Probing the Limits of the Standard Model of Nuclear Physics with the ^{4}He$(\vec{e}, e'\vec{p})^3$H Reaction

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Abstract

We propose high precision measurements of the double polarization ratio of polarization transfer coefficients, P'_x and P'_z, of the quasielastic $^4\mathrm{He}(\vec{e}, e'\vec{p})\,^3\mathrm{H}$ reaction with respect to the elastic $^1\mathrm{H}(\vec{e}, e'\vec{p})$ reaction, at a Q^2 of 0.8 (GeV/c)^2 and 1.3 (GeV/c)^2. Recently, measurements of this double ratio at both Mainz and JLab hinted at the need to include medium modifications of the proton form factors predicted by a quark-meson coupling model. The proposed experiment would reduce the statistical uncertainties in the double polarization ratio at each Q^2 by over a factor of two compared to the previous measurement, resulting in roughly equal contributions from statistical and systematic uncertainties. These two Q^2 values were selected since they lie in a region where theoretical calculations are expected to be reliable. This measurement would provide one of the most stringent tests to date of the applicability of conventional meson-nucleon calculations.

1 Introduction

Whether nucleons undergo considerable change of their internal structure when bound in the nuclear medium is a long standing issue in nuclear physics. At nuclear matter densities, $\approx 0.17\ \mathrm{fm}^{-3}$, nucleon wave functions have significant overlap. In the chiral limit, one expects the nucleons to lose their identity altogether and for nuclei to make a transition to a quark-gluon plasma.

Nuclear physics originated with the description of nuclei as consisting of protons and neutrons. These nucleons are held together by a long-range, attractive, strong force mediated by meson exchange, whereas the saturation properties of nuclear matter arise from the repulsive part of the strong interaction [1]. The development of Quantum ChromoDynamics (QCD) as the theory of the strong interaction has turned this historical description into an effective description, that works extremely well due to the QCD property of confinement. Still, at some level, one anticipates a breakdown of this effective description.

Experimentally, distinguishing possible changes in the spatial structure of nucleons embedded in a nucleus from more conventional many-body effects is only possible within the context of a model. The nucleus, as a bound many-body quantum system, has inherent many-body effects, such as meson-exchange currents (MEC) and isobar configurations (IC). In addition, when probing nuclear structure one has to deal with final state interactions (FSI). A change in the spatial structure of the nucleon, as expressed in medium modifications of the nucleon form factors, implies that one treats observed medium effects as one-body effects. There are two caveats here. Firstly, one needs to have excellent control of the description of many-body effects before drawing the conclusion that one requires medium-modified nucleon form factors. Secondly, if one defines medium-modified nucleon form factors, one needs in principle to also adopt medium-modified many-body effects to perform a rigorous calculation of nuclear structure. In the end, allowing for a modification of the one-body response may result in a more economical calculational approach, given the difficulties of rigorous, ab-initio calculations for bound quantum many-body systems.

In unpolarized A$(e, e'p)$ experiments involving light- and medium-mass nuclei, deviations were observed in the longitudinal/transverse character of the nuclear response (compared to the free proton case). These deviations could be interpreted as a change of nucleon form factor within the nuclear medium. However, strong interaction effects on the ejected proton (FSI) could also explain the observed effect [2]. This illustrates the potential hazards in not having excellent control of many-body effects.

Polarization transfer in quasielastic nucleon knockout is sensitive to the properties of the nucleon in the nuclear medium, including possible modification of the nucleon form factor and/or spinor. The target nucleus ^{4}He is optimal for further study since its relative simplicity allows for realistic microscopic calculations and since its high density enhances any possible medium effects. Also, a variety of calculations for the $^4\mathrm{He}(\vec{e}, e'\vec{p})\,^3\mathrm{H}$ reaction indicate that polarization transfer observables have minimal influence from FSI and MEC effects, amounting to only an $\approx$10% correction [3, 4, 5]. As mentioned, it is precisely these effects (especially FSI) that have so far prevented a clean determination of nucleon medium modifications from unpolarized response functions in $(e, e'p)$ experiments.

A calculation by D.H. Lu *et al.* [6], using a quark-meson coupling (QMC) model, suggests a measurable deviation from the free space form factor ratio over the Q^2 range $0.0 < Q^2 < 2.5$ (GeV/c)^2, as shown in Fig. 1. Note that the calculation is consistent with present constraints on possible medium modifications for both the electric form factor (from the Coulomb Sum Rule, with $Q^2 < 0.5$ (GeV/c)^2 [7, 8]), and the magnetic form factor (from a y-scaling analysis [9], for $Q^2 > 1$ (GeV/c)^2). The calculation seems to predict too large an effect for the magnetic form factor at higher Q^2; however, it has been suggested that in order to interpolate smoothly between confined and deconfined phases, the bag constant might decrease as the baryon density increases [6]. Such an effect would reduce the Q^2-dependence of the medium modification of the magnetic form factor, while still having a measurable effect in the ratio of G_E/G_M. Similar measurable effects have been calculated in the light-front constituent quark model of Frank *et al.* [10].

