Recent results from BESIII

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Selected results of BESIII are reported, including the observation of charged, charmonium-like states, the $Z_c(3900)$, $Z_c(4020)$, and $Z_c(4025)$; observation of $e^+e^- \rightarrow \gamma X(3872)$; study of $\eta\eta$ system in $J/\psi \rightarrow \gamma\eta\eta$; baryon excited study in $\psi(3686) \rightarrow p\bar{p}\pi^0$; precise measurements of the decay constant f_D from $D^+ \rightarrow \mu^+\nu$ and form-factors in $D^0 \rightarrow K^-e^+\nu, \pi^-e^+\nu$.

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1. Introduction

The BESIII¹ experiment at the BEPCII collider has accumulated the world's largest datasets at J/ψ , $\psi(3686)$, and $\psi(3770)$ energy region. Moreover, about 2.9 fb^{-1} datasets at a center-of-mass energy above 4.0 GeV have accumulated recently for XYZ study.

Results show here are based on the datasets of 225 million J/ψ decays, 106 million $\psi(3686)$ decays, 2.9 fb^{-1} at $\psi(3770)$, and a fraction of datasets above 4.0 GeV.

2. Observation of $Z_c(3900)$

$Y(4260)$ ² was firstly discovered in the process $e^+e^- \rightarrow \gamma_{ISR}\pi^+\pi^-J/\psi$. Subsequent studies indicate that the $Y(4260)$ state is not a conventional state of charmonium.

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Fig. 1. Fit to the invariant mass of $\pi^\pm J/\psi$ for selected events $e^+e^- \rightarrow \pi^+\pi^- J/\psi$.

Using 525 pb $^{-1}$ data sample collected with the BESIII detector at a center-of-mass energy of 4.260 GeV, the process $e^+e^- \rightarrow \pi^+\pi^- J/\psi$ was studied. A structure named $Z_c(3900)$ was observed in the $\pi^\pm J/\psi$ mass spectrum (See Fig. 1) 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. It was also observed by Belle³ and confirmed with CLEO-c data.⁴ This structure couples to charmonium and has an electric charge, which is suggestive of a state containing more quarks than just a charm and anticharm quark.

3. Observation of $Y(4260) \rightarrow \gamma X(3872)$ (Preliminary)

The $X(3872)$ was observed by Belle in $B^\pm \rightarrow K^\pm \pi^+ \pi^- J/\psi$ decays ten years ago.⁵ Being near $D\bar{D}^*$ mass threshold, the $X(3872)$ was interpreted as a good candidate for a hadronic molecule or a tetraquark state. Currently, $X(3872)$ was only observed in B meson decays and hadron collisions. Since the quantum number of it is $J^{PC} = 1^{++}$, it could be produced through the radiative transition of the excited vector charmonium or charmonium-like states.

Using the datasets collected with the BESIII detector taken at center-of-mass energies from 4.009 GeV to 4.420 GeV, the process $e^+e^- \rightarrow \gamma X(3872) \rightarrow \gamma \pi^+ \pi^- J/\psi$ was observed for the first time.⁶ Figure 2 shows the fit results to the invariant mass of $\pi^+ \pi^- J/\psi$. The measured mass of $X(3872)$ is $(3871.9 \pm 0.7_{\text{stat.}} \pm 0.2_{\text{sys.}})$ MeV/ c^2 , in agreement with previous measurements. The product of the Born cross section and the branching fraction $\sigma^B[e^+e^- \rightarrow \gamma X(3872)] \times \mathcal{B}[X(3872) \rightarrow \pi^+ \pi^- J/\psi]$ was measured to be $(0.29 \pm 0.10 \pm 0.02)$ pb at $\sqrt{s} = 4.229$ GeV, $(0.36 \pm 0.13 \pm 0.03)$ pb at $\sqrt{s} = 4.260$ GeV, < 0.12 pb at $\sqrt{s} = 4.009$ GeV, and < 0.39 pb at $\sqrt{s} = 4.36$ GeV at the 90% C.L.

Fig. 2. Fit of the $M(\pi^+\pi^-J/\psi)$ distribution with a MC simulated histogram convolved with a Gaussian function for signal and a linear background function.

