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Measurement of the Spin-Dependent Asymmetry in Quasielastic Electron Scattering from Polarized Tritium

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Proposal to CEBAF PAC6

Measurement of the Spin-Dependent Asymmetry in Quasielastic Electron Scattering from Polarized Tritium

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ABSTRACT

A measurement of the transverse and transverse-longitudinal asymmetries and the unpolarized cross sections in ${}^3\vec{\mathrm{H}}(\vec{e},e')$ quasielastic scattering at $Q^2 = 0.23$, 0.50, and 0.80 $(\mathrm{GeV/c})^2$ is proposed. The experiment uses longitudinally polarized electrons of energy $0.96 - 1.90$ GeV and an optically-pumped polarized tritium target that operates on the same principle as the existing polarized deuterium target developed at Argonne National Laboratory (spin exchange with polarized potassium atoms). The target requires only 1 Curie of tritium for a target thickness of $2 \times 10^{17}/\mathrm{cm}^2$. The asymmetry measurement proposed is of sufficient accuracy to serve as a benchmark for theoretical calculations of the spin observables in the three-body system. Since tritium is a relatively dense nucleus, with approximately half the density of infinite nuclear matter, and since the polarization of tritium is predicted to be carried almost entirely by the proton in the kinematic range to be studied, the proposed experiment can also reveal possible effects of medium modification of the proton electromagnetic form factors.

I. Theory

I.A. Physics Motivation

For a given choice of nuclear potentials, the physical observables of two- and three-body nuclear systems can be calculated exactly, so comparisons of theoretical predictions with experimental data from ^{2}H, ^{3}H and ^{3}He will contribute significantly to our understanding of the nuclear dynamics. Although much electron scattering data[1,2,17] exists for ^{2}H and ^{3}He, to date most of the experiments have used unpolarized beams and targets, and few have used tritium targets. One unpolarized quasielastic scattering experiment using a tritium target[1] and two quasielastic scattering measurements using polarized ^{3}He targets[3] have been performed at the MIT-Bates Linear Accelerator Center. No electron scattering experiments using polarized tritium have been performed. Here we propose an experiment to measure the helicity-dependent asymmetry in inclusive polarized electron scattering from polarized tritium at quasielastic kinematics.

Recently, interest on the part of the nuclear and high energy physics community in the use of polarized ^{3}He targets was fueled by the suggestion that polarized ^{3}He is effectively a polarized neutron[4]. Motivated by the desire to study the electromagnetic properties of the neutron, such as the charge form factor G_E^n and the spin-dependent deep inelastic structure function $g_1^n(x)$, several nuclear and high energy experiments that use polarized ^{3}He targets are planned or were recently performed[5]. In view of the number of approved experiments that use polarized ^{3}He to study the neutron, the extraction of the nucleon properties from the three-body system must be thoroughly understood if the results of the experiments are to be interpreted correctly. The proposals to use polarized ^{3}He to study neutron properties are predicated upon the assumption that the three-body system is known sufficiently well for the nucleon properties to be separated from the response of the nuclear system. Because ^{3}He and ^{3}H are mirror nuclei, if it is true that the neutron contributes significantly to the spin-dependent properties of polarized ^{3}He, then the proton contribution will dominate the spin observables in polarized ^{3}H quasielastic measurements. Since the proton's electromagnetic form factors are experimentally well known[6], a comparison of polarized ^{3}H quasielastic asymmetry data with calculations is subject to far less uncertainty from the underlying nucleon properties than measurements that depend upon the neutron form factors. Studies of the polarization of the proton in tritium would not only serve as a benchmark for testing theoretical predictions of electron scattering spin observables in the three-body system, but is also a necessary step towards extracting the neutron form factors from experiments using polarized ^{3}He.

Polarized tritium can also be used to study medium modification of the proton form factors. It has been suggested that in a nucleus the neutron's charge form factor G_E^n is modified from the free value,[7] and that this may occur in ^{3}He, which has an average density of $\rho = 0.5\ \rho_{nm}$ (ρ_{nm} is the density of infinite nuclear matter). The modification of the form factors arises because the underlying QCD vacuum is modified in nuclear matter, changing the meson properties. The proton form factors are also predicted to be modified in the nuclear medium[8]. Figure 1 shows the estimated ratio of the proton and neutron charge form factors at $\rho = 0.5\ \rho_{\rm nm}$ to their free space values as a function of Q^2 calculated in the Nambu-Jona-Lasinio model with the pion decay constant, f_π, and vector meson

