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

Ryan Mitchell Joshua Jackson

Indiana University

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Motivation

- Explore evidence for opposing interpretations of $X(3872)$.
  - If $X(3872)$ is a charmonium state[1]:
    - 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 $\Gamma(X(3872) \to \pi^0\pi^0\chi_{c1}) \sim 1\text{keV}$.
  - If $X(3872)$ is a tetraquark:
    - Expect production of χ_{c1} and χ_{c2} to be similar, χ_{c0} to be strongly suppressed[1].
    - Expect two-pion transition to χ_{cJ} from $X(3872)$ to be on same order as single-pion transition[2].

[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

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

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

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

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

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

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Four different types of MC were generated.

$Y(4260)$ without ISR

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

$Y(4260)$ with ISR

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

ISR where $e^+e^- \to \gamma\psi'$

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

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

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

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

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 $4.15\ \mathrm{GeV}$ and $4.30\ \mathrm{GeV}$.

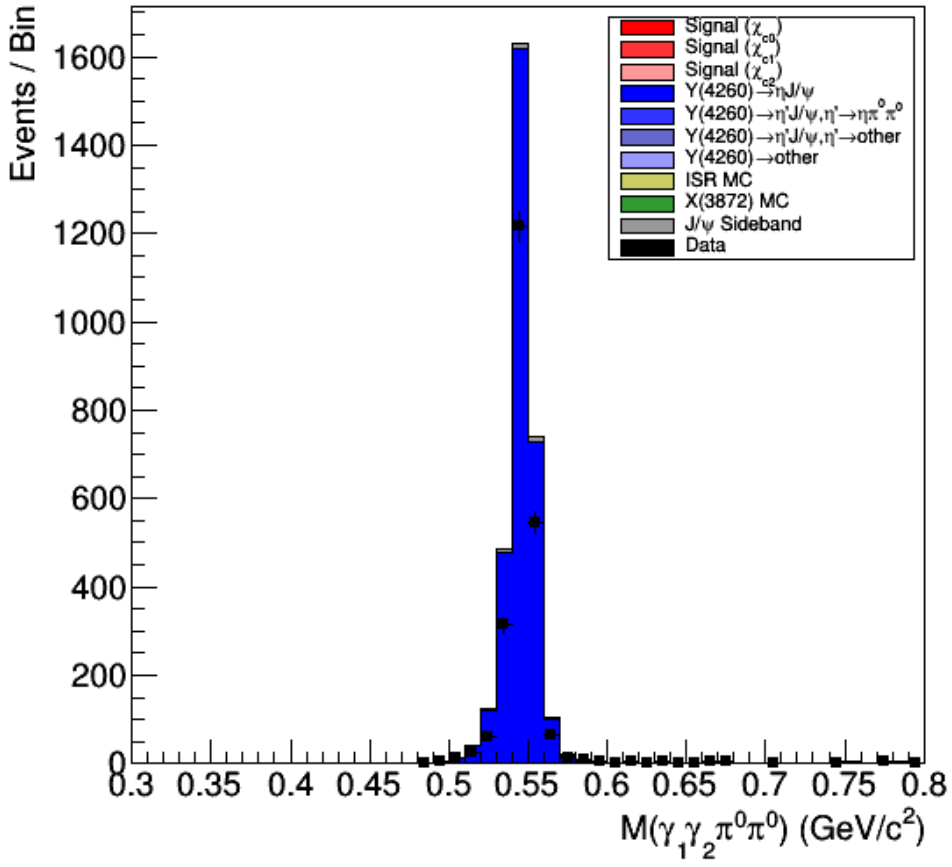
- Check against $e^+e^- \to \eta J/\psi, \eta \to 3\pi^0$ and $e^+e^- \to \eta' J/\psi, \eta' \to \pi^0\pi^0\eta$
  - Roughly select $\chi^2/DOF < 10$ for kinematic fit.
  - Select $M(l^+l^-)$ within $30\ \mathrm{MeV}$ of J/ψ mass.
  - Select sideband with $M(l^+l^-)$ between $35\ \mathrm{MeV}$ and $95\ \mathrm{MeV}$ from J/ψ mass.
  - For $\eta J/\psi$, select $M(\gamma\gamma)$ within $10\ \mathrm{MeV}$ of π^0 mass.
  - For $\eta' J/\psi$, select $M(\gamma\gamma)$ within $50\ \mathrm{MeV}$ of η mass.

- This is the only time we look at data!

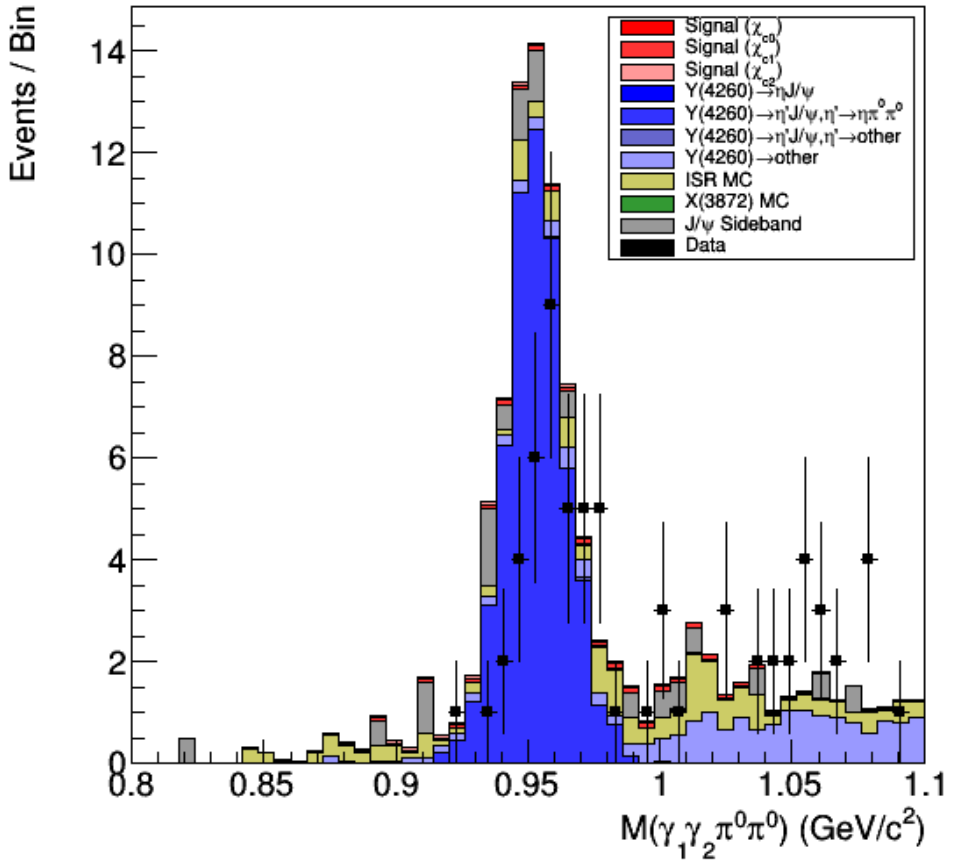
Final State: $l^+l^-\gamma\gamma\pi^0\pi^0$

