Search for $\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}\phi$

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HFP Group Meeting, April. 18th, 2022

Outline

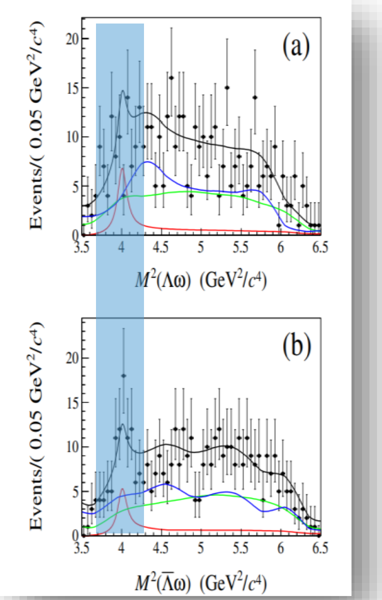
- Motivation
- Data Sample
- Event selection
- Background analysis
- Intermediate state
- Systematic uncertainty
- Summary

Motivation

a) Search for the potential excited baryons, refer to $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\eta$ [1] and $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\omega$ [2]

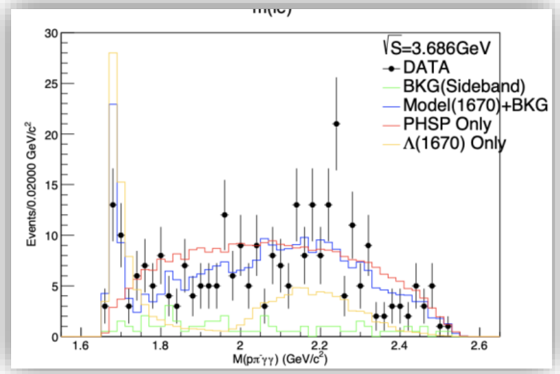
b) Search for the threshold enhancement in $M_{B\bar{B}}$, refer to $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\omega$ [2] and $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\phi$ [3]

c) Recently, $\chi_{cJ} \rightarrow B\bar{B}P$ ($\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}\eta$) are observed at BESIII [4], Similarly, Search for $\chi_{cJ} \rightarrow B\bar{B}V$ decays, such as $\chi_{cJ} \rightarrow \Lambda\bar{\Lambda}\phi$, is interested

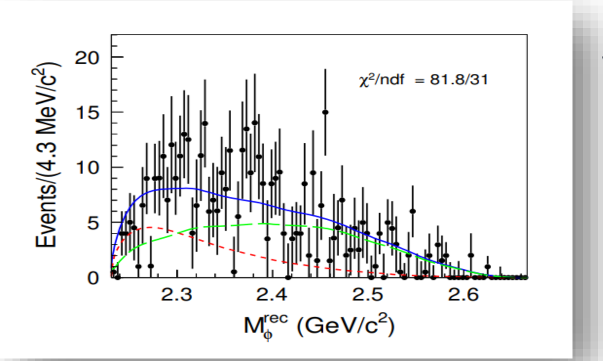


[2] $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\omega$

[1] $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\eta$



[3] $\psi(3686) \rightarrow \Lambda\bar{\Lambda}\phi$



[1] BAM-00538: Measurement of psi(3686)->eta/pi0 Lambda Lambdabar, by Shi Wang et al.
[2] BAM-00336, Honghong Zhang et al., Study of Psi' to omega Labamda Lambdabar.
[3] BAM-00421: Observation of psi(3686)->phi Lambda Lambda-bar decay, by Aonan Zhu et al.
[4] BAM-00496: Observation of chicJ-> eta Lambda Lambda-bar decay, by Yijia Zeng et al.

Data samples

Data set	Number of events	BOSS version
09+12 ψ(3686) data	4.5×10^8 } ~ 2.8Billion	6.6.4.p03
2021 ψ(3686) data	$\sim 2.3\times 10^9$	707p01
09+12 ψ(3686) inclusive MC	5.06×10^8	6.6.4.p03
2021 ψ(3686) inclusive MC	5×10^8	707p01
PHSP MC	0.5 million for each channel (09+12) 2.5 million for each channel (2021)	6.6.4.p03 707p01

Event selection

Charged tracks

- $|\cos\theta| < 0.93$
- **No vertex constraint**
- $\mathbf{N \geq 6, N_m \geq 3, N_p \geq 3}$

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

- 2nd vertex fit
- $\Delta_{\min} = (M_{p\pi^-} - m_{\Lambda})^2 + (M_{\bar{p}\pi^+} - m_{\bar{\Lambda}})^2 \Rightarrow \Lambda_{\min}, \bar{\Lambda}_{\min}$

Particle identification

- For Kaon:
  Prob(K)> Prob(p), Prob(K)> Prob(pi)
- $\mathbf{N_{K^+} = N_{K^-} = 1;}$
- $|V_z| < 10, |V_{xy}| < 1$

Good photon

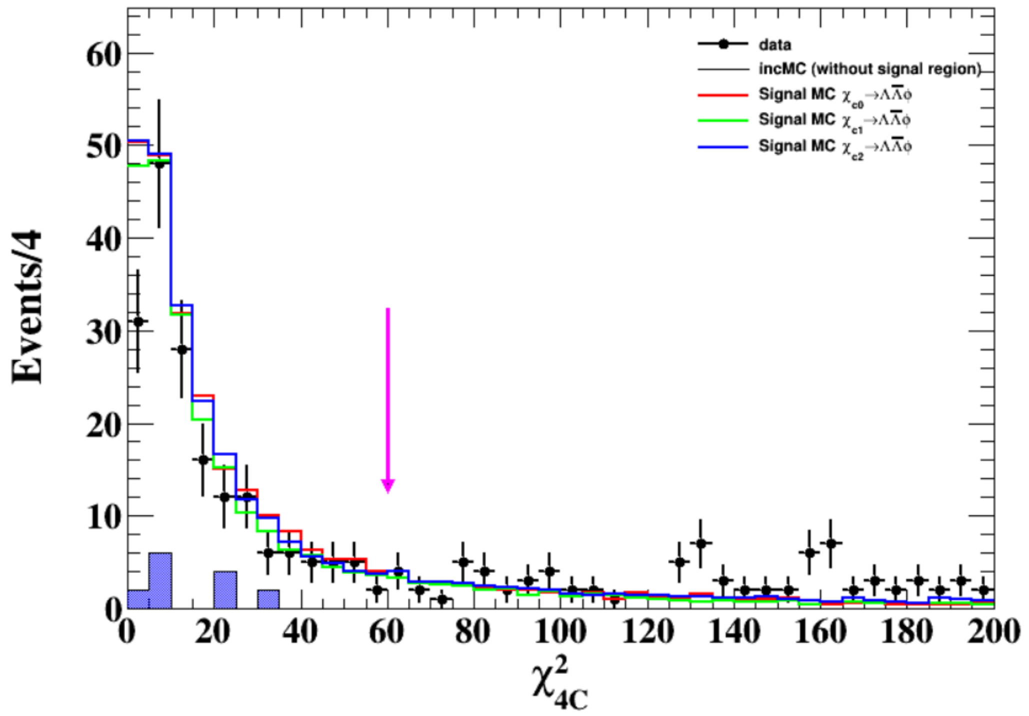
- $0 \leq \mathrm{TDC} \leq 14$
- Barrel : $E > 0.025$ GeV, $|\cos\theta| < 0.8$
- End cap : $E > 0.050$ GeV, $0.86 < |\cos\theta| < 0.92$
- $\mathbf{N_\gamma \geq 1}$

4C-kinematic fit with

$\psi(3686) \rightarrow \gamma\Lambda\bar{\Lambda}K^+K^-$

- Additional 4C kinematic for $\mathbf{2\gamma\Lambda\bar{\Lambda}K^+K^-}$ final states.

