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A MEASUREMENT OF NUCLEAR EFFECTS IN DEEP INELASTIC MUON SCATTERING ON DEUTERIUM, NITROGEN AND IRON TARGETS

BCDMS Collaboration

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For several years, there has been incresing experimental evidence that the structure of a free nucleon is different from the one of a nucleon embeded in a nucleus. Indications for this effect were first observed /1/ in a comparison of deep inelastic scattering data from hydrogen, deuterium and iron targets measured by the SLAC-MIT and EMC experiments. A first measurement was presented by the EMC collaboration in 1982 /2/. Their experiment compared structure functions measured with iron and deuterium targets and they observed a strong dependence of the ratio $F_2^{Fe}(x)/F_2^{D_2}(x)$ on the Bjorken scaling variable $x = Q^2/2M\nu$, where Q^2 is the squared 4-momentum transfer; and ν, the energy transfer of the scattered muon to the hadronic system. An effect has also been observed, at much lower Q^2, by a reanalysis /3/ of old SLAC data on deep inelastic electron scattering and by a dedicated experiment /4/ at SLAC which investigated the effect for a variety of nuclear targets. In this paper, we report on a comparison of structure functions at high Q^2 measured with deuterium, nitrogen, and iron targets in deep inelastic scattering at the CERN SPS muon beam.

The BCDMS muon spectrometer, which has been employed for this measurement, is extensively described elsewhere /5/. To collect the data reported here, we have used a slightly modified configuration which is shown in fig.1. The apparatus consists of a 40 m long magnetized iron toroid which is subdivided in 8 modules and instrumented with scintillation trigger counters and multiwire proportional chambers. The central bores of the first five modules contain target vessels ("internal" targets) which can be filled with liquid deuterium or nitrogen. Two external targets in front of the magnet, followed by a set of MWPC with three-coordinate readout, extend the acceptance of the spectrometer to small angles, i.e. to smaller Q^2 and x than are accessible with the internal targets.

The modularity of this apparatus and the extended target structure allow data to be taken with different target meterials simultaneously, thus minimizing systematic errors from uncertainties on energy calibrations of incoming and scattered muons, on detector efficiencies, and from the relative normalization. Also, variations of the spectrometer acceptance along the beam direction are small for muons interacting in the internal targets. The target vessel of the third module was therefore replaced by a 75 cm long iron target; this length matches the luminosity of the deuterium target and minimizes the influence of energy loss and the mutual contamination of data samples from different target materials due to the vertex resolution of the spectrometer.

The data was recorded with a beam of 280 GeV positive muons and with combinations of D_2-Fe-D_2 and N_2-Fe-N_2 targets. For background subtraction, data was also taken with N_2-empty-N_2, empty-Fe-empty, and "all empty" targets. The typical beam intensity was $1\cdot10^7$ muons per 2 sec SPS burst and the total integrated beam flux amounts to $1.08\cdot10^{12}$ muons.

Vertex cuts were applied which limit the contamination of the D_2 and N_2 data samples by events from the Fe target to 1.4% and 0.3%, respectively. The inverse contamination of Fe data by D_2 events is negligible. The background from target wall interactions was subtracted from the D_2 and N_2 data (1.2% resp. 0.3%). Data was corrected for acceptance and resolution of the spectrometer by a detailed Monte-Carlo simulation of the experiment. The experimental cross sections were converted to structure functions $F_2(x,Q^2)$ assuming a constant value $R=\sigma_L/\sigma_T=0$ [6], where σ_L and σ_T are the absorption cross sections for longitudinal and transverse polarized virtual photons. $F_2^{D_2}(x,Q^2)$ and $F_2^{N_2}(x,Q^2)$ were evaluated separately for events from internal and external targets for which the acceptance of the spectrometer is very different; in the kinematical region of overlap, the stricture functions are in agreement within statistical errors and were combined for the subsequent analysis. For the $Fe-D_2$ comparison, only data recorded simultaneously were used to evaluate the F_2 ratio. The iron data was corrected for the non-isoscalarity of ^{56}Fe assuming a neutron/proton structure function ratio $F_2^n/F_2^p = 1-0.75x$. No corrections were applied for the Fermi motion of nucleons inside the nucleus.

