Measurement of $X(3872) \to \gamma J/\psi$, $\gamma\psi(2S)$, and $D^{*0}D$

Junhao Yin, Jingyi Liu, Jielei Zhang, Changzheng Yuan, Jingzhi Zhang

IHEP, CAS

Introduction

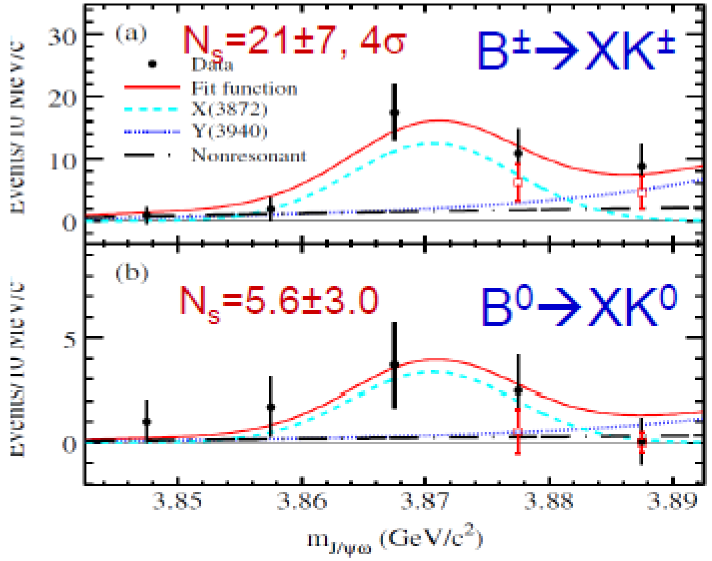
- After the first observation of $X(3872)$, our knowledge of $X(3872)$ has been greatly improved.
- The mass and width are measured preciously using $\pi\pi J/\psi$ decay mode

VALUE (MeV)	EVTS		DOCUMENT ID		TECN	COMMENT
3871.69 ± 0.17 OUR AVERAGE						
$3871.9 \pm 0.7 \pm 0.2$	20 ± 5		ABLIKIM	14	BES3	$e^+e^- \to J/\psi\pi^+\pi^-\gamma$
$3871.95 \pm 0.48 \pm 0.12$	0.6k		AAIJ	12H	LHCB	$pp \to J/\psi\pi^+\pi^- X$
$3871.85 \pm 0.27 \pm 0.19$	~ 170	1	CHOI	11	BELL	$B \to K\pi^+\pi^- J/\psi$
$3873 {}^{+1.8}_{-1.6} \pm 1.3$	27 ± 8	2	DEL-AMO-SA.	10B	BABR	$B \to \omega J/\psi K$
$3871.61 \pm 0.16 \pm 0.19$	6k	2,3	AALTONEN	09AU	CDF2	$p\overline{p} \to J/\psi\pi^+\pi^- X$
$3871.4 \pm 0.6 \pm 0.1$	93.4		AUBERT	08Y	BABR	$B^+ \to K^+ J/\psi\pi^+\pi^-$
$3868.7 \pm 1.5 \pm 0.4$	9.4		AUBERT	08Y	BABR	$B^0 \to K^0_S J/\psi\pi^+\pi^-$
$3871.8 \pm 3.1 \pm 3.0$	522	2,4	ABAZOV	04F	D0	$p\overline{p} \to J/\psi\pi^+\pi^- X$

VALUE (MeV)	CL%	EVTS	DOCUMENT ID		TECN	COMMENT
<1.2	90		CHOI	11	BELL	$B \to K\pi^+\pi^- J/\psi$

Γ_1	$e^+ e^-$	
Γ_2	$\pi^+\pi^- J/\psi(1S)$	$> 2.6\%$
Γ_3	$\rho^0 J/\psi(1S)$	
Γ_4	$\omega J/\psi(1S)$	$> 1.9\%$
Γ_5	$D^0 \overline{D}{}^0 \pi^0$	$> 32\%$
Γ_6	$\overline{D}{}^{*0} D^0$	$> 24\%$
Γ_7	$\gamma\gamma$	
Γ_8	$D^0 \overline{D}{}^0$	
Γ_9	$D^+ D^-$	
Γ_{10}	$\gamma\chi_{c1}$	
Γ_{11}	$\gamma\chi_{c2}$	
Γ_{12}	$\gamma J/\psi$	$> 6 \times 10^{-3}$
Γ_{13}	$\gamma\psi(2S)$	$> 3.0\%$
Γ_{14}	$\pi^+\pi^-\eta_c(1S)$	not seen
Γ_{15}	$\pi^+\pi^-\chi_{c1}$	not seen
Γ_{16}	$p\overline{p}$	not seen

PRD 82, 111101 (2010) 426 fb^{-1}



$$\frac{\mathcal{B}(X \to \pi^+\pi^-\pi^0 J/\psi)}{\mathcal{B}(X \to \pi^+\pi^- J/\psi)} = 1.0 \pm 0.4(\mathrm{stat}) \pm 0.3(\mathrm{syst})$$

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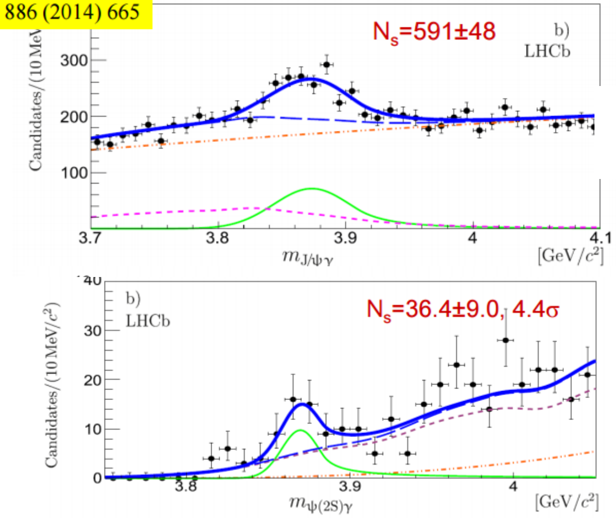
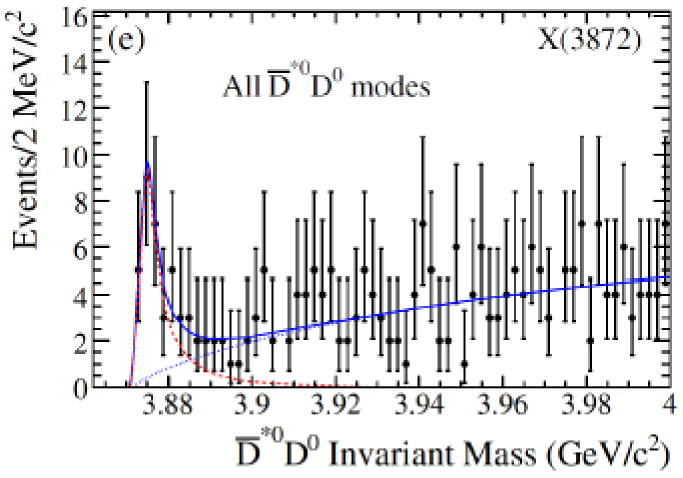


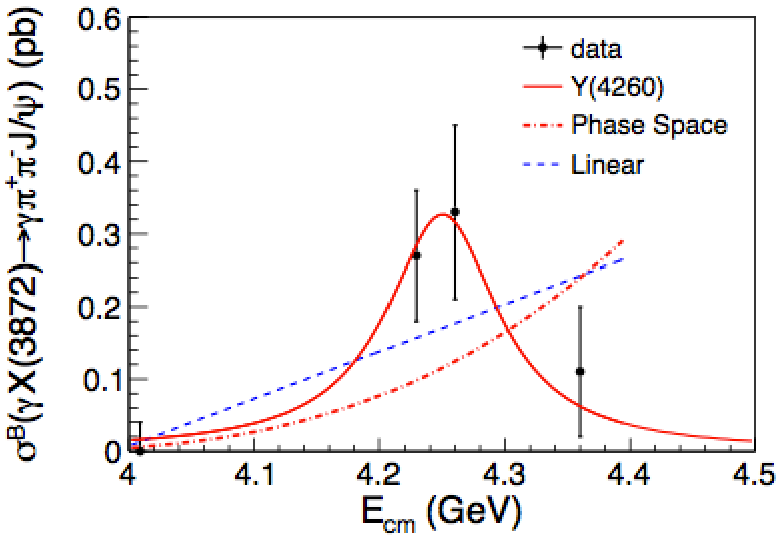
$$\frac{\mathcal{B}(X(3872) \to \psi(2S)\gamma)}{\mathcal{B}(X(3872) \to J/\psi\gamma)} = 2.46 \pm 0.64 \pm 0.29$$

agrees with expectation for a pure charmonium interpretation and a molecular-charmonium mixture interpretations.



Datasets

- XYZ data around 4230:
- BOSS version: 7.0.3



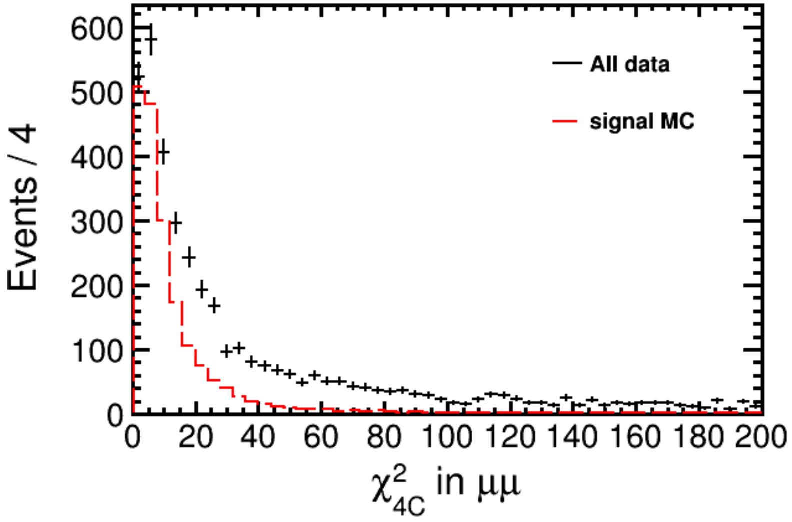
$\sqrt{s}$ (GeV)	Luminosity (pb^{-1})
4.1783	3189.0
4.1888	521.9
4.1989	523.7
4.2092	511.2
4.2187	508.2
4.2263	1092
4.2357	528.9
4.2438	532.7
4.2580	826
4.2668	529.3
4.2777	174.5

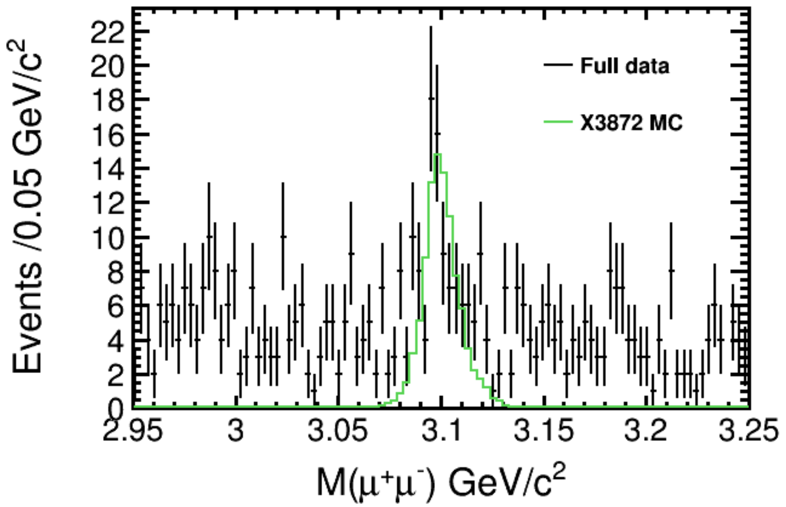
$X(3872) \to \gamma J/\psi$

• Event Selection

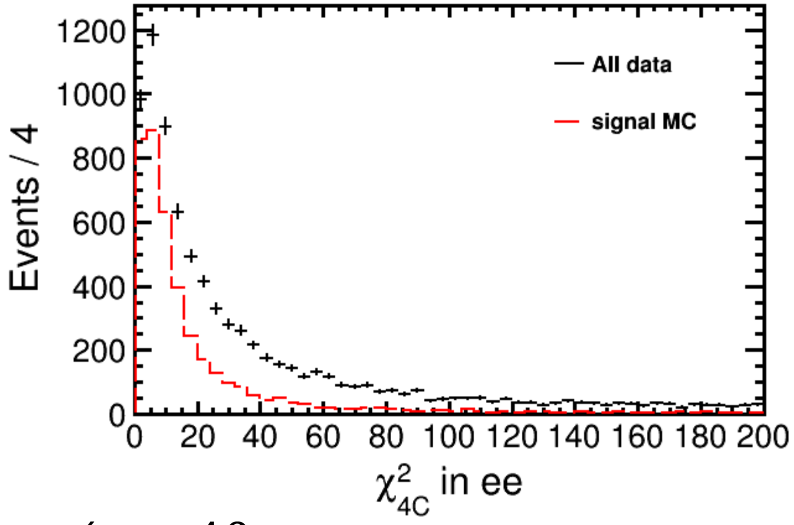
- Two good charged tracks
  - μ: $p_{MDC} > 1.0, E_{EMC} < 0.4$
  - e: $p_{MDC} > 1.0, E_{EMC} > 0.8$
- At least two good photons
  - Cluster from barrel: $E > 25$ MeV
  - Cluster from endcap: $E > 50$ MeV
- 4C kinematic fit
  - The two photons with largest deposit energy are used
  - Photon with larger energy after 4C named γ_H, the other one named γ_L

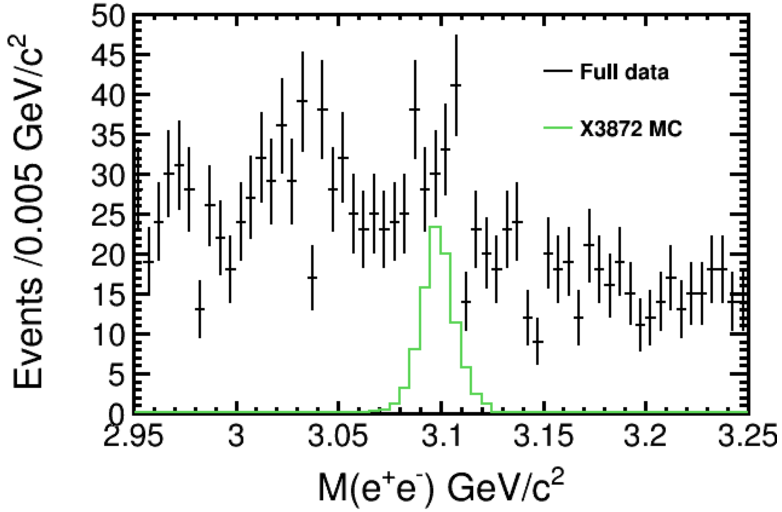
For uu mode





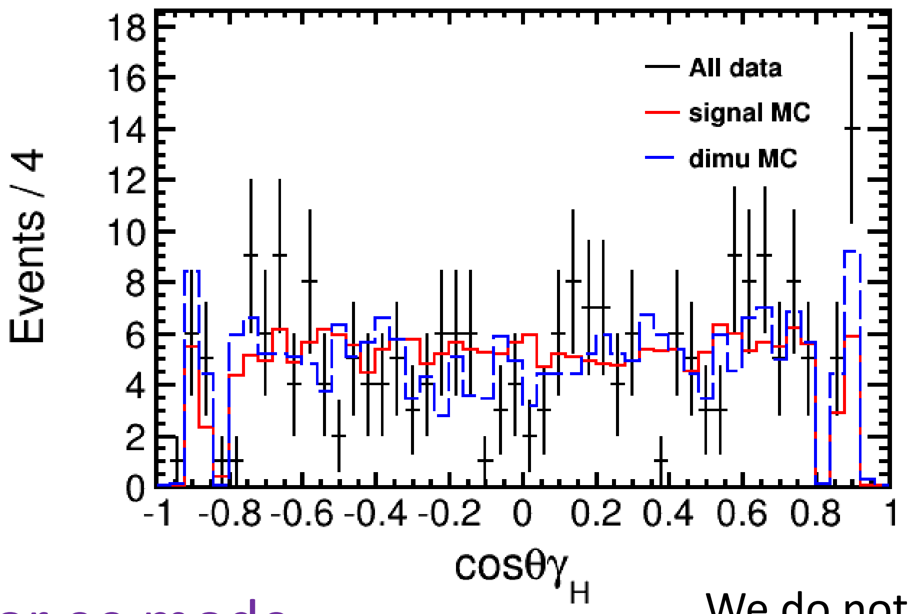
For ee mode

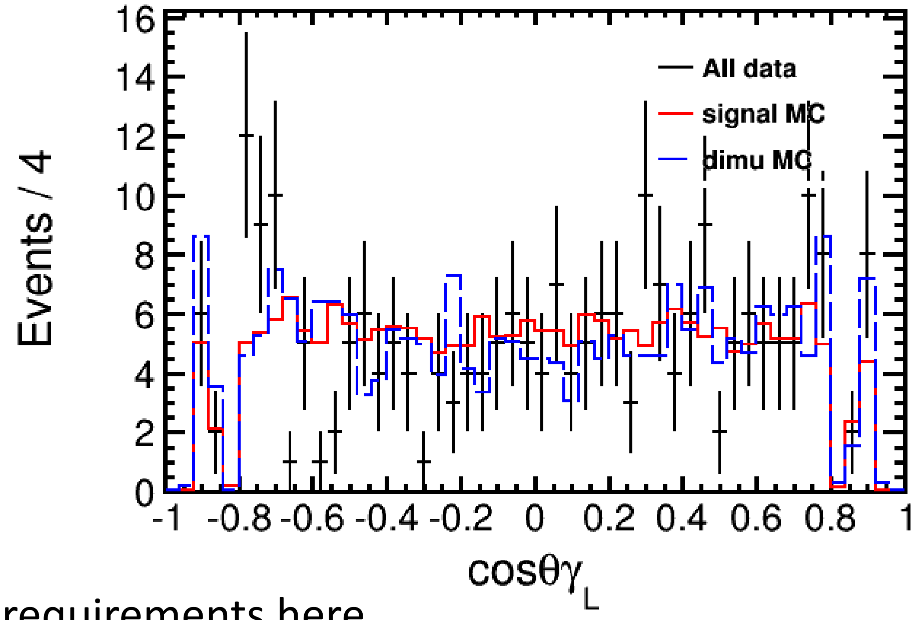




We require $\chi_{4C}^{2} < 40$.
Very clear signal in $\mu\mu$ mode, but not so evident in ee mode because the QED background is much higher.
Set signal region: $M(ll) \in [3.08, 3.12]$ and sideband region: $M(ll) \in [3.02, 3.06]$ and $M(ll) \in [3.14,\ 3.18]$.

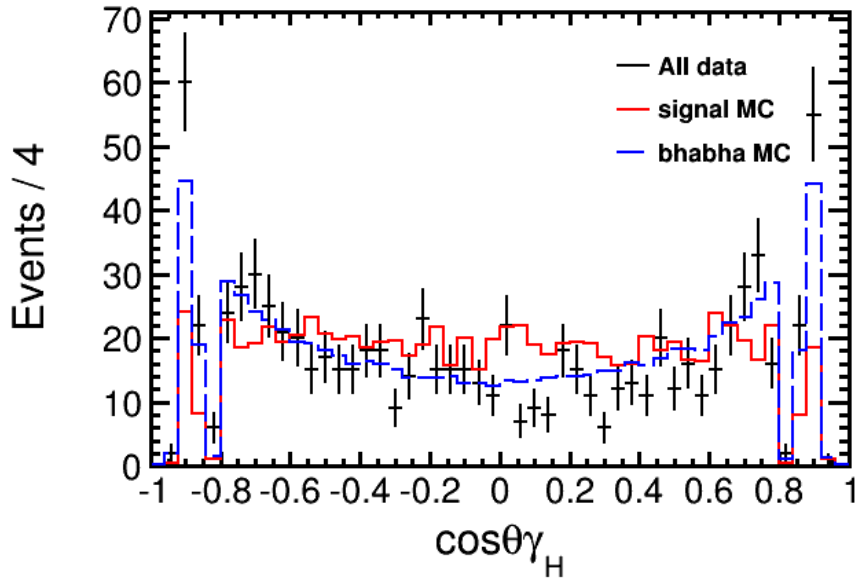
For uu mode

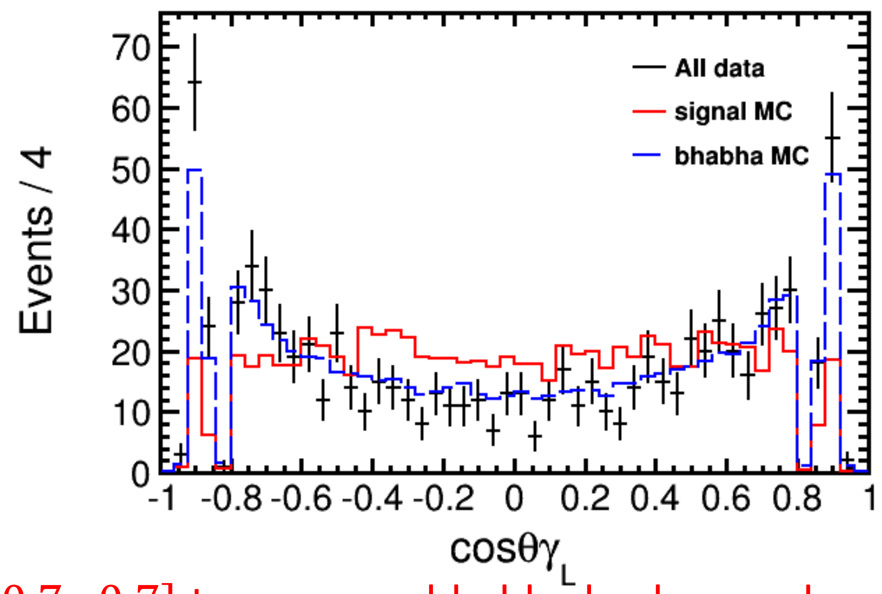




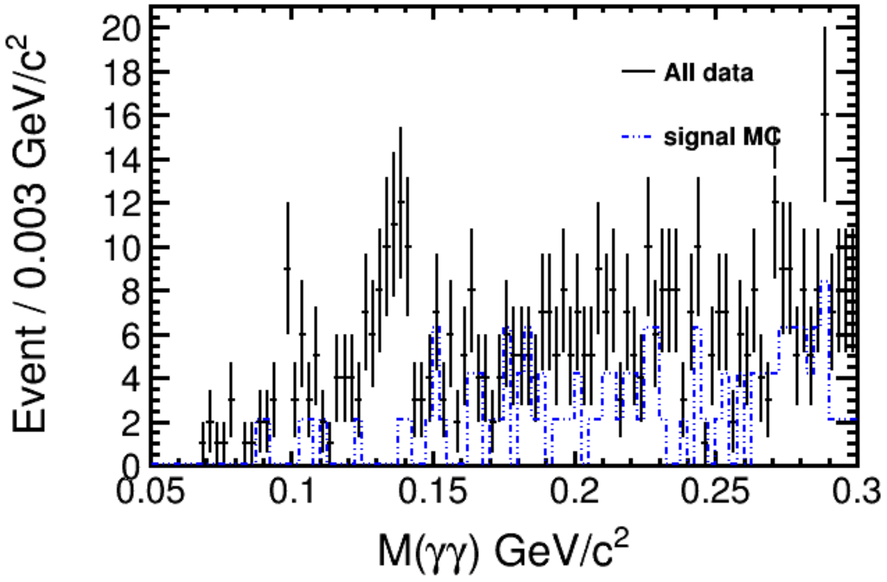
We do not set any requirements here….

