Evidence for the High-Energy Photoproduction of Charmed Mesons

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We report on a search for the photoproduction of D^0 ($\bar{D}^0$) mesons in events which have zero total visible strangeness. We observe an enhancement of 94 ± 19 events in the $K^\pm\pi^\mp$ decay mode, corresponding to a cross section of ~720 nb assuming a branching ratio of 0.018.

Our current knowledge of the properties of charmed particles, in particular the charmed mesons, comes almost exclusively from work done in e^+e^- storage rings.[1] Outside of the e^+e^- storage rings the only direct observation of charmed mesons comes from a neutrino experiment,[2] while observation of charmed baryons has been made in a separate neutrino experiment[3] and a photoproduction experiment.[4] Expectations are that the level of charm production in photon interactions should be on the order of 10^{-2} of the total cross section, i.e., 1 μb.[5]

We report the results of a search for the production of $D^0\bar{D}^0$ pairs in the wide-band neutral beam at Fermilab. The photon-beam spectrum produced with 400-GeV protons incident on a 12-in. Be production target is shown in Fig. 1. Our exposure consisted of 10^{17} incident primary protons, which produced 6×10^{11} photons in the range 50 GeV$<E_\gamma<$200 GeV. Data were collected with the multiparticle spectrometer system shown in Fig. 2. Photons interacted in a segmented target consisting of 20 pieces of 1-mm-thick scintillator (a total of 0.05 radiation lengths), each viewed by its own phototube. Momentum analysis was provided by two analyzing magnets and a set of five proportional chambers. Each chamber contained three wire planes, one made up of vertical wires, the other two made up of wires rotated by $\pm\tan^{-1}(\frac{1}{5})$ with respect to the horizontal. The solid-angle acceptance for the full five-chamber system was 70×80 mr^2 and for the front three chambers 140×190 mr^2. The proportional chambers were incorporated into a trigger which selected events with at least three charged tracks in addition to ~40 GeV deposited in the hadron calorimeter.

Two multicell threshold Cherenkov counters, a lead-glass array, and a large muon hodoscope counter provided information for particle identification. The pion thresholds of the two Cherenkov counters were 6 and 12 GeV, respectively. Kaons and protons were separable from pions in the range 6 GeV$<P_K<$20 GeV, and kaons were separable from pions and protons in the range 20 GeV$<P_K<$40 GeV. Provisions were also made for inserting 6 radiation lengths of lead into the

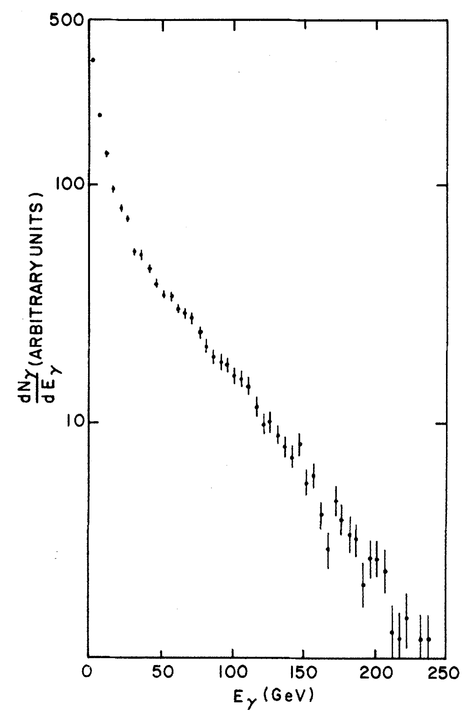

FIG. 1. The photon energy spectrum generated by 400-GeV protons incident on the Be production target.

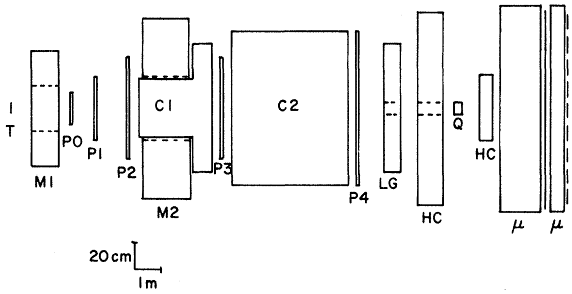

FIG. 2. A schematic view of the spectrometer: M1, M2 are dipole magnets; C1, C2 are Cherenkov counters, P0–P4 are multwire proportional chambers; LG is a lead-glass array; and HC is a hadron calorimeter.

