Measurements of $\sigma(e^+e^- \rightarrow J/\psi X)$ in Range from 3.645 to 3.891 GeV

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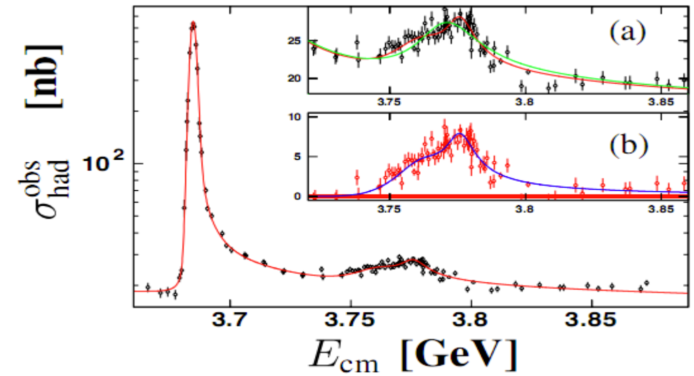
OUTLINE

- **Introduction**
- **Measurements of Cross Sections**
- **Analysis of Observed Cross Sections**
- **Summary**

Introduction

Measurements of cross sections for $e^+e^- \rightarrow J/\psi X$ would help better understanding



- ✓ the anomaly line-shape of cross sections for $e^+e^- \rightarrow$ hadrons observed at the BES-II Expt.
- ✓ the non-open charm decays of heavy cc-bar states or cc-bar-like states
- ✓ the dynamics of heavy charmonium production and decays
- ✓ the non-DD decays of $\psi(3770)$ decays

It would also help in searching for new structure(s) in the open-charm energy region

Data Samples & Software

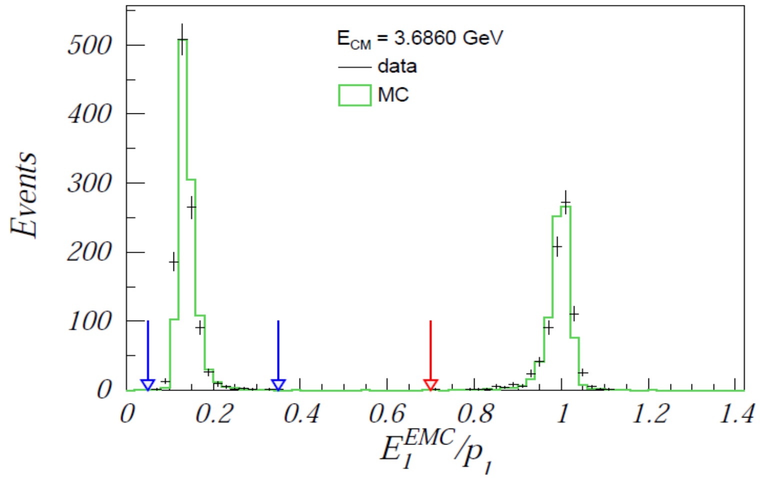
- **Data Samples**
  - 44.5 pb^{-1} @ 3.650 GeV
  - 928 pb^{-1} @ 3.773 GeV
  - About 2 pb^{-1} fast $\psi(3686)$ scan data
  - About 70 pb^{-1} energy scan data taken in range from 3.700 to 3.891 GeV

New reconstructed data and a complete New Analysis

- **Software**
  - BOSS software 6.6.4.p01
  - Monte Carlo events were generated with KKMC + BesEvtGen

Event Selection

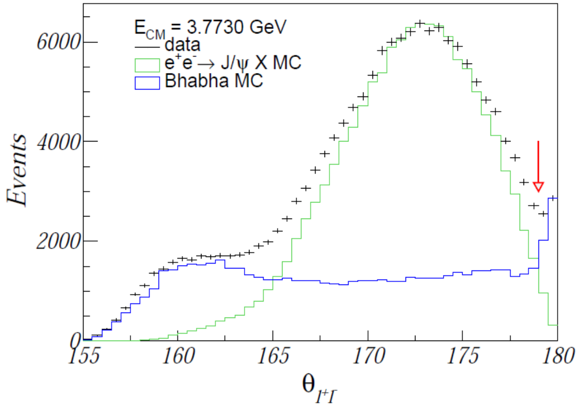
- **Charged track selection**
  - $|R_{xy}| < 1.0$ cm and $|R_z| < 10.0$ cm;
  - $|\cos\theta| < 0.93$
  - $|\cos\theta| < 0.81$ for leptons (to reject Bhabha scattering events);
- **Lepton selection**
  - $1.0 \text{ GeV} < p < 0.47\, E_{cm}$
  - $E/p > 0.7$ for electron
  - $0.05 < E/p < 0.35$ for muon



- **Photon selection:**
  - $E_{EMC} > 25\ (50)$ MeV for barrel (end-cap) calorimeter
  - $\theta_{\gamma,charge} > 10^\circ$
  - $0 \le TDC \le 14$

Event Selection

- **Number of good charged tracks and photons satisfy:**
  - $N_{good} = 2$ and $N_{\gamma} \geq 2$
  - $3 \leq N_{good\ charge} \leq 4$

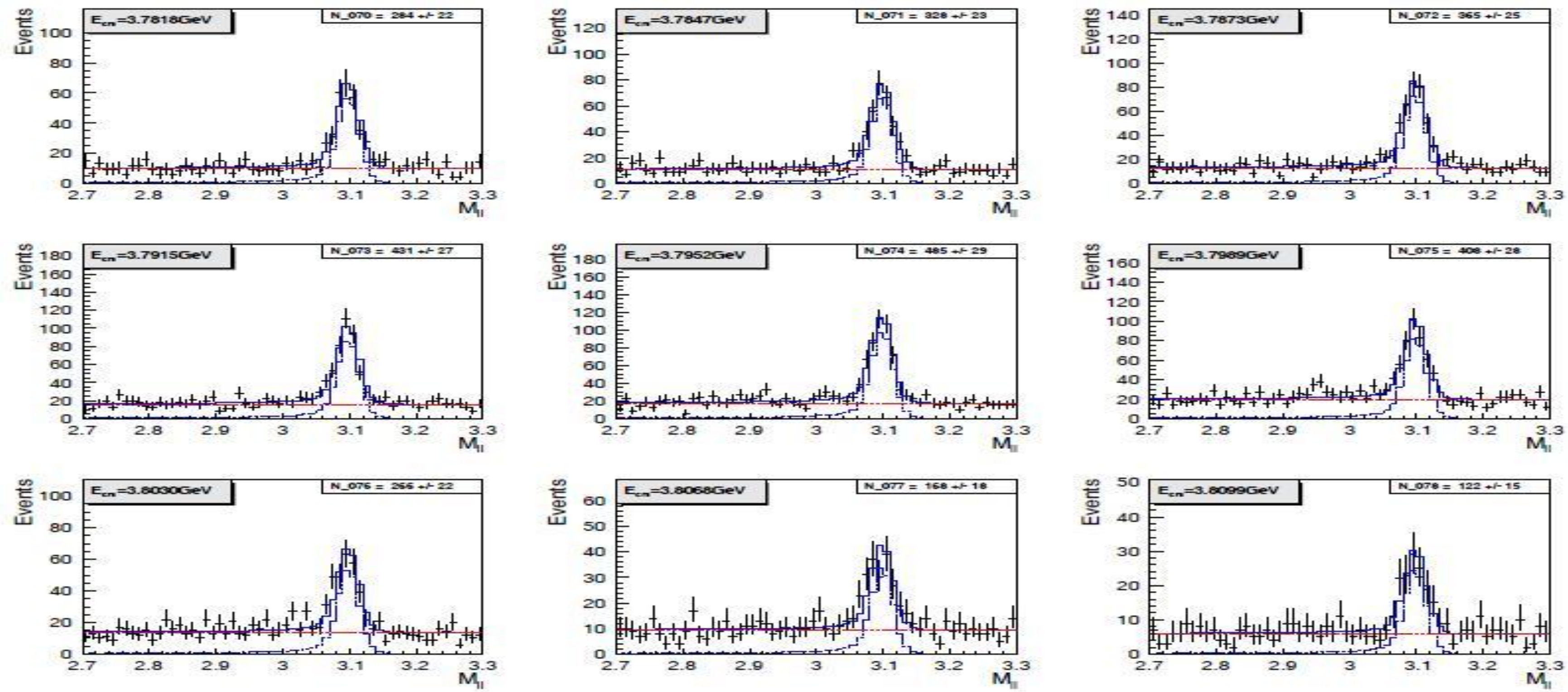


- **Other requirements**
  - – l^+l^- opening angle $\theta_{e+e- \text{ or } \mu+\mu-} < 179^\circ$
  - – Charged tracks not identified as leptons are subject to particle identification (based on dE/dx and TOF): CL(π) > CL(K) to select $\pi^{+/-}$
- **Signal of J/ψX**

Examine invariant mass of l^+l^- to get number of J/ψ X events from data set

Lepton-pair Mass Spectra

Only show a few mass spectra as an example (More plots in Back Up slides)

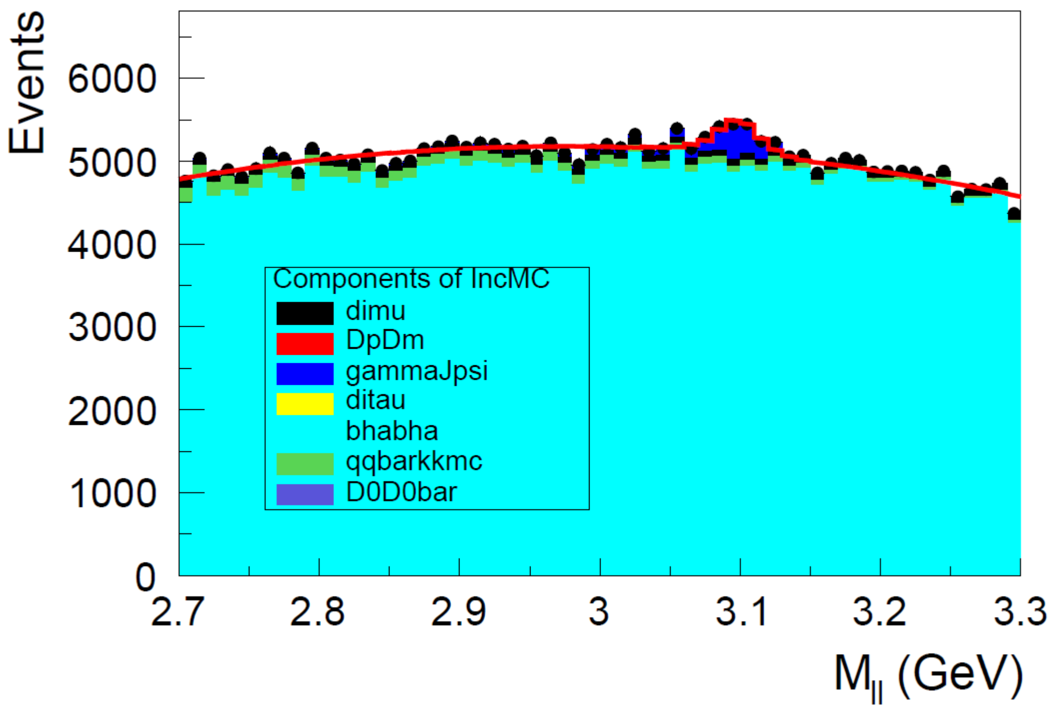


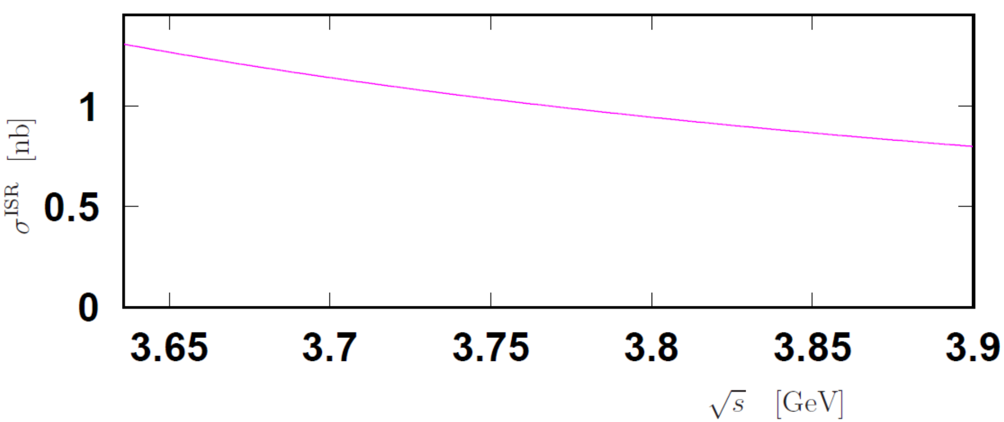
The signal and background shapes are described by MC-Shape of the mass distribution of lepton pair and 2nd order Chebychev polynomial, respectively.

