A Measurement of Nucleon Strange Form Factors at High Q^2

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We propose to measure the parity-violating asymmetry in the elastic scattering of ~ 3.4 GeV electrons from a liquid Hydrogen target in Hall A at an average Q^2 of $0.6\,\mathrm{GeV}^2$. This region of Q^2 is especially interesting in light of the trend of recent results to show positive values for the

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combination of G_E^s and G_M^s. The data now existing is suggestive of a significant non-zero strange quark vector form factor at high Q^2, but it is important to confirm this non-zero contribution at a high confidence level. The addition of a single high precision point will greatly constrain the possible contributions in this region.

From the proposed measurement, the linear combination of strange-quark vector form factors $G_E^s + 0.48\, G_M^s$ would be extracted with a precision of ± 0.011. A measurement of such precision would be $\sim$4 standard deviations from zero, if the result matched the average of presently existing world data in this kinematic region. The technique of using the HRS to focus elastically scattered electrons on an integrating counter have been shown to be robust in several measurements, starting with HAPPEX-I in 1998. The proposed precision can be achieved in 30 days of beam time (including time for systematics studies), at 100 μA with 80% beam polarization.

I. MOTIVATION

The data set available for weak form factors has dramatically increased with the submission for publication of results from HAPPEX-II ([1],[2]) and G0 [3] (Fig. 1). Data from the G0 collaboration, when combined with world data ([4]-[7]), suggests that strange quarks make a non-zero, Q^2-dependent contribution to elastic form factors. These results show several features which, if confirmed, would be quite surprising. Specifically, the strange form factors appear to be quite large at certain values of Q^2, with $G_E^s + \eta\, G_M^s$ at the level of 0.05 at $Q^2 < 0.2\,\mathrm{GeV}^2$ and 0.04 in the range of Q^2 from 0.4-0.8 GeV^2. Moreover, the data suggests that the Q^2 dependence of $G_E^s + \eta\, G_M^s$ below $Q^2 = 0.2\,\mathrm{GeV}^2$ is much more rapid than what might be expected from, for example, comparison to the neutron electric form factor.

The evaluation of the presence of non-zero strange form factors (SFF) in the existing data is difficult due to sensitivity to two independent functions of Q^2, G_E^s and G_M^s, and the fact that the Q^2-dependences of these functions is not a priori known. Therefore a large number of parameters might be used to describe the data, enhancing the probability that some statistical fluctuation is interpreted as signal. We feel that the key need in the field is a measurement, which can be interpreted without assumptions regarding Q^2 evolution, with $>$ 3-sigma significance that is also consistent with the rest of the data.

In our assessment of the data, we consider three different ranges of Q^2; 0.1-0.16, 0.16-0.4, and $> 0.4\,\mathrm{GeV}^2$. There is data from 4 experiments ([1],[2],[7],[5]) at the lowest Q^2, as shown in Fig. 2, plus a band extrapolated from the G0 points at low Q^2 [3]. The result is that SFF's are required at about the 95% CL. This is highly suggestive, but not conclusive. If the SFF effect is as large as the present world average, HAPPEX-II (E99-115, E00-114) should be able to establish the presence of SFF's by the above criteria in a run scheduled to start in July, 2005.

Given the suggestion for the observation of SFF's at $Q^2 = 0.1\,\mathrm{GeV}^2$, one would also expect sizable SFF's at $Q^2 = 0.2$-$0.3\,\mathrm{GeV}^2$ under the assumption that SFF's have a Q^2-dependence similar to that of G_E^n. However, a striking feature of the G0 data is the fact that the data there require no SFF, with stringent limits. This raises the question of whether the suggestive results at $Q^2 = 0.1\,\mathrm{GeV}^2$ is a statistical fluctuation, which, as mentioned above, will be well tested by HAPPEX-II. Alternatively, it is also possible that there is a rapid Q^2 variation of the SFF's, a result which would be important and therefore requires strong evidence to be established convincingly.

The G0 collaboration also reports a large value of SFF's for $Q^2 > 0.5\,\mathrm{GeV}^2$. In this region, the only other data is from HAPPEX-I [4], which is consistent with both the G0 data or zero SFF's. Implications about this region by extrapolation from the low Q^2 data are limited. Thus it is important for the G0 result to be independently confirmed by data at $Q^2 > 0.5\,\mathrm{GeV}^2$.

We believe that the HAPPEX apparatus in Hall A is ideally suited for this purpose. Since HAPPEX-I ran, large improvements in polarized luminosity have been achieved, and it is now possible to obtain a point with 1/3 the HAPPEX-I error. In turn, this data will provide a >4-sigma nonzero measurement of the SFF's if the signal is comparable to the G0 average between $Q^2 = 0.5 - 0.8\,\mathrm{GeV}^2$.

