PROCEEDINGS OF SCIENCE

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 $e^+e^- \to \gamma X(3872)$; partial wave analysis of $J/\psi \to \gamma\eta\eta$; measurement of $D^+ \to \mu^+\nu$ and $D^0 \to K^-e^+\nu$, $\pi^-e^+\nu$. 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/ψ and $\psi(3770)$ resonances.

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1. Introduction

The BESIII experiment at the BEPCII collider has accumulated the world's largest data samples at J/ψ, $\psi(2S)$, 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 Table1, J/ψ data sample of 225 million events, and $\psi(3770)$ data sample of 2.92 fb^{-1} integrated luminosity.

Table 1: The CM energies and luminosities of each data sample.

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

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

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 $D\bar{D}$ 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 $e^+e^- \to \pi^+\pi^- J/\psi$ [1]. 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 $\pi^\pm J/\psi$ 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 $e^+e^- \to \gamma X(3872)$ (preliminary)

The $X(3872)$ state was first observed by Belle [4] in $B^\pm \to K^\pm \pi^+\pi^- J/\psi$ and was subsequently confirmed by several other experiments [5, 6, 7]. Since its discovery, X(3872) has stimulated special interest for its nature. Both BABAR and Belle have observed $X(3872) \to \gamma J/\psi$ 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 $e^+e^- \to \gamma X(3872) \to \gamma\pi^+\pi^- J/\psi, J/\psi \to l^+l^-$ ($l^+l^- = e^+e^-$ or $\mu^+\mu^-$) 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 σ. The production rate $\sigma^B[e^+e^- \to \gamma X(3872)] \times \mathscr{B}[X(3872) \to \pi^+\pi^- J/\psi]$ is measured to be $(0.32 \pm 0.15 \pm 0.02)$ pb at $\sqrt{s} = 4.229$ GeV, $(0.35 \pm 0.12 \pm 0.02)$ pb at $\sqrt{s} = 4.26$ GeV, < 0.13 pb at $\sqrt{s} = 4.009$ GeV, and < 0.39 pb at $\sqrt{s} = 4.36$ GeV at the 90% C.L.

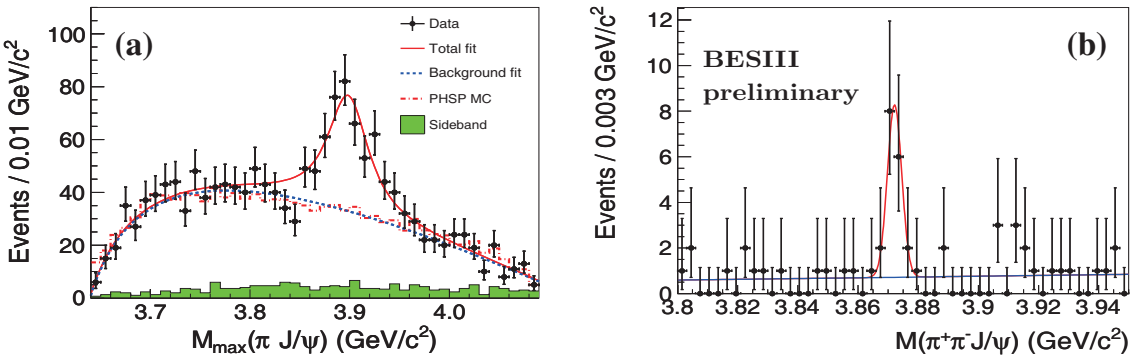

Figure 1: (a): Fit to the $M_{\max}(\pi^{\pm}J/\psi)$ distribution of $e^+e^- \to \pi^+\pi^- J/\psi$. (b): Fit to the $M(\pi^+\pi^- J/\psi)$ distribution of $e^+e^- \to \gamma\pi^+\pi^- J/\psi$. Dots with error bars are data, the red solid curve shows the total fit. In (a), the blue dotted curve the 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/ψ sideband events. In (b), the blue curve shows the background contribution.

