CEBAF Program Advisory Committee Nine
Extension and Update Cover Sheet

This update must be received by close of business on Thursday, December 1, 1994 at:

CEBAF
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12000 Jefferson Avenue
Newport News, VA 23606

Experiment: **Check Applicable Boxes:**

E - ☐ Extension ☐ Update ☐ Hall B Update

Contact Person

Name:
Institution:
Address:
Address:
City, State ZIP/Country:
Phone: **FAX:**
E-Mail → Internet:

CEBAF Use Only

Receipt Date: 12/15/94

By: gp PR 94-135

CEBAF Program Advisory Committee Nine Proposal Cover Sheet

This proposal must be received by close of business on Thursday, December 1, 1994 at:

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12000 Jefferson Avenue
Newport News, VA 23606

Proposal Title

Measurement of Small components of the ^3He Wave Function using $^3\vec{He}(\vec{e},e'p)$ in Hall A.

Contact Person

Name: Bill Hersman
Institution: University of New Hampshire
Address: Physics Dept.
Address: Demeritt Hall
City, State ZIP/Country: Durham, N.H. 03824 USA
Phone: 603-862-3512 **FAX:** 603-862-2998
E-Mail → Internet: Hersman@curie.unh.edu

Experimental Hall: A **Days Requested for Approval:** 24

Hall B proposals only, list any experiments and days for concurrent running:

CEBAF Use Only UPDATE 94-023

Receipt Date: 12/15/94 ~~PR 94-121~~

By: T

UPDATE ON PROPOSAL PR-94-023 TO THE 12/94 CEBAF PAC

Measurement of small components of the ^{3}He wave function using $^3\overrightarrow{\mathrm{He}}$ ($\vec{e}$,e′p) in Hall A

F. W. Hersman, L. C. Balling, V. Boykin, J. Calarco,
J. Distelbrink, L. Gelinas, J. Heisenberg, M. Kennedy,
V. Pomeroy, Timothy P. Smith, I. The, A. Tutein, J. Wright
University of New Hampshire

M. B. Leuschner
Indiana University

J. LeRose, B. Wojtsekowski
CEBAF

R. Lourie, S. vanVerst
University of Virginia

currently seeking the endorsement of the Hall A Collaboration

F. W. Hersman, contact person

ABSTRACT

Proposal PR94-023 to measure small components of the ^{3}He wave function using $^3\overrightarrow{\mathrm{He}}$($\vec{e}$,e′p) in Hall A was deferred by the PAC8. Concern about the optimal choice of kinematics was the reason given for deferral, suggesting that a single more optimal proposal be presented. In this update we address the concerns raised by the PAC.

1. Introduction

Helium-3 is an important testing ground for our understanding of nuclear structure. Like the deuteron, the ground state wave function is exactly solvable for modern two-body potentials. Unlike the deuteron, the number and complexity of the allowed components in the wave function are large. Helium is also subject to three body forces. Furthermore, subnucleon degrees of freedom may be enhanced since the density is considerably greater.

The dominant component of the ground state wave function is the spatially symmetric S-wave. With the protons paired to spin S=0, the spin of the nucleus is given by the spin of the unpaired neutron, exploited in measurements of the neutron electric form factor using polarized ^{3}He. In attempting to understand the corrections to this simple picture from a structure point of view, it is the small components of the wave function, S$'$ and D-states that hold interesting information.

Polarization observables are particularly useful in extracting small wave function components. Since scattering from polarized protons has a large asymmetry characteristic of their electric to magnetic form factor ratio, components of the ^{3}He wave function with net proton polarization may exhibit an asymmetry proportional to their probability.

This one-body direct knockout interpretation is modified in real reactions. Two-body terms in the nuclear current, specifically meson-exchange currents (MEC) lead to modifications of the asymmetries. Furthermore final state interactions (FSI) between the outgoing nucleons and the residual nucleus can also lead to alterations in the asymmetries. Contributions of these effects to different response functions can, in principle, be different, although they can be related through model calculations.

In our proposal we already took precautions to minimize the uncertainty in interpreting measured asymmetries in terms of ^{3}He structure.

