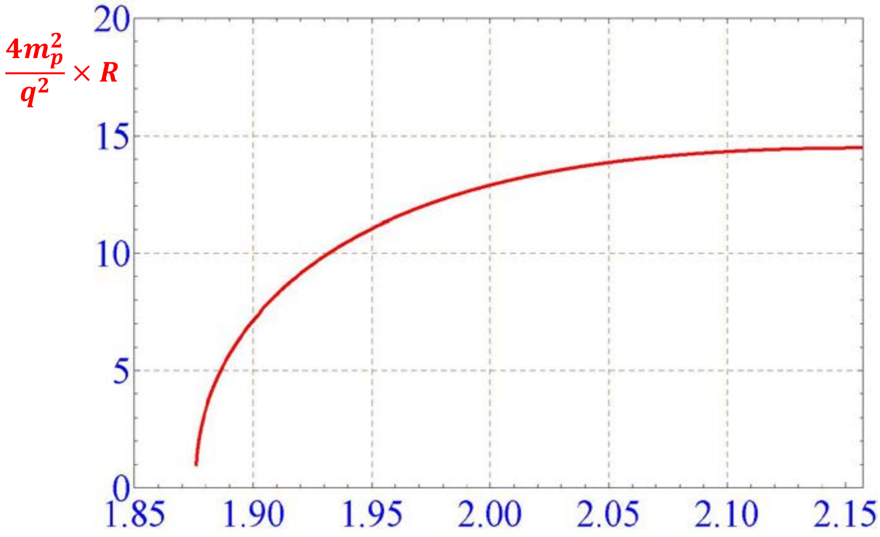
$$C = \frac{\pi\alpha}{\beta} \times R_s = \frac{\pi\alpha}{\beta}\frac{\sqrt{1-\beta^2}}{1-\exp(-\pi\alpha_s/\beta)} \qquad \text{(b)}$$

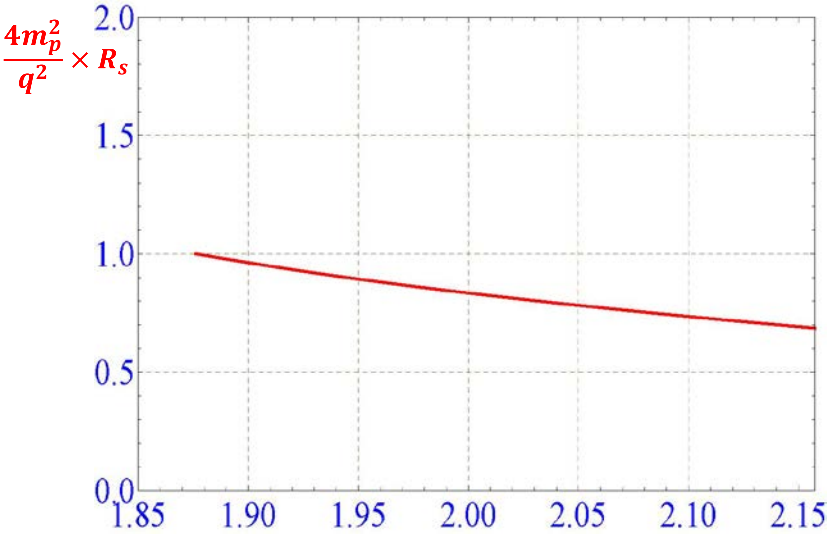
where $\alpha = 1/137$, $\alpha_s = 0.5$.

Why the cross section near threshold?

At threshold, the formula of production cross section can be written as follows:

$$\sigma_{p\bar{p}}(q^2) = 850 \times \frac{4m_p^2}{q^2} \times R \quad \text{(pb)} \quad \text{or} \quad \sigma_{p\bar{p}}(q^2) = 850 \times \frac{4m_p^2}{q^2} \times R_s \quad \text{(pb)}$$





Picture (a) for no strong interaction correction, (b) for taking appropriate strong interaction correction into consideration.

Why the cross section near threshold?

The result indicates:

* appropriate Coulomb interaction and strong interaction should be considered when we explain the production behavior of $e^+e^- \longrightarrow p\bar{p}$ near threshold.
* form factor $|G|\approx 1$ at threshold for the process $e^+e^- \longrightarrow p\bar{p}$.

So, what if we study the process $e^+e^- \longrightarrow \Lambda_c^+\bar{\Lambda}_c^-$, and whether we can obtain further information about the form factors of the particle Λ_c^+?

Data sets

- Boss version: 6.6.4.p01
- Data sample(online Luminosity)
  - ＊ 4.575 GeV, 42.0 pb^{-1}
  - ＊ 4.580 GeV, 7.94 pb^{-1}
  - ＊ 4.590 GeV, 7.65 pb^{-1}
  - ＊ 4.600 GeV, 506 pb^{-1}
- MC sample
  - ＊MC Generator: KKMC + BesEvtGen
  - ＊inclusive Λ_c^+ channel, in PHSP
  - ＊inclusive Λ_c^- channel, in PHSP

Decay mode

Mode	Decay modes	Br(modeN)/Br(mode1)	Branching fraction
1	$\Lambda_c^+ \to p^+\pi^+K^-$	1	(6.84±0.36)%
2	$\Lambda_c^+ \to p^+K_s^0,\ K_s^0 \to \pi^+\pi^-$	(0.47± 0.04) ×50%×69.2%	(1.11±0.11)%
3	$\Lambda_c^+ \to \Lambda\pi^+, \Lambda \to p^+\pi^-$	(0.20± 0.02) ×63.9%	(0.87±0.10)%
4	$\Lambda_c^+ \to p^+\pi^+K^-\pi^0,\ \pi^0 \to \gamma\gamma$	(0.67± 0.12) ×98.8%	(4.53±0.84)%
5	$\Lambda_c^+ \to p^+K_s^0\pi^0,\ K_s^0 \to \pi^+\pi^-,\ \pi^0 \to \gamma\gamma$	(0.66± 0.09) ×50%×69.2%×98.8%	(1.54±0.23)%
6	$\Lambda_c^+ \to \Lambda\pi^+\pi^0, \Lambda \to p^+\pi^-,\ \pi^0 \to \gamma\gamma$	(0.73± 0.18) ×63.9%×98.8%	(3.15±0.79)%
7	$\Lambda_c^+ \to p^+K_s^0\pi^+\pi^-,\ K_s^0 \to \pi^+\pi^-$	(0.51± 0.06) ×50%×69.2%	(1.21±0.16)%
8	$\Lambda_c^+ \to \Lambda\pi^+\pi^+\pi^-, \Lambda \to p^+\pi^-$	(0.52± 0.03) ×63.9%	(2.27±0.18)%
9	$\Lambda_c^+ \to \Sigma^0\pi^+, \Sigma^0 \to \Lambda\gamma, \Lambda \to p^+\pi^-$	(0.20± 0.04) ×63.9%	(0.87±0.18)%
10	$\Lambda_c^+ \to \Sigma^+\pi^+\pi^-, \Sigma^+ \to p\pi^0\ ,\ \pi^0 \to \gamma\gamma$	(0.69±0.08) ×51.6%×98.8%	(2.41±0.31)%

For instance, $$Br(\,mode\ 2) = \left(\frac{\Gamma_{mode\ 2}}{\Gamma_{mode\ 1}}\right) \times \left(\frac{K_S^0}{\overline{K}^0}\right) \times Br.\,(K_S^0 \to \pi^+\pi^-\,)$$

The errors was obtained according to error transfer formula.

Event selection

- Charged tracks: $|\cos\theta| <= 0.93$, $|V_r| < 1$ cm, $|V_z| < 10$ cm
- Neutral track: $0<T<14$, $E_{barrel}>25$ MeV, $E_{endcap}>50$MeV
- PID identification: proton, kaon, pion
- π^0 candidates: $|M_{\gamma\gamma} - M_{\pi^0}| < 0.06$ GeV, $\chi^2_{1c} < 50$
- K_s^0 candidates: L/Lerr > 2, $|M_{\pi^+\pi^-} - M_{K_S^0}| <= 5\sigma$
- Λ candidates: L/Lerr > 2, $|M_{p\pi^-} - M_{\Lambda}| <= 5\sigma$

Event selection

The variables beam-constrained mass M_{BC} and energy difference $\varDelta E$ are used to identify the signals, which defined as follows:

$$M_{BC} = \sqrt{E_{beam}^2 - |\vec{p}_{\varLambda_c^+}|^2}$$

$$\varDelta E = E_{\varLambda_c^+} - E_{beam}$$

Here $\vec{p}_{\varLambda_c^+}$ and $E_{\varLambda_c^+}$ are the total momentum and energy of $\varLambda_c^+$ candidate, and E_{beam} is the beam energy. Only the $\varLambda_c^+$ candidates with the least $|\Delta E|$ will be kept.