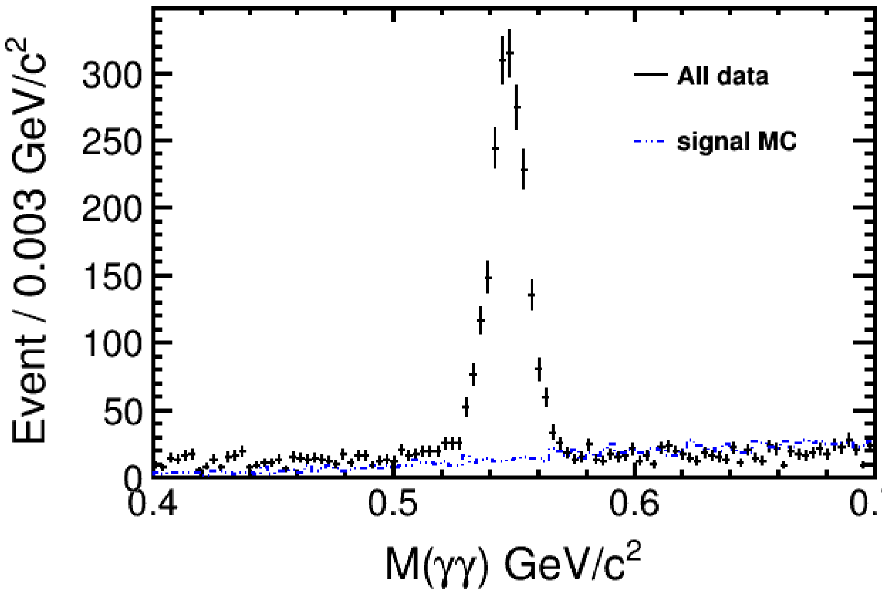
For ee mode

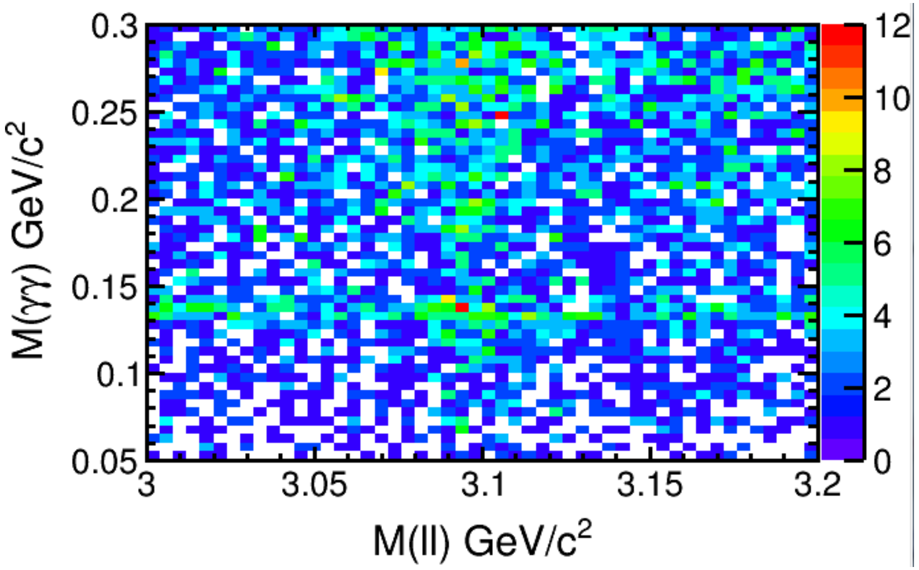




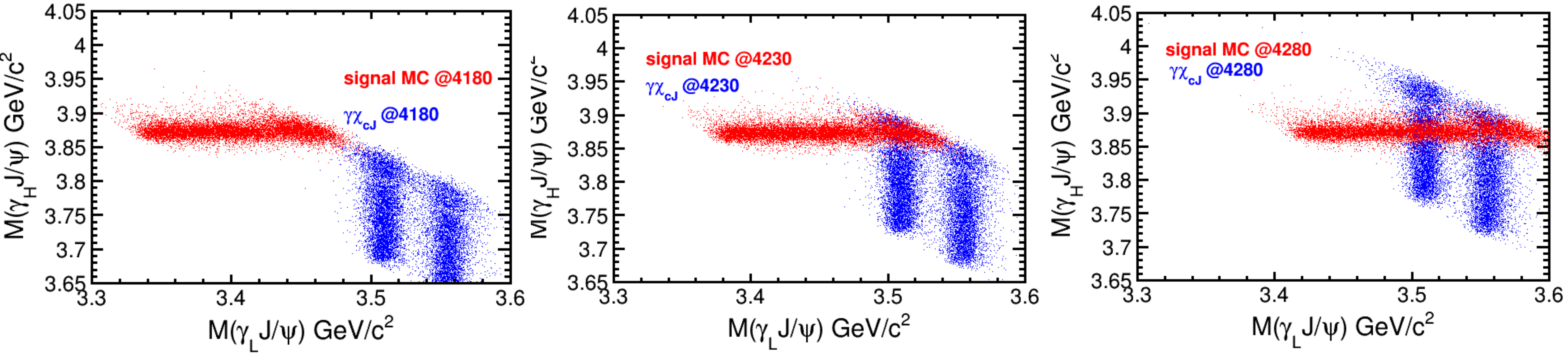
The angle between $\gamma_{H(L)}$ and Z axis should be $\in [-0.7,\ 0.7]$ to suppress bhabha backgrounds.



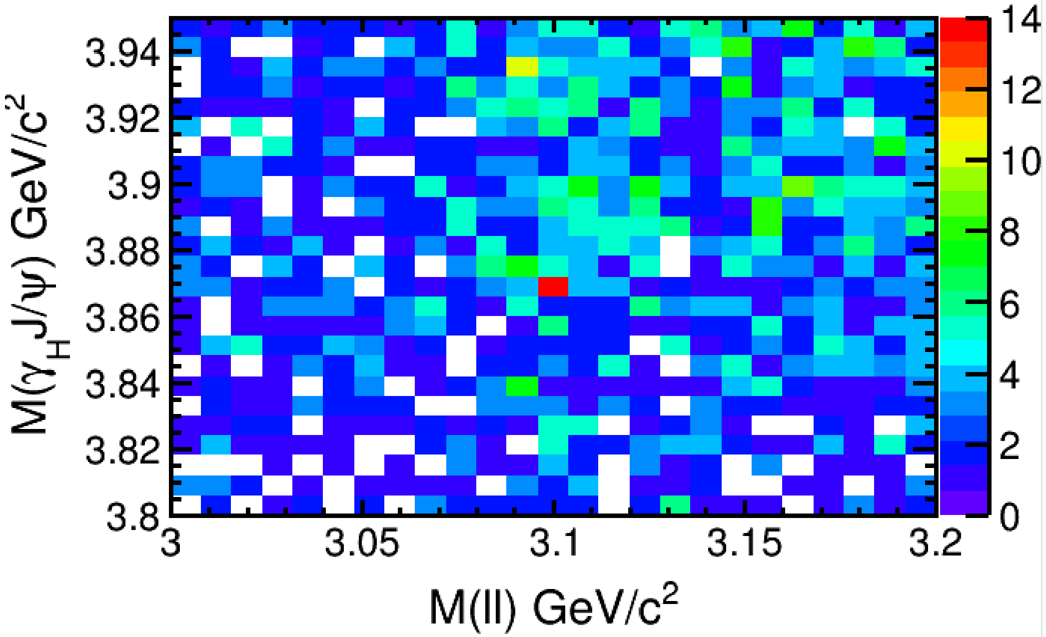


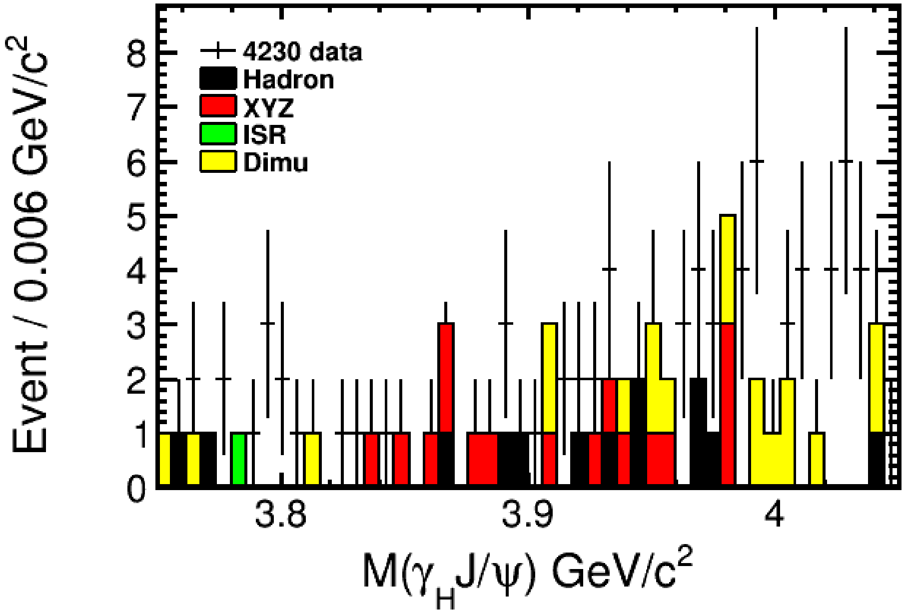


- From the 2D plot we can find that there are some wrong-identified Jpsi with two photons peaking around π^0.
- There are also many $e^+e^- \rightarrow \eta J/\psi$ events.
- Require
  $|M(\gamma\gamma) - m(\pi^0)| > 0.015, |M(\gamma\gamma) - m(\eta)| > 0.03.$

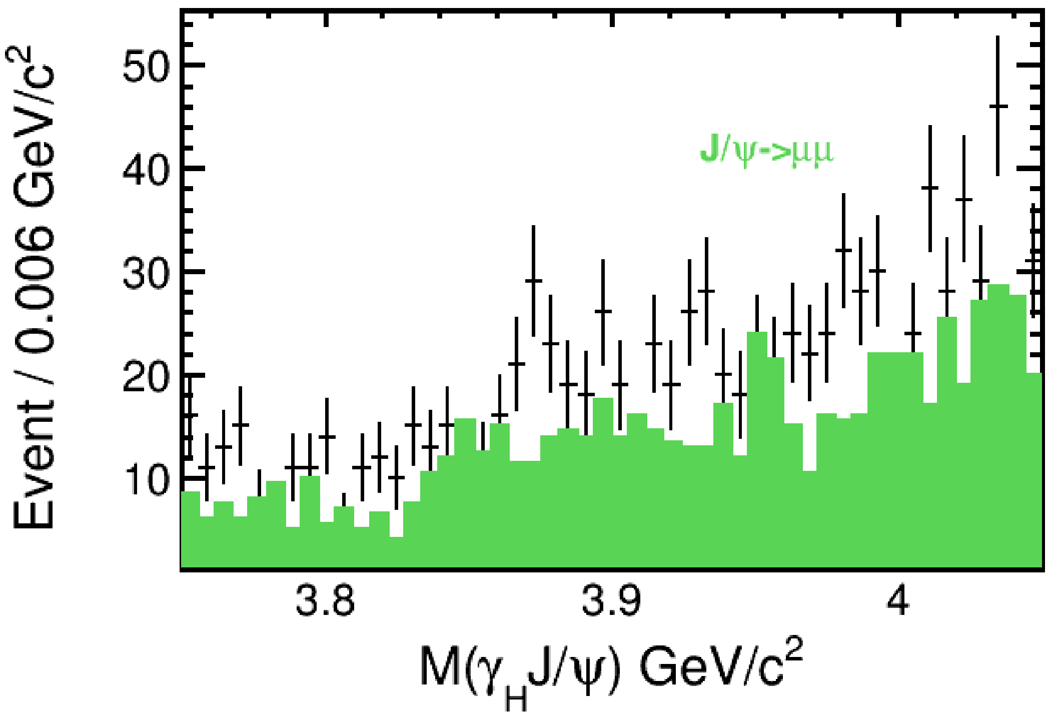


To reject the background from $e^+e^- \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$,
require $\left|M\left(\gamma_L J/\psi - m(\chi_{c1,2})\right)\right| > 0.02$

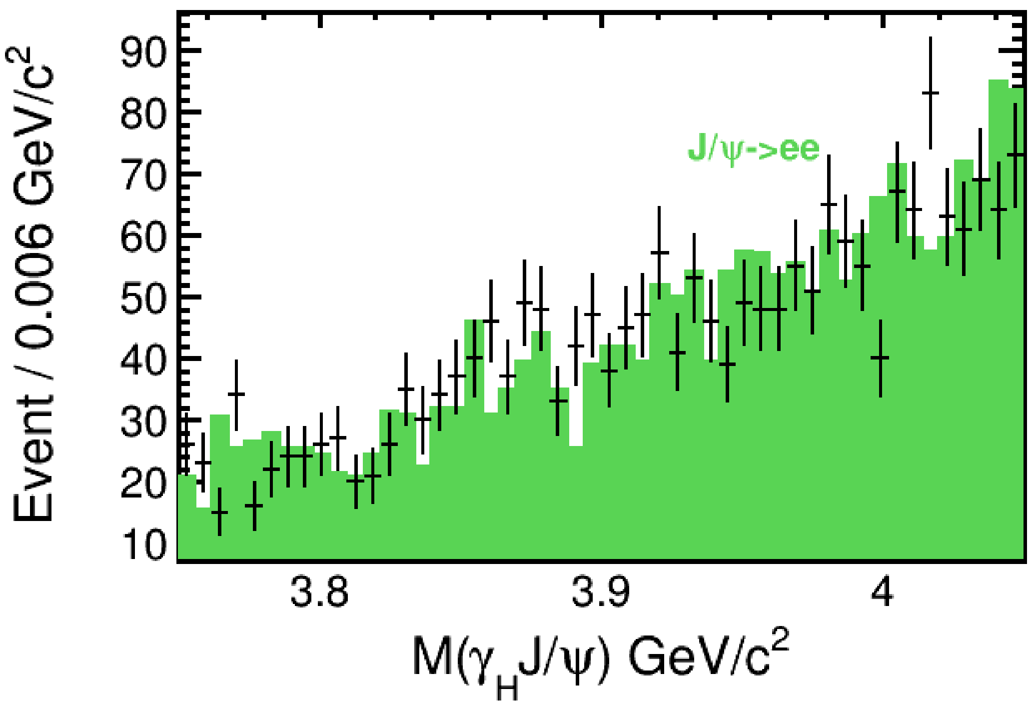




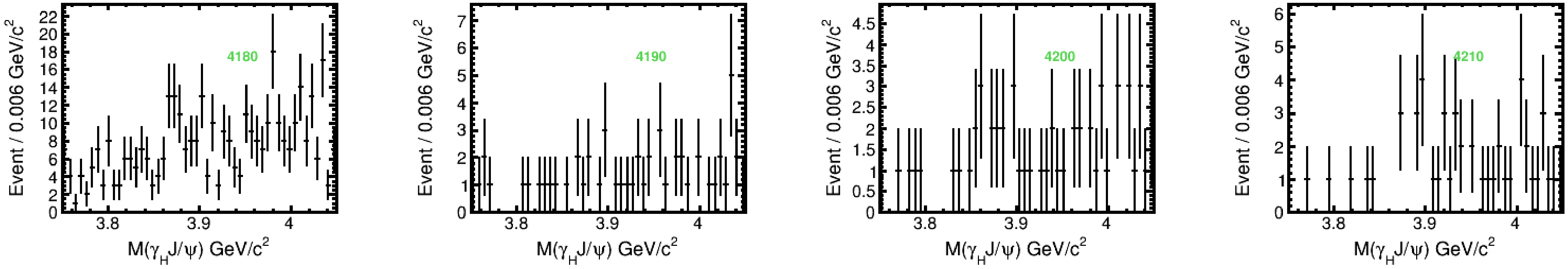
The 2D view on $\mathrm{M}(\gamma J/\psi)$ versus $M(ll)$ in $\mu\mu$ mode shows clear signal of $X(3872)$.
There is no peaking background from the inclusive MC study.

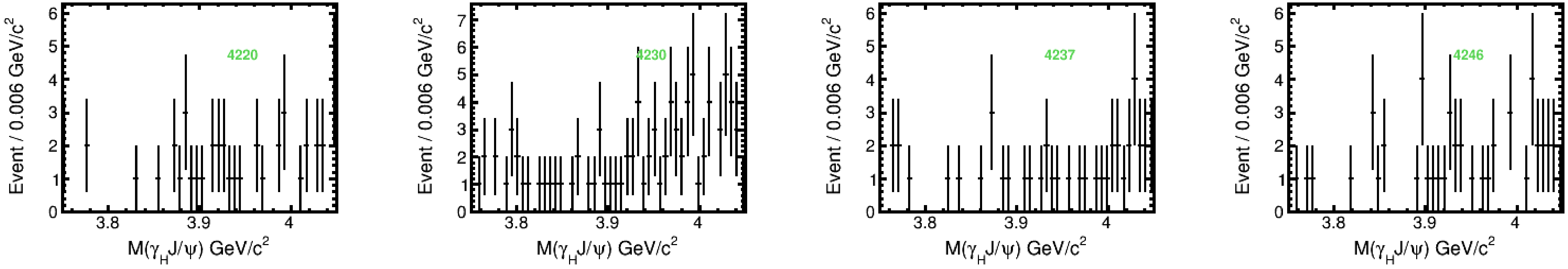


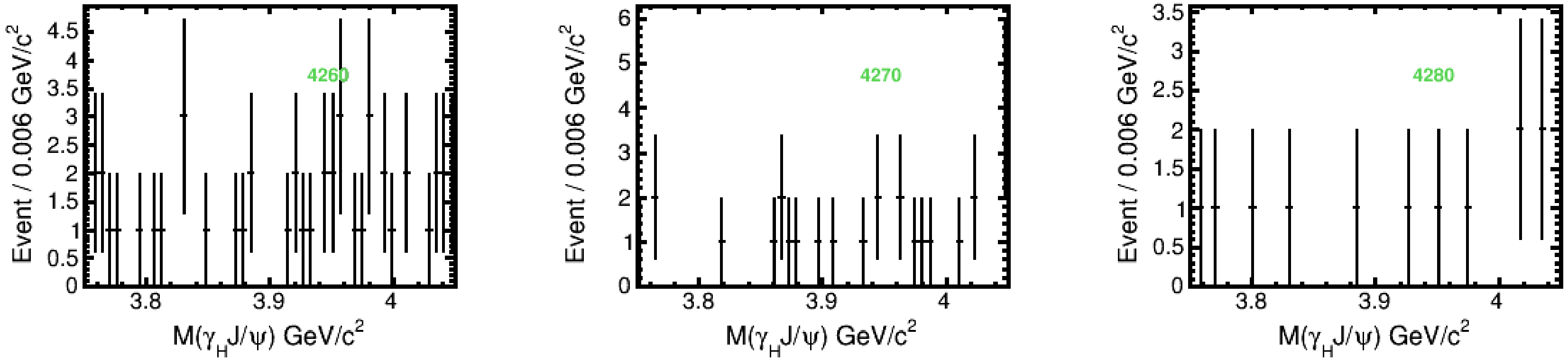
Event / 0.006 GeV/c^2
J/ψ->μμ
M(γ_HJ/ψ) GeV/c^2



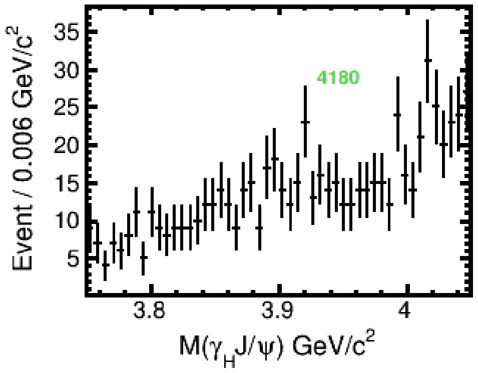
Event / 0.006 GeV/c^2
J/ψ->ee
M(γ_HJ/ψ) GeV/c^2

