MEASUREMENTS OF THE NUCLEON STRUCTURE FUNCTIONS F_2^N IN
DEEP INELASTIC MUON SCATTERING FROM DEUTERIUM AND COMPARISON
WITH THOSE FROM HYDROGEN AND IRON

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ABSTRACT

Measurements of the nucleon structure function F_2^N from deep inelastic muon scattering on deuterium are presented. The neutron structure function is deduced from a comparison with hydrogen data. In addition the charge and the momentum distributions of the u and d valence quarks in the nucleon are extracted together with an estimate of the momentum distribution of the sea quarks. A comparison of the nucleon structure functions in deuterium and iron shows that the quark distributions in the quasi-free nucleons of deuterium are different from those for bound nucleons in iron.

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1. INTRODUCTION

The European Muon Collaboration (EMC) has previously reported measurements of deep inelastic muon scattering using targets of hydrogen [1] and iron [2]. This paper presents the data taken with a deuterium target and completes the studies of structure functions from the first phase of the EMC experiment (NA2). The motivation for the use of a deuterium target was to measure the structure function of the deuteron F_2^d and thereby deduce the neutron structure function, F_2^n , for comparison with that of the proton, F_2^p . The first results of these measurements were given in [3].

In addition to the neutron structure function F_2^n we present and discuss the related quantities F_2^n/F_2^p and $F_2^p - F_2^n$. Their deviations from scaling are compared with the predictions of the theory of strong interactions, quantum chromodynamics (QCD). The momentum distributions of the valence and sea quarks are studied by comparing F_2^p and F_2^n . The fraction of the momentum of the nucleon carried by quarks is measured and the Gottfried sum rule and the u and d quark charge assignments are tested. Measurements of the nucleon structure function $F_2^N = \frac{1}{2}(F_2^p + F_2^n)$, from iron and deuterium targets allows a comparison of quasi-free and bound nucleon systems.

The kinematics, the apparatus and the analysis chain have been described elsewhere [1,2,5] and so here we present only those experimental details specific to the measurements with the deuterium target. The results on deuterium and the comparison between the structure functions measured on hydrogen, deuterium and iron targets supersede the data of references [3,4].

2. DEFINITIONS AND KINEMATICS

The double differential cross section per nucleon for deep inelastic charged lepton scattering from an unpolarised target can be written in the one-photon exchange approximation in terms of two structure functions F_1^N and F_2^N :

$$\frac{d^2\sigma}{dQ^2 dx} = \frac{4\pi\alpha^2}{Q^4} \left[\left(1-y-\frac{Mxy}{2E}\right) \frac{F_2^N(x, Q^2)}{x} + y^2 F_1^N(x, Q^2) \right] \quad (2.1)$$

where E is the incident muon energy, M is taken to be the proton mass, Q^2 is the negative of the square of the four momentum transfer, $x = Q^2/2M\nu$ is the Bjorken scaling variable, ν is the energy transfer, $y = \nu/E$ and α is the coupling constant of electromagnetic interactions.

The structure functions $F_1^N(x, Q^2)$ and $F_2^N(x, Q^2)$ are related to $R^N(x, Q^2)$, the ratio of the absorption cross sections σ_L and σ_T for longitudinally and transversely polarised virtual photons, by the expression

$$2xF_1^N(x, Q^2) = F_2^N(x, Q^2) \frac{(1+4M^2x^2/Q^2)}{1+R^N(x, Q^2)} \quad (2.2)$$

In the quark-parton model the structure function F_2^N is given by

$$F_2^N = \sum_f e_f^2 x [q_f(x) + \bar{q}_f(x)] \quad (2.3)$$

where e_f is the charge number of the quark (antiquark) of flavour f which has a distribution $q_f(x)$ ($\bar{q}_f$). For an isoscalar target this reduces to

$$F_2^N(x, Q^2) = \frac{1}{2}(F_2^p + F_2^n) = \frac{5}{18} x(u+\bar{u}+d+\bar{d}+s+\bar{s}+c+\bar{c}) + \frac{1}{6} x(c+\bar{c}-s-\bar{s}). \quad (2.4)$$

Here $u, d, s, c, (\bar{u}, \bar{d}, \bar{s}, \bar{c})$ are the up, down, strange and charmed quark (anti-quark) distributions, respectively, inside a proton which, in the naïve quark-parton model, are functions only of x . The measurements however, show a weak Q^2 dependence which arises from QCD corrections to the quark-parton model.

3. DATA SELECTION

The measurements were made in the M2 muon beam at the CERN SPS using the EMC forward spectrometer [5]. The apparatus was identical to that used for the hydrogen experiment [1] except that the 6 m long target contained liquid deuterium at a density of 0.1614 g cm^{-3} . The data were taken in two experimental runs at an incident muon energy of 280 GeV giving a total of 216000 deep inelastic scattering events from 5.8×10^{11} incident muons.

The method used to analyse the data was identical to that described in [1] for hydrogen apart from slight differences in the treatment of radiative corrections. In calculating the radiative tails from elastic $\mu d \rightarrow \mu d$ and quasi-elastic $\mu p \rightarrow \mu p$ and $\mu n \rightarrow \mu n$, coherent elastic scattering was ignored and, in compensation, the quasi-elastic scattering was not suppressed at low Q^2 . This produces a good approximation to the deuteron form factor at low Q^2 [6] and was considered adequate since the radiative tail is nowhere more than 12% of the cross-section for the data presented.

The cuts applied to the data were the same as those applied in the hydrogen analysis and the same requirements were made for each (x, Q^2) bin to be accepted into the final data sample (tables 3 and 6 of reference 1).

4. RESULTS

The cross sections measured from the two experimental runs agreed with each other within the relative normalisation uncertainties (discussed below) and the results were averaged. The hydrogen data were taken in 12 experimental runs at different incident beam energies. The results at each energy were normalised by factors close to unity within the relative normalisation uncertainty to make them self-consistent. The measured values of F_2^d , presented here have been increased by 1.9%. This is the relative normalisation factor determined for the hydrogen data [1] taken at the same incident energy of 280 GeV and under similar experimental conditions. This normalisation factor was not included in the data presented in reference [3].

4.1 The Measured Structure Functions

The deuteron structure function F_2^d was determined as described in [1] assuming the ratio $R^N(x, Q^2)$ to be zero. This assumption is consistent with measurements from hydrogen and iron [1,2]. The results for F_2^N (i.e. $F_2^d/2$) are given in table 1 and fig. 1 together with the statistical and total systematic errors. The latter were obtained by adding in quadrature the individual systematic errors listed in columns 6-12 (see below).

The statistical errors on the data are small. At $x \leq 0.25$ they are typically of the order 2%, rising to ~10-20% at $x = 0.75$. The systematic errors are generally somewhat larger and the careful investigation of their sources and magnitudes have been fully discussed in reference [1]. The same arguments apply to the deuterium data and so are not repeated here. The estimated magnitude of the point-to-point systematic errors for the individual sources are listed in columns 6-12 in table 1. These arise from uncertainties in

1) acceptance $A(x, Q^2)$	$1/A(x, Q^2)\%$
2) radiative corrections $\eta(x, Q^2)$	$15 1-\eta(x, Q^2) \%$
3) experimental resolution $S(x, Q^2)$	$20 1-S(x, Q^2) \%$
4) losses due to chamber inefficiencies $\epsilon(x, Q^2)$	$20\{1-\epsilon(x, Q^2)\}\%$
5) bin centering correction $CE(x, Q^2)$	$20 CE(x, Q^2) \%$
6) incoming beam energy ($\delta E/E \sim 0.4\%$)	
7) scattered muon energy ($\delta E'/E' \sim 0.2-1\%$).	

These systematic errors are labelled ACC, RAD, SME, EFF, CENT, BEAM and PP, respectively, in the table.

In addition to these point-to-point systematic errors we assign an absolute normalisation error of $\pm 5\%$ to $F_2^N(x, Q^2)$. This is due to a combination [1] of

- a) $\sim 2.5\%$ uncertainty on the final integrated luminosity,
- b) $\sim 4\%$ uncertainty in the determination of the losses in the reconstruction software.
- c) $\sim 1.5\%$ uncertainty due to losses of events caused by readout truncations.

Some of these uncertainties are common to the different data sets. Taking this into account and combining all these errors gives a relative normalisation uncertainty of 3% between the hydrogen [1] and deuterium data presented here. The iron data [2] were taken under different experimental conditions from the data using the liquid hydrogen and deuterium targets so that the error due to the reconstruction losses does not cancel when making comparisons. Thus the absolute normalisation uncertainty of 5% becomes a 7% relative normalisation uncertainty between the iron data and the data from the liquid targets.

Table 2 gives the values of the single photon exchange double differential cross sections $d^2\sigma/dQ^2dx$, at the bin average values of x and Q^2 . These were obtained by recalculating $F_2^N(x, Q^2)$ at the mean x and Q^2 of each bin and using equations (2.1) and (2.2) taking $R^N(x, Q^2)$ to be zero. These cross sections are almost independent of any assumption on the value of R^N .

Earlier data from the SLAC-MIT [7] and SLAC groups [8] on electron-deuteron scattering were obtained at energies below 20 GeV giving values of $F_2^N(x, Q^2)$ in a range of x and Q^2 which does not overlap with the range of the data presented here. In order to make comparisons the SLAC-MIT data has been rebinned in x by interpolation and multiplied by a renormalisation factor of 0.925 following the arguments in [1]. This factor is consistent with unity within the normalisation uncertainty of the two experiments. Figure 2 shows the values F_2^N as a function of Q^2 in different x bins for the SLAC-MIT data and those given in table 1 from this experiment. The two data samples show a good continuity from one to the other within the systematic and statistical errors of the two experiments.

