Measurement of the D^0 Lifetime

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We have used an electronic tracking system to measure the lifetime of D^0 mesons produced in e^+e^- annihilation at 29 GeV. Based on a sample of 27 events, the lifetime is found to be $(4.2^{+1.3}_{-1.0} \pm 1.0) \times 10^{-13}$ s.

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Since the discovery of the D^0 and D^+ mesons in 1976,[1,2] there has been considerable experimental work performed to measure their lifetimes. Such studies yield valuable information on the decay mechanisms and the charm-quark mass. Most lifetime experiments have used nuclear emulsions or bubble chambers where events must have measurable decay lengths to be recognized as charm candidates. This Letter is a report on a measurement of the lifetime of D^0 mesons produced in e^+e^- annihilation using an electronic detector. This approach provides a clean sample of D^0 mesons with a detection efficiency independent of lifetime.

The data used in this analysis were collected with the Mark II detector at the PEP storage ring (29-GeV center-of-mass energy) and correspond to an integrated luminosity of 136 pb^{-1}. The Mark II detector at PEP has been described elsewhere.[3] A recent addition, vital to the analysis reported here, is a high-resolution drift chamber, known as the vertex chamber,[4] which is inside and concentric with the inner shell of the main drift chamber. The vertex chamber comprises two bands of axial drift cells, the first band of four layers starting 10 cm from the beam axis, and the other band of three layers starting at 30 cm. The average spatial resolution is 110 μm/layer for tracks in hadronic events, thereby giving a position resolution for a track at the beam interaction point of $\sigma_\perp(\mu) = [95^2 + (95/p)^2]^{1/2}$ (cp in gigaelectronvolts) in the plane perpendicular to the beams. The inner shell of the vertex chamber serves as the beam pipe, and its thickness (0.6% of a radiation length) is the only material between the interaction point and the first position measurement. The vertex chamber and drift chamber operate in a solenoidal magnetic field of 2.3 kG and have a combined charged particle momentum resolution of $\delta p/p = [(0.02)^2 + (0.011p)^2]^{1/2}$ when tracks are not constrained to pass through the interaction point.

The sample of D^0 mesons was obtained by observing the decay

$$D^{*+} \to D^0\pi^+$$
$$\quad\quad \hookrightarrow K^-\pi^+.$$

(Reference to a particle state will always imply the sum of that state and its charge conjugate state.) It has previously been shown[5] that this decay can be isolated with very little background at high values of z, where z is the energy of the D^{*+} divided by the beam energy. For the analysis presented here, no attempt to identify particles was made, but all tracks were tried as kaons and pions. All oppositely charged $K\pi$ pairs with invariant mass between 1.72 GeV/c^2 and 2.00 GeV/c^2 were considered as D^0 candidates, and their momenta constrained using the D^0 mass. Each D^0 candidate was then combined with the additional pions of appropriate sign in the event, and those combinations with a small mass difference $(M_{D^0\pi} - M_{D^0})$ and $z > 0.6$ were considered as D^{*+} candidates.

Further cuts were then applied to ensure that the decay point of the D^0 was well measured. To minimize the probability that the K and π tracks from the D^0 had scattered or had suffered tracking confusion, we required that these tracks have momenta greater than 500 MeV/c and that none of the vertex-chamber measurement points be shared with nearby tracks in the event. The three tracks that made up the D^{*+} were each required to contain at least three measurement points in the vertex chamber, of which at least one was required to be in the inner band of drift cells. We also demanded that each track fit have an overall χ^2 per degree of freedom less than 5, and that the χ^2 per degree of freedom from the vertex chamber be less than 5. The π^+ originating from the D^{*+} decay passes very close to the decay vertex of the D^0. Thus it is possible to discriminate against events with tracks that have scattered or been mismeasured by requiring that all three particle trajectories be consistent with coming from a single vertex. We required the χ^2 of this three-particle vertex to be less than 15 for 3 degrees of freedom. The mass difference after all cuts is shown in Fig. 1. D^{*+} events were defined to be those with a mass difference between 143 and 149 MeV/c^2. A total of 27 events are seen in the D^{*+} region. From this figure, the combinatorial hadronic background is estimated to be two events. These 27 events were used for the lifetime analysis. In the standard model, B-meson decays may contribute up to 20% of the produced D^{*+} events, but phase-space considerations ensure that most of these D^{*+} events are of low momentum, whereas the charm fragmentation function is known to be hard.[5] It is estimated that 3% of the D^{*+} events with $z > 0.6$ originate from B decays.[6-9]

