Final results from the NMC

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Abstract. A summary of the results on deep inelastic muon nucleon and muon nucleus scattering experiments performed by the NMC collaboration is presented.

The New Muon Collaboration (NMC) has measured deep inelastic muon scattering at the M2 muon beam line of the CERN SPS at incident energies between 90 and 280 GeV. The data taken between 1986 and 1989 cover three main topics:

- A detailed study of the structure of free nucleons by measuring F_2^{p}, F_2^{d}, R, $R^{\mathrm{d}} - R^{\mathrm{p}}$ and $F_2^{\mathrm{d}}/F_2^{\mathrm{p}}$ using hydrogen and deuterium targets.
- A comparison of bound and free nucleons to study nuclear effects with a series of targets ranging from deuterium to lead.
- A study of the Q^2 dependence of nuclear effects using high luminosity measurements with thick carbon and tin targets.

All measurements were done simultaneously with two target materials in the muon beam which were frequently interchanged with a complementary target set where the sequence of the materials along the beam line was reversed. This results in a cancellation of systematic errors due to spectrometer acceptance and normalisation for the determination of cross section ratios and allows measurements in kinematic regions where the detector acceptance was small [1]. In the extraction of the structure functions F_2^{p} and F_2^{d} the spectrometer acceptance was substantially different for the upstream and the downstream targets, thus giving two separate measurements for each material allowing a good control of systematic errors due to reconstruction and detector acceptance [2].

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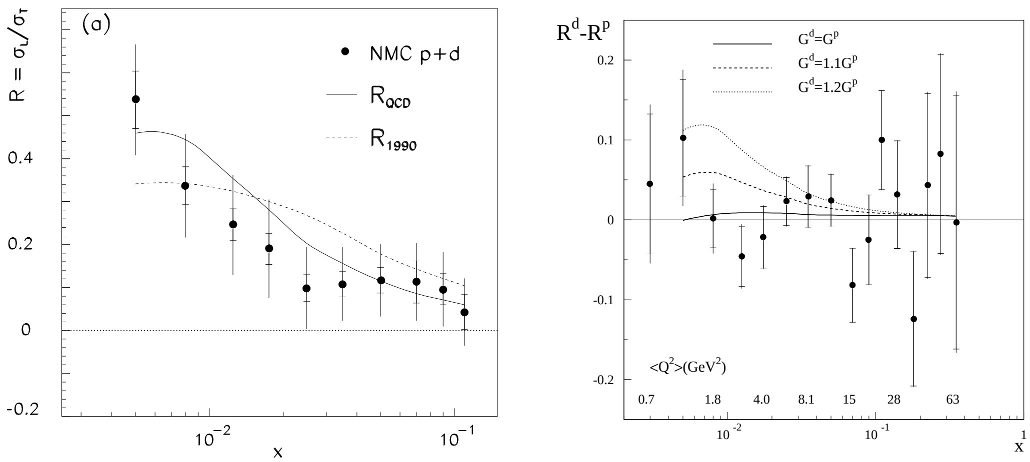

FIGURE 1. Left: Results for $R(x)$ averaged for the proton and the deuteron. The curves are discussed in the text. Right: Results for $R^{\rm d} - R^{\rm p}(x)$ compared to predictions from perturbative QCD (see text). The inner error bars correspond to statistical errors and the full ones to the quadratic sum of statistical and systematic errors.

Measurements with hydrogen and deuterium were done to determine the dependence on the Bjorken scaling variable x and the four momentum squared Q^2 of the structure functions $F_2^{\rm p}$ and $F_2^{\rm d}$. As data were taken at four incident energies also R, the ratio of the longitudinally to transversely polarised virtual photon absorption cross sections, could be extracted from the small differences in cross section at the same values of x and Q^2 but at different values of the relative energy transfer y, i.e. at different beam energies. Due to the use of a small angle trigger the covered x and y range was extended downwards, thus increasing the sensitivity to R [3]. We chose to determine $R(x)$ averaged over Q^2 as the statistics of the data ($2.4 \cdot 10^6$ events) did not allow to determine both its x and Q^2 dependence.

The results for R are shown in fig.1 (left) in the range $0.002 < x < 0.12$ compared to a QCD prediction (solid line) obtained using a QCD analysis of part of the data [4] and a parametrisation of previous R measurements [5]. Within the largely correlated systematic errors good agreement is observed.

In the extraction of structure functions the SLAC R parametrisation was used for $x > 0.12$. The results for $F_2^{\rm d}$ covering a kinematic range of $0.0045 < x < 0.6$ and $0.5 < Q^2 < 75$ GeV^2 are shown in fig.2. The additional normalisation error of the NMC data is 2.5%. The results for $F_2^{\rm p}$ and $F_2^{\rm d}$ compare well with previous measurements from SLAC [6] and BCDMS [7] (see figure) and E665 [8] and extrapolate smoothly to the recent H1 and ZEUS data.

