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Study of the $K\bar{K}\pi$ Final State in J/ψ Hadronic Decays*

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ABSTRACT

The reactions $J/\psi \rightarrow \omega K\bar{K}\pi$ and $J/\psi \rightarrow \phi K\bar{K}\pi$ have been studied using a sample of 5.8×10^6 produced J/ψ decays. The $K^{\pm}K^0_S\pi^{\mp}$ and $K^+K^-\pi^0$ systems produced in association with an ω have enhancements in the mass distribution near 1.44 GeV/c^2. The observed angular distributions are consistent with $J^P = 1^+$ and do not favor a $J^P = 0^-$ assignment. No signal is seen at the nominal $f_1(1285)$ mass. The reverse pattern is observed in the $K\bar{K}\pi$ system produced in association with a ϕ, which shows an enhancement near 1.280 GeV/c^2, and no evidence for structure at 1.4 GeV/c^2.

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The study of the decays $J/\psi \to \{\gamma, \omega, \phi\}X$ is a useful tool in the investigation of the quark and possible gluonium content of a given state X.[1] In this letter, we have used this technique to examine the $\eta(1440)$,[2] a prime gluonium candidate produced copiously in J/ψ radiative decays, and other more conventional $q\bar{q}$ states such as the $f_1(1285)$ and the $f_1(1420)$.

We report on a study of the $K\bar{K}\pi$ final state in the reactions $J/\psi \to$

$$\omega K^+K^-\pi^0 \to \pi^+\pi^-\pi^0K^+K^-\pi^0, \qquad (1)$$

$$\omega K^\pm K^0_S\pi^\mp \to \pi^+\pi^-\pi^0K^\pm\pi^+\pi^-\pi^\mp, \qquad (2)$$

$$\phi K^+K^-\pi^0 \to K^+K^-K^+K^-\pi^0, \qquad \text{and} \qquad (3)$$

$$\phi K^\pm K^0_S\pi^\mp \to [K^+K^-, K^0_SK^0_L]K^\pm\pi^+\pi^-\pi^\mp, \qquad (4)$$

based on a sample of 5.8×10^6 produced J/ψ's collected with the Mark III detector at the SLAC e^+e^- storage ring SPEAR.

The Mark III detector has been described in detail elsewhere.[3] Charged particles are identified by time-of-flight (TOF) and energy loss (dE/dx). A charged particle is called *consistent* with a π, K or p by TOF (dE/dx) if the measured and calculated times of flight (energy losses) differ by less than three standard deviations for the given mass hypothesis; it is called *identified* with a particle type if it is consistent with only that particle hypothesis.

The first step in the analysis is to select topologically consistent events: those events having the correct number of charged particles and at most four additional neutral showers.[4] At least one track must be consistent (identified) with a $K^\pm$ by TOF (dE/dx). Depending on the reaction, one- to six-constraint kinematic fits are applied, trying all possible photon combinations and/or particle mass assignments. The best combination with regard to particle identification and kinematic fit is retained if the χ^2 probability of the fit, $P(\chi^2_{fit})$, exceeds a minimum value, chosen to optimize the signal to background ratio. The particles assigned to be kaons by the kinematic fit are not allowed to be identified as pions by the TOF measurement. To remove background events in which a π^0 is falsely reconstructed from a high energy photon and a spurious second shower, the requirement $|E_{\gamma_1} - E_{\gamma_2}|/P_{\pi^0} < 0.95$ is imposed in reactions (1) and (3).

The $J/\psi \to \omega K^+K^-\pi^0 \to \pi^+\pi^-K^+K^-4\gamma$ events are selected by six-constraint kinematic fits to the hypothesis $J/\psi \to \pi^+\pi^-\pi^0K^+K^-\pi^0$, requiring at least one track to be consistent with a kaon by TOF and $P(\chi^2_{fit}) > 0.05$.

The $J/\psi \to \omega K^{\pm}K^0_S\pi^{\mp} \to 2(\pi^+\pi^-)K^{\pm}\pi^{\mp}2\gamma$ are selected by five-constraint kinematic fits to the hypothesis $J/\psi \to \pi^+\pi^-\pi^0K^{\pm}\pi^+\pi^-\pi^{\mp}$, requiring $P(\chi^2_{fit}) > 0.05$. To select events with a K^0_S, at least one of the six possible $\pi^+\pi^-$ combinations must have a vertex detached from the primary vertex and an invariant mass within 0.02 GeV/c^2 of the K^0_S mass.

