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Lifetimes of Charmed Particles Produced in a 20 GeV γp Experiment*

SLAC Hybrid Facility Photon Collaboration

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Eleven neutral and nine charged decays of charmed particles have been observed in a sample of 205000 hadronic interactions in a 1.2 million picture exposure of the SLAC hybrid facility to a 20 GeV/c backward scattered laser beam. The charged and neutral lifetimes were determined to be $8.2 \, ^{+4.5}_{-2.5} \times 10^{-13}$ sec and $6.7 \, ^{+3.5}_{-2.0} \times 10^{-13}$ sec, respectively, with a ratio of $1.2 \, ^{+0.9}_{-0.5}$.
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The lifetimes of charged and neutral charmed particles have been the subject of recent experimental and theoretical interest[1,2]. In this letter, we present new measurements of these lifetimes.

The experiment was performed at the SLAC Hybrid Facility with a backward scattered laser beam incident on the 1 m hydrogen bubble chamber operated at 10 Hz. The beam was 3 mm in diameter, peaked at 20 GeV with a FWHM of 2 GeV, and usually contained 25 photons per pulse. Following the bubble chamber were four sets of multiwire proportional chambers (MWPC's), two atmospheric pressure Cerenkov counters, and a lead-glass wall[3]. All the downstream detectors were deadened in the region containing the e^+e^- pairs from beam conversions.

In order to detect charm decays near the interaction vertex, a fourth camera having a resolution of 55 microns over a depth of ±6 mm, was used. The bubble chamber was operated at an elevated temperature and the flash lamps were triggered 200 microseconds after the beam passage. This resulted in 70 bubbles/cm of 55 micron diameter.

The cameras were triggered on either of two conditions. The first condition was the passage through three MWPC stations of any charged particle originating in the fiducial volume of the bubble chamber. The required calculation was performed within the 200 μsec time limit by a 168/E processor[4]. The second trigger condition was based on the energy deposited in the lead-glass wall[3]. With this combination, we triggered on 90 percent of the total hadronic cross section with a yield of 1 event per 6 photographs. Monte Carlo studies indicate that approximately 80 percent of the charm cross section is included by the trigger.

The results presented here are based on 1.2×10^6 pictures containing approximately 205000 hadronic interactions. All hadronic events were closely examined for the decays of short-lived particles within 1 cm of the interaction vertex. In order for an event to be considered a charm candidate, either the decay point had to be visible or the backward projection of one of the tracks in the event had to miss the production vertex (the impact distance) by at least one track width. Only decays having two or more charged tracks were considered. Decays consistent with strange particle hypotheses were eliminated. Twenty-nine events remained with one or two visible charm particle decays. Three cuts were imposed on these events:

C1. An impact distance greater than 110 μm (2 track widths) was required for at least one track in each event to ensure high efficiency for finding charged and neutral decays (see d^{max} in Figure 1).

C2. A minimum impact distance cut of 40 μm was imposed on a second track from the same decay vertex to eliminate 1-prong decays, which happen to be superimposed on other tracks (see d_2 in Figure 1).

C3. A minimum decay length cut of 500 μm was imposed to allow a clean separation of the charged and neutral decays.

After imposing these cuts, 21 events remained; 14 had a single visible decay and 7 had two, where the second decay needed only to have one track with an impact distance greater than 40 μm.

A total of 23 decays satisfied all three conditions. These included 11 neutral (7 two-prongs and 4 four-prongs), 4 positive (all three-prongs, but one with an additional Dalitz pair), 5 negative (all three-prongs), and 3 charged/neutral ambiguous decays. Three of the neutral and 5 of the charged decays are compatible with Cabibbo-allowed D decays with no missing neutral particles; the rest are compatible if a missing π^o, $\overset{(-)}{K}{}^o$, or ν is assumed. In most cases, not all charged tracks are identified. Thus, for most $D^{\pm}$ candidates, the $F^{\pm}$ hypothesis cannot be excluded, and for two candidates, Λ_c^+ is also possible. Despite the lack of complete neutral particle detection, it has often been possible, because of the relatively low beam energy, to obtain good limits on the momentum used for the flight time determination.

