



# Observation of $\chi_{c1,2} \rightarrow \Xi^-\bar{\Xi}^+$ and $\Xi^0\bar{\Xi}^0$

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Charmonium group meeting

# Outline

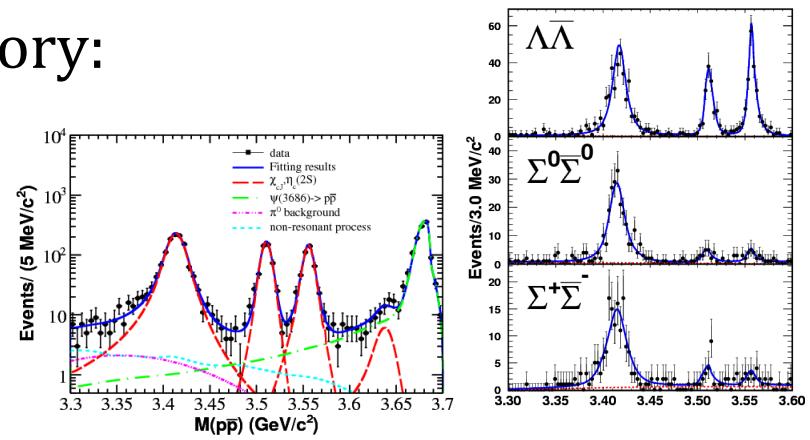
- Motivation
- Datasets
- $\chi_{cJ} \rightarrow \Xi^0 \bar{\Xi}^0$ 
  - ✓ Event selection
  - ✓ Background study
  - ✓ Signal yields extraction
  - ✓ Calculation of branch fractions
  - ☐ Systematic uncertainty
- $\chi_{cJ} \rightarrow \Xi^- \bar{\Xi}^+$ 
  - ✓ Event selection
  - ✓ Background study
  - ✓ Signal yields extraction
  - ✓ Calculation of branch fractions
  - ☐ Systematic uncertainty
- Summary

✓ Done

☐ Ongoing

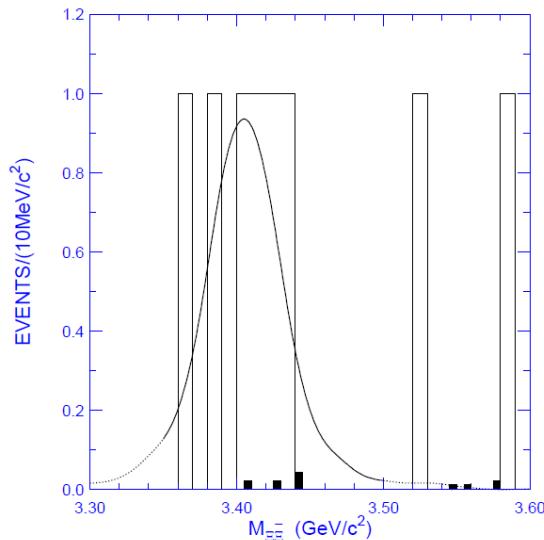
# Motivation

- The large branching fractions of  $\psi(2S) \rightarrow \gamma\chi_{cJ}$  make  $e^+e^-$  collisions at the  $\psi(2S)$  energy a very clean environment for  $\chi_{cJ}$  investigation.
- Charmonia decay properties are essential to test the QCD based effective field theory:
  - Helicity Selection Rule
  - Color Octet Mechanism

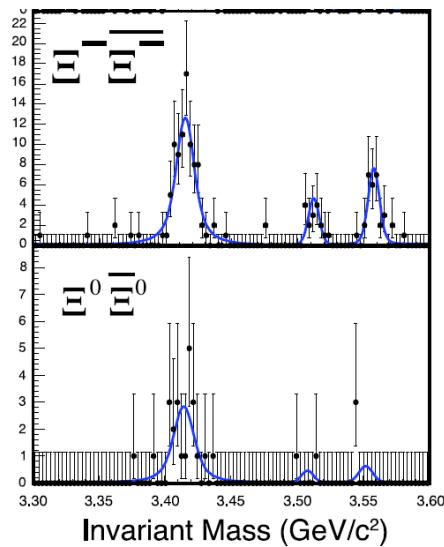


- BES<sup>[1]</sup> and CLEO<sup>[2]</sup>'s result:

Mode	$\chi_{c0}$	$\chi_{c1}$	$\chi_{c2}$
$B(\chi_{cJ} \rightarrow \Xi^- \bar{\Xi}^+) \times 10^{-4}$	BES: $5.3 \pm 2.7 \pm 0.9$ CLEO: $5.1 \pm 0.6 \pm 0.5$ PDG: $4.8 \pm 0.7$	BES: $< 3.4$ CLEO: $0.9 \pm 0.2 \pm 0.1$ PDG: $0.8 \pm 0.2$	BES: $< 3.7$ CLEO: $1.5 \pm 0.3 \pm 0.2$ PDG: $1.4 \pm 0.3$
$B(\chi_{cJ} \rightarrow \Xi^0 \bar{\Xi}^0) \times 10^{-4}$	CLEO: $3.3 \pm 0.7 \pm 0.5$ PDG: $3.1 \pm 0.8$	CLEO: $< 0.6$ PDG: $< 0.6$	CLEO: $< 1.0$ PDG: $< 1.0$



[1]PhysRevD.73.052006



[2]PhysRevD.78.031101

- Limited statistics, more precise measurements are needed

# Datasets

- $\psi(2S)$  data:  $107 \pm 0.8$  M(2009) and  $341.1 \pm 2.1$  M(2012)
- Signal MC (100k for each decay mode):
  - $e^+e^- \rightarrow \psi(2S) \rightarrow \gamma\chi_{cJ} \rightarrow \gamma\Xi^-\bar{\Xi}^+ \rightarrow Anything$  (KKMC)
  - $e^+e^- \rightarrow \psi(2S) \rightarrow \gamma\chi_{cJ} \rightarrow \gamma\Xi^0\bar{\Xi}^0 \rightarrow Anything$  (KKMC)
- Inclusive MC: 506M,  $\psi(2S) \rightarrow Anything$
- BOSS version: 664p03

# **Part I:**

$$\chi_{cJ} \rightarrow \Xi^- \overline{\Xi}^+$$

# Event Selection

① Tagging Final State:  $\gamma \Xi^- \rightarrow \gamma \Lambda^0 \pi^- \rightarrow \gamma p \pi^- \pi^- + \text{c.c.}$

- Good Charged Track :

$$|\cos\theta| < 0.93 ,$$

$$N_+ \geq 1 \ \&\& N_- \geq 2 ,$$

- PID with dE/dx and TOF :

$$N_p = 1 \ \&\& N_\pi = 2 ,$$

- Good Neutral Shower :

$$\theta \geq 10 ,$$

Barrel :

$$E \geq 25 \text{ MeV} \ \&\& |\cos\theta| \leq 0.8 ,$$

End cap :

$$E \geq 50 \text{ MeV} \ \&\& 0.86 \leq |\cos\theta| \leq 0.92 ,$$

$$N_\gamma \geq 1 ,$$

- Reconstruction of  $\Lambda$  :

*Do Vertex and Second Vertex Fit of  $\Lambda$  by looping all  $\langle p\pi \rangle$  combinations, keep the one with minimum value of  $|M_{p\pi} - M_\Lambda^{PDG}|$*

- Reconstruction of  $\Xi$  :

*Same strategy as  $\Lambda$  by using the other  $\pi$  with  $\Lambda$ , keep the one with minimum values of  $|M_{\Lambda\pi} - M_\Xi^{PDG}|$ .*

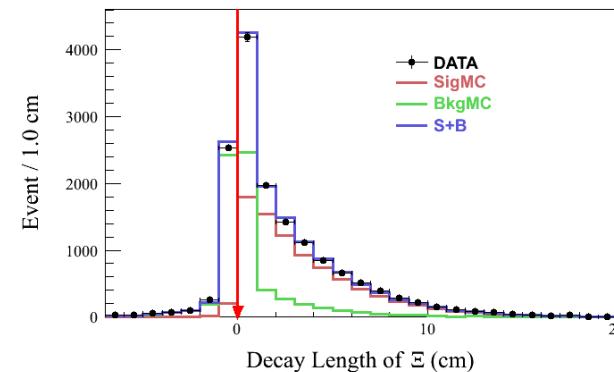
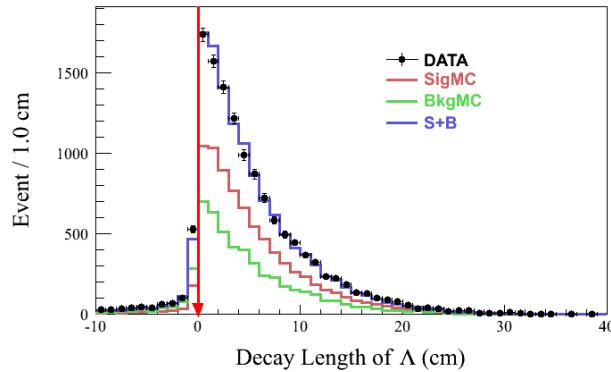
- Gamma Selection :

