

Direct Measurement of Charmed D^+ and D^0 Semileptonic Branching Ratios

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Measurements of the semileptonic branching ratios of charmed D^+ and D^0 mesons are presented, from data collected at the $\psi(3770)$ in the Mark III detector at SPEAR. From a sample of events kinematically selected as charmed D^+D^- or $D^0\bar{D}^0$ pairs, the branching ratios $R(D^+ \rightarrow e^+ + X) = (17.0 \pm 1.9 \pm 0.7)\%$ and $R(D^0 \rightarrow e^+ + X) = (7.5 \pm 1.1 \pm 0.4)\%$ are obtained. The ratio of these measurements can be interpreted as the ratio of D^+ and D^0 lifetimes $\tau^+/\tau^0 = 2.3^{+0.5}_{-0.4}$ by neglect of the contribution of Cabibbo-suppressed decays to the total decay width.

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The semileptonic branching ratios of charmed mesons provide valuable information on their decay mechanisms. If we assume isospin symmetry, the partial widths to Cabibbo-favored semileptonic final states are equal for D^+ and D^0 . Thus, to the extent that Cabibbo-suppressed semileptonic widths are small, the ratio of semileptonic branching ratios is equal to the ratio of D^+ and D^0 lifetimes.¹ The ratio of D^+ and D^0 semileptonic branching fractions measured by Schindler *et al.*² (Mark II Collaboration) and Bacino *et al.*³ (DELCO Collaboration) indicated that the D^+ lifetime was larger than that for the D^0 . Direct measurements of lifetimes have since confirmed this result.⁴ Furthermore, a knowledge of the individual semileptonic branching ratios is necessary to determine whether the difference in lifetime arises from an enhancement of the D^0 or a suppression of the D^+ nonleptonic width.

The data reported here were collected by the Mark III detector at SPEAR, near the peak of the $\psi(3770)$ resonance, which lies just above $D\bar{D}$ threshold but below $D\bar{D}^*$ threshold. This data sample, which comprises 8650 nb^{-1} , represents about 50 000 produced $D\bar{D}$ pairs. The Mark III detector has been described in detail elsewhere.⁵

The analysis, which takes advantage of the decay of the $\psi(3770)$ to pairs of D mesons, proceeds in two stages. A search is first performed to isolate those events in which one D meson of the produced $D\bar{D}$ pair can be reconstructed in a hadronic decay mode.

Events in which the recoil D undergoes a semileptonic decay are then identified by the observation of electrons.

The reconstruction of exclusive hadronic D decay modes exploits both the small energy spread of the beam ($\sigma \sim 1.5 \text{ MeV}$) and the kinematics of $D\bar{D}$ pair production near threshold. Charged particles are identified by time of flight (TOF). Appropriate combinations are then formed to isolate three D^0 decay channels ($K^-\pi^+, K^-\pi^+\pi^0, K^-\pi^+\pi^+\pi^-$) and three D^+ decay channels ($\bar{K}^0\pi^+, K^-\pi^+\pi^+, \bar{K}^0\pi^+\pi^+\pi^-$). To improve the mass resolution and reduce backgrounds the total energy of each candidate D^+ or D^0 is constrained to equal the beam energy. Clear signals of $\sim 3\text{-MeV}$ width on small backgrounds are seen in all six channels (Fig. 1). In each of these mass plots a signal region centered on the D mass and a control region between 1.820 and 1.856 GeV/c^2 are defined. The control region is used in the subsequent analysis to correct for background events under the signal. The number of background events under each signal is determined by a fit to the mass plot. The D^0 signal region contains 4541 events, of which 1106 ± 39 are background. The D^+ signal region contains 2062 events, of which 333 ± 20 are background. Here, we are only interested in counting the number of signal events, and not in measuring the production rate. Thus, only the uncertainty in the number of background events must be propagated.

