Jefferson Lab PAC18
Proposal Cover Sheet

This document must be received by close of business Thursday, June 1, 2000 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: A

Days Requested for Approval: 24

❒ **Proposal Title:**
Measurement of small components of the 3He wave function using $\overrightarrow{^3He}(\vec{e},e'p)$ in Hall A.

Proposal Physics Goals
Indicate any experiments that have physics goals similar to those in your proposal.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

None

Contact Person

Name: F. W. Hersman
Institution: University of New Hampshire
Address: Department of Physics
Address: 9 Library Way
City, State, ZIP/Country: Durham, NH 03824
Phone: 603-862-3512 **Fax:** 603-862-2998
E-Mail: hersman@unh.edu

Jefferson Lab Use Only

Receipt Date: 6/1/00

By: M. Connors

00-106

LAB RESOURCES LIST

JLab Proposal No.: ____________________ Date 5/29/00
(For JLab ULO use only.)

List below significant resources — both equipment and human — that you are requesting from Jefferson Lab 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 JLab)*

New Support Structures:

Data Acquisition/Reduction

Computing Resources:

New Software:

Major Equipment

Magnets:

Power Supplies:

Targets: $^3\vec{He}$ target

Detectors:

Electronics:

Computer Hardware:

Other:

Other:

BEAM REQUIREMENTS LIST

JLab Proposal No.: ____________ Date: 5/29/00

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

Spokesperson: F. W. Hersman
Phone: 603 862 3512
E-mail: hersman@unh.edu

Hall Liaison: J.P. Chen

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/cm^2)	Est. Beam-On Time for Cond. No. (hours)
1	4000	10	high pol	$^3\vec{He}$ *	30	10.5
2	3200	10	high pol	$^3\vec{He}$	30	4.5
3	2400	10	high pol	$^3\vec{He}$	30	8
				* also 30	mg/cm^2	glass

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

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

Date: 5/29/00

Check all items for which there is an anticipated need.

Cryogenics	Electrical Equipment	Radioactive/Hazardous Materials
___ beamline magnets ___ analysis magnets ___ target type: ___ flow rate: ___ capacity: ___	___ cryo/electrical devices ___ capacitor banks ___ high voltage ___ exposed equipment	List any radioactive or hazadorous/ toxic materials planned for use: ___ ___ ___ ___
Pressure Vessels ___ inside diameter ___ operating pressure ___ window material ___ window thickness $^3\vec{He}$ target	**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: diode wattage: 100 W class: ___ Installation: ___ permanent ✓ temporary Use: polarization ___ 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: ___ ___

Computing Requirements List

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

Spokesperson: F. W. Hersman Experimental Hall: A

Raw Data Expected

Total: ____________ Per Year (long duration experiments only): ____________

Simulation Compute Power (SPECint95 hours) Required: ____________

On-Line Disk Storage Required: ____________

Imported Data Amount from Outside Institutions: ____________

Exported Data Amount to Outside Institutions:w ____________

Expected Mechanism for Imported/Exported Data: ____________

Special Requirements

For example, special configuration of data acquisition systems) that may require resources and/or coordination with JLab's Computer Center. Please indicate, if possible, what fraction of these resources will be provided by collaborating institutions and how much is expected to be provided by JLab.

no special requirement for computing

UPDATE ON PROPOSAL PR-94-023 TO THE 7/2000 JLAB PAC

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

originally approved by the Hall A Collaboration (1997)
intending to seek reapproval

F. W. Hersman, spokesperson

ABSTRACT

Experiment E94-023 to measure small components of the ^{3}He wave function using $^3\overrightarrow{\mathrm{He}}$($\vec{\mathrm{e}}$,e′p) in Hall A has not received beam time during the three years since it was approved. The goals remain as timely as ever. We review the configuration of these small components, their connection to interpreting ^{3}He experiments on neutron prooperties, our plan for the measurement, and our approach to controlling uncertainties.

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.

