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Evidence for Unequal Lifetimes of the D^o and D^{+}*

W. Bacino, T. Ferguson†, L. Nodulman‡, W. Slater and H. Ticho

Physics Department
University of California, Los Angeles, California 90024

A. Diamant-Berger§, G. Donaldson, M. Duro, A. Hall¶, G. Irwin,
J. Kirkby, F. Merritt**, and S. Wojcicki

Stanford Linear Accelerator Center and Physics Department
Stanford University, Stanford, California 94305

R. Burns‖, P. Condon‖‖, and P. Cowell§§

Physics Department
University of California, Irvine, California 92664

J. Kirz

Physics Department
State University of New York, Stony Brook, N.Y. 11794

Abstract

In the reaction $e^+e^- \rightarrow \psi''(3770)$, we have observed events containing either one to two electrons originating in semileptonic decays of D mesons. A comparison of these samples provides a determination of the branching ratios: $b(D^o \rightarrow Xe\nu) < 4.0\%$ (95% CL) and $b(D^+ \rightarrow Xe\nu) = (22.0 {}^{+4.4}_{-2.2})\%$. These values imply that the ratio of D^o and D^+ lifetimes is $\tau(D^+)/\tau(D^o) > 4.3$ (95% CL).

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† Current address: Cornell University, Ithaca, New York 14853

‡ Current address: Argonne National Laboratory, Argonne, Illinois /60439

§ Permanent address: CEN, Saclay, France

¶ Current address: Varian Associates, Palo Alto, California 94303

** Current address: University of Chicago, Chicago, Illinois 60637

‖ Current address: Hughes Aircraft Co., Newport Beach, California 92663

‖‖ Current address: Lawrence Berkeley Laboratory, Berkeley 94720

§§ Current address: Systems Control, Inc., Palo Alto, California 94303

The conventional model of the decay of charmed mesons[1] assumes that the light quarks are merely spectators and therefore predicts the D^0 and D^+ lifetimes to be equal. We report here a measurement of unequal lifetimes from a study of $D\bar{D}$ pairs produced in e^+e^- annihilations.[2] The analysis is based on a comparison of two data samples: in one, both D and $\bar{D}$ decay semileptonically, leading to events with a detected e^+ and e^- ('2e events'); in the other, only one semileptonic decay is observed ('1e'). The data, recorded by the DELCO detector[3] at SPEAR, are selected from energies at the ψ'' and below. The ψ'' provides a pure sample of $D\bar{D}$ events with known charged and neutral composition, and the lower energy data are used in the background measurements.

The selection criteria for the 1e sample[4] require that events contain $\geq$ 3 observed charged tracks, of which one is identified as an electron by having in-time Cherenkov and shower counter pulses. The backgrounds to the 1e sample come largely from τ decays, accidental coincidences of a hadronic track and a Cherenkov pulse, misidentified photon conversions and Dalitz decays, and two-photon processes. Subtracting contributions from these backgrounds, we obtain 734 ± 44 1e events due to charm decays at the ψ''.

Events in the 2e sample must have two electrons and at least one non-electron, defined as a track having momentum above 200 MeV/c, which passes through the Cherenkov counter but produces no Cherenkov pulse. To obtain unambiguous electron identification, we demand that only one track enter each triggered Cherenkov cell. The candidates are scanned to eliminate the majority of $ee\gamma$ final states and misidentified photon conversions in hadronic events. A background due to $\psi' \rightarrow \psi\, \pi^+\pi^- \rightarrow e^+e^-\pi^+\pi^-$

is reduced by requiring an acolinearity of at least 20° between the e^+ and e^- in the azimuthal projection. Events involving π^{o} or η Dalitz decays are suppressed by requiring that the electron pair mass exceed $m_{\pi^{o}}$. Twenty-one 2e events satisfy these criteria at the ψ''.