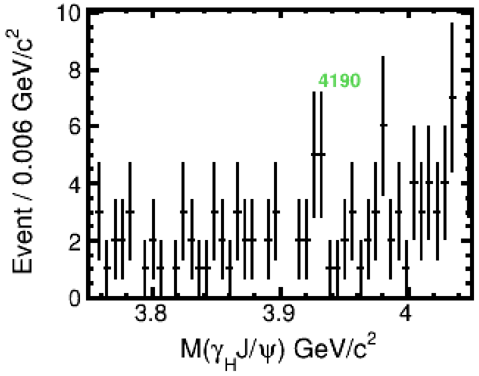

4180
4190
4200
4210
Event / 0.006 GeV/c²
M(γ_H J/ψ) GeV/c²

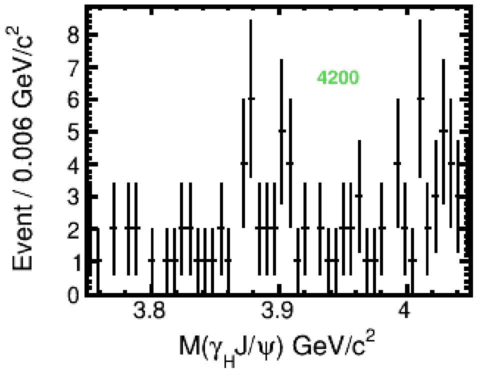

4220
4230
4237
4246
Event / 0.006 GeV/c²
M(γ_H J/ψ) GeV/c²

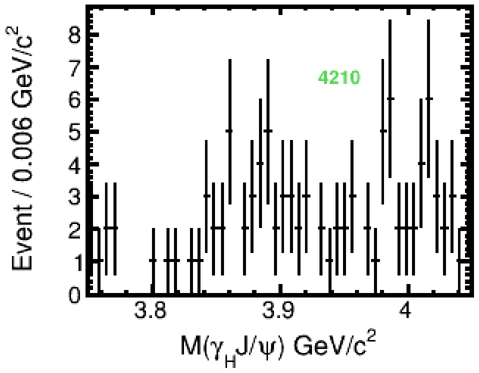

4260
4270
4280
Event / 0.006 GeV/c²
M(γ_H J/ψ) GeV/c²

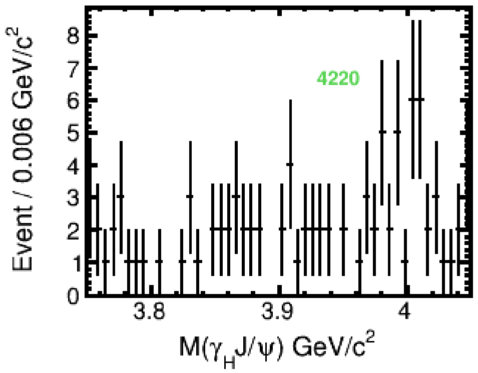
For uu mode

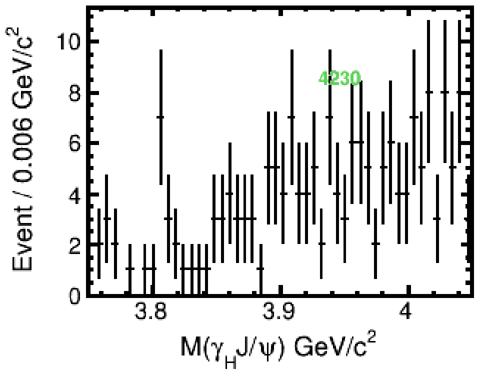

4180
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

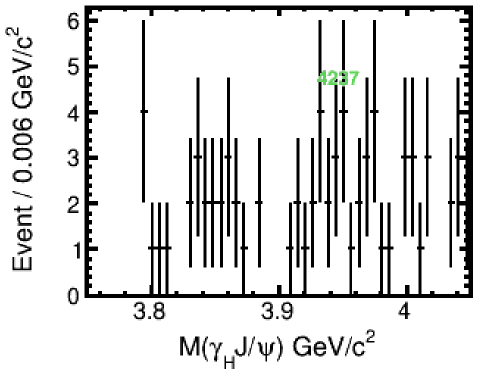

4190
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

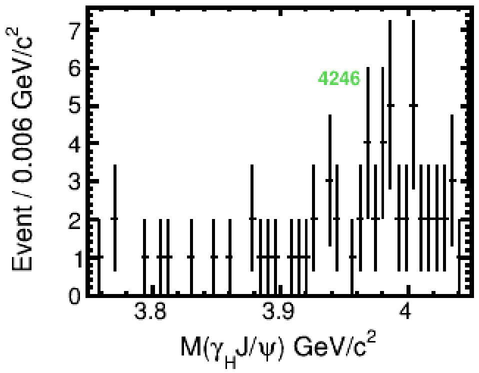

4200
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

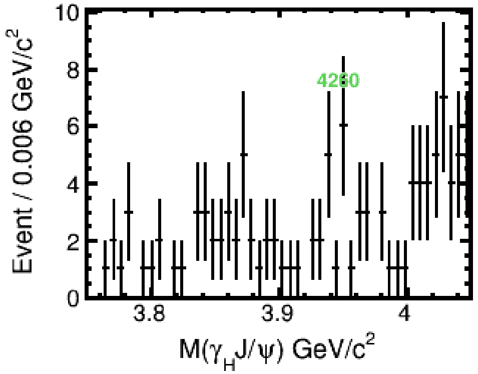

4210
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

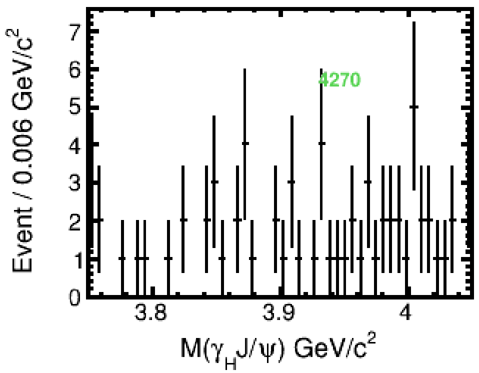

4220
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

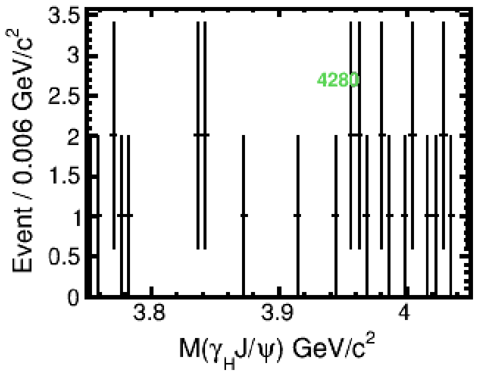

4230
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2


4237
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

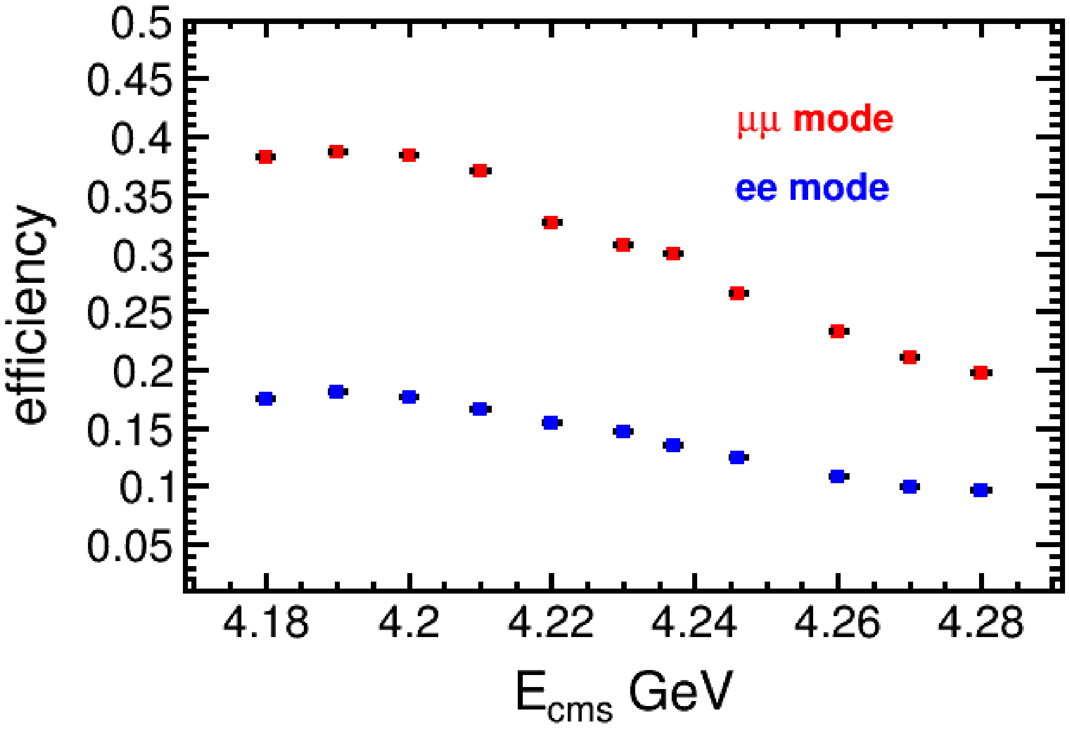

4246
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2


4260
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2


4270
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2


4280
Event / 0.006 GeV/c^2
M(γ_HJ/ψ) GeV/c^2

For ee mode

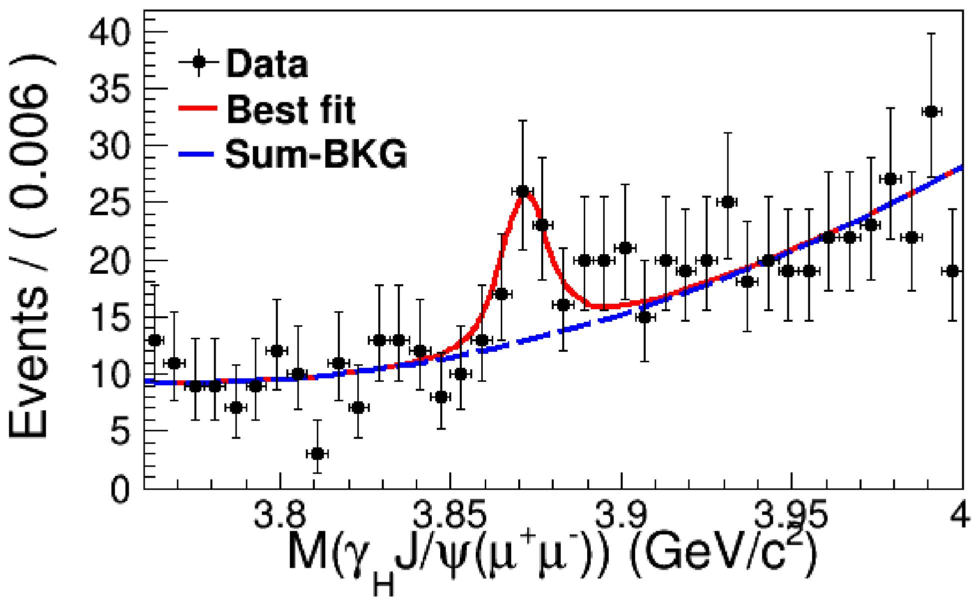


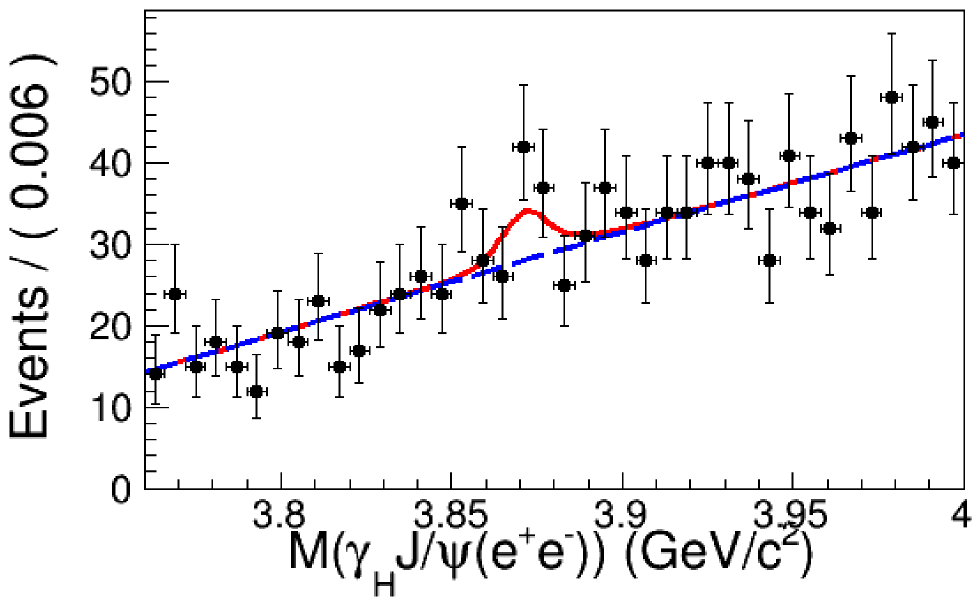
We generate $e^+e^- \to \gamma X(3872)$ assuming the signal come from $Y(4230)$, the weighted reconstruction efficiency is computed as:

$$\epsilon = \frac{\sum_i^{11} \epsilon_i \cdot \mathcal{L}_i \cdot \sigma_i \cdot (1+\delta) \cdot (1+\delta)_{vp}}{\sum_i^{11} \mathcal{L}_i \cdot \sigma_i \cdot (1+\delta) \cdot (1+\delta)_{vp}}$$
$$= 31.7\% (14.7\% \text{ for } ee)$$

where the cross section is obtained assuming $X(3872)$ decay from $Y4230$ decays.

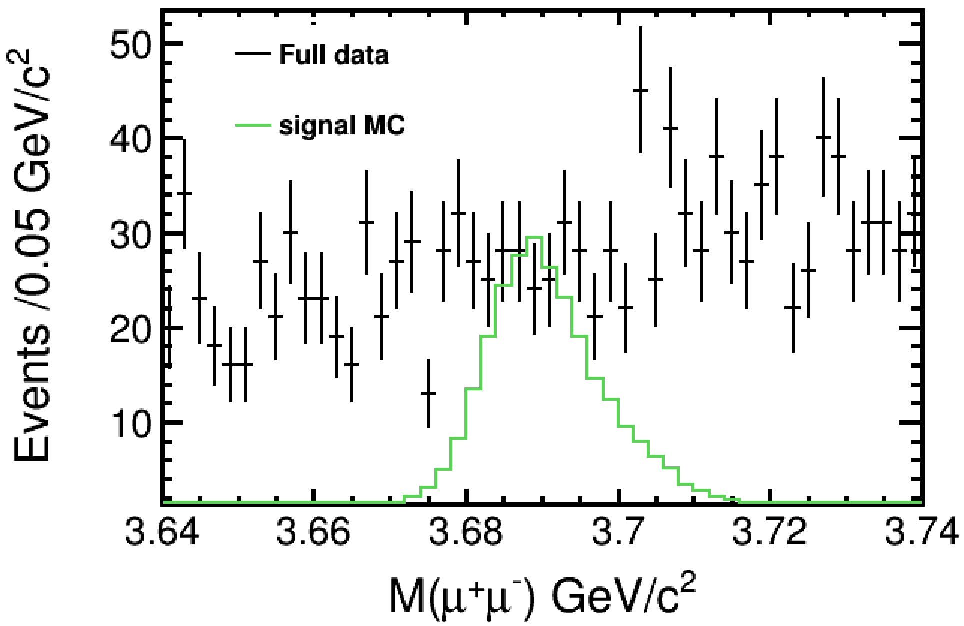
The parameters of Y4230 are obtained from PDG:
$M = 4230 \text{ MeV}, \Gamma = 55 \text{ MeV}.$

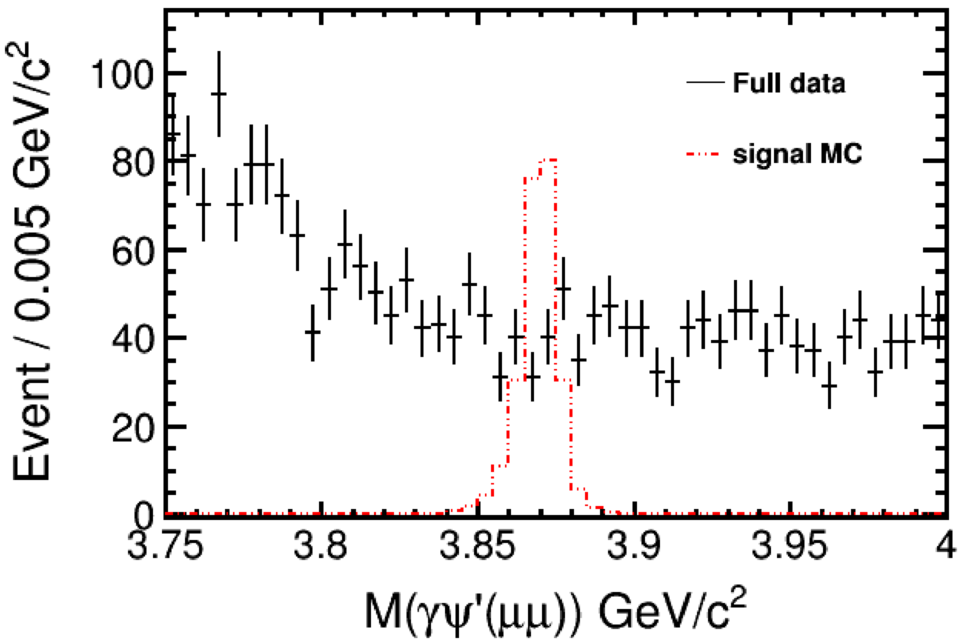




- Unbinned maximum likelihood fit is performed simultaneously. The mass spectrum is fitted with two components:
  - Signal: described with MC shape, assuming $M(X3872) = 3.87246\ \text{GeV}, \Gamma = 0.0012\ \text{GeV}$
  - Background: described with a 2^{nd}-order Chebychev polynomial
- Goodness of the fit: 90.9/92=0.99; the statistical significance of X3872 is 4.1σ
- The efficiency and branching fraction corrected signal yields: $(24.3 \pm 6.6) \times 10^2$, branching fraction means $\text{Br}(J/\psi \to \mu\mu/ee)$.
- The average Born cross section is 0.27 ± 0.07 pb for $\sqrt{s} = 4.18 -- -4.28$ GeV

$X(3872) \to \gamma\psi(2S)(\mu\mu)$





$\psi(2S) \to \mu\mu$ mode is also used in reconstruction require

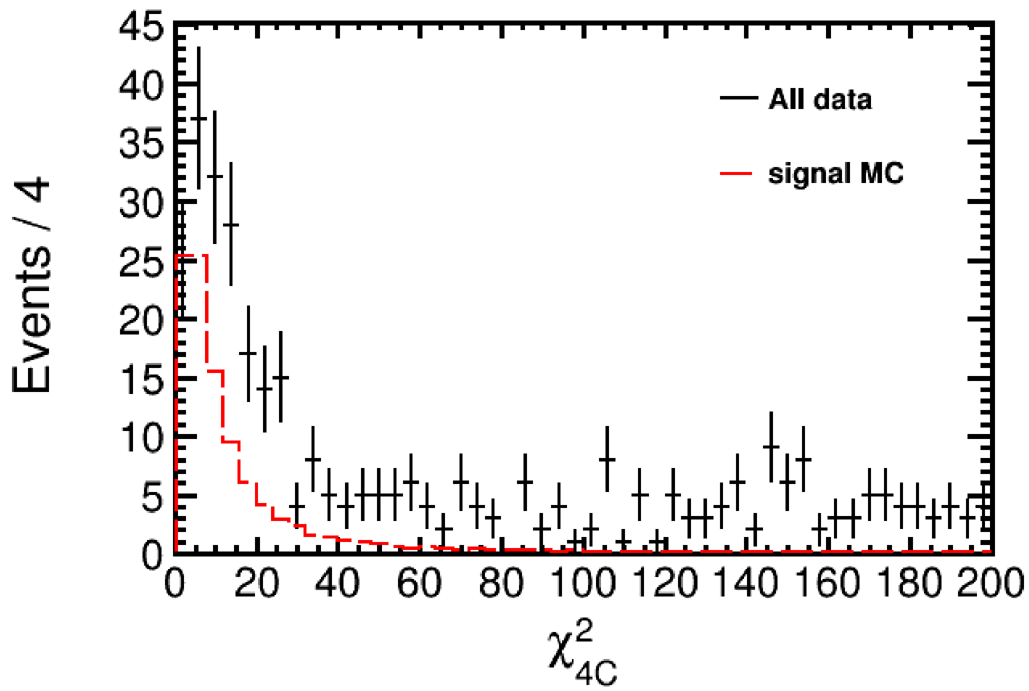
$$M(\mu\mu) \in [m_{\psi'} - 0.02,\ m_{\psi'} + 0.02], \chi^2_{4C} < 40.$$

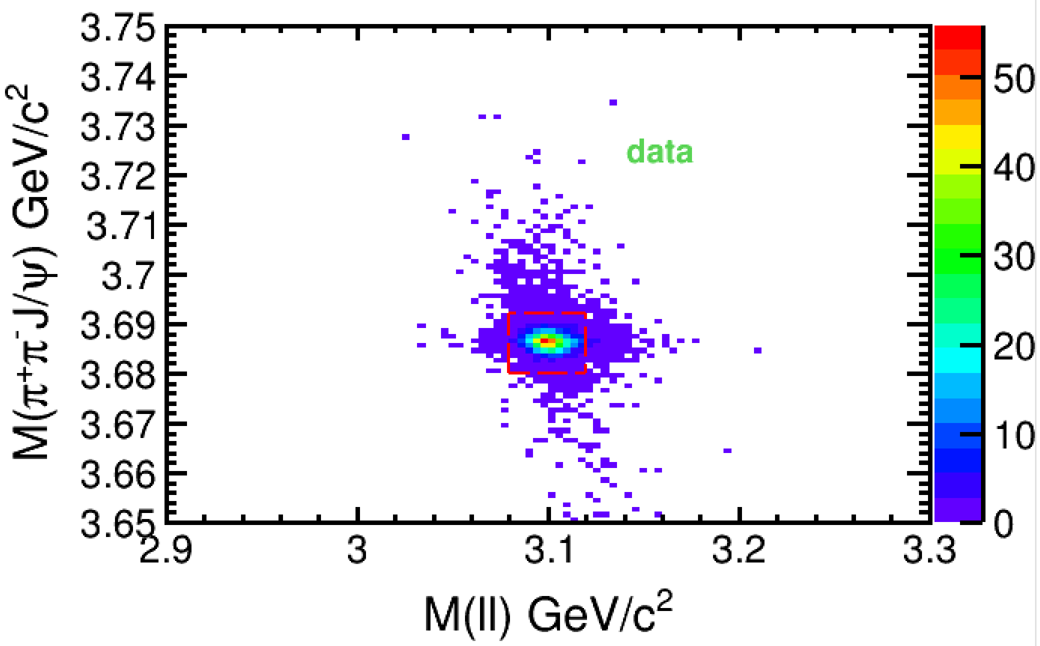
The QED background is high and the signal of $\psi(2S)$ or $X(3872)$ is not evident.
The QED background in $\psi(2S) \to ee$ mode is much higher, which is not used.

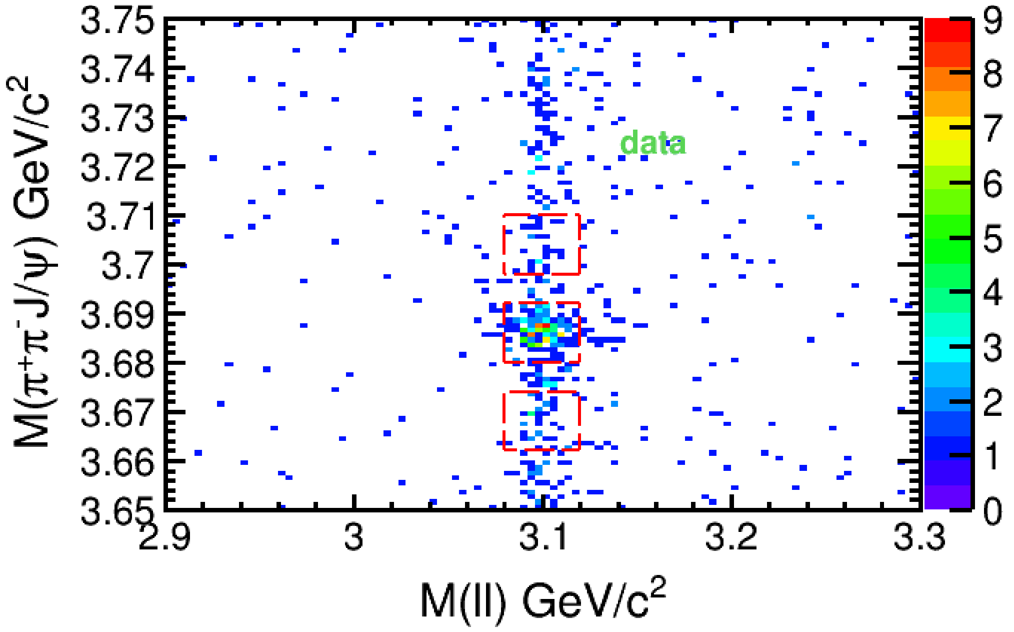
$X(3872) \to \gamma\psi(2S)(\pi\pi J/\psi)$

• Event Selection

- Four good charged tracks
  - μ: $p_{MDC} > 1.0, E_{EMC} < 0.4$
  - e: $p_{MDC} > 1.0, E_{EMC} > 0.8$
  - π: $p_{MDC} < 1.0$
- At least two good photons
  - Cluster from barrel: $E > 25$ MeV
  - Cluster from endcap: $E > 50$ MeV
- 4C kinematic fit
  - The combination with least χ^2_{4C} is kept as best candidate
  - Photon with larger energy after 4C named γ_H, the other one named γ_L

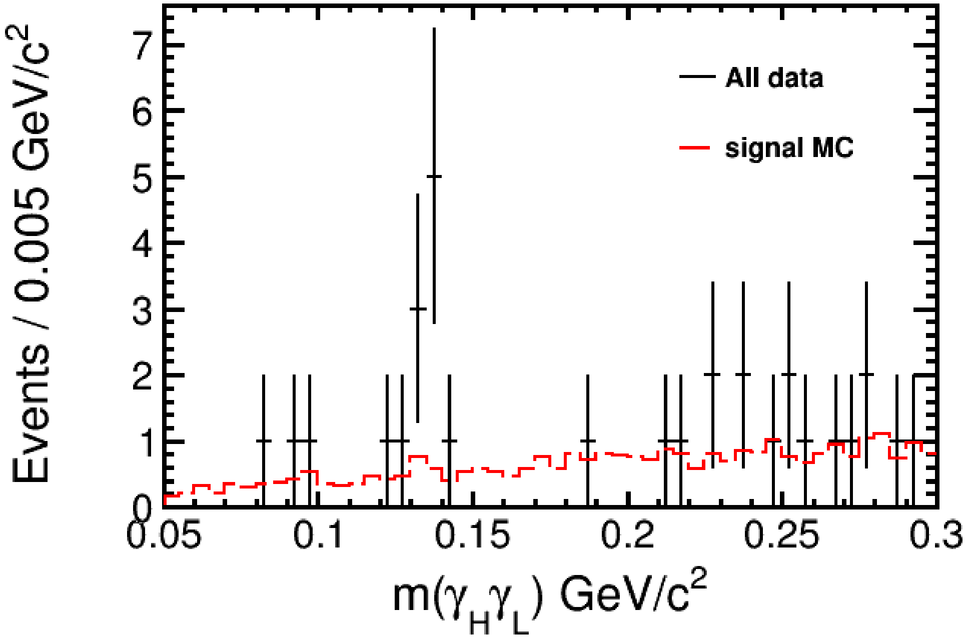


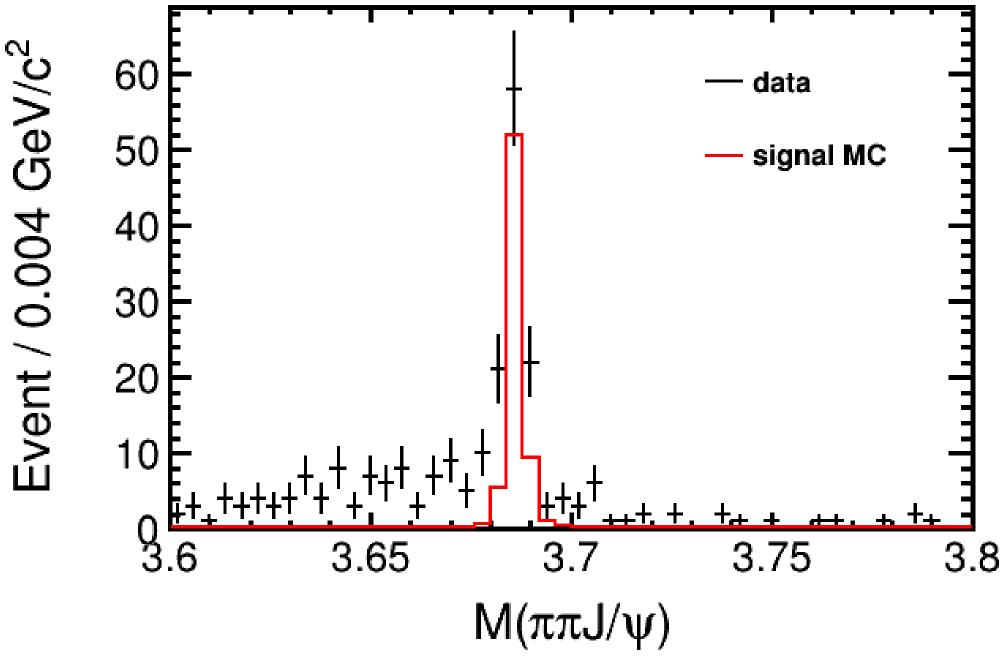




$\chi^2_{4C} < 40$, $M(ll) \in [3.08,\ 3.12]$ and $[M(\pi\pi J/\psi) - m^0(\psi')] < 0.006$ are required.

