Measurement of Radiative J/ψ Decays in $K\bar{K}$ States

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(Received 18 December 1987)

The decays $J/\psi \to \gamma K^+K^-$ and $\gamma K_S^0 K_S^0$ have been studied by use of 8.6×10^6 J/ψ's produced in the DM2 detector. Clean and well-separated signals of $f_2'(1525)$ and $f_2(1720)$ are observed in both channels and the measured product branching ratios are given. In neither channel is the $\xi(2230)$ seen; upper limits are given. Last, an as-yet-unexplained production of events is observed in the $K_S^0 K_S^0$ mass spectrum between 2.0 and 2.5 GeV/c^2.

PACS numbers: 13.40.Hq, 14.40.Cs

Interest in radiative decays of the J/ψ stems from the fact that these decays are expected to be a copious source of glueball states. The $f_2(1720)$ has been first observed by the Crystal Ball Collaboration[1] in the $\eta\eta$ final state and by Franklin[2] in the K^+K^- final state. More recently, a high-statistics study has been performed by the Mark III Collaboration[3] in the K^+K^- and $K_S^0K_S^0$ final states. This experiment has also reported the observation of a narrower signal named $\xi(2230)$ in both modes. In this Letter we present an analysis of K^+K^- and $K_S^0K_S^0$ mass spectra in the radiative decay of the J/ψ. The data come from 8.6×10^6 J/ψ's observed in the DM2 detector.

The DM2 detector is a large magnetic spectrometer[4] operated on the Orsay e^+e^- storage ring DCI. The charged-particle detector covers $0.87\times4\pi$ sr; the momentum resolution is 3.5% at $P_t=1$ GeV/c. Time-of-flight (TOF) information is given on $0.80\times4\pi$ sr and allows a 2σ π/K separation up to 520 MeV/c at 90°. The photon detector, outside the coil, covers $0.70\times4\pi$ sr. The detection efficiency is $\simeq100\%$ for $E_\gamma \geq 100$ MeV and the resolution on apexes is 10 mrad in azimuth and 7 mrad in polar angle. The fine spatial resolution and the absence of noise give tracking capabilities to the photon detector. Thus, matching is performed between the charged tracks and the tracks reconstructed in the photon detector in order to distinguish true photons from fake ones induced by π and K interactions in the coil or photon detector.

The $J/\psi \to \gamma K^+K^-$ events are selected by the requirement of two oppositely charged tracks and one photon. Energy and coplanarity consistency are imposed by our requiring

$$|E_{K^+}+E_{K^-}+P_{\text{miss}}-M_\psi| < 200 \text{ MeV}$$

and

$$P_t^2 = 4P_{\text{miss}}^2 \sin^2(\alpha/2) < 2500 \ (\text{MeV}/c)^2,$$

where P_{miss} is the missing momentum to the K^+K^- pair and α the angle between the photon and the missing momentum.

The main identified backgrounds to γK^+K^- events are as follows:

(a) $\rho\pi$ production with asymmetric π^0 decay. The $\rho^0\pi^0$ events feed the K^+K^- mass region under 1.3 GeV/c^2, whereas $\rho^\pm\pi^\mp$ events are mostly over 2 GeV/c^2.

(b) $K^\pm K^\mp \pi^0$ from $K^{*\pm}K^\mp$ events which contaminate mainly the 2-3-GeV/c^2 region, while $K_L^0 K^\pm \pi^\mp$ from $\bar{K}^0K^{*0}$, $K^0\bar{K}^{*0}$, and $K^{*\pm}K^\mp$, where the K_L^0 interacts in the apparatus and appears as a nonshowering γ, populate respectively the mass region around 1.1 GeV/c^2 and over 2 GeV/c^2.

(c) Radiative Bhabha events which are peaked at high K^+K^- masses.

In order to reduce the background from final states with pions and electrons each event must have at least one measured time of flight compatible with the K hypothesis within 2.5σ. When both tracks have TOF information, the cut is made on the weighted average of the two measurements in order to handle all the events on the same footing. This TOF cut is independent of the K momenta. We do not require two TOF measurements for the following reasons: (i) In the $f_2'(1525)$-$f_2(1720)$

region, where the π background is small, it does not improve the signal-over-background ratio; (ii) it has a drawback on efficiencies, especially for the $f_2'(1525)$ where one of the kaons is likely to be slow enough not to reach the TOF counters before its decay; and (iii) in the mass region over 2 GeV/c^2, the events from all the background channels have preferentially their charged tracks almost back to back and thus two measured TOF's.

