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CHARMED MESON LIFETIMES FROM 20 GEV PHOTOPRODUCTION

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A sample of 134 events containing 159 visible multiprong charm decays has been obtained from the 20 GeV charm photoproduction experiment at the SLAC Hybrid Facility. Following a selection procedure which ensures high and uniform detection efficiency for selected events, 47 charged, 46 neutral and five topologically ambiguous decays remain. These decays yield preliminary lifetimes of

$$\tau_{D^{\pm}} = (9.2 \pm 1.5 \pm 0.5) \times 10^{-13} \text{ secs}$$

$$\tau_{D^0} = (6.1 \pm 1.1 \pm 0.4) \times 10^{-13} \text{ secs}$$

and a ratio

$$\frac{\tau_{D^{\pm}}}{\tau_{D^0}} = 1.5^{+0.6}_{-0.3} \pm 0.1$$

One fully reconstructed four-body D^0 decay has a proper flight time of 55×10^{-13} seconds.

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Introduction

The SLAC Hybrid Facility Photon Collaboration⁽¹⁾ has recently completed the scanning and preliminary analysis of 3.6 million bubble chamber pictures taken with a high resolution camera capable of detecting charmed particle decays (Experiments BC72-73 and BC75). A comparison of charged and neutral D meson lifetimes is interesting since it reveals the role of non-spectator processes in the decay (these processes being Cabibbo suppressed for the D^+ meson).⁽²⁾ The absence of non-spectator processes (a simple spectator model) would predict equal charged and neutral D lifetimes.

The Experiment

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 10-12 Hz. The beam was 3 mm in diameter, peaked at 20 GeV with a FWHM of 2 GeV, and contained an average of 25 photons per pulse. Following the bubble chamber were four sets of multiwire proportional chambers (MWPC), two atmospheric pressure Cerenkov counters, and a lead-glass wall. The Cerenkov counters (filled with Freon) separated pions from kaons and protons in the momentum range 3 GeV/c to 10.7 GeV/c during BC72/73 and from 2.6 GeV/c to 9.3 GeV/c during BC72/73. The lead glass wall measures pi zeros with a mass resolution of about 10 MeV/c. Details of the apparatus are described in Reference 1.

In order to detect charm decays near the interaction vertex, a fourth camera with high resolution optics (HRO) was used. This camera resolved 55 micron bubbles over a depth of field of ± 6 mm for BC72/73 and 40 micron bubbles over ± 3 mm for BC75 when a new camera employing two lenses was installed. Each lens viewed approximately one-half of the bubble chamber. The bubble chamber was operated at an elevated temperature of 27°K to give a high bubble density of 60 per cm but a slow bubble growth to allow sufficient time to trigger the camera.

The cameras were triggered on either of two conditions. The first condition was the passage through three MWPC stations of any charged particles originating in the fiducial volume of the bubble chamber. The required calculation was performed by a 168/E processor. The second trigger condition was based on the energy deposited in the lead-glass wall. With this combination, we triggered on 88 ± 6 percent of the charm cross section as indicated by untriggered data and by Monte Carlo studies.

The Data

The results presented here are based on approximately 678,000 hadronic interactions within a useable fiducial volume. The fiducial volume has been

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restricted to ensure a high and uniform detection efficiency, to ease interpretation, and to yield good momentum measurements. All hadronic events were closely examined at least twice for the decays of short-lived particles within 1 cm of the interaction vertex. For BC75 the search was extended to 1.5 cm. 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 by an impact distance of at least one track width. Only decays having two or more charged tracks are considered here. Decays consistent with strange particle hypotheses were eliminated. One hundred thirty-four events remained with one hundred fifty-nine visible multiprong charmed particle decays. Examples of events from this experiment with charmed particle decays have been published.⁽¹⁾

Three cuts were imposed on all events:

1. An impact distance greater than 110 μm (2-3 track widths) was required for at least one track in each event to ensure high efficiency for finding charged and neutral decays. This defines d_{max} .
2. A second track from the same decay vertex was required to have an impact distance of at least 40 μm to select multiprong decays. This is d_2 .
3. A minimum decay length cut of 600 μm was imposed to allow a clean separation of the charged and neutral decays.

We have investigated possible sources of background which would simulate charmed particle decays. These studies, based on calculations and searching for decays at distances greater than 1 cm, show that backgrounds from all sources are small compared to 1 event.