4. Observation of $Z_c(4020)$ in $e^+e^- \to \pi^+\pi^- h_c$

The $Z_c(3900)$, observed in $e^+e^- \to \pi^+\pi^- J/\psi$, may couple to $\pi^{\pm}h_c$ and thus can be searched for in $e^+e^- \to \pi^+\pi^- h_c$. This final state has been studied by CLEO [11] 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 $e^+e^- \to \pi^+\pi^- h_c$ [12] at 13 CM energies from 3.9000 to 4.420 GeV using data samples collected with the BESIII detector, and are listed in Table 1. The Born cross sections are measured at 13 energies, and are found to be of the same order of magnitude as those of $e^+e^- \to \pi^+\pi^- J/\psi$ but with a different line shape. A narrow structure very close to the $(D^*\bar{D}^*)^{\pm}$ 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 2(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 $Z_c(3900) \to \pi^{\pm}h_c$ 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 $e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$

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 $e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp}$ [13] 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 $(D^*\bar{D}^*)^{\pm}$ threshold (referred to as $Z_c(4025)$) in the $\pi^{\mp}$ recoil mass spectrum is observed, as shown in Figure 2(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 $\frac{\sigma(e^+e^- \to Z_c^{\pm}(4025)\pi^{\mp} \to (D^*\bar{D}^*)^{\pm}\pi^{\mp})}{\sigma(e^+e^- \to (D^*\bar{D}^*)^{\pm}\pi^{\mp})}$ is determined to be $0.65 \pm 0.09 \pm 0.06$.

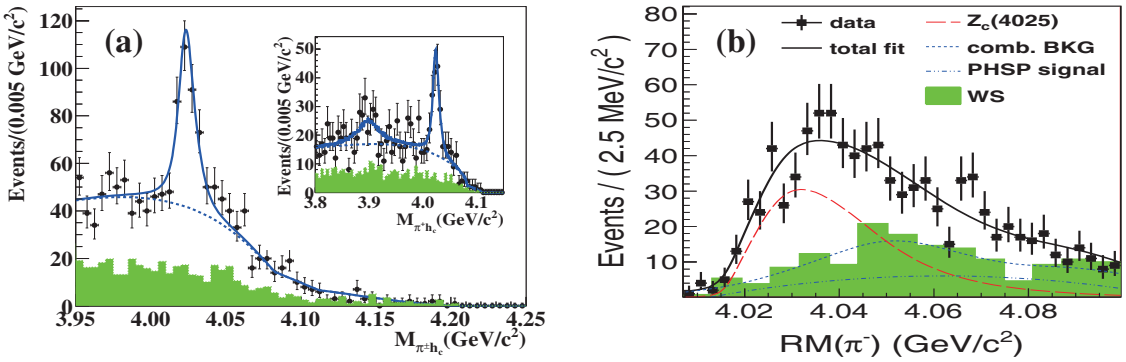

Figure 2: (a): Sum of the simultaneous fits to the $M_{\pi^\pm h_c}$ distributions of $e^+e^- \to \pi^+\pi^- J/\psi$ at 4.23 GeV, 4.26 GeV, and 4.36 GeV; the inset shows the sum of the simultaneous fits to the $M_{\pi^+ h_c}$ distributions at 4.23 GeV and 4.26 GeV with $Z_c(3900)$ and $Z_c(4020)$. (b): Fit to the π^- recoil mass spectrum of $e^+e^- \to (D^*\bar{D}^*)^\pm\pi^\mp$ at 4.26 GeV. Dots with error bars are data; the solid curves are the total fit.

6. Partial wave analysis of $J/\psi \to \gamma\eta\eta$

Radiative J/ψ 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/ψ radiative decay to two pseudoscalar mesons, it offers a very clean laboratory to search for scalar and tensor glueballs because only intermediate states with $J^{PC} = even^{++}$ are possible.

Using 225 million J/ψ events collected with the BESIII detector, a partial wave analysis (PWA) on $J/\psi \to \gamma\eta\eta$ [14] 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/ψ radiative decays predicted by the lattice QCD [15] was found to be compatible with the production rate of J/ψ radiative decays to $f_0(1710)$; this suggests that $f_0(1710)$ has a larger overlap with the glueball compared to other glueball candidates (eg. $f_0(1500)$).

Table 2: Summary of the PWA results, including the masses and widths for resonances, branching ratios of $J/\psi \to \gamma X$, as well as the significance. The first errors are statistical and the second ones are systematic.

