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A. TITLE:

PARITY VIOLATION IN ELASTIC SCATTERING FROM THE PROTON AND ^{4}He

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PARITY VIOLATION IN ELASTIC SCATTERING FROM THE PROTON AND ^{4}He

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Abstract

We are proposing to measure the parity-violating electroweak asymmetry in the scattering of polarized electrons from the proton and ^{4}He. This is a Hall A collaboration assisted experiment which will use both spectrometers as independent instruments. We plan to obtain unique information about the weak form factors of the nucleon, emphasizing the "electric" form factor. Our measurement will be extremely sensitive to contributions from strange quarks, even if they are somewhat smaller than suggested recently by Jaffe. Our initial run will be at one or two points for hydrogen where the effects of the strange quarks are likely to be the largest.

PARITY VIOLATION FROM ELASTIC SCATTERING
FROM THE PROTON AND ^{4}He

I. INTRODUCTION

We describe here an experiment which uses the precision spectrometers in Hall A to measure the parity violating asymmetry in the scattering of polarized electrons from light nuclei, including hydrogen, deuterium, and helium.[1] The first phase will focus on one or two optimal kinematic points for hydrogen. The results will provide unique information about the neutral weak nucleon current of the nucleon. We believe that our proposal will be a comparatively easy parity experiment, both in terms of equipment required and controlling of systematic errors. Nevertheless, it has great physics interest, as described below. Thus we believe that it will be suitable for running at CEBAF at an early stage.

II. PHYSICS MOTIVATION

The existence of the neutral weak boson, the Z_0, provides a new current for the nucleon

$$\langle p|J_\mu^Z|p\rangle = \overline{U}\Big(\gamma_\mu F_{1p}^Z(Q^2) + \frac{i\sigma_{\mu\nu}q^\nu}{2M_N}F_{2p}^Z(Q^2) + \gamma_\mu\gamma_5 G_{Ap}(Q^2)\Big)U$$

where U is the nucleon spinor. Thus there are three new form factors for the proton, F_{1p}^Z, F_{2p}^Z, and G_{Ap}, which are fundamental quantities that are important to measure as a function of Q^2. In the Standard Model[2], the couplings of the Z^0 to the quarks are known[3], and it is possible to express the weak form factors in terms of the electromagnetic ones:[4]

$$F_{ip}^Z = \frac{1}{4}\Big((1-4\sin^2\theta_W)F_{ip}^\gamma(Q^2) - F_{in}^\gamma(Q^2) - F_i^s(Q^2)\Big), \qquad 1$$

where $i = 1, 2$. Here $F_{ip}^\gamma(Q^2)$ and $F_{in}^\gamma(Q^2)$ are the electromagnetic form factors for the proton and neutron, respectively, and the $F_i^s(Q^2)$ are a new pair of form factors which result from the presence of strange quark-antiquark pairs in the nucleon.[5,6] The $F_i^s(Q^2)$ are isoscalar. If the electromagnetic form factors are known with sufficient precision[6], the $F_i^s(Q^2)$ may be determined by measuring F_{ip}^Z.

One way to measure these new form factors is to determine the parity-violating asymmetry for the scattering of polarized electrons from the proton[6]

$$A^{PV} = (\sigma_R - \sigma_L)/(\sigma_R + \sigma_L),$$

where $\sigma_L(\sigma_R)$ is the differential cross section for the scattering of electrons with left (right) helicity. The asymmetry, given in terms of the "Sachs" form factors $G_E = F_1 - \tau F_2$, and $G_M = F_1 + F_2$, is

$$A = -\frac{G_F Q^2}{\sqrt{2}\pi\alpha\xi}[\epsilon G^{\gamma}_{Ep} G^{Z}_{Ep} + \tau G^{\gamma}_{Mp} G^{Z}_{Mp} - \frac{1}{2}(1 - 4\sin^2\theta_W)\sqrt{1-\epsilon^2}\sqrt{\tau(1+\tau)} G^{\gamma}_{Mp} G^{Z}_{Ap}]$$

where $\xi = \epsilon(G^{\gamma}_{Ep})^2 + \tau(G^{\gamma}_{Mp})^2$, ϵ is the longitudinal photon polarization, and $\tau = Q^2/4M^2$.

An amusing feature of this result is that in the approximation that $sin^2\theta_W \sim \frac{1}{4}$, $F^{\gamma}_{1n} \sim 0$, and $F^{s}_{i} \sim 0$, the entire asymmetry comes from the F^{γ}_{2n} term in equation 1.[7] The asymmetry with these assumptions is denoted the 0th *order approximation.* In other words, the observed parity asymmetry in the proton is dominated by the ordinary electromagnetic form factor of the neutron.

At fixed Q^2, the role of each of the weak form factors changes as a function of scattering angle θ. The coefficient in front of G^{Z}_{Ep} is largest at $\theta = 0$ and vanishes as $\theta \rightarrow 180°$; the one in front of G^{Z}_{Ap} is largest at $\theta = 180°$ and vanishes as $\theta \rightarrow 0$; and the one in front of G^{Z}_{Mp} is finite at all angles but larger at larger angles. Separating the form factors requires measurements at three different angles at the same Q^2. A suitable set of angles might be $\theta < 15°, \theta \sim 60°$, and $\theta > 120°$. This requires a large dynamic range in energy.[8]

Hall A will have excellent facilities for parity measurements *at forward angles.* The ideal parity spectrometer might have a $\Delta\theta/\theta$ acceptance of $\sim 20\%$, a ϕ acceptance of 2π, and a momentum acceptance of the detector of $\sim 2\%$. The cost of such a device designed for a 4 GeV/c beam would be prohibitive. On the other hand, at the minimum θ of 12.5° of the Hall A spectrometers, the solid angle coverage is about 25% of the ideal. In addition, the resolution is excellent. Thus Hall A at CEBAF is ideal for the forward angle part of a program to measure the F^{Z}_{ip}.

Significance of the Weak Form Factors

Our main motivation for this experiment is to obtain information about the F^{Z}_{ip} because they are a fundamental property of the nucleon. Presently the greatest interest in these form factors stems from the possibility that they have a substantial contribution from strange quarks.[9] Surprising results from the EMC collaboration on spin-dependence in deep inelastic scattering have given credibility to the idea that strange quarks may have sizable matrix elements in ordinary nucleons and significantly contribute to the form factors. According to simple arguments using vector dominance, however, one might expect that this contribution should be negligible.[10] Indeed, measuring the weak form factors may be one of the most practical ways to settle this issue.

One important question is which of the three form factors is the best candidate for a first experiment. One might be tempted to focus on G_A, which lacks the constraints of CVC and is closely related to the EMC effect. However, for parity violation in polarized electron scattering, it is a poor candidate for the following reasons:

1. G_{Ap}^Z is multiplied by $(1-4\sin^2\theta_W)$, which is small since $\sin^2\theta_W \sim 0.233$. Therefore it makes a relatively small contribution to the asymmetry.

2. The radiative corrections for G_{Ap}^Z are relatively large because they do not have the $(1-4\sin^2\theta_W)$ factor. In addition, these corrections involve hadronic effects that presently are not amenable to rigorous calculation.[11,12] Thus the G_{Ap}^Z term may be regarded as a nuisance in ep scattering. For neutrino scattering, the above two comments do not apply; neutrino scattering is probably the best place to seek information about G_{Ap}^Z.

The SAMPLE collaboration[13] at Bates is seeking to find strangeness in the nucleon by determining F_2^s, which at Q^2=0 is simply the strange contribution μ_s to the magnetic moment anomaly. Establishing a nonzero value for μ_s would be quite exciting because it is a fundamental static property of the proton and moreover contributes to the well-behaved vector current.

In our opinion, however, measuring F_1^s presents one of the best practical opportunities for experimentally establishing significant strange matrix elements in the nucleon. At first glance this does not appear to be true because $F_1^s(0) = 0$. However, if we measure parity violation at CEBAF at small angles, there are a number of advantages relative to the SAMPLE measurement:

1. The optimum Q^2 for parity experiments tends to be at the Q^2 corresponding to the radius of the object. For the nucleon, this is 0.2-0.5 $(\mathrm{GeV/c})^2$, where F_1^s is large.

2. The asymmetry in the 0th order approximation is small at these kinematics. The only contribution is the F_{2n}^γ term which is suppressed at forward angles. Therefore the *fractional* asymmetry due to F_1^s is enhanced.