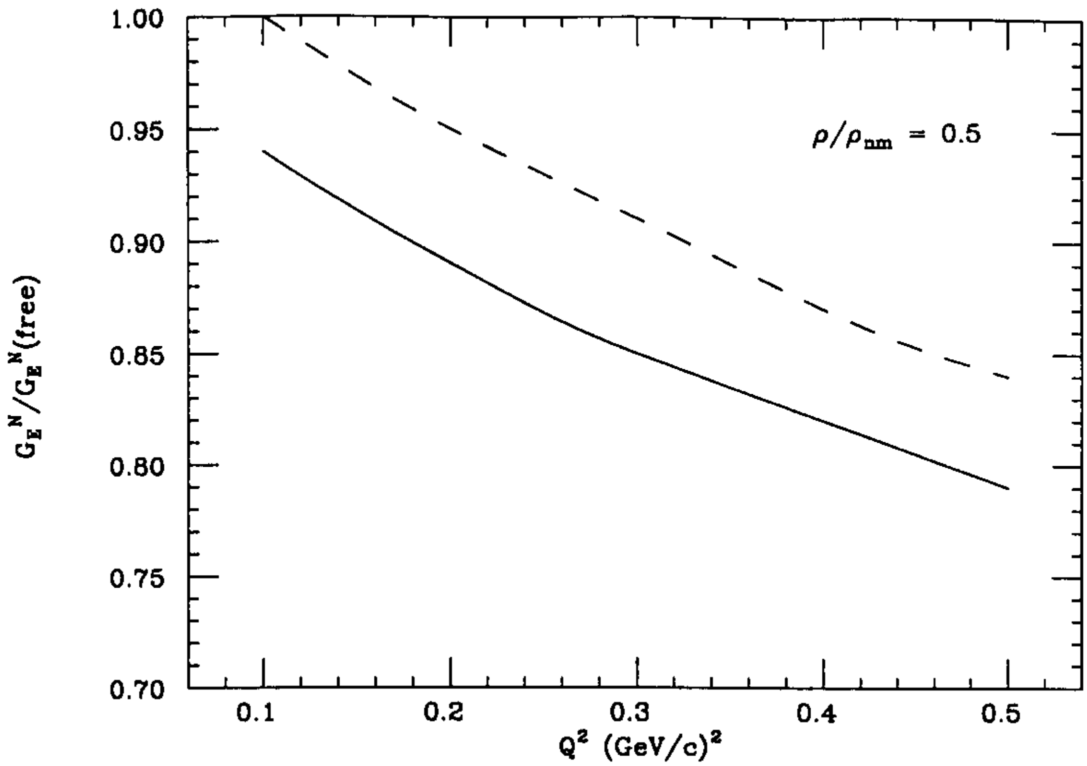

Figure 1. Ratio of the proton (solid) and neutron (dash) charge form factor at density $\rho = 0.5\ \rho_{nm}$ to the free space values, calculated assuming renormalization of the pion decay constant and the vector meson masses in the nuclear medium.[8]

masses, m_ρ and m_ω, modified in the nuclear medium. Since the free space values of G_E^p and G_M^p are known to $\sim \pm5\%$ accuracy, a comparison with the values extracted from the quasielastic asymmetry in $^3\overrightarrow{\mathrm{H}}(\vec{e}, e')$ scattering can provide information about whether medium modification is observable in nuclei. Polarized tritium, a relatively dense nucleus, should behave substantially like a polarized proton and thus provides an excellent case for such studies.

I.B. Quasielastic Scattering from Polarized Tritium

The detailed formalism for inclusive electron scattering including polarization degrees of freedom is given by Donnelly and Raskin[9]. The expressions for the cross section are derived assuming the Born approximation, a single photon exchange interaction, and the extreme relativistic limit for the electrons. The kinematic dependence is expressed in terms of the electron scattering angle θ, the energy transfer ω, the three-momentum transfer $\vec{q}$, and $Q^2 \equiv |\vec{q}|^2 - \omega^2$. In general, the target spin can be oriented in any direction; the spin direction $\vec{S}$ is specified relative to the direction of the three-momentum transfer $\vec{q}$ by the two Euler angles θ^* and ϕ^*, where $\cos\theta^* = \vec{S}\cdot\vec{q}/|\vec{q}|$ and ϕ^* is the angle between the electron scattering plane and the plane containing $\vec{S}$ and $\vec{q}$.

For inclusive quasielastic scattering from a spin-$\frac{1}{2}$ particle, the differential cross section separates into two terms, one that is independent of the polarizations of the beam and target and one that contributes only if both beam and target are polarized. The cross section can be written in terms of quasielastic response functions, which depend upon Q^2 and ω, as

$$\frac{d^2\sigma}{d\Omega dE} = \Sigma + h\Delta, \tag{1}$$

where

$$\Sigma = \sigma_{Mott}\left(v_L R_L(Q^2,\omega) + v_T R_T(Q^2,\omega)\right) \tag{2}$$

and

$$\Delta = -\sigma_{Mott}\left(\cos\theta^* v_{T'} R_{T'}(Q^2,\omega) + 2\sin\theta^*\cos\phi^* v_{TL'} R_{TL'}(Q^2,\omega)\right). \tag{3}$$

h is the helicity of the incident electron, σ_{Mott} is the Mott cross section, and the v_K are kinematic factors defined as

$$v_L = \left(\frac{Q^2}{|\vec{q}|^2}\right)^2, \tag{4}$$

$$v_T = \frac{1}{2}\left(\frac{Q^2}{|\vec{q}|^2}\right) + \tan^2\frac{\theta}{2}, \tag{5}$$

$$v_{T'} = \tan\frac{\theta}{2}\sqrt{\left(\frac{Q^2}{|\vec{q}|^2}\right) + \tan^2\frac{\theta}{2}}, \tag{6}$$

$$v_{TL'} = -\frac{1}{\sqrt{2}}\left(\frac{Q^2}{|\vec{q}|^2}\right)\tan\frac{\theta}{2}. \tag{7}$$

The response functions contain the information about the electromagnetic structure of the hadronic system; The R_L response function contains Coulomb matrix elements only; R_T and $R_{T'}$ depend only upon products of transverse electromagnetic matrix elements; and $R_{TL'}$ results from the interference of Coulomb and transverse matrix elements.