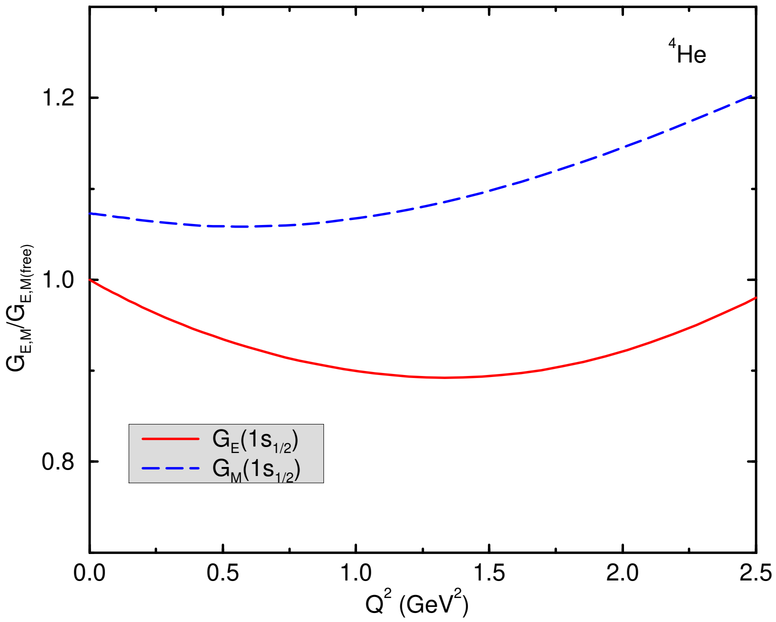

Figure 1: *Ratio of in-medium to free space electric and magnetic form factors of the proton in ^{4}He [6]. The free bag radius was taken to be 0.8 fm.*

For free electron-nucleon scattering, the ratio of the electric to magnetic Sachs form factors, G_E and G_M, is given by [11]:

$$\frac{G_E}{G_M} = -\frac{P'_x}{P'_z} \cdot \frac{E_e + E_{e'}}{2m_p} \tan(\theta_e/2), \tag{1}$$

where P'_x and P'_z are the transverse and longitudinal transferred polarizations [12]. The beam energy is E_e, the energy (angle) of the scattered electron is $E_{e'}$ (θ_e) and m_p is the proton mass. The relation in Eq. (1) was recently used to extract G_E/G_M for the proton [13, 14]. For quasielastic nucleon knockout of a bound proton this relation is only approximately correct, but polarization transfer remains sensitive to the properties of the nucleon in the nuclear medium: although proper interpretation of the results requires accounting for such effects as FSI and MEC, their effects on polarization transfer are, as mentioned, calculated to be small.

2 Recent Experimental Results

Recently, polarization transfer in the $^4\mathrm{He}(\vec{e}, e'\vec{p})\,^3\mathrm{H}$ reaction at $Q^2 = 0.4$ (GeV/c)^2 was reported [15]. The addition of medium-modified proton form factors, as predicted by the QMC model, to a state-of-the-art, fully relativistic model [4], rendered a good description of the data. The authors concluded that the data favor models with a medium-modified form factor, but that the statistical significance was not sufficient to rule out calculations without form factor modification.

A similar experiment, E93–049, was performed in Hall A at JLab in April/May 2000 [16, 17]. As this experiment was designed to detect differences between the in-medium polarizations compared to the free values, both ^{4}He and ^{1}H targets were employed (due to beam time constraints, at $Q^2 = 2.6$ (GeV/c)^2 only ^{4}He data was acquired). The statistical precision for the polarization double ratio was roughly 5.5%, 4.5%, 4.5% and 10% at Q^2 of 0.5, 1.0, 1.6, and 2.6 (GeV/c)^2 respectively. The systematic uncertainty, predominantly due to uncertainties in the spin transport through the HRS spectrometer, is estimated to be 1.3% at $Q^2 = 1.0$ (GeV/c)^2.

The E93–049 results are shown in Fig. 2, for all four values of Q^2. The results are expressed in terms of the polarization double ratio

$$R_{Exp} = \frac{(P'_x/P'_z)_{^4\mathrm{He}}}{(P'_x/P'_z)_{^1\mathrm{H}}}. \tag{2}$$

Here, the helium polarization ratio is normalized to the hydrogen polarization ratio measured in the identical setting. Such a double ratio nearly cancels all systematic uncertainties. As a cross check, the hydrogen results were also used to extract the free proton form factor ratio G_E/G_M and found to be in excellent agreement with previous data [13, 14]. In addition, the E93–049 result at Q^2 = 0.5 (GeV/c)^2 closely coincides with the recent results at Q^2 = 0.4 (GeV/c)^2 of Mainz [15], also shown in Fig. 2.