3. The contribution from G_{Ap}^Z, with its uncertainties, is very small at forward angles.

Theory of F_1^s

There is no rigorous theory for F_1^s. The only estimates that we have come from rather speculative models. At low Q^2, F_1^s may be approximated in terms of a strange charge radius squared,

$$r_s^2 = -6[dF_1^s/dQ^2]_{Q^2=0}.$$

This leads to three questions:

1. How large might r_s^2 be?

2. Does the approximation $F_1^s = -\frac{1}{6} r_s^2 Q^2$ hold at the Q^2 of the experiment, and if not, how far off is this extrapolation?

3. For the neutron, $F_1 \sim \tau\mu_N$ at low Q^2. Is a similar relation true for strange quarks or does the $\tau\mu_s$ term make a small contribution to r_s^2?

A number of speculative predictions for $r_s^2$and μ_s appear in the literature[10,14] and are presented in Table I. There seem to be two classes, those with $|r_s^2| < 0.01$ fm^2 and those with $|r_s^2| > 0.1$ fm^2. Establishing the validity of one of the large predictions would be important. Establishing a value near the low prediction (vector dominance) would indicate that strange quarks are unimportant for the vector form factors.

From the table we see that $|r_s^2| \gg \tau\mu_s$ for all cases. Therefore F_1^s and F_2^s are independent.

Table I. Predictions for Strange Quarks in the Nucleon

Model	r_s^2(fm^2)	μ_s
SU(3) Skyrme Model	-0.19	-0.33
Skyrme, broken symmetry	-0.10	-0.13
Jaffe, 8.1	0.11	-0.25
Jaffe, 8.2	0.22	-0.24
Jaffe, 7.1	0.16	-0.43
Vector Dominance	0.01	-0.003

Figure 1 shows the Q^2 dependence of F_1^s for several models[10,14,15,16]. Again, it is not clear how seriously these predictions should be taken. For the Jaffe parameterization, the higher the Q^2 the better, at least up to Q^2=0.5 (GeV/c)^2. For the broken symmetry Skyrme model, Q^2~0.2 (GeV/c)^2 may be more appropriate. Thus determining the optimal Q^2 for studying strange quarks is an experimental question.

Figure 2 shows the fractional change in the parity asymmetry for hydrogen using the same models. The effects are quite large (20-50% or more) at feasible kinematics. Our experiment will have a dramatic impact if the strange quarks do indeed contribute that much to the structure of the proton.

Figure 1. (21-0

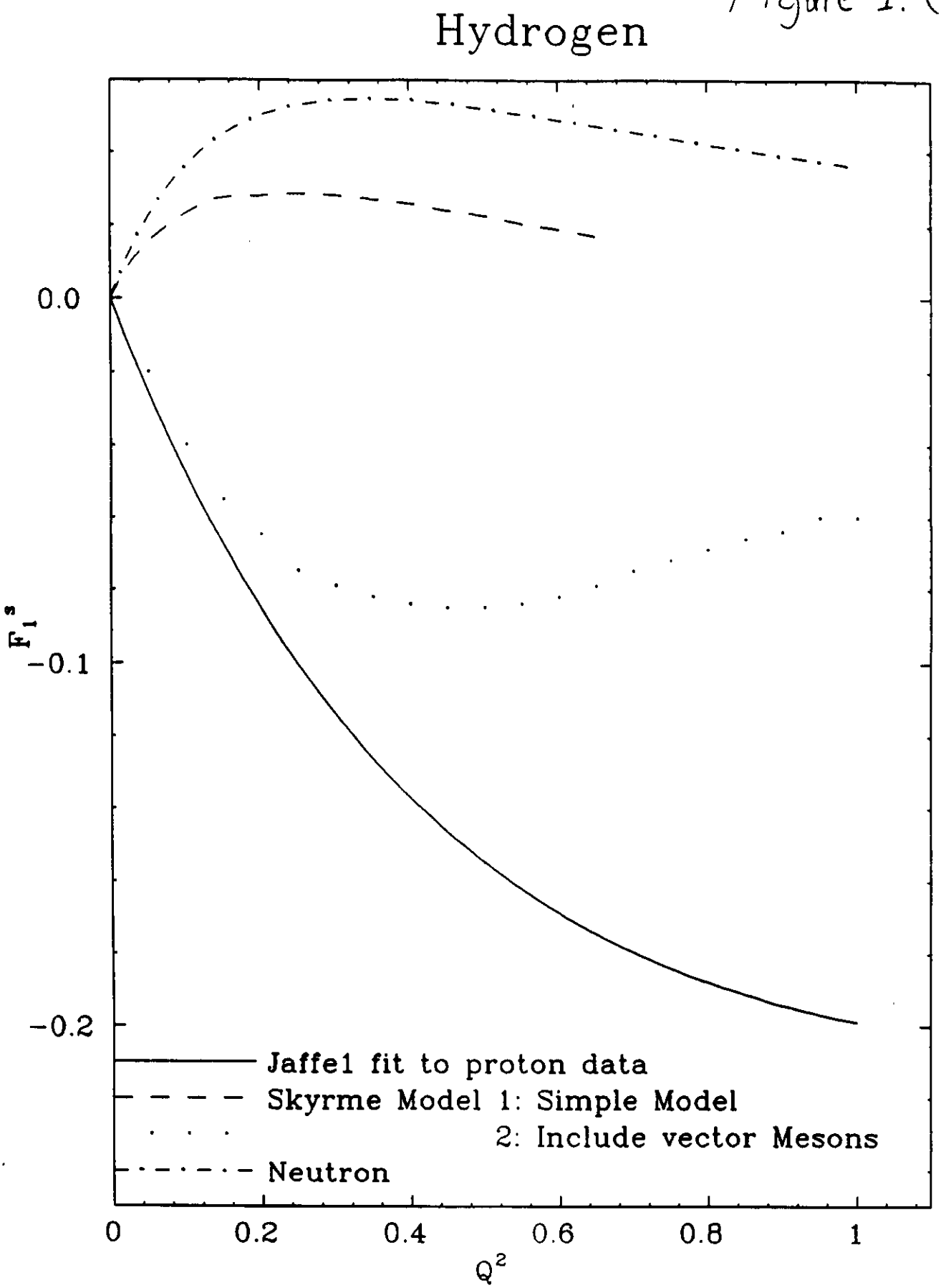

Figure 1. F_1^s as a function of Q^2 for various models. The curve labeled Jaffe is the smallest of his three estimates for F_1^s.

