[2] It is commonly assumed that the strange quarks are heavier than the u and d quarks by something like 100 MeV/c^2 in order to explain observed mass differences. In discussing charm recently M. K. Gaillard, B. W. Lee, and J. L. Rosner [Rev. Mod. Phys. 47, 277 (1975)] have in addition adopted the relation $m_u \approx m_d \approx 4$ MeV/c^2.

[3] Gaillard, Lee, and Rosner, Ref. 2.

[4] M. Gell-Mann, R. J. Oakes, and B. Renner, Phys. Rev. 175, 2195 (1968); S. L. Glashow and S. Weinberg, Phys. Rev. Lett. 20, 244 (1968).

[5] In a naive model we would write $\alpha = m_u/(m_s + m_u)$.

[6] Such an increase with hadronic s_{hh} is seen in bubble-chamber pp data between 10 and 200 GeV; H. Bøggild and T. Ferbel, Annu. Rev. Nucl. Sci. 24, 474 (1974), Fig. 17.

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Experimental Study of Inclusive Deep Inelastic Neutrino-Proton Scattering*

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A neutrino-proton scattering experiment has been performed at Fermilab using a wide-band horn-focused neutrino beam and the 15-ft bubble chamber filled with hydrogen. For the inclusive reaction $\nu_\mu + p \rightarrow \mu^- +$hadrons, the mean value of Q^2 is found to increase linearly with energy as is expected from Bjorken scaling and a fit to the data gives $\langle Q^2 \rangle = (0.18 \pm 0.01)E$. The distribution in the Bjorken scaling variable x shows evidence for deviations from predictions based on electron-scattering data and the quark-parton model.

Existing data[1,2] on inclusive deep inelastic neutrino scattering at high energies come from experiments using nuclear targets. These experiments have yielded information of a fundamental nature about the structure of the neutron and proton. The data presented here come from a neutrino-proton scattering experiment[3] performed in a wide-band horn-focused neutrino beam at Fermilab using the 15-ft bubble chamber filled with hydrogen. An experiment using a free-proton target provides independent information which cannot be obtained from experiments using nuclear targets alone.

The data are based on a study of approximately 450 charged-current neutrino events in the energy range 15–200 GeV which are examples of the reaction

$$\nu_\mu + p \rightarrow \mu^- + \text{hadrons}. \tag{1}$$

The events occurred in an exposure of approximately 62 000 pictures and the mean proton intensity on the target was approximately 0.5×10^{13} protons per pulse. The muon flux in the shielding was monitored throughout the exposure and an external muon identifier[4] was operated in conjunction with the experiment. The beam-monitoring data and the data from the external muon identifier are not yet fully analyzed and the results presented here are based on analysis of information from the bare bubble chamber only.

The analysis of Reaction (1) requires the identification of the muon amongst the charged secondaries. We select from the noninteracting negative tracks in each event the track with the highest transverse momentum relative to the neutrino direction. In a charged-current event the probability that the muon is correctly chosen using this procedure is estimated to be better than 95%.

In the hydrogen bubble chamber neutral hadrons are detected with low efficiency. The neutrino energy is determined by transverse momentum balance, assuming that the momentum of the visible hadrons projected onto the plane defined by the outgoing muon and the incoming neutrino is a good estimate for the direction of the total hadron momentum. It is estimated that 50% of the events have errors in energy less than approximately ± 8%.

For those events in which the track chosen as the muon lies on the same side of the neutrino direction as the momentum vector of the visible hadrons it is not possible to determine the neutrino energy using transverse momentum balance. It is estimated that approximately 55% of the neutral-current events will behave in this way. In this analysis all the events in this class are classified as neutral-current events and are eliminated from the sample. The fraction of genuine charged-current events which are misclassified as neutral-current events is estimated to be approximately 8%.

The analysis methods used here were suggested by studies of the behavior of neutrino interactions at energies of a few GeV.[5,6] The estimates given for the efficiencies of the selection procedures and for the energy resolution are based on the results of studies using Monte Carlo events generated according to expectations based on scaling and the quark-parton model. Further details of these calculations together with details of various experimental checks made to test their accuracy are given in Ref. 3.

For the distributions presented here the following cuts have been applied to the data. (a) The total visible momentum along the beam direction p_x must be greater than 10 GeV/c. (b) The incident neutrino energy E must lie in the range 15-200 GeV. Within these cuts the number of events due to the interactions of incoming charged tracks or due to neutrons and neutral kaons has been shown to be negligible.[3] The raw event rate is shown in Table I.

