# A STUDY OF THE NUCLEAR AND KINEMATIC DEPENDENCE OF $R=\sigma_L/\sigma_T$ IN DEEP INELASTIC ELECTRON SCATTERING

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## ABSTRACT

We report preliminary results on the nuclear dependence of $R=\sigma_L/\sigma_T$ in the deep inelastic electron scattering from deuterium, iron, and gold nuclei. In the x, $Q^2$ range of $0.2 \leq x \leq 0.5$ and $1 \leq Q^2 \leq 5$ $(GeV/c)^2$, the average $R^{Fe}-R^D$ is $0.03 \pm 0.02$ (stat) $\pm 0.06$ (syst); the final systematic errors are expected to be reduced to $\pm0.03$. The results indicate that there are no significant spin-0 constituents or higher twist effects in nuclei as compared to free nucleons. Models for the EMC effect with significant nuclear dependence of R are ruled out. The discrepancy, at low x, between CERN and SLAC results for the cross section ratio $\sigma^{Fe}/\sigma^D$ cannot be attributed to a nuclear dependence of R as suggested by some authors. The kinematic variation of $R^D$ with x and $Q^2$ in the SLAC energy is in agreement with the predictions of QCD with the addition of target mass effects.

The discovery of the difference in the structure function $F_2(x)$ for Iron and Deuterium targets [1-3], the EMC effect, has sparked considerable activity in the theoretical study of the deep inelastic lepton scattering from nuclear targets. There are numerous models [4] for the EMC effect which are built on a variety of ideas like $Q^2$-rescaling, x-rescaling, convolution of structure functions of clusters of nuclear matter ( pions in nuclei, $\Delta$-isobars, multiquark clusters ...) and others. Further experimental results are needed for a better understanding of the origin of the EMC effect. Some models [5] predict a large difference in the quantity $R=\sigma_L/\sigma_T$, while Quantum Chromodynamics (QCD) models [6] and some others predict a negligible difference. Some authors [7] have conjectured that higher twist effects might be different for different nuclei, and yield a nuclear dependence of R. The quantity $R=\sigma_L/\sigma_T$ is a sensitive measure of the effects such as spin-0 constituents (e.g.tightly bound diquarks, and tightly bound pion like objects at large values of x) of nucleus and nuclear higher twist effects. Therefore, a nuclear dependence of R could result in a change in our view of nuclear structure in terms of quarks and gluons. Such a nuclear dependence of R has been proposed [8] as a possible explanation for the experimental difference between $\sigma^{Fe}/\sigma^{D}$ as measured at CERN and at SLAC. There were hints in previous data that such a difference in R may have been observed [3].

We have undertaken precision measurements at the Stanford Linear Accelerator Center, SLAC, of the deep inelastic electron scattering cross sections on deuterium, iron and gold targets in a single experiment in order to measure the kinematic and nuclear dependence of R.

The differential cross section for scattering of an unpolarized charged lepton, with an incident energy E, scattering angle $\theta$ and final energy $E'$, can be written in terms of two structure functions as:

$$d^2\sigma/d\Omega dE' = \sigma_M\ [F_2(x,Q^2)/\nu + 2F_1(x,Q^2)\tan^2(\theta/2)/M]$$

$$= \Gamma\ [\sigma_T(x,Q^2) + \epsilon\sigma_L(x,Q^2)], \qquad (1)$$

where $\nu=E-E'$ is the energy of the virtual photon which mediates the interaction, $Q^2=4EE'\sin^2(\theta/2)$ is the invariant four-momentum transfered, $\epsilon=[1+2(1+Q^2/(4M^2x^2))\tan^2(\theta/2)]^{-1}$ is its polarization, $\Gamma=\alpha(1/x-1)E'/(4\pi^2ME(1-\epsilon))$ is a kinematic factor representing its flux, $\sigma_M$ is Mott cross section and M is the nucleon mass. The Bjorken variable $x=Q^2/2M\nu$ is a measure of the longitudinal momentum carried by nucleon constituents. The ratio $R=\sigma_L/\sigma_T$ can be expressed in terms of the structure functions as

$$R = (1+4M^2x^2/Q^2)F_2/(2xF_1)-1 = F_L/(2xF_1), \quad (2)$$

where the longitudinal structure function $F_L=(1+4M^2x^2/Q^2)F_2-2xF_1$, is proportional to $\sigma_L$. The values of R, for each target, can be extracted from cross sections measured at various values of $\epsilon$. These results are presented at the end of this article. First we concentrate on the results for $R^{Fe}-R^D$ (and $R^{Au}-R^D$), obtained by fitting the cross section ratio,

$$\sigma^{Fe}/\sigma^D = \sigma_T^{Fe}/\sigma_T^D \; (1+\epsilon'(R^{Fe}-R^D)), \quad (3)$$

where $\epsilon'=\epsilon/(1+\epsilon R^D)$. This ratio has smaller systematic uncertainty since most errors in acceptance and radiative corrections cancel.

