

Cross section measurement of $e^+e^- \rightarrow \eta J/\psi$ and searches for $e^+e^- \rightarrow \pi^0 J/\psi$ at center of mass energy between 3.81 and 4.60 GeV at BESIII

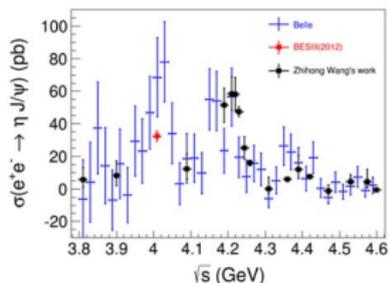
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State Key Laboratory of Particle Detection and Electronics

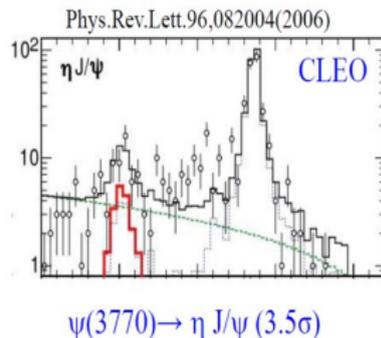
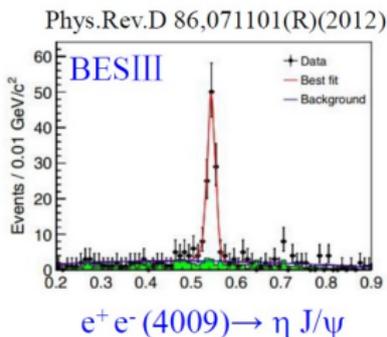
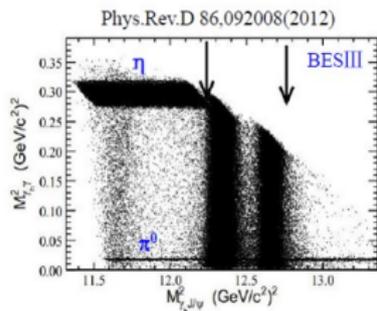
June 12, 2018

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Introduction



- Hadronic transitions play an important role in understanding the nature of excited charmonium.
- Non-DD decay of charmonium states above DD threshold is an interesting question.
- Based on BESIII experimental data, we could measure cross section of $e^+e^- \rightarrow \eta J/\psi$ and $\pi^0 J/\psi$.



- BOSS 7.0.3
- 9 XYZ data samples taken at 2017
16 XYZ data samples taken at 2015
1 XYZ data sample taken at 2012
- MC sample
 - $e^+e^- \rightarrow \eta J/\psi \rightarrow \gamma\gamma\mu^+\mu^-$
 - $e^+e^- \rightarrow \eta J/\psi \rightarrow \gamma\gamma e^+e^-$
 - $e^+e^- \rightarrow \pi^0 J/\psi \rightarrow \gamma\gamma\mu^+\mu^-$
 - $e^+e^- \rightarrow \eta J/\psi \rightarrow \pi^+\pi^-\pi^0\mu^+\mu^-$
 - $e^+e^- \rightarrow \eta J/\psi \rightarrow \pi^+\pi^-\pi^0 e^+e^-$

Event selection

- Charged tracks

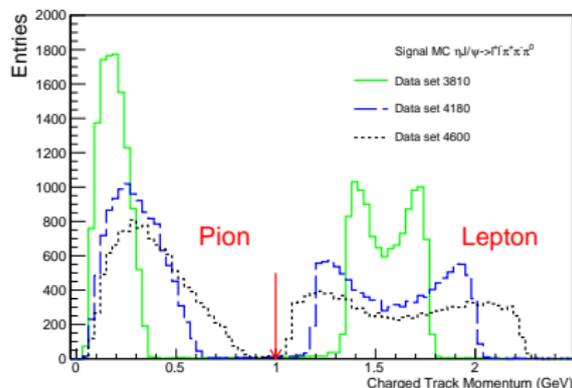
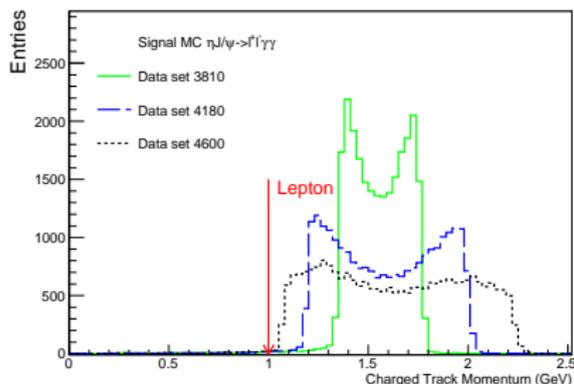
$$|R_{XY}| < 1.0\text{cm}, |Z_0| < 10.0\text{cm}, |\cos\theta| < 0.93$$

$$n_{\text{Good}} = 2, n_{\text{charge}} = 0 \quad (J/\psi \rightarrow l^+l^- \quad \eta \rightarrow \gamma\gamma)$$

$$n_{\text{Good}} = 4, n_{\text{charge}} = 0 \quad (J/\psi \rightarrow l^+l^- \quad \eta \rightarrow \pi^+\pi^-\pi^0)$$

