Charmonium Group Meeting

Inclusive production of Charmonium mesons above 4 GeV

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22/05/2018

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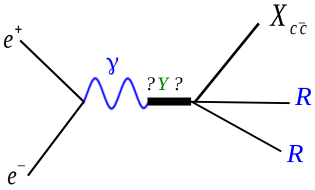
Motivation

- **Improve our understanding of the XYZ Charmonium-like states using the recoil mass technique.**



$$\text{Recoils} = \pi^+\pi^-, K^+K^-, K^\pm\pi^\mp, \pi^0\pi^0, K_sK_s$$

$$X_{c\bar{c}} = J/\psi, h_c, \psi(2S)\ldots$$

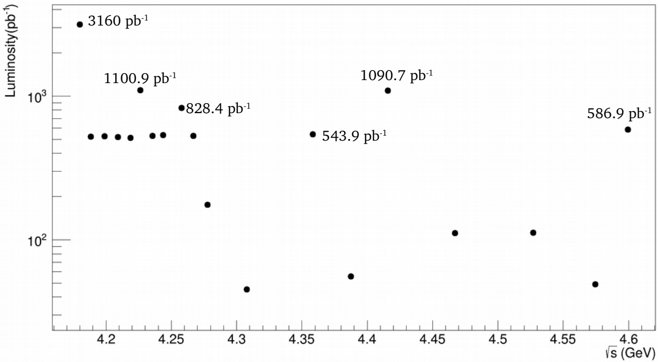
$$MM^2 = (P_{e^+e^-} - P_{RR})^2$$

- **Provide a complementary to previous exclusive analyses.**

- **Search for new Y-state decays**

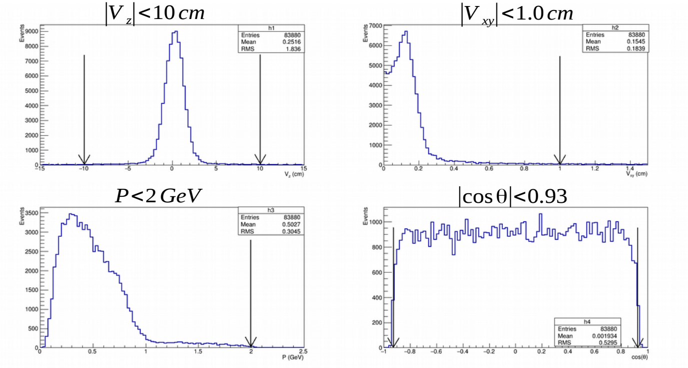
DATA & Monte Carlo samples

- **BESIII Software : Boss Version 7.0.3**
- **Monte Carlo Sample : 25k events simulated for every channel.**
  Generator : "ConExc"
- **DATA Sample : 19 XYZ energy points between 4.18 and 4.6 GeV**



Selection Criteria

- **Charged tracks selection (Pions & Kaons) :**



$|V_z| < 10\,cm$

$|V_{xy}| < 1.0\,cm$

$P < 2\,GeV$

$|\cos\theta| < 0.93$

$PID(\pi) > PID(K,p)$

$PID(K) > PID(\pi,p)$

- **Neutral Candidates selection :**

$|\cos\theta| < 0.8 \rightarrow E_{barrel} > 25\ MeV$

$0 < TDC < 14$

$0.86 < |\cos\theta| < 0.92 \rightarrow E_{endcap} > 50\ MeV$

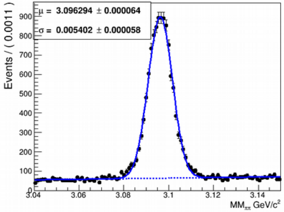
$100 < M(\gamma\gamma) < 160\ MeV/c^2$

$\Delta(\Omega) > 10°$

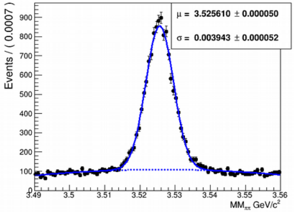
Monte Carlo Simulation

- **Missing mass recoiling against (RR) :**

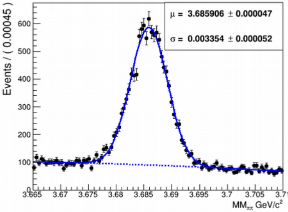
$e^+e^- \rightarrow J/\psi\pi^+\pi^-$



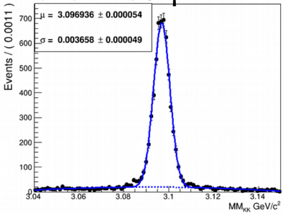
$e^+e^- \rightarrow h_c\pi^+\pi^-$



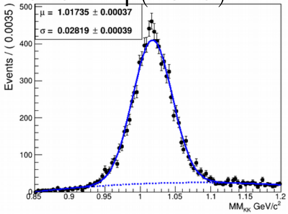
$e^+e^- \rightarrow \psi(2S)\pi^+\pi^-$



$e^+e^- \rightarrow J/\psi K^+K^-$



$e^+e^- \rightarrow \phi(1020)K^+K^-$

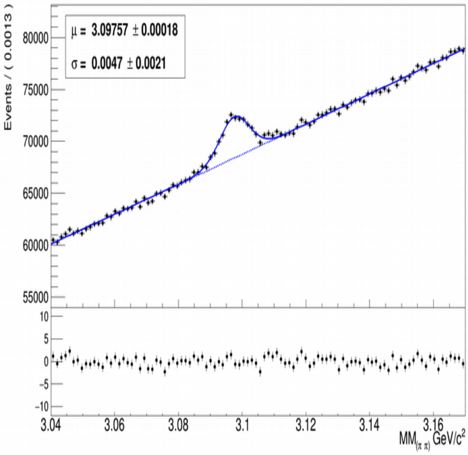


$$e^{+}e^{-} \rightarrow X_{c\bar{c}}\pi^{+}\pi^{-}$$

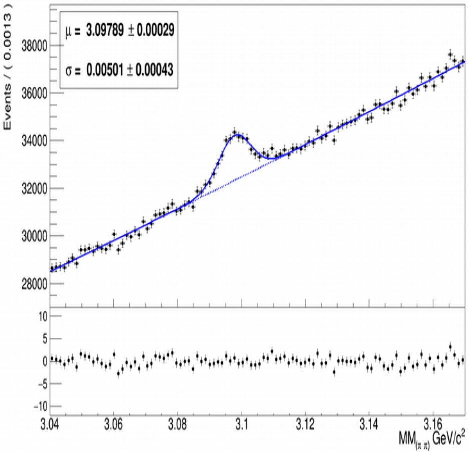
Analysis of $e^+e^- \rightarrow J/\psi\pi^+\pi^-$

