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A. **TITLE:**

MEASUREMENT OF STRANGE QUARK EFFECTS USING PARITY-VIOLATING ELASTIC/SCATTERING FROM ^{4}He AT $Q^2 = 0.6$

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By M. Arizal

Proposal to the CEBAF PAC5

Measurement of Strange Quark Effects Using Parity Violating Elastic Electron Scattering from ^{4}He at $Q^2 = 0.6$ (GeV/c)^2

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We propose to use parity-violating elastic electron scattering from ^{4}He to measure strange quark contributions to the nuclear wave function. In a simple nonrelativistic model these effects can be interpreted as the strange electric contribution to the nucleon, $G_E^s(Q^2)$. Although this form factor is constrained to be 0 at $Q^2 = 0$, no information is currently available about its Q^2 dependence. We propose to measure the parity violating asymmetry at $Q^2 = 0.6$ (GeV/c)^2, using a 3.6 GeV beam with both Hall A spectrometers at 12.5°. At this momentum transfer the Standard Model asymmetry is 5×10^{-5}. A 40% statistical measurement of this asymmetry would determine G_E^s to an absolute error of $\Delta G_E^s \sim 0.06$, which is more than 3σ from the estimated average value of the only published prediction of G_E^s.

I. Introduction

Recently considerable theoretical effort has been focussed on the issue of whether strange quarks contribute significantly to nucleon matrix elements. Evidence for the existence of a sizeable matrix element $\langle N \mid \bar{s}\gamma_\mu\gamma_5 s \mid N \rangle$ comes from deep-inelastic muon scattering[1] and elastic neutrino-proton scattering[2]. Analysis of low energy π-nucleon scattering data[3,4] indicates that the contribution of s-quarks to the proton mass could also be substantial. Very little is currently known about the vector matrix element $\langle N \mid \bar{s}\gamma_\mu s \mid N \rangle$. In this proposal we suggest that parity-violating elastic electron scattering from ^{4}He is an excellent way to obtain information on the vector strange quark effects at finite Q^2. The parity-violating asymmetry is proportional to the neutral weak coupling, from which in a simple model one may extract a component G_E^s, the s-quark contribution to the charge form factor of the nucleon. At $Q^2 = 0$, G_E^s is constrained to be 0, but the Q^2 dependence of this form factor is completely unknown.

We propose to measure the parity-violating asymmetry in elastic scattering from ^{4}He at $Q^2 = 0.6$ GeV/c^2 using the Hall A high resolution spectrometers. At these kinematics the Standard Model asymmetry (assuming no s-quark contributions) is 5×10^{-5}. Using the only theoretical model currently available[5] for the Q^2 dependence of G_E^s, the presence of s-quark effects could change this value by as much as 200%, changing the sign of the asymmetry. Thus even a measurement with moderate statistical precision could yield significant information on the existence of strange quark effects in the proton. This level of precision is approximately the same as that achieved at SLAC fourteen years ago[6], and 100 times larger than that achieved at Bates[7]. Using a ^{4}He gas target and high resolution spectrometers, it is possible to explicitly detect elastically scattered electrons, thereby minimizing dilution effects and uncertainties due to inelastic backgrounds.

Ideally, one might argue that it is preferable to extract information on the strangeness content of a free nucleon, where one does not have to worry about the complications of a nuclear target. For example, it is possible that medium modifications of the nucleon might have an effect on the distribution of strange quark effects (this topic is itself of some interest), or that isospin violation or relativistic effects in the nuclear ground state would complicate the interpretation of the strange form factors. However, in order to extract information on G_E^s from a proton target it is necessary to know the magnetic strange form factor G_M^s at the same value of Q^2. If deviations from the Standard Model asymmetry are seen in the proton, roughly half of the effect is expected to come from G_M^s. The magnetic form factor will be measured in the SAMPLE experiment at Bates[8] at $Q^2 \sim 0.1$ GeV^2. Performing a forward angle experiment on the proton at this momentum transfer and using the results of the SAMPLE experiment would allow one to determine information on the low Q^2 behavior of G_E^s. Several members of our collaboration are involved in efforts for such an experiment on a proton target. In order to more generally understand the Q^2 dependence of G_E^s, one would also like to have information at at least one other, preferably higher, value of Q^2. An elastic scattering measurement on ^{4}He would provide this information directly, without having to perform more SAMPLE-equivalent experiments in order to separate the effects of G_E^s and G_M^s. This experiment is therefore complementary to measurements on the proton.

The remainder of this proposal will be laid out as follows. In section II will be a more detailed discussion of the physics motivation for the experiment. Section III will outline the proposed measurement, in which there will also be a discussion of expected backgrounds and systematic uncertainties. The final section will contain the beam request.

II. Physics Background

Throughout this discussion we will assume that the Standard Model provides a correct description of electroweak interactions. In this context, we note that $\sin^2 \theta_W$ is known with high precision from measurements of the Z boson mass[9,10]. We will demonstrate that the level of precision required to extract significant preliminary information about strange quark effects is substantially less than the sensitivity to possible deviations from the Standard Model.

We begin by writing down the nucleon form factors. The electromagnetic and neutral weak form factors can be constructed as a sum of individual quark distribution functions multiplied by coupling constants given by the Standard Model:

$$G^\gamma_{E,M} = \sum a_j G^j_{E,M} \qquad (1a)$$

$$G^Z_{E,M} = \sum b_j G^j_{E,M} \, , \qquad (1b)$$

where

$$a_j = \begin{cases} \frac{2}{3} \\ \frac{-1}{3} \end{cases} \quad \text{and} \quad b_j = \begin{cases} \frac{1}{4} - \frac{2}{3}\sin^2 \theta_W & j = u,t,c \\ \frac{-1}{4} + \frac{1}{3}\sin^2 \theta_W & j = s,d,b \end{cases} .$$

