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Observation of a Narrow $K\bar{K}$ State in J/ψ Radiative Decays*

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Abstract

Evidence is presented for a narrow state, called ξ, in the decay modes $J/\psi \to \gamma\xi, \xi \to K^+K^-$ and $\xi \to K^0_S K^0_S$. In the K^+K^- mode, the ξ has a mass of $2.230 \pm 0.006 \pm 0.014$ GeV/c^2, a width of $\Gamma = 0.026^{+0.020}_{-0.016} \pm 0.017$ GeV/c^2, a product branching ratio of $(4.2^{+1.7}_{-1.4} \pm 0.8) \times 10^{-5}$ and a statistical significance of ~ 4.5 standard deviations. In the $K^0_S K^0_S$ mode, it has a mass of $2.232 \pm 0.007 \pm 0.007$ GeV/c^2, a width of $\Gamma = 0.018^{+0.023}_{-0.015} \pm 0.010$ GeV/c^2, a product branching ratio of $(3.2^{+1.6}_{-1.3} \pm 0.7) \times 10^{-5}$ and a statistical significance of ~ 3.6 standard deviations. Limits on ξ decay to other final states are presented.

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In an ongoing study of 5.8×10^6 J/ψ decays, the MARK III experiment at SPEAR has observed a new narrow state in the radiative decays to K^+K^- and $K^0_SK^0_S$. Limits on the branching ratios of this state into six other final states have also been determined.

The MARK III is a general purpose solenoidal magnetic spectrometer[1] installed at SPEAR. The detector features relevant to the analysis reported in this paper are: a central cylindrical drift chamber consisting of 34 wire planes in a 0.4 T magnetic field which provides a momentum resolution of $\delta p/p = 1.5\% \sqrt{1+p^2}$ where p is in GeV/c; a set of 48 axial time-of-flight (TOF) counters covering 0.80 of 4π sr,which has a resolution of 191 ps; and a 12 rl gas-sampling calorimeter, located within the magnet coil and covering 0.95 of 4π sr, which has a resolution of $\delta E/E = 17\%/\sqrt{E}$ where E is in GeV. The detector performance varied over the separate data sets[2] which comprise the full sample.

The $J/\psi \rightarrow \gamma K^+K^-$ events are selected by requiring two oppositely charged tracks, each having TOF information, and one or more detected photons. In order to distinguish between pions and kaons, the sum of the measured flight times of the two charged tracks is required to be at least 100 ps greater than the mean of the times predicted for kaon and pion hypotheses: $\frac{1}{2}\times(t_{\pi^+}+t_{K^+}+t_{\pi^-}+t_{K^-})$. This requirement discriminates against backgrounds from $J/\psi \rightarrow \pi^+\pi^- + neutrals$ and $J/\psi \rightarrow e^+e^- + neutrals$, while selecting events of the type $J/\psi \rightarrow \mathrm{K}^+\mathrm{K}^- + neutrals$.

Radiative e^+e^- events are suppressed by removing candidates in which each charged track has at least 1 GeV of shower counter energy. Backgrounds from $J/\psi \rightarrow \rho\pi$ and $\mathrm{K}^{*\pm}(892)\mathrm{K}^{\mp}$ are suppressed by kinematically fitting events having more than one photon to the hypotheses $J/\psi \rightarrow \pi^+\pi^-\gamma\gamma$ and $J/\psi \rightarrow \mathrm{K}^+\mathrm{K}^-\gamma\gamma$. Those events whose fitted $\gamma\gamma$ invariant mass is within 50 MeV/c^2 of the π^0 mass, and having a fit χ^2 probability $\mathrm{P}(\chi^2) > 0.02$, are rejected. The remaining events are fit to the hypothesis $J/\psi \rightarrow \gamma\mathrm{K}^+\mathrm{K}^-$ and are required to have $P(\chi^2) > 0.02$. This procedure improves the $\mathrm{K}^+\mathrm{K}^-$ mass resolution by a factor of three at 2.2 GeV/c^2 and provides additional background rejection.

