(A Letter of Intent to Jefferson Laboratory PAC 30)
Precision Measurement of the Parity-Violating Asymmetry in Deep Inelastic Scattering off Deuterium using Baseline 12 GeV Equipment in Hall C

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We propose a measurement of the parity-violating (PV) asymmetry in $\vec{e}$–^{2}H deep inelastic scattering (DIS) at $Q^2 = 3.3$ GeV^2, $\langle W^2 \rangle = 7.3$ GeV^2 and $\langle x \rangle = 0.34$. The experiment will use the baseline 12 GeV Hall C spectrometer with a 40 cm liquid deuterium target and an 85 μA beam with 85% polarization. The predicted asymmetry is approximately 280 ppm at these kinematics, which is relatively large for a PV asymmetry. A relative statistical error of 0.5% is achievable with 24 days of production beam. An additional 6 days would be required for various systematic studies. The goal would be to limit the total systematic error to the size of the statistical error. While the errors from corrections to the asymmetry from beam effects and backgrounds should be straightforward to control, normalization errors especially from the beam polarization at this level of accuracy will present a significant, although not insurmountable, challenge.

These data can be used to obtain, with unprecedented precision, a linear combination of two poorly known low energy weak neutral current coupling constants: $2C_{2u} - C_{2d}$. Within the context of the Standard Model, these coupling constants are functions of a single parameter, the weak mixing angle $\sin^2 \theta_W$. At the proposed precision, the measurement would provide unique constraints on physics beyond the Standard Model at the multi-TeV scale and could potentially help the analysis of observed anomalies in high energy collider data. Interpreting the asymmetry measurement at the proposed level of accuracy in terms

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of Standard Model parameters will require tight constraints on several aspects of nucleon structure at high Bjorken x that are beyond the scope of this single measurement. These issues, interesting in their own right, are discussed briefly. It is likely that the proposed measurement will be part of a larger program that would use PV-DIS to simultaneously search for physics beyond the Standard Model as well as address long-standing fundamental issues in valence quark physics.

Contents

1. INTRODUCTION

Although there exist a large amount of data confirming the electroweak sector of the Standard Model at the level of a few parts per thousand, there also exist strong conceptual reasons (*e.g.*, the so-called high-energy desert from $M_{\text{weak}} \approx 250$ GeV up to the Planck scale $M_P \approx 2.4 \times 10^{18}$ GeV) to believe that the Standard Model is only a piece of some larger framework [1]. This framework should provide answers to the conceptual puzzles of the Standard Model; but must also leave the $SU(3)_C \times SU(2)_L \times U(1)_Y$ symmetry of the Standard Model intact at $M_{\text{weak}} \approx 250$ GeV. Hence, there exists intense interest in the search for physics beyond the Standard Model.

1.1. The Running of $\sin^2\theta_W$

The weak mixing angle, θ_W, is one of the fundamental parameters of the Standard Model. The tangent of the weak mixing angle represents the relative coupling strength of the $SU(2)_L$ and $U(1)_Y$ groups (g and g'). At the Z-pole, $Q^2 = M_Z^2$, the value of $\sin^2\theta_W$ is experimentally well established to remarkable precision, $\sin^2\theta_W[M_Z]_{\overline{MS}} = 0.23120 \pm 0.00015$ [2]; however, careful comparison of measurements involving purely leptonic and semi-leptonic electroweak currents shows a three standard deviation inconsistency. This strongly suggests additional physics not included in the Standard Model or that one or more of the experiments has significantly understated its uncertainties [3, 4].

One of the features of the Standard Model is that the value of $\sin^2\theta_W$ will vary, or run, as a function of the momentum transfer, Q^2, at which it is probed, so that the measurements at the Z-pole do not provide the complete picture. For $Q^2 < M_Z^2$, there are only three precise measurements. Atomic parity violation (APV) in Cs atoms [5] yields a result which while in agreement with Standard Model predictions has somewhat large uncertainties, and a difficult theoretical calculation is necessary to extract $\sin^2\theta_W$ from the measured asymmetry. The NuTeV experiment at Fermilab measured $\sin^2\theta_W$ through a careful comparison of neutrino and anti-neutrino deep inelastic scattering (DIS). Their result is approximately three standard deviations from Standard Model predictions [6]; although, the NuTeV result is not without considerable controversy. Most recently, the SLAC E-158 [7] experiment used the asymmetry in Moller scattering to determine a precise value of $\sin^2\theta_W$ that is consistent with the Standard Model prediction. A fourth measurement, QWeak, is planned for Jefferson Laboratory [8], and will determine $\sin^2\theta_W$ to 0.3% by measuring

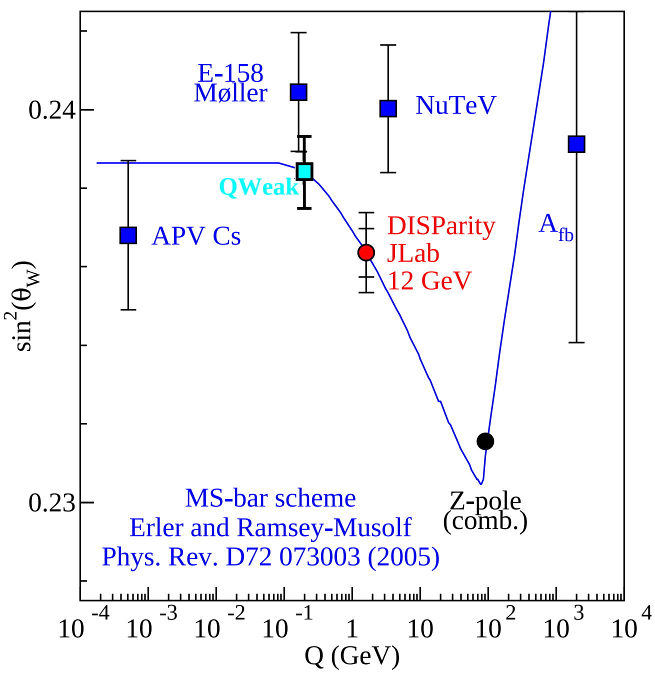


FIG. 1: The curve illustrates the running of $\sin^2\theta_W$ [9] and the anticipated precision of the measurement described herein, as well as the measurements from APV [5], Fermilab NuTeV [6], SLAC E-158 Møller [7] and expected uncertainty of JLab QWeak [8].

the weak charge of the proton. The results or projected data from these experiments are shown in Fig. 1 [9].

1.2. Phenomenological WNC Couplings at Low Q^2

Low energy precision tests of the electroweak Standard Model have and will continue to provide sensitive probes of possible extensions to the Standard Model. While all of the low energy measurement shown in Fig. 1 measure $\sin^2\theta_W$, they do so in different ways and thus have sensitivity to different possible extensions of the Standard Model. In lepton-quark scattering with two active flavors of quarks, there are six couplings. Assuming the Standard Model is complete, these are

$$C_{1u} = g_A^e g_V^u = -\frac{1}{2} + \frac{4}{3}\sin^2(\theta_W) \approx -0.19, \quad (1)$$

$$C_{1d} = g_A^e g_V^d = \frac{1}{2} - \frac{2}{3}\sin^2(\theta_W) \approx 0.35, \quad (2)$$

$$C_{2u} = g_V^e g_A^u = -\frac{1}{2} + 2\sin^2(\theta_W) \approx -0.04, \quad (3)$$

$$C_{2d} = g_V^e g_A^d = \frac{1}{2} - 2\sin^2(\theta_W) \approx 0.04, \quad (4)$$

$$C_{3u} = g_A^e g_A^u = -\frac{1}{2}, \text{ and} \quad (5)$$

$$C_{3d} = g_A^e g_A^d = \frac{1}{2}, \quad (6)$$

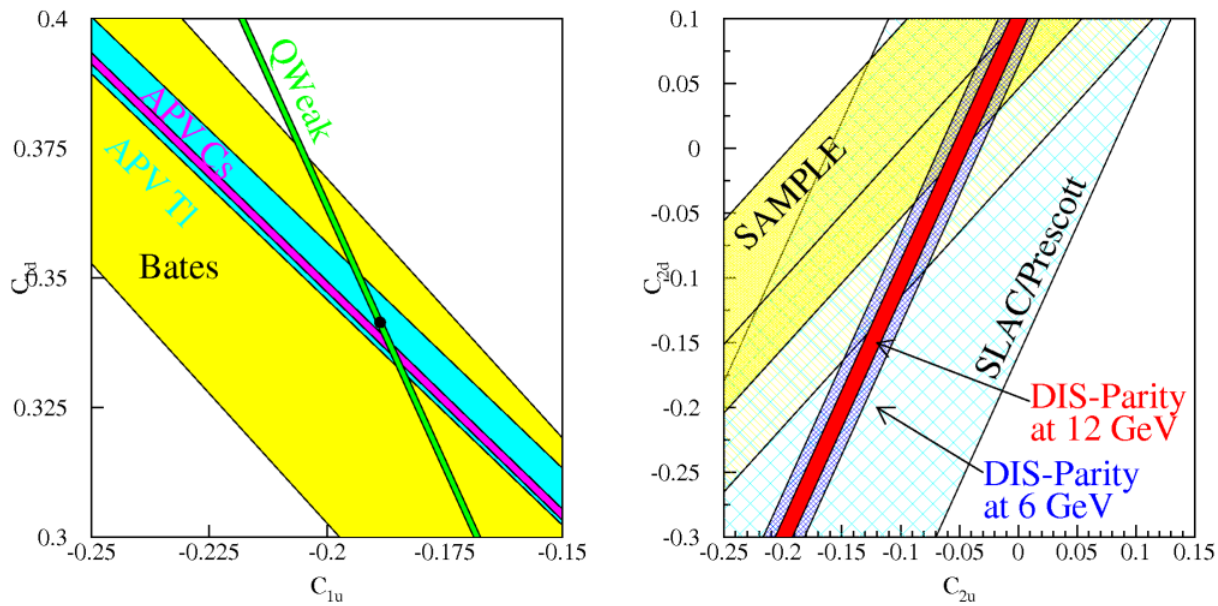
taking $\sin^2\theta_W \approx 0.23$. Here, $g^e_{A(V)}$ is the electron's axial (vector) coupling and $g^q_{A(V)}$ is the axial (vector) coupling of a quark of flavor $q \in \{u, d\}$. Among the previously mentioned experiments, SLAC E-158 Møller is purely leptonic and not sensitive to these couplings. APV and QWeak are semileptonic but only access the Z-electron axial times Z-quark vector couplings, $C_{\mathbf{1}q}$. Parity violating deep inelastic scattering (DIS-Parity) has a unique sensitivity to the C_{2q} couplings and the physics which they can uncover.

