Cross section Measurement of e+e-→ ηψ(2S) above center-of-mass energy $\sqrt{\boldsymbol{s}} = \mathbf{4.235}\ \boldsymbol{GeV}$

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Outline

- *Motivation*
- *Data* set
- *Event* selection
- *Cross section measurement*
- *Systematic* uncertainties
- *Summary*

Motivation

- Many exotic charmoniumlike states have been discovered around 4 GeV, which means hidden charm coupling is also prominent for new states lying in this energy region. Thus, careful investigation of hidden charm cross section is necessary and will give us a chance to clarify new charmoniumlike states.

- BESIII has collected a largescale sample above 4.0 GeV. It is a good opportunity to investigate hidden charm decays, such as $e^+e^- \to \eta\psi(2S)$.

Data set

- Decay channels:
  - $e^+e^- \rightarrow \eta\psi(2s)$,
  - $\psi(2s) \rightarrow \pi^+\pi^- J/\psi$, $\eta \rightarrow \gamma\gamma$, $J/\psi \rightarrow e^+e^-/\mu^+\mu^-$
- Signal MC: 100K events for each channel;
- BOSS version:7.0.3

XYZ Data 14 energy points
SUM :5251.77(pb^{-1})

$\sqrt{s}$(GeV)	Luminosity(pb^{-1})
4.237	530.6
4.245	55.88
4.246	537.4
4.260	828.4
4.270	529.7
4.280	175.5
4.310	45.08
4.360	543.9
4.390	55.57
4.420	1090.7
4.470	111.09
4.530	112.12
4.575	48.93
4.600	586.9

Event selection

charge tracks:

$|Rxy|<1cm$ $|Rz|<10cm$ $|\cos\theta|<0.93$;

$\sum Q=0$ N_good=4

good photons:

$0\leqslant TDC\leqslant 14$ Barrel: $E\geqslant 25$ MeV $|\cos\theta|\leqslant 0.8$

dang $\geqslant 10$ Endcap: $E\geqslant 50$ MeV $0.86\leqslant|\cos\theta|\leqslant 0.92$

$N\gamma\geqslant 2$

Particle identification:

$\pi^{\pm}$: Pmdc<0.8GeV

$e^{\pm}$: Pmdc>1.0GeV&Eemc>1GeV

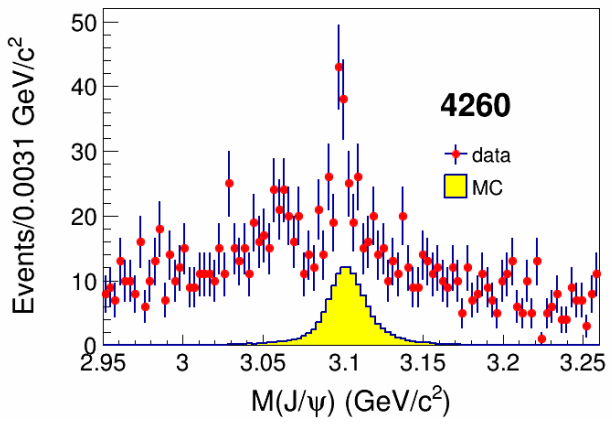
$\mu^{\pm}$: Pmdc>1.0GeV&Eemc<0.6GeV

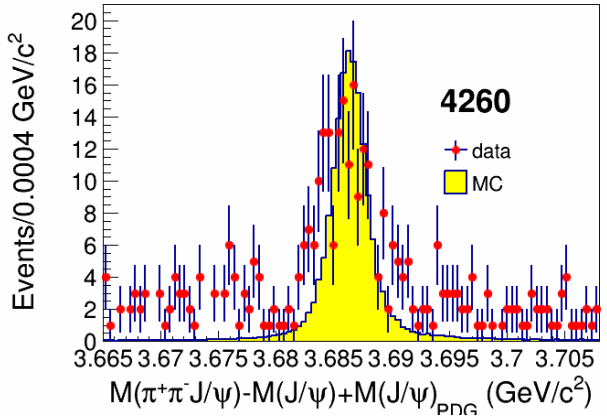
$N(l^{+})*N(l^{-})*N(\pi^{+})*N(\pi^{-})=1$

