PWA of $e^+e^- \to \pi^+\pi^- J/\Psi$

Longzhou Liao, Zhentian Sun, Changzheng Yuan
IHEP

OUTLINE

- Introduction
- Datasets and Boss version
- Event selection
- Background Analysis
- Cross section of $\pi^+\pi^- J/\psi$
- About MUC
- Partial wave analysis (PWA)
- Summary

◆ Introduction

BESIII has give the J^p of Zc(3900) by using 4230 and 4260 data samples. And we have 9 new energy points data samples, also we have did more detail background analysis and have effectively excluded it. With lower background level, we can do more analysis in spite of the fewer events.

We will give precise cross section of $\pi^+\pi^- J/\psi$ and Zc(3900), and fit to the cross section line shape.

◆ Datasets and Boss version

➢ Data samples

4180 data sample (about 3000pb^{-1}).
XYZ data samples (8 energy points, about 3700pb^{-1} in total).

➢ MC samples

Using KKMC and BesEvtgen to simulate the signal events.
We simulate 0.2M events with each channel of each energy point.

➢ Boss version

BOSS 7.0.2.p01 (4180 data sample)
BOSS7.0.3(new XYZ data samples)

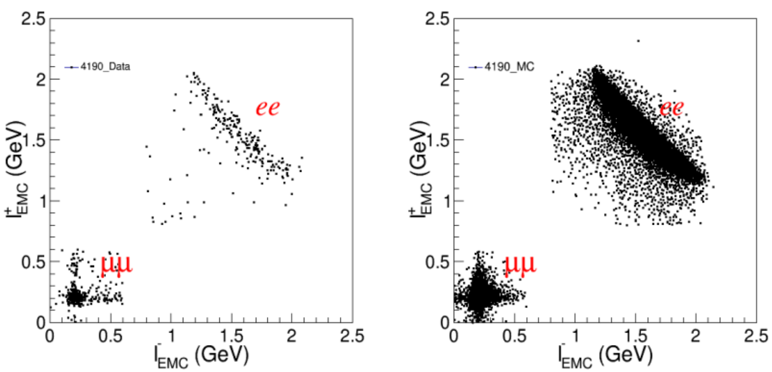
◆ Event selection

- $|V_z| < 10.0cm$
- $V_r < 1.0cm$
- Four charged tracks
- Total charges = 0
- EMC_e>1.15GeV
- EMC_m<0.40GeV
- 4C fit chisq<60
- BDT for ee channel only
- MUC depth for PWA only

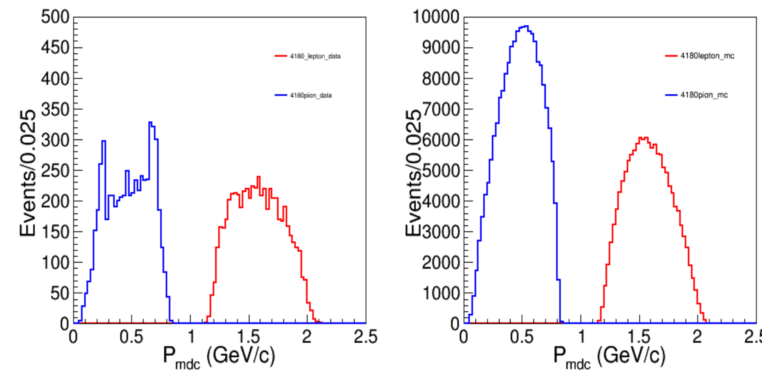
From the EMC deposit energy distribution, we can distinguish the electron and muon. And from the distribution of momentum, we can distinguish pion and leptons(electron and muon).

◆Selected π and leptons

The distribution of EMC deposited energy and momentum. From the distribution we can see that the leptons distinguish will use same criteria, EMC_mu<0.40GeV and EMC_e>1.15GeV. And the momentum distinguish criteria will change with the energy.



4180:
EMC_mu<0.40GeV andEMC_e>1.15GeV



4180:
P_pion<0.82GeV/c, P_lepton>1.12GeV/c

Summary:

EMC_mu<0.40GeV, EMC_e>1.15GeV

Energy	4180	4190	4200	4210	4220	4237	4246	4270	4280
P_pion (GeV/c)	0.82	0.83	0.84	0.85	0.86	0.87	0.88	0.89	0.90

◆Background Analysis

Because of the low cross section and a big data sample of 4180, we can do detail analysis of the background.