Further Event selection:
4C kinematic fit

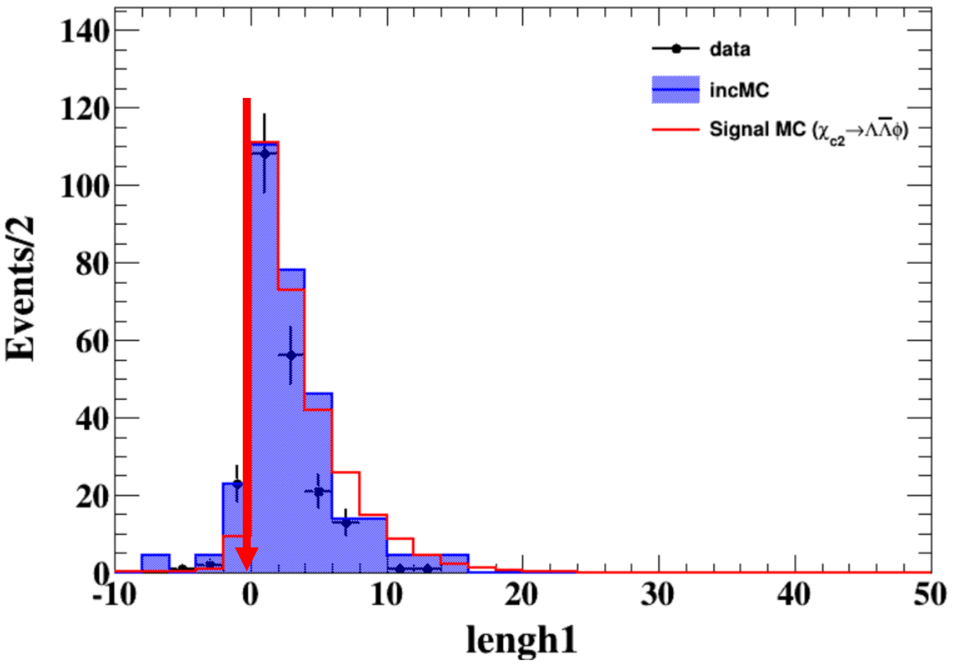


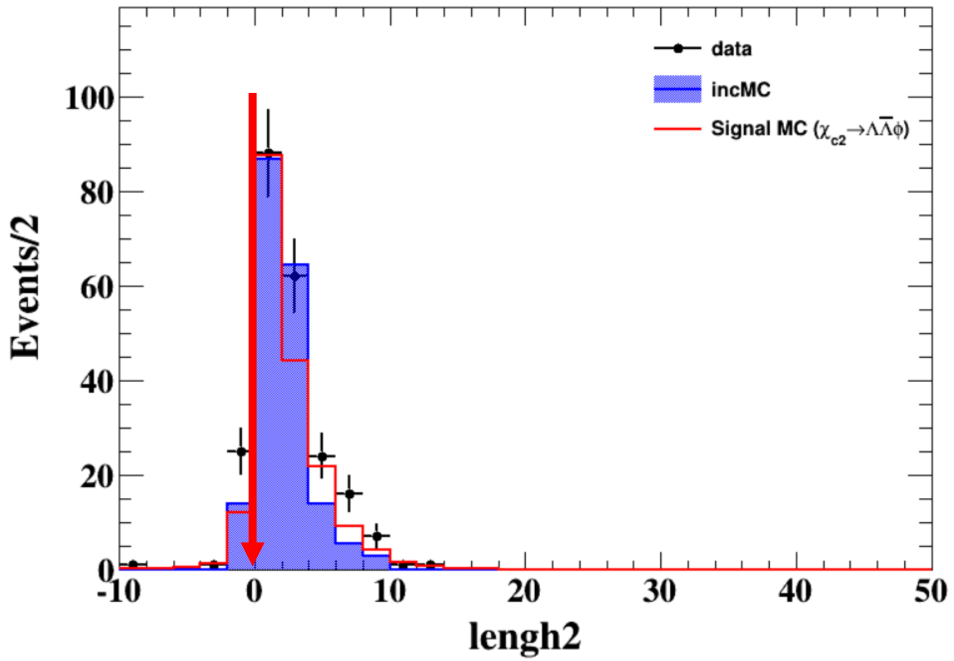
Final event selection:

- $\chi^2_{4c}(\gamma\bar{p}p^-K^+K^-\pi^+\pi^-) < 60$
- $\chi^2_{4c}(\gamma\bar{p}p^-K^+K^-\pi^+\pi^-) < \chi^2_{4c}\ (2\gamma\bar{p}p^-K^+K^-\pi^+\pi^-)$

*The blue histograms are backgrounds from inclusive MC which remove signal channel, the same below.

Further Event selection:
Decay length

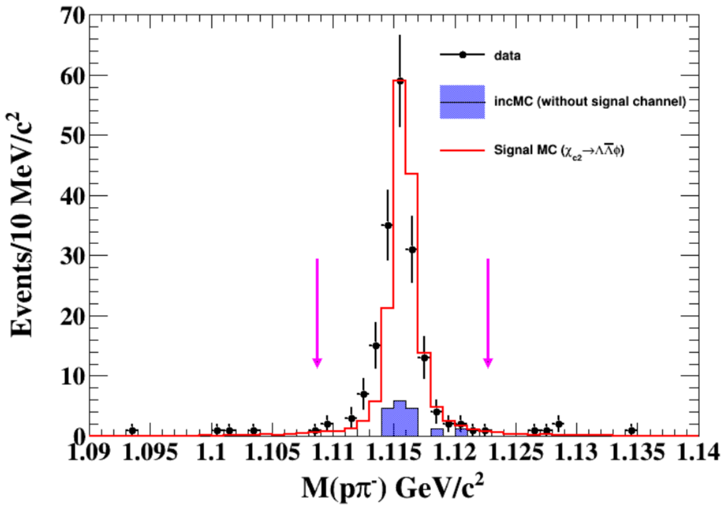


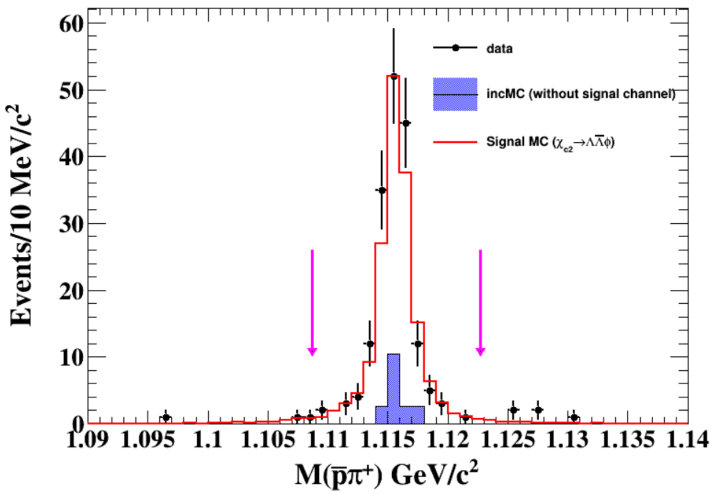


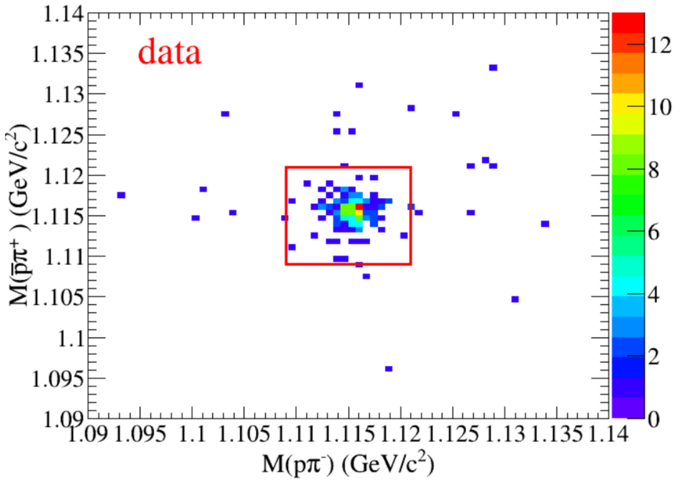
Final event selection:

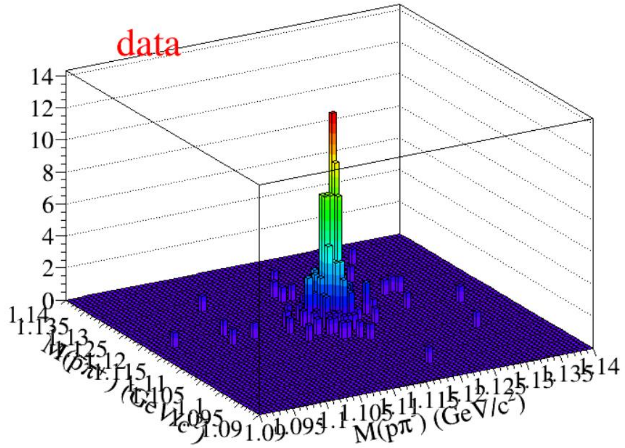
- lengh1>0
- lengh2>0

Further Event selection:
M(Λ) & scatter plot: $M(\bar{p}\pi^{+})$ v.s. $M(p\pi^{-})$







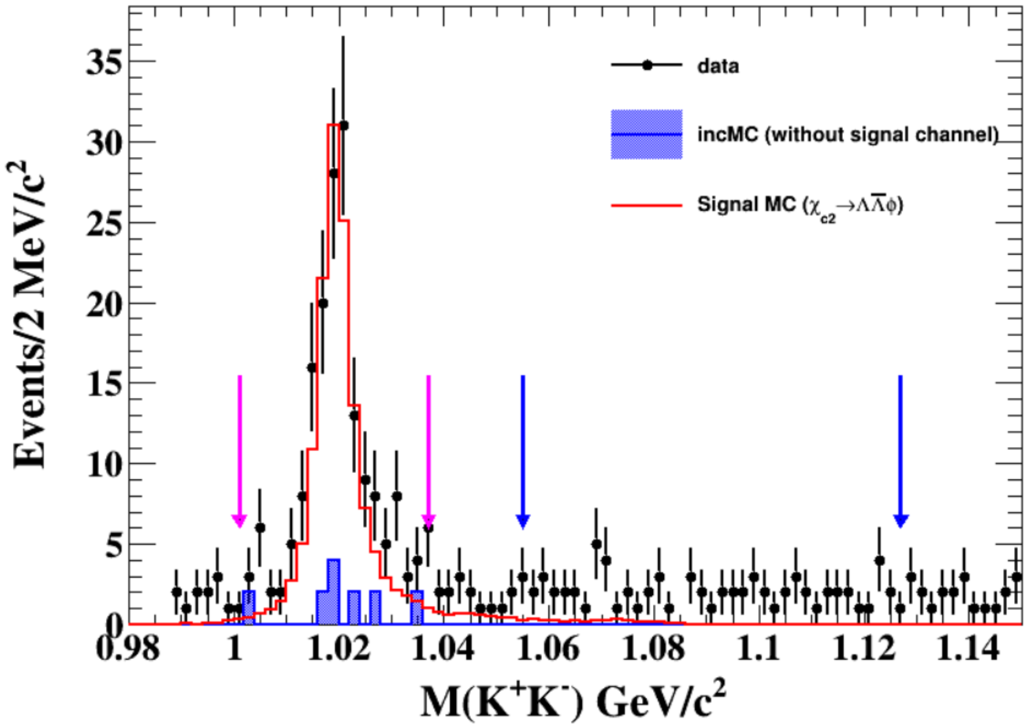


1D Signal region:

$|M(p\pi^{-}) - m(\Lambda)| < 6\ \mathrm{MeV/c^2}$

$|M(\bar{p}\pi^{+}) - m(\bar{\Lambda})| < 6\ \mathrm{MeV/c^2}$

Further Event selection: Mass window of ϕ



ϕ Signal region:

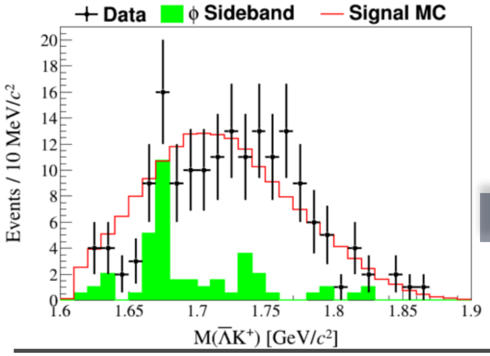
$|M(K^+K^-) - m(\phi)| < 0.018\ \mathrm{GeV/c^2}$