II. EXPERIMENTAL STRATEGY AND ANTICIPATED RESULTS

At tree-level, the expression for the parity-violating elastic scattering asymmetry (A_{PV}) from hydrogen is [8]:

$$A_{\mathrm{PV}} = -\frac{G_F Q^2}{4\pi\alpha\sqrt{2}} \times \left\{ (1 - 4\sin^2\theta_W) - \frac{\epsilon G_E^p G_E^n + \tau G_M^p G_M^n}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2} - \frac{\epsilon G_E^p G_E^s + \tau G_M^p G_M^s}{\epsilon (G_E^p)^2 + \tau (G_M^p)^2}\right.$$

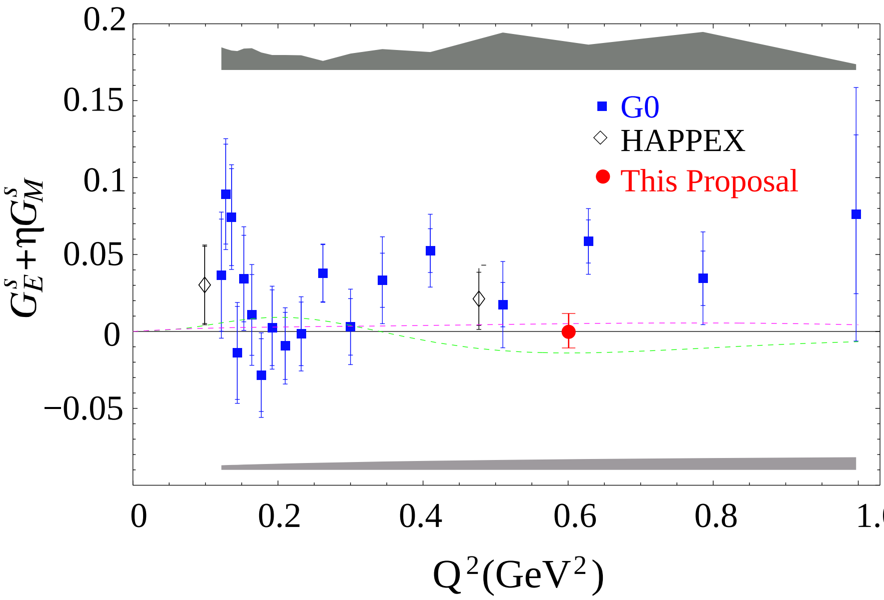

FIG. 1: Results from HAPPEX and G0 for the linear combination $G_E^s + \eta\, G_M^s$. $\eta \sim Q^2$ for these measurements taken with similar beam energy. The HAPPEX-I data point has been modified to account for the fact that it was taken at a different beam energy. The top error band represents correlated systematic errors between the G0 data points. A4 data is not shown on this plot, as it was taken with a significantly different beam energy. This figure is taken from reference [3]. A data point representing the proposed measurement and anticipated precision is shown, superimposed on zero.

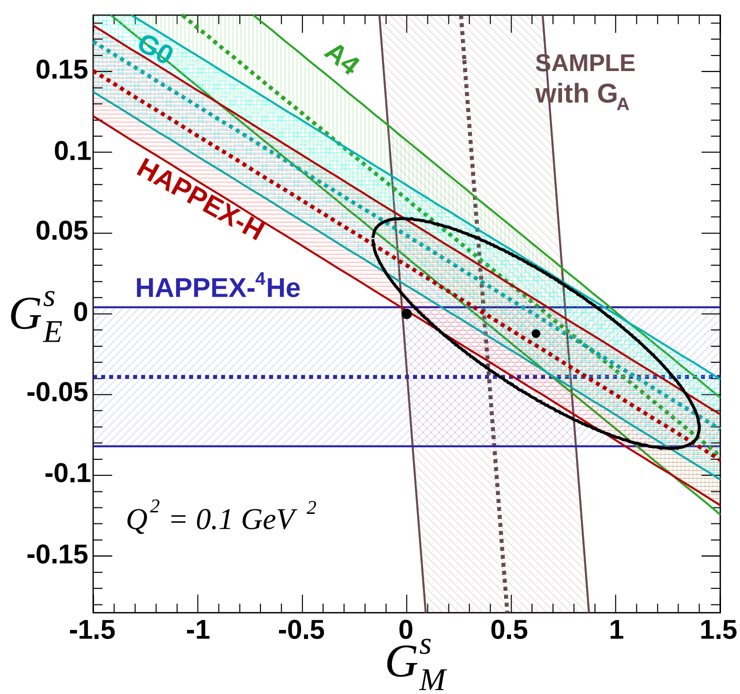

FIG. 2: World Data at $Q^2 = 0.1\,\mathrm{GeV}^2$ for G_E^s and G_M^s, with an extrapolated, averaged result from the recent G0 results. The contour represents a 95% confidence level region, and points are shown at $G_s = 0$ and the current best fit point.

