CEBAF PROPOSAL COVER SHEET

This Proposal must be mailed to:

CEBAF
Scientific Director's Office
12000 Jefferson Avenue
Newport News, VA 23606

and received on or before 1 October 1991.

A. TITLE:

Study of Nuclear Medium Effects by Recoil Polarization upto High Momentum Transfers

B. CONTACT PERSON:

A. Saha, CEBAF

ADDRESS, PHONE, AND ELECTRONIC MAIL ADDRESS:

Physics Division, CEBAF
(804) 249-7605
SAHA@CEBAF

C. IS THIS PROPOSAL BASED ON A PREVIOUSLY SUBMITTED PROPOSAL OR LETT OF INTENT?

[ ] YES [x] NO

IF YES, TITLE OF PREVIOUSLY SUBMITTED PROPOSAL OR LETTER OF INTENT

****

(CEBAF USE ONLY)

Receipt Date 27 SEP 91

Log Number Assigned PR-91-006

By [redacted]

Proposal to the CEBAF PAC5

Study of Nuclear Medium Effects by Recoil Polarization up to High Momentum Transfers

J. Gomez, J. LeRose, J. Mougey, S. Nanda, A. Saha (Spokesperson), P.E. Ulmer
Continuous Electron Beam Accelerator Facility

J.M. Finn, P. Markowitz and P. Rutt
College of William and Mary

R. Lourie and S. VanVerst
University of Virginia

C.C. Chang, H. Holmgren and P.G. Roos
University of Maryland

R. Gilman, C. Glashausser and R. Ransome
Rutgers University

K. Aniol, M. Epstein and D. Margaziotis
California State University at Los Angeles

Contact Person: A. Saha (CEBAF)

Submitted: *September 27, 1991*

In the absence of any nuclear medium effects the normal component of the polarization of the recoiling proton P_n in an (e,e$'\vec{p}$) reaction should be zero to first order. This effect can therefore be used to great advantage as an effective filter in the study of FSI phenomena in nuclei and to also observe the onset of color transparency in nuclei at high momentum transfers. We would therefore carry out this experiment (e,e$'\vec{p}$) on deuterium (^{2}H) and other nuclei (^{4}He, ^{12}C and ^{16}O) at essentially the same kinematics for each nuclus in the Q^2 range of 1 to 6 (GeV/c)^2. The reaction would also be performed on the proton, where $P_n = 0$ at all momentum transfers (due to absence of FSI).

INTRODUCTION

The effect of the nuclear medium on the propagation of nucleons is of fundamental importance in the study of the nuclear many body problem. At present there is no consistent set of theories to describe this phenomena. At lower energies non-relativistic optical potentials are used to describe the propagation of the proton through the nucleus, at medium energies (200 MeV to 1 GeV) relativistic formalisms are used and at very high energies the Glauber model for the scattering of protons on nuclei is employed. Spectroscopic factors derived from (e,e′p) reactions at low outgoing proton energies have always shown a quenching of the order of 20% to 40% from the shell model values after all distortions of the proton have been taken into account, contrary to results obtained from hadron scattering reaction studies. It is possible that various effects such as relativistic dynamics (most of the low energy (e,e′p) studies were analyzed with non-relativistic formalisms), off shell effects and final state interactions are important and should be incorporated in the analysis. It would also be of great help to isolate these effects and study their importance. In this respect, new observables which are sensitive to specific aspects of the reaction mechanism e.g. spin response functions, would be very useful to study.

In the absence of any nuclear medium effects the normal component of the polarization of the recoiling proton P_n in an $(e,e'\vec{p})$ reaction should be zero to first order. This effect can therefore be used to great advantage as an effective filter in the study of FSI phenomena in nuclei and to also observe the onset of color transparency in nuclei at high momentum transfers. We would therefore carry out this experiment $(e,e'\vec{p})$ on deuterium (^{2}H) and other nuclei (^{4}He, ^{12}C and ^{16}O) at essentially the same kinematics for each nucleus in the Q^2 range of 1 to 6 $(GeV/c)^2$. The reaction would also be performed on the proton, where $P_n = 0$ at all momentum transfers (due to absence of FSI).

PHYSICS OVERVIEW

Introduction

Electron scattering reactions have provided a wealth of information about the structure of nucleons and nuclei. Since electrons interact weakly with the nuclear system and since the electromagnetic interaction is well understood, one can deduce quantitative information about the electromagnetic structure of the nucleus under study. By detecting particles emitted from the nucleus in coincidence with the scattered electron one can derive more detailed information of the reaction than in single arm (e,e′) measurements alone. Quasielastic (e,e′p) coincidence reactions can be described in the impulse approximation as a one step process with the virtual photon coupling to the free nucleon current and can therefore directly measure the single particle structure of the nucleus. In the Plane Wave Impulse Approximation (PWIA) assuming one-photon exchange, the coincidence (e,e′p) cross section can be factored into an elastic off-shell electron proton cross section σ_{ep} and the proton spectral function $S(\vec{p}_R, e_m)$ which contains all the nuclear structure information[1]:

$$\frac{d^6\sigma}{d\vec{e'}d\vec{p'}} = K\sigma_{ep}S(\vec{p}_R, e_m) \tag{1}$$

where K is a kinematic factor, p_R is the recoil momentum and e_m the missing mass of the residual system.

$$\vec{p}_R = -\vec{p}_i = \vec{p'} - \vec{q}$$

$$e_m = \omega - T_{p'} - T_R$$

The nuclear spectral function $S(\vec{p}_R, e_m)$ denotes the joint probability of finding a nucleon of momentum $\vec{p}_R$ and separation energy e_m in the target nucleus. In Distorted Wave Impulse Approximation (DWIA), due to Final State Interactions (FSI), the initial momentum of the nucleon is no longer related to $\vec{p}_R$ the factorization is no longer valid. However, if the optical potential is spin independent, the factorization in eqn. 1 is still valid provided $S(\vec{p}_R, e_m)$ is replaced by the distorted spectral function $S^D(\vec{p}_R, e_m, \vec{p'})$.

