Search for X(3872)$\rightarrow \pi^0\chi_{c0}$

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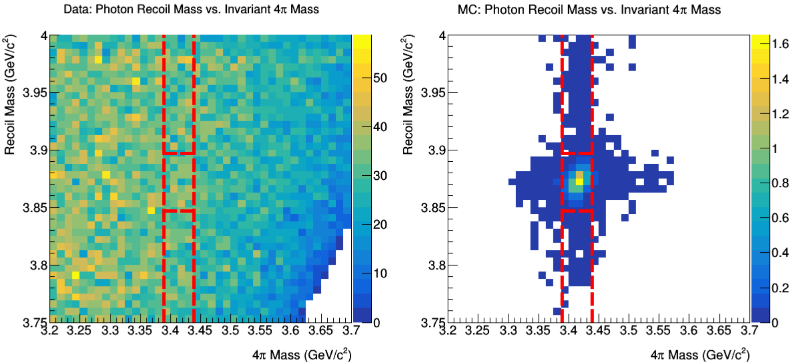
Motivation

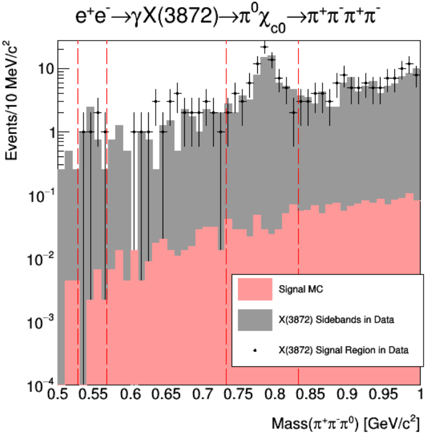
- Have evidence for $X(3872) \rightarrow \pi^0 \chi_{c1}(1P)$ (BAM-00321)
- Reconstructed in $\chi_{cJ} \rightarrow \gamma J/\psi$ with J/$\psi \rightarrow \ell^+\ell^-$
- $\frac{\mathcal{B}(X(3872)\rightarrow\pi^0\chi_{c1})}{\mathcal{B}(X(3872)\rightarrow\pi^+\pi^-J/\psi)} = 0.88^{+0.31}_{-0.26} \pm 0.16$
- For χ_{c0}, $\mathcal{B}(\chi_{c0} \rightarrow \gamma J/\psi) * \mathcal{B}(J/\psi \rightarrow \ell^+\ell^-) = 0.152\%$
- Upper limit for $\frac{\mathcal{B}(X(3872)\rightarrow\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\rightarrow\pi^+\pi^-J/\psi)} = 19$
- Better to use $\mathcal{B}(\chi_{c0} \rightarrow \pi^+\pi^-\pi^+\pi^-) = 2.24\%$
- Goal: Use this channel to lower upper limit of the ratio of branching fractions to something more interesting

Initial Selection Criteria



- Decay: $e^+e^- \to \gamma X(3872) \to \pi^0\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$
- Require recoil mass of γ to be between 3.75 and 4.0 GeV$/c^2$
- Require 3.2$<$ $M(\pi^+\pi^-\pi^+\pi^-)$ $<$3.7 GeV/c^2
- Standard track cuts
- Kinematic $\chi^2/dof < 10$
- $4.15 < E_{CM} < 4.3$ GeV

Background Vetos



- Require $|\, M(\pi^+\pi^-\pi^0) - M(\eta)\, | > 20$ MeV/c^2
- Require $|\, M(\pi^+\pi^-\pi^0) - M(\omega)\, | > 50$ MeV/c^2

Additional Cuts

- Smallest angle between transition γ and charged track - rejects γ from charged particles
- π^0 pull cut for transition γ - rejects γ from π^0
- Tighter cut on kinematic χ^2/dof
- Optimize cuts using figure of merit.

