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Vector charmonium-like states at BESIII

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BESIII experiment is the only electron positron experiment working in the τ-charm energy region in the world now, and on which the largest sample about Charmonium states has been taken. The Charmonium-like states, which are hadron states beyond the naive quark model are studied with this sample, in the Charmonium plus light hadron, light hadron only and leptonic final states.

Keywords: Charmonium states; BESIII.

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1. Introduction

Charmonium-like states are hadron states with similar properties as the $c\bar{c}$ system, but do not fit into the naive quark model if we assume their inner components are pure $c\bar{c}$. Above the open charm threshold, four well-established Charmonium states have been observed in the inclusive hadronic cross section, *i.e.*, $\psi(3770)$, $\psi(4040)$, $\psi(4160)$ and $\psi(4415)$. However a few additional states, i.e., Y(4008), Y(4260), Y(4360) and Y(4660) were reported, of which the properties are not well determined. For a recent review, please refer to [1].

For the vector Charmonium-like state with $J^{PC} = 1^{--}$, it could be produced directly from electron positron annihilation as photon has the same quantum numbers also. Thus the basic method for searching for such states at BESIII is to look for the cross section enhancement in different final states, such as the Charmonium plus light hadron final states, pure light hadron final states and leptonic final states.

2. Charmonium plus light hadron final states

For a vector Charmonium-like states, there is often the $c\bar{c}$ component inside, even though the $c\bar{c}$ should not be the only component, its transition to conventional Charmonium state plus light hadron is believed to be allowed. Actually, for most of the vector Charmonium-like states, they were observed firstly in the Charmonium plus hight hadron final states.

2.1. Observation of the Y(4220) and Y(4390) in the process $\mathrm{e^+e^-} \to \eta \mathrm{J}/\psi$

With roughly 13.1 fb^{-1} of data at centre of mass energy between 3.81 and 4.60 GeV [2], the cross section of $\mathrm{e^+e^-} \to \eta \mathrm{J}/\psi$ is measured precisely [3]. As shown by the top-left plot in Fig. 1, the cross section of $\mathrm{e^+e^-} \to \eta \mathrm{J}/\psi$ is at the same order as $\mathrm{e^+e^-} \to \pi\pi \mathrm{J}/\psi$, and there are three structures on the cross section line shape, which are found to be consistent with $\psi(4040)$, Y(4220) and Y(4390), respectively. The same process has been studied by Belle Collaboration [4], due the statistics, they claimed two structures on the cross section line shape, one is $\psi(4040)$, and the other is $\psi(4160)$. With the higher statistics at BESIII, we found that when assuming the second structure to be $\psi(4160)$, the significance is 8.1σ less than the assumption of Y(4220).

2.2. Cross section measurement of $\mathrm{e^+e^-} \to \eta' \mathrm{J}/\psi$ from $\sqrt{s}$ = 4.178 to 4.600 GeV

If we change the η to its excited state, η', in the above channel, it is straightforward to study the cross section line shape of $\mathrm{e^+e^-} \to \eta' \mathrm{J}/\psi$ [5], as shown by top right plot in Fig. 1. Enhancement around 4.2 GeV is observed, however it should not be described well by single $\psi(4160)$ or Y(4260). The coherent sum of the two offers a better description.

2.3. Observation of $\mathrm{e^+e^-} \to \eta\psi(2\mathrm{S})$ at center-of-mass energies from 4.236 to 4.600 GeV

Again, if we change the J/ψ to its exited state, $\psi(2S)$, the decay channel becomes $\mathrm{e^+e^-} \to \eta\psi(2\mathrm{S})$. After combining a few data samples together, this process is observed for the first time [6], as shown by the bottom left plot in Fig. 1. Due to the low statistics, it is hard to get the information about whether there is a vector Charmonium-like state or not, and this means that more data is needed.

2.4. Study of the process $\mathrm{e^+e^-} \to \eta_\mathrm{c} 3\pi$

The cross section of $\mathrm{e^+e^-} \to \eta_\mathrm{c} 3\pi$ is measured [7], as shown by bottom left plot in Fig. 1. The process is observed for the first time with the significance of 5.2σ, and the cross section line shape is consistent with Y(4260) even though more data is needed to pin it down.