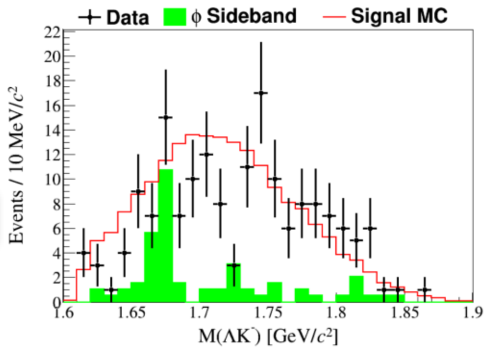
ϕ Sideband region:

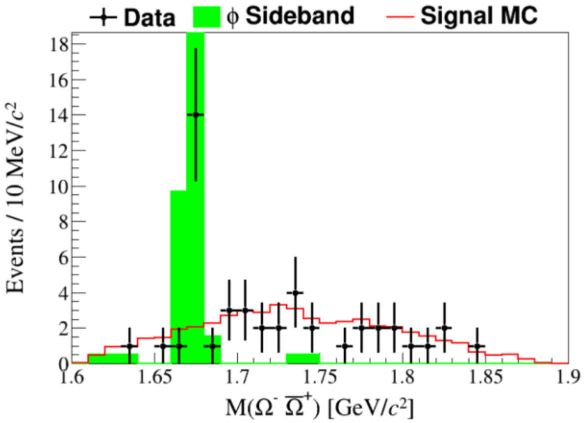
$1.055 < M(K^+K^-) < 1..127\ \mathrm{GeV/c^2}$

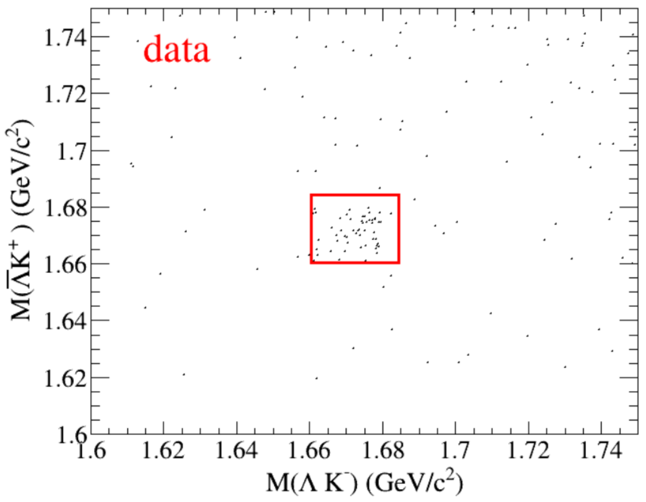
We fit the mass spectrum of K^+K^-,$\sigma = 6.07$MeV . And a sideband region is selected. Details can be found in the backup.

Further Event selection:
M(ΛK) & scatter plot: $M(\bar{\Lambda}K^{+})\ v.s.\ M(\Lambda K^{-})$









- Veto on $\chi_{cJ} \to \Omega^{-}\bar{\Omega}^{+}$:

! ($|M(\Lambda K^{-}) - m(\Omega^{-})| < 12\ \mathrm{MeV}/c^2$. & $|M(\bar{\Lambda}K^{+}) - m(\bar{\Omega}^{+})| < 12\ \mathrm{MeV}/c^2$)

- After the above event selection, the reconstruction efficiency for $\chi_{c0,1,2} \to \Lambda\bar{\Lambda}\phi$ is estimated to be:

  0.3%, 1.2% and 1.65% , respectively

Background study

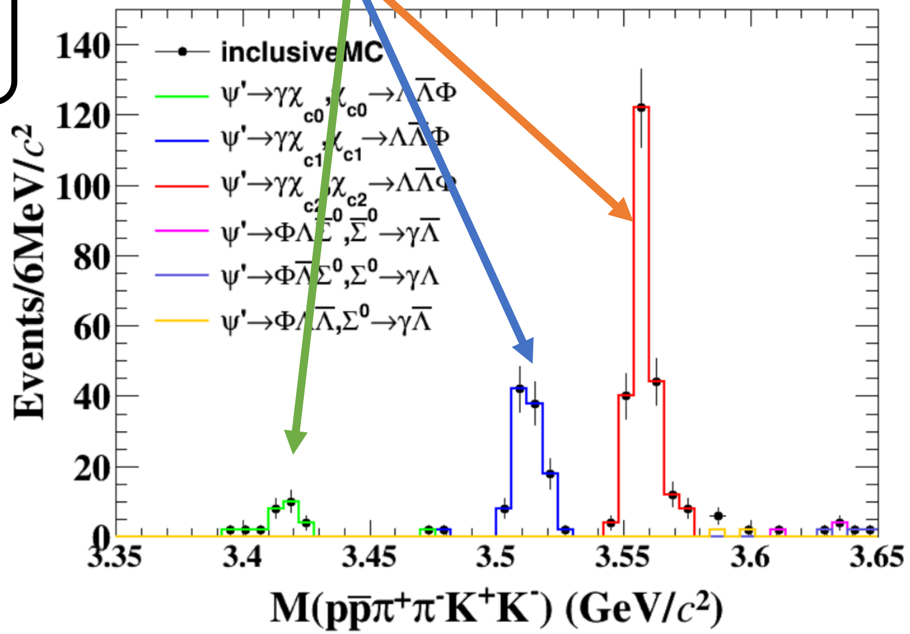
Table 1: Decay trees and their respective final states.

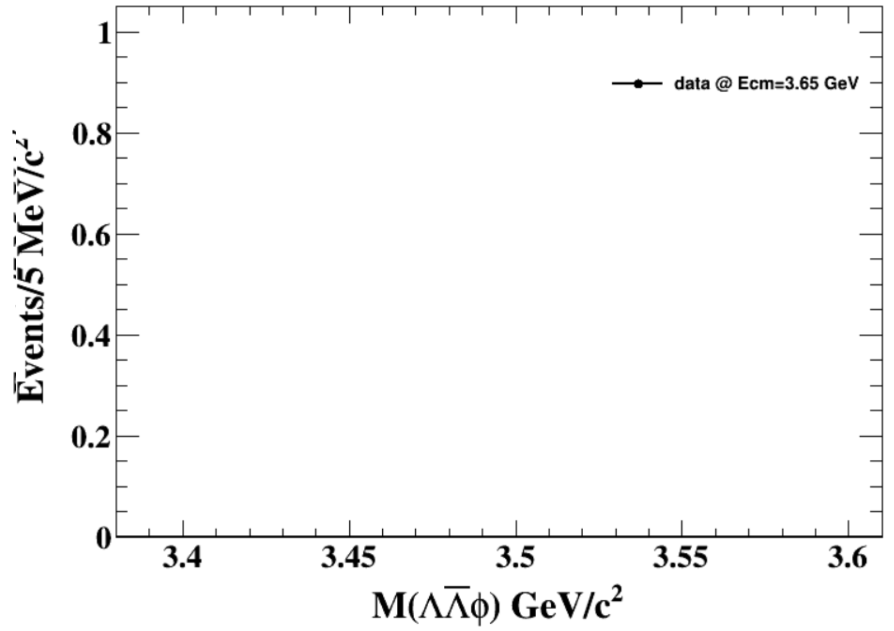
rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \chi_{c2}\gamma, \chi_{c2} \to \phi\Lambda\bar{\Lambda}, \phi \to K^+K^-, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^-K^+K^-p\bar{p}\gamma$	0	232	232
2	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to \phi\Lambda\bar{\Lambda}, \phi \to K^+K^-, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^-K^+K^-p\bar{p}\gamma$	1	110	342
3	$\psi' \to \chi_{c0}\gamma, \chi_{c0} \to \phi\Lambda\bar{\Lambda}, \phi \to K^+K^-, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^-K^+K^-p\bar{p}\gamma$	2	30	372
4	$\psi' \to \phi\Lambda\bar{\Sigma}^0, \phi \to K^+K^-, \Lambda \to \pi^-p, \bar{\Sigma}^0 \to \bar{\Lambda}\gamma, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^-K^+K^-p\bar{p}\gamma$	4	8	380
5	$\psi' \to \phi\Lambda\bar{\Lambda}, \phi \to K^+K^-, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^-K^+K^-p\bar{p}$	5	6	386
6	$\psi' \to \phi\bar{\Lambda}\Sigma^0, \phi \to K^+K^-, \bar{\Lambda} \to \pi^+\bar{p}, \Sigma^0 \to \Lambda\gamma, \Lambda \to \pi^-p$	$\pi^+\pi^-K^+K^-p\bar{p}\gamma$	3	4	390

To investigate possible background from continuum processes, the same selection criteria are applied to a data sample of collected at $\sqrt{s} = 3.65$ GeV. No events survived from the data at 3.65 GeV.