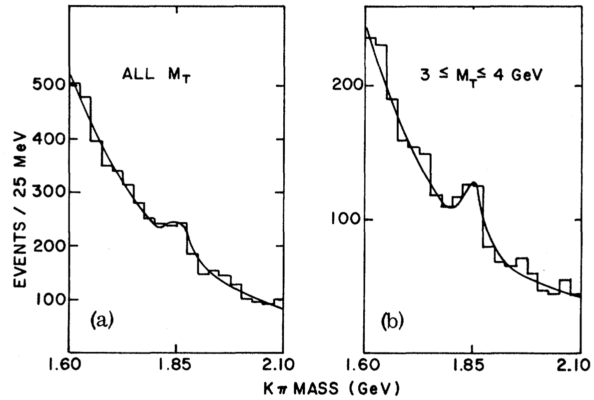

FIG. 3. (a) The $K^{\pm}\pi^{\mp}$ mass distribution subject to the cuts described in the text. For (b) data are subject to a cut on the total invariant mass of the event. The fits are described in the text.

neutral beam so as to attentuate the photon component relative to the $K_L{}^0$ and n component. Approximately one-quarter of our data were taken in this mode.

We present results here based on a sample of 127 000 events which contain one K^+ and one K^- with no other identified heavy hadron in the event. At least one of the kaons is required to lie outside the region of K/p ambiguity. Events with one neutral kaon plus a charged kaon are also examined in the search for decays involving neutral kaons. In order to help suppress the hadron-induced background, the events are required to have total visible energy less than 200 GeV. An additional requirement is that the K^+K^- mass fall outside the range 1.01–1.03 GeV, i.e., they do not form a φ meson.

Subject to the above cuts we have plotted mass distributions for the $K^{\pm}\pi^{\mp}$, $K^{\pm}\pi^{\mp}\pi^+\pi^-$, and $K_s{}^0\pi^+\pi^-$ decay modes of the D^0 ($\bar{D}^0$). To keep the number of combinations within the event from growing too large, we require the number of pions in the event to be at most three more than the number of pions in the combination. We estimate that $\sim\frac{3}{4}$ of the entries in these plots are $K_L{}^0$ or neutron induced rather than photon induced. The only signal we have found near the known D mass with a statistical significance greater than 4 standard deviations appears in the $K^{\pm}\pi^{\mp}$ decay mode of the D^0 ($\bar{D}^0$). This mass distribution is shown in Fig. 3(a), along with a best fit to a smooth background plus superimposed Gaussian. The best-fit parameters are

$$M = 1861 \pm 6 \text{ MeV and } \sigma = 17 \pm 5 \text{ MeV}$$

with 99 ± 24 events above background ($\chi^2 = 11$ for fourteen degrees of freedom). Our calculated resolution for this state is $\sigma_{\text{calc}} \approx 17$ MeV. In Fig. 3(b) we plot the same data subject to the additional requirement that the total invariant mass visible in the event lie in the range 3–4 GeV. The best fit here is

$$M = 1854 \pm 6 \text{ MeV and } \sigma = 20 \pm 5 \text{ MeV}$$

with 94 ± 19 events above background ($\chi^2 = 9$ for fourteen degrees of freedom). The data show no evidence for any signal among events with total invariant mass outside the range 3–4 GeV. We have performed an identical fit to the data taken with 6 radiation lengths of lead in the neutral beam. This fit indicates that the number of events above background in Fig. 3(b) which are due to $K_L{}^0$ or n interactions is 5 ± 20.

To calculate our detection efficiency for the various states, we have written a Monte Carlo program based on a model of photons interacting to produce $D^0\bar{D}^0$ with the $D^0\bar{D}^0$ produced at a mass of 4.0 GeV and carrying the full energy of the photons. Photons are generated in the range 50–250 GeV, according to Fig. 1, and all photons are assumed to be equally likely to produce $D^0\bar{D}^0$. The D^0 is forced to decay to $K^-\pi^+$ while the $\bar{D}^0$ is allowed to decay through sixteen different decay modes. The $\bar{D}^0$decay in our simulation is characterized by an average charged multiplicity of 2.2 and a K^+ to $\bar{K}^0$ ratio of 57 to 43. In our model, ~ 90% of the events generated with 4.0-GeV invariant mass upon reconstruction. The results of the calculation are sensitive on the 10% level to the mass chosen for the $D^0\bar{D}^0$ pair (varied from 4–4.5 GeV) and to the energy range we use for photons to produce charm (varied from 50 to 100 GeV threshold). The cross sections obtained are directly proportional to the assumed $\bar{K}^0/(K^+ + \bar{K}^0)$

