Search for $X(3823)$ new decay modes

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Outline

1、Motivation
2、Data sets
3、Study of $e^+e^- \to \pi^+\pi^- X(3823), X(3823) \to \gamma\chi_{c1}$
4、Search for $X(3823)$ new decay modes
$X(3823) \to \gamma\chi_{c0}, \gamma\chi_{c2}, \eta J/\psi, \pi^0 J/\psi, \pi^+\pi^- J/\psi, \pi^0\pi^0 J/\psi$
5、Systematic uncertainty estimation
6、Summary

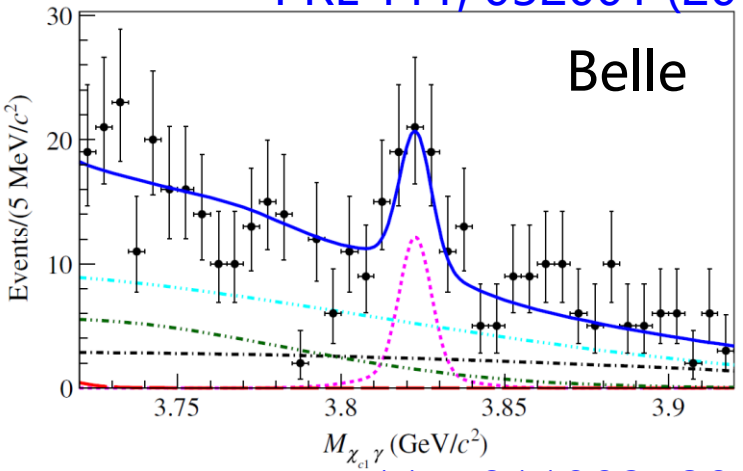
Motivation

1. Evidence of $X(3823)$ was found by Belle, then BESIII observed the state.

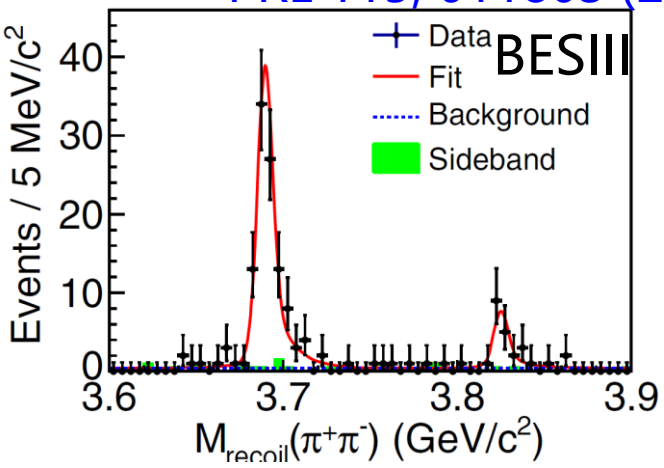
2. Until now, only $X(3823)$ decay mode $X(3823) \to \gamma\chi_{c1}$ is observed. More decay modes will be searched for, such as $\gamma\chi_{c0}$, $\gamma\chi_{c2}$, $\eta J/\psi$, $\pi^0 J/\psi$, $\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$. It is useful to understand the nature of $X(3823)$.

3. In this work, we will try to search for these $X(3823)$ decay modes.

PRL 111, 032001 (2013)



PRL 115, 011803 (2015)



PDG

$\psi_2(3823)$ MASS	3822.2 ± 1.2 MeV
$\psi_2(3823)$ WIDTH	< 16 MeV CL=90.0%

Decay Modes

Mode		Fraction (Γ_i/Γ)	Scale Factor/ Conf. Level	P (MeV/c)
Γ_1	$\chi_{c1}\gamma$	seen		299
Γ_2	$\chi_{c2}\gamma$	not seen		257

Data sets

Boss Version : 7.0.3 and 7.0.4

Data sets :

All XYZ data at $\sqrt{s}$ >4.3 GeV, it includes:

Previous data:

4310scan,4360,4390scan,4420,4420scan,4470,4530,4575,4600
(9 energy points)

New data:

4315,4340,4380,4400,4440
(5 energy points)

Data sets

Signal MC :

1、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \gamma\chi_{c1}$, $\chi_{c1} \to \gamma J/\psi$
2、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \gamma\chi_{c2}$, $\chi_{c2} \to \gamma J/\psi$
3、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \eta J/\psi$, $\eta \to \gamma\gamma$
4、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \pi^0 J/\psi$, $\pi^0 \to \gamma\gamma$
5、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \pi^0\pi^0 J/\psi$, $\pi^0 \to \gamma\gamma$
6、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \pi^+\pi^- J/\psi$
7、$e^+e^- \to \pi^+\pi^- X(3823)$, $X(3823) \to \gamma\chi_{c0}$, $\chi_{c0} \to \pi^+\pi^-/K^+K^-$

Some possible background MC :

1、$e^+e^- \to \eta J/\psi$, $\eta \to \pi^+\pi^-\pi^0$
2、$e^+e^- \to \eta' J/\psi$, $\eta' \to \pi^+\pi^-\eta$
3、$e^+e^- \to \eta\psi'$, $\psi' \to \pi^+\pi^- J/\psi$
4、$e^+e^- \to \pi^0\psi'$, $\psi' \to \pi^+\pi^- J/\psi$
5、$e^+e^- \to \pi^+\pi^-\psi'$, $\psi' \to \pi^+\pi^- J/\psi$
6、$e^+e^- \to \pi^0\pi^0\psi'$, $\psi' \to \pi^+\pi^- J/\psi$

$$X(3823) \to \gamma\chi_{c1}$$

$$\chi_{c1} \to \gamma J/\psi \to \gamma e^+e^-/\mu^+\mu^-$$

Event selections

Charged tracks
- $|R_{xy}| < 1cm, |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $N = 4, \sum Q = 0$

Particle identification
- π : $P_{mdc} < 1$ GeV
- e : $P_{mdc} > 1$ GeV&&$E_{emc} > 1$ GeV
- μ : $P_{mdc} > 1$ GeV&&$E_{emc} < 0.4$ GeV

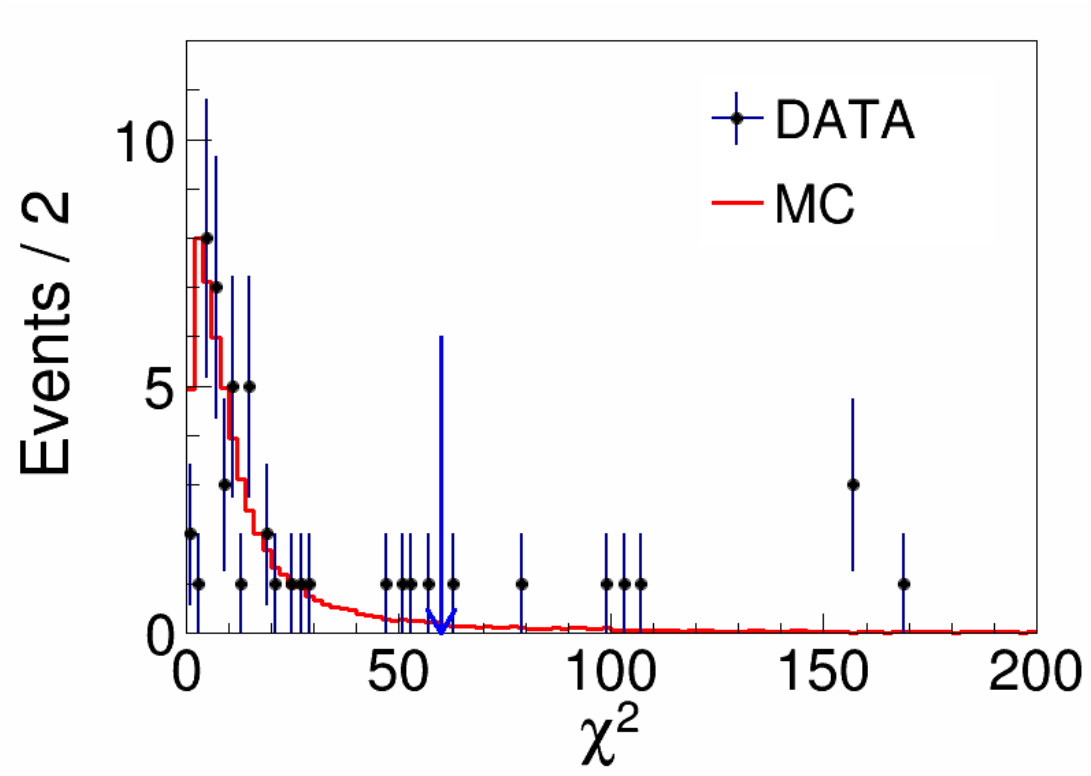
Good photon
- $0 \leq TDC \leq 14$
- Barrel :
  $E > 0.025$ GeV, $|cos\theta| < 0.8$
- Endcap :
  $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\Delta\theta > 10^0$
- $N_\gamma \geq 2$

4C kinematic fit
- Choose the photons with least χ^2
- $\chi^2 < 60$

Other selections
- J/ψ mass window : (3.075, 3.125) GeV
- Veto π^0 : (0.11, 0.16) GeV
- Veto η : (0.51, 0.58) GeV
- χ_{c1} mass window : (3.49, 3.53) GeV

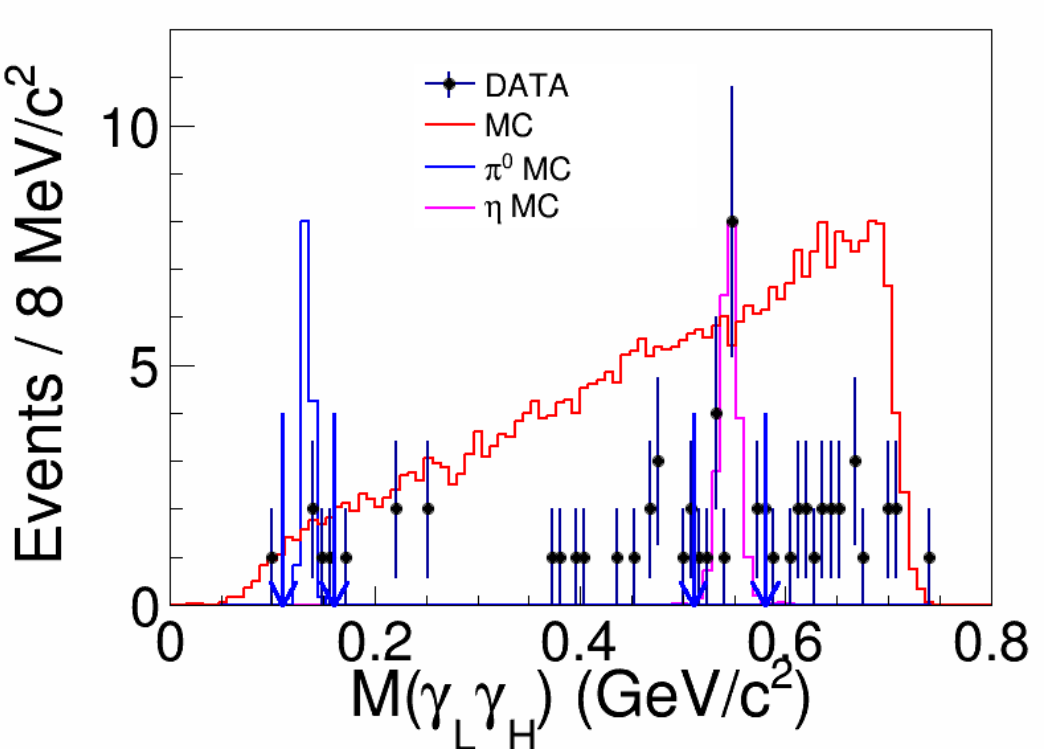
χ^2 distribution

Note: All the figures below are for events in $X(3823)$ fit region [3.77, 3.88] GeV, and after all other requirements are applied.



χ^2 distribution from 4C: $\chi^2 < 60$

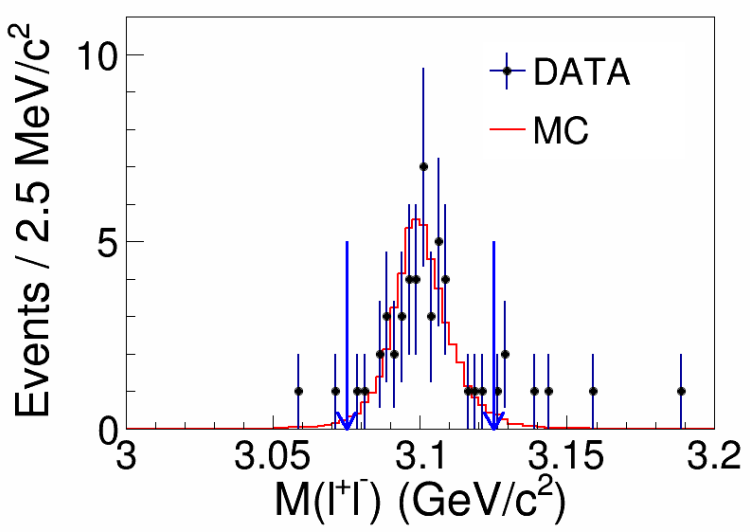
Background study

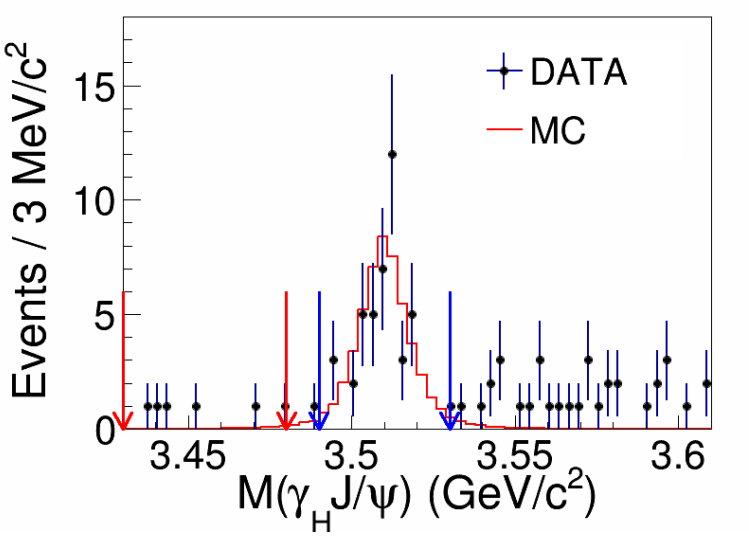


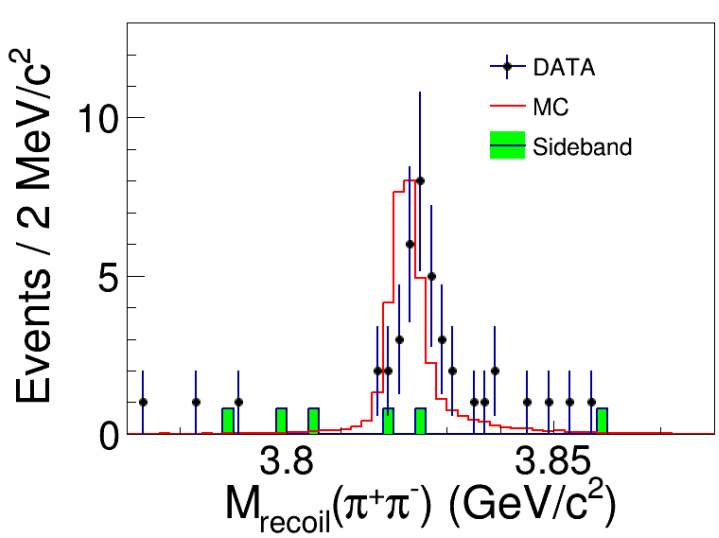
To veto π^0 and η backgrounds:

1. $M(\gamma\gamma) < 0.11 || M(\gamma\gamma) > 0.16$ GeV
2. $M(\gamma\gamma) < 0.51 || M(\gamma\gamma) > 0.58$ GeV

Some distributions







- J/ψ mass window : (3.075, 3.125) GeV
- χ_{c1} mass window : (3.49, 3.53) GeV
- χ_{c1} sideband region : (3.43, 3.48) GeV

Clear $X(3823)$ signals

$$X(3823) \to \gamma\chi_{c2}$$

$$\chi_{c2} \to \gamma J/\psi \to \gamma e^+e^-/\mu^+\mu^-$$

Event selections

Charged tracks
- $|R_{xy}| < 1cm, |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $N = 4, \sum Q = 0$

