CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

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Experiment: E -

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CEBAF EXTENSION

Measurement of the Nuclear Dependence and Momentum Transfer Dependence of Quasielastic (e,e′p) Scattering at Large Momentum Transfer

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I. Physics Motivation

The Color Transparency (CT) conjecture by Mueller and Brodsky [1] has stimulated great interest. CT was first discussed in terms of perturbative QCD considerations. However, recent work [2] indicates that this phenomenon occurs in a wide variety of model calculations with nonperturbative reaction mechanisms. The existence of CT requires that high momentum transfer scattering should take place via selection of amplitudes in the initial and final state hadrons characterized by a small transverse size. Secondly, this small object should be 'color neutral' outside of this small radius in order not to radiate gluons. Finally, this compact size must be maintained for some distance in traversing the nuclear medium. Unambiguous observation of CT would provide a new means to study the strong interaction in nuclei.

Experimentally, measurements of the transparency of the nuclear medium to high energy protons in quasielastic A(p,2p) and A(e,e′p) and to ρ mesons have been carried out over the last several years. The nuclear transparency measured in A(p,2p) at Brookhaven [3] has shown a rise consistent with CT but decreases at higher momentum transfer. The NE-18 A(e,e′p) measurements at SLAC [4] yield distributions in missing energy and momentum completely consistent with conventional nuclear physics predictions and the extracted transparencies exclude sizable CT effects up to $Q^2 = 7$ $(GeV/c)^2$ (see Fig. 1). At Fermilab the nuclear transparencies have been measured [5] in exclusive incoherent ρ^0 meson production from nuclei. Increases in the nuclear transparencies have been observed as the virtuality of the photon increases, as expected from CT.

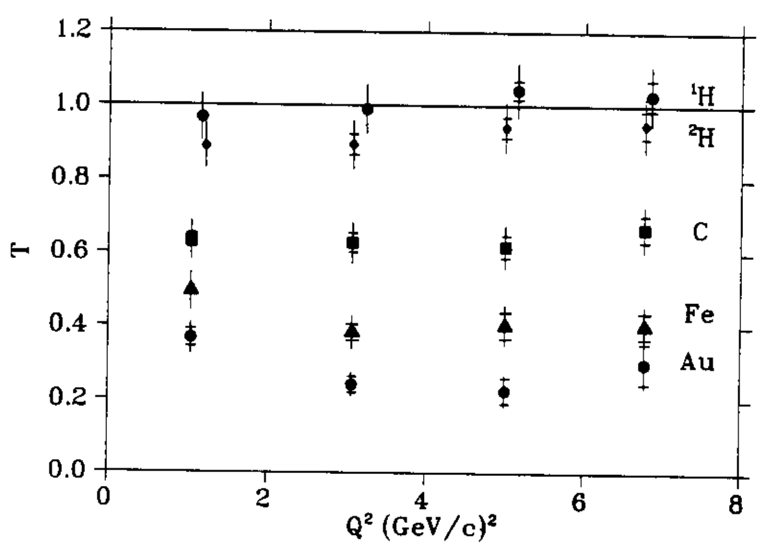

Figure 1. Nuclear transparencies for $A(e,e'p)$ as a function of Q^2 from SLAC experiment NE-18.

CEBAF has several advantages to offer in searching for CT effects in quasielastic A(e,e′p) measurements. Data from experiments NE18 at SLAC and E91-013 and E91-007 at CEBAF will provide a baseline for conventional Glauber calculations; the fundamental electron-proton scattering cross-section is smoothly varying and accurately known in this kinematic range; the high duty factor, the high luminosity, the large solid angle high momentum Hall C spectrometers and the high missing energy resolution all contribute to making high quality, precision measurements feasible. In particular, the high missing energy resolution at high Q^2 will provide an unprecedented opportunity to study the dependence of the nuclear transparency on the initial proton state. As the beam energy at CEBAF increases the momentum transfer accessible also rises. 6 GeV beam energy allows measurements at almost 9 $(GeV/c)^2$.

We propose to measure the nuclear transparency in quasielastic (e,e′p) scattering from nuclei to the highest momentum transfers accessible at CEBAF. In this extension we request 342 hours of 6 GeV beamtime to measure the quasielastic cross-section at Q^2 = 7.5 and 8.7 $(GeV/c)^2$. As shown in Fig. 2 this will allow us to distinguish between conventional Glauber calculations and state-of-the-art CT predictions of Nikolaev *et al.* [6] and Frankfurt *et al.* [7].

