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:

The Energy Dependence of Nucleon Propagation in Nuclei as Measured in the (e,e'p) Reaction

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

☒ YES ☐ NO UPDATE

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

Same Title 89-022
#LOI 36

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(CEBAF USE ONLY)

The Energy Dependence of Nucleon Propagation in Nuclei as Measured in the (e,e'p) Reaction

Update - CEBAF Proposal 89-022

September 1991

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ABSTRACT

The energy dependence of proton propagation through nuclei will be examined in measurements of the A dependence of the quasifree (e,e'p) reaction on four targets, ^{12}C, ^{28}Si, ^{58}Ni and ^{208}Pb for average emergent proton energies, T_p of 400, 700, 1000, and 2000 MeV. At $T_p = 400$ MeV and 1000 MeV, Rosenbluth separations will be performed to study the reaction mechanism. A consistent data set covering this large range of proton energy would be unique and provide an important survey of the reaction mechanism in the quasifree region. The experiment would be performed using the coincidence spectrometer pair in Hall C to detect the electron and proton. The A dependence of the integrated coincidence yield provides a direct measure of the proton attenuation. Recent theoretical work suggests that two-body correlations have a significant effect on the proton attenuation.

Introduction

The propagation of nucleons through the nuclear medium is a fundamental characteristic of the nuclear many body problem. There remains considerable uncertainty in how to evaluate the propagation of nucleons participating in nuclear reactions. For medium energy, 100-500 MeV, protons, there are substantial variations between the "proton mean free paths" extracted from various parameterizations of the proton optical potential and from calculations based on the free nucleon-nucleon cross sections. Furthermore, especially in experiments at higher energies, it is often not possible to resolve protons which are coherently diffracted by the nucleus from those which undergo small angle or small energy loss interactions. For these experiments, a more macroscopic examination of nucleon propagation in nuclei is necessary.

Quasifree electron-proton scattering provides an excellent tool to study nucleon propagation effects. The electron-nucleon vertex is well understood on shell, so that these reactions can be viewed as tagging a source of protons emerging from throughout the nuclear volume. We propose to fix the electron kinematics to restrict the scattered electron energies to be close to the quasifree peak at which the reaction mechanism has a large single nucleon component. The integrated quasifree coincidence yield (integrated over missing-energy and recoil momentum ranges corresponding to single-particle knockout) provides a measure of the macroscopic attenuation, averaged over the binding energies of single-particle states and the angular range of the quasifree angular correlation ($p_f/|q|$ where $p_f \sim 250$ MeV is the Fermi momentum of the nucleus and $|q|$ is the magnitude of the three momentum transfer).

We have published the first results[1] of an experiment at the MIT Bates laboratory with similar goals for proton kinetic energies, $T_p \sim 180$ MeV. These results support this simple interpretation of the (e,e'p) reaction at this low four momentum transfer squared, Q^2, ($T_p \sim Q^2/2M_p$) where the reaction mechanism has a large longitudinal component. A significant new development in understanding these data is the observation by Benhar et al.[2] and Pandharipande and Pieper[3] that the calculations of the trasmission in (e,e'p) reactions are sensitive to the two-body correlations in the nuclear medium. This is illustrated in Figure 1. The final results of our Bates experiment[4] are compared to the correlated Glauber calculations of Pandharipande and Pieper. These calculations, which have no free parameters, compute the absorption of a proton in nuclear matter and fold the results with realistic nuclear density distributions using the local density approximation. The solid curve is the result of the full calculation. The dotted curve shows the calculation with just the free N-N cross sections. As other ingredients are added (Pauli blocking - dashed curve, density-dependent effects of the N-N cross section - dot-dashed curve, two-nucleon correlations - solid curve) the results approach the experimental data. As Pandharipande and Pieper show, the two-nucleon correlations have a significant impact on the transmission. This is largely due to the fact that the struck proton cannot reinteract with itself and because the repulsive core of the NN interaction creates a hole around the struck nucleon. This effect is not included in the usual DWIA calculations of (e,e'p) reactions.

