QUARK–HADRON DUALITY IN INCLUSIVE ELECTRON–NUCLEUS SCATTERING

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Recent inclusive electron–nucleus scattering data have been utilized for precision tests of quark–hadron duality. The data are in the resonance and quasielastic regions and cover a range in Q^2 from 0.5 to 7 $(\mathrm{GeV/c})^2$. The Q^2 dependence of the moments of the F_2 structure function were investigated and indicate that duality holds for nuclei, even at low Q^2.

Inclusive electron scattering is a firmly–established tool for investigation of the quark distributions in a nucleon or nucleus. At large enough values of invariant mass, W and four–momentum transfer, Q^2, the logarithmic Q^2 dependence of the nucleon structure function F_2 can be rigorously described in the framework of Quantum Chromodynamics (QCD). At lower momentum transfer however, the data can no longer be described in terms of single parton densities with simple logarithmic Q^2 dependence. Inverse power violations in Q^2, representing initial and final state interactions between the struck quark and the spectator quarks (higher twist effects), become important.

While a smooth scaling curve is not observed for the proton structure functions in the resonance region, it was observed that the F_2 structure function in the resonance and the DIS regions can still be related [1]. Bloom and Gilman showed that, when the structure function was taken as a function of $\omega' = 1 + W^2/Q^2$ and *averaged* over the resonance region, the result was identical to the DIS structure function averaged over the same region in ω'. Recent data taken at Jefferson Lab [2] dramatically verified this scaling in the resonance–averaged structure function. These data were analyzed in terms of the Nachtmann variable $\xi = 2x/[1 + \sqrt{1 + 4m^2x^2/Q^2}]$, which has been shown to be the correct variable for studies of scaling violations [3]. The new data show that the scaling–like behavior extends beyond the DIS and well into the resonance region, all the way down to $Q^2 \approx 0.5$ $(\mathrm{GeV/c})^2$.

Experiments at SLAC [4] and Jefferson Lab [5] measured inclusive electron–nucleus scattering cross section in the resonance and quasielastic ($x > 1$) regions. The structure function in nuclei is averaged by the Fermi–motion of the nucleons and the resonant structure is no longer visible. Figure 1 shows the structure function per nucleon for deuterium as a function of Q^2 at several

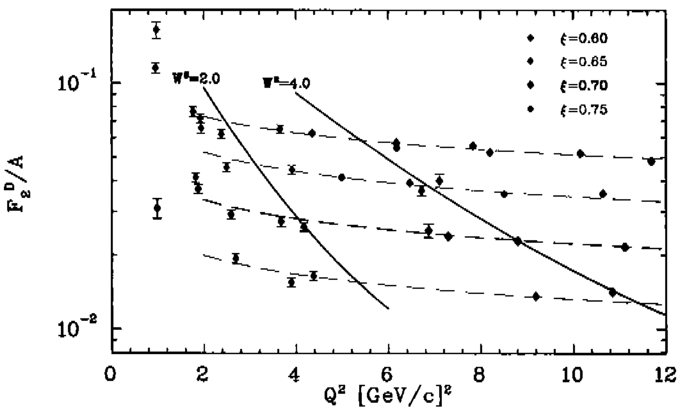

Figure 1. Structure function vs. Q^2 for deuterium at fixed values of ξ. Dashed lines are dlnF2/dlnQ2 fit to higher Q^2 data. Solid lines denote fixed W^2. Errors are statistical only.

values of ξ. Even though the Fermi momentum is small in deuterium, the data in the resonance region do not show significant deviations from scaling (dashed lines) even down to $W^2 = 2.0$ GeV^2. At extremely low Q^2, the structure function deviates from the scaling curve only as we approach the quasielastic peak. It appears that, in nuclei, the Fermi motion serves to kinematically average over the resonances, creating a smooth duality–type scaling curve in the resonance region.

An analysis of the resonance region in terms of QCD was first presented in ref. [8], where Bloom and Gilman's approach was re–interpreted, and the integrals of the average scaling curves were equated to the $n = 2$ QCD moments of F_2. These moments can be expanded, according to the operator product expansion (OPE), in powers of $1/Q^2$, and the fall of the resonances along a smooth scaling curve with incresing Q^2 was explained in terms of this QCD twist expansion. Duality is expected to hold so long as the higher twist effects (terms in $(1/Q^2)^n$ in the OPE expansion) are small. In the present analysis, the Cornwall–Norton moments for nuclear structure function were calculated: $M_n^{CN}(Q^2) = \int_0^A \; dx \; F_2^A(x, Q^2) \; x^{n-2}$. The structure function data used were obtained in experiments at SLAC [11,4], CERN [9], Fermilab [10] and JLab [5]. The quasielastic and elastic contributions, important for low Q^2, were added to the moments.

