Study of the decay $\psi' \to \phi\Lambda\bar{\Lambda}$

Aonan Zhu[1], Liming Gu [2],Hai-Bo Li[1]
1.IHEP
2.Nanjing University

2018.6.6

Outline

- Motivation
- Dataset
- Event selection
- Back ground study
- Fitting result
- Systematic uncertainty
- Summary and next to do

Motivation

- Help to understand the decay of these particles.
- Firstly measure the branch fraction of $\psi' \rightarrow \phi\Lambda\bar{\Lambda}$.
- Search for potential resonance of $\Lambda\bar{\Lambda}$, $\phi\Lambda$.

Data set

- BOSS version: 6.6.4.p03
- Data: $(448.1\pm2.9)\times10^{6}\ \psi'$ events(2009+2012)
- Inclusive MC : 5.06×10^{8}(2009+2012)
  analysis the background events;
- Signal MC : study the efficiency (4.16×10^{5} per channel)
  1. $\psi'\to\phi f_2(2340), f_2(2340)\to\Lambda\bar{\Lambda}, \phi\to K^{+}K^{-}, \Lambda\to p\pi^{-}, \bar{\Lambda}\to\bar{p}\pi^{+}$;
  2. $\psi'\to\phi X(\Lambda\bar{\Lambda}), X(\Lambda\bar{\Lambda})\to\Lambda\bar{\Lambda}, \phi\to K^{+}K^{-}, \Lambda\to p\pi^{-}, \bar{\Lambda}\to\bar{p}\pi^{+}$;
  3. $\psi'\to\phi\Lambda\bar{\Lambda}$ **(PHSP)** , $\phi\to K^{+}K^{-}, \Lambda\to p\pi^{-}, \bar{\Lambda}\to\bar{p}\pi^{+}$

Event Selection

- Good charged tracks:

  $|V_z|$<20 cm, cos(θ) < 0.93;

  Number of good charged tracks == 6

- PID (dE/dx and TOF):

  For (anti)proton: $\mathrm{prob(p) > prob(K), prob(p) > prob(\pi)}$;

  For Kaon: $\mathrm{prob(K) > prob(p), prob(K) > prob(\pi)}$;

  The rest are π by default.

- $\Lambda/\bar{\Lambda}$ candidates:

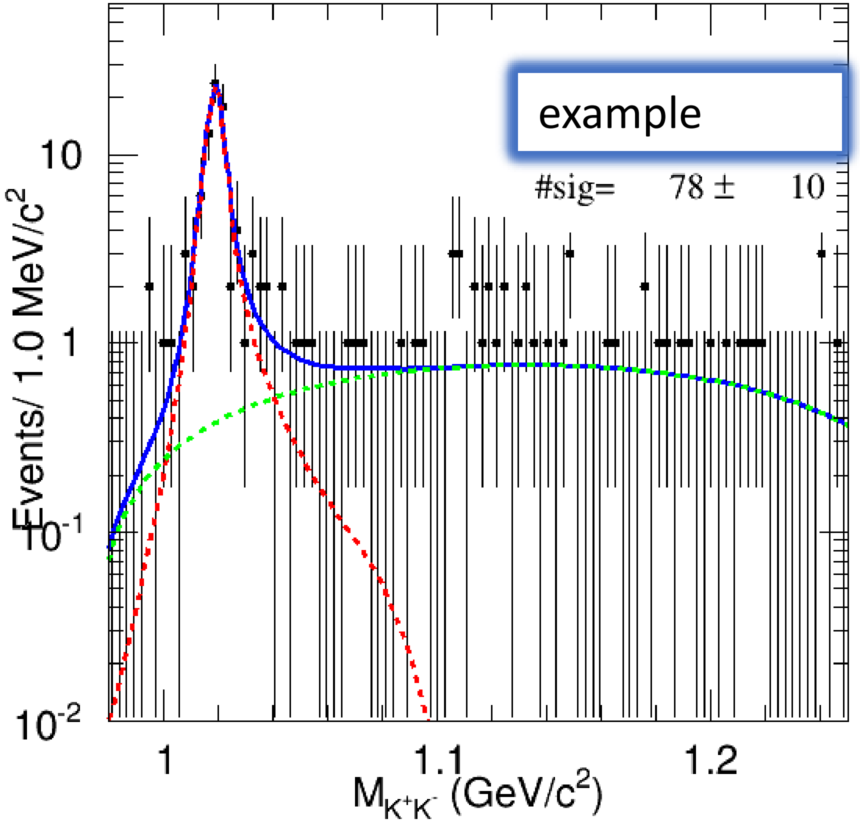
  Primary vertex fit , $\chi^2 < 200$

- 4c fit :

  $\chi^2_{4C}(\mathrm{p}\pi^-\bar{p}\pi^+ K^+K^-) < 200$

Method

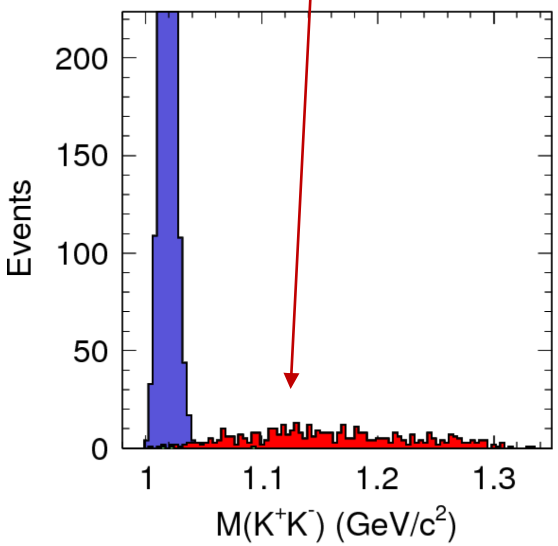
Signal: Fit to M(K^+K^-)
Peak: Esitimate from Λ /$\bar{\Lambda}$ side band.

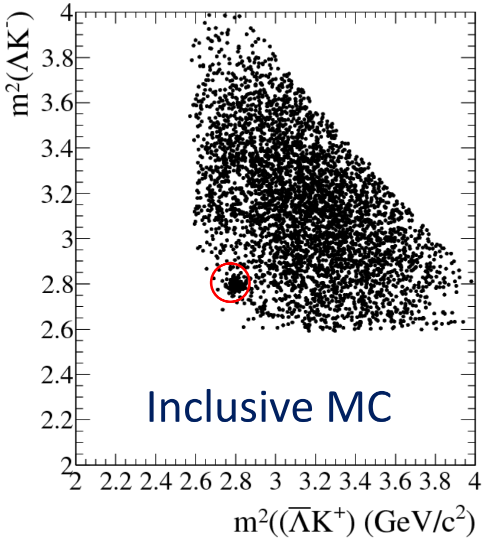


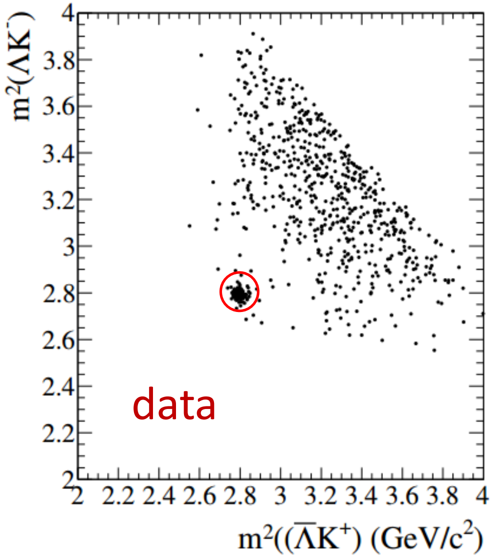
Background study

Main background comes from $\Omega^-\bar{\Omega}^+$

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi' \to \Lambda\phi\Lambda, \Lambda \to p\pi^-, \phi \to K^+K^-, \Lambda \to \bar{p}\pi^+$	$\pi^-\bar{p}K^-\pi^+pK^+$	1	4158	4158
1	$\psi' \to \Omega^-\bar{\Omega}^+, \Omega^- \to \Lambda K^-, \bar{\Omega}^+ \to \bar{\Lambda}K^+, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$\pi^-\bar{p}K^-\pi^+pK^+$	0	420	4578
2	$\psi' \to \Lambda\bar{\Lambda}\phi, \Lambda \to pe^-\bar{\nu}_e, \bar{\Lambda} \to \bar{p}\pi^+, \phi \to K^+K^-$	$\bar{\nu}_e\bar{p}K^-e^-\pi^+pK^+$	2	1	4579
3	$\psi' \to \Lambda\bar{\Lambda}\phi, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}e^+\nu_e, \phi \to K^+K^-$	$e^+\pi^-\bar{p}K^-\nu_e pK^+$	3	1	4580
4	$\psi' \to K^+\Lambda\bar{\Lambda}K^-, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$\pi^-\bar{p}K^-\pi^+pK^+$	4	1	4581