1. Parallel kinematics were selected to allow only one response function to contribute to the asymmetries.
2. We chose to minimize the contribution of FSI to each of the measured asymmetry points. This is accomplished by choosing the relative kinetic energy value in the final state system in the minimum in the nucleon-nucleon interaction.

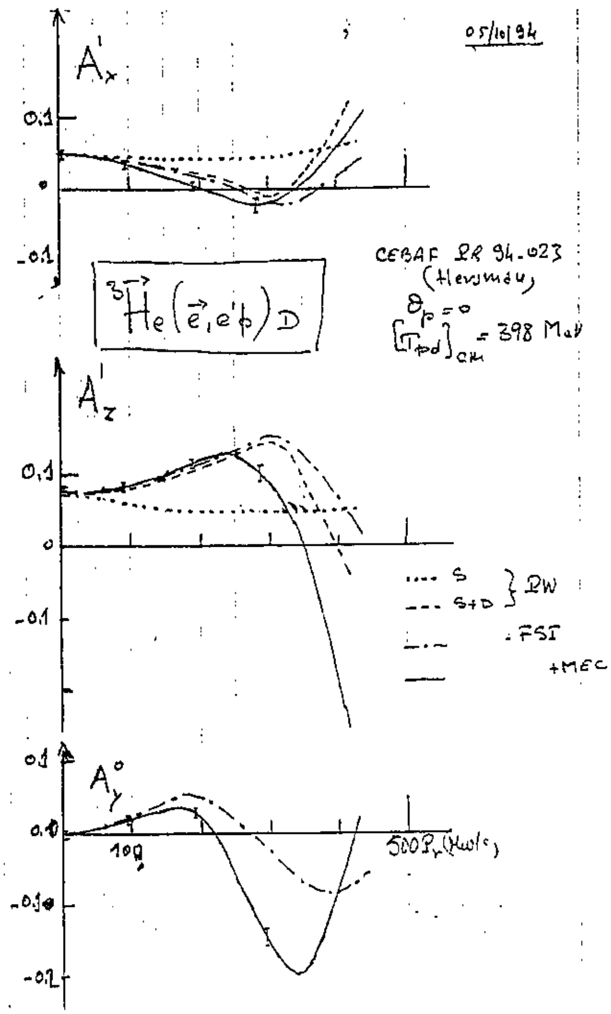


Fig. 1. The three target asymmetries which do not vanish in collinear kinematics are plotted against the momentum p_R of the deuteron recoiling in the reaction $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e}'\mathrm{p})\mathrm{d}$ at the proposed kinematics given in Table 1. The dotted lines and dashed lines correspond to PWIA when only the S-wave or both the S- and D-wave are respectively taken into account. The full lines include FSI and MEC. The data points indicate the kinematics and projected uncertainties of the present proposal.

3. We also chose this value to be constant to minimize any point to point changes in the contribution of FSI.

4. We chose the maximum value of Q^2 consistent with these considerations.

5. Finally we included as part of our plan the measurement of the additional asymmetry A_y^0 to calibrate any remaining contribution from FSI and MEC.

New calculations comparing various kinematic choices were performed by J-M Laget. We adjust our request based on these calculations and based on the recommendation of PAC. We review those calculations below and contrast our suggested kinematics with alternative choices, in particular the perpendicular kinematics like those proposed in PR94-020. [1)]

2. Asymmetry calculations

Laget has calculated the quasielastic scattering $^3\overrightarrow{\mathrm{He}}(\vec{e},e'p)$ reaction at various kinematics and target angles. His objective was to explore the non-vanishing asymmetries A'_x, A'_z, and A^0_y, and determine their sensitivity to ingredients in the wave-function and reaction dynamics. Of particular interest is whether wave function information can be extracted unambiguously from the polarization observables.

Calculations were performed in parallel kinematics and high momentum transfer to minimize the effects of final state interactions. Reactions leading to the two body final state (Fig. 1) and to the three-body continuum (Fig. 2) were studied. (Calculations to the quasi-two-body d* final state are not yet available.) The sensitivity of these calculations on the small components in the structure was explored by including different choices of partial waves. Plane wave results and results including FSI and MEC were provided for comparison.

