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THE RATIO OF THE NUCLEON STRUCTURE FUNCTIONS F_2^N FOR IRON AND DEUTERIUM

The European Muon Collaboration

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ABSTRACT

Using the data on deep inelastic muon scattering on iron and deuterium the ratio of the nucleon structure functions $F_2^N(\mathrm{Fe})/F_2^N(\mathrm{D})$ is presented. The observed x-dependence of this ratio is in disagreement with existing theoretical predictions.

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Many of the recent deep inelastic muon and neutrino nucleon scattering experiments have been performed using nuclear targets like carbon, marble, heavy liquids or iron [1]. The data of these experiments have been used to determine the nucleon structure functions F_2^N and xF_3^N, the sea-quark distribution $(\bar{q})^N$ and gluon distribution g^N over a wide range of x and Q^2. x is defined as $x = Q^2/2M_p\nu$, where Q^2 is the square of the 4-momentum transfer from the lepton, M_p is the proton mass and ν is the energy transferred from the lepton to the nucleon. The observed pattern of scaling violations has been found to be in good agreement with the theoretical expectations of Quantum Chromodynamics.

The results conventionally represent the distributions of quarks and gluons in nucleons which are embedded in nuclei. They may differ from the free nucleon case not only due to kinematical smearing caused by the Fermi motion of the nucleons in the nucleus but also due to other effects.

Information about the size of these effects and their influence on the structure functions has been obtained by the European Muon Collaboration from extensive muon scattering experiments using targets of liquid hydrogen [2], deuterium [3] and of iron [4]. Apart from the different targets the same apparatus has been used for all measurements.

The measurements with hydrogen and deuterium targets allow the determination of the structure functions for free nucleons. The proton structure function F_2^p has been extracted from the hydrogen data alone. The neutron structure function F_2^n has been obtained by a combined treatment of the hydrogen and the deuterium data. This then determines the ratio F_2^n/F_2^p which, for large x, represents the ratio of the d- and u-quark distributions. In this procedure, corrections have been applied to take into account effects due to the nucleon motion in the deuteron which is a loosely bound p-n system. In the kinematical range covered by the data $(0.03 < x < 0.65)$ these corrections are smaller than 3% [3].

In a similar way the nucleon structure function and the free nucleon quark and gluon distributions could be extracted from the high A target data, provided one knew how to calculate the corrections due to nuclear effects which are different in this case since the nucleons in the nucleus are packed much tighter together than in the deuteron.

If these corrections covered all effects caused by the quark structure of nuclei and were completely understood, they certainly should be applied to the deep inelastic scattering data before these are compared with the predictions of QCD. This appears to be desirable as the Altarelli-Parisi equations [5] in their original form require an integration from x to 1 (if they are not modified to allow an x range up to x = A [6]) and the commonly used parameterizations of the quark and gluon distributions are bounded to zero at x = 1.

Up to now only those corrections due to the motion of the nucleons in the nucleus have been calculated. For these calculations it is common to view the nucleus as a collection of slowly moving nucleons weakly bound to each other with their internal properties unchanged compared to the free nucleon case. The methods used to calculate the deuterium corrections [7] are simply transferred to the heavy nucleus case. Depending on the way the nucleus wave function is calculated, and on the assumptions made on the momentum tail and the momentum balance, the results [8,9,10], shown in fig. 1, differ by several percent, but show in each case a similar global behaviour. The ratio of the structure function F_2^A for a nucleus with mass number A and of the sum of the free nucleon structure functions for proton and neutron weighted with the corresponding nucleon numbers ($Z\ F_2^p + (A-Z)\ F_2^n$) is rising with x for $x \gtrsim 0.2$. The value of this ratio is about 1.2 - 1.3 at x = 0.65 and increases rapidly to higher values of x. In terms of quarks this means [9,10] that in a nucleus the quark distributions are enhanced at high x and extend far beyond x = 1, the kinematic limit being x = A.

The validity of these calculations can be tested by extracting the ratio of the free nucleon structure functions F_2^n/F_2^p from the iron and hydrogen data of the EMC. Applying, for example, the smearing correction factors for the proton and the neutron as given by Bodek and Ritchie (Table 13 of ref. [8]), one gets a ratio which is very different from the one obtained with the deuterium data [3]. It falls from a value of ~ 1.15 at x = 0.05 to a value of ~ 0.1 at x = 0.65 which is even below the Quark-Model lower bound of 0.25.