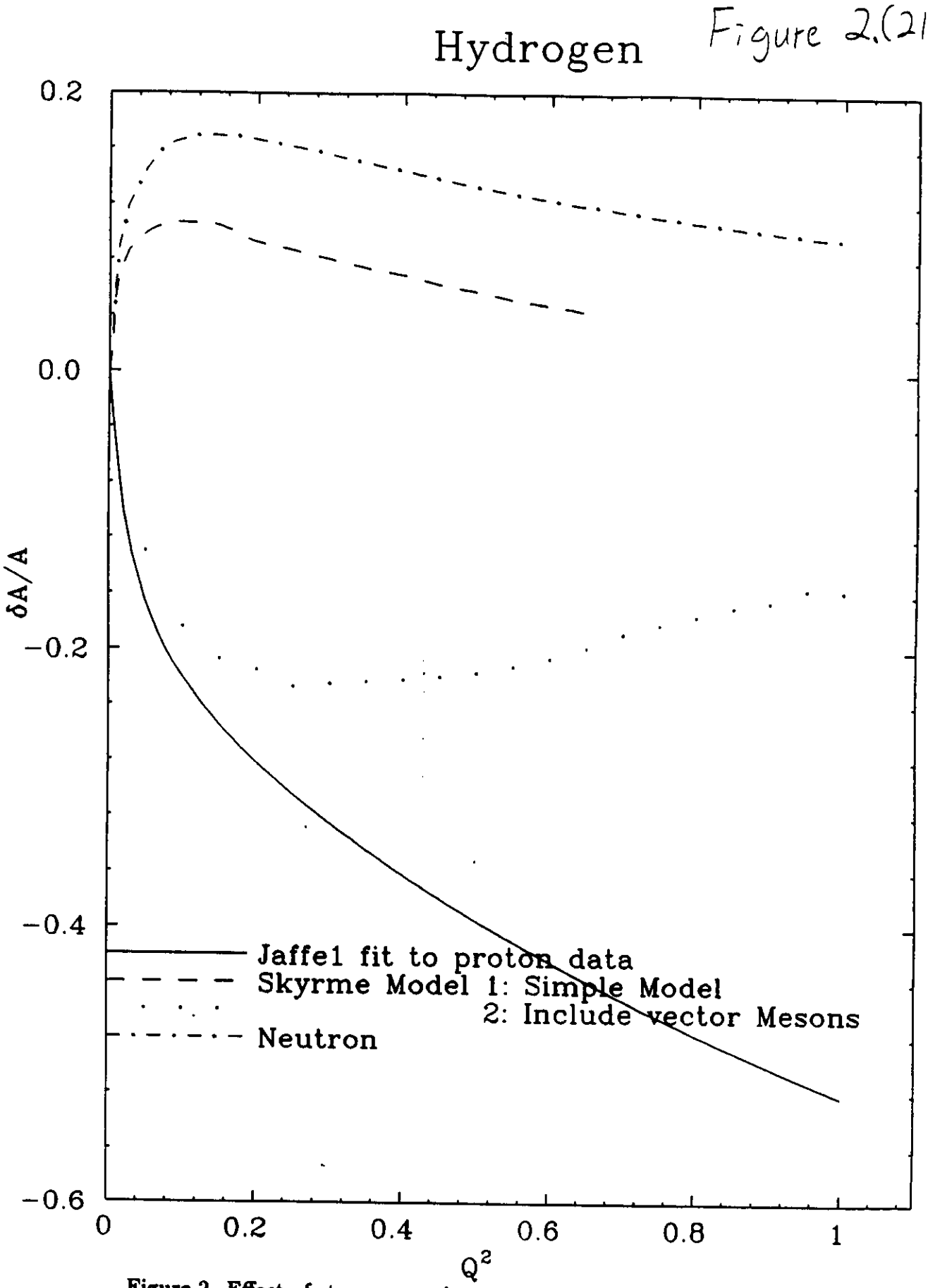

Figure 2. Effect of strange quarks on the parity asymmetry for hydrogen at small angles as a function of Q^2. The curve labeled Jaffe is the smallest of his three estimates, a second is $\sim 50\%$ bigger and the third is twice as big. Note that even the small Jaffe model predicts a 50% effect!

Figure 3. (21-00

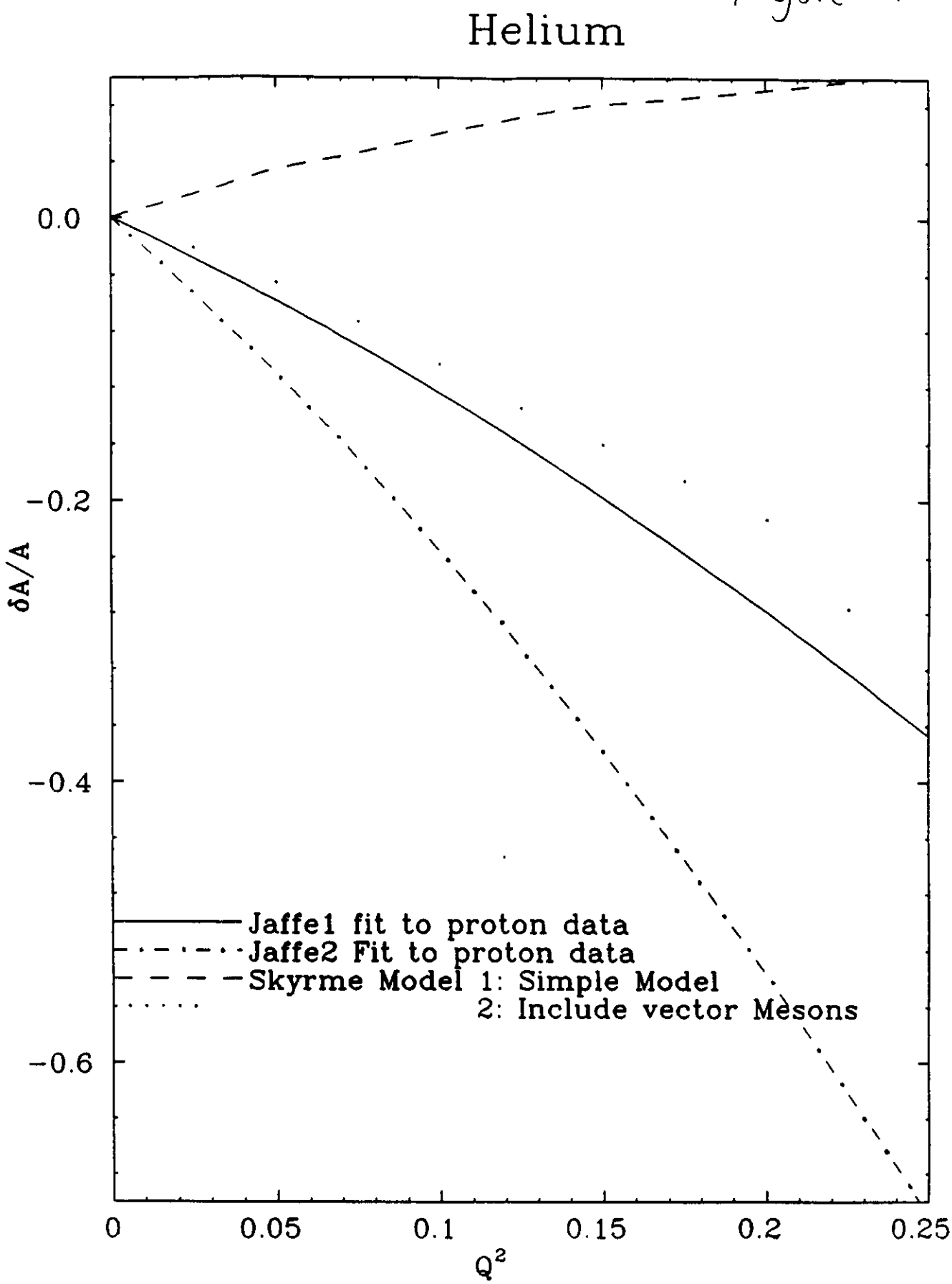

Figure 3. Effect of strange quarks on the parity asymmetry for helium at small angles as a function of Q^2. The theoretical models are the same as for Figure 2.

Parity Measurements with ^{4}He

When a spinless, isoscalar target, such as ^{4}He or ^{12}C, is used, the asymmetry becomes[17,18]

$$\mathcal{A} = \frac{GQ^2}{\pi\alpha\sqrt{2}}\left(\sin^2\theta_W + \frac{AF_1^s}{4ZF_{1p}^\gamma}\right)$$

where A is the number of nucleons and Z is the number of protons. Due to the spinless nature of these nuclei, complications due to magnetic moments or axial-vector form factors are absent. Isovector contamination of the ^{4}He ground state is expected to be small.[19] At moderately low Q^2, the contributions due to parity admixtures should be negligible. Thus it represents one of the cleanest systems for fundamental studies.

Since the asymmetry is proportional to Q^2, it is desirable to run at the highest Q^2 possible. If one is studying F_1^s, which itself is approximately proportional to Q^2 at low Q^2, it is even more desirable to run at the highest possible Q^2. Thus the primary advantage of using ^{4}He, rather than a larger nucleus such as ^{12}C, is that the elastic form factor falls relatively slowly with Q^2. to measure a larger F_1^s, where there is As described below, the optimal F_1^s point is near Q^2=0.1 (GeV/c)^2. The fractional change in the asymmetry, $\sim 2AF_1^s/F_{1p}^\gamma$, which is shown in Figure 3, is typically on the order of 10% for this point.

Helium is of course more difficult to use than hydrogen because the cross section falls much faster with Q^2 and the region where F_1^s is largest has a very low counting rate. However, if F_1^s is as large as some theories suggest (20%), the experiment is practical. The result would be especially easy to interpret because questions about μ_s and F_{1n}^γ would not apply.

Testing the Standard Model

At low enough Q^2 values, uncertainties in the form factors become negligible, and parity experiments become possible laboratories for testing the standard model. In particular, they give information about the parity-violating aspects of the coupling of the Z^0 to light quarks, information which is difficult to obtain at high energies. Violations of the standard model may arise from extra Z^0 particles, composite quarks, leptoquarks, or contributions of new physics to radiative corrections.[20]

Presently one major consideration in this field is the success of recent parity-violation experiments on the atom Cs[21]. These experiments measure essentially the same physics as do parity experiments at CEBAF. It is projected that the atomic physics results may achieve a precision of about 1% in the near future and perhaps even 0.1% within the present decade. Experiments with different isotopes of Cs may provide information about both isoscalar and isovector contributions.

