

# CEBAF Program Advisory Committee Seven Update Cover Sheet

This proposal update must be received by close of business on November <sup>13</sup>/<sub>16</sub>, 1993 at:

CEBAF  
User Liaison Office  
12000 Jefferson Avenue  
Newport News, VA 23606

## Present Conditionally Approved Proposal Title and Number

91-020

Experiments with a Polarized <sup>3</sup>He Target and the CLAS

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Experimental Hall: B

Total Days Requested for Approval: 30

Minimum and Maximum Beam Energies (GeV): 2.5

Minimum and Maximum Beam Currents ( $\mu$ Amps): 10

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Receipt Date: 11/23/93

By: JP

PR 93-105

## UPDATE

### Experiments with a Polarized $^3\text{He}$ Target and the CLAS (CEBAF Experiment 91-020)

*November, 1993*

R. D. McKeown, spokesperson

## ABSTRACT

We report on progress towards the realization of an optimized experimental design for experiment 91-020: "Experiments with a polarized  $^3\text{He}$  target with the CLAS." The density of the target will be increased compared to the original proposal to allow for utilization of higher polarization beam ( $\sim 80\%$ ) at lower beam currents. As a result, the statistical uncertainties are a factor of 2 lower than in the original proposal. Other developments and further improvements are also discussed.

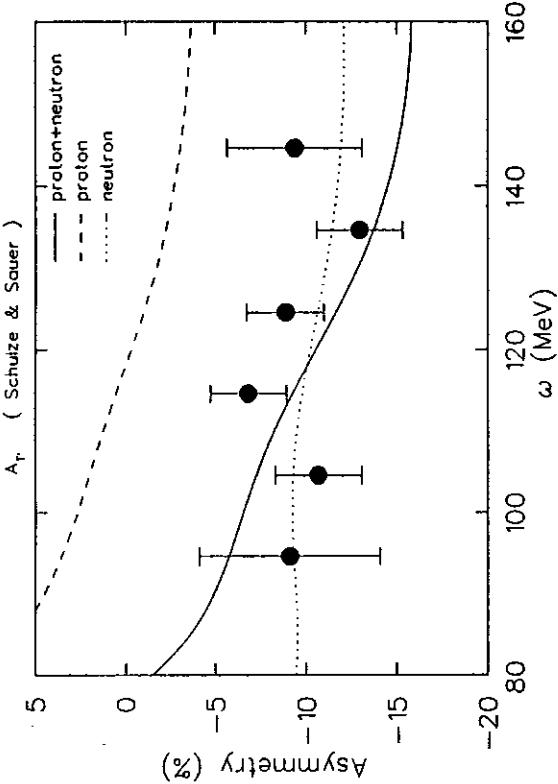
During the last two years, there has been a great deal of activity in the field of spin-dependent electron scattering. In particular, many experiments with polarized  $^3\text{He}$  targets have been performed. These efforts were all quite successful, and there is now a considerable base of experience with this new technology. Our group recently performed a new experiment at Bates using a cryogenic polarized  $^3\text{He}$  target which we developed at Caltech. This effort is discussed in Section I below. In addition, a major technical effort at SLAC resulted in the construction of a polarized  $^3\text{He}$  target that was used in a spin-dependent deep inelastic scattering experiment.<sup>1</sup> Furthermore, a new high-density ( $\sim 1$  atm) target based on a compression scheme is now in use at Mainz.<sup>2</sup>

Based on this experience, we are pursuing several approaches towards the development of a polarized  $^3\text{He}$  target for experiment 91-020 (and possibly others) at CEBAF. These efforts are described in Section II below. We are presently developing a novel version of the type of target we employed at Bates while also developing (in collaboration with NIST) a simpler and more reliable compression scheme similar to Mainz.

There have also been significant theoretical developments in the treatment of both inclusive and exclusive spin-dependent quasielastic scattering from  $^3\text{He}$ . Furthermore, important information from quasielastic spin-dependent  $p\text{-}^3\text{He}$  is available from new data taken at IUCF. These developments both provide new additional motivation to pursue the experimental plan outlined in CEBAF proposal 91-020.

