Observation of a Narrow Charged State at 1876 MeV/c^2 Decaying to an Exotic Combination of $K\pi\pi$†

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We report evidence for the production of a new narrow charged state in e^+e^- annihilation at a center-of-mass energy of 4.03 GeV. This state, which has a mass of 1876 ± 15 MeV/c^2, is observed in the exotic channel $K^\mp\pi^\pm\pi^\pm$, but not in the nonexotic channel $K^\mp\pi^+\pi^-$. It is produced primarily in association with a system of mass 2.01 ± 0.02 GeV/c^2. These characteristics are just those expected of a charged charmed meson.

In a previous Letter we reported the observation in e^+e^- annihilation of a new narrow neutral state of mass 1865 MeV/c^2 which decays into $K^\mp\pi^\pm$ and $K^\mp\pi^\pm\pi^+\pi^-$.[1] This state was observed in 29 000 hadronic events in the center-of-mass energy ($E_{\text{c.m.}}$) range from 3.9 to 4.6 GeV. To study the properties of this state and to search for other new states, we subsequently obtained 19 000 additional events at a fixed $E_{\text{c.m.}}$ of 4.03 GeV. In these new data, there is clear evidence for a new narrow charged state of mass 1876 ± 15 MeV/c^2 which decays into the exotic channel $K^\mp\pi^\pm\pi^\pm$, but not into the normal K^* channel $K^\mp\pi^+\pi^-$. This behavior is just that expected for the weak decay of a charged charmed meson.[2]

The data were obtained with the Stanford Linear Accelerator Center–Lawrence Berkeley Laboratory magnetic detector at SPEAR.[3] $E_{\text{c.m.}}$ was chosen to be 4.03 GeV because the total hadronic cross section appears to peak at this energy after a very sharp rise, indicating the possible existence of a resonance or a threshold for new channels.[4] The analytical techniques are substantially the same as those used in Ref. 1. Briefly, each particle in a multihadronic event is assigned a weight proportional to the probability that it is a π or K. These weights are determined from the measured momentum and time of flight over a 1.5- to 2.0-m flight path using a Gaussian time distribution with a 0.4-nsec standard deviation. The π-K weights are normalized so that for each track their sum is unity. All possible combinations of tracks and particle hypotheses are made with each combination weighted by the joint probability that the tracks satisfy the particular particle hypotheses assigned to them.

Invariant mass spectra for $K\pi\pi$ mass combinations weighted in the manner explained above are presented in Fig. 1. In Fig. 1(a) there is a peak near 1.87 GeV/c^2 in the exotic channel $K^\mp\pi^\pm\pi^\pm$ with a statistical significance of greater than 5

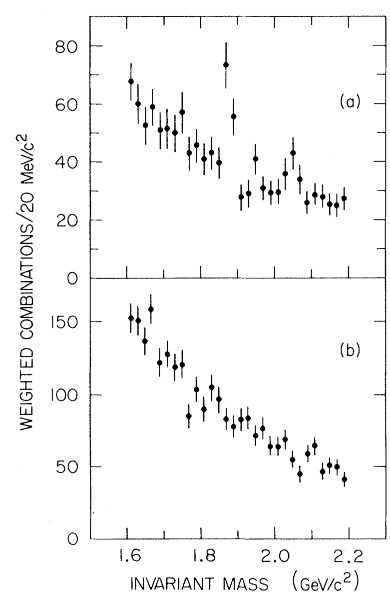

FIG. 1. Invariant mass spectra for $K\pi\pi$ combinations from 19 000 multihadronic events at $E_{\text{c.m.}} = 4.03$ GeV. (a) $K^\mp\pi^\pm\pi^\pm$, (b) $K^\mp\pi^+\pi^-$.

standard deviations.[5] No structure is seen in the corresponding nonexotic channel, $K^{\mp}\pi^{+}\pi^{-}$ [Fig. 1(b)], nor in any other combination of three charged particles. There is also no structure observed in such doubly charged modes as $K^{\mp}\pi^{\mp}$, $K^{\mp}\pi^{\mp}\pi^{+}\pi^{-}$, or $K^{\mp}\pi^{\pm}\pi^{\pm}\pi^{\pm}$.