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

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



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



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

Pre-selection Cuts

- Center of Mass Energy:

$$4.15\ GeV < E^* < 4.30\ GeV$$

- Shower Selection:

$$0 < T < 14$$
$$E_{endcap} > 50\ MeV \text{ or } E_{barrel} > 25\ MeV$$

- Track Selection:

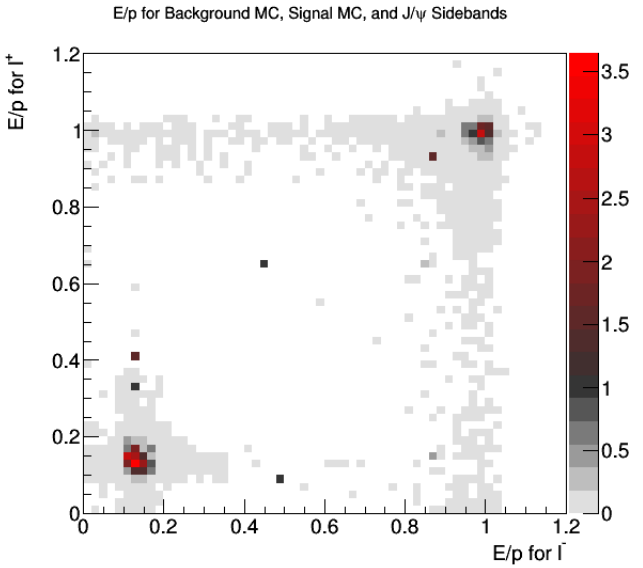
$$z < 10\ \text{cm and } r < 1\ \text{cm}$$
$$|\cos\theta| < 0.93$$

- Signal Region:

$$3.75\ GeV < M_{recoil}(\gamma_1) < 4.00\ GeV$$
$$3.35\ GeV < M(\gamma_2 l^+ l^-) < 3.60\ GeV$$

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

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:

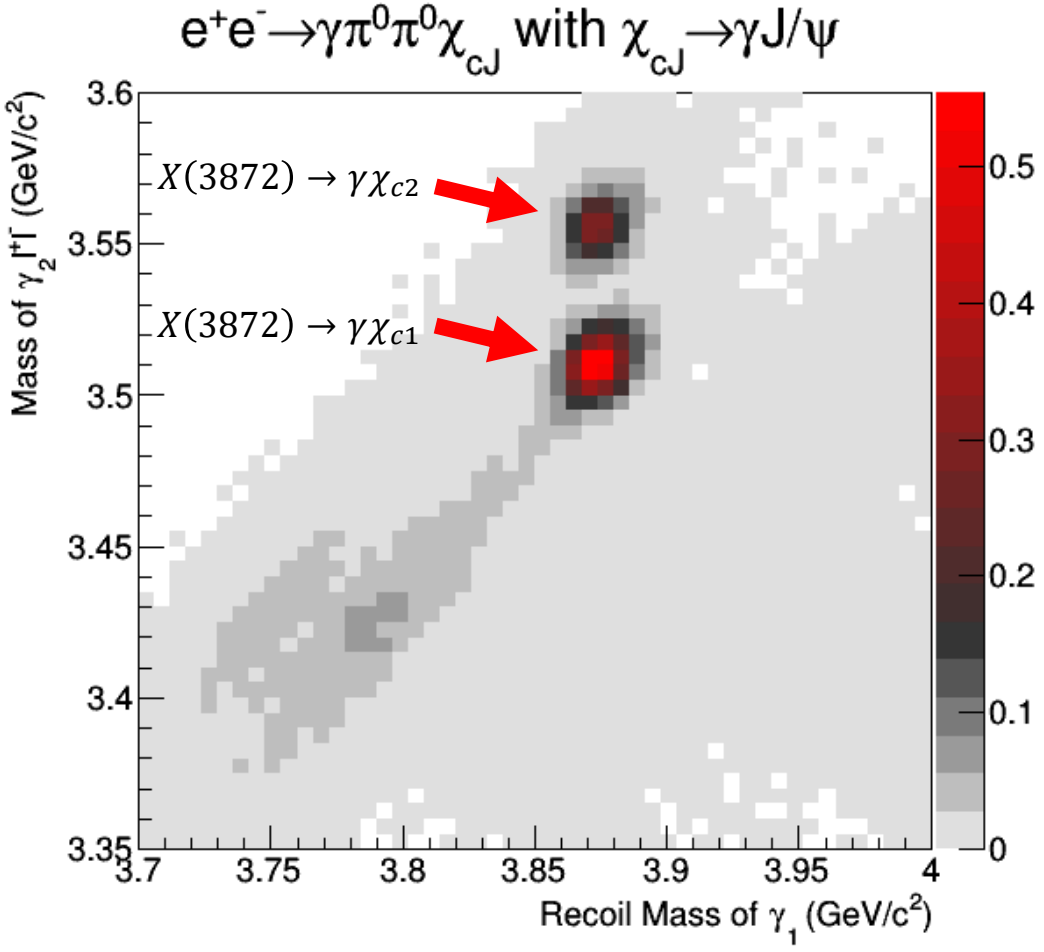
$$|M(l^+l^-) - M(J/\psi)| < 30 \text{ MeV}$$

- J/ψ Sideband:

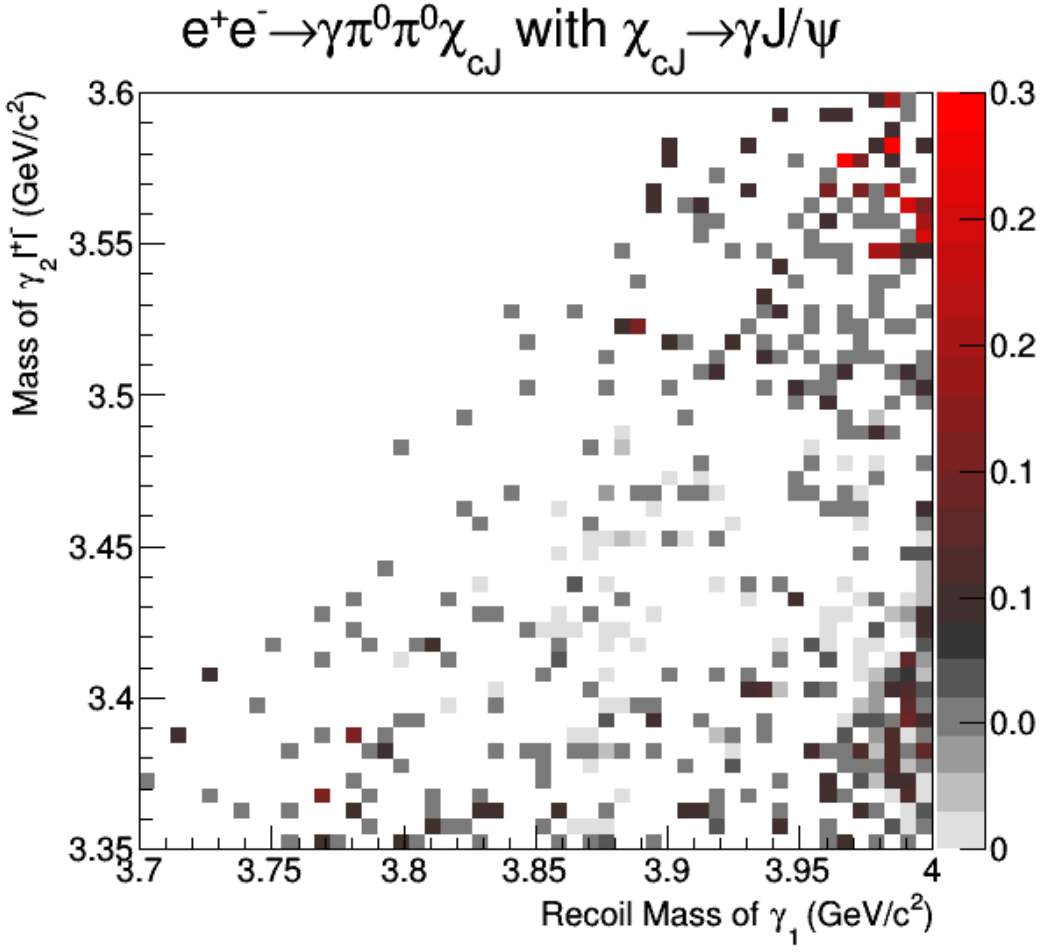
$$35 \text{ MeV} < |M(l^+l^-) - M(J/\psi)| < 95 \text{ MeV}$$