## I. Bates Experiment (June, 1993)

This year we returned to Bates with a similar target to the one employed in a previous run in 1990. In our earlier run<sup>3</sup> (the first  $e^- - ^3\text{He}$  experiment), poor performance of the Bates ~~scattering~~ had resulted in asymmetry measurements with very marginal statistical precision. This time we redesigned the experiment to employ a new Wein spin-rotator in the polarized injector. This enabled us to deliver longitudinal spin in



**Figure 1** Preliminary asymmetry results for the inclusive quasielastic  ${}^3\text{He}(\bar{e}, e')$  reaction with  $\vec{q} \parallel \vec{S}$  at  $Q^2 = 0.2$  ( $\text{GeV}/c$ ) $^2$ . The theoretical curves are from Schulze and Sauer<sup>5</sup> and show the decomposition of the asymmetry into neutron and proton contributions.

the South experimental hall with single-pass beam (370 MeV). The beam was much more reliable and the typical beam current was  $25\mu\text{A}$  at 37% polarization. We measured spin-dependent quasielastic scattering with two spectrometers simultaneously. MEPS was set up to measure the asymmetry with  $\vec{q} \parallel \vec{S}$  at  $Q^2 = 0.2$  ( $\text{GeV}/c$ ) $^2$ . OHIPS was used to measure the asymmetry with  $\vec{q} \perp \vec{S}$  at  $Q^2 = 0.143$  ( $\text{GeV}/c$ ) $^2$ .

In addition, we used OHIPS to measure the asymmetry in elastic  $e\text{-}{}^3\text{He}$  scattering. In this case, the form factors are well-known from previous experiments that employed Rosenbluth separation techniques so the asymmetry can be predicted with very little uncertainty. The average measured asymmetry was  $28.8 \pm 3.3\%$  in excellent agreement with the predicted 29.2%. This is good evidence that the experiment is well calibrated (especially the beam and target polarizations). It should be mentioned that we previously performed a detailed series of high precision NMR calibration studies at Caltech<sup>4</sup> which resulted in a renormalization of the polarization monitor signal by about 10%. Clearly, this type of calibration effort is crucial to obtaining precise results in physics experiments.

The preliminary quasielastic asymmetry results obtained with MEPS are shown in figure 1. This asymmetry is dominated by the magnetic form factor of the neutron which is rather well-known in this  $Q^2$  range, and our result is in good agreement with PWIA theoretical expectations. The experimental result (integrated over the spectrometer acceptance) is  $9.6 \pm 1.0\%$  to be compared with the theoretical prediction of  $10.1\%$ <sup>5</sup>.

Figure 2 shows the OHIPS quasielastic asymmetry results. Here the asymmetry is more sensitive to the electric form factor of the neutron, but at low  $Q^2$  final state interactions could play a significant role. When averaged over the momentum acceptance of the spectrometer, the experimental result for the asymmetry is  $1.7 \pm 0.5\%$  to be compared with the theoretical prediction (using the Galster parametrization for  $G_E^n$ ) of  $2.8\%$ <sup>6</sup>. The apparent lack of good agreement with PWIA predictions here is actually quite interesting

