0 0 0 0 4 6 0 0 3 3 0

Submitted to Physical Review Letters

LBL-5309 c.1
SLAC-1762
Preprint

OBSERVATION IN e^+e^- ANNIHILATION OF A NARROW STATE AT 1865 MeV/c^2 DECAYING TO $K\pi$ AND $K\pi\pi\pi$

G. Goldhaber, F. M. Pierre, G. S. Abrams, M. S. Alam, A. M. Boyarski, M. Breidenbach, W. C. Carithers, W. Chinowsky, S. C. Cooper, R. G. DeVoe, J. M. Dorfan, G. J. Feldman, C. E. Friedberg, D. Fryberger, G. Hanson, J. Jaros, A. D. Johnson, J. A. Kadyk, R. R. Larsen, D. Lüke, V. Lüth, H. L. Lynch, R. J. Madaras, C. C. Morehouse, H. K. Nguyen, J. M. Paterson, M. L. Perl, I. Peruzzi, M. Piccolo, T. P. Pun, P. Rapidis, B. Richter, B. Sadoulet, R. H. Schindler, R. F. Schwitters, J. Siegrist, W. Tanenbaum, G. H. Trilling, F. Vannucci, J. S. Whitaker, and J. E. Wiss

June 11, 1976

Prepared for the U. S. Energy Research and Development Administration under Contract W-7405-ENG-48

For Reference

Not to be taken from this room

LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY

LBL-5309 c.1

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

Submitted to Physical Review Letters

LBL-5309
SLAC-1762

OBSERVATION IN e^+e^- ANNIHILATION OF A NARROW STATE AT 1865 MeV/c^2 DECAYING TO $K\pi$ and $K\pi\pi\pi$*

G. Goldhaber,[Φ] F. M. Pierre,[†] G. S. Abrams, M. S. Alam, A. M. Boyarski, M. Breidenbach, W. C. Carithers, W. Chinowsky, S. C. Cooper, R. G. DeVoe, J. M. Dorfan, G. J. Feldman, C. E. Friedberg, D. Fryberger, G. Hanson, J. Jaros, A. D. Johnson, J. A. Kadyk, R. R. Larsen, D. Lüke,[††] V. Lüth, H. L. Lynch, R. J. Madaras, C. C. Morehouse,[‡] H. K. Nguyen,[ΦΦ] J. M. Paterson, M. L. Perl, I. Peruzzi,[‡‡] M. Piccolo,[‡‡] T. P. Pun, P. Rapidis, B. Richter, B. Sadoulet, R. H. Schindler, R. F. Schwitters, J. Siegrist, W. Tanenbaum, G. H. Trilling, F. Vannucci,[†††] J. S. Whitaker, J. E. Wiss.

Lawrence Berkeley Laboratory and Department of Physics
University of California, Berkeley, California 94720

and

Stanford Linear Accelerator Center
Stanford University, Stanford, California 94305

ABSTRACT

We present evidence, from a study of multihadronic final states produced in e^+e^- annihilation at center-of-mass energies between 3.90 GeV and 4.60 GeV, for the production of a new neutral state with mass 1865 $\pm$ 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.

---

*Work supported by the Energy Research and Development Administration

Φ Miller Institute for Basic Research in Science, Berkeley, Ca. (1975-1976)

† Permanent address Centre d'Etudes Nucleaires de Saclay, France

†† Fellow of Deutsche Forschungsgemeinschaft

‡ Permanent address Varian Associates, Palo Alto, California

‡‡ Permanent address Laboratori Nazionali, Frascati, Rome, Italy

††† Permanent address Institut de Physique Nucleaire, Orsay, France

ΦΦ Permanent address LPNHE, Universite Paris VI, Paris, France

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 $\pm$ 15 MeV/c^2 and its decay width (FWHM) 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 SLAC/LBL magnetic detector operating at the Stanford Linear Accelerator Center 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 x 20 cm x 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 56 DVP photomultiplier tubes (PM); anode signals from each PM are sent to separate TDC's, ADC's, 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 ns long beam pulses; the period between successive collisions is 780 ns. 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 ns.

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 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. 1a), 1.87 GeV/c^2 in the case of $K^+\pi^-$ or $K^-\pi^+$ (Fig. 1b), and 1.98 GeV/c^2 for K^+K^- (Fig. 1c).

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 ns, 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 ns. 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. 1e) for the peak at the $K\pi$ mass 1.87 GeV/c^2 is clearly preferred over either $\pi^+\pi^-$ (Fig. 1d) or K^+K^- (Fig. 1f). 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 Fig.1d,e, and 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. 1e 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. 1h, 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 uncertainity 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.

