Study of $e^+e^- \to \pi^0 X(3872)\gamma$ line-shape and search for $Z_c(4020)^0 \to X(3872)\gamma$

Tengjiao Zhu[1] Zhiyong Wang[2] Jielei Zhang[1]
[1]Xinyang Normal University
[2]Insitute of High Energy Physics

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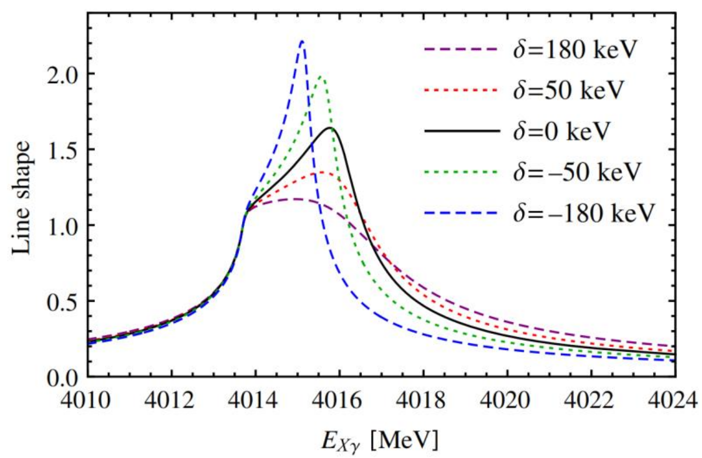
7. Summary

1.Motivation(1)

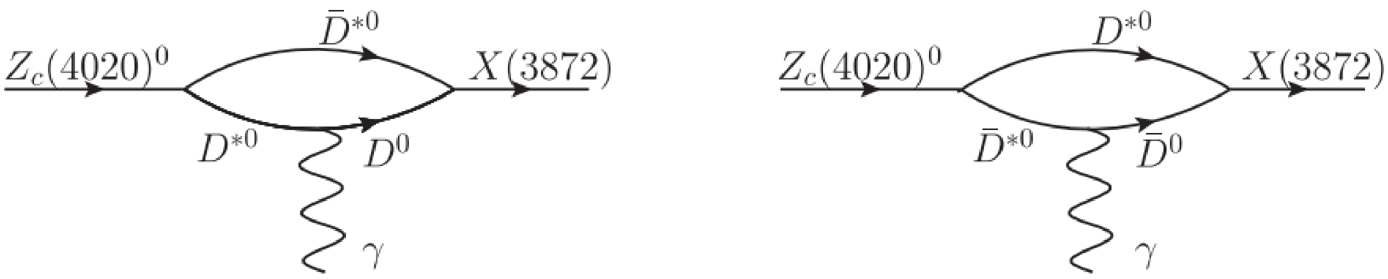
- The mass difference between $X(3872)$ and the $D^0\bar{D}^{*0}$ threshold can be expressed as $\delta \equiv m_{D^0} + m_{D^{*0}} - m_{X(3872)}$,which is about 180 keV. However, whether $X(3872)$ is exactly above or below the $D^0\bar{D}^{*0}$ threshold is still unknown. A completely new method to measure the $X(3872)$ mass precisely by measuring the $X(3872)\gamma$ line shape is proposed in *PRL122,202002* in which someone predicts that this line shape is very sensitive to the δ value (see the attached plot below).
- The method can be applied at electron-positron facilities such as BES-III and possible future super charm-tau facilities, where the **X(3872)γ** pair needs to be produced associated with another positive C-parity neutral meson, e.g., $e^+e^- \to \pi^0 X(3872)\gamma$. Therefore, we try to study the process $e^+e^- \to \pi^0 X(3872)\gamma$ at BES-III.



PRL122,202002(2019)

1.Motivation(2)

- In the scenario where $X(3872)$ is dominantly an S-wave $(D^0\bar{D}^{*0} + \bar{D}^0 D^{*0})/\sqrt{2}$ molecule and the $Z_c(4020)$ state is an isotopic triplet of near-threshold S-wave $D^*\bar{D}^*$ resonances, there should be transitions $Z_c(4020)^0 \rightarrow X(3872)\gamma$ induced by the free-meson processes $D^{*0} \rightarrow D^0\gamma$. Therefore, we can also try to search for the $Z_c(4020)^0$ via $e^+e^- \rightarrow \pi^0 X(3872)\gamma$ process at BES-III.



PRD99,054028(2019)

2.Strategy

- In this analysis, $X(3872)$ is reconstructed by $\pi^+\pi^-J/\psi$ final state, the J/ψ is reconstructed by lepton pair, the π^0 is reconstructed by photon pair. The decay chain is expressed as below:

$$e^+e^- \to \pi^0 X(3872)\gamma$$
$$\to \gamma\pi^0\pi^+\pi^-J/\psi \to \gamma\gamma\gamma\pi^+\pi^-e^+e^-/\mu^+\mu^-$$

and

$$e^+e^- \to \pi^0 Z_c(4020)^0 \to \pi^0 X(3872)\gamma$$
$$\to \gamma\pi^0\pi^+\pi^-J/\psi \to \gamma\gamma\gamma\pi^+\pi^-e^+e^-/\mu^+\mu^-$$

3.Data sets

Boss version: 7.0.3

$\sqrt{s}(GeV)$	$\mathcal{L}(pb^{-1})$	Run Number
4.178	3160	43716-47066
4.189	527	47543-48170
4.199	526	48172-48713
4.209	517	48714-49293
4.219	515	49270-49787
4.226	1056	32239-33484
4.236	530	49788-50254
4.244	538	50255-50793
4.258	828	29677-30367 31561-31981

$\sqrt{s}(GeV)$	$\mathcal{L}(pb^{-1})$	Run Number
4.267	531	50796-51302
4.278	176	51303-51498
4.358	544	30616-31279
4.416	1044	36773-38140
4.467	111	36245-36393
4.527	112	36398-36588
4.574	49	36603-36699
4.600	587	35227-36213

Boss version : 7.0.4

$\sqrt{s}(GeV)$	$\mathcal{L}(pb^{-1})$	Run Number
4.288	500	59902-60363
4.312	500	60364-60805
4.337	500	60808-61242
4.377	500	61249-61762
4.396	500	61763-62285
4.436	570	62286-62823

Signal MC1:

$e^+e^- \to \pi^0 X(3872)\gamma$, $X(3872) \to \pi^+\pi^- J/\psi$, $J/\psi \to e^+e^-/\mu^+\mu^-$, $\pi^0 \to \gamma\gamma$

Signal MC2:

$e^+e^- \to \pi^0 Z_c(4020)^0$,$Z_c(4020)^0 \to X(3872)\gamma$,$X(3872) \to \pi^+\pi^- J/\psi$, $J/\psi \to e^+e^-/\mu^+\mu^-$, $\pi^0 \to \gamma\gamma$

4.Event Selection

Charged tracks
- $|R_{xy}| < 1cm, |R_z| < 10cm$
- $|cos\theta| < 0.93$
- $N = 4, \sum Q = 0$

Particle separation
- π : $P_{mdc} < 1$ GeV
- e : $P_{mdc} > 1$ GeV&&$E_{emc} > 1$ GeV
- μ : $P_{mdc} > 1$ GeV&&$E_{emc} < 0.4$ GeV

Good photon
- $0 \le TDC \le 14$
- Barrel :
  $E > 0.025$ GeV, $|cos\theta| < 0.8$
- End cap :
  $E > 0.050$ GeV, $0.86 < |cos\theta| < 0.92$
- $\Delta\theta > 10^0$
- $3 \le N_\gamma \le 15$

π^0 selection
- $\mathrm{M}(\gamma\gamma)$: (0.11, 0.15) GeV

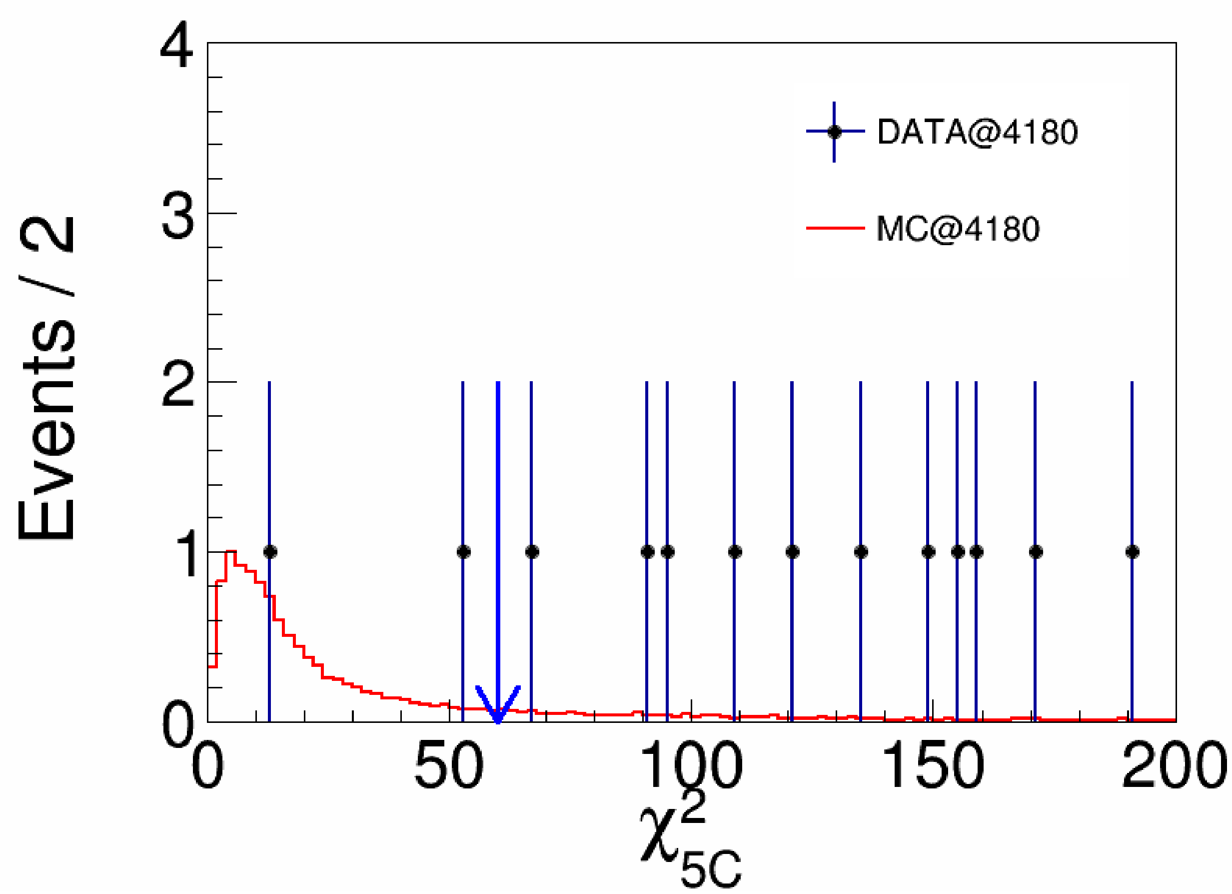
5C kinematic fit
- $\mathrm{M}(\gamma\gamma)$ is constrained to $\mathrm{M}(\pi^0)$
- Choose the photons with least χ^2
- $\chi^2_{5C} < 60$

Other selections
- J/ψ mass window : $(3.08, 3.12)$ GeV

5. Study of $e^+e^- \to \pi^0 X(3872)\gamma$ line-shape

We generate MC1($e^+e^- \to \pi^0 X(3872)\gamma$, $X(3872) \to \pi^+\pi^- J/\psi$, $J/\psi \to e^+e^-/\mu^+\mu^-$, $\pi^0 \to \gamma\gamma$) , and we use data at $\sqrt{s} = 4.178$ GeV to introduce the analysis method.

5.1 MC and data analysis

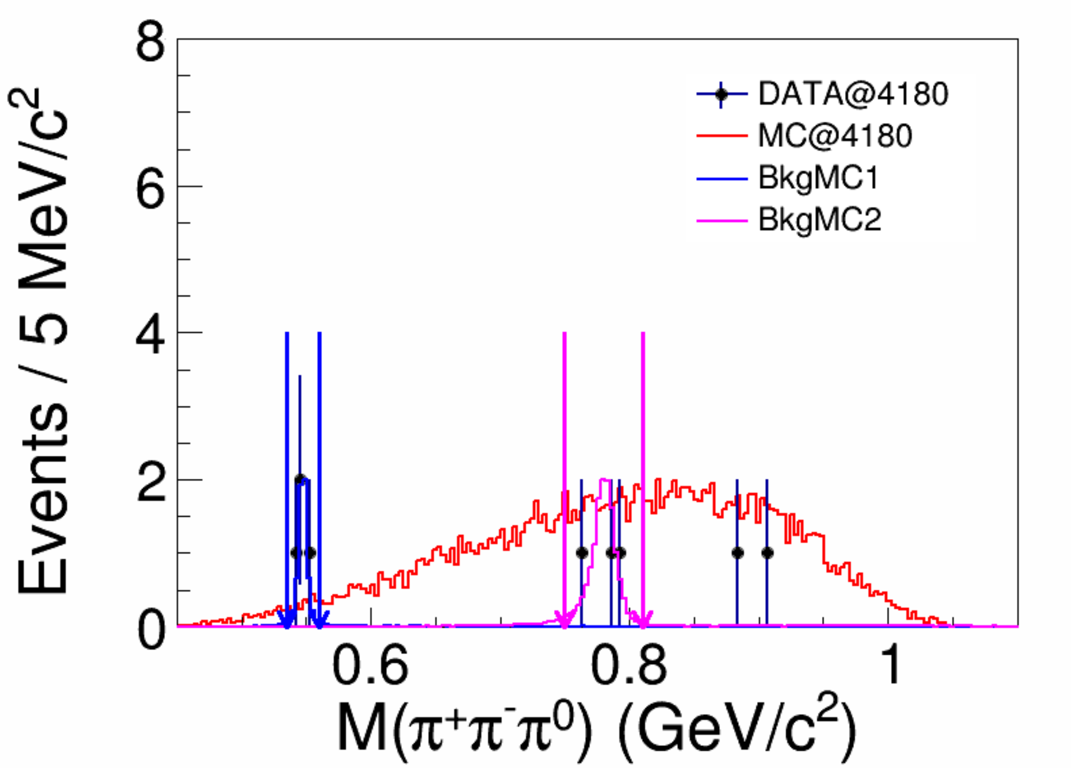


χ^2 distribution : $\chi^2_{5C} < 60$

5.1 MC and data analysis

BkgMC1: $\eta \to \pi^+\pi^-\pi^0$.

BkgMC2: $\omega \to \pi^+\pi^-\pi^0$.

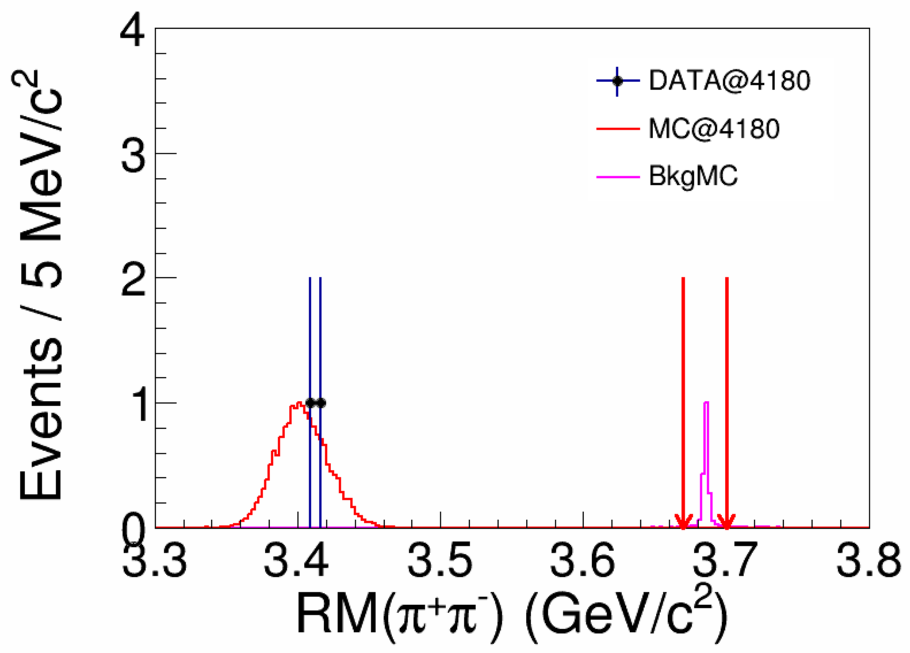


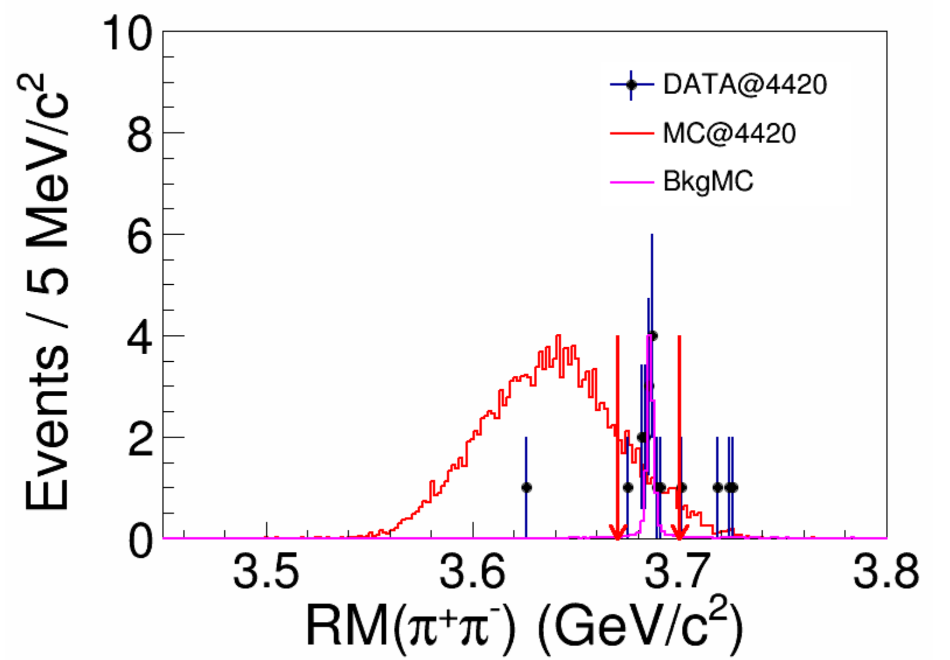
$$M(\pi^+\pi^-\pi^0) < 0.535\ \mathrm{GeV} || M(\pi^+\pi^-\pi^0) > 0.56\ \mathrm{GeV}$$

$$M(\pi^+\pi^-\pi^0) < 0.75\ \mathrm{GeV} || M(\pi^+\pi^-\pi^0) > 0.81\ \mathrm{GeV}$$

5.1 MC and data analysis

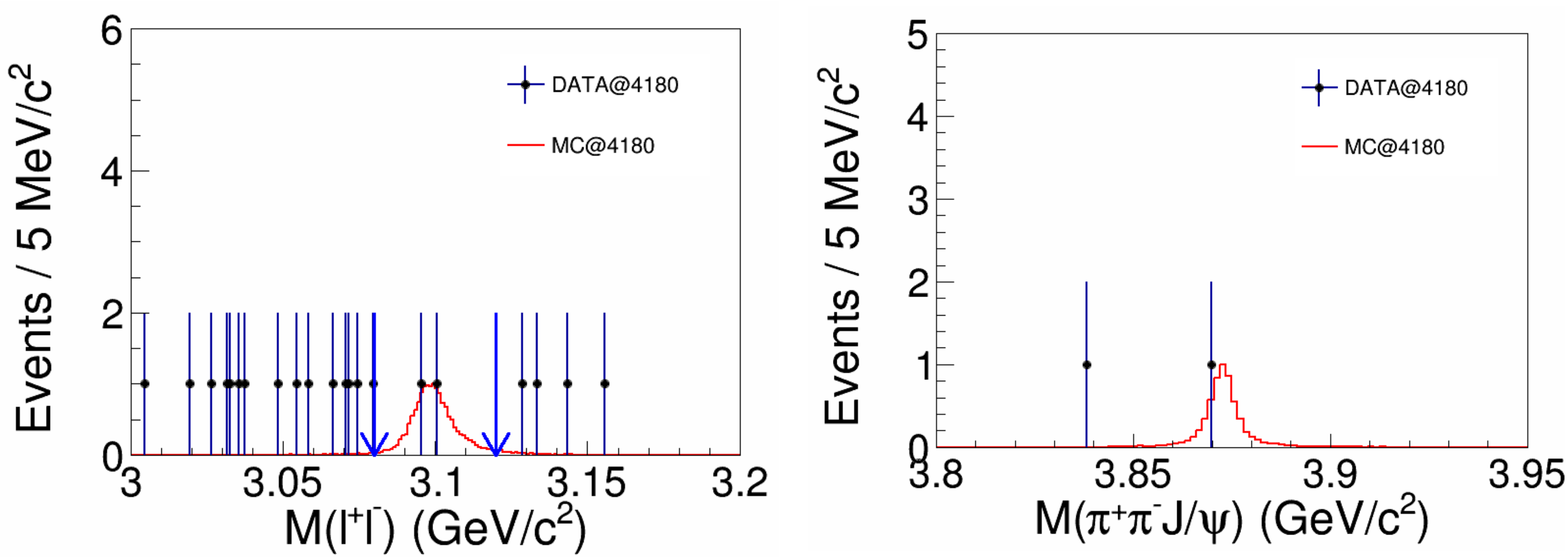
BkgMC: $e^+e^- \to \pi^+\pi^-\psi(2S)$





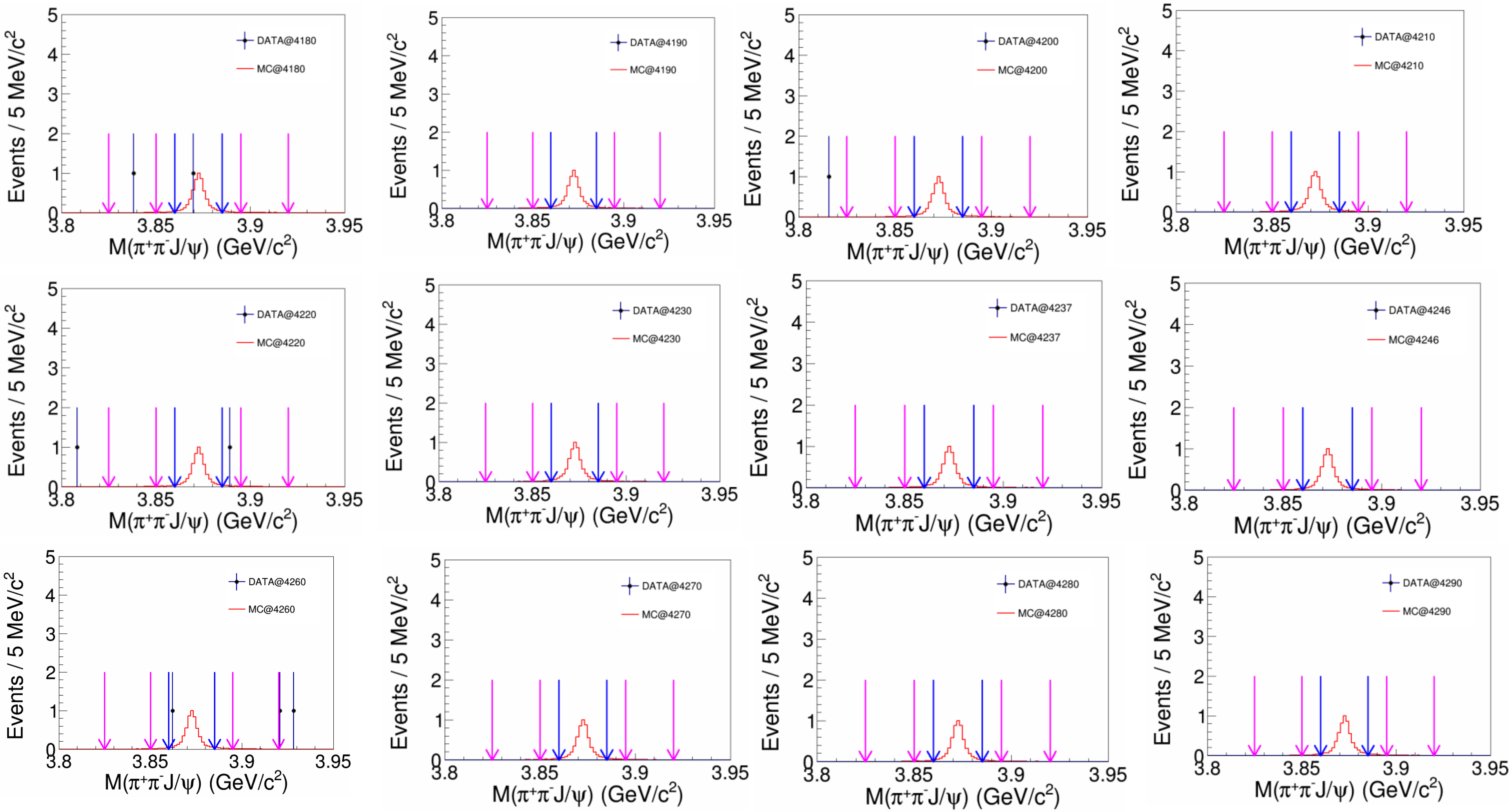
$$RM(\pi^+\pi^-) < 3.67\ \text{GeV} || RM(\pi^+\pi^-) > 3.7\ \text{GeV}$$

5.1 MC and data analysis



J/ψ Signal region: (3.08,3.12) GeV
We search for the $X(3872)$ signal in $X(3872)$ signal region and estimate the number of background events in sideband region.

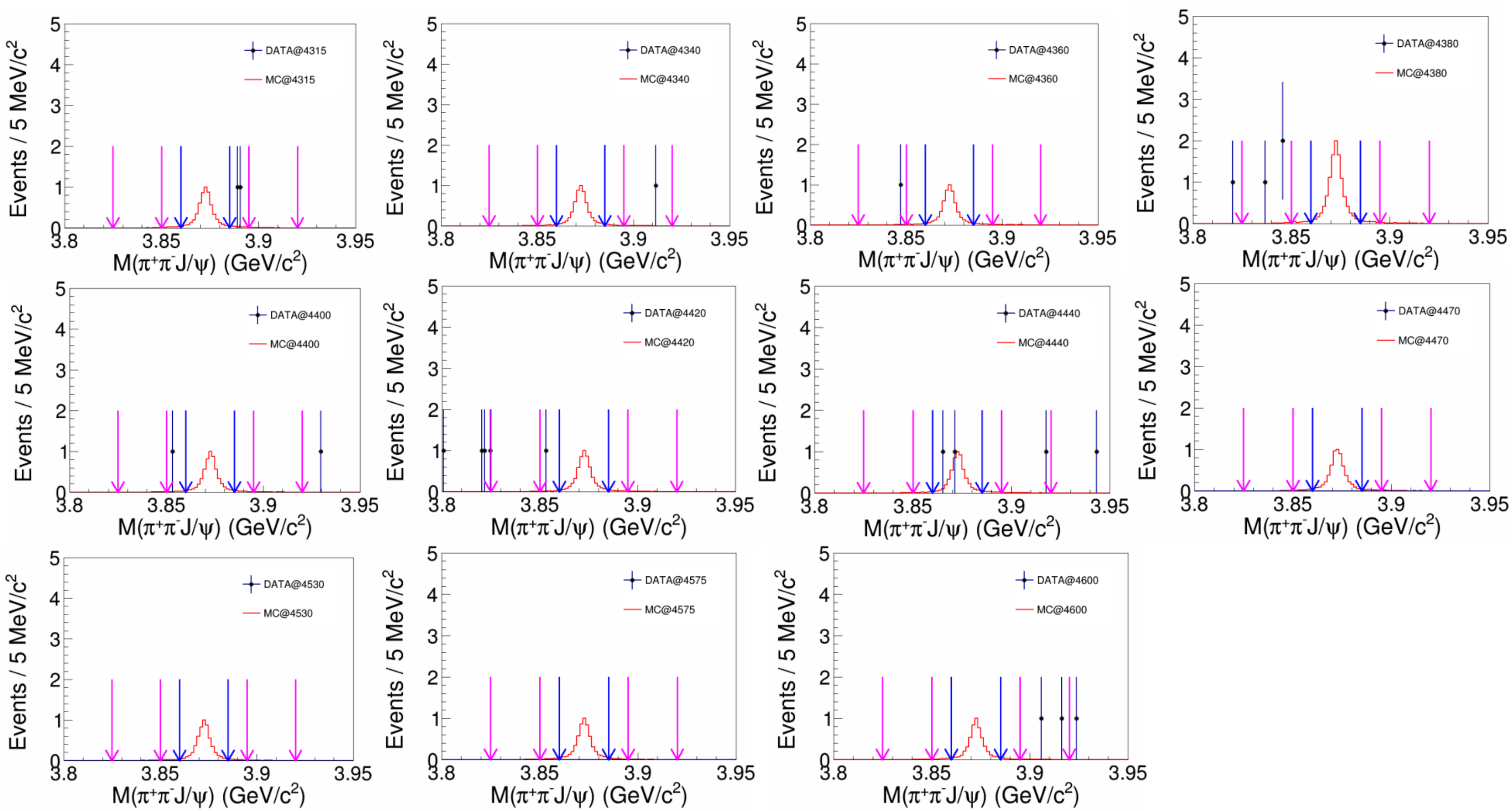
5.1 MC and data analysis



Signal region: (3.86,3.885) GeV

Sideband region: (3.825,3.85) GeV and (3.895,3.92) GeV

5.1 MC and data analysis



Signal region:(3.86,3.885) GeV

Sideband region:(3.825,3.85) GeV and (3.895,3.92) GeV

5.1 MC and data analysis

$\sqrt{s}(GeV)$	N^{obs}	N^{sid}	N
4.178	1	1	<2.5
4.189	0	0	<2.0
4.199	0	0	<2.0
4.209	0	0	<2.0
4.219	0	0	<2.0
4.226	0	0	<2.0
4.236	0	0	<2.0
4.244	0	0	<2.0
4.258	1	0	<3.7
4.267	0	0	<2.0
4.278	0	0	<2.0
4.288	0	0	<2.0

$\sqrt{s}(GeV)$	N^{obs}	N^{sid}	N
4.312	**0**	**0**	**<2.0**
4.337	**0**	**1**	**<0.8**
4.358	**0**	**1**	**<0.8**
4.377	**0**	**3**	**<1.3**
4.396	**0**	**0**	**<2.0**
4.416	**0**	**0**	**<2.0**
4.436	**2**	**1**	**<4.1**
4.467	**0**	**0**	**<2.0**
4.527	**0**	**0**	**<2.0**
4.574	**0**	**0**	**<2.0**
4.600	**0**	**2**	**<1.2**

N^{obs} is the number of events in signal region , N^{sid} is the number of events in sideband region, N is the upper limit(at the 90%C.L.). We use the TRolke (in the root) to get the upper limit (at the 90%C.L.)(include systematic uncertainty).

