Observation of a broad 1^{--} resonant structure around 1.5 GeV/c^2 in the K^+K^- mass spectrum in $J/\psi \to K^+K^-\pi^0$

M. Ablikim[1], J. Z. Bai[1], Y. Ban[11], X. Cai[1], H. F. Chen[16], H. S. Chen[1], H. X. Chen[1], J. C. Chen[1], Jin Chen[1], Y. B. Chen[1], S. P. Chi[2], Y. P. Chu[1], X. Z. Cui[1], Y. S. Dai[18], Z. Y. Deng[1], L. Y. Dong[1a], Q. F. Dong[14], S. X. Du[1], Z. Z. Du[1], J. Fang[1], S. S. Fang[2], C. D. Fu[1], C. S. Gao[1], Y. N. Gao[14], S. D. Gu[1], Y. T. Gu[4], Y. N. Guo[1], Y. Q. Guo[1], Z. J. Guo[15], F. A. Harris[15], K. L. He[1], M. He[12], Y. K. Heng[1], H. M. Hu[1], T. Hu[1], G. S. Huang[1b], X. P. Huang[1], X. T. Huang[12], X. B. Ji[1], X. S. Jiang[1], J. B. Jiao[12], D. P. Jin[1], S. Jin[1], Yi Jin[1], Y. F. Lai[1], G. Li[2], H. B. Li[1], H. H. Li[1], J. Li[1], R. Y. Li[1], S. M. Li[1], W. D. Li[1], W. G. Li[1], X. L. Li[8], X. Q. Li[10], Y. L. Li[4], Y. F. Liang[13], H. B. Liao[6], C. X. Liu[1], F. Liu[6], Fang Liu[16], H. H. Liu[1], H. M. Liu[1], J. Liu[11], J. B. Liu[1], J. P. Liu[17], R. G. Liu[1], Z. A. Liu[1], F. Lu[1], G. R. Lu[5], H. J. Lu[16], J. G. Lu[1], C. L. Luo[9], F. C. Ma[8], H. L. Ma[1], L. L. Ma[1], Q. M. Ma[1], X. B. Ma[5], Z. P. Mao[1], X. H. Mo[1], J. Nie[1], S. L. Olsen[15], H. P. Peng[16], N. D. Qi[1], H. Qin[9], J. F. Qiu[1], Z. Y. Ren[1], G. Rong[1], L. Y. Shan[1], L. Shang[1], D. L. Shen[1], X. Y. Shen[1], H. Y. Sheng[1], F. Shi[1], X. Shi[11c], H. S. Sun[1], J. F. Sun[1], S. S. Sun[1], Y. Z. Sun[1], Z. J. Sun[1], Z. Q. Tan[4], X. Tang[1], Y. R. Tian[14], G. L. Tong[1], G. S. Varner[15], D. Y. Wang[1], L. Wang[1], L. S. Wang[1], M. Wang[1], P. Wang[1], P. L. Wang[1], W. F. Wang[1d], Y. F. Wang[1], Z. Wang[1], Z. Y. Wang[1], Zhe Wang[1], Zheng Wang[2], C. L. Wei[1], D. H. Wei[1], N. Wu[1], X. M. Xia[1], X. X. Xie[1], B. Xin[8b], G. F. Xu[1], Y. Xu[10], M. L. Yan[16], F. Yang[10], H. X. Yang[1], J. Yang[16], Y. X. Yang[3], M. H. Ye[2], Y. X. Ye[16], Z. Y. Yi[1], G. W. Yu[1], C. Z. Yuan[1], J. M. Yuan[1], Y. Yuan[1], S. L. Zang[1], Y. Zeng[7], Yu Zeng[1], B. X. Zhang[1], B. Y. Zhang[1], C. C. Zhang[1], D. H. Zhang[1], H. Y. Zhang[1], J. W. Zhang[1], J. Y. Zhang[1], Q. J. Zhang[1], X. M. Zhang[1], X. Y. Zhang[12], Y. Y. Zhang[13], Z. P. Zhang[16], Z. Q. Zhang[5], D. X. Zhao[1], J. W. Zhao[1], M. G. Zhao[10], P. P. Zhao[1], W. R. Zhao[1], Z. G. Zhao[1e], H. Q. Zheng[11], J. P. Zheng[1], Z. P. Zheng[1], L. Zhou[1], N. F. Zhou[1], K. J. Zhu[1], Q. M. Zhu[1], Y. C. Zhu[1], Yingchun Zhu[1f], Y. S. Zhu[1], Z. A. Zhu[1], B. A. Zhuang[1], X. A. Zhuang[1], B. S. Zou[1]