TABLE I: Existing data on P or C violating coefficients C_{iq} from Ref. [10]. The uncertainties are combined (in quadrature) statistical, systematic and theoretical uncertainties. The Bates e^-D quasi-elastic (QE) results on $C_{2u} - C_{2d}$ are from Ref. [11]. For some of the quantities listed here, global analysis gives slightly different values, please see Ref. [2] for the most recent updates.

facility	process	$< Q^2 >$ $(\mathrm{GeV}/c)^2$	C_{iq} combination	result	SM value
SLAC	e^-D DIS	1.39	$2C_{1u} - C_{1d}$	-0.90 ± 0.17	-0.7185
SLAC	e^-D DIS	1.39	$2C_{2u} - C_{2d}$	$+0.62 \pm 0.81$	-0.0983
CERN	$\mu^\pm$C DIS	34	$0.66(2C_{2u} - C_{2d})$ $+ 2C_{3u} - C_{3d}$	$+1.80 \pm 0.83$	$+1.4351$
CERN	$\mu^\pm$C DIS	66	$0.81(2C_{2u} - C_{2d})$ $+ 2C_{3u} - C_{3d}$	$+1.53 \pm 0.45$	$+1.4204$
Mainz	e^-Be QE	0.20	$2.68C_{1u} - 0.64C_{1d}$ $+ 2.16C_{2u} - 2.00C_{2d}$	-0.94 ± 0.21	-0.8544
Bates	e^-C elastic	0.0225	$C_{1u} + C_{1d}$	0.138 ± 0.034	$+0.1528$
Bates	e^-D QE	0.1	$C_{2u} - C_{2d}$	-0.042 ± 0.057	-0.0624
Bates	e^-D QE	0.04	$C_{2u} - C_{2d}$	-0.12 ± 0.074	-0.0624
JLAB	e^-p elastic	0.03	$2C_{1u} + C_{1d}$	approved	$+0.0357$
$--$	^{133}Cs APV	0	$-376C_{1u} - 422C_{1d}$	-72.69 ± 0.48	-73.16
$--$	^{205}Tl APV	0	$-572C_{1u} - 658C_{1d}$	-116.6 ± 3.7	-116.8

Table I summarizes the current knowledge of C_{iq} [10]. In contrast to C_{1q}, the weak coupling C_{2q} and C_{3q} are poorly known. From existing data, $2C_{2u} - C_{2d} = -0.08 \pm 0.24$. This constraint is poor and must be improved in order to enhance sensitivity to many possible extensions of the SM, such as quark compositeness and new gauge bosons. $e-{}^2$H PV DIS can provide precise data on $2C_{2u} - C_{2d}$ which are not accessible through other processes. We expect to improve the uncertainty on $2C_{2u} - C_{2d}$ by a factor of 17. It will also impact our knowledge of the C_{3q}, since the only observable sensitive to the C_{3q} is the the CERN $\mu^{\pm}$C DIS experiment [12], which provide a combination of C_{2q} and C_{3q} (see Table I).

FIG. 2: The effective couplings C_{1u}, C_{1d} (left), C_{2u} and C_{2d} (right). The future Qweak experiment (purple band), combined with the APV-Cs result (red band), will provide the most precise data and the best Standard Model test on C_{1u} and C_{1d}. The SAMPLE result for $C_{2u} - C_{2d}$ at $Q^2 = 0.1$ (GeV/c)^2 and the projected results from the 6 GeV PVDIS experiment (E05-007) [13] are shown. Assuming the SM prediction of $2C_{1u} - C_{1d}$, the value of $2C_{2u} - C_{2d}$ can be determined from the proposed measurement to $\Delta(2C_{2u} - C_{2d}) = 0.015$ (red band).



Here, we propose to use DIS-Parity to measure $\sin^2\theta_W$ and more generally $2C_{2u} - C_{2d}$ as a test of the Standard Model. The experiment presented will use the 12 GeV upgrade baseline spectrometers in Jefferson Laboratory Hall C, namely the HMS and the SHMS. As will be shown in Sec. 2.1, the asymmetry due to parity violation is relatively large, providing statistical sensitivity in a modest beam time. This experiment builds on the approved 6 GeV PVDIS (E05-007) experiment [13], and much of the theoretical motivation is common with that experiment.

2. PARITY VIOLATION IN DEEP INELASTIC SCATTERING AND THE STANDARD MODEL

Historically, parity violation in deep inelastic scattering (DIS-Parity) was one of the first tests of the Standard Model and an early measurement of DIS-Parity by Prescott *et al.* (SLAC E122) in the 1970's served to establish the value of $\sin^2\theta_W$ [14, 15] at $\sin^2\theta_W \approx 1/4$. Since this groundbreaking experiment, parity violation has become an important tool not only for probing the Standard Model [5, 7, 8] but also for probing the structure of the nucleon [16, 17, 18].

2.1. Parity Violation in Deep Inelastic Scattering

Prior to the SLAC E122 experiment, electron beams were used solely as an electromagnetic probe of the nucleon because of the comparatively small amplitude of the weak neutral-current scattering at low energy. A number of facilities (JLab, SLAC, MIT-Bates, Mainz) have developed the capabilities to provide high enough luminosity to make studies of the weak neutral current and its couplings feasible. The weak neutral current can be accessed by measuring a parity-violating asymmetry that is proportional to the interference term between weak and electromagnetic scattering amplitudes [19].

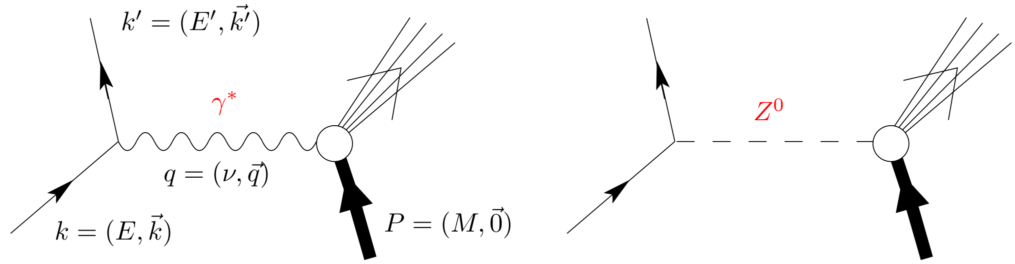


FIG. 3: Tree-level Feynman diagrams for electron scattering.

The scattering amplitude, $\mathcal{M}$, for the process is a product of current for the electron with the photon or the Z^0 propagator and the hadron current:

$$\mathcal{M}_\gamma = j_\mu \Big(\frac{1}{q^2}\Big) J^\mu; \quad \mathcal{M}_Z = j_\mu \Big(\frac{1}{M_Z^2}\Big) J^\mu. \tag{7}$$

The cross sections for scattering right- and left-handed electrons off an unpolarized target are proportional to the square of the total amplitudes:

$$\sigma^r \propto (\mathcal{M}_\gamma + \mathcal{M}_Z^r)^2, \quad \sigma^l \propto (\mathcal{M}_\gamma + \mathcal{M}_Z^l)^2, \tag{8}$$

where only a longitudinally polarized electron beam was considered and $\mathcal{M}_Z^r$ and $\mathcal{M}_Z^l$ represent the incident right- and left-handed electrons, respectively. The parity-violating asymmetry may be expressed as [19]

$$A_{LR} \equiv \frac{\sigma^r - \sigma^l}{\sigma^r + \sigma^l} = \frac{(\mathcal{M}_\gamma + \mathcal{M}_Z^r)^2 - (\mathcal{M}_\gamma + \mathcal{M}_Z^l)^2}{(\mathcal{M}_\gamma + \mathcal{M}_Z^r)^2 + (\mathcal{M}_\gamma + \mathcal{M}_Z^l)^2} \approx \frac{\mathcal{M}_Z^r - \mathcal{M}_Z^l}{\mathcal{M}_\gamma}. \tag{9}$$

Thus, measuring the parity-violating asymmetry gives access to the weak neutral current in a ratio of amplitudes rather than the square of this ratio, greatly enhancing its relative contribution. The size of the asymmetry can be *estimated* based on the ratio of the propagators:

$$A_{LR} \approx \frac{Q^2}{M_Z^2} \approx 360 \text{ ppm at } \langle Q^2 \rangle = 3 \text{ GeV}^2 \tag{10}$$

with $M_Z = 91.2$ GeV [2]–a very large asymmetry for a parity violation experiment.