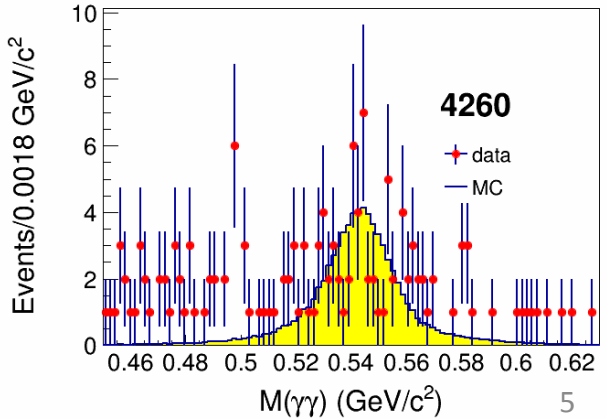
4C fit

4C kinematic fit

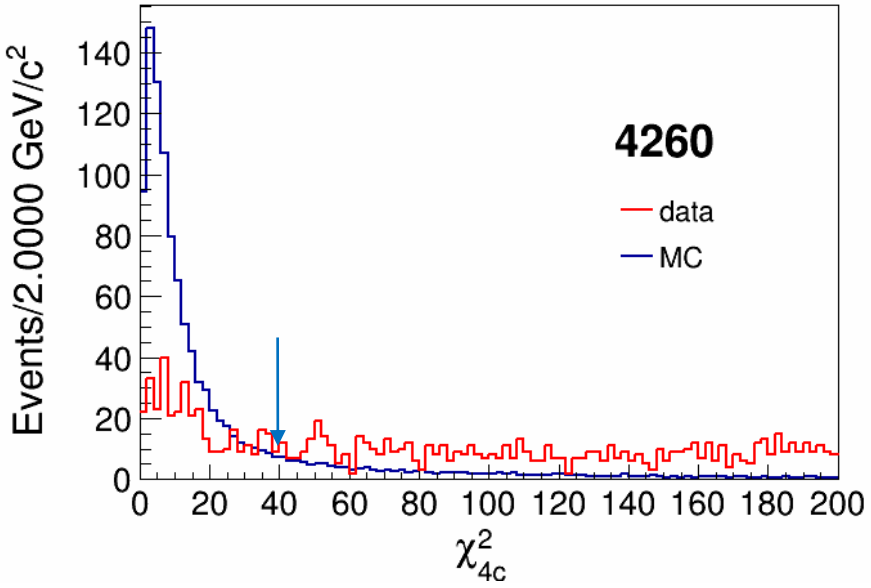
and the minimum chisquare requirement

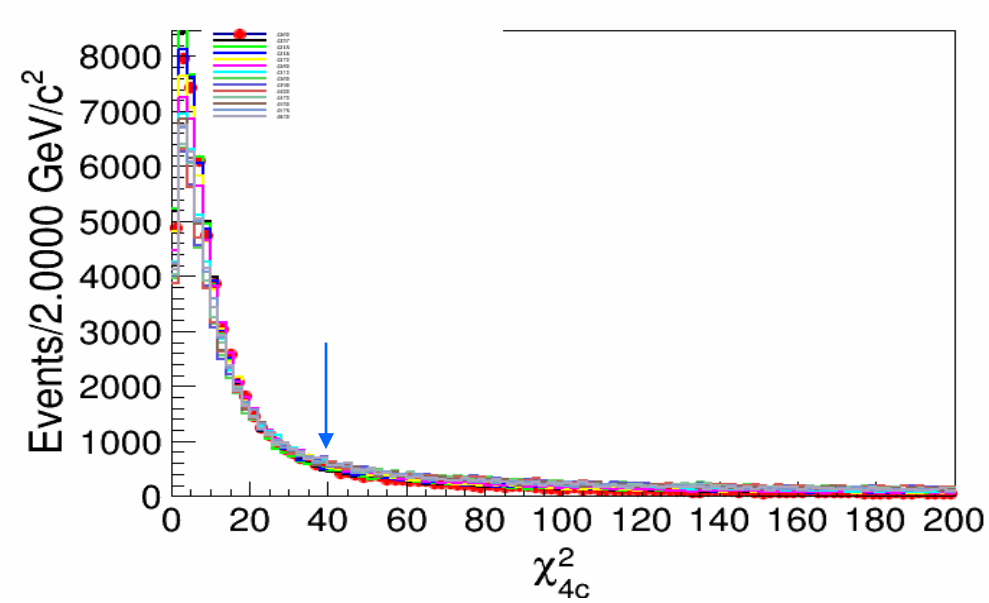






Further event selection criteria

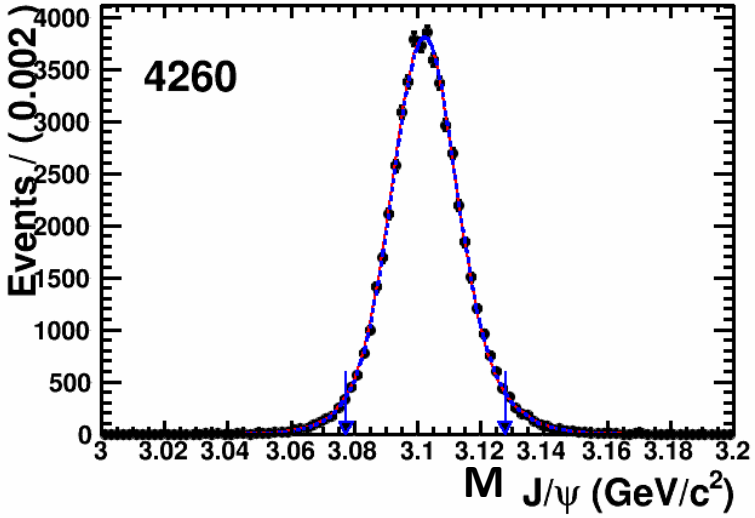