If the spectral function is corrected for distortions and integrated over the recoil momentum $\vec{p}_R$ and the missing energy e_m, then one should obtain the total number of protons in the nucleus:

$$\int\int S(\vec{p}_R, e_m)d\vec{p}_R de_m = Z \tag{2}$$

Due to limitations in beam energy and low duty factors of existing facilities (Saclay, Mainz and Bates) most (e,e′p) studies of nucleon and nuclear structure have been performed at low Q^2 values ($\leq 0.5\ (\text{GeV/c})^2$). At these low Q^2 values, various effects dealing with the interaction of the recoiling nucleon with the residual nucleus have to be taken into account before any reliable nuclear structure information can be inferred. The study of the spectroscopic sum rule (eqn. 2) has therefore been carried out in the shell model region with $\vec{p}_R \leq 300$ MeV/c and $e_m \leq 100$ MeV and is shown in figure 1.

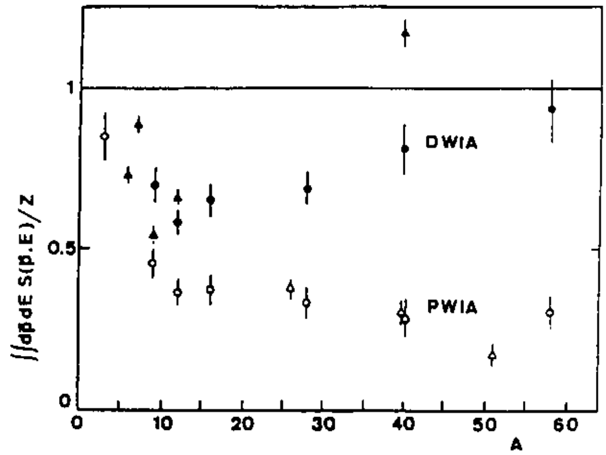

Figure 1. *The spectroscopic sum rule obtained in (e,e'p) reactions* [1].

It is quite obvious that the sum rule is violated in practically all nuclei at the level of 20 % to 40 %. This indicates that processes other than those assumed to be of single particle nature contribute (e.g. three-body forces etc.). It is hoped that at higher values of Q^2 ($\geq 1(\mathrm{GeV/c})^2$), these final state interactions (FSI) gradually decrease and the reaction becomes more single particle in nature. No reliable data exists here and one of the goals of the present study would be to investigate this region.

QCD predictions

At high Q^2 one would naively expect the predictions of perturbative QCD (PQCD) for quasielastic (e,e'p) to become evident. In these kinematic regions, the possible occurence of "color transparency" (CT) has been predicted by Brodsky[2] and Muller[3]. This can be qualitatively understood by considering the expansion of the hadronic wave function onto a complete basis set of Fock states representing free quarks and gluons. Since the amplitudes for exclusive processes involve a factor $1/Q^2$ for each constituent[4], at large momentum transfer the valence state, corresponding to the lowest number of constituents, is expected to be dominant. This is evidently the three quark $|qqq\rangle$ point like configuration (p.l.c.). Since this Fock state has small color electric dipole moment it interacts only weakly with nuclear matter. If such a hadron absorbs a large momentum without additional particle production, it is contracted to a small size whose transverse spatial extent is given by $1/Q$ from the uncertainty principle. It then evolves back to its standard configuration within a distance from the interaction point, l_h, which increases with increasing Q^2, due to virtual emission of $q\bar{q}$ and gluons. Explicit models to describe the evolution of the hadronic cross section associated with the occurance of color transparency, in the context of the parton model and PQCD have been proposed[5,6]. An experiment to measure the effect of color transparency in proton-nucleus scattering has recently been performed at Brookhaven[7]. The data agree fairly well with the PQCD model proposed[5] up to incident proton momenta of 10 GeV/c, while showing a completely different behaviour at higher momenta.

Experimental evidence of color transparency can also be inferred from (e,e'p) electron scattering reactions at high momentum transfers by studying the A and Q^2 dependence of the nuclear absorption of the knocked out proton. Color transparency is expected to lead to a modification of the final state interaction (FSI) of the struck nucleon with respect to the prediction of the conventional picture in which the nucleons are assumed to be structureless. Frankfurt, Strikman and Zhalov[8] have examined the possibility to observe color transparency in (e,e'p) reactions to specific final hole states in the residual (A-1) nucleus. If color transparency is absent or the length of path, l_h, which is necessary for expansion of p.l.c. to normal proton size is small in comparison to nuclear radius R ($l_h \leq$ R), one expects that $\sigma[A(e,e'p)A-1] \sim A^{2/3}\sigma_{ep}$ because of strong absorption in the center of the nucleus due to proton - residual nucleus FSI. If on the other hand, $l_h \gg$ R, then one should expect $\sigma[A(e,e'p)A-1] \sim A\sigma_{ep}$.

The effective p-N interaction is then written in the form[8]:

$$\sigma_{pN}^{eff} = \sigma_{pN}^{tot}[\{(\frac{z}{l_h})^v + \frac{\langle n^2 k_t^2\rangle}{Q^2}(1-(\frac{z}{l_h})^v)\}\Theta(l_h - z) + \Theta(z - l_h)] \qquad (3)$$

where σ_{pN}^{tot} = 40 mb is the total NN cross section, $\langle n^2 k_t^2\rangle \sim 1$ (GeV/c)^2, $\Delta m^2 = 0.7$ (GeV/c)^2 (which agrees reasonably with the BNL data[7]) and the expansion length given by $l_h = 2p_N/\langle\Delta m^2\rangle$. Here $v = 0$ corresponds to the classical Glauber model i.e. no transverse shrinkage, $v = 1$ corresponds to the quantum diffusion model (PQCD) and $v = 2$ is the prediction of the naive parton model.

Calculations were performed[8] for the lowest s- and p- levels in ^{12}C, ^{16}O and ^{40}Ca. Distorted spectral functions $F(k, p_N)$ (which is the same as our previous $S^D(\vec{p}_R, e_m, \vec{p}'))$ is shown in figure 2 for the $1s_{1/2}$ and $1p_{3/2}$ levels in ^{12}C.

