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Measurement of Nucleon Structure Function in Muon Scattering at 147 GeV/c*

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Results on the nucleon structure function, νW_2, are presented for $0.2 \leq q^2 \leq 50$ $(\mathrm{GeV}/c)^2$ and $5 \leq \nu \leq 130$ GeV. They were obtained by scattering 147-GeV positiive muons inelastically from a liquid deuterium target.

In this Letter, we report the results on the nucleon structure function, νW_2, measured at Fermilab by scattering 2.1×10^{10} positive muons of energy 147 GeV from a liquid deuterium target. Preliminary results for νW_2 and some results for the distributions of muoproduced hadrons from hydrogen have already been reported.[1]

In the first Born approximation, the differential cross section for the scattering of muons of energy E to a final energy E' through an angle θ is related to the two inelastic structure functions W_1 and W_2 by[2]

$$\frac{d^2\sigma}{dq^2 d\nu} = \left(\frac{\pi}{PP'}\right)\frac{2\alpha^2}{q^4}\left(\frac{P'}{P}\right)\left[\left(2EE' - \frac{q^2}{2}\right)W_2(q^2,\nu) + (q^2 - 2m_\mu^{\,2})W_1(q^2,\nu)\right],$$

where $\nu = E - E'$ and $q^2 = 2(EE' - PP'\cos\theta - m_\mu^{\,2})$. The ratio of the inelastic structure functions can be expressed as $W_1/W_2 = (1+\nu^2/q^2)/(1+R)$, where $R \equiv \sigma_L/\sigma_T$ is the ratio of the photoabsorption cross sections for the longitudinal and transverse photons.[3] The values of the nucleon structure function $\nu W_2(\omega, q^2)$ are obtained by assuming $R = 0.18$,[4] where $\omega = 2M\nu/q^2$ is the Bjorken scaling variable.[5] We propose to measure the value of R in subsequent experiments.

Figure 1 is a schematic drawing of the apparatus. Positive muons of 147 GeV/c strike a 122-cm-long, 17.8-cm-diam, liquid deuterium target. The apparatus is triggered when the counter logic condition $\mathrm{B}\cdot\overline{\mathrm{N}}\cdot\mathrm{G}\cdot\mathrm{M}$ is satisfied. B signals the incident muon with no accompanying halo muon (vetoed by hodoscope V). N is the downstream

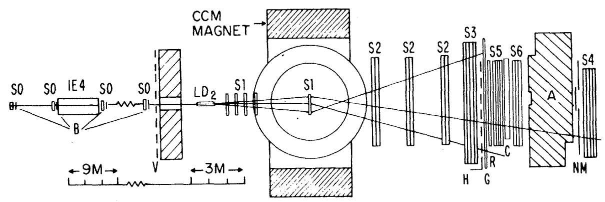

FIG. 1. Schematic layout of muon scattering spectrometer. S0 and S1 are multiwire proportional chambers; S2, S3, S4, S5, and S6 are multiwire spark chambers; B, G, H, M, N, and V are counter hodoscopes; 1E4 and CCM are magnets; R, C, and A are absorbers.

beam veto, and G and M are the counter hodoscopes before and after the 2.44-m steel hadron absorber A. During most of the runs, the muon beam intensity was 7.5×10^5 μ/pulse. The pion contamination of the beam was measured to be less than 10^{-6}, which is negligible. The typical trigger rate was 4 per pulse. The incident muon track is reconstructed from the proportional chambers S0 and the momentum measured using the magnet 1E4. The scattered muon is identified from among the tracks reconstructed in the chambers downstream of the magnet CCM. The muon track must satisfy the following requirements: (i) Set the appropriate elements of counter hodoscopes G, H, and M. (ii) Link to a track in S4 or point to a cluster of sparks in S4. (iii) Link through the magnet CCM to a track in S1 by demanding that both tracks should have (a) in the nonbending plane the same slope and intercept at the middle of the magnet, and (b) in the bending plane the same impact parameter with respect to the center of the magnet CCM as required by the cylindrical symmetry of the magnetic field. (iv) Link to the incoming muon track by demanding that the linked track in S1 intersect the incoming muon track. The momentum of the scattered muon is measured from the track linked through the magnet CCM while the scattering angle is measured by the tracks in S0 and S1. The momentum resolution is 1.5% (rms) at 100 GeV/c for a 15-kG central field in the magnet CCM. The scattering-angle resolution is 0.6 mrad (rms).

Each event is then weighted by an acceptance averaged over the beam phase space. Allowance is made for those scattered muons that create electromagnetic showers and set the beam veto N. This effect has been measured to be at worst a 7% correction. Corrections have been made for the efficiency of reconstructing the muon trajectory (measured to be 76%), counter efficiencies (99.5%), track-finding efficiencies in the multiwire chambers (95%), the random vetoing of good scatters by the beam veto N (1.8%), and equipment dead time (20%). Two independent analyses of the data have been made using different track-finding methods and different treatments of the background events. The results are in overall agreement and the differences are both statistical and systematic in origin. The average difference between the two analyses is 10% per point in Fig. 3, and the largest difference is 26% at $\langle\omega\rangle = 800$ which is a statistical fluctuation of the difference in background subtraction. The average values are reported here with errors appropriately increased. The systematic errors vary from approximately 11% in bins with $\omega < 5$ to approximately 5% in the high-ω bins. In addition there is an overall normalization uncertainty of 5%. An empty-target subtraction has been made using data where the target contained only deuterium vapor.