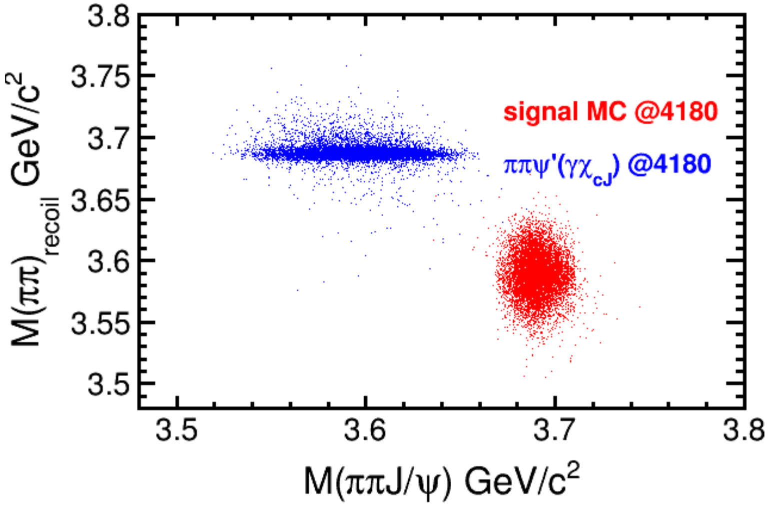
Sideband: $[M(\pi\pi J/\psi) - 3.668] < 0.006 || [M(\pi\pi J/\psi) - 3.704] < 0.006$

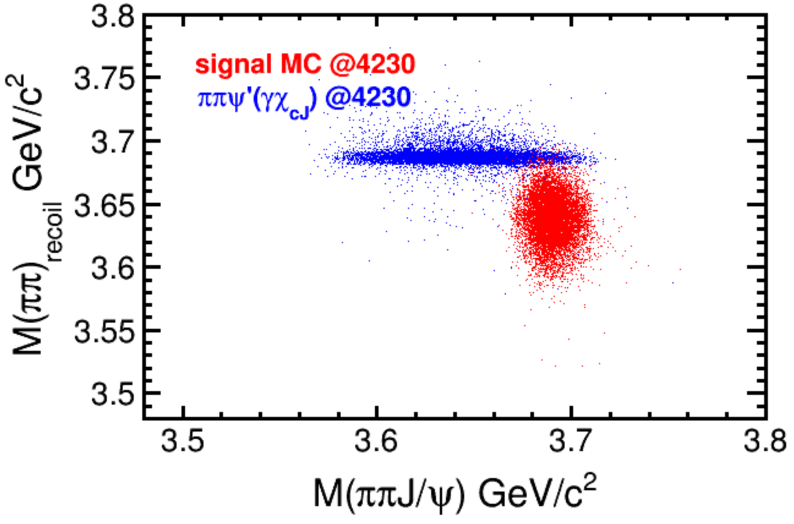


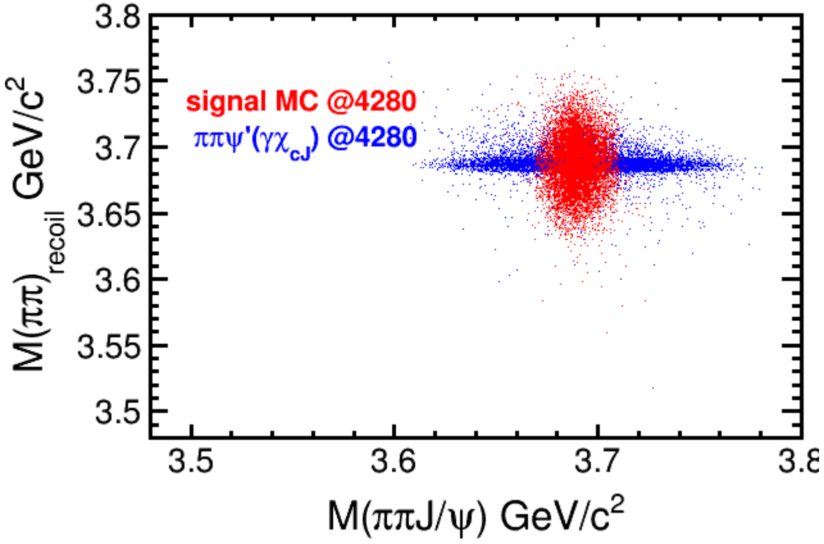


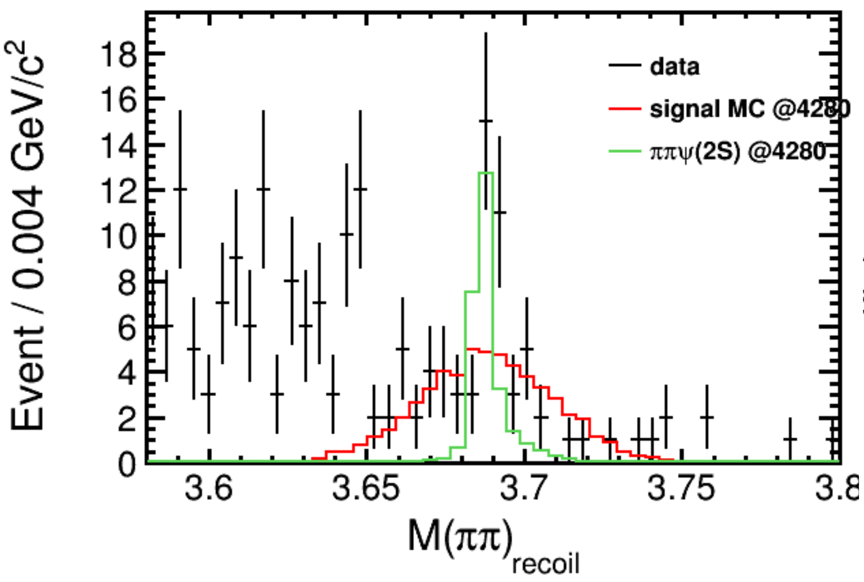
One kind of background is $ee \to \eta J/\psi, \eta \to \pi^+\pi^-\pi^0$, which has the same final states as signal MC.
$|M(\gamma\gamma) - m(\pi^0)| > 0.015$ is required to veto this process.

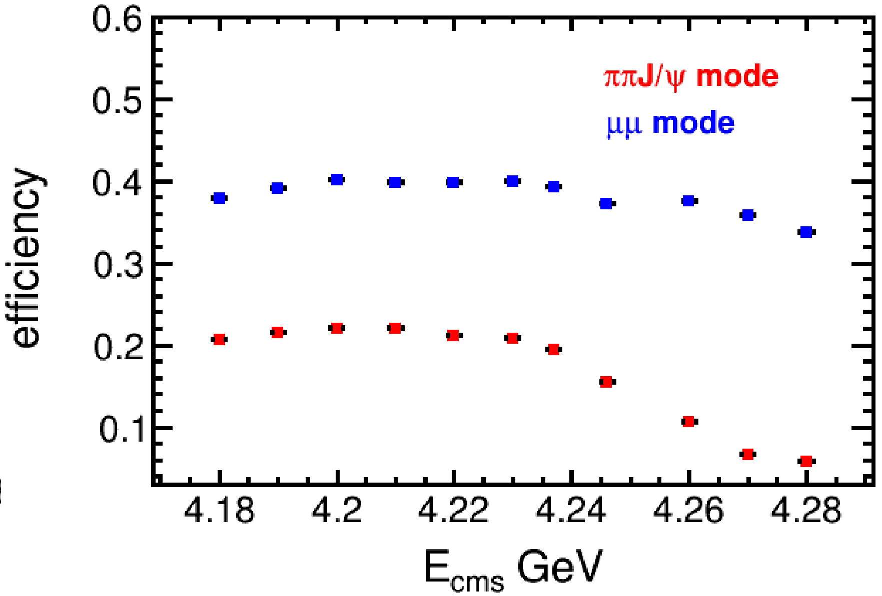
The process of $e^+e^- \to \pi^+\pi^-\psi(2S), \psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$ also share the same final states with the signal.
We require $|M(\pi\pi)_{recoil} - (\psi')|$>0.02 GeV to veto the $e^+e^- \to \pi^+\pi^-\psi(2S)$ backgrounds.



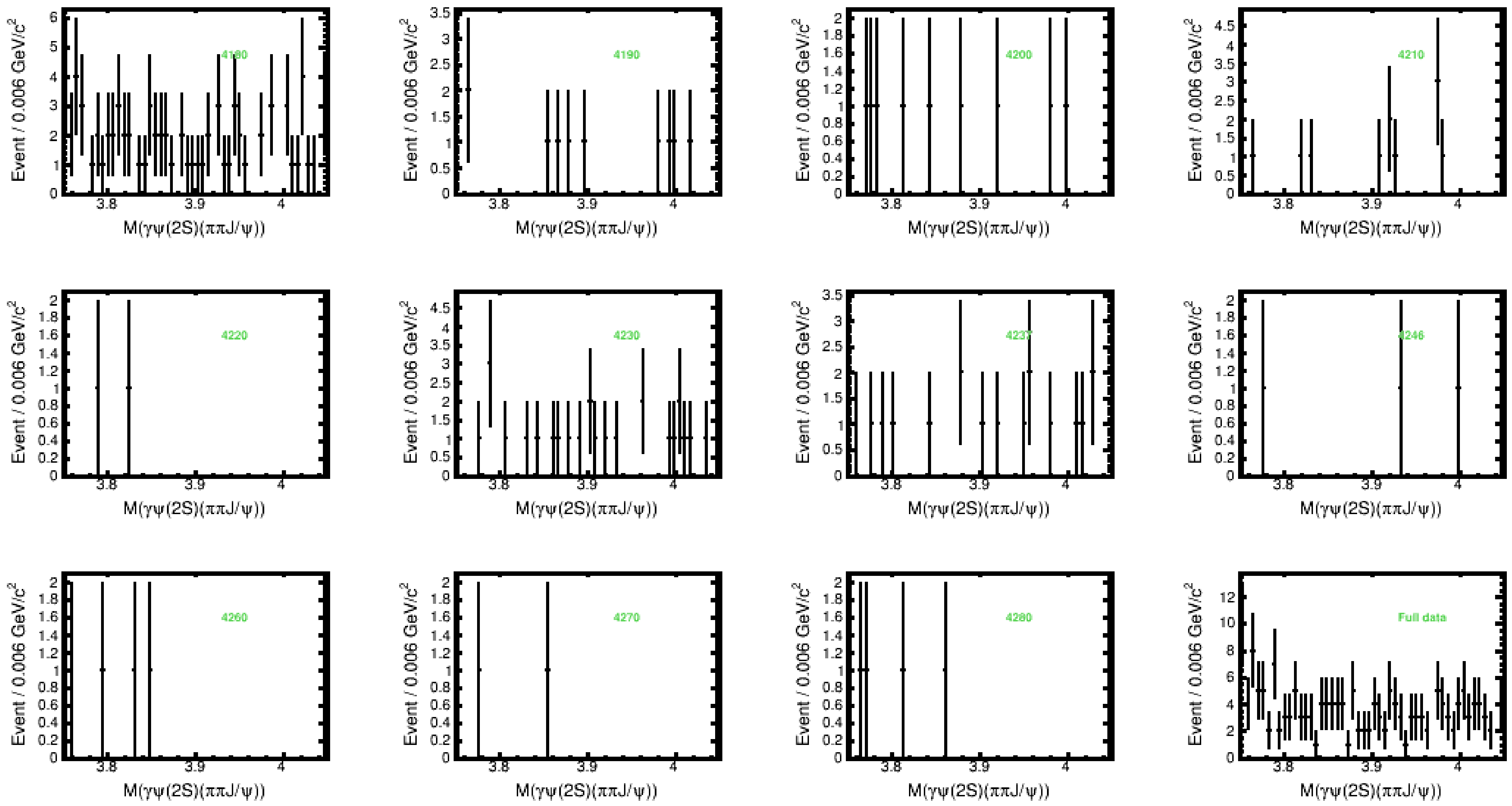


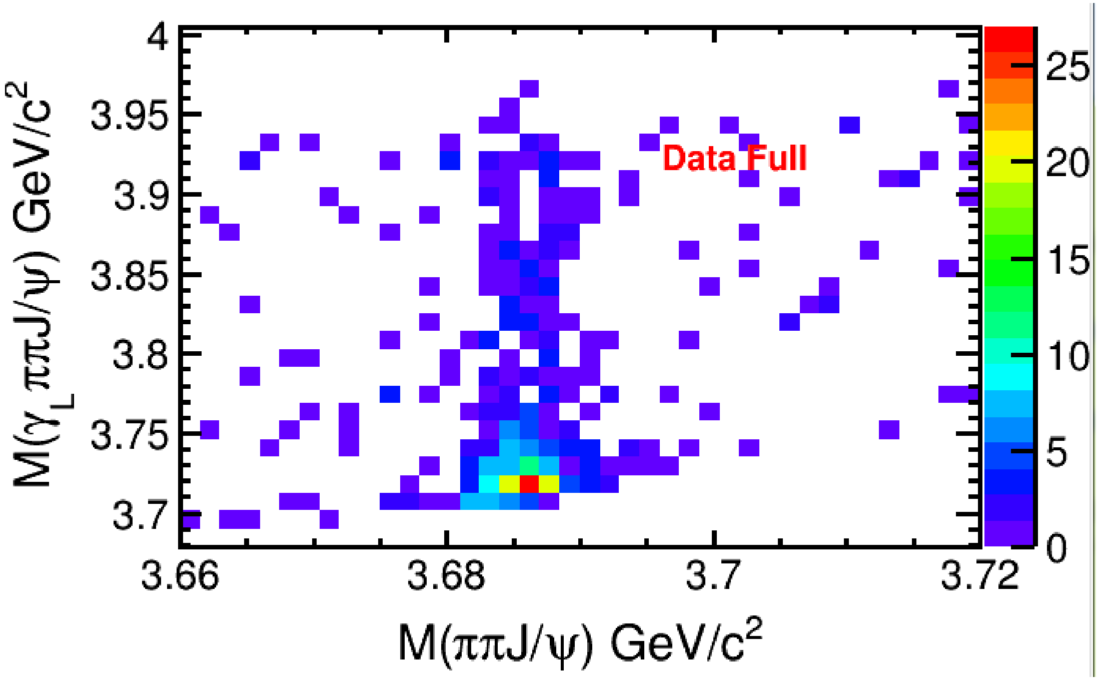


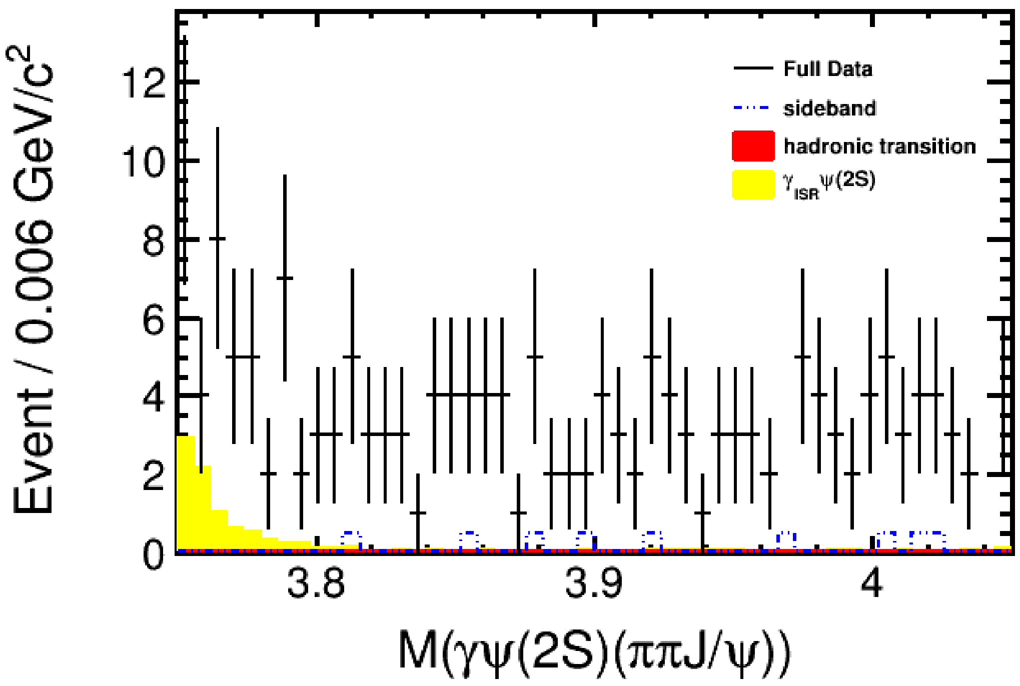




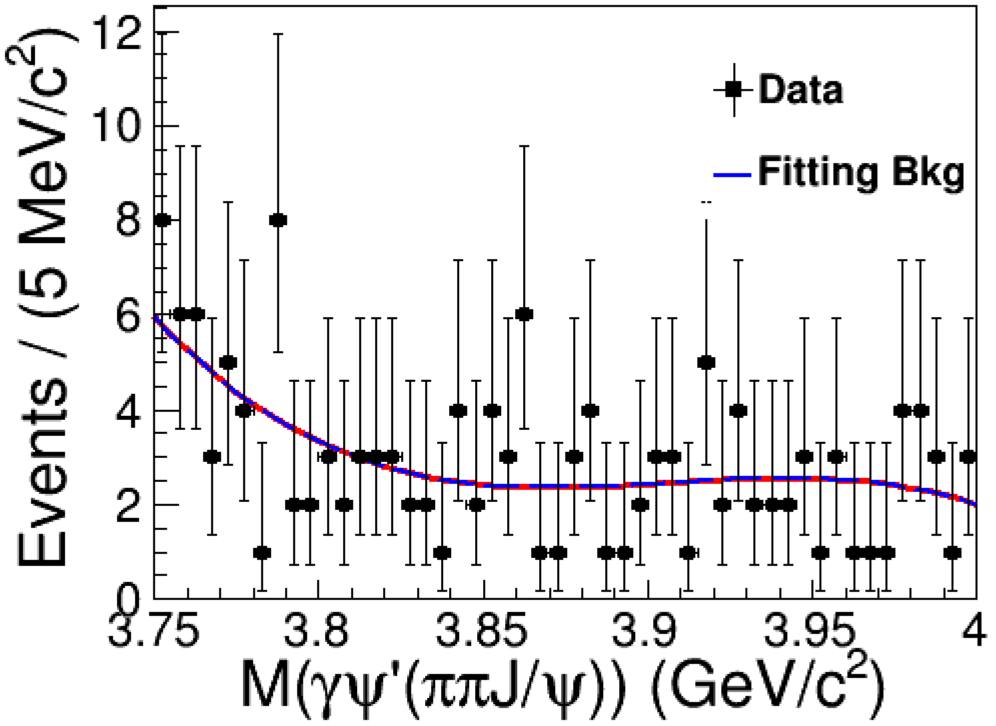
Efficiency curve if we require $|M(\pi\pi)_{recoil} - (\psi')|$>0.02 GeV
Weighted efficiency are 18.8% and 39.0% for $\pi\pi J/\psi$ and $\mu\mu$, respectively.

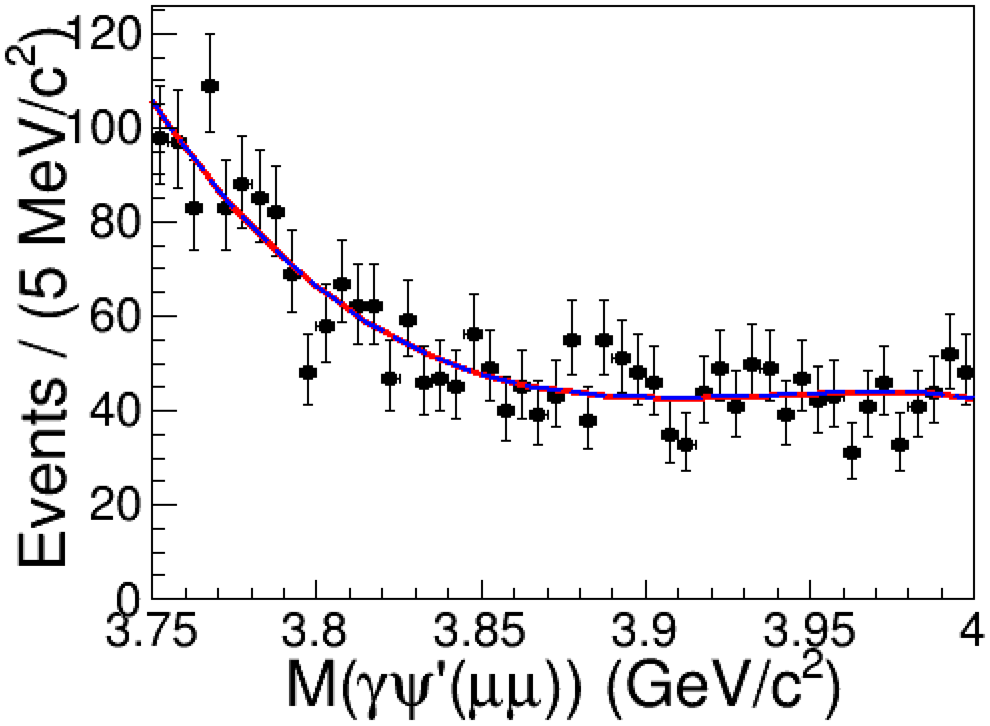

4180
4190
4200
4210
4220
4230
4237
4246
4260
4270
4280
Full data
Event / 0.006 GeV/c2
M(γψ(2S)(ππJ/ψ))



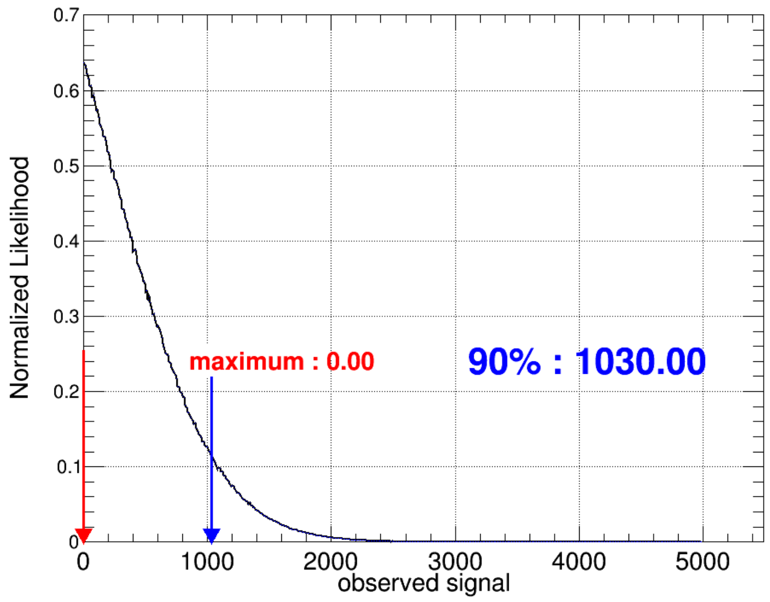


40 steams Inclusive MC study implies low level of background and no peaking background.
The background level from inclusive MC is under-estimated compared with data.

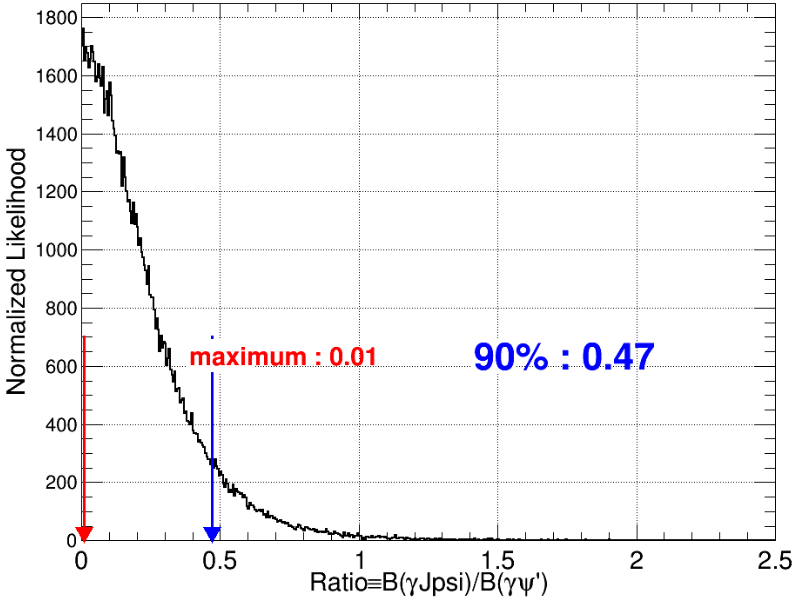




- Unbinned simultaneous maximum likelihood fit to extract signal yields.
  - Ratios of $X3872$ from the two samples are constraint to the corresponding branching fractions and reconstruction efficiencies.
- The mass spectrum is fitted with two components:
  - Signal: described with MC shape, assuming $M(X3872) = 3.8719\ \mathrm{GeV}, \Gamma = 0.0012\ \mathrm{GeV}$
  - Background: described with a 2nd-order Chebychev polynomial
- Corresponding reconstruction efficiency and branching fraction corrected signal yields: $(0.0 \pm 5.1) \times 10^2$
- Goodness of fit: 68.2/92=0.74



After considering the systematic uncertainty, the upper limit at 90% confidence level of the number of production events is 10.3×10^2.