Figs. 1a and 1b show the distributions of invariant $\pi^+\pi^-\pi^0$ masses from reaction (1) and (2). Clear η and ω signals are apparent. Figs. 2a and 2b show the $K^{\pm}K^0_S\pi^{\mp}$ and $K^+K^-\pi^0$ invariant mass spectra for events in which the mass of the recoiling system is within 0.03 GeV/c^2 of the nominal ω mass; the summed spectrum is displayed in Fig. 2c. The shaded bands represent the background of events not containing ω's as obtained from 0.06 GeV/c^2 wide sidebands centered 0.09 GeV/c^2 above and below the nominal ω mass. The overall shapes of the mass distributions resemble that of $J/\psi \to \omega K\bar{K}\pi$ or $J/\psi \to \omega K^*(890)K$ phase space.[5] The mass spectra in Fig. 2 show similar signals near 1.4 GeV/c^2, which are correlated with an ω.

For the two data sets, and their sum, maximum-likelihood fits are performed in the 1.25 – 1.80 GeV/c^2 mass region to extract the mass and width of the resonant state. These fits include a quadratic polynominal for the background plus a Breit-Wigner parametrization convoluted with a Gaussian resolution function for the resonance. Since the mass resolution (σ = 0.01 GeV/c^2) is the same for both channels, it is valid to fit the summed spectrum of Fig. 2c to obtain average values. The results of the fits, assuming $K\bar{K}\pi$ phase space production, are listed in Table I. To account for a possible K^*K decay mode of the resonance a parametrization using a Breit-Wigner shape modified by K^*K phase space is also employed. These fits yield mass values 0.007 GeV/c^2 lower, due to the rapidly rising phase space above K^*K threshold ($\approx$ 1.38 GeV/c^2). The systematic error is estimated by varying the fit intervals and background shapes. The error also includes a contribution from unresolved discrepancies in the mass scale ($\pm$0.01 GeV/c^2) and accounts for possible mass shifts due to the $K\bar{K}\pi$ substructure (*i.e.*, K^*K, $a_0(980)\pi$).

The angular distributions of the final state particles can be used to determine the spin and parity of the intermediate $K\bar{K}\pi$ state. Fig. 2d shows the acceptance corrected distribution of the normal of the ω-decay plane in the ω helicity system together with the prediction for a $J^P = 0^-$ state. The curve does not follow the data; a fit yields a probability of 6% for the hypothesis that all signal events arise from a pseudoscalar resonance. This result is supported by a three-channel analysis[6] where the $K\bar{K}\pi$ system is assumed to be composed of a $J^P = 0^-$

state decaying via the $a_0(980)\pi$ intermediate state, a $J^P = 1^+$ state decaying via K^*K, and an isotropic distribution. The analysis assigns the resonant structure to the axial vector component.

The $J/\psi \to \phi K^+K^-\pi^0 \to 2(K^+K^-)2\gamma$ events are selected by five-constraint kinematic fits to the hypothesis $J/\psi \to 2(K^+K^-)\pi^0$, requiring at least one track to be consistent with a kaon by TOF and $P(\chi^2_{fit}) > 0.05$.

The $J/\psi \to \phi K^\pm K^0_S\pi^\mp \to K^+K^-K^\pm\pi^+\pi^-\pi^\mp$ events are selected by requiring five and six charged tracks with total charge ± 1 and 0, respectively. In the case of six detected charged tracks (reaction (4a)), four-constraint kinematic fits to the hypothesis $J/\psi \to K^+K^-K^\pm\pi^+\pi^-\pi^\mp$ are applied, and the event is retained if $P(\chi^2_{fit}) > 0.005$. In the case of five detected charged particles (reaction (4b)), events are accepted if at least two tracks are consistent with kaons by TOF or dE/dx. One-constraint kinematic fits are then applied, and the event is retained if $P(\chi^2_{fit}) > 0.10$. It is required that at least one $\pi^+\pi^-$ pair has a mass within 0.02 GeV/c^2 of the K^0_S mass.

