Structure Analysis of the $f_J(1710)$ in the Radiative Decay $J/\psi \to \gamma K^+K^-$

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The data on $J/\psi \to \gamma K^+K^-$ from the BES experiment at the Beijing electron-positron collider have been analyzed. We find two resonances in the 1.7 GeV region which were identified as $f_J(1710)$: a scalar with mass $1781 \pm 8^{+10}_{-31}$(MeV) and width $85 \pm 24^{+22}_{-19}$(MeV), and a tensor with mass $1696 \pm 5^{+9}_{-34}$(MeV) and width $103 \pm 18^{+30}_{-11}$(MeV). The resulting branching ratios $B(J/\psi \to \gamma f_J)B(f_J \to K^+K^-)$ are $(0.8 \pm 0.1^{+0.3}_{-0.1})10^{-4}$ for $J = 0$ and $(2.5 \pm 0.4^{+0.9}_{-0.4})10^{-4}$ for $J = 2$, respectively. [S0031-9007(96)01490-1]

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There has been considerable recent interest in the $f_J(1710)$ and its role in glueball spectroscopy. Phenomenologically, since the $f_J(1710)$ was first discovered by the Crystal Ball Collaboration in $J/\psi \to \gamma\eta\eta$ [1], it has been observed in other channels of J/ψ decay [2,3], the pp central production [4], and $\pi^- p$ induced reactions [5,6], in which the production of glueballs is expected to be enhanced, while there is no evidence of the $f_J(1710)$ in $\gamma\gamma$ collisions [7] where glueball production should be suppressed. Moreover, the $f_J(1710)$ has not been observed in the $K^- p$ reaction [8], which suggests that it is unlikely to be an $s\bar{s}$ state. A recent investigation [9] shows that the nature of this state depends critically on whether its spin parity is 0^{++} or 2^{++}; a scalar $f_J(1710)$ is likely a glueball state. The calculations on QCD lattice predict [10,11] that the lightest glueball should be a scalar with mass ~1.5–1.7 GeV, which is consistent with the mass of $f_J(1710)$. The study by Amsler and Close [12] suggests that the $f_0(1500)$ should be a glueball mixed with the nearby flavorless member of the $3P_0$ $q\bar{q}$ nonet. If this is indeed to be the case, another state orthogonal to the $f_0(1500)$ is believed to be in this region. Such a state orthogonal to the $f_0(1500)$ is expected to have a large branching ratio in its decay into $K\bar{K}$, as the data [13] from the Crystal Barrel show that the branching ratio of the $f_0(1500)$ decaying into $K\bar{K}$ is smaller than that expected for a glueball state. If the $f_J(1710)$ proves to be $J = 0$, it fits the profile of such a state and becomes an important glueball candidate. Thus, the reaction $J/\psi \to \gamma K\bar{K}$ would be a very important channel to investigate the $f_J(1710)$, because the production of a scalar glueball with a relative large $K\bar{K}$ branching ratio is assumed to be enhanced in this reaction.

The spin of the $f_J(1710)$ has not been well determined experimentally [14]. The result from the MARK III collaboration showed that it is dominated by the spin zero state [15]. The $f_J(1710)$ produced in the central region of the reaction $pp \to p_f(K\bar{K})p_s$ [4] favors strongly spin two at $m = 1713$ MeV, while a spin zero resonance with mass 1771 MeV is claimed in another reaction $\pi^-(23\ \text{GeV}/c^2)p \to K_s^0 K_s^0 n$ [5]. The recent analysis [16] of the $J/\psi \to \gamma\pi^+\pi^-\pi^+\pi^-$ data from the MARK

III showed the presence of both 0^{++} and 2^{++} states in this region. In this Letter, we present an analysis of the recent $J/\psi \to \gamma K^+K^-$ data from the BES experiment at the Beijing electron-positron collider (BEPC). Our result clearly shows the existence of both scalar and tensor states in the $f_J(1710)$ region.