The theoretical predictions are results of the acceptance-averaging of calculations by the Madrid group [4, 18]. We note that these relativistic calculations provide good description of, e.g., the induced polarizations as measured at Bates in the ^{12}C(e,e$'\vec{p}$) reaction [19] and of A_{TL} in $^{16}\mathrm{O}(\vec{e}, e'\vec{p})$ as previously measured at JLab [20].

At Q^2 = 0.5 and 1.0 (GeV/c)^2 the plane-wave impulse approximation (PWIA) calculation overestimates the data by ≈10%. The relativistic distorted-wave impulse approximation (RDWIA) calculation gives a slightly smaller (≈ 3%) value of R_{Exp} but still overpredicts the data. The inclusion of a medium modification of the proton form factor as predicted by Lu *et al.* [6] in the RDWIA calculation is in excellent agreement with both settings. All calculations shown use the Coulomb gauge, the CC1 current operator as defined in [21], and the MRW optical potential of [22]. The CC2 current operator gives higher values of R_{Exp}, worsening agreement with the data. In general, various choices for, e.g., spinor distortions, current operators, and relativistic corrections, affect the theoretical predictions by ≤3%, and can presently not explain the disagreement between the data and the RDWIA calculations.

A statistical analysis of the measured double ratios and various theoretical predictions was performed. Table I presents the χ^2 per degree of freedom and the confidence level of each calculation. It is obvious that the best description can be found for calculations including medium modifications. In fact, calculations without such effects have a relatively small (< 10%) confidence level, whereas the calculation with such effects has an appreciable, ≈

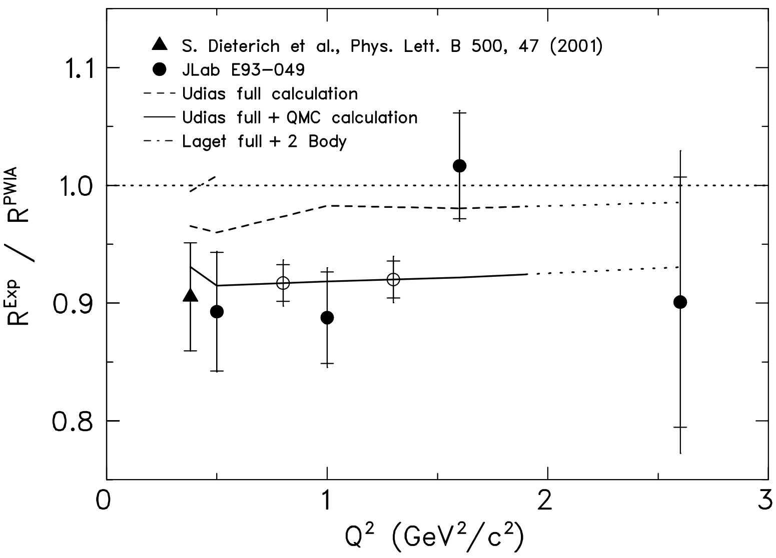

Figure 2: *Superratio R_{Exp}/R_{PWIA} as a function of Q^2 (closed circles). In PWIA (short-dashed line) the double polarization ratio, R_{PWIA}, is identically unity (barring acceptance-averaging effects). The dashed line shows the results of the full relativistic calculation of Udias et al. [4]. The dot-dashed line shows the results of the full calculation, including two-body currents, of Laget [3]. The solid line indicates the full relativistic calculation of Udias [18] including medium modifications as predicted by a quark-meson coupling model [6]. For Q^2 > 1.8 $(GeV/c)^2$ the Udias calculations are indicated as short-dashed lines as one extrapolates beyond the region of validity of the relativistic optical potential used. The lines connecting the acceptance-averaged theory calculations are to guide the eye only. The open circles indicate the projected data from this proposal.*

Table 1: *Statistical comparisons of the polarization double ratio R^{Exp} (see text) with various model calculations. The first entry is a Plane-Wave Impulse Approximation calculation only. The second entry is the full relativistic RDWIA calculation of Udias et al. [4]. The third entry incorporates [18] medium modifications to the latter, as predicted by a quark-meson coupling model [6]. The fourth entry is the full nonrelativistic model of Debruyne et al. [23, 24]. The last entry is a full nonrelativistic calculation of Laget including two-body currents [3] (only data up to Q^2 = 0.5 (GeV/c)^2 are taken into account).*

Ref.	χ^2/d.f.	conf. level
[4] (PWIA)	3.6	0.3%
[4] (RDWIA)	2.1	5.7%
[4, 18] (+ QMC)	1.1	34.4%
[23, 24] (Full)	4.4	0.1%
[3] (Full + 2Body)	4.5	1.1%

35%, confidence level.

