PRECISION MEASUREMENT OF $R=\sigma_L/\sigma_T$ AND F_2 IN DEEP INELASTIC ELECTRON SCATTERING

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Abstract

We report new results on a precision measurement of the ratio $R=\sigma_L/\sigma_T$, and the structure function F_2, for deep inelastic electron-nucleon scattering in the range $0.2 \leq x \leq 0.5$ and $1 \leq Q^2 \leq 10$ $(GeV/c)^2$. Our results show, for the first time, a clear falloff of R with increasing Q^2. Our R and F_2 results are in good agreement with QCD predictions only when corrections for target mass effects are included.

The ratio $R=\sigma_L/\sigma_T$ of the longitudinal (σ_L) and transverse (σ_T) virtual photon absorption cross sections, measured in deep inelastic lepton-nucleon scattering is a sensitive measure of the spin and the transverse momentum of the nucleon constituents. Previous measurements[1-3] of R, at the Stanford Linear Accelerator Center (SLAC), indicated that scattering from spin-1/2 constituents (e.g. quarks) dominates. However, the results for R were larger than expected, and were consistent with a constant value of 0.2. The errors on those results left room for speculations about small admixtures of spin-0 constituents in nucleons[4] (e.g. tightly bound diquarks), and of unexpectedly large primordial transverse momentum for quarks. Experiments[2] in the SLAC Q^2 range ($1 \leq Q^2 \leq 20$ GeV^2) have also indicated deviations from the scaling of the structure functions $F_{1,2}$ in the variable x. In the theory of Quantum Chromodynamics (QCD), logarithmic scaling violations[5] occur due to quark-gluon interactions. In addition, target mass[6] and dynamical higher twist[7] (non-perturbative effect due to binding of quarks in a nucleon) effects yield power law violations of scaling. These effects lead to non-zero contributions to R which decrease with increasing Q^2. Since the quality of the previous data was inadequate to test such predictions for R, we have made precision measurements of deep inelastic electron-nucleon scattering cross sections from D_2, Fe and Au targets, with particular emphasis on the extraction of the ratio R, and the structure functions F_1 and F_2. Studies of the difference $R^{Fe}-R^D$ and the ratio F_2^{Fe}/F_2^D were presented earlier.[8]

The SLAC electron beams and the 8 GeV spectrometer facility were used to measure cross sections accurate to ±1% in the kinematic range $0.2 \lesssim x \lesssim 0.5$ and $1 \lesssim Q^2 \lesssim 10$ $(GeV/c)^2$ at up to five different values of ϵ (with a typical ϵ-range of 0.35). Extensive measures were taken in this experiment to reduce systematic errors. Radiative corrections were calculated using the "exact" prescription of Bardin et al,[9] with additional "external" corrections (due to the straggling of electrons in the target material) calculated in the complete formalism of Mo and Tsai.[8,10]

The values of R, F_1 and F_2 were extracted from cross sections measured at various values of ϵ at fixed (x,Q^2) by making linear fits, weighted by the statistical and point-to-point systematic uncertainty. The average χ^2/df for these fits is 0.7, indicating that the estimate of systematic uncertainty is conservative. R values are insensitive to the absolute normalization of beam flux, target length, radiative corrections and spectrometer acceptance. Since the differences R^A-R^D are consistent with zero,[8] the results plotted in Figs. 1a-c are averaged for different targets at the same x and Q^2. Our results have small errors (see Fig. 1a) compared to previous SLAC experiments[2,3] because a) our cross sections were measured to better than ±1% statistical accuracy with large ϵ-separation, b) uncertainties in radiative corrections were reduced to below ±1% level, and c) a single spectrometer with well determined acceptance was used. Our results at x of 0.2, 0.35 and 0.5, shown in the Figs. 1a-c show a clear falloff of R with increasing Q^2. The agreement with a constant value of R=0.2 is poor (χ^2=3.4/df). The high Q^2 results from CDHS[11] and BCDMS[12] collaborations for ν-Fe and μ-C/H scattering respectively, are also plotted on Figs. 1a-c. These results reinforce the conclusion that R decreases with increasing Q^2. The values of F_2^D are plotted against Q^2 at various x in Fig. 2. Our F_2 results are preliminary since the absolute normalization studies (presently known to ±3%) are not complete.