There is, of course, an additional axial neutral weak form factor, G^Z_A, which comes from parity-violating hadronic interactions. For the purposes of this discussion we will ignore G^Z_A since it does not play a role in elastic scattering from a $J = 0$ nucleus. If we now neglect quarks heavier than the s-quark and make the assumption that the neutron and the proton differ only by the interchange of u and d quarks, it is possible to rewrite the neutral weak vector form factors in terms of the electromagnetic form factors plus an additional contribution due to strange quarks. For clarity the electromagnetic form factors will be written as $G^{p,n}_{E,M}$ with no γ superscript.

$$G^Z_{E,M_p} = \left(\frac{1}{4} - \sin^2 \theta_W \right) G^p_{E,M} - \frac{1}{4}G^n_{E,M} - \frac{1}{4}G^s_{E,M} \qquad (2a)$$

$$G^Z_{E,M_n} = \left(\frac{1}{4} - \sin^2 \theta_W \right) G^n_{E,M} - \frac{1}{4}G^p_{E,M} - \frac{1}{4}G^s_{E,M} \qquad (2b)$$

With the exception of G^n_E, the electromagnetic form factors are known with fairly good precision ($\sim 5 - 10\%$). Thus, a measure of the neutral weak form factors G^Z_E and G^Z_M will allow one to extract direct information on the strange form factors G^s_E and G^s_M. These form factors can be measured with parity violating elastic electron scattering from the proton[11,12]. Similar effects can be determined from elastic scattering from a $J = 0, T = 0$ nucleus[13]. At present there is no detailed theoretical description for strange quark contributions to the nuclear wave function. Nonetheless it is possible to get an estimate of the size of these effects using factorized nonrelativistic nuclear form factors.

3

Elastic electron scattering from a spinless nucleus occurs only through charge scattering. The parity-violating asymmetry is[13-15]

$$A = \frac{d\sigma_R - d\sigma_L}{d\sigma_R + d\sigma_L} = \frac{-G_F Q^2}{\pi \alpha \sqrt{2}} \frac{\mathcal{R}_c^Z}{\mathcal{R}_c^\gamma} . \tag{3}$$

In this expression $\mathcal{R}_c^\gamma$ is an electromagnetic charge response function of the nucleus, and $\mathcal{R}_c^Z$ is the equivalent neutral weak "charge" response function. Let us now make the assumption that the nuclear form factors can be factorized into nucleon form factors and a function $f(Q^2)$ which represents the distribution of nucleons within the nucleus. In doing so we have used SU(2) isospin to assume that the neutron and proton distributions within the nucleus are the same. Then $\mathcal{R}_c^\gamma$ and $\mathcal{R}_c^Z$ can be written as

$$\mathcal{R}_c^\gamma = \left[Z G_E^p + N G_E^n \right] f(Q^2) \tag{4a}$$

$$\mathcal{R}_c^Z = \left[Z G_{E_p}^Z + N G_{E_n}^Z \right] f(Q^2) \tag{4b}$$

$$= \left[-\sin^2 \theta_W \left(Z G_E^p + N G_E^n \right) + \frac{1}{4} (Z - N) \left(G_E^p - G_E^n \right) - \frac{1}{4} A G_E^s \right] f(Q^2) .$$

For nuclei with $N = Z$, the asymmetry reduces to

$$A = \frac{G_F Q^2}{\pi \alpha \sqrt{(2)}} \left[\sin^2 \theta_W + \frac{1}{2} \frac{G_E^s}{(G_E^p + G_E^n)} \right] . \tag{5}$$

It is important to note that the first term in this expression, that which is derived in the absence of strange quark effects in the nucleon, is model independent as long as the ground state of the $J = 0$ nucleus is truly isoscalar. Any asymmetry measurement which deviates from this term alone is either an indication of isospin violation or of the presence of strange quark effects. In a light nucleus such as ^{4}He, isospin violations are expected to be quite small, so a large effect is likely to come from the presence of strange quarks.

Note that this expression is the same for ^{12}C and ^{4}He. This is in fact the same asymmetry as was measured in the ^{12}C experiment at Bates[7]. However, the Bates experiment was performed at $Q^2 = 0.02$ (GeV/c)^2, and was therefore not sensitive to the presence of strange quark effects. By performing a measurement at somewhat higher values of Q^2, one gains both in the overall size of the asymmetry and in the fact that the denominator of the strange term decreases with Q^2. In addition, it is reasonable to expect that G_E^s grows with Q^2, so that for a fixed absolute error in G_E^s, the relative error increasingly improves.

In order to evaluate the sensitivity of a new experiment to G_E^s at higher values of Q^2, it is necessary to have some model for its Q^2 dependence. There is currently only one available model in the literature, a phenomenological one given by Jaffe[5]. He formulates the hypothesis that the Q^2 dependences of F_1^s and F_2^s are described by dispersion relations with poles corresponding to vector mesons. His analysis uses the results of the Höhler, et al.[16] description of the electromagnetic form factors. This results in average values of a "strange anomalous magnetic moment" $\mu_s \equiv F_2^s(0) = -0.31 \pm 0.09$ and a "strangeness

4

radius" $r_s^2 \equiv -6[dF_1^s/dQ^2]_{Q^2=0} = 0.16 \pm 0.06$ fm^2. Here F_1^s and F_2^s are the strange equivalents to the Pauli and Dirac form factors F_1 and F_2, where $G_E = F_1 - \tau F_2$ and $G_M = F_1 + F_2$. This model is not meant to provide a rigorous theoretical prediction for the strange form factors, but rather to give a simple estimate of the size of these effects. The value of $\mu_s = -0.31$ is within the range of predictions of $-0.88 < \mu_s < 0$, given in reference 17.

