JLab PAC12 Proposal Cover Sheet

RC

This document must be received by close of business on Thursday, June 26, 1997

Jefferson Lab
User Liaison Office, Mail Stop 12 B
12000 Jefferson Avenue
Newport News, VA 23606

(Choose one)

☐ New Proposal Title: Measurement of Small Components of the ^3He wave function using $^3\vec{He}(\vec{e},e'p)$

☒ Update Experiment Number: 94-023

☐ Letter-of-Intent Title:

Contact Person

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Experimental Hall: A   Days Requested for Approval: 24

Jefferson Lab Use Only

Receipt Date: 6/26/97

By: gp

PR 97-014

BEAM REQUIREMENTS LIST

Lab Proposal No.: 94-023　　Date: 6/26/97

Hall: A　　Anticipated Run Date: ______　　PAC Approved Days: 24

Spokesperson: Bill Hersman　　Hall Liaison: ______
Phone: 603 862 3512
E-mail: hersman@unh.edu

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 No.	Beam Energy (MeV)	Mean Beam Current (μA)	Polarization and Other Special Requirements (e.g., time structure)	Target Material (use multiple rows for complex targets — e.g., w/windows)	Material Thickness (mg/cm²)	Est. Beam-On Time for Cond. No. (hours)
1	4	10	70%	$^3\vec{He}$	20	8+1
2	3.2	10	70%	$^3\vec{He}$	20	4+1
3	2.4	10	70%	$^3\vec{He}$	20	9+1

The beam energies, E_{Beam}, available are: $E_{Beam} = N \times E_{Linac}$ where N = 1, 2, 3, 4, or 5. E_{Linac} = 800 MeV, i.e., available E_{Beam} are 800, 1600, 2400, 3200, and 4000 MeV. Other energies should be arranged with the Hall Leader before listing.

HAZARD IDENTIFICATION CHECKLIST

CEBAF Experiment: 94-023 Date: 6/26/97

Check all items for which there is an anticipated need—do not check items that are part of the CEBAF standard experiment (HRSE, HRSH, CLAS, HMS, SOS in standard configurations).

Cryogenics
- ______ beamline magnets
- ______ analysis magnets
- ______ target
- ______ drift chambers
- ______ other

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

polarized ^{3}He target

Flammable Gas or Liquids
(incl. target)

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
- ______ other

Lasers
type: diode bar

wattage: 20W x 8

class: ______

Installation
- ______ permanent
- ✓ temporary

Use
- ______ calibration
- ______ alignment

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

______

______

______

Notes:

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______

LAB RESOURCES REQUIREMENTS LIST

CEBAF Proposal No.: 94-023 (For CEBAF User Liaison Office use only.) Date: 6/26/97

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 support for polarized target

networking target control system into Hall A

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets

Power Supplies

Targets: polarized ^3He

Detectors

Electronics

Computer Hardware

Other

Other

UPDATE ON PROPOSAL PR-94-023 TO THE 8/97 CEBAF PAC

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

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T. P. Smith, T. Streeter
University of New Hampshire

J. LeRose, B. Wojtsekowski
TJNAF

R. Lourie
SUNY

currently seeking the endorsement of the Hall A Collaboration

F. W. Hersman, contact person

ABSTRACT

In this update to proposal PR94-023 we review the current status of the theoretical calculations, the target technology, the kinematics and the projected uncertainties for that experiment. We also report on the completion of the institutional commitments of the proponents.

1. Introduction

^{3}He is a 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.

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. 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. These components take on additional relevance since polarized ^{3}He is used as an effective polarized neutron target in measurements to determine the neutron electric form factor and the deep inelastic spin structure. A determination of the spin dependent momentum distribution of protons in ^{3}He would serve as a calibration of important corrections to these measurements.

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.

Our original proposal presented a plan for measuring the three spin observables which are non-vanishing in parallel kinematics, A'_x, A'_z, and A^0_y. The proposal and subsequent updates outline several precautions we took to minimize the uncertainty in interpreting measured asymmetries in terms of ^{3}He structure.

1. Parallel kinematics are selected to allow only one response function to contribute to the asymmetries.

2. We intend to minimize the contribution of FSI to each of the measured asymmetry points. This can be accomplished by choosing the relative kinetic energy value in the final state system in the minimum in the nucleon-nucleon interaction.

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

4. We choose the most forward scattering angle and highest beam energy consistent with these considerations to maximize count rate.

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

Our original proposal also detailed the institutional commitments to the general instrumentation of Hall A. At the time proposal PR94-023 was first submitted, the UNH group was in the process of assembling the trigger electronics for Hall A. During the three years since, the UNH group completed and installed the trigger for Hall A, and subsequently developed the trigger software. We are active in several Hall A experiments.

Proposal PR94-023 describes measurements with an alkali spin exchange polarized ^{3}He target. The UNH group has approved experiments at Bates and at Saskatchewan to measure polarization asymmetries with such a polarized ^{3}He target. While neither of those approved experiments with electron beams has run (our experiment at Bates has been delayed, and our experiment at Saskatchewan will probably not occur due to changes in the funding status of that laboratory), we have recently use our polarized ^{3}He cells with neutron beams at LANSCE. The UNH group produced several polarized ^{3}He cells for polarizing neutrons, installed them in the beam line, and collaborated in several experiments. We have fabricated scores of polarized ^{3}He cells at pressures up to 10 atmospheres, and achieved as high as 63% polarization.

