α in pp scattering at ~ 250 GeV/c [V. Bartenev *et al.*, Phys. Rev. Lett. 31, 1367 (1973)], we fix the α_i parameters at the reasonable values $\alpha_i = 0$.

[6]The diffractive and electromagnetic amplitudes are of comparable magnitude in only a small range of momentum transfers, and are, in any case, likely to be approximately orthogonal in phase.

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[8]G. Fäldt, Nucl. Phys. B43, 591 (1972).

[9]C. Bemporad *et al.*, Nucl. Phys. B51, 1 (1973).

[10]The differential cross section for Coulomb production of an object of mass m, at an incident neutron momentum $p_{\rm inc}$, peaks at $t = 2t_{\rm min}$, where $t_{\rm min} \approx (m^2 - m_n^2)^2/(2p_{\rm inc})$. For m near the $p\pi^-$ threshold and $p_{\rm inc} \approx 300$ GeV/c, $t_{\rm min}$ corresponds to a distance on the order of 100 fm.

[11]The spectrometer's angular resolution (55 μrad) was determined by fitting the resolution-broadened Coulomb calculation to the measured differential cross section on Pb, at very small t, for masses near $\Delta(1236)$. We have also included in our analysis effects of multiple Coulomb scattering in the targets.

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Observation of μe Events in $\bar{\nu}$ and ν Interactions in Neon

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Based on four μ^+e^-X and six μ^-e^+X events (with estimated backgrounds 1.1 and 0.6 events, respectively), in the Fermilab 15-in. neon (64 at.%) hydrogen bubble chamber, the fractions of μ^+e^- and μ^-e^+ production relative to $\bar{\nu}_\mu$ and ν_μ charged-current interactions in a broad band $\overset{(-)}{\nu}$ beam are, respectively, $\bar{f} = (0.15^{+0.14}_{-0.08})\%$ and $f = (0.34^{+0.23}_{-0.13})\%$; $\bar{f}/f = 0.45^{+0.6}_{-0.3}$.

Considerable attention has been given to the reaction $\nu_\mu N \rightarrow \mu^- e^+ X$ which occurs at a fractional rate $f \sim \frac{1}{2}\%$ of all ν_μ charged-current (CC) interactions.[1] The most popular interpretation of this phenomenon, and of the $\mu^-\mu^+$ events reported in both ν_μ and $\bar{\nu}_\mu$ interactions,[2] is that they are due to the production of charmed particles which decay (semi-) leptonically. A 90%-confidence upper limit of $\frac{1}{2}\%$ was set[3] previously on the fractional rate $\bar{f}$ of the $\bar{\nu}_\mu$ reaction $\bar{\nu}_\mu N \rightarrow \mu^+ e^- X$. The ratio of rates $\bar{f}/f$ is expected to be sensitive to the fraction of the nucleon momentum carried by the strange quarks of the sea.[4] We report here a simultaneous measurement of $\bar{f}$ and f which results in a determination of $\bar{f}/f$ relatively free of systematic effects.[5]

The data come from 45×10^3 pictures produced by an exposure of the Fermilab 15-in. bubble chamber (BC) with external muon identifier[6] (EMI) to a one-horn-focused wide-band antineutrino beam produced by 10^{13} (400 GeV) protons/pulse in a 12-in.-long aluminum oxide target. The BC has a 30-kG field and was filled with a heavy mixture of neon and hydrogen (64% Ne atomic fraction). This liquid's short radiation length (39 cm) yields high electron identification and γ-ray conversion efficiencies, and its short interaction length ($\sim$1.3 m for pions), together with the EMI, permits good separation of muons and hadrons. Because only one horn (downstream) was in place and no plug was inserted into the beam, the flux was such that the relative numbers of CC events which satisfy our cuts[7] are $\bar{\nu}_\mu : \nu_\mu : \bar{\nu}_e : \nu_e = 2.8 \times 10^3 : 2.3 \times 10^3 : 36 : 71$; and median event energies and energy distribution rms widths are (in GeV) 30:47:32:32 and 25:46:20:24. This experiment is thus in a unique position to compare $\bar{\nu}$ with ν interactions.

The film was double scanned (~15% was third scanned) for all neutral-induced events (except one-leaving-prong events[8]). Events with one or more possibly primary $e^{\pm}$ among the outgoing tracks were reviewed by physicists, who eliminated identifiable Dalitz and close e^+e^- pairs, Compton electrons, δ rays, π and K decays, etc. and verified that the remaining single primary $e^{\pm}$ showed ≥2 independent signatures.[9] The $e^{\pm}$ track momenta reconstructed with TVGP or HYDRA were corrected for bremsstrahlung losses by a Behr-Mittner method,[10] and for early, catastrophic bremsstrahlung by adding the energy of the corresponding converted pairs.