$$FOM = \frac{signal}{\sqrt{signal + backgroud}}$$

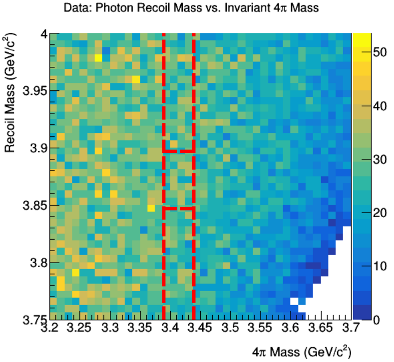
- Signal is signal MC scaled so

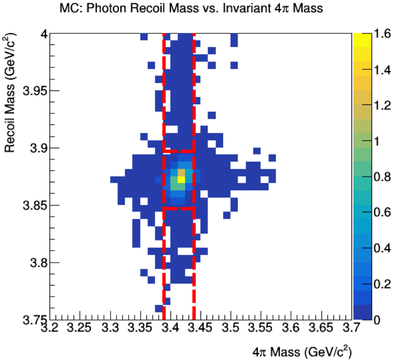
$$\frac{\mathcal{B}(X(3872) \to \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \to \pi^+ \pi^- J/\psi)} = 1$$

- Background from X(3872) sidebands

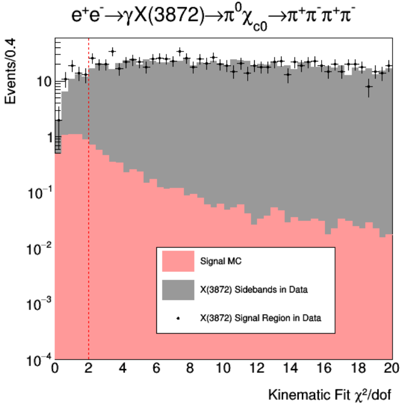
Cut Optimization

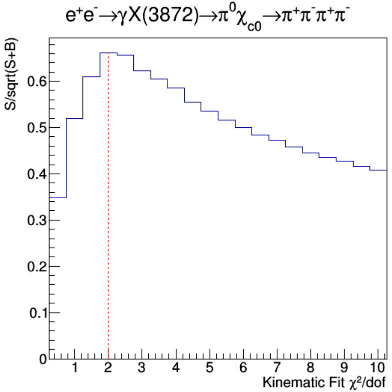
- Use 50 MeV window in M(4π) centered at χ_{c0} mass
- Signal region is 50 MeV/c^2 window centered at X(3872)
- X(3872) sidebands are points outside of the signal region.





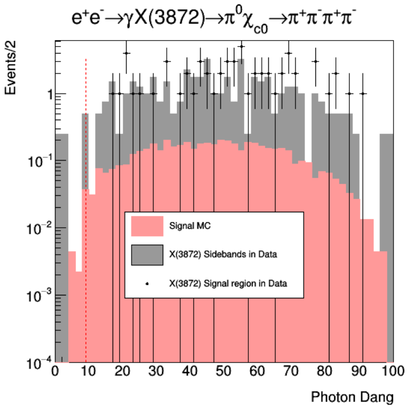
χ^2/DOF Cut Optimization

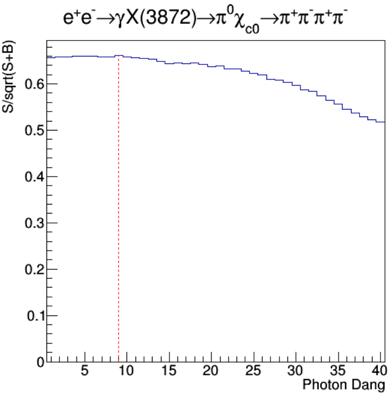




Photon Angle Cut Optimization

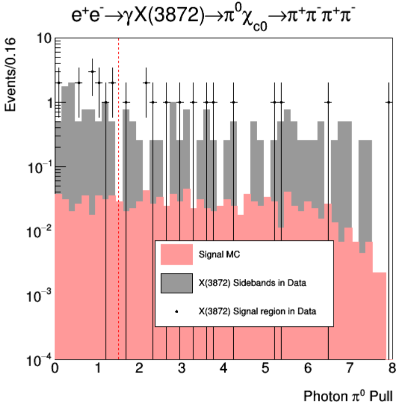
Smallest angle between transition photon and charged track