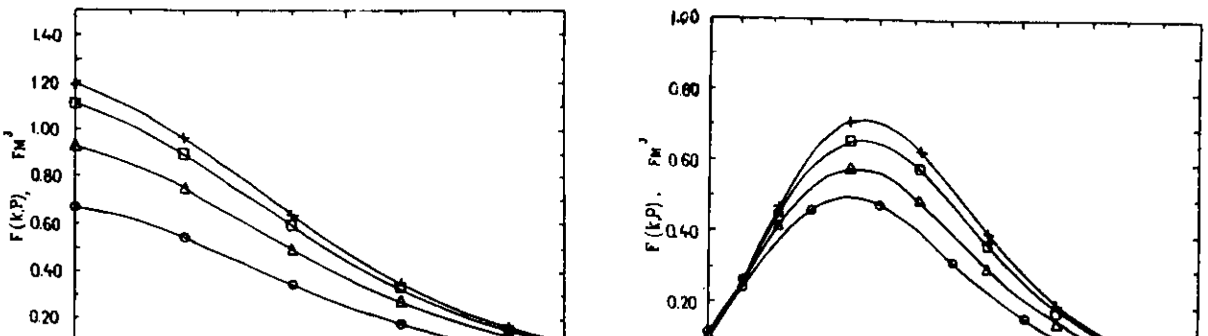

Figure 2. *12C(e,e'p) reaction for (a) the $1s_{1/2}$ shell and (b) the $1p_{3/2}$ shell. Calculations[8] for the momentum distributions F(k,p_N) for no transparency (standard Glauber theory): v=0 (circles); and for v = 1 for p = 5 GeV/c (triangles); p = 10 GeV/c (squares) and p = 15 GeV/c (plusses).*

The total nuclear transparency effect is defined as

$$\eta = \frac{Z_{eff}}{Z} = \frac{1}{Z}\int d^3k \int de_m S^D(\vec{p}_R, e_m, \vec{p}')$$

A plot of this function as a function of Q^2 in the kinematics of this proposal is shown in figure 3 for ^{12}C and ^{16}O.

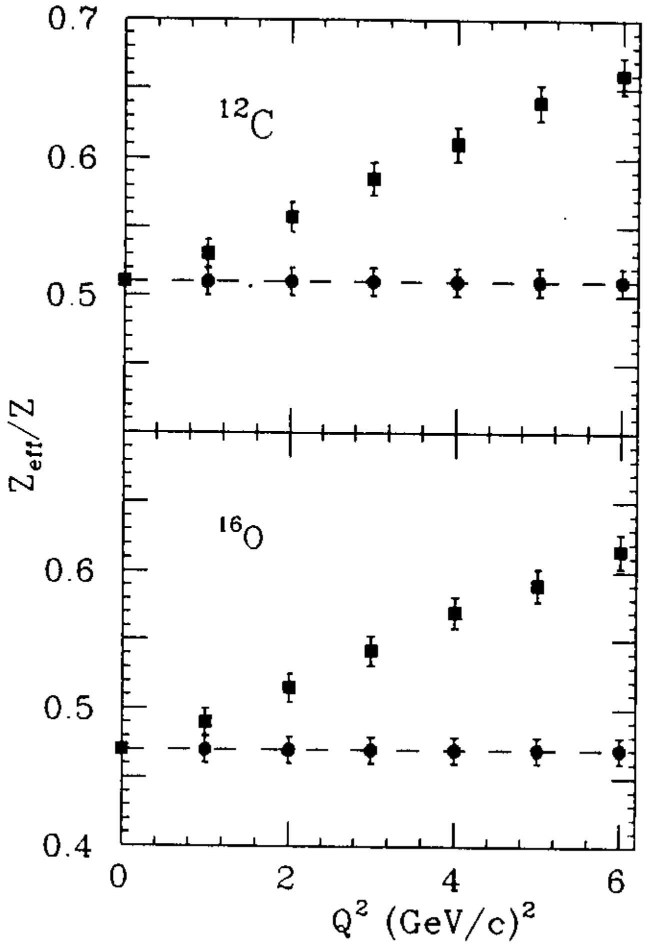

Figure 3. *The nuclear transparency factor η for $^{12}C(e,e'p)$ and $^{16}O(e,e'p)$ reactions, denoted as squares*[8] *for $v = 1$ (PQCD), as compared to predictions of the standard Glauber model (no color transparency) denoted as circles as a function of Q^2. The errors on the points reflect the 2% experimental uncertainty (<1 % of which is due to statistical uncertainty) on the cross section determinations with which we are able to extract η.*

We see that there is a 30 % effect in the change in transparency of the hadron as it moves through these nuclei (^{12}C and ^{16}O) at Q^2 values between 1 and 6 $(GeV/c)^2$ as predicted in (e,e'p) reactions[8]. Since we shall be able to determine the quantity η from our cross section measurements, we should be able to determine this effect if it exists.

Spin Response

In this proposal we look for other variables, unlike the cross section measurements, which are sensitive only to the FSI of the outgoing nucleon. Spin degrees of freedom of the recoiling nucleon give additional information on the study of nuclear structure and are sensitive to many features of the reaction mechanism. For in-plane measurements, the normal component of the measured recoil polarization, P_n, is independent of the polarization of the beam and vanishes in PWIA due to time reversal symmetry[9]. Hence it can be used as a effective filter in the study of final state interactions (FSI).

The full $(\vec{e},e'\vec{p})$ reaction cross section involving both a polarized beam and the recoil proton polarization can be expressed in terms of 18 independent response functions[9] . It can be expressed as:

$$\begin{aligned}\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_p} = \frac{m|\vec{p}\,'|}{2(2\pi)^3}\left[\frac{d\sigma}{d\Omega_e}\right]_{Mott} & \times \{v_L(R_L + R_L^n S_n) + v_T(R_T + R_T^n S_n) \\ & + v_{TT}\left[(R_{TT} + R_{TT}^n S_n)\cos 2\beta + (R_{TT}^l S_l + R_{TT}^t S_t)\sin 2\beta\right] \\ & + v_{LT}\left[(R_{LT} + R_{LT}^n S_n)\cos\beta + (R_{LT}^l S_l + R_{LT}^t S_t)\sin\beta\right] \\ & + h v_{LT'}\left[(R_{LT'} + R_{LT'}^n S_n)\sin\beta + (R_{LT'}^l S_l + R_{LT'}^t S_t)\cos\beta\right] \\ & + h v_{TT'}(R_{TT'}^l S_l + R_{TT'}^t S_t)\}\end{aligned} \tag{4}$$

The 18 independent response functions, R, are functions of $\vec{q}$, ω, T_p (the proton kinetic energy) and θ_{pq} (the angle included by the proton and $\vec{q}$). The v's are the known kinematic factors weighting the various virtual photon polarization states and β is the angle between the electron scattering plane and the plane containing $\vec{q}$ and the detected proton. $[d\sigma/d\Omega_e]_{Mott}$ is the Mott cross section and S's are the three components of a unit vector pointing along the proton spin direction.

