MEASUREMENT OF $R = \sigma_{\rm L}/\sigma_{\rm T}$ IN DEEP-INELASTIC SCATTERING ON NUCLEI*

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Cross section ratios for deep-inelastic scattering from ^{3}He, ^{14}N and ^{84}Kr with respect to ^{2}H have been measured by the HERMES Collaboration at DESY using a 27.5 GeV positron beam. The data cover a range in the Bjorken scaling variable x from 0.010 to 0.65 while Q^2 varies from 0.5 to 15 GeV^2. From the dependence of the data on the virtual photon polarisation parameter ε, values for $R_A/R_{\rm D}$ have been derived, where R is the ratio $\sigma_{\rm L}/\sigma_{\rm T}$ of longitudinal to transverse DIS cross sections. The helium-3 and nitrogen data were published in 1999. Recently, those data were found to be subject to an A-dependent tracking inefficiency of the HERMES spectrometer, which was not recognised in the previous analysis. The resulting correction of the cross section ratios is significant at low values of x and Q^2 and substantially changes the interpretation of those data.

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1. Introduction

Since the first observation of a medium modification of the nucleon structure function $F_2(x)$ by the EMC collaboration [1], several experiments at SLAC, CERN and Fermilab have measured the x-, Q^2- and A-dependence of this effect over a large kinematic range and for many nuclei [2]. While the nucleon structure function has been found to depend on the mass of the atomic nucleus over the entire x range — a phenomenon known nowadays as the EMC effect at $x > 0.1$ and as shadowing at lower values of x — no or only a very weak Q^2 dependence has been observed. In contrast to these

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nuclear modifications of F_2, no experimental evidence was found for a nuclear effect in $R = \sigma_{\rm L}/\sigma_{\rm T} = F_{\rm L}/2xF_2$ [3], indicating that the nuclear effects in the longitudinal and transverse components of the cross section are the same.

In 1999, the HERMES collaboration at DESY reported measurements of the cross section ratios of ^{3}He/D and ^{14}N/D which differed significantly from the earlier measurements for x values below $x = 0.06$ [4]. As the only significant difference from the earlier measurements appeared to be the kinematic variable y, and hence the photon polarisation parameter ε, the new results were interpreted as evidence for a nuclear influence on the ratio R of the cross sections for longitudinal and transverse photons. Values as large as 5 were found for the ratio R in nitrogen compared to deuterium at x values around 0.01 and $Q^2 \sim 0.5$ GeV^2.

2. Re-analysis of the HERMES results on $\sigma^A/\sigma^{\rm D}$

To further investigate this very surprising effect, additional data were collected on a heavier target (^{84}Kr) and at a different beam energy. However, the analysis of the krypton data revealed a serious problem: the krypton deep-inelastic cross section at very low x and Q^2 became negative! This obviously unphysical behaviour was finally traced to a peculiar instrumental effect related to the reconstruction efficiency for radiative events associated with elastic scattering. At small values of apparent x and Q^2, corresponding to large values of y and small values of ε, the contribution from such radiative elastic scattering becomes large and — more importantly — very different for different nuclei ($\propto Z^2$). Unlike radiation associated with inelastic processes, which is predominantly emitted in the direction of either the beam lepton (ISR) or the scattered lepton (FSR), the hard photons associated with nuclear elastic scattering involve negligible momentum transfer q to the target nucleus (Compton peak). Especially at small values of apparent x and Q^2, the Compton peak becomes much more prominent compared to ISR and FSR. Additionally, the nuclear form factor strongly suppresses the cross section for significant momentum transfer to the target, leaving only the Compton peak (Fig. 1 (left)). With negligible nuclear recoil momentum, essentially all of the transverse momentum of the scattered lepton must be balanced by that of the radiated hard photon, which also carries away most of the beam energy at these large values of apparent y. In the mirror-symmetric open geometry of the HERMES spectrometer, this can have drastic consequences. These energetic photons from nuclear targets have a high probability of hitting the detector frames surrounding the beam line in front of the dipole magnet, and producing extensive electromagnetic showers that cause very high hit multiplicities in these tracking detectors.