Candidate pion and electron tracks recoiling from

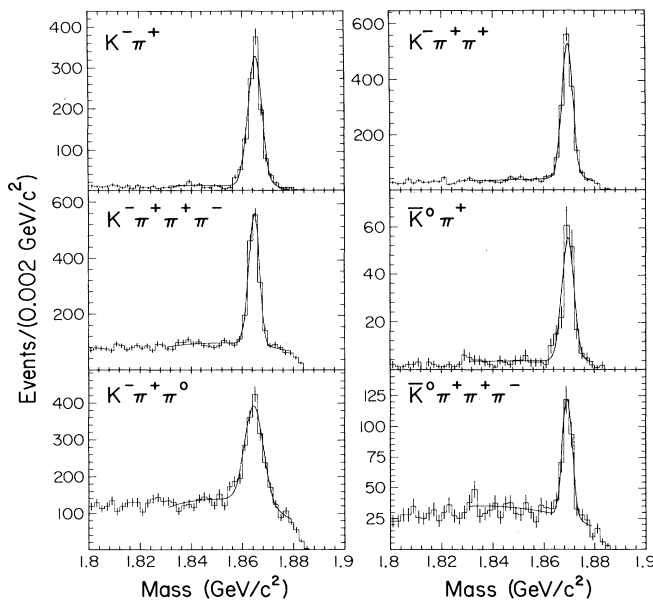


FIG. 1. Hadronic D -decay signals. Here and throughout this paper, we adopt the convention that reference to a state also implies reference to its charge conjugate.

these D decays must have momentum > 150 MeV/ c , originate near the event's primary vertex within 0.01 m perpendicular and 0.15 m parallel to the beam axis, and deposit energy in the barrel calorimeter. All tracks must also lie in a limited fiducial region ($|\cos\theta| < 0.77$, where θ is the polar angle) in which charged kaons and protons can be rejected by TOF. Most gamma conversions and Dalitz decays are removed by requiring candidate electron tracks to have opening angles greater than 8° with any other oppositely charged track in the event.

Electrons are separated from charged pions by a sequence of cuts which use track-momentum, TOF, shower-energy, and both longitudinal- and transverse-shower-development information. The procedure was optimized by use of samples of pions and electrons from lower center-of-mass energy data. The resulting misidentification rates, shown in Fig. 2, were then determined with pure samples of pions from K_S^0 decays and electrons from radiative Bhabha events in the $\psi(3770)$ data set.

The expected charge of a recoil electron is uniquely determined by the charm of the reconstructed hadronic D decay. Corrections for charge-symmetric sources of electron candidates such as gamma conversions and Dalitz decays not removed by the opening-angle cut are thus made by subtracting the number of wrong-sign electron candidates from the number of right-sign candidates. A right-sign candidate electron is one with the expected charge, given the charm of the hadronic decay. To correct for electron candidates coming from pion misidentification (20% and 14% for D^+ and D^0 ,

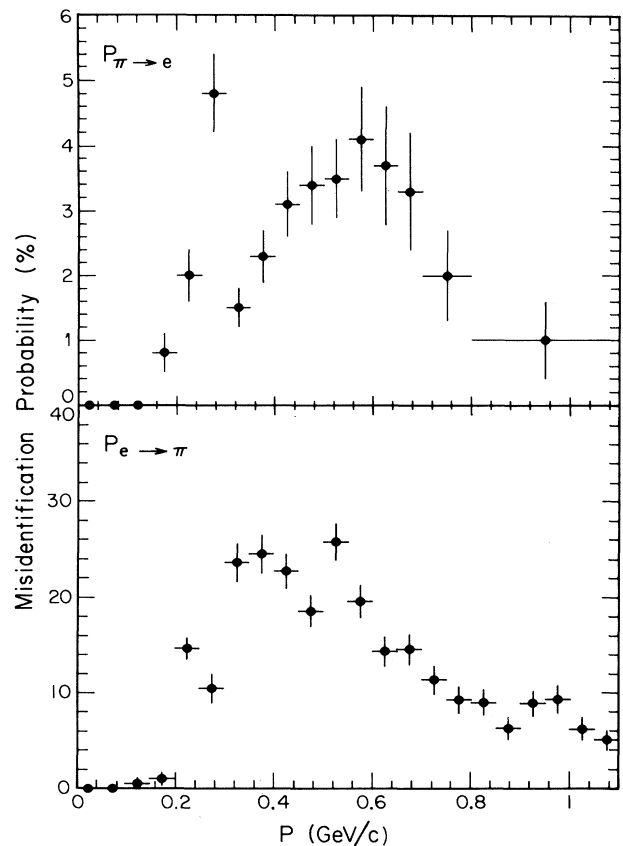


FIG. 2. Misidentification probabilities for pions and electrons. For $p < 300$ MeV/ c , only TOF is used for particle identification. For $p > 300$ MeV/ c , TOF and shower information are used.

