longitudinally polarized electrons from unpolarized nucleons by measuring the asymmetry $r = (d\sigma^- - d\sigma^+)/(d\sigma^- + d\sigma^+)$ in which the superscripts refer to the electron helicity for a fully polarized electron beam. From the data in Table I for Q^2 between 1 and 4 $(\mathrm{GeV}/c)^2$, we have $|r| < 3\times10^{-3}$ at a 95% confidence level.

We are indebted to L. Boyer, M. Browne, S. Dhawan, S. Dyer, R. Eisele, R. Fong-Tom, W. Kapica, H. Martin, J. Sodja, and L. Trudell for their exceptional efforts in the prepration and running of this experiment. This research was supported in part by the U. S. Department of Energy under Contracts No. EY-76-C-02-3075 and No. EY-76-C-03-0515, the German Federal Ministry of Research and Technology, and the Japan Society for the Promotion of Science.

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Charmed-*D*-Meson Production by Neutrinos

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(Received 4 May 1978)

We have observed the production of the D^0 meson by neutrinos followed by the decay $D^0 \to K_S{}^0 + \pi^+ + \pi^-$. Correcting for detection efficiencies and K^0 decay branching ratios, we find that the production of the D^0 followed by decay into $K^0\pi^+\pi^-$ corresponds to (0.7 ± 0.2)% of all charged-current neutrino interactions.

The hadronic quantum number charm was postulated[1,2] to explain, among other things, the absence of strangeness-changing weak neutral currents. The recently discovered $J/\psi(3100)$, and the associated ψ' and χ states,[3] possess the attributes of hidden charm. The first direct observation of a charmed meson, the $D(1865)$, was in e^+e^- collisions at SPEAR.[4] In this paper, we report the only other direct observation of the D meson, produced in this case in neutrino-hadron interactions. The decay mode observed is $D^0 \to K_s{}^0\pi^+\pi^-$ with $K_s{}^0 \to \pi^+\pi^-$.

The experiment was carried out at the Fermi National Accelerator Laboratory using the twohorn focused wide-band muon-neutrino beam,[5] and the 15-ft chamber filled with a heavy neon-hydrogen mixture (64 at.% neon). A total of 150 000 pictures with an average of 10^{13} 400-GeV protons per pulse on the neutrino target has been taken. The results presented here are based on the analysis of the first 80 000 pictures, which correspond to approximately 50 000 charged-current neutrino interactions.

The interaction length for hadrons in the heavy neon mix is ~125 cm, so that hadrons typically interact, while muons leave the chamber without interaction, and can thus be identified on the scanning table. Neutral strange particles were detected via their decays, such as $K^0 \to \pi^+ + \pi^-$ and $\Lambda^0 \to p + \pi^-$. The film was scanned, and partially double scanned, for events with a possible neutral strange-particle decay (vee). All such events were measured and geometrically reconstructed and the decays kinematically fitted. Any event with a leaving negative track was considered to be a charged-current event and the muon was defined to be the fastest leaving negative track. For the present analysis, charged-current events with muon momentum (P_μ) greater then 2 GeV/c were used in order to reduce the background of noninteracting pions.

In the sample of 46 000 charged-current events with $P_\mu \geq 2$ GeV/c, 2913 events had one or more vees that made a satisfactory two- or three-constraint kinematical fit to $K_s^0 \to \pi^+\pi^-$, $\Lambda \to p\pi^-$, or $\bar{\Lambda} \to \bar{p}\pi^+$. Kinematical ambiguities between K_s^0, Λ, or $\bar{\Lambda}$ were resolved using the decay angular distributions. This resulted in 1815 charged-current events with a K_s^0. Approximately 89% of these were unambiguous K_s^0 decays.