Particle identification
- π : $P_{mdc} < 1$ GeV
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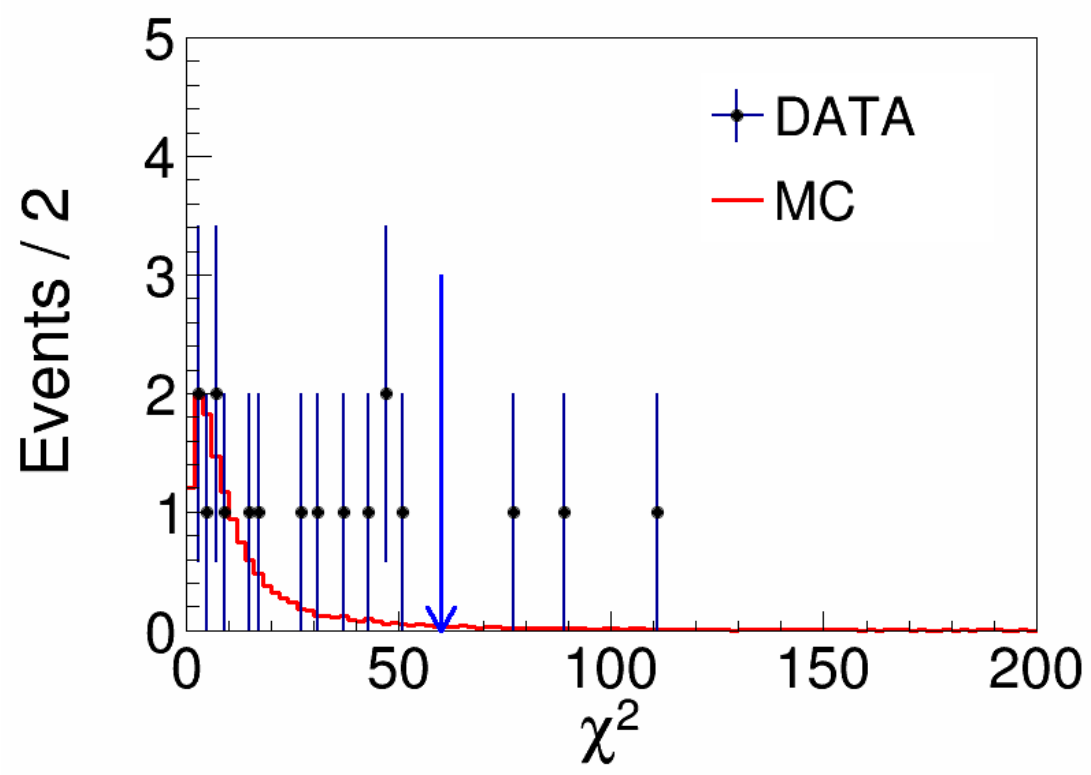
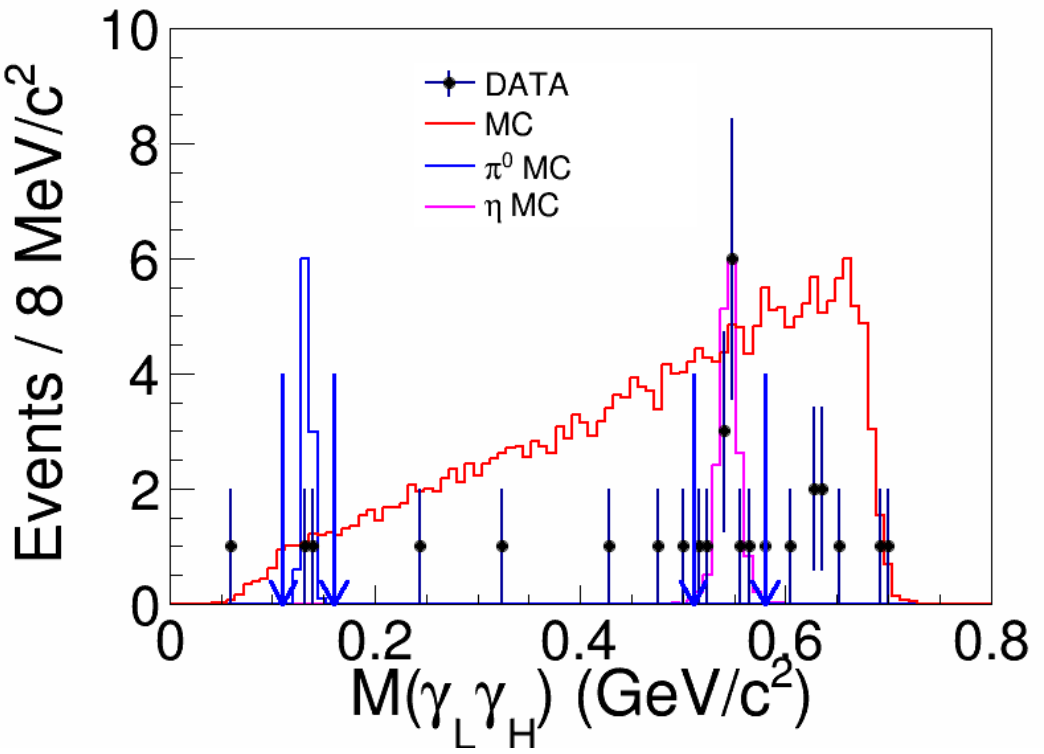
χ^2 distribution



χ^2 distribution from 4C: $\chi^2 < 60$

Background study



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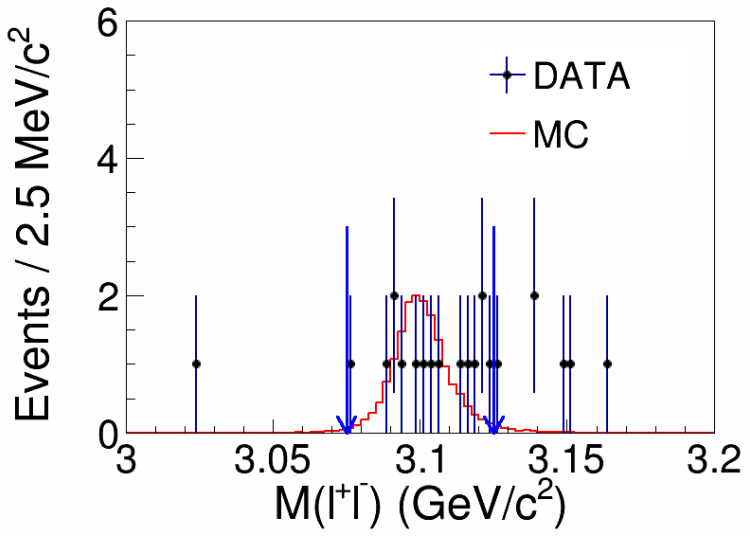
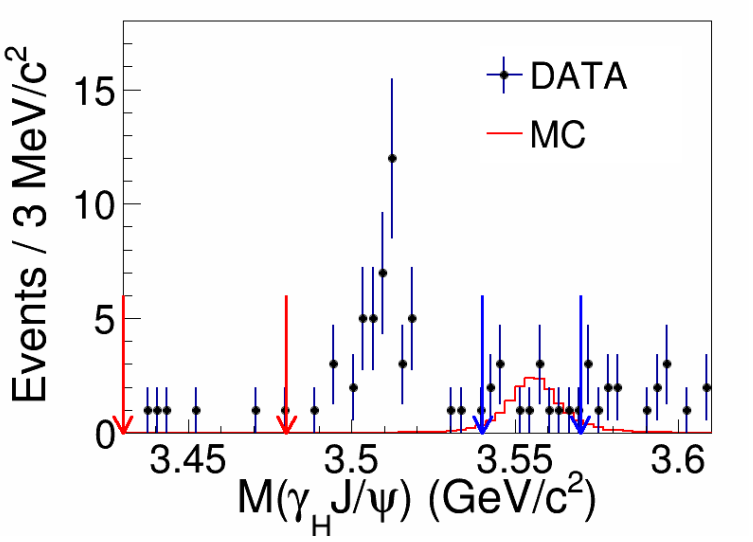
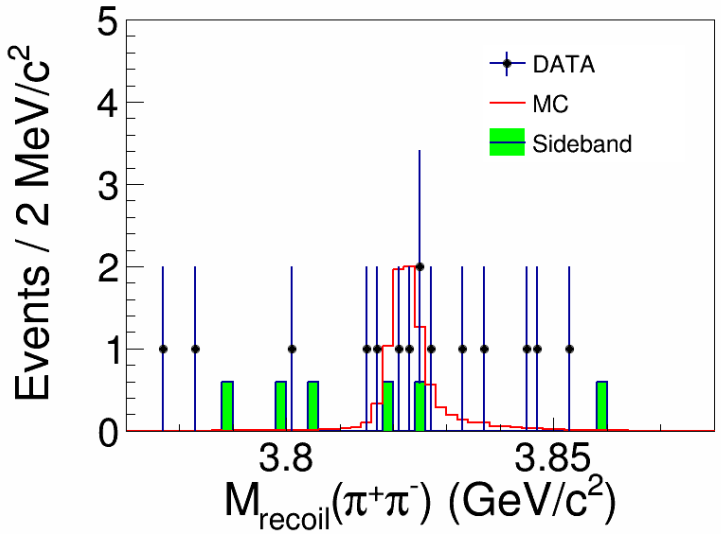
Some distributions







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- χ_{c2} sideband region : (3.43, 3.48) GeV

Some $X(3823)$ signals

$$X(3823) \to \eta J/\psi$$

$$\eta \to \gamma\gamma$$

$$J/\psi \to e^+e^-/\mu^+\mu^-$$

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- Choose the photons with least χ^2
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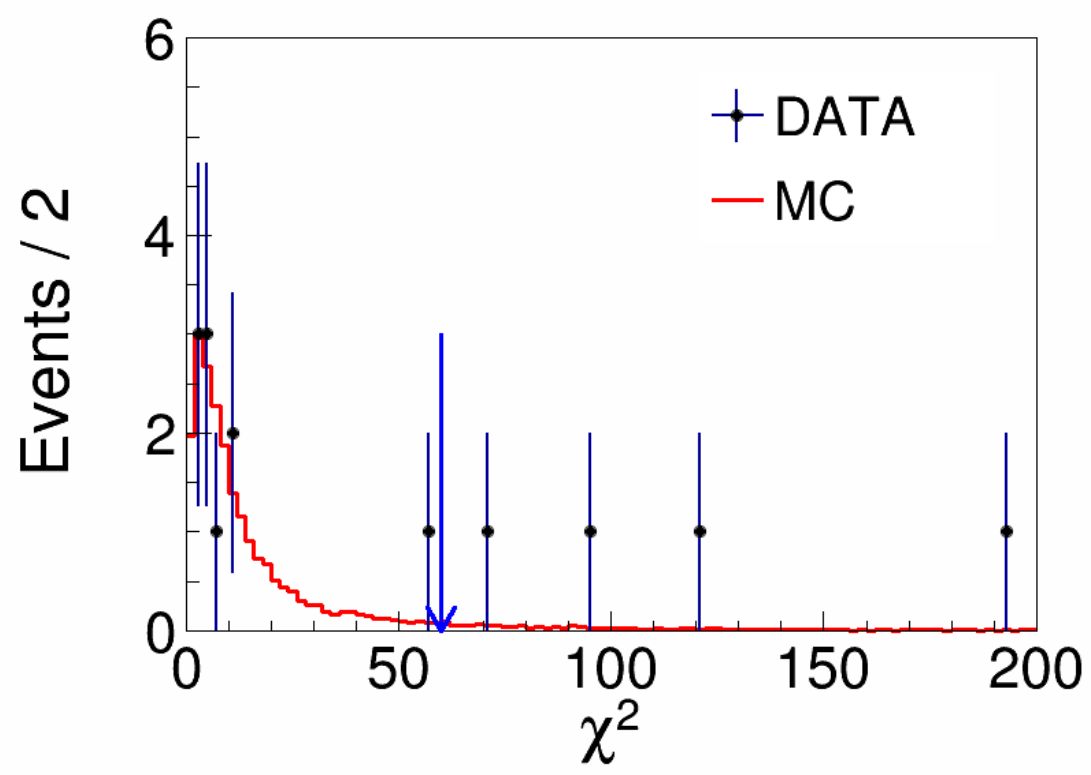
Other selections
- J/ψ mass window : (3.075, 3.125) GeV
- η mass window : (0.52, 0.57) GeV
- Veto $\chi_{c1,2}$: (3.49, 3.57) GeV
- Veto η' : (0.94, 0.97) GeV
- Veto $\psi(3686)$: (3.675, 3.695) GeV

χ^2 distribution



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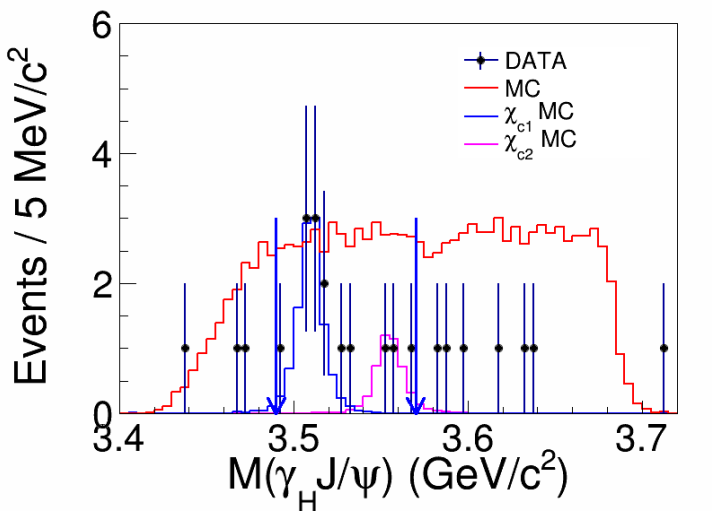
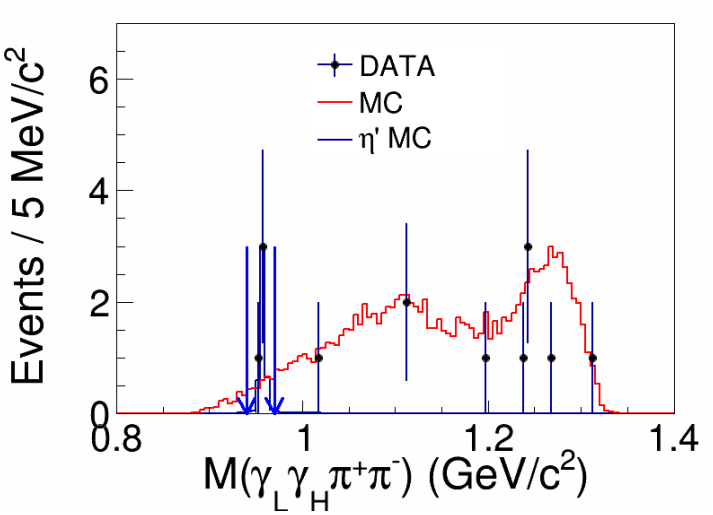


To veto $\chi_{c1,2}$ background:

$M(\gamma_H J/\psi) < 3.49 || M(\gamma_H J/\psi) > 3.57$ GeV



To veto η' background:

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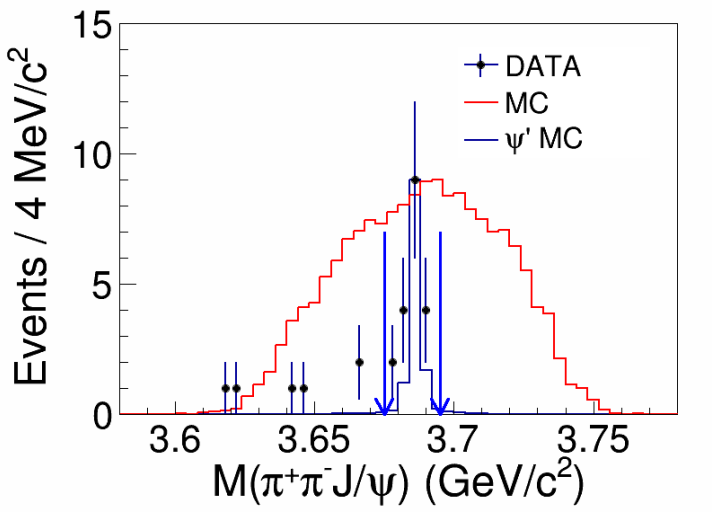
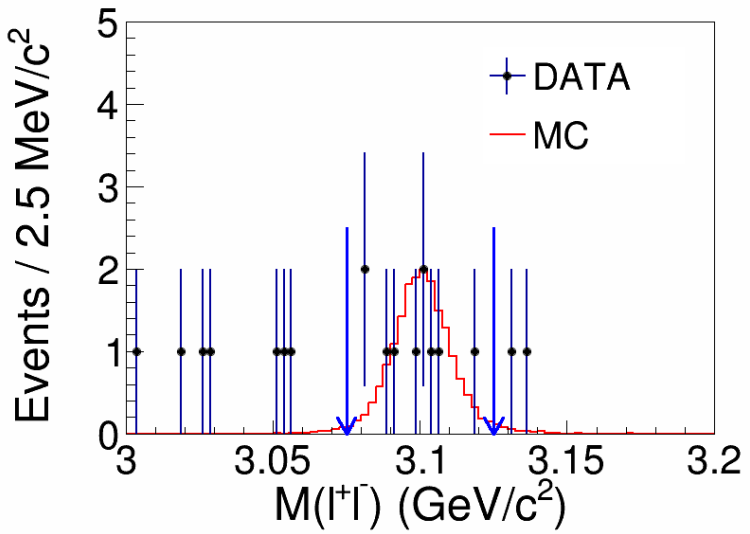
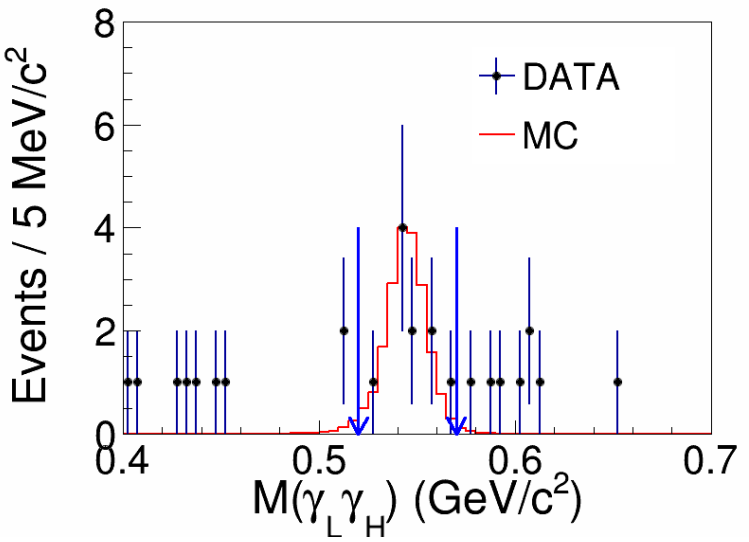