We propose to extend these measurements from T_p=400 MeV to 2000 MeV (Q^2 of 0.76, 1.3, 1.9 and 3.8 $(GeV/c)^2$). At the larger momentum transfers considered here, the transverse contribution always dominates ($\sigma_T/\sigma_L = Q^2 * \mu_p^2/4M_p^2$ where μ_p is the proton magnetic moment).

To validate this interpretation of the (e,e'p) reaction in terms of single nucleon knockout, at two energies a Rosenbluth separation will be performed to separately study the A dependence of the longitudinal and transverse yield. While the longitudinal response is expected to be determined by the single-nucleon spectral function, the transverse response will certainly contain some contributions from meson exchange currents or other multi-nucleon mechanisms. However, the cross sections in the quasifree region are still known to scale approximately with A, even when the transverse response dominates. The single particle knockout mechanism is further supported by the phenomenology of y scaling at these momentum transfers[5]. If the transverse response is not predominantly due to single-particle knockout, then one would expect the missing-energy spectra to be rather different for the longitudinal and tranverse response functions and the A dependence of the transverse yield to differ from that of the longitudinal yield. At BATES energies, the kinematics could be chosen to emphasize the longitudinal contribution, and relatively little yield is observed for missing-energies greater than 80 MeV except at initial proton momenta larger than the Fermi momentum (Figure 2). There, we were able to interpret the double ratio of experimental coincidence/singles yields to PWIA calculated coincidence/singles yields as the proton transmission. This same technique should be effective for the longitudinal data. An accurate Rosenbluth separation at each energy would consume excessive beam time. However, if the A dependence of the transverse yield is observed to follow that of the longitudinal yield at T_p=400 and 1000 MeV, it is reasonable to use the total cross section to measure the attenuation. An appropriate region of single-particle response can be determined for the T_p=400 MeV longitudinal missing-energy spectra. At the higher energies, inelastic scattering from the nucleon can contribute to the (e,e') cross sections and the A dependence of the absolute coincidence yield may provide the best measure of proton propagation. The ratio of coincidence to singles yields will provide important information on the reaction mechanism. We have followed the suggestion of PAC89 and added a lower precision Rosenbluth separation at T_p=1000 MeV to validate the reaction mechanism, but only on two of the four targets.

In a related proposal (89-010), it is proposed to study the A dependence of the (e,e'p) reaction at very high momentum transfer to search for evidence of "color transparency", the concept that high momentum transfer processes must occur on physically small objects. The methodology of that proposal is the same as for this proposal. The studies considered here will be an important test on this methodology. At the highest Q^2, we may indeed observe the onset of this phenomena. The effect of two body correlations are still predicted to be significant.

The data sample proposed here would provide a single body of systematic data over most of the proton energy range important at CEBAF, TRIUMF and LAMPF. The proposed experiment places quite modest requirements on the incident beam and coincident spectrometers. However, the large solid angles, high incident beam energies, and the need for a large, internally consistent data set make this experiment uniquely suited for CEBAF's facilities.

The wide range of proton energies involved in this experiment does present a challenge in providing a consistent theoretical interpretation. No single calculational scheme is, at present, able to deal with the entire range. We expect that the experiment proposed here will stimulate such theoretical activity. The correlated Glauber calculations undertaken to explain the lower energy data are an excellent example. But, if a successful approach does not become evident, then this experiment becomes even more important in providing a benchmark to calibrate proton reinteraction effects for a number of CEBAF (e,e'p) and (e,e'pp) experiments on heavier nuclei.

