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Observation of the Vector Meson Cabibbo Suppressed Decay $D^+ \to \rho^0 \mu^+ \nu$

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We report on the first statistically significant observation of the vector meson Cabibbo suppressed semileptonic decay $D^+ \to \varrho^0 \mu^+ \nu$. We measure the branching ratio of the decay mode $D^+ \to \varrho^0 \mu^+ \nu$ with respect to the decay mode $D^+ \to \overline{K}^{*0} \mu^+ \nu$ to be $\frac{BR\ (D^+ \to \varrho^0 \mu^+ \nu)}{BR\ (D^+ \to \overline{K}^{*0} \mu^+ \nu)} = 0.079 \pm 0.019\ (stat)\ \pm 0.013\ (syst)$. Data were collected by Fermilab photoproduction experiment E687.

There continue to be few experimental data on Cabibbo suppressed charm semileptonic decays. Evidence for the scalar decays $D^0 \rightarrow \pi^- l^+ \nu$ and $D^+ \rightarrow \pi^0 l^+ \nu$ has been reported by the E687 [1], CLEO [2][3] and MARK III [4] collaborations. Up to now, the only evidence of Cabibbo suppressed vector meson decay was reported by the E653 [5] collaboration, which observed a signal of $4.0^{+2.8}_{-2.3} \pm 1.3$ events in the decay mode $D^+ \rightarrow \varrho^0 \mu^+ \nu$ and measured the branching ratio $\frac{BR\ (D^+ \rightarrow \varrho^0 \mu^+ \nu)}{BR\ (D^+ \rightarrow \overline{K}^{*0} \mu^+ \nu)}$ $= 0.044^{+0.031}_{-0.025} \pm 0.014$ [6]. When large statistical samples become available, Cabibbo suppressed semileptonic decays will be used to compare the structure of the hadronic current to the Cabibbo favored case. Also, if the theoretical knowledge of the hadronic form factors is improved, such decays will present the best tool to measure the CKM matrix element V_{cd}. In this paper we report on the observation of the Cabibbo suppressed vector meson semileptonic decay $D^+ \rightarrow \varrho^0 \mu^+ \nu$, in data collected by experiment E687.

E687 is a high energy photoproduction experiment at the Fermi National Accelerator Laboratory whose goal is the study of charm particle physics. The E687 beamline and spectrometer are described in detail elsewhere [7][8]. Briefly, charm particles were produced by a photon beam of average tagged energy $\sim 220\ GeV$ interacting on a $\sim 4\ cm$ Beryllium target. The charged products of the charm decays were tracked through twelve planes of silicon microstrip detectors (organized in four stations) and twenty planes of multi-wire proportional chambers (grouped in five stations). Charged particle momentum was determined from the track bending in the fields of two large magnets operated with opposite polarities. Charged particle identification was provided by a system of three Čerenkov detectors working in threshold mode. Muons were detected in the downstream end of the spectrometer by a system of three scintillator arrays and four proportional tube planes; shielding was provided by the upstream detectors (mainly the inner electromagnetic and the hadronic calorimeters) and two blocks of steel. This analysis is based on the full data sample collected during the 1990 and 1991 Fermilab fixed target runs.

We reconstructed decay candidates of the form $D^+ \to h^* \mu^+ \nu$, $h^* \to h^- h^+$, where h^* is a resonant vector meson decaying into two bodies: $\overline{K}^{*0}(892) \to K^- \pi^+$ or $\rho^0(770) \to \pi^- \pi^+$ (throughout this paper, charged conjugate states are implicitly assumed). A combination of three charged tracks of the form $(h^- h^+)\mu^+$ was selected and required to originate from a common point in space (the D^+ decay vertex) with a confidence level greater than 1%. The muon candidate μ^+ was required to be identified by the muon detector and was not compatible with being either a kaon or a proton in the Čerenkov counters. The opposite-sign hadron h^- was required to be identified as kaon definite or kaon/proton ambiguous for $D^+ \to \overline{K}^{*0} \mu^+ \nu$ candidates, and as pion definite or pion/electron ambiguous for $D^+ \to \rho^0 \mu^+ \nu$ candidates [9]. The like-sign hadron $h^+ = \pi^+$ was more loosely required not to be identified as kaon or proton for both decays. We used all the tracks reconstructed in the silicon microvertex (excluding those already assigned to the secondary vertex) to form all the possible vertices of the event with a confidence level greater than 1%; we then chose the primary vertex to be the highest multiplicity vertex within the target region. In order to reduce contamination from D_s^+ semileptonic decays, we exploited the longer lifetime of the D^+ and required a large significance of separation between the primary and the secondary vertex: $L/\sigma_L > 20$ [10]. We also constrained the secondary vertex to be outside the target region: besides helping to reduce contamination from D_s^+ semileptonic decays, this requirement proved very effective in suppressing background from misidentified charm hadronic decays (discussed in further detail later). Background from higher multiplicity semileptonic decays was suppressed by requiring the confidence level that any other track in the event (i.e. a track not already assigned to the primary or secondary vertex) originate from the secondary vertex be less than

1%. For both the $D^+ \to \overline{K}^{*0}\mu^+\nu$ and $D^+ \to \varrho^0\mu^+\nu$ decay candidates, we plotted the two-hadron invariant mass $M(h^-h^+)$ and looked for a signal at the mass of the parent vector meson: $\overline{K}^*(892)$ or $\varrho^0(770)$.