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

Phase Space



Signal MC

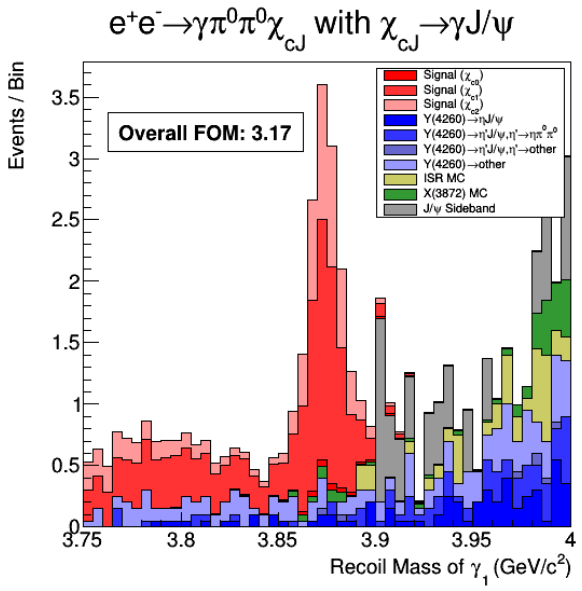


Background MC

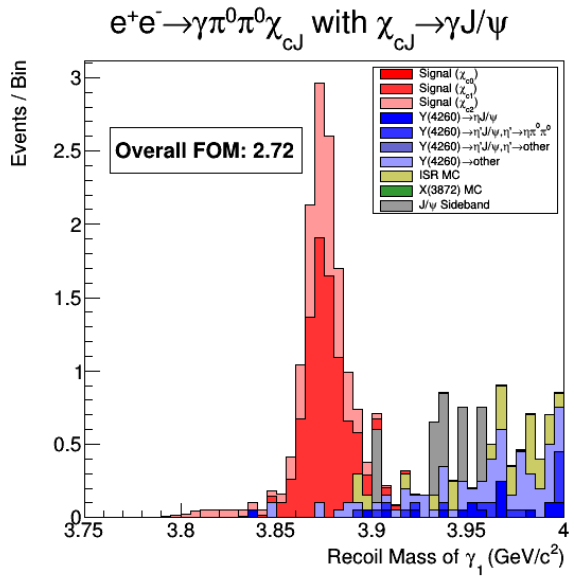
Final State: $l^+l^-\gamma\gamma\pi^0\pi^0$

Choosing the best χ_{cJ} combination

- Choose the best χ_{cJ} combination by selecting the γl^+l^- combination which is closest to the PDG mass of χ_{cJ} in the appropriate J region.
- Only two possible combinations since we have two photons in the final state.



Without choosing best χ_{cJ} combination.



Choosing best χ_{cJ} combination.

The broad χ_{cJ} region is split into three narrow regions corresponding to each J.

- Not sensitive to $J = 0$
- $J = 1$: (3.49 GeV, 3.53 GeV)
- $J = 2$: (3.54 GeV, 3.58 GeV)

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

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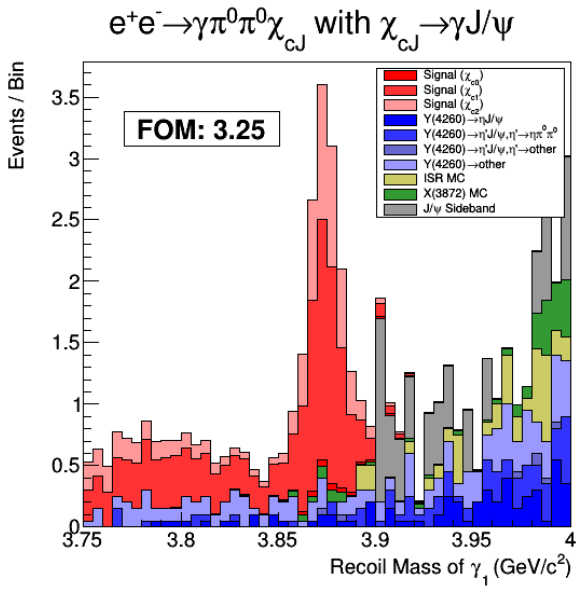

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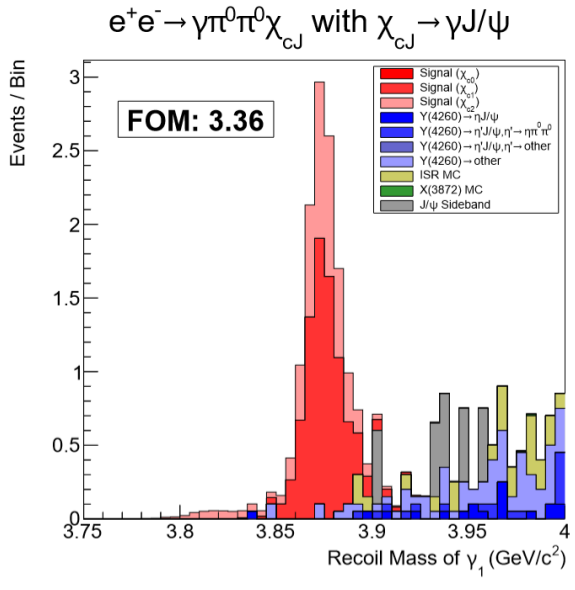