Following this formalism, derived by Cahn and Gilman [19], the parity-violating asymmetry for scattering longitudinally polarized electrons from an unpolarized isoscaler target such as deuterium (assuming isospin symmetry–this assumption will be discussed in Sec. 4.4) is given by [19, 20]

$$A_d = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \tag{11}$$

$$= -\left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right) \frac{2C_{1u} - C_{1d}\left[1 + R_s(x)\right] + Y(2C_{2u} - C_{2d})R_v}{5 + R_s(x)}. \tag{12}$$

Here, the kinematic variable Y is defined as

$$Y = \frac{1 - (1-y)^2}{1 + (1-y)^2 - y^2 \frac{R_{\mathrm{LT}}}{1+R_{\mathrm{LT}}}} \tag{13}$$

with $y = \nu/E$ and $\nu = E - E'$ is the energy lost by an incident electron of energy E scattering to an electron of energy E'. The ratio $R_{\mathrm{LT}} = \sigma_L/\sigma_T \approx 0.2$ depends on x and Q^2. The ratios $R_s(x)$ and $R_v(x)$ depend on the parton distribution functions[1]:

$$R_s(x) = \frac{s(x) + \bar{s}(x)}{u(x) + \bar{u}(x) + d(x) + \bar{d}(x)} \tag{14}$$

and

$$R_v(x) = \frac{u_v(x) + d_v(x)}{u(x) + \bar{u}(x) + d(x) + \bar{d}(x)}. \tag{15}$$

As described in the introduction, $C_{1u(d)}$ represents the axial Z-electron coupling times the vector Z-u quark (d quark) coupling, while the $C_{2u(d)}$ is the vector Z-electron coupling times the axial Z-u quark (d quark) coupling.

[1] Charmed quark contributions may be considered as well; although their contribution is small.

In an approximation of moderately large-x, where sea quark contributions vanish, $R_v \approx 1$ and $R_s \approx 0$. Using $\sin^2\theta_W \approx 0.23$ for C_{1u}, C_{1d}, C_{2u} and C_{2d} from above,

$$A_d \approx 10^{-4} Q^2 (0.73 + 0.12Y) \tag{16}$$

where Q^2 is in GeV^2. The sensitivity to $\sin^2\theta_W$ is approximately given by

$$\frac{\delta \sin^2\theta_W}{\sin^2\theta_W} \approx \left(\frac{\delta A}{A}\right) \frac{1+0.2Y}{1+1.8Y}. \tag{17}$$

2.2. Exploring New Physics Beyond the Standard Model

Since the SLAC E-122 experiment [14, 15], other experiments have succeeded in verifying the electroweak sector of the Standard Model to within a few parts per thousand. Still, there are numerous reasons to believe that what is known as the Standard Model is only part of a larger framework. DIS-Parity involves exchange of Z^0 between electrons and quarks and thus is sensitive to physical processes that might not be seen in purely leptonic observables, such as the precision A_{LR} at SLC and A^l_{FB} at LEP. There is currently a *three standard deviation* disagreement [3, 4] in $\sin^2\theta_W$ between purely leptonic and semi-leptonic observables at the Z-pole from SLC and LEP. The recent NuTeV [6] result on $\sin^2\theta_W$ at low Q^2 involves a particular set of semi-leptonic charged and neutral current reactions and disagrees with the Standard Model prediction by three standard deviations. A precision measurement of DIS-Parity will provide a clean semi-leptonic observable to the world data below the Z-pole and will provide essential clues as to the source of these discrepancies.

A precision DIS-Parity measurement would examine the Z coupling to electrons and quarks at low Q^2 far below the Z-pole. DIS-Parity is sensitive to a particular combination of couplings and has different sensitivities to extensions of the Standard Model than other semi-leptonic processes (*e.g.*, Qweak). For example, a large axial quark coupling could cause the NuTeV effect, but cannot be seen in C_{1q}. Quark and lepton compositeness is accessible only through C_{2q} but not C_{1q} if a particular symmetry, SU(12), is respected. DIS-Parity will significantly strengthen the constraints on these possible extensions to the Standard Model. This section describes how DIS-Parity can explore physics beyond the Standard Model in a complementary way to Atomic Parity Violation [5], JLab QWeak [8], SLAC E-158 Møller [7] and Fermilab NuTeV [6]. Special attention is paid to extensions to the Standard Model to which the C_{2q} couplings are sensitive, as these are unique to DIS-Parity. A few possible models for new physics that can be probed via measurement of A_d

and C_{2q}'s are discussed, including the search for extra neutral gauge boson Z', compositeness and leptoquark.

Frequently proposed experiments are characterized by a "mass scale" for which they are sensitive to physics beyond the Standard Model. This can be estimated by considering the low energy effective electron-quark Lagrangian. In analogy to Eqs. 25-27 and 29 of Erler, Kurylov and Ramsey-Musolf [21], the approximate mass scale reached by this experiment would be[22]

$$\frac{\Lambda}{g} = \frac{1}{\sqrt{2\sqrt{2}G_F\ \delta(2C_{2u} - C_{2d})}} \approx 1.5 \text{ TeV}. \tag{18}$$

In the following sections we will review possible New Physics search from DIS-parity given in literature. We are currently working with theorists on an updated list of New Physics limits achievable from the measurement proposed here and we expect to include them in the full proposal [23].

2.2.1. Z' Searches

Neutral gauge structures beyond the photon and the Z boson (*i.e.* the Z') have long been considered as one of the best motivated extensions of the Standard Model [2]. They are predicted in most Grand Unified Theories (GUT) and appear in superstring theories. While there may be many such states near the Planck scale, many models predict a Z' near the weak scale.

A Z' which couples to Z^0 will strongly affect the observables around the Z-pole, which have been measured to a remarkable precision. Direct searches at Fermilab have ruled out any Z' with $M_{Z'} < M_Z$ but a heavier Z' (most likely above ≈ 600 GeV) is possible. Such Z' can arise in E_6 [24], a rank-6 group and a possible candidate for the GUT. This E_6 breaks down at the Planck scale and becomes the $\mathrm{SU}(3)_C\times\mathrm{SU}(2)_L\times\mathrm{U}(1)_Y$ symmetry of the familiar Standard Model. The breaking of E_6 to the Standard Model will lead to extra Z's and it is possible that at least one of these is light enough to be observed. The effect of Z' in E_6 might be observed in ν-DIS, PV e-N scattering, PV Møller scattering and APV [25]

2.2.2. Compositeness and Leptoquarks

If quarks and leptons have intrinsic structure (compositeness), then there may be interchange of fermion constituents at very short distances [1]. The lowest dimension contact interactions are the four-fermion contact interactions between quarks and leptons, described by 8 relevant terms $\bar{e}_i \gamma_\mu e_i \bar{q}_j \gamma^\mu q_j$ where $i, j = L, R$ and $q = u, d$ [26]. These lead to the following shifts in the couplings: [27]

$$\delta C_{1q} = \frac{1}{2\sqrt{2} G_F \left(\eta^{eq}_{RL} + \eta^{eq}_{RR} - \eta^{eq}_{LL} - \eta^{eq}_{LR} \right)} \tag{19}$$

$$\delta C_{2q} = \frac{1}{2\sqrt{2} G_F \left(-\eta^{eq}_{RL} + \eta^{eq}_{RR} - \eta^{eq}_{LL} + \eta^{eq}_{LR} \right)}. \tag{20}$$

In theories that predict quark and lepton compositeness, there are new strong confining dynamics at a scale Λ. Any contact terms produced by the strong dynamics will respect its global symmetries, and it is not difficult to find such global symmetry (other than parity) which ensure cancellations in δC_{1q}'s. For instance, an approximate global SU(12) acting on all left handed first generation quark states will have no effect on C_{1q}'s while still allowing a non-zero contribution to C_{2q}'s ($LL = -LR$ and $RL = -RR$) [28]. Therefore, measurement of C_{2q}'s will provide a unique opportunity to explore quark and lepton compositeness. Using the formalism of Ref. [25], a four-fermion contact interaction of form

$$L_1 = \pm \frac{4\pi}{\Lambda_1^2} \bar{l}_{\mu L} \gamma^\mu l_{\mu L} \bar{q}_L \gamma_\mu q_L \tag{21}$$

will change C_{2q}'s by

$$\delta C_{2q} \approx \pm \frac{\sqrt{2}}{G_F} \frac{\pi}{\Lambda_1^2}, \tag{22}$$

where Λ gives the scale of the interaction. Thus the measurement on C_{2q}'s proposed here will set a limit of $\Lambda_1 > 5.0$ TeV Although this limit is somewhat lower than other mass limits [27, 29] where the most recent HERA data [30, 31] are included, those limits were obtained by only allowing one contact term at a time with all others set to zero. Ultimately, these must be allowed to vary simultaneously and the results from the proposed measurement will provide important input to these fits.

Leptoquarks are vector or scalar particles carrying both lepton and baryon numbers. For DIS-Parity, the existence of leptoquarks will change the observed asymmetry by an amount proportional to $\frac{\lambda^2}{4M_{LQ}^2}$ where M_{LQ} is the mass of leptoquark and λ is its coupling to electron and quarks. Hence a deviation of the measured A_d from its Standard Model prediction can be interpreted as caused by leptoquarks and can set constraint on the leptoquark properties λ and M_{LQ}. Assuming for simplicity creation of a scalar leptoquark from interactions with u quarks but not d quarks, the 2% measurement on A_d proposed here will set a limit of $\lambda_s \leq 1.0(M_{LQ}/100$ GeV), comparable to the current limit from the Cs APV experiment.

2.2.3. Supersymmetry (SUSY)

Supersymmetry (SUSY) is a symmetry between bosons and fermions [32]. It requires a Lagrangian which is invariant under transformations which mix the fermionic and bosonic degrees of freedom. In any supersymmetric scheme, all particles fall into supermultiplets with at least one boson and one fermion having the same gauge quantum numbers. Hence, to each fermion and to each vector boson of a gauge theory there will correspond superpartners. If the symmetry were unbroken, the pairs of bosons and fermions would have the same mass – in contradiction with experimental results. Thus if they exist, one must assume heavy masses (above TeV range) because no supersymmetric particles have ever been detected.