The radiative corrections were made by calculating the ratio

$$\delta_R = \sigma^{\rm inel}/(\sigma_{\rm rad}{}^{\rm inel} + \sigma_{\rm tail}{}^{\rm quasi} + \sigma_{\rm tail}{}^{\rm el}),$$

where $\sigma^{\rm inel}$ is the assumed inelastic scattering cross section, $\sigma_{\rm rad}{}^{\rm inel}$ the inelastic scattering cross section with radiation effects folded in, $\sigma_{\rm tail}{}^{\rm quasi}$ the radiative tail from quasi-elastic scattering from the deuteron, and $\sigma_{\rm tail}{}^{\rm el}$ the radiative tail from elastic muon-deuteron scattering.[6] The true cross section was given by the product of the experimental cross section and δ_R. The results were compared with the input cross sections, and iterative corrections were applied until the differences became negligible. The magnitude of the radiative corrections ranged from 0 to $\lesssim 30\%$.

The region of q^2 and ν covered by the data is shown in Fig. 2. The acceptance is too small to be useful. The acceptance outside this region is greater than 10% and is calculated to better than 5%. In addition, the low limit is set so that there is no significant contamination from μe scattering. It should also be noted that for ω values of greater than 60, the kinematics and the apparatus acceptance limit our data to ranges of q^2 which become rapidly narrower and progressively lower as ω increases.

Figure 3 shows $\nu W_2(q^2, \omega)$ per nucleon as a function of q^2 for various ω values. The results show that, for $\omega < 3$, νW_2 decreases with increasing q^2 in agreement with muon scattering from an iron

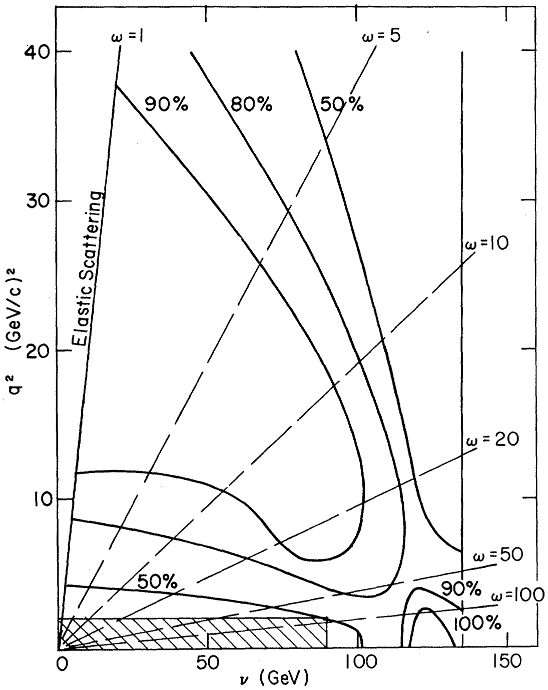

FIG. 2. The kinematical region explored by this experiment. The lower shaded area contains no events because of the beam veto counter. Some acceptance contours are also shown.

target at Fermilab[7] and with the Stanford Linear Accelerator Center measurements at lower energy.[8] For $3<\omega<80$, there are no gross violations of scaling for νW_2. However, in order to make a test of any violation we have taken all data in the ranges $2<q^2<50$ $(\mathrm{GeV}/c)^2$ and $3<\omega<80$ and have fitted by the form[9]

$$\nu W_2(\omega,q^2)=\nu W_2(\omega,q_0^{\,2})\left[1+a\ln\left(\frac{q^2}{q_0^{\,2}}\right)\ln\left(\frac{\omega}{\omega_0}\right)\right].$$

We find $a=0.072\pm0.038$ for $\chi^2=16.9$ for 23 degrees of freedom with $\omega_0=6$ and $q_0^2=3$ $(\mathrm{GeV}/c)^2$ fixed. This parametrization for scaling violations is essentially the same, as far as the value of a is concerned, as that used by Chang *et al.*[7] for muon scattering from an iron target. They find $a=0.099\pm0.018$ for data in the range $3<\omega<50$, $1<q^2<50$ $(\mathrm{GeV}/c)^2$. Scaling violations of this nature have been predicted.[10]

In Fig. 4, we plot νW_2 averaged over the appropriate q^2 range against ω. The values of νW_2 and their q^2 range are given in Table I. The data show a decrease of νW_2 for $\omega>60$. One possible explanation of this behavior is that the measurements of νW_2 are not in the scaling region but rather indicate that the onset of scaling is at $q^2\gtrsim 3$ $(\mathrm{GeV}/c)^2$. Lower-energy measurements[11] at

