Measurement of cross section of $e^+e^- \to \pi^0\pi^0 J/\psi$ for XYZ data

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Outline

- Motivation
- Data sets
- Events selection
- Background study
- Fit to invariant mass of leptons
- Cross section
- Next to do

Motivation

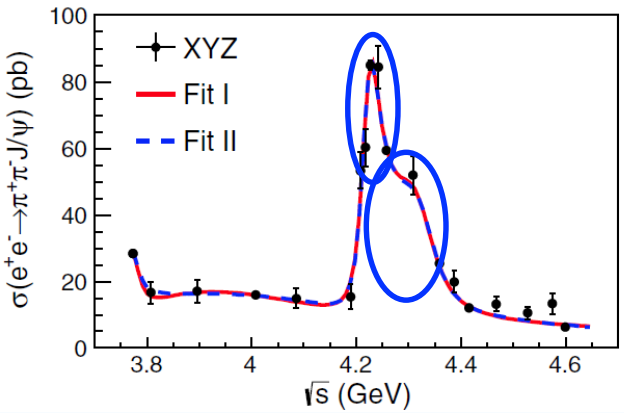
- Recently, a series of Y states have been observed by Belle, BaBar and BESIII experiments, the observation of Y states has stimulated substantial theoretical discussions on their nature.
- The Y(4260) state was once considered as a good hybrid candidate, anti-diquark tetraquark, meson molecule, and hadrocharmonium etc.
- To be better identify the nature of the Y states and distinguish various models, more precise experimental measurements, including the production cross section and the mass and width of the Y states, are essential.

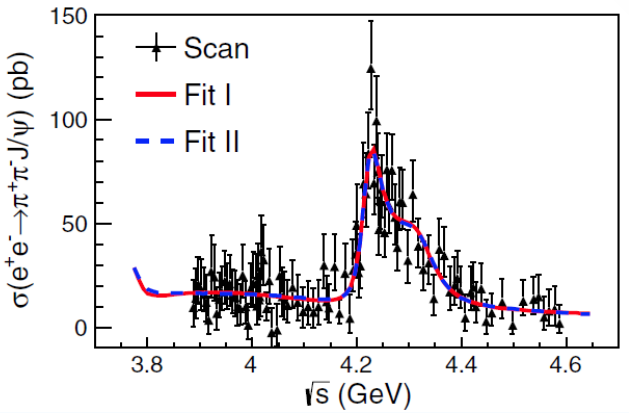
Motivation

- BESIII has measured the cross section for the process $e^+e^- \to \pi^+\pi^- J/\psi$ precisely, and two resonant structures are observed in a fit to the cross section.

(4222.0±3.1±1.4)MeV

(4320.0±10.4 ±7.0)MeV





- Measuring the $e^+e^- \to \pi^0\pi^0 J/\psi$ cross section line shape will be helpful to understand the resonances around 4.220 GeV and 4.320 GeV.
- Meanwhile, the ratio of cross section for neutral and charged processes of $e^+e^- \to \pi\pi J/\psi$ will be given.

Data sets

- Decay channel: $e^+e^- \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-/\mu^+\mu^-$
- Boss version: 702p01 + 664p01
- Signal MC: 100K for each decay channel at each energy point
- Inclusive MC: generated at 4.260 GeV

  (bhabha, di-γ, di-μ, di-τ, resDD, two-γ, hadron, ISR, qqbar, γXYZ)
- Data: 3.810~4.600 GeV old XYZ data

  + new XYZ data (~4.2GeV)

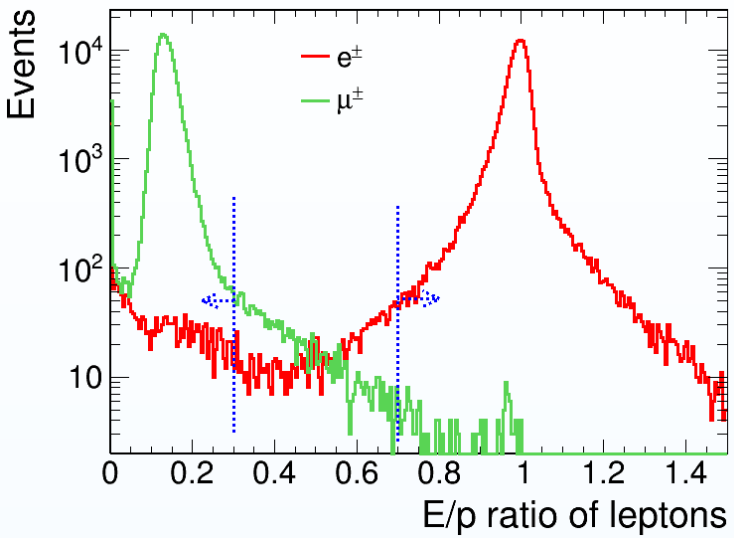
Events selection

- Only two Good tracks with total charge =0
  - Electron: E/p>0.7 for both tracks, $\theta_{e^+e^-} < 177°$ if $\cos\theta_{e^+}$>0.5 or $\cos\theta_{e^-}$<-0.5
  - Muon: E/p<0.3 for both tracks, at least one matches more than 6 MUC layers
- At least 4 good photons
  - Barrel: E>0.025GeV && |cosθ|<0.8
  - Endcap: E>0.05GeV && 0.86<|cosθ|<0.92
  - Time: 0 < t < 14 (×50ns)
  - θ_{chgTrk}>5°
- $N_{\pi^0\pi^0}$<=2 for $M_{\gamma\gamma} \in (0.11, 0.15)\mathrm{GeV/c^2}$
- 4C + 1C(two π^0s) fit to select two π^0s with minimal $\chi^2=\chi^2_{4C}+\chi^2_{1C}+\chi^2_{1C}$, χ^2_{4C} < 90
- Mass window requirement: $\mathrm{M_{\pi^0}} \in (0.11, 0.15)\mathrm{GeV/c^2}$

