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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 $J/\psi \to \omega K\bar{K}\pi$ and $J/\psi \to \phi K^{\pm}K^0_S\pi^{\mp}$ 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 recoiling against an ω show enhancements in the mass distribution around 1.445 GeV/c^2 with consistent branching ratios. No such structure is observed in the mass distribution of the $K^{\pm}K^0_S\pi^{\mp}$ system recoiling against a ϕ. A comparison of these observations with the corresponding channels in radiative J/ψ decays permits a detailed study of the structures seen in the $\iota(1440)$ and $E(1420)$ signal regions.

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The pseudoscalar $\iota(1440)$[1] state is considered to be a prime glueball candidate because it is produced copiously in the gluon-enriched J/ψ radiative decay.[2] However, this assertion rests on the premise that it is distinct from the $E(1420)$ state whose spin parity assignment ($J^{PC} = 0^{-+}$ or 1^{++}) is still in question.[3] By comparing spectra obtained in radiative and hadronic J/ψ decays, this topic can be addressed in one experiment. By means of quark correlations, the $J/\psi \to \omega X$ and $J/\psi \to \phi X$ reactions allow one to determine the quark content of the final state X.[4]

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

$$J/\psi \to \omega K^+K^-\pi^0 \to \pi^+\pi^-\pi^0K^+K^-\pi^0,$$
$$J/\psi \to \omega K^\pm K^0_S\pi^\mp \to \pi^+\pi^-\pi^0K^\pm\pi^+\pi^-\pi^\mp,$$
$$\text{and} \quad J/\psi \to \phi K^\pm K^0_S\pi^\mp \to [K^+K^-, K^0_SK^0_L]K^\pm\pi^+\pi^-\pi^\mp,$$

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

The Mark III detector[5] is a general purpose solenoidal magnetic spectrometer. The features relevant to this analysis are the following: a central cylindrical drift chamber consisting of 34 wire planes enabling momentum measurements of charged tracks with a resolution of 2% at 1 GeV/c over 0.84 of 4π sr, and ionization sampling (dE/dx) using the inner 12 layers;[6] a set of 48 axial time of flight (TOF) counters covering 0.80 of 4π sr, which have a resolution of 191 ps; and a 12 radiation length gas sampling calorimeter located within the magnet coil and covering 0.94 of 4π sr, which has a resolution of $\delta E/E = 17\%/[E(\mathrm{GeV})]^{\frac{1}{2}}$ and a 100% detection efficiency for photons with energies greater than 0.1 GeV/c^2 .

Throughout the following discussion a charged particle is called *consistent* with a π, K or p by TOF if the measured and calculated times of flight differ by less than three standard deviations for the given particle mass hypothesis; it is called consistent with a particle type by dE/dx, if the measured energy loss is within 3σ (4.5σ) of the predicted value on the low (high) side. Particles are called *identified* with a particle type by TOF or dE/dx if they are inconsistent with any other particle type hypothesis. The particle within the event with the highest probability to be a kaon is treated as such throughout the analysis.

The $J/\psi \rightarrow \omega K^+K^-\pi^0 \rightarrow \pi^+\pi^-K^+K^-4\gamma$ events are selected by the requirement of exactly four charged particles with zero total charge. At least one track has to be consistent with a kaon by TOF. Events are also required to have between four and eight neutral showers with energies greater than 0.01 GeV. More than four showers are allowed because spurious showers associated with K-decays or hadrons interacting in the shower counters are often observed.

Six-constraint kinematic fits to the hypothesis $J/\psi \rightarrow \pi^+\pi^-\pi^0K^+K^-\pi^0$ are then applied, trying all possible photon combinations and particle type assignments. The best combination with regard to particle identification and kinematic fit χ^2 is retained, if the χ^2 probability is greater than 0.05. The particle which is independently assigned to be a $K^\pm$ by the kinematic fit is required not to be identified as a pion by the TOF measurement. To remove background events in which a π^0 is falsely reconstructed from a high energy photon and a second spurious shower, a cut $|(E_{\gamma_1} - E_{\gamma_2})/P_{\pi^0}| < 0.95$ is applied to both π^0's. For the selected events, Fig. 1a shows the distribution of invariant $\pi^+\pi^-\pi^0$ masses with two possible combinations per event. Clear η and ω signals are observed.