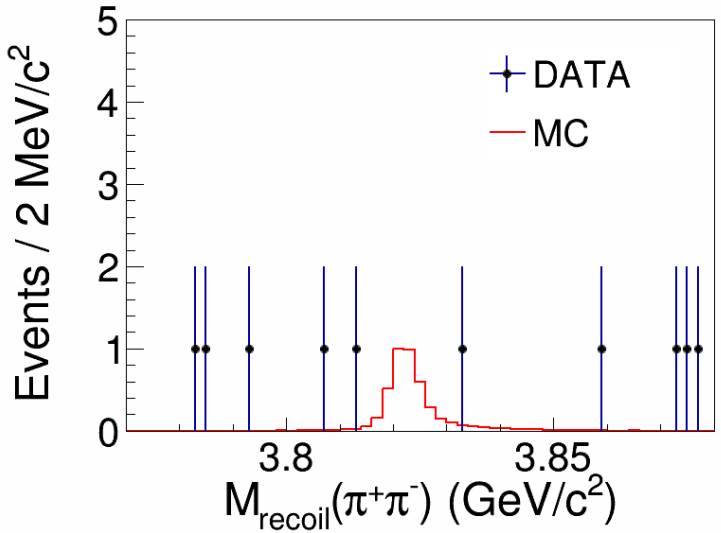
To veto $\psi(3686)$ background:

$M(\pi^+\pi^- J/\psi) < 3.675 || M(\pi^+\pi^- J/\psi) > 3.695$ GeV

Some distributions







- J/ψ mass window : (3.075, 3.125) GeV
- η mass window : (0.52, 0.57) GeV

No significant $X(3823)$ signals

$$X(3823) \to \pi^0 J/\psi$$
$$\pi^0 \to \gamma\gamma$$
$$J/\psi \to e^+e^-/\mu^+\mu^-$$

Event selections

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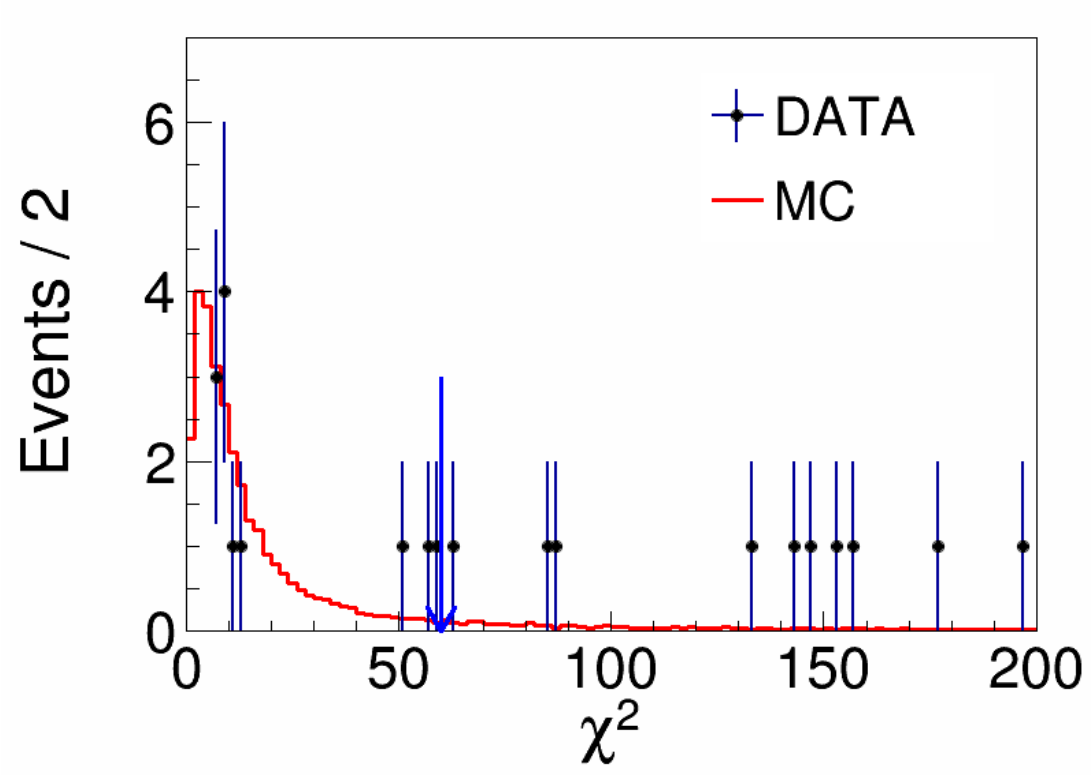
4C kinematic fit
- Choose the photons with least χ^2
- $\chi^2 < 60$

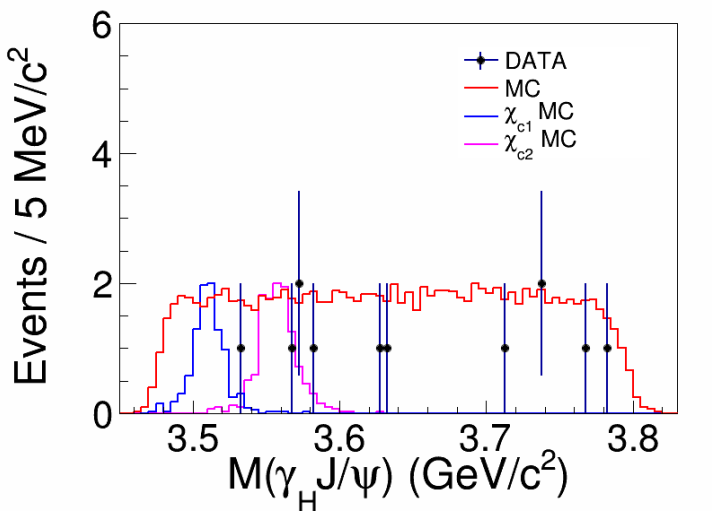
Other selections
- J/ψ mass window : (3.075, 3.125) GeV
- π^0 mass window : (0.12, 0.15) GeV
- Veto η : (0.51, 0.58) GeV
- Veto $\psi(3686)$: (3.675, 3.695) GeV

χ^2 distribution

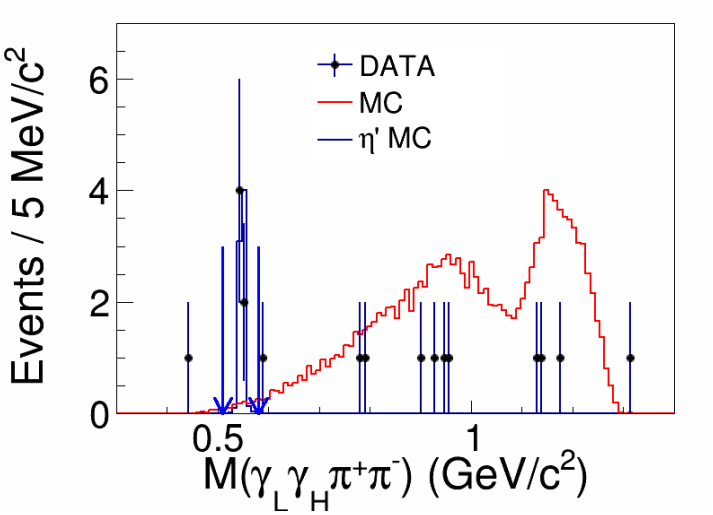


χ^2 distribution from 4C: $\chi^2 < 60$

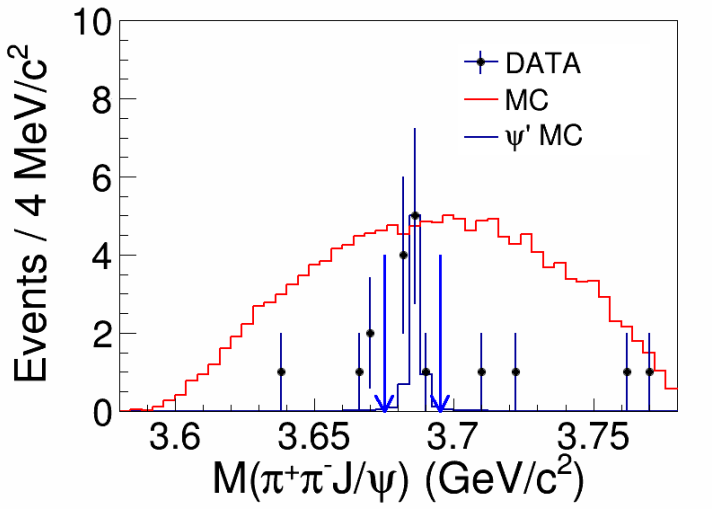
Background study



No significant $\chi_{c1,2}$ background

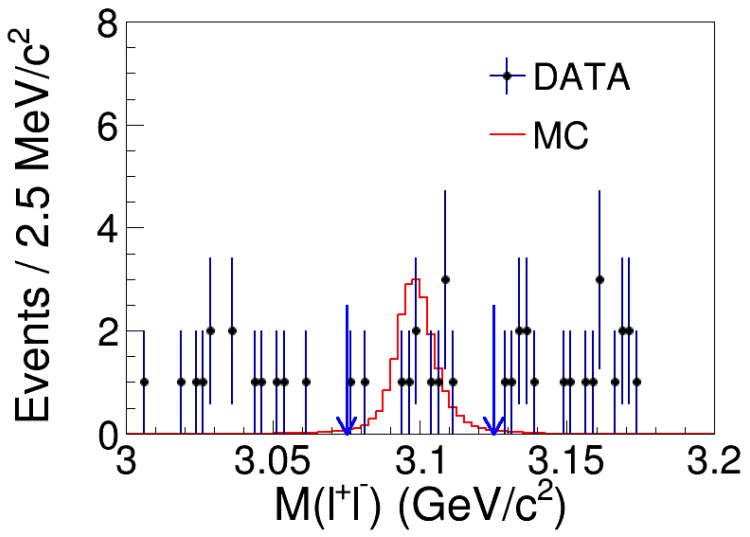


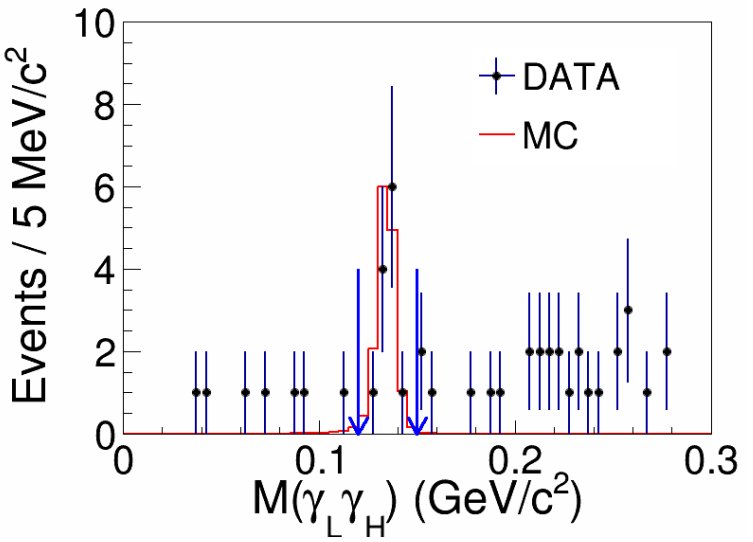
To veto η background:
$M(\gamma\gamma\pi^+\pi^-) < 0.51 || M(\gamma\gamma\pi^+\pi^-) > 0.58$ GeV

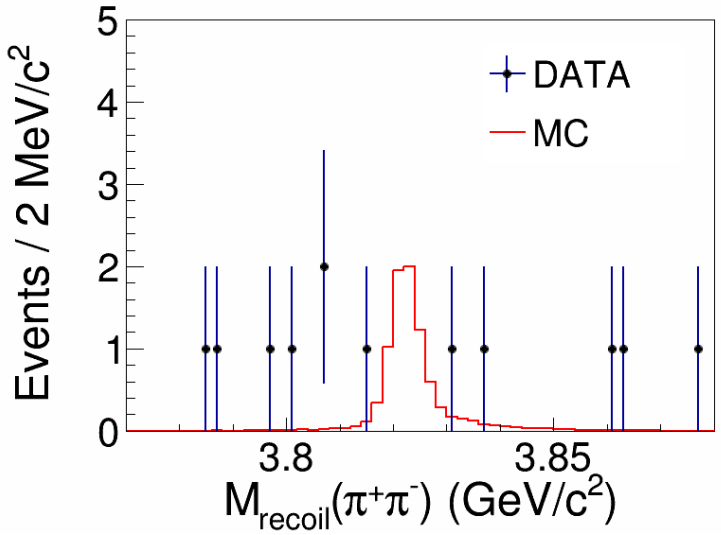


To veto $\psi(3686)$ background:
$M(\pi^+\pi^- J/\psi) < 3.675 || M(\pi^+\pi^- J/\psi) > 3.695$ GeV

Some distributions







- J/ψ mass window : (3.075, 3.125) GeV
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No significant $X(3823)$ signals

$$X(3823) \to \pi^0\pi^0 J/\psi$$
$$\pi^0 \to \gamma\gamma$$
$$J/\psi \to e^+e^-/\mu^+\mu^-$$

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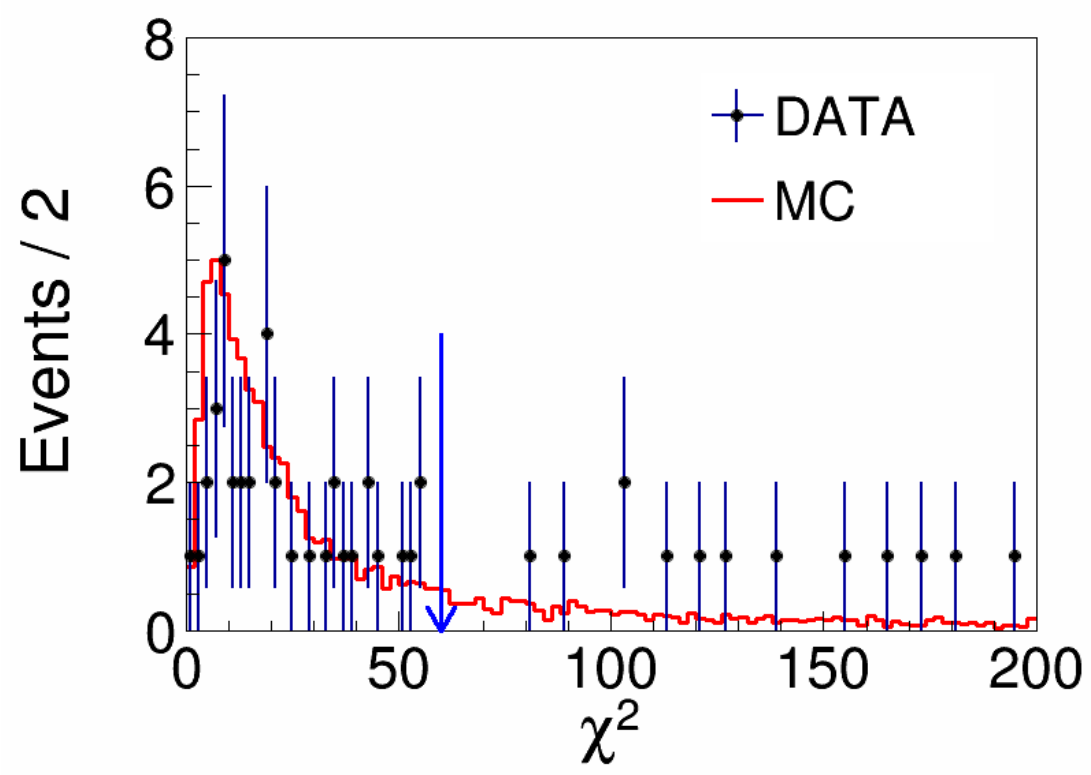
- Endcap :
  $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\Delta\theta > 10^0$
- $N_\gamma \geq 4$