- PID

Leptons: Momentum $> 1.0\text{GeV}$



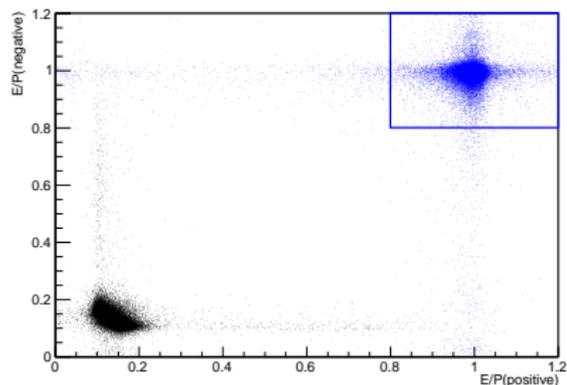
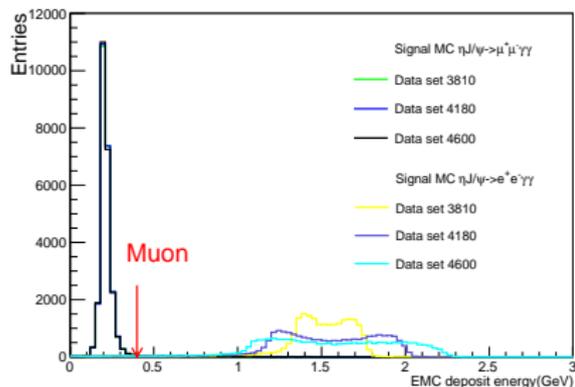
Event selection

- PID

Leptons: Momentum $> 1.0\text{GeV}$

Muons: Both tracks have $E_{EMC} < 0.4\text{GeV}$

Electrons: Both tracks have $E_{EMC}/P > 0.8$



Event selection

- PID

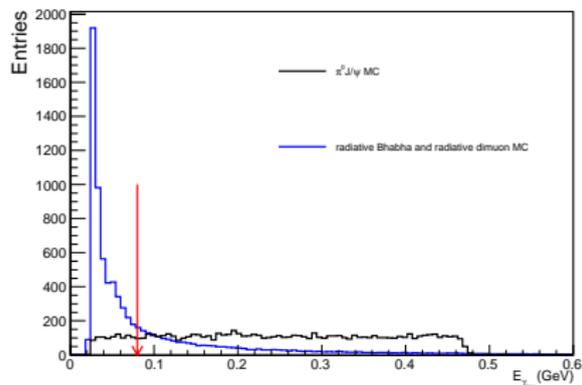
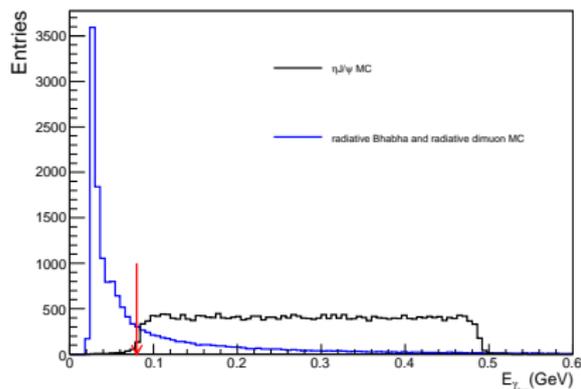
Leptons: Momentum $> 1.0\text{GeV}$

Muons: Both tracks have $E_{EMC} < 0.4\text{GeV}$

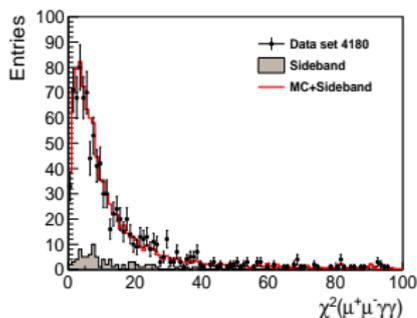
Electrons: Both tracks have $E_{EMC}/P > 0.8$

Pions: Momentum $< 1.0\text{GeV}$ ($J/\psi \rightarrow I^+I^- \eta \rightarrow \pi^+\pi^-\pi^0$)

- $E_{\gamma_{low}} > 0.08\text{GeV}$ ($J/\psi \rightarrow I^+I^- \eta \rightarrow \gamma\gamma$)



Event selection

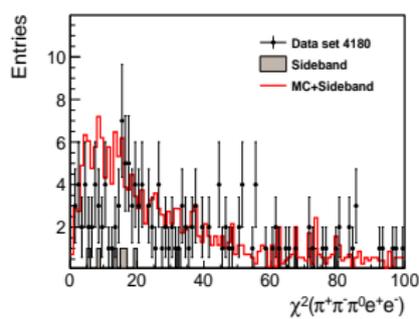
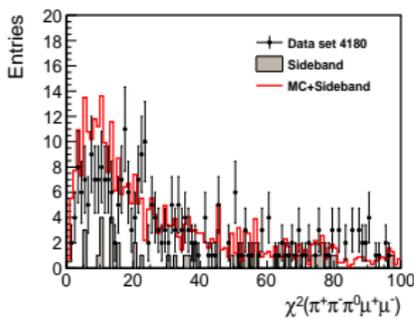
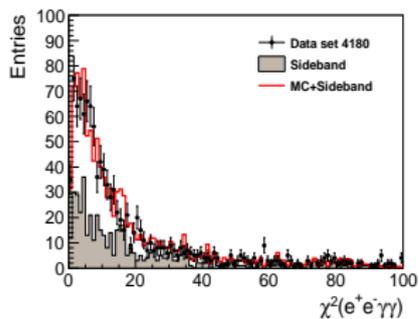