The $K_s^0\pi^+\pi^-$ effective-mass distribution with two different bin sizes is shown in Figs. 1(a) and 2(a) (events with two V^0's have been removed). There is a peak in the $K_s^0\pi^+\pi^-$ spectrum in the D^0 mass region. The best fit to a polynomial background plus a Gaussian, shown by the curve in Fig. 2(a), gives the following parameters[6]:

$$\text{mass} = 1850 \pm 15 \text{ MeV}, \quad \sigma = 20 \pm 8 \text{ MeV},$$

corresponding to 64 events above a background of 180 events, with a statistical significance in excess of 4 standard deviations.[7] Since the mass is consistent with the D^0 measured at SPEAR,[4] the width is compatible with our experimental mass resolution of 20 MeV, and there are no narrow K^*'s in this mass region, we interpret this peak as the production of a D^0 meson followed by the decay $D^0 \to K^0\pi^+\pi^-$.

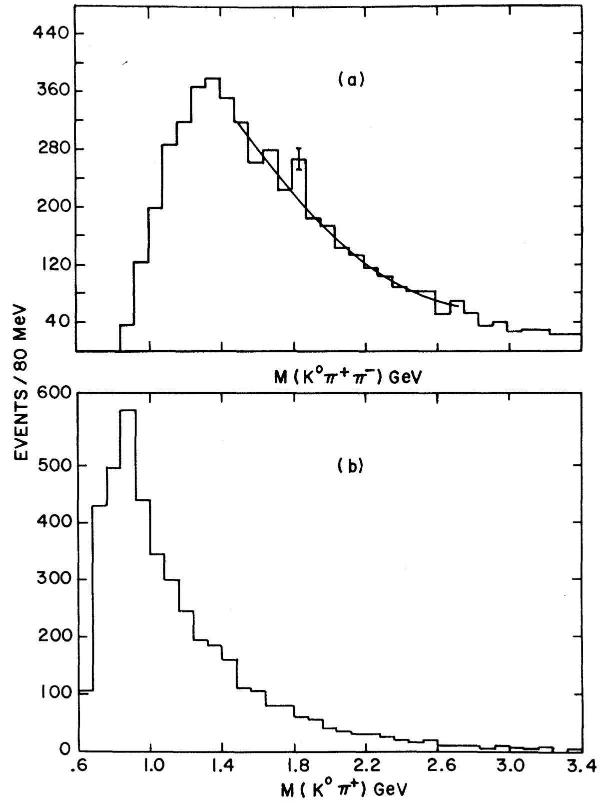

FIG. 1. Distributions of the (a) $K^0\pi^+\pi^-$ and (b) $K^0\pi^+$ effective masses in the reaction $\nu_\mu + \text{Ne} \to \mu^- + K_s^0$ + pions. The curve in (a) is a polynomial fit to the mass region near the D^0.

No corresponding peak is apparent near the D mass in the events without a μ^- [Fig. 2(b)]. This is consistent with the prediction of the Glashow-Iliopoulos-Maiani model that the charm-changing neutral-current interactions are absent. If the peak were due to K^* production, then one might expect it to be present in events both with and without a μ^-.

We have investigated the substructure of this decay using the $K^0\pi^+\pi^-$ Dalitz-plot distribution. There is no statistically significant evidence for a larger fraction of $K^*\pi$, $K\rho$, or $K^*(1420)\pi$ in the D^0 region than in the adjacent bands.

The $K_s^0\pi^+$ effective-mass distribution is shown in Fig. 1(b). No significant peak is apparent near the D^+ mass in the $K^0\pi^+$ distribution. The best fit to a polynomial background plus a Gaussian yields 11 ± 8 D^+ events, using a mass of 1868 MeV and a width equal to our mass resolution.