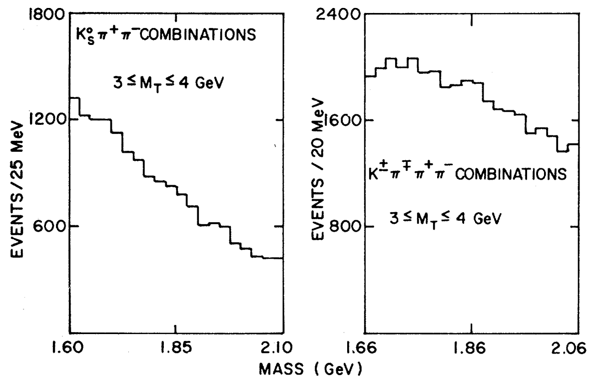

FIG. 4. $K_S{}^0\pi^+\pi^-$ and $K^\pm\pi^\mp\pi^+\pi^-$ mass distributions subject to the cuts described in the text.

ratio in $\overline{D}^0$ decays.

The data are also corrected for a number of effects of a nongeometric origin. Included are electronics deadtime (24%), chamber inefficiency (3% per track), random hits in the Cherenkov counters (13%), absorption in the target (2.5% per track), and K decay (7% per kaon). We estimate our systematic error in the calculation of the $D^0\overline{D}^0$ cross section to be approximately ± 40%.

Based on the above model and the known branching ratio[1] for $D \to K\pi$ (1.8%), the 94 ± 19 events of Fig. 3(b) correspond to a cross section of

$$\sigma(\gamma N \to D^0\overline{D}^0) = 720 \pm 290 \text{ nb},$$

where the error includes our estimated systematic error.

We can check the internal consistency of the data by asking at what level signals are present in the $K^\pm\pi^\mp\pi^+\pi^-$ and $K_S{}^0\pi^+\pi^-$ decay modes. Using the known branching ratios to these channels, we can calculate the corresponding cross sections for $D^0\overline{D}^0$ and compare to our value based on the $K^\pm\pi^\mp$ mode. Figure 4 shows the mass distributions for these two decay modes subject to the same cuts as Fig. 3(b). In Table I we list the results of fits to these distributions and the corresponding cross sections. The fits to Fig. 4 are of the form of a polynomial background plus a Gaussian centered at 1.862 GeV and with a width given by the Monte Carlo. All three measurements are consistent with a cross section for $D^0\overline{D}^0$ production of 700 ± 300 nb.

We have also made a search within our sample of $K\pi$ events for accompanying pions consistent

TABLE I. A calculation of the best fits to the $D^0\overline{D}^0$ cross section based on the distributions presented in Fig. 3(b) and Fig. 4 assuming the branching ratios listed. Errors on the cross section include the estimated 40% systematic error.

Decay mode	Branching ratio	No. of events	σ (nb)
$K^\pm\pi^\mp$	0.018	94 ± 19	720 ± 290
$K^\pm\pi^\mp\pi^+\pi^-$	0.035	177 ± 69	660 ± 370
$K_S\pi^+\pi^-$	0.044	54 ± 47	680 ± 600

with the decay,

$$D^{*\pm} \to D^0\pi^\pm \to K^\mp\pi^\pm\pi^\pm .$$

For events with the $K\pi$ mass in the range 1.825 GeV$<M(K\pi)<$1.900 GeV, we find only two in which the mass difference between the $K^\mp\pi^\pm\pi^\pm$ parent and one of the $K^\mp\pi^\pm$ daughters is less than 165 MeV. We can place an upper limit (95% confidence level) on the production of $D^{*\pm}$ of

$$D^{*+}/(D^{*0}+D^0) \le 0.15 .$$

In conclusion we have seen evidence for the photoproduction of neutral charmed mesons decaying through the $K\pi$ mode. Our best estimate of the cross section for $D^0\overline{D}^0$ photoproduction is that it is of the order of 700 nb/nucleon, averaged over the range 50–200 GeV.

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[1] I. Perruzzi *et al.*, Phys. Rev. Lett. 39, 1301 (1977); M. Piccolo *et al.*, Phys. Lett. 70B, 260 (1977).

[2] C. Baltay *et al.*, Phys. Rev. Lett. 41, 73 (1978).

[3] A. M. Cnops *et al.*, Phys. Rev. Lett. 42, 197 (1979).

[4] B. Knapp *et al.*, Phys. Rev. Lett. 37, 882 (1976).

[5] D. Sivers *et al.*, Phys. Rev. D 13, 1234 (1976); B. Margolis, Phys. Rev. D 17, 1310 (1978).