Bhabha events are suppressed by the demand that the charged tracks not be associated with energetic electromagnetic showers in the photon detector. Events with a K_L^0 are removed by our requiring the radiative photon shower to have the number of tubes versus the number of hit planes consistent with the photon energy in a γK^+K^- event.

Finally, the events are fitted [three constraints (3C)] to the γK^+K^- and $\gamma\pi^+\pi^-$ hypotheses and are required to fit the first one ($\chi^2_{\gamma KK} \lesssim 7$) and not to fit the second one ($\chi^2_{\gamma\pi\pi} \gtrsim 10$). The actual cuts are smoothly dependent on the K^+K^- invariant mass, since the two hypotheses get kinematically closer as the K^+K^- mass gets higher. As a consequence the overall efficiency for γK^+K^- events has a slight dependence on the K^+K^- mass: It is almost constant at about 20% up to 2 GeV/c^2 and decreases smoothly to 15% at 2.3 GeV/c^2 and 10% at 2.6 GeV/c^2. Furthermore, Monte Carlo studies show that the efficiency is practically independent of the spin and polarization parameters of the K^+K^- system. It has also been checked in the $f_2'(1525)$ and $f_2(1720)$ regions, where γK^+K^- events are almost free of background, that the Monte Carlo simulation fully reproduces the behavior of the χ^2 distributions of the experimental events.

The final mass plot is shown in Fig. 1(a), and the Dalitz plot in Fig. 2(a). The $f_2'(1525)$ and $f_2(1720)$ peaks are well separated, a broad structure is observed on the left-hand side of the $f_2'(1525)$ where a contribution from $J/\psi \to \gamma f_2(1270) \to \gamma K^+K^-$ is expected, and no narrow enhancement is visible around 2.23 GeV/c^2.

To fit the mass region below 1.9 GeV/c^2 the following assumptions have been made: The $f_2(1270)$ parameters (mass, width, and branching ratio into K^+K^-) are fixed according to the Particle Data Group[5] tables, and the $f_2(1270)$ Breit-Wigner form corrected for phase space is forced to interfere with the $f_2'(1525)$ with a relative

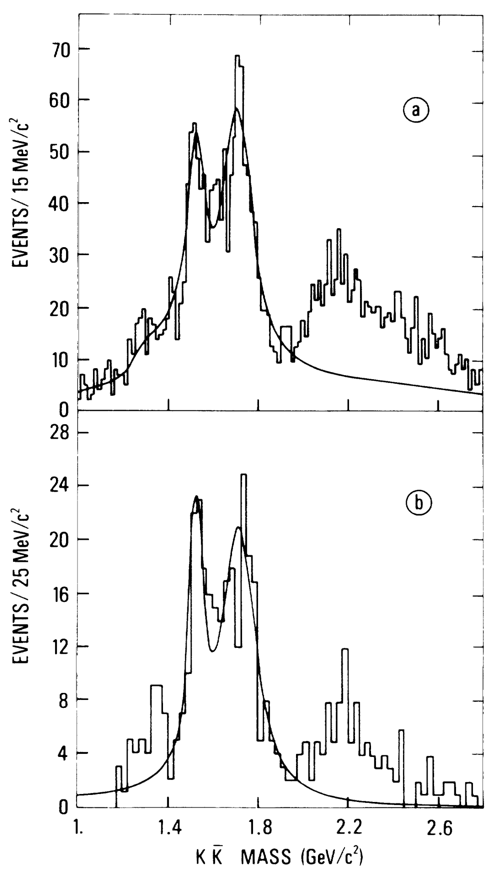

FIG. 1. $K\bar{K}$ invariant-mass distribution with the fit of the $f_2'(1525)$-$f_2(1720)$ mass region. (a) K^+K^- final state. (b) $K_S^0K_S^0$ final state.