For ee channel,

I. Gamma-conversion events (pion and lepton intersection angle)
II. Misidentifying of electron and pion (low momentum pion) (dE/dx distribution)
III. The $ee\mu\mu$ of two-photon process (BDT)

For $\mu\mu$ channel,

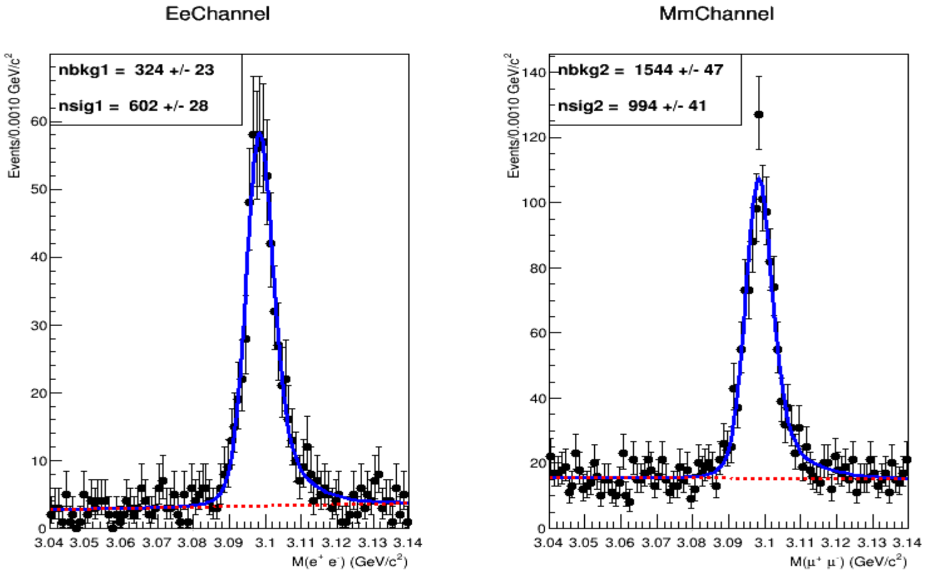
I. Misidentifying of muon and pion (dE/dx distribution)
II. 4pion(main $a_2^{\pm}\pi^{\mp}$ and $\rho^0\pi^+\pi^-$)

For more detail information about the process of excluding those background you can turn to my last report about $\pi^+\pi^-J/\psi$ cross section:
https://indico.ihep.ac.cn/event/7878/contribution/2/material/slides/0.pdf

◆Cross section of $\pi^+\pi^-J/\psi$

After using BDT method and dE/dx information, we have effectively exclude the ee channel backgrounds. Because the efficiency problem of MUC, we can't using MUC information to exclude the 4pi background of $\mu\mu$ channel.

But the events MUC not recorded didn't change the angler distribution, so we can still using MUC information in PWA.



we get our final results and use simultaneous fit to constraint the two channels. And we use the MC shape convolute Gaussian to describe the signal and Chebyshev polynomial to describe the background.

◆The cross section

$$\sigma = \frac{N^{sig}}{\mathcal{L}_{int}(1+\delta)\mathcal{E}\mathcal{B}}$$

$$\mathcal{B}_e = (5.971 \pm 0.032)\%$$
$$\mathcal{B}_\mu = (5.961 \pm 0.033)\%$$

Energy	Events_ee	Events_mm	Ee_efficiency	Mm_efficiency	1+delta	Luminosity(pb-1)	Cross_section_ee(pb)	Cross_section_mm(pb)
4180	602+/-28	994+/-41	30.92%	47.98%	0.9359	3194.5 ±0.2±31.9	12.22+/-0.57	13.07+/-0.54
4190	139+/-13	221+/-19	31.96%	48.85%	0.8852	522.5±0.1±3.4	16.86+/-1.58	17.57+/-1.5
4200	234+/-17	355+/-22	32.74%	49.29%	0.8161	524.6±0.1±2.5	27.76+/-2.02	28.02+/-1.74
4210	343+/-20	577+/-27	32.75%	49.01%	0.7590	518.1±0.1±1.8	42.09+/-2.4	46.85+/-2.19
4220	555+/-24	840+/-32	33.26%	49.56%	0.7323	514.3±0.1±1.9	66.93+/-2.89	68.1+/-2.59
4237	679+/-27	1085+/-36	34.17%	50.57%	0.7726	530.6±0.1±2.4	78.08+/-3.10	85.67+/-2.87
4246	638+/-27	969+/-34	33.96%	50.59%	0.8085	537.4±0.1±2.6	72.35+/-3.06	73.89+/-2.59
4270	489+/-24	745+/-31	33.69%	50.41%	0.8699	529.7±0.1±2.8	55.73+/-2.74	56.84+/-2.37
4280	150+/-13	249+/-18	32.70%	49.50%	0.8834	175.5±0.1±0.9	53.13+/-4.61	58.37+/-4.22

◆ About MUC

From the analysis ahead, we have as much as possible excluded ee channel backgrounds, but not reduce $\mu\mu$ channel backgrounds effectively.