Figure 1 shows that F_2^N rises with Q^2 at small values of x and tends to fall with Q^2 at large values of x . Apart from these small changes F_2^N is approximately independent of Q^2 i.e. it is independent of any length scale. Such scaling shows that the nucleon is composed of point-like constituents. The small deviations from scaling are expected from QCD. These are similar to those observed in the hydrogen and iron measurements from this experiment [1,2] and from other charged lepton experiments on hydrogen [7,8,9], deuterium [7,8] and iron and carbon [10]. Such deviations from scaling have also been studied in neutrino experiments on hydrogen [11], deuterium [12] and heavier nuclear targets [13].

4.2 The Neutron Structure Function F_2^n

The neutron structure function, F_2^n , can be obtained from the difference between the measured deuteron and proton structure functions with appropriate corrections as described below. Since the deuteron is a loosely bound object (binding energy 2.2 MeV) the neutron and proton constituents can be assumed to be quasi-free. Thus deep inelastic lepton scattering from deuterium can be regarded as an incoherent sum of scattering from neutron and proton targets. It follows that,

$$F_2^d = 2F_2^N \approx F_2^p + F_2^n. \quad (4.2.1)$$

Small corrections to this simple expression are necessary for the Fermi motion of the proton and neutron. No evidence for other nuclear effects has been found in a comparison of ep, en and vp scattering [14]. The neutron structure function has been extracted by comparing the deuterium and hydrogen data assuming that only corrections for the effects of smearing due to the Fermi motion are needed. These were calculated using the method of Frankfurt and Strikman [15]. Several forms of the wave function of the deuteron are available [16,17]. The "Paris wave function" [18] has been used in the analysis presented here as this is one of the most recent and has the advantage of being available in momentum space in a parametric form. It also gives a good description of the data on the deuteron form factor [18,19].

The procedure used to extract the neutron structure function, F_2^n , corrected for Fermi motion, from the measured values of F_2^d and F_2^p is as follows. At a fixed Q^2 , F_2^p was smeared by Fermi motion to give F_{2s}^p where $F_{2s}^p = F_2^p / S_p$, using the convolution integrals of Frankfurt and Strikman [15]. The smeared neutron structure function, F_{2s}^n , is then

$$F_{2s}^n = F_2^d - F_{2s}^p. \quad (4.2.2)$$

But $F_{2s}^n = F_2^n / S_n$, hence

$$F_2^n = S_n (F_2^d - F_{2s}^p / S_p). \quad (4.2.3)$$

The proton smearing factor S_p at each x and Q^2 was found by using the data on F_2^p from hydrogen in the parametric form described in [1] and taking the ratio of this to the values obtained after smearing. F_2^n was then derived from equation 4.2.3 taking $S_n = S_p$ as a first guess. These values of F_2^n were then parameterised and the results smeared by the convolution integrals. In this way a better estimate was obtained for S_n which was used (via equation 4.2.3) to obtain an improved value of F_2^n . The process was repeated until the values of S_n converged.

The values of $F_2^n(x, Q^2)$ as a function of Q^2 in fixed intervals of x are given in table 3 including the values of the smearing correction factors S_n and S_p in each bin. The data were obtained as described above from the deuterium data in table 1 and the hydrogen data from table 10 of reference [1].

The systematic errors on F_2^n were estimated as follows. Since F_2^n originates essentially from the difference of F_2^d and F_2^p , which were obtained by identical methods, some of the systematic errors cancel. For such systematic errors the corrections applied are uncertain in the same sense for both data sets. These errors were calculated by taking the deviation from the true F_2 value, if both data sets were shifted by the particular systematic error. The effects of the systematic errors which did not cancel were added in quadrature. All contributions were finally added in quadrature to form a total systematic error which included the systematic error due to the relative normalisation uncertainty of 3% between the data sets.

Figure 3 shows the structure functions F_2^n for fixed values of x as a function of Q^2 . At small values of x there is a tendency for F_2^n to rise whereas at larger x , F_2^n shows little variation with Q^2 within the errors. Thus, scaling violations in the neutron structure function are clearly visible at small x , but are rather weak at larger x . This is consistent with the expectations of QCD, where the scaling violation at large x is proportional to the convolution integral over the quark distribution functions times the splitting function (section 4.5.1). Such scaling violations should be smaller for the neutron than for the proton since the neutron structure function is smaller than the proton structure function especially at large x .

4.3 The Ratio of the Neutron and the Proton Structure Functions, F_2^n/F_2^p

The study of the ratio F_2^n/F_2^p at large x can be used to estimate the relative proportions of u and d quarks in each nucleon.

The ratios F_2^n/F_2^p were calculated using

$$\frac{F_2^n}{F_2^p} = \frac{S_n}{F_2^p} \left(F_2^d - \frac{F_2^p}{S_p} \right) \quad (4.3.1)$$

where S_n and S_p are the Fermi smearing correction factors from table 3. It is advantageous to start from the independent data sets F_2^p and F_2^d in order to calculate reliably the statistical and systematic errors. The resulting ratios F_2^n/F_2^p are given in table 4 together with the statistical and systematic errors. The latter were calculated in the same way as those for the neutron structure function.

Since the evolution of F_2^n/F_2^p with Q^2 is observed to be small, as expected from QCD, the ratios were averaged over Q^2 taking the geometric mean [39]. The averaged ratios are given in table 5 and are shown as a function of x in fig. 4 together with the data from SLAC-MIT [7]. These were obtained from the SLAC-MIT values of F_2^p and F_2^d following the same procedure as outlined in section 4.2, i.e. using the Frankfurt and Strikman method [15] for the calculation of the Fermi smearing corrections. Within the errors data from the two experiments is consistent although the SLAC-MIT ratios tend to be somewhat higher than those presented here. This shows that any change of the ratio between the SLAC-MIT Q^2 range (2 to 20 GeV^2) and that of the data presented here (7 to 170 GeV^2) is rather small.

In the region of large x where the contributions from the sea quarks are negligible, the ratio is given by

$$\frac{F_2^n}{F_2^p} = \frac{1+4d/u}{4+d/u} \quad \text{i.e.} \quad \frac{1}{4} < \frac{F_2^n}{F_2^p} < 4 \quad . \quad (4.3.2)$$

The axis on the right hand side of fig. 4 gives the ratio d/u obtained from equation 4.3.2. As $x \rightarrow 1$ the data tend to approach a value of d/u which is lower than that expected from the naïve quark-parton model ($u = 2d$) and from the model of Farrar and Jackson [20] ($u = 5d$). This is interpreted as the dominance of the u quark in the proton at large x and has also been observed previously in both muon [3] and neutrino [21] experiments.

Donnachie and Landshoff suggested [22] that the ratio F_2^n/F_2^p could be strongly influenced by scattering from diquarks. This contribution has a $1/Q^2$ dependence and should be relatively important in the SLAC-MIT data at lower Q^2 . In this model, at the higher values of Q^2 of the data presented here, such a $1/Q^2$ contribution should be much smaller and F_2^n/F_2^p is expected to approach the limit of $u = 2d$. Such

a process is excluded by the data in fig. 4. In the diquark model of Frederiksson et al. [23], F_2^n/F_2^p is expected to decrease more rapidly with increasing x for data at higher Q^2 as shown by the smooth curves in fig. 4. The data are consistent with such behaviour but they are too imprecise to be conclusive.

4.4 The Structure Function $F_2^p - F_2^n$

The difference of the proton and neutron structure function $F_2^p - F_2^n$ calculated as

$$F_2^p - F_2^n = \left(\frac{S_p + S_n}{S_p} \right) F_2^p - S_n F_2^d \quad (4.4.1)$$

is shown in fig. 5 and table 6 together with the statistical and systematic errors derived according to the procedure described above. Since $F_2^p - F_2^n$ is the difference of two measurements which approach each other at low x , the errors are relatively larger than for either F_2^p or F_2^d .

The data at each value of x in table 6 were averaged over Q^2 using the method described in [1]. The mean Q^2 increases from 10 GeV^2 at $x = 0.03$ to 90 GeV^2 at $x = 0.65$. The results are given in table 7 and shown in fig. 6. The values from the SLAC-MIT measurements of F_2^p and F_2^d [7] at lower Q^2 obtained using the same smearing correction procedure are also shown. These values are consistent with the data presented here indicating that $F_2^p - F_2^n$ does not change strongly with Q^2 within the errors although some shrinkage of the distribution is visible as expected from QCD.

4.5 Comparison of the Measured Structure Functions with the Predictions of QCD

4.5.1 Non-Singlet QCD Fits to $F_2^N(x, Q^2)$

Non-singlet QCD fits, using the procedure described in [1,2], were performed to the Q^2 variation of the structure function $F_2^N(x, Q^2)$ in the range $0.3 < x < 0.8$ in order to determine the QCD mass scale parameter, Λ . In this range of x , the effects of sea quarks and gluons are assumed to be negligible, so that F_2^N is a non-singlet distribution [1,2].

The method of Abbott et al. [24] was used to solve the Altarelli-Parisi equation [25] in next-to-leading order for a non-singlet structure function. F_2^N was parameterised at $Q_0^2 = 5 \text{ GeV}^2$ as

$$F_2^N(x, Q_0^2) = Ax^\alpha(1-x)^\beta(1-\gamma x) \quad (4.5.1)$$

and a simultaneous fit was performed using the programme MINUIT [26] with A , α , β , γ and Λ as free parameters. The results are given in table 8, together with the systematic errors corresponding to the sum in quadrature of the changes in $\log \Lambda$ caused by each systematic error given in table 1. The values of χ^2 given in table 8 were obtained from the statistical errors only. The presence of systematic errors causes these values of χ^2 to be somewhat large.

