ASSOCIATED PHOTOPRODUCTION OF A CHARMED MESON AND A CHARMED BARYON

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ABSTRACT

In the course of an experiment using nuclear emulsions exposed to the CERN Super Proton Synchrotron tagged photon beam, the first example of associated photoproduction of a charmed meson and a charmed baryon has been observed. A few straightforward assumptions allow a complete reconstruction of the event. The charmed meson, identified as a $\bar{D}^0$, has a proper decay time $t_{\bar{D}^0} = (0.86 \pm \pm 0.01) \times 10^{-13}$ s, and the charmed baryon, identified as a Λ_c^+ , has a proper decay time $t_{\Lambda_c^+} = (0.57 \pm 0.02) \times 10^{-13}$ s.

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In this letter we give a detailed description of an event in which associated photoproduction of a charmed meson and a charmed baryon has been observed. The event was recorded in the course of an experiment using nuclear emulsions^{*)} exposed to the CERN Super Proton Synchrotron (SPS) tagged photon beam and coupled to the Omega prime spectrometer (experiment WA58). Single emulsion pellicles of size $(20 \times 5) \text{ cm}^2$ and $600 \text{ }\mu\text{m}$ thickness were automatically placed, one at a time, at an angle of 5° to the beam axis, and exposed to a dose of about 10^6 tagged photons with energies between 20 and 70 GeV. Secondary particles from photon interactions were detected and analysed by the spectrometer. The events recorded by the spectrometer are reconstructed by the CERN geometry program TRIDENT [1], and a search is then made for the event in the emulsion around the predicted vertex coordinates. This method is similar to the one used in a previous experiment (WA45), where a $\bar{D}^0$ meson was observed [2].

The event in question, produced by a 25 GeV photon, was found at a distance of 4 mm from the predicted position. At the primary vertex 0 there are seven black and five minimum ionization tracks (fig. 1). After $(50 \pm 1) \text{ }\mu\text{m}$, one of the minimum ionization tracks (No. 4) undergoes a deflection of about 10° (secondary vertex $0'$) without ionization change and without visible recoil. This deflected track was not detected by the spectrometer, possibly because it interacted in the plexiglas support of the emulsion. Of the remaining four minimum ionization tracks, only the one emitted at a small angle to the beam axis (No. 3) was detected by the spectrometer (see table 1).

A third vertex (denoted as $0''$) is seen in the emulsion at a distance of $(124 \pm 1) \text{ }\mu\text{m}$ from the primary one. It consists of four minimum ionization tracks (Nos. 6.1-4), which were all detected by the spectrometer, and there is no visible recoil. Table 1 illustrates the quality of the track matching. The total momentum of the four particles is $p_6 = (8.990 \pm 0.008) \text{ GeV}/c$, and the transverse momentum with respect to the line connecting the $0''$ vertex to the primary one is

*) The BR2-type emulsions were manufactured by the State Research Institute for Photochemical Projects (GCPP), Moscow, USSR.

$p_T = (0.04 \pm 0.06)$ GeV/c, compatible with zero. Because each of the four particles has a momentum below the Čerenkov threshold for mass identification, the effective mass of the four particles has been computed for different combinations of mass assignments. In one case it turns out to be very close to the mass of the D meson, i.e. when the kaon mass is assigned to track 6.2 and the pion mass to the other three, giving $m_6 (\pi^- K^+ \pi^- \pi^+) = (1.847 \pm 0.007)$ GeV/c² *). The hypothesis of a $\bar{D}^0$ decay appears then very likely. From its total momentum and decay length, one derives a proper decay time $t_{\bar{D}^0} = (0.86 \pm 0.01) \times 10^{-13}$ s.

In order to find the second charmed particle produced in the primary photo-hadronic interaction, the secondary vertex O' and the particles detected by the spectrometer but not seen in the emulsion were examined. Assuming that tracks 7 and 8 are respectively a proton and a negative pion, their effective mass is $m_{7,8} = (1.115 \pm 0.011)$ GeV/c², i.e. that of a Λ^0 . This Λ^0 can also be associated with the secondary vertex O' , which is very near to the primary one. Moreover, its line of flight is coplanar with tracks 4 and 4.1 within the errors:

$[\vec{u}_4 \times \vec{u}_{4.1}] \cdot \vec{u}_{\Lambda^0} = 0.007 \pm 0.010$. This strongly suggests that the vertex O' corresponds to a two-body decay. The momentum of the Λ^0 is $p_{\Lambda^0} = (2.967 \pm 0.003)$ GeV/c, that of the outgoing charged particle is then calculated to be $p_{4.1} = (3.96 \pm 0.24)$ GeV/c, and that of the decaying particle $p_4 = (6.73 \pm 0.23)$ GeV/c. Assuming that particle 4.1 is a pion, the effective mass of the decaying particle is $m_4 = (2.33 \pm 0.05)$ GeV/c², which is consistent with the mass of the Λ_c^+ baryon [3]. We can therefore assume that the vertex O' results from the decay of a Λ_c^+ into $\Lambda^0 \pi^+$. The proper decay time of this Λ_c^+ is found to be $t_{\Lambda_c^+} = (0.57 \pm 0.02) \times 10^{-13}$ s.

The effective masses computed by associating either of the above charmed particle with the charged particle from the primary interaction which was detected by the spectrometer (No. 3) are inconsistent with any known charmed states with higher mass.

*) The mass values and the errors quoted are the present estimates from TRIDENT.

We conclude that the event described can be interpreted as the associated photoproduction of a charmed meson and charmed baryon. It is the first completely reconstructed example that has been observed. The charmed meson, identified as a $\bar{D}^0$, has a proper decay time $t_{\bar{D}^0} = (0.86 \pm 0.01) \times 10^{-13}$ s, and the charmed baryon, identified as a Λ_c^+ , has a proper decay time $t_{\Lambda_c^+} = (0.57 \pm 0.02) \times 10^{-13}$ s.

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Table 1

Main features of the event

Vertex	Track No.	Measurements					Interpretation			
		Emulsion		Spectrometer			Particle	Computed mass (GeV/c ²)	Charm decay mode	Decay time (10 ⁻¹³ s)
		Decay length (μ m)	Azimuth (deg.)	Dip (deg.)	Azimuth (deg.)	Dip (deg.)	Charge	p (GeV/c)		
0	1		-39.0	17.8						
	2		-29.3	-0.9						
	3		-11.2	1.3	-11.3	1.6	+	1.54		
	5		59.4	-11.6						
0'	4	50 $\pm$ 1	-1.8	4.7						
	4.1		9.1	0.8					$\Lambda^0 \pi^+$	0.57 $\pm$ 0.02
0''	(6)	124 $\pm$ 1	-2.7	0.1			0		$\bar{D}^0$	
	6.1		-7.7	-2.5	-8.7	-3.9	-	2.35	π^-	
	6.2		-4.0	-10.3	-3.9	-10.7	+	1.02	K^+	
	6.3		-0.2	3.2	-0.7	2.3	-	4.47	π^-	
	6.4		0.5	9.4	0.2	9.5	+	1.21	π^+	
	7	Not seen			-17.0	11.0	+	2.28	$P \left. \begin{array}{l} \Lambda^0 \\ \pi^- \end{array} \right\}$	
	8	Not seen			-15.2	5.1	-	0.69		
	9	Not seen			5.3	0.4	+	0.79

Fig. 1 Micrograph of the event. (Track numbers with an asterisk are for tracks recorded in the spectrometer. Tracks 7 and 8 were not seen in the emulsion.)