The spin-dependent asymmetry, which is the ratio of the helicity-dependent term in the cross section to the helicity-independent term, is given by

$$A = -\frac{\cos\theta^* v_{T'} R_{T'}(Q^2,\omega) + 2\sin\theta^*\cos\phi^* v_{TL'} R_{TL'}(Q^2,\omega)}{v_L R_L(Q^2,\omega) + v_T R_T(Q^2,\omega)}. \tag{8}$$

In practice, the asymmetry that one measures experimentally is reduced from the value given above by the degree of polarization of the target and beam,

$$A_{\mathrm{exp}} = P_t P_b A. \tag{9}$$

The sensitivity of A_{exp} to each spin-dependent response function can be optimized by varying θ^*, the angle between the nuclear spin and $\vec{q}$. The shorthand notation $A_{T'}$ and $A_{TL'}$ are used here to refer to the asymmetries one obtains with $\theta^* = 0°$ (maximally sensitive to $R_{T'}$) and $\theta^* = 90°, \phi^* = 0°$ (maximally sensitive to $R_{TL'}$), respectively.

At quasielastic kinematics, the values of R_T and R_L for the three-body systems in the range 200 MeV/c $\leq q \leq$ 550 MeV/c are available from unpolarized inclusive scattering

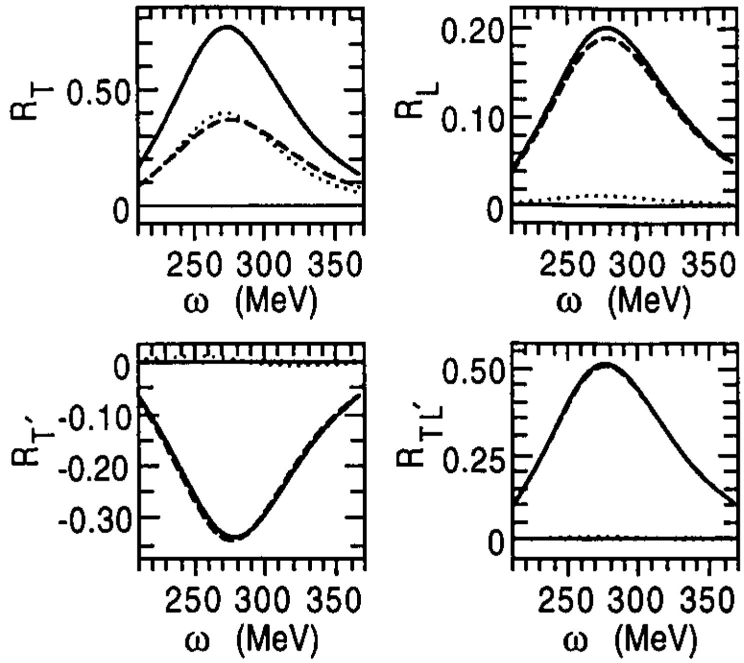

Figure 2. The four tritium response functions, R_T, R_L, $R_{T'}$, and $R_{TL'}$, calculated for $E = 1.5$ GeV and $\theta = 30°$ ($Q^2 = 0.5$ (GeV/c)^2 at the top of the quasielastic peak) as a function of energy transfer. The dashed line indicates the proton contribution, the dotted line is the neutron contribution, and the solid line is the total for ^{3}H.[11]

data taken at MIT-Bates[1]. Data were collected using ^{3}He and ^{3}H high pressure gas targets of identical geometry with the same spectrometer setup, and the longitudinal and transverse response functions over the quasielastic peak were extracted for ^{3}He and ^{3}H. We propose to perform an experiment to measure the asymmetries sensitive to $R_{T'}$ and $R_{TL'}$. Calculations of the spin-dependent response functions using a fully spin-dependent spectral function and the PWIA for both ^{3}H and ^{3}He were recently performed[10]. Figure 2 shows the four tritium response functions calculated for $E = 1.5$ GeV and $\theta = 30°$ ($Q^2 = 0.5$ (GeV/c)^2 at the top of the quasielastic peak) as a function of energy transfer over the quasielastic peak, and Figure 3 shows the corresponding values of $A_{T'}$ and $A_{TL'}$.[11] In both figures the proton and neutron contributions are shown. As expected, the proton dominates the asymmetry for all directions of the nuclear spin. In the range $0.23 \leq Q^2 \leq 0.8$ (GeV/c)^2, which is considered here for experimental investigation, one finds that the neutron contribution to $A_{TL'}$ is negligible at all Q^2 values, as one would expect since G_E^n is much smaller than G_E^p. The neutron contribution to $A_{T'}$ diminishes as one goes to higher Q^2. However, even at $Q^2 = 0.23$ (GeV/c)^2 the neutron contribution to $A_{T'}$ is small, as shown in Figure 4. More sophisticated calculations of the inclusive quasielastic asymmetry that account for final state interactions and meson exchange currents are expected to be available in the near future.