*looping all the neutral showers, keep the one with minimum values of  $|M_{\gamma\Lambda\pi}^{recoil} - M_\Xi^{PDG}|$ , where:*

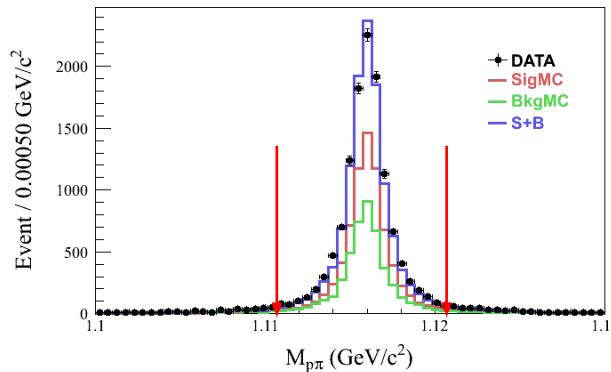
$$M_{\gamma\Lambda\pi}^{recoil} = \sqrt{(E_{e+e-} - E_{\Lambda\pi} - E_\gamma)^2 - (\vec{p}_{e+e-} - \vec{p}_{\Lambda\pi} - \vec{p}_\gamma)^2}$$

# Further Selection

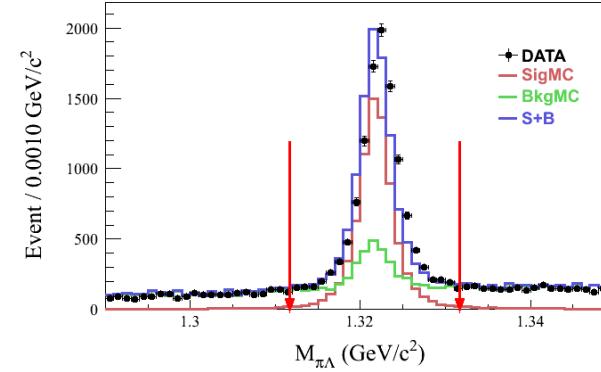
- The decay length of  $\Lambda$  and  $\Xi$  larger than zero



- Mass window of  $\Lambda$  and  $\Xi$



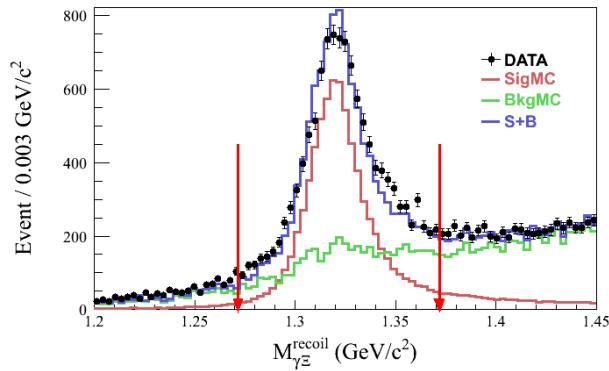
$$|M_{p\pi} - M_\Lambda^{PDG}| < 5 \text{ MeV}$$



$$|M_{\Lambda\pi} - M_\Xi^{PDG}| < 10 \text{ MeV}$$

# Further Selection

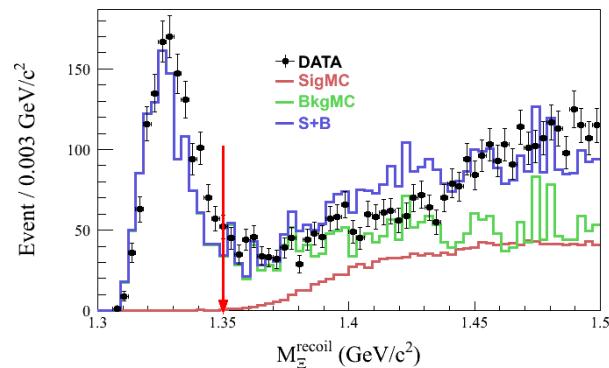
- Mass window of  $(\gamma \Xi)^{recoil}$



$$|M_{\gamma\Xi}^{recoil} - M_{\Xi}^{PDG}| < 50 \text{ MeV}$$

$$M_{\gamma\Xi}^{recoil} = \sqrt{(E_{e+e-} - E_{\Lambda\pi} - E_{\gamma})^2 - (\vec{p}_{e+e-} - \vec{p}_{\Lambda\pi} - \vec{p}_{\gamma})^2}$$

- Remove background:  $e^+ e^- \rightarrow X \rightarrow \Xi^- \bar{\Xi}^+$

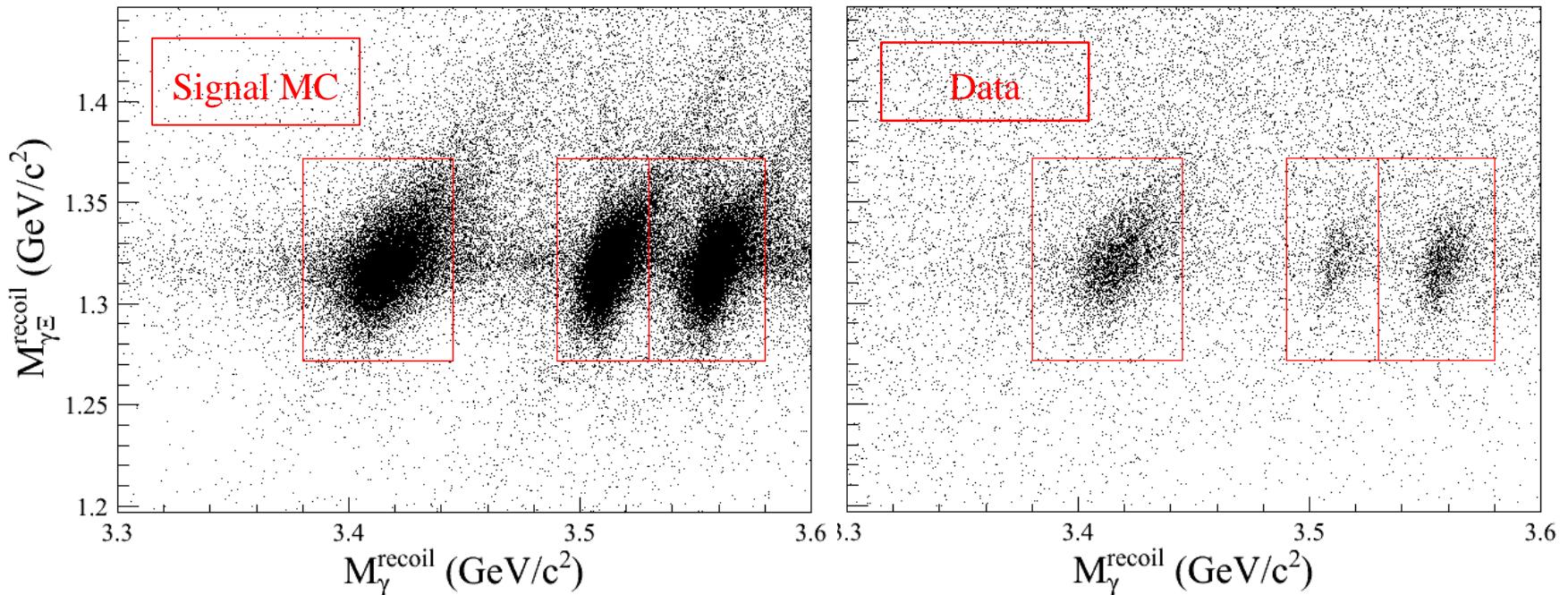


$$M_{\Xi}^{recoil} > 1.35 \text{ GeV}$$

$$M_{\Xi}^{recoil} = \sqrt{(E_{e+e-} - E_{\Lambda\pi})^2 - (\vec{p}_{e+e-} - \vec{p}_{\Lambda\pi})^2}$$