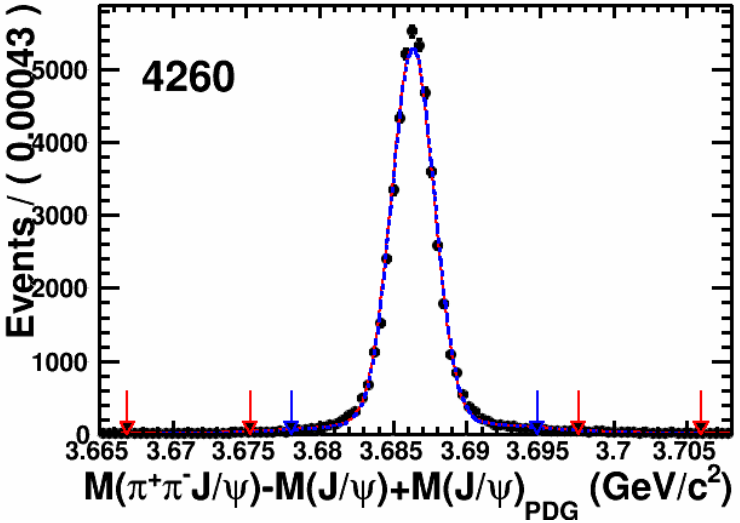


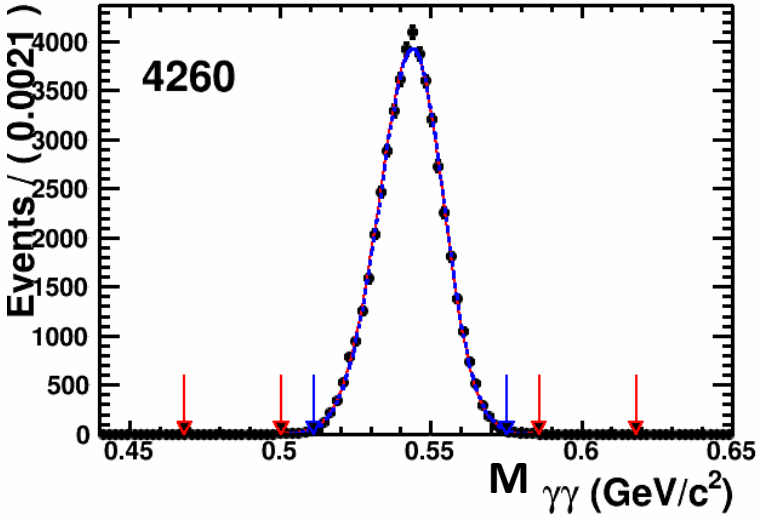
χ^2_{4C} distribution at the center-of-mass energy $\sqrt{s}$ = 4.258 GeV (Left) and 14 energy points (Right)

χ^2_{4C}<40 has no energy dependence.

