OBSERVATION OF PAIRS OF CHARMED PARTICLES PRODUCED BY HIGH-ENERGY PHOTONS
IN NUCLEAR EMULSIONS COUPLED WITH A MAGNETIC SPECTROMETER*(Photon-Emulsion Collaboration)*(Bologna^{1*}-CERN²-Florence^{3†}-Genoa^{4×}-Madrid (JEN)⁵-Moscow⁶-
Paris (LPNHE)⁷-Santander⁸-Valencia⁹)M.I. Adamovich⁶, Y.A. Alexandrov⁶, J.M. Bolta⁹, L. Bravo⁸, A.M. Cartacci³,
M.M. Chernyavski⁶, B. Conforto³, A. Conti³, M.G. Dagliana³, M. Dameri⁴,
G. Diambri-Palazzi⁴, G. Di Caporiacco³, A. Fiorino¹, R. Gessaroli¹,
E. Higon⁹, S.P. Kharlamov⁶, V.G. Larionova⁶, R. Llosa⁵, J. Lory⁷, A. Mattei³,
C. Meton⁷, G.I. Orlova⁶, B. Osculati⁴, G. Parrini³, N.G. Peresadko⁶,
C. Persano⁴, A. Quarenì Vignudelli¹, A. Ruiz⁸, K.M. Romanovskaya⁶,
M. Sannino⁴, D. Schune⁷, G. Tomasini⁴, M.I. Tretyakova⁶, Tsai Chu⁷,
G. Vanderhaeghe², E. Villar⁸ and B. Willot⁷

and

(Omega-Photon Collaboration)(Bonn¹⁰-CERN²-Glasgow¹¹-Lancaster¹²-Manchester¹³-Rutherford¹⁴-Sheffield¹⁵)M. Atkinson¹⁴, T. Brodbeck¹², G.R. Brookes¹⁵, P.J. Bussey¹¹, M. Davenport¹⁴,
J.-P. Dufey², R.J. Ellison¹³, W. Galbraith¹⁵, K. Heinloth¹⁰, J.S. Hutton¹⁴,
R.E. Hughes-Jones¹³, M. Ibbotson¹³, B.R. Kumar¹⁴, G.D. Lafferty²,
J.B. Lane¹³, J.-C. Lassalle², R. McClatchey¹⁵, D. Mercer¹³, J.V. Morris¹⁴,
D. Newton¹², G.N. Patrick¹¹, C. Raine¹¹, A. Schlösser¹⁰,
K.M. Storr¹² and A.P. Waite¹³ABSTRACT

Preliminary results of an experiment using nuclear emulsions exposed to a tagged photon beam at the CERN SPS (Experiment WA58) are presented. Six events showing pairs of charmed particles have been found. One of these has been interpreted as an associated production of Λ_c^+ and $\bar{D}^0$. The mean lifetime of the neutral D particle based on three events is

$$\tau^0 = \left(0.58 \pm 0.8 \right) \times 10^{-13} \text{ s} ,$$

whereas a statistical analysis of eight charged charmed particles, assumed to be charged D, leads to an estimate of the mean lifetime of

$$\tau^\pm \simeq 4.4 \times 10^{-13} \text{ s} .$$

(Submitted to Physics Letters B)

* Istituto di Fisica dell'Università di Bologna and INFN, Sezione di Bologna, Italy.
† Istituto di Fisica dell'Università di Firenze and INFN, Sezione di Firenze, Italy.
× Istituto di Fisica dell'Università di Genova and INFN, Sezione di Genova, Italy.

The charmed events which we present in this letter have been observed in nuclear emulsion pellicles exposed to the CERN SPS tagged photon beam in the Omega Prime Spectrometer (Experiment WA58). Six thousand BR2-type emulsion pellicles of $20\text{ cm} \times 5\text{ cm} \times 600\text{ }\mu\text{m}$ (36 litres) were used^{*)}. A mechanical device brought single pellicles, one at a time, to the target position where they were put at an angle of 5° to the beam axis, so that their effective thickness was approximately 6 mm. Each pellicle was exposed to a dose of about 10^6 tagged photons with energies between 20 and 70 GeV. The spectrometer detected and analysed the secondary particles from the photon interactions, the trigger logic efficiently excluding electromagnetic background. Only events with multiplicities greater than or equal to three were recorded and they were reconstructed by the CERN geometry program TRIDENT [1].

The emulsions have been scanned, in order to find the events recorded by the spectrometer, over an area up to 75 mm^2 (15 mm parallel to the beam direction and 5 mm perpendicular to it) centred on the vertex position predicted by TRIDENT. For about 50% of the triggers localized in the target region, stars have been found in the vicinity of the predicted point with a good agreement between measured and predicted angles of the fast particles (matched events). The mean absolute differences between measurement and predictions are 0.5° in azimuth and 1.5° in dip. When the search was not successful, any events with at least one minimum ionizing track in the forward direction found in the scanned area were analysed.

