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

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ABSTRACT

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 positive muons inelastically from a liquid deuterium target.

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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 muo-produced 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]

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

where $\nu = E-E'$, $q^2 = 2(EE' - PP'\cos\theta - m_\mu{}^2)$. The ratio of the inelastic structure functions can be expressed as $W_1/W_2 = (1 + \nu^2/q^2)/(1 + R)$, where $R \equiv \sigma_L/\sigma_T$, the ratio of the photo-absorption 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 $\omega = 2M\nu/q^2$, 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 diameter, liquid deuterium target. The apparatus is triggered when the counter logic condition $B.\overline{N}.G.M.$ is satisfied. B signals the incident muon with no accompanying halo muon (vetoed by hodoscope V). N is the downstream 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's/pulse. The pion contamination of the beam was measured to be less than 10^{-6}. The typical trigger rate was 4/pulse. The incident muon track is reconstructed from the proportional cham-

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have been made using different trackfinding 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 figure 3, and the largest difference is 26% at $< \omega > = 800$ 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

$$\delta_R = \sigma^{inel}/(\sigma^{inel}_{radiated} + \sigma^{quasi}_{tail} + \sigma^{elastic}_{tail})$$

where σ^{inel} is the assumed inelastic scattering cross section; $\sigma^{inel}_{radiated}$, the inelastic scattering cross section with radiation effects folded in; σ^{quasi}_{tail}, the radiative tail from quasi-elastic scattering from the deuteron; $\sigma^{elastic}_{tail}$, 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 Figure 2. The limits have been chosen so that the acceptance in the (q^2,ν) region is greater than 10%. In addition the low q^2 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 target at Fermilab[7] and with the SLAC 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 fitted to the form [9]

$$\nu W_2(\omega,q^2) = \nu W_2(\omega,q_o^{\,2})\left[1 + a \ln (q^2/q_o^{\,2}) \ln (\omega/\omega_o)\right].$$

We find $a = .072 \pm .038$ for $\chi^2 = 16.9$ for 23 degrees of freedom with $\omega_o = 6$ and $q_o^{\,2} = 3(\mathrm{GeV/c})^2$ fixed. This parameterisation 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 $a = 0.099 \pm 0.018$ 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 Figure 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 behaviour is that the measurements of νW_2 are not in the scaling region but rather indicate that the onset of scaling is at $q^2 \gtrsim 3$ (GeV/c)^2. Lower energy measurements[11] at lower ω indicate scaling at $q^2 \gtrsim 1$ (GeV/c)^2.

An alternative explanation is that the data lies 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 of ω.[15, 16, 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 $q^2 > 1.0\ (\mathrm{GeV}/c)^2$. We obtain for the Gottfried sum rule[18]

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

and for the Callan-Gross sum rule[19],

$$\int_1^{240} \nu W_2 \, \frac{d\omega}{\omega^2} = 0.153 \pm 0.005 \text{ per nucleon}$$

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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