Event selection

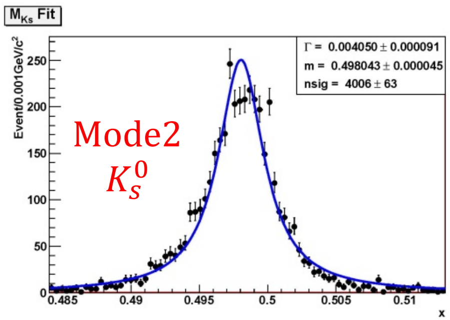
ΔE cuts(MeV) for each mode of each energy points:

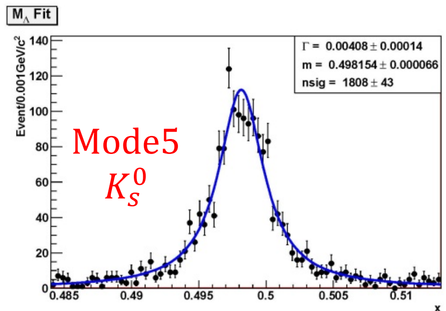
mode	4.575	4.580	4.590	4.600
1	4.0	4.1	4.7	4.6
2	5.2	5.4	5.2	5.4
3	5.5	4.9	5.1	5.1
4	7.5	8.1	8.1	7.4
5	6.8	6.6	6.6	6.0
6	5.5	5.8	6.1	5.4
7	2.6	3.0	3.3	7.9
8	3.1	3.7	3.8	4.0
9	5.8	5.0	6.0	6.5
10	4.8	5.5	6.5	6.7

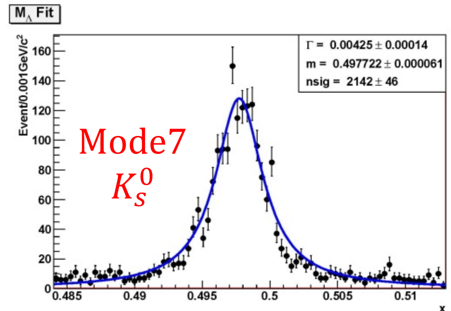
We used the criteria fabs(ΔE) $\leq 5\sigma$ to constrain the Λ_c^+ candidates.

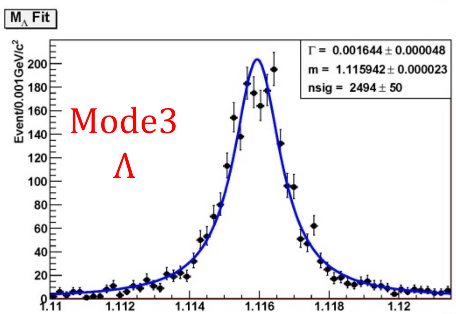
Fit result

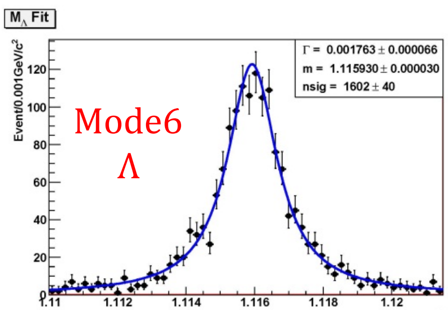
We fitted the invariance mass of these intermediate states of MC data respectively to obtain resolutions of them.

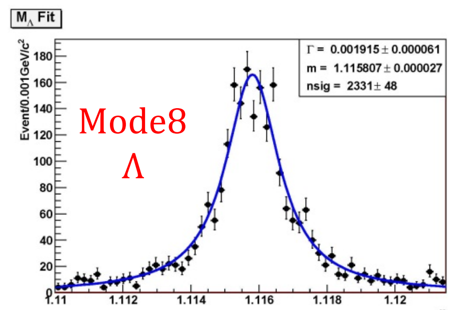


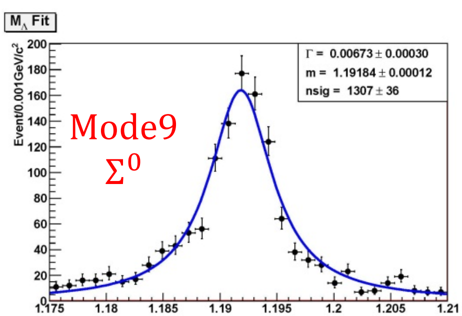


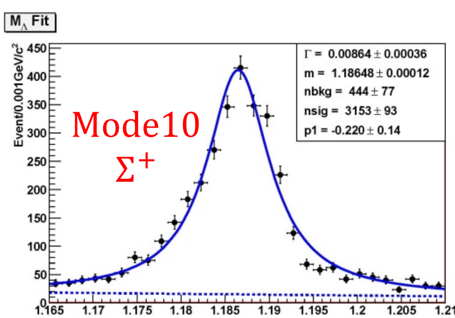












Event selection

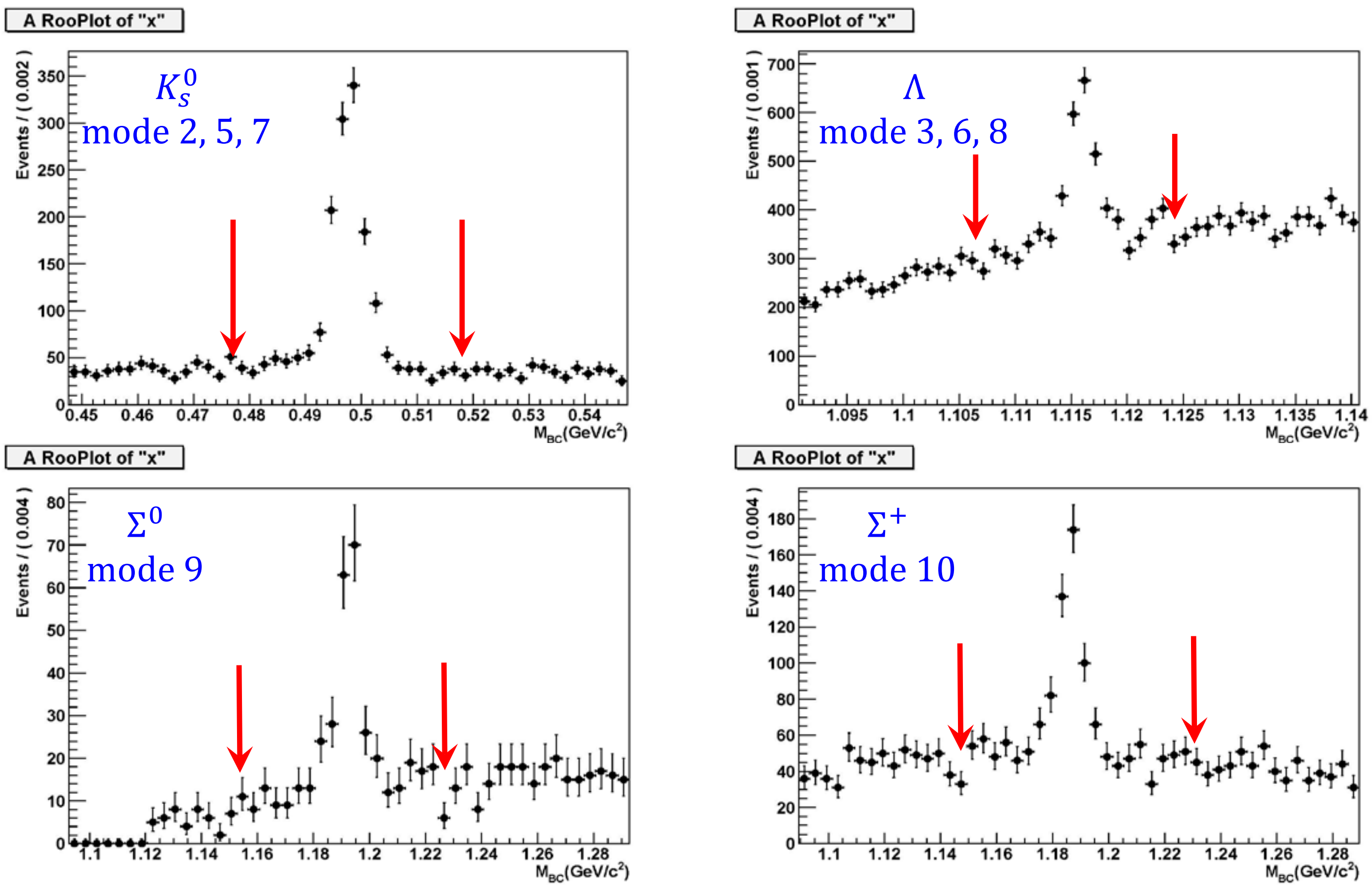
The intermediate states mass window for each mode (weighted average for K_s and Λ):

mode	intermediate state	σ(MeV)
1, 4	None	----
2, 5, 7	K_s	4.1
3, 6, 8	Λ	1.8
9	Σ^0	6.7
10	Σ^+	8.6

We used the criteria fabs($M_{intermediate} - M_{PDG}$) $\leq$ 5σ to constrain the Λ_c^+ candidates, and the result of 4.600 was applied to other energy points directly since there is no remarkable difference between them.