The $J/\psi \to \phi K^\pm K^0_S\pi^\mp \to \pi^+\pi^-K^\pm\pi^+\pi^-\pi^\mp$ events (reaction (4c)), are selected by one-constraint kinematic fits assuming that a K^0_L is missing in the event. The event is retained if $P(\chi^2_{fit}) > 0.05$. To select $J/\psi \to K^0_L K^0_S K^\pm K^0_S\pi^\mp$ events it is required that at least one of the six possible $(\pi^+\pi^-)(\pi^+\pi^-)$ pairings has both $\pi^+\pi^-$ masses within 0.02 GeV/c^2 of the K^0_S mass, and that at least one $\pi^+\pi^-$ pair has a detached vertex.

Figure 3a and 3b show the K^+K^- invariant mass distributions from reaction (3) and (4a,b). The $K^0_S K^0_L$ mass distribution from reaction (4c) is displayed in

Fig. 3c. Clear ϕ signals are observed. The summed $K^{\pm}K_S^0\pi^{\mp}$ and $K^+K^-\pi^0$ mass spectra, for events in which the mass of the recoiling $K\bar{K}$ system is within 0.015 GeV/c^2 of the nominal ϕ mass, is shown in Fig. 4a. The shaded area represents the background of events not containing a ϕ, obtained from a ϕ sideband (1.075 ± 0.030 GeV/c^2). The main feature is a broad distribution following the shape of $J/\psi \to \phi K^*K$ phase space. The K^*K dominance is confirmed by a study of the $K^{\pm}K_S^0\pi^{\mp}$ system using the background free subsample of reaction (4a). No enhancement in the 1.4 GeV/c^2 mass region is seen. A small signal at 1.28 GeV/c^2 is enhanced by requiring the $K\bar{K}$ invariant mass of the $K\bar{K}\pi$ system to be below 1.15 GeV/c^2 (Fig. 4b).

Upper limits for the production of the $f_1(1420)$ and the $\eta(1440)$ are derived from maximum-likelihood fits performed on the invariant mass spectrum in Fig. 4a in the 1.35 – 1.60 GeV/c^2 mass region. These fits include a $J/\psi \to \phi K^*K$ phase space distribution plus a Breit-Wigner parametrization for the resonance. The upper limits, as well as the fitted parameters of the structure at 1.28 GeV/c^2, are listed in Table I.

The detection efficiencies for reactions (1)-(4) are obtained by assuming isotropic decay angular distributions for the $K\bar{K}\pi$ part,[7] with the exception of the pseudoscalar $\eta(1440)$. The deduced branching fractions are listed in Table I. An isoscalar $K\bar{K}\pi$ system is assumed in the correction for unobserved decay modes. The errors include uncertainties due to the fit procedure, event selection criteria, Monte Carlo simulation of low energy photon showers, and flux determination.

In summary, the $J/\psi \to \omega K\bar{K}\pi$ and $J/\psi \to \phi K\bar{K}\pi$ reactions are dominated by phase space distributed ωK^*K and ϕK^*K intermediate states. The ratio $B(J/\psi \to \omega K^*\bar{K} + \text{c.c.})/B(J/\psi \to \phi K^*\bar{K} + \text{c.c.}) = 2.7 \pm 1.0$ is larger than expected in the SU(3) symmetric limit (0.93).[8] We have observed an enhancement at $1.442 \pm 0.005^{+0.010}_{-0.017}$ GeV/c^2 in the $K^{\pm}K^0_S\pi^{\mp}$ and $K^+K^-\pi^0$ systems recoiling against an ω. The width of 0.024$< \Gamma <$ 0.084 GeV/c^2 (90% C.L limits) and the observed decay angular distributions are not consistent with that of the pseudoscalar $\eta(1440)$.[9] No signal at the nominal $f_1(1285)$ mass is seen. The reverse pattern is observed in the $K\bar{K}\pi$ system recoiling against the ϕ. There is no indication for either $f_1(1420)$ or $\eta(1440)$ production, but a small signal at 1.28 GeV/c^2. If the observed enhancements are identified with the $f_1(1420)$ and $f_1(1280)$ mesons, quark correlations imply a non-ideal mixing of the axial vector nonet.[10]