Some study about MUC indicates that maybe the time window of MUC is too small and results to lose some events randomly.

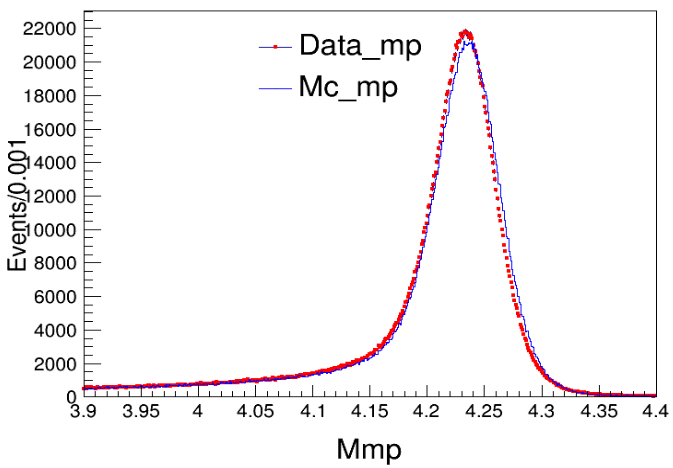
We have did some analysis about the events MUC not recorded. And we have chosen dimu events and compare the two parts events. (Recorded and not Recorded).

The analysis results are that the events MUC not recorded will not change the angler distribution.

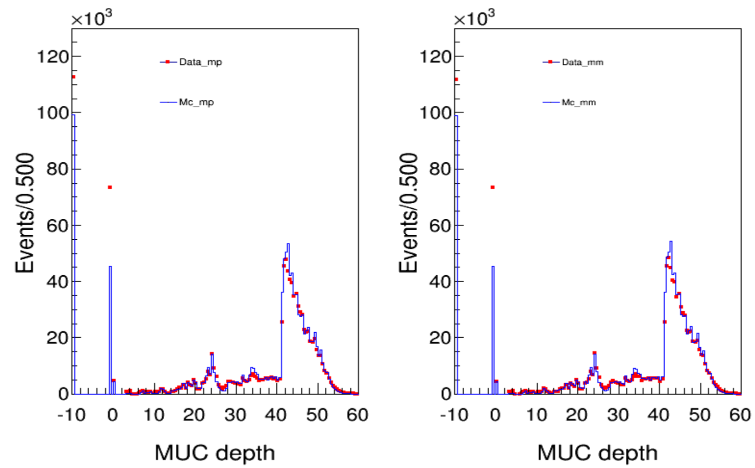
◆ About MUC

Dimu events:

- EMC<0.3GeV
- fabs(Tof)<3.0ns
- $\mathrm{Mmp} > 4.0\mathrm{Gev}/\mathrm{c}^2 \&\& \mathrm{Mmp} < 4.3\mathrm{GeV}/\mathrm{c}^2$

