Recent Results on Light Hadron Spectroscopy at BESIII

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Using about $2.25 \times 10^8 J/\psi$ events and $1.06 \times 10^8 \psi'$ events accumulated with BESIII detector operating at BEPCII e^+e^- collider, a partial wave analysis of $p\bar{p}$ mass threshold enhancement is used in $J/\psi(\psi') \to \gamma p\bar{p}$. $X(1835)$ is confirmed in $J/\psi \to \gamma\eta'\pi^+\pi^-$ and $X(2120)$ and $X(2370)$ are observed. A new structure $X(1870)$ is observed with a significance of 7.1σ in $J/\psi \to \omega\eta\pi^+\pi^-$. For the decays $J/\psi \to \gamma\pi^+\pi^-\pi^0$ and $J/\psi \to \gamma\pi^0\pi^0\pi^0$, the isospin violating decay $\eta(1405) \to f_0(980)\pi^0$ is observed for the first time. New measurements of the $J/\psi \to \pi^+\pi^-\pi^0$ and $\psi' \to \pi^+\pi^-\pi^0$ are presented with high precision.

1 BESIII and BEPCII

BEPCII/BESIII [1] is a major upgrade of the BEPC(Beijing Electron Positron Collider) accelerator and BESII(the Beijing Spectrometer) detector. The primary physics purposes are aimed at the study of light hadron spectroscopy and τ-charm physics. The analysis reported here are based on the data samples of $2.25 \times 10^8 J/\psi$ and $1.06 \times 10^8 \psi'$ events.

2 $p\bar{p}$ mass threshold structure

An anomalously strong $p\bar{p}$ mass threshold enhancement was first observed by BESII experiment in the radiative decay of $J/\psi \to \gamma p\bar{p}$ [2]. One intriguing feature of this enhancement structure is that the corresponding structures are absent in the relative channels, including B-meson decays [3], Υ [4], and the decay of $J/\psi \to \omega p\bar{p}$ [5].

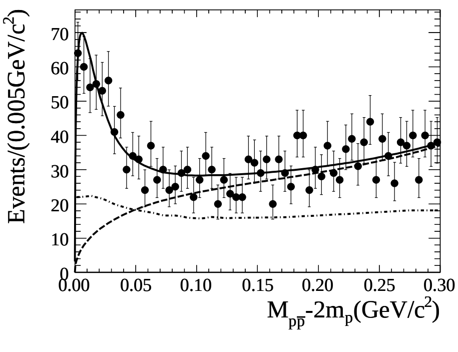

Figure 1: The $p\bar{p}$ mass spectrum for the $\psi' \to \pi^+\pi^- J/\psi(\gamma p\bar{p})$ at BESIII. The solid curve is the fit result; the dashed curve shows the fitted background function, and the dash-dotted curve indicates how the acceptance varies with $p\bar{p}$ invariant mass.

The mass threshold enhancement was confirmed by an analysis of $\psi' \to \pi^+\pi^- J/\psi, J/\psi \to$

$\gamma p\bar{p}$ by the BESIII experiment [6], shown in Fig.1 and the data were fitted by an S-wave Breit-Wigner resonance function, obtaining $M = 1861 \pm 6.13(stat) + 7.26(syst)$. Recently, a partial wave analysis(PWA) of $p\bar{p}$ mass-threshold enhancement in the reaction $J/\psi \to \gamma p\bar{p}$ is used to determine [7]: its J^{PC} quantum numbers to be 0^{-+}; its peak mass to be below threshold at $M = 1832^{+19}_{-5}(stat.)^{+18}_{-17}(syst.)19(model)\mathrm{MeV}/c^2$; and its total width to be $\Gamma < 76$ MeV at 90% CL. A similar PWA analysis is performed on $\psi' \to \gamma p\bar{p}$ decays and the $p\bar{p}$ mass threshold is observed, but it is not obvious due to limited statistics of ψ' events. The produce branching fractions for $X(p\bar{p})$ in J/ψ and ψ' decays are measured to be $Br(J/\psi \to \gamma X)Br(X \to p\bar{p}) = (9.0^{+0.4}_{-1.1}(stat.)^{+1.5}_{-5.0}(syst.) \pm 2.3(model)) \times 10^{-5}$ and $Br(\psi(2S) \to \gamma X)Br(X \to p\bar{p}) = (4.57 \pm 0.36(stat.)^{+1.23}_{-4.07}(syst.) \pm 1.28(model)) \times 10^{-6}$, respectively. And the production ratio of the $p\bar{p}$ between J/ψ and ψ' radiative decays is $R = \frac{Br(\psi(2S)\to\gamma X(p\bar{p}))}{Br(J/\psi\to\gamma X(p\bar{p}))} = (5.08^{+0.71}_{-0.45}(stat.)^{+0.67}_{-3.58}(syst.) \pm 0.12(model))\%$, which is suppressed compared with 12% rule.

