B. $D_s^+ \to \phi \ell^+ \nu_\ell$ Form Factor Ratios

We have measured the form factor ratios r_V and r_2 for the decay $D_S^+ \to \phi \ell^+ \nu_\ell$, $\phi \to K^- K^+$ in both the electron and muon channels [11]. The form factor ratios in the electron channel were measured using 144(22) signal (background) events and yield $r_V = 2.24 \pm 0.47 \pm 0.21$ and $r_2 = 1.64 \pm 0.34 \pm 0.20$. In the muon channel there were 127(34) signal (background) events, yielding $r_V = 2.32 \pm 0.54 \pm 0.26$ and $r_2 = 1.49 \pm 0.36 \pm 0.20$. The combined electron and muon form factor ratios, for approximately 271 events, are $r_V = 2.27 \pm 0.35 \pm 0.22$ and $r_2 = 1.57 \pm 0.25 \pm 0.19$.

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III. D_S LIFETIME MEASUREMENTS

Accurate measurements of the lifetimes of the weakly decaying charm mesons are useful for understanding the contributions of various weak decay mechanisms. Despite the fact that they are all tied to the charm quark decay, the decays of the ground state charm mesons can have *different* contributions from the four first-order processes (two spectator, W-annihilation, and W-exchange) and their lifetimes are, in fact, quite varied [6].

$$\tau\left(D^{+}\right) : \tau\left(D^{0}\right) : \tau\left(D_{\mathrm{S}}\right) = 2.5 : 1 : 1.1 \tag{3}$$

We have made a new precise measurement of the D_{S} lifetime [7] using 1662 ± 56 fully reconstructed $D_{\mathrm{S}}^{+} \rightarrow \phi\pi^{+}$ decays. The D_{S} lifetime is measured using an unbinned maximum-likelihood fit to be $0.518 \pm 0.014 \pm 0.007$ ps. This value is somewhat higher than the world average D^0 lifetime [6] of 0.467 ± 0.017 ps. Using our result and the world average D^0 lifetime [6], we find that the ratio of the D_{S} lifetime to the D^0 lifetime to be

$$\frac{\tau\left(D_{\mathrm{S}}\right)}{\tau\left(D^{0}\right)} = 1.25 \pm 0.04 \text{ (a } 6\sigma \text{ difference from unity)} \tag{4}$$

showing, for the first time, significantly different lifetimes for the D_{S} and D^0. This result may be used to constrain the contributions of various decay mechanisms to charm decay and further refine our quantitative understanding of the hierarchy of charm particle lifetimes.

IV. MEASUREMENT OF THE LIFETIME DIFFERENCE BETWEEN $D^0 \rightarrow K^-\pi^+$ AND $D^0 \rightarrow K^-K^+$

We report the first directly measured constraint on the decay-width difference $\Delta ,$ for the mass eigenstates of the $D^0 - \overline{D}^0$ system [8]. We obtain our result from lifetime measurements of the decays $D^0 \rightarrow K^-\pi^+$ and $D^0 \rightarrow K^-K^+$, under the assumption of CP invariance, which implies that the CP eigenstates and the mass eigenstates are the same. The lifetime of the CP-even final state $D^0 \rightarrow K^-K^+$, as calculated from 6683 ± 161 weighted events, is $\tau_{KK} = 0.410 \pm 0.011 \pm 0.006$ ps. The lifetime of an equal mixture of CP-odd and CP-even final states $D^0 \rightarrow K^-\pi^+$, as calculated from 60581 ± 353 weighted events, is $\tau_{K\pi} = 0.413 \pm 0.003 \pm 0.004$ ps. We find that $\Delta , = 2\left(,_{KK} - ,_{K\pi}\right)$ $= 0.04 \pm 0.14 \pm 0.05$ ps^{-1}, leading to a limit of $-0.20 < \Delta , < 0.28$ ps^{-1} at 90% C.L. The value of $\Delta ,$ is consistent with zero and thus, at our level of sensitivity, is consistent with the Standard Model.