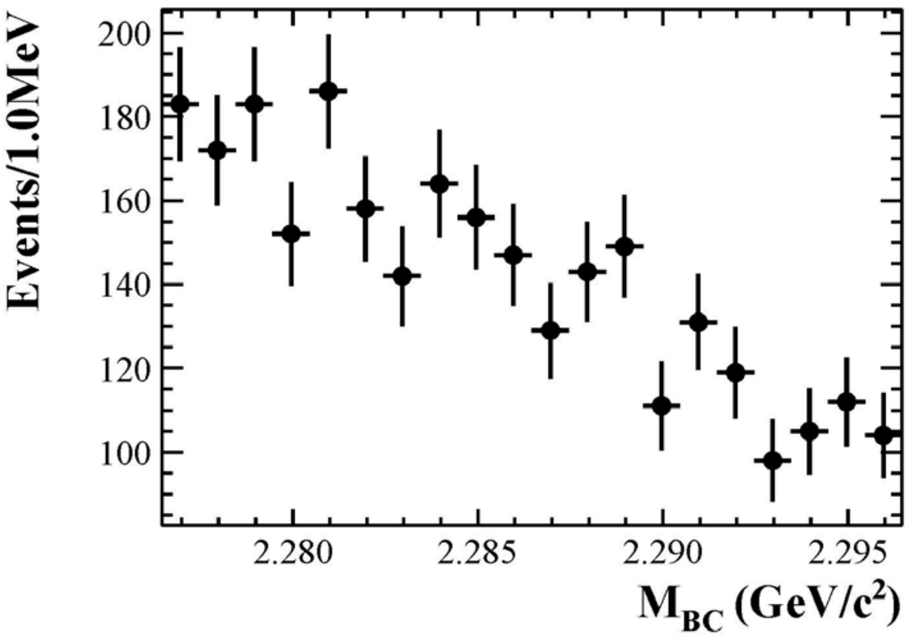
Event selection

Mass window implemented to intermediate states of real data:



background study

The contribution of $q\bar{q}$ and DD events to M_{bc} makes up main part of the background of M_{bc}. But no enhancement around Λ_c^+ is observed.



background study

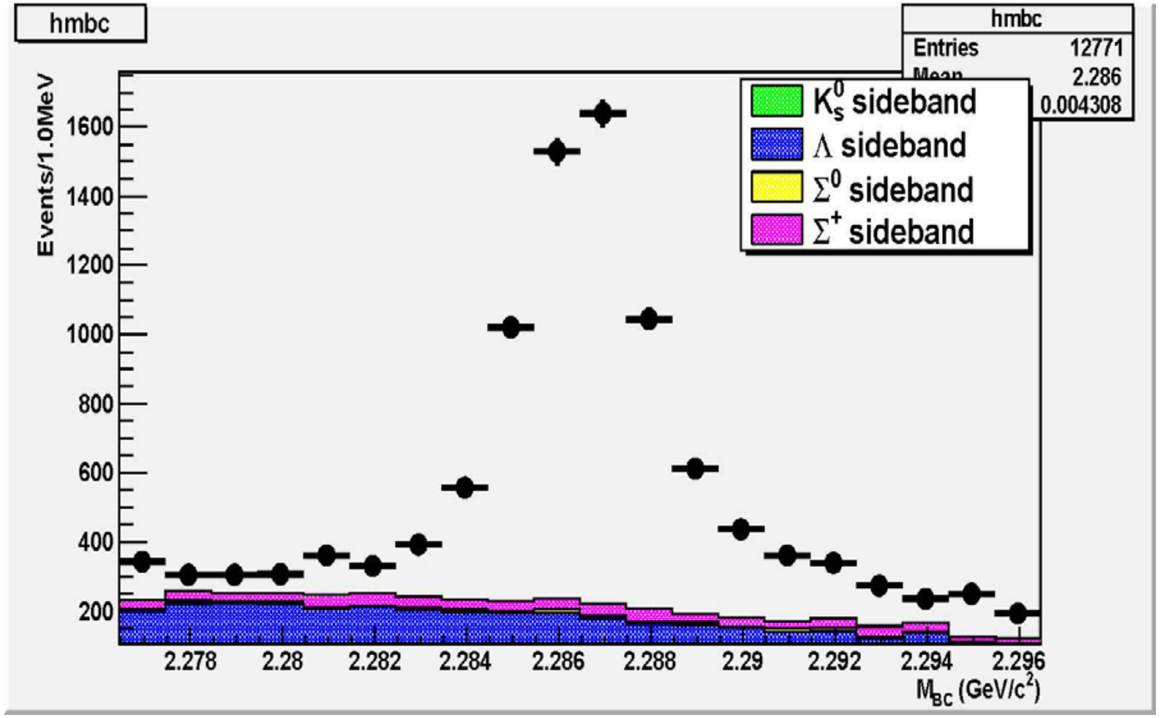
The sideband of the intermediate states are also used to estimate background. The Sideband region for this intermediate states are:

* K_S^0 (mode2, 5, 7): $0.45645 < M_{K_S^0} < 0.47700$ && $0.52000 < M_{K_S^0} < 0.54055$
* Λ (mode3, 6, 8) : $1.09112 < M_\Lambda < 1.10000$ && $1.13000 < M_\Lambda < 1.13888$
* Σ^0 (mode9) : $1.12135 < M_{\Sigma^0} < 1.14500$ && $1.23000 < M_{\Sigma^0} < 1.26365$
* Σ^+(mode10): $1.1018 < M_{\Sigma^+} < 1.1450$ && $1.2500 < M_{\Sigma^+} < 1.2932$

The range of each mass interval covers 5 resolution.

background study

The distribution of M_{bc} in data at 4.60 GeV, where the hatched histograms are from the sideband of intermediate states.



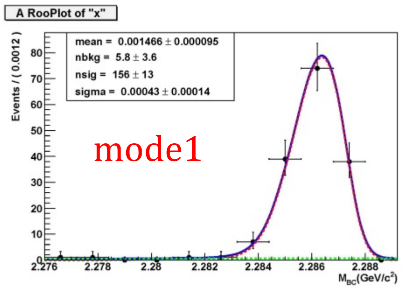
From the background study above, we can conclude that there is no peaking background in M_{bc} distribution.

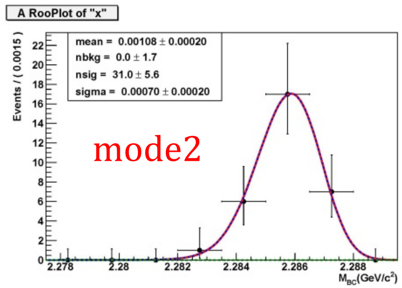
fit method

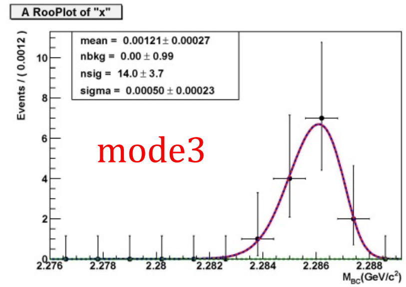
* The signal is fitted by MC shape convoluted with a Gaussian function, and the mean value and sigma is float in the fitting of data at energy point 4.60
* The background is described by a third(or second)-order polynomial, and for energy point 4.60 , the parameters of the polynomial are float.
* For other energy points, the parameters of Gaussian function and polynomial is fixed by that of energy point 4.60, since the low statistic.

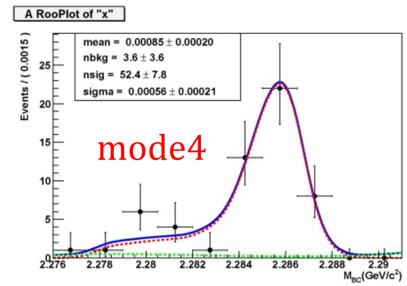
Fit result (tagging Λ_c^+)

