# XYZ states at BESIII

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**Abstract.** In this proceeding, I report the most recent experimental results from BESIII about the XYZ sates. Two new $X(3872)$ decay modes are observed, which is $X(3872) \to \omega J/\psi$ and $X(3872) \to \pi^0\chi_{c1}(1P)$. Precise measurement of cross sections of various channels reveal more fine structure about Y states. To study the property of $Z_c$ states, the $J^P$ of $Z_c(3900)$ is determined with partial wave analysis, and a hint of new decay mode of $Zc^{\pm}(3900) \to \rho^{\pm}\eta_c$ are observed.

## 1 Introduction

BESIII has collected about $12fb^{-1}$ data above $E_{cms} = 3.8$ GeV. Within this energy region, BESIII has observed a lot of unclassified states which don't suit the standard quark model. These states are named as XYZ states, such as X(3872), Y(4260), $Z_c(3900)$. In BESIII's energy region, the perturbative QCD doesn't works very well. Theoretical method used in this region are not accurate enough, such as lattice QCD, QCD sum rule, effective field theory [1]. This reduce the discrimination power of theoretical calculation with different models. The X(3872) and $Z_c(3900)$ are interpreted as tetra-quark states, molecular states or hybrid, and their nature are still under debate. And also the Y(4260), Y(4360) are not predicted by $(c\bar{c})$ potential model, and don't corresponding to the peak in R-value spectrum [2]. Their property are also under study. So more experimental result would help to understand the nature of these XYZ states.

## 2 X states result

### 2.1 Observation of $X(3872) \to \omega J/\psi$

Using $11.6fb^{-1}$ $e^+e^-$ annihilation data taken at center-of-mass energies from 4.008 GeV to 4.600 GeV, the process $e^+e^- \to \gamma\omega J/\psi$ is studied [3]. The invariant mass of $\omega J/\psi$ of the full data sets is shown in Fig. 1, A clear X(3872) signal can be seen. In the higher mass range, there also seems to be some structures. The fit with additional two structures (Fig. 1(a)) or one structure (Fig. 1(b)) is attempted. The significance of the $X(3872)$ in both cases is estimated to be larger than $5.1\sigma$ after all systematic studies considered. The measured cross section of $e^+e^- \to \gamma X(3872), X(3872) \to \omega J/\psi$ and $e^+e^- \to \gamma X(3872), X(3872) \to \pi^+\pi^- J/\psi$ are both measured and the result are shown in Fig. 1(c)(d). A simultaneous fit is performed to the two distributions, and the peak is fitted with Breit-Wigner function. $M[Y(4200) = 4200.6^{+7.9}_{-13.3} \pm 3.0$ MeV$/c^2$, $\Gamma[Y(4200)] = 115^{+38}_{-26} \pm 12$ MeV. The branching fraction ratio is measured to be $\frac{\mathscr{B}(X(3872)\to\omega J/\psi)}{\mathscr{B}(X(3872)\to\pi^+\pi^- J/\psi)} = 1.6^{+0.4}_{-0.3} \pm 0.2$.

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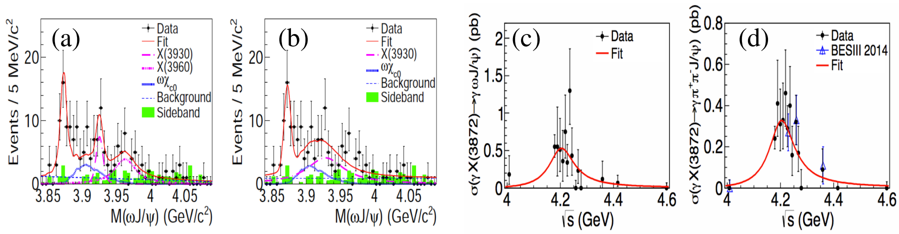


**Figure 1.** The $M(\omega J/\psi)$ fitted with (a) X(3872)+X(3930)+X(3960), (b) X(3872)+ X(3930). The cross section of $\sigma(e^+e^- \to \gamma X(3872)$ times the branching fraction of (c) $X(3872) \to \omega J/\psi$, (d) $X(3872) \to \pi^+\pi^- J/\psi$.