The preliminary selection of the γK^+K^- events chooses those that have two oppositely charged tracks, of which the momentum is smaller than the mass of J/ψ. Each charged track should have a good helix fit in order to ensure a correct corresponding error matrix in the kinematic fit. Moreover, more than one photon per event is allowed to consider the possible existence of the fake photons which come from the interactions of the charged tracks with the shower counter or from electronic noise in the shower counter. The following selection criteria are used to remove the Bhabha events: (i) The opening angle of the two tracks satisfies $\theta_{\text{op}} < 175°$. (ii) The energy deposit of each track in barrel shower counter (BSC) satisfies $E_{\text{sc}} < 1.0$ GeV. (iii) The angle between each track and the Z direction (positron beam direction) satisfies $|\cos\theta| < 0.7$. If the two charged tracks are accollinear and the muon counter is hit, the event is rejected as a $\gamma\mu^+\mu^-$ event. It is required that the kinematic variable $|U| = |E_{\text{miss}} - |\mathbf{P}_{\text{miss}}|| < 0.1$, where E_{miss} and $\mathbf{P}_{\text{miss}}$ are the missing energy and missing momentum of all charged particles, respectively, and they are calculated by assuming two charged particles as a K^+K^- pair. This requirement can remove most background contributions from the events having multipion or other neutral particles. Another important cut $P_{t\gamma}^2 \equiv 4|\mathbf{P}_{\text{miss}}|^2 \sin^2(\theta_{m\gamma}/2) < 0.0035\ \text{GeV}^2$ is used to eliminate background photons, where $\theta_{m\gamma}$ is the angle between the missing momentum and the photon direction. The 4-C kinematic fits are performed by assuming the final state as a $\gamma\pi^+\pi^-$ or a γK^+K^- separately for each event, and the event is excluded if $\chi^2_{\gamma\pi^+\pi^-} < \chi^2_{\gamma K^+K^-}$. Thus, after all these cuts, the background from following reactions is greatly removed: (1) $J/\psi \to K^{*\pm}K^\mp$, (2) $J/\psi \to \rho^\pm\pi^\mp$, (3) $J/\psi \to \rho^0\pi^0$, (4) $J/\psi \to \gamma f_2(1270)$, and (5) $J/\psi \to \gamma\eta(1440)$. The Monte Carlo simulations indicate that the efficiencies for these reactions are 3.3%, 0.7%, 0.02%, 0.2%, and 0.09%, respectively. Furthermore, most events with $K^{*\pm}K^\mp$ and $\rho^\pm\pi^\mp$ final states are distributed on a high mass region (>2 GeV). The K^+K^- invariant mass spectrum is shown in Fig. 1, wherein the resonance structure in the 1.5 and 1.7 GeV regions is clearly seen.

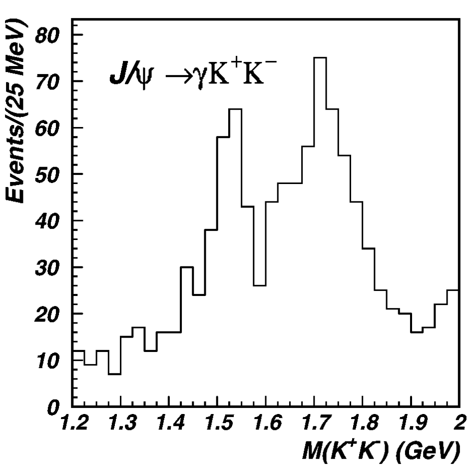

FIG. 1. Mass distribution for $J/\psi \to \gamma K^+K^-$.

For the process $J/\psi \to VX(X \to P\bar{P})$, the moment is defined as

$$T_r = \int W(\theta_V, \Omega)\text{Re} \times [D^j_{0,-m}(0,\theta_V,0)D^{l}_{m,0}{}^*(\Omega)]d\cos\theta_V\, d\Omega\,, \quad (1)$$

where $W(\theta_V, \Omega)$ is the angular distribution, r denotes (j, l, m), and P represents a pseudoscalar particle. The measured moment is

$$N'_\mu = \sum_{\text{events}} \text{Re}[D^j_{0,-m}(0,\theta_V,0) \cdot D^l_{m,0}{}^*(\Omega)], \quad (2)$$

and the correlation matrix of N'_μ is

$$O_{\mu\nu} = \sum_{\text{events}} \text{Re}[D^{j'}_{0,-m'}(0,\theta_V,0)D^{l'}_{m',0}{}^*(\Omega)] \cdot \text{Re}[D^j_{0,-m}(0,\theta_V,0)D^l_{m,0}{}^*(\Omega)], \quad (3)$$

where μ and ν denote the indices (j', l', m') and (j, l, m), respectively.

The efficiency-corrected measured can be expressed as

$$N = C^{-1}N' \quad (4)$$

or

$$N_\mu = \sum_\nu C^{-1}_{\mu\nu}N'_\nu\,. \quad (5)$$

The quantity C in Eqs. (4) and (5) is the efficiency correction matrix,

$$C_{\mu\nu} = \frac{1}{N_g}\sum_{i=1}^{N_a} \text{Re}[D^{j'}_{0,-m'}(0,\theta_V,0)D^{l'}_{m',0}{}^*(\Omega)] \cdot (2 - \delta_{m0})\text{Re}[D^j_{0,-m}(0,\theta_V,0)D^l_{m,0}{}^*(\Omega)], \quad (6)$$

The covariance matrix of N is

$$V = C^{-1}O(C^{-1})^T, \quad (7)$$

where N_a is the events number accepted by detector after the events selection, and N_g is the events number generated in Monte Carlo simulation.