Q^2 (GeV^2)	Beam Energy (GeV)	Angle (degrees)	Rate (MHz)	A_{PV} (ppm)	δA (ppm)	δA (%)	η	$\delta(G_E^s + \eta\, G_M^s)$ (statistical)
0.50	3.37	12.6	4.0	-16.9	0.41	2.4	0.39	0.0064
0.60	3.42	13.7	2.2	-22.1	0.55	2.5	0.48	0.0070
0.70	3.47	14.7	1.3	-27.7	0.72	2.6	0.57	0.0075

TABLE I: Description of optimal kinematics and anticipated precision for a range of Q^2 points. Uncertainty estimates are based on a 27-day run. Additional assumptions are described in the text.

$$+ \left. \frac{2\,\epsilon'\,(1-4\sin^2\theta_W)\,G_M^p\,G_A^{Zp}}{\epsilon(G_E^p)^2 + \tau(G_M^p)^2} \right\} \tag{1}$$

where G_F is the Fermi coupling constant and $G_{E(M)}^{p(n)}$ is the electric (magnetic) Sachs form factor of the proton (neutron), θ_W is the electroweak mixing angle, G_A^{Zp} is the neutral weak axial form factor of the proton, and

$$\tau = \frac{Q^2}{4\,M_p}, \quad \epsilon = \left[1 + 2\,(1+\tau)\,\tan^2(\frac{\theta}{2})\right]^{-1}, \quad \text{and } \epsilon' = \sqrt{\tau\,(1+\tau)\,(1-\epsilon^2)} \tag{2}$$

are kinematic quantities. $G_{E(M)}^s$ are the electric (magnetic) strange vector form factors. The derivation of this expression assumes charge symmetry is respected in the nucleon. The strange form factors appear in this expression as the combination $G_E^s + \eta\,G_M^s$, with $\eta = \tau\,G_M^p/(\epsilon\,G_E^p)$.

With knowledge of the electromagnetic form factors of the nucleon, this linear combination of strange vector form factors can be extracted from a measurement of A_{PV} in forward-angle scattering from hydrogen, with the sensitivity to G_A suppressed by the small values of ϵ' for small angles. A_{PV} ranges from around -1 part per million (ppm) at $Q^2 \sim 0.1\,\mathrm{GeV}^2$ to around -50 ppm for $Q^2 \sim 1.0\,\mathrm{GeV}^2$ for beam energies typical at CEBAF.

As a general rule, the figure of merit at a given Q^2 for these asymmetry measurements is enhanced by measuring at the smallest angle possible, and thus the highest possible energy. In this case, the highest possible beam energy is limited by the maximum spectrometer momentum of 3.1 GeV, while the smallest possible angle for the spectrometer pair is 12.5 degrees.

Various quantities describing the optimal configuration at each Q^2 are shown in Fig. 3: beam energy, scattering angle, expected counting rate, and A_{PV} (in the assumption of no SFF). The results of 27 day measurement, with a 20 cm liquid hydrogen target, 100 μA beam, and 80% beam polarization, are also shown as the expected statistical error in the asymmetry (in ppm) and the corresponding fractional error (in %). Information on a range of optimal Q^2 settings is summarized in Table I.

The statistical uncertainty on the combination $G_E^s + \eta\,G_M^s$ which can be extracted at each Q^2, under the above assumptions, is shown in Fig.4. This is minimized near $Q^2 = 0.5\,\mathrm{GeV}^2$, as expected. However, it varies slowly over Q^2, suggesting that one can select any point of interest in the high Q^2 region (0.4-0.9 GeV^2) without a significant loss of figure of merit.

It is our opinion that at least one high precision point is very highly motivated, but there would be less benefit to multiple measurements of intermediate precision. The capability of HAPPEX to make a precise, and nearly background-free, measurement at high Q^2 is unique. We have focused attention on the point $Q^2 = 0.6\,\mathrm{GeV}^2$, for which experimental precision is not greatly reduced.

III. EXPERIMENTAL TECHNIQUE

The experimental technique is explained in detail for the measurement at similar kinematics, HAPPEX-I [4]. This technique is summarized here, with emphasis on describing important developments in relevant experimental techniques since HAPPEX-I.

Previous HAPPEX measurements at $Q^2 = 0.48\,\mathrm{GeV}^2$ (HAPPEX-I) and $Q^2 = 0.1\,\mathrm{GeV}^2$ (HAPPEX-H [2] and HAPPEX-He [1]) have demonstrated the simplicity and robust nature of the the experimental technique. A recent measurement at low Q^2 on hydrogen dealt with rates an order of magnitude higher and asymmetries an order of magnitude smaller than the measurement proposed here, which demonstrates that this proposed experiment would not present significant challenges in terms of absolute precision or control of false asymmetries.

