J. Rich, W. Smith, and M. Yudis aided in the setup and initial running of the experiment.

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Observation in e^+e^- Annihilation of a Narrow State at 1865 MeV/c^2 Decaying to $K\pi$ and $K\pi\pi\pi$ †

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We present evidence, from a study of multihadronic final states produced in e^+e^- annihilation at center-of-mass energies between 3.90 and 4.60 GeV, for the production of a new neutral state with mass 1865 ± 15 MeV/c^2 and decay width less than 40 MeV/c^2 that decays to $K^\pm\pi^\mp$ and $K^\pm\pi^\mp\pi^\pm\pi^\mp$. The recoil-mass spectrum for this state suggests that it is produced only in association with systems of comparable or larger mass.

We have observed narrow peaks near 1.87 GeV/c^2 in the invariant-mass spectra for neutral combinations of the charged particles $K^\pm\pi^\mp$ ($K\pi$) and $K^\pm\pi^\mp\pi^\pm\pi^\mp$ ($K3\pi$) produced in e^+e^- annihilation. The agreement in mass, width, and recoil-mass spectrum for these peaks strongly suggests they represent different decay modes of the same object. The mass of this state is 1865 ± 15 MeV/c^2 and its decay width (full width at half-maximum) is less than 40 MeV/c^2 (90% confidence level). The state appears to be produced only in association with systems of comparable or higher mass.

Our results are based on studies of multihadronic events recorded by the Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory magnetic detector operating at the colliding-beam facility SPEAR. Descriptions of the detector and event-selection procedures have been published.[1,2]

A new feature in our analysis is the use of time of flight (TOF) information to help identify hadrons. The TOF system includes 48 2.5 cm×20 cm×260 cm Pilot *Y* scintillation counters arranged in a cylindrical array immediately outside the tracking spark chambers at a radius of 1.5 m from the beam axis. Both ends of each counter are viewed by Amperex 56DVP photomultiplier tubes (PM); anode signals from each PM are sent to separate time-to-digital converters (TDC's), analog-to-digital converters, and latches. Pulse-height information is used to correct times given by the TDC's. The collision time is derived from a pickup electrode that senses the passage of the 0.2-nsec-long beam pulses; the period between successive collisions is 780 nsec. Run-to-run calibrations of the TOF system are performed with Bhabha scattering ($e^+e^- \rightarrow e^+e^-$) events. The rms resolution of the TOF system is 0.4 nsec.

Evidence for a new state in the $K\pi$ system was found among 29 000 hadronic events collected at center-of-mass (c.m.) energies between 3.90 and 4.60 GeV. As shown by the top row of Fig. 1, a