We present our thorough measurement strategy including the normal target asymmetry, our extensive study (with J.-M. Laget) of calculated asymmetries, and our ongoing kinematics optimizations. We detail our long term institutional commitment to Hall A, and the completion of our multi-year effort to assemble and commission Hall A general purpose instrumentation. We report on our offer to Hall A collaboration members to make this a collaboration proposal, and remind the PAC of our unrelenting submission of proposal updates to PAC meetings. We review our plan for extracting the physical polarization asymmetries with uncertainties better than 0.01. We also describe some of our new developments in polarized ^{3}He cell technology. Nevertheless, this proposal and proposal PR94-020 [1] seek essentially the same physics. Unfortunately it has not been possible to merge the proposals, as the PAC suggested. We request approval of 16 days polarized beam and 8 days unpolarized beam.

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)to the d* quasi-two-body final state (Fig. 2) were studied. The sensitivity of the two-body calculations to 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.

Calculations presented in the original proposal show strong sensitivity to the presence of the D-state, particularly in the asymmetry A'_x. Final state interaction effects show only minor corrections. The situation regarding the S'-state is less clear. Nogorny has demonstrated that the S'-state will not contribute to asymmetries in the two-body final state reaction. It can, however, contribute to the asymmetries in the three body reaction. Indeed, since both the S' and D-states can be viewed as $1\hbar\omega$ states, one would expect their contribution to be strongest around 25 MeV of missing energy.

It is clear from the original calculations that the asymmetries are strongly dependent on the D-state admixture. The purpose of the new calculations was to explore the sensitivity of the asymmetries to the S'-state. Laget performed calculations (Fig. 3, Fig. 4) with two models for the S-wave, one where the $^1S_0$ and the $^3S_1$ established by the solutions to the Faddeev equations with the Paris potential, and one where the $^3S_1$ was set equal to the $^1S_0$. Although this is not the same as exploring the S'-state over