The $J/\psi \rightarrow \omega K^\pm K^0_S\pi^\mp \rightarrow \pi^+\pi^-\gamma\gamma K^\pm\pi^+\pi^-\pi^\mp$ events are selected by the requirement of exactly six charged tracks with zero total charge. At least one track has to be consistent with being a $K^\pm$ by TOF or dE/dx; if the TOF requirement is not fulfilled, it must be inconsistent with being a $\pi^\pm$ or proton by dE/dx. Events are also required to have between two and six neutral showers with energies greater than 0.01 GeV. Five-constraint kinematic fits to the hypothesis $J/\psi \rightarrow \pi^+\pi^-\pi^0K^\pm\pi^+\pi^-\pi^\mp$ are then applied, with all possible photon combinations. The combination with the best fit is retained, provided the χ^2 probability is greater than 0.05. To select K^0_S's, the invariant mass for at least one of the six possible $\pi^+\pi^-$ combinations must lie within 0.020 GeV/c^2 of the

K_S^0 mass. To reduce the remaining background from $\pi^+\pi^-$ combinations not arising from K_S^0's the direction of the $\pi^+\pi^-$ pair is required to be aligned with the vector joining the $\pi^+\pi^-$ vertex and the primary vertex within 37°. For the selected events, Figure 1b shows the distribution of invariant $\pi^+\pi^-\pi^0$ masses with six possible combinations per event. Clear η and ω signals are observed.

Figs. 2a and 2b show the $K^\pm K_S^0\pi^\mp$ 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. Both distributions show similar signals in the E/ι mass region; their sum is displayed in Fig. 2c. The shaded bands represent the background of events not containing real 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. Since this background varies smoothly we conclude that the resonant structures are correlated with an ω.

For the two data sets, as well as their sum, an unbinned maximum-likelihood fit is performed in the 1.25 – 1.80 GeV/c^2 mass region to extract the mass and width of the resonant state. This fit includes a quadratic polynominal for the background plus a Breit-Wigner parametrization convoluted with a Gaussian resolution function for the resonance. The mass resolution as determined by a Monte Carlo simulation is 0.01 GeV/c^2 for both channels. Therefore it is valid to fit the summed spectrum of Fig. 2c to obtain average values. The mass, width and number of events attributed to the resonant state by the fit are:

$$m = 1.442 \pm 0.007 \text{ GeV/c}^2;\ \Gamma = 0.033^{+0.022}_{-0.016} \text{ GeV/c}^2;\ 53^{+21}_{-17} \text{ evts.} \quad (K^+K^-\pi^0);$$
$$m = 1.445 \pm 0.008 \text{ GeV/c}^2;\ \Gamma = 0.044^{+0.024}_{-0.018} \text{ GeV/c}^2;\ 58^{+23}_{-18} \text{ evts.} \quad (K^\pm K_S^0\pi^\mp);$$
$$m = 1.444 \pm 0.007 \text{ GeV/c}^2;\ \Gamma = 0.040^{+0.017}_{-0.013} \text{ GeV/c}^2;\ 111^{+31}_{-26} \text{ evts.} \quad \text{(both modes)}.$$

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 (± 0.01 GeV/c^2) and accounts for possible mass shifts due to the $K\bar{K}\pi$ substructure. The final averaged values for mass and width of the resonance are

$$m = 1.444 \pm 0.007^{+0.010}_{-0.020} \quad \mathrm{GeV/c^2}$$

$$\text{and} \ \Gamma = 0.040^{+0.017}_{-0.013} \pm 0.010 \quad \mathrm{GeV/c^2},$$

where the first error is statistical and the second systematic.