Fitting these M_{ll} spectra yields the observed number of signal events for $e^+e^- \rightarrow J/\psi X$ at these energy points.

Background Subtraction

- **Major background: $e^+e^- \rightarrow (\gamma_{ISR})J/\psi \rightarrow l^+l^-$**





- The mis-identification rate is determined from MC simulation:

$$\eta = (0.200 \pm 0.024)\%$$

- The expected cross section is calculated using resonance parameters of J/ψ.

- The number of background events:

$$N_{\mathrm{BCK}} = L \times \sigma_{J/\psi}\eta$$

Monte Carlo Events & Efficiencies

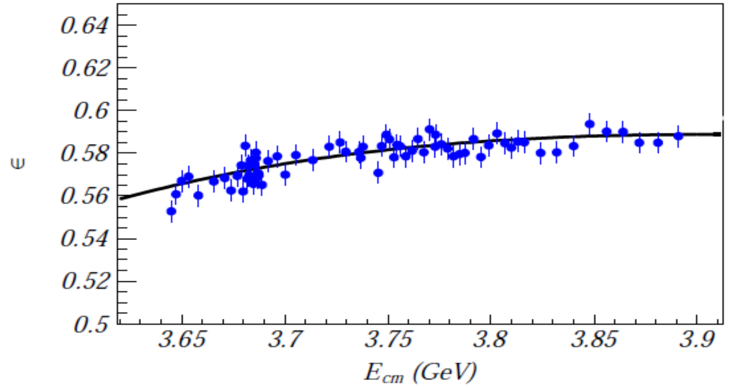
- Monte Carlo events are generated with the BES-III Standard ISR KKMC + EvtGen MC generator.
  - π^0 and η are set to decay into any possible final states;
  - J/ψ is set to decay into e^+e^- or $\mu^+\mu^-$;
  - The ratio of each process is determined with its branching fraction.

- In determination of the efficiency for $e^+e^- \rightarrow J/\psi X$, we consider the mixture of the $\psi(3686)$ and $\psi(3770)$ decay into these final states.

Monte Carlo Events & Efficiencies

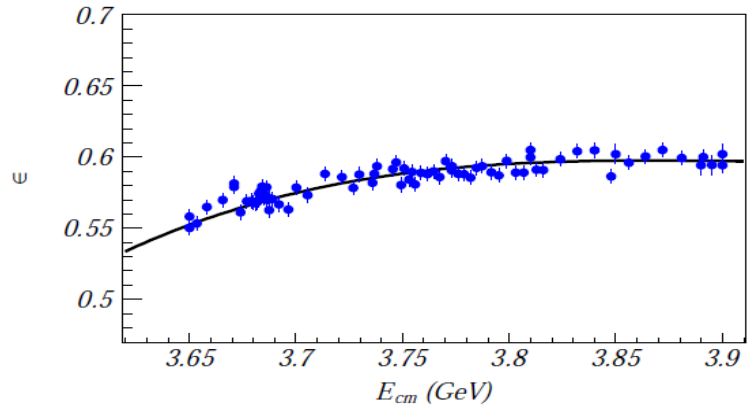
- **ψ(3686)→ J/ψ X**

$\psi(3686) \to$	Br	Ratio	MODEL
$J/\psi\pi^+\pi^-$	$(34.45 \pm 0.30)\%$	0.5631	JPIPI+PHOTOS VLL
$J/\psi\pi^0\pi^0$	$(18.13 \pm 0.31)\%$	0.2963	JPIPI+PHOTOS VLL
$J/\psi\eta$	$(3.36 \pm 0.05)\%$	0.0549	HELAMP+PHOTOS VLL
$J/\psi\pi^0$	$(0.1268 \pm 0.0032)\%$	0.0021	HELAMP+PHOTOS VLL
$\gamma\chi_{c0}, \chi_{c0} \to \gamma J/\psi$	$(9.99 \pm 0.27)\% \times (1.27 \pm 0.06)\%$	0.0021	P2GC0+S2GV+PHOTOS VLL
$\gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi$	$(9.55 \pm 0.31)\% \times (33.9 \pm 1.2)\%$	0.0529	P2GC1+AV2GV+PHOTOS VLL
$\gamma\chi_{c2}, \chi_{c2} \to \gamma J/\psi$	$(9.11 \pm 0.31)\% \times (19.2 \pm 0.7)\%$	0.0286	P2GC2+PHSP+PHOTOS VLL



- **ψ(3770)→ J/ψ X**

$\psi(3770) \to$	Br	Ratio	MODEL
$J/\psi\pi^+\pi^-$	$(1.93 \pm 0.28) \times 10^{-3}$	0.3956	JPIPI+PHOTOS VLL
$J/\psi\pi^0\pi^0$	$(8.0 \pm 3.0) \times 10^{-4}$	0.1640	JPIPI+PHOTOS VLL
$J/\psi\eta$	$(9.0 \pm 4.0) \times 10^{-4}$	0.1845	HELAMP+PHOTOS VLL
$\gamma\chi_{c0}, \chi_{c0} \to \gamma J/\psi$	$(7.3 \pm 0.9) \times 10^{-3} \times (1.27 \pm 0.06)\%$	0.0190	P2GC0+S2GV+PHOTOS VLL
$\gamma\chi_{c1}, \chi_{c1} \to \gamma J/\psi$	$(2.9 \pm 0.6) \times 10^{-3} \times (33.9 \pm 1.2)\%$	0.2015	P2GC1+AV2GV+PHOTOS VLL
$\gamma\chi_{c2}, \chi_{c2} \to \gamma J/\psi$	$9.0 \times 10^{-4} \times (19.2 \pm 0.7)\%$	0.0354	PHSP+PHSP+PHOTOS VLL



- **Efficiency of e^+e^- →J/ψ X**

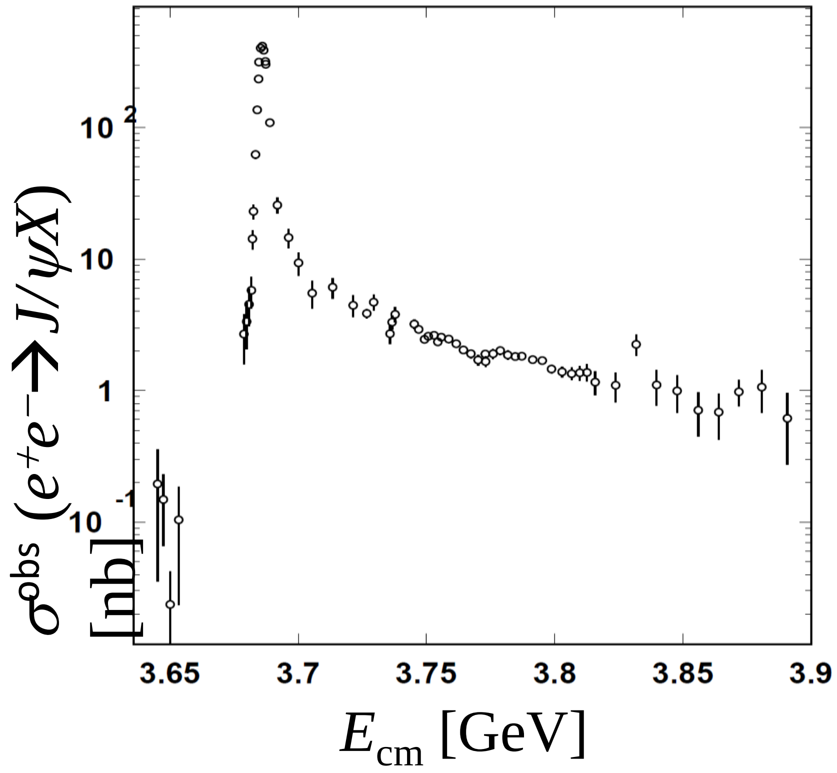
$$\bar{\epsilon} = \frac{1}{\sigma_{J/\psi X}^{\psi(3686)} + \sigma_{J/\psi X}^{\psi(3770)}} \left(\sigma_{J/\psi X}^{\psi(3686)} \times \epsilon_{\psi(3686)} + \sigma_{J/\psi X}^{\psi(3770)} \times \epsilon_{\psi(3770)}\right)$$

Observed Cross Sections

➢ Cross Sections

$$\sigma^{\text{obs}} = \frac{N^{\text{obs}}(e^+e^- \to J/\psi X)}{L \times \varepsilon \times B(J/\psi \to l^+l^-)}$$

- N^{obs}: Number of signal events;
- L: Luminosity;
- ε: Efficiency
- B: Branching fraction of $J/\psi \to l^+l^-$



Analysis of this observed cross section needs the expected-observed cross sections for this final state, which can be obtained with BW function and ISR sampling function.

Number of events & Cross Sections

E_{cm} (GeV)	$N^{obs}_{J/\psi X}$	N^{obs}_{BCK}	$\mathcal{L}$ (nb^{-1})	$\epsilon^{\psi(3686)}_{J/\psi X}$	$\epsilon^{\psi(3770)}_{J/\psi X}$	$\sigma^{\psi(3686)}_{J/\psi X}$	$\sigma^{\psi(3770)}_{J/\psi X}$	$\epsilon_{J/\psi X}$	σ (nb)
3.6451	8.9 ± 6.1	2.0 ± 0.1	568.6682 ± 2.4146	0.5646	0.5490	0.0529	0.0012	0.5643	0.1802± 0.1602
3.6789	9.1 ± 3.7	0.2 ± 0.0	49.1467 ± 0.7153	0.5714	0.5661	1.6603	0.0021	0.5714	2.6809± 1.1107
3.6799	10.7 ± 4.1	0.2 ± 0.0	46.5151 ± 0.6954	0.5716	0.5665	2.3268	0.0021	0.5716	3.3414± 1.3001
3.6809	15.3 ± 4.8	0.2 ± 0.0	49.5699 ± 0.7180	0.5718	0.5670	3.7884	0.0022	0.5718	4.4987± 1.4282
3.6818	20.6 ± 5.5	0.2 ± 0.0	52.1996 ± 0.7368	0.5720	0.5674	8.1814	0.0022	0.5720	5.7637± 1.5540
3.6822	49.4 ± 8.0	0.2 ± 0.0	50.9609 ± 0.7277	0.5720	0.5676	13.1367	0.0022	0.5720	14.2313± 2.3215
3.6826	80.1 ± 9.8	0.2 ± 0.0	51.1923 ± 0.7287	0.5721	0.5677	22.2338	0.0023	0.5721	22.9926± 2.8380
3.6834	219.8 ± 16.0	0.2 ± 0.0	51.7823 ± 0.7309	0.5723	0.5680	64.1992	0.0023	0.5723	62.4359± 4.6330
3.6840	469.1 ± 22.9	0.2 ± 0.0	50.6911 ± 0.7202	0.5724	0.5683	128.2829	0.0023	0.5724	138.1535± 6.9246
3.6846	776.3 ± 29.8	0.2 ± 0.0	48.7171 ± 0.7040	0.5725	0.5685	222.0155	0.0024	0.5725	234.4403± 9.6178
3.6848	854.0 ± 31.4	0.1 ± 0.0	39.8739 ± 0.6365	0.5725	0.5686	267.1420	0.0024	0.5725	315.1202± 12.6328
3.6854	1039.2 ± 33.8	0.1 ± 0.0	38.0340 ± 0.6197	0.5726	0.5689	356.6788	0.0024	0.5726	401.9508± 14.6235
3.6860	1097.4 ± 34.8	0.1 ± 0.0	41.1700 ± 0.6458	0.5727	0.5691	416.1883	0.0024	0.5727	392.0602± 13.8720
3.6866	1065.4 ± 33.6	0.1 ± 0.0	40.1444 ± 0.6402	0.5728	0.5694	409.2658	0.0025	0.5728	388.6200± 13.7678
3.6873	878.6 ± 30.5	0.1 ± 0.0	40.6680 ± 0.6480	0.5729	0.5696	327.2611	0.0025	0.5729	317.6458± 12.1345
3.6874	828.2 ± 29.6	0.1 ± 0.0	40.0998 ± 0.6440	0.5729	0.5697	311.8015	0.0025	0.5729	303.6685± 11.9000
3.6890	302.3 ± 18.6	0.1 ± 0.0	40.6698 ± 0.6540	0.5732	0.5703	100.3777	0.0026	0.5732	109.1996± 6.9474
3.6920	73.0 ± 9.8	0.1 ± 0.0	41.5815 ± 0.6621	0.5737	0.5716	26.2155	0.0028	0.5737	25.7451± 3.4868
3.6964	49.5 ± 8.1	0.2 ± 0.0	49.6530 ± 0.7243	0.5744	0.5732	14.3660	0.0031	0.5744	14.5745± 2.4021
3.7002	32.5 ± 6.4	0.2 ± 0.0	50.7208 ± 0.7329	0.5750	0.5746	10.4916	0.0034	0.5750	9.3414± 1.8537
3.7055	22.9 ± 5.5	0.2 ± 0.0	60.4078 ± 0.8006	0.5759	0.5764	7.6777	0.0039	0.5759	5.4995± 1.3339