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 the cross section is the sum of squares of amplitudes, small components can be difficult to extract. Asymmetries are often due to the product of a small and large amplitude, magnifying the small contribution. Scattering from a free polarized proton has a large asymmetry characteristic of its electric to magnetic form factor ratio. Consequently, components of the ^{3}He wave function with net proton polarization exhibit an asymmetry characteristic of their amplitude. Furthermore, this asymmetry will complicate the interpretation of experiments that are designed to extract fundamental neutron properties from inclusive asymmetry measurements.

The simple 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.

We have optimized our measurement 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 choose the relative kinetic energy value in the final state system in the minimum in the nucleon-nucleon interaction.

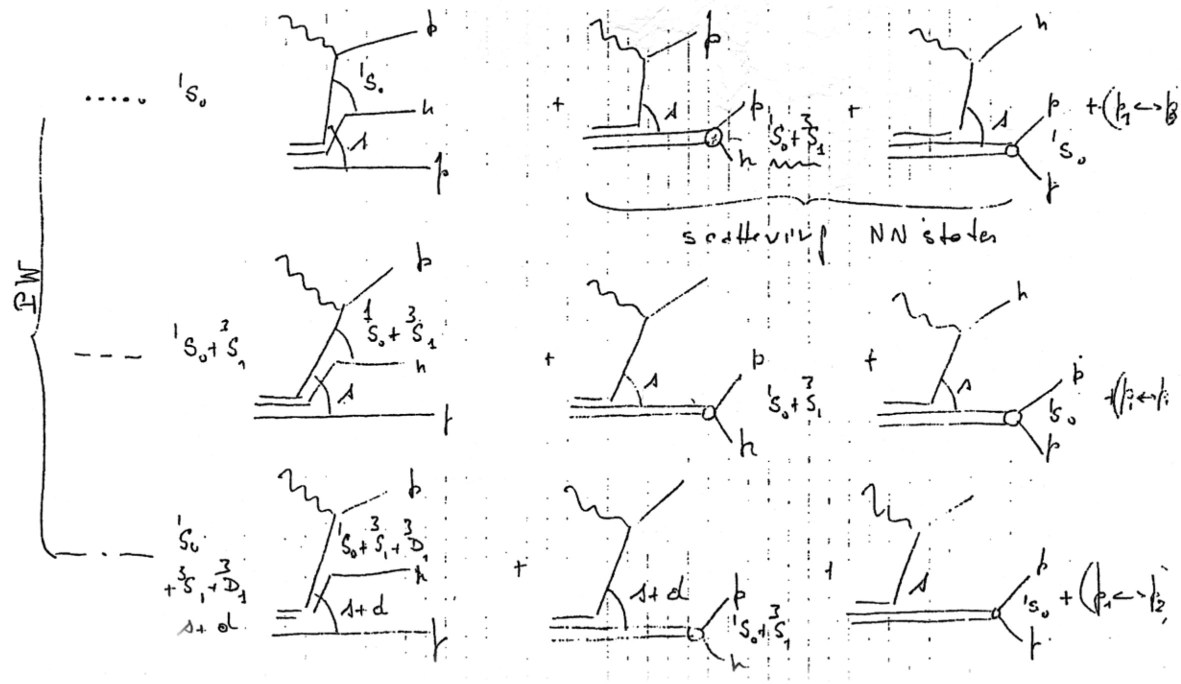

Fig. 1. Diagrams included in the various calculations performed by J.-M. Laget.

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 maximum value of Q^2 consistent with these considerations.

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.

In this presentation we review the elements of our experiment. To provide the framework for our discussions we present calculations performed by J-M Laget. We base our kinematic choices and beam requirements on these calculations. We describe the target, including the particular requirements of this experiment. Finally we present our uncertainty estimates and beam requirements.

