

Measurement of the D^+ and D^0 Lifetimes

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(Received 14 October 1986)

We have used a silicon-microstrip vertex detector with the Tagged Photon Spectrometer to measure the lifetimes of charmed mesons produced by a high-energy photon beam at Fermilab. The D^+ lifetime, based on 969 $D^+ \rightarrow K^- \pi^+ \pi^+$ decays, is measured to be $(1.06 \pm 0.05 \pm 0.03) \times 10^{-12}$ s. Using 1360 D^0 decays into the modes $K^- \pi^+$ and $K^- \pi^+ \pi^- \pi^+$, we determine the lifetime to be $(0.435 \pm 0.015 \pm 0.010) \times 10^{-12}$ s. The ratio $\tau(D^+)/\tau(D^0)$ obtained from these two measurements is $2.44 \pm 0.14 \pm 0.08$.

PACS numbers: 13.25.+m, 14.40.Jz

The area of charmed-particle lifetimes has recently received much attention from both experimental and theoretical physicists. The large difference between the D^0 and D^+ lifetimes contradicts the simple spectator-quark model. Explanations for this difference include enhancement of the D^0 decay rate due to the W -exchange diagram, and suppression of the D^+ decay due to destructive interference, among others.¹ Accurate measurements of the lifetimes of all the charmed particles are a necessary part of understanding the charm decay. This paper presents results from the analysis of D^+ and D^0 lifetimes in a high-energy photoproduction experiment using the Fermilab Tagged Photon Spectrometer (TPS). The characteristics of the experiment which are important for the lifetime measurement are high statistics with low background, proper time resolution much smaller than the lifetime, and good control of systematic errors.

The TPS is a two-magnet spectrometer of large acceptance, with drift chambers, Cherenkov counters, and electromagnetic and hadronic calorimetry. The original configuration of the spectrometer has been described elsewhere.² For the present experiment, more drift-chamber planes were added and the Cherenkov counters were improved. In addition, nine silicon-microstrip detectors³ (SMD's) were installed downstream of a 5-cm beryllium target. These detectors, with 50- μ m strip

spacing, provided measurement of charged tracks with enough precision to resolve the charm vertex for approximately half of the decays. The trigger required a total transverse energy (E_T) in the calorimetry of at least 2.2 GeV. This requirement was about 80% efficient for events with charm, and suppressed the total hadronic interaction rate by a factor of about 2.5. The incident-photon energy spectrum had approximately a bremsstrahlung form from 100 to 260 GeV. We recorded about 10^8 events, of which 10% were taken without the E_T requirement; the present results are based on analysis of about 3×10^7 events.

The events were reconstructed in the SMD-drift-chamber tracking system and the Cherenkov-counter information was used to identify particles. For each channel, there was a minimum requirement on the joint probability for the appropriate particle-identification assignment. The charm-decay tracks were required to form a good vertex, and all other tracks in the event were used to form possible primary vertices. A search was made for all primary-vertex candidates within a transverse distance of 80 μ m from the line of flight of the reconstructed charm candidate. This selection of maximum transverse distance keeps about 80% of the charm decays, almost independently of the decay time, and reduces the background significantly. To reduce the noncharm background, only charm candidates were chosen which de-

TABLE I. Characteristics of the samples used for the D^0 lifetime. L is the minimum decay length accepted and σ is the error in measurement of the decay length. The error quoted on the expected background is the statistical error in determination of the background from the mass region near the D^0 .

Mode	L/σ	No. signal	No. Background	Lifetime (ps)
$D^{*+} \rightarrow \pi^+ D^0, D^0 \rightarrow K^- \pi^+$	5	385	16 ± 2	0.46 ± 0.03
$D^{*+} \rightarrow \pi^+ D^0, D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$	7	228	37 ± 3	0.40 ± 0.03
$D^0 \rightarrow K^- \pi^+$	8	746	450 ± 10	0.43 ± 0.02

cayed at least a distance L downstream of the primary vertex. The distance L was chosen to be $(5-10)\sigma$, depending on decay mode, where σ is the error on the distance between primary and secondary vertices. The value of σ is typically $300 \mu\text{m}$ for a D momentum of $60 \text{ GeV}/c$, and increases almost linearly with momentum. In the 20% of the events with multiple primary-vertex candidates, L was calculated from the most downstream candidate, to be sure that it was downstream of any possible production point. The proper time was calculated from the point a distance L downstream of the primary vertex to the observed decay vertex. The shape of the distribution is therefore insensitive to errors in the primary vertex position which are less than L . Errors larger than this occur in only about 1% of the events. The fiducial region for decays was defined to end at the first SMD plane. In the D^0 analysis we used only events for which the proper time corresponding to the end of this region, t_{max} , was beyond the maximum time used in the fit (1.8 ps). For the D^+ , the fit to the time spectrum extended to a maximum decay time of 4.0 ps. There was some loss of events at long decay times due to decay beyond the end of the fiducial region, which was taken into account in the fitting of the spectrum. D^+ events with $t_{\text{max}} < 2.0$ ps were not used, regardless of the measured decay time t , because for these events the correction was relatively large.