For an unpolarized beam (h=0) and in-plane kinematics (β = nπ), this reduces to:

$$\boxed{\frac{d^3\sigma}{d\omega d\Omega_e d\Omega_p} = \sigma_0[1 + P_n]} \tag{5}$$

where

$$\sigma_0 = K[v_L R_L + v_T R_T + v_{TT} R_{TT}\cos 2\beta + v_{LT} R_{LT}\cos\beta]$$

$$P_n = \frac{K}{\sigma_0}[v_L R_L^n + v_T R_T^n + v_{TT} R_{TT}^n \cos 2\beta + v_{LT} R_{LT}^n \cos\beta]$$

and $$K = \frac{m|\vec{p}\,'|}{2(2\pi)^3}\left[\frac{d\sigma}{d\Omega_e}\right]_{Mott}$$

In coplanar kinematics only the normal polarization component is helicity independent as it is an induced polarization. Therefore with an unpolarized beam, only P_n survives. Since P_n is determined from a ratio of sums of response functions it is therefore much less susceptible to systematic errors (e.g. beam luminosity, etc.).

Fully relativistic calculations of the $(e,e'\vec{p})$ reaction on ^{16}O at Q^2 = 0.93 $(GeV/c)^2$ has been performed by Van Orden[9] using Dirac distorted waves for the ejected proton and Dirac-Hartree wave functions for the bound state. The results are shown in figure 4 for the $1p_{3/2}$ (g.s.) and the $1p_{3/2}$ (6.32 MeV) levels. We see that $P_n = 0$ for the case of relativistic PWIA (dashed curves) which indicates the absence of any distortions for the ejected proton.

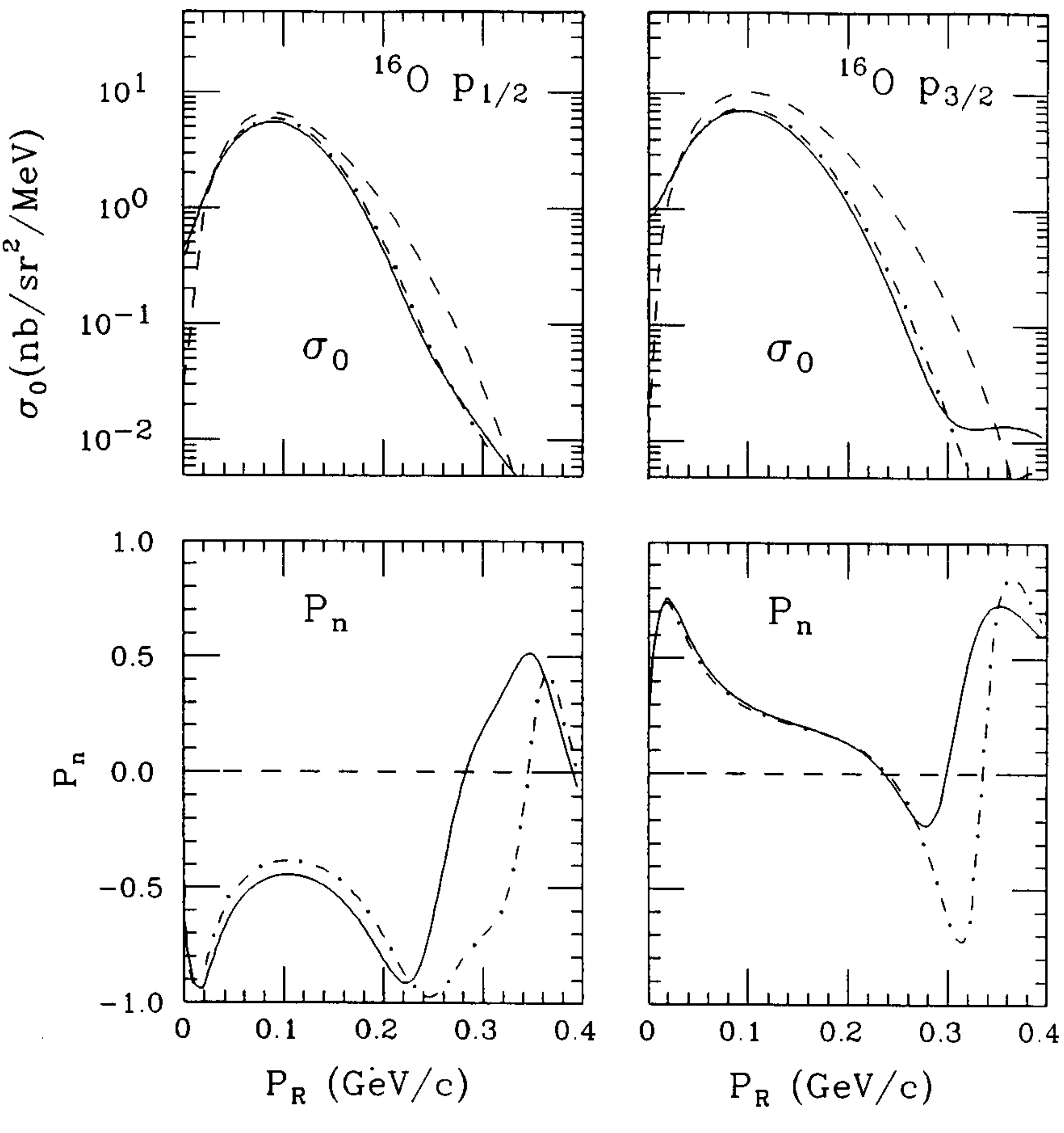

Figure 4. *The cross section σ_0 and the polarization vector, P_n, for the $^{16}O(e,e'\vec{p})$ reaction for the $1p_{1/2}$ and $1p_{3/2}$ levels at an incident electron energy of 4 GeV and Q^2 = 0.93 $(GeV/c)^2$. Calculations*[9] *are shown for Dirac DWIA (solid line), for nonrelativistic DWIA (dot-dashed line) and for relativistic PWIA (dashed line).*