The fits were not sensitive to the inclusion of conventional target mass corrections, since such effects have a $\sim 1/Q^2$ dependence, and so have died out at the Q^2 values of these data [1].

The value of the QCD mass scale parameter Λ obtained from the next-to-leading order fit was

$$\Lambda_{\overline{MS}} = 65^{+90}_{-50} {}^{+150}_{-45} \text{ MeV}, \quad (4.5.2)$$

which is consistent with the more precise determinations from the structure functions measured on hydrogen [1] and iron [2].

4.5.2 Non-Singlet QCD Fits to $F_2^P - F_2^n$

Assuming that the sea quark distributions in the proton and neutron are the same the structure function $F_2^P - F_2^n$ is a non-singlet distribution. The QCD prediction for such a non-singlet structure function is insensitive to the gluon and sea distributions in the Altarelli-Parisi equations [25]. However, the relatively large errors of the data in fig. 5 prevent any improvement on the existing determination of the QCD mass scale parameter, Λ [1,2].

In order to parameterise the behaviour of the structure function, $F_2^P - F_2^n$, a fit was performed in leading order with the value of Λ_{LO} fixed to be 90 MeV, as obtained from the hydrogen [1] and iron data [2]. The resulting parameterisation at $Q_0^2 = 5 \text{ GeV}^2$ was:

$$F_2^{NS}(x, Q_0^2) = 0.35 x^{0.54} (1-x)^{2.81} (1+9.44x) \quad (4.5.3)$$

using the relation $(F_2^P - F_2^n) = F_2^{NS}/3$, where F_2^{NS} is a non-singlet distribution function. The fit is superimposed in fig. 5 and gives a good description of the data. A similar parameterisation was used in [1] for the singlet QCD fits to the proton structure function. The actual parameters are slightly different from those given in [1] due to the small normalisation change in the deuterium data mentioned above.

4.5.3 Confronting the Structure Functions F_2^p , F_2^n and F_2^d with QCD

In contrast to the structure function $F_2^p - F_2^n$ there are difficulties when comparing F_2^p , F_2^n or F_2^d with the scaling violation predicted by QCD over the whole x range. Fits show a strong correlation between the form of the gluon distribution $xG(x, Q_0^2)$ and the value of the QCD scale parameter Λ . The only experimental knowledge of $xG(x, Q_0^2)$ comes from neutrino experiments [27] which have access to the sea quark distribution, and hence can constrain $xG(x, Q^2)$. However, since these measurements were made with nuclear targets for which the structure functions show non-trivial deviations from those obtained from free nucleons [4], it is inappropriate to use them for free nucleons.

In the analysis of F_2^p already reported [1], the following strategy was adopted to obtain an estimate of the gluon distribution:

1. Obtain Λ_{LO} (90 Mev) from fits to F_2^p at high x where its evolution is unaffected by the gluon distribution.
2. Obtain $F^{NS}(x, Q_0^2)$ from the analysis described in section 4.5.2.
3. Assume reasonable functional forms for $xG(x, Q_0^2)$ and for the singlet distribution function $F^S(x, Q_0^2)$.
4. Fit to the F_2^p data (excluding points affected by the charm threshold).

It is now possible to add a final step:

5. Calculate F_2^n and F_2^d from F^S , F^{NS} and xG and compare with the data.

The fit to F_2^P was repeated using $\Lambda_{LO} = 90$ MeV and the parameterisation of F^{NS} described above (section 4.5.2). From the best fit to F_2^P derived under the assumption of $R = R^{QCD}$, (the leading order prediction for $R = \sigma_L/\sigma_T$), the gluon distribution of the proton was estimated, at $Q_o^2 = 5 \text{ GeV}^2$, to be

$$xG(x, Q_o^2) \propto (1-x)^{7.5 \pm 2.5}$$

in close agreement with that found in [1]. The updated parameters from this singlet fit to F_2^P are given below*.

The final step in the analysis comes from the relations:

$$F_2^P = \frac{5}{18} F^S + \frac{1}{6} F^{NS} \quad (4.5.5)$$

$$F_2^n = \frac{5}{18} F^S - \frac{1}{6} F^{NS} \quad (4.5.6)$$

$$F_2^N = \frac{5}{18} F^S \quad (4.5.7)$$

where

$$F^S = \sum_f x(q_f + \bar{q}_f) \text{ and } F^{NS} = \sum_f x(q_f - \bar{q}_f)$$

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* Updated parameters from the fits to the proton data [1] using equation (4.5.3) for the non-singlet piece of F_2^P . The parameters are given for $\Lambda_{LO}=90$ MeV, $Q_o^2=5 \text{ GeV}^2$.

$$\left. \begin{aligned} F^S(x, Q_o^2) &= 6.47 x^{0.70} (1-x)^{3.44} + 1.06 (1-x)^{15.0} \\ xG(x, Q_o^2) &= 4.44 (1-x)^{7.47} \end{aligned} \right\} \text{ for } R=R^{QCD}$$

$$\left. \begin{aligned} F^S(x, Q_o^2) &= 6.71 x^{0.71} (1-x)^{3.48} + 1.04 (1-x)^{15.7} \\ xG(x, Q_o^2) &= 5.86 (1-x)^{10.15} \end{aligned} \right\} \text{ for } R=0.0$$

Here the explicit x and Q^2 dependence is omitted for simplicity and the small additional contributions from the charm and strange quark seas are neglected. The values for F_2^n and F_2^N were calculated using equations 4.5.6 and 4.5.7, where F^S and F^{NS} evolved with Q^2 according to the QCD predictions for $\Lambda_{LO} = 90$ MeV. $R = 0$ was assumed throughout since it seems to be preferred by the proton data [1].

Figure 7 shows these QCD predictions as the smooth curves superimposed on the data for F_2^n and F_2^N . The bands drawn around the curves demonstrate the spread of the fits allowed within the systematic errors on the data. The predictions of QCD show good overall agreement with the data except in the lowest x bin, which was not used in the fit to F_2^P due to the theoretical uncertainties in this region. The good agreement between the data and the smooth curves shows that QCD and the quark-parton model of the nucleon provides an excellent description of the structure functions over the kinematic range of the data.

5. THE STRUCTURE OF THE NUCLEON

The structure functions F_2^n and F_2^P are related to the quark charges and the quark distribution functions by equation 2.3. In this section these structure functions are used through equation 2.3 to measure the quark charges, the fraction of the momentum of the nucleon carried by gluons and the quark distribution functions.

5.1 Evaluation of Sum Rules

5.1.1 Test of the Gottfried Sum Rule

The application of the Gottfried sum rule [28] to the structure function $F_2^P - F_2^n$ yields

$$I = \int_0^1 \frac{F_2^P - F_2^n}{x} dx = \frac{1}{3} \quad (5.1.1)$$

This is derived from equations 2.3 assuming that the sea of u and d quarks and antiquarks is equal and isospin invariance is valid so that the d quark distribution in the neutron is the same as the u quark in the proton and vice versa. Since the measurements only extend over a limited range in x and because of the 1/x in the integrand, the evaluation of the integral is affected by substantial uncertainties.

The integral was evaluated using the Q^2 averaged data given in table 7. The calculation of the integral over the measured region yielded:

$$\int_{0.02}^{0.8} \frac{1}{x} (F_2^P - F_2^n) dx = 0.197 \pm 0.011 \text{ (stat.)} \pm 0.083 \text{ (syst.)} \quad (5.1.2)$$

The evaluation of the full integral assumes that $F_2^P - F_2^n$ is well behaved as x approaches zero. The contribution to the integral from the unmeasured region was calculated from the functional form fitted to the measurements (equation 4.5.3). The uncertainty originating from this extrapolation, especially at small x, is included in the total error, which is a combination of the statistical and systematic errors. The value of the integral obtained was

$$\int_0^1 \frac{1}{x} (F_2^P - F_2^n) dx = 0.235 \pm \begin{matrix} 0.110 \\ 0.099 \end{matrix} \quad (5.1.3)$$

which is consistent with the expected value of 1/3 (equation 5.1.1) within the error and could be confirming the assumptions made in deriving the sum rule. However, it should be noted that the value obtained is rather lower than expected. It is interesting that other groups have also found rather low values of this integral [7,8,9].

5.1.2 The Energy Momentum Sum Rule

The integrals $\int_0^1 F_2^p dx$, $\int_0^1 F_2^n dx$ and $\int_0^1 F_2^d dx$ represent the charge weighted momentum fractions carried by the quarks for each target.

In order to evaluate the integrals the structure functions were extrapolated to $Q^2 = 15 \text{ GeV}^2$, chosen to be close to the average value, by linear least squares fits to F_2 as a function of $\log Q^2$. This method was chosen because there is no common Q^2 value where the data on F_2^n and F_2^d extend over the full x range of the experiment.

Since the integral extends from 0 to 1, corrections were applied for the unmeasured regions at small and large x , by extrapolation using a functional form fitted to the measured region.

From equation 2.3 this integral can be written

$$\int_0^1 F_2 dx = \sum_f e_f^2 \int_0^1 x [q_f(x) + \bar{q}_f(x)] dx \quad (5.1.4)$$

It is well known that only about half the momentum of the proton is carried by quarks, the remainder by gluons. Furthermore, the momentum fraction carried by quarks cannot be calculated for protons and neutrons separately without knowledge of the separate u , $\bar{u}$, d and $\bar{d}$ distributions. If we were to ignore these difficulties, and to assume $u = d$, $\bar{u} = \bar{d}$, with all momentum carried by quarks then $\int_0^1 F_2^p dx$ and $\int_0^1 F_2^n dx$ would be $1/3$ and $2/9$, respectively. The observed values of the integrals are 0.148 ± 0.007 for the proton, in agreement with that found in [1], and 0.101 ± 0.009 for the neutron. The error quoted is a combination of the statistical and systematic error and also contains estimates of the uncertainty originating from the extrapolation into the unmeasured regions. The systematic error is dominant. The integrals indicate that roughly half of the momentum of the proton and of the neutron are carried by quarks.

