Update cross section of $e^+e^- \to \gamma X(3872)$

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Motivation

- Update on $e^+e^- \to \gamma X(3872)$ cross section measurement with new data sets.

MC simulation and Datasets

BOSS Version:

- BOSS 7.0.3

Generator:

- $Y(4260) \to \gamma X(3872)$ P2GC1;
- $X(3872) \to \rho^0 J/\psi$ PHSP;
- $\rho^0 \to \pi^+\pi^-$ VSS;
- $J/\psi \to e^+e^-/\mu^+\mu^-$ PHOTOS VLL;

Signal MC:

- $Y(4260)$ is generated by 'KKMC'
- 'EvtGen' for the following decays
- 30000 signal MC events at each energy points

Datasets:

$\sqrt{s}(\mathrm{GeV})$	4.0076	4.2263	4.2580	4.3583
$\mathcal{L}(\mathrm{pb}^{-1})$	482.0	1101	828.4	543.9

Initial event selection

Charged Tracks:

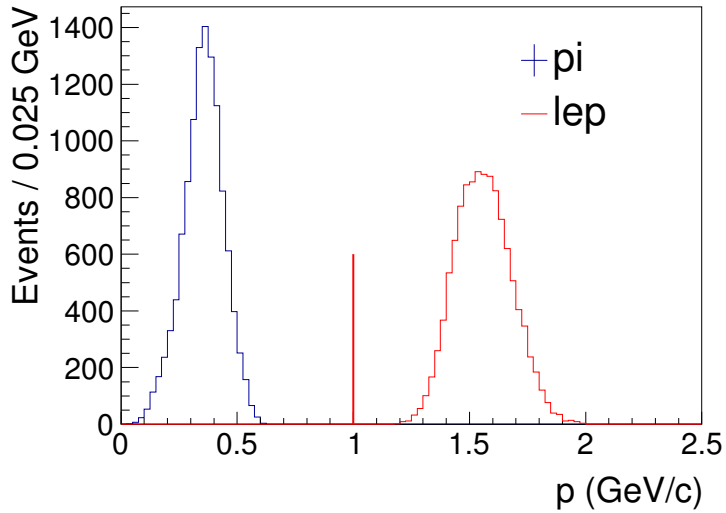
- $|z| < 10$ cm, $r < 1$ cm;
- nGood=4 && nCharge=0;
- $p_l > 1.0$ GeV/c, $p_\pi < 1.0$ GeV/c;
- $E_e > 1.1$ GeV, $E_\mu < 0.35$ GeV.

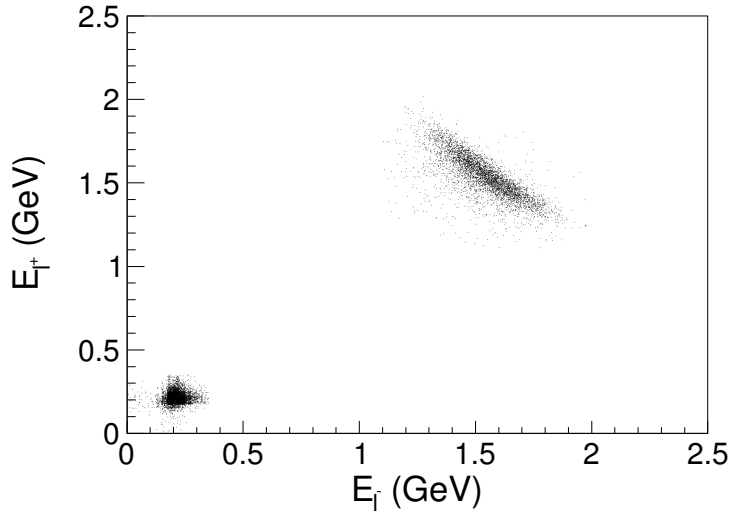
Good Photons:

- $E_\gamma \geq 25$ MeV in barrel EMC ($|\cos\theta| \leq 0.8$);
- $E_\gamma \geq 50$ MeV in end-cap ($0.86 \leq |\cos\theta| \leq 0.92$);
- $\Delta_{\text{angle}} \geq 20$;
- $0 < t < 14$ (in unit of 50 ns).

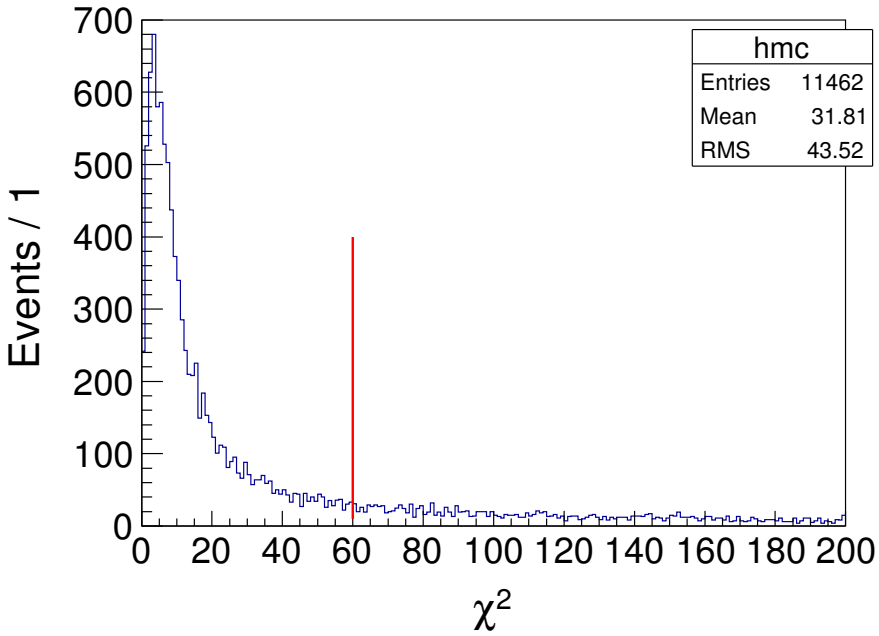
Vertex Fit: for $\pi^+\pi^- l^+ l^-$.

4C Fit: for $\gamma\pi^+\pi^- l^+ l^-$, $\chi^2 < 200$.



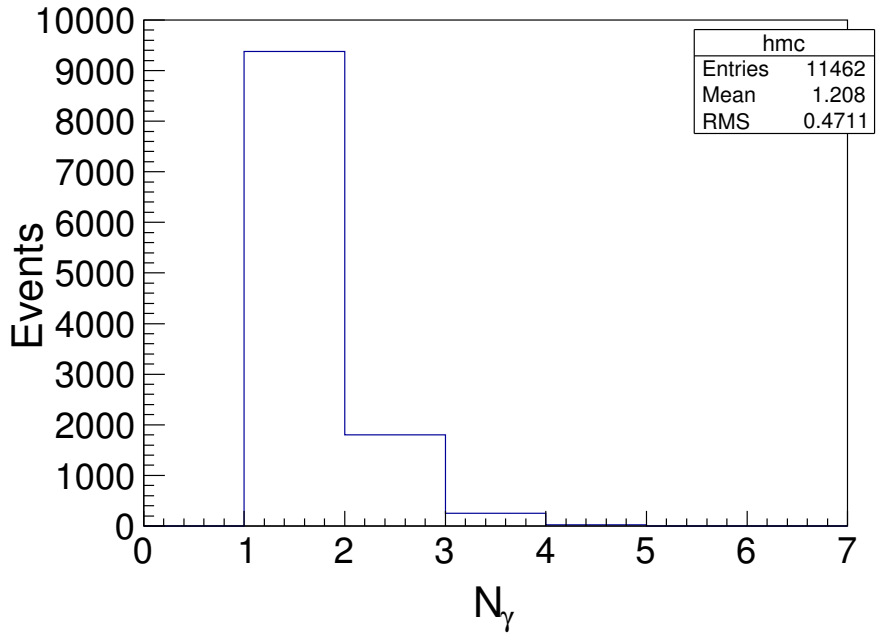


Further event selection



(c) 4C kinematic fit χ^2 for signal MC events at 4.26 GeV.

$$\chi^2 < 60$$

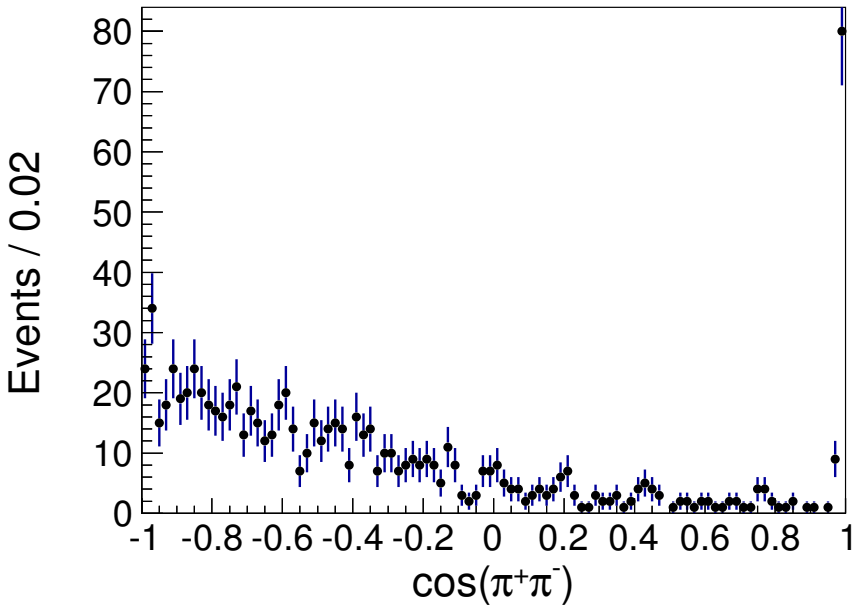


(d) The number of good photon candidate.