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References

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2. The new nomenclature for hadrons is adopted (Review of Particle Properties, Particle Data Group, Phys. Lett. **170B**, 1 (1986)). $\eta(1440)$, $f_1(1285)$, and $f_1(1420)$ were formerly called ι, D, and E, respectively.
3. D. Bernstein *et al.*, Nucl. Instr. and Meth. **226**, 310 (1984).
4. Spurious showers associated with decays or interactions of charged and neutral hadrons in the shower counters are often observed.
5. From a fit to the $K^{\pm}\pi^{\mp}$ and $K_S^0\pi^{\mp}$ mass spectra it is estimated that $(60 \pm 15)\%$ of the $J/\psi \rightarrow \omega K^{\pm}K_S^0\pi^{\mp}$ events form an $\omega K^* K$ intermediate state.
6. A similar analysis is described in R. M. Baltrusaitis *et al.*, Phys. Rev. **D33**, 1222 (1986).
7. For the $J/\psi \rightarrow \omega K\bar{K}\pi$ reaction the detection efficiency is $\approx 6\%$ lower if $J^P = 0^-$ is assumed for the $K\bar{K}\pi$ system.
8. Ref. 10; S–wave phase space has been taken into account.
9. See, *e.g.*, J. D. Richman, Proc. XX Rencontre de Moriond, Les Arcs, France, March 10-17, 1985.
10. H. E. Haber and J. Perrier, Phys. Rev. **D32**, 2961 (1985).

Figure Captions

Fig. 1. Three pion invariant mass distribution (a) from the reaction $J/\psi \rightarrow \pi^+\pi^-\pi^0K^+K^-\pi^0$, and (b) from $J/\psi \rightarrow \pi^+\pi^-\pi^0K^\pm K^0_S\pi^\mp$, with (a) two and (b) six possible entries per event.

Fig. 2. (a) $K^\pm K^0_S\pi^\mp$ invariant mass distribution from $J/\psi \rightarrow \omega K^\pm K^0_S\pi^\mp$; (b) $K^+K^-\pi^0$ invariant mass distribution from $J/\psi \rightarrow \omega K^+K^-\pi^0$; (c) sum. The shaded bands show the estimate of the background. (d) Distribution of $\mid \cos\Theta_\omega \mid$ with prediction for $J^P = 0^-$ (solid curve).

