Update on CEBAF Experiment E–91–004

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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I: Introduction

The following is an update on CEBAF experiment E-91-004, in which we propose to measure the parity-violating asymmetry in elastic scattering from ^{4}He at a momentum transfer $Q^2 = 0.6$ (GeV/c)^2, using the pair of high resolution spectrometers in Hall A. Within the context of the Standard Model and assuming that u, d and s quarks will contribute to the low energy properties of the nucleon sea, the parity-violating asymmetry in elastic electron scattering is

$$A = \frac{G_F Q^2}{\pi\alpha\sqrt{2}}\left[\sin^2\theta_W + \frac{F^s}{4F_C}\right],$$

where F_C is the charge form factor of ^{4}He and F^s is the form factor in ^{4}He associated with the matrix element $\langle N|\bar{s}\gamma_\mu s|N\rangle$. In a simple "one-body" description of ^{4}He, nuclear structure effects will cancel in the ratio of the form factors and the second term of the asymmetry can be replaced with the ratio

$$\frac{F^s}{4F_C} \longrightarrow \frac{G_E^s}{2\left(G_E^p + G_E^n\right)},$$

where G_E^s is the strange "electric" form factor of the proton. The Standard Model asymmetry with no strange quarks is 5×10^{-5}. A 40% statistical measurement of this asymmetry would determine F^s to an absolute error of $\Delta F^s \sim 10^{-3}$. There is currently no theoretical prediction for the magnitude of this form factor. In the simple one-body picture this would correspond to an absolute error on G_E^s of ~ 0.06. The magnitude of G_E^s at $Q^2 = 0.6$ (GeV/c)^2 has been estimated by Jaffe [Jaf89] to be $-0.3 \rightarrow 0$.

This proposal was conditionally approved for 65 days of beam time at PAC5 in January 1992. In June 1992 the experiment was endorsed as a Hall A Collaboration experiment. In July 1992, a Technical Advisory Panel, headed by B. Barish, was convened to evaluate the three existing proposals for parity violation experiments, 91-004, 91-010 [Sou91], and 91-017 [Bec91]. The experiments were evaluated on both physics and technical issues. All three experiments were given strong endorsements regarding the physics and were recommended to be given high priority in the CEBAF program. The part of the report pertaining to this experiment is attached as appendix A. The specific technical issues related to E–91–004 which were highlighted by the TAP were those relating to luminosity: the high density ^{4}He target and the availability of high current polarized beam. In this update we have therefore paid particular attention to the target and the source.

Since the original proposal was submitted, three institutions have been added to the collaboration: MIT-Bates, Rensselaer Polytechnic, and the University of Maryland. The Bates group is presently involved in the SAMPLE experiment and will contribute expertise in parity violation measurements. The Maryland and RPI groups have been added as affiliations within the collaboration have changed.

II.1 Theoretical Progress

No new calculations of the higher Q^2-dependence of strange form factors have been published since the original submission of this proposal. However, here have been other theoretical efforts relevant to this measurement. The vector strange matrix elements are described in the literature by the "strange magnetic moment", $\mu_s = G_M^s(0)$, and the "strangeness radius", $r_s^2 = -6dF_1^s/dQ^2|_{Q^2=0}$, which describes the low-momentum behavior of G_E^s. In a recent review article [Mus93b], Musolf *et al.* have tabulated many of the published predictions for μ_s and r_s^2. The calculations fall into three general categories. In the first, such as that of Jaffe [Jaf89], nonzero strange matrix elements arise from poles of strange mesons (ϕ, ω, etc.). In the second, such as in Musolf and Burkardt [Mus93a], virtual $\overline{s}s$ pairs appear as strange baryon-kaon intermediate states ("loops"). These two descriptions appear to be comparable in the case of the magnetic moment but differ by an order of magnitude in the strangeness radius. Skryme model calculations, such as that in [Par91], predict values of the same order of magnitude as [Jaf89] but opposite sign. More recently, Cohen *et al.* [Coh93] have attempted to link the pole and loop pictures, getting a result for r_s^2 somewhere in between [Jaf89] and [Mus93a]. They have furthermore made an estimate of the higher-Q^2 behavior [Nie93], and get a preliminary result for G_E^s at $Q^2 = 0.6$ of about 0.03 (to be compared to values of -0.1 to -0.3 from [Jaf89]). This experiment would not distinguish between such a small value of G_E^s and no contribution from strange quarks, but would determine whether G_E^s were as large as the Jaffe result.