Experiment

The experimental conditions assumed in this proposal are presented in Table I. The Hall C HMS and SOS spectrometers will be used. The measurements at the highest proton energies will be made by reversing the role of the spectrometers. A representative set of measurements is given in Table II. The counting rates are estimated based on Fermi gas predictions. Beam time would be distributed between the four targets roughly as 1:1.2:1.8:3.5 (carbon, silicon, nickel, lead) as determined from the BATES results and the Glauber calculations. The outgoing protons are confined to a cone with an opening angle of $p_f/|q|$. This kinematic focusing improves with increasing proton energy. At each energy the number of proton angles is chosen to span the range in recoil momentum (p_r) from $0 < p_r < 300$ MeV/c. The kinematic focusing coupled with the CW nature of the CEBAF beam and the fact that quasifree scattering remains a dominant reaction mechanism in this range of electron energy loss minimize the random coincidence rate as a problem for this experiment. Calculations using the Lightbody and O Connell codes[6] for proton and pion rates demonstrate that the real to random rates are always greater than 20. The minimum time per point was assumed to be 20 minutes for 10000 coincidence events. At Tp=400 MeV, 20000 events per angle setting would be acquired. The T_p=400 MeV Rosenbluth separation will use data at three energies corresponding to virtual photon polarizations of 0.14, 0.47 and 0.87. The T_p=1000 MeV Rosenbluth separation will use data at two energies corresponding to virtual photon polarizations of 0.16 and 0.89. The net time involved would be 17 days of data taking and 7 days of calibration and contingency. Roughly one third of the time is required for each Rosenbluth separation and the rest for the energy dependence.

Calibration will be performed with a CH_2 target to ensure the same source geometry as the experimental data. It will involve a careful mapping of the singles acceptence of each spectrometer and studies of the coincidence response of the pair with ^{1}H(e,ep) elastic scattering.

Resources Required

Table 1: Experimental Conditions

Duty Factor	100 %
Beam current	10-100 uA
Target Thickness	50-200 mg/cm^2
Targets	^{12}C, ^{28}Si, ^{58}Ni, ^{208}Pb
Beam energy spread	$< 0.1\%$
Electron Spectrometer	
Momentum Acceptance	10%
Solid Angle	5 msr
P maximum	3 GeV
P resolution	0.1 %
Particle Identification	electron-pion pion-proton (for T_p=2000)
Hadron Spectrometer	
Momentum Acceptance	$>$20%
Solid angle	9 msr
P maximum	2 GeV
P resolution	0.1 %
Particle Identification	pion-proton electron-pion (for T_p=2000)

Table 2: Kinematics and Rates

Proton Energy (MeV)	Beam Energy (MeV)	Coincidence Fraction†	Electron angle	Proton angle	Hours per target‡	Total Days
400	750	0.044	115	19,23,27,31,34	1.5	3
400	1000	0.044	69	35,39,43,47,51	0.7	2
400	2000	0.044	28	52,56,60,64,68	0.3	1
700	3000	0.084	25	47,50,53,56,59	0.3	1
1000	1500	0.134	105	16,19,22,25	12	6*
1000	4000	0.134	23	43,46,49,52	0.3	1
2000	4000	0.200	40	28,31,34	3	3

† Coincidence fraction = spectrometer solid angle / solid angle of Fermi cone.
‡ For a single angle on the ^{12}C target. ^{208}Pb runs will require up to a factor of 3.5 more time.
⋆ Only two of the four targets, i.e. ^{28}Si and ^{208}Pb.

The experiment will use the standard electron (HMS) and hadron (SOS) spectrometers of the Hall C system. The momentum resolution requirements are modest. A momentum bite > 18% is required for the hadron spectrometer at T_p=400 MeV to cover the entire missing-energy range. Particle identification is important: particularly pion-proton resolution in the hadron spectrometer and electron-pion resolution in the electron spectrometer. Of more concern is the angular resolution of the spectrometer detection systems which is important for the recoil momentum resolution. The targets involved are all self supporting foils, and, with the exception of lead, relatively durable.

This experiment would also be suited for the Hall A coincidence spectrometer system. However, two momemtum bites would be required to cover the appropriate kinematic range, increasing the required beam time by 10 days. Given that resolution is not a crucial issue, Hall C would seem to be a more appropriate place for these experiments.