The E93–049 results, binned versus missing momentum, are shown in Fig. 3 for three of the four kinematical settings along with theoretical results, again in terms of the polarization double ratio R_{Exp}. The statistics at the Q^2 = 2.6 (GeV/c)^2 kinematics are not sufficient to make a meaningful comparison with calculations. Hence, this highest Q^2 point has been omitted from Fig. 3. Negative values of missing momentum correspond to the recoiling nucleus having a momentum component antiparallel to the direction of the three-momentum transfer. Both the PWIA and the RDWIA can be seen to give a reasonable, but not perfect, description of the missing momentum dependence found in the data. As in Fig. 2, the normalization difference between the RDWIA calculation and the data can be largely cured by including the QMC medium modifications.

One can argue that the case is not so clear for the Q^2 = 1.6 (GeV/c)^2 kinematics, and that the calculation without QMC medium modifications gives a satisfactory description of the data. This in essence mimics what can be seen in Fig. 2: The Q^2 = 1.6 (GeV/c)^2 kinematics lies "above" the calculation with QMC modifications. Still, the statistical analysis seems to indicate that this is merely a statistical fluctuation. Obviously, more precise data could settle this issue unambiguously, with high confidence level, and would constitute a demanding test of modern-day nucleon/meson descriptions of nuclear physics.

Lastly, we show in Fig. 4 the induced polarizations, P_y, corrected for (small) false asymmetries, as a function of missing momentum. These induced polarizations are identically zero in the absence of FSI effects (in the one-photon exchange approximation) and constitute a stringent test of various model calculations. One sees that the induced polarizations are small for all measured Q^2 values. The dashed and dot-dashed curves constitute RDWIA calculations by Udias *et al.* [4] with widely differing choices for the relativistic optical potentials. For the induced polarization case, the RDWIA curves with and without medium modifications are identical: as mentioned earlier the QMC model only incorporates modifications to the one-body form factors. For a rigorous calculation of the ${}^4\mathrm{He}(e, e'\vec{p})^3\mathrm{H}$ results presented here, one would need to take into account possible medium modifications to both one-body form factors and many-body FSI effects.

Figure 4 confirms the expected smallness of the induced polarizations, and seems to indicate a reasonable agreement with the RDWIA calculation of Udias *et al.* [4, 18]. This is important, as any imperfect knowledge of reaction mechanism effects in the theoretical calculations of the ${}^4\mathrm{He}(\vec{e}, e'\vec{p})\,{}^3\mathrm{H}$ reaction should also show up as imperfect agreement with the induced polarizations. For example, an underestimate of reaction mechanism effects in the present calculation [18] may be due to the neglect of IC and the choice of what to include as MEC within the relativistic calculation.

A far more detailed check of whether reaction mechanism effects in the ${}^4\mathrm{He}(\vec{e}, e'\vec{p})\,{}^3\mathrm{H}$ reaction are fully understood is precluded by the systematic uncertainty of the induced polarizations: false asymmetries are typically checked with the ${}^1\mathrm{H}(\vec{e}, e'\vec{p})$ reaction, but the ${}^4\mathrm{He}(\vec{e}, e'\vec{p})\,{}^3\mathrm{H}$ reaction populates a different phase space in the proton spectrometer than the ${}^1\mathrm{H}(\vec{e}, e'\vec{p})$ reaction, and more careful checkout of the false asymmetries in the Focal Plane Polarimeter are required. This can be easily accomplished by "scanning" the angle and/or momentum of the proton spectrometer while taking ${}^1\mathrm{H}(\vec{e}, e'\vec{p})$ data, thus expanding the effective phase space coverage with the