For each of the 23 accepted decays, an effective length (L_{eff}) was calculated. This is defined as the actual distance (L) travelled by the particle, minus the length from the production vertex to the first point along its path where its decay would have satisfied all three acceptance conditions (C1, C2, C3). Note that this first detection point is uncorrelated with the decay distance. Thus, L_{eff} is the path length over which a charmed particle would have been accepted as such, and it provides an unbiased means for calculating the lifetime. When the momentum, P, of each of N charmed particles of mass M is known, then the mean lifetime is given by:

$$\tau = \frac{1}{N} \sum_{i=1}^{N} \left(\frac{L_{eff}}{P} \frac{M}{c} \right)_i .$$

This method (Method I) allows us to use only 5 charged and 3 neutral decays.

In order to use all the events, several other methods for estimating the lifetimes were also employed. One of these (Method II) used upper (P_{max}) and lower (P_{min}) limits on the momentum P determined on an event by event basis to calculate an average lifetime $\bar{T}_{eff}$:

$$<\bar{T}_{eff}> = \frac{K}{N} \sum_{i=1}^{N} \frac{L_{eff}.M}{P'.c}$$

where P' is an estimate of the real momentum.

$$\frac{1}{P'} = \frac{1}{2} \left(\frac{1}{P_{max}} + \frac{1}{P_{min}} \right)$$

Monte Carlo studies suggest that $<\bar{T}_{eff}>$ is good estimator of the lifetime with the value of K in the range 0.85 to 1.0.

Other methods involved generating Monte Carlo events with the same cuts as applied to the data. The lifetime dependences of the means of various distributions were calculated. The means of the corresponding experimental distributions were then used to determine the lifetimes. The distributions chosen were the maximum projected impact distance d^{max} (Method III), the projected total length L (Method IV), and the projected effective length L_{eff} (Method V). The lifetime as determined from different charm production models differs by less than 20 percent.

Figure 2 gives the experimental distributions of L, L_{eff}, d^{max} and $\bar{T}_{eff}$. In comparing the charged and neutral decays, note the similarities in the distributions and their mean values. The momentum distributions were also similar. The distributions of the ambiguous decays are compatible with both the charged and neutral distributions.

Table I gives the values of the lifetimes obtained by each of the methods described above. It can be seen from this table that all methods give consistent results. We have combined the parameters of Methods II, III, IV and V in a maximum likelihood determination of the lifetime, where these parameters (T_{eff}, d^{max}, L, L_{eff}) are compared on an event by event basis to the Monte Carlo. From this we obtain:

$$\tau^{\pm} = (8.2 \begin{smallmatrix} +4.5 \\ -2.5 \end{smallmatrix}) \times 10^{-13} \text{ sec,}$$

$$\tau^{o} = (6.7 \begin{smallmatrix} +3.5 \\ -2.0 \end{smallmatrix}) \times 10^{-13} \text{ sec, and}$$

$$\tau^{\pm}/\tau^{o} = 1.2 \begin{smallmatrix} +0.9 \\ -0.5 \end{smallmatrix}$$

The errors are dominated by statistics but include also systematic effects. The results are insensitive to reasonable changes in the values of the cuts C1, C2, C3. The curves on Figure 2 represent the distributions expected for these lifetimes. One neutral four-prong decay is worthy of mention because it has the invariant mass of a $\bar{D}^o$ without missing neutral particles and has an effective proper flight time of 21.8×10^{-13} sec.

In conclusion, we have examined the decays of 11 neutral and 9 charged charmed particles photoproduced in a high-resolution bubble chamber. Backgrounds from all sources are small compared to 1 event. The charged lifetime obtained is compatible with previous measurements of $D^{\pm}$ lifetimes; however, the neutral lifetime is significantly longer than has been found in previous experiments[1], and leads to a charged to neutral lifetime ratio consistent with unity.

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TABLE I. Lifetimes of charged and neutral charmed particles and their ratios, as determined by various methods explained in the test.