2.5. Measurement of $\mathrm{e^+e^-} \to \gamma\chi_{\mathrm{c0,c1,c2}}$ cross sections at center-of-mass energies between 3.77 and 4.60 GeV

As shown by Fig. 2, the $\mathrm{e^+e^-} \to \gamma\chi_{\mathrm{c1}}$ and $\mathrm{e^+e^-} \to \gamma\chi_{\mathrm{c2}}$ are observed for the first time at BESIII, with a significance of 7.6σ and 6.0σ, respectively, at 4.178 GeV [8]; as for $\mathrm{e^+e^-} \to \gamma\chi_{\mathrm{c0}}$, only a production cross section upper limit is reported. One new resonance is needed to describe the cross section of $\mathrm{e^+e^-} \to \gamma\chi_{\mathrm{c2}}$, whose mass and width are

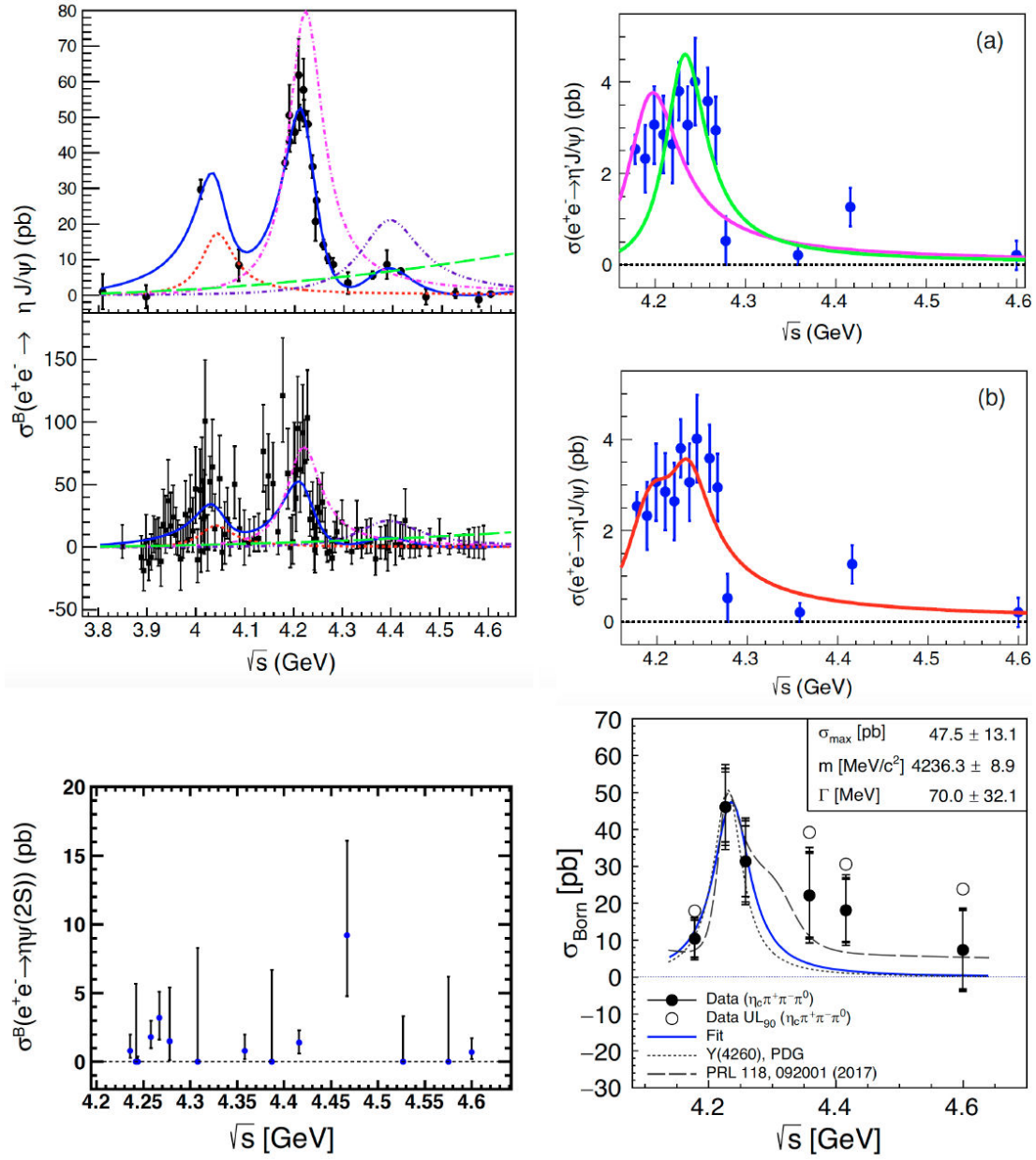

FIGURE 1. The cross section lineshape of $e^+e^- \to \eta J/\psi$ (top-left), $e^+e^- \to \eta\psi(2S)$ (top-right), $e^+e^- \to \eta' J/\psi$ (bottom-left) and $e^+e^- \to \eta_c\pi^+\pi^-\pi^0$ (bottom-right).

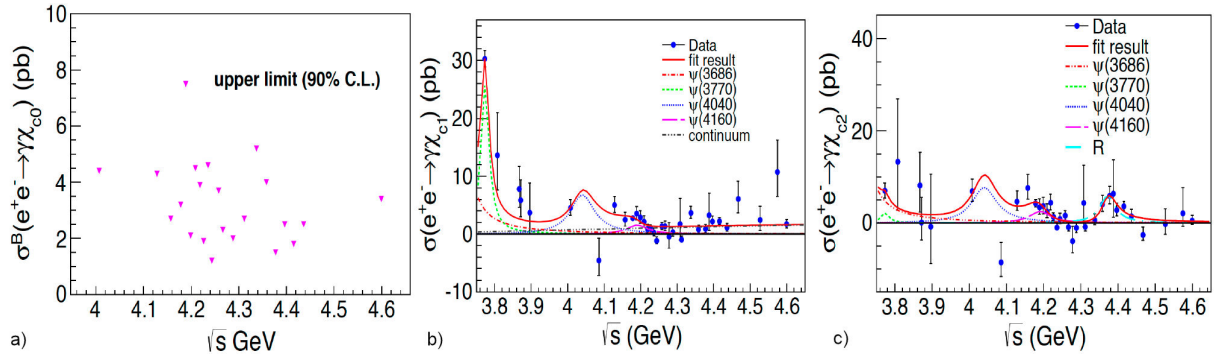

FIGURE 2. The cross section line shape of $e^+e^- \to \gamma\chi_{c0}$ (left), $e^+e^- \to \gamma\chi_{c1}$ (middle), $e^+e^- \to \gamma\chi_{c2}$ (right).