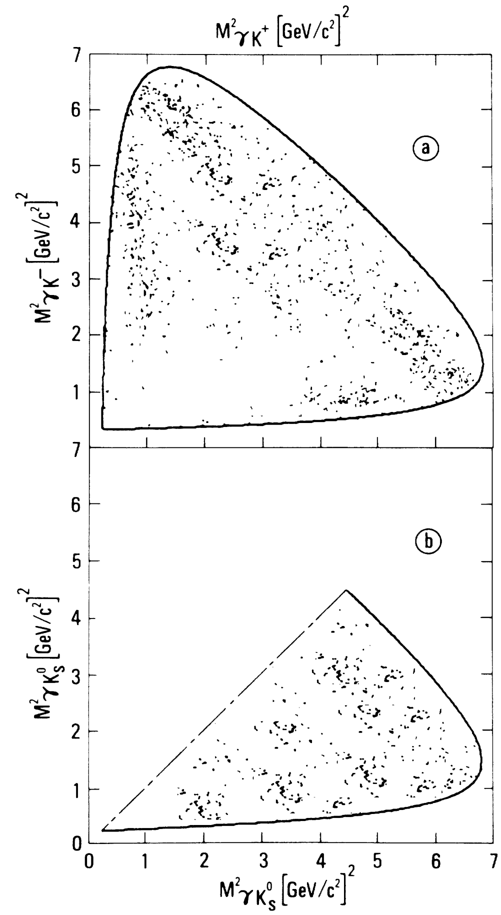

FIG. 2. Dalitz plots. (a) K^+K^- channel. (b) $K_S^0K_S^0$ channel; this plot is folded to account for the symmetry between the two K_S^0.

phase fixed at 180°. [It is natural to expect a full interference between $f_2(1270)$ and $f_2'(1525)$ with real relative amplitudes. Furthermore, a fit with the phase left free yields a value close to 180°.] This contribution is incoherently added to the $f_2(1720)$ Breit-Wigner form. The background is assumed to behave as γK^+K^- phase space. The parameters obtained are

$$B(J/\psi \to \gamma f_2'(1525))B(f_2'(1525) \to K^+K^-) = (2.5 \pm 0.6 \pm 0.4) \times 10^{-4},$$

$$M_{f_2'(1525)} = 1531.6 \pm 10.0 \text{ MeV}/c^2, \quad \Gamma_{f_2'(1525)} = 102.6 \pm 29.7 \text{ MeV}/c^2,$$

$$B(J/\psi \to \gamma f_2(1720))B(f_2(1720) \to K^+K^-) = (4.6 \pm 0.7 \pm 0.7) \times 10^{-4},$$

$$M_{f_2(1720)} = 1707.0 \pm 10.0 \text{ MeV}/c^2, \quad \Gamma_{f_2(1720)} = 166.4 \pm 33.2 \text{ MeV}/c^2.$$

These results agree with previous measurements[2,6] but have to be considered with some care since, the nature of the $f_2(1720)$ being still unclear, it is not known whether the fit should include some interference effect between the $f_2'(1525)$ and the $f_2(1720)$.

At 2230 MeV/c^2 there is no evidence for the narrow ξ resonance which was reported by the Mark III Collaboration[3] with the parameters

$$M_\xi = 2230 \pm 6 \pm 14 \text{ MeV}/c^2, \quad \Gamma_\xi = 26^{+20}_{-16} \pm 17 \text{ MeV}/c^2,$$

$$B(J/\psi \to \gamma\xi)B(\xi \to K^+K^-) = (4.2^{+1.7}_{-1.4} \pm 0.8) \times 10^{-5}.$$

The quoted value would correspond to a signal of 65 events in our plot. An unbinned fit of the 2230-MeV/c^2 region with a Breit-Wigner form convoluted with the experimental resolution ($\sigma = 12$ MeV/c^2) over a polynomial background leads to the following upper limit for $\Gamma_\xi = 26$ MeV/c^2:

$$B(J/\psi \to \gamma\xi)B(\xi \to K^+K^-) < 2.3 \times 10^{-5} \text{ [95\% confidence level (C.L.)]}.$$

The limit as a function of the ξ width is shown in Fig. 3. The probability not to observe in the DM2 data the signal with the parameters of Ref. 3 is estimated to be 3×10^{-3} with use of a likelihood-ratio technique.