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Number of events & Cross Sections

Table 3 – continued from previous page

E_{cm} (GeV)	$N^{obs}_{J/\psi X}$	N^{obs}_{BCK}	$\mathcal{L}$ (nb^{-1})	$\varepsilon^{\psi(3686)}_{J/\psi X}$	$\varepsilon^{\psi(3770)}_{J/\psi X}$	$\sigma^{\psi(3686)}_{J/\psi X}$	$\sigma^{\psi(3770)}_{J/\psi X}$	$\varepsilon_{J/\psi X}$	σ (nb)
3.7136	44.6 ± 7.8	0.3 ± 0.0	106.1170 ± 1.0643	0.5771	0.5791	5.4790	0.0049	0.5771	6.0902± 1.0748
3.7215	41.8 ± 7.7	0.4 ± 0.0	136.0553 ± 1.2068	0.5781	0.5814	4.2963	0.0063	0.5781	4.4327± 0.8257
3.7296	74.7 ± 10.1	0.7 ± 0.0	229.2306 ± 1.5703	0.5792	0.5837	3.5229	0.0086	0.5792	4.6961± 0.6417
3.7368	113.6 ± 13.0	1.5 ± 0.1	494.1513 ± 2.3094	0.5801	0.5855	3.0389	0.0117	0.5801	3.2954± 0.3824
3.7454	213.4 ± 17.7	2.8 ± 0.2	955.3906 ± 3.2190	0.5810	0.5874	2.6113	0.0181	0.5810	3.1963± 0.2688
3.7470	287.8 ± 20.7	4.1 ± 0.3	1409.9951 ± 3.9121	0.5812	0.5878	2.5447	0.0199	0.5813	2.9163± 0.2129
3.7493	391.3 ± 24.7	6.6 ± 0.5	2278.7526 ± 4.9773	0.5815	0.5883	2.4547	0.0228	0.5816	2.4456± 0.1571
3.7508	540.0 ± 29.0	8.6 ± 0.6	2979.2289 ± 5.6927	0.5816	0.5886	2.3994	0.0250	0.5817	2.5834± 0.1411
3.7530	611.3 ± 31.0	9.5 ± 0.7	3317.8297 ± 6.0108	0.5819	0.5890	2.3227	0.0288	0.5820	2.6255± 0.1353
3.7544	563.7 ± 30.0	9.8 ± 0.7	3426.9142 ± 6.1112	0.5820	0.5893	2.2763	0.0317	0.5821	2.3392± 0.1268
3.7558	691.0 ± 33.2	11.1 ± 0.8	3883.0165 ± 6.5083	0.5821	0.5895	2.2318	0.0348	0.5822	2.5336± 0.1238
3.7587	769.2 ± 34.7	12.7 ± 0.9	4451.5534 ± 6.9739	0.5824	0.5901	2.1448	0.0428	0.5826	2.4577± 0.1128
3.7617	716.4 ± 34.0	12.7 ± 0.9	4503.1526 ± 7.0189	0.5827	0.5906	2.0617	0.0530	0.5829	2.2584± 0.1092
3.7645	469.6 ± 27.8	9.3 ± 0.7	3292.6249 ± 6.0069	0.5830	0.5911	1.9896	0.0642	0.5833	2.0194± 0.1220
3.7674	327.5 ± 23.3	6.9 ± 0.5	2448.9506 ± 5.1843	0.5832	0.5916	1.9201	0.0764	0.5835	1.8904± 0.1374
3.7702	243.1 ± 20.3	5.6 ± 0.4	2021.5679 ± 4.7135	0.5835	0.5920	1.8574	0.0865	0.5839	1.6949± 0.1449
3.7731	214.4 ± 19.5	5.1 ± 0.4	1831.6311 ± 4.4906	0.5837	0.5924	1.7966	0.0920	0.5841	1.6483± 0.1536
3.7760	245.9 ± 20.0	5.0 ± 0.4	1829.4733 ± 4.4909	0.5840	0.5928	1.7393	0.0914	0.5844	1.8978± 0.1577
3.7789	277.0 ± 21.2	5.4 ± 0.4	1956.8374 ± 4.6491	0.5842	0.5932	1.6858	0.0839	0.5846	2.0004± 0.1562
3.7818	283.9 ± 21.6	5.9 ± 0.4	2156.7390 ± 4.8840	0.5844	0.5935	1.6354	0.0735	0.5848	1.8571± 0.1443
3.7847	327.6 ± 23.2	6.9 ± 0.5	2556.7382 ± 5.3213	0.5847	0.5939	1.5879	0.0627	0.5850	1.8060± 0.1307
3.7873	364.8 ± 24.7	7.7 ± 0.5	2840.9075 ± 5.6136	0.5849	0.5942	1.5475	0.0540	0.5852	1.8097± 0.1262
3.7915	430.6 ± 26.9	9.5 ± 0.7	3542.7657 ± 6.2762	0.5852	0.5946	1.4864	0.0426	0.5855	1.7104± 0.1093
3.7952	484.5 ± 28.5	10.8 ± 0.8	4060.9293 ± 6.7263	0.5854	0.5950	1.4363	0.0351	0.5856	1.6780± 0.1010
3.7989	408.0 ± 27.5	10.4 ± 0.7	3941.2619 ± 6.6322	0.5856	0.5953	1.3896	0.0293	0.5858	1.4508± 0.1004
3.8030	266.0 ± 22.5	7.1 ± 0.5	2701.8225 ± 5.4977	0.5859	0.5957	1.3409	0.0245	0.5861	1.3775± 0.1197
3.8068	168.5 ± 18.2	4.6 ± 0.3	1765.8710 ± 4.4484	0.5861	0.5960	1.2987	0.0211	0.5863	1.3338± 0.1481
3.8099	121.8 ± 14.9	3.3 ± 0.2	1258.1692 ± 3.7580	0.5863	0.5962	1.2661	0.0188	0.5864	1.3535± 0.1702
3.8128	87.9 ± 12.8	2.3 ± 0.2	899.8812 ± 3.1812	0.5865	0.5964	1.2371	0.0170	0.5866	1.3657± 0.2043
3.8160	56.5 ± 11.1	1.8 ± 0.1	682.4762 ± 2.7732	0.5866	0.5966	1.2065	0.0154	0.5867	1.1519± 0.2336
3.8240	31.4 ± 7.8	1.0 ± 0.1	400.9534 ± 2.1299	0.5870	0.5970	1.1360	0.0123	0.5871	1.0877± 0.2792
3.8319	45.2 ± 8.2	0.7 ± 0.1	285.5685 ± 1.8016	0.5874	0.5972	1.0738	0.0101	0.5875	2.2340± 0.4120
3.8400	22.1 ± 6.5	0.7 ± 0.0	281.1397 ± 1.7910	0.5877	0.5974	1.0165	0.0086	0.5878	1.0914± 0.3315
3.8479	19.7 ± 6.1	0.7 ± 0.0	277.4507 ± 1.7823	0.5879	0.5975	0.9659	0.0074	0.5880	0.9826± 0.3151
3.8561	16.4 ± 5.8	0.8 ± 0.1	319.9245 ± 1.9191	0.5881	0.5976	0.9182	0.0065	0.5882	0.6999± 0.2597
3.8640	14.9 ± 5.5	0.7 ± 0.1	301.2150 ± 1.8657	0.5883	0.5975	0.8764	0.0057	0.5884	0.6744± 0.2615
3.8719	36.1 ± 8.1	1.2 ± 0.1	514.1173 ± 2.4421	0.5885	0.5974	0.8379	0.0052	0.5886	0.9717± 0.2256
3.8809	14.4 ± 5.0	0.4 ± 0.0	190.1108 ± 1.4884	0.5886	0.5972	0.7979	0.0046	0.5886	1.0611± 0.3765
3.8909	8.2 ± 4.4	0.4 ± 0.0	183.4354 ± 1.4658	0.5887	0.5970	0.7574	0.0041	0.5887	0.6073± 0.3433
3.6474	28.3 ± 12.5	8.1 ± 0.6	2260.9186 ± 4.8176	0.5651	0.5504	0.0591	0.0012	0.5648	0.1336± 0.0826
3.6534	21.1 ± 12.0	7.8 ± 0.6	2217.7081 ± 4.7789	0.5664	0.5537	0.0819	0.0013	0.5662	0.0893± 0.0806
3.7269	239.4 ± 18.7	2.7 ± 0.2	896.5586 ± 3.1023	0.5788	0.5829	3.7473	0.0077	0.5788	3.8425± 0.3039
3.7359	63.6 ± 10.3	1.0 ± 0.1	337.7342 ± 1.9090	0.5800	0.5853	3.0919	0.0112	0.5800	2.6921± 0.4432
3.7379	87.1 ± 11.3	1.0 ± 0.1	329.6546 ± 1.8872	0.5802	0.5857	2.9765	0.0123	0.5802	3.7934± 0.4962
3.6500	183.4 ± 54.8	157.5 ± 11.3	44490.0000 ± 20.0000	0.5657	0.5518	0.0675	0.0013	0.5654	0.0087± 0.0184
3.7730	124069.9 ± 479.6	2568.8 ± 184.2	927670.0000 ±100.0000	0.5837	0.5924	1.7986	0.0920	0.5841	1.8890± 0.0075
3.6861	4593716.1 ± 2311.3	533.9 ± 38.3	162800.0000 ± 10.0000	0.5727	0.5692	419.9274	0.0024	0.5727	415.0318± 0.2104

Systematic Uncertainty

Source	Systematic uncertainty (%)
$\theta_{\ell^+\ell^-} < 179^\circ$ cut	0.0
$\lvert\cos\theta_\ell\rvert < 0.81$ cut	0.4
E_{EMC}/p cut	0.3
Momentum cut	0.2
N_{good} and N_γ cut	0.4
Fit to $M_{\ell^+\ell^-}$ spectrum	1.5
MC modeling	0.9
π identification	1.0
$\mathcal{B}(J/\psi \to \ell^+\ell^-)$	0.4
Background subtraction $N_{\mathrm{BCK}}^{\mathrm{obs}}$	< 0.1
Luminosity	1.0
Total	2.4

Expected-Observed Cross Section

$$\sigma_{J/\psi X}^{\text{expected}}(s) = \int_0^\infty ds' G(s,s') \int_0^{x_{\max}} dx\, F(x,s)\, \sigma^{\text{dress}}(s(1-x))$$

$\sigma^{\text{dress}}(s)$ is dressed cross section

$$x = 1 - \frac{s'}{s}$$

Effective c.m. energy

Nominal c.m. energy

$$G(s,s') = \frac{1}{\sqrt{2\pi}\sigma_{E_{\text{BEPC-II}}}} \exp\left[-\frac{(\sqrt{s}-\sqrt{s'})^2}{2\sigma_{E_{\text{BEPC-II}}}^2} \right]$$

$F(x,s)$ *is sampling function*

Kuraev & Fadin

$$F(x,s) = \beta x^{\beta-1}\delta^{V+S} + \delta^{H}$$

$$\beta = \frac{2\alpha}{\pi}\left(\ln\frac{s}{m_e^2} - 1 \right)$$

$$\delta^{V+S} = 1 + \frac{3}{4}\beta + \frac{\alpha}{\pi}\left(\frac{\pi^2}{3} - \frac{1}{2} \right) - \frac{\beta^2}{24}\left(\frac{1}{3}\ln\frac{s}{m_e^2} + 2\pi^2 - \frac{37}{4} \right)$$

$$\delta^H = \delta_1^H + \delta_2^H \qquad \delta_1^H = -\beta\left(1 - \frac{x}{2}\right)$$

$$\delta_2^H = \frac{1}{8}\beta^2\left[4(2-x)\ln\frac{1}{x} - \frac{1+3(1-x)^2}{x}\ln(1-x) - 6 - x \right]$$

Amplitude Analysis

$$\sigma^{\mathrm{Dress}}_{J/\psi\, X}(s) = \left| A_{\psi(3686)} + e^{i\phi 1} A_1 + e^{i\phi 2} A_2 + \ldots \right|^2$$