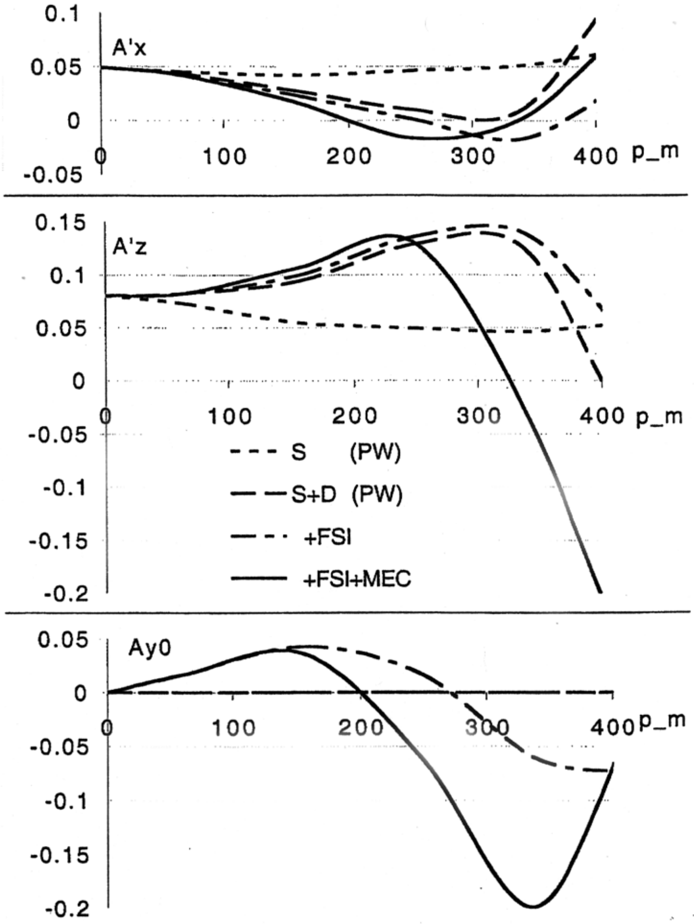

Fig. 2. The three target asymmetries which do not vanish in collinear kinematics are plotted against the momentum p_R of the deuteron recoiling in the reaction $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e'p})\mathrm{d}$ at the proposed kinematics given in Table 1. The dotted lines and dashed lines correspond to PWIA when only the S-wave or both the S- and D-wave are respectively taken into account. The dash-dot includes FSI. The full lines include FSI and MEC.

2. Asymmetry calculations

Laget has calculated the quasielastic scattering $^3\overrightarrow{\mathrm{He}}(\vec{\mathrm{e}},\mathrm{e'p})$ reaction using his diagrammatic expansion. 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.