Despite the large number of calculations for the three-body system, the quasielastic response functions are not well understood. First, the best calculations available from

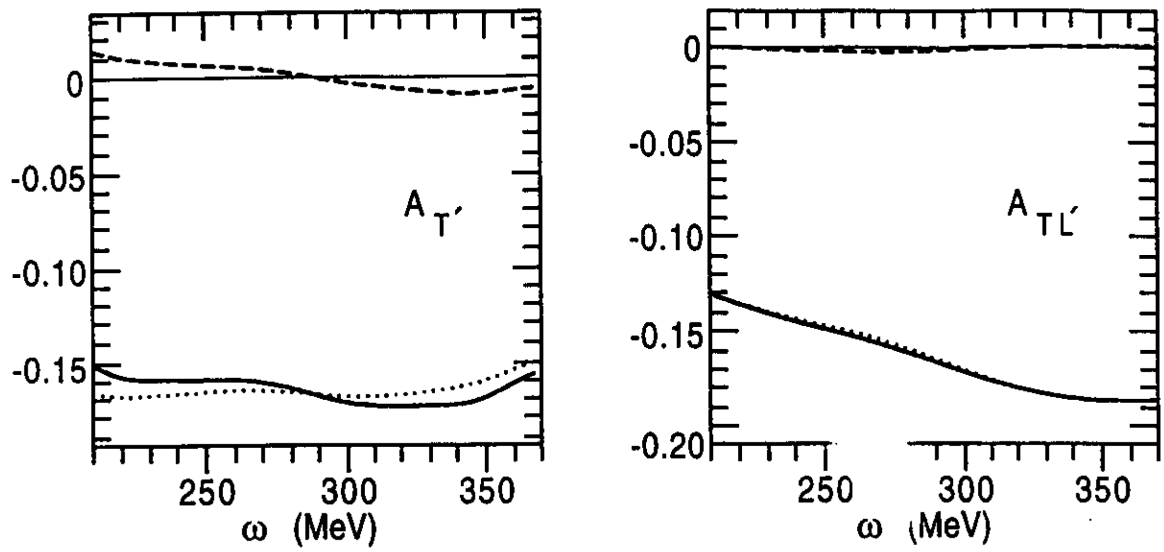

Figure 3. The values of $A_{T'}$ (left) and $A_{TL'}$ (right) for tritium calculated for $E = 1.5$ GeV and $\theta = 30°$ ($Q^2 = 0.5$ (GeV/c)^2 at the top of the quasielastic peak) as a function of energy transfer over the quasielastic peak. The solid line is the full value for 100% polarized ^{3}H, and the dotted (dashed) line indicates the proton (neutron) contribution.[11]

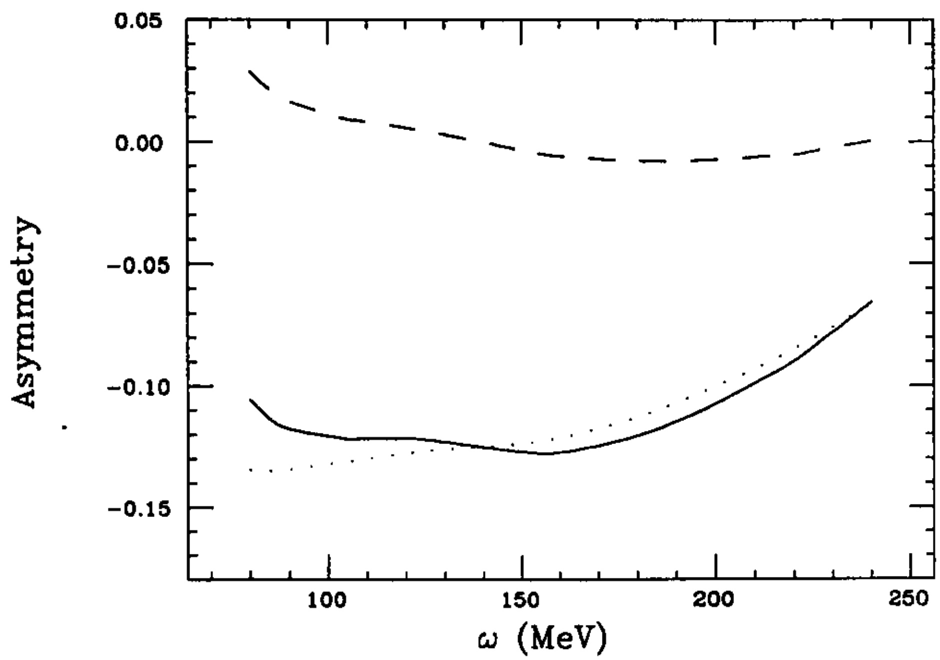

Figure 4. The value of $A_{T'}$ for tritium calculated for $E = 960$ MeV and $\theta = 31°$ ($Q^2 = 0.23$ (GeV/c)^2 at the top of the quasielastic peak) as a function of energy transfer over the quasielastic peak. The solid line is the full value for 100% polarized ^{3}H, and the dotted (dashed) line indicates the proton (neutron) contribution.[11]

van Meijgaard and Tjon[12] do not reproduce simultaneously the experimental values of the transverse and longitudinal response functions. Their values for the longitudinal response function R_L show reasonable agreement with the experimental data for both ^{3}H and ^{3}He over the quasielastic peak at q = 300, 400, and 500 MeV/c. The calculation uses the Malfliet-Tjon S-wave potential to describe the NN interaction, nonrelativistic nuclear dynamics, and includes final state interactions, relativistic kinematics to describe the three-body breakup, and both S- and D-state components of the wave function. Using this model, they significantly underestimate the transverse response R_T for both ^{3}H and ^{3}He over the entire quasielastic peak at all three kinematics. Although the authors suggest that the inclusion of meson exchange currents may resolve the discrepancy between data and theory, other calculations indicate that the corrections to the transverse response function from meson exchange currents are small[13].

