The BESIII experiment

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Abstract.

In this article, we review the recent BESIII experimental studies. We discuss the results on the $X(3872)$, Z_c states [$Z_c(3900)^{\pm}$, $Z_c(3900)^0$ and $Z_c(4020)^0$], and the first observation of $e^+e^- \to \omega\chi_{c0}$ at $\sqrt{s} = 4.23$ and 4.26 GeV.

1. Introduction

Exotic hadrons including glueballs, hybrids, multi-quark states and hadron molecules have been searched for and many candidates were proposed. However, no solid conclusion was reached.

The BESIII [1] experiment at the BEPCII collider started data taking in 2009, and lots of data were accumulated at the peaks of the J/ψ, $\psi(2S)$, and $\psi(3770)$, as well as at above 4 GeV, these high energy data make the study of the exotic states (XYZ states) possible.

2. Observation of $e^+e^- \to \gamma X(3872)$

The $X(3872)$ was first observed by Belle in $B^{\pm} \to K^{\pm}\pi^+\pi^- J/\psi$ decays. Since its discovery, the $X(3872)$ has been interpreted as a candidate for a hadronic molecule or a tetraquark state. Until now, the $X(3872)$ was only observed in B meson decays and hadron collisions.

BESIII measured the process $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi$, $J/\psi \to \ell^+\ell^-$ ($\ell^+\ell^- = e^+e^-$ or $\mu^+\mu^-$) at e^+e^- center-of-mass (CM) energies from $\sqrt{s} = 4.009$ GeV to 4.420 GeV [2].

Figure 1 shows the $M(\pi^+\pi^- J/\psi)$ distribution (summed over all CM energy data sets) with the fitted results, which gives $M[X(3872)] = (3871.9 \pm 0.7_{\text{stat.}} \pm 0.2_{\text{sys.}})$ MeV/c^2. The statistical significance of $X(3872)$ is 6.3σ. Figure 2 shows the energy-dependent cross section together with the fitted results with a $Y(4260)$ resonance, a linear continuum, or a $E1$-transition phase space term. The $Y(4260)$ resonance describes the data better than the other two options, which strongly supports the existence of the radiative transition process $Y(4260) \to \gamma X(3872)$.

3. Observation of charged charmoniumlike state $Z_c(3900)$

Motivated by the striking observations of charged charmoniumlike and bottomoniumlike states, Belle and BESIII investigate the existence of similar states as intermediate resonances in $Y(4260) \to \pi^+\pi^- J/\psi$ decays [3].

Unbinned maximum likelihood fits are applied to the distributions of $M_{\max}(\pi^{\pm}J/\psi)$ from Belle and BESIII data. The signal shape is parameterized as an S-wave Breit-Wigner function convolved with a Gaussian with a mass resolution fixed at the MC simulated value. Figure 3 shows the fit results. The measured masses are $(3899.0 \pm 3.6 \pm 4.9)$ MeV/c^2 and $(3894.5 \pm 6.6 \pm 4.5)$ MeV/c^2 and the measured widths are $(46 \pm 10 \pm 20)$ MeV and $(63 \pm 24 \pm 26)$ MeV/c^2 from

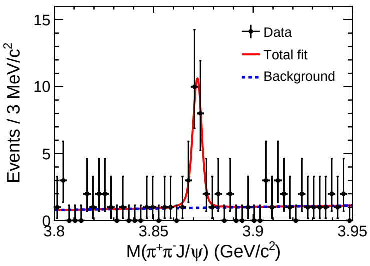

Figure 1. Fit of the $M(\pi^+\pi^-J/\psi)$ distribution. The curve is the total fit result, and the dashed curve shows the background.

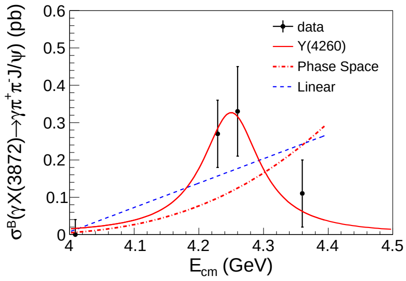

Figure 2. The fit to $\sigma^B[e^+e^- \to \gamma X(3872)] \times \mathcal{B}[X(3872) \to \pi^+\pi^-J/\psi]$.