Up to now, the scanning of about 2000 triggers out of the 160,000 hadronic ones recorded by Omega Prime has been completed. Out of 1400 events found in the emulsion, about 1000 are matched. Three of the matched events show evidence of production and decay of pairs of charmed particles. In addition, among the unmatched events, three with two decay-like vertices at short distances from the primary interaction vertex have been observed. It should be stressed that such

^{*)} The emulsion was manufactured by the State Research Institute for Photochemical Projects (GCPP) in Moscow, USSR.

a topology is a strong indication of double production of charmed particles. Indeed, the expected number of events with two secondary interactions or strange particle decays, in our experimental conditions, can be estimated at 3×10^{-3} in the whole sample of 1400 events.

The main features of the three matched events are reported in Table 1: $00'$ and $00''$ are the lines connecting the primary vertex to the two secondary vertices. The first event, showing a secondary neutral star with four prongs and a deflection of about 10° of a track from the primary star, has been described in detail elsewhere [2]. The neutral particle has been identified as a $\bar{D}^0 \rightarrow K^+ \pi^+ \pi^- \pi^-$, with a proper decay time $t_{\bar{D}^0} = (0.86 \pm 0.01) \times 10^{-13}$ s. The charged particle has been identified as a Λ_c^+ charmed baryon decaying into $\Lambda^0 \pi^+$ with a proper decay time $t_{\Lambda_c^+} = (0.57 \pm 0.02) \times 10^{-13}$ s. Therefore the event has been interpreted as an example of associated photoproduction of a charmed meson and a charmed baryon.

The second event (Fig. 1) has a V^0 and a three-prong decay. All the tracks were recorded by the spectrometer, so that their charge and momentum are known. As the charge of the particle decaying with a three-prong configuration is negative, the most reasonable interpretation for the two charmed particles is that of a $D^0 D^-$ pair. The transverse momentum of the three-prong decay with respect to the line $00'$ is $p_T = (0.442 \pm 0.028)$ GeV/c, which is clearly unbalanced. Taking the three outgoing particles as pions and assuming the presence of an extra K^0 to balance the transverse momentum, the hypothesis of a $D^- \rightarrow K^0 \pi^+ \pi^- \pi^-$ gives two solutions for the D momentum: 6.6 and 10.3 GeV/c. No other Cabibbo-favoured hadronic or semileptonic decay modes are consistent with the data. The corresponding decay times are $t_1 = 0.88 \times 10^{-13}$ s and $t_2 = 0.57 \times 10^{-13}$ s, respectively. For the neutral particle decay the hypothesis of a $D^0 \rightarrow 2$ bodies is not compatible with the measured parameters, because the effective mass of a $K^- \pi^+$ final state turns out to be $1.26 \text{ GeV}/c^2$. However, solutions are possible with one or more neutral particles in the final state. Assuming a $D^0 \rightarrow K^- \pi^+ \pi^0$, there are two solutions for the D momentum -- 20 and 38 GeV/c -- while decays with more than one neutral particle give intermediate values. Therefore the proper decay time of the D^0 is between 0.45×10^{-13} s and 0.85×10^{-13} s.

The third matched event, with two three-prong decays, is an example of double production of charged charmed particles. The first trident, with transverse momentum clearly unbalanced, has two prongs detected by the spectrometer and the second has only one prong detected. It is therefore not possible to know the mass and the charge of the two charmed particles and to find the accurate values of their proper decay times.

The same problems are encountered for the three unmatched events reported in Table 2, since for them no information is available from the spectrometer.

The whole sample of charmed particles presented in this paper consists then of nine charged and three neutral particles, to which can be added a $\bar{D}^0$ found in a previous experiment (WA45), where a similar method of exposure and analysis to that of the present experiment was used [3].

In order to estimate the mean lifetime of the D^0 particles, we have assigned to the decay time of the D^0 from event No. 2 in Table 1 the central value 0.65×10^{-13} s. Using our sample of two $\bar{D}^0$ and one D^0 , and assuming that the D^0 finding efficiency is constant with respect to the decay length^{*)}, we obtained by the maximum likelihood method

$$\tau^0 = \left(0.58 \pm 0.8 \right) \times 10^{-13} \text{ s} .$$

Taking the extreme values for the decay time of the D^0 from event No. 2 changes this value by at most 12%.

A rough estimate, based on a statistical method [4], is possible for the lifetime of decaying particles, even if no information is available about their momenta. Assuming that the eight unidentified charged particles are D mesons, we have computed the distance $\Delta_i = L \sin \theta_i$ from the primary vertex to the line of flight of each of the charged particles from the decay vertex. In the above relation, L is the decay path length and θ_i is the angle between the line of flight of the decaying particle and the secondary track direction.

*) This assumption is reasonable for events where a D^0 is associated with a charged particle decaying in the emulsion, since the scanning for a neutral particle in this case is done very carefully.