(BES Collaboration)

[1] *Institute of High Energy Physics, Beijing 100049, People's Republic of China*
[2] *China Center for Advanced Science and Technology(CCAST), Beijing 100080, People's Republic of China*
[3] *Guangxi Normal University, Guilin 541004, People's Republic of China*
[4] *Guangxi University, Nanning 530004, People's Republic of China*
[5] *Henan Normal University, Xinxiang 453002, People's Republic of China*
[6] *Huazhong Normal University, Wuhan 430079, People's Republic of China*
[7] *Hunan University, Changsha 410082, People's Republic of China*
[8] *Liaoning University, Shenyang 110036, People's Republic of China*
[9] *Nanjing Normal University, Nanjing 210097, People's Republic of China*
[10] *Nankai University, Tianjin 300071, People's Republic of China*
[11] *Peking University, Beijing 100871, People's Republic of China*
[12] *Shandong University, Jinan 250100, People's Republic of China*
[13] *Sichuan University, Chengdu 610064, People's Republic of China*
[14] *Tsinghua University, Beijing 100084, People's Republic of China*
[15] *University of Hawaii, Honolulu, HI 96822, USA*
[16] *University of Science and Technology of China, Hefei 230026, People's Republic of China*
[17] *Wuhan University, Wuhan 430072, People's Republic of China*
[18] *Zhejiang University, Hangzhou 310028, People's Republic of China*
[a] *Current address: Iowa State University, Ames, IA 50011-3160, USA*
[b] *Current address: Purdue University, West Lafayette, IN 47907, USA*
[c] *Current address: Cornell University, Ithaca, NY 14853, USA*
[d] *Current address: Laboratoire de l'Accélératear Linéaire, Orsay, F-91898, France*

[e] *Current address: University of Michigan, Ann Arbor, MI 48109, USA*
[f] *Current address: DESY, D-22607, Hamburg, Germany*

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A broad peak is observed at low K^+K^- invariant mass in $J/\psi \to K^+K^-\pi^0$ decays found in a sample of 5.8×10^7 J/ψ events collected with the BESII detector. A partial wave analysis shows that the J^{pc} of this structure is 1^{--}. Its pole position is determined to be $(1576^{+49}_{-55}(\mathrm{stat})^{+98}_{-91}(\mathrm{syst}))$ MeV/c^2 - $i(409^{+11}_{-12}(\mathrm{stat})^{+32}_{-67}(\mathrm{syst}))$ MeV/c^2. These parameters are not compatible with any known meson resonances.

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The J/ψ meson has been useful for searches for new hadrons and studies of light hadron spectroscopy. Recently, a number of new structures have been observed in J/ψ decays. These include strong near-threshold mass enhancements in the $p\overline{p}$ invariant mass spectrum from $J/\psi \to \gamma p\overline{p}$ decays [1], the $p\overline{\Lambda}$ and the $K^-\overline{\Lambda}$ mass spectra in $J/\psi \to pK^-\overline{\Lambda}$ decays [2], the $\omega\phi$ mass spectrum in the double-OZI suppressed decay $J/\psi \to \gamma\omega\phi$ [3], and a new resonance, the $X(1835)$, in $J/\psi \to \gamma\pi^+\pi^-\eta'$ decays [4]. Some of these new structures have not been observed in other experiments. For example, the strong $p\overline{p}$ mass threshold enhancement is neither observed in $p\overline{p}$ cross section measurements, nor in B decays [5]. These experimental observations are unexpected and have stimulated interest in searching for other new hadron states in J/ψ decays. Since the J/ψ has $J^{PC} = 1^{--}$ and zero isospin, its decays are particularly useful for spin-parity and isospin determinations of hadronic states found in its decays. In this Letter, we report the first observation of a broad 1^{--} resonant structure in the invariant mass spectrum of K^+K^- in the channel $J/\psi \to K^+K^-\pi^0$. The results come from an analysis of 5.8×10^7 J/ψ decays detected with the upgraded Beijing Spectrometer (BESII) at the Beijing Electron-Positron Collider (BEPC).