Commitment of Collaborators

This experiment is one of several which we anticipate for the HALL C spectrometer system. It is expected that these experiments will be a major fraction of the research effort of this collaboration once CEBAF is in operation and to that end, Argonne has agreed to build the SOS spectrometer as the required hadron arm. A substantial fraction of the collaboration have heavy commitments to other research until at least 1992.

Response to PAC comments

In giving this proposal conditional approval, the 1989 PAC had the following requests.

1) Discuss the feasibility of doing L/T separations at the largest Q^2 where the difficulty in the reaction mechanism (MEC) are largest.

2) Perform a Glauber calculation to estimate the conventional absorption effect.

3) Perform an analysis of the effects of charge exchange processes.

We certainly agree with the PAC that a L/T separation at the higher energies is an important addition. The accuracy of any L/T separation is inherently limited by the overall systematic errors and the L/T ratios of the elementary cross sections.

$$\Delta\sigma_L/\sigma_L = \sqrt{2}(\Delta\sigma/\sigma)(\sigma/\sigma_L)/\Delta\epsilon$$

We assume that the relative systematic errors can be controlled to the 1% level, and designed the lowest energy L/T separation to achieve a 3% determination of the separated cross sections. At T_p= 2000 MeV, the best that can be achieved with the same systematic errors is $\Delta\sigma_L/\sigma_L \sim 10\%$ at the cost of roughly six weeks of additional beam time. At T_p=1000 MeV, a comparable $\sim$ 10% L/T separation requires 1 additional week of beam time for one light and one heavy target. We have added this to the proposal.

Since the original proposal, the correlated Glauber calculations of references 2 and 3 have been carried out and will soon appear in the literature. These support the cross section estimates used here for count rate estimates and provide a much firmer foundation for interpreting the experimental results. More importantly, they have sharpened the physics issues and interest in the experiment.

We are still in the process of evaluating the charge exchange contribution to our results. We must distinguish two charge exchange effects. The first is quasifree n-p scattering and charge exchange. This is a multiple scattering background just as p-p scattering. In the Bates experiment, calculations suggest that less than 3% of the yield within our missing-energy cut came from multiple scattering based on a calculation that gave yields comparable to the experimental yield at missing-energies above the single-particle response region. This contribution is significantly reduced from naive estimates by Pauli blocking.

Proton-nucleus charge exchange leaving the final nucleus in a low-lying excited state provides a different type of background which does not have a signature at larger missing-energy. We are working to estimate the size of this effect for our experimental conditions. To the extent that the e-n and e-p cross sections become similar at higher energies, n-nucleus and p-nucleus charge exchange will very roughly compensate each other. Estimates based on the (n,p) data of Hicks et al.[7] at 300 MeV and the (p,n) data of Mercer et al.[8] at 500 MeV suggest that p-nucleus and n-nucleus charge exchange are less important at the higher energies and never more than a 5% effect.

Independent of the magnitude of the charge exchange effects, we see our data as providing a macroscopic measure of the attenuation of protons through nuclei and a benchmark for interpreting other experiments. To the extent that nucleon-nucleus charge exchange is a ubiquitous process, it will be present in these other experiments as well.

We would like to emphasize that with the additional L/T separation the experiment divides naturally into three phases. The first phase, a survey of proton propagation, places minimal requirements on the maximum beam energy and current of the accelerator and can be performed with revised choices of energies, angles and target thicknesses even if the initial beam energy or current are less than expected. The L/T separation at T_p=400 MeV does not require high beam energies or currents but does place additional requirements on the understanding of the experimental equipment. We believe this is still appropriate for a first round experiment. The higher energy L/T separation places the most stringent requirements on the accelerator. We originally viewed this as a second generation experiment but have included it here in response to the PAC comments. Given the significance of these results for interpreting many measurements at CEBAF, we believe that it is important to carry out at least part of this experiment in the earliest stages of the CEBAF experimental program.