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. 2a show a large signal for recoil masses in the range 1.96 GeV/c^2 to 2.20 GeV/c^2 with contributions up to 2.5 GeV/c^2. The $K3\pi$ recoil mass spectrum (Fig. 2b) 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 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_{cm}= 3.1 GeV) and 350,000 events at the ψ' mass (E_{cm}= 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% CL) 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 the 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 σ.BR (errors quoted are statistical) averaged over our 3.9 GeV - 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 σ.BR of 0.10 ± 0.07 nb. This signal set the upper limit quoted in the paper (σ.BR < 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 GeV to 7.8 GeV the $K\pi$ σ.BR 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]

References and Footnotes

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).
8. J. Siegrist et al., Phys. Rev. Lett. 36, 700 (1976).
9. S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D2, 1285 (1970). S. L. Glashow, Experimental Meson Spectroscopy, A.I.P. Conf. Proc. No. 21, Particles and Fields Subseries No. 8, p. 387 (1974).

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. Blietschau 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).

Figure Captions

1. Invariant mass spectra for neutral combinations of charged particles. (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 KK 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.

2. Recoil mass spectra for combinations in the $K\pi$ and $K3\pi$ peaks. Smooth curves, obtained from combinations whose invariant masses are on either side of the peak mass region, are estimates of the background. (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.

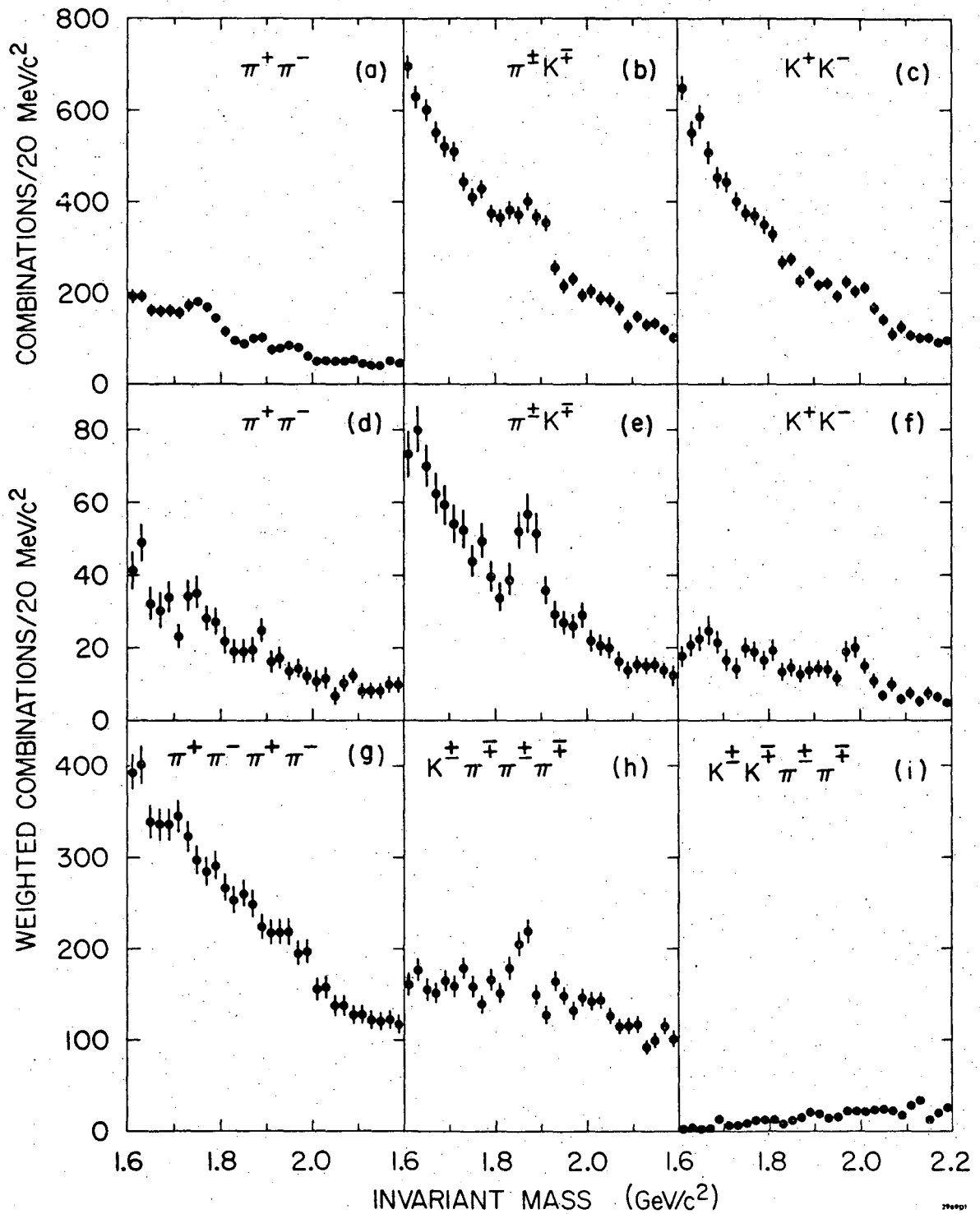
COMBINATIONS/20 MeV/c²
WEIGHTED COMBINATIONS/20 MeV/c²
π⁺π⁻ (a)
π±K∓ (b)
K⁺K⁻ (c)
π⁺π⁻ (d)
π±K∓ (e)
K⁺K⁻ (f)
π⁺π⁻π⁺π⁻ (g)
K±π∓π±π∓ (h)
K±K∓π±π∓ (i)
INVARIANT MASS (GeV/c²)