The resulting $\mathrm{K}^+\mathrm{K}^-$ mass distribution is shown in Fig. 1a. The $f'(1525)$ and $\theta(1690)$ states are visible, as is a new narrow structure near 2.2 GeV/c^2, which we call $\xi(2230)$. An important background above 2 GeV/c^2 arises from $J/\psi \rightarrow \mathrm{K}^+\mathrm{K}^-\pi^0$ in which the π^0 decays asymmetrically and one photon is not detected. Such events cannot be distinguished kinematically from $J/\psi \rightarrow \gamma\mathrm{K}^+\mathrm{K}^-$ signal events. The $J/\psi \rightarrow \mathrm{K}^+\mathrm{K}^-\pi^0$ final state, which is dominated by the $\mathrm{K}^{*\pm}\mathrm{K}^{\mp}$ intermediate state, produces a smooth distribution of events throughout the 1.9–2.6 GeV/c^2 mass region. The

Dalitz plot is shown in Fig. 2a, where diagonal bands corresponding to the f' and θ are visible. Two $K^{*\pm}$ bands are evident and $e^+e^-\gamma$ events appear at the boundary.

In order to check that the ξ signal events do not arise from $K^{*\pm}K^{\mp}$ or $e^+e^-\gamma$ backgrounds, events having 0.7 $(GeV/c^2)^2 < M^2_{K\gamma} <$ 0.9 $(GeV/c^2)^2$ or $|cos(\theta_{K\gamma})| >$ 0.99, in the center of mass frame of the charged particle pair, have been removed. Each of these cuts reduces the number of signal events by 12% ; the significance of the signal does not vary appreciably. Since these criteria bias the acceptance against higher spin states, they have not been applied in determining the ξ parameters. As a further check, the ξ is observed in the K^+K^- mass distribution of the first data set[3], Fig. 3a, and it is confirmed in the second data set, Fig. 3b, with comparable statistical significance.

For the combined data set, an unbinned maximum likelihood fit is performed in the 1.9–2.6 GeV/c^2 mass region to extract the mass and width of the ξ. This fit includes a smooth background plus a Breit-Wigner resonance convoluted with a Gaussian resolution function. The mass resolution as determined by Monte Carlo simulation is 10 MeV/c^2. The results of the fit, which is displayed in the inset in Fig. 1a, are

$$m(\xi) = 2.230 \pm 0.006 \pm 0.014 \text{ GeV/c}^2,$$

$$\Gamma(\xi) = 0.026^{+0.020}_{-0.016} \pm 0.017 \text{ GeV/c}^2,$$

where the first error is statistical and the second systematic. The systematic error includes an uncertainty due to the background shape as well as a contribution for unresolved discrepancies in the mass scale.[4] The number of events in the signal, as determined by the fit, is 93. The significance of the signal, determined by comparing the likelihood for the fit described above with that obtained for a fit containing no signal, is found to be 4.5 standard deviations (S.D.). Other choices of background parametrization lead to fits in which the statistical significance of the ξ signal varies from 3.9 to 5.8 S.D. A detection efficiency[5] of 0.38 is determined by Monte Carlo simulation. This efficiency varies smoothly by less than 20% in the 1-3 GeV/c^2 mass region. The resulting product branching ratio is:

$$\text{BR}(J/\psi \rightarrow \gamma\xi) \times \text{BR}(\xi \rightarrow K^+K^-) = (4.2^{+1.7}_{-1.4} \pm 0.8) \times 10^{-5},$$

where the first error is statistical and the second is the systematic error due to the fit procedure, event selection criteria and flux determination. The likelihood function used in determining the branching ratio is displayed in Fig. 4 .

The $K^0_S K^0_S$ final state, examined in the $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$ channel, contains little background since the direct decays $J/\psi \rightarrow K^0_S K^0_S$ and $K^0_S K^0_S \pi^0$ are forbidden by