BESII is a large solid-angle magnetic spectrometer that is described in detail in Ref. [6]. Charged particle momenta are determined with a resolution of $\sigma_p/p = 1.78\%\sqrt{1+p^2(\mathrm{GeV/c^2})}$ in a 40-layer cylindrical main drift chamber (MDC). Particle identification is accomplished by specific ionization (dE/dx) measurements in the MDC and time-of-flight (TOF) measurements in a barrel-like array of 48 scintillation counters. The dE/dx resolution is $\sigma_{dE/dx} = 8.0\%$; the TOF resolution is measured to be $\sigma_{TOF} = 180$ ps for Bhabha events. Outside of the time-of-flight counters is a 12-radiation-length barrel shower counter (BSC) comprised of gas tubes interleaved with lead sheets. The BSC measures the energies and directions of photons with resolutions of $\sigma_E/E \simeq 21\%/\sqrt{E(\mathrm{GeV})}$, $\sigma_\phi = 7.9$ mrad, and $\sigma_z = 2.3$ cm. The iron flux return of the magnet is instrumented with three double layers of counters that are used to identify muons. In this analysis, a GEANT3-based Monte Carlo (MC) package with detailed consideration of the detector performance is used. The consistency between data and MC has been carefully checked in many high-purity physics channels, and the agreement is reasonable [7].

Candidate $J/\psi \to K^+K^-\pi^0$ events are required to have two oppositely charged tracks, each of which is well fitted to a helix that is within the polar angle region $|\cos\theta| < 0.8$ and with a transverse momentum larger than 70 MeV/c. For each track, the TOF and dE/dx information are combined to form particle identification confidence levels for the π, K and p hypotheses; the particle type with the highest confidence level is assigned to each track. The two charged tracks are required to be identified as kaons. Candidate photons are required to have an energy deposit in the BSC greater than 50 MeV and to be isolated from charged tracks by more than 15°; at least two photons are required. A four-constraint (4C) energy-momentum conservation kinematic fit is performed to the $K^+K^-\gamma\gamma$ hypothesis and $\chi^2 < 10$ is required. For events with more than two selected photons, the combination with the smallest χ^2 is chosen. Figure 1(a) shows the fitted $\gamma\gamma$ invariant mass distribution, where a π^0 signal is evident. Candidate π^0s are identified by the requirement $\mid M_{\gamma\gamma} - m_{\pi^0} \mid < 0.04$ GeV/c^2. To reduce the background events with mis-reconstructed π^0's, the energies $(E_{\gamma 1}, E_{\gamma 2})$ of the two photons from the π^0 are required to satisfy $|(E_{\gamma 1} - E_{\gamma 2})/(E_{\gamma 1} + E_{\gamma 2})| < 0.8$. To suppress background from the radiative decay process $J/\psi \to \gamma\pi^0K^+K^-$, we require the candidate events to fail a five-constraint kinematic fit to the $\gamma\pi^0K^+K^-$ hypothesis ($\chi^2_{\gamma\pi^0K^+K^-} > 50$), where the invariant mass of the $\gamma\gamma$ pair associated with the π^0 is constrained to m_{π^0} [8].

The Dalitz plot for the selected events is shown in Fig. 1(b), where a broad K^+K^- band is evident in addition to the $K^*(892)$ and $K^*(1410)$ signals. This band corresponds to the broad peak observed around 1.5 GeV/c^2 in the K^+K^- invariant mass projection shown in Fig. 1(c).