5.1 MC and data analysis

$$\sigma(e^+e^- \to \pi^0 X(3872)\gamma)\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) = \frac{N}{\mathcal{L}(1+\delta)\frac{1}{|1-\Pi^2|}\varepsilon\mathcal{B}(J/\psi \to l^+l^-)\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

$\sqrt{s}(GeV)$	$\mathcal{L}_{int}(pb^{-1})$	$\boldsymbol{N}$	$1+\delta$	$\frac{1}{\lvert 1-\Pi\rvert^2}$	$\varepsilon(\%)$	$\boldsymbol{\sigma \cdot \mathcal{B}(pb)}$
4.178	3160	<2.5	0.70	1.055	11.74	<0.08
4.189	527	<2.0	0.70	1.056	11.92	<0.36
4.199	526	<2.0	0.70	1.057	12.21	<0.35
4.209	517	<2.0	0.71	1.057	12.07	<0.36
4.219	515	<2.0	0.70	1.057	12.25	<0.35
4.226	1056	<2.0	0.74	1.056	12.49	<0.16
4.236	530	<2.0	0.76	1.056	12.35	<0.32
4.244	538	<2.0	0.78	1.056	12.37	<0.31
4.258	828	<3.7	0.82	1.054	12.23	<0.36
4.267	531	<2.0	0.83	1.053	12.06	<0.30
4.278	176	<2.0	0.84	1.053	11.63	<0.93
4.288	500	<2.0	0.84	1.053	11.60	<0.33

5.1 MC and data analysis

$$\sigma(e^+e^- \to \pi^0 X(3872)\gamma)\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) = \frac{N}{\mathcal{L}(1+\delta)\frac{1}{|1-\Pi^2|}\varepsilon\mathcal{B}(J/\psi \to l^+l^-)\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

$\sqrt{s}(GeV)$	$\mathcal{L}_{int}(pb^{-1})$	$\boldsymbol{N}$	$1+\delta$	$\frac{1}{\lvert 1-\Pi\rvert^2}$	$\varepsilon(\%)$	$\boldsymbol{\sigma\cdot\mathcal{B}(pb)}$
4.312	500	<2.0	0.84	1.052	11.64	<0.33
4.337	500	<0.8	0.83	1.051	12.11	<0.13
4.358	544	<0.8	0.83	1.051	12.58	<0.11
4.377	500	<1.3	0.84	1.052	12.28	<0.20
4.396	500	<2.0	0.86	1.051	11.67	<0.32
4.416	1044	<2.0	0.90	1.052	12.26	<0.14
4.436	570	<4.1	0.97	1.054	8.64	<0.69
4.467	111	<2.0	1.09	1.055	10.47	<1.26
4.527	112	<2.0	1.38	1.055	8.58	<1.21
4.574	49	<2.0	1.62	1.055	7.59	<2.65
4.600	587	<1.2	1.76	1.055	7.10	<0.13

5.2 Systematic uncertainty estimation

(1) Luminosity (1%)

(2) Tracking (1% per track)

(3) Photon (1% per photon)

(4) Kinematic fit

The difference in MC efficiency between before and after the helix parameters correction is taken as the systematic uncertainty.

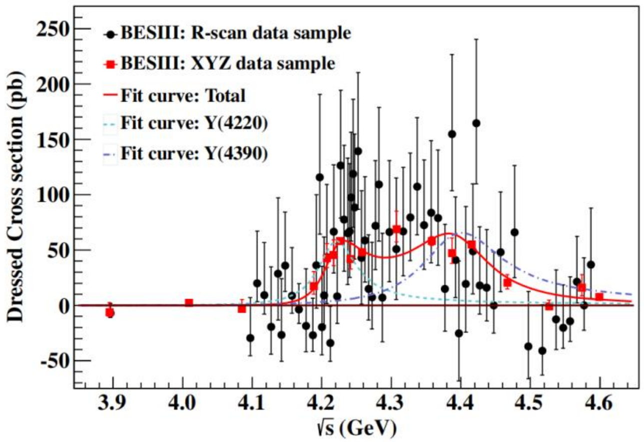
5.2 Systematic uncertainty estimation

(5) J/ψ mass window

Choosing the control sample $e^+e^- \to \gamma_{ISR}\psi', \psi' \to \pi^+\pi^- J/\psi$ events to study the systematic uncertainty from J/ψ mass window. The efficiency difference between data and MC is about 1.6%.

(6) Line shape

We take a coherent sum of $Y(4220)$ BW function and $Y(4390)$ BW function as the line-shape to get the nominal results. And to get uncertainty, we change the line-shape to the $\psi(4260)$ BW function or $\psi(4415)$ BW function in PDG, the largest of difference is taken as the systematic uncertainty.



PRL 118,092002(2017)

5.2 Systematic uncertainty estimation

(7) Generator model

We use the $e^+e^- \to \pi^0 X(3872)\gamma$ three-body phase-space MC to get the normal results, and change the MC to $e^+e^- \to \pi^0 Z_c(4020)^0$, $Z_c(4020)^0 \to X(3872)\gamma$ two–body phase-space MC to get the uncertainty.

(8) Branching fraction

The systematic uncertainty of the branching fraction is quoted from PDG.

5.2 Systematic uncertainty estimation

Relative systematic uncertainties (in %) from the different sources

Source/$\sqrt{s}(GeV)$	4.178	4.189	4.199	4.209	4.219	4.226	4.236	4.244	4.258	4.267	4.278	4.288
Luminosity	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tracking efficiency	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Photon detection	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kinematic fit	2.3	2.7	2.6	2.5	2.2	2.3	2.5	2.5	2.1	2.7	2.4	2.2
J/ψ mass window	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Line shape	6.1	5.3	4.5	4.9	1.0	1.0	1.1	3.6	4.4	5.7	6.5	7.7
Generator model	8.5	5.4	2.1	1.7	0.1	1.6	0.3	1.5	0.2	2.1	2.5	1.4
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sum	12.0	9.7	7.8	7.9	5.9	6.2	6.1	7.1	7.3	8.6	9.1	9.8

5.2 Systematic uncertainty estimation

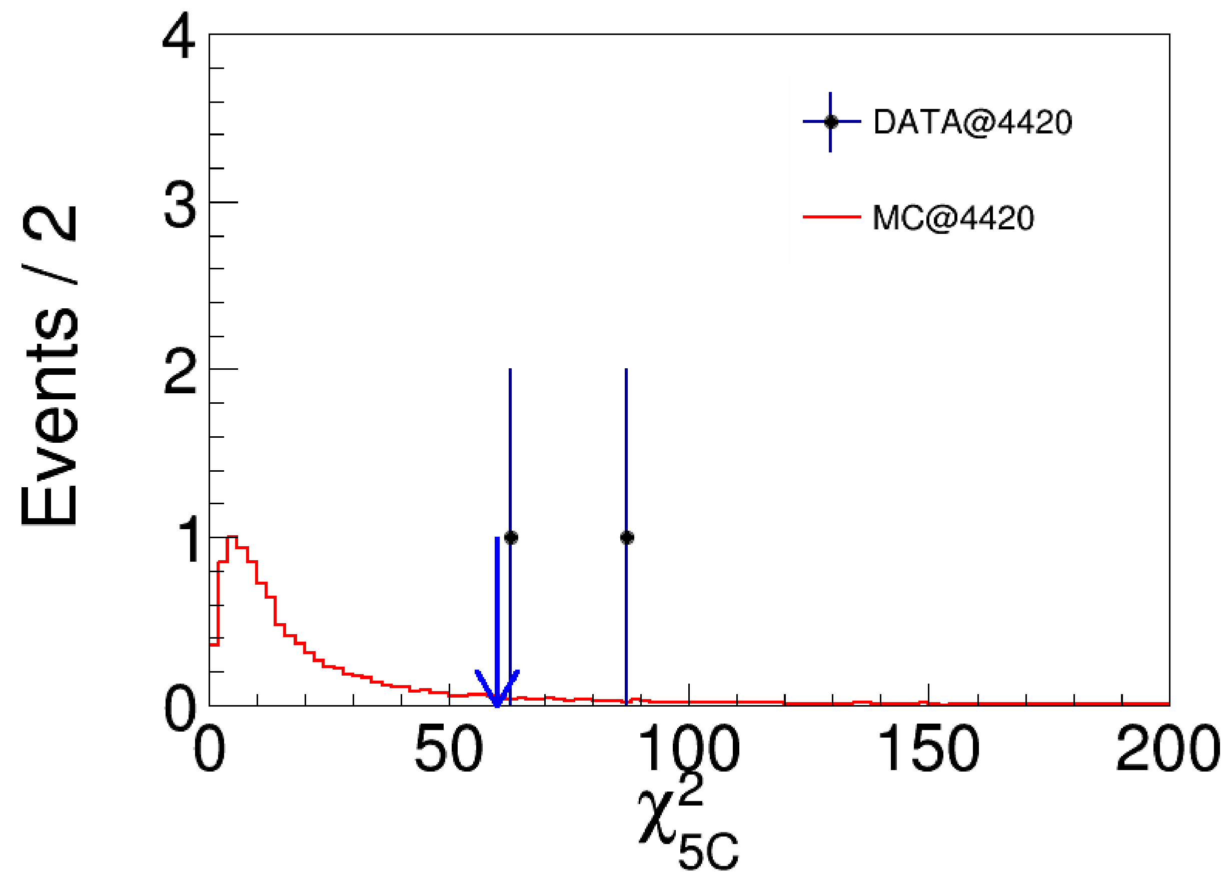
Relative systematic uncertainties (in %) from the different sources

Source/$\sqrt{s}(GeV)$	4.312	4.337	4.358	4.377	4.396	4.416	4.436	4.467	4.527	4.575	4.600
Luminosity	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tracking efficiency	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Photon detection	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kinematic fit	2.2	2.2	2.4	2.2	2.3	1.8	2.1	2.7	2.1	2.3	2.8
J/ψ mass window	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
Line shape	8.6	7.5	4.3	5.4	4.6	5.8	2.0	5.4	1.9	3.0	2.0
Generator model	2.9	4.7	4.9	4.6	7.4	8.1	11.4	11.1	11.9	11.4	8.2
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sum	10.8	10.6	8.8	9.2	10.5	11.5	13.0	13.8	13.4	13.1	10.4

6.Search for $Z_c(4020)^0 \to \pi^0 X(3872)\gamma$

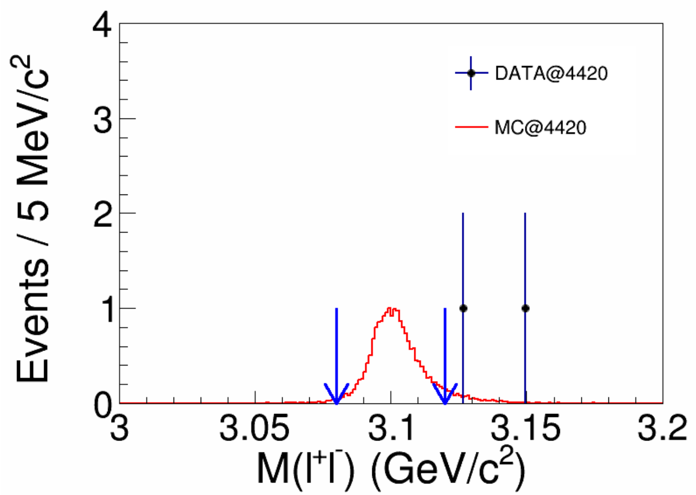
We generate MC2($e^+e^- \to \pi^0 Z_c(4020)^0$,$Z_c(4020)^0 \to X(3872)\gamma$,$X(3872) \to \pi^+\pi^- J/\psi$, $J/\psi \to e^+e^-/\mu^+\mu^-$, $\pi^0 \to \gamma\gamma$), and we use data at $\sqrt{s} = 4.416$ GeV to introduce the analysis method.

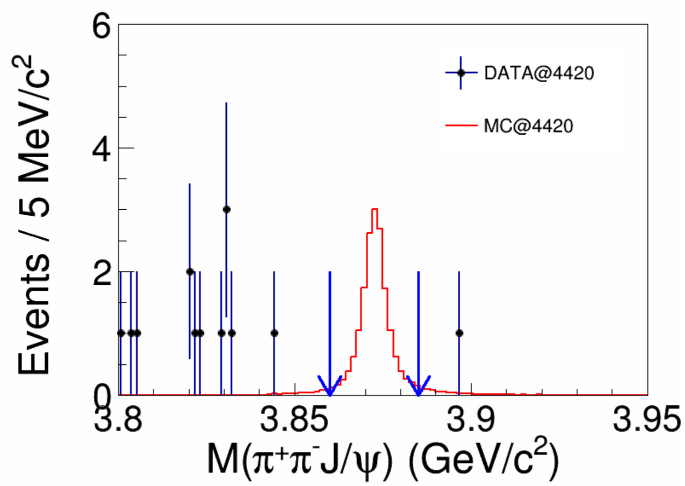
6.1 MC and data analysis



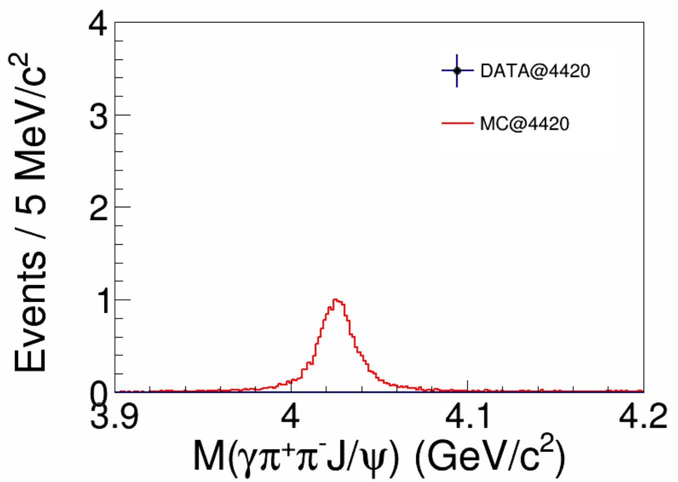
χ^2 distribution : $\chi^2_{5C} < 60$

6.1 MC and data analysis



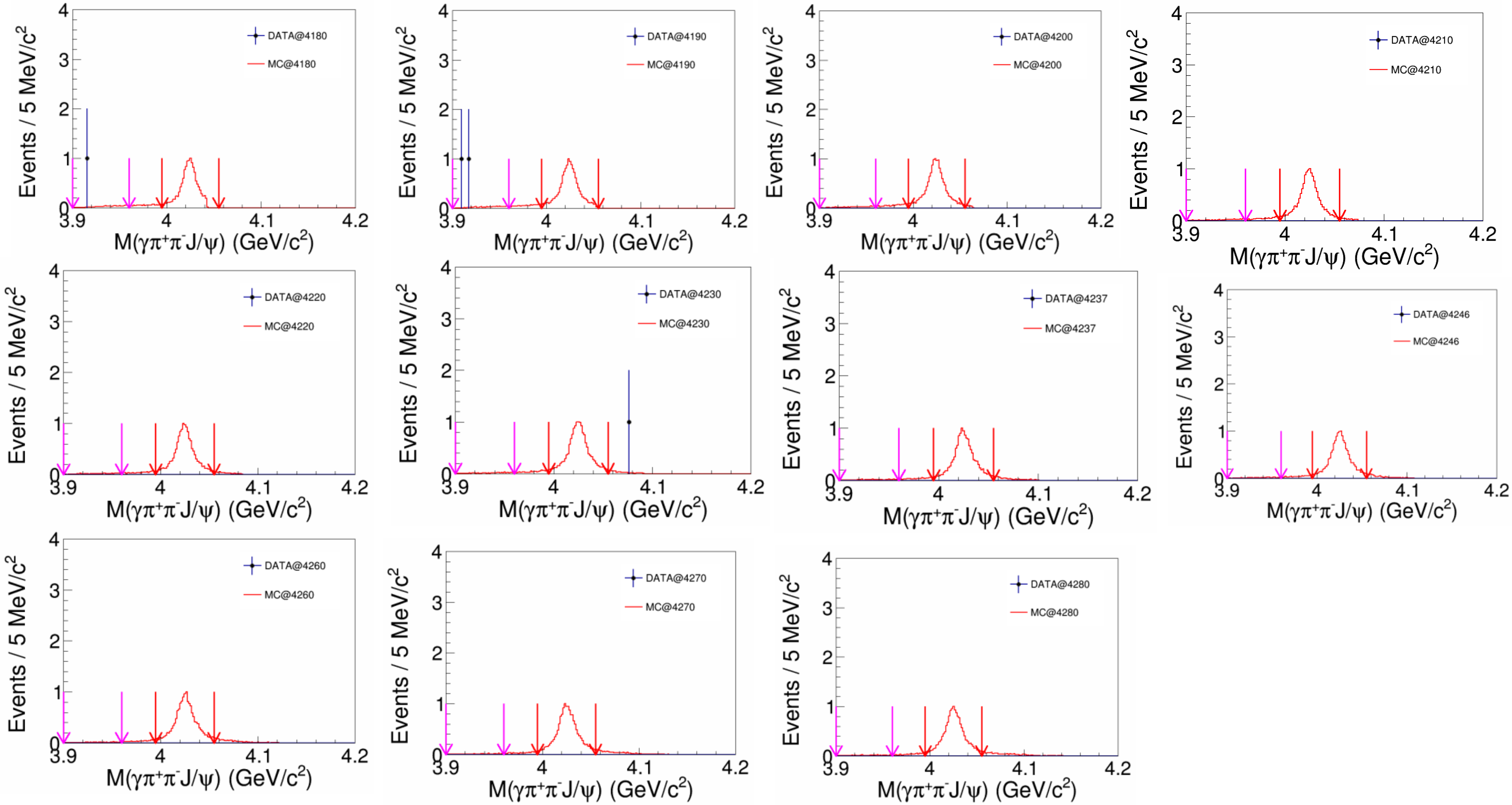


J/ψ Signal region: (3.08,3.12) GeV $X(3872)$ Signal region: (3.86,3.885) GeV



We search for the $Z_c(4020)^0$ signal in $Z_c(4020)^0$ signal region and estimate the number of background events in sideband region.

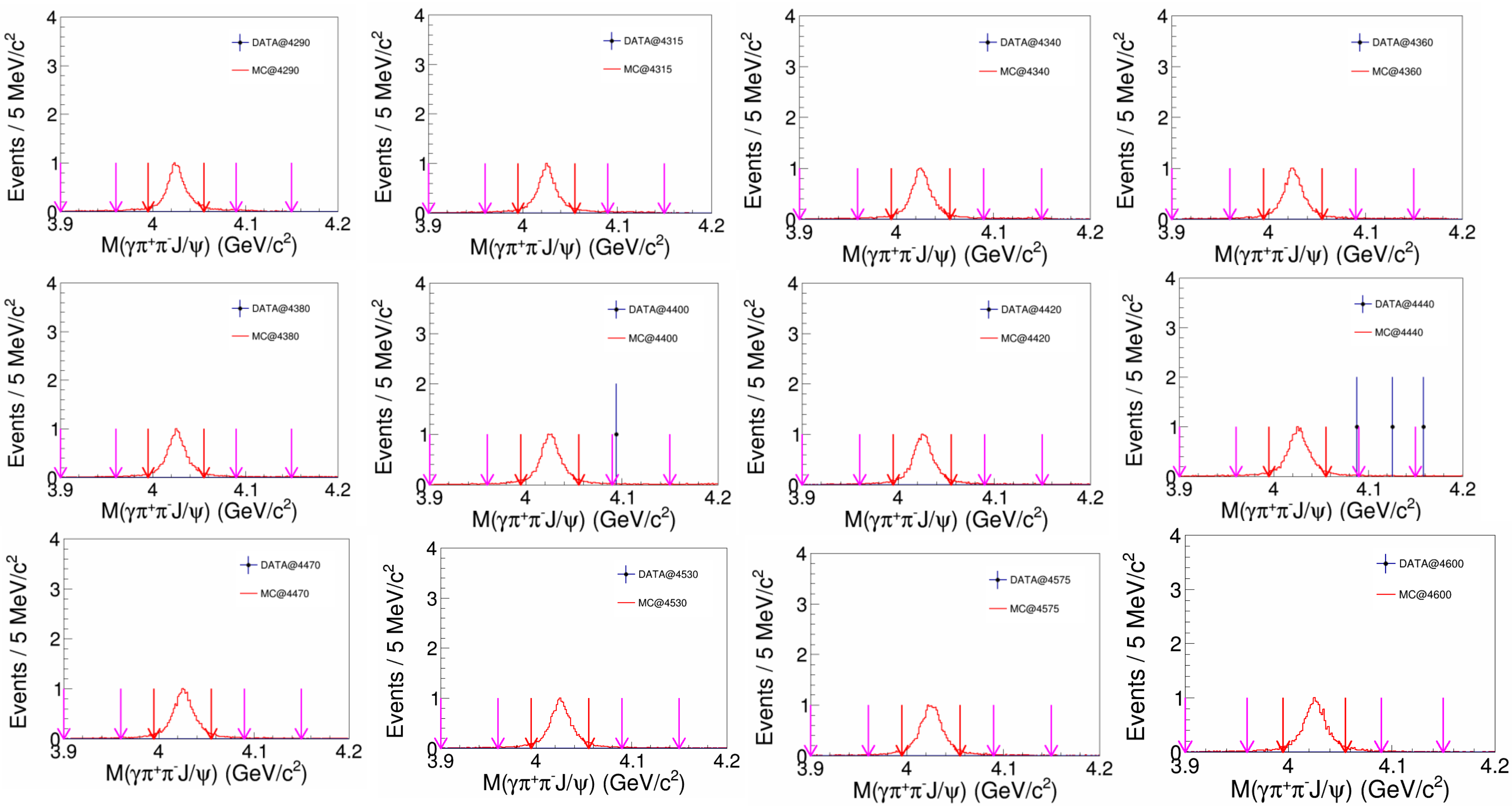
6.1 MC and data analysis



Signal region:(3.995,4.055) GeV   Sideband region:(3.9,3.96) GeV and (4.09,4.15) GeV

If $\sqrt{s}$<4.28 GeV, due to the restriction of phase-space, we only choose the left sideband region.

6.1 MC and data analysis



Signal region:(3.995,4.055) GeV

Sideband region:(3.9,3.96) GeV , (4.09,4.15) GeV

6.1 MC and data analysis

$\sqrt{s}(GeV)$	N^{obs}	N^{sid}	N
4.178	0	1	<1.3
4.189	0	2	<0.5
4.199	0	0	<2.0
4.209	0	0	<2.0
4.219	0	0	<2.0
4.226	0	0	<2.0
4.236	0	0	<2.0
4.244	0	0	<2.0
4.258	0	0	<2.0
4.267	0	0	<2.0
4.278	0	0	<2.0
4.288	0	0	<2.0

$\sqrt{s}(GeV)$	N^{obs}	N^{sid}	N
4.312	0	0	<2.0
4.337	0	0	<2.0
4.358	0	0	<2.0
4.377	0	0	<2.0
4.396	0	1	<0.8
4.416	0	0	<2.0
4.436	0	1	<0.8
4.467	0	0	<2.0
4.527	0	0	<2.0
4.574	0	0	<2.0
4.600	0	0	<2.1

N^{obs} is the number of events in signal region , N^{sid} is the number of events in sideband region, N is the upper limit(at the 90%C.L.). We use the TRolke (in the root) to get the upper limit (at the 90%C.L.)(include systematic uncertainty).

6.1 MC and data analysis

$$\sigma(e^+e^- \to \pi^0 Z_c(4020)^0)\mathcal{B}(Z_c(4020)^0 \to X(3872)\gamma)\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) = \frac{N}{\mathcal{L}(1+\delta)\frac{1}{|1-\Pi^2|}\varepsilon\mathcal{B}(J/\psi \to l^+l^-)\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

$\sqrt{s}(GeV)$	$\mathcal{L}_{int}(pb^{-1})$	N	$1+\delta$	$\frac{1}{\lvert 1-\Pi\rvert^2}$	$\varepsilon(\%)$	$\sigma\cdot\mathcal{B}(pb)$
4.178	3160	<1.3	0.69	1.055	13.69	<0.03
4.189	527	<0.5	0.70	1.056	13.69	<0.08
4.199	526	<2.0	0.70	1.057	13.61	<0.32
4.209	517	<2.0	0.71	1.057	13.41	<0.32
4.219	515	<2.0	0.72	1.057	13.50	<0.32
4.226	1056	<2.0	0.74	1.056	13.81	<0.15
4.236	530	<2.0	0.76	1.056	13.25	<0.30
4.244	538	<2.0	0.78	1.056	13.82	<0.30
4.258	828	<2.0	0.81	1.054	13.44	<0.19
4.267	531	<2.0	0.83	1.053	12.05	<0.30
4.278	176	<2.0	0.84	1.053	11.80	<0.92
4.288	500	<2.0	0.84	1.053	11.50	<0.33

6.1 MC and data analysis

$$\sigma(e^+e^- \to \pi^0 Z_c(4020)^0)\mathcal{B}(Z_c(4020)^0 \to X(3872)\gamma)\mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi) = \frac{N}{\mathcal{L}(1+\delta)\frac{1}{|1-\Pi^2|}\varepsilon\mathcal{B}(J/\psi \to l^+l^-)\mathcal{B}(\pi^0 \to \gamma\gamma)}$$

$\sqrt{s}(GeV)$	$\mathcal{L}_{int}(pb^{-1})$	N	$1+\delta$	$\frac{1}{\|1-\Pi\|^2}$	$\varepsilon(\%)$	$\sigma \cdot \mathcal{B}(pb)$
4.312	500	<2.0	0.84	1.052	11.43	<0.33
4.337	500	<2.0	0.83	1.051	11.83	<0.33
4.358	544	<2.0	0.83	1.051	12.24	<0.29
4.377	500	<2.0	0.84	1.052	11.91	<0.32
4.396	500	<0.8	0.86	1.051	11.93	<0.13
4.416	1044	<2.0	0.90	1.052	12.00	<0.14
4.436	570	<0.8	0.97	1.054	11.41	<0.10
4.467	111	<2.0	1.09	1.055	10.30	<1.28
4.527	112	<2.0	1.38	1.055	8.42	<1.23
4.574	49	<2.0	1.62	1.055	7.42	<2.71
4.600	587	<2.1	1.75	1.055	6.72	<0.24

6.2 Systematic uncertainty estimation

(1) Luminosity (1%)

(2) Tracking (1% per track)

(3) Photon (1% per photon)

(4) Kinematic fit

The difference in MC efficiency between before and after the helix parameters correction is taken as the systematic uncertainty.

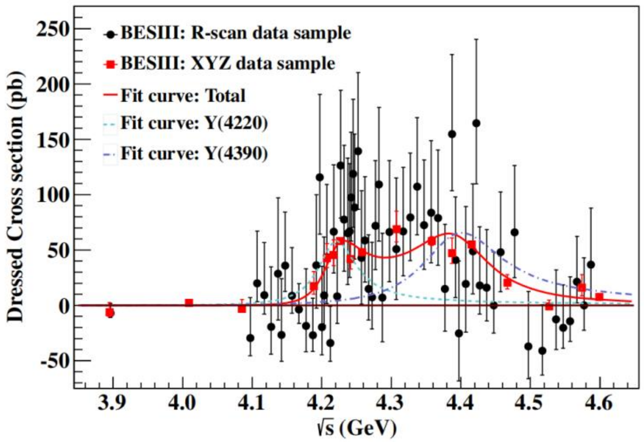
6.2 Systematic uncertainty estimation

(5) J/ψ mass window

Choosing the control sample $e^+e^- \to \gamma_{ISR}\psi', \psi' \to \pi^+\pi^- J/\psi$ events to study the systematic uncertainty from J/ψ mass window. The efficiency difference between data and MC is about 1.6%.

(6) Line shape

We take a coherent sum of $Y(4220)$ BW function and $Y(4390)$ BW function as the line-shape to get the nominal results. And to get uncertainty, we change the line-shape to the $\psi(4260)$ BW function or $\psi(4415)$ BW function in PDG, the largest of difference is taken as the systematic uncertainty.



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6.2 Systematic uncertainty estimation

(7) $X(3872)$ mass window

The $X(3872)$ mass window is shifted by 10% in both directions and the largest difference of the resulting efficiency from the standard efficiency is taken as systematic uncertainty.

(8) $Z_c(4020)^0$ parameters

The mass and width of $Z_c(4020)^0$ are shifted by $\pm 1\sigma$, then largest difference of the efficiency is taken as systematic uncertainty.

(9) Angular distribution

We generate a MC sample with phase-space of $e^+e^- \to \pi^0 Z_c(4020)^0$ to get the normal results, and changing the MC sample from phase-space to angular distribution of $1 \pm \cos^2\theta$ to get the systematic uncertainty.

(10) Branching fraction

The systematic uncertainty of the branching fraction is quoted from PDG.

6.2 Systematic uncertainty estimation

Relative systematic uncertainties (in %) from the different sources

Source/$\sqrt{s}(GeV)$	4.178	4.189	4.199	4.209	4.219	4.226	4.236	4.244	4.258	4.267	4.278	4.288
Luminosity	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tracking efficiency	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Photon detection	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kinematic fit	2.1	2.1	2.0	2.5	2.2	2.8	2.5	2.1	2.5	3.1	2.2	2.1
J/ψ mass window	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
$X(3872)$ mass window	1.4	1.3	1.3	1.5	1.4	1.4	1.4	1.3	1.4	1.4	1.5	1.4
Line shape	6.6	5.9	5.5	3.5	2.6	1.2	1.6	2.9	7.0	7.8	5.1	5.3
$Z_c(4020)^0$ parameters	3.8	3.0	5.1	4.7	5.1	4.8	5.0	6.9	5.7	4.7	6.6	4.3
Angular distribution	2.2	4.0	6.0	3.3	6.4	8.7	9.1	10.4	12.4	12.5	12.9	14.2
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sum	9.9	9.8	11.3	9.1	10.5	11.8	12.1	13.3	17.0	17.0	15.9	16.8

6.2 Systematic uncertainty estimation

Relative systematic uncertainties (in %) from the different sources

Source/$\sqrt{s}(GeV)$	4.312	4.337	4.358	4.377	4.396	4.416	4.436	4.467	4.527	4.575	4.600
Luminosity	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Tracking efficiency	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Photon detection	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
Kinematic fit	1.6	2.5	2.3	2.1	1.7	2.3	1.2	2.4	2.0	2.0	2.1
J/ψ mass window	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6	1.6
$X(3872)$ mass window	1.4	1.4	1.4	1.6	1.3	1.3	1.3	1.5	1.5	1.4	1.5
Line shape	5.6	3.7	3.9	3.2	3.9	4.6	2.1	4.6	2.4	2.3	3.4
$Z_c(4020)^0$ parameters	7.0	7.0	6.5	7.1	6.8	7.3	6.9	6.6	6.6	7.1	8.2
Angular distribution	15.1	15.3	17.4	17.1	16.5	15.6	13.9	16.9	18.6	15.3	20.6
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Sum	18.5	18.3	19.9	19.7	19.2	18.8	16.7	19.7	20.8	18.0	23.2

7.Summary

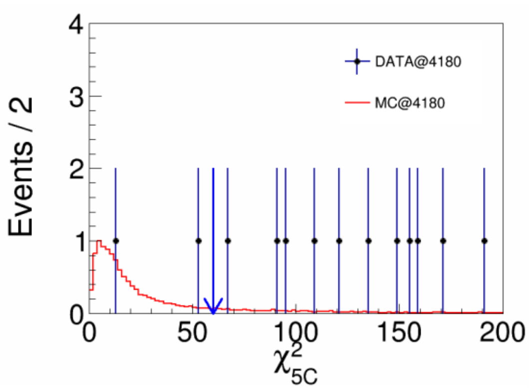
(1)We have studied the $X(3872)\gamma$ line-shape via the process $e^+e^- \to \pi^0 X(3872)\gamma$ between 4.178 and 4.6 GeV, no significant signals are observed and upper limits on the production rate $\sigma(e^+e^- \to \pi^0 X(3872)\gamma) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi))$ with a confidence level of 90% are given.

