Study of $\psi(3686) \to \Lambda\bar{\Lambda}\phi$ decay

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Outline

- Motivation
- Analysis method
- Data set
- Event selection
- Fitting result
- Systematic uncertainty
- Summary and next to do

Motivation

1. The branching fraction of $\boldsymbol{\psi}(3686) \to \Lambda\bar{\Lambda}\phi$ has not been measured in PDG.
2. Search for new intermediated states in $\Lambda\bar{\Lambda}$ and $\bar{\Lambda}\phi$.

Analysis Method

1. Partial reconstruction:
   only one Λ or one $\bar{\Lambda}$.

2. Fit the recoil mass of $\phi\Lambda$ to obtain signal yield.

Data set

- BOSS version: 6.6.4.p03
- Data: $(448.1\pm2.9)\times10^6$ $\psi(3686)$ events (2009+2012)[1].
- Inclusive MC: 5.06×10^8 (2009+2012), study backgrounds.
- Signal MC: 6.84×10^6 events, study the efficiency.

$\psi(3686)\to\phi\Lambda\bar{\Lambda}$ (PHSP) ;
$\phi\to K^+K^-$(VSS);
$\Lambda\to p\pi^-$(PHSP);
$\bar{\Lambda}\to\bar{p}\pi^+$(PHSP).

$\psi(3686)\to\phi\Lambda\bar{\Lambda}$ (PHSP) ;
$\phi\to K^+K^-$(VSS);
$\Lambda\to p\pi^+$(PHSP);
$\bar{\Lambda}\to$ non $\bar{p}\pi^+$.

$\psi(3686)\to\phi\Lambda\bar{\Lambda}$ (PHSP) ;
$\phi\to K^+K^-$(VSS);
$\Lambda\to$ non $p\,\pi^-$;
$\bar{\Lambda}\to\bar{p}\pi^+$(PHSP).

[1] M. Ablikim et al. (BESIII Collaboration), Chin. Phys. C **42**, 023001 (2018).

Event Selection

- Good charged tracks:

  $|V_z|$ < 20 cm, |cos θ| < 0.93;

  $N_{\mathrm{Good}} \geq 4$.

- PID (dE/dx and TOF):

  For (anti-) proton: $prob(p) > prob(K), prob(p) > prob(\pi)$;

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

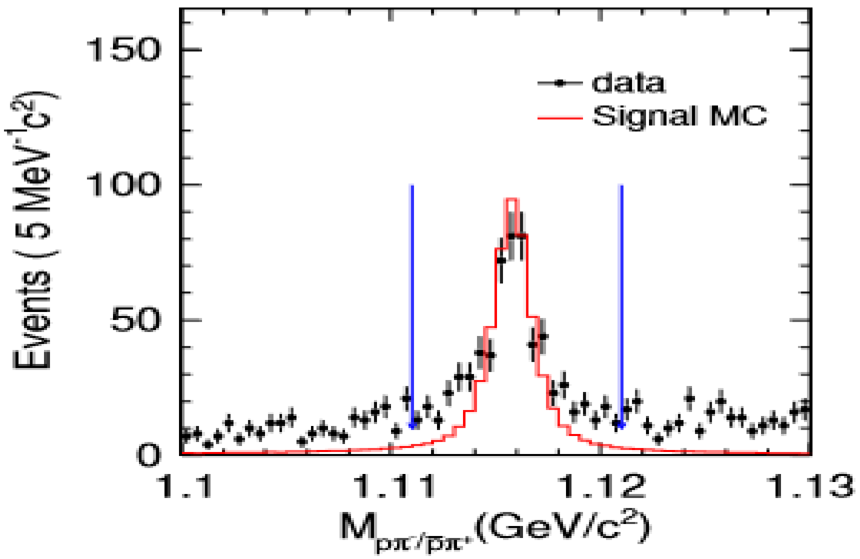
- $N_{K^+} = 1$, $N_{K^-} = 1$.
- Vertex fit on K^+K^-, but no requirement on χ^2_{ver}.
- $\Lambda(\bar{\Lambda})$ candidate:

Second vertex fit; If there are more than one $\Lambda(\bar{\Lambda})$ candidates, select the best candidate with the smallest χ^2_{sec}.

Further Selection

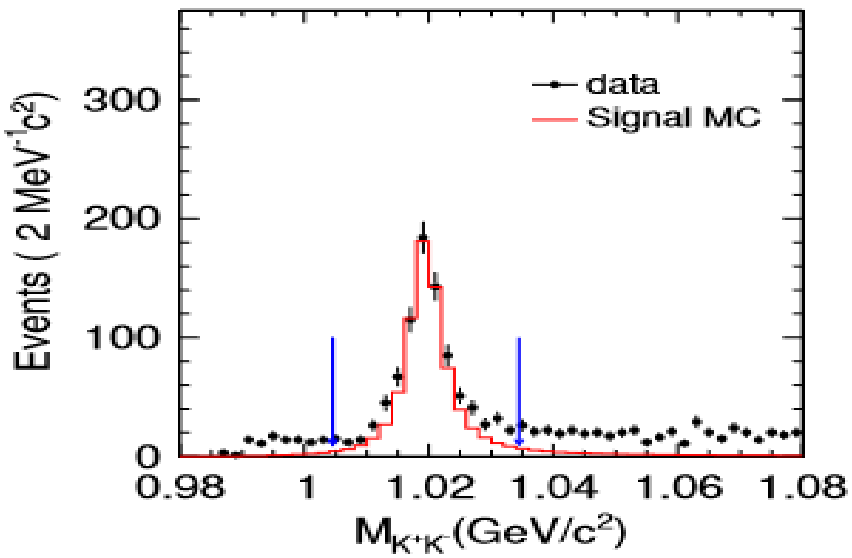
$\Lambda(\bar{\Lambda})$ candidate:

$M_{p\pi^-(\bar{p}\pi^+)}$: $[1.111, 1.121]\mathrm{GeV}/c^2$



ϕ candidate:

$M_{K^+K^-}$: $[1.005, 1.035]$ GeV/c^2



Background study

- Peaking background
- Non-peaking background

Peaking background

veto *Ω* background

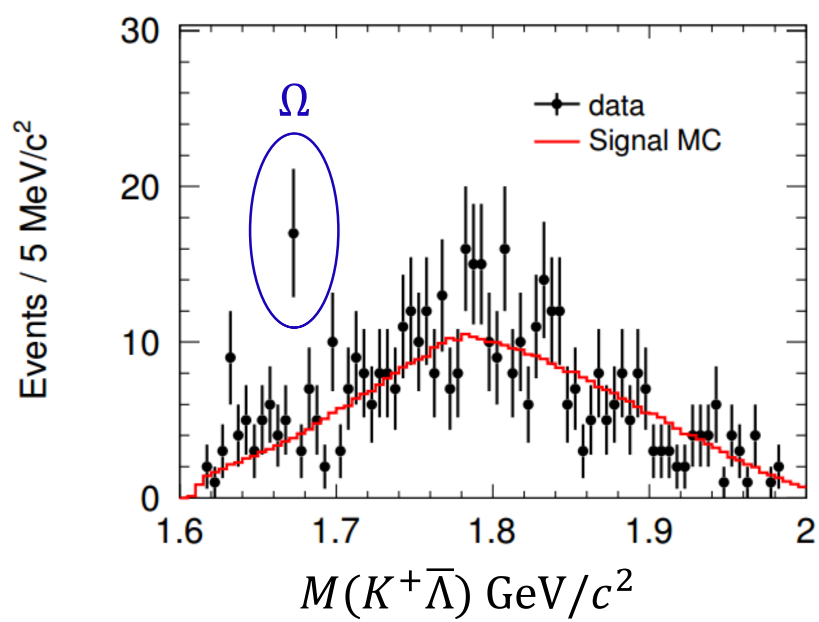
The observed events from inclusive MC sample after above event selection criteria:

No.	Decay mode	final states	nEvt
0	$\psi' \to \phi\Lambda\bar{\Lambda}, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{p}\pi^+$	$p\,\pi^- K^+ K^- \bar{p}\pi^+$	9537
1	$\psi' \to \phi\Lambda\bar{\Lambda}, \Lambda \to p\pi^-, \bar{\Lambda} \to \bar{n}\pi^0$	$p\,\pi^- K^+ K^- \bar{n}\pi^0$	3589
2	$\psi' \to \phi\Lambda\bar{\Lambda}, \Lambda \to n\pi^0, \bar{\Lambda} \to \bar{p}\pi^+$	$n\,\pi^0 K^+ K^- \bar{p}\pi^+$	3515
3	$\psi' \to \Omega^-\bar{\Omega}^+, \Omega^- \to \Lambda K^-$	$p\,\pi^- K^+ K^- \bar{p}\pi^+$	12
4	$\psi' \to \gamma\chi_{c1}, \chi_{c1} \to \Lambda\bar{\Lambda}\phi$	$p\,\pi^- K^+ K^- \bar{p}\pi^+\gamma$	1

Suppress Ω background:

$$|M(K^+\bar{\Lambda}) - m(\bar{\Omega}^+)| > 0.01\ \mathrm{GeV/c^2}$$

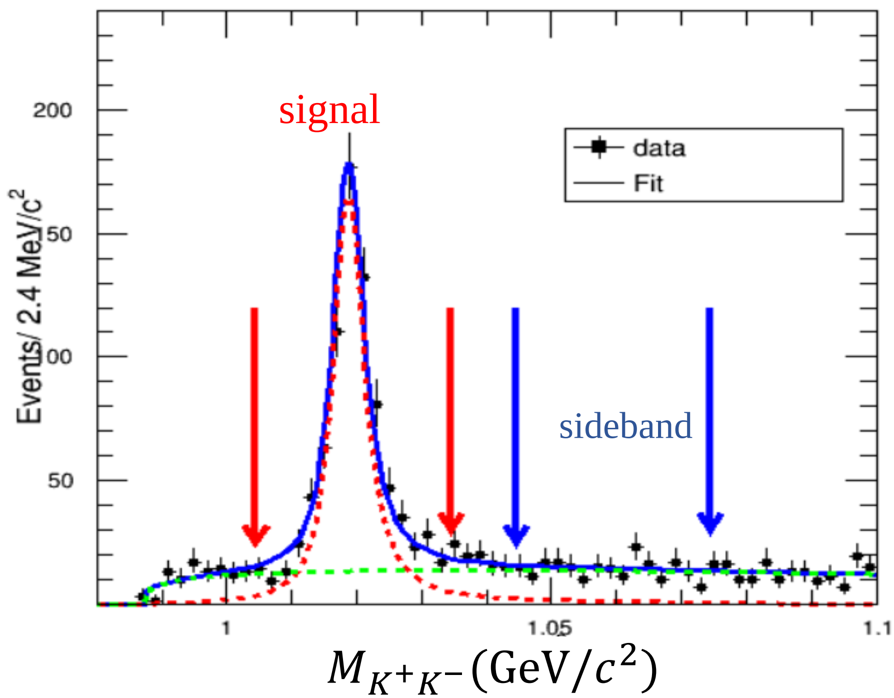
$$|M(K^-\Lambda) - m(\Omega^-)| > 0.01\ \mathrm{GeV/c^2}$$



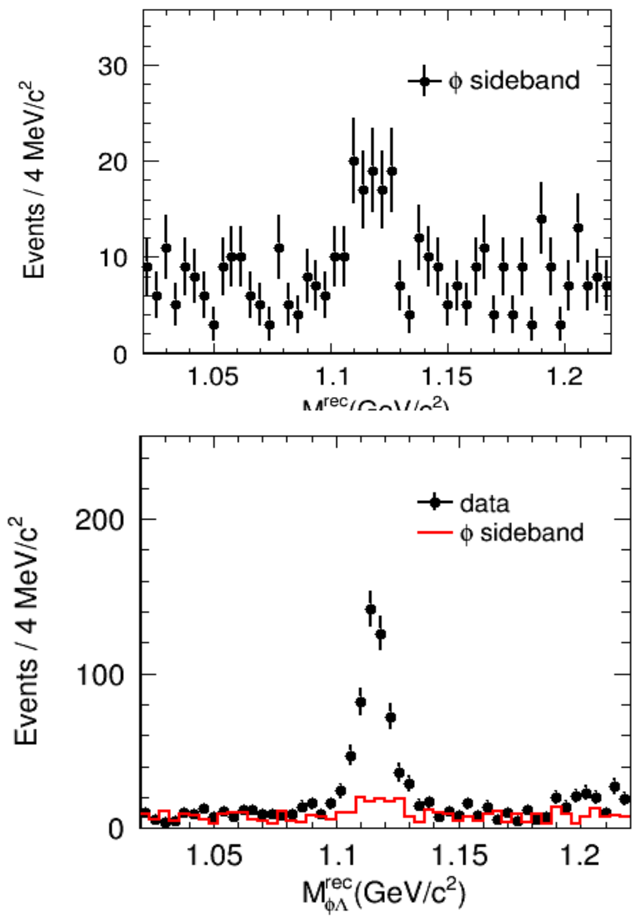
Peaking background

The events in the ϕ sideband region:

$M_{K^+K^-}$: $[1.045, 1.075]\ \mathrm{GeV}/c^2$



Non-ϕ background

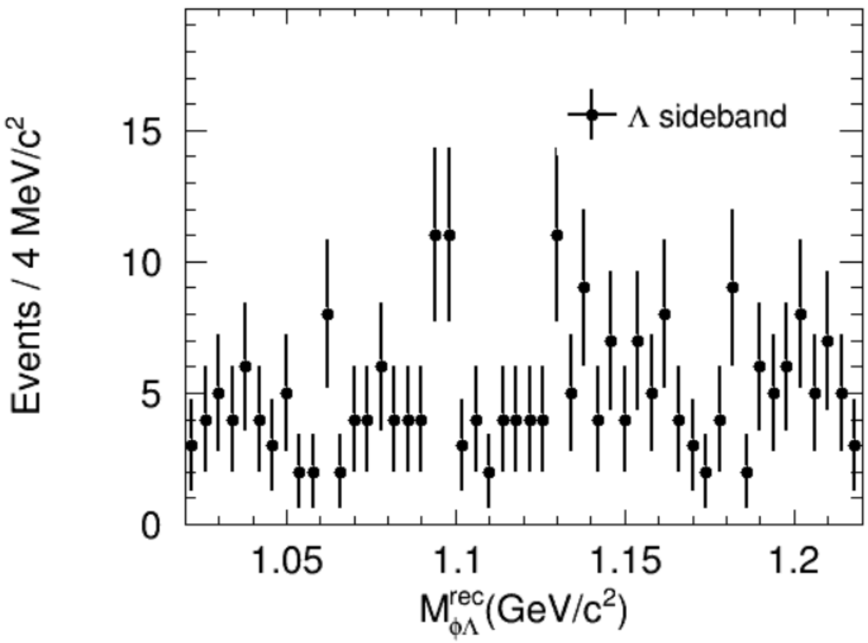


The normalization factor $f_\phi = 0.988$.

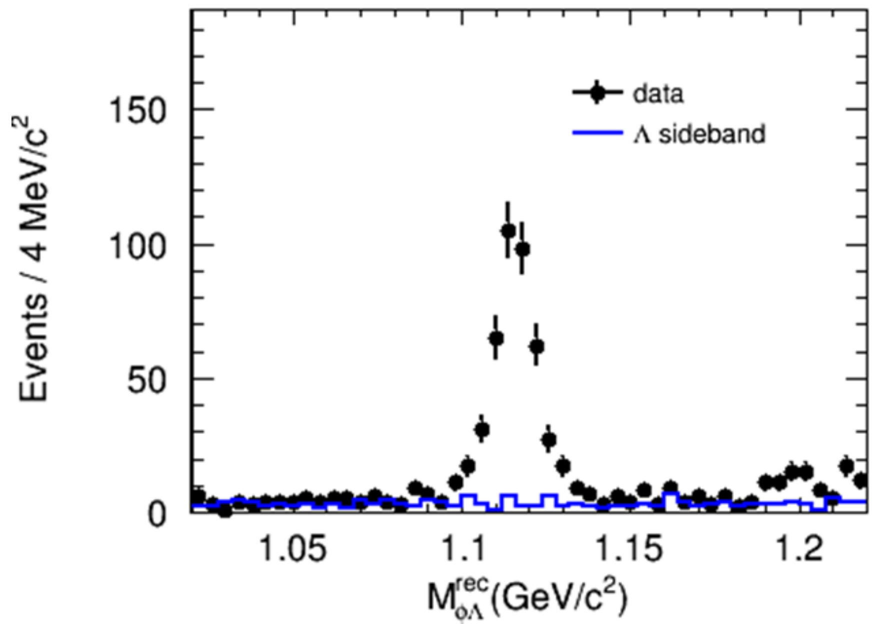
Non-peaking background

The events in the Λ sideband region:

$$M_{p\pi^-(\bar{p}\pi^+)}:\ [1.091, 1.101]\ \text{U}[1.131, 1.141]\ \text{GeV}/c^2$$



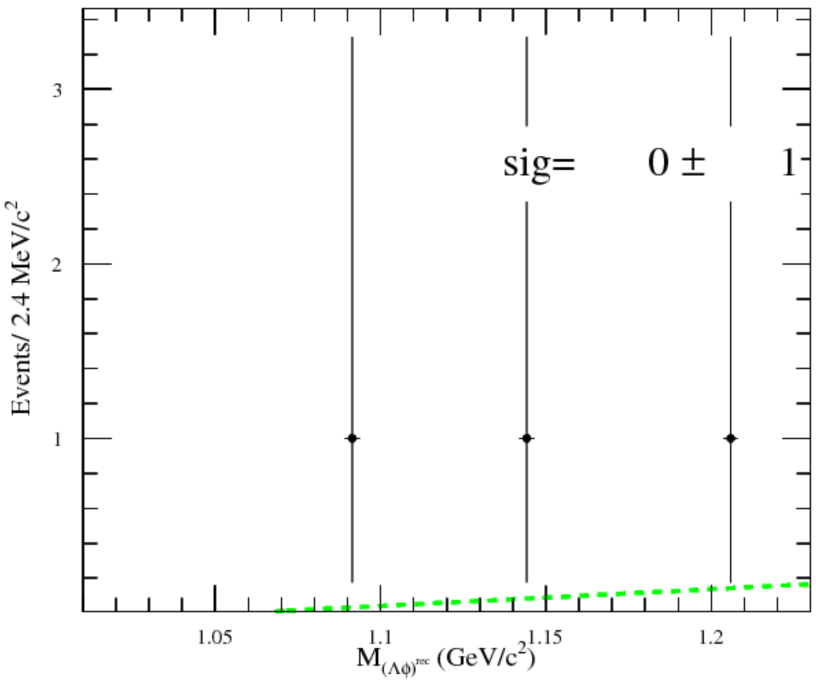
No obvious peaking background.



Non-Λ background

Non-peaking background

The background from the continum process $e^+e^- \rightarrow \Lambda\bar{\Lambda}\phi$ is studied using the off-resonance samples of 44.49 pb−1 taken at $\sqrt{s}$= 3.650 GeV, No significant signal can be observed here, so we can ignore the continuous contribution .



Cut flow from signal MC

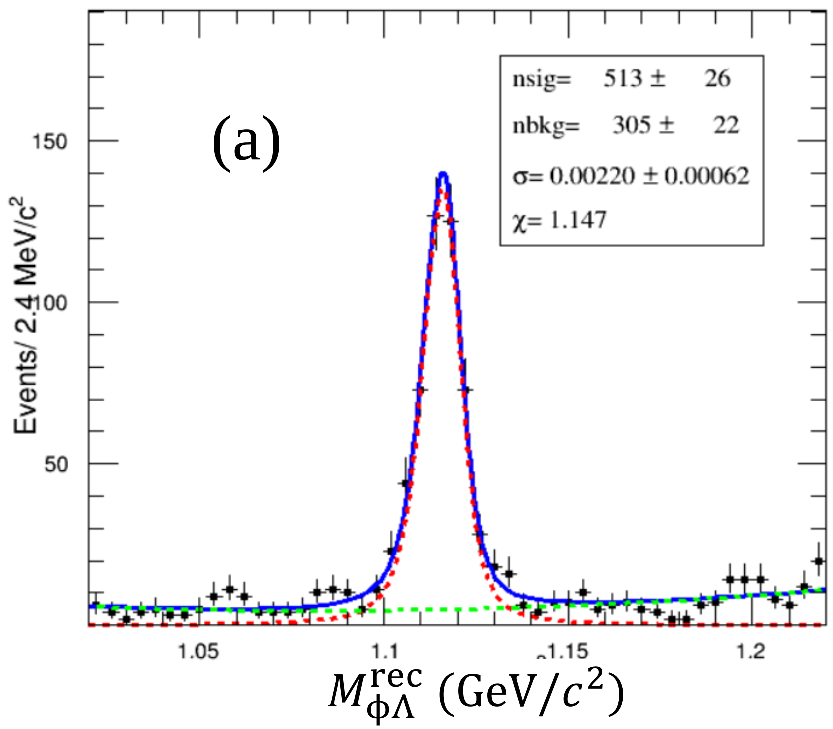
Cut flow	**Number of events (efficiency %)**
Number of generated events	6839520 (100.00)
$N_{\text{good}} \geq 4$ & $\lvert\cos\theta\rvert < 0.93$	4533917 (66.29)
$N_{K^+} = 1, N_{K^-} = 1$	1915065 (27.99)
$\boldsymbol{\Lambda}/\overline{\boldsymbol{\Lambda}}$ Reconstruction	1645201 (24.05)
$\lvert M_{K^+K^-} - m_{\boldsymbol{\phi}}\rvert < 15$ MeV$/c^2$	1515955 (22.16)
$\lvert M_{p\pi} - m_{\boldsymbol{\Lambda}}\rvert < 5$ MeV$/c^2$	1229695 (17.97)
$\chi^2_{\boldsymbol{\Lambda}} < 100$	1216394 (17.78)
$\lvert M_{K^-\Lambda} - m_{\Omega}\rvert > 10$ MeV$/c^2$	1175046 (17.18)
$1.02 < M^{\boldsymbol{rec}}_{\boldsymbol{\phi\Lambda}} < 1.22$ GeV$/c^2$	1171682 (17.12)

