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Hadronic transitions above 4 GeV at BESIII

Liang Yan[*†]
University of Turin and INFN
E-mail: liang.yan@to.infn.it

The vector Charmounium(-like) states 1^{--} could be generated via e^+e^- collision and their properties are still mysterious. Recently, more than $5fb^{-1}$ data above 4 GeV are accumulated at BESIII, which supply a good chance to study these states. In this paper, we present the studies of hadronic transitions including $e^+e^- \to \pi^+\pi^- J/\psi$, $e^+e^- \to \pi^+\pi^- h_c$, $e^+e^- \to \pi^+\pi^-\psi(3686)$, $e^+e^- \to \omega\chi_{cJ}$, $e^+e^- \to \eta J/\psi$, $e^+e^- \to \eta' J/\psi$ and $e^+e^- \to \pi^0\eta J/\psi$.

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[*]Speaker.

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1. Introduction

In the charmonium family, all of the (narrow) states below the $2m_D$ open-charm mass threshold have been established and found to have properties that are well described by the potential model. Although all of the $J^{PC} = 1^{--}$ states above the $2m_D$ open-charm threshold have also been predicted, not all of them has been observed in experiment. Starting from B-factories, a large number of charmonium-like states or called XYZ states are observed in the final states with a $c\bar{c}$ states and light hadrons, which could be the charmonium states, but they also have some strange properties, which makes them more like exotic states. $Y(4260)$ was observed by BaBar [1] in the $\pi^+\pi^- J/\psi$ spectrum, then confirmed by Belle [2] and CLEO [3] experiments. Besides, there is a board structure around 4008 MeV in Belle data, which still need confirmation. In the process of $e^+e^- \to \gamma_{\rm ISR}\pi^+\pi^-\psi(3686)$, BaBar [4] observed a structure around 4320 MeV, while Belle observed two structures at 4360 and 4660 MeV [5]. The updated BaBar measurement confirmed these two states [6]. From the end of 2012, BESIII started to taken data above 4 GeV. Around the Y states peak positions, there are several data samples with large statistics, which can be used to study the decays of these states. There are scan data samples at different energy points from 3.8 GeV to 4.6 GeV, which can be used to study the Y states themselves. In this paper, the studies of the hadronic transitions of the Y states based on the BESIII data are presented.

2. $e^+e^- \to \pi^+\pi^- J/\psi$, $e^+e^- \to \pi^+\pi^- h_c$ and $e^+e^- \to \pi^+\pi^-\psi(3686)$

Based on the data sample collected at center-of-mass (CM) energies from $\sqrt{s} = 3.77$ to 4.60 GeV, the Born cross sections of $e^+e^- \to \pi^+\pi^- J/\psi$ are measured [7]. Two groups of data samples have been used, the one with luminosity larger than 40 pb^{-1} is referred as XYZ data sample, the one with luminosity smaller than 20 pb^{-1} is referred as scan data sample. As the Fig. 1 shows, two resonant structures are observed, one with a mass of $(4222.0 \pm 3.1 \pm 1.4)$ MeV/c^2 and a width of $(44.1 \pm 4.3 \pm 2.0)$ MeV, and the other with a mass of $(4320.0 \pm 10.4 \pm 7.0)$ MeV/c^2 and a width of $(101.4^{+25.3}_{-19.7} \pm 10.2)$ MeV, where the first errors are statistical and the second ones systematic. The first resonance with a mass near 4.22 GeV corresponds to the $Y(4260)$ resonance reported by *BABAR*, CLEO and Belle. But the mass is lower and the width is narrower than the $Y(4260)$ parameters reported by previous experiments. The second resonance near 4.32 GeV/c^2 is observed for the first time in the process $e^+e^- \to \pi^+\pi^- J/\psi$. Its statistical significance is estimated to be larger than 7.6σ. Since the continuum term could also describe the cross sections around 4 GeV, the existence of the $Y(4008)$ is not confirmed with our measurement.