After imposing the three cuts, ninety-two events remain containing ninety-eight decays satisfying all three conditions. These included forty-six neutral (twenty-one two-prongs and twenty-five four-prongs), sixteen positive (one five-prong and one three-prong with an additional Dalitz pair), thirty-one negative (twenty-nine three-prongs and two five-prongs) and five charge/neutral ambiguous decays.

Results

The lifetime for a D meson which travels a distance z and has a momentum P is

$$\tau = \frac{zM_D}{Pc}$$

where M_D is the D meson mass and c is the speed of light. For the purpose of determining the lifetime of the D meson from a sample of decays we must measure the proper flight time of each decay beyond the point at which it would pass all cuts described above. We therefore replace z with z_{eff} , where

$$z_{\text{eff}} = \min \left\{ \left(1 - \frac{110\mu\text{m}}{d_{\text{max}}}\right)z, \left(1 - \frac{40\mu\text{m}}{d_2}\right)z, z - 600\mu\text{m} \right\}.$$

In order to estimate p for all decays which pass the cuts described above we use p_{vis} , the momentum obtained from the charged tracks and m_{vis} , the visible mass obtained by assuming all charged tracks are pions. We then determine the relationship between m_{vis} and the actual visible mass, $m_{\text{vis}}^{\text{actual}}$ by a Monte Carlo which incorporates the current best knowledge of D decay branching ratios. This study yields, for decays that have missing neutrals or are Cabibbo suppressed, $\alpha = \langle \frac{m_{\text{vis}}^{\text{actual}}}{m_{\text{vis}}} \rangle = 1.10 \pm .02$ where the error indicates the uncertainty due to errors in the branching ratios. The standard deviation of α on an event to event basis is 0.13, indicating the level of uncertainty in estimating $m_{\text{vis}}^{\text{actual}}$ from m_{vis} . The lifetime estimation is then

$$\tau_{\text{est}} = \frac{z_{\text{eff}} \alpha m_{\text{vis}}}{p_{\text{vis}} c}$$

and it is only dependent on decay model assumptions (with an uncertainty of less than two per cent) and is independent of particle momentum (and consequently production model). It is also reasonably insensitive to the specific cuts used to select data, as long as the cuts chosen ensure uniform detection efficiency as a function of length, as ours do.

The total sample of forty-seven charged and forty-six neutral decays have distributions of τ_{est} shown in Figures 1 and 2. The mean proper flight times

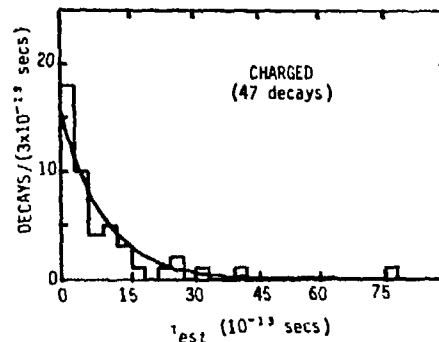


Figure 1) The τ_{est} distribution for charged decays. The curve is an exponential with lifetime of 9.1×10^{-13} seconds normalized to 46 decays.

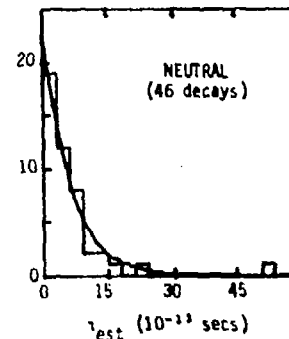


Figure 2) The τ_{est} distribution for neutral decays. The curve is for a lifetime of 6.2×10^{-13} seconds normalized to 47 decays.

are 9.1×10^{-13} s and 6.2×10^{-13} s.⁽³⁾ These must be corrected for the loss of decays to the charged/neutral ambiguous sample. To estimate this effect, we have considered the 32 possible assignments of the five ambiguous decays between charged and neutral. For each event t_{eff} is independent of this choice but p_{vis} and m_{vis} depend on it. The effect of the ambiguous decays is to shift our best estimates downward to 8.8×10^{-13} s and 6.1×10^{-13} s.