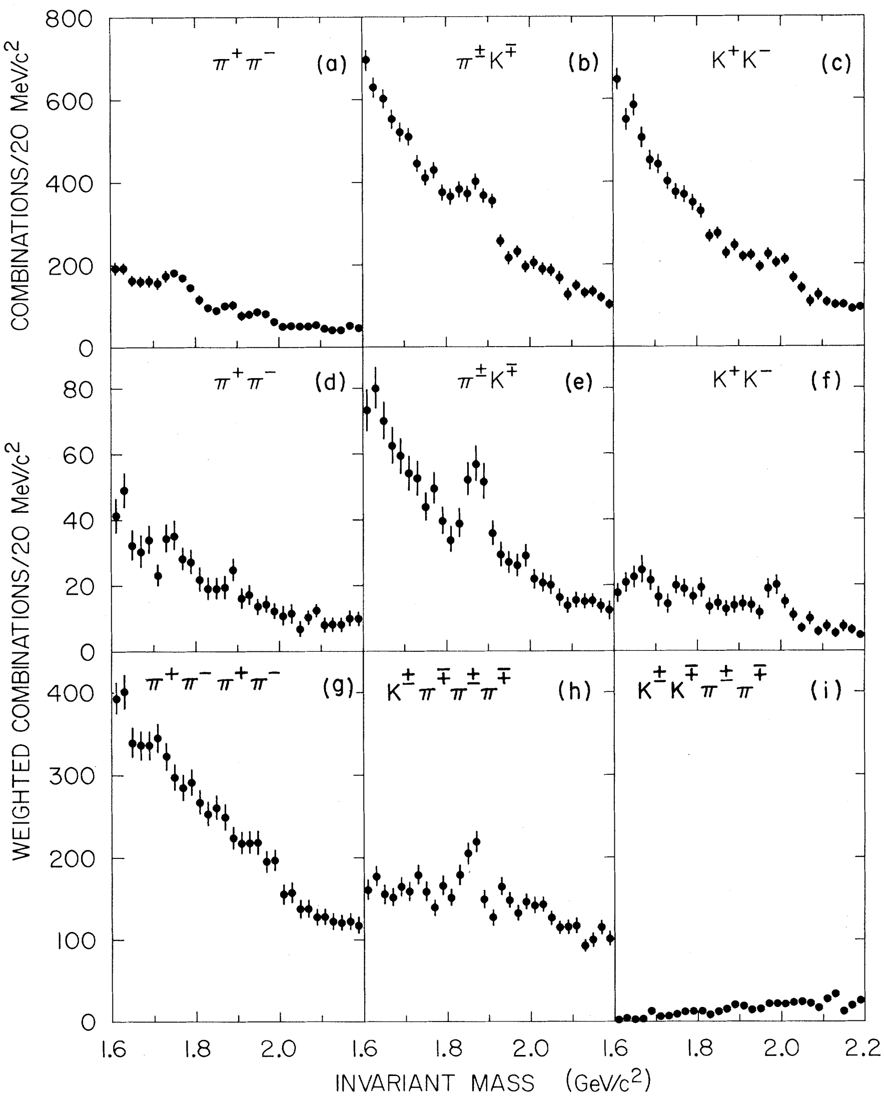

FIG. 1. Invariant-mass spectra for neutral combinations of charged particle. (a) $\pi^+\pi^-$ assigning π mass to all tracks, (b) $K^\mp\pi^\pm$ assigning K and π masses to all tracks, (c) K^+K^- assigning K mass to all tracks, (d) $\pi^+\pi^-$ weighted by $\pi\pi$ TOF probability, (e) $K^\pm\pi^\mp$ weighted by $K\pi$ TOF probability, (f) K^+K^- weighted by KK TOF probability, (g) $\pi^+\pi^-\pi^+\pi^-$ weighted by 4π TOF probability, (h) $K^\pm\pi^\mp\pi^\pm\pi^\mp$ weighted by $K3\pi$ TOF probability, (i) $K^+K^-\pi^+\pi^-$ weighted by $KK\pi\pi$ TOF probability.

significant signal[3] appears when we simply consider invariant-mass spectra for all possible neutral combinations of two charged particles *assuming* both π and K masses for the particles as was done in our previous search for the production of narrow peaks.[4] Through kinematic reflections, the signal appears near 1.74 GeV/c^2 for the $\pi^+\pi^-$ hypothesis [Fig. 1(a)], 1.87 GeV/c^2 in the case of $K^+\pi^-$ or $K^-\pi^+$ [Fig. 1(b)], and 1.98 GeV/c^2 for K^+K^- [Fig. 1(c)].

To establish the correct choice of final-state particles associated with these peaks, we use the TOF information. Because the typical time difference between a π and a K in the $K\pi$ signal is only about 0.5 nsec, we have used the following technique to extract maximal information on particle identity. First, tracks are required to have good timing information from both PM's, consistent with the extrapolated position of the track in the counter. Next, each track is assigned probabilities that it is a π or K; they are determined from the measured momentum and TOF assuming a Gaussian probability distribution with standard deviation 0.4 nsec. Tracks with net (π plus K) probability less than 1% are rejected.[5] Then, the relative π-K probabilities are renormalized so that their sum is unity, and two-particle combinations are weighted by the joint probability that the particles satisfy the particular π or K hypothesis assigned to them. In this way, the total weight assigned to all $\pi\pi$, $K\pi$, and KK combinations equals the number of two-body combinations and no double counting occurs.