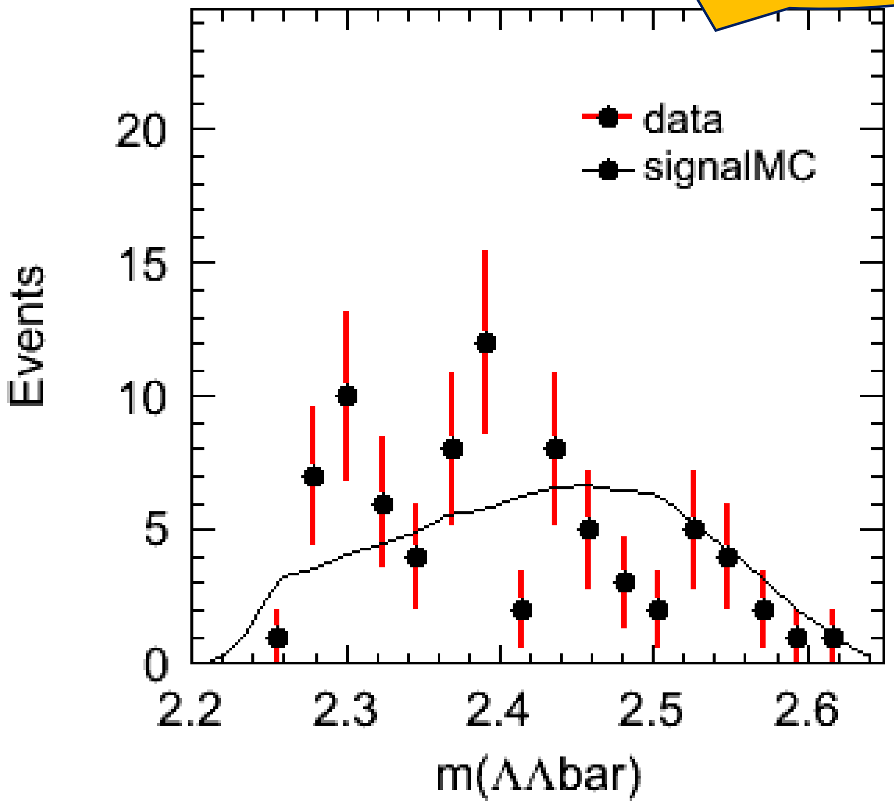


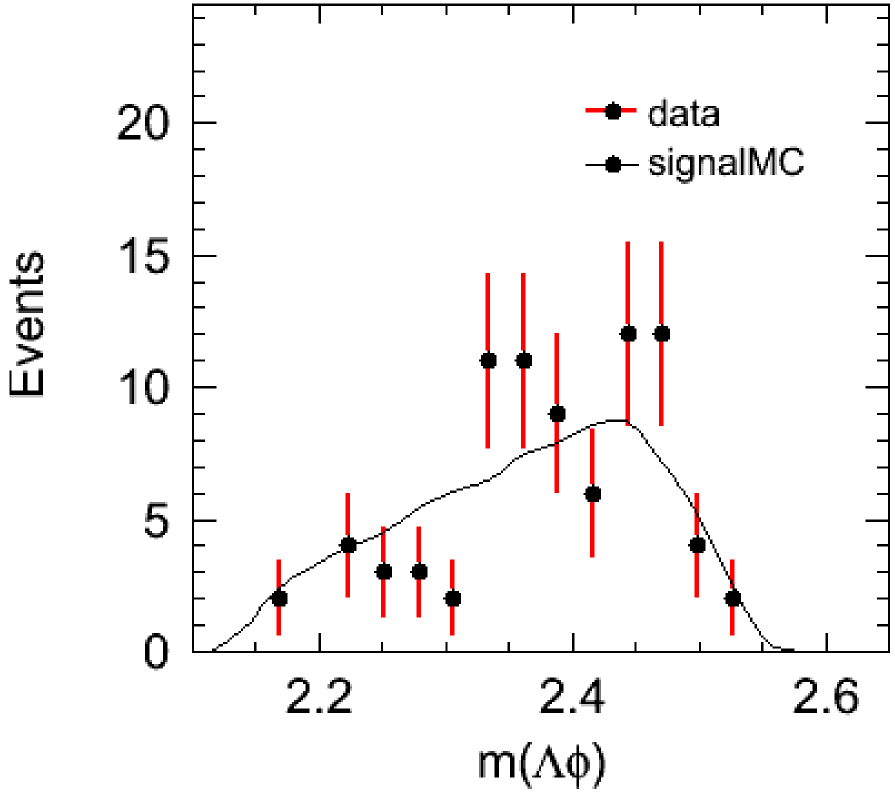


Veto: $\sqrt{(M(K^+\bar{\Lambda}) - m(\bar{\Omega}^+))^2 + (M(K^-\Lambda) - m(\Omega^-))^2} > 0.015\ \mathrm{GeV}/c^2$

potential resonance

$2^{++}, 2^{-+}, 0^{-+}, 0^{++}, ??$

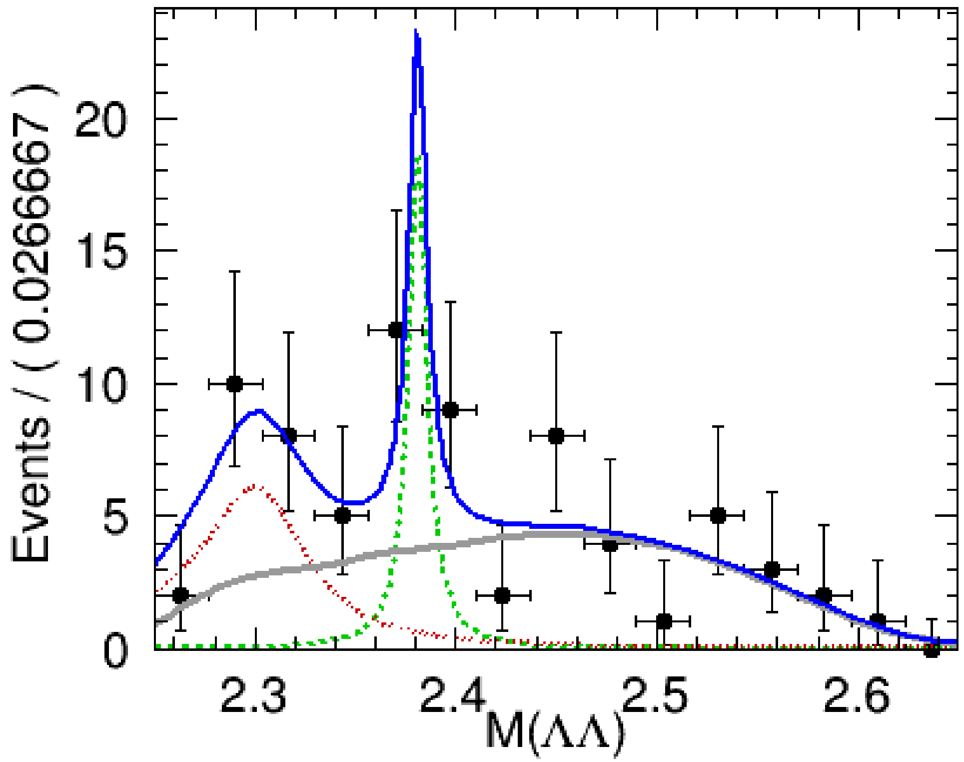




potential resonance(2)

Fitting : $a_1 \times BW(\boldsymbol{f_2}) + a_2 \times BW(\boldsymbol{X}) + a_3 \times PHSP$

Parameters	$f_2(2340)$	X	PHSP
Lineshape	BW	BW	MC shape
Mass	2340(fixed)	2381± 30	
Width	180(fixed)	11± 9	
a_i (yields)	17±6	11±5	42±9