The function

$$Nf(t)(1/\tau)\exp(-t/\tau) + B(t)$$

was used to fit the proper time distribution. In this expression, $B(t)$ is the normalized time distribution for the background, as determined from the regions of the mass plot just outside the signal. The two parameters allowed to vary in the fit were N , the number of events in the charm signal, and τ the charm lifetime. The function $f(t)$, which was obtained from the Monte Carlo simulation, corrects for effects of absorption, acceptance, resolution, and efficiency. The effect of $f(t)$ on the lifetime is small; use of $f(t) = 1$ rather than the function obtained from the Monte Carlo simulation would change the lifetime by less than 10%.

For the D^0 -lifetime study, three independent samples were used (throughout the paper, the charge-conjugate

states are implicitly included):

$$(A) D^{*+} \rightarrow \pi^+ D^0, D^0 \rightarrow K^- \pi^+,$$

$$(B) D^{*+} \rightarrow \pi^+ D^0, D^0 \rightarrow K^- \pi^+ \pi^- \pi^+,$$

$$(C) D^0 \rightarrow K^- \pi^+ \text{ (no } D^{*+}\text{)}.$$

Events which satisfied the requirements for sample (A) were excluded from sample (C) so that the samples are indeed independent for the purpose of lifetime measurement. For samples (A) and (B) the mass difference $m(D^{*+}) - m(D^0)$ was required to be between 0.1435 and $0.1475 \text{ GeV}/c^2$. The minimum decay length L used for each mode is shown in Table I. The mass distributions for the events which satisfy the vertex cuts are shown in Fig. 1; there is a clear D^0 peak in each of the three modes. Table I gives the numbers of events in the

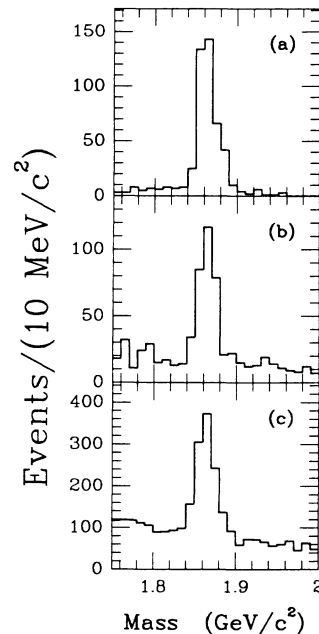


FIG. 1. Invariant-mass spectra for three D^0 channels with vertex cuts as described in the text. (a) $D^{*+} \rightarrow \pi^+ D^0, D^0 \rightarrow K^- \pi^+$; (b) $D^{*+} \rightarrow \pi^+ D^0, D^0 \rightarrow K^- \pi^+ \pi^- \pi^+$; and (c) $D^0 \rightarrow K^- \pi^+$, no D^{*+} .

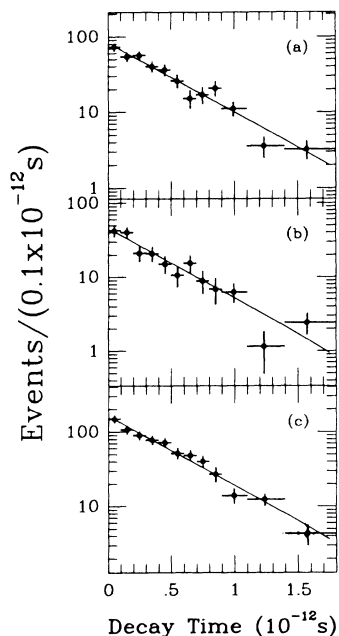


FIG. 2. Proper-time spectra for the three D^0 channels, in the same order as Fig. 1. The data points are shown with background subtracted. The error bars represent the statistical error, including that on the background. The smooth curve represents the best fit as described in the text.

signal and background for the mass range 1.839–1.889 GeV/c^2 . The time distributions for the three D^0 channels, shown in Fig. 2, all follow an exponential form. The maximum-likelihood fits to the three distributions give the lifetimes shown in Table I. The three samples are statistically independent, and have different corrections and backgrounds. The fact that the three measurements agree within statistical errors provides some check of the corrections used. A global fit to all three samples gives our best number for the D^0 lifetime, $\tau(D^0) = 0.435 \pm 0.015$ ps. The correction $f(t)$ was determined from the Monte Carlo program, and the resulting shift in the D^0 lifetime is -0.03 ps, with an associated systematic error ± 0.007 ps. The background subtraction is negligible for the two D^* modes, and for channel (C) causes a correction of $+0.05$ ps. The corresponding change in the average D^0 lifetime is $+0.02$ ps, with an error of ± 0.005 ps. The total systematic error is thus ± 0.010 ps.