Invariant-mass spectra weighted by the above procedure are presented in the second row of Fig. 1. We see that the $K\pi$ hypothesis [Fig. 1(e)] for the peak at the $K\pi$ mass 1.87 GeV/c^2 is clearly preferred over either $\pi^+\pi^-$ [Fig. 1(d)] or K^+K^- [Fig. 1(f)]. The areas under the small peaks remaining in the $\pi^+\pi^-$ and K^+K^- channels are consistent with the entire signal being $K\pi$ and the resulting misidentification of true $K\pi$ events expected for our TOF system. From consideration of possible residual uncertainties in the TOF calibration, we estimate that the confidence level for this signal to arise only from $\pi^+\pi^-$ or K^+K^- is less than 1%. Assuming the entire signal in Figs. 1(d)–1(f) to be in the $K\pi$ channel, we find a total of 110 ± 25 decays of the new state; the significance of the peak in Fig. 1(e) is greater than 5 standard deviations. No signal occurs in the corresponding doubly charged channels.

Evidence for the decay of this state to neutral combinations of a charged K and three charged π's is presented in the third row of Fig. 1. Again, we employ the TOF weighting technique discussed above; the hadron event sample is the same as that used for the $K\pi$ study. Four-body mass combinations are weighted by their joint π-K probabilities. In order to recover tracks when an extra particle is present in the TOF counter, or when they miss a counter, all tracks failing the timing quality criteria are called π.

As can be seen in Fig. 1(h), a clear signal is obtained in the $K3\pi$ system at a mass near 1.86 GeV/c^2. No corresponding signal is evident at this mass or the appropriate kinematically reflected mass for either the $\pi^+\pi^-\pi^+\pi^-$ or $K^+K^-\pi^+\pi^-$ systems. We estimate the number of $K3\pi$ decays in the 1.86-GeV/c^2 peak to be 124 ± 21, an effect of more than 5 standard deviations. Again, there is no signal in the corresponding doubly charged channel.

To determine the masses and widths of the peaks in the $K\pi$ and $K3\pi$ mass spectra, we have fitted the data represented by Fig. 1 with a Gaussian for the peak and linear and quadratic background terms under various conditions of bin size, event-selection criteria, and kinematic cuts. Masses for the $K\pi$ signal center at 1870 MeV/c^2; those for the $K3\pi$ signal center at 1860 MeV/c^2. The spread in central-mass values for the various fits is $\pm$ 5 MeV/c^2. Within the statistical errors of $\pm$ 3 to 4 MeV/c^2, the widths obtained by these fits agree with those expected from experimental resolution alone. From Monte Carlo calculations we expect a rms mass resolution of 25 MeV/c^2 for the $K\pi$ system and 13 MeV/c^2 for the $K3\pi$ system. Systematic errors in momentum measurement are estimated to contribute a $\pm$ 10-MeV/c^2 uncertainty in the absolute mass determination, and can account for the 10-MeV/c^2 mass difference observed between the $K\pi$ and $K3\pi$ systems. Thus, both signals are consistent with being decays of the same state and, from our mass resolution, we deduce a 90%-confidence-level upper limit of 40 MeV/c^2 for the decay width of this state.

In Fig. 2, we show the spectra of masses recoiling against neutral $K\pi$ and $K3\pi$ systems in the signal region. The entries are weighted by the TOF likelihood as discussed above. Background estimates are obtained by plotting smooth curves corresponding to the recoil spectra for $K\pi$ and $K3\pi$ invariant-mass combinations in bands on either side of the signal region. The normalizations of these curves are fixed by the areas of the respective control regions.