3 Confirmation of $X(1835)$ and observation of two new structures in $J/\psi \to \gamma\pi\pi\eta'$

A $\pi^+\pi^-\eta'$ resonance, the $X(1835)$, was first observed in $J/\psi \to \gamma\pi^+\pi^-\eta'$ at BESII with a statistical significance of 7.7σ [8]. Extensive theoretical interpretations have been raised to settle the nature of this resonance, such as the $p\bar{p}$ bound state [9], glueball [10], radial excitation of η' [11] and so on. At BESIII, two decay modes of η', $\eta' \to \gamma\rho$ and $\eta' \to \eta\pi^+\pi^-$ are utilized to study the channel of $J/\psi \to \gamma\pi^+\pi^-\eta'$ [12]. Fig. 2(a) and Fig. 2(b) show the mass spectrum of $\pi^+\pi^-\eta'$ in both decay modes of η'. In addition to the clear $X(1835)$ peak, two structures located at around 2.1 and 2.3 GeV/c^2 are also clearly observed.

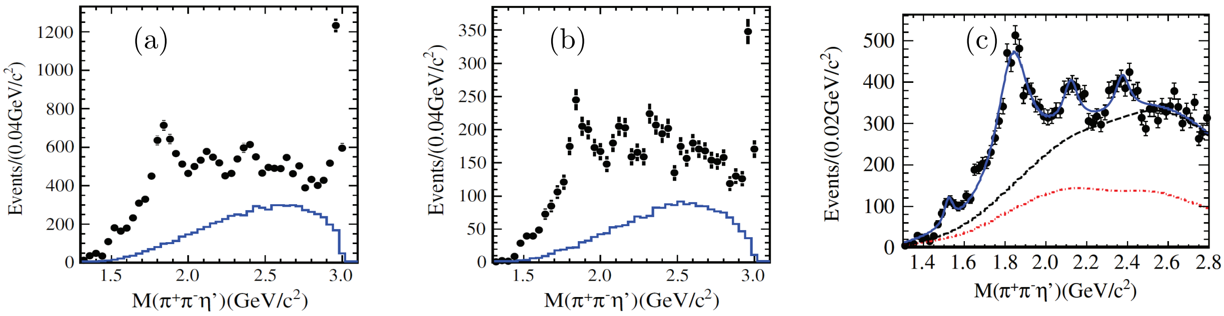

Figure 2: (a) the mass spectrum of $\pi^+\pi^-\eta'$ with $\eta' \to \gamma\rho$; (b) the mass spectrum of $\pi^+\pi^-\eta'$ with $\eta' \to \eta\pi^+\pi^-$. (c) the mass spectrum fitting with four resonances. The dots with error bars show the data, and the blue histogram in (a) and (b) stands for the distribution of arbitrarily normalized phase space Monte Carlo sample. The dash-dotted red curve in (c) is the contribution from non-η' events and $J/\psi \to \pi^0\pi^+\pi^-\eta'$ events, and the dashed black curve in (c) represents the total background.

Figure 2(c) shows the fitting result of the $\pi^+\pi^-\eta'$ mass spectrum with the contribution of two decay modes of η' combined together. The existence of $X(1835)$ is confirmed with a significance of larger than 20σ. The statistical significance of $X(2120)$ and $X(2370)$ are determined to be 7.2σ and 6.4σ respectively. $\cos\theta_\gamma$ distribution of the $X(1835)$, where θ_γ is the polar angle of the photon in the J/ψ center of mass system, agrees with $1 + \cos^2\theta_\gamma$, which is expected for a pseudoscalar meson.

4 Observation of $X(1870)$ in $J/\psi \to \omega\eta\pi^+\pi^-$

$X(1835)$ is reported in the analysis of $J/\psi \to \gamma\pi^+\pi^-\eta'$ as covered in the last section. The study of the decay patterns of the resonance, i.e. to search for similar structures in relative channels and with other side particles is very important to clarify its nature. In this sense, the analysis of $J/\psi \to \omega\eta\pi^+\pi^-$ [14] will shed light on the properties of the resonance.