Instead, the significant challenge of the proposed experiment is the very stringent limit on the fractional systematic error, which is budgeted at 1.4%. This is comparable to other approved high-precision parity-violation experiments

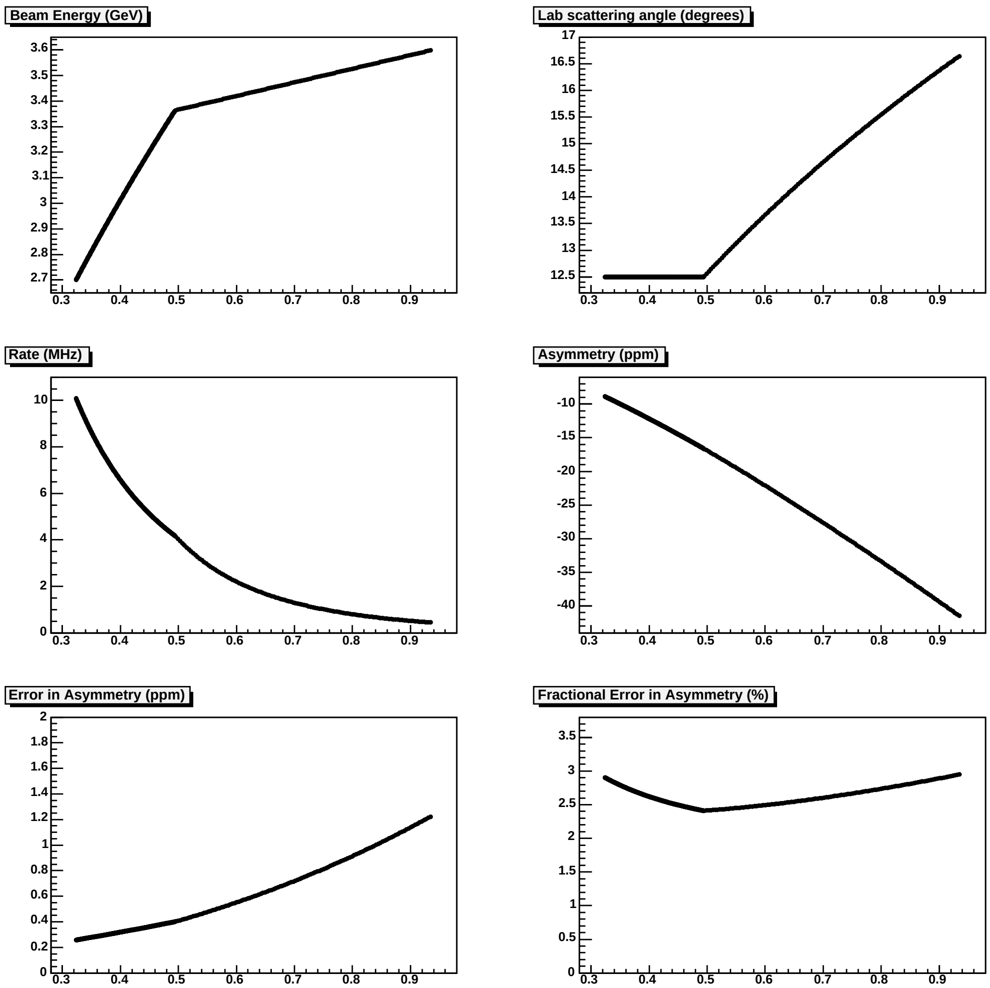

FIG. 3: Beam energy, scattering angle, A_{PV}, expected rate, and anticipated statistical error in the measured asymmetry in absolute (ppm) and fractional (%) terms, plotted versus Q^2 for configurations with optimized figure of merit.

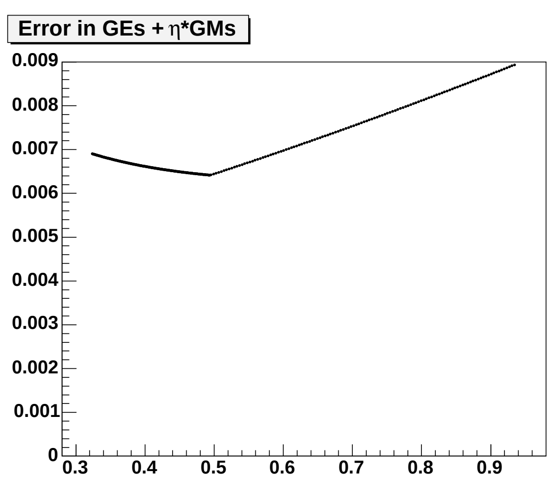

FIG. 4: The anticipated statistical precision in the extraction of $G_E^s + \eta G_M^s$, plotted versus Q^2.

at Jefferson Lab, such as PREx (E03-003) and PV-DIS (E05-007). The most significant change to the apparatus to meet this goal will be improvements in polarimetry.

The basis of the technique is the use of the High Resolution Spectrometers in Hall A to focus the elastic electron signal on an integrating calorimeter, while sweeping away any inelastically scattered electrons. This technique provides low background and the ability to accept extremely high rates. A long cryogenic liquid target is used to achieve high luminosity, and high polarization at high current on the electron beam is achievable from the Jefferson Lab polarized source. The Hall A Compton polarimeter is used in Hall A for continuous, precision measurement of the beam polarization. Specific aspects of the experimental apparatus are discussed below.