V. MEASUREMENTS OF $D^+ \rightarrow K^{*0}\ell^+\nu_\ell$ AND $D_S^+ \rightarrow \phi\ell^+\nu_\ell$ FORM FACTORS

The Vector and Axial form factors are used to extract elements of the Cabibbo-Kobayashi-Maskawa mixing matrix. Here we present measurements of the form factor ratios, evaluated at $q^2 = 0$ (GeV$/c)^2$, $r_V = V(0)/A_1(0)$, $r_2 = A_2(0)/A_1(0)$, for both the muon and electron channels, and $r3 = A_3(0)/A_1(0)$ in the muon channel. This is the first simultaneous measurement of both the muon and electron channels.

A. $D^+ \rightarrow K^{*0}\ell^+\nu_\ell$ Form Factor Ratios

We have already reported the form factor ratios r_V and r_2 for the decay $D^+ \rightarrow K^{*0}e^+\nu_e$, $K^{*0} \rightarrow K^-\pi^+$ [9] . The form factor ratios in the decay $D^+ \rightarrow K^{*0}\mu^+\nu_\mu$, $K^{*0} \rightarrow K^-\pi^+$ were measured using 3034(595) signal (background) events and yield [10] $r_V = 1.84 \pm 0.11 \pm 0.09$, $r_2 = 0.75 \pm 0.08 \pm 0.09$, and as a first measurement $r_3 = 0.04 \pm 0.33 \pm 0.29$. The combined electron and muon form factor ratios, for approximately 6000 events, are $r_V = 1.87 \pm 0.08 \pm 0.07$ and $r_2 = 0.73 \pm 0.06 \pm 0.08$.

TABLE II. Preliminary Results 90% C.L. Upper Limits

Mode	Estimated Background	Observed	Calculated[a] N_X	Branching Ratio	1998 PDG BR
$D^+ \to \pi^+ e^+ e^-$	0.6	1	3.76	$< 4.3 \times 10^{-5}$	$< 6.6 \times 10^{-5}$
$D^+ \to \pi^+ \mu^\pm e^\mp$	0.0	1	4.36	$< 3.2 \times 10^{-5}$	$< 1.2 \times 10^{-4}$
$D^+ \to \pi^- e^+ e^+$	0.0	2	5.91	$< 7.7 \times 10^{-5}$	$< 1.1 \times 10^{-4}$
$D^+ \to \pi^- \mu^+ e^+$	0.6	1	3.76	$< 3.6 \times 10^{-5}$	$< 1.1 \times 10^{-4}$
$D^0 \to e^+ e^-$	1.8	0	1.30	$< 5.2 \times 10^{-6}$	$< 1.3 \times 10^{-5}$
$D^0 \to \mu^\pm e^\mp$	2.6	3	4.80	$< 1.0 \times 10^{-5}$	$< 1.9 \times 10^{-5}$

[a] By Method of Feldman and Cousins

A comparison between our calculated 90% confidence level upper limit branching ratios and the previous results [6] is shown by the plot of the 90% C.L. upper limits in Figure 2.

