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A Direct Measurement Of Charmed D^+ and D^0 Semileptonic Branching Ratios†

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ABSTRACT

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 $D^0\overline{D}^0$ pairs, the branching ratios: $\mathrm{Br}(D^+ \to e^+ + X) = (17.0\pm1.9\pm0.7)\%$, and $\mathrm{Br}(D^0 \to e^+ + X) = (7.5\pm1.1\pm0.4)\%$ are obtained. The ratio of these measurements can be interpreted as the ratio of D^+ and D^0 lifetimes $\tau^+/\tau^0 = 2.3^{+0.5+0.1}_{-0.4-0.1}$.

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The semileptonic branching ratios of charmed mesons provide valuable information on their decay mechanisms. Assuming 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^+ to D^0 semileptonic branching fractions measured by Mark II[2] and DELCO[3] 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 lifetimes arises from an enhancement of the D^0 or a suppression of the D^+ non-leptonic width.

The data reported herewere collected by the Mark III detector at SPEAR, near the peak of the $\psi(3770)$ resonance, which lies just above $D\overline{D}$ threshold but below $D\overline{D}^*$ threshold. This data sample, which comprises 8650 nb^{-1}, represents about 50000 produced $D\overline{D}$ 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 $D\overline{D}$ 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 ($\sigma \sim 1.5$ MeV) and the kinematics of $D\overline{D}$ 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 ($\overline{K}^0\pi^+$, $K^-\pi^+\pi^+$, $\overline{K}^0\pi^+\pi^+\pi^-$). To improve the mass resolution and reduce backgrounds the total energy of each candidate D^+ or D^0 is constrained to the beam energy. Clear signals of ~3 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±34 are background. The D^+ signal region contains 2062 events, of which 333±20 are background.

Candidate pion and electron tracks recoiling from these D decays must have momentum >150 MeV/c, originate near the event's primary vertex within 0.01m perpendicular and 0.15m 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 using samples of pions and electrons from lower center-of-mass energy data. The resulting misidentification rates, shown in Fig. 2, were then determined using 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 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 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 $D^0 \to K^-\pi^+$ 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 1.

The probability for an electron to satisfy the track requirements which allow pion-electron classification is 69.9% for electrons from D^+ or D^0. 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 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 $Br(D^+ \to e^+ + X) = (17.0 \pm 1.9 \pm 0.7)\%$, $Br(D^0 \to e^+ + X) = (7.5 \pm 1.1 \pm 0.4)\%$, and thus to the ratio:

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

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 $D^0 \to K^-\pi^+\pi^0$. 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±1.0±0.5)% is consistent with the value of (10.0 ± 3.2)% derived using the same technique by Mark II,[2] but significantly higher than both the DELCO and LGW measurements[9] of (8.0±1.5)% and (7.2±2.8)% respectively. It should be noted, however, that the current result is an absolute measurement, while the DELCO and LGW results 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 equal lifetimes at 4.3 standard deviations, and agrees with the less precise determinations by individual decay length measurements.[4]

In the naïve 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 non-leptonic 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^+ non-leptonic width is required. These modifications could arise, for example, from the existence of non-spectator diagrams for D^0 decay,[11] interference between D^+ final states,[12] or additional non-perturbative corrections.[13] The relative importance of these processes can only be determined through a systematic study of the non-leptonic decays of the D.

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TABLE 1 - Electron Unfold Procedure and Corrections

	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

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Figure Captions

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.

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.