The residual backgrounds in the 2e events result from: 1) 2 real electrons, such as from two-photon processes or Dalitz decays, 2) 1 real electron + 1 false electron, such as a D or τ decay together with a hadron misidentified as an electron, and 3) 2 false electrons. We study 1e events at the $\psi(3100)$ to determine the misidentification probability for a track as an electron (1.9×10^{-3}). Backgrounds 2) and 3) are then measured from the 1e sample at the ψ'' by randomly assigning a Cherenkov tag to eligible tracks at a rate equal to this misidentification probability. The resulting events are subjected to requirements identical to the actual 2e data sample. This technique has the advantage of including the proper mixture of electrons from D and τ decays and from backgrounds such as photon conversions. The contribution from two-photon events is determined by a Monte Carlo calculation[5]. Finally, any remaining backgrounds are determined from the residual 2e events observed at the ψ and ψ' after subtracting all the other backgrounds. The results of these calculations, which are summarized in Table I, indicate that 16.4 ± 4.6 2e events at the ψ'' are due to both D and $\bar{D}$ decaying semileptonically.

The values of the D^{o} and D^{+} semileptonic branching ratios (b^{o} and b^{+}, respectively) are determined by finding a common solution to the following expressions for the number of 1e events (N_{1e}) and 2e events (N_{2e}) after background subtractions:

$$N_{1e} = N_o \varepsilon_1^o 2b^o(1-b^o) + N_+ \varepsilon_1^+ 2b^+(1-b^+) + \text{smaller terms in } b^2 \qquad (1)$$

$$N_{2e} = N_o \varepsilon_2^o b^{o2} + N_+ \varepsilon_2^+ b^{+2} \quad , \qquad (2)$$

where N_o and N_+ are the number of produced $D^o\bar{D}^o$ and D^+D^- pairs[6] from which the data sample is drawn. The efficiency ε_1^o (ε_1^+) is the probability of detecting a 1e event from a $D^o\bar{D}^o$ (D^+D^-) initial state in which only one D decays to an electron. ($\varepsilon_2^{o,+}$ is defined similarly for 2e events.) The smaller terms in equation (1) are due to the correction for events involving two semileptonic decays but with only one detected electron. The allowed regions for b^o and b^+, as deduced from equations (1) and (2), are shown as shaded bands[7] in Fig. 1. The bands correspond to $\pm$ 1σ statistical variations in the number of observed events. The data are displayed for two extreme assumptions which affect the detection efficiencies: either all events originate as $D \to Ke\nu$ or all as $D \to K^*e\nu$. The data show that either $b^o \gg b^+$ or $b^+ \gg b^o$, and the regions of overlap are approximately independent of the K vs. K^* assumption. In order to assess the statistical significance of this result, we calculate the probability of observing 21 or more 2e events (including background) if $b^o = b^+$. For $b^o = b^+ = 8\%$,[2] the predicted number of 2e events is 10.7 for which the corresponding probability is 0.3%. If we take $b^o = b^+ =$ 9.1% (1σ above the world average value), the predicted number is 12.3 which gives a probability of 1.5%. It is therefore unlikely that the excess 2e events are a statistical fluctuation.

The ambiguity of which branching fraction is the larger one is resolved by measuring the K^o yield, which in general is different for D^+

and D^o semileptonic decays. We identify a K_S^o decay by the presence of a V, defined as one or two "detached" tracks, which do not point back to the origin in the azimuthal view. A Monte Carlo simulation indicates that typically only one detached track is observed from the decay $K_S^o \to \pi^+\pi^-$, since the other prong frequently either misses the detector or aligns with the event vertex. Of the twenty-one 2e events, 8 have a V.

The backgrounds of the 2e+V events consist of: (a) false V's with real or false electrons, or (b) real V's with at least one false electron. False V's result mainly from particle interactions in the beam pipe, or from in-time cosmic rays which traverse only part of the cylindrical chambers. These contributions to the false V probability are determined from the fraction of $\psi' \to \pi^+\pi^- \to e^+e^-\pi^+\pi^-$ events which exhibit a detached track. Background a) (1.2 events) is then determined from the product of the number of 2e events and this false V probability, with an additional small correction for charm-produced $K^\pm$ decays (0.3 events). Background b) (0.6 events) is the product of the number of 2e background events and the probability of a real V, which is determined by a measurement of the 1e + V rate at the ψ''. After subtracting the backgrounds, we find that 5.9 ± 2.1 events contain 2 electrons and a detected K_S^o decay. The expected numbers, under different decay-mode assumptions, are shown in Table II. We see that this large K_S^o signal implies both that the solution $b^+ >> b^o$ is favored and that $D^+ \to \bar{K}^o e^+\nu$ is an important decay mode.