Fig. 1

0 0 0 0 4 6 0 0 3 4 1

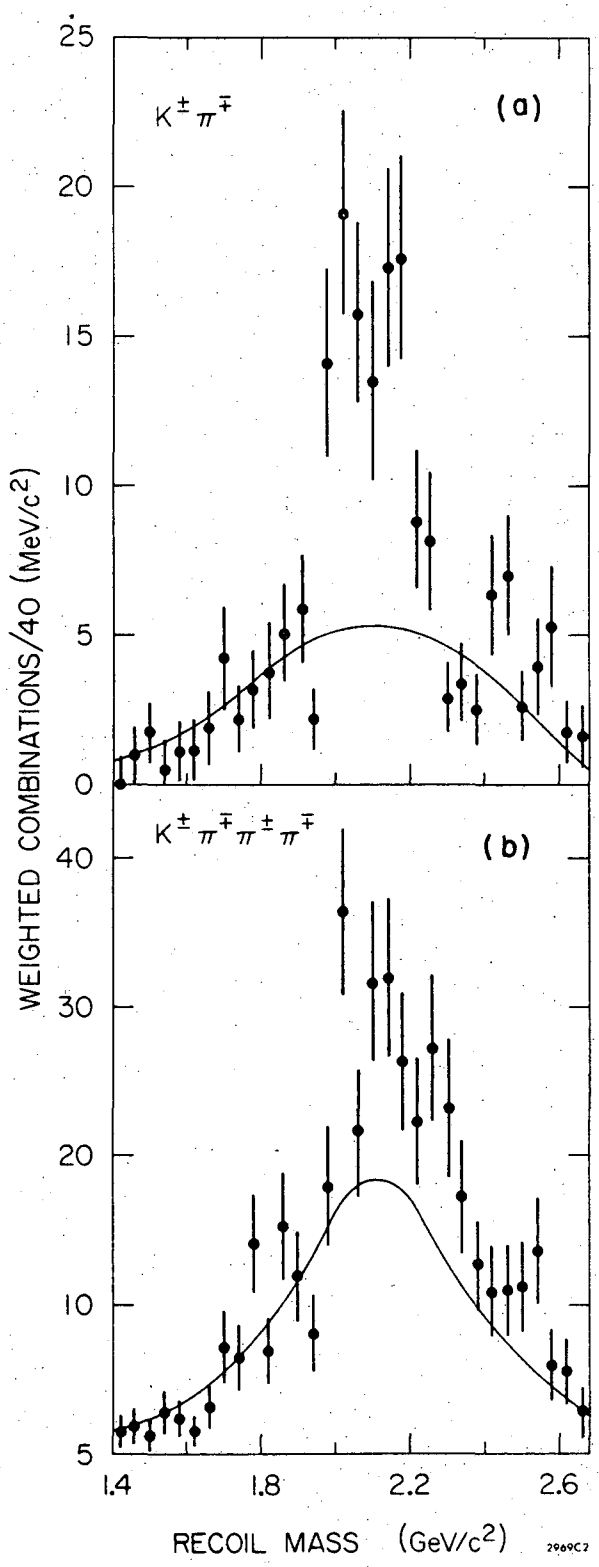

Fig. 2

0 0 1 0 4 6 0 0 3 4 2

LEGAL NOTICE

This report was prepared as an account of work sponsored by the United States Government. Neither the United States nor the United States Energy Research and Development Administration, nor any of their employees, nor any of their contractors, subcontractors, or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness or usefulness of any information, apparatus, product or process disclosed, or represents that its use would not infringe privately owned rights.

TECHNICAL INFORMATION DIVISION
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720