Observation of the photoproduction of a $\bar{D}^0D^0$ pair of charmed mesons

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(Submitted 7 September 1981)

Pis'ma Zh. Eksp. Teor. Fiz. **34**, No. 8, 477–482 (20 October 1981)

An interesting event has been observed in an experiment on the production of charmed particles by tagged photons from the CERN supersynchrotron. The event was detected simultaneously in a nuclear emulsion and by the Omega Prime magnetic spectrometer. It is interpreted as the first observed case of the photoproduction of a pair of charmed neutral mesons, $\bar{D}^0D^0$. A decay time $\tau(\bar{D}^0) = (0.14 \pm 0.01)\cdot 10^{-13}$ s has been found for the decay $\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$, while two solutions have been found for the decay $D^0 \to \bar{K}^0\pi^- e^+\nu$: $\tau_1(D^0) = (3.4 \pm 0.3)\cdot 10^{-13}$ s and $\tau_2(D^0) = (7.5 \pm 0.3)\cdot 10^{-13}$ s.

PACS numbers: 13.60.Mf, 14.40.Pe

In this letter we will describe an event in which the photoproduction of the charmed mesons $\bar{D}^0D^0$ was observed. The interaction was observed in a nuclear-emulsion target exposed to a beam of tagged photons from the supersynchrotron of the European Center for Nuclear Research (CERN).[1-3] The secondary particles were

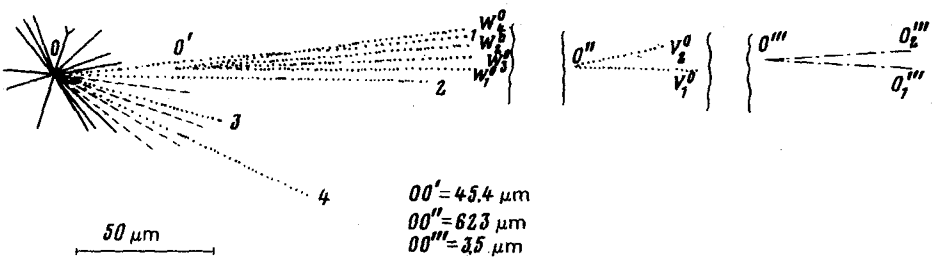

FIG. 1.

detected with the Omega Prime magnetic spectrometer.

We will simply summarize the experimental procedure here; a more detailed description will be published in the near future. The individual layers of a GOSNIIKh-IMFORTOPROEKT BR-2 nuclear photographic emulsion, each 600 μm thick and 5 $\times$ 20 cm^2 in area, were exposed in succession to the beam of tagged photons with energies from 20 to 70 GeV. The plane of the emulsion was oriented at 5° from the beam axis during the exposure, so that the photons encountered a total thickness of 6.88 mm. The trigger logic of the magnetic spectrometer effectively suppressed the electromagnetic background noise, singling out photohadron events for detection. The TRIDENT geometric-reconstruction program[4] reconstructed the geometry of the detected events and predicted the position of the interaction vertex in the emulsion. These predictions were then used to search for the interaction in the emulsion over an area of 11 $\times$ 3 mm^2. Another program, the JULIET program, jointly analyzed the geometric information and the data from the counter systems (the Čerenkov counter, the hodoscopes, the scintillation counters of the large shower detector, etc.) with the goals of identifying the particles, searching for π^0 mesons, and accurately determining the energy of the primary γ ray.

The event being reported here was caused by a γ ray with an energy of 48.861 GeV. At the primary vertex, O, there are four relativistic tracks, four gray tracks, and 13 black tracks[1)] (Fig. 1). At distances 45.4 ± 0.5 μm and 623 ± 2 μm from the primary vertex we observed two secondary neutral vertices, W^0 and V^0, consisting respectively of four and two relativistic tracks, without any black tracks or recoil tracks. It can be seen from Table I that the four relativistic tracks and one of the gray tracks from the primary vertex, and also all four tracks of the vertex W^0 and one track of the vertex V^0, run in the same directions as the tracks reconstructed from the spectrometer data. Both of the secondary neutral vertices are thus genetically related to the primary vertex, and we are justified in considering the possibility that they may be interpreted as the decays of charmed particles. It follows from Table I that the spectrometer detected two other tracks of oppositely charged particles which were not observed in the emulsion. If both of these particles are assumed to be pions, the effective mass of the pair is found to agree with the K^0 mass.

The total momentum of the four particles from the vertex W^0 is $P_T(W^0) = 19.935$ GeV/c. The momentum transverse with respect to the emission direction of the neutral particle W^0 is $P_T(W^0) = 0.1$–0.2 GeV/c—not distinguishable from zero within

TABLE I. Basic properties of the observed events.