To determine the branching ratios, we form a statistical likelihood function $L(b^o,b^+)$ which is the product of the probabilities to observe three quantities: a) N_{1e} (using a Gaussian probability density), b) N_{2e} (Poisson) and, c) the number of 2e+V events given an observed signal of

16.4 2e events (Poisson). This computation depends on the ratio r_K = $\Gamma(D \rightarrow Ke\nu)/\Gamma(D \rightarrow Xe\nu)$, and we take $r_K = (0.6 \pm 0.2)$[4,8]. Systematic errors in this parameter and in other numbers such as normalization, Cherenkov efficiency and $D^0\bar{D}^0 : D^+D^-$ ratio are treated by including additional factors in the likelihood function. All these parameters are then varied along with b^0 and b^+ in the likelihood analysis. The result is displayed in Fig. 2, which shows the projection of equal probability contours in b^0 and b^+ corresponding to χ^2 variations of 1 and 4, where $\chi^2 = -2 \ln L(b^0,b^+)$. The D^0 and D^+ semileptonic branching ratios are found to be $b^0 < 4.0\%$ (95% CL) and $b^+ = (22.0\ ^{+4.4}_{-2.2})\%$, respectively. The lower limit for the ratio b^+/b^0 is 4.3 (95% CL).

Isospin symmetry leads to equal D^0 and D^+ semileptonic rates, and so these measurements imply that the D^+ lifetime is greater than the D^0 lifetime: $\tau(D^+)/\tau(D^0) > 4.3$ (95% CL), presumably due to a stronger hadronic enhancement in D^0 decay. The actual lifetimes may be derived from the theoretical rate[9], $\Gamma(D \rightarrow Ke\nu) = 1.4\ 10^{-11}\ \text{sec}^{-1}$, which yields $\tau(D^0) < 2.1\ 10^{-13}$ sec (95% CL), and $\tau(D^+) = (10.4^{+3.9}_{-2.9})10^{-13}$ sec. These results are in agreement with the direct lifetime measurements made in the Fermilab ν-emulsion experiment[10] and with the semileptonic branching ratios obtained by the SPEAR MkII collaboration[8].

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References and Footnotes

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2. Preliminary results were presented by J. Kirkby, Proceedings of the International Symposium on Lepton and Photon Interactions at High Energies, Fermilab, Batavia, Illinois, 1979 (to be published).
3. W. Bacino et al., Phys. Rev. Lett. 40, 671 (1978).
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5. We thank J.A.M. Vermaseren for calculations of the two-photon cross-sections.
6. We take the $D^o\bar{D}^o$: D^+D^- ratio to be $0.56 \pm 0.03 : 0.44 \pm 0.03$, according to phase space. The total data sample consists of 15.4×10^3 produced $D\bar{D}$ pairs. This is derived from the hadronic cross section at the ψ'' in conjunction with Monte Carlo calculations of hadronic efficiencies. The phase space model used in the efficiency calculation has been adjusted to reproduce the multiplicity distributions reported by the Mark I collaboration. J. Siegrist, Ph.D. thesis, Stanford University, SLAC Report 225 (1979) unpublished.
7. The asymmetry of the linear and elliptical regions arises partly due to the difference in the neutral vs. charged production rates, and partly due to different experimental detection efficiencies for the D^o and D^+ modes.
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Table I

