OBSERVATION OF THE RADIATIVE TRANSITION $\psi \to \gamma E(1420)$*

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ABSTRACT

We have observed a radiative transition from the ψ to a state decaying into $K_S K^\pm \pi^\mp$, with mass $M = 1.44^{+0.01}_{-0.015}$ GeV/c^2 and width $\Gamma = 0.05^{+0.03}_{-0.02}$ GeV/c^2. We tentatively identify this state as the E(1420). Assuming that this state is an isospin singlet, we have determined the branching fraction product $B(\psi \to \gamma E) \times B(E \to K\bar{K}\pi) = (3.6 \pm 1.4) \times 10^{-3}$.

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We have previously reported[1] a measurement of direct photon production in $\psi(3095)$ decay. Within the framework of perturbative QCD, the dominant contribution to direct photon production is expected to come from the process $\psi \rightarrow \gamma gg$,[2] where the final-state hadrons are produced from the fragmentation of the two gluons. If gluonium states (i.e., bound states of two or more gluons) exist, it is likely that some would be produced in such radiative (i.e., direct photon) transitions from the ψ.[2]

A small fraction of the observed direct photon production[1] can be accounted for by the previously established transitions to the exclusive final states $\gamma\pi^0$, $\gamma\eta$, $\gamma\eta'(958)$, and $\gamma f(1270)$.[3] Motivated by the possibility of observing gluonium production, we have looked for additional radiative transitions to exclusive final states. We observe a transition to a state with mass 1.44 GeV/c^2 which, in turn, decays into $K_S K^\pm \pi^\mp$. Although identification cannot be made with certainty, the observed properties of this state are consistent with those of the E(1420) which has been observed in $p\bar{p}$ and πp interactions.[4]

The data were collected with the SLAC-LBL Mark II magnetic detector at the SLAC $e^+ e^-$ storage ring facility SPEAR at energies near the peaks of the $\psi(3095)$ and $\psi'(3684)$ resonances. The detector[5] and the track reconstruction[1,5] have been described in detail elsewhere, and only a brief description is presented here. Charged particle momenta are reconstructed from hits in the sixteen cylindrical drift chamber layers which cover 85% of 4π sr. Charged particle identification over 75% of 4π sr is provided by 48 time-of-flight (TOF) counters. Photons are detected in eight lead-liquid argon (LA) shower counter modules. The detection efficiency for photons with energy greater than 0.4 GeV which fall within the LA solid angle (64% of 4π sr) is greater than 90%.

This analysis is based on a total sample of 360,000 observed $\geq$2-prong hadron events with energies near the peak of the $\psi(3095)$ and 680,000 observed hadron events with energies near the peak of the $\psi'(3684)$. From the ψ' data, 92,000 events corresponding to the decay $\psi' \rightarrow \pi^+\pi^-\psi$, as identified by the missing mass recoiling against the $\pi^+\pi^-$ system, were used in the analysis.[1] The total event sample corresponds to 660,000 ψ decays.[6]

Events with four charged tracks, one of which was identified as a kaon by the TOF system, and a photon were constrained kinematically according to the hypothesis

$$\psi \rightarrow K_S K^{\pm}\pi^{\mp}\gamma \qquad , \qquad K_S \rightarrow \pi^+\pi^- \qquad . \tag{1}$$

The ψ was assumed to be at rest for the direct ψ decays and was given a momentum determined by the recoiling $\pi^+\pi^-$ system for the ψ decays originating from ψ' events. Figure 1(a) shows the $K_S K^{\pm}\pi^{\mp}$ invariant mass distribution for events which satisfy this 5-constraint (5C) fit with $\chi^2 < 15$. A peak is observed near 1.4 GeV/c^2. A possible source of background can arise from the decay

$$\psi \rightarrow K_S K^{\pm}\pi^{\mp}\pi^{o} \qquad . \tag{2}$$

To check this, we analyzed events consistent with (2), that is, events with an identified charged kaon, three charged pions, and a π^o observed to decay into $\gamma\gamma$. No signal was observed near 1.4 GeV/c^2 and we estimate the feeddown to (1) from this final state to be less than two events in the mass region below 1.6 GeV/c^2. We know of no other backgrounds which would simulate the observed signal.