Further event selection criteria







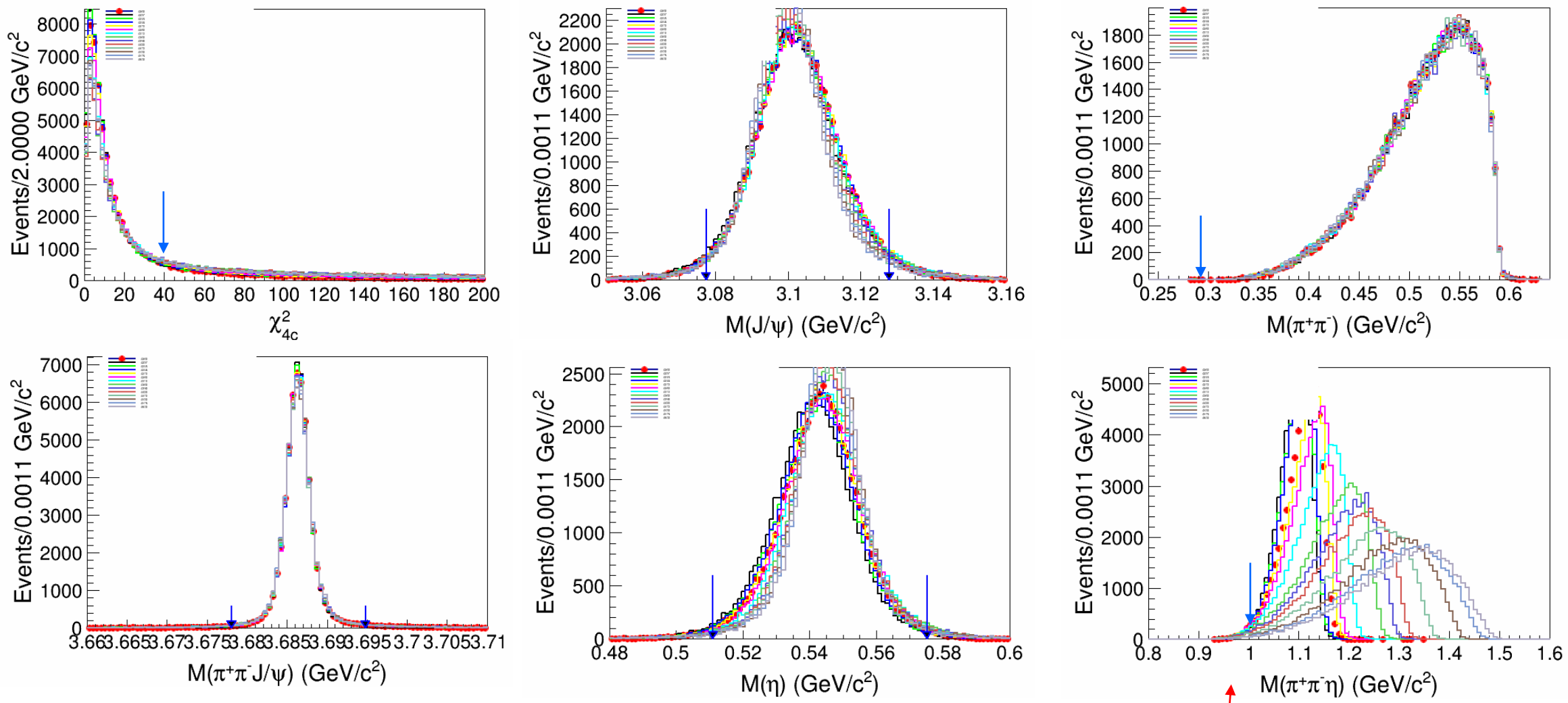
Signal region:(3.0775 ,3.1278) GeV

Signal region:(3.6781 , 3.6948) GeV
Sideband region:(3.6669 , 3.6753) GeV,
(3.6976 , 3.7060) GeV

Signal region:(0.5111 , 0.5753) GeV
Sideband region:(0.4683 , 0.5004) GeV,
(0.5860 , 0.6181) GeV

For further study, I will extend the mass range of J/ψ.

Distribution of χ^2_{4C}, *Mass* (J/ψ , *ππη*, *ππ* , η , *ππ*J/ψ) *for 14 energy points*

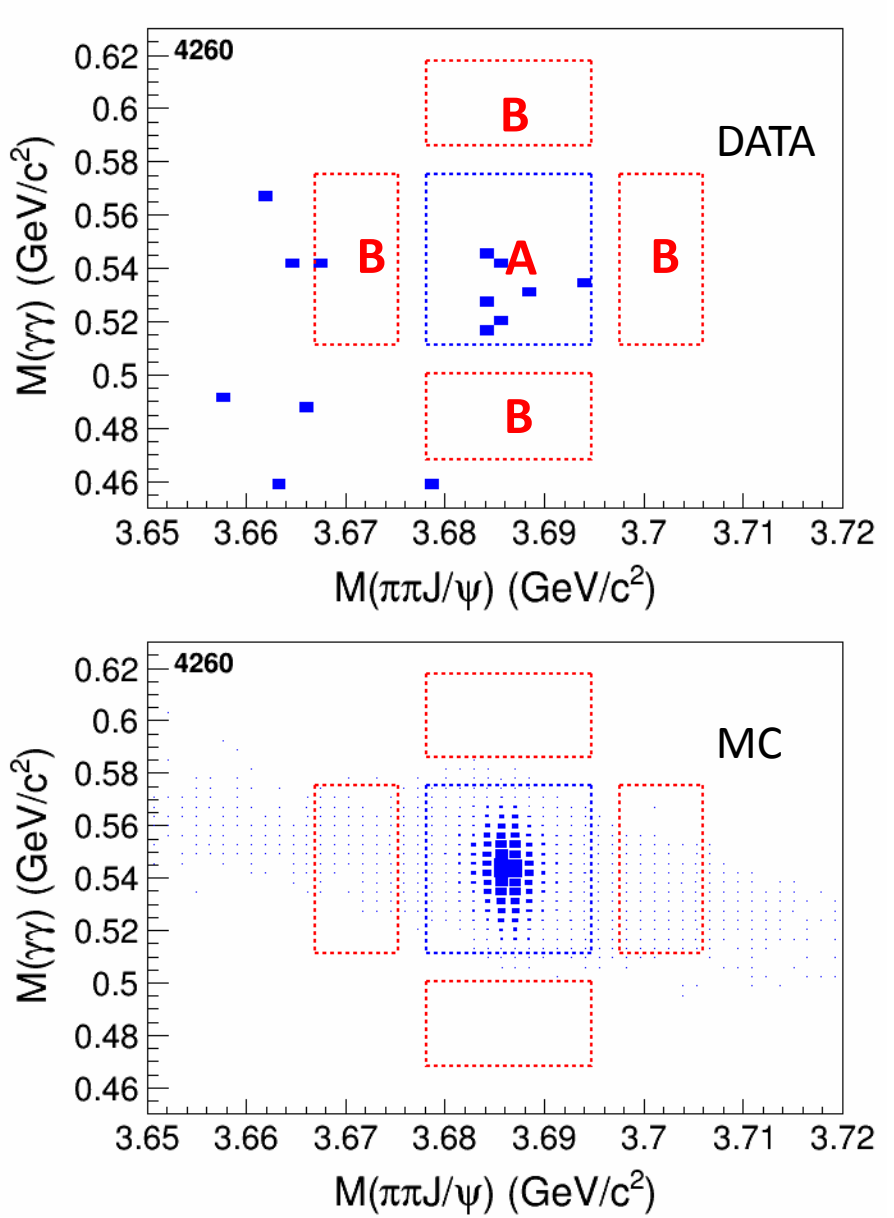


Above event selection criteria have no energy dependence.

Reasonable!