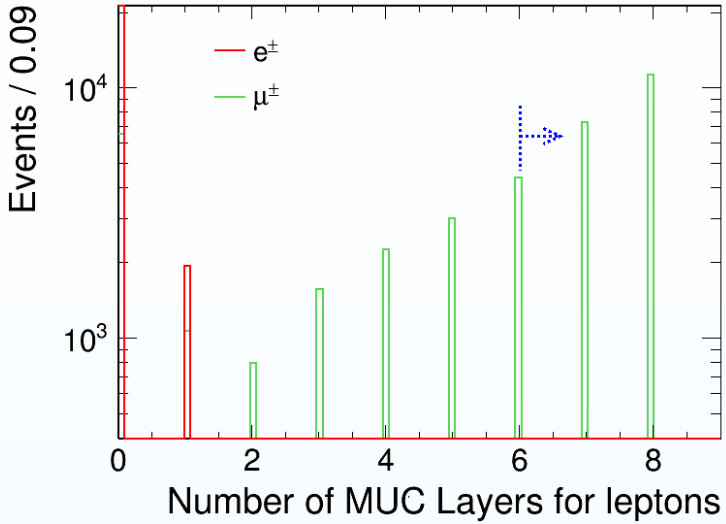
Events selections

Signal MC

- E/p ratio for leptons @4180



- Number of MUC layers @4180

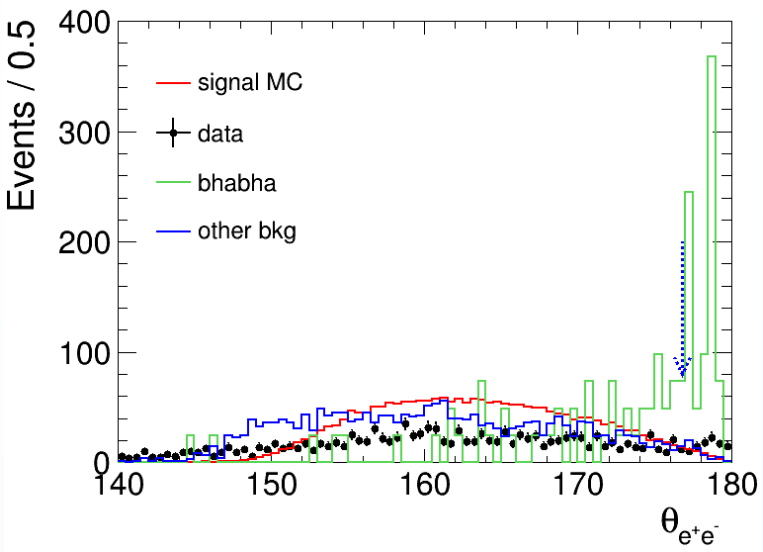


- Electron: E/p>0.7 for both tracks
- Muon: E/p<0.3 for both tracks, at least one matches more than 6 MUC layers

Optimization of events selection

@4.260 GeV

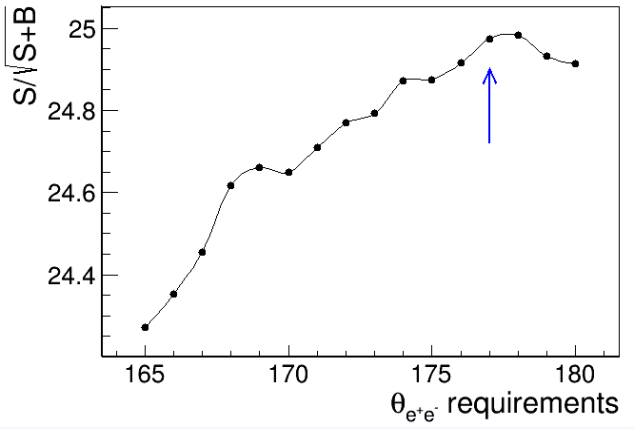
- Electron: $\theta_{e^+e^-}$ <177° if cosθ_{e^+}>0.5 or cosθ_{e^-}<0.5

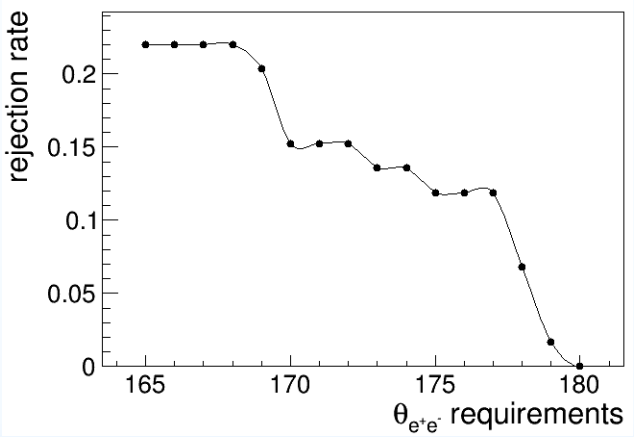


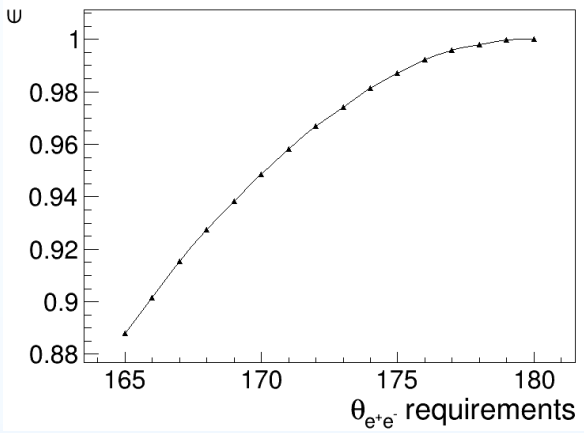
- Use inclusive MC to optimize the requirements with the form of merit

$$S/\sqrt{S+B}$$

- The requirement causes the loss of efficiency about 1%.



