# CEBAF Program Advisory Committee Nine
# Extension and Update Cover Sheet

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**Experiment:** E 89-008

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# Inclusive Scattering from Nuclei at $x > 1$ and High $Q^2$ with a 6 GeV Beam

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We propose an extension to CEBAF Experiment 89-008, an inclusive electron-nucleus scattering experiment in the domain of large $x$ and $Q^2$. Additional measurements with a 6 GeV beam would allow study of the scaling behavior at large $Q^2$ and provide important constraints on the components of the nuclear wave function at large momentum and removal energy.

## I. INTRODUCTION

The physics motivation for this proposed extension is similar to that of the original proposal (89-0008), but with some new components that are the result of several new analyses and theoretical studies. These are discussed in the three following sections. We then discuss the program of measurements to be performed with a 4 GeV beam within the previously approved Experiment 89-008, followed by a presentation of new physics possibilities accessible with a 6 GeV beam.

### A. Connection to DIS

The response of the nucleus in the range $x > 1$ is expected to be composed of both deep-inelastic scattering from quarks in the nucleus and elastic scattering from the bound nucleons (quasielastic). In addition there is the possibility [1] that new non-nucleonic degrees of freedom (eg. 6-quark, 9-quark, etc clusters ) could contribute in this region.

For both the bound quark and bound nucleon cases it is the non-zero momentum of the bound nucleons that permits scattering into a kinematic region that is forbidden for the free nucleon. The scattering from the quarks exhibits scaling in the Bjorken $x$ variable (experimentally verified for $x < 1$), while the scattering from the nucleons exhibits $y$ scaling (discussed below). However the respective scaling functions for the two processes are dramatically different. It is the inclusive structure functions (eg. $\nu W_2^A$) alone that scale for the quark case but for the nucleon case it is the structure functions scaled by the elastic form factors [$G_E(Q^2)$ and $G_M(Q^2)$]. It is this scaling by the form factors, which have a strong dependence on $Q^2$, that causes the quasielastic response to vanish in the limit of $Q^2 = \infty$. In this limit the deep inelastic scattering from the quarks dominates the response for $x > 1$. Thus the two types of scaling appear to be drastically different. A possible connection between the two has been suggested in a new analysis of the previous data [2]. Here the nuclear structure function is analyzed vs the Nachtmann scaling variable [3] $\xi = 2x/[1+(1+4M^2x^2/Q^2)^{1/2}$ and an interesting scaling is suggested (see Fig. 1). However the $Q^2$ range of the previous data is too limited to draw firm conclusions.

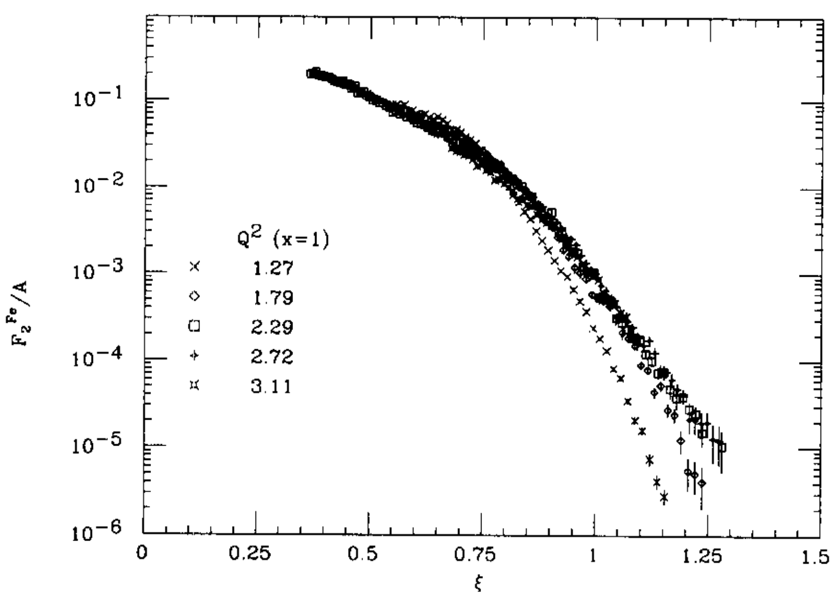


FIG. 1 Nuclear structure function for Fe vs. the Nachtmann scaling variable.

