A Re-Evaluation of the Nuclear Structure Function Ratios for D, He, $^6$Li, C and Ca

The New Muon Collaboration (NMC)

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Abstract

We present a re-evaluation of the structure function ratios $F_{2}^{He}/F_{2}^{D}$, $F_{2}^{C}/F_{2}^{D}$ and $F_{2}^{Ca}/F_{2}^{D}$ measured in deep inelastic muon-nucleus scattering at an incident muon momentum of 200 GeV. We also present the ratios $F_{2}^{C}/F_{2}^{Li}$, $F_{2}^{Ca}/F_{2}^{Li}$ and $F_{2}^{Ca}/F_{2}^{C}$ measured at 90 GeV. The results are based on data already published by NMC; the main difference in the analysis is a correction for the masses of the deuterium targets and an improvement in the radiative corrections. The kinematic range covered is $0.0035 < x < 0.65$, $0.5 < Q^2 < 90$ GeV$^2$ for the He/D, C/D and Ca/D data and $0.0085 < x < 0.6$, $0.84 < Q^2 < 17$ GeV$^2$ for the Li/C/Ca ones.

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Results on the structure function ratios $F_2^{He}/F_2^D$, $F_2^{C}/F_2^D$ and $F_2^{Ca}/F_2^D$ [1] as well as $F_2^{C}/F_2^{Li}$, $F_2^{Ca}/F_2^{Li}$ and $F_2^{Ca}/F_2^{C}$ [2] were recently published by NMC. The kinematic range covered was $0.0035 < x < 0.65$, $0.5 < Q^2 < 90$ GeV$^2$ for the He/D, C/D and Ca/D data and $0.0085 < x < 0.6$, $0.84 < Q^2 < 17$ GeV$^2$ for the $^6$Li/C/Ca ones. Here $-Q^2$ is four momentum squared of the virtual photon and $x = Q^2/(2M\nu)$ is the Bjorken scaling variable, with $M$ the proton mass and $\nu$ the virtual photon energy in the laboratory frame. In this paper we present the results of a re-evaluation of these ratios.

The data were collected using the NMC spectrometer [3] at the CERN SPS muon beam line at nominal incident energies of 200 GeV for the He/D, C/D and Ca/D data and 90 GeV for the $^6$Li/C/Ca ones.

In refs. [1, 2] radiative corrections were computed according to the prescription of Mo and Tsai [4]. The procedure corrects for the radiative tails of coherent elastic scattering from nuclei and of quasi-elastic scattering from nucleons, as well as for the inelastic radiative tails. The evaluation of the inelastic tail requires the knowledge of $F_2$ over a large range of $x$ and $Q^2$. A fit [5] to the results of deep inelastic scattering experiments and to low energy data in the resonance region was used for $F_2^d$. The bound nucleon structure functions $F_2^A$ were obtained by multiplying $F_2^d$ with empirical fits to our cross section ratios together with the SLAC-E139 data [6] for $x > 0.4$.

Since the publication of refs. [1, 2] new measurements of the structure function $F_2^d$ in the range $0.006 < x < 0.6$ and $0.5 < Q^2 < 55$ GeV$^2$ have become available [7]. At $x$ less than 0.07 the measured values of $F_2^d$ differ from those of the fit [5], by up to 18% at $x = 0.0035$ and $Q^2 = 0.6$ GeV$^2$. Furthermore the SLAC structure function ratios have been reanalysed [8]. These new ratios differ from the old ones by up to a few per cent.

In addition, it was found that the masses of the liquid deuterium targets used in ref. [1] for the C/D and Ca/D data had been incorrectly evaluated. Correcting these has increased the corresponding structure function ratios by 0.74%.

We therefore recomputed the radiative corrections using the new $F_2^d$ data, the results of the SLAC reanalysis and the correct deuterium target masses for our C/D and Ca/D ratios. This has resulted in an increase of the structure function ratios at the smallest values of $x$ which is negligible for the He/D data but ranges up to 2.5% for Ca/D.

Radiative corrections were calculated with three different programs. The first was the one used to obtain the results presented in refs. [1, 2], based on the Mo and Tsai formalism; the second was an improved version of the first including vacuum polarisation by quark and $\tau$ loops and electroweak interference terms. The third program is based on the covariant approach described in ref. [9]. The results obtained with the three methods are consistent.

The ratios presented in this paper were obtained with the third method.

