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ELECTROMAGNETIC PROBES OF NUCLEONS AND NUCLEI*

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ABSTRACT

A brief review is given of recent experimental results from high energy electron and muon scattering on nuclear targets. Electron-proton elastic scattering at SLAC, the A-dependence of deep inelastic scattering at SLAC and CERN, and recent electron scattering experiments in the new program Nuclear Physics at SLAC are described. Some planned future experiments using high energy electrons and muons to probe nuclear targets are outlined.

1. INTRODUCTION

This talk is a brief review of selected topics in the experimental study of nucleons and nuclei using the electromagnetic probe, mostly done at SLAC. Elastic and inelastic electron and muon scattering from nuclei at GeV energies is uniquely suited to gather evidence for the major open question in nuclear physics today: Where are quarks relevant to understand nuclear structure? The virtual photon in electron or muon scattering probes the target by connecting to the electromagnetic currents carried by the quarks, and the resolution for the probe can be varied experimentally from nuclear size down to subnucleon size. The experiments described here were conducted in the kinematic regime where it is thought that quark constituents of nucleons become visible. The main aim of this talk is to show the experimental evidence for a few cases, and indicate what are the experimental limitations and hopes and plans for future experiments.

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A major subset of the question about the relevance of quarks to nuclear physics is: Where is perturbative QCD applicable? We know from nearly two decades of experiments in the GeV region that hadronic matter is in some sense 'made' of quarks, and therefore all nuclear physics must ultimately be understood to arise from quark interactions. This new substructure is a peculiar one, however. The constituents apparently can't get out. The force between them grows with separation, and at large distances (of the order of nucleon size) things become horribly complicated. At short distances the force between quarks becomes weaker and the interactions get simpler. The hope is that at some sufficiently large momentum and energy transfer the measured scattering processes are dominated by the short distance interaction among a few quarks, and meaningful calculations can be made in perturbation expansions.

One of the first applications of perturbative QCD to nuclear structure was the development of the dimensional scaling laws[1] for hadronic form factors. A central theme of our present attempts to identify processes and kinematic regions where quarks are necessary is to find if and where the data agree with the predictions of perturbative QCD. Several of the experiments I describe were designed with this question in mind.

The present consensus after nearly two decades of experiments and theoretical interpretation, is that deep inelastic lepton scattering probes the distribution of individual quarks in the target. For this interpretation to apply, the data must be in the scaling region, where the virtual photon transfers momentum Q^2 above 2 $(GeV/c)^2$ and the missing mass W^2 is greater than 4 GeV^2 to be above the coherent scattering on the nucleon resonances. Much effort has been devoted to 'tests of QCD' using deep inelastic data from nuclear targets under the assumption that heavy nuclei can provide convenient high density collections of quarks to scatter from without introducing any unwanted effects. The recent results from CERN[2] and SLAC [3,4] show that the quark momentum distributions get modified when nucleons are embedded in nuclei. The existence of this phenomenon opens up another window onto the behavior of quarks and offers the possibility to use nuclear targets as laboratories for exploring aspects of quark dynamics not present in isolated nucleons. I will briefly describe the status of the experiments measuring the so called EMC effect, and indicate some of the open questions that will be addressed in future experiments.

2. RECENT EXPERIMENTS

2.1 Electron-Proton Elastic Scattering

One of the major predictions of perturbative QCD is for the behavior of the nucleon form factors at large momentum transfer.[1,5] The basic assumption here is that at large momentum transfer the scattering process factorizes into a part which describes the initial and final wave functions and a part which describes the hard scattering among the valence quarks. At large momentum transfer the contribution from scattering on soft components of the wave function containing additional quark-antiquark pairs dies away, and electron-proton scattering can be thought of as electron-quark scattering followed by two hard quark-quark scatterings. Brodsky and Lepage[5] predict the proton form factor G_{Mp} should behave like

$$G_{Mp} \propto \frac{\alpha_s^2(Q^2)}{Q^4} f(\phi_i, \phi_f).$$

The $1/Q^4$ factor follows from the hard scattering on three pointlike quarks, and the two powers of $\alpha_s(Q^2)$ come from the quark-gluon couplings. The factor $f(\phi_i, \phi_f)$ contains the dependence on the initial and final state wavefunctions. The functions ϕ_i and ϕ_f describe the momentum distributions of the valence quarks, and in principle must also be calculated in QCD, but at present they are only guessed at using various models and assumptions. Brodsky and Lepage made predictions for G_{Mp} using models of the form $\phi \sim (x_1 x_2 x_3)^\eta$, where η is a parameter, and x_i is the fraction of the nucleon momentum carried by each quark. The momentum is distributed symmetrically among the valence quarks. Some of their predictions are shown in Fig. 1.

The form factor G_{Mp} is predicted to fall faster than $1/Q^4$ due to the Q^2 dependence of $\alpha_s(Q^2)$ set by the size of the QCD scale parameter Λ_{QCD}. If the perturbative regime can be reached at experimentally accessible Q^2, then that electron-proton scattering might be used to observe the coupling constant of QCD