- **Polarized Electron Source:** The development of high polarization electron beams at Jefferson Lab have enabled the present-day program of precision asymmetry measurement. The last major change of technology has been the transition from the bulk GaAs photocathode to the high-polarization strained-layer GaAs photocathode, which provided an increase in beam polarization from 40% to ~75% while allowing beam currents as high as 100 μA. Recent developments suggest that a new technology, the superlattice GaAs photocathode, may provide even higher beam currents with polarizations > 85%. It is reasonable to believe that by the time this proposed measurement is scheduled, beam polarizations > 85% will be common at Jefferson Lab. However, for this proposal, we have conservatively estimated 80% polarization, which is achievable without technological advance.

  Parity-violation experiments, typically measuring asymmetries on order of 1 ppm, are very sensitive to the problem of misinterpreting a helicity-correlated asymmetry on the beam as a parity-violating physics asymmetry. For this reason, it is necessary for such experiments to carefully control helicity-correlated asymmetries on the electron beam. The HAPPEX collaboration has worked closely with the source group to develop an understanding of the sources of intensity and position asymmetries on the beam and techniques for suppression of these effects. Careful configuration techniques and active feedback has suppressed both helicity-correlated intensity and position differences at a level well beyond that which is required for this proposal. In particular, helicity-correlated beam differences were suitably controlled for the HAPPEX-H measurement. That measurement was made at a very forward angle, in which requirements were an order of magnitude more stringent than the proposed experiment. No new developments in the control of helicity-correlated beam differences are necessary to meet the modest demands of this proposed measurement.

- **Target:** New, thick targets have significantly boosted the luminosity available for these parity-violation studies. This proposal assumes the use of a 20 cm liquid hydrogen cryogenic target with transverse cryogen flow, of the type employed by HAPPEX-H. The dominant concern with cryogenic targets in parity-violation experiments is the problem of density fluctuations, in which localized beam heating creates bubbles in the liquid and causes a rapid jitter in the rate of detected scattering electrons by changing the target density. Such an effect injects noise into the measurement; if the effect is significant, it can limit the statistical precision of the measurement.

  The targets currently being used have been seen to be stable, without significant density fluctuations, in beam up to 70 μA. In a run scheduled for late 2005, HAPPEX-H is intending to use such a target up to 100 μA beam current, which should verify the performance of this technology. In the event that these targets are seen to be unsuitable at full current, development of a new target geometry may be necessary in order to achieve full luminosity.

- **Spectrometers:** Both Hall A HRS will be used, placed at symmetric angles and each collecting events which should be fully uncorrelated with the other arm. They would be positioned at an angle of approximately 13.7 degrees and tuned to accept 3.1 GeV/c electrons for the proposed $Q^2 = 0.6\,\mathrm{GeV}^2$ measurement. The HRS pair is ideally suited for the high rate integration technique, as the 12 meter dispersion in the focal plane allows the elastically scattered electrons to be focused onto an integrating detector in a region which is otherwise free of background. The elastic electrons will be focused into a thin stripe on the focal plane, where a total absorption calorimeter with a single phototube will be placed. The output of this phototube will be integrated over each 30ms helicity window. Electrons associated with pion production at the target will be focused into an area approximately 60 cm from the elastic stripe.

- **Focal Plane Detector:** The distribution of elastic events in the focal plane will be very similar to that measured during HAPPEX-I. This distribution with be less-sharply peaked than for the low-Q^2 measurements running this year, and will thus require a return to a larger detector. It is our intention to use the focal plane detectors which were used for HAPPEX-I. These detectors are composed of alternating layers of acrylic and lead. Cerenkov light in the acrylic layers from the electromagnetic shower is collected by a photomultiplier tube, and the signal integrated over 30 ms helicity windows. We anticipate using the photomultiplier tubes presently used for the low-Q^2 measurements. If the original detectors prove to be unsuitable for the slight change in kinematics, we anticipate building detectors in a similar style. The cost for replacing these systems would be low, and would not require any significant technological development.

- **Polarimeter:** In the initial run of HAPPEX-He and HAPPEX-H, the Hall A Compton polarimeter was used to provide a continuous, non-invasive beam polarization measurement over the course of the entire run. The systematic uncertainty in this polarization measurement, with a beam energy of 3.0 GeV, was estimated at 2%. The measurements are easier at higher energies, and the systematic uncertainty in measurements with a beam energy of 4.5 GeV can achieve 1.4% precision .

  An upgrade is planned to provide the $< 1\%$ polarimetry required for approved, high-precision experiments (E03-003, E05-007). The performance of the polarimeter will be improved by a factor of $\sim$2 by upgrading to a green laser cavity from the current infrared cavity, which will be especially beneficial at lower beam energies. Upgrades to laser polarimetry, electron detectors, and photon detector readout electronics are also included. Additionally, the development of an analysis using integrated readout of the photon detector will provide a significant improvement.

  With this upgrade, reliable, continuous, high beam current electron beam polarimetry should be available in Hall A, even at low beam energies, which can achieve $< 1\%$ statistical error in short time periods and $\sim$1% systematic error.