A direct way to check the corrections due to nuclear effects is to compare the deuteron and iron data for they should be influenced similarly by the neutron content of these nuclei. The iron data are the final combined data sets for the four muon beam energies of 120, 200, 250 and 280 GeV; the deuterium data have been obtained with a single beam energy of 280 GeV. The ratio of the measured nucleon structure functions for iron $F_2^N(Fe) = \frac{1}{56} F_2^{\mu\, Fe}$ and for deuterium $F_2^N(D) = \frac{1}{2} F_2^{\mu D}$, neither corrected for Fermi motion, has been calculated point by point. For this comparison only data points with a total systematic error less than 15% have been used. The iron data have been corrected for the non-isoscalarity of ${}_{26}Fe^{56}$ assuming that the neutron structure function behaves like $F_2^n = (1 - 0.75\,x)\, F_2^p$. This gives a correction of $\sim$ +2.3% at $x = 0.65$ and of less than 1% for $x < 0.3$. The Q^2 range, which is limited by the extent of the deuterium data, is different for each x-value, varying from $9 < Q^2 < 27$ GeV² for $x = 0.05$ over $11.5 < Q^2 < 90$ GeV² for $x = 0.25$ up to $36 < Q^2 < 170$ GeV² for $x = 0.65$.

Within the limits of statistical and systematic errors no significant Q^2 dependence of the ratio $F_2^N(Fe)/F_2^N(D)$ is observed. The x-dependence of the Q^2 averaged ratio is shown in fig. 2 where the error bars are statistical only. For a straight line fit of the form

$$F_2^N(Fe)/F_2^N(D) = a + bx$$

one gets for the slope

$$b = -0.52 \pm 0.04 \text{ (statistical)} \pm 0.21 \text{ (systematic)}.$$

The systematic error has been calculated by distorting the measured F_2^N values by the individual systematic errors of the data sets, calculating the corresponding slope for each error and adding the differences quadratically. The possible effect of the systematic uncertainties on the slope is indicated by the shaded area in fig. 2. Uncertainties in the relative normalisation of the two data sets will not change the slope of the observed x-dependence of the ratio but can only move it up or down by up to seven percent. The difference $F_2^N(Fe) - F_2^N(D)$ however is very sensitive to the relative normalisation.

The result is in complete disagreement with the calculations illustrated in fig. 1. At high x, where an enhancement of the quark distributions compared to the free nucleon case is predicted, the measured structure function per nucleon for iron is smaller than that for the deuteron. The ratio of the two is falling from $\simeq 1.15$ at $x = 0.05$ to a value of ~ 0.89 at $x = 0.65$ while it is expected to rise up to 1.2 - 1.3 at this x value.

We are not aware of any published detailed prediction presently available which can explain the behaviour of these data. However there are several effects known and discussed which can change the quark distributions in a high A nucleus compared to the free nucleon case and can contribute to the observed effect. Amongst them one can list: the change of mass or radius of nucleons embedded in nuclei [11], the existence of excited baryon states like Δ's [12] or of six-(nine, ...)- quark states inside the nucleus [13], the presence of an additional nuclear sea component due to the mutual interactions between the nucleons [14] and possibly several other effects.

In conclusion, we have measured for the first time the ratio of the nucleon structure functions F_2^N for iron and deuterium in deep inelastic muon scattering at high Q^2 which is in disagreement with the existing calculations of nuclear corrections.

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FIGURE CAPTIONS

Fig. 1 - Theoretical predictions for the Fermi motion correction of the nucleon structure function F_2^N for iron.

...... Few-Nucleon-Correlation-Model of Frankfurt and Strikman [9],

- - - - Collective-Tube-Model of Berlad, Dar and Eilam [10],

_____ Correction according to Bodek and Ritchie [8],

-·-·-·- Same authors, but no high momentum tail included,

···-···- Same authors, momentum balance always by a A-1 nucleus.

The last two curves should not be understood as predictions but as an indication of the sensitivity of the calculations to several assumptions which are only poorly known.