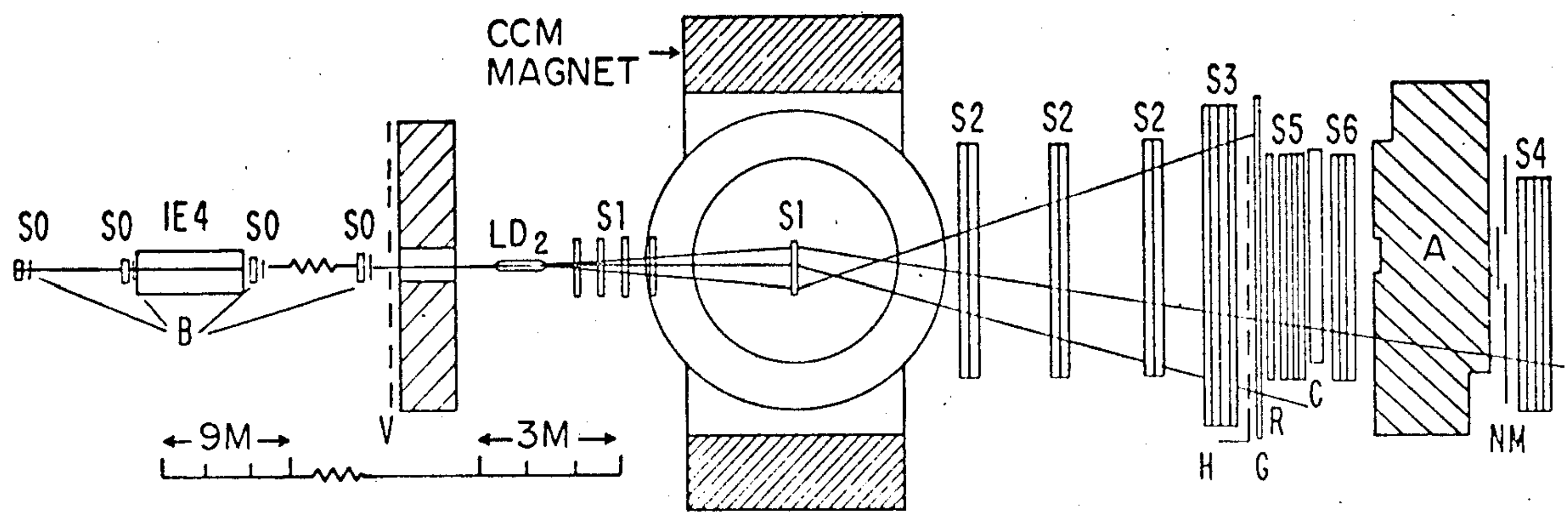
FIGURE CAPTIONS

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

Figure 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.

Figure 3 νW_2 per nucleon as a function of q^2 for various ω bins. The open circles indicate data measured at SLAC by Riordan et al. (Ref. 4).

Figure 4 νW_2 per nucleon vs. $\omega = 2M\nu/q^2$. The open circles indicate q^2 less than 2 $(GeV/c)^2$.