The detection efficiencies averaged over the period of data taking and assuming isotropic decay angular distributions for the $K\bar{K}\pi$ part[7] are $(7.7 \pm 2.1)\%$ and $(7.7 \pm 2.2)\%$ for the $J/\psi \rightarrow \omega K^+K^-\pi^0 \rightarrow \pi^+\pi^-K^+K^-4\gamma$ and $J/\psi \rightarrow \omega K^\pm K^0_S\pi^\mp \rightarrow \pi^+\pi^-K^\pm\pi^+\pi^-\pi^\mp 2\gamma$ reactions respectively. The errors include uncertainties due to the fit procedure, event selection criteria, Monte Carlo handling of low energy photon showers, and flux determination. The variation of the photon-acceptance cuts produces no significant change in the branching fractions. From the number of observed events and the flux of 5.8×10^6 produced J/ψ's, the branching fractions

$$B(J/\psi \rightarrow \omega X) \cdot B(X \rightarrow K^+K^-\pi^0) = (1.2^{+0.5}_{-0.4} \pm 0.3) \times 10^{-4} \quad \text{and}$$

$$B(J/\psi \rightarrow \omega X) \cdot B(X \rightarrow K^\pm K^0_S\pi^\mp) = (2.2^{+0.8}_{-0.7} \pm 0.6) \times 10^{-4}$$

are calculated. Their ratio is consistent with the value 2 expected for an isoscalar meson. From the fit to the summed spectrum in Fig. 2c, the branching fraction

$$B(J/\psi \rightarrow \omega X) \cdot B(X \rightarrow K\bar{K}\pi) = (6.8^{+1.9}_{-1.6} \pm 1.7) \times 10^{-4}$$

is obtained assuming zero isospin when correcting for unobserved decay modes.

The $J/\psi \rightarrow \phi K^\pm K^0_S\pi^\mp \rightarrow K^+K^-K^\pm\pi^+\pi^-\pi^\mp$ events are selected by requiring five or six charged tracks with total charge ±1 and 0, respectively. In the case of six detected charged tracks, at least one track is required to be consistent with being a $K^\pm$ by TOF or dE/dx; if the TOF requirement is not fulfilled, it must be inconsistent with being a $\pi^\pm$ or proton by dE/dx. Four-constraint kinematic fits to the hypothesis $J/\psi \rightarrow K^+K^-K^\pm\pi^+\pi^-\pi^\mp$ are then applied, with all possible permutations of particle type assignments. The best combination with regard to particle identification and kinematic fit is retained, if the χ^2 probability is greater than 0.005.

In the case of five detected charged particles, at least two tracks are required to be consistent with kaons by TOF; if this criterion is fulfilled by only one track, at least one other track must be consistent with a kaon by dE/dx. One-constraint kinematic fits are then applied with all possible permutations of particle type assignments and allowing the missing particle to be a kaon or pion. The best combination with regard to particle identification and kinematic fit is retained if the χ^2 probability is greater than 0.10. The two particles that are independently assigned as kaons by the kinematic fit are required not to be identified as pions by dE/dx or TOF.

To select events with a K^0_S, 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. Figure 3a shows the K^+K^- mass distributions for the events with five and six detected charged tracks with two combinations per event. The background from events not containing a K^0_S, as obtained from 0.04 GeV/c^2 wide sidebands in the invariant $\pi^+\pi^-$ mass spectrum centered 0.06 GeV/c^2 below and above the K^0_S mass, is subtracted.

The $J/\psi \rightarrow \phi K^\pm K^0_S \pi^\mp \rightarrow \pi^+\pi^-(K^0_L)K^\pm\pi^+\pi^-\pi^\mp$ events are selected by requiring six charged tracks with zero total charge and a missing mass within 0.3 GeV/c^2 of the K^0_L mass. At least one track is required to be consistent with being a $K^\pm$ by TOF or dE/dx; if the TOF requirement is not fulfilled, it must be inconsistent with being a $\pi^\pm$ or proton by dE/dx. One-constraint kinematic fits are then applied assuming that a K^0_L is missing in the event. The event is retained if the χ^2 probability of the kinematic fit is greater that 0.05. To select $J/\psi \rightarrow K^0_L K^0_S K^\pm K^0_S \pi^\mp$ events it is required that at least one of the six possible $\pi^+\pi^- - \pi^+\pi^-$ combinations has both $\pi^+\pi^-$ masses within 0.02 GeV/c^2 of the K^0_S mass, and that the direction of at least one $\pi^+\pi^-$ pair must align with the vector joining the $\pi^+\pi^-$ vertex and the primary vertex within 11°. Figure 3b shows the $K^0_S K^0_L$ mass distribution with up to six combinations per event. The background from events which do not contain a K^0_S pair, as obtained from 0.04 GeV/c^2 wide sidebands centered 0.06 GeV/c^2 below and above the K^0_S mass, is subtracted.