From the same data $R^{\rm d} - R^{\rm p}$ and $F_2^{\rm d}/F_2^{\rm p}$ could be determined in an enlarged

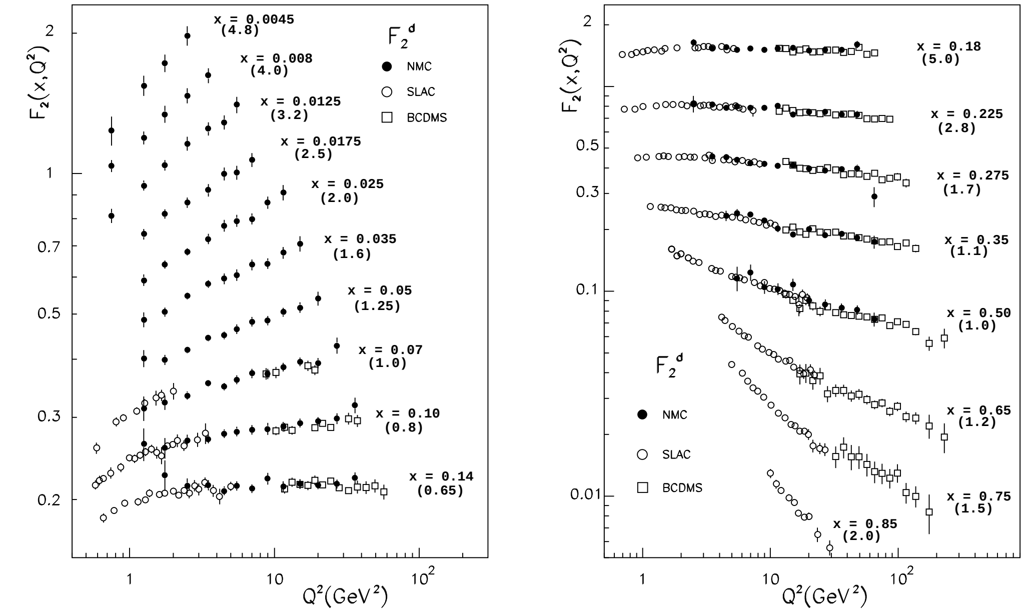

FIGURE 2. NMC results for $F_2^{\rm d}$ compared to SLAC and BCDMS results. The error bars represent the total errors, apart from normalisation uncertainties.

kinematic range due to the use of the complementary targets ($8.4 \cdot 10^6$ events) [9]. The results for $R^{\rm d} - R^{\rm p}$ are shown in fig.1 (right) in the x range from 0.003 to 0.35. The values of ΔR are small; this is especially significant at small x where R is large. No significant x dependence is observed. Averaging the measurements one obtains at $Q^2 = 10$ GeV^2 a value of $R^{\rm d} - R^{\rm p} = 0.004 \pm 0.012(\text{stat.}) \pm 0.011(\text{syst.})$ compatible with zero. The results are compared to NLO perturbative QCD computations of ΔR using various assumptions for the difference of the gluon distribution in the proton and the deuteron showing that the data set a limit of about 10% to this difference.

The results for the structure function ratio $F_2^{\rm d}/F_2^{\rm p}$ cover the x range from 0.001 to 0.8 and the Q^2 range from 0.1 to 145 GeV^2 with high accuracy, thus allowing to investigate the Q^2 dependence in a large x range. Fitting a linear function in $\ln Q^2$ at fixed x to the results yields the logarithmic slopes shown in fig.3 (left). They are compared to NLO QCD calculations based on analyses of the NMC [4] and the SLAC/BCDMS [10] data. The measured slopes are consistent with these calculations although there may be deviations at $x > 0.1$, as was suggested in [1].

Averaging over Q^2 one obtains results for the x dependence of $F_2^{\rm d}/F_2^{\rm p}$ with total errors of less than 1% in a large range of x. The ratio shows the well known x dependence dropping to about 0.7 at high x and approaching unity at small x indicating no sizeable shadowing. From the results for $F_2^{\rm d}/F_2^{\rm p}$ the