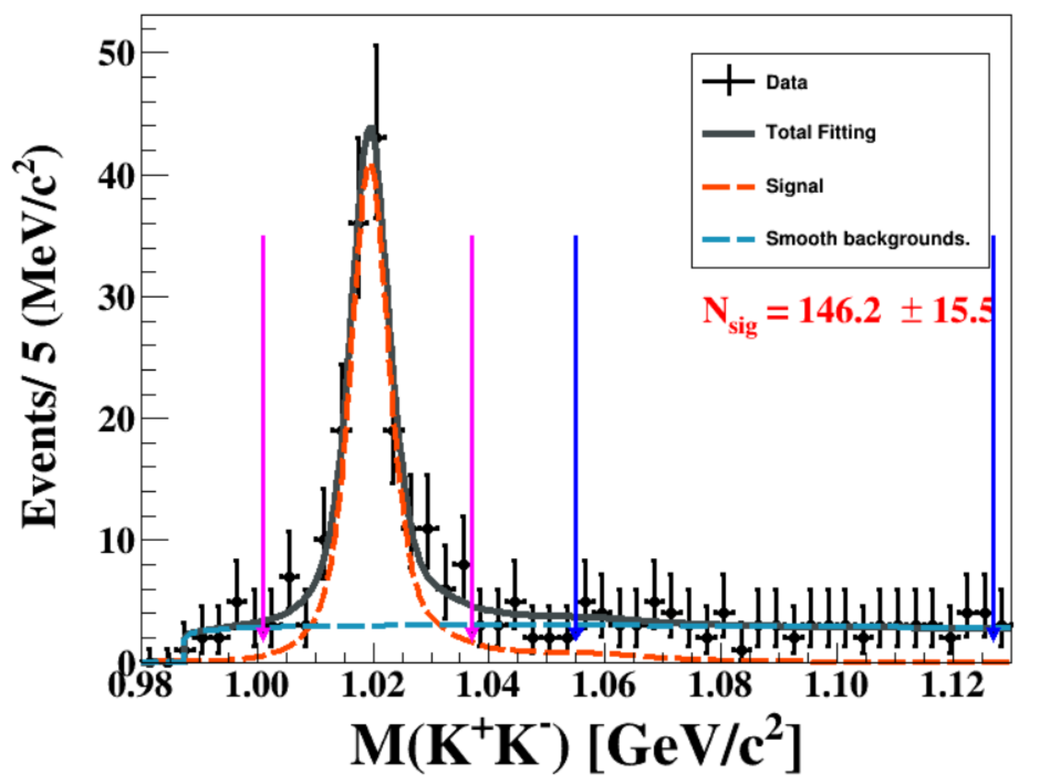
Signal Channel

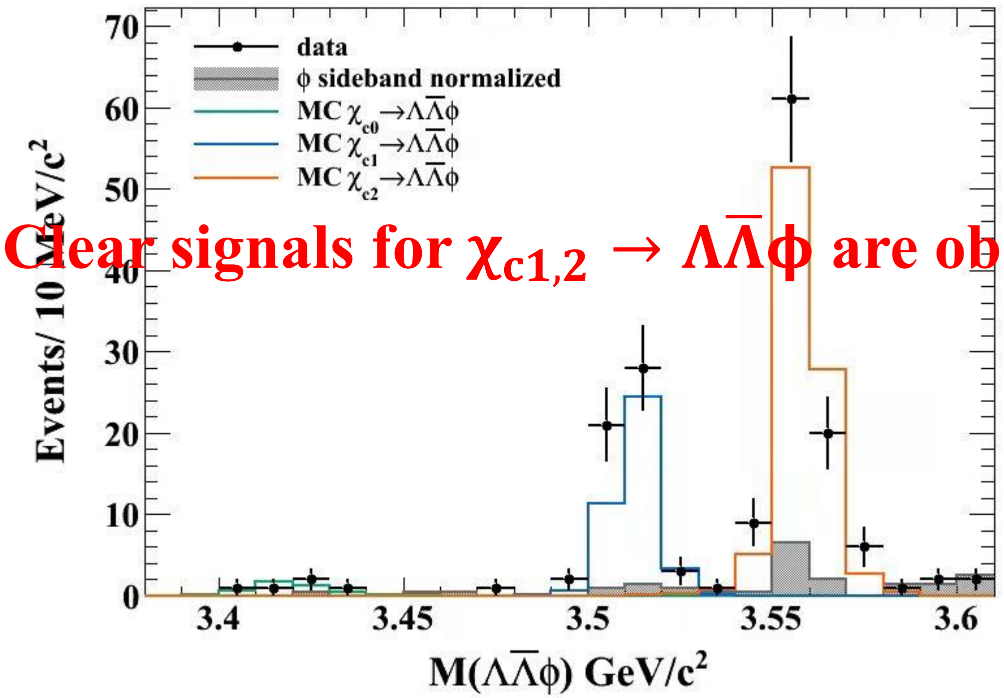
No peaking background





Background study

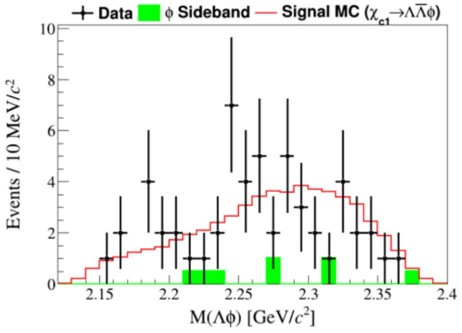


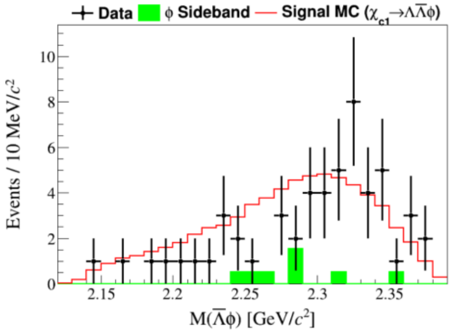


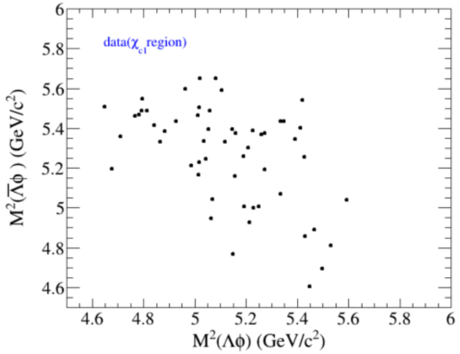
Clear signals for $\chi_{c1,2} \to \Lambda\bar{\Lambda}\phi$ are observed

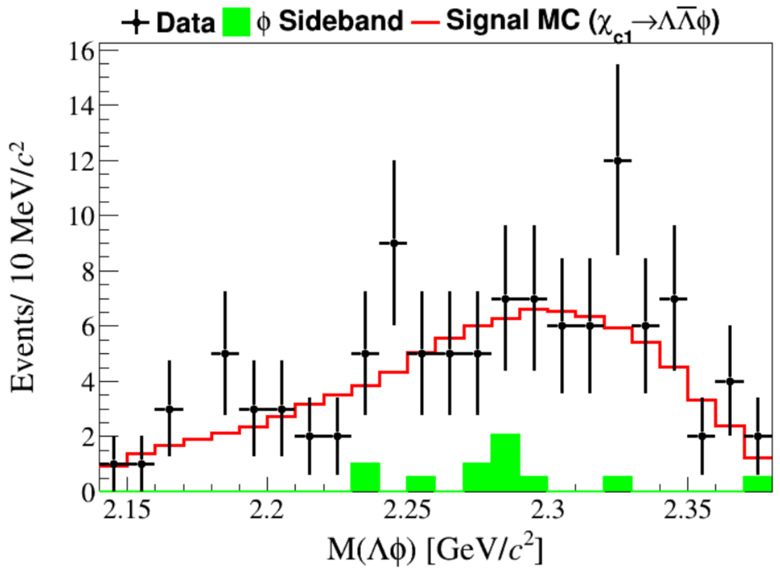
Signal region normalization : 25.6%
Sideband region normalization : 50.7%
normalization factor:
f_{ϕ} = 25.6% / 50.7% = 0.51