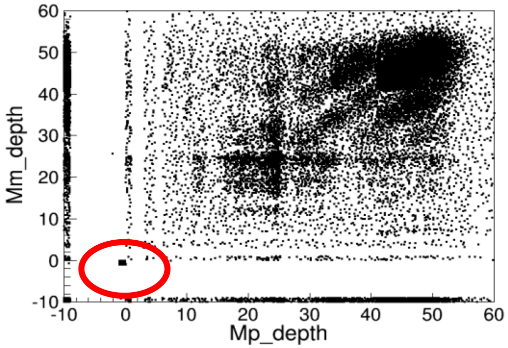


Invariant mass of $\mu\mu$

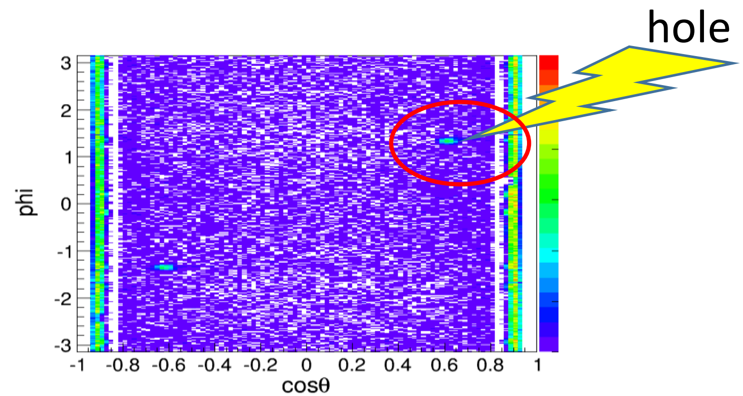


MUC not recorded events corresponding to Depth=-1

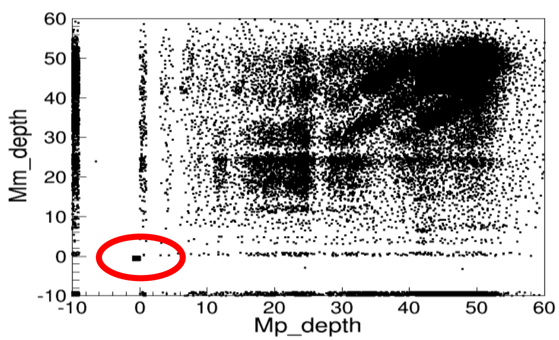
◆ About MUC



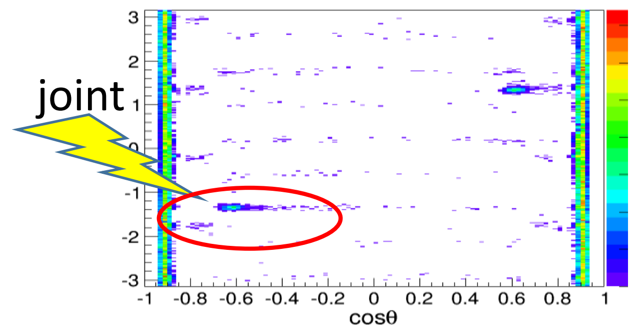
Data:(depth_mp, depth_mm)



Data:(pcost,PhiMp)



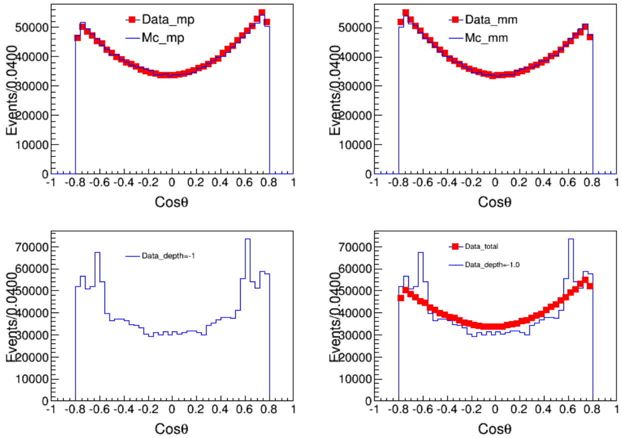
MC:(depth_mp, depth_mm)



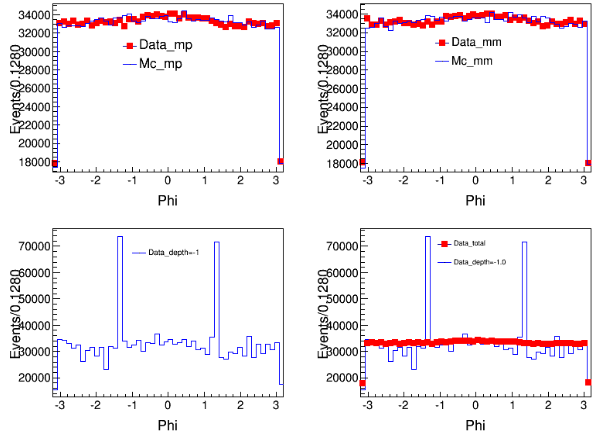
MC:(pcost,PhiMp)

The events of depth=-1 are not recorded by MUC. Because of the correlation of dimu, if one muon in the hole, another will in the joint.

