Recent results from BESIII experiment

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In this talk, we present a selection of recent results from BESIII collaboration, including observation of the charmoniumlike states, $Z_c(3900)$, $Z_c(4020)$ and $Z_c(4025)$; observation of $e^+e^- \rightarrow \gamma X(3872)$; partial wave analysis of $J/\psi \rightarrow \gamma \eta \eta$; measurement of $D^+ \rightarrow \mu^+ \nu$ and $D^0 \rightarrow K^- e^+ \nu$, $\pi^- e^+ \nu$. The results are based on the data samples collected with the BESIII detector at central-of-mass energies from 3.900 to 4.420 GeV, and at the energies of $J/\psi$ and $\psi(3770)$ resonances.
1. Introduction

The BESIII experiment at the BEPCII collider has accumulated the world’s largest data samples at $J/\psi$, $\psi(2S)$, and $\psi(3770)$ resonance energies. Moreover, the BESIII experiment has recently accumulated the data samples at central-of-mass (CM) energies from 3.900 to 4.420 GeV for XYZ physics. Table 1 lists the CM energies and the corresponding luminosities of each energy point. The results in this presentation are based on the data samples in Table 1, $J/\psi$ data sample of 225 million events, and $\psi(3770)$ data sample of 2.92 fb$^{-1}$ integrated luminosity.

| $\sqrt{s}$ (GeV) | $\mathcal{L}$ (pb$^{-1}$) |
|------------------|-------------------------|
| 3.900            | 52.8                    |
| 4.009            | 482.0                   |
| 4.090            | 51.0                    |
| 4.190            | 43.0                    |
| 4.210            | 54.7                    |
| 4.220            | 54.6                    |
| 4.230            | 1090.0                  |
| 4.245            | 56.0                    |
| 4.260            | 826.8                   |
| 4.310            | 44.9                    |
| 4.360            | 544.5                   |
| 4.390            | 55.1                    |
| 4.420            | 44.7                    |

2. Observation of $Z_c(3900)$ in $e^+e^- \rightarrow \pi^+\pi^-J/\psi$

Study of the nature of the $Y(4260)$ becomes one of the BESIII current interests. Unlike other charmonium states with the same quantum numbers and in the same mass region, such as the $\psi(4040)$, $\psi(4160)$, and $\psi(4415)$, the $Y(4260)$ state does not have a natural place within the quark model of charmonium. Furthermore, while being well above the $DD$ threshold, the $Y(4260)$ shows strong coupling to the $\pi^+\pi^-J/\psi$ final state, but relatively small coupling to open charm decay modes. These properties perhaps indicate that the $Y(4260)$ state is not a conventional state of charmonium.

Using 525 pb$^{-1}$ data collected with the BESIII detector at a CM energy of 4.260 GeV, BESIII studies the process $e^+e^- \rightarrow \pi^+\pi^-J/\psi$. The cross section is measured to be $(62.9 \pm 1.9 \pm 3.7)$ pb. In addition, a structure (denoted as $Z_c(3900)$) with a mass of $(3899.0 \pm 3.6 \pm 4.9)$ MeV/$c^2$ and a width of $(46 \pm 10 \pm 20)$ MeV is observed in the $\pi^+\pi^-J/\psi$ mass spectrum, as shown in Figure 1(a). This has also been observed by Belle [2] and confirmed with CLEO data at a CM energy of 4.17 GeV [3]. This structure couples to charmonium and has an electric charge, which is suggestive of a state containing more quarks than just a charm and anti-charm quark.

3. Observation of $e^+e^- \rightarrow \gamma X(3872)$ (preliminary)

The $X(3872)$ state was first observed by Belle [3] in $B^\pm \rightarrow K^\pm\pi^+\pi^-J/\psi$ and was subsequently confirmed by several other experiments [4, 5, 6, 7]. Since its discovery, $X(3872)$ has stimulated special interest for its nature. Both BABAR and Belle have observed $X(3872) \rightarrow \gamma J/\psi$ decay, which supports $X(3872)$ being a C-even state [8, 9].