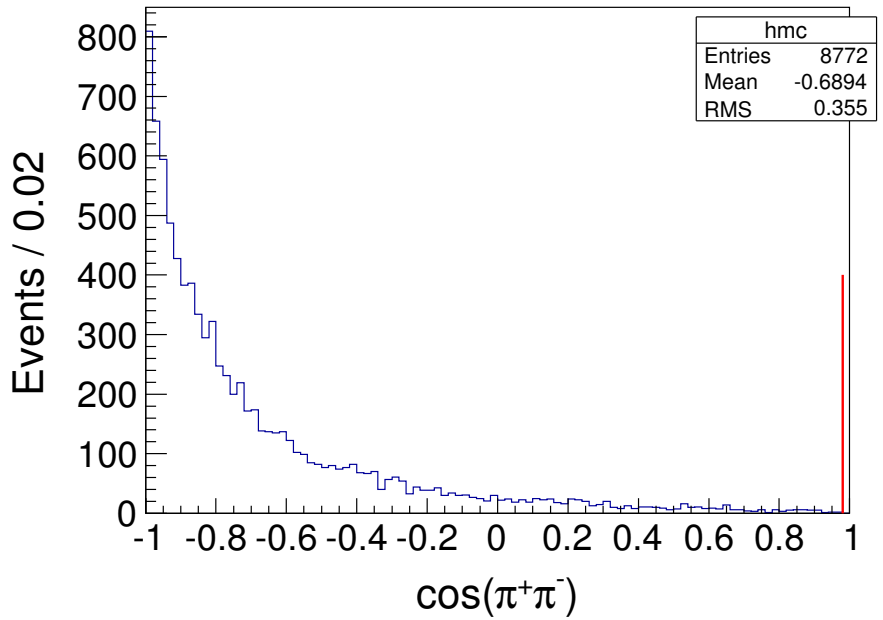
$$1 \leq N_\gamma \leq 5$$

Further event selection

- γ-conversion background



(e) The open angle of $\pi^+\pi^-$ for 4.26 GeV data sample.

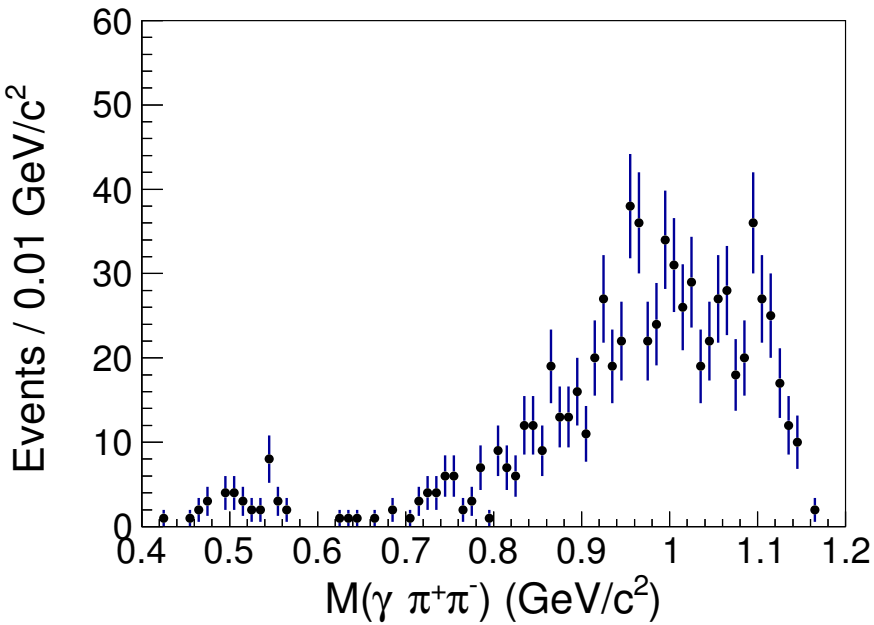


(f) The open angle of $\pi^+\pi^-$ for signal MC events at 4.26 GeV.

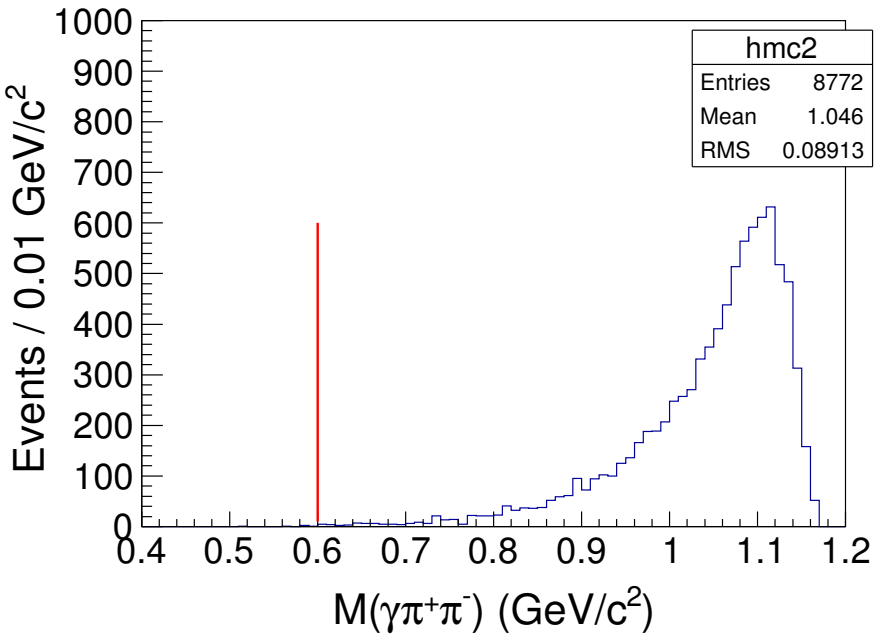
$\cos(\pi^+\pi^-) < 0.98$, barely loose no efficiency

Further event selection

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



(g) $\gamma\pi^+\pi^-$ mass distribution for 4.26 GeV data sample.



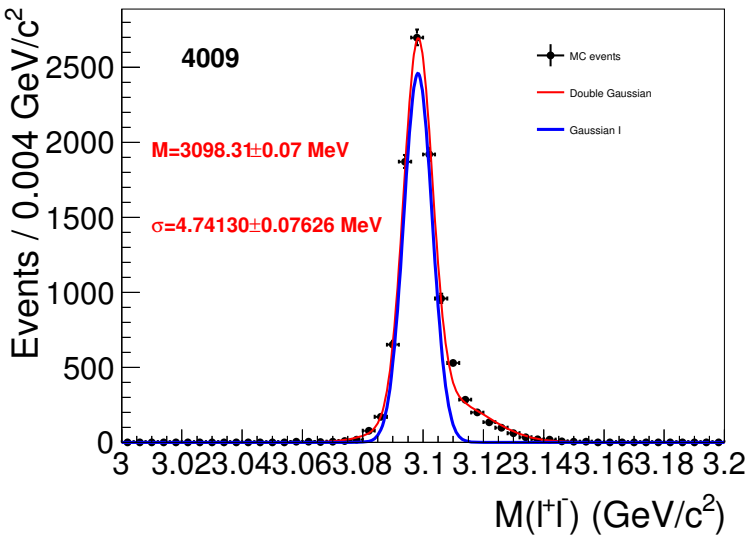
(h) $\gamma\pi^+\pi^-$ mass distribution for signal MC events at 4.26 GeV.

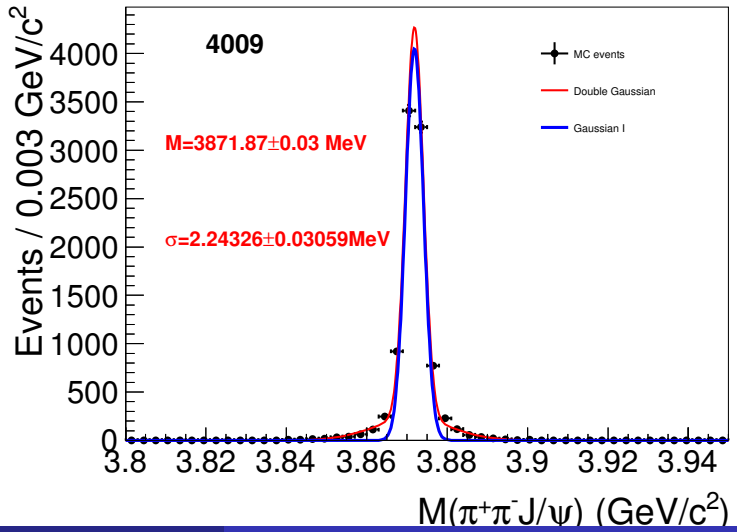
$M(\gamma\pi^+\pi^-) > 0.6\mathrm{GeV/c^2}$, with $\epsilon > 99.8\%$

Cut flow for signal MC at 4.009 GeV

Total	30000
nGood=4&&nCharge=0	21354
$1 \leq$ nGam ≤ 5	17433
$1\pi^+1\pi^-1l^+1l^-$	15549
$2.8 < M_{J/\psi} < 4.0$	14879
vertex fit	14762
4C fit $(\chi^2 < 200)$	11726
4C fit $(\chi^2 < 60)$	9996
$\cos(\pi^+\pi^-) < 0.98$	9995
$M_{\gamma\pi^+\pi^-} > 0.6$	9789
$3.08 < M_{J/\psi} < 3.12$	9359
e^+e^- events	3880
$\mu^+\mu^-$ events	5479
final efficiency	31.2%