Fitting result

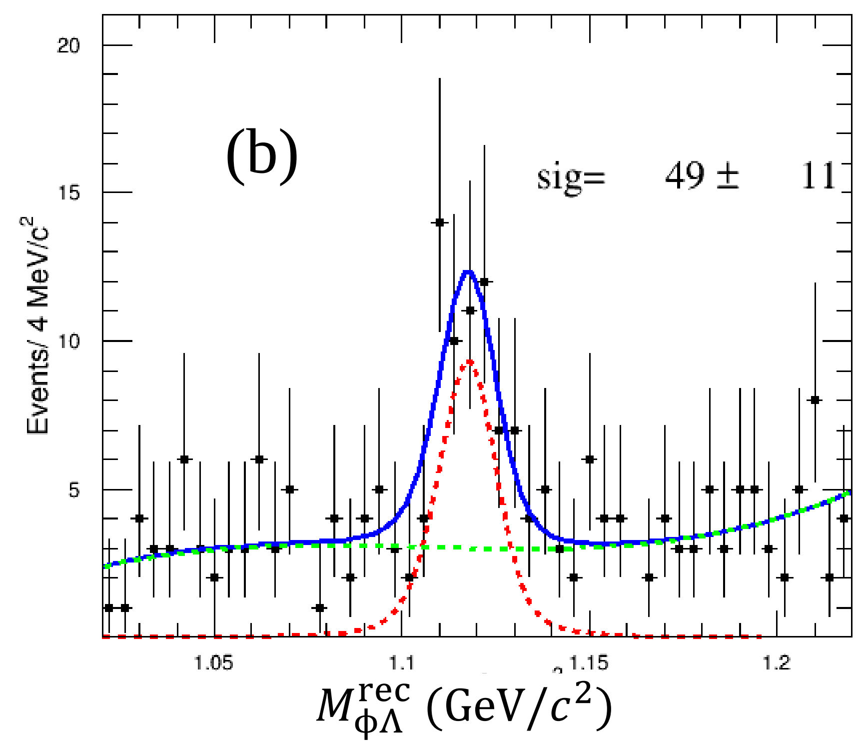
Dots with error bar is from Data

Fitting function: **Signal MC simulation ⊗ a free Gaussian + 2nd Chebychev**

(a). In ϕ and Λ signal regions

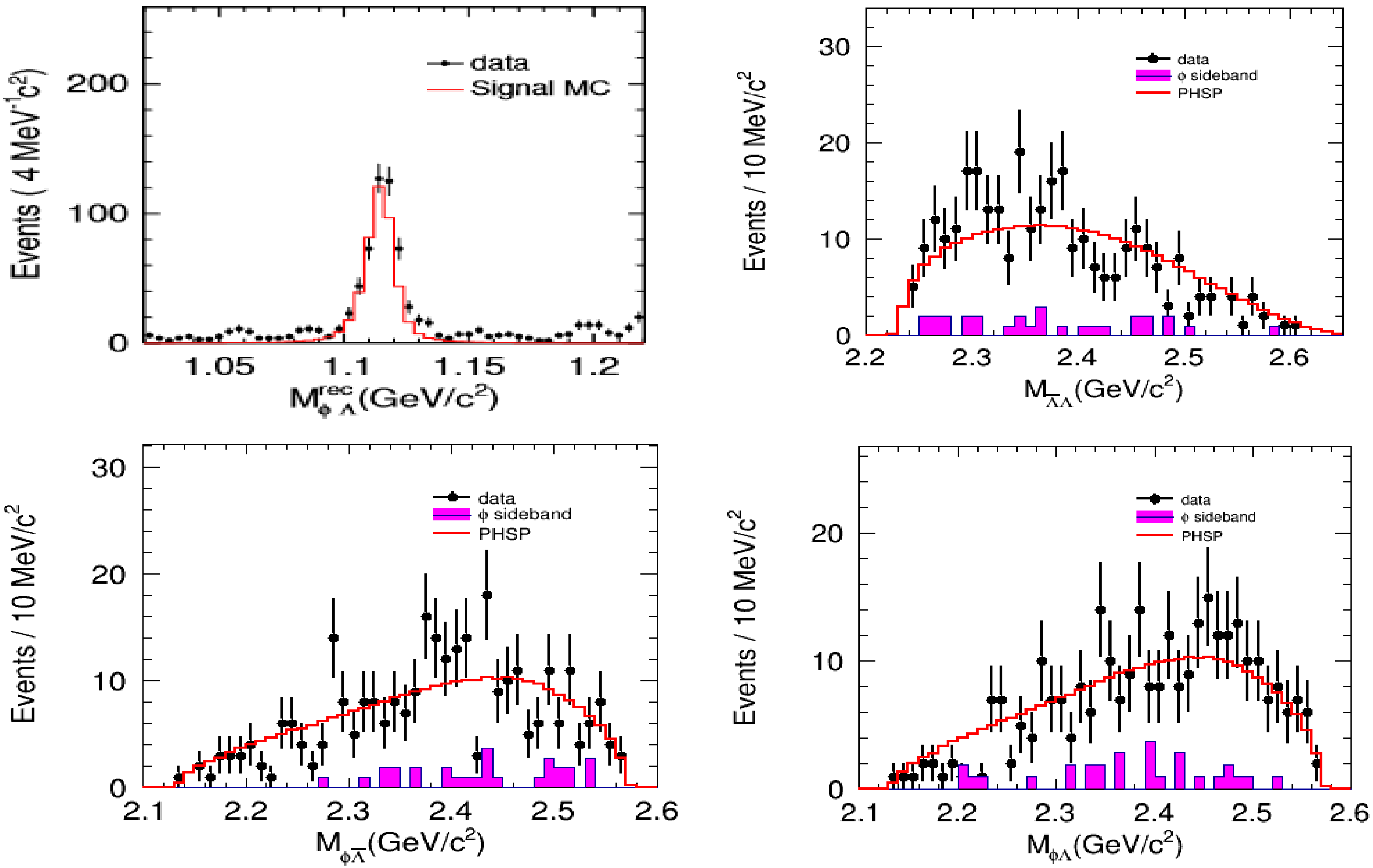


(b). In ϕ sideband region

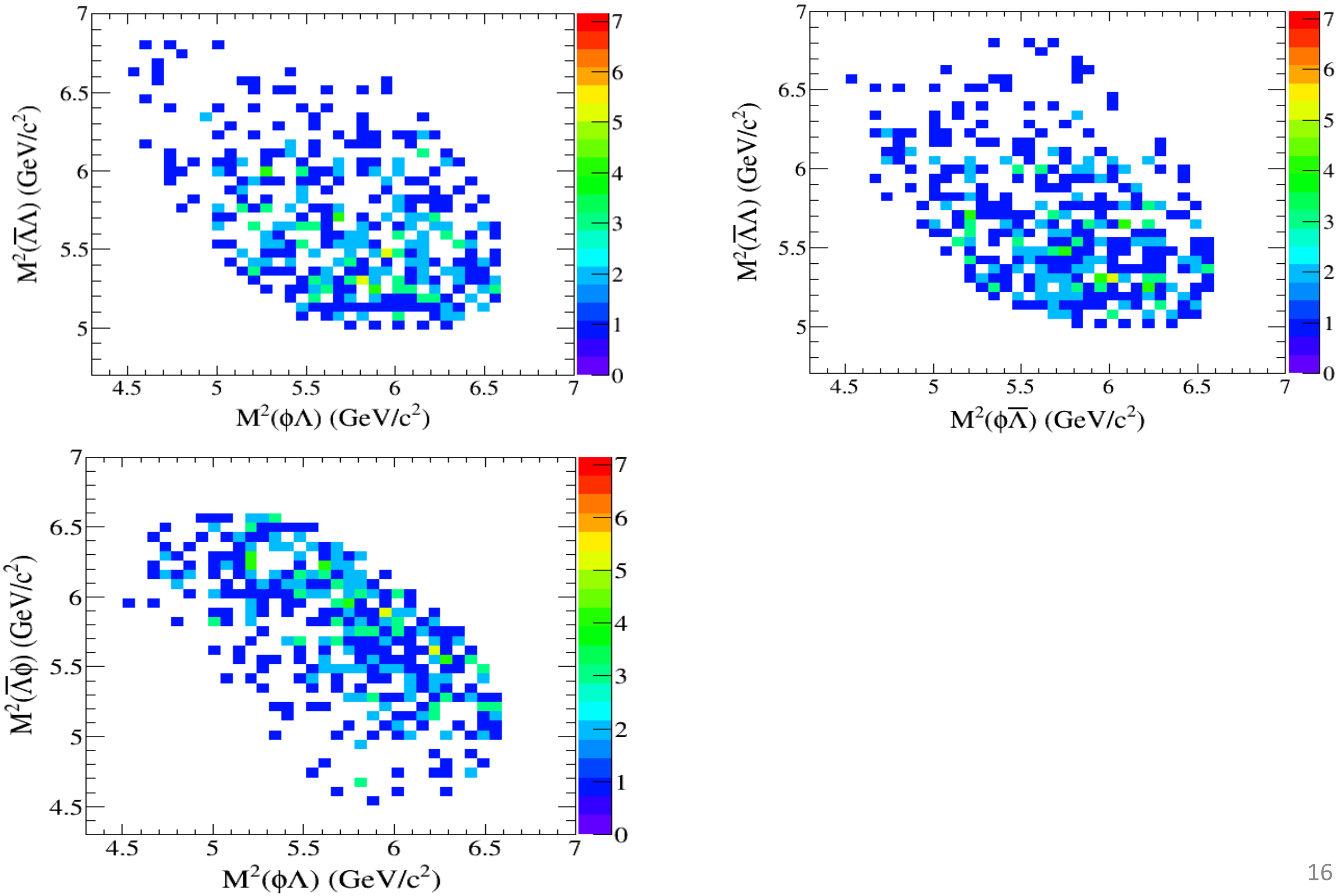


Net signal yield: $N^{net}_{sig} = N^{(a)}_{sig} - f_{\phi} * N^{(b)}_{sig}$

Projections on invariant mass



Dalitz plot



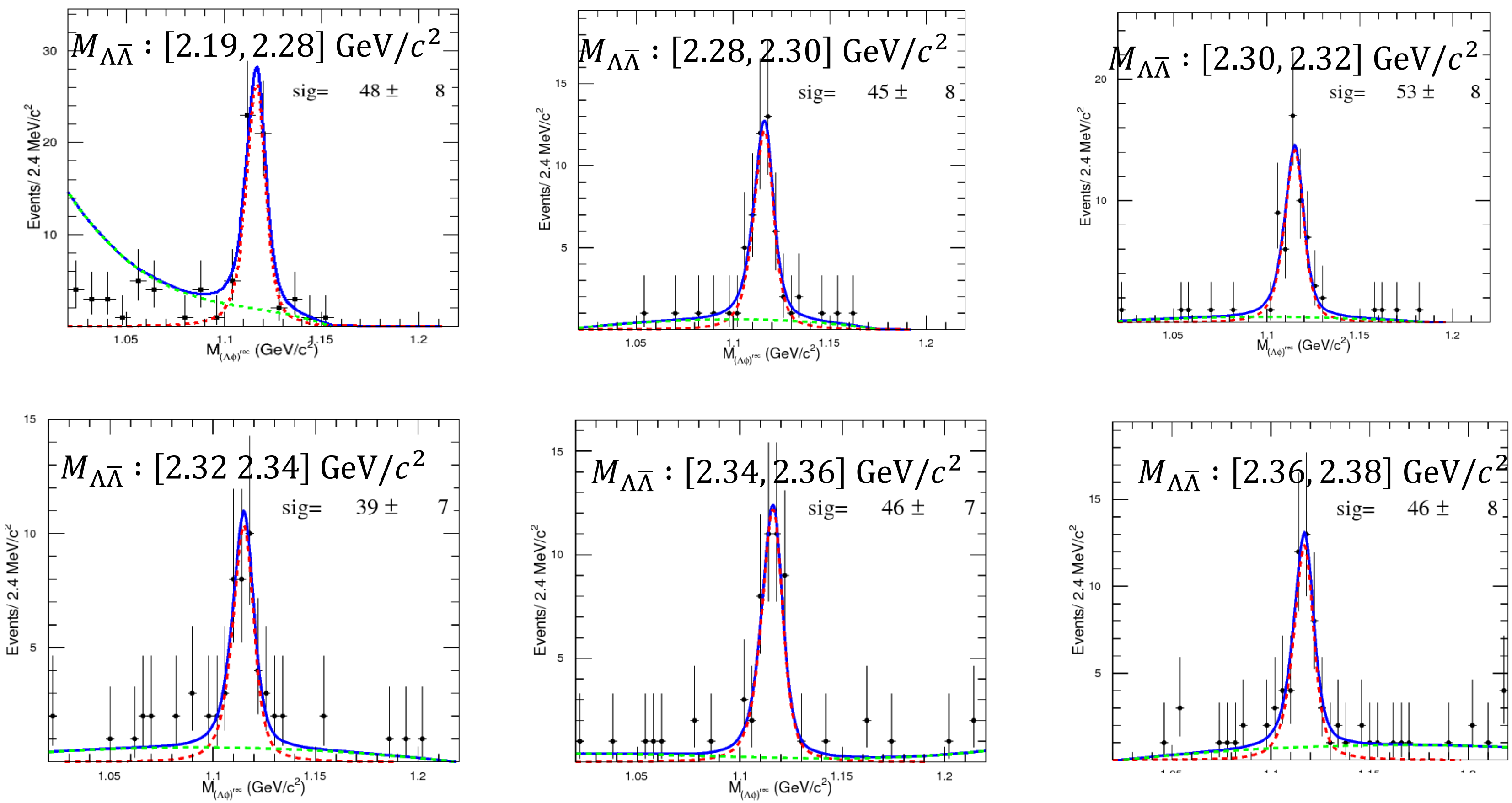
$M^2(\bar{\Lambda}\Lambda)$ (GeV/c^2)
$M^2(\phi\Lambda)$ (GeV/c^2)
$M^2(\bar{\Lambda}\Lambda)$ (GeV/c^2)
$M^2(\phi\bar{\Lambda})$ (GeV/c^2)
$M^2(\bar{\Lambda}\phi)$ (GeV/c^2)
$M^2(\phi\Lambda)$ (GeV/c^2)