We found that the background to the $M(h^-h^+)$ invariant mass distribution is adequately described by a combination of three sources: other D^+ and D_s^+ semileptonic decays involving two pions, semileptonic decays of D^0 produced in D^{*+} decays, and charm hadronic decays.

Both D^+ and D_s^+ mesons decay semileptonically into several final states containing two oppositely charged pions, which can therefore affect the $M(\pi^-\pi^+)$ mass distribution of $D^+ \to \varrho^0\mu^+\nu$ candidates. Table I lists the decays which were considered in this analysis. Of all the background channels, the only ones which have been experimentally observed are those of D_s^+ into $\eta(547)$ and $\eta'(958)$, for which CLEO measured the branching ratios [11]: $\frac{BR(D_s^+\to\eta' e^+\nu)}{BR(D_s^+\to\phi e^+\nu)} = 0.43 \pm 0.11 \pm 0.07$ and $\frac{BR(D_s^+\to\eta e^+\nu)}{BR(D_s^+\to\phi e^+\nu)} = 1.24 \pm 0.12 \pm 0.15$. Contamination from these decays was reduced by computing the invariant mass of the three charged daughters of the decay and requiring $1.2 < M(\pi^-\pi^+\mu^+) < 1.8\ GeV/c^2$ for $D^+ \to \varrho^0\mu^+\nu$ candidates, $1.0 < M(K^-\pi^+\mu^+) < 1.8\ GeV/c^2$ for $D^+ \to \overline{K}^{*0}\mu^+\nu$ candidates. Monte Carlo studies showed that this requirement almost completely removes any contribution from $D^+, D_s^+ \to \eta'\mu^+\nu$, $\eta' \to \eta X$, while suppressing contributions from $D^+, D_s^+ \to \eta\mu^+\nu$ and $D^+ \to \omega^0\mu^+\nu$. The D_s^+ decays, which have shorter lifetime than the D^+ decays, are further suppressed by the out-of-target and $L/\sigma_L > 20$ requirements.

D^0 pseudoscalar semileptonic decays originating from an excited D^{*+}, such as $D^{*+} \to D^0\pi^+$, $D^0 \to K^-\mu^+\nu$ and $D^{*+} \to D^0\pi^+$, $D^0 \to \pi^-\mu^+\nu$, can also be a source of background if the soft pion from the D^{*+} is erroneously assigned to the secondary vertex. We found that these contributions can be completely eliminated by imposing a lower limit on the invariant mass difference $M(h^-\pi^+\mu^+) - M(h^-\mu^+) > 0.25\ GeV/c^2$.

Finally, contamination from charm hadronic decays, where one of the hadrons is misidentified as a muon, was estimated with the following technique. We ran the analysis algorithm on a subsample of the full data set, with identification requirements on the "μ^+" prong exactly opposite to our standard muon identification. Each entry in the histogram was weighted according to the momentum-dependent misidentification probability. The level of misidentification background was then boosted by the ratio of the charm yield in the total data sample relative to the charm yield in the subsample considered.

In Figures 1 and 2 we show (as solid points) the invariant mass distributions $M(K^-\pi^+)$ and $M(\pi^-\pi^+)$ for $D^+ \to \overline{K}^{*0}\mu^+\nu$ and $D^+ \to \rho^0\mu^+\nu$ candidates, respectively, after all the analysis cuts are applied. To fit the data histograms, we used a *binned maximum likelihood* technique. For either the $D^+ \to \overline{K}^{*0}\mu^+\nu$ or $D^+ \to \rho^0\mu^+\nu$ decay, the likelihood function was defined as:

$$\mathcal{L} = \prod_{i=1}^{\#bins} \frac{n_i^{s_i} e^{-n_i}}{s_i!} ,$$

where:

s_i = number of events in bin i of data histogram,

n_i = number of events in bin i of fit histogram .

The fit histogram was composed of the following contributions: a signal term ($D^+ \to \overline{K}^{*0}\mu^+\nu$ or $D^+ \to \rho^0\mu^+\nu$), with shape given by the Monte Carlo [12] and with the yield as a fit parameter; several terms for the charm semileptonic backgrounds with shapes given by the Monte Carlo, and amplitudes which were estimated with various techniques and then fixed in the fit; a term for the misidentified hadronic background, modelled with the technique described above and then fixed in the fit. Since the experimental conditions changed slightly between the 1990 and the 1991 runs, we performed separate fits for the two periods, and then combined the results as independent samples.