To veto the background η′ J/ψ

Extraction of signal yields



Dashed box A: 2-D Signal-region：

Mη ∈(0.5111, 0.5753),

(MππJ/ψ- MJ/ψ + MJ/ψ_{PDG}) ∈ (3.6781, 3.6948)

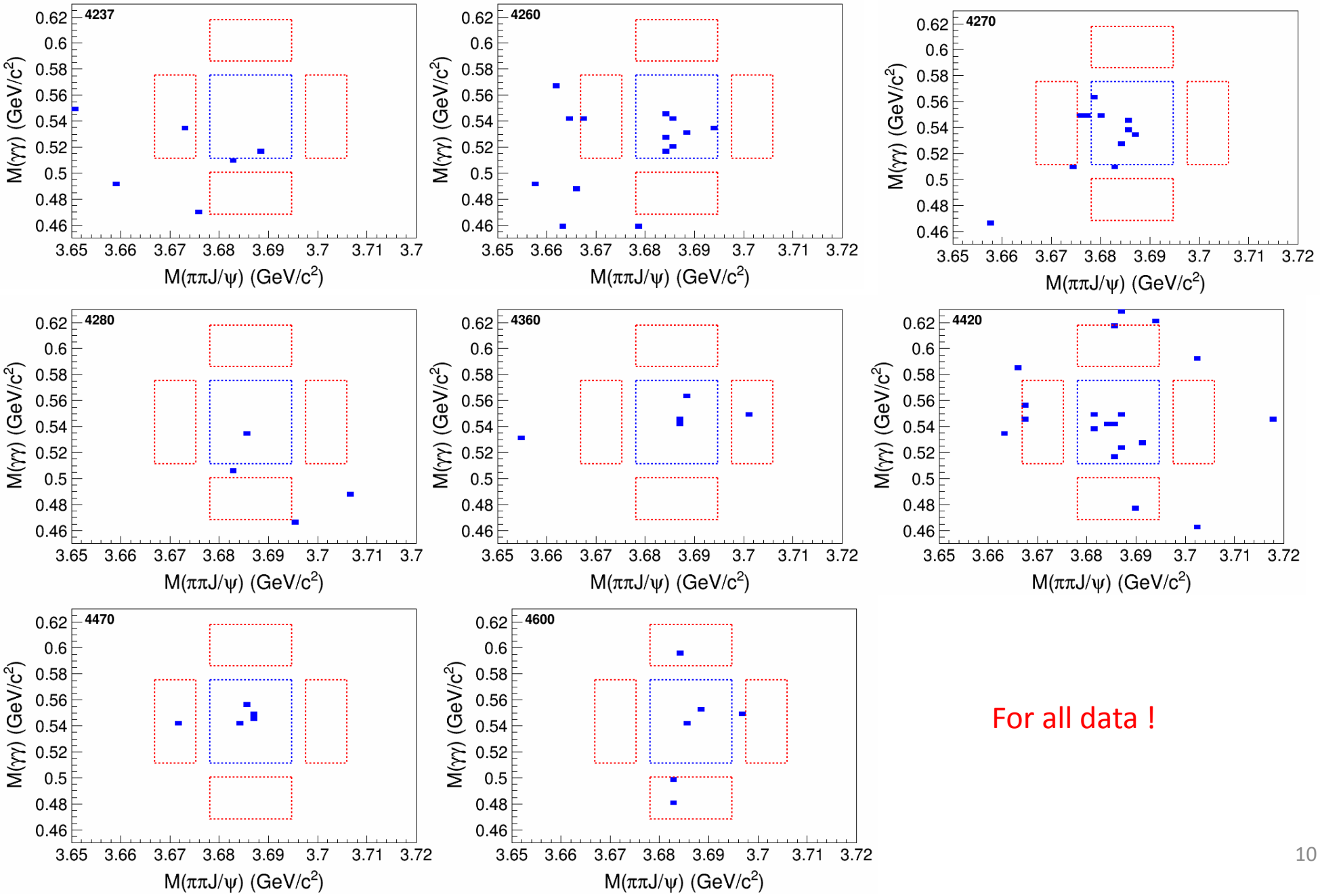
Dashed boxes B: 2-D Sideband-region：

Mη ∈(0.4683,0.5004), (0.5111,0.5753)

(MππJ/ψ- MJ/ψ + MJ/ψ_{PDG}) ∈ (3.6976,3.7060), (3.6669,3.6753)

Using Counting method to get the ***signal yields***

Extraction of signal yields



For all data !

Cross section measurement

Using following formula to calculate the number of background with the known cross section from BES3 memo or paper.