Efficiency

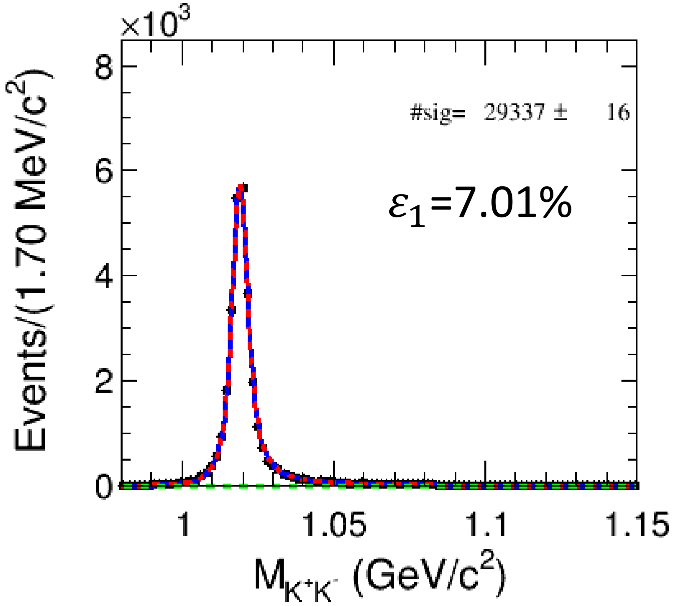
The efficiencies are obtained by using signal MC sample with :

① $\psi' \rightarrow \phi f_2(2340), f_2(2340) \rightarrow \Lambda\bar{\Lambda}, \phi \rightarrow K^+K^-$

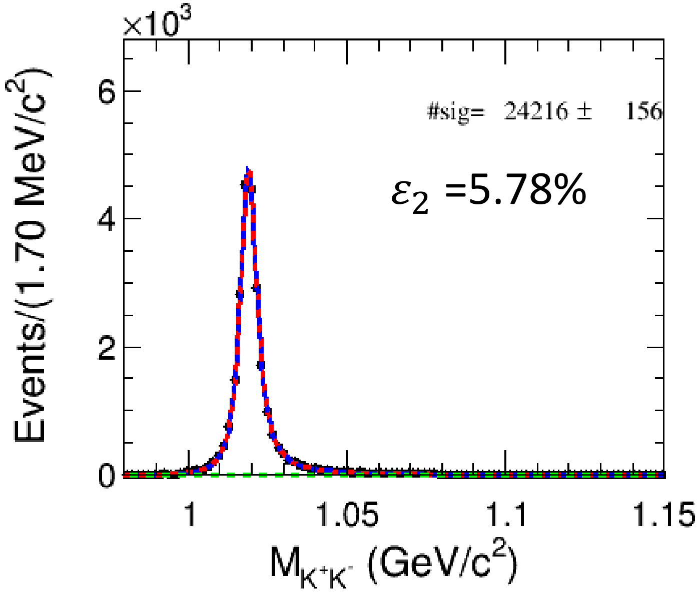
② $\psi' \rightarrow \phi X, X \rightarrow \Lambda\bar{\Lambda}, \phi \rightarrow K^+K^-$

③ $\psi' \rightarrow \phi\Lambda\bar{\Lambda}, \phi \rightarrow K^+K^-$

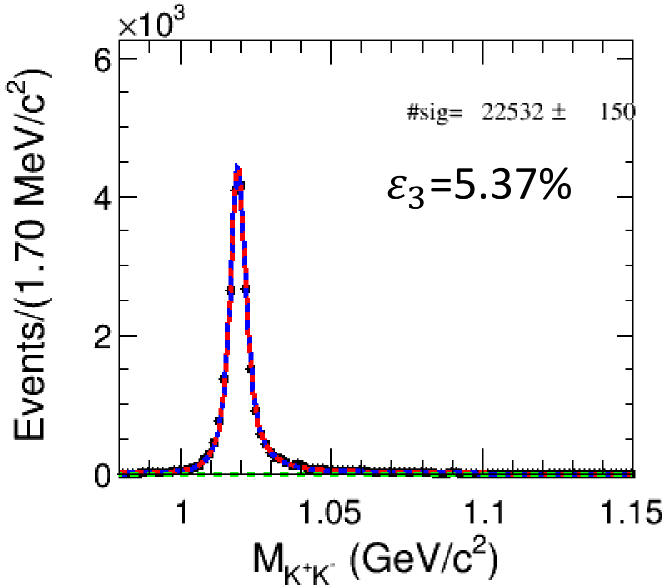
weighted efficiency = $\frac{a_1\times\varepsilon_1+a_2\times\varepsilon_2+a_3\times\varepsilon_3}{a_1+a_2+a_3}$ =(5.83±0.21)%