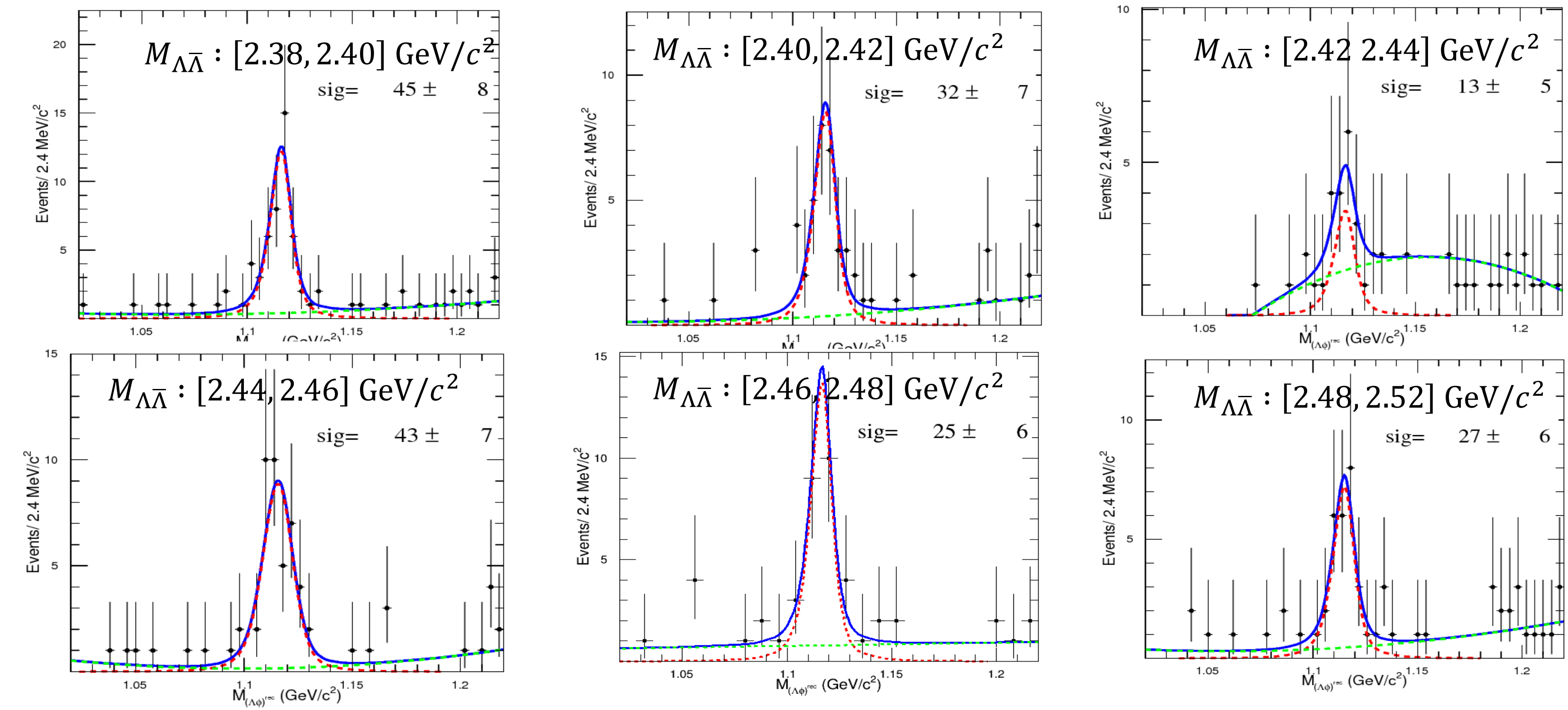
Efficiency

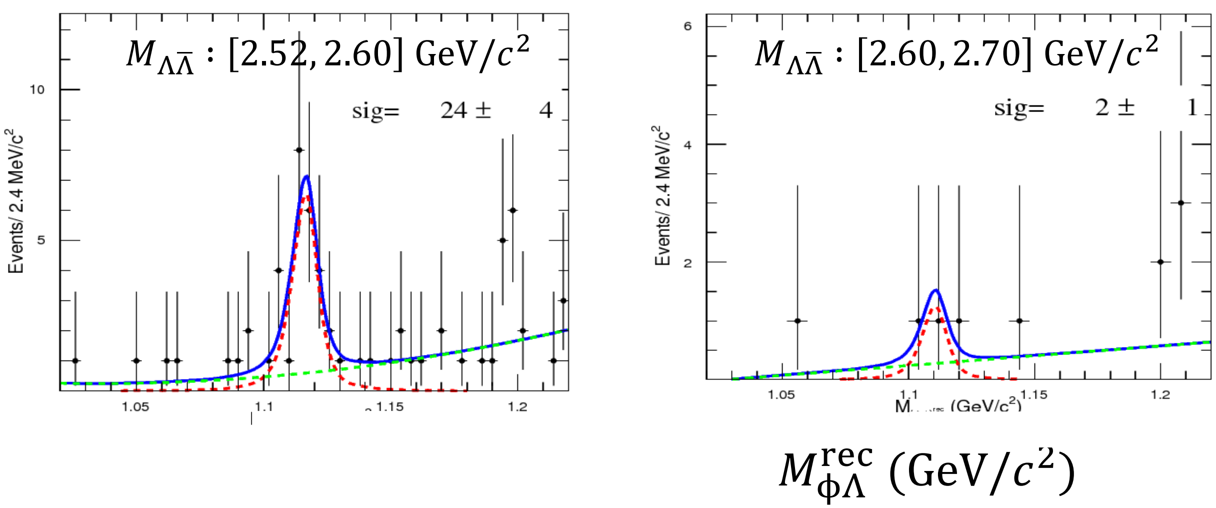
Since the shapes from the signal MC (PHSP) is different from Data, we choose $M_{\Lambda\bar{\Lambda}}$ to reweight the signal MC to get the right efficiency.

Divide $M_{\Lambda\bar{\Lambda}}$ into 14 bins from 2.19 to 2.70 GeV/c^2 :

Fit results in the ϕ and Λ signal regions for each bin

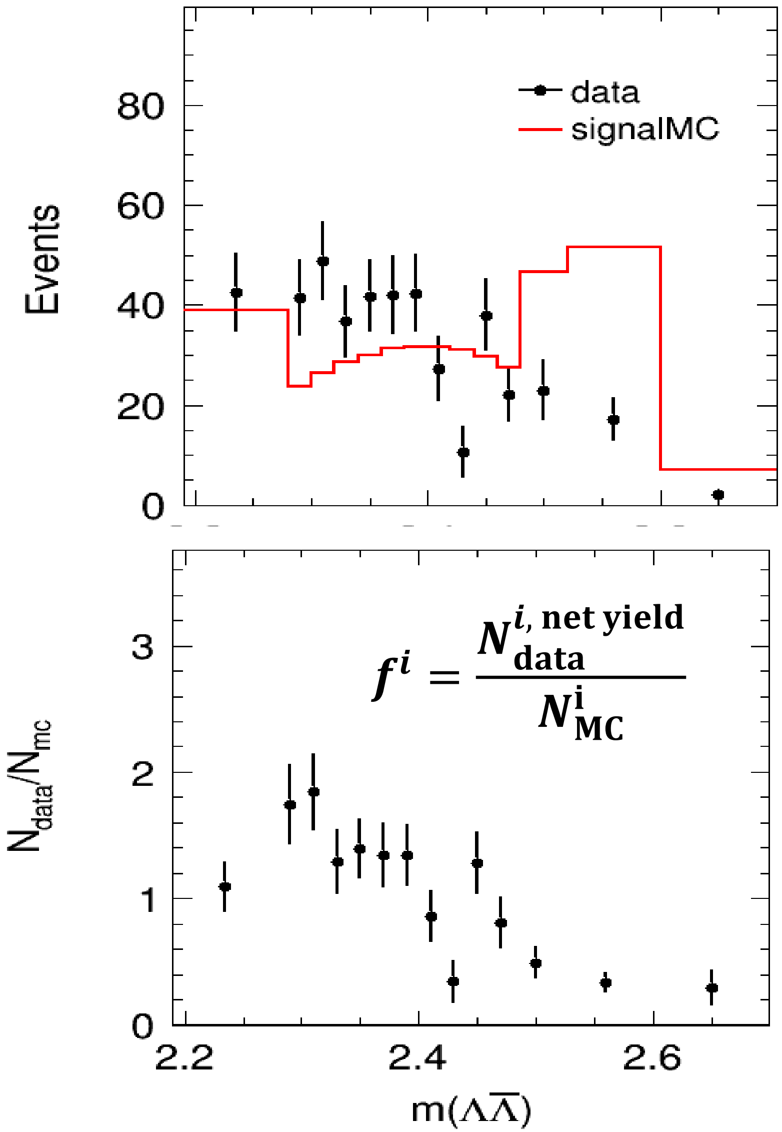




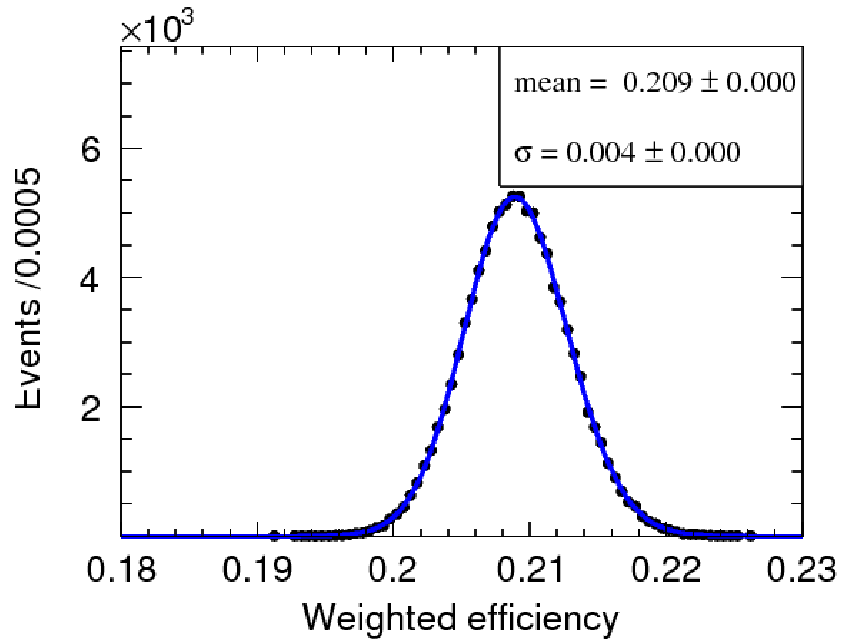


Dots with error bar is from data.

Efficiency



Reweighted detection efficiency:



$$\boldsymbol{\varepsilon^{sig} = \frac{\sum_i N_{MC}^i * f^i}{\sum_i N_{generate}^i * f^i} = 20.9\%}$$

Here, *i* means the *i*-th bin.

Branching fraction

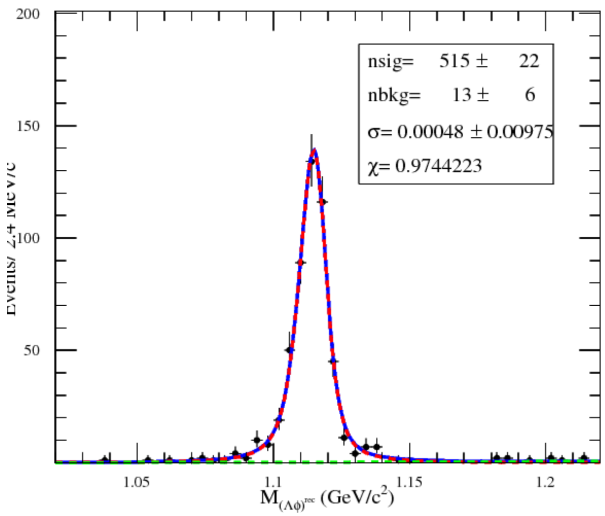
$$B(\psi(3686) \to \phi\Lambda\overline{\Lambda}) = \frac{N_{\mathrm{sig}}^{\mathrm{net}}}{N_{\psi(3686)} \cdot \varepsilon^{sig} \cdot B(\phi \to K^+K^-) \cdot B_0}$$

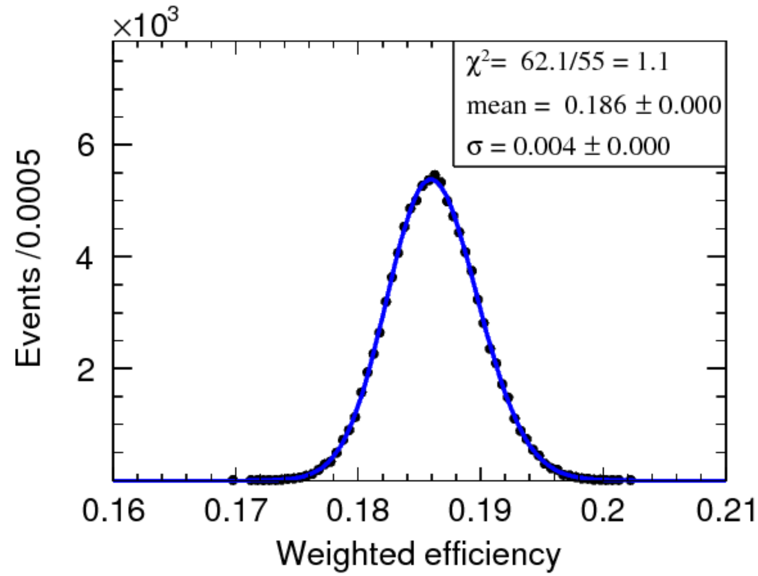
$$= (1.16 \pm 0.06_{\mathrm{stat}}) \times 10^{-5}$$

where $\mathrm{B}_0 = 1 - [1 - B\ (\Lambda \to p\ \pi^-)]^2$ based on the following three processes:

$\psi(3686) \to \phi\Lambda\bar{\Lambda}$ (PHSP) ;	$\psi(3686) \to \phi\Lambda\bar{\Lambda}$ (PHSP) ;	$\psi(3686) \to \phi\Lambda\bar{\Lambda}$ (PHSP) ;
$\phi \to K^+ K^-$(VSS);	$\phi \to K^+ K^-$(VSS);	$\phi \to K^+ K^-$(VSS);
$\Lambda \to p\pi^-$(PHSP);	$\Lambda \to p\pi^+$(PHSP);	$\Lambda \to$ non $p\ \pi^-$;
$\bar{\Lambda} \to \bar{p}\pi^+$(PHSP).	$\bar{\Lambda} \to$ non $\bar{p}\pi^+$.	$\bar{\Lambda} \to \bar{p}\pi^+$(PHSP).