C parity. The $J/\psi \rightarrow \gamma K_S^0 K_S^0$ events are selected by kinematic fits to the hypothesis $J/\psi \rightarrow \gamma\pi^+\pi^-\pi^+\pi^-$. Pion momenta are calculated at the K_S^0 decay vertex. Events with $P(\chi^2) > 0.01$ and $(m_{\pi_1^+\pi_1^-} - 0.497 \text{ GeV/c}^2)^2 + (m_{\pi_2^+\pi_2^-} - 0.497 \text{ GeV/c}^2)^2 < (0.020 \text{ GeV/c}^2)^2$ are retained. The resulting mass distribution is shown in Fig. 1b ; the Dalitz plot is shown in Fig. 2b. The $K_S^0 K_S^0$ mass distribution again shows evidence for the f' and the θ, as well as the ξ which appears above a broad structure. The non-$K_S^0 K_S^0$ background is estimated by selecting events with $(0.028 \text{ GeV/c}^2)^2 < (m_{\pi_1^+\pi_1^-} - 0.497 \text{ GeV/c}^2)^2 + (m_{\pi_2^+\pi_2^-} - 0.497 \text{ GeV/c}^2)^2 < (0.035 \text{ GeV/c}^2)^2$, a region in the $(m_{\pi_1^+\pi_1^-}, m_{\pi_2^+\pi_2^-})$ plane that has area equal to that of the signal region. This background is shown cross-hatched in Fig. 1b; there are 14 background events in the 1.9–2.6 GeV/c^2 mass region. The K_S^0 mass resolution, 4.8 MeV/c^2, and the observed K_S^0 decay length distribution are well reproduced by the Monte Carlo simulation. A fit is performed to the 1.9–2.6 GeV/c^2 mass region using a smooth background plus a Breit-Wigner resonance convoluted with a Gaussian resolution function with the experimental mass resolution of 10 MeV/c^2. The fit yields the following parameters for the ξ:

$$m(\xi) = 2.232 \pm 0.007 \pm 0.007 \text{ GeV/c}^2,$$

$$\Gamma(\xi) = 0.018^{+0.023}_{-0.015} \pm 0.010 \text{ GeV/c}^2.$$

The number of events in the signal, as determined by the fit, is 23. The statistical significance of this fit is 3.6 S.D. For other background parameterizations the significance varies from 3.0 to 4.7 S.D. The fit is displayed in the inset in Fig. 1b. The detection efficiency[5] is 0.28, yielding the product branching ratio

$$\mathrm{BR}(\mathrm{J}/\psi \to \gamma\xi) \times \mathrm{BR}(\xi \to \mathrm{K^0_S K^0_S}) = (3.2^{+1.6}_{-1.3} \pm 0.7) \times 10^{-5}.$$

The likelihood function used in determining the branching ratio is shown in Fig. 4.

Searches for additional decay modes of the ξ have been performed. No significant signals are seen. The results are summarized in Table 1, where corrections for unobserved decay modes are made assuming that the isospin of the ξ is zero.

In summary, we have observed a new narrow state, the ξ, in two decay modes $\mathrm{K^+K^-}$ and $\mathrm{K^0_S K^0_S}$. The ratio of branching fractions for these modes, $1.3 \pm 0.8 \pm 0.4$, is consistent with the value 2 expected for an isoscalar meson. The allowed quantum numbers for this neutral state are $J^{PC} = (even)^{++}$. Limits have been set on six additional decay modes. Production limits for the ξ in Υ decays have also been set at CESR.[6] Theoretical interpretations of the ξ, based on preliminary versions of the data reported here,[3] include its possible identification as a Higgs boson,[7] a glueball or hybrid state,[8] and a high spin $q\bar{q}$ meson,[9] among others.[10]

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2. The data were acquired in sets of 2.7 $\times 10^6$ and 3.1 $\times 10^6$ produced J/ψ. The TOF resolution on hadrons is 191 ps for the first data set. The resolution is 222 ps for the second data set. The decrease in TOF resolution is due to counter degradation and to an increase in the beam bunch length. These resolutions provide 2σ K/π separation up to 1.2 GeV/c and 1.1 GeV/c respectively. The outermost three planes of the drift chamber were inoperative for the final $2.3\times 10^6 J/\psi$ collected, degrading the momentum resolution for high momentum tracks by 25% for this portion of the second data set. For a detailed description of the J/ψ flux determination see:

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4. The systematic errors in the mass and the width due to uncertainties in the background shape are 7 MeV/c^2 and 14 MeV/c^2 respectively. The discrepancy in the mass between the data sets is inferred from $J/\psi \to p\bar{p}$ and $J/\psi \to \mu^+\mu^-$. The uncertainties in mass and width due to this difference are 7 MeV/c^2 and 3 MeV/c^2, respectively.

5. The detection efficiency for both K^+K^- and $K^0_S K^0_S$ is insensitive to the production and decay parameters of the parent state. Three models were tested: spin 0, and two spin 2 models in which the measured f' helicity amplitude ratios[3] ($x = .65, y = .17$) and the θ helicity ratios ($x = -1.07, y = -1.09$) were used. The relative acceptances differed by less than 3%.