②



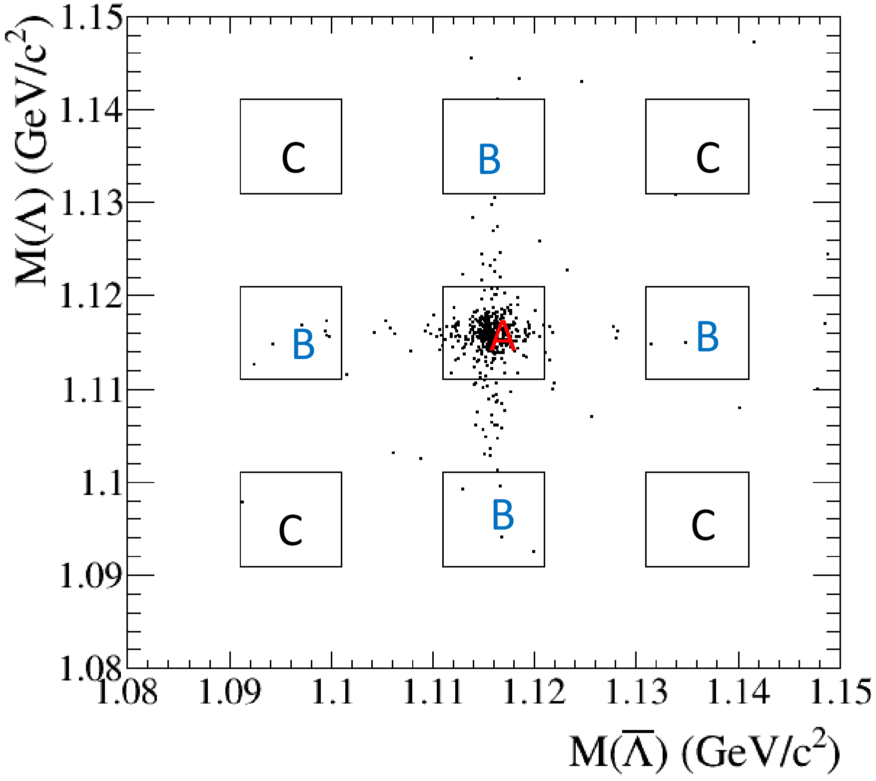
③

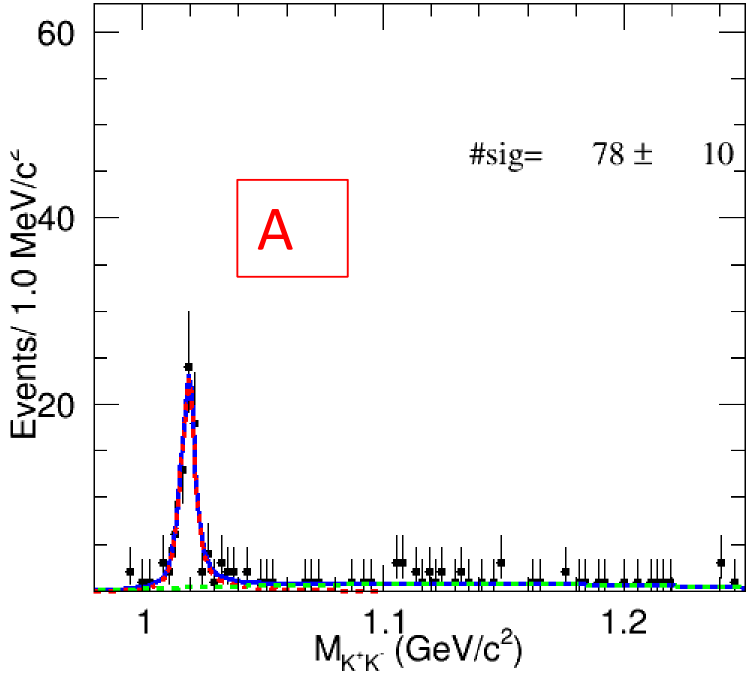


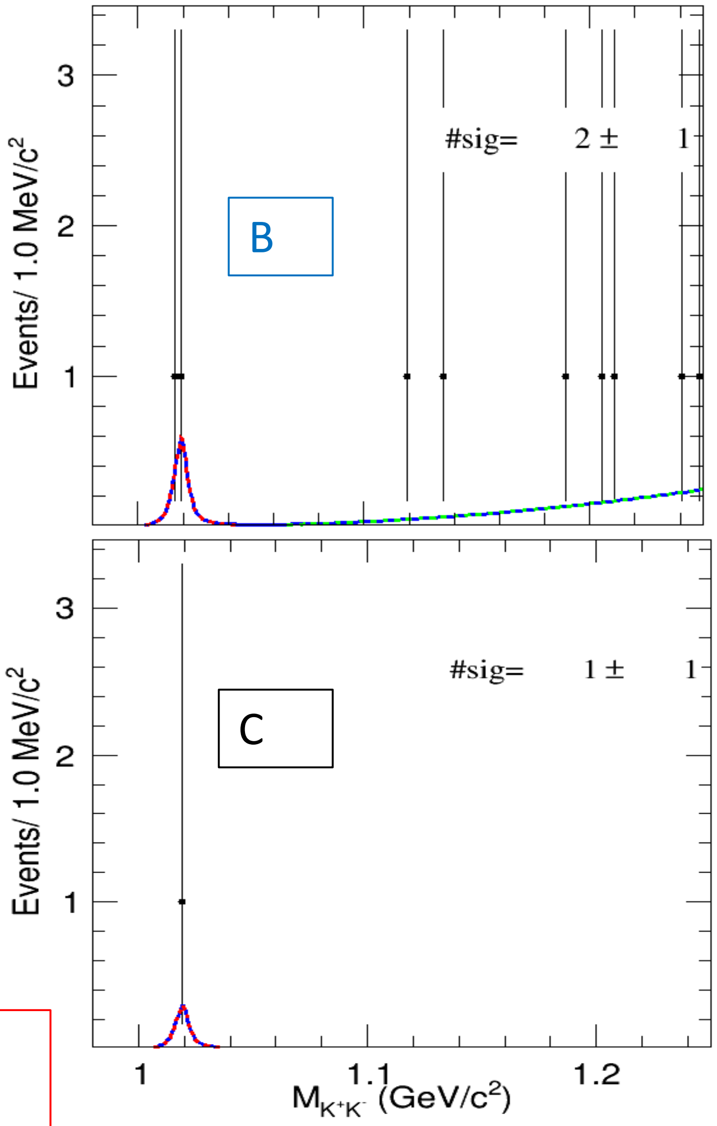
Signal Yield

Fitting method: 1-D unbined-maximum-likelihood fit on M(K^+K^-):

MC Shape⊗ Guassian +2nd Chebychev







$$N_{sig} = N_{sig}^{A} - \frac{1}{2} N_{sig}^{B} + \frac{1}{4} N_{sig}^{C} = (77.5 \pm 9.8);$$

$$B(\psi' \to \phi\Lambda\bar{\Lambda}) = \frac{N_{sig}}{N_{\psi'} \cdot \varepsilon \cdot B(\phi \to K^+K^-) \cdot B(\Lambda \to p\pi^-) \cdot B(\bar{\Lambda} \to \bar{p}\,\pi^+)} = (1.47 \pm 0.19) \times 10^{-6}.$$

Systematic uncertainty

From Event Selection:

tracking	6%
PID	4%
Λ construction	1%
4c fit	
veto $\Omega^{-}\bar{\Omega}^{+}$	0.1%

From Fitting:

Fit	
Branch of Lambda and phi	1.5%
number of $\psi(3686)$ events.	0.6%
MC model	3%

System uncertainty from MC Model

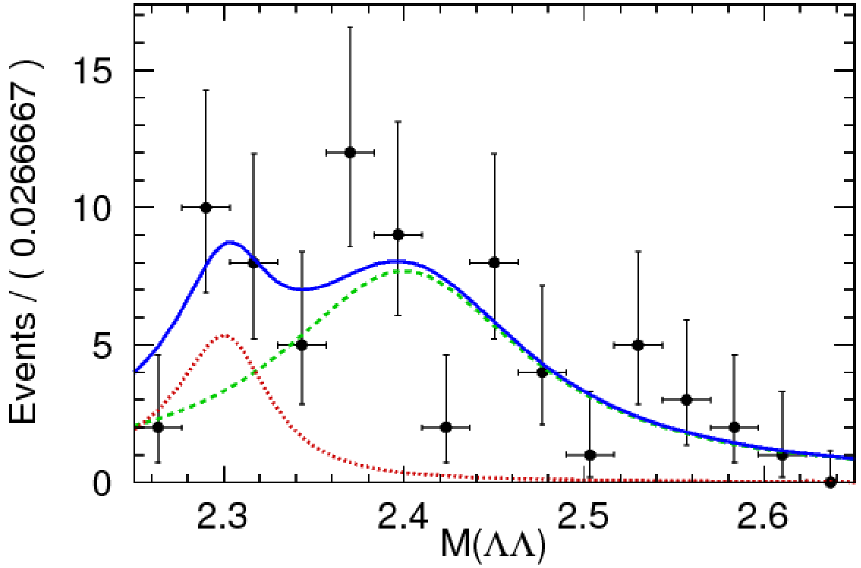
Use another model to get the efficiencies with :

① $\psi' \to \phi f_2(2340), f_2(2340) \to \Lambda\bar{\Lambda}, \phi \to K^+K^-$

② $\psi' \to \phi X, \phi X, \to \Lambda\bar{\Lambda}, \phi \to K^+K^-$

weighted efficiency = $\frac{a_1\times\varepsilon_1+a_2\times\varepsilon_2}{a_1+a_2}$ =(5.98±0.15)%

So the System uncertainty from MC Model is : $\frac{\varepsilon_{modle1}-\varepsilon_{model2}}{\varepsilon_{modle1}}$= 2.58±0.17%



Parameters	$f_2(2340)$	X
Lineshape	BW	BW
Mass	2340(fixed)	2470 ± 36
Width	180(fixed)	280 ± 15
a_i (the number of events)	15 ± 8	57 ± 10

Systematic uncertainty of Lambda construction

$\|\cos\theta\|$	$\epsilon_{data}(\%)$			
	P (GeV/c)			
	(0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.15)	8.88 ± 0.27	29.61 ± 0.42	36.23 ± 0.46	40.55 ± 0.66
(0.15, 0.30)	8.12 ± 0.26	28.92 ± 0.41	35.89 ± 0.45	40.87 ± 0.66
(0.30, 0.50)	8.41 ± 0.23	28.43 ± 0.36	35.22 ± 0.39	39.47 ± 0.56
(0.50, 0.70)	7.74 ± 0.22	25.46 ± 0.33	33.01 ± 0.38	36.65 ± 0.55
(0.70, 1.00)	4.40 ± 0.14	13.99 ± 0.20	19.12 ± 0.23	23.89 ± 0.37
$\|\cos\theta\|$	N_{signal}			
	P (GeV/c)			
	(0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 1.0)
(0.00, 0.15)	5.4 ± 3.6	45.9 ± 8.2	66.3 ± 8.7	37.1 ± 7.5
(0.15, 0.30)	2.3 ± 3.9	40.6 ± 7.7	65.4 ± 8.6	31.5 ± 7.1
(0.30, 0.50)	13.6 ± 4.4	43.8 ± 8.4	58.1 ± 9.0	55.7 ± 8.8
(0.50, 0.70)	1.0 ± 3.7	51.9 ± 8.9	53.6 ± 8.1	34.9 ± 6.9
(0.70, 1.00)	4.7 ± 3.5	19.1 ± 6.5	41.6 ± 7.8	39.8 ± 7.5

Cited from Xiaodong

We divide the control sample of $J/\psi \rightarrow pK^{+}\Lambda$ into 4×5 bins to obtain the corresponding reconstruction efficiency of Λ, and then divide the data sample and signal MC into the same way to get the average effiencency .

$$\varepsilon^{data} = 24.88\%$$

$$\varepsilon^{mc} = \frac{a_1 \times \varepsilon_1 + a_2 \times \varepsilon_2 + a_3 \times \varepsilon_3}{a_1 + a_2 + a_3} = 25.13\%$$

Uncertainty: $\frac{\varepsilon^{data} - \varepsilon^{mc}}{\varepsilon^{data}} = 1.0\%$

Summary and next to do

- Based on $(448.1 \pm 2.9) \times 10^{6}\ \psi'$ events, the absolute branching fraction of the decay of $\boldsymbol{\psi'} \rightarrow \phi\Lambda\bar{\Lambda}$ is measured to be :

$$B(\psi' \rightarrow \phi\Lambda\bar{\Lambda}) = (1.47 \pm 0.19) \times 10^{-6}$$

- Next is to finish the system uncertainty and finish the memo.

