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

K. Abe, T. C. Bacon, J. Ballam, L. Berny, A. V. Bevan, H. H. Bingham, J. E. Brau, D. Brick, W. M. Bugg, J. Butler, W. Cameron, J. T. Carroll, C. V. Cautis, J. S. Chima, H. O. Cohn, D. C. Colley, G. T. Condo, S. Dado, R. Diamond, P. J. Dornan, R. Erickson, T. Fieguth, R. C. Field, L. Fortney, B. Franek, N. Fujiwara, R. Gearhart, J. Goldberg, G. P. Gopal, A. T. Goshaw, E. S. Hafen, V. Hagopian, G. Hall, E. R. Hancock, T. Handler, H. J. Hargis, E. L. Hart, P. Haridas, K. Hasegawa, T. Hayashino, D. Q. Huang,[a] R. I. Hulsizer, S. Isaacson, M. Jobes, G. E. Kalmus, D. P. Kelsey, J. Kent, T. Kitagaki, P. Lang,[a] J. Lannutti, A. Levy, P. W. Lucas, W. A. Mann, T. Maruyama, M. MacDermott, R. Merenyi, R. Milburn, C. Milstene, K. C. Moffeit, J. J. Murray, A. Napier, S. Noguchi, F. Ochiai, S. O'Neale, A. P. T. Palounek, I. A. Pless, M. Rabin,[b] P. Rankin, W. J. Robertson, A. H. Rogers, E. Ronat, H. Rudnicka, T. Sato, J. Schneps, J. Shank, A. M. Shapiro, C. Sinclair, R. Sugahara, A. Suzuki, K. Takahashi, K. Tamai, S. Tanaka, S. Tether, H. B. Wald, W. D. Walker, M. Widgoff, C. G. Wilkins, S. Wolbers, C. A. Woods, Y. Wu, A. Yamaguchi, R. K. Yamamoto, S. Yamashita, G. Yekutieli, Y. Yoshimura, G. P. Yost, and H. Yuta

Birmingham University, Birmingham, B15 2TT, England, and Brown University, Providence, Rhode Island 02912, and Duke University, Durham, North Carolina 27706, and Florida State University, Tallahassee, Florida 32306, and Imperial College, London, SW7 2AZ, England, and National Laboratory for High Energy Physics (KEK), Oho-machi, Tsukuba-gun, Ibaraki-ken 300-32, Japan, and Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, and Nara Women's University, Nara, Japan 630, and Oak Ridge National Laboratory, Oak Ridge, Tennessee 37830, and Rutherford Appleton Laboratory, Didcot, Oxon, OX11 0QX, England, and Stanford Linear Accelerator Center, Stanford University, Stanford, California 94305, and Technion-Israel Institute of Technology, Haifa 32000, Israel, and Tohoku University, Sendai 980, Japan, and Tufts University, Medford, Massachusetts 02155, and University of California, Berkeley, California 94720, and University of Tel Aviv, Ramat-Aviv, Tel Aviv, Israel, and University of Tennessee, Knoxville, Tennessee 37916, and Weizmann Institute, Rehovot, Israel

(Stanford Linear Accelerator Center Hybrid Facility Photon Collaboration)

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Eleven neutral and nine charged decays of charmed particles have been observed in a sample of 205 000 hadronic interactions in a 1.2-million-picture exposure of the SLAC Hybrid Facility bubble chamber to a 20-GeV/c backward-scattered laser beam. The charged and neutral lifetimes were determined to be $8.2^{+4.5}_{-2.5}\times 10^{-13}$ 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 roughly monochromatic gamma-ray beam incident on the 1-m hydrogen bubble chamber operated at 10 Hz. A photon beam was chosen, rather than a hadron beam of comparable energy, to enhance the fraction of interactions producing charmed particles. It uses 30-GeV electron-beam pulses to scatter backwards the ultraviolet photon pulse from a frequency quadrupled neodymium-doped yttrium aluminum garnet laser. This Compton-scattered beam was collimated to 3 mm in diameter. Its spectrum peaked at 20 GeV with a full width at half maximum of 2 GeV, and it usually contained 25 photons per pulse.

Following the bubble chamber were four sets of multiwire proportional chambers (MWPC's), two atmospheric pressure Cherenkov counters, and a lead-glass wall.[3] All the downstream detectors were deadened in the region containing e^+e^- pairs from beam conversions.

In order to detect charm decays near the interaction vertex, a fourth camera having a resolution of 55 μm over a depth of $\pm$ 6 mm was used.