Figure 3 shows the fitting result of $\eta\pi^+\pi^-$ mass spectrum within the $a_0^0(980)$ signal region in $M(\eta\pi^\pm)$. The signal peaks of $f_1(1285)$, $\eta(1405)$ and $X(1870)$ are parameterized with efficiency-corrected Breit-Wigner function convoluted with Gaussian resolution function, and the background curve is described by a floating polynomial. The mass and width of $f_1(1285)$ and $\eta(1405)$ agree quite well with their PDG values [13]. The fit yields the mass and width of $X(1870)$ to be $M = 1877.3 \pm 6.3$ MeV/c^2, and $\Gamma = 57 \pm 12$MeV/c^2. The statistical significance of $X(1870)$ is conservatively estimated as 7.1σ. Whether the $X(1870)$, $X(1860)$ and $X(1835)$ are the same particle need further study.

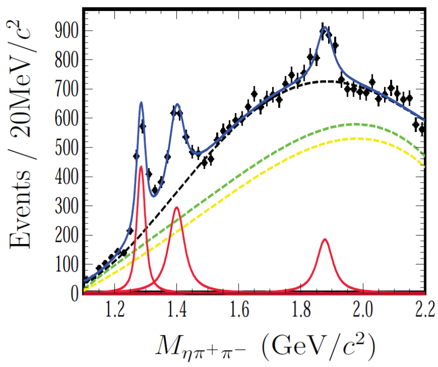

Figure 3: Mass spectrum fitting results with either $\eta\pi^+$ or $\eta\pi^-$ located in the 100 MeV/c2 mass window of $a_0(980)$. The yellow dashed curve shows the contribution of non-ω and/or non-$a_0(980)$ background, green dashed line in addition includes the contribution of $J/\psi \to b_1(1235)a_0(980)$, the black dashed curve stands for the total background with the non-resonant $J/\psi \to \omega a_0^\pm(980)\pi^\mp$ included.

5 Observation of $\eta(1405) \to f_0(980)\pi^0$ in $J/\psi \to \gamma 3\pi$

The spectrum of radial excitation states of isoscalar η and η' is still not well known. An important issue is about the nature of $\eta(1405)$ and $\eta(1475)$ states, which are not well established. The decays $J/\psi \to \gamma\pi^+\pi^-\pi^0$ and $\gamma\pi^0\pi^0\pi^0$ are analyzed at BESIII [15]. In both modes, clear $f_0(980)$ signals are observed on both $\pi^+\pi^-$ and $\pi^0\pi^0$ spectra, and the width of observed $f_0(980)$ is much narrower(about 10 MeV) than that in other processes [16]. Fig.4 shows the invariant mass of $f_0(980)\pi^0$ by taking events in the window of $f_0(980)$ on the $\pi\pi$ mass spectrum and $f_1(1285)/\eta(1295)$ can be observed with a significance of about 3.7σ for $f_1(1285)/\eta(1295) \to f_0(980)\pi^0$ in $f_0 \to \pi^+\pi^-$ mode(1.2σ in $f_0(980) \to \pi^0\pi^0$). A clear peak around 1400MeV is also observed on the mass of $f_0(980)\pi^0$ and angular analysis indicates that the peak on 1400MeV is from $\eta(1405) \to f_0(980)\pi^0$ decay. The combined branching fraction of $\eta(1405)$ production is determined to be $Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^+\pi^-) = (1.50 \pm 0.11(stat.) \pm 0.11(sys.)) \times 10^{-5}$ and $Br(J/\psi \to \gamma\eta(1405) \to \gamma\pi^0 f_0(980) \to \gamma\pi^0\pi^0\pi^0) = (7.10 \pm 0.82(stat.) \pm 0.72(sys.)) \times 10^{-6}$, respectively. It is the first time that we observe anomalously large isospin violation in the strong decay of $\eta(1405) \to f_0(980)\pi^0$. A possible explanation [17] to this puzzle is an intermediate on-shell $K\bar{K}^*+c.c.$ rescattering to the isospin violating $f_0(980)\pi^0$ by exchanging on-shell kaon.