The experiment (E140) was performed at SLAC using an upgraded 8 GeV spectrometer facility. This facility is uniquely suited to measure $R(x,Q^2)$ because the SLAC beam can be tuned in a broad energy range (between 3.75 and 19.5 GeV in this experiment) with a precision of ±0.2%, and with instantaneous currents ranging between 0.1 and 30 mA. This ability to adjust incident beam energy and current is important to control dead time, pion background contamination, and Dalitz pair contamination, which constrain the kinematic region over which good measurements can be made. Limited by these restrictions and by the size of radiative corrections, we were able to measure cross sections with a typical accuracy of ±1% in the $x,Q^2$ range of $0.2 \le x \le 0.5$ and $1 \le Q^2 \le 10$ $(GeV/c)^2$. Data were taken at upto five different values of $\epsilon$ with a typical $\epsilon$ range of 0.35 for targets of liquid $D_2$ (2.6% radiation lengths), Fe (2.6% and 6% r.l.) and Au (6% r.l.).

Accurate determination of cross section demanded careful monitoring of the apparatus during data taking. The beam position and angle were monitored using a microwave cavity and two wire arrays upstream of the pivot and adjusted continuously using micro computer controlled magnets. The total incident charge was monitored using two precision toroidal charge monitors accurate to ±0.3%. The use of single spectrometer helped reduce the systematic uncertainties due to detector acceptance and efficiency. The spectrometer was set at angles between 11.5° and 46° and momenta between 1.0 and 8.0 GeV/c.

It was essential to reject the flux of pions which, at large angles and small momentum, exceeded the electrons by factors of up to a hundred. For this purpose a new detector package was installed. It includes a new hydrogen gas Cerenkov counter, a recently installed 10 plane proportional wire chamber system, a new 5 layer lead glass shower counter array and three planes of plastic scintillation counters. The Cerenkov and lead glass detectors had a combined rejection factor for pions of about $10^5$ and an efficiency for electrons of 99.5%. The need for high precision cross sections limited our main data runs to regions where ratio of yields, $\pi/e < 100$. The spectrometer optics and wire chamber system together allowed momentum resolution of ±0.1% and angular resolution of ±0.1 mr.

Electron contamination from charge symmetric processes like Dalitz pair creation was estimated by reversing spectrometer polarity and measuring positron yields. Spectrometer settings were limited to those kinematic regions where these 'positron' backgrounds were less than 10%. Dummy targets were used to determine the background from the aluminium target walls for the $D_2$ targets. To reduce the systematic errors in the $R_A$-$R_d$ the data was accumulated in small runs alternating between various targets. Target temperatures were continuously monitored.

The radiative corrections using the prescription of Bardin [9] for internal bremstrahlung and corrections due to external bremstrahlung using the prescription of Mo-Tsai (as in reference [3]) were applied to obtain the final cross sections. The slope to the fits, at each x and $Q^2$, to $\sigma^{Fe}/\sigma^D$ vs $\epsilon'$ and the intercepts at $\epsilon'=0$ and $\epsilon'=1$ yield $R^{Fe}-R^D$, and the ratios $F_1^{Fe}/F_1^D$ and $F_2^{Fe}/F_2^D$. Most systematic errors, e.g. those from acceptance, a part of the radiative corrections and target length cancel for $R^{Fe}-R^D$. The remaining systematic error in $R^{Fe}-R^D$ is about ±0.06, mostly coming from radiative corrections. This error is expected to reduce to ±0.03 when the study of the radiative corrections is completed. Results for $R^{Fe}-R^D$ are plotted against x for various $Q^2$ values in Fig 1. The average $R^{Fe}-R^D$ for all the points is
0.03 ±0.02(stat)±0.06(syst). The single measurement for gold, solid point on fig 1, is consistent with iron results.