- Neutral tracks

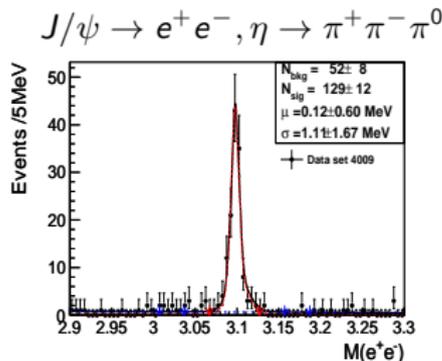
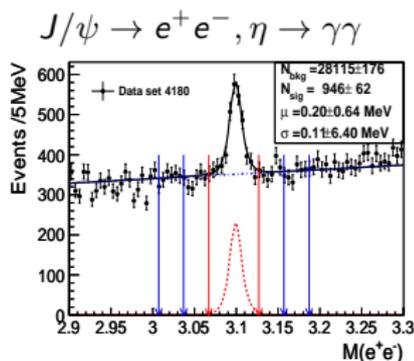
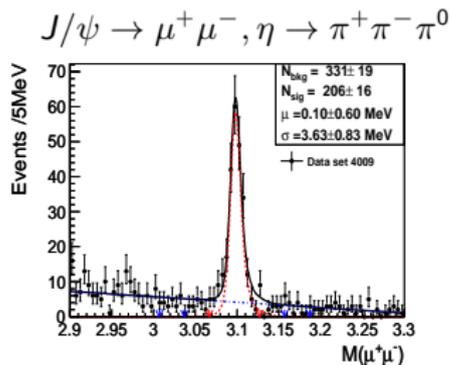
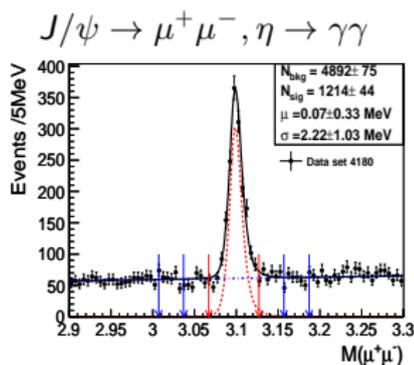
$E_{barrel} > 25\text{MeV}$, $E_{endcap} > 50\text{MeV}$, $|\cos\theta| < 0.8$
or $0.86 < |\cos\theta| < 0.92$
 $0 \leq TDC \leq 14$, $\Delta\theta > 20^\circ$, $N_\gamma \geq 2$

- Kinematic fit

$\chi_{4C}^2 < 40$ ($J/\psi \rightarrow l^+l^- \eta \rightarrow \gamma\gamma$)
 $\chi_{5C}^2 < 80$ ($J/\psi \rightarrow l^+l^- \eta \rightarrow \pi^+\pi^-\pi^0$)

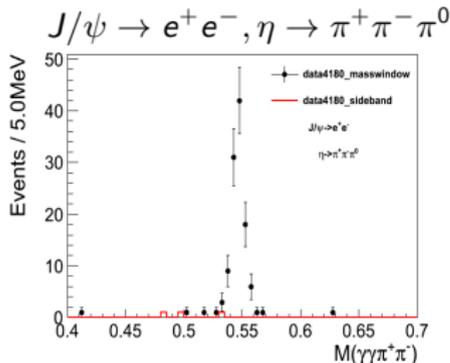
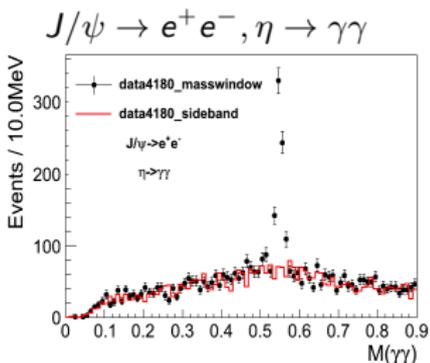
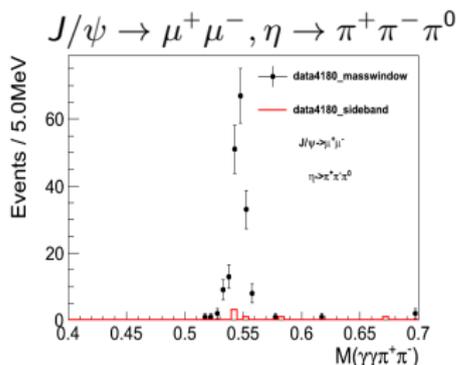
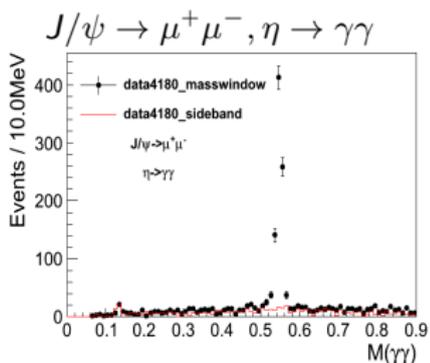


Signal of J/ψ



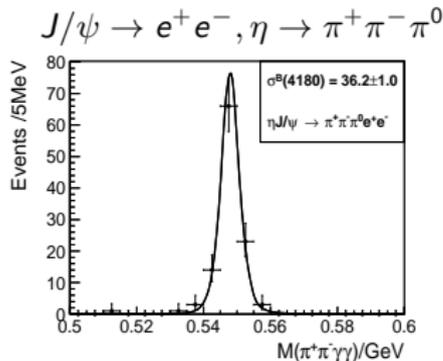
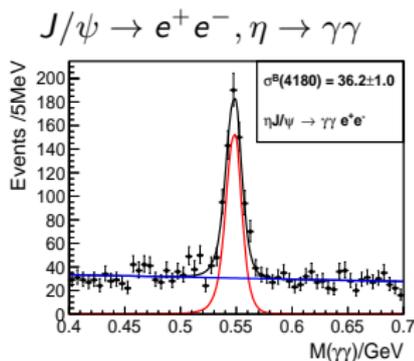
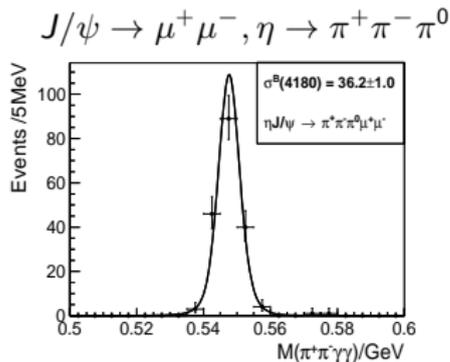
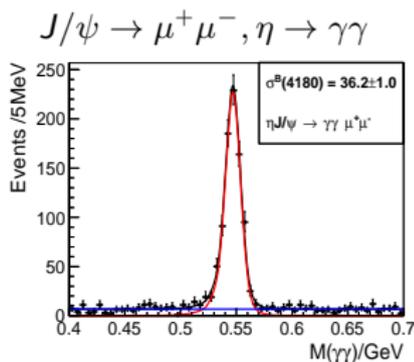
- Signal : MC shape ⊗ Gaussian function
- Background : 1^{st} polynomial

Signal of η



- A clear signal of η is observed.
- J/ψ sideband events could describe the contributions from background.