PROPOSED EXPERIMENT

Overview

The proposed experiment involves measuring the $(e,e'\vec{p})$ reaction in quasielastic kinematics (see table 1) on various nuclei (^1H, ^2H, ^4He, ^{12}C and ^{16}O) and measuring both the unpolarized cross section σ_0 , and the normal component of the polarization of the recoiling proton, P_n. The experiment does not involve a polarized beam, but does require a focal plane polarimeter in the hadron arm to measure P_n. The beam energy is kept fixed at 4 GeV to measure the Q^2 range from 1 to 6 $(GeV/c)^2$. The various Q^2 kinematics are shown in Table 1 for the case of ^{16}O where the momentum distribution of the $p_{3/2}$ state (at E_x = 6.32 MeV) peaks at a p_R value of 80 MeV/c. The same kinematics was also used for ^{12}C since its g.s. $(1p_{3/2})$ also peaks at $p_R \simeq 80$ MeV/c. For ^1H, ^2H, and ^4He, the calculations were done at $p_R = 0$. The electron kinematics remain the same in the two cases, whereas the proton kinematics change only slightly. Also shown in Table 1 are the kinematics for the 6 GeV incident electron beam which will enable us to reach Q^2 = 8 $(GeV/c)^2$. In this table, $\epsilon = A_c^2 f$ is the efficiency of the polarimeter.

Table 1: Kinematics

Q^2 $(GeV/c)^2$	e_i (GeV)	e_f (GeV)	θ_e (deg)	q (GeV/c)	θ_p (deg)	p (GeV/c)	T_p (GeV)	χ (deg)	$\epsilon = A_c^2 f$ $\times 10^{-3}$
1	4.0	3.467	15.43	1.133	58.41	1.109	0.515	125	17.5
2	4.0	2.934	23.82	1.771	44.53	1.750	1.048	171	7.8
3	4.0	2.401	32.82	2.357	35.03	2.237	1.580	216	5.6
4	4.0	1.868	42.91	2.923	27.33	2.904	2.113	262	4.7
5	4.0	1.335	57.86	3.478	20.26	3.460	2.646	308	4.0
6	4.0	0.803	86.24	4.028	12.58	4.009	3.179	354	3.5
6	6.0	2.803	34.76	4.028	24.48	4.009	3.179	354	3.5
7	6.0	2.270	42.01	4.573	20.38	4.535	3.712	399	3.25
8	6.0	1.737	51.97	5.116	16.38	5.098	4.245	445	3.0

The hall A high resolution spectrometers are well suited for this study. The kinematical ranges of both spectrometers are utilized in this experiment. The high resolution of the spectrometers will be necessary to separate the discrete states in the residual nucleus and also to control systematic errors and reduce accidental rates and background. Examples of (e,e'p) reaction spectra for ^4He[10], ^{12}C[11] and ^{16}O[12] are shown in figure 5. With the present setup of the Hall A spectrometers we shall obtain a missing energy resolution of $\sim$ 1 MeV or better at all Q^2 and be able to examine a missing energy range of $\sim$ 100 MeV (in each setting) even at the lowest Q^2 value. The experiment proposed here requires that the hadron spectrometer be equipped with a focal plane polarimeter (FPP) with good performance up to T_p = 3.2 GeV.