Another calculation of relevance to this experiment is an estimate of the nuclear structure uncertainties in the extraction of G_E^s from a measurement in a J=0, T=0 nucleus. Nuclear structure contributions to the measured asymmetry could come either from isospin mixing or from meson exchange currents. In ^{4}He, isospin mixing effects are estimated to be negligible at less than 1%. Meson exchange current contributions may complicate the issue of directly extracting a proton strange form factor from a measurement in ^{4}He, but the experimental result will still be a direct measure of $\overline{s}s$ contributions to a hadronic system. Musolf and Donnelly [Mus93c] have recently calculated MEC effects in the parity violating asymmetry at low Q^2 and find them to be small. A calculation at higher momentum transfer closer to the kinematics of this experiment is currently in progress [Sch93a].

II.2 Complementary Measurements

Recently there has been a reanalysis of Brookhaven experiment E734 [Gar93], which was a measurement of $\sigma(\nu p \to \nu p)$ and $\sigma(\overline{\nu} p \to \overline{\nu} p)$ at $0.4 < Q^2 < 1.1$ (GeV/c)^2 (approximately 80% of the detected protons were bound in carbon and aluminum). An earlier analysis of these data [Ahr87] gave a nonzero value for the axial strange matrix element, similar in magnitude to the well known EMC result [Ash89]. However, this earlier analysis assumed that both vector strange form factors were identically zero. The more recent analysis investigates the possibility of nonzero vector strange terms, as well as employing a more modern value of the axial vector dipole mass parameter M_A. The difference in the (ν, p) and $(\overline{\nu}, p)$ cross sections can be sensitive to the vector strange terms. Values for G_E^s and G_M^s can be extracted by averaging the data over the range of momentum transfer, corresponding to an average value of $Q^2 = 0.75$ $(\mathrm{GeV/c})^2$. Preliminary results [Lou93] give a value of $G_E^s = 0.1 \pm 0.12$, similar in magnitude to that calculated by Jaffe (but also consistent with 0). The present experiment would improve this error by about a factor of two, and would be sensitive to different systematic effects and theoretical issues.

III: Experimental Update

The basic goal and method of the experiment has not changed since it was conditionally approved, and the original proposal is for the most part still relevant. The only significant changes have been related to luminosity. We now assume 100 μA of available polarized beam current. In order to get back the full integrated luminosity in the original proposal, we have increased the target length (viewable) from 10 to 15 cm and we request additional 20 days of running time, bringing the full request up to 85 days. The following paragraphs outline in more detail the present status of the target, polarized source, beam line, and spectrometers. The update is concluded with a brief outline of a schedule for the experiment and a division of responsibilities of the collaboration.

III.1 Target

Significant progress had been made on the Hall A cryogenic target since 1992. The target loop has been constructed and assembled and is presently undergoing tests at Cal State Los Angeles. Both the target loop and the cells have withstood pressures up to 100 atm at room temperature, significantly higher than the desired operating pressure of 70 atm. Tests at 70 K will start at the beginning of 1994. A location at CEBAF for 20 K tests has been identified and the target loop will be brought to CEBAF in the spring of 1994. Both the Cal State Los Angeles and the University of Maryland groups will participate in the 20 K tests in conjunction with CEBAF personnel.

A target cell with a viewable length of 16.5 cm has also been constructed and pressure tested. This experiment will most likely use this longer target cell.

Additional information has been obtained on a similar system, the SAMPLE liquid hydrogen target. Both the SAMPLE target and the Hall A target were designed by John Mark of SLAC and have many common features. The SAMPLE target was constructed by the Caltech group. The main differences in the two target loops are in the heat exchanger and target cells, due to the Hall A requirement of high pressure operation. Tests of the SAMPLE target at 20 K both in and out of beam have been performed. The target and refrigeration system have withstood bulk internal heating of up to 600 watts while the target liquid was maintained at 1 K subcooling. Up to 35 μA have been incident on the target, corresponding to about 450 watts of beam heating. At present, no quantitative information on density fluctuations is available, although we expect to be able to perform these tests early in 1994. Although data on density fluctuations with the SAMPLE target will be interesting to see, they will not provide much information on the performance of the ^{4}He gas target. For the gas target, we estimate an overall density reduction of a few percent. The resulting effect on the measured asymmetry will be negligible if the net helicity correlated shift in beam current is small compared to the net statistical error. This requirement must be met by the already required direct constraint on helicity correlated current shifts.