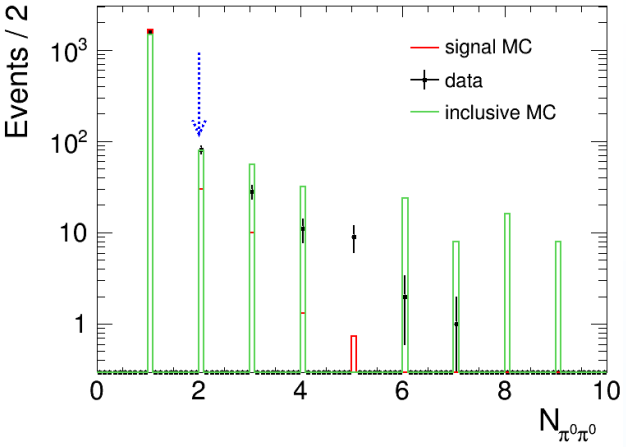


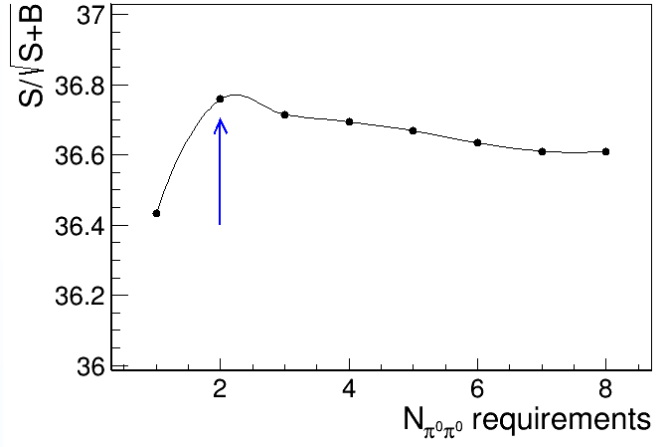


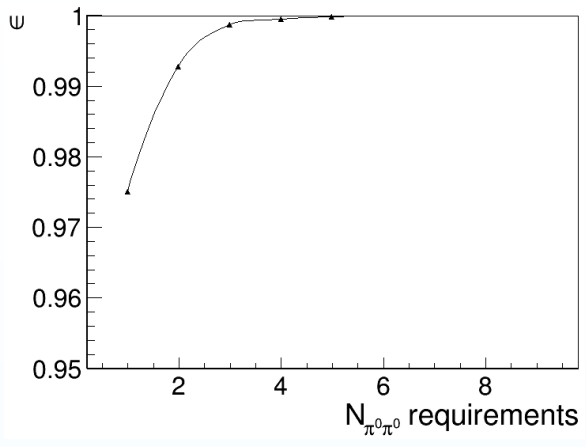
Optimization of Events selection

- $N_{\pi^0\pi^0}$ <= 2

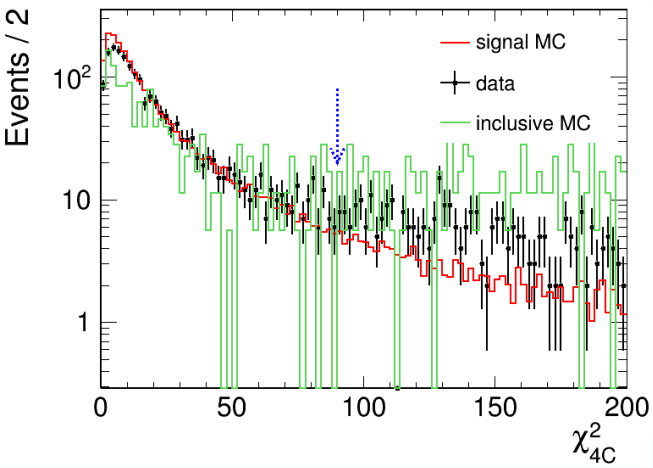
@4.260 Gev

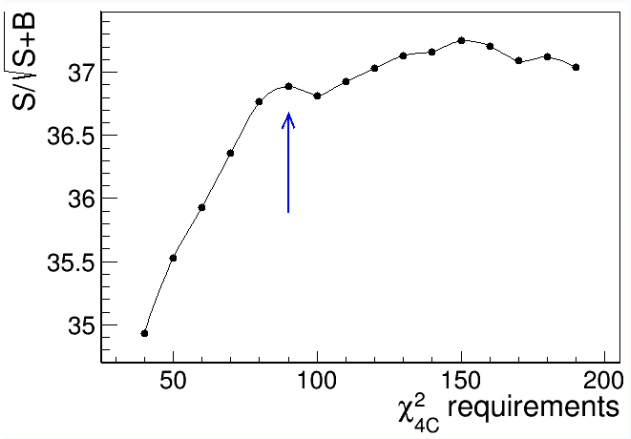


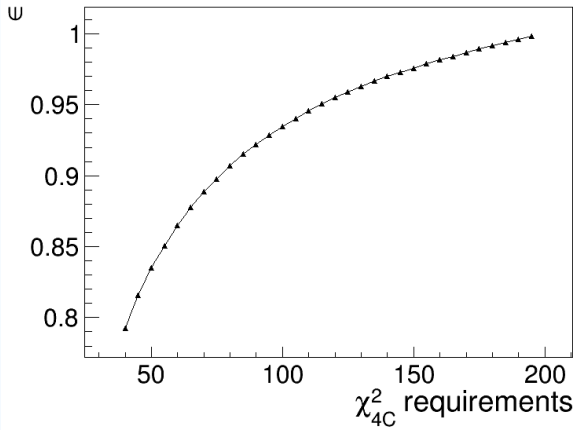




- χ^2_{4C} < 90







Background analysis (Inclusive MC)

- 4260-hadrons ($e^+e^- \to X(\eta, \eta\eta \ldots)\mathrm{J}/\psi$ will be considered in systematic)