Resonance	Mass(MeV/c^2)	Width(MeV/c^2)	$\mathcal{B}(J/\psi \to \gamma X \to \gamma\eta\eta)$	Significance
$f_0(1500)$	1468^{+14+23}_{-15-74}	$136^{+41+28}_{-26-100}$	$(1.65^{+0.26+0.51}_{-0.31-1.40}) \times 10^{-5}$	8.2 σ
$f_0(1710)$	$1759 \pm 6^{+14}_{-25}$	$172 \pm 10^{+32}_{-16}$	$(2.35^{+0.13+1.24}_{-0.11-0.74}) \times 10^{-4}$	25.0 σ
$f_0(2100)$	$2081 \pm 13^{+24}_{-36}$	273^{+27+70}_{-24-23}	$(1.13^{+0.09+0.64}_{-0.10-0.28}) \times 10^{-4}$	13.9 σ
$f_2'(1525)$	$1513 \pm 5^{+4}_{-10}$	75^{+12+16}_{-10-8}	$(3.42^{+0.43+1.37}_{-0.51-1.30}) \times 10^{-5}$	11.0 σ
$f_2(1810)$	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 σ
$f_2(2340)$	$2362^{+31+140}_{-30-63}$	$334^{+62+165}_{-54-100}$	$(5.60^{+0.62+2.37}_{-0.65-2.07}) \times 10^{-5}$	7.6 σ

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_{cd}.

BESIII extracts the f_D from the leptonic decays $D^+ \to \mu^+\nu$ [16] using 2.92 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 $M^2_{miss} = E^2_{miss} - p^2_{miss}$, where E_{miss} and p_{miss} are the missing energy and momentum due to the undetectable neutrino in the detector. The M^2_{miss} 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: $\mathscr{B}(D^+ \to \mu^+\nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$ 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 pb^{-1} from CLEO-c[17].

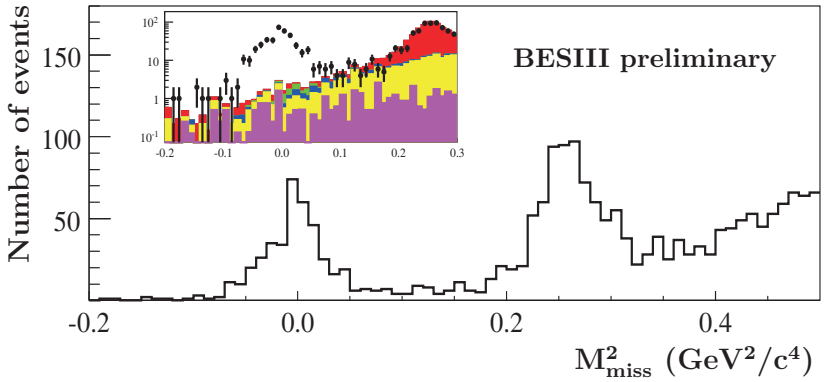

Figure 3: M^2_{miss} distribution. Inset: log plots of M^2_{miss} with stacked backgrounds in color (non-$D\bar{D}$ events in magenta, other $D\bar{D}$ in yellow, $D^+ \to \tau^+\nu$ in blue, $D^+ \to \pi^+\pi^0$ in green, and $D+ \to K_L\pi^+$ in red).

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 $D^0 \to \pi^-e^+\nu$[18] using one-third of 2.92 fb^{-1} data taken at $\sqrt{s} = 3.773$ GeV. Here, $q^2 = m^2_{e\nu}$ 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 $U = E_{miss} - p_{miss}$; 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: $\mathscr{B}(D^0 \to K^-e^+\nu) = (3.542 \pm 0.030 \pm 0.067)\%$ and $\mathscr{B}(D^0 \to \pi^-e^+\nu) = (0.288 \pm 0.008 \pm 0.005)\%$, which are consistent with the previous measurement from CLEO [19]. The form-factor analysis is provided in Ref. [18].

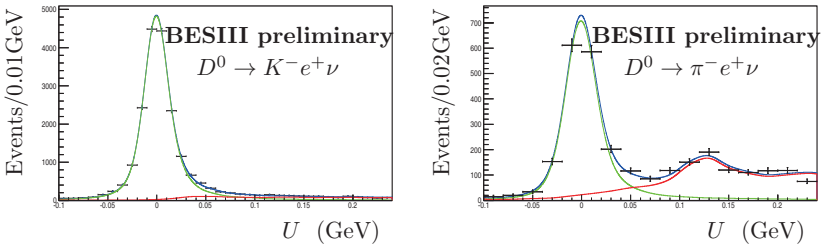

Figure 4: $U = E_{miss} - p_{miss}$ distributions for $D^0 \to K^- e^+ \nu$ (left), $D^0 \to \pi^- e^+ \nu$ (right). The blue total fit curve is the sum of a green signal shape and a red background term.

9. Summary

The BESIII experiment has collected the world's largest samples of J/ψ, $\psi(2S)$, $\psi(3770)$, $\psi(4040)$, $Y(4260)$ 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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