For the reasons given above, these integrals cannot be compared to 1/3 and 2/9 to obtain the momentum fraction carried by quarks in the neutron and proton separately. However, the integral over the deuteron structure function can be used to make a precise measurement of the gluon momentum fraction assuming isospin invariance, as follows:

$$\int_0^1 F_2^d dx = \frac{1}{2} \int_0^1 (F_2^p + F_2^n) dx \quad (5.1.6)$$

$$= \frac{5}{18} \left[\int_0^1 \sum_i x (q_i + \bar{q}_i) dx \right] + \frac{1}{6} \left[\int_0^1 x(c + \bar{c}) dx - \int_0^1 x(s + \bar{s}) dx \right] \quad (5.1.7)$$

The c and s quark distributions were assumed to be the same in the proton and the neutron. The last term in equation 5.1.7 was calculated to be -0.003 from the EMC measurements of the charm quark structure function [29] and the CDHS measurements for that of the strange quark [30]. Applying this correction to the measured value of the integral of 0.127 ± 0.005 shows that $47 \pm 2\%$ of the momentum of the nucleon is carried by quarks, implying that $53 \pm 2\%$ is carried by gluons at $Q^2 = 15 \text{ GeV}^2$.

The measured value of the quark momentum fraction of the nucleon in iron was $49 \pm 4\%$ [2] which is consistent with that deduced from the deuterium data and consequently the total momentum fractions carried by gluons remains similar for nucleons in iron and deuterium.

5.2 Comparison with the Neutrino Structure Functions $F_2^{\nu N}$

In deep inelastic scattering of ν and $\bar{\nu}$ from nucleons

$$F_2^{\nu N} = \frac{1}{2} (F_2^{\nu p} + F_2^{\nu n}) = \sum_f x (q_f(x) + \bar{q}_f(x)) \quad (5.2.1)$$

Thus the ratio of this structure function to that measured in deep inelastic muon scattering (from equation 2.3) is

$$\frac{F_2^{\mu N}}{F_2^{\nu N}} = \frac{5}{18} (1+\delta) \quad (5.2.2)$$

where the factor 5/18 is the mean square charge of the quarks in the nucleon and the factor δ is a correction for the charm and strange quark constituents. From equations 2.3 it follows that

$$\delta = \frac{3}{5} \left[\frac{x(c+\bar{c}) - x(s+\bar{s})}{F_2^{\nu N}} \right] \quad (5.2.3)$$

Figure 8 shows the values of $\frac{5}{18} \frac{F_2^{\nu N}}{F_2^{\mu N}}$ as a function of x at $Q^2 = 15 \text{ GeV}^2$. The values of $F_2^{\mu N}$ were taken from table 1 and $F_2^{\nu N}$ from the data on deuterium of the CERN-WA25 collaboration [12] and each extrapolated to $Q^2 = 15 \text{ GeV}^2$. The smooth curve shows the behaviour expected from equation 5.2.2 where the small corrections for the charmed quark distributions were made using the data of [29] while those for the strange quark came from the measurements of $\bar{d}+\bar{s}$ [12,31] assuming $\bar{s}/\bar{d} = 0.5$ [32]. As can be seen from the figure, the data presented here agree reasonably with those of WA25. However, there is a tendency for the ratio of the structure functions to rise with x and the same trend is observed [32] in comparing the measurements of the WA21 collaboration [11] on hydrogen with those of the EMC [1]. Such an effect could be explained by a small systematic error in the measurement of the incident neutrino energy. Here and in subsequent comparisons this effect is neglected and the neutrino data are used as published. The mean value of the ratio is

$$\left\langle \frac{5}{18} \frac{F_2^{\nu N}}{F_2^{\mu N}} \right\rangle = 0.96 \pm 0.02 \pm 0.05$$

which is compatible with unity. The systematic error is the normalisation uncertainty of the data presented here.

5.3 The Electric Charges on the Quarks

These can be derived from the Gottfried sum rule presented in section 5.1 and the ratio $F_2^{\mu N}/F_2^{\nu N}$ in section 5.2 as follows. Assuming that the u and d quark sea distributions are the same in the nucleon, equation 5.1.1 can be written

$$I = \int_0^1 \frac{F_2^p - F_2^n}{x} dx = e_u^2 - e_d^2 \quad (5.3.1)$$

Similarly the ratio of the muon and neutrino structure function can be written, neglecting the correction factor δ for s and c quarks (which is about 6% at the lowest value of x and decreases as x increases)

$$r = \frac{F_2^{\mu N}}{F_2^{\nu N}} = \frac{e_u^2 + e_d^2}{2} \quad (5.3.2)$$

From the measured value of $I = 0.235^{+0.110}_{-0.099}$ (section 5.1) and $r = 0.29 \pm 0.02$ (section 5.2) equations 5.3.1 and 5.3.2 can be solved to give

$$|e_u| = 0.64 \pm 0.05 \quad \text{and} \quad |e_d| = 0.41 \pm 0.07$$

Thus the measured structure functions in neutrino and muon deep inelastic scattering show that the u and d quark charges are consistent with the expected values of 2/3 and 1/3, respectively.

5.4 The Quark Distribution Functions in Free Nucleons

Since the virtual photon couples only to electric charge, discrimination between quark flavours in deep inelastic muon scattering is less straightforward than in neutrino scattering. The technique described below allows the extraction of the u and d valence quark distributions from F_2^p and F_2^n , under the reasonable assumption that the shapes of sea quark distributions are substantially different from those of the valence quarks.

The quantities $U(x)$ and $D(x)$ can be derived from the measured structure functions. These project out the contributions of the u and d quarks;

$$D(x) = \frac{9}{15}[4F_2^n - F_2^p] = x(d+\bar{d}) + \frac{4}{5} x(c+\bar{c}) + \frac{1}{5} x(s+\bar{s}) \quad (5.4.1)$$

$$U(x) = \frac{9}{15}[4F_2^p - F_2^n] = x(u+\bar{u}) + \frac{4}{5} x(c+\bar{c}) + \frac{1}{5} x(s+\bar{s}). \quad (5.4.2)$$

Here isospin invariance is assumed so that the momentum distribution of the u quarks in the proton is the same as that for the d quarks in the neutron and vice versa.

The u and d quark distributions can be written as the sums of the distributions of the valence and sea quarks, labelled by suffixes v and s, respectively, where antiquarks are assumed to arise only from the sea. Thus $U(x)$ and $D(x)$ can be expressed as

$$U(x) = xu_v + 2x\bar{u}_s + \frac{8}{5} x\bar{c} + \frac{2}{5} x\bar{s} \quad (5.4.3)$$

and

$$D(x) = xd_v + 2x\bar{d}_s + \frac{8}{5} x\bar{c} + \frac{2}{5} x\bar{s} \quad (5.4.4)$$

where the assumption is made that the quark and antiquark distributions in the sea are the same. The sea quark distribution, $\bar{q}$ is then defined as

$$\bar{q} = \bar{u}_s = \bar{d}_s \quad (5.4.5)$$

and $\bar{s}/\bar{d}$ is assumed to be 0.5 [32] from neutrino measurements and $\bar{s} = s$. The fits were insensitive to the assumptions on the value of $\bar{s}/\bar{d}$.

These expressions may then be simplified

$$U(x) = xu_v + 2.2 x\bar{q} + \frac{8}{5} x\bar{c} \quad (5.4.6)$$

and

$$D(x) = xd_v + 2.2 x\bar{q} + \frac{8}{5} x\bar{c} \quad (5.4.7)$$

The values of $U(x)$ and $D(x)$ were calculated from the measured structure functions at each Q^2 and then extrapolated to $Q^2 = 15 \text{ GeV}^2$ using a linear least squares fit as a function of $\log Q^2$. Table 9 gives the values of the structure functions extrapolated to $Q^2 = 15 \text{ GeV}^2$ and of $U^*(x)$ and $D^*(x)$ defined as

$$U^*(x) = U(x) - \frac{8}{5} x \bar{c}(x) \quad (5.4.8)$$

$$D^*(x) = D(x) - \frac{8}{5} x \bar{c}(x) \quad (5.4.9)$$

where the corrections for the charmed quark distribution, $\bar{c}(x)$, were taken from a parameterisation of the EMC iron data in [29]. The correction is small, being $\sim 10\%$ at the lowest x value and decreases with x . Figure 9 shows the values of U^* and D^* as a function of x at $Q^2 = 15 \text{ GeV}^2$.