In the $D^+ \to \overline{K}^{*0}\mu^+\nu$ case, the fit histogram was constructed as:

$$n_i = Y_{K^*\mu\nu} S_{1i} + \mathcal{M} S_{2i} \; .$$

where $Y_{K^*\mu\nu}$ is the $D^+ \to \overline{K}^{*0}\mu^+\nu$ yield (the only parameter of the fit), S_{1i} is the corresponding normalized Monte Carlo shape, and $\mathcal{M} S_{2i}$ is the amount of background from hadron/muon misidentification (for each histogram bin). The two components of the fit to the data histogram are shown in Figure 1 with different hatching styles. The combined 1990+1991 yield for $D^+ \to \overline{K}^{*0}\mu^+\nu$ was estimated to be $Y_{K^*\mu\nu} = 443 \pm 22$ events.

In the $D^+ \to \varrho^0\mu^+\nu$ case, the fit histogram was constructed as:

$$\begin{aligned}
n_i = {} & Y_{\varrho\mu\nu}\; S_{1i} + \mathcal{M}\; S_{2i} + Y'_{K^*\mu\nu}\; S_{3i} \\
& + Y_{\eta\mu\nu}\left[S^a_{4i} + \frac{BR(\eta\to\pi^+\pi^-\gamma)}{BR(\eta\to\pi^+\pi^-\pi^0)}\frac{\epsilon(\eta\mu\nu,\ \pi^+\pi^-\gamma)}{\epsilon(\eta\mu\nu,\pi^+\pi^-\pi^0)}\; S^b_{4i}\right] \\
& + \frac{Y_{\phi\mu\nu}}{\epsilon(\phi\mu\nu, K^-K^+)}\frac{1}{BR(\phi\to K^-K^+)}\times \\
& \Big\{ \mathcal{A}\cdot\Big[\; BR(\eta'\to\gamma\varrho^0)\;\epsilon(\eta'\mu^+\nu,\ \gamma\varrho^0)\; S^a_{5i} \\
& + BR(\eta'\to\eta\pi^+\pi^-)\;\epsilon(\eta'\mu^+\nu,\ \eta\pi^+\pi^-)\; S^b_{5i} \\
& + BR(\eta'\to\eta\pi^0\pi^0)\; BR(\eta\to\pi^+\pi^-\pi^0)\;\epsilon(\eta'\mu^+\nu,\ \eta\pi^0\pi^0,\ \pi^+\pi^-\pi^0)\; S^c_{5i} \\
& + BR(\eta'\to\eta\pi^0\pi^0)\; BR(\eta\to\pi^+\pi^-\gamma)\;\epsilon(\eta'\mu^+\nu,\ \eta\pi^0\pi^0,\ \pi^+\pi^-\gamma)\; S^d_{5i}\;\Big] \\
& + \mathcal{B}\cdot\Big[\; BR(\eta\to\pi^+\pi^-\pi^0)\;\epsilon(\eta\mu^+\nu,\ \pi^+\pi^-\pi^0)\; S^a_{6i} \\
& + BR(\eta\to\pi^+\pi^-\gamma)\;\epsilon(\eta\mu^+\nu,\ \pi^+\pi^-\gamma)\; S^b_{6i}\;\Big]\Big\}
\end{aligned}$$

where: $Y_{\varrho\mu\nu}$ is the fitted yield for $D^+ \to \varrho^0\mu^+\nu$; $\mathcal{M}$ is the background from misidentified hadronic decays; $Y'_{K^*\mu\nu} = \frac{Y_{K^*\mu\nu}}{\epsilon(K^*\mu\nu)}\;\epsilon(K^*\mu\nu \to \varrho\mu\nu)$ is the background from $D^+ \to \overline{K}^{*0}\mu^+\nu$ events where the kaon is misidentified as a pion by the Čerenkov counters; $Y_{\eta\mu\nu}$ is the fitted yield for $D^+ \to \eta\mu^+\nu$, $\eta \to \pi^+\pi^-\pi^0$; and all the other terms (from the third line on) represent the residual contamination from the decays $D_s^+ \to \eta\mu\nu$, $D_s^+ \to \eta'\mu\nu$, which was estimated using the branching ratios $\mathcal{A} \equiv \frac{BR(D_s^+ \to \eta' e^+ \nu)}{BR(D_s^+ \to \phi e^+ \nu)}$ and $\mathcal{B} \equiv \frac{BR(D_s^+ \to \eta e^+ \nu)}{BR(D_s^+ \to \phi e^+ \nu)}$ measured by CLEO [11], and reconstructing the decay $D_s^+ \to \phi\mu\nu$ from E687 data [14][15]. (In the above formula, ϵ denotes a reconstruction efficiency and BR a branching ratio.) The final likelihood for the $D^+ \to \varrho^0\mu^+\nu$ histogram was defined as:

$$\mathcal{L}_{\varrho\mu\nu} = \left\{ \prod_{i=1}^{\#bins} \frac{n_i^{s_i} e^{-n_i}}{s_i!} \right\} \times exp\left\{ -\frac{1}{2} \left[\frac{\mathcal{A} - A_0}{\sigma_{A_0}} \right]^2 \right\} \times exp\left\{ -\frac{1}{2} \left[\frac{\mathcal{B} - B_0}{\sigma_{B_0}} \right]^2 \right\}$$