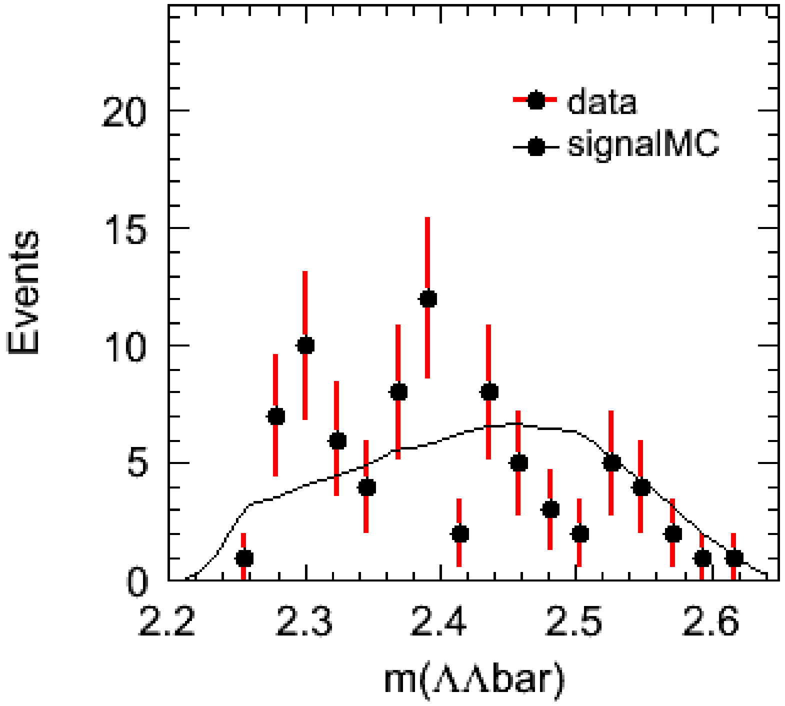
Thank you !

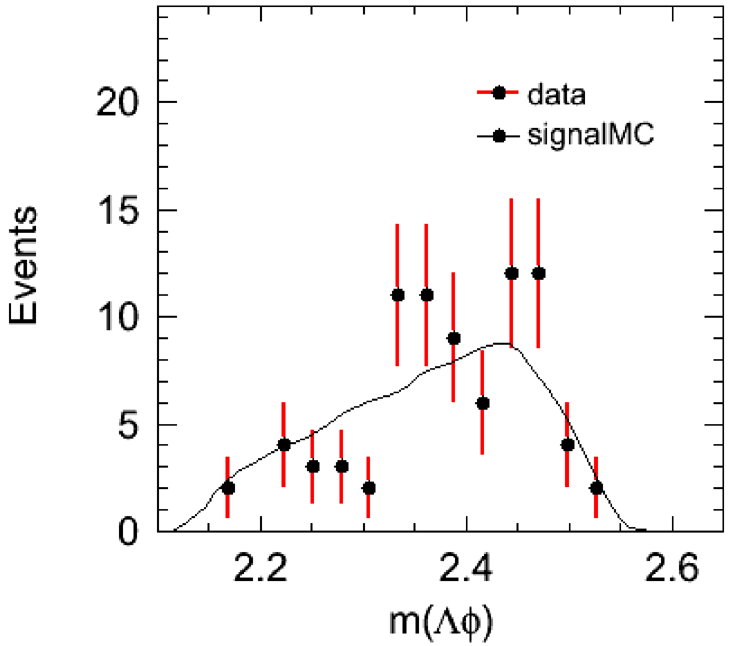
Back up

If there is some resonance for $\Lambda\bar{\Lambda}$, the state $may\ be$:

candidates

- 0^{-+} L =1,3,…
- 0^{++} L =0,2,…
- 2^{-+} L=1,3….
- 2^{++} $L = 0{,}2\ \ldots$ f_2(2340)





Signal MC :
$\psi' \to \phi\Lambda\bar{\Lambda}$ PHSP

The Generator of Singal MC samples:

1. $\psi' \rightarrow \phi f_2(2340)$ AngSam 1 c1 c2 ;
   $f_2(2340) \rightarrow \Lambda\bar{\Lambda}$ PHSP;
   $\phi \rightarrow K^+ K^-$ VSS;
   $\Lambda \rightarrow p\,\pi^-$ HypWK;
   $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ HypWK;

2. $\psi' \rightarrow \phi X\,(\boldsymbol{\Lambda\bar{\Lambda}})$ AngSam 1 c11 c22 ;
   $X\,(\boldsymbol{\Lambda\bar{\Lambda}}) \rightarrow \Lambda\bar{\Lambda}$ PHSP;
   $\phi \rightarrow K^+ K^-$ VSS;
   $\Lambda \rightarrow p\,\pi^-$ HypWK;
   $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ HypWK;

3. $\psi' \rightarrow \phi\Lambda\bar{\Lambda}$ PHSP;
   $\phi \rightarrow K^+ K^-$ VSS;
   $\Lambda \rightarrow p\,\pi^-$ HypWK;
   $\bar{\Lambda} \rightarrow \bar{p}\pi^+$ HypWK;

c1,c2,c11,c22 are obtained from fitting $\cos\theta_\phi$ with different range of $M(\Lambda\bar{\Lambda})$ in Data.

The mass and width of $X\,(\boldsymbol{\Lambda\bar{\Lambda}})$ are obtained from fitting $M(\Lambda\bar{\Lambda})$ in Data.

Two resonance candidates:

X(2340)

M: 2340 ± 20

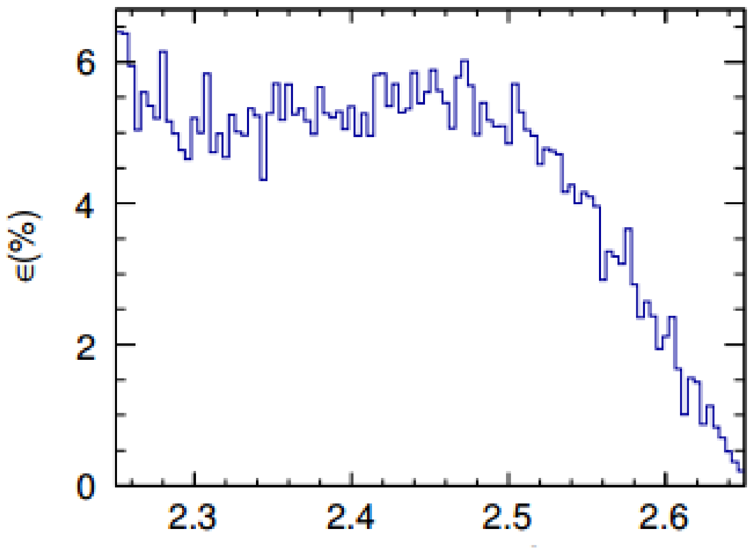
Width: 180 ± 60

Assume: J = 2

X(2450):

X Mass, width: float

X Assume: J = 2



M($\Lambda\bar{\Lambda}$) depended efficiency

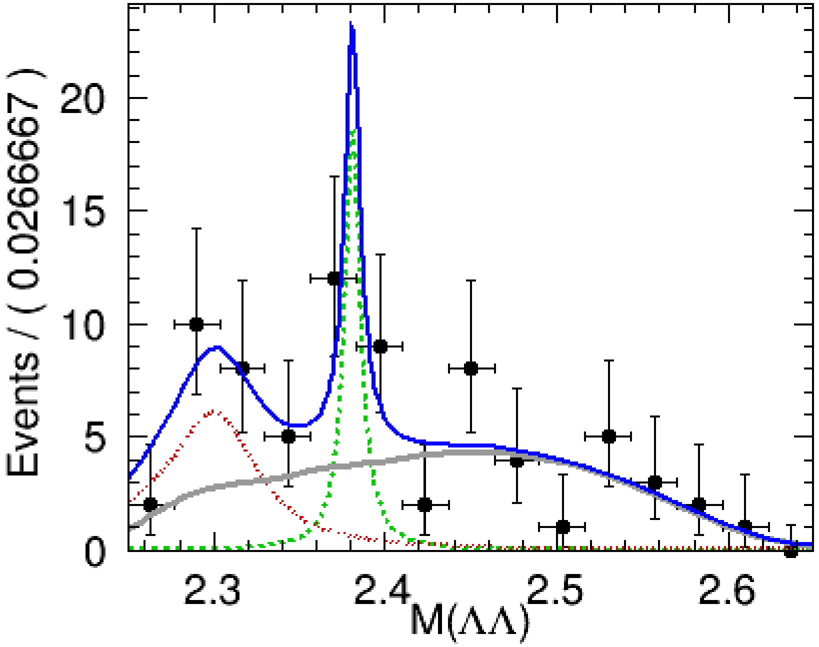
Line Shipe(resonance): $T_R = \frac{1}{(m_R^2 - m_{AB}^2) - i m_R \Gamma_R(m_{AB})}$

where the mass dependent width is

$$\Gamma_R(m_{AB}) = \Gamma_R\left[B_J^R(q, q_0, d_R)\right]^2 \frac{m_R}{m_{AB}}\left(\frac{q}{q_0}\right)^2$$