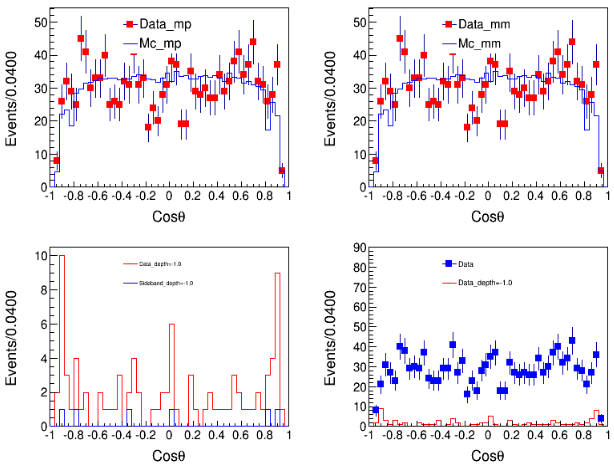
◆ About MUC



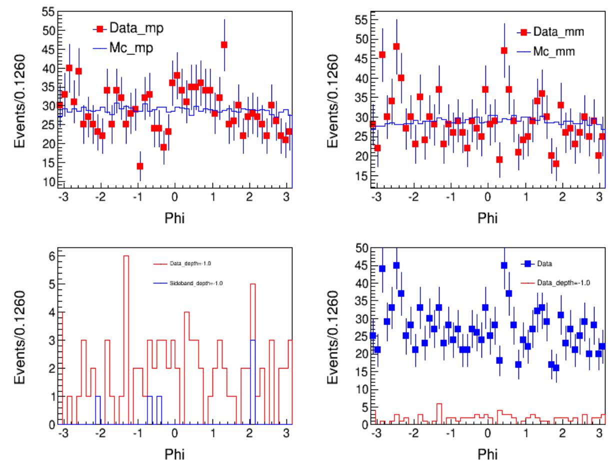
Dimu: cos(theta) of muon



Dimu:phi of muon



Pipijpsi: cos(theta) of muon



Pipjpsi:phi of muon

From the angler distribution of muon, we can see that the MUC missing parts will not change the distribution of events.

◆ About MUC

Excluding the 4pi background of $\mu\mu$ channel

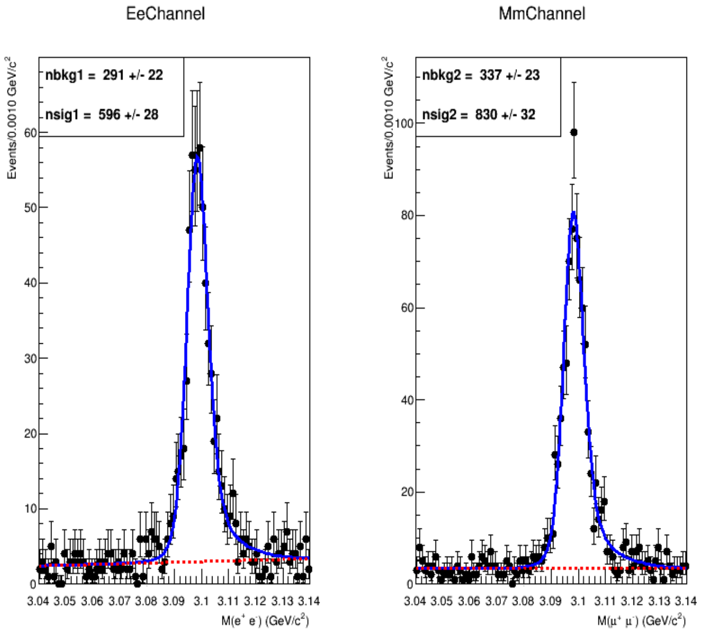
Energy point	Depth _mm	Depth _mp	S/sqrt(S+B)	Before_data	After_data	Efficiency_data	Before_mc	After_mc	Efficiency_mc	Correction
4180	31	31	28.2011	984+/-40	830+/-32	0.843496 +/-0.0472575	84591	78464	0.927569 +/-0.00459744	0.909362 +/-0.0511466
4190	30	29	13.5148	218+/-19	179+/-15	0.821101 +/-0.0992765	88789	83083	0.935735 +/-0.00451669	0.877493 +/-0.106179
4200	29	22	17.5289	352+/-22	316+/-19	0.897727 +/-0.0778566	94492	90055	0.953044 +/-0.00443828	0.941958 +/-0.0818103
4210	22	22	22.8907	574+/-26	501+/-24	0.872822 +/-0.0575438	98735	95329	0.965504 +/-0.00438408	0.904007 +/-0.0597409
4220	22	21	27.8262	834+/-31	734+/-29	0.880096 +/-0.0477417	102026	98664	0.967048 +/-0.00431793	0.910085 +/-0.0495355
4237	19	21	31.9604	1096+/-37	990+/-33	0.903285 +/-0.0428541	104760	101628	0.970103 +/-0.00427126	0.931122 +/-0.0443646
4246	22	21	29.8488	962+/-34	905+/-32	0.940748 +/-0.0470318	103703	100251	0.966713 +/-0.00428177	0.973142 +/-0.0488418
4270	22	22	26.0922	747+/-31	719+/-29	0.962517 +/-0.0557014	97441	94166	0.96639 +/-0.00441611	0.995992 +/-0.0578181
4280	22	22	15.1839	250+/-18	227+/-16	0.908 +/-0.0914878	94232	91082	0.966572 +/-0.00449131	0.939402 +/-0.0947525