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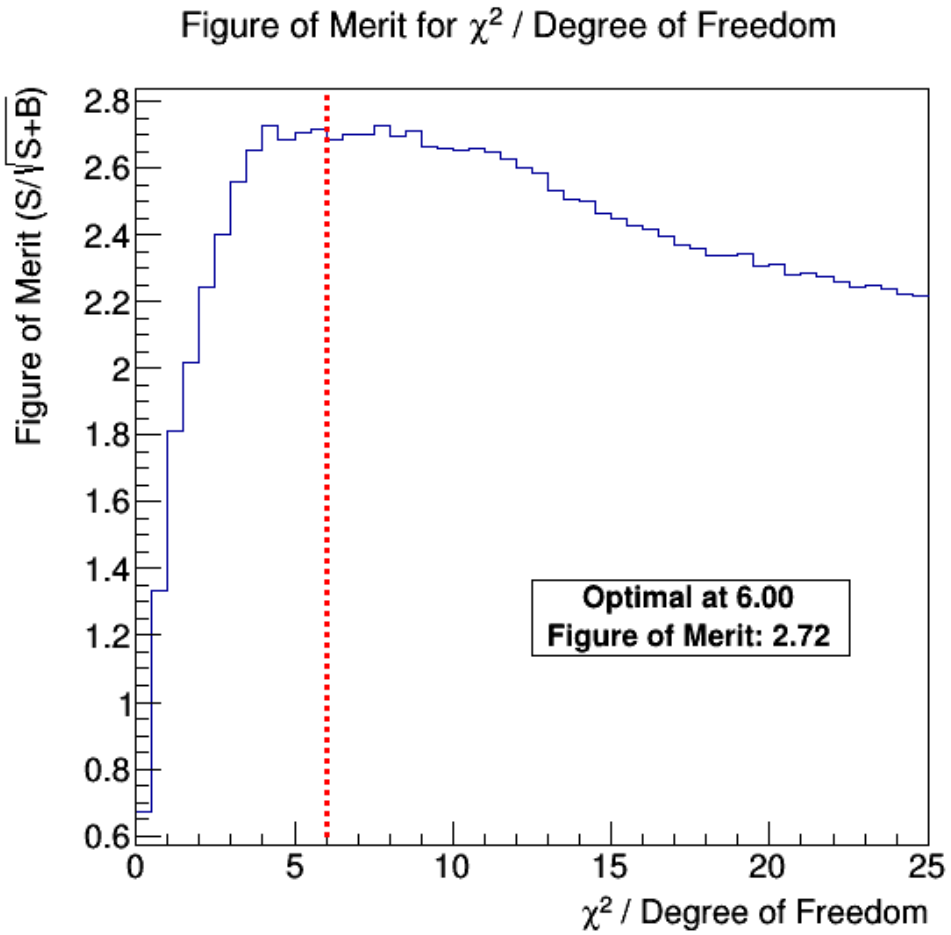
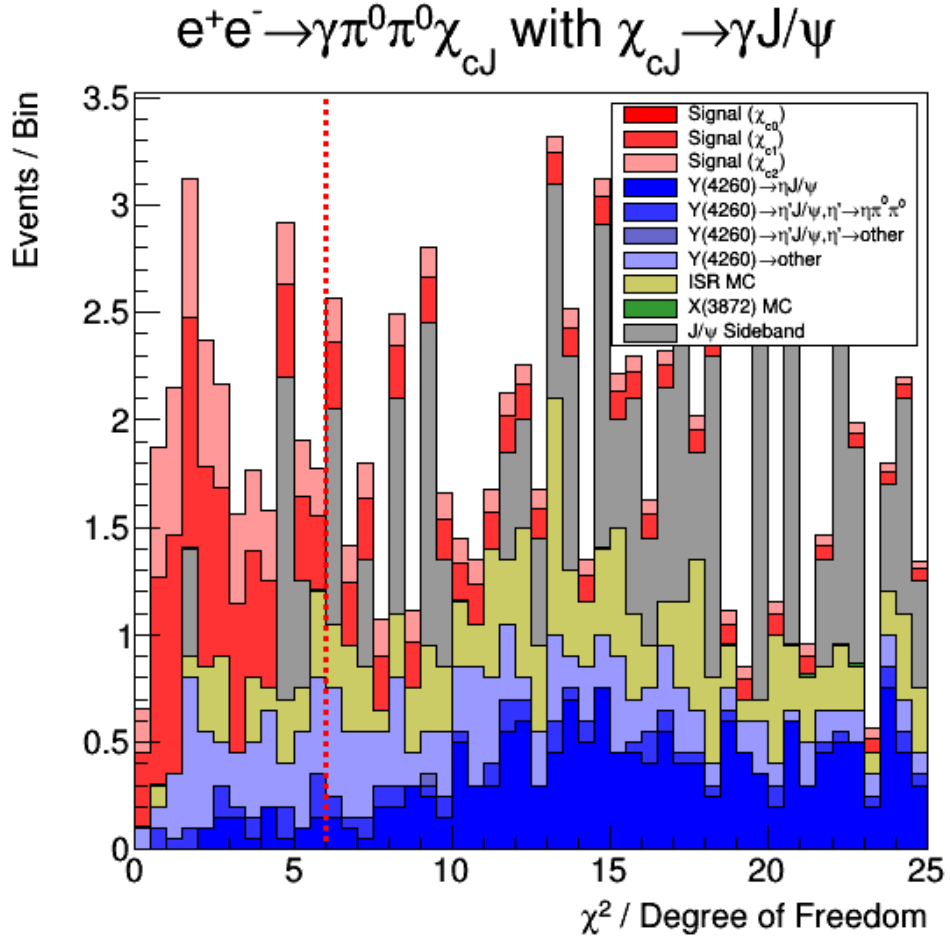
* FOM calculated near the signal peak: 3.85 GeV to 3.91 GeV