III.2 Polarized Beam

When PR–91–004 was submitted, a beam current of 200 μA and beam polarization of 50% were assumed. Although these figures are consistent with the design luminosity of CEBAF, they may not be achievable in the early stages of CEBAF running [Sin93]. For a given target length, the relevant figure of merit is the product P^2I. With 100 μA of beam and a 15 cm target cell instead of the originally proposed 10 cm, the effective figure of merit is about 30% lower than that stated in the proposal. A beam current of 100 μA and polarization of 49% could be achieved with a thin GaAs crystal (with a quantum efficiency of about 1%) and a CW laser, technology which is at present considered conventional. To achieve a comparable asymmetry measurement as originally proposed, we request an increase in total beam time from 65 to 85 days. With 100 μA coming from a thin GaAs crystal and CW laser, this experiment could run in parallel with experiments in the other halls.

As more laboratories have interest in high current polarized electron beams, progress continues to be made on the development of crystals with high polarization and high quantum efficiency. By the time this experiment is ready to take production data, it may be possible to regain the original figure of merit or perhaps improve it with a high polarization crystal. Various types of crystals have been grown and tested; the most promising developments have come from strained photocathodes. Such crystals have been used at SLAC, where polarizations up to 80% and quantum efficiencies in the range of 0.1-0.3% have been achieved. At CEBAF a quantum efficiency (QE) of 0.3% corresponds to a beam current of 55 μA with the presently available CW laser power. At 80% polarization, a beam current of 78 μA would be required in order to achieve our original figure of merit, corresponding to a QE of 0.5%. It is important to point out, however, that with a conventional CW laser, dedicated use of the accelerator would be required in order to achieve such high beam current from a strained GaAs crystal.

With a mode-locked laser matched to the RF structure of the CEBAF beam, 100 μA beam could be achieved with QE $\sim$ 0.1%. Such a laser is under development at Lightwave Electronics with a DOE-sponsored SBIR grant. It is clear that the development of the mode-locked laser would be a significant benefit to this experiment. Table III.1 summarizes the above scenarios and their effect on the proposed experiment.

In one instance at SLAC a quantum efficiency of 1% was achieved with 76% polarization and long source lifetime [Sch93]. The operating conditions at SLAC (high peak current and low duty cycle) are very different than the CEBAF environment, and in particular are at an average current of a few microamps. Nonetheless, if such results could be reliably reproduced at CEBAF, the full CEBAF beam current could be achieved at high beam polarization. A very recent development in crystal technology is that of Saka

Table III.1

Relative comparisons of the figure of merit, P^2It for different possible improvements in the polarized source. The original proposal assumed the first line in the table. The present update assumes the conditions in the *second* line.

Source	P	I (μA)	t (cm)	FOM	power on target (W)
Thin GaAs	0.49	200	10	500	1000
"	0.49	100	15	375	700
Strained GaAs	0.80	18-55	"	172-528	140-400
(3)+pulsed laser	0.80	100	"	960	700

et al., [Sak93]. They have developed a crystal with a Bragg reflector on the back surface which allows the laser light to pass several times through the strained cathode layer. With this technique, a polarization of 70% and quantum efficiency of 1.3% was achieved. If such a technology were to develop more fully in the next few years, it would be a significant contribution to polarized source technology and could very likely be used at CEBAF.

III.3 Beam Line and Beam Property Measurements

The required beam property measurements are the same as presented in the original proposal, and are reiterated in table III.2. We assume that the helicity of the beam can be flipped in a random fashion at a fixed rate of 30 Hz, phase-locked to the line frequency of the accelerator. This frequency was chosen to average out any 60 Hz noise, which is assumed to be the dominant source of noise in the accelerator. The helicity of the electron beam can be reversed by flipping the helicity of the laser light incident on the photocathode. Such a technique is used at both SLAC and Bates. A voltage is applied to a Pockel's cell to switch the polarity in a random fashion. In addition, slow reversal of the laser light can be accomplished manually by inserting a half-wave plate into the laser beam path. Thirdly, the electron beam helicity can be flipped using the spin manipulator planned to be installed in the CEBAF injection line.