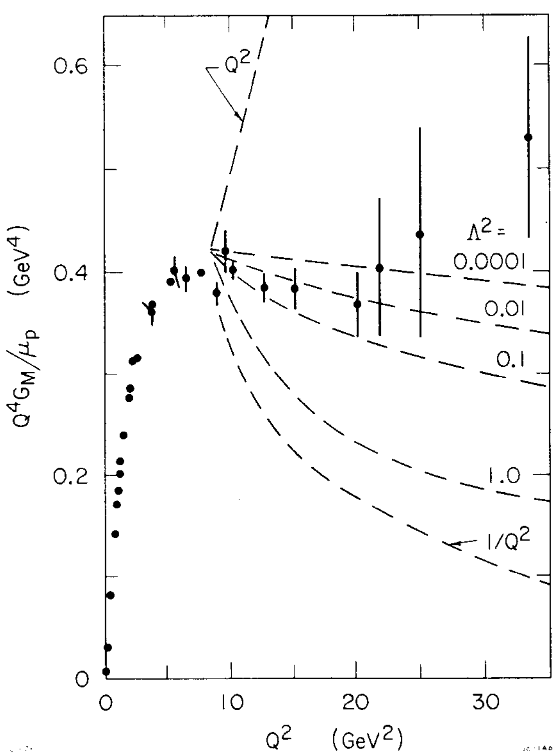


Fig. 1. Previous world data for the proton magnetic form factor G_{Mp} multiplied by Q^4 and plotted versus Q^2. The curves are perturbative QCD predictions from Brodsky and Lepage (Ref. 5).

change with Q^2. The previous data for G_{Mp} in Fig. 1 fall approximately like $1/Q^4$ for $Q^2 > 10\ (GeV/c)^2$, but the experimental uncertainties are too large to distinguish any small deviations from pure $1/Q^4$ behavior that might arise from the Q^2 dependence of $\alpha_s(Q^2)$.

Recently there has been a lot of discussion[6,7] about the relevance of exclusive processes for testing perturbative QCD at measurable Q^2. Isgur and Llewellyn Smith have argued[6] that the proton form factor is dominated by scattering on soft components of the wave function even up to very high Q^2. If these arguments are correct, then the data for nucleon form factors at large Q^2 are determined more by the complicated higher order QCD processes in the wave function than by the first order hard scattering process involving only the valence quarks.

In another development, Chernyak and Zhitnitsky[8] have generated a set of nucleon wave functions using QCD sum rule techniques in which the valence quarks do not share the proton momentum equally. With asymmetric wave functions the low order hard scattering processes in the form factors are large at measurable Q^2.

Whatever the outcome of the present debate about the applicability of perturbative QCD in the measurable Q^2 range, data for the nucleon form factors at large Q^2 contain fundamental information about the nucleon ground state and will provide important constraints on ideas about quark dynamics.

A new measurement of *ep* elastic scattering has recently been made at SLAC[9]. The primary motivation for Experiment E136 was to measure *ep* elastic scattering with substantially better precision than previous experiments over a range in Q^2 to measure the slope of $Q^4 G_{Mp}$ for Q^2 above 10 $(GeV/c)^2$. Most of the previous data above 10 $(GeV/c)^2$ was taken as auxiliary data in SLAC experiments[10] not optimized for *ep* elastic measurements. The experimental uncertainties could be substantially reduced in reasonable running time in an experiment dedicated to measuring *ep* elastic.

The new experiment was designed as a single arm measurement using the 8 GeV/c spectrometer. The detector package was upgraded with new wire chambers for tracking and a new lead-glass total-absorption shower counter. A new liquid hydrogen target was designed with target end caps shielded from view by the spectrometer to reduce end-cap background. The data taking was completed in May 1984 and preliminary results are now available.

The new data are shown in Fig. 2. The points extend from $Q^2 = 2.9$ to 31.2 $(GeV/c)^2$. The errors are substantially reduced compared to the previous data. The new points show a slight deviation below the pure $1/Q^4$ dependence for Q^2 above 10 $(GeV/c)^2$. There is no evidence that $Q^4 G_{Mp}$ rises at large Q^2, which would be in stark contrast to the QCD predictions

The new data are also plotted in Fig. 3 along with the theoretical predictions of Chernyak and Zhitnitsky. The theoretical curves fall faster than $1/Q^4$ due to the Q^2 dependence of $\alpha_s(Q^2)$, and they have about the same slope as the new data. The absolute magnitude of the theoretical curves is determined by details of the wave functions, and is in fair agreement with the data.

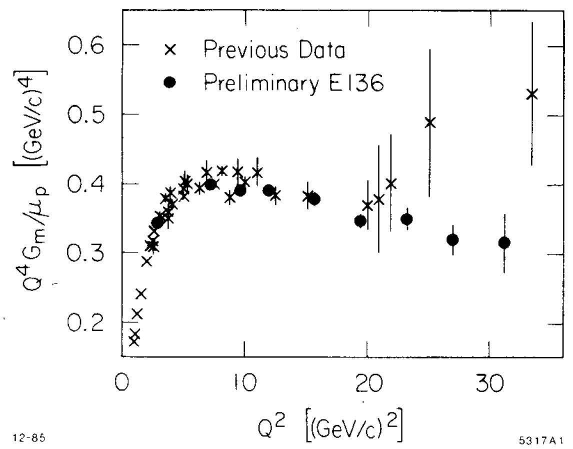


Fig. 2. Preliminary results for G_{M_p} from SLAC experiment E136 (Ref. 9).