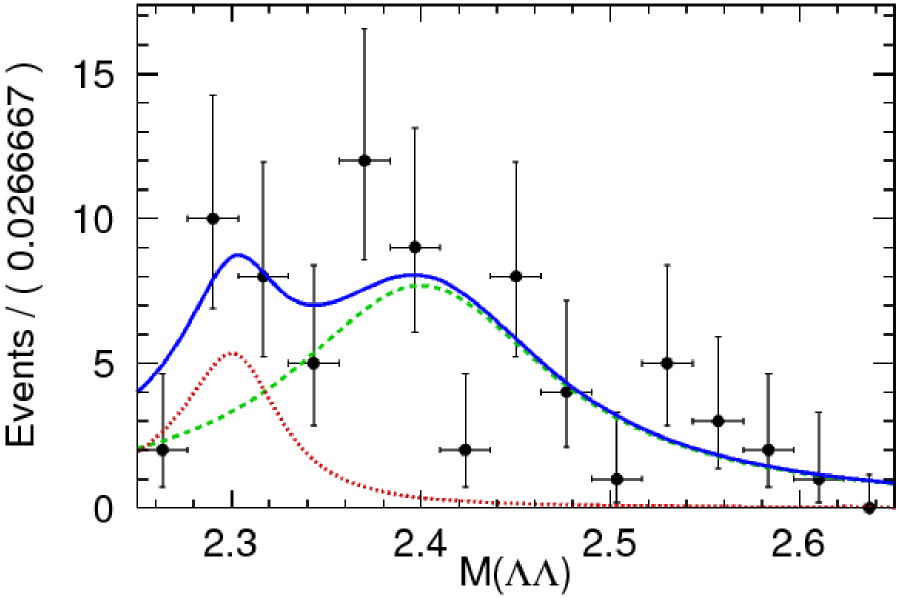
Fitting result

Model 1

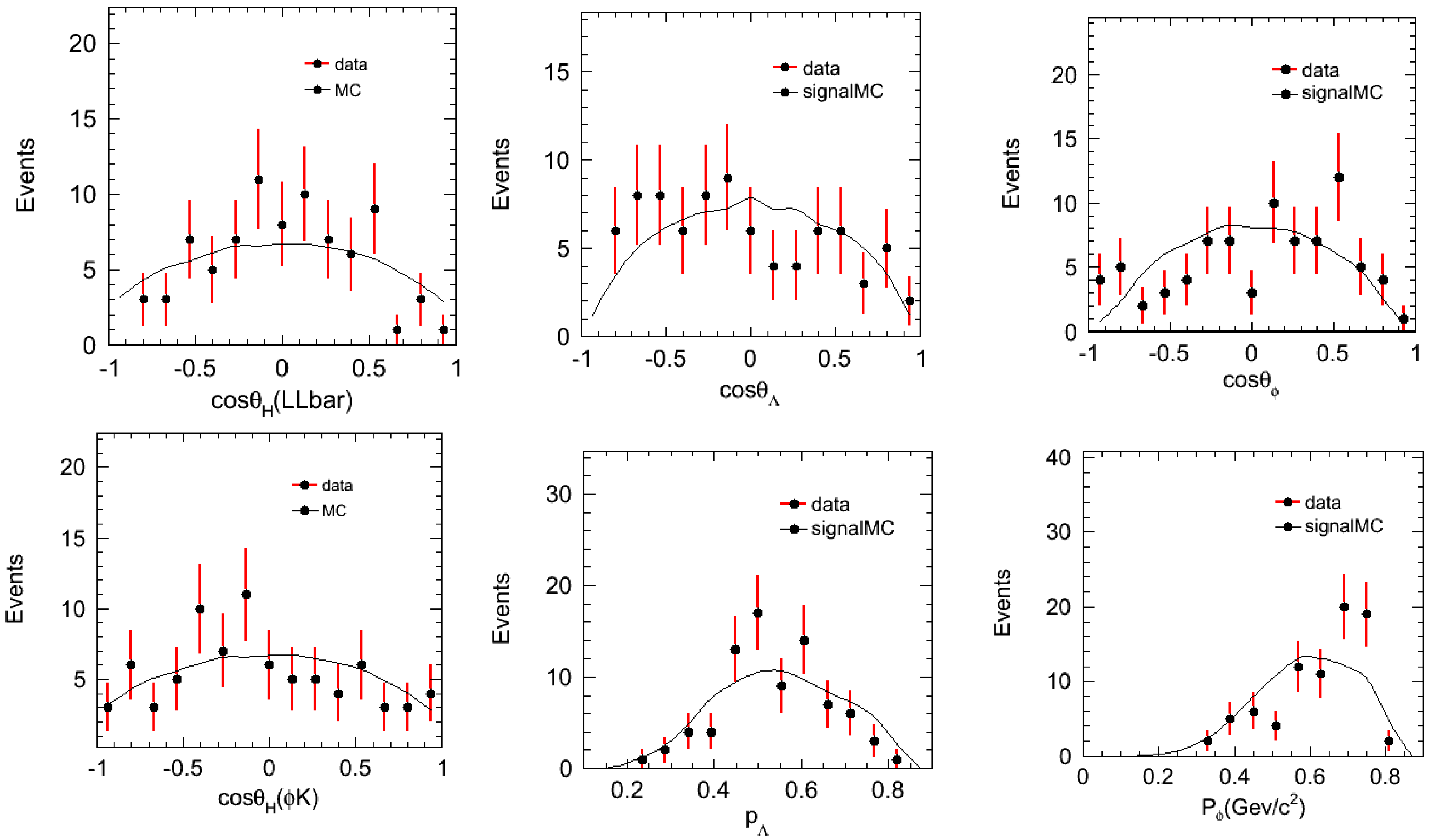


mass: 2380± 30 MeV
X width: 11± 8 MeV
X # X(2340): 17 ± 6
X # X(2380): 11± 5 new resonanc
PhiLLbar :42 ±9

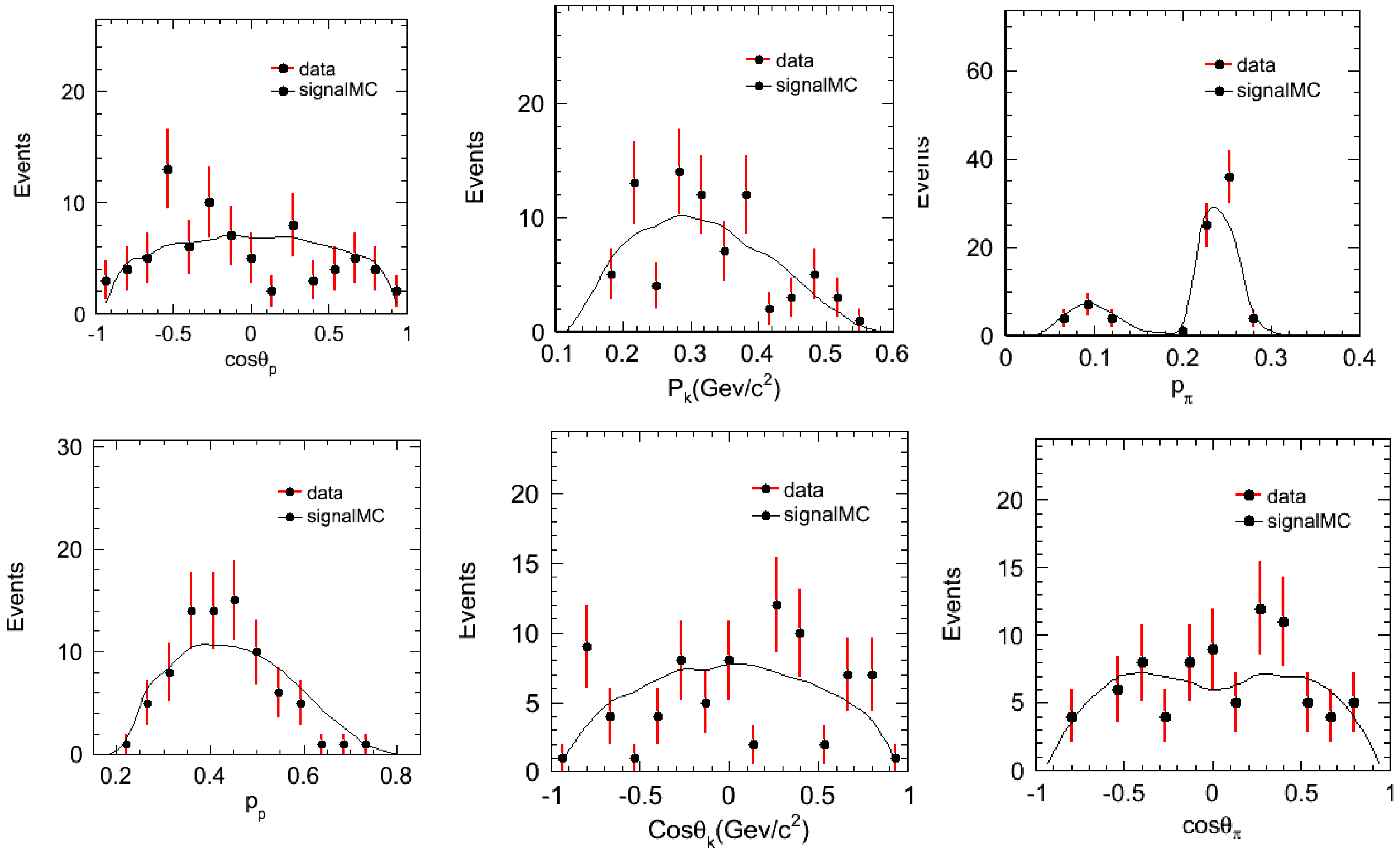
Model 2



mass: 2470 ± 36 MeV
X width: 280 ± 15 MeV
X # X(2340): 15 ± 8
X # X(2470): 57 ± 10 new resonanc