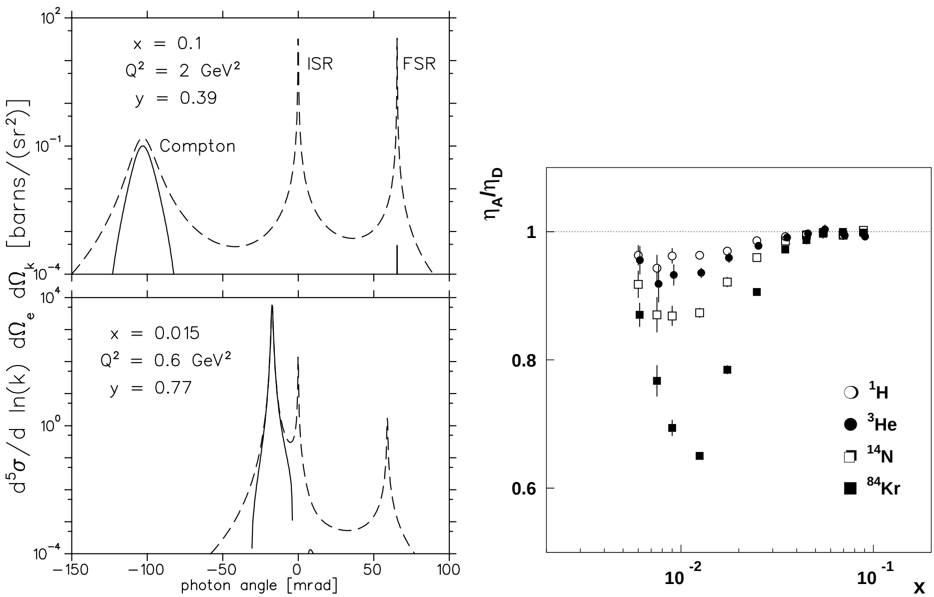

Fig. 1. (left) The nuclear-elastic Bethe–Heitler cross section on ^{14}N for two different coplanar kinematic conditions. The continuous curves include the effects of the nuclear form factor. (right) Ratio of track reconstruction efficiencies in ^{1}H, ^{3}He, ^{14}N and ^{84}Kr with respect to ^{2}H as function of x.

For many of these nuclear-elastic events, track reconstruction is therefore impossible, resulting in a large tracking inefficiency that is strictly correlated with only this process and kinematic situation. A simulation of the experiment reveals the problem only if it includes both the nuclear target with its particular radiative effects, and a complete treatment of showers in material outside of the geometric acceptance, which was not included in the original data analysis. These track reconstruction losses in the HERMES detector have now been simulated in detail. The resulting reconstruction losses at low x and Q^2 strongly depend on the target material and show a strong variation with y, and consequently with x and Q^2 (Fig. 1 (right)).

After the correction for the reconstruction inefficiencies, the cross section ratios of ^{3}He/D, ^{14}N/D and ^{84}Kr/D are shown in Fig. 2 as a function of x in comparison to the earlier measurements of SLAC and NMC. On average, the present data on $\sigma_{\rm He}/\sigma_{\rm D}$ and $\sigma_{\rm N}/\sigma_{\rm D}$ are about 1.5 % below the cross section ratio reported by NMC and SLAC. As the normalisation uncertainty of the present data (1–1.8%) is considerably larger than that of the NMC data (0.4%), the $\sigma_{\rm He}/\sigma_{\rm D}$ and $\sigma_{\rm N}/\sigma_{\rm D}$ results have been renormalised by 1.5%. No such renormalisation has been applied to the Kr/D cross section ratios. For x values below $x = 0.1$, the present data on N/D and Kr/D are slightly below

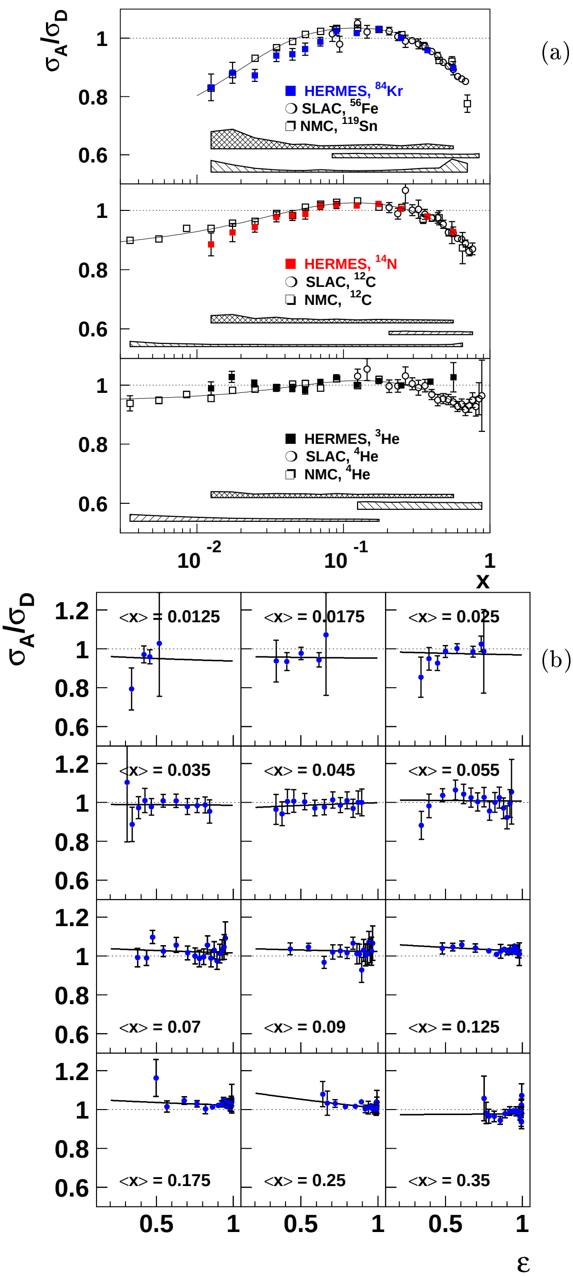

Fig. 2. (a) — Ratio of isoscalar Born cross sections *versus* x. (b) — σ_N/σ_D as function of ε for fixed values of x.