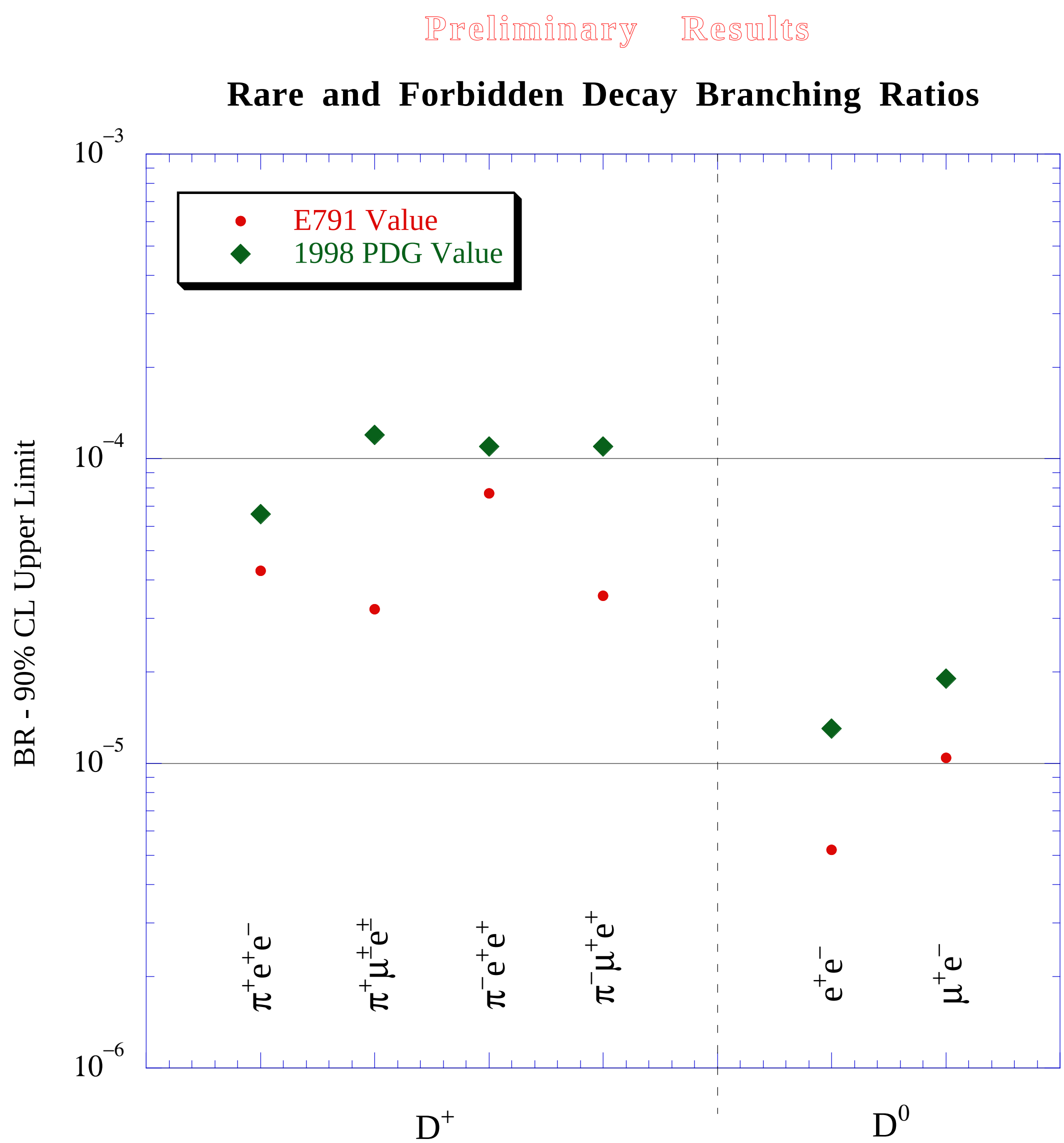

FIG. 2. The 90% C.L. upper limit branching ratios for E791 data and for the 1998 PDG values.