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

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

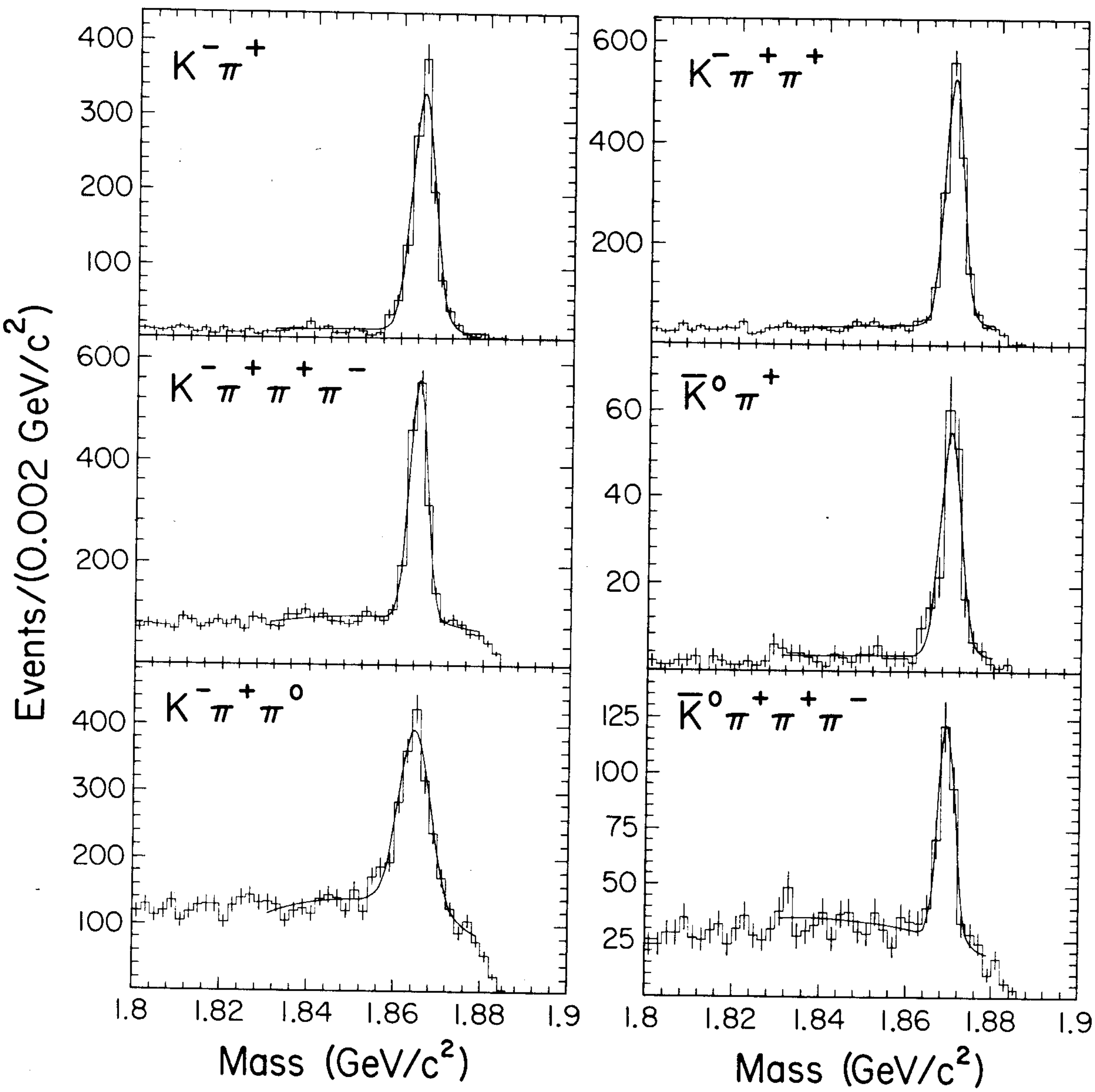
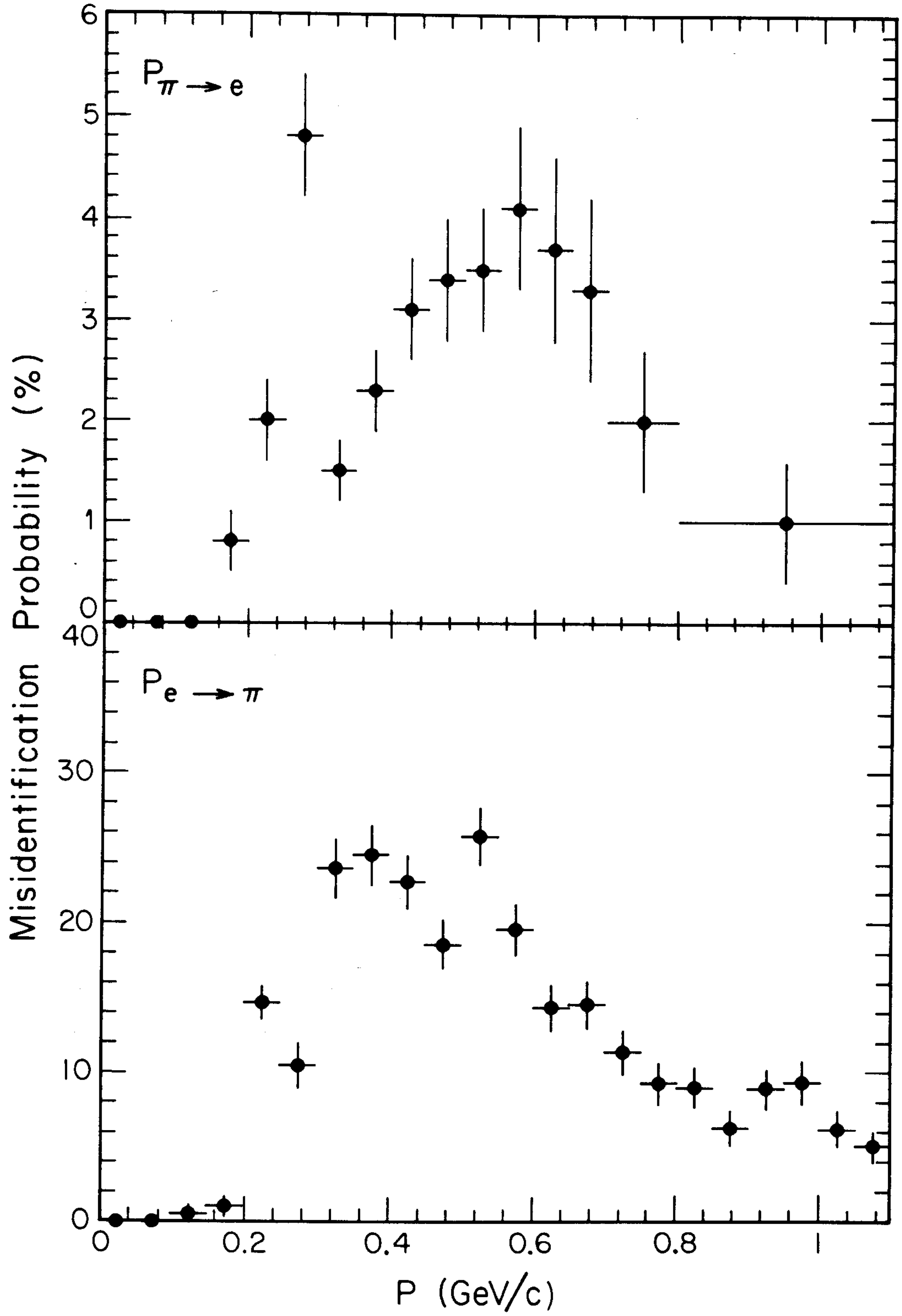