No.	decay chain	final states	iTopology	nEvt	nTot
0	$\psi(4260) \to \pi^0\pi^0 J/\psi, J/\psi \to \mu^+\mu^-$	$\mu^+\pi^0\pi^0\mu^-$	0	688	688
1	$\psi(4260) \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-$	$e^+e^-\pi^0\pi^0$	1	537	1225
2	$\psi(4260) \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-\gamma_{FSR}$	$e^+e^-\pi^0\pi^0$	4	60	1285
3	$\psi(4260) \to \pi^0\pi^0 J/\psi, J/\psi \to \mu^+\mu^-\gamma_{FSR}$	$\mu^+\pi^0\pi^0\mu^-$	5	21	1306
4	$\psi(4260) \to \eta\eta J/\psi, \eta \to \gamma\gamma, \eta \to \gamma\gamma, J/\psi \to \mu^+\mu^-$	$\mu^+\mu^-\gamma\gamma\gamma\gamma$	3	8	1314
5	$\psi(4260) \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to \mu^+\mu^-$	$\mu^+\pi^0\pi^0\pi^0\mu^-$	7	5	1319
6	$\psi(4260) \to \pi^0\pi^0 J/\psi, J/\psi \to e^+e^-\gamma_{FSR}\gamma_{FSR}$	$e^+e^-\pi^0\pi^0$	8	4	1323
7	$\psi(4260) \to \eta\eta J/\psi, \eta \to \gamma\gamma, \eta \to \gamma\gamma, J/\psi \to e^+e^-$	$e^+e^-\gamma\gamma\gamma\gamma$	6	3	1326
8	$\psi(4260) \to \eta J/\psi, \eta \to \pi^0\pi^0\pi^0, J/\psi \to e^+e^-$	$e^+e^-\pi^0\pi^0\pi^0$	9	2	1328
9	$\psi(4260) \to \eta\eta J/\psi, \eta \to \gamma\gamma, \eta \to \gamma\gamma, J/\psi \to e^+e^-\gamma_{FSR}$	$e^+e^-\gamma\gamma\gamma\gamma$	2	1	1329

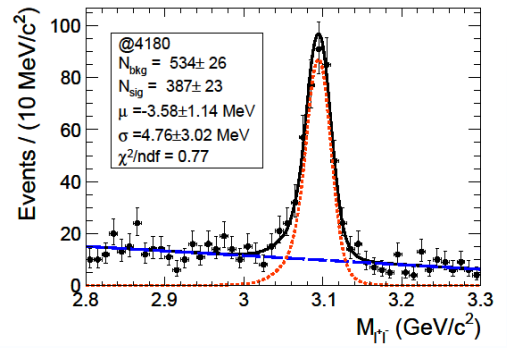
- 4260-qqbar

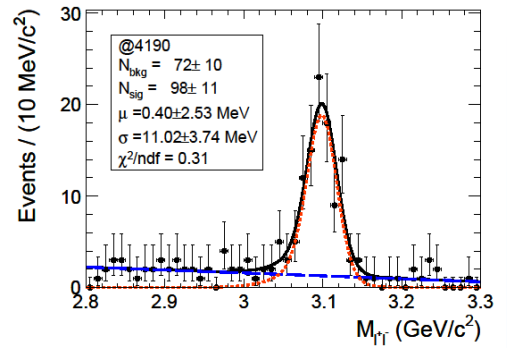
No.	decay chain	final states	iTopology	nEvt	nTot
0	$string \to \rho^+\pi^0\pi^-, \rho^+ \to \pi^+\pi^0$	$\pi^-\pi^0\pi^0\pi^+$	0	5	5
1	$string \to \pi^+\pi^0\rho^-, \rho^- \to \pi^-\pi^0$	$\pi^-\pi^0\pi^0\pi^+$	2	3	8
2	$string \to \rho^+\pi^-\pi^0, \rho^+ \to \pi^+\pi^0\gamma$	$\pi^-\pi^0\pi^0\pi^+\gamma$	1	1	9
3	$string \to K_2^{*+}K^-\pi^0, K_2^{*+} \to K^+\pi^0$	$K^-\pi^0\pi^0K^+$	3	1	10

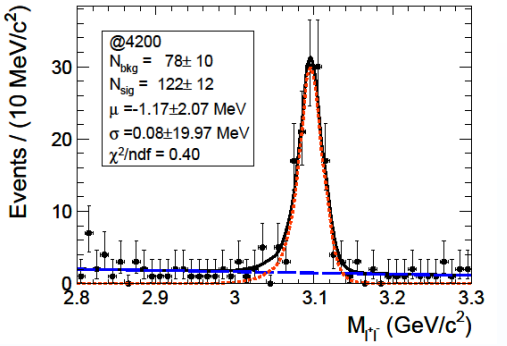
Modes	ISR	Bhabha	Dimu	Ditau	resDD
Number of event	5	8	0	0	0

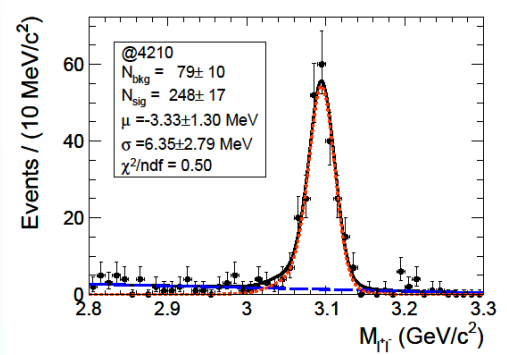
Fit to invariant mass M(l^+l^-)