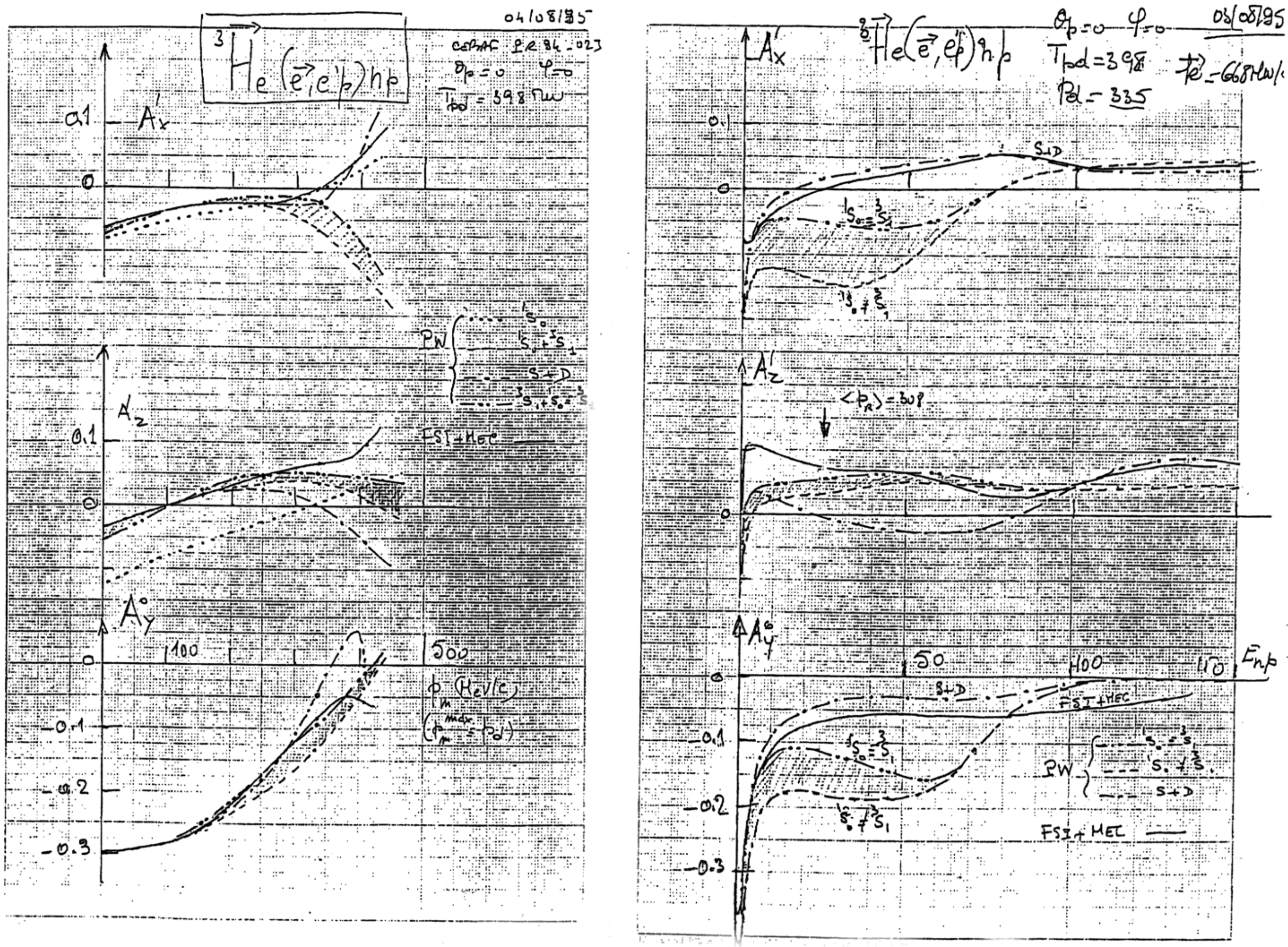

Fig. 3. Calculation of asymmetries for the three body final state as a function of missing momentum at a fixed missing energy of 24 MeV (left), and as a function of missing energy at a fixed missing momentum of 335 MeV/c.

For all calculations he used the solution to the Faddeev equations with the Paris potential as the initial ground state wave function. He used three different models for the final state to explore the sensitivity to the the the ^{3}He structure. The full plane wave calculation allows singlet S, triplet S and triplet D waves between the struck proton and the residual system, as well as between the residual proton and neutron. The plots with both singlet and triplet S exclude the D wave in the final state. The plot labeled