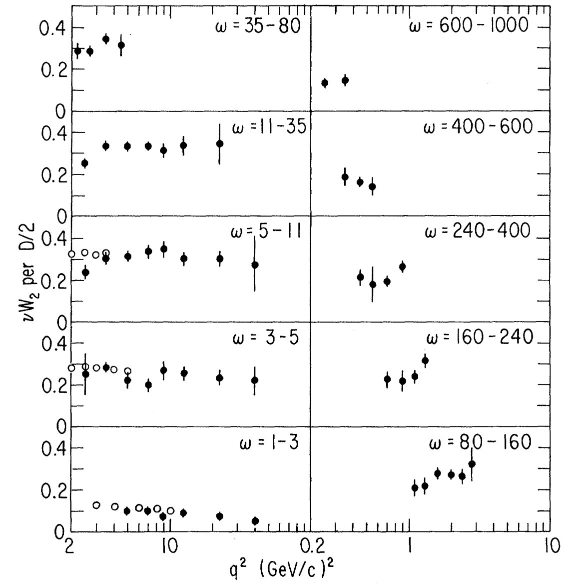

FIG. 3. νW_2 per nucleon as a function of q^2 for various ω bins. The open circles indicate data measured at Stanford Linear Accelerator Center by Riordan *et al.* (Ref. 4).

lower ω indicate scaling at $q^2\gtrsim 1$ $(\mathrm{GeV}/c)^2$.

An alternative explanation is that the data lie within the scaling region and νW_2 decreases with increasing ω. The decrease of νW_2 at large ω is predicted by a few specific models, using valence quarks and an infinite sea of parton pairs, as suggested by Kuti and Weisskopf,[12] and by Altarelli *et al.*[13] Regge-pole models can also predict the same behavior.[14]

There is no indication in these data of a threshold excitation of a new or heavy quark that would be signified by an increase of νW_2 at large values

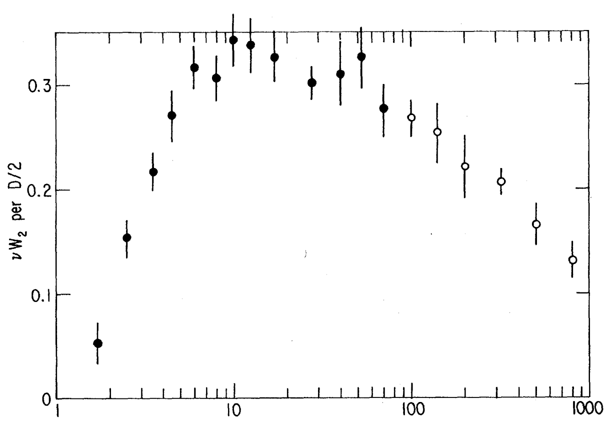

FIG. 4. νW_2 per nucleon versus $\omega=2M\nu/q^2$. The open circles indicate q^2 less than 2 $(\mathrm{GeV}/c)^2$.

TABLE I. νW_2 for 147-GeV/c deuterium data.

< ω >	ω Range	q^2 Range (GeV/c)^2	νW_2 (per nucleon)
1.7	1 - 2	9 - 50	0.05 ± 0.02
2.5	2 - 3	3 - 50	0.15 ± 0.02
3.5	3 - 4	2 - 50	0.22 ± 0.02
4.5	4 - 5	2 - 50	0.27 ± 0.03
6.0	5 - 7	2 - 30	0.32 ± 0.02
8.0	7 - 9	2 - 30	0.31 ± 0.02
10.0	9 - 11	2 - 15	0.34 ± 0.03
12.5	11 - 14	2 - 15	0.34 ± 0.03
17.0	14 - 20	2 - 15	0.33 ± 0.02
27.5	20 - 35	2 - 10	0.30 ± 0.02
40.0	35 - 45	2 - 6	0.31 ± 0.03
52.5	45 - 60	2 - 6	0.33 ± 0.03
70.0	60 - 80	2 - 4	0.28 ± 0.03
100.0	80 - 120	1 - 3	0.27 ± 0.02
140.0	120 - 160	1 - 2	0.26 ± 0.03
200.0	160 - 240	0.8 - 1.4	0.22 ± 0.02
320.0	240 - 400	0.4 - 1.0	0.21 ± 0.01
500.0	400 - 600	0.3 - 0.6	0.17 ± 0.02
800.0	600 - 1000	0.2 - 0.5	0.13 ± 0.02

of ω.[15-17]

The results permit an extension of the integration limit for evaluating the sum rules involving νW_2 using average measured values of νW_2 for $q^2 > 1.0$ (GeV/c)^2. We obtain for the Gottfried sum rule[18]

$$\int_1^{240}(\nu W_2/\omega)d\omega = 1.38 \pm 0.07 \text{ per nucleon,}$$

and for the Callan-Gross sum rule[19]

$$\int_1^{240}(\nu W_2/\omega^2)d\omega = 0.153 \pm 0.005 \text{ per nucleon.}$$

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