

Search for
 $X(3872) \rightarrow \pi^0 \pi^0 \chi_{cJ}$

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August 2018

Motivation

- Explore evidence for opposing interpretations of $X(3872)$.
 - If $X(3872)$ is a charmonium state¹:
 - Expect two-pion transitions to χ_{cJ} from $X(3872)$ to be enhanced relative to single-pion transitions (by a factor of 25).
 - Expect production of χ_{c1} to be dominant with $\Gamma(X(3872) \rightarrow \pi^0\pi^0\chi_{c1}) \sim 1\text{keV}$.
 - If $X(3872)$ is a tetraquark:
 - Expect production of χ_{c1} and χ_{c2} to be similar, χ_{c0} to be strongly suppressed¹.
 - Expect two-pion transition to χ_{cJ} from $X(3872)$ to be on same order as single-pion transition².

¹ S. Dubynskiy and M. B. Voloshin. "Pionic transitions from $X(3872)$ to χ_{cJ} ". In: *Phys. Rev. D* 77 (1 Jan. 2008), p. 014013.

² Sean Fleming and Thomas Mehen. "Hadronic decays of the $X(3872)$ to χ_{cJ} in effective field theory". In: *Phys. Rev. D* 78 (9 Nov. 2008), p. 094019.

Final State

$$e^+e^- \rightarrow \gamma X(3872)$$

$$X(3872) \rightarrow \pi^0\pi^0\chi_{cJ}$$

$$\chi_{cJ} \rightarrow \gamma J/\psi$$

$$J/\psi \rightarrow l^+l^-$$

Final State: $l^+l^-\gamma\gamma\pi^0\pi^0$

Four different types of MC were generated.

$Y(4260)$ without ISR

- $e^+e^- \rightarrow \omega\chi_{cJ}$
- $e^+e^- \rightarrow \eta J/\psi$
- $e^+e^- \rightarrow \eta' J/\psi$

$Y(4260)$ with ISR

- $e^+e^- \rightarrow \pi\pi J/\psi$
- ISR where $e^+e^- \rightarrow \gamma\psi'$

$X(3872)$ with $e^+e^- \rightarrow \gamma X(3872)$

- $X(3872) \rightarrow \pi^+\pi^- J/\psi$
- $X(3872) \rightarrow \pi^0\chi_{cJ}$
- $X(3872) \rightarrow \gamma\psi'$
- $X(3872) \rightarrow \gamma J/\psi$
- $X(3872) \rightarrow \omega J/\psi$

Model background, including continuum, with J/ψ sideband:
 $35 \text{ MeV} < |M(l^+l^-) - M(J/\psi)| < 95 \text{ MeV}$

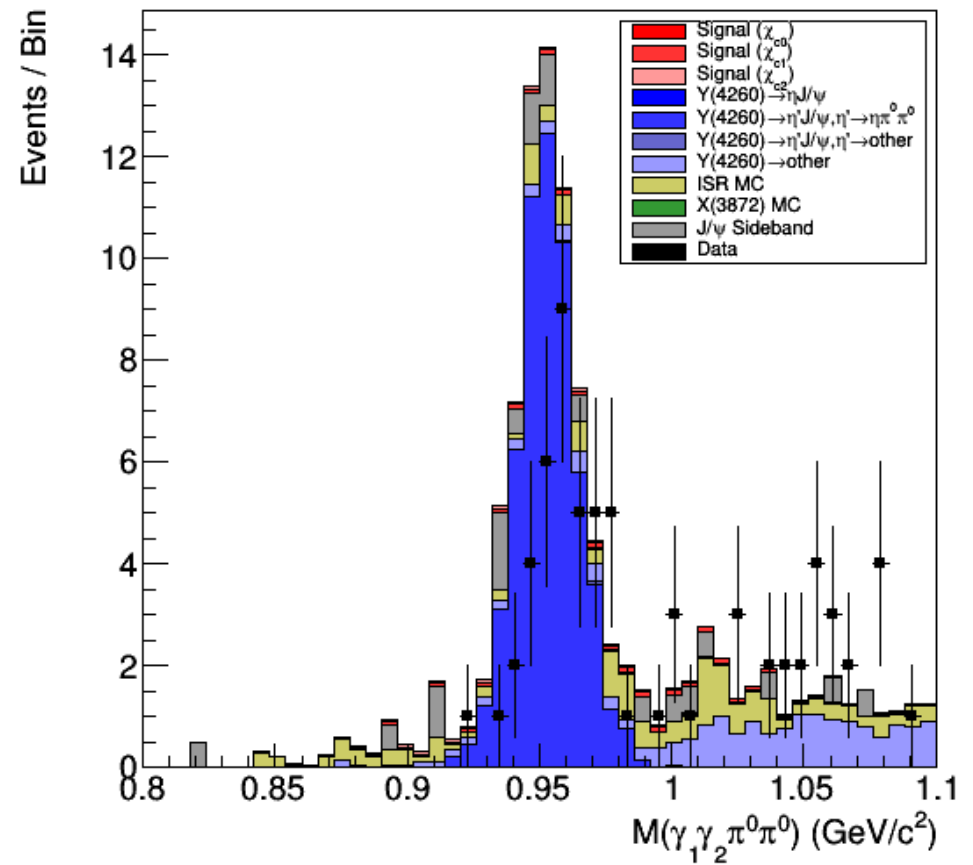
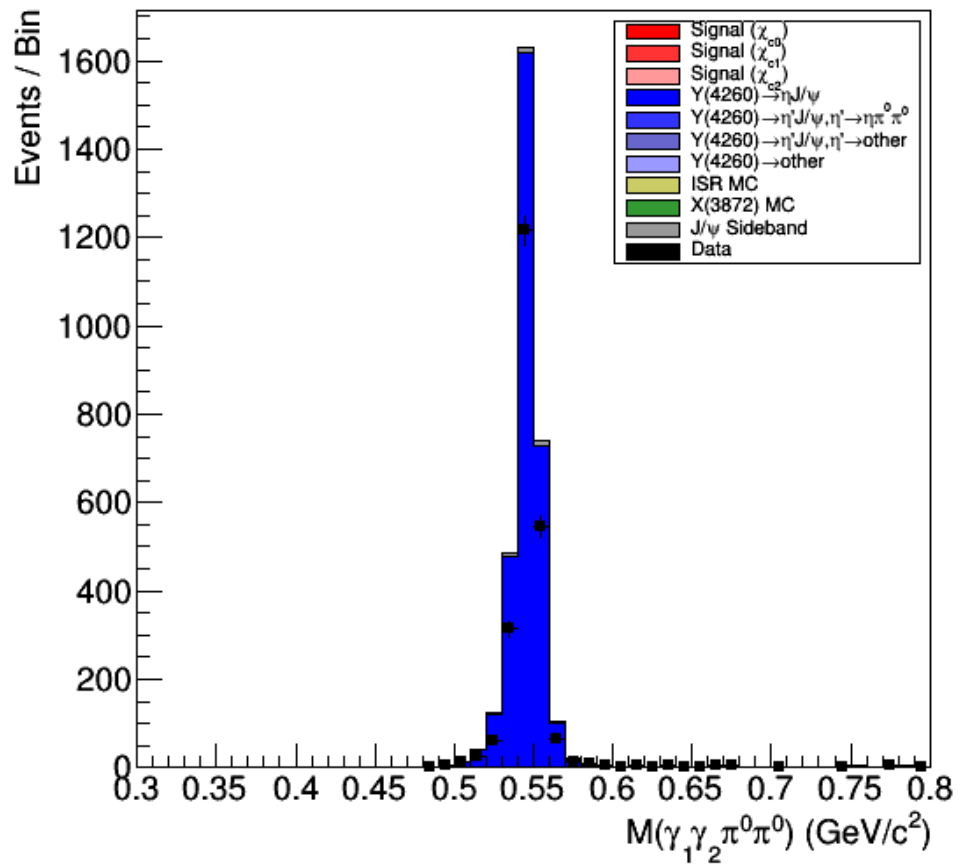
Compatibility between MC and data was verified with an $\eta J/\psi$ cross check.