In addition, a recent calculation of the proton-proton correlations and the Coulomb sum for ^{4}He, ^{3}He, and ^{3}H by Schiavilla, Wiringa, and Carlson[14] using Faddeev wave functions obtained with the Argonne V14 two-nucleon and Urbana VII three-nucleon potentials, finds good agreement between the calculated Coulomb sum and experimental data for ^{3}He and ^{4}He, but underestimates the Coulomb sum for ^{3}H. The calculation includes one- and two-body components of the nuclear charge operator. Figure 5 shows the Coulomb sum for the three nuclei[14,15]; the solid line is the Coulomb sum calculated in the PWIA; the dot-dashed line includes neutron contributions and relativistic Darwin-Foldy and spin-orbit corrections to the one-body charge operator; and the hatched line is the full calculation including one and two-body components, where the hatching is an estimate of the model uncertainty. One sees that the full calculation describes the ^{3}He and ^{4}He data very well, but underestimates the ^{3}H Coulomb sum. In this calculation, which uses a realistic potential, the PWIA prediction lies below the ^{3}H data, in disagreement with the calculation by van Meijgaard and Tjon[12]. In Reference 18, Tjon mentions that the simple S-wave potential used in the calculations of the spin-independent response functions must be extended to include D-waves in order to describe polarization observables in electron scattering. The high accuracy measurements proposed here would provide a strict constraint on three-body calculations such as these.

I.C. Sensitivity to Medium Modifications of the Proton Electromagnetic Form Factors

As discussed in Section I.B., the theoretical calculations support the claim that polarized tritium behaves substantially like a polarized proton over a broad kinematic range. The asymmetry one would measure with a polarized tritium target are therefore proportional to the free proton asymmetry,

$$A_{\vec{e}\vec{p}} = -\frac{2\tau v_{T'}\cos\theta^*(G_M^p)^2 - 2\sqrt{2\tau(1+\tau)}v_{TL'}\sin\theta^*\cos\phi^*(G_M^p)(G_E^p)}{(1+\tau)v_L(G_E^p)^2 + 2\tau v_T(G_M^p)^2}, \tag{10}$$

where $\tau \equiv Q^2/4m_p^2$. The transverse and transverse-longitudinal asymmetries both depend upon the ratio $R \equiv G_M^p/G_E^p$:

$$A_{T'} = \frac{-2\tau v_{T'}R^2}{(1+\tau)v_L + 2\tau v_T R^2}, \tag{11}$$

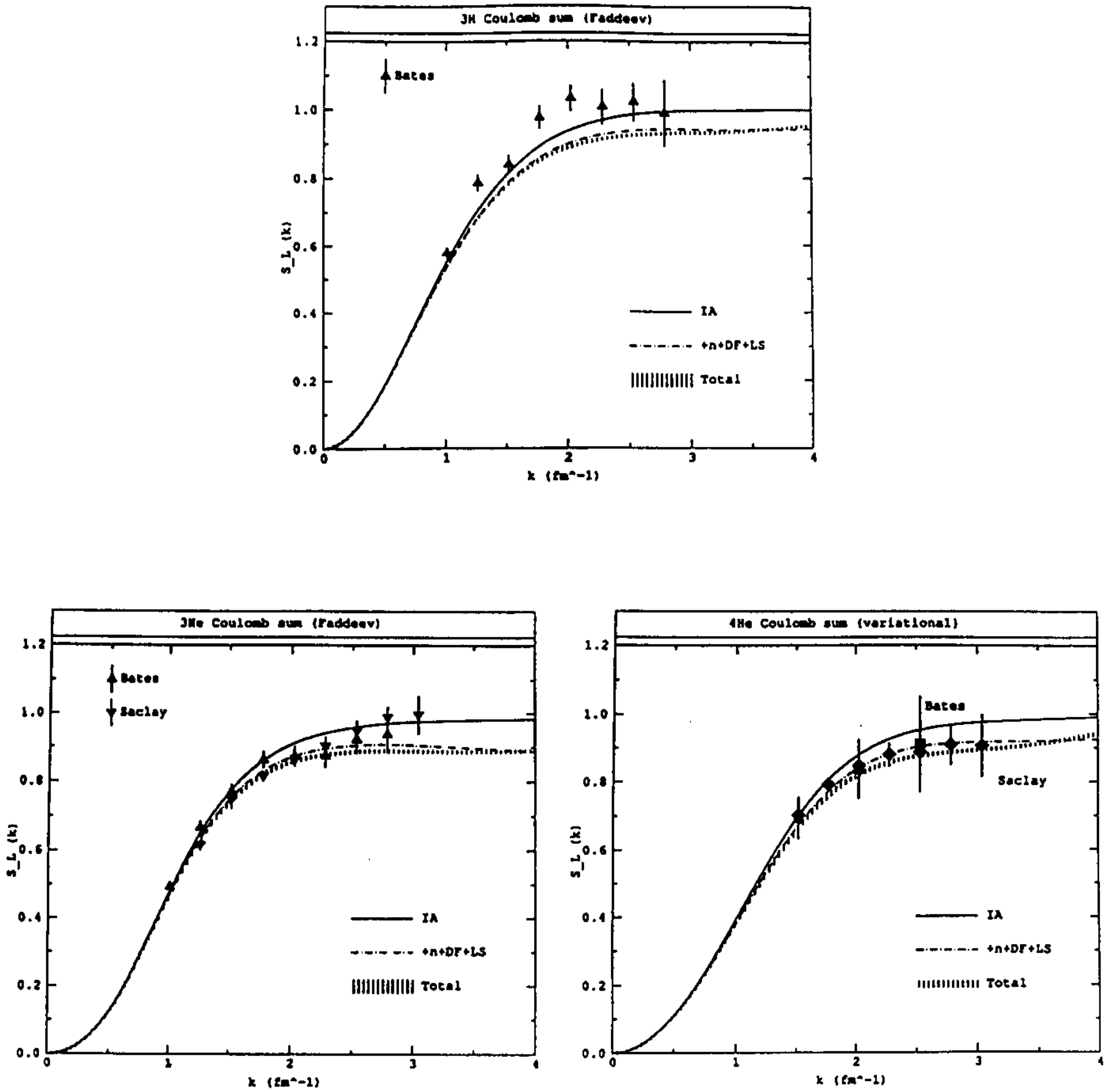

Figure 5. The Coulomb sum for ^{4}He, ^{3}He, and ^{3}H, calculated by Schiavilla, Wiringa, and Carlson[14,15] using Faddeev wave functions obtained with the Argonne V14 two-nucleon and Urbana VII three-nucleon potentials. The data points are from MIT-Bates[1,16] and Saclay[17]. The solid line is the Coulomb sum calculated in the PWIA, the dot-dashed line includes neutron contributions and relativistic Darwin-Foldy and spin-orbit corrections to the one-body charge operator, and the hatched line is the full calculation including one and two-body components of the nuclear charge operator. The hatching is an estimate of the model uncertainty in the calculation.

and

$$A_{TL'} = \frac{2\sqrt{2\tau(1+\tau)}v_{TL'}R}{(1+\tau)v_L + 2\tau v_T R^2}, \tag{12}$$

The ratio of the two asymmetries also can be used to extract R. However, under most kinematic conditions $A_{T'}$ is most sensitive to the ratio of the magnetic to charge form factors.

In Figure 1 it is shown that calculations predict that the nucleon charge form factors are suppressed in the nuclear medium as one goes to higher Q^2. The degree of suppression depends upon the renormalization of the fundamental meson parameters in the medium[8]. In general both the magnetic and charge form factors are modified, but variation of the modification with Q^2 depends sensitively upon the medium suppression of the pion decay constant f_π and the masses of the vector mesons. If the meson parameters are changed by roughly the same percentage, then the charge and magnetic form factors are both modified with approximately the same Q^2 dependence. However, this is not expected to be the case[8], and the magnetic form factor is predicted to be modified less than the charge form factor, making a measurement of the ratio of the form factors sensitive to the medium modifications. A measurement of the asymmetries as a function of Q^2 for protons imbedded in ^{3}H would provide a clear signature for a change in G_M^p/G_E^p. In addition, combined knowledge of the asymmetries and the unpolarized cross sections allows the separate extraction of the two proton form factors in the nuclear medium.

II. Experimental Details

II.A. Overview

The proposed experiment would run in Hall C using the SOS and HMS spectrometers, longitudinally polarized electrons in the energy range $0.96 \leq E \leq 1.9$ GeV, and an optically-pumped polarized tritium target. The target, which uses spin exchange of ^{3}H with optically pumped potassium, is discussed in more detail below. Electrons from inclusive $^3\vec{\mathrm{H}}(\vec{e},e')$ quasielastic scattering would be detected in both SOS and HMS, to collect data sensitive to $A_{T'}$ and $A_{TL'}$ simultaneously.

Table 1 shows the acceptances of the two spectrometers. For the measurements the spectrometers will be set up on opposite sides of the beam line at the same scattering angle so that quasielastic measurements at the same Q^2 value are made in both. The target spin direction is chosen so that the asymmetry measured in the SOS spectrometer is purely $A_{T'}$. With this choice of spin alignment, the asymmetry measured in the HMS spectrometer depends upon both $R_{T'}$ and $R_{TL'}$, but is dominated by the contribution from the interference term. The statistical precisions $\Delta A_{T'}/A_{T'}$ and $\Delta A_{TL'}/A_{TL'}$ are approximately the same with this spectrometer arrangement.