We have plotted the data shown in Fig. 1 in finer bins and have fitted them by Gaussian peaks with backgrounds given by quadratic polynomials. The mass of the $K^{\mp}\pi^{\pm}\pi^{\pm}$ peak is 1876 ± 15 MeV/c^2 where the quoted uncertainty includes both statistical and systematic contributions. The observed width of the $K^{\mp}\pi^{\pm}\pi^{\pm}$ peak is consistent with what is expected from experimental resolution alone. At the 90% confidence level, the decay (full) width of this state is less than 40 MeV/c^2.

Figure 2 shows the mass spectrum recoiling against the $K^{\mp}\pi^{\pm}\pi^{\pm}$ peak in Fig. 1(a). The background is derived from the mass spectrum recoiling against the same mass region in the $K^{\mp}\pi^{+}\pi^{-}$ mode. The $K^{\mp}\pi^{\pm}\pi^{\pm}$ peak appears to recoil primarily against a narrow system of mass 2.01 ± 0.02 GeV/c^2, whose observed width is consistent with experimental resolution.

We estimate the product between the cross section and the branching ratio to be 0.3 nb at $E_{\text{c.m.}} = 4.03$ GeV, with a systematic uncertainty which could be as large as $\pm 50\%$. This value is about half as large as that for the $K^{\mp}\pi^{\pm}$ mode of the neutral state at this $E_{\text{c.m.}}$. The total hadronic cross section at 4.03 GeV is 33 ± 5 nb.[4]

In summary, we have observed a significant peak in the $K^{\mp}\pi^{\pm}\pi^{\pm}$ mass spectrum that we associate with the decay of a new state of mass 1876 ± 15 MeV/c^2 and width less than 40 MeV/c^2. At $E_{\text{c.m.}} = 4.03$ GeV, the state is produced primarily in association with a system of mass 2.01 ± 0.02 GeV/c^2. If this $K\pi\pi$ peak were to arise from the strong decay of a strange-meson resonance, the isospin of that resonance would have to be $\frac{3}{2}$ or $\frac{5}{2}$. One might then expect to observe doubly charged decay modes, but no evidence for such modes has been observed. Furthermore, no strange-meson resonance of isospin other than $\frac{1}{2}$ has ever been observed. On the other hand, the charm theory predicts that the necessarily weak decay of the lowest lying charged meson with unit charm and zero strangeness will strongly prefer exotic over nonexotic decay modes. Thus, the similarity in mass of this charged state and the previously reported neutral state, their narrow widths, their recoil mass spectra, their decays to strange channels, and the decay of the charged state to an exotic channel but not to the corresponding normal channels all strongly suggest that they are the predicted (D^+, D^0) isodoublet of charmed mesons.[6]

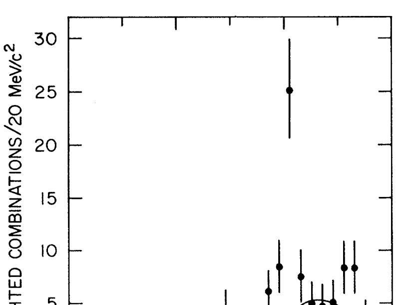

FIG. 2. Recoil mass spectra for the $K^{\mp}\pi^{\pm}\pi^{\pm}$ peak mass region, 1.86 to 1.90 GeV/c^2. The smooth curve is an estimate of the background obtained from the same region in the $K^{\mp}\pi^{+}\pi^{-}$ spectrum.

These data were obtained in a new mode of SPEAR running in which beams were injected directly into the operating configuration. Substantial gains in both peak and time-averaged luminosities were achieved using this method. We would particularly like to thank the SPEAR operating staff for their enthusiastic efforts.

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[1]G. Goldhaber *et al.*, Phys. Rev. Lett. 37, 255 (1976).