Belle and BESIII experiments, respectively. They are consistent each other within the errors. The signal significance is greater than 5σ in both of the measurements. This state is close to the $D\bar{D}^*$ mass threshold. As the $Z(3900)^\pm$ state has a strong coupling to charmonium and is charged, it cannot be a conventional $c\bar{c}$ state. Since the observation of the $Z_c(3900)$, there have been a number of different interpretations, including tetraquark state, hadronic molecule, hadron-charmonium state and so on.

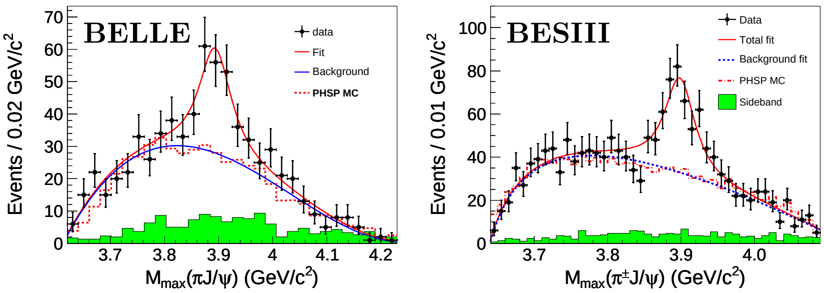

Figure 3. Unbinned maximum likelihood fits to the distributions of the $M_{\max}(\pi J/\psi)$ from Belle and BESIII experimental data. The solid curves are the best fits, the dashed histograms represent the results of phase space distribution and the shaded histograms are J/ψ sidebands.

4. Observation of $e^+e^- \to \pi^0\pi^0 J/\psi$, $\pi^0\pi^0 h_c$ and $Z_c(3900)^0$, $Z_c(4020)^0$

After charged charmoniumlike states $Z_c(3900)^\pm$ [3] and $Z_c(4020)^\pm$ [4] were observed, an important question is whether isospin=0 neutral Z_c partners exist.

Figure 4 shows $M(\pi^0 J/\psi)$ invariant mass distributions including both combinations of $\pi^0 J/\psi$ for events from $\sqrt{s} = 4.26$, 4.36 and 4.23 GeV data samples, respectively. There is a significant peak around 3.9 GeV/c^2 that corresponds to $Z_c(3900)^0$. An unbinned maximum simultaneous likelihood fit is performed to the distributions of $M(\pi^0 J/\psi)$ to extract $Z_c(3900)^0$ parameters. Here the Breit-Wigner functions for the signal shapes are constrained to be the same for all energy points, while the Argus functions as backgrounds have independent parameters. The fitted results are shown in Fig 4. The statistical significance of $Z_c(3900)^0$ is 10.4σ and the measured mass and width are 3894.8 ± 2.3 MeV/c^2 and 29.6 ± 8.2 MeV/c^2, respectively, where the errors are statistical only.

The selections of $\pi^0\pi^0 h_c$ follow closely the analysis of $e^+e^- \to \pi^+\pi^- h_c$ [4] with the selection of $\pi^+\pi^-$ replaced with the selection of a pair of π^0s. The h_c is reconstructed via $h_c \to \gamma\eta_c$

with $\eta_c \to X_i$, where X_i denotes 16 hadronic final states. After the event selections, in the η_c signal region, a clear peak at the h_c mass is observed. The measured Born cross sections together with other information including the ratios of the Born cross sections for the neutral and charged $e^+e^- \to \pi\pi h_c$ modes are listed in Table 1. The combined ratio $\mathcal{R}_{\pi\pi h_c}$ is determined to be (0.63 ± 0.09), which is within 2σ of the expectation of isospin symmetry, 0.5.