In perturbative QCD (to the order α_s) hard gluon bremsstrahlung from quarks, and photon-gluon interaction effects yield contributions to leptoproduction.[5] The leading Q^2 dependence of the structure functions is in α_s, and is therefore logarithmic. Our R data (see Figs. 1a-c) are not in agreement with these calculations[13] (χ^2/df=9). The scaling violations in F_2 (see Fig. 2) are also not described completely by these QCD interaction effects alone. Target mass effects[6,13] introduce terms proportional to M^2/Q^2, and give large contributions to R and F_2 at small Q^2 and large x. Our data for R (Figs. 1a-c) and F_2 (Fig. 2) are in agreement (χ^2=1.1/df) with theory when the target mass effects are added to perturbative QCD. Our results at all Q^2 show only a weak x-dependence in the range $0.2 \leq x \leq 0.5$ in agreement with these predictions.

It has been speculated[4] that two of the valence quarks in a nucleon may form a tightly bound spin-0 diquark. The spin-0 diquarks are predicted to give large contributions to R at large x and low Q^2. Our highest x (=0.5) results for R do not favor this possibility. The target mass effects[6] appear to account for all the $1/Q^2$ dependence of R, and therefore the speculations[7] that dynamical higher twist contributions to R (for $x \lesssim 0.5$) are large are not favored by our data.

In conclusion, we report that our results show for the first time a clear falloff of R with increasing Q^2 in the range $1 \leq Q^2 \leq 10$ GeV^2 for x=0.2, 0.35 and 0.5. Our R and F_2 results are in good agreement with QCD predictions of scaling violations only when corrections for target mass effects are included.

References

1. M. Breidenbach et al., Phys. Rev. Lett. **23**, 930 (1969);
   G. Miller et al., Phys. Rev. D 5, 528 (1972).
2. A. Bodek et al, Phys. Rev. D **20**, 1471 (1979).
3. M. D. Mestayer et al., Phys. Rev. D **27**, 285 (1983).
4. L. F. Abbott et al., Phys. Lett. **88B**, 157 (1979);
   S. Ekelin and S. Fredriksson, Phys. Lett. **162B**, 373 (1985).
5. G. Altarelli and G. Martinelli, Phys. Lett. 76B ,89 (1978);
6. H. Georgi and D. Politzer, Phys. Rev. D14, 1829 (1976).

7. J. L. Miramontes and J. Sanchez Guillen, Univ. of Santiago de Copostela (Spain), preprint US/FT-1/88.
8. S. Dasu et al., University of Rochester preprint UR-997, (Jan 1987).
9. A. A. Akhundov, D. Yu. Bardin, N. M. Shumeiko, Sov. J. Nucl. Phys. **26(6)**, 660 (1978), and references therin.
10. Y. S. Tsai, SLAC-PUB-848 (1971).
11. P. Buchholz, Report of CDHS collaboration in the Proceedings of the EPS International Conference on High Energy Physics, Bari, Italy, 1985.
12. A. C. Benvenuti et al. (BCDMS), Phys. Lett. **195** B, 91 (1987).
13. S. Dasu, Ph. D. Thesis, University of Rochester (1988).

Figure Captions

Fig. 1a-c The values of R at (a) x=0.5, (b) x=0.35, and (c) x=0.2 are plotted versus Q^2, with statistical and systematic errors added in quadrature. Predictions from perturbative QCD (quark-gluon interaction effects; the dash curve), QCD with target mass effects (solid curve), Ekelin and Fredriksson diquark model (dot-dash curve) and the data from high Q^2 CDHS (ν-Fe) and BCDMS (μ-C/H) experiments are also plotted.

Fig. 2 The values of F_2 extracted from our data at x=0.2, 0.35, and 0.5 are plotted versus Q^2. Only statistical and point-to-point systematic errors are shown - There is an additional normalization error of ±3%. The QCD structure function (dashed curve), and F_2 including the target mass effects (solid curve) are also plotted.