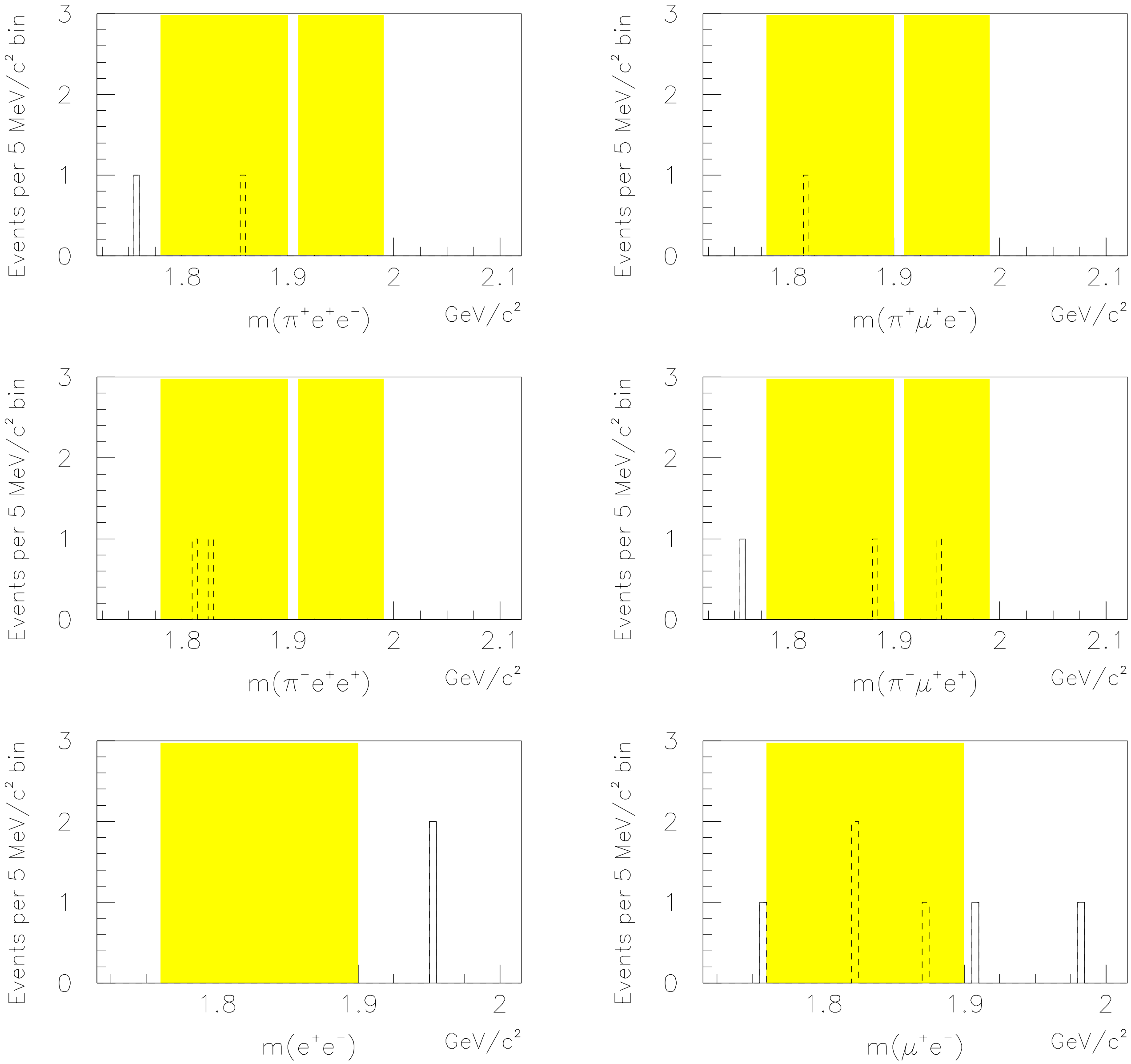

FIG. 1. The preliminary data for the D^+ and D^0 decay modes presented here.

We estimate the mean background assuming a flat distribution calculated from the events seen in the regions that are outside the "boxes". Then the Poisson signal mean μ for the total number of observed events for a 90% confidence level upper limit are calculated, using the method of Feldman and Cousins [5], and this number, N_X, is substituted into Equation 1 thus giving a 90% confidence level upper limit branching ratio. The estimated background, total number of events within the "box", the number N_X for a 90% confidence level upper limit, the calculated upper limit branching ratios and the previously measured upper limits [6] are given in Table II.