In fig. [1] the present results are shown as a function of $x$ and are compared with the old ones. The new results are also given in table [3] and table [4] for the measurements at 200 GeV and 90 GeV, respectively. In fig. [2] we present our data for He/D, C/D and Ca/D together with the reanalysed SLAC results [8]. Finally, fig. [3] shows the logarithmic $Q^2$ slopes $b$ obtained from fits of the form $F_2^A/F_2^d = a + b \ln Q^2$ to the He/D, C/D and Ca/D ratios in each $x$ bin separately. The $Q^2$ dependences are essentially unchanged with respect to those presented in ref. [1].
Figure 1: Structure function ratios as function of $x$, averaged over $Q^2$. The full circles represent the re-evaluated ratios, the open circles the old ratios. Only statistical errors are shown.
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Table 1: The structure function ratios $F_{2}^{A} / F_{2}^{D}$ measured at 200 GeV and averaged over $Q^{2}$. The normalisation uncertainty of 0.4% is not included in the systematic errors. The variable $y$ is defined as $\nu/E$, where $E$ is the incident muon energy.
| $x$   | $\langle Q^2 \rangle_{[\text{GeV}^2]}$ | $\langle y \rangle$ | $F_C^2/F_{Li}^2$ stat syst | $F_{Ca}^2/F_{Li}^2$ stat syst | $F_{Ca}^2/F_C^2$ stat syst |
|-------|-----------------|-----------------|-----------------|-----------------|-----------------|
| 0.0085 | 0.8 0.57        | 0.910 0.009 0.012 | 0.856 0.008 0.022 | 0.941 0.009 0.023 |
| 0.0113 | 1.1 0.59        | 0.956 0.010 0.009 | 0.882 0.009 0.017 | 0.923 0.009 0.015 |
| 0.0138 | 1.2 0.53        | 0.966 0.010 0.007 | 0.908 0.009 0.013 | 0.939 0.010 0.011 |
| 0.0163 | 1.4 0.52        | 0.954 0.010 0.005 | 0.911 0.010 0.010 | 0.955 0.010 0.008 |
| 0.0188 | 1.6 0.52        | 0.988 0.011 0.004 | 0.962 0.010 0.008 | 0.972 0.010 0.007 |
| 0.0225 | 1.8 0.49        | 0.972 0.008 0.004 | 0.939 0.007 0.006 | 0.965 0.008 0.005 |
| 0.0275 | 2.0 0.44        | 0.964 0.008 0.003 | 0.937 0.008 0.004 | 0.972 0.008 0.003 |
| 0.0325 | 2.2 0.41        | 0.974 0.009 0.002 | 0.965 0.009 0.003 | 0.991 0.009 0.003 |
| 0.0375 | 2.3 0.37        | 0.979 0.009 0.002 | 0.981 0.009 0.002 | 1.003 0.009 0.002 |
| 0.0425 | 2.4 0.34        | 1.001 0.010 0.002 | 0.975 0.010 0.002 | 0.975 0.009 0.002 |
| 0.0475 | 2.6 0.33        | 0.998 0.010 0.002 | 0.967 0.010 0.002 | 0.970 0.010 0.002 |
| 0.0525 | 2.7 0.31        | 1.019 0.011 0.002 | 1.012 0.011 0.002 | 0.993 0.010 0.002 |
| 0.0575 | 2.8 0.29        | 1.020 0.012 0.002 | 1.013 0.011 0.002 | 0.992 0.011 0.002 |
| 0.065  | 3.0 0.28        | 0.999 0.009 0.002 | 1.006 0.008 0.002 | 1.007 0.008 0.002 |
| 0.075  | 3.3 0.27        | 1.012 0.009 0.002 | 1.008 0.009 0.002 | 0.995 0.009 0.002 |
| 0.085  | 3.6 0.26        | 1.004 0.010 0.002 | 1.012 0.010 0.002 | 1.009 0.010 0.002 |
| 0.095  | 3.9 0.25        | 1.009 0.011 0.002 | 1.010 0.011 0.002 | 1.001 0.011 0.002 |
| 0.113  | 4.3 0.23        | 1.028 0.008 0.002 | 1.020 0.008 0.002 | 0.994 0.008 0.002 |
| 0.138  | 5.1 0.22        | 1.012 0.010 0.002 | 1.017 0.010 0.002 | 1.007 0.010 0.002 |
| 0.175  | 6.2 0.22        | 1.018 0.009 0.002 | 1.018 0.009 0.002 | 1.001 0.009 0.002 |
| 0.225  | 7.7 0.21        | 1.002 0.013 0.002 | 1.017 0.013 0.002 | 1.015 0.012 0.002 |
| 0.275  | 9.1 0.20        | 1.000 0.017 0.002 | 0.998 0.016 0.002 | 0.998 0.016 0.002 |
| 0.35   | 11.0 0.19       | 0.987 0.017 0.002 | 0.983 0.017 0.002 | 0.996 0.017 0.002 |
| 0.45   | 14.0 0.18       | 0.965 0.028 0.002 | 0.988 0.028 0.002 | 1.024 0.029 0.002 |
| 0.60   | 17.0 0.17       | 1.012 0.040 0.004 | 0.966 0.038 0.004 | 0.955 0.036 0.002 |

Table 2: The nuclear structure function ratios measured at 90 GeV and averaged over $Q^2$. The normalisation uncertainties (not included in the systematic errors) are 0.7%, 0.8% and 0.5% for C/Li, Ca/Li and Ca/C, respectively. The variable $y$ is defined as $\nu/E$, where $E$ is the incident muon energy.
Figure 2: The re-evaluated NMC structure function ratios for He/D, C/D, Ca/D together with the reanalysed SLAC results. The error bars show the statistical and systematic errors added in quadrature. The normalisation uncertainties are not included.
Figure 3: The slopes $b$ from a linear fit in $\ln Q^2$ for each $x$ bin separately. The errors shown are statistical only.