Experimental Study of J/ψ Radiative Decay to $\pi^0\pi^0$

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The decay $J/\psi \to \gamma\pi^0\pi^0$ is studied with 7.0×10^6 J/ψ events collected in the neutral trigger mode by the Beijing Spectrometer at the Beijing Electron-Positron Collider. Evidence for the existence of $f_J(1710)$ and $\xi(2230)$ in this channel is presented, and the corresponding masses as well as the product branching ratios are obtained. An interpretation of the $\xi(2230)$ as a glueball is favored. [S0031-9007(98)06780-5]

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It is well known that QCD predicts the existence of glueballs, the bound states of gluons. A pure glueball is considered to have the characteristics of narrow width, flavor symmetric decays, and copious production in J/ψ radiative decays [1]. In the past decades, considerable efforts were made both theoretically and experimentally to search for glueballs. Based on these studies, the four states, $f_J(1710)$ [2,3], $\xi(2230)$ [1,4], $f_0(1500)$ [5,6], and $\eta(1440)$ [7] are claimed to be prime glueball candidates. The recent analysis from the Beijing Spectrometer (BES) on the $J/\psi \to \gamma K^+K^-$ decay showed the appearance of the scalar state $f_0(1780)$ in the $f_J(1710)$ mass region [8], thus it provided useful information in understanding $f_J(1710)$. For $\xi(2230)$, using 8.0×10^6 J/ψ events collected by the BES at the Beijing Electron-Positron Collider (BEPC), BES experiments not only confirmed in the decay $J/\psi \to \gamma K\overline{K}$ the existence of $\xi(2230)$, which was first observed by Mark III Collaboration [9], but also found two nonstrange decay modes of $\xi(2230) \to \pi^+\pi^-$ and $p\bar{p}$. The observation of these nonstrange decay modes of $\xi(2230)$ has generated great experimental and theoretical interests in the possibility of its being a tensor glueball state [1,4]. However, the information to identify these states is still insufficient. In theory, it still remains a difficulty to predict glueball masses, decay widths, decay modes, and production cross sections. The experimental situation may in fact be much complicated, since glueballs may mix with nearby ordinary $q\bar{q}$ states. Thus, the identification of a glueball state requires detailed knowledge of production cross sections in different reactions, branching ratios into different final states and all quantum numbers. However, up to now, only a few decay modes have been observed for both $\xi(2230)$ and $f_J(1710)$. The investigation of $\xi(2230)$ and $f_J(1710)$ in the other channels therefore becomes increasingly important.

The neutral decay channel $J/\psi \to \gamma\pi^0\pi^0$ is of particular advantage over the corresponding charged channel $J/\psi \to \gamma\pi^+\pi^-$ because of being free of $J/\psi \to \rho\pi$ contamination, which is of great help in suppressing the background to distinguish the structures around 1.7 and

2.2 GeV regions. The Crystal Ball Collaboration analyzed the $J/\psi \to \gamma\pi^0\pi^0$ channel [10]; however, no $\xi(2230)$ is observed in their $\pi^0\pi^0$ invariant mass spectrum. In this Letter, we report our analysis on $J/\psi \to \gamma\pi^0\pi^0$ using 7.0×10^6 J/ψ events collected by BES with the neutral trigger mode.

The BES detector has been outlined in detail elsewhere [11]. Here we give only a brief description of the BES Barrel Shower Counter (BSC), which is a main component used in our measurements for photon detection. The position resolution along the z axis (the e^+ beam direction) and the angular resolution in the plane perpendicular to the z axis are $\sigma_z = 36$ mm and $\sigma_\phi = 7.9$ mrad, respectively, while the energy resolution is $\Delta E/E = 22\%/\sqrt{E}$ (E is the energy in GeV) for the BSC. It is expected that the better angular and position resolutions of the BSC in photon detection may compensate its relatively poor energy resolution. Therefore, the information of the position and direction of photon in shower counter is used as much as possible in event selection.

A selection of zero-prong events with more than four neutral clusters inside BSC within the polar angle region $|\cos\theta| < 0.75$ is carried out. In this stage, much effort is devoted to the selection of photon candidates. Neutral clusters that hit at least two layers and have deposit energies larger than 50 MeV inside the BSC are identified as photon candidates. Furthermore, the clusters in the BSC, which are not from the interaction region, are excluded by imposing $\delta_c < 0.2$, where

$$\delta_c = (\mathrm{cx} - \mathrm{scx})^2 + (\mathrm{cy} - \mathrm{scy})^2 + (\mathrm{cz} - \mathrm{scz})^2, \quad (1)$$

cx, cy, and cz are the direction cosines of photon candidates, and scx, scy, scz are the direction cosines of clusters developed inside the BSC. Then, the momenta and energy constraints kinematic fit is implemented for five photon final states. If the number of the selected photon candidates is larger than five, the fit is performed over all possible five photon combinations, and the combination with the smallest χ^2 is chosen for further analysis. There are 15 combinations using five photons to construct the $\gamma\pi^0\pi^0$ final state. Introducing a variable δ as

$$\delta = \sqrt{(m_{\gamma_1\gamma_2} - m_{\pi^0})^2 + (m_{\gamma_3\gamma_4} - m_{\pi^0})^2}, \quad (2)$$

we then choose the combination with the minimum value of the δ for all 15 possibilities.