- J/ψ in the missing mass recoiling against $\pi^+\pi^-$
- In 12 energy points

@ 4.23 GeV



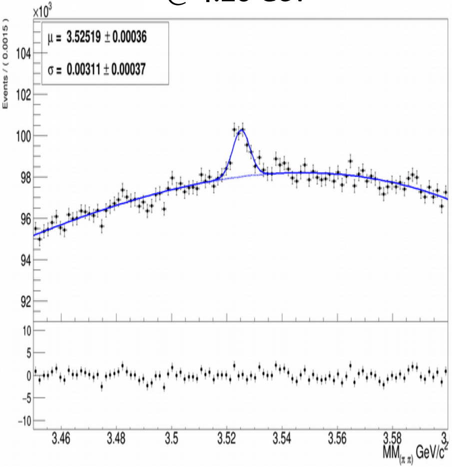
@ 4.246 GeV



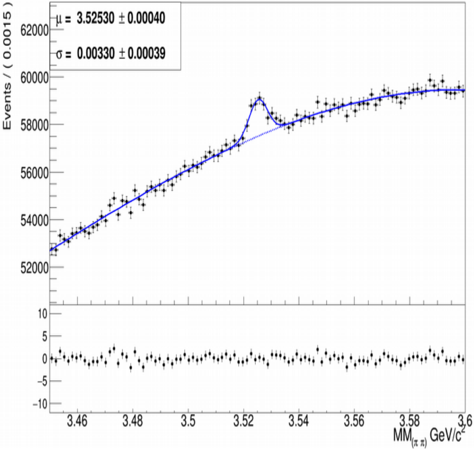
Analysis of $e^+e^- \rightarrow h_c\pi^+\pi^-$

- h_c in the missing mass recoiling against $\pi^+\pi^-$
- In 14 energy points

@ 4.26 GeV



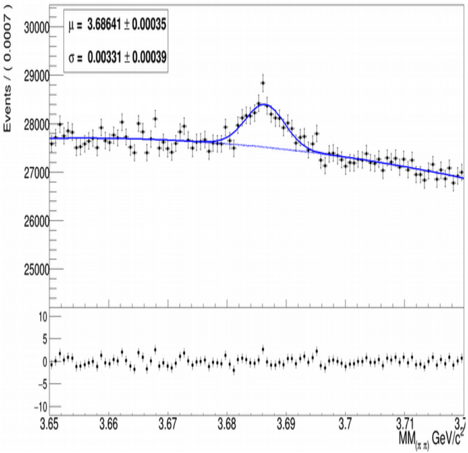
@ 4.36 GeV



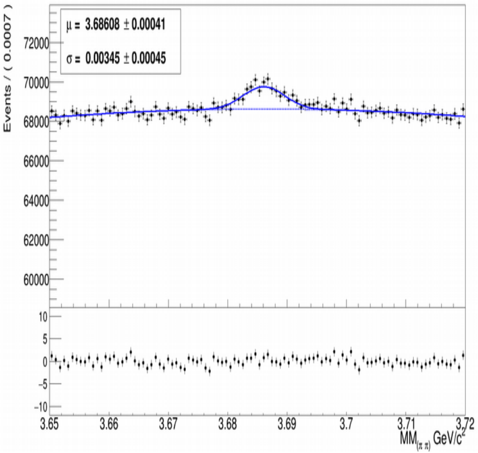
Analysis of $e^+e^- \to \psi(2S)\pi^+\pi^-$

- $\psi(2S)$ in the missing mass recoiling against $\pi^+\pi^-$
- In 9 energy points

@ 4.36 GeV



@ 4.42 GeV



Born Cross section & ISR correction factor-1

(Reminder-Last Collaboration Meeting)

- **The Born cross section is given by:**

$$\sigma^{Born} = \frac{N^{sig}}{L_{integrated}\, \epsilon\, \kappa \left(1+\delta_{VP}\right)}$$

N^{sig} : Number of signal events
L_{Inte} : Integrated luminosity
ϵ : Selection efficiency
κ : ISR correction factor
$(1+\delta_{VP})$: VP correction factor

- **ISR correction factor :**

$$N = L \int W(x)\sigma(x)\epsilon(x)dx$$

$$\kappa = \int W(x) \frac{\sigma(x)}{\sigma_0} \frac{\epsilon(x)}{\epsilon_0} dx$$

$w(x)$: Radiator function
$x = \frac{E_\gamma}{E_{CM}}$: Fractional energy carried by ISR photons
σ_0 : Cross section at a fixed energy

Born Cross section & ISR correction factor-1

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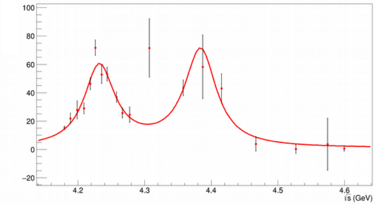

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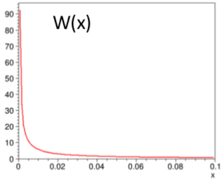


