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XYZ states at BESIII

Weimin Song[a,*]

[a] *College of Physics, Jilin University, 2699 Qianjin Street, Changchun, China*

E-mail: weiminsong@jlu.edu.cn

Exotic hadron states, which are called XYZ particles also, are beyond the quark model scope, even though they are allowed by the Quantum Chromodynamics. As a τ-charm factory, BESIII experiment has collected the largest electron-positron collision data in the τ-charm region, which could be used to study XYZ states. In this paper, the recent results from BESIII about X(3872) and vector Charmonium-like states will be reviewed.

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*Speaker

1. The study of X(3872) decays

The X(3872) state, which was observed by Belle Collaboration in 2003 [1], has been studied in very details for its mass, quantum numbers, production and decay properties, however its inside structure is not pinned down yet. In other words, we still do not know how this state is constructed with quarks and gluons. At BESIII, the X(3872) could be produced via the radiative decay of the Y(4260) [2], and the production cross section peaks around 4.23 GeV, where a huge data set has been collected by BESIII.

1.1 $\mathrm{X(3872)} \to \bar{\mathrm{D}}^0\mathrm{D}^{*0}$

$\mathrm{X(3872)} \to \bar{\mathrm{D}}^0\mathrm{D}^{*0}$ is the main decay mode of X(3872), even though it was discovered in $\mathrm{X(3872)} \to \pi^+\pi^-\mathrm{J}/\psi$ mode. With data of $\sqrt{s}$ between 4.178 GeV and 4.278 GeV at BESIII, $\mathrm{X(3872)} \to \bar{\mathrm{D}}^0\mathrm{D}^{*0}$ is observed with a significance of 7.4σ [3]. The relative branching ratio between $\mathrm{X(3872)} \to \bar{\mathrm{D}}^0\mathrm{D}^{*0}$ and $\mathrm{X(3872)} \to \pi^+\pi^-\mathrm{J}/\psi$ is measured to be 11.77 ± 3.09. The nonresonant three body open charm decay modes, $\mathrm{X(3872)} \to \gamma\bar{\mathrm{D}}^0\mathrm{D}^0$, $\mathrm{X(3872)} \to \pi^0\bar{\mathrm{D}}^0\mathrm{D}^0$ and $\mathrm{X(3872)} \to \gamma\mathrm{D}^+\mathrm{D}^-$ are searched also, however no significant signal is observed.

1.2 $\mathrm{X(3872)} \to \gamma\mathrm{J}/\psi, \gamma\psi(2\mathrm{S})$

The ratio of the branching ratio between $\mathrm{X(3872)} \to \gamma\psi(2\mathrm{S})$ and $\mathrm{X(3872)} \to \gamma\mathrm{J}/\psi$ is predicted based one different scenarios, such as the value to be $(3-4)\times 10^{-3}$ if X(3872) is a $\bar{\mathrm{D}}^0\mathrm{D}^{*0}$ molecule, 1.2-15 if it is a pure charmonium state. The ratio was measured by LHCb [5] and BABAR [5], to be $2.46 \pm 0.64 \pm 0.29$ and 3.4 ± 1.4, respectively. However, the result from Belle is less than 2.1 at 90% confidence level [6]. At BESIII, we find the hint of $\mathrm{X(3872)} \to \gamma\mathrm{J}/\psi$ with 3.5σ, but no $\mathrm{X(3872)} \to \gamma\psi(2\mathrm{S})$. The upper limit on the above ratio is 0.59 at 90% confidence level [3].

1.3 $\mathrm{X(3872)} \to \pi^0\chi_{c1}(1\mathrm{P})$

Using 9.0 fb^{-1} of $\mathrm{e}^+\mathrm{e}^-$ collision data at $\sqrt{s}$ between 4.15 and 4.30 GeV, the $\mathrm{X(3872)} \to \pi^0\chi_{c1}(1\mathrm{P})$ is observed for the first time with the significance greater than 5σ [7]. The ratio between branching fraction of $\mathrm{X(3872)} \to \pi^0\chi_{c1}(1\mathrm{P})$ and that of $\mathrm{X(3872)} \to \pi^+\pi^-\mathrm{J}/\psi$ is measured to be $0.88^{+0.33}_{-0.27} \pm 0.10$. The upper limits at the 90% confidence level for the corresponding ratios for $\mathrm{X(3872)} \to \pi^0\chi_{c0}(1\mathrm{P})$ and $\mathrm{X(3872)} \to \pi^0\chi_{c2}(1\mathrm{P})$ are 19 and 1.1, respectively. The results disfavours the $c\bar{c}$ interpretation of X(3872).

1.4 $\mathrm{X(3872)} \to \omega\mathrm{J}/\psi$

In the decay of $\mathrm{X(3872)} \to \pi^+\pi^-\mathrm{J}/\psi$, the $\pi^+\pi^-$ is found to be mainly from ρ, which means that this process violates the isospin symmetry. For the $\mathrm{X(3872)} \to \omega\mathrm{J}/\psi$, which does not break the isospin symmetry will shed light on the nature of X(3872), if it was discovered solidly. With roughly 11 fb^{-1} data, this process is finally observed with significance larger than 5σ [8], and the ratio between $\mathrm{X(3872)} \to \omega\mathrm{J}/\psi$ and $\mathrm{X(3872)} \to \pi^+\pi^-\mathrm{J}/\psi$ is measured to be $1.6^{+0.4}_{-0.3} \pm 0.2$.