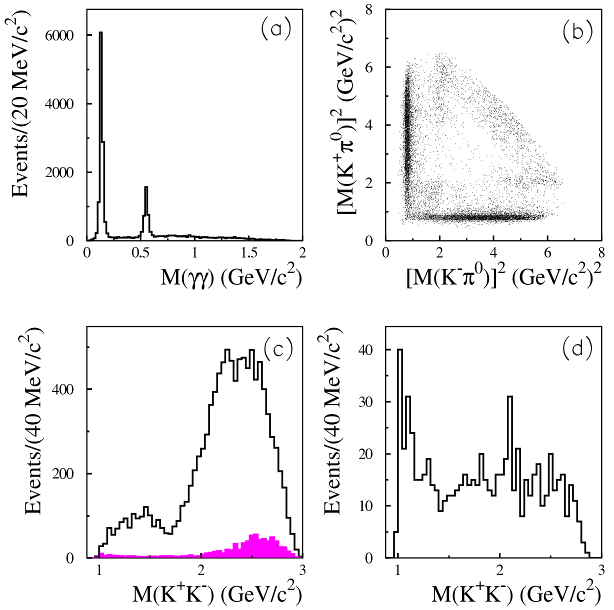

FIG. 1: (a) The $\gamma\gamma$ invariant mass distribution. (b) The Dalitz plot for $K^+K^-\pi^0$ candidate events. (c) The K^+K^- invariant mass distribution for $K^+K^-\pi^0$ candidate events; the solid histogram is data and the shaded histogram is the background (normalized to data). (d) The K^+K^- invariant mass distribution for the π^0 mass sideband events (not normalized).

Backgrounds for this decay channel have been studied using both data and MC. The cleanliness of the π^0 signal shown in Fig. 1(a) indicates that non-π^0 background processes correspond to only about 2% of the selected events. The K^+K^- mass distribution for the π^0 sideband events, shown in Fig. 1(d), has a different character from that of the signal (shown in Fig. 1(c)). A Monte Carlo (MC) study indicates that background from $J/\psi \to \rho\pi \to \pi^+\pi^-\pi^0$ decays, which produces a π^0 peak, comprises about 6% of the selected event sample. These events are dominantly peaked at high K^+K^- masses as shown by the shaded histogram in Fig. 1(c); the $\pi^+\pi^-\pi^0$ contamination to the low K^+K^- invariant mass region is almost completely eliminated by the particle identification and kinematical fit requirements. Backgrounds from processes such as $J/\psi \to \omega\pi^+\pi^-$ and $J/\psi \to \gamma\eta_C \to \gamma K^+K^-\pi^0$ are found to be negligible. From these studies, we conclude that the broad low K^+K^- mass peak is not from any background process.

A partial wave analysis (PWA) is used to determine the mass, width and spin-parity of the broad peak at low mass, which is denoted as X. The amplitudes are constructed using the relativistic covariant tensor amplitude method [9], and the maximum likelihood method is used in the fit. The decay process is modeled by a phase space contribution (i.e., direct three body decays with correct angular distributions) plus several sequential two-body decays: $J/\psi \to X\pi^0$, $X \to K^+K^-$, $J/\psi \to \rho\pi^0$, $\rho \to K^+K^-$ and $J/\psi \to (K^*)^\pm K^\mp$, $(K^*)^\pm \to K^\pm\pi^0$. The broad resonance X is parameterized by a Breit-Wigner (BW) function with a mass-dependent width [10]. Background contributions are removed by subtracting the log-likelihood value of background events from that of data [11].

Five components, the X, $K^\star(892)$, $K^\star(1410)$, $\rho(1700)$ and phase space, are included in the PWA fit. The $K^\star(892)$, $K^\star(1410)$ and $\rho(1700)$ parameters are fixed at Particle Data Group (PDG) values [12], and their uncertainties are included in the systematic errors on the parameters of the X. Parity conservation in $J/\psi \to K^+K^-\pi^0$ decay restricts the possible spin-parity of the K^+K^- system to $1^{--}, 3^{--}, \ldots$. The PWA determines the spin-parity of X to be 1^{--}. The log-likelihood value of the fit becomes worse by 325 for a J^{PC} assignment of 3^{--}; even higher spin states are unlikely at such a low mass. The σ and κ resonance studies at BESII [11] show that the parameters of a broad resonance are better described by the pole position since it has less dependence on the details of the BW formula that is used. From the PWA fit, the X pole position is determined to be (1576^{+49}_{-55}) MeV/c^2 - $i(409^{+11}_{-12})$ MeV/c^2, and the branching ratio is $B(J/\psi \to X\pi^0) \cdot B(X \to K^+K^-) = (8.5 \pm 0.6) \times 10^{-4}$, where the errors are statistical only. In the PWA fit, there is large destructive interference between the X, the $\rho(1700)$ and phase space, which produces the 'hole' seen in the center of the Dalitz plot. The comparisons of the mass distributions between the data and the PWA fit projections (weighted by MC efficiencies) are displayed in Fig. 2. The angular distributions of the events with $M_{K^+K^-} < 1.7$ GeV/c^2 are shown in Fig. 3.