[2]In the charm model the Cabibbo favored decays involve a c quark going to an s quark, giving $\Delta C = \Delta S$. Thus the D^+ with $C = +1$, decays to a system with $S = -1$ and positive charge, which is exotic.

[3]J.-E. Augustin *et al.*, Phys. Rev. Lett. 34, 233, 764 (1975).

[4]J. Siegrist *et al.*, Phys. Rev. Lett. 36, 700 (1976).

[5]The 2.7-standard-deviation peak near 2.05 GeV/c^2

in the $K^{\mp}\pi^{\pm}\pi^{\pm}$ mass spectrum does not contain 1.865-GeV/c^2 $K^{\mp}\pi^{\pm}$ combinations and its recoil mass spectrum does not contain any clear structure. We do not consider it significant.

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Dimuon Production on Nuclear Targets

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We have measured the production of $\rho+\omega$ and J vector mesons, through their dimuon decay modes, by high-energy neutrons on nuclear targets at Fermilab. We determined the A dependence to be $A^{0.62\pm0.03}$ for $\rho+\omega$, $A^{0.93\pm0.04}$ for J, and $A^{0.85\pm0.05}$ for the continuum of dimuons between the $\rho+\omega$ and J masses.

Several recent experiments at Fermilab, the CERN intersecting storage rings, and Serpukhov have extended the study of dilepton production in high-energy hadron-hadron collisions.[1-3] These experiments showed the presence of two strong resonances above a continuum, one due to the $\rho+\omega$ and the other due to the J.[4] Between these two masses the cross section decreases monotonically as the mass increases. Because of the relevance of dilepton production to several open experimental questions, such as the nature of J production in hadronic collisions, the contribution of dileptons to single-lepton production, and the possible existence of the Drell-Yan process[5] for dilepton production, it is important to measure the features of dilepton production in greater detail than in previous experiments.

The primary purpose of this experiment was to measure the A dependence of the total inclusive cross section for $\rho+\omega$, J, and the continuum between those resonances in neutron-nucleus collisions. The second objective, which is discussed in a subsequent paper, was to determine the $p_\perp$ and X_f dependence $[X_f=(p/p_{\max})_{nA\ \mathrm{c.m.}}]$ of the invariant cross section for this process. By making measurements on four elements it was possible to extrapolate the yields to the cross section for production on a single nucleon. The details of the beam and the apparatus were reported in a previous publication.[1] The neutron beam was produced by the interaction of 400-GeV protons, rather than 300-GeV protons as in our previously published work.

We detected muon pairs only after they emerged from an absorber as shown in Fig. 1. The target was placed close to the absorber in order to limit the number of muon pairs from meson decays. During this run the absorber consisted of 144 g/cm² of Be, a steel-scintillator hadron calorimeter of mass 530 g/cm², and an additional 760 g/cm² of uninstrumented steel. The absorber was located 78 cm downstream from the target. The bulk of the data which were used to determine the A dependence were obtained using Be, Al, Cu, and Pb targets which were 15 cm long and which had a mass per unit area of 28.5 g/cm². They were segmented in order to obtain equal length and density. Data were also taken with a solid Pb

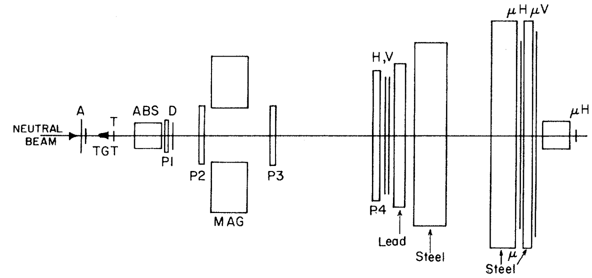

FIG. 1. Schematic layout of experimental apparatus. A, T, and D are scintillation counters; H, V, μH, and μV are scintillation counter hodoscopes. $P1$, $P2$, $P3$, and $P4$ are multiwire proportional chambers.