2. The study of the vector Charmonium-like states

The vector Charmonium-like states with $J^{PC} = 1^{--}$, could be produced directly form electron-positron collision. These states are studied by the cross section line shape scan for different finial states at BESIII.

2.1 Open charm final state

The cross section of $e^+e^- \to \pi^+ D^0 D^{*-}$ for centre of mass energy from 4.05 to 4.60 GeV is measured precisely at BESIII, and two enhancements on the cross section lineshape are observed, as shown by Fig. 1 [9]. For the first structure, its mass if found to be consistent with the Y(4220), and this is the first observation of the Y(4220) in the open charm final state. For the second peak, it could not be explained by any single known resonance, and more data is needed to understand it.

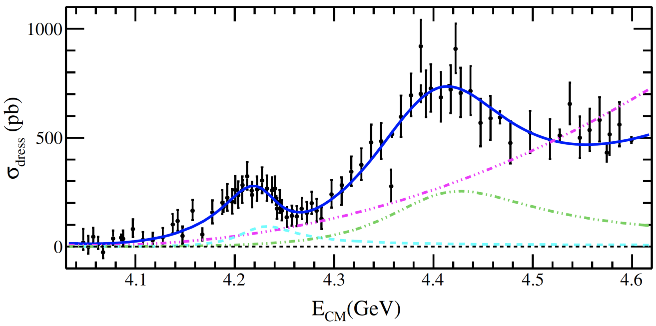

Figure 1: The dressed cross section of $e^+e^- \to \pi^+ D^0 D^{*-}$, where the black dots with error bars are the measured cross sections and the blue line shows the fit result. The error bars are statistical only.

2.2 Light hadron + Charmonium final state

The cross section lineshape of $e^+e^- \to \eta J/\psi$ [10], $e^+e^- \to \eta\psi(2S)$ [11], $e^+e^- \to \eta' J/\psi$ [12] and $e^+e^- \to \eta_c \pi^+\pi^-\pi^0$ [13] are measured, as shown in Fig. 2. The cross section of $e^+e^- \to \eta J/\psi$ is found to be in the same order as the $e^+e^- \to \pi^+\pi^- J/\psi$, and there are 3 structures observed on the cross section line shape which are consistent with the combination of ψ(44040)+Y (4220)+Y(4390). For $e^+e^- \to \eta' J/\psi$, an enhancement on the cross section around 4.2 GeV is observed, but it could not be described by single $\psi(4160)$ nor Y(4260) well. The process of $e^+e^- \to \eta\psi(2S)$ is first observed at BESIII by combining a few data sets together. For the process of $e^+e^- \to \eta_c \pi^+\pi^-\pi^0$, it is first observed at BESIII, and its cross section line shape is consistent with Y(4260).

2.3 Light hadron final state

The cross sections of $e^+e^- \to 2(p\bar{p})$ [14], $e^+e^- \to p\bar{p}\eta$ and $e^+e^- \to p\bar{p}\omega$ [15] are measured, as shown by Fig. 3, no significant structure is observed yet.

3. Summary

As a charm factory, BESIII provides a lot of information about XYZ particles, however there are still lots of open questions about exotic hadron states. BESIII will run an other 10 years [16].

