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A. TITLE:

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| Experiments with a polarized $^3$He tsrget and the CEBAF large acceptance spectrometer |

B. CONTACT PERSON:



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# PROPOSAL TO CEBAF PAC4

## Experiments with a polarized $^3$He target and the CEBAF Large Acceptance Spectrometer

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ABSTRACT

Recent progress in the development of polarized $^3$He targets offers the possibility of performing many new electron scattering experiments using polarized electrons and the CEBAF Large Acceptance Spectrometer (CLAS). These include measurements of neutron form-factors, $\Delta(1232)$ electroproduction amplitudes, and small amplitudes in the $^3$He ground state wave-function. We propose a program of such measurements with a target which we will construct for use with the CLAS.

**Physics Motivation**

Over the last few years, polarized $^3$He targets of sufficient density and polarization to perform interesting electron scattering experiments have been developed.[1] A target of density $2 \times 10^{19}$ atoms/cm$^2$ has been constructed and tested in the 40 $\mu$A electron beam at the Bates laboratory. The polarization with beam present was $\sim 30\%$, and is expected to improve as we develop the laser technology. The Bates target will be used for the first measurements of the spin-dependent quasielastic electron scattering from $^3$He during the next six months. Thus, the technical feasibility of using polarized $^3$He targets capable of luminosities in the range of $10^{33} - 10^{34}\,\mathrm{cm}^{-2}\mathrm{s}^{-1}$ with a polarized electron beam at CEBAF has been demonstrated. We propose here a program of measurements aimed at studying both the electromagnetic structure of the neutron at relatively high $Q^2$ and the details of the nuclear wave function of $^3$He.

The formalism for electron scattering with spin degrees of freedom has been developed to a point where the physics potential of this technique is now clearly evident.[2] For example, the measurement of the helicity asymmetry with the target spin pointed perpendicular to $\vec{q}$ generally selects structure functions arising from interference between relatively real longitudinal and transverse amplitudes. Many interesting and fundamental physics quantities can be studied by measuring such a structure function. The additional use of final state correlations in coincidence with the electron scattered from a polarized target offers a powerful technique for studying the multipole structure of these interference terms.[3] Such experiments that use the spin degrees of freedom and correlations of final state particles in coincidence with the scattered electron will fully exploit the polarized, high-intensity, CW beam and the large acceptance experimental equipment at CEBAF to perform new fundamental experiments in electronuclear physics. As has been the case in the past, the three-nucleon system offers a unique laboratory for the study of the nucleon and its interactions.

A subject of long-standing interest is the electric form-factor of the neutron, $\mathrm{G}_E^n$. Our best information at present derives from a rather model-dependent analysis of elastic e-d scattering.[4] Recent theoretical work[5] suggests that at higher $Q^2$ the ratio $G_E^n/G_M^n = Q^2/4M^2$ is expected in order to connect with perturbative QCD predictions. CEBAF offers the opportunity to make precision masurements of $G_E^n$ at high $Q^2$ which are of great interest in this context. Polarized $^3$He offers the possibility of studying this quantity in a new way: the $^3$He spin is primarily due to the neutron spin and measurement of the L-T interference enhances the sensitivity to the small longitudinal amplitude which contains the information on $\mathrm{G}_E^n$. We thus propose a measurement of $\mathrm{G}_E^n$ in quasi-elastic $\vec{e}$ scattering from polarized $^3$He.

