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CHARGED CHARMED PARTICLE LIFETIME

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ABSTRACT

We present the lifetime values obtained for D± and Λ_c^+, photoproduced in nuclear emulsion in the WA58 experiment. In photohadronic interactions, pairs of charmed particles are produced. Out of 20 charged charmed particles used for lifetime evaluation, 17 have their charmed partner seen in emulsion, being then essentially free from any background. The values of the lifetimes are

$$\tau_{D^\pm} = (3.91^{+2.35}_{-1.25}) \times 10^{-13}\ \mathrm{s}; \quad \tau_{\Lambda_c^+} = 2.22^{+1.34}_{-0.75}) \times 10^{-13}\ \mathrm{s}$$

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In recent years a considerable effort has been devoted to determining the lifetimes of charged charmed particles produced by different targets and beams: neutrino [1], hadron [2], and photon [3] beams.

In this paper, we present a measurement of the charged charmed particle lifetimes. The charmed particles were produced by photohadronic interactions in nuclear emulsion. The experiment has been performed exposing emulsion, coupled with the Ω' spectrometer [4], to the tagged photon beam of an energy between 20 and 70 GeV/c at the CERN SPS [5]. Single emulsion pellicles, 200 x 50 x 0.6 mm^3 were exposed one at a time and at an angle of 5 degrees with respect to the direction of the incident photon beam. The effective thickness crossed by the photons is thus 6.9 mm. Each pellicle was exposed to a dose of about 10^6 tagged photons.

The photohadronic interactions were selected by means of a trigger logic accepting charged-particle multiplicities greater than 3. A Cherenkov gas counter for hadrons and a lead-glass forward shower detector for electrons and photons allow the identification of particles within certain ranges of momentum and angular acceptance.

The CERN program chain, TRIDENT [6] and JULIET, reconstructs the recorded events, giving the particle momenta, mass assignments to the particles (if possible), the vertex coordinates, and the overall event topology.

The emulsion was scanned through its whole thickness inside a fiducial area centred at the predicted vertex position. The average area scanned per event was 45 mm^2. When an event was found the angles of the tracks were measured and compared with those predicted by TRIDENT. In this way, about 9000 matched events were found.

To find charged charmed particle decays all the minimum ionizing tracks of the matched events were followed until they left the plate or interacted; an area scanning was performed for neutral decays. All secondary events were recorded. The scanning efficiency for scatterings of

1 degree or more and for white secondary stars were measured by repeating the track following on a sample of events and its value is found to be $\varepsilon = 0.94$, constant with the distance from the primary vertex. In Fig. 1, we report the nuclear interaction length plotted against the distance from the primary star for all the secondary interactions and for the white stars. The two distributions are constant within the errors. The mean free path for nuclear interactions is $\lambda = (33.3 \pm 1.4)$ cm and for white stars it is $\lambda = (303 \pm 40)$ cm, in very good agreement with the expected values.

For all the candidate events an accurate study of the signals recorded by the spectrometer was achieved, in order to reconstruct the tracks and the K° and Λ° if missed by the pattern recognition.

Concerning the charm selection some preliminary checks were effected to avoid background. A candidate was rejected if any of the combinations of one positive and one negative decay product gave an invariant mass as (e^+e^-) lower than 0.1 GeV/c². Furthermore, the average path length being 3.45 mm, we expected a few K's decaying inside the emulsion, but anyway we checked to avoid this background.

Photohadronic interactions produce pairs of charmed particles but there is the possibility that one of them leaves the emulsion before decaying (around 30% if $\tau = 5 \times 10^{-13}$ s) For this reason we expected to have some events with only one visible decay.

A background evaluation for the different types of decays was calculated in order to set further selection criteria. There were 14 events found with two charm candidates, of which at least one was charged. The expected background being 1 event, they were all accepted as good candidates. We also found 24 interactions in which there was only one charged decay-like secondary event (3 or more prongs). Only 3 of these events with a good 3C fit for charm hypothesis, were accepted because the expected background was 18 events. The expected number of single and double one-prong-secondary events being rather high, essentially because of the Coulomb scattering, this type of candidate was not taken into account.