the NMC data but consistent within the present statistical and systematic uncertainties. When comparing the different data sets in more detail as a function of Q^2 at fixed values of x, no significant Q^2 dependence is observed in the cross section ratios of ^{3}He/D and ^{14}N/D, while the Kr/D data seem to imply a somewhat weaker Q^2 dependence than reported by the NMC measurement of $\sigma_{\rm Sn}/\sigma_{\rm D}$.

3. Resulting values for $R_A/R_{\rm D}$

To investigate a possible A-dependence of $R(x, Q^2)$, the cross section ratios have been fitted as a function of ε for fixed values of x. In these fits a parameterisation of $R_{\rm D}$ [5] has been used, while the ratios $R_A/R_{\rm D}$ and $F_2^A/F_2^{\rm D}$ have been treated as free parameters. A single value of $R_A/R_{\rm D}$ and $F_2^A/F_2^{\rm D}$ has been extracted from each x-bin. As an example, the ε-dependence of the ^{14}N/D cross section ratio is shown in the right panel of Fig. 2. No significant ε-dependence is observed. Similar conclusions hold for the other target nuclei. The values of $F_2^A/F_2^{\rm D}$ derived from the fit of the HERMES data are found to be consistent with previous measurements of NMC and SLAC. The resulting values of $R_A/R_{\rm D}$ are shown in Fig. 3. Also shown are the results of the NMC experiment using the same procedure and previously published studies of the A-dependence of R [3, 5]. All data are found to be consistent with unity. As the HERMES results on $F_2^{\rm He}/F_2^{\rm D}$ and

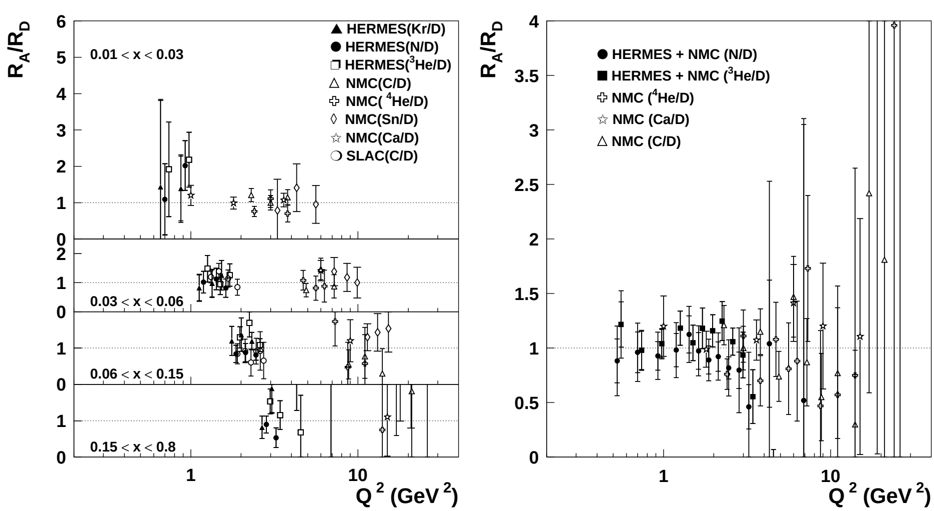

Fig. 3. The isoscalar-corrected ratio $R_A/R_{\rm D}$ for several nuclei (A) with respect to deuterium as a function of Q^2 for four different x bins. (left) HERMES data only (right) fit to combination of HERMES and NMC data.

$F_2^{\rm N}/F_2^{\rm D}$ are found to be consistent with the NMC results and independent of Q^2, the HERMES and NMC measurements of $\sigma_A/\sigma_{\rm D}$ have been combined to determine $R_A/R_{\rm D}$. While the NMC measurements mainly cover the high ε values and thus determine the ratio $F_2^A/F_2^{\rm D}$, the HERMES data extend to lower ε values. Combining the two measurements thus significantly increases the precision on $R_A/R_{\rm D}$. For Q^2 values between 0.5 and 20 GeV^2 and nuclei from He to Ca, R_A is found to be consistent with $R_{\rm D}$ within about 25% with an average value for $R_A/R_{\rm D}$ of 0.96 ± 0.03.

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