Cut criterion: depth_mp>depth1 or depth_mm>depth2

We use MC simulation to do the optimizing. And compare with and without the cut, to get the correction factor.

◆ Partial wave analysis

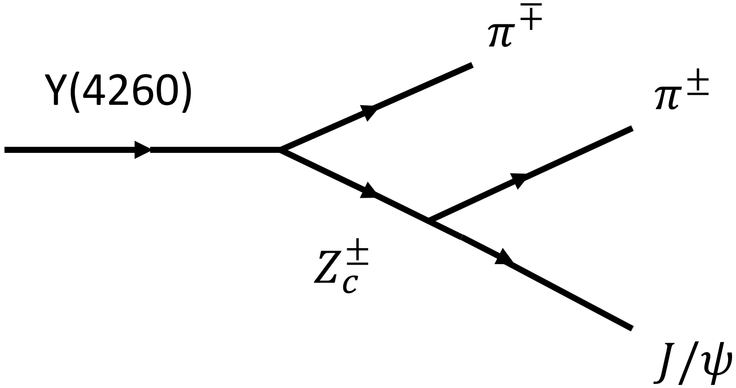
The data samples for PWA



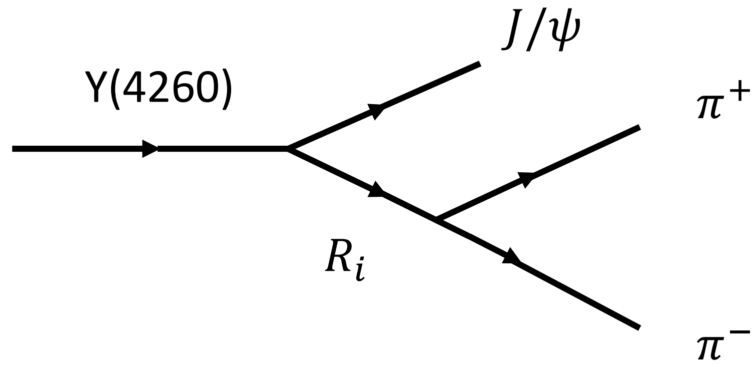
Energy points	Sig_ee	Bkg_ee	Ratio_ee*1/4	Sig_mm	Bkg_mm*1/4	Ratio_mm
4180	602	55	9.14%	833	66.25	7.95%
4190	138	12	8.70%	177	10.5	5.93%
4200	223	16.25	7.29%	296	12.5	4.22%
4210	317	14.5	4.57%	481	16.75	3.27%
4220	538	16.25	3.02%	683	14	2.05%
4237	648	13.75	2.12%	926	20	2.16%
4246	593	14.75	2.49%	834	16.25	1.95%
4270	458	15.25	3.33%	654	18.25	2.79%
4280	133	6.25	4.70%	208	4.75	2.28%

J/ψ signal mass window: $3.090\text{GeV} < m(l^+l^-) < 3.110\text{GeV}$.
400thousand $e^+e^- \rightarrow \pi^+\pi^-l^+l^-$ PHSP MC events are generated to perform the mc integration for PWA.