The list of the 20 charged events selected in the above-described way is reported in Table 1.

If all the charm decay products, charged and neutral, are detected by the spectrometer, the charm momentum is unambiguously determined (3C fit). If a neutral particle is missed by the apparatus (0C constraint), two solutions are kinematically possible for the decay momentum. The 3C fit was always tried taking into account all the possible decay modes compatible with the event topology and with particle identification, if any. Also alternative hypotheses with a neutral missing particle were tried. Sometimes, one of the two solutions was not acceptable either because the momentum was too low, and so incompatible with the measured ionization of the charm, or because it was too high, and so incompatible with the overall energy of the event. In this case a lower or an upper limit, compatible with the ionization or with the energy conservation, respectively, was imposed.

To help in the selection between different hypotheses, a Monte Carlo technique was used. Samples of D, Λ_c^+, and F were generated under our experimental conditions. The program allows the particle decay in different possible channels according to the phase space. The obtained events were processed as the real events. In this way the percentage of misidentified hypotheses was evaluated. The results showed that, when one or more 3C fits have succeeded, all the alternative 0C hypotheses can be rejected. Then, each time a 3C fit is possible, only this is reported in Table 1; if more than one 3C fits are obtained, they are all reported with a weight related to the χ^2 of the fits. If no 3C fit is possible, the 0C solution for D or that for Λ_c^+ is reported. For one event (No. 9), the hypotheses D and Λ_c^+ were both plausible and the weights written in Table 1 were evaluated according to the Monte Carlo results.

In our sample of charm candidates, there is no example of production of F^+F^- pairs. This can be due to a cross-section for F pair production lower than the cross-section for D pair production. Two events (No. 19 and No. 20 in Table 1), if taken as $(K^+K^-\pi^+\pi^0)$ and $(\pi^+\pi^-\pi^+\pi^0\pi^0)$ respectively, give M = (2073±18) MeV/c^2 and M = (2065±31)MeV/c^2, compatible with the F mass of 2021 MeV/c^2 [7], but hardly compatible with the recent value of 1970 MeV/c^2 [8]. All the other D's in our sample can have the alternative 0C solution with $F \rightarrow \pi\pi\pi\ (\pi^0)$. The Monte Carlo results show that this type of misidentification is always present. For all these reasons, the alternative F hypotheses was not taken into account.

For the lifetime calculation the hypotheses will be used all together, each with its weight.

From the 3C fit events quoted in Table 1, we have calculated the mean of the charmed particle masses. The values obtained are $M_{D^\pm} = (1860 \pm 16)\ \mathrm{MeV}/c^2$, $M_{\Lambda_c^+} = (2285 \pm 23)\ \mathrm{MeV}/c$.

The likelihood function used to evaluate the lifetimes is

$$L = -\log \prod_{i=1}^{n} \sum_{H=1}^{2} \frac{w_H^i \exp(-t_H^i/\tau_H)}{\tau_H[\exp(-t^i_{H\,\min}/\tau_H) - \exp(-t^i_{H\,\max}/\tau_H)]} ,$$

where H stands for D and Λ_c^+, w_H^i are the weights, and $t^i_{H\min}$ and $t^i_{H\max}$ are the times corresponding to the minimum detectable length and to the potential length. The minimum length has been set at 20 μm. The potential length is the maximum path the particle can travel before leaving the plate. The values that maximize the L functions are

$$\tau_{D^\pm} = (3.91^{+2.35}_{-1.25}) \times 10^{-13}\ \mathrm{s}; \quad \tau_{\Lambda_c^+} = 2.22^{+1.34}_{-0.75}) \times 10^{-13}\ \mathrm{s}$$

In Fig. 2, the equal likelihood contour plots in the τ_D-$\tau_{\Lambda_c^+}$ plane are shown. The curves I and II correspond to the values $L_{\max} - 0.5$ and $L_{\max} - 1$. A possible source of systematic error has been considered. The uncertainty arises from the events with a double solution. To estimate it, we have performed the lifetime calculations taking all the minimum and all the maximum proper times. The resulting values are 2.6 and 5.1×10^{-13} s for the D and 1.7 and 2.8×10^{-13}s for the Λ_c^+.