The measurement errors on the beam properties assume that each uncertainty should contribute no more than 10% of the statistical uncertainty to the overall systematic error. The total systematic error associated with these four measurements would be 20-40% of the statistical error, depending on how the beam properties are correlated. As indicated below, in some instances we believe we will be able to make measurements somewhat better than required.

Table III.2

Required measurement accuracy of beam properties in 1/30th sec.

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 (do not measure)

The beam energy will be measured between the fourth and fifth dipoles of the Hall A arc transport line, where the dispersion is 2.1 cm/%. Relative changes in the beam energy will be monitored continuously at this location with a beam position monitor. A monitor with 200 μm resolution will provide a relative energy measurement of 10^{-4}, an order of magnitude better than required. Precise *absolute* knowledge of the beam energy enters only in the determination of the momentum transfer, and any of the several proposed methods for determining the absolute energy will be sufficient.

The current plan for beam monitors in the hall is a combination of destructive "harp" monitors and nondestructive strip-line monitors such as will be used in the accelerator. Two of each such monitors will be placed 2 m and 8 m upstream of the target location. This separation is 1.7 times longer than that assumed in the original proposal. If the position monitor resolution were only 0.5 mm, the corresponding angular measurement would be 85 μrad, 3 times better than required. As indicated below there is good reason to believe that beam position measurements can be done with somewhat greater accuracy.

The harp monitors will be useful as a calibration of the non-destructive monitors. At present it is not yet known whether the strip-line monitors as designed for the use in the accelerator will suffice to make the required measurements on a 30 ms time scale. If the strip line monitors cannot meet the proposed requirements, it is likely that cavity monitors can be used in their place. Such monitors, which are sensitive to both current and position, have been used at pulsed-beam accelerators with longer integration time, high peak current and low average current. An example of such a measurement was with a SLAC monitor at Bates, where 15 μm resolution was achieved for a 15 μsec long pulse of 4 mA peak current (and 1% duty cycle) [Kum90]. A similar type of monitor was developed for the NIST microtron [You85] for lower current CW beams (100 μA peak) and very short integration times (40 nsec), and had a position resolution of 20 μm and a current resolution of 8 μA. These monitors were designed to operate at 2.4 GHz. A modification of such a monitor to operate at the CEBAF RF frequency would provide a position resolution more than adequate for the present experiment. It is likely that the current resolution would at least improve inversely with the square root of the measurement time, so a 1/30th sec sampling could improve the current resolution by at least a factor of 100, somewhat better than the required value of 5×10^{-3}.

The requirements for beam polarization measurements for this experiment are not very stringent, about 10%, since the overall statistical error on the asymmetry will be large. Either a Compton polarimeter or a Moller polarimeter, both of which are planned for Hall A, will be adequate. A Compton polarimeter has the advantage of being non-instrusive and could provide a continuous monitor of the beam polarization. In addition, a Compton polarimeter will operate at the high beam current of 100 μA. However, Moller polarimetry is a more proven technique and may be ready at an earlier stage, although it would be necessary to reduce the beam current during the polarization measurements.

III.4 Spectrometers

The elastic rate into each spectrometer will be about 1 kHz. In both spectrometers the first plane of scintillators will be segmented into six pieces with phototubes at both ends. We had originally anticipated limiting the momentum acceptance of the spectrometer either by moving the elastic peak to the low-momentum side of the focal plane or by installing a small trigger scintillator upstream of the first plane of the detector package. Since this experiment was proposed, the decision has been made to segment the first plane of scintillators into six pieces with tubes at either end. Turning off several segments in both the first and second plane of scintillators will limit the momentum acceptance of the focal plane to a region containing only the elastic peak. In this way, the raw trigger rate in each spectrometer arm can be kept relatively low, minimizing possible dead time effects. We previously estimated the effect of a few percent dead time on the measured asymmetry to be negligible.