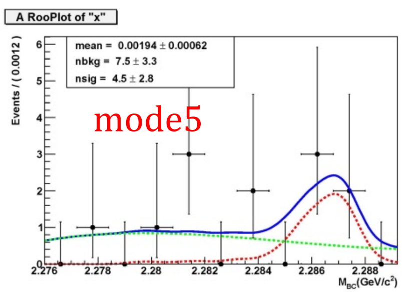
Ecm = 4.575 GeV

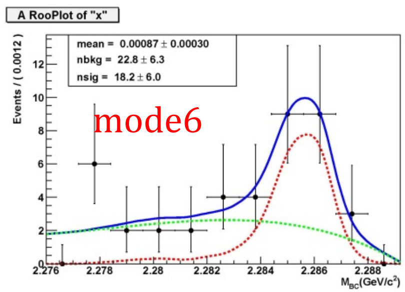


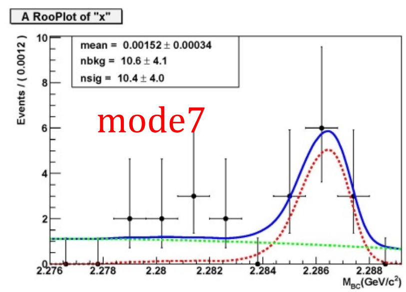


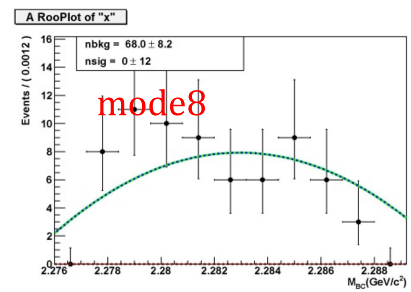


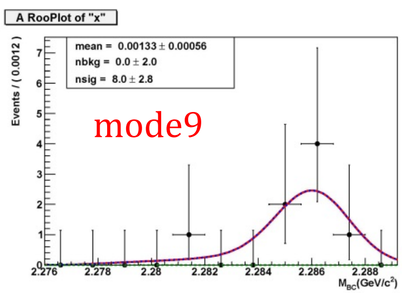


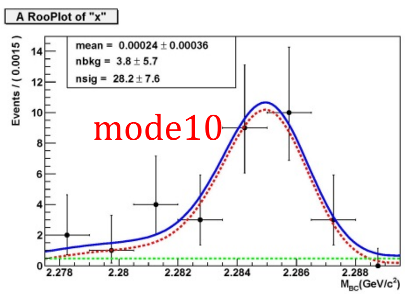






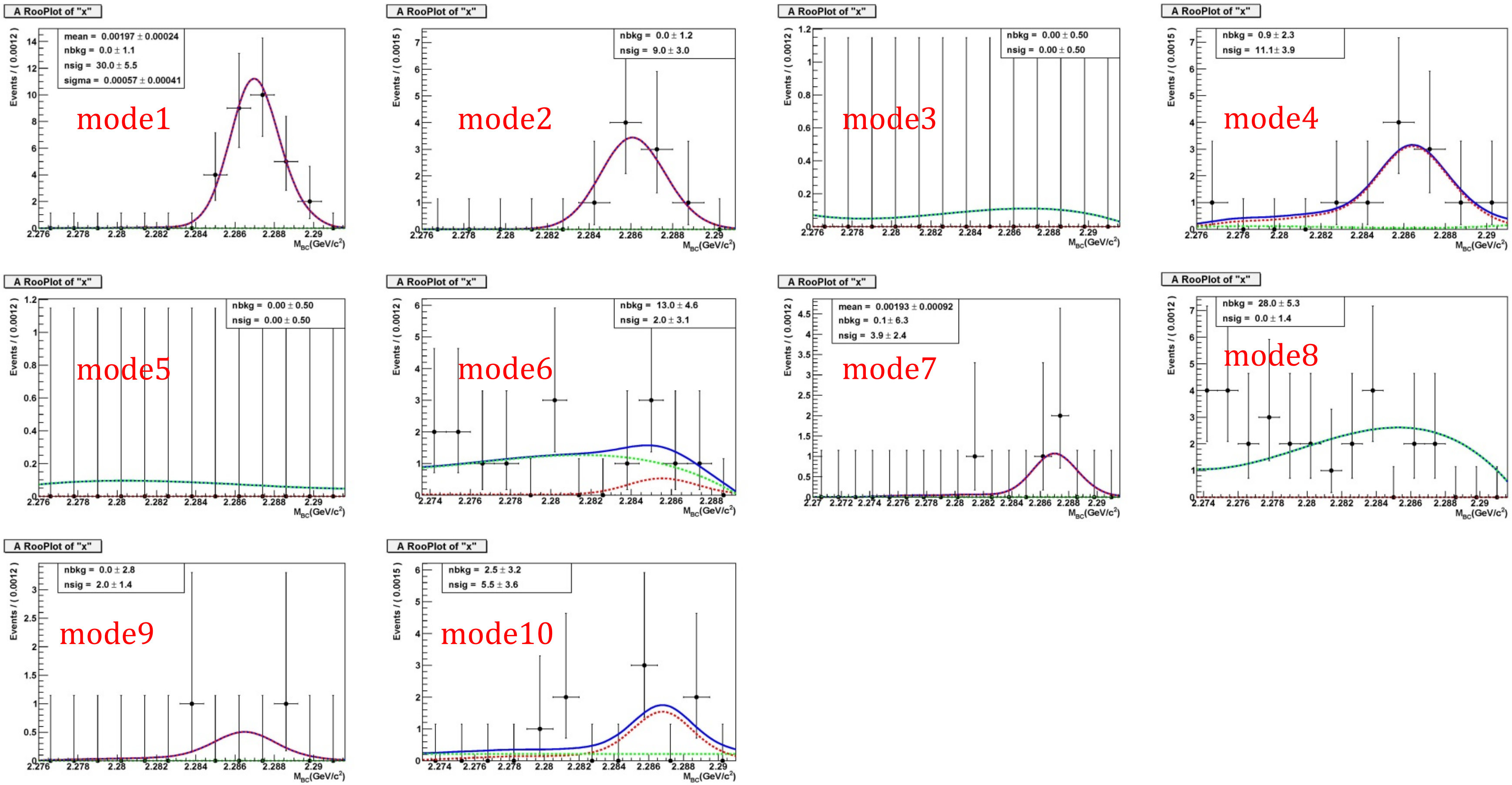






Fit result (tagging Λ_c^+)

Ecm = 4.580 GeV



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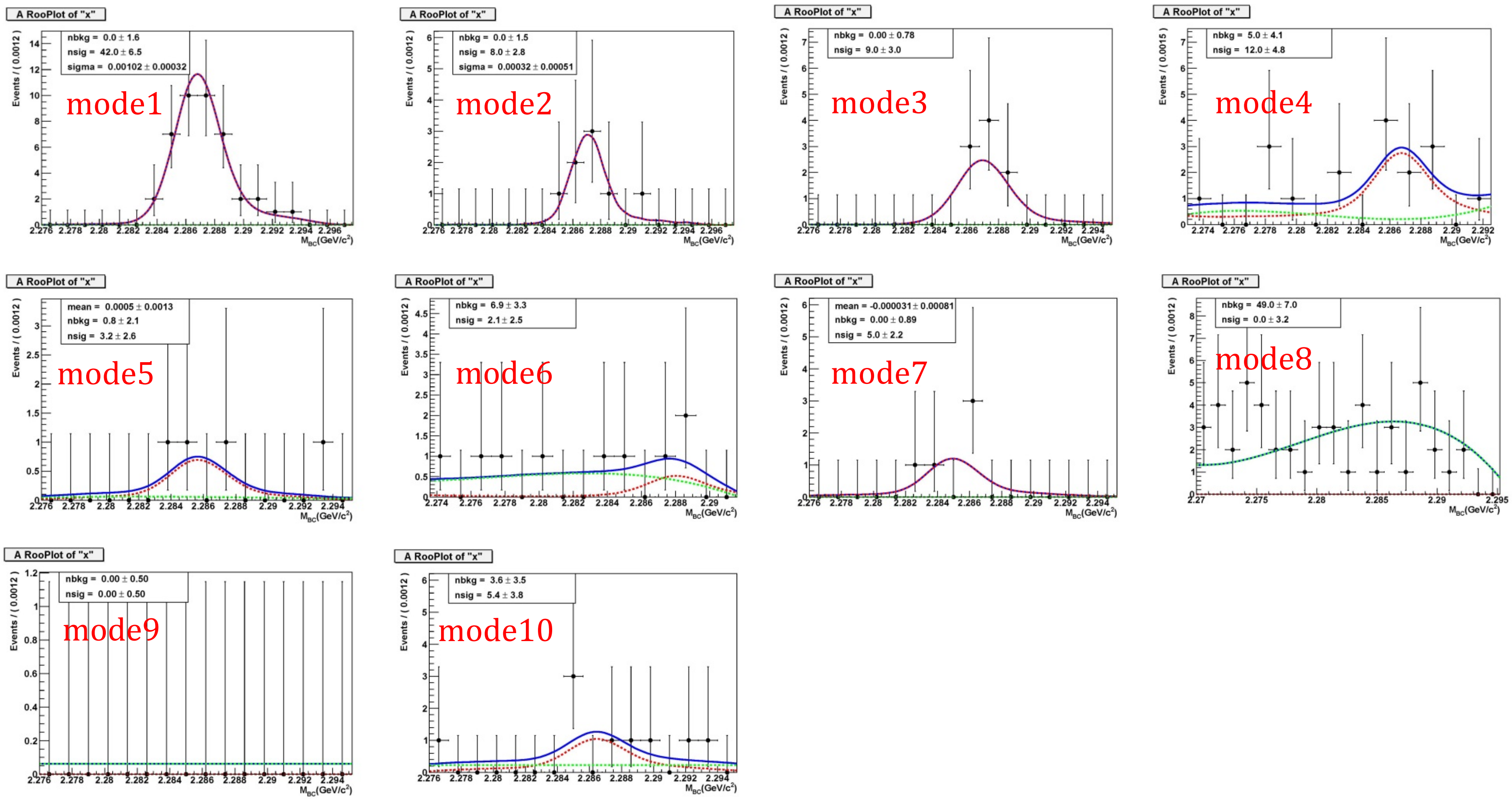
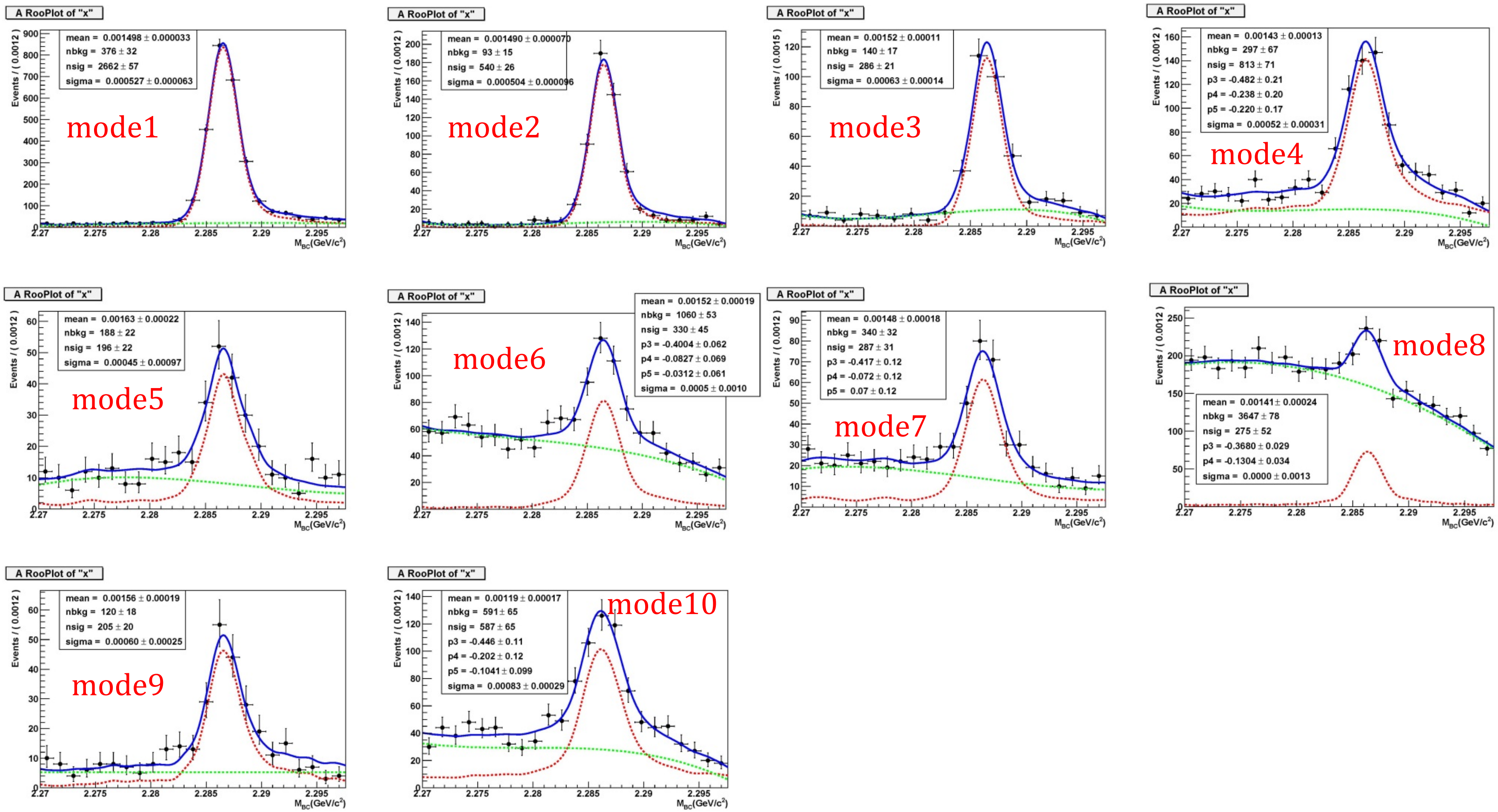