Although no supersymmetric particle has yet been discovered, there exists strong motivation for believing that SUSY is a component of the "new" Standard Model. For example, the existence of low-energy SUSY is a prediction of many string theories; it offers a solution to the hierarchy problem. providing a mechanism for maintaining the stability of the electroweak scale against large radiative corrections; it results in coupling unification close to the Planck scale; and more excitingly it can be extended to gravity (the extended version including gravity is called supergravity). In light of such arguments, it is clearly of interest to determine what insight about SUSY the new DIS-Parity measurements might provide.

The effect of SUSY on the coupling coefficients $C_{1,2u(d)}$ in the one-loop correction is different from that in the Standard Model. Therefore the asymmetry A_d is sensitive to possible SUSY effect in the PV scattering.

3. EXPERIMENTAL CONFIGURATION

The 12 GeV upgrade to the CEBAF accelerator will vastly increase the kinematics accessible to DIS experiments at Jefferson Laboratory. From the formalism developed in Sec. 2.1, it is clear that the interpretation of these measurements depends on quark scattering and so must be done with DIS kinematics.[2] The experiment will run in Hall C with an 85 μA polarized beam on a 40 cm liquid deuterium target. Scattered electrons will be detected in both of the Hall C baseline spectrometers, the HMS and SHMS. As with any parity experiment, tight control must be maintained over various

[2] The Res-Parity experiment has proposed studying parity violation in the resonance region. A summary of the additional physics which can be probed may be found in the Res-Parity proposal [33].

systematic effects. Fortunately, however, the DIS-Parity asymmetry is relatively large. First, this section will describe the measurement, rates for the experiment and the baseline spectrometers. Then, the basic instrumentation and the systematic uncertainties associated with the measurement of A_d will be discussed, including the beamline, polarimetry and luminosity monitors.

3.1. The Measurement with the 12 GeV Baseline Spectrometers

The choice of kinematics for this experiment must meet several criteria. The most important is that the experiment is measuring A_d in the DIS region, namely $Q^2 > 1$ GeV^2 and $W^2 > 4$ GeV^2. In particular, to be optimized for sensitivity to Standard Model parameters, it is desired to keep Q^2 and W^2 as high as possible. Additional considerations are then focused on minimizing systematic uncertainties in the measured asymmetry or in its interpretation, including rates in the spectrometers, the electron/pion ratio and parton density uncertainties. These criteria could be met by employing the HMS and SHMS spectrometers at 13.5°, with a central momentum of 6.0 GeV in the HMS and 5.8 GeV in the SHMS. The lower central momentum in the SHMS serves to reduce a $W^2 < 4$ tail allowed by the large momentum bite. At these settings, the experiment would have $\langle Q^2 \rangle = 3.3$ GeV^2, $\langle W^2 \rangle = 7.3$ GeV^2 and $\langle x \rangle = 0.34$. The distribution of rate over these kinematic variables for this configuration is shown in Figures 4-6. A summary of some of the properties of the HMS and SHMS are given in Tab. II. Further details of these spectrometers may be found in Ref. [34, 35, 36]. The total rate in this configuration would provide a statistical precision $\delta A_d/A_d = 0.5\%$ in 576 beam hours (assuming 85 μA beam with polarization equal to 85%).

3.1.1. Particle Identification and Pion Contamination

The pion rates were calculated using a fit to pion photo-production data of Wiser [37] taken at SLAC. As can be seen from Tab. II, the average π^-/e^- ratio, $R_{\pi/e}$ is relatively small for this measurement. In some regions of the each spectrometer's acceptance (the lowest E' values accepted) however this ratio can be greater than 50%. In the SHRS, particle identification will be done by means of a lead-glass shower counter and a 2.5 m long atmospheric pressure Čerenkov counter. The shower counter is expected to have a pion rejection factor of $(1-5)\times 10^{-2}$ [34]. Combined with the Čerenkov counter, a pion rejection factor of $\epsilon = 1 \times 10^{-4}$ should be achievable. The HMS uses a

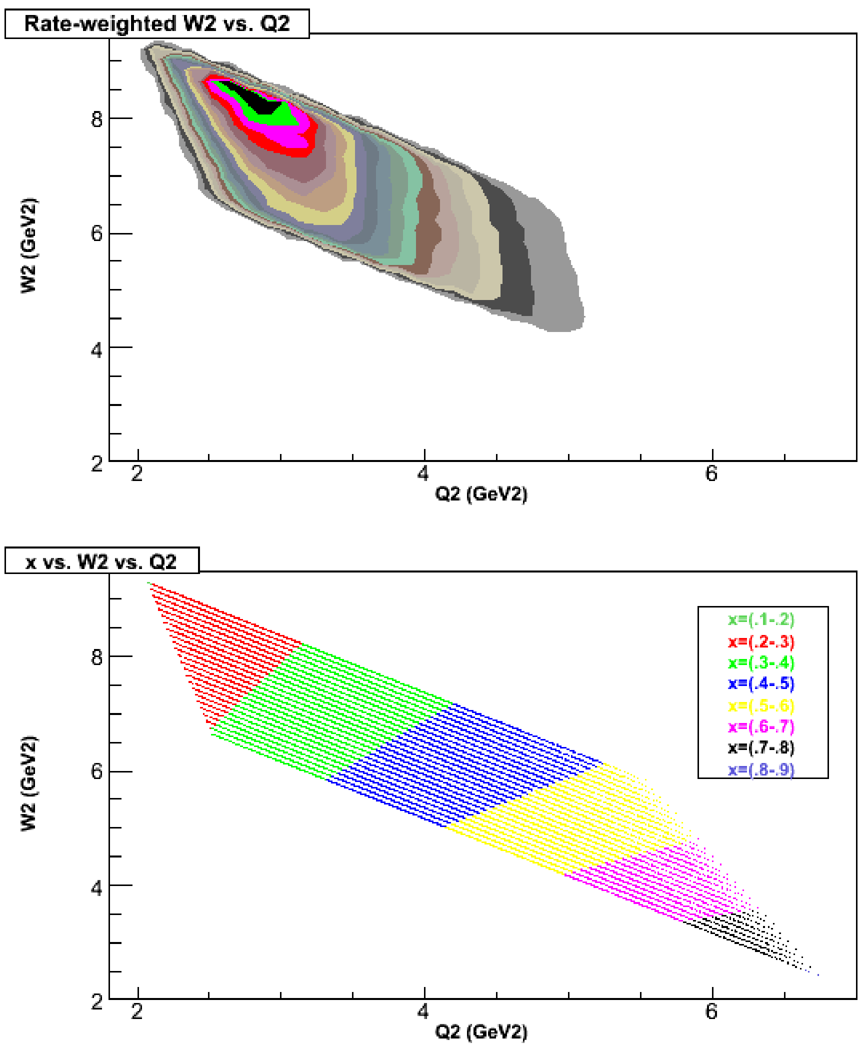


FIG. 4: The kinematic coverage of the HMS spectrometer, configured as proposed, shown as W^2 vs. Q^2. Top plot: color contours show the rate distribution. Bottom plot: color bands display ranges of Bjorken x.

pressurized Čerenkov counter as well as a shower counter for π^-/e^- separation. This combination has a combined pion rejection factor of 1×10^{-4}.

The pion asymmetry, A_d^π, will be measured at the same time as A_d simply by requiring a pion rather than rejecting it, with fewer statistics since $R_{\pi/e} < 1$. This will lead to a determination of $\delta A_d^\pi / A_d^\pi = 1.1 \times 10^{-2}$, if A_d^π is approximately the same size as A_d. Assuming the worst case, $\epsilon \approx 10^{-3}$ and $R_{\pi/e} \approx 1$, the uncertainty due to pion contamination is given by

$$\left.\frac{\delta A_d}{A_d}\right|_{\pi \text{ contam.}} = \epsilon R_{\pi/e} \left(\frac{\delta A_d^\pi}{A_d^\pi} \right) \approx 1.1 \times 10^{-5}, \tag{23}$$

which is a negligible amount.

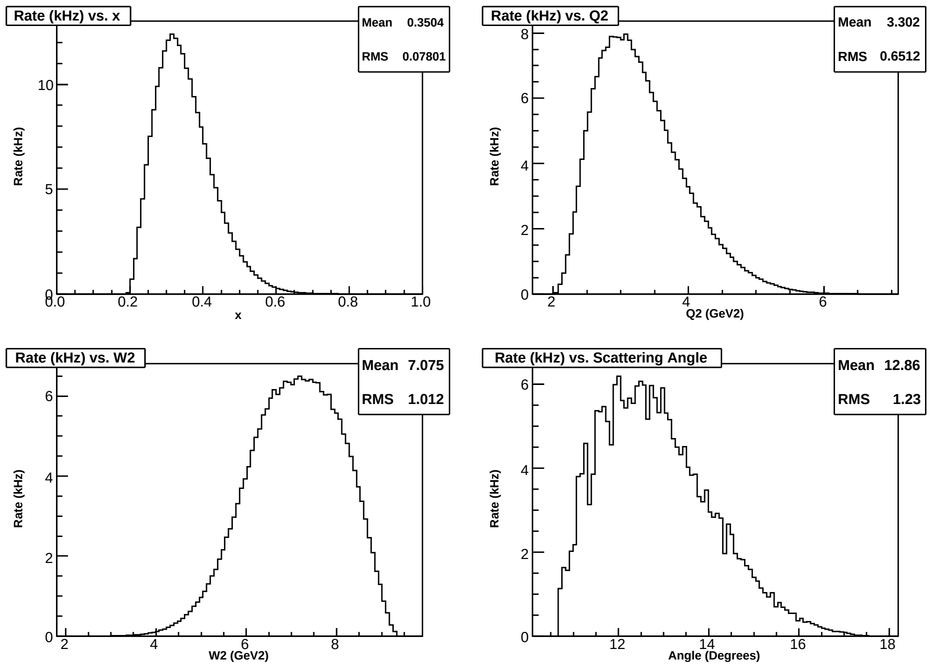


FIG. 5: Rate distribution plotted versus kinematic variables x, Q^2, W^2, and lab scattering angle for the assumed acceptance of the HMS spectrometer with central angle 13.5° and central momentum 6.0 GeV.