The invariant mass distribution of the $K^{\pm}K^0_S\pi^{\mp}$ systems recoiling against ϕ's is displayed in Fig. 4, summed over the two analysed ϕ decay modes. No enhancement in the 1.4 GeV/c^2 mass region is seen.

For the invariant mass spectrum in Fig. 4, an unbinned maximum-likelihood fit is performed in the 1.35 – 1.60 GeV/c^2 mass region to determine upper limits for the production of the structures seen in the 1.4 GeV/c^2 mass region. This fit includes a quadratic polynominal for the background plus a Breit-Wigner parametrization for the resonance. Upper limits of 17 events at the 90% confidence level are obtained if mass and width are fixed at the nominal values for the $E(1420)$ or the central values of the structure seen recoiling against the ω. In the case of the $\iota(1440)$, an upper limit of 24 events is obtained.

The $J/\psi \to \phi K^{\pm}K^0_S\pi^{\mp} \to \phi K^{\pm}\pi^+\pi^-\pi^{\mp}$ detection efficiency is $(14.7 \pm 3.4)\%$ if isotropic decay angular distributions are assumed and $(13.0 \pm 2.7)\%$ in the case of the pseudoscalar ι. The resulting branching fractions

$$B(J/\psi \to \phi E(1420)) \cdot B(E(1420) \to K\bar{K}\pi) < 1.1 \times 10^{-4} \quad \text{and}$$
$$B(J/\psi \to \phi\iota(1440)) \cdot B(\iota(1440) \to K\bar{K}\pi) < 1.8 \times 10^{-4}$$

are corrected for unobserved decay modes under the assumption of zero isospin.

In summary, we have observed a structure at $1.442 \pm 0.007^{+0.010}_{-0.020}$ 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) is not consistent with that of the $\iota(1440)$.[8] If the enhancement is identified as the $E(1420)$, its absence in the $K^{\pm}K^0_S\pi^{\mp}$ system recoiling against a ϕ would imply that the $E(1420)$ is not a pure $s\bar{s}$ state.

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References

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3. See, e.g., S.U.Chung *et al.*, Phys.Rev.Lett. **55**, 774 (1985); C.Dionisi *et al.*, Nucl.Phys. **B169**, 1 (1980).
4. See, e.g., H.E.Haber and J.Perrier, Phys.Rev. **D 32**, 2961 (1985).
5. D.Bernstein et al., Nucl. Instr. and Methods **226**, 301 (1984).
6. For dE/dx measurements, 6 to 12 ionization measurements are used to calculate a truncated mean from the lowest 70% of the pulse heights. The resulting distribution in truncated mean is roughly Gaussian with a σ of $\approx$ 15% of the peak value. For further description of the dE/dx system see: J.Roehrig et al., Nucl.Instr.Meth. **226**, 319 (1984).
7. The detection efficiency is $\approx$ 6% lower if $J^P = 0^-$ is assumed for the $K\bar{K}\pi$ system. The Dalitz decay of the ω is correctly parametrized.
8. See, e.g., J.D.Richman, Proc. XX Rencontre de Moriond, Les Arcs, France, March 10-17, 1985.