We thus obtain 75 e^- and 42 e^+ events (with $p_e > 0.8$ GeV and satisfying other cuts[7]), most of which we interpret as ν_e and $\bar{\nu}_e$ interactions, respectively. The four μ^+e^- and six μ^-e^+ candidates among them, whose characteristics are given in Table I (No. 1 of which is shown in Fig. 1), all have $y_e = 1 - p_e/\sum p_x \gtrsim 0.8$. The y_e distributions (Fig. 2) of the other $e^{\pm}$ events are approximately uniform for e^- and peaked at low y_e for e^+, and thus resemble those observed for $\mu^{\pm}$ events.[2,3] The four e^+ events in Fig. 2(b) with $y_e > 0.8$ and no μ are compatible with what is expected from $\bar{\nu}_e$ events (1.9 event, assuming a 10% fraction of antiquarks in the nucleon[2,3]), plus various background sources (1.2 event).

The important backgrounds (and losses) to the

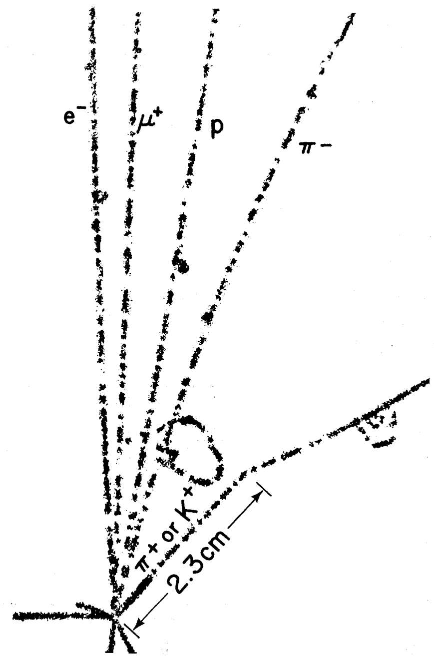

FIG. 1. The vertex region of event No. 1 (see Table I). The invariant mass of the proton and the π^- is compatible with the Λ^0 mass. The kinking track may be a K^+. The other tracks are protons (or nuclear debris).

μe events, summarized in Table II, are of two types: (i) a false μ due to "punchthrough," i.e., a leaving hadron ($L^{\pm}$) from a $\overset{(-)}{\nu}_e$ event falsely reg-

TABLE I. Characteristics of the μe events (Refs. 7 and 12). Events 1–4 are μ^+e^-, 5–10 are μ^-e^+; n_{ch} is the number of outgoing prongs (not counting protons of range ≲ 4 cm) and ΣQ their net charge. The momenta are in GeV/c. $\Sigma p_x \approx E_\nu$. SP is the strange particle.

	n_{ch}	ΣQ	Σp_x	p_μ	p_e	x_{vis}	y_{vis}	SP
1	7	+3	26	20.5[a]	3.6	0.17	0.22	
2	8	0	37	8.2[a]	6.4	0.07	0.77	Λ
3	4	0	17	4.9[a]	3.4	0.02	0.70	
4	5	+1	28	4.9[a]	2.0	0.10	0.83	Λ
5	9	+1	82	31.5[a]	1.1	0.18	0.62	
6	7	+1	42	23.2[a]	0.9	0.24	0.45	
7	5	+1	70	59.0[a]	5.1	0.66	0.16	
8	5	+1	33	25.1[a]	0.9	0.13	0.25	K^+
9	11	+1	60	28.9[a]	7.6	0.31	0.55	
10	6	0	73	49.1[a]	10.9	0.23	0.33	K^0

[a]This track has highest transverse momentum, relative to the incident ν direction, of any outgoing track of the event.

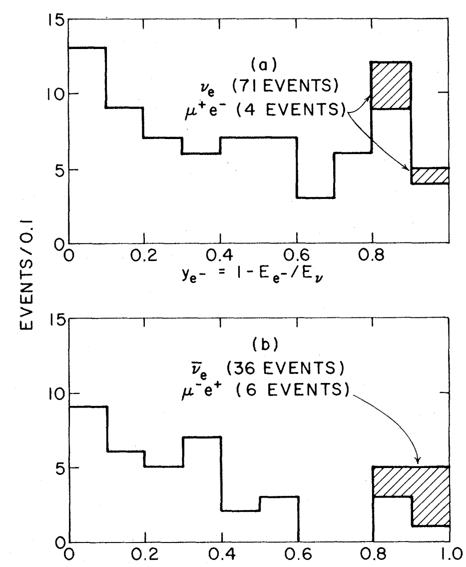

FIG. 2. y_e distribution (Ref. 12) of the events (Ref. 7) with (a) a single primary e^- or (b) a single primary e^+. The events with an identified (Ref. 7) μ^+ or μ^- are shown hatched.