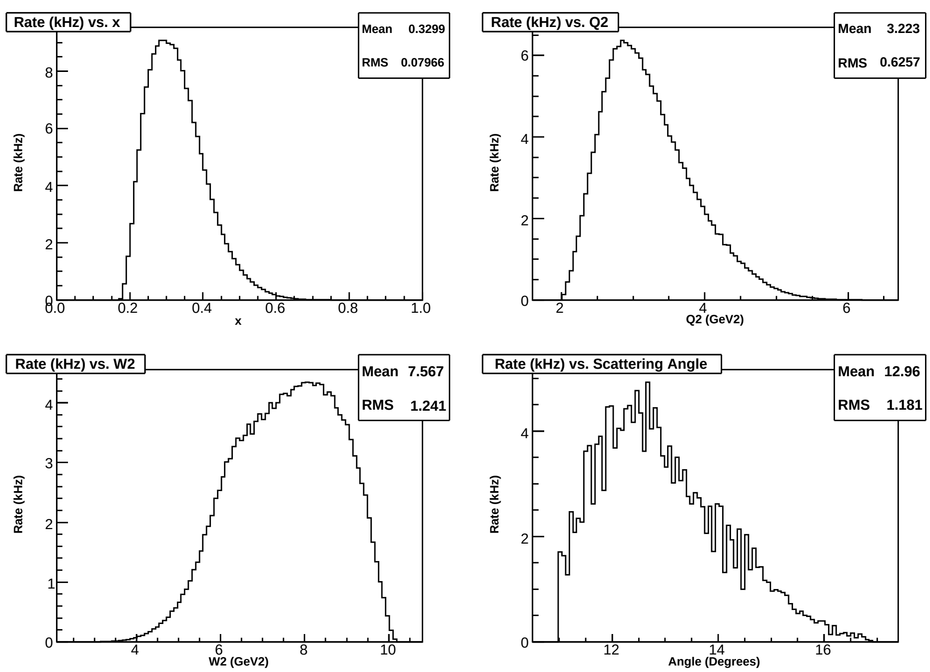


FIG. 6: Rate distribution plotted versus kinematic variables x, Q^2, W^2, and lab scattering angle for the assumed acceptance of the SHMS spectrometer with central angle 13.5° and central momentum 5.8 GeV.

TABLE II: This table lists the spectrometer settings, kinematic variables (and their ranges) as well as expected rates for both spectrometers [34, 36]. The combined statistical uncertainty on A_d is 0.05%.

	HMS		SHMS	
	Average	Range	Average	Range
Central Angle	13.5°	-	13.5°	-
Momentum (GeV)	6.0	$5.4 - 6.6$	5.8	$4.9 - 6.7$
		$\pm10\%$		$-15/+15\%^a$
$\delta\Omega$ (msr)	-	6.8	-	3.8^b
Q^2 (GeV^2)	3.3	$2.6 - 4.0^c$	3.2	$2.6 - 3.8$
W^2 (GeV^2)	7.1	$6.1 - 8.1$	7.6	$6.3 - 8.8$
x	0.35	$0.27 - 0.43$	0.33	$0.25 - 0.41$
DIS Rate (kHz)	190		150	
${A_d}^d$	285×10^{-6}	$(220 - 350) \times 10^{-6}$	280×10^{-6}	$(210 - 340) \times 10^{-6}$
$\delta A_d/A_d$[%] (576 hours)	0.66		0.75	
π/e ratio^e	0.3	$0.1 - 0.6$	0.45	$0.1 - 1.0$
Total Rate (kHz)	240		220	

[a] While the SHMS momentum acceptance is nominally quoted as -15%/+20%, the high end of this acceptance is not complete. As we did not have a reliable model for this high momentum acceptance, we used a cut off at +15% for the purposes of this rate estimate.
[b] The spectrometer is still being optimized and it is possible that this will increase to > 4.5 msr [36].
[c] The range for these kinematic variables describes the coverage of the RMS width.
[d] The range gives the variation in the asymmetry over each spectrometers acceptance.
[e] The range of π/e depends on the difference between the π or e momentum and the central spectrometer momentum.

3.2. Rescatter Background

The rescattering of high-energy electrons or pions from the walls of the spectrometer creates a potential source of background for the proposed measurement. This "rescattering" background, which is typically easily rejected using a combination of tracking and particle identification in low-rate experiments, may provide a non-negligible contribution due to the limited information available in each event in this high-rate measurement.

The magnitude of this effect will be combination of the probability for products of this scattering in the spectrometer to reach the detectors and the effectiveness of the detector/DAQ package to distinguish those tracks from tracks originating in the target. A detailed analysis of this possible problem will require a careful simulation of the spectrometer and detector geometry. Measurements will be taken with a low beam current (to allow the use the tracking chambers and the standard DAQ) to study this small background and verify the accuracy of the simulation.

We also intend to directly estimate the rescattering contribution using a series of dedicated measurements with a hydrogen target at lower beam energy. At a beam energy of 6.6 GeV, the spectrometer will be tuned to place the hydrogen elastic peak at various points inside the spectrometer. The detected rate will be used to estimate the "rescattering probability": the probability that an electron, interacting at a given point in the spectrometer, produces a count in the production DAQ. At this beam energy, the spectrometer optics will be similar to that used in the production running. Therefore, the rescattering probability can be convoluted with the electron flux distribution to estimate the total count-rate contribution from interactions in the walls of the spectrometer during production running. This empirical measure of the contribution of electron interactions with the spectrometer walls also serves to cross-check the simulation, which must still be used to estimate the rescattered contribution from pions.

The rescattering contribution from electrons was studied in this way by the HAPPEX collaboration (E99-115 and E00-114). These experiments used an analog-integrating detector, and therefore had no method for excluding rescattered background particles. The experiment used the Hall A High Resolution Spectrometers. In those measurements, the rescattering probability was around 1% for momenta near to the central momenta (within a few percent of $\delta p/p$). This probability rapidly dropped to 10^{-5} for interactions with the spectrometer wall took place before the last spectrometer quadrupole element. For HAPPEX-Helium, the rate of quasi-elastic scattering from the Helium target which was steered into the spectrometer walls was several times the elastic signal rate, leading to a rescattering in the focal plane on order 0.2% of the detected elastic rate. It is reasonable to expect that the detected rescattering signal in the proposed measurement will also form a dilution at the few 10^{-3} level. Factors that would argue for a larger contribution, such as the continuous DIS momentum distribution and the relatively open spectrometer geometry, will be counteracted by the ability to exclude background through position, energy, or PID information from the fast counting DAQ.

In the case of DIS electrons, the asymmetry of this background will be very similar to the primary measurement, and so the effect of this dilution will be further minimized. This is not true for pion rescattering (although we will have an on-line measure of the pion asymmetry, see Sec. 3.1.1) or for scattering from the resonance region. It is thought that these will contribute a small fraction of the total rescattered rate, although this has not yet been verified through simulation. With these assumptions, one would expect the total uncertainty due to the rescattered background to be in the 10^{-3} range.

3.3. Polarized Electron Source

Parity-violation experiments are typically 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. Previous collaborations on parity-violation experiments have 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 about 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 demands of this proposed measurement.

3.4. Beam Line and Polarimetry

The rates and beam allocations in this letter of intent assume an 11 GeV beam at 85 μA of current with 85% polarization[3]. An uncertainty of 0.1% in the absolute energy of the electron beam from arc measurements in Hall C is expected to be easily achieved with an 11 GeV beam [34]. This should be controlled as tightly as possible, since this uncertainty feeds into the Q^2 uncertainty and hence the extracted value of $\sin^2\theta_W$ and $2C_{2u} - C_{2d}$. (See Sec. 3.7.)

The measurement of the electron beam's polarization is crucial to this experiment's success. The experiment will employ both Møller and Compton polarimeters. The Møller polarimeter is expected to operate at 11 GeV and measure the polarization to approximately 0.5%, which would be sufficient for this experiment. Unfortunately, this device will only work at low current (a few μA) and an extrapolation is necessary to reach the 85 μA necessary for this experiment. Alternatively, the

[3] The current and polarization requirements could be relaxed in exchange for an increased beam time allocation at the discretion of the PAC

planed Compton polarimeter works well at high current. The planned Hall C Compton polarimeter will have an uncertainty of $< 1\%$. While this is quite good, if this experiment is approved a significant effort will be devoted to improving its precision to 0.5%. A Compton polarimeter of this precsion has already been achieved at SLAC SLD [38] operating with a > 30 GeV electron beam. For a DIS-Parity experiment at SLAC (the experiment was ultimately not approved) and as a development for the ILC, a 0.3% Compton polarimeter was proposed. In light of these, it is not unreasonably to believe that a 0.5% Compton polarimeter can be achieved at JLab. Clearly should this experiment go forward, the lead institutes would need to take a major role in the development of this polarimeter.