Figure 1 shows the Q^2 dependence of G_E^s for the three fits of ref. 5 (dashed lines) plus the average value (solid line). Figure 2 shows Standard Model asymmetry as a function of Q^2 (solid line) compared to the asymmetry with the estimated nonzero values of G_E^s (dashed lines). It is clear that even an approximate measure of the asymmetry at $Q^2 > 0.5$ (GeV/c)^2 could provide significant information on the size of these strange quark effects.
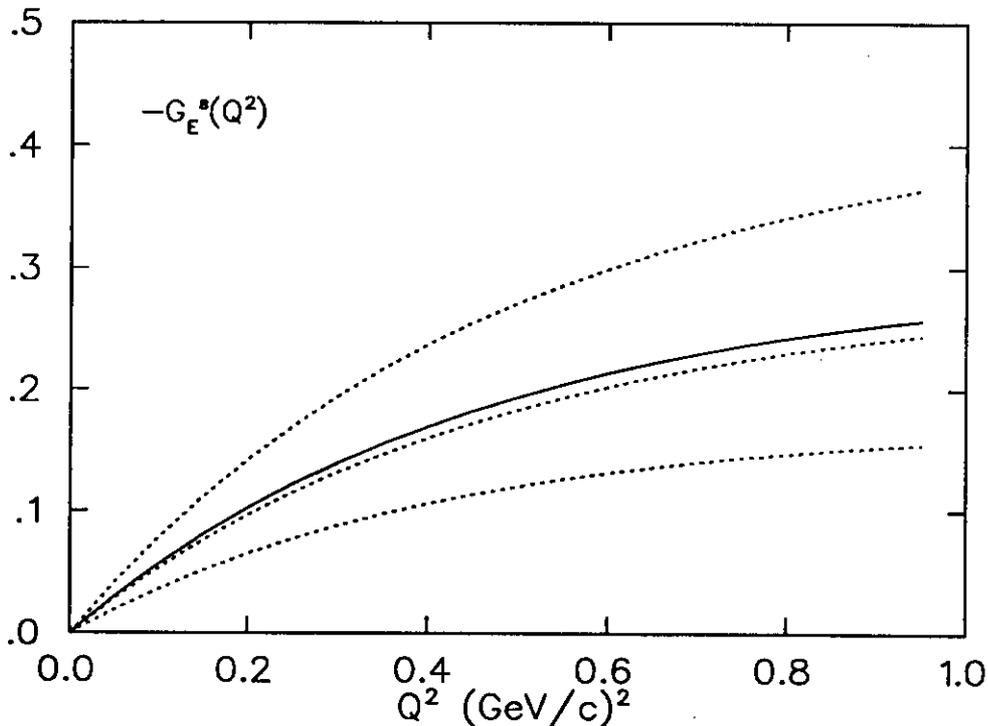

Figure 1 – $G_E^s(Q^2)$ as calculated by ref. 5 for three fits (dashed lines) and the average of the three fits (solid line).

One potential source of concern is the sensitivity of the asymmetry to the neutron electric form factor. At $Q^2 = 0.6$ (GeV/c)^2, G_E^n contributes approximately 15% to the denominator of G_E^s. Recent data[18] have become available from a high precision experiment on elastic scattering from deuterium, with an overall error of $\sim 50\%$ on the value of G_E^n in this Q^2 range. Even this large uncertainty in G_E^n represents at most a 10% uncertainty in extraction of G_E^s. Future experiments using both the recoil neutron technique[19] and using quasielastic scattering of polarized electrons from polarized ^{3}He[20,21] should reduce the level of uncertainty in G_E^n even further.
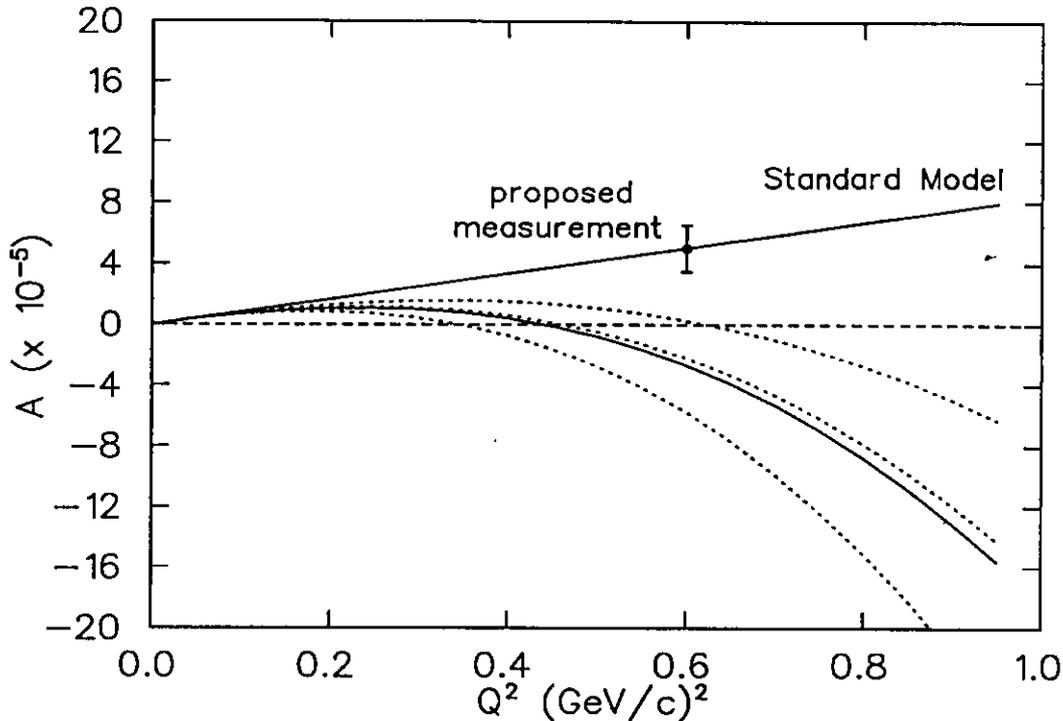
Figure 2 – Standard model asymmetry (solid line) compared to the asymmetry using values of $G_E^s(Q^2)$ from the three fits in ref. 5 (dashed lines). The data point corresponds to a measurement of $\frac{\Delta A}{A} = 30\%$.