- Want to verify that exclusive MC agrees with data.
 - Use all of the data with E^* between 4.15 GeV and 4.30 GeV.
- Check against $e^+e^- \rightarrow \eta J/\psi, \eta \rightarrow 3\pi^0$ and $e^+e^- \rightarrow \eta' J/\psi, \eta' \rightarrow \pi^0\pi^0\eta$
 - Roughly select $\chi^2/DOF < 10$ for kinematic fit.
 - Select $M(l^+l^-)$ within 30 MeV of J/ψ mass.
 - Select sideband with $M(l^+l^-)$ between 35 MeV and 95 MeV from J/ψ mass.
 - For $\eta J/\psi$, select $M(\gamma\gamma)$ within 10 MeV of π^0 mass.
 - For $\eta' J/\psi$, select $M(\gamma\gamma)$ within 50 MeV of η mass.
- This is the only time we look at data!

Compatibility between MC and data was verified with an $\eta J/\psi$ cross check.

$e^+e^- \rightarrow \eta J/\psi, \eta \rightarrow \gamma\gamma\pi^0\pi^0$

$e^+e^- \rightarrow \eta' J/\psi, \eta' \rightarrow \pi^0\pi^0\eta$



Pre-selection Cuts

- Center of Mass Energy:

$$4.15 \text{ GeV} < E^* < 4.30 \text{ GeV}$$

- Shower Selection:

$$0 < T < 14$$

$$E_{endcap} > 50 \text{ MeV} \text{ or } E_{barrel} > 25 \text{ MeV}$$

- Track Selection:

$$z < 10 \text{ cm and } r < 1 \text{ cm}$$

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

- Signal Region:

$$3.75 \text{ GeV} < M_{recoil}(\gamma_1) < 4.00 \text{ GeV}$$

$$3.35 \text{ GeV} < M(\gamma_2 l^+ l^-) < 3.60 \text{ GeV}$$

Additional Cuts

- Electron Selection:

$$(E/p)^+ > 0.85 \text{ or } (E/p)^- > 0.85$$

- Muon Selection:

$$(E/p)^+ < 0.25 \text{ and } (E/p)^- < 0.25$$

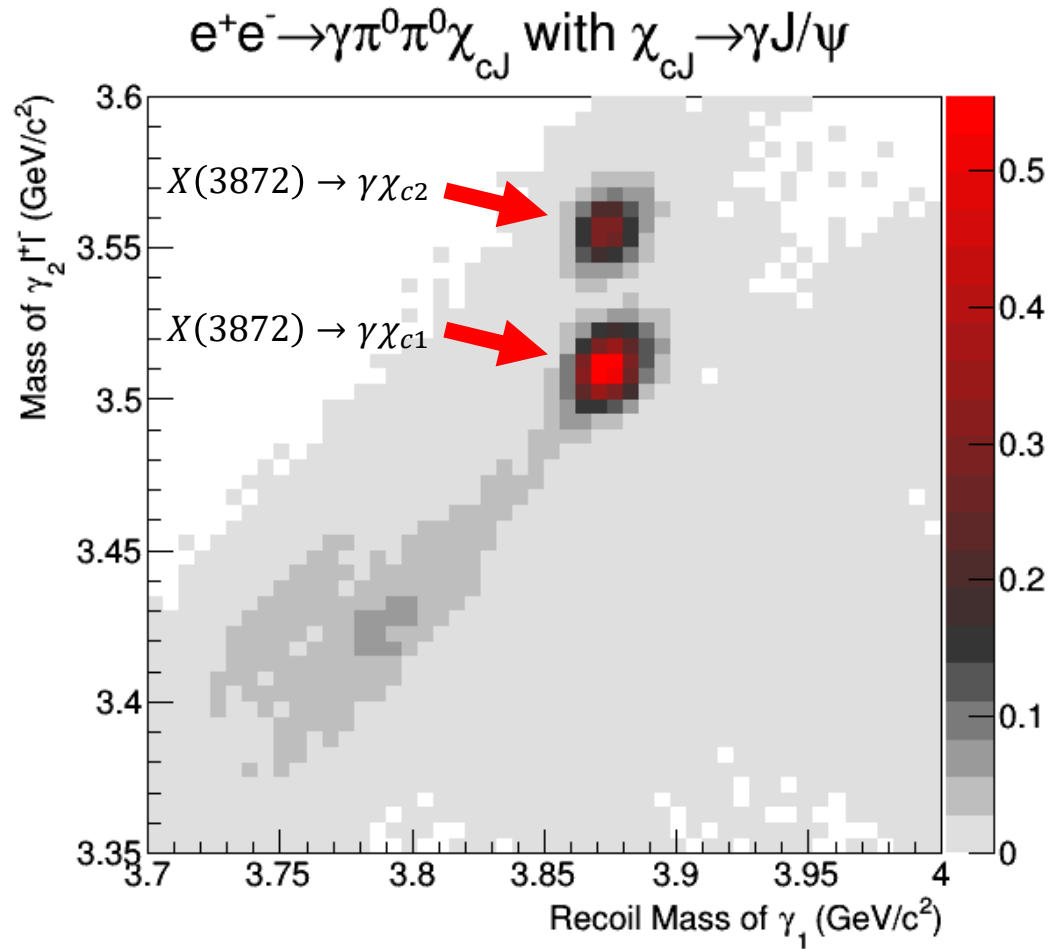
- J/ψ Selection:

$$|M(l^+l^-) - M(J/\psi)| < 30 \text{ MeV}$$

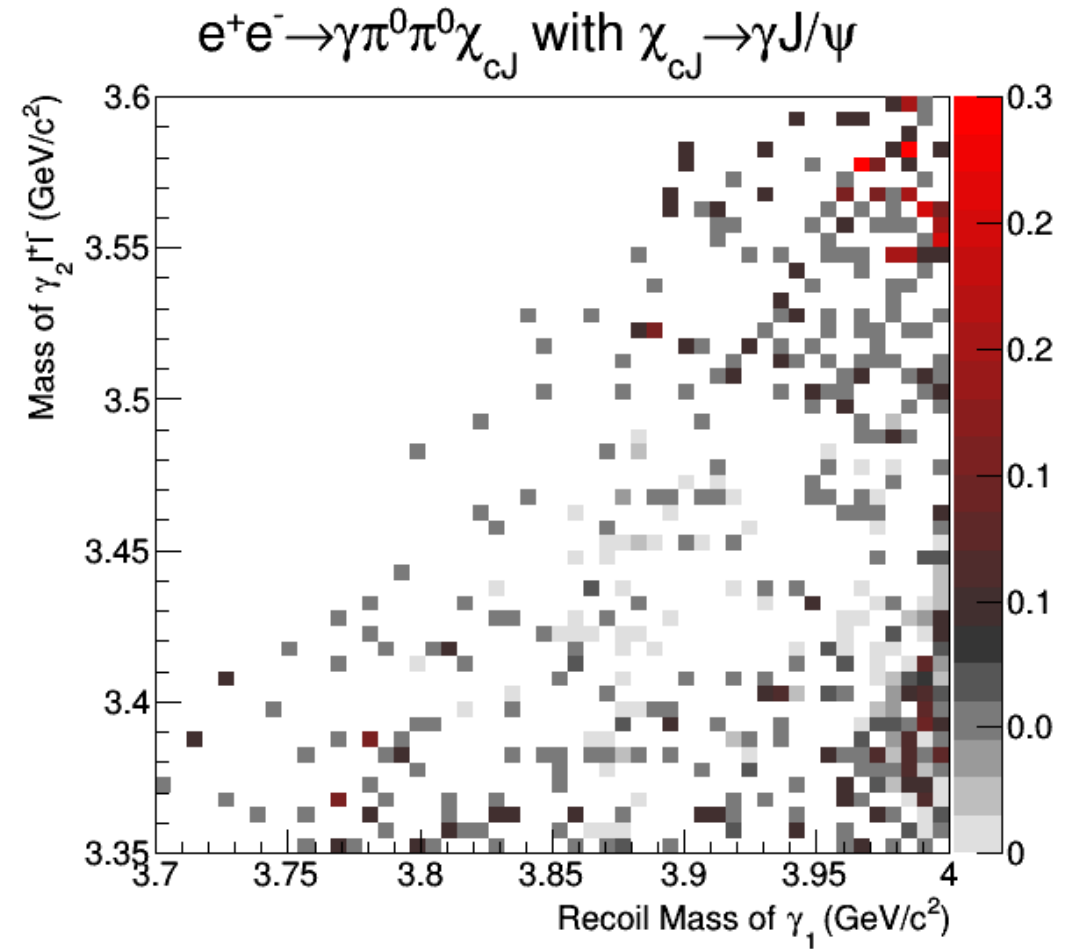
- J/ψ Sideband:

$$35 \text{ MeV} < |M(l^+l^-) - M(J/\psi)| < 95 \text{ MeV}$$

Phase Space



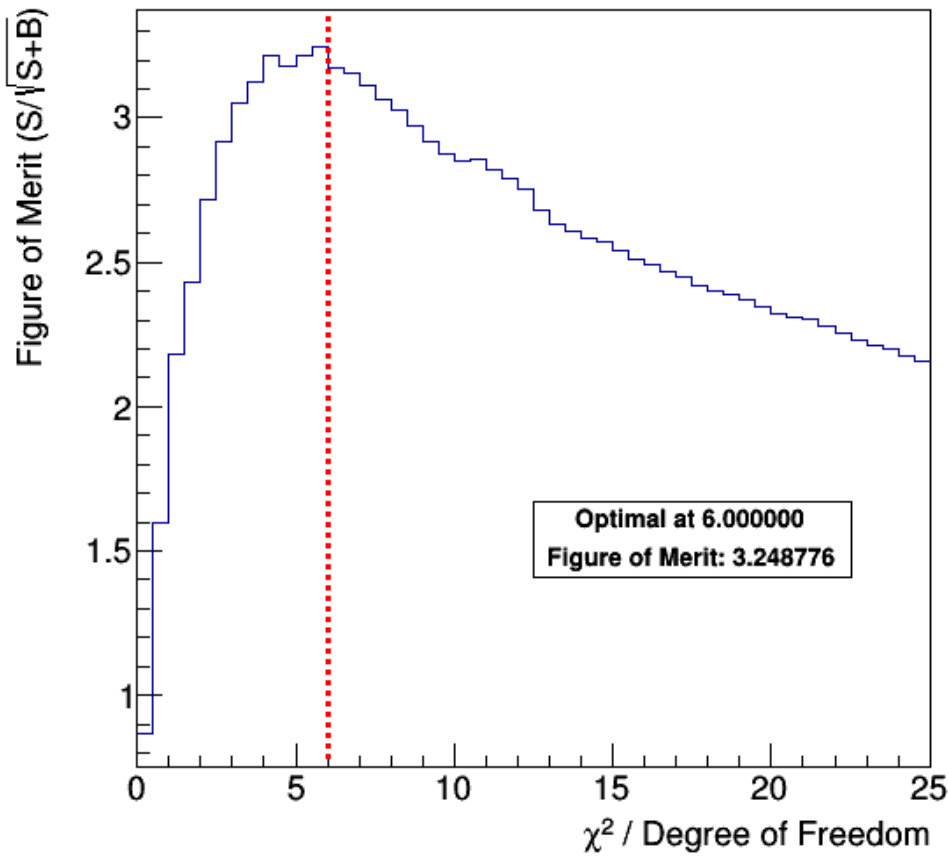
Signal MC



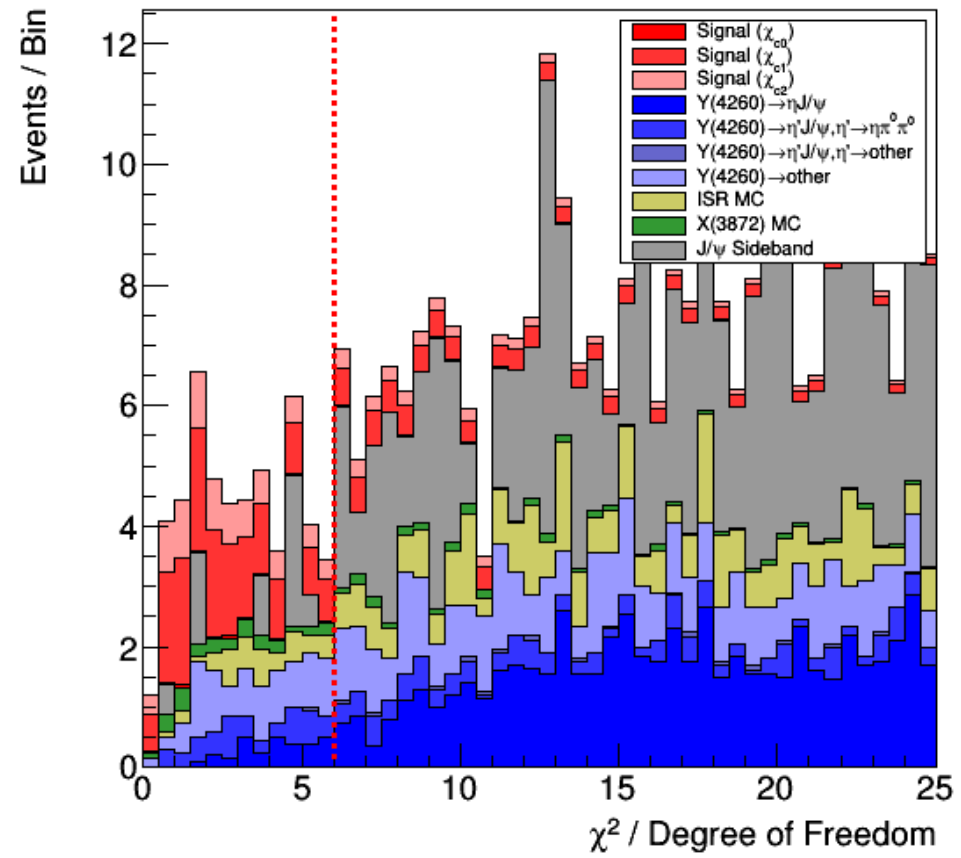
Background MC

Cut Optimization: Kinematic Fit χ^2 / DOF

Figure of Merit for $\chi^2 / \text{Degree of Freedom}$

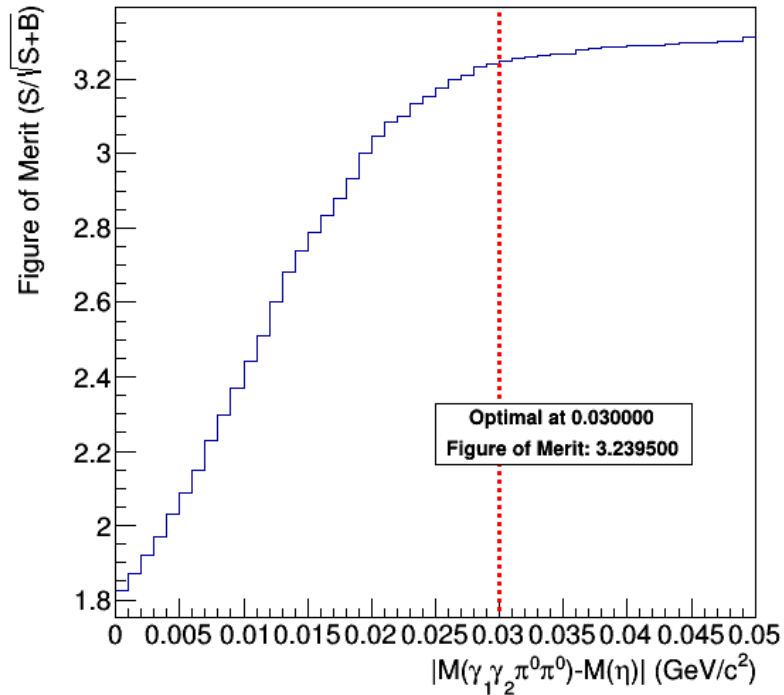


$e^+e^- \rightarrow \gamma_1 \pi^0 \pi^0 \chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma_2 J/\psi$