A $_{\psi(3686)}$ is BW amplitude for ψ(3686)→J/ψ X decays

A_1, A_2, … are other BW amplitudes for structures S→J/ψ X decays

φ1, φ2, … **are relative phase of the amplitudes**

χ^2 fit to the observed cross sections

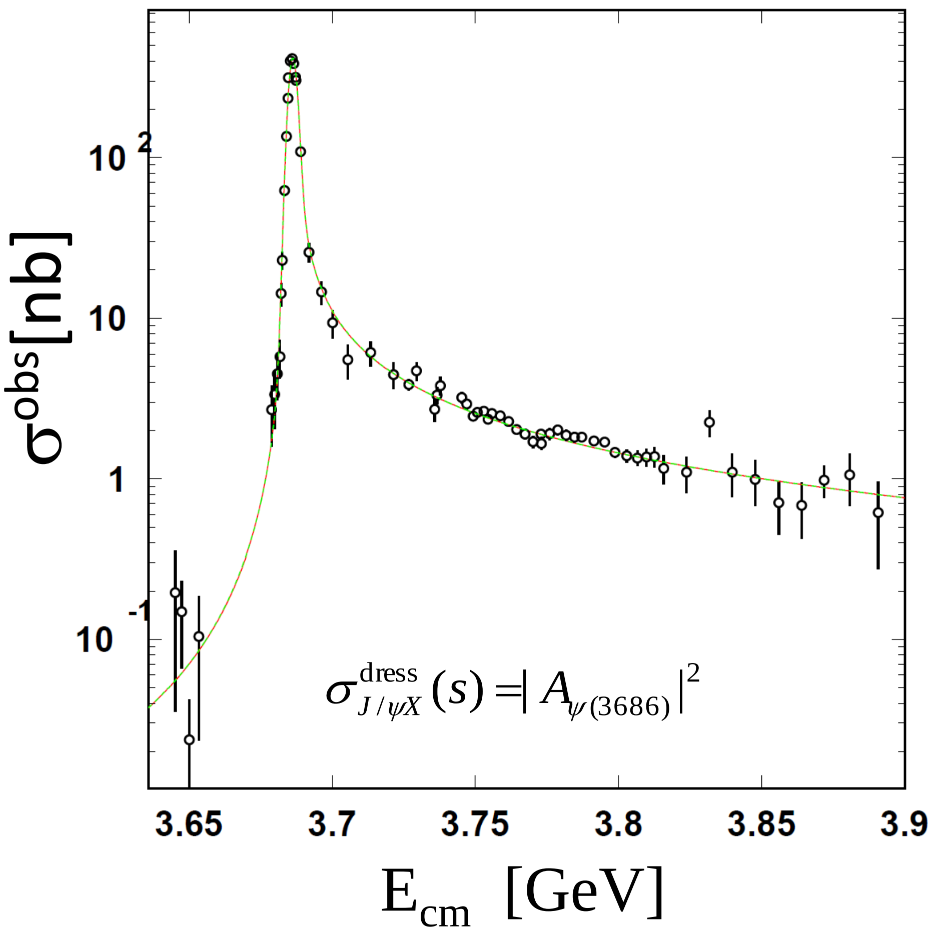
$$\chi^2 = \sum_{i=1}^{n} \left[\frac{\sigma^{obs}_{J/\psi\, X}(s)_i - \sigma^{\mathrm{expected}}_{J/\psi\, X}(s)_i}{\Delta_{\sigma^{obs}_{J/\psi\, X}}(s)_i} \right]^2$$

$\sigma^{\mathrm{expected}}_{J/\psi X}(s)$ **is the expected cross sections**

Fit the Observed Cross Sections

- **Hypotheses #1**

  Assuming that there is ψ(3686) only



Our measurements :

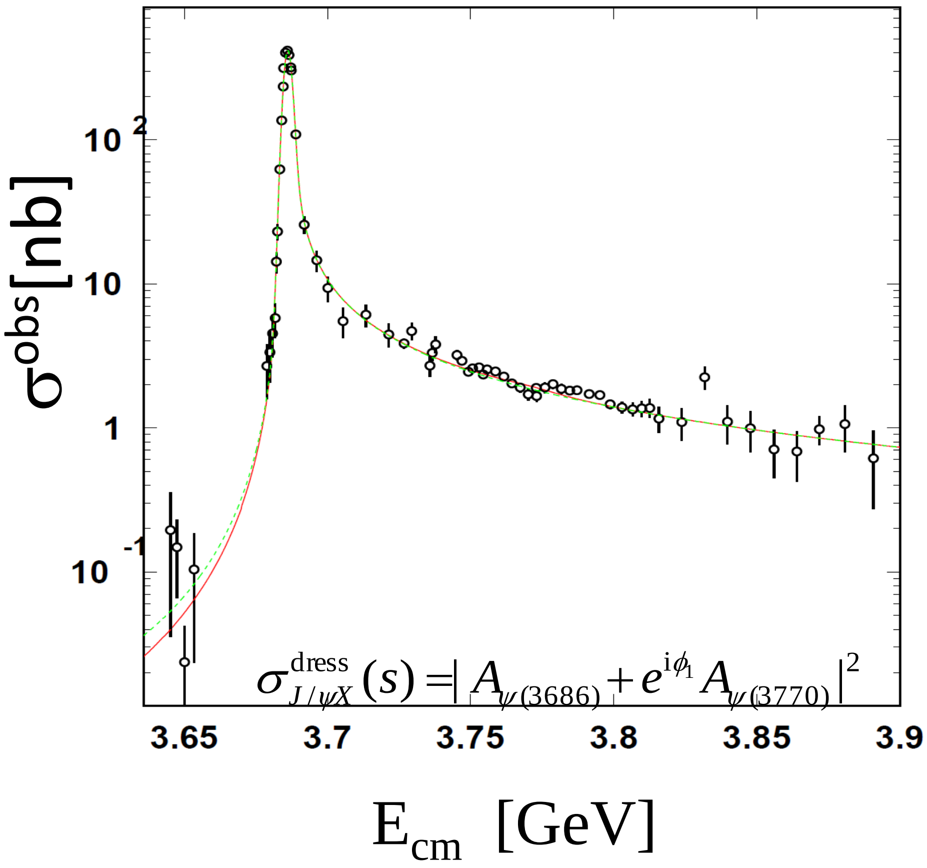
B[ψ(3686)→J/ψ X]=
(66.69±0.239±1.60±1.12)%

Parameter	Solution
χ^2	128.326
$n_{\text{pnts}} - n_{\text{PRMT}}$	$68 - 3 = 65$
Energy Spread [MeV]	$1.4382 \pm 0.006 \pm 0.003$
$M_{\psi(3686)}$ [MeV/c^2]	$3686.10 \pm 0.02 \pm 0.01 \pm 0.00$
$\Gamma^{ee}_{\psi(3686)}$ [keV/c^2]	2.34
$\psi^{\text{tot}}_{\psi(3686)}$ [keV]	296
$B(\psi(3686) \to J/\psi X)$ [%]	$66.69 \pm 0.239 \pm 1.60 \pm 1.12$

Fit the Observed Cross Sections

- **Hypotheses #2**

Assuming that there are ψ(3686) and ψ(3770) only



Our measurements :

B[ψ(3686)→J/ψ X]= (64.26±0.40±1.51±1.08)%

B[ψ(3770)→J/ψ X]= (1.21±0.83±0.03±0.00)%

ϕ_1 = (-168.3 ±51.0 ±0.0±0.3)°

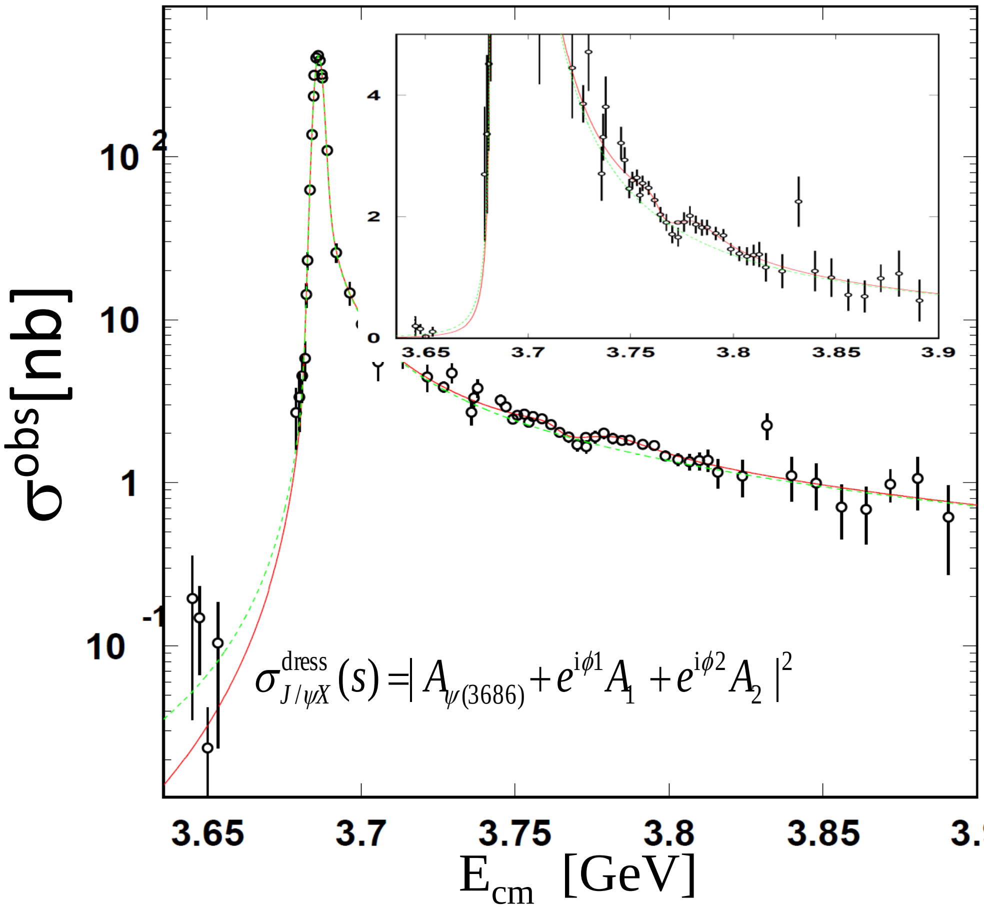
Summing over the known Bfs for exclusive modes given in PDG yields

B[ψ(3770)→J/ψ X]= (1.4±0.1)%

Fit the Observed Cross Sections

➢ **Hypotheses #3**

Assuming that there are ψ(3686), S_1(3760) and S_2(3780)