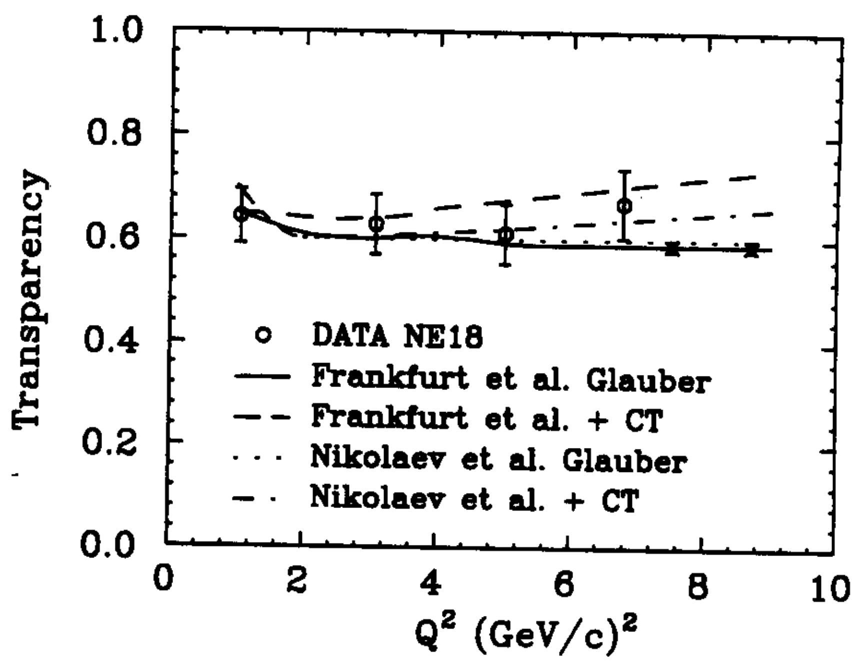

Figure 2. The nuclear transparency for carbon from NE-18 together with theoretical predictions which include CT effects for the kinematics of the proposed measurements. Statistical uncertainties of 1% are expected at the proposed kinematics (crosses).

II. The Experiment

The proposed experiment will measure the (e,e′p) cross section as a function of A and Q^2 at the highest Q^2 attainable at CEBAF. This proposal will extend the Q^2 range of the approved experiments E91-013 and E91-007 to 8.7 $(GeV/c)^2$. Experiments E91-013 and E91-007 will measure the (e,e′p) reaction at momentum transfer values of 0.8, 1.3, 1.9, 3.8, and 6.2 $(GeV/c)^2$, and are scheduled to run in 1995 in Hall C. At the highest Q^2 proposed here one hopes to see conclusive effects of color transparency, the effect of the diminishing of Final-State Interactions if the scattering occurs on a small object.

At each Q^2 we intend to perform $^1H(e,e'p)$ calibration experiments. Further we intend to use the target nuclei ^2H, ^4He, ^{12}C and ^{56}Fe. The use of ^2H as a second calibration target to check radiative corrections contributions has proved to be very valuable for the analysis of the NE18 data. Note that in experiments E91-013 and E91-007 the lowest count rates are obtained for the heaviest target nuclei ^{197}Au, which we do not intend to use.

The SOS and HMS spectrometers in Hall C will be used to detect the scattered electron and the knocked-out proton.

III. Count Rate and Running Time Estimates

3.1 Kinematics

The full kinematics, chosen to be close to the top of the quasielastic peak, are given in Table 3.1. At each Q^2 we will measure an angular distribution (perpendicular kinematics) and carry out measurements of the spectral function $S(E,\mathbf{p})$ over a large missing energy range and a large missing momentum range. The kinematics extend to 300 MeV in missing energy. The missing momentum range covered extends up to 600 MeV/c.

Table 3.1. Kinematics for the proposed (e,e′p) experiments.

Q^2	E	E′	$\theta_{e'}$	p′	θ_q	θ_p
$(GeV/c)^2$	GeV	GeV	deg	GeV/c	deg	deg
7.5	6.0	1.98	47.0	4.87	17.3	17,20
8.7	6.0	1.35	62.5	5.51	12.6	12,14

The phase space acceptances are such that at the large values of Q^2 proposed here. only two kinematic settings are sufficient, given the large acceptances of the SOS and HMS spectrometers.