Previous work by BES at BEPC [17] indicates that there exists a spin 0 and a spin 2 component in the mass region of $f_J(1710)$. The higher spin components are excluded as the results from perturbative quantum chromodynamics [18] show that the contributions from the high spin (>2) components are very small. The

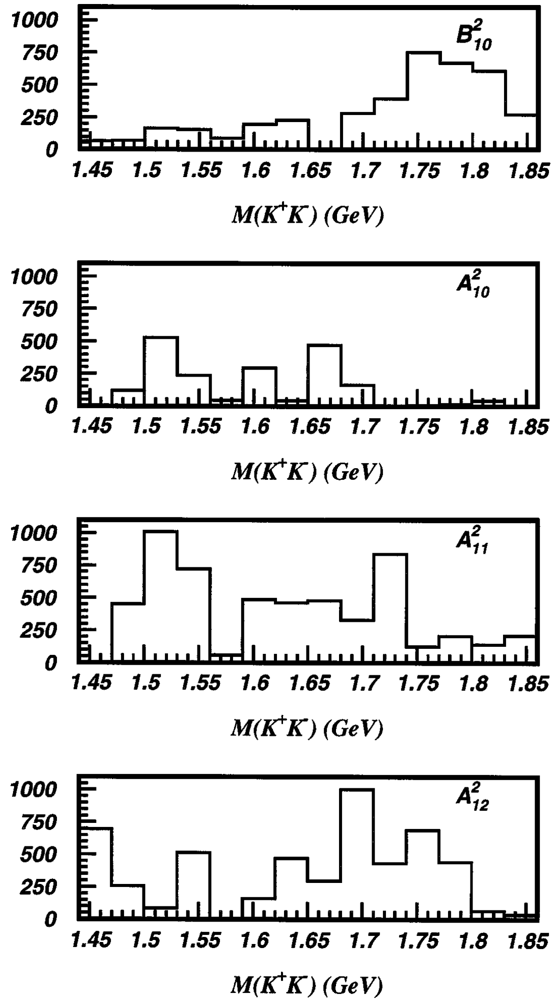

FIG. 2. The helicity amplitudes versus invariant mass K^+K^-.

theoretical moments of radiative decay $J/\psi \to \gamma X(X - P\overline{P})$, $T_r \equiv T(j,l,m)$ with 0^{++} and 2^{++} components can be written as [19]

$$T(000) \sim 8[(A_{10}^2 + A_{11}^2 + A_{12}^2) + B_{10}^2], \qquad (8)$$

$$T(200) \sim \frac{4}{5}[(A_{10}^2 - 2A_{11}^2 + A_{12}^2) + B_{10}^2], \qquad (9)$$

$$T(020) \sim 8\left[\frac{1}{7}(2A_{10}^2 + A_{11}^2 - 2A_{12}^2) + \frac{1}{\sqrt{5}}A_{10}B_{10}\gamma\right], \qquad (10)$$

$$T(220) \sim \frac{8}{5}\left[\frac{1}{7}(A_{10}^2 - A_{11}^2 - 2A_{12}^2) + \frac{1}{2\sqrt{5}}A_{10}B_{10}\gamma\right], \qquad (11)$$

$$T(221) \sim \frac{4}{5}\left[\frac{1}{7}(\sqrt{3}A_{10}A_{11} - -3\sqrt{2}A_{11}A_{12}) + \frac{\sqrt{3}}{2\sqrt{5}}A_{11}B_{10}\gamma\right], \qquad (12)$$

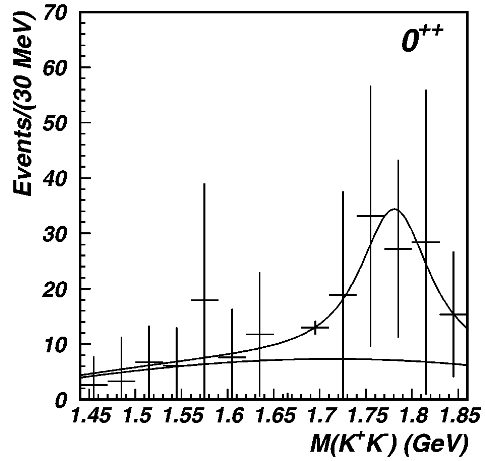

FIG. 3. The separated 0^{++} from $f_J(1710)$.

$$T(222) \sim \frac{4\sqrt{6}}{5}\left[-\frac{2}{7}A_{10}A_{12} + \frac{1}{2\sqrt{5}}A_{12}B_{10}\gamma\right], \qquad (13)$$

$$T(040) \sim \frac{8}{21}(6A_{10}^2 - 4A_{11}^2 + A_{12}^2), \qquad (14)$$

$$T(240) \sim \frac{4}{105}(6A_{10}^2 - 8A_{11}^2 + A_{12}^2), \qquad (15)$$

$$T(241) \sim \frac{4}{105}(3\sqrt{10}A_{10}A_{11} + \sqrt{15}A_{11}A_{12}), \qquad (16)$$

$$T(242) \sim \frac{4\sqrt{10}}{35}A_{10}A_{12}, \qquad (17)$$

where B_{10} is the helicity amplitude for 0^{++} component, A_{10}, A_{11}, and A_{12} are those for 2^{++}, and $\gamma \equiv 2\cos\phi$ represents the interference between 0^{++} and 2^{++}.