3. Target

We will use a ^{3}He target pressurized to 10 atmospheres of helium, or $2.7\times10^{20}/\mathrm{cm}^3$. The physical target length is 25 cm. The extended target acceptance of the HRS of 10 cm (in both nominal and forward quad modes) allows the windows to be just outside the acceptance of the proton arm of the most forward angle setting of 28° and well outside for larger angles. An effective target length of 22 cm provides for a thickness of $6\times10^{21}/\mathrm{cm}^2$ or 30 mg/cm^2. A beam current of 10 μA (6×10^{13}) will provide a luminosity of 3.6×10^{35} electron-^{3}He/cm^{2}sec. At the lowest missing momenta (where the counting rate is highest) the effective length is 13 cm, reducing the luminosity to 60% of maximum, or 2.2×10^{35}.

The UNH group has approval for 400 hours to measure the target asymmetry A^0_y of the reaction $^3\overrightarrow{\mathrm{He}}(e,e'n)$ at the Saskatchewan Accelerator Laboratory and for 335 hours

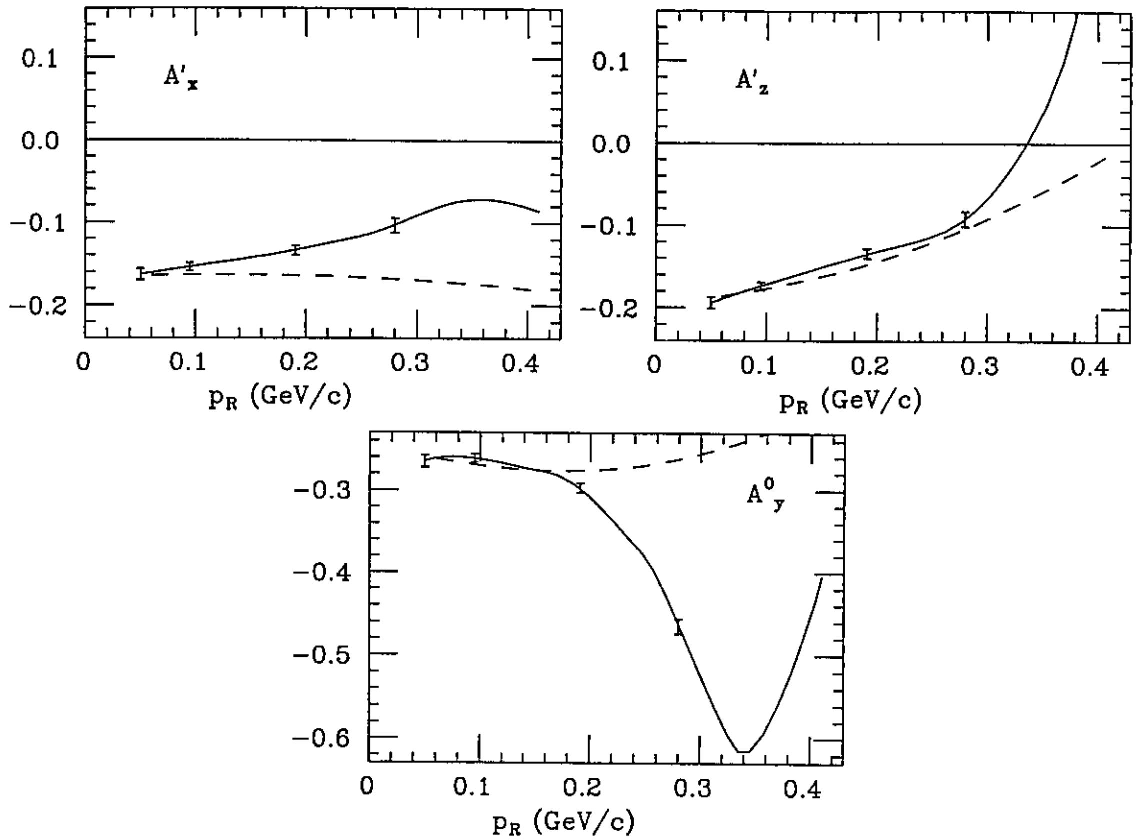


Fig. 2. The three target asymmetries which do not vanish in collinear kinematics are plotted against the momentum p_R of the p-n system recoiling in the reaction $^3\overrightarrow{\rm He}(\vec{\rm e},{\rm e'p}){\rm d}^*$ at the proposed kinematics given in Table 1. The dashed lines correspond to PWIA while the full lines include FSI and MEC. The data points indicate the kinematics and projected uncertainties of the present proposal.