CCM
MAGNET
S0
S0
IE4
S0
S0
B
V
LD$_2$
S1
S1
S2
S2
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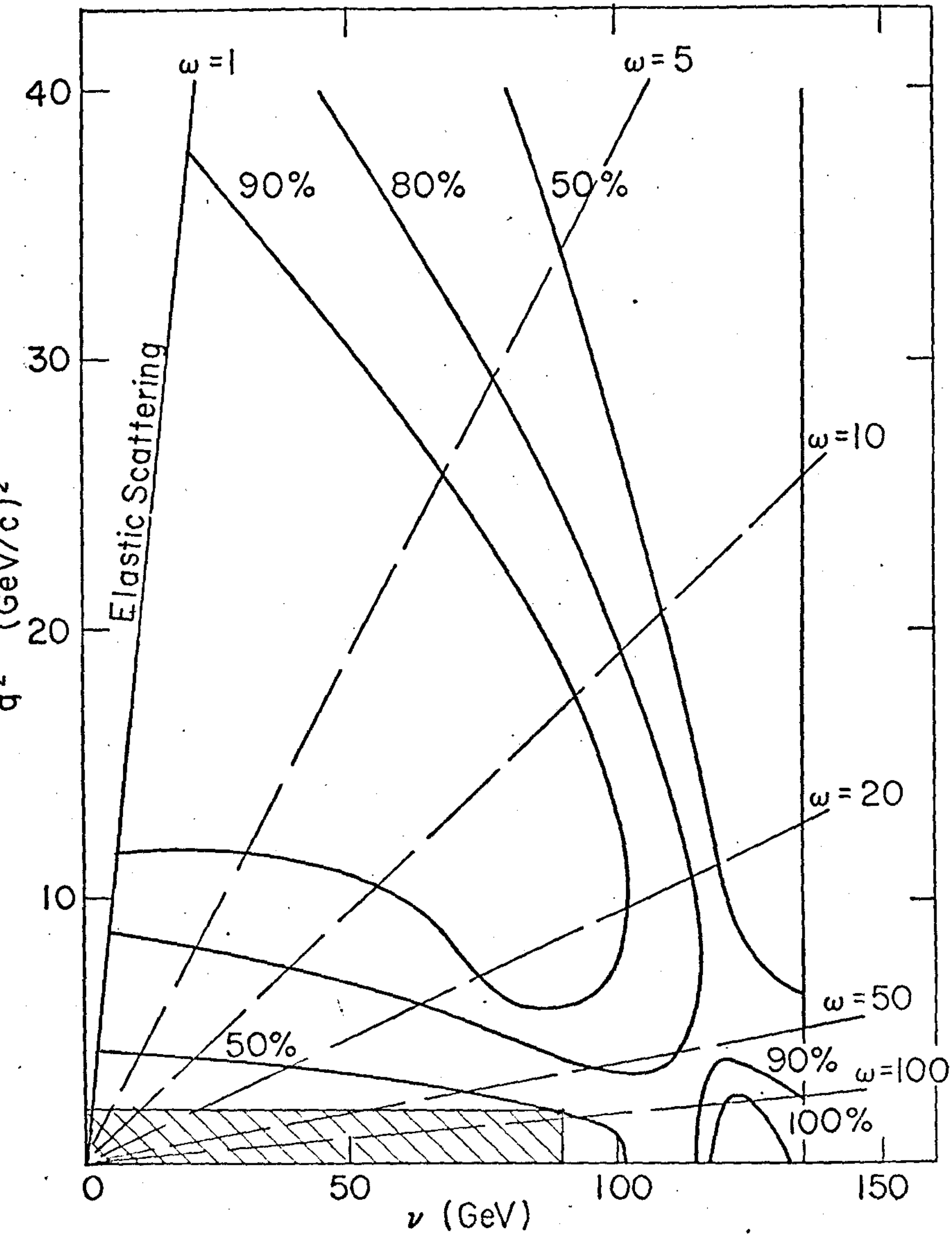
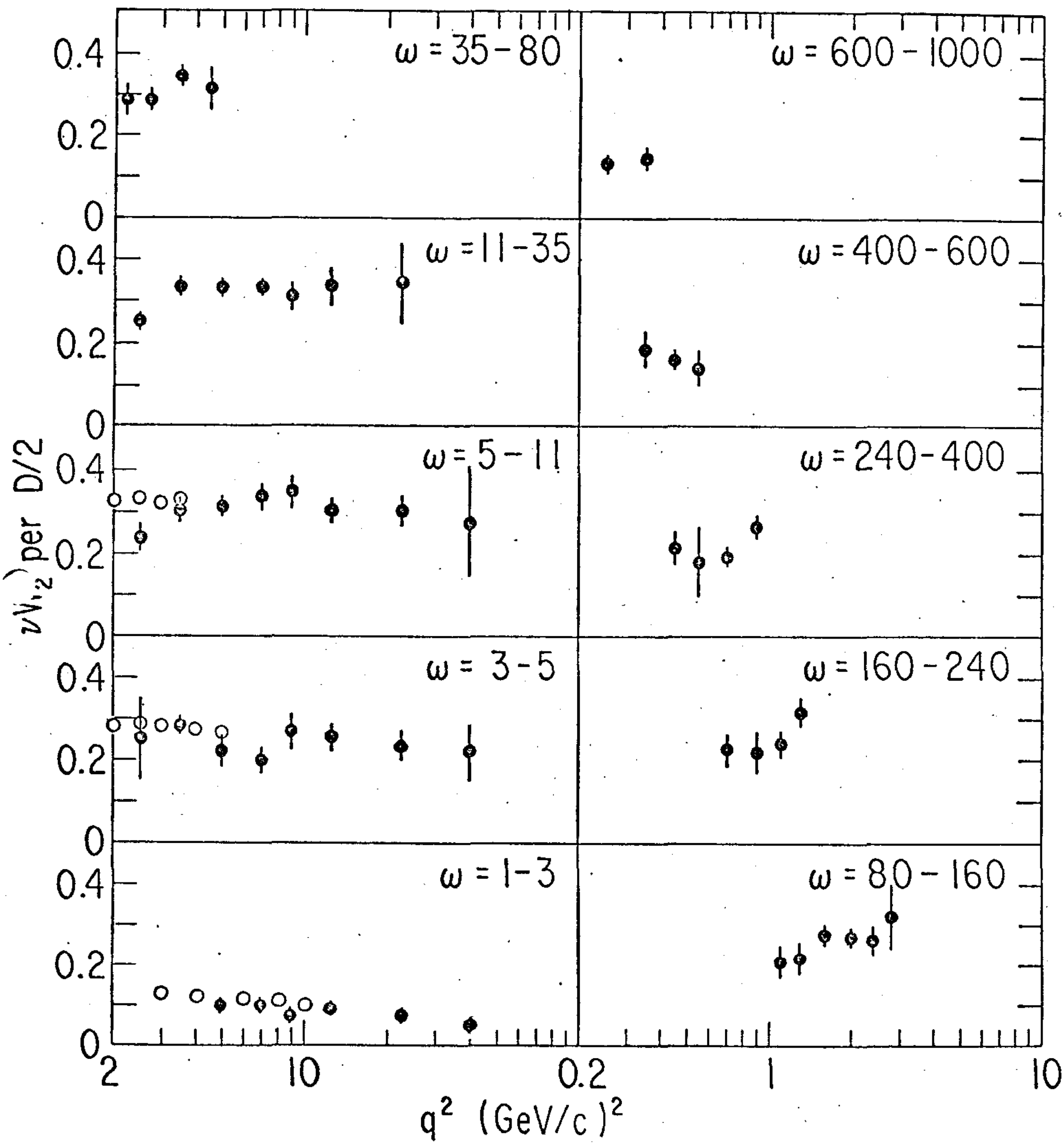
S3
S5
S6
A
S4
H
G
R
C
NM
9M
3M

Figure 1



ω = 1
ω = 5
ω = 10
ω = 20
ω = 50
ω = 100
90%
80%
50%
50%
90%
100%
Elastic Scattering
q² (GeV/c)²
ν (GeV)
0
10
20
30
40
0
50
100
150

Figure 2



ω = 35-80
ω = 600-1000
ω = 11-35
ω = 400-600
ω = 5-11
ω = 240-400
ω = 3-5
ω = 160-240
ω = 1-3
ω = 80-160
νW₂ per D/2
0.4
0.2
0
2
10
0.2
1
10
q² (GeV/c)²

Figure 3.