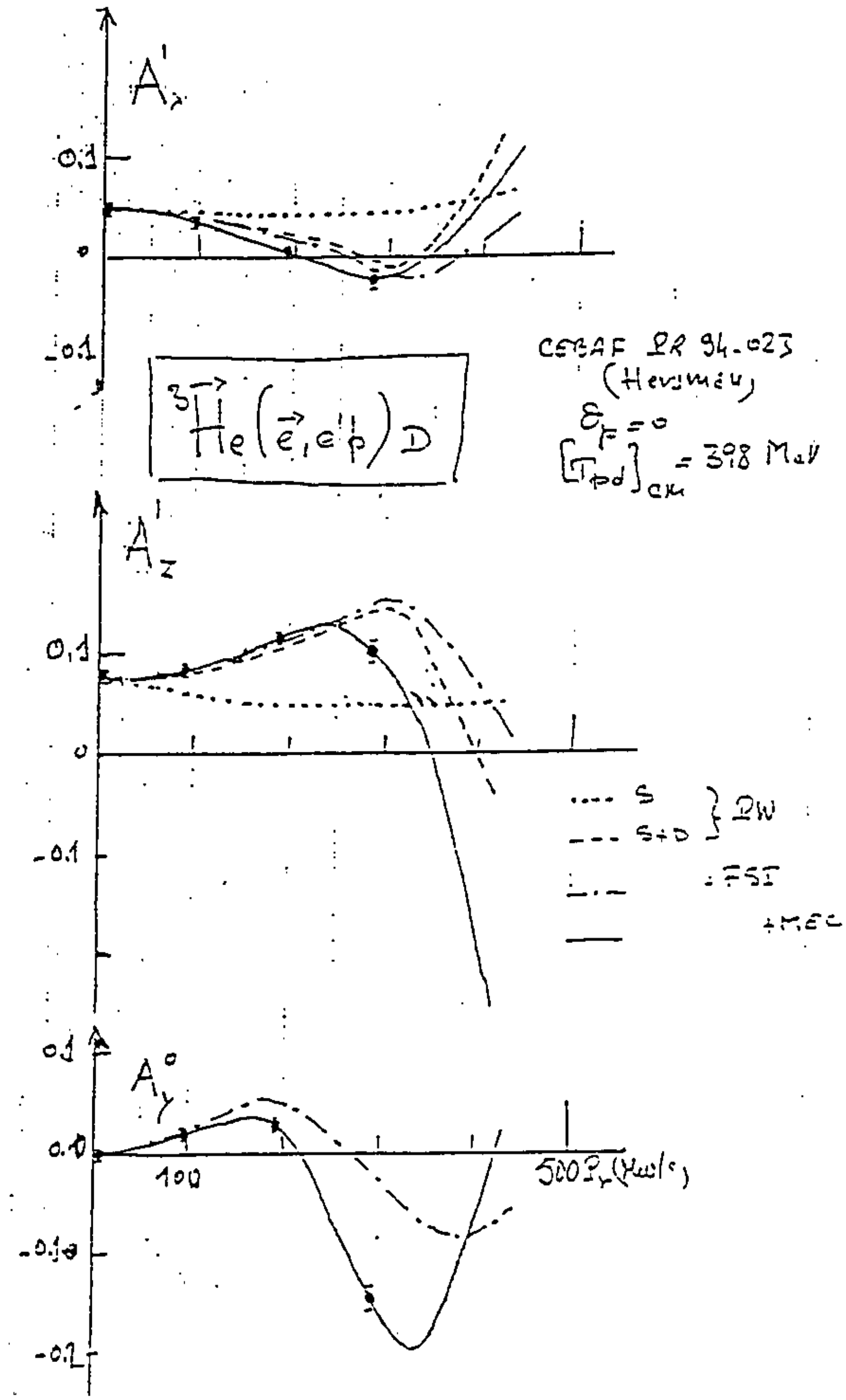

Fig. 1 The three target asymmetries which do not vanish in collinear kinematics are plotted against the momentum p_R of the deuteron recoiling in the reaction $^3\overrightarrow{He}(\vec{e},e'p)d$ at the proposed kinematics given in Table 2. The dotted lines and dashed lines correspond to PWIA when only 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.

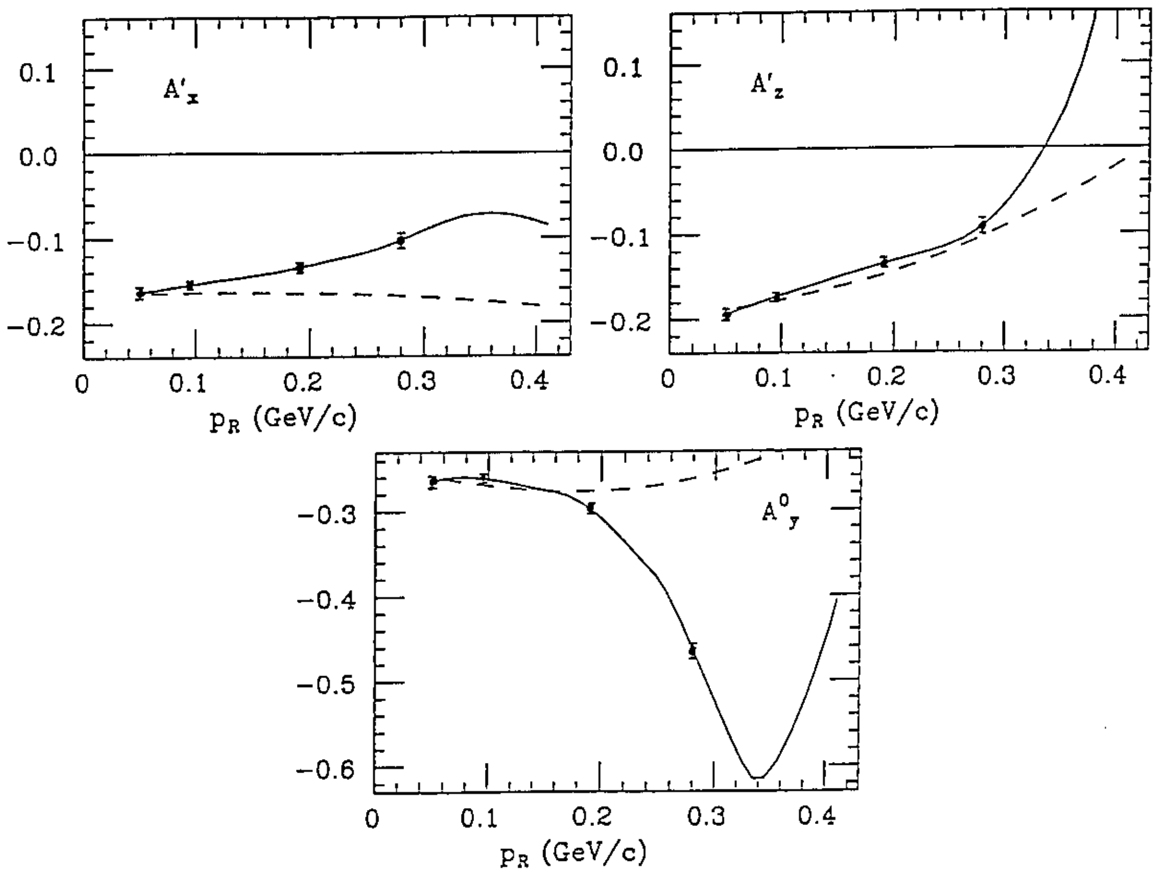

Fig. 2 The three target asymmetries which do not vanish in collinear kinematics are plotted against the momentum p_R of the p-n system recoiling in the reaction $^3\overrightarrow{\mathrm{He}}(\vec{e},e'p)d^*$ at the proposed kinematics given in Table 1. The dashed lines correspond to PWIA while the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