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

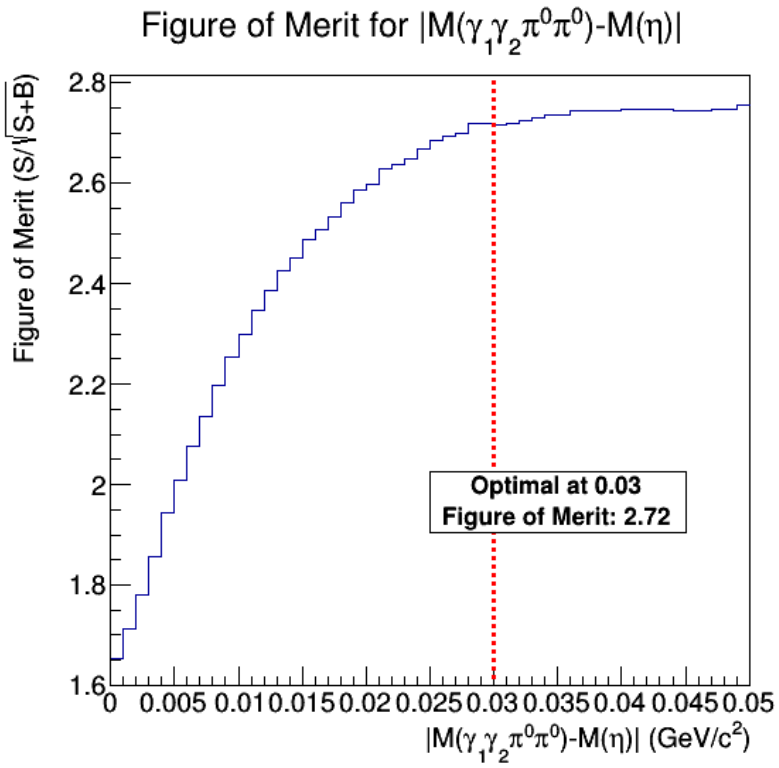
Cut Optimization: Kinematic Fit χ^2/DOF

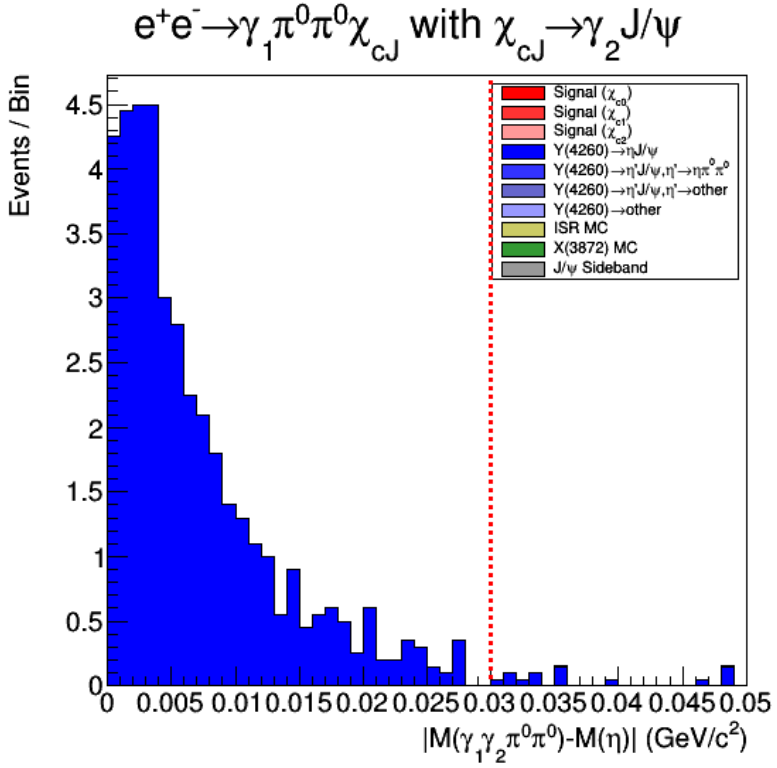


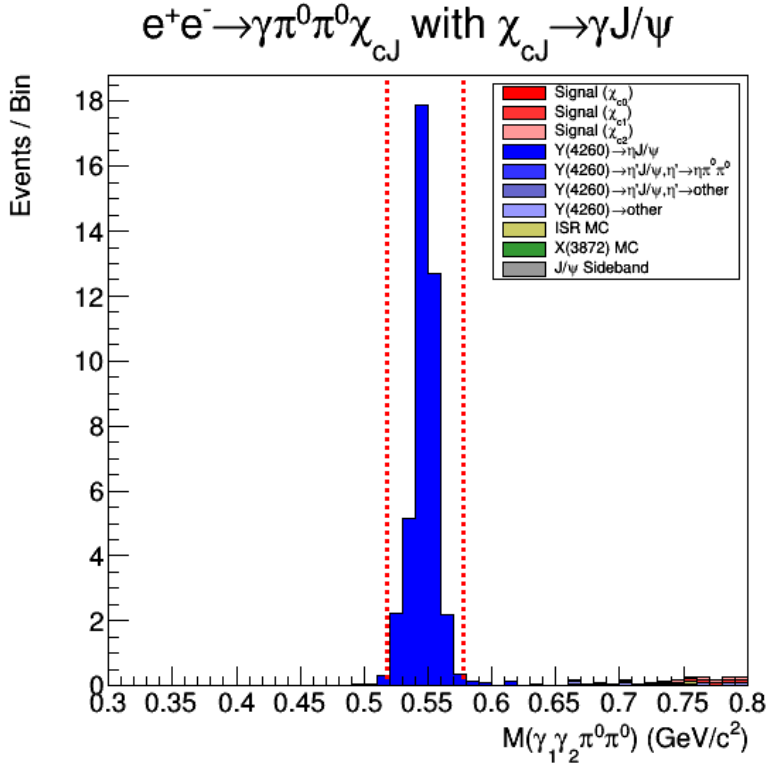


Final State: $l^+l^-\gamma\gamma\pi^0\pi^0$