IV. PRECISION GOALS

The proposed precision measurement will be made to an absolute measurement on $A_{\rm PV}$ of 550 parts per billion (ppb), or about 2.5%, statistical, and 310 ppb, or about 1.4%, systematic. HAPPEX-H, running at low-Q^2 on hydrogen, dealt with rates an order of magnitude higher and asymmetries an order of magnitude smaller than the measurement proposed here, resulting in a measurement of $A_{\rm PV}$ with a systematic error of 60 ppb [2]. The absolute precision of the proposed measurement does not present an extreme challenge, in comparison to recent measurements performed by the HAPPEX collaboration.

However, the fractional systematic precision goal of 1.4% is a significant challenge. Most crucially, the polarimetry available in Hall A, currently at the level of 2% precision, must be improved to a level at or below 1% systematic error. On most other sources of uncertainty, the fractional systematic precision goal represents a modest improvement over HAPPEX-I. HAPPEX-I quoted a systematic error of 3.7%, which was dominated by a 3.2% uncertainty from polarimetry. Small improvements should be possible in controlling most sources of systematic error, given that careful study of systematic error contributions below 1% was not motivated in E91-010 analysis, due to the overall dominance of the statistical uncertainty.

It is worth noting that in the upcoming full run of HAPPEX-He (E00-114), the systematic uncertainty on $A_{\rm PV}$ is to be controlled at the level of 2.2%. This error is dominated by polarimetry in Hall A, which currently is limited near 2%.

Various sources of experimental systematic error or noise (which would limit the statistical precision) are discussed in the sections below. Estimates are given of the total contribution to systematic uncertainties, and this information is summarized in a total error budget.

In addition to experimental uncertainties in the extraction of the strange vector form factor contributions, the most significant sources of theoretical uncertainty are discussed.

A. Random Noise

At the expected rate, the statistical error for each window pair is expected to be about 2600 ppm. It is necessary to keep sources of random noise (electronics noise, target density fluctuations) below that level. In the 2004 run of HAPPEX-H, the window pair width was 600 ppm, with negligible contributions from electronics noise. Target density fluctuations were measured to be negligible at the 200 ppm level up to beam currents of 70 μA. The 2005 run of HAPPEX-H should demonstrate the function of this target at full current. Noise comparable to the statistical jitter of the 30 Hz helicity window measurement is not expected to be a problem in the proposed measurement.

B. False Asymmetries

The recent publication of initial data HAPPEX-H demonstrates the excellent potential control of sources of false asymmetries in the HAPPEX measurements. The systematic precision, which includes potential errors due to helicity-correlated electronics noise or helicity-correlated changes in the electron beam, was limited to 60 ppb, well in excess of what is required for the current proposal. Sensitivity to helicity-correlated position differences will be an order of magnitude smaller in the current proposal.

C. Normalization Errors

The proposed experiment requires stringent control of sources of experimental systematic errors which contribute as a fraction of the measured asymmetry. There are two significant contributions to this experimental normalization uncertainty.

- **Polarimetry:** The Hall A Compton polarimeter will be used for a continuous, non-invasive polarization measurement under run conditions. The recent publication of the initial results from HAPPEX-He reported a systematic error in polarization measurement of 2.0% at a beam energy similar to the kinematics of this proposed measurement. A planned upgrade will soon be performed, motivated by the needs of other high-precision parity-violation experiments (E03-003, E05-007), which require ∼1% beam polarimetry. Improvements to laser polarimetry, electron detector resolution, photon detector readout, and a move from infrared to a green laser cavity will significantly reduce systematic uncertainties. This planned upgrade, and the development of the new integrated photon detection technique, are expected to provide the ∼1% polarimetry in Hall A necessary for this proposed measurement.

  This high precision polarimetry is the primary difference in systematic precision between HAPPEX-I and this proposal, as HAPPEX-I quoted a 3.2% polarimetry uncertainty as the dominant systematic error.

- **Linearity:** Because this measurement technique uses analog integration of the photomultiplier tube (PMT) response, any deviation in linearity of this response relative to input flux distorts the measured asymmetry. This effect is analogous to the effect of rate-dependent deadtime in a counting experiment. An integral non-linearity relative to zero input signal is just as troublesome as a more local non-linearity which might be expected to exist for large signals. Measurement of PMT linearity then requires a test signal with verified linearity all the way down to zero signal.

  In order to minimize sensitivity to this source of uncertainty, the linearity of the PMT response will be studied on a test stand using filtered light levels and voltages comparable to what is expected in production running. Beam studies are expected to provide the most effective and precise measurements of non-linearity effects, in which the linearity of the PMTs can be cross-compared with the PMTs of the forward-angle luminosity monitor in Hall A and with the Unser monitor which is highly linear with a true zero pedestal. Taking recent experience as a guide, it is estimated that non-linearities will contribute ∼0.6% to the measured asymmetry.

D. Background

In the integrating technique employed by HAPPEX, there is no opportunity to reject background; all flux in the detector, regardless of the source, is integrated as signal. The experience of HAPPEX-I provides reliable guidance on the backgrounds which can be expected.