◆ Partial wave analysis



(a)



(b)

(a) $$A_{Z_c}(\lambda_Y, \lambda_{Z_c}, \lambda_{l^+}, \lambda_{l^-}) = F^{J_Y}_{\lambda_{Z_c},0} D^{J_Y}_{\lambda_Y,\lambda_{Z_c}}\left(\theta_{Z_c}, \phi_{Z_c}\right) BW(Z_c) F^{J_{Z_c}}_{\lambda_{J/\psi},0} D^{J_{Z_c}}_{\lambda_{Z_c},\lambda_{J/\psi}}\left(\theta_{J/\psi}, \Phi_{J\psi}\right) \cdot F^{J_{J/\psi}}_{\lambda_{l^+},\lambda_{l^-}} D^{J_{J/\psi}}_{\lambda_{J/\psi},\lambda_{l^+}-\lambda_{l^-}}(\theta_{l^+}, \phi_{l^+})$$

(b) $$A^i_R(\lambda_Y, \lambda_R, \lambda_{l^+}, \lambda_{l^-}) = F^{J_Y}_{\lambda_R,\lambda_{J/\psi}} D^{J_Y}_{\lambda_Y,\lambda_R-\lambda_{J/\psi}}(\theta_R, \phi_R) BW_i(R) F^{J_R}_{0,0} D^{J_R}_{\lambda_R,0}(\theta_{\pi^+}, \phi_{\pi^+}) \cdot F^{J_{J/\psi}}_{\lambda_{l^+},\lambda_{l^+}} D^{J_{J/\psi}}_{\lambda_{J/\psi},\lambda_{l^+}-\lambda_{l^-}}(\theta_{l^+}, \phi_{l^+})$$

◆ Parameterization of intermediate states

Z_c are parameterized with the Flatte-like formula:

$$f = \frac{1}{M^2 - s - i(g1\rho_{DD^*}(s) + g2\rho_{\pi J/\psi}(s))}$$

- For $\pi^+\pi^-$ S wave, we consider the Resonance $\sigma_0, f_0(980), f_0(1370)$, and the $\pi^+\pi^-$ D wave $f_2(1270)$ is used.

- For $f_0(980)$, the Flatte formula: $f = \frac{1}{M^2 - s - i(g1\rho_{\pi\pi}(s) + g2\rho_{K\bar{K}}(s))}$
- For σ_0:$\Gamma_X(s) = \sqrt{1 - \frac{4m_\pi^2}{s}\Gamma}$
- For $f_0(1370)$: M = 1.35GeV, $\Gamma = 0.35\text{GeV}$
- For $f_2(1270)$: M = 1.275GeV, $\Gamma = 0.186\text{GeV}$
- Relativistic Breit-Wigner function:$BW(m) = \frac{1}{m^2 - m_0^2 + im\Gamma_X(m)}$

◆ Fitting method

We use an Extended Maximum Likelihood to fit the data.

$S = -\ln\mathcal{L}$ is minimized using the package TMINUIT

$$\ln\mathcal{L} = \ln\mathcal{L}_{\mathrm{data}} - \ln\mathcal{L}_{\mathrm{bkg}}$$

$$\mathcal{L} = \frac{e^{-\mu}\mu^{N}}{N!}\prod_{i=1}^{N}\frac{P(x_i)}{\mu},$$

(the μ is predicted signal event numebr)

$$P(x_i) = \frac{(d\sigma/d\phi)_i}{\sigma_{MC}}, \sigma_{MC} = \frac{1}{N_{MC}}\sum_{i=1}^{N_{MC}}\left(\frac{d\sigma}{d\phi}\right)_i$$