Fig. 2 - The ratio of the nucleon structure functions F_2^N measured on iron and deuterium as a function of $x = Q^2/2M_p\nu$. The iron data are corrected for the non-isoscalarity of $_{26}Fe^{56}$, both data sets are not corrected for Fermi motion. The full curve is a linear fit $F_2^N(Fe)/F_2^N(D) = a + bx$ which results in a slope $b = -0.52 \pm 0.04$ (stat.) $\pm$ 0.21 (syst.). The shaded area indicates the effect of systematic errors on this slope.

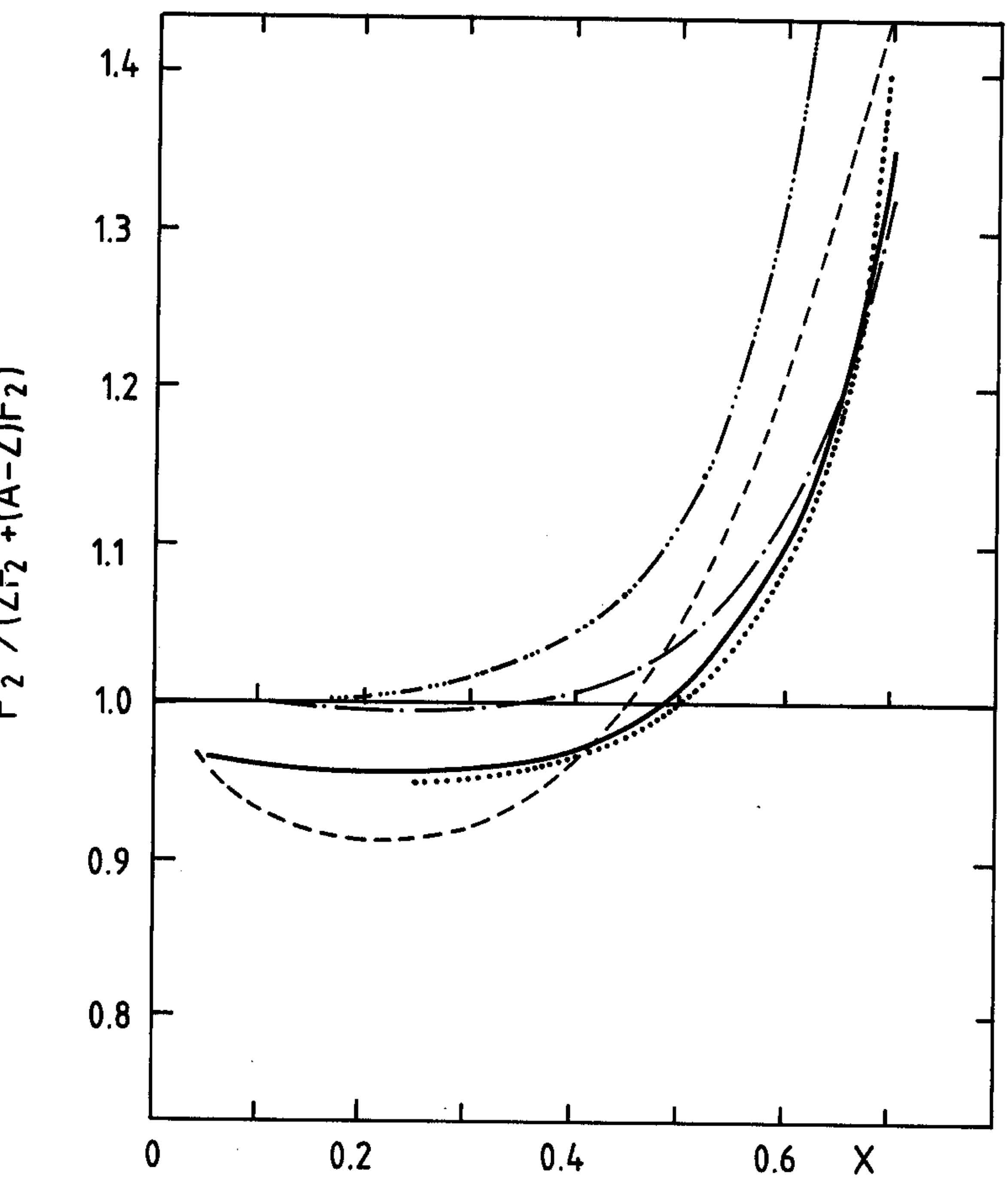

Fig. 1

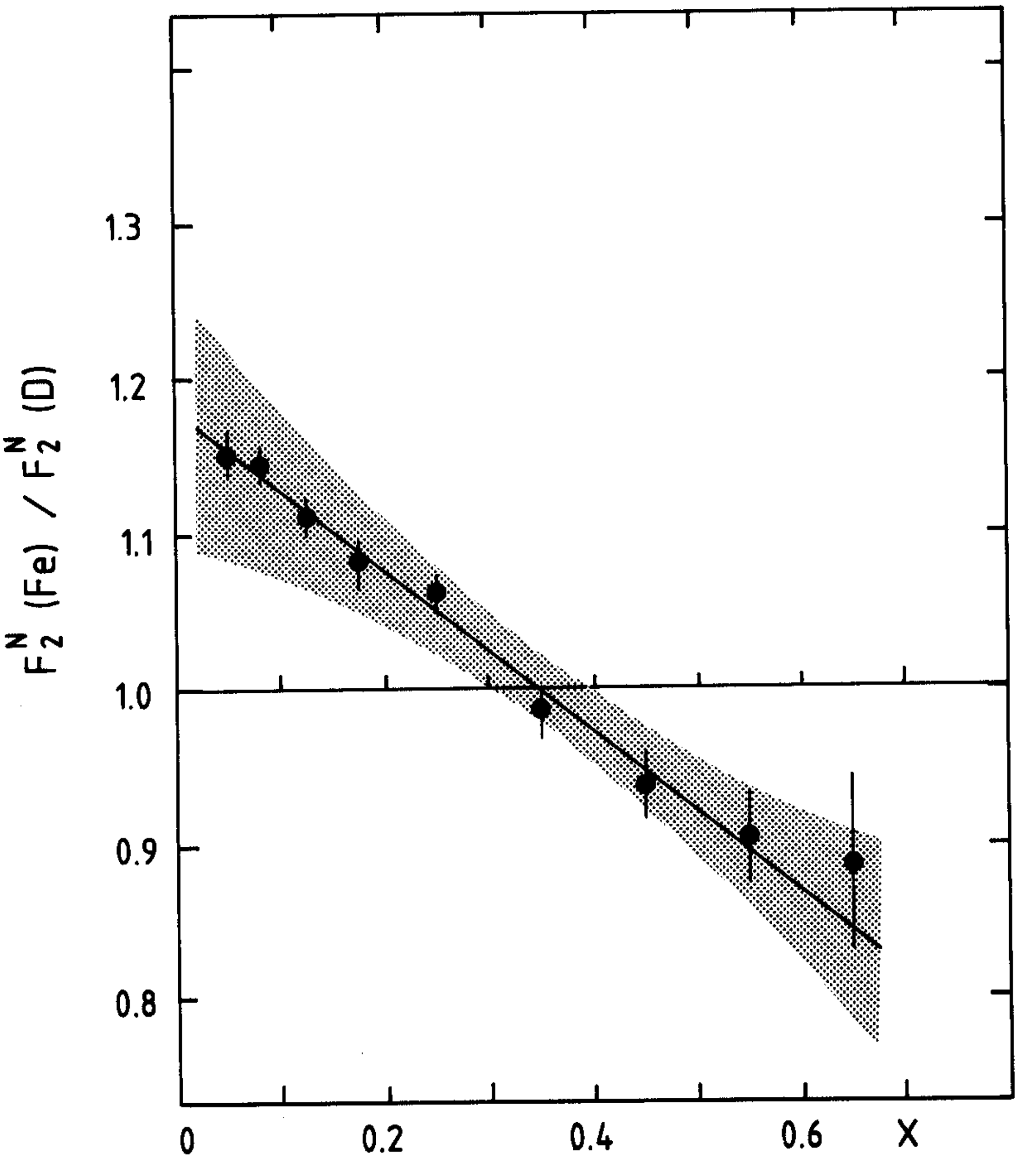

Fig. 2