OBSERVATION OF A CHARMED NEUTRAL MESON PRODUCED IN A HIGH-ENERGY
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ABSTRACT

The production and decay of a $\bar{D}^0$ have been observed in a nuclear emulsion exposed to a photon beam from the CERN Super Proton Synchrotron in conjunction with the Omega spectrometer. All the decay products have been detected and measured in the emulsion and in the spectrometer. The mass of the charmed particle is $(1866 \pm 8) \text{ MeV}/c^2$ and its decay time is $(2.26 \pm 0.05) \times 10^{-14} \text{ s}$.

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Several examples of decays of charmed particles produced in different experiments have been reported up to now [1]. In this letter we present the first example of a neutral charmed meson produced in a high-energy photoproduction experiment.

The event was found in a nuclear emulsion experiment performed at CERN in the 80 GeV tagged photon beam from the Super Proton Synchrotron (SPS). The experimental set-up is sketched in Fig. 1. Some five thousand Ilford emulsion pellicles, $15 \times 3.5 \times 0.06 \text{ cm}^3$ each, were successively exposed to a dose of about 10^6 tagged photons with energy from 20 to 70 GeV. The pellicles were put at an angle of 11° with respect to the beam direction, so that an emulsion thickness of 3 mm was crossed by the beam. Secondary particles were detected by the Omega spectrometer, enabling the selection of interactions with at least four charged secondaries and the reconstruction of their vertex position in the emulsion [2]. The pellicles were scanned within a fiducial volume around each predicted vertex position, about one thousand interactions having been found so far[†]). All forward minimum ionizing tracks from each interaction were followed to search for decays.

In the event presented here, the spectrometer detected thirteen charged particles and two γ -rays. The reconstruction program has well associated ten charged particles and the two γ -rays to the same vertex. The remaining three particles were not associated (extra tracks). The corresponding emulsion star has five minimum ionizing tracks and seven grey or black tracks (Fig. 2). Four of the five minimum ionizing tracks match four of the spectrometer tracks very well and the fifth one matches the extra track nearest to the vertex (No. 8e). Following one of these minimum ionizing tracks (No. 9), a neutral star without visible recoil and with four minimum ionizing tracks was observed at a distance of about 120 μm from the primary star (Fig. 3). These tracks match closely four of the remaining spectrometer tracks.

[†]) Details of the experimental set-up, measurement accuracy and efficiency of locating interactions in the emulsion have been given in a contributed paper to the 1978 Tokyo Conference [3] and will be given more extensively elsewhere.

Figure 4 shows the very good correspondence between the predicted and the observed tracks and Table 1 summarizes the main features of the event. The particle identification is given by the Čerenkov counter and other electronic equipment. It has to be pointed out that while the 14.5 GeV/c negative particle (No. 9) hits the Čerenkov in an insensitive zone just near the separating wall between two adjacent cells, some light has nevertheless been seen in one of these. There is therefore good reason to consider this particle as a pion. Regarding two of the unseen tracks, it should be noted that the positive one was identified as a positron (No. 11); if the negative one (No. 10) is assumed to be an electron, their invariant mass turns out to be $(20 \pm 15) \text{ MeV}/c^2$ and the electron pair may be interpreted as a third converted γ -ray.

The analysis of the secondary star may be summarized as follows:

- a) The four tracks (1d, 2d, 3d, 4d) form a vertex at a distance of $(122.7 \pm 2.2) \mu\text{m}$ from the centre of the primary star and at a projected distance in the emulsion plane of $(0.82 \pm 0.08) \mu\text{m}$ from track No. 9.
- b) The unbalanced transverse momentum $p_T = (0.23 \pm 0.26) \text{ GeV}/c$ is compatible with zero.
- c) Assuming that particles 1d, 2d, 3d, 4d are respectively $\pi^+ \pi^- \pi^- K^+$, the invariant mass turns out to be $(1866 \pm 8) \text{ MeV}/c^2$ [†]).

On the basis of the above analysis we can interpret the secondary vertex as a $\bar{D}^0$ decaying into $K^+ \pi^- \pi^+ \pi^-$ ^{††}). The $\beta\gamma$ of the decaying particle being equal to 18.1, its decay time is $(2.26 \pm 0.05) \times 10^{-14} \text{ s}$.

If the secondary star were not a $\bar{D}^0$, it would have to be interpreted as a secondary interaction of a neutral particle, such as a K^0 , coming from the star.

[†]) This value is obtained using the measurements and their errors from the spectrometer. Using instead the angular measurements in the emulsion the invariant mass turns out to be $(1880 \pm 27) \text{ MeV}/c^2$.

^{††}) It may be worth mentioning that particles 4d and 2d (K^+ , π^-) have an invariant mass of $(911 \pm 5) \text{ MeV}/c^2$ and particles 1d and 3d (π^+ , π^-) of $(727 \pm 3) \text{ MeV}/c^2$, quite close to the masses of the K^* (892) and of the ρ mesons, respectively.