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Table 1

Limits on the product branching ratios of the ξ to other final states. The full data sample is used to obtain the $\mu^+\mu^-$ limit. All other limits are based on a sample of 2.7 $\times 10^6$ produced J/ψ. All limits are set using $\Gamma_\xi = 0.015$ GeV/c^2 except for the $\mu^+\mu^-$, where a width of zero is used. The limits are 90% C.L.

Final State	$B(J/\psi \rightarrow \gamma\xi)\cdot B(\xi \rightarrow X)$
$\xi \rightarrow \mu^+\mu^-$	$< 5 \times 10^{-6}$
$\xi \rightarrow \pi\pi$	$< 2 \times 10^{-5}$
$\xi \rightarrow K^*K$	$< 2.5 \times 10^{-4}$
$\xi \rightarrow K^*\bar{K}^*$	$< 3 \times 10^{-4}$
$\xi \rightarrow \eta\eta$	$< 7 \times 10^{-5}$
$\xi \rightarrow p\bar{p}$	$< 2 \times 10^{-5}$

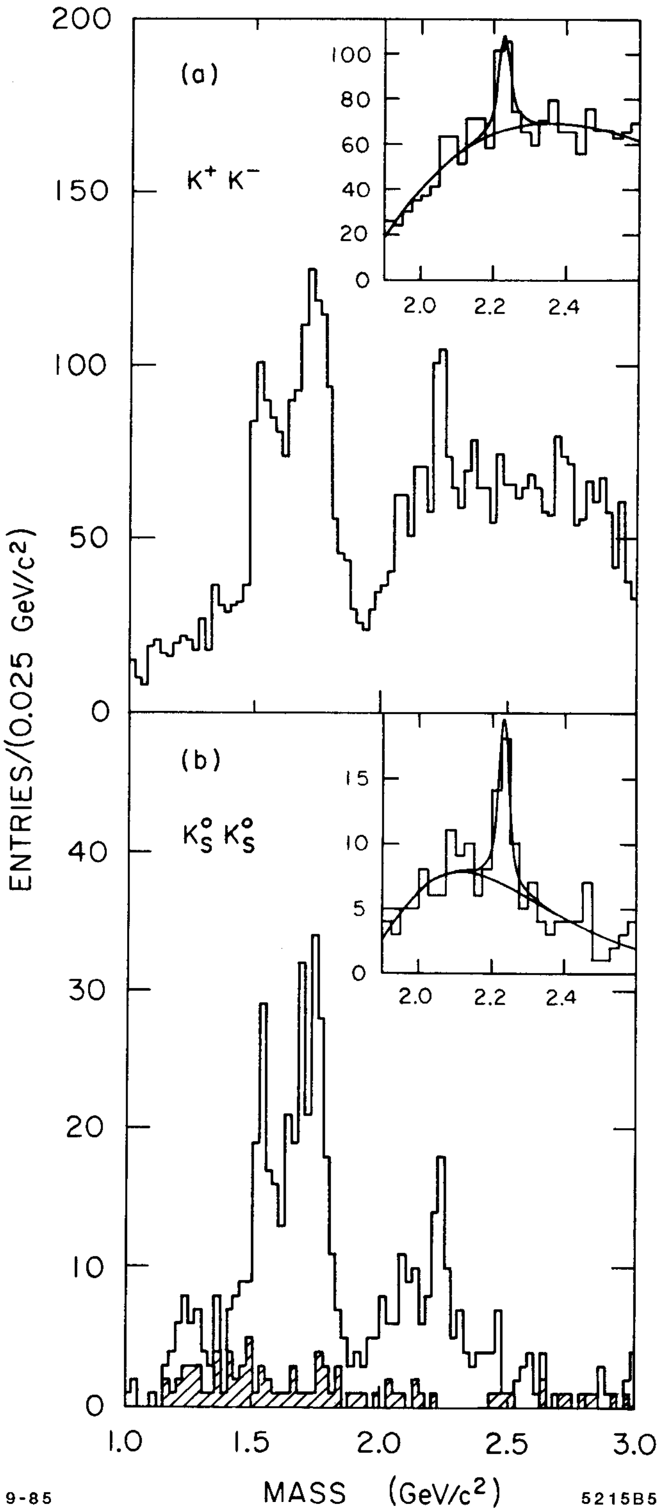
Figure Captions

1. $\mathrm{K\bar{K}}$ invariant mass distributions for the full sample of 5.8 $\times 10^6 J/\psi$ are shown for (a) the $\mathrm{K^+K^-}$ final state and for (b) the $\mathrm{K^0_SK^0_S}$ final state, where the four pion background is shown cross-hatched. Fits to the 1.9–2.6 GeV/c^2 mass region are displayed in the insets.