Equations (5.4.6) and (5.4.7) cannot be solved for u_v , d_v and $\bar{q}$ point by point. However, parameterisations of the quark distributions can be fitted to them. The functions $xu_v(x)$, $xd_v(x)$ and $x\bar{q}(x)$ were parameterised in the form

$$xu_v(x) = C_1 x^{\alpha_u} (1-x)^{\beta_u} \quad (5.4.10)$$

$$xd_v(x) = C_2 x^{\alpha_d} (1-x)^{\beta_d} \quad (5.4.11)$$

$$x\bar{q}(x) = C_3 (1+\gamma) (1-x)^{\gamma} \quad (5.4.12)$$

and a fit made to the data given in table 9. Here α_u , β_u , α_d , β_d , γ and C_3 were parameters determined from the fit. The constants C_1 and C_2 were constrained to fix the number of u and d valence quarks to two and one, respectively, as indicated by the measurements of the Adler and Gross-Llewellyn Smith sum rules in neutrino experiments [12,32]. Table 10 and the smooth curves in fig. 9 show the results of the fit. Good fits were obtained indicating that the parameterisations are sensible. The integrals of the distributions of xu_v , xd_v and $5x\bar{q}$, which represent the momentum fractions of the proton carried by the valence and sea quarks, are also given in table 10. The quoted systematic errors on the fits were obtained from the changes to the fitted parameters as the values of F_2^d and F_2^p were changed by each individual systematic error. The final systematic error is the sum in quadrature of all these changes.

It can be seen from equations 5.4.6 and 5.4.7 that in the region $x \gtrsim 0.3$ $U^*(x)$ and $D^*(x)$ give directly the valence quark distributions since the sea quark distributions are negligible in this range of x . In the region $0.1 < x < 0.3$ small corrections are necessary for the sea whereas in the range $x < 0.1$ large corrections are needed. The values of $U^*(x)$ and $D^*(x)$ (table 9) were corrected for the fitted $\bar{q}(x)$ distribution to obtain the valence quark distributions. These are shown in figs. 10a and 10b while fig. 10c shows the fitted $\bar{q}(x)$ distribution. The neutrino measurements of these quantities are also shown for comparison.

It can be seen from fig. 10c that there is a reasonable agreement between the fitted sea distribution and the neutrino measurements although the fitted sea is somewhat softer than the neutrino data. From fig. 10a it can be seen that the values of xu_v are in reasonable agreement although somewhat higher than the neutrino measurements. However, from fig. 10b our values of xd_v are significantly larger than those from the neutrino experiments. It should be noted that similar values of xu_v and xd_v are obtained from our data if the neutrino measurements are used to correct for the sea distribution rather than the fitted sea.

This disagreement is illustrated further in figs. 11 which show the values of $F_2^{\mu p}$ and $F_2^{\mu n}$ extrapolated to $Q^2 = 15 \text{ GeV}^2$ from the data presented here. The values of $F_2^{\mu p}$ and $F_2^{\mu n}$ calculated from the neutrino measurements of the quark distribution functions (equation 2.3) using the assumptions in equations 5.4.5 are also shown. It can be seen that the agreement in $F_2^{\mu p}$ is reasonable, whereas that in $F_2^{\mu n}$ reflects the disagreement in xd_v seen in fig. 10.

A physical explanation of these disagreements requires objects in the nucleon which couple to photons but not to intermediate vector bosons. Such an explanation seems unlikely. The effects are more likely to be due to systematic effects in the experiments. It should be noted that the parameterisations shown in fig. 9 which give good fits to the data are constrained to two u and one d valence quarks in the proton as verified by the neutrino measurements of the Adler [12] and Gross-Llewellyn Smith [32] sum rules. The WA25 collaboration [21] give parameterisations of their measured values of xu_v and xd_v . Integrating these parameterisations gives $\int_0^1 u_v dx = 1.51 \pm 0.20$ and $\int_0^1 d_v dx = 0.61 \pm 0.15$ which are lower than the observed numbers of valence quarks indicating that the neutrino measurements of xu_v and xd_v are possibly too low. However, the latter integrals are very sensitive to the low x behaviour.

6. COMPARISON OF THE NUCLEON STRUCTURE FUNCTION F_2^N FOR IRON AND DEUTERIUM

The majority of deep inelastic lepton nucleon scattering experiments so far have used nuclear targets [10,13]. The intention of these experiments was to determine the distribution functions of quarks, antiquarks and gluons inside the nucleon and their Q^2 evolution. It had generally been assumed that these quantities are identical for free and bound nucleons and are not influenced by the neighbouring nucleons apart from kinematic effects due to Fermi-motion [34]. This assumption has been found to be invalid in this experiment by comparing the nucleon structure functions F_2^N for iron and deuterium measured under similar experimental conditions [4].

Using data for the structure function $F_2(\text{Fe})$ from [2] and that for $F_2(\text{D})$ presented in this paper, we have repeated the analysis in [4] in order to finalise our results for $F_2(\text{Fe})/F_2(\text{D})$ from the first phase of the experiment.

For this comparison the iron data (table 7 of reference 2) are corrected for the non-isoscalarity of iron. Ignoring binding and other nuclear effects $F_2^N(\text{D})$ and $F_2^N(\text{Fe})$ are given by

$$F_2^N(\text{D}) = \frac{1}{2} (F_2^p + F_2^n) \quad (6.1.1)$$

$$F_2^N(\text{Fe}) = \frac{1}{56} (ZF_2^p + NF_2^n) = \frac{1}{2} (F_2^p + F_2^n) (1-K(x)) \quad (6.1.2)$$

$$\text{with} \quad K(x) = \left[\frac{N-Z}{N+Z} \right] \frac{1-F_2^n/F_2^p}{1+F_2^n/F_2^p} \quad (6.1.3)$$

where N and Z are the numbers of neutrons and protons in the nucleus, respectively. The non-isoscalarity correction factor $K(x)$ was calculated for iron using a linear fit to the measurements of

F_2^N/F_2^P presented in section 4.3. The values of this correction factor are smaller than 1% for $x < 0.3$ and rise to 3.6% at $x = 0.65$. Having applied this correction the iron data correspond to a hypothetical target with the same number of protons and neutrons.

The values of $F_2^N(\text{Fe})$ obtained in this way are shown in fig. 12 together with the data for the nucleon structure function from the deuterium, $F_2^N(\text{D})$. Neither data set has been corrected for Fermi-motion. At small x the nucleon structure function for iron is larger than that for deuterium whilst at large x the values from iron become smaller. Table 11 and fig. 13 show the ratios of $F_2^N(\text{Fe})/F_2^N(\text{D})$ as a function of Q^2 in fixed x intervals. No significant Q^2 -dependence of the ratio is observed. The ratio has been averaged over Q^2 for each x and the values are given in table 12 and shown in figs. 14. The ratio falls from 1.14 at $x = 0.05$ to 0.84 at $x = 0.65$ in stark contrast to the predictions from Fermi-motion indicated by the smooth curve [34]. The inner error bars are statistical and the outer bars represent an estimate of the systematic error.

The systematic errors were calculated as follows. The assumption was made that none of the systematic errors cancel in taking the ratios of the structure functions. The systematic error was calculated by increasing sequentially the measured values of F_2 for iron by each of the systematic errors given in [2] and simultaneously decreasing F_2 for deuterium by each of the systematic errors given above. For each systematic error in turn the difference between the ratio of $F_2(\text{Fe})/F_2(\text{D})$ from the central value was calculated. The total systematic error was then obtained by adding each of these differences in quadrature. These are the systematic errors given in tables 11 and 12. The ratios in tables 11 and 12 have in addition a further normalisation uncertainty (not included in these tables) of 7% arising from adding in quadrature the normalisation uncertainties of the deuterium and iron data.

The decrease of the ratios of the structure function with x has been confirmed at $x \gtrsim 0.2$ by electron scattering experiments at SLAC [35] at much lower Q^2 and by the BCDMS experiment at CERN [36]. At $x \lesssim 0.2$ there are some discrepancies between the different measurements of the ratios. More recent measurements of the ratios of the structure function by the EMC [33] and by BCDMS [37] show that these ratios tend to peak at $x \sim 0.1$. However, the data in fig. 14 are not inconsistent with the more recent data within the systematic errors. It should be noted that the systematic error band shown in fig. 2 of [4] was the systematic error on the slope of the fitted straight line only.

The results clearly demonstrate that the quark distributions measured from nuclear targets are modified by nuclear effects. Many models have been proposed [38] to explain these nuclear effects but there is still no consensus about their origin.

7. CONCLUSIONS

Measurements of the nucleon structure function, F_2^N , from a deuterium target have been presented. Comparison of these with the measurements for free protons in hydrogen allow values of the structure function of the neutron, F_2^n , to be derived.

The pattern of scale breaking for F_2^N , F_2^n and the non-singlet structure function $F_2^p - F_2^n$ are consistent with the predictions of QCD. The values of Λ , the QCD mass scale parameter, determined from the observed scaling violations is consistent with the measurements from this experiment for hydrogen and iron. The fraction of the momentum of the nucleon carried by gluons in deuterium was measured to be $53 \pm 2\%$. The values of this fraction are found to be similar for free protons and neutrons as well as for nucleons bound in an iron nucleus.

The charges of the u flavour and d flavour quarks were measured to be 0.64 ± 0.05 and 0.41 ± 0.07 , consistent with the values of $2/3$ and $1/3$, respectively, expected from the quark parton model. Together with the neutrino measurements of the Adler and Gross-Llewellyn Smith sum rules, which are consistent with there being two u and one d valence quark in the proton, these data illustrate quantitatively the success of the quark-parton model in describing the structure of the nucleon.

The momentum distribution functions of the valence and sea quarks in the nucleon are derived. These highlight some differences with the measurements made by the neutrino experiments particularly in the d valence quark distribution.

Comparison of the nucleon structure functions measured for bound nucleons in iron and quasi free nucleons in deuterium shows that the quark distribution functions for bound nucleons are different from those for free nucleons. This shows that nuclear forces and the nuclear medium alter the quark and gluon structures within the nucleons bound in a nucleus.