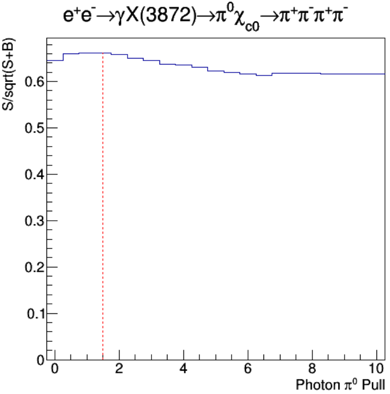




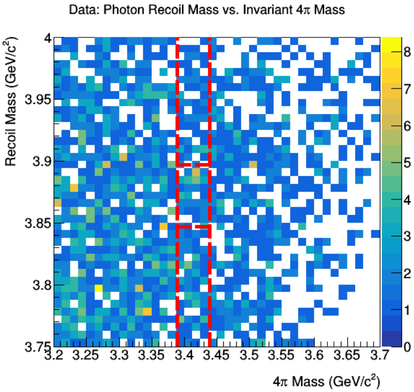
Photon π^0 Pull Cut Optimization

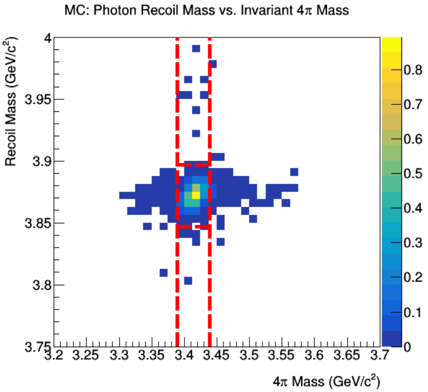
σ from π^0 mass when transition photon is combined with other photons in the event



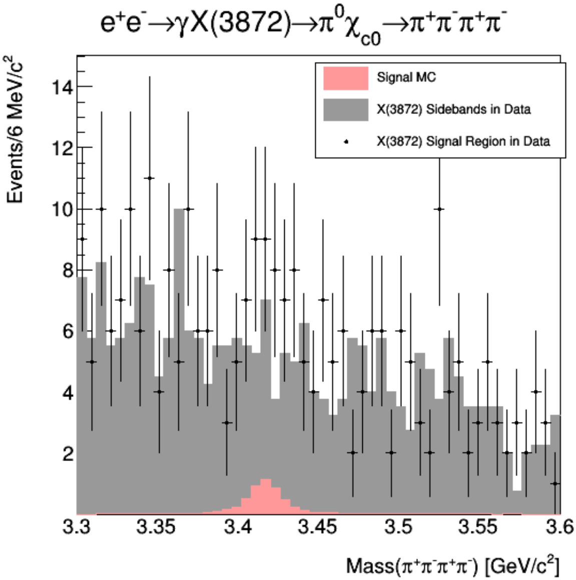


Final 2D Plots

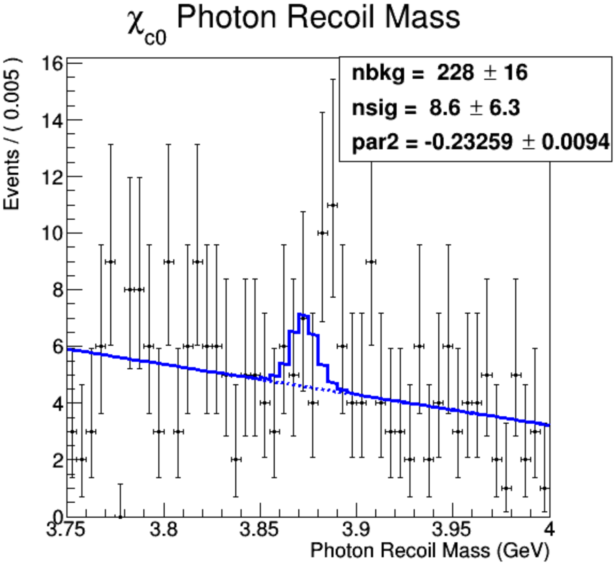




4π Mass 1D Projection



Photon Recoil 1D Projection



Systematic Uncertainties

- χ^2/dof - Largest difference: 4.7%

χ^2/dof Cut	Number of Events	ϵ	Upper Limit (ratio)
1.5	5.6±5.1	7.3%	3.42
2.5	9.3 ± 7.5	11.4%	3.43