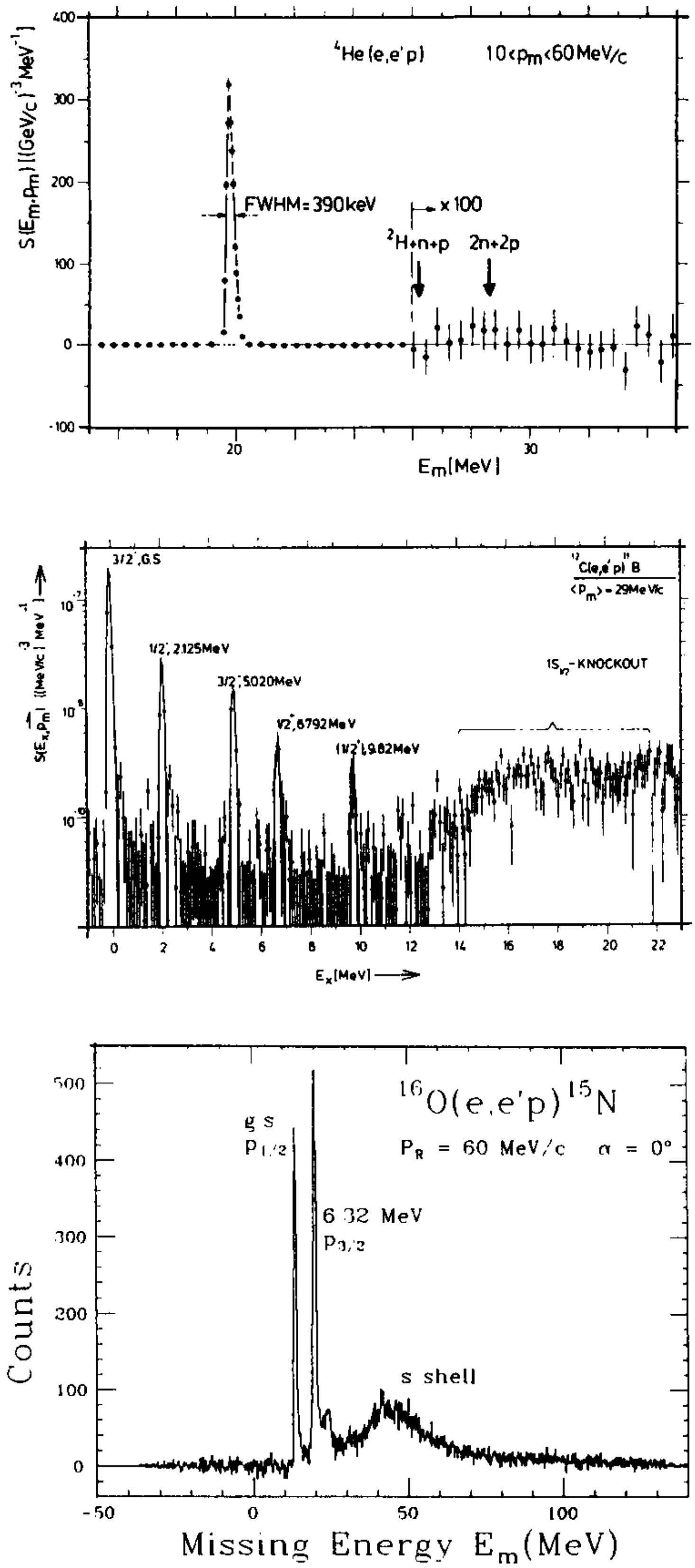

Figure 5. *Missing energy spectra for the (e,e'p) reactions on* ^4He[10], ^{12}C[11] *and* ^{16}O[12].

Targets

We shall use cryotargets for the ^{1}H, ^{2}H, and ^{4}He targets which are being developed by the Hall A collaboration[13]. The $LH_2$and LD_2 targets will operate at 20K and a pressure of 17 atm. which is suitable for suppression of macro bubble formation. The ^{4}He gas target will operate at 10K at 70 atm. The targets cells for these targets will have a physical length of 10 cm and will be able to operate with beam currents of 150 μA. The design specifications will allow initial operation of these targets at moderate levels of power dissipation (200-500 W) at a luminosity of 1.5 x 10^{38} ($cm^{-2}s^{-1}$).

The ^{12}C target will be a solid target foil of thickness 500 mg/cm^2. With a beam current of 150 μA, a luminosity of 2.35 x 10^{37} ($cm^{-2}s^{-1}$) can be achieved. The ^{16}O target will be a gas target of 10 cm length at a density of 50 mg/cc. Alternatively, we could use a vertically oriented cylindrical flowing water target of diameter 5 mm and having 2 micron (1.6 mg/cm^2) thick Havar walls (the total wall thickness will be less than 1% of the target thickness). With a beam current of 150 μA, a luminosity of 1.76 x 10^{37} ($cm^{-2}s^{-1}$) can be achieved. The count rate estimates in Table 2 use these values of luminosities for the various targets.

Focal Plane Polarimeter

The focal plane polarimeter (FPP) in the hadron spectrometer is being developed by the Hall A collaboration and its design is similar in principle to the ones used successfully at other hadron facilities (LAMPF, IUCF, TRIUMF and SATURNE). A full description of the polarimeter is given in the CEBAF Conceptual Design Report[13] and only its parameters relevant to this proposal will be discussed here.

In principle, one can measure the left-right and up-down asymmetries in the scattering of the protons from a thick carbon analyzer, thus yielding the normal P_X and sideways P_Y components of the polarization of the proton in the focal plane. Due to the precession of the spin of the proton through the spectrometer, these quantities are related to the polarization of the proton at the target. At the focal plane, one measures the azimuthal distribution (after the second scattering from the carbon block) given by:

$$N(\theta,\phi) = N_0(\theta)[1 + P_Y A_c \sin\phi + P_X A_c \cos\phi] f(\theta,\phi) \tag{5}$$

where θ and ϕ are the polar and azimuthal scattering angle in the analyzer; $N_0(\theta)$ is the unpolarized cross section, $A_c(\theta)$ is the analyzing power of the analyzer and $f(\theta,\phi)$ is the acceptance function of the FPP. A Fourier decomposition of the complete azimuthal distribution thus determines the transverse components of the proton polarization P_X and P_Y for known analyzing powers.

Due to the precession of the proton polarization in the spectrometer, the measured quantities P_X and P_Y at the FPP are related to the polarizations at the target point in coplanar kinematics ($\beta = 0$) by:

$$\begin{aligned} P_X &= P_n \cos\chi + P_l' \sin\chi \\ P_Y &= P_t' \end{aligned} \tag{6}$$

where the precession angle χ is given by $\chi = \left(\frac{g-2}{2}\right)\gamma\Omega$ and g is the proton g-factor(=5.586), γ is the Lorentz factor ($=E_p/m$) and Ω is the total bend angle for the spectrometer central ray.

For an unpolarized beam (h=0) we obtain

$$
\begin{aligned}
P_X &= P_n cos\chi \\
P_Y &= 0
\end{aligned}
\tag{7}
$$

and the distribution function reduces to

$$
N(\theta,\phi) = N_0(\theta)[1 + (P_n \cos\chi A_c)\cos\phi] f(\theta,\phi) \tag{8}
$$

We therefore see that the normal component of the proton polarization P_n can be easily obtained from the amplitude of the cosine function. To maximize this amplitude, one needs to maximize A_c and $cos\chi$. The statistical uncertainty in the measured polarization is given by:

$$
\Delta P_n = \frac{\pi}{2}\sqrt{\frac{1}{N_o\epsilon}} \tag{9}
$$

where the efficiency of the FPP is defined as $\epsilon = A_c^2 f$ and $f = N_F/N_0$ is the useful fraction of events accepted by the FPP. N_0 is the number of particles incident on the FPP after the first scattering at the experimental target.