The reaction $J/\psi \to \gamma K_S^0 K_S^0$ has less background than the preceding one, especially in the mass region over 2 GeV/c^2, but the signals are smaller. The identified background sources are events from the reaction $J/\psi \to \gamma\iota \to \gamma K_S^0 K^\pm \pi^\mp$ where the $K\pi$ pair mimics a K_S^0, and $\pi^+\pi^-\pi^+\pi^-\pi^0$ events with asymmetric π^0 decay and two π pairs close in mass to a K_S^0.

The first level of selection requires events with four charged tracks of zero total charge and one photon; two $\pi^+\pi^-$ masses have to lie within 50 MeV/c^2 around the K_S^0 mass, the total reconstructed energy has to be greater than 2.9 GeV, and a coplanarity cut of 6000 (MeV/c)^2 is applied on the variable P_t^2. No cut is necessary on the flight distance of the K_S^0's. The events are then 3C-fitted to the $\gamma K_S^0 K_S^0$ hypothesis ($\chi^2 < 20$). In addition, all the measured TOF in an event are required to be consistent within 2.5σ with π hypothesis. The efficiency to $J/\psi \to \gamma K_S^0 K_S^0$ ($\approx 20\%$) is nearly independent of the mass of the $K_S^0 K_S^0$ system and of the angular distribu-

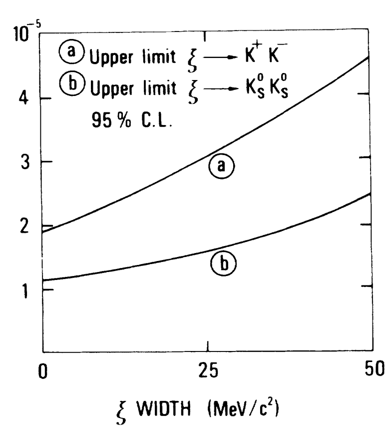

FIG. 3. Upper limits for $\xi(2230)$ production as a function of the width. Curve a, K^+K^- final state. Curve b, $K_S^0 K_S^0$ final state.

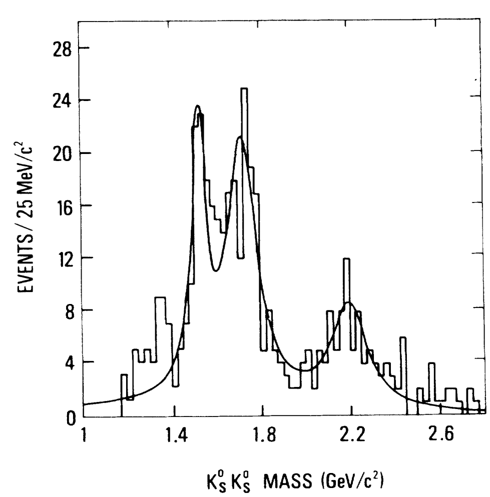

FIG. 4. Fit to the $K_S^0 K_S^0$ mass distribution with three Breit-Wigner forms.

tions.

The $K_S^0K_S^0$ mass distribution is shown in Fig. 1(b) and the Dalitz plot in Fig. 2(b). The $f_2'(1525)$ and $f_2(1720)$ signals appear clearly separated. In the region under 1.4 GeV/c^2 some contamination expected from the ι decay into $K_S^0K^{\pm}\pi^{\mp}$ (shifted in mass because of the π mass misassignment to a K) is visible, and possibly the f decay into $K_S^0K_S^0$. In the region from 2 to 2.5 GeV/c^2 a significant number of events appear as a broad structure. The $f_2'(1525)$-$f_2(1720)$ region has been fitted by two incoherent Breit-Wigner forms with the $f_2'(1525)$ mass and width fixed at the values of the Particle Data Group[5] tables. One obtains

$$B(J/\psi\to\gamma f_2'(1525))B(f_2'(1525)\to K_S^0K_S^0)=(1.0\pm0.1\pm0.2)\times10^{-4},$$

$$B(J/\psi\to\gamma f_2(1720))B(f_2(1720)\to K_S^0K_S^0)=(2.6\pm0.3\pm0.4)\times10^{-4},$$

$$M_{f_2(1720)}=1711\pm9\ \mathrm{MeV}/c^2,\quad \Gamma_{f_2(1720)}=173\pm22\ \mathrm{MeV}/c^2.$$