# Background study

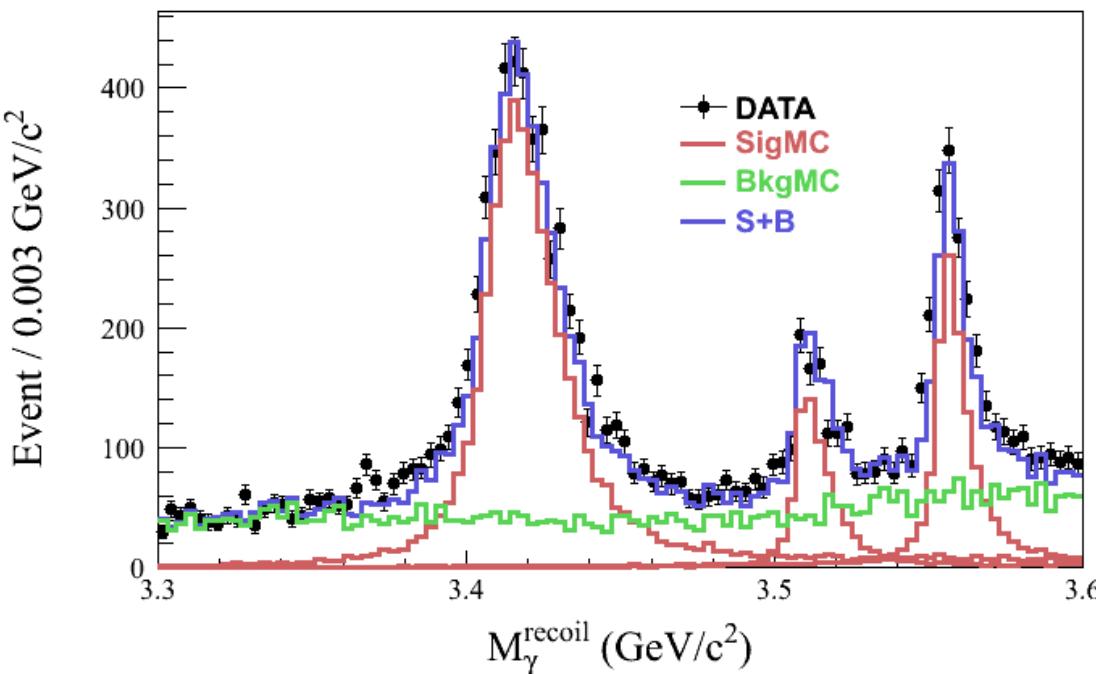
Recoil mass of gamma:  $M_\gamma^{\text{recoil}} = \sqrt{(E_{e+e-} - E_\gamma)^2 - (\vec{p}_{e^+e^-} - \vec{p}_\gamma)^2}$



- Signal is clear;
- Sideband is smooth.

# Background study

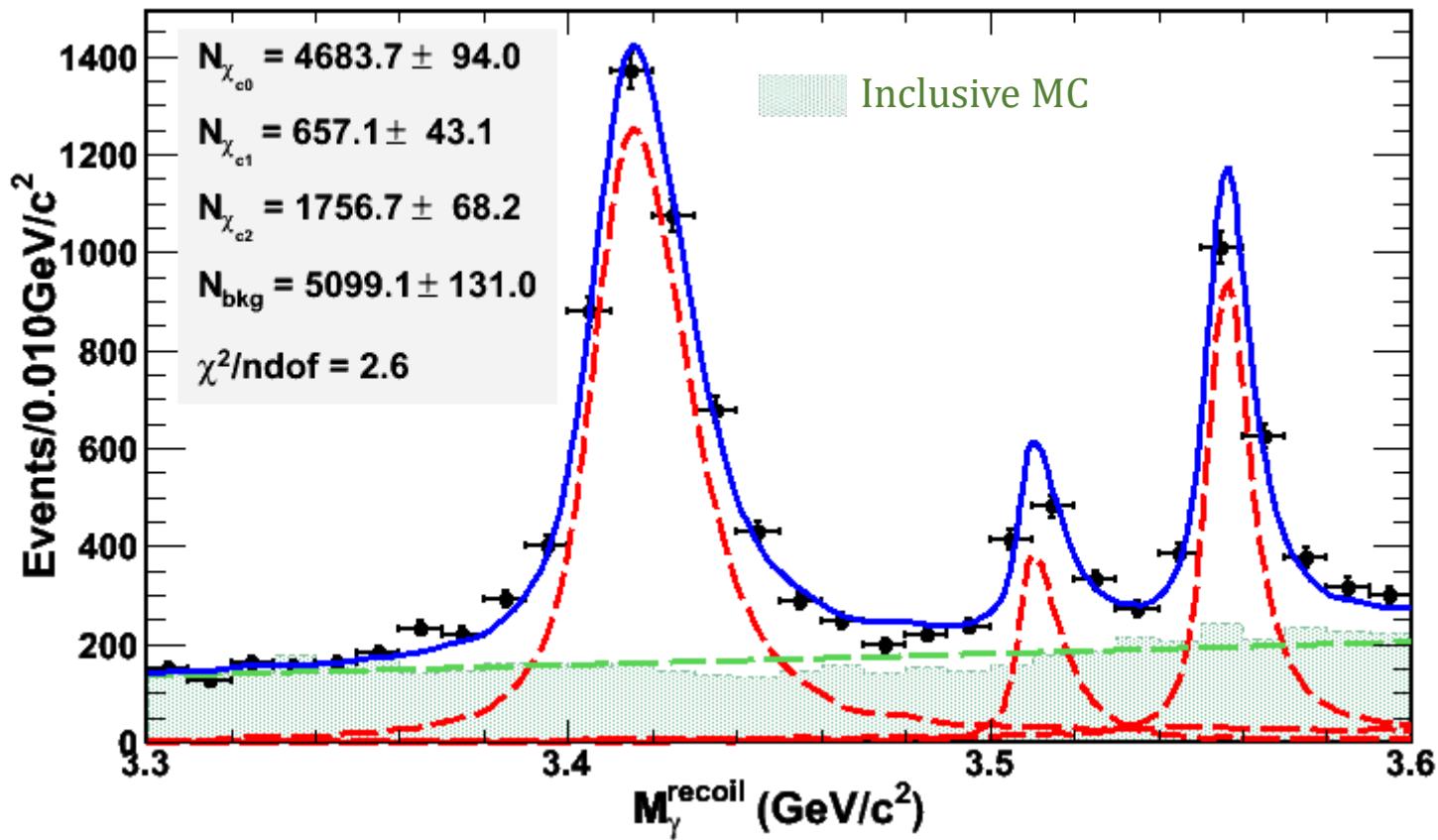
Recoil mass of gamma:  $M_\gamma^{\text{recoil}} = \sqrt{(E_{e^+e^-} - E_\gamma)^2 - (\vec{p}_{e^+e^-} - \vec{p}_\gamma)^2}$



- $\psi' \rightarrow \pi\pi J/\psi$
- $J/\psi \rightarrow \Sigma^0 \bar{\Sigma}^0, \Xi^- \bar{\Xi}^+, \Lambda \bar{\Lambda}$
- $J/\psi \rightarrow \Lambda \bar{\Sigma}^0, \Sigma^0 \bar{\Lambda}$
- $\psi' \rightarrow \Xi^- \bar{\Xi}^+$
- $\psi' \rightarrow \gamma \chi_{cJ}$ 
  - $\chi_{cJ} \rightarrow \gamma J/\psi$
  - $\chi_{cJ} \rightarrow 3 \text{ hadrons}$
- $\psi' \rightarrow 3 \text{ or } 4 \text{ hadrons}$

- Backgrounds distribute smoothly on recoil mass spectrum;
- Cuts on recoil mass can remove most of these backgrounds.

# Signal yields extraction



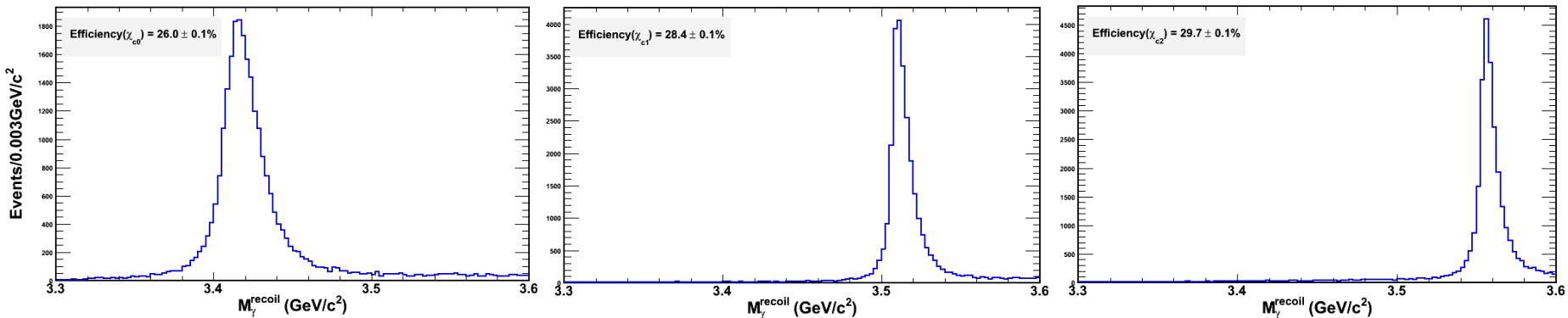
Signal: MC shape  $\otimes$  Gaussian

Bkg: 2<sup>nd</sup> order polynomial function

# Calculation of branch fraction

$$\mathcal{B}_{\chi_{cJ} \rightarrow \Xi^- \bar{\Xi}^+} = \frac{N_{obs}}{\epsilon \times N_{\psi(3686)} \times \mathcal{B}_{\psi(3686) \rightarrow \gamma \chi_{cJ}}}$$