- Tracking - 4%
- Photons - 2 photons not in reference channel - 2%
- Background shape - Largest difference: 1.2%

Polynomial Order	Number of Events	Upper Limit (N_1)
0	8.5±6.3	16.6
2	8.5 ± 6.3	16.6
3	8.3 ± 6.3	16.5

- Input branching fractions - 8%

Decay	Branching Fraction	Relative Uncertainty
$\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$	2.24±.18%	8%

- Uncertainty in N_0: 12%

Upper Limit Calculation

- Upper limit for N_1 calculated assuming the uncertainty is gaussian
- Add systematic and statistical uncertainties in quadrature

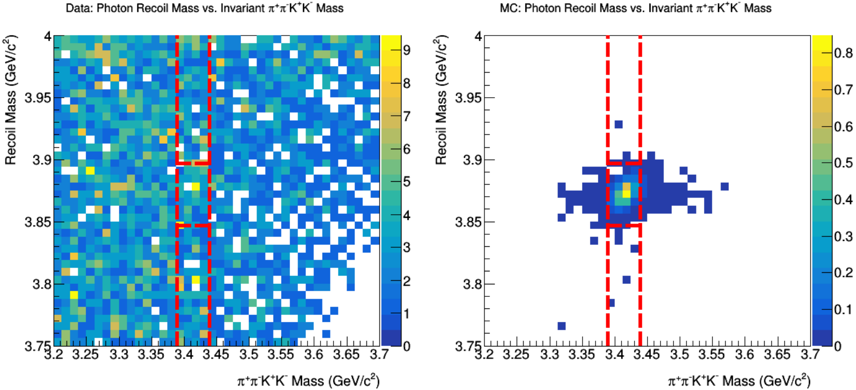
Polynomial Order	Number of Events	Upper Limit (N_1)
1	8.6±6.3±1.3	16.8

- Calculate upper limit of ratio using

$$\frac{\mathcal{B}(X(3872) \to \pi^0 \chi_{c0})}{\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)} = \frac{N_1}{N_0}\frac{\epsilon_0}{\epsilon_1}\frac{\mathcal{B}(J/\psi \to \ell^+\ell^-)}{\mathcal{B}(\pi^0 \to \gamma\gamma) * \mathcal{B}(\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-)}$$

- Here $N_1 = 16.8$ and $\epsilon_1 = 9.61\%$
- $N_0 = 84.1$ and $\epsilon_0 = 32.3\%$ are taken from BAM-00321
- Branching fractions taken from PDG
- New upper limit for the ratio of branching fractions is 3.63

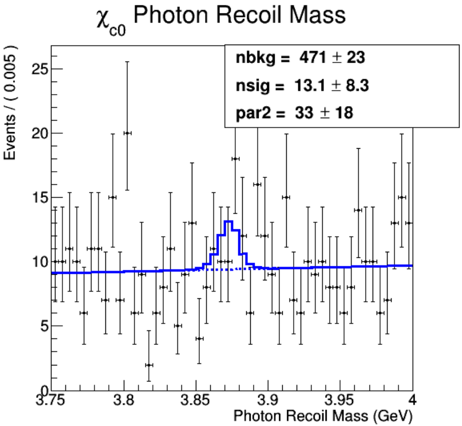
Other hadronic modes - $\chi_{c0} \to \pi^+\pi^-K^+K^-$