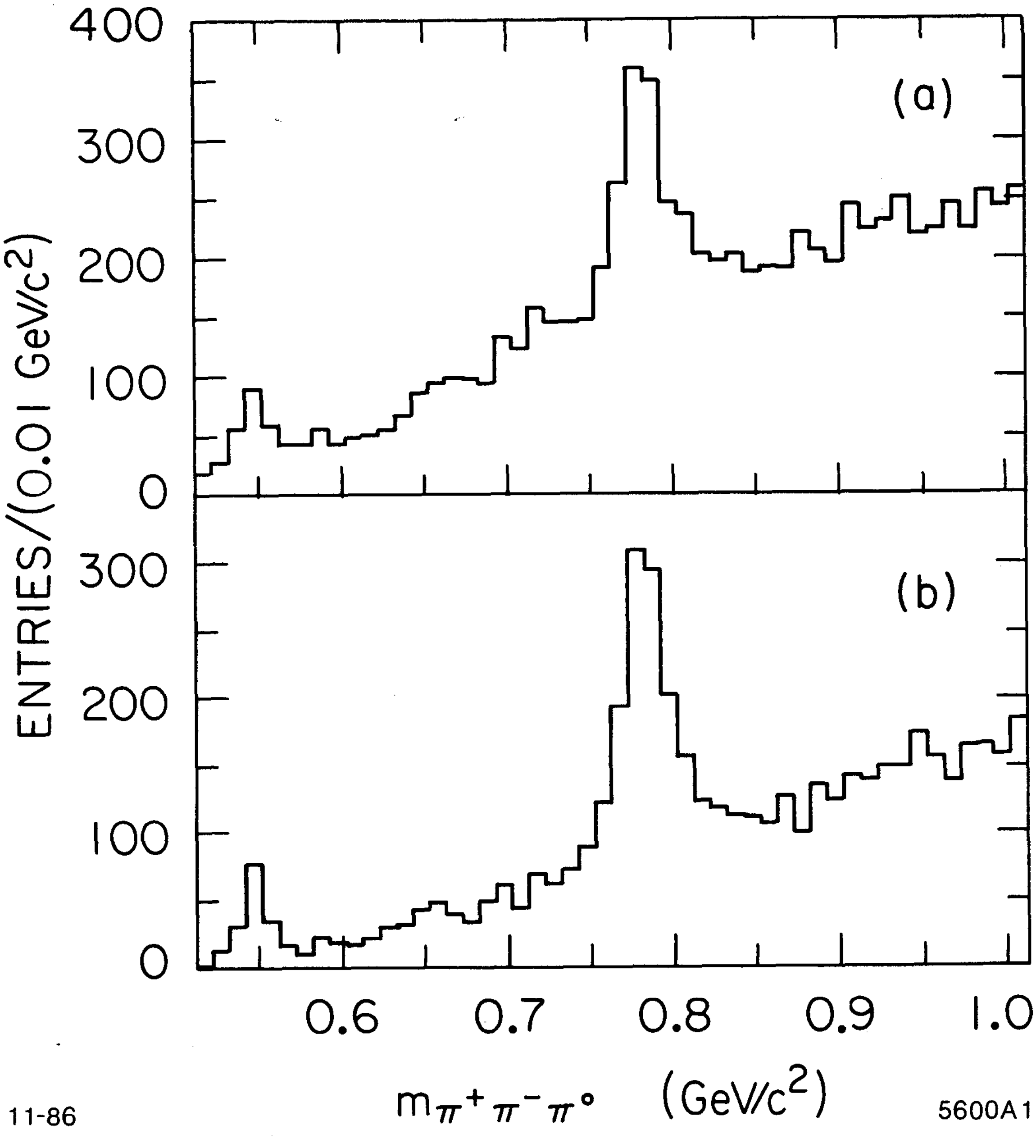
Fig. 3. K^+K^- invariant mass distribution (a) from $J/\psi \rightarrow K^+K^-K^+K^-\pi^0$, and (b) from $J/\psi \rightarrow K^+K^-K^\pm K^0_S\pi^\mp$, with (a) four and (b) two possible entries per event; (c) $K^0_S K^0_L$ invariant mass distribution from $J/\psi \rightarrow K^0_S K^0_L K^\pm K^0_S \pi^\mp$ with up to six entries per event. Background from events not containing K^0_S's is subtracted in (b) and (c).

Fig. 4. (a) Summed $K^+K^-\pi^0$ and $K^\pm K^0_S\pi^\mp$ invariant mass distributions. (b) Detail of 1.2 GeV/c^2 mass region after selecting $m(K\bar{K}) <$ 1.15 GeV/c^2. The shaded area shows the estimate of the background.