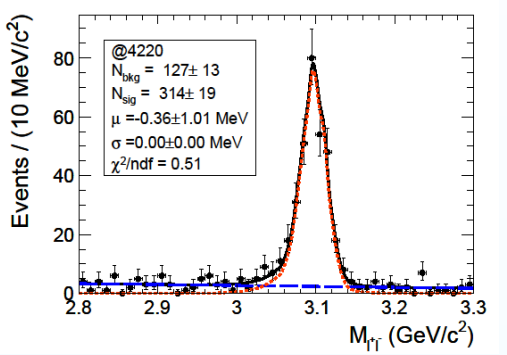
- MC shape⊗Gaussian +1st polynomial

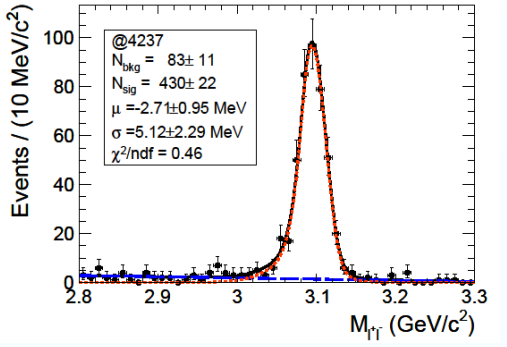


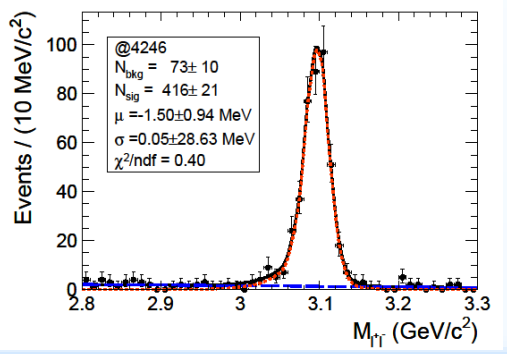


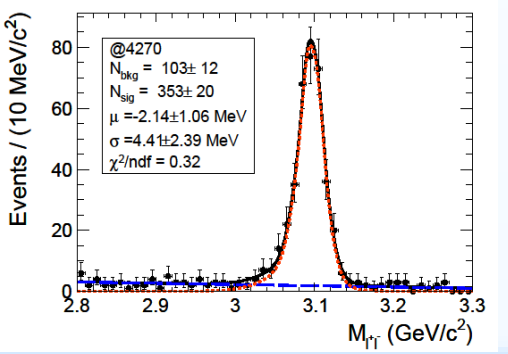


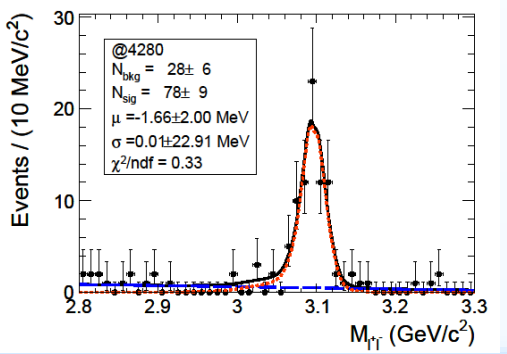








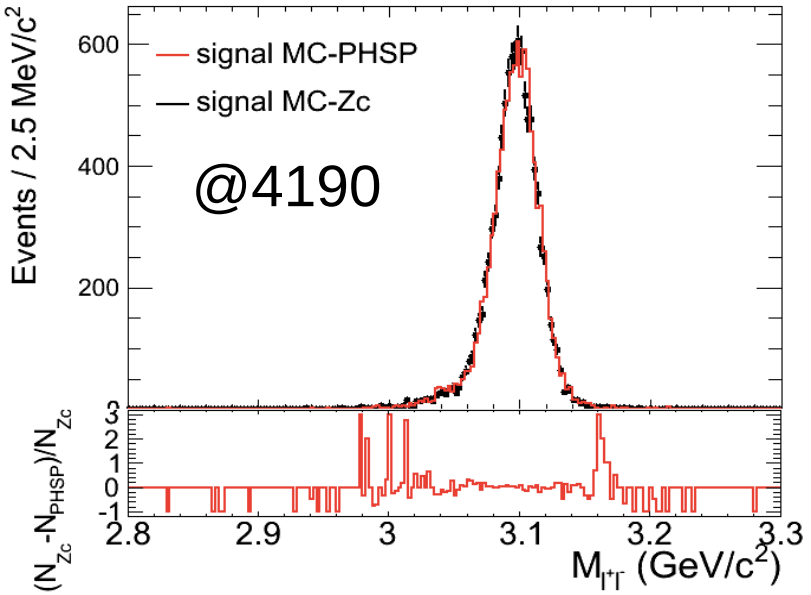


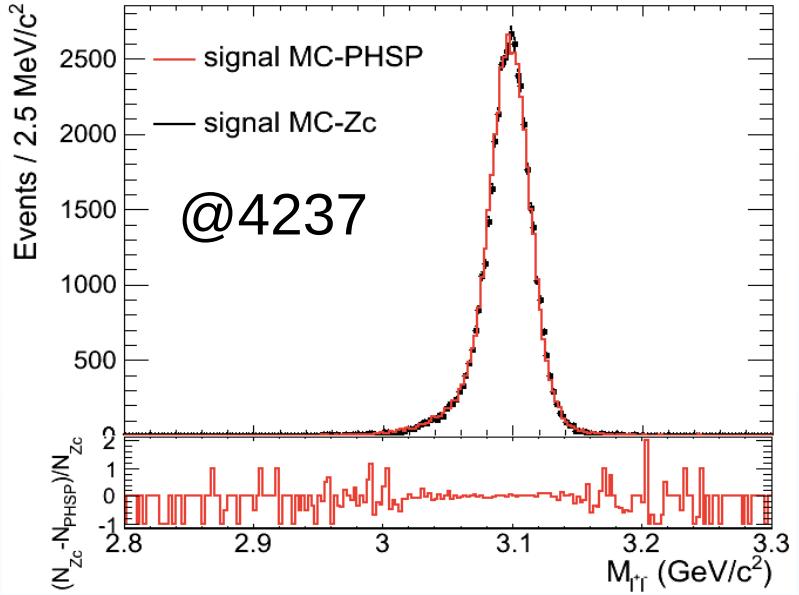


MC comparison

Two kinds of signal MC:

- With intermediate Zc(3900) - PHSP





- Two kinds of MC have comparable resolution for invariant mass distribution M(l^+l^-)
- PSPH MC shape convolute with Gaussian to describe signal
- The weighted efficiency will be calculated by weighting the 2-D spectrum of M($\pi^0 J/\psi$) and M($\pi^0\pi^0$) from PHSP to data .

Cross section

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

- N^{obs} is observed events from data
- ε is selection efficiency calculated from the MC samples
- Br stands for the branching ratio of $J/\psi \to e^+e^-(\mu^+\mu^-)$
- $(1+\delta^v)$ is vacuum polarization factor taken from QED
- $(1+\delta^r)$ is the radiative correction factor