Table 1. Energies ($\sqrt{s}$), luminosities ($\mathcal{L}$), numbers of events ($n^{\rm obs}_{h_c}$), Born cross sections $\sigma^{\rm B}(e^+e^- \to \pi^0\pi^0 h_c)$ and ratios $\mathcal{R}_{\pi\pi h_c} = \frac{\sigma(e^+e^- \to \pi^0\pi^0 h_c)}{\sigma(e^+e^- \to \pi^+\pi^- h_c)}$.

$\sqrt{s}$ (GeV)	$\mathcal{L}$ (pb^{-1})	$n^{\rm obs}_{h_c}$	$\sigma^{\rm B}(e^+e^- \to \pi^0\pi^0 h_c)$ (pb)	$\mathcal{R}_{\pi\pi h_c}$
4.230	1090.0	82.5 ± 15.6	$25.6 \pm 4.8 \pm 2.6 \pm 4.0$	$0.54 \pm 0.11 \pm 0.06$
4.260	826.8	62.8 ± 13.3	$24.4 \pm 5.2 \pm 3.2 \pm 3.8$	$0.63 \pm 0.14 \pm 0.10$
4.360	544.5	64.3 ± 11.5	$36.2 \pm 6.5 \pm 4.1 \pm 5.7$	$0.73 \pm 0.14 \pm 0.10$

The h_c signal events are selected by requiring 3.51 GeV/c^2 $< M^{\rm recoil}_{\pi^0\pi^0} <$3.55 GeV/c^2. Figure 5 shows the $M^{\rm recoil}_{\pi^0}|_{\rm max}$ distribution where there is an obvious peak near 4.02 GeV/c^2, which corresponds to the expected position of a $Z_c(4020)^0$ signal.

An unbinned maximum likelihood fit is applied to the $M^{\rm recoil}_{\pi^0}|_{\rm max}$ distribution summed over all 16 η_c decay modes. The data at $\sqrt{s}$ = 4.23, 4.26, and 4.36 GeV are fitted simultaneously with the same signal function with common mass and width. Because of the limited statistics of the $Z_c(4020)^0$ signal, its width is fixed to that of its charged partner [4]. The solid curve in Fig. 5 shows the fit results, which yields a $Z_c(4020)^0$ mass of $4023.6 \pm 2.2_{\rm stat.} \pm 3.9_{\rm sys.}$. The statistical significance is greater than 5.0σ.

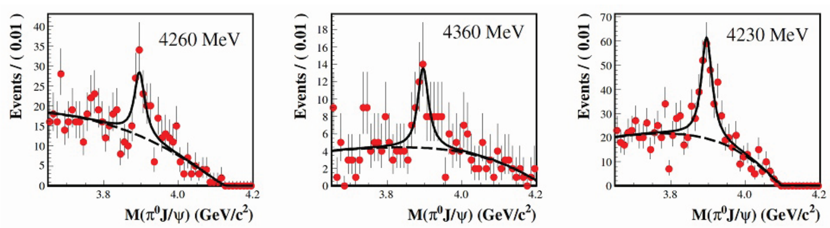

Figure 4. Distributions of $\pi^0 J/\psi$ invariant mass including both combinations of $\pi^0 J/\psi$ from $\sqrt{s}$ = 4.26, 4.36 and 4.23 GeV data samples, respectively. The solid line shows the simultaneous fit result, and the dashed line is the fitted background shape.

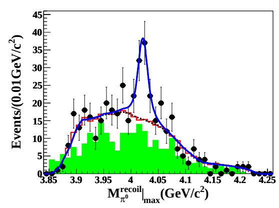

Figure 5. Sum of the simultaneous fit to the $M^{\rm recoil}_{\pi^0}|_{\rm max}$ distribution at $\sqrt{s}$ = 4.23, 4.26 and 4.36 GeV.

5. Study of $e^+e^- \to \omega\chi_{c0}$ at $\sqrt{s}$ from 4.21 to 4.42 GeV

Since the $Y(4260)$ was observed by BaBar, CLEO and Belle experiments [5], many theoretical models were proposed to interpret the $Y(4260)$, *e.g.*, as a quark-gluon charmonium hybrid, a tetraquark state, a hadroncharmonium, or a hadronic molecule. Very recently, the charged charmoniumlike states $Z_c(3900)$ [3] was observed in the data around the $Y(4260)$, which may hint a complicated structure of the $Y(4260)$. Searching for new decay modes and measuring the line shape are very important for understanding the nature of the $Y(4260)$.