The moments for iron can be constructed (assuming that nuclear effects are small) by adding the proton and neutron contributions, extracted from

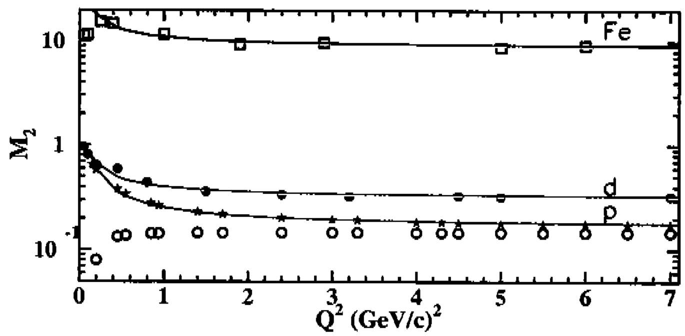

Figure 2. The second moment of F_2 for proton (stars), deuteron (full circles), iron (squares), and neutron (empty circles), The neutron data are obtained as the difference between the deuterium and proton moments. The solid lines are obtained by fitting the data for proton and deuteron, and using the procedure described in the text for iron.

proton and deuteron data: $M(Fe) = Z \times M(p) + (A - Z) \times M(n)$, where $M(n)$ is taken to be $M(d) - M(p)$ and is shown in Fig. 2 (empty circles). The differences between the moments calculated this way, and those actually measured on iron, and measured moments are smaller than 5% for Q^2 above 2 $(\mathrm{GeV/c})^2$, and between 5 and 10% for Q^2 between 0.1 and 2 $(\mathrm{GeV/c})^2$.

We next examine the nuclear dependence of the EMC effect in the resonance region, and compare this to precise measurements made in the DIS regime. For this analysis, we take the cross section ratio of iron to deuterium *in the resonance region* for $Q^2 \sim 4$ $(\mathrm{GeV/c})^2$, requiring $W^2 > 1.3$ GeV^2 to exclude the region very close to the quasielastic peak where the scaling violations become significant. Figure 3 shows this ratio for the SLAC measurement [6] and for the JLab resonance region data. The resonance region measurement is consistent with the DIS measurements and is more precise in the high–x region.

In conclusion, we utilized inclusive electron–nucleus scattering data for precision tests of quark-hadron duality. Duality is observed to hold for nuclei even in the low Q^2 regime of $Q^2 \approx 0.5$ $(\mathrm{GeV/c})^2$, well below the DIS limit. Structure functions extracted in the resonance region appear consistent with the DIS results. In the QCD moment explanation this indicates that higher twist contributions are small or cancelling. Further, the EMC effect on the structure function in the nuclear environment is observed to hold in the resonance region.

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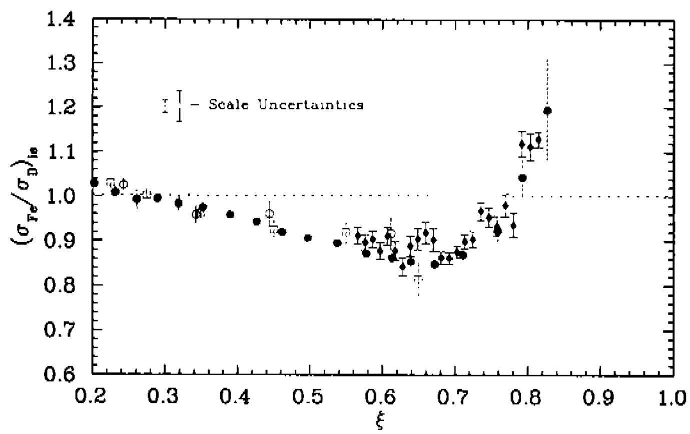

Figure 3. Ratio of nuclear to deuterium cross section. The diamonds are the Jefferson lab data for iron (resonance region). The circles are data for iron from SLAC (DIS region).

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