For new data

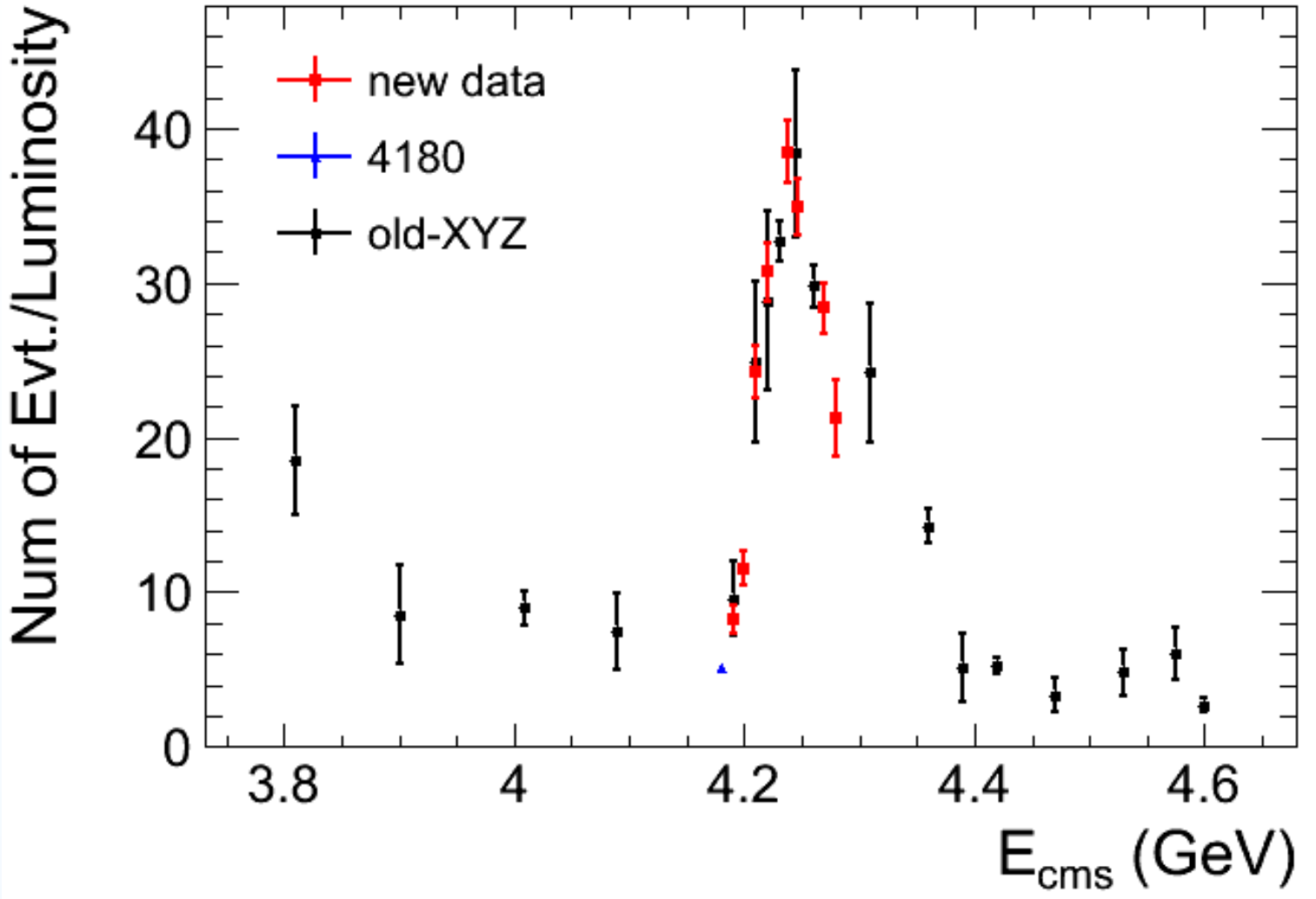
Energy (MeV)	$\mathcal{L}$ (pb^{-1})	$\varepsilon^{PHSP}_{\pi^0\pi^0 J/\psi}$(%)	$N^{obs}_{\pi^0\pi^0 J/\psi}$	$1+\delta^r$	$1+\delta^{vac}$	σ^{Born}(pb)
4180	3162.8±0.0	20.396	387±23	0.933	1.055	5.13 ± 0.31
4190	493.14±0.0	22.021	98±11	0.877	1.056	8.20 ± 0.92
4200	497.03±0.0	20.841	122±12	0.812	1.057	11.55± 1.14
4210	496.84±0.0	21.723	248±17	0.756	1.057	24.21± 1.68
4220	498.32±0.0	22.417	314±19	0.728	1.057	30.75± 1.89
4237	505.71±0.0	22.773	430±22	0.773	1.056	38.50± 2.01
4246	499.83±0.0	23.175	416±21	0.820	1.055	34.94± 1.80
4270	498.51±0.0	22.731	353±20	0.878	1.053	28.36± 1.63
4280	146.57±0.0	22.732	78 ±9	0.879	1.053	21.29± 2.47

Cross section

For old data

Energy (MeV)	$\mathcal{L}$ (pb^{-1})	$\varepsilon^{PHSP}_{\pi^0\pi^0 J/\psi}(\%)$	$N^{obs}_{\pi^0\pi^0 J/\psi}$	$1+\delta^r$	$1+\delta^{vac}$	σ^{Born}(pb)
3810	50.5 ±0.5	20.642	21 ±4	0.869	1.056	18.48± 3.53
3900	52.6 ±0.5	16.408	8 ±3	0.870	1.049	8.55 ± 3.21
4009	482.0 ±4.8	18.781	92 ±11	0.913	1.044	8.98 ± 1.08
4090	52.6 ±0.5	0.156	9 ±3	0.958	1.052	7.42 ± 2.47
4190	493.14±0.0	22.021	98 ±11	0.877	1.056	9.59 ±2.46
4210	54.55±0.03	21.723	28 ±6	0.756	1.057	24.89± 5.19
4220	54.13±0.03	22.417	32 ±6	0.728	1.057	28.84± 5.77
4230	1091.7±10.9	22.788	821±30	0.805	1.056	32.68± 1.28
4245	55.59 ±0.04	23.175	50 ±7	0.806	1.056	38.38± 5.39
4260	825.7 ±8.2	22.448	564±25	0.815	1.054	29.82± 1.39
4310	44.9 ±0.4	21.677	27 ±5	0.916	1.052	24.23± 4.50
4360	539.8 ±5.4	19.247	192±15	1.038	1.051	14.26± 1.13
4390	55.2 ±0.5	17.392	7 ±3	1.132	1.051	5.16 ± 2.21
4420	1073.6±10.7	15.420	142±13	1.309	1.053	5.24 ± 0.49
4470	109.9 ±1.1	14.646	9 ±3	1.348	1.055	3.31 ± 1.10
4530	110.0 ±1.1	14.582	13 ±4	1.341	1.055	4.82 ± 1.49
4575	47.7 ±0.4	14.785	7 ±2	1.325	1.055	5.98 ± 1.71
4600	566.9 ±5.7	14.785	38 ±7	1.343	1.055	2.69 ± 0.49