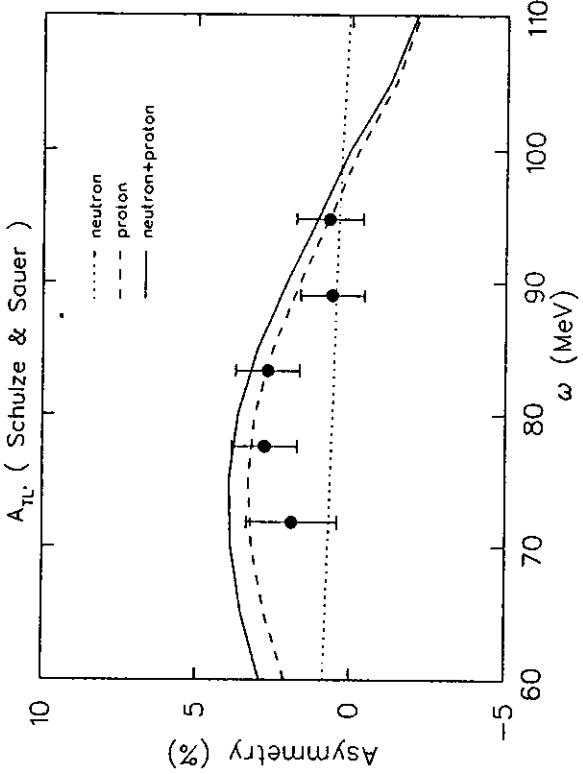


Figure 2 Preliminary asymmetry results for the inclusive quasielastic  ${}^3\text{He}(\bar{e}, e')$  reaction with  $\vec{q} \perp \vec{S}$  at  $Q^2 = 0.143$  ( $\text{GeV}/c$ ) $^2$ . The theoretical curves are from Schulze and Sauer<sup>6</sup> and show the prediction for the Galster parametrization of the neutron electric form factor.

and underscores the need for a complete set of inclusive and exclusive data as proposed for CEBAF experiment 91-020.

The elastic kinematics setting for OHIPS also allowed a study of the asymmetry in the threshold region. Recent theoretical studies indicated that this region is very sensitive to the extraction scheme used to compute the response function  $R_{TL'}$  from the hadronic tensor  $W^{\mu\nu}$ .<sup>7</sup> As can be seen in figure 3, the results overwhelmingly favor scheme "A" over the previously used scheme "C". Further implications of this determination are discussed below in Section III.

The polarized target used at Bates was a metastability exchange target, optically pumped by an LN<sub>2</sub> laser (typically 3-4 Watts). It was constructed as a 2-cell system, with a glass optical-pumping cell at room temperature and a copper target cell at 12K (cooled by a closed-cycle He gas refrigerator). The target windows were 5  $\mu\text{m}$  thick copper foils, and the inside of the target cell was coated with a layer of nitrogen to reduce wall relaxation. In the absence of beam, the target was polarized to 45-50%. The 25  $\mu\text{A}$  electron beam reduced the polarization to 36-40%. Figure 4 shows a histogram of the target polarization during the  $\sim 4$  week run, and one can see that it was very stable over a rather extended run period. (Actually the target was polarized and ready for beam for about 1 month prior to the beginning of data taking. Problems with the polarized electron source and Bates linac delayed the beginning of the experiment for about 1 month.) Therefore, this system has been shown to be extremely robust and reliable under realistic running conditions.

## II. CEBAF Polarized ${}^3\text{He}$ Target Design

In a conservative approach which relies heavily on our experience at Bates, we have been designing a variation of our Bates target for use with the CLAS at CEBAF. The thrust of the effort was to raise the density of the target so that the beam current could