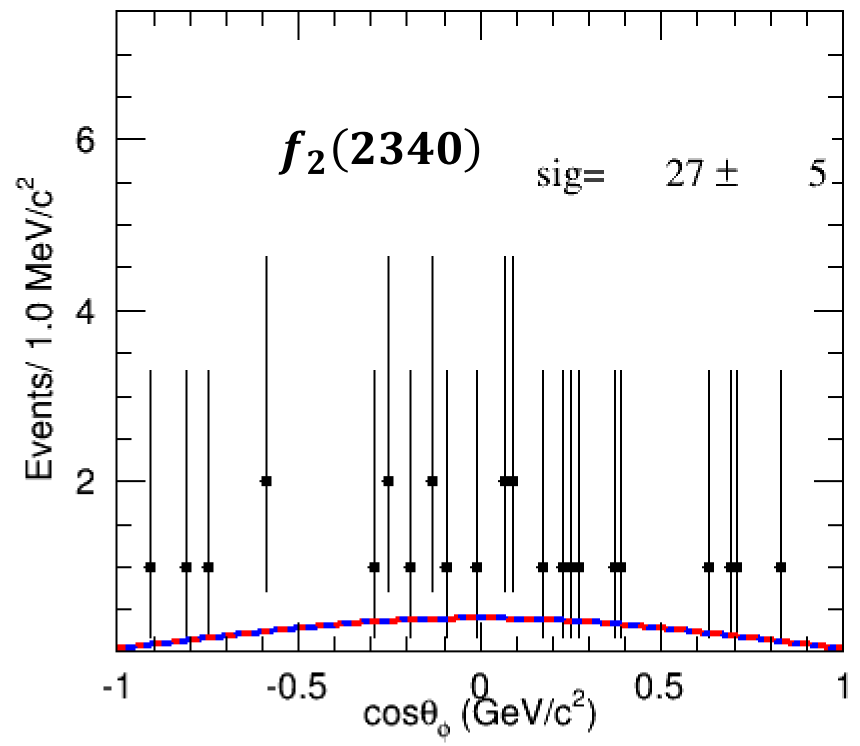
Events
cosθ_H(LLbar)
data
MC
cosθ_Λ
signalMC
cosθ_φ
cosθ_H(φK)
p_Λ
P_φ(Gev/c^2)



data
signalMC
Events
cosθp
-1
-0.5
0
0.5
1
0
10
20
data
signalMC
Events
Pk(Gev/c2)
0.1
0.2
0.3
0.4
0.5
0.6
0
10
20
data
signalMC
pπ
0
0.1
0.2
0.3
0.4
0
20
40
60
data
signalMC
Events
pp
0.2
0.4
0.6
0.8
0
10
20
30
data
signalMC
Events
Cosθk(Gev/c2)
-1
-0.5
0
0.5
1
0
5
10
15
20
data
signalMC
Events
cosθπ
-1
-0.5
0
0.5
1
0
5
10
15
20

Fitting :1+c1 $\times cos\theta^2 + c2 \times cos\theta^4$

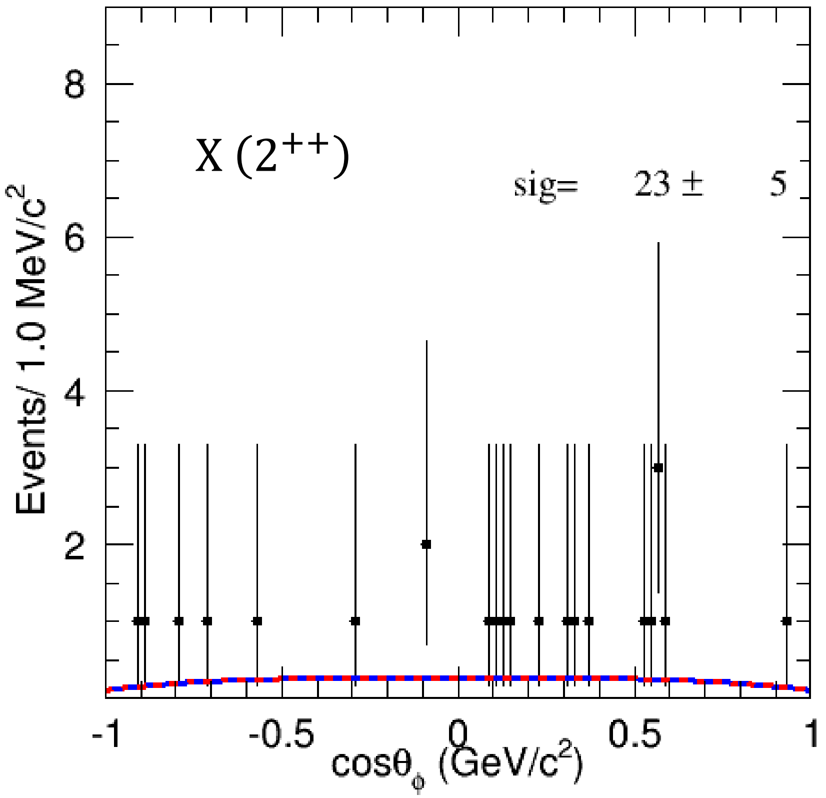
mLLbar~[0,2.2345]



c1=-1.19, c2=0.33

Fitting :1+c11 $\times cos\theta^2 + c22 \times cos\theta^4$

mLLbar~[2.2345,2.42]