In addition, several recent analyses [4,5] explore the ratio of cross sections for heavy nuclei compared to deuterium. The existing data are shown in Fig. 2 as the ratio of $\sigma^{Fe}/\sigma^D$ at six momentum transfers, $0.9 < Q^2 < 3.2$ GeV/c$^2$. These ratios have some distinctive features. First, at $x \sim 1$ and at all $Q^2$ the ratio of $\sigma^{Fe}/\sigma^D$ is less than one. This is to be expected for quasielastic scattering since the deuteron momentum distribution is narrower than that of iron. As $x$ increases, the ratio rises quickly reflecting the larger fermi momenta in iron as compared to deuterium. By $x \approx 1.3$ the ratios indicate an unexpected plateau. Plateaus in the ratio of DIS scattering of a heavy to a light nucleus has been suggested [1] to result from the presence of 3,6 and 9 – quark clusters in nuclei. Others [4] have argued that these ratios allow a direct measure of the Short Range Correlations (SRC) in nuclei.

Exploring the transition from $y$ scaling to $x$ scaling (i.e. quasielastic to DIS scattering) requires measurements at the highest possible $Q^2$. Measurements with a 6 GeV beam will significantly extend the accessible $Q^2$ range (up to 60%) compared to what is possible with a 4 GeV beam.

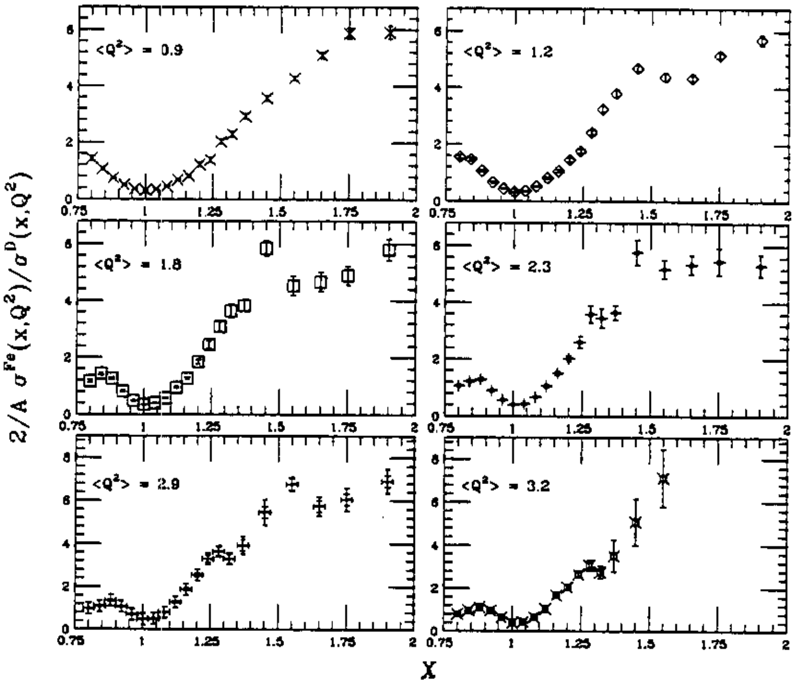


FIG. 2 Ratio of Iron to Deuterium cross sections for six values of four-momentum transfer versus Bjorken $x$. The average $Q^2$ in $(\mathrm{GeV/c})^2$ is given. Data is from SLAC experiments as presented in Ref. 3.