The bubble chamber was operated at an elevated temperature and the flash lamps were triggered 200 μsec after the beam passage. This resulted in 70 bubbles/cm of 55 μm 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% of the multiprong hadronic cross section with a yield of one event per six photographs. This trigger efficiency was determined by taking some untriggered photographs throughout the experiment but recording the trigger decision. Monte Carlo studies indicate that approximately 80% of the charm cross section is included by the trigger.

The results presented here are based on 1.2 $\times 10^6$ pictures containing approximately 205 000 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. The impact distance was measured to $\pm \frac{1}{4}$ track width. Only decays having two or more charged tracks were considered. Decays consistent with strange-particle hypotheses were eliminated. This was accomplished by making cuts on the invariant mass. To eliminate K^0 decays, the two-body (assumed to be $\pi\pi$) invariant mass had to be greater than 550 MeV/c^2 and also more than 5 standard deviations above the K^0 mass in order to be accepted. Analogous criteria were used for Λ and $K_{\pi 3}$ decays. 29 events remained with one or two visible charmed-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 Fig. 1). (C2) A minimum impact distance cut of 40 μm was imposed on a second track from the same decay vertex to eliminate one-prong decays which happen to be superimposed on other tracks (see d_2 in Fig. 1). (C3) A minimum decay length cut of 500 μm was imposed to allow a clean separation of the charged and neutral decays.

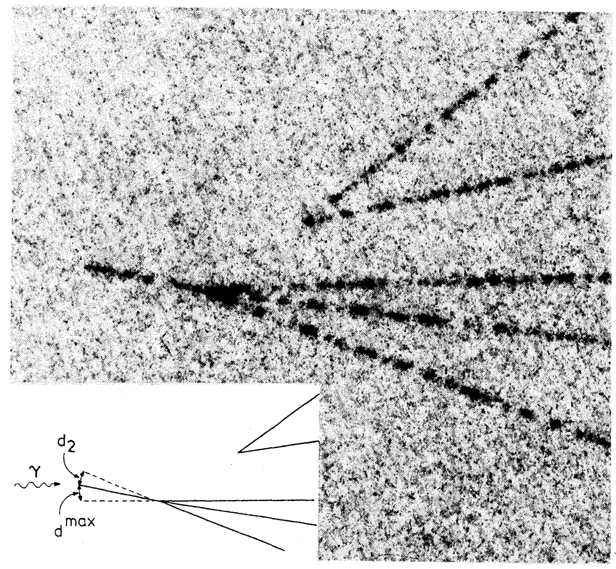

FIG. 1. An event showing the decay of a positive charmed particle into three charged tracks after 0.86 mm and the decay of a neutral charmed particle after 1.8 mm. Both decays contain missing neutrals and cannot come from strange particles. The quantities $d^{\max}$ and d_2, the largest and second-largest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

After these cuts were imposed, 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 five of the charged decays are compatible with Cabibbo-allowed D decays with no missing neutral particles. Typical invariant-mass errors on these events are 15 MeV/c^2. The rest of the decays are compatible with D's if a missing π^0, $\overset{(-)}{K}{}^0$, 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 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) traveled 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, and 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 five charged and three 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 $\overline{T}_{eff}$:

$$\langle \overline{T}_{eff}\rangle = \frac{K}{N}\sum_{i=1}^{N}\left(\frac{L_{eff}M}{P'c}\right)_i ,$$

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 $\langle \overline{T}_{eff}\rangle$ is a 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 lifetimes as determined from different charm production models differ by less than 20%.

Figure 2 gives the experimental distributions of L, L_{eff}, d^{max}, and $\overline{T}_{eff}$. 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 the methods which use all the decays (methods II, III, IV, and V) in a maximum-likelihood determination of the lifetimes, where these parameters ($\overline{T}_{eff}$, d^{max}, L, and L_{eff}) are compared on an event-by-event basis to the Monte Carlo calculation. From this we obtain

$$\tau^{\pm} = (8.2^{+4.5}_{-2.5})\times 10^{-13}\ \mathrm{sec},$$

$$\tau^{0} = (6.7^{+3.5}_{-2.0})\times 10^{-13}\ \mathrm{sec},$$

$$\tau^{\pm}/\tau^{0} = 1.2^{+0.9}_{-0.5}.$$

The errors are dominated by statistics but also include systematic effects. The values obtained by