3.2 Count Rate Estimates

We have assumed the following spectrometer acceptances: for SOS ± 20 % in momentum and a solid angle of 9 msr, for HMS ± 10 % in momentum and a solid angle of 6.4 msr. As SOS can see only 4 cm transverse length of the extended target (for a spectrometer angle of 90 degrees), a target thickness of 200 mg/cm^2 has been used in the estimates for a ^{4}He target nucleus (assuming a high-pressure cryogenic gas target at a temperature of 20 K and a pressure of 20 atm). For the measurements on ^{1}H and ^{2}H we assume liquid targets of 4 cm length, but will reduce the beam currents to 60 μA only, corresponding to a safe limit of 100 W of power dissipated in the target. The count rates estimated assume a 3% radiation length ^{12}C and a 3% radiation length ^{56}Fe target. The coincidence count rate N_C is calculated from the five-fold differential cross section, the beam current, the target thickness, and the angular and momentum acceptances. The coincidence cross section for the discrete transition is given in PWIA by:

$$\frac{d^5\sigma}{dEd\Omega_e d\Omega_x} = \int_{\Delta E_m} \frac{d^6\sigma}{dE_e dT_x d\Omega_e d\Omega_x} \frac{\partial T_x}{\partial E_m} dE_m = \frac{E_x|\mathbf{p_x}|}{1 - \frac{E_x}{E_{A-1}} \frac{\mathbf{p_{A-1}} \cdot \mathbf{p_x}}{\mathbf{p_x^2}}} \sigma_{ep}\rho(|\mathbf{p_m}|).$$

Here $\rho(|\mathbf{p_m}|)$ is the single-particle momentum distribution and for σ_{ep} we used the off-shell electron-proton cross section description σ_{cc}^1 by De Forest.

We have written a Monte Carlo code to estimate the expected count rates for different E_m and p_m slices. We use numerical input spectral functions, taken from fits to previous data, corrected for Final-State Interaction effects. Final-State Interaction effects are estimated by using a global absorption probability, estimated from Glauber calculations.

Coincidence rates for ^{56}Fe(e,e′p) are given in Table 3.2, assuming an average current of 100 μA. Table 3.2 also shows the (e,e′) and (e,p) singles rates. We assume that the negatively charged pions will be rejected by the electron trigger, using a combination of the Cherenkov and the Shower Counter in the detectors. This worked satisfactorily for rejecting pions in the NE18 experiment. The electron singles rate is determined by adding both the inclusive quasielastic contribution and the Fermi-smeared deep-inelastic contribution. The hadron singles rate is determined from parameterization of previous measurements with incident Bremsstrahlung photons of energy 5-19 GeV. This parameterization gave good agreement with measured hadron singles rates in NE18. The real-to-random ratio has been determined by assuming a resolving time of 2 ns.

Table 3.2. Single-arm counting rates, coincidence rate and the real-to accidental coincidence ratio R/A for the proposed kinematics. All rates are given for a 3% radiation length ^{56}Fe target. Coincidence rates are given for the central proton spectrometer setting. A coincidence resolving time of 2 ns and a duty factor of 100% have been assumed in the calculation of R/A. Coincidence rates are given for the missing energy region up to 100 MeV. Time requested is the sum for all target nuclei, including ^{1}H calibrations.

Q^2	(e,e′)	(e,h)	$N_C(I)$	R/A	Time
$(GeV/c)^2$	[Hz]	[Hz]	[hr^{-1}]		[hr]
7.5	5	280	125	1.7×10^4	84
8.7	3	100	50	3.5×10^4	210

The total time requested is the sum for all target nuclei, including ^{1}H calibrations, and will yield 5,000 counts in the ^{56}Fe(e,e′p) reaction, and 10,000 counts in all other reactions.

3.3 Beam Time Request

We request 342 hours of beamtime to extend the approved experiments 91-013 and 91-007 to momentum transfer values of 7.5 and 8.7 $(GeV/c)^2$, for the target nuclei ^{2}H, ^{4}He, ^{12}C, and ^{56}Fe. Note that only a few kinematics settings are required here, such that only a small amount of overhead is included in the requested beam time. The experiment will yield good statistical precision for all target nuclei, i.e. at least 10,000 events for ^{2}H, ^{4}He, and ^{12}C, and 5,000 events for ^{56}Fe. The beam time required is 84 hours for a momentum transfer value of 7.5 $(GeV/c)^2$, 210 hours for the maximum momentum transfer value of 8.7 $(GeV/c)^2$, and 48 hours of checkout. The total beam time requested is thus 342 hours or 14 days (see Table 3.3).

References

[1] A.H.Mueller, in *Proceedings of the Seventeenth Recontre de Moriond Conference on Elementary Particel Physics, Les Arcs, France, 1982*, edited by J. Tran Thanh Van (Editions Frontieres, Gif-sur-Yvette, France,1982); S.J.Brodsky, in *Proceedings of*

Table 3.3. Beam time request.

	Time [hours]
Data Acquisition: extension of E91-007 to $Q^2 = 7.5$	84
Data Acquisition: extension of E91-007 to $Q^2 = 8.7$	210
Data Acquisition: Checkout	48
TOTAL	342

the Thirteenth International Symposium on Multiparticle Dynamics, Volendam, The Netherlands, 1982, edited by W. Kittel *et al.* (World Scientific, Singapore, 1983).