## 2.2 Observation of $X(3872) \to \pi^0\chi_{c1}(1P)$

Using a total of $9fb^{-1}$ of $e^+e^-$ collision data with center-of-mass energies between 4.15 and 4.3 GeV, the process $e^+e^- \to \gamma X(3872)$ with $X(3872) \to \pi^0\chi_{cJ}$ are searched [4]. And Fig. 2(a) shows the sum of all the three $\pi^0\chi_{cJ}$ invariant mass distribution, a clear $X(3872)$ peak can be seen. And Fig. 2(b) shows the $M(\gamma\chi_{cJ})(J = 1, 2, 3)$ after selecting the $X(3872)$ signal region, most of the signal is within $\chi_{c1}$ region. The $X(3872)$ signal within $\chi_{c1}$ region is shown in Fig. 2(c) . The statistical significance of $X(3872) \to \pi^0\chi_{c1}$ is greater than $5\sigma$ for all systematic variations. The $X(3872) \to \pi^+\pi^- J/\psi$ channel is also measured as reference channel, and the branching fraction ratio $\frac{\mathcal{B}(X(3872)\to\pi^0\chi_{c1})}{\mathcal{B}(X(3872)\to\pi^+\pi^- J/\psi)} = 0.88^{+0.33}_{-0.27} \pm 0.10$. The upper limits(at the 90% C.L.) for the corresponding ratios for the $\pi^0\chi_{c0}$ and $\pi^0\chi_{c2}$ are 19 and 1.1, respectively. This measured ratio is too large for the charmonium interpretation of the $X(3872)$ [5].

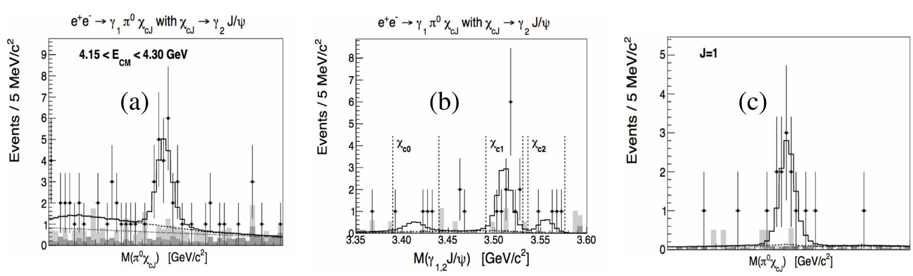


**Figure 2.** (a)The $M(\pi^0\chi_{cJ})(J = 0, 1, 2)$ for data samples with $4.15 < E_{cms} < 4.3$ GeV. (b) $M(\gamma J/\psi)$ after selecting the $X(3872)$ signal region. (c) $M(\pi^0\chi_{cJ})$ within $\chi_{c1}$ region.

# 3 Y states result

Thanks to the high luminosity data samples taken by BESIII at dozens of energy points in open charm region. We can measure the cross sections more precisely than before. Some fine structure can be seen now. For example, the cross section of $e^+e^- \to \pi^+\pi^- J/\psi$, which was though to be dominated by one Y(4260) peak, now need to be explained by two Breit-Wigner structure [6], Fig. 3(a). And the mass of the previous Y(4260) now has a much lower mass $M(Y(4220)) = 4222.0 \pm 3.1 \pm 1.4$ MeV, and smaller width $\Gamma(Y(4220)) = 44.1 \pm 4.3 \pm 2.0$

MeV. And in $e^+e^- \to \pi^+\pi^-\psi'$, besides the $Y(4360)$ signal, we also observed a small peak which might be Y(4220) with statistical significance of $5.8\sigma$ [7], Fig. 3(b). Similar two peaks structure are also observed on the cross section of $e^+e^- \to \pi^+\pi^-h_c$ [8] and $e^+e^- \to \pi^+D^0D^{*-}$ [9], Fig. 3(c, d). On the cross section of $e^+e^- \to \omega\chi_{c0}$, we only observed one peak with $M = 4218.4 \pm 1.6 \pm 1.3$ MeV, and $\Gamma = 28.3 \pm 3.9 \pm 6.4$ MeV [10], Fig. 3(e). If we plot the mass and width of the peak around 4.2 GeV measured from all these channels on one plot as shown in Fig. 3(f), we can see the mass of all these measurement agree with each other, but the width varied a lot. Further study is needed to clarify this.