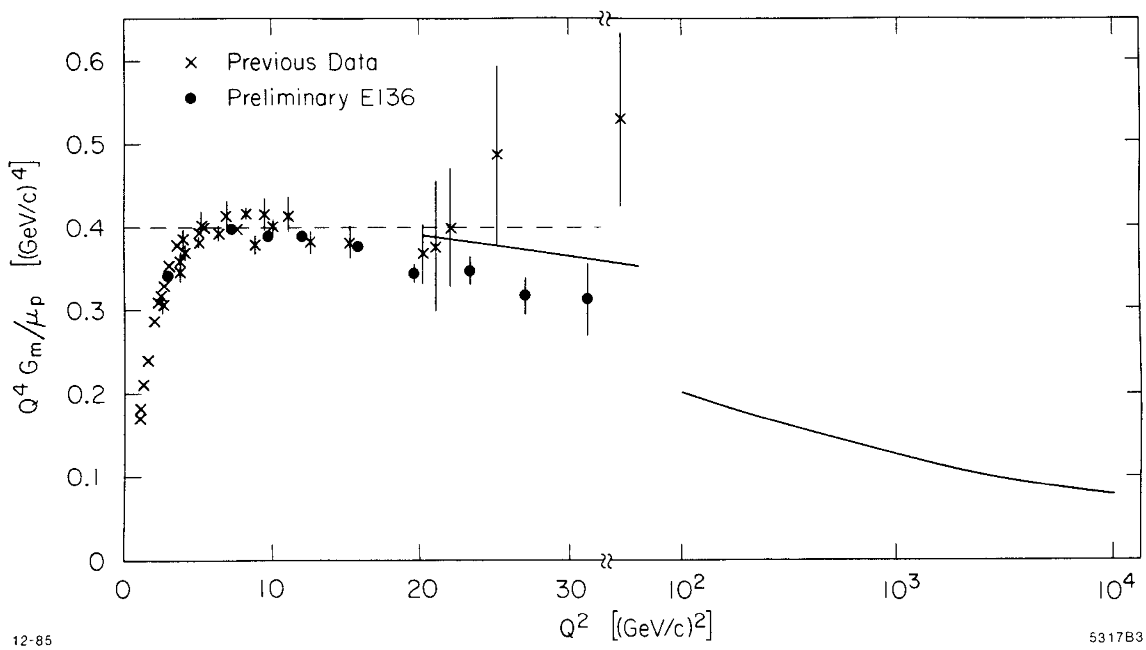


Fig. 3. Proton form factor G_M at large Q^2 . The curves are perturbative QCD results from Chernyak and Zhitnitsky (Ref. 8). Preliminary results from E136 (Fig. 2) are also plotted.

These data provide an important new look at proton structure, but it is too early to make firm statements about specific tests of QCD or to deduce values of Λ_{QCD}. If the ideas of Chernyak and Zhitnitsky are correct, this data may help to establish a rather surprising result, that the valence quarks in the proton do not share the momentum more or less equally. That would have far reaching consequences for our understanding of hadron structure and would affect our interpretation of other areas of physics, such as deep inelastic scattering.

2.2 A-Dependence of Deep Inelastic Scattering

Following the now famous discovery[2] by the EMC collaboration, subsequently verified[3] in archival SLAC data, of a difference between deep inelastic scattering on iron and deuterium, it became clear that more measurements of this effect were needed, and that the facilities at SLAC were ideal for this purpose. The 8 GeV/c spectrometer with its detectors and electronics were set up and operating for E136. All that was needed was a different target. Therefore the E136 collaboration elected to interrupt that experiment and quickly proposed and ran SLAC Experiment E139, a measurement[43] of the A-dependence of deep inelastic scattering (DIS).

The aim of this short experiment was to measure the A-dependence of the cross section ratio σ_A/σ_d for DIS over a range of kinematics $0.1 \leq x \leq 0.9$ and $2 \leq Q^2 \leq 15$ $(GeV/c)^2$ readily accessible using the SLAC beam energy $E_i \leq 24.5$ GeV and the 8 GeV/c spectrometer. A primary goal was to look for the A-dependence versus x at $Q^2 = 5$ $(GeV/c)^2$, which is safely in the deep inelastic scaling region. In addition we wanted to measure at $x = 0.6$ where the nuclear effect is large over a range in Q^2 to look for any possible deviation from scaling. Finally measurements were made at several values of fixed x and Q^2 but at various scattering angles to look for a possible variation with A in the ratio of longitudinal to transverse cross sections $R = \sigma_L/\sigma_T$.

The targets chosen were readily available materials of natural isotopic abundance spanning the A range from ^{4}He to ^{197}Au. Since the size of the effect was expected to be only a few percent in the ratio σ_A/σ_d, while the individual cross sections vary over several orders of magnitude, special efforts were made to keep the systematic errors in the ratio small. The overall systematic uncertainty for most kinematic points is estimated to be in the range 1% to 2% in the ratio σ_A/σ_d.

An overview of the data, obtained in approximately 80 hours of beam time, is displayed in Fig. 4. The results showed no significant variation with Q^2 in the range from 2 to 15 $(GeV/c)^2$, as indicated in part (a) of Fig. 4, which supports the idea that the scattering takes place incoherently on individual pointlike quarks. The ratio σ_A/σ_d is not constant for any nucleus. It is less than one for $x > 0.3$, and the deviation from unity increases with nuclear size. In contrast to the EMC data[2], the E139 data for σ_A/σ_d does not extend much above one for $x < 0.3$.

The observed difference in cross section per nucleon for nuclear targets indicates that the quark momentum distributions are distorted for nucleons embedded in nuclei. The shift in σ_A/σ_d to values below one for $x > 0.3$, where the contribution from scattering on ocean quarks is negligible, indicates a shift of momentum away from the valence quarks in that x region in nuclei. The magnitude of this shift increases smoothly with increased nuclear size, roughly proportional to the log of A, as shown in Fig. 5.