TABLE I

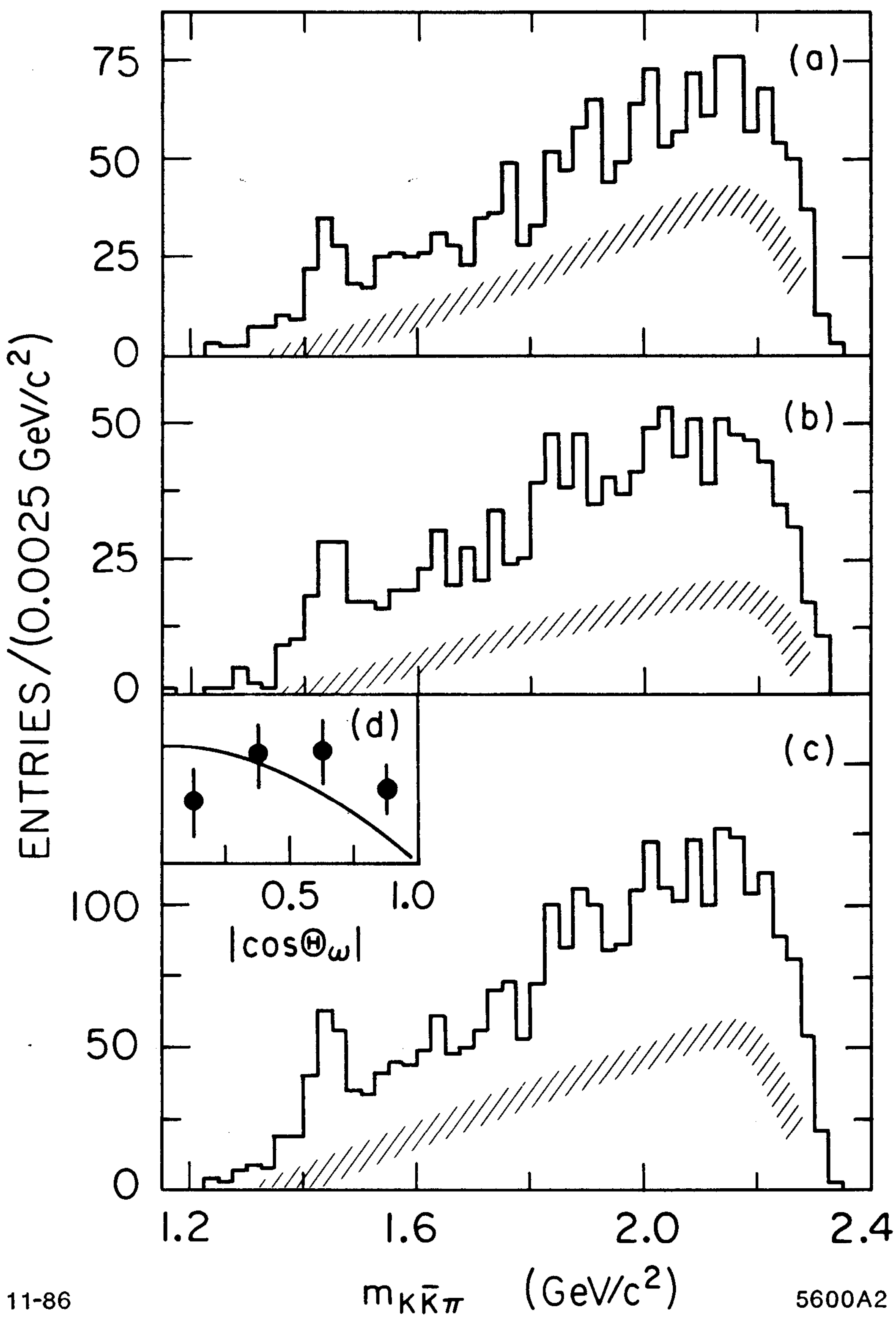
Branching ratios and parameters of resonance X. The first four entries correspond to total branching ratios integrated over the allowed kinematic range.

Mass(X) MeV/c^2	Width(X) MeV/c^2	#Events Observed	Reaction $J/\psi \to$	Branching Ratio (Units of 10^{-4})
–	–	879 ± 41	$\omega K^{\pm} K_S^0 \pi^{\mp}$	$29.5 \pm 1.4 \pm 7.0$
–	–	530 ± 140	$\omega K^* \bar{K} +$ c.c.	$53 \pm 14 \pm 14$
–	–	163 ± 15	$\phi K^{\pm} K_S^0 \pi^{\mp}$	$7.0 \pm 0.6 \pm 1.0$
–	–	155 ± 20	$\phi K^* \bar{K} +$ c.c.	$20 \pm 3 \pm 3$
			$\omega X; X \to$	
$1440 \pm 7^{+10}_{-17}$	$34^{+22}_{-16} \pm 5$	53^{+21}_{-17}	$K^+ K^- \pi^0$	$1.3^{+0.5}_{-0.4} \pm 0.3$
$1442 \pm 7^{+10}_{-17}$	$44^{+22}_{-16}{}^{+12}_{-5}$	58^{+23}_{-18}	$K^{\pm} K_S^0 \pi^{\mp}$	$2.1^{+0.8}_{-0.7} \pm 0.6$
$1442 \pm 5^{+10}_{-17}$	$40^{+17}_{-13} \pm 5$	111^{+31}_{-26}	$K\bar{K}\pi$	$6.8^{+1.9}_{-1.6} \pm 1.7$
1285	24	< 12	$K\bar{K}\pi$	< 1.1@90% C.L.
			$\phi X; X \to$	
$1420 - 1440$	$40 - 60$	< 21	$K\bar{K}\pi$	< 1.2@90% C.L.
1460	92	< 32	$K\bar{K}\pi$	< 2.1@90% C.L.
$1279 \pm 6 \pm 10$	$14^{+20}_{-14} \pm 10$	16 ± 6	$K\bar{K}\pi$	$0.6 \pm 0.2 \pm 0.1$