Point-to-point systematic errors arise mainly from the corrections for spectrometer resolution, which depend on the variation of the deep inelastic cross section with the kinematic variables and on the target material. They were estimated by varying slightly the response of the apparatus in the simulation of the spectrometer resolution and are most important for the data at $x>0.6$. Other effects considered include small uncertainties on the energy loss and multiple scattering in the different target materials, and different multiplicities of hadronic shower feed-through which can effect the reconstruction of the scattered muon track. For the N_2-D_2 data comparison where the data was taken at different times, errors also account for the reproducibility of the beam energy calibration ($<6\cdot10^{-4}$), of the spectrometer magnetic field ($<2\cdot10^{-4}$), and of detector efficiencies. For the $Fe-D_2$ comparison, where tracks from different targets are momentum analyzed in different parts of the spectrometer (fig.1), the effect of small variations of the magnetic field along the beam direction ($\Delta B/B<3\cdot10^{-3}$) is also included in the error estimate.

Residual errors on the relative luminosity calibration of the N_2-D_2 resp. $Fe-D_2$ comparisons are due to a small beam leakage from the target caused by beam divergence and multiple scattering, to uncertainties on the densities of the liquid targets, and to the corrections for mutual contaminations of data from different target materials. Additional uncertainties on the N_2/D_2 ratio which arise from deadtime corrections to the beam counting were found to be smaller than 0.3%. We therefore estimate the systematic uncertainty on the relative luminosity calibration to 1.5% for both the N_2-D_2 and $Fe-D_2$ structure function ratios. As an independent verification, we compare the event samples from the Fe target which were recorded simultaneously with both the N_2 and D_2 data. This constrains the error on the N_2/D_2 relative luminosity to be smaller than 1.3%.

The structure function ratio $F_2^{N_2}(x,Q^2)/F_2^{D_2}(x,Q^2)$ is shown in fig.2 in bins of x and Q^2. In agreement with earlier experiments [2-4] no significant Q^2 dependence is observed within the statistical accuracy of the data; the same applies to the $F_2^{Fe}/F_2^{D_2}$ ratio. We therefore average the data over Q^2, assigning to each data point a weight equal to the inverse square of its relative error; the mean values are presented in bins of x in Fig.3 and the Table. The $F_2^{Fe}/F_2^{D_2}$ ratio is shown in Fig.3a and compared to the EMC data which cover a similar range in Q^2 [2]. Over the x range which is common to both data sets, we observe agreement between the two experiments. There is also good agreement with the data of ref.[4] on σ^{Fe}/σ^{D_2} which, in this range of x, are approximately equal to $F_2^{Fe}/F_2^{D_2}$ even if we take into account a possible dependence of $R=\sigma_L/\sigma_T$ on the nuclear weight A [7].

The $F_2^{N_2}/F_2^{D_2}$ ratio (Fig.3b) shows a behaviour similar to that of $F_2^{Fe}/F_2^{D_2}$ for $x>0.2$, but with a less pronounced x dependence. In the low x regime, the N_2/D_2 data deviates from the linear decrease observed at higher x and is compatible with no nuclear effect at all; including the estimate of systematic uncertainties, we find that the probability of the data points in the range $0.08\le x\le 0.20$ to be compatible with a straight line extrapolation of the data for $0.20\le x\le 0.70$

Table. Structure function ratios vs. $x = Q^2/2M\nu$

(a) Data for $R_{Fe} = F_2^{Fe}(x)/F_2^{D_2}(x)$

x bin[1]	Q^2 range (GeV^2)	R_{Fe}	Statistical error	Systematic error
0.20 - 0.25	46 - 106	1.056	0.023	0.013
0.25 - 0.30	46 - 106	0.997	0.025	0.012
0.30 - 0.40	53 - 150	0.978	0.022	0.011
0.40 - 0.50	53 - 200	0.910	0.027	0.012
0.50 - 0.60	70 - 200	0.879	0.041	0.017
0.60 - 0.70	80 - 200	0.819	0.058	0.033

Straight line fit $R_{Fe} = a + bx$: $a = 1.17 \pm 0.04$ (stat.) ± 0.01 (syst.); $b = -0.55 \pm 0.10$ (stat.) ± 0.04 (syst.)

(b) Data for $R_{N_2} = F_2^{N_2}(x)/F_2^{D_2}(x)$

x bin[1]	Q^2 range (GeV^2)	R_{N_2}	Statistical error	Systematic error
0.08 - 0.12	26 - 40	1.018	0.027	0.012
0.12 - 0.16	26 - 61	1.018	0.021	0.010
0.16 - 0.20	30 - 80	1.002	0.015	0.009
0.20 - 0.25	30 - 106	1.035	0.016	0.009
0.25 - 0.30	30 - 106	1.024	0.018	0.009
0.30 - 0.40	30 - 150	0.983	0.016	0.009
0.40 - 0.50	30 - 200	0.941	0.021	0.010
0.50 - 0.60	35 - 200	0.891	0.030	0.017
0.60 - 0.70	46 - 200	0.826	0.042	0.033

Straight line fit $R_{N_2} = a + bx$ for $0.2 \le x \le 0.7$: $a = 1.15 \pm 0.03$ (stat.) ± 0.01 (syst.); $b = -0.47 \pm 0.07$ (stat.) ± 0.04 (syst.)