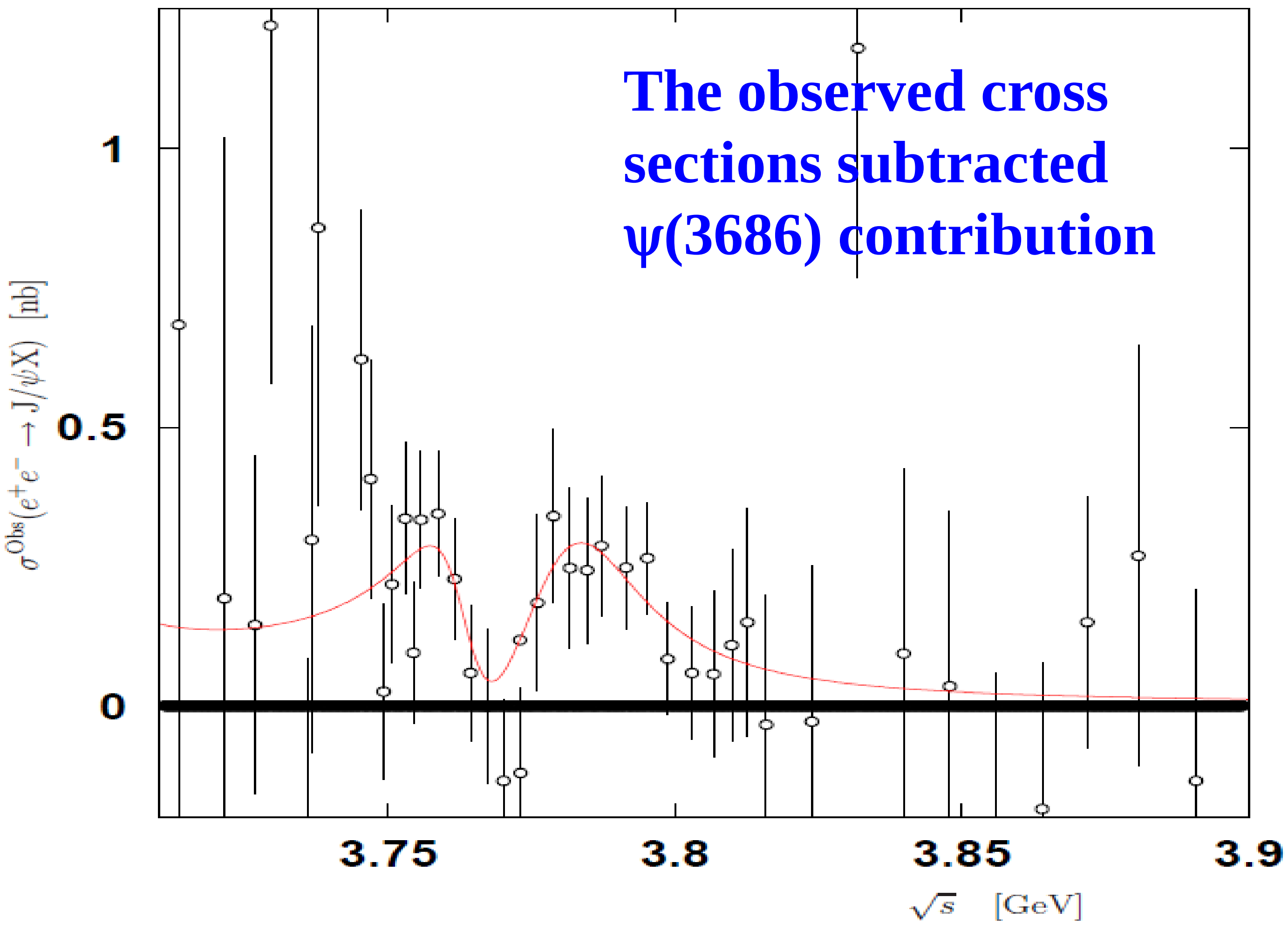


Parameter	Solution1
χ^2	76.497
$n_{pnts} - n_{PRMT}$	$68 - 11 = 57$
Energy Spread [MeV]	$1.352 \pm 0.017 \pm 0.000$ ± 0.003
$M_{\psi(3686)}$ [MeV/c^2]	$3686.00 \pm 0.03 \pm 0.00$ ± 0.00
$\Gamma^{ee}_{\psi(3686)}$ [keV/c^2]	2.34
$\psi^{tot}_{\psi(3686)}$ [keV]	296
$B(\psi(3686) \rightarrow J/\psi X)$ [%]	$62.88 \pm 0.84 \pm 1.51$ ± 0.15
$M_{s(3760)}$ [MeV/c^2]	$3763.5 \pm 5.5 \pm 0.1$ ± 0.4
$\Gamma^{ee}_{s(3760)}$ [keV/c^2]	0.186
$\Gamma^{tot}_{s(3760)}$ [MeV]	$12.8 \pm 12.3 \pm 0.1$ ± 0.4
$B[s(3760) \rightarrow J/\psi X]$ [%]	$4.96 \pm 10.19 \pm 0.17$ ± 0.30
ϕ_1 [degree]	$233.9 \pm 61.3 \pm 1.2$ ± 4.5
$M_{s(3780)}$ [MeV/c^2]	$3780.7 \pm 10.9 \pm 0.1$ ± 0.4
$\Gamma^{ee}_{s(3780)}$ [keV/c^2]	0.243
$\Gamma^{tot}_{s(3780)}$ [MeV]	$27.7 \pm 12.7 \pm 0.1$ ± 0.2
$B[s(3780) \rightarrow J/\psi X]$ [%]	$7.77 \pm 10.40 \pm 0.41$ ± 0.20
ϕ_2 [degree]	$128.7 \pm 108.7 \pm 0.1$ ± 6.4

PDG: B[ψ(3686)→J/ψ X]= (60.9±0.6)%

The signal significance of the Di-structure(s) decay into J/ψ X is more than 4σ [from analyzing the observed cross sections]

Fit the Observed Cross Sections



Four Solutions

Parameter	Solution1	Solution2	Solution3	Solution4
χ^2	76.497	76.497	76.641	76.600
$n_{\text{pnts}} - n_{\text{PRMT}}$	$68 - 11 = 57$	$68 - 11 = 57$	$68 - 11 = 57$	$68 - 11 = 57$
Energy Spread [MeV]	$1.352 \pm 0.017 \pm 0.000 \pm 0.003$	$1.351 \pm 0.017 \pm 0.006 \pm 0.003$	$1.351 \pm 0.020 \pm 0.006 \pm 0.003$	$1.350 \pm 0.019 \pm 0.006 \pm 0.003$
$\mathrm{M}_{\psi(3686)}$ [MeV/c^2]	$3686.00 \pm 0.03 \pm 0.00 \pm 0.00$	$3686.00 \pm 0.03 \pm 0.00 \pm 0.00$	$3686.00 \pm 0.03 \pm 0.00 \pm 0.00$	$3686.0 \pm 0.01 \pm 0.00 \pm 0.00$
$\Gamma^{ee}_{\psi(3686)}$ [keV/c^2]	2.34	2.34	2.34	2.34
$\psi^{tot}_{\psi(3686)}$ [keV]	296	296	296	296
$B(\psi(3686) \to \mathrm{J}/\psi\mathrm{X})$ [%]	$62.88 \pm 0.84 \pm 1.51 \pm 0.15$	$63.06 \pm 0.70 \pm 1.51 \pm 0.15$	$62.76 \pm 0.89 \pm 1.51 \pm 0.15$	$63.07 \pm 0.72 \pm 1.51 \pm 0.15$
$\mathrm{M}_{s(3760)}$ [MeV/c^2]	$3763.5 \pm 5.5 \pm 0.1 \pm 0.4$	$3763.5 \pm 5.7 \pm 0.1 \pm 0.4$	$3767.5 \pm 6.0 \pm 0.1 \pm 0.4$	$3766.1 \pm 13.6 \pm 0.1 \pm 0.4$
$\Gamma^{ee}_{s(3760)}$ [keV/c^2]	0.186	0.186	0.186	0.186
$\Gamma^{tot}_{s(3760)}$ [MeV]	$12.8 \pm 12.3 \pm 0.1 \pm 0.4$	$12.8 \pm 12.5 \pm 0.1 \pm 0.4$	$20.1 \pm 8.4 \pm 0.1 \pm 0.4$	$18.3 \pm 11.5 \pm 0.1 \pm 0.4$
$B[s(3760) \to \mathrm{J}/\psi\mathrm{X}]$ [%]	$4.96 \pm 10.19 \pm 0.17 \pm 0.30$	$5.52 \pm 12.62 \pm 0.17 \pm 0.30$	$38.94 \pm 57.44 \pm 0.17 \pm 2.40$	$21.48 \pm 51.58 \pm 0.17 \pm 1.34$
ϕ_1 [degree]	$233.9 \pm 61.3 \pm 1.2 \pm 4.5$	$-88.4 \pm 103.1 \pm 1.2 \pm 1.7$	$-105.3.1 \pm 139.0 \pm 1.2 \pm 2.0$	$-52.2 \pm 206.3 \pm 1.2 \pm 1.0$
$\mathrm{M}_{s(3780)}$ [MeV/c^2]	$3780.7 \pm 10.9 \pm 0.1 \pm 0.4$	$3780.7 \pm 11.1 \pm 0.1 \pm 0.4$	$3773.7 \pm 5.9 \pm 0.1 \pm 0.4$	$3775.6 \pm 17.1 \pm 0.1 \pm 0.4$
$\Gamma^{ee}_{s(3780)}$ [keV/c^2]	0.243	0.243	0.243	0.243
$\Gamma^{tot}_{s(3780)}$ [MeV]	$27.7 \pm 12.7 \pm 0.1 \pm 0.2$	$27.7 \pm 12.8 \pm 0.1 \pm 0.2$	$29.1 \pm 19.1 \pm 0.1 \pm 0.2$	$29.1 \pm 25.3 \pm 0.1 \pm 0.2$
$B[s(3780) \to \mathrm{J}/\psi\mathrm{X}]$ [%]	$7.77 \pm 10.40 \pm 0.41 \pm 0.20$	$9.50 \pm 25.80 \pm 0.41 \pm 0.24$	$41.78 \pm 33.50 \pm 0.41 \pm 1.07$	$27.78 \pm 27.19 \pm 0.41 \pm 0.71$
ϕ_2 [degree]	$128.7 \pm 108.7 \pm 0.1 \pm 6.4$	$173.0 \pm 56.8 \pm 0.1 \pm 8.7$	$99.3 \pm 94.3 \pm 0.1 \pm 5.0$	$172.0 \pm 70.3 \pm 0.1 \pm 8.6$

Comparison with BES-II Result

BES-III $e^+e^- \to J/\psi\ X$

$M_1 = 3763.5 \pm 5.5 \pm 0.4$ MeV

$\Gamma_1 = 12.8 \pm 12.3 \pm 0.4$ MeV

$M_2 = 3780.7 \pm 10.9 \pm 4.7$ MeV

$\Gamma_2 = 27.7 \pm 12.7 \pm 0.2$ MeV

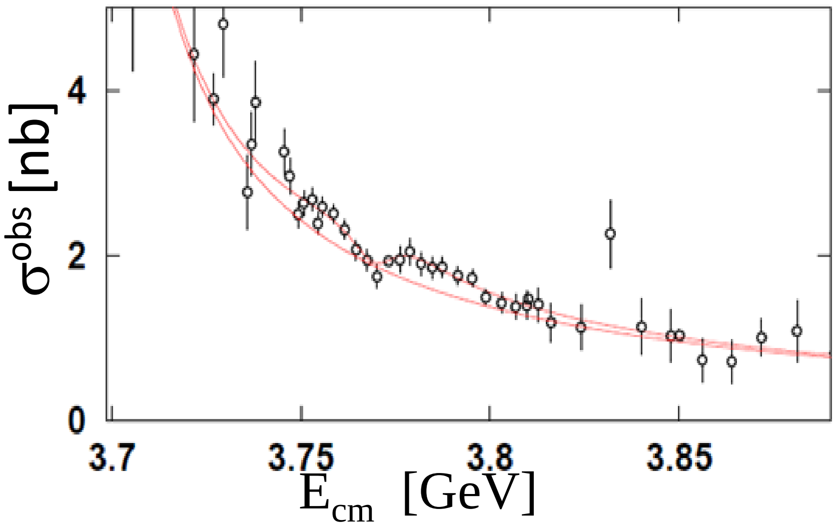
BES-II $e^+e^- \to$ hadrons

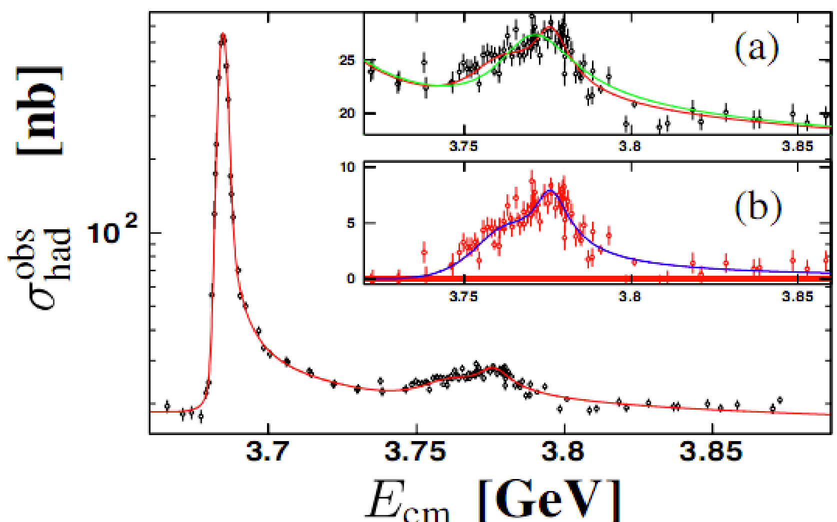
$M_1 = 3762.6 \pm 11.8 \pm 0.5$ MeV

$\Gamma_1 = 49.9 \pm 32.1 \pm 0.1$ MeV

$M_2 = 3781.0 \pm 1.3 \pm 0.5$ MeV

$\Gamma_2 = 19.3 \pm 3.1 \pm 0.1$ MeV





PRL 101, 102004(2008)

This J/ψX result confirms (at ~4.5 σ) the BES-II observation of Di-Structure Rs(3770) in the range from 3.71 to 3.87 GeV.

Conclusion

- We measured the observed cross sections for $e^+e^- \rightarrow J/\psi\ X$ in range from 3.645 to 3.87 GeV.

