Light Hadron Spectroscopy at BESIII

Xingtao Huang

*School of Physics, Shandong University, No. 27 Shanda NanLu
Jinan, Shandong 250100, China
huangxt@sdu.edu.cn*

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BESIII has collected $1.3 \times 10^8 J/\psi$ and 0.4×10^8 of ψ' , which are the world's largest data samples of J/ψ and ψ' from e^+e^- collision. Radiative decays of charmonium provide a gluon-rich environment and are therefore regarded as one of the most promising hunting grounds for gluonic excitations. Significant progresses in the light-quark sector have been made with the unprecedented high statistics data sets. Several recent results on light hadron spectroscopy and light hadron decays will be reported, including: 1, the observation of the anomalous line shape of $X(1835)$ near $p\bar{p}$ mass threshold and related studies; 2, studies of glueballs in J/ψ radiative decays; 3, search for 1^{-+} exotic in $\chi_{c1} \rightarrow \eta\pi\pi$.

Keywords: BESIII; Light Hadron; Glueball.

1. Introduction

The unambiguous identification and systematic study of bound states beyond the constituent quark degrees of freedom, e.g., multi-quark states or states with gluonic degrees of freedom (hybrids, glueballs) would provide valuable input to the quantitative understanding of quantum chromodynamics (QCD). Hadron spectroscopy is one of the most important physics goals of the Beijing Spectrometer (BESIII). Since 2009, BESIII has collected $1.3 \times 10^8 J/\psi$ and 0.4×10^8 of ψ' , which are the world's largest data samples of J/ψ and ψ' from e^+e^- collision. Radiative decays of charmonium provide a gluon-rich environment and are therefore regarded as one of the most promising hunting grounds for gluonic excitations. Significant progresses in the light-quark sector have been made with the unprecedented high statistics data sets. Several recent results on light hadron spectroscopy and light hadron decays will be reported.

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2. BESIII at BEPCII

BESIII operates with the collisions provided by the Beijing Electron Positron Collider II (BEPCII), which is hosted at the Institute of High Energy Physics (IHEP) of Beijing, China. BEPCII is a double-ring symmetric collider which center of mass energy ranges in the interval between 2 and 4.6 GeV. BESIII consists of a series of subdetectors: from inside to outside, they are the Main Drift Chamber (MDC), the Time of Flight (TOF), the Super Conduct Magnet, the Electromagnetic Calorimeters (EMC) and the Muon Counters (MUC). The acceptance for charged particles and photons is 93% of the 4π solid angle, The MDC provides the spatial and relative momentum resolution for charged particles at 1 GeV/c are 130 μm and 0.5%, respectively. The TOF have a time resolution of 90(110) ps for the barrel (end caps). The EMC provides The photon energy resolution of 2.5% at 1.0 GeV in the barrel and 5% in the end caps.

3. An anomalous line shape of the $\eta'\pi^+\pi^-$ mass spectrum

The state $X(1835)$ was first observed by the BESII experiment as a peak in the $\eta'\pi^+\pi^-$ invariant mass distribution in $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$ ¹. This observation was later confirmed by BESIII studies of the same process²; the $X(1835)$ was also observed in the $\eta K_s^0 K_s^0$ channel in $J/\psi \rightarrow \gamma\eta K_s^0 K_s^0$ decays, where its spin parity was determined to be $J^P = 0^-$ by a partial wave analysis³. An anomalously strong enhancement at the proton-antiproton mass threshold, called $X(p\bar{p})$, was first observed by BESII in $J/\psi \rightarrow \gamma p\bar{p}$ decays⁴; this observation was confirmed by BESIII⁵ and CLEO⁶. This enhancement structure was subsequently determined to have spin parity $J^P = 0^-$ by BESIII⁷. In order to investigate the relation between $X(1835)$ and $X(p\bar{p})$, and understand the nature of the $X(1835)$ and $X(p\bar{p})$, a study of the $\eta'\pi^+\pi^-$ line shape of $X(1835)$ with high statistical precision is conducted.

