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[1]A. R. Clark *et al.*, Phys. Rev. Lett. 26, 1667 (1971). The experimental upper limit has since been increased to 3×10^{-9}. This is due to the change in the accepted value for $\Gamma(K_L\to\pi^+\pi^-)/\Gamma(K_L\to \text{all})$ as well as to a recalculation of their $K_L\to\pi^+\pi^-$ and $K_L\to\mu^+\mu^-$ acceptances. R. C. Field, SLAC Report No. SLAC-PUB-1498 (to be published).

[2]L. M. Sehgal, Phys. Rev. 183, 1511 (1969); C. Quigg and J. D. Jackson, University of California Radiation Laboratory Report No. 18487 (unpublished).

[3]W. C. Carithers *et al.*, Phys. Rev. Lett. 30, 1336 (1973); W. C. Carithers *et al.*, Phys. Rev. Lett. 31, 1025 (1973).

[4]Y. Fukushima *et al.*, Phys. Rev. Lett. 36, 348 (1976).

[5]T. A. Nunamaker, Rev. Sci. Instrum. 42, 1701 (1971).

[6]R. DeVoe *et al.*, Phys. Rev. D 16, (1977).

[7]K. Kleinknecht, Annu. Rev. Nucl. Sci. 26, 1 (1976).

Dilepton Production by Neutrinos in Neon[a]

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In an exposure of the Fermilab 15-ft bubble chamber filled with a heavy neon-hydrogen mixture to a broadband neutrino beam, we have observed 81 dilepton events of the type $\nu_\mu+\text{Ne}\to\mu^-+e^++\dots$. This corresponds to $(0.5\pm0.15)\%$ of the total charged-current neutrino interactions. A total of fifteen neutral strange-particle decays ($K_s^0\to\pi^+\pi^-$, $\Lambda^0\to p\pi^-$) were found in these dilepton events. When corrected for detection efficiencies and unobservable strange particles, this is consistent with the production of approximately one strange particle per event.

The discovery of high-mass (3 GeV), narrow-width (keV) states, the J/ψ,[1] indicated the onset of a new phenomenon. The subsequent observation of bare charm[2] verified that this was indeed the uncovering of a new quantum number. The observed production of dilepton pairs ($\mu^-\mu^+$), (μ^-e^+) in high-energy neutrino interactions[3] could be a further manifestation of charm or something new. In this Letter, we report on 81 μ^-e^+ pairs produced by the interaction of high-energy neutrinos in neon, the rate and strange-particle content being consistent with charmed-particle production.

We present the results obtained in a run at the Fermi National Accelerator Laboratory consisting of 46 000 photographs in the 15-ft bubble chamber. The two-horn focused wide-band neutrino beam was used, with an average of 1×10^{13} 400-GeV protons per pulse indicent on a 12-in. long aluminum oxide target. The relative fluxes of the four kinds of neutrinos have been calculated to be of the order of $\nu_\mu:\bar\nu_\mu:\nu_e:\bar\nu_e\approx100:3:1:0.2$. The ν_μ energy spectrum peaks near 25 GeV and extends to well over 100 GeV. The chamber was filled with a neon-hydrogen mix with the following properties: 64 at.% neon, 0.8-g/cm^2 density, 40-cm radiation length, and 125-cm interaction length. The chamber magnetic field was 30 kG. In this heavy mixture electrons are likely to radiate (the chamber is ~10 radiation lengths across), hadrons to interact visibly (the chamber is ~3 interaction lengths), and muons to escape without any visible interaction.

In a selective scan, all events with an e^+ or an e^- candidate were recorded, regardless of any other feature of the event. The $e^\pm$ was visually identified on the scan tables by the following cri-

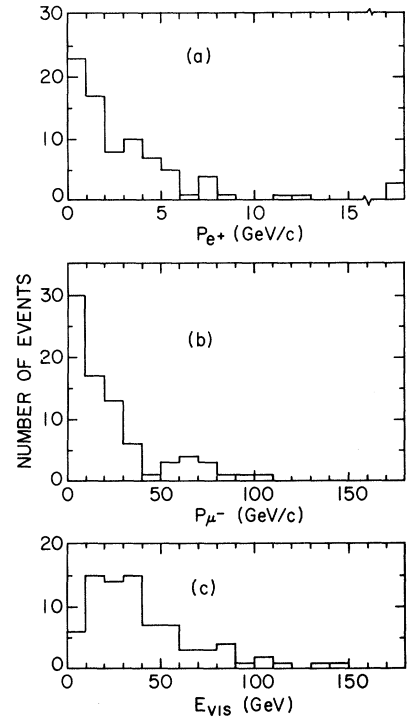

FIG. 1. Distributions in (a) P_{e^+}, (b) P_{μ^-}, and (c) $E_{\rm vis}$ for the 81 $\mu^- e^+$ events. The crosshatched events are the backgrounds due to asymmetric Dalitz pairs in (a) and fake μ^- in (b).