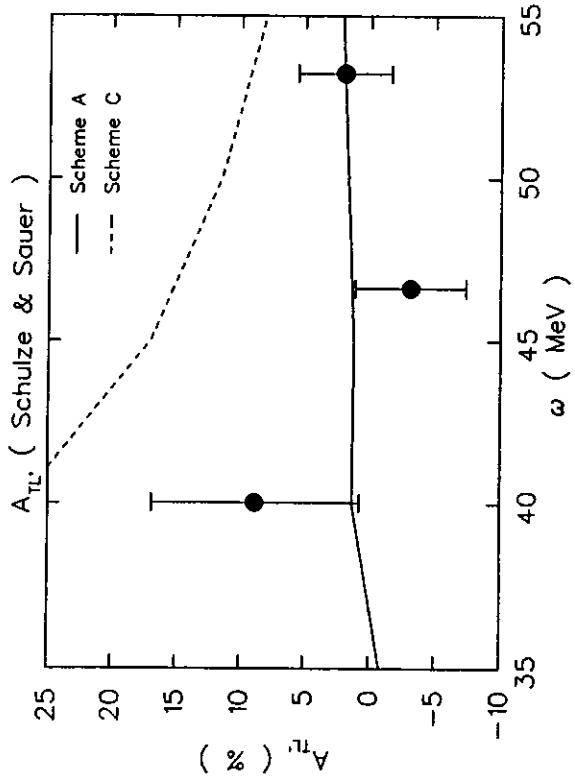


Figure 3 Preliminary asymmetry results for the inclusive  ${}^3\tilde{\text{He}}(\vec{e}, e')$  reaction in the threshold excitation energy region with  $\vec{q} \perp \vec{S}$  at  $Q^2 \sim 0.15 (\text{GeV}/c)^2$ . The theoretical curves are from Schulze and Sauer<sup>6</sup> and show the sensitivity to the calculational scheme used to extract  $R_{TL}$  from the hadronic tensor.

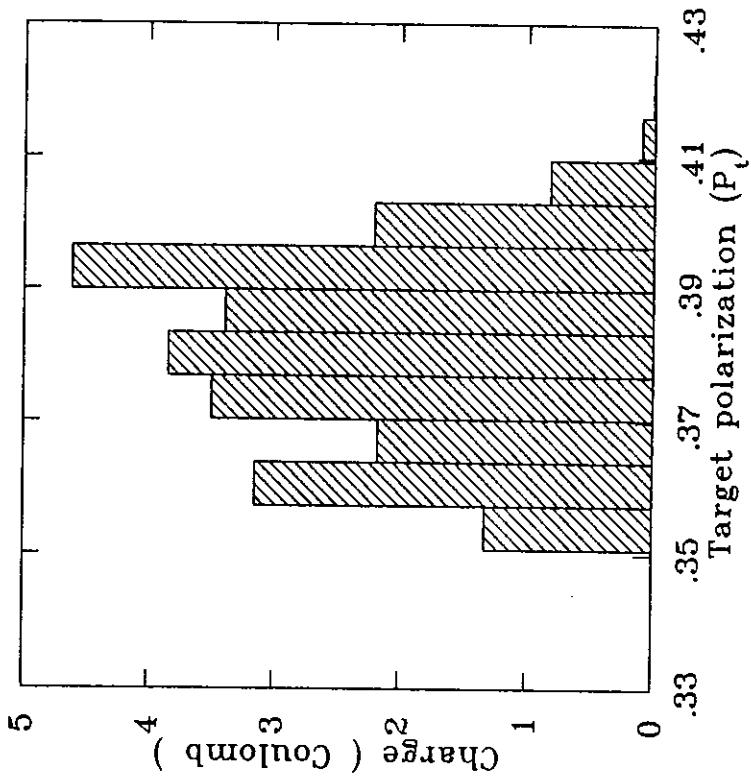


Figure 4 Histogram of beam charge vs. polarization for the polarized Caltech  ${}^3\text{He}$  during the recent run at Bates.

be reduced and keep the same luminosity. The reduced beam current ( $10\mu\text{A}$  rather than  $60\mu\text{A}$ ) has two advantages: it is much less demanding from the point of view of a beam dump for Hall B and it will allow the possibility of higher beam polarization ( $\sim 80\%$  rather than  $40\%$ ).