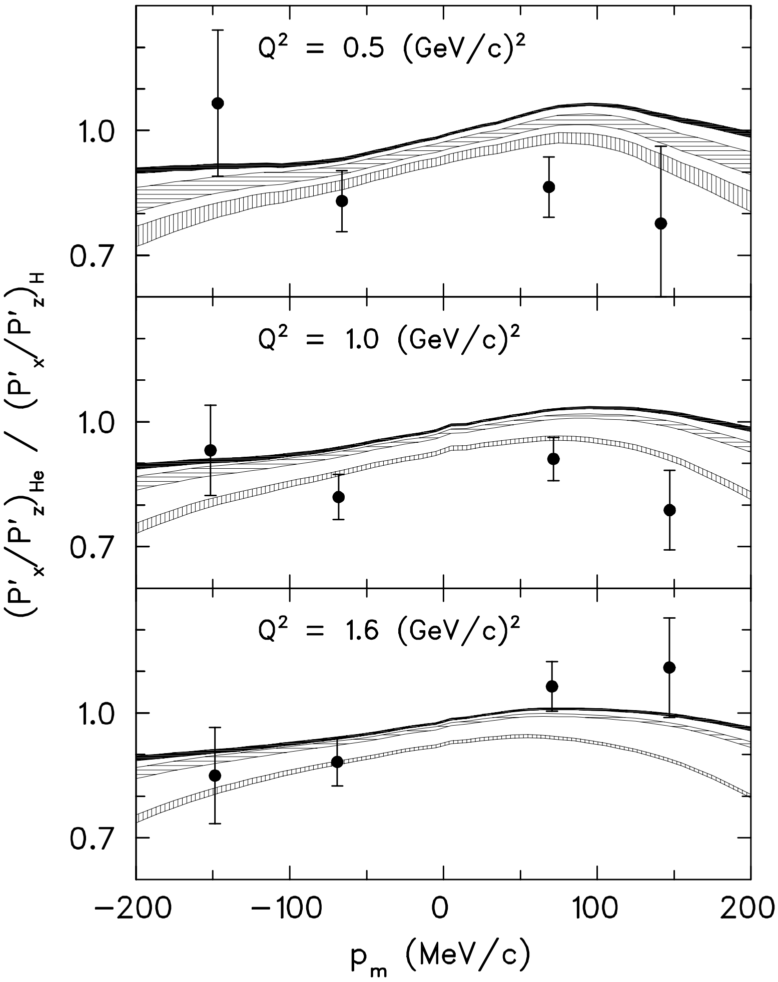

Figure 3: *Measured values of the polarization double ratio R_{Exp} for $^4He(\vec{e}, e'\vec{p})^3H$ at Q^2 = 0.5 $(GeV/c)^2$ (top), Q^2 = 1.0 $(GeV/c)^2$ (middle), and Q^2 = 1.6 $(GeV/c)^2$ (bottom). The shaded bands represent PWIA calculations (solid), relativistic DWIA calculations (horizontal dashes) and relativistic DWIA calculations including QMC medium–modified form factors [6] by Udias et al. [4] (vertical dashes). The bands take into account variations due to choice of current operator, optical potential, and bound-state wave function (see also Ref. [15]).*

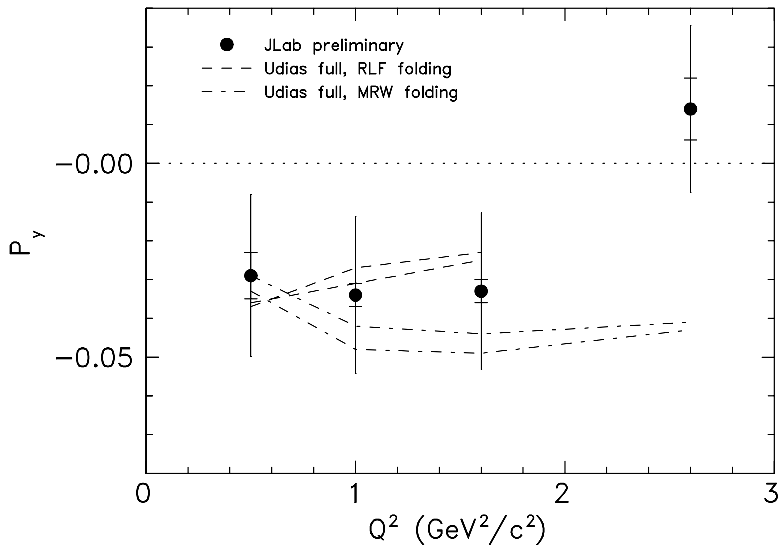

Figure 4: *Measured values of the induced polarizations for the* $^4He(\vec{e}, e'\vec{p})\,^3H$ *reaction. The inner uncertainty is statistical only, the total uncertainty includes a systematic uncertainty of* ± 0.02*, due to the imperfect knowledge of the false asymmetries. The dashed and dot-dashed curves show the results for the full relativistic calculations of Udias et al. [4, 18], using widely differing assumptions for the relativistic optical potentials used in the RDWIA calculations. All theoretical curves are averaged over the experimental acceptance.*

Focal Plane Polarimeter.

3 The Experiment

The proposed experiment is rather simple: we wish to improve on the precision of the polarization double ratio

$$R_{Exp} = \frac{(P'_x/P'_z)_{^4\mathrm{He}}}{(P'_x/P'_z)_{^1\mathrm{H}}}, \tag{3}$$

in a region of Q^2 where theoretical calculations are reliable: final-state interactions are reduced as much as possible, but relativistic optical potentials are still available. In essence, this proposal would bring the statistical uncertainties, $\approx$ 1.7%, down to the same level as the systematic uncertainty, $\approx$1.3%, for the double ratio.