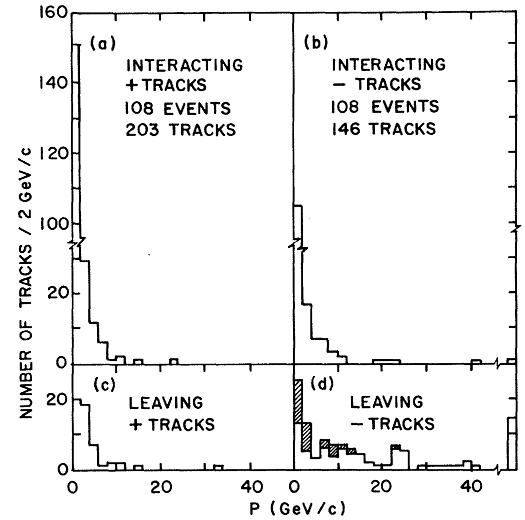

FIG. 2. Momentum distributions for (a) interacting positive, (b) interacting negative, (c) leaving positive, and (d) leaving negative tracks in the 108 events with an e^+. The crosshatched tracks in (d) correspond to leaving negative tracks in addition to the μ^- candidate.

teria: (a) bremsstrahlung with a visible $\gamma \to e^+e^-$ conversion, and (b) spiraling track with minimum ionization.

All of these events were measured and geometrically reconstructed by the program TVGP. Events where the e^+ was identified by at least two signatures[4] and had a momentum greater than 300 MeV/c were selected. A final sample of 108 events with a single e^+ coming directly from the interaction vertex was obtained.

The fastest negative tract in each event that leaves the chamber without a visible interaction is a μ^- candidate. Some of these tracks will in fact be hadrons which escape without interaction; however, this background is small, as discussed below. Of the 108 events with an e^+, 81 have a μ^- candidate. We interpret these events as

$$\nu_\mu + \text{neon} \to \mu^- + e^+ + \ldots \quad (81 \text{ events}).$$

The average multiplicity of charged tracks including the μ^- and the e^+ in these events is 6. The distributions in the momenta of the μ^- and the e^+ and the total visible energy in these events is shown in Fig. 1. There is no evidence in the visible energy distribution for a threshold for this process in the vicinity of 30 GeV. As is apparent from these distributions, on the average the e^+ carried much less energy than the μ^-. The ratio of their average momenta is $\langle P_{\mu^-}\rangle / \langle P_{e^+}\rangle = 6 \pm 1.5$, indicating that these events are not likely to come from the decay of a neutral heavy lepton.[5]

The major backgrounds[6] are e^+ tracks arising from asymmetric Dalitz pairs (where the e^- track is not visible) in genuine charged-current ν_μ interactions and fake μ^- tracks from negative hadrons failing to interact in $\bar{\nu}_e$ interactions ($\bar{\nu}_e + \text{Ne} \to e^+ + \ldots$).

The background due to asymmetric Dalitz pairs has been experimentally determined by (i) measuring the fraction of Dalitz pairs with total energy over 300 MeV (including externally converted γ's that appear on the scanning table to originate at the vertex of the event) associated with charged-current events to be 4.2%, and (ii) measuring the probability of a Dalitz pair to have an e^+ satisfying our selection criteria and an invisible e^- to be 0.3%.[7] This leads to a background of 3 ± 3 events in our sample.

The background due to fake μ^- (π^- punchthrough) is determined from a comparison of the interacting and noninteracting tracks of both signs. Since the noninteracting tracks in the e^+ event sample travel an average of $1\frac{1}{3}$ interaction lengths, 75% of all hadrons should interact. More precisely, the ratio of interacting to noninteracting positive tracks (excluding recoil protons and pion decays) in these e^+ events determines the interaction probability for hadrons as a function of momentum. Then from the observed number of interacting negative tracks, the expected number of π^- punchthroughs as a function of momentum were calculated taking into account the fact that some of the μ^-e^+ events had a slow leaving negative track, in addition to the μ^- candidate [the cross-hatched tracks in Fig. 2(d)]. We thus obtain a background of 9 ± 8 events due to fake muons in the 81 μ^-e^+ events.[8] The striking difference between the noninteracting positive [Fig. 2(c)] and negative [Fig. 2(d)] tracks indicates the validity of the μ^- interpretation for noninteracting negatives.