1- The line shape of the observed cross section is used to compute κ

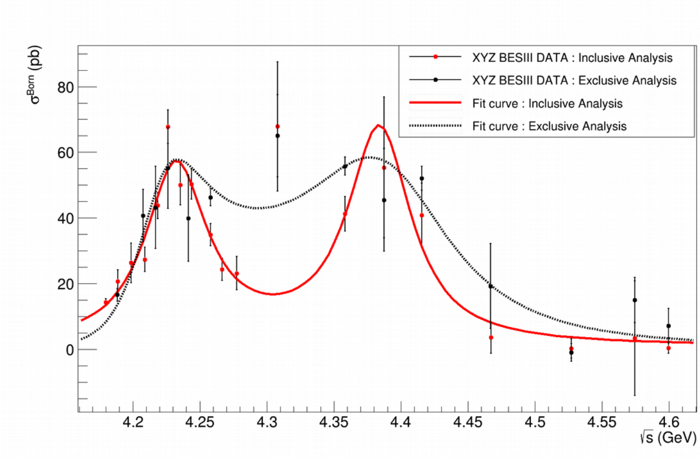
2- $\epsilon(x)$ is constant (No 4C Kinematic fit applied)

Analysis of $e^+e^- \to h_c\pi^+\pi^-$

(Reminder-Last Collaboration Meeting)

- **Energy dependent dressed cross section: Inclusive measurements fitted with the coherent sum of two Breit-Wigner & exponential (In Red).**

- **Compared to the exclusive measurements of BAM-00183.**



$Y(4220)$

$\mu_{4220} = 4231.8 \pm 2.99\ MeV/c^2$

$\Gamma_{4220} = 58.12 \pm 4.70\ MeV$

$Y(4390)$

$\mu_{4390} = 4384.0 \pm 5.86\ MeV/c^2$

$\Gamma_{4390} = 57.99 \pm 13.8\ MeV$

BAM-00183

$Y(4220)$

$\mu_{4220} = 4218.4^{+5.5}_{-4.5}\ MeV/c^2$

$\Gamma_{4220} = 66.0^{+12.3}_{-8.3}\ MeV$

$Y(4390)$

$\mu_{4390} = 4319.5^{+6.3}_{6.8}\ MeV/c^2$

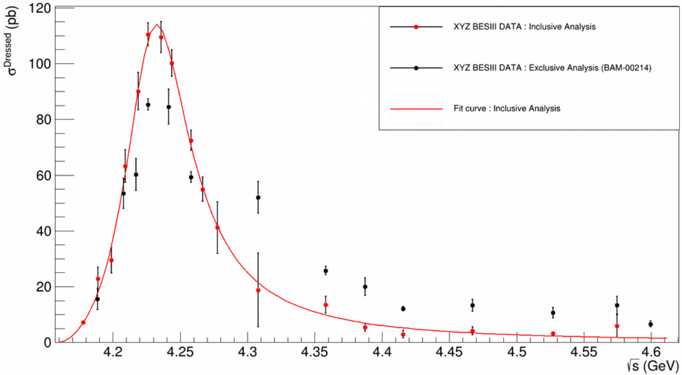
$\Gamma_{4390} = 139.5^{+16.2}_{-20.6}\ MeV$

Analysis of $e^+e^- \to J/\psi\pi^+\pi^-$

(Reminder-Last Collaboration Meeting)

- Energy dependent dressed cross section: Inclusive measurements fitted with the coherent sum of two Breit-Wigner & exponential (In Red).

- Compared to the exclusive measurements of BAM-00214 (In green).



BAM-00214

$Y(4220)$

$\mu_{4220} = 4223.7 \pm 3.2\ MeV/c^2$

$\Gamma_{4220} = 43.1 \pm 4.1\ MeV$

$Y(4320)$

$\mu_{4320} = 4318.6^{+9.4}_{-10.2}\ MeV/c^2$

$\Gamma_{4320} = 95.7^{+22.7}_{-18.0}\ MeV$

Analysis of $e^+e^- \to J/\psi\pi^+\pi^-$

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- Energy dependent dressed cross section: Inclusive measurements fitted with the coherent sum of two Breit-Wigner & exponential (In Red).

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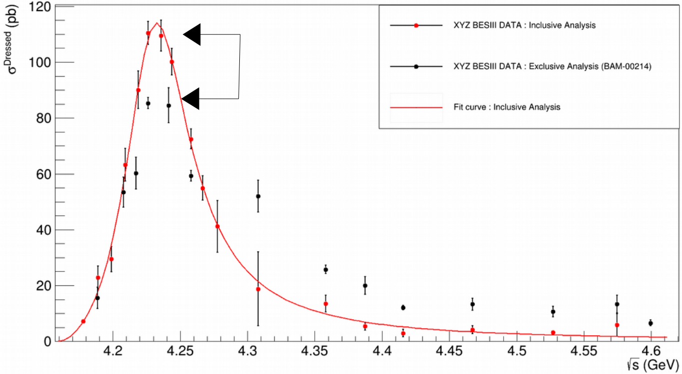

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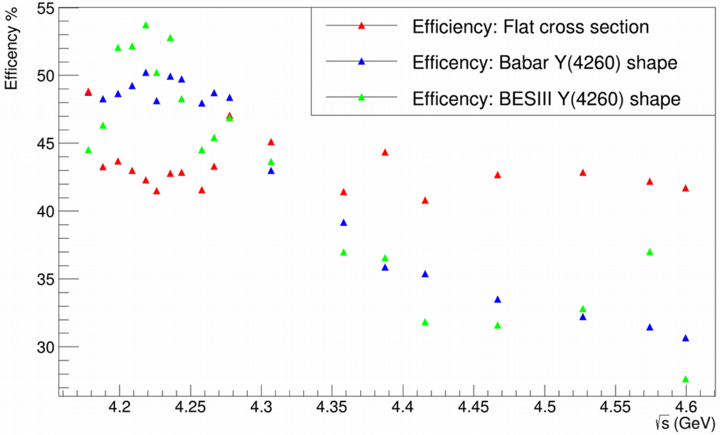
$\Gamma_{4320} = 95.7^{+22.7}_{-18.0}\ MeV$