We have also measured the cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ [11], the result is shown in Fig. 4. Currently, BESIII only have result at four energy points close to the ($\Lambda_c^+\bar{\Lambda}_c^-$) threshold. BelleII has previous measured this process [12] and the result is also shown on Fig. 4. There is a peak on the cross section which is named as Y(4660). Y(4660) coupled to baryonic final states much stronger than to mesonic states, so Y(4660) was proposed to be a charmed baryonium [13]. However, we can see the BESIII's result doesn't agree with Belle's result very well. BESIII has the plan to take more data above 4.6 GeV, we can expected this to be confirmed when we have more data.

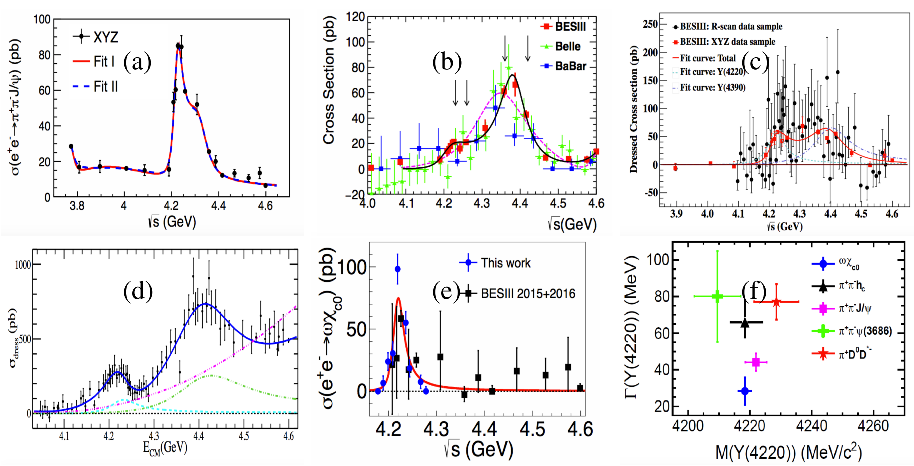


**Figure 3.** The cross section of (a) $e^+e^- \to \pi^+\pi^-J/\psi$, (b)$e^+e^- \to \pi^+\pi^-\psi'$, (c) $e^+e^- \to \pi^+\pi^-h_c$, (d)$e^+e^- \to \pi^+D^0D^{*-}$, (e)$e^+e^- \to \omega\chi_{c0}$. (f)The mass and width of the peak around 4.22 GeV measured from different channels.

## 4 $Z_c$ states result

After the first observation of $Z_c(3900)$, two isospin triplet $Z_c(3900)/Z_c(3885)$ and $Z_c(4020)/Z_c(4025)$ are established by BESIII. They should be the exotic four quark states. Here we reasonably assume that $Z_c(3900)$ and $Z_c(3885)$ are same states, and same for $Z_c(4020)$ and $Z_c(4025)$. The mass of $Z_c(3900)$ and $Z_c(4020)$ are just about 10 MeV higher than $DD^*$ and $D^*D^*$ mass threshold, respectively. And they have strong coupling to $DD^*(D^*D^*)$ channels. About their inner scheme of the four quarks, there are different theoretical models, such as the tetraquark states, $DD^*(D^*D^*)$ molecular states and hybrid. Here we show two result form BESIII aim to study the property of these $Z_c$ states.

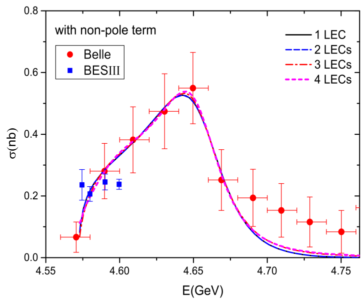


**Figure 4.** The cross section of $e^+e^- \to \Lambda_c^+\bar{\Lambda}_c^-$ from BESIII(blue points) and Belle(red points).