2. Dalitz plots for (a) the $\mathrm{K^+K^-}$ channel and for (b) the $\mathrm{K^0_SK^0_S}$ channel.

3. $\mathrm{K^+K^-}$ invariant mass distributions for (a) the $2.7\times 10^6 J/\psi$ sample and for (b) the 3.1 $\times 10^6$ sample.

4. The negative log likelihood values obtained from the fitting procedure described in the text are plotted as a function of the branching ratios for the decays $J/\psi \to \gamma\xi, \xi \to \mathrm{K^+K^-}$ (solid curve) and $J/\psi \to \gamma\xi, \xi \to \mathrm{K^0_SK^0_S}$ (dashed curve). The curves are normalized to give negative log likelihoods of zero for the most probable values of the branching ratios. The significances obtained from the negative log likelihood values at zero branching ratios are 3.6 S.D. and 4.5 S.D. for the $\mathrm{K^0_SK^0_S}$ and $\mathrm{K^+K^-}$ channels, respectively.



200
150
100
50
0
40
30
20
10
0
ENTRIES/(0.025 GeV/c²)
(a)
K⁺ K⁻
100
80
60
40
20
0
2.0
2.2
2.4
(b)
K°S K°S
15
10
5
0
2.0
2.2
2.4
1.0
1.5
2.0
2.5
3.0
MASS (GeV/c²)
9-85
5215B5