IO Check

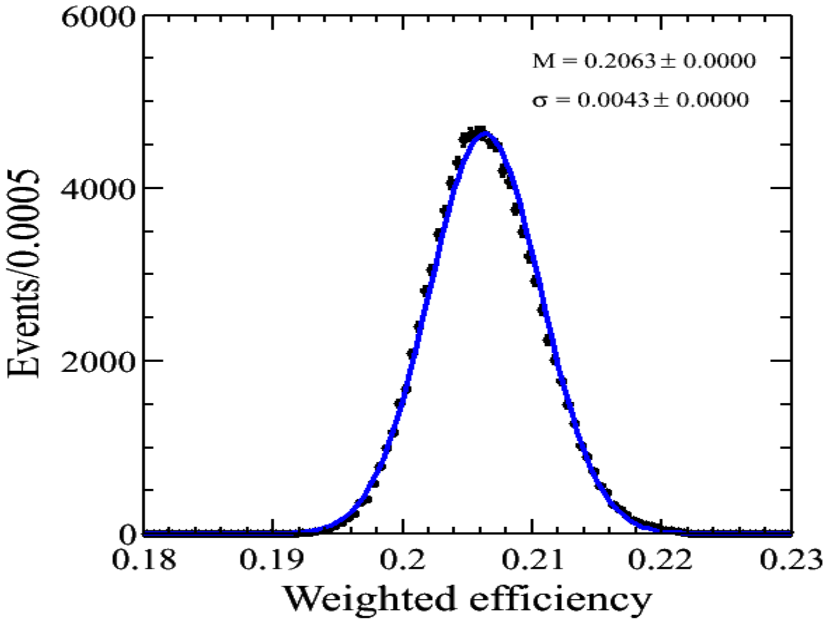




	Input	Output
$B(\psi(3686) \to \Lambda\bar{\Lambda}\phi)$	$7.80 * 10^{-4}$	$7.63(\pm 0.32_{stat}) * 10^{-4}$

Systematic uncertainty from MC model

change the number of reweight bins to 20,



$$B(\psi' \to \phi\Lambda\bar{\Lambda}) \ = (1.18 \pm 0.06) \times 10^{-5}$$

Finally, we assign 1.7% as this uncertainty.

Systematic uncertainty of Λ reconstruction

Reconstruction efficiency of Λ is different for Data and Signal MC, we reweight the signal MC to get the right reconstruction efficiency :

- Λ vertex fit efficiency is calculated in 4×5 (cos$\theta, p_{\Lambda/\bar{\Lambda}}$)bins;
- Correction factor: $f^{i} = \frac{\varepsilon_{data}}{\varepsilon_{sig}}$, where the efficiencies are obtained from the control sample $J/\psi \rightarrow pK^{+}\Lambda$[1].

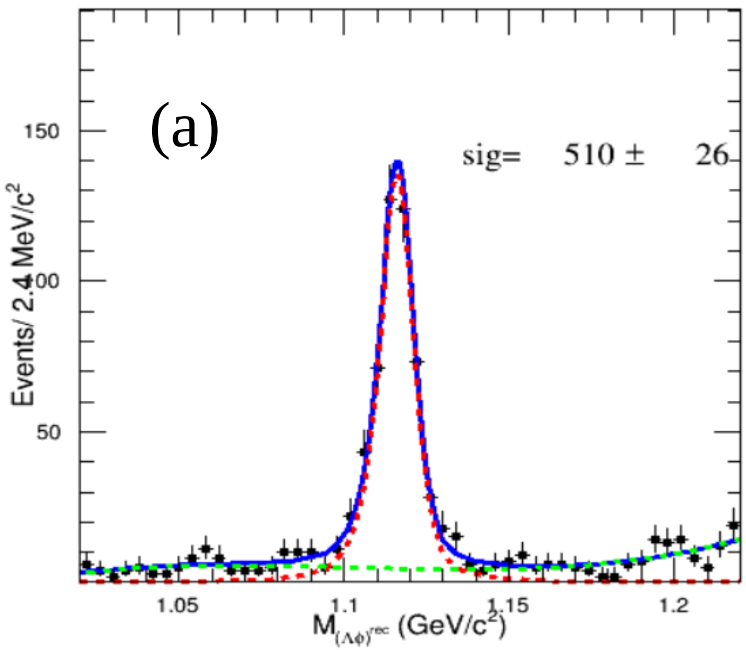
After doing the correction,the final efficiency changes from 20.9% to 21.3%.The difference (1.9%) between corrected MC sample and with uncorrected MC sample is taken as the systematic uncertainty of Λ reconstruction.

[1] M. Ablikim et al. (BESIII Collaboration), Phys. Rev. Lett. **121**, 062003 (2018).

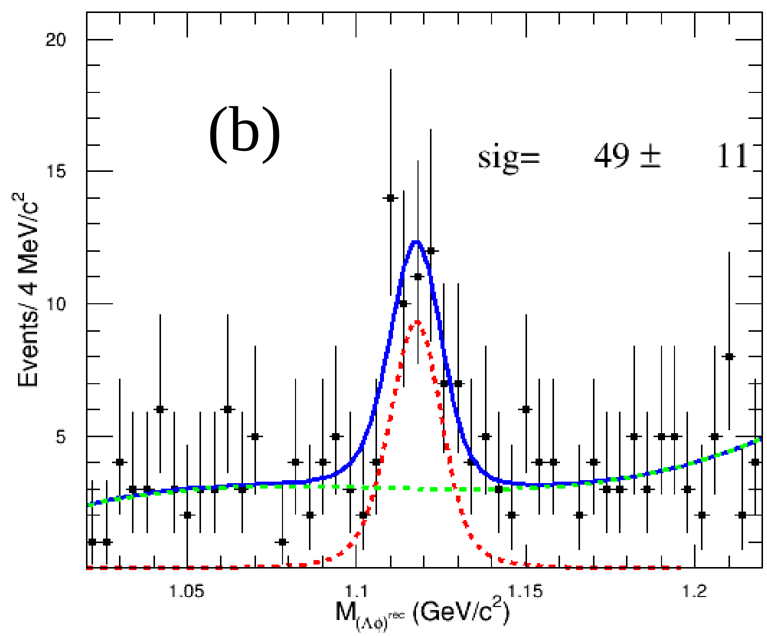
Systematic uncertainty of vetoing $\Omega^{-}\bar{\Omega}^{+}$

changing $|M(K^{+}\bar{\Lambda}) - m(\bar{\Omega}^{+})| > 0.010$ GeV/c^2 to $|M(K^{+}\bar{\Lambda}) - m(\bar{\Omega}^{+})| > 0.015$ GeV/c^2

(a). In ϕ and Λ signal regions



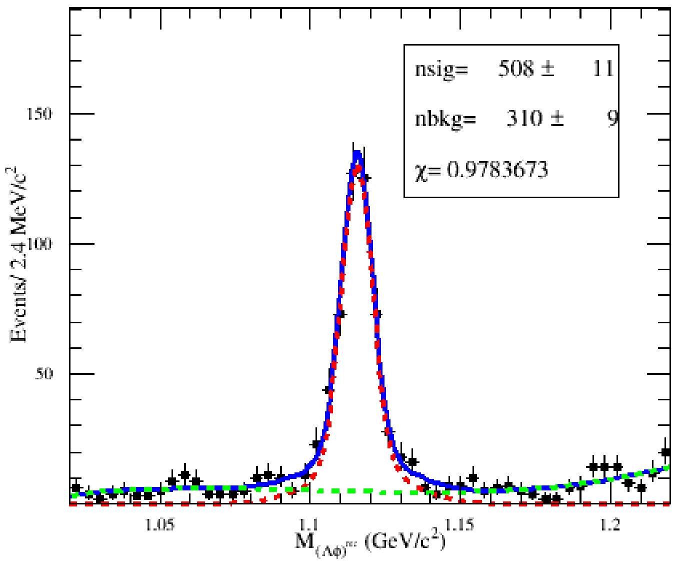
(b). In ϕ sideband region



The difference (0.6%) on the net signal yield is taken as this systematic uncertainty.

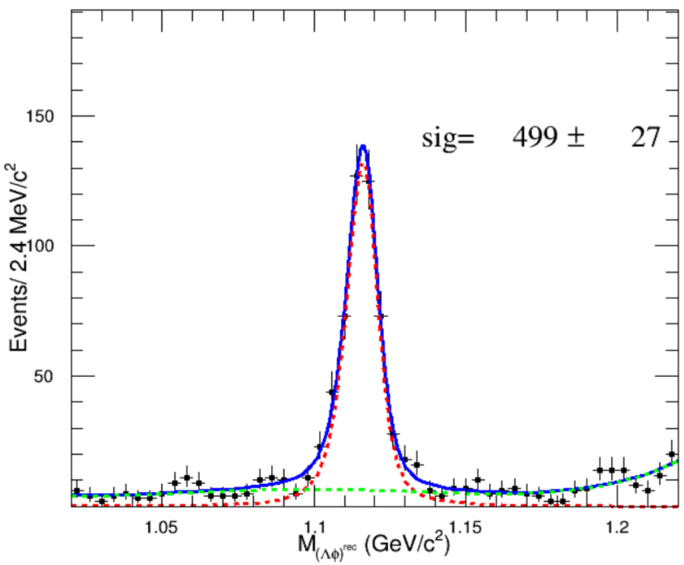
Systematic uncertainty from Fitting

From Signal shape



Fitting function: **Double Gaussian**⊗free Gaussian **+2nd Chebychev**

From background shape



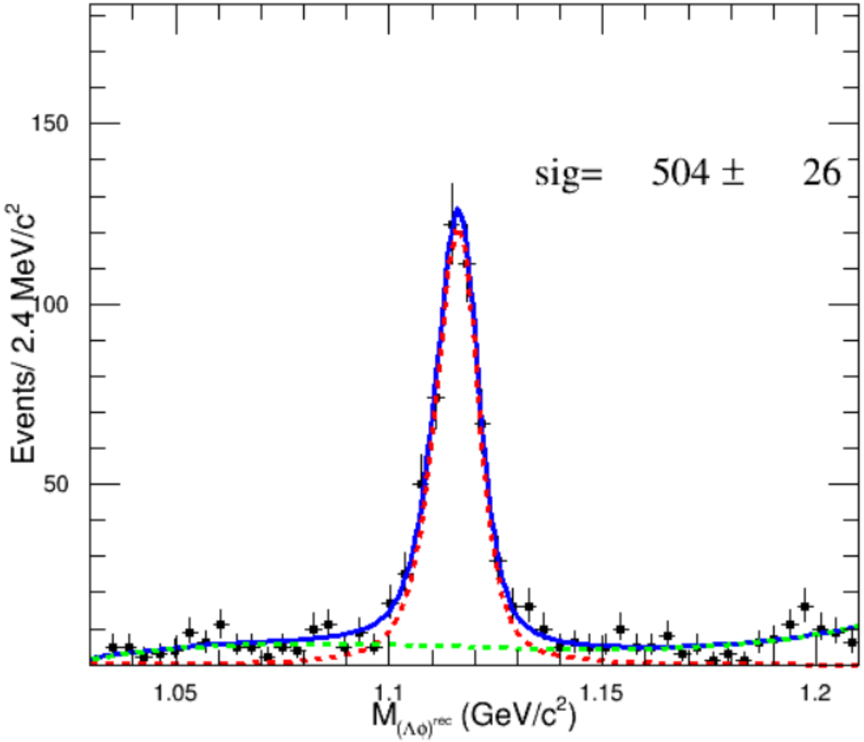
Fitting function: **Signal MC simulation**⊗free Gaussian **+3nd Chebychev**

Source	uncertainty(%)
Signal Shape	1.0
Background Shape	3.2

Systematic uncertainty from Fitting

From fitting range

Vary the range of $M_{\phi\Lambda}^{\rm rec}$ from [1.02, 1.22] GeV/c^2 to [1.02 ± 0.01, 1.22 ± 0.01] GeV/c^2 .