Each of the five PWA components has a statistical significance that is larger than 5σ. In the PWA fit, when we remove the X, $K^\star(892)$, $K^\star(1410)$, $\rho(1700)$ and phase space components one at a time, the log-likelihood val-

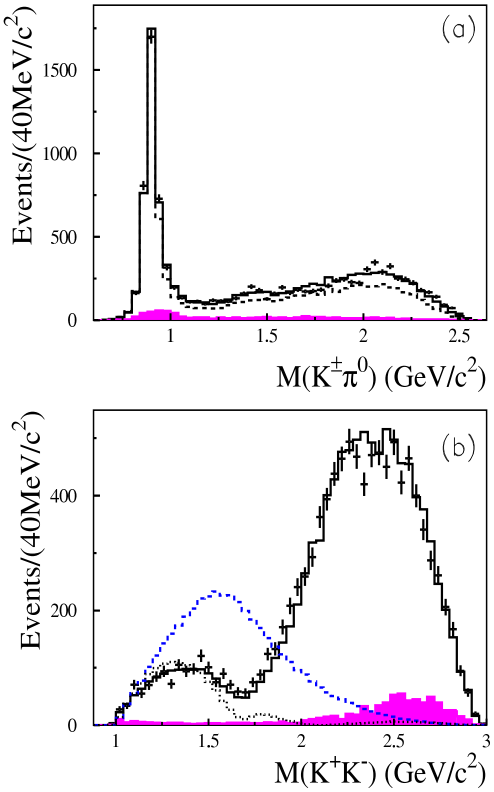

FIG. 2: (a) The $K^{\pm}\pi^0$ invariant mass distribution; the error bars are data, the solid histogram is the PWA fit projection, the dashed histogram is the 1^- component of $K^{\pm}\pi^0$ system and the shaded histogram is the background. (b) The K^+K^- invariant mass distribution; the error bars are data, the solid histogram is the PWA fit projection, the upper dashed histogram is the X component, the lower dotted histogram is the 1^{--} component of K^+K^- system and the shaded histogram is the background.