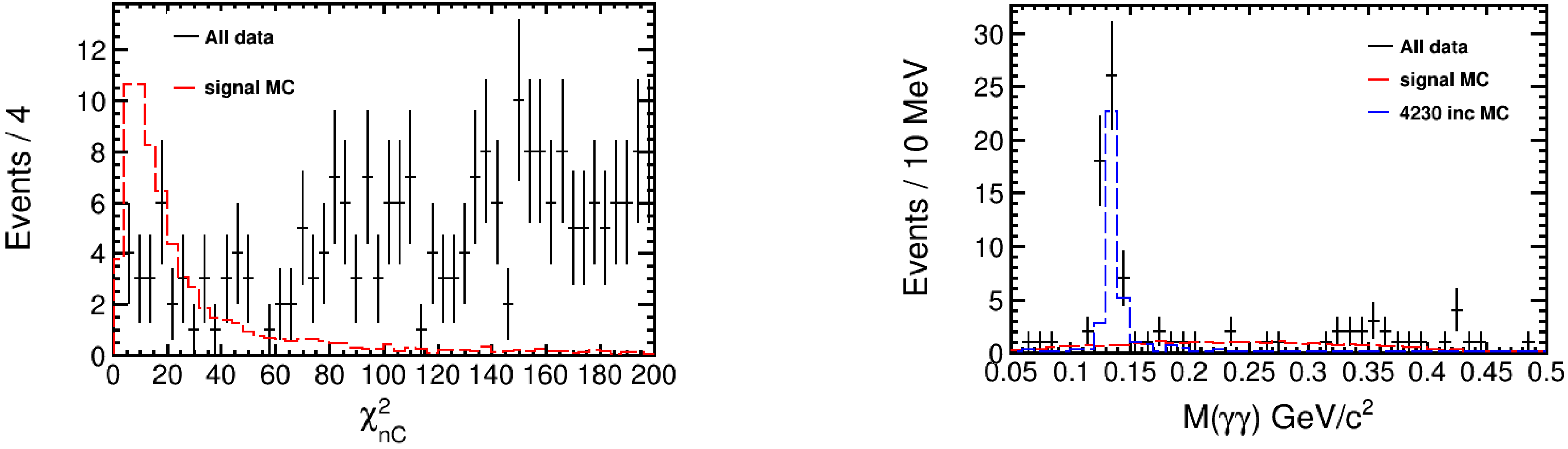


The upper limit at 90% C.L. of the relative branching fractions ratio is calculated by sampling the $\gamma J/\psi$ and $\gamma\psi'$ likelihood distribution. The UL is set to be 0.47 after systematic uncertainty consideration where the common ones are cancelled.

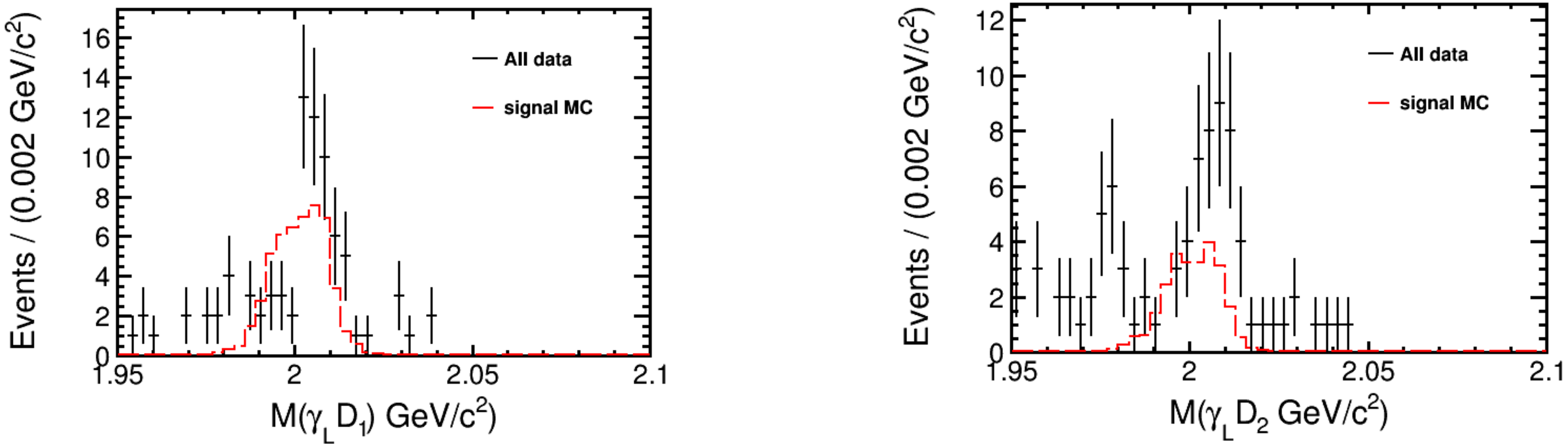
$X(3872) \to \gamma DD$

• Event Selection

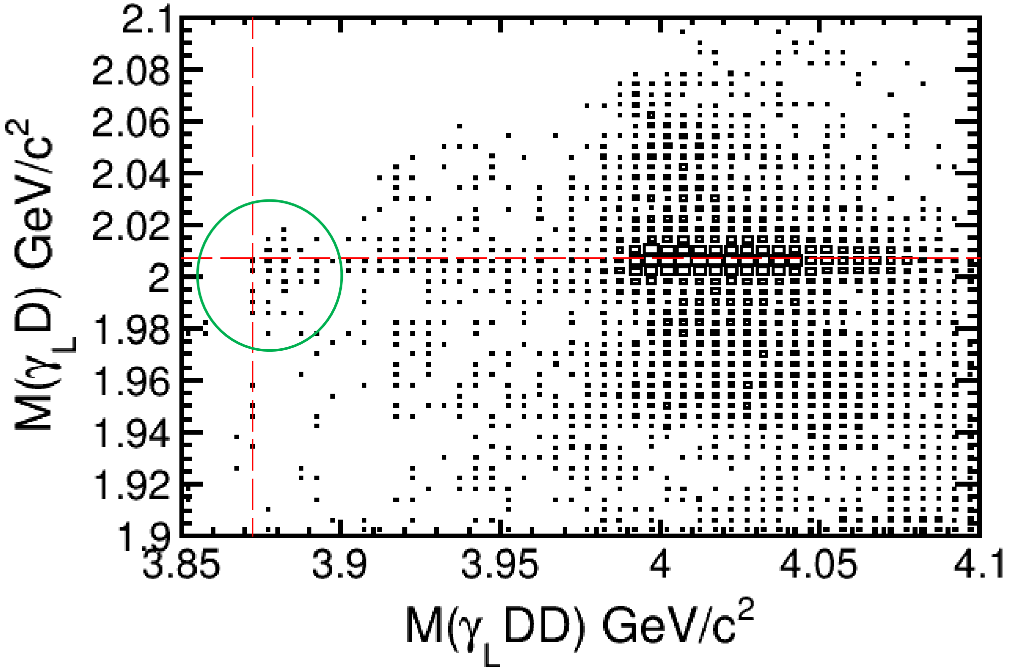
- Use double Dtag to reconstruct $D^0 \to K\pi, K\pi\pi\pi, K\pi\pi^0$
- At least two good photons
  - Cluster from barrel: $E > 25 \text{ MeV}$
  - Cluster from endcap: $E > 50 \text{ MeV}$
  - Cluster is not from D candidate
- 4+n(pi0 mass)+2(D mass)C kinematic fit
  - The combination with least χ^2_{nC} is kept as best candidate
  - Photon with larger energy after 4C named γ_H, the other one named γ_L
  - $\chi^2_{4C}(\gamma DD) < \chi^2_{4C}(\pi^0 DD)$

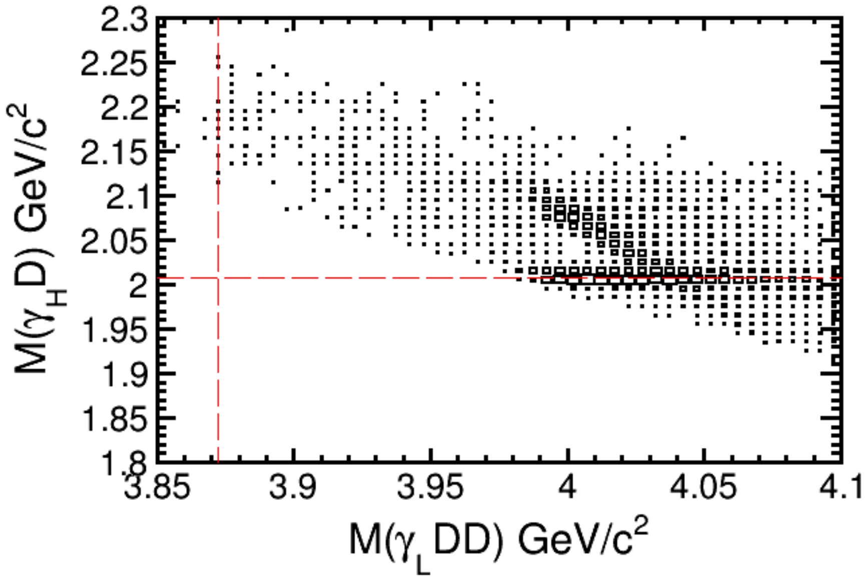


$\chi^2_{nC} < 60$, very clear background of $\pi^0 \to \gamma\gamma$, use $|M(\gamma\gamma) - m_\pi^0| > 0.02$ to veto.

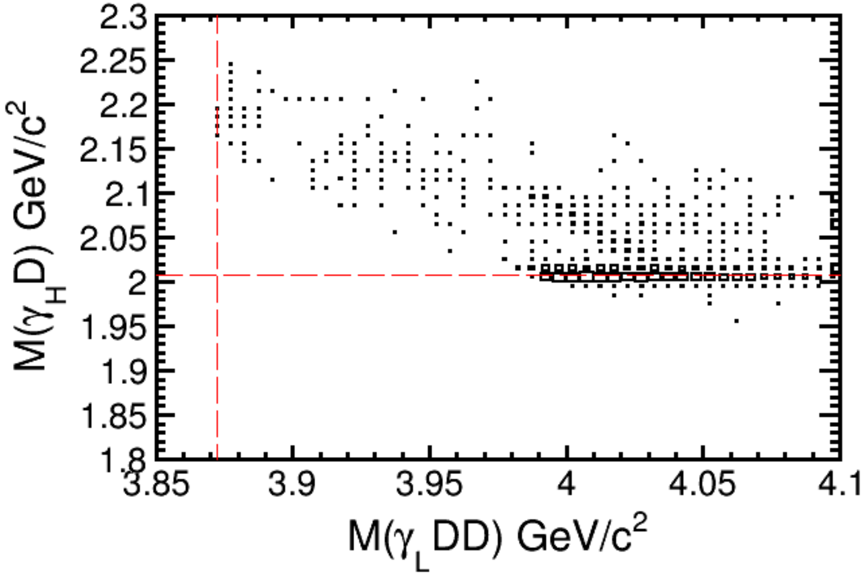


The internal look shows clear signal of $D^{*0}(2007)$.



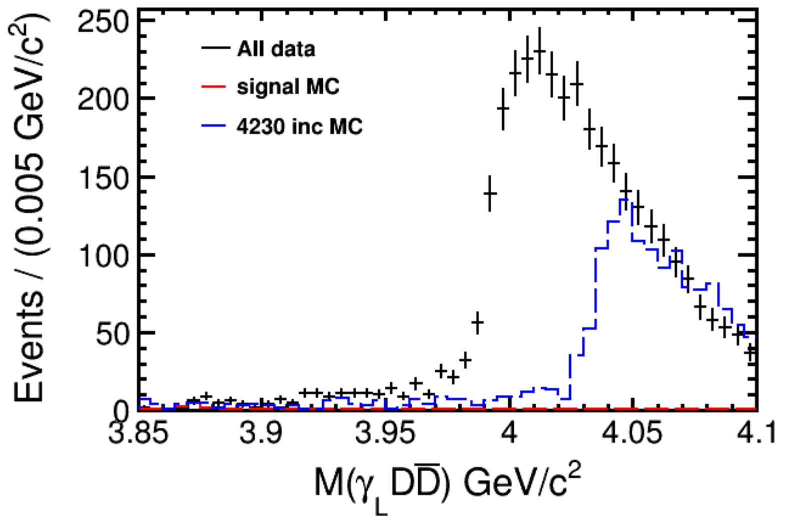


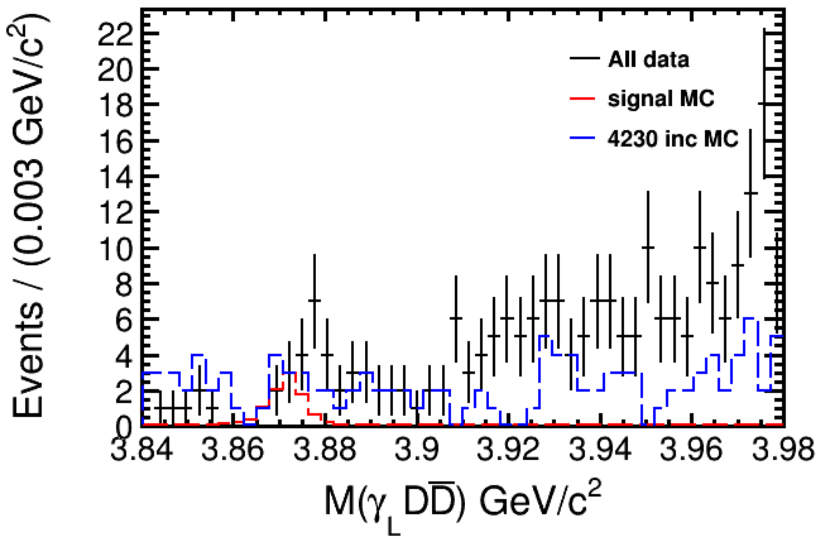
$M(\gamma_L D) \in [m_{D^{0*}} - 0.006, m_{D^{0*}} + 0.006]$:



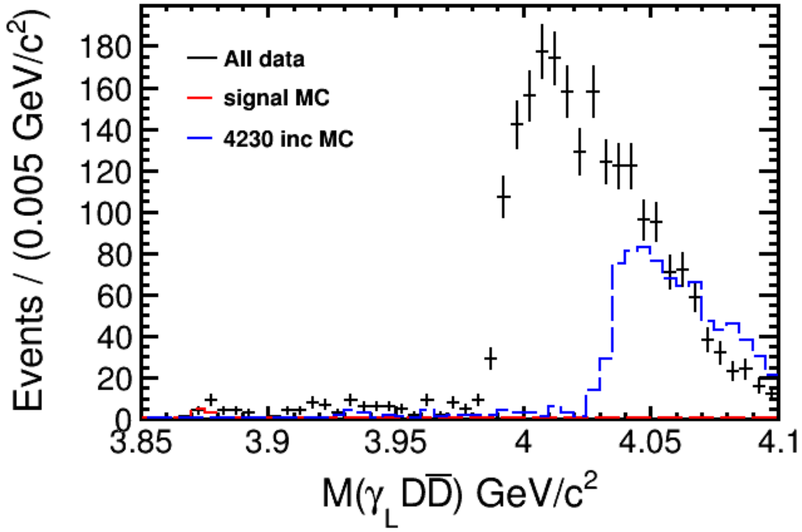
The main background learnt from the inclusive MC is $ee \to \gamma D^0 D^{*0}$, which will not contribute a peaking background.

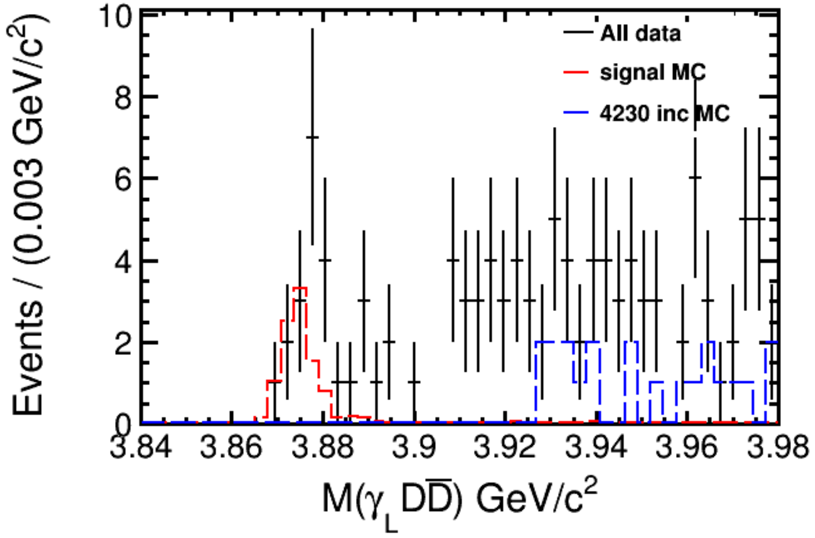
Full rD region:

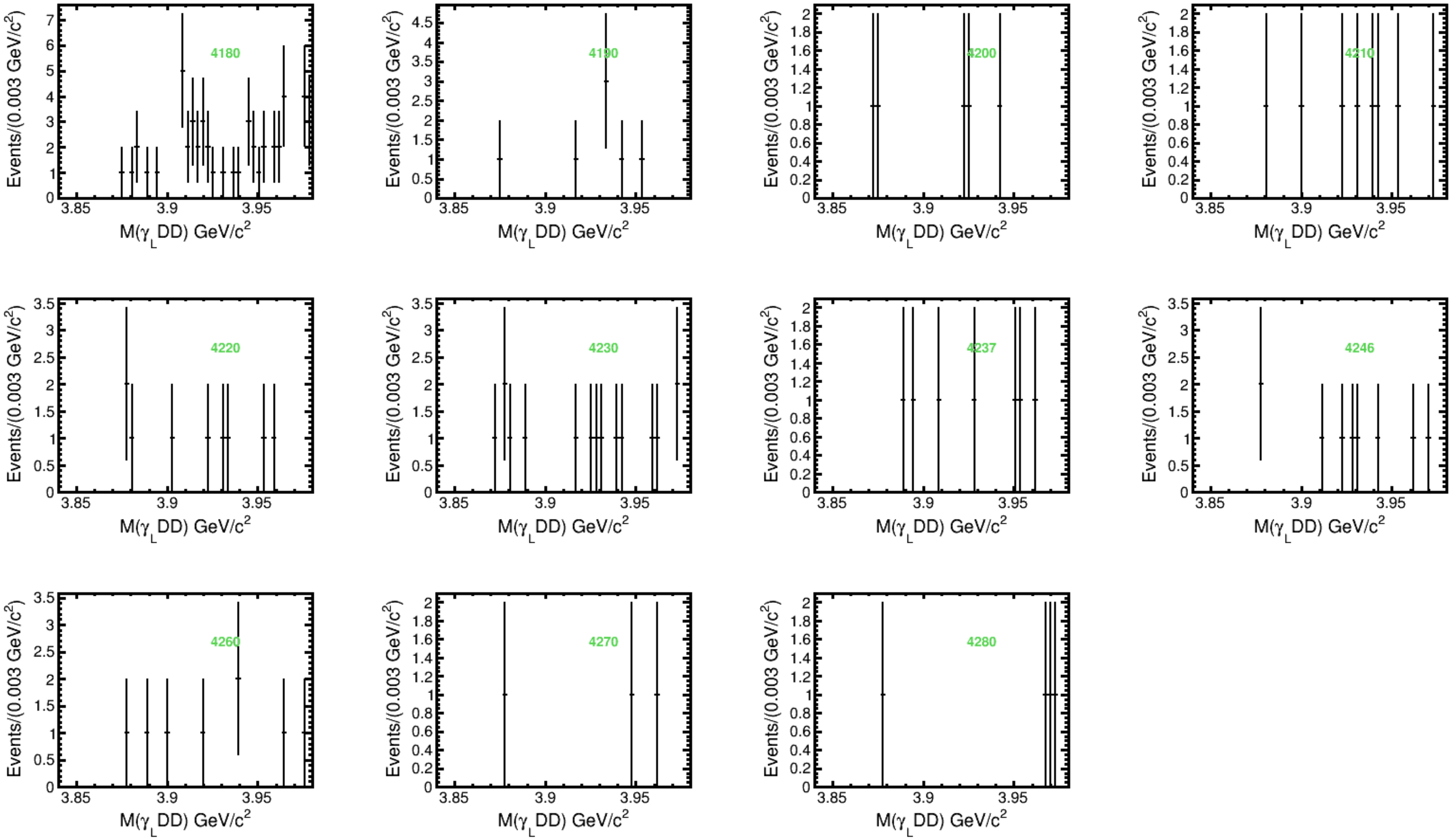




$M(\gamma D) \in [m_{D^{0*}} - 0.006, m_{D^{0*}} + 0.006]$:



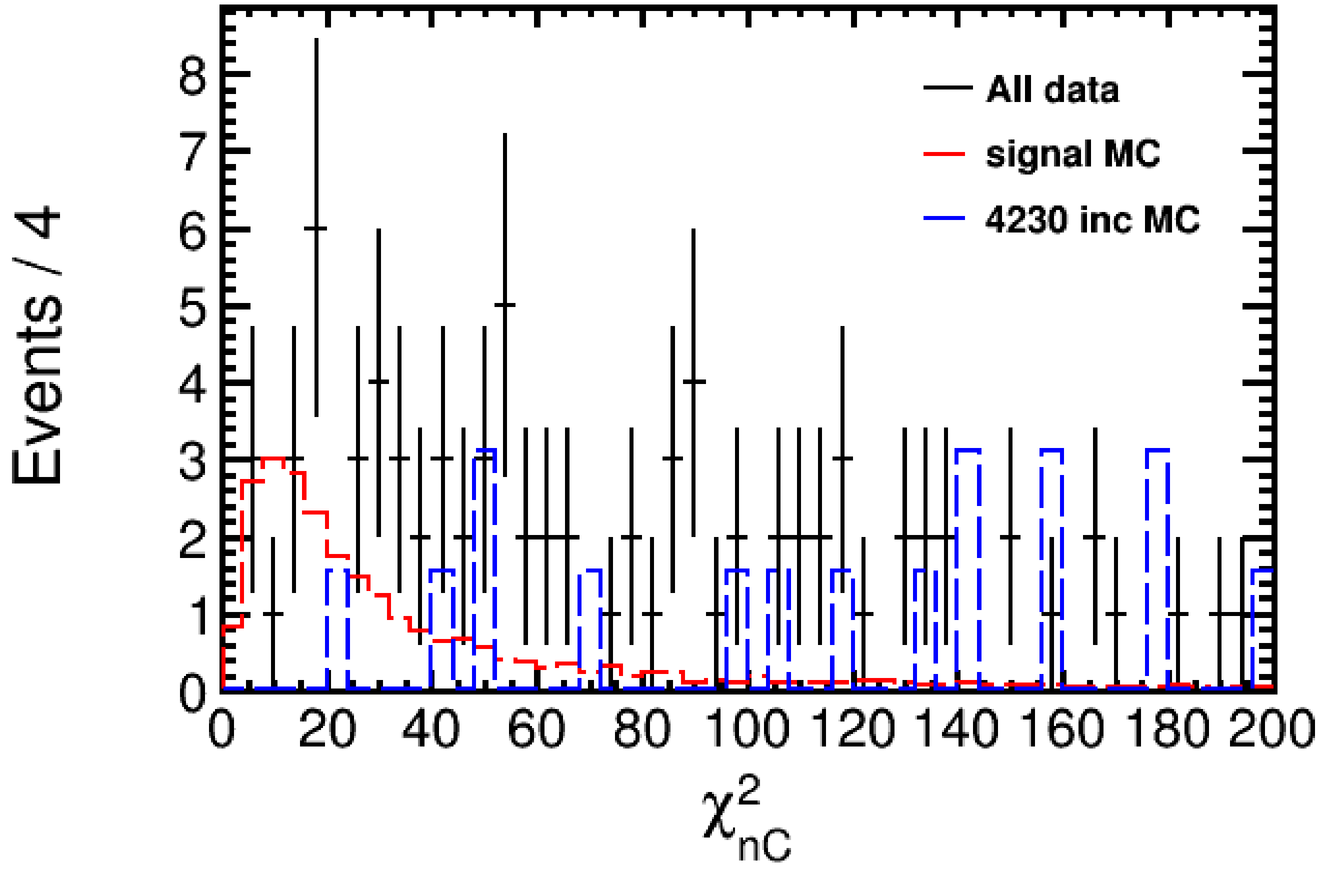



4180
4190
4200
4210
4220
4230
4237
4246
4260
4270
4280
Events/(0.003 GeV/c^2)
M(γ_LDD) GeV/c^2