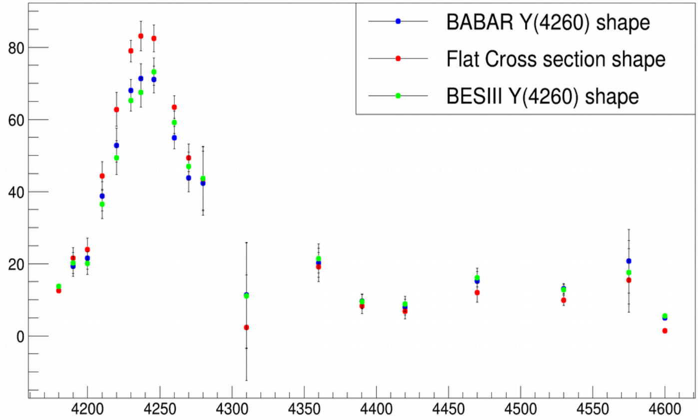
Analysis of $e^+e^- \to J/\psi\pi^+\pi^-$: Reconstruction efficiency

- Input cross section for ConExc : Flat cross section Vs BABAR Y(4260) vs BESIII Y(4260)shape



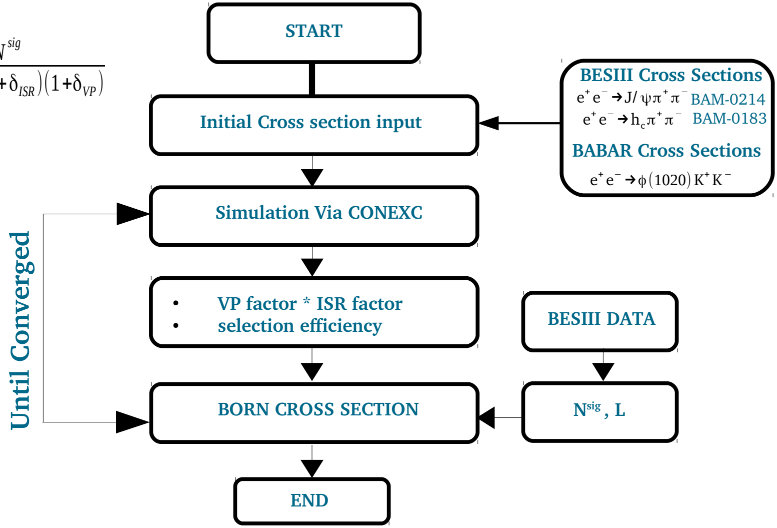
Analysis of $e^+e^- \to J/\psi\pi^+\pi^-$: Observed Cross section

- **Input ConExc cross section : Flat cross section Vs BABAR Y(4260) Vs BESIII Y(4260) line shape**
- **Observed Cross sections for different inputs**



Born Cross section & ISR correction factor -2

$$\sigma^{Born} = \frac{N^{sig}}{L_{integrated}\,\epsilon\left(1+\delta_{ISR}\right)\left(1+\delta_{VP}\right)}$$



Analysis of $e^+ e^- \to h_c \pi^+ \pi^-$

- **Energy dependent dressed cross section: Inclusive measurements fitted with the coherent sum of two Breit-Wigner & exponential (In Red).**
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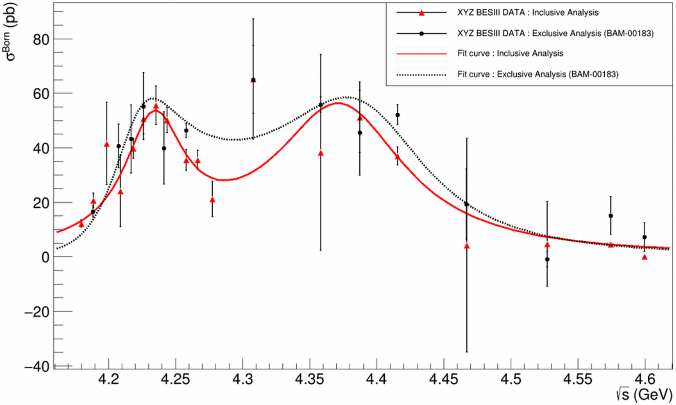


$Y(4220)$

$\mu_{4220} = 4233.4 \pm 4.18\ MeV/c^2$

$\Gamma_{4220} = 53.65 \pm 9.90\ MeV$

$Y(4390)$

$\mu_{4390} = 4372.5 \pm 18.14\ MeV/c^2$

$\Gamma_{4390} = 119.4 \pm 17.32\ MeV$

BAM-00183

$Y(4220)$

$\mu_{4220} = 4218.4^{+5.5}_{-4.5}\ MeV/c^2$

$\Gamma_{4220} = 66.0^{+12.3}_{-8.3}\ MeV$

$Y(4390)$

$\mu_{4390} = 4319.5^{+6.3}_{6.8}\ MeV/c^2$

$\Gamma_{4390} = 139.5^{+16.2}_{-20.6}\ MeV$

Analysis of $e^+e^- \rightarrow h_c\pi^+\pi^-$

- **Born Cross section measured using the recoils mass technique for 19 energy points**