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TABLE CAPTIONS

1. The nucleon structure function, F_2^N , obtained from deuterium at an incident muon energy of 280 GeV assuming $R^N=0$ (Fermi smearing corrections were not applied) as a function of x and Q^2 .
2. The differential cross sections, $d^2\sigma/dxdQ^2$, for deep inelastic muon-deuterium scattering at an incident muon energy of 280 GeV as a function of x and Q^2 .
3. The neutron structure function, F_2^n , obtained using the method of Frankfurt and Strikman [15] for the smearing corrections, as a function of x and Q^2 .
4. The ratio F_2^n/F_2^p as a function of x and Q^2 .

5. The ratio F_2^n/F_2^p averaged over Q^2 as a function of x .
6. The difference, $F_2^p - F_2^n$, as a function of x and Q^2 .
7. The difference, $F_2^p - F_2^n$, averaged over Q^2 as a function of x .
8. The results of non-singlet QCD fits to $F_2^N(x, Q^2)$ for $0.3 < x < 0.8$.
9. The values of F_2^p , F_2^N , F_2^n , U^* and D^* , each extrapolated to $Q^2 = 15 \text{ GeV}^2$, as a function of x .
10. Results of the fits of parameterisations of xu_v , xd_v and $x\bar{q}$ to the values of U^* and D^* .
11. The ratio $F_2^N(\text{Fe})/F_2^N(\text{D})$ as a function of x and Q^2 .
12. The Q^2 averaged values of $F_2^N(\text{Fe})/F_2^N(\text{D})$ as a function of x .

Table 1

Values of the Nucleon Structure Function F_2^N
 Extracted assuming $R = 0.0$.
 No Fermi Motions Corrections

x	Q^2 (GeV ²)	F_2	Errors		Values of the individual Systematic Errors on F_2 (%)							
			Stat.	Syst.	ACC	RAD	SME	EFF	CENT	BEAM	PP	
0.030	7.0	0.3039	0.0074	0.0239	7.0	2.1	0.2	2.6	0.2	1.2	0.0	
	9.0	0.3221	0.0052	0.0129	2.4	2.5	0.0	1.7	0.1	1.1	0.0	
	11.5	0.3307	0.0050	0.0123	2.2	2.6	0.2	1.1	0.1	1.0	0.0	
0.050	9.0	0.3111	0.0117	0.0204	5.2	1.3	0.8	3.3	0.0	1.7	0.2	
	11.5	0.3327	0.0073	0.0131	2.3	1.5	0.4	2.4	0.0	1.4	0.0	
	20.0	0.3583	0.0055	0.0093	1.4	1.9	0.2	1.0	0.0	1.1	0.0	
0.080	11.5	0.3060	0.0082	0.0140	3.0	1.0	0.7	2.5	0.0	2.0	0.5	
	15.0	0.3369	0.0065	0.0113	1.9	1.2	0.2	1.9	0.0	1.6	0.0	
	20.0	0.3529	0.0049	0.0079	1.3	1.4	0.0	0.8	0.0	1.3	0.0	
0.125	11.5	0.3084	0.0128	0.0188	4.2	0.6	0.5	3.3	0.1	2.6	1.1	
	15.0	0.3319	0.0086	0.0125	2.1	0.7	0.3	2.4	0.0	2.2	0.6	
	20.0	0.3510	0.0066	0.0090	1.6	0.9	0.2	1.3	0.0	1.8	0.1	
0.175	11.5	0.2867	0.0176	0.0202	4.5	0.2	2.9	3.1	0.1	3.0	1.6	
	15.0	0.2807	0.0110	0.0118	2.4	0.4	0.5	2.1	0.1	2.5	0.9	
	20.0	0.2902	0.0085	0.0097	1.7	0.5	0.8	1.8	0.0	2.2	0.4	
0.250	11.5	0.2356	0.0153	0.0168	5.4	0.2	2.2	3.0	0.5	2.5	1.1	
	15.0	0.2525	0.0088	0.0093	2.4	0.0	1.0	2.4	0.4	2.2	0.5	
	20.0	0.2633	0.0065	0.0068	1.7	0.1	0.4	1.6	0.4	2.1	0.0	
0.350	11.5	0.1650	0.0071	0.0055	2.0	0.4	1.4	1.6	0.6	0.2	0.4	
	15.0	0.1750	0.0066	0.0042	1.6	0.3	1.1	1.0	0.6	0.0	0.1	
	20.0	0.1866	0.0050	0.0034	1.4	0.1	0.8	0.7	0.6	0.0	0.0	
0.450	11.5	0.1030	0.0077	0.0066	2.2	0.7	1.0	1.5	0.0	0.3	0.1	
	15.0	0.1030	0.0061	0.0042	1.5	0.6	0.7	1.0	0.0	0.3	0.1	
	20.0	0.1030	0.0048	0.0031	1.4	0.5	0.5	0.7	0.0	0.3	0.1	
0.550	11.5	0.0553	0.0040	0.0055	1.3	0.9	1.1	0.0	0.0	0.0	0.0	
	15.0	0.0553	0.0033	0.0037	1.1	0.8	0.8	0.0	0.0	0.0	0.0	
	20.0	0.0553	0.0025	0.0025	1.1	0.7	0.7	0.0	0.0	0.0	0.0	
0.650	11.5	0.0321	0.0032	0.0042	1.5	0.9	1.1	0.0	0.0	0.0	0.0	
	15.0	0.0321	0.0022	0.0022	1.1	0.8	0.8	0.0	0.0	0.0	0.0	
	20.0	0.0321	0.0015	0.0015	1.1	0.7	0.7	0.0	0.0	0.0	0.0	
0.750	11.5	0.0118	0.0018	0.0018	1.2	1.1	0.0	0.0	0.0	0.0	0.0	
	15.0	0.0118	0.0015	0.0015	1.1	1.0	0.0	0.0	0.0	0.0	0.0	
	20.0	0.0118	0.0011	0.0011	1.1	0.9	0.0	0.0	0.0	0.0	0.0	

Table 2

Values of the Single Photon Exchange Differential Cross-Sections
for Deep Inelastic Muon-Deuteron Scattering at 280 GeV

x	Q ² (GeV ²)	Energy (GeV)	X-Section (mb/GeV ²)	Stat. Errors	Syst.
0.0263	7.20	275.1	0.357E-04	0.870E-06	0.278E-05
0.0276	9.00	277.2	0.314E-04	0.149E-06	0.858E-06
0.0314	11.30	279.3	0.117E-04	0.176E-06	0.439E-06
0.0483	9.10	275.2	0.142E-04	0.537E-06	0.934E-06
0.0489	11.50	277.4	0.872E-05	0.191E-06	0.342E-06
0.0489	14.90	278.4	0.468E-05	0.771E-07	0.130E-06
0.0511	19.33	280.3	0.262E-05	0.440E-07	0.833E-07
0.0776	11.60	276.9	0.577E-05	0.153E-06	0.263E-06
0.0777	14.90	277.8	0.357E-05	0.687E-07	0.119E-06
0.0776	19.77	278.1	0.179E-05	0.268E-07	0.428E-07
0.0790	26.40	279.4	0.924E-06	0.139E-07	0.230E-07
0.0877	34.57	281.5	0.459E-06	0.112E-07	0.149E-07
0.1229	11.60	276.1	0.406E-05	0.168E-06	0.247E-06
0.1233	14.90	277.7	0.232E-05	0.657E-07	0.945E-07
0.1233	19.80	278.6	0.124E-05	0.263E-07	0.360E-07
0.1233	26.60	278.8	0.624E-06	0.119E-07	0.142E-07
0.1233	35.00	279.2	0.311E-06	0.512E-08	0.672E-08
0.1261	46.23	280.4	0.165E-06	0.384E-08	0.415E-08
0.1727	11.60	275.7	0.283E-05	0.174E-06	0.199E-06
0.1736	14.90	277.5	0.159E-05	0.626E-07	0.667E-07
0.1733	19.76	278.4	0.902E-06	0.263E-07	0.300E-07
0.1734	26.57	278.8	0.424E-06	0.112E-07	0.103E-07
0.1735	34.33	279.9	0.234E-06	0.600E-08	0.499E-08
0.1737	47.00	279.9	0.114E-06	0.294E-08	0.226E-08
0.1755	63.00	280.3	0.548E-07	0.175E-08	0.122E-08
0.2390	11.70	275.9	0.175E-05	0.114E-06	0.121E-06
0.2434	14.90	277.7	0.961E-06	0.378E-07	0.392E-07
0.2437	19.80	278.8	0.533E-06	0.153E-07	0.159E-07
0.2440	26.60	278.8	0.294E-06	0.741E-08	0.684E-08
0.2444	35.00	279.2	0.153E-06	0.370E-08	0.295E-08
0.2452	46.23	279.8	0.765E-07	0.183E-08	0.134E-08
0.2455	63.00	280.3	0.363E-07	0.948E-09	0.647E-09
0.2507	85.85	280.3	0.170E-07	0.604E-09	0.367E-09
0.3430	19.83	277.8	0.293E-06	0.125E-07	0.948E-08
0.3440	26.57	278.8	0.162E-06	0.594E-08	0.386E-08
0.3444	34.40	278.8	0.870E-07	0.297E-08	0.166E-08
0.3444	47.00	279.9	0.414E-07	0.141E-08	0.624E-09
0.3455	63.39	279.3	0.213E-07	0.757E-09	0.327E-09
0.3455	85.85	279.9	0.941E-08	0.389E-09	0.146E-09
0.3460	119.63	281.1	0.465E-08	0.292E-09	0.992E-10
0.4415	19.90	277.6	0.146E-06	0.109E-07	0.897E-08
0.4426	26.70	278.0	0.751E-07	0.457E-08	0.307E-08
0.4440	34.46	278.4	0.423E-07	0.199E-08	0.125E-08
0.4449	47.30	278.3	0.230E-07	0.109E-08	0.480E-09
0.4453	63.87	278.2	0.124E-07	0.588E-09	0.194E-09
0.4456	85.52	279.9	0.509E-08	0.283E-09	0.684E-09
0.4456	119.72	279.9	0.215E-08	0.168E-09	0.360E-09
0.4545	161.97	283.0	0.882E-09	0.144E-09	0.293E-10
0.5462	26.76	279.1	0.343E-07	0.246E-08	0.334E-08
0.5440	34.68	277.7	0.183E-07	0.144E-08	0.121E-08
0.5449	47.60	279.9	0.106E-07	0.799E-09	0.445E-09
0.5436	63.93	278.3	0.541E-08	0.166E-09	0.161E-09
0.5433	85.77	278.3	0.237E-08	0.103E-09	0.448E-10
0.5433	119.90	277.7	0.133E-08	0.133E-09	0.210E-10
0.5405	160.91	279.5	0.559E-09	0.983E-10	0.124E-10
0.6470	36.04	278.9	0.912E-08	0.901E-09	0.118E-09
0.6466	46.98	279.9	0.414E-08	0.420E-09	0.362E-09
0.6440	64.41	279.9	0.243E-08	0.249E-09	0.131E-09
0.6355	88.80	277.7	0.110E-08	0.130E-09	0.358E-10
0.6500	119.85	283.0	0.417E-09	0.697E-10	0.105E-10
0.6455	165.90	274.7	0.196E-09	0.493E-10	0.383E-11
0.7421	47.71	279.1	0.172E-08	0.261E-09	0.248E-09
0.7451	63.19	278.7	0.127E-08	0.195E-09	0.134E-09
0.7168	84.14	272.4	0.326E-09	0.928E-10	0.183E-10
0.7449	114.60	275.7	0.997E-10	0.397E-10	0.477E-11
0.7485	160.50	278.0	0.129E-09	0.412E-10	0.409E-11