[1] Data points are calculated at the center of each x bin.

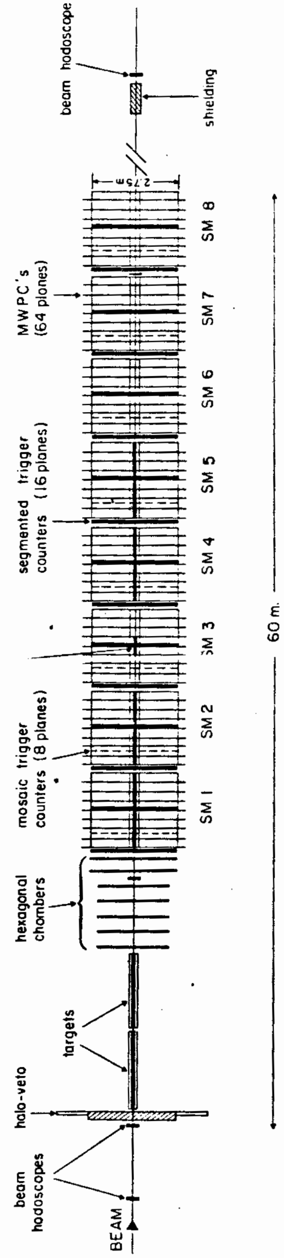

Fig. 1. Layout of the experimental apparatus.

(see the Table) is smaller than 1%. For $x > 0.2$, these data is in agreement with the carbon data from ref. [4] measured at much lower Q^2.

In conclusion, we have presented a first measurement of the nitrogen/deuterium structure function ratio which is compatible with unity for $x < 0.3$ and decreases linearly for higher values of x. Our measurement with iron and deuterium targets over the kinematic range $0.2 \le x \le 0.7$ confirms the measurement of the EMC [2] with improved systematic accuracy. Both with N_2 and Fe targets, no Q^2 dependence of the structure function ratios is observed over the entire kinematic range of the experiment.

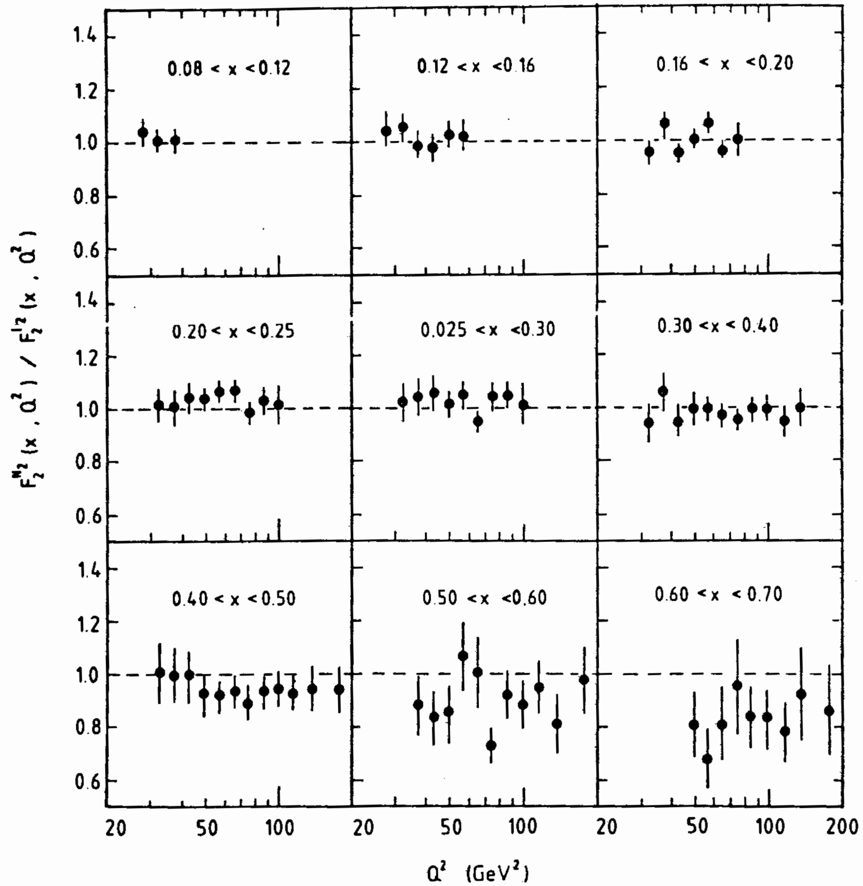

Fig. 2. The structure function ratio $F_2^{N_2}/F_2^{D_2}$ in bins of x and Q^2. Only statistical errors are shown.