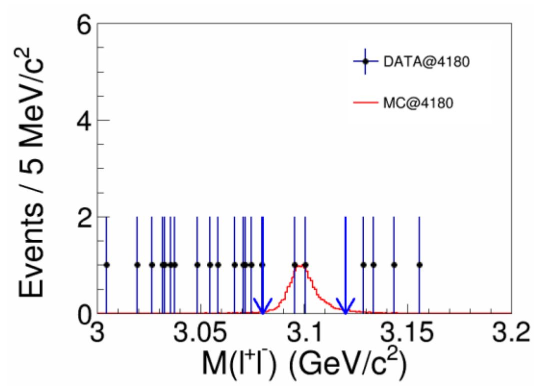
(2) We have searched for the process $Z_c(4020)^0 \to X(3872)\gamma$ in $e^+e^- \to \pi^0 X(3872)\gamma$ between 4.178 and 4.6 GeV, no significant signals are observed and upper limits on the production rate $\sigma(e^+e^- \to \pi^0 Z_c(4020)^0) \cdot \mathcal{B}(Z_c(4020)^0 \to X(3872)\gamma) \cdot \mathcal{B}(X(3872) \to \pi^+\pi^- J/\psi)$ with a confidence level of 90% are given.

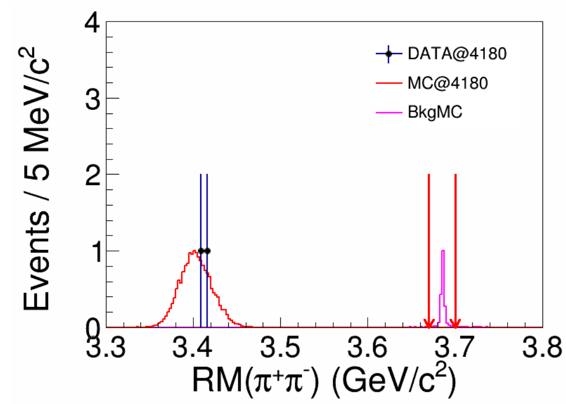
Thanks for your attention !

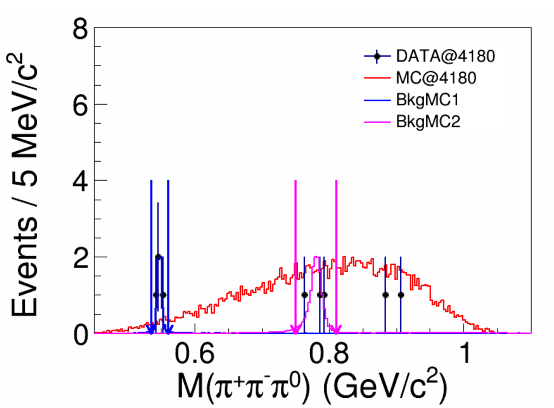
BACK UP

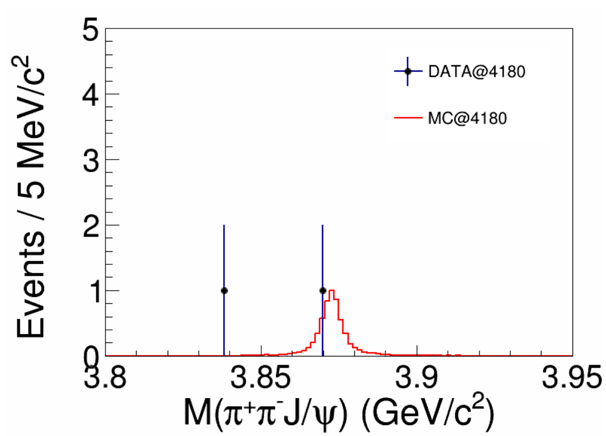
Data at $\sqrt{s} = 4.178$ GeV

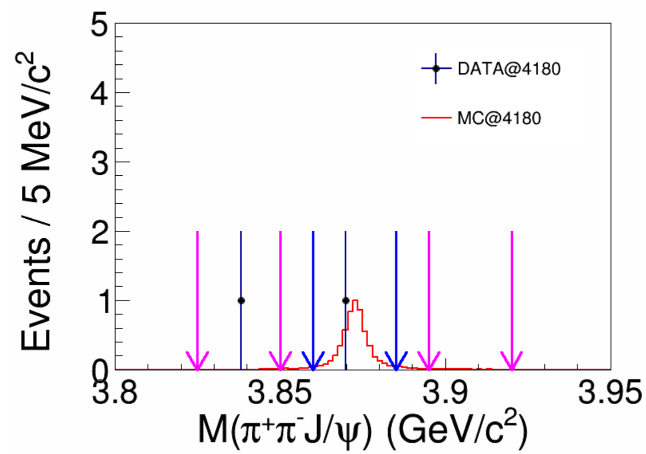




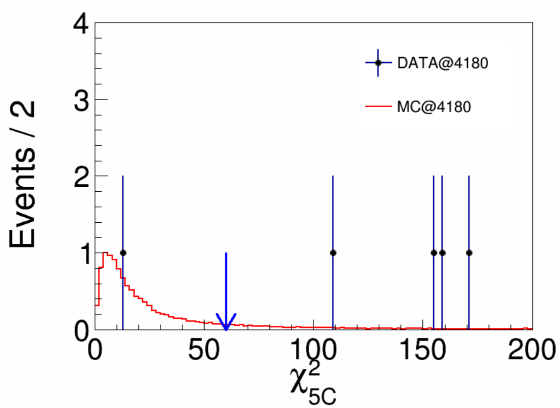


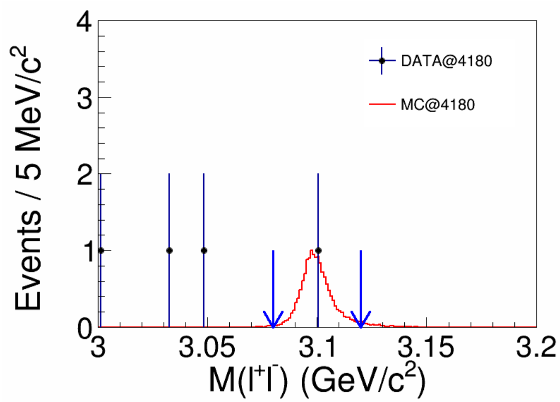


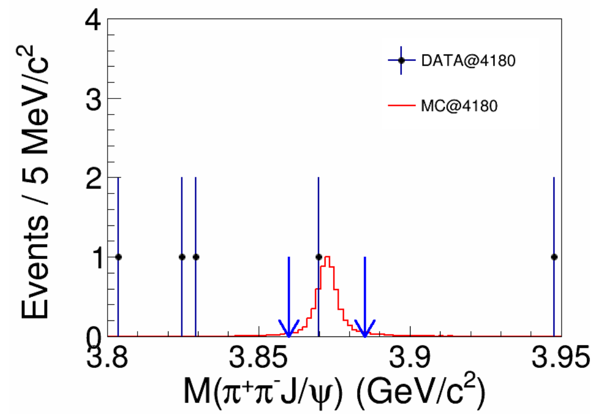


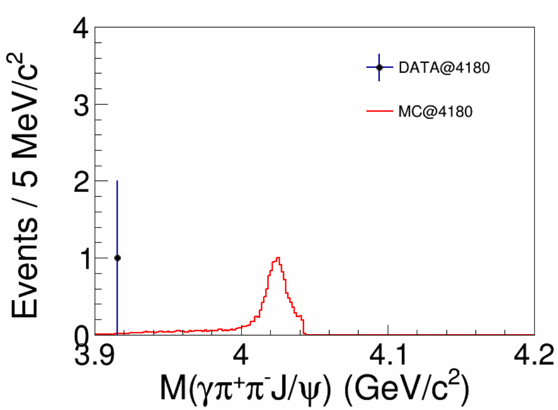


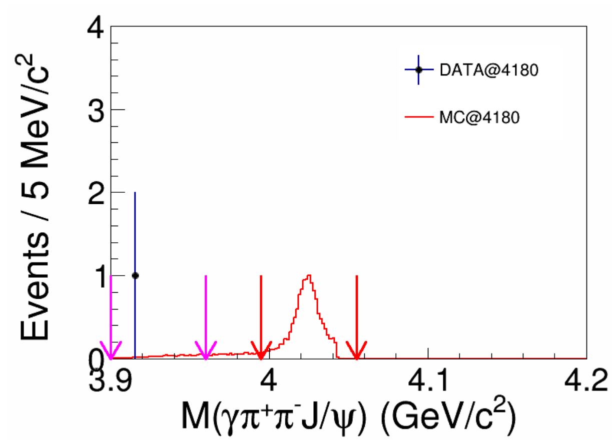
Data at $\sqrt{s} = 4.178$ GeV



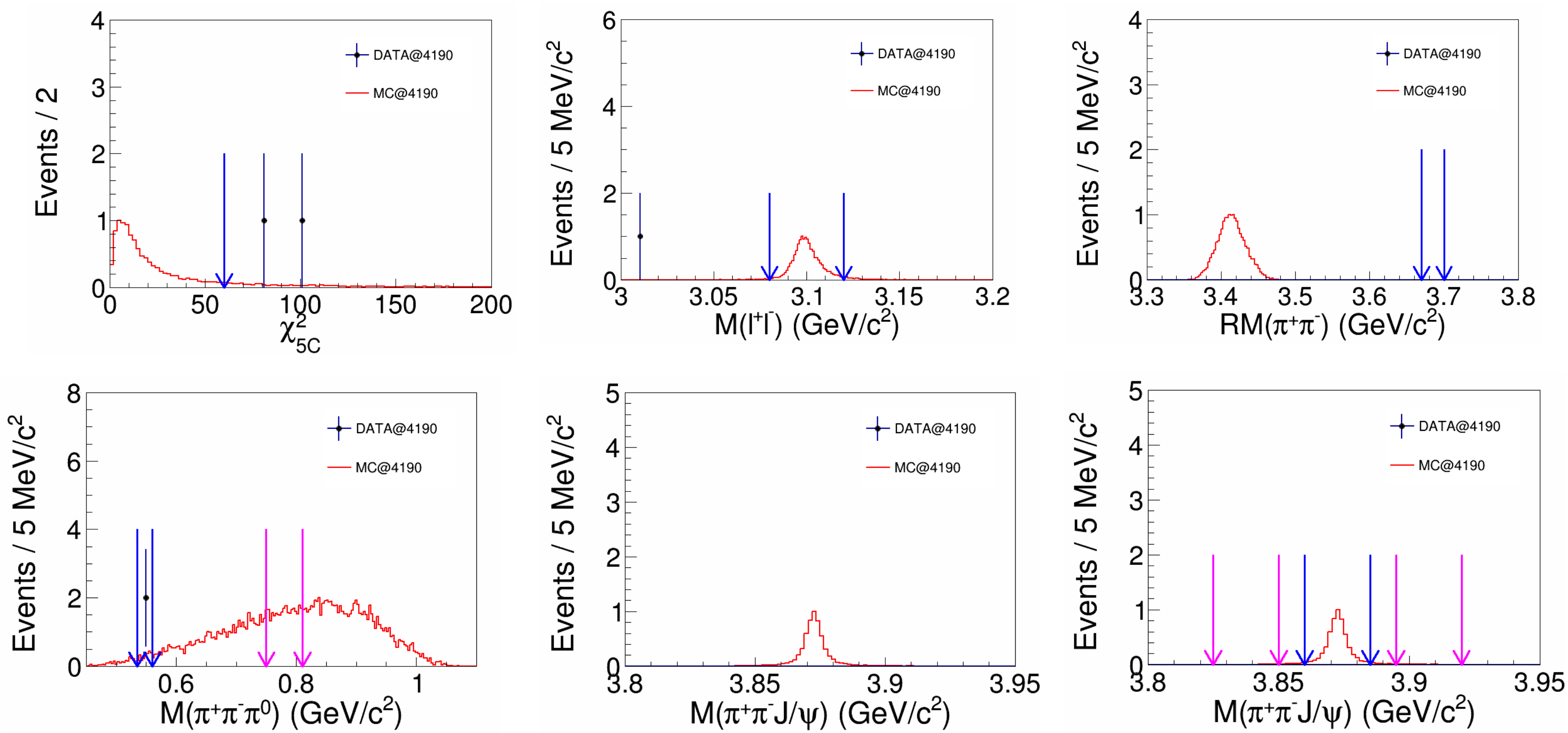








Data at $\sqrt{s} = 4.189$ GeV



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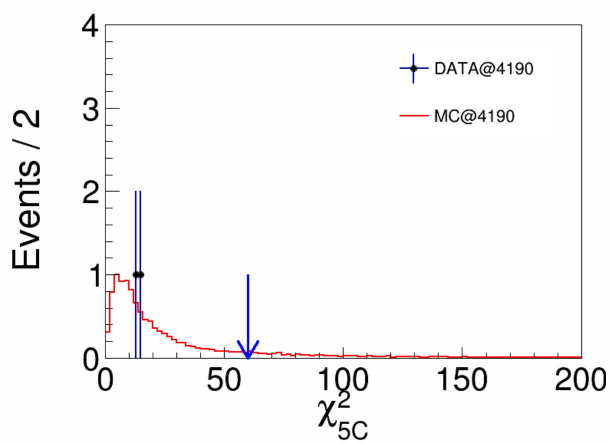

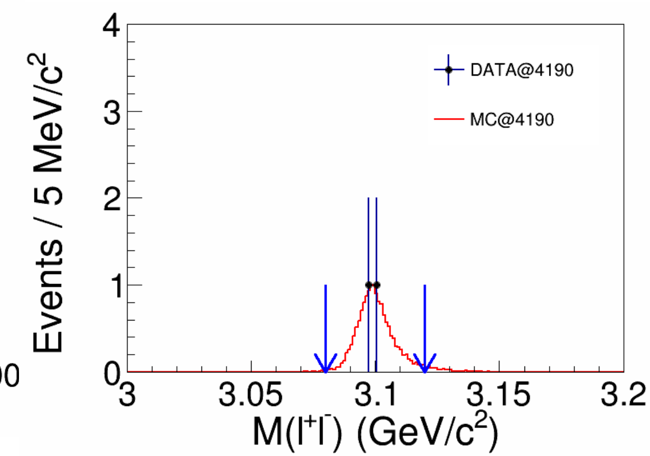

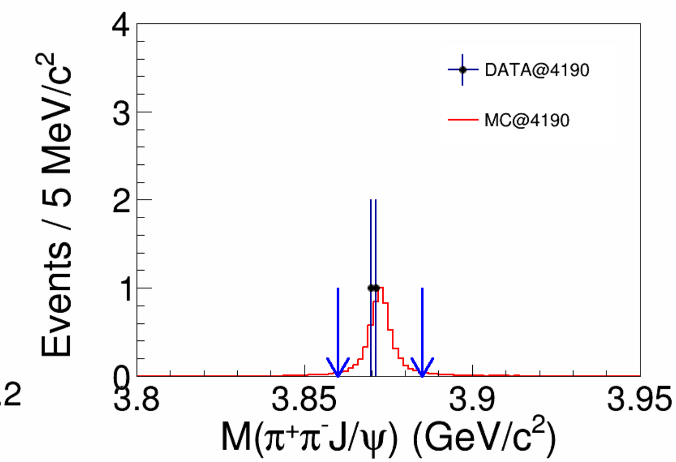

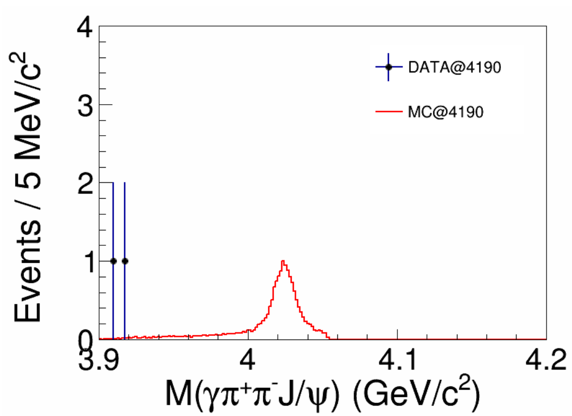

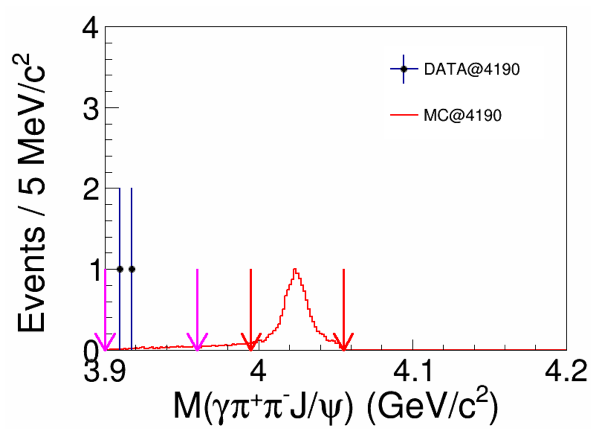

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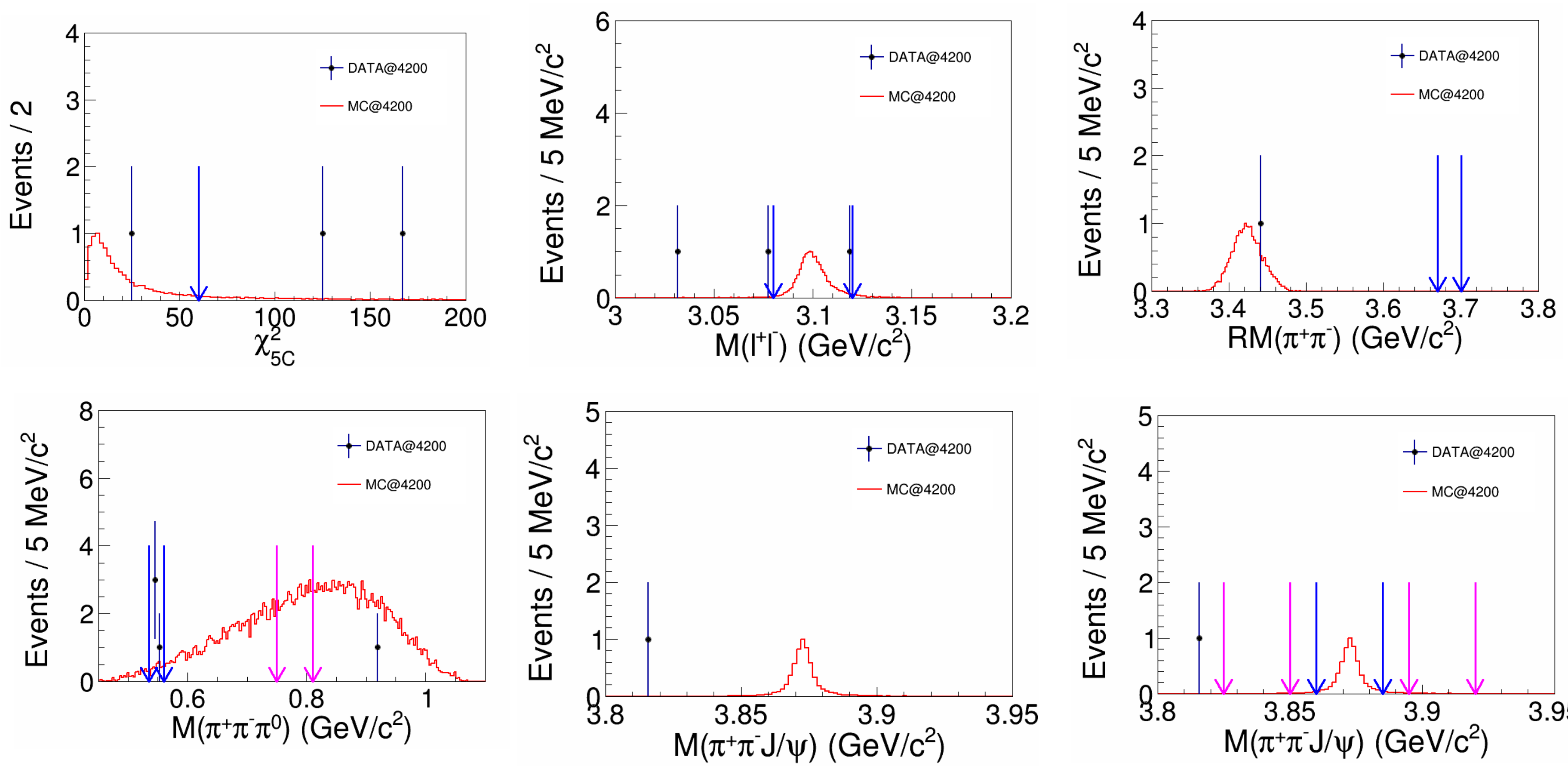
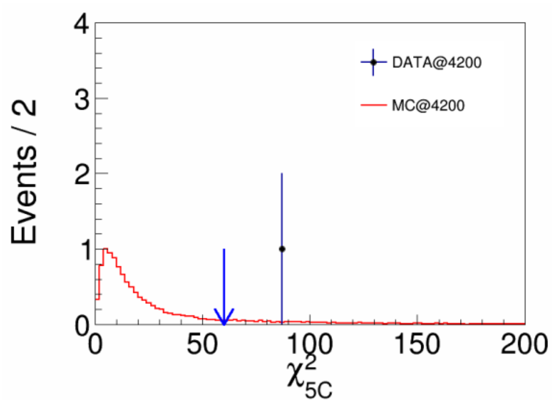
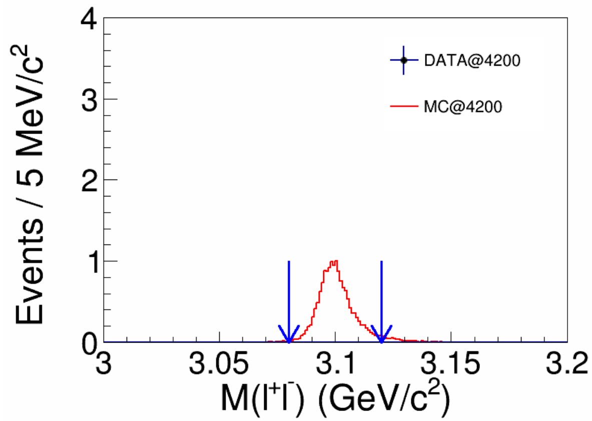
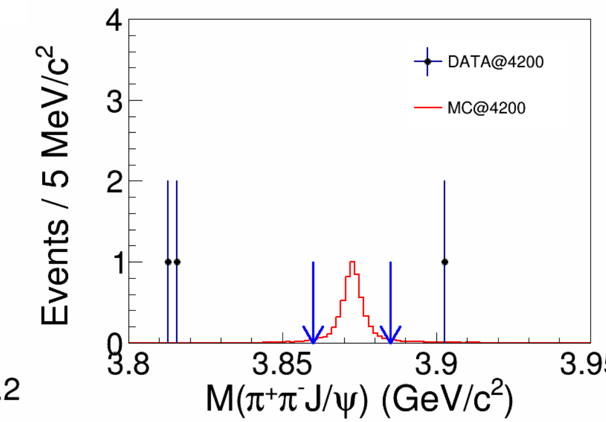
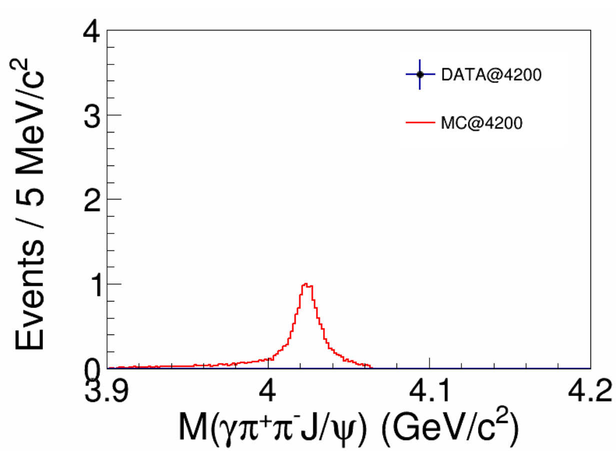


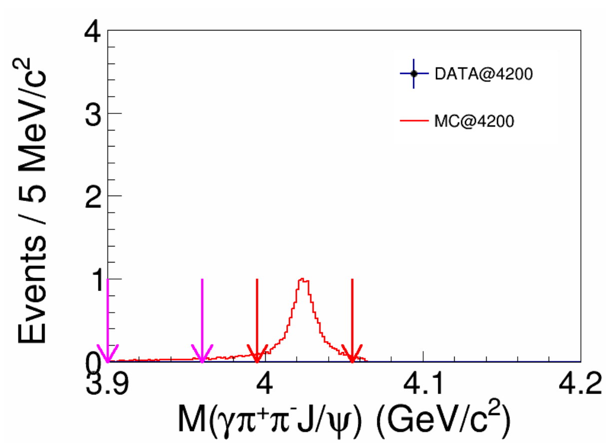
Data at $\sqrt{s} = 4.199$ GeV











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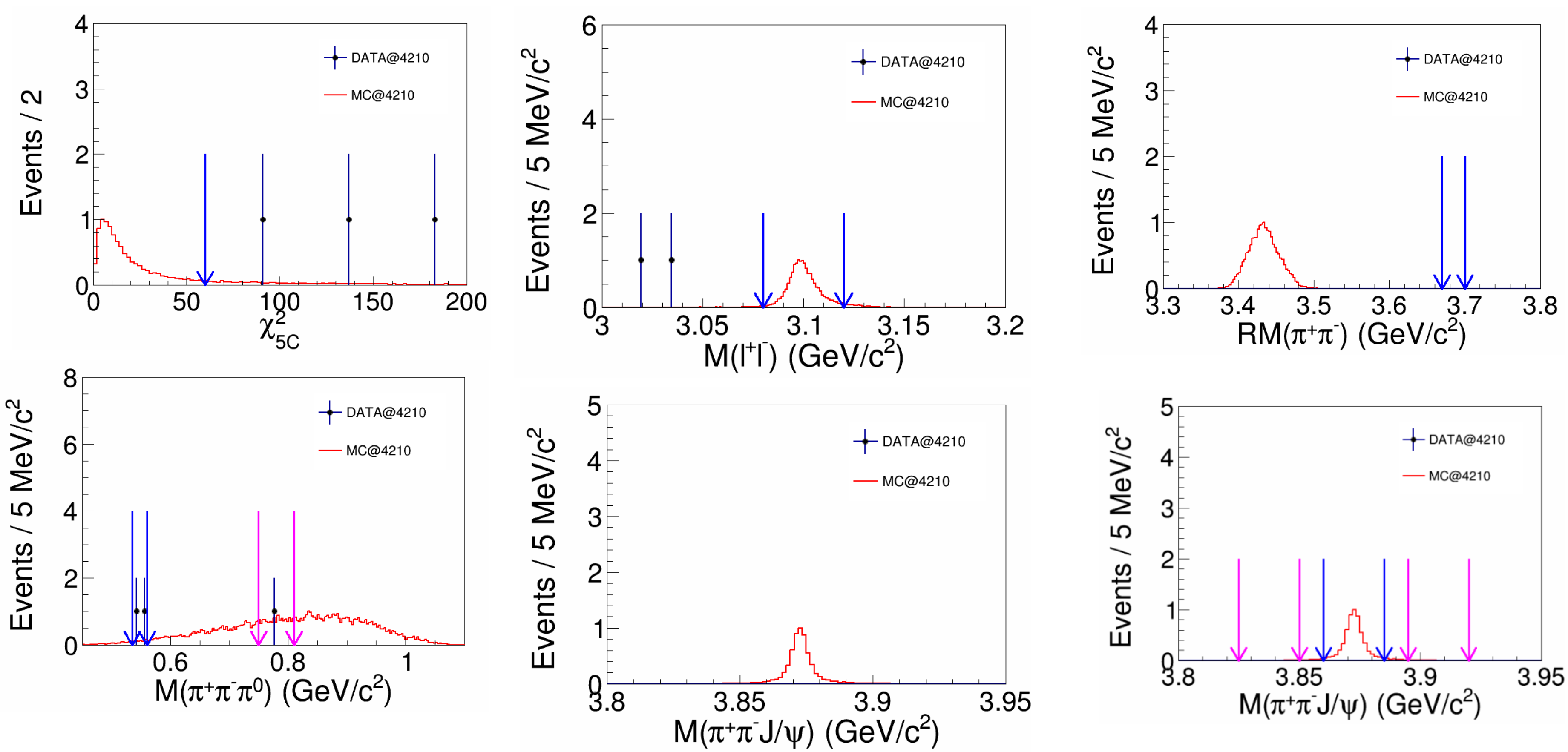