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Table 1

	Decay length (μm)	Potent. length (μm)	Hypothesis a)	Weight	P (GeV/c)	t (10^{-13} s)	Mass (MeV/c^2)	Partner
1	94	1782	$D^- \to \pi^+\pi^-\pi^-(K^\circ)$	1.00	6.08 - 11.39	0.74		D°
2	733	797	$D^- \to K^+\pi^-\pi^-(\pi^\circ)$	1.00	2.71 - 3.94	14.18		D^+
			$D^- \to \pi^+\pi^-\pi^-(K^\circ)$		2.81 - 5.84	12.04		
3	970	4140	$D^- \to \pi^+\pi^-\pi^-(K^\circ)$	1.00	16.17 - 19.75	3.40		D°
4	21.4	150	$D^+ \to K^-\pi^+\pi^+(\pi^\circ)$	1.00	8.34 - 8.86	0.16		$\bar{D}^\circ$
5	982	3760	$D^+ \to K^-\pi^+\pi^+$	1.00	19.05	3.21	1882 ± 72	D^-
6	224	7502	$D^+ \to K^\circ\pi^-\pi^+\pi^+$	1.00	12.45	1.12	1806 ± 59	$\bar{D}^\circ$
7	388	15743	$D^- \to K^+\pi^-\pi^-$	1.00	14.82	1.63	1873 ± 69	b)
8c)	602	6614	$D^- \to K^+\pi^-\pi^-(\pi^\circ)$	1.00	14.82 - 17.73	2.32		Λ_c^+
9	677	827	$D^+ \to \pi^+(k^\circ)$	0.46	3.2 - 13.66	8.14		$\bar{D}^\circ$
			$\Lambda_c^+ \to \pi^+(\Lambda^\circ)$	0.54	4.0 - 16.65	7.98		
			$\Lambda_c^+ \to P\ (K^\circ)$		4.0 - 6.96	10.14		
10	34.1	441	$D^+ \to K^-\pi^+\pi^+$	0.43	8.12	0.26	1882 ± 31	
			$\Lambda_c^+ \to K^-p\pi^+$	0.57	8.12	0.32	2284 ± 27	
11	100	630	$D^+ \to K^-\pi^+\pi^+$	0.83	5.81	1.07	1813 ± 36	$\bar{D}^\circ$
			$\Lambda_c^+ \to K^-p\pi^+$	0.17	5.81	1.31	2327 ± 22	
12	50	2851	$\Lambda_c^+ \to \pi^+\Lambda^\circ$	1.00	6.70	0.57	2323 ± 42	$\bar{D}^\circ$
13	274	3353	$\Lambda_c^+ \to \pi^+\Lambda^\circ\ \pi^\circ$	1.00	38.99	0.54	2261 ± 149	$\bar{D}^\circ$
14	122	5129	$\Lambda_c^+ \to \pi^+\Lambda^\circ(\pi^\circ)$	1.00	5.55 - 7.54	1.46		D^-
15	527	2366	$\Lambda_c^+ \to \pi^+\Lambda^\circ(\pi^\circ)$	1.00	5.50 - 10.32	5.59		$\bar{D}^\circ$
16	144	15682	$\Lambda_c^+ \to \pi^+\Lambda^\circ(\pi^\circ)$	1.00	6.30 - 11.40	1.35		D^-
17	156	721	$\Lambda_c^+ \to \pi^+\Lambda^\circ(\pi^\circ)$	1.00	3.14 - 5.35	3.00		$\bar{D}^\circ$
18d)	314	3136	$\Lambda_c^+ \to p\bar{K}^\circ\ (\pi^\circ)$	1.00	6.46	3.70		$\bar{D}^\circ$
19	390	744	$D^+ \to \pi^+K^-\pi^+\pi^\circ\pi^\circ$	1.00	15.96	1.53	1914 ± 30	
20	492	2077	$D^- \to \pi^+\pi^-\pi^-\pi^\circ$	1.00	19.07	1.61	1855 ± 35	Λ_c^+

a) In brackets are the missed neutral particles

b) Particles detected only by the spectrometer and consistent with a D^+ decaying outside the emulsion

c) K^+ is identified by the Cherenkov

d) Λ_c^+ coming from $\Sigma_c^{++} \to \Lambda_c^+\pi^+$ with $M(\Sigma_c^{++}) = 2.48$ GeV/c². One of the K° (π°) combinations has the $K^{*\circ}$ mass, and the corresponding value of charm momentum has been accepted.