We also measure the $e^+e^- \to \pi^+\pi^- h_c$ Born cross section using data at 79 CM energy points from 3.896 to 4.600 GeV [8]. Comparing with the cross sections of $e^+e^- \to \pi^+\pi^- J/\psi$, they are in the same order of magnitude, but different line shape. In Fig. 2, two resonances are used to describe $\pi^+\pi^- h_c$ cross section. We obtain $M = (4218.4 \pm 4.0 \pm 0.9)$ MeV/c^2 and $\Gamma = (66.0 \pm 9.0 \pm 0.4)$ MeV for $Y(4220)$, and $M = (4391.6 \pm 6.3 \pm 1.0)$ MeV/c^2 and $\Gamma = (139.5 \pm 16.1 \pm 0.6)$ MeV for $Y(4390)$, with a relative phase of $\phi = (3.1 \pm 1.5 \pm 0.2)$ rad. The parameters of these structures are different from those of $Y(4260)$, $Y(4360)$, and $\psi(4415)$. The resonance parameters of $Y(4220)$ are consistent with those of the resonance observed in $e^+e^- \to \omega\chi_{cJ}$ [9]. The two resonances observed in $e^+e^- \to \pi^+\pi^- h_c$ process are located in the mass region between 4.2 and 4.4 GeV/c^2,

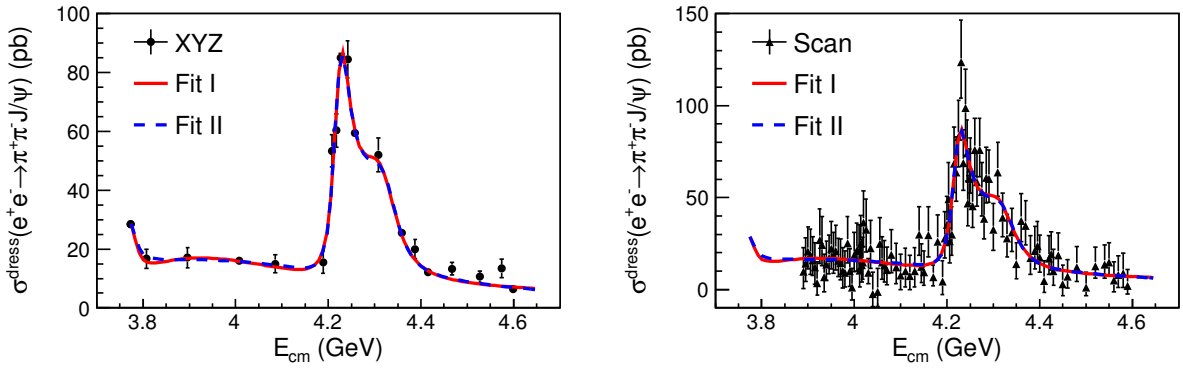

Figure 1: Measured dressed cross section $\sigma^{\rm dress}(e^+e^-\to\pi^+\pi^-J/\psi)$ and simultaneous fit to the "XYZ data" (left) and "Scan data" (right) with the coherent sum of three Breit-Wigner functions (red solid curves) and the coherent sum of an exponential continuum and two Breit-Wigner functions (blue dashed curves). Dots with error bars are data.

where the vector charmonium hybrid states are predicted from various QCD calculations [10, 11]. The mass of $Y(4220)$ is lower than that of the previous $Y(4260)$ observed B-factories, and consistent with the new BESIII measurement. The smaller mass is consistent with some of the theoretical calculations for the mass of $Y(4260)$ when explaining it as a $D_1\bar{D}$ molecule [12, 13].

Based on the data samples collected at 16 CM energy points from 4.008 to 4.6 GeV, two $\psi(3686)$ decay modes $\pi^+\pi^-J/\psi$ and $\pi^0\pi^0J/\psi$ are used to measure the cross sections of $e^+e^-\to\pi^+\pi^-\psi(3686)$. The preliminary results of the line shape confirm the $Y(4360)$, and more data will be taken for the study in the region between 4.2 and 4.3 GeV.