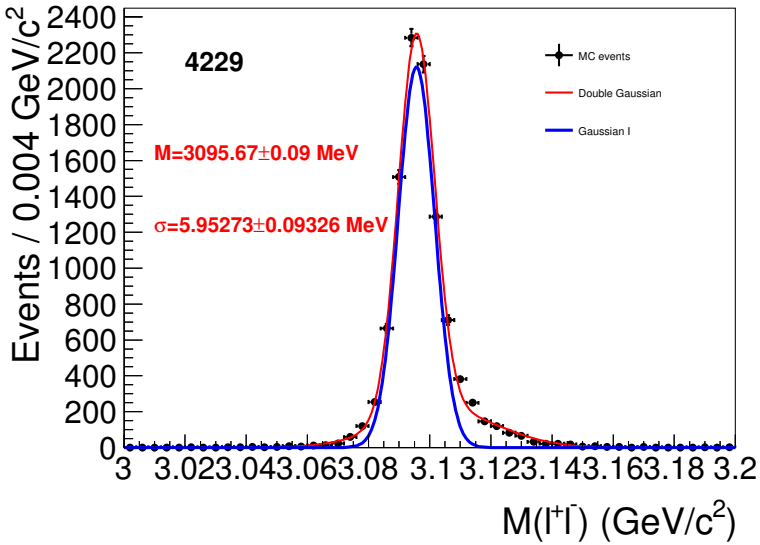
Double Gaussian Fit

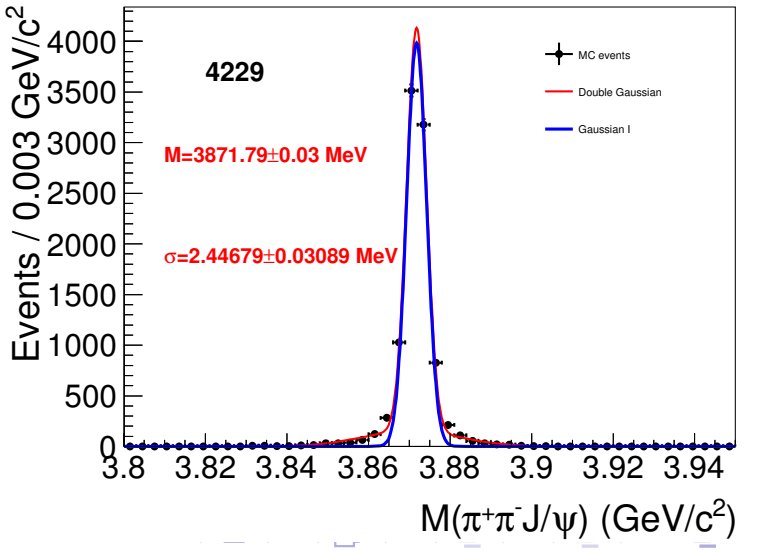




Cut flow for signal MC at 4.229 GeV

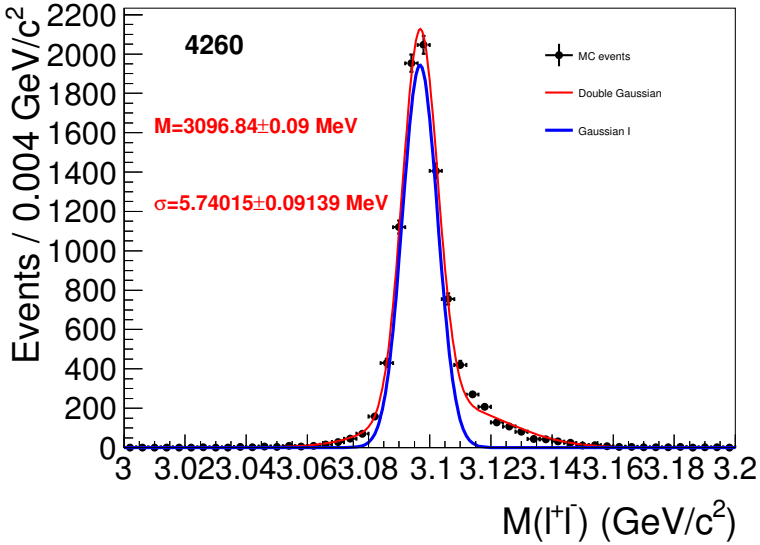
Total	30000
nGood=4&&nCharge=0	21351
$1 \leq$ nGam ≤ 5	17938
$1\pi^+1\pi^-1l^+1l^-$	15949
$2.8 < M_{J/\psi} < 4.0$	15332
vertex fit	15157
4C fit ($\chi^2 < 200$)	12141
4C fit ($\chi^2 < 60$)	10285
$\cos(\pi^+\pi^-) < 0.98$	10284
$M_{\gamma\pi^+\pi^-} > 0.6$	10264
$3.08 < M_{J/\psi} < 3.12$	9624
e^+e^- events	3995
$\mu^+\mu^-$ events	5629
final efficiency	32.1%

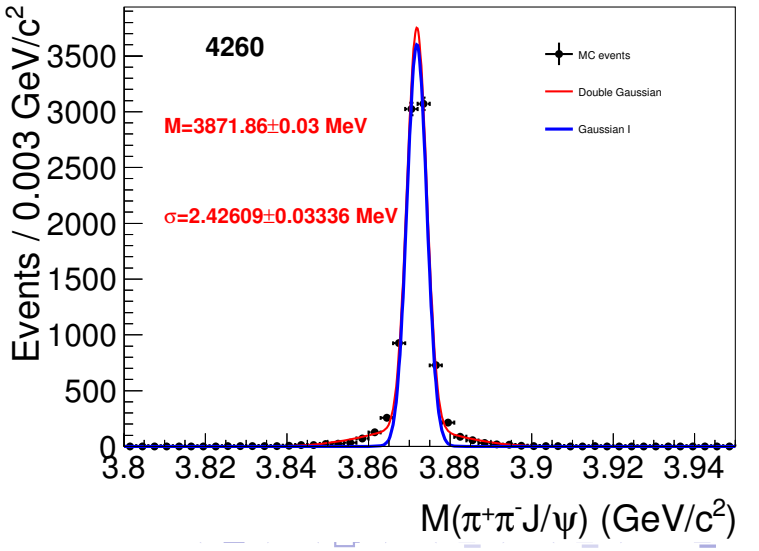




Cut flow for signal MC at 4.260 GeV

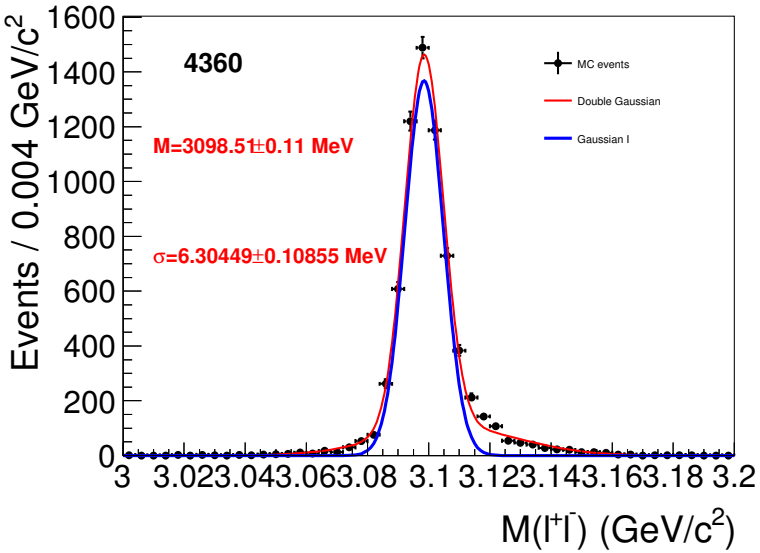
Total	30000
nGood=4&&nCharge=0	21276
$1 \leq$ nGam ≤ 5	17839
$1\pi^+1\pi^-1l^+1l^-$	15868
$2.8 < M_{J/\psi} < 4.0$	15268
vertex fit	15090
4C fit ($\chi^2 < 200$)	11462
4C fit ($\chi^2 < 60$)	9472
$\cos(\pi^+\pi^-) < 0.98$	9472
$M_{\gamma\pi^+\pi^-} > 0.6$	9467
$3.08 < M_{J/\psi} < 3.12$	8767
e^+e^- events	3659
$\mu^+\mu^-$ events	5108
final efficiency	29.2%

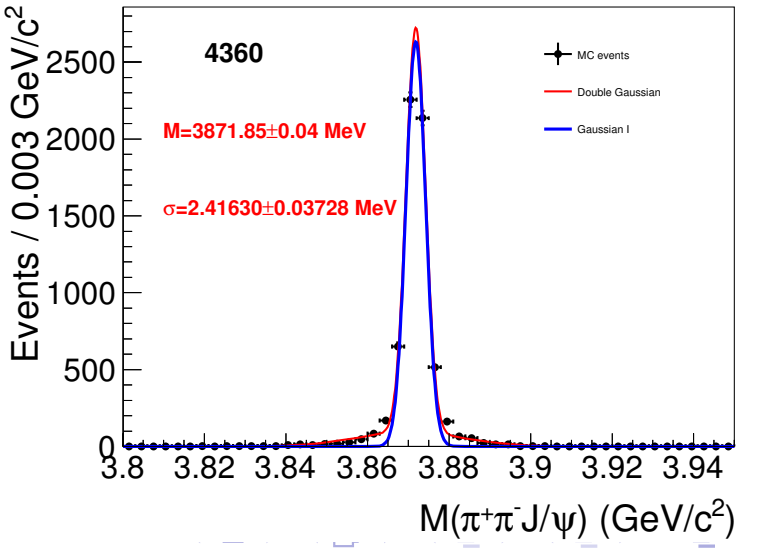




Cut flow for signal MC at 4.360 GeV

Total	30000
nGood=4&&nCharge=0	21323
$1 \leq$ nGam ≤ 5	17964
$1\pi^+1\pi^-1l^+1l^-$	15894
$2.8 < M_{J/\psi} < 4.0$	15280
vertex fit	15105
4C fit ($\chi^2 < 200$)	8348
4C fit ($\chi^2 < 60$)	6846
$\cos(\pi^+\pi^-) < 0.98$	6846
$M_{\gamma\pi^+\pi^-} > 0.6$	6842
$3.08 < M_{J/\psi} < 3.12$	6310
e^+e^- events	2656
$\mu^+\mu^-$ events	3654
final efficiency	21.0%