Summary of the 2e data sample

Ecm	2e Events: Observed	2e Events: Calculated Backgrounds	2e Events with K_S^o: Observed	2e Events with K_S^o: Calculated Backgrounds
$\psi + \psi'$	14	14 ± 3.1	4	3.8 ± .7
3.50 → 3.67GeV	2	1.9 ± 1.1	0	0.0 ± 0.1
ψ''	21	4.6 ± 0.9	8	2.1 ± 0.7

Table II

Predicted number of 2e+V events for different decay modes

Initial State, Decay Mode	Predicted 2e+V Events (including background)	Probability (%)
D^+D^-, $D \rightarrow K e \nu$	7.9	53
D^+D^-, $D \rightarrow K^* e \nu$	3.7	3.5
$D^0\bar{D}^0$, $D \rightarrow K e \nu$	2.6	0.5
$D^0\bar{D}^0$, $D \rightarrow K^* e \nu$	3.8	4.0

The probability of observing 8 or more 2e+V events given the predicted number. The calculation is based on 16.4 charm 2e events and includes a background of 1.8 - 2.6 depending on the initial state and decay mode.

Figure Captions

Figure 1: The values (shaded area) of b^o and b^+ which correspond to $\pm 1\sigma$ statistical variations in the observed number of 1e and 2e events. The data are shown under two extreme assumptions for the detection efficiencies: a) all semileptonic D decays occur as $D \rightarrow Ke\nu$; (b) all semileptonic D decays occur as $D \rightarrow K^* e\nu$.

Figure 2: Probability contours corresponding to χ^2 changes of 1 and 4 (1σ and 2σ in b^o and b^+) calculated from the likelihood function for observing the measured number of 1e, 2e, and 2e+V events. Both the statistical and systematic uncertainties have been included. The dashed line indicates the best value for b^+ vs. b^o.