to allow the two ratios $\mathcal{A}$, $\mathcal{B}$ to fluctuate within the error around their measured values A_0, B_0. $\mathcal{L}$ depends on four fitting parameters: $Y_{\varrho\mu\nu}$, $Y_{\eta\mu\nu}$, $\mathcal{A}$ and $\mathcal{B}$. The various components of the fit are shown in Figure 2 (a)-(b) with different hatching styles, and the corresponding yields are reported in Table II. In particular, the combined 1990+1991 yield returned for $D^+ \to \varrho^0\mu^+\nu$ is $Y_{\varrho\mu\nu} = 39 \pm 9$ events. Because of our low reconstruction efficiency for photons, we could not distinguish the decay $D^+ \to \varrho^0\mu^+\nu$ from the decay $D^+ \to \eta'\mu^+\nu$, $\eta' \to \gamma\varrho^0$; the fitted yield for $D^+ \to \varrho^0\mu^+\nu$ must therefore be considered in an *inclusive* sense.

In Figures 3 (a)-(b) we compare the surviving yield as a function of the L/σ_L cut between the reconstructed data sample and the generated Monte Carlo sample, for both $D^+ \to \overline{K}^{*0}\mu^+\nu$ and $D^+ \to \varrho^0\mu^+\nu$ candidates: the good agreement between the two sets of points is a confirmation that the observed signals behave with the expected D^+ lifetime [16].

We used the fitted yields and the Monte Carlo computed efficiencies to measure the ratio of the branching ratios for the two decay channels $D^+ \to \varrho^0\mu^+\nu$ and $D^+ \to \overline{K}^{*0}\mu^+\nu$. Combining the 1990 and 1991 results as a weighted average, we found:

$$\frac{BR\ (D^+ \to \varrho^0\mu^+\nu)}{BR\ (D^+ \to \overline{K}^{*0}\mu^+\nu)} = \frac{Y_{\varrho\mu\nu}/\epsilon(\varrho\mu\nu)}{Y_{K^*\mu\nu}/\epsilon(K^*\mu\nu,\ K^* \to K^-\pi^+)}\ BR(\overline{K}^{*0} \to K^-\pi^+)$$

$$= 0.079 \pm 0.019,$$

where again the decay mode at numerator must be considered in an inclusive sense [17]. The quoted statistical error in the branching ratio includes the effect of correlation between the $D^+ \rightarrow \overline{K}^{*0}\mu^+\nu$ and $D^+ \rightarrow \varrho^0\mu^+\nu$ fitted yields.

Several analysis techniques were used to evaluate a possible bias in our measurement (we notice that, because of the nearly identical topology of the two decays $D^+ \rightarrow \varrho^0\mu^+\nu$ and $D^+ \rightarrow \overline{K}^{*0}\mu^+\nu$, most of the systematic uncertainty should cancel out when the ratio of the modes is taken). We found that the major source of systematic uncertainty originated from our choice of the technique used to fit the data histograms. In order to estimate this error, we performed several reasonable variations of the fitting process: we changed the bin size of the data histograms, we tried different mass ranges for the fit, we used different parametrizations for the background, and finally we let the hadron/muon misidentification background vary freely, instead of fixing it in the fit [18]. By statistically combining the results from the different fit variants, we computed a systematic uncertainty of 16.5%. In order to investigate possible bias originating from specific analysis cuts, we divided the total data sample into two approximately equal, statistically independent subsamples, below and above a particular value of the cut. We performed the measurement for the two independent subsamples, and compared the results to the value obtained with the total data sample. All the split sample measurements were consistent with the quoted value, thus giving no indication of systematic uncertainty from the particular choice of analysis conditions. Finally, we included a conservative systematic error of 2.5% on the branching ratio due to Čerenkov identification. All sources of systematic error were combined incoherently to obtain the total systematic error of 16.7%.

In conclusion, we reported the first statistically significant observation of the vector meson Cabibbo suppressed semileptonic decay $D^+ \rightarrow \varrho^0\mu^+\nu$. We measured the following ratio of branching ratios of the decay mode $D^+ \rightarrow \varrho^0\mu^+\nu\ (+\gamma\ )$ with respect to the decay mode $D^+ \to \overline{K}^{*0} \mu^+ \nu$:

$$\frac{BR\ (D^+ \to \rho^0 \mu^+ \nu)}{BR\ (D^+ \to \overline{K}^{*0} \mu^+ \nu)} = 0.079 \pm 0.019\ (stat)\ \pm 0.013\ (syst)\ .$$

In the future, larger samples will allow the measurement of the hadronic form factors involved in this decay and comparison to those of the Cabibbo-favored decay $D^+ \to \overline{K}^{*0} \mu^+ \nu$.