Method		Charged lifetime (10^{-13}s)	Neutral lifetime (10^{-13}s)	$\frac{\text{Charged}}{\text{Neutral}}$
I.	$\langle L_{eff} \rangle$ constrained decays	$8.2^{+6.5}_{-2.5}$ (5 decays)	$9.4^{+12.0}_{-4.0}$ (3 decays)	0.9
II.	$\langle T_{eff} \rangle$	7.6	6.4	1.1
III.	$\langle d^{max} \rangle$	9.6	7.4	1.3
IV.	$\langle L \rangle$	8.4	6.8	1.3
V.	$\langle L_{eff} \rangle$	8.1	6.7	1.2

Figure Captions

Figure 1 An event showing the decay of a positive charmed particle into 3 charged tracks after 0.86 mm and the decay of a neutral charmed particle after 1.8 mm. Both decays contain missing neutrals and cannot come from strange particles. The quantities d^{max} and d_2, the largest and second largest impact distances for the 3-prong decay are indicated.

Figure 2 Distributions of L, L_{eff}, d^{max} and $\bar{T}_{eff}$. The curves are from Monte Carlo calculations using the charged and neutral lifetimes given in the text normalised to the number of decays.

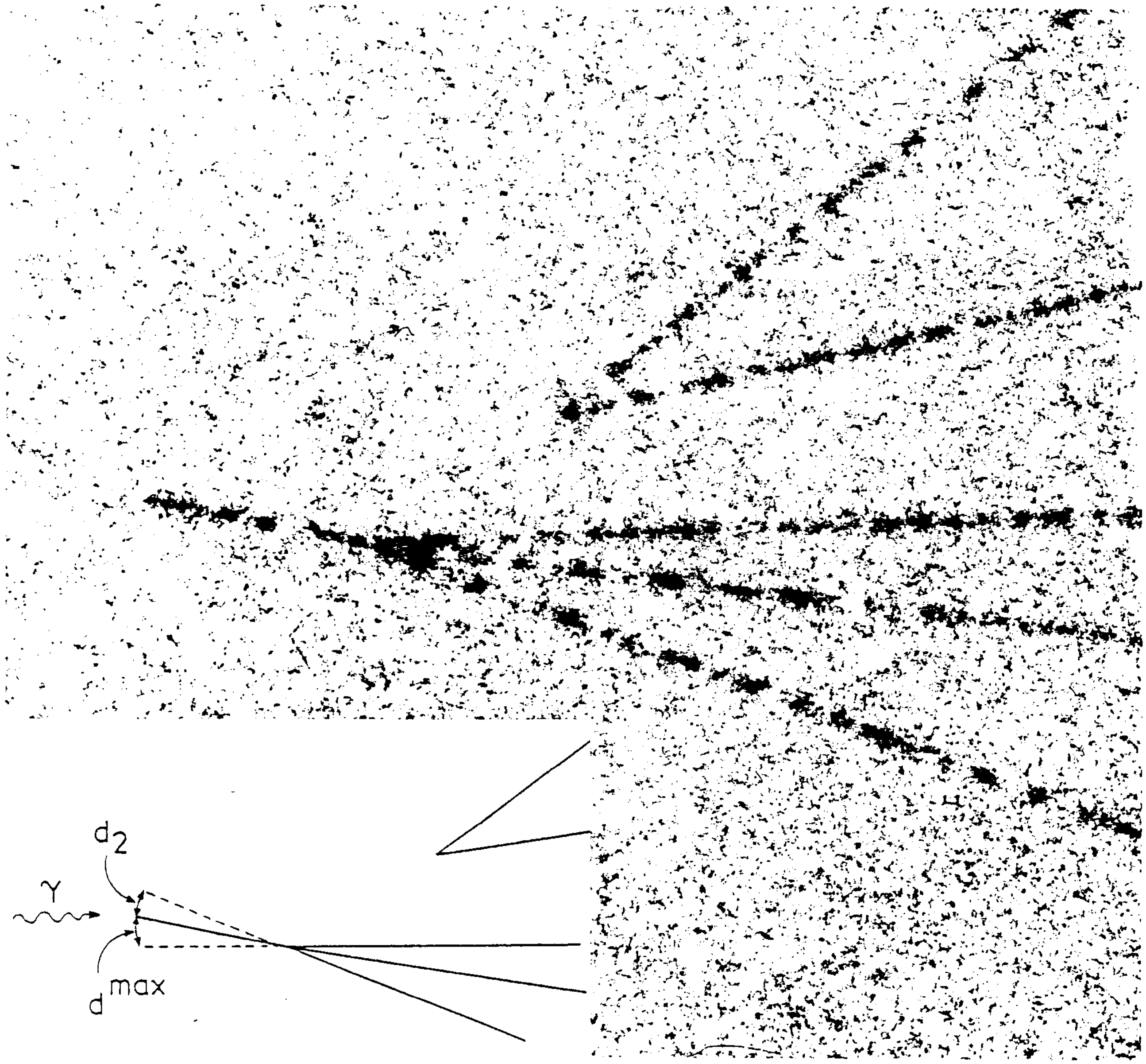
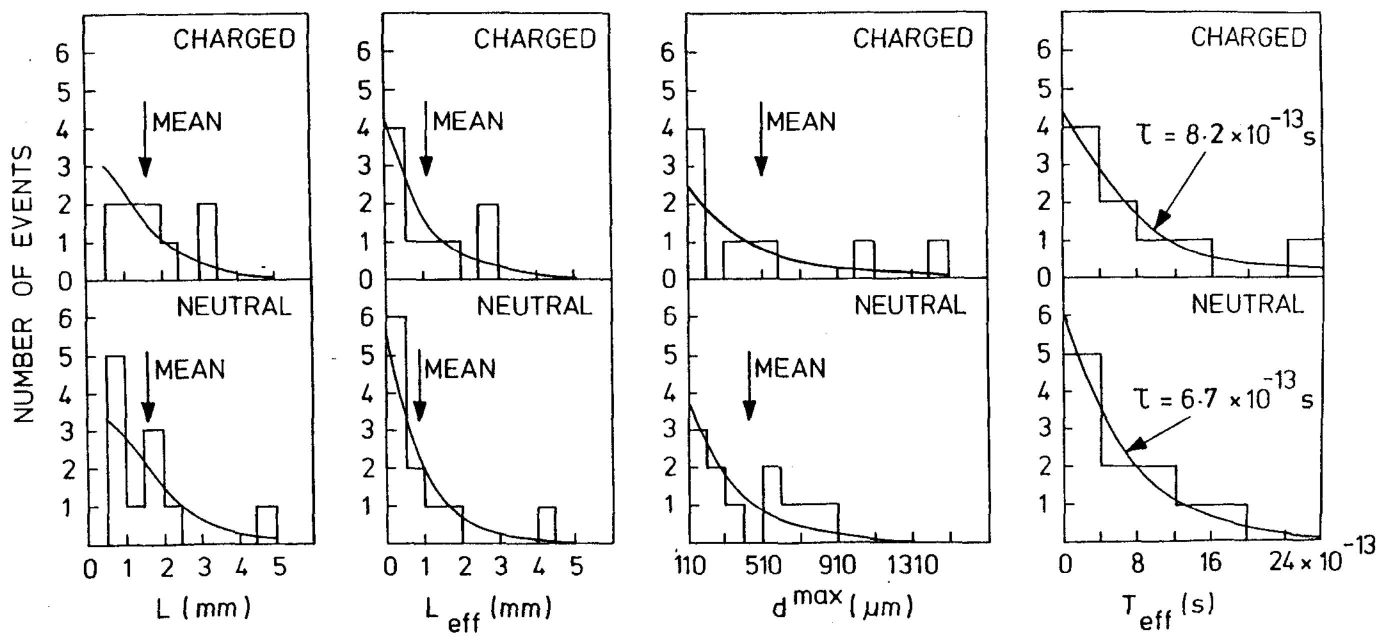


Fig. 1



NUMBER OF EVENTS
CHARGED
MEAN
NEUTRAL
L (mm)
L eff (mm)
d max (μm)
T eff (s)
τ = 8·2 × 10⁻¹³ s
τ = 6·7 × 10⁻¹³ s
0 1 2 3 4 5
110 510 910 1310
0 8 16 24 × 10⁻¹³

Fig. 2