

Recent Results on Light Hadron Spectroscopy at BESIII

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Using about $226 \times 10^6 J/\psi$ events and $106 \times 10^6 \psi'$ events accumulated with BESIII detector operating at BEPCII e^+e^- collider, the existence of $p\bar{p}$ mass threshold enhancement and $X(1835)$ is confirmed. Two resonances, $X(2120)$ and $X(2370)$ are first observed in $J/\psi \rightarrow \gamma\gamma'\pi^+\pi^-$. In the study of $J/\psi \rightarrow \omega\eta\pi^+\pi^-$, a narrow structure denoted as $X(1870)$ is seen with a significance of 7.1σ . In addition, a direct measurement of $f_0(980) \rightarrow a_0^0(980)$ and $a_0^0(980) \rightarrow f_0(980)$ mixing transitions is presented to probe the nature of the two scalar states.

1 BESIII and BEPCII

BEPCII/BESIII¹ is a major upgrade of the BEPC accelerator and BESII detector. The primary physics purposes are aimed at the study of hadron spectroscopy and τ -charm physics. The analysis reported here are based on the data samples of $226 \times 10^6 J/\psi$ and $106 \times 10^6 \psi'$ events.

2 Confirmation of $p\bar{p}$ Mass Threshold Enhancement

An anomalously strong $p\bar{p}$ mass threshold enhancement was first observed by BESII experiment in the radiative decay of $J/\psi \rightarrow \gamma p\bar{p}$ ² in 2003. A fit with an S-wave Breit-Wigner resonance function indicates that the peak mass is at $M = 1859_{-10}^{+3}(\text{stat.})_{-25}^{+5}(\text{sys.})$ MeV/ c^2 , and the total width is $\Gamma < 30\text{MeV}/c^2$ (at the 90% C.L.). One intriguing feature of this enhancement structure is that the corresponding structures are absent in the relative channels, including B-meson decays³, radiative decays of ψ' ⁴ and Υ ⁵, and the decay of $J/\psi \rightarrow \omega p\bar{p}$ ⁶. These negative observations disfavor the interpretation of pure final state interaction(FSI).

Fig. 1 shows the fitting results of $p\bar{p}$ mass spectrum in $\psi' \rightarrow \pi^+\pi^- J/\psi(\gamma p\bar{p})$ and the threshold enhancement structure can be observed. The mass of fitted resonant parameters are $M = 1861_{-13}^{+6}(\text{stat.})_{-26}^{+7}(\text{sys.})$ MeV/ c^2 , and the total width is $\Gamma < 38\text{MeV}/c^2$ at the 90% C.L..

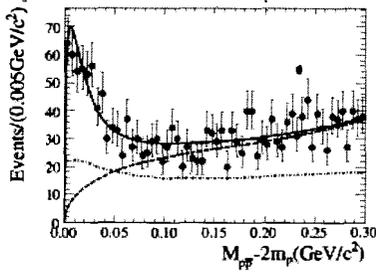


Figure 1: The $p\bar{p}$ mass spectrum for the $\psi' \rightarrow \pi^+ \pi^- J/\psi(\gamma p\bar{p})$ after final event selection. The solid curve is the fit result; the dashed curve shows the fitted background function, and the dash-dotted curve indicates how the acceptance varies with $p\bar{p}$ invariant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

3 Observation of $X(1835)$ and Two New Resonances in $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$

$X(1835)$ is first observed in the study of $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$ at BESII with a statistical significance of 7.7σ ⁷. Extensive theoretical interpretations have been raised to settle the nature of this resonance, such as the $p\bar{p}$ bound state⁸, glueball⁹, radial excitation of η' ¹⁰ and so on.

At BESIII, two decay modes of η' , $\eta' \rightarrow \gamma \rho$ and $\eta' \rightarrow \eta \pi^+ \pi^-$ are utilized to study the channel of $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$. Fig. 2(a) and Fig. 2(b) show the mass spectrum of $\eta' \pi^+ \pi^-$ 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 first observed.

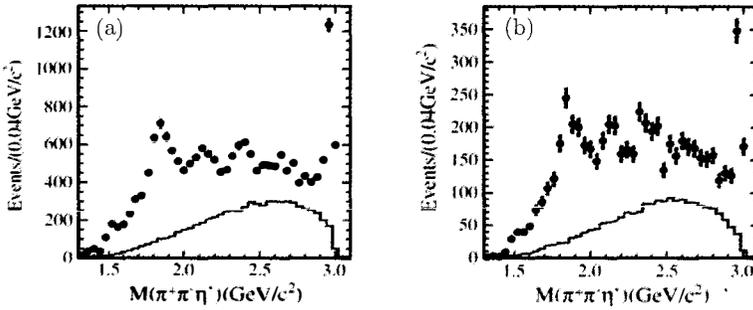


Figure 2: (a) is the mass spectrum of $\eta' \pi^+ \pi^-$ with $\eta' \rightarrow \gamma \rho$; (b) is the mass spectrum of $\eta' \pi^+ \pi^-$ with $\eta' \rightarrow \eta \pi^+ \pi^-$. The dots with error bars show the data, and the blue histogram in (a) and (b) stands for the distribution of arbitrarily normalized phase space Monte Carlo sample.

Fig. 3 shows the fitting result of the $\eta' \pi^+ \pi^-$ 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.

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

$X(1835)$ is reported in the analysis of $J/\psi \rightarrow \gamma \eta' \pi^+ \pi^-$ 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 $J/\psi \rightarrow \omega \eta \pi^+ \pi^-$ will shed light on the properties of the resonance.