One additional correction is needed to convert the lifetimes to D-meson lifetimes: the contamination of A_C^+ and F decays within the charged decay sample must be corrected for. When this is done, we find

$$\tau_{D^+} = (9.2 \pm 1.5 \pm 0.5) \times 10^{-13} \text{ sec}$$

$$\tau_{D^0} = (6.1 \pm 1.1 \pm 0.4) \times 10^{-13} \text{ sec}$$

and the charged to neutral lifetime ratio is

$$\frac{\tau_{D^+}}{\tau_{D^0}} = 1.5_{-0.3}^{+0.6} \pm 0.1$$

This measurement of the D^{\pm} lifetime is fully consistent with the two world average lifetimes reported in the Leipzig Conference⁽⁴⁾ Proceedings ($\sim 9.0 \pm 1.0 \times 10^{-13}$ s), while the neutral lifetime is just over one standard deviation above the world average value of $\sim (4.2 \pm 0.4) \times 10^{-13}$ s. This is not particularly alarming, but one of the neutral decays in the experiment is extremely long, highly unlikely to have emerged from a lifetime of 4.2×10^{-13} s. This event, shown in Figure 3, contains two charm decays, one of which is a four prong decay 9.0 mm from the production vertex. The decay is identified as $K^+ \pi^+ \pi^+ \pi^-$, either by

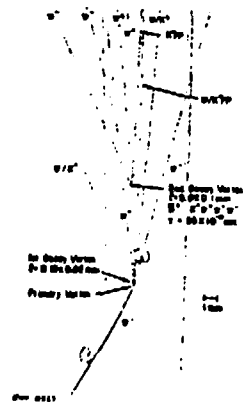


Figure 3) A photograph showing an event with a D^0 decay after 9 mm. The proper flight time for this $D^0 \rightarrow K^+ \pi^+ \pi^+ \pi^-$ decay is 55×10^{-13} s.

information from the Cerenkov counter or ionization in the bubble chamber (although the K is ambiguous with p and the pions with e or μ). It has an effective mass of $1862 \pm 8 \text{ MeV}/c^2$. Further details on the event are given in reference 5 where it is shown that the background sources for this event are extremely small (less than 1 in 6×10^7 experiments of our size). Figure 4 shows the relative probability that the event would appear in an experiment the size of ours as a function of the charm lifetime. The D^+/\bar{D}^0 is required to decay to $K^+ \pi^+ \pi^+ \pi^-$ (with a 7.5% branching ratio) and to decay after 55×10^{-13} seconds. The probability for an experiment of our size to see a D^0 surviving 55×10^{-13} seconds when the D^0 lifetime is 6.1×10^{-13} seconds is about two percent while it would be about 3×10^{-4} if the D^0 lifetime were 4.2×10^{-13} seconds.

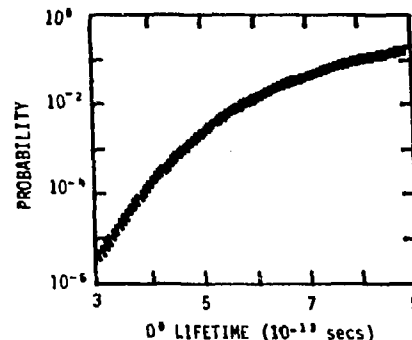


Figure 4) Probability that an experiment of this size would contain an acceptable D^0/\bar{D}^0 with proper flight time $> 55 \times 10^{-13}$ seconds.

References

1. K. Abe et al., "Charm Photoproduction at 20 GeV," *Physical Review D* **30**, 1 (1984).
2. N. Cabibbo and L. Maiani, *Phys. Lett.* **79B**, 109 (1978); N. Cabibbo, G. Corbo, and L. Maiani, *Nucl. Phys.* **B115**, 93 (1979); B. Guberina et al., *Phys. Lett.* **89B**, 111 (1979); W. Bernreuther, O. Nachtmann, and B. Stech, *Z. Phys.* **C 4**, 257 (1980); H. Fritzsch and P. Minkowski, *Phys. Lett.* **90B**, 455 (1980); M. Bander, B. Silverman, and A. Soni, *Phys. Rev. Lett.* **44**, 7 (1980).
3. This procedure for determining lifetimes is preferred over that used in reference 1 since it is more direct while retaining the model independence of our earlier method. The latter, based on a comparison of the parameters t , t_{eff} , d_{max} , and t_{eff} to Monte Carlo events on an event by event basis, yields for the present data sample (ignoring the ambiguous decays) a charged lifetime of $8.1 \pm 1.2 \times 10^{-13}$ s and a neutral lifetime of $6.2_{-0.9}^{+1.1} \times 10^{-13}$ s (statistical errors only). These numbers are well within the errors of our current method.
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