Neutral-current events which have been misclassified as charged-current events constitute a background in the charged-current sample. The probability for a neutral-current event to be classified as a charged-current event is estimated using the charged-current events. The muon is ignored and the remaining hadron shower is classified as a neutral-current or charged-current event. The ratio of the neutral-current to charged-current cross section on protons is unknown and has been assumed to be equal to 0.30 as is predicted by Weinberg's theory.[7] The estimated background from this source is included in Table I.

The contamination of antineutrinos in the neutrino beam is believed to be approximately 10%. The estimated background due to antineutrino events misclassified as neutrino events is also shown in Table I. The ratio of the antineutrino to the neutrino cross section on protons has been assumed to be $\frac{2}{3}$.

The overall contamination of hadrons in the final muon sample is (15 ± 4)% as measured directly by counting interactions in the bubble chamber. This result is consistent with the expected overall contamination from the various sources discussed above.

Incorrect muon selection, loss of events misclassified as neutral-current events, and errors in the neutrino energy lead to systematic biases in the experimental distributions. For the distributions presented here an attempt has been made to correct for these effects by computing a correction factor for each bin based on the results of the Monte Carlo study. The corrections applied to the data after the background subtractions are typically of order 10%.

It should be clear that since the efficiency of

TABLE I. Event rates and background estimates as a function of neutrino energy.

Energy (GeV)	Raw events	Neutral-current background	Antineutrino background	Corrected events
15–20	57	2.4	3.9	59.8
20–25	64	3.0	3.6	69.2
25–30	62	0.9	2.4	76.0
30–40	81	3.0	3.1	84.8
40–50	51	2.1	1.3	53.0
50–60	27	0.6	0.7	25.9
60–80	40	2.4	0.8	32.2
80–100	30	1.5	0.4	27.6
100–150	25	0.9	0.3	23.6
150–200	12	0.3	0.2	10.5

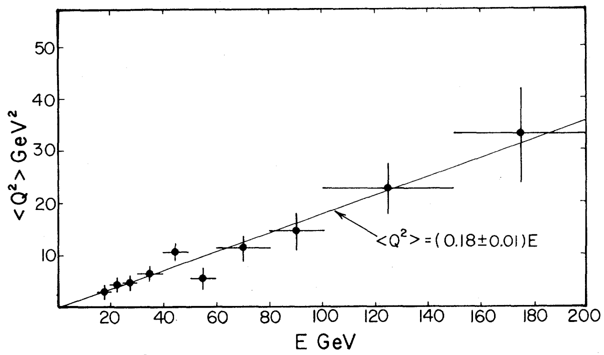

FIG. 1. $\langle Q^2\rangle$ plotted as a function of E. The straight line is a fit to the data points.

the analysis procedures depends in part on the distributions we are attempting to measure, it is not possible to correct for systematic errors introduced in the analysis in a completely unbiased way. Nonetheless the experiment as analyzed is capable of measuring deviations from the distributions assumed in the Monte Carlo study in a first-order sense.

Figure 1 shows the mean value of Q^2, the square of the four-momentum transfer, plotted as a function of neutrino energy. The data are consistent with a linear increase as is expected from Bjorken scaling. A straight-line fit through the origin gives the result

$$\langle Q^2\rangle = (0.18 \pm 0.01)E. \tag{2}$$

This result for the slope is slightly lower than the expected value (~ 0.21) based on electron-scattering data and the simple quark-parton model discussed below.

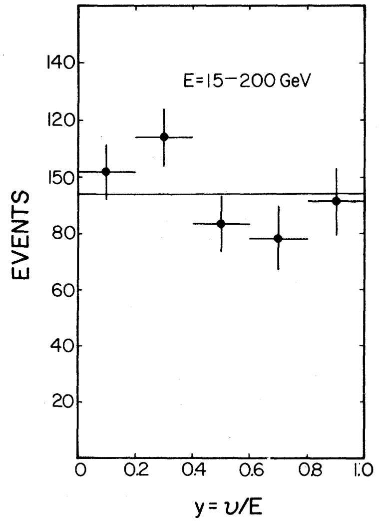

FIG. 2. The distribution in $y = \nu/E$. The straight line shows a flat distribution.