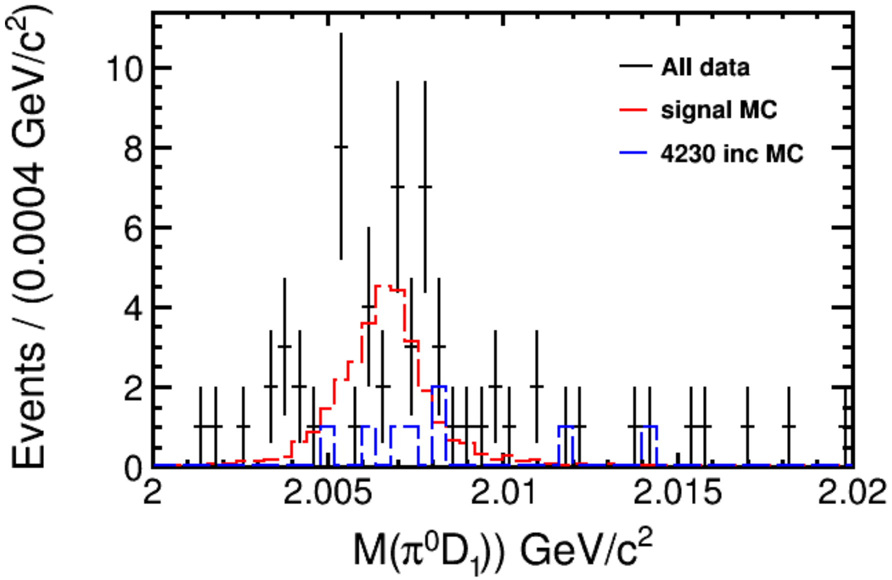
$X(3872) \to \pi^0 DD$

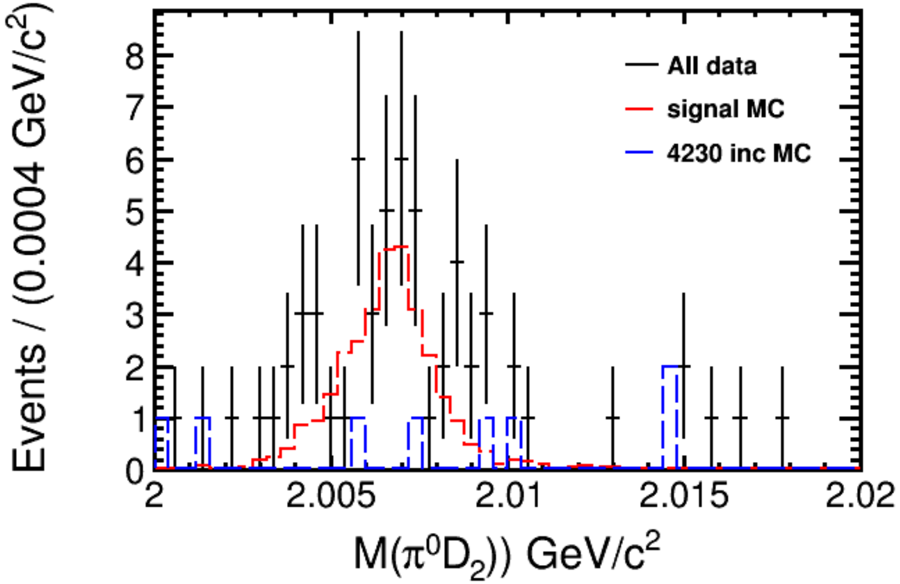
•Event Selection

- Use double Dtag to reconstruct $D^0 \to K\pi, K\pi\pi\pi, K\pi\pi^0$
- At least three good photons
  - Cluster from barrel: $E > 25 \text{ MeV}$
  - Cluster from endcap: $E > 50 \text{ MeV}$
  - Cluster is not from D candidate
- 4+n(pi0 mass)C+2(D mass)C kinematic fit
  - The combination with least χ^2_{nC} is kept as best candidate
  - Photon with larger energy after 4C named γ_H, the other one named γ_L
  - $\chi^2_{4C}(\gamma DD) > \chi^2_{4C}(\pi^0 DD)$

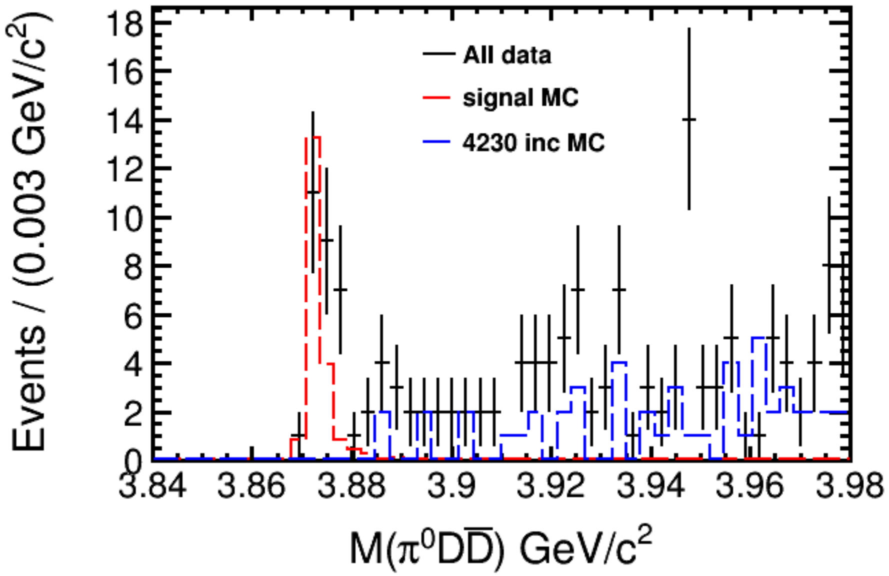


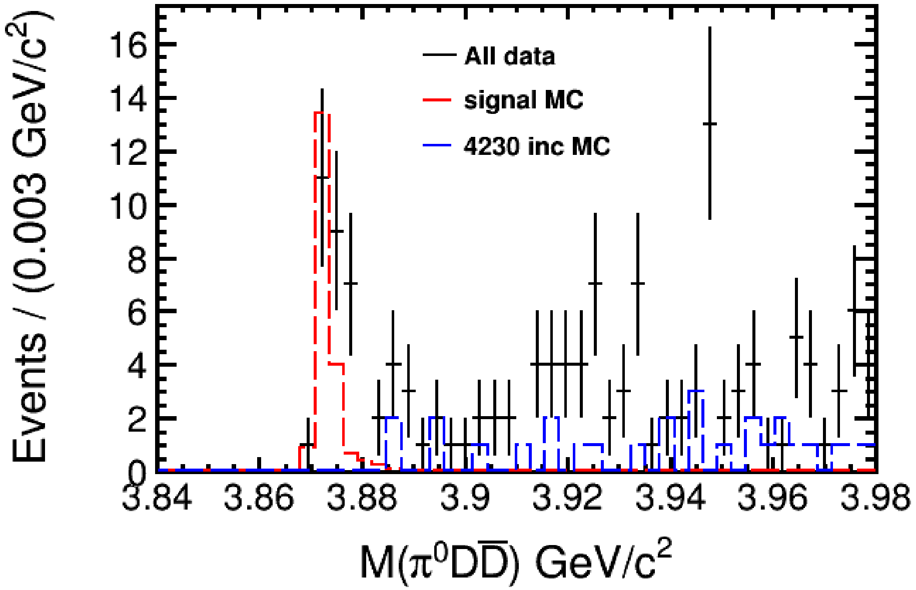
Comparison between data, signal MC, and inclusive MC, the χ^2_{nC} is required to be less than 60.



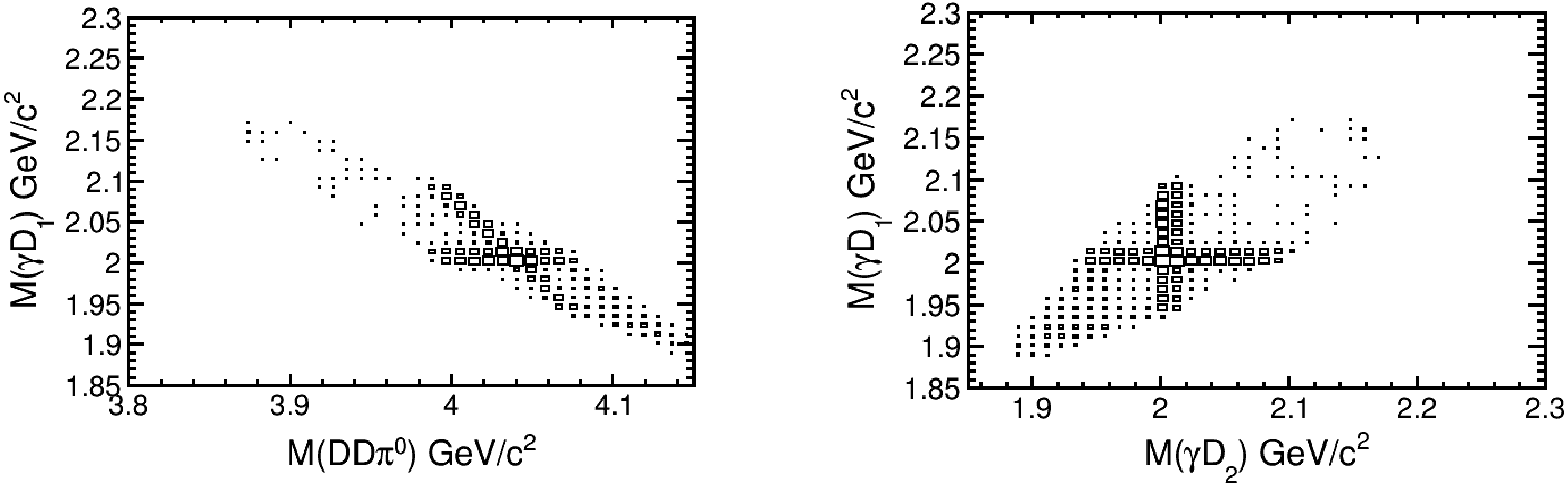


The internal look shows clear signal of $D^*(2007)$

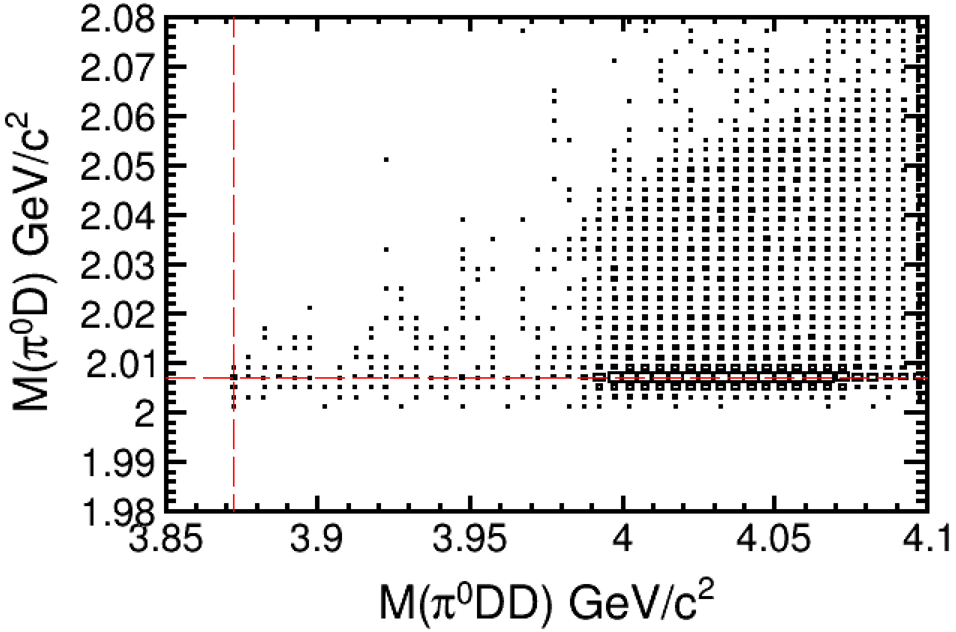




After require $D^*(2007)$ mass window($m_{D^*} \pm 0.004$ GeV/c^2), the signal of $X(3872)$ does not change.

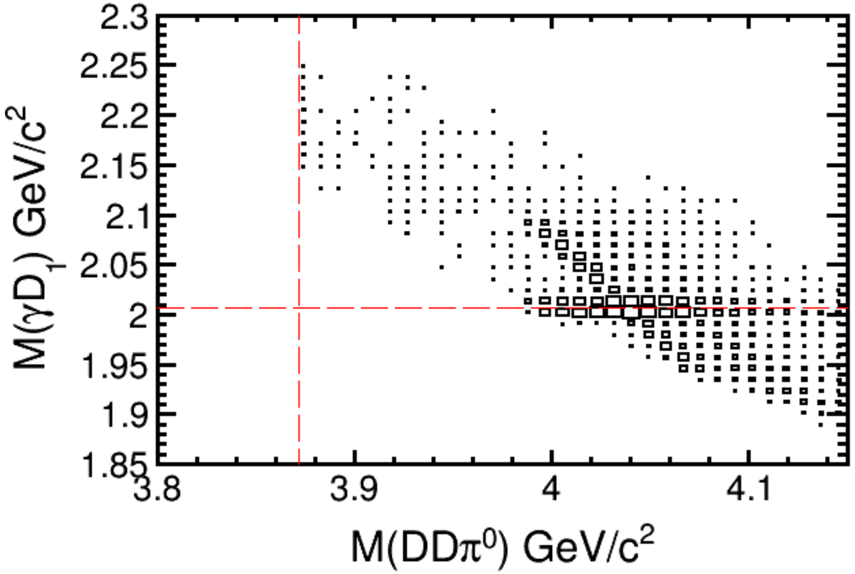


Very clear signal of $D^{*0} \to \gamma D^0$ in the higher side in the $M(DD\pi^0)$ spectrum.

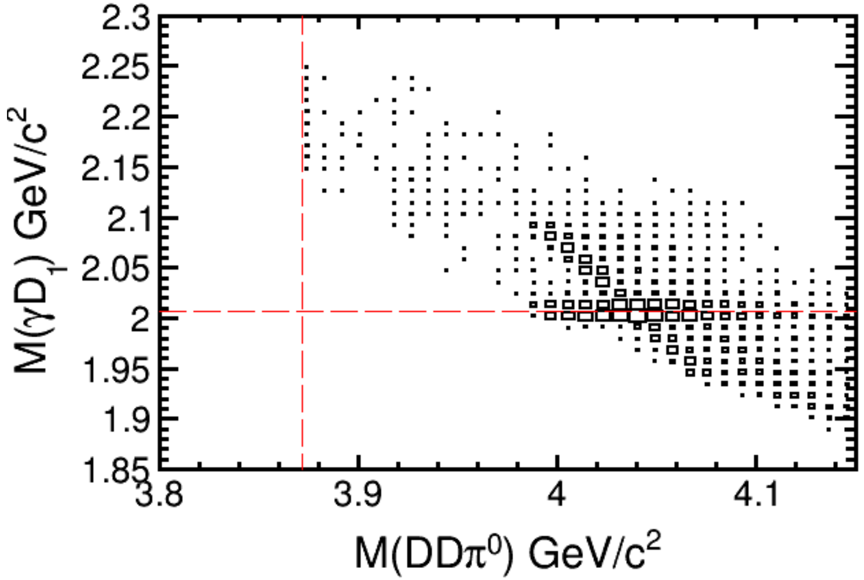


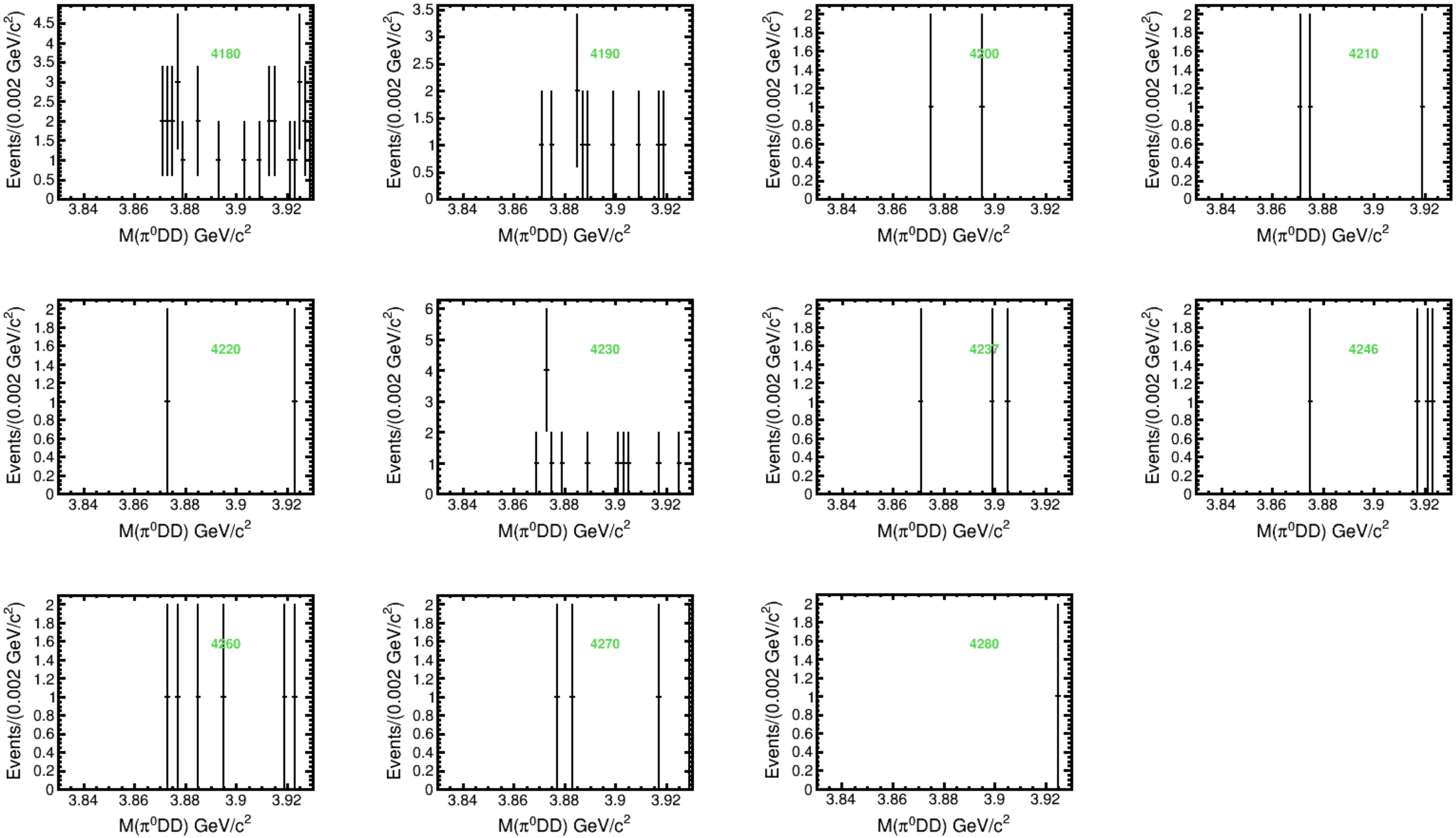
Here $\pi^0 D$ include $\pi^0 D_1$ and $\pi^0 D_2$

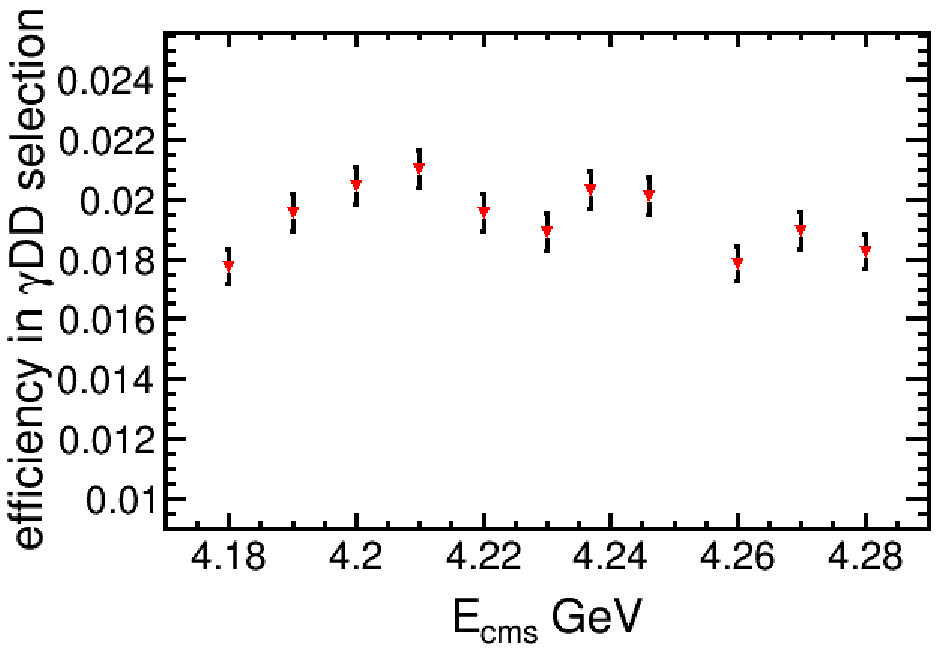
Full region:

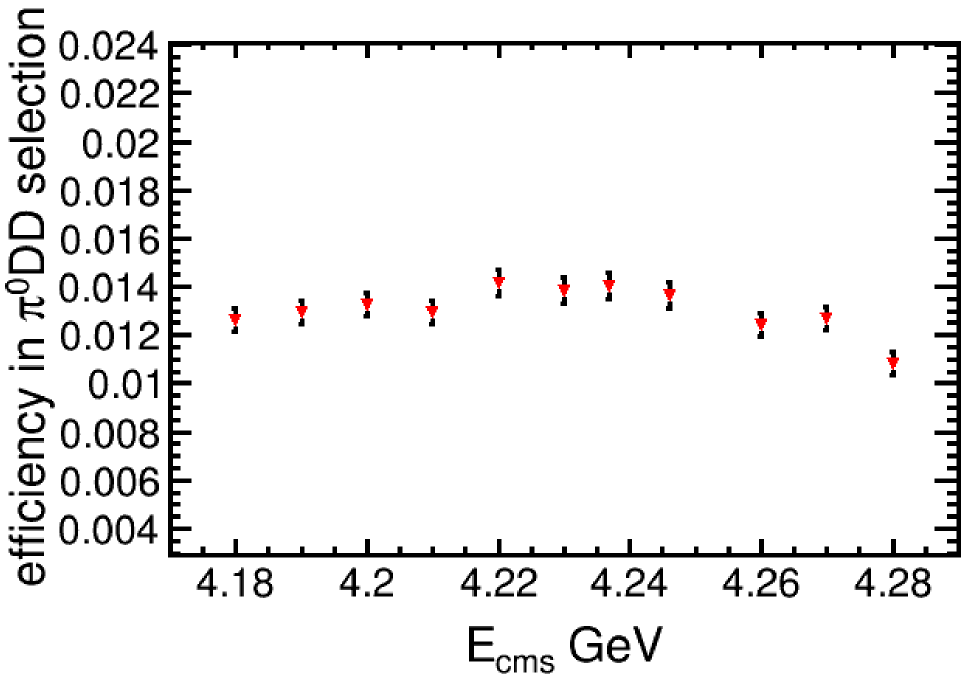


$M(\pi^0 D) \in [m_{D^{0*}} - 0.004, m_{D^{0*}} + 0.004]$:

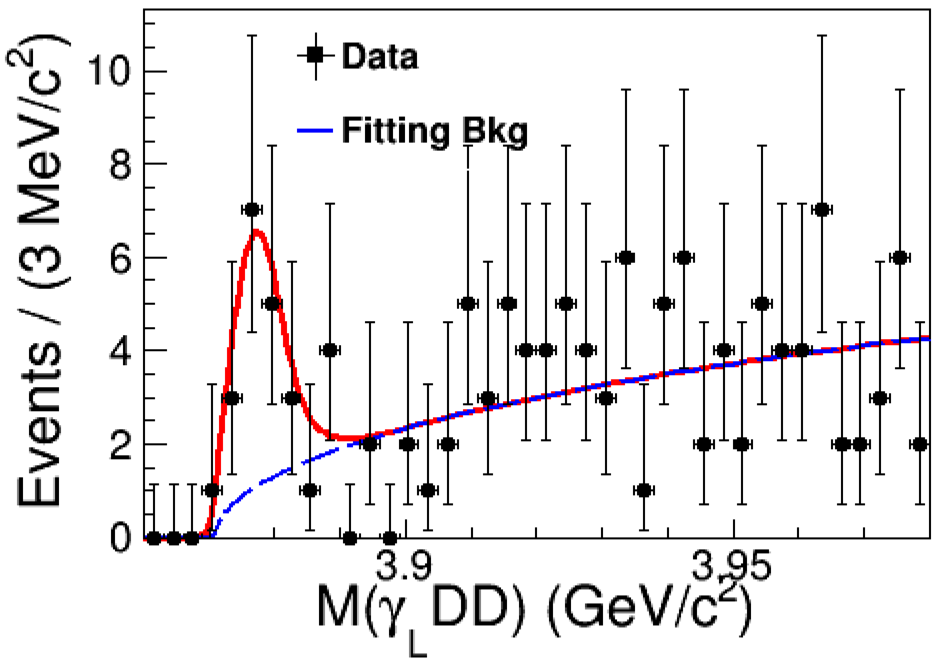


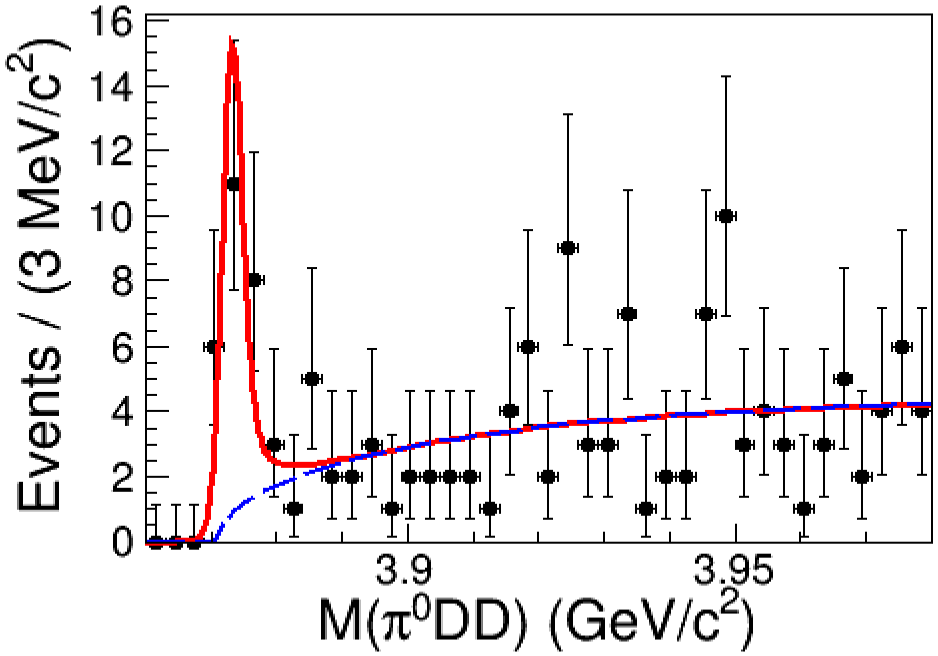

4180
4190
4200
4210
4220
4230
4237
4246
4260
4270
4280
Events/(0.002 GeV/c^2)
M(π^0DD) GeV/c^2
3.84
3.86
3.88
3.9
3.92



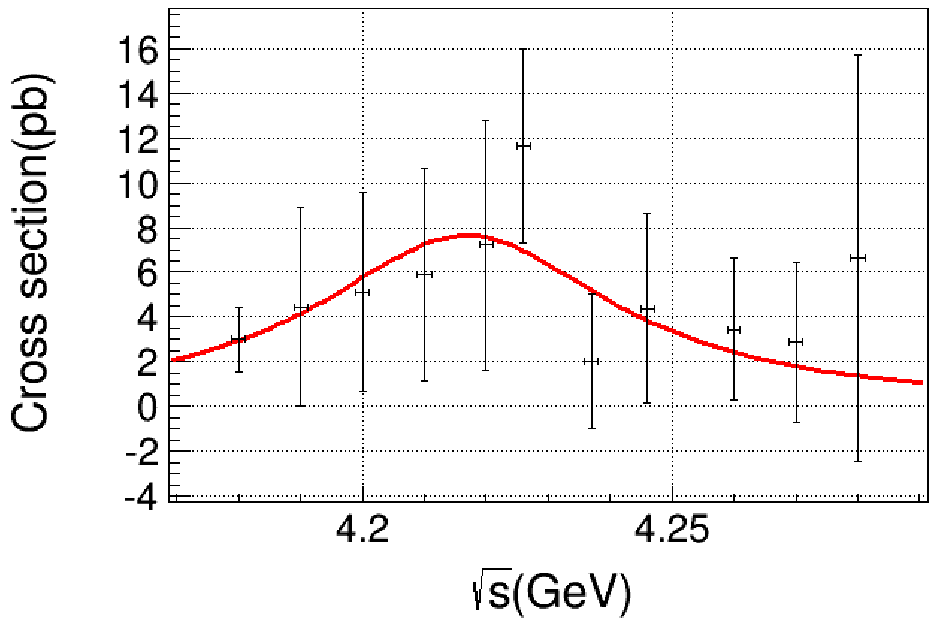


The weighted efficiency for γDD and $\pi^0 DD$ mode are 1.9% and 1.3%, respectively.