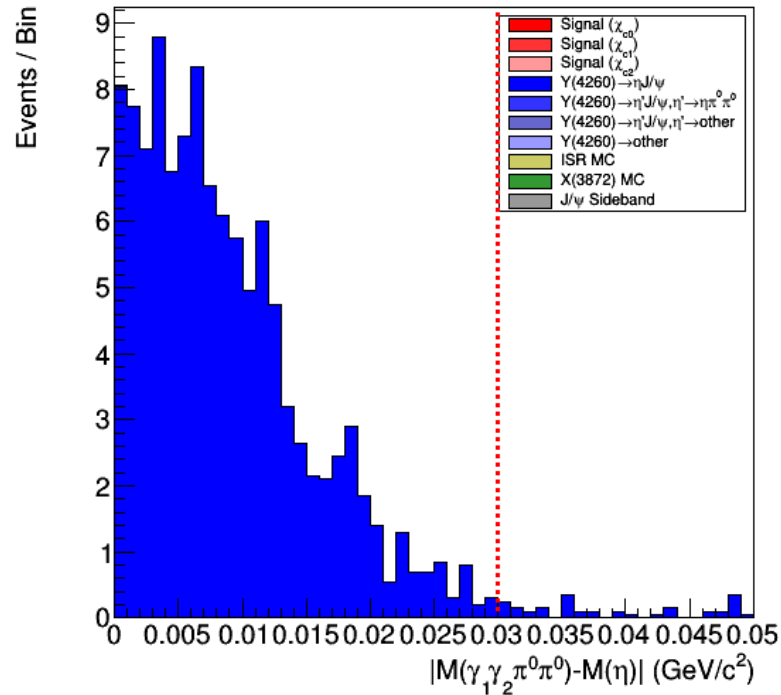


Cut Optimization: $\eta \rightarrow \gamma\gamma\pi^0\pi^0$ Veto

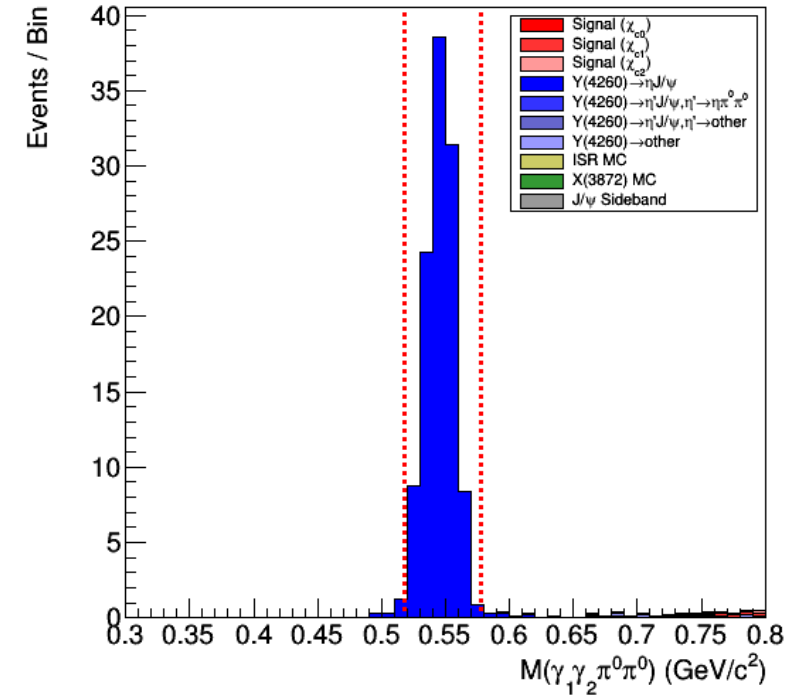
Figure of Merit for $|M(\gamma_1\gamma_2\pi^0\pi^0)-M(\eta)|$



$e^+e^- \rightarrow \gamma_1\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma_2 J/\psi$



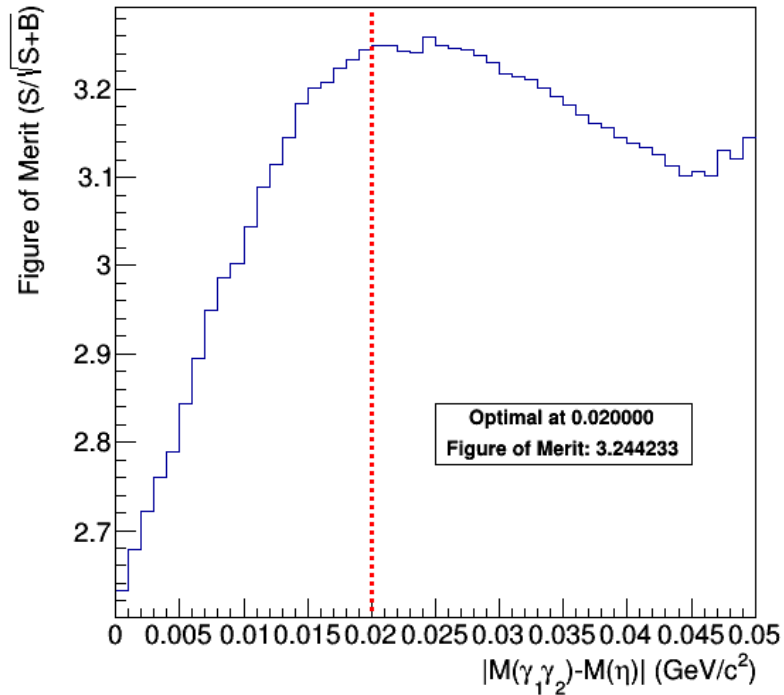
$e^+e^- \rightarrow \gamma\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma J/\psi$



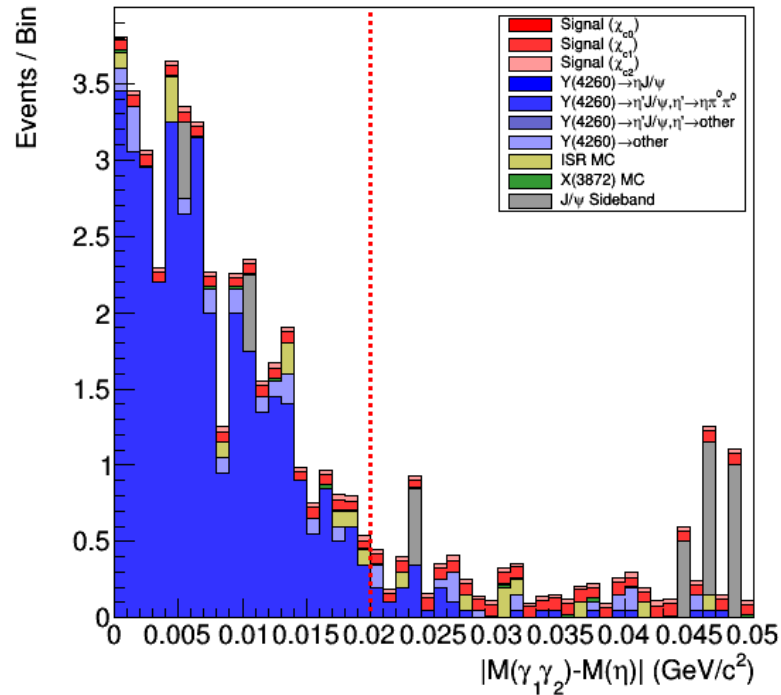
Eliminates $e^+e^- \rightarrow \eta J/\psi$ events.