Compared to the previous E93–049 experiment, the statistical uncertainties here would be improved by a factor of over a factor of two. This would be accomplished by two measures:

- E93–049 used a beam current of 40 μA for the lower Q^2 values, combined with a beam polarization of $\approx$77%. Presently, the strained GaAs polarized source can deliver 100 μA of similarly polarized beam, such as also requested/used by the HAPPEX experiments.
- E93–049 was approved for 12 days, and measured at four Q^2 values. This experiment would only measure at $Q^2 = 0.8$ and 1.3 (GeV/c)^2, at optimized beam energies.
- The Focal Plane Polarimeter performance will be improved by adding a CH_2 analyzer between the Vertical Drift Chambers and the front FPP chamber.

We also wish to improve on the precision of the induced polarizations, by precisely mapping out the false asymmetries using the $^1\mathrm{H}(\vec{e}, e'\vec{p})$ reaction, while slightly varying the angle of the proton spectrometer. In this way, the recoiling protons scan over the full phase space of the Focal Plane Polarimeter.

We intend to use 10 cm long cryogenic Helium and Hydrogen targets, and Aluminum dummy targets for window subtraction.

The choice of $Q^2 = 0.8$ and 1.3 (GeV/c)^2 is motivated as follows: (i) An extensive set of previous ^{16}O(e,e$'$p) data exist from Hall A experiments (E89-003, E89-033, and, more recently, E00-102) that form a benchmark for RDWIA calculations at $Q^2 = 0.8$ (GeV/c)^2; (ii) A combination of better precession angle and higher rate allows for a significant improvement in figure-of-merit for a small decrease in Q^2 from E93-049's 1.6 (GeV/c)^2 to the proposed 1.3 (GeV/c)^2; (iii) RDWIA calculations are reliable in the proposed Q^2 region, whereas reaction mechanism effects are calculated to have only small effect on the polarization double ratio, as can be seen from Fig. 2.

3.1 Choice of Target

We earlier mentioned some reasons why ^{4}He is the obvious target of choice for an initial exploration: its relative simplicity and high density. In addition, a technical reason is that ^{4}He can easily withstand high beam currents (possible target boiling effects do not affect the double polarization ratio measured).

If, instead of ^{4}He, one would be able to use a heavier target nucleus, or any nuclear transition, that effectively probes some higher nuclear density region than in the $^4\mathrm{He}(\vec{e}, e'\vec{p})\,^3\mathrm{H}$ region, this would be worthwhile. This is illustrated in Fig. 5, showing the calculated dependence on nuclear density in the range of the ^{4}He nucleus.

However, in practice one "samples" the nuclear density when using the $\mathrm{A}(e, e'p)$ reaction, and, when calculating the effective nuclear density as probed in this reaction, ^{4}He remains the obvious target of choice. The average density as sampled in, e.g., the $^{16}\mathrm{O}(e, e'p)$ reaction is only slightly larger than that for the $^4\mathrm{He}(e, e'p)$ reaction, whereas microscopic calculations may be more troublesome, and experimental rates are smaller. Furthermore, Coulomb corrections are less of an issue when using the light ^{4}He nucleus.