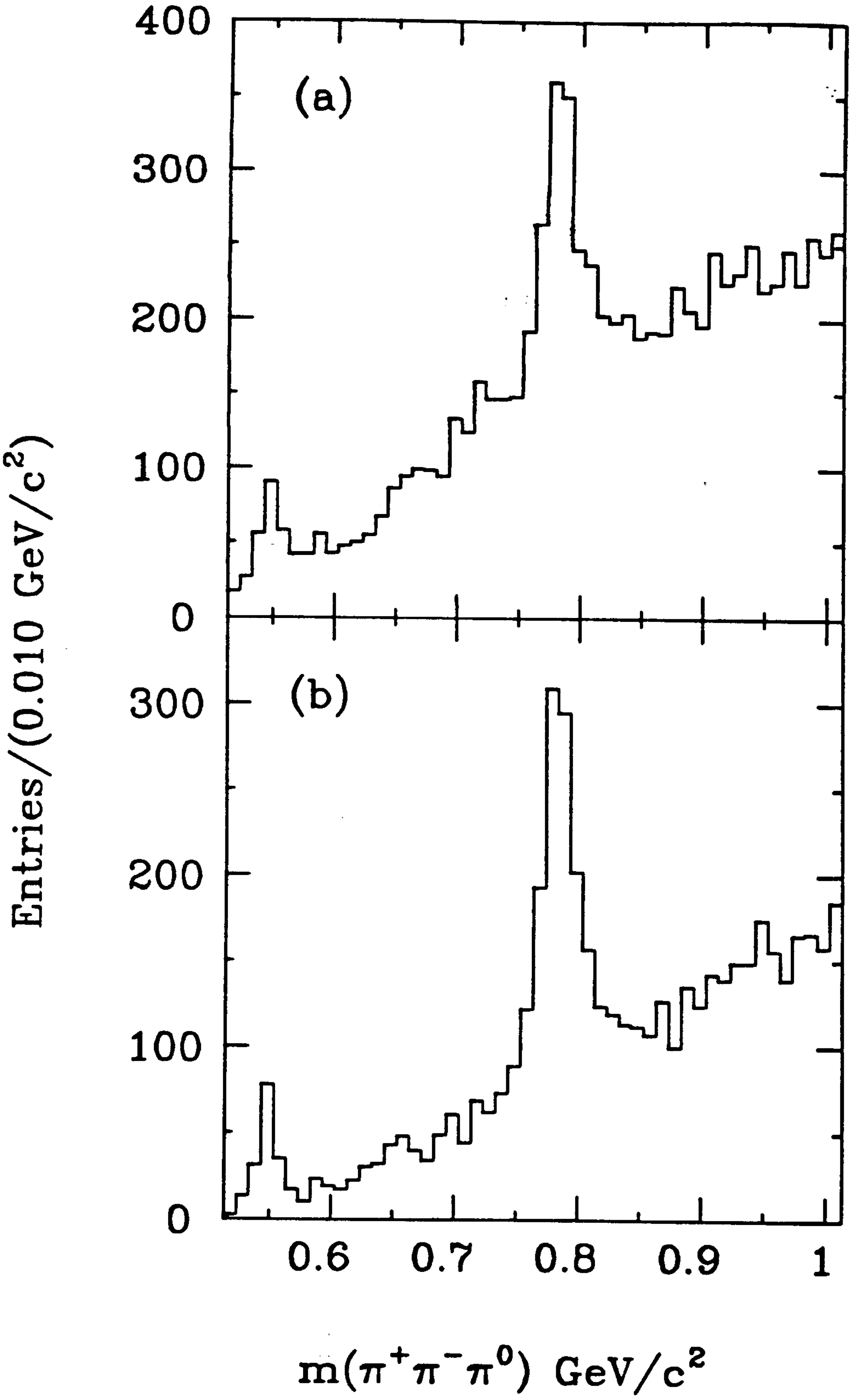
Figure Captions

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

Fig. 2. $K^\pm K^0_S \pi^\mp$ invariant mass distribution (a) from $J/\psi \rightarrow \omega K^\pm K^0_S \pi^\mp$ reaction; (b) $K^+K^-\pi^0$ invariant mass distribution from $J/\psi \rightarrow \omega K^+K^-\pi^0$ reaction; (c) sum of both.