to measure the two beam-target asymmetries $^3\overrightarrow{\rm He}(\vec{\rm e},{\rm e'n})$ and the target asymmetry A_y^0 of the reaction $^3\overrightarrow{\rm He}({\rm e},{\rm e'n})$ at the MIT-Bates Accelerator Center. Target fabrication at UNH is in the advanced stages. A new concave inward design for the window [2] has been developed at UNH. A sample cell has been pressure tested to 13 atmospheres without any problem. In-beam tests have been carried out on 10 atmosphere (unpolarized) cells at both Bates and Saskatchewan, successfully withstanding a tightly focussed (3-5

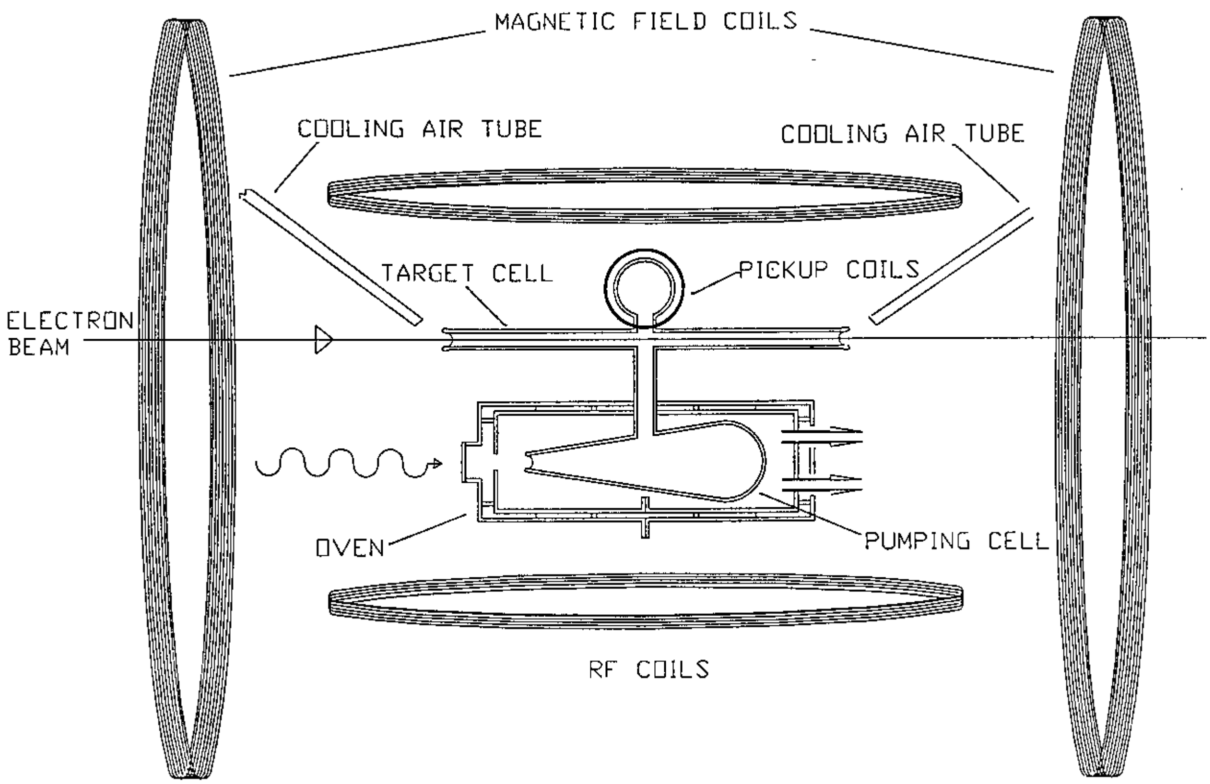


Fig. 3. The UNH alkali spin exchange helium target assembly, showing the conical pumping cell and concave windows, two UNH developments.

mm^2) 12 μA beam. In-beam heating has been identified as an important contribution to beam related helium depolarization and cell window failure. Windows in these tests supported the full cell pressure with increasing beam until the softening temperature of the glass was reached. Furthermore, the target cell reached temperatures comparable to the rubidium oven, which would allow high concentrations of rubidium vapor into the target cell. Ionization of rubidium would then quickly destroy the helium polarization. Active cooling of the windows and target with pressurized air has been added to the target design.