In order to estimate the rate of D^0 production followed by decay into $K_s^0\pi^+\pi^-$, we correct the

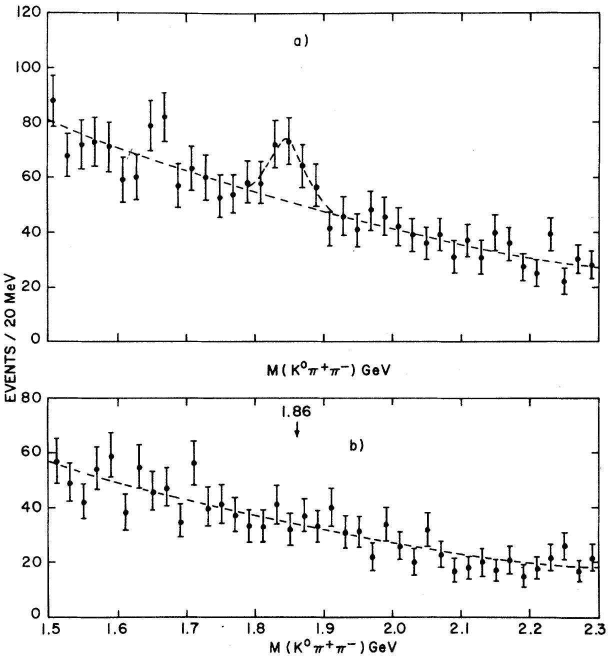

FIG. 2. Distributions of the $K^0\pi^+\pi^-$ effective mass in 20-MeV bins (a) for events with a μ^- with $P_\mu \geq 2$ GeV/c, and (b) for events with no μ^- in the final state. The curves are the best fits to the mass distributions using a polynomial background plus a Gaussian shape for the D^0.

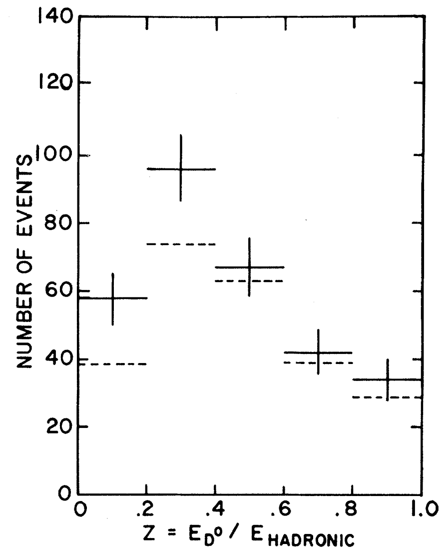

FIG. 3. Distribution of z of the D^0, where $z = E_{D^0}/E_{\text{hadronic}}$. The solid lines are all of the events in the D^0 region; the dashed lines are the estimate of the background under the D^0.

number of observed events above background for the $K^0 \to \pi^+\pi^-$ branching ratio (0.34), the vee scan and detection efficiencies (76%), and other efficiencies in the measurement and track reconstruction (76%), and obtain 325 ± 90 for the corrected number of $D^0 \to K^0\pi^+\pi^-$ decays. Comparing this to 46 400, the total number of charged-current ν_μ events with $P_\mu \geq 2$ GeV/c in the same amount of film, we obtain the ratio

$$\frac{\nu_\mu + \text{Ne} \to \mu^- + D^0 + \ldots,\ D^0 \to K^0\pi^+\pi^-}{\nu_\mu + \text{Ne} \to \mu^- + \ldots} = (0.7 \pm 0.2)\%.$$

A similar calculation for D^+ production gives

$$\frac{\nu_\mu + \text{Ne} \to \mu^- + D^+ + \ldots,\ D^+ \to K^0\pi^+}{\nu_\mu + \text{Ne} \to \mu^- + \ldots} = (0.1 \pm 0.1)\%.$$

These rates are not sensitive to the handling of the K^0/Λ^0 ambiguities or to the muon momentum cut.