Using the data collected with the BESIII detector at CM energies from 4.001 GeV to 4.420 GeV, BESIII observes $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma\pi^+\pi^-J/\psi, J/\psi \rightarrow l^+l^-$ for the first time. Figure 1(b) shows the fit results to the $X(3872)$ signal. The measured mass of the $X(3872)$, $M(X(3872)) = (3872.1 \pm 0.8 \pm 0.3)$ MeV/$c^2$, agree well with previous measurements [10].

The statistical significance of $X(3872)$ is $5.3 \sigma$. The production rate $\sigma[B^\pm e^+e^- \rightarrow \gamma X(3872)] \times \mathcal{B}[X(3872) \rightarrow \pi^+\pi^-J/\psi]$ is measured to be $(0.32 \pm 0.15 \pm 0.02)$ fb at $\sqrt{s} = 4.229$ GeV, $(0.35 \pm 0.12 \pm 0.02)$ fb at $\sqrt{s} = 4.26$ GeV, $< 0.13$ fb at $\sqrt{s} = 4.009$ GeV, and $< 0.39$ fb at $\sqrt{s} = 4.36$ GeV at the 90% C.L.
4. Observation of $Z_c(4020)$ in $e^+e^- \rightarrow \pi^+\pi^-h_c$

The $Z_c(3900)$, observed in $e^+e^- \rightarrow \pi^+\pi^-J/\psi$, may couple to $\pi^\pm h_c$ and thus can be searched for in $e^+e^- \rightarrow \pi^\pm h_c$. This final state has been studied by CLEO \cite{1} at CM energies from 4.000 to 4.260 GeV, and a hint of a rising cross section at 4.26 GeV has been observed. An improved measurement may shed light on understanding the nature of the $Y(4260)$ as well.

BESIII studies the process $e^+e^- \rightarrow \pi^+\pi^-h_c$ \cite{11} at 13 CM energies from 3.900 to 4.420 GeV using data samples collected with the BESIII detector, and are listed in Table \ref{tb:1}. The Born cross sections are measured at 13 energies, and are found to be of the same order of magnitude as those of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$ with a different line shape. A narrow structure very close to the $(D^*\bar{D}^*)^\mp$ threshold (referred to as $Z_c(4020)$) with a mass of $4022.9 \pm 0.8 \pm 2.7$ MeV/$c^2$ and a width of $(7.9 \pm 2.7 \pm 2.6)$ MeV is observed in the $\pi^\pm h_c$ mass spectrum, as shown in Figure \ref{fig:3}(a). This structure couples to charmonium and has an electric charge, which is suggestive of a state containing more quarks than just a charm and an anti-charm quark. We do not find a significant signal for $Z_c(3900) \rightarrow \pi^\pm h_c$ and the production cross section is found to be smaller than 11 pb at the 90% C.L. at 4.26 GeV.

5. Observation of $Z_c(4025)$ in $e^+e^- \rightarrow (D^*\bar{D}^*)^\mp\pi^\mp$

The mass of the $Z_c(3900)$ is about 20 MeV higher than the $D\bar{D}^*$ mass threshold. Therefore, a search of $Z_c$ candidates via their direct decays into $D^*\bar{D}^*$ pairs is strongly motivated. BESIII studies the process $e^+e^- \rightarrow (D^*\bar{D}^*)^\mp\pi^\mp$ \cite{12} at a CM energy of 4.26 GeV using a 827 pb$^{-1}$ data sample obtained with the BESIII detector. Based on a partial reconstruction technique, the Born cross section is measured to be $(137 \pm 9 \pm 15)$ pb. A structure near the $(D^*\bar{D}^*)^\mp$ threshold (referred to as $Z_c(4025)$) in the $\pi^\mp$ recoil mass spectrum is observed, as shown in Figure \ref{fig:3}(b). The measured mass and width of the structure are $(4026.3 \pm 2.6 \pm 3.7)$ MeV/$c^2$ and $(24.8 \pm 5.6 \pm 7.7)$ MeV, respectively. Its production ratio $\frac{\sigma(e^+e^- \rightarrow Z_c(4025)\pi^- \rightarrow (D^*\bar{D}^*)^\mp\pi^\mp)}{\sigma(e^+e^- \rightarrow (D^*\bar{D}^*)^\mp\pi^\mp)}$ is determined to be $0.65 \pm 0.09 \pm 0.06$. 