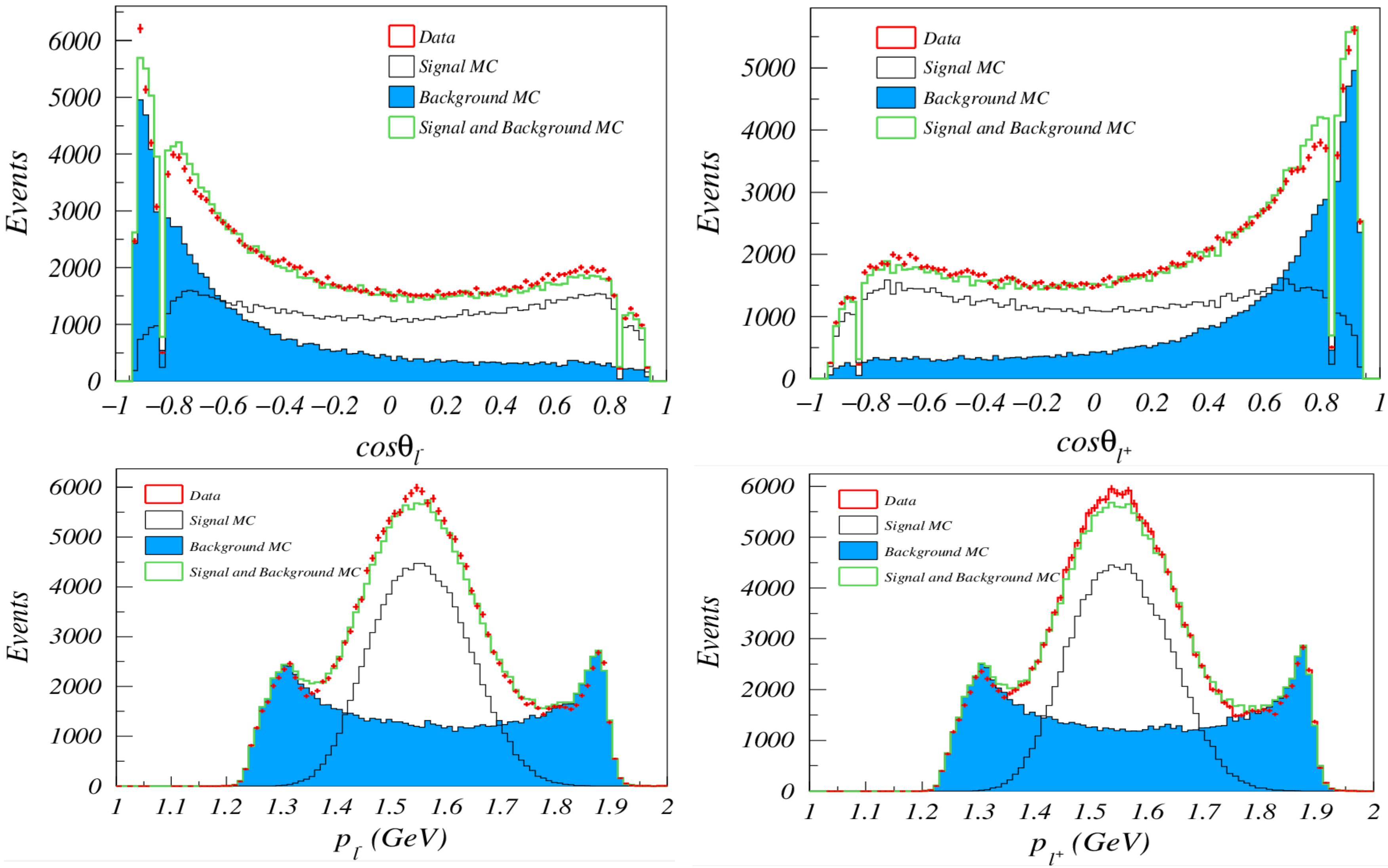
- To well describe the line-shape of these observed cross sections, needing one more BW amplitude additional $\psi(3770)$.

- We observed the Di-Structures "S(3760)+S(3780)" in $J/\psi\ X$ (X=anything) final states, and the parameters of the Di-structure are consistent within errors with those measured at BES-II.

BES-III $e^+e^- \rightarrow J/\psi\ X$	BES-II $e^+e^- \rightarrow$ hadrons
$M_1 = 3763.5 \pm 5.5 \pm 0.4$ MeV	$M_1 = 3762.6 \pm 11.8 \pm 0.5$ MeV
$\Gamma_1 = 12.8 \pm 12.3 \pm 0.4$ MeV	$\Gamma_1 = 49.9 \pm 32.1 \pm 0.1$ MeV
$M_2 = 3780.7 \pm 10.9 \pm 4.7$ MeV	$M_2 = 3781.0 \pm 1.3 \pm 0.5$ MeV
$\Gamma_2 = 27.7 \pm 12.7 \pm 0.2$ MeV	$\Gamma_2 = 19.3 \pm 3.1 \pm 0.1$ MeV

Thank You!

Comparison of Data and Monte Carlo



Systematic Uncertainty

Selection of $\ell^+\ell^-$

Sources

1. Uncertainty in angle cut ($\theta_{\ell^+\ell^-} < 179°$) for the leptons
2. Uncertainty in polar angle cut ($|\cos\theta_\ell| < 0.81$) for the charged tracks
3. Uncertainty in lepton PID

   $e^{\pm}$ $E_{\mathrm{EMC}}/p > 0.7$

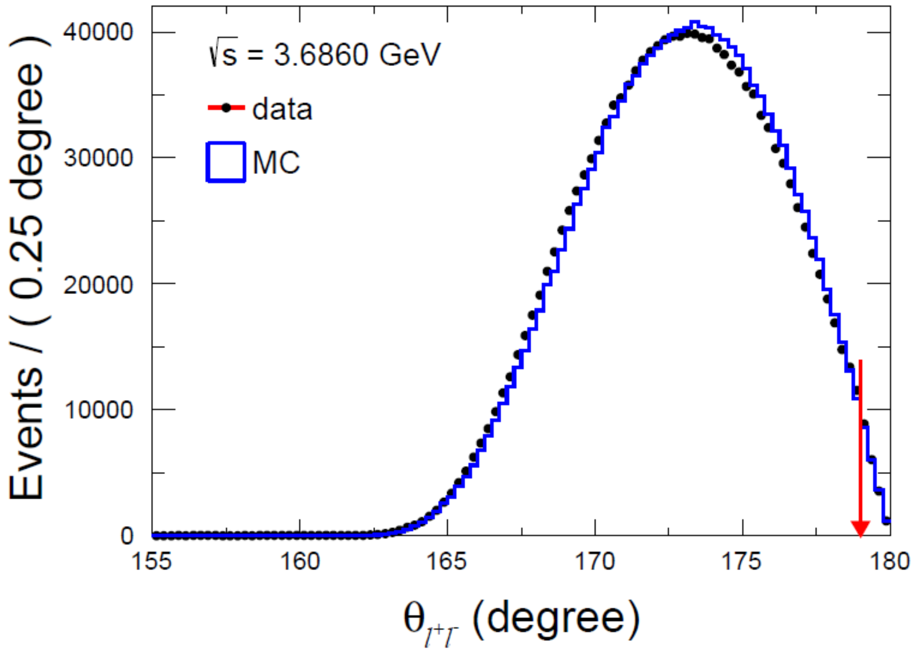
   $\mu^{\pm}$ $0.05 < E_{\mathrm{EMC}}/p < 0.35$
4. Uncertainty in momentum cut ($1.0 < p < 0.47 \times E_{\mathrm{cm}}$)

Mehtod

- *Compare the corresponding efficiencies for data and MC events, which are measured using the lepton samples selected from the $\psi(3686) \to \pi^+\pi^- J/\psi$, $J/\psi \to \ell^+\ell^-$ process*

Systematic Uncertainty

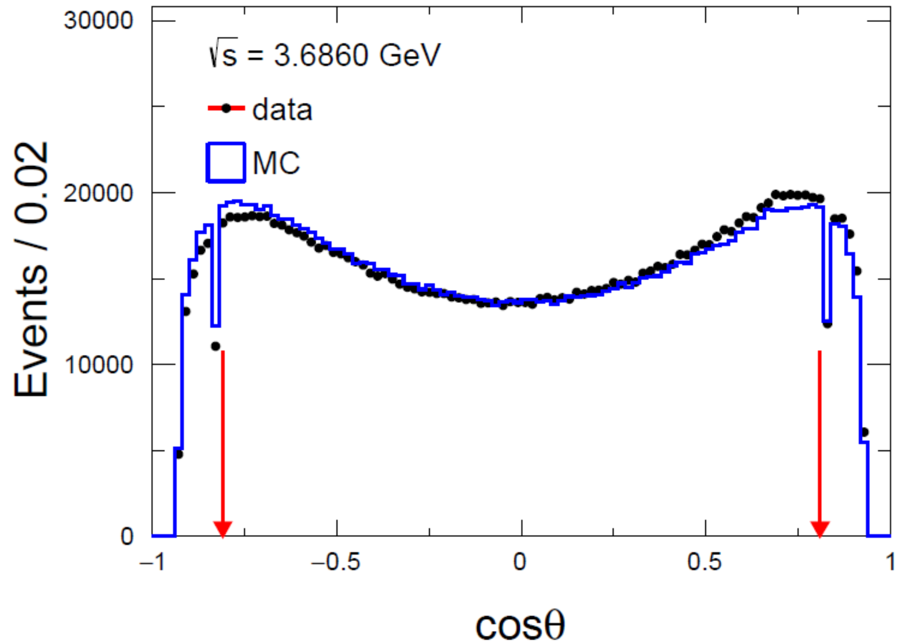
$\theta_{\ell^+\ell^-} < 179^\circ$ Cut



	$N_{\rm tot}$	$N_{\rm cut}$	$R \equiv N_{\rm cut}/N_{\rm tot}$
data	1456805	1437505	0.9868 ± 0.0001
MC	1322668	1305311	0.9869 ± 0.0001
$R_{\rm data}/R_{\rm MC} - 1$	$(-0.01 \pm 0.01)\%$		

Systematic Uncertainty

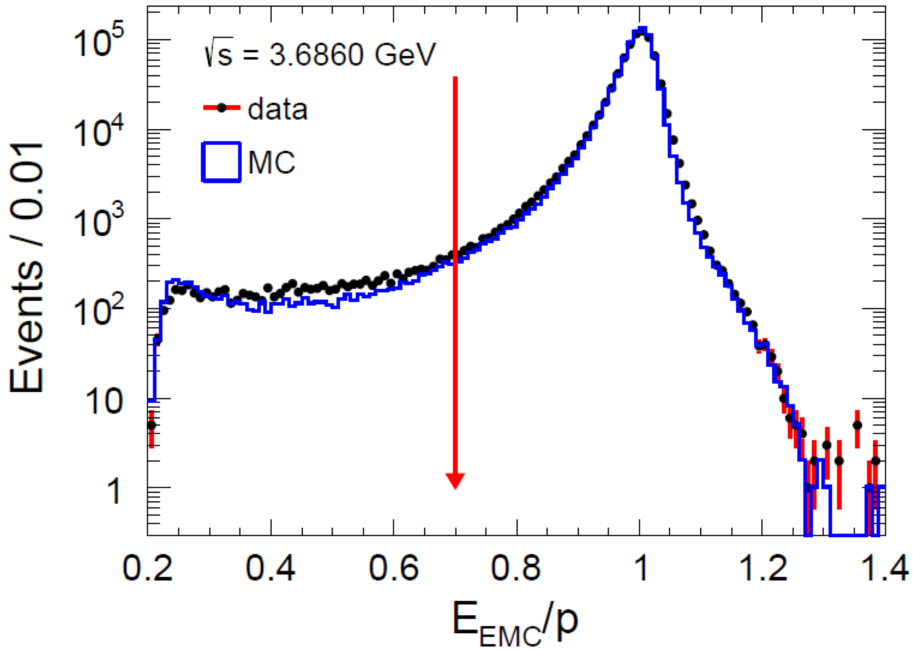
$|\cos\theta_\ell| < 0.81$ Cut



	N_{tot}	N_{cut}	$R \equiv N_{\text{cut}}/N_{\text{tot}}$
data	1456805	1259484	0.8646 ± 0.0003
MC	1322668	1139355	0.8614 ± 0.0003
$R_{\text{data}}/R_{\text{MC}} - 1$	$(0.37 \pm 0.05)\%$		