$$\sigma^{Born} = \frac{N^{sig}}{L_{integrated}\,\epsilon\, f_{ISR} f_{VP}}$$

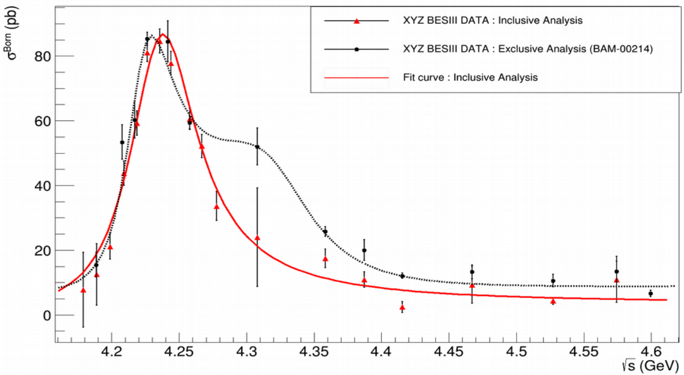
$\sqrt{s}$ (MeV)	$\epsilon(\%)$	N_s	$f_{ISR}f_{VP}$	$\sigma^{Born}(pb)$
4180	44.27	14391 ± 1833	0.843	12.19 ± 1.32
4190	48.00	4061 ± 661	0.787	20.59± 2.65
4200	46.98	8213 ± 3693	0.805	41.45± 15.02
4210	44.04	4699 ± 2952	0.874	23.85± 13.11
4220	46.05	7438 ± 842	0.801	39.64± 3.64
4230	45.42	19926 ± 2777	0.794	50.54± 5.64
4237	47.20	11399 ± 1757	0.824	55.40± 7.09
4246	44.83	10392± 1087	0.868	50.12± 4.63
4260	40.06	10899± 1232	0.924	35.50± 3.76
4270	39.70	7292± 736	0.980	35.39± 3.57
4280	43.14	1610± 490	1.011	21.02± 6.48
4310	44.17	1078± 439	0.830	65.16± 22.06
4360	41.41	8227± 9890	0.955	38.23± 43.91
4390	42.95	1106± 307	0.905	51.17± 12.88
4420	39.52	15970 ± 1422	1.005	36.85± 3.375
4470	18.35	207±800	2.443	4.15± 39.243
4530	26.01	230±456	1.678	4.69± 15.63
4575	24.51	93±200	1.707	4.54± 16.67
4600	3.57	156 ± 32	128.38	0.03± 2.45

$f_{ISR} f_{VP} \gg$ → (4600)

Analysis of $e^+e^- \rightarrow J/\psi\pi^+\pi^-$

- **Energy dependent dressed cross section: Inclusive measurements fitted with the coherent sum of two Breit-Wigner & exponential (In Red).**

- **Compared to the exclusive measurements of BAM-00214 (In green).**



$Y(4220)$

$\mu_{4220} = 4234.4 \pm 4.927\ MeV/c^2$

$\Gamma_{4220} = 61.01 \pm 3.507\ MeV$

With the assumption of a second Breight Wigner under 4 GeV

BAM-00214

$Y(4220)$

$\mu_{4220} = 4223.7 \pm 3.2\ MeV/c^2$

$\Gamma_{4220} = 43.1 \pm 4.1\ MeV$

$Y(4320)$

$\mu_{4320} = 4318.6^{+9.4}_{-10.2}\ MeV/c^2$

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Analysis of $e^+e^- \rightarrow J/\psi\pi^+\pi^-$

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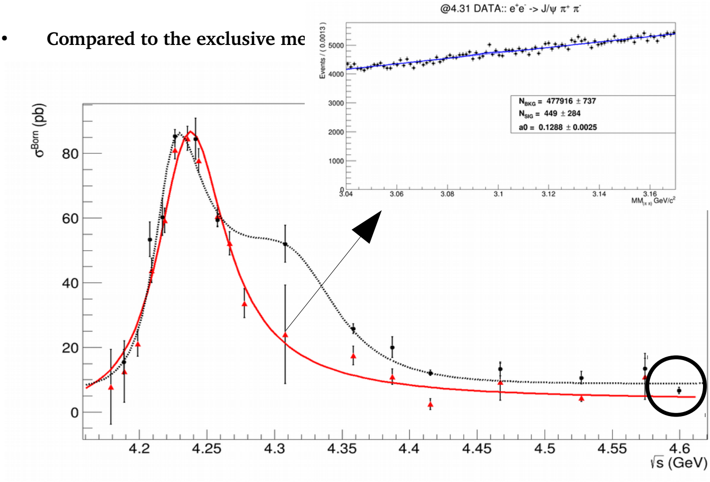

Still working on a better fit

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With the assumption of a second Breight Wigner under 4 GeV

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Analysis of $e^+e^- \rightarrow J/\psi\pi^+\pi^-$

- **Born Cross section for 19 energy points**

$$\sigma^{Born} = \frac{N^{sig}}{L_{integrated}\,\epsilon\, f_{ISR} f_{VP}}$$

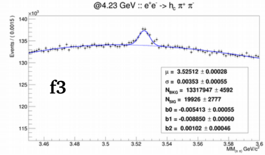
$\sqrt{s}$ (MeV)	$\epsilon(\%)$	N_s	$f_{ISR}f_{VP}$	$\sigma^{Born}(pb)$
4180	51.24	10660± 15828	0.845	7.78 ± 11.56
4190	52.19	2722± 2065	0.798	12.51 ± 9.49
4200	55.36	4732± 866	0.772	21.11 ± 3.87
4210	56.72	9547± 803	0.751	43.78 ± 3.75
4220	55.93	12808± 787	0.760	59.28 ± 3.77
4230	52.42	35786± 1091	0.771	81.04 ± 2.77
4237	51.98	18835±767	0.809	84.62 ± 3.72
4246	50.10	17523±758	0.843	77.79 ±3.62
4260	47.10	20921± 1068	0.886	60.49 ±3.24
4270	44.71	11530± 748	0.933	52.16 ± 3.55
4280	43.57	2495 ±327	0.970	33.62 ± 4.45
4310	39.05	449 ± 284	1.059	24.07±15.23
4360	39.01	4037 ±671	1.091	17.43±2.91
4390	32.78	253±55	1.273	10.90±2.38
4420	18.27	1235±863	2.512	2.46± 1.72
4470	36.40	420±259	1.114	9.31± 5.74
4530	28.86	205±51	1.459	4.33± 1.08
4575	40.76	228±147	1.041	10.97±7.08
4600	8.74	874±699	59.34	0.028 ± 0.02

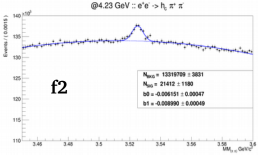
$f_{ISR} f_{VP} \gg$ → 4600

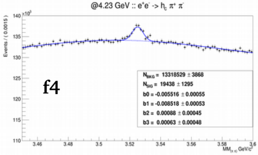
Analysis of $e^+e^- \to h_c \pi^+ \pi^-$: Systematic Uncertainties

- 1% for Luminosity
- 1% for every charged track reconstructed → 2%
- Background shape : Nominal fit (f3) a 3rd order Chebyshev polynomial
  → fitting the background with (f2) a 2nd and (f4) a 4th order chebyshev polynomial.