Background studies are carried out using the Monte Carlo technique. $J/\psi \to \gamma\pi^0$, $\gamma\eta$, $\gamma\eta'$, $\omega\pi^0$ and $\omega f_2(1270)$ are considered as possible backgrounds to the decay $J/\psi \to \gamma\pi^0\pi^0$. The branching ratio of the decay $J/\psi \to \gamma\pi^0$ is small ($\sim 10^{-5}$) and the energies of its final state photons are pretty large; therefore, it is almost impossible to pass through the selection criteria for the decay $J/\psi \to \gamma\pi^0\pi^0$. For processes $J/\psi \to \gamma\eta$, $\eta \to 3\pi^0$, there are about 160 events surviving after the selection. Fortunately, all of these events peak below 0.8 GeV in the $\pi^0\pi^0$ invariant mass spectrum and contaminate quite little in our analyzed mass region. For $J/\psi \to \gamma\eta'$, $\eta' \to 2\pi^0\eta$ decays, about 36 events remain in the $\pi^0\pi^0$ invariant mass spectrum after the selection, which pile up in the region below 1.2 GeV. As to $\omega\pi^0$ events, most of this background can be rejected by a cut

$$|M_{\gamma\pi^0} - M_\omega| > 30 \text{ MeV}.$$

The branching ratio of $J/\psi \to 7\gamma$ via $\omega f_2(1270)$ is 1.0×10^{-4} and the selection efficiency for this channel is about 1.4%, with a total of 11 events still left after the selection. These remaining events present an almost flat distribution in the $\pi^0\pi^0$ invariant mass spectrum.

In order to remove the backgrounds to a greater extent, further cuts containing $\delta < 0.1$ GeV/c^2, $\chi^2_{4c} < 13$, $|m_{\gamma\gamma} - m_{\pi^0}| < 50$ MeV, and the number of photon candidates less than 7 are applied; thus a final $\gamma\pi^0\pi^0$ sample is obtained.

The invariant mass distributions of two pairs of photons for the final sample are shown in Figs. 1(a) and 1(b), from which one can see clear π^0 signals. Figure 2 presents the $\pi^0\pi^0$ invariant mass spectrum. It provides the evidence for the existences of $\xi(2230)$, $f_J(1710)$, $X(1480)$, as well as other resonances, including $f_2(1270)$ and the possible $X(2050)$. According to the Monte Carlo simulation, in the mass region of 1.71 and 2.23 GeV, the mass resolutions are about 50 MeV and the detection efficiencies 5.42% and 4.62%, respectively. An unbinned maximum-likelihood method which uses a smooth background plus five Breit-Wigner resonances convoluted with Gaussian resolution functions is utilized in fitting the $\pi^0\pi^0$ invariant mass spectrum. Because of the poor mass resolution and low statistics, we fix the mass and width of $f_2(1270)$ to PDG values and fix the widths of $f_J(1710)$ and $\xi(2230)$ to the values obtained in Ref. [8] and Ref. [4] in our fit. There are 18.4 and 29.2 events for $\xi(2230)$ and $f_J(1710)$ signals and the statistical significances are 3.6σ and 4.1σ, respectively. The fitted masses and the corresponding branching ratios $B(J/\psi \to \gamma X) \times B(X \to \pi^0\pi^0)$ for $f_J(1710)$ and $\xi(2230)$ are listed below.

$$M_{f_J(1710)} = (1720 \pm 39) \text{ MeV}$$

$$\Gamma_{f_J(1710)} = 100 \text{ MeV} \quad (\text{fixed})$$

$$B(J/\psi \to \gamma f_J(1710)) \times B(f_J(1710) \to \pi^0\pi^0) = (8.3 \pm 5.3 \pm 2.8) \times 10^{-5},$$

$$M_{\xi(2230)} = (2246 \pm 36) \text{ MeV}$$

$$\Gamma_{\xi(2230)} = 20 \text{ MeV} \quad (\text{fixed})$$

$$B(J/\psi \to \gamma\xi(2230)) \times B(\xi(2230) \to \pi^0\pi^0) = (4.5 \pm 2.6 \pm 1.3) \times 10^{-5}.$$