There are also electroweak radiative corrections that should be made to equation (5). The term proportional to $\sin^2 \theta_W$ should be multiplied by an isoscalar correction term $(1 + R_V^{T=0})$, and G_E^s should be multiplied by an SU(3) singlet correction factor $(1 + R_V^{(0)})$. These have been calculated by Musolf[22] to be $R_V^{T=0} \sim 0.05$ and $R_V^{(0)} \sim 0.015$. Both of these corrections are much smaller than the expected error on the measurement. At present the main uncertainty in the vector corrections comes from the mass of the top quark. Precision measurements of the vector boson masses have significantly reduced the range of predictions for the mass of the top quark[23], resulting in errors in the vector corrections which are negligible to the present measurement. In addition, we anticipate that the mass of the top quark will be known by the time of this experiment.

III. Experiment
III.1 Overview

Although this experiment could in principal be performed on any target with $J = 0$ and $T = 0$, there are a number of reasons why we believe ^{4}He is the best choice. It is the lightest $J = 0$, $T = 0$ nucleus, which means the cross section does not fall as rapidly with Q^2 as with heavier nuclei and it is possible to maintain a reasonable counting rate. In this proposal we estimate the cross section using the form factor parameterization of Frosch, et al.[26]. This parameterization is shown along with existing data in figure 3. The

ground state of ^{4}He is considered to be a relatively "pure" isoscalar state. Donnelly has estimated the effect of isospin mixing out to $Q^2 = 0.6$ (GeV/c)^2, for several $J = 0$, $T = 0$ nuclei[24]; the effect on the Standard Model asymmetry is on the order of a few percent for ^{12}C; although the calculation was not published for ^{4}He, a conservative estimate of $\sim 1\%$ was given. In addition, with 20 MeV between the ground state and first excited level it is straightforward to be sure that the detected particles are elastically scattered electrons. With a beam energy of 3.6 GeV, the required resolution is $\sim 3 \times 10^{-3}$, more than ten times worse than the design goal of 10^{-4}.
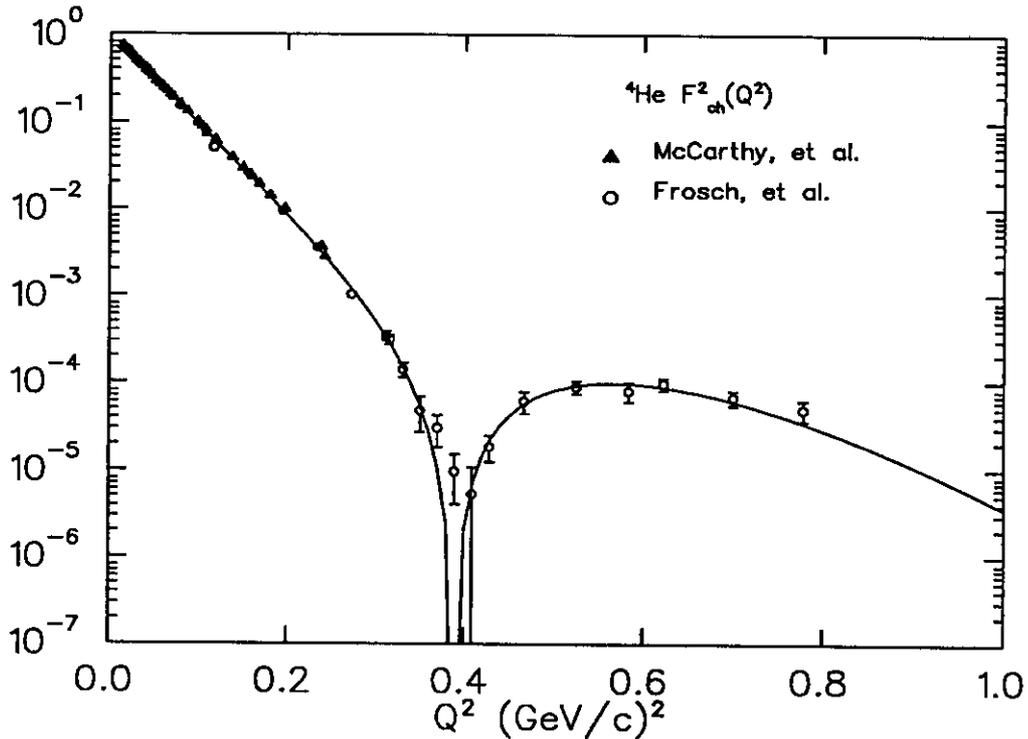

Figure 3 – Measured charge form factor[26,27] of ^{4}He, along with the parameterization of reference 26.

The choice of $Q^2 = 0.6$ is dictated by a number of reasons. Firstly, the Standard Model asymmetry is 5×10^{-5} at this momentum transfer. This number is relatively large on the scale of recently completed parity violation experiments[7,25] and the required level of performance from the accelerator is not very stringent. It is about the same as that achieved in the SLAC Endstation A experiment, (ref. 6). The beam requirements will be discussed in more detail below. In addition, as can be seen in figure 3 the ^{4}He cross section is at a maximum at this momentum transfer and thus the cross section is relatively insensitive to helicity correlated variations in beam energy and position. Finally, if strange quark effects exist in the nucleon, they should increase with Q^2 since not only might one expect that G_E^s grows with Q^2, but the proton form factor is falling, which increases the overall sensitivity of the asymmetry to G_E^s. These arguments are demonstrated in figure 4. Using the experimental assumptions listed in the figure, the best *absolute* error ΔG_E^s