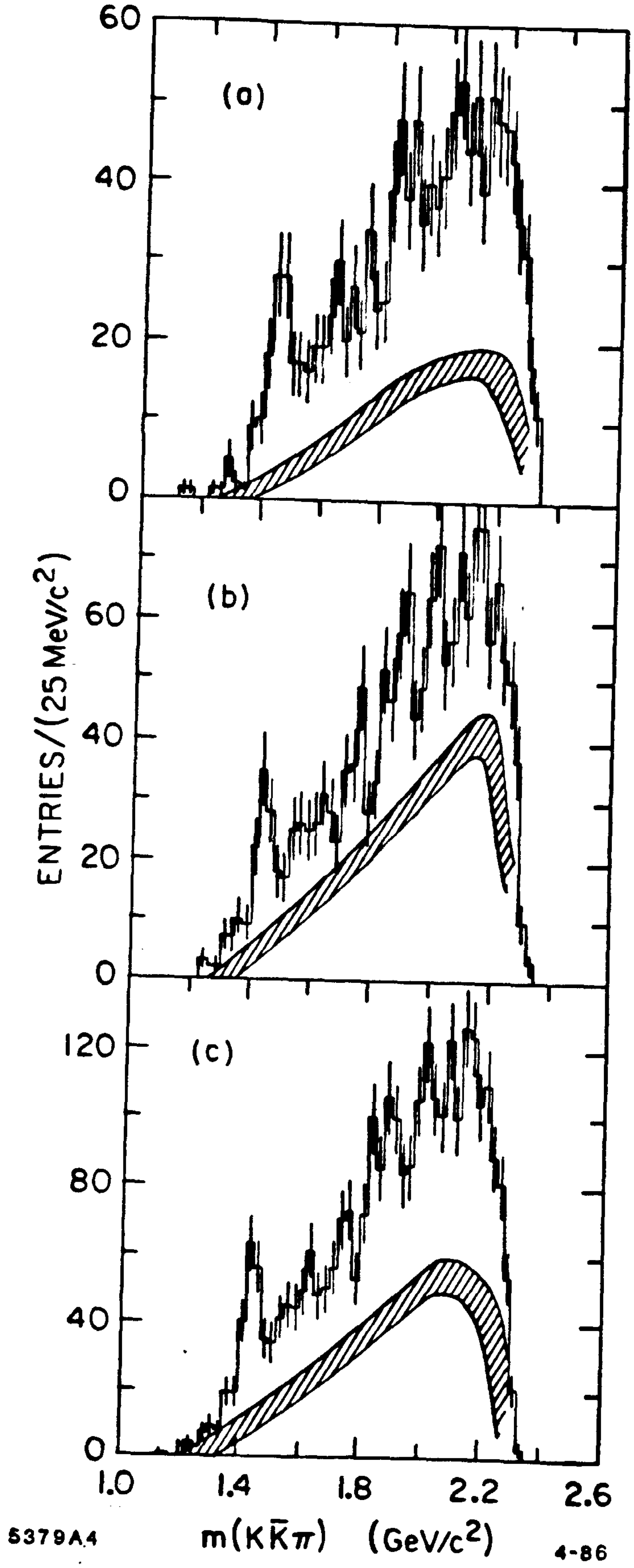
Fig. 3. K^+K^- invariant mass distribution (a) from $J/\psi \rightarrow K^+K^-K^\pm K^0_S \pi^\mp$; (b) $K^0_S K^0_L$ invariant mass distribution from $J/\psi \rightarrow K^0_S K^0_L K^\pm K^0_S \pi^\mp$.

Fig. 4. Combined $K^\pm K^0_S \pi^\mp$ invariant mass distribution from the reactions $J/\psi \rightarrow K^+K^-K^\pm K^0_S \pi^\mp$ and $J/\psi \rightarrow K^0_S K^0_L K^\pm K^0_S \pi^\mp$.