The corrections to the above picture to account for the nuclear structure of $^3$He have been calculated by Blankleider and Woloshyn[6] and studied in further detail by

Friar[7]. The asymmetry for $\vec{q}$ perpendicular to the target spin is predominantly due to the neutron electric form factor. The major effect of the $^3$He nucleus is to dilute the asymmetry due to the contribution of the protons to the unpolarized cross section and to smear the quasielastic strength due to the momentum distribution of the nucleons in the nucleus. In addition, small components of the $^3$He wave function where the protons are polarized contribute $\sim$ 15% to the asymmetry in the region of momentum transfer proposed here. One should also consider the possibility that processes not included in these calculations can diminish the expected sensitivity to the neutron form-factors. Our proposed experiment is inclusive, and hence should not be as sensitive to final state interactions (FSI) as exclusive measurements because there is an experimental integration over final states. One can expect that the theoretical treatment of the three-body continuum in nuclear physics will advance to the point where these issues can be quantitatively addressed during the next few years before the experiment is performed. Indeed, first calculations of the quasielastic response in the $A = 3$ system by solving the Fadeev equations in the continuum have recently been published.[8] The possible influence of meson exchange currents remains to be investigated theoretically. We expect our initial results at Bates at lower $Q^2$ will stimulate theoretical activity on these issues before the CEBAF experiments can be performed.

We note that the small amplitudes with the protons in spin $S = 1$ states can be studied in a rather direct fashion using the $(\vec{e}, e'p)$ reaction on a polarized $^3$He target. (In the plane-wave impulse approximation the quasielastic asymmetry would vanish if the protons are in spin $S = 0$ states only.) These amplitudes are of fundamental interest themselves and can be studied in detail using this technique. These data will be obtained simultaneously during the $G_E^n$ measurements.

The longitudinal C2 amplitude in electroproduction of the $\Delta(1232)$ resonance is of fundamental interest because of its implications for deformation and/or D-waves in the quark structure of the nucleon. This amplitude will be accessible in quasi-free $\Delta$ production using a polarized $^3$He target.[9]

A more exotic component of the $^3$He ground state wave-function consists of the presence of a $\Delta$ with the other two nucleons coupled to $L = 2$, $S = 0$ and $T = 1$. It was noted by Lipkin and Lee [10] that this component would cause a small anomaly in the ratio of $\pi^+$ to $\pi^-$ production. More recently, Milner and Donnelly [11] have shown that the ratio of *asymmetries* (again $\pi^+/\pi^-$) from polarized $^3$He is much more sensitive to this part of the wave-function: the presence of $\Delta$ components in the ground state with probability of 2% would cause changes in this ratio of order factor of 2. These data could also be obtained simultaneously with the C2 data.

**Discussion of Experiment**

The experiments with polarized $^3$He targets are well-suited to the proposed CLAS in

Hall B. Firstly, the luminosity is limited to $10^{33} - 10^{34}$ by beam depolarization of the target and the low density of the gas target[1]. Thus, it is important to utilize the large acceptance of the CLAS in order to obtain sufficient count rates. Secondly, many of these experiments require the detection of various final state hadrons which may populate a very large solid angle. Efficient data collection will require the very large acceptance of the CLAS. Finally, optically- pumped polarized $^3$He targets use small magnetic fields to orient the spins. This physics program *requires* that the spins be oriented in directions other than parallel to the beam (e.g., most need the spin perpendicular to $\vec{q}$). Thus, the target region must be free of magnetic fields at the milligauss level. This is a very useful feature of the CLAS toroidal design.

The $G_E^n$ measurements would be performed in quasi-elastic kinematics, and we could either detect the final state neutron, veto on energetic protons in the $\vec{q}$ direction, or use the inclusive data. It may be possible to efficiently detect the presence of a neutron in the vicinity of $\vec{q}$ using the shower counter. By triggering on the scattered electron in the quasi-elastic region, we would collect all these data at once. The different types of events would be separated in the off-line analysis; different processes could be analyzed for the quantity $G_E^n$ and compared to test the reliability of different corrections for nuclear structure and/or final state interactions.

As noted above, we could simultaneously collect data on the $(\vec{e}, e'p)$ reaction to study the ground state wave-function of $^3$He. In addition, data would be collected over a wide range of $Q^2$ from 0.5 GeV/$c^2$ to 3.0 GeV/$c^2$ simultaneously. Analysis of events with $\vec{q}$ parallel to the target spin will also allow extraction of the neutron magnetic form-factor in this range of $Q^2$.