In determining the rate of dilepton production, there are further corrections for detection efficiencies and normalizations that must be applied. In particular, there are the following: (i) Scanning efficiency for finding μ^-e^+ events. [A value of $(90\pm5)\%$ was derived by a double scan of 85% of the film.] (ii) Identification efficiency for e^+. [A sample of externally converted $\gamma\to e^+e^-$ pairs was used to determine the probability, as a function of momentum and length of the e^+, of obtaining two identification signatures. This gave an average e^+ identification probability of $(85\pm5)\%$ for the fiducial volume used.] (iii) Loss due to obscured events, $(10\pm5)\%$. (iv) Miscellaneous losses, such as true e^+ from vertex looking like Dalitz pair with δ ray or other track tangent to e^+, $(5\pm5)\%$. (v) Normalization. By measuring ~800 neutrino events in an unbiased sample of frames spread throughout the run, and applying the μ^- identification procedure described above, we find 0.6 charged-current events per picture, 85% of which are in the restricted fiducial volume[9] used for the scan for $e^\pm$ events, and thus a denominator of 23 500 $\nu_\mu+\text{Ne}\to\mu^-+\ldots$ events.

The resulting dileptonic rate is

$$R=\frac{\nu_\mu+\text{Ne}\to\mu^-+e^++\ldots}{\nu_\mu+\text{Ne}\to\mu^-+\ldots}=(0.5\pm0.15)\%.$$

This result is in general agreement with results obtained in other experiments.[10]

The sample of μ^-e^+ events has been examined for associated $K_s^0\to\pi^++\pi^-$ and $\Lambda^0\to p+\pi^-$ decays (vees). All such vees were measured, geometrically reconstructed, and subjected to two- and three-constraint kinematic fits in SQUAW. In the 81 μ^-e^+ events, we find fifteen associated vees; nine made unambiguous fits to $K_s^0\to\pi^+\pi^-$, three were unambiguous $\Lambda^0\to p\pi^-$, and three were ambiguous between Λ^0 and K_s^0. One of the ambiguous vees occurred in the same event as one of the Λ^0's; we thus call it a K^0, and call the other two ambiguous vees, Λ^0's. Correcting for detection efficiency and branching ratios,[11] we obtain 39 K^0's and 9 Λ^0's for a total of 48 ± 14 neutral strange particles.

We have measured ~1300 vees associated with charged-current neutrino events. From this, we find that 6% of these events have a visible vee.[12] If the μ^-e^+ events had the same fraction of strange-particle production as the average charged-current events, we would expect to see five vees with the 81 events, whereas we see fifteen vees. This is a clear indication that the μ^-e^+ events have a higher level of strange-particle production than ordinary charged-current ν interactions.

Figures 3(a) and 3(b) show the distributions in $X_{\text{vis}}=q^2/2m(E_{\text{vis}}-E_\mu)$ and $Y_{\text{vis}}=E_{\text{hadron}}/E_{\text{vis}}$, respectively. These distributions have been corrected for our estimate of the fake μ^- background. For comparison, the distributions for charged-current ν_μ events are shown by the smooth curves. Figure 3(c) shows the distributions in the total hadronic mass $W=[m_p^2+2m_p(E_{\text{vis}}-E_\mu)-q^2]^{1/2}$, and Fig. 3(d) shows the K^0e^+ and Λ^0e^+ effective-

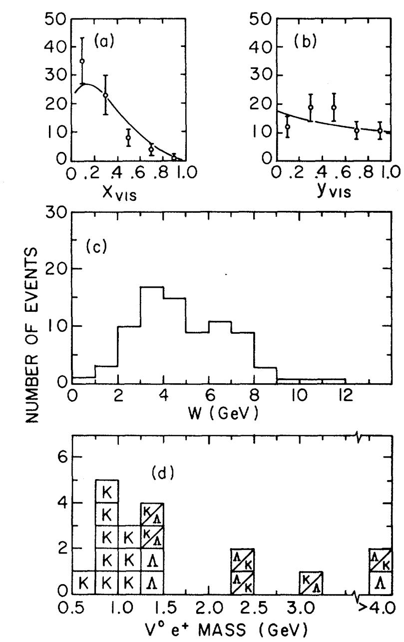

FIG. 3. Distributions in (a) X_{vis}, (b) Y_{vis}, (c) W, and (d) the K^0e^+ and Λ^0e^+ effective masses for the μ^-e^+ events. The curves on (a) and (b) represent the X and Y distributions for the charged-current ν_μ interactions for comparison. In (d), the ambiguous vees are plotted twice. The labels K/Λ and Λ/K refer to the K^0e^+ and Λ^0e^+ interpretations, respectively, of the three ambiguous vees.

mass distributions. The K^0e^+ effective-mass distribution peaks low, and the W distribution high, consistent with what would be expected from the production and semileptonic decay of a particle with mass $\lesssim 2$ GeV.