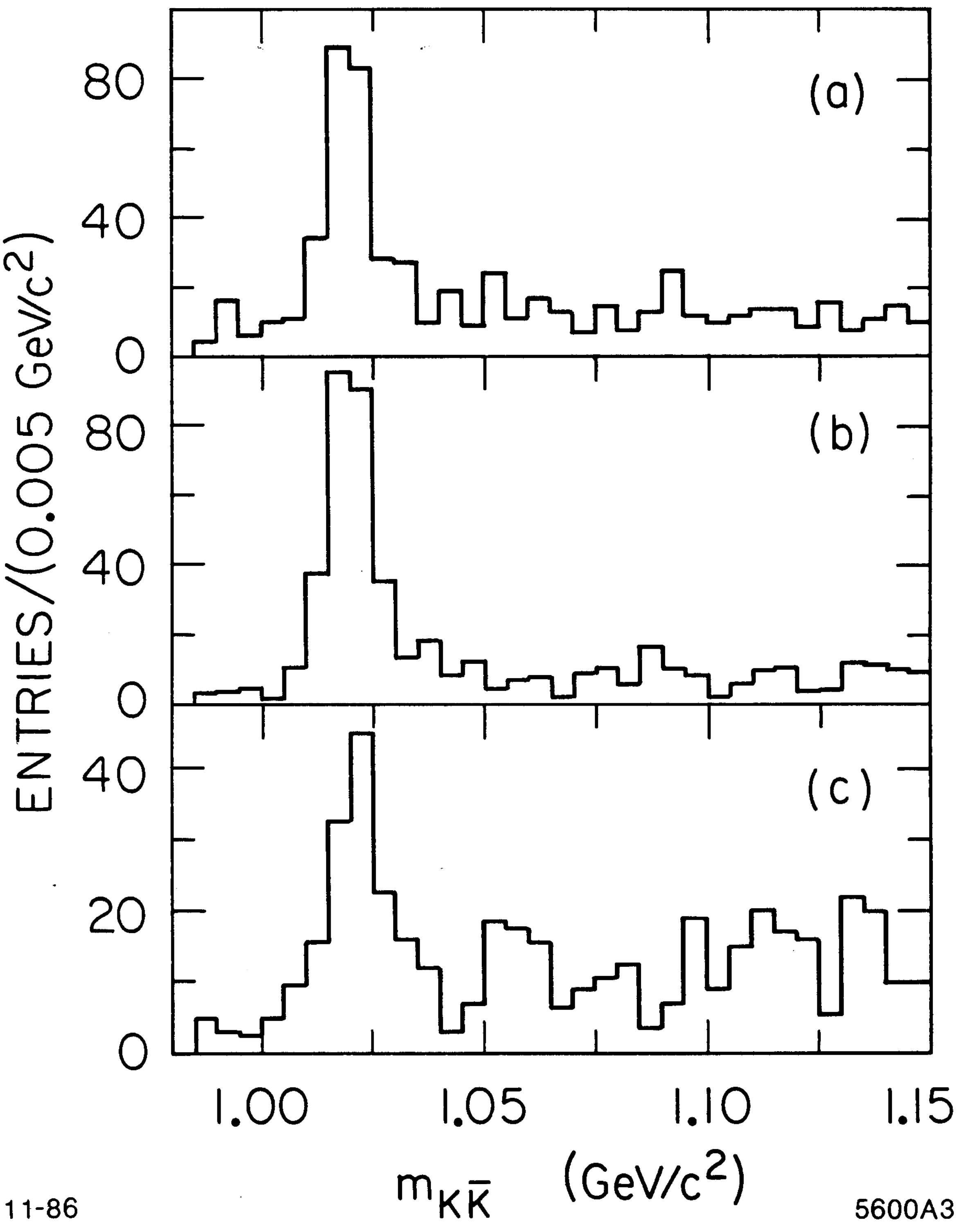
400
300
200
100
0
300
200
100
0
(a)
(b)
ENTRIES/(0.01 GeV/c2)
0.6
0.7
0.8
0.9
1.0
mπ+π−π° (GeV/c2)
11-86
5600A1