- Efficiency from signal MC ( $\sim 28\%$ ):



- Branch fraction:

Mode	$\epsilon(\%)$	$N_{obs}$	$\mathcal{B}_{\psi' \rightarrow \gamma \chi_{cJ}}(\%)$	$\mathcal{B}(\times 10^{-4})$
$\chi_{c0} \rightarrow \Xi^- \bar{\Xi}^+$	$26.0 \pm 0.1$	$4683.7 \pm 94.0$	$9.79 \pm 0.20$	$4.11 \pm 0.12$
$\chi_{c1} \rightarrow \Xi^- \bar{\Xi}^+$	$28.4 \pm 0.1$	$657.1 \pm 43.1$	$9.75 \pm 0.24$	$0.53 \pm 0.04$
$\chi_{c2} \rightarrow \Xi^- \bar{\Xi}^+$	$29.7 \pm 0.1$	$1756.7 \pm 68.2$	$9.52 \pm 0.20$	$1.39 \pm 0.06$

## **Part II:**

$$\chi_{cJ} \rightarrow \Xi^0 \bar{\Xi}^0$$

# Event Selection

⌚ Tagging Final State:  $\gamma \Xi^0 \rightarrow \gamma \Lambda^0 \pi^0 \rightarrow \gamma p \pi^- \gamma \gamma + \text{c.c.}$

- Good Charged Track :

$$|\cos\theta| < 0.93 ,$$

$$N_+ \geq 1 \ \&\& N_- \geq 1 ,$$

- PID with dE/dx and TOF :

$$N_p = 1 \ \&\& N_\pi = 1 ,$$

- Good Neutral Shower :

$$\theta \geq 10 ,$$

Barrel :

$$E \geq 25 \text{ MeV} \ \&\& |\cos\theta| \leq 0.8 ,$$

End cap :

$$E \geq 50 \text{ MeV} \ \&\& 0.86 \leq |\cos\theta| \leq 0.92 ,$$

$$N_\gamma \geq 3 ,$$

- Reconstruction of  $\Lambda$  :

*Do Vertex and Second Vertex Fit of  $\Lambda$  by proton and pion.*

- Reconstruction of  $\pi^0$  :

*Do 1C Kinematic Fit of  $\pi^0$  by looping all  $\langle \gamma\gamma \rangle$  combinations, keep the one with minimum value of  $|M_{\gamma\gamma} - M_{\pi^0}^{PDG}|$ .*

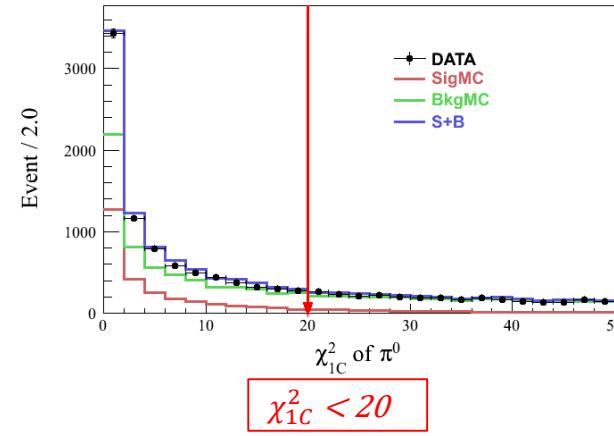
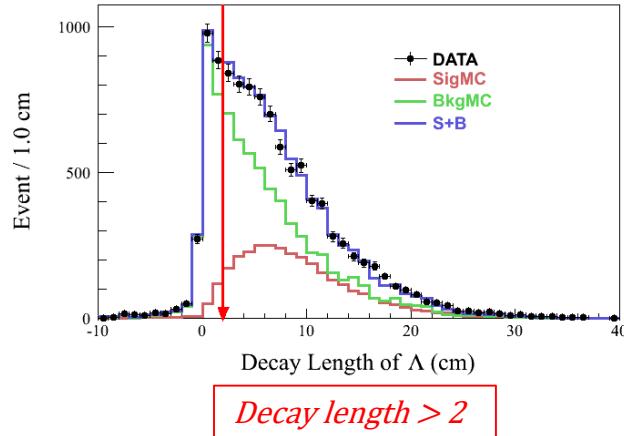
- Gamma Selection :

*looping all the other neutral showers, keep the one with minimum value of  $|M_{\gamma\Lambda\pi^0}^{recoil} - M_{\Xi^0}^{PDG}|$ , where:*

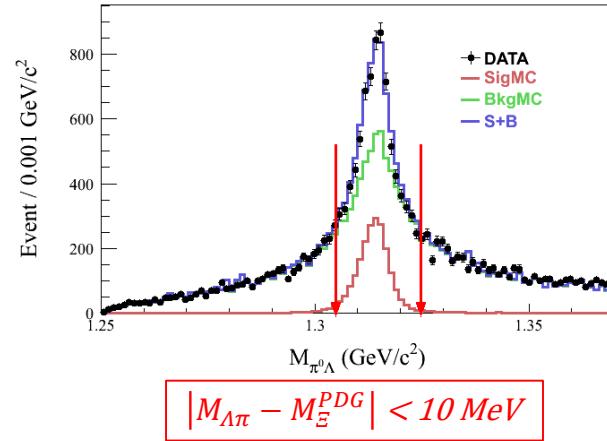
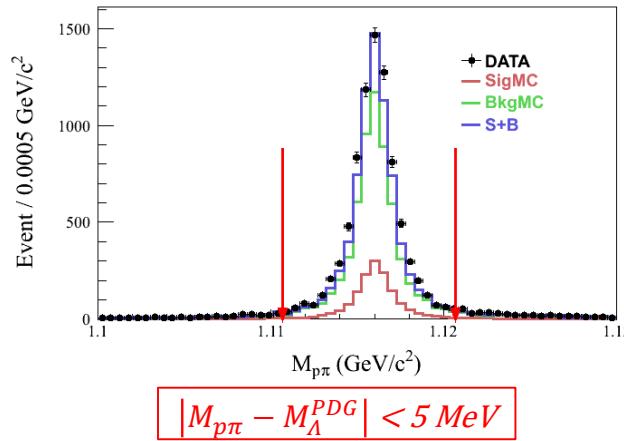
$$M_{\gamma\Lambda\pi^0}^{recoil} = \sqrt{(E_{e+e-} - E_{\Lambda\pi^0} - E_\gamma)^2 - (\vec{p}_{e+e-} - \vec{p}_{\Lambda\pi^0} - \vec{p}_\gamma)^2}$$

# Further Selection

- Decay length of  $\Lambda$  and  $\chi^2_{1C}$  of  $\pi^0$ :

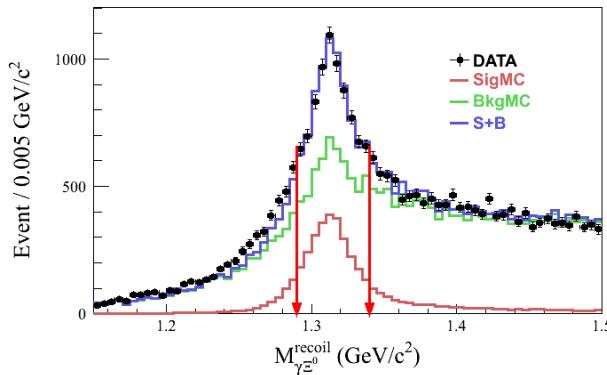


- Mass window of  $\Lambda$  and  $\Xi^0$



# Further Selection

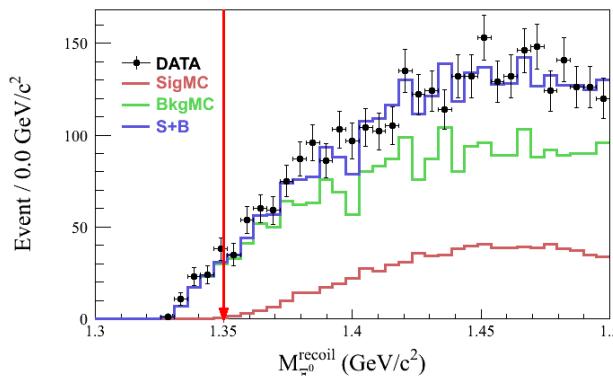
- Mass window of  $(\gamma \Xi)^{recoil}$



$$|M_{\gamma\Xi}^{recoil} - M_{\Xi}^{PDG}| < 25 \text{ MeV}$$

$$M_{\gamma\Xi}^{recoil} = \sqrt{(E_{e^+e^-} - E_{\Lambda\pi} - E_\gamma)^2 - (\vec{p}_{e^+e^-} - \vec{p}_{\Lambda\pi} - \vec{p}_\gamma)^2}$$