3.5. Liquid Deuterium Target

The experiment will use a 40 cm long cryogenic liquid deuterium target, corresponding to 0.055 radiation lengths. This length permits the entire target to be seen by the HMS at 12.5°. The heat load for a 85 μA beam on this target is approximately 1.6 kW. This is well under the heat load for the QWeak target [8] and the anticipated target cooling capacity for the post-upgrade Hall C cryo-target system [35]

The target endcaps will be made out of 4 mil Be. The end cap contamination will be measured with the use of empty targets with thick Be windows. The ratio of yield from end caps to that from LD_2 is estimate to be $L_{Be}/L_{LD_2} \times \rho_{Be}/\rho_{LD_2} = 0.55\%$, where L_x denotes the length of material x with ρ_x the corresponding density. This ratio can be measured quickly using an empty target with 100x thicker end caps (1 cm) than the LD_2 cell. With careful measurement of the end cap thickness, the dilution fraction can be determined to within 10% relative error. Since Be has Z=4, N=5, the asymmetry A_{Be} of e-Be scattering is not significantly different than A_d. The similarity in A_{PV} further suppresses the effect of the uncertainty in end-cap contribution. The dummy target with thicker end-caps will give approximately half the rate of the production target. This would allow a measurement of this background asymmetry $\delta A_{Be}/A_{Be}$ to 5%, with an addition of only 2% of the total beamtime.

The liquid deuterium usually used contains [39] 1889 ppm HD, < 100 ppm H_2, 4.4 ppm N_2, 0.7 ppm O_2, 1.5 ppm CO (carbon monoxide), < 1 ppm methane and 0.9 ppm CO_2 (carbon dioxide). Compared to the statistical accuracy of the measurement all of these contributions are small. The largest would be the contamination to the measured asymmetry is from the proton in HD. Since the asymmetry of the proton is given by [20]

$$A_p = \left(\frac{3G_F Q^2}{\pi\alpha 2\sqrt{2}}\right) \frac{2C_{1u}u(x) - C_{1d}\left[d(x)+s(x)\right] + Y\left[2C_{2u}u_v(x) - C_{2d}d_v(x)\right]}{4u(x)+d(x)+s(x)} \tag{24}$$

which is within 20% of the asymmetry of the deuteron, the proton in HD and H_2 contributes $\delta A_d/A_d < 0.4 \times 10^{-3}$ uncertainty to the measured asymmetry.

The dominant concern with cryogenic targets in parity-violation experiments is density fluctuations where localized beam heating creates bubbles in the liquid and causes a rapid jitter in the instantaneous luminosity 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.

In the proposed measurement, the detected rate is around 340 kHz (see Tab. II). The statistical uncertainty on the asymmetry per beam pulse pair (33 ms H+ and 33 ms H-, 66 ms total) is on the order 6500 ppm. The noise effect should be kept small to cost less than $< 5\%$ of statistical precision; at the proposed rate, this corresponds to density fluctuations of around 2100 ppm. The recent HAPPEX experiment found a noise of level of approximately 250 ppm at 70 μA on a 20 cm LH2 cell, while the approved HAPPEX-III (E05-109) and QWeak (E05-008) experiments each have much more stringent requirements for target fluctuations. In light of this, the comparatively loose requirements for this proposal should be easily achieved.

An additional concern can be found in the possible coupling of target density to the helicity state of the beam. One example would be a helicity-correlated beam spot size asymmetry, with a target density fluctuation that significantly couples to beam spot size. Such an effect (which has never been observed and remains entirely speculative) would be very dangerous for the high-precision parity-violation experiments such as HAPPEX-III and QWeak. Of necessity, these experiments will establish methods for estimating and reducing both these possible helicity correlations in the electron beam, and any coupling of these beam parameters to target density. These experiments, which will run in the near future, will be forced to develop solutions to these potential problems in order to meet far more stringent requirements on both random noise and helicity-correlated effects.

3.6. Data Acquisition

The requirements for the front end electronics and the data acquisition (DAQ) are determined by the high rate and the need to separate electrons from pions. In Tab. II, the estimated total rate is under 400 kHz. As a conservative estimate, the DAQ should be able to accept rates on the order of twice that, or 800 kHz. The electron/pion separation requirement necessitates the use of a counting rather than an integrating DAQ as used in previous parity violation experiments at JLab. The exception to this statement is the 6 GeV PV-DIS (E05-007) [13] experiment which has similar requirement to the present measurement. For each spectrometer, the experiment will need to read the hit patterns from the trigger hodoscopes and ADC measurement for the Čerenkov and shower counters. For the production data, the wire chambers will not be active.

For the proposed experiment we are considering two possible read out methods, one using an array of scalers to count events, and a second, more sophisticated method using flash ADC's (FADC). Both of these methods are applicable to the present DIS-Parity experiment. In the scaler method, particle identification is determined via preset thresholds on the Čerenkov and shower counters. Prior to production running, these threshold must be carefully set and then checked for drift during production data collection. In the FADC method, the detector signals (PID and scintillator) would be digitized and then an on-board processor (FPGA) would determine the particle identification based on a pre-existing algorithm. Over each helicity pulse (33 ms) the FPGA would keep track of both the total number of electrons and pions separately. In both methods the readout dead time and pileup must be carefully watched. The 6 GeV E05-007 will employ both methods for use with the HRS in Hall A. And their feasibility will be well tested during this experiment.

FADC's are currently being developed both commercially (*e.g.* Struck) and in house at JLab (for Hall D). In both cases, the FADC's have resolutions better than 8 bit and sampling speeds greater than 100 MHz. The Hall C SHMS effort is already considering using these units [34]. Little additional effort would be required to equip the HMS scintillators, Čerenkov and shower counters with similar units. To continuously monitor the PID efficiency a prescaled fraction of the events will be read out entirely. In a zero-suppressed mode, the FADC/FPGA combination could provide to the VME bus the hodoscope hit pattern (4 bytes), the Čerenkov ADC values (2 bytes) and the above pedestal shower counter ADC values (approx. 8 to 12 bytes) for a total of approximately 16 bytes per event.

In addition, the experiment will need to collect data with lower luminosity to study issues related to rate dependencies, electronic dead time, computer dead time and PID efficiency. Two days of beam time is allocated to lower rate running which will address these issues as well as other issues related to backgrounds.

TABLE III: This table lists the systematic uncertainties in the measurement of A_d. These contributions to the uncertainty if the measured asymmetry is to be interpreted in terms of $\sin^2\theta_W$ are also shown.

Source	$\frac{\delta A_d}{A_d}$	$\frac{\delta \sin^2\theta_W}{\sin^2\theta_W}$
Polarization measurement	5.0×10^{-3}	2.5×10^{-3}
Determination of Q^2	3.9×10^{-3}	2.0×10^{-3}
Target Endcaps	0.5×10^{-3}	0.28×10^{-3}
Target Purity	0.4×10^{-3}	0.22×10^{-3}
Rescatter background	0.2×10^{-3}	0.11×10^{-3}
π^- contamination	0.01×10^{-3}	0.006×10^{-3}
Total	6.4×10^{-3}	3.2×10^{-3}

3.7. Determination of Q^2

Since the measured asymmetry is directly proportional to Q^2, this uncertainty will feed directly into any interpretation of the measured asymmetry. Thus, the uncertainty in the measured kinematics will act as an error on the reported asymmetry A_d. The uncertainty in the beam energy from arc measurements will be $\delta E/E = 1 \times 10^{-3}$ [34]. The uncertainty in the scattered electron's energy as measured by the HRS or SHRS is $\delta E'/E' = 1 \times 10^{-3}$ [34], and the angular resolution of the pointing of the spectrometers is $\delta\theta = 0.17$ mrad [34]. Previous measurements in Hall C have achieved $\delta\theta = 0.4$ mrad [40]. Combining these (using $\delta\theta = 0.4$ mrad) gives $\delta Q^2/Q^2 = 3.9 \times 10^{-3}$.

3.8. Summary of Experimental Systematic Uncertainties

Given the relatively large asymmetry of this measurement, small statistical uncertainty can be achieved with a relatively modest beam allocation. Care must be taken to control the experimental systematic uncertainties at the same level. Expectations for experimental uncertainties are summarized in Tab. III.

3.9. Expected Running Time

The goal of this experiment is to achieve 0.5% statistical precision, with comparable systematic uncertainty, on the parity violating asymmetry in deep inelastic scattering, A_d. Because of the

TABLE IV: This table outlines the expected beam request for production data collection as well as for studies of systematic effects.

Beam Use	time (days)	Beam Energy (GeV)
Production	24	11
DAQ Commissioning and Low Rate	2	11
Rate Issues (High Rate Running)	1	11
Optics Calibration	0.5	11
e^+e^- Pair Background	0.5	11
Empty Target Asymmetry	1	11
Elastic Measurement	1	6.6
Total	30	

relative large asymmetry, $A_d \approx 280$ ppm, this can be realized in a relatively short period of production running–24 days. In addition to this beam time allocation, beam time will also be needed to study rate effects, particle identification efficiencies, empty target asymmetries and backgrounds. These studies are discussed in more detail in Secs. 3. Anticipated beam time requirements for these studies are outlined in Tab. IV. Including the various times to study systematic effects, this measurement will require 30 days of beam allocation.

4. HADRONIC PHYSICS ISSUES

While the experimental challenges described in the previous section are significant, a measurement of A_d approaching 0.5% (stat) + 0.5% (syst) appears to be feasible. However, there are open questions in hadronic physics at this level of precision which complicate the interpretation of this asymmetry in terms of Standard Model parameters. This section will describe some of these interesting issues.