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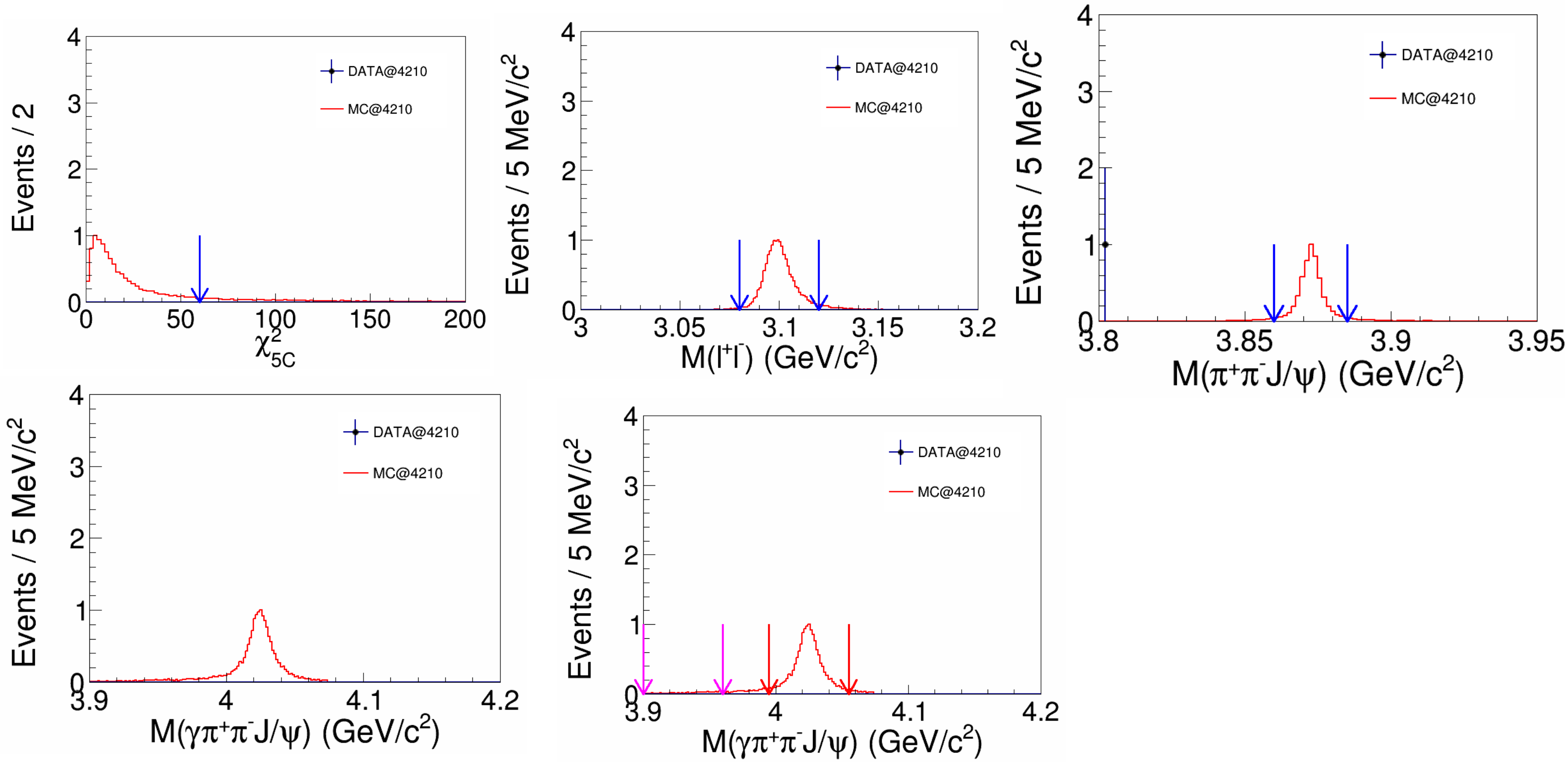

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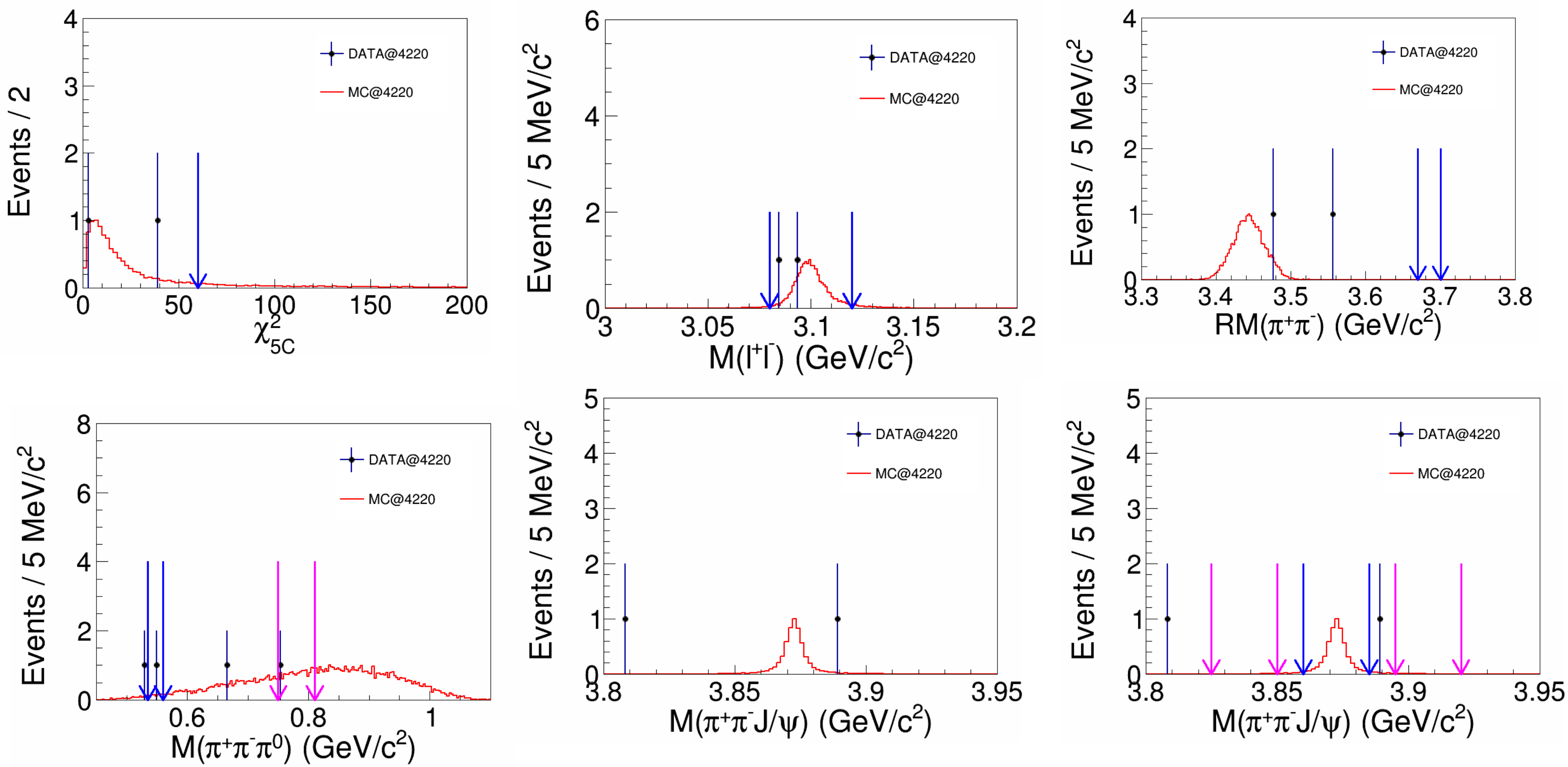
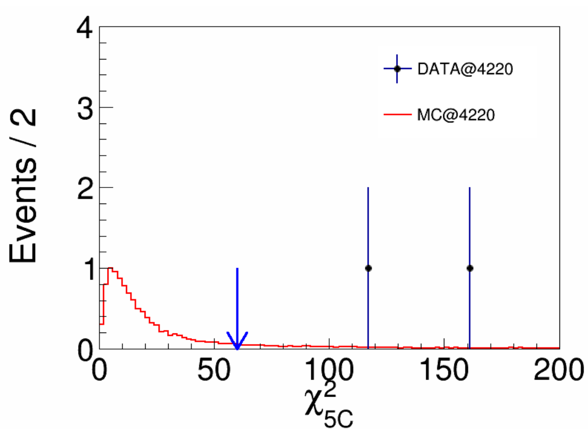
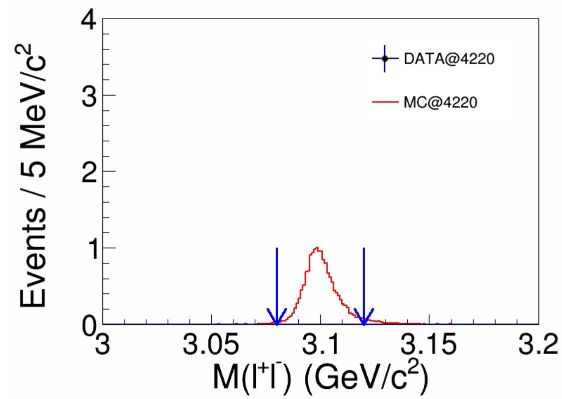
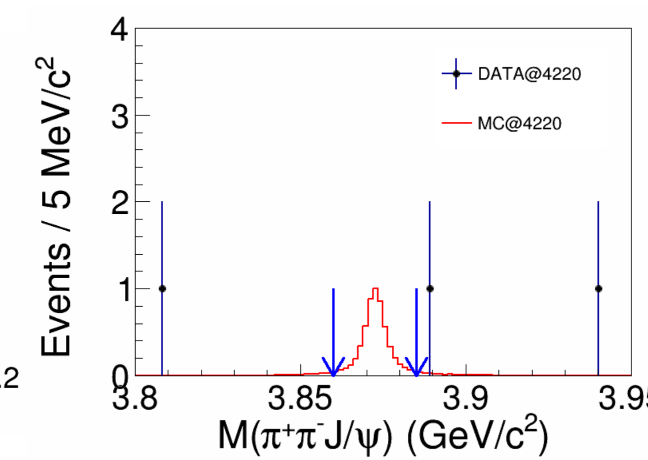
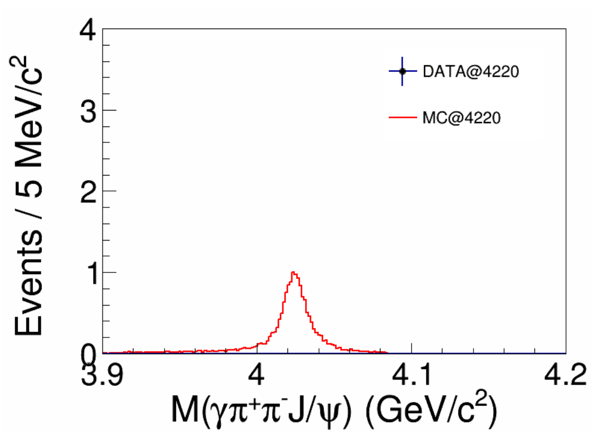


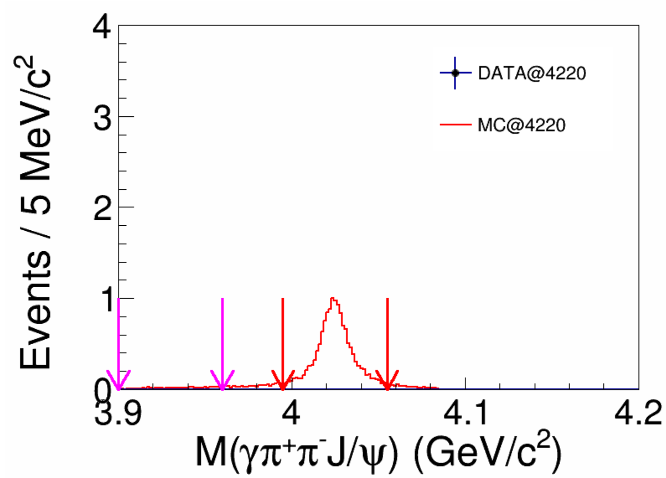
Data at $\sqrt{s} = 4.219$ GeV











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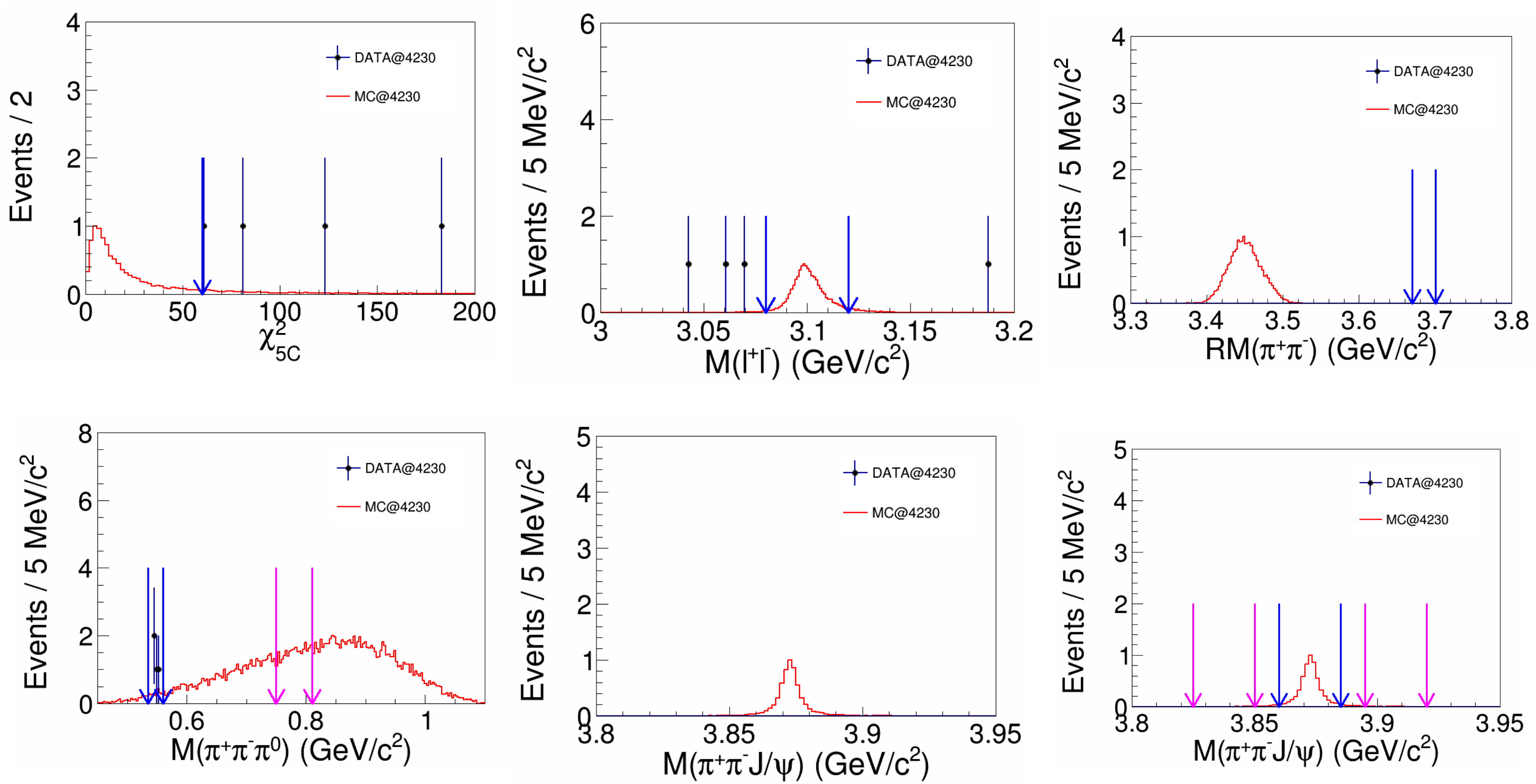

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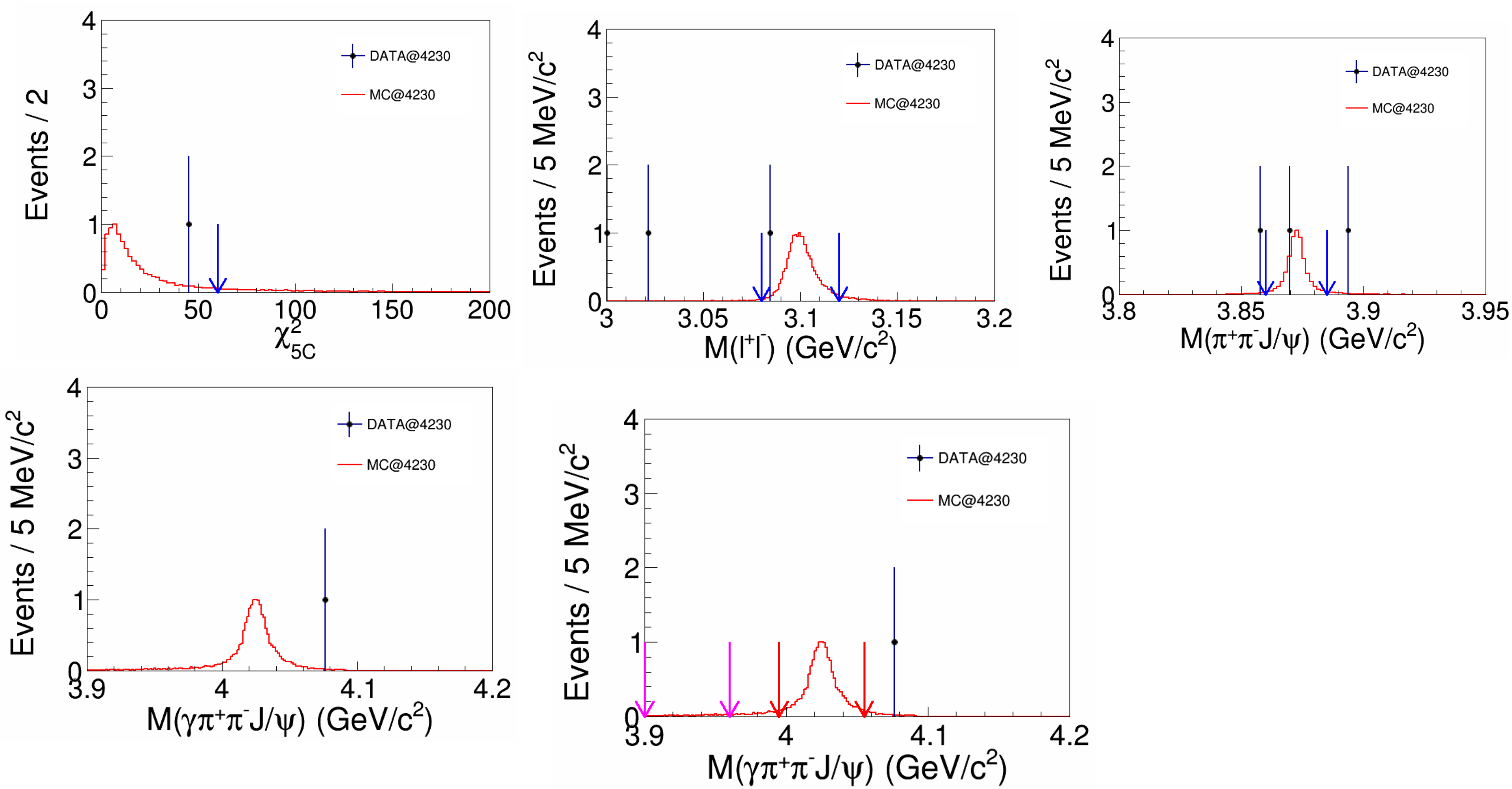

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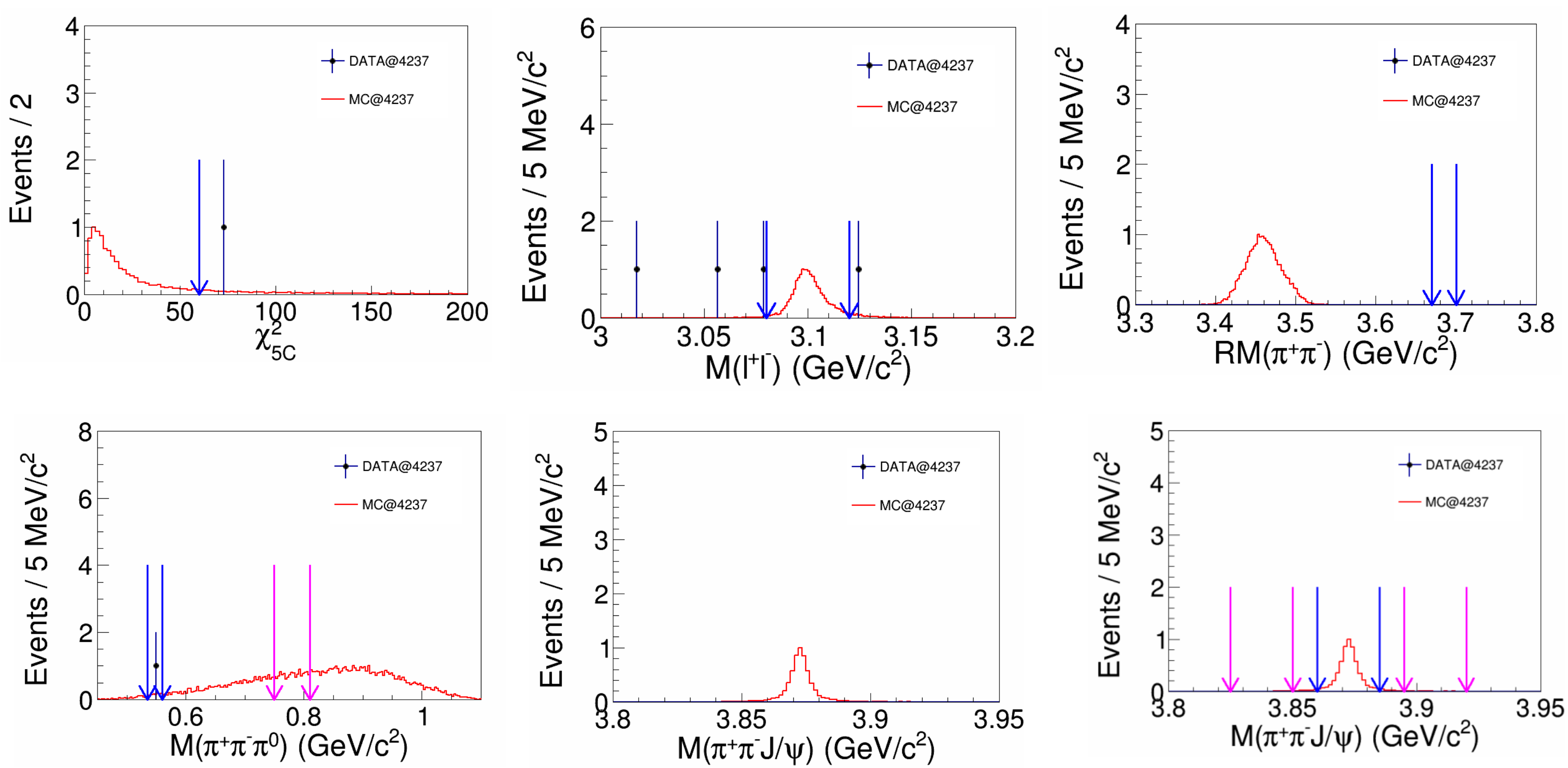

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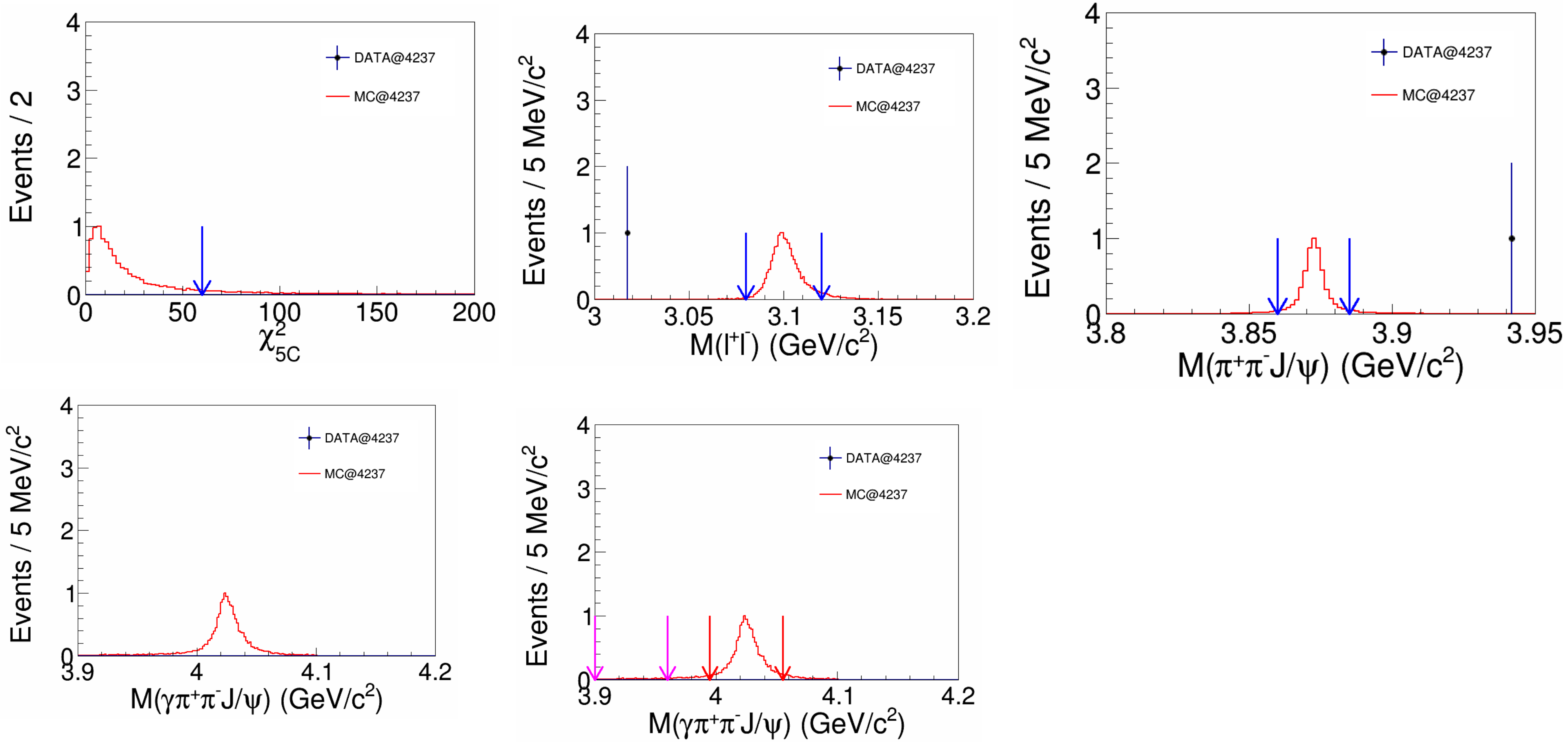
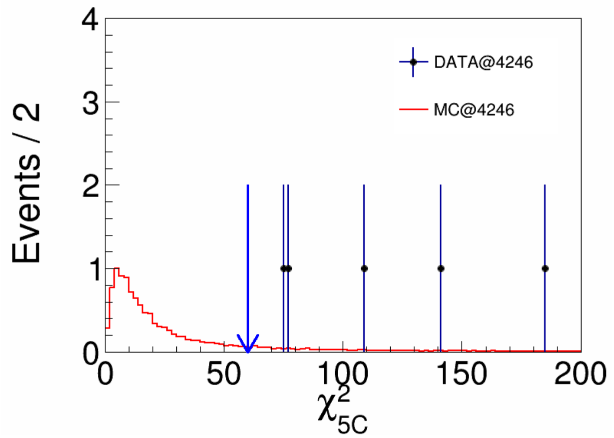
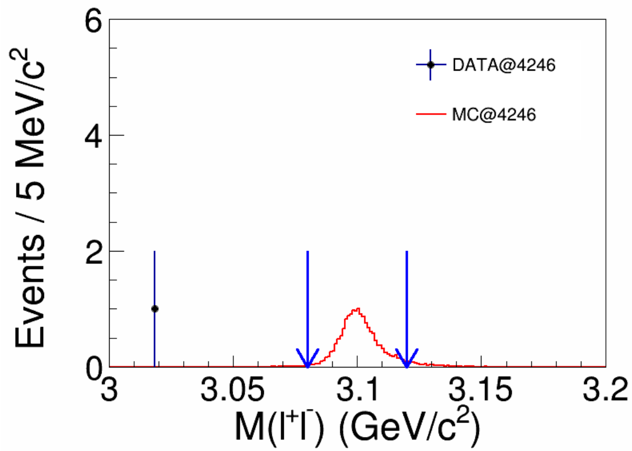
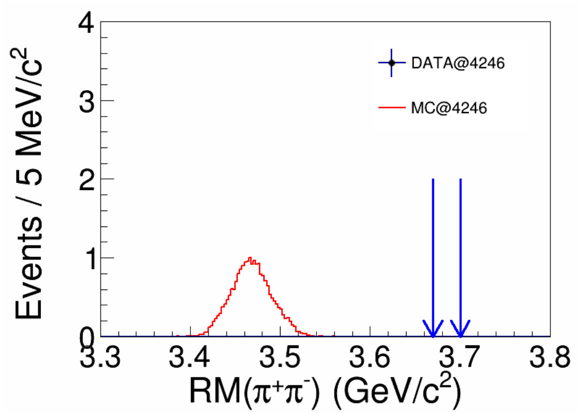
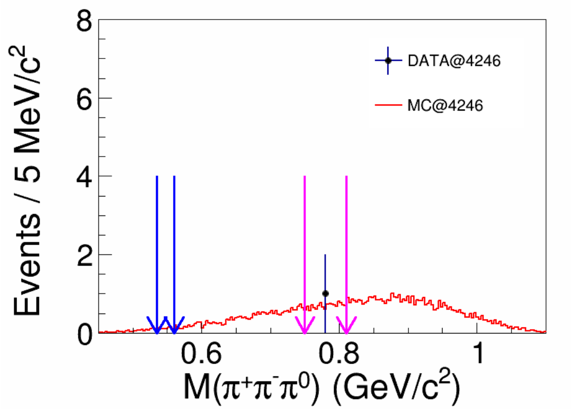