Cut Optimization: $\eta \rightarrow \gamma\gamma$ Veto

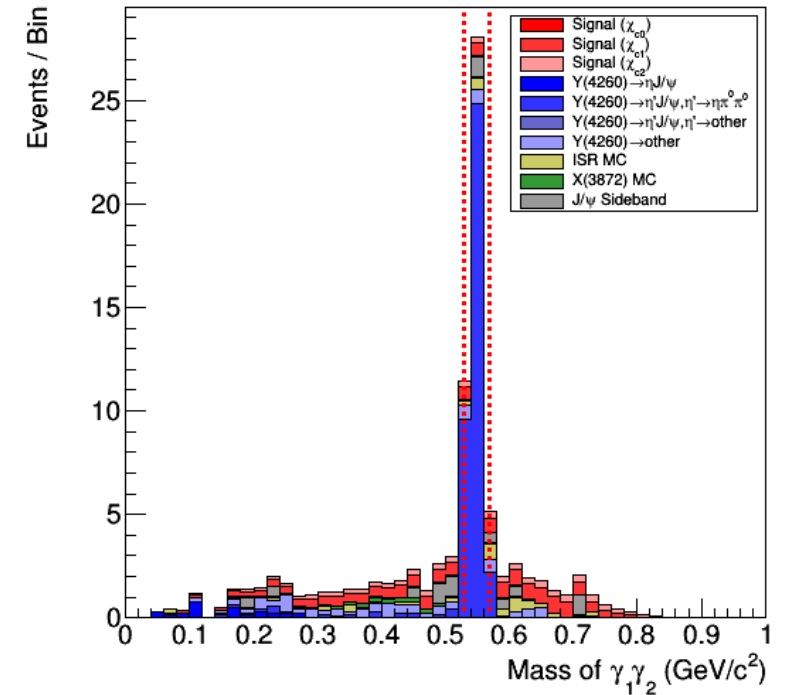
Figure of Merit for $|M(\gamma_1\gamma_2)-M(\eta)|$



$e^+e^- \rightarrow \gamma_1\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma_2 J/\psi$



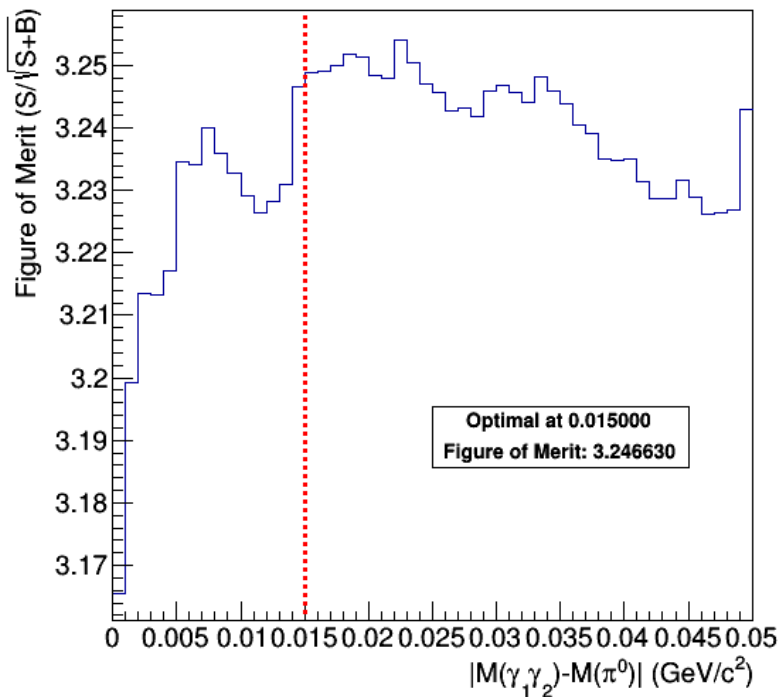
$e^+e^- \rightarrow \gamma\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma J/\psi$



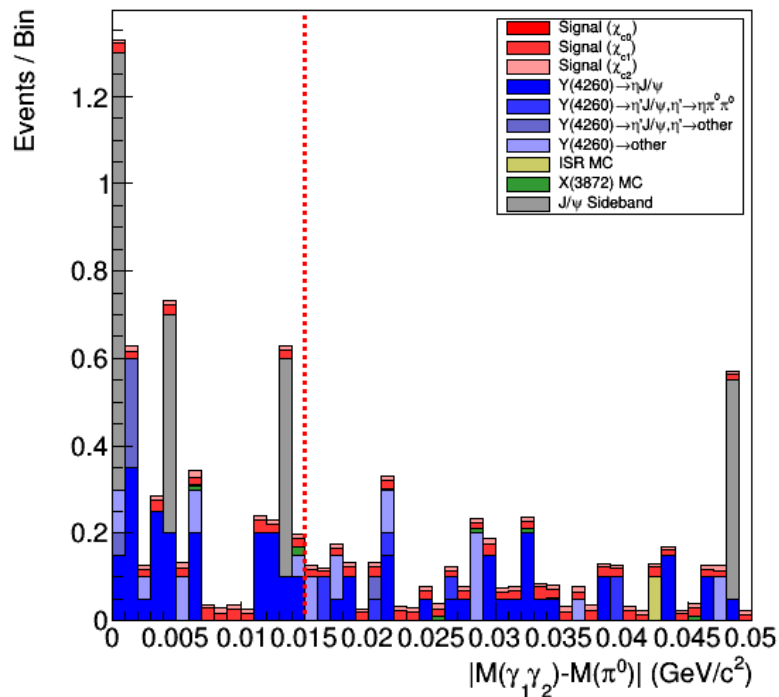
Eliminates $e^+e^- \rightarrow \eta' J/\psi$ events.

Cut Optimization: π^0 Veto

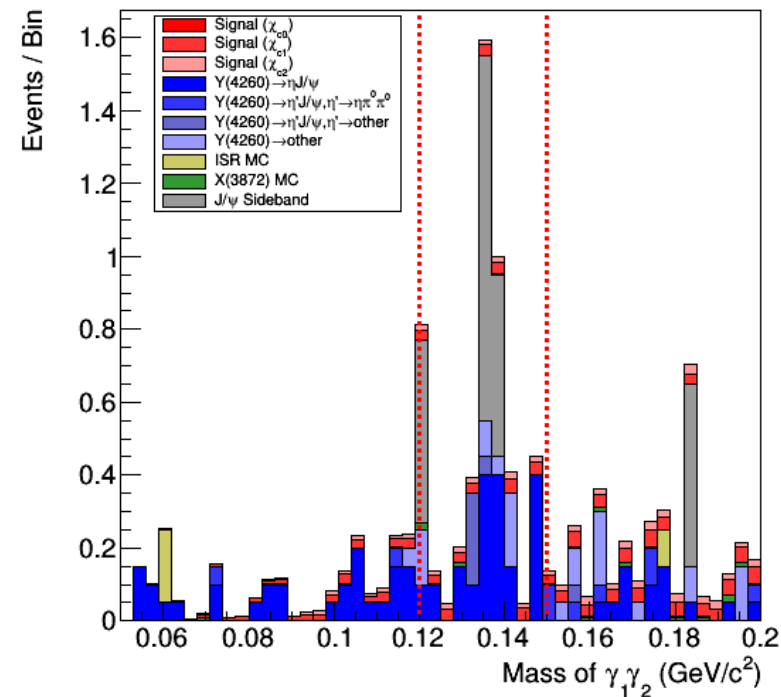
Figure of Merit for $|M(\gamma_1\gamma_2)-M(\pi^0)|$