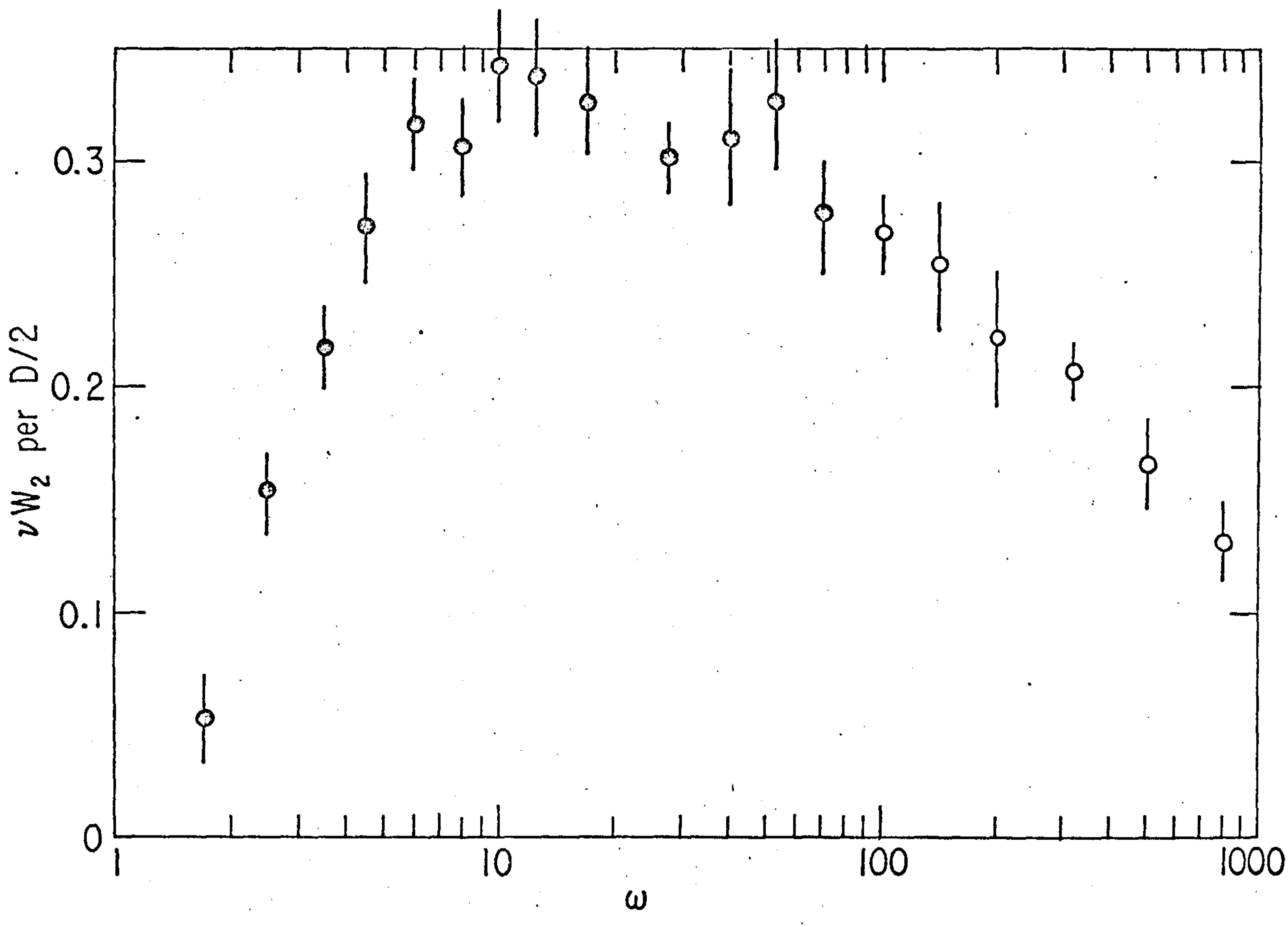


Figure 4