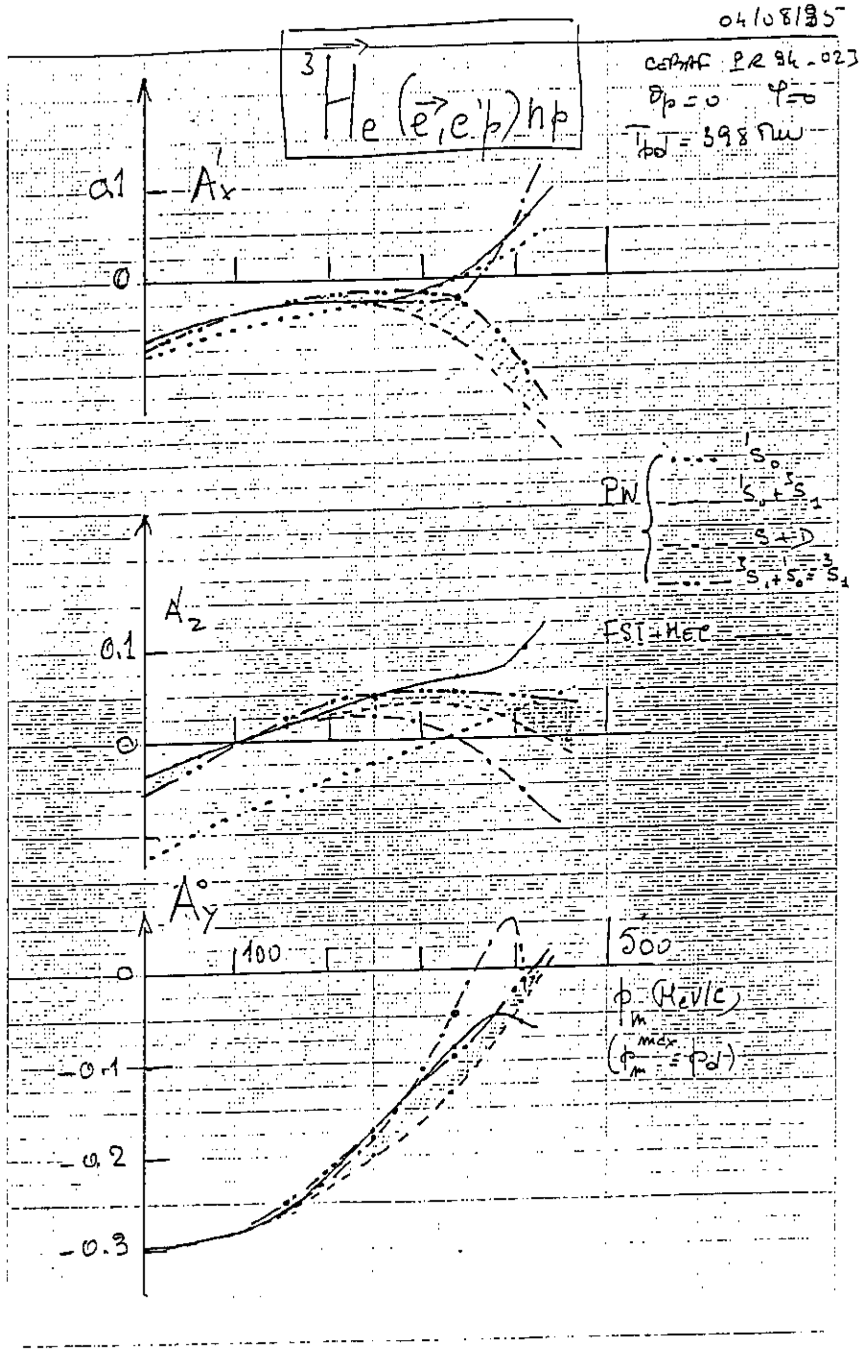

Fig. 3 Calculations of asymmetries for the three body final state as a function of missing momentum at fixed missing energy of 25 MeV.