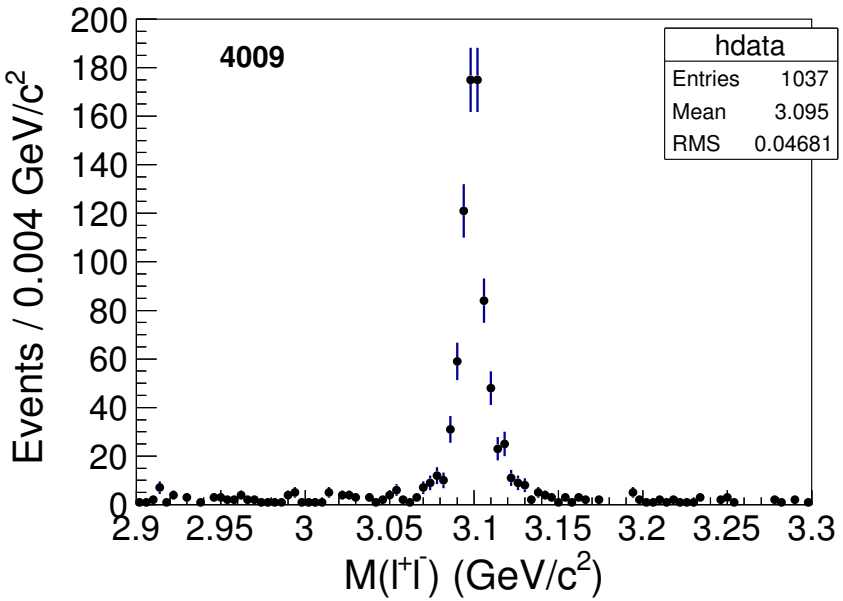


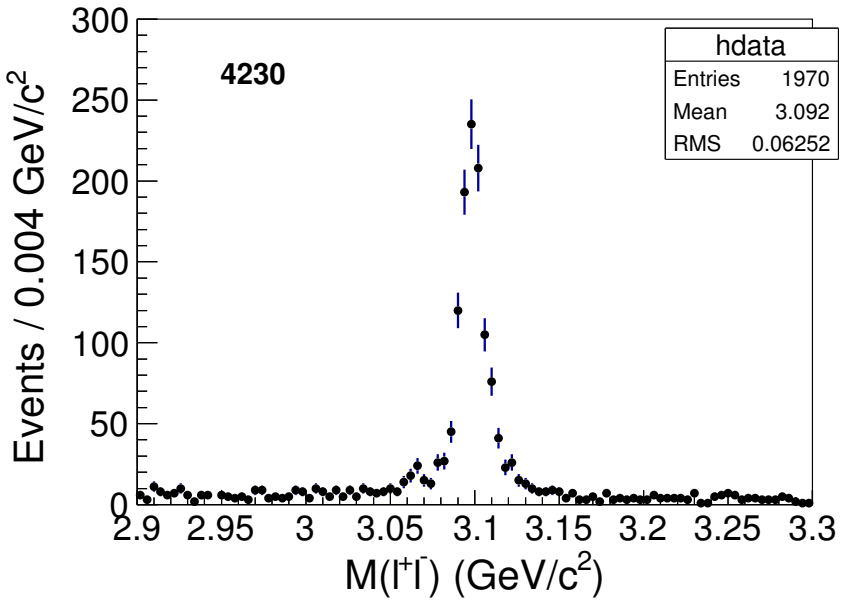
Remaining background

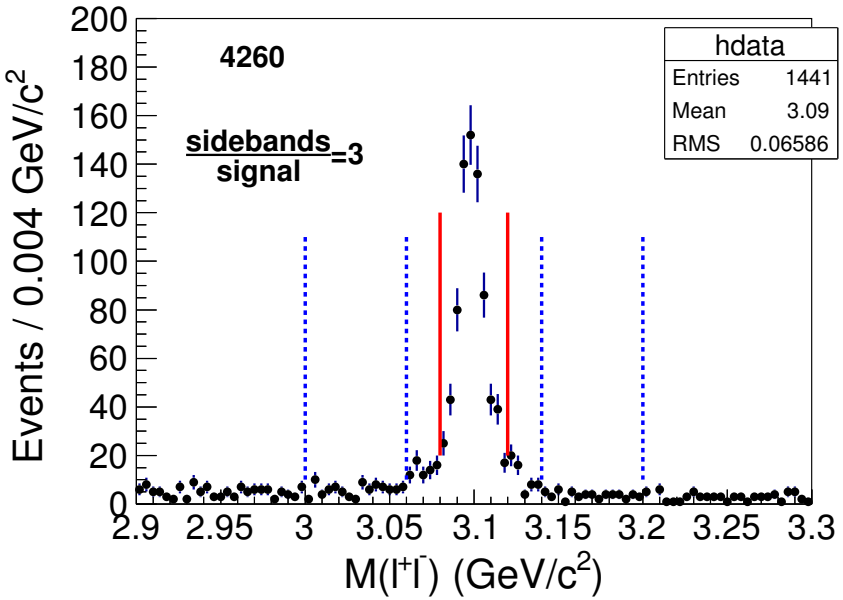
- $e^+e^- \to \gamma_{\rm ISR}\psi(2S)$, $\psi(2S) \to \pi^+\pi^- J/\psi$;
- $e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^- J/\psi$;
- $e^+e^- \to \eta' J/\psi$, $\eta' \to \gamma\pi^+\pi^-$;
- $e^+e^- \to \pi^+\pi^-\pi^+\pi^-(\pi^0/\gamma)$.

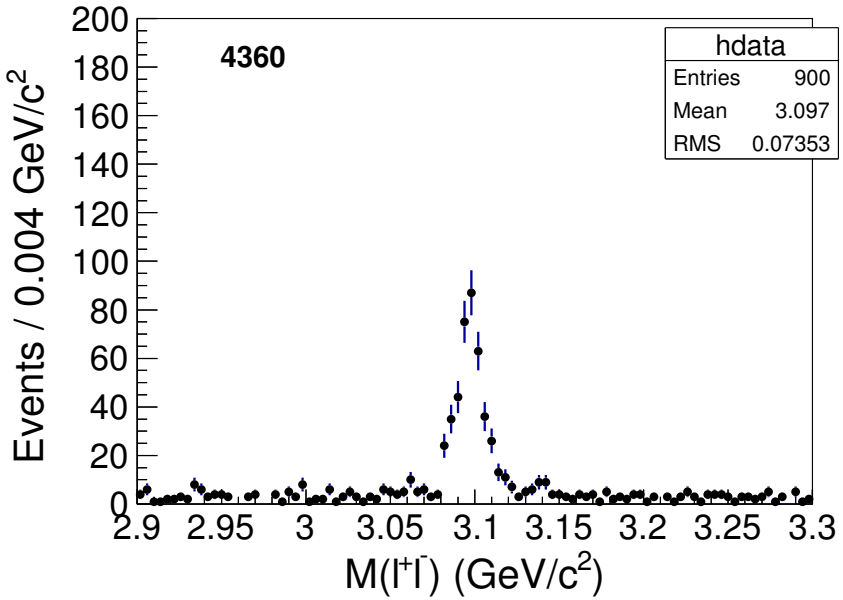
Since there is no peak background in the $X(3872)$ signal region or very small contribution to our signal, such background can be estimated through J/ψ sidebands.