respectively), the known misidentification rates are used to unfold the true number of electrons from the observed populations of electrons and pions of each sign. The observed populations of right-sign pions include contributions from semileptonic D decays to muons. The number of muons, estimated from the derived semileptonic branching ratio to electrons, is subtracted from the number of right-sign pions, since they do not suffer misidentification as electrons. To correct for background events in the \bar{D} signal region, the unfolded electrons in the control region are subtracted from the number of remaining signal-region electrons. No dependence on the choice of the control region is observed. A small correction of 1.8 ± 0.9 electrons is applied to account for TOF misidentification of both kaon and pion in the $D^0 \rightarrow K^- \pi^+$ decay mode. Finally, the number of electrons is increased by 0.3 ± 0.2 and 0.8 ± 0.4 in the D^+ and D^0 samples, respectively, to account for K_{e3} decays. These corrections are summarized in Table I.

The probability for an electron to satisfy the track requirements which allow pion-electron classification

TABLE I. Electron unfold procedure and corrections. The errors here reflect the statistical uncertainty in the number of background events only (see text).

| | D^+ | D^0 |
|----------------------------|------------------|------------------|
| Signal events | 1729 ± 20 | 3435 ± 39 |
| Signal electrons | | |
| Right sign | 177.0 ± 13.3 | 193.0 ± 13.9 |
| Wrong sign | 14.0 ± 3.7 | 57.0 ± 7.5 |
| Net | 163.0 ± 13.8 | 136.0 ± 15.8 |
| Unfolded | 160.7 ± 17.4 | 141.8 ± 19.9 |
| Unfolded control electrons | 2.5 ± 2.9 | 5.2 ± 4.5 |
| Net electrons | 158.2 ± 17.6 | 136.6 ± 20.4 |
| Corrections | | |
| Classification efficiency | 226.1 ± 25.1 | 195.7 ± 29.2 |
| K_{e3} decays | 226.4 ± 25.1 | 196.5 ± 29.2 |
| $K^-\pi^+$ interchange | 226.4 ± 25.1 | 198.3 ± 29.2 |
| Solid angle | 294.0 ± 32.6 | 257.5 ± 37.9 |

is 69.9% for electrons from D^+ or D^- . The efficiency is determined as a function of electron momentum by Monte Carlo simulation of $D\bar{D}$ events, in which one D decays into $Ke\nu$ or $K^*e\nu$ and the recoil \bar{D} decays into a

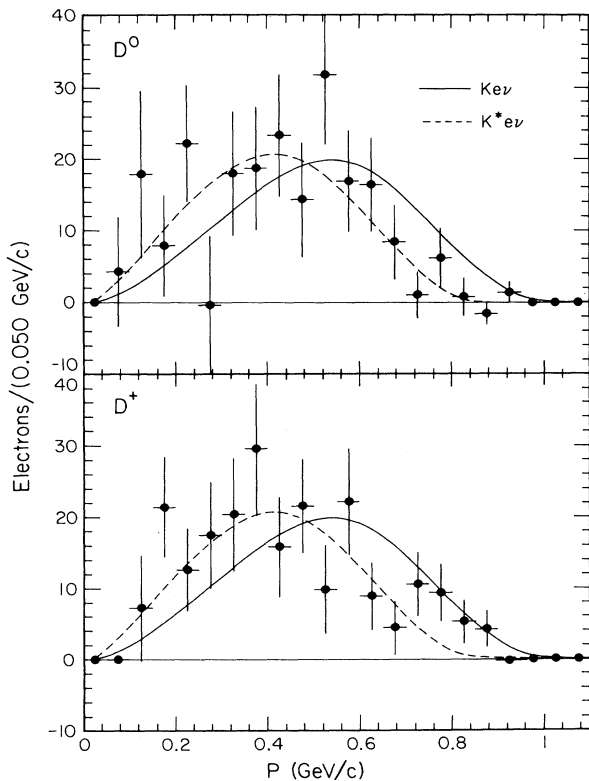


FIG. 3. D^0 and D^+ electron spectra. The curves represent the shape of spectra expected from $Ke\nu$ and $K^*e\nu$ decays.