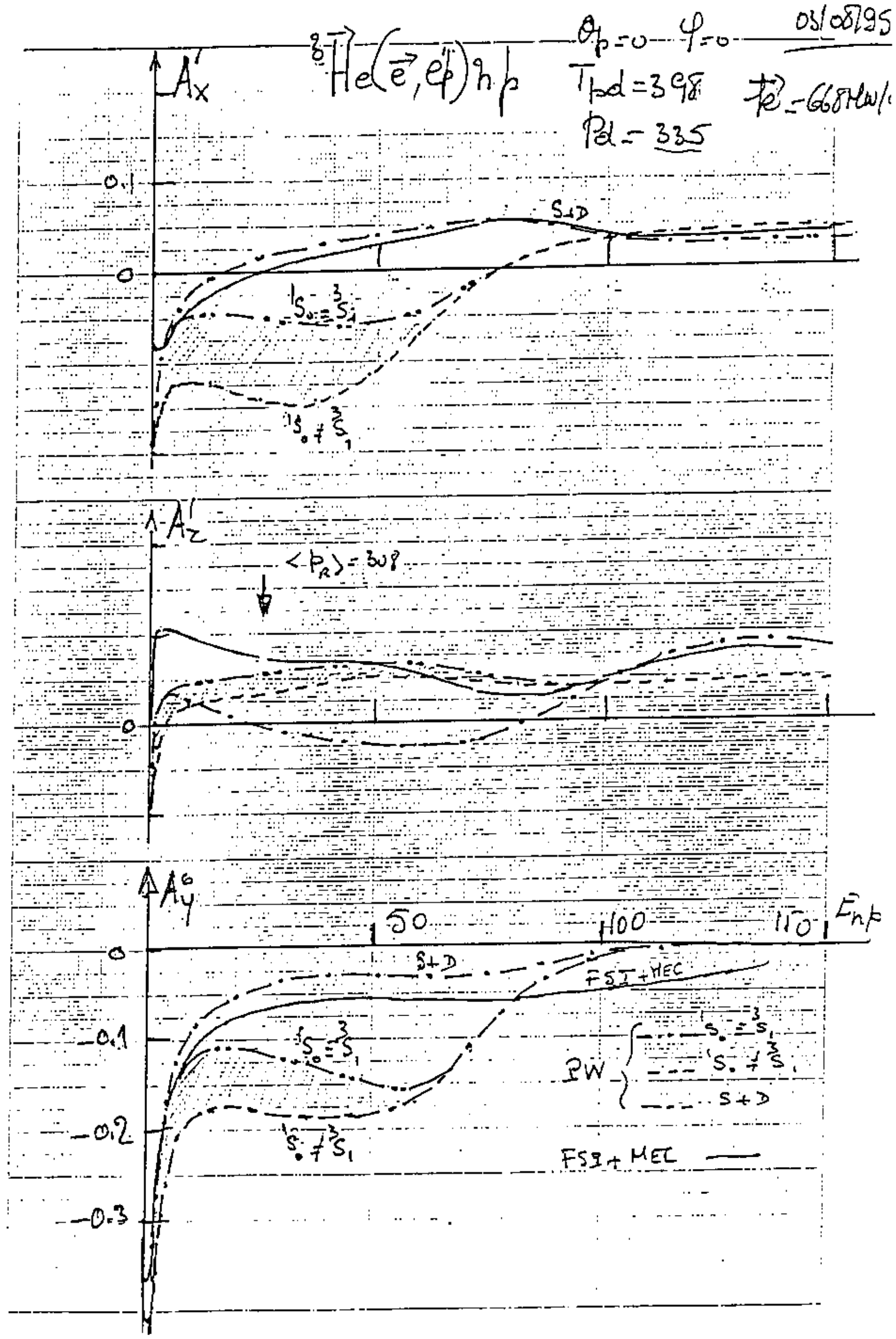

Fig. 4 Calculation of asymmetries for the three body final state as a function of missing energy at fixed missing momentum of 335 MeV/c.

allowed ranges, it does reveal kinematic regions that should be sensitive to the form of the S-wave structure. We continue to explore various kinematic regions for particular sensitivity to S wave structure.

3. Target

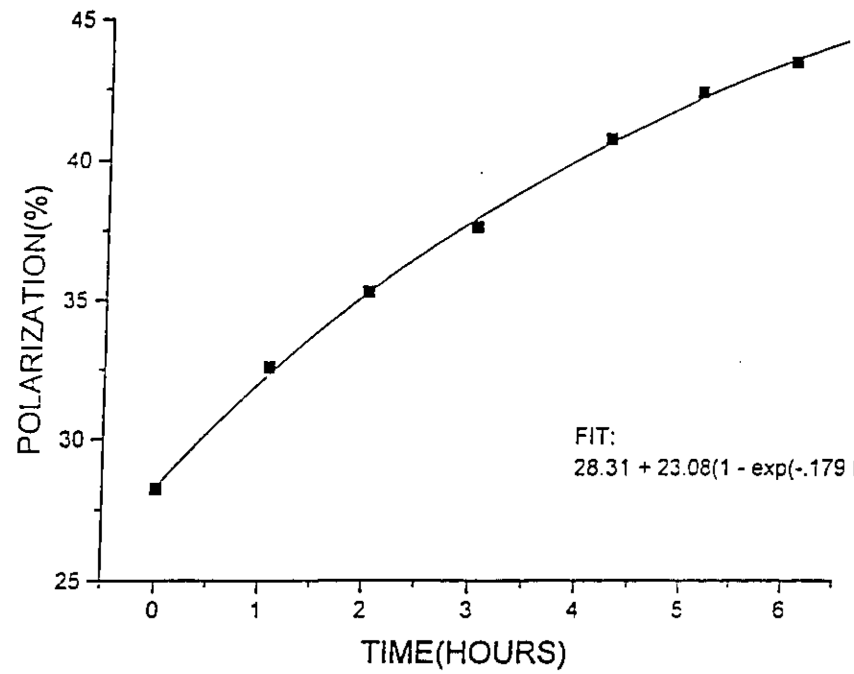

Fig. 5. Polarization of the Los Alamos ^{3}He cell as a function of pumping time.

The target technology that we have selected for this measurement is the optically pumped rubidium spin exchange type that has been developed by Chupp and collaborators over the past decade. The high density offered by this technology provedes high luminosity at moderate beam currents. We will use a ^{3}He target pressurized to 10 atmospheres of helium, or $2.7\times10^{20}/\text{cm}^3$. 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 $6\times10^{21}/\text{cm}^2$ 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}.