Do the fit again, and take the largest difference (1.9%) of branching fraction as systematic error.

From others

- For tracking efficiency of $K^{\pm}$, a clean control sample of $J/\psi \to K_S^0 K^{\pm}\pi^{\mp}$[1] is used, and 1.0% is taken as the systematic uncertainty from tracking efficiency per kaon.
- For the PID of $K^{\pm}$, control sample $J/\psi \to K^+K^-\pi^0$ is used. It is found that the difference on the PID efficiency between data and MC is less than 1% for each kaon[1].
- The systematic uncertainty due to the total ψ' number is determined to be 0.6% according to[2]
- Uncertainty in Branch of Λ and ϕ is quoted from PDG[3],which is 0.5% both.

[1] M. Ablikim et al. [BESIII Collaboration], Phys. Rev. D 83, 112005 (2011)
[2] https://arxiv.org/pdf/1709.03653.pdf
[3] http://pdglive.lbl.gov/Particle.action?init=0&node=S018&home=BXXX020

Systematic uncertainty

Source		Relative systematic uncertainty(%)
Tracking for K^+K^-		2.0
PID for K^+K^-		2.0
Λ reconstruction		1.9
Veto $\Omega^-\bar{\Omega}^+$		0.6
$B(\phi \to K^+K^-) \cdot B(\Lambda \to p\,\pi^-)$		0.7
$N_{\psi(3686)}$		0.6
MC modeling		1.7
Fitting	signal shape	1.0
	background shape	3.4
	fitting range	1.9
Total		5.7

Summary

Based on 4.48 $\times 10^8$ $\psi(3686)$ data collected with the BESIII detector at BEPCII, we measure the absolute branching fraction of $\psi(3686) \to \phi\Lambda\bar{\Lambda}$ for the first time ,which is $\left(1.16 \pm 0.06_{\mathrm{stat}} \pm 0.07_{\mathrm{syst}}\right) \times 10^{-5}$.

Thank You !

Back Up

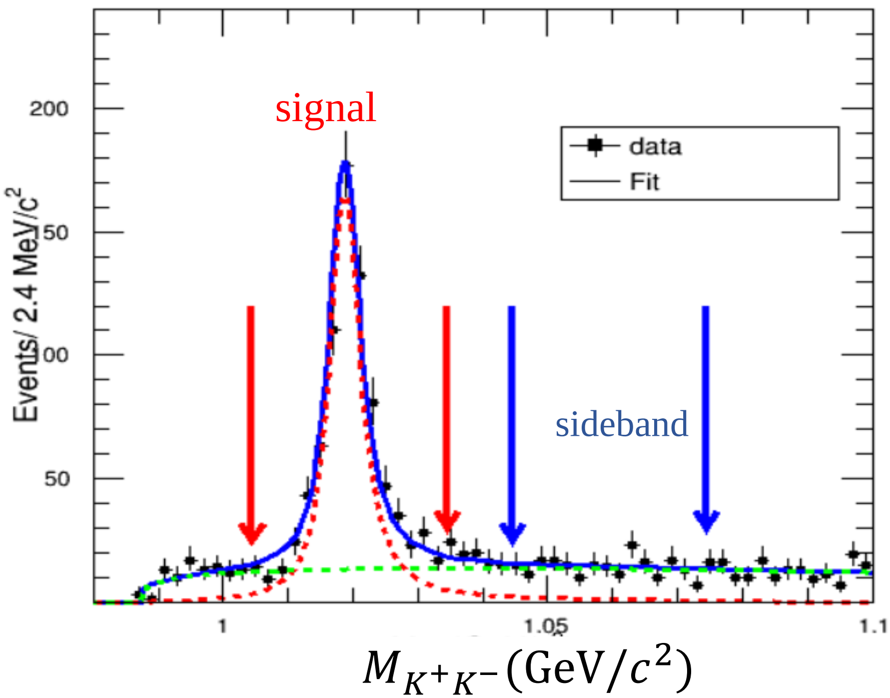
Λ construction

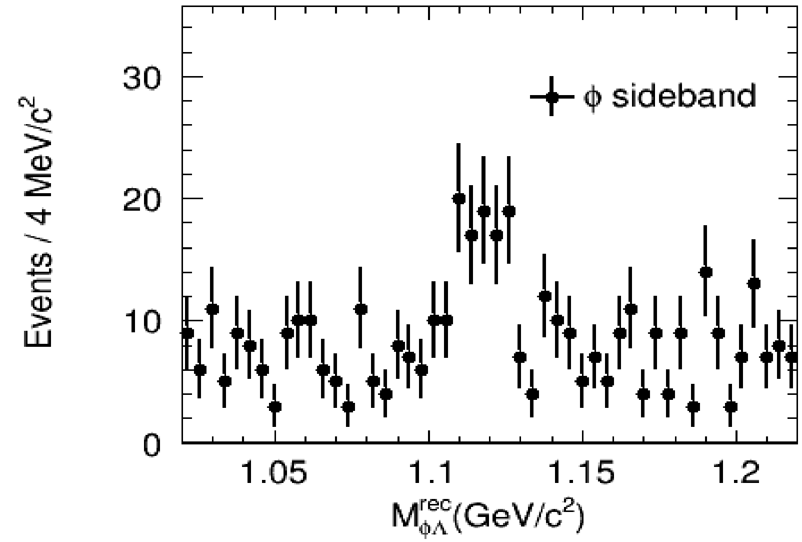
$\epsilon_{data}(\%)$	$P\,(\mathrm{GeV}/c)$				
$\lvert\cos\theta\rvert$	(0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 0.9)	(0.9, 1.1)
(0.00, 0.20)	8.28 ± 0.38	29.03 ± 0.37	35.43 ± 0.32	39.68 ± 0.47	40.82 ± 0.14
(0.20, 0.40)	8.22 ± 0.37	28.28 ± 0.37	35.00 ± 0.33	39.27 ± 0.50	40.21 ± 0.14
(0.40, 0.65)	8.01 ± 0.31	26.56 ± 0.33	33.25 ± 0.32	36.56 ± 0.50	37.76 ± 0.12
(0.65, 1.00)	4.45 ± 0.21	14.98 ± 0.21	20.15 ± 0.25	23.80 ± 0.51	29.97 ± 0.11

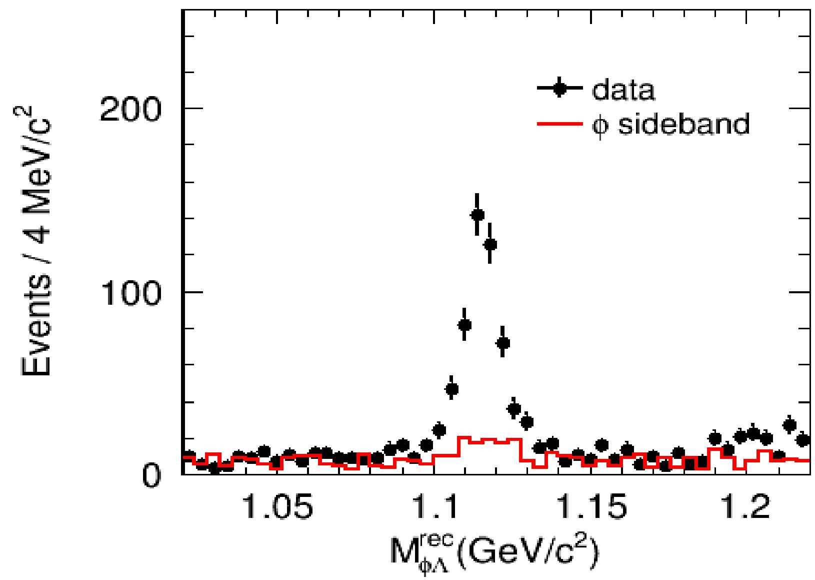
$\lvert\cos\theta\rvert$	$\epsilon_{MC}(\%)$				
	$P\,(\mathrm{GeV}/c)$				
	(0.0, 0.3)	(0.3, 0.5)	(0.5, 0.7)	(0.7, 0.9)	(0.9, 1.1)
(0.00, 0.20)	8.31 ± 0.25	28.38 ± 0.29	34.94 ± 0.27	39.11 ± 0.34	39.98 ± 0.14
(0.20, 0.40)	7.73 ± 0.25	27.78 ± 0.28	34.22 ± 0.26	38.11 ± 0.33	39.33 ± 0.14
(0.40, 0.65)	6.77 ± 0.21	25.52 ± 0.24	32.20 ± 0.23	35.52 ± 0.31	37.00 ± 0.12
(0.65, 1.00)	3.93 ± 0.14	14.66 ± 0.15	18.98 ± 0.15	22.06 ± 0.32	28.43 ± 0.11