400
300
200
100
0
(a)
300
200
100
0
(b)
0.6
0.7
0.8
0.9
1
Entries/(0.010 GeV/c²)
m(π⁺π⁻π⁰) GeV/c²

Fig. 1



(a)
(b)
(c)
ENTRIES/(25 MeV/c²)
0
20
40
60
0
20
40
60
0
40
80
120
1.0
1.4
1.8
2.2
2.6
m(KK̄π) (GeV/c²)
5379A4
4-86

Fig. 2

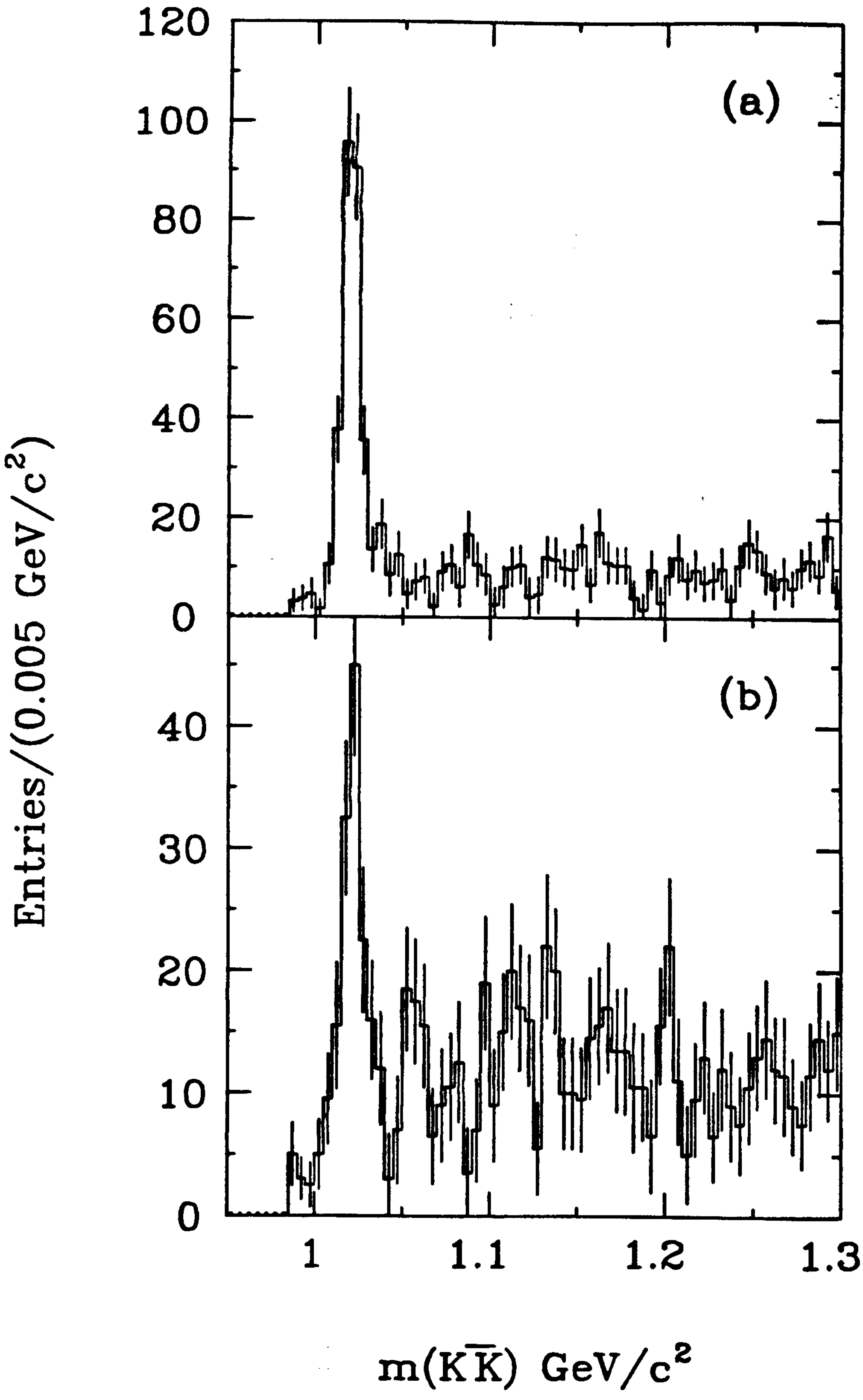

(a)
(b)
120
100
80
60
40
20
0
40
30
20
10
0
1
1.1
1.2
1.3
Entries/(0.005 GeV/c^2)
m(K$\overline{K}$) GeV/c^2