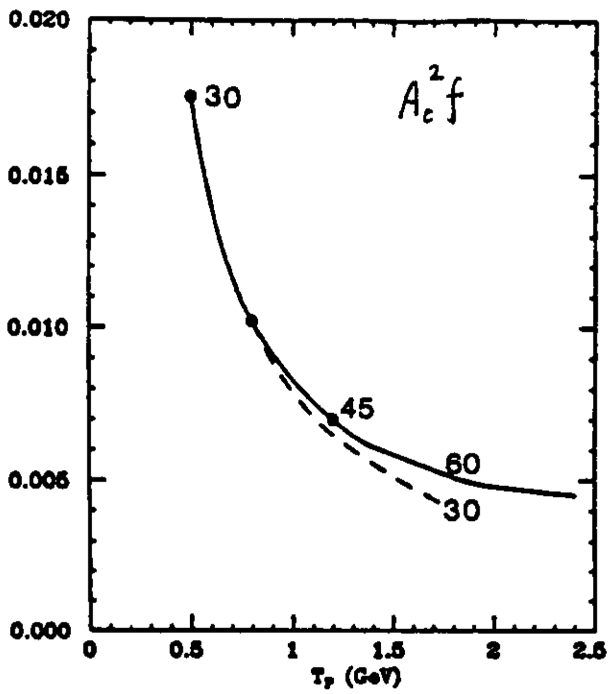

Figure 6. *Values of efficiency $\epsilon = A_c^2 f$ for the polarimeter used in the present proposal. The full circles correspond to the calibration points from Saclay. The full line follows a graphite schedule considered for CEBAF; the thickness is increased from 30 cm at 0.5 GeV up to a maximum of 60 cm above 1.8 GeV. The dashed line is for constant graphite thickness d = 30 cm (ρ of 1.7 gm/cm^2).*

The material for the analyzer is usually taken to be carbon for intermediate energies due to its large analyzing power in the forward angle cone ($\theta = 5°$ to $20°$). At higher energies ($T_p \geq 2$ GeV) no calibration data exists and so the analyzer will have to be calibrated. We propose here a self-calibration technique as has been described in Proposal PR-89-014[14]. The method uses the simultaneous measurement of the sideways (P_t) and the longitudinal (P_l) components of the proton polarization for elastic p($\vec{e}$,e'$\vec{p}$) and values of G_{Mp} and G_{Ep} from the existing or forthcoming data pool at the same T_p values as the polarization experiment. Table 1 includes the precession angle, χ, and the values of the efficiency parameter $\epsilon = A_c^2 f$. The values of ϵ were taken from a smooth extrapolation of the curve in figure 6, and also given in Proposal PR-89-014[14].

Count Rate Estimates and Time Request

Count rate estimates were made assuming the standard spectrometer acceptances of the two Hall A high resolution spectrometers[13]. The singles (e,e') and (e,p) rates have been calculated with the codes QFSV and EPC[15] and are never a problem even at the most forward electron kinematics (lowest Q^2 value).The coincident (e,e'p) reaction cross sections were calculated with the Monte-Carlo computer program MCEEP[16]. This code performs a folding of the cross section over the experimental acceptances and gives realistic count rate estimates. In determining the cross section, we assume the Plane Wave Impulse Approximation (PWIA) which enables the (e,e'p)cross section to be factored into an elementary off-shell *ep* cross section times the spectral function which contains all the nuclear structure information[1]:

$$\sigma_{eep} = K\sigma_{ep}\frac{1}{\eta}S(\vec{p}_R, \epsilon_m)$$

where K is a kinematical factor and η is a recoil factor. For the off-shell ep cross section, σ_{ep}, we have used the "CC1" presciption of de Forest[17]. For the various nuclei, we have used different bound state spectral functions which have then been normalized to obtain the experimentally determined values at the respective p_R values (0 or 80 MeV/c).

We find that the accidental coincidence rates, determined from the singles rates in each arm, is very small in all cases compared to the true coincidences. The signal to noise ratio (trues to accidentals) is therefore extremely favourable in all cases ($\geq 10^4$) and is therefore not explicitly tabulated. The (e,e'p) rates are given in Tables 2 and 3 for each nucleus. The time required to obtain a certain precision in the determination of ΔP_n (see equation 9) is also given in these tables. In figure 7 we show how well we shall be able to measure the polarization vector, P_n, absolutely for the light nuclei (^{1}H, ^{2}H and ^{4}He) and ^{16}O. Calculations[9] for P_n at the lowest Q^2 value (~ 1 (GeV/c)^2) for the $1p_{3/2}$ level of ^{16}O shows that it is about 0.36 and for the $1p_{1/2}$ level it is about -0.47 (see figure 4). We see that the highest Q^2 data point requires an inordinately long running time to obtain reasonable values for ΔP_n especially for ^{12}C and ^{16}O and a judicious choice has to be made between measuring the $Q^2 = 5$ (GeV/c)^2 with better statistics at the expense of the $Q^2 = 6$ (GeV/c)^2 point.

It is the development of this vector, P_n, as a function of Q^2 and A which is the motivation of this proposal. At present, no such calculations exist to predict its behaviour, but several theorists have shown considerable interest in pursuing this further and are setting up their programs to study this effect[6,8]. It is expected that eventually P_n should decrease to zero at some high value of Q^2 for all nuclei. This would signal the onset of color transparency and the region where PQCD becomes applicable. One could then use the (e,e'$\vec{p}$) reaction as a useful tool to study PQCD in nuclear interactions in these regions.