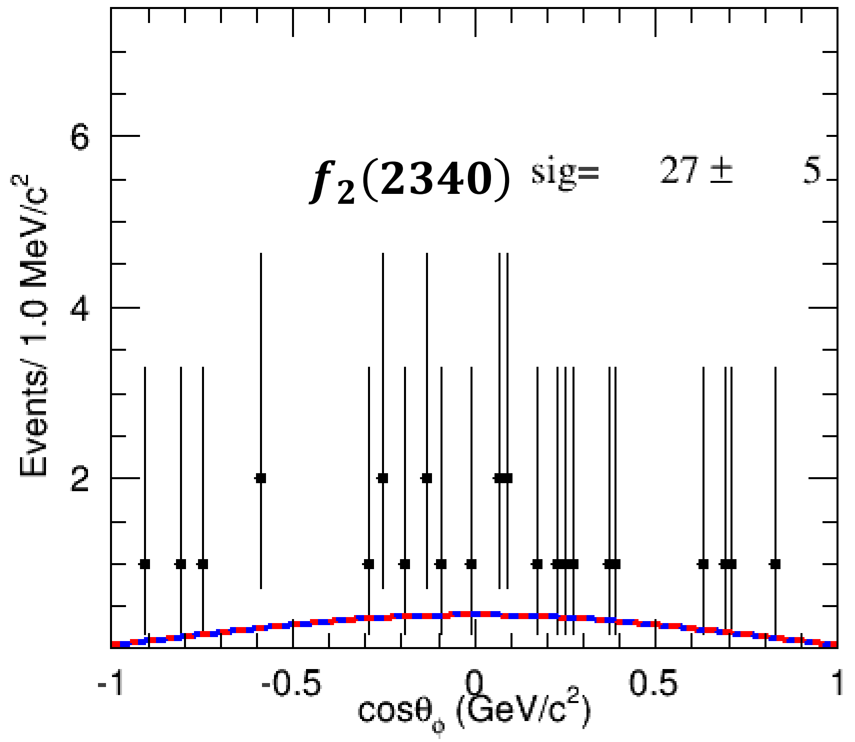
c11=-0.15, c22=-0.46

System uncertainty from MC Model

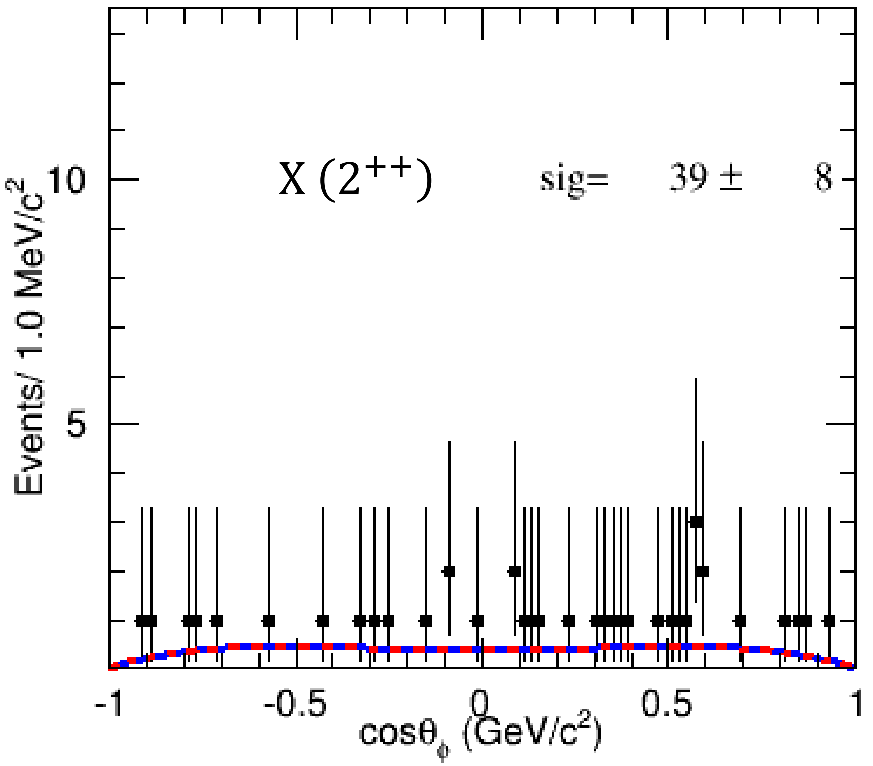
Fitting :1+c1 $\times cos\theta^2 + c2 \times cos\theta^4$

mLLbar~[0,2.2345]

mLLbar~[2.2345,2.5]

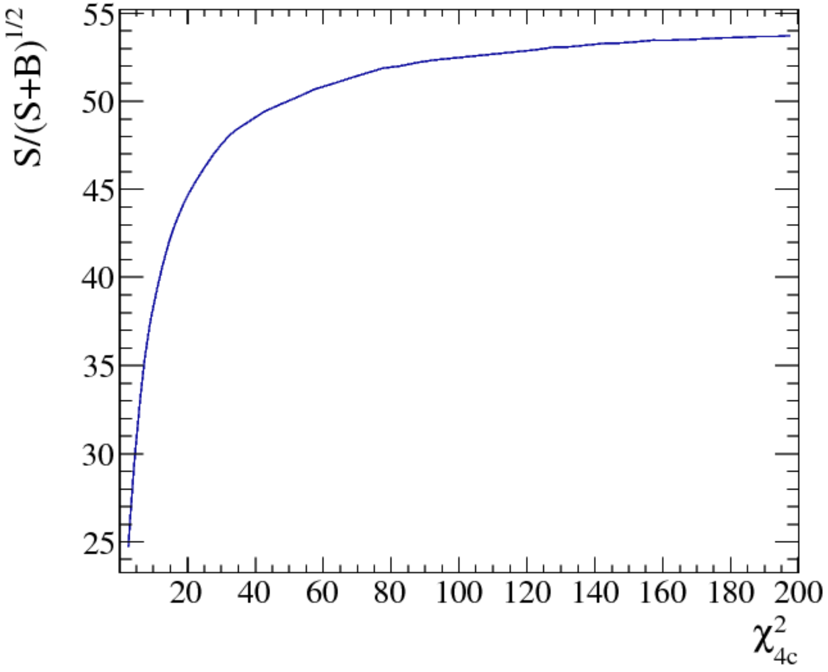


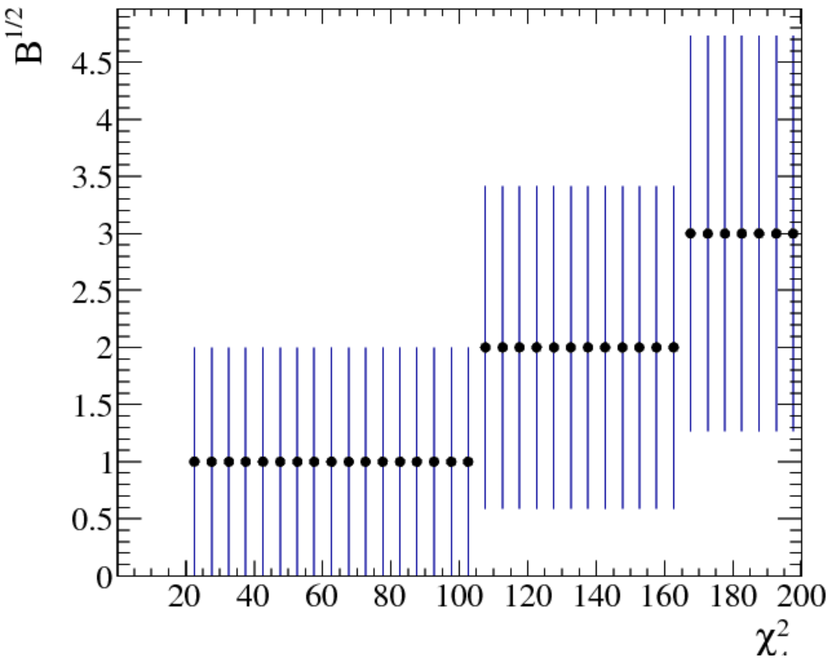
c1=-1.19,c2=0.33

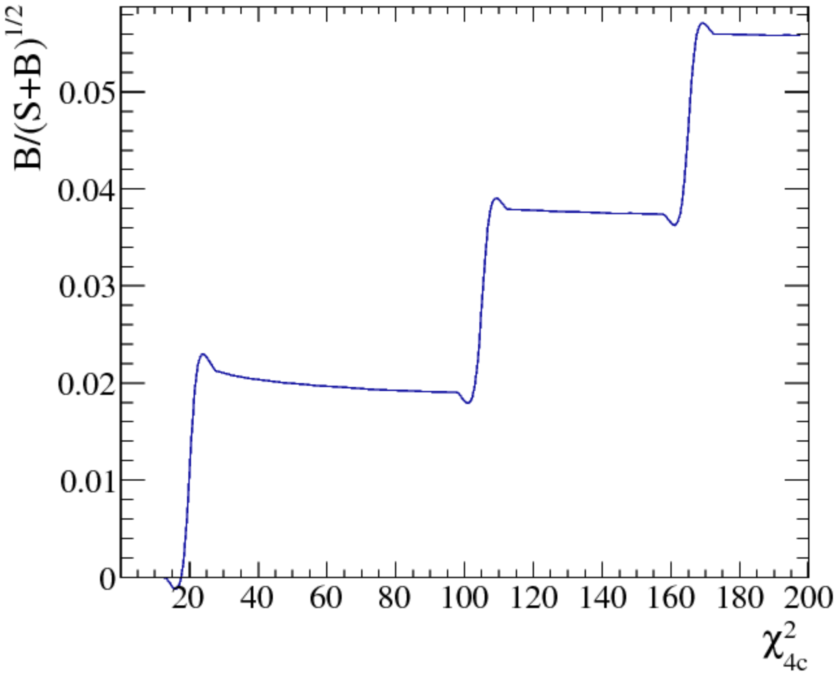


c1=1.26,c2=-2.2

4c optimize







So we still use cut $\chi^{4c} < 200$

Efficiency

The efficiencies are obtained by using signal MC sample with :

① $\psi' \to \phi f_2(2340), f_2(2340) \to \Lambda\bar{\Lambda}, \phi \to K^+K^-$
② $\psi' \to \phi X(2^{++}), X(2^{++}) \to \Lambda\bar{\Lambda}, \phi \to K^+K^-$
③ $\psi' \to \phi\Lambda\bar{\Lambda}, \phi \to K^+K^-$

$$\text{weighted efficiency} = \frac{a_1\times\varepsilon_1 + a_2\times\varepsilon_2 + a_3\times\varepsilon_3}{a_1+a_2+a_3} = (5.83\pm0.21)\%$$

a_1 =17±6
a_2 =11±5
a_3=42±9
Obtained from fitting $M(\Lambda\bar{\Lambda})$

Fitting method: Signal KeysPDf +2nd Chebychev