3. $e^+e^-\to\omega\chi_{cJ}$

To understand the properties of the $Y(4260)$, the $e^+e^-\to\omega\chi_{cJ}$ modes are measured based on the data samples collected with BESIII detector [9]. The ω meson is reconstructed via its $\pi^+\pi^-\pi^0$ decay mode, the χ_{c0} state is via $\pi^+\pi^-$ and K^+K^- decays, and the $\chi_{c1,2}$ states are via $\chi_{c1,2}\to\gamma J/\psi$, $J/\psi\to\ell^+\ell^-$ $(\ell=e,\ \mu)$. The process $e^+e^-\to\omega\chi_{c0}$ is observed at $\sqrt{s}=4.23$ and 4.26 GeV for the first time. The Born cross sections are measured to be $(55.4\pm6.0\pm5.9)$ and $(23.7\pm5.3\pm3.5)$ pb, respectively, for other energy points, no significant signals are found and upper limits on the cross section at the 90% C.L. are determined. Figure 3 shows the measured cross section at each energy point. Assuming the $\omega\chi_{c0}$ signals are from one single resonance, a phase-space modified Breit-Wigner function is used to extract the parameters of this resonance with mass $(4230\pm8\pm6)$ MeV/c^2 and width $(38\pm12\pm2)$ MeV. The parameters are not consistent with those of the $Y(4260)$ [1]. This suggests that the observed $\omega\chi_{c0}$ signals be unlikely to originate from the $Y(4260)$.

4. $e^+e^-\to\eta J/\psi$ and $\eta' J/\psi$

The studies of $e^+e^-\to\eta J/\psi$ and $e^+e^-\to\eta' J/\psi$ are also performed, which can be used

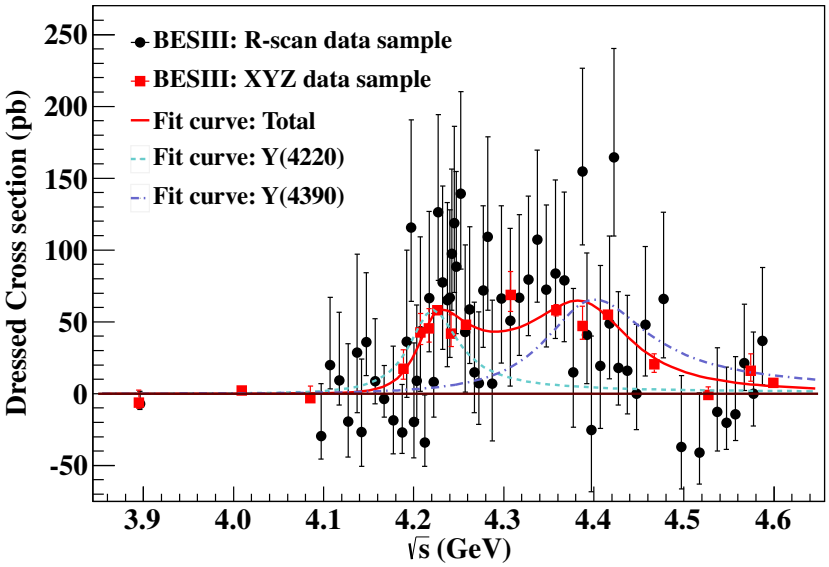

Figure 2: Fit to the dressed cross section of $e^+e^- \to \pi^+\pi^- h_c$ with the coherent sum of two Breit-Wigner functions (solid curve). The dash (dash-dot) curve shows the contribution from the two structures $Y(4220)$ ($Y(4390)$). The dots with error bars are the cross sections for scan data sample, the squares with error bars are the cross sections for XYZ data sample. Here the error bars are statistical uncertainty only.