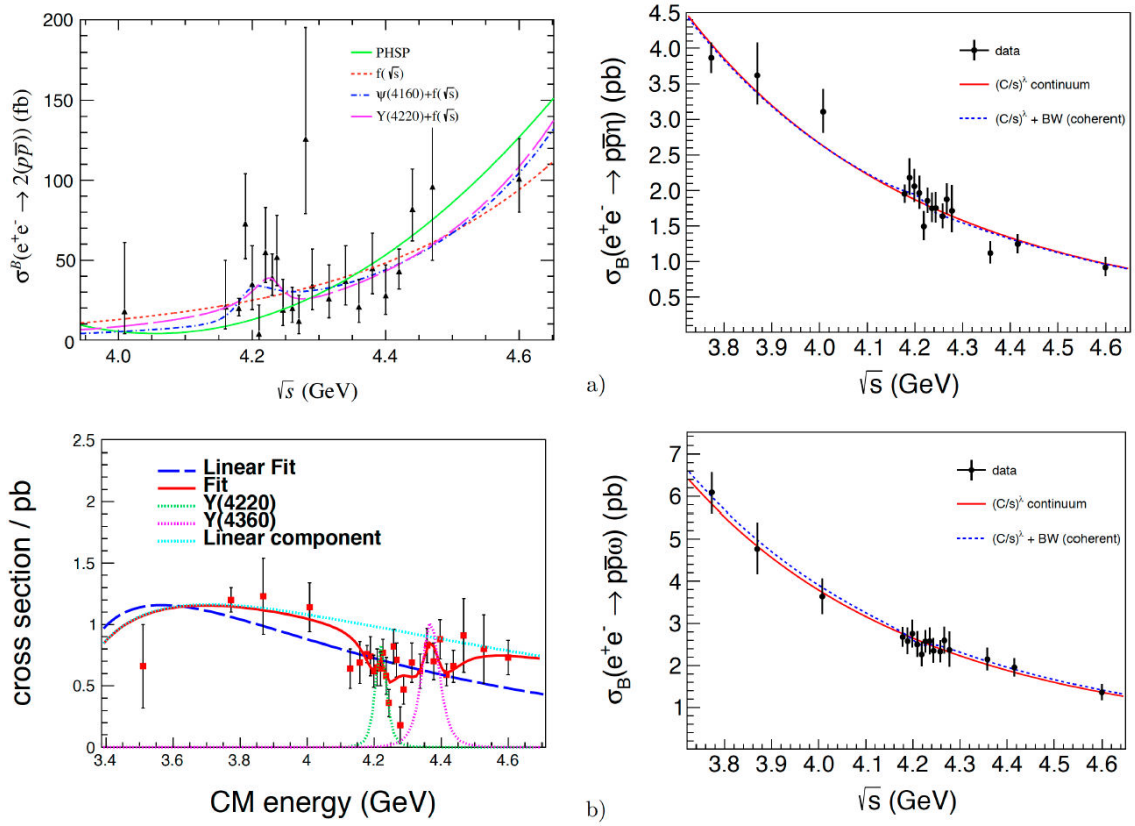

FIGURE 3. The cross section lineshape of $e^+e^- \to 2(p\bar{p})$ (top-left), $e^+e^- \to \eta(p\bar{p})$ (top-right), $e^+e^- \to \phi\Lambda\bar{\Lambda}$ (bottom-left) and $e^+e^- \to \omega(p\bar{p})$ (bottom-right).

consistent with Y(4360). We found that the branching fraction of $\psi(4160) \to \gamma\chi_{c2}$ is larger than the prediction from the potential model [9].

3. Light hadron final states

Until now, even though all the vector Charmonium-like states are observed in the final states which contain charm quark, the search for in the light hadron final states will shed light on their properties. As shown in Fig. 3, the cross section line shapes of $e^+e^- \to \phi\Lambda\bar{\Lambda}$, $e^+e^- \to 2(p\bar{p})$, $e^+e^- \to \eta(p\bar{p})$ and $e^+e^- \to \omega(p\bar{p})$ are measured [10–12]. With the current precision, no significant vector Charmonium-like state is observed in the above mentioned final states.

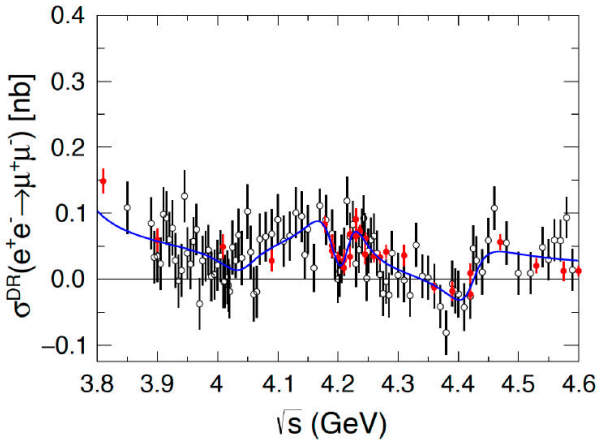

FIGURE 4. The cross section of $e^+e^- \to \mu^+\mu^-$ after subtracting the continuum and $\psi(3686) \to \mu^+\mu^-$.

4. Leptonic final states

Even though the background from continuum $e^+e^- \to \mu^+\mu^-$ is high, the search for vector Charmonium-like state is performed at center-of-mass energies from 3.80 to 4.60 GeV [13], as shown by Fig. 4. After subtracting the continuum and $\psi(3686) \to \mu^+\mu^-$ contribution, a hint for a resonance with mass around 4.22 GeV is observed.

5. Summary

The vector Charmonium-like states are studied in a various of different final states, and the results about open charm final states which are believed to be the main decay channels will be released soon.

The BESIII experiment will continue to run for roughly 10 years at higher energy with higher luminosity [14]. With the new data, along with newly developed analysis technique, such as the newly proposed method to deal with the initial state radiation [15], more results will be published on this topic in the near future.

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