The largest source of rubidium depolarization is wall contact, which must be overcome with laser intensity. We intend to maximize the polarization by reducing the diameter of the entrance window of the pumping cell, minimizing the surface area and concentrating the laser power. Approximately 25 W of usable laser power will be delivered by solid state lasers.

4. Kinematics

Raskin and Donnelly[3] provide a framework for discussing the response functions that make up the coincidence cross section with polarization observables. In general there are five non-vanishing beam-target asymmetries, four of them measurable in the scattering plane, two each for the two target orientations x and z (all time reversal even). In the special case of the normal target asymmetry A_y^0, four (time-reversal odd) response functions contribute.

We chose to measure in parallel kinematics so that only one response function contributes to the z and x beam-target asymmetries. We reasoned that such measurements could be interpreted in a more straight forward manner in terms of ^{3}He structure. An alternative scheme, perpendicular kinematics, would measure a combination of response functions contributing to the reaction, introducing unnecessary complication into the interpretation of the asymmetries.

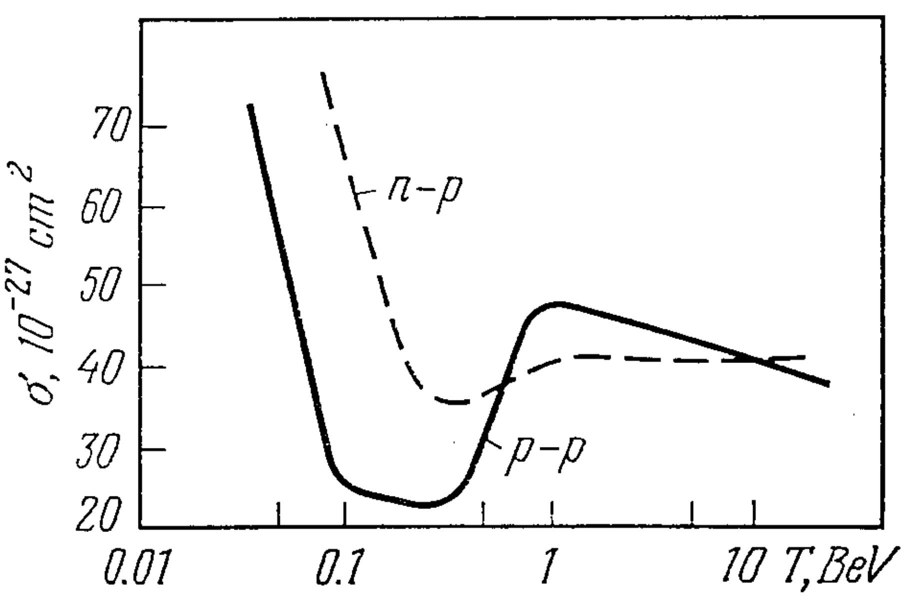


Fig. 4. Total cross section as a function of energy of p-p and p-n scattering.

Given our concern for minimizing FSI and allowing a consistent interpretation for different kinematics, we chose a single value of the relative final state kinetic energy, and attempted to identify an optimal value. An examination of the total nucleon-nucleon cross section in the p-p and n-p channels dips though a minimum around 0.25–0.4 GeV kinetic energy and rises for higher kinetic energies. (Fig. 3) We chose relative kinetic energy on the high end of this range, 0.35 GeV.