The objective function is defined as

$$\Lambda^2 = (N - T)V^{-1}(N - T), \qquad (18)$$

and the standard Minuit Program in CERN LIBRARY is used to minimize Λ^2. The invariant mass spectrum K^+K^- (from 1.44–1.86 GeV$/c^2$) is divided into 14 bins

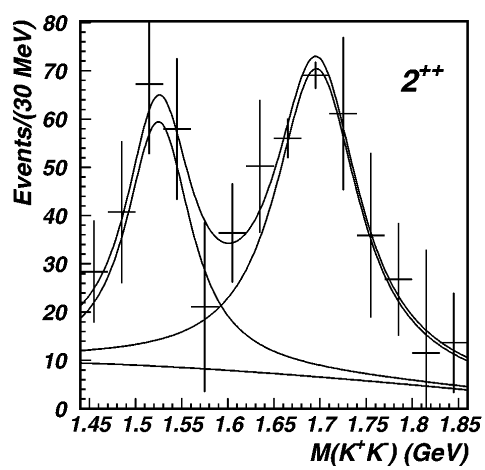

FIG. 4. The separated 2^{++} from $f_J(1710)$.

TABLE I. The masses, widths, and branching ratios of $X_{0^{++}}$ and $X_{2^{++}}$.

Spin	Mass (MeV)	Width (MeV)	$B(J/\psi \to \gamma X)\,(X \to K^+K^-)\,(10^{-4})$
0^{++}	$1781 \pm 8^{+10}_{-31}$	$85 \pm 24^{+22}_{-19}$	$0.8 \pm 0.1^{+0.3}_{-0.1}$
2^{++}	$1696 \pm 5^{+9}_{-34}$	$103 \pm 18^{+30}_{-11}$	$2.5 \pm 0.4^{+0.9}_{-0.4}$
$f_2'(1525)$	$1516 \pm 5^{+9}_{-15}$	$60 \pm 23^{+13}_{-20}$	$1.6 \pm 0.2^{+0.6}_{-0.2}$

with a 30 MeV bin width in order to ensure both high statistics in each bin and a small enough mass interval for performing a moment analysis. The helicity parameters are obtained for each bin, respectively, by minimizing the Λ^2, in which $\gamma \equiv 2\cos\phi$ ranges from -2 to 2. The helicity amplitudes $B_{10}, A_{10}, \ldots$ from above fits are shown in Fig. 2. There are multisolution problem for some bins, and we resolve this by finding all possible solutions for the bin and choosing the one that has the smallest Λ^2 and small errors of helicity amplitudes.

The contributions to the γK^+K^- mass spectrum from 0^{++} and 2^{++} components are shown in Figs. 3 and 4, respectively, which are renormalized to the observed mass spectrum. The $f_2'(1525)$ is well reproduced in Fig. 4, and a second 2^{++} resonance $X_{2^{++}}$ appears in the lower part of the $f_J(1710)$ mass region. Figure 3 shows the presence of a 0^{++} resonance $X_{0^{++}}$ in the higher part of $f_J(1710)$ mass region, and it accounts for 30% of $f_J(1710)$ with nearly 10% uncertainty. The masses, widths, and branching ratios of 0^{++} and 2^{++} are given in Table I, in which the errors come from the Breit-Wigner fit and the uncertainties of the background shape and the bin widths, respectively. The branching ratios are estimated by using the acceptance efficiency from Monte Carlo simulation and the fit of the spectra of these resonances.

The hadronic decay $J/\psi \to \omega K^+K^-$ is also useful to study the identification of the $f_J(1710)$ because the $f_2'(1525)$ in this channel is below the threshold. It is expected that this can be carried out with the upgraded BES and more J/ψ events in the near future.

In summary, a scalar and a tensor are separated from the broad resonance around 1.7 GeV. The scalar $X_{0^{++}}(1780)$ in the $f_J(1710)$ mass region is clearly established in our analysis. Further investigation on the other channels, such as $J/\psi \to \gamma 4\pi$ and the $J/\psi \to \gamma\pi\pi$ will be helpful to understand the nature of the scalar and tensor.

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