6C kinematic fit
- M$(\gamma\gamma)$ is constrained to M(π^0)
- Choose the photons with least χ^2
- $\chi^2 < 60$

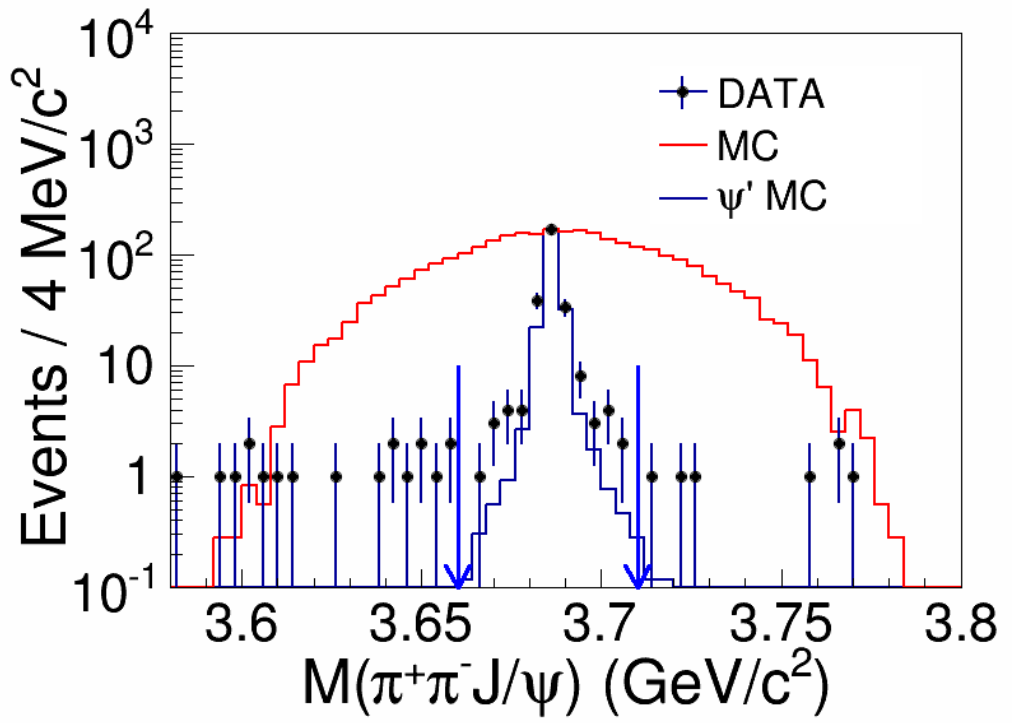
Other selections
- J/ψ mass window : (3.075, 3.125) GeV
- Veto $\psi(3686)$: (3.66, 3.71) GeV

χ^2 distribution



χ^2 distribution from 6C: $\chi^2 < 60$

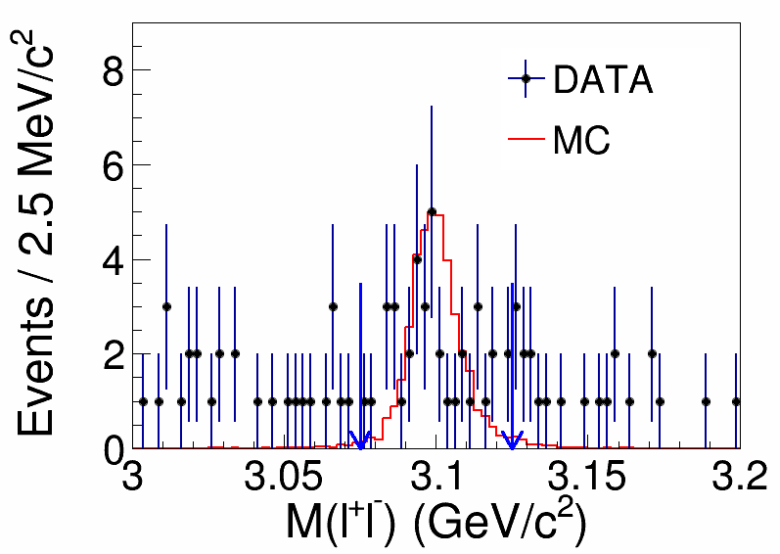
Background study

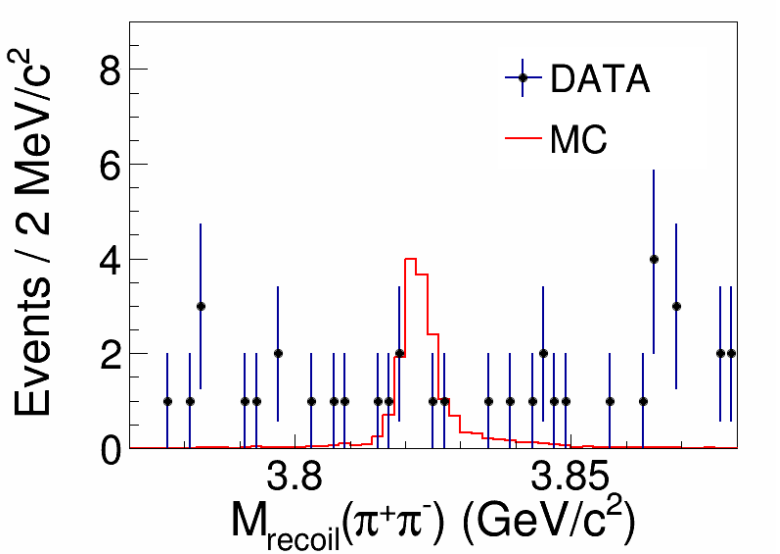


To veto $\psi(3686)$ background:

$M(\pi^+\pi^- J/\psi) < 3.66 || M(\pi^+\pi^- J/\psi) > 3.71$ GeV

Some distributions





No significant $X(3823)$ signals

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$$J/\psi \to e^+e^-/\mu^+\mu^-$$

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4C kinematic fit
- $\chi^2 < 60$

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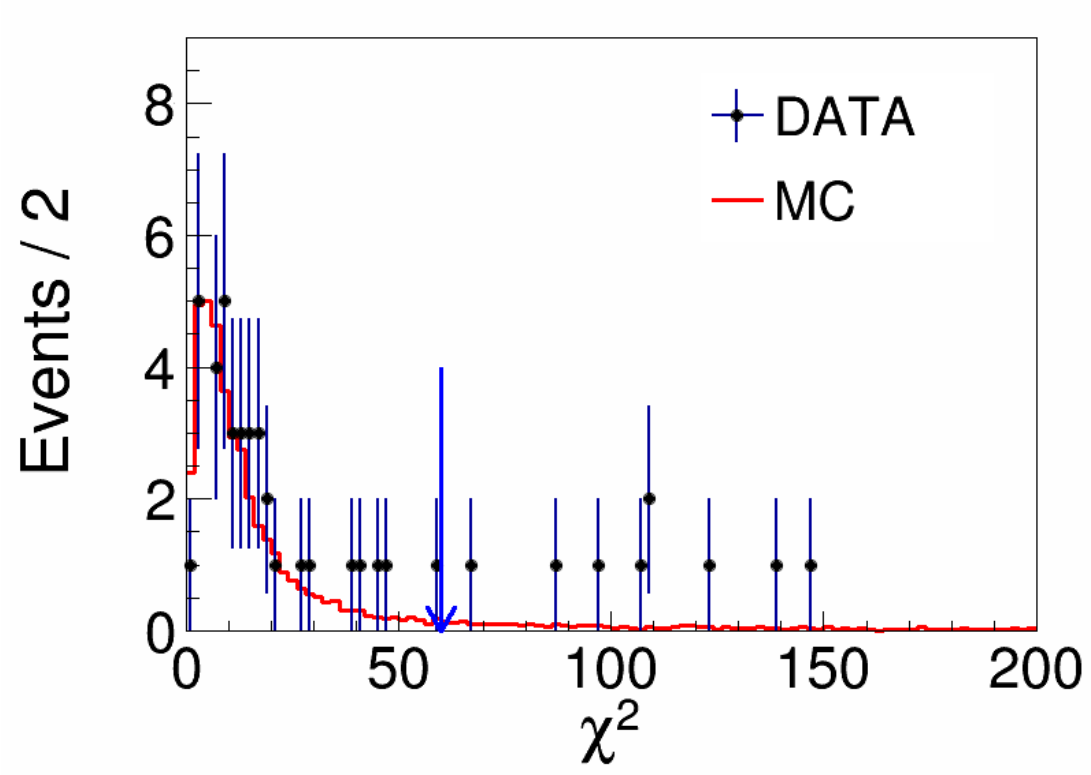
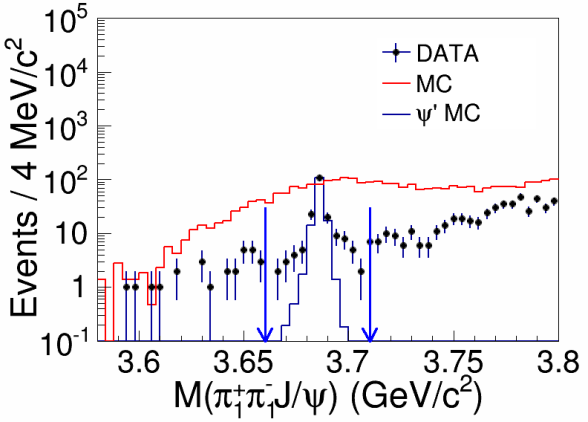
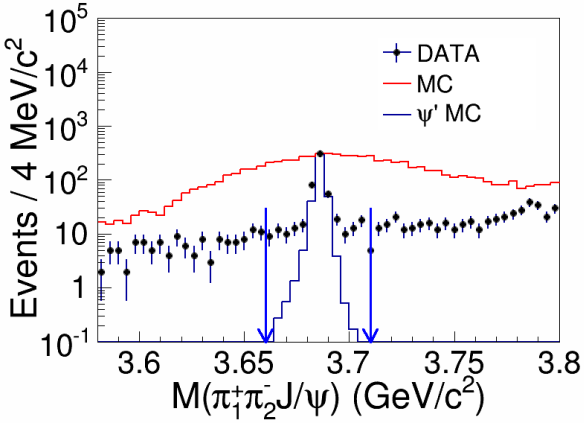
χ^2 distribution

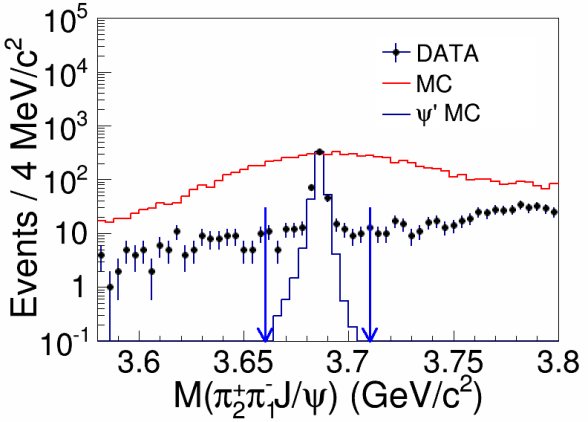


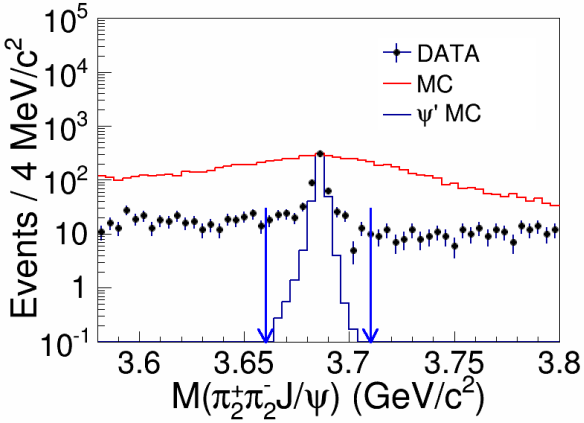
χ^2 distribution from 4C: $\chi^2 < 60$

Background study







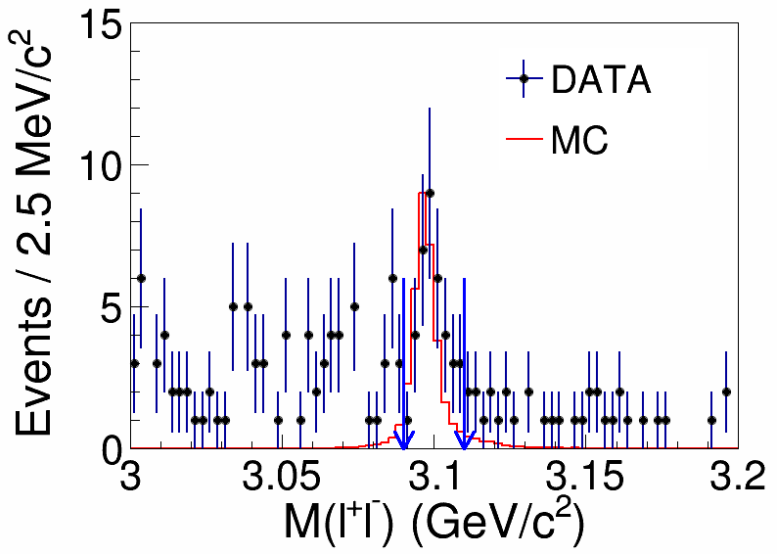


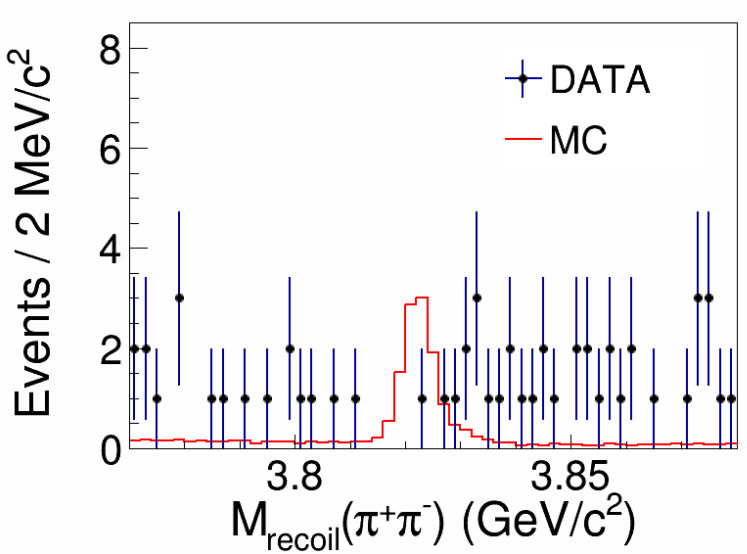
To veto $\psi(3686)$ background:

$M(\pi^+\pi^- J/\psi) < 3.66 || M(\pi^+\pi^- J/\psi) > 3.71$ GeV

Some distributions

- Save all $\mathrm{M_{recoil}}(\pi^+\pi^-)$ combinations





- J/ψ mass window : (3.09, 3.11) GeV

No significant $X(3823)$ signals

$$X(3823) \to \gamma\chi_{c0}$$

$$\chi_{c0} \to \pi^+\pi^-/K^+K^-$$

Event selections

Charged tracks
- $|R_{xy}| < 1cm, |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $N = 4, \sum Q = 0$