### B. High momentum components

In impulse approximation (IA) the strength at large momentum transfer $Q^2$ and small energy transfer $\nu$ originates from nucleons that have large momenta $k$ before the scattering. The energy of the recoiling nucleon, which is of order $(\vec{k}+\vec{q})^2/2m_N$, is provided by $\nu$. Small $\nu$ and large Q imply $\vec{q} \simeq -\vec{k}$. Study of the inclusive response at low $\nu$ thus allows the study of properties of the nuclear spectral function $S(k,E)$ at large $k$.

In IA, it can be shown [6] that the quasi-elastic cross section should exhibit a scaling behavior in the variable $y$, where $y$ is the minimal momentum allowing energy and momentum conservation and can be calculated from q and $\nu$. This scaling is exact if the spectral function can be approximated by a momentum distribution $\rho(k)$, where $\rho(k)$ is the integral over E of S($k$,E); in this case the scaling function F($y$) can be used to obtain directly the probability to find nucleons of momentum $y$ in the nucleus. Non-negligible spread of S($k$,E) over E leads to deviations from scaling at finite $Q^2$, with convergence of F($y$) to the asymptotic value ($Q^2 = \infty$) from *below* [7].

When going beyond IA, the scaling behavior is changed due to the effect of the final state interaction (FSI) of the recoiling nucleon. This FSI is particularly important for low recoil momenta, *i.e.* low momentum transfer. Near the top of the quasi-elastic peak, the FSI has a relatively small effect, while in the tails, where the IA strength becomes very small due to the small probability of high-$k$ components, FSI can have a major effect, leading to convergence of F($y$) from *above* [8].

The study of the convergence of F($y$) with increasing $Q^2$ yields valuable information on the effect of the FSI and the properties of the spectral function at large $k$. More extensive data in the region of large $Q^2$, but moderate $x$ (moderate $\nu$) would allow a much better understanding of the convergence properties of F($y$).

### C. Response at large $x$

The inclusive response at large $x$ is expected to be dominated by FSI at low $Q^2$. A calculation of this response by Benhar *et al* [8] shows that at very low $\nu$ the effects of FSI completely dominate over the IA contributions resulting from components of large $k$ in the spectral function. The cross section, which is too low in IA, actually becomes *too large* once the purely nucleonic FSI as calculated within correlated Glauber theory are included (see Fig. 3). This shows that the calculated FSI is too strong. One possible reason for this discrepancy is that the struck nucleon experiences a reduced final-state interaction from eg. color transparency [9,10]. The inclusion of color transparency effects, using standard expressions for the effective cross section, leads to good agreement with the data. However the interpretation in terms of color transparency is complicated by the fact that the nucleon is far off-shell.

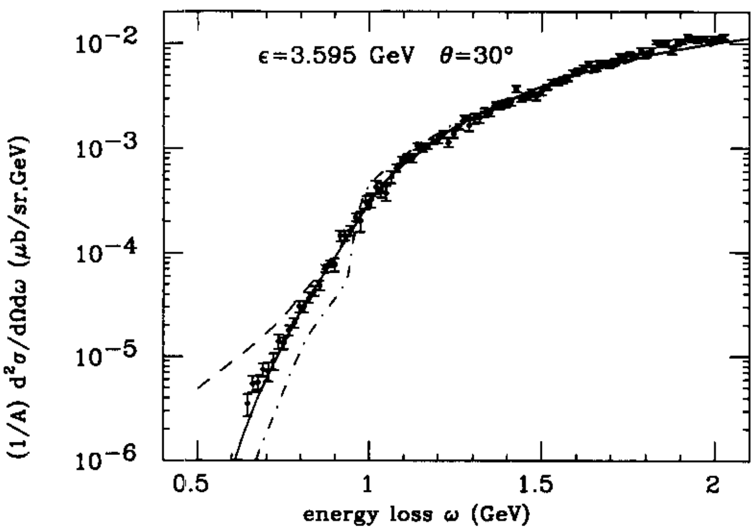


FIG. 3 Inclusive cross section from Fe compared with the calculation of ref. [8]. The curves show Impulse Approximation (dotdash), IA including nucleonic FSI in correlated Glauber theory (dash), and full calculation including color transparency (solid).