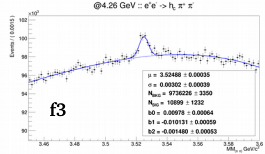
$$\Delta N_f = \frac{1}{n}\sum\left|N_{f_3} - N_{f_i}\right| = \frac{1}{2}\left(\left|N_{f_3} - N_{f_4}\right| + \left|N_{f_3} - N_{f_2}\right|\right)$$

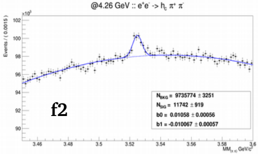


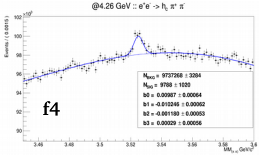




$$\frac{\Delta N_f}{N_f} = 4.95\ \%$$







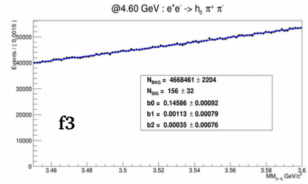
$$\frac{\Delta N_f}{N_f} = 8.96\ \%$$

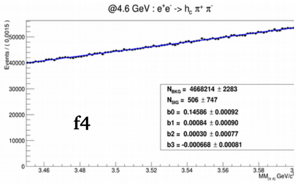
Analysis of $e^+e^- \to h_c \pi^+ \pi^-$: Systematic Uncertainties

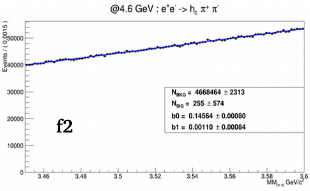
- 1% for Luminosity
- 1% for every charged track reconstructed → 2%
- Background shape : Nominal fit (f3) a 3rd order Chebyshev polynomial
  → fitting the background with (f2) a 2nd and (f4) a 4th order chebyshev polynomial.

$$\Delta N_f = \frac{1}{n} \Sigma \left| N_{f_3} - N_{f_i} \right| = \frac{1}{2} \left(\left| N_{f_3} - N_{f_4} \right| + \left| N_{f_3} - N_{f_2} \right| \right)$$

No hc observation





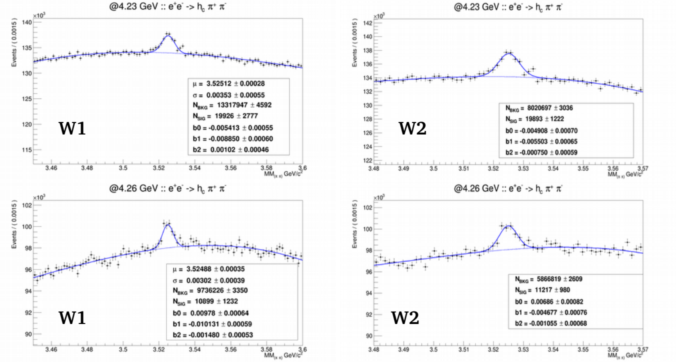


$$\frac{\Delta N_f}{N_f} = 143\ \%$$

Analysis of $e^+e^- \rightarrow h_c \pi^+ \pi^-$: Systematic Uncertainties

- 1% for Luminosity
- 1% for every charged track reconstructed → 2%
- Fit Window : Nominal fit Window (W1) [4.45,4.6]
  → Fit window (W2) [4.48,4.57]

$$\Delta N_W = \frac{1}{n} \Sigma \left| N_{W1} - N_{Wi} \right| = \left| N_{W1} - N_{W2} \right|$$



$$\frac{\Delta N_W}{N_{W1}} = 0.16\ \%$$

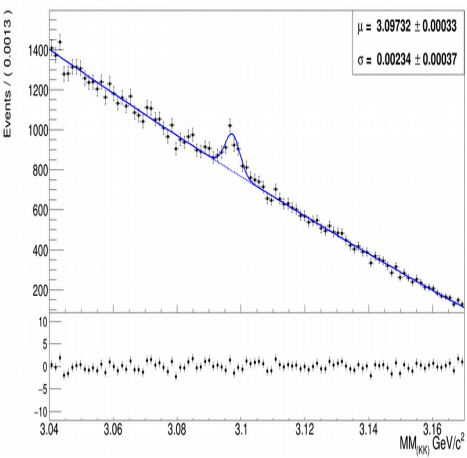
$$\frac{\Delta N_W}{N_{W1}} = 2.91\ \%$$