Systematic Uncertainty

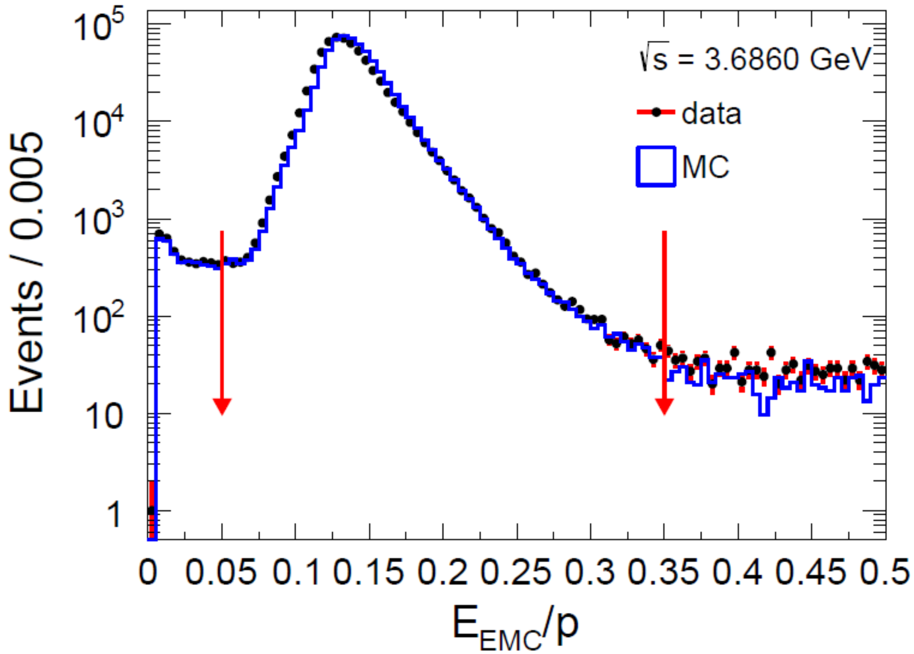
$e^{\pm}$ PID



	N_{tot}	N_{cut}	$R \equiv N_{\mathrm{cut}}/N_{\mathrm{tot}}$
data	803718	786977	0.9792 ± 0.0002
MC	783994	770110	0.9823 ± 0.0001
$R_{\mathrm{data}}/R_{\mathrm{MC}} - 1$	$(-0.32 \pm 0.02)\%$		

Systematic Uncertainty

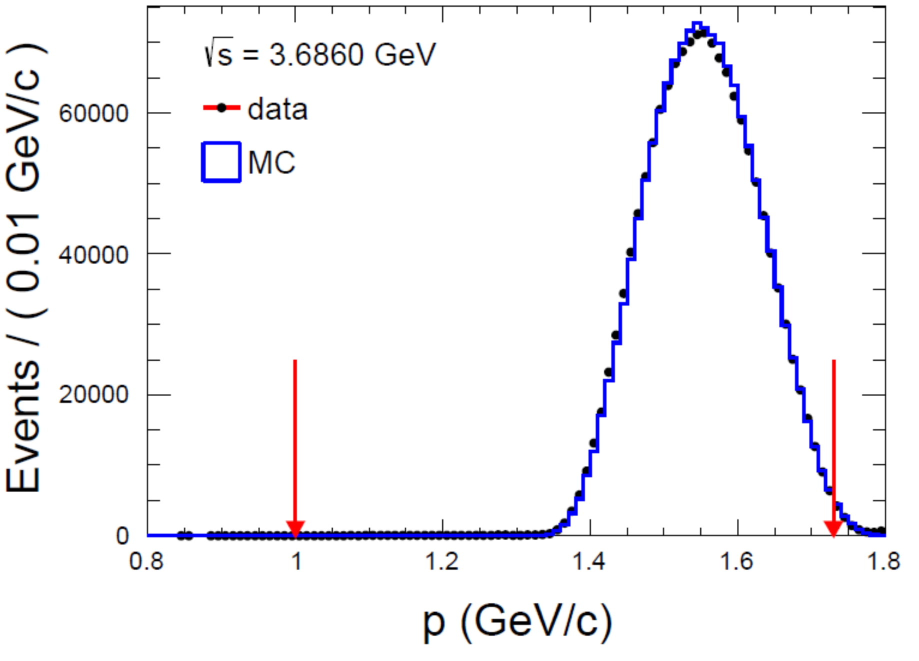
$\mu^{\pm}$ PID



	N_{tot}	N_{cut}	$R \equiv N_{\mathrm{cut}}/N_{\mathrm{tot}}$
data	653087	644969	0.9876 ± 0.0001
MC	538674	532596	0.9887 ± 0.0001
$R_{\mathrm{data}}/R_{\mathrm{MC}} - 1$	$(-0.12 \pm 0.02)\%$		

Systematic Uncertainty

Momentum Cut

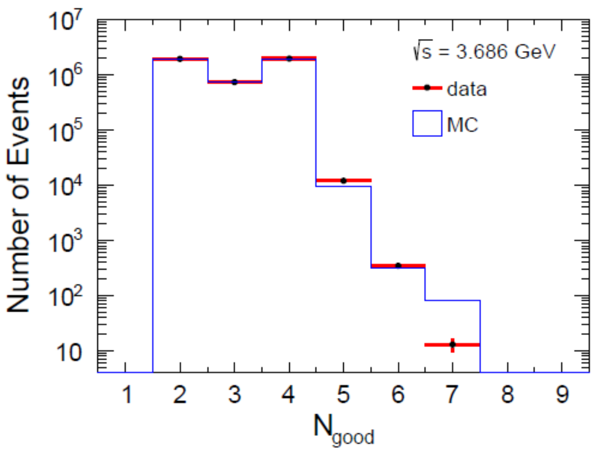


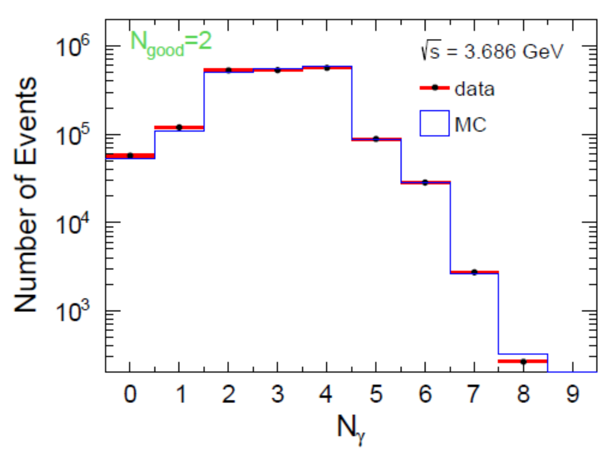
	N_{tot}	N_{cut}	$R \equiv N_{\mathrm{cut}}/N_{\mathrm{tot}}$
data	1456805	1435805	0.9856 ± 0.0001
MC	1322668	1306778	0.9880 ± 0.0001
$R_{\mathrm{data}}/R_{\mathrm{MC}} - 1$	$(-0.24 \pm 0.01)\%$		

Systematic Uncertainty

$N_{\rm good}$ and N_γ Cut

- After subtracting QED and $\gamma_{\rm ISR}J/\psi$ backgrounds





	$N_{\rm tot}$	$N_{\rm cut}$	$R \equiv N_{\rm cut}/N_{\rm tot}$
data	4644114	4454535	0.9592 ± 0.0001
MC	57820	55682	0.9630 ± 0.0008
$R_{\rm data}/R_{\rm MC} - 1$	$(-0.40 \pm 0.08)\%$		

Systematic Uncertainty

Fit to $M_{\ell^+\ell^-}$ Spectrum

- Nominal fit: $N_{\rm obs} = 124069.9 \pm 479.6$ at $E_{\rm cm} = 3.773$ GeV

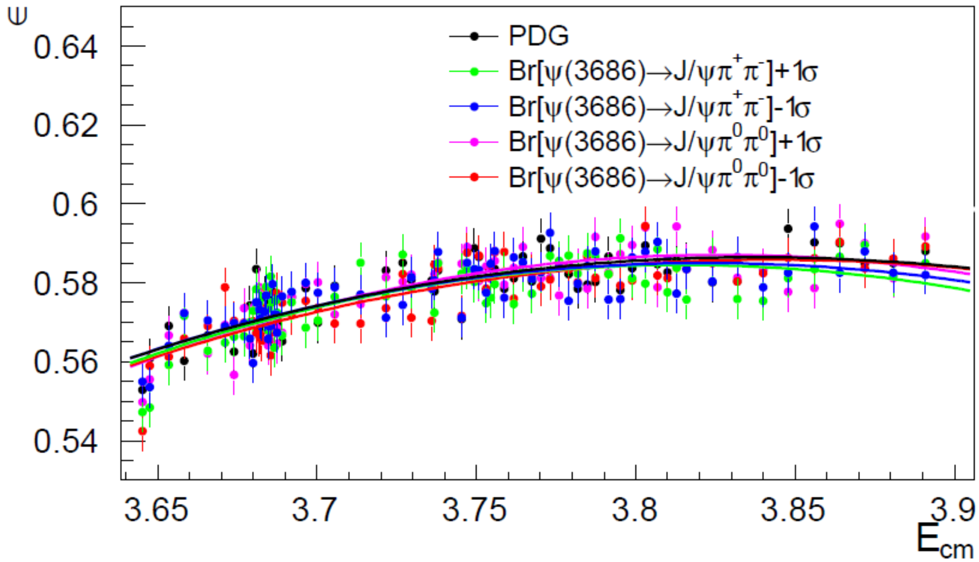
  1. Signal shape
     - Crystal Ball function — 0.53%
  2. Background shape
     - $4^{\rm th}$ order polynomial — 0.63%
  3. Fit region — 0.88%
  4. Bin width — 0.93%

- Total systematic uncertainty from fit to mass spectrum: $\sqrt{0.53^2 + 0.63^2 + 0.88^2 + 0.93^2}\% = 1.52\%$

Systematic Uncertainty

Efficiency

- Vary the normalization of several of the largest components ($J/\psi\pi^+\pi^-$, $J/\psi\pi^0\pi^0$) based on branching fraction uncertainties



- The maximum changes (0.86%) is taken as systematic uncertainty

Systematic Uncertainty

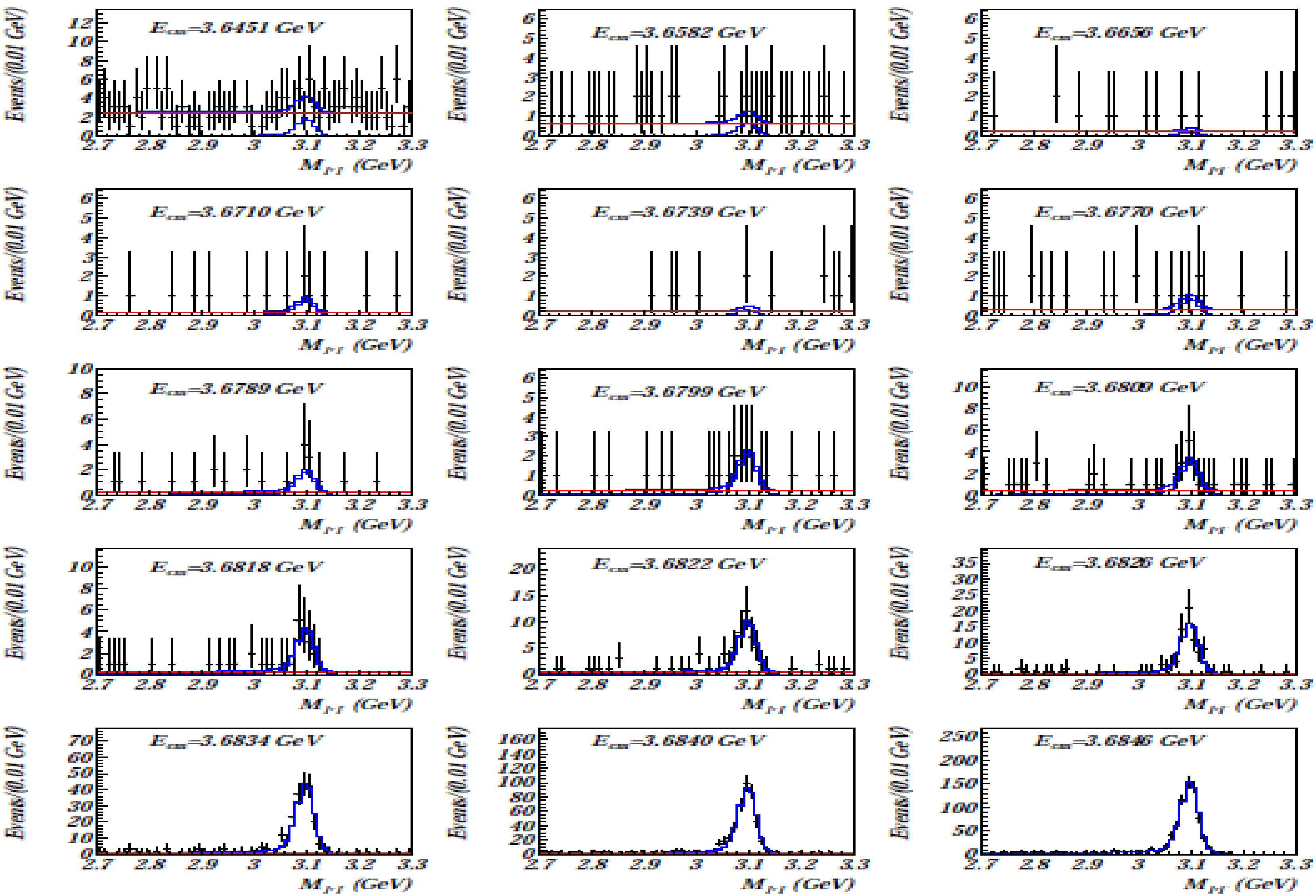
Quoted Systematic Uncertainties

- π PID
  - 1.0% per pion
  - Weighted by the distribution of charged track multiplicity at $E_{\text{cm}} = 3.686$ GeV