Cross section



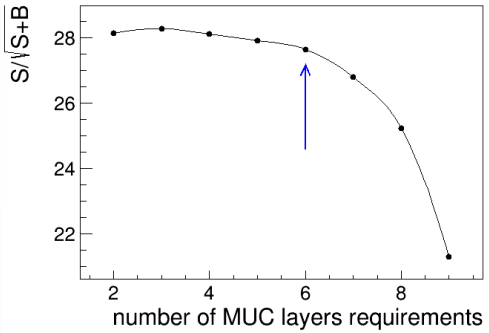
Next to do

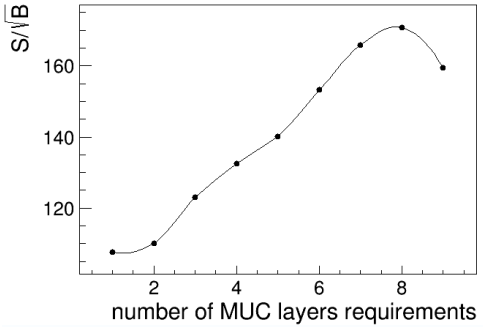
- Efficiency correction
- Calculate the Born Cross section
- Fit to cross section and iteration (put cross section line shape of $e^+e^- \to \pi^+\pi^- J/\psi$ as input)
- Systematic uncertainties

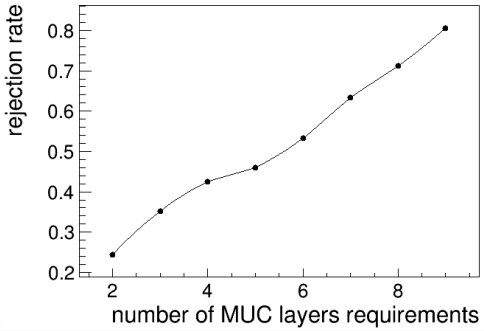
Thanks for your attention!

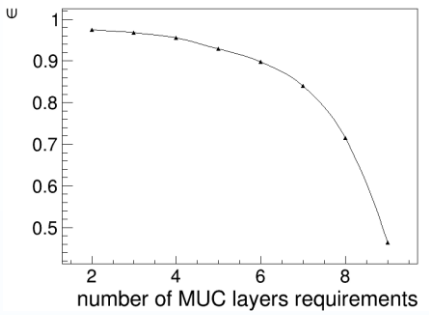
Back up

- Optimization for MUC layer requirement

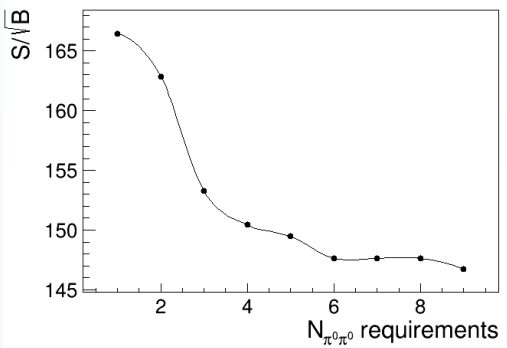


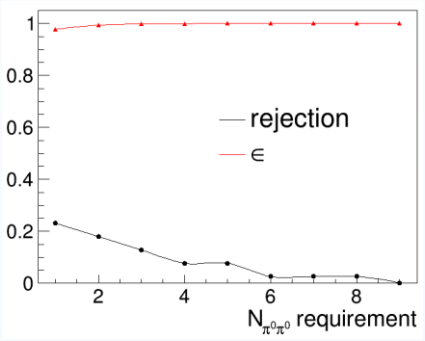




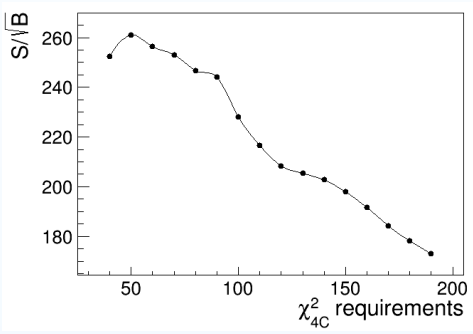


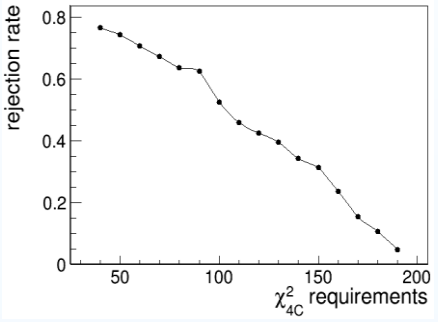
- $N_{\pi^0\pi^0}$ <= 2





- χ^2_{4C}<90





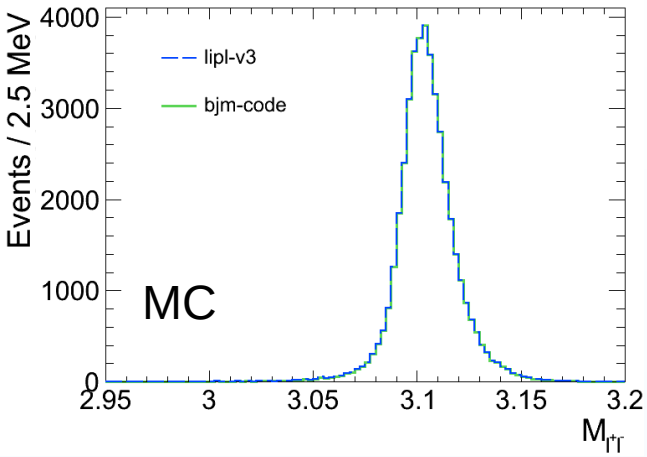
Back up

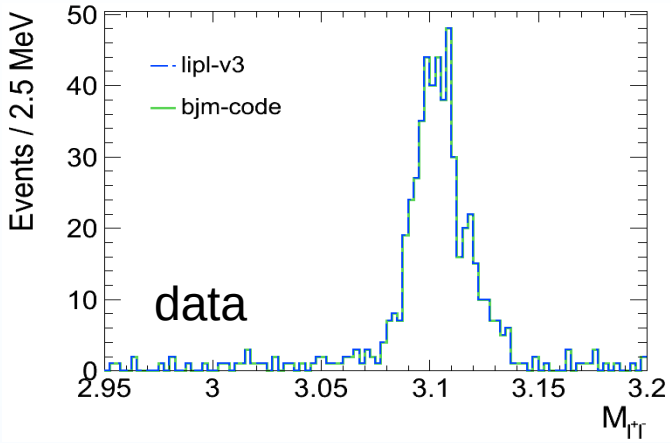
663p01

- Compare with BianJM's codes - using same events selection to check our procedure