Same cut optimization procedure gives

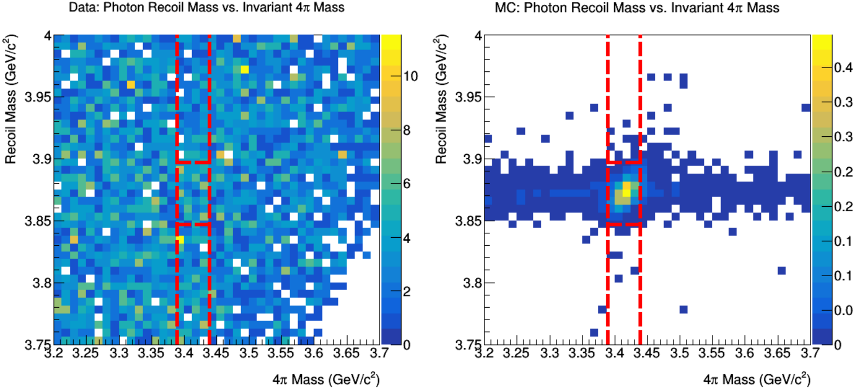
- $\chi^2/dof < 3.5$
- π^0 pull >2
- Angle between γ and nearest track >12
- Keep same veto on ω and η

Other hadronic modes - $\chi_{c0} \to \pi^+\pi^-K^+K^-$



- $\mathcal{B}(\chi_{c0} \to \pi^+\pi^-K^+K^-)$=1.75%
- $N_1 = 23.7$ and ϵ_1=12.4%
- Upper Limit for ratio of branching fractions: 5.07

Other hadronic modes - $\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0$



Same cut optimization procedure gives

- $\chi^2/dof < 2$
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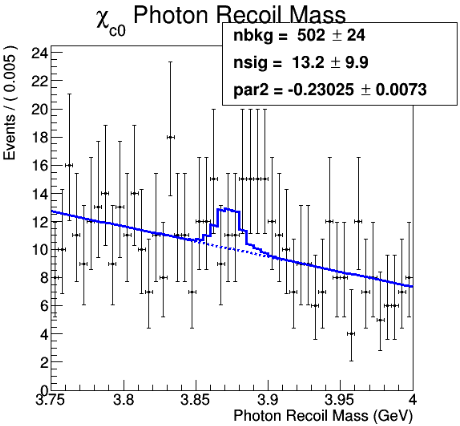
Other hadronic modes - $\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0$



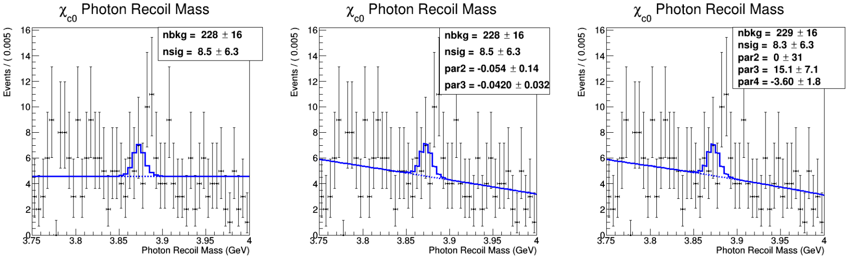
- $\mathcal{B}(\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0)$=3.3%
- N_1=25.87 and ϵ_1 =5.05%
- Upper Limit of ratio: 7.2

Summary

- Reconstructing X(3872)$\rightarrow \pi^0\chi_{c0}$ with $\chi_{c0} \rightarrow \pi^+\pi^-\pi^+\pi^-$ improves upper limit of $\frac{\mathcal{B}(X(3872)\rightarrow\pi^0\chi_{c0})}{\mathcal{B}(X(3872)\rightarrow\pi^+\pi^-J/\psi)}$ from 19 to 3.63
- Ratio of branching fractions still much larger than χ_{c1} value
- No clear signal for $X(3872) \rightarrow \pi^0\chi_{c0}$ yet
- Next steps
  - Can event selection be improved?
  - Simultaneous fit of $\chi_{c0} \rightarrow \pi^+\pi^-\pi^+\pi^-$, $\chi_{c0} \rightarrow \pi^+\pi^-K^+K^-$, and $\chi_{c0} \rightarrow \pi^+\pi^-\pi^0\pi^0$?