[1] arXiv:1803.05706

Non-ϕ background

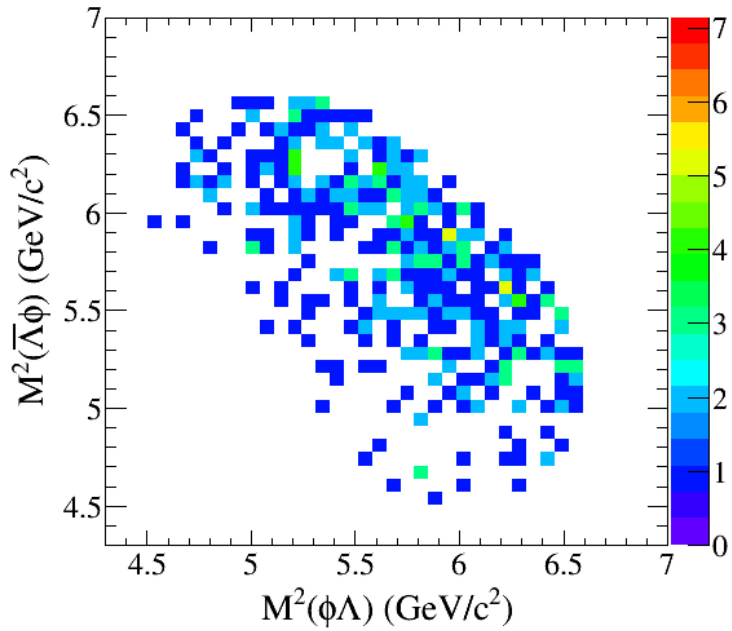


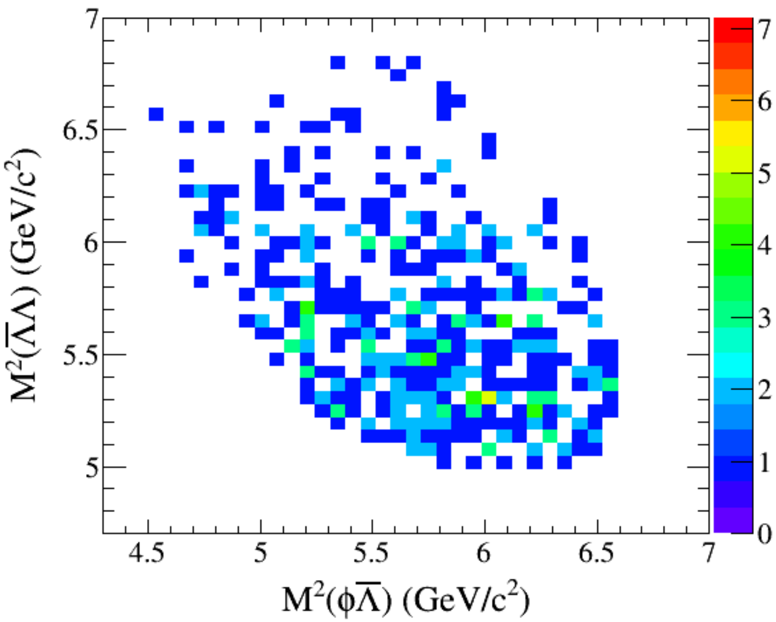


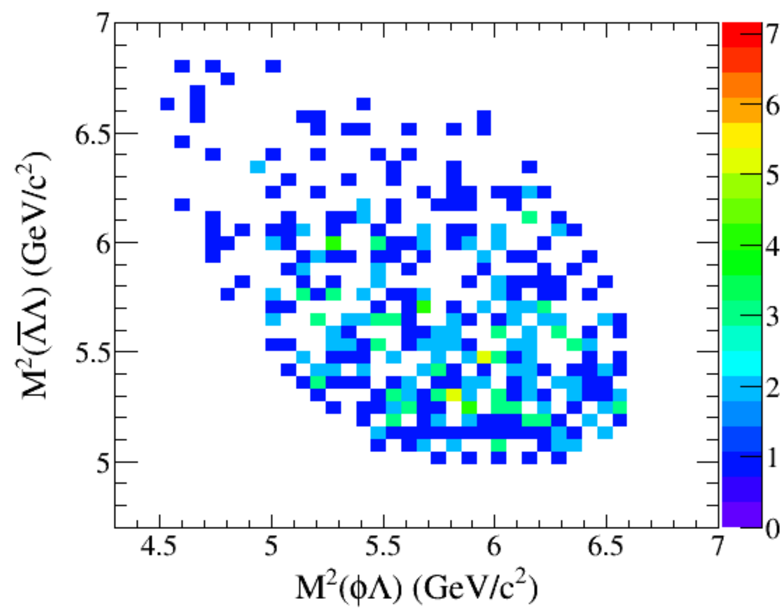


The nomalizating fator is 0.988

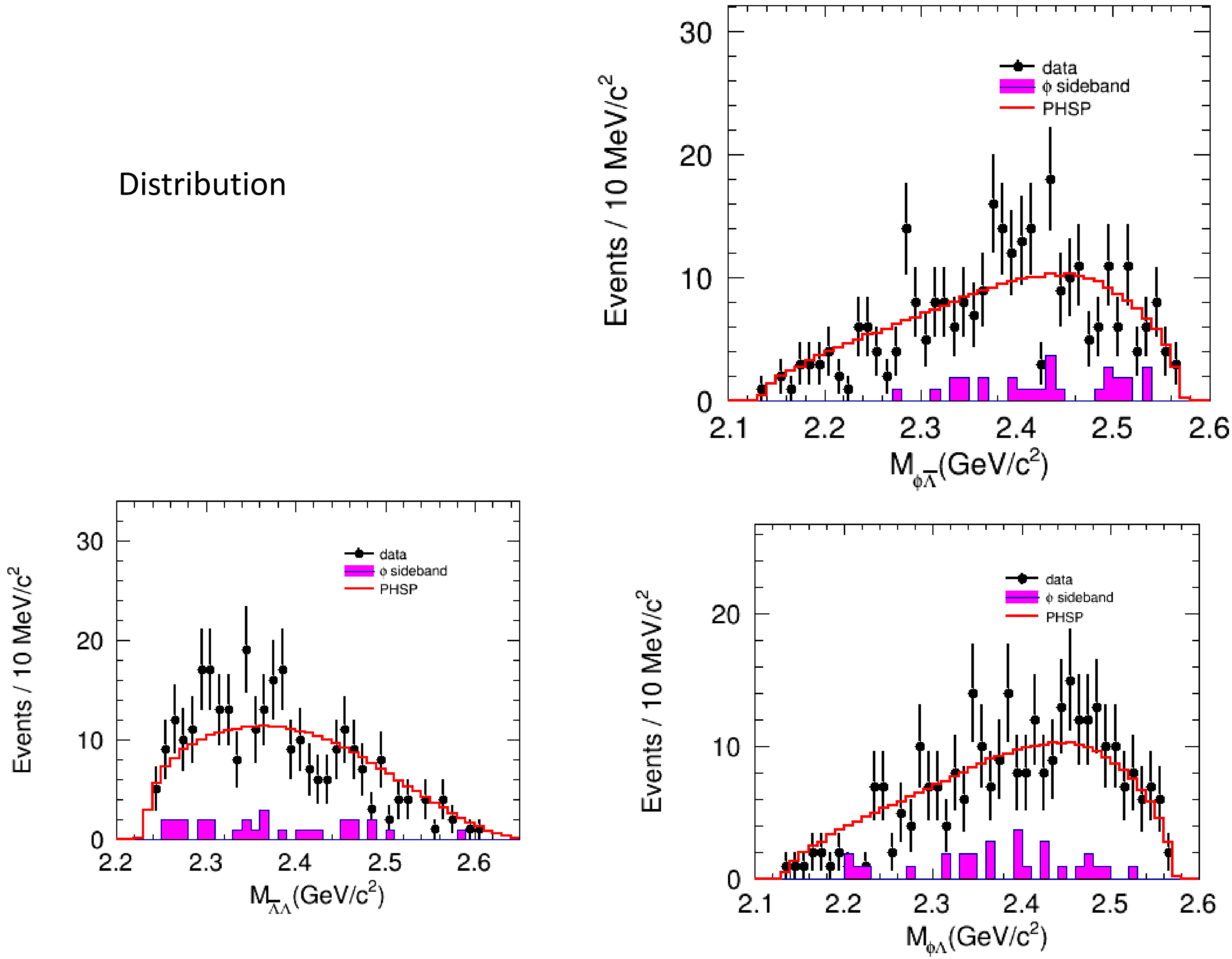
Daliz plot


M²(Λ̄φ) (GeV/c²)
M²(φΛ) (GeV/c²)

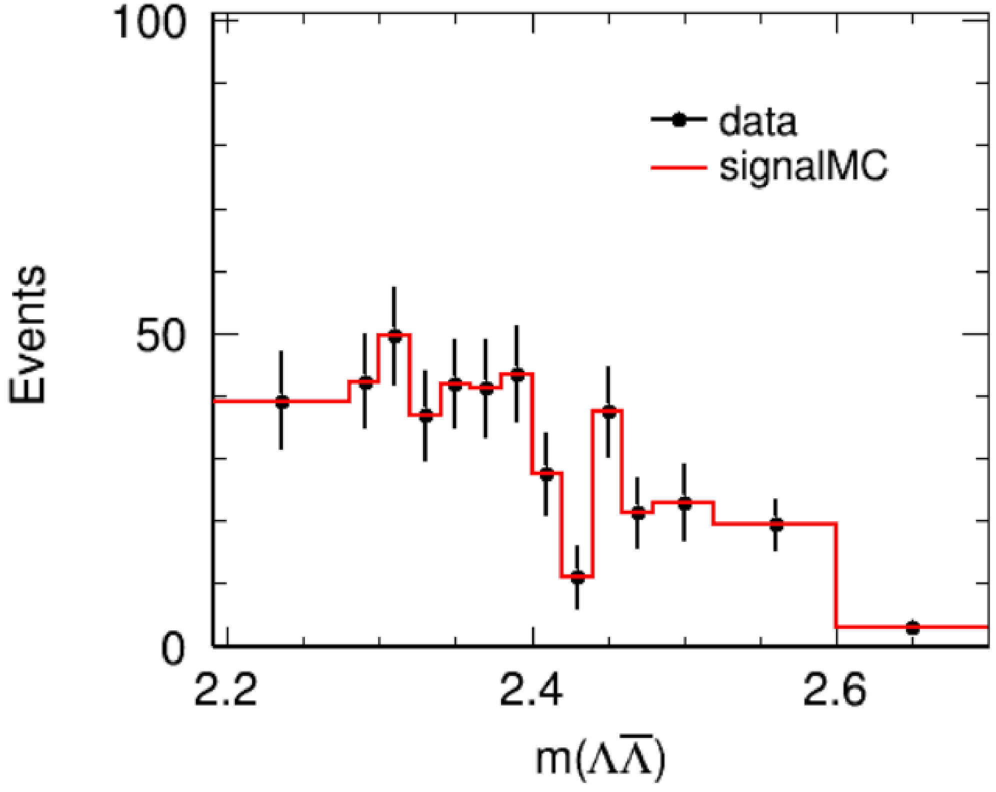

M²(Λ̄Λ) (GeV/c²)
M²(φΛ̄) (GeV/c²)

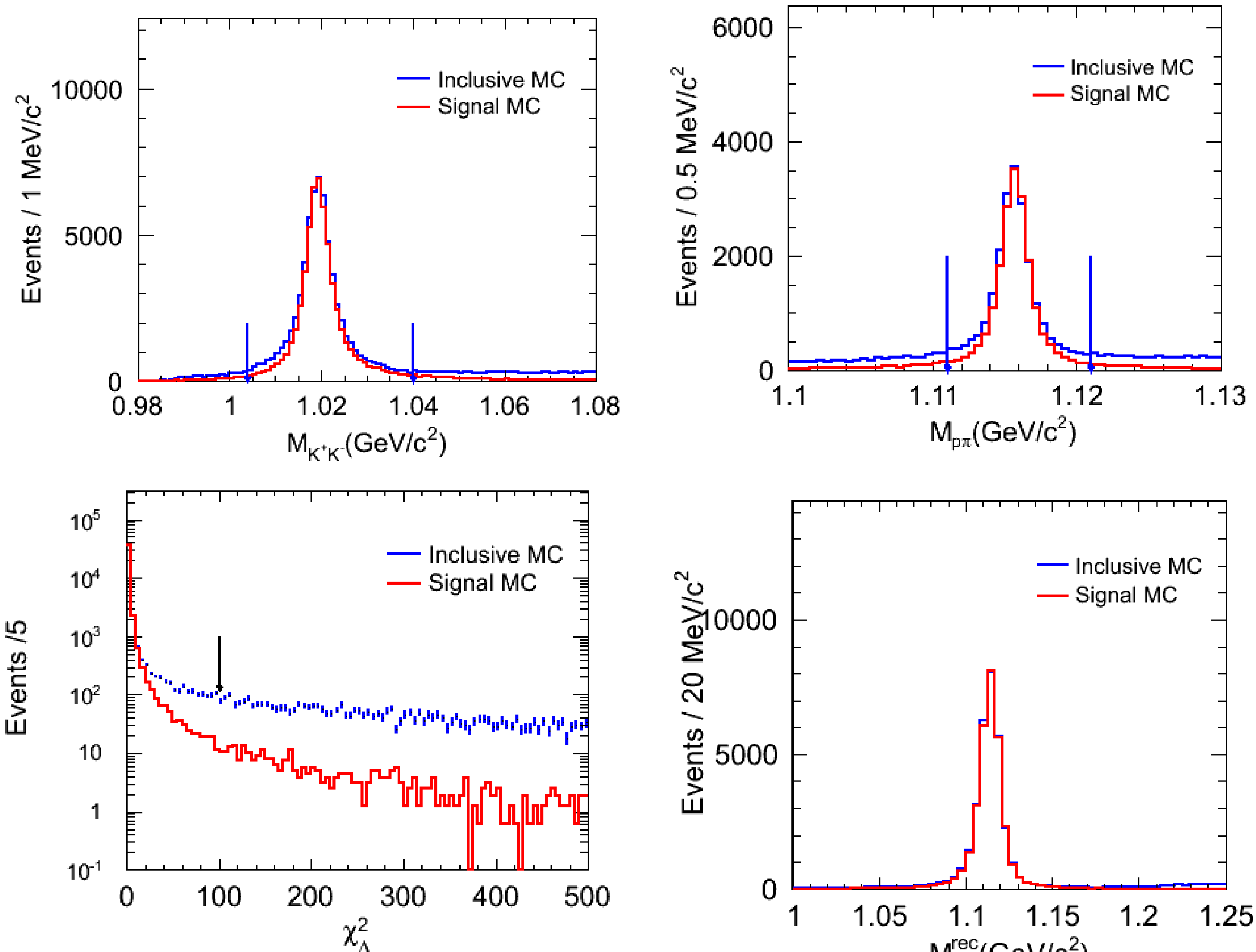

M²(Λ̄Λ) (GeV/c²)
M²(φΛ) (GeV/c²)