7

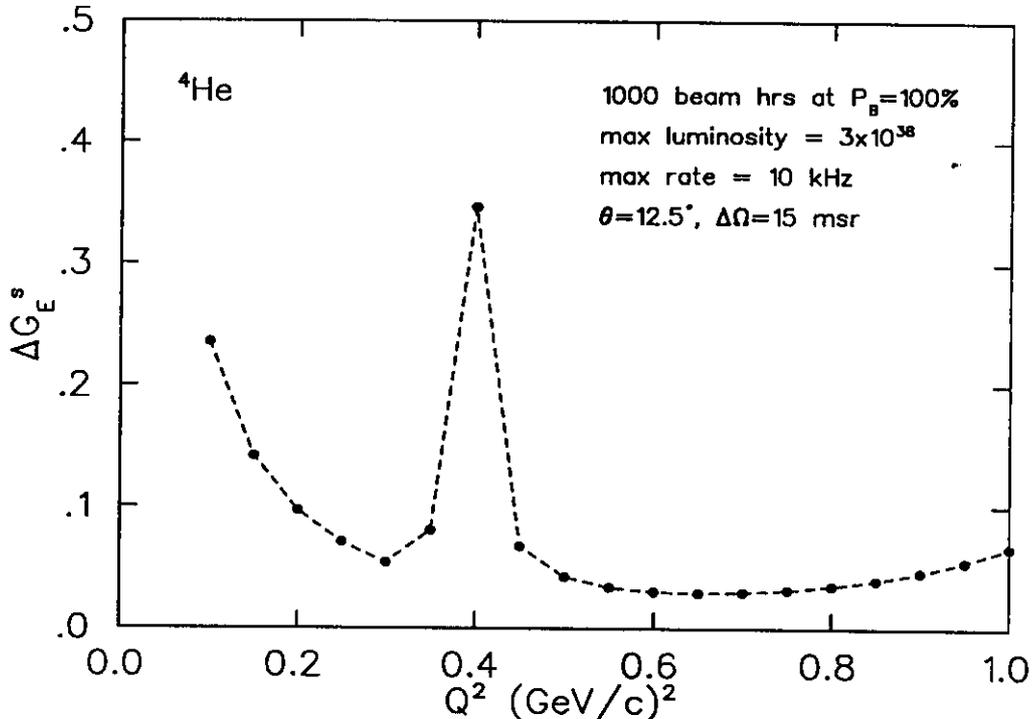due to statistics would be achieved at $Q^2 \sim 0.6$, independent of any model assumption for G_E^s.

Figure 4 – Absolute error on G_E^s as a function of Q^2 that could be achieved in 1000 hours of beam time with a 100% polarized beam. The graph assumes a maximum counting rate of 10 kHz per spectrometer, a maximum luminosity of 3×10^{38}, and a total solid angle of 15 msr.

The experiment we propose here is elastic scattering from ^{4}He at $Q^2 = 0.6$ GeV^2, using the Hall A high resolution spectrometers at 12.5° and a beam energy of 3.6 GeV. At these kinematics, the ^{4}He cross section is 1.4 nb/sr. We propose to measure the asymmetry with a statistical error of 40%. This would give an absolute error of $\Delta G_E^s \sim 0.06$. This error is more than 3σ from the estimated average value of $G_E^s = -0.21$ of reference 5. Assuming a beam polarization of $P_B = 50\%$, the required total number of counts is 1×10^{10}. With a luminosity of $\mathcal{L} = 3.2 \times 10^{38}$ and a radiative correction factor of 0.5, this measurement requires 925 hours of running time. It is very likely that by the time CEBAF is available for experiments, somewhat higher beam polarization will be achieved [27]: for $P_B = 70\%$ with the same amount of running time, the relative error on the asymmetry would be reduced to about 28% and the absolute error on G_E^s would be 0.044. This measurement is plotted in figure 2 along with the curves of reference 5.

This type of measurement would clearly benefit from the highest available luminosity. The design goal of the CEBAF cryogenic ^{4}He target is $\mathcal{L} = 3.2 \times 10^{38}$. We have considered

the possibility of making a thicker target and have concluded that the CEBAF design is the most appropriate for this experiment. We therefore require the highest available beam current, and for this proposal assume 200 μA. This experiment is a single-arm measurement and does not require both Hall A spectrometers, but would clearly benefit from having both the approximate symmetry and the additional solid angle of the second arm. We assume an available solid angle of 7.5 msr per spectrometer arm, so $\Delta\Omega = 15$ msr. The elastic rate into each spectrometer will be ~ 1.5 kHz.

This experiment does not place very stringent requirement on accelerator performance, particularly compared to either high precision cross section measurements or lower Q^2 parity measurements. It will, however, require a substantial amount of beam time and thus stable operation of the accelerator for a reasonably long period of time. We therefore propose to first demonstrate that one can make a measurement of the elastic cross section with good resolution and low background, and that one can achieve the required high luminosity without a substantial density reduction to the target or unreasonably high radiative losses. We note that there are already two approved experiments[28,29] requiring the same luminosity on ^{4}He, one of which is to measure the elastic electromagnetic form factor at approximately the same kinematics. We would also like to demonstrate that the accelerator performance is at the level required for a parity measurement of this type. All of these measurements can be made in several days with one spectrometer, and are likely to be of use to a number of experiments proposed for Hall A.

III.2 Beam Requirements

This experiment requires 200 μA of longitudinally polarized beam in Hall A, in a beam spot of 2 mm by 0.1 mm. For an experiment of this type, one would like to flip the helicity of the beam as often as possible. However, one would also like to have a measure of all beam properties as frequently as the beam helicity is changed. We assume here that the beam helicity can be flipped randomly at a rate of 30 Hz, and that therefore all beam properties can be measured on a time scale of 30 ms. The required level of precision of the beam properties is listed in Table 1. Each of these requirements will be discussed in detail in section III.6.

The Hall A CDR calls for either a Compton polarimeter or a Møller polarimeter (or both) for measurement of the beam polarization. Either method is likely to be adequate for this experiment, since we require knowledge of the beam polarization only to $\sim 10\%$. The Compton polarimeter is better suited to high average current and high energy, although it is a more complicated device technically. The beam polarization is determined by scattering a longitudinally polarized photon beam off of the electron beam and detecting an asymmetry in the yield of backward scattered photons. For an electron beam polarization of 50% and assuming a 100% polarized photon beam, the longitudinal asymmetry in Compton scattering is about 6%. A 5% statistical measurement of this asymmetry can be achieved in a few minutes with a 200 μA electron beam, assuming the polarimeter parameters given in the CEBAF CDR.