- $N_{bkgi} = \sigma^{B}_{bkgi} L_{int} \sum_i \epsilon_{bkgi} B_{bkgi} \ (1+\delta)(1+\delta^{V})$

Getting the expected number of signal event by using Feldman-Cousins(F-C) method with the known expected number of background event and total number of observed event. (F-C) method use Poisson formula to calculate the expected number of signal and provide the statistical uncertainty in 68.27% and 90% confidence level.

$$P(n|\mu) = (\mu + b)^{n} \exp[-(\mu + b)]/n!$$

Finally , cross section of signal event calculated by the formula:

$$\sigma^{Born} = \frac{N_{sig}}{L_{int}\epsilon_{sig} B_r(\psi' \to \pi^+\pi^- J/\psi) B_r(\eta \to \gamma\gamma)[B_r(J/\psi \to e^+e^-) + B_r(J/\psi \to \mu^+\mu^-)]\ (1+\delta)(1+\delta^{V})}$$

These are all backgrounds:

- $\boxed{\Psi(4260) \to \pi^+\pi^-\psi', \quad \psi' \to J/\psi\eta}$ → The main background !
- $\Psi(4260) \to \pi^+\pi^-\psi', \quad \psi' \to \gamma\chi_{c0,1,2}, \quad \chi_{c0,1,2} \to \gamma\, J/\psi$
- $\Psi(4260) \to \omega\chi_{c0,1,2}, \quad \omega \to \pi^+\pi^-\pi^0, \quad \chi_{c0,1,2} \to \gamma\, J/\psi$
- $\Psi(4260) \to \pi^0\pi^0\psi', \quad \psi' \to \pi^+\pi^- J/\psi$
- $\Psi(4260) \to \gamma\, X(3872), \quad X(3872) \to \omega\, J/\psi, \quad \omega \to \pi^+\pi^-\pi^0$
- $\Psi(4260) \to \phi\chi_{c1,2}, \quad \phi \to \pi^+\pi^-\pi^0, \quad \chi_{c1,2} \to \gamma\, J/\psi$

The expected numbers for different background events at each energy point in the signal region

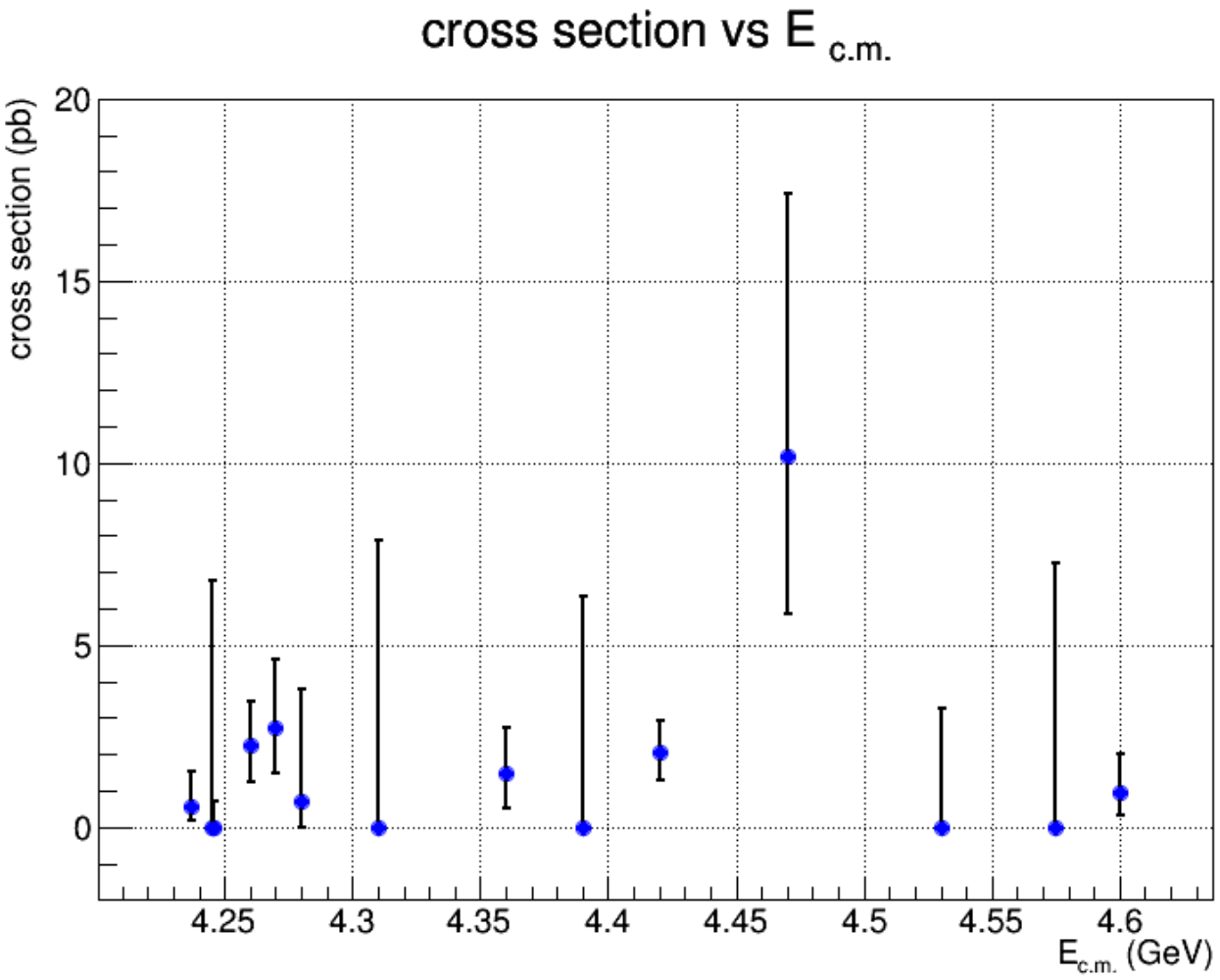
Energy(GeV)	$\pi^+\pi^-\psi'\_\eta J/\psi$	$\pi^+\pi^-\psi'\_\gamma\chi_{c0}$	$\pi^+\pi^-\psi'\_\gamma\chi_{c1}$	$\pi^+\pi^-\psi'\_\gamma\chi_{c2}$	$\omega\chi_{c0}$	$\omega\chi_{c1}$	$\omega\chi_{c2}$	$\pi^0\pi^0\psi'$	$\gamma X(3872)-\omega J/\psi$	$\phi\chi_{c1}$	$\phi\chi_{c1}$	total
4.236	0.0029	4.42E-05	0	0	0.0019				0			0.0048
4.242	0.0004	7.14E-06	4.36E-05	0	0.0001			0.0015	0			0.0021
4.244	0.0103	0.0002	0.0002	0	0.0018			0.0180	5.04E-06			0.0305
4.258	0.6949	0.0113	0.0831	0.0002	0.0042			0.0237	0			0.8174
4.267	1.1279	0.0211	0.1284	0.0001	0.0013			0.0154	5.23E-06			1.2941
4.278	0.5281	0.0108	0.0556	0.0001	0	0		0.0078	0			0.6026
4.308	0.0542	0.0010	0.0111	4.65E-05	0.0004	0.0146	0	0.0108	0			0.0922
4.358	0.0010	0.0002	0.0025	0	-0.0001	0.0057	0.0796	0.1777	7.54E-05			0.2666
4.387	0	4.19E-06	0	0	0.0002	0.0125	0.0465	0.0298	0			0.0889
4.416	0	0	0	0	0.0018	0.0443	0.2135	0.2513	9.23E-05			0.5110
4.467	0	0	0	0	0.0018	0.0193	0.0324	0.0246	0			0.0781
4.527	0	0	0	0	0.0007	0.0035	0.0041	0.0215	0			0.0298
4.575	0	0	0	0	0.0003	0	0.0144	0.0202	0			0.0350
4.600	0	0	0	0	0.0007		0.0181	0.0288	0	0.0031	0.0031	0.0538
sum	2.4198	0.0447	0.2808	0.0004	0.0150	0.0998	0.4087	0.6311	0.0002	0.0031	0.0031	3.9067