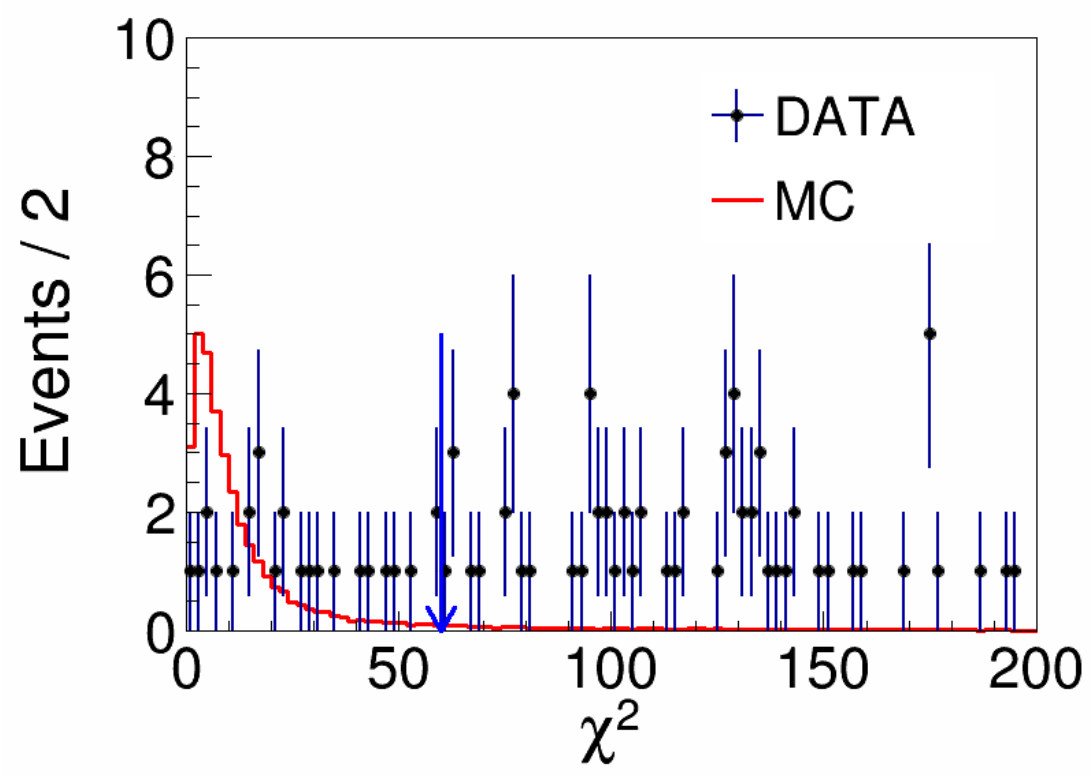
Particle identification
- π : $P_{mdc} < 1$ GeV
- $\pi/K(\chi_{c0})$: $P_{mdc} > 1$ GeV

Good photon
- $0 \leq TDC \leq 14$
- Barrel :
  $E > 0.025$ GeV, $|cos\theta| < 0.8$
- Endcap :
  $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\Delta\theta > 10^0$
- $N_\gamma \geq 1$

4C kinematic fit
- Choose the photon with least χ^2
- $\chi^2 < 60$
- $\pi(\chi_{c0})$: $\chi^2(\pi\pi) < \chi^2(KK)$
- $K(\chi_{c0})$: $\chi^2(KK) < \chi^2(\pi\pi)$

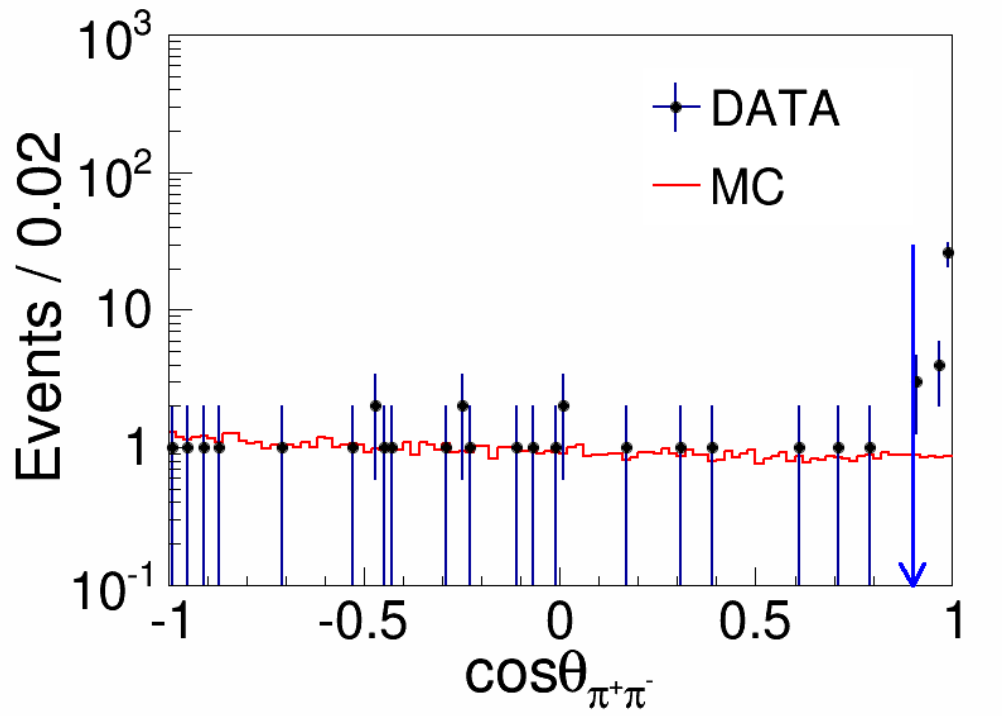
Other selections
- χ_{c0} mass window : (3.39, 3.44) GeV
- Veto γ conversion : $\cos\theta_{\pi^+\pi^-} < 0.9$

χ^2 distribution



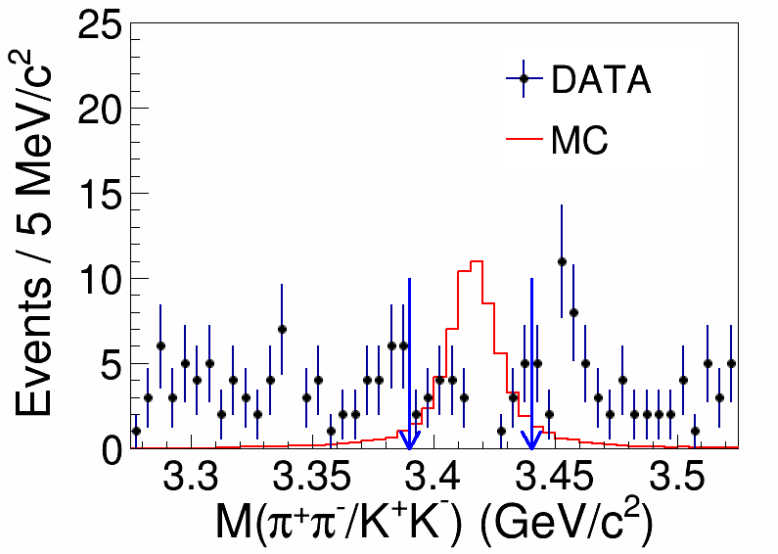
χ^2 distribution from 4C: $\chi^2 < 60$

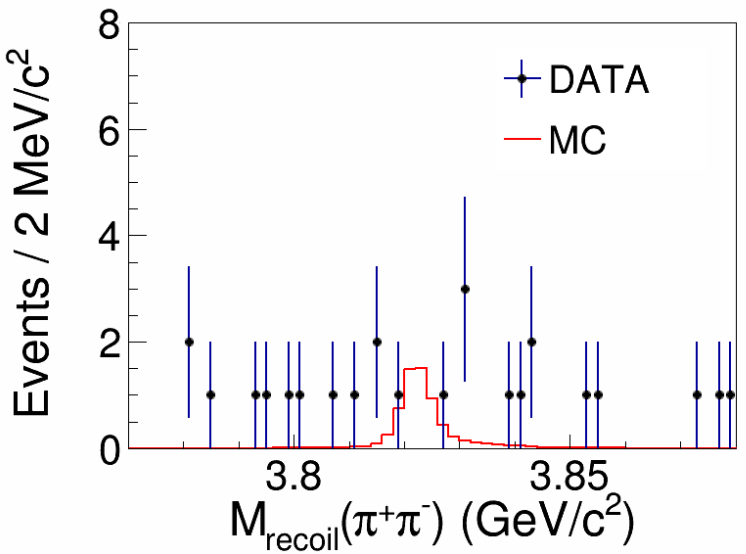
Background study



To veto γ conversion events : $\cos\theta_{\pi^+\pi^-} < 0.9$

Some distributions





- χ_{c0} mass window : (3.39, 3.44) GeV

No significant $X(3823)$ signals

Simultaneous fit

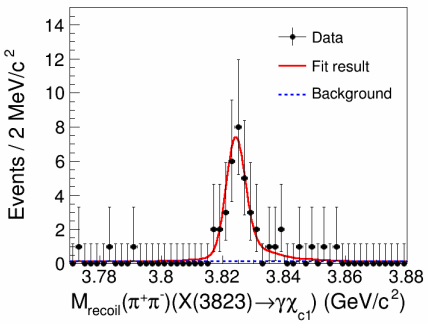
Signal :

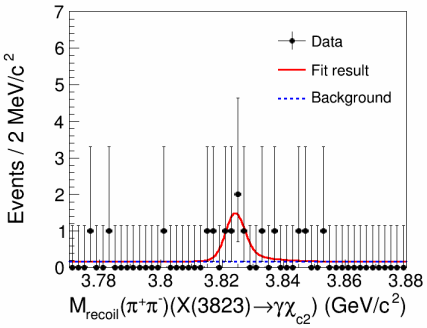
MC-determined signal MC shape convolved with a Gaussian function, the Gaussian function’ s mean and width parameters are free, and are constrained to be same in all decay channels.

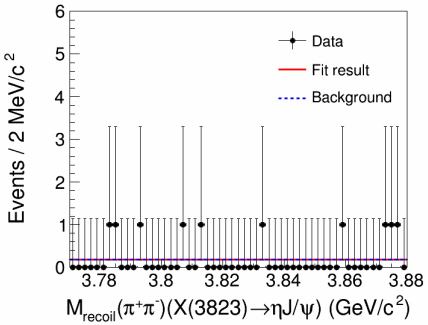
Background :

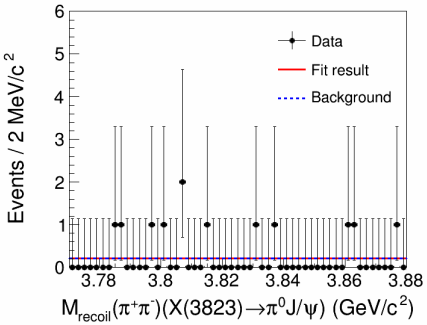
0th-order polynomial function.

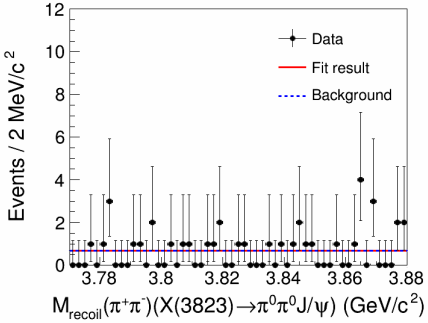
Mode	N	S
$X(3823) \to \gamma\chi_{c1}$	35.1 ± 6.4	9.4σ
$X(3823) \to \gamma\chi_{c2}$	$6.3^{+3.5}_{-2.8}$	3.1σ
$X(3823) \to \eta J/\psi$	$0.0^{+1.4}_{-0.0}(< 2.8)$	–
$X(3823) \to \pi^0 J/\psi$	$0.0^{+1.6}_{-0.0}(< 3.2)$	–
$X(3823) \to \pi^0\pi^0 J/\psi$	$0.0^{+2.8}_{-0.0}(< 5.6)$	–
$X(3823) \to \pi^+\pi^- J/\psi$	$0.0^{+3.4}_{-0.0}(< 6.6)$	–
$X(3823) \to \gamma\chi_{c0}$	$0.0^{+3.1}_{-0.0}(< 6.1)$	–

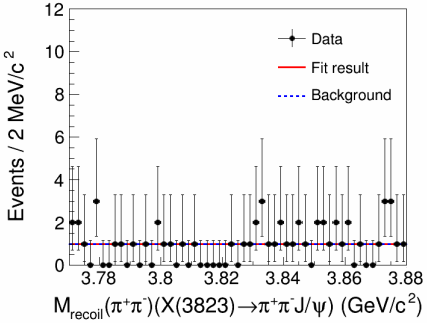


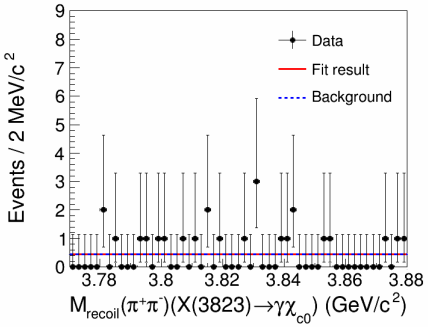












$X(3823) \to \gamma\chi_{c2}$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c2}} \mathcal{B}(X(3823) \to \gamma\chi_{c2}) \mathcal{B}(\chi_{c2} \to \gamma J/\psi) \mathcal{B}(J/\psi \to l^+ l^-) = N_{\gamma\chi_{c2}}$$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}} \mathcal{B}(X(3823) \to \gamma\chi_{c1}) \mathcal{B}(\chi_{c1} \to \gamma J/\psi) \mathcal{B}(J/\psi \to l^+ l^-) = N_{\gamma\chi_{c1}}$$

$$\frac{\mathcal{B}(X(3823) \to \gamma\chi_{c2})}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})} = \frac{N_{\gamma\chi_{c2}}}{N_{\gamma\chi_{c1}}} \frac{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}}}{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c2}}} \frac{\mathcal{B}(\chi_{c1} \to \gamma J/\psi)}{\mathcal{B}(\chi_{c2} \to \gamma J/\psi)}$$

$$= 0.36^{+0.20}_{-0.16} \pm 0.03$$

$X(3823) \to \eta J/\psi$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\eta J/\psi} \mathcal{B}(X(3823) \to \eta J/\psi) \mathcal{B}(\eta \to \gamma\gamma) \mathcal{B}(J/\psi \to l^+ l^-) = N_{\eta J/\psi}$$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma \chi_{c1}} \mathcal{B}(X(3823) \to \gamma \chi_{c1}) \mathcal{B}(\chi_{c1} \to \gamma J/\psi) \mathcal{B}(J/\psi \to l^+ l^-) = N_{\gamma \chi_{c1}}$$

$$\frac{\mathcal{B}(X(3823) \to \eta J/\psi)}{\mathcal{B}(X(3823) \to \gamma \chi_{c1})} = \frac{N_{\eta J/\psi}}{N_{\gamma \chi_{c1}}} \frac{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma \chi_{c1}}}{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\eta J/\psi}} \frac{\mathcal{B}(\chi_{c1} \to \gamma J/\psi)}{\mathcal{B}(\eta \to \gamma\gamma)}$$

< 0.11 at 90% C.L.

$X(3823) \to \pi^0 J/\psi$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\pi^0 J/\psi} \mathcal{B}(X(3823) \to \pi^0 J/\psi) \mathcal{B}(\pi^0 \to \gamma\gamma) \mathcal{B}(J/\psi \to l^+ l^-) = N_{\pi^0 J/\psi}$$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma \chi_{c1}} \mathcal{B}(X(3823) \to \gamma \chi_{c1}) \mathcal{B}(\chi_{c1} \to \gamma J/\psi) \mathcal{B}(J/\psi \to l^+ l^-) = N_{\gamma \chi_{c1}}$$

$$\frac{\mathcal{B}(X(3823) \to \pi^0 J/\psi)}{\mathcal{B}(X(3823) \to \gamma \chi_{c1})} = \frac{N_{\pi^0 J/\psi}}{N_{\gamma \chi_{c1}}} \frac{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma \chi_{c1}}}{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\pi^0 J/\psi}} \frac{\mathcal{B}(\chi_{c1} \to \gamma J/\psi)}{\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

< 0.03 at 90% C.L.

$X(3823) \to \pi^0\pi^0 J/\psi$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\pi^0\pi^0 J/\psi} \mathcal{B}(X(3823) \to \pi^0\pi^0 J/\psi)\mathcal{B}^2(\pi^0 \to \gamma\gamma)\mathcal{B}(J/\psi \to l^+l^-) = N_{\pi^0\pi^0 J/\psi}$$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}} \mathcal{B}(X(3823) \to \gamma\chi_{c1})\mathcal{B}(\chi_{c1} \to \gamma J/\psi)\mathcal{B}(J/\psi \to l^+l^-) = N_{\gamma\chi_{c1}}$$

$$\frac{\mathcal{B}(X(3823) \to \pi^0\pi^0 J/\psi)}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})} = \frac{N_{\pi^0\pi^0 J/\psi}}{N_{\gamma\chi_{c1}}} \frac{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}}}{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\pi^0\pi^0 J/\psi}} \frac{\mathcal{B}(\chi_{c1} \to \gamma J/\psi)}{\mathcal{B}^2(\pi^0 \to \gamma\gamma)}$$

< 0.19 at 90% C.L.

$X(3823) \to \pi^+\pi^- J/\psi$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\pi^+\pi^- J/\psi} \mathcal{B}(X(3823) \to \pi^+\pi^- J/\psi)\mathcal{B}(J/\psi \to l^+l^-) = N_{\pi^+\pi^- J/\psi}$$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}} \mathcal{B}(X(3823) \to \gamma\chi_{c1})\mathcal{B}(\chi_{c1} \to \gamma J/\psi)\mathcal{B}(J/\psi \to l^+l^-) = N_{\gamma\chi_{c1}}$$

$$\frac{\mathcal{B}(X(3823) \to \pi^+\pi^- J/\psi)}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})} = \frac{N_{\pi^+\pi^- J/\psi}}{N_{\gamma\chi_{c1}}} \frac{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}}}{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\pi^+\pi^- J/\psi}} \mathcal{B}(\chi_{c1} \to \gamma J/\psi)$$

< 0.08 at 90% C.L.