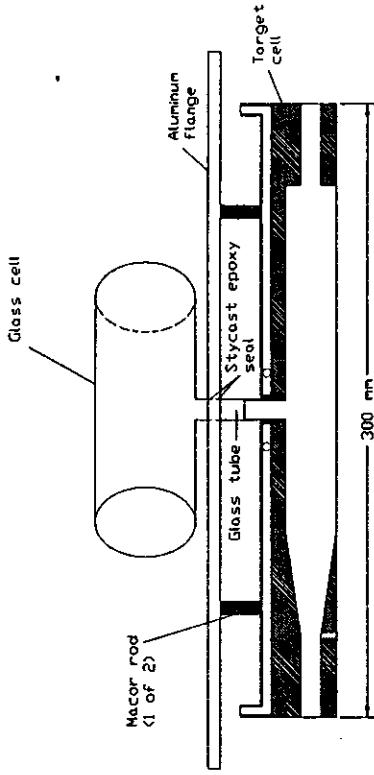
The previous reference design presented to the PAC was a simple approach where the target temperature was only 77K and we could avoid the use of a refrigeration system like the Bates target used. We have been studying the possibility of cooling the target to 10K using the He gas available from the boiloff of the liquid He used to cool the CLAS coils. This would have the effect of raising the target density by a factor of 7.7, which is more than enough to meet the above goal. Note that the temperature is quite similar to the Bates target, so we are confident that the system will perform well at this temperature. In addition, the  $10\mu\text{A}$  current proposed for this experiment will be a factor of 2.5-3 below the currents used at Bates so beam depolarization will be much smaller and the polarization will be somewhat higher. This refrigeration concept has been adopted for the HERMES polarized  $^3\text{He}$  target being built by Milner's group at MIT. They have in fact constructed and tested a cryogenic cell using just this technique we are exploring for CEBAF, and it performs quite well. (The heat loads for the HERMES target are actually quite similar to those we expect at CEBAF.)

CEBAF Hall B engineer Walter Tuzel has studied the cryogenics and it appears straightforward to cool the system using the He gas from the CLAS "service module". The heat load of the target is about 1.5 Watts, dominated by the loss through the insulating support rods. The other major heat load is the transfer lines from the "service module" to the polarized target, which is estimated by Walter Tuzel to be 9.4 Watts. These loads are well within the budget for liquid He use in Hall B. The temperature variation along the target cell walls is less than 1K.

Another consideration in the design was the limitation on the acceptance due to various factors such as pumping cell and mounting hardware, the target chamber, the end-window shielding, etc. The preliminary layout of the design is shown in figures 5-7. The full  $\theta$  acceptance of the CLAS is available for a 12 cm target length. The  $\phi$  acceptance is limited to 4 out of 6 sectors, as can be seen in figure 6.

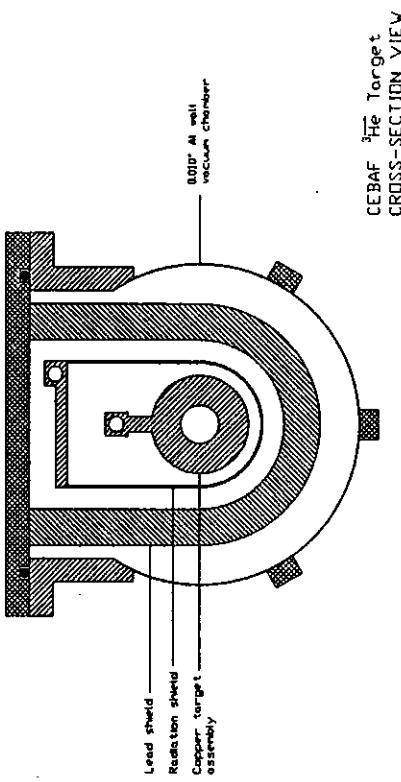
Thus it appears quite realistic to construct a target of this type. We plan to construct a prototype at Caltech which can be cooled using He from a liquid He dewar. Issues to address with such a prototype are the possibility of lower temperatures, alternate wall coatings, and thinner end-windows.

We are also beginning a collaboration with G. Greene and T. Gentile at NIST to further develop the compression scheme pioneered at Mainz. The group at Mainz has successfully compressed polarized  $^3\text{He}$  gas to about 1 atm. This technique has many advantages over the Rb spin-exchange method. First it uses laser photons much more efficiently, so the reliable, inexpensive LNA type laser we have been using is sufficient. (At SLAC, 5 Ti-sapphire lasers pumped by 5 ion lasers was used to polarize the target for E142. This was a very costly and complex system.) In addition, the  $^3\text{He}$  gas is pure, without any buffer gas, which is preferable especially for the exclusive reactions. The initial goal of our study (in collaboration with NIST) is to use a simpler compressor to increase the reliability of the system. NIST is very interested in this scheme for use as a spin-filter for



**Figure 5** Assembly drawing of the proposed cryogenic polarized  $^3\text{He}$  target. (Side view, without Pb shielding)