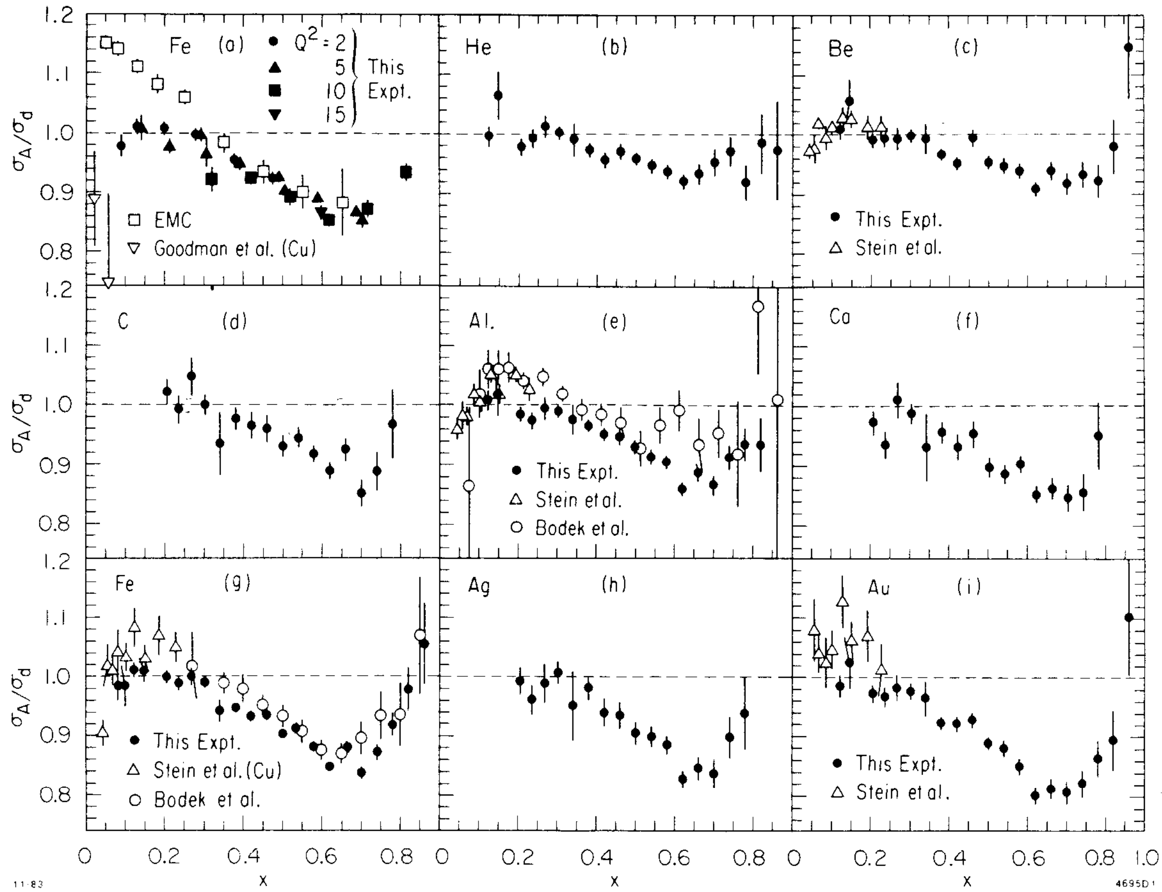
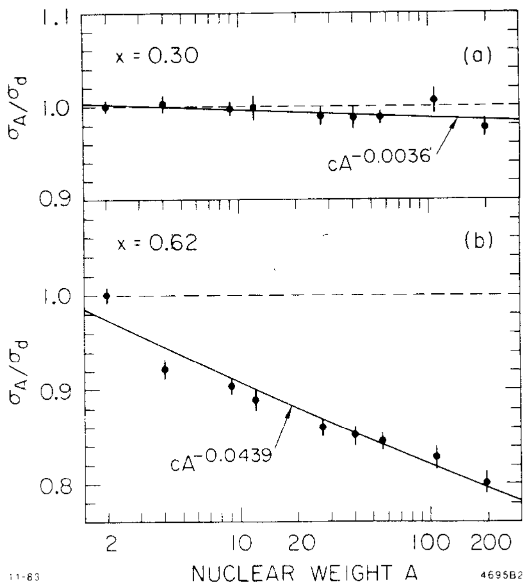


Fig. 4. (a) E139 results for σ_{Fe}/σ_d as a function of x for various values of Q^2 as well as higher energy muon data from Refs. 2 and 12. (b)-(i) σ_A/σ_d averaged over Q^2 as a function of x for various nuclei, as well as electron data from Refs. 3 and 11. The error bars are statistical only.

Subsequent to E139 a new measurement[13] was made by the BCDMS group at CERN using high energy muon beams and deuterium, nitrogen, and iron targets. The results for σ_{Fe}/σ_d along with the EMC and SLAC data are shown in Fig. 6. The BCDMS data are taken in the range $25 < Q^2 < 200$ $(GeV/c)^2$ similar to the EMC data. The BCDMS data confirms the effect and agrees with the EMC results where they overlap. This seems to indicate there is no large systematic error in the EMC data which would affect the overall normalization, and tends to strengthen the discrepancy between EMC and SLAC data at low x.

Precisely where the valence quark momentum is shifted when nucleons are bound in heavy nuclei remains a subject of intense theoretical investigation and debate[14]. Some suggestions are that it goes to the glue, to excess ocean quark pairs, to valence quarks at low x, and to valence quarks in the kinematically forbidden region for free nucleons at $x > 1$. It is likely that all these mechanisms



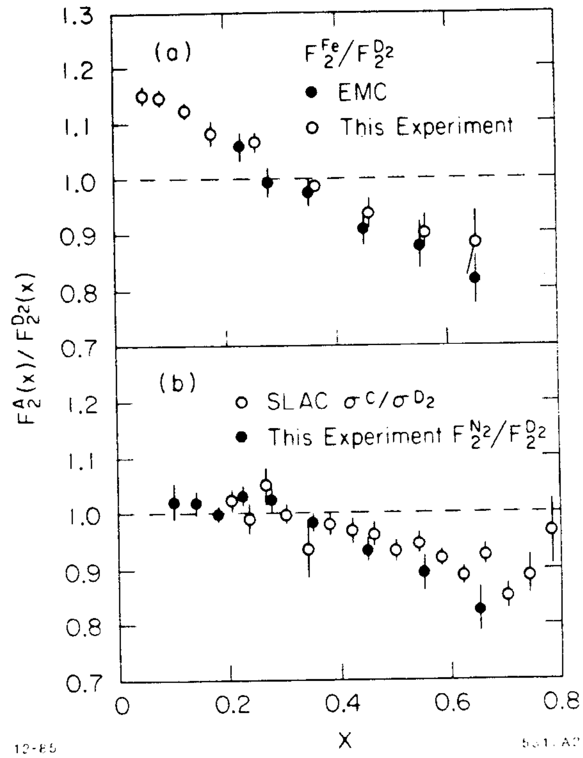


Fig. 5. E139 results for Q^2-averaged ratios σ_A/σ_d versus log A at fixed x. (a)$x = 0.3$, (b) $x = 0.62$. The solid line is a fit of the form $\sigma_A/\sigma_d = cA^{\alpha}$. The errors shown are statistical only.