References

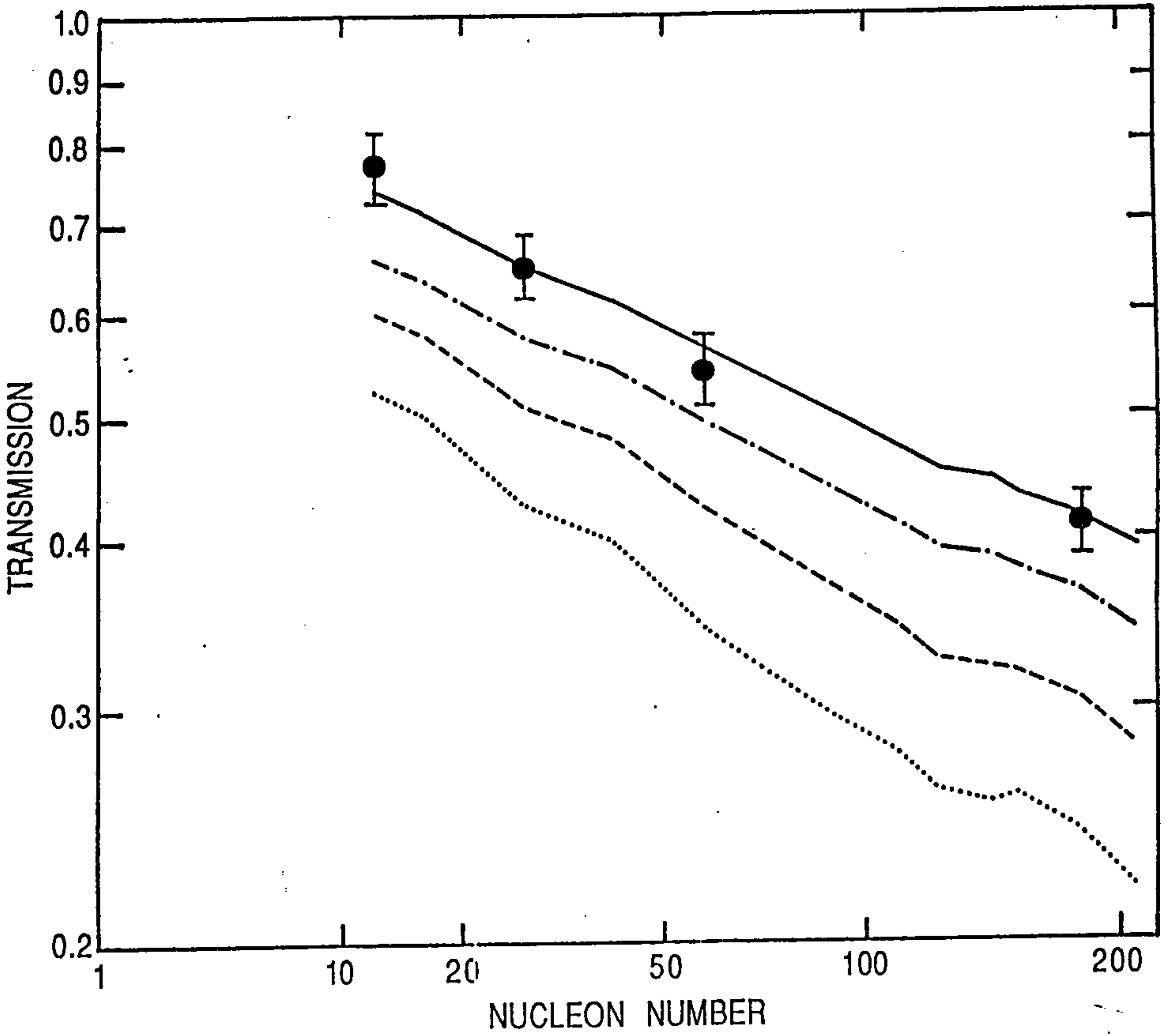
1. D. F. Geesaman et al., Phys. Rev. Lett. 63, 734 (1989).
2. O. Benhar, A. Fabrocini, S. Fantoni, V. R. Pandharipande and I. Sick, to be published.
3. V.R. Pandharipande and S.C. Pieper, to be published.
4. G. Garino et al, to be published.; G. Garino, Ph. D. Thesis Northwestern University (1990).
5. D. B. Day et al., Phys. Rev. Lett. 59,427 (1987).
6. J. W. Lightbody and J. S. O Connell, Comp. in Phys. May/June 57 (1988)
7. K. H. Hicks et al, Phys. Rev. C43, 2554 (1991).
8. D. Mercer et al., University of Colorado Report NPL 1056, 28 (1991).