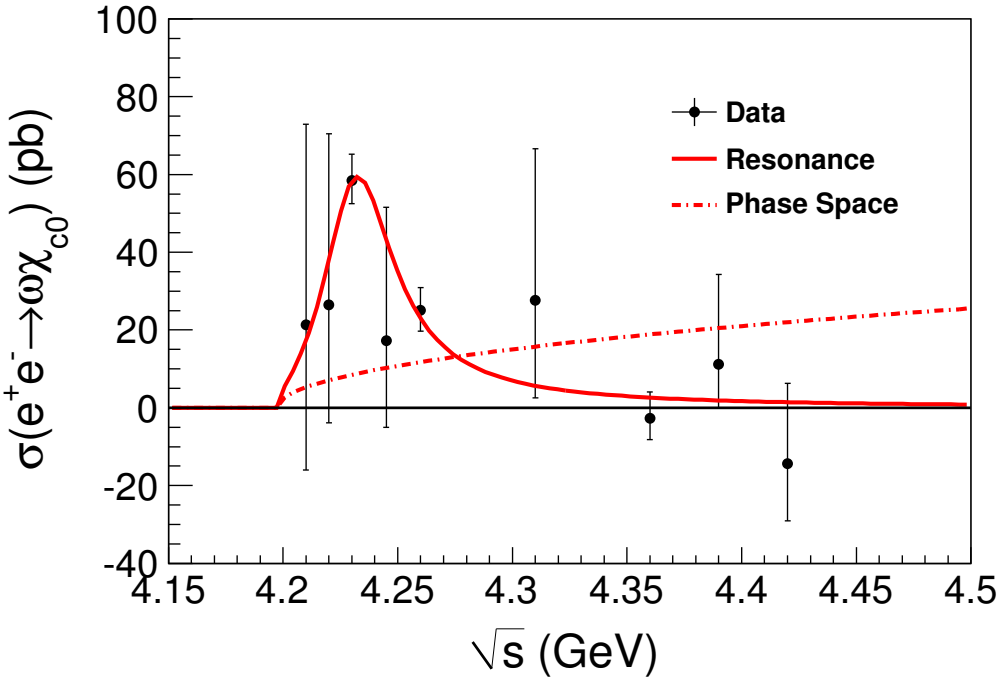

Figure 3: Fit to $\sigma(e^+e^- \to \omega\chi_{c0})$ with a resonance (solid curve), or a phase space term (dot-dashed curve). Dots with error bars are the dressed cross sections. The uncertainties are statistical only.

to provide useful information about Y states. For the $\eta J/\psi$ process, Belle, BESIII and CLEO-c have measured its cross sections above the $2m_D$ open-charm threshold [14, 15, 16]. Recently, BESIII measured the cross sections of $e^+e^- \to \eta J/\psi$ in the CM energies from 3.810 GeV to 4.600 GeV [17], where η are reconstructed by two photons, and J/ψ by the lepton pairs. Statistically significant signals are observed at $\sqrt{s}$ = 4.190, 4210, 4220, 4230, 4245, 4260, 4360 and 4420 GeV, and the corresponding Born cross sections are measured. We searched for the process $e^+e^- \to \pi^0 J/\psi$ using same data samples. No significant signals are observed and the upper limits at the 90% C.L. on the Born cross section are set. The measured Born cross sections are compared to