UNH began polarizing ^{3}He intended for use as targets in approved experiments at Saskatchewan and Bates. The UNH group has approval for 400 hours to measure the target asymmetry A_y^0 of the reaction $^3\overrightarrow{\mathrm{He}}$(e,e′n) at the Saskatchewan Accelerator Laboratory and for 335 hours to measure the two beam-target asymmetries $^3\overrightarrow{\mathrm{He}}(\vec{e}$,e′n) and the target asymmetry A_y^0 of the reaction $^3\overrightarrow{\mathrm{He}}$(e,e′n) at the MIT-Bates Accelerator Center. Unfortunately the elimination of the electronuclear program at Saskatchewan prevents our experiment from running there. While preparing for the experiment at Saskatchewan we installed the target apparatus in the beamline and had begun tests of the backgrounds when the electron program was eliminated.

TABLE 1

Polarization lifetimes of ^{3}He cells produced at UNH for LANSCE

Identity	density (amagat)	lifetime (hours)
V1	3.3	84.
V2	5.2	48.5
V3	6.0	38.1
V4	6.1	47.3
V5	6.0	41.1

UNH has been providing polarized ^{3}He cells for use as a neutron spin filter at the LANSCE facility. A recent measurement of the neutron polarization was just completed using a 3.3 atmosphere cell that was fabricated at UNH. The geometry of this cell is cylindrical with 3.4 cm diameter flat end windows and a 10 cm length. The life time for this cell is 84 hours. Fig. 5 shows the ramp up of the cell in our lab while pumping with 2 W from a argon ion pumped titanium sapphire laser and 15 W from a fiber coupled diode laser. This cell was eventually polarized to 64% after optimizing the rubidium number density to the incident laser intensity. During the neutron polarization measurement the cell was polarized to 43% using 2 diode lasers which produced neutron polarizations of 35% at 1 eV and 80% at 0.1 eV. Neutron polarizations were measured over a range of 25 meV to 10 eV. UNH is also providing polarized 3He cells to be used as a neutron spin filter and as a neutron spin analyzer for measurement of the parity-violating neutron spin rotation in the n-^{139}La p-wave resonance at LANSCE. A total of 5 cells have been sent to LANSCE; their properties are given in Table 1.

We are currently testing a procedure that we have developed to increase the lifetimes of fabricated cells that show poor relaxation times. In our first test we increased the lifetime of a 3 atmosphere test cell from 11.6 hours to 33 hours. We plan on doing further tests to increase the lifetime. Once perfected, this technique will allow for increased production of usable cells.

Fig. 6 is a drawing of the UNH target design. The pumping cell is conical to increase the overlap of the resonant light plume with the rubidium vapor. The target cell has thin 50 micron inverted windows. These windows withstand high pressures while generating and retaining a minimum of heat.