$e^+e^- \rightarrow \gamma_1\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma_2 J/\psi$

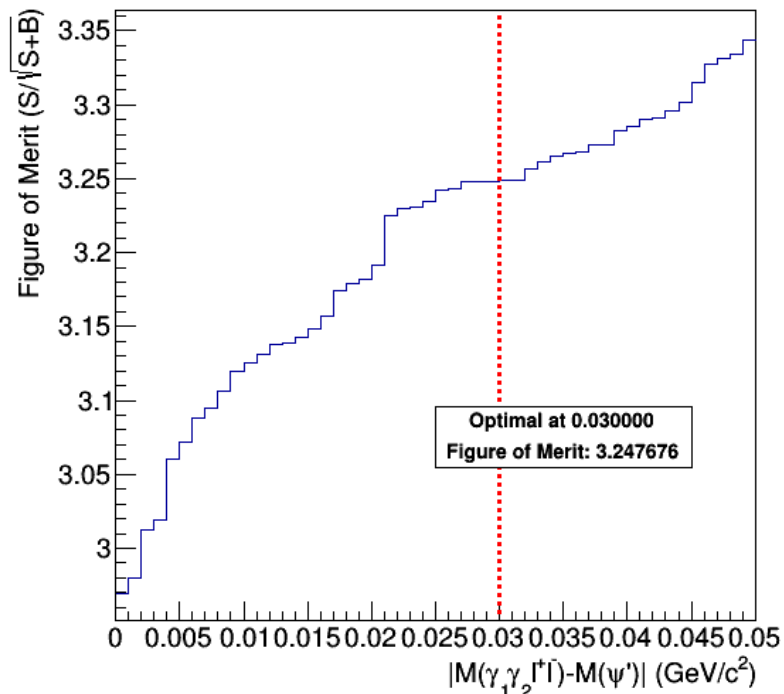


$e^+e^- \rightarrow \gamma\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma J/\psi$

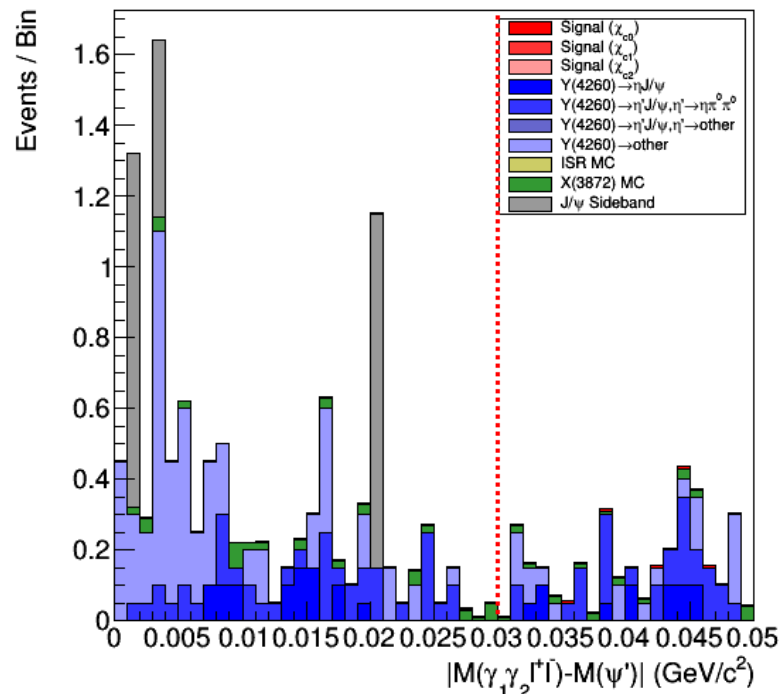


Cut Optimization: ψ' Veto

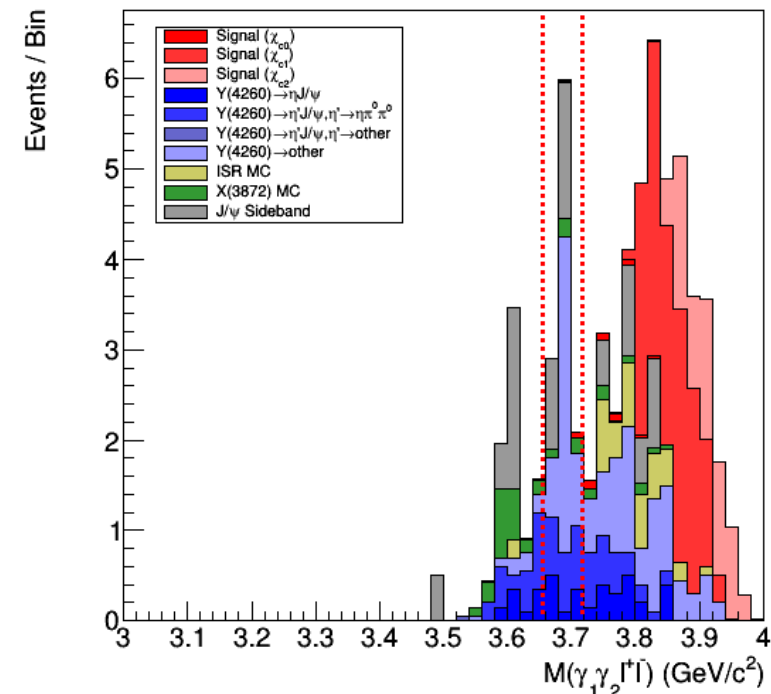
Figure of Merit for $|M(\gamma_1\gamma_2\Gamma^+\Gamma^-)-M(\psi')|$



$e^+e^- \rightarrow \gamma_1\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma_2 J/\psi$