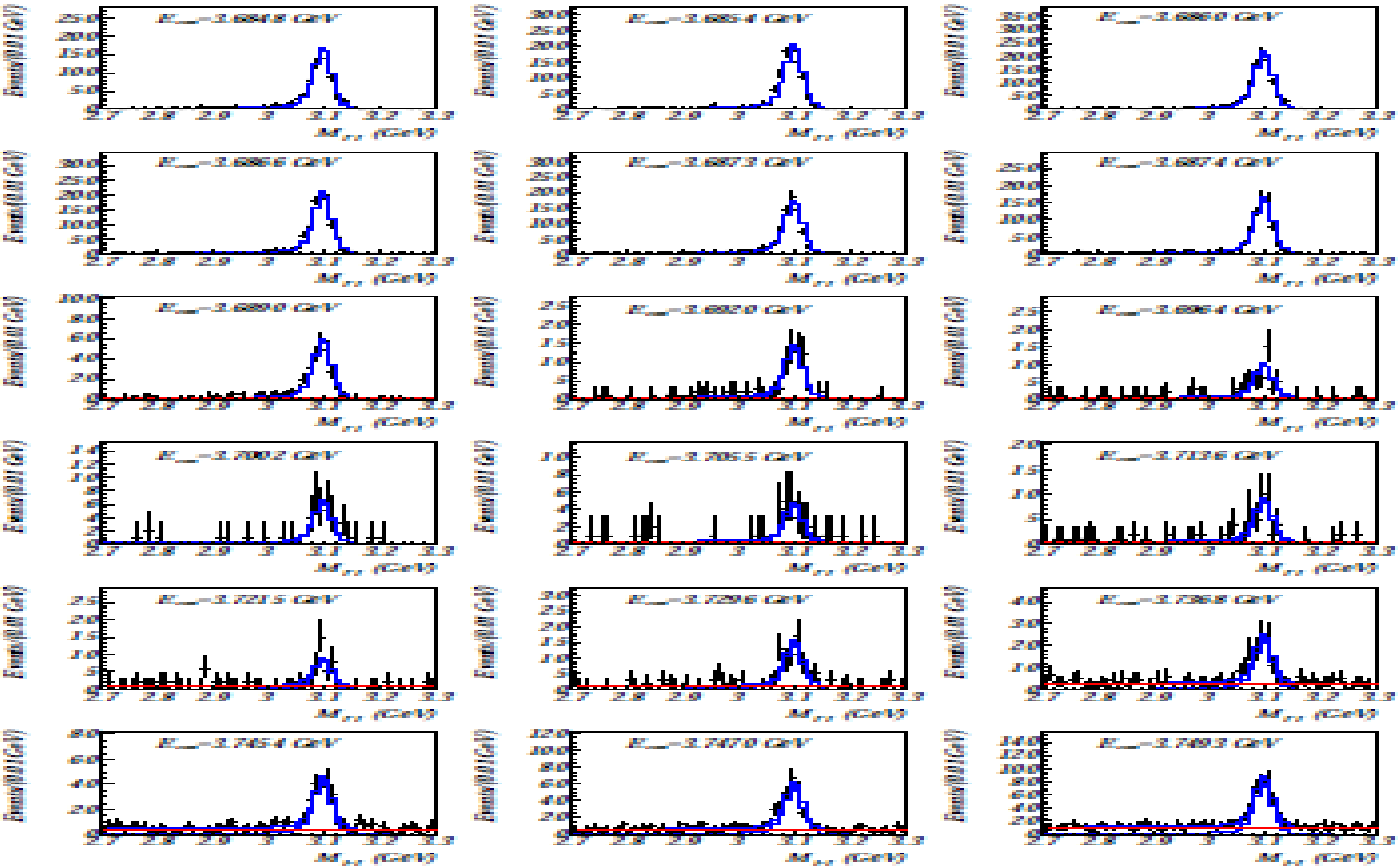
N_{good}	N_{obs}	Δ (%)
2	1989790	0.0
3	763368	1.0
4	1980909	2.0
Average	3734067	1.0

- Branching Fraction
  - $\mathcal{B}(J/\psi \to \ell^+\ell^-) = (11.932 \pm 0.046)\%$ (PDG2016)
  - 0.39%
- Luminosity
  - 1.0% (Chin. Phys. C **37**, 123001 (2013))

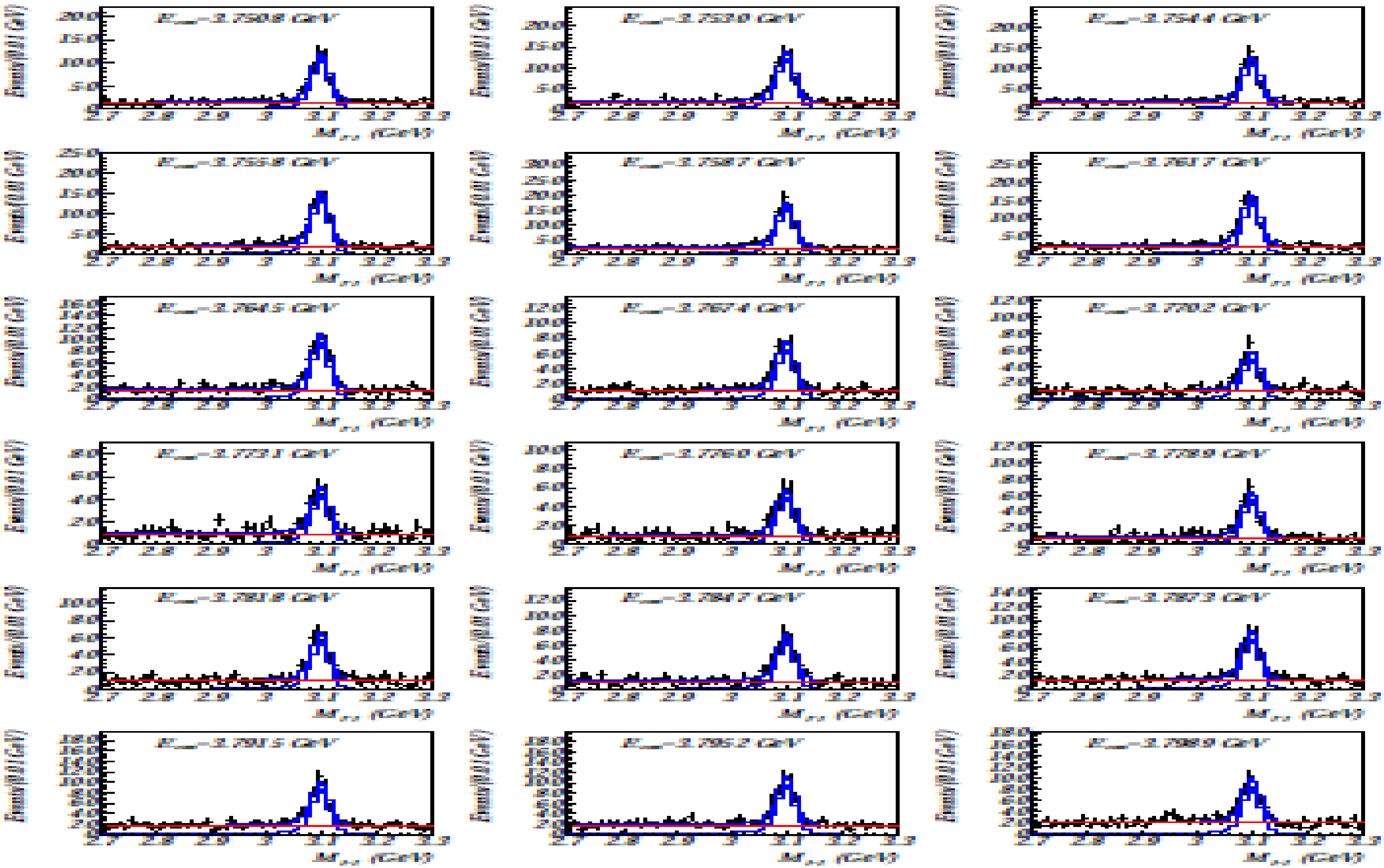
Invariant mass spectra at each energy



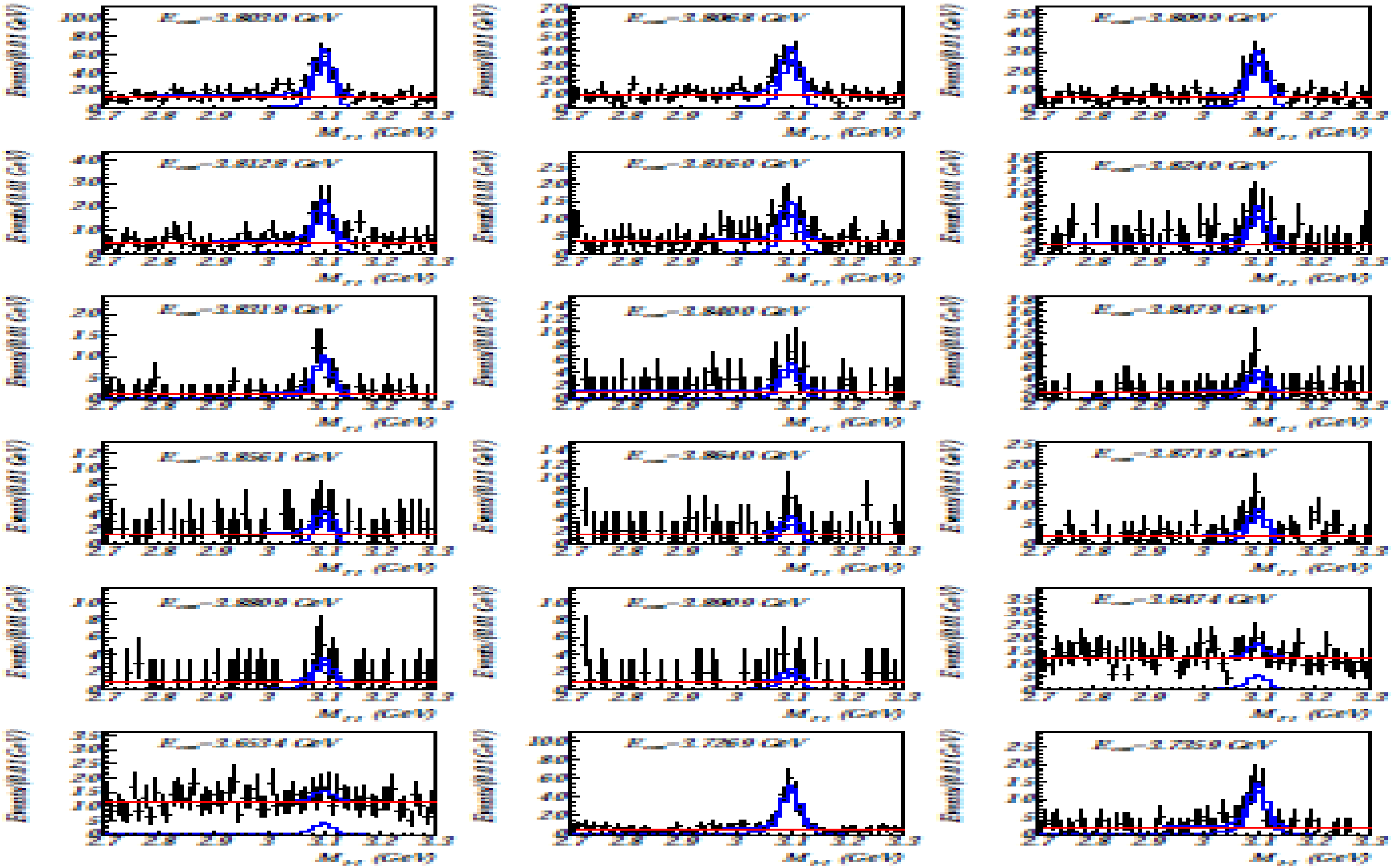
Invariant mass spectra at each energy



Invariant mass spectra at each energy



Invariant mass spectra at each energy



Invariant mass spectra at each energy