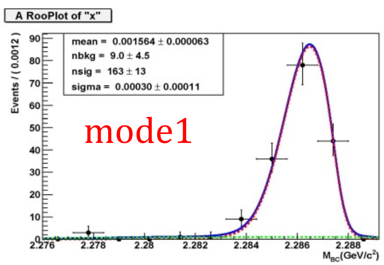
Fit result (tagging Λ_c^+)

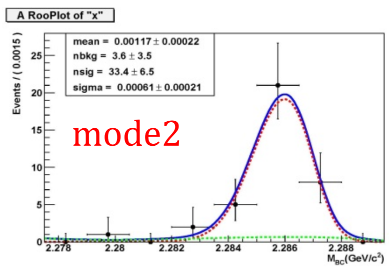
Ecm = 4.600 GeV

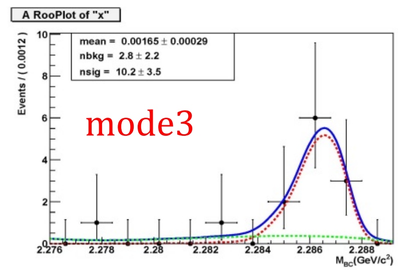


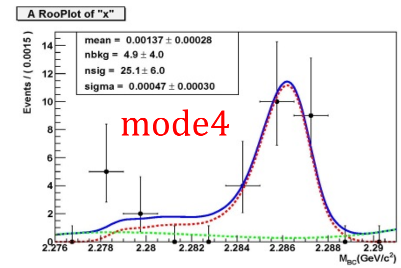
Fit result (tagging Λ_c^-)

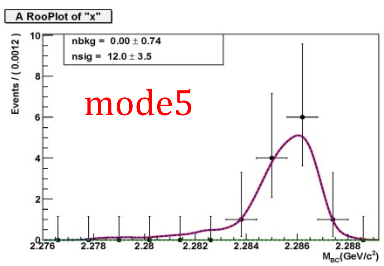
Ecm = 4.575 GeV

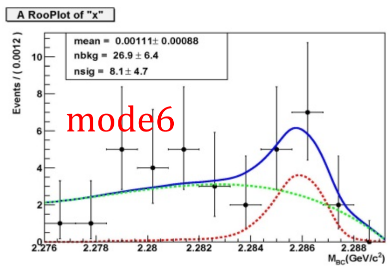


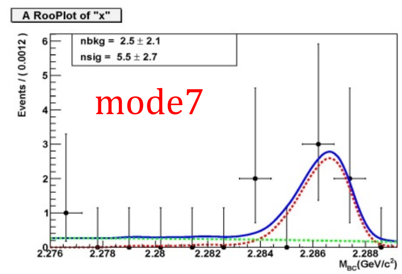


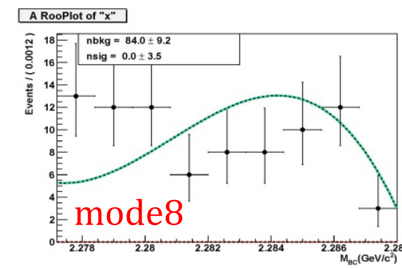


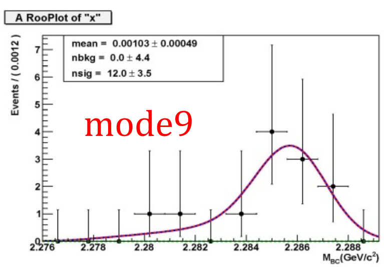


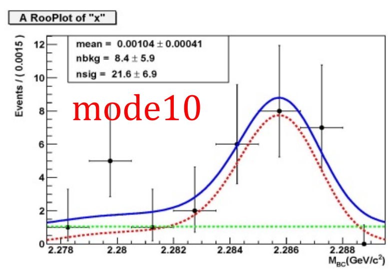












Fit result (tagging Λ_c^-)

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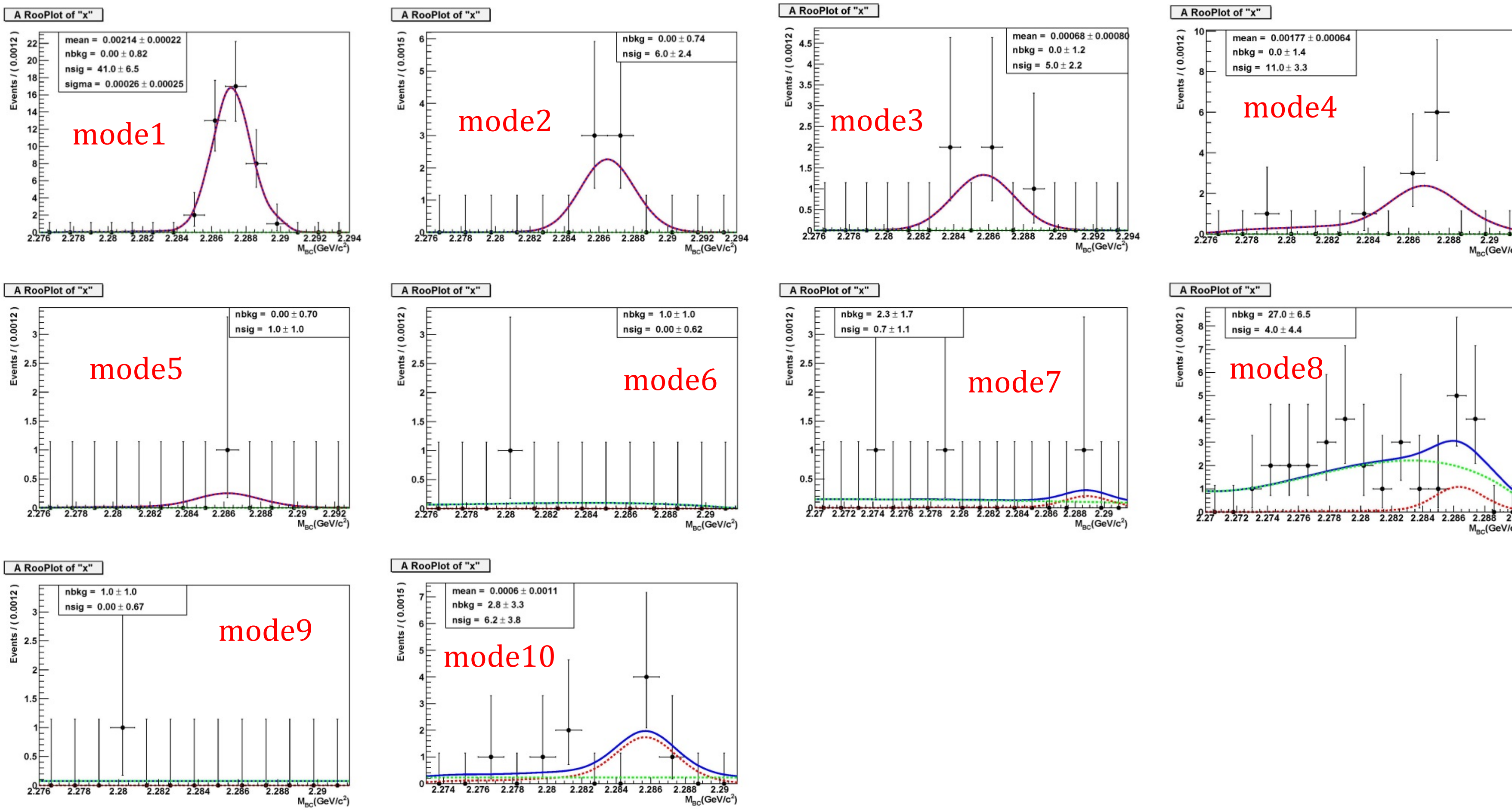
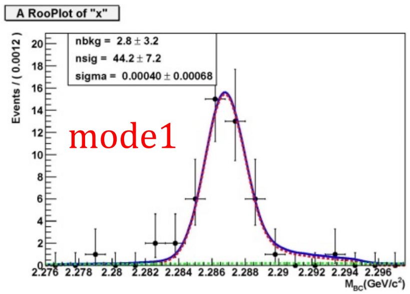
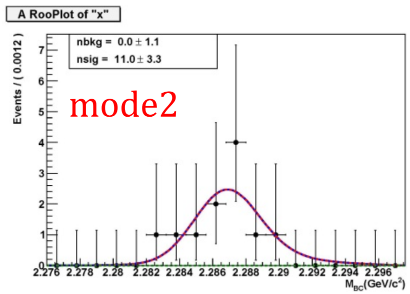
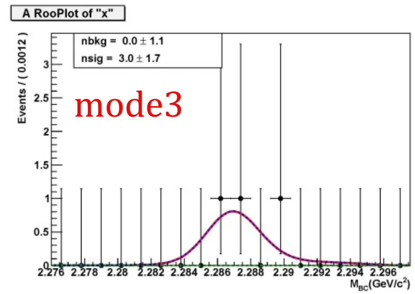