As an example of how one could use this technique with the CLAS, we consider an inclusive quasielastic experiment with the following kinematics:

Incident electron energy = 2.5 GeV

Target spin angle = 43°

Electron scattering angle = 15° − 45°.

Of course, the "magic angle" where $\vec{q}$ is perpendicular to the target spin is only approximately maintained over this range of electron scattering angles. However, by considering the range of azimuthal angles for a sector of the CLAS the magic condition is approximately satisfied at every $\theta$. Thus, one can simultaneously measure the asymmetry corresponding to the neutron electric form factor over a wide range of $\theta$ and therefore over a wide range of $Q^2$. Of course, the rate drops off as $\theta$ increases so the statistical precision is less at higher $Q^2$. We assume that only one sector (1/6) of the CLAS is instrumented with shower counters, and the $\phi$-acceptance is assumed to linearly vary from 30° to 45° as $\theta$ varied from 15° to 45°. About 1% energy resolution for the scattered electrons is sufficient to obtain a clear quasielastic peak in the measurement, so the CLAS momentum resolution is quite sufficient. In addition, we have assumed 50% target polarization, 40% electron beam polarization and luminosity $10^{33}$ cm$^{-2}$ sec$^{-1}$ for a 30 day run.

Table I shows the anticipated count rates (the total trigger rate is about 12 Hz), experimental asymmetries (for both Galster and Gari-Krumpelmann parametrizations with beam and target polarizations included), and statistical uncertainties (assumed dominant). The resulting statistical precision for the ratio $G_E^n/G_M^n$ is shown in figure 3. We reemphasize that all these data points are obtained simultaneously in a single run. The typical solid angle for each $Q^2$ point is $\sim$ 50 msr, so such an experiment is very inefficient with a traditional magnetic spectrometer.

The study of pion electroproduction from polarized $^3$He will allow both the $\Delta$ production amplitudes to be studied as well as the existence of $\Delta$'s in the $^3$He ground state. The electroproduction of the $\Delta$ is best studied with the $(e, e'\pi^0)$ reaction to minimize the contribution of the Born terms. The CLAS shower counter would be used to detect the coincident $\pi^0$ in the final state. The study of pre-existing $\Delta$ components requires the detection of charged pions in the final state. Subject to the availability of equipment (e.g., shower counters) these experiments might be performed simultaneously.

### Resources Required

As stated above, these measurements rely on the CLAS and require that there be a field-free region at the target position. Availability of a high-intensity ($\gtrsim$ 10 $\mu$A) of polarized electron beam and polarimeter for monitoring polarization are also required. We would construct the polarized $^3$He target at Caltech. A total of 30 days running time with perhaps a week of tune-up are necessary to perform these measurements. Additional running may be necessary to properly explore the resonance region, although some information could probably be obtained during the quasielastic running.

The $G_E^n$ measurements do not require the full shower counter, but only the region from $15° - 45°$ with $\Delta\phi \sim 60°$ for electron detection. A measurement of C2 in $\Delta$ electroproduction may require the full shower counter, although a preliminary measurement could be performed without it (simultaneously with the measurement of the charged pion asymmetry ratio).

### Commitment of Collaborators

At present several of us are expending significant effort to build and test a polarized $^3$He target. This target will be used for similar measurements at lower $Q^2$ at Bates. Although we have many other commitments and also interests in the Hall C program, we hope to participate in some construction and commissioning of the CLAS.