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TABLES

TABLE I. Relative reconstruction efficiencies† for some D^+, D_s^+ semileptonic decays

Decay	D^+	D_s^+
$\overline{K}^{*0}\mu^+\nu$	1.35	
$\varrho^0\mu^+\nu$	1	
$\overline{K}^{*0}\mu^+\nu$, K/π misid	0.04	
$\eta\mu^+\nu$, $\eta\to\pi^+\pi^-\pi^0$	0.26	0.11
$\eta\mu^+\nu$, $\eta\to\pi^+\pi^-\gamma$	0.50	0.17
$\eta'\mu^+\nu$, $\eta'\to\gamma\varrho^0$	1.00	0.40
$\eta'\mu^+\nu$, $\eta'\to\eta\pi^+\pi^-$, $\eta\to X$	$\sim 10^{-3}$	$\sim 10^{-3}$
$\eta'\mu^+\nu$, $\eta'\to\eta\pi^0\pi^0$, $\eta\to\pi^+\pi^-\pi^0$	$\sim 10^{-3}$	$\sim 10^{-3}$
$\eta'\mu^+\nu$, $\eta'\to\eta\pi^0\pi^0$, $\eta\to\pi^+\pi^-\gamma$	0.03	0.02
$\omega^0\mu^+\nu$, $\omega^0\to\pi^+\pi^-\pi^0$	0.31	

† For each decay channel, we quote the global reconstruction efficiency relative to the mode $D^+\to\varrho^0\mu^+\nu$, after all the analysis cuts are applied (the average between the 1990 and 1991 runs is taken). The difference in efficiency is due primarily to the mass cuts (D^+ and D_s^+ modes) and the detachment cut (D_s^+ modes).

TABLE II. Yields of different fit components

decay	1990	1991	90+91
$D^+ \to \overline{K}^{*0}\mu^+\nu$	228.8 ± 16.2	214.2 ± 15.3	443.0 ± 22.3
$D^+ \to \varrho^0\mu^+\nu$	16.1 ± 6.5	23.0 ± 6.3	39.2 ± 9.0
$D^+ \to \overline{K}^{*0}\mu^+\nu,\ K/\pi$ misid	7.9 ± 1.0	6.2 ± 0.9	14.1 ± 1.3
$D_s^+ \to \eta'\mu^+\nu,\ \eta' \to \gamma\varrho^0$	2.4 ± 0.9	1.8 ± 0.6	4.2 ± 1.1
$D_s^+ \to \eta\mu^+\nu,\ \eta \to \pi^+\pi^-\pi^0$	1.6 ± 0.4	1.2 ± 0.3	2.8 ± 0.5
$D_s^+ \to \eta\mu^+\nu,\ \eta \to \pi^+\pi^-\gamma$	0.5 ± 0.1	0.4 ± 0.1	0.9 ± 0.1
$D^+ \to \eta\mu^+\nu,\ \eta \to \pi^+\pi^-\pi^0$	3.0 ± 2.3	3.7 ± 2.1	6.7 ± 3.1
$D^+ \to \eta\mu^+\nu,\ \eta \to \pi^+\pi^-\gamma$	1.1 ± 0.9	1.6 ± 0.9	2.7 ± 1.3

REFERENCES

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[1] E687 Collab., P. L. Frabetti *et al.*, Phys. Lett. B **382** (1996) 312.

[2] CLEO Collab., F. Butler *et al.*, Phys. Rev. D **52** (1995) 2656.

[3] CLEO Collab., M.S. Alam *et al.*, Phys. Rev. Lett. **71** (1993) 1311.

[4] MARK III Collab., J. Adler *et al.*, Phys. Rev. Lett. **62** (1989) 1821.

[5] E653 Collab., K. Kodama *et al.*, Phys. Lett. B **316** (1993) 455.

[6] Based on pure quark content, we can naively expect $\frac{BR\ (D^+\to\varrho^0 l^+\nu)}{BR\ (D^+\to\overline{K}^{*0} l^+\nu)} \sim \frac{BR\ (D^+\to\pi^0 l^+\nu)}{BR\ (D^+\to\overline{K}^0 l^+\nu)} \sim \frac{1}{2}\frac{BR\ (D^0\to\pi^- l^+\nu)}{BR\ (D^0\to K^- l^+\nu)}$, where the factor of $\frac{1}{2}$ arises from the $\frac{1}{\sqrt{2}}$ coupling of $d\overline{d}$ to the ϱ^0 or π^0 wave function.

[7] E687 Collab., P. L. Frabetti *et al.*, Nucl. Instrum. Methods. A329 (1993) 62.

[8] E687 Collab., P. L. Frabetti *et al.*, Nucl. Instrum. Methods. A320 (1992) 519.

[9] The tight requirement on the opposite sign pion π^- from the decay $D^+ \to \varrho^0\mu^+\nu$ is intended to reduce contamination from $D^+ \to \overline{K}^{*0}\mu^+\nu$ events where the K^- is misidentified by the Čerenkov counters as a π^-.

[10] L is the distance in space between primary and secondary vertex, σ_L is the corresponding error computed on an event by event basis.

[11] CLEO collab., G.Brandenburg et al.,Phys. Rev. Lett. **75** (1995) 3804.