Backup

$\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$ - Background Systematic



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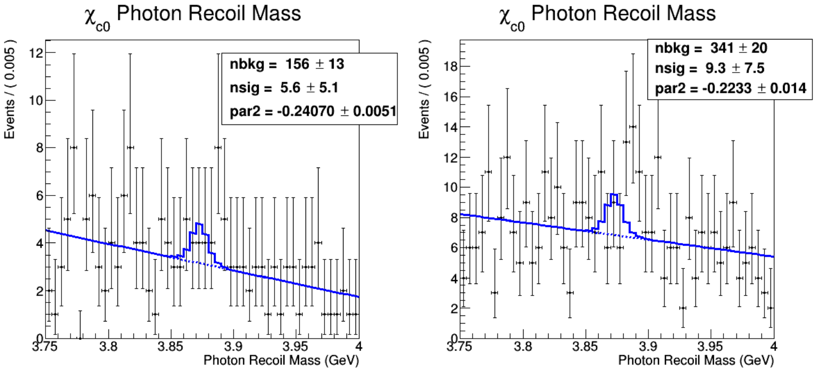
$\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$ - χ^2/dof Systematic



χ^2/dof Cut	Number of Events	ϵ	Upper Limit (ratio)
1.5	5.6±5.1	7.3%	3.42
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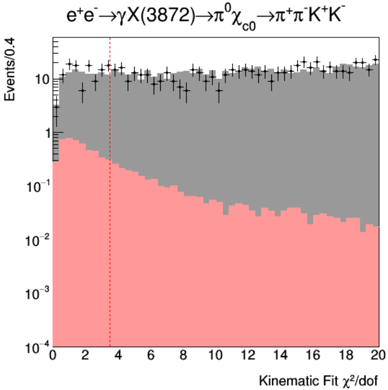
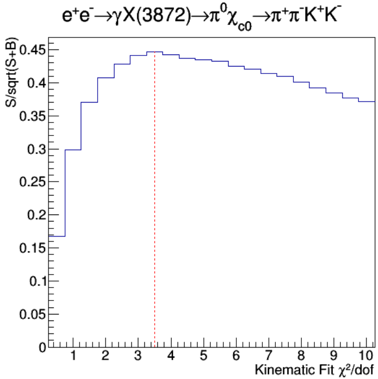
$\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$ - Input Branching Fractions

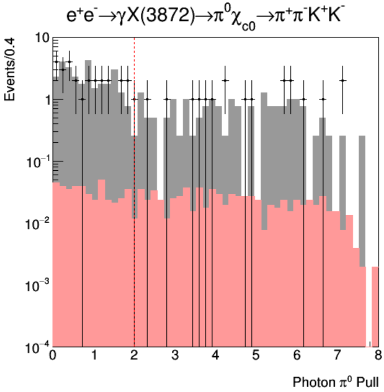
Decay	Branching Fraction	Relative Uncertainty
$\chi_{c0} \to \pi^+\pi^-\pi^+\pi^-$	2.24$\pm$.18%	8%
$J/\psi \to \ell^+\ell^-$	11.932 ± 0.77%	0.06%
$\pi^0 \to \gamma\gamma$	98.823 ± 0.034%	0.03%

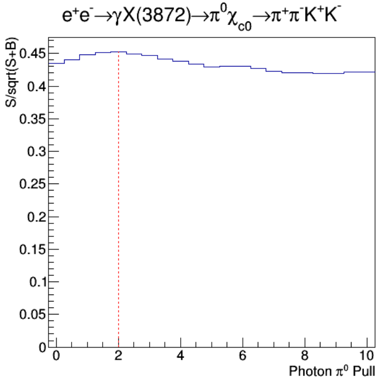
$\chi_{c0} \to \pi^+\pi^-K^+K^-$ - χ^2/dof