Parity experiments at electron accelerators have the potential to reach perhaps the 1% level if a major program is undertaken. This is certainly much more difficult than answering the present issues about strange quarks. However, the electroweak physics is extremely important, and verifying the Cs results at the 1% level of precision is a worthy project. If the future Cs results should differ in any way from the Standard Model predictions, parity-violation experiments at electron facilities will be of the greatest importance.

For the present proposal, we plan to operate at large Q^2 values where the sensitivity is greatest to form factors. Thus we will deemphasize possible tests of the standard model. However, the limits that we will set on the form factors may prove to be crucial to future low Q^2 experiments which are aimed at testing the standard model.

CHOICE OF KINEMATICS

Scattering from Hydrogen and Deuterium Targets

The asymmetry for hydrogen is given above. We also consider the possibility of quasielastic scattering from deuterium. This process has a different selectivity than elastic proton scattering, with deuterium scattering being more sensitive to the electric neutron form factor and less sensitive to the strange magnetic form factor due to the isospin selection rules. Making the quasielastic approximation[17], we obtain:

$$\mathcal{A} = \frac{Z\mathcal{A}^p\sigma_0^p + N\mathcal{A}^n\sigma_0^n}{Z\sigma_0^p + N\sigma_0^n}$$

where $\mathcal{A}^p$ and $\mathcal{A}^n$ are the proton and neutron asymmetries and σ_0^p and σ_0^p are the unpolarized proton and neutron cross sections, respectively.

Another concern with deuterium scattering is the presence of other open channels in the quasifree region. The effective Fermi momentum for deuterium is small however, and the quasielastic channel can be separated from the quasifree pion channel, which is the other major competing mechanism.

Figures 4 and 5 show hydrogen and deuterium scattering at the minimum scattering angle of 12.5 degrees for different beam energies. Due to kinematical recoil the final electron energy is below 4 GeV for the optimum incident electron energy of 4.35 GeV and θ_e of 12.5 degrees. This corresponds to the maximum of the figure-of-merit (defined as $< \mathcal{A}^2 d\sigma/d\Omega >$) at the minimum obtainable scattering angle. Measurements can therefore be made up to a Q^2 of 0.95 GeV/c^2 before reaching the design limit of the spectrometers. To reach higher Q^2 values one can fix the incident electron energy at 4.35 GeV and increase the scattering angle. The general behavior is similar for deuterium and hydrogen, with the figures-of-merit varying by a factor of two over the range 0.27 (GeV/c)^2 $< Q^2 <$ 1.3 (GeV/c)^2. A reasonable goal might be to make five measurements in this range (Q^2 = 0.27, 0.52, 0.81, 1.05, 1.30 (GeV/c)^2).

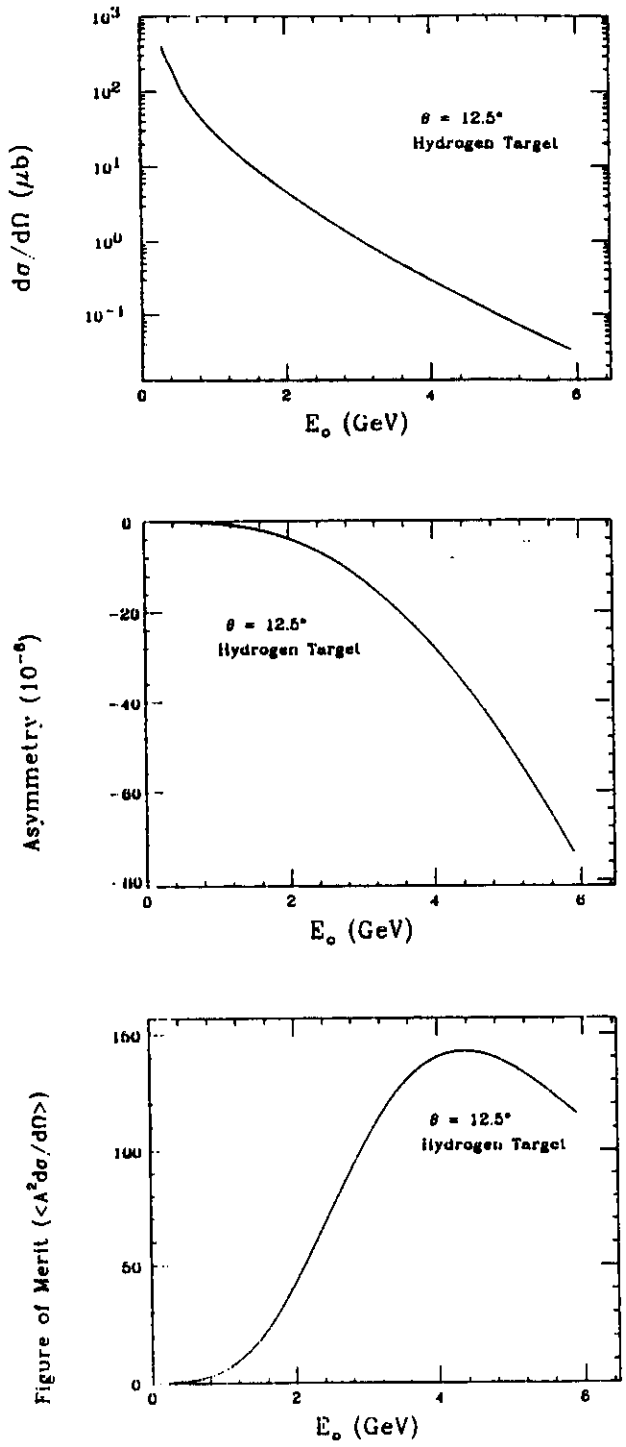

Figure 4. Cross section, asymmetry, and figure-of-merit for hydrogen.

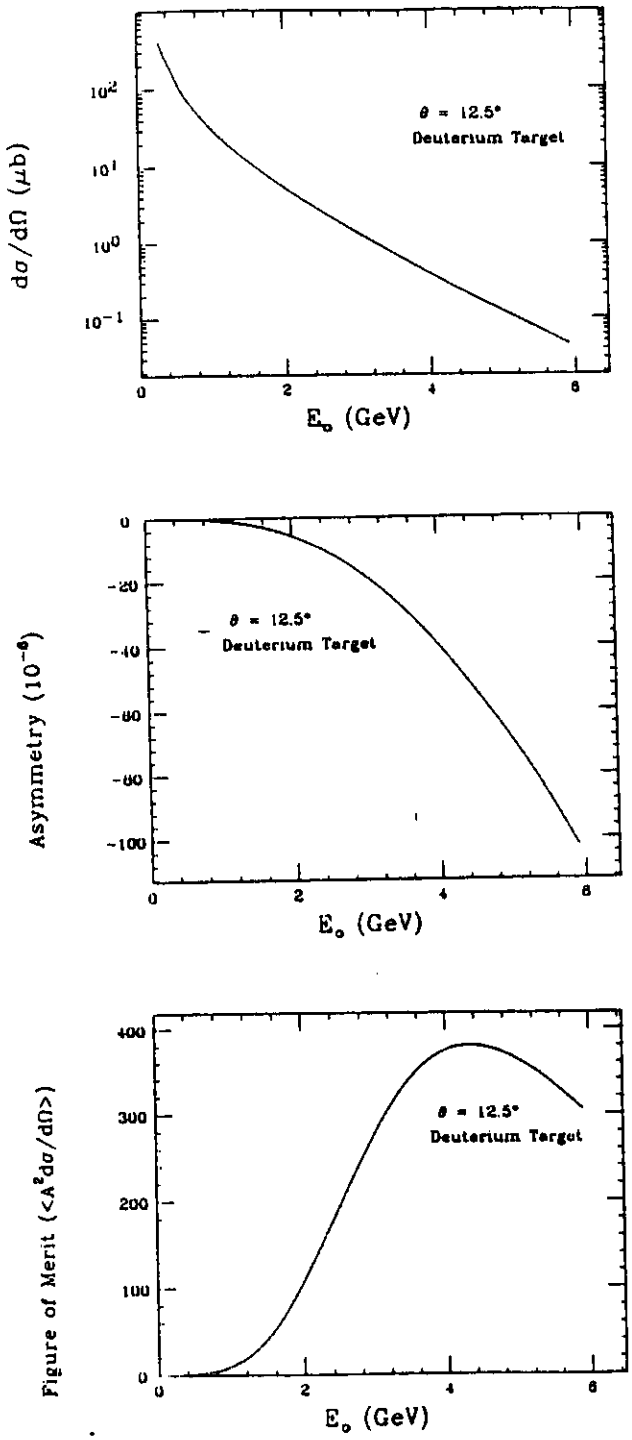

Figure 5. Cross section, asymmetry, and figure-of-merit for deuterium.