[12] The Monte Carlo samples were generated with a full simulation of the semileptonic matrix element for vector meson decays. As pole mass values, we used $M_V = 2.1\ GeV/c^2$, $M_A = 2.5\ GeV/c^2$ for $D^+ \to \overline{K}^{*0}\mu^+\nu$ and $M_V = 2.0\ GeV/c^2$, $M_A = 2.45\ GeV/c^2$ for $D^+ \to \varrho^0\mu^+\nu$. The ratios of form factors normalizations were fixed to $R_V = 1.75$ and $R_2 = 0.78$ for both decays [13].

[13] E687 Collab., P. L. Frabetti *et al.*, Phys. Lett. B **307** (1993) 262.

[14] Contamination to the $M(\pi^+\pi^-)$ distribution from doubly-misidentified $D_s^+ \to \phi\mu^+\nu$ events is negligible, because of the low double-misidentification probability, the invariant mass cuts applied and the $L/\sigma_L > 20$ and out-of-target requirements.

[15] Background from $D^+ \rightarrow \omega^0\mu^+\nu$, $\omega^0 \rightarrow \pi^+\pi^-\pi^0$ can also contaminate the $M(\pi^+\pi^-)$ distribution in the region between the partially reconstructed $\eta \rightarrow \pi^+\pi^-\pi^0$ and the ρ^0. Unfortunately, this source of contamination could not be estimated a priori, since the decay has never been observed. Because of the invariant mass cuts, the reconstruction efficiency for $D^+ \rightarrow \omega^0\mu^+\nu$ is about three times lower than for $D^+ \rightarrow \rho^0\mu^+\nu$. In Figure 2, a large ω^0 contamination is not apparent. However, it was not possible to make a precise estimate of the contamination, since we could not fit to the broad $M(\pi^+\pi^-)$ mass peak from $\omega^0 \rightarrow \pi^+\pi^-\pi^0$. Eventually, the effect of this source of background was included in our *fit variant* systematic error (see footnote [18]).

[16] E687 Collab., P. L. Frabetti *et al.*, Phys. Lett. B **323** (1994) 459.

[17] The ratio of branching fractions $\frac{BR(D^+\rightarrow\rho^0\mu^+\nu)}{BR(D^+\rightarrow\eta'\mu^+\nu)}$ depends on the $\eta - \eta'$ mixing angle. Assuming a mixing angle of $-20°$, Scora and Isgur [19] estimated $\frac{BR(D^+\rightarrow\eta'\mu^+\nu)}{BR(D^+\rightarrow\rho^0\mu^+\nu)} = 0.24$, which would imply a correction to our quoted branching ratio of $\frac{BR(D^+\rightarrow\eta'\mu^+\nu)}{BR(D^+\rightarrow\rho^0\mu^+\nu)} \times BR(\eta' \rightarrow \gamma\rho^0) = 7\%$

[18] In particular, one of the fit variants performed was a fit to the $M(\pi^-\pi^+)$ distribution in the mass range $0.5 - 1.75\ GeV/c^2$, which used a linear background to simulate possible contamination from partially reconstructed decays $D^+ \rightarrow \omega^0\mu^+\nu$. This technique allowed us to include the effects of possible low dipion mass backgrounds as part of a controllable systematic error.