Within QCD, a finite value of R originates from the transverse momentum ($P_t$) of the quarks. This $P_t$ can originate from gluon emission ($R^{QCD}$) as well as from target mass effects[10]. Target mass effects lead to a form of R which falls like powers of $1/Q^2$, and gluon processes leads to a form which falls like $1/\ln(Q^2/\Lambda^2)$. Figures 2a, 2b and 2c show the data for deuterium for fixed x as a function of $Q^2$. The data at high $Q^2$ is from the CDHS (iron) and BCDMS (carbon) collaborations [11]. The two curves are for

R from 1) the QCD and 2) the QCD plus target **mass** contributions. The results indicate good agreement with the QCD plus target mass calculations.

In conclusion, our preliminary results on $R^{Fe}-R^{D}$ is in agreement with models which predict no nuclear dependence of R and rule out valon models [5]. The data indicate that the contribution from nuclear higher twist effects and spin-0 constituents in nuclei as compared to free nucleons are small. The speculation [8] that the EMC vs SLAC difference at low x can be resolved if the difference $R^{Fe}-R^{D}\approx 0.15$ is not substantiated by our data. The kinematic dependence of the absolute values of R for deuterium as a function of x and $Q^2$ are in agreement with calculations incorporating QCD and target mass effects. Further work on radiative corrections, acceptance and target density/length measurements are expected to result in a final systematic error of ±0.03 on R, as well as precise results for the ratios $\sigma^{Fe}/\sigma^{D}$ with errors of ±1%.

**References**


1. J. J. Aubert et al., Phys. Lett. **123B** (1983) 275;
   A. Argento et al., Report submitted to the 22nd International Conference on High energy physics (Leipzig, 1984).

2. A. Bodek et al., Phys. Rev. Lett. **50** (1983) 1431; 51 (1983) 534;

3 R. G. Arnold et al., Phys. Rev. Lett. **52** (1984) 724;
   S. Rock, Proceedings of the 22nd International Conference on High Energy Physics (Leipzig, 1984).

4. K. Rith, MPI H-1986-V15, to be published in the Proceedings of the International Nuclear Physics Conference, (Harrogate, 1986) and references therein.

5. Bo-Qiang Ma and Ji Sun, Print-86-1217, Beijing University, China (1986).

6. F. E. Close et al., Phys. Lett. **129B** 346 (1983).

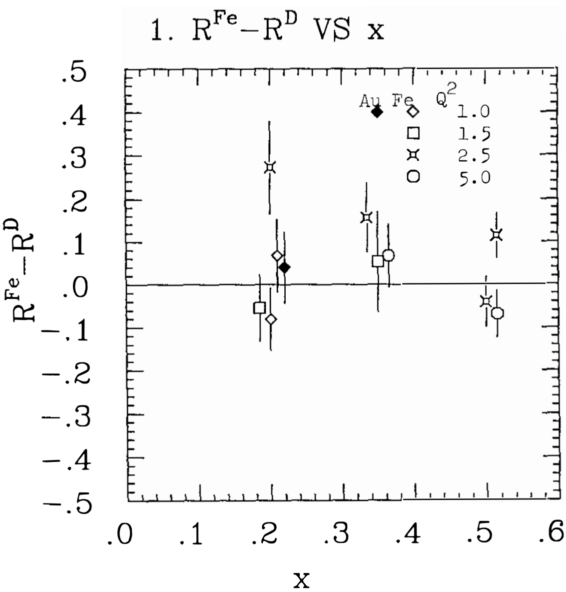
7. E. V. Shuryak, Nucl. Phys. **A446** 259C (1985).

8. I. A. Savin and G. I. Smirnov, Phys. Lett. **145B** (1984) 438;

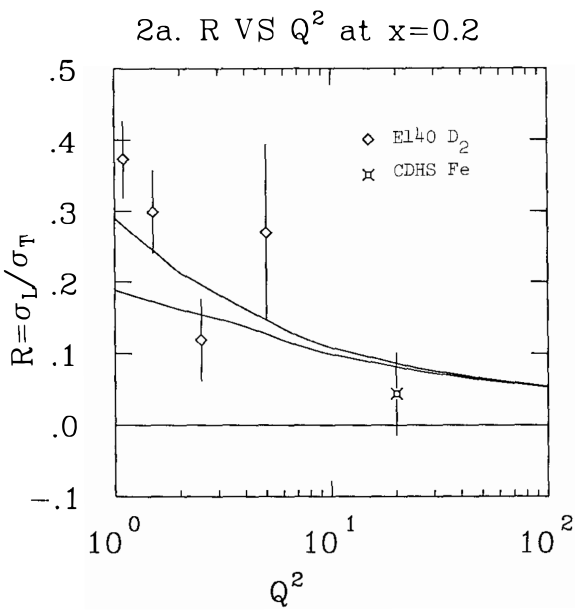
9. D. Y. Bardin et al., Yad. Phys. **29** (1979) 499;
   D. Y. Bardin et al., Nucl. Phys. **B197** (1982) 1.