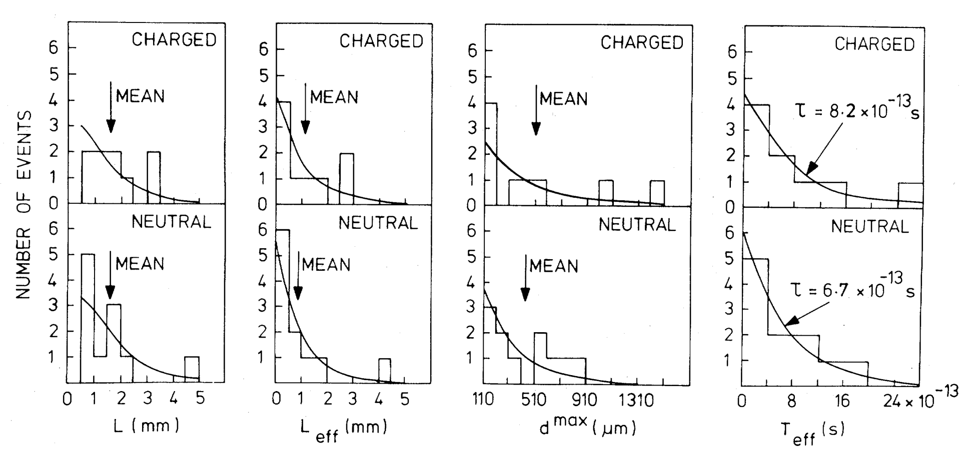

FIG. 2. Distributions of L, L_{eff}, d^{max}, and $\overline{T}_{eff}$. The curves are from Monte Carlo calculations using the charged and neutral lifetimes given in the text normalized to the number of decays.

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

Method	Charged lifetime (10^{-13} sec)	Neutral lifetime (10^{-13} sec)	Charged/Neutral
I. $\langle L_{\rm eff}\rangle$, decays with no missing neutrals	$8.2^{+6.5}_{-2.5}$ (5 decays)	$9.4^{+12.0}_{-4.0}$ (3 decays)	$0.9^{+1.0}_{-0.6}$
II. $\langle \overline{T}_{\rm eff}\rangle$	$7.6^{+4.5}_{-2.5}$	$6.4^{+3.5}_{-2.0}$	$1.2^{+0.9}_{-0.5}$
III. $\langle d^{\rm max}\rangle$	$9.6^{+6.5}_{-3.5}$	$7.4^{+5.0}_{-3.0}$	$1.3^{+1.2}_{-0.6}$
IV. $\langle L\rangle$	$8.4^{+4.5}_{-2.5}$	$6.8^{+3.5}_{-2.0}$	$1.2^{+0.9}_{-0.5}$
V. $\langle L_{\rm eff}\rangle$	$8.1^{+4.5}_{-2.5}$	$6.7^{+3.5}_{-2.0}$	$1.2^{+0.9}_{-0.5}$

method I given in Table I are consistent with these, but are not as significant because of the small number of events. The results are insensitive to reasonable changes in the values of the cuts C1, C2, and C3. The curves in Fig. 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 $\overline{D}^0$ without missing neutral particles and has an effective proper flight time of 21.8×10^{-13} sec. This decay would be an unlikely occurrence if the lifetime were considerably shorter than that measured by this experiment, e.g., for lifetimes less than 3×10^{-13} sec.

In conclusion, we have examined the decays of eleven neutral and nine 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.

We wish to thank the SLAC bubble chamber crew for their dedication in achieving high quality under difficult conditions. We are especially indebted to the film scanners for their efforts in finding the events.

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[a]On leave of absence from the Institute of High Energy Physics, Beijing, China.

[b]Permanent address: University of Massachusetts, Amherst, Mass. 01003.

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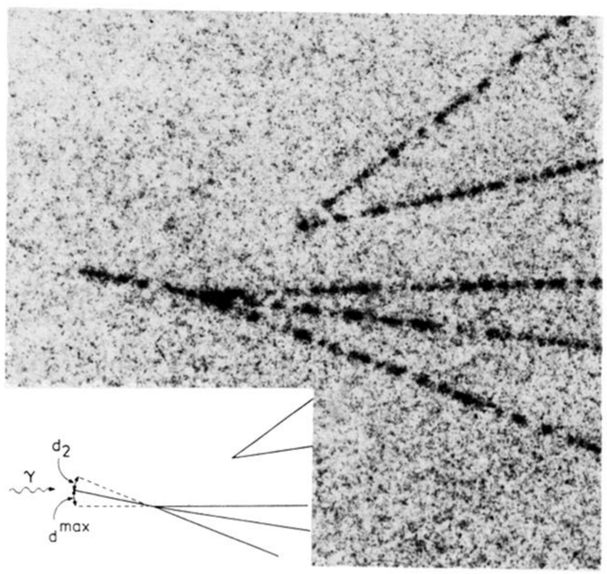

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