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



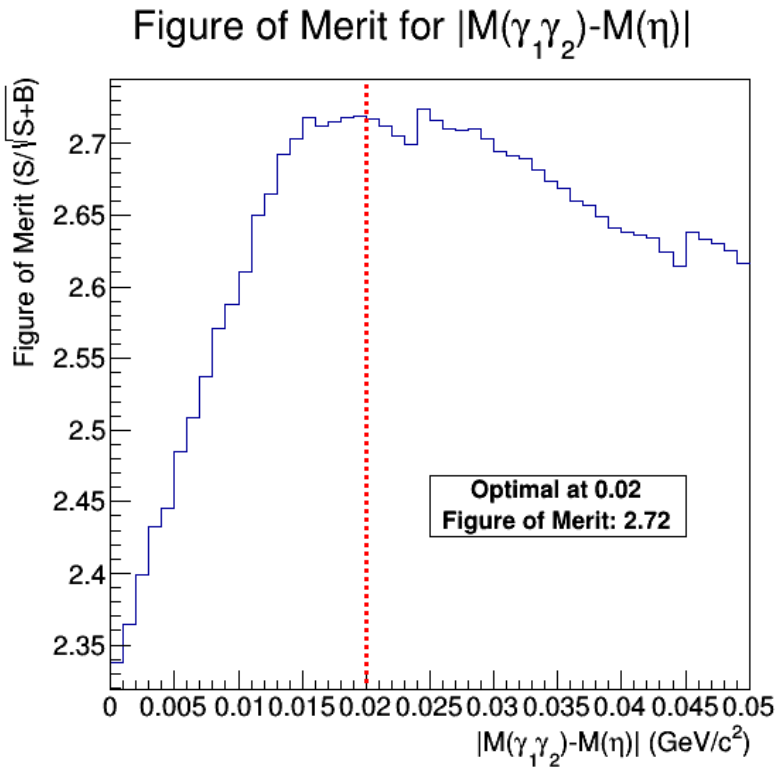


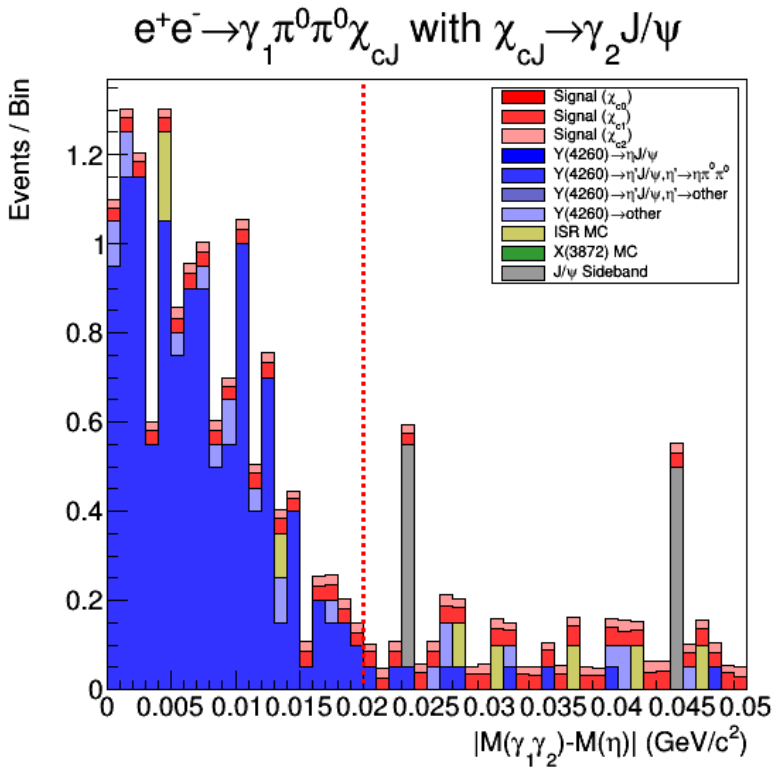


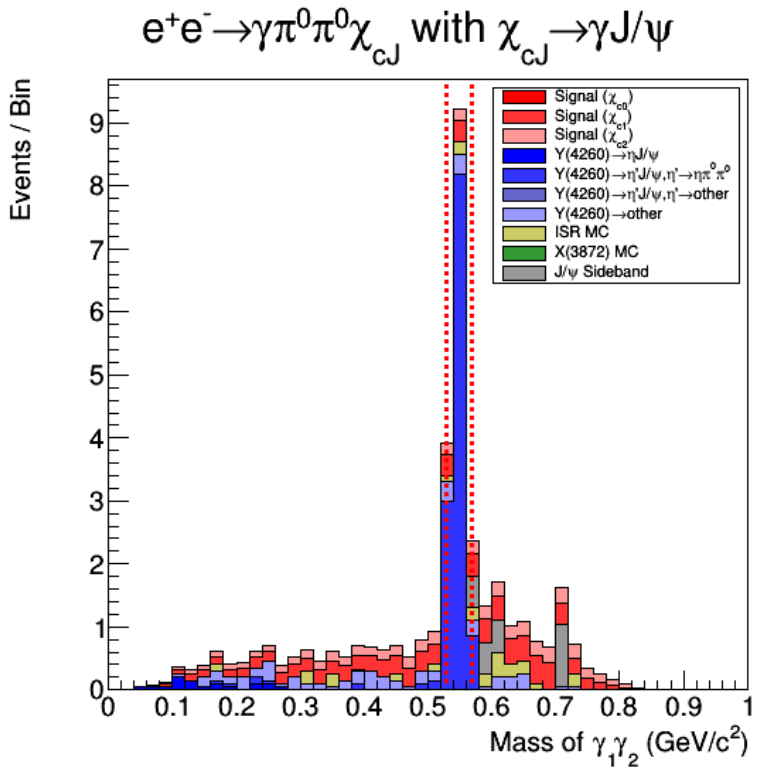
Eliminates $e^+e^- \to \eta J/\psi$ events.