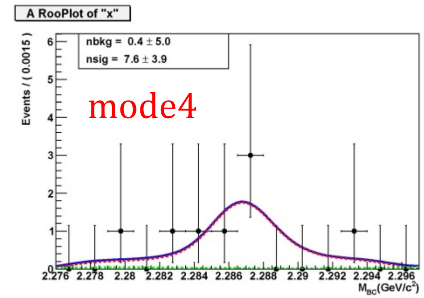
Fit result (tagging $\bar{\Lambda}_c^-$)

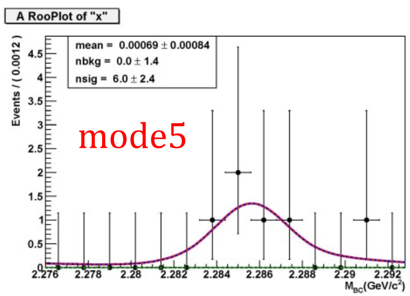
Ecm = 4.590 GeV

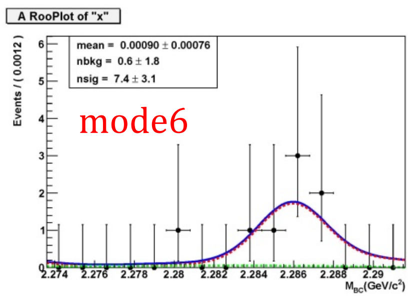


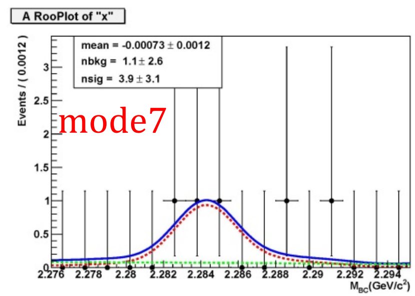


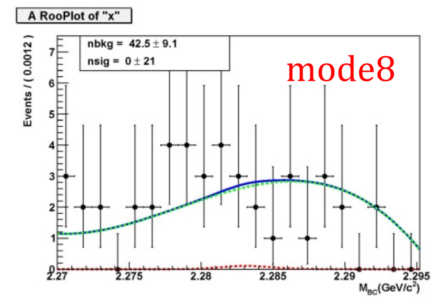


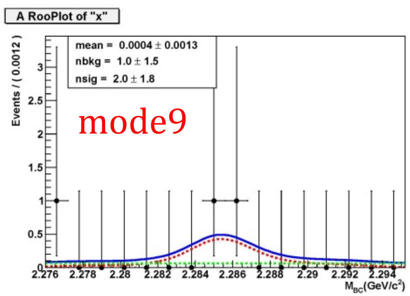


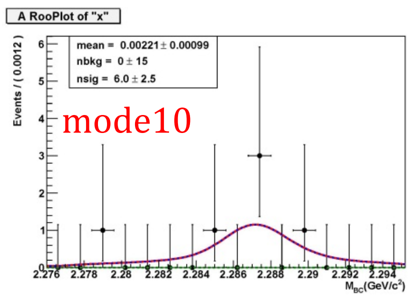






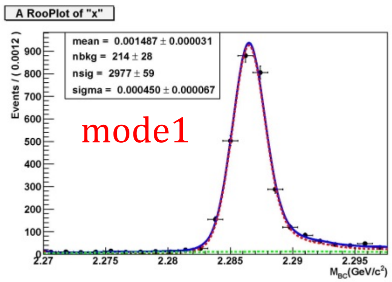


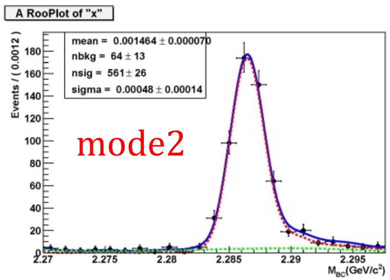


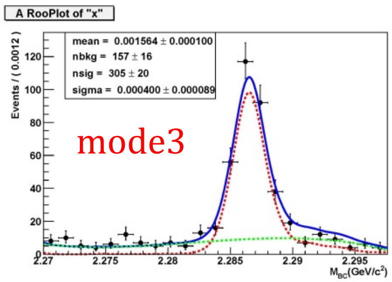


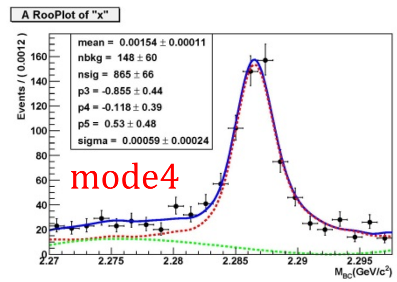
Fit result (tagging $\bar{\Lambda}_c^-$)

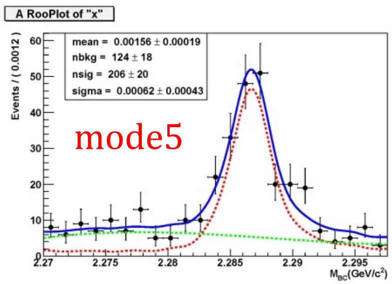
Ecm = 4.600 GeV

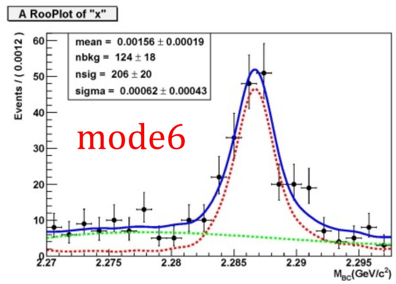


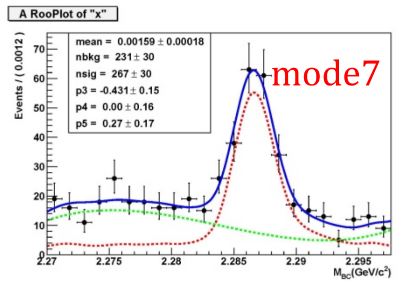


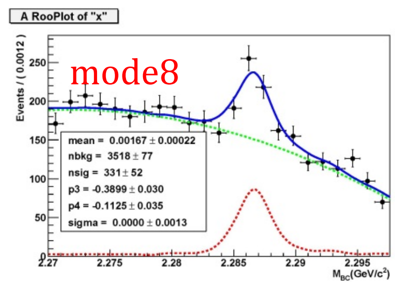


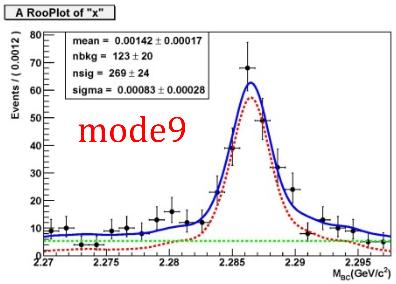


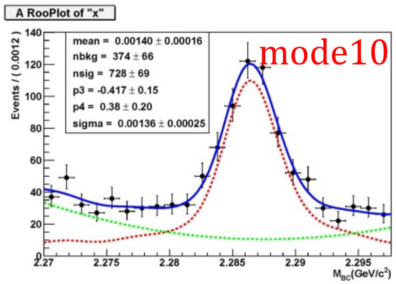












Systematic error

The systematic uncertainty includes the uncertainties from tracking, PID, ΔE requirement, mass window for intermediate states, fitting method of M_{bc}, ISR correction and luminosity.

The uncertainty of ΔE is estimated by varying the requirement on ΔE from 5σ to 8σ.

The uncertainty of the mass window of the intermediate states is estimated by varying the mass window from 5σ to 8σ.

The uncertainty of the fit of M_{bc} is studied from two aspects, one is changing the fitting range of the M_{bc}, and the second is changing the background shape to 2-order or 3-order polynomial and the largest error is taken as the systematic uncertainty.

Systematic error

This table shows the systematic uncertainty at the energy point 4.60 by tagging Λ_c^+:

mode	tracking	PID	Ks	Λ	π^0	ΔE	mass win.	fit range	bkg. shape	lum.	total
1	3.0	3.0	0	0	0	0.36	0	6.43	1.54	1.0	7.93
2	1.0	1.0	3.5	0	0	2.44	1.29	6.85	2.22	1.0	8.64
3	1.0	1.0	0	2.5	0	5.86	4.20	1.13	5.30	1.0	9.52
4	3.0	3.0	0	0	1.0	3.18	0	1.81	5.04	1.0	7.67
5	1.0	1.0	3.5	0	1.0	2.70	5.91	5.39	5.29	1.0	10.75
6	1.0	1.0	0	2.5	1.0	3.41	7.80	**16.84**	3.94	1.0	19.51
7	3.0	3.0	3.5	0	0	3.14	7.85	**11.78**	2.44	1.0	15.75
8	3.0	3.0	0	2.5	0	7.54	8.80	3.64	1.45	1.0	13.22
9	1.0	1.0	0	2.5	0	0.56	2.84	5.17	0	1.0	6.17
10	3.0	3.0	0	0	1.0	1.45	1.77	9.77	4.96	1.0	12.05

The systematic errors of the reconstruction of Ks and Λ was chosen as 3.5% and 2.5% for the sake of conservative, and it will be analyzed in detail soon.