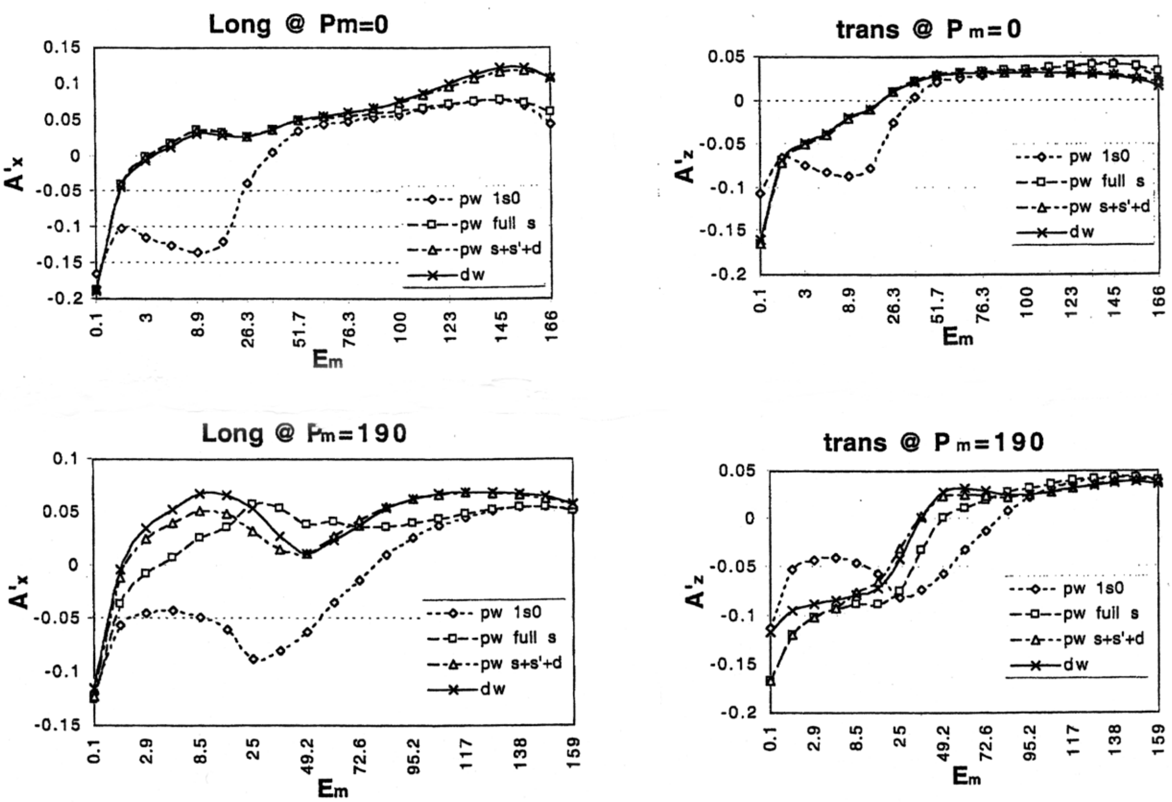

Fig. 4. Calculation of A'_x (left) and A'_z (right) asymmetries for the three body final state as a function of missing energy at fixed missing momenta zero (upper) and 190 MeV/c (lower).

singlet S was calculated allowing that state only for the outgoing proton.

Comparison of the curves allows an estimation of the contribution of various partial waves to the asymmetries. Laget was not able to provide two curves with and without the S'-state, since it could not be selectively removed from the ground state wave function without changing other properties. Nevertheless, the two curves with different constraints on the S-wave should reveal kinematics that are sensitive to the S-wave structure.

Laget also explored sensitivity to MEC and FSI by adding them to the full plane wave curves. A kinematic choice that exhibits large sensitivity to structure with little influence due to FSI and MEC would be optimal from the point of view of minimizing the uncertainty of interpretation. Of course, reasonable counting rates are required for minimizing statistical uncertainty.

Calculations were performed in parallel and perpendicular kinematics and at low and high momentum transfer. The high momentum transfer asymmetries were less modified due to FSI. Parallel kinematics, in addition to simplifying the interpretation by allowing only one response function to contribute, also seemed to offer lower FSI overall.

Reactions leading to the p-d two body final state (Fig.2) and to the p-pn continuum were studied. For the two body final state, the in-plane asymmetries are nonzero at zero recoil momentum. Although the probability is equal for finding a proton in either spin state, the probability of knocking them out leaving a deuteron intact is not equal. For higher recoil momentum, the D-wave significantly modifies the in-plane asymmetries. The addition of FSI in the calculations gives a relatively small correction. MEC, however, influence the asymmetries rather strongly. The relatively large contribution of MEC may be due to the fact that measurements are performed at electron inelasticities in the dip region. In contrast, the calculations in perpendicular kinematics are influenced much more strongly by FSI, and somewhat less by MEC.

The normal target asymmetry vanishes for direct reactions. The asymmetry is nonzero if FSI or MEC are present. We view measurement of this asymmetry as an important and unique determination of those fundamentally interesting processes. For this measurement of few-body structure, however, FSI and MEC are contaminants that must be calibrated. We include companion measurements of the normal target asymmetry in this determination of nuclear strucure as a calibration.