Distribution

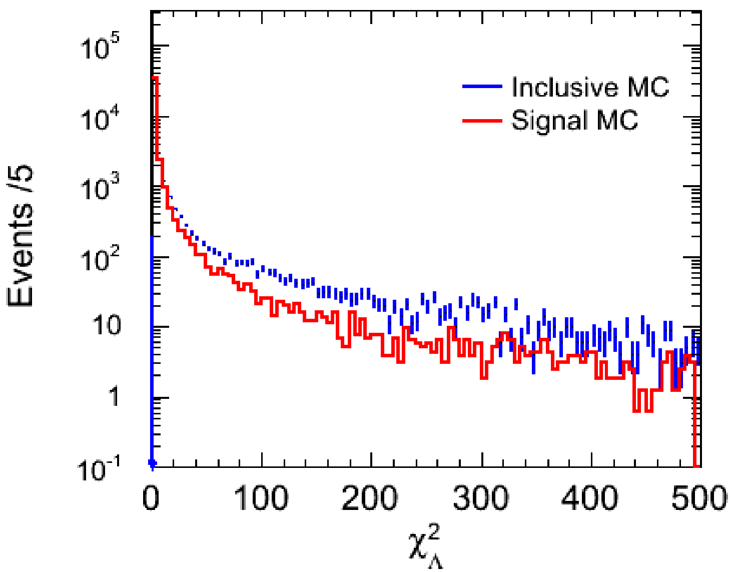


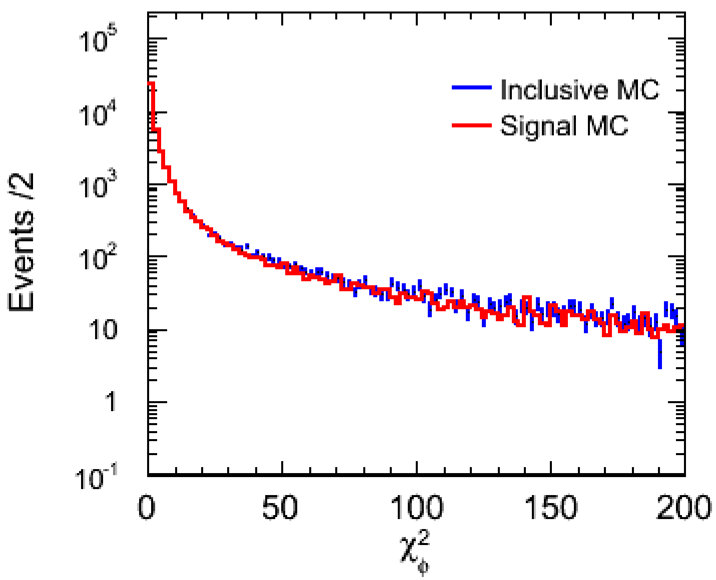
After reweighted:



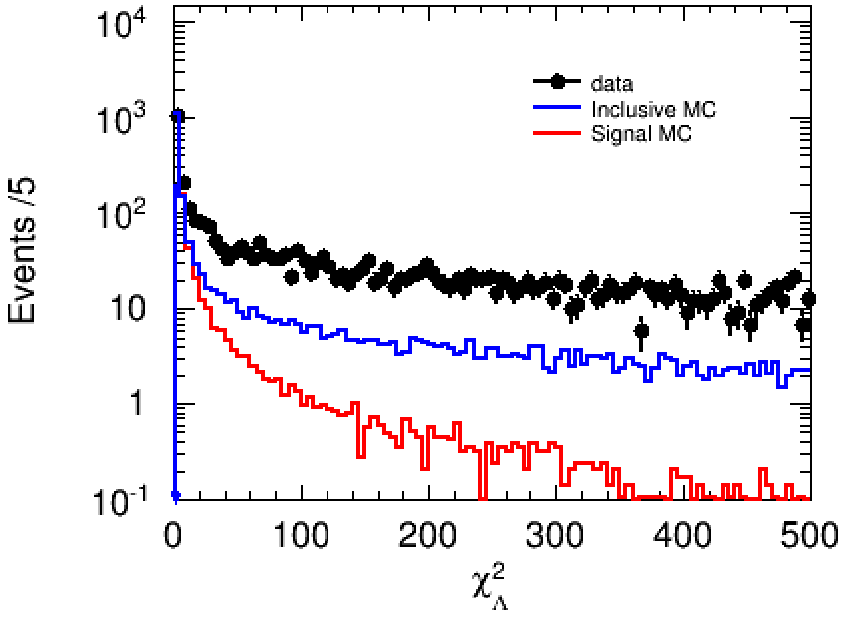


Second vetex fit

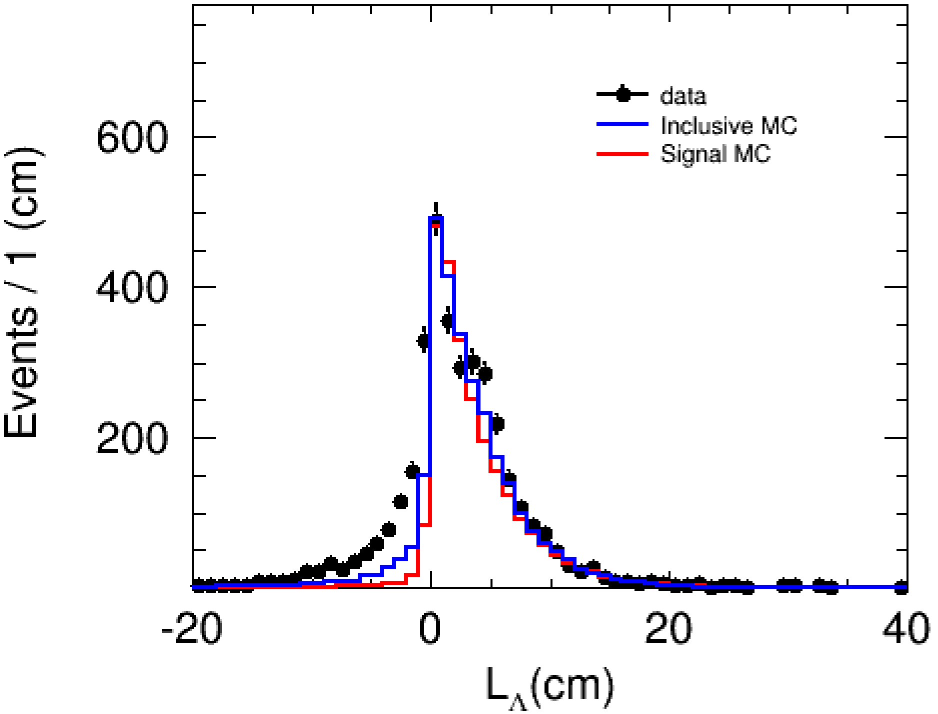

Events /5
Inclusive MC
Signal MC
10^5
10^4
10^3
10^2
10
1
10^{-1}
0
100
200
300
400
500
χ^2_Λ


Events /2
Inclusive MC
Signal MC
10^5
10^4
10^3
10^2
10
1
10^{-1}
0
50
100
150
200
χ^2_ϕ

Primary

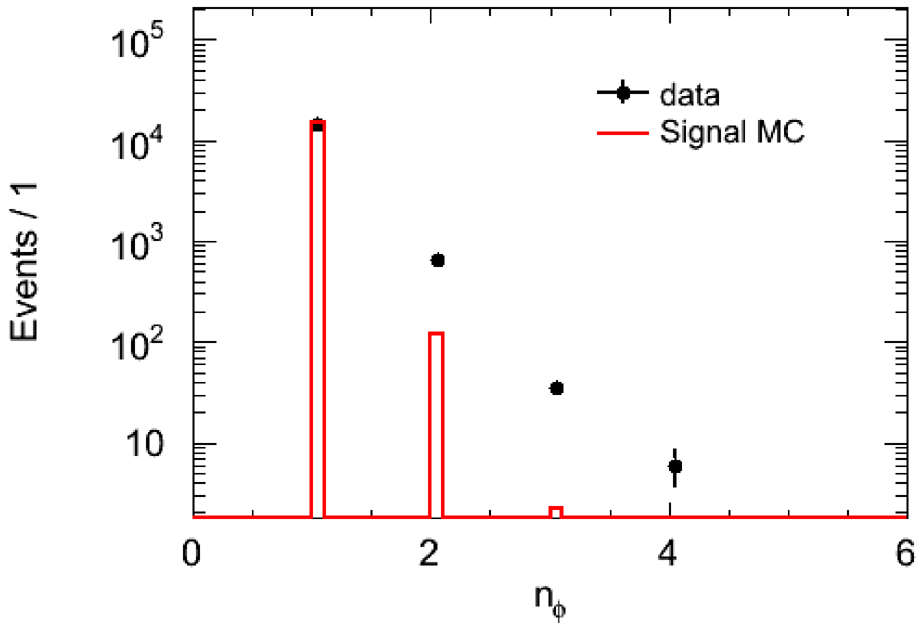


data
Inclusive MC
Signal MC
Events /5
χ^2_Λ



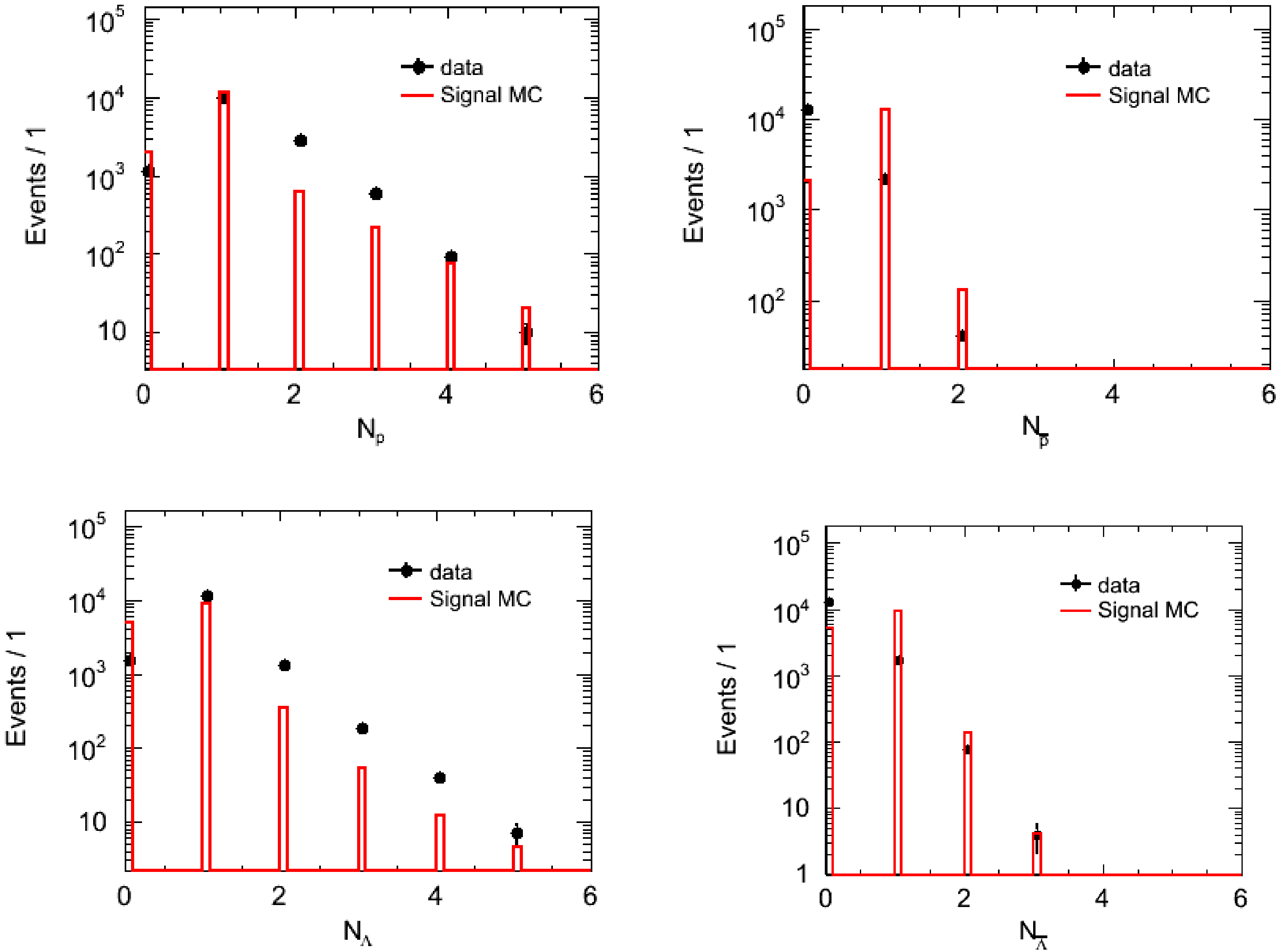
data
Inclusive MC
Signal MC
Events / 1 (cm)
L_Λ(cm)

Multi research



$N_{\phi} == 1$

ε ： ↓0. 19%


Events / 1
data
Signal MC
N_p
Events / 1
data
Signal MC
$N_{\bar{p}}$
Events / 1
data
Signal MC
N_Λ
Events / 1
data
Signal MC
$N_{\bar{\Lambda}}$

Efficiency for signal MC