l^+l^- invariant mass distribution of data

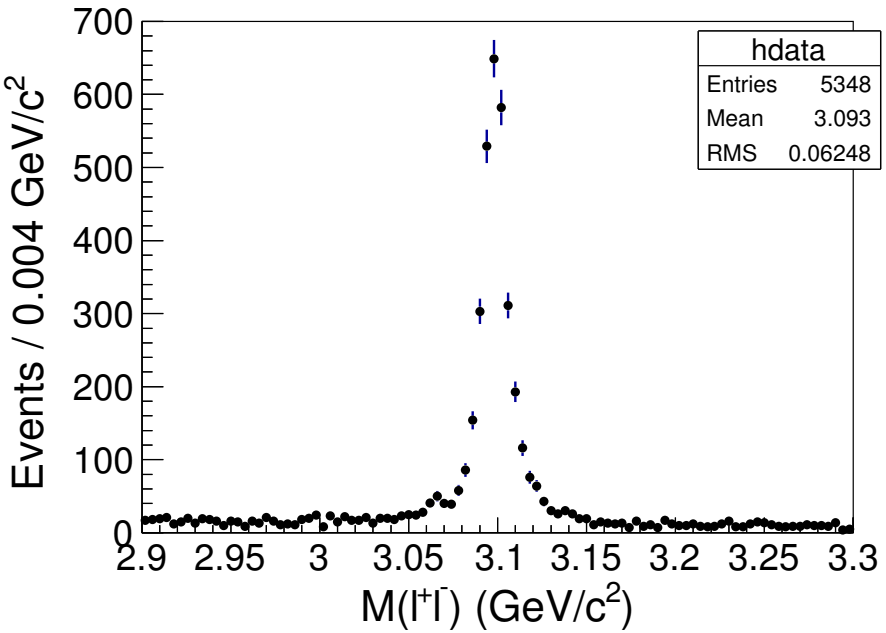


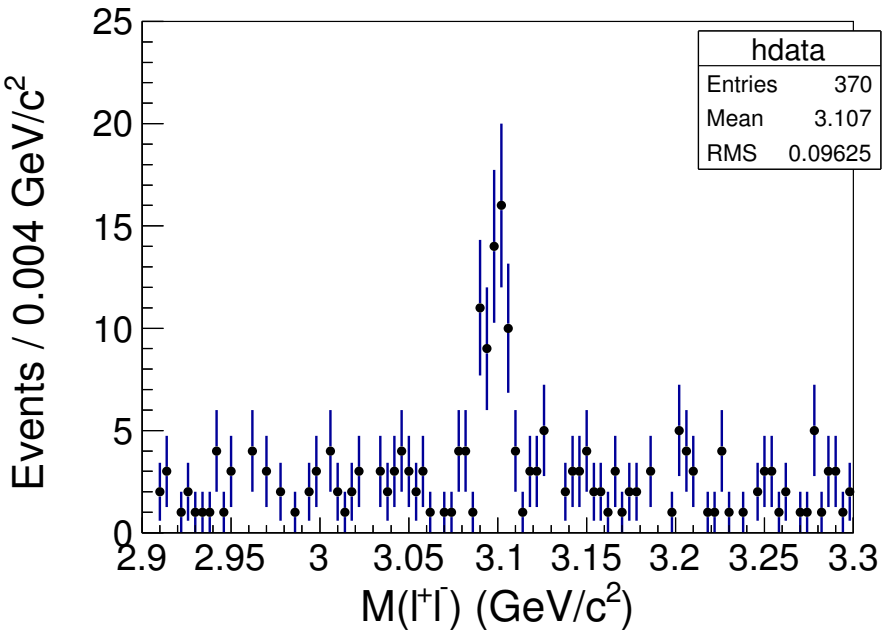






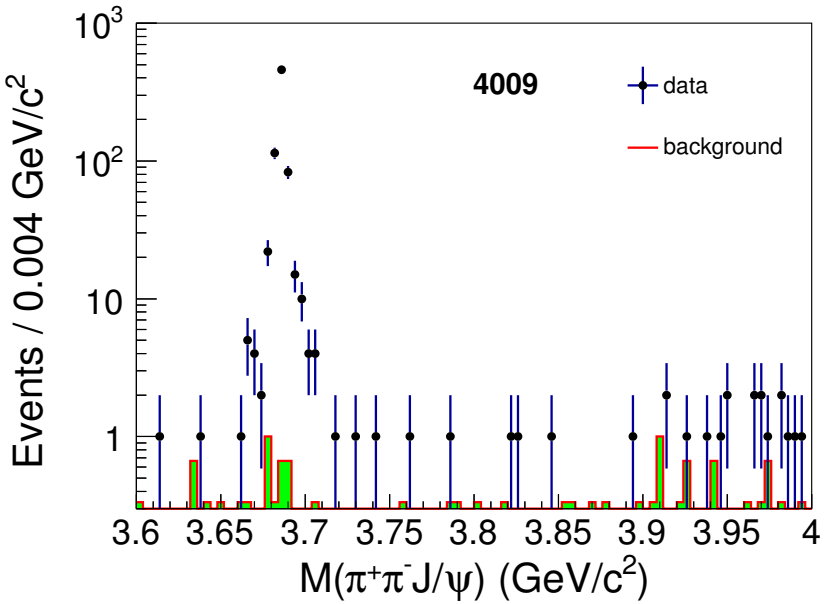
l^+l^- invariant mass of all data samples combined