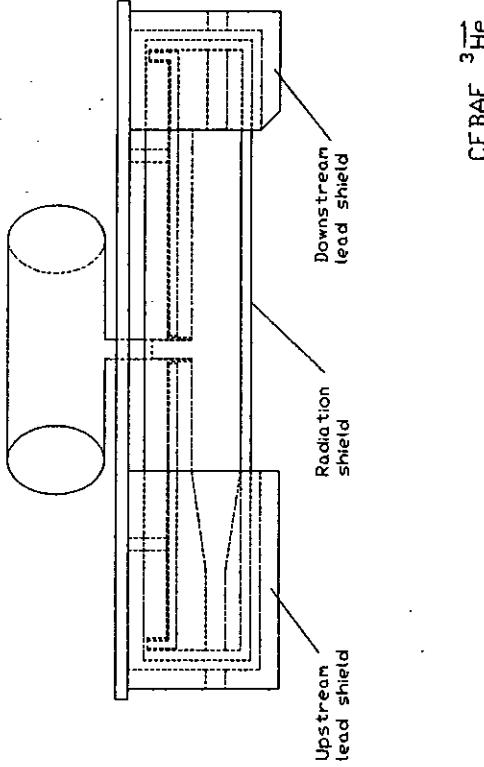
CEBAF  $^3\text{He}$   
PARTIAL ASSEMBLY



**Figure 6** Assembly drawing of the proposed cryogenic polarized  $^3\text{He}$  target. (End view, with Pb shielding)

neutron beams and they have begun purchasing hardware for this project.

Finally, there is considerable interest in the Hall B collaboration to develop a polarized  $^3\text{He}$  target which will fit in the small space within the inner drift chambers (DC1) and the mini-toroid. The major problem is to create a uniform magnetic holding field without field gradients (at the 10 mG/cm level) in such a small space. We are involved in preliminary discussions aimed at solving this problem, but a viable technical solution is not presently in hand. If this possibility becomes reality on the time scale of this experiment, we would probably prefer to run the experiment in this configuration. (The polarized target could be essentially the same as for the larger field configuration.) It would allow better energy and momentum resolution so that we could, for example, study the  $(\vec{\epsilon}, e' p)d$  reaction on polarized  $^3\text{He}$ .



**Figure 7** Assembly drawing of the proposed cryogenic polarized  $^3\text{He}$  target. (Side view, with Pb shielding)

### III. Theoretical Developments

Preliminary theoretical studies of spin-dependent quasielastic  $e^- - ^3\text{He}$  scattering in the plane-wave impulse approximation (PWIA) by Blankleider and Woloshyn<sup>8</sup> explored the sensitivity to nuclear structure as well as neutron form factors. In their study, the excitation of the residual  $2N$  system was treated in the closure approximation. Friar, et al.<sup>9</sup> used a spin density-matrix approach (integrated over the nucleon momenta and energies) to examine the effect of various ground state wave functions.

More sophisticated calculations have recently been performed by Ciolfi degli Atti and co-workers as well as by Schulze and Sauer<sup>7</sup>. These groups both employ a full spin-dependent spectral function to describe the ground state and compute the spin-dependent quasielastic scattering in PWIA. In addition, they prefer a new extraction scheme for computing the response functions; this new method yields different results for the  $R_{TL'}$  interference response function than the one used by Blankleider and Woloshyn.

All of these calculations show that the spin-dependent inclusive cross section for  $\vec{q}$  parallel to the target spin is dominated by the neutron contribution proportional to  $(G_M^n)^2$ . The major effect of the  $^3\text{He}$  nucleus is a dilution of the asymmetry due to the contribution of the protons to the unpolarized cross section and a smearing of the quasielastic strength due to the momentum distribution of the nucleons in the nucleus. In addition, small components of the  $^3\text{He}$  wave function in which the protons are polarized contribute to the asymmetry.