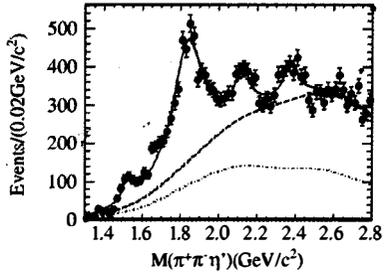


Figure 3: Mass spectrum fitting with four resonances. The dash-dotted red curve is the contribution from non- η' events and $J/\psi \rightarrow \pi^0 \eta' \pi^+ \pi^-$ events, and the dashed black curve represents the total background.

Fig. 4 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 values¹¹. The fit yields the mass and width of $X(1870)$ to be $M = 1877.3 \pm 6.3 \text{ MeV}/c^2$, and $\Gamma = 57 \pm 12 \text{ MeV}/c^2$. 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.

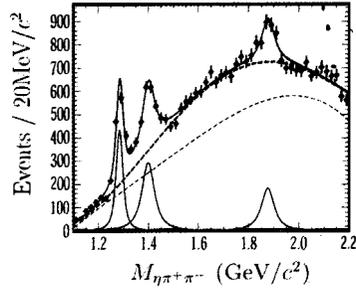


Figure 4: Mass spectrum fitting results with either $\eta\pi^+$ or $\eta\pi^-$ located in the 100 MeV/ c^2 mass window of $a_0(980)$. The yellow dashed curve shows the contribution of non- ω and/or non- $a_0(980)$ background, green dashed line in addition includes the contribution of $J/\psi \rightarrow b_1(1235)a_0(980)$, the black dashed curve stands for the total background with the non-resonant $J/\psi \rightarrow \omega a_0^0(980)\pi^\mp$ included.

5 Study of $a_0^0(980) - f_0(980)$ Mixing

The nature of the scalar mesons $a_0^0(980)$ and $f_0(980)$ has been a hot topic in light hadron physics for many years. The possibility of mixing between $a_0^0(980)$ and $f_0(980)$ was suggested long ago, and its measurement will shed light on the nature of these two resonances¹². There has been various theoretical predications with various models, yet no firm experimental evidence is available. The most significant signature of this isospin-violating mixing process is a very narrow peak of about 8 MeV/ c^2 in the mass spectrum of $a_0^0(980)/f_0(980)$ ¹³. At BESIII, we perform a direct measurement of $a_0^0(980) \leftrightarrow f_0(980)$ mixing intensity via the process of $J/\psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi\eta\pi^0$ and $\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-$.

For the decay of $J/\psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi\eta\pi^0$, a simultaneous fit is performed to

the $\eta\pi^0$ mass spectrum recoiling against the ϕ mass signal and the ϕ mass side band, as shown in Fig. 5(a). The upper limit of the mixing branching ratio is set to be $Br(J/\psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi\eta\pi^0) < 5.4 \times 10^{-6}$ at the 90% C.L.. The upper limit (90% C.L.) of the mixing intensity for the $f_0(980) \rightarrow a_0^0(980)$ transition is defined and calculated to be¹⁴:

$$\xi_{fa} = \frac{Br(J/\psi \rightarrow \phi f_0(980) \rightarrow \phi a_0^0(980) \rightarrow \phi\eta\pi^0)}{Br(J/\psi \rightarrow \phi f_0(980) \rightarrow \phi\pi\pi)} < 1.1\% \quad (1)$$

For the decay of $\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-$, a simultaneous fit is performed to the $\pi^+ \pi^-$ mass spectrum in the χ_{c1} signal region and the χ_{c1} mass side band, as shown in Fig. 5(b). The upper limit of the mixing branching ratio is set to be $Br(\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-) < 6.0 \times 10^{-7}$ at the 90% C.L.. The upper limit (90% C.L.) of the mixing intensity for the $a_0^0(980) \rightarrow f_0(980)$ transition is defined and calculated to be¹¹:

$$\xi_{af} = \frac{\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 f_0(980) \rightarrow \pi^0 \pi^+ \pi^-}{\chi_{c1} \rightarrow \pi^0 a_0^0(980) \rightarrow \pi^0 \pi^0 \eta} < 1.0\% \quad (2)$$

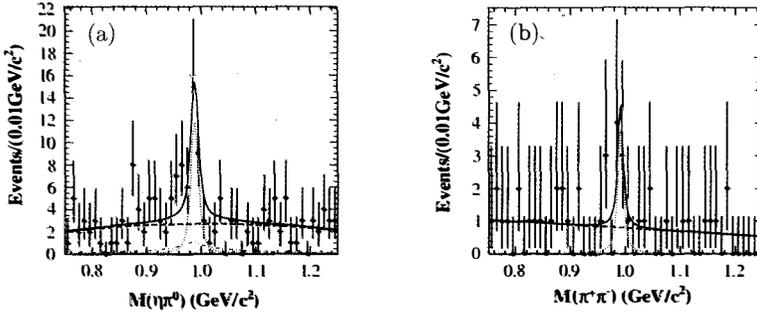


Figure 5: (a) is the fitting result of $\eta\pi^0$ mass spectrum recoiling against ϕ signal; (b) is the fitting result of $\pi^+ \pi^-$ mass spectrum in the signal region of χ_{c1} . The red dotted line stands for the mixing signal, the green dash-dotted line shows the $a_0^0(980)/f_0(980)$ contribution from other processes, and the blue dashed line is the background polynomial.

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