Table 3

Values of the Neutron Structure Function F_2^n

[illegible]

Table 4
Values of the Ratio F_2^n / F_2^p

x	Q^2 (GeV ²)	F_2^n / F_2^p	Stat. Errors	Syst.
0.000000	7.0	0.952	0.062	0.124
0.000000	9.0	0.883	0.045	0.082
0.000000	11.5	0.897	0.045	0.074
0.000000	19.0	0.812	0.078	0.117
0.000000	22.0	0.864	0.053	0.099
0.000000	25.0	0.869	0.057	0.079
0.000000	20.0	0.856	0.050	0.076
0.000000	11.5	0.741	0.054	0.092
0.000000	13.5	0.880	0.046	0.079
0.000000	15.5	0.870	0.037	0.063
0.000000	17.5	0.890	0.046	0.062
0.000000	36.0	0.892	0.064	0.061
0.000000	11.5	0.799	0.151	0.110
0.000000	13.5	0.905	0.071	0.087
0.000000	15.5	0.855	0.059	0.068
0.000000	17.5	0.851	0.047	0.062
0.000000	19.5	0.819	0.053	0.063
0.000000	48.0	0.818	0.059	0.058
0.000000	11.5	0.780	0.119	0.115
0.000000	13.5	0.737	0.077	0.092
0.000000	15.5	0.760	0.074	0.087
0.000000	17.5	0.760	0.062	0.076
0.000000	19.5	0.769	0.059	0.081
0.000000	21.5	0.734	0.064	0.073
0.000000	58.0	0.735	0.075	0.072
0.000000	11.5	0.592	0.110	0.110
0.000000	13.5	0.632	0.070	0.080
0.000000	15.5	0.662	0.050	0.061
0.000000	17.5	0.662	0.042	0.056
0.000000	19.5	0.644	0.038	0.051
0.000000	21.5	0.637	0.038	0.046
0.000000	90.0	0.633	0.081	0.040
0.000000	20.0	0.522	0.078	0.061
0.000000	22.0	0.610	0.060	0.054
0.000000	24.0	0.604	0.057	0.047
0.000000	26.0	0.620	0.050	0.043
0.000000	28.0	0.590	0.040	0.041
0.000000	30.0	0.536	0.030	0.040
0.000000	125.0	0.531	0.133	0.049
0.000000	20.0	0.356	0.114	0.070
0.000000	22.0	0.388	0.084	0.063
0.000000	24.0	0.399	0.080	0.053
0.000000	26.0	0.622	0.098	0.050
0.000000	28.0	0.807	0.154	0.050
0.000000	30.0	0.635	0.153	0.050
0.000000	125.0	0.554	0.153	0.050
0.000000	27.0	0.375	0.207	0.083
0.000000	36.0	0.249	0.120	0.060
0.000000	48.0	0.703	0.251	0.060
0.000000	65.0	0.463	0.155	0.048
0.000000	90.0	0.473	0.153	0.047
0.000000	120.0	0.995	0.284	0.064
0.000000	170.0	0.837	0.449	0.059
0.000000	36.0	0.418	0.271	0.132
0.000000	48.0	0.444	0.369	0.092
0.000000	65.0	0.257	0.234	0.056
0.000000	90.0	0.253	0.193	0.040
0.000000	120.0	0.153	0.233	0.037
0.000000	170.0	0.736	0.462	0.079

Table 5

Values of the Ratio F_2^n / F_2^p
averaged over Q^2

x	F_2^n / F_2^p	Errors	
		Stat.	Syst.
0.030	0.906	0.028	0.089
0.050	0.899	0.029	0.089
0.080	0.862	0.021	0.069
0.125	0.874	0.025	0.067
0.175	0.797	0.027	0.082
0.250	0.696	0.023	0.065
0.350	0.613	0.032	0.056
0.450	0.509	0.041	0.056
0.550	0.483	0.067	0.057
0.650	0.386	0.109	0.072

Table 6
Values of the Difference $F_2^p - F_2^n$

x	Q^2 (GeV ²)	$F_2^p - F_2^n$	Stat.	Errors Syst.
0.030	7.0	0.015	0.019	0.039
0.030	9.0	0.038	0.016	0.029
0.030	11.5	0.036	0.016	0.026
0.050	9.0	0.065	0.027	0.041
0.050	11.5	0.012	0.018	0.034
0.050	15.0	0.046	0.021	0.029
0.050	20.0	0.039	0.019	0.030
0.080	11.5	0.091	0.020	0.034
0.080	15.0	0.043	0.017	0.029
0.080	20.0	0.045	0.013	0.023
0.080	27.0	0.038	0.017	0.023
0.080	36.0	0.040	0.025	0.033
0.110	11.5	0.069	0.056	0.039
0.110	15.0	0.031	0.024	0.029
0.110	20.0	0.057	0.021	0.023
0.110	27.0	0.036	0.016	0.021
0.110	36.0	0.026	0.018	0.020
0.110	48.0	0.063	0.022	0.021
0.140	11.5	0.071	0.039	0.037
0.140	15.0	0.085	0.026	0.022
0.140	20.0	0.065	0.026	0.022
0.140	27.0	0.071	0.021	0.020
0.140	36.0	0.027	0.018	0.020
0.140	48.0	0.083	0.025	0.025
0.170	11.5	0.082	0.025	0.025
0.170	15.0	0.121	0.034	0.033
0.170	20.0	0.103	0.022	0.020
0.170	27.0	0.094	0.019	0.018
0.170	36.0	0.037	0.011	0.010
0.170	48.0	0.068	0.011	0.010
0.170	55.0	0.074	0.015	0.014
0.170	65.0	0.097	0.024	0.024
0.200	20.0	0.104	0.019	0.014
0.200	27.0	0.085	0.011	0.011
0.200	36.0	0.060	0.011	0.011
0.200	48.0	0.074	0.011	0.011
0.200	55.0	0.081	0.011	0.011
0.200	65.0	0.055	0.011	0.011
0.250	20.0	0.098	0.019	0.011
0.250	27.0	0.112	0.020	0.013
0.250	36.0	0.088	0.014	0.010
0.250	48.0	0.049	0.014	0.009
0.250	55.0	0.024	0.020	0.007
0.250	65.0	0.051	0.020	0.006
0.300	27.0	0.050	0.023	0.005
0.300	36.0	0.064	0.014	0.005
0.300	48.0	0.020	0.019	0.004
0.300	55.0	0.041	0.011	0.004
0.300	65.0	0.034	0.011	0.003
0.350	36.0	0.009	0.026	0.003
0.350	48.0	0.009	0.026	0.003
0.400	36.0	0.025	0.016	0.005
0.400	48.0	0.019	0.017	0.005
0.400	55.0	0.010	0.010	0.002
0.400	65.0	0.011	0.011	0.002
0.400	75.0	0.016	0.016	0.001

Table 7

Values of the Difference $F_2^p - F_2^n$
averaged over Q^2

x	$F_2^p - F_2^n$	Errors	
		Stat.	Syst.
0.030	0.034	0.010	0.031
0.050	0.045	0.012	0.033
0.080	0.056	0.008	0.026
0.125	0.047	0.009	0.023
0.175	0.071	0.009	0.027
0.250	0.088	0.007	0.020
0.350	0.082	0.007	0.012
0.450	0.077	0.007	0.009
0.550	0.046	0.006	0.004
0.650	0.025	0.005	0.003