The dependence of the asymmetry measurements on the structure of the S-state was explored to provide an indication of the sensitivity to the S'-state. Because the two protons are symmetric in spin and isospin and have identical angular momentum, they are spatially antisymmetric, differing in principal quantum number. Higher principal quantum number orbitals provide strength at higher recoil momentum. Since the spins of both protons oppose the neutron, the residual system can not recouple to form a deuteron. Consequently the two-body final state has no sensitivity to the S'-state. The spin-singlet channel of the three-body breakup reaction should show evidence of the S'-state at nonzero missing energy and high recoil momentum.

Laget's formalism has no provision for identifying this component and exploring its contribution to cross sections or asymmetries. Instead he provided additional means for exploring sensitivity of the asymmetries in three-body breakup to the structure of the S-wave. As before he preformed the calculations with singlet-S-only, with singlet and triplet-S, and with the full S and D-wave structure. He also included a fourth calculation that fixed the triplet-S and singlet-S components to the spatial form of the triplet-S. The various curves are seen to diverge above recoil momentum of 200 MeV/c and become significantly different at 300 MeV/c and above.

This study supports the view that the combination of asymmetry measurements from the the two-body and three-body breakup reactions over a wide range of recoil momentum should constrain the important small components of the three body wave function.

3. Target

The Hall A polarized ^{3}He target began operation in September 1998. Two experiments, E94-010 and E95-001, have been completed. The ^{3}He target operates at densities of 10 amagat, or $2.7\times10^{20}/cm^3$. We plan for a physical target length of 25 cm. The extended target acceptance of the HRS of 10 cm allows the windows to be just outside the acceptance of the proton arm at 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 $6\times10^{21}/cm^2$ 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 polarization of the target depends on the luminosity as well as the particular properties of the cell. Without beam, cells are able to achieve polarization as high as 50% or above. During E94-010 and E95-001 the polarization with beam on traget averaged around 35%. We base our estimates of uncertainties below on an expectation that 40% polarization will become routine over the next year or so.

This experiment requires two new capabilities from the target infrastructure. We need polarization in the vertical direction in order to measure the normal target asymmetry. Previously the target has been configured to measure the two in-plane asymmetries. We also need to measure these three different asymmetries for four different kinematics. Since we plan for parallel kinematics rather than fixed-q kinematics, each set requires a change in laser and magnetic field direction. This motivates a less labor-intensive method for changing the quantization axis.

4. Kinematics

Raskin and Donnelly[2)] 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 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. 5) 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

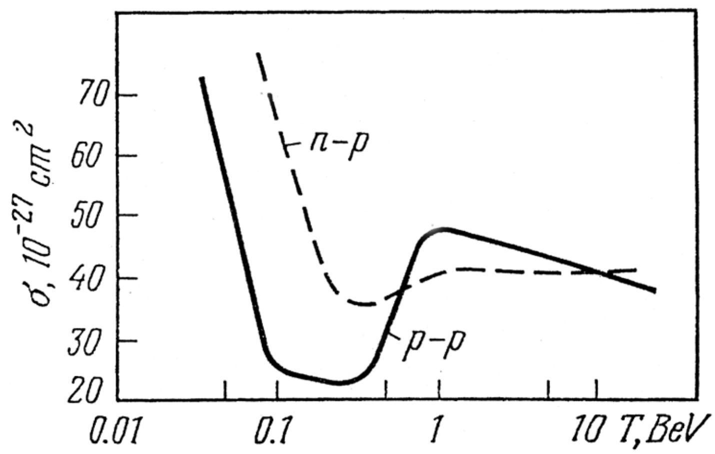

Fig. 5. Total cross section as a function of energy of p-p and p-n scattering.

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 of p_m=0.32 GeV/c. In contrast the FSI contribution to the normal target asymmetry for perpendicular kinematics 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.

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. [illegible] 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. Kinematics for the four kinematic settings proposed here (calculated for zero missing energy) are presented in Table 1.