Fitting results of η



- Signal : MC shape ⊗ Gaussian function
- Background : 1st polynomial

Cross section measurement

$$\sigma^B = \frac{N^{obs}}{L_{int}(1+\delta^{ISR})(1+\delta^V)\epsilon Br}$$

Data set	$L(pb^{-1})$	$\epsilon_\mu(\%)^1$	$\epsilon_e(\%)^2$	$\epsilon_\mu(\%)^3$	$\epsilon_e(\%)^4$	$1 + \delta^{ISR}$	$1 + \delta^V$	$\sigma(pb)$
4180	3189.0	35.3	24.5	12.5	8.6	0.845	1.056	$36.2 \pm 0.9 \pm 1.3$
4190	522.5	35.6	24.3	12.4	8.5	0.865	1.056	$41.4 \pm 2.4 \pm 1.5$
4200	524.6	34.8	24.2	12.5	8.4	0.888	1.056	$43.6 \pm 2.5 \pm 1.7$
4210	518.1	33.9	23.5	11.8	8.2	0.909	1.057	$48.0 \pm 2.6 \pm 2.5$
4220	514.3	33.7	22.9	11.5	8.1	0.933	1.057	$49.8 \pm 2.6 \pm 2.6$
4237	530.6	32.0	22.1	11.5	7.8	0.971	1.056	$37.2 \pm 2.3 \pm 2.3$
4246	537.4	31.7	22.1	10.8	7.6	0.989	1.056	$28.1 \pm 2.0 \pm 1.4$
4270	529.7	30.1	20.6	10.5	7.5	1.033	1.054	$12.0 \pm 1.4 \pm 0.5$
4280	175.5	29.6	20.0	10.1	7.3	1.054	1.054	$10.4 \pm 2.2 \pm 1.8$

¹ $J/\psi \rightarrow \mu^+\mu^-, \eta \rightarrow \gamma\gamma$

² $J/\psi \rightarrow e^+e^-, \eta \rightarrow \gamma\gamma$

³ $J/\psi \rightarrow \mu^+\mu^-, \eta \rightarrow \pi^+\pi^-\pi^0$

⁴ $J/\psi \rightarrow e^+e^-, \eta \rightarrow \pi^+\pi^-\pi^0$

Cross section measurement

$$\sigma^B = \frac{N^{obs}}{L_{int}(1+\delta^{ISR})(1+\delta^V)\epsilon Br}$$

Data set	$L(pb^{-1})$	$\epsilon_\mu(\%)^1$	$\epsilon_e(\%)^2$	$\epsilon_\mu(\%)^3$	$\epsilon_e(\%)^4$	$1 + \delta^{ISR}$	$1 + \delta^V$	$\sigma(pb)$
3810	50.5	40.2	27.5	12.4	8.7	0.771	1.056	$3.8 \pm 3.6 \pm 0.2$
3900	52.6	39.1	27.1	12.9	8.9	0.775	1.049	$1.1 \pm 2.5 \pm 0.1$
4009	482.0	39.4	27.4	13.5	9.5	0.757	1.05	$30.1 \pm 2.3 \pm 1.5$
4090	52.9	32.9	22.5	11.2	7.6	1.087	1.052	$11.8 \pm 5.1 \pm 1.3$
4190	43.3	35.7	24.8	12.8	8.8	0.866	1.056	$51.2 \pm 9.8 \pm 1.9$
4210	54.9	34.0	23.9	12.3	8.5	0.914	1.057	$51.5 \pm 8.1 \pm 3.1$
4220	54.6	33.8	23.6	11.8	8.4	0.937	1.057	$61.5 \pm 9.5 \pm 3.8$
4230	1088.4	33.0	23.1	11.5	8.1	0.96	1.056	$47.3 \pm 1.8 \pm 3.1$
4245	55.9	32.2	22.3	11.2	7.7	0.992	1.056	$23.6 \pm 6.1 \pm 1.7$
4260	828.4	30.7	21.1	10.7	7.5	1.021	1.054	$15.9 \pm 1.3 \pm 1.4$
4310	45.1	28.1	19.6	9.8	6.8	1.105	1.053	$4.2 \pm 4.1 \pm 0.2$
4360	543.9	25.9	18.1	9.2	6.5	1.168	1.051	$4.7 \pm 1.0 \pm 0.6$
4390	55.6	25.4	17.4	8.8	6.2	1.198	1.051	$13.1 \pm 5.8 \pm 1.4$
4420	1090.7	24.8	17.1	8.2	5.8	1.225	1.053	$6.9 \pm 0.8 \pm 0.8$
4470	111.1	24.0	16.0	7.9	5.4	1.258	1.061	$4.5 \pm 3.1 \pm 0.3$
4530	112.1	22.9	15.8	7.3	5.1	1.295	1.059	$1.8 \pm 1.7 \pm 0.1$
4575	48.9	22.8	15.4	6.9	4.8	1.314	1.059	$9.6 \pm 5.4 \pm 0.3$
4600	586.9	22.5	15.3	6.9	4.8	1.323	1.059	$1.5 \pm 0.8 \pm 0.1$