To separate charm candidates from background, we require the secondary vertex to be well-separated from the primary vertex and located well outside the target foils and other solid material, the momentum vector of the candidate D^+ or D^0 to point back to the primary vertex, and the decay track candidates to pass closer to the secondary vertex than the primary vertex. Specifically, the secondary vertex must be separated by $> 20\,\sigma_L$ for D^+, ($> 12\,\sigma_L$ for D^0) from the primary vertex and by $> 5.0\,\sigma_L$ from the closest material in the target foils, where σ_L in each case is the calculated longitudinal resolution in the measured separation. The sum of the momentum vectors of the three tracks from this secondary vertex must miss the primary vertex by $< 40\ \mu$m in the plane perpendicular to the beam. We form the ratio of each track's smallest distance from the secondary vertex to its smallest distance from the primary vertex, and require the product of these ratios to be less than 10^{-n} where n is the number of tracks in the secondary vertex. There is also a cut on the lifetime of the D^+ or D^0 candidate; it is < 5 picoseconds for the D^+ and < 3 picoseconds for the D^0. Finally, the net momentum of the D^+ candidate transverse to the line connecting the primary and secondary vertices must be less than 250 MeV/c (300 MeV/c for the D^0).

For this analysis we use a "blind" analysis technique. This method entailed the following steps: first covering the signal region with a "box", then optimizing ALL cuts using Monte Carlo simulated signal events and data from the wings outside the "box" before opening the "box" and only then opening the "box" that covers the signal region. The closed "box" mass windows are: $1.84 < M(D^+) < 1.90$ GeV/c^2 for $D^+ \to \pi\mu\mu$, $1.78 < M(D^+) < 1.90$ GeV/c^2 for $D^+ \to \pi ee$ and $\pi\mu e$, $1.95 < M(D_s^+) < 1.99$ GeV/c^2 for $D_s^+ \to K\mu\mu$, $1.91 < M(D_s^+) < 1.99$ GeV/c^2 for $D_s^+ \to Kee$ and $K\mu e$, $1.83 < M(D^0) < 1.90$ GeV/c^2 for $D^0 \to \mu\mu$, and $1.76 < M(D^0) < 1.90$ GeV/c^2 for $D^0 \to ee$ and μe. One should note the asymmetric windows for the decay modes containing electrons. This is to account for the electron bremsstrahlung tail. The upper limit of the branching ratio is calculated using the following formulae:

$$BR_X = \frac{N_X/\varepsilon_X}{N_{norm}/\varepsilon_{norm}} \cdot BR_{norm} = \frac{N_X}{N_{norm}} \frac{\varepsilon_{norm}}{\varepsilon_X} \cdot BR_{norm} \tag{1}$$

where N_X is the number of observed events for a given decay mode and ε is the detection efficiency. The ratio of the detector efficiencies for the normalization decay mode versus the unknown decay mode is

$$\frac{\varepsilon_{norm}}{\varepsilon_X} = \frac{N_{norm}^{MC}}{N_X^{MC}}. \tag{2}$$

N_X is corrected, using the method of Feldman and Cousins [5], for background. We have not yet corrected for systematic errors. The number of normalization events for the D^+ decay modes is $N_{norm} = 25330 \pm 169$, $D^+ \to K^-\pi^+\pi^+$ events, and for the D^0 decay modes is $N_{norm} = 26980 \pm 185$, $D^0 \to K^-\pi^+$ events.

In addition to the cuts made on the kinematic variables described above, particle identification cuts are used to reduce the background. These cuts tagged the dilepton candidates, thereby greatly reducing the background. Events which could also be reconstructed as a reflection, due to particle misidentification, from other purely hadronic decay modes into a region outside the "boxes", but within the overall mass window, were removed. Examples of this would include $D^+ \to K^-\pi^+\pi^+$ reconstructed as $D^+ \to \pi^-\ell^+\ell^+$ or $D^0 \to K^-\pi^+$ reconstructed as $D^0 \to \ell^+\ell^-$. In Figure 1, we present preliminary plots of the data for the D^+ and D^0 decay modes described in this paper. The yellow boxes are the part of the plot that were originally covered by the "boxes". The events observed within these "boxes" are the total number of observed events, signal plus background. In the plots of the D^+ decay modes the lower yellow box is the D^+ "box" and the upper yellow box is the D_s^+ "box".