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

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



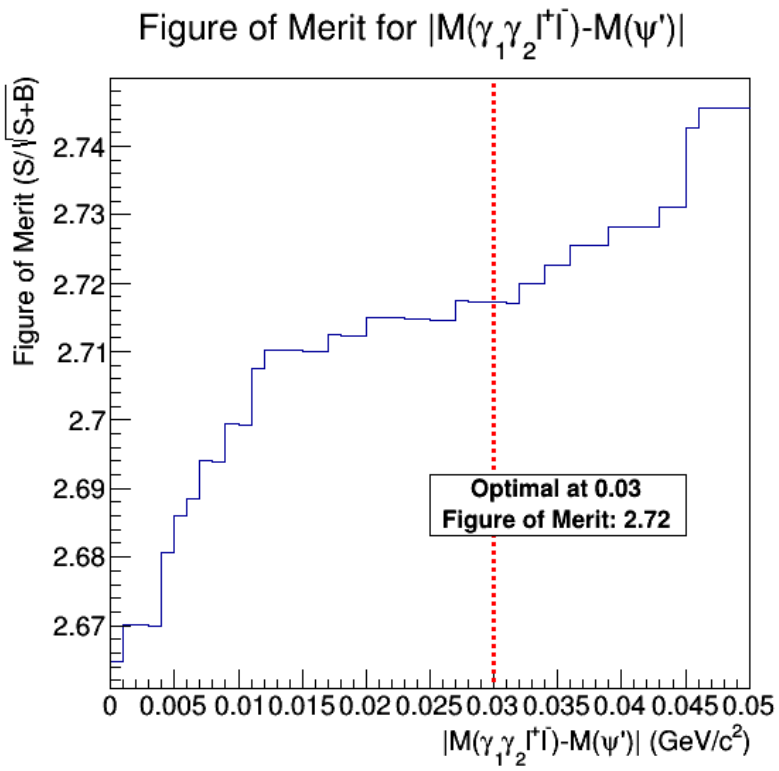


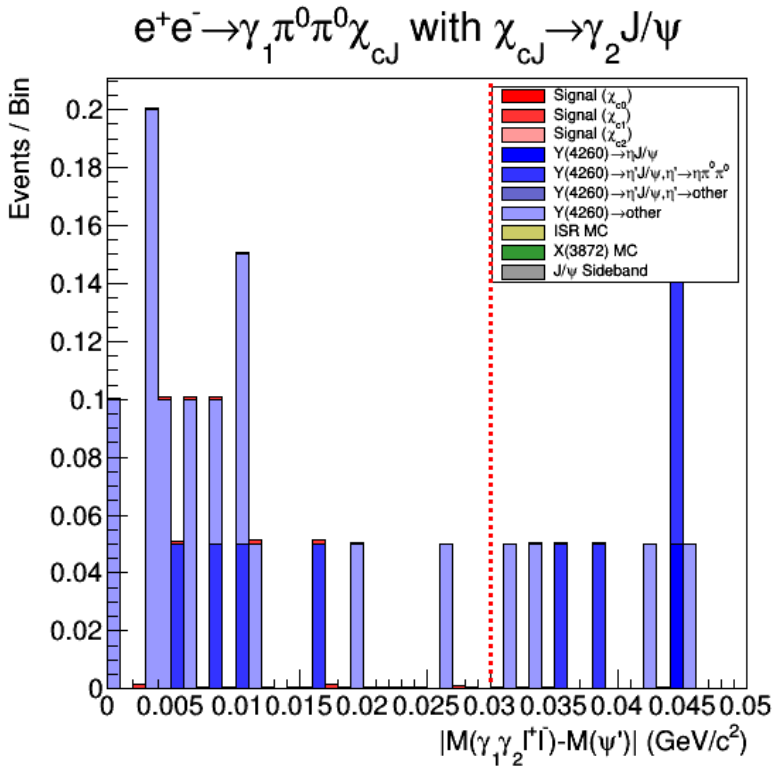


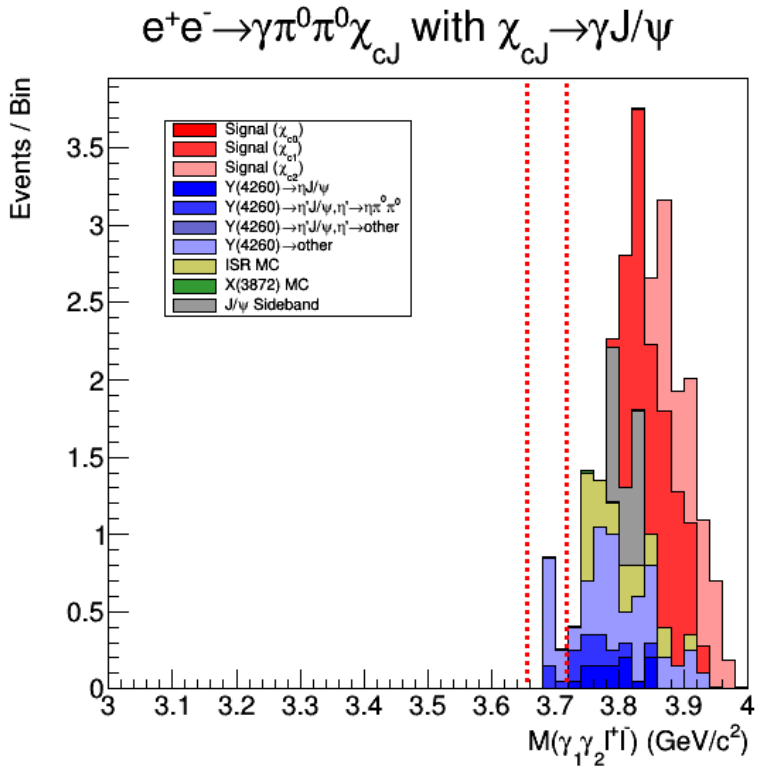
Eliminates $e^+e^- \to \eta' J/\psi$ events.

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

Cut Optimization: ψ' Veto



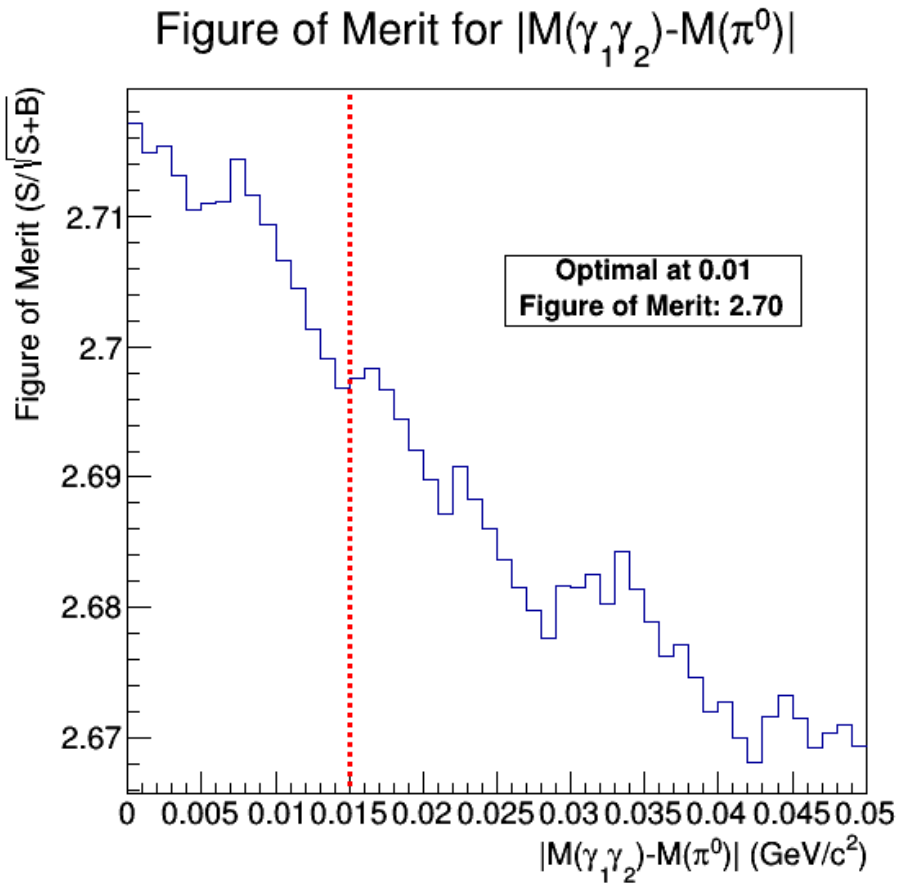




Eliminates $e^+e^- \to \pi\pi\psi'$ events.

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

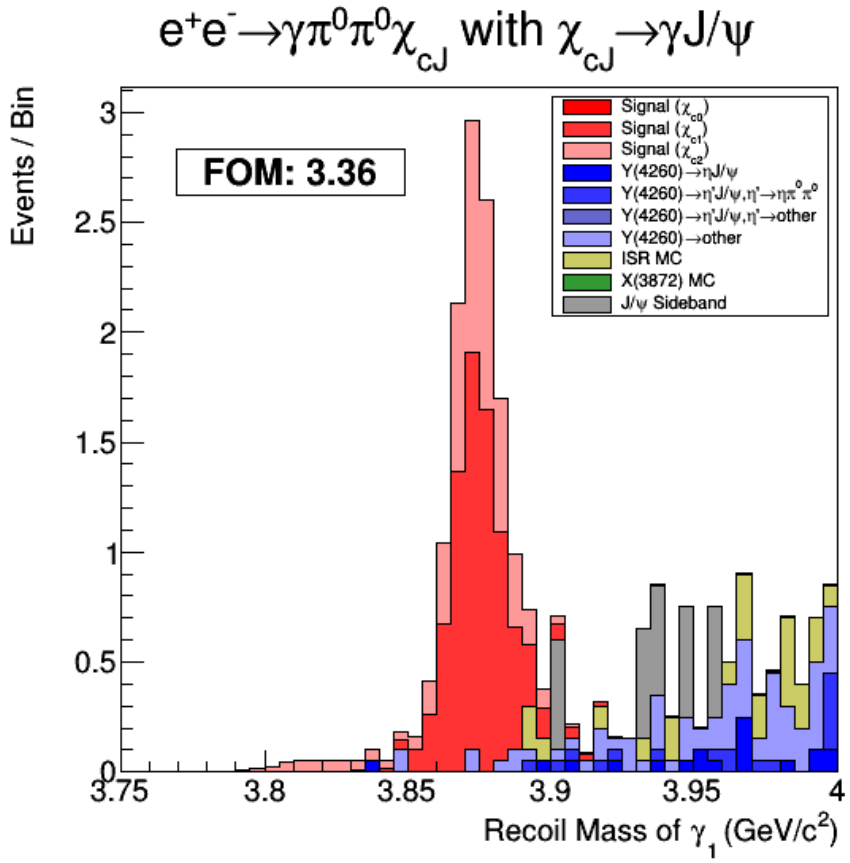
The π^0 veto only diminishes the FOM.



Thus we elect not to use the π^0 veto.

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

Signal Region



Includes all pre-selection cuts as well as:

- Kinematic Fit $\chi^2/DOF < 6$
- 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.
- Best χ_{cJ} combination.