Fig. 6. a) The ratio of the structure functions F_2 for iron and deuterium as measured by BCDMS (Ref. 13) and EMC (Ref. 2). b) BCDMS nitrogen data compared to SLAC data (Ref. 4) for carbon. Only statistical errors are shown.

play a role to some degree. Untangling this puzzle will take time, and progress would be aided by additional data. In particular it is essential to understand the source of the disagreement between the electron experiments and the EMC experiment for $x < 0.3$.

One suggestion for this difference is that nonscaling is observed, because the EMC data is predominantly at Q^2 above 10 $(GeV/c)^2$ while the electron data at $x < 0.3$ are only in the range $Q^2 = 1$ to 5 $(GeV/c)^2$. We note however that there is no substantial Q^2 variation within the data sets of each experiment [See Fig. 4(a)], and it seems improbable that scaling violations could cause such a large jump between SLAC data at Q^2 of 5 $(GeV/c)^2$ and the muon data at Q^2 of 15 to 20 $(GeV/c)^2$.

Another suggestion is that $R = \sigma_L/\sigma_T$ varies with A. One way to examine the data for variations in R is to look at the ratio σ_A/σ_d versus the virtual photon polarization parameter ϵ, as in Fig. 7. If R is independent of A the ratio σ_A/σ_d at a given x and Q^2 would be constant versus ϵ. The sloped lines in Fig. 7 were obtained by fitting straight lines to the six data points from E139 at $Q^2 = 5$ $(GeV/c)^2$ and $x = 0.3$, 0.5, and 0.7, using the same slope versus ϵ at all x.

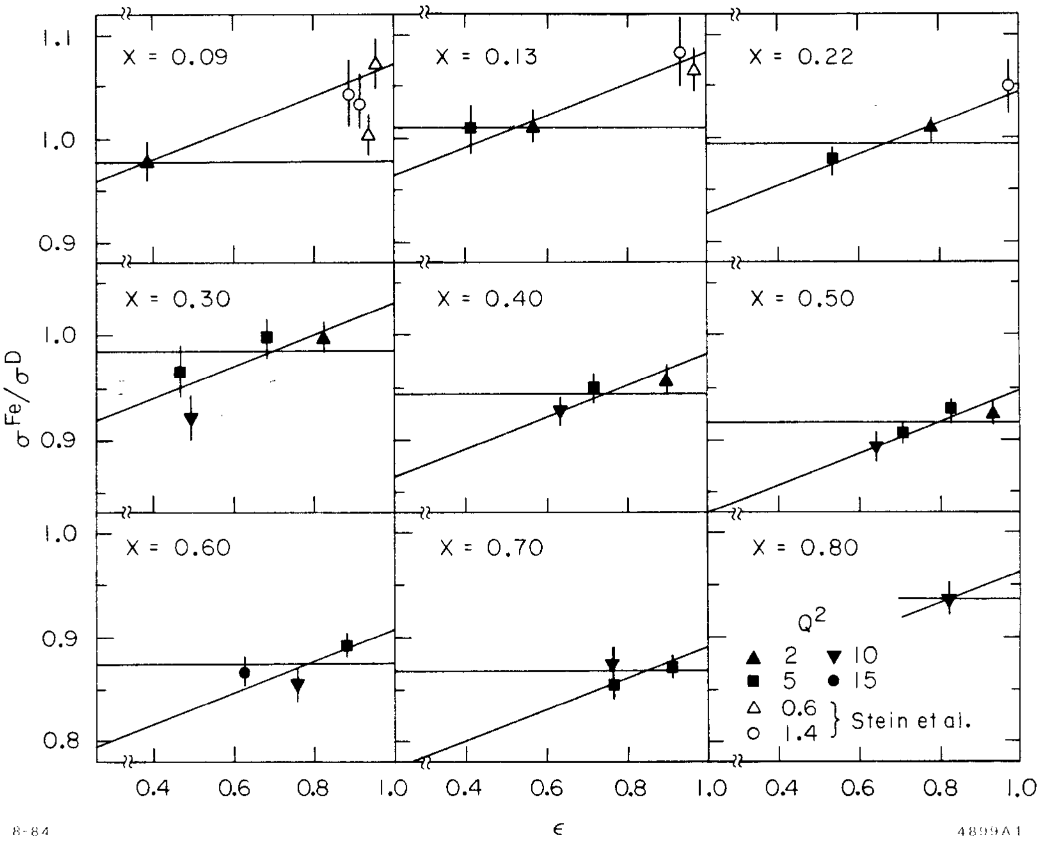


Fig. 7. E139 results for σ_{Fe}/σ_d at various x and Q^2 values versus the virtual photon polarization parameter ϵ. The error bars are statistical only. Also shown are data from a Cu target from Ref. 11.

The data for the other Q^2 values not used in the fit are then plotted for comparison. While the data are limited in ϵ range and in precision, the better agreement of all the data with the sloped lines is suggestive that R may vary with nuclear size ($\chi^2 = 16$ for 14 degrees of freedom for the sloped lines versus $\chi^2 = 35$ for zero slope).