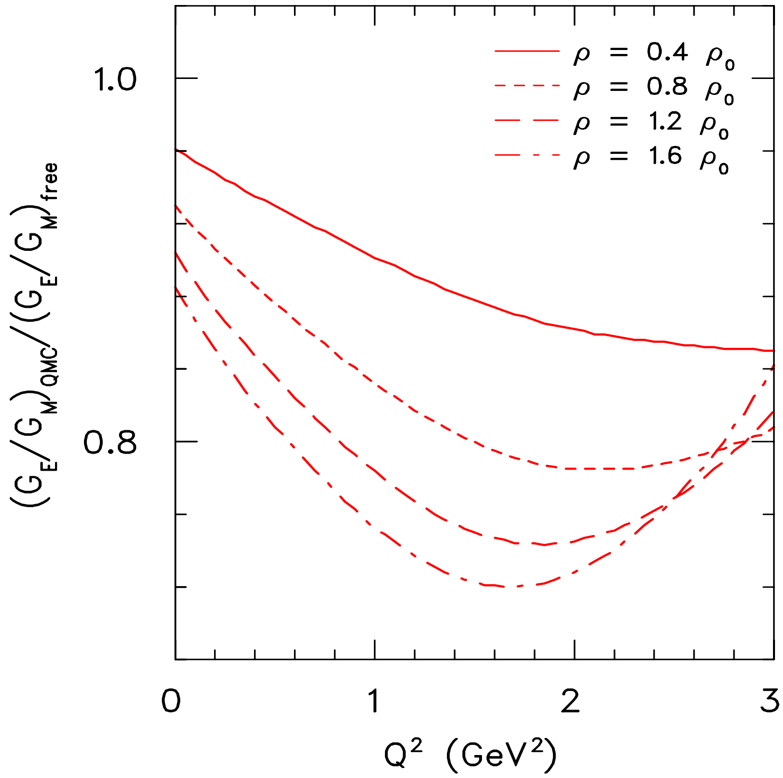

Figure 5: *Ratio of in-medium to free space ratio of electric to magnetic form factors of the proton, as a function of nuclear density [6]. The free bag radius was taken to be 0.8 fm.*

Hence, our approach is to do the best experimental job possible using the $^4\mathrm{He}(\vec{e},e'\vec{p})\,^3\mathrm{H}$ reaction, to put forward as great a challenge as possible for conventional meson-nucleon calculations.

3.2 Kinematics and Running Time Estimates

The kinematics are chosen to be in a region of Q^2 where state-of-the-art theoretical calculations are readily available, and where these calculations predict minimal impact on the measured ratio of polarization transfer coefficients due to reaction mechanism effects. In addition, the kinematics and running time estimates for the ^{1}H and ^{4}He targets are optimized to minimize the running time for a certain uncertainty in the double polarization ratio. It has to be noted that this minimization technique is not too dependent on the exact choice of beam energy: there is a rather wide, shallow minimum around the quoted beam energies. Kinematics are given in Table 2.

Table 2: *Kinematics and FPP analyzer thickness for the $^4He(e,e'p)^3H$ reaction.*

Q^2 $(\mathrm{GeV/c})^2$	E_e GeV	$E_{e'}$ GeV	$\Theta_{e'}$ deg	p_p GeV/c	Θ_p deg	CH_2 inch	Carbon inch
0.8	1.500	1.045	41.9	1.004	-44.0	12	9
1.3	2.250	1.522	35.9	1.353	-41.3	12	9+6+1.5

Since this proposal is a higher-statistics version of experiment E93–049, we refer to that experiment for experimental issues such as particle identification. We have verified that, for this higher-luminosity proposal, real to random ratios are still estimated to be better than 9:1, even without particle identification, within a 5 ns coincidence timing window.

In essence, this is a rather simple experiment, where the main requirements are to run the $^4\mathrm{He}(\vec{e},e'\vec{p})\,^3\mathrm{H}$ and $^1\mathrm{H}(\vec{e},e'\vec{p})$ reactions back to back, and to add more data to minimize false asymmetries of relevance for the induced polarization measurements. We additionally have optimized the focal plane polarimeter performance by adding a CH_2 analyzer before the front straw chamber. This in essence "splits" the focal plane polarimeter in two parts, giving a larger efficiency. However, for ease of installation of the CH_2 analyzer, we assume a single thickness for both Q^2 values. This technique has been successfully used for Hall A's Real Compton Scattering experiment.

Lastly, one has to keep in mind that the maximum reasonable data acquisition rate is 2 kHz for coincidence experiments, with a dead time of 20%. Furthermore, this maximum data acquisition rate includes events in the 3- or 4-body breakup channels, randoms, and events not making several cuts in the FPP analysis. Hence, the practical data acquisition rate for events of interest in this case is estimated to be 768 Hz (990 Hz for the hydrogen target). We propose to obtain a 1.7% statistical uncertainty in the experimental ratio R_{Exp}, close to matching the statistical and systematic uncertainties in this ratio. This would constitute a decrease in the E93–049 uncertainties of over a factor of two. Our beam time estimates are given in Table 3.

Table 3: *Beam time estimates.*

Q^2	Helium			Hydrogen		
	Rate	time	statistical unc.	Rate	time	statistical unc.
$(\mathrm{GeV/c})^2$	Hz	hours	%	Hz	hours	%
0.8	143	75	1.4	990	26	0.9
1.3	79	157	1.5	990	39	0.8

3.3 Beam Time Request

The total beam time requested is 409 hours or 17 days (see Table 4). Of these 17 days, 2.5 days are for mapping out the false asymmetries of the Focal Plane Polarimeter system using the $^1\mathrm{H}(\vec{e}, e'\vec{p})$ reaction. Production data taking amounts to 12.5 days, split over the $Q^2 = 0.8$ and 1.3 $(\mathrm{GeV/c})^2$ kinematics ($\approx$ 4.3 and 8.2 days, respectively). Finally, one day is dedicated to kinematics changes and beam polarization measurements, and one day to measurements of the target wall background. The experiment will use beam energies of 1.50 and 2.25 GeV, with two dedicated beam polarization measurements for each beam energy.