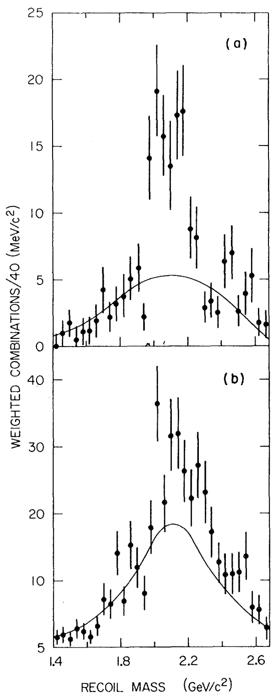

FIG. 2. Recoil-mass spectra for combinations in the $K\pi$ and $K3\pi$ peaks. Smooth curves are estimates of the background obtained from combinations whose invariant masses are on either side of the peak mass region. (a) $K^\pm\pi^\mp$, peak mass region of 1.84 to 1.90 GeV/c^2 and background mass regions of 1.70 to 1.82 GeV/c^2 and 1.92 to 2.04 GeV/c^2. (b) $K^\pm\pi^\mp\pi^\pm\pi^\mp$, peak mass region of 1.84 to 1.88 GeV/c^2 and background mass regions of 1.74 to 1.82 GeV/c^2 and 1.90 to 1.98 GeV/c^2.

From Fig. 2 we find no evidence for the production of recoil systems having masses less than or equal to 1.87 GeV/c^2 in either spectrum. The $K\pi$ data of Fig. 2(a) show a large signal for recoil masses in the range 1.96 to 2.20 GeV/c^2 with contributions up to 2.5 GeV/c^2. The $K3\pi$ recoil-mass spectrum [Fig. 2(b)] has more background, but appears to be consistent with the $K\pi$ spectrum. These spectra suggest that the $K\pi$ and $K3\pi$ systems are produced with thresholds occuring above 3.7-GeV c.m. energy; more detailed interpretations of Fig. 2 are made difficult by the broad range of c.m. energies over which this data sample was collected.

As a further test of this apparent threshold behavior, we have examined 150 000 multihadronic events collected at the ψ mass ($E_{\text{c.m.}} = 3.1$ GeV) and 350 000 events at the ψ' mass ($E_{\text{c.m.}} = 3.7$ GeV) for $K\pi$ and $K3\pi$ signals near 1.87 GeV/c^2. Because of the large cascade decay rate[6] of ψ' to ψ and the large second-order electromagnetic decay rate[7] of the ψ, the resonance events contain 72 000 examples of hadron production by a virtual photon of c.m. energy 3.1 GeV. From fits to invariant-mass spectra (with the signal mass near 1.87 GeV/c^2) we find no $K\pi$ signal larger than 0.3 standard deviations and no $K3\pi$ signal larger than 1.2 standard deviations in this large sample of events. The upper limits (90% confidence level) are 60 events for the $K\pi$ signal and 200 events for the $K3\pi$ signal.

The threshold behavior noted above as well as the narrow widths argue against the interpretation of the structure in Fig. 1 as being a conventional K^*, e.g., the strange counterpart of the $g(1680)$.

Preliminary Monte Carlo calculations to estimate detection efficiencies for two modes have been performed; present systematic uncertainties in these detection efficiencies could be as large as ± 50%. Our estimate of the cross section times branching ratio σB (errors quoted are statistical) averaged over our 3.9–4.6-GeV c.m. energy data is 0.20 ± 0.05 nb for the $K\pi$ mode and 0.67 ± 0.11 nb for the $K3\pi$ mode. These are to be compared with the average total hadronic cross section σ_T in this energy region[8] of 27 ± 3 nb. We have also searched for these signals in the events at higher c.m. energies. In our previous search for the production of narrow peaks[4] at 4.8 GeV, there was a small $K\pi$ signal at 1.87 GeV/c^2 corresponding to a σB of 0.10 ± 0.07 nb. This signal set the upper limit quoted in the paper ($\sigma B < 0.18$ nb for the $K\pi$ system of mass between 1.85 and 2.40 GeV/c^2) but lacked the statistical significance necessary to be considered a convincing peak. The value of σ_T at 4.8 GeV is 18 ± 2 nb.[2] In the c.m. energy range 6.3 to 7.8 GeV the $K\pi$ σB is 0.04 ± 0.03 nb and the average σ_T is 10 ± 2 nb.

In summary, we have observed significant peaks in the invariant-mass spectra of $K^\pm\pi^\mp$ and $K^\pm\pi^\mp\pi^+\pi^-$ that we associate with the decay of a state of mass 1865 ± 15 MeV/c^2 and width less than 40 MeV/c^2. The recoil-mass spectra indicate that this state is produced in association with systems of comparable or larger mass.