The mass and width of the peak, as determined from a fit to the distribution in Fig. 1(a) with a relativistic Breit-Wigner of adjustable central mass and width, are $M = 1.44^{+0.01}_{-0.015}$ GeV/c^2 and $\Gamma = 0.05^{+0.03}_{-0.02}$ GeV/c^2. The errors include our estimated systematic uncertainties. The mass, width, and decay mode of our observed structure are consistent with those of the E(1420) meson observed in hadronic interactions,[4] and we henceforth use this name to refer to it. The production of this state in a radiative decay of the ψ establishes its charge conjugation parity (C-parity) to be even.

Based on our estimated detection efficiency of 0.060, we calculate for the branching fraction product

$$B(\psi \rightarrow \gamma E) \times B(E \rightarrow K_S K^{\pm} \pi^{\mp}) = (1.2 \pm 0.5) \times 10^{-3} \quad .$$

With the assumption that the E is an isoscalar and the assumption of equal K_S and K_L production, we estimate the decay rates into the $K^+ K^- \pi^0$ and $K^0 \bar{K}^0 \pi^0$ modes and determine the branching fraction product,[7]

$$B(\psi \rightarrow \gamma E) \times B(E \rightarrow K\bar{K}\pi) = (3.6 \pm 1.4) \times 10^{-3} \quad .$$

This number is comparable to branching fractions for decays of the ψ into $\gamma\eta$, $\gamma\eta'$, and γf.[3]

In an attempt to identify possible quasi two-body decay modes of the E, we have studied the decay Dalitz plot distribution. To improve our statistics, we took advantage of the almost total absence of background from (2) with $K_S K^{\pm} \pi^{\mp}$ mass below 1.6 GeV/c^2 and expanded our data sample by including events consistent with (1) in which the photon was not observed.[8] Figure 1(b) shows the $K_S K^{\pm} \pi^{\mp}$ invariant mass distribution for events which satisfy the 2C fit to

$$\psi \to K_S K^{\pm} \pi^{\mp}(\gamma) \qquad , \qquad K_S \to \pi^+ \pi^- \qquad . \qquad (3)$$

The E signal is observed with substantially larger statistics. The increased background at high mass is presumably due to events with a missing π^o rather than a γ.

The Dalitz plot for events in Fig. 1(b) with $K_S K^{\pm} \pi^{\mp}$ invariant mass between 1.375 and 1.500 GeV/c^2 (henceforth referred to as the signal region) is shown in Fig. 2. The two curves represent the kinematic limits corresponding to the mass cuts. The distribution of events is inconsistent with a phase space distribution.[9] In particular, there is a substantial excess of events in the upper right-hand corner of the Dalitz plot which appears to be associated with a low-mass $K\bar{K}$ enhancement, interpretable as the $\delta(980)$. Figure 3 shows the $K_S K^{\pm}$ invariant mass distribution for events in the signal region compared with the expected phase space distribution (dashed curve). The low-mass enhancement is clearly associated with the E as shown by the shaded regions in Fig. 1 where the requirement $M_{K_S K^{\pm}} < 1.05$ GeV/c^2 is imposed.

We have fitted the Dalitz plot distribution with a probability function which included $K^* \bar{K}$ (the inclusion of both this state and the charge conjugate state are implied by this notation), $\delta\pi$, and phase space contributions. These three contributions were added incoherently, but the $K^* \bar{K}$ contribution included components from both the charged and neutral K^* states, which were assumed to interfere constructively where they cross on the Dalitz plot (as demanded by the even C-parity of the E). The $K^* \bar{K}$ contribution alone cannot account for the low-mass $K\bar{K}$ enhancement seen in Fig. 3. The best fit favors predominantly decay into $\delta\pi$, but because of possible systematic uncertainties, it is impossible to rule

out a sizable $K^{*}\overline{K}$ contribution.[10] We have attempted a determination of the spin of the E. However, the limited statistics, coupled with the geometrical biases imposed by the detector, do not permit any firm conclusion.[11]