4.1. Uncertainty from Parton Distributions

As described in Section 2.1, A_d is specified by Standard Model parameters and the parton distribution functions (PDF), with the latter entering Eq. 12 through the ratios R_s and R_v defined in Eqs. 14, 15. These PDFs are well described by global fits to world data and additionally some sources of uncertainty (such as Q^2 evolution) may cancel out in these ratios.

The parton distributions provided by CTEQ [41, 42] and MRST [43, 44] also provide uncertainty estimates. These set the scale for the impact of the statistical uncertainties of the global fit on interpretation of A_d at around 0.1%. Both give similar results for the uncertainty in extracting $\sin^2\theta_W$ from A_d. In particular, CTEQ's parametrization yields $\delta\sin^2\theta_W/\sin^2\theta_W = 0.47\times10^{-3}$. In addition, the difference between the CTEQ and MRST parton distributions falls well within this uncertainty.

4.2. Uncertainty in R_{LT}

The ratio $R_{\mathrm{LT}} = \sigma_L/\sigma_T$ is taken from a global fit, R1998 [45]. It enters A_d through the calculation of the kinematic quantity Y defined in Eq. 13. Propagation of the uncertainty from the this fit yields an uncertainty in the extracted value for $\sin^2\theta_W$ of $\delta\sin^2\theta_W/\sin^2\theta_W = 0.08\times10^{-3}$.

4.3. Higher-Twist Effects

Among all hadronic effects that could contribute to PV electron scattering observables, the higher-twist (HT) effect is expected to be the most probable for kinematics at Jefferson Lab. Here higher-twist effects refer to the fact that the color interactions between the quarks become observable at low Q^2 and the process cannot be described by the leading twist process of $\gamma(Z)$ exchange between the electron and a single quark. For electro-magnetic scattering processes, these interactions introduce a scaling violation to the structure functions in the low Q^2 region below 1 GeV/c^2 that is stronger than the $\ln(Q^2)$-dependence of the DGLAP equations of pQCD. For PV $\vec{e}$–^{2}H scattering, HT effects start from twist-four terms which diminish as $1/Q^2$.

The theory for HT effects is not well established. Most of the knowledge for HT is from experimental data, which itself faces difficult theoretical issues in interpretation. For example, when determining the HT effects from DIS structure functions F_1 and F_2, the leading twist contribution often cannot be subtracted cleanly because of the uncertainty due to the cutoff in summing the α_s series, and the uncertainty in α_s itself in the low Q^2 region. In another example, the first parametrization of the HT coefficient C_{HT}, performed using a Next-Leading-Order (NLO) pQCD calculation to describe Q^2 evolution, showed a sizable effect for all x values that increases dramatically at higher x [46]. The latest fit to the HT coefficient, however, shows that the effect for $0.1 < x < 0.4$ diminishes quickly to $< 1\%/Q^2$ as higher order terms (NNLO and NNNLO) are included when evaluating the leading-twist term [43].

By contrast, the prospects for observing HT contributions in PV-DIS are relatively uncomplicated. Many QCD complications which are present in cross-section measurements are suppressed in the parity-violating asymmetry. The observation of any Q^2-dependent deviation from the expected asymmetry would strongly imply a contribution from HT. With the prospect of pushing precision to the sub-1% level, it may be that parity-violating electron scattering will provide the most accessible method for a transparent study of HT.

Despite the existence of this experimental opportunity, there is almost no information from data on how HT effects PV observables. The 6 GeV PV-DIS experiment E05-007 [13] will be the first one exploring this effect, at moderate x and at two Q^2 value of 1.1 and 1.9 (GeV^2). Theoretically, estimates of the twist-four corrections to the asymmetry in $\vec{e}$–^{2}H scattering have been carried out in various models, with results that do not definitively limit the possible contributions of HT in this kinematic range to negligible levels. In a work by Castorina and Mulders [47], the expansion of the product of electromagnetic and weak currents within the MIT bag model was used to estimate a 0.3% correction to the asymmetry at $Q^2 = 1.0$ GeV/c^2 (thus 0.1% to our proposed kinematics). In a similar work by Fajfer and Oakes, an upper limit on the effect was found corresponding to an effect on the asymmetry of $< 2\%$ [48].

Another approach to estimate HT correction to DIS-parity is based on experimental data on C_{HT} and the assumption that the HT effects partly cancel in the numerator and the denominator of the asymmetry. One possible effect that does not cancel comes from the different coupling strength of the EM and weak interactions in the interference term, which is proportional to the EM and weak charges, respectively. Quantitative calculations for the HT correction to A_d were performed in the QCD LO, NLO and NNLO framework [49], showing the HT correction to A_d is at level of $1\%/Q^2$ for $0.1 < x < 0.3$ in NLO or higher order analysis.

We are currently working with theorists on a modern estimation of the HT in DIS-parity from QCD [23]. Due to the non-trivial calculations needed by this task, we expect to have some results in about one year.

One interesting remark is that, it has been shown that although the NuTeV measurement was performed at $\langle Q^2 \rangle = 20$ GeV/c^2, the HT contribution to the typically measured Paschos-Wolfenstein (P-W) ratio could be of the same magnitude as that to the DIS-parity observable at $Q^2 \approx 2$ GeV/c^2 [50]. If the NuTeV deviation from the Standard Model is fully due to higher twist, than this would imply a 1.7% contribution to our proposed measurement. Although this is a model-dependent calculation, it underscores the uncertainty in determination of HT effects in other contexts. The precision measurement proposed here would clearly be sensitive to this magnitude of HT correction.

It is clear that the HT effects present a significant challenge to the interpretation of this proposed measurement in terms of impact on Standard Model. Most likely, HT effects will only be constrained with the addition of new data. The approved 6 GeV PV-DIS experiment would be an excellent start, providing a first glimpse of possible HT effects at low Q^2 and moderate x. A more comprehensive study would be enabled by a large acceptance spectrometer, which would extend precision coverage into the high x kinematics where DIS scattering rates are low.

4.4. Charge Symmetry Violation (CSV)

Charge symmetry implies the equivalence between the $u(d)$ distributions in the proton and the $d(u)$ distributions in the neutron. This symmetry is trivially violated by the mass difference between the u and d quarks, but most low energy tests appear to justify the common assumption that this symmetry is good to at least the 1% level [51]. Since charge symmetry is satisfied at lower energies, it is natural to assume that it holds for parton distribution functions as well. Calculations applying the MIT bag model [52],[53] or the Meson Cloud models [54] have produced results for CSV ranging from $< 0.1\%$ to a few percent. Recent global fits of the quark distributions have now also included the possibility of charge symmetry violation in valence and sea quarks [43]. The subject is particular sensitive for precision new-physics searches; CSV effects have become a leading suspected cause for the 3σ deviation from the Standard Model observed by the NuTeV collaboration [55].

The CSV distributions are defined as

$$\delta u(x) = u^p(x) - d^n(x) \tag{25}$$

$$\delta d(x) = d^p(x) - u^n(x) \tag{26}$$

To a good approximation, these CSV parameters enter the expression for the parity-violating asymmetry as a ratio:

$$\frac{\Delta A_d}{A_d} \sim 0.3\, \frac{\delta u - \delta d}{u + d} \tag{27}$$

For illustrative purposes, one can compare the implied effect on A_d for a calculation using the MIT Bag Model and including "QED splitting" [56] with that for the global MRST PDF fit [43].

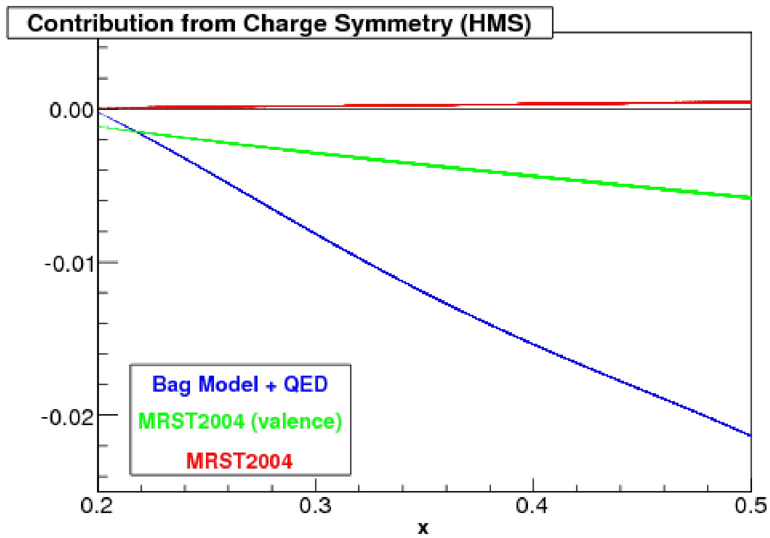


FIG. 7: Various predictions for the fractional change in the parity-violating asymmetry $\Delta A_d/A_d$, plotted against x, for the proposed measurement. The valance contribution for the MRST fit is shown independently, to stress the high degree of cancellation between sea and valance CSV.

Figure 7 shows these effects, plotted against Bjorken x. The model calculation would suggest a 1.2% change in A_d realative to the assumption of charge symmetry, while the MRST fit suggests a change of only 0.02%. The MRST result is actually a result of a high degree of cancellation between CSV of the valance quarks and CSV of the quark sea. This cancellation is evident also in Fig. 8, which shows the individual CSV violation parameters for both the MRST fit and the model calculation under discussion. It is worth noting that the MRST fits allow a wide range of values for these parameters. For example, the value of the valance contribution alone might range from 4 times larger to 3 times larger with the opposite sign, within the 90% confidence level of the fit.