$$e^{+}e^{-} \rightarrow X\, K^{+} K^{-}$$

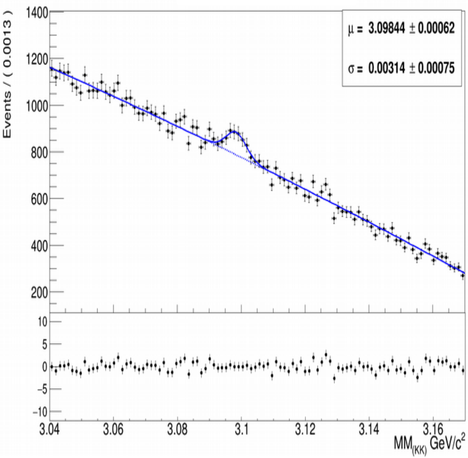
Analysis of $e^+e^- \to J/\psi K^+K^-$

- J/ψ in the missing mass recoiling against K^+K^-
- In 6 energy points

@ 4.23 GeV



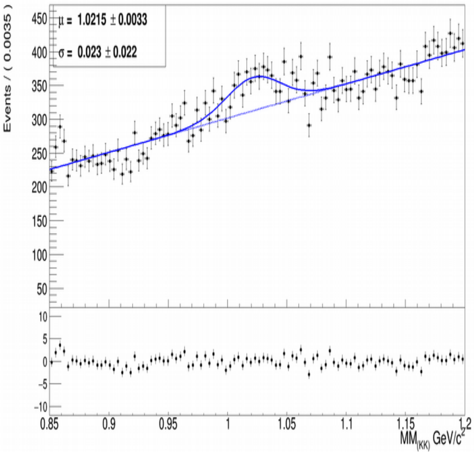
@ 4.26 GeV



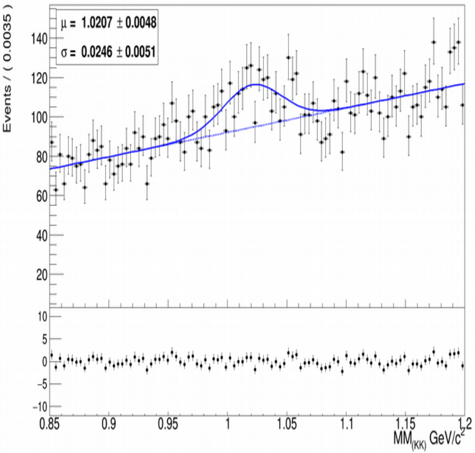
Analysis of $e^+e^- \to \phi(1020)K^+K^-$

- **ϕ(1020) in the missing mass recoiling against** K^+K^-
- **In 15 energy points**

@ 4.22 GeV

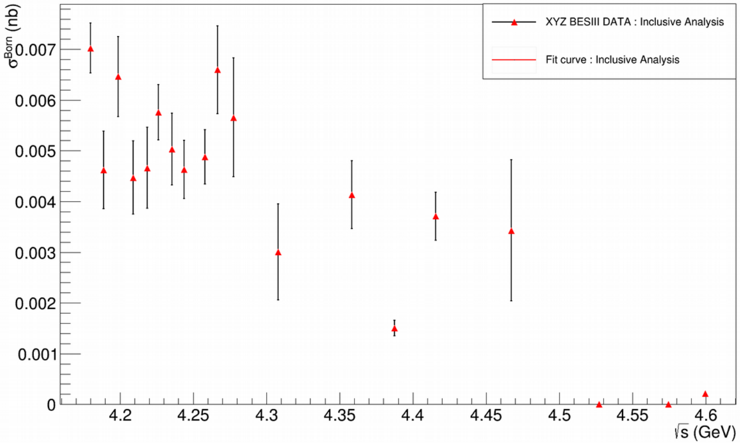


@ 4.28 GeV



Analysis of $e^+e^- \to \phi(1020)K^+K^-$

- **Energy dependent Born cross section of $e^+e^- \to \phi(1020)K^+K^-$ after 1st iteration**



Analysis of $e^+e^- \to \phi(1020) K^+ K^-$

- **Born Cross section measured for 19 energy points**

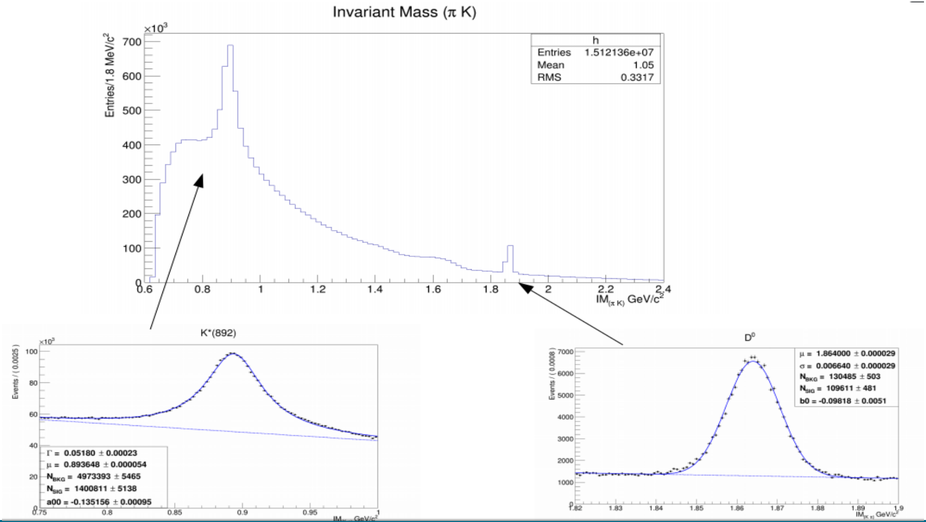
$$\sigma^{Born} = \frac{N^{sig}}{L_{integrated}\,\epsilon\, f_{ISR}\, f_{VP}}$$

$\sqrt{s}$ (MeV)	$\epsilon(\%)$	N_s	$f_{ISR}f_{VP}$	$\sigma^{Born}(pb)$
4180	24.38	8676 ± 575	1.271	8.85 ± 0.62
4190	24.70	969 ± 159	1.269	5.91 ±0.98
4200	25.42	1350 ± 162	1.271	7.97±0.97
4210	24.47	895±143	1.269	5.60 ± 0.90
4220	24.50	951± 162	1.27	6.00 ± 1.03
4230	24.03	2438± 226	1.26	7.33 ± 0.69
4237	24.87	1060± 147	1.25	6.43 ± 0.90
4246	25.81	998 ± 122	1.24	5.84 ± 0.72
4260	22.63	1719 ± 184	1.45	6.28 ± 0.68
4270	22.41	1335 ±172	1.36	8.23 ± 1.08
4280	19.63	380 ± 78	1.52	4.69 ± 4.86
4310	4.39	18 ± 17	2.19	4.14 ± 3.93
4360	21.72	898±144	1.40	5.39 ± 0.87
4390	25.77	3.2 ± 3.3	1.13	0.19 ± 0.20
4420	31.97	1520± 192	1.17	3.70 ± 0.47
4470	14.08	148 ± 60	2.09	4.52 ± 1.83
4530	12.46	0 ± 59	2.09	0
4575	6.04	0± 27	4.69	0
4600	5.95	488 ± 89	4.86	0.28 ± 0.05