- The most significant source of background for HAPPEX-I was quasi-elastic scattering from the aluminum target walls. The contribution at the proposed kinematics should be similar in magnitude. The asymmetry of this contribution is comparable in magnitude to $A_{\rm PV}$ from hydrogen, and of the same sign. This background was measured to be 1.4% of the signal during HAPPEX-I, and contributed a total of 0.3% to the systematic error. The contribution in the proposed experiment will be similar, and with careful measurement the uncertainty should be constrained at or below this level.

- Electrons associated with pion production lie below the momentum acceptance of the spectrometer for the proposed measurement. However, electrons which are swept into the beam pipe in the spectrometer can rescatter back into the focal plane. The most significant source of rescattered electrons is from the Delta resonance, which has a significantly larger asymmetry than elastic scattering from hydrogen. The fraction of inelastic rescattered background during HAPPEX-I was 0.2%, contributing about 0.1% systematic error. This background fraction would be expected to rise by approximately a factor of two for a $Q^2 = 0.6\,\mathrm{GeV}^2$ measurement for these comparable systematics. With careful study beyond that performed for HAPPEX-I, the uncertainty in this contribution can at least be held to the same level for the proposed measurement despite the expected increase in total level.

- Exposed polarized iron in the bore of the HRS creates a potential source of false asymmetry through a spin-dependent attenuation of scattered flux at the edge of the acceptance generated from the Moller scattering in the polarized iron. The potential asymmetry of this process is orders of magnitude above the parity violating asymmetry, but the effect is suppressed by several large factors, including the small fraction of rescattered electrons which penetrate iron but still reach the focal plane, the fraction of polarized electrons in saturated iron, and the angle between the magnetization and the incident electron. An upper bound has been placed on this potential false asymmetry through direct measurement of the probability of various scattering centers in the spectrometer reaching the focal plane. This background was entirely negligible for HAPPEX-I, and was estimated to contribute less than 26 ppb to the 2004 HAPPEX-H results (which did not perform studies necessary to further reduce that upper limit).

Taking these contributions in quadrature, the total systematic error due to backgrounds for the proposed measurement is expected to be 0.3%.

E. Determination of the Average Kinematics

Since the parity violating asymmetry varies almost linearly with Q^2, the average value of Q^2 over the acceptance of the HRS must be known with a precision at or below that of the measurement of $A_{\rm PV}$. This problem was more severe for the low-Q^2 measurements, in which relative precision on the smaller central angle is more difficult to achieve, and the high rates and sharp elastic peak on the focal plane present challenges to the effort to measure the distribution with individual tracks. In that more challenging situation, the Q^2 was measured with a relative precision of 1.0%, with the uncertainty dominated by factors related to the sharply peaked elastic distribution and the lack of an unbiased trigger for this analysis. For the proposed measurement, the lower rates and the use of an trigger scintillator below the detector will allow the determination of average Q^2 to better than 0.5%.

A related uncertainty concerns the changing asymmetry and cross-section over the finite acceptance of the HRS. An average theoretical asymmetry must be calculated, using Monte Carlo to simulate the averaging over the spectrometer acceptance. This simulation includes effects from interaction of beam or scattered electrons with material in the target region, which potentially can change the kinematics at the scattering vertex. This simulation can be done with high precision, and the result is somewhat insensitive to small details in defining the acceptance. The precision of this calculation for HAPPEX-H was roughly estimated at 0.6%. A more complete effort to reduce and to quantify this uncertainty, along with the larger scattering angle of the proposed measurement, is expected to allow an increased precision of 0.3%.

F. Theoretical Uncertainties

The proposed measurement would have theoretical uncertainties similar to that of HAPPEX-I and G0 in this range of Q^2, arising from uncertainties in radiative corrections, the proton axial form factor, and the nucleon electromagnetic form factors. Estimates for the most significant contributions are summarized below.

- The contribution from the axial form factor of the proton G_A^{Zp} is suppressed by the kinematic factor ϵ' for this proposed forward-angle measurement. This contribution is estimated by assuming a dipole form for the Q^2 evolution of this form factor and using the well-measured axial coupling constant g_A at $Q^2 = 0$. Significant uncertainty is introduced in the large electroweak radiative corrections, which include hadronic uncertainties. These corrections have been calculated by Zhu *et al.* [9]. The effect of these uncertainties leads to ~ 0.34 ppm uncertainty in $A_{\rm PV}$ calculated with zero strange form factors at $Q^2 \sim 0.6\,{\rm GeV}^2$. A back-angle measurement by the G0 collaboration scheduled for early 2006 should provide an additional constraint on the axial form factor at high Q^2, which may lead to a reduction in this contributed uncertainty.

- At this time, there are significant discrepancies between experimental results for the neutron magnetic form factor G_M^n around this range of Q^2. These region of disagreement is very close to overlapping, high precision data sets which agree very well, thereby constraining the estimated uncertainty in G_M^n. The uncertainty in G_M^n is taken to be $\sim$2%. This level of uncertainty leads to an error of $\sim$0.44 ppm on the predicted $A_{\rm PV}$ (calculated with no strangeness contribution).