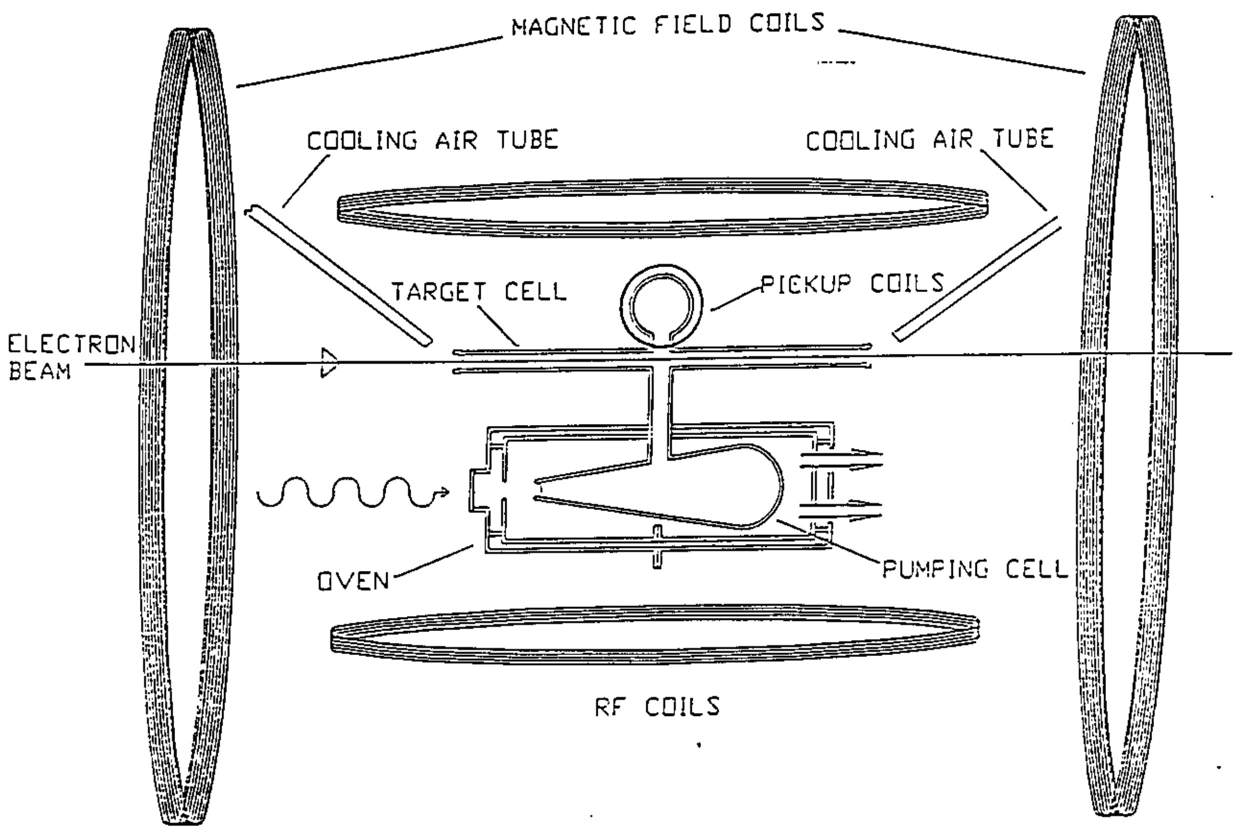

Fig. 6. The UNH alkali spin exchange helium target assembly, showing the conical pumping cell and concave windows, two UNH developments.

Polarized targets suffer from depolarization in the beam. An optimal figure of merit is achieved if the beam current is chosen that maximizes polarization-squared times luminosity. This figure of merit can be written in terms of the spin exchange rate γ_{SE}, the average rubidium density P_{Rb}, the rubidium unrelated target depolarization rate Γ_{target}, and the beam induced depolarization rate Γ_{beam}. Since Γ_{beam} depends linearly on luminosity, the highest figure of merit

$$f(L) = p^2 L = \left[\frac{\gamma_{SE} P_{Rb}}{\gamma_{SE} + \Gamma_{target} + \Gamma_{beam}}\right]^2 L$$

is found where $\Gamma_{beam} = \gamma_{SE} + \Gamma_{target}$. Note that this optimal figure of merit is achieved with a luminosity that depolarizes the target by one-half and is achieved at 36 μA. Nevertheless the peak is broad. Our request of 10 μA is conservative, but still offers 70% of the maximum possible figure of merit.

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.

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 attempt 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 0.6-1.0 GeV/c beam momentum (0.1-0.2 GeV total center of mass kinetic energy) and rises for higher kinetic energies (Fig. 7). The proton-deuteron cross section also has a minimum around