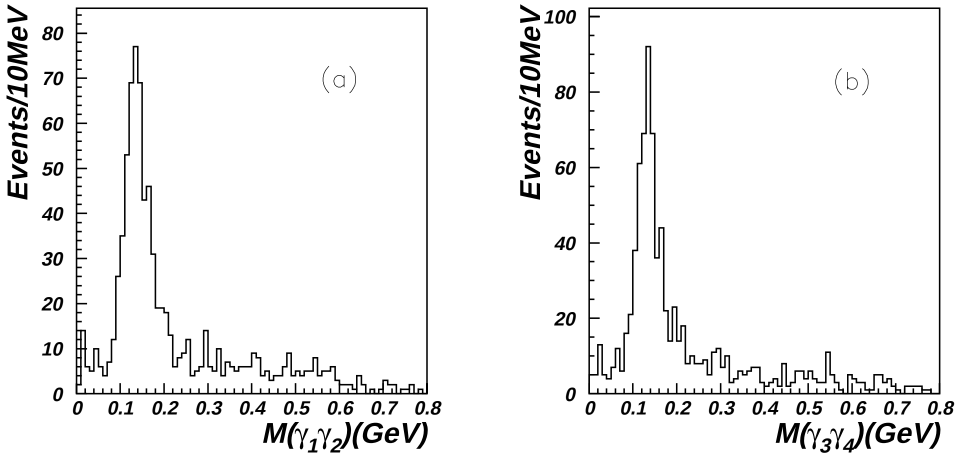

FIG. 1. Invariant mass spectrum of (a) $\gamma_1\gamma_2$ and (b) $\gamma_3\gamma_4$.

The systematic errors of the masses are neglected, since they are around 10% of the statistical ones, for which reason, only the statistical errors are listed in the masses. The first error of the product branching ratio is the statistical error and the second is the systematic one, which comes from the different fixed widths of the resonances, the variation of the event selection criteria, the uncertainties of the detection efficiency, background shape, and the J/ψ total events number.

From the fitted value of $B(J/\psi \to \gamma f_2(1270)) \times B(f_2(1270) \to \pi^0\pi^0) = (3.1 \pm 0.8 \pm 1.1) \times 10^{-4}$, one yields $B(J/\psi \to \gamma f_2(1270)) = (1.1 \pm 0.7) \times 10^{-3}$, which is in good agreement with the PDG value. On the other hand, the result of branching ratio $B(J/\psi \to \gamma f_J(1710)) \times B(f_J(1710) \to \pi\pi)$ listed above implies that the relative strength of $f_J(1710)$ decaying into $K\overline{K}$ [8] is larger than that into $\pi\pi$. In addition, the width of $f_J(1710)$ is relatively large and this also disfavors the $f_J(1710)$ as being a pure glueball. The branching ratio $B(J/\psi \to \gamma\xi(2230)) \times B(\xi(2230) \to \pi^0\pi^0)$ is compatible with that in the decay $J/\psi \to \gamma\pi^+\pi^-$ [4], taking into account the isospin factor, thus favors a glueball interpretation, together with its narrow width. The possibility that $\xi(2230)$ is a high spin $s\bar{s}$ state is strongly disfavored because of the observation of the nonstrange decay modes.

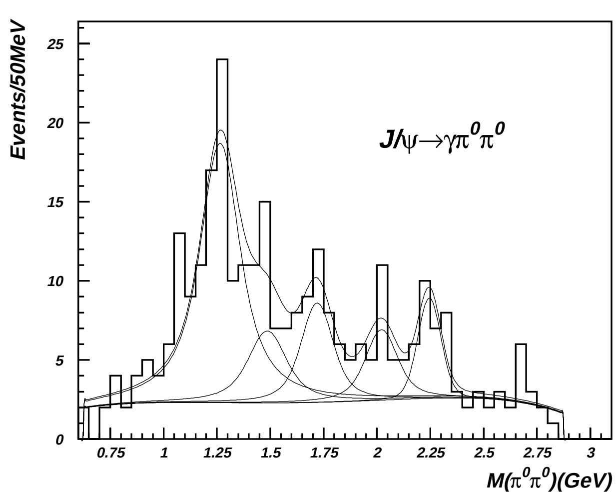

FIG. 2. Fitted invariant mass spectrum of $\pi^0\pi^0$.

In summary, we have presented the BES analysis on the decay $J/\psi \to \gamma\pi^0\pi^0$, in which the states $\xi(2230)$, $f_J(1710)$ are observed. There is also an indication for the existence of $X(1480)$, which is observed only as a "shoulder" of $f_2(1270)$ in $\pi^+\pi^-$ invariant mass spectrum. The appearance of $\xi(2230)$ and $f_J(1710)$ in this channel provides us, to some extent, important information for understanding their nature. The production of $\xi(2230)$ in the decay channel studied herein is consistent with that in J/ψ radiative decay to $\pi^+\pi^-$. Therefore, the observed properties of $\xi(2230)$ in this paper and our previous paper [4] have the characteristics expected of a glueball.

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