Precise Measurement of $e^+e^- \to \pi^+\pi^- J/\psi$ Cross Section

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JC 75 report

Introduction

- The Y states — $J^{PC}=1^{--}$
- Y states may not be conventional charmonium states, and they are good candidates for new types of exotic particles, such as hybrids, tetraquarks, or meson molecules.
- Another possible interpretation describes the Y(4260) as a heavy charmonium (J/ψ) being bound inside light hadronic matter—hadrocharmonium.
- To better identify the nature of the Y states and distinguish various models, more precise experimental measurements, including the production cross section and the mass and width of the Y states, are essential.

Question from Xin

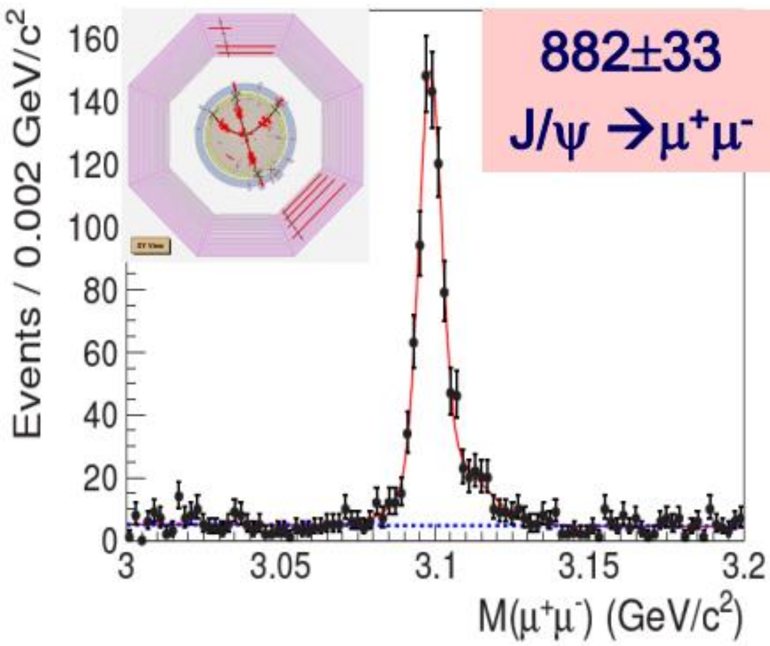
What's the key feature of this "hadrocharmonium" state?

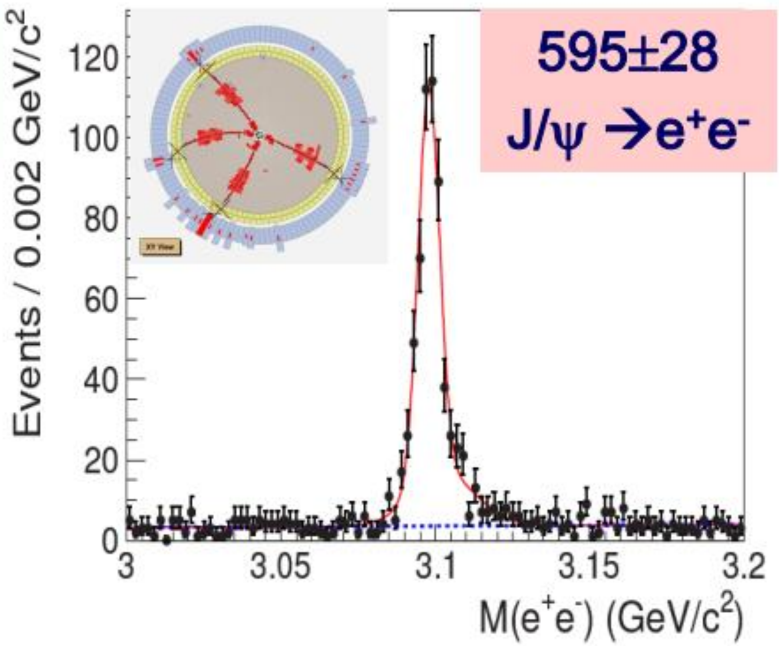
As mentioned below in the paper:

Another possible interpretation describes the Y(4260) as a heavy charmonium (J/ψ) being bound inside light hadronic matter—hadrocharmonium.