It is interesting to see the effect such a variation in R has upon the extraction of the ratio of structure functions F_2 at $\epsilon = 1$ from the E139 data, as shown in Fig. 8. Note that the EMC data is measured close to $\epsilon = 1$ and thus extraction of F_2 from their cross sections is not very sensitive to uncertainty in R. The improvement in agreement with the EMC data at low x is significant, although the systematic uncertainties on the E139 data are large due to the extrapolation to $\epsilon = 1$.

The main conclusion to be drawn from these observations is that there is a substantial sensitivity at low x to a possible variation of R with A. It remains a mystery why R should vary with nuclear size. More measurements of σ_A/σ_d in the region below $x = 0.3$ are needed to sort out any possible Q^2 dependence.

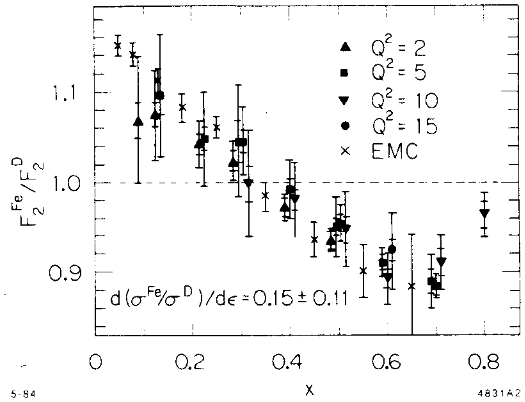


Fig. 8. E139 results for the ratio of deep inelastic structure functions per nucleon F_2^{Fe}/F_2^d extracted at $\epsilon = 1$ from measurements of the section ratios σ_A/σ_d at various ϵ using the slope $d(\sigma_{Fe}/\sigma d)/d\epsilon = 0.15 \pm 0.11$ shown in Fig. 7. The inner error bar is the statistical error, while the outer bar indicates the additional systematic uncertainty from the extrapolation to $\epsilon = 1$. Also shown are the EMC data from Ref. 2.

Also more extensive and accurate measurements of R versus A are needed to see if the present hint of A dependence is real.

2.3 Recent Experiments in the NPAS Program at SLAC

A new program of experiments, called Nuclear Physics at SLAC (NPAS) has recently been approved and funded and is now underway. This program is based upon a new high intensity electron beam produced by a new injector, called the Nuclear Physics Injector (NPI), located at a point 20% from the downstream end of the SLAC linac[15]. The NPI produces electron beams in the energy range 0.5 to 6 GeV with intensity larger by factors of 10 to 50 than presently available from the full SLAC linac in that energy range.

Inclusive threshold inelastic and quasi-elastic scattering. So far two experiments have taken data in the NPAS program. The first Experiment NE3 measured inclusive electron cross sections in the 8 GeV/c spectrometer from a series of nuclei in the kinematic region covering the quasi elastic peak and extending to the inelastic threshold.[16] The kinematic region where the scaling variable $x = Q^2/2M_p\nu$ is larger than one, forbidden for scattering on free nucleons, is sensitive to high momentum components of the nuclear wave functions.

Previous measurements at high Q^2 in this region on deuterium, ^3He, and ^4He have been analyzed[17] by dividing out the nucleon form factors and plotting the results versus the nuclear scaling variable y, which is approximately the component of the bound nucleon momentum parallel to the momentum transfer. This data in Fig. 9 shows a remarkable scaling behavior, which is taken as evidence that up to Q^2 of 4 $(GeV/c)^2$, the virtual photon couples primarily to nucleons. The data plotted versus y are interpreted as a measure of the nucleon momentum distributions, with y extending up to 800 MeV/c. That is a very large internal momentum for systems bound by only a few MeV, and we might expect the high momentum region to contain more exotic phenomena than single nucleon distributions. The present models for ^3He wave functions do not contain enough high momentum components for Fermi smearing of individual nucleons to agree with the data at large y. One suggestion is that some of the high momentum components are carried on nucleon clusters[18] that might be formed when nucleons occasionally make hard collisions in the wave function.

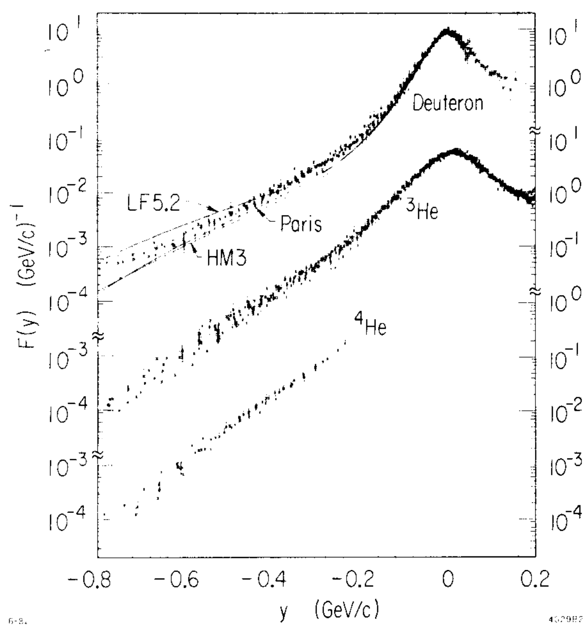


Fig. 9. Experimental values for the nuclear scaling function F(y), obtained from SLAC data on inclusive electron scattering from d, ^3He and ^4He (Ref. 17). The nuclear scaling variable y is approximately the component of the bound nucleon momentum parallel to the momentum transfer.

Some interpretations[19] of the EMC effect in the deep inelastic region suggest that the confinement volumes of individual nucleons may overlap in nuclei causing momentum on the valence quarks to shift, mostly to quarks at lower x. Nucleon clusters would also contain quarks with momentum above $x = 1$, and this could be a source of strength in the cross section at high y in addition to that produced by individual nucleons Fermi smeared up to high momentum.