For the one-prong decay, the value of the distance gives all the information, whereas for the three-prong decays the average of the three computed distances Δ_i is taken. It is known that for an isotropic decay in the centre of mass, the mean value of Δ for a sample of events is proportional to the mean lifetime of the particles and only weakly dependent on their momentum distribution and on the number of neutral particles in the final state. By a Monte Carlo method, the coefficients of proportionality between $\langle \Delta \rangle$ and $c\tau$ have been evaluated for one-prong and three-prong decays, under different hypotheses. The resulting values are 1.15 and 0.88, respectively, and they are steady within about 15% for different decay-mode assumptions. From this, the mean lifetime of the eight charged particles considered is estimated to be

$$\tau^{\pm} \approx 4.4 \times 10^{-13} \text{ s} .$$

As a check, we can estimate the mean lifetime of the three neutral mesons quoted above, using the same statistical method as for charged decays. In this case we obtain

$$\tau^0 \approx 0.43 \times 10^{-13} \text{ s} ,$$

which is consistent with the directly computed value given above.

In conclusion, the result of this analysis gives a further indication that the mean lifetime of the charged D is larger than that of the neutral D.

We acknowledge the invaluable help of the mechanical assistance groups of CERN EP Division and of Messrs. F. Conforti and C. Ricci throughout the experiment. We are very much indebted to the Omega technical staff for their essential contribution during the run. We wish to express our thanks to Dr. C. Lubomilov and his team at Dubna as well as to the CERN Emulsion Treatment Group for the successful processing of the emulsions. Our gratitude is also due to the scanning teams of the Photon Emulsion Collaboration for their enthusiasm and efficiency.

The Omega-Photon Collaboration thanks the Science Research Council (UK) and the Bundesministerium für Forschung und Technologie (FRG) for their support.

REFERENCES

- [1] J.C. Lassalle et al., Internal Report CERN-DD/EE/79-2.
- [2] M.I. Adamovich et al., Associated photoproduction of a charmed meson and a charmed baryon, submitted to Physics Letters B.
- [3] M.I. Adamovich et al., Phys. Lett. 89B, 427 (1980).
- [4] ABCLMOS Collaboration, Preprint CERN/EP/PHYS. 78-25, submitted to the Topical Conf. on Neutrino Physics, Oxford, July 1978.

Table 1

Parameters of charm decays from matched events

Event no.	Type of primary star a) and γ energy	Emulsion					Spectrometer			
		Sec. vertex b)	Track	Path (μm)	Azimuth (deg.)	Dip (deg.)	Azimuth (deg.)	Dip (deg.)	Charge	p (GeV/c)
1	7b + 0g + 5s $E_Y = 25 \text{ GeV}$	1p	00'	50 ± 1	-1.8	4.7				
			1		9.1	0.8				
		4n	00''	124 ± 1	-2.7	0.1				
			1		-7.7	-2.5	-8.7	-3.9	-	2.35
			2		-4.0	-10.3	-3.9	-10.7	+	1.02
			3		-0.2	3.2	-0.7	2.3	-	4.47
2	4b + 0g + 4s $E_Y = 60 \text{ GeV}$	3p	00'	94 ± 1	-4.5	4.1				
			1		-24.1	0.7	-23.4	0.2	+	0.88
			2		-14.2	4.6	-13.8	5.2	-	2.38
		2n	00''	267 ± 2	0.9	3.1				
			1		-0.2	3.1	-0.2	3.6	+	14.32
3	1b + 0g + 3s $E_Y = 65 \text{ GeV}$	3p	00'	685 ± 5	-1.3	20.8				
			1		1.0	11.3	0.9	11.1	+	0.97
			2		6.4	8.5	-	-	-	-
		3p	00''	980 ± 5	0.2	4.1				
			1		-9.2	4.6	-9.1	4.1	+	3.69
			2		1.4	2.6	-	-	-	-
			3		9.8	6.8	-	-	-	-

a) b stands for "black" track, g for "grey" track, and s for "shower" or relativistic track.

b) 1p (3p) indicates the decay of a charged particle into 1 prong (3 prongs).

2n (4n) indicates the decay of a neutral particle into 2 prongs (4 prongs).

Table 2

Parameters of charm decays from unmatched events

Event no.	Type of primary star	Sec. vertex	Track	Path (μm)	Azimuth (deg.)	Dip (deg.)
1	2b + 2g + 6s	2n	00'	44 $\pm$ 1	1.0	2.5
			1		1.0	0.0
			2		5.0	3.0
		1p	00'' 1	260 $\pm$ 2	-2.0 13.0	0.0 -39.0
2	2b + 4g + 6s	3p	00'	32 $\pm$ 1	12.5	-2.4
			1		0.2	-2.9
			2		32.0	35.8
			3		35.0	0.0
		1p	00'' 1	1900 $\pm$ 6	-1.0 1.5	7.7 3.7
3	4b + 0g + 8s	3p	00'	3236 $\pm$ 15	-1.9	4.0
			1		-3.3	5.1
			2		-2.5	7.9
			3		2.8	11.7
		1p	00'' 1	341 $\pm$ 2	-3.4 -6.6	2.0 7.9

Fig. 1 Micrograph of event No. 2 in Table 1