- Requiring at least one of D mesons coming from D^{*0}, unbinned maximum likelihood fit are performed simultaneously to the mass spectra.
- Two components are included in each fit:
  - Signal: described with MC simulated shape convolved free Gaussians. The fraction between two signals are fixed to the corresponding reconstruction efficiencies and branching fractions.
  - Background: described with an ARGUS function.
- Goodness of fit: 53.6/70=0.77; statistical significance: 8.0σ;
- Signal yields after efficiency and branching fraction correction: $(38.0 \pm 7.0) \times 10^3$
- Fitted mass of Gaussian:
  - 5.3+-1.0 MeV for γDD and 1.3+-0.5 MeV for $\pi^0 DD$



We fit the $M(\pi^0 DD)$ and $M(\gamma DD)$ in each energy point simultaneously, and yield the number of production events.

The Born cross section is calculated with formula:

$$\sigma^{Born} = \frac{N_{pro}}{L \cdot (1+\delta) \cdot \frac{1}{(1-\Pi)^2}}$$

where N_{pro} is the number of production events, L is the corresponding luminosity, $(1+\delta)$ is the ISR correction factor and $\left(\frac{1}{(1-\Pi)^2}\right)$ is the vacuum polarization factor.

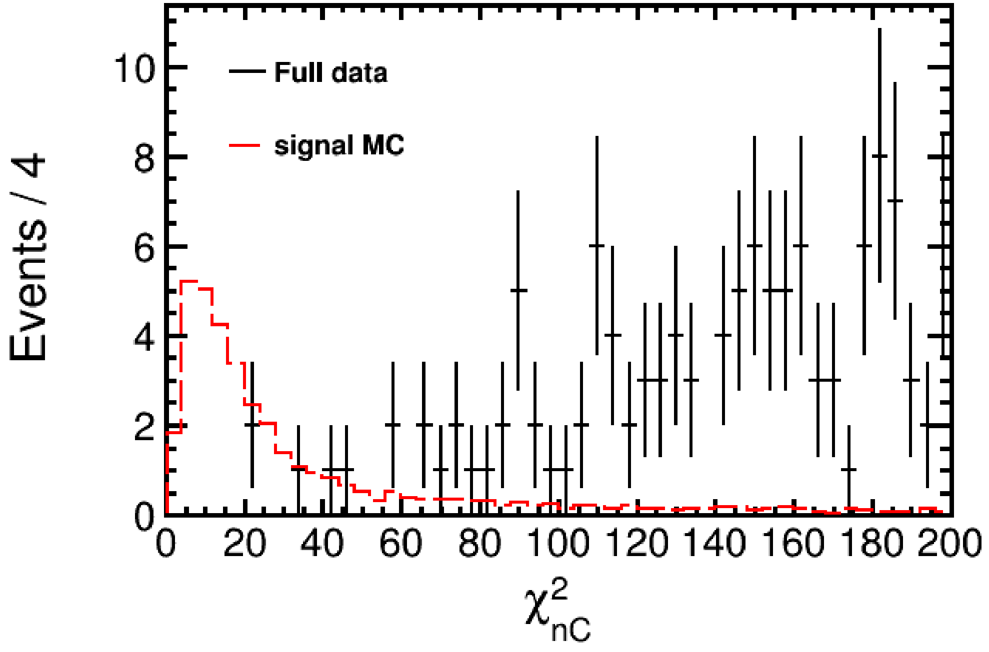
We fit the Born cross section with a BW and the fitted parameters are:

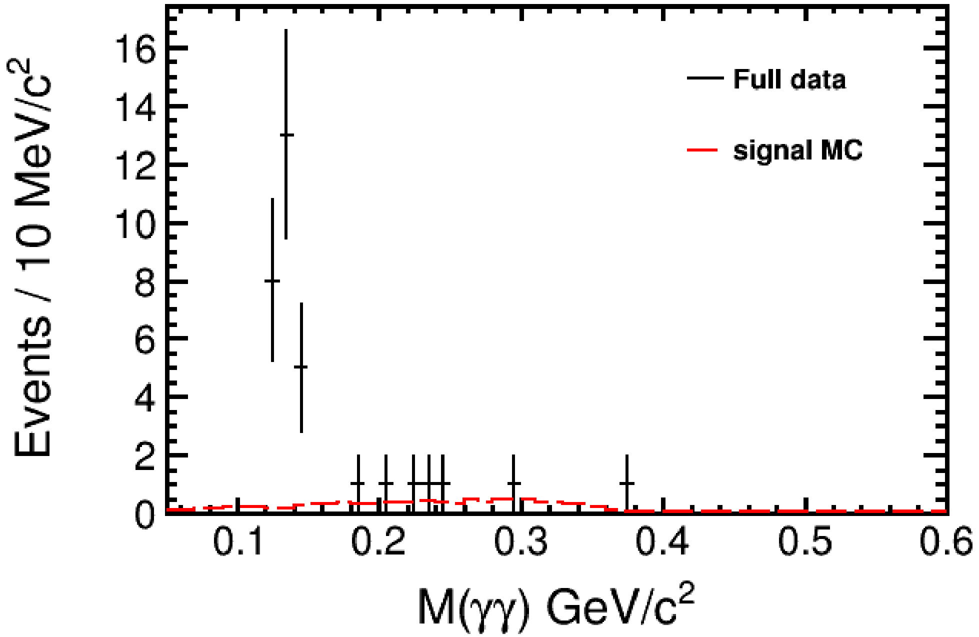
$M = 4217 \pm 8\ \mathrm{MeV}, \Gamma = 59 \pm 36\ \mathrm{MeV}, \Gamma_{ee} \cdot B(Y4260 \to \gamma X3872) \cdot B(X3872 \to DD^*) = (5 \pm 2) \times 10^{-10}$

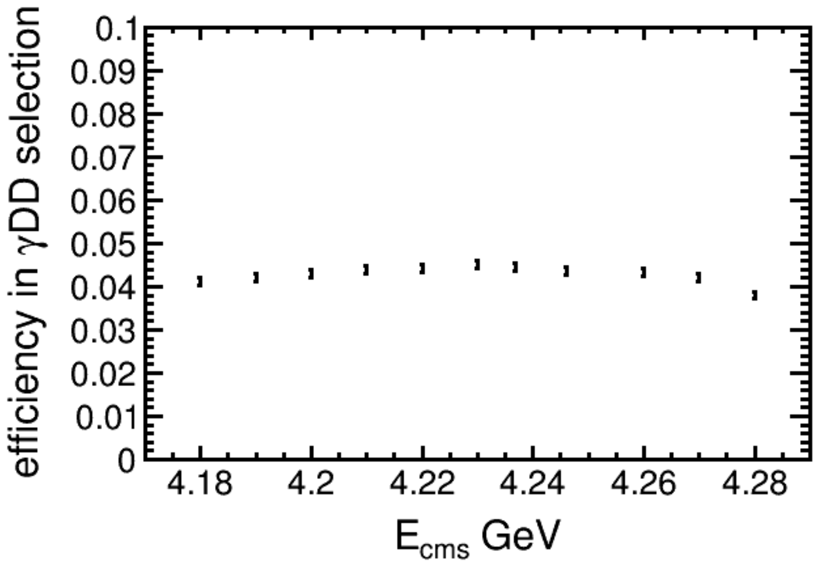
$X(3872) \rightarrow \gamma D^+ D^-$

• Event Selection

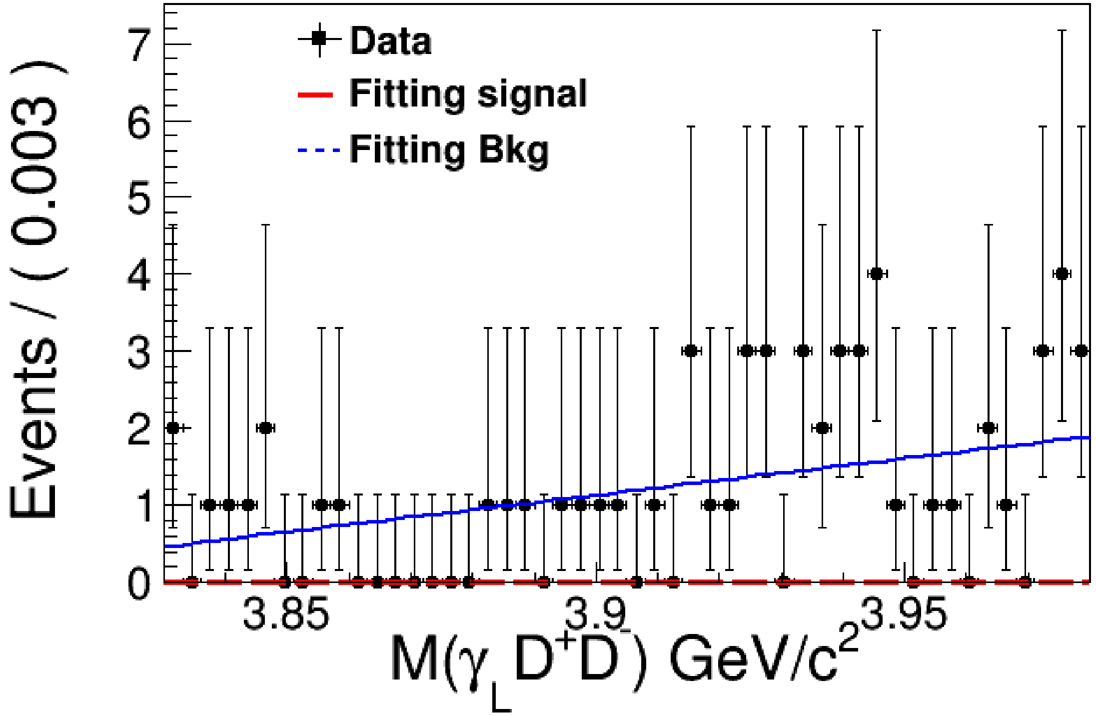
- Use double Dtag to reconstruct $D^{\pm} \rightarrow K\pi\pi, K\pi\pi\pi^0$
- At least two good photons
  - Cluster from barrel: $E > 25\ \mathrm{MeV}$
  - Cluster from endcap: $E > 50\ \mathrm{MeV}$
  - Cluster is not from D candidate
- 4+n(pi0 mass)+2(D mass)C kinematic fit
  - The combination with least χ^2_{nC} is kept as best candidate
  - Photon with larger energy after 4C named γ_H, the other one named γ_L
  - $\chi^2_{4C}(\gamma DD) < \chi^2_{4C}(\pi^0 DD)$



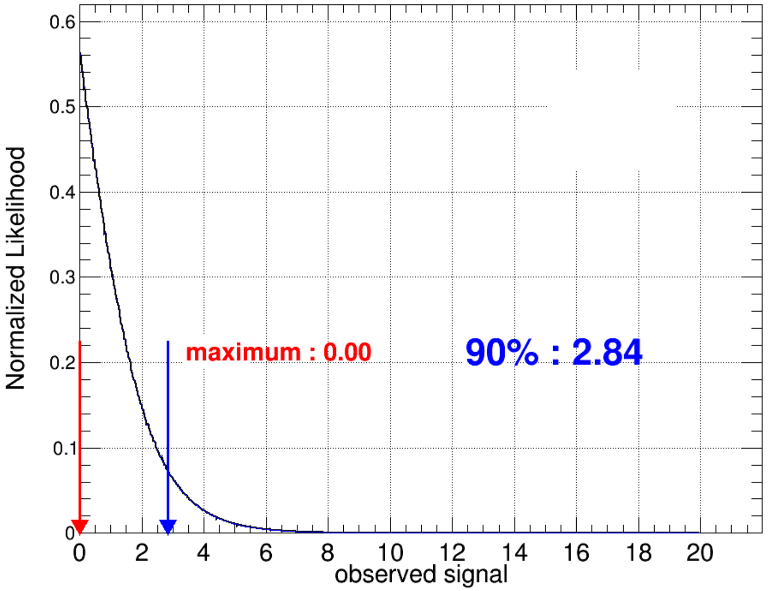




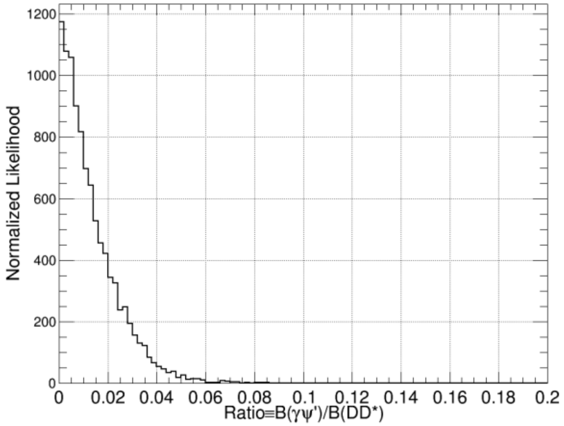
$\chi^2_{nC} < 60, |M(\gamma\gamma) - m_{\pi}^{0}| > 0.02.$
Weighted efficiency is 4.4%.

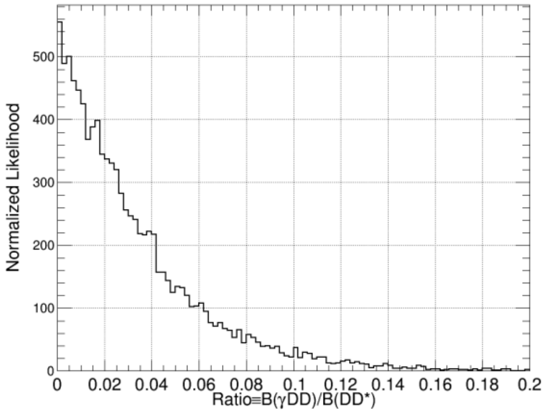


- Use unbinned maximum likelihood fit to extract signal yields.
- The mass spectrum is fitted with two components:
  - Signal: described with MC shape, assuming $M(X3872) = 3.8719\ \mathrm{GeV}, \Gamma = 0.0012\ \mathrm{GeV}$
  - Background: described with a 1^{st}-order Chebychev polynomial
- Corresponding reconstruction efficiency and branching fraction corrected signal yields: $(0.0 \pm 4.2) \times 10^2$
- Goodness of fit: 0.52



After considering the systematic uncertainty, the upper limit at 90% C.L. of the number of observed events is 2.84.
After considering the corresponding branching fraction, reconstruction effieicny, ISR correction, and vacuum polarization, the UL of the production number is 2.7×10^3





We also calculate the relative ratio of branching fractions $\gamma J/\psi$, $\gamma\psi'$, and γD^+D^- compared with that of $D^{*0}D^0$.

$$\mathcal{R}(\gamma J/\psi) = 0.06 \pm 0.02$$
$$\mathcal{R}(\gamma J\psi') < 0.03$$
$$\mathcal{R}(\gamma D^+D^-) < 0.07$$

Systematic uncertainty

- Tracking, photon detection, PID, luminosity, π^0 reconstruction
- Decay model
- kinematic fit
- Cross feed
- Fitting
  - Background description
  - Fitting range
- Lineshape
  - Use measured $\pi\pi J/\psi$ lineshape; take 1%.
- Branching fraction

Fitting procedure

- For $X3872 \rightarrow \gamma J/\psi$

	Enlarge range	Normal range	Narrow range
2^{nd} order Chebychev	11.5%	-	8.3%
3^{rd} order Chebychev	5.6%	2.8%	5.2%

- For $X3872 \rightarrow D^{*0}D$

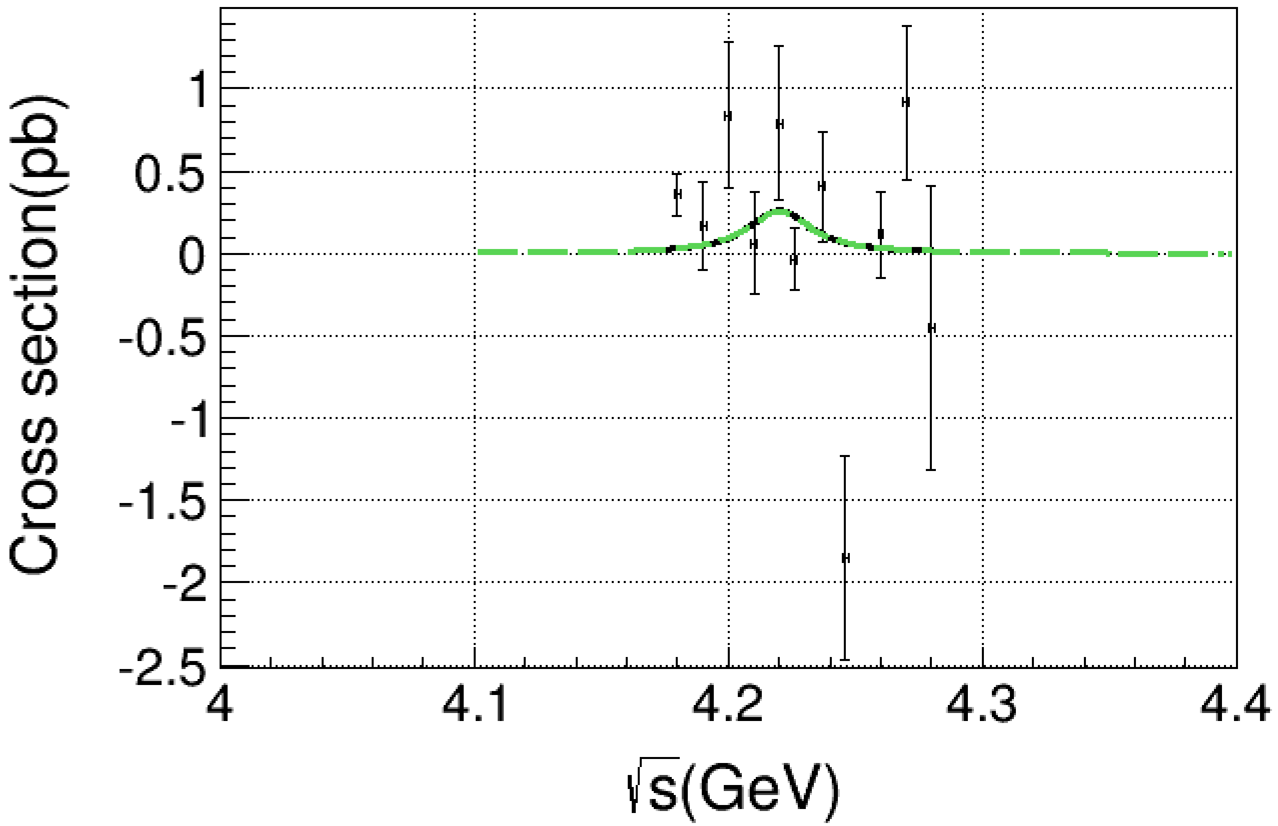
	Enlarge range	Normal range	Narrow range
Argus Function	2.5%	-	0.4%
2^{nd} order Chebychev	12.7%	13.2%	10.1%

	$\gamma J/\psi$	$\gamma\psi'$	$D^{*0}D$	D^+D^-
Tracking	2	4	5.1	6
Photon detection	2	2	4.7	2.5
PID			5.1	6
Pi0 reconstruction			1.7	2.7
Kinematic fit	1	1	1	1
Cross feed			0.2	0.2
Luminosity	1	1	1	1
lineshape	1	1	1	1
Fitting	11.5	-	13.2	-
Branching ratio	0.5	6.7	6.4	3.7
Total	12.0	8.2	17.1	10.1

Summary

- The processes of $e^+e^- \to \gamma X(3872)$ are searched for at BESIII based on current XYZ data around 4230 GeV with $X(3872) \to \gamma J/\psi$, $\gamma\psi'$, $D^{*0}D$, and γD^+D^- modes.
- We find evidence of $\gamma J/\psi$ but no signal of $\gamma\psi'$. The upper limits of the relative ratio $R \equiv \frac{\mathcal{B}\left(X(3872)\to\gamma\psi(2S)\right)}{\mathcal{B}(X(3872)\to\gamma J\psi)} < 0.47$ @ 90% C.L. is obtained, which disagree with LHCb's result.
- We observe $X(3872) \to D^{*0}D$ with statistical significance of 8σ. The relative ratios are also given.