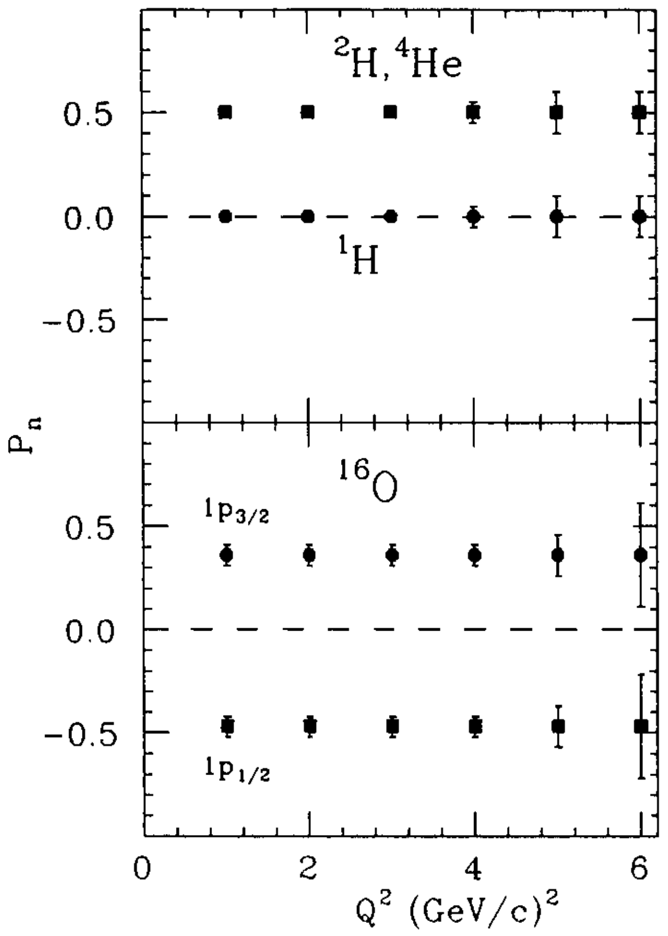

Figure 7. *Projected absolute uncertainties in P_n from the proposed (e,e'$\vec{p}$) experiment on the light nuclei (^1H, ^2H and ^4He) and ^{16}O permit distinguishing between various models. For ^1H, $P_n = 0$ for all Q^2 values, whereas for ^2H and ^4He the $P_n = 0.5$ value was chosen for illustrative purposes only to show the absolute uncetainty with which we are able to determine P_n. Calculations [9] for P_n for ^{16}O at $Q^2 \sim 1.0\ (GeV/C)^2$ for the $p_{3/2}$ level is $\sim$ 0.36 and for the $p_{1/2}$ level is $\sim$ -0.47. See figure 4.*

In figure 3, we show the model predictions[8] of the parameter Z_{eff}/Z as a function of Q^2 for ^{12}C and ^{16}O. This parameter Z_{eff}/Z is obtained from the cross section measurements and we are able to determine this very precisely ($\pm$2%, the statistical errors are $\leq$ 1%) as a byproduct in our effort to measure the normal polarization component P_n. The horizontal dashed lines are the predictions without any color transparency whereas the square points indicate the calculations with color transparency. The errors with which we shall be able to determine either prediction with this proposed experiment is also shown with each point.

The run time for the experiment can be divided basically into two parts and is summarized in Table 4. The data taking on the lighter nuclei ^{1}H, ^{2}H and ^{4}He will require cryotargets and can be completed in approximately 190 hours. The heavier ^{12}C and ^{16}O targets will require approximately 437 hours of running time. A setup time of 25 hours is requested for tests and calibration and for angle/field changes.

References

[1] S. Frullani and J. Mougey, *Advances in Nuclear Physics*, vol. **14**, ed. J.W. Negele and E. Vogt, Plenum Press (1985).

[2] S.J. Brodsky, in *Proceedings of the Thirteenth International Symposium on Multiparticle Dynamics*. Eds. E.W. Kittel, W. Metzger and A. Stergion (World Scientific, Singapore), 963 (1982).

[3] A. Muller, in *Proceedings of the Seventh Recontre de Moriond.* Ed. J. Thran Thanh Van (Editions Frontieres, Gif-sur-Yvette), 13 (1982).

[4] S.J. Brodsky and G.R. Farrar, Phys. Rev. Lett. **31**, 1153 (1973).

[5] G.R. Farrar *et al*, Phys. Rev. Lett. **62**, 1095 (1989).

[6] O. Benhar, priv. comm..(1991).

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

[8] L.L. Frankfurt, M.I. Strikman and M.B. Zhalov, Nucl. Phys. **A515**, 599 (1990) and M.B.Zhalov, priv. comm. (1990).

[9] A. Picklesimer *et al*, Phys. Rev. **C32**, 1312 (1985); A. Picklesimer and J.W. van Orden, Phys. Rev. **C40**, 290 (1989); J.W. van Orden, priv. comm. (1991).

[10] J.F.J. van den Brand *et al*, Phys. Rev. Lett. **60**, 2006 (1988).

[11] G. van der Steenhoven *et al*, Phys. Lett. **156B**, 151 (1985).

[12] L. Chinitz *et al*, Phys. Rev. lett. **67**, 568 (1991).

[13] Conceptual Design Report, Basic Experimental Equipment, CEBAF, (1990).

[14] CEBAF Proposal PR-89-014 Spokespersons: C.F. Perdrisat, V. Punjabi (1989).

[15] J.W. Lightbody and J.S. O'Connell, Computers in Physics, 57 (1988).

[16] P.Ulmer, Computer Program MCEEP (1989).

[17] T. de Forest, Nucl. Phys. **A392**, 232 (1983).

Table 2: Count Rate Estimates for ^{1}H, ^{2}H, ^{4}He

Q^2	Proton (^{1}H)			Deuteron (^{2}H)			^{4}He $s_{\frac{1}{2}}$ (g.s.)		
$(GeV/c)^2$	cts/hr	t(hrs)	ΔP_n	cts/hr	t(hrs)	ΔP_n	cts/hr	t(hrs)	ΔP_n
1	3.66E 7	<0.1	0.01	1.74E 7	<0.1	0.01	1.67E 7	<0.1	0.01
2	3.91E 6	0.8	0.01	2.14E 6	1.5	0.01	2.11E 6	1.5	0.01
3	7.27E 5	1.5	0.02	4.08E 5	2.7	0.01	4.13E 5	2.7	0.02
4	1.10E 5	1.9	0.05	67700	3.1	0.05	71800	2.9	0.05
5	16500	3.7	0.1	10800	5.7	0.1	11500	5.4	0.1
6	2190	32.2	0.1	1370	51.4	0.1	1460	48.2	0.1

Table 3: Count Rate Estimates for ^{12}C and ^{16}O

Q^2	^{12}C $p_{\frac{3}{2}}$ (g.s.)			^{16}O $p_{\frac{3}{2}}$ (6.32 MeV)		
$(GeV/c)^2$	cts/hr	t(hrs)	ΔP_n	cts/hr	t(hrs)	ΔP_n
1	1.68E 6	<0.1	0.05	1.21E 6	<0.1	0.05
2	2.01E 5	0.6	0.05	1.44E 5	0.8	0.05
3	39100	4.5	0.05	28200	6.2	0.05
4	6790	31	0.05	4910	43	0.05
5	1100	56	0.1	792	78	0.1
6	140	81	0.25	101	111	0.25

Table 4: Run Time Estimate

1.	1 H	40 hours
	2 H	65 hours
	4 He	60 hours
	Set up	25 hours
		190 hours
2.	^{12}C	173 hours
	^{16}O	239 hours
	Set up	25 hours
		437 hours