The degree to which the CEBAF beam is polarized in the longitudinal direction is a potential concern. Given the large number of turns in the accelerator, the spin precession

Beam parameter		Precision in 30 ms
Energy	$\delta E/E$	1×10^{-3}
Position	δx	0.5 mm
Angle	$\delta\theta$	0.3 mrad
Intensity	$\delta I/I$	5×10^{-3}
Radius	δr	1 mm

Table 1 – Table of beam tolerances to be measured in a 30 ms time period

of the electron beam will be large. A transverse component to the beam polarization will produce an asymmetry due to Mott scattering if the spectrometers are not perfectly up-down symmetric. This asymmetry is estimated to be $A_{Mott} \sim 3 \times 10^{-8} P_t \sin\phi$, where P_t is the average transverse polarization of the beam and ϕ is the average azimuthal scattering angle. This effect is expected to be negligible.

III.3 Target

The initial design goal of the proposed CEBAF cryogenic ^{4}He target system calls for a 15 cm long target, collimated to 10 cm, at 70 atm and 10K with a transverse flow rate of about 1-5 m/s. With a 100 μA beam the luminosity will be $\mathcal{L} = 1.6 \times 10^{38}/\text{cm}^2/\text{s}$. However, radiative corrections for elastic scattering from this target will be approximately 0.5, which effectively reduces the luminosity by a factor of two. The limitations chosen for these target design parameters are to keep the target density reduction below 5%, which can be achieved by spreading the beam out horizontally to 2 mm, and the overall power deposition at about 500 W. Increasing the beam current to 200 μA will give the desired luminosity and the density reduction could be kept below 5% with a flow rate of 3 m/s. The required cooling power will be approximately 1 kW. It is important to note that absolute knowledge of the density is not required for this experiment. Helicity correlated fluctuations in density will be negligible if the beam helicity is flipped every 1/30 sec.

The only other possible way of increasing the luminosity is to increase the target length. Longer targets of both helium and hydrogen have been successfully used at SLAC. As an example, let us assume a 45 cm long target with 0.5 mm thick Al walls and 2 cm diameter. This would increase the luminosity by about a factor of 3, but if one is to stay within the range of available cooling power of 1 kW, the incident beam current must be reduced accordingly. It may be easier to achieve a low current beam and long target than a high current beam, though, particularly in the early stages of CEBAF running. In order to maintain a high flow rate the flow direction must be longitudinal to the beam. The required flow rate to keep the density reductions at a reasonable level ($\lesssim 10\%$) is then greater than 10 m/s, unless a small transverse component is introduced to the flow. This type of flow pattern can probably be achieved; it is similar to that designed for the SAMPLE target at Bates.

However, there is an important disadvantage to using a longer target. The radiative corrections get somewhat larger, so for constant beam current the effective luminosity does not increase linearly with target length. In addition, if the radiative corrections are very

large, the helicity-correlated radiative effects can also be important (see the discussion below). The planned CEBAF target design, with maximum available beam current, is approximately the best combination of highest luminosity with a minimum of radiative effects.

III.4 Spectrometer

This experiment will use both Hall A spectrometers at a central momentum of about 3.5 GeV/c and a scattering angle of 12.5°. For the count rate estimates we have assumed a solid angle of 7.5 msr in each spectrometer. The elastic rate into each detector will be approximately 1.5 kHz. There will be additional rate from the tail of the quasielastic peak and other inelastic scattering, but the overall rate will be well below the 1 MHz counting limit. It should be possible to limit the data written to storage by putting the elastic peak a little to the low momentum side of the acceptance, turning off some of the side elements of the detector package and/or preprocessing the data. It will be desirable to keep the number of data words written to tape at a minimum, since there will be a total of 10^{10} events recorded. As some preprocessing will normally be required when the spectrometers are used in coincidence mode, we assume that it will be possible to make some straightforward modifications to the "standard" system for our purposes.

Scattered electrons will be counted individually, and the momentum spectrum will be integrated over approximately the top 20 MeV. A spectrometer resolution of only $\sim 10^{-3}$ is required to exclude inelastic scattering events. However, as will be described below, it would be useful to have a momentum resolution of $\sim 10^{-4}$ in order to use the spectrometer to measure helicity correlated energy changes to the level required for the experiment.

Since this experiment is a single-arm scattering experiment, only one spectrometer is actually required to make the measurement. Most of the required checkout before real data taking can be done with one spectrometer. The data taking will, however, benefit greatly from two spectrometers, both from the point of view of counting rate and because the detector system will then be approximately left-right symmetric about the beam line, which reduces the sensitivity to helicity correlated beam motion.

III.5 Background

Because this experiment is detecting elastically scattered electrons, very little background is expected in the Hall A spectrometers. The elastic peak ($\omega = 0$) is at a momentum of 3.5 GeV, and the π production threshold is $\omega = 200$ MeV. We therefore expect no pion contamination. The CEBAF beam is expected to be of a sufficiently high quality that there will be essentially no beam halo, thus scattering from the target walls is unlikely to contribute significantly to the spectrum. The ^{4}He elastic counting rate is sufficiently high that room background should not contribute much either.

There will be rate going into the spectrometer from inelastic and quasielastic scattering. With the elastic peak placed at $\delta = -2\%$ in the focal plane, the excitation energy acceptance will be about 150 MeV. The elastic peak would still be well within the flat region of acceptance in the focal plane. The integrated quasielastic cross section in this region is about 11 nb/sr, which gives a rate of 28 kHz, well below the maximum counting

rate in the detectors.

One potential source of concern is scattering from the pole tips of the magnets in the spectrometer. We use as a benchmark the SLAC experiment, which detected scattering electrons with a magnetic spectrometer at an angle of 4° in Endstation A. Since we are making a measurement to approximately the same level of precision with a much smaller momentum bite, we expect that with an adequate collimation system that electrons scattered from the pole tips should make a minimal contribution to the top 20 MeV of yield. We propose to demonstrate the validity of all of these assumptions with a test run to measure the ^{4}He elastic cross section at high luminosity.