- Background:  $e^+e^- \rightarrow X \rightarrow \Xi^0 \bar{\Xi}^0$

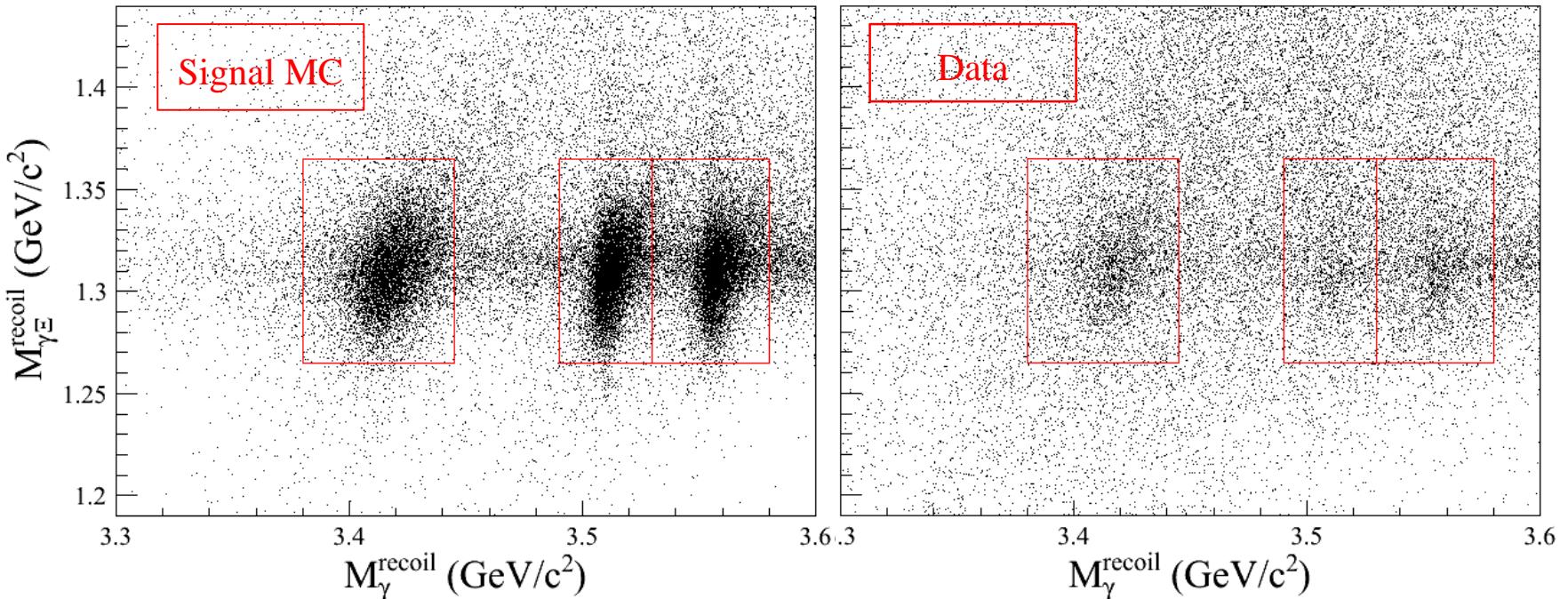


$$M_{\Xi}^{recoil} > 1.35 \text{ GeV}$$

$$M_{\Xi}^{recoil} = \sqrt{(E_{e^+e^-} - E_{\Lambda\pi})^2 - (\vec{p}_{e^+e^-} - \vec{p}_{\Lambda\pi})^2}$$

# Background study

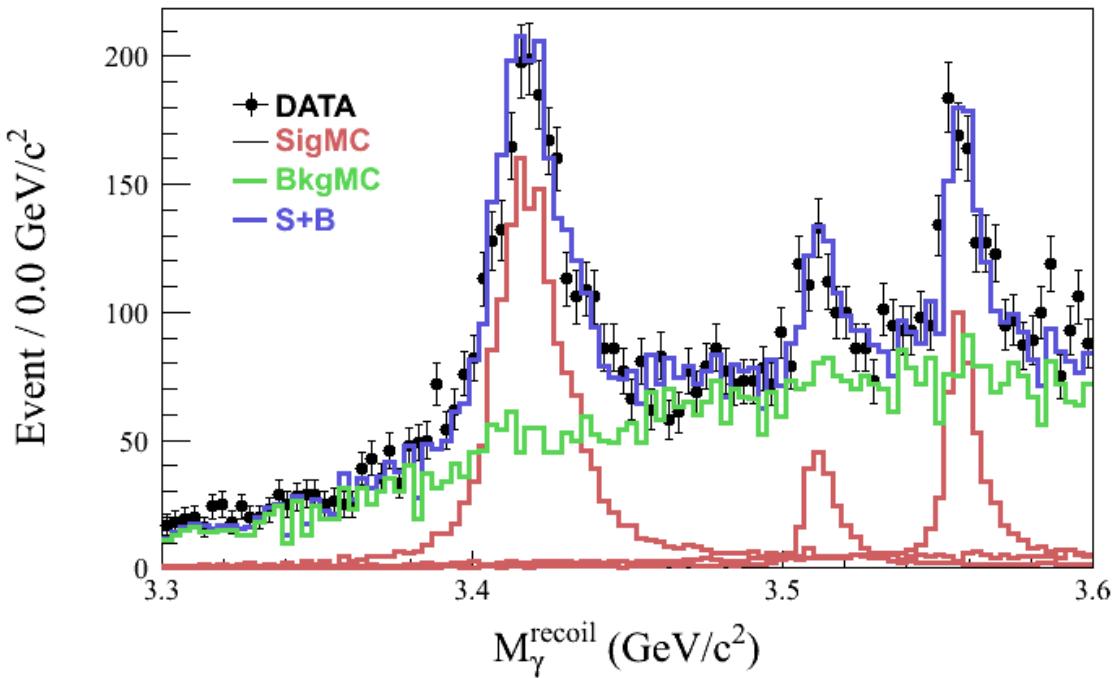
Recoil mass of gamma:  $M_\gamma^{\text{recoil}} = \sqrt{(E_{e+e-} - E_\gamma)^2 - (\vec{p}_{e^+e^-} - \vec{p}_\gamma)^2}$



- Signal can be seen in data, background is too much;
- Sideband is smooth.

# Background study

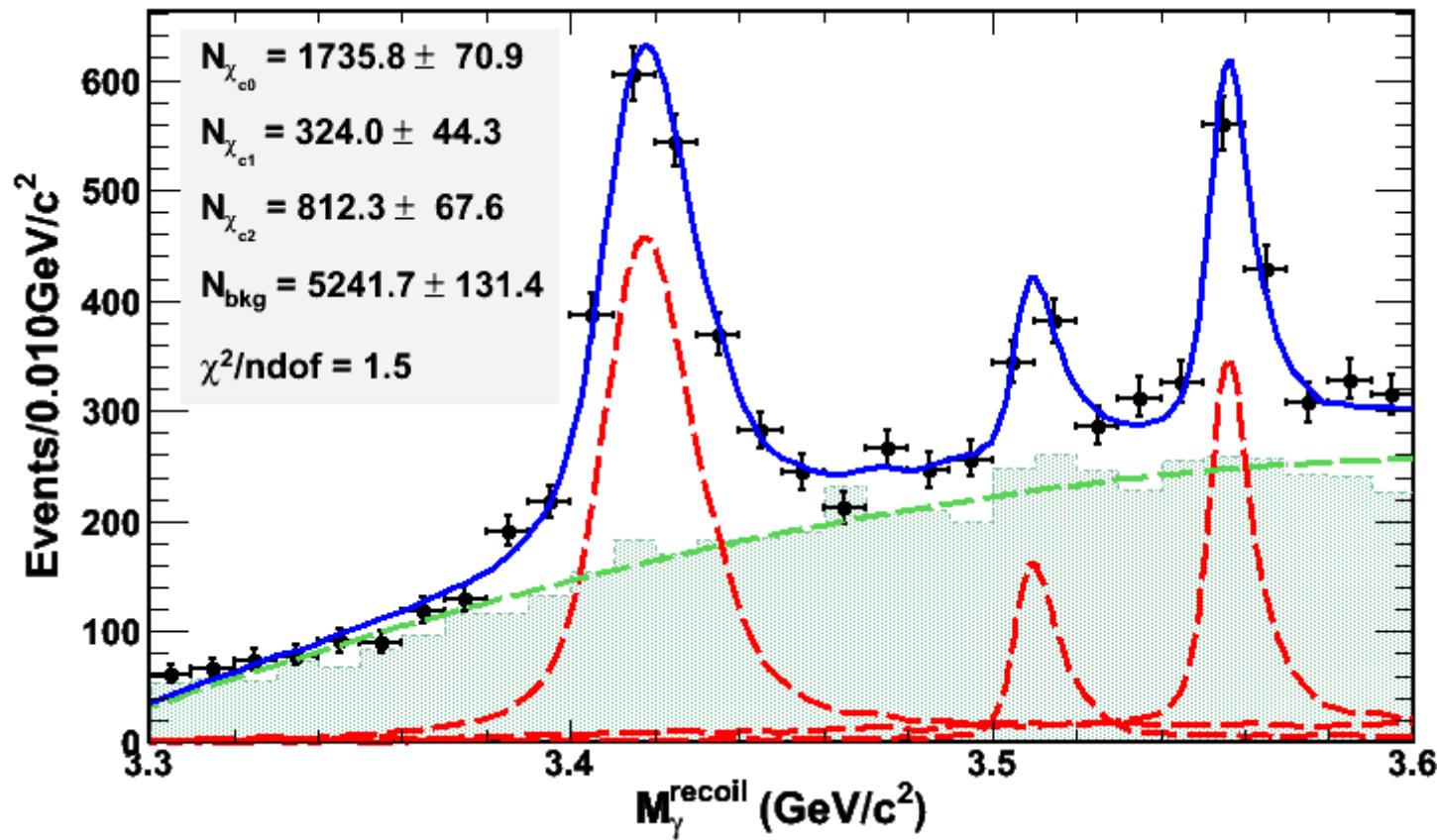
Recoil mass of gamma:  $M_{\gamma}^{recoil} = \sqrt{(E_{e+e-} - E_{\gamma})^2 - (\vec{p}_{e^+e^-} - \vec{p}_{\gamma})^2}$