II.B. Polarized Tritium Target

Based on experience[19] from the spin-exchange optical pumping[20] of hydrogen and deuterium atoms, it is expected that a tritium target of total thickness $4 \times 10^{17}/\mathrm{cm}^2$ in 20 cm target length with 50% polarization can be produced. Collimation to exclude the

Spectrometer	$\Delta\Omega$	$\frac{\Delta p}{p}$	l_{eff}
SOS	9 msr	40%	5 cm
HMS	7 msr	10%	20 cm

Table 1. Spectrometer acceptances; solid angle, momentum bite, and effective target length within the acceptance.

end windows from the spectrometer acceptance will reduce the usable target thickness somewhat. Although all high-power optical pumping spin-exchange experience with hydrogen, to date, is with an open geometry, it appears feasible to polarize the tritium in a completely closed cell. Under far from optimal conditions (tests of a flowing system for an internal target), the highest density of ^{1}H polarized by the spin-exchange method is $6 \times 10^{14}/\mathrm{cm}^3$ with a polarization of 35%. The tests were performed in an open-geometry cell so that (i) depolarization from recombination of the H atoms was minimized and (ii) the polarization measurement of the extracted atoms could be performed with relative ease. However, the first condition can be relaxed if the atoms can be re-dissociated after recombining. Here, rather than allowing the atoms to leak out of the cell, we permit them to leak back into the dissociation region after approximately 1000 wall bounces in the target cell. In this way, a target density of approximately $2 \times 10^{16}/\mathrm{cm}^3$ in a 20 cm long target cell can be achieved *with a very small amount of tritium, only one Curie.* (We note that the MIT-Bates experiment[1] was performed with approximately 0.2 Mega-Curies of tritium.) At present, a high density polarized hydrogen target test is being planned at Argonne.

The closed target system has two regions: (i) a plasma discharge region where the tritium molecules are dissociated and (ii) an optical pumping region, where the ^{3}H atoms are polarized. A small amount of K is leaked into the cell from an ampoule. The K/T ratio is approximately 10^{-4}, and represents a negligible contamination ($\leq 0.2\%$) to the quasielastic scattering process. To prevent the potassium from plating out on the walls, the system must be heated to $\sim 300°$ C. Beam heating will provide more than enough power to maintain this temperature. In order to withstand the heat load from the electron beam on the entrance and exit windows, the target cell will have copper ends (including the windows) connected to a heat sink to dissipate the excess heat. The electron beam will be rastered to avoid overheating any one spot.

The K atoms will be optically pumped by a Ti-sapphire laser system. The laser beam will be brought into the cell at an angle of approximately 60° with respect to the electron beam, and the atoms will be polarized along the direction of momentum transfer for electrons detected in the SOS spectrometer. The center of the target cell will have radiation-resistant glass windows for the optical pumping light to enter the cell. A magnetic holding field of approximately 0.9 kG will be used to minimize depolarization from radiation trapping of the K atoms. Since this field is not sufficient to decouple the nucleus spin from the electron spin in ^{3}H, the nucleus becomes polarized[21] through the hyperfine interaction. The polarization can be reversed by changing the circular polarization of the laser beam.

The effect of the holding field on the primary electron beam will be minimal. A deflection of the beam by only about 5 mr in the vertical direction is expected in the worst case. The beam can be compensated by placing a relatively small dipole magnet downstream of the target. The compensating field will be adjusted to redirect the electron beam to the beam dump.

The polarization of the tritium target will be measured and monitored relative to a polarized ^{1}H target. This will be accomplished by placing a known quantity of ^{1}H in the tritium target cell. The target cell will be connected by valves to solid uranium hydride and uranium tritide, which serve as reservoirs of the hydrogen isotopes. The advantage of uranium, which was used in the Bates experiment, is that at room temperature the vapor pressure is very low (1.6×10^{-6} torr) so that the tritium can be stored easily and safely at room temperature. A baratron will monitor the pressure in the target system.

Although only a one-Curie sample of tritium does not pose a large safety problem, precautions will be taken to ensure containment if the glass cell fractures. In particular, we propose to enclose the glass cell in a secondary vessel which can be evacuated. The vessel will have thin windows for the electron beam to enter and exit the target. The vessel will also contain windows for the laser beam to enter the cell. This vessel need not be evacuated during the experiment, but only serves as a secondary containment vessel for the tritium. If the glass fractures and releases the tritium into the secondary vessel, the entire unit can be shipped to Argonne for decontamination.

II.C. Hydrogen Calibration

Because the spin-exchange optical pumping technique works on all of the hydrogen isotopes, one can mix ^{3}H and ^{1}H in the target cell and monitor the polarization using the well-known asymmetry for electron-proton scattering as a standard for the asymmetry measurement. Through collisions the hydrogen and tritium will reach a spin-temperature equilibrium[21] where they have the same polarization. This procedure will minimize the uncertainties in the target and electron beam polarizations by providing continuous measurements of the polarization collected simultaneously with the tritium quasielastic data. A ratio of 70% tritium to 30% hydrogen gives a good match of the statistical precision of the tritium measurement and the systematic error on the product of the beam and target polarizations obtained from the hydrogen asymmetry.

The hydrogen will also be used as calibration data so that unpolarized absolute cross sections can be extracted from the experimental data. The H/T ratio will be measured with a pressure gauge while filling the system and by measuring the relative yield in e−p and e−^{3}H elastic scattering. The simultaneous measurements - scattering from protons and tritium using the same target, spectrometers, and beam - is an extremely clean way to minimize systematic errors.