Preliminary results

Energy (GeV)	Lint(pb-1)	N_obs	N_bk	N_sig	1+δ	1+δ^v	σ (pb)	90% C.l.	P_value	Significance
4.236	530.6	1	0.00	$1.00^{+1.75}_{-0.64}$	0.763	1.064	$0.55^{+0.97}_{-0.35}$	(0.06,2.41)	4.8e-03	2.6σ
4.242	55.88	0	0.00	$0.00^{+1.29}_{-0.00}$	0.765	1.065	$0.00^{+6.75}_{-0.00}$	*(0.00,12.74)*		-
4.244	537.4	0	0.03	$0.00^{+1.26}_{-0.00}$	0.766	1.065	$0.00^{+0.70}_{-0.00}$	*(0.00,1.34)*		-
4.258	828.4	7	0.82	$6.18^{+3.31}_{-2.75}$	0.778	1.059	$2.25^{+1.20}_{-1.00}$	(1.00,4.26)	2.4e-05	4.1σ
4.267	529.7	6	1.29	$4.71^{+3.28}_{-2.18}$	0.794	1.058	$2.72^{+1.89}_{-1.26}$	(0.84,5.88)	2.2e-03	2.9σ
4.278	175.5	1	0.60	$0.40^{+1.75}_{-0.40}$	0.823	1.057	$0.70^{+3.07}_{-0.70}$	(0.00,6.58)		-
4.308	45.08	0	0.09	$0.00^{+1.20}_{-0.00}$	0.941	1.055	$0.00^{+7.88}_{-0.00}$	(0.00,15.40)		-
4.358	543.9	3	0.27	$2.73^{+2.31}_{-1.79}$	1.180	1.052	$1.48^{+1.25}_{-0.97}$	(0.46,3.88)	2.6e-03	2.8σ
4.387	55.57	0	0.09	$0.00^{+1.21}_{-0.00}$	1.322	1.052	$0.00^{+6.35}_{-0.00}$	(0.00,12.38)		The maximum!
4.416	1090.7	8	0.51	$7.49^{+3.32}_{-2.70}$	1.464	1.055	$2.03^{+0.90}_{-0.73}$	(0.94,3.66)	7.3e-08	5.3σ
4.467	111.09	4	0.08	$3.92^{+2.78}_{-1.66}$	1.719	1.061	$10.18^{+7.22}_{-4.31}$	(3.70,22.12)	1.5e-06	4.7σ
4.527	112.12	0	0.03	$0.00^{+1.27}_{-0.00}$	2.019	1.059	$0.00^{+3.25}_{-0.00}$	(0.00,6.18)		-
4.575	48.93	0	0.03	$0.00^{+1.26}_{-0.00}$	2.255	1.059	$0.00^{+7.25}_{-0.00}$	(0.00,13.84)		-
4.600	586.9	2	0.05	$1.95^{+2.25}_{-1.25}$	2.381	1.059	$0.94^{+1.08}_{-0.60}$	(0.23,2.81)	1.4e-03	3.0σ
total		32	3.91						7.5e-19	8.8σ

Born Cross sections are measured with large statistical errors; No obvious line shape, but total statistical significance is 8.8σ!