Another suggested interpretation of the EMC effect is that nucleons swell up in nuclei.[20] This shows up in deep inelastic scattering as a shift in valence quark momentum to lower x, and presumably also implies an increase in the charge radii for bound nucleons. One way to test that hypothesis is to look for modifications of the radii of bound nucleons by measuring quasi elastic electron scattering. There are hints from quasi elastic data[21] at energies below 1 GeV that something strange is happening to nucleons in nuclei. When the data are analyzed assuming that the cross section arises from scattering on a collection of moving nucleons having the same form factors as free nucleons, there is a large suppression of the longitudinal strength. This could be accounted for if the data had been analyzed with the wrong nucleon form factors and bound nucleons have larger charge radii than free ones.

More quasi elastic data on more nuclei extending up to the maximum accessible Q^2 is needed to test all these ideas. The recent NPAS experiment NE3 has extended the quasi elastic data to Q^2 in the range 1 to 3 $(GeV/c)^2$ and to a series of nuclei from ^4He to gold. Analysis of these data is in progress and results will be forthcoming soon. Data at large x and large Q^2 is difficult to obtain because the cross sections decrease rapidly. The high current beam from the new injector at SLAC is important for obtaining this data. The NE3 Experiment was recently approved for another short run planned for January 1986 to extend these measurement further in Q^2 and y.

Another NPAS proposal[22] has recently been made to separate longitudinal and transverse structure functions in the quasi elastic region. The previous data have been taken at only a few angles and are dominated by the transverse cross section. Longitudinal-transverse separations for x above 1 will be important for helping to distinguish among the various proposals for swollen or overlapped nucleons, and to sort out the scattering mechanisms.

Electron-deuteron scattering at 180°. The second NPAS experiment to obtain data was Experiment NE4, a measurement of elastic and inelastic electron scattering from deuterium at scattering angles around 180 degrees to determine the deuteron magnetic structure functions. This experiment was performed in a specially constructed double arm 180 degrees spectrometer in which the elastically scattered electrons were detected in coincidence with the recoiling nuclei. The data taking for the first phase ended in July 1985 and analysis is in progress.

A primary objective of this experiment was to measure the elastic magnetic form factor $B(Q^2)$ out to the largest possible Q^2. The deuteron has three electromagnetic form factors – the charge, quadrupole and magnetic– G_C, G_Q, and G_M. The cross section for electron-deuteron elastic scattering has the form

$$\sigma_d(Q^2) = \sigma_M\left[A(Q^2) + B(Q^2)\tan^2(\theta/2)\right]. \tag{17}$$

The structure function $A(Q^2)$ measured at forward angles is a combination of the squares of all three form factors. The $B(Q^2)$ function depends on G_M only, and it can be extracted from the cross section by measuring at backward angles. The previous data[23] at the highest Q^2 is a measurement of $A(Q^2)$ out to 4 $(GeV/c)^2$. The previous data[24] for $B(Q^2)$ extend only up to $Q^2 = 1$ $(GeV/c)^2$.

There are many ways to view deuteron structure depending upon your starting point in physics. Traditionally the deuteron form factors are calculated in the nonrelativistic impulse approximation as the sum of scattering from the moving neutron and proton. It is expected that the nonrelativistic impulse approximation does not contain the whole story, and that there will be modifications at high Q^2

from scattering on meson exchange currents or from relativistic effects. In the framework of the traditional models, the data can be viewed either as a test of the product of deuteron wave functions and nucleon form factors, or as a search for modifications to the simple impulse picture from higher order effects.

On the other hand if you are interested in looking for quarks in a nucleus, then you would compare the data to the dimensional scaling predictions and look for power law behavior. One of the crucial tests for the applicability of the dimensional scaling ideas is that the form factors must fall smoothly with increasing Q^2, and there can be no diffraction features. Such features would be determined by relatively long range properties of the nucleon interaction (of the order of the nucleon size), not by the hard scattering of the valence quarks interacting at short distance.

Unfortunately by a conspiracy of nature the beautiful diffractive shapes predicted for the individual form factors G_C, G_Q, and G_M in most traditional models are completely merged into a smooth curve when squared and added together in $A(Q^2)$. Therefore the crucial tests of models from the location and size of diffractive features are not possible from data on $A(Q^2)$. We need separate experimental determination of the individual form factors over a range of Q^2. The G_C and G_Q can only be extracted if deuteron polarization in either the initial or final state is measured. The existing data for $A(Q^2)$ and $B(Q^2)$ and three dramatically different predictions for $B(Q^2)$ are shown in Fig. 10.

The desire to measure magnetic form factors for deuterium and other light nuclei out to high Q^2 was a primary motivation for building the new Nuclear Physics Injector at SLAC. These experiments require modest beam energy but the cross sections at backward angles are very small, so the beam intensity must be high to achieve useful counting rates.

The new *ed* elastic data points are at Q^2 of 1.2, 1.5, 1.75, 2.0, 2.25, and 2.5 $(GeV/c)^2$. The magnetic form factor $B(Q^2)$ drops precipitously out to $Q^2 = 2\ (GeV/c)^2$. The last two data points deviate substantially above a smooth curve through the points at lower Q^2. These data perhaps show evidence for a diffraction feature, but it is not possible with only a few data points to see the complete shape of this new feature. The experiment has recently been approved for additional running in 1986; this will be extremely important for uncovering the shape of $B(Q^2)$ above $Q^2 = 2\ (GeV/c)^2$. If a diffraction feature exists, we will learn much about the short range nucleon interaction from its precise location and shape. The existence of a diffraction feature would force us to look to Q^2 higher than $2\ (GeV/c)^2$ for the region where perturbative QCD models are appropriate. This would be a big step forward in our study of the question: Where do we see quarks in nuclei?

3. FUTURE EXPERIMENTS

There are many open questions in the physics of nucleon and nuclear structure that need to be pursued with more electron and muon scattering measurements. There are now in progress, or in the planning stages, several experiments which will aid in this study.