$$e^+e^- \rightarrow X\,K\pi$$

Analysis of $e^+e^- \to X\, K\, \pi$

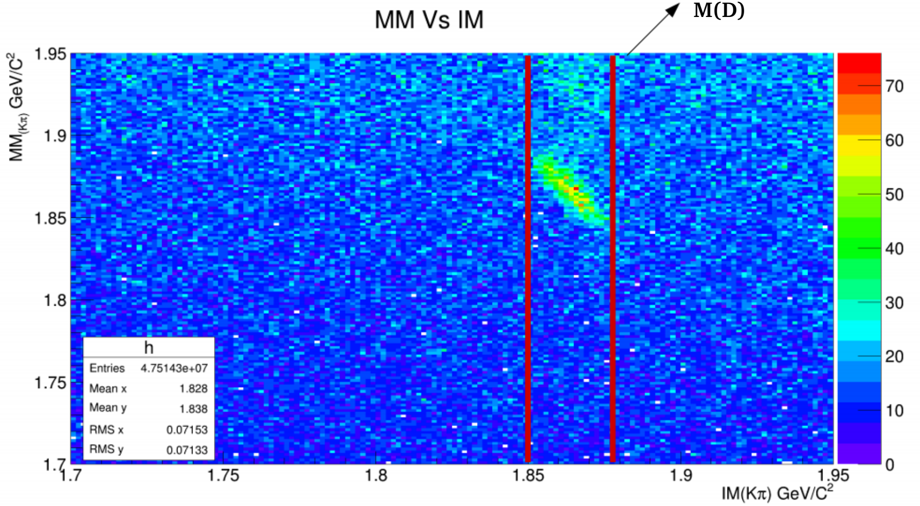
- **K*(892) & D⁰ in the invariant mass of (K pi)**



Analysis of $e^+e^- \to X K \pi$

- **MM recoiling against (k pi) VS IM of (K pi)**

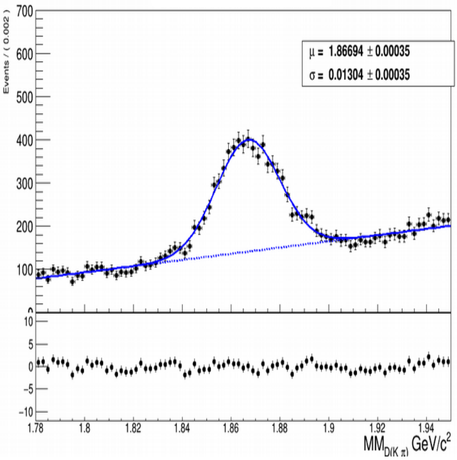
3 sigmas around M(D)



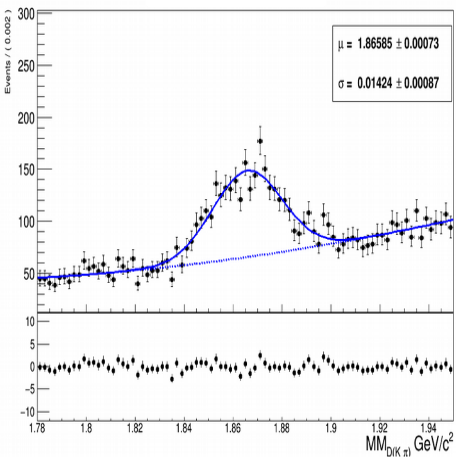
Analysis of $e^+e^- \to D^0\bar{D}^0[K\pi]$

- D **in the missing mass recoiling against** D[kpi]

@ 4.23 GeV



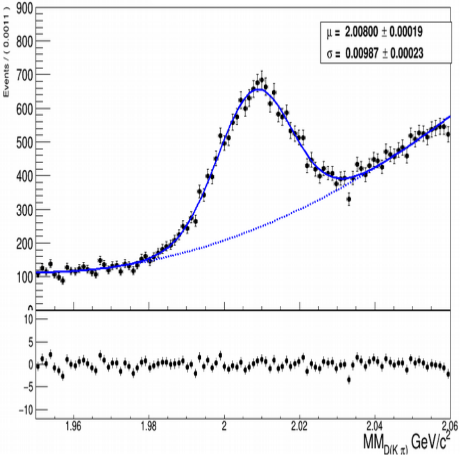
@ 4.246 GeV



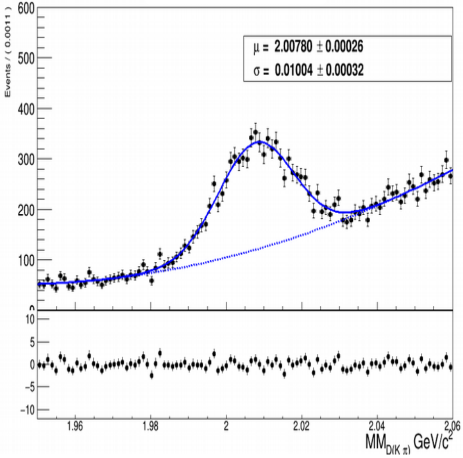
Analysis of $e^+e^- \to D^{*0}\bar{D}^0[K\pi]$

- D* **in the missing mass recoiling against** D[Kpi]

@ 4.230 GeV



@ 4.246 GeV



Outlook - Future Plans

- **Inclusive Energy dependent cross sections :**

  → **For all decay channels**
  → **Finalizing the systematic uncertainty studies**

- **Selection criteria**

  → **Large amount of background → Cuts optimization**
  → **Background study/subtraction**

- **Recoils**
  → **Semi inclusive analysis**
  → $\pi^+\pi^-$ $\pi^0\pi^0$ $\pi^0\pi^+\pi^-$ $\eta\pi^\pm$
  K^+K^- K_sK_s $\pi^0K^+K^-$ $\eta K^\pm$
  $K^\pm\pi^\mp$ $K_s\pi^0$ $\eta\eta$

Thank You

For Your Attention

Analysis of $e^+e^- \to \psi(2S)\pi^+\pi^-$ / $e^+e^- \to J/\psi K^+K^-$

- Lack of (psi pi+ pi-) and (J/psi K+ K-) observations → cannot rely on fixing the MC parameters for some energy points
  → Introduces huge inconsistency

In the exclusive analysis:
Cross section = 0.75 pb