The 48 ± 14 neutral strange particles correspond to a rate of 0.6 ± 0.2 per event. If charged and neutral strange-particle production were equal, this would correspond to 1.2 strange particles per event, in good agreement with that expected from the Glashow-Iliopoulos-Maiani[13] model of charm production by neutrinos. This result is in disagreement with the Bosetti *et al.*[3] result of $1.84^{+0.67}_{-0.50}$ neutral strange particles per event, or under the same assumptions as above ~4 strange particles per event. This discrepancy is not understood.

We are very grateful to the many people at Fermilab whose hard work made this experiment possible. We also thank the scanning and measuring groups at Brookhaven National Laboratory and Columbia University for their efforts on this experiment.

[a]Research supported by the National Science Foundation and the U. S. Energy and Research Development Administration.

[1]J. J. Aubert *et al.*, Phys. Rev. Lett. 33, 1404 (1974); J.-E. Augustin *et al.*, Phys. Rev. Lett. 33, 1406 (1974); C. Bocci *et al.*, Phys. Rev. Lett. 33, 1408 (1974).

[2]E. G. Cazzoli *et al.*, Phys. Rev. Lett. 34, 1125 (1975); G. Goldhaber *et al.*, Phys. Rev. Lett. 37, 255 (1976); B. Knapp *et al.*, Phys. Rev. Lett. 37, 882 (1976).

[3]A. Benvenuti *et al.*, Phys. Rev. Lett. 34, 419 (1975), and 35, 1199 (1975); B. C. Barish *et al.*, Phys. Rev. Lett. 36, 939 (1976); J. Blietschau *et al.*, Phys. Lett. 60B, 207 (1976); P. Bosetti *et al.*, Phys. Rev. Lett. 38, 1248 (1977).

[4]Events in which the e^+ was part of a Dalitz pair or an external $\gamma \to e^+e^-$ conversion were not included.

[5]A. Pais and S. B. Treiman, Phys. Rev. Lett. 35, 1206 (1975).

[6]Many other backgrounds were considered; e.g., (a) e^+ from hadronic decays such as $\pi^+ \to e^+\nu$, $K^+ \to e^+\nu$, $K^+ \to \pi^0 e^+\nu$, $K_L{}^0 \to \pi^- e^+\nu$ at the vertex; (b) fake e^+ from hadronic interactions such as positive hadrons producing π^0's with no visible hadrons and subsequent π^0 Dalitz decay. The total contribution to the background from these sources is less than one event.

[7]In a sample of 1300 $\gamma \to e^+e^-$ externally converted pairs with a total energy over 300 MeV, only four had an e^+ satisfying our identification criteria and an e^- which might not be visible in a busy primary vertex. This agrees well with what we expect from the theoretical e^+e^- asymmetry distribution with a $P_{e^-} \leq 10$ MeV/c cut (corresponding to a ~2 cm diameter e^-).

[8]Background in the $\mu^- e^+$ sample due to neutral-current and neutron-induced events is negligible since these events have to have both a fake e^+ and a fake μ^-. However, this background is explicitly included in the 9 ± 8 event fake-muon background estimate.

[9]Normalization events were measured using the volume visible to all three neutrino cameras. The fiducial volume used for the e^+ events had the additional restriction that the event vertex had to be further than 50 cm from the back wall of the chamber.

[10]We can compare our result with two other experiments by applying appropriate cuts. In particular, with $P_e > 0.8$ GeV/c^2, we have 61 $\mu^- e^+$ events with eleven vees, corresponding to a value $R = (0.4 \pm 0.15)\%$ to be compared with $(0.8 \pm 0.3)\%$ of Bosetti *et al.* (Ref. 3). We have 14 events with both P_{e^+} and P_{μ^-} larger than 4 GeV/c and $E_{\text{vis}} \geq 40$ GeV. This corresponds to $(0.5 \pm 0.2)\%$ of the number of charged-current events with $E_{\text{vis}} \geq 40$ GeV. This last number might be compared to the $(0.8 \pm 0.3)\%$ obtained by Benvenuti *et al.* (Ref. 3).

[11]The corrections are as follows: $\frac{1}{0.9}$ is to correct for interactions before decay; $\frac{1}{0.85}$ and $\frac{1}{0.89}$ are corrections for K^0 and Λ^0 losses, respectively, when the vee decay is too close to the ν interaction vertex; $\frac{3}{2}$ correction is for branching ratios, and 2 in the K^0 case corrects for $K_L{}^0$. No scanning-efficiency correction in addition to the above corrections is needed.

[12]This value is in excellent agreement with the visible strange particle (38 V^0's in 543 ν_μ charged-current events) observed in H_2 in the 15-ft chamber at Fermilab if we correct for the strange particles lost in neon because they interact before they decay (10% correction). J. P. Berge *et al.*, Phys. Rev. Lett. 36, 127 (1976).

[13]S. L. Glashow, J. Iliopoulos, and L. Maiani, Phys. Rev. D 2, 1285 (1970).