Fig. 3

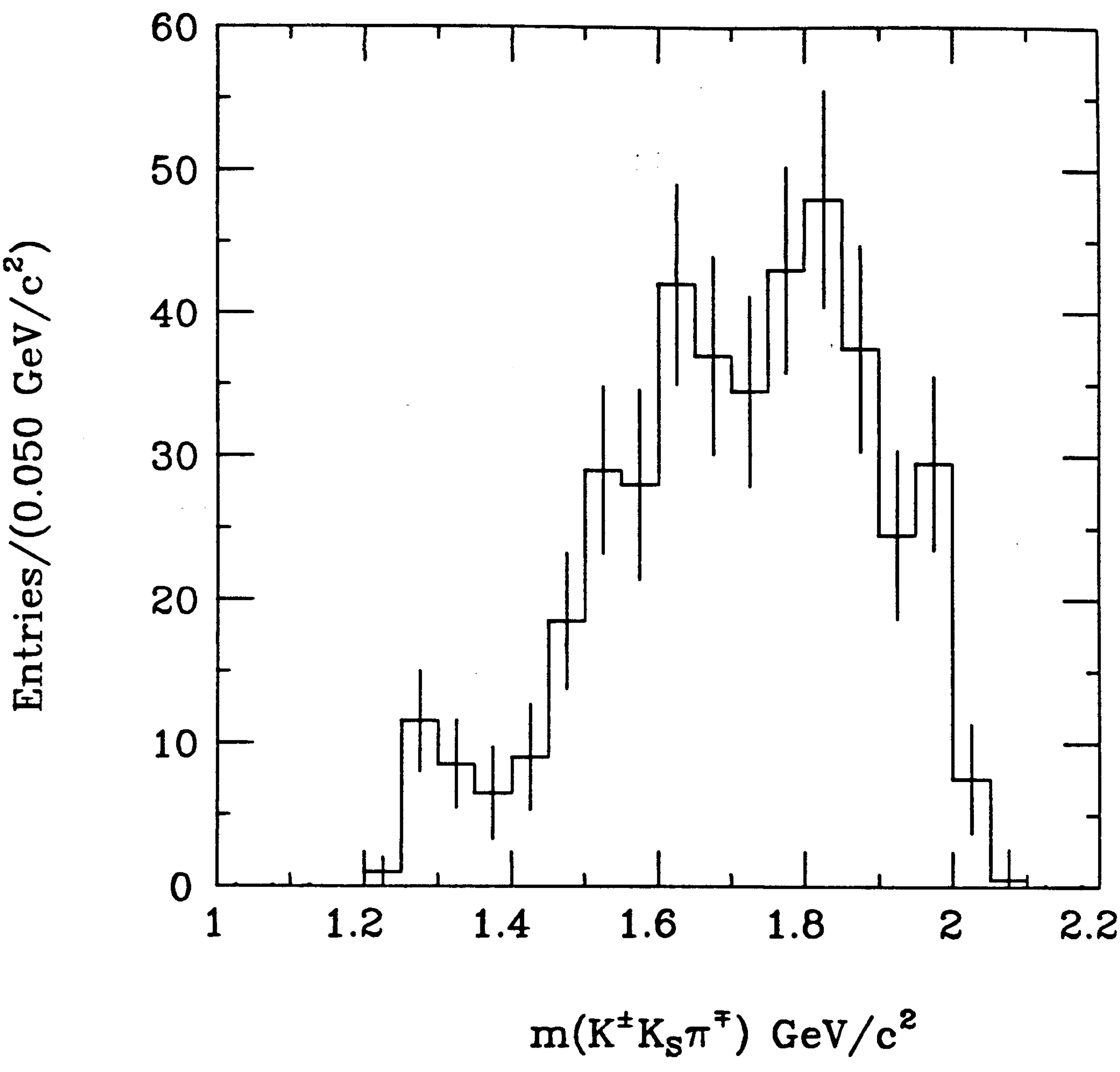

60
50
40
30
20
10
0
1
1.2
1.4
1.6
1.8
2
2.2
Entries/(0.050 GeV/c^2)
m($K^{\pm}K_S\pi^{\mp}$) GeV/c^2

Fig. 4