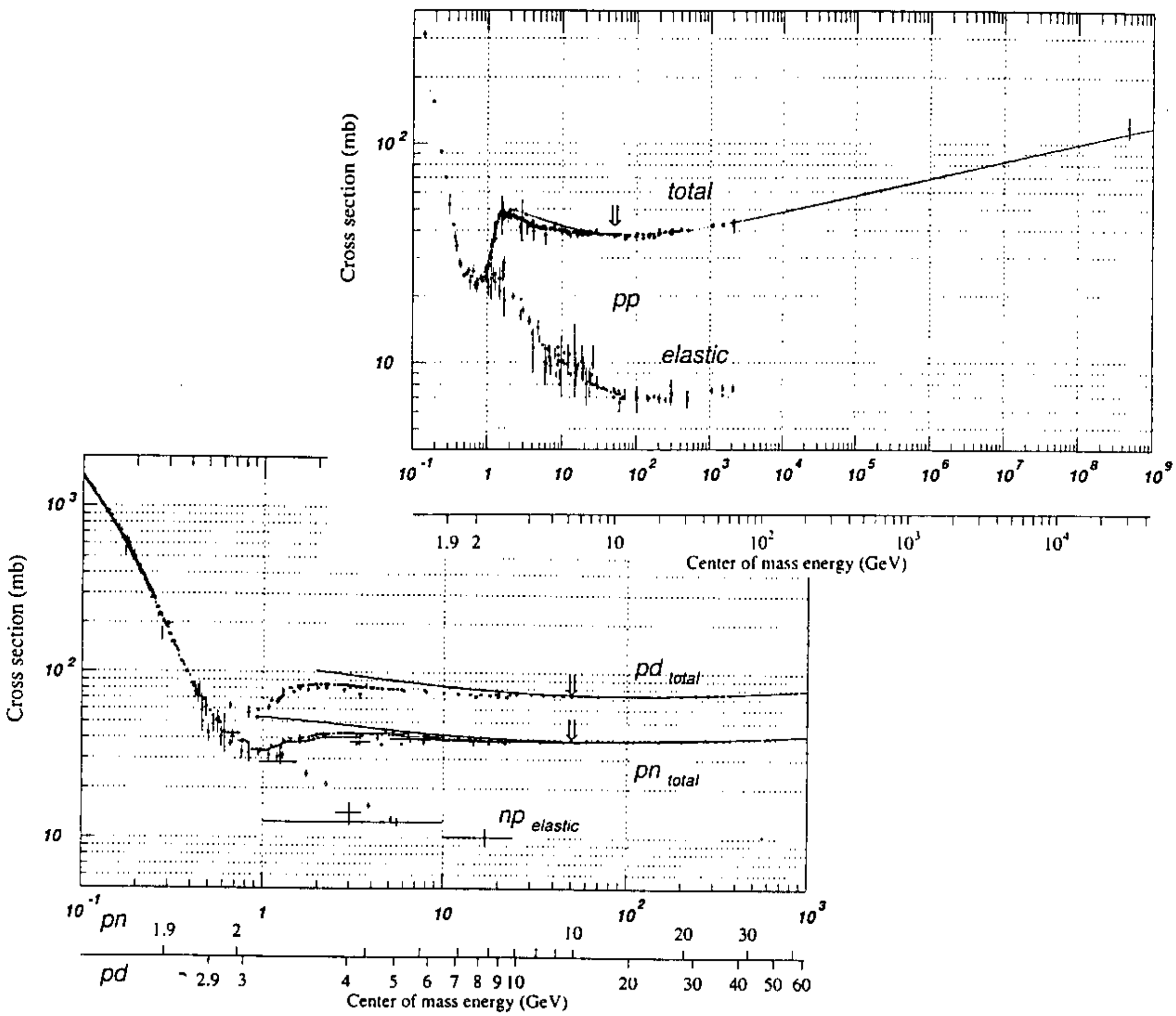

Fig. 7. Total cross section as a function of energy for p-p and p-d scattering.

0.8-1.1 GeV/c beam momentum. We are considering a revision of our choice of final state center of mass kinetic energy to the high end of this range, 0.20 GeV. Our previous choice was 0.35. We plan to explore the role of final state interactions with calculations at the lower relative energy. Until new calculations confirm a reduction in FSI and MEC, however, we continue to report the already good results obtained thus far.

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^0_y peaks at a value of –0.08 at p_m=0.38 GeV/c. MEC increases A^0_y to –0.2 at its peak of p_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^0_y was not included in PR94-020.

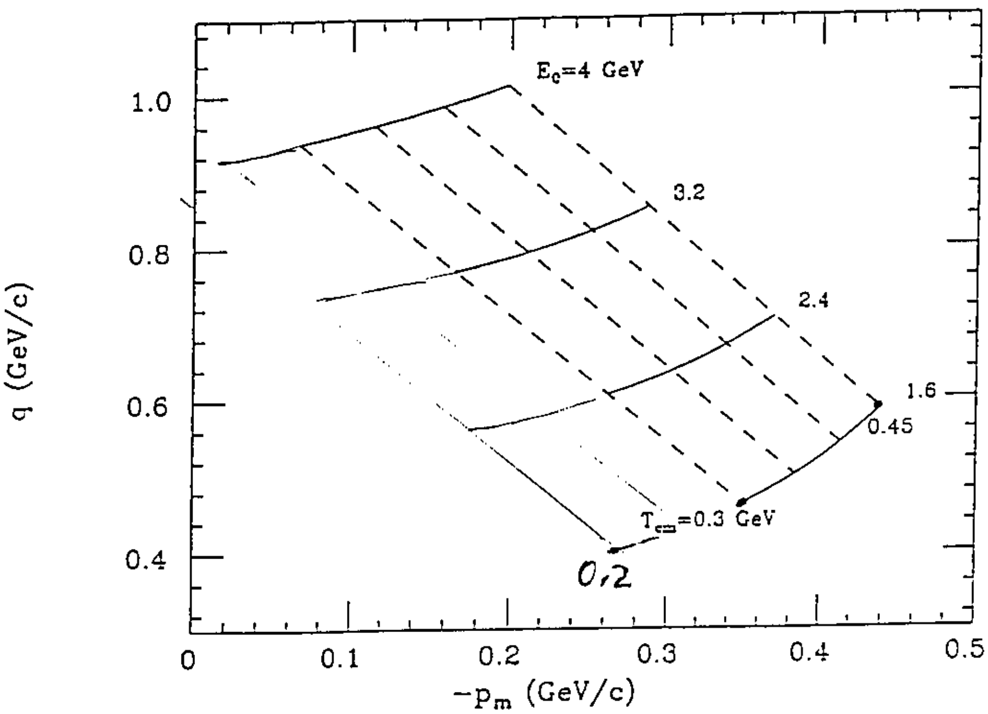

Fig. 8. Kinematic choices for the forward electron scattering angle θ_e=12.6° restricted to parallel geometry. Different missing momentum p_m and three momentum transfer q determine the required beam energy E_0 and final state kinetic energy.

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. 8) 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. Kinematics for the four kinematic settings proposed are presented in Table 2. A fifth point in the original proposal, the highest p_m point, was deleted due to concerns about ambiguities in its interpretation. If new calculations are successful in finding kinematics with lower final state interactions and meson exchange currents, these will be reported to the PAC.

TABLE 2

Kinematics for asymmetry measurements

	E_0 GeV	$\vec{q}$ GeV/c	ω GeV	$\theta_{e'}$	θ_q	p GeV/c	p_m 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 3. 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 3

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

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

TABLE 4

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 4). 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 1, against a calculation by Laget in these kinematics. In Figure 2 the uncertainty of the three body breakup at the d* missing energy is plotted. 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 and calibration 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 has been closely involved in the Hall A collaboration since its formation. UNH signed an MOU to design and implement the Hall A trigger for the two HRS spectrometers. That project was successfully completed. A subsequent project, development of the trigger software, has also been completed by the UNH group. The group is currently examining the possibility of improving the timing resolution of the scintillation detectors, using expertise developed during the Hall B time-of-flight project.

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