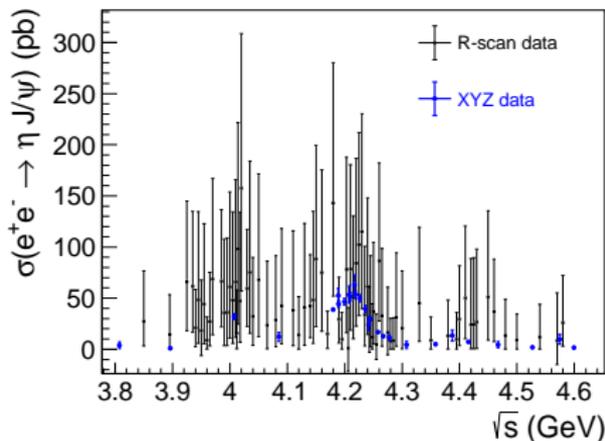
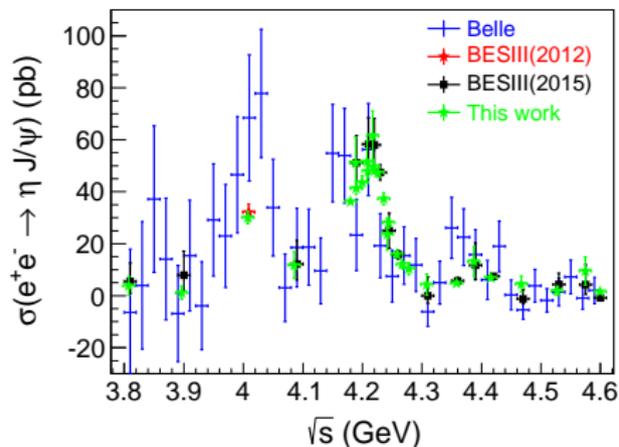
$$^1 J/\psi \rightarrow \mu^+ \mu^-, \eta \rightarrow \gamma\gamma$$

$$^2 J/\psi \rightarrow e^+ e^-, \eta \rightarrow \gamma\gamma$$

$$^3 J/\psi \rightarrow \mu^+ \mu^-, \eta \rightarrow \pi^+ \pi^- \pi^0$$

$$^4 J/\psi \rightarrow e^+ e^-, \eta \rightarrow \pi^+ \pi^- \pi^0$$

Cross section measurement



- Since low luminosity at each energy point of R-scan data, we use counting method to obtain η signal events subtracting normalized sideband contribution.

Systematics uncertainties

- **Integrated luminosity measurement** : 1.0% .
- **Tracking efficiency for leptons** : 2.0%, **photon detection efficiency** : 2.0% .
- **Tracking efficiency for pions** : change efficiency of $\pi^+\pi^-\pi^0$ processes by 2% and fit the cross section again and get the average difference of 9 energy points.
- **J/ψ mass window** : Convolution to MC a Gaussian (Gaussian parameters are the average of different energy points when convolving MC with gaussian to fit J/ψ signal), add the mass window cut to get the efficiency difference of mass window . Give relative changes to the original efficiency and re-fit the cross section to obtain systematic errors.
- **Kinematic fit** : The PULL distribution of charged tracks parameters are corrected to make MC agree well with data .
- **shape of background** : change the background shape from 1st order polynomial to 2nd order.
- **Fitting range of η** : varying the range from [0.4, 0.7]GeV to [0.45, 0.65]GeV .
- **Radiative correction factors** : use Belle's fitting line-shape to get the $(1+\delta)\cdot\epsilon$; then use 3-BW fitting line-shape to get a new $(1+\delta)\cdot\epsilon$.
- **Branching fraction**: $\text{Br}(J/\psi \rightarrow \mu^+\mu^-/e^+e^-)$: 0.6% , $\text{Br}(\eta \rightarrow \gamma\gamma)$: 0.5%. Total : 0.8%.
- **Others**: less than 1.0%.

Systematics uncertainties

Table: Summary of systematic uncertainties (%) on the cross section of $e^+e^- \rightarrow \eta J/\psi$ at each energy point. The sources with star markers are the common relative systematic errors for different energy points.

Data set	4180	4190	4200	4210	4220	4237	4246	4270	4280
Luminosity *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Photon detection*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\mu^+\mu^-/e^+e^-$)*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\pi^+\pi^-$)*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lepton pair mass window	0.2	0.2	0.2	0.2	0.1	0.2	0.2	0.2	0.5
4C kinematic fitting	1.1	1.3	1.3	1.4	1.4	1.2	1.3	1.1	0.9
Background shape	0.4	0.5	0.4	0.4	0.3	0.2	0.1	0.1	16.2
Fitting range1	0.1	0.3	0.5	0.3	0.2	0.2	0.4	0.5	0.7
Fitting range2	0.1	0.4	0.1	0.0	0.0	0.8	0.1	0.1	4.9
Radiative correction	0.6	0.2	1.8	3.9	3.8	5.1	3.4	2.6	2.2
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	3.5	3.6	4.0	5.3	5.2	6.2	4.9	4.3	17.5

Systematics uncertainties

Table: Summary of systematic uncertainties (%) on the cross section of $e^+e^- \rightarrow \eta J/\psi$ at each energy point. The sources with star markers are the common relative systematic errors for different energy points.

Data set	3810	3900	4009	4090	4190	4210	4220	4230	4245
Luminosity *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Photon detection*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\mu^+\mu^-/e^+e^-$)*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\pi^+\pi^-$)*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lepton pair mass window	0.2	1.3	0.3	0.0	0.2	1.4	1.0	0.2	1.3
4C kinematic fitting	0.8	0.4	1.3	1.2	1.3	1.0	1.0	1.3	1.4
Background shape	0.7	6.0	0.6	0.1	0.8	0.0	2.1	0.3	4.2
Fitting range1	1.0	3.3	3.5	0.4	0.8	0.8	0.3	0.3	0.5
Fitting range2	0.2	1.0	0.7	0.0	0.8	0.9	0.6	0.0	1.2
Radiative correction	2.5	0.5	0.3	10.6	0.3	4.7	4.5	5.5	4.3
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	4.4	7.8	5.1	11.1	3.8	6.1	6.1	6.6	7.3

Systematics uncertainties

Table: Summary of systematic uncertainties (%) on the cross section of $e^+e^- \rightarrow \eta J/\psi$ at each energy point. The sources with star markers are the common relative systematic errors for different energy points.