III. Kinematics and Rates

We request beam time to make measurements of $A_{T'}$ and $A_{TL'}$ at Q^2 =0.23, 0.50, and 0.80 (GeV/c)^2. For the rate calculation we assume a beam current of 190 μA and beam polarization of 49%, and a target polarization of 50% and thickness of $2 \times 10^{17}/\mathrm{cm}^2$. This gives a total luminosity of $\sim 1 \times 10^{32}/\mathrm{cm}^2$-s (varies slightly with spectrometer angle and acceptance). The standard detector packages, electronics, and data acquisition software of the SOS and HMS spectrometers will be used. Table 2 shows the kinematics, requested beam hours, asymmetries, and anticipated statistical precision of the measurements of the quasielastic asymmetry in $e-{}^3\mathrm{H}$ inclusive scattering. Relative uncertainties of 5% in $A_{T'}$ and $5-8\%$ in $A_{TL'}$ are achievable. Asymmetry information of this precision should serve as a benchmark for three-body calculations that include polarization degrees of freedom.

Energy (GeV)	θ (degrees)	Q^2 ((GeV/c)^2)	time (hours)	$A_{T'}$	$\frac{\Delta A_{T'}}{A_{T'}}$	$A_{TL'}$	$\frac{\Delta A_{TL'}}{A_{TL'}}$
0.96	31	0.23	120	-0.124	0.050	-0.162	0.048
1.50	30	0.50	240	-0.164	0.050	-0.145	0.065
1.90	31	0.80	570	-0.196	0.050	-0.135	0.080

Table 2. Kinematics for the polarized tritium measurement, along with the predicted asymmetries, requested run time, and anticipated precision of the measurement.

One additional day of beam is requested for tune-up runs on the empty target to minimize background from the target walls, collect unpolarized cross section information with ${}^1\mathrm{H}$ only in the target cell at the lowest Q^2 value (these data are needed for radiative corrections since the hydrogen yield must be subtracted from the spectra collected with the tritium/hydrogen mixture), and prepare the target for production runs. During the run, one shift per week is requested for target maintanance ($\sim$ 48 hours total).

The major sources of systematic error in the asymmetry are the uncertainties in the target and beam polarizations, background from non-target nuclei, and separation of the elastic proton peak from the tritium quasielastic yield. Using hydrogen as a polarization monitor, one can achieve a $\leq \pm 5\%$ systematic determination of $\Delta(P_b P_t)/P_b P_t$ with a mixture of 30% hydrogen and 70% tritium in the target cell. A test run with target cells of different diameters will be made to determine the cell geometry needed to eliminate background from beam halo and multiple scattering (See Section IV. below.). The subtraction of the proton elastic tail can be performed in a straightforward manner: The run with hydrogen only will determine the shape of the elastic tail, and since the asymmetry in the tritium quasielastic peak is expected to be less than a factor of two smaller than the proton asymmetry, the subtraction of the proton yield is not as critical as it would be for the case where the quasielastic asymmetry were much smaller than the asymmetry in the background.

Because the hydrogen serves as a calibration for the cross section measurement, the unpolarized cross section for quasielastic electron-tritium scattering is also obtained in this experiment. In the time required to make a high precision measurement of the quasielastic asymmetry, the statistics collected on the unpolarized cross section is very precise ($\sim 2-5\%$ in 5 MeV bins across most of the quasielastic peak), so systematic uncertainties will dominate the uncertainty in the cross section measurement. The major uncertainty in the extraction of the absolute cross section will be the determination of the H/T ratio. Tests using ^1H and ^2H will be made at Argonne to refine the pressure measurement technique.

In a total of 930 hours, high precision data on both $A_{T'}$ and $A_{TL'}$ at three different Q^2 values can be collected. Simultaneously an accurate measurement of the tritium unpolarized cross section will be made. Table 3 shows the statistical precision of the determination of the ratio G_M^p / G_E^p from the measurement of $A_{T'}$ and from the measured ratio $A_{T'} / A_{TL'}$. The uncertainty is comparable to the uncertainty in the free proton form factors. Using the measured unpolarized cross section, one can extract G_M^p and G_E^p from the asymmetry data. If the nuclear medium affects the nucleon electromagnetic form factors at the level predicted by theory, it should be seen in experimental polarized tritium data of this precision.

Q^2 GeV	$\Delta R/R$ ($A_{T'}$)	$\Delta R/R$ ($A_{T'} / A_{TL'}$)
0.23	0.037	0.071
0.50	0.048	0.078
0.80	0.060	0.082

Table 3. Predicted precision in the extraction of the ratio $R \equiv G_M^p/G_E^p$ at each Q^2 value calculated from $A_{T'}$ only and from the ratio $A_{T'} / A_{TL'}$.

IV. Test Runs

The questions of background rates from the target walls and windows and of the viability of the tritium target in the presence of the CEBAF electron beam require serious consideration before the production runs. We request 50 hours of beam time for a test run to study the background from target cells of different diameters. This information will be used to determine the size of the final target cell and the amount of laser power needed to optically pump the system. It will also test the integrity of the metal/glass target cell in the electron beam. Once the target system is fabricated, we request 150 hours of beam time for a test using polarized hydrogen and a polarized electron beam. The purpose of the test is to measure the asymmetry with hydrogen and to verify the integrity of the design before operating with tritium.

V. Beam Request

We request 1000 hours for the tritium production run with 190 μA polarized electron beam current and 200 hours for target test runs, for a total of 1200 beam hours. The first test run (50 hours) does not require polarized electrons.

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