Table II.
Hydrogen

E_o GeV	θ deg	Q^2 GeV/c^2	σ μb/sr	$<\sigma>$ μb/sr	$\mathcal{A}$ 10^{-6}	$<\mathcal{A}>$ 10^{-6}	FOM $<\sigma\mathcal{A}^2>$	Rate Counts/sec	Error %
2.45	12.5	0.268	2.379	2.590	−6.981	−6.524	70.5	0.150E+08	5.02
3.45	12.5	0.519	0.598	0.669	−18.537	−17.133	125.7	0.387E+07	3.76
4.35	12.5	0.808	0.192	0.221	−34.561	−31.748	142.6	0.128E+07	3.53
4.35	14.5	1.050	0.065	0.073	−49.670	−46.656	101.1	0.419E+06	4.20
4.35	16.4	1.295	0.025	0.028	−65.878	−62.802	70.2	0.161E+06	5.03

Table II. Kinematics and rates for ^{1}H measurement. Rates assume a 100μA beam and 80% beam polarization, 16 msr total acceptance for the HRS spectrometer pair and a 1.0 gm/cm^2 target. Running times are 270 hours per point. Errors are adjusted to account for radiative losses.

Table III.
Deuterium

E_o GeV	θ deg	Q^2 GeV/c^2	σ μb/sr	$<\sigma>$ μb/sr	$\mathcal{A}$ 10^{-6}	$<\mathcal{A}>$ 10^{-6}	FOM $<\sigma\mathcal{A}^2>$	Rate Counts/sec	Error %
2.45	12.5	0.268	2.816	3.049	−10.374	−9.720	184.4	0.202E+08	5.03
3.45	12.5	0.519	0.756	0.841	−26.940	−25.008	336.5	0.556E+07	3.72
4.35	12.5	0.808	0.253	0.289	−49.134	−45.349	380.6	0.191E+07	3.50
4.35	14.5	1.050	0.087	0.097	−69.642	−65.630	267.9	0.643E+06	4.17
4.35	16.4	1.295	0.035	0.038	−91.398	−87.332	185.0	0.251E+06	5.02

Table III. Kinematics and rates for deuterium measurement. Rates assume a 100μA beam and 80% beam polarization, 16 msr total acceptance for the HRS spectrometer pair and a 2.3 gm/cm^2 target. Running times are 90 hours per point. Errors are adjusted to account for radiative losses.

The asymmetry of deuterium is somewhat larger than that of hydrogen and the density of liquid deuterium is 2.3 times that of liquid hydrogen. Although deuterium is denser than hydrogen, the energy deposited in two identical cells (one containing liquid deuterium and the other containing liquid hydrogen) will be nearly the same. The net result is that an experiment on deuterium will take approximately one third the amount of time as one on hydrogen for the same statistical precision.

Rates for hydrogen and deuterium scattering are shown in Tables II and III. These rates assume a 100 μA beam with 80% polarization and a 1.0 (2.3) g/cm^2 hydrogen (deuterium) target. Errors shown in the tables assume 270 (90) hours for hydrogen (deuterium), with errors averaging 3.5 $\sim$ 5.0% per point. Corrections for radiative losses will increase these statistical errors to 4.5 $\sim$ 5.7% per point. Logically, runs on deuterium and hydrogen should be done at the same time with each kinematics requiring a 15 day run. The total time required for measuring five points is 75 days.

Helium

Figure 6a shows the cross sectional variation for ^{4}He as a function of Q^2. The charge form factor is obtained from a fit to a Gaussian distribution by Frosch[22] *et al.* using an RMS radius of 1.68 fm. Figure 6b shows the asymmetry assuming no strange quark admixture. The plotted values are for point cross sections and asymmetries at a 12.5° scattering angle. Since these values vary rapidly with scattering angle we have also evaluated the effect of the finite acceptances of the Hall A spectrometers in Table IV. Q^2 changes by $\pm$23% over the acceptances. Typically the difference between the average and central values of the cross section and asymmetry are on the order of 10% each. Figure 6c shows the figure-of-merit as a function of Q^2 including finite acceptance effects. The figure-of-merit peaks at a beam energy of approximately 0.95 GeV.

The energy range over which a useful set of measurements might be made is from 0.45 to 1.55 GeV. This represents the energies at which the figure-of-merit has fallen by a factor of two from its maximum value. The equivalent Q^2 range is from 0.01 to 0.11 (GeV/c)^2. A practical second generation program might measure three points at beam energies of 0.45, 0.95, and 1.55 GeV. If the same statistical precision is desired for all three points, the middle point will require half the counting time than for either of the other two points. If one can control the systematic errors only as well as done in the parity experiment at Bates,[23] (2×10^{-8}) the systematic error will be approximately 3.3% at the lowest Q^2 point and 0.3% at the highest Q^2 point. We expect to be able to do better at CEBAF.

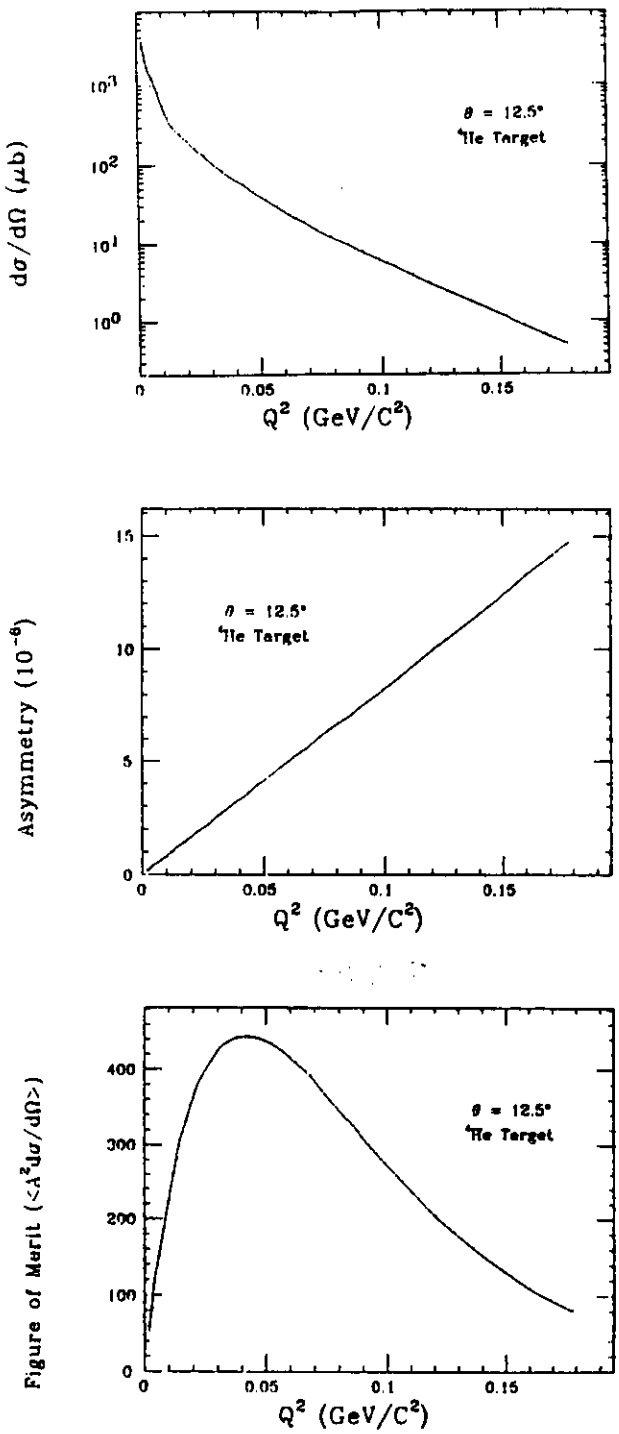

Figure 6. Cross section, asymmetry, and figure-of-merit for ^{4}He.