Clearly, in order to understand the inclusive response at large $x$, the contribution of FSI needs to be determined. In inclusive scattering the electron is only sensitive to the FSI that occur within a distance of order $1/Q$ of the interaction vertex. Thus, study of the $Q^2$ dependence extending to high $Q^2$ as proposed in this experiment will allow clarification of the role of FSI.

## II. PROPOSED MEASUREMENTS

### A. Expected results from 4 GeV and 6 GeV Running

CEBAF offers the possibility of significant improvement over previous experiments. The solid angle of the HMS as well as it's large momentum acceptance will allow measurements in previously unexplored regions of $x$ and $Q^2$. A program of measurements with 4 GeV beam has been approved (CEBAF 89-008) to run in Hall C in Summer 1995, and will greatly increase the $x$ range of the available data for $1.0 < Q^2 < 8.5$ $(\mathrm{GeV/c})^2$ . Fig. 3 shows the kinematic range in the Bjorken $x$ variable and $Q^2$. The region to the left of the dashed curve indicates the coverage of previous SLAC data, while the unshaded area below the solid curve is what will be measured in CEBAF Experiment 89-008. The $x$ range of the available data for $Q^2 < 2.0$ (GeV/c)$^2$ will almost double to $x = 5.7$ while data for $2.0 < Q^2 < 8.5$ (GeV/c)$^2$ will also be greatly increased.

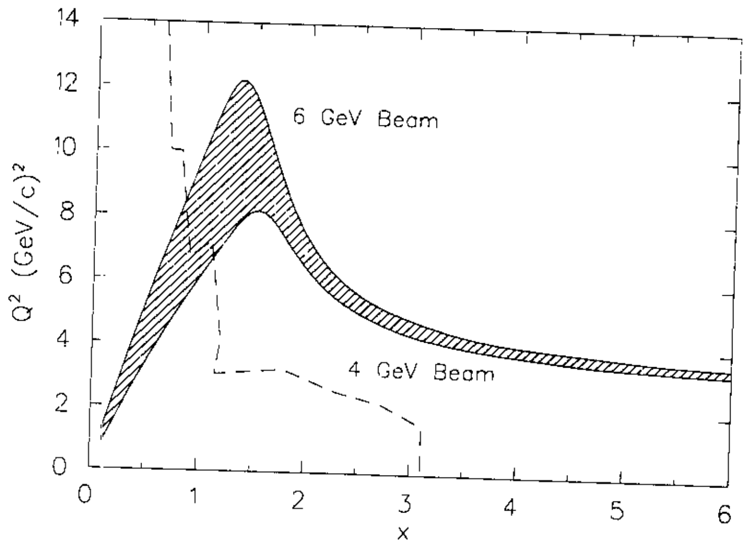


FIG. 4 The kinematic range in $Q^2$ and the Bjorken $x$ variable. The region to the left of the dashed curve is the range of currently available data from SLAC. The unshaded region below the solid curve is the measurement planned for Experiment 89-008. The shaded region indicates the increased range possible with a 6 GeV beam.

An increase in beam energy to 6 GeV would have the greatest impact on the $Q^2$ range for kinematic points with $x < 1.6$. For example, at $x = 1.4$ the $Q^2$ range would increase by 60% from 7.5 to 12.4 (GeV/c)$^2$. This is shown in Fig. 3 where the shaded region below the solid curve indicates the increase in achievable kinematic range with a 6 GeV beam. This extended $Q^2$ data is critical to studies of the transition from scattering from nucleons to scattering from quarks.

## III. EXPERIMENTAL EQUIPMENT

The experimental set-up for measurements with a 6 GeV beam will be the same as used for the 4 GeV measurements. No new detectors or targets will be needed. Data will be taken in the HMS spectrometer using a detector package including a threshold gas Cerenkov counter and a lead glass shower counter for rejection of pion background. Several nuclear targets (eg. $^{12}C$, $^{56}Fe$, and $^{197}Au$) will be used as well as a cryogenic liquid hydrogen target for calibration.