Answer : Hadronic objects, containing a particular charmonium state embedded in a light hadronic matter, can be called hadro-charmonium.
Relatively compact charmonium states, J/ψ, $\psi(2S), \chi_c$, can very likely be bound inside light hadronic matter, in particular inside higher resonances made from light quarks and/or gluons. The charmonium state in such binding essentially retains its properties, so that the bound system decays into light mesons and the particular charmonium resonance.

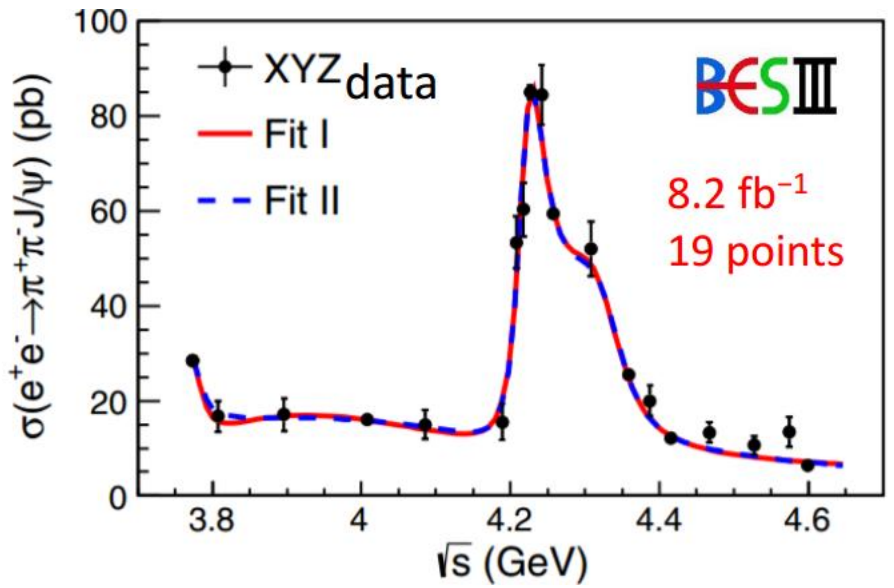
Calculation of the $e^+e^- \to \pi^+ \pi^- J/\psi$ Cross Section

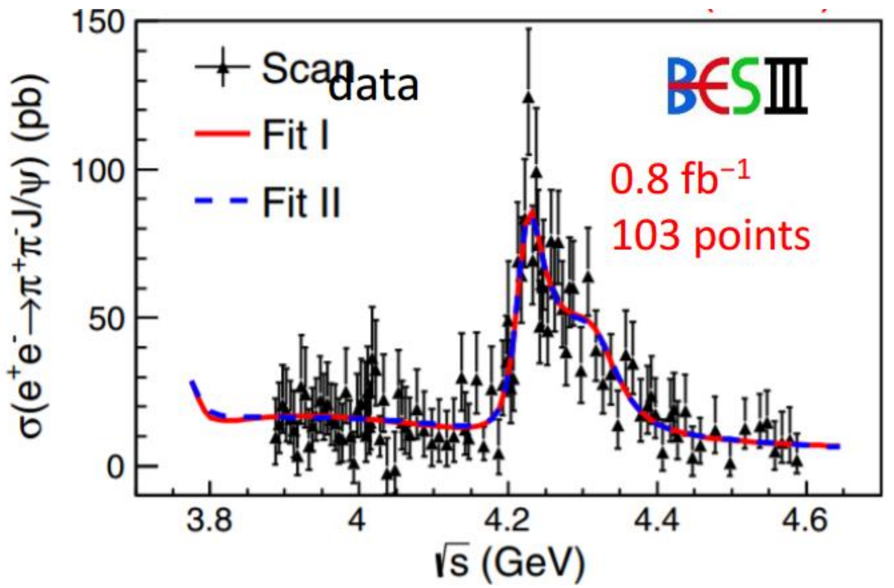




$$\sigma(\sqrt{s}) = \frac{N^{\mathrm{sig}}}{\mathcal{L}_{\mathrm{int}}(1+\delta)\epsilon\mathcal{B}},$$

where N^{sig} is the number of signal events, $\mathcal{L}_{\mathrm{int}}$ is the integrated luminosity of data, $1+\delta$ is the ISR correction factor, ϵ is the detection efficiency, and $\mathcal{B}$ is the branching fraction of $J/\psi \to \ell^+\ell^-$ [8]. The ISR correction factor is