Systematic error

Two notes :

＊ the uncertainty of MC model was not given since there are some additional complication.

＊ Further research on background at mode6 and mode7 will reduce the uncertainty of their fit range.

cross section

The calculation of cross section of each mode:

$$X_{sec}^{i} = \frac{N_{data}^{i}}{Lum.\times f_{VP} \times f_{cor} \times Eff.^{i} \times Br.^{i}} \qquad \text{(a)}$$

The weighted least squares methods

A data set (x_i, y_i) contains n elements, where $i = 1, 2, \cdots, n$, and a linear function $f(\vec{x}, \vec{\beta}) = \sum_{j=1}^{m} \beta_j \phi_j(\vec{x})$, which contains m parameters was used to fit the data. The least square method told us that when

$$\frac{\partial S}{\partial \beta_j} = 0 \qquad \text{for } j = 1, 2, \cdots, m$$

where

$$S = \sum_{i=1}^{n} r_i^2 = \sum_{i=1}^{n} [y_i - f(x_i, \vec{\beta})]^2$$

will gets its minimum value, and we can obtain that

$$\mathrm{X^T X}\hat{\beta} = \mathrm{X^T}\hat{\mathrm{y}} \quad \text{or} \quad \hat{\beta} = (\mathrm{X^T X})^{-1}\, \mathrm{X^T}\hat{\mathrm{y}}$$

and the error of $\vec{\beta}$ can be obtained according the error transfer formula

$$\mathrm{M}_\beta = (\mathrm{X^T X})^{-1}\, \mathrm{X^T M_y X} (\mathrm{X^T X})^{-1}$$

The weighted least squares methods

where $M_\beta \in \boldsymbol{R}^{m\times m}$, $M_y \in \boldsymbol{R}^{n\times n}$, is the variance-covariance matrix of $\vec{\beta}$ and $\vec{y}$ respectively, and $X_{ij} = \frac{\partial f\left(x_i,\vec{\beta}\right)}{\partial \beta_j} = \phi_j(x_i), X \in \boldsymbol{R}^{n\times m}$, and $\hat{\beta} \in \boldsymbol{R}^{m\times 1}$, $\hat{y} \in \boldsymbol{R}^{n\times 1}$ is the parameter set and data set respectively.

However, in the weighted case, we written S as

$$S = \sum_{i=1}^{n} W_{ii} r_i^2 = \sum_{i=1}^{n} W_{ii}[y_i - f\left(x_i, \vec{\beta}\right)]^2$$

where the matrix W denotes the weights matrix, then the least square method told us that

$$\hat{\beta} = (X^T W X)^{-1} X^T W \hat{y} \qquad \text{(b)}$$

$$M_\beta = (X^T W X)^{-1} X^T W M_y W^T X (X^T W^T X)^{-1} \qquad \text{(c)}$$

are the best liner unbiased estimator of parameter set $\hat{\beta}$ and its error respectively, when $W = M_y^{-1}$ is the case.

The weighted least squares methods

As for the case of my analysis, $m = 1$, and $n = 10$. The function which we used to fit the data set (x_i, y_i) is $f\left(\vec{x}, \vec{\beta}\right) = \sum_{j=1}^{1} \beta_j \phi_j(\vec{x}) = \beta$, so $X_{ij} = \frac{\partial f\left(x_i, \vec{\beta}\right)}{\partial \beta_j} = 1$, and $X^T =(1, 1, \cdots, 1)$. $\mathrm{M}_\beta \in \boldsymbol{R}$, and $\mathrm{M}_\mathrm{y} \in \boldsymbol{R}^{10\times10}$.

When we choose the weights matrix as the inverse of variance-covariance matrix M_y, that is, $\mathrm{W} = \mathrm{M}_\mathrm{y}{}^{-1}$, we can obtain the weighted average of cross section and its total error as follow

$$\bar{\beta} \pm \overline{\delta\beta} = \frac{\sum_j y_j \cdot \sum_i \omega_{ij}}{\sum_j \sum_i \omega_{ij}} \pm \sqrt{\frac{1}{\sum_j \sum_i \omega_{ij}}} \qquad \text{(d)}$$

where ω_{ij} is element of (i, j) position of weights matrix, which will be defined later.

The weighted least squares methods

When we want to calculate the error comes from different sources, we can use the original formula (c) by using the variance-covariance matrix of the error comes from different sources, that is

$$\mathrm{M} = (\mathrm{X}^{\mathrm{T}}\mathrm{W}\mathrm{X})^{-1}\, \mathrm{X}^{\mathrm{T}}\mathrm{W}\mathrm{M}_{\mathrm{i}}\mathrm{W}^{\mathrm{T}}\mathrm{X}(\mathrm{X}^{\mathrm{T}}\mathrm{W}^{\mathrm{T}}\mathrm{X})^{-1} \qquad \text{(e)}$$

where M_{i} is the variance-covariance matrix of i-th error which shares the same definition with that of total error.

In my analysis, this formula can be simplified as

$$\overline{\delta\beta}_i = M = \frac{\sum_{i=1}^{i=10}\sum_{j=1}^{j=10} \omega_i\omega_j m_{ij}}{(\sum_{i=1}^{i-10} \omega_i)^2} \qquad \text{(e)}$$

where m_{ij} is the (i, j) position element of M_{i} , and $\omega_i = \sum_{k=1}^{k=10} \omega_{ik}$, and ω_{ik} is the (i, k) position element of weight matrix W.

Error Matrix

The covariance error matrix M_y is:

$$\begin{pmatrix} \sigma_{T1}^2 & Cov(x_1, x_2) & \cdots & Cov(x_1, x_n) \\ Cov(x_2, x_1) & \sigma_{T2}^2 & \cdots & Cov(x_2, x_n) \\ \cdots & \cdots & \cdots & \cdots \\ Cov(x_n, x_1) & Cov(x_n, x_2) & \cdots & \sigma_{Tn}^2 \end{pmatrix}$$

$$\sigma_{Ti}^2 = \sigma_i^2(stat.) + \sigma_i^2(sys1.) + \sigma_i^2(sys2.) + \cdots$$

$$Cov(x_i, x_j) = x_i \cdot \varepsilon_{ij} \cdot x_j \cdot \varepsilon_{ji}$$

Where σ_{Ti} stands for the total uncertainty in the measurement of mode i, and $\sigma_i(stat.)$ and $\sigma_i(sysj.)$ are the statistical error and the systematic error for source j in mode i respectively. $Cov(x_i, x_j)$ is the covariance systematic error between mode i and j. x_i is The measured value of mode i, and $\varepsilon_{ij} = \varepsilon_{ji}$ is the common relative systematic error (in percentage) between mode i and j.

Weighted average

As for the variance-covariance matrix of i-th error source(i.e. $\mathrm{M_i}$), the only difference is that $\varepsilon_{ij} = \varepsilon_{ji}$ just contains the common relative error which comes from source i only. We can find that

$$\mathrm{M_y} = \sum_i \mathrm{M_i} \qquad \text{(f)}$$

The inverse of the covariance matrix ${\mathrm{M_y}}^{-1}$ is:

$$\begin{pmatrix} \omega_{11} & \omega_{12} & \cdots & \omega_{1n} \\ \omega_{21} & \omega_{22} & \cdots & \omega_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ \omega_{n1} & \omega_{n2} & \cdots & \omega_{nn} \end{pmatrix}$$

The weighted average cross section and the corresponding total uncertainty can be calculated according to formula(d).

According this formula, the production cross section of $\Lambda_c^+\overline{\Lambda_c}^-$ is 232.22 pb, with the total error 18.01 pb.