TABLE II. Summary of data (Ref. 7).

	μ^-e^+	μ^+e^-
$\overset{(-)}{\nu}_\mu$CC	$2.3\times10^3\ \mu^-$	$2.8\times10^3\ \mu^+$ [a]
$\overset{(-)}{\nu}_\mu$CC	36 e^+	71 e^-
μe events	6 μ^-e^+	4 μ^+e^-
Backgrounds		
1. $\overset{(-)}{\nu}_\mu$ + false e		
Asym. DP	0.04	0.04
Close asym. pairs	0.13	0.12
Close Compton e^-	...	0.16
Charge exchange	...	0.12
$K_{e3}^{\pm}$	0.17	0.09
Subtotal	0.34 ± 0.2	0.53 ± 0.3
2. $\overset{(-)}{\nu}_e$ + false μ	0.23 ± 0.2	0.58 ± 0.3
Total background	0.57 ± 0.3	1.11 ± 0.4
Losses		
DP cut	1%	3%
δ-ray cut	...	3%
False DP, etc.	11%	5%
Vertex gap	...	5%
$e^{\pm}$ cuts loss	(12 ± 8)%	(15 ± 8)%
Corr.[b] No. μe	7.6	4.2
$\mu e/\mathrm{CC}\equiv\overset{(-)}{f}$	$(0.34^{+0.23}_{-0.13})$%	$(0.15^{+0.14}_{-0.08})$%

[a]Ref. 8.

[b]Corrected for $e^{\pm}$ losses (Ref. 7).

isters as a μ in the EMI, and (ii) a false single primary $e^{\pm}$ on a $\overset{(-)}{\nu}_\mu$ event, coming from an asymmetric Dalitz pair, etc. The punchthrough probability of (7.7 ± 2.3)% per $L^{\pm}$ was determined from a study of 343 μ^+ and 324 μ^- events some 23% of which had ≥1 $L^{\pm}$ in addition to the μ. It is compatible with momentum independence above 4 GeV/c. The estimated punchthrough backgrounds to $\mu^{\mp}e^{\pm}$ and $\mu^{\mp}e^{\mp}$ are reduced by factors of 2 or more by our requirement $p_L^{\pm}>p_e$.[11] (All of our μe events have $p_\mu>p_e$.) We have assumed that an $e^{\pm}$ above 5 MeV, a gap $\gtrsim5$ mm (±3 mm) between vertex and pair or Compton, and a kink of 6° in projection are detectable in the average μe event (see Fig. 1); also that 9% of the $\overset{(-)}{\nu}$ CC events have a K^+ and 5% a K^-. By false DP (Table II) we mean single primary $e^{\pm}$ which are mistaken as part of showers caused by Dalitz (or close) pairs or close triplets because of the chance superposition of a real Dalitz pair, close δ ray, etc.

The total estimated false e^- background to the μ^+e^- sample is thus 0.53 ± 0.3 event for $p_{e^-}\geq0.8$ GeV/c. For $p_{e^-}\geq0.3$, 1.6, 3.0 GeV/c, it would be 1.60, 0.20, and 0.07 event, respectively. For $0.3<p_e<0.8$ GeV/c, we have one additional μ^+e^- candidate and one μ^-e^+. We have no μ^+e^+ and one μ^-e^- candidate event; this is compatible with the expected false $e^{\mp}$ plus false $\mu^{\mp}$ background which is similar to that for $\mu^{\pm}e^{\mp}$.

After corrections, the four μ^+e^- and six μ^-e^+ correspond to $\bar{f}=(0.15^{+0.14}_{-0.08})$% and $f=(0.34^{+0.23}_{-0.13})$%, relative to all $\overset{(-)}{\nu}_\mu$ CC events satisfying our cuts.[7] Thus $\bar{f}/f=0.45^{+0.6}_{-0.3}$. (Here systematic errors cancel approximately.) We emphasize that the total false single primary e^- background expected for $p_e>3.0$ GeV/c is <0.1 event. Therefore the probability that events No. 1, No. 2, and No. 3 are all false single primary e^- events is $\lesssim10^{-4}$. The sum of the probabilities that all four (or more) μ^+e^- events arise from the various possible combinations of punchthrough and false e^- background is ~1%.