We include in our plan measurements of the normal target asymmetry A_y^0. This asymmetry is composed of time reversal odd response functions. It vanishes in the absence of FSI and MEC. Consequently its value can be used to calibrate the FSI and MEC contributions to the asymmetries A'_x and A'_z for model dependent extractions of structure information on the small components. This asymmetry can also be used to estimate the relative importance of FSI and MEC for different choices of kinematics. In the kinematics proposed here, the FSI contribution to A_y^0 peaks at a value of −0.08 at p_m=0.38 GeV/c. MEC increases A_y^0 to −0.2 at its peak ofp_m=0.32 GeV/c. In contrast the FSI contribution to the normal target asymmetry for perpendicular kinematics, like those of proposal PR94-020[1)], rises above 0.42 at its peak at p_m=0.32 GeV/c, more than a factor of five larger than in parallel kinematics (see Appendix). Measurement of A_y^0 was not included in PR94-020.

Different values of missing momentum are achieved by reducing the momentum transfer (by a greater amount than the observed proton momentum). The count rate is maximized at each value of momentum transfer. This is achieved by reducing the beam energy and maintaining the scattering angle as far forward as possible, set equal to 12.6°. Consequently, the steps in missing momentum have been determined by the routinely available beam energies. (Fig. 4) This procedure has an additional advantage: the lower momentum transfer measurements provide increased counting rates for the large missing momentum points, allowing the study to extend out almost to p_m=0.3 GeV/c. Note, however, that low momentum transfer does NOT imply larger FSI, since FSI are dependent on relative kinetic energy in the final state system which is held constant at an optimal value. Kinematics for the four kinematic settings proposed here are presented in Table 1. A fifth point in the original proposal, the highest p_m point, has been deleted due to concerns about ambiguities in its interpretation.

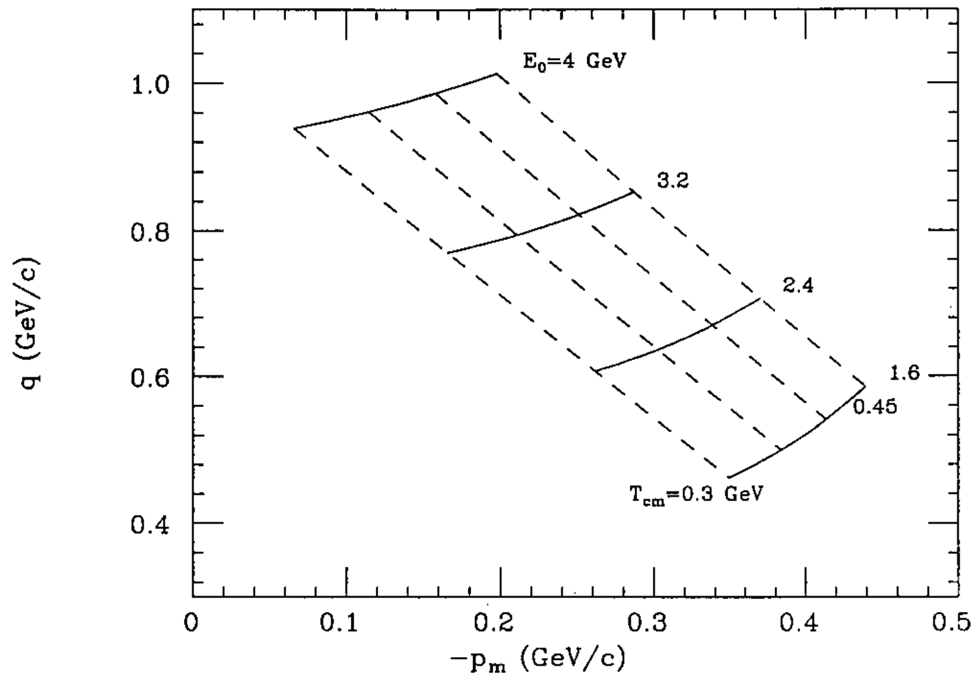


Fig. 5. Kinematic choices for the forward electron scattering angle θ_e=12.6° restricted to parallel geometry. Different missing momentum p_m and three momentum transfer q determine the required beam energy E_0 and final state kinetic energy.