FIGURE CAPTIONS

Fig. 1: Nuclear interaction length plotted against the distance from the primary star for all secondary interactions (full lines) and for white secondary interactions (dotted lines).

Fig. 2: Equal likelihood contour plot in the τ_D-$\tau_{\Lambda c}$ plane. The curves I and II correspond to the values L_{max} - 0.5 and L_{max} - 1, respectively.

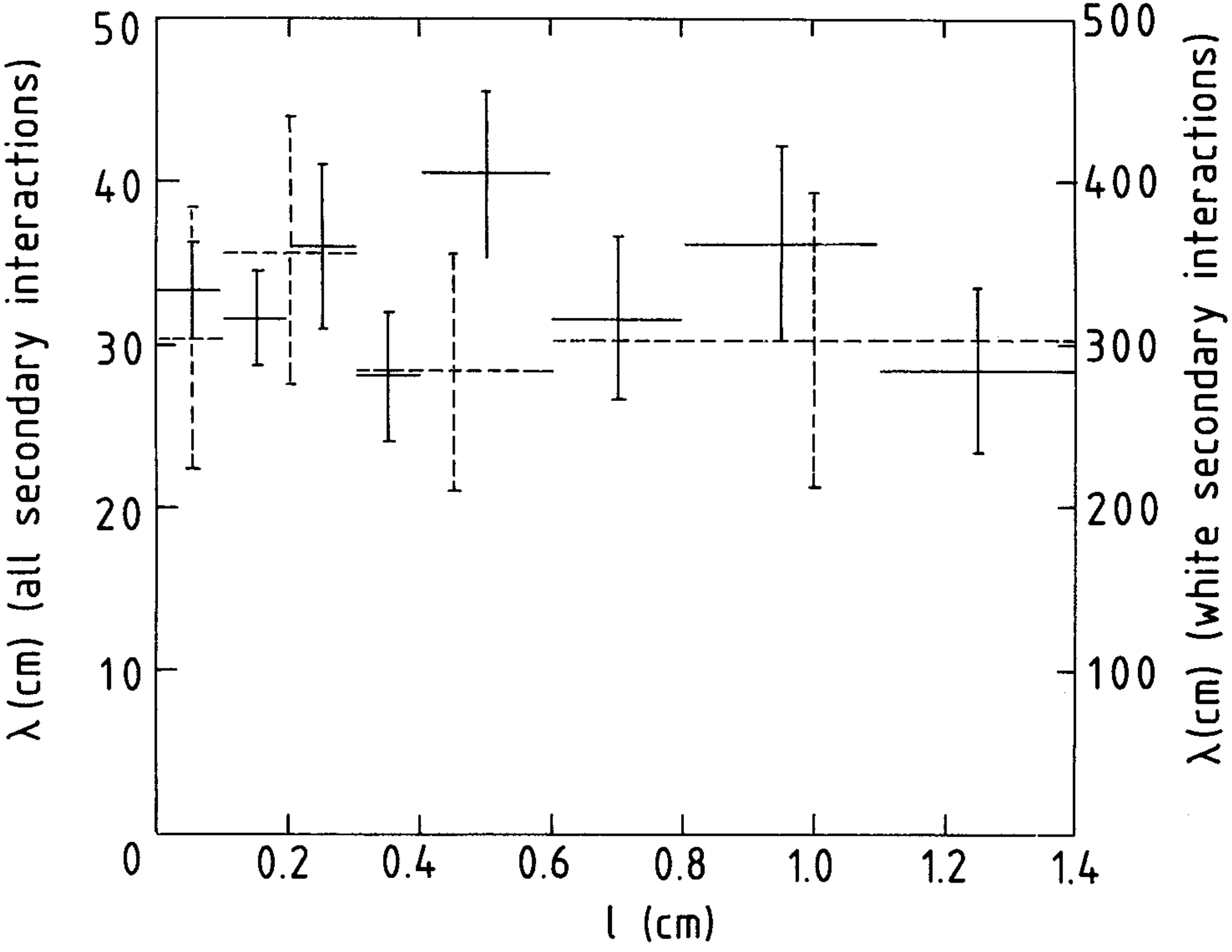
λ(cm) (all secondary interactions)
λ(cm) (white secondary interactions)
l (cm)
0
10
20
30
40
50
100
200
300
400
500
0.2
0.4
0.6
0.8
1.0
1.2
1.4