We require to run the ^{4}He$(\vec{e}, e'\vec{p})\,^3$H and ^{1}H$(\vec{e}, e'\vec{p})$ reactions back to back in order to minimize systematic uncertainties, for both values of Q^2. The experiment requires a cryogenic target with 10 cm long ^{4}He and ^{1}H cells. Depending on scheduling, a few-day installation period may be needed to change the cryotarget configuration. No time is requested in the proposal for the changeover, since it may not be necessary.

We request a beam current of 100 μA, on both targets (40 μA for the Al "dummy" target), and a beam polarization of at least 70%.

The summary of the beam time request is given in Table 4.

Table 4: *Summary of beam time request.*

Target	Purpose	Time hr
H	False Asymmetries $Q^2 = 0.8$ (GeV/c)^2	24
H	Production $Q^2 = 0.8$ (GeV/c)^2	26
He	Production $Q^2 = 0.8$ (GeV/c)^2	75
Al	Wall subtraction $Q^2 = 0.8$ (GeV/c)^2	12
Al	Wall subtraction $Q^2 = 1.3$ (GeV/c)^2	12
He	Production $Q^2 = 1.3$ (GeV/c)^2	157
H	Production $Q^2 = 1.3$ (GeV/c)^2	39
H	False Asymmetries $Q^2 = 1.3$ (GeV/c)^2	36
–	Beam Energy Change (1)	8
–	Additional Spectrometer Changes (2)	8
–	Møller Measurements (4)	12

References

[1] S.A. Moszkowski and B.L. Scott, Ann. Phys. **11** (1960) 65.

[2] T.D. Cohen, J.W. Van Orden, and A. Picklesimer, Phys. Rev. Lett. **59** (1987) 1267.

[3] J.-M. Laget, Nucl. Phys. **A579** (1994) 333.

[4] J.M. Udias *et al.*, Phys. Rev. Lett. **83** (1991) 5451; J.A. Caballero, T.W. Donnelly, E. Moya de Guerra, and J.M. Udias, Nucl. Phys. **A632** (1998) 323; J.M. Udias and J.R. Vignote, Phys. Rev. C **62** (2000) 034302.

[5] J.J. Kelly, Phys. Rev. C **60** (1999) 044609.

[6] D.H. Lu, K. Tsushima, A.W. Thomas, A.G. Williams and K. Saito, Phys. Lett. **B417** (1998) 217 and Phys. Rev. C **60** (1999) 068201.

[7] J. Jourdan, Phys. Lett. **B353** (1995) 189.

[8] J. Morgenstern and Z.-E. Meziani, Phys. Lett. **B515** (2001) 269.

[9] I. Sick, Comm. Nucl. Part. Phys. **18** (1988) 109.

[10] M.R. Frank, B.K. Jennings and G.A. Miller, Phys. Rev. C **54** (1996) 920.

[11] A.I. Akhiezer and M.P. Rekalo, Sov. J. Part. Nucl. **3** (1974) 277; R. Arnold, C. Carlson and F. Gross, Phys. Rev. C **23** (1981) 363.

[12] With the initial and final electron momentum $\vec{k}_i$ and $\vec{k}_f$, the coordinate system is given by the unit vectors $\hat{z} = (\vec{k}_i - \vec{k}_f)/|\vec{k}_i - \vec{k}_f|$, $\hat{y} = (\vec{k}_i \times \vec{k}_f)/|\vec{k}_i \times \vec{k}_f|$, and $\hat{x} = \hat{y} \times \hat{z}$.

[13] M.K. Jones *et al.*, Phys. Rev. Lett. **84** (2000) 1389.

[14] O. Gayou *et al.*, Phys. Rev. C **64** (2001) 038202.

[15] S. Dieterich *et al.*, Phys. Lett. **B500** (2001) 47.

[16] S. Dieterich, Ph.D. thesis, Rutgers University (2002).

[17] S. Dieterich *et al.*, to be submitted to Phys. Rev. Lett. (2002).

[18] J. Udias, private communications.

[19] J. Gao *et al.*, Phys. Rev. Lett. **84** (2000) 3265.

[20] S. Malov *et al.*, Phys. Rev. C **62** (2000) 057302.

[21] T. de Forest, Nucl. Phys. **A392** (1983) 232.

[22] J.A. McNeil, L. Ray, and S.J. Wallace, Phys. Rev. C **27**, (1983) 2123.

[23] J. Ryckebusch, D. Debruyne, W. Van Nespen, and S. Janssen, Phys. Rev. C **60** (1999) 034604.

[24] D. Debruyne, Ph.D. thesis, University of Gent (2001).