- **Simultaneous fit to the cross section from XYZ data(left) and R-scan data (right)**
- **Fit I = $T^2(s, \psi(3770)) + |BW1+BW2*e^{i\phi 2}+BW3*e^{i\phi 3}|^2$**

  or Fit II = $T^2(s, \psi(3770)) + |exp+BW2*e^{i\phi 2}+BW3*e^{i\phi 3}|^2$

Resonance I: M = (4222.0±3.1±1.4) MeV, Γ = (44.1±4.3±2.0) MeV ,

Lower and narrower than previous Y(4260) PDG value

Resonance II: M = (4320.0±10.4±7) MeV, Γ = (101.4±25±10) MeV ,

a little bit lower than Y(4360) PDG value

- **The significance of the second resonance is 7.6σ**
- **The first observation of Y(4360) → $\pi^+\pi^- J/\psi$.**

Question from Ryuta : about the amplitude

$$\mathcal{A}(\sqrt{s}) = \frac{M}{\sqrt{s}} \frac{\sqrt{12\pi\Gamma_{e^+e^-}\Gamma_{tot}\mathcal{B}_R}}{s - M^2 + iM\Gamma_{tot}} \sqrt{\frac{\Phi(\sqrt{s})}{\Phi(M)}} e^{i\phi}, \quad (2)$$

If it is represented as "T(s, Y(****))"

(1) does the total amplitude looks like bellow ?

$$A_{total}(s) = T(s, Y(3770))e^{i\phi(3770)} + T(s, Y(4008))e^{i\phi(4008)} + T(s, Y(4260))e^{i\phi(4260)} + T(s, Y(4360))e^{i\phi(4360)}$$

(and then, one of ϕ can be set as 0 , since they are relative phases ?)

(2) what is the relationship between the amplitude and the number of events ? (I can assume,,, $N(\pi^+\pi^- J/\psi)$ ~ Luminosity x $|A|^2$ x eff. ??)

One of ϕ can be set as 0

Answer : 1)Fit I = $T^2(s,\psi(3770)) + |BW1+BW2*e^{i\phi 2}+BW3* e^{i\phi 3}|^2$

$$\sigma(\sqrt{s}) = T^2(s,\psi(3770)) + |T(s,Y(4008)*e^{i\phi 1}) + T(s,Y(4260)*e^{i\phi 2}) + T(s,Y(4360)*e^{i\phi 3})|^2$$

2) $$|\mathcal{A}^2| = \sigma(\sqrt{s}) = \frac{N^{sig}}{\mathcal{L}_{int}(1+\delta)\epsilon\mathcal{B}}$$

Question from Kai

possible hadronic structures are very interesting in the open charm mass range. We could search for them by measuring the cross sections at many energy points for the final states interests us. Could you give a review on such kind of results on BESIII?

$e^+e^- \to \pi^+\pi^-\psi(3686)$

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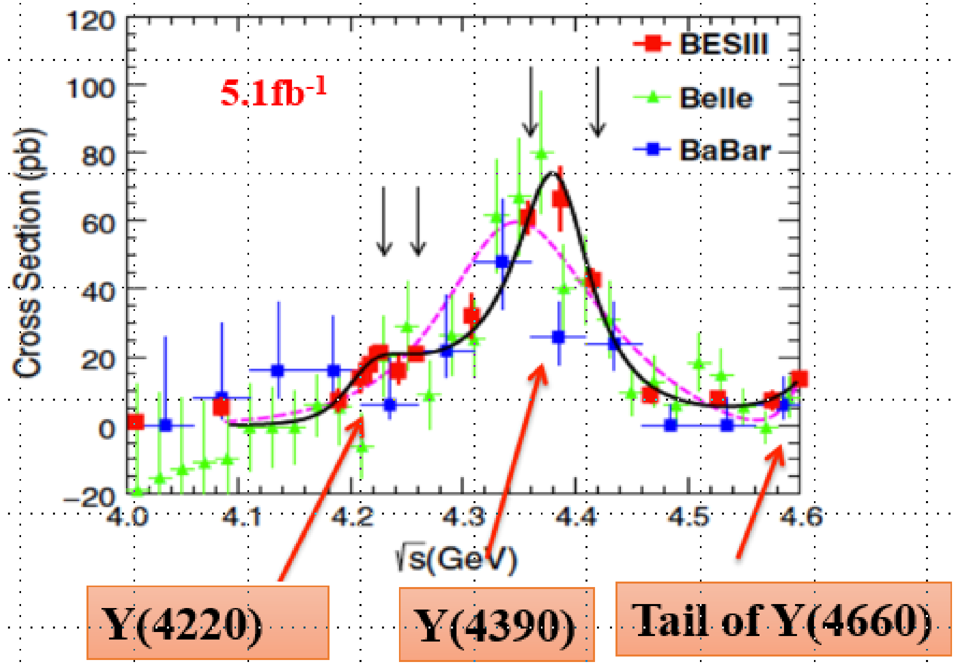