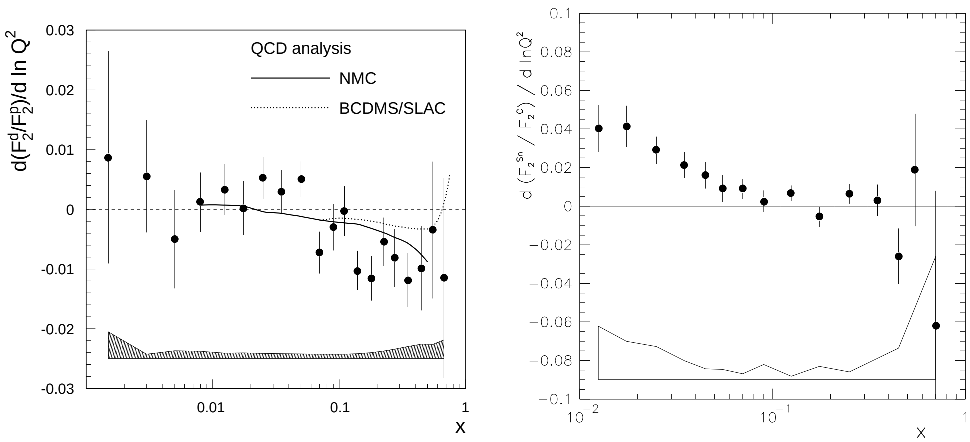

FIGURE 3. Left: The logarithmic slopes $\mathrm{d}(F_2^{\mathrm{d}}/F_2^{\mathrm{p}})/\mathrm{d}\ln Q^2$, curves see text. Right: The logarithmic slopes $\mathrm{d}(F_2^{\mathrm{SN}}/F_2^{\mathrm{C}})/\mathrm{d}\ln Q^2$. The error bars represent the statistical uncertainty. The bands show the sizes of the systematic uncertainties.

Gottfried sum $S_G = \int(F_2^{\mathrm{p}} - F_2^{\mathrm{n}})\mathrm{d}x/x$ can be calculated using a parametrisation of F_2^{d}. In the measured range of $0.004 < x < 0.8$ one obtains a contribution of 0.2281 ± 0.0065(stat.) to S_G at $Q^2 = 4$ GeV^2. This agrees within statistical errors with the previously published value [11].

Nuclear effects were investigated studying the dependence on the mass number A in the shadowing region (small x), the enhancement region (at $x \approx 0.1$) and the EMC effect region (large x) by measuring with a series of nuclei. A clear increase with A was observed for all effects [12].

A more detailed study of the ratio $F_2^{\mathrm{Sn}}/F_2^{\mathrm{C}}$ was performed by using a special high luminosity setup with a total target thickness of 600 g/cm^3 and an active target calorimeter to trigger on DIS events. Due to the increased multiple Coulomb scattering tighter kinematic cuts had to be applied resulting in a more limited range in x and Q^2 and a Monte Carlo simulation of vertex migration and kinematic smearing was necessary. Measurements were done at 280, 200 and 120 GeV resulting in $8.4 \cdot 10^6$ events [13].

The results for $R^{\mathrm{Sn}} - R^{\mathrm{C}}$ are shown in fig.4 (left) for the x range of 0.01 to 0.5. No x dependence is observed and the average value is 0.040 ± 0.21(stat.)$\pm$ 0.026(syst.) at a mean Q^2 of 10 GeV^2. The results for the x dependence of $F_2^{\mathrm{Sn}}/F_2^{\mathrm{C}}$ in the x range $0.01 < x < 0.75$ in fig.4 (right) confirm the well known x dependence of nuclear effects in the structure function F_2 and give a very precise measurement of the small enhancement of about 1% at $x \approx 0.1$. The Q^2 dependence was investigated in the range $1 < Q^2 < 140$ GeV^2. Fitting linear functions in $\ln Q^2$ to the results at fixed x yields the logarithmic slopes shown in fig.3 (right), indicating that the amount of shadowing decreases with

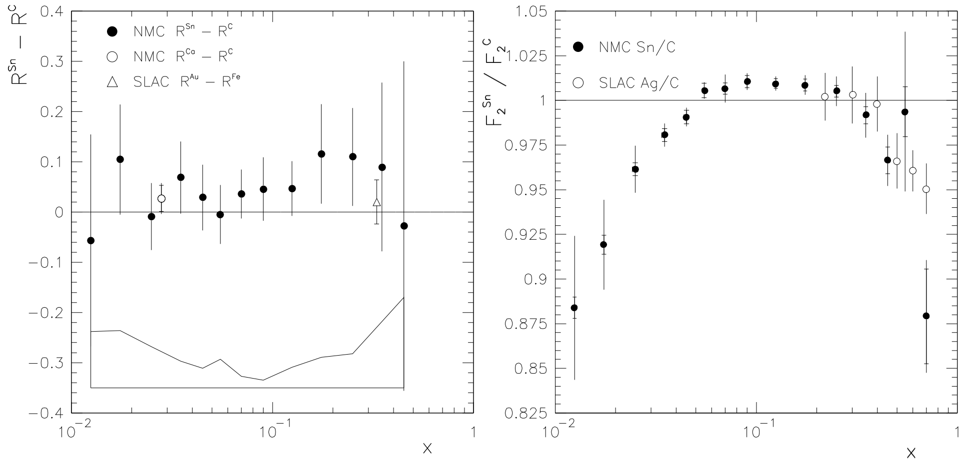

FIGURE 4. Left: $R^{Sn} - R^C$ as a function of x, averaged over Q^2. Also shown are the NMC result for the average value of $R^{Ca} - R^C$ [14] (open circle) and the SLAC one for $R^{Au} - R^{Fe}$ [15] (triangle). Right: $F_2^{\rm Sn}/F_2^{\rm C}$ as a function of x, averaged over Q^2. The SLAC-E139 [16] ratios for silver and carbon are also plotted (open points).

Q^2. No Q^2 dependence is observed at higher x.

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