Figure Captions

Figure 1. The experimental transmissions (on a logarithmic scale) from reference 4 for a missing-energy range of 0-80 MeV vs nucleon number of the target nucleus (on a cube-root scale) are shown including the systematic errors. The lines represent the calculations of reference [3]. The solid curve is the result of the full calculation. The other curves are for the free N-N cross sections (dotted), adding Pauli blocking (dashed) and adding density-dependent effects of the N-N cross section (dot-dashed).

Figure 2 Invariant missing energy spectra for the ^{58}Ni(e,e'p) reaction at average initial momenta for the struck proton of 60, 130, 220 and 280 MeV/c respectively (corresponding to proton angles of 50.1, 58.2, 67.9 and 72.9 degrees).

ANL-P-20,435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100
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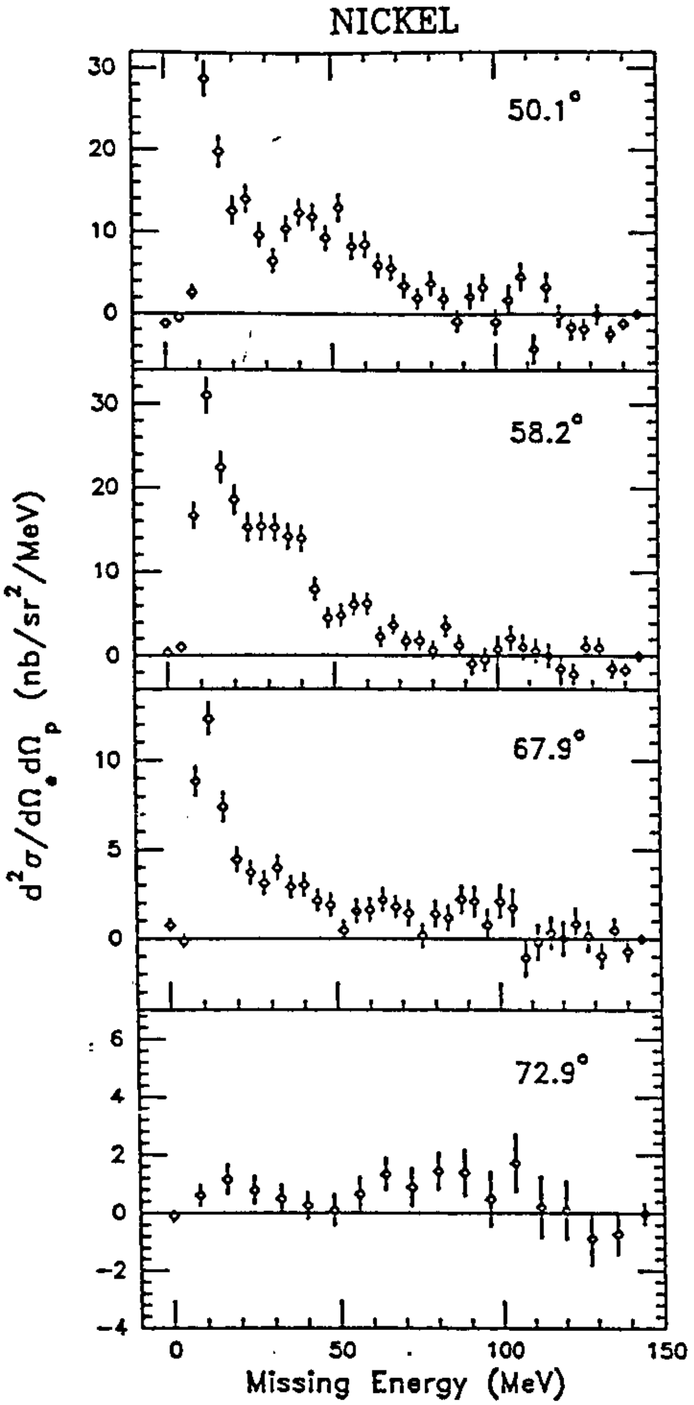
NUCLEON NUMBER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58.2°
67.9°
72.9°
30
20
10
0
5
6
4
2
-2
-4
d$^2\sigma$/dΩ_edΩ_p (nb/sr^2/MeV)
0
50
100
150
Missing Energy (MeV)