The decay mode $D^+ \rightarrow K^- \pi^+ \pi^+$ was used for the D^+ lifetime study. The mass spectrum for the accepted events, with use of a minimum decay length $L = 10\sigma$, is shown in Fig. 3. There are 969 D^+ events in the selected mass region 1.848–1.890 GeV . The expected number of background events, as determined from the number of events outside the D^+ region, is 383 ± 9 . This represents a reduction of the background by a factor of 300 as a result of the cuts on vertex separation.

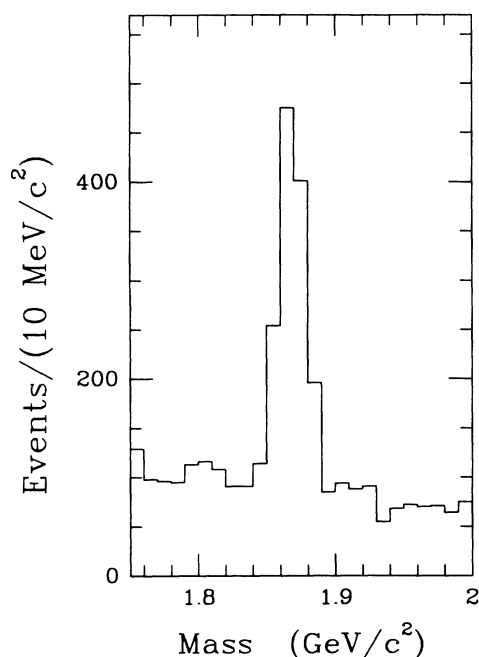


FIG. 3. Invariant-mass spectrum for $K^- \pi^+ \pi^+$.

The D^+ time distribution is shown in Fig. 4. The maximum-likelihood fit, including the correction at long times described above, gives a lifetime of 1.06 ± 0.05 ps. The contributions to the systematic error for the D^+ are somewhat different from those for the D^0 because of the longer lifetime. The correction to the D^+ lifetime for the effects of resolution, efficiency, acceptance, and false primary vertices is -0.05 ps, with a systematic error of ± 0.015 ps. The absorption of the decay products in the beryllium target leads to an additional correction of -0.03 ps, with an error of ± 0.005 ps. The background subtraction produces a correction to the D^+ mean life-

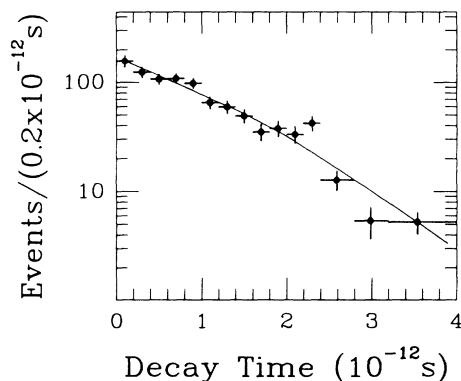


FIG. 4. Proper-time spectrum for D^+ events. The data points are shown with background subtracted, as in Fig. 2. The smooth curve represents the best fit as described in the text.

time of $+0.25$ ps, which is relatively large because the effective lifetime of the background is much shorter than that of the signal. For the same reason, we were able to test the background subtraction by choosing samples with more or less background. The systematic error due to this subtraction is ± 0.025 ps. On addition of these systematic errors in quadrature, the total systematic error is ± 0.03 ps.

The D^0 lifetime of $0.435 \pm 0.015 \pm 0.010$ ps that we measure is consistent with the world average of $0.43^{+0.05}_{-0.04}$ ps.⁴ The D^+ lifetime of $1.06 \pm 0.05 \pm 0.03$ ps is somewhat higher than the world average of $0.92^{+0.13}_{-0.08}$ ps.⁴ The ratio of the average lifetimes is $2.1^{+0.04}_{-0.03}$. The ratio of lifetimes can also be inferred from the ratio of semileptonic branching ratios $B(D^+ \rightarrow e^+ + X)/B(D^0 \rightarrow e^+ + X)$, which Baltrusaitis *et al.* have measured to be $2.3^{+0.05}_{-0.04} \pm 0.1$.⁵ This is equal to the ratio of lifetimes if one ignores the Cabibbo-angle-suppressed nonspectator process which only contributes to the D^+ semileptonic decay. Our measurement of the ratio of lifetimes is $2.44 \pm 0.14 \pm 0.08$.

We gratefully acknowledge the assistance of the staff of Fermilab and of all the participating institutions. This research was supported by the U.S. Department of Energy, by the Natural Science and Engineering Research Council of Canada through the Institute of Particle Physics, by the National Research Council of Canada,

and by the Brazilian Conselho Nacional de Desenvolvimento Científico e Tecnológico.

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