III.6 Systematic Errors and Beam Fluctuations

Based on discussions with the members of the CEBAF accelerator staff, we will assume that the helicity can be flipped at a rate of 30 Hz, and that measurements of the beam charge, energy, position and angle can be made on this time scale (30 ms). Any nonzero asymmetry due to helicity correlated beam effects will then become a correction to the measured asymmetry, based on the measurements made. In the discussion below we will analyze the required accuracy of these beam measurements, based on the (somewhat arbitrary) assumption that the measurements should give a sensitivity to false asymmetries in 1/30 sec to the level of 5% of the statistical error in the same time bin. The statistical error per 1/30 sec time bin is $\sim$ 10%. We then require that all beam properties can be measured to a sensitivity such that $A_{false} < 5 \times 10^{-3}$ in this same amount of time. It is important to point out, however, that the completed experiment will constitute 10^7 such measurements, and the resulting errors on beam measurements should average to values much smaller, $\sim 10^{-4}$ of those calculated here, particularly if feedback systems are used to make adjustments in the short term drifts of the beam. This has, for example, been demonstrated in the ^{12}C parity experiment performed at Bates[7], where there was no observed helicity correlated beam shift when the measurements were averaged over a two week running period. In the following section we will demonstrate that with the beam requirements in table 1 all helicity correlated beam effects can be controlled to the require level of accuracy.

False asymmetries due to helicity correlated beam changes can come from several effects. Here we break these effects down into three categories: "direct" effects, which are direct changes in the cross section, "radiative", which are changes in the radiative losses in the target, and "other", such as helicity correlated changes in background, acceptance or efficiency.

The experimentally measured asymmetry is

$$A_{meas} = \frac{Y_R - Y_L}{Y_R + Y_L} \tag{6}$$

where Y_R (Y_L) is the elastic yield in the spectrometer normalized to beam charge C, binned by helicity state, over a given time period Δt,

$$Y = \frac{(d\sigma/d\Omega)\, r_c \mathcal{L} \Delta\Omega\, (\Delta t)\, \varepsilon}{C}. \tag{7}$$

The radiative correction factor r_c is taken to be 0.5, and ε is the product of detector efficiency and computer live time. The only beam property which enters the yield directly is the beam charge, or the beam current integrated over time Δt. It is not necessary to know *absolutely* the beam current to a high degree of precision, since it appears in both the numerator and denominator of the measured asymmetry. However, if the incident current is dependent on helicity, there will be a false asymmetry of the size of the fluctuation. We would therefore like to measure the incident beam current with a relative precision of $\delta I/I = 0.5\%$ in a 30 ms time period.

The elastic cross section $d\sigma/d\Omega$ is dependent on both the beam energy and angle. The false asymmetry associated with changes in the cross section due to helicity correlated changes in beam energy is

$$A_{false} = \left| \frac{1}{\sigma} \frac{\partial \sigma}{\partial E} \right| E \left(\frac{\delta E}{E} \right) = 4 \frac{\delta E}{E} .$$

This constrains the beam energy measurement resolution to $\delta E/E < 1 \times 10^{-3}$. This tolerance is larger than the resolution of the spectrometer, so in principal we will automatically get this information by comparing helicity-left and -right momentum spectra. However, it could also be accomplished with a position monitor at a place of dispersion in the beam line. In the Hall A (or C) beam transport there is a point with a dispersion of 2.1 cm/%. A position monitor with a resolution of 1 mm could achieve the desired energy resolution. The absolute energy of the beam comes in only in the determination of the momentum transfer, and so need not be known to better than a few percent.

The cross section will also change with beam angle, since this will generate a change in the scattering angle:

$$A_{false} = \left| \frac{1}{\sigma} \frac{\partial \sigma}{\partial \theta} \right| \delta\theta = 17 \, \delta\theta \, /\text{rad}$$

We therefore require that the scattering angle (including the beam angle) be known to $\delta\theta < 0.3$ mrad. This is only slightly smaller than the expected angular resolution of the spectrometer, and the centroid of the angle distribution in the spectrometer should be known to somewhat better than this. Again, if we do not want to rely on the spectrometer, the beam angle could be measured with two beam position monitors separated by come distance. The current beam line design for Hall A calls for two position monitors separated by 3.5 m. With a position resolution of 0.5 mm, the required resolution in beam angle could be achieved.

In addition to direct changes in the cross section, helicity correlated beam parameters will change the measured cross section by changing the radiative losses in the target in a helicity correlated way. The radiative losses in the target are dependent on beam energy and target length. The change in the radiative losses with beam energy is negligible compared to the direct change in the cross section with beam energy.

Since the target will be collimated such that the windows are not seen by the spectrometer, the yield in the the spectrometer should not change directly as a function of

beam position. However, the radiative losses will change as a function of beam position. The proposed CEBAF target design is for a 15 cm long target, 2 cm diameter with hemispherical endcaps and 10 mil thick walls. If the beam is exactly centered on the target and the target entrance window is symmetric, there will be no effect. If, however, there is an average offset x_0 to the beam, the helicity correlated change in target length will be

$$\delta L = \frac{x_0 \delta x}{R}$$

where $R = 1$ cm is the radius of curvature of the entrance window, and δx is the difference in position between right- and left-handed electrons. The false asymmetry generated by changes in the radiative losses with target thickness is

$$A_{false} = \left| \frac{1}{r_c} \frac{\partial r_c}{\partial L} \right| \delta L$$
$$= \left| \frac{1}{r_c} \frac{\partial r_c}{\partial L} \right| \frac{1}{R} (x_0 \delta x) = 0.02 (x_0 \delta x) \text{ cm}^{-2}.$$

In addition to the change in target length, there is also a change in window thickness,

$$\frac{\delta t_W}{t_W} = \frac{x_0 \delta x}{R^2}$$

and the associated false asymmetry is $A_{false} = 0.2 (x_0 \delta x) \text{ cm}^{-2}$. Assuming that we could measure the beam position to at least 0.5 mm, and a beam displacement of the same magnitude, both of these effects would be negligible.

Another possible effect coming from helicity correlated changes in target length is the energy loss at the entrance to the target. The average energy loss in the target before scattering is about 2.5 MeV. The helicity correlated asymmetry associated with the change in energy loss is

$$A_{false} = \frac{\delta(\Delta E)}{E} = \frac{1}{2R} (x_0 \delta x) \left[\frac{\partial E}{\partial L} + \frac{t_W}{R} \frac{\partial E}{\partial t_W} \right] \frac{1}{E}$$
$$= 2 \times 10^{-4} (x_0 \delta x) \text{ cm}^{-2}.$$

This effect is much smaller than the radiative effects of window thickness changes.