Relative to the magnitude of theoretical uncertainty introduced by G_M^n and G_A^{Zp}, theoretical uncertainties from radiative corrections or other electromagnetic form factors are well-controlled. The total theoretical uncertainty is thus estimated to be 0.56 ppm in the prediction for $A_{\rm PV}$ with no strangeness contribution, or $\delta(G_E^s + \eta G_M^s) \sim 0.0071$, at $Q^2 \sim 0.6\,{\rm GeV}^2$.

Source	$\delta A_{\rm PV}/A_{\rm PV}$	$\delta(G_E^s + \eta G_M^s)$
Polarimetry	1.0%	0.0028
Q^2	0.5%	0.0014
Backgrounds	0.3%	0.0009
Linearity	0.6%	0.0017
Finite Acceptance	0.3%	0.0009
False Asymmetries	0.3%	0.0009
Total Systematic Error	1.4%	0.0041
Statistics	2.5%	0.0070
Total Experimental Uncertainty	2.9%	0.0081
Form Factor	2.5%	0.0071
Total Uncertainty	4.2%	0.011

TABLE II: Error Budget for the proposed measurement at $Q^2 = 0.6\,\mathrm{GeV}^2$.

G. Error Budget

The anticipated experimental and theoretical errors are shown in Table II.

V. BEAM TIME REQUEST

We are requesting 720 beam hours (30 days), assuming 100% efficiency with an electron beam current of 100 μA and an average electron beam polarization of 80%. There are no major configuration changes planned during the run. This request includes approximately 3 days which will be required for commissioning and aligning the detector, studying backgrounds, calibrating optics, and measuring the average kinematics. There is no major, non-standard equipment required for this measurement in Hall A.

VI. RELATION TO OTHER EXPERIMENTS

The forward angle HAPPEX measurements are scheduled to resume taking data in July 2005, completing in November 2005. The precision of these measurements is expected to improve by a factor of three, which will significantly clarify the contribution from strange quark form factors at $Q^2 = 0.1\,\mathrm{GeV}^2$. Although a significant non-zero result would certainly suggest that large contributions at high Q^2 were also reasonable, these measurements will not directly constrain possible contributions in that region.

The PV-A4 collaboration in Mainz also remains active in this field. The A4 measurements employ a non-magnetic spectrometer, using energy resolution in a fast crystal calorimeter with specialized clustering and histogramming electronics to identify and count elastically-scattered electrons. The A4 detector system has now been configured to collect data at back angles. Problems with pion backgrounds are being addressed with the addition of a supplemental Cerenkov detector. A run is planned for back angle hydrogen scattering at $Q^2 = 0.23\,\mathrm{GeV}^2$. A run at $Q^2 = 0.5\,\mathrm{GeV}^2$ is also being considered.

The G0 experiment has been approved for one measurement at backward angle, to be carried out in early 2006 with a central value of $Q^2 = 0.85\,\mathrm{GeV}^2$. This measurement on hydrogen will be sensitive to a different combination of G_E^s and G_M^s. These kinematics will also increase the contribution of axial form-factor, and a separate measurement using deuterium will be used to constrain that contribution. The anticipated uncertainty on this extraction would correspond to a sensitivity of $\delta G_M^s = 0.1$. This error bar might reasonably be compared to the central value of the forward-angle hydrogen data in that region of Q^2, shown in Fig. 1. The central value of data near $Q^2 = 0.8\,\mathrm{GeV}^2$ is $G_E^s + \eta G_M^s \sim 0.04$, with the factor $\eta \sim 0.7$ at $Q^2 = 0.8\,\mathrm{GeV}^2$. Such a measurement will usefully distinguish large strange vector form-factors which may cancel in the linear combination $G_E^s + \eta G_M^s$ of the forward-angle measurements. However, only the precision of the measurement proposed here will provide a definitive non-zero result even in the case of moderate strange quark vector form factor contributions.

At this time, there are no experiments planned, beyond those listed above, which will directly constrain the strange quark contributions to the elastic vector form factors. The experiment proposed here is unique in its ability to place a precise data point on possible contributions of G_E^s and G_M^s in the high Q^2 region.

VII. CONCLUSION

We have proposed to measure the parity-violating asymmetry in forward angle elastic scattering from hydrogen, with a beam energy of 3.4 GeV at an average Q^2 of $0.6\,\mathrm{GeV}^2$. From this measurement, the linear combination of strange-quark vector form factors $G_E^s + 0.48 G_M^s$ would be extracted with a precision of ± 0.0081 (experimental) ± 0.0071 (theoretical). A measurement of such precision would be >4 standard deviations from zero, if the result matched the average of presently existing world data in this kinematic region. The data now existing is suggestive of significant non-zero strange quark vector form factors but is not definitive. For this reason, we believe a single high-precision point is very well motivated.

The techniques employed by the HAPPEX experiment allow very precise measurements in terms of both systematic and statistical error estimates. The proposed precision can be achieved in 30 days of beam time, at 100 μA with 80% beam polarization, and with no major non-standard equipment in Hall A.

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