10. G. Altarelli and G. Martinelli, Phys. Lett. **28B**, (1978) 89;
    R. D. Field in **Quantum Chromodynamics**, p97, La Jolla, 1978, AIP Conference Proceedings No. 55, (1979);
    R. Barbieri et al., Nucl. Phys. **B117**, (1976) 50;
    A. de Rujula et al., Ann. Phys. **103**, (1977) 315;
    A. Buras et al., Nucl. Phys. **B131**, (1977) 308;

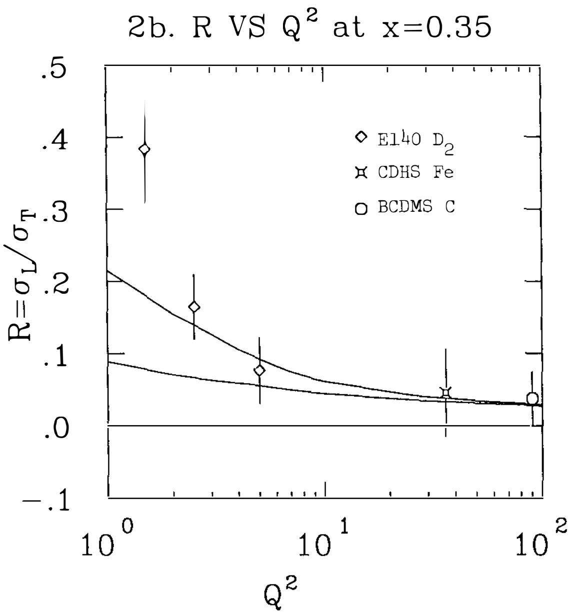
11. BCDMS report in these proceedings;
    CDHS report in the Proceedings of XXIII International Conference on High Energy Physics (Berkeley '86).



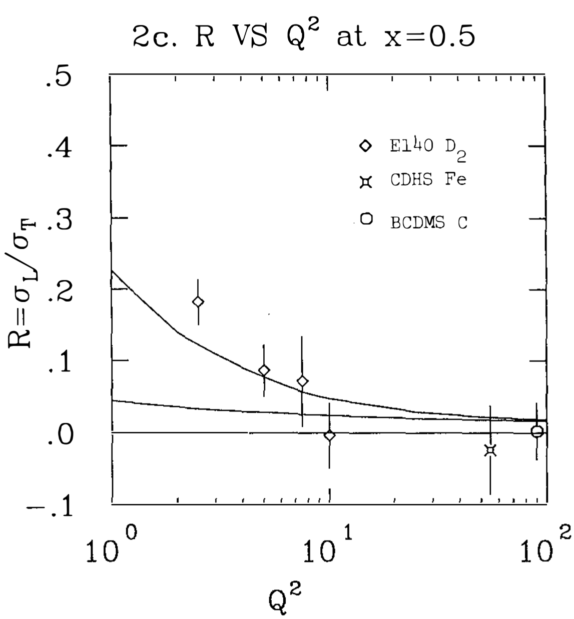

1. $R^{Fe}-R^D$: The values for for $R^{Fe}-R^D$ are plotted against x for various $Q^2$ values. The bold point for Au target is also plotted. The two points for $Q^2=1.0$ and 2.5 $(GeV/c)^2$ are for Fe targets of 6% and 2.6% radiation lengths. The rest of the points are for 6% Fe target.




2a. $R^D$ at x=0.2 is plotted against $Q^2$. The lower curve is $R(Q^2)$ at x=0.2, calculated in perturbative QCD including gluon contributions. The upper curve includes the target mass contributions.




2b. $R^D$ at x=0.35 is plotted against $Q^2$. The lower curve is $R(Q^2)$ at x=0.35, calculated in perturbative QCD including gluon contributions. The upper curve includes the target mass contributions.




2c. $R^D$ at x=0.5 is plotted against $Q^2$. The lower curve is $R(Q^2)$ at x=0.5, calculated in perturbative QCD including gluon contributions. The upper curve includes the target mass contributions.