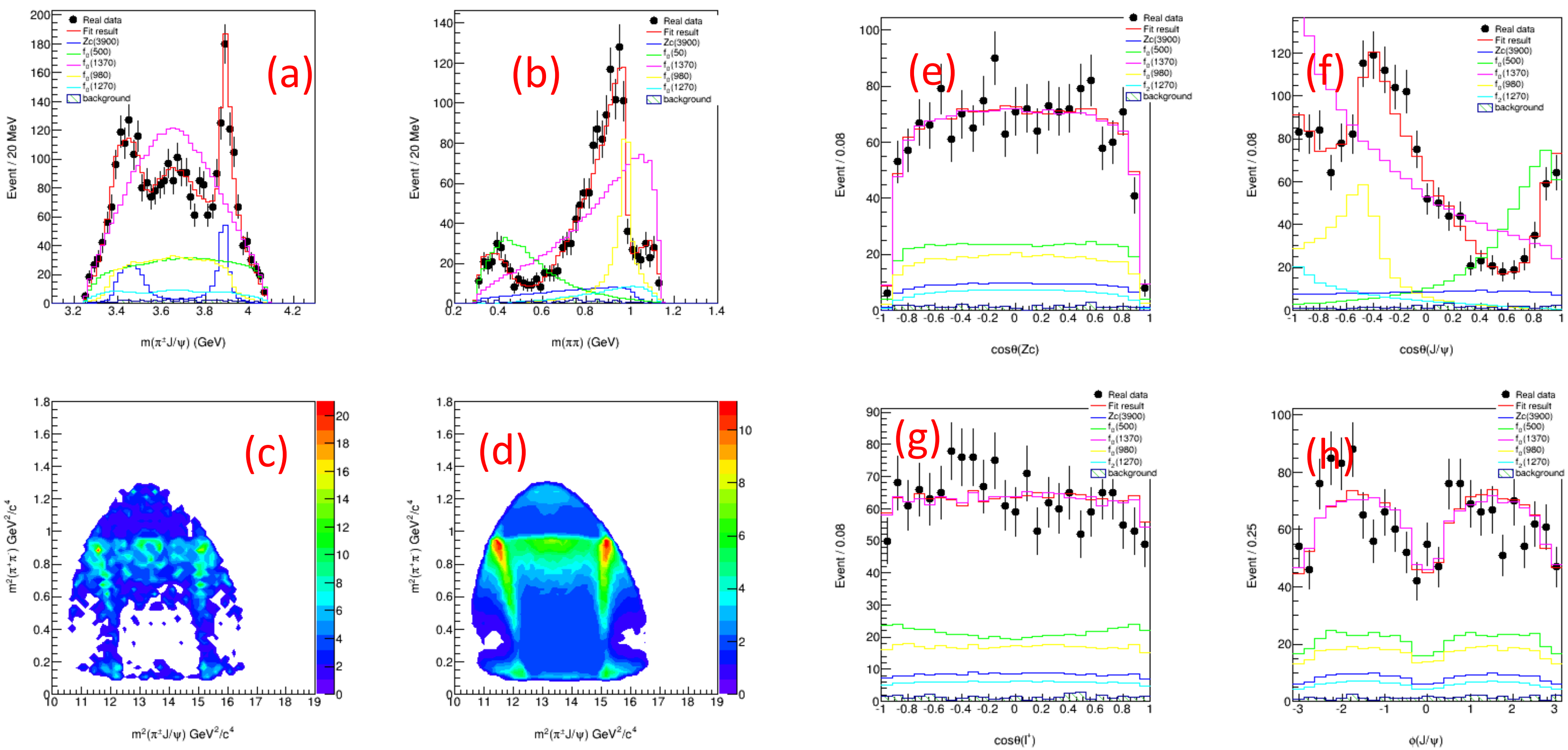
$$\frac{d\sigma}{d\phi} = \sum_{\lambda_Y,\Delta\lambda_l}\left|\sum_{\lambda_{Z_c},\lambda_R}\left(A_R + e^{i\Delta\lambda_l\alpha_l(Z_c)}A_{Z_c}\right)\right|^2$$

Signal yields:

$$N_i = R_i \times \left(N_{obs} - N_{big}\right), R_i = \frac{\sigma_i}{\sigma_{tot}}$$

where σ_i is the cross section of the i-th resonance

◆ Fit Results@4237



The projection of the fit for 4237 real data. The black dots are real data, the red line is the sum of the fit result and background. (a) $m(\pi^{\pm}J/\psi)$, (b) $m(\pi^+\pi^-)$, (c) real data, (d) fit result, (e) $\cos\theta(Z_c)$, (f) $\cos\theta(J/\psi)$, (g) $\cos\theta(l^+)$, (h) $\phi(J/\psi)$

◆ Fit Results@4237

$$M_{Z_c} = 3.8839 \pm 0.0026 GeV$$
$$\Gamma_{Z_c} = 0.0414 \pm 0.0062 GeV$$

Resonant	Z_c	σ_0	$f_0(1370)$	$f_0(980)$	$f_2(1270)$	total
Numofevt	500.0 ± 120.3	1655.0 ± 282.7	4167.9 ± 373.8	1094.5 ± 158.2	352.6 ± 129.0	4037.3 ± 125.9
Ratio%	12.38 ± 3.00	40.99 ± 7.12	103.24 ± 9.80	27.11 ± 4.01	8.73 ± 3.21	100.00 ± 3.21

◆ Summary

We have finished the preliminary work of $\pi^+\pi^-J/\psi$. And we will give other energy points results and use the PWA results to update the MC simulation and give the right efficiency.

Including those parts:

- Zc cross section (line shape)
- Update BDT
- Right efficiency
- Systematic uncertainty

Thank you !