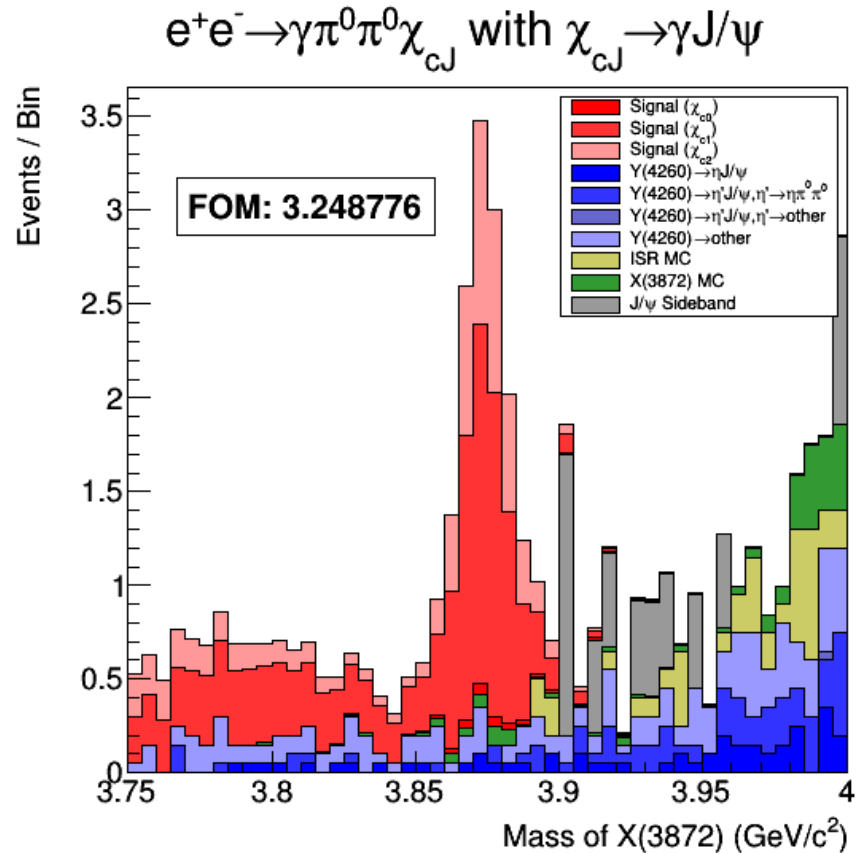


$e^+e^- \rightarrow \gamma\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma J/\psi$



Eliminates $e^+e^- \rightarrow \pi\pi\psi'$ events
where $\psi' \rightarrow \gamma\chi_{cJ}, \chi_{cJ} \rightarrow \gamma J/\psi$.

Signal Region



Includes all pre-selection cuts as well as:

- Kinematic Fit $\chi^2 / DOF < 6$
- Veto $M(\gamma\gamma)$ within 15 MeV of π^0 mass.
- Veto $M(\gamma\gamma)$ within 20 MeV of η mass.
- Veto $M(\gamma\gamma\pi^0\pi^0)$ within 30 MeV of η mass.
- Veto $M(\gamma\gamma l^+ l^-)$ within 30 MeV of ψ' mass.

Total Signal Events: 23

Total Background Events: 29

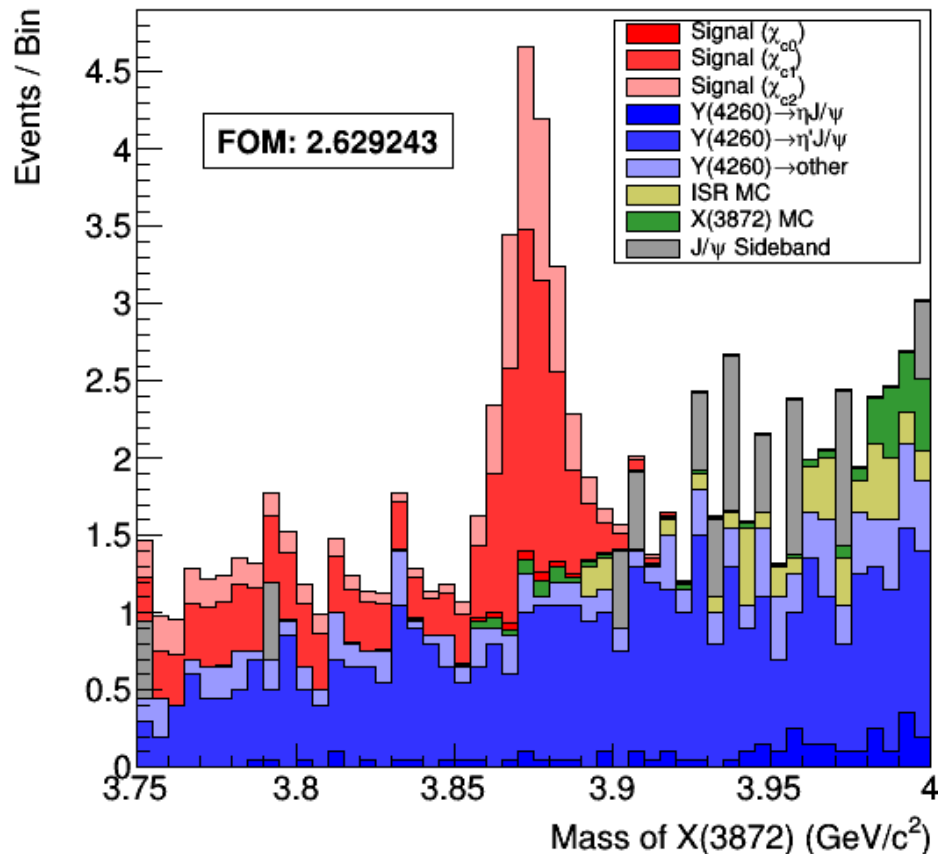
Questions

References

- ¹ S. Dubynskiy and M. B. Voloshin. “Pionic transitions from $X(3872)$ to χ_{cJ} ”. In: *Phys. Rev. D* 77 (1 Jan. 2008), p. 014013. DOI: 10.1103/PhysRevD.77.014013. URL: <https://link.aps.org/doi/10.1103/PhysRevD.77.014013>.
- ² Sean Fleming and Thomas Mehen. “Hadronic decays of the $X(3872)$ to χ_{cJ} in effective field theory”. In: *Phys. Rev. D* 78 (9 Nov. 2008), p. 094019. DOI: 10.1103/PhysRevD.78.094019. URL: <https://link.aps.org/doi/10.1103/PhysRevD.78.094019>.

Cut Optimization – Electron Selection

$e^+e^- \rightarrow \gamma\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma J/\psi$ (Electron Selection OR)



$e^+e^- \rightarrow \gamma\pi^0\pi^0\chi_{cJ}$ with $\chi_{cJ} \rightarrow \gamma J/\psi$ (Electron Selection AND)