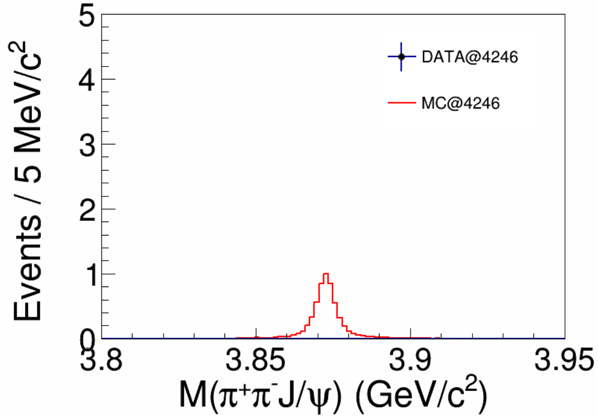
Data at $\sqrt{s} = 4.244$ GeV

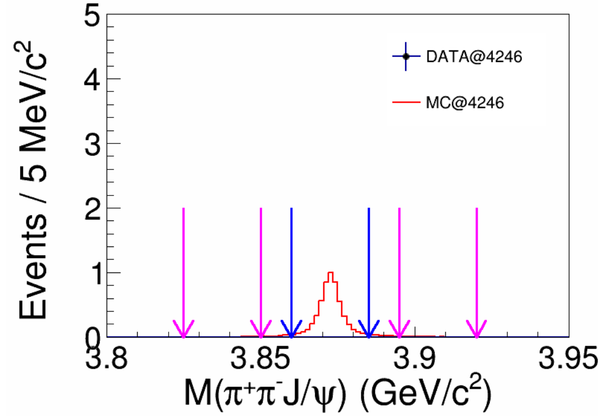




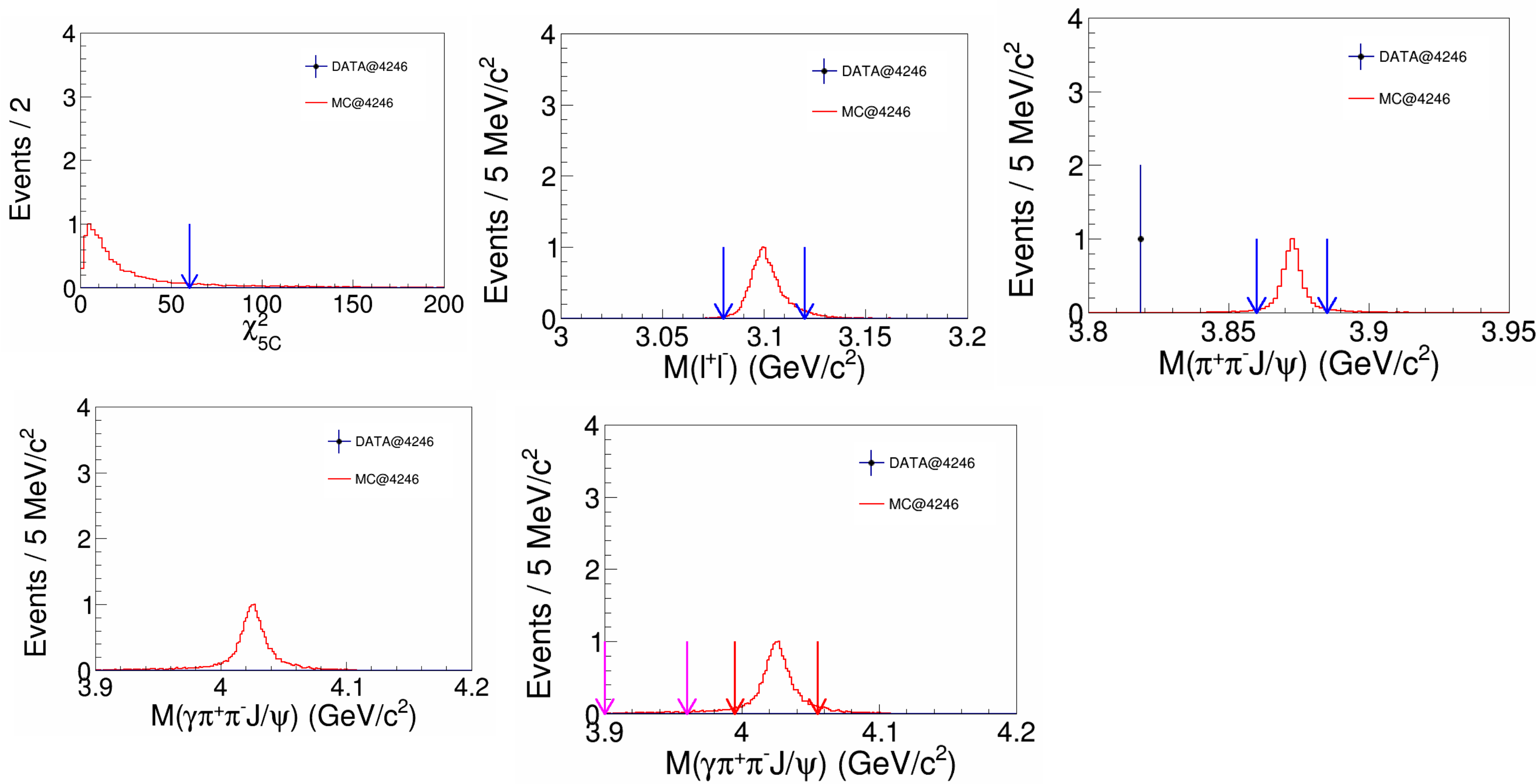








Data at $\sqrt{s} = 4.244$ GeV



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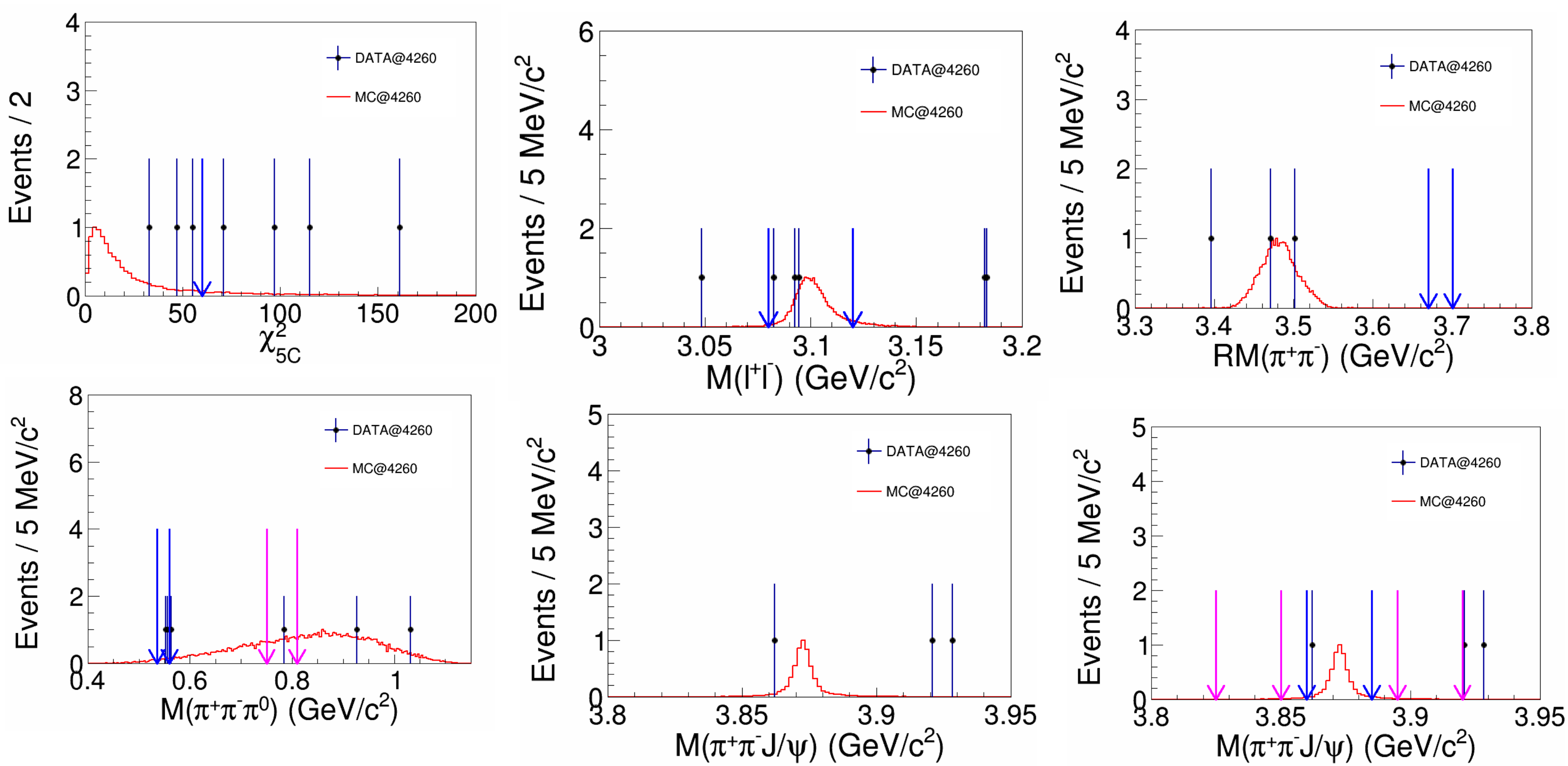
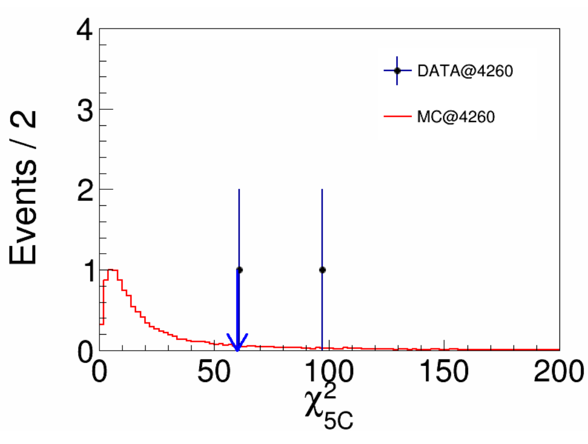
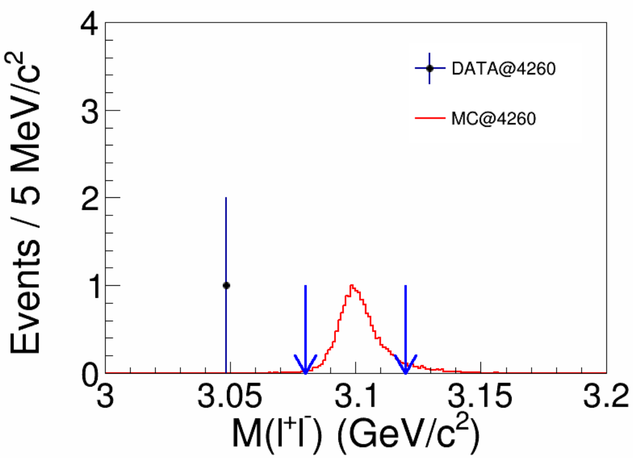
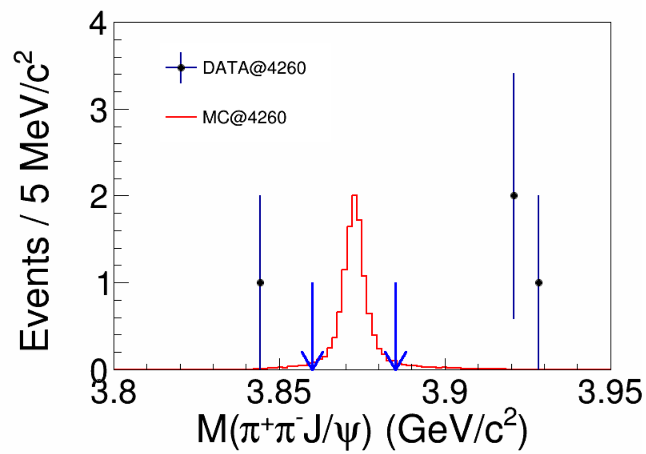
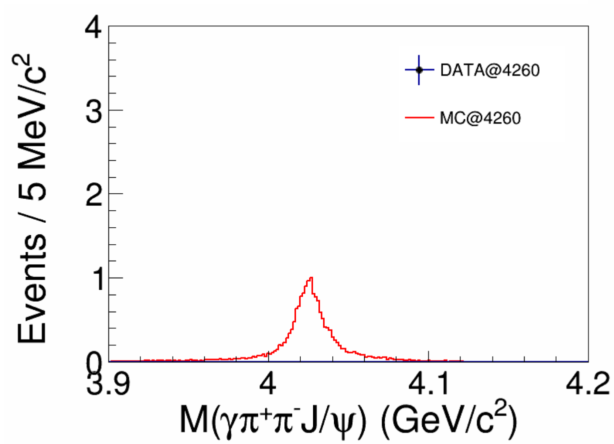