In Ref. [6], authors predicted a sizeable coupling between the $Y(4260)$ and the $\omega\chi_{c0}$ channel and suggested the $Y(4260)$ resonance to be a conventional $c\bar{c}$ state renormalized by the $\omega\chi_{c0}$ continuum which plays a role in reducing the decay rates into open charm channels.

Based on data samples collected with the BESIII detector at 9 CM energies from 4.21 to 4.42 GeV, we search for the production of $e^+e^- \to \omega\chi_{c0}$, where ω is reconstructed with $\pi^+\pi^-\pi^0$ decay mode, χ_{c0} is reconstructed with $\pi^+\pi^-$ and K^+K^- decay modes.

After all the event selections, an unbinned maximum likelihood fit is performed to the $M(\pi^+\pi^-)$ and $M(K^+K^-)$ distributions at $\sqrt{s} = 4.23$ and 4.26 GeV on the $\pi^+\pi^-$ and K^+K^- modes simultaneously. For data at $\sqrt{s} = 4.23$ GeV, the total signal yields of the two modes are 125.3 ± 13.5 with a statistical significance 11.9σ. For data at 4.26 GeV, the total signal yields are 45.5 ± 10.2 with a statistical significance of 5.5σ. The Born cross sections are measured to be $(55.4 \pm 6.0 \pm 5.9)$ pb and $(23.7 \pm 5.3 \pm 3.5)$ pb, respectively. For other energy points, no significant signals are found and the upper limits on the cross section at the 90% C.L. are determined. Figure 6 shows the Born cross sections of $e^+e^- \to \omega\chi_{c0}$ in the full energy region.

We fit the cross section by using a $Y(4260)$ resonance, the fit gives $\chi^2/ndf = 40.2/8$, so the $Y(4260)$ resonance can not describe the data well. It indicates that the $\omega\chi_{c0}$ signals are very unlikely from the $Y(4260)$ decays. By assuming the $\omega\chi_{c0}$ signals come from a resonance, the fitting results are $\Gamma_{ee}\mathcal{B}(\omega\chi_{c0}) = (2.7 \pm 0.7)$ eV, $M = (4229 \pm 11)$ MeV/c^2, and $\Gamma_t = (40 \pm 14)$ MeV/c^2, which are consistent with the $Y(4220)$ state observed in the cross section of $e^+e^- \to \pi^+\pi^-h_c$ [7]. The data may suggest that the $Y(4260)$ observed in $e^+e^- \to \pi^+\pi^-J/\psi$ [5] have fine structures as observed in $e^+e^- \to \pi^+\pi^-h_c$ [7], and the lower mass structure at about 4230 MeV/c^2 has a sizable coupling to the $\omega\chi_{c0}$ channel as predicted in Ref. [6].

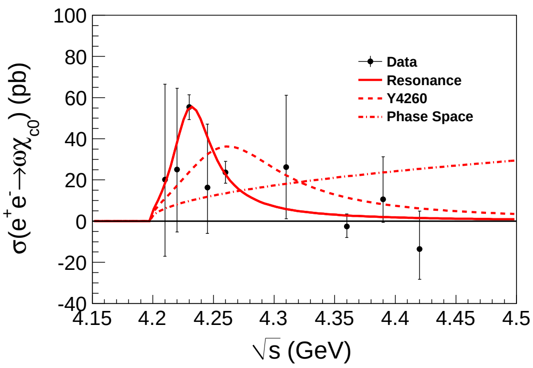

Figure 6. Fit to $\sigma(e^+e^- \to \omega\chi_{c0})$ with a resonance (solid curve), the $Y(4260)$ (dashed curve), or a phase space term (dot-dashed curve). Dots with error bars are the Born cross sections.

Acknowledgments

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