Vertex	№ Track	Measurements in emulsion				Measurements in spectrometer				Interpretation			
		L, nm	$\phi°$	tg *dip*	I/I_0	$\phi°$	tg *dip*	Charge	Momentum, GeV/c	Particle	M_{inv}, GeV/c^2	Decay mode	τ 10^{-13} s
0	1		7,2	0,073		7,6	0,087	–	2,018				
0'	W^0	45,4	3,2	0,107					19,935	$\bar{D}^0$	1,883	$K^+\pi^-\pi^-\pi^+$	0,14 ± 0,02
	W^0_1		– 0.4	0,173	0,86 ± 0,06	– 0,35	0,196	+	4,603 ± 0,093	K^+	± 0,030		
	W^0_2		1.6	0,108	0,91 ± 0,04	1,56	0,107	–	7,261 ± 0,203	π^-			
	W^0_3		5.4	0,042	0,96 ± 0,03	5,15	0,037	–	3,371 ± 0,036	π^-			
	W^0_4		8.2	0,080	0,98 ± 0,03	8,2	0,075	+	4,729 ± 0,025	π^+			
	2		– 0.7	0,268		0,06	0,292	+	1,103				
	3		– 12,0	0,052		– 11.6	0,070	–	4,912				
	4		– 17,5	0,269		– 16,6	0,290	+	2,686				
0''	V^0	623	2,64	– 0,0066				0	11,16 or 5,20	D^0	(1,863)	$\bar{K}^0\pi^-e^+\nu$	3.4 ± 0,3 or 7,5 ± 0,3
	V^0_1		0.3	0,144		0,06	0,165	–	3,024	π^-			
	V^0_2		16,5	– 0,125	0,99 ± 0,11	> 0.1			≤ 0,160	e^+ or μ^+			
0'''						8,6	– 0,077	0	1,724	$\bar{K}^0$	0,512	$\bar{K}^0 \to \pi^-\pi^+$	
	$0'''_1$					– 0.6	0,266	–	0.467 ± 0,050		± 0,014		
	$0'''_2$					11.9	– 0,2	+	1.370 ± 0,080				
	5		23,2	0,170	"gray"	– 23,3	0,24	+	0,936				
	6		– 6,1	– 0,497	"gray"								
	7		– 16,0	– 0,975	"gray"								
	8		– 35,8	– 0.469	"gray"								
						– 1,8	0,075	0	1.400	π^0			
						3,8	0,137	0	1,350	π^0			
						– 2,1	– 0,302		0,115	γ			

1)All angles are expressed in the coordinate system of the emulsion.

TABLE II. Invariant masses of the neutral particle for various hypotheses regarding its decay at the vertex (identified particles are underscored).

Track	Decay hypothesis		
	$\bar{D}^0 \to K^+\pi^-\pi^-\pi^+$	$\bar{D}^0 \to \pi^+\pi^-\pi^- K^+$	$\bar{D}^0 \to \pi^+\pi^- K^-\pi^+$
W_1^0	K^+	π^+	π^+
W_2^0	π^-	π^-	π^-
W_3^0	π^-	π^-	K^-
W_4^0	π^+	K^+	π^+
M_{inv}	1.883 ± 0.030	1.872 ± 0.030	1.976 ± 0.030

* K^+ identified on the basis of the ionization and the momentum.

π^- identified by the Čerenkov counter.

the experimental errors. Consequently, in interpreting this vertex in terms of a decay there is no need to assume any additional neutral particle. Table II shows the effective masses calculated for these four particles under various assumptions regarding the nature of each of the particles (the particle W_2^0 is identified unambiguously as a pion by the Čerenkov counter). Two of the combinations listed here lead to a mass corresponding to that of the neutral antimeson $\bar{D}^0$. A third combination, which would correspond to the decay of a D^0 meson, does not yield a plausible effective mass. Ionization measurements in the emulsion give preference to the first of the two possible assumptions according to which W_1^0 or W_4^0 is a positive kaon. We thus interpret the vertex W^0 as a result of the decay of a charmed antimeson $\bar{D}^0$: $\bar{D}^0 \to K^+ \pi^-\pi^-\pi^+$. From the magnitude of the particle's momentum and from the decay length, we find the decay time of the charmed antimeson to be

$$\tau(\bar{D}^0) = (0.14 \pm 0.01)\cdot 10^{-13}\ \text{s}.$$

For the other neutral vertex, V^0, the particle V_1^0 detected by the spectrometer turned out to have a negative charge and a momentum of about 3 GeV/c. The particle V_2^0 was not detected by the spectrometer. Measurements of the multiple scattering of the track in the emulsion yield an estimated lower limit of $p_\beta = 0.1$ GeV/c for the momentum of this particle. On the other hand, since the particle is positively charged, it could enter the proportional counters if its momentum were smaller than 0.16 GeV/c. The ionization measurements yield $I/I_0 = 0.99$–0.11, where I_0 is the ionization on the plateau for the relativistic tracks and electrons, measured in the same emulsion. We may thus conclude that this particle is a positron or a muon.