## 4.1 Determination of the Spin and Parity of $Z_c(3900)$

We performed amplitude analysis to $e^+e^- \to \pi^+\pi^- J/\psi$ selected from two samples with $E_{cms}$=4.23 GeV and 4.26 GeV [14]. The spin and parity of $Z_c(3900)^{\pm}$ are determined to be $1^+$ with statistical significance larger than $7\sigma$ than other quantum numbers. The projection of the fit is shown in Fig. 5(a)(b). No hint of $Z_c(4020)$ signal is found in this channel, the statistical significance of $Z_c(4020)$ is $3\sigma$.

## 4.2 Search for $e^+e^- \to \pi^{\mp}Z_c^{(\prime)\pm}, Zc^{(\prime)\pm} \to \rho^{\pm}\eta_c$

The measurement of this channel is important to discriminate different inner scheme of the four quark states. Nine $\eta_c$ decay modes are used to reconstruct $\eta_c$. After the $\eta_c$ and $\rho^{\pm}$ mass window cut, a hint of $Z_c(3900)$ peak can be seen on the recoiled mass of bachelor $\pi^{\mp}$, as shown in Fig. 5(c). At $E_{cms}$ = 4.23 GeV, the statistical significance of $Z_c(3900)^{\pm} \to \rho^{\pm}\eta_c$ is $4.3\sigma$( $3.9\sigma$ when systematic uncertainty considered). No significant $Z_c(4020)^{\pm} \to \rho^{\pm}\eta_c$ is observed. Born cross section at $E_{cms}$ = 4.23 GeV is also measured, $\sigma^B(e^+e^- \to \pi^+\pi^-\pi^0\eta_c)$ = $(46 \pm 12 \pm 10)pb$, $\sigma^B(e^+e^- \to \pi^{\mp}Z_c^{(\prime)\pm}, Zc^{(\prime)\pm} \to \rho^{\pm}\eta_c) = (47 \pm 11 \pm 11)pb$. Combining with the result of $Z_c \to \pi J/\psi$, we can calculate the ratio $R_z = \frac{Z_c \to \rho\eta_c}{Z_c \to \pi J/\psi} = 2.1 \pm 0.8$. If we compare with the theoretical predication given in Ref. [15], we can see our measurement doesn't agree with the molecular states and Type-1 tetraquark model.

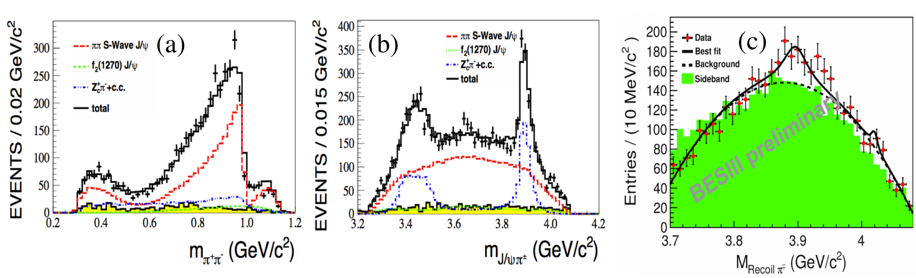


**Figure 5.** The PWA result for $e^+e^- \to \pi^+\pi^- J/\psi$ at 4.23GeV. (a) $M(\pi^+\pi^-)$, (b) $M(\pi^{\pm}J/\psi)$. (c) The recoiled mass of bachelor $\pi^{\mp}$ after the $\rho$ and $\eta_c$ signal region selected.

## 5 Summary

Based on about $12 fb^{-1}$ data samples taken above 3.8 GeV, BESIII has published many new result about the XYZ states, which set more constrain on the models that describe these states. For example, we observed two new $X(3872)$ decay modes, especially the observation of $X(3872) \to \pi^0 \chi_{c1}$ disfavor the charmonium interpretation of X(3872). The hint of $Z_c(3900) \to \rho\eta_c$ disfavor the molecular states and Type-1 tetraquark model interpretation of $Z_c(3900)$. BESIII plan to take more data above 3.8 GeV, more result about XYZ states can be expected.

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