Table IV.
Helium

E_o	θ	Q^2	σ	$<\sigma>$	$\mathcal{A}$	$<\mathcal{A}>$	FOM	Rate	Error
GeV	deg	GeV/c^2	μb/sr	μb/sr	10^{-6}	10^{-6}	$<\sigma\mathcal{A}^2>$	Counts/sec	%
0.45	12.5	0.010	569.938	603.950	0.792	0.761	224.0	0.174E+10	4.23
0.55	12.5	0.014	340.206	362.149	1.182	1.134	298.0	0.105E+10	3.67
0.65	12.5	0.020	212.330	227.330	1.650	1.579	362.6	0.657E+09	3.32
0.75	12.5	0.027	135.912	146.558	2.195	2.094	411.2	0.423E+09	3.12
0.85	12.5	0.034	88.162	95.901	2.818	2.678	440.2	0.277E+09	3.02
0.95	12.5	0.043	57.493	63.203	3.518	3.330	448.5	0.183E+09	2.99
1.05	12.5	0.052	37.485	41.731	4.295	4.047	437.5	0.121E+09	3.03
1.15	12.5	0.062	24.337	27.502	5.148	4.828	410.3	0.794E+08	3.12
1.25	12.5	0.073	15.687	18.041	6.079	5.670	371.2	0.521E+08	3.29
1.35	12.5	0.086	10.015	11.758	7.086	6.571	324.9	0.340E+08	3.51
1.45	12.5	0.099	6.322	7.602	8.169	7.527	275.7	0.220E+08	3.81
1.55	12.5	0.113	3.940	4.871	9.329	8.538	227.2	0.141E+08	4.20
1.65	12.5	0.128	2.422	3.091	10.565	9.599	182.2	0.893E+07	4.69
1.75	12.5	0.144	1.467	1.941	11.877	10.707	142.4	0.561E+07	5.30
1.85	12.5	0.160	0.875	1.206	13.265	11.860	108.6	0.348E+07	6.07
1.95	12.5	0.178	0.513	0.741	14.729	13.055	80.9	0.214E+07	7.04

Table IV. Cross sections and rates for ^{4}He(e,e') parity violation measurements assuming 100 μA beam, 2.0gm/cm^2 target, and a 16 msr total acceptance for the HRS spectrometer pair. Error shown is the statistical error (after correction for radiative losses) for a 240 hour measurement per point. A complete program for helium might include three of the above points.

In order to obtain a time estimate we have made the following assumptions: an average beam current of 100 μA, a beam helicity polarization of 80%, a target thickness of 2.0 gm/cm^2, and a spectrometer solid angle of 8.0 msr (16.0 msr total for both spectrometers). With these assumptions a 400W cryogenic gas target is required. In addition, improvement of the beam polarization above the demonstrated 50% polarization is required. A beam polarization of 80% appears to be a reasonable goal in light of current research and development of sources. With these assumptions a 3% measurement of the asymmetry can be made in 10 days for the central point or approximately 50 days for all three points. This should result in an overall statistical error in $\sin^2\theta_W$ of 1.7%. These estimates do not include radiative corrections which reduce the cross sections by about 30% and increase the error in $\sin^2\theta_W$ to 3.4% per point or 2% overall for the same 50 day running period. The production runs can be broken into three runs of 10, 20, and 20 days each.

For a preliminary run, a more appropriate goal is to search for the effect of a nonzero F_1^s. Since this form factor is expected to grow linearly at the low Q^2 values accessible with ^{4}He, a more appropriate figure-of-merit is $< (Q^2)^2 A^2 d\sigma/d\Omega >$. This maximizes at $Q^2 = 0.1\text{-}0.15$ (GeV/c)^2. A 270 hour measurement, providing a 4% statistical error and a 6% overall error including systematics, would establish the presence of an F_1^s of a size predicted by many models. Our exact plans for this proposal are discussed under the section entitled "Run Plan."

III. APPARATUS

The implementation of a parity experiment requires an extensive amount of apparatus. Remarkably, most of this equipment is planned for use in other experiments. Major systems include a pair of spectrometers, detectors, a high-power liquid hydrogen and helium targets, an instrumented beam transport line, an electron polarimeter, a polarized electron source, and electronics to control systematic errors.

Equipment unique to the parity experiment includes the detector package, electronics that integrates the signals instead of counting, and control electronics to reduce and monitor systematic errors.

Spectrometers

The parity experiment will use both standard Hall A spectrometers positioned (mostly) at the most forward angle of 12.5°. The distribution of the elastically scattered events for the 4 GeV proton point is shown in Figures 7 and 8. Since the dispersion of the spectrometers is 12.5 cm/%, the nearest inelastic events (pion production) are 30 cm away. Even for ^{4}He, where the inelastic threshold is only 20 MeV, inelastic events are separated by more than 15 cm at an energy of 1.5 GeV. Thus the spectrometers provide a region where the detectors will see only elastic events. This makes integration techniques practical.

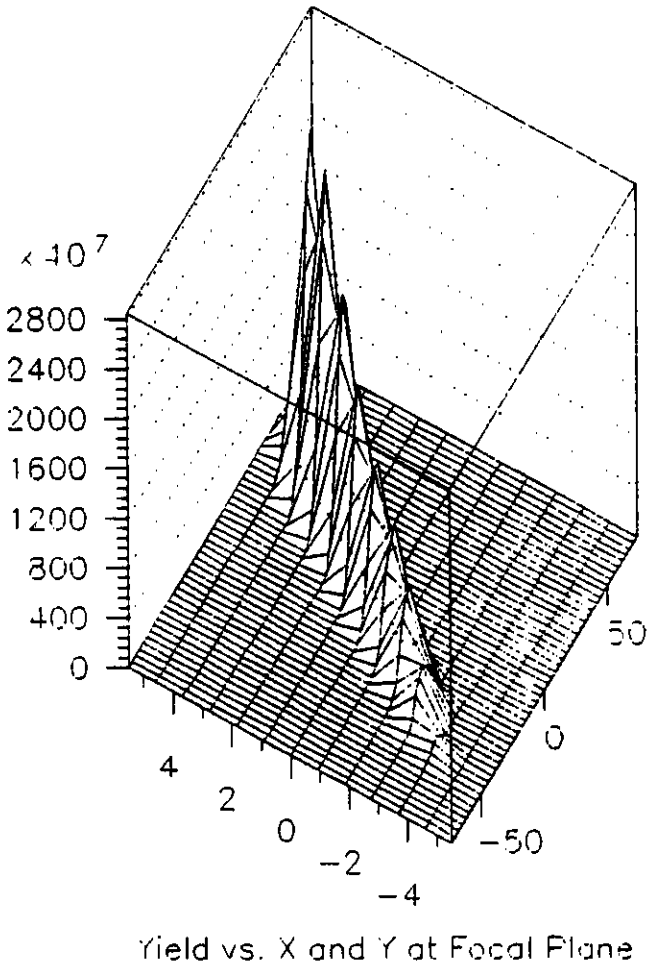

Figure 7. Distribution of unradiated elastic ^{1}H($\vec{e}$,e') events in the focal plane of the spectrometers. Radiative corrections add a low energy loss tail (smaller x). x is the dispersive direction and y, the transverse direction. The Monte Carlo data is for a 270 hour run at $E - 0 = 4.35$ GeV/c and $\Theta_e = 12.5°$. A 100 μA beam current, 80% polarization and 7.2 mstr acceptance (60mr horizonal by 120mr vertical) were assumed.