Events/(0.002 GeV/c²)
K⁻π⁺
K⁻π⁺π⁺
K⁻π⁺π⁺π⁻
K̄⁰π⁺
K⁻π⁺π⁰
K̄⁰π⁺π⁺π⁻
Mass (GeV/c²)
Mass (GeV/c²)

Fig. 1



Pπ → e
Pe → π
Misidentification Probability (%)
P (GeV/c)
0
0.2
0.4
0.6
0.8
1
0
1
2
3
4
5
6
10
20
30
40

Fig. 2

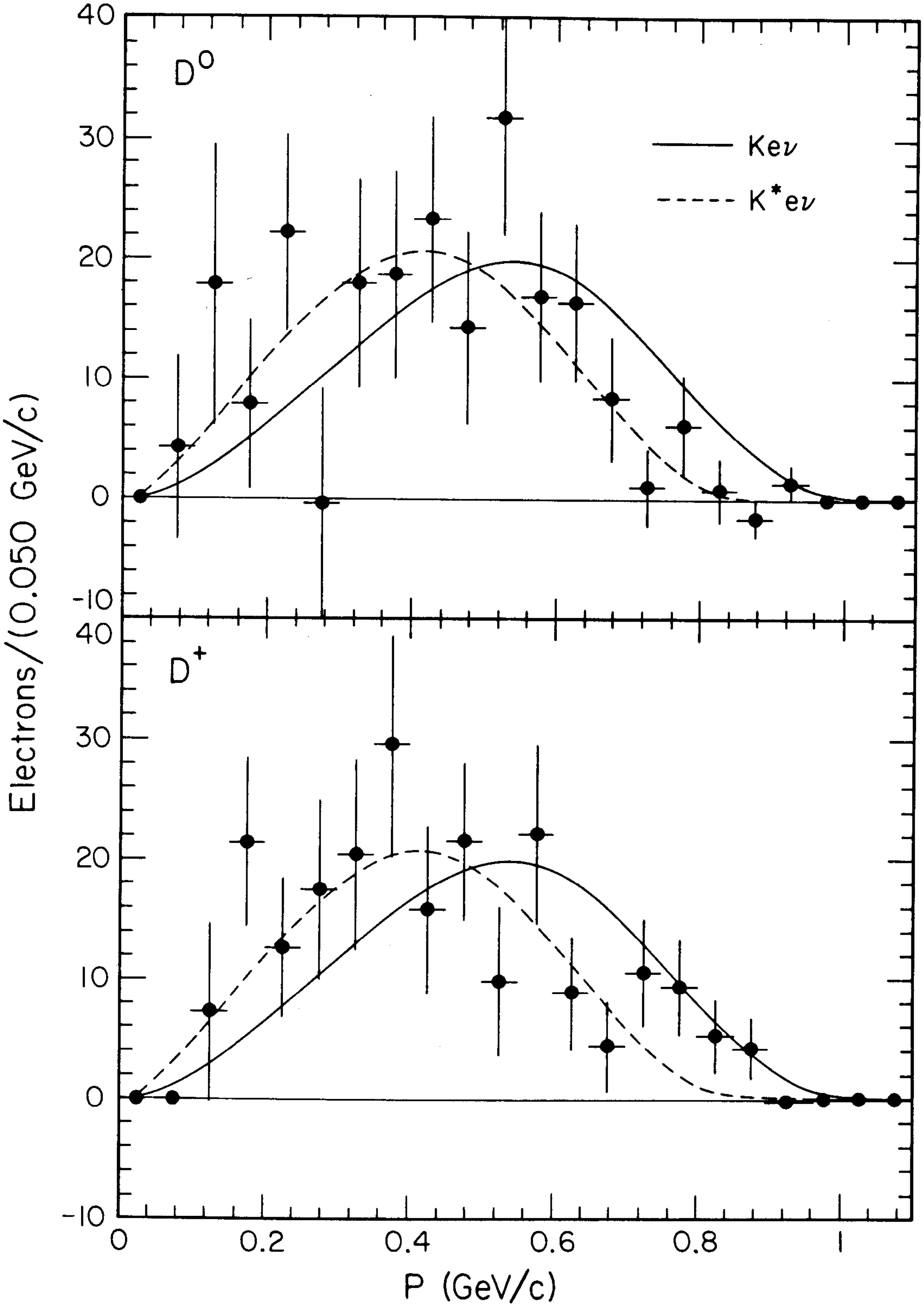

D⁰
D⁺
Keν
K*eν
Electrons/(0.050 GeV/c)
P (GeV/c)
40
30
20
10
0
-10
0
0.2
0.4
0.6
0.8
1

Fig. 3

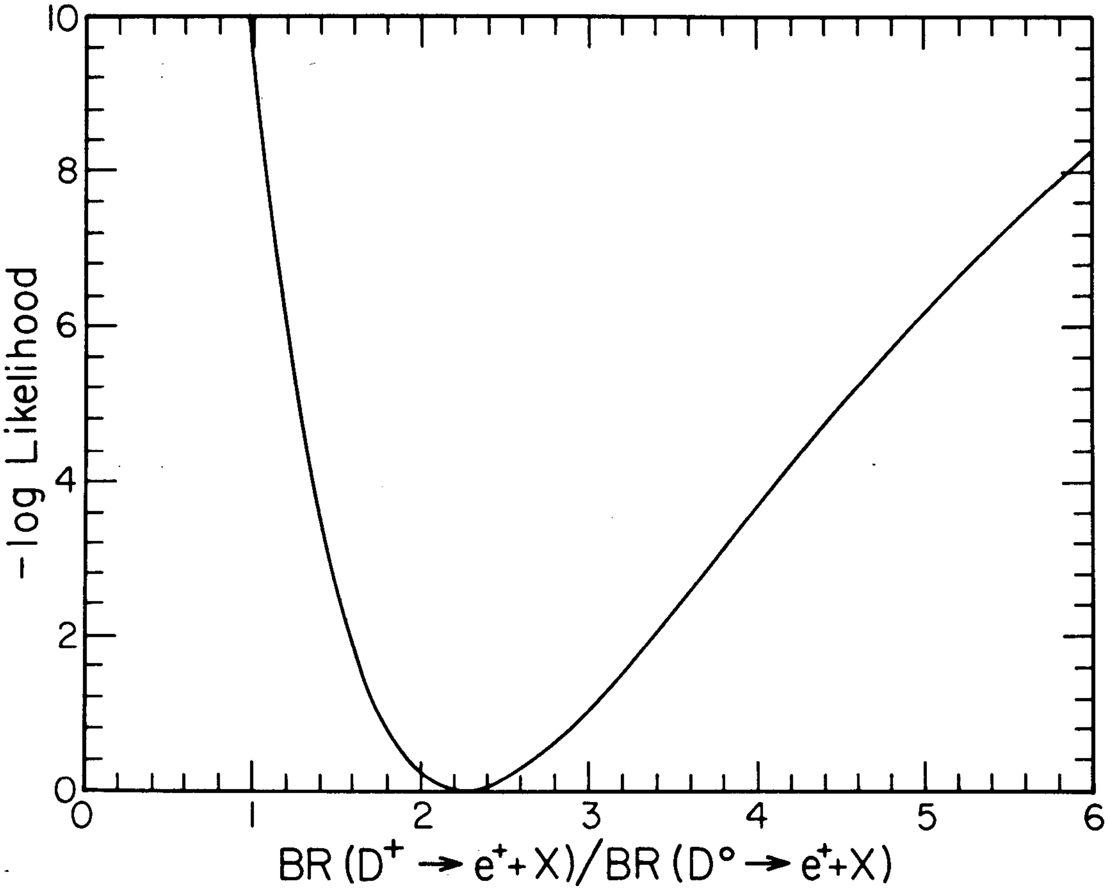


Fig. 4