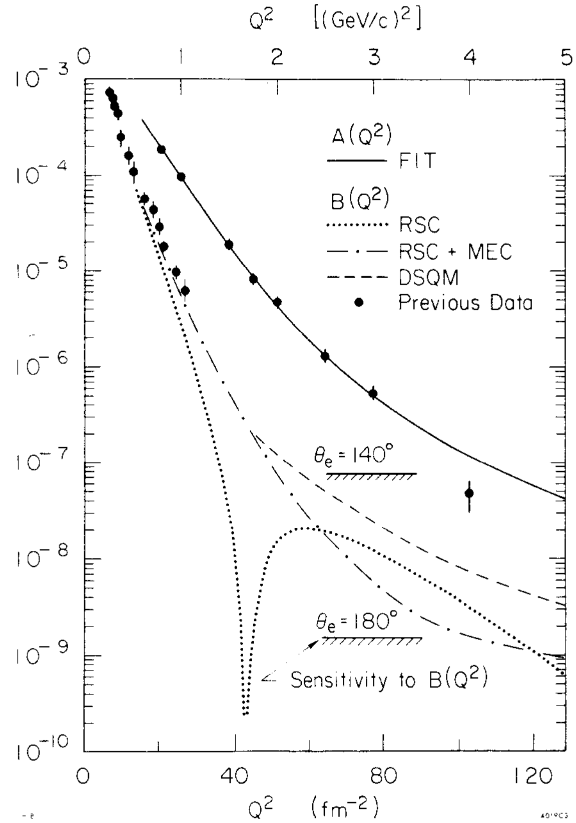


Fig. 10. Deuteron form factors $A(Q^2)$ and $B(Q^2)$. The theoretical curves for $B(Q^2)$ are : RSC – impulse approximation using Reid soft core wave functions; RSC+MEC – Reid soft core plus meson exchange currents (Ref. 25); DSQM – dimensional scaling quark model (Ref. 1) arbitrarily normalized at $Q^2 = 1.75\ (GeV/c)^2$. The sensitivity for measurements of $B(Q^2)$ at large scattering angles is indicated.

A-dependence of $R = \sigma_L/\sigma_T$ at SLAC. A new experiment[26] E140 is presently underway at SLAC to separate longitudinal and transverse structure functions in deep inelastic scattering on hydrogen, deuterium, and some heavy nuclei. The quantity $R = \sigma_L/\sigma_T$ is a fundamental source of information about the internal structure of nucleons. In the standard quark-parton model, and from explicit predictions of perturbative QCD, R is expected to be small. If high energy leptons scatter from individual pointlike quarks with spin-one-half, then contributions to R only arise from quark mass and transverse momentum, and from higher order QCD effects. If there are significant nonperturbative QCD or higher twist effects, in which the lepton scatters on coherent groups of quarks coupled to spin-zero or spin-one, this could give large longitudinal cross sections and larger values of R than perturbative QCD predicts.

Previous measurements have determined that R for hydrogen and deuterium are small, around 0.2 to 0.4, but the experimental uncertainties are large.

The smallest error bars are obtained in electron scattering measurements at SLAC[27] where the high intensity beam and small aperture movable spectrometers gives high statistics data with small systematic errors. Muon experiments generally cannot compete for measurements of R due to lower statistics and larger systematic errors in extraction of angular distributions in fixed angle spectrometers. To date the only measurements of R for heavy nuclei with electrons is the few data points from E139.

Better measurements of absolute values of R on hydrogen and deuterium are essential for determining the relevance of perturbative QCD in the deep inelastic region. New measurements to look for possible A-dependence to R hinted at in the E139 data are essential for understanding the behavior of quarks in the nuclear medium. If R changes with nuclear size, this could be a hint that higher twist terms make a larger contribution to the cross sections in the deep inelastic region than is generally recognized, and that these effects are enhanced when nucleons have many near neighbors.

The E140 experiment aims at high quality absolute measurements of R at selected kinematic points in the region $0.2 \leq x \leq 0.5$ and $2 \leq Q^2 \leq 10$ $(GeV/c)^2$. Relative measurements of R for heavy nuclei (iron) compared to deuterium can be made with even smaller errors because many systematic errors cancel in the ratio of cross sections. This experiment will take data in September-December 1985.

High energy muon scattering from nucleons and nuclei. Two new experiments for improving and extending the structure function data using high energy are in the planning and building stages muon beams. A new collaboration has been formed to continue measurements at CERN using an upgraded version of the EMC apparatus.[28] This experiment aims to obtain data for absolute cross sections on hydrogen, deuterium, and some heavy nuclei, as well as measurements of ratios of structure functions ratios with reduced systematic errors, in the Q^2 region 1 to 200 $(GeV/c)^2$ and x region 0.005 to 0.75. This experiment will be particularly important for exploring the region at low x to look for the x, Q^2 and A-dependence, where the present data gives confusing results. Measurements of the difference in R between lead and beryllium are also planned using various beam energies. Measuring the change in R with nuclear size is easier than absolute measurements because that only depends on cross section ratios and is therefore much less sensitive to systematic errors. Measurements of J/ψ production will be used to examine the modifications of the gluon distributions in heavy nuclei. The previous EMC results[29] showed an enhancement of J/ψ production in iron over that in deuterium. Such data could help pin down the mechanisms for the EMC effect.

Another high energy muon experiment is being constructed to use the new muon beam from the Fermilab tevetron.[30] This experiment will be primarily aimed at studying the final states using a powerful series of detectors to identify and measure the particles emerging from high multiplicity events. So far there is not much theoretical guidance as to how the modifications of the quark distributions in nuclei would affect the particles in the final state. Perhaps this experiment will find effects that give new clues to the behavior of quarks in the nuclear medium.

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