In our sample of about 1000 stars, the expected number of K^0 interactions which can simulate a $\bar{D}^0$ decaying into $K^+\pi^-\pi^+\pi^-$ can be estimated to be^{†)} $N \leq 3 \times 10^{-5}$. On the other hand, if we assume [5] a cross-section for $D^0\bar{D}^0$ photoproduction of about $0.7 \mu\text{b}$ and a branching ratio ($\bar{D}^0 \rightarrow K^+\pi^-\pi^+\pi^-/\bar{D}^0 \rightarrow \text{anything}$) = 0.035, we would expect in our experiment about 8 $D^0\bar{D}^0$ events and 0.3 $\bar{D}^0$ decays into $K^+\pi^-\pi^+\pi^-$. The comparison between this last number and the number N calculated above makes the interpretation of the present event as a background interaction an unlikely one.

None of the possible combinations of the $\bar{D}^0$ with the charged particles and the γ -rays of the primary interaction give an invariant mass value compatible with that of a D^* .

The charged particles from the primary star were carefully followed for their whole range in the emulsion (from 1.5 to 3.0 mm), but the associated charmed particle was not found. On the other hand, the missing mass from the primary interaction is of about $3.4 \text{ GeV}/c^2$, leaving room for a neutral charmed particle. Therefore, area scanning was carried out in the forward direction from the primary star for 2.5 mm, but no other charged decay was observed.

We conclude that the production and decay of a $\bar{D}^0$ charmed meson have been observed and completely measured for the first time in a high-energy photoproduction experiment. The decay time of the particle is $(2.26 \pm 0.05) \times 10^{-14} \text{ s}$.

^{†)} The number of K^0 per star is about 0.1, as evaluated from the K^0 detected in this experiment. The mean free path λ_K of a K^0 is obtained by assuming a dissociation process $K^0 \rightarrow K3\pi$ which has a cross-section on nucleons of about $200 \mu\text{b}$ [4]. From the fact that the mean free path for pions in emulsion ($\lambda_\pi \approx 40 \text{ cm}$) corresponds to a total cross-section on nucleons of 25 mb, one obtains $\lambda_K \approx 5000 \text{ cm}$. The mean path of secondary particles in our emulsions is 0.15 cm. Therefore the expected number of K^0 interactions is 3×10^{-3} , of which less than 1% should have an invariant mass of $(1866 \pm 8) \text{ MeV}/c^2$.

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Table 1

Main features of the event

Track No.	Parameters given by the spectrometer				Parameters measured in emulsion	
	P (GeV/c)	Dip (mrad)	Azimuth (mrad)	Particle identi- fication	Dip (mrad)	Azimuth (mrad)
1d	3.369 ± 0.012	26.6 ± 0.2	-129.2 ± 0.8	+	24 ± 10	-127.9 ± 2.0
2d	1.083 ± 0.006	90.5 ± 1.4	-37.6 ± 2.2	-	103 ± 7	-44.7 ± 0.6
3d	10.590 ± 0.123	12.0 ± 0.2	-21.2 ± 0.6	π^-	7 ± 6	-21.8 ± 0.4
4d	18.769 ± 0.132	-2.4 ± 0.2	6.9 ± 0.3	K^+ or p	-3 ± 5	6.9 ± 0.5
5	3.113 ± 0.011	-37.8 ± 0.2	50.4 ± 0.8	-	-33 ± 40	53 ± 7
6	1.921 ± 0.060	34.8 ± 4.2	259.7 ± 3.9	+	-17 ± 53	257 ± 32
7	0.271 ± 0.061	-451.0 ± 25.9	414.7 ± 197.0	+	-444 ± 53	262 ± 25
8e	1.469 ± 0.020	287.0 ± 2.4	209.5 ± 2.7	-	271 ± 73	178 ± 22
9	14.505 ± 0.229	-0.3 ± 0.2	-9.5 ± 0.6	$K^-?$	4 ± 3	-9.5 ± 0.3
10	0.245 ± 0.003	-117.4 ± 16.2	-28.7 ± 10.4	-	NOT SEEN	
11	2.973 ± 0.006	-94.9 ± 0.2	-34.5 ± 0.6	e^+	NOT SEEN	
G1	0.790	11.4	-25.7			
G2	0.374	-99.1	-20.5			
Incident momentum = 64.3 GeV/c; Missing momentum = 9.5 GeV/c; Missing mass ≈ 3.4 GeV/c ²						

The angles are given with respect to a reference system with the x axis parallel to the beam direction and the z axis parallel to the direction of the magnetic field. Missing mass and missing momentum have been calculated ignoring Fermi motion, using only particles seen in the emulsion and assuming particle No. 9 to be a pion.

The momentum components of the decaying particle calculated with respect to its line of flight are: $p_{x'} = 33.8 \pm 0.12$, $p_{y'} = -0.045 \pm 0.057$, $p_{z'} = 0.22 \pm 0.26$ GeV/c. The line of flight of the decaying particle has an angle of 16 mrad with respect to the beam.

Figure captions

- Fig. 1 : Layout of the Omega spectrometer for the present experiment.
- Fig. 2 : Picture of the event made with a microscope drawing attachment.
- Fig. 3 : Best fit lines through measured positions of grains in the emulsion for all minimum ionizing tracks of the event.
- Fig. 4 : Angular matching of the minimum ionizing tracks as measured in emulsion and as given by the spectrometer. Track No. 7 is out of the picture.

Fig. 1

Fig. 2

Fig. 3

Fig. 4