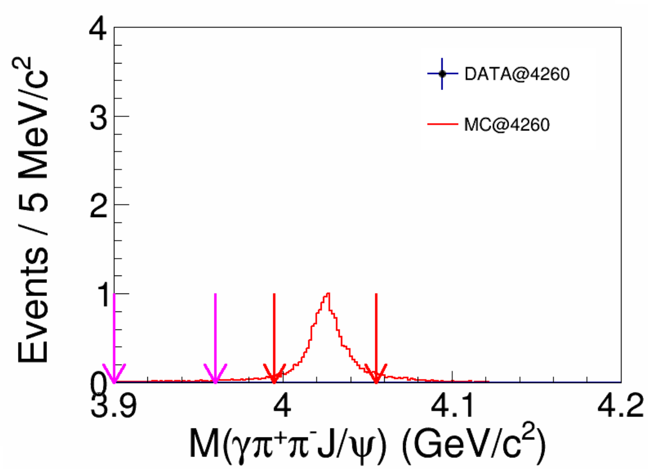
Data at $\sqrt{s} = 4.258$ GeV



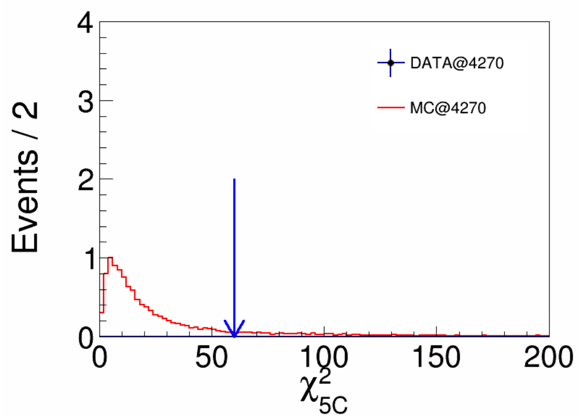


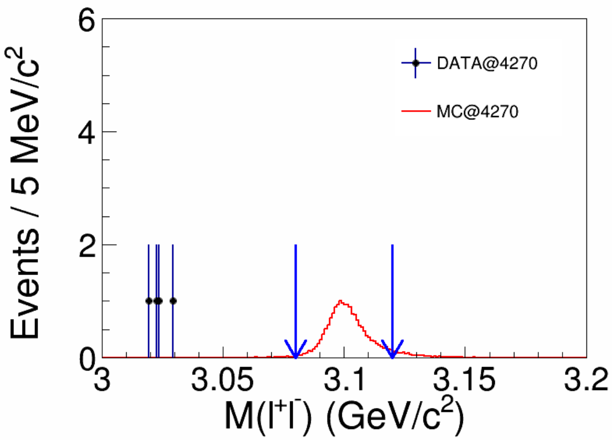


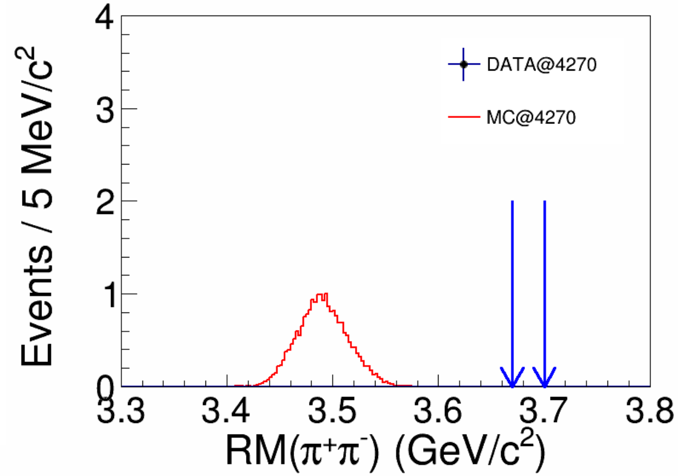


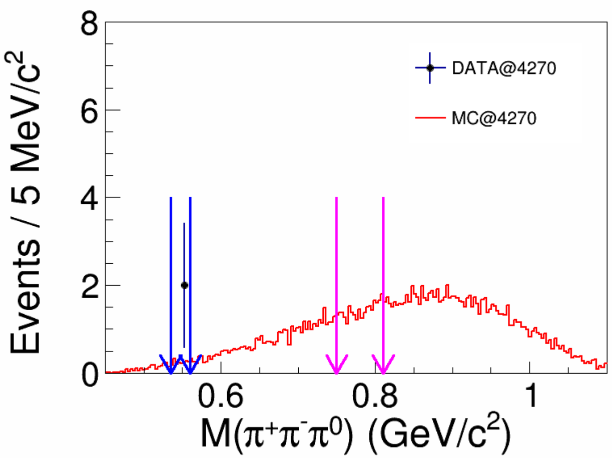


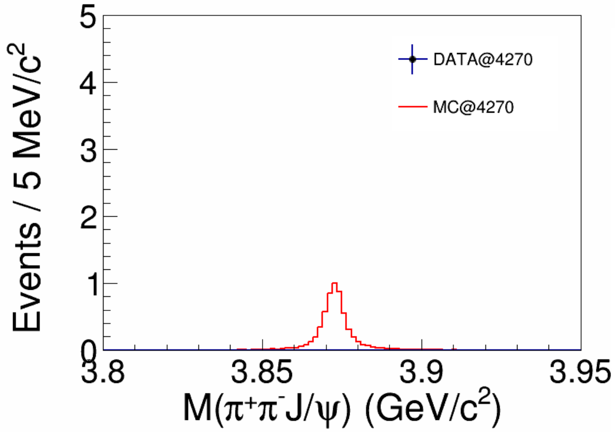
Data at $\sqrt{s} = 4.267$ GeV

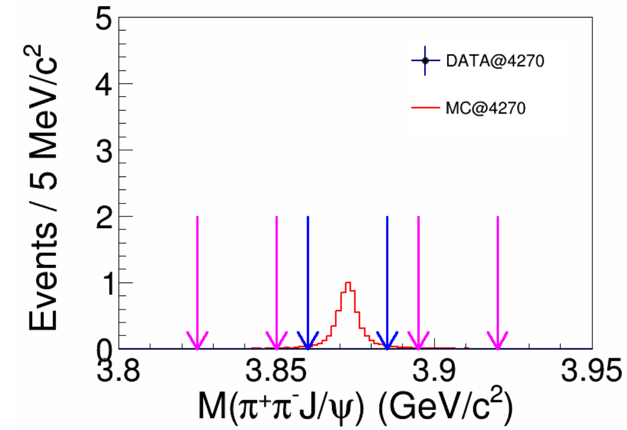




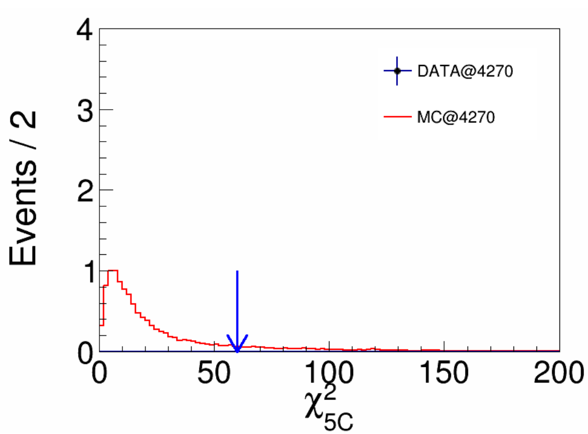


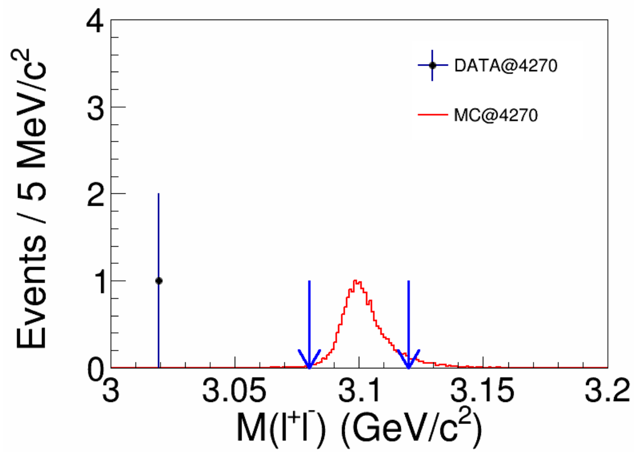


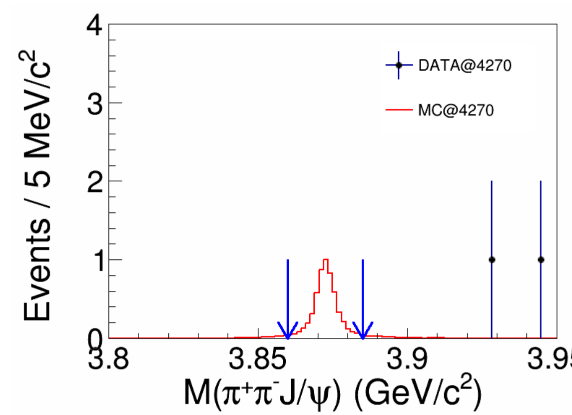


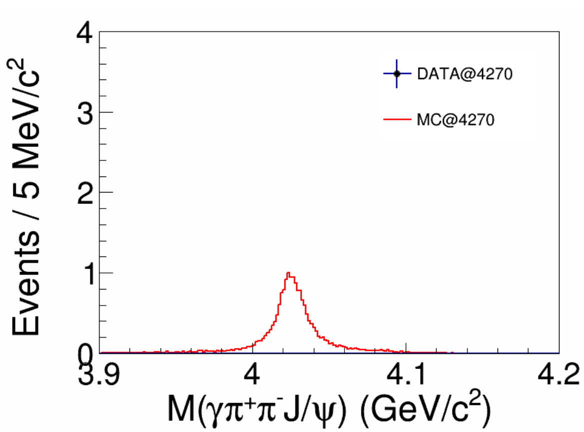


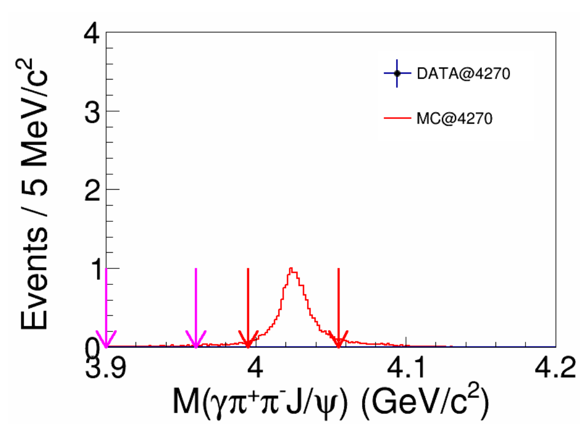
Data at $\sqrt{s} = 4.267$ GeV



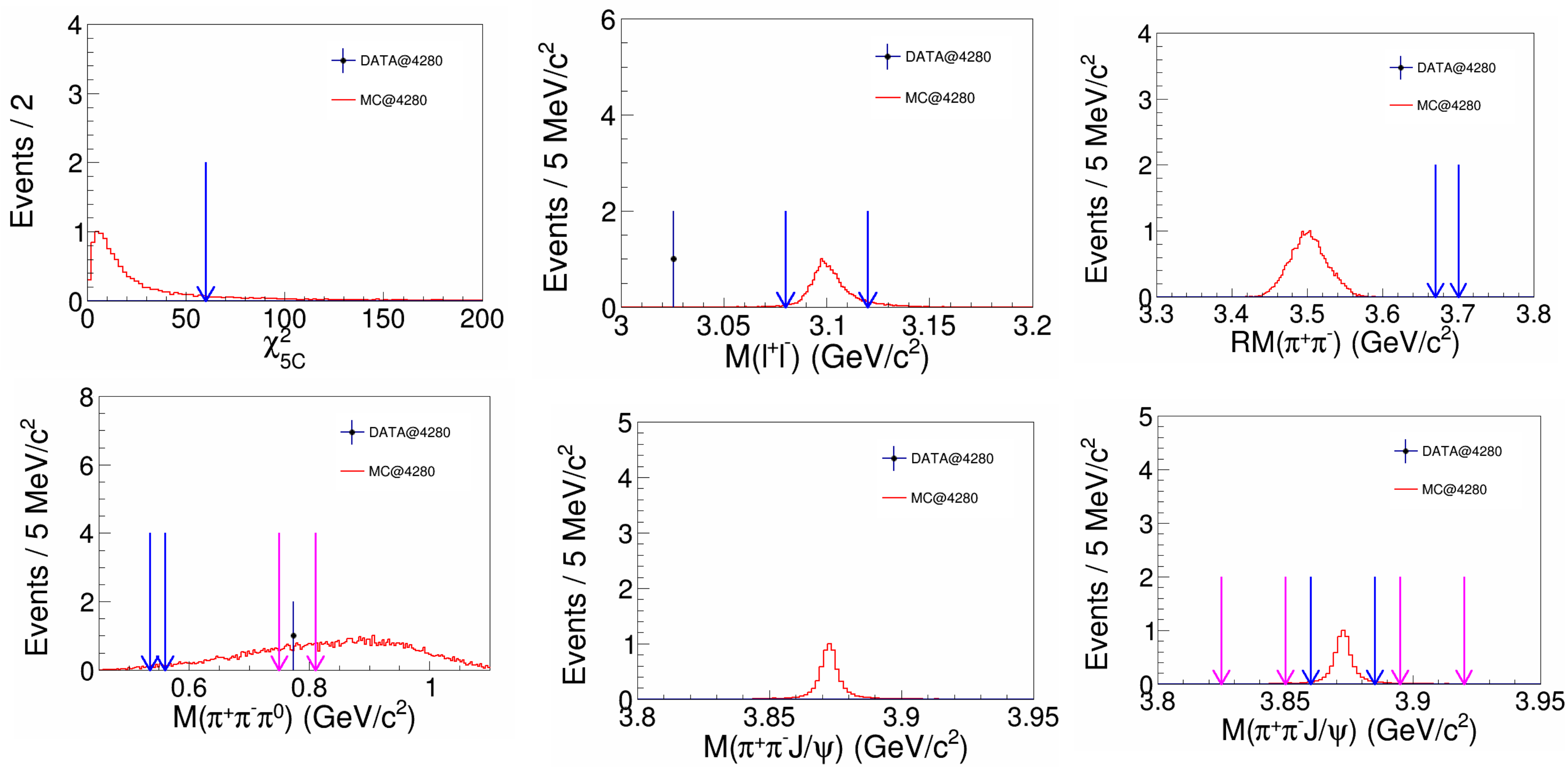




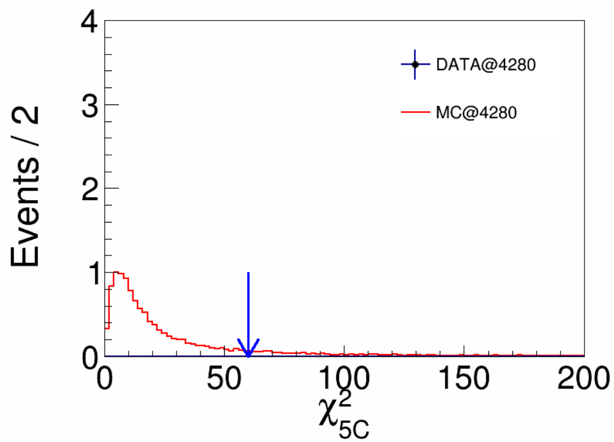


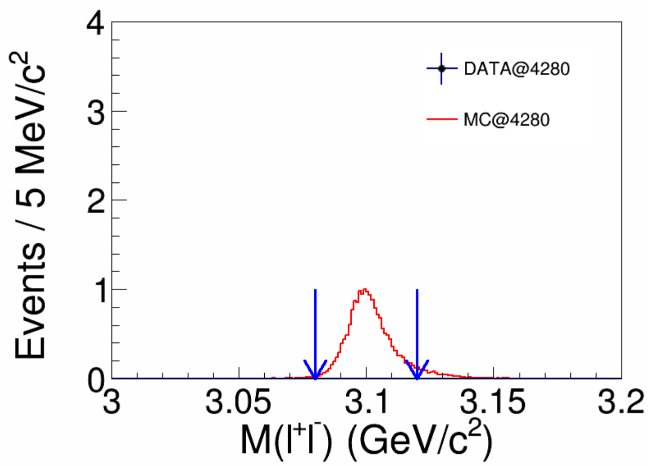


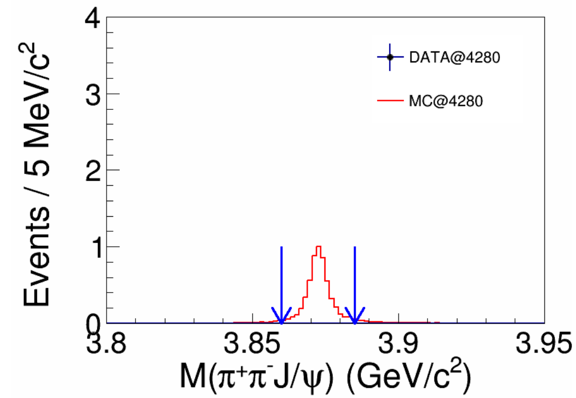
Data at $\sqrt{s} = 4.278$ GeV

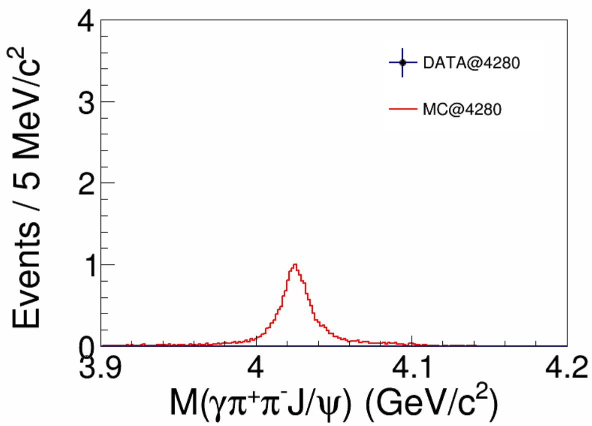


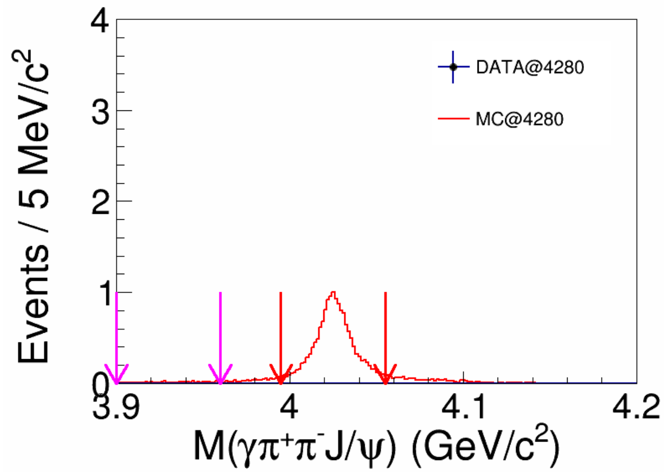
Data at $\sqrt{s} = 4.278$ GeV



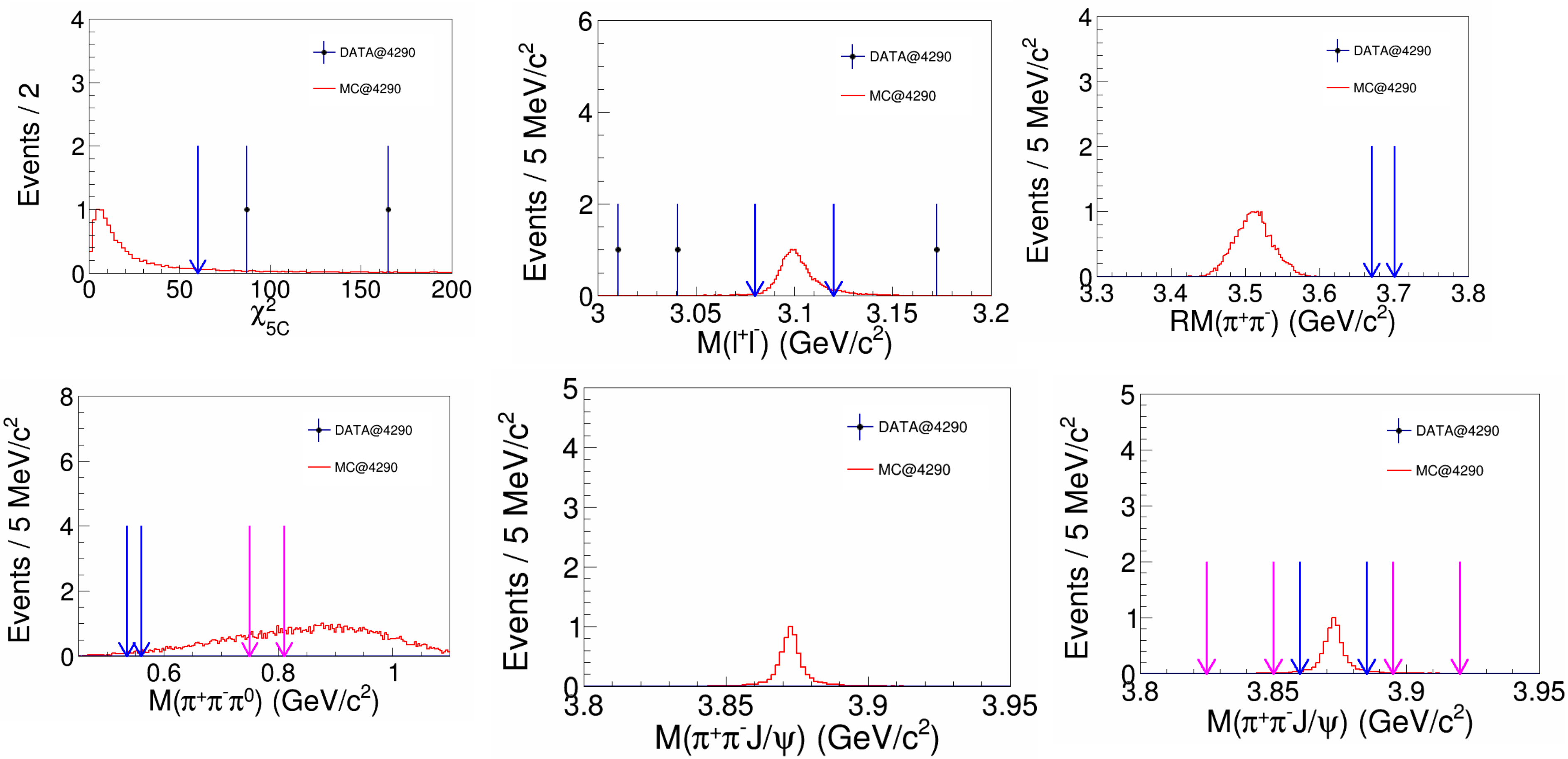




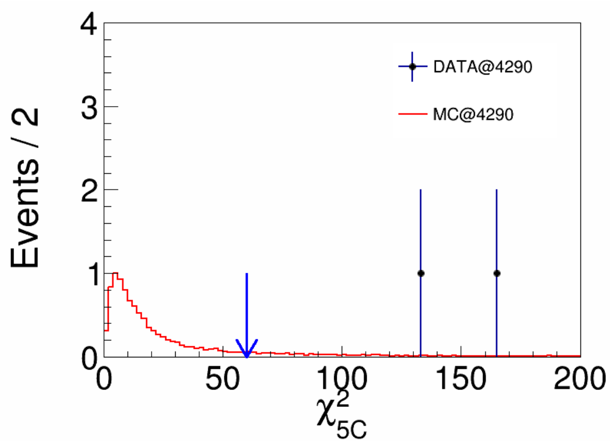


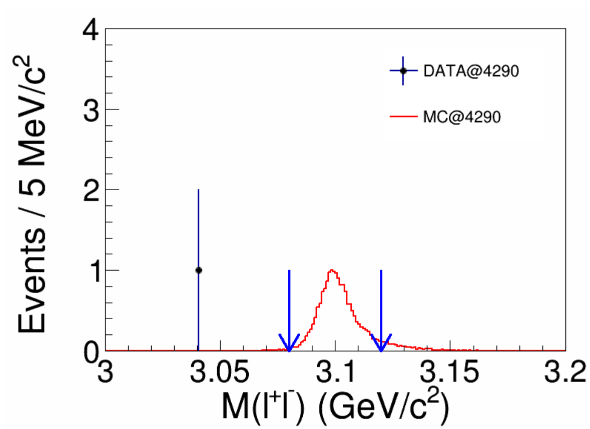


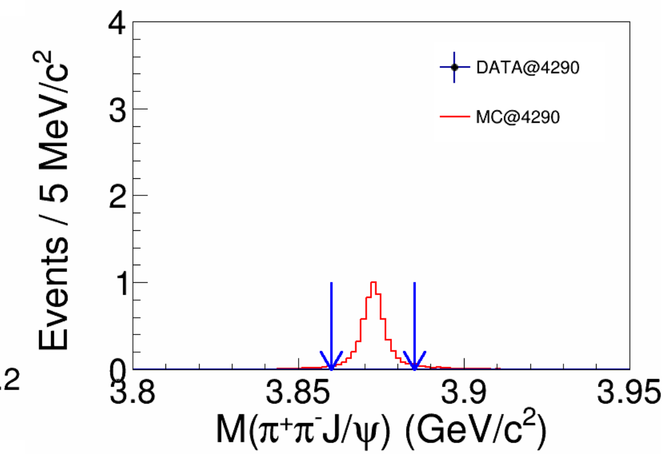
Data at $\sqrt{s} = 4.288$ GeV

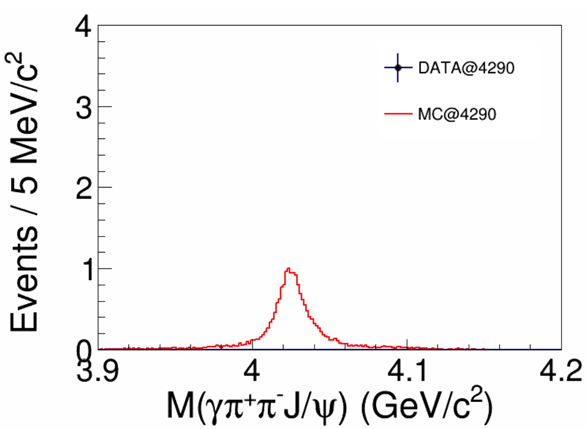


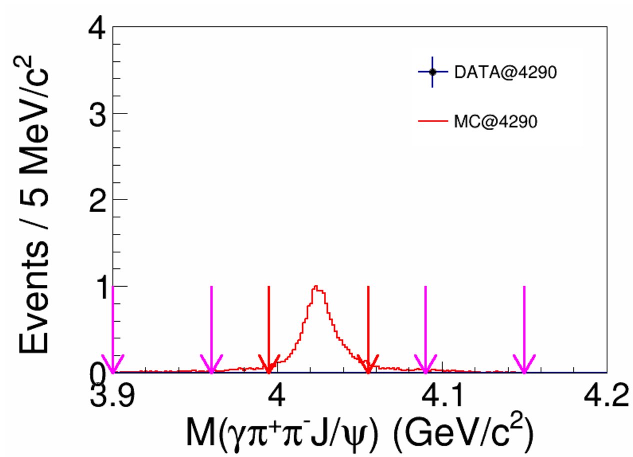
Data at $\sqrt{s} = 4.288$ GeV











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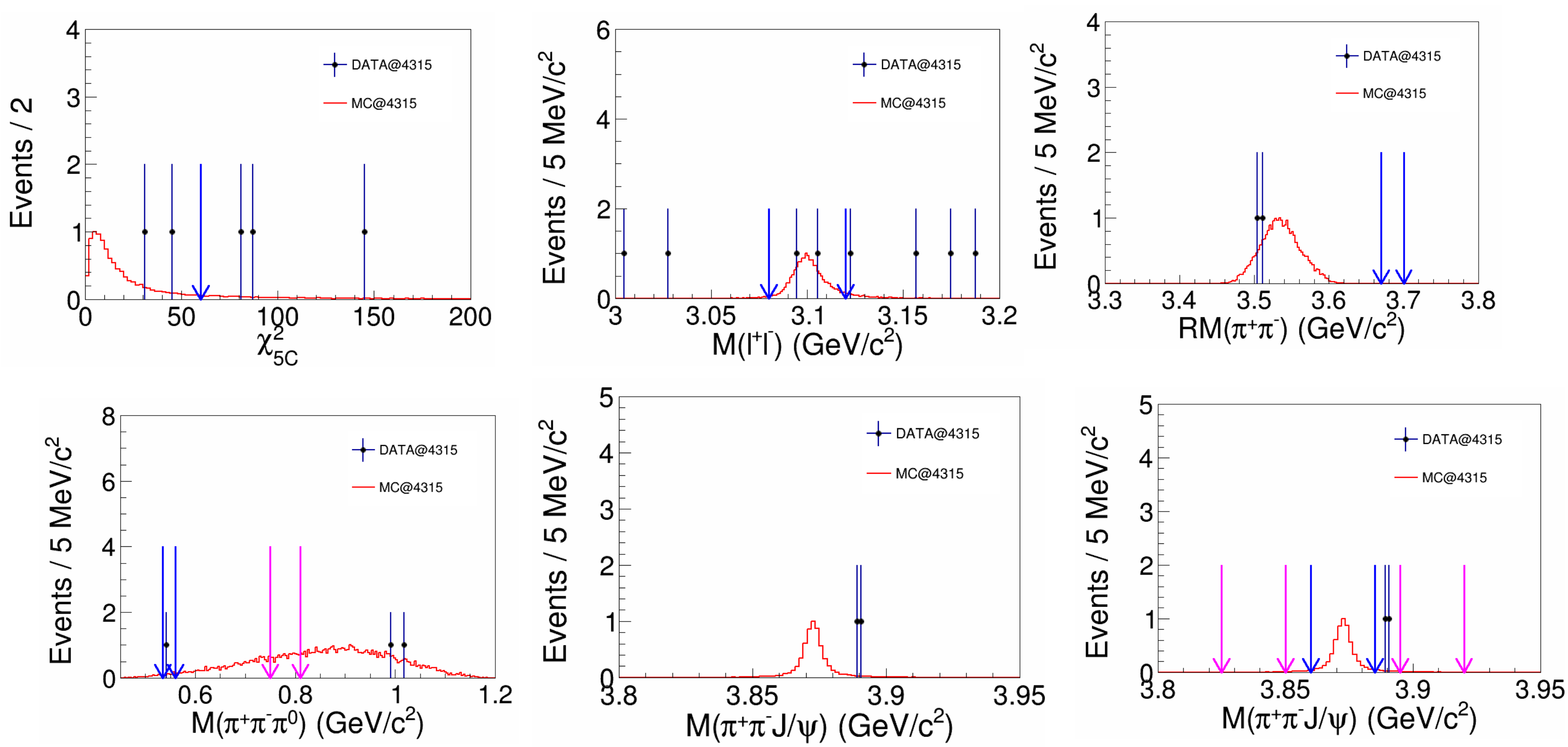
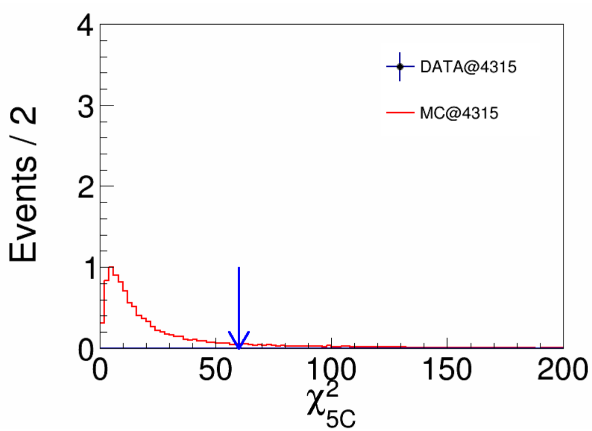
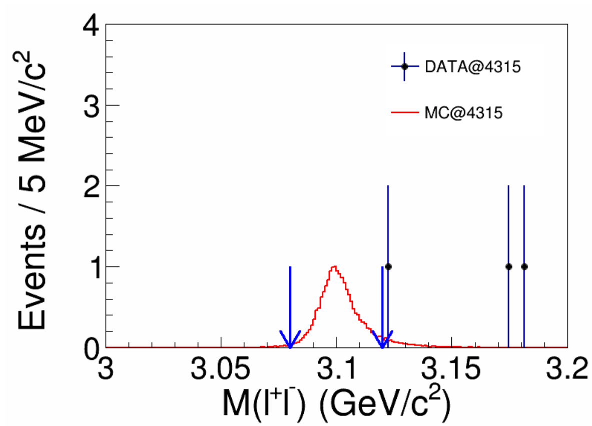
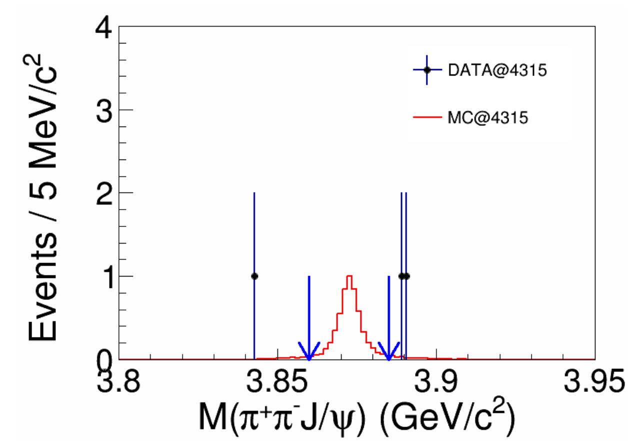
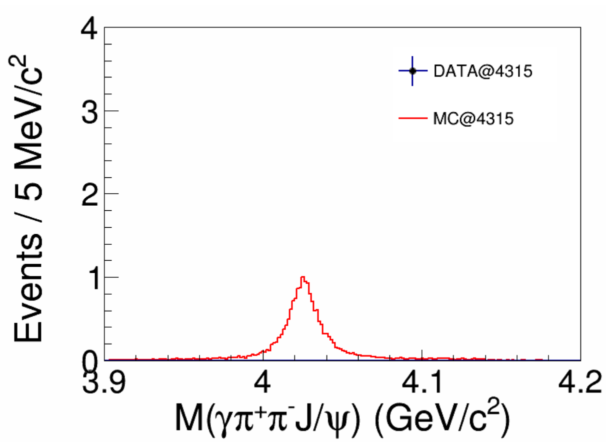


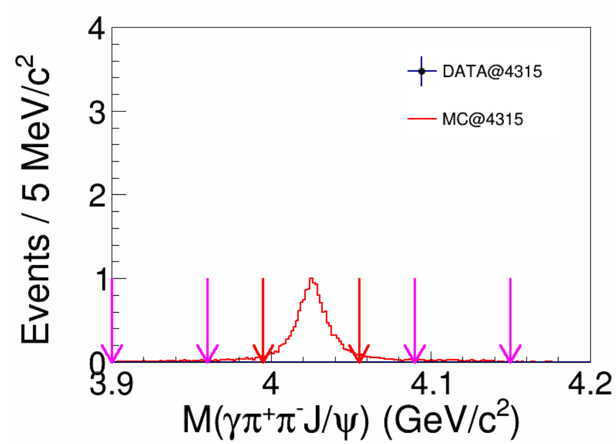
Data at $\sqrt{s} = 4.312$ GeV



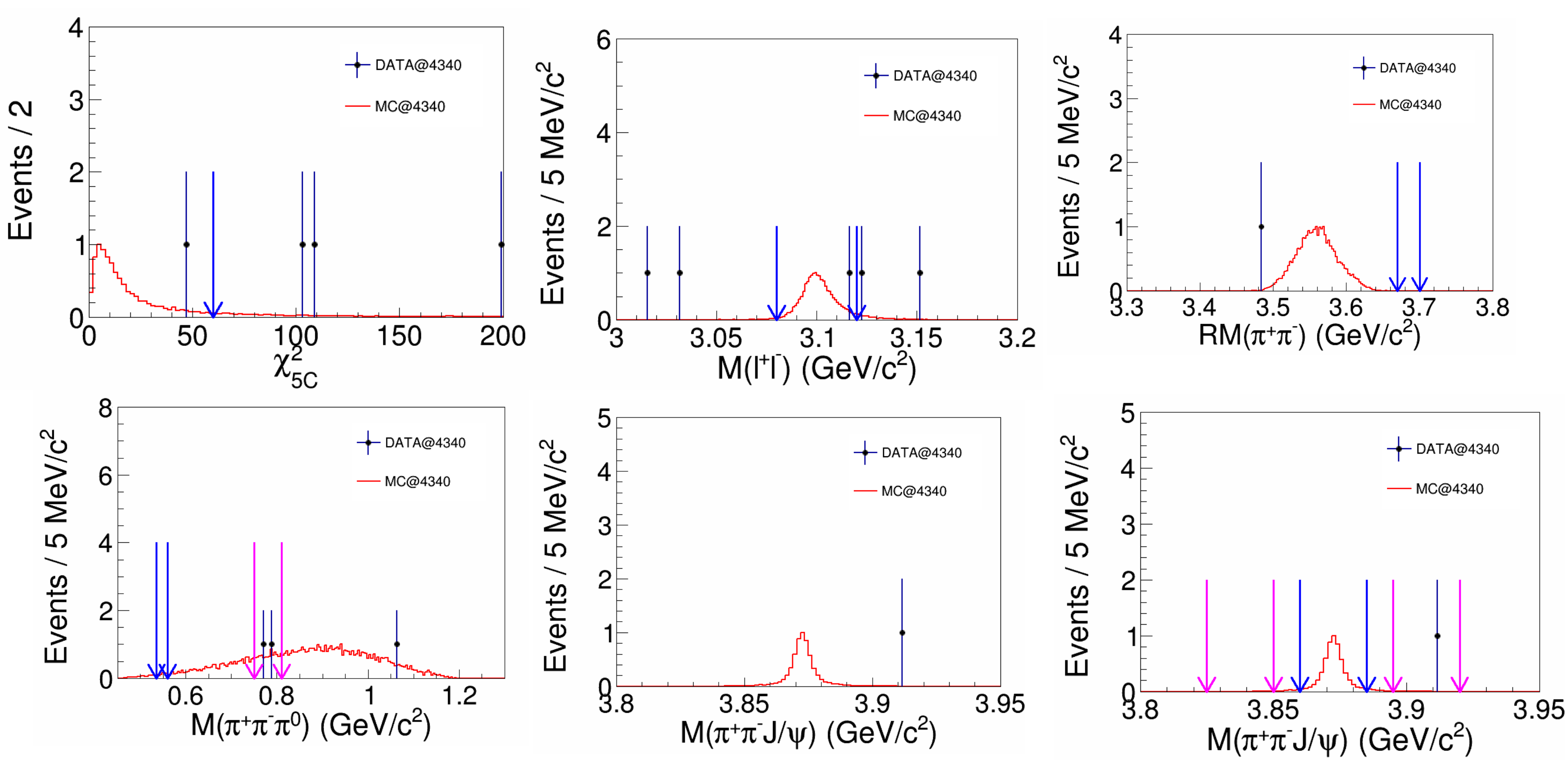




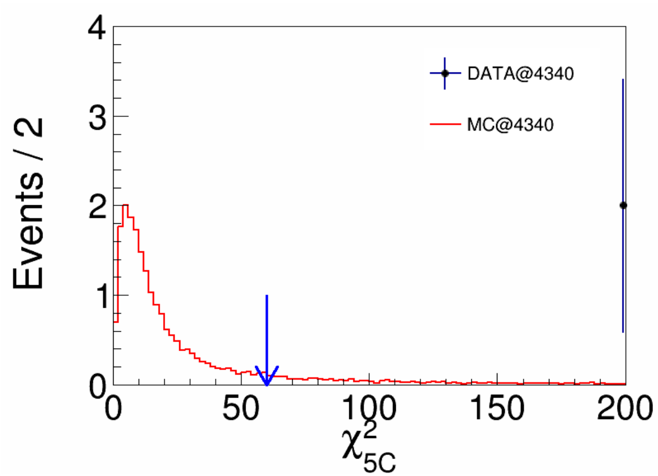


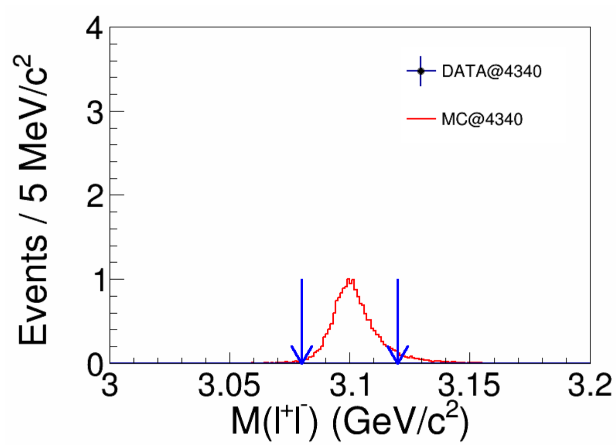


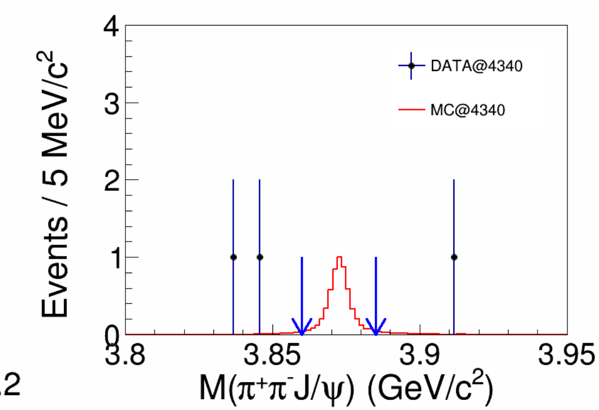
Data at $\sqrt{s} = 4.337$ GeV

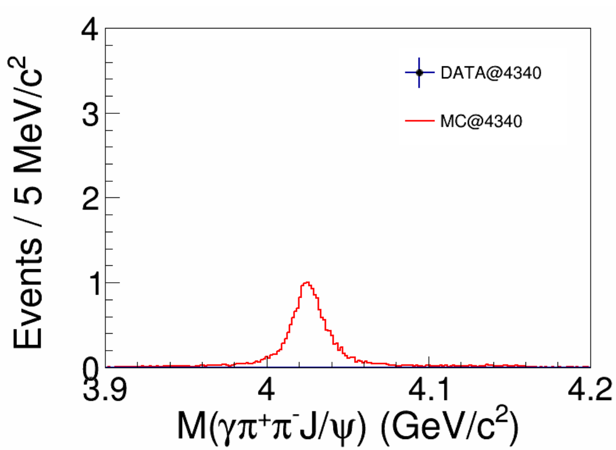


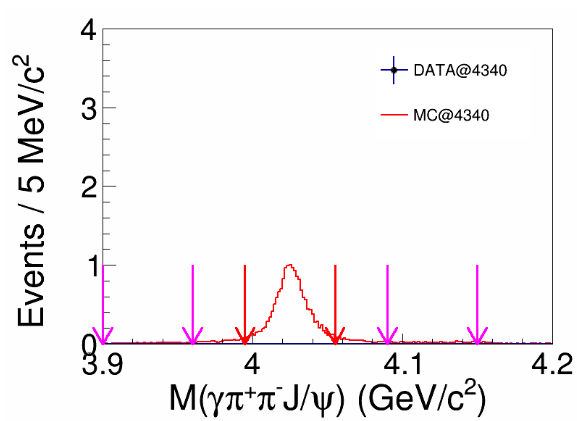
Data at $\sqrt{s} = 4.337$ GeV











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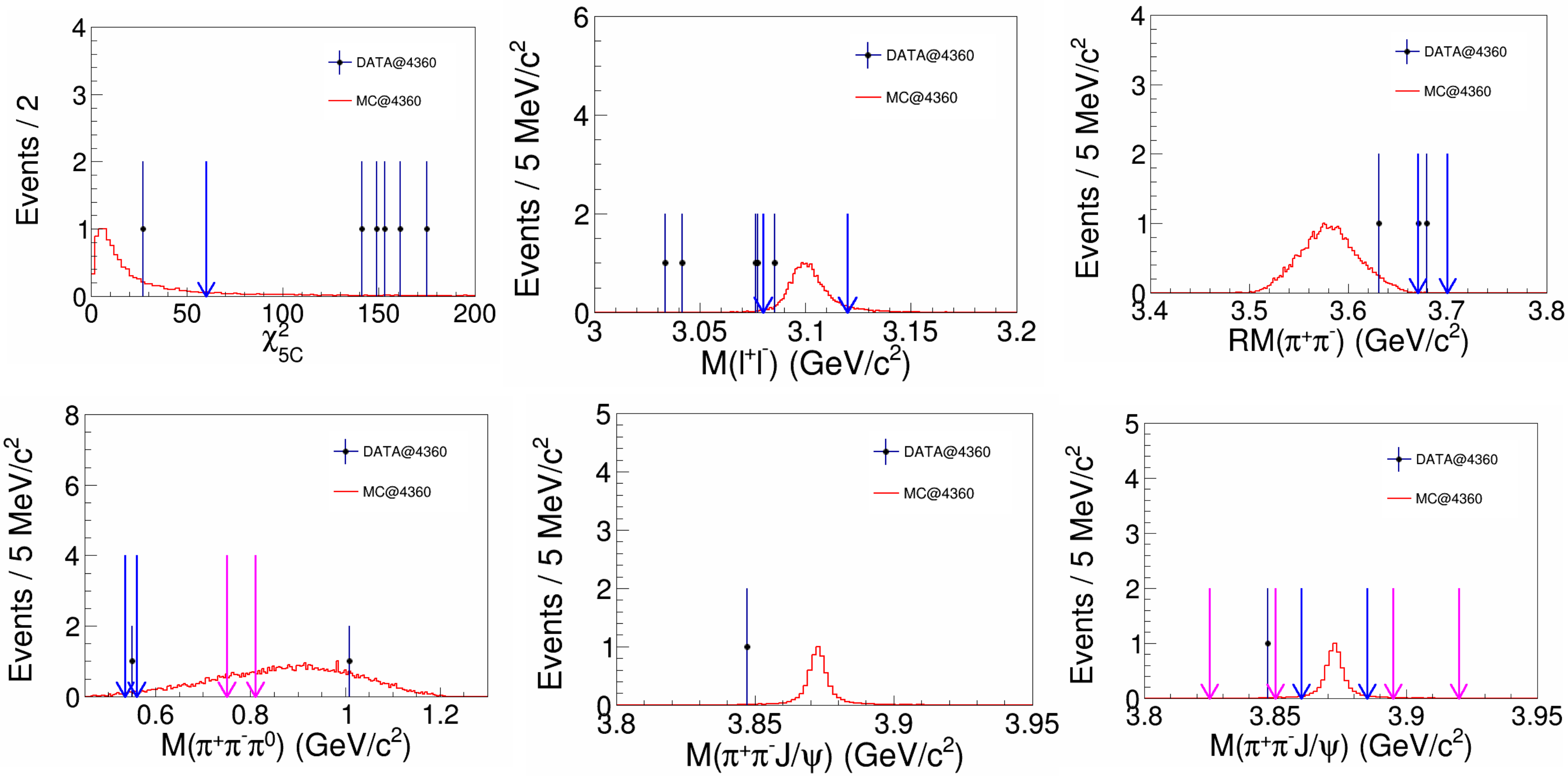
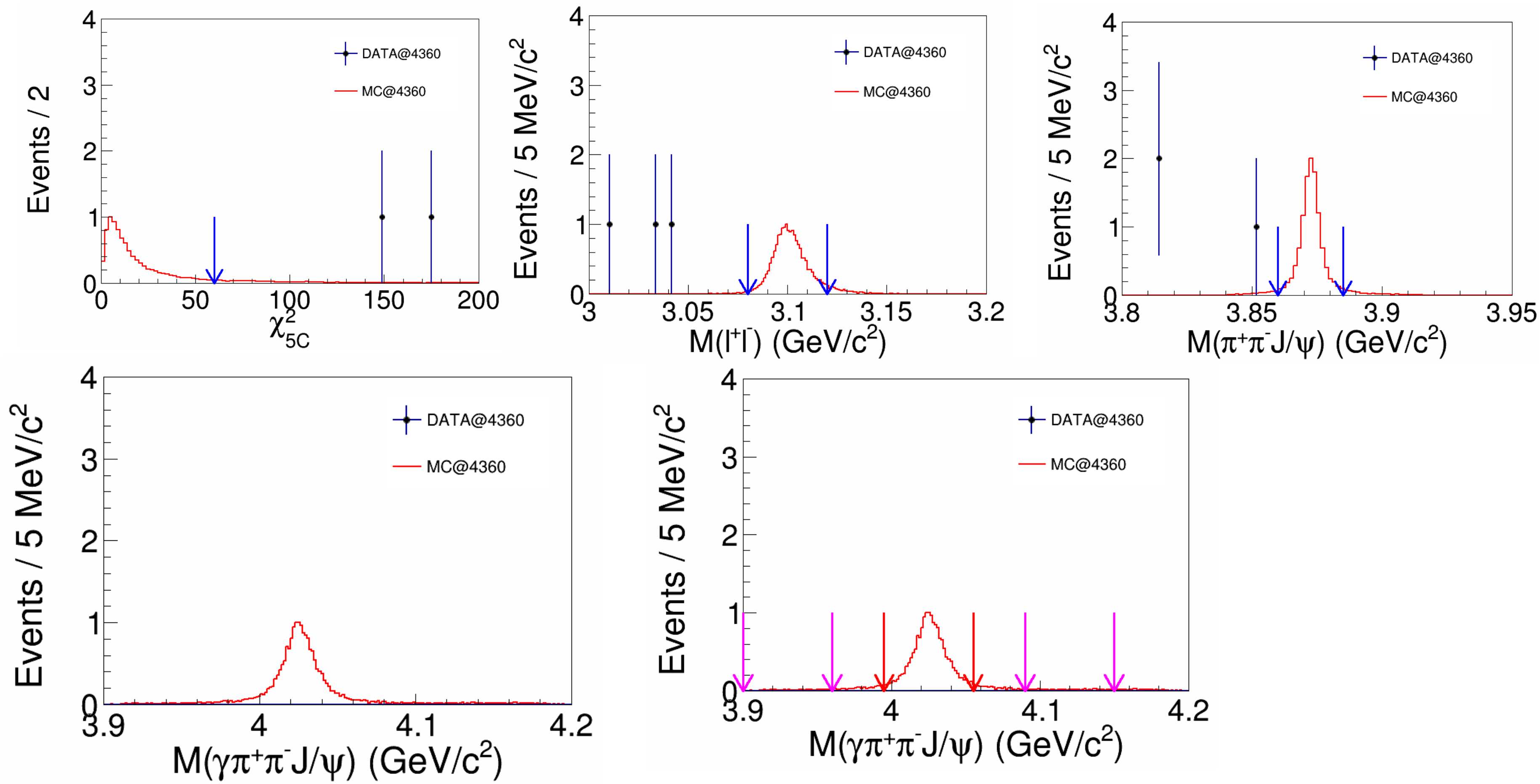
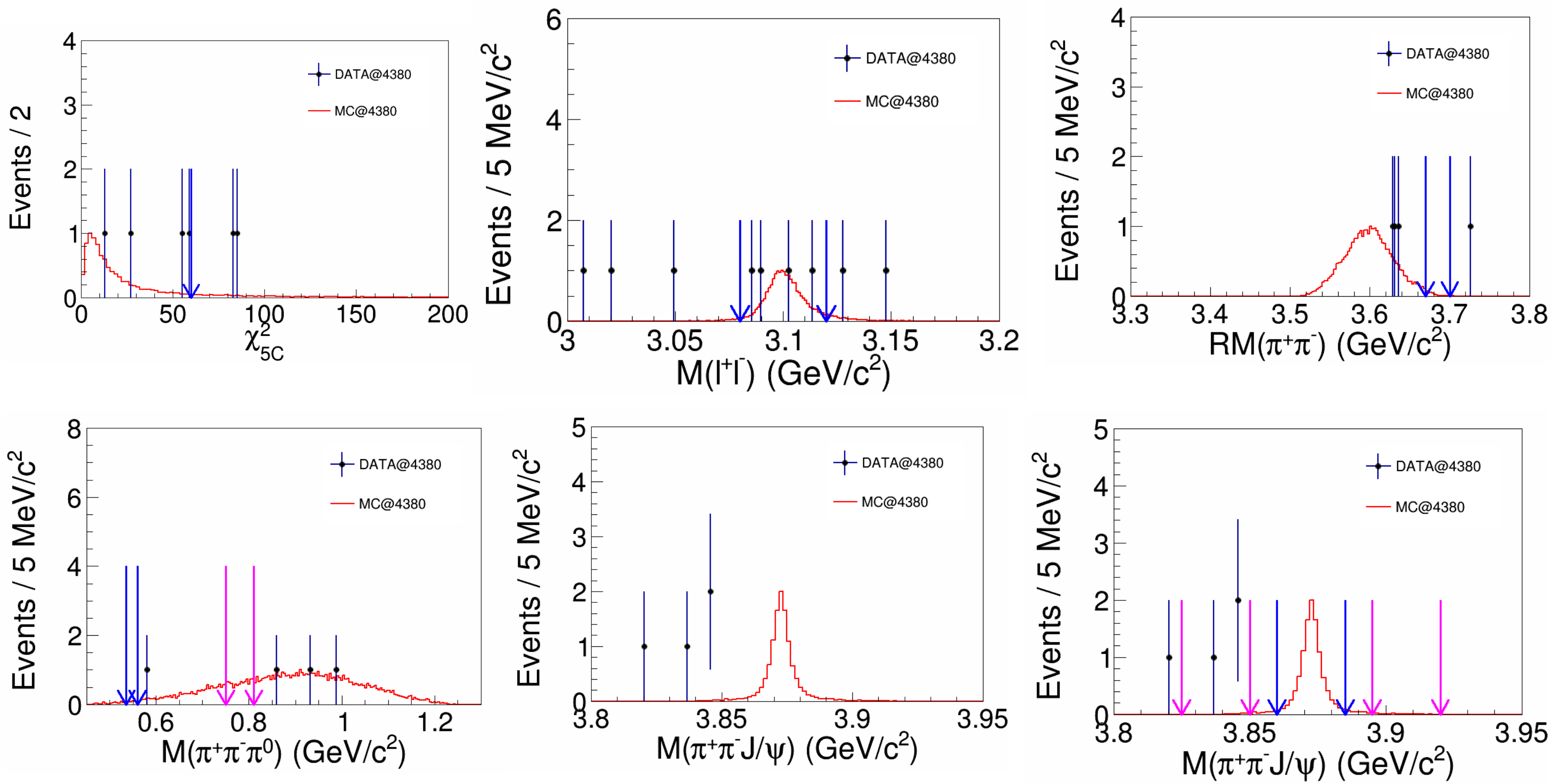