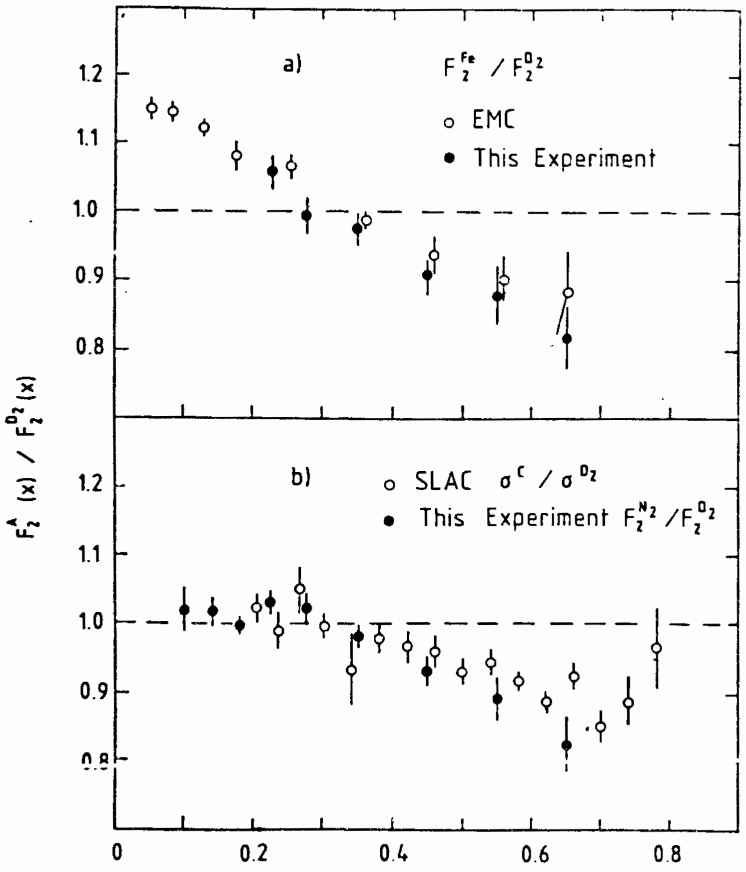

Fig.3. Q^2-averaged data for structure function of x. Only statistical errors are shown. For systematic errors see Table 1 and refs. [2,4] *, respectively.*

a) Data for $F_2^{Fe}/F_2^{D_2}$ *compared to the EMC results* [2].

b) Data for $F_2^{N_2}/F_2^{D_2}$ *compared to results of SLAC experiment E139* [4] *for carbon.*

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Бари Г. и др. E1-85-747

Измерение ядерных эффектов в глубоконеупругом мюонном рассеянии на дейтериевой, азотной и железной мишенях

Представлены новые данные по отношениям структурных функций $F_2(x,Q^2)$, измеренным в глубоконеупругом рассеянии мюонов на дейтериевой, азотной и железной мишенях. Существование ядерных эффектов при больших Q^2 подтверждено с лучшей систематической точностью. Отношение $F_2^{Fe}(x)/F_2^{D_2}(x)$ в интервале $0.20 \le x \le 0.70$ находится в согласии с более ранними измерениями. Отношение $F_2^{N_2}(x)/F_2^{D_2}(x)$ измерено в области $0.08 \le x \le 0.70$ и для $x \le 0.30$ ее величина совместна с единицей.

Препринт Объединенного института ядерных исследований. Дубна 1985

Bari G. et al. E1-85-747

A Measurement of Nuclear Effects in Deep Inelastic Muon Scattering on Deuterium, Nitrogen and Iron Targets

New data is presented on the ratios of structure functions $F_2(x,Q^2)$ measured in deep inelastic muon scattering with deuterium, nitrogen, and iron targets. The existence of nuclear effects at large Q^2 is confirmed with improved systematic accuracy. The ratio $F_2^{Fe}(x)/F_2^{D_2}(x)$ covers the range $0.20 \le x \le 0.70$ and is in agreement with earlier measurements. The ratio $F_2^{N_2}(x)/F_2^{D_2}(x)$ is measured over the range $0.08 \le x \le 0.70$ and is compatible with unity below $x = 0.3$.

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