4. Observation of $Z_c(4020)$ and $Z_c(4025)$ (Preliminary)

We measured the cross sections of $e^+e^- \rightarrow \pi^+\pi^-h_c$ at 13 center-of-mass energies from 3.90 GeV to 4.42 GeV using data samples collected with the BESIII detector.⁷ In the $\pi^\pm h_c$ mass spectrum, a narrow structure very close to the $(D^*\bar{D}^*)^\pm$ threshold, referred to as $Z_c(4020)$, is observed at $4.02 \text{ GeV}/c^2$. The fitted mass and width are $(4022.9 \pm 0.8 \pm 2.7) \text{ MeV}/c^2$ and $(7.9 \pm 2.7 \pm 2.6) \text{ MeV}$ respectively (Fig. 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 an anti-charm quark, as the $Z_c(3900)$ mentioned above. 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, which is lower than that of $Z_c(3900) \rightarrow \pi^\pm J/\psi$.

We also studied the process $e^+e^- \rightarrow (D^*\bar{D}^*)^\pm \pi^\mp$ at a center-of-mass energy of 4.26 GeV using a 827 pb^{-1} data sample obtained with the BESIII detector.⁸ Based on a partial reconstruction technique, the Born cross section was measured to be $(137 \pm 9 \pm 15) \text{ pb}$. We observe a structure near the $(D^*\bar{D}^*)^\pm$ threshold in the $\pi^\mp$ recoil mass spectrum, which we denote as the $Z_c^\pm(4025)$ (Fig. 4). The measured mass and width of the structure are $(4026.3 \pm 2.6 \pm 3.7) \text{ MeV}/c^2$ and $(24.8 \pm 5.6 \pm 7.7) \text{ MeV}$, respectively. Its production ratio $\frac{\sigma(e^+e^- \rightarrow Z_c^\pm(4025)\pi^\mp \rightarrow (D^*\bar{D}^*)^\pm \pi^\mp)}{\sigma(e^+e^- \rightarrow (D^*\bar{D}^*)^\pm \pi^\mp)}$ is determined to be $0.65 \pm 0.09 \pm 0.06$.

5. Partial Wave Analysis of $J/\psi \rightarrow \gamma\eta\eta$

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

Fig. 3. Sum of the simultaneous fits to the $M_{\pi^{\pm}h_c}$ distributions at 4.23 GeV, 4.26 GeV, and 4.36 GeV; the inset shows the sum of the simultaneous fit to the $M_{\pi^+h_c}$ distributions at 4.23 GeV and 4.26 GeV with $Z_c(3900)$ and $Z_c(4020)$. Dots with error bars are data; shaded histograms are normalized sideband background; the solid curves show the total fit, and the dotted curves the backgrounds from the fit.

Fig. 4. Unbinned maximum likelihood fit to the π^- recoil mass spectrum in data.

scalar and tensor glueballs because only intermediate states with $J^{PC} = \text{even}^{++}$ are possible.

Based on a sample of 2.25×10^8 J/ψ events collected with the BESIII detector, a full partial wave analysis on $J/\psi \rightarrow \gamma\eta\eta$ was performed using the relativistic covariant tensor amplitude method.⁹ The results show that the dominant 0^{++} and 2^{++} components are from the $f_0(1710)$, $f_0(2100)$, $f_0(1500)$, $f'_2(1525)$, $f_2(1810)$ and $f_2(2340)$.

Fig. 5. The contribution of each intermediate resonance in the $p\pi^0$ mass spectra. The interferences with other resonances are included.

6. Baryon Excited Study

A very important source of information for the nucleon internal structure is the N^* mass spectrum as well as its various production and decay rates. There are much more predicted excited baryon resonances in theory than found in experiment ("missing baryon excited states problem"). Study baryon excited states from charmonium decay has its advantages: clean signal and isospin filter. Several decay modes had been studied by BESII and BESIII.^{10–12}

Based on 106 million $\psi(3686)$ events collected with the BESIII, a partial wave analysis of $\psi(3686) \rightarrow p\bar{p}\pi^0$ was performed.¹³ In this process, seven N^* intermediate resonances were observed. Among these, two possible new resonances are found. one $1/2^+$ resonance with a mass of $2300^{+40+109}_{-30-0}$ MeV/ c^2 and width of $340^{+30+110}_{-30-58}$ MeV, and one $5/2^-$ resonance with a mass of 2570^{+19+34}_{-10-10} MeV/ c^2 and width of 250^{+14+69}_{-24-21} MeV.

