CHARMONIUM(-LIKE) SPECTROSCOPY AND DECAYS FROM BESIII

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The recent results about charmonium and charmonium-like spectroscopy and decays from BESIII are presented in this talk. We report the observation of $X(3872)$ from $Y(4260)$ radiative transition, $\pi^+\pi^-h_c$ line shape measurement and Z_c states. In addition, the accurate measurement of η_c parameters, the analysis on h_c exclusive decays into $\gamma\eta_c$, and the first observation of the M1 transition $\psi' \rightarrow \gamma\eta_c(2S)$ are included in this talk.

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1. Introduction

In 2009, the upgraded Beijing spectrometer (BESIII)¹ at Beijing Electron Positron Collider (BEPCII) started to take data. Recently, a lot of data at different energy points above the 4 GeV are taken for studying the charmoniumlike states, such as $X(3872)$, Z_c states. The results about η_c , h_c and $\eta_c(2S)$ in this talk are based on the 1.06×10^8 ψ' event data sample.

2. Charmonium states

The η_c is the lowest-lying state of the $c\bar{c}$ system, but its properties are not well measured. The η_c is reconstructed through six different channels: $\psi' \rightarrow \gamma\eta_c$, $\eta_c \rightarrow X_i$, $X_i = (K_S^0 K^\pm \pi^\mp, K^+ K^- \pi^0, \pi^+ \pi^- \eta, K_S^0 K^\pm \pi^\mp \pi^+ \pi^-, 3(\pi^+ \pi^-), K^+ K^- \pi^+ \pi^- \pi^0)$,² as shown in Fig. 1. A simultaneous fit that incorporates interference between the signal reaction and a non-resonant radiative background determine the mass and width of η_c to be $m_{\eta_c} = (2984.3 \pm 0.6 \pm 0.6) \text{ MeV}/c^2$ and

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Fig. 1. The invariant mass distributions in $\psi' \rightarrow \gamma\eta_c$ for the decays $K_S^0 K^\pm \pi^\mp$, $K^+ K^- \pi^+ \pi^-$, $\pi^+ \pi^- \eta$, $K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$, $K^+ K^- \pi^+ \pi^- \pi^0$, and $3(\pi^+ \pi^-)$, respectively, with the fit results (constructive) superimposed.

$\Gamma_{\eta_c} = (32.0 \pm 1.2 \pm 1.0)$ MeV. The new BESIII results are so far the most precise measurement of the properties of η_c , which agree with the values found in photon-photon fusion and B decays.

The h_c is the P-wave spin singlet charmonium below open-charm threshold. It could be studied through the mode of $\psi' \rightarrow \pi^0 h_c$, $h_c \rightarrow \gamma\eta_c$. In BESIII, sixteen kinds of exclusive hadronic final states are used to reconstruct η_c .³ To extract the h_c resonant parameters and the yield for each η_c decay channel, the sixteen π^0 recoil mass distributions are fitted simultaneously with a binned maximum likelihood method.

$\eta_c(2S)$, the first radial excitation of η_c , is poorly understood relative to the other charmonium below open-charm threshold. In BESIII, $\eta_c(2S)$ was observed with the transition of $\psi' \rightarrow \gamma\eta_c(2S)$, $\eta_c(2S) \rightarrow K_S^0 K^\pm \pi^\mp$ and $K^+ K^- \pi^0$.⁴ Recently, the evidence of $\eta_c(2S) \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$ ⁵ is reported with the product branching fraction $\mathcal{B}(\psi' \rightarrow \gamma\eta_c(2S), \eta_c(2S) \rightarrow K_S^0 K^\pm \pi^\mp \pi^+ \pi^-) = (7.03 \pm 2.10 \pm 0.70) \times 10^{-6}$.

3. Charmonium-like states

The $X(3872)$ was observed by Belle in $B^\pm \rightarrow K^\pm \pi^+ \pi^- J/\psi$ decays.⁶ In BESIII, we report the observation of $X(3872)$ in the channel of $e^+ e^- \rightarrow \gamma X(3872)$,⁷ $X(3872) \rightarrow \pi^+ \pi^- J/\psi$ based on the accumulated data taken at 4.009, 4.230, 4.260, 4.360 GeV. Fig. 2 shows the fit of the invariant mass of $\pi^+ \pi^- J/\psi$. The measured mass of $X(3872)$ is $(3872.1 \pm 0.8 \pm 0.2)$ MeV/ c^2 , and the statistical significance is 5.2σ .

In BESIII, we study the $e^+ e^- \rightarrow \pi^+ \pi^- h_c$ at thirteen center of mass energy points from 3.900 to 4.420 GeV.⁸ In order to include more h_c signals, sixteen exclusive hadronic final states are used: $p\bar{p}$, $\pi^+ \pi^- \pi^+ \pi^-$, $K^+ K^- \pi^+ \pi^-$, $p\bar{p} \pi^+ \pi^-$, $K^+ K^- \pi^+ \pi^- \pi^+ \pi^-$, $\pi^+ \pi^- \pi^+ \pi^- \pi^+ \pi^-$, $K^+ K^- \pi^+ \pi^- \pi^+ \pi^-$, $K_S^0 K^\pm \pi^\mp$, $K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$, $K^+ K^- \pi^0$, $p^+ p^- \pi^0$, $\pi^+ \pi^- \eta$, $K^+ K^- \eta$, $\pi^+ \pi^- \pi^+ \pi^- \eta$, $\pi^+ \pi^- \pi^0 \pi^0$,

Fig. 2. Fit to the invariant mass of $\pi^+\pi^-J/\psi$ with MC simulated histogram convolving a Gaussian function for signal and a linear background term. Dots with error bars are data, the curves are the best fit.