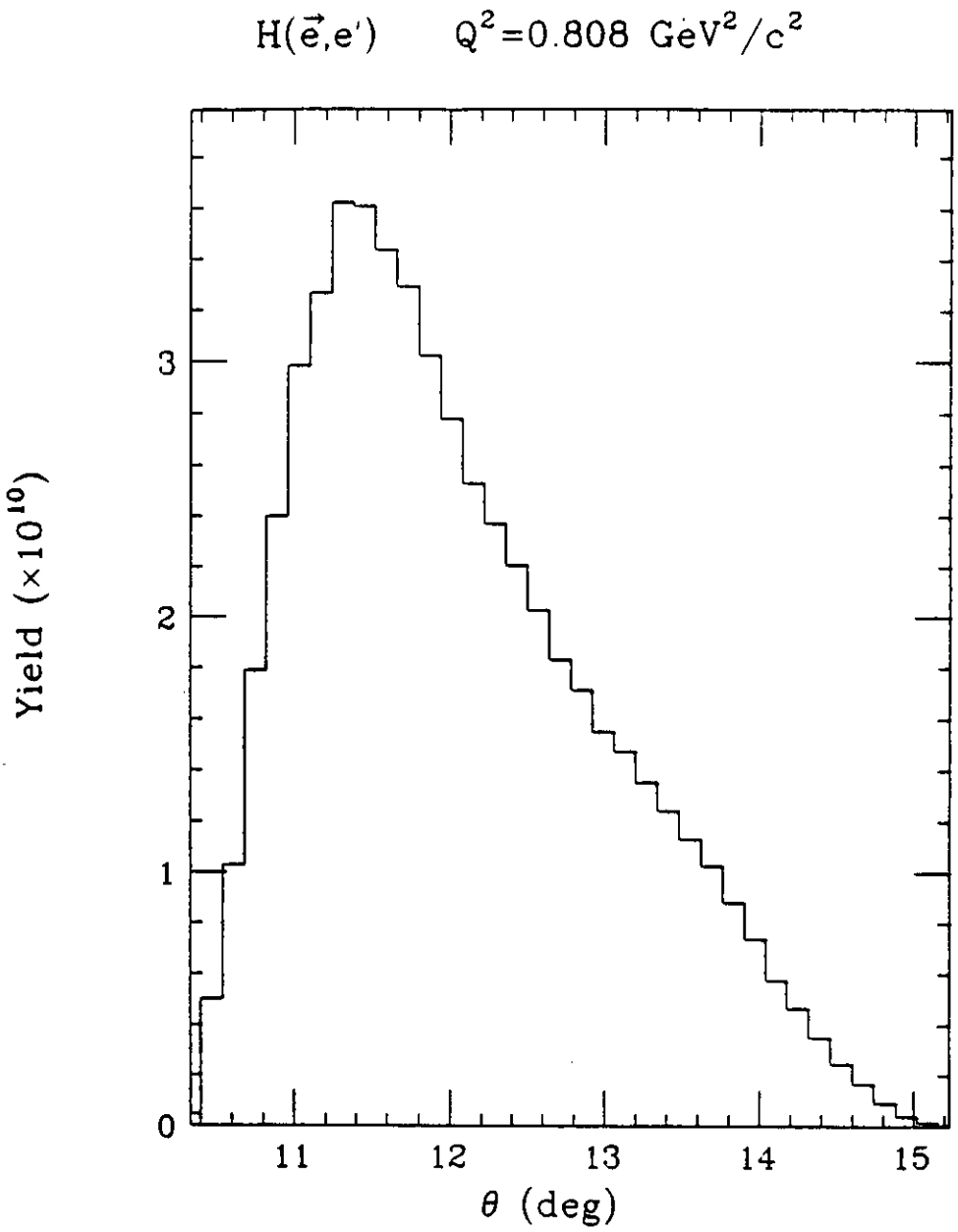

Figure 8. Yield versus angle averaged over the spectrometer acceptance for the same kinematics and conditions as in Figure 7.

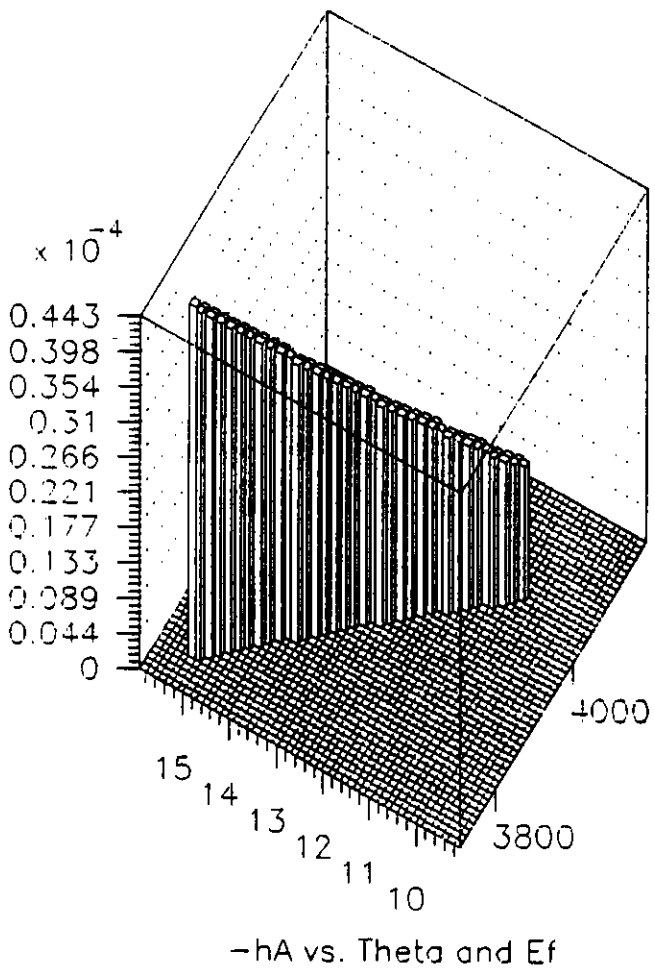

Figure 9. Measured asymmetry verses energy and angle restricted by the spectrometer acceptance for the kinematics and conditions of Figure 7.

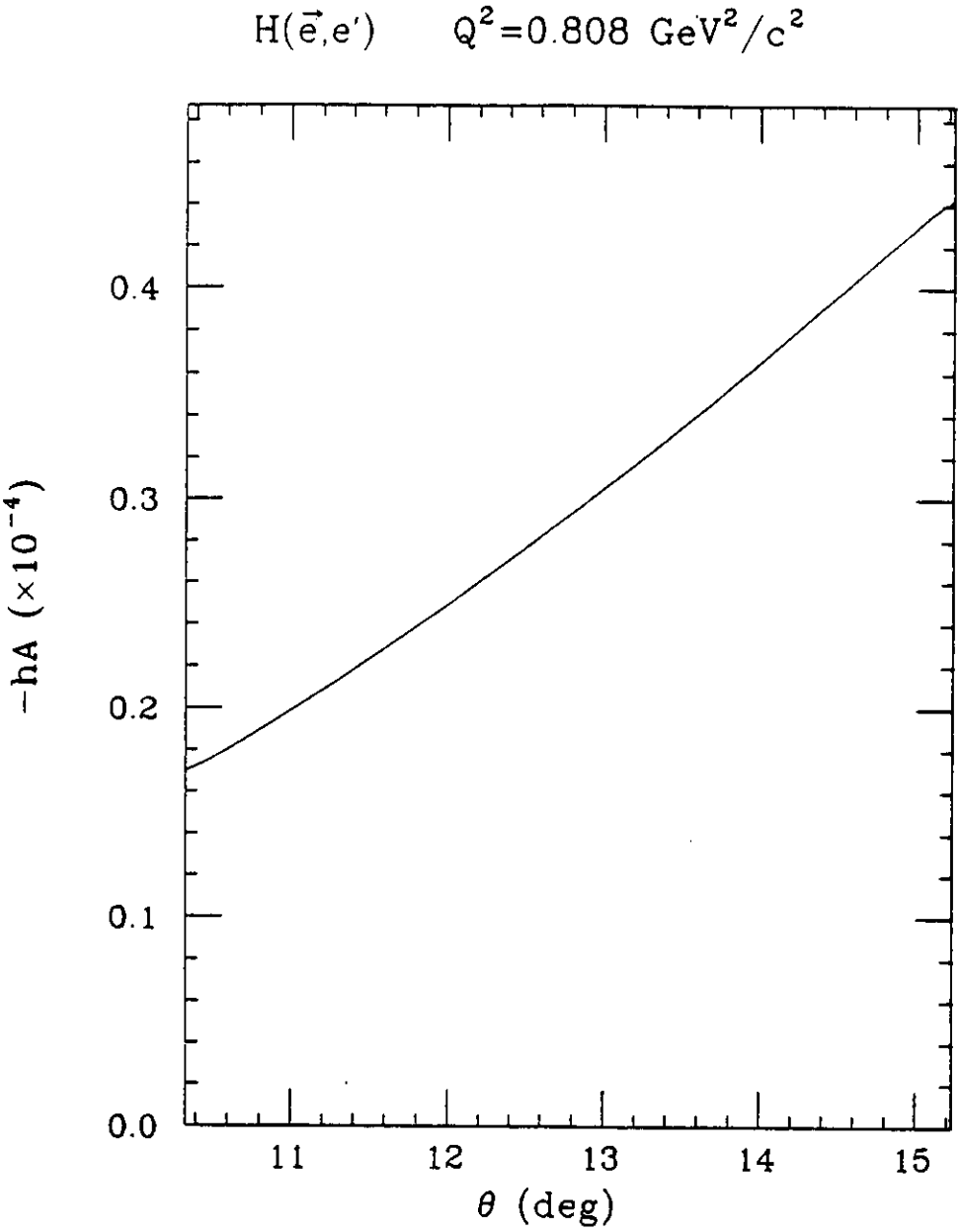

Figure 10. Measured asymmetry versus angle for the kinematics and conditions of Figure 7.