Data set	4260	4310	4360	4390	4420	4470	4530	4575	4600
Luminosity *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Photon detection*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\mu^+\mu^-/e^+e^-$)*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\pi^+\pi^-$)*	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Lepton pair mass window	0.2	0.2	0.1	0.0	0.1	0.5	0.2	0.1	0.3
4C kinematic fitting	1.3	0.8	0.6	0.9	0.9	1.6	0.5	0.7	1.6
Background shape	0.8	0.7	0.6	0.0	0.1	0.3	0.7	0.1	0.1
Fitting range1	3.3	0.9	7.4	0.2	0.1	0.0	0.4	0.2	0.1
Fitting range2	1.1	0.2	1.7	0.0	0.0	0.0	0.1	0.0	0.0
Radiative correction	7.4	1.2	10.6	10.3	10.6	4.9	0.8	1.1	0.3
Branching fraction	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	9.0	3.7	13.5	10.9	11.2	6.1	3.5	3.5	3.7

Fit the cross section of $e^+e^- \rightarrow \eta J/\psi$

$$\sigma_{fit} = \left| a/(\sqrt{s})^2 + BW_{\psi(4040)}(s)e^{i\phi_1} + BW_{\Upsilon(4230)}(s)e^{i\phi_2} \right|^2 \quad (1)$$

- Do a simultaneous maximum-likelihood fit to the cross sections measured both from XYZ data and Rscan data.
- For XYZ data sets, $\sigma_{fit}(\sqrt{s})$ is expected to follow a Gaussian distribution G_j . The mean and standard deviation values of the Gaussian distribution are the measured cross section and independent error (include statistic error and independent systematic errors).
- For R-scan data sets, the expected number of signal events is N^{exp_j} . It is written as :

$$N^{exp_j} = L_j \sigma_{fit}^j(\sqrt{s_j}) \epsilon_j Br(J/\psi \rightarrow l^+l^-) Br(\eta \rightarrow \gamma\gamma) (1 + \delta)_j \quad (2)$$

Since low luminosity, the actually counted number of events in the signal region N_j^{count} (including both signal and background) will follow a poisson distribution. The mean value of poisson distribution is $N^{exp_j} + N^{bkg_j}$. Here N^{bkg_j} is estimated through sideband events.

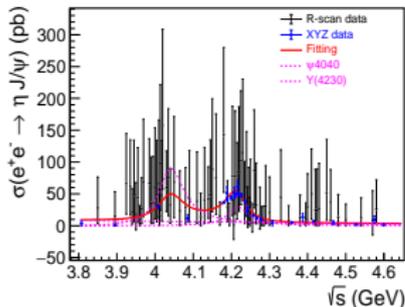
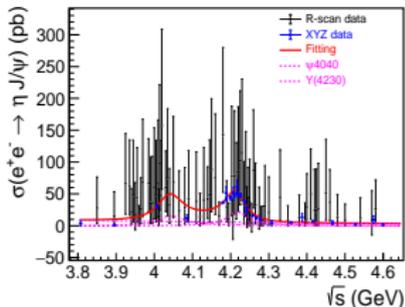
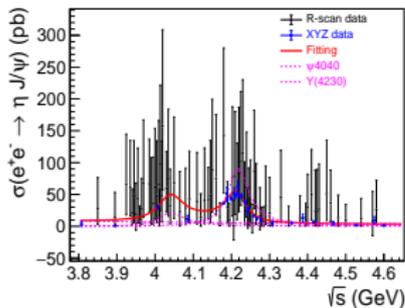
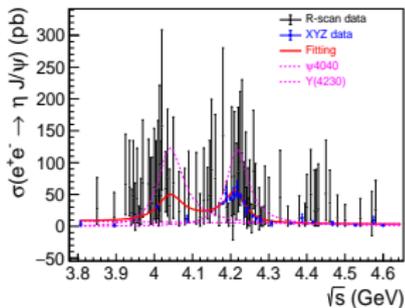
Fit the cross section of $e^+e^- \rightarrow \eta J/\psi$

- $-\ln L$ is minimized to get the best estimation of the parameters. The likelihood function is defined as:

$$L = \int \left[\prod_{i=1}^{XYZ} G_i(\sigma_{fit}(1-x)) \right] G(x, 0, \sigma_{common}) dx \prod_{j=1}^{R-scan} P_j \quad (3)$$

Parameters	Solution 1	Solution 2	Solution 3	Solution 4
$Mass(\psi 4040)$ (MeV)		4039(fixed)		
$Width(\psi 4040)$ (MeV)		80(fixed)		
$\Gamma_{ee} Br(\psi 4040 \rightarrow \eta J/\psi)$ (eV)	13.3 ± 7.0	2.7 ± 1.3	2.2 ± 1.2	87.6 ± 88.7
$Mass(Y(4230))$ (MeV)		4215.7 ± 3.4		
$Width(Y(4230))$ (MeV)		66.8 ± 4.2		
$\Gamma_{ee} Br(Y(4230) \rightarrow \eta J/\psi)$ (eV)	12.0 ± 6.3	10.6 ± 4.4	2.9 ± 1.5	25.8 ± 17.0
$\phi 1$ (rad)	3.4 ± 0.1	4.8 ± 0.2	2.4 ± 0.1	1.0 ± 0.2
$\phi 2$ (rad)	4.9 ± 0.1	2.0 ± 0.2	1.4 ± 0.2	4.3 ± 0.1
$a(\times 10^{-3})$	2.3 ± 0.6	2.5 ± 0.6	2.7 ± 0.7	7.0 ± 2.4

Fit the cross section of $e^+e^- \rightarrow \eta J/\psi$



The systematic uncertainties

The systematic uncertainties associated with the resonance parameters include the following.

- The center-of-mass energy(CME) spread : Considering σ_{CME} to σ_{idp} ($\sigma_{idp}^2 + \sigma_{CME}^2$), the fit differences of the resonance parameters are taken as systematic uncertainty.