Fig. 3. The cross section of $\pi^+\pi^-h_c$. Red dots with error bars for BESIII and blue circles with error bars for BELLE.

and $\pi^+\pi^-\pi^+\pi^-\pi^0$. The cross sections are shown in Fig 3, and the line shape is different from the Belle measurement on $e^+e^- \rightarrow \pi^+\pi^-J/\psi$.

We observe a structure around 3.9 GeV/ c^2 in the $\pi^\pm J/\psi$ mass spectrum from the process of $e^+e^- \rightarrow \pi^+\pi^-J/\psi$.⁹ As the Fig. 4 shows, a fit yields a mass of $(3899.0 \pm 3.6 \pm 4.9)$ MeV/ c^2 , a width of $(46 \pm 10 \pm 20)$ MeV, and larger than 8σ statistical significance. Its production ratio is measured to be $R = \frac{\sigma(e^+e^- \rightarrow \pi^\pm Z_c(3900)^\mp \rightarrow \pi^+\pi^-J/\psi)}{\sigma(e^+e^- \rightarrow \pi^+\pi^-J/\psi)} = (21.5 \pm 3.3 \pm 7.5)\%$. This state denoted $Z_c(3900)$, has a strong coupling to charmonium and electronic charge, so it cannot be interpreted as a conventional $c\bar{c}$ state.

By analyzing the Dalitz plot of $\pi^+\pi^-h_c$ system in the $e^+e^- \rightarrow \pi^+\pi^-h_c$ process,⁸ we observe a narrow structure close to the $(D^*\bar{D}^*)^\pm$ threshold in the $\pi^\pm h_c$ mass spectrum. As the Fig. 5 shows, fitting to the $\pi^\pm h_c$ mass spectrum at 4.230, 4.260 and 4.360 GeV simultaneously, yields 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. Similar to the $Z_c(3900)$ observed in the $\pi^\pm J/\psi$ mass

Fig. 4. Unbinned maximum likelihood fit to the distribution of the $M_{max}(\pi^\pm J/\psi)$. Points with error bars are data, the curve are the best fit, the dashed histogram are the phase space distribution and the shaded histograms is the non- $\pi^+\pi^- J/\psi$ background estimated from the normalized J/ψ sideband.

Fig. 5. Sum of the simultaneous fits to the invariant mass spectrum of $\pi^\pm h_c$ at 4.230 GeV, 4.260 GeV and 4.360 GeV; the inset shows the sum of the simultaneous fit to the $\pi^\pm h_c$ mass distribution at 4.230 GeV and 4.260 GeV with $Z_c(3900)$ and $Z_c(4025)$. Dots with error bars are data; shaded histograms are normalized sideband background; the solid curves show the total fit, and the dotted curves the background from the fit.

spectrum, this structure also couples to charmonium and has an electric charge, which is suggestive a state containing more quarks than just a pair of charm quark. There is no 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 90% confidence level at 4.260 GeV, which is lower than that of $Z_c(3900) \rightarrow \pi^\pm J/\psi$.

Using a partial reconstruction technique, BESIII also studies the process $e^+e^- \rightarrow (D^*\bar{D}^*)^\pm \pi^\mp$ at 4.260 GeV using 827 pb $^{-1}$ data sample.¹⁰ In Fig. 6, a structure near the $(D^*\bar{D}^*)^\pm$ threshold in the $\pi^\mp$ recoil mass spectrum is observed, which is denoted as the $Z_c(4025)$. The mass and width are measured to be $(4026.3 \pm 2.6 \pm 3.7)$ MeV/ c^2 and $(24.8 \pm 5.6 \pm 7.7)$ MeV, respectively. The Born cross section is measured to be $(139 \pm 9 \pm 15)$ pb, and the production ratio $\frac{\sigma(e^+e^- \rightarrow Z_c(4025)^\pm \pi^\mp \rightarrow (D^*\bar{D}^*)^\pm \pi^\mp)}{\sigma(e^+e^- \rightarrow (D^*\bar{D}^*)^\pm \pi^\mp)}$ is determined to be $0.65 \pm 0.09 \pm 0.06$. The parameters of $Z_c(4020)$ agree with those

Fig. 6. Unbinned maximum likelihood fit to the π^- recoil mass spectrum in data.

of $Z_c(4025)$ within 1.5σ . Further study will help us to understand whether they are the same state.

4. Summary

In summary, the charmonium states are studied based on the largest ψ' data sample, including η_c parameter measurement with high precision, the analysis on h_c exclusive decays into $\gamma\eta_c$, and the evidence of $\eta_c(2S)$ decay to $K_S^0 K^\pm \pi^\mp \pi^+ \pi^-$. For studying the XYZ states, the $X(3872)$ has been observed through $e^+e^- \rightarrow \gamma\pi^+\pi^- J/\psi$, and the line shape of $\pi^+\pi^- h_c$ has been measured in BESIII. The charged charmoniumlike states, $Z_c(3900)$, $Z_c(4020)$, and $Z_c(4025)$ has been observed, which may be new type of hadrons.

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