$e^+e^- \to \pi^+\pi^- h_c$

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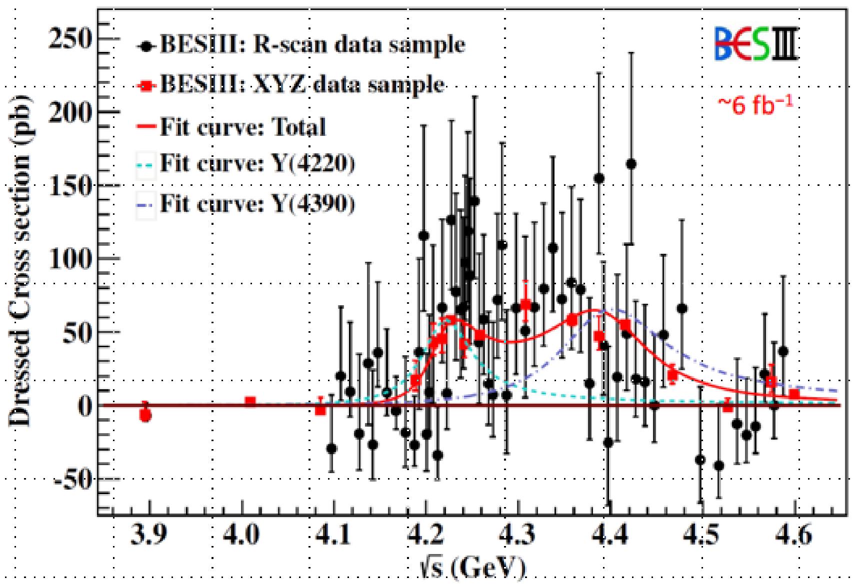

The cross sections are of the same order of magnitude as those of the $e^+e^- \to \pi^+\pi^- J/\psi(\psi(3686))$, but follow a different line shape.

- Fitted with coherent sum of two Breit-Wigner like structure

Neutral decay process

Observation of $Z_c(3900)^0$ in $e^+e^- \to \pi^0\pi^0 J/\psi$

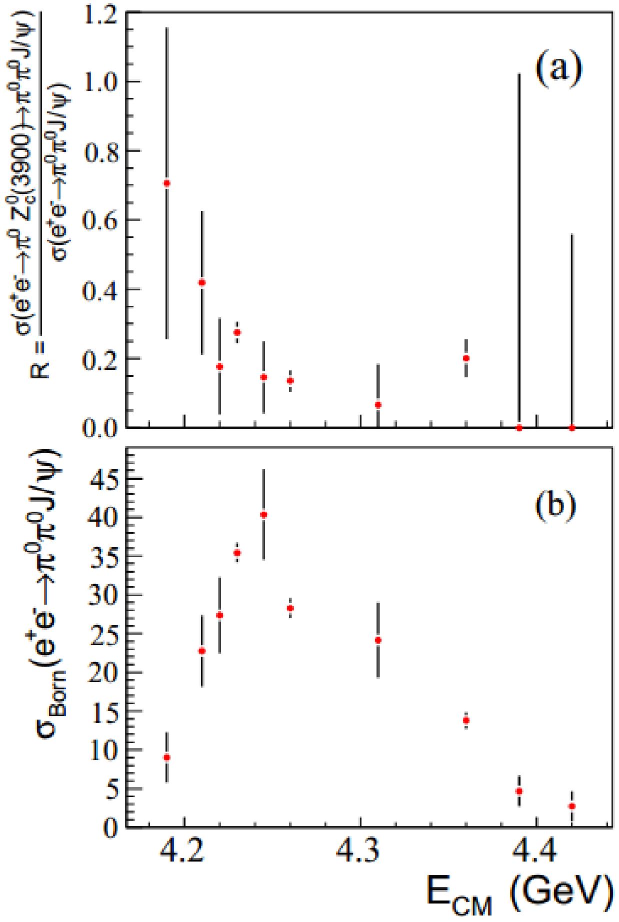

FIG. 3. (a) R (see text) and (b) $\sigma_{Born}(e^+e^- \to \pi^0\pi^0 J/\psi)$ as functions of E_{cm}. Error bars are statistical only.