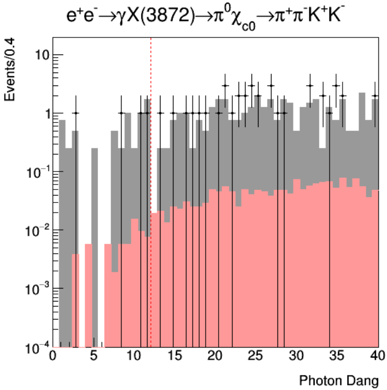


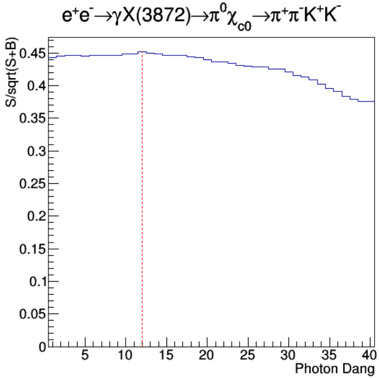
$\chi_{c0} \to \pi^+\pi^-K^+K^-$ - π^0 Pull



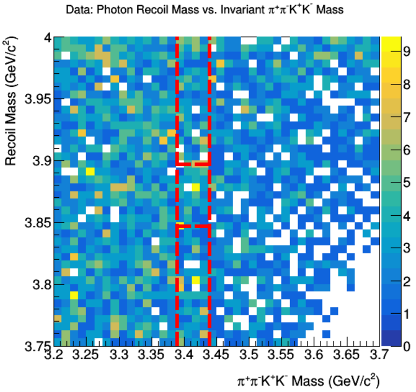


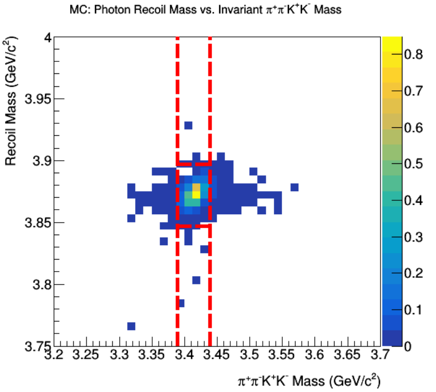
$\chi_{c0} \to \pi^+\pi^-K^+K^-$ - Dang



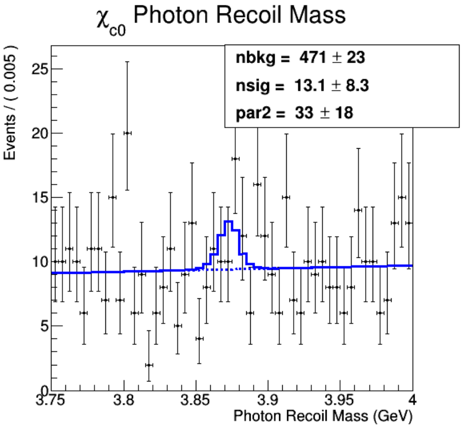


$\chi_{c0} \to \pi^+\pi^- K^+ K^-$ - 2D Distributions





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



- $\mathcal{B}(\chi_{c0} \to \pi^+\pi^-K^+K^-)$=1.75%
- $N_1 = 23.7$ and ϵ_1=12.4%
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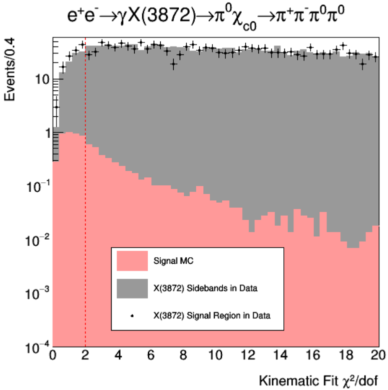
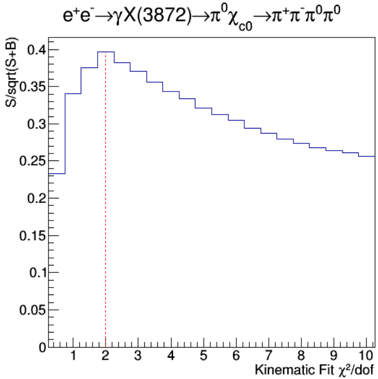
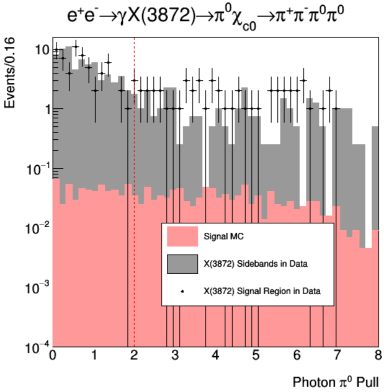
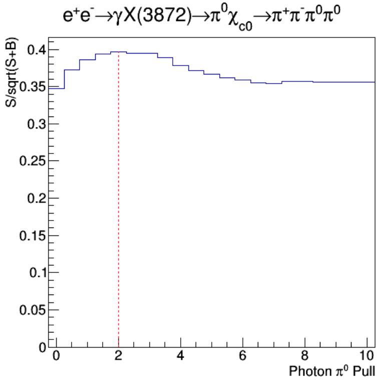
$\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0$ - χ^2/dof