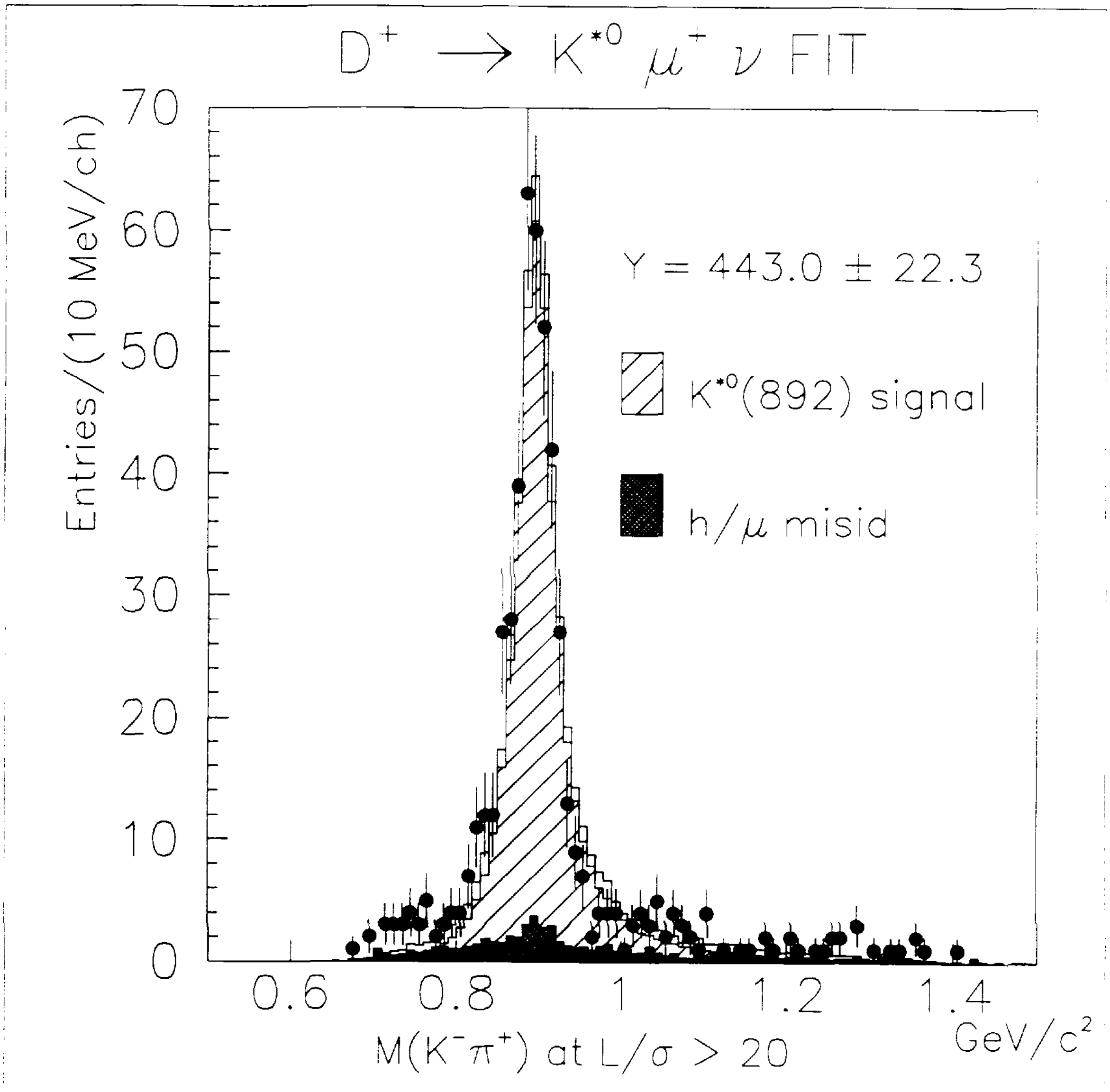
[19] D. Scora and N. Isgur, CEBAF-TH-94-14, HEP-PH-9503486 (1994) 72.

FIGURES

FIG. 1. $M(K^-\pi^+)$ invariant mass reconstructed from $D^+ \rightarrow \overline{K}^{*0}\mu^+\nu$ decay candidates (1990 and 1991 data are combined). The points are the data, the solid line is the total fit, the various fit components are represented with different hatching styles.

FIG. 2. $M(\pi^-\pi^+)$ invariant mass reconstructed from $D^+ \rightarrow \varrho^0\mu^+\nu$ decay candidates (1990 and 1991 data are combined). The points are the data, the solid line is the total fit, the various fit components are represented with different hatching styles. The fit components are shown in two separate histograms for better presentation.

FIG. 3. Surviving yield as a function of the L/σ_L cut for $D^+ \rightarrow \overline{K}^{*0}\mu^+\nu$ (a) and $D^+ \rightarrow \varrho^0\mu^+\nu$ (b) reconstructed decay candidates. In both cases, the data points (black) match well the lifetime evolution expected from a D^+ Monte Carlo signal (white). The two sets of points are normalized at $L/\sigma_L > 20$.



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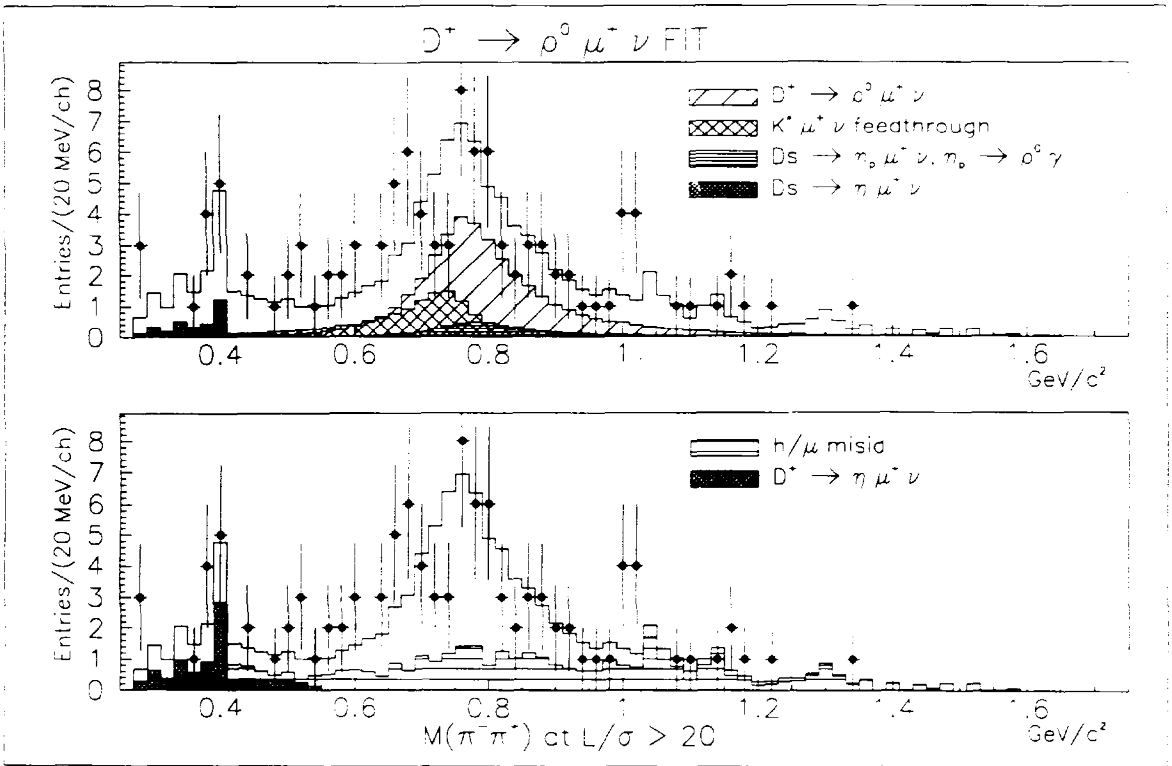