Measurement of $e^+e^- \to \pi^0\pi^0\psi(3686)$ at $\sqrt{s}$ from 4.009 to 4.600 GeV and observation of a neutral charmoniumlike structure

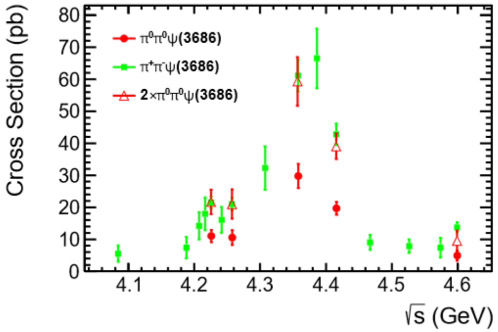

FIG. 2. Born cross section of $e^+e^- \to \pi^0\pi^0\psi(3686)$ at $\sqrt{s}$ = 4.226, 4.258, 4.358, 4.416, 4.600 GeV, respectively. The dots (red) are the results obtained in this analysis, the squares (blue) are the Born cross section of $e^+e^- \to \pi^+\pi^-\psi(3686)$ from Ref. [3]. we multiplied the $e^+e^- \to \pi^0\pi^0\psi(3686)$ cross section by 2 in order to compare it with cross section of $e^+e^- \to \pi^+\pi^-\psi(3686)$. The triangles (red) are twice of our results.

Observation of $e^+e^- \to \pi^0\pi^0 h_c$ and a Neutral Charmoniumlike Structure $Z_c(4020)^0$

TABLE III. Energies ($\sqrt{s}$), numbers of events ($n^{obs}_{Z_c(4020)^0}$), initial state radiative correction factor $(1+\delta^r)$ [4], vacuum polarization factor $(1+\delta^v)$, average efficiencies $[\sum_{i=1}^{16}\epsilon_i\mathcal{B}(\eta_c\to X_i)]$, Born cross sections $\sigma(e^+e^-\to\pi^0 Z_c(4020)^0\to\pi^0\pi^0 h_c)$, and ratios $\mathcal{R}_{\pi Z_c(4020)} = \sigma(e^+e^-\to\pi^0 Z_c(4020)^0\to\pi^0\pi^0 h_c)/\sigma(e^+e^-\to\pi^\pm Z_c(4020)^\mp\to\pi^\pm\pi^\mp h_c)$, where the third errors are from the uncertainty in $\mathcal{B}(h_c\to\gamma\eta_c)$ [15].

$\sqrt{s}$ (GeV)	$n^{obs}_{Z_c(4020)^0}$	$(1+\delta^r)$	$1+\delta^v$	$\sum_{i=1}^{16}\epsilon_i\mathcal{B}(\eta_c\to X_i)$	$\sigma^B(e^+e^-\to\pi^0 Z_c(4020)^0\to\pi^0\pi^0 h_c)$ (pb)	$R_{\pi Z_c(4020)}$
4.230	21.7 ± 7.4	0.756	1.056	7.08×10^{-3}	$6.5\pm2.2\pm0.7\pm1.0$	$0.77\pm0.31\pm0.25$
4.260	22.5 ± 7.7	0.831	1.054	6.72×10^{-3}	$8.5\pm2.9\pm1.1\pm1.3$	$1.21\pm0.50\pm0.38$
4.360	17.2 ± 7.2	0.856	1.051	6.56×10^{-3}	$9.9\pm4.1\pm1.3\pm1.5$	$1.00\pm0.48\pm0.32$

Summary

- The cross section for the process $e^+e^- \rightarrow \pi^+ \pi^- J/\psi$ is measured precisely at center-of-mass energies from 3.77 to 4.60 GeV.
- Two resonant structures are observed in a fit to the cross section. The first resonance agrees with the Y(4260) resonance reported by previous experiments. The mass and width of the second resonance agree with the Y(4360) resonance reported by the BABAR and Belle experiments within errors.
- We also give a review on the measurement of Born cross-section for different channels from BESIII.