We have searched for decay modes of the E other than the observed $K_S K^{\pm} \pi^{\mp}$. We observe a signal in $K^+ K^- \pi^0$ which is consistent in magnitude with expectations, but with poorer mass resolution and more background than our $K_S K^{\pm} \pi^{\mp}$ signal. We have looked for the $\eta \pi^+ \pi^-$ decay mode and see no signal, which results in the 90% confidence level upper limit

$$B(E \to \eta \pi \pi)/B(E \to K\overline{K}\pi) < 1.1 \qquad ,$$

where we have included the $\eta \pi^0 \pi^0$ as well as the $\eta \pi^+ \pi^-$ final states. We have also looked for the decay $\psi'(3684) \to \gamma E$ (using our total sample of ψ' data), but observe no signal. We set a 90% confidence level upper limit of

$$B(\psi' \to \gamma E) \times B(E \to K\overline{K}\pi) < 1.2 \times 10^{-4} \qquad .$$

Hadronic experiments which observe E production in the $K\overline{K}\pi$ channel generally observe production of D(1285) with a similar cross section. We see no evidence for the transition $\psi \to \gamma D$ and set a 90% confidence level upper limit of[12]

$$B(\psi \to \gamma D) \times B(D \to K\overline{K}\pi) < 0.7 \times 10^{-3} \qquad .$$

In conclusion, we have observed a radiative transition from the ψ to a state which we tentatively associate with the E(1420) with a branching fraction comparable to other radiative transitions from the ψ. The C-parity of this state is established to be even, but our statistics

are too limited to determine the spin. A determination of the spin-parity of this state would be particularly important for understanding its relation to the established meson resonances. In terms of the standard quark model, the natural assignment would be $J^{PC} = 1^{++}$ (which makes it an isoscalar partner of the A_1 and the D). If, on the other hand, the J^{PC} assignment were 0^{-+}, it would not fit well into the standard quark model, and it would be plausible to interpret this state as a gluonium bound state.[13] Since the radiative transition from the ψ produces an E signal almost totally free of background, one can anticipate that future experiments of this type with improved statistics will unambiguously determine the spin of the E.

REFERENCES

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3. For a review, see D. L. Scharre, Stanford Linear Accelerator Center Report No. SLAC-PUB-2519, 1980 (to be published in the Proceedings of the VI International Conference on Experimental Meson Spectroscopy, Brookhaven National Laboratory, Upton, New York, April 25-26, 1980).

4. Early evidence for the E was seen in $p\bar{p}$ interactions at rest. References can be found in Particle Data Group, Phys. Lett. 75B, 1 (1978). More recently, the E has been observed in πp interactions: C. Dionisi et al., CERN Report No. CERN/EP 80-1, 1980 (submitted for publication).

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6. The ψ trigger efficiency was determined from analysis of the sample of $\psi' \to \psi\pi^+\pi^-$ decays. See Ref. 1 for details.

7. Due to the limited angular acceptance of the detector, the efficiency depends strongly on the photon angular distribution with respect to the beam axis. This distribution is proportional to $1 + \cos^2\theta$ for spin 0 and is not uniquely predicted for spin 1. In our quoted branching ratio determination, we have assumed an isotropic distribution. If the E spin were zero, the branching ratio product should be increased by 19%.

8. The increase in sample size arises principally from the fact that during half of the ψ running time the LA system was not operational.

9. Monte Carlo analysis shows the acceptance to be roughly flat over the entire Dalitz plot. Hence, the observed structure is not the result of variations in the acceptance.

10. In a study of the process $\pi^- p \to En$ at 3.95 GeV/c, Dionisi et al. (see Ref. 4) find the E decay into $K\bar{K}\pi$ dominated by $K^*\bar{K}$ with relatively little $\delta\pi$.

11. Dionisi et al. (see Ref. 4) have measured $J^P = 1^+$ for the E, based on the assumed dominance of the $K^*\bar{K}$ decay mode (see Ref. 10).

12. This apparent inconsistency with results of the hadronic experiments poses no real problem, even if the D and E are assumed to be members of the same SU(3) nonet. A suitable choice of the singlet-octet mixing angle can sufficiently suppress the γD transition to agree with the data [see Ref. 3 and P. Carruthers, Phys. Rev. Lett. 26, 1346 (1971)].

13. Other interpretations such as a radial excitation of one of the members of the $J^P = 0^-$ ground state nonet or an exotic $q\bar{q}q\bar{q}$ state are also possible.