The median energy is ~65 (27) GeV for the μ^-e^+ (μ^+e^-) events compared with 47 (30) GeV for the ν_μ ($\bar{\nu}_\mu$) CC events. We have therefore no evidence that the μ^+e^- events are produced by higher energy $\bar{\nu}$ than are typical $\bar{\nu}$ CC events, contrary to what might be expected,[4] for example, if they came from a heavy particle carrying a new quantum number beyond charm.

In the Glashow-Iliopoulos-Maiani (GIM)[4] model context, $\bar{f}/f$ provides a constraint on the fraction of the nucleon momentum carried by the nonstrange and strange antiquarks of the sea. For example, if there were no sea, $\bar{f}/f$ would be zero; in the limit that the strange sea dominated both μe production reactions, $\bar{f}/f$ would approach $\sigma(\nu_\mu\to\mu^-)/\sigma(\bar{\nu}_\mu\to\mu^+)$ which is experimentally[2] approximately 2.5. If the x distributions[12] of the valence and sea quarks are as assumed by Field and Feynman[4,13] (with $\frac{1}{4}$ of the sea strange) and if the charmed quark mass is of order 2 GeV, then a value of $\bar{f}/f\approx0.6$ is predicted,[4] compatible with our result. If there were no strange quarks in the sea then this calculation would predict $\bar{f}/f<0.1$. In this case, assuming $f=0.5$%, the probability of observing four or more μ^+e^- events is 16%.

We conclude that our results for the rate and characteristics of $\nu_\mu\to\mu^-e^+X$ production are compatible with other recent experiments,[1] and that our $\overset{(-)}{\nu}_\mu\to\mu^{\pm}e^{\mp}X$ rates and characteristics (Table I) are understandable in the framework of the GIM model.[4,13]

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[7]We require (i) $\Sigma p_x (\approx E_{\rm vis}) > 10$ GeV where the sum is over all measured particles (including γ rays, V^0's, and neutral stars) and x is the beam direction; for $e^\pm$ we require also each of (ii) $p_e > 0.8$ GeV/c, (iii) $\geqslant 2$ independent signatures, $\geqslant 1$ of which occurs before p_e falls below ~ 0.1 GeV/c, (iv) $M_{e^\pm x^\mp} > m_{\pi^0}$, where $x^\mp$ is any possible $e^\mp$ track, (v) for e^-, inconsistency ($\geqslant 2\sigma$) with being a δ ray; for $\mu^\mp$ we require (vi) $p_\mu > 4$ GeV/c, and (vii) that this leaving track register in the EMI as a μ with likelihood (Ref. 6) $\mathfrak{L} > 5$. Within our ~ 14-m^3 fiducial volume (which provides $\geqslant 90$ cm of potential path length for forward tracks), the muon identification efficiency is $\sim 97\%$ (geometric) $*$ 93% (electronics) $*$ 95% ($\mathfrak{L} > 5$) $\approx 86\%$ for $p_\mu > 4$ GeV/c; an $e^\pm$ of $p_e > 0.8$ GeV/c has a $(95\pm 3)\%$ probability to show $\geqslant 2$ of the required signatures; the effective $e^\pm$ event scanning efficiency is $(85\pm 5)\%$.

[8]The number of one-prong events, $(15\pm 5)\%$ of $\bar{\nu}_\mu$ CC, was estimated by multiplying the number of events with only a μ^+ and evaporation prongs by the ratio (events with only a μ^- and a proton)/(events with only a μ^-, proton, and evaporation prongs).

[9]To be considered an $e^\pm$, a track had to show $\geqslant 1$ ($\geqslant 2$ after analysis) of these "signatures": (i) spiralization to a point in the chamber; (ii) sudden change of curvature and/or materialization in the chamber of the radiated bremsstrahlung quantum; (iii) δ ray or trident of an energy such that only an $e^\pm$ could have yielded it; (iv) for e^+, annihilation in flight yielding a tangent γ ray.

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[11]The punchthrough background estimates of Table II are arrived at by multiplying the observed number of leaving tracks satisfying the cuts on $e^\pm$ events (three tracks for e^+, seven tracks for e^-) with no identified muon by $0.077/(1-0.077)$.

[12]We define $x_{\rm vis} = \Sigma p_x E_\mu (1-\cos\theta_\mu)/M_p(\Sigma p_x - E_\mu)$, $y_{\rm vis} = 1 - E_\mu/\Sigma p_x$, $y_e = 1 - p_e/\Sigma p_x$, where $\Sigma p_x \approx E_\nu \approx E_{\rm vis}$.

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