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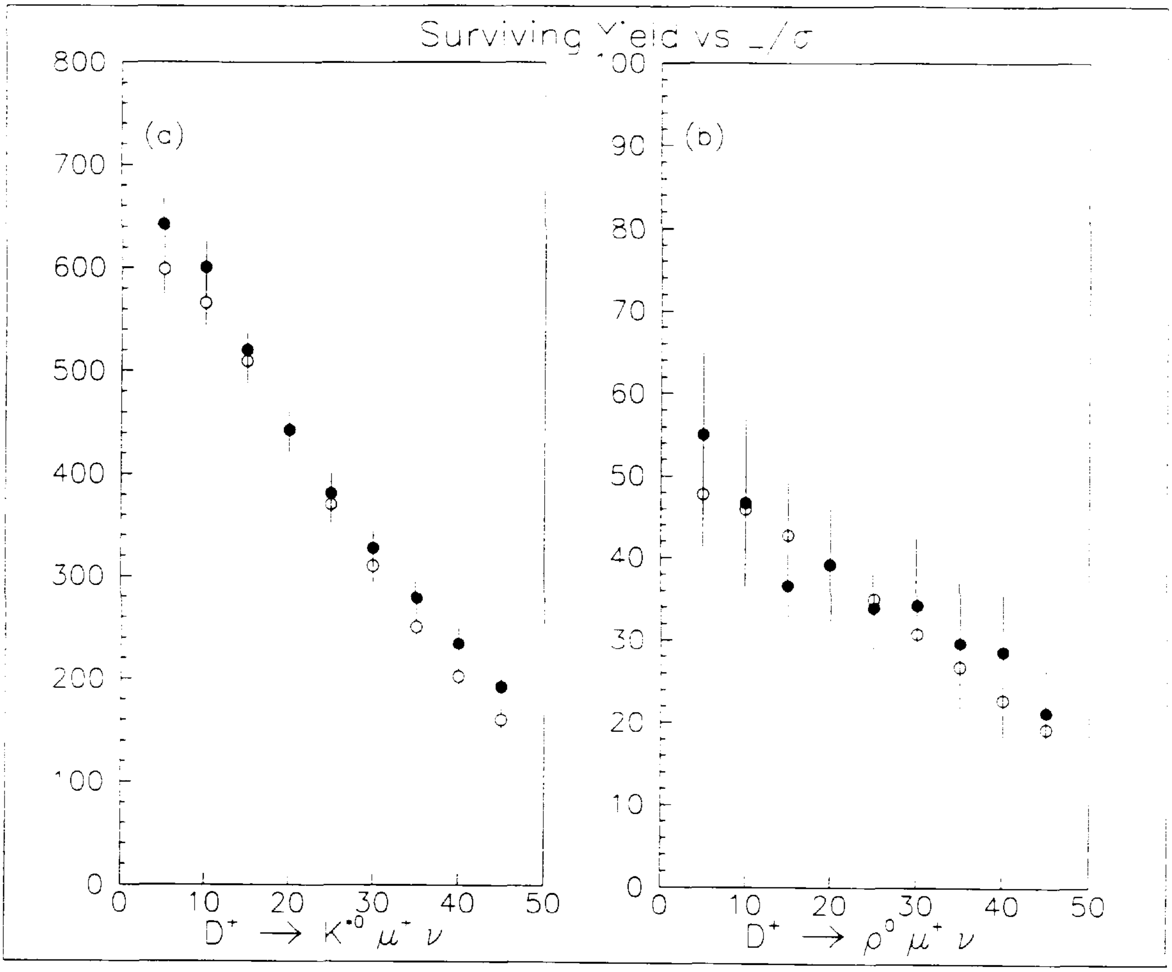

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