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**Table I**

| $\theta$ | $Q^2$ (GeV$^2$) | Rate (Hz) | $A_{\text{Galster}}$ (%) | $A_{G-K}$ (%) | $\Delta A$ (%) |
|---|---|---|---|---|---|
| 15° | 0.39 | 5.1 | 0.36 | 0.43 | 0.05 |
| 18° | 0.54 | 2.7 | 0.43 | 0.56 | 0.06 |
| 21.5° | 0.73 | 1.4 | 0.49 | 0.71 | 0.09 |
| 25.7° | 0.98 | 0.69 | 0.41 | 0.86 | 0.13 |
| 30.7° | 1.27 | 0.33 | 0.27 | 1.0 | 0.19 |
| 36.5° | 1.61 | 0.16 | 0.16 | 1.1 | 0.27 |
| 43.3° | 1.97 | 0.08 | −0.09 | 1.2 | 0.37 |

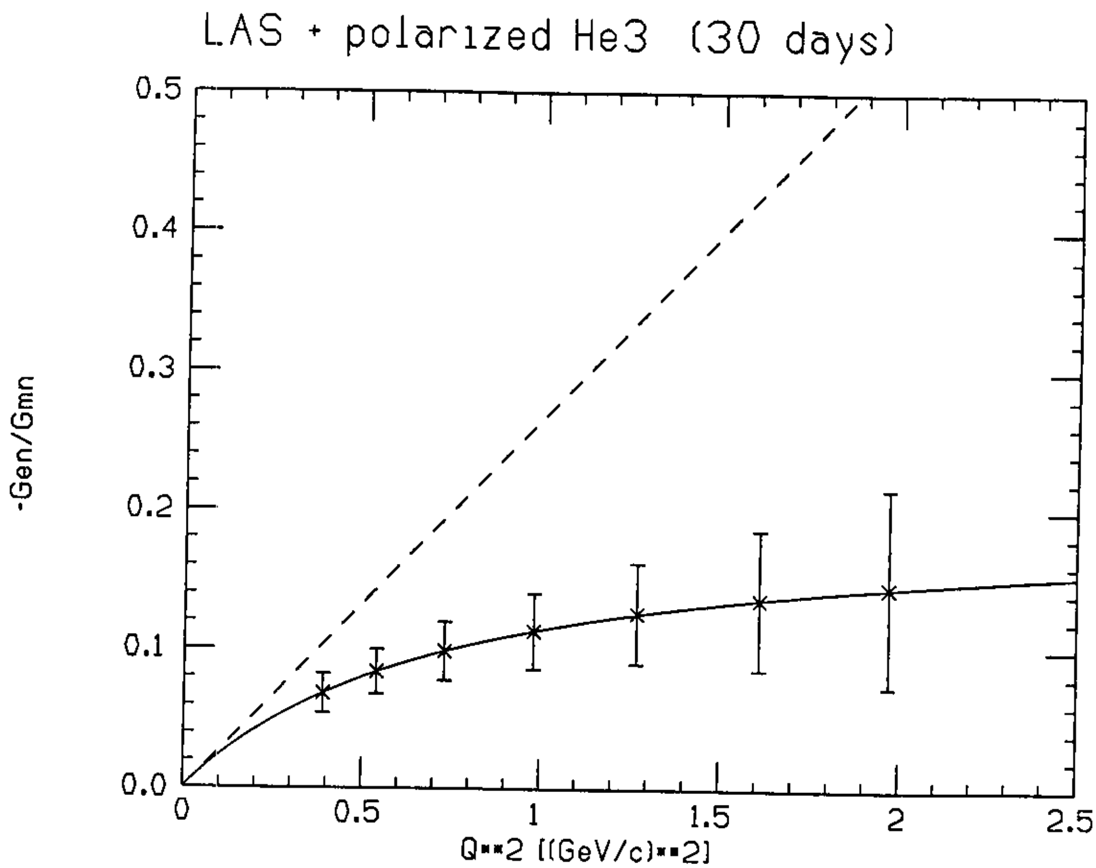


Figure 3. Attainable statistical precision for a single 30 day run for the neutron electric form-factor as a function of the momentum transfer. The ratio to the magnetic form-factor is plotted, and the solid line is a standard parametrization used in Galster *et al.*[4], while the dashed line is the recent prediction of Gari and Krumpelmann[5].