Updated cross section(@4600)

Mode	N^{+}_{total}	Eff.$^{+}$(%)	Br.(%)	X^{+}_{sec}(pb)
1	2662±57	46.95	6.84±0.36	211.71±4.53±16.78±11.14±0.00
2	540±26	47.40	1.11±0.11	262.13±12.62±22.66±13.80±22.31
3	286±21	32.76	0.87±0.10	256.28±18.82±24.39±13.49±25.63
4	813±71	18.30	4.53±0.84	250.47±21.87±19.20±13.18±44.86
5	196±22	13.34	1.54±0.23	242.04±27.17±26.01±12.74±33.00
6	330±45	6.48	3.15±0.79	412.90±56.30±80.54±21.73±101.81
7	287±31	21.90	1.21±0.16	276.61±29.88±43.55±14.56±32.54
8	275±52	12.69	2.27±0.18	243.82±46.10±32.24±12.83±14.07
9	205±20	20.41	0.87±0.18	294.86±28.77±18.20±15.52±58.97
10	587±65	19.53	2.41±0.31	318.52±35.27±38.39±16.76±36.93
summary				232.22±4.56±11.53±12.22±4.63

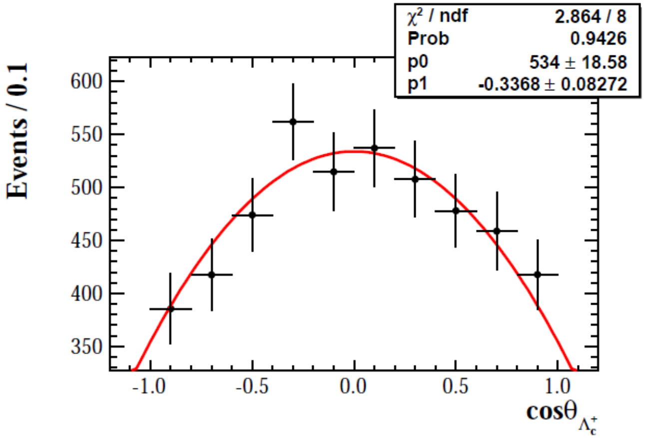
The combined error comes from absolute branch fraction of these multiple modes is $\sqrt{4.63^2+12.22^2}/232.22 = 13.07/232.22 = 5.63\%$

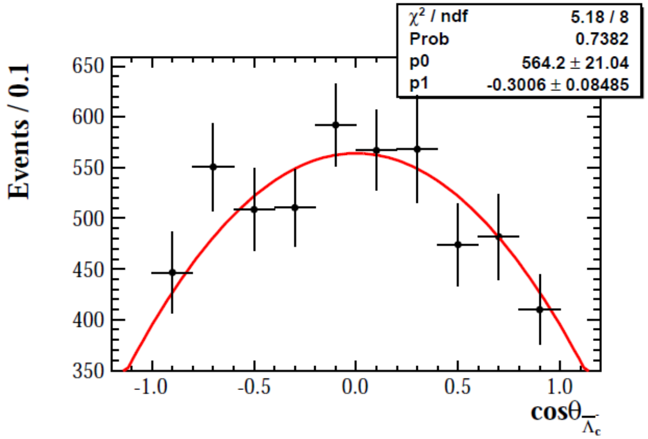
$|G_E/G_M|$ ratio measurement at 4.6 GeV

Angular distribution:

Data of mode $pK^-\pi^+$ only.

The angular distribution is then fitted by $1+\alpha\cos^2\theta$.





Ecm (GeV)	$\alpha_{\Lambda_c^+}$	$\alpha_{\Lambda_c^-}$	α
4.60	-0.34±0.083	-0.30±0.08	-0.32±0.06

$|G_E/G_M|$ ratio measurement at 4.6 GeV

The differential cross section can be expressed as:

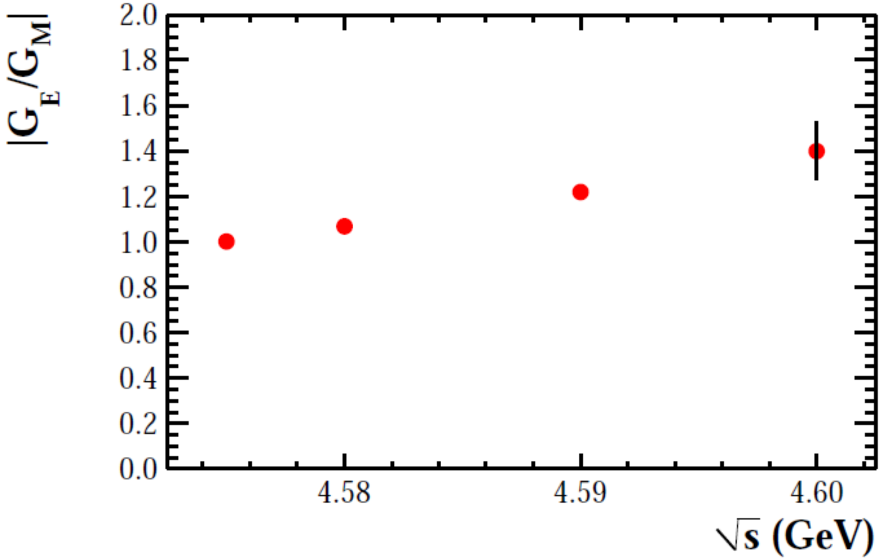
$$\frac{d\sigma_{Born}(s)}{d\Omega} = \frac{\alpha^2\beta C}{4s}[|G_M(s)|^2\left(1 + cos^2\theta_{\Lambda_c}\right) + \frac{4m_{\Lambda_c}^2}{s}|G_E(s)|^2(sin^2\theta_{\Lambda_c})]$$

$|G_E/G_M|$ ratio can be described by the following:

$$\left|\frac{G_E}{G_M}\right|^2 = (1-\alpha)/(\frac{4m_{\Lambda_c}^2}{s}\alpha + \frac{4m_{\Lambda_c}^2}{s})$$

$|G_E/G_M|$ ratio is calculated to be 1.40 ± 0.13 at 4.60 GeV.

$|G_E/G_M|$ ratio measurement at 4.6 GeV



* At threshold (4.575 GeV), we assume $|G_E/G_M|=1$.
* At 4.58, 4.59 GeV, $|G_E/G_M|$ is obtained by interpolation.
* The result of $|G_E/G_M|$ ratio is needed in the line-shape fitting.

fit the line-shape

The function of non-resonant (NonR) contribution can be parameterized as:

$$NonR = \frac{4\pi\alpha^2\beta C}{3q^2}[|G_M(q^2)|^2 + \frac{1}{2\tau}|G_E(q^2)|^2]$$

where $\beta=\sqrt{(1-4m^2_{\Lambda c}/q^2)}$,$\tau=q^2/4m^2_{\Lambda c}$.

The Coulomb factor $C=\varepsilon\times R$, $\varepsilon=\pi\alpha/\beta$ is the enhancement factor, and R is the resummation factor . In traditional prediction: $R=\sqrt{1-\beta^2}/(1\text{-}e^{-\pi\alpha/\beta})$

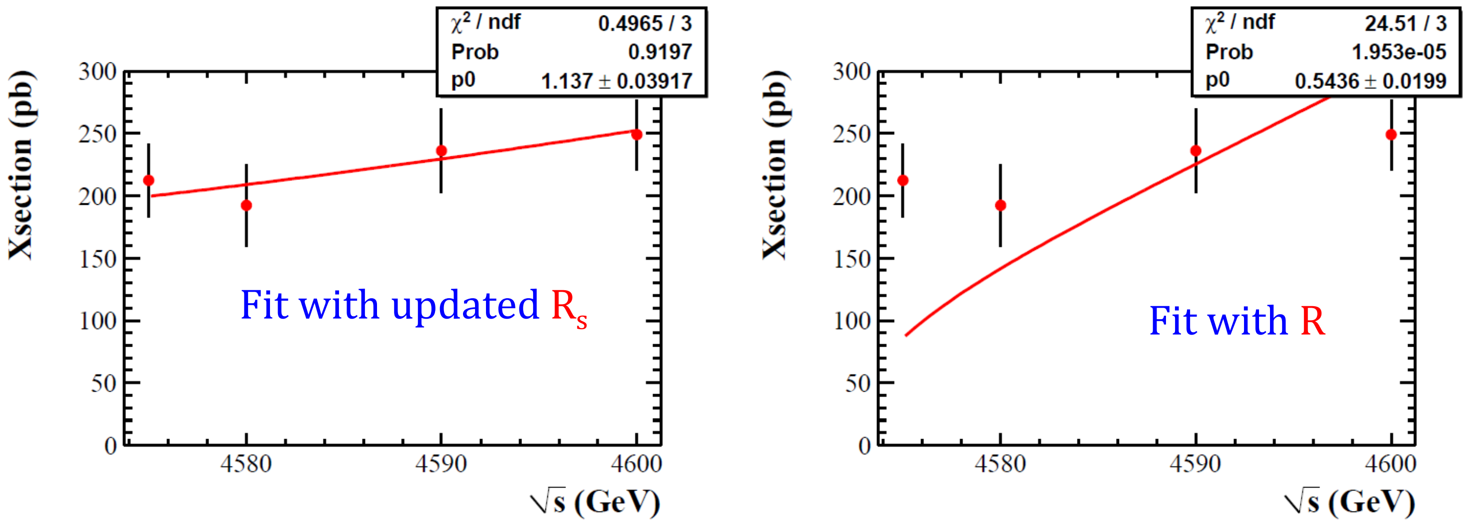
From the prediction by R. Baldini Ferroli, S. Pacetti

$$C = \frac{\pi\alpha}{\beta}\times R_s = \frac{\pi\alpha}{\beta}\frac{\sqrt{1-\beta^2}}{1-\exp(-\pi\alpha_s/\beta)}$$

where the coupling constant $\alpha=1/137$, $\alpha_s = 0.5$.

fit the line-shape

The fitting results with previous formula, $|G_E/G_M|$ ratio is inputted in the fitting, G_M is the only fitting parameter :



- ⋆ Using the updated R_s to fit line-shape, the fit status is good, and $|G_M|$ is 1.137 ± 0.039.
- ⋆ Using the traditional R to fit line-shape, the fit status is bad, and $|G_M|$ is 0.5436 ± 0.0199.

Summary

- We present the measurement of $\Lambda_c^+\bar{\Lambda}_c^-$ production cross section at threshold by tagging 10 decay modes, the systematic uncertainty at 4.6 GeV is studied by tagging Λ_c^+, and it is about 7.5%.

- The $|G_E/G_M|$ ratio at 4.60 GeV is obtained, to be 1.40 ± 0.13, which is significantly larger than 1.

- The line-shape of $\Lambda_c^+\bar{\Lambda}_c^-$ production is fitted, and the result favors the prediction with $R\to R_s$ in the fitting. The fitted form factor $|G_M|$ is 1.14 ± 0.04.

Thanks!