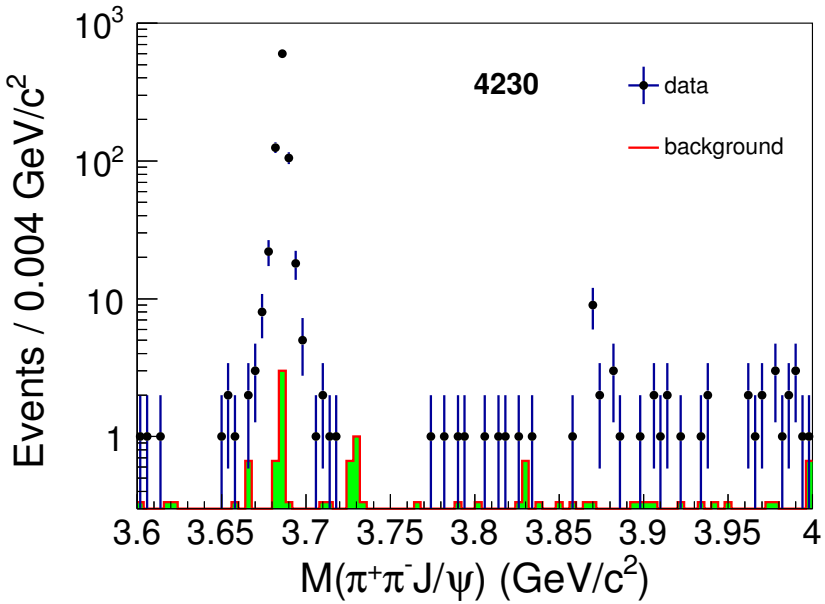


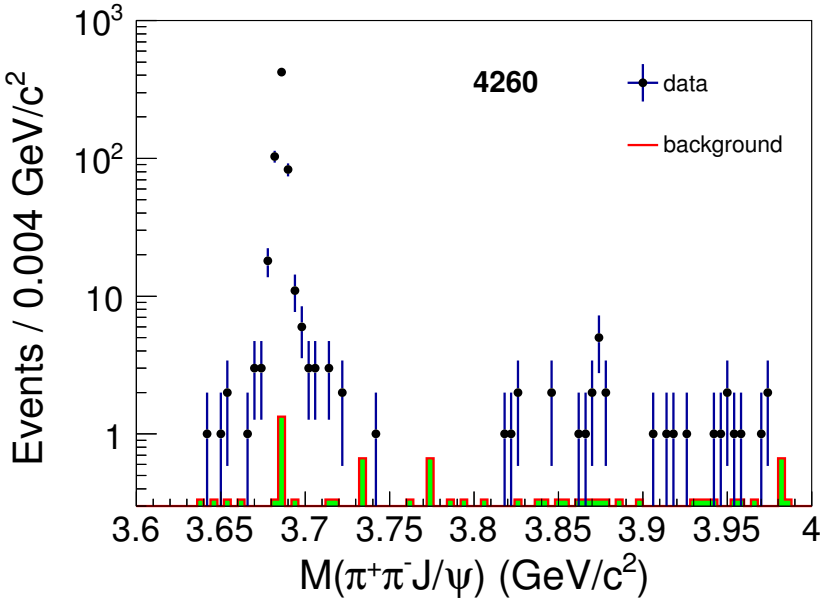


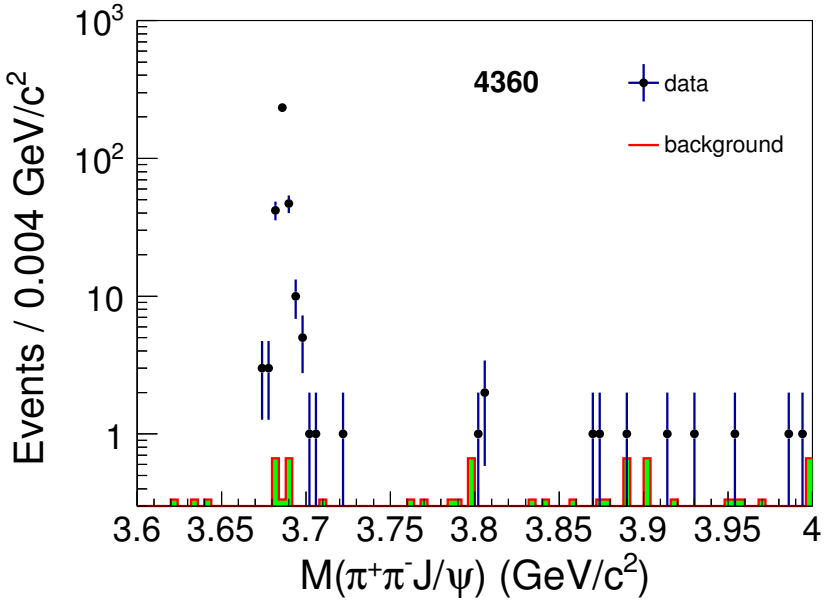
$$3.80 < M_{\pi^+\pi^- J/\psi} < 3.95$$

$\pi^+\pi^- J/\psi$ invariant mass distribution of data

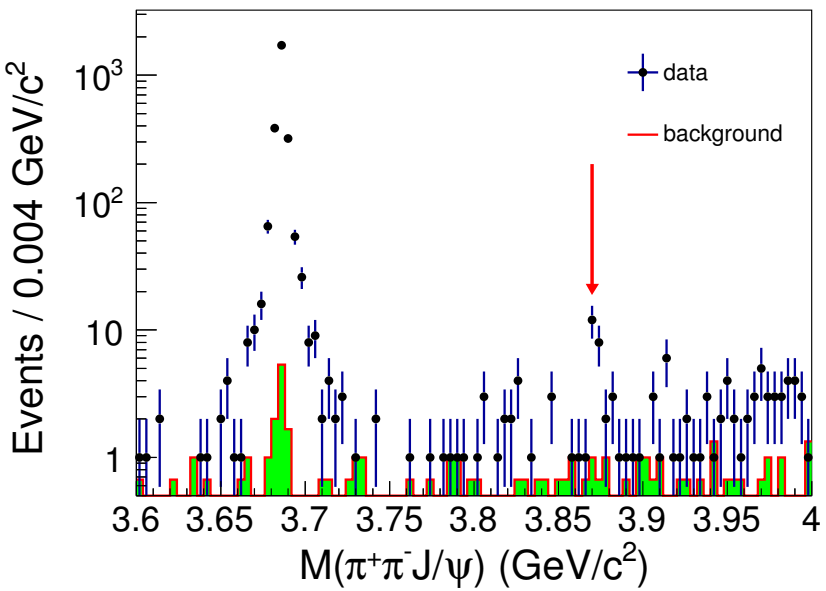


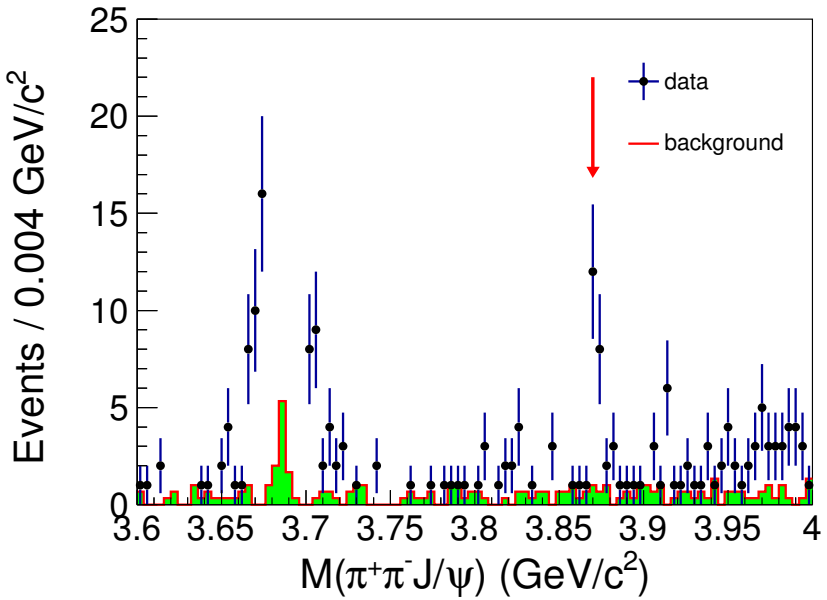


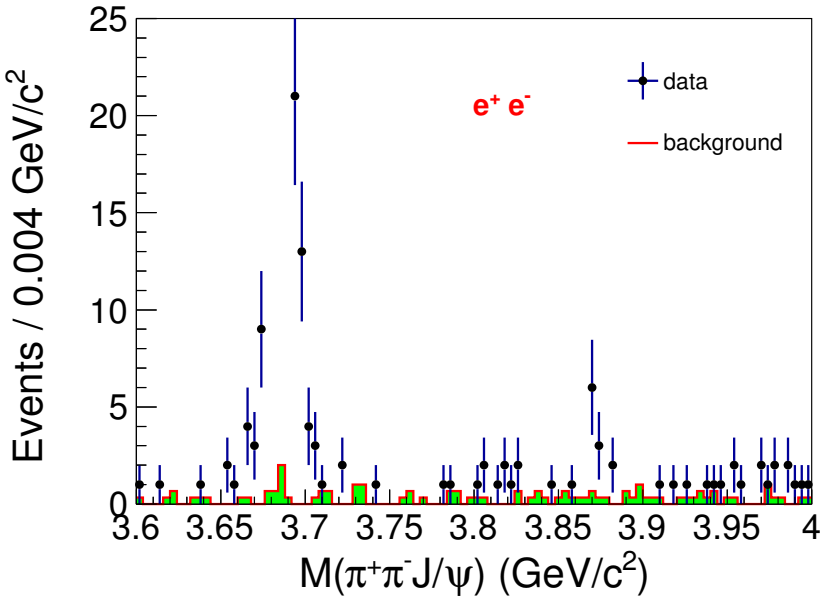


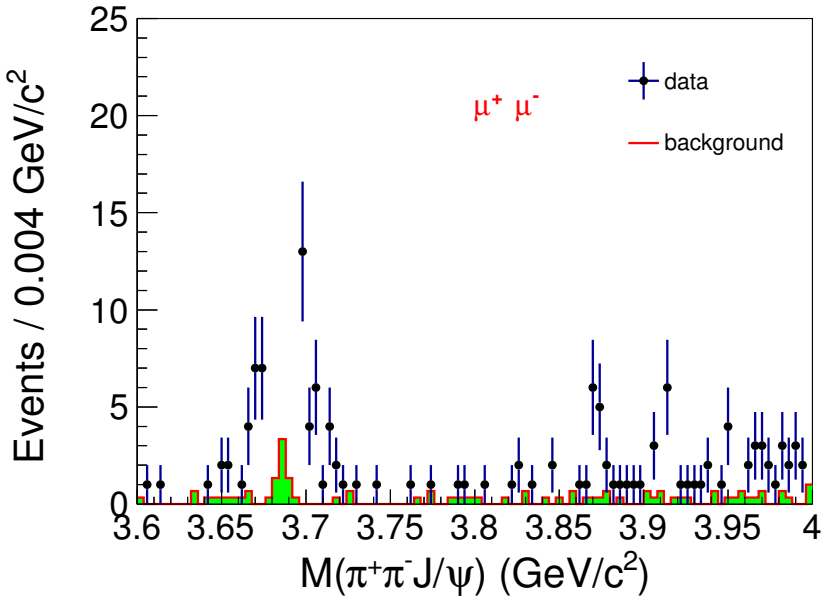


$\pi^+\pi^- J/\psi$ invariant mass of all data samples combined



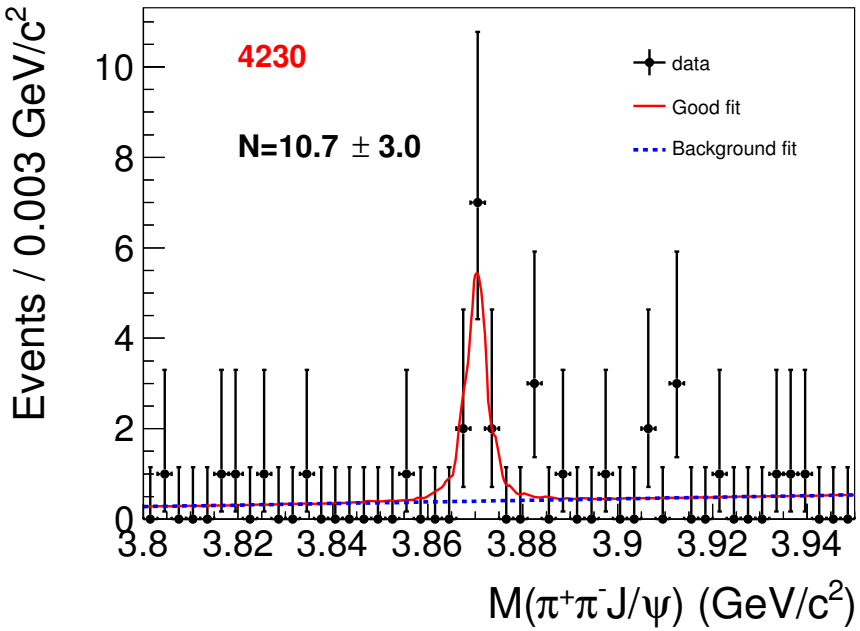


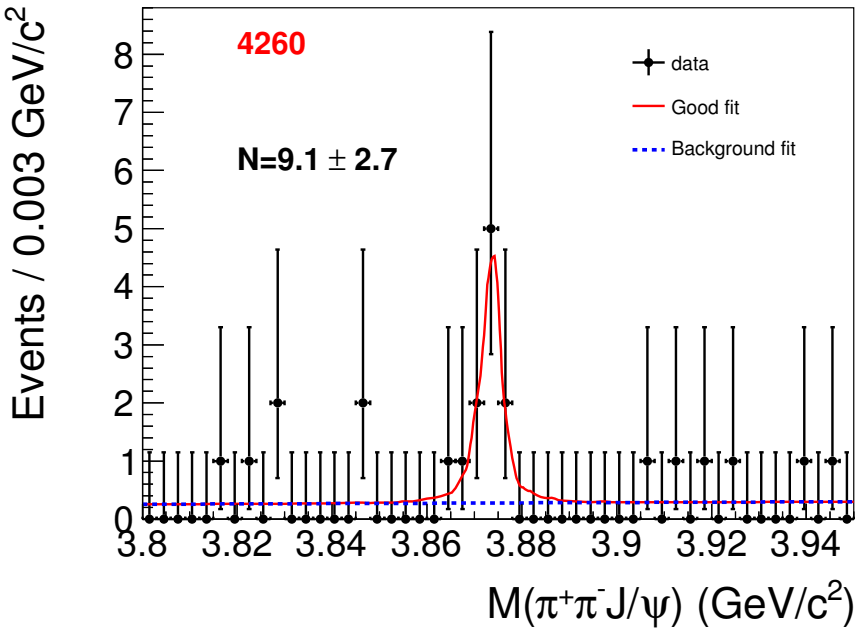




Fit $X(3872)$ signal events in data

- Fit $\pi^+\pi^- J/\psi$ invariant mass with MC simulated histogram shape convolving a Gaussian function, plus a liner background term.





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

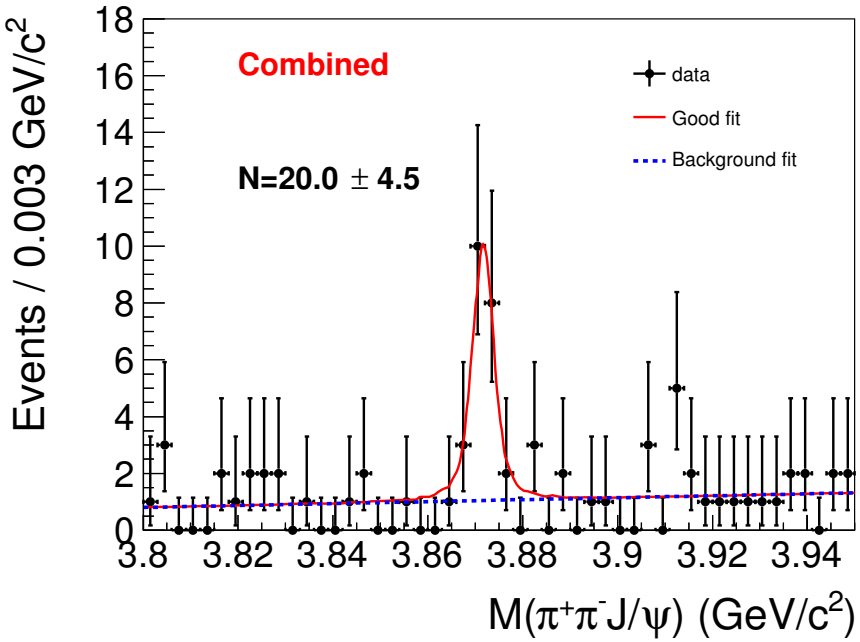
The Born cross section:

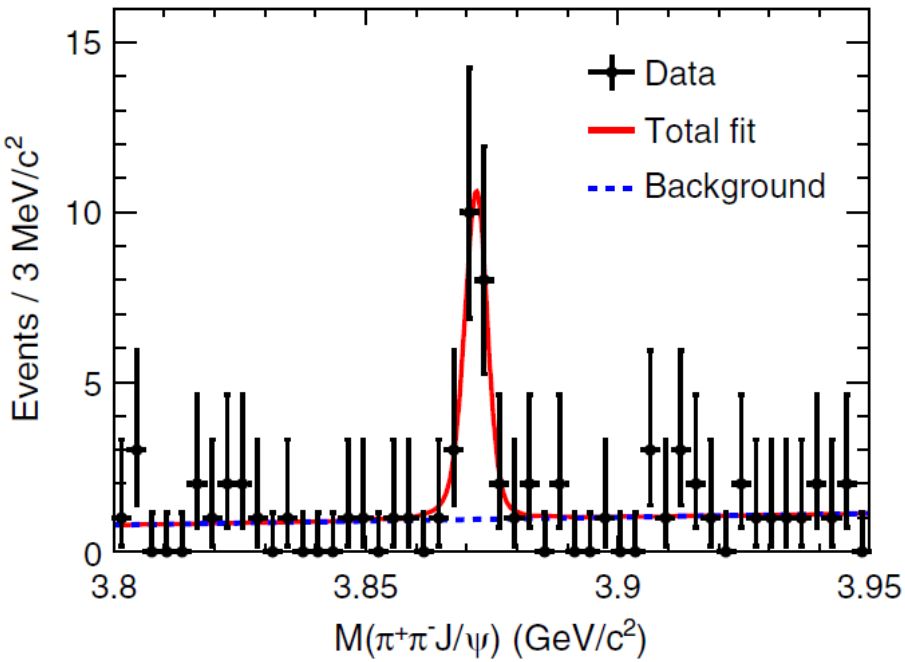
$$\sigma^{\rm B} = \frac{N^{\rm obs}}{\mathcal{L}_{\rm int}(1+\delta)\epsilon\mathcal{B}}$$

$\sqrt{s}$(GeV)	$\mathcal{L}$(pb^{-1})	ϵ(%)	$1+\delta$	$N^{\rm obs}$	$\sigma \cdot \mathcal{B}_{\pi^+\pi^- J/\psi}$
4.0076	482.0	31.2%	0.796		
4.2263	1101	32.1%	0.854	10.7 ± 3.0	0.30 ± 0.08
4.2580	828.4	29.2%	0.958	9.1 ± 2.7	0.33 ± 0.10
4.3583	543.9	21.0%	1.343		

Fit $X(3872)$ signal events from all data samples combined

- $\mathrm{MC}_{4260} \otimes$ Gaussian + linear background.

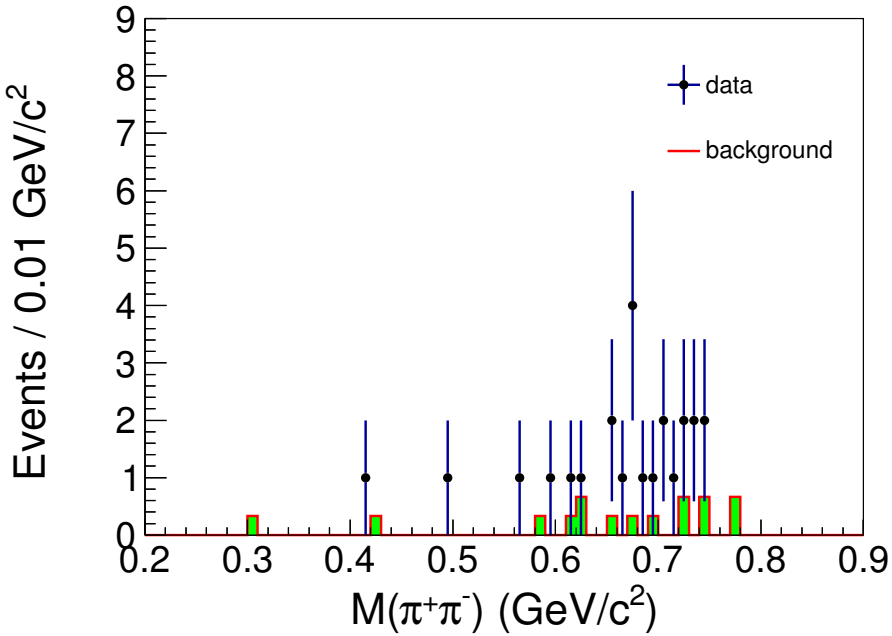




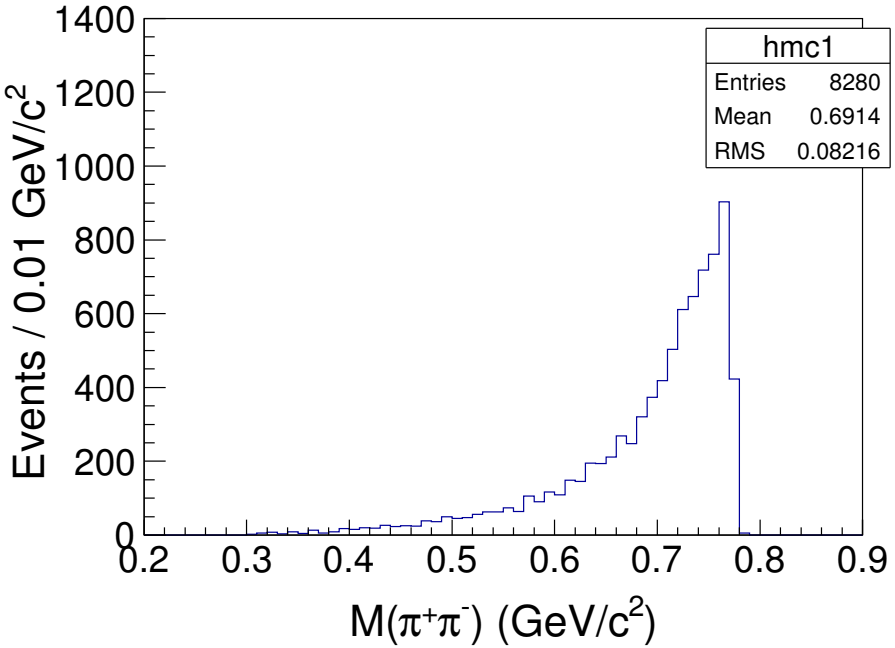
$$N[X(3872)] = 20.1 \pm 4.5$$

Phys. Rev. Lett. 112, 092001 (2014)

$\pi^+\pi^-$ mass distribution from $X(3872) \to \pi^+\pi^- J/\psi$



(q) $\pi^+\pi^-$ mass distribution from combined data.



(r) $\pi^+\pi^-$ mass distribution from 4.26 GeV signal MC.

$X(3872)$ mass window:

$3.86 < M(\pi^+\pi^- J/\psi) < 3.88$ GeV

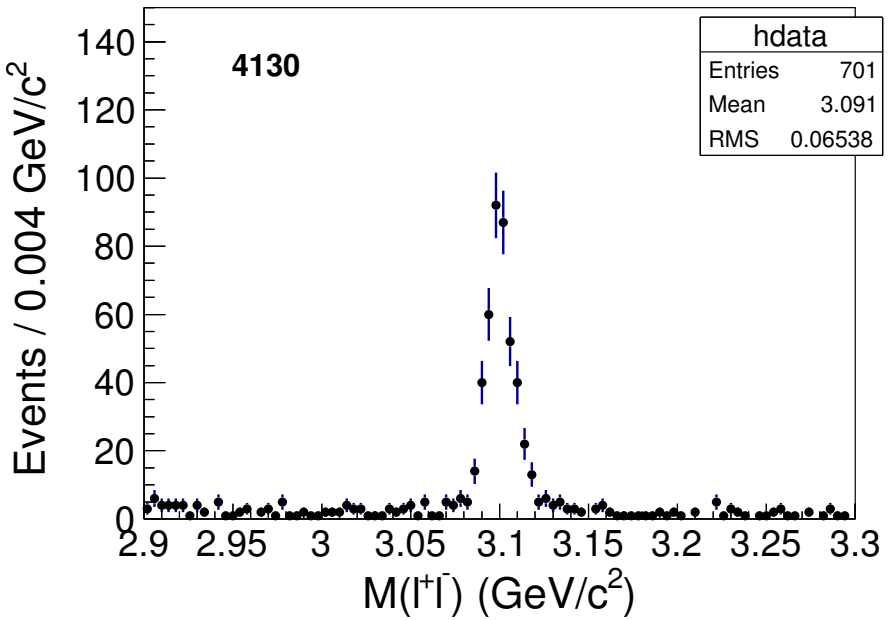
$X(3872)$ sideband:

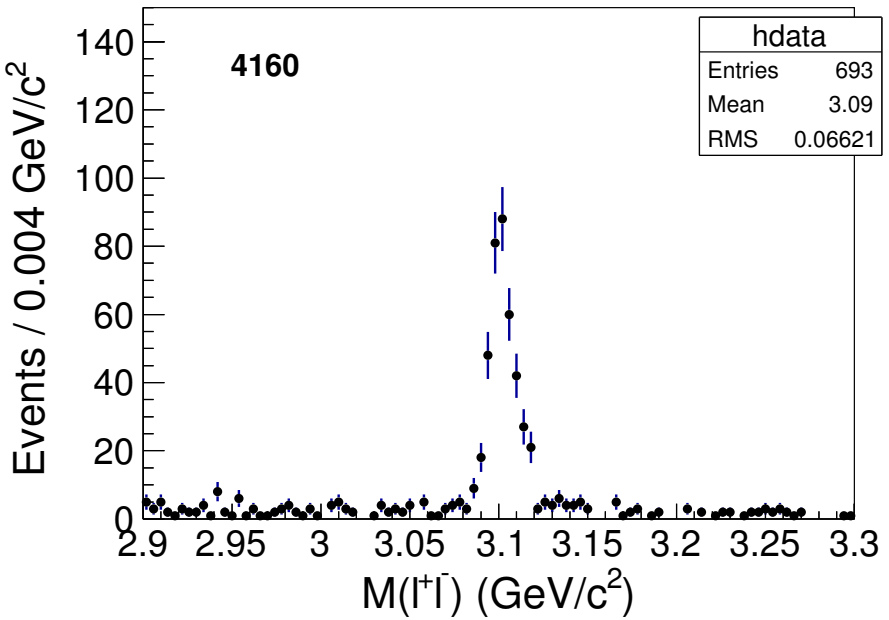
$3.83 < M(\pi^+\pi^- J/\psi) < 3.86$ or

$3.88 < M(\pi^+\pi^- J/\psi) < 3.91$ GeV

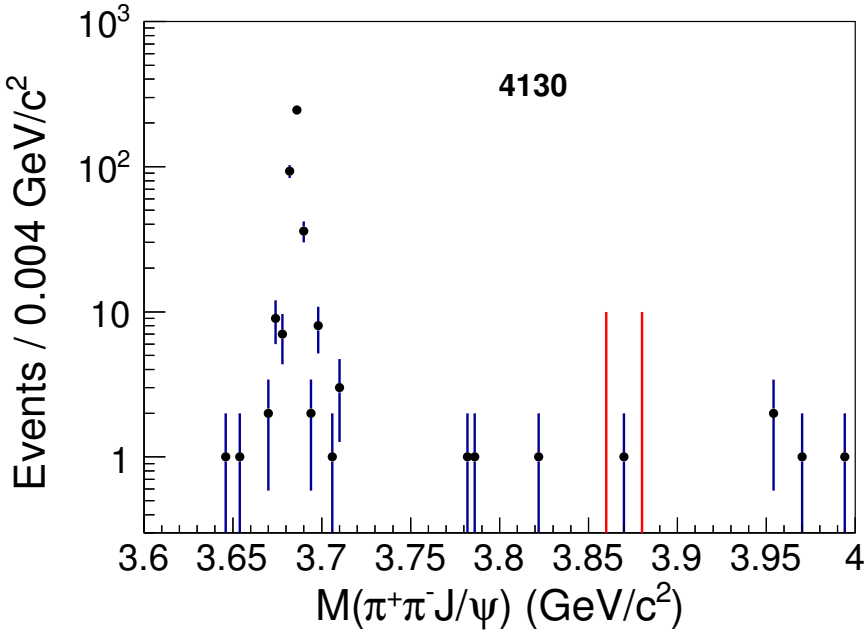
Take a glance at the new data

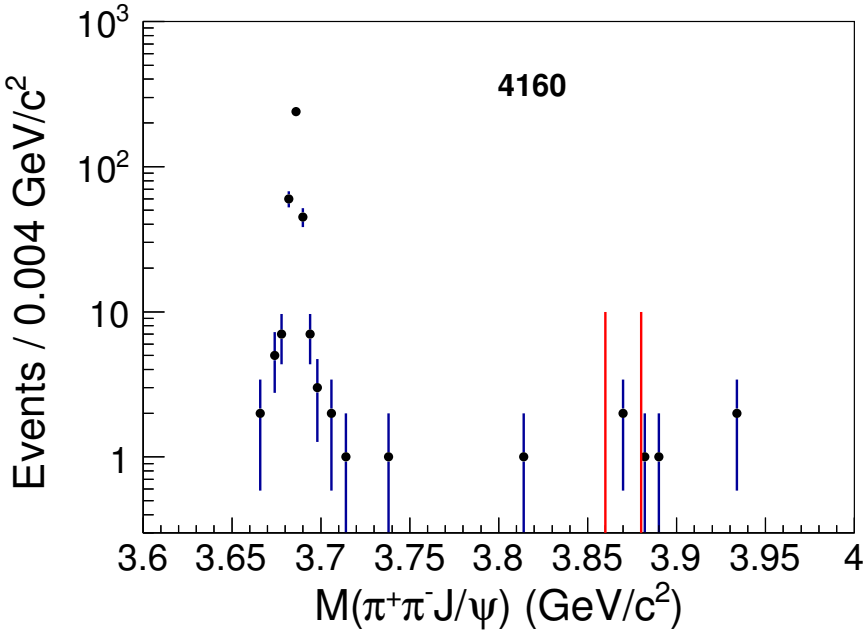
- Data simples: 4.13 GeV ($\sim 400\mathrm{pb}^{-1}$) and 4.16 GeV ($\sim 408\mathrm{pb}^{-1}$)
- BOSS version: 7.0.4





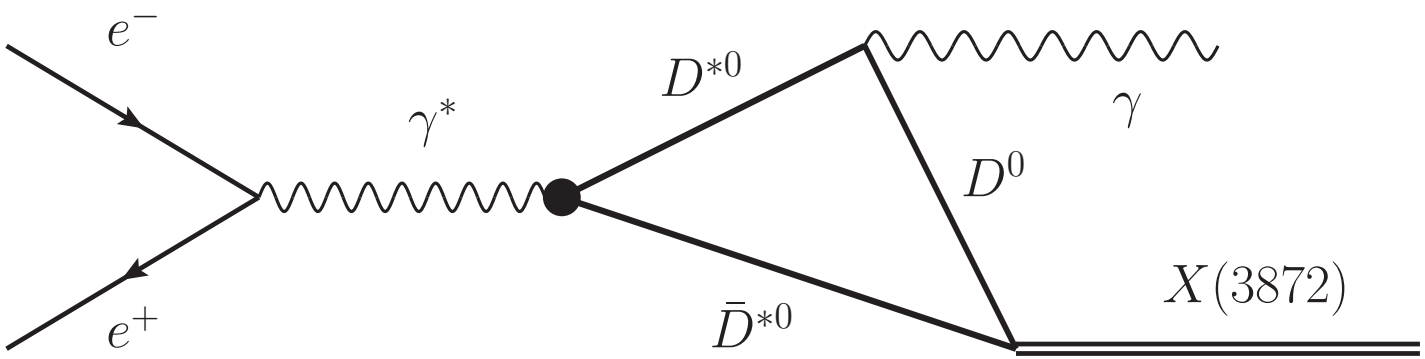
$\pi^+\pi^- J/\psi$ invariant mass for 4.13 and 4.16 GeV data





Triangle singularity in the production of $\gamma X(3872)$

- If the $X(3872)$ is a weakly bound charm-meson molecule, it can be produced via below process.



arXiv: 1904.12915

The predicted cross section for $e^+e^- \to \gamma X(3872)$

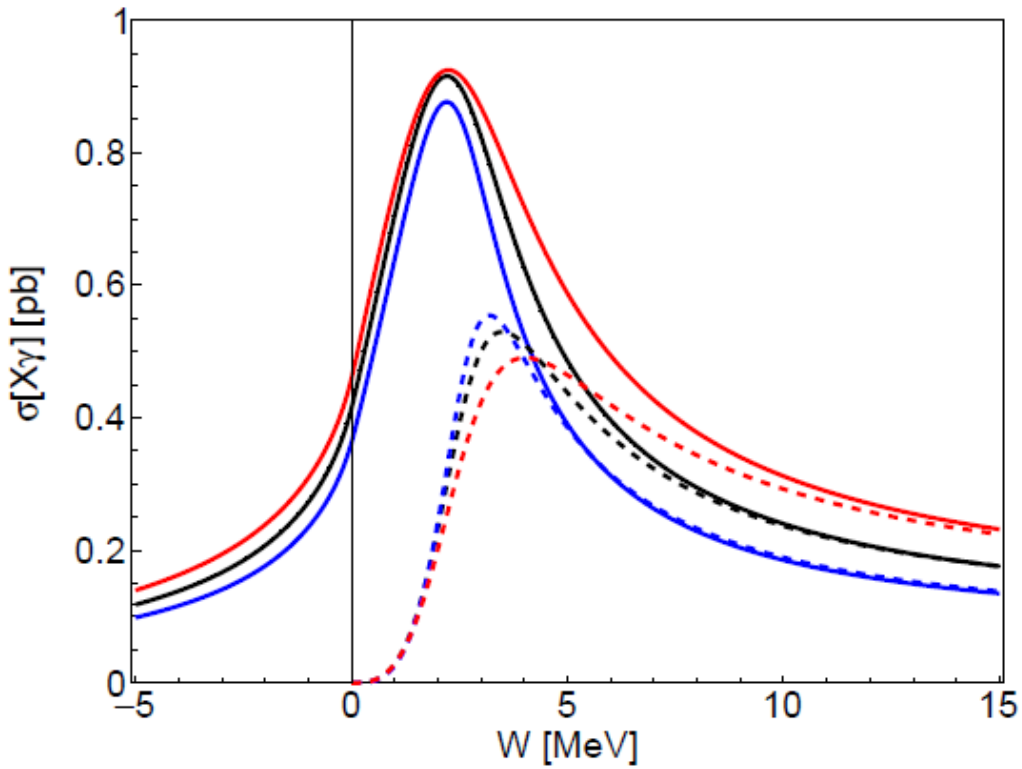


FIG. 3: Cross section for $e^+e^- \to X(3872)\gamma$ as a function of the center-of-mass energy W relative to the $D^{*0}\bar{D}^{*0}$ threshold. The solid curves in order of decreasing cross sections are for binding energies $|E_X| = 0.30$ MeV, 0.17 MeV, and 0.10 MeV. The dashed curves are the absorptive contributions, which approach the corresponding cross sections as W increases.

1) The peak is 2.2 MeV above the $D^{*0}\bar{D}^{*0}$ threshold (4.016 GeV);
2) The position of the peak is insensitive to $|E_X|$;
3) The height of the peak is insensitive to $|E_X|$

Conclusion:

$\sigma(e^+e^- \to \gamma X(3872)) \sim 0.9\text{pb} \ @ \ 4.016\text{GeV}$

$3\% < \mathcal{B}_{X\to\pi^+\pi^- J/\psi} < 33\%$

arXiv: 1903.04355

Summary and Next

- So far the results of these four energy points (4.0076, 4.2263, 4.2580, 4.3583 GeV) are consistent with previous work;
- Only one $X(3872)$ signal event in 4.130 GeV data set and two in 4.160 GeV data set;
- Taking data at 4.016 GeV is suggested.

Thanks for your attention!