![Figure 1: (a): Fit to the $M_{\text{max}}(\pi^\pm J/\psi)$ distribution of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$. (b): Fit to the $M(\pi^\pm J/\psi)$ distribution of $e^+e^- \rightarrow \gamma\pi^\pm J/\psi$. Dots with error bars are data, the red solid curve shows the total fit. In (a), the blue dotted curve the shows background from the fit; the red dot-dashed histogram shows the result of a phase space MC simulation; and the green shaded histogram shows the normalized $J/\psi$ sideband events. In (b), the blue curve shows the background contribution.](image)
6. Partial wave analysis of $J/\psi \rightarrow \gamma \eta \eta$

Radiative $J/\psi$ decay is a gluon-rich process and has long been regarded as one of the most promising hunting grounds for glueballs. In particular, for a $J/\psi$ radiative decay to two pseudoscalar mesons, it offers a very clean laboratory to search for scalar and tensor glueballs because only intermediate states with $J^{PC} = \text{even}^{++}$ are possible.

Using 225 million $J/\psi$ events collected with the BESIII detector, a partial wave analysis (PWA) on $J/\psi \rightarrow \gamma \eta \eta$ was performed using the relativistic covariant tensor amplitude method, and the results are summarized in Table 2. The scalar contributions are mainly from $f_0(1500)$, $f_0(1710)$ and $f_0(2100)$, while no evident contributions from $f_0(1370)$ and $f_0(1790)$ are seen. Recently, the production rate of the pure gauge scalar glueball in $J/\psi$ radiative decays predicted by the lattice QCD was found to be compatible with the production rate of $J/\psi$ radiative decays to $f_0(1710)$; this suggests that $f_0(1710)$ has a larger overlap with the glueball compared to other glueball candidates (e.g. $f_0(1500)$).

| Resonance | Mass(MeV/$c^2$) | Width(MeV/$c^2$) | $\mathcal{B}(J/\psi \rightarrow \gamma X \rightarrow \gamma \eta \eta)$ | Significance |
|-----------|----------------|-----------------|-------------------------------------------------|--------------|
| $f_0(1500)$ | $1468^{+14+23}_{-15-74}$ | $136^{+41+28}_{-26+100}$ | $(1.65^{+0.26+0.31}_{-0.31-1.40}) \times 10^{-5}$ | 8.2 $\sigma$ |
| $f_0(1710)$ | $1759^{+6+14}_{-25}$ | $172^{+6+32}_{-16}$ | $(2.35^{+0.13+0.24}_{-0.11-0.74}) \times 10^{-4}$ | 25.0 $\sigma$ |
| $f_0(2100)$ | $2081^{+13+24}_{-26}$ | $273^{+27+70}_{-24-23}$ | $(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$ | 13.9 $\sigma$ |
| $f_2(1525)$ | $1513^{+5+10}_{-9}$ | $75^{+12+16}_{-10-8}$ | $(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$ | 11.0 $\sigma$ |
| $f_2(1810)$ | $1822^{+29+66}_{-24-57}$ | $229^{+52+88}_{-42-155}$ | $(5.40^{+0.60+3.42}_{-0.67-2.35}) \times 10^{-5}$ | 6.4 $\sigma$ |
| $f_2(2340)$ | $236^{+31+140}_{-30-63}$ | $334^{+62+165}_{-54-100}$ | $(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$ | 7.6 $\sigma$ |
7. Measurement of $D^+ \to \mu^+ \nu$ (preliminary)

The decay rate is proportional $f_D^2$, here $f_D$ is the $D^+$ decay constant. By measuring the branching fraction of $D^+ \to \mu^+ \nu$, the $f_D$ can be extracted with external input of $V_{ud}$.