hadronic channel. The resulting electron angular distributions are found to be isotropic in the laboratory frame. The final electron momentum spectra, after efficiency corrections, are shown in Fig. 3, along with those expected for $Ke\nu$ and $K^*e\nu$ decays.⁶

The numbers of electrons seen recoiling against the detected D^+ and D^0 lead to the branching fractions $R(D^+ \rightarrow e^+ + X) = (17.0 \pm 1.9 \pm 0.7)\%$, $R(D^0 \rightarrow e^+ + X) = (7.5 \pm 1.1 \pm 0.4)\%$, and thus to the ratio

$$R(D^+ \rightarrow e^+ + X)/R(D^0 \rightarrow e^+ + X) = 2.3^{+0.5+0.1}_{-0.4-0.1}.$$

Contributions to the systematic errors common to D^+ and D^0 arise from the uncertainty in the pion misidentification rate ($\sim 2.0\%$), the Monte Carlo determination of the classification efficiency (3%), the sensitivity to the $Ke\nu/K^*e\nu$ fractions (1%),⁷ and muon contamination of the pion samples (1.3%). There is a 3% uncertainty in the background subtraction for $D^0 \rightarrow K^-\pi^+\pi^0$. Combining these uncertainties, we assign 4.1% and 4.9% systematic errors for the D^+ and D^0 branching fractions, respectively, and a 3.0% error for their ratio.

The average D semileptonic branching ratio at the $\psi(3770)$ ⁸ of $(11.7 \pm 1.0 \pm 0.5)\%$ is consistent with the value of $(10.0 \pm 3.2)\%$ derived with the same technique by Schindler *et al.*² but significantly higher than both the measurements by Bacino *et al.*⁹ and Feller *et al.*⁹ of $(8.0 \pm 1.5)\%$ and $(7.2 \pm 2.8)\%$, respectively. It should be noted, however, that the current result is an absolute measurement, while the results of Bacino *et al.* and Feller *et al.* rely on normalization of the electron signal using the measured cross section for $\psi(3770)$ production.

The likelihood function for the ratio of semileptonic branching fractions is shown in Fig. 4. To the extent that this ratio represents the ratio of D^+ and D^0 lifetimes,¹ this measurement excludes the possibility of

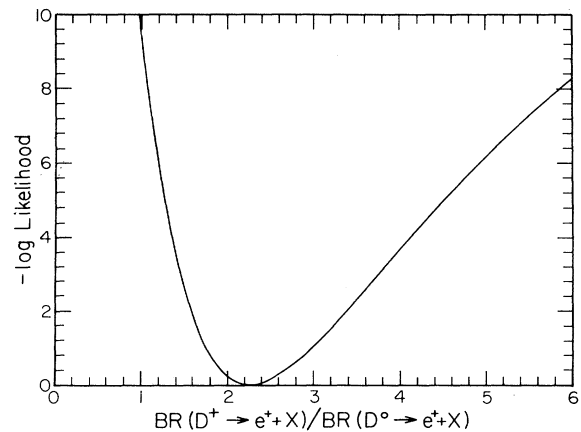


FIG. 4. The negative log(likelihood) function for the ratio of D^+ to D^0 semileptonic branching ratios.

equal lifetimes at 4.3 standard deviations, and agrees with the less precise determinations by individual decay-length measurements.⁴

In the naive spectator model, D^+ and D^0 semileptonic branching fractions to electrons would both be equal to 20%. That the measured branching ratios of both D^+ and D^0 are smaller than this value can be attributed in part to the nonleptonic enhancement suggested by hard-gluon corrections to the weak Hamiltonian.¹⁰ However, the large difference observed between D^+ and D^0 cannot be explained in this way. Additional enhancement of the D^0 or suppression of the D^+ nonleptonic width is required. These modifications could arise, for example, from the existence of nonspectator diagrams for D^0 decay,¹¹ interference between D^+ final states,¹² or additional nonperturbative corrections.¹³ The relative importance of these processes can only be determined through a systematic study of the nonleptonic decays of the D .

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