The total 1.09×10^9 J/ψ events⁸ accumulated by the BESIII experiment in 2012 is analyzed in the decay channel $J/\psi \rightarrow \gamma\eta'\pi^+\pi^-$ with two η' major decay modes: $\eta' \rightarrow \gamma\pi^+\pi^-$ and $\eta' \rightarrow \gamma\gamma$. The $\eta'\pi^+\pi^-$ invariant mass spectra are shown in Fig. 1, where an abrupt change in slope of the $X(1835)$ line shape at the $p\bar{p}$ mass threshold is evident in both η' decay modes. We perform simultaneous fits to the $\eta'\pi^+\pi^-$ invariant mass distributions between 1.3 and 2.25 GeV/ c^2 for both event samples with two fit models. In the first model, the state around 1.85 GeV/ c^2 coupling to $p\bar{p}$ is assumed. The line shape of $\eta'\pi^+\pi^-$ above the $p\bar{p}$ threshold is affected by the opening of the $X(1835) \rightarrow p\bar{p}$ decay channel, therefore, we use the Flatté formula to describe the $X(1835)$ line shape. The fit results for the first model are shown in Fig. 2 (left); In the second model, we assume the existence of a narrow resonance, denoted as $X(1870)$, near the $p\bar{p}$ threshold and that the interference between $X(1870)$ and the $X(1835)$ produces the line shape distortion. The fit results for the second model are shown in Fig. 2 (right). Both models fit the data well and both suggest the existence of a state, either a broad state with strong couplings to $p\bar{p}$, or a narrow state just below the $p\bar{p}$ mass threshold. For the broad

Fig. 1. The $\eta'\pi^+\pi^-$ invariant mass spectra, The left plot for $\eta' \rightarrow \gamma\pi^+\pi^-$ mode and the right plot for $\eta' \rightarrow \gamma\gamma$, the dots with error bars are data, the shaded histograms are the background, the solid histograms are phase space MC, and the dotted vertical line shows the $p\bar{p}$ mass threshold position.

Fig. 2. Fit results of using Flatté formula (Left) and using a coherent sum of two Breit-Wigner amplitudes (Right). The dashed dotted vertical line shows the position of $p\bar{p}$ mass threshold, the dots with error bars are data, the solid curves are total fit results.

state above the $p\bar{p}$ mass threshold, its strong couplings to $p\bar{p}$ suggests the existence of a $p\bar{p}$ molecule-like state. For the narrow state just below $p\bar{p}$ mass threshold, its very narrow width suggests that it be an unconventional meson, most likely a $p\bar{p}$ bound state.

4. Glueball Searches

In QCD, *gluons* carry color charge and thus can form bound states called glueballs. The search for glueballs is an important field of research in hadron physics. The glueball spectrum has been predicted by Lattice QCD^{9–11}, where the lowest-lying glueballs are scalar (mass 1.5–1.7 GeV/ c^2), tensor (mass 2.3–2.4 GeV/ c^2), and pseudoscalar (mass 2.3–2.6 GeV/ c^2). Radiative decays of the J/ψ meson provide a gluon-rich environment and are therefore regarded as one of the most promising hunting grounds for glueballs. BESIII have conducted several studies to search for glueballs with Partial Wave Analysis (PWA).

4.1. PWA of $J/\psi \rightarrow \gamma\pi^0\pi^0$

A mass independent amplitude analysis of the $\pi^0\pi^0$ system in radiative $J/\psi \rightarrow \gamma\pi^0\pi^0$ decays is performed. In order to describes the dynamics of the $\pi^0\pi^0$ system and provide a description of its scalar and tensor components, a piecewise function is determined as a function of $M_{\pi^0\pi^0}$ from an analysis of the $(1.311 \pm 0.011) \times 10^9$ J/ψ decays. The results of the mass independent analysis are given in two ways: the intensities and phase differences for the amplitudes as a function of $M_{\pi^0\pi^0}$, as shown in Fig. 3 and Fig. 4, respectively. The branching fraction of radiative J/ψ decays to $\pi^0\pi^0$ is first measured to be $(1.15 \pm 0.05) \times 10^{-3}$, where the error is systematic only and the statistical error is negligible.