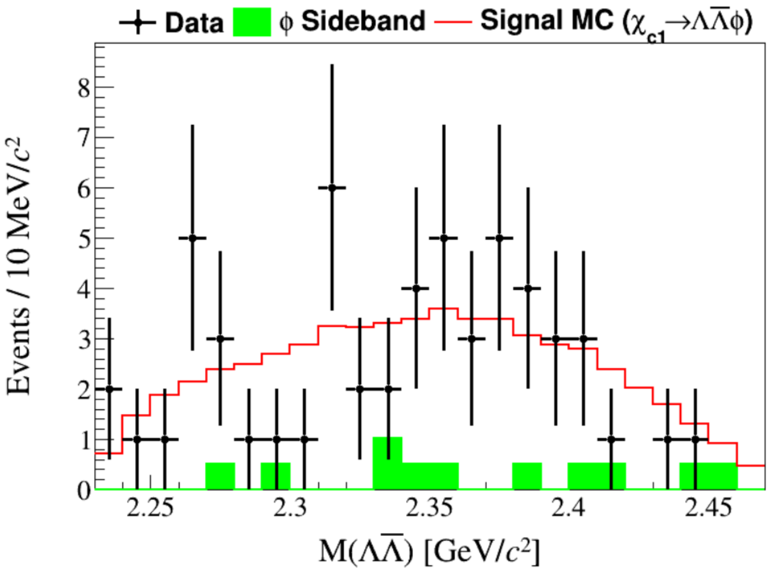
Dalitz Plot (I)
in χ_{c1} mass region

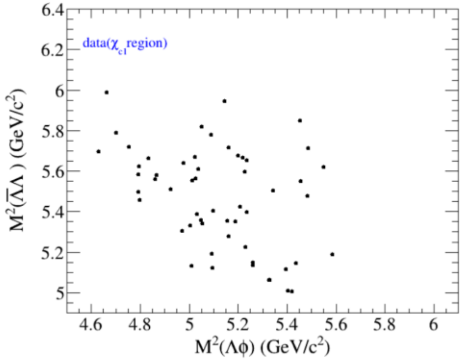


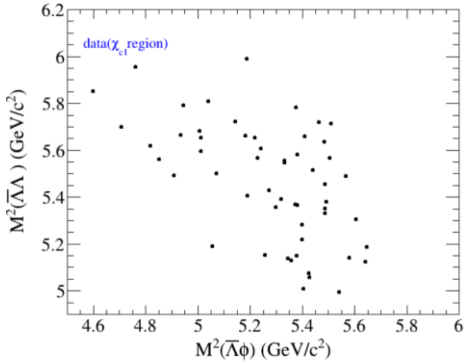






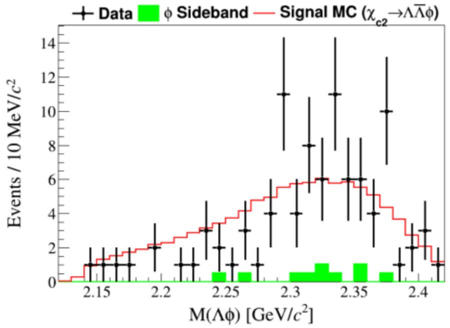


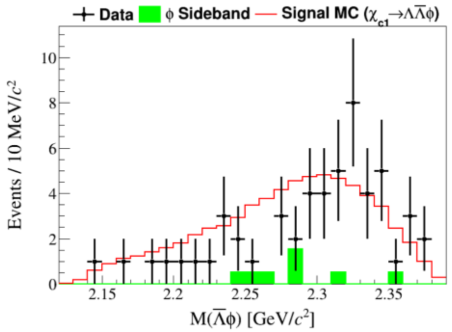


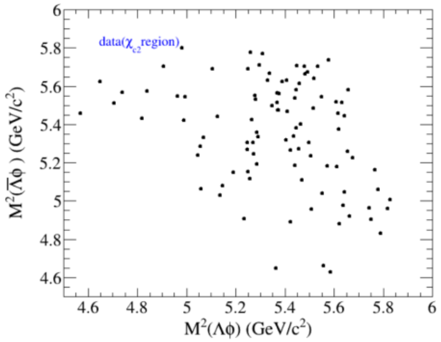


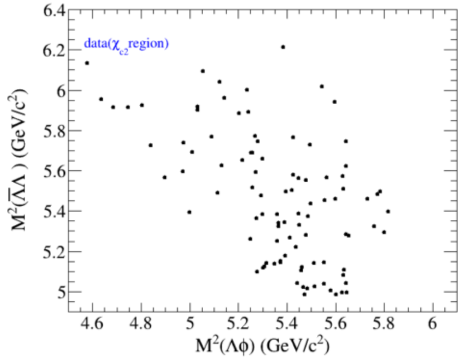
Dalitz Plot (II)

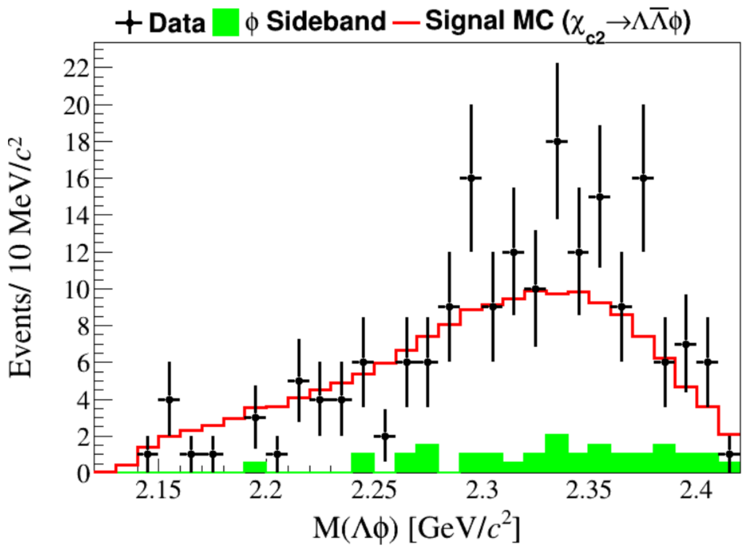
in χ_{c2} mass region

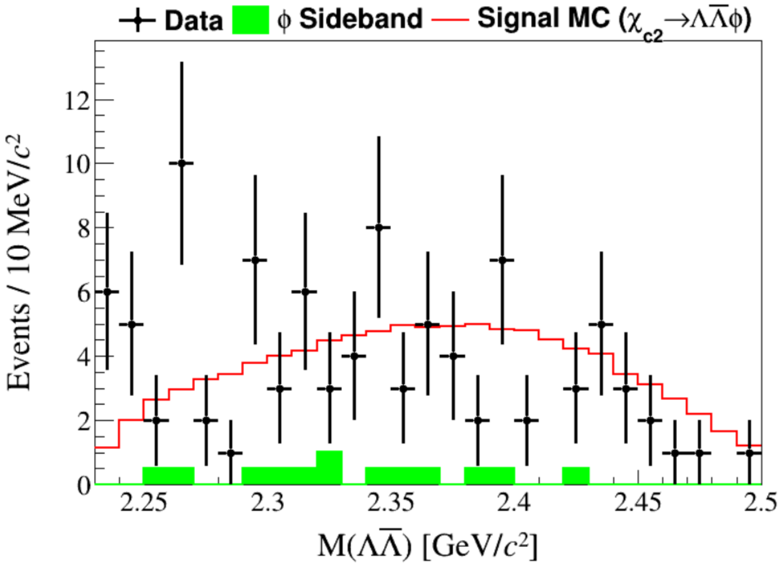


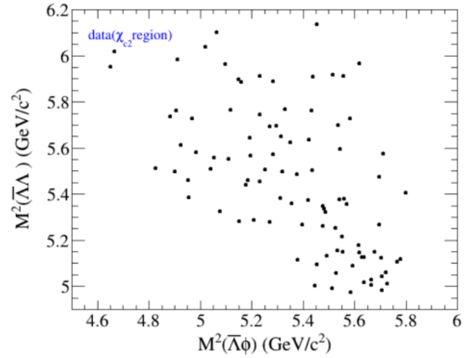




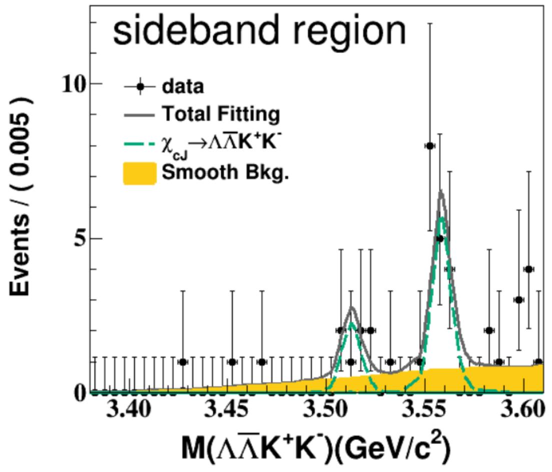


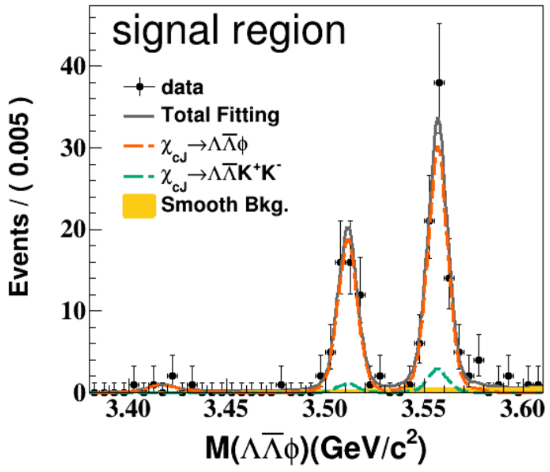






Fit to data





Mode	N^{obs}	ε(%)	$\mathcal{B}(\times 10^{-5})$	Significance(σ)
$\chi_{c0}\to\phi\Lambda\bar{\Lambda}$	4.6±2.3	0.3	~2.29	>5.5
$\chi_{c1}\to\phi\Lambda\bar{\Lambda}$	47.3±7.4	1.2	~7.28	10.9
$\chi_{c2}\to\phi\Lambda\bar{\Lambda}$	82.8±9.8	1.7	~8.46	14.1

$$\mathcal{B}(\chi_{cJ}\to\Lambda\bar{\Lambda}\phi)=\frac{N^{obs}_{\chi_{cJ}}}{N^{tot}_{\psi(3686)}\cdot\mathcal{B}(\psi(3686)\to\gamma\chi_{cJ})\cdot\mathcal{B}(\Lambda\to p\pi^-)\cdot\mathcal{B}(\bar{\Lambda}\to\bar{p}\pi^+)\cdot\mathcal{B}(\phi\to K^+K^-)\cdot\varepsilon_{\chi_{cJ}}}$$

- For the decay of $\chi_{cJ\to\Lambda\bar{\Lambda}\phi}$ (**φ sideband region**), the fitting function is described as below:

$$N_I^{obs}\cdot \text{SDMCShape}^{I} + N_I^{bkg}\cdot \text{BkgMCShape}^{I}$$

- For the decay of $\chi_{cJ\to\Lambda\bar{\Lambda}\phi}$ (**φ signal region**), the fitting function is described as below : $N^{obs}_{\chi_{cJ}}\cdot \text{SigMCShape}\otimes\text{Gauss} + f_\phi\cdot N_I^{obs}\cdot\text{SDMCShape}^{II} + N_{II}^{bkg}\cdot \text{BkgMCShape}^{II}$
  - The SDMCShape is the MC-simulated shape of decay $\psi(3686)\to\gamma\chi_{cJ}$, $\chi_{cJ}\to\Lambda\bar{\Lambda}K^+K^-$
  - The BkgMCShape is the MC-simulated shape of decay $\psi(3686)\to\gamma\Lambda\bar{\Lambda}\phi$
  - N_I^{obs} is fixed according to the previous fitting of the sideband region.
    - Assume that $N^{data}_{\psi(3686)}$ = 2.8 Billion

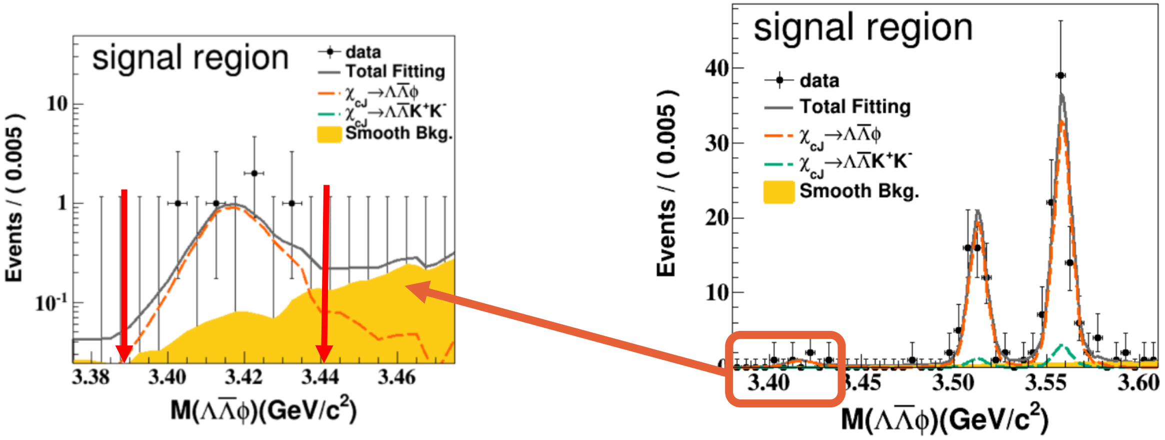
Determining the statistical significance of χ_{c0}

- Assuming that the numbers of total events (**n**) in χ_{c0} signal region , n = s + b, s and b are denote signal and background, respectively. The probability distribution is expressed as

$$\mathbf{P}(n; s, b) = \frac{(\mathbf{s}+\mathbf{b})^{n}}{n!} e^{-(\mathbf{s}+\mathbf{b})},$$

- If taking 2σ width as the signal region, we have **n** = 5, b = 0.03, and s = $\lfloor n-b \rfloor \approx 4$. Suppose s = 0, P-value= 4.06×10^{-9} . The statistical significance is 5.5σ.