The spin-dependent inclusive cross section for  $\vec{q}$  perpendicular to the target spin is sensitive to the neutron electric form factor. The early calculations of Blankleider and Woloshyn<sup>8</sup> indicated that the neutron contribution was quite substantial which would imply that information on  $G_E^n$  could be reliably extracted from measurements of this quantity. However, the more recent calculations<sup>7</sup> of the response function  $R_{TL'}$  obtain a result with a much smaller neutron contribution. This smaller neutron contribution is associated with the use of the new extraction scheme "A" rather than "C", which is

supported by the preliminary result from our Bates experiment earlier this year (see section I). Therefore, the use of this response function in inclusive scattering for determining  $G_E^n$  at low  $Q^2$  may be somewhat questionable. Further theoretical investigation of this issue would appear to be very useful at this time. The group of Ciof degli Atti is working on including the effects of final state interactions.

Measurements of the exclusive quasielastic reactions  $(e, e'p)$  and  $(e, e'n)$  will allow detailed testing of the nuclear effects (both final and initial states) mentioned above. Studying the  $(e, e'n)$  reaction with  $\vec{q}$  parallel to the target spin  $\vec{S}$  will test the effect of final state interactions of the outgoing nucleon in the spin-dependent response (the neutron magnetic form factor and the initial neutron wave function are relatively well known a priori in this case). Laget has performed calculations<sup>10</sup> that indicate final state interactions are a small correction for  $Q^2 > 0.2 \text{ GeV}/c^2$ . Comparison of  $(e, e'n)$  asymmetries with measurements of the inclusive  $(e, e')$  asymmetries and the neutron energy dependence should help reveal the contributions of final state interactions.

The small amplitudes with the protons in spin  $S = 1$  states referred to above can be studied in a rather direct fashion using the quasielastic  $(\vec{e}, e'p)$  reaction on a polarized  ${}^3\text{He}$  target. (In the plane-wave impulse approximation the quasielastic asymmetry would vanish if the protons are in spin  $S = 0$  states only.) Therefore, one can quantitatively study the  $S'$  and  $D$  state effects on the spin dependent response in  $(e, e'p)$  (note that the proton form factors are well known). In fact, preliminary calculations by Laget<sup>11</sup> show that the  $(e, e'p)$  asymmetries are quite sensitive to these wave function components and that final state effects and meson exchange corrections are quite small.

Armed with the results of this type of analysis, one can then confidently proceed to apply nuclear corrections to the inclusive  $(e, e')$  and exclusive  $(e, e'n)$  data in order to reliably extract the neutron form factors with good precision. The calculations by Laget<sup>10,11</sup> indicate that this technique for studying the neutron form factors appears very promising.

It should be pointed out that recent data from IUCF on the reactions  ${}^3\tilde{\text{He}}(\vec{p}, pp)$  and  ${}^3\tilde{\text{He}}(\vec{p}, pn)$  are quite relevant to this issue. In this case, one is studying the validity of the spin-dependent nucleon knockout reaction in quasielastic kinematics. Preliminary results show effects very similar to the Laget calculations for electron-induced knockout.<sup>12</sup> At very low  $Q^2$  (much lower than our CEBAF proposal), one can see substantial deviations from the PWIA as seen in earlier data from TRIUMF. However, these deviations seem to disappear and the PWIA becomes quite valid as the  $Q^2$  increases to about  $0.5 \text{ (GeV}/c)^2$  in agreement with the Laget predictions. Thus, it appears that the program proposed in 91-020 for CEBAF will in fact address interesting issues of 3-body physics and neutron form factors.

#### IV. Summary

In summary, the  ${}^3\text{He}$  target technology, experimental experience at various laboratories, and the theoretical understanding have all progressed significantly over the last few years. The motivation for and feasibility of performing this measurement at CEBAF have both increased over time. We have made significant progress in developing a conservative and reliable design for a cryogenic polarized  ${}^3\text{He}$  target and we are exploring

other promising alternatives. We are at the point where we must begin to devote significant manpower to the development of the target for this experiment, including graduate students. However, this is problematic when the experiment is not approved. Since we have made excellent progress we would like to request that the PAC approve the experiment so we can proceed with optimum efficiency towards realization of this experiment at CEBAF.

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