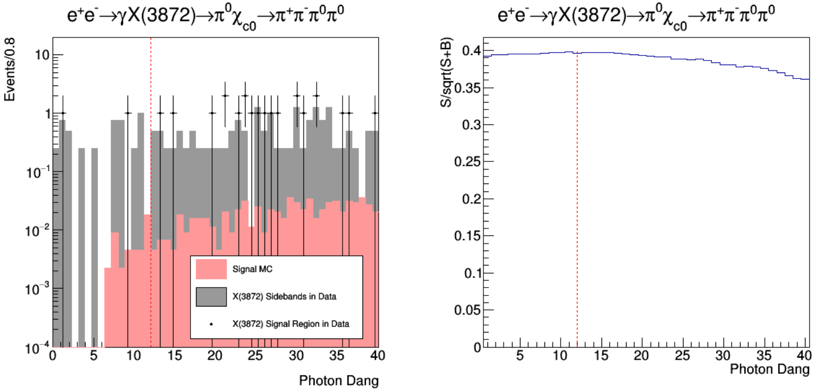


$\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0$ - π^0 Pull

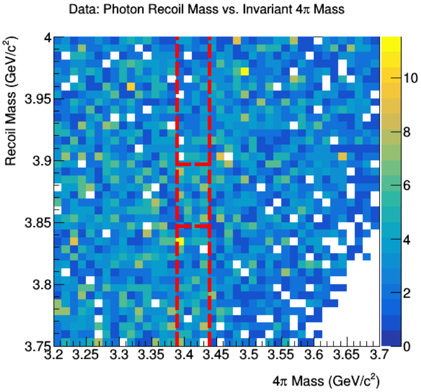


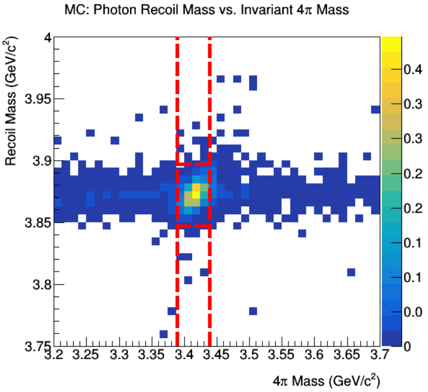


$\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0$ - Dang

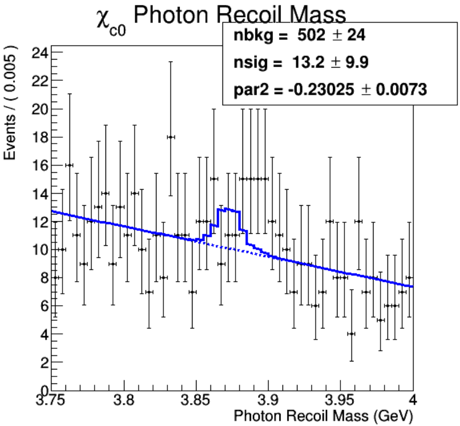


$\chi_{c0} \to \pi^+\pi^-\pi^0\pi^0$ - 2D Distributions





$\chi_{c0} \to \pi + \pi^- \pi^0 \pi^0$



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- N_1=25.87 and ϵ_1 =5.05%
- Upper Limit of ratio: 7.2