BACK UP



The average Born cross section is 0.27+-0.07 pb for $\sqrt{s} = 4.18 -- -4.28\ GeV$

Etac由16个道重建：

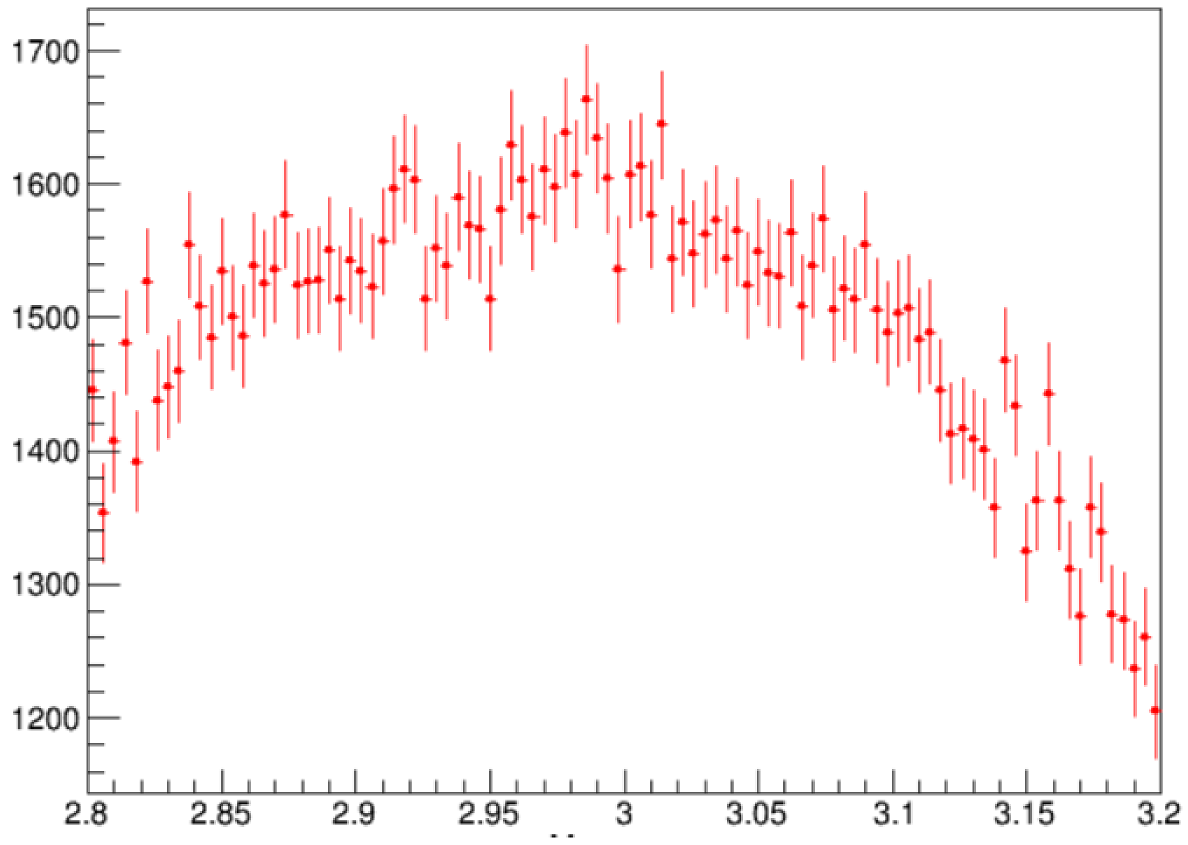
states: $p\bar{p}$, $2(\pi^+\pi^-)$, $2(K^+K^-)$, $\pi^+\pi^-K^+K^-$, $\pi^+\pi^-p\bar{p}$, $3(\pi^+\pi^-)$, $2(\pi^+\pi^-)K^+K^-$, $K_S^0K^\pm\pi^\mp$, $K_S^0K^\pm\pi^\mp\pi^+\pi^-$, $K^+K^-\pi^0$, $p\bar{p}\pi^0$, $K^+K^-\eta$, $\pi^+\pi^-\eta$, $2(\pi^+\pi^-)\eta$, $\pi^+\pi^-\pi^0\pi^0$, and $2(\pi^+\pi^-\pi^0)$.

部分作业失败：
N(末态含pi0或eta)：10/448
C(末态不含pi0或eta或Ks)：10/448
K(含Ks)：0

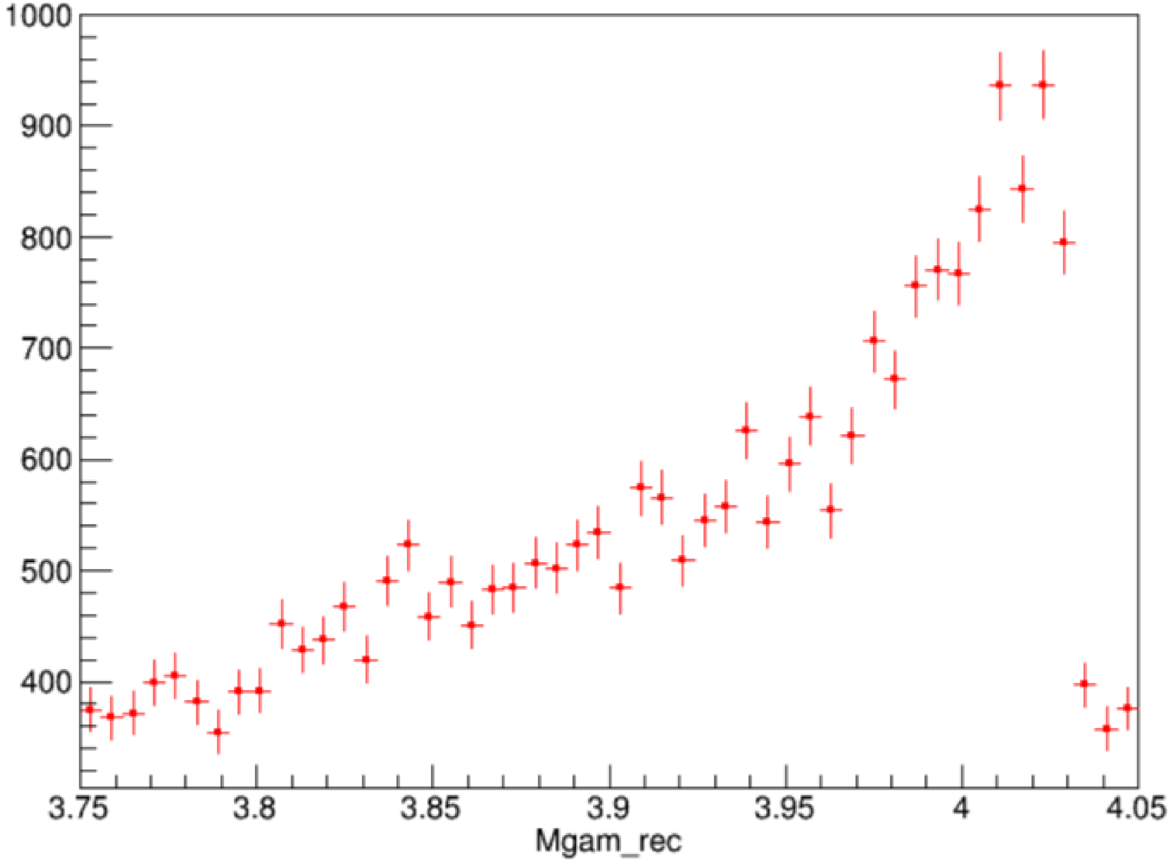
事例筛选后重新组合所有pi+pi-，gam：
要求pi的动量小于：
sqrt((3.872*3.872-(mpi+2.983+mpi)*(mpi+2.983+mpi))*(3.872*3.872-2.983*2.983))/(2*3.872)+0.1;
要求gam能量：在(m_ecms*m_ecms-3.872*3.872)/(2*m_ecms)左右0.15范围内
要求剩余gamma：可以两两组合为eta或者pi0（左右15MeV）
要求gamma反冲在3.872左右250MeV,gammapipi反冲在2.8-3.2

gamma反冲：
对含pi0或eta的末态，要求gampipi反冲在2.9386-3.0286，chisq4c<20
对其它末态，要求gampipi反冲在2.9336-3.0336，chisq4c<35

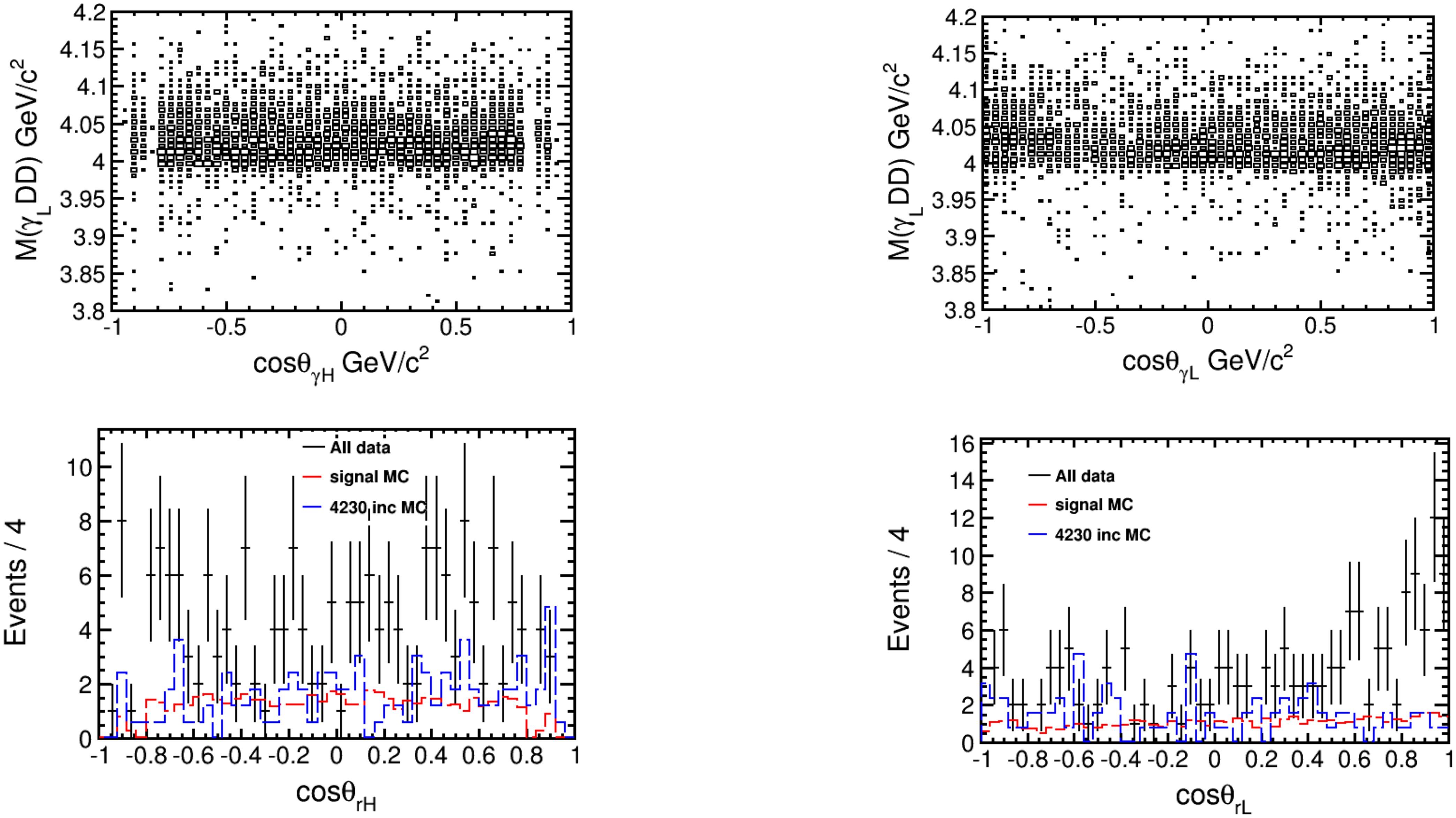
Gammapipi反冲：上述chisq cut



Gammapipi反冲，etac不明显



Gamma反冲



M(γ_L DD) GeV/c^2
cosθ_γH GeV/c^2
cosθ_γL GeV/c^2
All data
signal MC
4230 inc MC
Events / 4
cosθ_rH
cosθ_rL

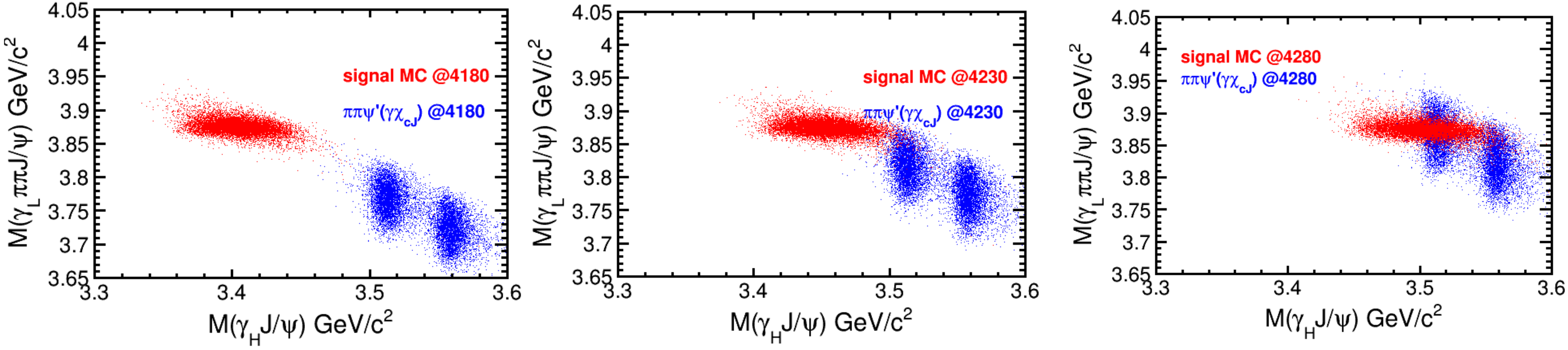
Summary

- The ratio

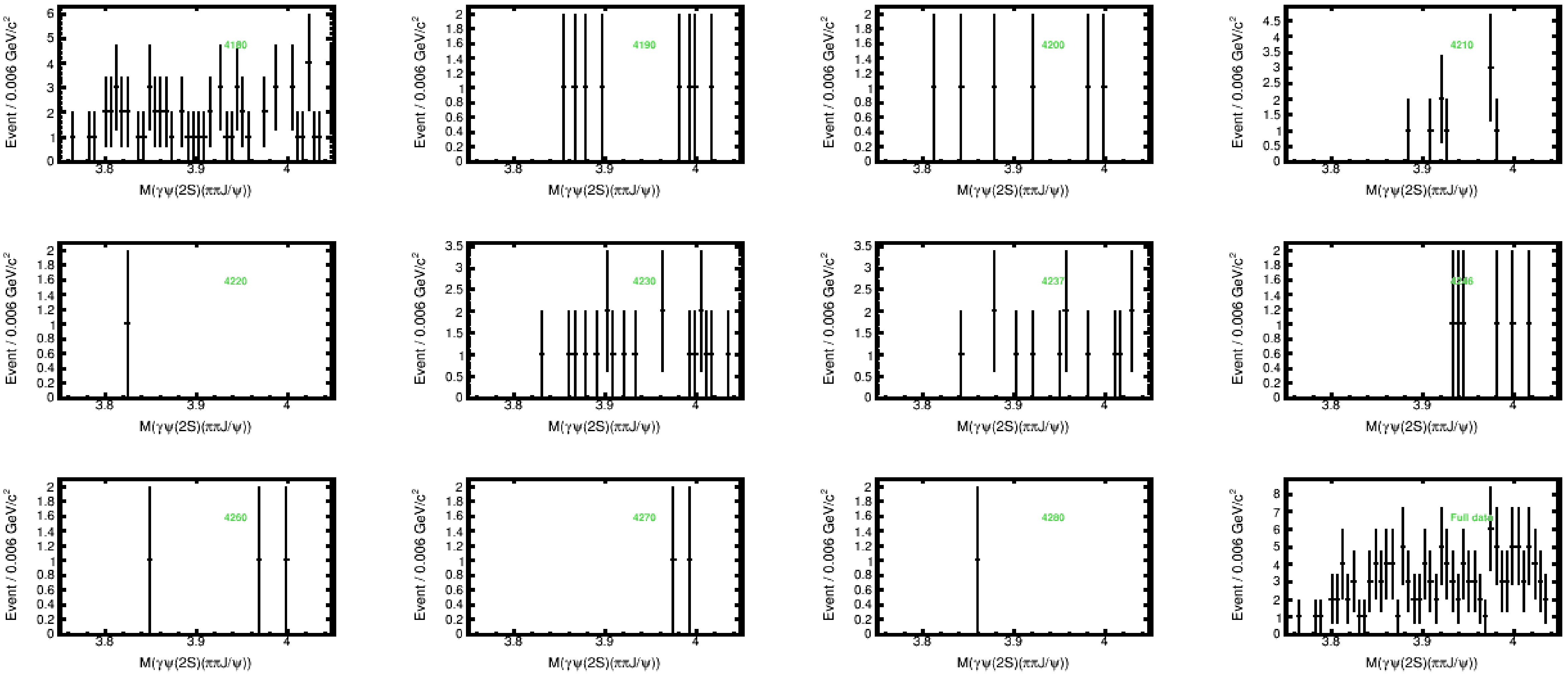
$$R \equiv \frac{\mathcal{B}\big(X(3872) \to \gamma\psi(2S)\big)}{\mathcal{B}(X(3872) \to \gamma J/\psi)}$$

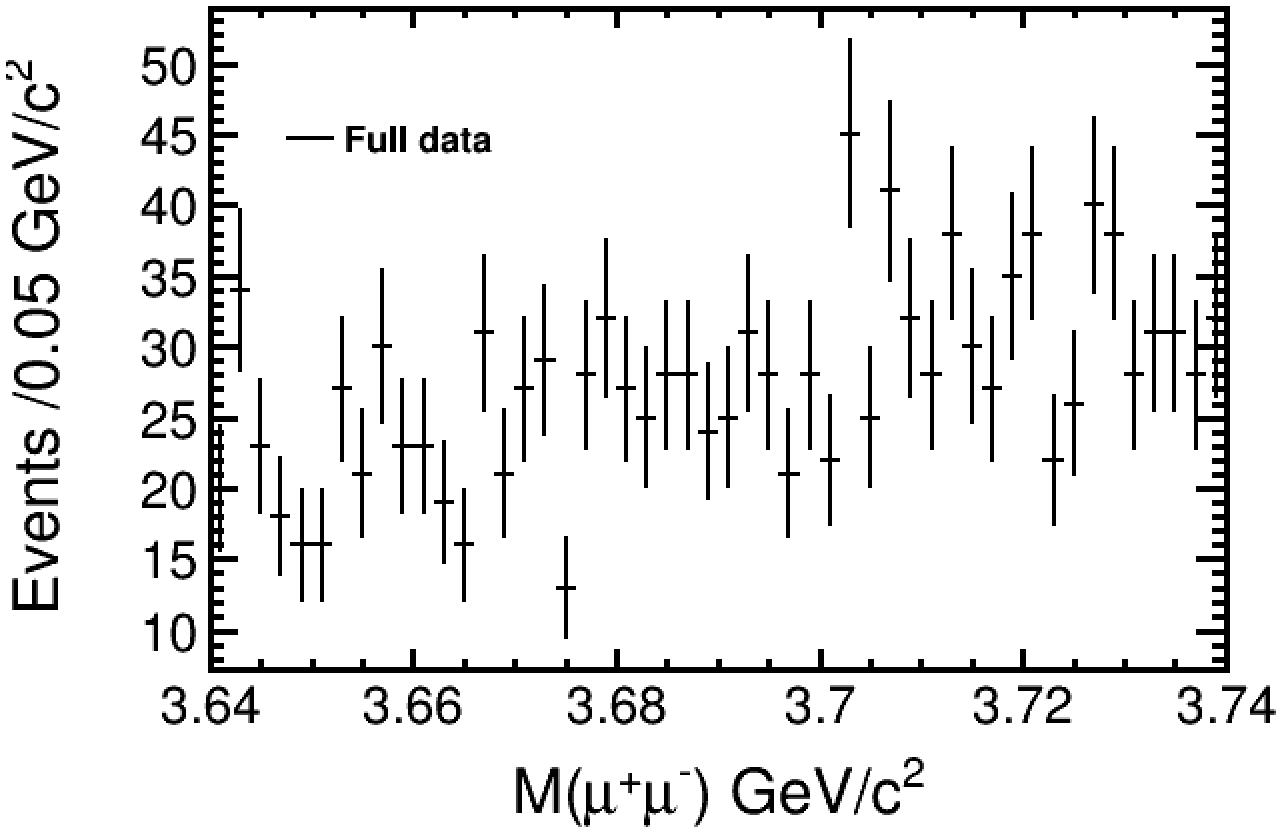
$$= \frac{N_{\gamma\psi(2S)}/\epsilon_{\gamma\psi(2S)}/\mathcal{B}(\psi(2S)\to\pi^+\pi^- J/\psi)}{N_{\gamma J/\psi}/\epsilon_{\gamma J/\psi}} = 0.2 \pm 0.4 (< 0.8 \text{ @ } 90\% \; C.L.)$$ (stat. err only)

- This result is consistent with Belle's result(~0.47), while is way much different from LHCb's result (~2.46).
- Next to do
  - Systematic uncertainty
  - Analysis on $X(3872) \to D^0 D^0 \pi^0, D^{\pm} D^{\mp *}, D^0 \overline{D^0} \gamma$ are urgent work to do

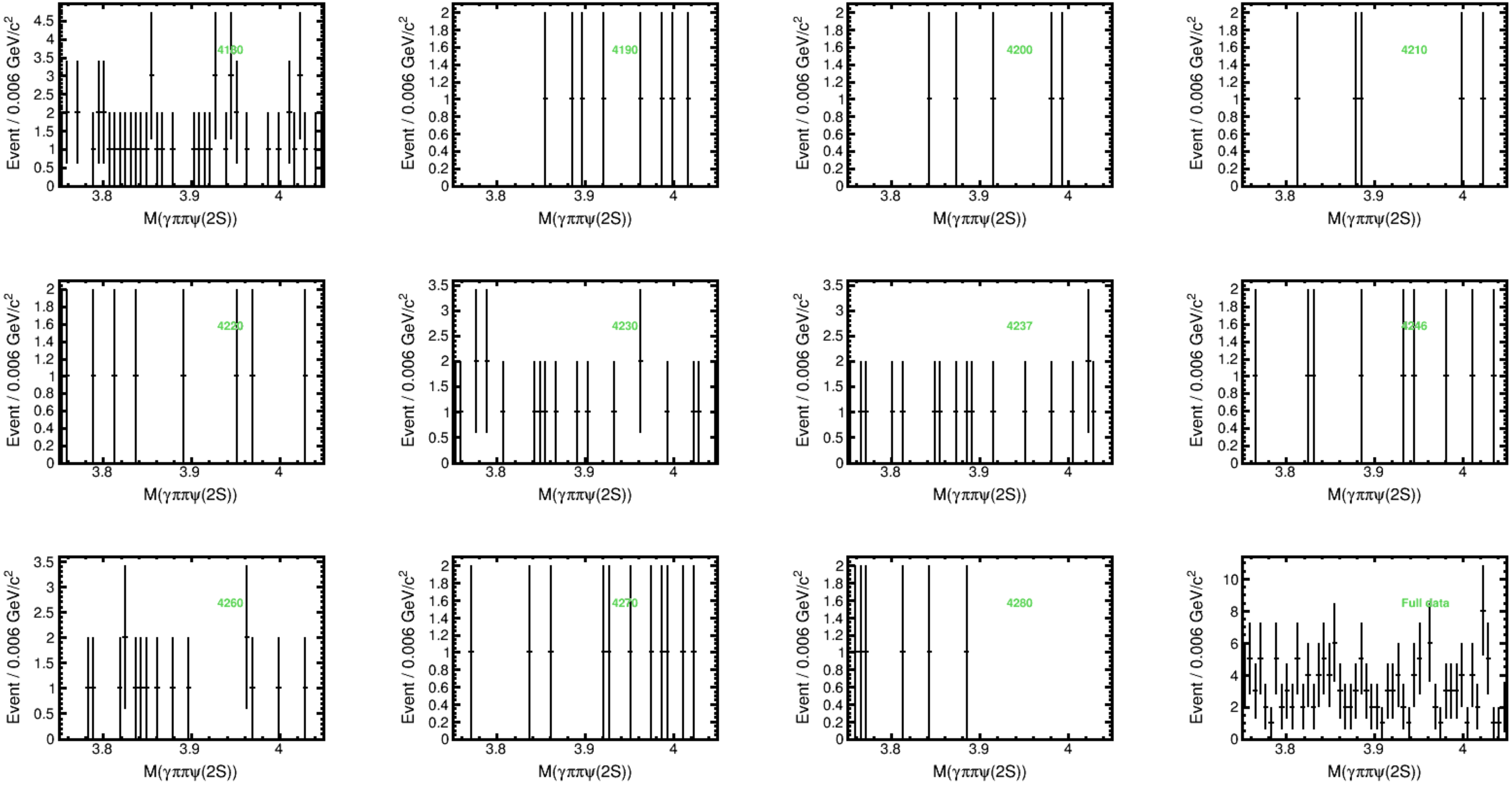


The process of $e^+e^- \to \pi^+\pi^-\psi(2S), \psi(2S) \to \gamma\chi_{cJ}, \chi_{cJ} \to \gamma J/\psi$ also share the same final states with the signal. We require $M(\gamma_H J/\psi) < 3.49$ to veto the $e^+e^- \to \pi^+\pi^-\psi(2S)$ backgrounds.


4180
4190
4200
4210
4220
4230
4237
4246
4260
4270
4280
Full data
Event / 0.006 GeV/c²
M(γψ(2S)(ππJ/ψ))



Require $\chi^2_{4C} < 40$, and the signal region $M(\gamma_L \pi\pi J/\psi) \in [3.85,\ 3.9]$ GeV/c2.
The signal of ψ' is not evident.
The $\psi' \to \mu\mu$ mode is not used.


4180
4190
4200
4210
4220
4230
4237
4246
4260
4270
4280
Full data
Event / 0.006 GeV/c²
M(γππψ(2S))

Fitting procedure

- For $X3872 \to \gamma J/\psi$

	Enlarge range	Normal range	Narrow range
2^{nd} order Chebychev	11.5%	-	8.3%
3^{rd} order Chebychev	5.6%	2.8%	5.2%

- For $X3872 \to \gamma\psi(2S)$

	Enlarge range	Normal range	Narrow range
3^{rd} order Chebychev	0.8	0.0	-0.8
2^{nd} order Chebychev	-2.1	-1.2	-1.3

- For $X3872 \to D^{*0}D$

	Enlarge range	Normal range	Narrow range
Argus Function	2.5%	-	0.4%
2^{nd} order Chebychev	12.7%	13.2%	10.1%