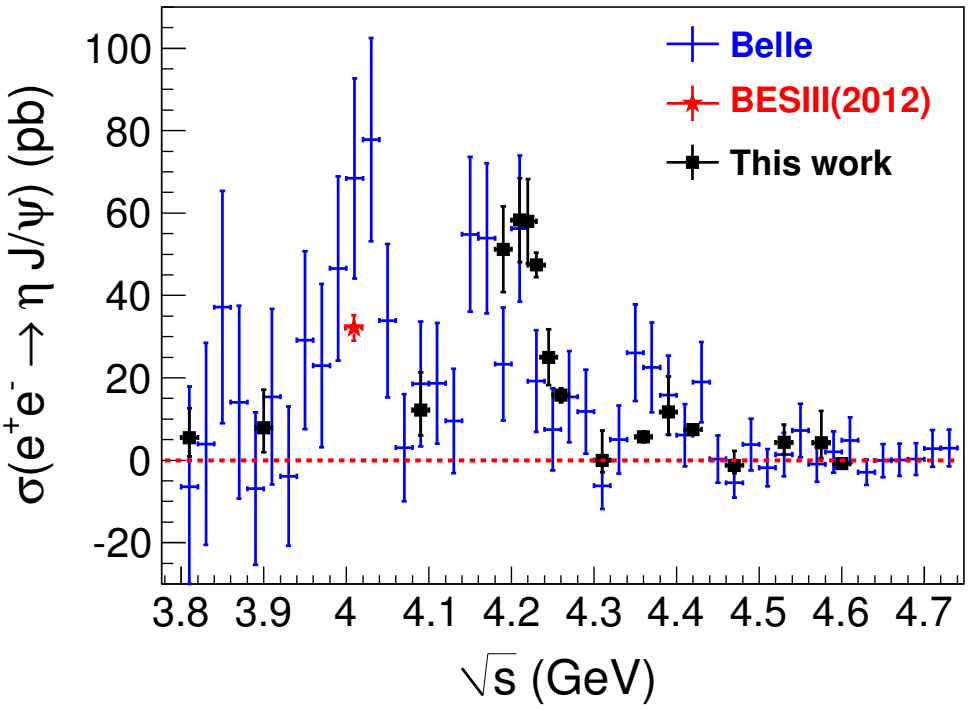

Figure 4: The black square dots are the results of $\eta J/\psi$ obtained in this work, the red star dots are from BESIII(2012) and the blue dots are results of $\pi^+\pi^- J/\psi$ from Belle.

that of $e^+e^- \to \pi^+\pi^- J/\psi$ obtained from Belle [18] as shown in Fig. 4. Different lineshapes are observed in these two processes, which indicate that the production mechanism of the $\eta J/\psi$ differs from that of $\pi^+\pi^- J/\psi$ in the vicinity of $\sqrt{s}$ = 4.1-4.6 GeV. This could indicate the existence of a rich spectrum of Y states in this energy region with different coupling strengths to the various decay modes.

To measure the cross sections of $e^+e^- \to \eta' J/\psi$, the data collected at 14 energy points $\sqrt{s}$ from 4.189 to 4.600 GeV are used [19]. The J/ψ is reconstructed through its decays into lepton pairs $J/\psi \to \ell^+\ell^-$ ($\ell = e$ or μ), while the η' is reconstructed in two decay channels, $\eta' \to \eta\pi^+\pi^-$ (with $\eta \to \gamma\gamma$) and $\eta' \to \gamma\pi^+\pi^-$. Significant $e^+e^- \to \eta' J/\psi$ signals are observed at $\sqrt{s} = 4.226$ and 4.258 GeV for the first time, and the corresponding Born cross sections are measured to be $(3.7 \pm 0.7 \pm 0.3)$ and $(3.9 \pm 0.8 \pm 0.3)$ pb, respectively. The upper limits of Born cross sections at the 90% C.L. are set for the other 12 center-of-mass energy points where no significant signal is

observed. The measured cross sections support the hypothesis that signal events of $\eta' J/\psi$ come from $\psi(4160)$ decays, the contribution of $\psi(4415)$ is not evident.

5. $Y(4260) \to \eta\pi^0 J/\psi$

The isospin violation process $Y(4260) \to \eta\pi^0 J/\psi$ with $J/\psi \to e^+e^-/\mu^+\mu^-$, $\pi^0 \to \gamma\gamma$, and $\eta \to \gamma\gamma$ is used to probe the nature of heavy quarkonium based on data samples at CM energies of $\sqrt{s}$ = 4.009, 4.226, 4.257, 4.358, 4.416, and 4.599 GeV [20]. No statistically significant signal is observed. The Born cross sections of $e^+e^- \to J/\psi\eta\pi^0$ at the 90% confidence level limits are determined to be 3.6, 1.7, 2.4, 1.4, 0.9, and 1.9 pb, respectively. The upper limits are well above the prediction for the molecule model [21].

6. Summary

With the data collected at BESIII above 4 GeV, different hadronic transitions are studied to provide better understanding of the Y states. By comparing with previous measurements from *BABAR*, CLEO and Belle, the nature of famous $Y(4260)$ state are well discussed. In the further, more exciting results are expected from BESIII to help us further understand Y states.

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