The vertex angle of the V^0 fork is $\sim 16°$. The total momentum of the charged particles in the fork is 3.173 GeV/c and is not collinear with the direction in which the particle is emitted from the primary vertex, O. An interpretation in terms of the decay of a charmed particle is possible, however, if we assign the neutral kaon reconstructed from the decay products (Table I) to the decay vertex[1] V^0. The presumed decay scheme in this case is

$$D^0 \to \bar{K}^0 \pi^- e^+ \nu$$

(it follows from the fact that the vertex W^0 is a $\bar{D}^0$, ν decay that a D^0 decay occurs at the vertex V^0 and that the kaon is a $\bar{K}^0$). Assuming the momentum of the positron to be 0.16 GeV/c, we find two solutions for the neutrino momentum which satisfy the requirements on the transverse-momentum balance and on the effective mass of the D^0 meson. These values are

$$p_1(\nu) = 0.8 \pm 0.2 \text{ GeV}/c, \qquad p_2(\nu) = 2.5 \pm 0.2 \text{ GeV}/c.$$

The corresponding momenta of the D^0 meson and the corresponding decay times are

$$p(D^0) = 5.1 \pm 0.2 \text{ GeV}/c, \qquad \tau_1(D^0) = (7.5 \pm 0.3) \cdot 10^{-13} \text{ s},$$

$$p(D^0) = 11.3 \pm 0.2 \text{ GeV}/c \qquad \tau_2(D^0) = (3.4 \pm 0.1) \cdot 10^{-13} \text{ s}.$$

There is essentially no change in these values when the e^+ is replaced by a μ^+.

Under the assumption that the negatively charged particle at V^0 is a K^- meson, there are no other combinations of the tracks of the vertex V^0 with the π^0 mesons detected by the shower detector of the spectrometer which satisfy the condition for a transverse-momentum balance and also yield reasonable effective masses for the known strange and charmed particles.

In summary, this event is interpreted as the production and decay of a pair of neutral charmed mesons in accordance with the following scheme:

$$\gamma + A \to \bar{D}^0 + D^0 + X$$
$$D^0 \to \bar{K}^0 \pi^- e^+ \nu$$
$$\bar{D}^0 \to K^+ \pi^- \pi^- \pi^+$$

This is the first completely reconstructed event in which a pair of neutral charmed mesons has been produced in a photon beam. Adeva *et al.*[5] have recently reported a similar event, generated by a π^- meson and detected in a high-resolution hydrogen bubble chamber.

We wish to thank F. Conforti, C. Ricci, the technical staff of the Department of Experimental Physics of CERN, and the Omega Prime users group for much assistance during the exposure. We also wish to thank the staff at the Development Center at Dubna, its director S. I. Lyubomilov, and the CERN Development Group for successfully developing the emulsions. We sincerely thank the members of the scanning groups of the Photon-Emulsion Collaboration for their enthusiasm and effective work. The Omega-Photon Collaboration wishes to thank the SRC (Great Britain) and the BMFT (Federal Republic of Germany) for support.

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[1] A "relativistic track" is the track of a particle moving at a velocity $\beta \geq 0.7$ and producing an ionization $I/I_0 < 1.4$ (I_0 is the ionization on the plateau); a "gray track" is the track of a particle with $\beta < 0.7$ and $I/I_0 \geq 1.4$ (for protons the corresponding energy interval is from 26 to 400 MeV); and a "black track" is a track with a range of less than 3 mm (the corresponding energy for protons is ≤26 MeV).

[2]Regarding the analysis of the secondary vertex V^0 we should point out that this vertex V^0 was not originally observed in the emulsion. The magnetic spectrometer, however, detected the tracks O_1''' and O_2''' (which give the vertex O''' the effective mass of the K^0; see Table I). The vertex V^0 and the track V_2^0 were found in the emulsion when it was scanned in the direction of the resultant momentum of these three particles.

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1. M. I. Adamovich *et al.*, Phys. Lett. **89B**, 427 (1980).
2. A. Forino *et al.*, Lett. Nuovo Cimento **30**, 166 (1981).
3. M. I. Adamovich *et al.*, Phys. Lett. **99B**, 271 (1981).
4. J. C. Lassalle *et al.*, Internal Report CERN-DD/EE/79-2, 1979.
5. B. Adeva *et al.*, (LEBC-EHS-Collaboration) Phys. Lett. **102B**, 285 (1981).

Translated by Dave Parsons
Edited by S. J. Amoretty