Table 8

The Results of Non-Singlet QCD Fits to $F_2^N(x, Q^2)$ for $x > 0.3$

Fit	A	α	β	γ	$\Lambda_{\overline{MS}}(\text{MeV})$	Errors (MeV) (stat.) (syst.)	χ^2/dof
2nd order	1.03	0.34	2.60	0.55	65	+90 -50 +150 - 45	47 / 28
2nd order + T.M.C.	1.05	0.35	2.76	0.39	65	+95 -50 +155 - 45	46 / 28
Leading Order	1.05	0.35	2.67	0.50	55	+85 -45 +135 -40	47 / 28

T.M.C. = Target Mass Corrections

$$F_2^N(x, Q_o^2) = Ax^\alpha(1-x)^\beta(1-\gamma x)$$

$$Q_o^2 = 5 \text{ GeV}^2$$

Table 9

Data Extrapolated to $Q^2 = 15 \text{ GeV}^2$

X	F_2^p	F_2^d	F_2^n	U^*	D^*
0.03	$0.355 \pm 0.006 \pm 0.016$	$0.346 \pm 0.009 \pm 0.015$	$0.321 \pm 0.020 \pm 0.027$	$0.654 \pm 0.027 \pm 0.051$	$0.501 \pm 0.048 \pm 0.068$
0.05	$0.359 \pm 0.004 \pm 0.016$	$0.339 \pm 0.003 \pm 0.015$	$0.322 \pm 0.008 \pm 0.026$	$0.639 \pm 0.011 \pm 0.041$	$0.529 \pm 0.020 \pm 0.063$
0.08	$0.351 \pm 0.002 \pm 0.012$	$0.322 \pm 0.004 \pm 0.014$	$0.293 \pm 0.008 \pm 0.025$	$0.657 \pm 0.009 \pm 0.034$	$0.479 \pm 0.020 \pm 0.060$
0.125	$0.333 \pm 0.003 \pm 0.011$	$0.311 \pm 0.005 \pm 0.015$	$0.291 \pm 0.012 \pm 0.026$	$0.617 \pm 0.016 \pm 0.030$	$0.494 \pm 0.029 \pm 0.062$
0.175	$0.315 \pm 0.003 \pm 0.012$	$0.287 \pm 0.006 \pm 0.014$	$0.255 \pm 0.013 \pm 0.026$	$0.618 \pm 0.013 \pm 0.034$	$0.418 \pm 0.032 \pm 0.062$
0.25	$0.285 \pm 0.003 \pm 0.011$	$0.233 \pm 0.005 \pm 0.011$	$0.186 \pm 0.010 \pm 0.020$	$0.572 \pm 0.011 \pm 0.029$	$0.277 \pm 0.024 \pm 0.049$
0.35	$0.218 \pm 0.003 \pm 0.007$	$0.177 \pm 0.006 \pm 0.007$	$0.133 \pm 0.013 \pm 0.014$	$0.453 \pm 0.015 \pm 0.016$	$0.187 \pm 0.031 \pm 0.033$
0.45	$0.151 \pm 0.003 \pm 0.005$	$0.108 \pm 0.005 \pm 0.007$	$0.051 \pm 0.012 \pm 0.010$	$0.364 \pm 0.014 \pm 0.015$	$0.220 \pm 0.029 \pm 0.020$
0.55	$0.087 \pm 0.003 \pm 0.005$	$0.056 \pm 0.004 \pm 0.007$	$0.017 \pm 0.012 \pm 0.008$	$0.224 \pm 0.020 \pm 0.010$	$0.102 \pm 0.037 \pm 0.026$
0.65	$0.044 \pm 0.004 \pm 0.003$	$0.036 \pm 0.004 \pm 0.006$	$0.025 \pm 0.012 \pm 0.008$	$0.100 \pm 0.022 \pm 0.003$	$0.021 \pm 0.033 \pm 0.023$
0.75	$0.020 \pm 0.004 \pm 0.002$	$0.020 \pm 0.004 \pm 0.004$	$0.005 \pm 0.013 \pm 0.005$	$0.055 \pm 0.027 \pm 0.003$	$0.049 \pm 0.059 \pm 0.015$

Table 10

Results of the fit to U^* , D^* at $Q^2=15 \text{ GeV}^2$
and the parameterisations of xu_v , xd_v and $x\bar{q}$.

The parameterisations of

$$xu_v = \frac{2}{B(\alpha_u, \beta_u + 1)} x^{\alpha_u} (1-x)^{\beta_u}$$

$$xd_v = \frac{1}{B(\alpha_d, \beta_d + 1)} x^{\alpha_d} (1-x)^{\beta_d}$$

$$x\bar{q} = C_3 (1+\gamma) (1-x)^\gamma$$

where $B(\alpha, \beta)$ are the Euler beta functions.

The fitted parameters were

$$\begin{aligned} \alpha_u &= 0.588 \pm .020 \pm 0.05 \\ \beta_u &= 2.69 \pm 0.13 \pm 0.21 \\ \alpha_d &= 1.03 \pm 0.10 \pm 0.19 \\ \beta_d &= 6.87 \pm 0.64 \pm 0.80 \\ C_3 &= 0.0147 \pm 0.0008 \pm 0.0021 \\ \gamma &= 14.6 \pm 2.0 \pm 2.8 \end{aligned} \quad \chi^2 = 16.1 \text{ for } 16 \text{ d.o.f.}$$

The momentum integrals ($Q^2=15 \text{ GeV}^2$)

$$\int_0^1 xu_v dx = 0.275 \pm 0.011$$

$$\int_0^1 xd_v dx = 0.116 \pm 0.017$$

$$5 \int_0^1 x\bar{q} dx = 0.074 \pm 0.011$$

Total quark
Momentum   = 0.465 ± 0.023
Fraction

Table 12

Values of the Ratio $F_2(\text{Fe})/F_2(\text{D})$
averaged over Q^2

x	$F_2(\text{Fe})/F_2(\text{D})$	Stat.	Errors + Syst.	- Syst.
0.050	1.141	0.017	0.106	0.102
0.080	1.118	0.012	0.085	0.082
0.125	1.077	0.012	0.077	0.074
0.175	1.049	0.013	0.071	0.069
0.250	1.030	0.012	0.065	0.063
0.350	0.952	0.016	0.056	0.055
0.450	0.903	0.021	0.060	0.058
0.550	0.908	0.030	0.092	0.087
0.650	0.840	0.047	0.119	0.109

Figure Captions

1. Values of the nucleon structure function F_2^N from deuterium as a function of Q^2 in different bins of x .
2. Comparison of the structure functions F_2^N measured by SLAC [8] and SLAC-MIT [7] with the measurements presented here.
3. Values of the neutron structure function F_2^n as a function of Q^2 in different bins of x .
4. The ratio F_2^n/F_2^p , averaged over Q^2 , as a function of x . The closed circles show the data presented here and the open circles the values derived from the SLAC-MIT data [7]. The smooth curves show the predictions of the diquark model of [23], the solid curve for the Q^2 range of the SLAC-MIT and the dashed curve for the Q^2 range of this experiment. The systematic error on the data presented here is shown in the lower part of the figure.
5. The non-singlet structure function $F_2^p - F_2^n$ as a function of Q^2 in different bins of x . The values of F_2^p are from [1] and F_2^n from table 3. The smooth curves are the non-singlet QCD fit described in the text.
6. The variation of $F_2^p - F_2^n$ averaged over Q^2 , as a function of x . The systematic error on the ratios measured here is shown in the lower part of the figure.
7. The values of (a) F_2^N and (b) F_2^n as a function of Q^2 at fixed values of x . The smooth curves are the results of the QCD prediction described in the text.
8. The ratio $5/18 (F_2^{\nu N}/F_2^{\mu N})$ as a function of x at $Q^2=15 \text{ GeV}^2$. The neutrino data are from [12]. The smooth curve shows the expected behaviour allowing for the contribution of charm and strange quarks.

9. The quantities U^* and D^* (equations 5.4.8 and 5.4.9) extrapolated to $Q^2=15 \text{ GeV}^2$ as a function of x . The smooth curves show the results of the fit described in the text. The dashed curve is the parameterisation of xu_v and xd_v and the dash dotted curve that of $x\bar{q}(x)$. The inner (outer) error bars are the statistical (total) errors.
10. The valence quark distributions a) xu_v and b) xd_v at $Q^2=15 \text{ GeV}^2$. The muon data are corrected for the sea quarks as described in the text. The WA25 data [12] are extrapolated to $Q^2=15 \text{ GeV}^2$. c) The distribution of $x\bar{q}(x)$ obtained from the fit described is shown as the shaded band which indicates the range of values allowed within the error. The inner (outer) error bars are the statistical (total) errors.
11. The measured values of (a) $F_2^{\mu p}$ and (b) $F_2^{\mu n}$ extrapolated to $Q^2=15 \text{ GeV}^2$ as a function of x compared to the values calculated from the quark distribution functions measured in neutrino experiments [12,31]. The inner error bars are statistical and the outer the total errors.
12. The structure functions F_2^N from iron [2] and deuterium as a function of Q^2 at fixed x . The values from iron are corrected so that the data would be from a hypothetical target with equal numbers of protons and neutrons (see text).
- 13) The ratio $F_2(\text{Fe})/F_2(\text{D})$ as a function of Q^2 at fixed values of x . The iron data are from [2].
- 14) The ratio $F_2(\text{Fe})/F_2(\text{D})$ averaged over Q^2 as a function of x . The smooth curves shows the expected behaviour due to the Fermi motion of the nucleon in the nucleus [34].

FIG. 1

FIG. 2

FIG. 3

FIG. 4

FIG. 5

FIG. 6

FIG. 7a

FIG. 7b

FIG. 8

FIG. 9a

FIG. 9b

FIG. 10a

FIG. 10b

FIG. 10c

FIG. 11a

FIG. 11b

FIG. 12

FIG. 13

FIG. 14