- Therefore, the statistical significance of $\chi_{c0} \to \Lambda\bar{\Lambda}\phi$ is not less than 5.5σ.



[5] M. Ablikim *et al*. (BESIII Collaboration), Phys. Rev. D 97, 032008 (2018)

Systematic uncertainty [I]

I. **Total number of $\psi(3686)$**[6]

II. **Tracking Efficiency and Photon Detection efficiency**[7]

III. **PID**[7]

IV. **Mass window:** The main Background comes from decay $\chi_{cJ} \to \Omega^-\bar{\Omega}^+$, ϕ mass window and $\Lambda(\bar{\Lambda})$ mass window.

- The systematic error of the above mass window is obtained by changing the interval comparison of the mass window.

V. **ϕ sideband**

- The systematic error of ϕ sideband is obtained by changing the sideband region (changing the multiple of signal region).

VI. **Kinematic fit**： Two control samples are employed to study the systematic error due to 4-C kinematic fit， the are $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \Lambda\bar{\Lambda}$ and $\psi(3686) \to \eta J/\psi$, $J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}$.

- The signal events is extracted once again after imposing the 4-C kinematic fit on the candidate charged and neutral track.

We define the efficiency of 4-C kinematic fit systematic error as below:

$$\epsilon_{4C} = \frac{N_{obs}(with-4Cfit)}{N_{obs}(without-4Cfit)}$$

The difference between data and inclusive MC is found to be systematic uncertainty.

[6] ABLIKIM M, et al. Determination of the number of ψ(3686) events at BESIII[J/OL]. Chin.Phys. C, 2018, 42(2):023001. DOI: 10.1088/1674-1137/42/2/023001

[7] M. Ablikim et al. [BESIII], Phys. Rev. D 83 (2011), 112005

Systematic uncertainty [II]

VIII. Simultaneous fit

- Signal Shape: We describe the probability density function of the signal by replacing the **SigMCShape** ⊗ **Gauss** with **SigMCShape** , and take the difference between before and after as the systematic error.
- Background shape： Second order polynomial is used to describe the background shape, and the difference from the original result is taken as the systematic error of this term.
- Fitting range： By changing the fitting range , the one with greatest difference from the original result is taken as the systematic error.

IX. Branching fraction quoted

- The uncertainties to the quoted decay branching fraction of the intermediate particles are extracted from the PDG.

Systematic uncertainty [III]

mode	$\chi_{c0} \to \Lambda\bar{\Lambda}\phi$	$\chi_{c1} \to \Lambda\bar{\Lambda}\phi$	$\chi_{c2} \to \Lambda\bar{\Lambda}\phi$
Ω mass window	21%	0.8%	0.6%
ϕ mass window	11.3%	3.3%	0.8%
$\Lambda(\bar{\Lambda})$ mass window	4.5%	1.3%	0.4%
ϕ sideband	0.7%	1.3%	3.8%
Fit	4.9%	2.5%	2.4%
Kaon PID	2%	2%	2%
Tracking for Kaon	2%	2%	2%
Detection for proton	2%	2%	2%
Kinematic fit	1.28%	1.28%	1.28%
Branching fraction quoted（from PDG）	2.5%	2.9%	2.6%
The total number of $\psi(3686)$	0.6%	0.6%	0.6%
Total	25.2%	6.6%	6.5%

Summary & Next to do

Using about ~2.8 billion $\psi(3686)$ data sample collected at BESIII in 2009, 2012 and 2021:

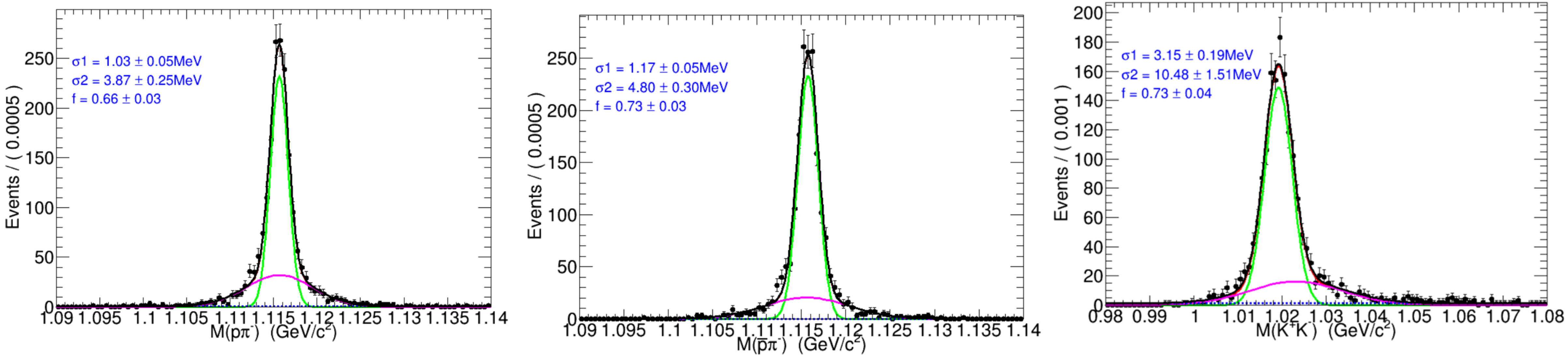
- ✓ The decay of $\chi_{cJ} \to \Lambda\bar{\Lambda}\phi$ is searched for the **first time, with full reconstruction.**
- ✓ Signal of $\chi_{c1,2} \to \Lambda\bar{\Lambda}\phi$ are observed with significance of 10.9σ and 14.1σ,respectively.
- ✓ Signal of $\chi_{c0} \to \Lambda\bar{\Lambda}\phi$ is observed with significance not less than 5.5σ.
- ✓ No obvious structure found in the $\Lambda\phi$ and $\Lambda\bar{\Lambda}$ system .
- ✓ The systematic uncertainty of the decay of $\chi_{c0,1,2} \to \Lambda\bar{\Lambda}\phi$ is 25.2%, 6.6% and 6.5%,respectively.

Next to do

- ☐ Systematic uncertainty of $\Lambda(\bar{\Lambda})$ reconstruction.
- ☐ Update the systematic uncertainty of tracking efficiency , photon detection efficiency and PID.

Thank
You!
;)

Back up



We fit the mass spectrum of $p\pi^-$, $\bar{p}\pi^+$, $\sigma_{p\pi^-} = 2.4MeV$, $\sigma_{\bar{p}\pi^+} = 2.6MeV$

We fit the mass spectrum of K^+K^-,$\sigma = 6.07MeV$. And a sideband region is selected.
$1.055 < \mathrm{M}(\mathrm{K}^+\mathrm{K}^-)_{\mathrm{sideband}} < 1.091\ \mathrm{GeV/c^2}$

Final Event selection:

Final event selection:

- $\chi^2_{4c}(\gamma\bar{p}p^-K^+K^-\pi^+\pi^-) < 60$
- $\chi^2_{4c}(\gamma\bar{p}p^-K^+K^-\pi^+\pi^-) < \chi^2_{4c}\ (2\gamma\bar{p}p^-K^+K^-\pi^+\pi^-)$
- lengh1>0 && lengh2>0
- $|M(p\pi^-) - m(\Lambda)| < 8\ \ MeV/c^2$&& $|M(\bar{p}\pi^+) - m(\bar{\Lambda})| < 8\ \ MeV/c^2$

ϕ Signal region:

- $|M(K^+K^-) - m(\phi)| < 0.018\ \ GeV/c^2$

ϕ Sideband region:

- $1.055 < M(K^+K^-)\ < 1.127\ GeV/c^2$

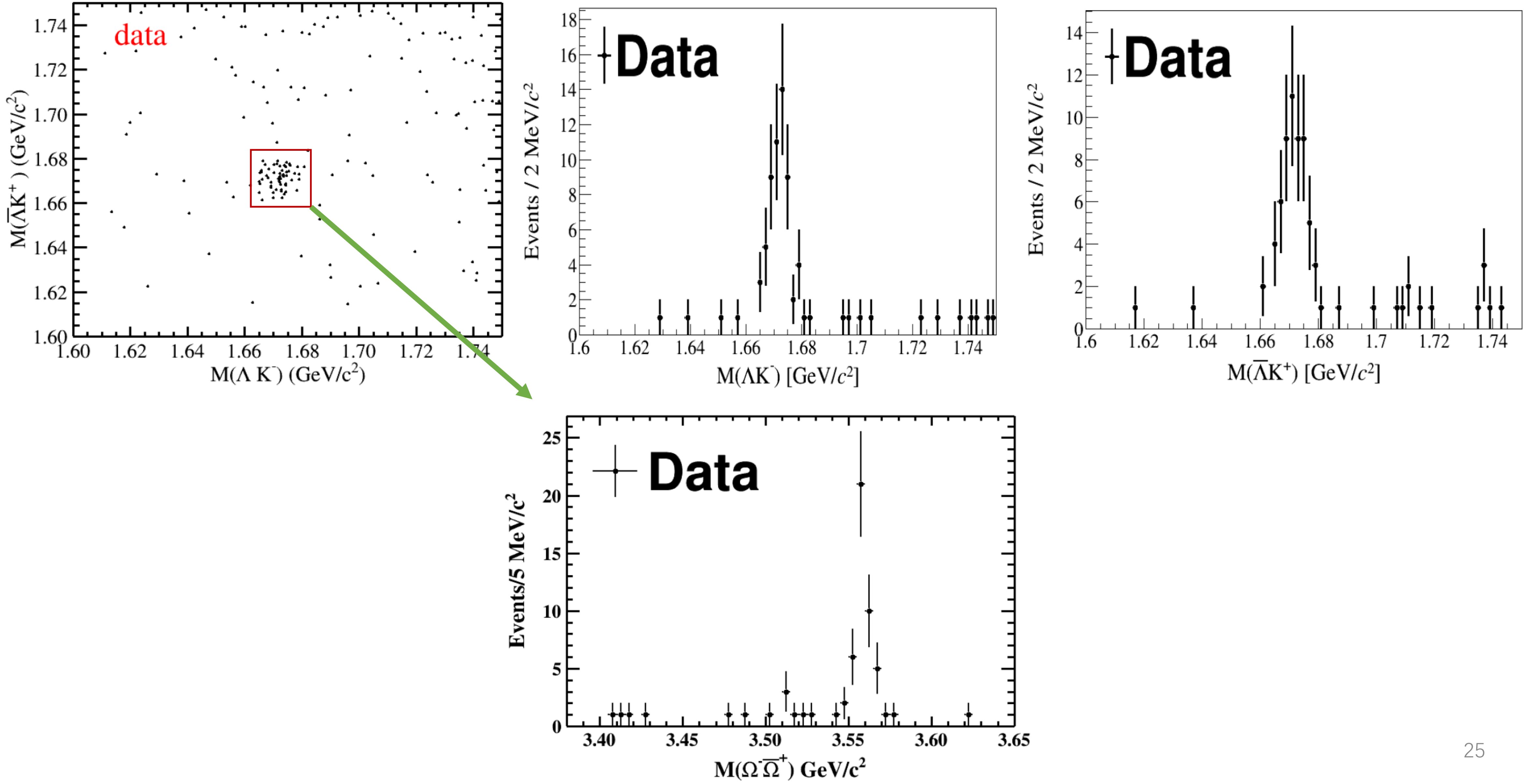
Veto $\chi_{cJ} \rightarrow \Omega^-\bar{\Omega}^+$:

- ! [$|M(\boldsymbol{\Lambda K^-}) - m(\boldsymbol{\Omega^-})| < 10\ \ MeV/c^2$ & $|M(\bar{\Lambda}\boldsymbol{K^+}) - m(\bar{\boldsymbol{\Omega}}^+)| < 10\ \ MeV/c^2$]

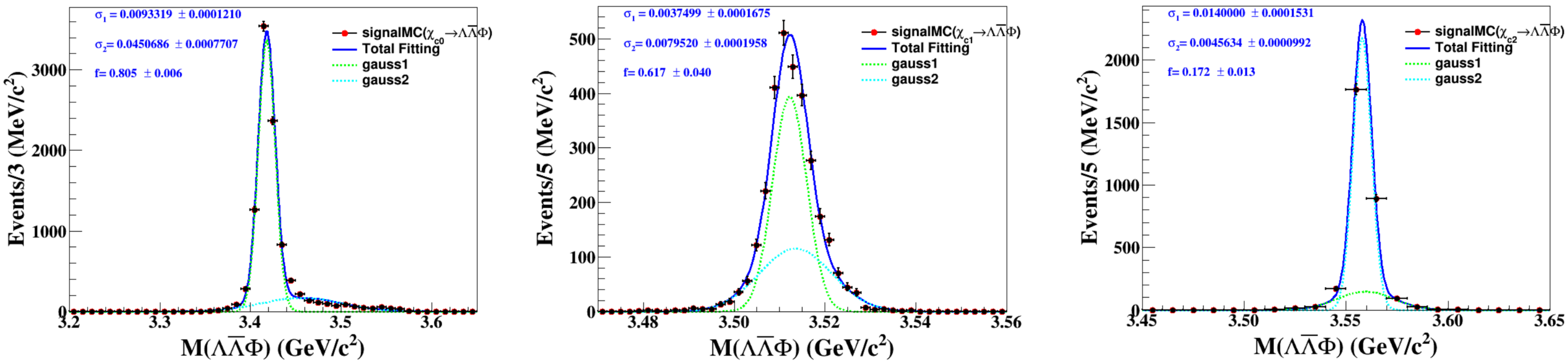
Argus Function * :

$$Argus(m; m_0, c, p) = \begin{cases} 0, & (\text{ if } m < m_0 \text{ }) \\ m \cdot u^p \cdot e^{c \cdot u}, & (\text{ if } m \geq m_0, u = 1 - (m/m_0)^2 \text{ }) \end{cases}$$

$\chi_{cJ} \to \Omega^- \overline{\Omega}^+$



Back up



Systematic uncertainty of Fit.

Mode	$\chi_{c0} \rightarrow \Lambda\bar{\Lambda}\phi$	$\chi_{c1} \rightarrow \Lambda\bar{\Lambda}\phi$	$\chi_{c2} \rightarrow \Lambda\bar{\Lambda}\phi$
Signal shape	2.5%	1.4%	0.26%
Background shape	3.3%	0.4%	1.8%
Fitting range	2.8%	2.1%	1.5%
Fit	4.9%	2.5%	2.4%

Event selection of $\psi \to \eta J/\psi,\ J/\psi \to \Lambda\bar{\Lambda}\pi^{+}\pi^{-}$[1]

- **Charge track**

- With the same selection criteria as $\psi(3686) \to \gamma\chi_{cJ} \to \gamma\Lambda\bar{\Lambda}$
- $\mathrm{N_{positive}} \geq 3, \mathrm{N_{negative}} \geq 3$

- **Good photon**

- $\mathbf{N_{\gamma}} \geq 2$

- **Λ ($\bar{\Lambda}$)reconstruction**

Looping over all the combination of positive and negative charged tracks pairs. We require two virtual particle, Λ and $\bar{\Lambda}$ can be reconstructed in this combinations. Then ,the minimum mass deviation is combined (Δ, see previous description) of $\Lambda\bar{\Lambda}$ to selected them.

$$\Delta_{\min} = \left(M_{p\pi^-} - m_{\Lambda}\right)^2 + \left(M_{\bar{p}\pi^+} - m_{\bar{\Lambda}}\right)^2 \Rightarrow \Lambda_{\min}, \bar{\Lambda}_{\min}$$

- **η list**
  - A kinematic fit is performed on the selected photon pairs by constraining their invariant mass to the η mass.

- **π^{+} and and π^{-}(not from Λ or $\bar{\Lambda}$ decay) selection**
  - the charged track not belonging to any of $\Lambda(\bar{\Lambda})$ candidates
  - $|\mathrm{V_z}| < 10, |\mathrm{V_{xy}}| < 1$

- The signal events is extracted once again after imposing the 4-C kinematic fit on the candidate charged and neutral track. We define the efficiency of 4-C kinematic fit systematic error as below:

$$\epsilon_{4C} = \frac{N_{obs}(with{-}4Cfit)}{N_{obs}(without{-}4Cfit)}$$

The difference between data and inclusive MC is found to be systematic uncertainty.

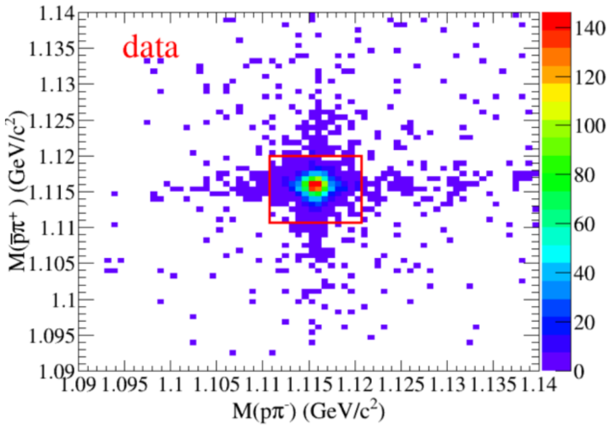
Final Event selection of $\psi \rightarrow \eta J/\psi,\ J/\psi \rightarrow \Lambda\bar{\Lambda}\pi^{+}\pi^{-}$[2]

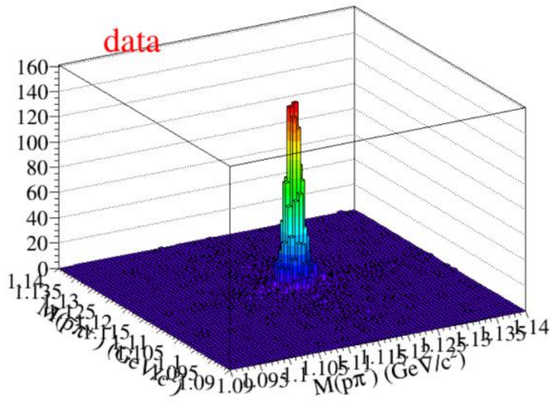
- lengh1>0
- lengh2>0
- $|M(p\pi^-) - m(\Lambda)| < 5\ MeV/c^2 \&\& |M(\bar{p}\pi^+) - m(\bar{\Lambda})| < 5\ MeV/c^2$
- $|M(\eta)^{rec} - m(J/\psi)| < 0.006\ GeV/c^2$
- $|M(\pi^+\pi^-)^{rec} - m(J/\psi)| > 0.005 GeV/c^2$

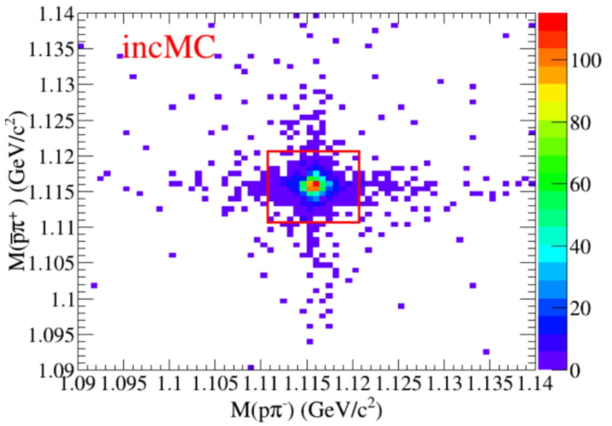
Table 1: Decay trees and their respective final states.