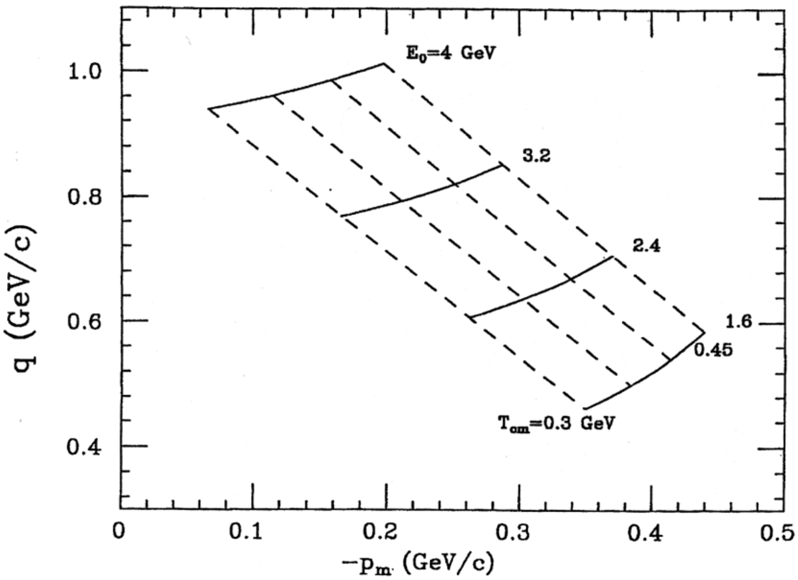

Fig. 6. Kinematic choices for the forward electron scattering angle θ_e=12.6° restricted to parallel geometry. Choices for missing momentum p_m and three momentum transfer q determine the required beam energy E_0 and final state kinetic energy.

TABLE 1

Kinematics for asymmetry measurements

	E_0 GeV	$\vec{q}$ GeV/c	ω GeV/c	$\theta_{e'}$	θ_q	p GeV/c	p_m GeV/c
A	4.0	1.165	0.565	15.80°	−53.4°	1.165	0.000
B	4.0	0.961	0.500	12.60°	−52.6°	1.076	0.115
C	3.2	0.794	0.455	12.60°	−49.0°	1.005	0.211
D	2.4	0.637	0.420	12.60°	−42.7°	0.939	0.302

We make one final comment regarding the selection of kinematics. During the time since these kinematics were optimized it has become clear the the original nominal beam energies, integer multiples of 800 MeV, no longer consititute a constraint. At this time integer multiples of 1000 MeV are more common. Also, an unpolarized study of the ground state structure of ^{3}He, E89-044, recently took data in Hall A. Some coordination between the kinematics of that experiment and this one may be justified. Nevertheless, the present study serves as guidance for count rate estimates.

Count rate estimates were performed with the Monte Carlo reaction code MCEEP.[3] 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 $\delta p = \pm 5\%$. (We used the forward quad mode, however, for the HRS proton spectrometer. Since it is now clear that only the normal position is available, the count rates have been reduced by a factor 0.7.) The two body breakup reaction process was modeled using the momentum distribution measured by Jans[4] and Marchand[5] for generation of events in the spectrometer acceptances. We used the spectral function of Meier-Hajduk[6] 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.

TABLE 2

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

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

TABLE 3

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

	$\Delta A'_x$(d)	$\Delta A'_x$(d*)	$\Delta A'_x$(pn)	days
A	0.003	0.005	0.013	3.0
B	0.004	0.005	0.010	1.5
C	0.005	0.006	0.008	1.5
D	0.009	0.009	0.007	3.0
	$\Delta A'_z$(d)	$\Delta A'_z$(d*)	$\Delta A'_z$(pn)	days
A	0.003	0.005	0.013	3.0
B	0.004	0.005	0.010	1.5
C	0.005	0.006	0.008	1.5
D	0.009	0.009	0.007	3.0
	ΔA^0_y(d)	ΔA^0_y(d*)	ΔA^0_y(pn)	days
A	0.004	0.007	0.015	1.0
B	0.003	0.004	0.010	1.0
C	0.004	0.005	0.007	1.0
D	0.009	0.009	0.007	1.5
empty	target			1.5

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% at 10 μA current were used in the calculations. (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 22.5 days of beam time to measure three asymmetries to three final state missing energy regions at four choices of missing momentum kinematics. One and a half days background subtraction and calibration is added to bring the total request to 24 beam days.

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