Predicts roughly:

- 13 signal events
- 11 background events

* FOM calculated near the signal peak: 3.85 GeV to 3.91 GeV

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

Signal Region

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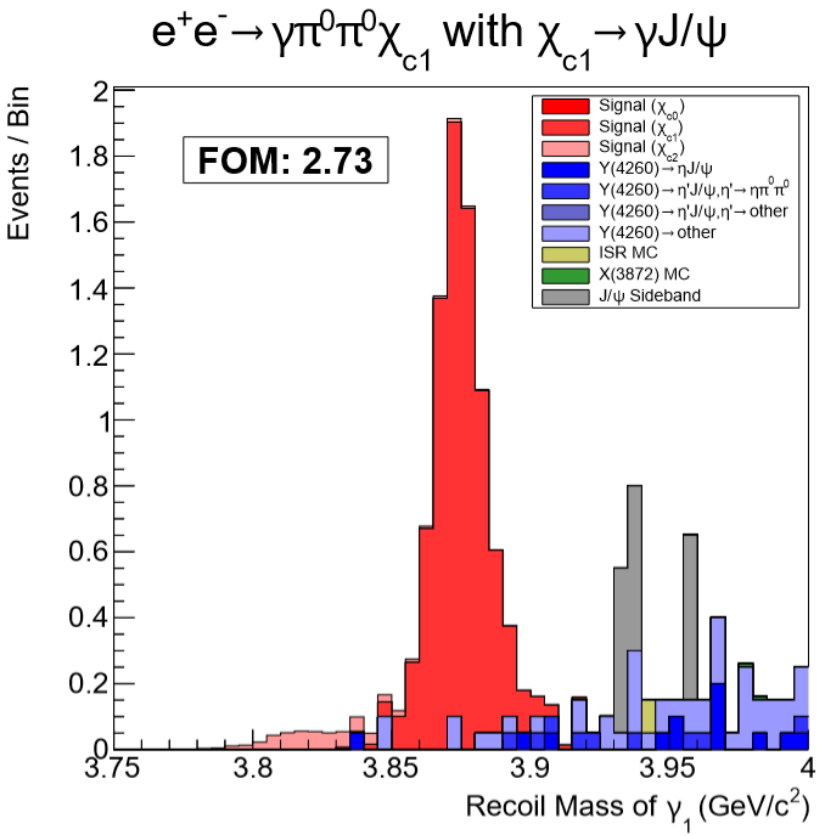
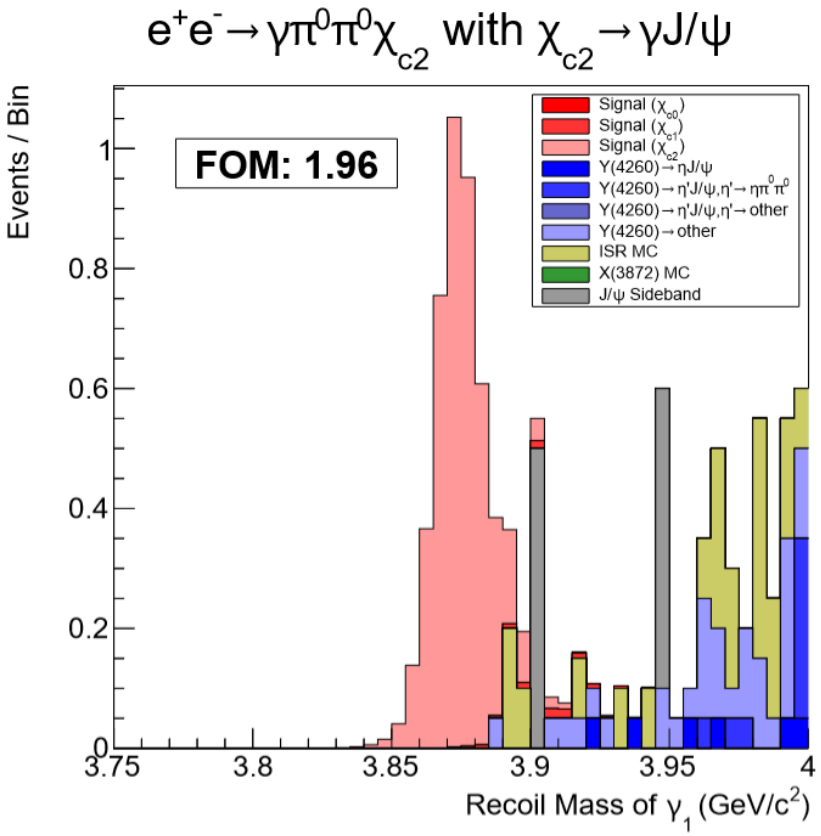
- Veto $M(\gamma\gamma l^+l^-)$ within 30 MeV of ψ' mass.
- Best χ_{cJ} combination.

Signal: 9
Background: 5



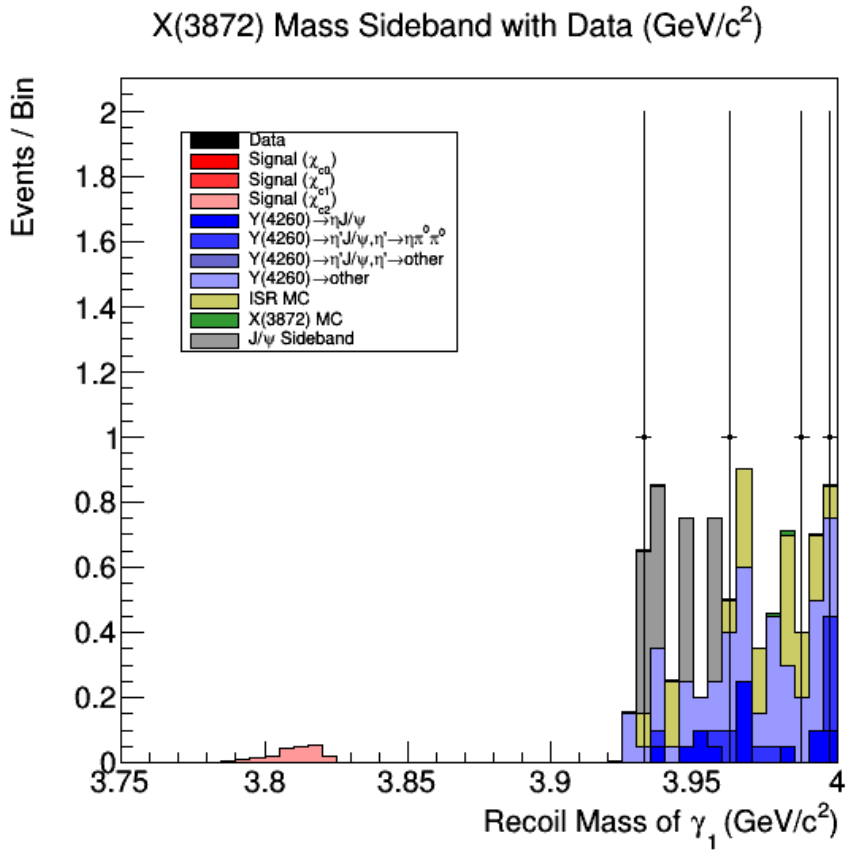


Signal: 5
Background: 6

* FOM calculated near the signal peak: 3.85 GeV to 3.91 GeV

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

Sideband Check



- Compare data to MC in region defined by a recoil mass of 50 MeV or more from 3872 MeV in any direction.
- No data in mass region less than signal peak – agrees with MC.
- 4 events in viewing window greater than signal region
  - MC predicts roughly 9 events in this region.

Next Steps

- Perform toy fits using small portion of signal MC.
  - Use signal MC shape to fit signal peak.
  - Check for fit stability by varying which portion of signal MC we use.

- Approach committee before unblinding data.

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

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.

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