Changes in the beam radius will have an effect similar to changes in beam position, again causing changes in the radiative losses. Although the ^{4}He thickness does not change with radius, the average window thickness seen by the beam changes with beam radius:

$$\Delta = \frac{\overline{t_W} - t_W}{t_W} = \frac{1}{\left[1 - \left(\frac{r}{R} \right)^2 \right]^{1/2}} - 1$$

where r is the beam radius. For $r = 1$ mm and $R = 1$ cm, $\Delta = 5 \times 10^{-3}$. In the vertical beam dimension the effect is about 20 times smaller. This is a very loose requirement on the beam radius we do not propose to measure it.

14

working with sufficient reliability to make the required asymmetry measurement. We would like to measure the ^{4}He elastic cross section with good precision and low background with as high a luminosity as possible. With a luminosity of 3.2×10^{38}, the elastic cross section can be measured with good statistical precision very quickly. It would be desirable to make cross section measurements at more than one energy and/or more than one target density to confirm our understanding of the radiative corrections. At this time we would also make measurements with an empty target as a function of beam position to demonstrate that the beam halo and background levels are sufficiently under control. This measurement requires that the beam position monitors be in place and working. These measurements would require only one working spectrometer and would not require polarized beam. However, they would require the full beam current and 1 kW of cooling power for the CEBAF targets. If polarized beam were available at this time it would be possible to do some studies of helicity-correlated beam properties as well. Studies of the beam properties would require only one spectrometer and would not require the full luminosity.

We then request an additional 60 days, contingent upon the successful completion of the above tests and upon demonstration of 200 μA of longitudinally polarized beam with $P_B \gtrsim 50\%$, measured to $\Delta P_B/P_B \sim 10\%$. Although it is likely that we would participate in initial measurements of beam polarization, we assume that time will be allocated as facility development and do not specifically request the time here. For the full measurement, two working spectrometers would be desirable in order to get the maximum available solid angle. We stress, however, that this measurement is a single arm measurement and could be done with one spectrometer at the expense of additional running time. The total requested beam time is 65 days.

V. Collaboration Responsibilities

This experiment requires high luminosity and polarized beam, but no special equipment outside of that proposed in the Hall A CDR. The members of the UVa group and the CEBAF staff will provide the necessary experience in the beam line and spectrometers, and in data acquisition. Both the Cal State and Caltech groups have over the past two years been working on the design of cryogenic targets, in close collaboration with John Mark, the head of the SLAC cryogenic target group. The Cal State group has in particular taken responsibility for the design of the Hall A cryogenic target system. Much of the design is based on the Caltech liquid hydrogen target currently being built for the SAMPLE experiment at Bates. The Caltech group is currently involved in SAMPLE and will provide the necessary experience in performing parity violating electron scattering measurements. The majority of the data analysis will be performed at Caltech.

The third category of systematic uncertainties arises from helicity correlated changes in detector acceptance and efficiency. Since the spectrometer acceptance is approximately symmetric in the vertical angle, to first order the acceptance is not sensitive to helicity correlated vertical beam shifts. In the horizontal direction to first order the change in solid angle with beam position is $\delta\Omega/\Omega = (2\delta x/D)\sin\theta$, where θ is the scattering angle and D is the distance to the main solid-angle defining aperture (we assume $D \sim 180$ cm). For $\delta x = 0.5$ mm, $\delta\Omega/\Omega \sim 1 \times 10^{-4}$. This effect is already 50 times smaller than our nominal requirement, and should be further reduced by the use of two spectrometers placed symmetrically about the beam line, even if the spectrometer acceptances are only approximately identical.

It is possible that either the spectrometer efficiency or data acquisition dead time could have helicity correlated fluctuations. We expect these effects to be small because the total elastic counting rate of 3 kHz is well under the maximum rate, and the total raw trigger rate is well under the maximum raw rate of 1 MHz. If we assume that the maximum throughput is 10 kHz, the expected dead time will be a few percent. The most direct helicity correlated change in dead time or efficiency will come from a change in beam intensity, and can be estimated in the following way. The dead time is related to the probability for two events to occur within the same readout time bin, 10^{-4} sec. Changes in this probability due to changes in beam intensity will cause a dead time asymmetry. We require that the helicity correlated beam intensity changes average to $\sim 5\%$ of the statistical error over the course of the run. For $\frac{\Delta I}{I} \sim 10^{-7}$ averaged over the run, the helicity correlated change in dead time will be about 3×10^{-8}, and thus negligible. In addition, the maximum throughput to tape should be somewhat higher because we expect to write a reduced event length to storage. The helicity correlated change in detector efficiency can be estimated in a similar fashion, and should be about a factor of 2 smaller.

Finally, if there is any beam halo, there may be a false asymmetry generated by scattering from the target walls. In order to estimate this effect one must be able to estimate the amount of background under the elastic peak (due to the target walls) and the change in beam halo as a function of radius. Calculations of the beam profile for Hall B, based on the required residual vacuum in the accelerator, indicate that the beam current at 0.5 cm from the beam center will about 10^{-10} of the main beam current. This would indicate that there will be virtually no scattering from the target walls and hence no helicity correlated background. Nonetheless, both the beam stability as a function of position and the beam halo are highly dependent on beam quality. The helicity correlated background can be studied before doing the experiment by taking data with an empty cell as a function of beam position. It would then be possible to calculate the required correction to the physics asymmetry.

IV. Beam Request

A statistical measurement of the asymmetry of 40% will require 40 days of running, assuming a 50% polarized beam. With a 70% polarized beam a statistical error of 28% would be achieved in that time. Since at this time higher polarizations have not been demonstrated, we will assume a maximum of $P_B = 50\%$ for our beam request. We request 5 days of initial running to demonstrate that the beam, beam monitors and spectrometer are

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