[2] L. Frankfurt, G.A. Miller, and M. Strikman, Comments Nucl. Part. Phys., **21**, 1 (1992).

[3] A.S. Carroll *et al.*, Phys. Rev. Lett. **61**, 1698 (1988).

[4] N.C.R. Makins *et al.*, Phys. Rev. Lett. **72**, 1986 (1994).

[5] M.R. Adams *et al.*, FERMILAB-PUB-94/233-E, submitted to Phys. Rev. Lett.

[6] N.N. Nikolaev *et al.*, Phys. Rev. C **50**, R1296 (1994).

[7] L.L. Frankfurt *et al.*, in Workshop on 'CEBAF at Higher Energies', Eds. N. Isgur and P. Stoler, Conf. Proc. p. 499 (1994).

HAZARD IDENTIFICATION CHECKLIST

CEBAF Proposal No.: ____________ (For CEBAF User Liaison Office use only.) Date: ____________

Check all items for which there is an anticipated need.

Cryogenics

- ___ beamline magnets
- ___ analysis magnets
- √ target

type: LH2, LD2
flow rate: 2 ℓ/s
capacity: 200 W

Electrical Equipment

- ___ cryo/electrical devices
- ___ capacitor banks
- ___ high voltage
- ___ exposed equipment

Radioactive/Hazardous Materials

List any radioactive or hazadorous/ toxic materials planned for use:

____

____

____

____

Pressure Vessels

- ___ inside diameter
- ___ operating pressure
- ___ window material
- ___ window thickness

Flammable Gas or Liquids

type: ____________
flow rate: ____________
capacity: ____________

Drift Chambers

type: ____________
flow rate: ____________
capacity: ____________

Other Target Materials

- ___ Beryllium (Be)
- ___ Lithium (Li)
- ___ Mercury (Hg)
- ___ Lead (Pb)
- ___ Tungsten (W)
- ___ Uranium (U)
- ___ Other (list below)

____

____

Vacuum Vessels

- ___ inside diameter
- ___ operating pressure
- ___ window material
- ___ window thickness

Radioactive Sources

- ___ permanent installation
- ___ temporary use

type: ____________
strength: ____________

Large Mech. Structure/System

- ___ lifting devices
- ___ motion controllers
- ___ scaffolding or elevated platforms

Lasers

type: ____________
wattage: ____________
class: ____________

Installation:

- ___ permanent
- ___ temporary

Use:

- ___ calibration
- ___ alignment

Hazardous Materials

- ___ cyanide plating materials
- ___ scintillation oil (from)
- ___ PCBs
- ___ methane
- ___ TMAE
- ___ TEA
- ___ photographic developers
- ___ other (list below)

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General:

Experiment Class:

- ___ Base Equipment
- ___ Temp. Mod. to Base Equip.
- ___ Permanent Mod. to Base Equipment
- ___ Major New Apparatus

Other: ____________

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BEAM REQUIREMENTS LIST

CEBAF Proposal No.: ______________________ Date: ______________
(For CEBAF User Liaison Office use only.)

List all combinations of anticipated targets and beam conditions required to execute the experiment. (This list will form the primary basis for the Radiation Safety Assesment Document (RSAD) calculations that must be performed for each experiment.)

Condition #	Beam Energy (MeV)	Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Target Material Thickness (mg/cm²)
1.	6000	60	–	4 cm LH_2	280
		60	–	4 cm LD_2	685
		100	–	^4He T=20K p=20 atm	200
		100	–	3% ^{12}C	1300
		100	–	3% ^{56}Fe	400

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. For 1995, E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Starting in 1996, in an evolutionary way (and not necessarily in the order given) the following additional values of E_{Linac} will become available: E_{Linac} = 400, 500, 600, 700, 900, 1000, 1100, and 1200 MeV. The sequence and timing of the available resultant energies, E_{Beam}, will be determined by physics priorities and technical capabilities.

LAB RESOURCES REQUIREMENTS LIST

CEBAF Proposal No.: ____________________ Date: ____________________
(For CEBAF User Liaison Office use only.)

List below significant resources — both equipment and human — that you are requesting *from CEBAF* in support of mounting and executing the proposed experiment. Do not include items that will be routinely supplied to all running experiments, such as the base equipment for the hall and technical support for routine operation, installation, and maintenance.

NO NEW EQUIPMENT REQUIRED, BASE EQUIPMENT ONLY

***Major Installations** (either your equip. or new equip. requested from CEBAF)*

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets

Power Supplies

Targets

Detectors

Electronics

Computer Hardware

Other

Other