Fig. 3. The intensities for the (a) 0^{++} , (b) 2^{++} E1, (c) 2^{++} M2 and (d) 2^{++} E3 amplitudes as a function of $M_{\pi^0\pi^0}$ for the nominal results. The solid black markers show the intensity calculated from one set of solutions, while the open red markers represent its ambiguous partner. Only statistical errors are presented.

Fig. 4. The phase differences relative to the reference amplitude (2^{++} E1) for the (a) 0^{++} , (b) 2^{++} M2, and (c) 2^{++} E3 amplitudes as a function of $M_{\pi^0\pi^0}$ for the nominal results. The solid black markers show the phase differences calculated from one set of solutions, while the open red markers represent the ambiguous partner solutions. An arbitrary phase convention is applied here in which the phase difference between the 0^{++} and 2^{++} E1 amplitudes is required to be positive. Only statistical errors are presented.

4.2. PWA of $J/\psi \rightarrow \gamma\phi\phi$

A PWA on $J/\psi \rightarrow \gamma\phi\phi$ has been performed based on the same J/ψ events. The most remarkable feature of the PWA results is that 0^{-+} states are dominant. The existence of the $\eta(2225)$ is confirmed and two additional pseudoscalar states, $\eta(2100)$ with a mass 2050^{+30+75}_{-24-26} MeV/ c^2 and a width $250^{+36+181}_{-30-164}$ MeV/ c^2 and $X(2500)$ with a mass $2470^{+15+101}_{-19-23}$ MeV/ c^2 and a width 230^{+64+56}_{-35-33} MeV/ c^2 , are observed.

Fig. 5. Superposition of data and the PWA fit projections. Intensities of individual J^{PC} components. The red dots, blue boxes and green triangles with error bars are the intensities of $J^{PC} = 0^{-+}$, 0^{++} and 2^{++} , respectively, from the model-independent fit in each bin. The short-dashed, dash-dotted and long-dashed histograms show the coherent superpositions of the BW resonances with $J^{PC} = 0^{-+}$, 0^{++} and 2^{++} , respectively, from the model-dependent fit.

5. Exotic Search in $\chi_{c1} \rightarrow \eta\pi^+\pi^-$

BESIII has collected 0.4×10^8 of ψ' , which produces the world's largest χ_{c1} data samples via $\psi' \rightarrow \gamma\chi_{c1}$. Therefore, we analyze $\chi_{c1} \rightarrow \eta\pi^+\pi^-$ sample, and find a very prominent $a_0(980)$ peak in the $\eta\pi^\pm$ invariant mass distribution. An amplitude analysis of the $\psi' \rightarrow \gamma\chi_{c1}, \chi_{c1} \rightarrow \eta\pi^+\pi^-$ decay is performed, and the parameters of the $a_0(980)$ are determined using a dispersion relation. The $a_0(980)$ line shape in its $\eta\pi$ final state appears to be sensitive to the details of the $a_0(980) \rightarrow \eta'\pi$ production, and for the first time, a significant nonzero coupling of the $a_0(980)$ to the $\eta'\pi$ mode is measured with a statistical significance of 8.9σ .

We also report $a_2(1700)\pi$ production in the $\chi_{c1} \rightarrow \eta\pi^+\pi^-$ decays for the first time, with the mass and width in agreement with world average values, and this analysis provides both qualitative and quantitative evidence for the existence of the $a_2(1700)$. This may help in listing the $a_2(1700)$ as an established resonance by the the PDG ¹².

6. Summary

Using the world's largest $1.3 \times 10^8 J/\psi$ and 0.4×10^8 of ψ' events collected with the BESIII detector, we conducted a series of study on radiative decays of charmonium. Several recent results on light hadron spectroscopy and light hadron decays are reported. More results will come soon with BESIII continuing data taking.

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