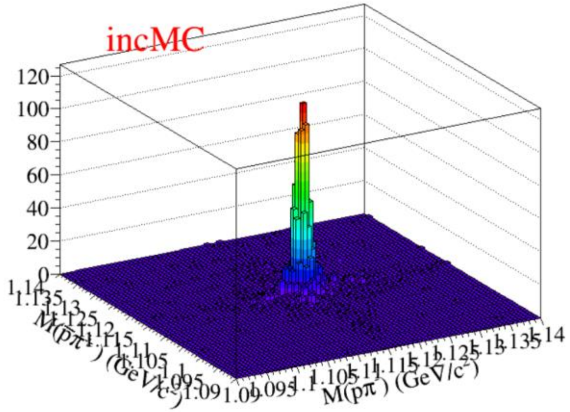
rowNo	decay tree	decay final state	iDcyTr	nEtr	nCEtr
1	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	101	540	540
2	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \Sigma^{*+}\bar{\Sigma}^{*-}, \Sigma^{*+} \to \pi^+\Lambda, \bar{\Sigma}^{*-} \to \pi^-\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	0	243	783
3	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \bar{\Sigma}^{*+}\Sigma^{*-}, \bar{\Sigma}^{*+} \to \pi^+\bar{\Lambda}, \Sigma^{*-} \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	7	239	1022
4	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	201	153	1175
5	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	11	123	1298
6	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \pi^+\Sigma^{*-}\bar{\Lambda}, \Sigma^{*-} \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	19	109	1407
7	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \pi^+\Lambda\bar{\Sigma}^{*-}, \Lambda \to \pi^-p, \bar{\Sigma}^{*-} \to \pi^-\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	10	107	1514
8	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to J/\psi\gamma, J/\psi \to \pi^+\pi^-\Lambda\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	200	105	1619
9	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \pi^-\bar{\Lambda}\Sigma^{*+}, \bar{\Lambda} \to \pi^+\bar{p}, \Sigma^{*+} \to \pi^+\Lambda, \Lambda \to \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	1	100	1719
10	$\psi' \to \eta J/\psi, \eta \to \gamma\gamma, J/\psi \to \pi^-\bar{\Sigma}^{*+}\Lambda, \bar{\Sigma}^{*+} \to \pi^+\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	17	92	1811
11	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \Sigma^{*+}\bar{\Sigma}^{*-}, \Sigma^{*+} \to \pi^+\Lambda, \bar{\Sigma}^{*-} \to \pi^-\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	3	62	1873
12	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \bar{\Sigma}^{*+}\Sigma^{*-}, \bar{\Sigma}^{*+} \to \pi^+\bar{\Lambda}, \Sigma^{*-} \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	4	53	1926
13	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to J/\psi\gamma, J/\psi \to \Sigma^{*+}\bar{\Sigma}^{*-}, \Sigma^{*+} \to \pi^+\Lambda, \bar{\Sigma}^{*-} \to \pi^-\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	25	46	1972
14	$\psi' \to \pi^+\pi^- J/\psi, J/\psi \to \eta\Lambda\bar{\Lambda}, \eta \to \gamma\gamma, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	9	45	2017
15	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	6	40	2057
16	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+\Sigma^{*-}\bar{\Lambda}, \Sigma^{*-} \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	14	34	2091
17	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^-\bar{\Lambda}\Sigma^{*+}, \bar{\Lambda} \to \pi^+\bar{p}, \Sigma^{*+} \to \pi^+\Lambda, \Lambda \to \pi^-p$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	59	32	2123
18	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to J/\psi\gamma, J/\psi \to \bar{\Sigma}^{*+}\Sigma^{*-}, \bar{\Sigma}^{*+} \to \pi^+\bar{\Lambda}, \Sigma^{*-} \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	36	32	2155
19	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to J/\psi\gamma, J/\psi \to \bar{\Xi}^+\Xi^-, \bar{\Xi}^+ \to \pi^+\bar{\Lambda}, \Xi^- \to \pi^-\Lambda, \bar{\Lambda} \to \pi^+\bar{p}, \Lambda \to \pi^-p$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	40	23	2178
20	$\psi' \to \pi^0\pi^0 J/\psi, J/\psi \to \pi^+\Lambda\bar{\Sigma}^{*-}, \Lambda \to \pi^-p, \bar{\Sigma}^{*-} \to \pi^-\bar{\Lambda}, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^0\pi^0\pi^+\pi^+\pi^-\pi^-p\bar{p}$	53	21	2199
21	$\psi' \to \chi_{c1}\gamma, \chi_{c1} \to J/\psi\gamma, J/\psi \to \pi^-\bar{\Sigma}^{*+}\Lambda, \bar{\Sigma}^{*+} \to \pi^+\bar{\Lambda}, \Lambda \to \pi^-p, \bar{\Lambda} \to \pi^+\bar{p}$	$\pi^+\pi^+\pi^-\pi^-p\bar{p}\gamma\gamma$	18	19	2218

scatter plot: $M(\bar{p}\pi^{+})\ v.s.\ M(p\pi^{-})$

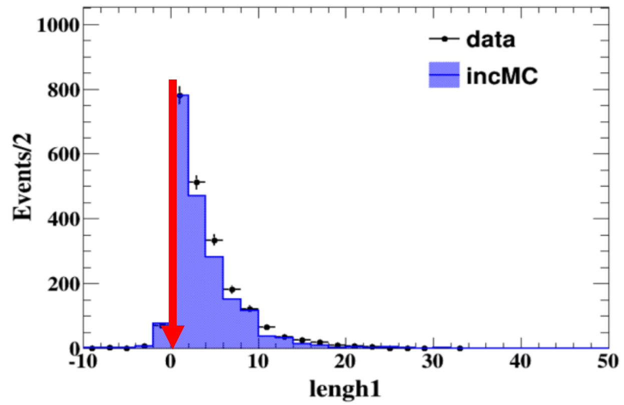


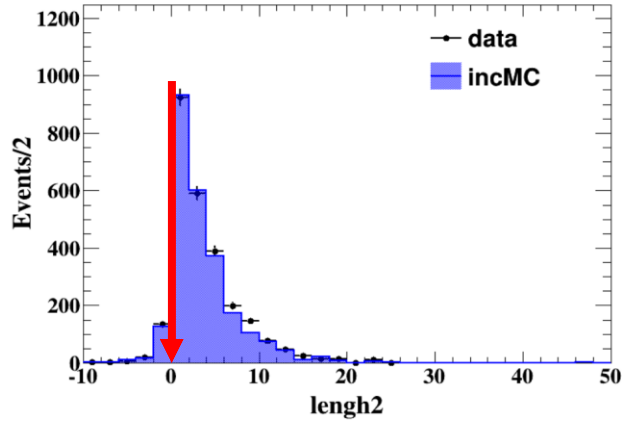






Decay length

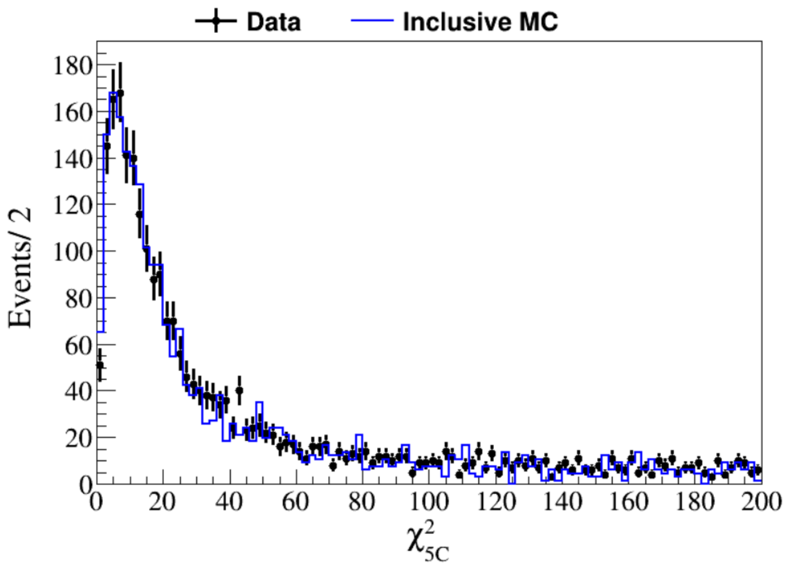


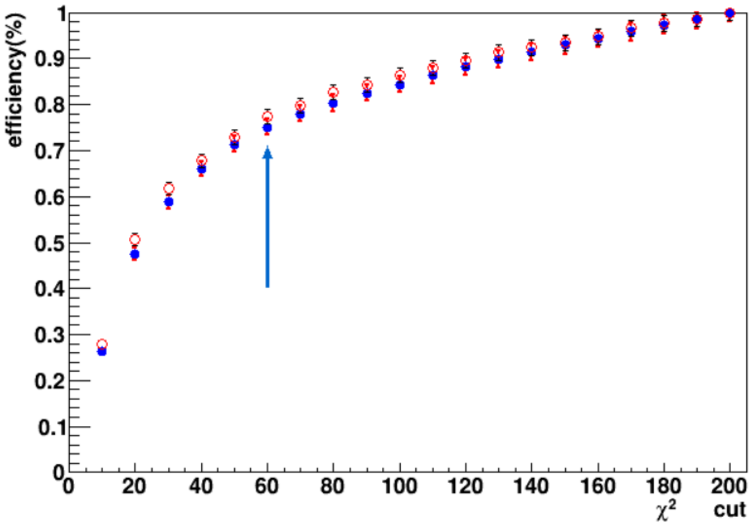


Final event selection:

- lengh1>0
- lengh2>0

Control sample: $\psi \to \eta J/\psi,\ J/\psi \to \Lambda\bar{\Lambda}\pi^+\pi^-$ [3]





$\chi^2 < 60\,,\epsilon_{5C} = 1.28\%$