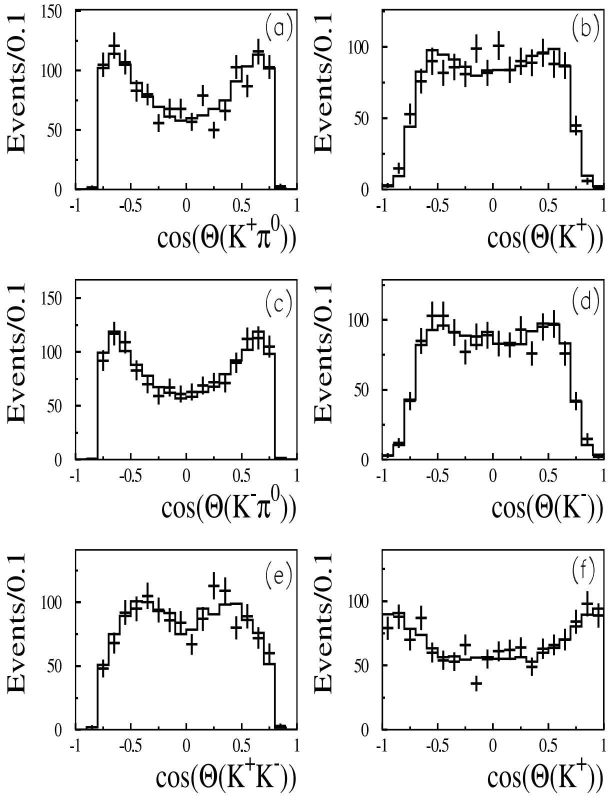

FIG. 3: Angular distributions of the events with $M_{K^+K^-} <$ 1.7 GeV/c^2; error bars are data and solid histograms are the PWA fit projections: (a), (c) and (e) are the angular distributions of $K^+\pi^0$, $K^-\pi^0$ and K^+K^- system in the laboratory frame; (b), (d) and (f) are the angular distributions of K^+, K^- and K^+ in the center of mass frames of the $K^+\pi^0$, $K^-\pi^0$ and K^+K^- systems, respectively.

ues worsen by 533, 11438, 465, 28 and 130, respectively. If we replace the X by three additional interfering resonances, the $\rho(770)$, the $\rho(1900)$ and the $\rho(2150)$, the log-likelihood value worsens by 85. The broad resonant structure X is unlikely to be due to the $\rho(1450)$; in addition to the fact that the parameters of the X resonance are incompatible with those of $\rho(1450)$, including various systematic uncertainties studied below, the $\rho(1450)$ is known to have a very small branching fraction to K^+K^- ($< 1.6 \times 10^{-3}$ at 95 % C.L.) [12]. We conclude that the broad peak at low K^+K^- mass is not described by any known mesons or their interferences.

If we do not include a $\rho(1700)$, which has the lowest relative statistical significance (7.2σ) of the five components used in the final PWA fit [13], the pole position moves to $(1428^{+17}_{-18}(\text{stat}))$ MeV/c^2 - $i(536^{+15}_{-12}(\text{stat}))$ MeV/c^2, and the branching ratio becomes $B(J/\psi \to X\pi^0) \cdot B(X \to K^+K^-) = (6.3 \pm 0.6(\text{stat}))\times 10^{-4}$.

We have studied the systematic uncertainties from inclusion of other possible resonances ($\rho(770)$, $\rho(1900)$, $\rho(2150)$, $K_2^*(1430)$, $K^*(1680)$ and the possible $K^*(2075)$ that is indicated by the $p\overline{\Lambda}$ mass threshold enhancement [1]) in the PWA fits [14], and the use of different BW formulae, background levels, parameters of the $K^\star(892)$, $K^\star(1410)$ and $\rho(1700)$, MDC wire resolution simulation, particle identification, photon selection and the total number of J/ψ events [15]. We find that the inclusion of other resonances causes the dominant shifts in the parameters of the X. For example, if the $\rho(770)$ is included in the PWA fit, the log-likelihood value improves by 13, and the pole position and the branching ratio change by $(-58-i(-56))$ MeV/c^2 and -30%, respectively. These changes are considered as systematic uncertainties. The total systematic uncertainties on the pole position and branching ratios are $(^{+98}_{-91}$ - $i^{+32}_{-67})$ MeV/c^2

and $^{+31\%}_{-42\%}$, respectively.

In summary, we observe a broad peak at low K^+K^- invariant mass in the channel $J/\psi \to K^+K^-\pi^0$. A partial wave analysis shows that the J^{pc} of this structure is 1^{--}. Its pole position is determined to be (1576^{+49+98}_{-55-91}) MeV/c^2 - $i(409^{+11+32}_{-12-67})$ MeV/c^2, and the branching ratio is $B(J/\psi \to X\pi^0) \cdot B(X \to K^+K^-)= (8.5 \pm 0.6^{+2.7}_{-3.6}) \times 10^{-4}$, where the first errors are statistical and the second are systematic. These parameters are not compatible with any known meson resonances [12].

To understand the nature of the broad 1^{--} peak, it is important to search for a similar structure in $J/\psi \to K_S K^{\pm}\pi^{\mp}$ decays to determine its isospin. It is also intriguing to search for $K^*K, KK\pi$ decay modes. In the mass region of the X, there are several other 1^{--} states, such as the $\rho(1450)$ and $\rho(1700)$, but the width of the X is much broader than the widths of these other mesons. This may be an indication that the X has a different nature than these other mesons. For example, very broad widths are expected for multiquark states [16].

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