7. Measurement of $D^+ \rightarrow \mu^+\nu$ (Preliminary)

Using 2.92 fb^{-1} data taken at $\sqrt{s} = 3.773 \text{ GeV}$ at BESIII, the pseudoscalar decay constant f_D was extracted from the leptonic decays $D^+ \rightarrow \mu^+\nu$.¹⁴ The decay rate is proportional to f_D^2 . The D^+ mesons were produced from $\psi(3770) \rightarrow D^+D^-$. The D^- mesons were reconstructed in nine non-leptonic decay modes. The signal for $D^+ \rightarrow \mu^+\nu$ was observed in the distribution of $M_{miss}^2 = E_{miss}^2 - p_{miss}^2$, where E_{miss} and p_{miss} are the missing energy and momentum due to the undetectable neutrino in the detector. The M_{miss}^2 distribution is shown in Fig. 6, 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. The branching ratio was measured to be $\mathcal{B}(D^+ \rightarrow \mu^+\nu) = (3.74 \pm 0.21 \pm 0.06) \times 10^{-4}$, and $f_D = (203.91 \pm 5.72 \pm 1.97) \text{ MeV}$. This is the highest precision measurement for f_D in the world to date.

Fig. 6. M_{miss}^2 distribution. Inset: log plots of M_{miss}^2 with stacked backgrounds in color (non- $D\bar{D}$ events in magenta, other $D\bar{D}$ in yellow, $D^+ \rightarrow \tau^+\nu$ in blue, $D^+ \rightarrow \pi^+\pi^0$ in green, and $D^+ \rightarrow K_L\pi^+$ in red).

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

BESIII extracted the form-factors $f_{\pi,K}(q^2)$ from the semileptonic decays $D^0 \rightarrow K^-e^+\nu$ and $D^0 \rightarrow \pi^-e^+\nu$ ¹⁶ using one-third of 2.92 fb^{-1} data taken at $\sqrt{s} = 3.773 \text{ GeV}$. Here, $q^2 = m_{e\nu}^2$ and these form factors describe the effects of meson structure in the decay, relative to idealized free-quark decay.

The D^0 mesons were produced from $\psi(3770) \rightarrow D^0\bar{D}^0$. The D^0 mesons were reconstructed in four non-leptonic decay modes. The amount of signal events is determined by fitting the distribution of $U_{miss} = E_{miss} - p_{miss}$ (See Fig. 7), where the "miss" quantities, representing the unobserved neutrino, are analogous to those in the previous analysis. The branching fractions of $D^0 \rightarrow K^-e^+\nu$ and $D^0 \rightarrow \pi^-e^+\nu$ are measured to be $(3.542 \pm 0.030 \pm 0.067)\%$ and $(0.288 \pm 0.008 \pm 0.005)\%$ respectively.

For the form-factor analysis, we divide the data into bins of q^2 to determine values of $d\Gamma/dq^2$ integrated over these bins. Numerical values of our form factor fit results are given in Table 1 for the three-parameter version of the popular series

Fig. 7. $U = E_{miss} - p_{miss}$ distributions for $D^0 \rightarrow K^-e^+\nu$ (left), $D^0 \rightarrow \pi^-e^+\nu$ (right). The blue total fit curve is the sum of a green signal shape and a red background term.

Table 1. Preliminary BESIII form-factor results. For brevity, only results from the three-parameter series fit are shown.

Mode	$f_+(0) V_{cs(d)} $	r_1	r_2
$D^0 \rightarrow K^- e^+ \nu$	$0.729 \pm 0.008 \pm 0.007$	$-2.179 \pm 0.355 \pm 0.053$	$4.359 \pm 8.927 \pm 1.103$
$D^0 \rightarrow \pi^- e^+ \nu$	$0.144 \pm 0.005 \pm 0.002$	$-2.728 \pm 0.482 \pm 0.076$	$4.194 \pm 3.122 \pm 0.448$

expansion¹⁵ prescription for parametrizing the form factor. The results for other fits are available in Ref. 16.

9. Summary

BESIII has collected world largest samples at J/ψ , $\psi(3686)$, $\psi(3770)$, $Y(4260)$ and so on. It is an excellent place for the precision measurement and new discoveries. BESIII has produced many results on the searches for XYZ states, charmonium spectroscopy and decays, light hadron spectroscopy, and D meson decays. More data will be available for next years. Many new discoveries and precision measurements are expected to coming soon.

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