The variable y is defined by $y = \nu/E$, where ν is the energy transfer to the hadrons in the lab. The y distribution is shown in Fig. 2 and is consistent with being flat. There is no strong energy dependence.

Figure 3 shows the distribution in the Bjorken scaling variable $x = Q^2/2m\nu$. In the quark-parton model the x distribution for neutrino-proton scattering measures the contribution of d and $\bar{u}$ quarks in the proton. Neglecting the contribution of strange quarks and antiquarks in the proton we expect

$$F_2^{\nu p} = \tfrac{24}{5}F_2^{ed} - 6F_2^{ep}. \tag{3}$$

In Fig. 3 the curve which has been normalized to the data for $x > 0.2$ is the quantity (3) computed from fits to the Stanford Linear Accelerator Center (SLAC) electron-scattering data.[8] While the general trend of the x distribution is similar to the prediction (3), there appears to be a significant excess of events at small x in the neutrino data.

This effect is present in the uncorrected data and cannot be explained by biases introduced as a result of the muon selection procedure or by an unexpectedly high rate of neutral-current events. Biases introduced as a result of the muon selection procedure have the opposite effect and tend to deplete the small-x region. On the basis of the study of the hadron showers in the charged-current events, neutral-current events

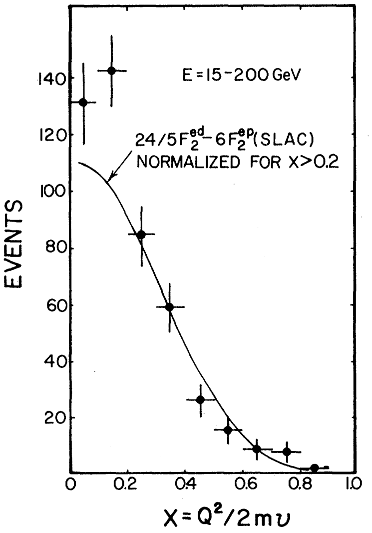

FIG. 3. The distribution in $x = \mathbf{Q}^2/2m\nu$. The curve which has been normalized to the data for $x > 0.2$ is a prediction from electron-scattering data (see text).

which are misinterpreted as charged-current events are not expected to populate the region $x > 0.1$. Thus the significance of the effect in the bin $x = 0.1-0.2$ does not depend on the assumed rate for neutral-current interactions in hydrogen. Within the statistical errors the effect shows no strong energy dependence.

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Inclusive Cross Sections for 180° Production of High-Energy Protons, Deuterons, and Tritons in *p*-Nucleus Collisions at 600 and 800 MeV

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The inclusive cross sections, measured up to large values of effective mass ($\equiv q^2/2\nu$), are well fitted by $d\sigma/d^3p = B_x \exp(-\alpha_x p^2/2m_x)$. Values of B_x and α_x are given for Be, C, Cu, and Ta at the incident proton energy of 600 MeV and for Ag, Ta, and Pt at 800 MeV. Extremely large d/p and t/p ratios and large A and q^2 dependences of the relative cross sections are observed.

In order to examine the most violent p-nucleus interactions, with the hope of studying interactions with "correlated" nucleons or with "chunks" of nuclear matter, it is necessary to study the region of high effective mass, m^*, with $m^* \equiv q^2/2\nu$. (q^2 is the invariant momentum transfer and $\nu \equiv E_0 - E$ is the difference between the laboratory energies of the incident and scattered particle.) Measurement of high-q^2 events at low effective mass is a less effective probe of the coherent properties of nuclear matter. The high-q^2, high-m^* region has not hitherto been studied experimentally nor is there any theoretical guide to this region.

By working directly in a primary beam at the Clinton P. Anderson Meson Physics Facility (LAMPF) (10^{13} protons/sec), and by studying 180° production which maximizes q^2, we have been able to achieve sensitivities that have allowed, for example, observation of backscattered protons up to the high momenta corresponding to elastic backscattering from "clusters" with $A^* \equiv m^*/m_p = 6.5$ in Be^9. The measurements reported here were carried out simultaneously with a search for condensed nuclear states.[1]

This experiment utilized accelerator-beam-line equipment as the major part of our experimental apparatus. As shown in Fig. 1, protons passing through the LAMPF LB-BM-05 bending magnet struck targets mounted in a LAMPF remotely ac-