- $\psi' \rightarrow \pi\pi J/\psi$
- $J/\psi \rightarrow \Sigma^0 \bar{\Sigma}^0, \Xi^0 \bar{\Xi}^0, \Lambda \bar{\Lambda}$
- $J/\psi \rightarrow \Lambda \bar{\Sigma}^0, \Sigma^0 \bar{\Lambda}$
- $\psi' \rightarrow \Xi^0 \bar{\Xi}^0$
- $\psi' \rightarrow \gamma \chi_{cJ}$ 
  - $\chi_{cJ} \rightarrow \gamma J/\psi$
  - $\chi_{cJ} \rightarrow 3 \text{ hadrons}$
- $\psi' \rightarrow 3 \text{ or } 4 \text{ hadrons}$

- Backgrounds distribute smoothly.

# Signal yields extraction



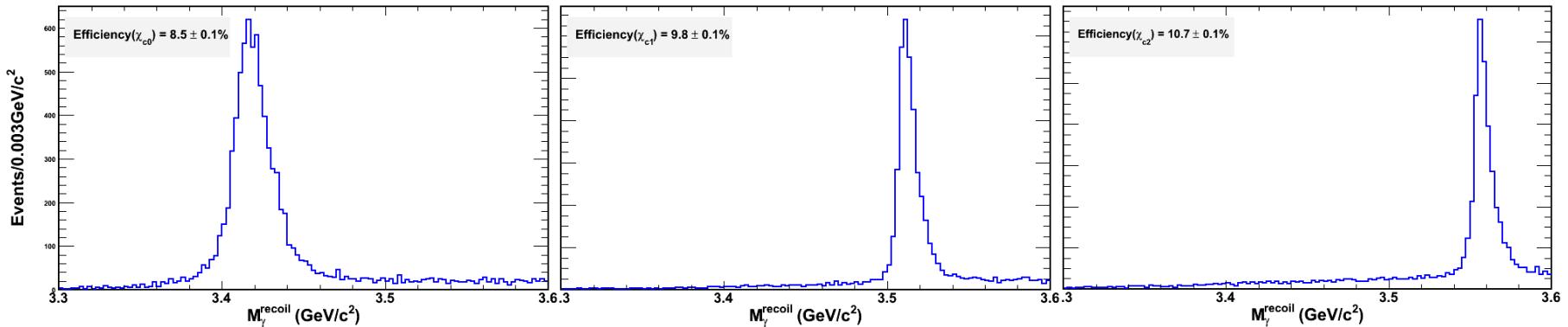
Signal: MC shape  $\otimes$  Gaussian

Bkg: 2<sup>nd</sup> order polynomial function

# Calculation of branch fraction

$$\mathcal{B}_{\chi_{cJ} \rightarrow \Xi^- \bar{\Xi}^+} = \frac{N_{obs}}{\epsilon \times N_{\psi(3686)} \times \mathcal{B}_{\psi(3686) \rightarrow \gamma \chi_{cJ}}}$$

- Efficiency from signal MC ( $\sim 7\%$ ):



- Branch fraction:

Mode	$\epsilon$ (%)	$N_{obs}$	$\mathcal{B}_{\psi' \rightarrow \gamma \chi_{cJ}}$ (%)	$\mathcal{B} (\times 10^{-4})$
$\chi_{c0} \rightarrow \Xi^0 \bar{\Xi}^0$	$8.5 \pm 0.1$	$1735.8 \pm 70.9$	$9.79 \pm 0.20$	$4.66 \pm 0.22$
$\chi_{c1} \rightarrow \Xi^0 \bar{\Xi}^0$	$9.8 \pm 0.1$	$324.0 \pm 44.3$	$9.75 \pm 0.24$	$0.76 \pm 0.11$
$\chi_{c2} \rightarrow \Xi^0 \bar{\Xi}^0$	$10.7 \pm 0.1$	$812.3 \pm 67.6$	$9.52 \pm 0.20$	$1.78 \pm 0.15$

# Summary

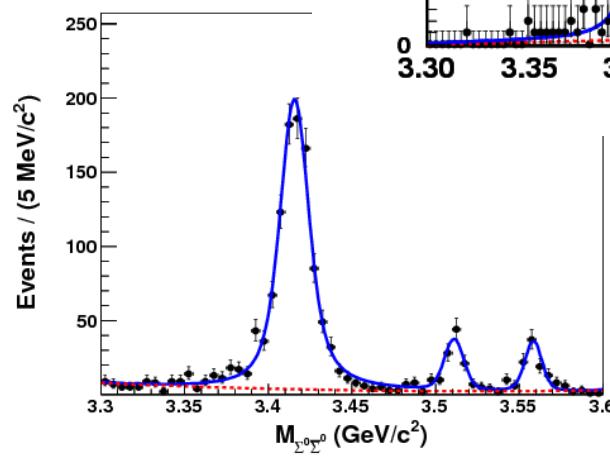
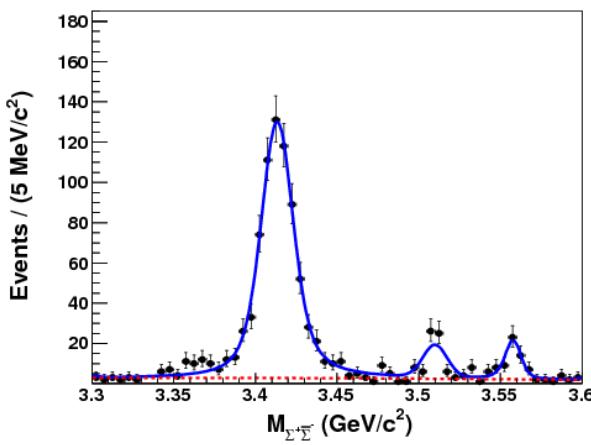
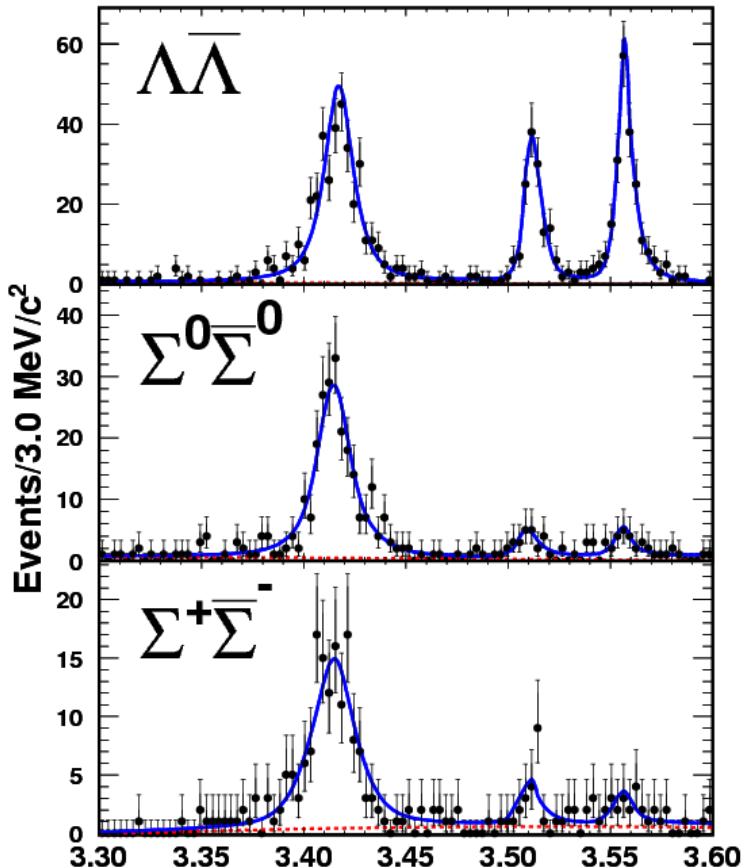
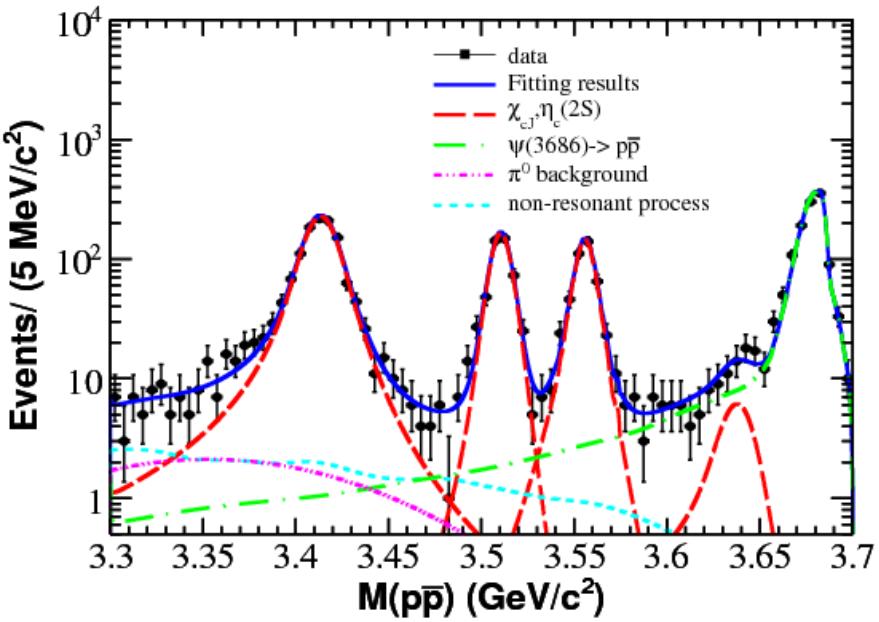
- Measured the branch fraction of  $\chi_{cJ} \rightarrow \Xi^-\bar{\Xi}^+$  and  $\Xi^0\bar{\Xi}^0$  by using the single tag method:

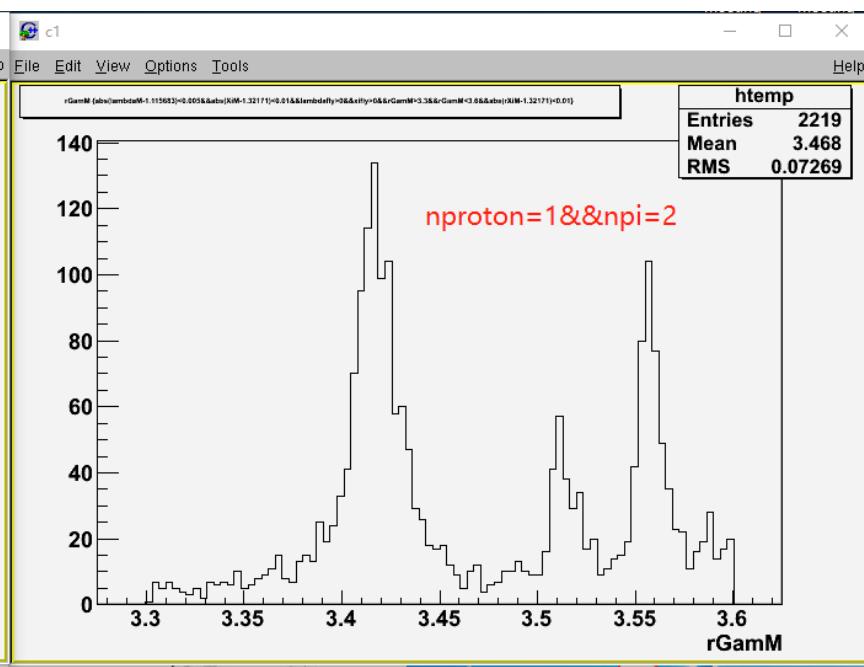
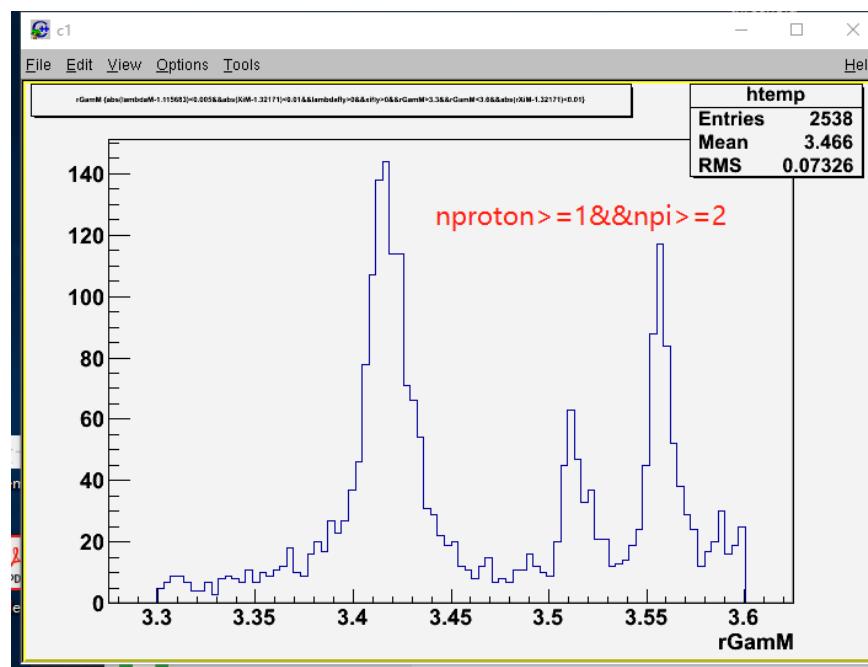
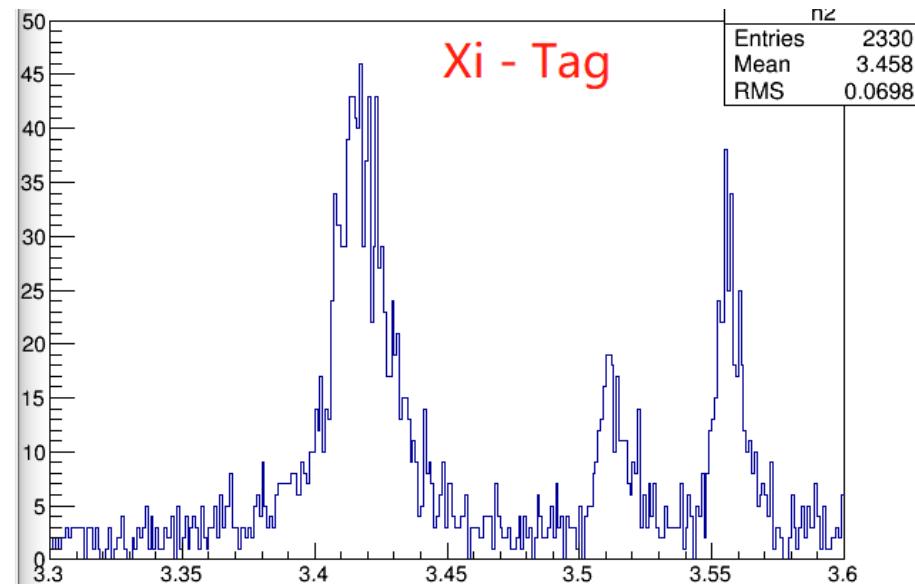
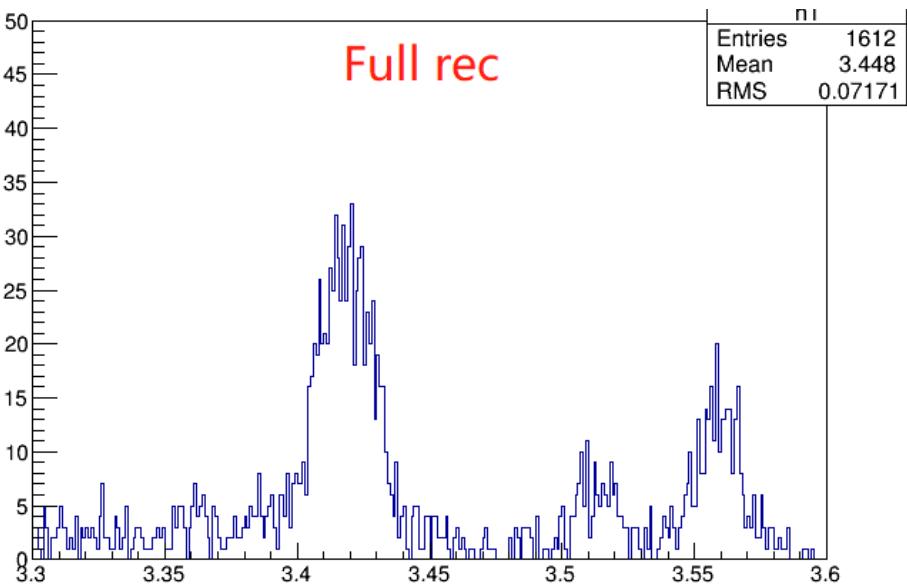
Decay Mode		$\chi_{c0}$		$\chi_{c1}$		$\chi_{c2}$
$\Xi^-\bar{\Xi}^+(\times 10^{-4})$	BES:	$5.3 \pm 2.7 \pm 0.9$	BES:	$< 3.4$	BES:	$< 3.7$
	CLEO:	$5.1 \pm 0.6 \pm 0.5$	CLEO:	$0.9 \pm 0.2 \pm 0.1$	CLEO:	$1.5 \pm 0.3 \pm 0.2$
	PDG:	$4.8 \pm 0.7$	PDG:	$0.8 \pm 0.2$	PDG:	$1.4 \pm 0.3$
	ThisWork:	$4.11 \pm 0.12$	ThisWork:	$0.53 \pm 0.04$	ThisWork:	$1.39 \pm 0.06$
$\Xi^0\bar{\Xi}^0(\times 10^{-4})$	CLEO:	$3.3 \pm 0.7 \pm 0.5$	CLEO:	$< 0.6$	CLEO:	$< 1.0$
	PDG:	$3.1 \pm 0.8$	PDG:	$< 0.6$	PDG:	$< 1.0$
	ThisWork:	$4.66 \pm 0.22$	ThisWork:	$0.76 \pm 0.11$	ThisWork:	$1.78 \pm 0.15$