CEBAF Experiment Requirements **Date Submitted** 9 /30 /91

Title & Spokesperson The Energy Dependence of Nucleon Propagation in Nuclei as Measured in the (e,e'p) Reaction. Donald F. Geesaman

Estimated total beam time (hours)	576
Electron beam energy(s) required	750, 1000, 1500, 2000, 3000, 4000
Beam current(s) (μA)	10-100
Total μA-hours required	28000
Solid target(s) material	C, Si, Ni, Pb, CH$_2$
Solid target(s) thickness	50-200 mg
Cryogenic target -type and length (cm)	--
Power deposition in cryogenic target (Watts)	-- watts
Polarized beam (y/n)	N
Polarized target (y/n)	N
Power deposition in polarized target	N
Effective beam spot diameter (≥100 microns)	Nominal
Scanned beam at target (y/n)	N
Dispersed beam (y/n)	N

Spectrometer Requirements	*e' Arm*	*Hadron Arm*
Solid angle acceptance (msr)	5	9
Momentum acceptance (FWHM %)	10	20
Momentum resolution (FWHM %)	0.1	0.1
Scattering angle (degrees)		
Minimum	23	19
Maximum	115	68
Scattering angle, uncertainty (mr)	1 mr	1 mr
Central orbit momenta (MeV/c)		
Minimum	350	950
Maximum	2900	1850
Spectrometer settings, reproducibility,		
Central angle (mr)	<1 mr	<1 mr
Central momentum (MeV/c)	2 MeV/c	2 MeV/c
Particle identification requirements		
Rejection type (e.g. π^-/e^-)	π^-/e^- π^+/p	π^-/e^- π^+/p
Required ratio (e.g. 10^{-3})	10^{-2}	10^{-2}
Traceback capability required (y/n)	Y	

Position accuracy along beam (mm)	----
Luminosity range (cm^{-2} sec^{-1})	Max. 6×10^{36} for ^{12}C

Remarks:

ARGONNE NATIONAL LABORATORY
9700 South Cass Avenue, Argonne, Illinois 60439

30 September 1991

Prof. J. D. Walecka
Scientific Director's Office
CEBAF
12000 Jefferson Avenue
Newport News, VA 23606

Dear Dirk,

I enclose 40 copies of an updated version of our CEBAF proposal 89-022, "The Energy Dependence of Nucleon Propagation in Nuclei as Measured in the (e,e'p) Reaction". Now that we have preliminary data from SLAC on (e,e'p) reactions from NE-18 and new theoretical calculations by Pandharipande and Pieper, I am more excited than ever over the physics of this experiment. I hope that in this update we have been able to resolve the Program Advisory Committee's concerns and will receive full approval. The success and limitations of NPAS NE-18 continue to illustrate the need for CEBAF.

Sincerely,

[redacted]

Donald F. Geesaman
Physics Division