Distribution of cross section at different energy points



No obvious line shape and large statistical errors

Systematic uncertainties

Energy(GeV)	Luminosity	Branch ratio	tracking	photon	radiation correction (1+δ)*ε	background	kinematic_fit	Sum
4.236	1.0%	1.15%	4.0%	2.0%	10.3%	0.1%	2.7%	11.6%
4.242	1.0%	1.15%	4.0%	2.0%	10.7%		2.4%	11.9%
4.244	1.0%	1.15%	4.0%	2.0%	10.5%		2.5%	11.8%
4.258	1.0%	1.15%	4.0%	2.0%	7.3%	0.7%	2.6%	9.1%
4.267	1.0%	1.15%	4.0%	2.0%	5.5%	0.1%	2.6%	7.7%
4.278	1.0%	1.15%	4.0%	2.0%	2.6%	0.1%	2.9%	6.1%
4.308	1.0%	1.15%	4.0%	2.0%	4.4%		2.7%	7.0%
4.358	1.0%	1.15%	4.0%	2.0%	9.6%	0.9%	2.7%	11.1%
4.387	1.0%	1.15%	4.0%	2.0%	11.5%		2.8%	12.7%
4.416	1.0%	1.15%	4.0%	2.0%	10.8%	0.6%	2.8%	12.1%
4.467	1.0%	1.15%	4.0%	2.0%	1.5%		2.8%	5.7%
4.527	1.0%	1.15%	4.0%	2.0%	1.2%		2.4%	5.4%
4.575	1.0%	1.15%	4.0%	2.0%	4.7%		2.5%	7.1%
4.600	1.0%	1.15%	4.0%	2.0%	5.0%	0.6%	2.7%	7.4%

Systematic uncertainty for mass window of J/ψ , η , ππJ/ψ and others need to be calculated.
Systematic uncertainty for kinematic fit need to be estimated with new helix parameters (e+ e- μ+ μ-).

Summary and to do

- Observed the $e^+e^- \to \eta\psi(2S)$ process with a statistical significance of 8.8σ from 14 energy points data sets, the maximum is 5.3σ.

- Systematic uncertainty for kinematic fit need to be estimated with new helix parameters (e+ e- μ+ μ-).
- Systematic uncertainty for mass window of J/ψ , η , $\pi\pi$J/ψ need to be calculated.

Thank you!

Back up

The expected number of different backgrounds and real data event number in the sideband region

Energy (GeV)	N_obs	$\pi^+\pi^-\psi'$_$\eta J/\psi$	$\pi^+\pi^-\psi'$_$\gamma\chi_{c0}$	$\pi^+\pi^-\psi'$_$\gamma\chi_{c1}$	$\pi^+\pi^-\psi'$_$\gamma\chi_{c2}$	$\omega\chi_{c0}$	$\omega\chi_{c1}$	$\omega\chi_{c2}$	$\pi^0\pi^0\psi'$	γ X(3872) _ω J/ψ	$\phi\chi_{c1}$	$\phi\chi_{c1}$	total_bkg	signalMC	total
4.236	1	0.0226	0.0003	0.0020	0	0.0085				0.0003			0.0337	0.0141	0.0478
4.242		0.0087	0.0001	0.0014	1.57E-05	0.0004			0.0022	0			0.0128	0	0.0128
4.244		0.1907	0.0035	0.0274	0.0002	0.0032			0.0108	0.0001			0.2359	0	0.2359
4.258	1	1.1785	0.0272	0.2633	0.0169	0.0096			0.0222	0			1.5178	0.0899	1.6078
4.267		0.7760	0.0225	0.2860	0.0229	0.0014			0.0154	7.06E-05			1.1242	0.0649	1.1891
4.278		0.3504	0.0098	0.1400	0.0129	0	0		0.0068	0			0.5200	0.0054	0.5254
4.308		0.0839	0.0023	0.0336	0.0036	0.0008	0.0200	0	0.0105	0			0.1547	0	0.1547
4.358	1	0.0069	0.0004	0.0090	0.0009	-0.0003	0.0115	0.1239	0.2149	9.32E-05			0.3673	0.0468	0.4141
4.387		4.07E-05	1.26E-05	0	0	0.0003	0.0271	0.0845	0.0261	0			0.1381	0	0.1381
4.416	4	0	0	0	0	0.0040	0.0682	0.3630	0.3328	0.0002			0.7681	0.1303	0.8984
4.467	1	0	0	0	0	0.0028	0.0353	0.0722	0.0264	0			0.1367	0.0679	0.2046
4.527		0	0	0	0	0.0010	0.0085	0.0092	0.0253	0			0.0440	0	0.0440
4.575		0	0	0	0	0.0008	0	0.0282	0.0184	0			0.0473	0	0.0473
4.600	3	0	0	0	0	0.0014		0.0428	0.0417	0	0.0062	0.0089	0.1010	0.0386	0.1396
sum	11	2.6177	0.0662	0.7627	0.0574	0.0338	0.1707	0.7238	0.7535	0.0008	0.0062	0.0089	5.2016		5.6595