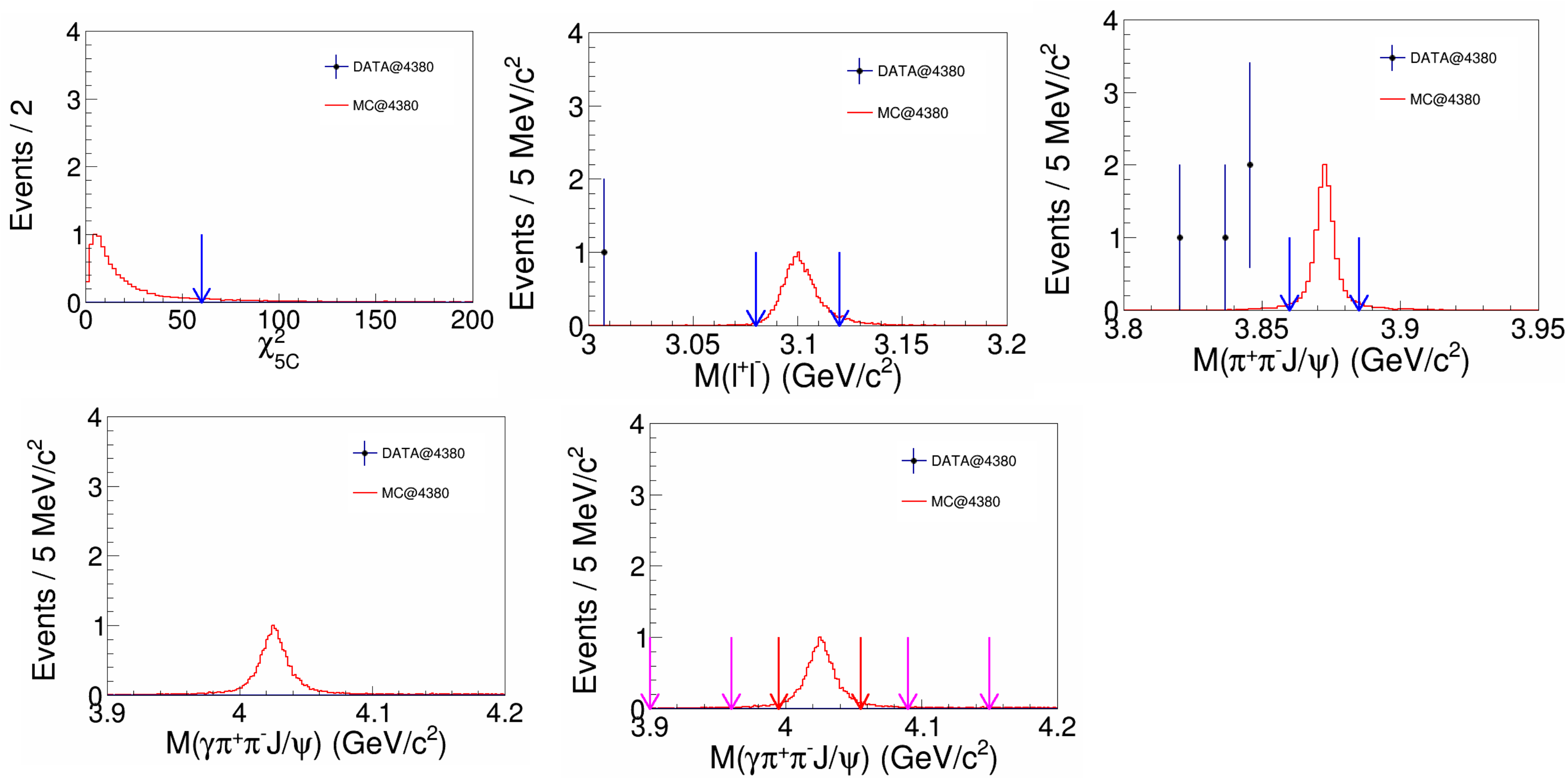
Data at $\sqrt{s} = 4.358$ GeV



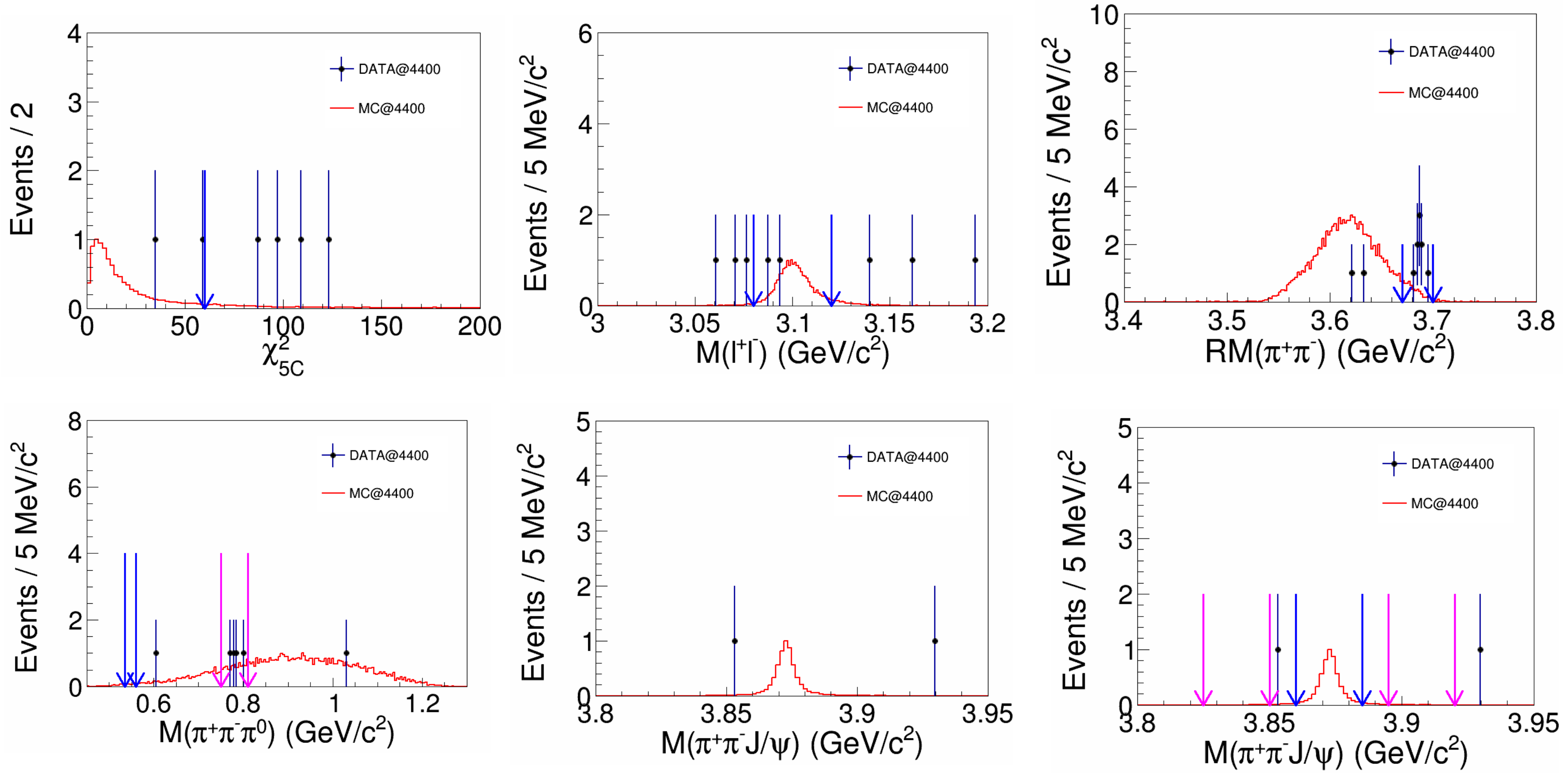
Data at $\sqrt{s} = 4.377$ GeV



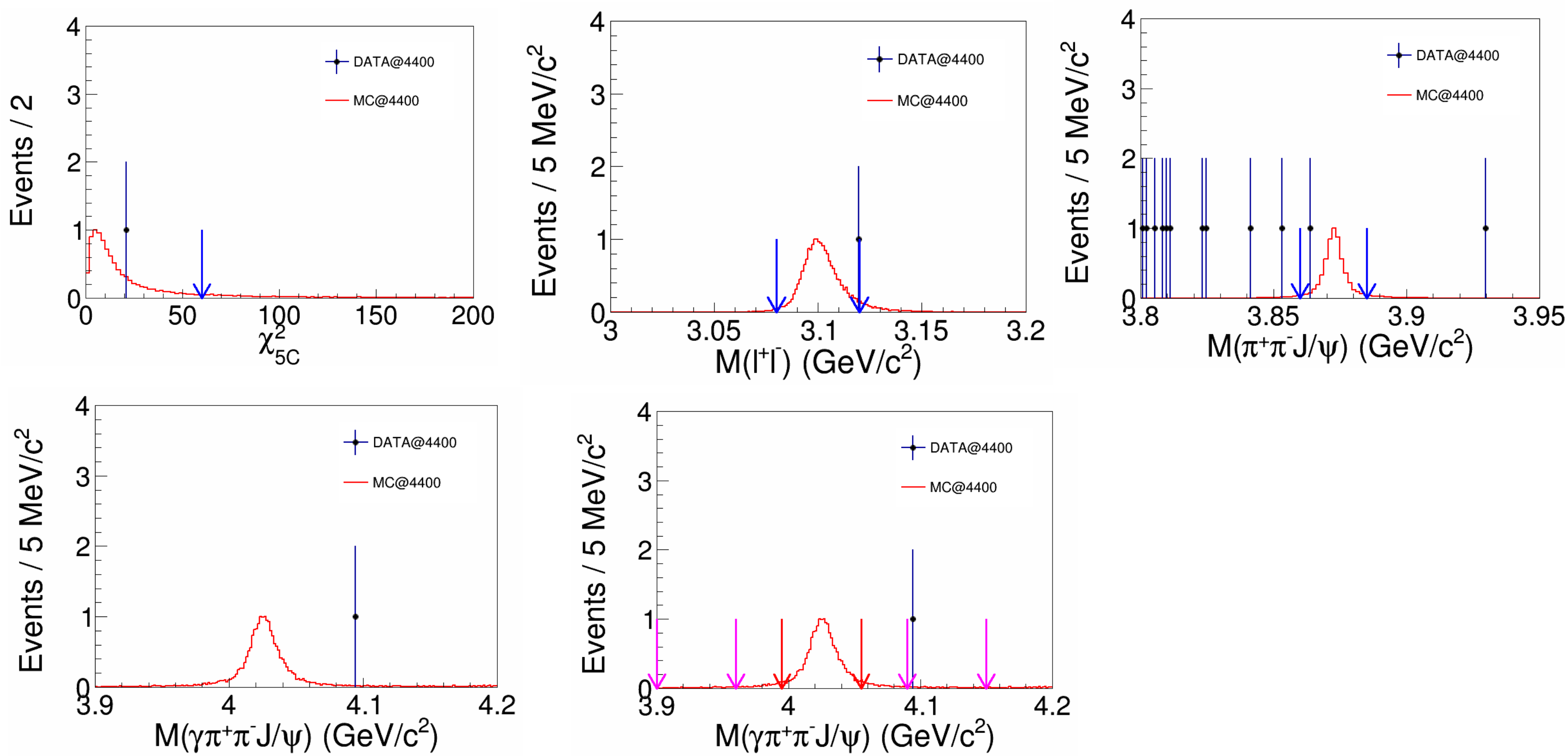
Data at $\sqrt{s} = 4.377$ GeV



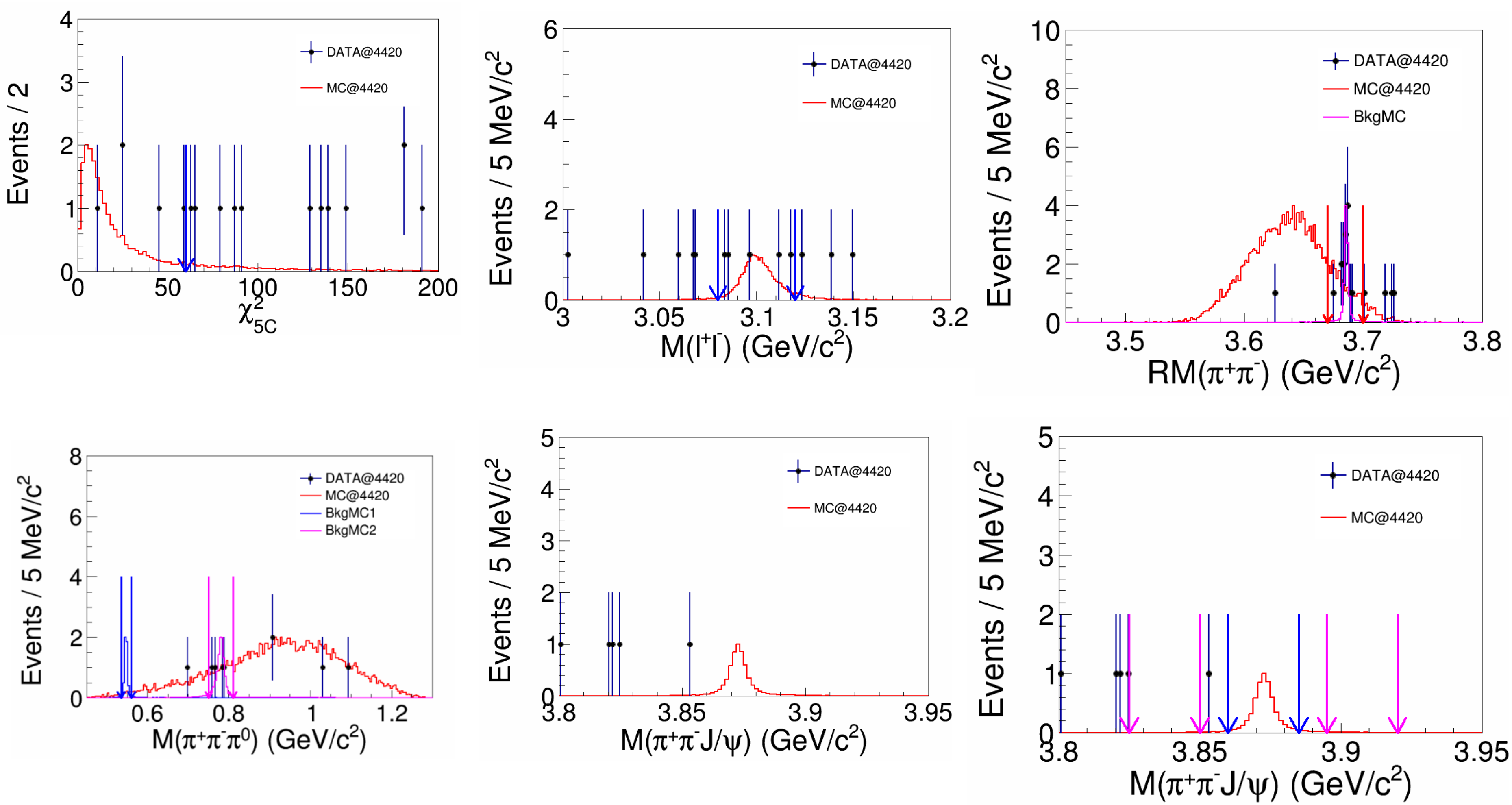
Data at $\sqrt{s} = 4.396$ GeV



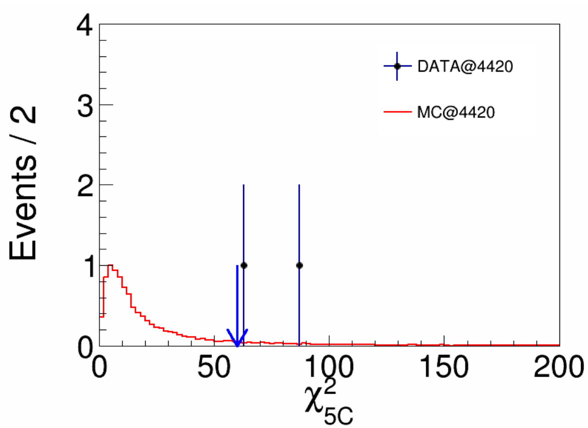
Data at $\sqrt{s} = 4.396$ GeV

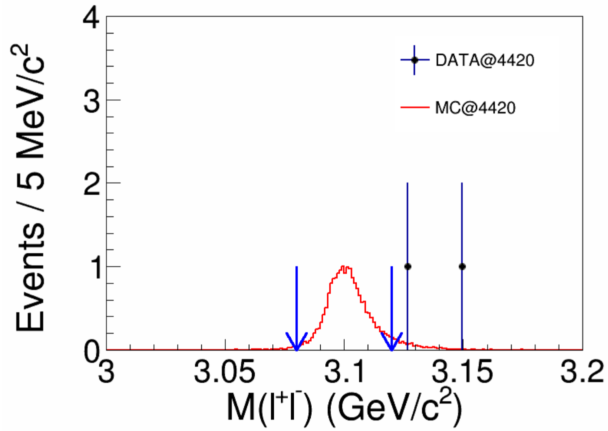


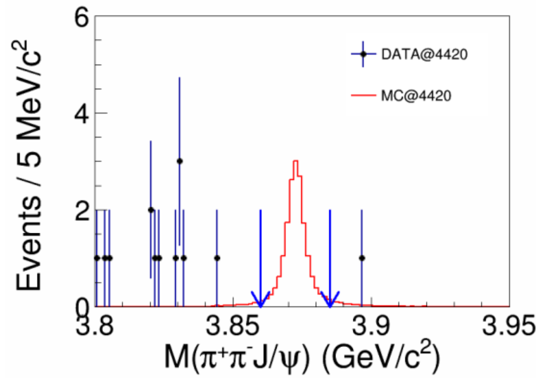
Data at $\sqrt{s} = 4.416$ GeV

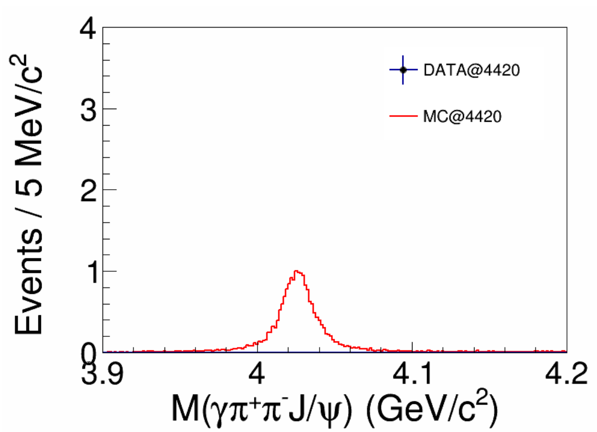


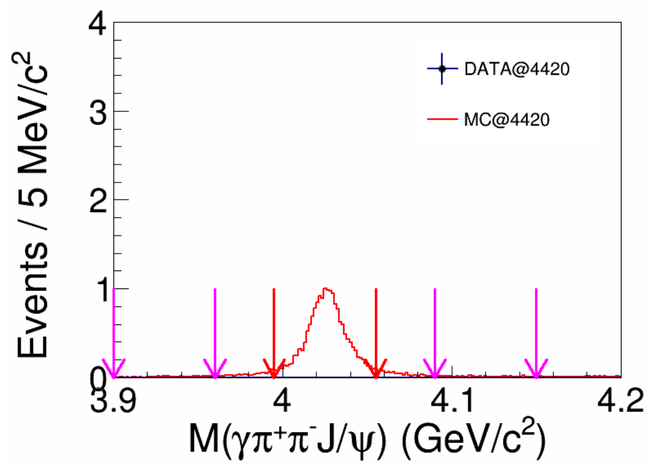
Data at $\sqrt{s} = 4.416$ GeV











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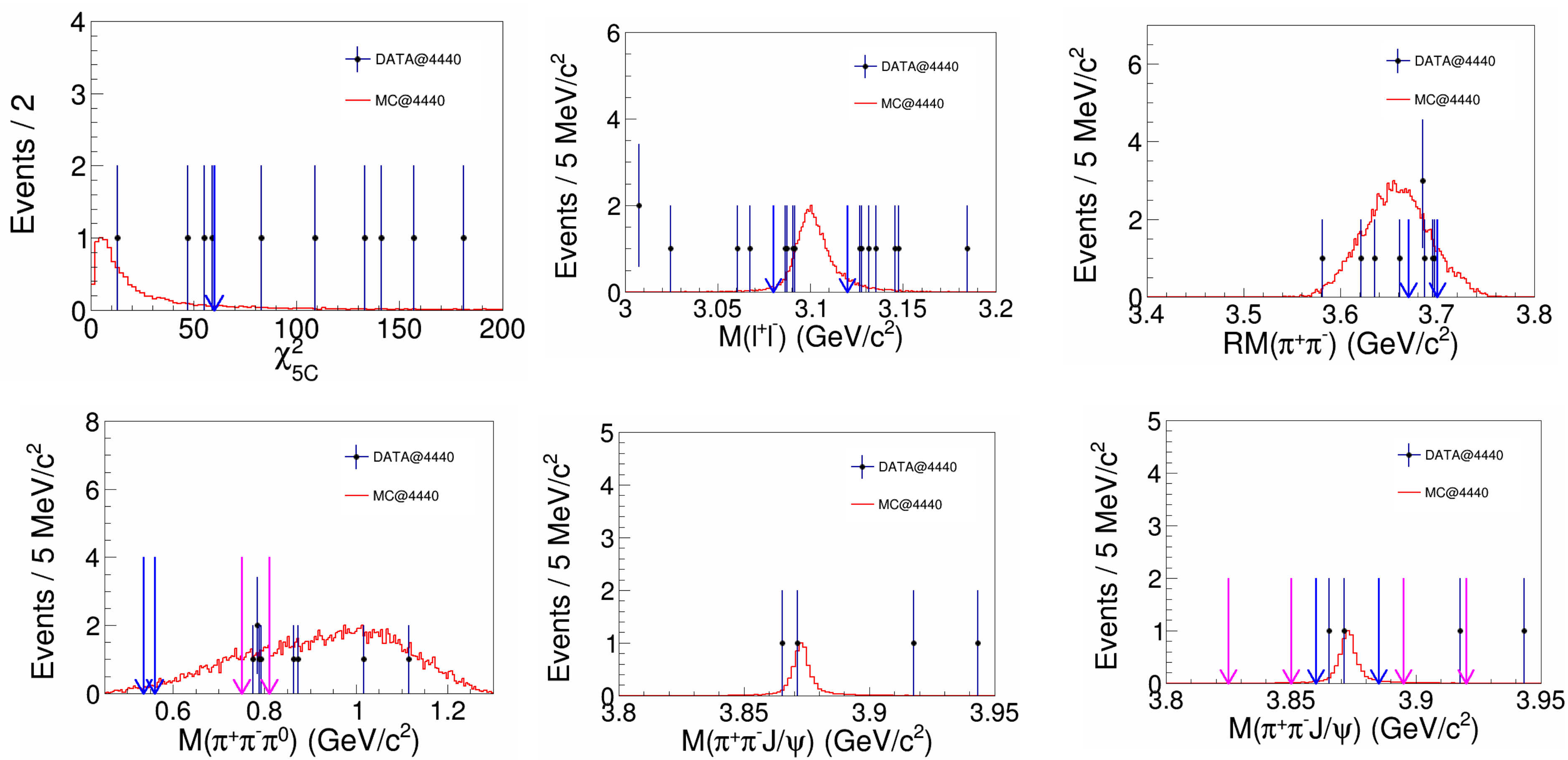
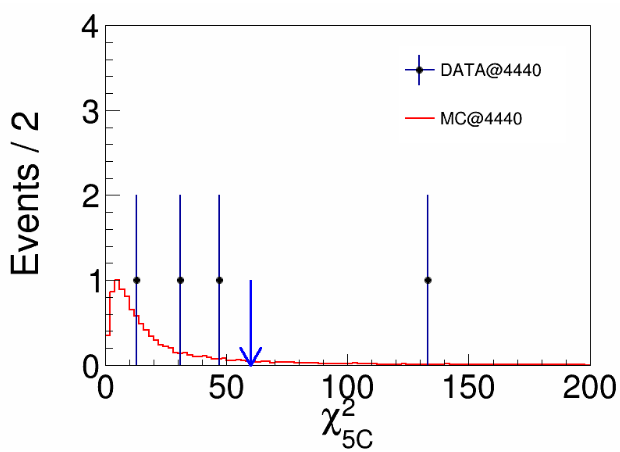
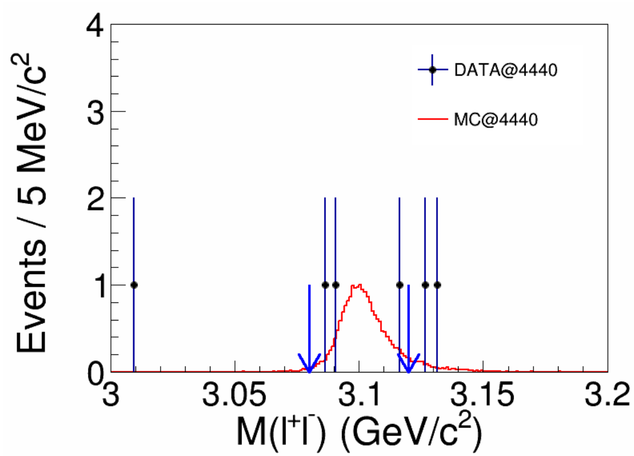
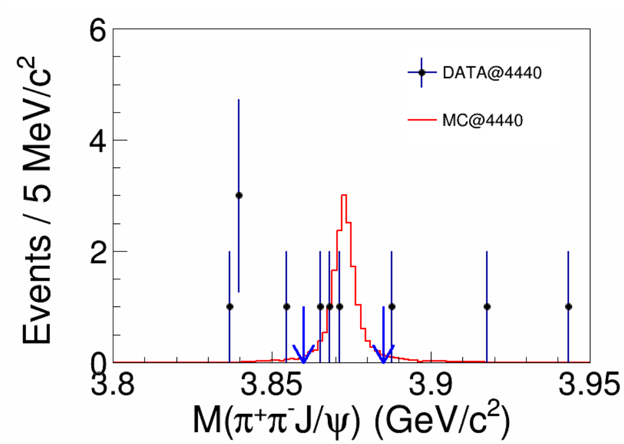
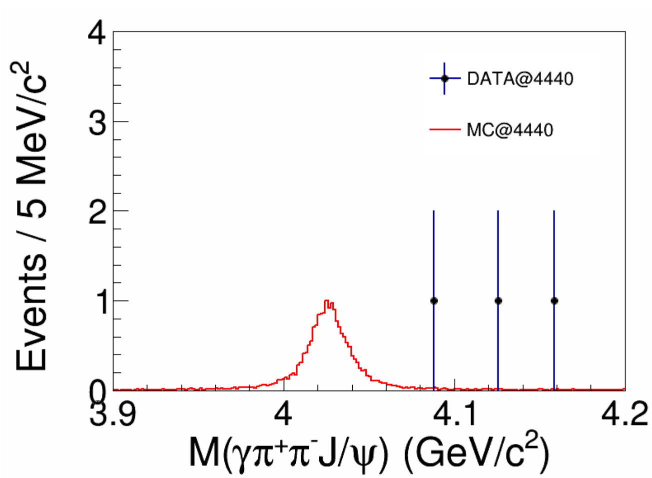