FIGURE CAPTIONS

1. $K_S K^{\pm} \pi^{\mp}$ invariant mass for (a) events which satisfy the 5C fit to

   process (1) and (b) events which satisfy the 2C fit to process (3).

   Shaded regions show combinations with $M_{K_S K^{\pm}} < 1.05$ GeV/c^2.

2. Dalitz plot for events with $1.375 \le M_{K_S K^{\pm} \pi^{\mp}} < 1.500$ GeV/c^2. Solid

   curves represent kinematic limits corresponding to the mass cuts.

   Dashed lines show $K^*(892)$ central mass values.

3. $K_S K^{\pm}$ invariant mass for events in the signal region. Dashed curve

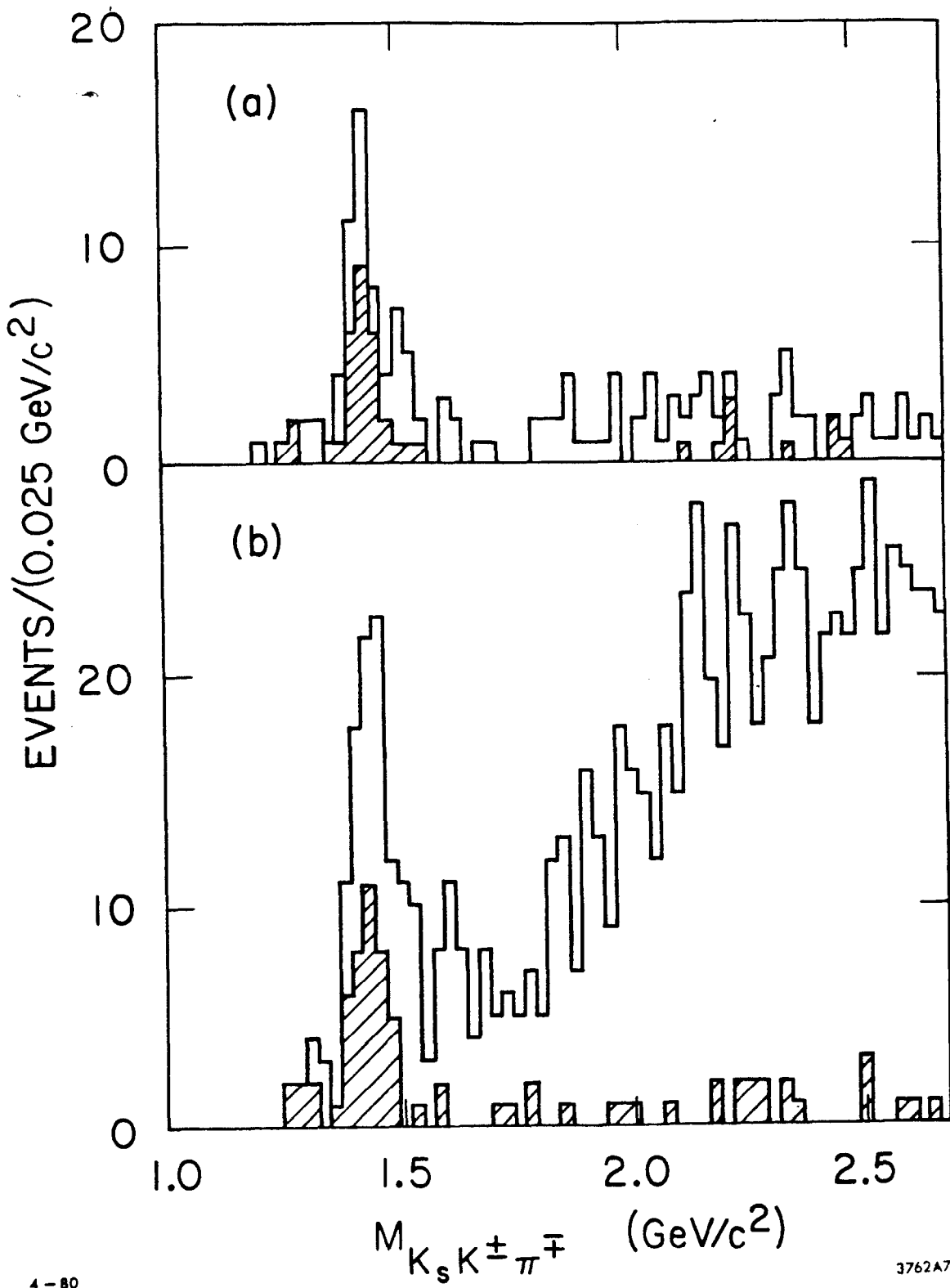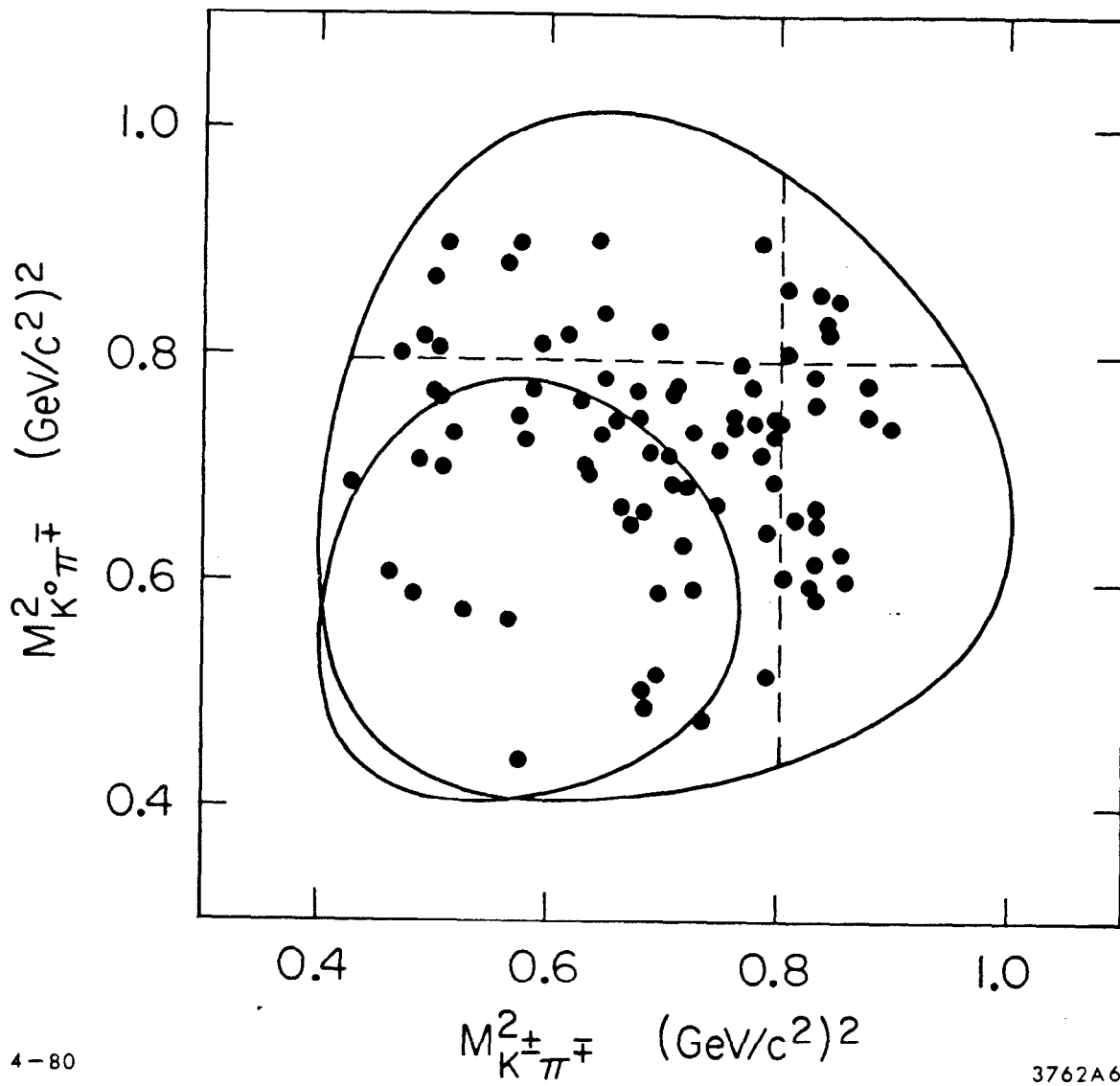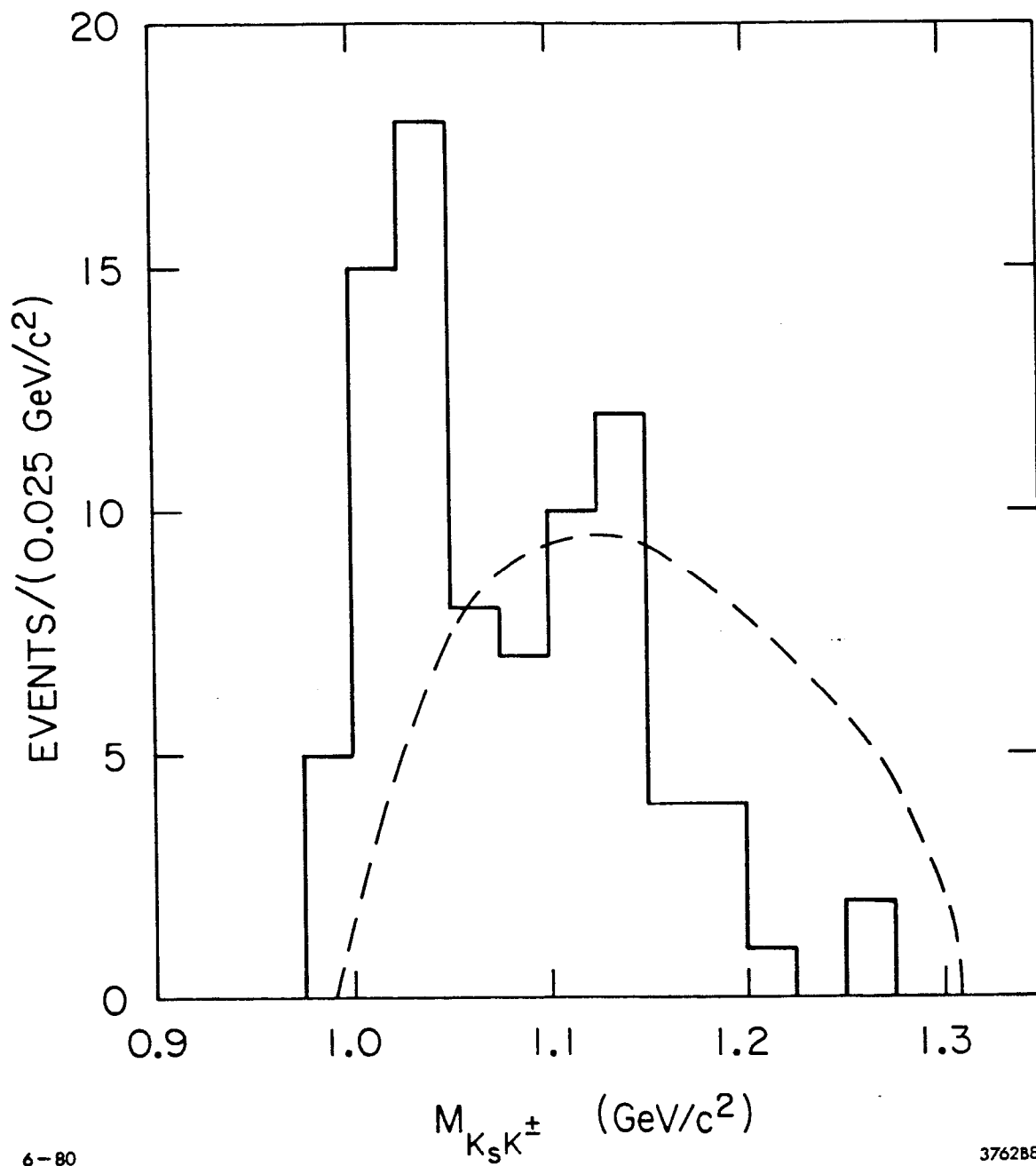   shows expected phase space distribution.

Fig. 1

Fig. 2

Fig. 3

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