$X(3823) \to \gamma\chi_{c0}$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c0}} \mathcal{B}(X(3823) \to \gamma\chi_{c0}) \mathcal{B}(\chi_{c0} \to \pi^+\pi^-/K^+K^-) = N_{\gamma\chi_{c0}}$$

$$\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}} \mathcal{B}(X(3823) \to \gamma\chi_{c1}) \mathcal{B}(\chi_{c1} \to \gamma J/\psi) \mathcal{B}(J/\psi \to l^+l^-) = N_{\gamma\chi_{c1}}$$

$$\frac{\mathcal{B}(X(3823) \to \gamma\chi_{c0})}{\mathcal{B}(X(3823) \to \gamma\chi_{c1})} = \frac{N_{\gamma\chi_{c0}}}{N_{\gamma\chi_{c1}}} \frac{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c1}}}{\sum_i \mathcal{L}_i \sigma_i (1+\delta)_i \varepsilon_i^{\gamma\chi_{c0}}} \frac{\mathcal{B}(\chi_{c1} \to \gamma J/\psi) \mathcal{B}(J/\psi \to l^+l^-)}{\mathcal{B}(\chi_{c0} \to \pi^+\pi^-/K^+K^-)}$$

< 0.41 at 90% C.L.

Systematic uncertainty

1、Tracking efficiency(1% per track)

2、Photon efficiency(1% per photon)

3、Input branching fraction

The systematic uncertainty of the branching fraction is quoted from PDG.

4、Kinematic fit

The difference in MC efficiency between before and after the helix parameters correction is taken as the systematic uncertainty.

5、Input line-shape

We take the $\psi(4415)$ line-shape with parameters from PDG as the input line-shape to get the nominal results. And to get uncertainty, we change the line-shape to the $\psi(4360)$ line-shape with parameters from PDG.

Systematic uncertainty

6、MC decay model

The process $e^+e^- \to \pi^+\pi^- X(3823)$ is generated by the three-body phase space model. To get uncertainty, we try to model the $e^+e^- \to \pi^+\pi^- X(3823)$ process with a D-wave in the MC simulation. The difference in the results between the D-wave model and three-body phase space is taken as the systematic uncertainty.

7、Fit method

For the fit range, we vary the limit of the fit range by $\pm 5\ \mathrm{MeV}/c^2$ to get the systematic uncertainty. For the background shape, we change the background shape from the 0th-order polynomial to a 1st-order polynomial to get the systematic uncertainty. About the upper limits, we try to change the fit range and background shape to choose the largest one as the nominal upper limits.

Systematic uncertainty

8、Mass window

The systematic uncertainty from J/ψ mass window is about 1.6% by the control sample $e^+e^- \to \gamma_{ISR}\psi' \to \gamma_{ISR}\pi^+\pi^- J/\psi$. The systematic uncertainty from π^0/η mass window is about 1% by the control sample $J/\psi \to p\bar{p}\pi^0/\eta$. For the $\chi_{c1,2}$ invariant mass distribution, the J/ψ' s resolution has been reduced, so the systematic uncertainty from $\chi_{c1,2}$ mass window is from the photon' s uncertainty, conservatively, we take 1% as the systematic uncertainty from $\chi_{c1,2}$ mass window. The systematic uncertainty from χ_{c0} mass window is about 1.5% by the analysis $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^-\chi_{c0}$ in BAM373.

Systematic uncertainty

The summary of systematic uncertainty

	$\frac{\mathcal{B}(X(3823)\to\ldots)}{\mathcal{B}(X(3823)\to\gamma\chi_{c1})}$					
	$\gamma\chi_{c2}$	$\eta J/\psi$	$\pi^0 J/\psi$	$\pi^0\pi^0 J/\psi$	$\pi^+\pi^- J/\psi$	$\gamma\chi_{c0}$
Track efficiency	–	–	–	–	2.0	–
Photon efficiency	–	–	–	2.0	2.0	1.0
Input branching fraction	3.9	3.0	2.9	2.9	2.9	4.4
Kinematic fit	0.5	0.4	0.3	0.2	0.7	0.5
Input line-shape	0.6	5.9	2.1	19.1	15.4	1.3
MC decay model	0.8	0.8	0.6	3.8	3.6	9.7
Fit method	6.2	–	–	–	–	–
Mass window	–	1.4	1.4	1.0	1.0	2.4
sum	7.4	6.8	3.9	19.8	16.4	11.1

The common systematic uncertainty has been cancelled

Summary

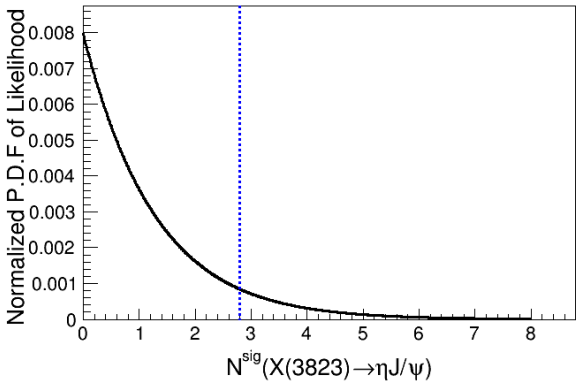
1. Some $X(3823)$ decay modes have been studied and searched.
2. Clear signals for $X(3823) \to \gamma\chi_{c1}$, the evidence for $X(3823) \to \gamma\chi_{c2}$, no significant signals for $X(3823) \to \eta J/\psi$, $\pi^0 J/\psi$, $\pi^+\pi^- J/\psi$, $\pi^0\pi^0 J/\psi$, $\gamma\chi_{c0}$.
3. The ratios of branching fractions $\frac{\mathcal{B}(X(3823)\to\cdots)}{\mathcal{B}(X(3823)\to\gamma\chi_{c1})}$ are also given.

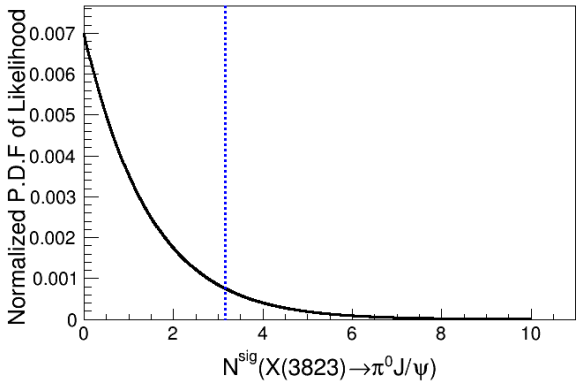
Mode	N	S	$\frac{\mathcal{B}(X(3823)\to\ldots)}{\mathcal{B}(X(3823)\to\gamma\chi_{c1})}$
$X(3823) \to \gamma\chi_{c1}$	35.1 ± 6.4	9.4σ	–
$X(3823) \to \gamma\chi_{c2}$	$6.3^{+3.5}_{-2.8}$	3.1σ	$0.36^{+0.20}_{-0.16} \pm 0.03$
$X(3823) \to \eta J/\psi$	$0.0^{+1.4}_{-0.0}(< 2.8)$	–	< 0.11
$X(3823) \to \pi^0 J/\psi$	$0.0^{+1.6}_{-0.0}(< 3.2)$	–	< 0.03
$X(3823) \to \pi^0\pi^0 J/\psi$	$0.0^{+2.8}_{-0.0}(< 5.6)$	–	< 0.19
$X(3823) \to \pi^+\pi^- J/\psi$	$0.0^{+3.4}_{-0.0}(< 6.6)$	–	< 0.08
$X(3823) \to \gamma\chi_{c0}$	$0.0^{+3.1}_{-0.0}(< 6.1)$	–	< 0.41

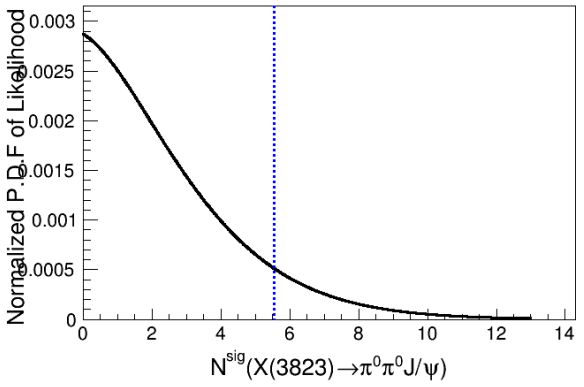
Thanks for your attention!

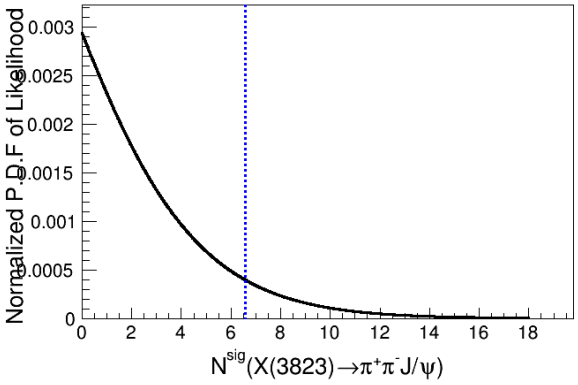
BACK UP

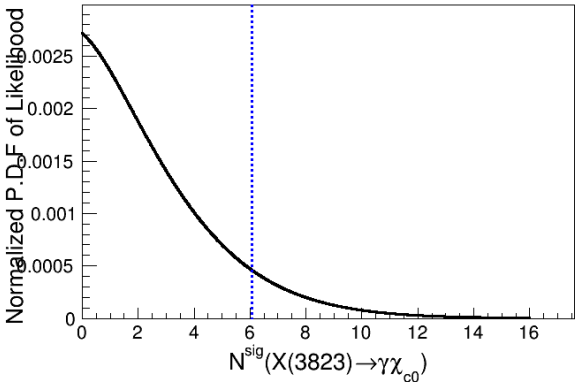
Likelihood distribution







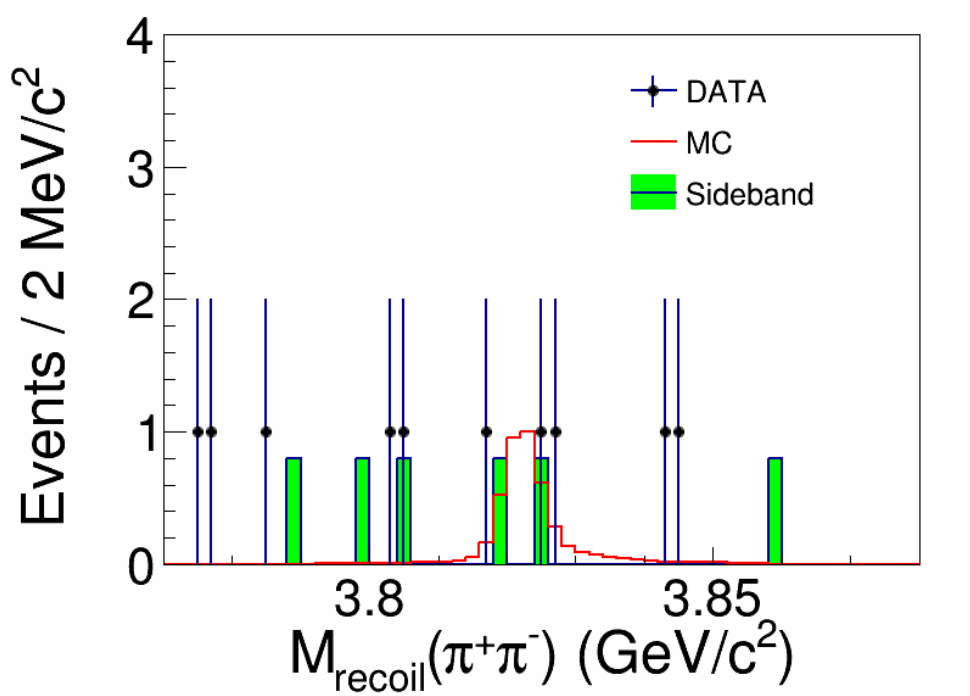




Efficiency at each $\sqrt{s}$

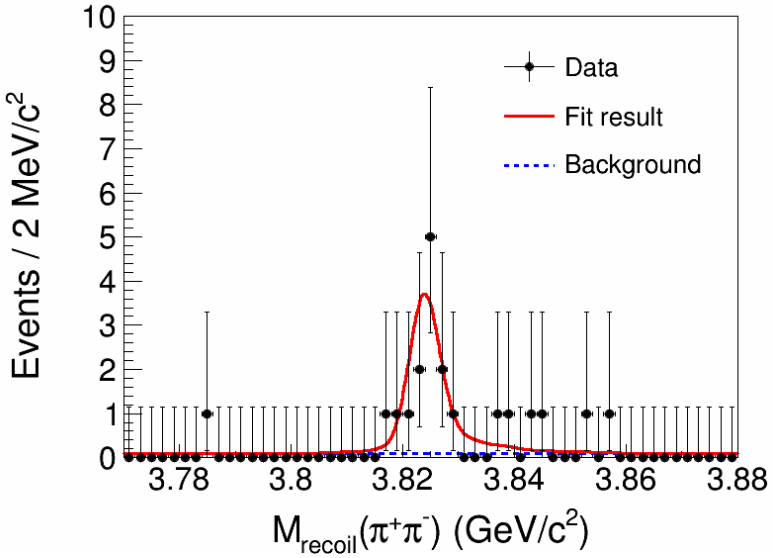
$\sqrt{s}$ (GeV)	$\epsilon_{\gamma\chi_{c1}}$ (%)	$\epsilon_{\gamma\chi_{c2}}$ (%)	$\epsilon_{\eta J/\psi}$ (%)	$\epsilon_{\pi^0 J/\psi}$ (%)	$\epsilon_{\pi^0\pi^0 J/\psi}$ (%)	$\epsilon_{\pi^+\pi^- J/\psi}$ (%)	$\epsilon_{\gamma\chi_{c0}}$ (%)
4.308	18.79	17.23	14.52	23.90	10.88	28.69	27.02
4.312	18.78	17.01	14.62	23.94	10.70	28.74	26.90
4.337	19.10	17.28	15.00	23.75	10.46	27.20	27.81
4.358	19.72	17.97	15.15	22.13	9.25	23.19	28.37
4.377	19.55	17.91	13.02	20.89	7.12	16.85	28.68
4.387	20.02	18.13	12.27	21.14	6.06	13.63	29.35
4.396	19.75	18.26	11.99	21.08	5.02	11.78	29.13
4.416	19.89	18.11	12.08	21.27	4.56	11.57	29.40
4.436	19.80	17.70	12.77	21.43	5.86	16.30	28.92
4.467	17.78	15.97	13.35	20.85	7.90	24.91	26.18
4.527	14.57	13.04	11.74	18.48	7.86	34.03	21.23
4.575	13.22	12.02	10.75	17.36	7.23	32.54	19.85
4.600	13.00	11.73	10.65	16.83	7.20	28.89	19.59