TABLE 1

Kinematics for asymmetry measurements

	E_0	$\vec{q}$	ω	$\theta_{e'}$	θ_q	p	p_m
	GeV	GeV/c	GeV/c			GeV/c	GeV/c
A	4.0	1.152	0.604	15.30°	-51.03°	1.152	0.000
B	4.0	0.984	0.551	12.60°	-49.86°	1.080	0.095
C	3.2	0.820	0.507	12.60°	-45.77°	1.011	0.191
D	2.4	0.668	0.473	12.60°	-39.00°	0.948	0.280

Count rate estimates were performed with the Monte Carlo reaction code MCEEP.[4] The nominal HRS acceptance in the electron arm of $\delta\theta = \pm 32$ mr and $\delta\phi = \pm 72$ mr was assumed, with momentum acceptance of $\delta p = \pm 5\%$. For the proton acceptance the forward quad mode for the HRS spectrometer was used, with $\delta\theta = \pm 36$ mr and $\delta\phi = \pm 93$ mr, and momentum acceptance of $\delta p = \pm 4\%$. The two body breakup reaction process was modeled using the momentum distribution measured by Jans[5] and Marchand[6] for generation of events in the spectrometer acceptances. The spectral function of

Meier-Hajduk[7)] was used to generate three body breakup events. Two missing energy regions were defined in the three body breakup channel: the d* corresponding to $5.5 < E_m < 12.5$ MeV, and the continuum with $E_m > 12.5$ MeV. Rates for the four kinematics in each of these missing energy regions are reported in Table 2. These rates differ from those in the original proposal due to reduced assumptions for the maximum luminosity, and the target length acceptance of the proton arm.

TABLE 2

Rates into the full acceptances (sec^{-1})

	p_m range (GeV/c)	d	d*	pn
A	0.000 → 0.065	4.97	2.00	0.31
B	0.045 → 0.125	7.42	3.74	0.96
C	0.105 → 0.225	3.84	3.12	1.69
D	0.205 → 0.325	0.55	0.58	0.99

TABLE 3

Uncertainties in physical asymmetries: $\Delta A = (p_e\ p_{^3\mathrm{He}}\sqrt{N})^{-1}$

	ΔA(d)	ΔA(d*)	ΔA(pn)	days
A	0.004	0.007	0.017	1.33×3
B	0.004	0.005	0.010	1.33×3
C	0.005	0.006	0.008	1.33×3
D	0.009	0.009	0.007	3.00×3

Uncertainties in the physical asymmetries are calculated from the total counts and the beam and target polarization by

$$\Delta A = (p_e\ p_{^3\mathrm{He}}\sqrt{N})^{-1}.$$

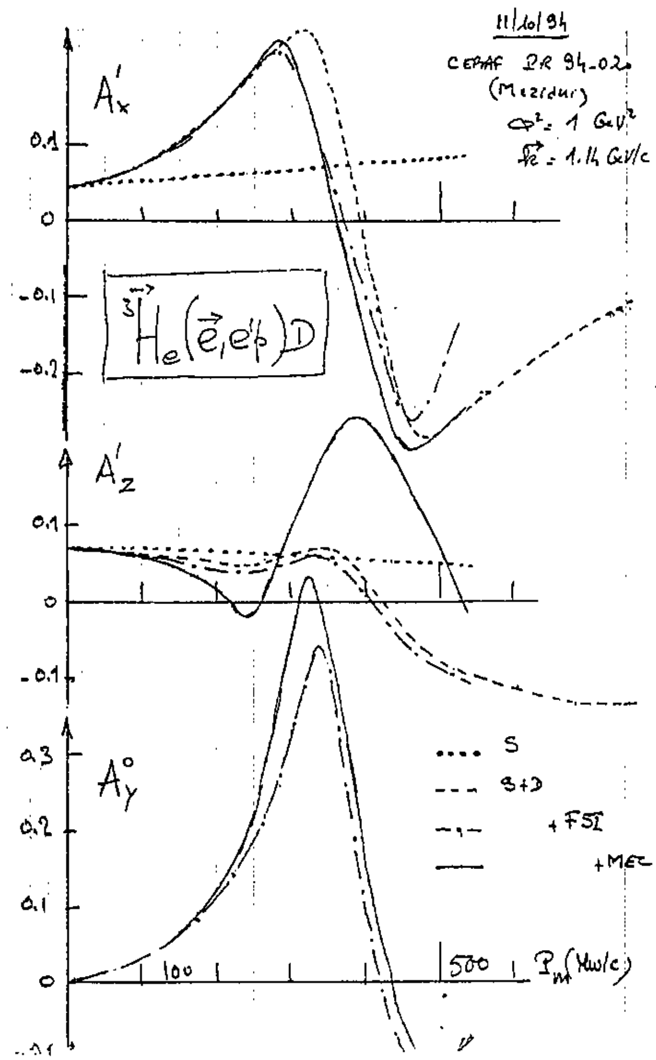
Beam polarization of 75% and target polarization of 40% were used in the calculations. Four shifts for each asymmetry are requested, with 12 shifts requested for each of the asymmetries at high missing momentum (Table 3). For the run times indicated, an extracted precision on the asymmetries of better than 1% can be obtained for most kinematics. Anticipated data for two body breakup are plotted in Figure 2, against a calculation by Laget in these kinematics. In Figure 3 the uncertainty of the three body breakup at the d* missing energy is plotted. (The study of the sensitivity of the d* asymmetries to the small components of the structure is in progress). The ability of the measurement to determine the asymmetries is apparent. We request a total of 21 days of beam time to measure three asymmetries to three final state missing energy regions at four choices of missing momentum kinematics. Three days target change time and background subtraction is added to bring the total request to 24 days.