Recent Results from Fermilab Charm Experiment E791

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We report the results of some recent E791 charm analyses. They include 1) a search for rare and forbidden decays, 2) measurements of form factors for $D^+ \to K^{*0}\ell^+\nu_\ell$ and $D_S^+ \to \phi\ell^+\nu_\ell$, and 3) D_S^+ and D^0 lifetime measurements including the lifetime difference between $D^0 \to K^-\pi^+$ and $D^0 \to K^-K^+$. The latter is the first direct search for a possible lifetime difference that could contribute to $D^0 - \overline{D}^0$ mixing.

I. INTRODUCTION

E791 is a high statistics charm experiment that acquired data at Fermilab during the 1991-1992 fixed-target run. The experiment combined a fast data acquisition system with an open trigger. Over 2×10^{10} events were collected with the Tagged Photon Spectrometer [1] using a 500 GeV π^- beam. There were five target foils with 15 mm center-to-center separations: one 0.5 mm thick platinum foil followed by four 1.6 mm thick diamond foils. The spectrometer included 23 planes of silicon microstrip detectors (6 upstream and 17 downstream of the target), 2 dipole magnets, 10 planes of proportional wire chambers (8 upstream and 2 downstream of the target), 35 drift chamber planes, 2 multi-cell Čerenkov counters that provided π/K separation in the 6-60 GeV/c momentum range [2], electromagnetic and hadronic calorimeters, and a muon detector.

II. RARE AND FORBIDDEN DECAYS OF D^+, D_S AND D^0

We report the preliminary results of a search for flavor-changing neutral-current (FCNC), lepton number violating (LNV) and lepton family violating (LFV) decays of D^+, D_S^+ and D^0, into modes[1] containing muons and electrons. This analysis is an extension of our previous work [3]. The search for rare and forbidden decays provides another test of the Standard Model. The contribution, within the Standard Model, of short distance electroweak processes to the branching ratios of the FCNC-like decay modes described here is expected [4] to be less than 10^{-8}. The LNV and LFV decay modes are totally forbidden by the Standard Model. Therefore, the search for these rare and forbidden decay modes allows tests for violations of the Standard Model from FCNC, neutrino oscillations or other even more exotic processes. We are currently examining all the modes described in Table II; however, we are only presenting the following searches in this paper: $D^+ \to \pi^+e^+e^-$, $D^+ \to \pi^+\mu^\pm e^\mp$, $D^+ \to \pi^-e^+e^+$, $D^+ \to \pi^-\mu^+e^+$, $D^0 \to e^+e^-$, and $D^0 \to \mu^\pm e^\mp$.

TABLE I. Rare and Forbidden Decay Modes.

FCNC	LFV	LNV
$D^+ \to \pi^+\mu^+\mu^-$	$D^+ \to \pi^+\mu^\pm e^\mp$	$D^+ \to \pi^-\mu^+\mu^+$
$D^+ \to \pi^+e^+e^-$	$D^+ \to \pi^-\mu^+e^+$	$D^+ \to \pi^-e^+e^+$
$D_S^+ \to K^+\mu^+\mu^-$	$D_S^+ \to K^+\mu^\pm e^\mp$	$D_S^+ \to K^-\mu^+\mu^+$
$D_S^+ \to K^+e^+e^-$	$D_S^+ \to K^-\mu^+e^+$	$D_S^+ \to K^-e^+e^+$
$D^0 \to \mu^+\mu^-$	$D^0 \to \mu^\pm e^\mp$	
$D^0 \to e^+e^-$		

[1] all references to D^+, D_S^+ and D^0 and their decay modes also imply the corresponding charge-conjugate states.