  - $M(l^+l^-)$ @4260

Totally same





- Updates in our analysis

- E/p (p): mdcKalTrk(pion)->mdcTrk
- Good photon: θ_{chgTrk}>5°
- reserve $J/\psi \rightarrow \mu^+\mu^-$candidates without energy deposited in EMC (E_{emc}=0)
- 1C & 4C kinematic fit: set same vertex information from charged tracks vtxfit
- Using inclusive MC @4.260GeV to some optimisations

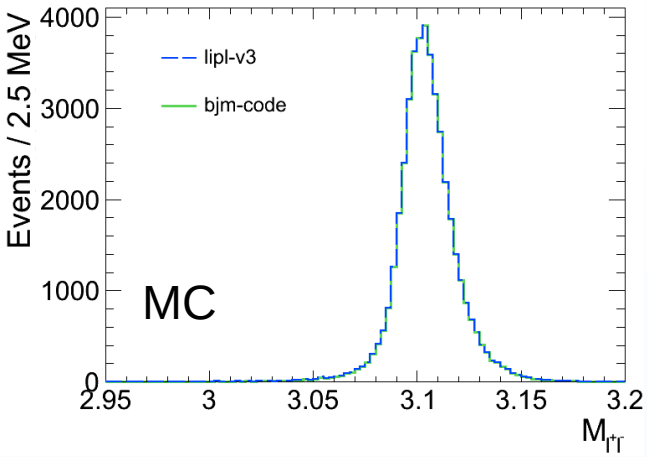
Back up

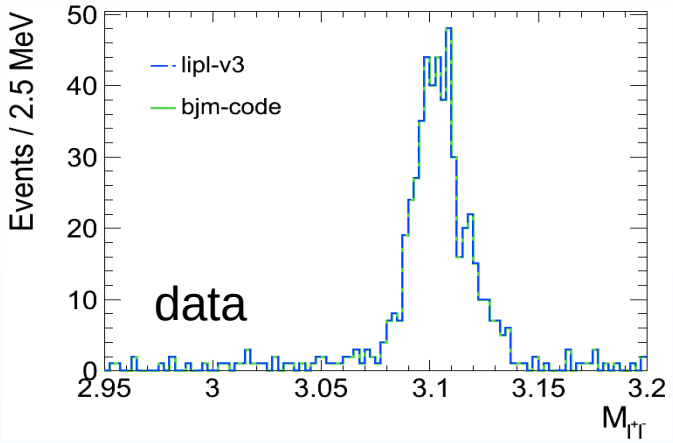
663p01

- Compare with BianJM's codes - using same events selection to check our procedure

  - M(l^+l^-) @4260

Totally same





-PhysRevLett.115.112003 (BianJM's work)

E_{cm} (GeV)	$\mathcal{L}$ (pb^{-1})	$\epsilon(Z_c^0)$ (%)	$\epsilon^{\pi^0\pi^0 J/\psi}(\pi^0\pi^0 J/\psi)$ (%)	$\epsilon^{Z_c^0}(\pi^0\pi^0 J/\psi)$ (%)	$\epsilon(\pi^0\pi^0 J/\psi)$ (%)	$N(Z_c^0)$ (90% confidence level)	$N(\pi^0\pi^0 J/\psi)$	R (90% confidence level)	$1+\delta$	$1+\delta^{vac}$	σ_{Born} (pb)
4.190	43.1	20.8	20.4	20.1	20.2	< 11.1	8.2 ± 3.0	< 1.00	0.828	1.056	$9.0 \pm 3.3 \pm 0.6$
4.210	54.6	21.5	21.0	20.8	20.9	< 18.9	26.6 ± 5.4	< 0.72	0.813	1.057	$22.7 \pm 4.6 \pm 1.5$
4.220	54.1	21.6	21.2	20.8	21.1	< 12.6	31.9 ± 5.7	< 0.41	0.810	1.057	$27.4 \pm 4.9 \pm 1.8$
4.230	1091.7	22.0	21.1	21.0	21.0	236.8 ± 25.0	825.1 ± 29.8	$0.28 \pm 0.03 \pm 0.02$	0.805	1.056	$35.4 \pm 1.3 \pm 2.2$
4.245	55.6	22.3	21.6	21.1	21.5	< 15.2	49.0 ± 7.1	< 0.32	0.806	1.056	$40.3 \pm 5.8 \pm 2.7$
4.260	825.7	22.6	21.2	21.4	21.2	73.1 ± 16.5	507.3 ± 23.4	$0.14 \pm 0.03 \pm 0.01$	0.815	1.054	$28.3 \pm 1.3 \pm 1.8$
4.310	44.9	22.5	20.4	20.7	20.5	< 7.9	25.5 ± 5.1	< 0.29	0.916	1.052	$24.1 \pm 4.9 \pm 1.6$
4.360	539.8	21.5	18.8	19.1	18.9	41.8 ± 10.8	182.8 ± 14.2	$0.20 \pm 0.05 \pm 0.02$	1.038	1.051	$13.8 \pm 1.1 \pm 0.9$
4.390	55.2	21.4	17.7	18.4	17.7	< 5.2	6.2 ± 2.6	< 0.71	1.088	1.051	$4.7 \pm 1.9 \pm 0.3$
4.420	44.7	21.7	16.8	17.9	16.8	< 3.8	2.9 ± 2.1	< 1.00	1.132	1.053	$2.7 \pm 1.9 \pm 0.2$