BESIII extracts the $f_D$ from the leptonic decays $D^+ \to \mu^+ \nu$ using $2.92 \text{ fb}^{-1}$ data taken at $\sqrt{s} = 3.773$ GeV. The $D^+$ meson are produced from $\psi(3770) \to D^+ D^-$. The $D^-$ mesons are reconstructed in nine non-leptonic decay modes. The signal for $D^+ \to \mu^+ \nu$ is observed in the distribution of $M_{\text{miss}}^2 = E_{\text{miss}}^2 - p_{\text{miss}}^2$, where $E_{\text{miss}}$ and $p_{\text{miss}}$ are the missing energy and momentum due to the undetectable neutrino in the detector. The $M_{\text{miss}}^2$ distribution is presented in Figure 3, where a remarkably clean signal peak at zero is evident.

We observe a signal of $377.3 \pm 20.6 \pm 2.6$ events above a background of $47.7$ events. From this signal, we extract: $\mathcal{B}(D^+ \to \mu^+ \nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$ and $f_D = (203.91 \pm 5.72 \pm 1.97)$ MeV. This is more precise than the previous best measurement of $f_D = (205.8 \pm 8.5 \pm 2.5)$ MeV, based on $818 \text{ pb}^{-1}$ from CLEO-c[17].

![BESIII preliminary](image)

Figure 3: $M_{\text{miss}}^2$ distribution. Inset: log plots of $M_{\text{miss}}^2$ with stacked backgrounds in color (non-$D\bar{D}$ events in magenta, other $D\bar{D}$ in yellow, $D^+ \to \tau^+ \nu$ in blue, $D^+ \to \pi^+ \pi^0$ in green, and $D^+ \to K\pi$ in red).

8. Measurement of $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$ (preliminary)

BESIII extracts the form-factors $f_{\pi,K}(q^2)$ from the semileptonic decays $D^0 \to K^- e^+ \nu$ and $D^0 \to \pi^- e^+ \nu$ using one-third of $2.92 \text{ fb}^{-1}$ data taken at $\sqrt{s} = 3.773$ GeV. Here, $q^2 = m_{\nu}^2$ and these form factors describe the effects of meson structure in the decay, relative to idealized free-quark decay.

The $D^0$ meson are produced from $\psi(3770) \to D^0 \bar{D}^0$. The $D^0$ mesons are reconstructed in four non-leptonic decay modes. The amount of signal events is determined by fitting the distribution of $U = E_{\text{miss}} - p_{\text{miss}}$; the “miss” quantities, representing the unobserved neutrino, are analogous to those in the previous analysis. For signal, $U$ peaks at zero and is similar to a missing-mass-squared. Fits to the $U$ distributions in Fig. 4 lead to the branching fraction results: $\mathcal{B}(D^0 \to K^- e^+ \nu) = (3.542 \pm 0.030 \pm 0.067)\%$ and $\mathcal{B}(D^0 \to \pi^- e^+ \nu) = (0.288 \pm 0.008 \pm 0.005)\%$, which are consistent with the previous measurement from CLEO[19]. The form-factor analysis is provided in Ref. [18].
9. Summary

The BESIII experiment has collected the world’s largest samples of $J/\psi$, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $Y(4260)$ and $Y(4360)$ decays. Based on these samples, BESIII has produced a large amount of results on the searches for $XYZ$ states, charmonium spectroscopy and decays, light hadron spectroscopy, and $D$ meson decays. The data taking at high luminosities will go on for years. Many new discoveries and precision measurements are expected to be coming soon.

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