We propose to do the measurements at several angles to cover the full kinematic range. Table I is a list of estimated running times for eight angle settings between $\theta = 20°$ and $90°$. The assumptions are 50 $\mu$A of beam current, a 3% Fe target, a spectrometer solid angle of 7 msr, a momentum bite of 20%, a fixed $x$ bin of 0.05, and a maximum statistical error of 15%.

## IV. REQUEST TO LABORATORY

We request approval to extend the measurements of inclusive scattering from nuclei at $x > 1$ and high $Q^2$ with a 6 GeV beam at CEBAF. The summed run time per target (see Table 1) is approximately 100 hours. An additional 2 hours of overhead for each angle change (total 14 hours), as well as a minimum run time of one hour per momentum setting to account for set-up overhead (total 56 hours) is estimated. The total run time per target is 170 hours. We request measurements on three nuclear targets, as well as hydrogen, for a total beam time request of 600 hours, or 25 beam days.

* Also with Hampton University.


[1] J. P. Vary, *Nucl. Phys.*. A478:397c, 1984.
[2] B. Filippone *et al. Phys. Rev.* C45:1582, 1992.
[3] H. Georgi and H. D. Politzer. *Phys. Rev.* D14:1829, 1976.
[4] L. Frankfurt, M. Strikman, D. Day, and M. Sargsyan. *Phys. Rev.* C48:2451, 1993.
[5] O. Benhar, A. Fabrocini, S. Fantoni, and I. Sick. *Nucl. Phys. A*, in print, 1994.
[6] I. Sick, D. Day, and J.S. McCarthy. *Phys. Rev. Lett.*, 45:871, 1980.
[7] D.Day, J.S.McCarthy, T.W. Donnelly, and I. Sick. *Ann.Rev.Nucl.Part.Sci.*, 40:357, 1990.
[8] O. Benhar, A.Fabrocini, S. Fantoni, G.A. Miller, V.R. Pandharipande, and I. Sick. *Phys. Rev.*, C44:2328, 1991.
[9] A. Mueller. *Proc. 17th Rencontre Moriond. Ed. J.Than Thanh Van, Ed. Front., Gif-sur-Yvette*, page 13, 1982.
[10] S.J. Brodsky. *Proc. 13th Int. Symp. on Multiparticle Dynamics. World Scient. Singapore*, page 963, 1982.


TABLE I. Kinematics of the proposed extension to CEBAF Experiment 89-008 for each target.

| $\theta$ (deg) | E′ (GeV) | $x_{range}$ | $y_{range}$ (GeV/c) | $Q^2_{range}$ (GeV/c)$^2$ | time (*hrs*) |
|---|---|---|---|---|---|
| 20.0 | 3.5 - 5.3 | 0.5 - 2.9 | -0.8 - 0.3 | 2.5 - 3.8 | 10 |
| 30.0 | 2.2 - 4.1 | 0.5 - 1.8 | -0.6 - 0.4 | 3.5 - 6.6 | 19 |
| 40.0 | 1.4 - 3.0 | 0.5 - 1.5 | -0.4 - 0.4 | 4.0 - 8.5 | 11 |
| 50.0 | 1.0 - 2.1 | 0.5 - 1.3 | -0.2 - 0.4 | 4.4 - 9.2 | 4 |
| 60.0 | 0.8 - 1.8 | 0.5 - 1.3 | -0.3 - 0.4 | 4.5 - 10.6 | 16 |
| 70.0 | 0.6 - 1.4 | 0.5 - 1.3 | -0.2 - 0.4 | 4.7 - 10.9 | 12 |
| 80.0 | 0.5 - 1.1 | 0.5 - 1.2 | -0.2 - 0.4 | 4.8 - 11.2 | 13 |
| 90.0 | 0.4 - 0.9 | 0.5 - 1.2 | -0.2 - 0.4 | 4.9 - 11.4 | 15 |