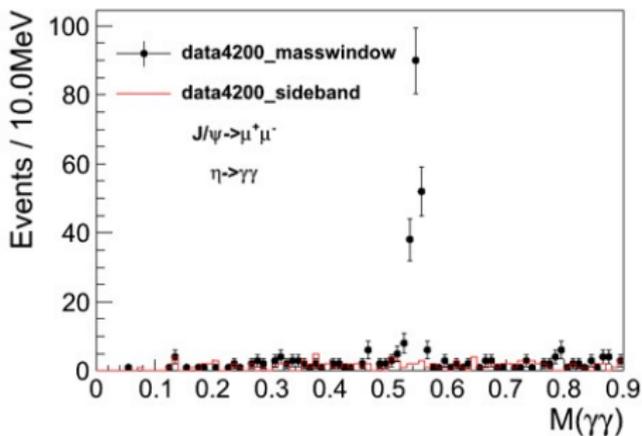
$$\sigma_{CME} = \frac{\partial \sigma_{fit}(\sqrt{s})}{\partial s_{CME}} \delta s_{CME} \quad (4)$$

δs_{CME} is estimated by the uncertainty of CME spread 0.8MeV, which is the energy spread determined by the Beam Energy Measurement System. So σ_{CME} is estimated by $\sigma_{CME} = \sigma_{fit}(\sqrt{s} + 0.4\text{MeV}) - \sigma_{fit}(\sqrt{s} - 0.4\text{MeV})$.

- The center-of-mass energy measurement
- The fit range
- The $\psi(4040)$ resonance

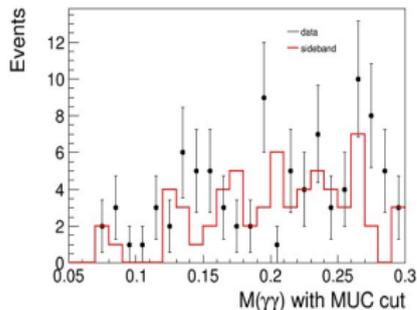
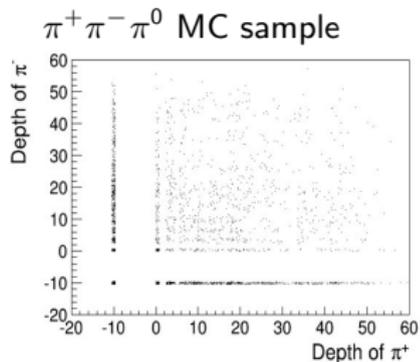
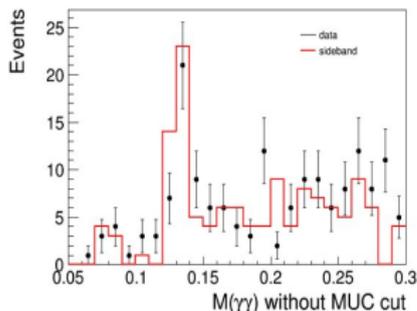
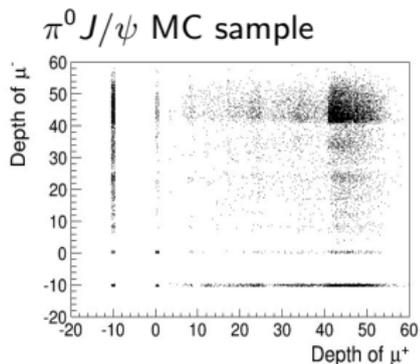
Sources	Mass(Ψ 4230)(MeV)	Width(Ψ 4230)(MeV)
Energy spread	0.01	0.1
Energy measurement	0.01	0.1
Fit range	0.02	0.1
$\psi(4040)$	0.8	1.9
Total	0.8	1.9

$M(\gamma\gamma)$ distribution of $e^+e^- \rightarrow \pi^0 J/\psi$



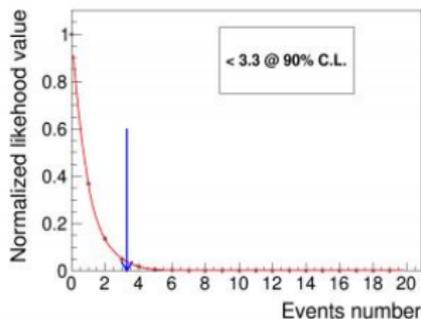
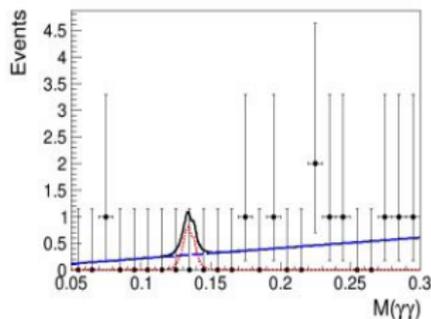
- Such a search is not performed for the $J/\psi \rightarrow e^+e^-$ mode due to the large background of radiative Bhabha events.
- Due to the misidentification of π^\pm as μ^\pm , the peaking background from $\pi^+\pi^-\pi^0$ would contaminate the π^0 signal for both candidate events within the J/ψ signal or sideband regions.

MUC information



- We require both tracks with MUC hit depth > 30.0 cm to suppress $e^+e^- \rightarrow \pi^+\pi^-\pi^0$ background.