These results are in agreement with a previous measurement[6] and with our results in γK^+K^-. Here again there is no evidence for a signal of the $\xi(2230)$ which has been reported by the Mark III Collaboration[3] with a product branching ratio of $(3.1^{+1.6}_{-1.3}\pm0.7)\times10^{-5}$. With this value we would expect 25 events in our plot (the mass resolution is $\sigma=11$ MeV/c^2). A fit similar to the one done in the γK^+K^- channel gives the following upper limit:

$$B(J/\psi\to\gamma\xi)B(\xi\to K_S^0K_S^0)<1.6\times10^{-5}\ (95\%\ \mathrm{C.L.}).$$

The dependence of the limit as a function of the ξ width is shown in Fig. 3. The probability not to observe the $K_S^0K_S^0$ signal with the parameters of Ref. 3 is 2×10^{-3}.

The excess of events observed over 2 GeV/c^2 cannot be explained by any known source of background. A fit (Fig. 4) by a Breit-Wigner curve, with the $f_2'(1525)$ and the $f_2(1720)$ mass and width fixed, gives the following parameters:

$$M_X=2197\pm17\ \mathrm{MeV}/c^2,\quad \Gamma_X=201\pm51\ \mathrm{MeV}/c^2,$$

$$B(J/\psi\to\gamma X)B(X\to K_S^0K_S^0)\approx1.5\times10^{-4}.$$

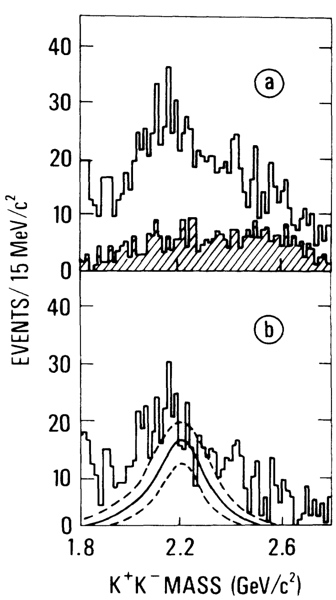

FIG. 5. K^+K^- invariant-mass distribution over 2 GeV/c^2. (a) The dashed histogram is the Monte Carlo estimate of the $\rho\pi$ and KK^* background contribution. (b) After background subtraction. The solid line shows the expectation from the $K_S^0K_S^0$ channel. The dashed lines represent the uncertainty on the background estimation.

In order to check the consistency of this signal it is important to see if the mass distribution obtained in the isospin-related channel γK^+K^- accommodates the presence of a corresponding signal. The K^+K^- spectrum over 2 GeV/c^2 is contaminated mainly by the reactions $J/\psi\to\rho^{\pm}\pi^{\mp}$ and $J/\psi\to K^{*\pm}K^{\mp}$. The background spectrum has been estimated by Monte Carlo simulation [Fig. 5(a)]. Although the predicted number of events can have large systematics the shape is reliably obtained. Figure 5(b) shows the K^+K^- spectrum after background subtraction and the shape of the expected signal. One can see that within the uncertainties of background estimations the K^+K^- mass distribution is compatible with the expectation from the $K_S^0K_S^0$ one.

In summary the $J/\psi\to\gamma K\bar{K}$ decay has been studied in its charged and neutral channels K^+K^- and $K_S^0K_S^0$. In the mass region below 2 GeV/c^2, the $K\bar{K}$ production is dominated by the $f_2'(1525)$ and $f_2(1720)$ signals which appear clearly separated in both channels. Improved measurements of their production parameters are given. We do not observe the $\xi(2230)$ in either modes: The probability not to observe its signal with the reported parameters is of the order of 10^{-3}. Finally a broad structure has been observed in $K_S^0K_S^0$ at invariant masses between 2 and 2.5 GeV/c^2 with a width and branching ratio, respectively, 8 times and 5 times larger than the quoted $\xi(2230)$ values with which it cannot be possibly related.

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