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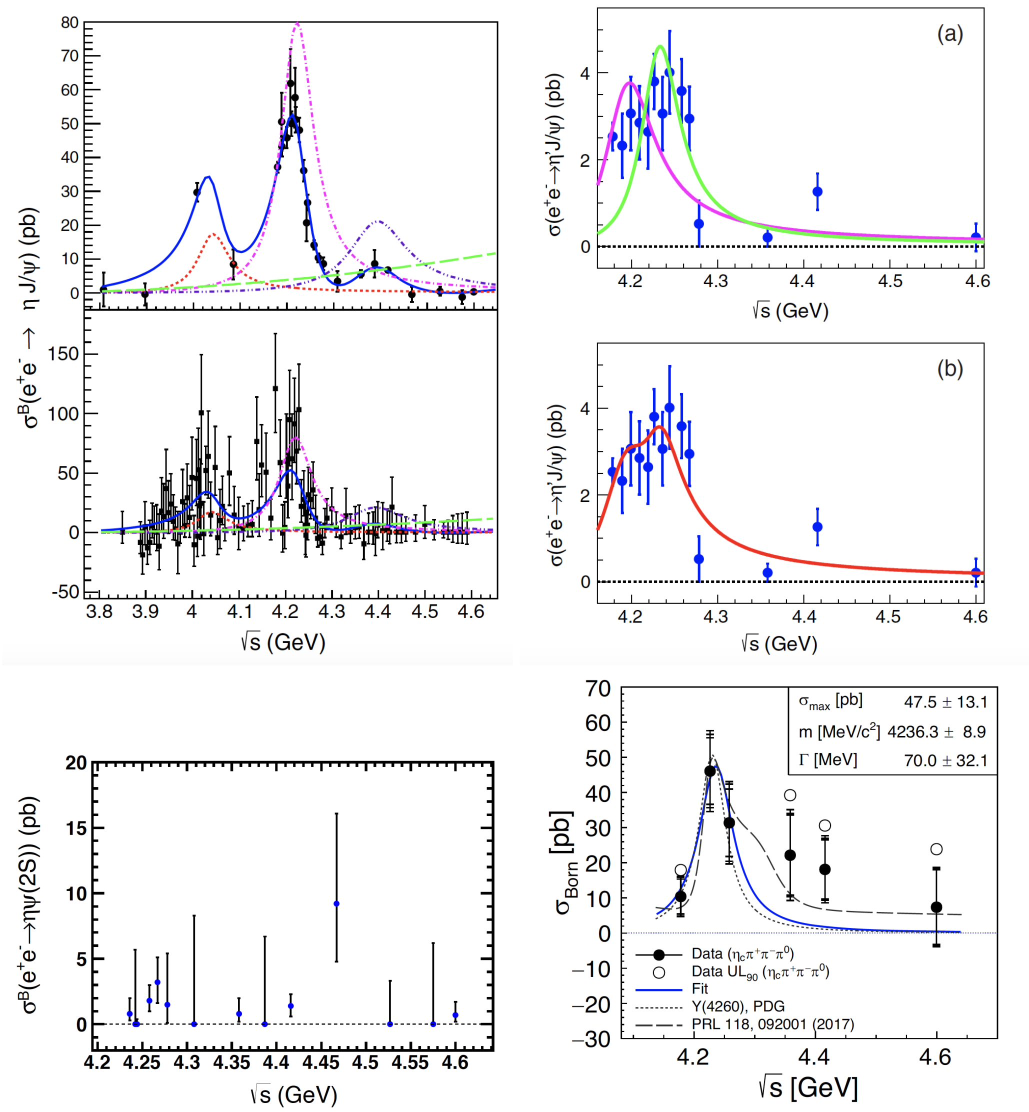

Figure 2: The cross section lineshape of $e^+e^- \to \eta J/\psi$ (top-left), $e^+e^- \to \eta\psi(2S)$ (top-right), $e^+e^- \to \eta' J/\psi$ (bottom-left) and $e^+e^- \to \eta_c\pi^+\pi^-\pi^0$ (bottom-right).

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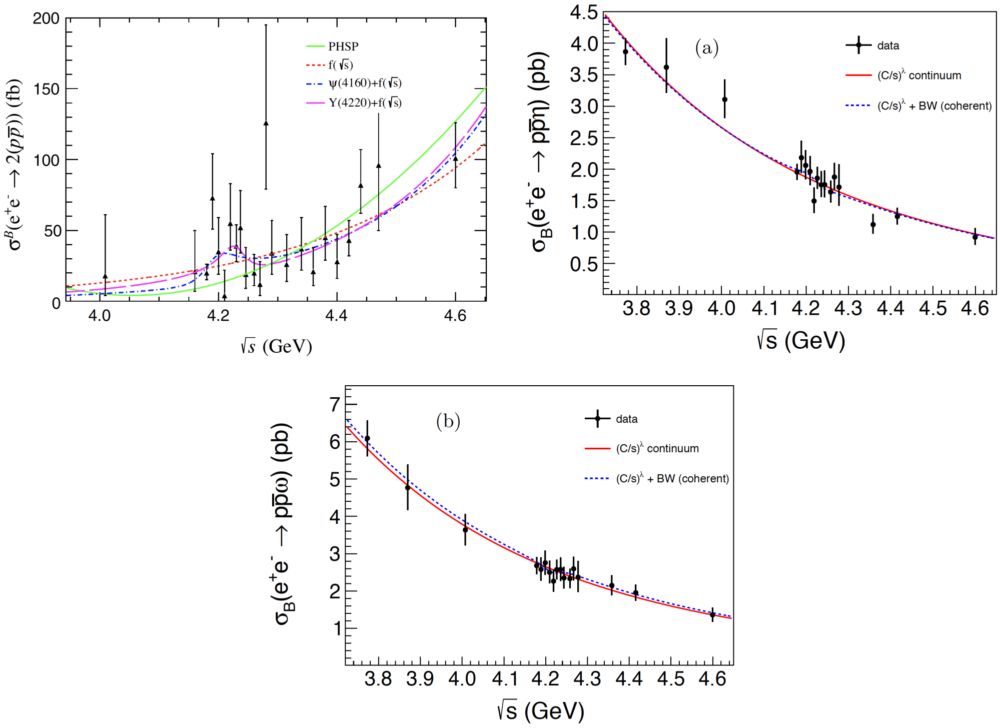

Figure 3: Cross section of $e^+e^- \to 2(p\bar{p})$ (top-left), $e^+e^- \to (p\bar{p}\eta)$ (top-right) and $e^+e^- \to (p\bar{p}\omega)$ (bottom)
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