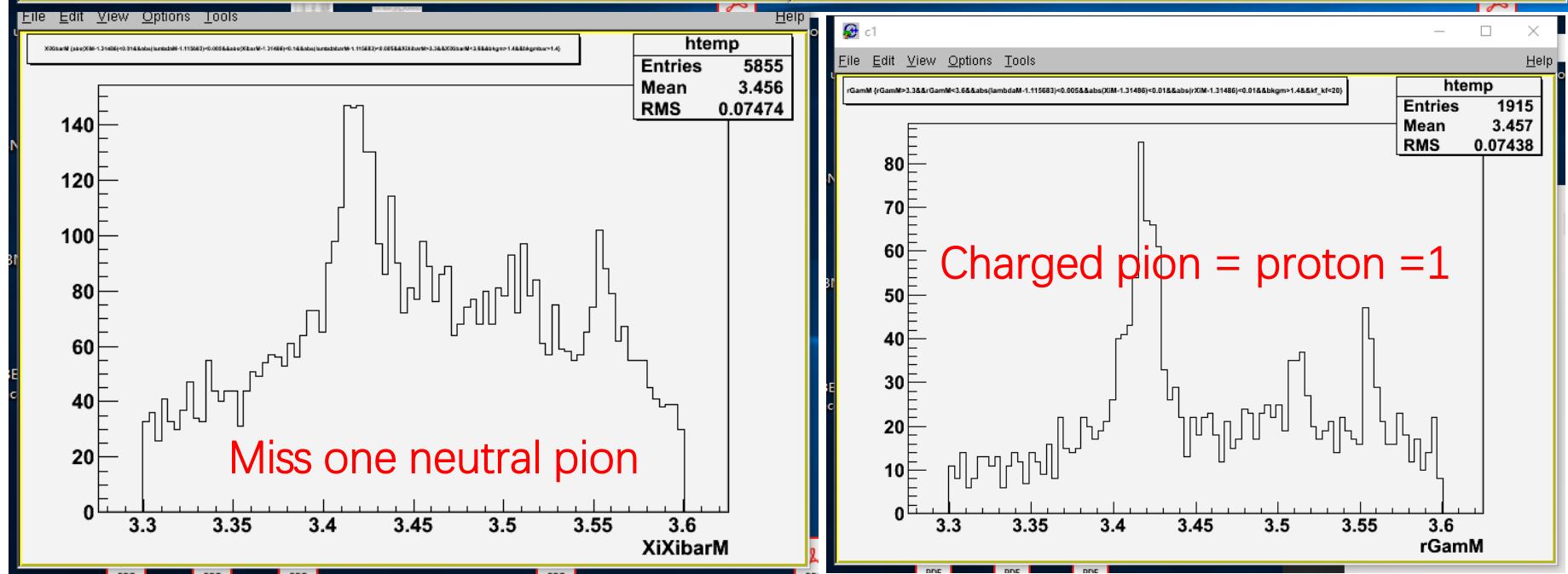
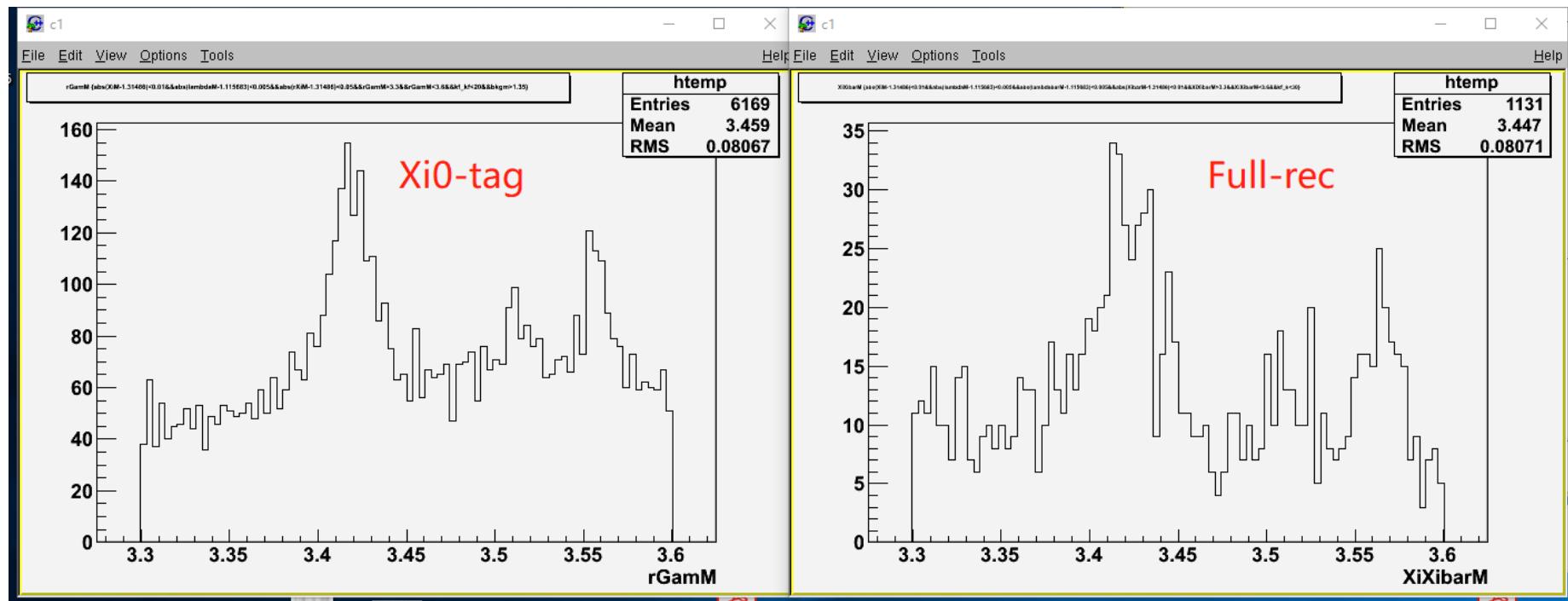
- First observation of  $\chi_{c1,2} \rightarrow \Xi^0\bar{\Xi}^0$ ,
- Next to
  - Systematic uncertainty
  - Angular distribution

Thank You!

# **Backup**







$$\chi_{cJ} \rightarrow \Xi^0 \bar{\Xi}^0$$