Fitting results of $\pi^0 J/\psi$



Data set	$L(pb^{-1})$	$N_{\pi^0}^{UP}$	$\varepsilon_e(\%)$	$1 + \delta^{ISR}$	$1 + \delta^V$	$\sigma_{up}^B(pb)$
4180	3189.0	< 14.9	19.1	0.845	1.056	< 0.5
4190	522.5	< 3.3	19.0	0.865	1.056	< 0.6
4200	524.6	< 5.8	18.7	0.888	1.056	< 1.2
4210	518.1	< 6.2	18.4	0.909	1.057	< 1.2
4220	514.3	< 3.1	18.1	0.933	1.057	< 0.6
4237	530.6	< 7.7	17.4	0.971	1.056	< 0.7
4246	537.4	< 3.7	17.2	0.989	1.056	< 0.7
4270	529.7	< 3.1	16.7	1.033	1.054	< 0.6
4280	175.5	< 9.1	16.3	1.054	1.054	< 4.6

Fitting results of $\pi^0 J/\psi$

Data set	$L(pb^{-1})$	$N_{\pi^0}^{up}$	$\epsilon_e(\%)$	$1 + \delta^{isr}$	$1 + \delta^v$	$\sigma_{up}^B(pb)$
3810	50.54	<3.1	17.6	0.771	1.056	<7.2
3900	52.61	<3.3	18.8	0.775	1.049	<6.9
4009	482.0	<13.4	20.0	0.757	1.05	<3.0
4090	52.86	<2.5	16.6	1.087	1.052	<5.6
4190	43.33	<2.5	19.2	0.866	1.056	<7.4
4210	54.95	<5.9	18.6	0.914	1.057	<11.9
4220	54.6	<3.0	18.5	0.937	1.057	<5.1
4230	1088.4	<9.1	17.8	0.96	1.056	<0.8
4245	55.88	<3.3	15.9	0.992	1.056	<6.0
4260	828.4	<8.4	16.8	1.021	1.054	<1.2
4310	45.08	<6.9	15.7	1.105	1.053	<6.8
4360	543.9	<8.3	14.7	1.168	1.051	<1.0
4390	55.57	<6.9	14.5	1.198	1.051	<5.5
4420	1090.7	<8.8	14.3	1.225	1.053	<0.6
4470	111.09	<6.9	14.0	1.258	1.061	<2.7
4530	112.12	<6.9	13.7	1.295	1.059	<2.6
4575	48.93	<6.9	13.6	1.314	1.059	<5.9
4600	586.9	<9.3	13.3	1.323	1.059	<1.3

Systematics uncertainties

Systematic errors mainly come from the luminosity measurement, detection efficiency, background estimation and branching fractions of intermediate states decay.

- **Integrated luminosity measurement** : 1.0% .
- **tracking efficiency for leptons** : 2.0% , **the photon detection efficiency** : 2.0% .
- **lepton pair mass window** : varying the J/ψ mass window from [3.067, 3.127] to [3.057, 3.137], the efficiency differences are taken as systematic errors .
- **Kinematic fit** the PULL distribution of charged tracks parameters are corrected to make χ_{4C}^2 agree well with each other between data and MC , the efficiency differences which is estimated as systematic error.
- **Radiative correction factors** : use Belle's fitting line-shape to get the $(1+\delta)\cdot\epsilon$; then use 3-BW fitting line-shape to get a new $(1+\delta)\cdot\epsilon$. The difference for $(1+\delta)\cdot\epsilon$ is taken as systematic error.
- **Branching fraction** : $\text{Br}(J/\psi \rightarrow \mu^+\mu^-)$: 0.6% and $\text{Br}(\pi^0 \rightarrow \gamma\gamma)$: 0.03%. The total error is 0.6%.
- **MUC hit depth cut** : 1.2% using zhihong's results.
- The efficiency for other cuts, the trigger simulation, the event star time determination and the final-state-radiation simulation are quite high ($> 99\%$), their systematic errors estimated to be less than 1.0%.

Table: Summary of systematic uncertainties (%) on the cross section of $e^+e^- \rightarrow \pi^0 J/\psi$ at each energy point.

Data set	4180	4190	4200	4210	4220	4237	4246	4270	4280
Luminosity *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Photon detection*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\mu^+\mu^-$)*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Lepton pair mass window	0.6	0.8	1.1	1.0	1.2	1.4	1.6	1.2	1.2
4C kinematic fitting	0.7	1.1	0.9	0.8	0.7	0.8	0.7	0.6	0.9
Radiative correction	1.9	0.6	1.3	5.6	3.3	5.4	6.2	1.1	2.1
Branching fraction	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
MUC cut	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	4.0	3.7	3.9	6.7	4.9	6.6	7.3	3.9	4.3

Table: Summary of systematic uncertainties (%) on the cross section of $e^+e^- \rightarrow \pi^0 J/\psi$ at each energy point.

Data set	3810	3900	4009	4090	4190	4210	4220	4230	4245
Luminosity *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Photon detection*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\mu^+\mu^-$)*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Lepton pair mass window	0.6	0.6	0.6	2.0	0.7	1.1	1.1	1.1	1.1
4C kinematic fitting	0.9	0.9	0.9	1.2	0.9	0.9	0.7	0.9	1.0
Radiative correction	1.8	2.3	0.2	7.7	0.0	4.4	4.2	5.6	3.7
Branching fraction	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
MUC cut	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	4.0	4.3	3.6	8.8	3.6	5.8	5.6	6.7	5.3

Table: Summary of systematic uncertainties (%) on the cross section of $e^+e^- \rightarrow \pi^0 J/\psi$ at each energy point.

Data set	4260	4310	4360	4390	4420	4470	4530	4575	4600
Luminosity *	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Photon detection*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Tracking($\mu^+\mu^-$)*	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Lepton pair mass window	1.2	1.3	1.2	1.3	0.9	0.9	1.1	1.1	1.1
4C kinematic fitting	0.9	1.1	0.6	0.5	0.8	0.8	0.9	0.8	0.6
Radiative correction	10.5	1.1	11.2	12.8	11.0	3.6	0.8	1.2	1.4
Branching fraction	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
MUC cut	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
Others	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Total	11.2	4.0	11.8	13.3	11.6	5.1	3.9	3.9	3.9

Summary

- Measured the cross section of $e^+e^- \rightarrow \eta J/\psi$.
- The upper limits at the 90% C.L. on the Born cross section of $e^+e^- \rightarrow \pi^0 J/\psi$.
- Fit the lineshape of $e^+e^- \rightarrow \eta J/\psi$, the mass and width of $Y(4230)$ is 4215.7 ± 3.4 MeV and 66.8 ± 4.2 MeV.
- Memo is ready