IV: Schedule and Collaboration Responsibilities

We would prefer early placement in the Hall A program, but realize that a number of milestones must be met before a production run could be undertaken. Many of these milestones are part of the commissioning procedure required in Hall A, and therefore are not included in the E–91–004 beam time request. These tasks include demonstration of operation of the spectrometers at high luminosity and forward angles, operation of the cryogenic target system with and without beam, preliminary checkout of a beam polarimeter, study of the beam line monitors, and implementation of the Hall A beam rastering system. The Hall A collaboration as a whole will take responsibility for these tasks.

Another subset of tasks are those which are required for all experiments using polarized beam, such as installation of the helicity control electronics and studies of the polarized injection line with respect to possible electronic false asymmetries. Much of this work can be done without beam. Our collaboration expects to participate in these tasks in cooperation with other experimenters requiring polarized beam.

Both Hall A parity violation experiments have in common the need for studies and reduction false asymmetry effects in the Hall A beam line, and although the makeup of the collaborations is somewhat different in these two experiments, we expect to work closely on beam line issues. Although some beam time is required for these studies, much can be learned in conjunction with production running of other experiments or during the commissioning procedure.

There are tasks which are specific to this experiment if one is to understand the operation of the detector package with polarized beam and look for possible false asymmetry effects. Checkout of electronics can be done without beam, as long as there is access to the trigger electronics. Past experience at Bates has shown that the dominant false asymmetry effects originate in the helicity controlling electronics, and can be studied by having the helicity control and Pockels cell high voltage, without actually producing polarized beam. However, checkout with beam will be required, and time for these studies is included in the overall beam request. Another important study which can be done without beam is the efficiency of triggers in view of the storage requirements for the large number of events.

The responsibilities of the specific collaboration members has not changed significantly since the original proposal. They are summarized below:

Spectrometers	Virginia, CEBAF (Hall A collaboration)
Beam monitors	CEBAF
Beam rastering	CEBAF, RPI
^{4}He Target	CSULA, Maryland, CEBAF
Beam polarization	CEBAF (Hall A collaboration)
Data acquisition	CEBAF, Virginia, Caltech, Maryland
Polarized source	CEBAF, Maryland
Data analysis	Caltech, Maryland
Data taking	all

References

[Ahr87] L. Ahrens *et al.* , Phys. Rev. **D35** (1987) 785.

[Ash89] J. Ashman *et al.* , Phys. Lett. **B206** (1988) 364. J. Ashman *et al.* , Nucl. Phys. **B328** (1989) 1.

[Bec91] CEBAF proposal PR-91-017, D. Beck, contact.

[Coh93] T. Cohen, H. Forkel, and M. Nielsen, Phys. Lett. **B316** (1993)1.

[Gar93 G.T. Garvey, W.C. Louis, and D.H. White, Phys. Rev. **C48** (1993) 761.

[Hon93] S.T. Hong and B.Y. Park, Nucl. Phys. **A561** (1993) 525.

[Jaf89] R.L. Jaffe, Phys. Lett. **B229** (1989) 275.

[Kum90] K. Kumar, Syracuse PhD thesis, unpublished (1990).

[Lou93] W.C. Louis, private communication.

[Mus93a] M. Musolf and M. Burkardt, CEBAF preprint # TH-93-01 (1993).

[Mus93b] M. Musolf *et al.*, CEBAF preprint # TH-93-11, prepared for Physics Reports, 1993.

[Mus93c] M. Musolf and T.W. Donnelly, CEBAF preprint # TH-93-16 (1993).

[Nie93] M. Nielsen, private communication.

[Par91] H.W. Park, J. Schechter, and H. Weigel, Phys. Rev. **D43** (1991) 869.

[Sak93] T. Saka *et al.*, Nagoya preprint # DPNU-93-26 (1993).

[Sch93] D. Schultz *et al.*, SLAC-PUB-6275 (1993).

[Sch93a] R. Schiavilla and M. Musolf, private communication.

[Sin92] C. Sinclair and L. Cardman, private communication.

[Sou91] CEBAF proposal PR91-010, P. Souder and J.M Finn, contact people.

[You85] L.M. Young and R.I. Cutler, IEEE Trans. Nucl. Sci., **NS-32** (1985) 1976.