All XYZ data at $\sqrt{s}$ <4.3 GeV



No significant $X(3823)$ signals for data at $\sqrt{s}$ <4.3 GeV

XYZ data: 4230,4260,4360,4420,4600



Consistent $N_{\gamma\chi_{c1}} = 15.3 \pm 4.5$

~15

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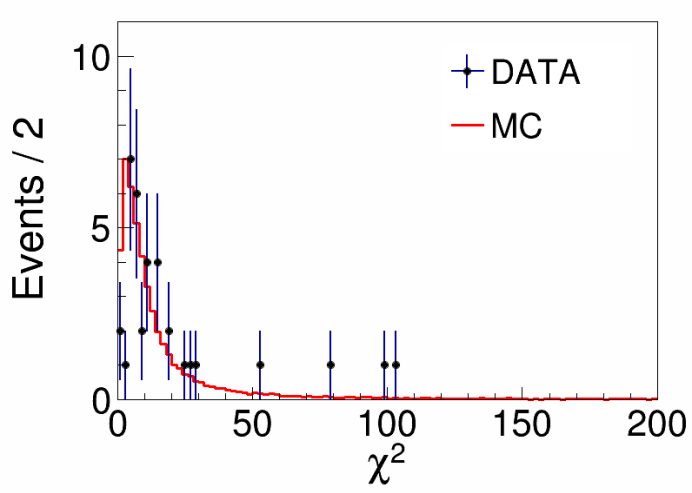
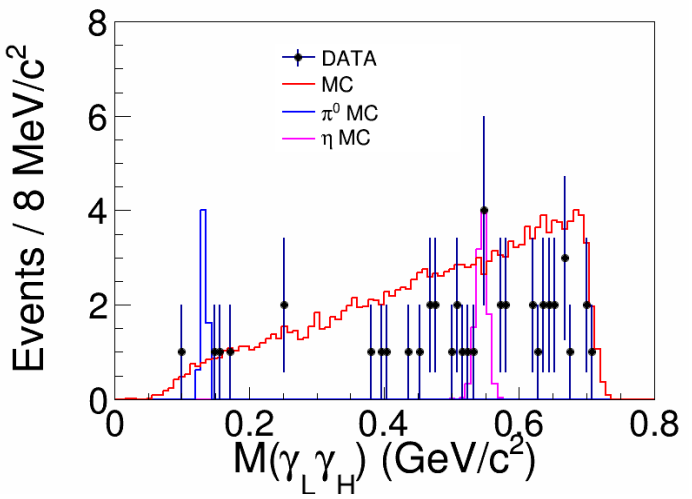
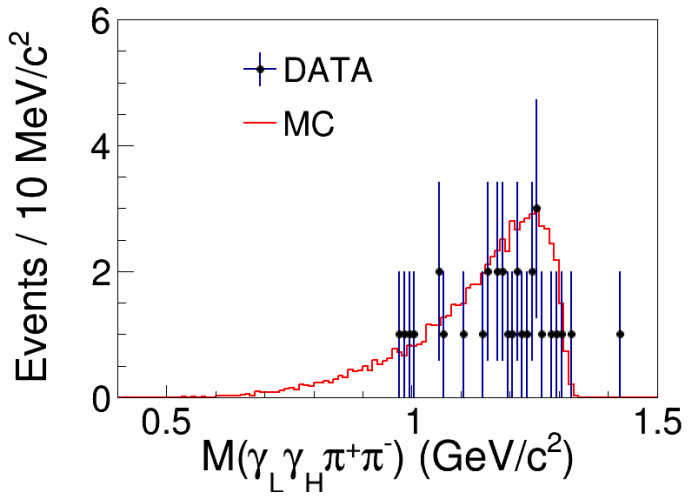
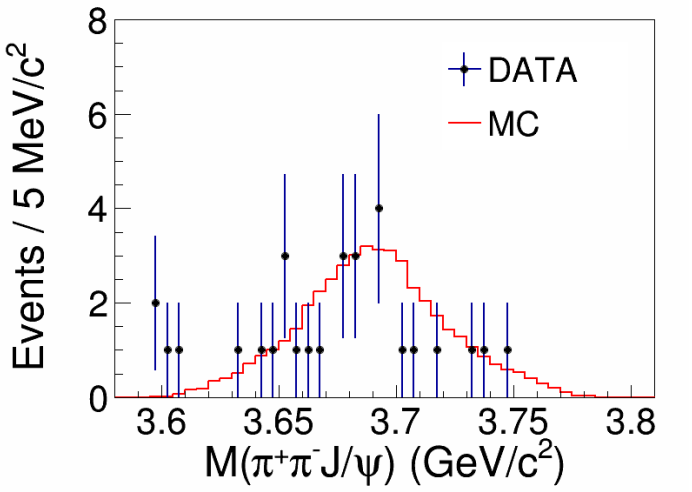
$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$N^{\rm obs}$	ϵ	$1+\delta$	$1/\lvert 1-\Pi\rvert^2$	$\sigma_X^B \cdot \mathcal{B}_1$ (pb)	$\sigma_X^B \cdot \mathcal{B}_2$ (pb)	$\sigma_{\psi'}^B$ (pb)	$\mathcal{R}_{\psi'}$
4.230	1092	$0.7^{+1.4}_{-0.7}$ (<3.8)	0.168	0.755	1.056	$0.12^{+0.24}_{-0.12} \pm 0.02$ (<0.64)	···	$34.1 \pm 8.1 \pm 4.7$	···
4.260	826	$1.1^{+1.8}_{-1.2}$ (<4.6)	0.178	0.751	1.054	$0.23^{+0.38}_{-0.24} \pm 0.04$ (<0.98)	···	$25.9 \pm 8.1 \pm 3.6$	···
4.360	540	$3.9^{+2.3}_{-1.7}$ (<8.2)	0.196	0.795	1.051	$1.10^{+0.64}_{-0.47} \pm 0.15$ (<2.27)	(<1.92)	$58.6 \pm 14.2 \pm 8.1$	$0.20^{+0.13}_{-0.10}$
4.420	1074	$7.5^{+3.6}_{-2.8}$ (<13.4)	0.145	0.967	1.053	$1.23^{+0.59}_{-0.46} \pm 0.17$ (<2.19)	(<0.54)	$33.4 \pm 7.8 \pm 4.6$	$0.39^{+0.21}_{-0.17}$
4.600	567	$1.9^{+1.8}_{-1.1}$ (<5.4)	0.157	1.075	1.055	$0.47^{+0.44}_{-0.27} \pm 0.07$ (<1.32)	···	$10.4^{+6.4}_{-4.7} \pm 1.5$	···

Events in $X(3823)$ signal region [3.815, 3.835] GeV for $X(3823) \to \gamma\chi_{c1}$

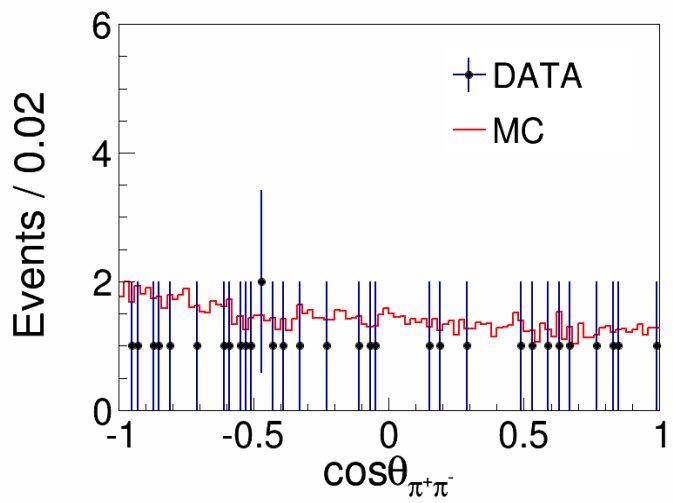


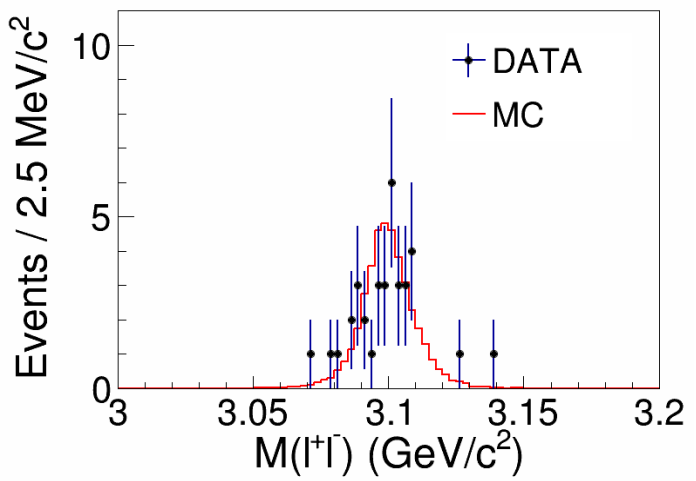


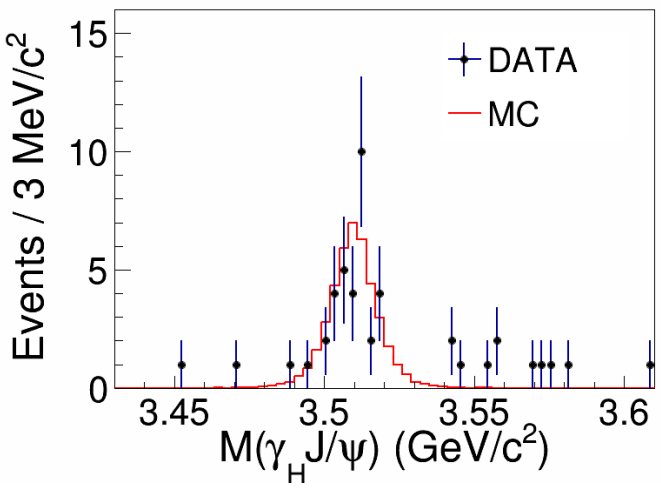




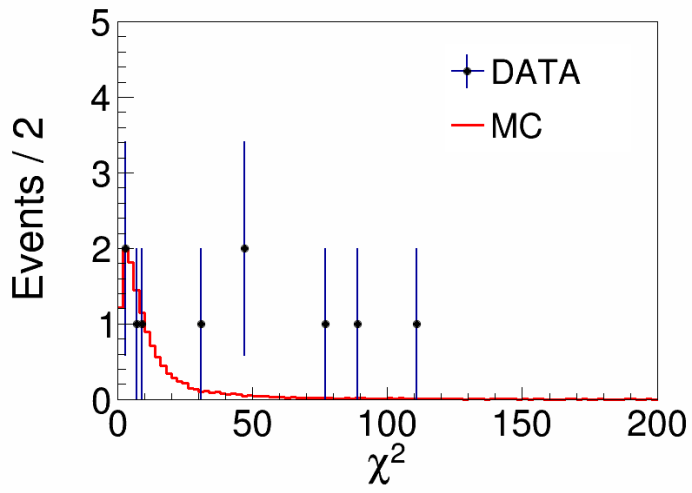
Events in $X(3823)$ signal region [3.815, 3.835] GeV for $X(3823) \to \gamma\chi_{c1}$

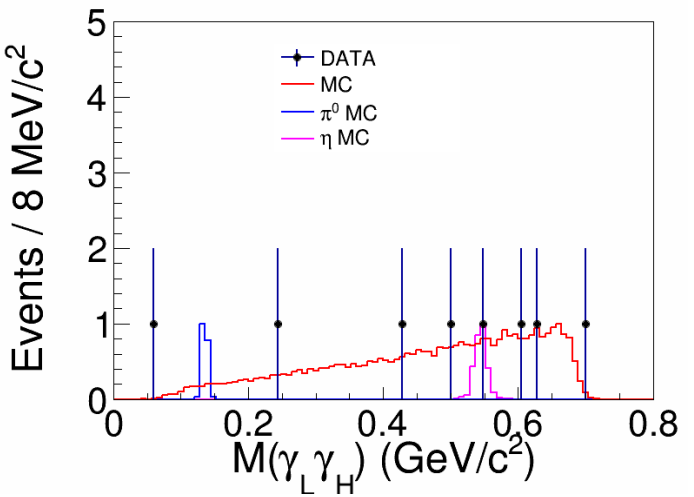


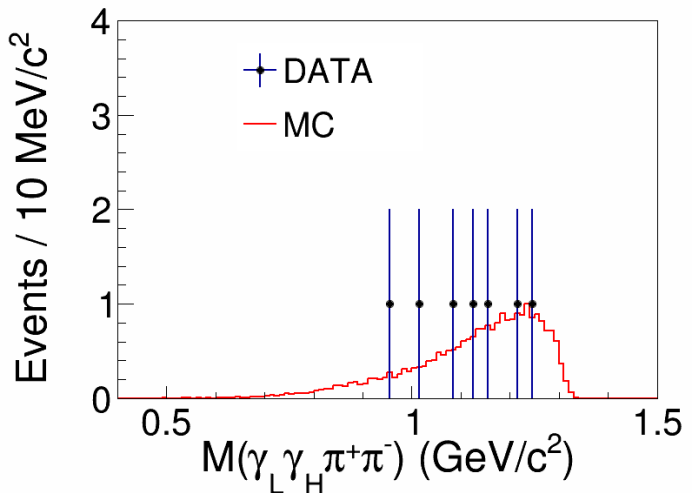


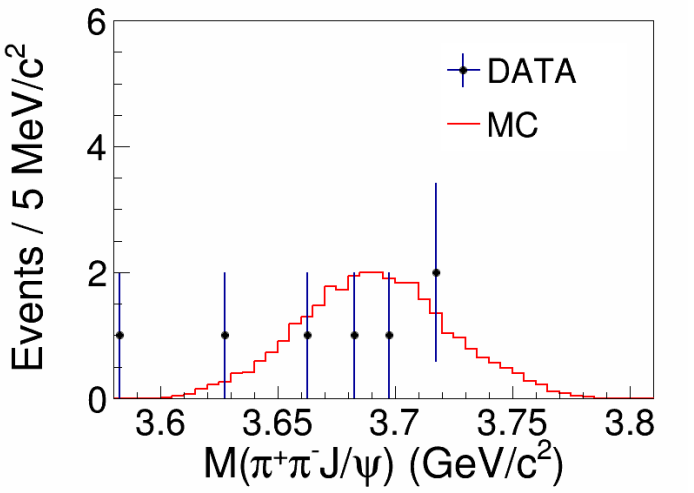


Events in $X(3823)$ signal region [3.815, 3.835] GeV for $X(3823) \to \gamma\chi_{c2}$

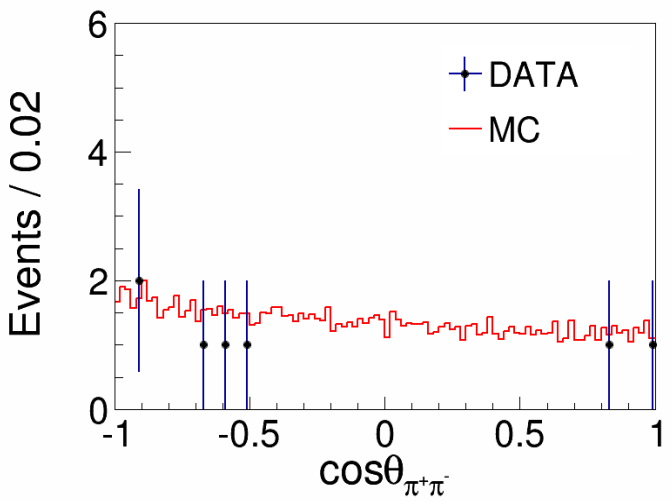


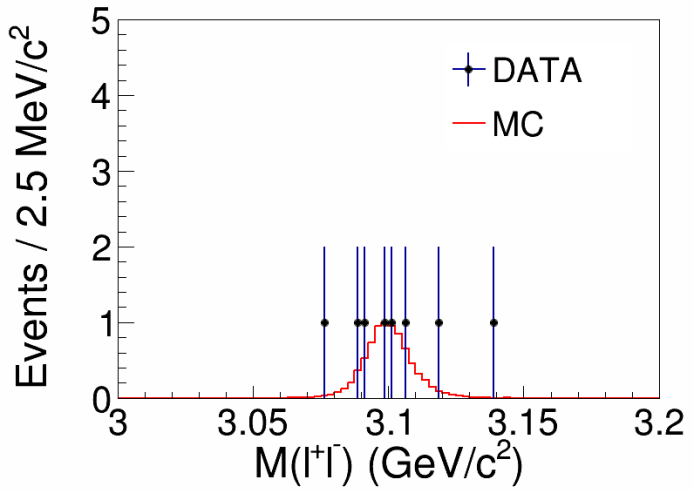


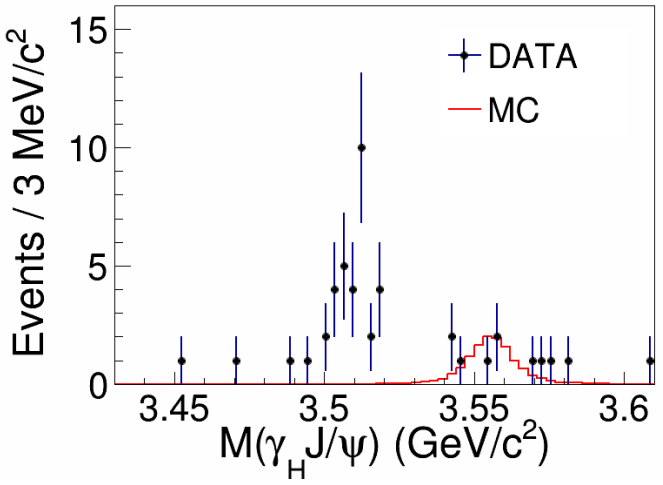




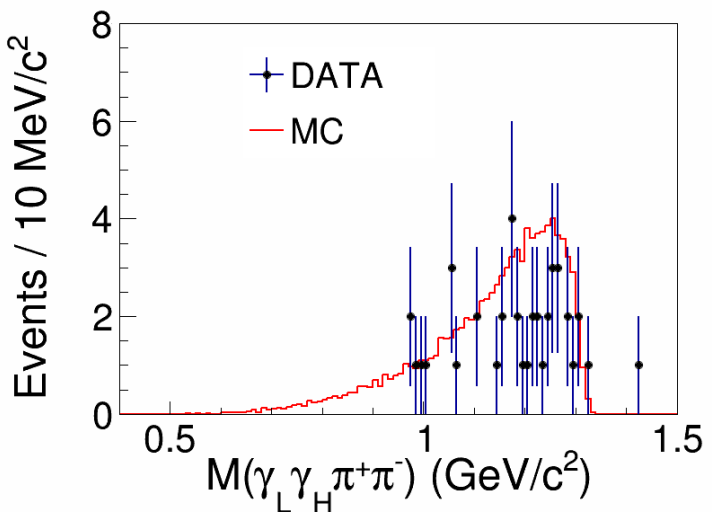
Events in $X(3823)$ signal region [3.815, 3.835] GeV for $X(3823) \to \gamma\chi_{c2}$