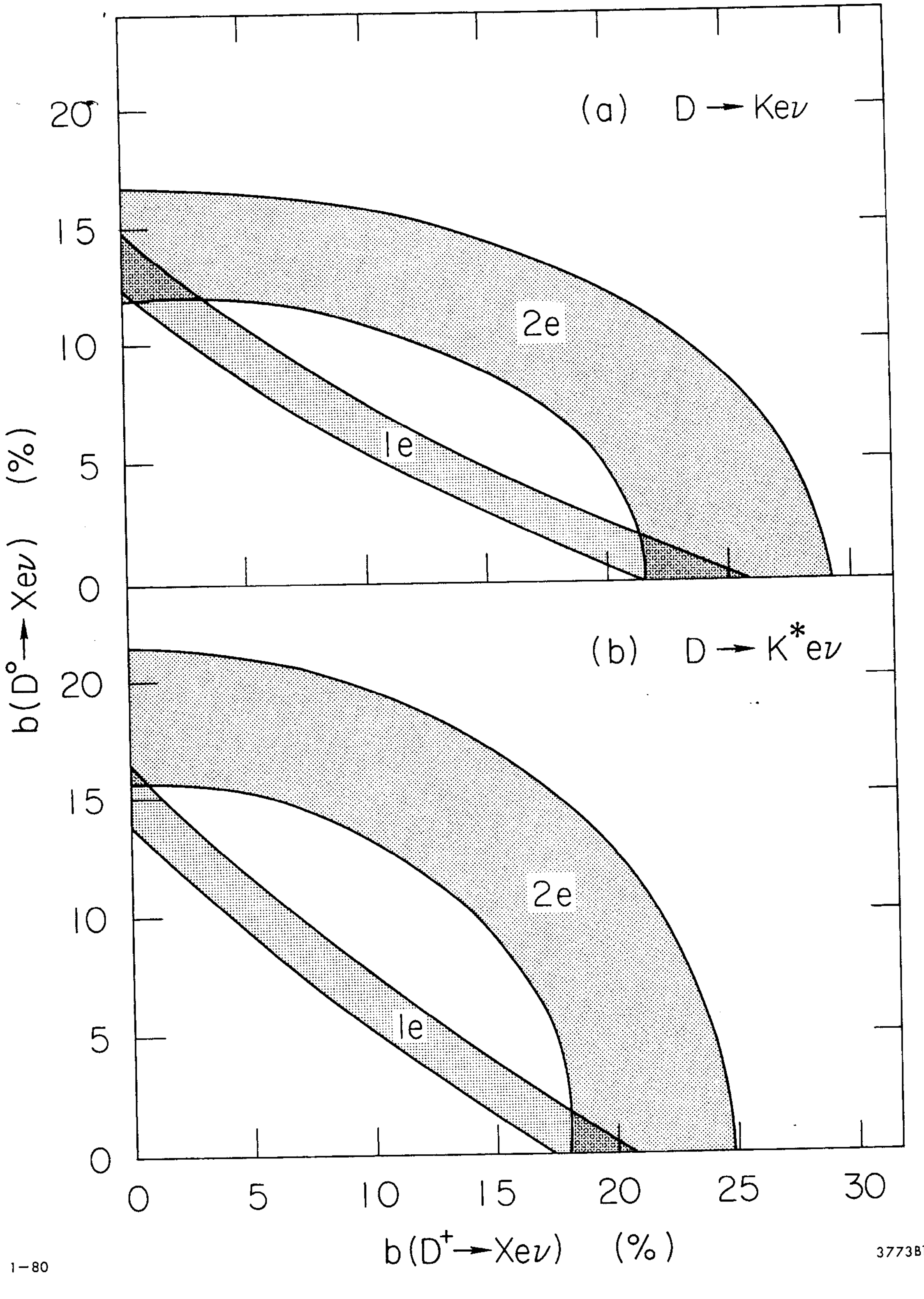

Fig. 1

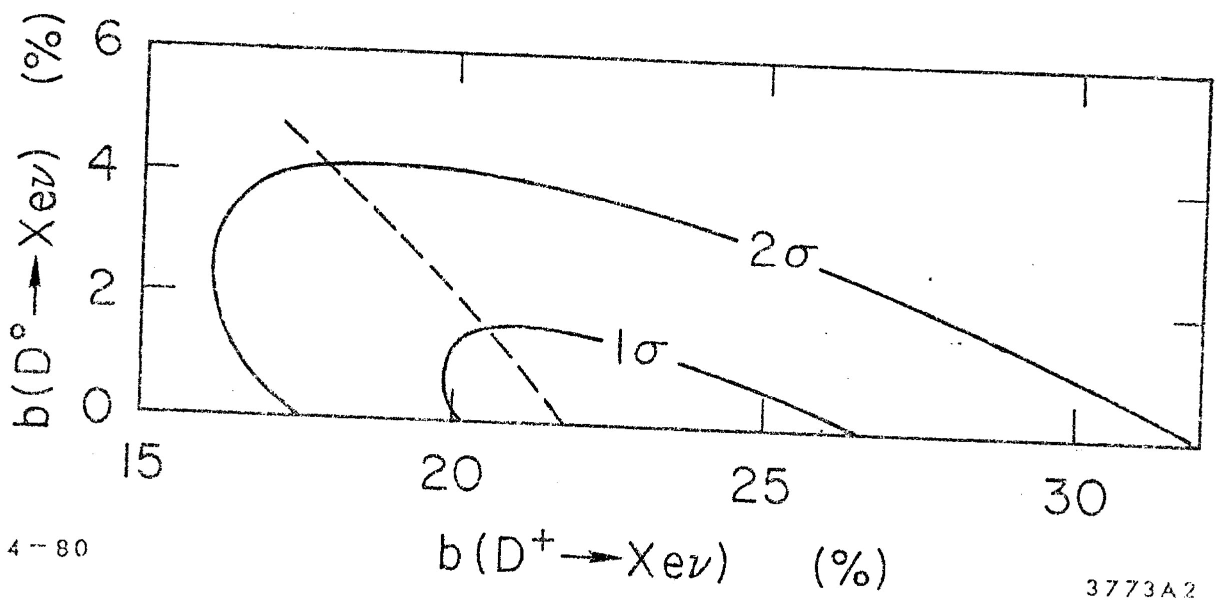

Fig. 2