For the actual measurement of the lifetime, a two-particle D^0 vertex was constructed.[10] The most probable decay length for each observed D^0 decay was then calculated from the D^0 direction and vertex position, the beam position, and the errors in these quantities.[11] The beam position was determined for every 2-h run by finding the position which minimized the distance of closest approach for well-measured tracks. Its location was found to be stable over blocks of runs. The rms beam sizes were measured to be 65 ± 15 μm in the vertical direction and 480 ± 10 μm in the horizontal direction. The calculated uncertainty in the D^0 vertex position was typically similar in magnitude to the horizontal beam size. The decay lengths of the D^0 mesons were converted to proper decay times with use of their measured momenta. The uncertainty in the lifetime introduced by the uncertainty in the measured momenta of the particles is small compared with that introduced by the uncertainty in the measurement of the decay lengths. A histogram of the 27 measurements is displayed in Fig. 2(a). The most probable mean decay time for the D^0 was found by a maximum-likelihood fit of the 27 measurements with an exponential decay distribution convoluted with Gaussian errors specific to each event. The fit included effects due to B-meson decays and the combinatorial hadronic background as described below. The result of the fit was a mean decay time of $(4.2^{+1.3}_{-1.0}) \times 10^{-13}$ s (statistical errors only).

Several potential sources of systematic error have been considered. To check for biases in the vertex reconstruction and fitting procedure, we simulated D^0 mesons produced according to the above decay mechanism using Monte Carlo techniques. For input mean lifetimes of (0, 3, and 6)$\times 10^{-13}$ s, the analysis yielded the mean input lifetimes within statistical errors (less than 5×10^{-14} s). We also generated a control sample by creating fake D^0 decays out of hadronic tracks having roughly the same kinematics as real D^0 combinations. Tracks which combined with any other opposite-charge track in the event to form an invariant mass consistent with that of the K_S^0 were rejected. The mean lifetime of the fake D^0 events was measured to be $(0.4 \pm 0.2) \times 10^{-13}$ s. A histogram of the control-sample lifetimes is shown in Fig. 2(b). In order to verify that the Monte Carlo programs accurately

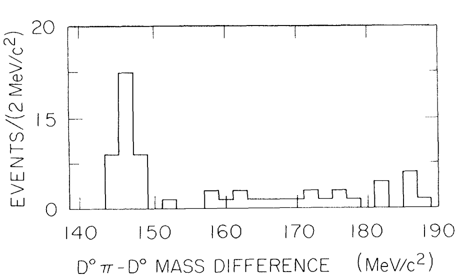

FIG. 1. The mass difference $M_{K\pi\pi} - M_{K\pi}$ for combinations with $1.72 < M_{K\pi} < 2$ GeV/c^2 and $z > 0.6$.

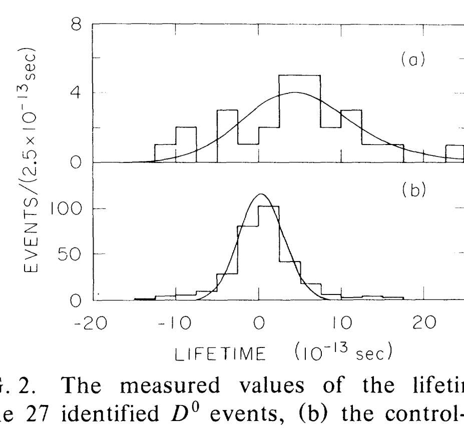

FIG. 2. The measured values of the lifetime for (a) the 27 identified D^0 events, (b) the control-sample hadrons. The solid curves are the result of the fit described in the text, and a fit by a Gaussian, respectively.

simulate the data, we used the same selection criteria to find a sample of fake D^0 mesons in Monte Carlo–simulated raw data. The mean lifetime of these fake D^0 events was $(0.5 \pm 0.2) \times 10^{-13}$ s. Therefore, we conclude that the Monte Carlo and real data-control samples agree to the level of 0.3×10^{-13} s. In the fit for the D^0 lifetime, the control-sample lifetime of 0.4×10^{-13} s was taken as the lifetime of the combinatorial hadronic background, and a value of 1.2×10^{-12} s was used for the B lifetime.[12] If the effects of events from these two sources are not included in the fit, the change in the measured value of the lifetime is -0.2×10^{-13} s and $+0.1 \times 10^{-13}$ s, respectively. We estimate the systematic error on the D^0 lifetime due to these effects to be 0.3×10^{-13} s. Reasonable variations in the errors assigned to the proper decay times of the events change the result by $\pm 0.4 \times 10^{-13}$ s. The measured lifetime is insensitive to small errors in the estimated beam position and size. From the above considerations, the systematic error on the measurement of the D^0 lifetime is estimated to be 1.0×10^{-13} s.

Therefore, based on a sample of 27 events, the lifetime of the D^0 has been measured to be $(4.2^{+1.3}_{-1.0} \pm 1.0) \times 10^{-13}$ s. This result is consistent with recent measurements of the D^0 lifetime from other experiments.[13–18]

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