We find it significant that the threshold energy for pair-producing this state lies in the small interval between the very narrow ψ' and the broader structures present in e^+e^- annihilation near 4 GeV.[8] In addition, the narrow width of this state, its production in association with systems of even greater mass, and the fact that the decays we observe involve kaons form a pattern of observation that would be expected for a state possessing the proposed new quantum number charm.[9,10]

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[1]J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 233 (1975).

[2]J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 764 (1975).

[3]The only other feature in the $K\pi$ system that we observe in this data sample is the $K^*(890)$.

[4]A. M. Boyarski *et al.*, Phys. Rev. Lett. 35, 196 (1975).

[5]This cut rejects most nucleons (p and $\bar{p}$) as well as tracks accompanied by extra particles in the TOF counter.

[6]G. S. Abrams *et al.*, Phys. Rev. Lett. 34, 1181 (1975).

[7]A. M. Boyarski *et al.*, Phys. Rev. Lett. 34, 1357 (1975).

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[9]S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970); S. L. Glashow, in *Experimental Meson Spectroscopy—1974*, AIP Conference Proceedings No. 21, edited by D. A. Garelick (American Institute of Physics, New York, 1974), p. 387.

[10]Other indications of possible charmed-particle production have come from experiments involving neutrino interactions. See, for example, A. Benvenuti *et al.*, Phys. Rev. Lett. 34, 419 (1975); E. G. Cazzoli *et al.*, Phys. Rev. Lett. 34, 1125 (1975); J. Bleitschau *et al.*, Phys. Lett. 60B, 207 (1976); J. von Krogh *et al.*, Phys. Rev. Lett. 36, 710 (1976); B. C. Barish *et al.*, Phys. Rev. Lett. 36, 939 (1976).

Inverse β Decay of ^{115}In $\rightarrow$ ^{115}Sn*: A New Possibility for Detecting Solar Neutrinos from the Proton-Proton Reaction

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The basis for a low-threshold, high-efficiency, direct-counting detector for solar neutrinos from the p-p fusion reaction is proposed. The inverse β decay of ^{115}In to the 614-keV excited state of ^{115}Sn ($T_{1/2}$=3.26 μsec) provides a unique delayed-coincidence signature and is estimated to yield a solar-neutrino capture rate of ~750 solar neutrino units, ~85 of which is due to $pp+pep$ neutrinos.

The persisting disparity between theoretical expectations of the solar-neutrino flux and the observational results of the Davis, Harmer, and Hoffman experiment[1] based on the inverse β decay of ^{37}Cl→ ^{37}Ar has intensified a re-examination of questions on the current models of the solar interior as well as those concerning basic physical theory.[2] The predictions of low-energy (~0.4 MeV) solar-neutrino flux from the proton-proton reaction is considered to be independent of astronomical uncertainties and requires only the principle that nuclear fusion is the basic energy-producing mechanism in the sun and that neutrinos are stable.[3] Since the ^{37}Cl experiment is dominantly sensitive only to high-energy (5–10 MeV) neutrinos, predictions of which are more critically dependent on models of the solar interior, the necessity of an experiment which clearly establishes the validity of the physical basis, namely, one which is sensitive mostly to the low-energy pp neutrinos, is becoming increasingly urgent. Although many inverse-β-decay candidates have been considered from this point of view over the years, at present only radiochemical experiments on the cases of ^{71}Ga→ ^{71}Ge or ^{7}Li→ ^{7}Be are judged to be even hopeful.[2] The purpose of this Letter is to propose a new candidate: the inverse β decay of ^{115}In to the excited state at 614 keV in ^{115}Sn (^{15}Sn*) having $T_{1/2}$=3.26 μsec and de-exciting by the emission of two γ rays of energies 116 and 498 keV. The present calculations show that this case is sensitive to the low-energy pp neutrinos and has a very large capture rate, $\varphi\sigma$~750 solar neutrino units (SNU's) [1 SNU