Fig. 1

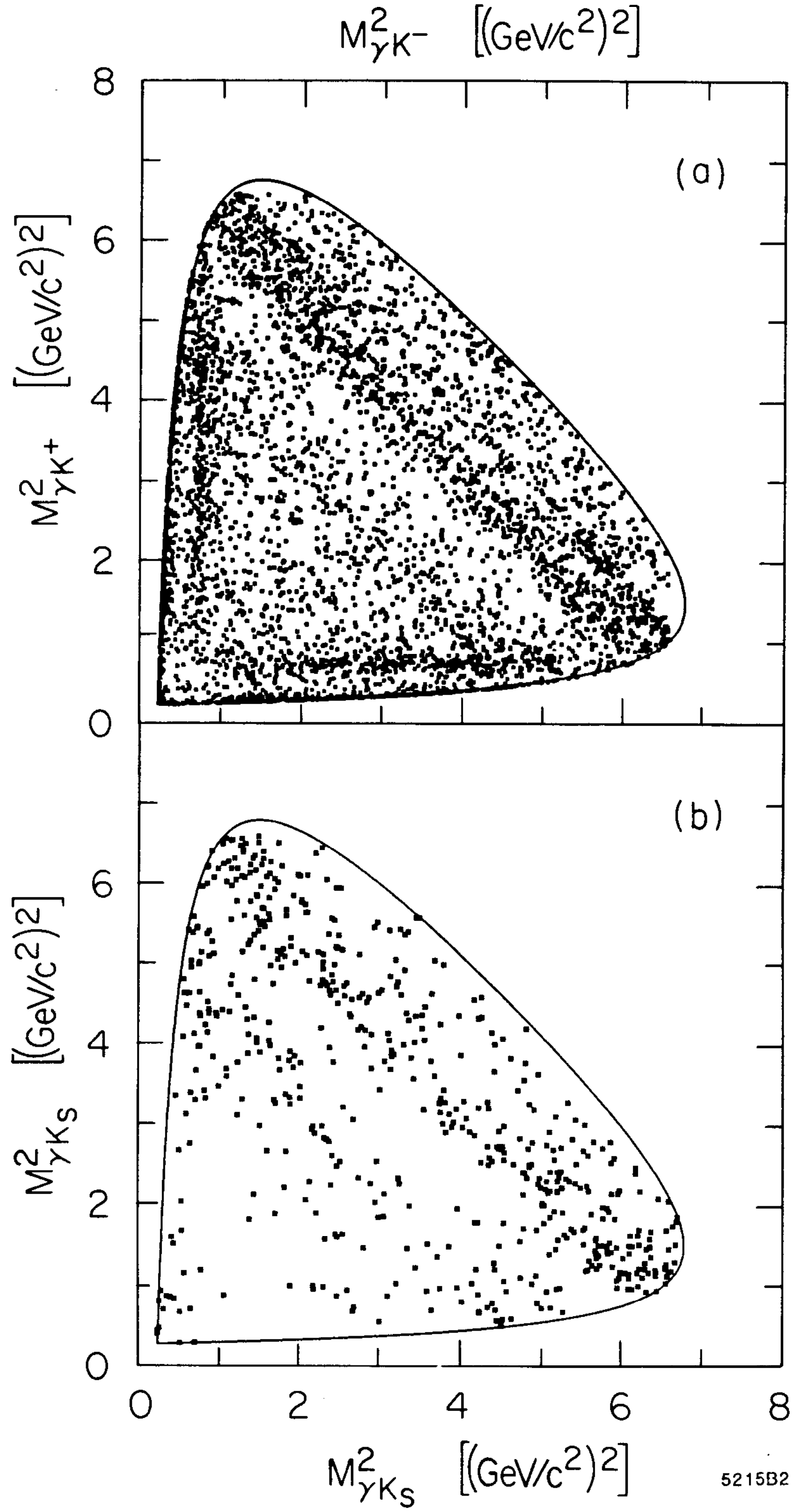
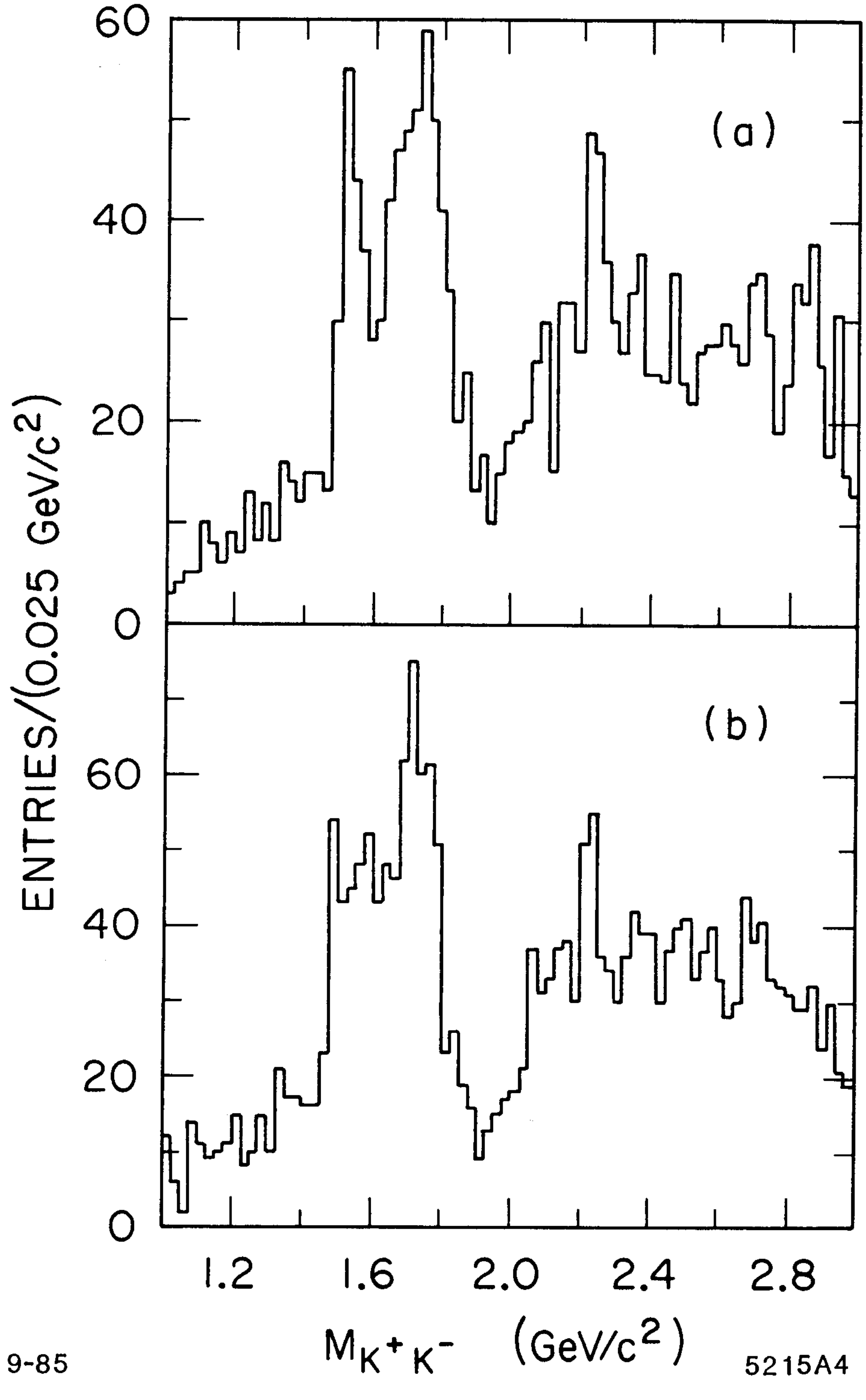
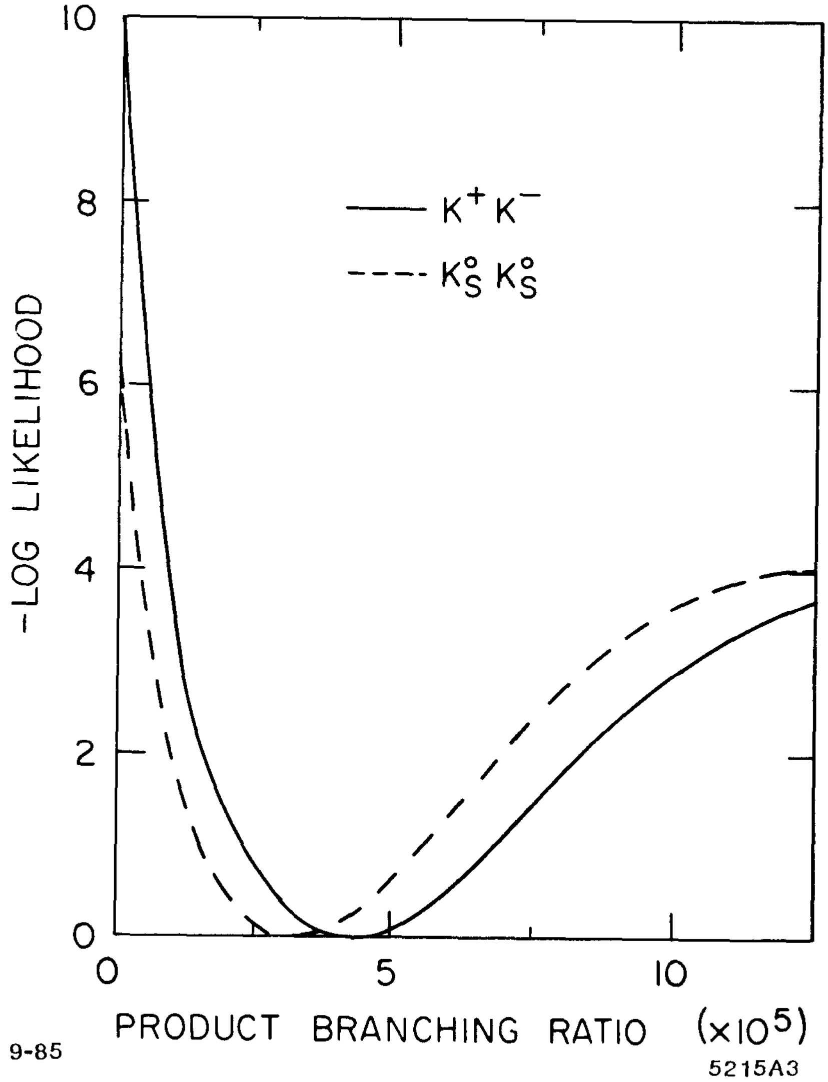

$M^2_{\gamma K^-}$ [(GeV/c^2)^2]
$M^2_{\gamma K^+}$ [(GeV/c^2)^2]
$M^2_{\gamma K_S}$ [(GeV/c^2)^2]
$M^2_{\gamma K_S}$ [(GeV/c^2)^2]
(a)
(b)
0
2
4
6
8
5215B2

Fig. 2



(a)
(b)
ENTRIES/(0.025 GeV/c²)
60
40
20
0
60
40
20
0
1.2
1.6
2.0
2.4
2.8
$M_{K^+K^-}$ (GeV/c²)
9-85
5215A4

Fig. 3



10
8
6
4
2
0
-LOG LIKELIHOOD
— K^+K^-
--- $K_S^o K_S^o$
0
5
10
PRODUCT BRANCHING RATIO (x10^5)
9-85
5215A3

Fig. 4