The decay rates for $\eta' \to 3\pi$ is determined to be $Br(\eta' \to \pi^+\pi^-\pi^0) = (3.83 \pm 0.15 \pm 0.39) \times 10^{-3}$ and $Br(\eta' \to 3\pi^0) = (3.56 \pm 0.22 \pm 0.34) \times 10^{-3}$, respectively. For $\eta' \to \pi^+\pi^-\pi^0$ decay, it is consistent with CLEO-c's measurements and precision is improved by a factor of 4. while, for $\eta' \to \pi^0\pi^-\pi^0$, it is two times larger than that in the PDG value [16].

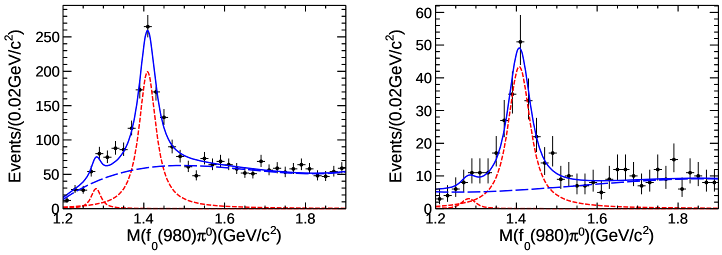

Figure 4: The invariant mass of $f_0\pi^0$ from $J/\psi \to \gamma\pi^+\pi^-\pi^0$ and $\gamma 3\pi^0$.

6 Precision measurement of the branching ratios of $J/\psi(\psi(2S)) \to \pi^+\pi^-\pi^0$

Previous studies[18 19 20] of $J/\psi \to \pi^+\pi^-\pi^0$ and $\psi(2S) \to \pi^+\pi^-\pi^0$ found not only an unexpectedly low branching fraction in the case of the $\psi(2S)$ but also a completely different shape of the di-pion mass spectrum and the Dalitz plot.

Figure 5 shows the invariant mass spectra and Dalitz plots for $J/\psi \to \pi^+\pi^-\pi^0$ and $\psi(2S) \to \pi^+\pi^-\pi^0$ at BESIII[21]. The decay $J/\psi \to \pi^+\pi^-\pi^0$ is dominated by $\rho(770)$ production; the absence of events in the center of the Dalitz plot points to negatively interfering higher ρ states. While for the $\psi(2S) \to \pi^+\pi^-\pi^0$ decay, a small $\rho(770)$ contribution can be discerned. Most of the events are however clustering around 2.2GeV$/c^2$ in di-pion mass. The branching fraction for $J/\psi \to \pi^+\pi^-\pi^0$ is determined to be $(2.137 \pm 0.004(stat.)^{+0.058}_{-0.056}(syst.)^{+0.027}_{-0.026}(norm.)) \times 10^{-2}$, and the branching fraction for $\psi(2S) \to \pi^+\pi^-\pi^0$ is measured as $(2.14{\pm}0.03(stat.)^{+0.08}_{-0.07}(syst.)^{+0.09}_{-0.08}(norm.))\times 10^{-4}$. The ratio of these two branching fractions is $\frac{Br(\psi(2S)\to\pi^+\pi^-\pi^0)}{Br(J/\psi\to\pi^+\pi^-\pi^0)} = (1.00{\pm}0.01(stat.)^{+0.06}_{-0.05}(syst.))\%$.

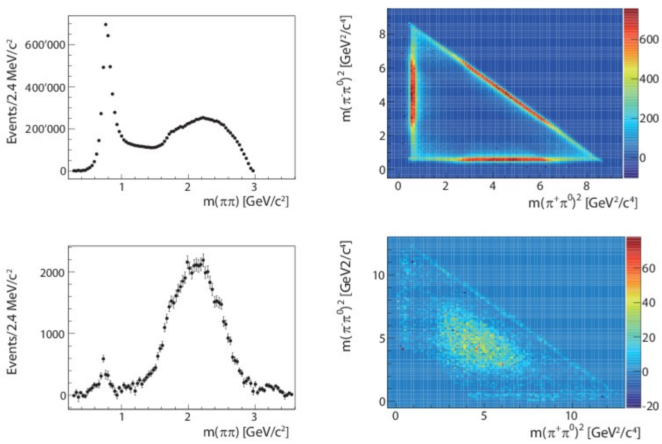

Figure 5: $\pi\pi$ invariant mass distribution(left) and Dalitz plot(right) with backgrounds subtracted and corrected for efficiency. Top and bottom graphs show the results for the $J/\psi \to \pi^+\pi^-\pi^0$ and $\psi(2S) \to \pi^+\pi^-\pi^0$ analysis, respectively.

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