4.1 Institutional commitment

The University of New Hampshire Nuclear Physics Group (UNHNPG) has had for many years an MOU to design and implement the Hall A trigger for the two HRS spectrometers. John Calarco is leading that effort. The design work is complete, the first batch of electronics has been purchased, and a window driven trigger software system has been written. The UNHNPG also has a collaborative effort with the UNH Atomic Physics group to fabricate a polarized target for an approved experiment at the Saskatchewan Accelerator Laboratory. We intend to provide a similar target for these measurements.

1. CEBAF proposal PR94-020, W. Korsch, R. McKeown, Z. Meziani, spokesmen
2. F. W. Hersman, Proceedings of the Conference on Polarized Ion Sources and Polarized Gas Targets, Madison, WI (1993)
3. A. S. Raskin and T. W. Donnelly, *Ann. Phys.* **191** (1989) 78.
4. P. E. Ulmer, MCEEP: Monte Carlo for Electro-Nuclear Coincidence Experiments, version 1.01 (1991)
5. E. Jans, *et al.*, *Phys. Rev. Lett.* **49** (1982) 974.
6. C. Marchand, *et al.*, *Phys. Rev. Lett.* **60** (1988) 1703.
7. H. Meier-Hajduk, *et al.*, *Nucl. Phys.* **A395** (1983) 332.

5. Appendix: Asymmetry calculations for perpendicular kinematics



BEAM REQUIREMENTS LIST

CEBAF Proposal No.: ______________________ (For CEBAF User Liaison Office use only.)   Date: 12/14/94

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	4,000	10	Beam Polarization 75%	^3He	30
				glass windows	5.84
2	3,200	10	Beam Polarization 75%	^3He	30
				glass windows	5.84
3	2,400	10	Beam Polarization 75%	^3He	30
				glass windows	5.84

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.

HAZARD IDENTIFICATION CHECKLIST

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

Date: 12/14/94

Check all items for which there is an anticipated need.

Cryogenics ___ beamline magnets ___ analysis magnets ___ target type: ______ flow rate: ______ capacity: ______	**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) ______ ______	**General:** Experiment Class: ✓ Base Equipment ___ Temp. Mod. to Base Equip. ___ Permanent Mod. to Base Equipment ___ Major New Apparatus Other: ______ ______

LAB RESOURCES REQUIREMENTS LIST

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

Date: 12/14/94

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.

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

Installation of polarized ^3He target, support structure, and laser system.

New Support Structures: ____________________

Data Acquisition/Reduction

Computing Resources: ____________________

New Software: ____________________

Major Equipment

Magnets ____________________

Power Supplies ____________________

Targets ____________________

Detectors ____________________

Electronics ____________________

Computer Hardware ____________________

Other ____________________

Other

____