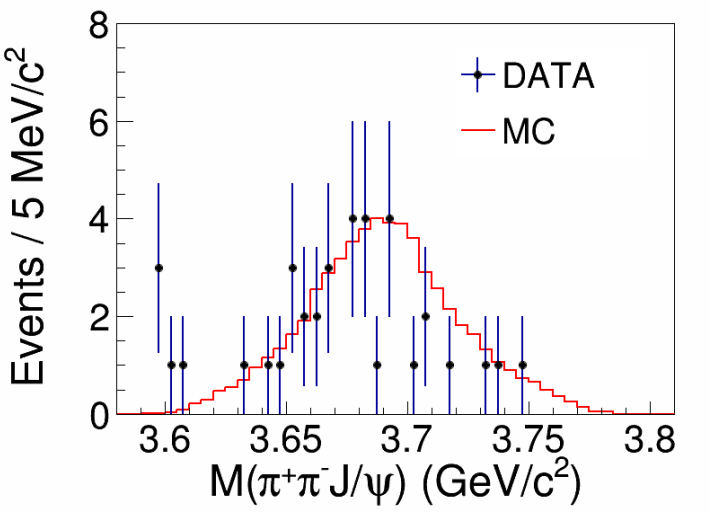




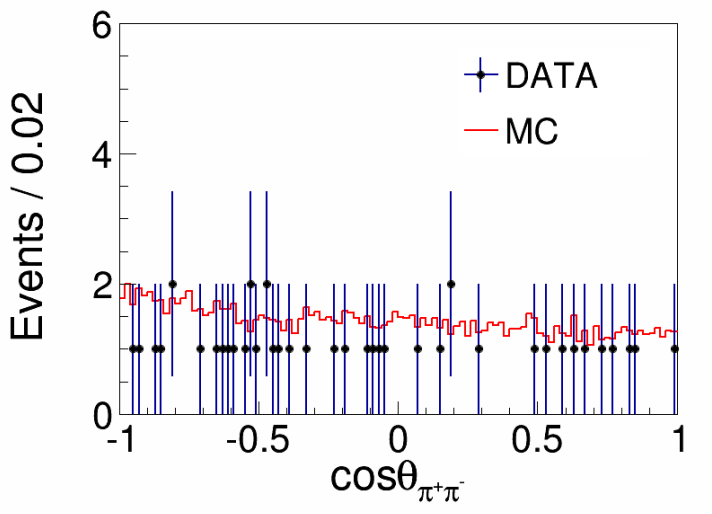
Background study



No significant η and η' events

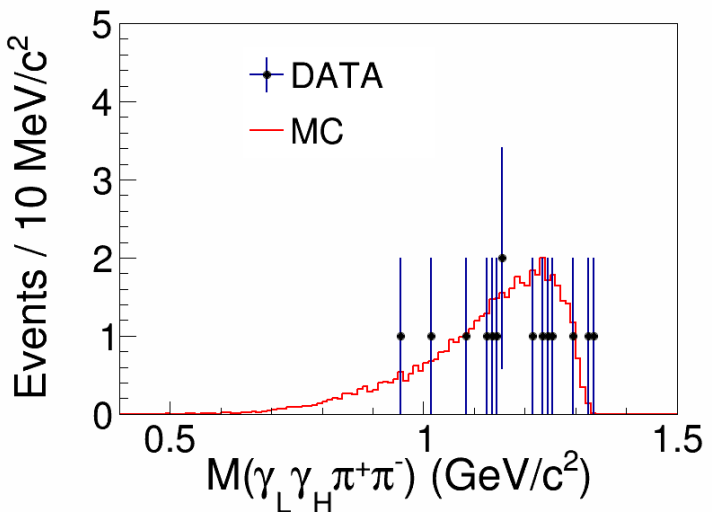


No significant $\psi(3686)$ events

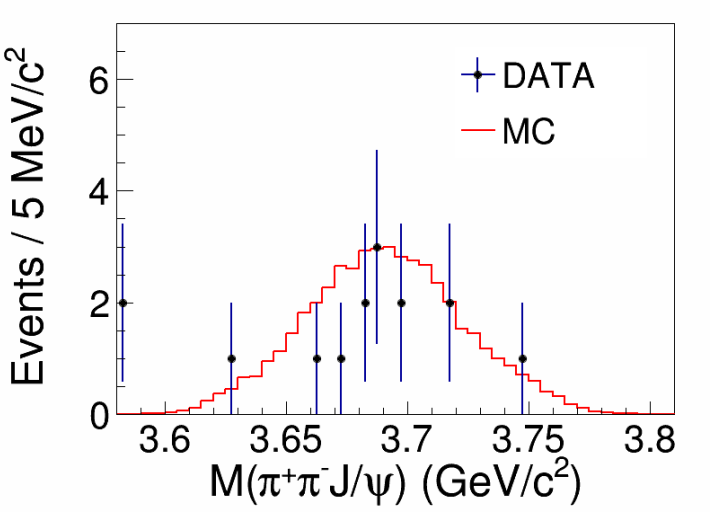


No significant γ conversion events

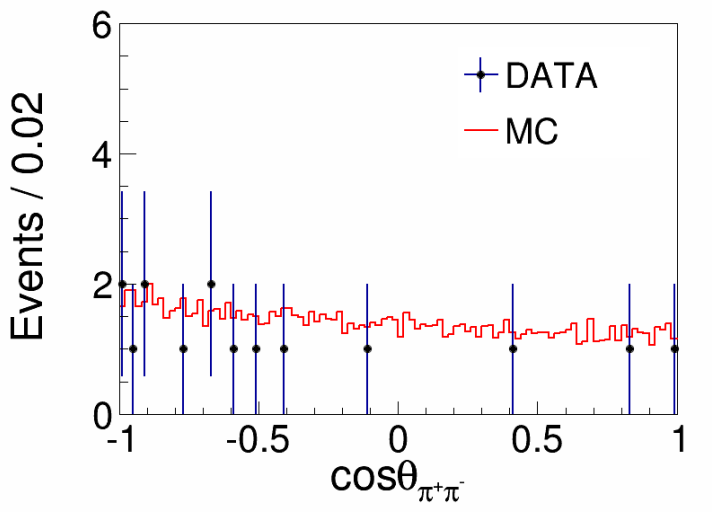
Background study



No significant η and η' events

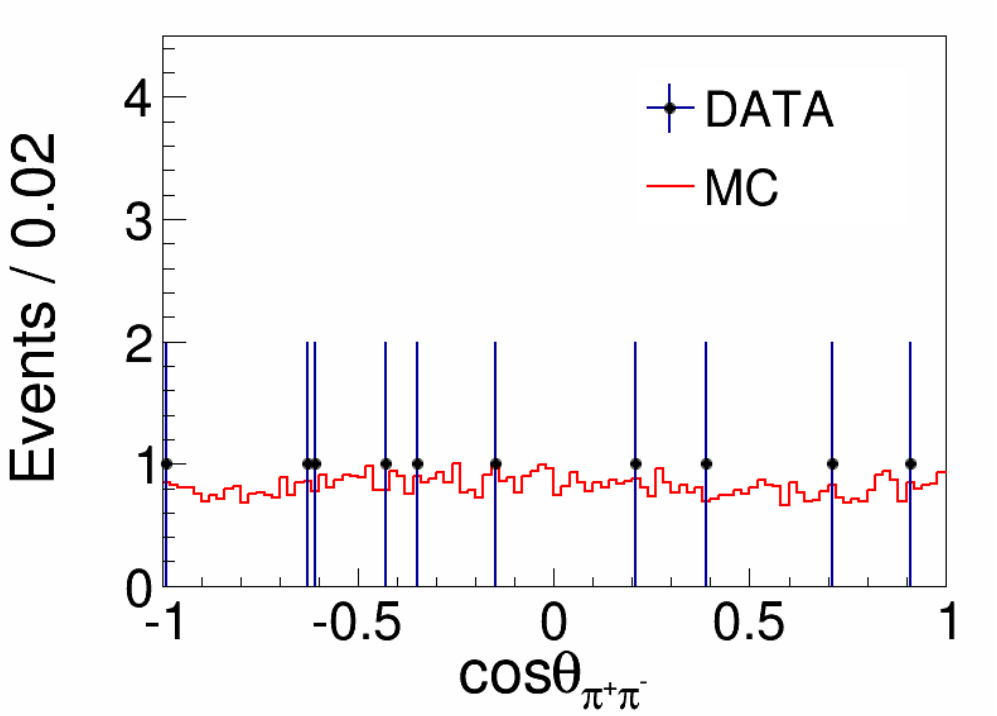


No significant $\psi(3686)$ events



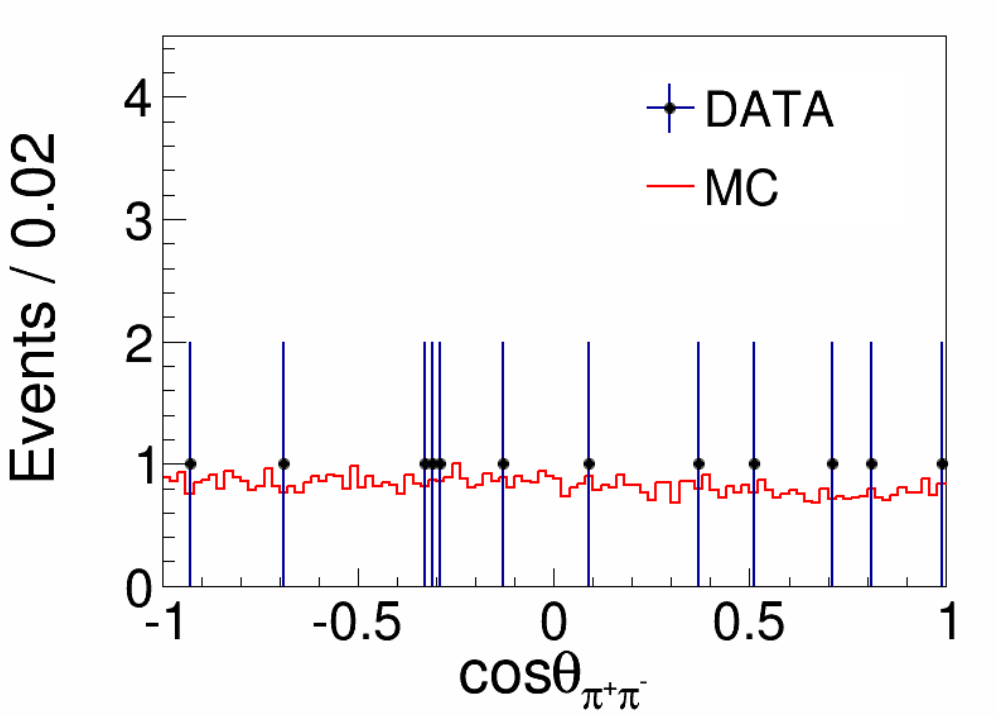
No significant γ conversion events

Background study



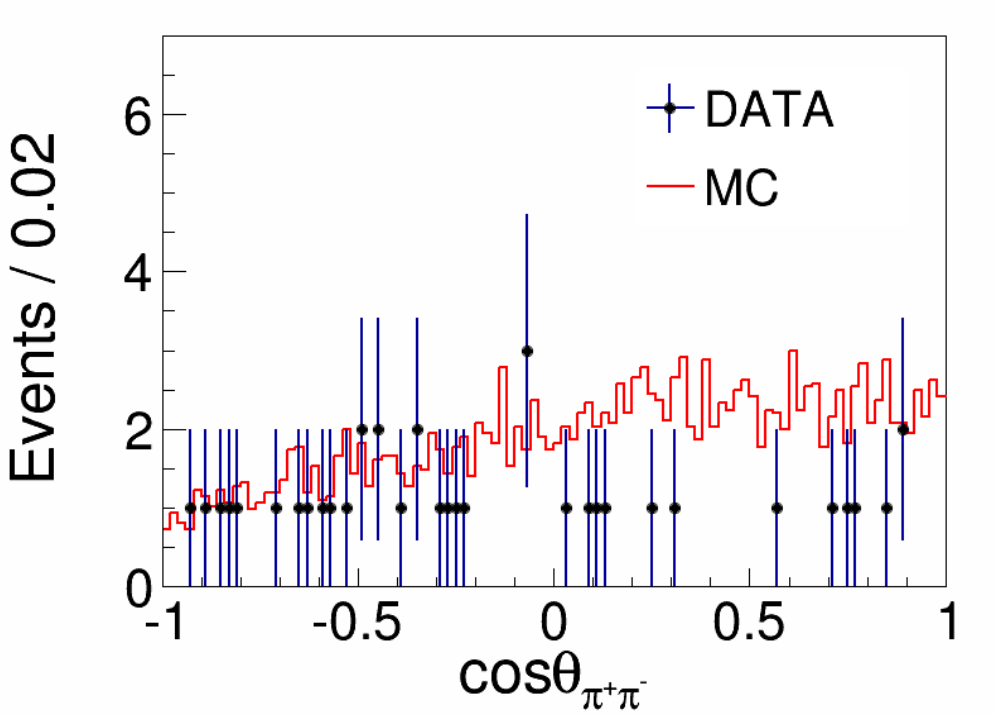
No significant γ conversion events

Background study



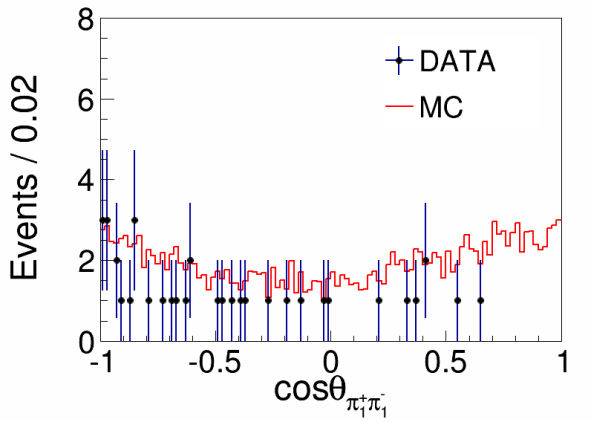
No significant γ conversion events

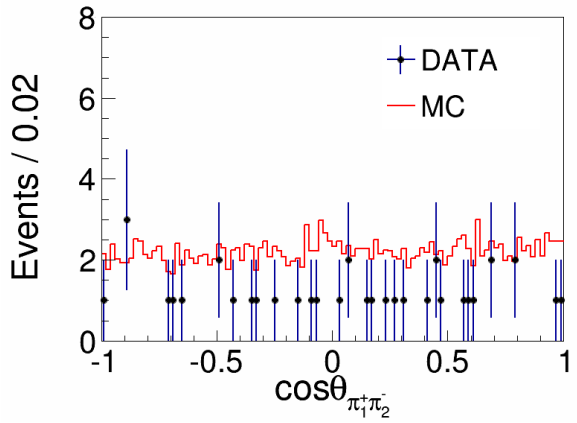
Background study

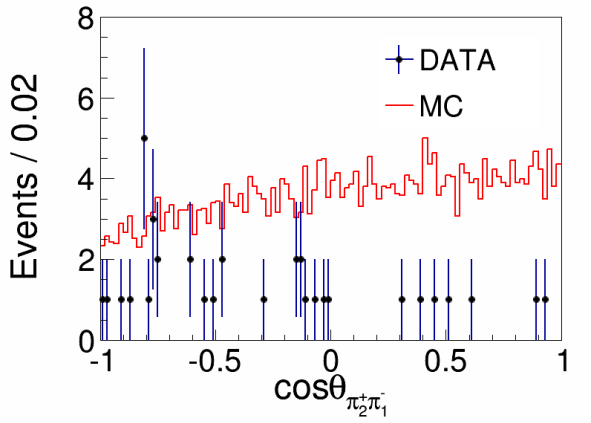


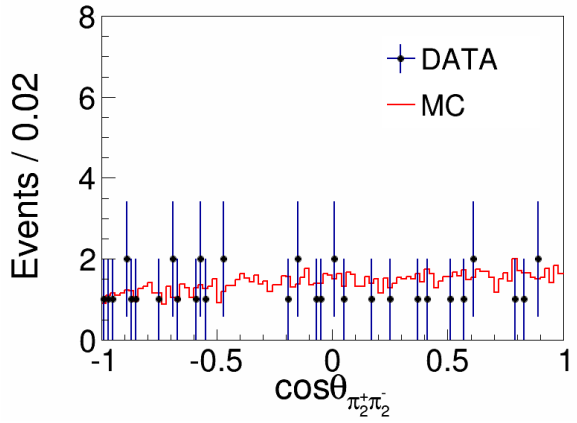
No significant γ conversion events

Background study









No significant γ conversion events