Fig. 1

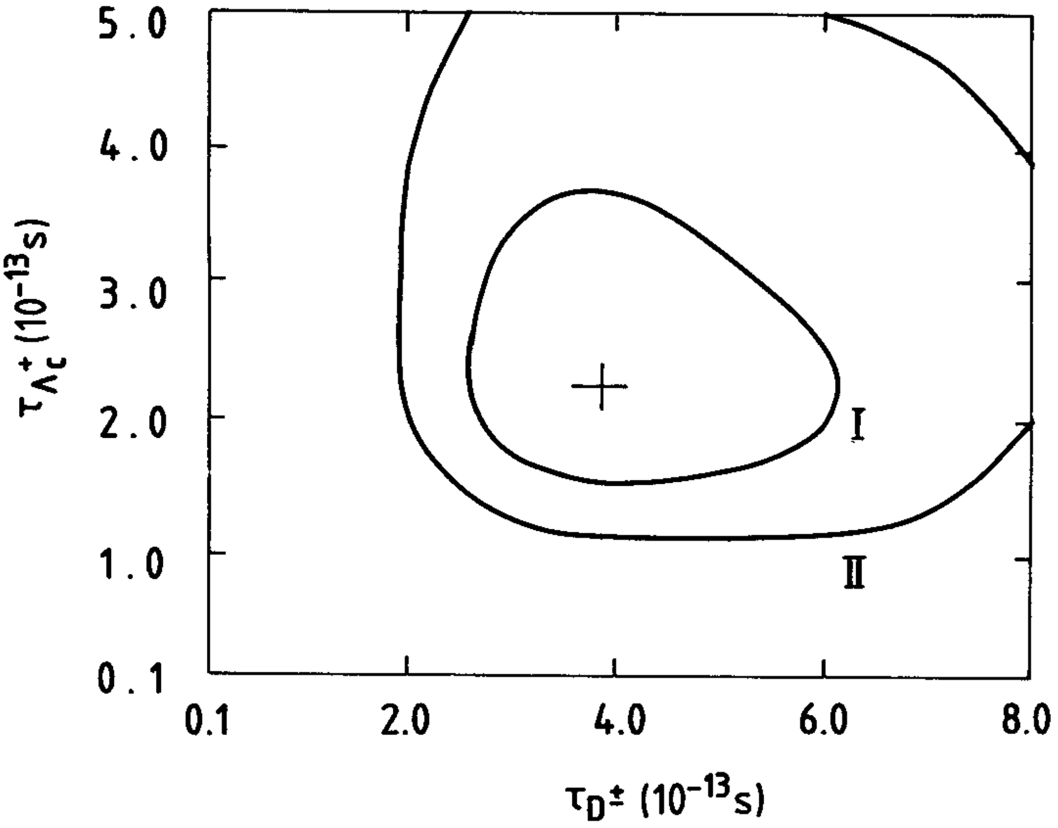
5.0
4.0
3.0
2.0
1.0
0.1
$\tau_{\Lambda_c^+}$ (10^{-13}s)
0.1
2.0
4.0
6.0
8.0
$\tau_{D^\pm}$ (10^{-13}s)
I
II

Fig. 2