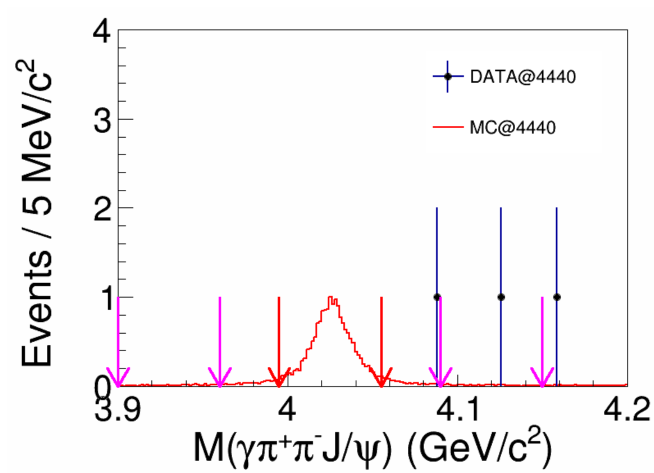
Data at $\sqrt{s} = 4.436$ GeV



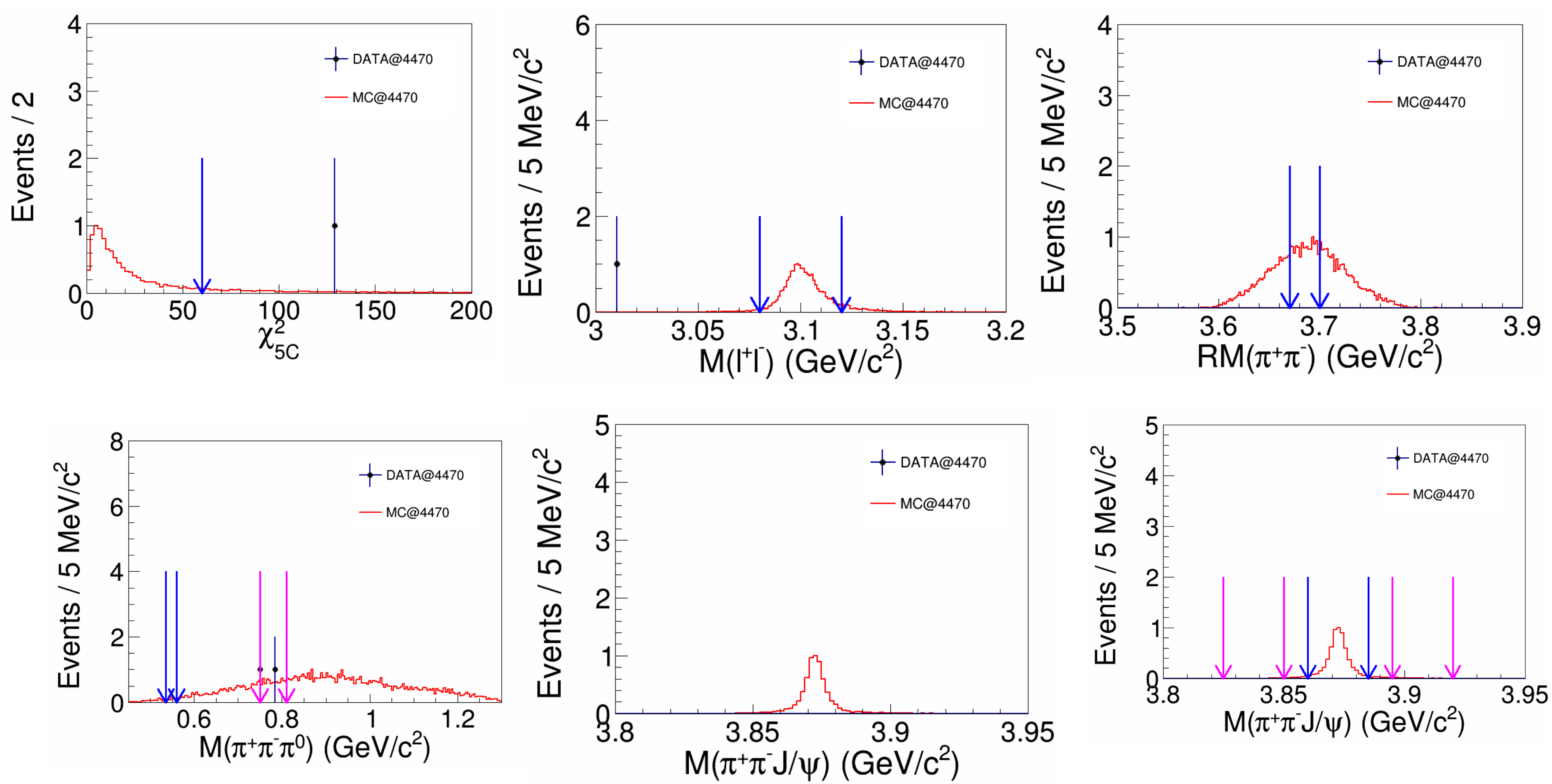




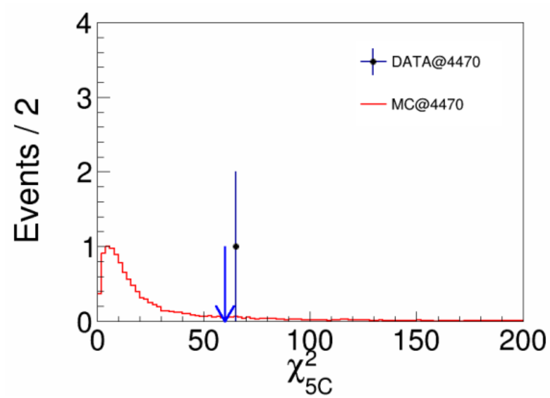


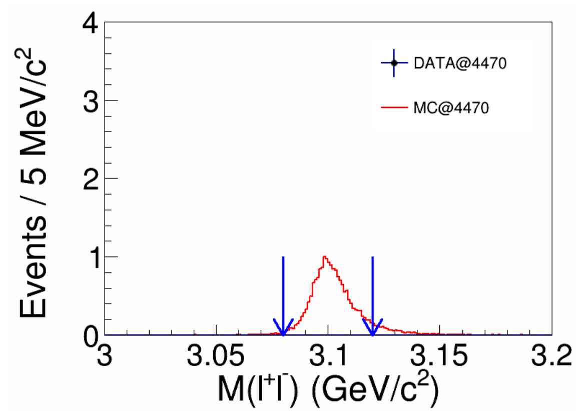


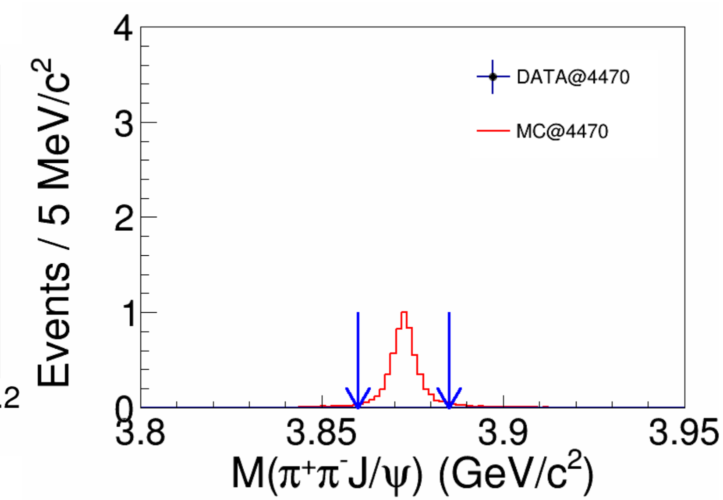
Data at $\sqrt{s} = 4.467$ GeV

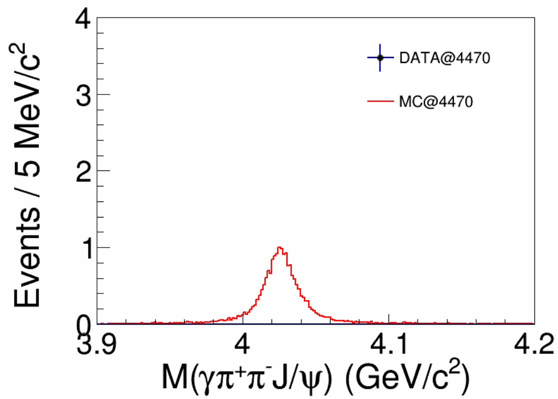


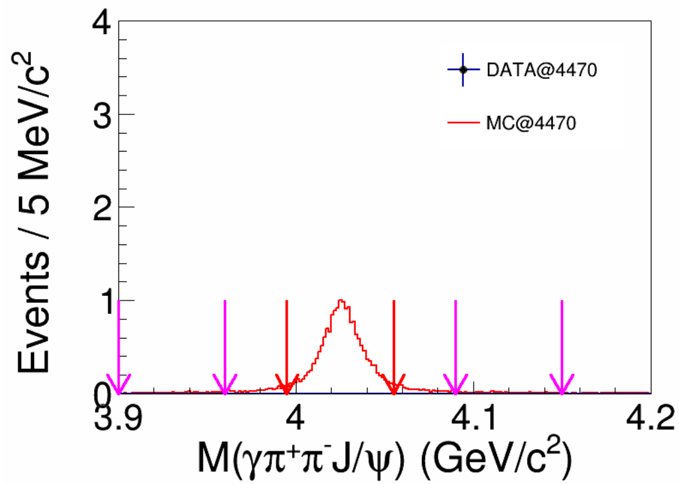
Data at $\sqrt{s} = 4.467$ GeV



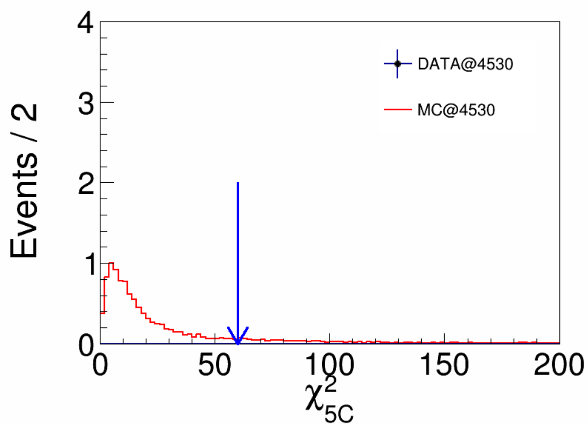


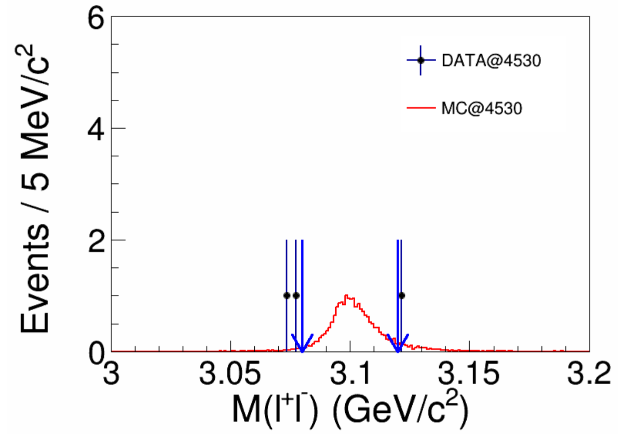


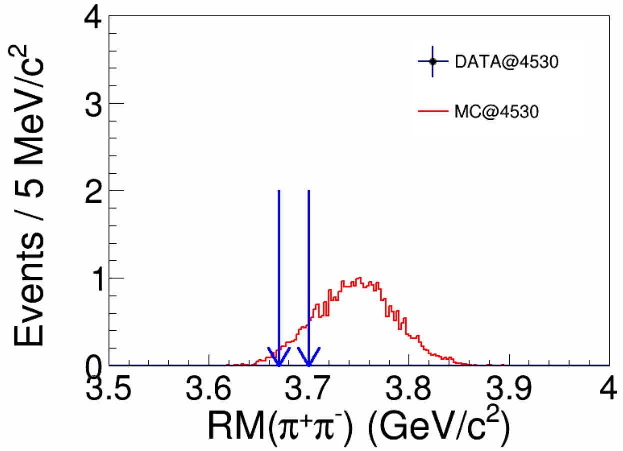


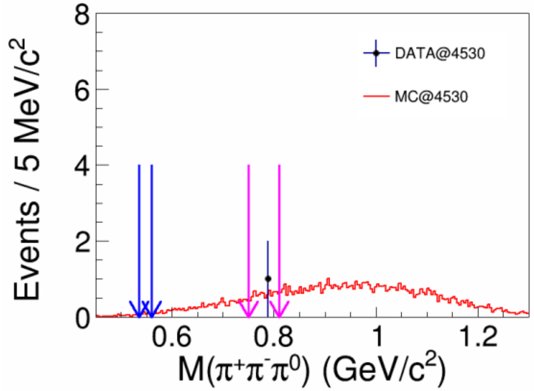


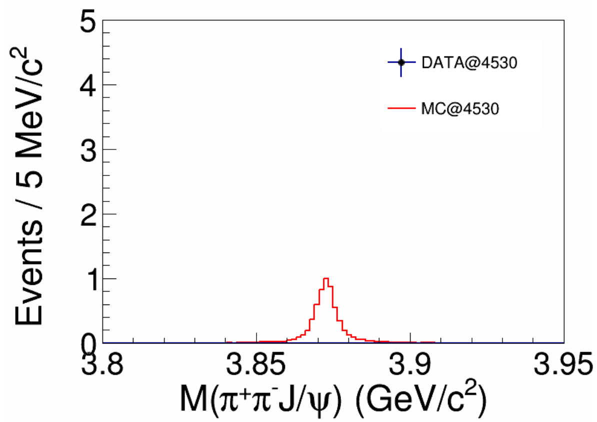
Data at $\sqrt{s} = 4.527$ GeV

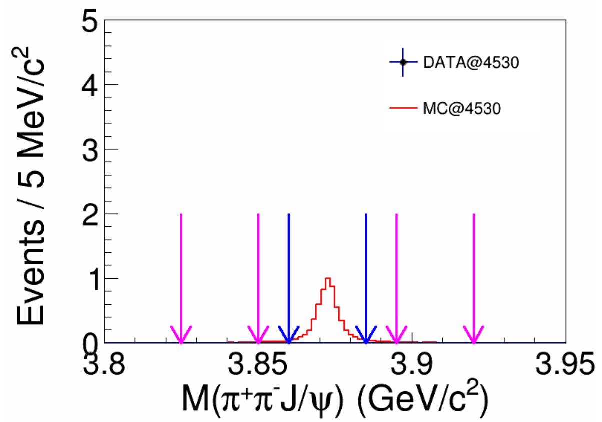




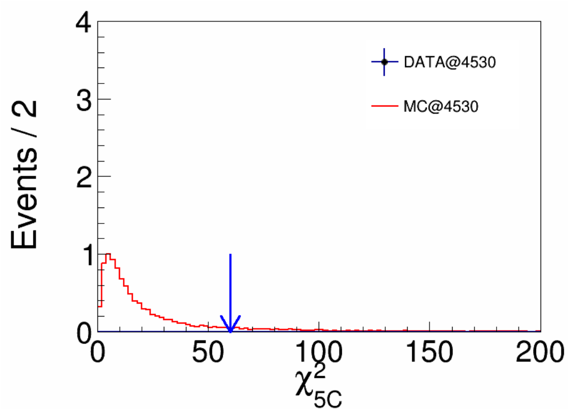


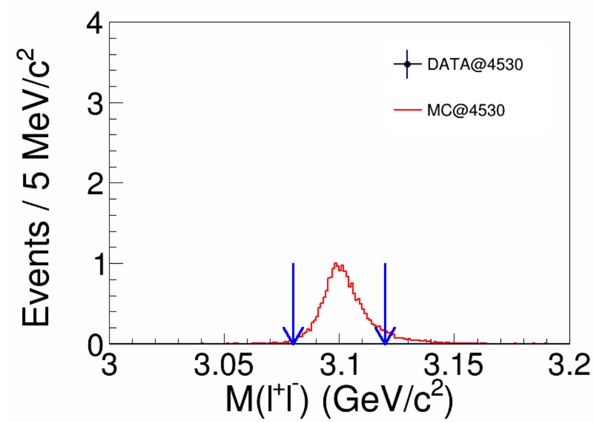


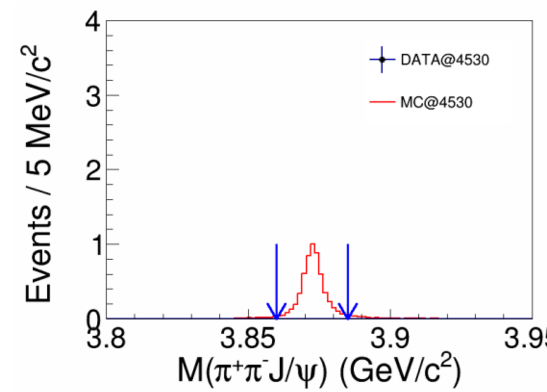


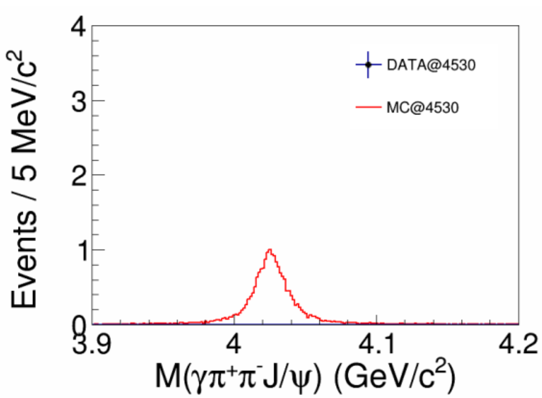


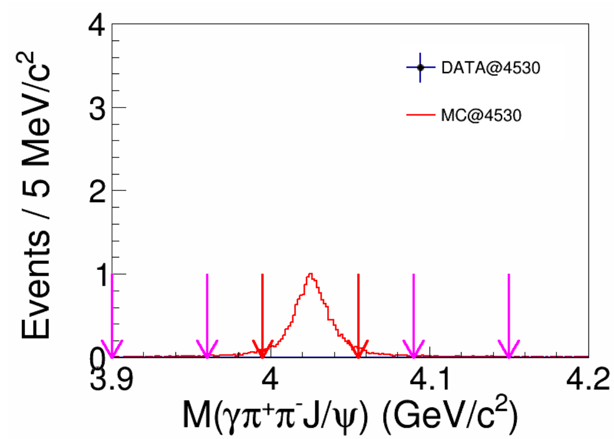
Data at $\sqrt{s} = 4.527$ GeV



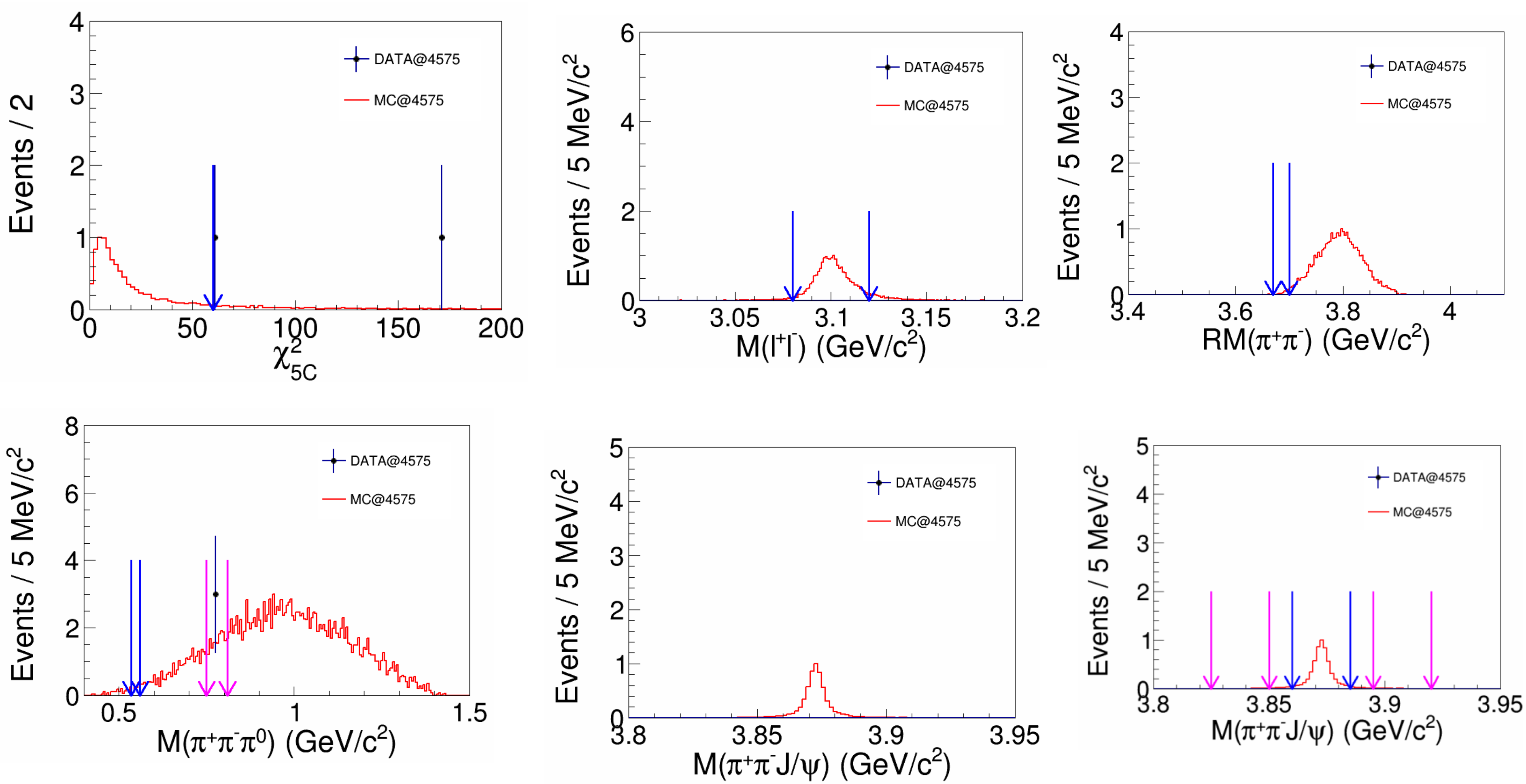




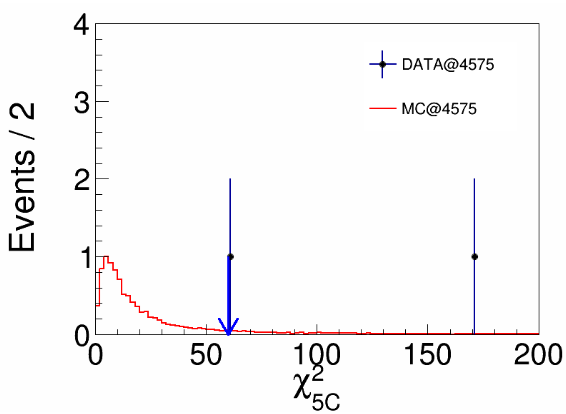


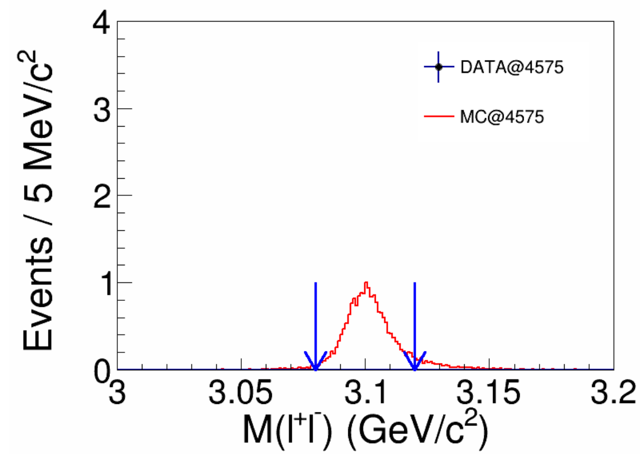


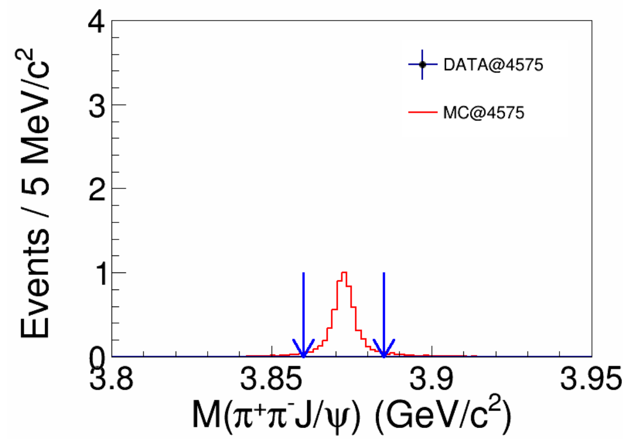
Data at $\sqrt{s} = 4.574$ GeV

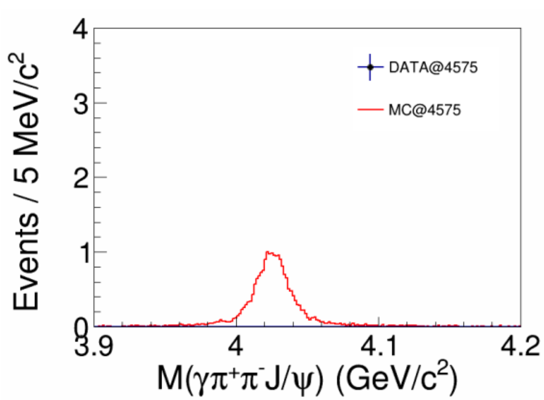


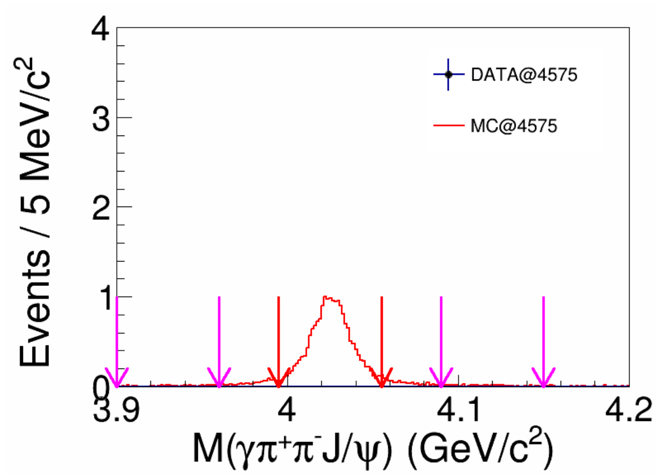
Data at $\sqrt{s} = 4.574$ GeV



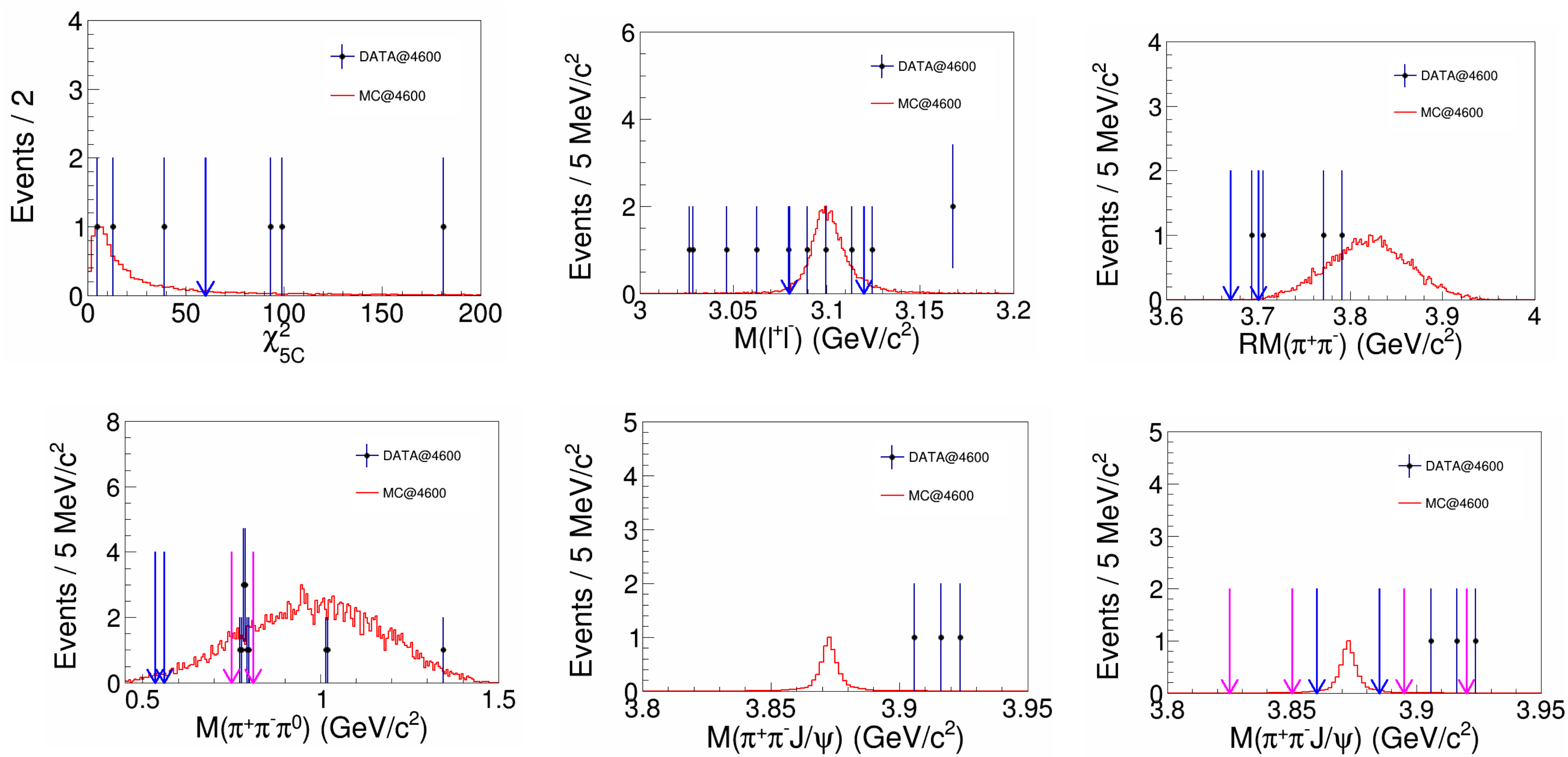








Data at $\sqrt{s} = 4.600$ GeV



Data at $\sqrt{s} = 4.600$ GeV