These uncertainties reflect the generally poor state of the world experimental data on CSV; the parameters are simply not tightly constrained by existing data. Future experiments may be able to provide significant new constraints on parton level CSV [57]. Although it cannot constrain CSV contributions at a sufficient level for this proposal, the 6 GeV PV-DIS experiment E05-007, which will run at the same x proposed here but a lower Q^2, would still be sensitive to large CSV effects and may spark additional interest in this question.

While an individual measurement of the asymmetry cannot completely disentangle uncertainties due to partonic CSV, higher twist, or poorly measured Standard Model parameters, these issues do have different kinematic dependencies. The well-known signature for HT effects is a contribution

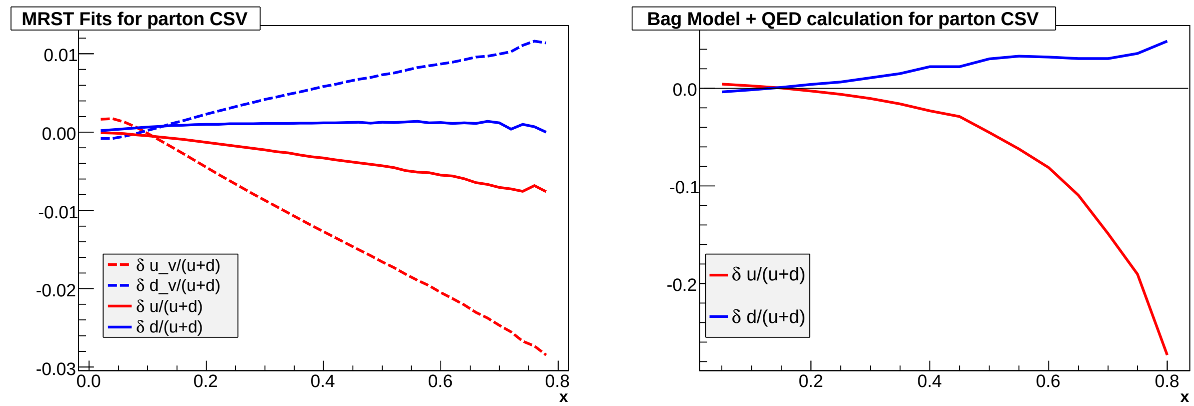


FIG. 8: Various predictions for the CSV parameters. Left: Results for valance and total CSV parameters fit by MRST [43], which demonstrates the high degree of cancellation with inclusion of the sea. Right: results of Bag Model calculation combined with QED splitting [56]. Averaged over the HMS acceptance, this calculation would imply a 1.1% change in A_d relative to the charge-symmetry-respecting expectation, compared to only 0.02% for the MRST fit.

which scales as $(1/Q^2)^n$, whereas CSV should exhibit a weak or negligible Q^2 dependence. Both HT and CSV are expected to grow large at high x. The Standard Model parameters $C_{1u(d)}$ and $C_{2u(d)}$ are independent of kinematics, but contribute proportionally according the kinematic parameter Y (defined in Eq. 13). Measurements over a range of x and Q^2 would provide an opportunity to set tight upper limits on contributions from each of these effects independently.

5. COMPLEMENTARITY WITH POSSIBLE LARGE ACCEPTANCE DEVICE PROGRAM

As described in Sec. 4, PV-DIS is sensitive to a combination of the poorly-measured Standard Model parameters $2C_{2u} - C_{2d}$, but also to two open issues in hadronic physics which are interesting in their own right: charge symmetry violation and higher twist. Measurement of A_d over a wide range of Q^2 and x should allow independent constraints on each of these effects. However, low DIS rates make covering a sufficient kinematic range with high precision a significant challenge.

The measurement proposed in this document, while it cannot independently separate these effects, would be probing unexplored territory. Any observed deviation from the expected A_d would be certain to inspire and inform further studies of these interesting hadronic issues and to focus interest on the poorly-measured $C_{2u(d)}$ Standard Model parameters. However, a full program to take advantage of this experimental opportunity requires a large acceptance (and high luminosity) device. As it appears that an effort to develop such a device is likely, it is necessary to discuss how this proposed measurement would fit in to a larger program.

Some of the options being considered for this large acceptance device (LAD) do not easily extend to a large range of scattering angle or E'. Once a stable spectrometer concept emerges, it will be possible to predict what the kinematic coverage will be available. At that stage, the full importance of the HMS/SHMS spectrometers to make a key contribution to the kinematic coverage will become apparent.

It may also be that experimental challenges in approaching the ultimately desired systematic precision near 0.5% are best met by a reduced aperture spectrometer such as the HMS/SHMS. Such a spectrometer has a clear advantage (over the open geometry of a LAD) in determination of the central kinematics, averaging over the accepted kinematics, and in background suppression. In such a case, the LAD might be used with systematics at the 0.7% or 1.0% level to constrain CSV and HT in kinematic regions where they are expected to be more easily accessible (i.e. high x). Tight constraints could then still constrain these effects enough to allow a clean interpretation of the HMS/SHMS point at moderate x in terms of the Standard Model C_2s.

Given the expected experimental complexity of such a precise measurement, an independent measurement, even at overlapping kinematics and similar precision, would be a powerful cross-check. Finally, if a LAD program is launched in Hall A, an early running of this proposed measurement in Hall C with baseline equipment might be expected to help direct the emphasis of the Hall A program.

6. CONCLUSION

Parity violation in deep inelastic (DIS-Parity) scattering has and will continue to play an important role in our understanding of the Standard Model. DIS-Parity offers sensitivity to the vector Z-electron times axial Z-quark couplings, C_{2q}, not offered by other experiments and thereby provides complementary constraints on processes and particles not included in the Standard Model. At the same time, the asymmetry is relative large, allowing for statistically sensitive measurements to be completed with modest beam time.

The interpretation of this asymmetry is clouded by possible contributions from higher twist and charge symmetry violation. These effects, which are themselves topics of great interest in hadronic physics, can be constrained by further PV-DIS studies over a broad range of x and Q^2. Such a program is not feasible with existing spectrometers at Jefferson Lab, which will likely motivate the development of a new, dedicated apparatus. Thus, the proposed measurement will likely serve as an important part of a larger program of PV-DIS study.

This letter of intent has outlined a measurement of parity violation asymmetry in $\vec{e}$–^{2}H DIS at $Q^2 = 3.3$ GeV^2, $\langle W^2 \rangle = 7.3$ GeV^2 and $\langle x \rangle = 0.34$. With a total beam allocation of only 30 days, an uncertainty on the asymmetry of $\delta A_d/A_d = \pm 0.005(stat.) \pm 0.006(syst.)$ can be achieved. Within the framework of the Standard Model, the value of $\sin^2\theta_W$ and the weak coupling constant combinations $2C_{2u} - C_{2d}$ can be extracted and we expect uncertainties of $\delta \sin^2\theta_W / \sin^2\theta_W = \pm 0.0025(stat.) \pm 0.0032(syst.)$ and $2C_{2u} - C_{2d} = 0.015$. These results could provide constraints on different possible extensions of the Standard Model.

APPENDIX A: RELATION TO PV-DIS (JLAB E05-007)

Some of the motivation for this 12 GeV experiment is similar to the 6 GeV PV-DIS (JLab E05-007) experiment. Both experiments are using parity violation in deep inelastic scattering, but the goals of these two experiments are quite complementary. The PV-DIS experiment will be studying the Q^2 dependence A_d. As such, the 6 GeV PV-DIS measurement is important to the interpretation of the measurement proposed here, since they will constrain the $1/Q^2$ dependence of possible higher twist hadronic effects. (See Sec. 4.3.) As a probe of the Standard Model, the 6 GeV PV-DIS experiment, while good, lacks the statistical and systematic sensitivity of this measurement. In addition, the measurement proposed here is at kinematics (both higher Q^2 and W^2) which put it firmly into the DIS region.

APPENDIX B: TECHNICAL PARTICIPATION OF ARGONNE NATIONAL LABORATORY

The Physics Division at Argonne National Laboratory is actively involved in this Letter of Intent for JLab Hall C. The Argonne Group is responsible for the initial optics design of the SHMS and for the spectrometer field maps and verification of the SHMS optics. In addition, should this Letter of Intent become an approved experiment, the Argonne group will make a commitment to the realization of the Compton Polarimeter for Hall C.

APPENDIX C: OPTION OF RUNNING IN HALL A WITH BOTH HRS SPECTROMETERS

This experiment can also be realized with the Hall A baseline equipment; although, the situation is not optimal for this experiment in Hall A. In terms of this measurement, the primary differences are a more limited solid angle in the HRS pair and a significantly lower maximum momentum. To reach the same Q^2 range, it is then necessary to move to a larger angle and with a correspondingly smaller cross section. Nevertheless, it is worth considering since the it is quite likely that Hall A will be running with 11 GeV beam and the pair of HRS spectrometers well before the upgrades are completed in Hall C. Additionally, it is likely that the backlog for 11 GeV beam time in Hall C may be significantly larger than the corresponding backlog in Hall A.

One possible choice of kinematics for a Hall A measurement would be to set both HRS spectrometers to a 4 GeV central momentum[4] at 14°. This would give $\langle Q^2 \rangle = 2.6$ GeV^2, $\langle W^2 \rangle = 11.4$ GeV^2 and $\langle x \rangle = 0.2$. Unfortunately, the rate is only about 54 kHz/spectrometer in this configuration. To obtain approximately the same statistical precision on A_d requires approximately 100 days of beam rather than the 17 days of production running in Hall C. The π/e ratio, as well as the absolute flux of pions is much worse at in these kinematics with $pi/e \approx 8$ and the absolute pion rate at around 430 Hz, based on the measurements of Wiser *et al.* [37]. Most of the systematic uncertainties would remain approximately the same.

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