The D^0 rate can be compared with our previously measured rate for $(\nu_\mu + \text{Ne} \to \mu^- + e^+ + \ldots)/(\nu_\mu + \text{Ne} \to \mu^- + \ldots)$ of $(0.5 \pm 0.15)\%$.[8] We cannot obtain an exact value for the ratio of semileptonic to $K^0\pi^+\pi^-$ decays of the D^0 since we do not know what fraction of the μ^-e^+ events come from D^0 decays. We obtain an upper limit on the ratio $R = (D^0 \to e^+ \ldots)/(D^0 \to K^0\pi^+\pi^-)$ of $R \leq 0.7 \pm 0.3$ if we assume that all of the μ^-e^+ events are due to semileptonic D^0 decays. If, on the other hand, only a fraction of the μ^-e^+ events is due to D^0 decays, which is more reasonable since there is likely to be some D^+ and charmed baryon decays contributing to the μ^-e^+ events, then the value for R is less than that given above. Recent measurements at SPEAR yielded the branching ratios of $(4.0 \pm 1.3)\%$ for $D^0 \to K^0\pi^+\pi^-$,[9] and $(7.2 \pm 2.8)\%$ for $D \to e^+ + \ldots$,[10] which correspond to a value of $R = 1.8 \pm 0.9$, assuming equal semileptonic branching ratios for the D^0 and the D^+. Our values, with any assumption about the D^0 contribution to the μ^-e^+ events, are lower than the SPEAR value for R. However, the errors on all of these numbers are rather large at present.

All of the decay products of the D^0 are measured in the $K^0\pi^+\pi^-$ decay mode. Thus the energy and momentum of the D^0 can be reconstructed and we can study the production properties of the D^0. In Fig. 3, we show the distribution in z, the fraction of the hadronic energy carried by the D^0 ($z = E_D/E_{\text{hadronic}}$).[11] The solid lines represent all of the events in the D^0 region of the $K^0\pi^+\pi^-$ mass distribution, 1820 MeV $\leq M(K\pi\pi) \leq$ 1900 MeV. The distribution for the non-D^0 background in this region, obtained by averaging the control regions below and above the D^0 region, is shown by the dashed lines. These distributions are relevant to the behavior of the charmed-quark fragmentation function.

We would like to thank the people at Fermilab and the scanning and measuring staffs at Brookhaven National Laboratory and Columbia University whose efforts made this experiment possible.

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[7]We have investigated the narrow structure at 1660 MeV. Using the procedures defined above but with the width constrained to our resolution, we find its significance to be ≤ 2.5 standard deviations.

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[11]The measured energy consists of three parts, $E_{\text{meas}} = E_{\mu^-} + E_{D^0} + E_{\text{other hadrons}}$. The hadronic energy used in the calculation of z has been corrected for neutral particles, which were not measured in this sample, and charged tracks that interact and are too short for a measurement of their energy, by the formula $E_{\text{hadronic}} = E_{D^0} + (E_{\text{other hadrons}}/0.75)$. The distributions of Fig. 3 are not sensitive to the details of this correction.

Residual Proton Production in Deep-Inelastic Electron Scattering

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We have measured residual proton yields from deep-inelastic electron scattering as a function of the fractional longitudinal momentum, z_p $(=p_l/p_{l\max})$, imparted to the proton. We find a peaked distribution in z_p centered near $z_p = -0.25$.

The distribution of the nucleonic component in hadron-proton collisions has been studied extensively for both residual protons[1,2] and neutrons.[3] Briefly, one finds a peak in the yield corresponding to collisions with small momentum transfer to the target proton ($z_p \simeq -1$); these are commonly called diffractive collisions.[1] There is also a substantial yield of protons and neutrons corresponding to more highly inelastic collisions.[2,3] This yield is broadly distributed in z $(-p_l/p_{l\max}$ in the center-of-mass system) but clearly separated from the diffractive component by a minimum in the cross section. The yield of antiprotons[2] has also been measured; except for small z_p ($|z_p| \lesssim 0.2$) it is well below the proton yield. This difference in yield must represent the excess baryonic charge of the initial state and therefore the residual proton; we suppose that the antiprotons are a measure of those protons produced as baryon-antibaryon pairs. The corresponding measurement in inelastic lepton-nucleon scattering has been studied less extensively; it is known that there is a diffractive component[4] and that the nucleon yield falls with z for $z > -0.2$.[5] This paper reports on more accurate measurements of this recoil-proton distribution in inelastic elec-