Fig. 1



75
50
25
0
(a)
50
25
0
(b)
(d)
0.5
1.0
|cos Θ_ω|
(c)
100
50
0
ENTRIES/(0.0025 GeV/c²)
1.2
1.6
2.0
2.4
m_KK̄π (GeV/c²)
11-86
5600A2

Fig. 2



ENTRIES/(0.005 GeV/c^2)
80
40
0
(a)
80
40
0
(b)
40
20
0
(c)
1.00
1.05
1.10
1.15
$m_{K\bar{K}}$ (GeV/c^2)
11-86
5600A3

Fig. 3

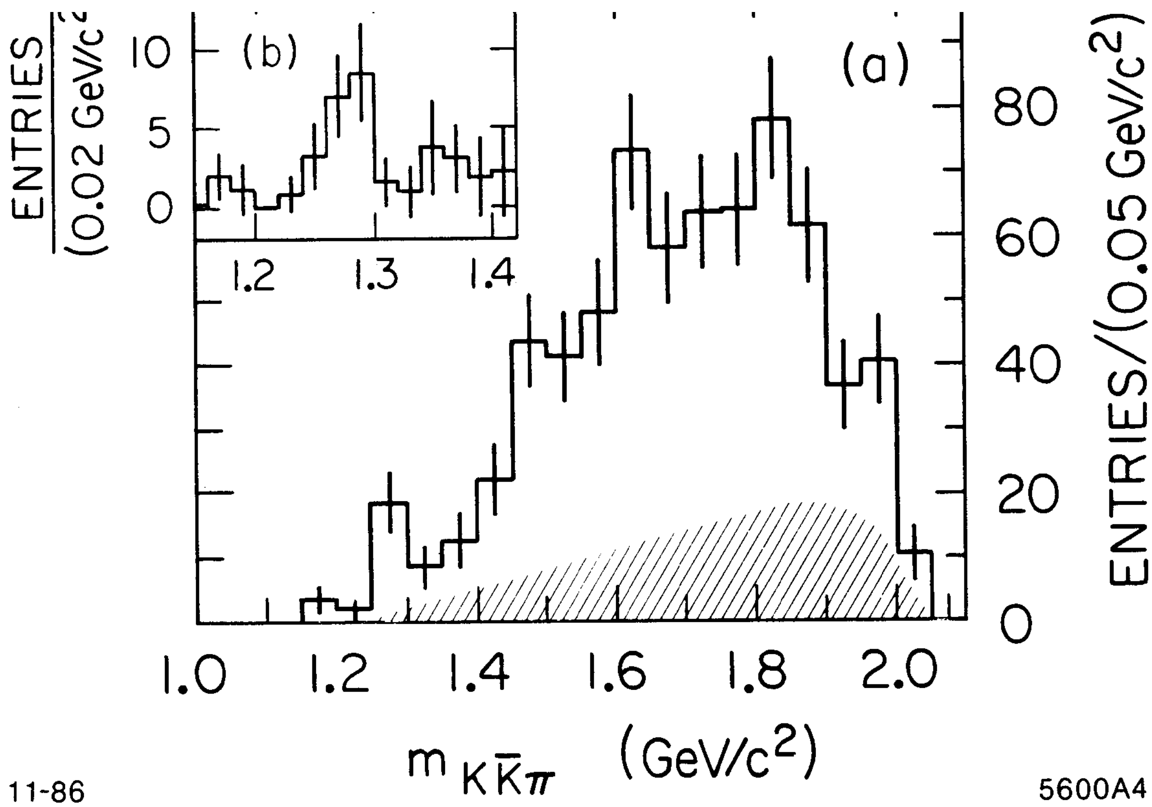

ENTRIES/(0.02 GeV/c2)
10
5
0
(b)
1.2
1.3
1.4
(a)
80
60
40
20
0
ENTRIES/(0.05 GeV/c2)
1.0
1.2
1.4
1.6
1.8
2.0
m KK̄π (GeV/c2)
11-86
5600A4

Fig. 4