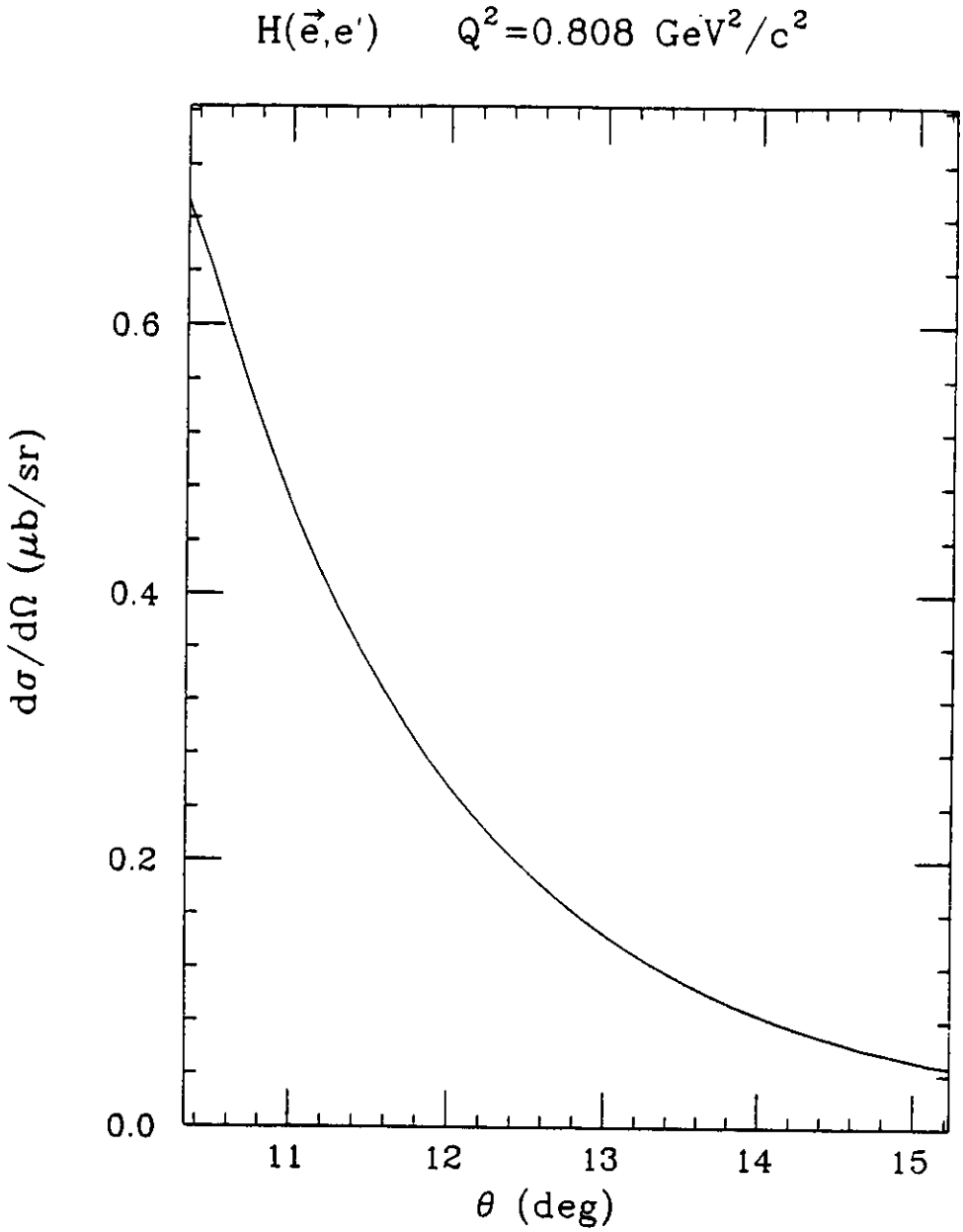

Figure 11. Cross section versus angle for the kinematics of Figure 7.

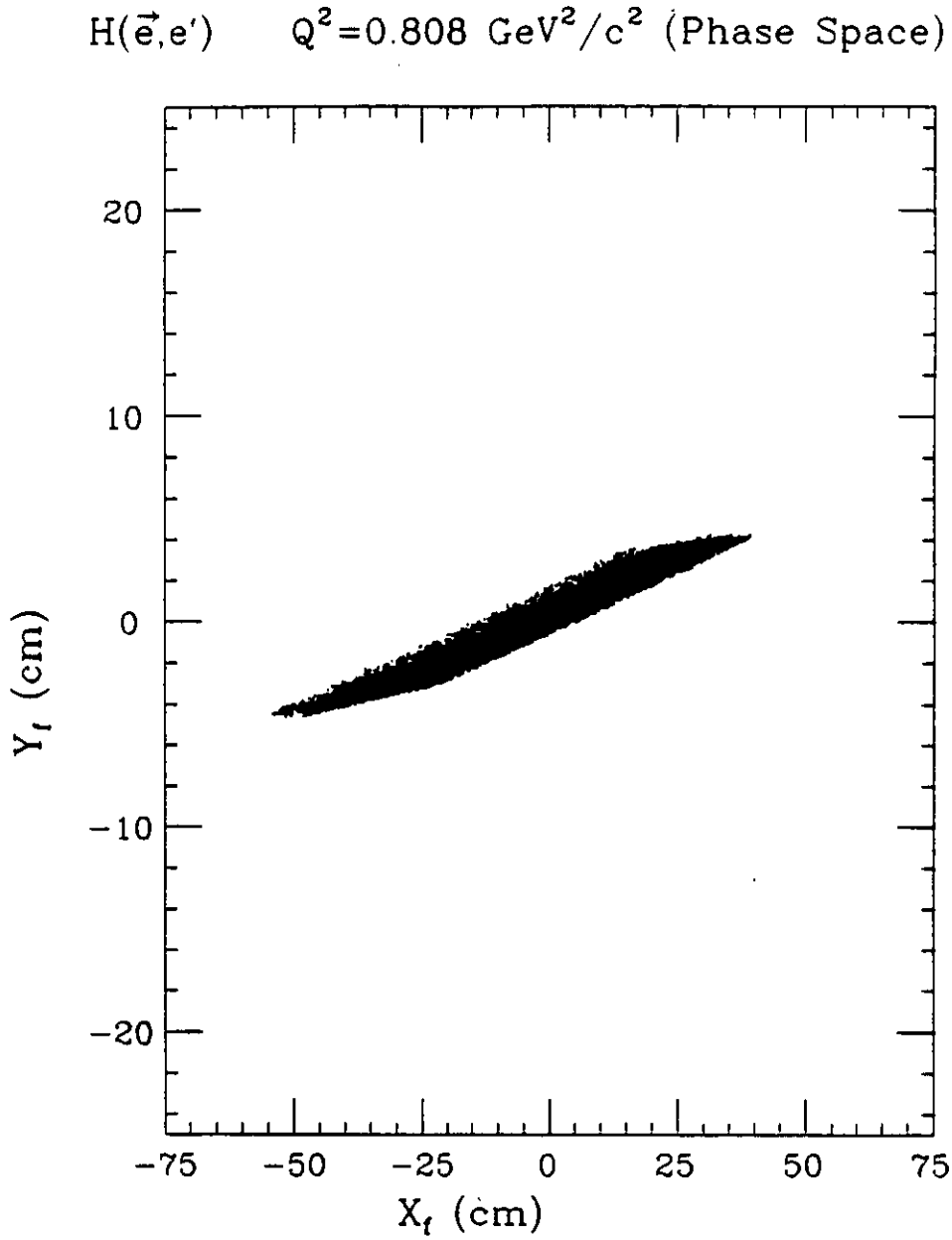

Figure 12. Phase space acceptance of the Hall A spectrometers for the kinematics and solid angle of Figure 7.

One important detail is the fact that the cross section and asymmetry vary over the acceptance of the spectrometer as shown in Figures 9, 10 and 11. A Monte Carlo calculation of our acceptance is given in Figure 12. The variations are substantial, but the average asymmetry is nearly equal to the asymmetry of the central ray. Thus the corrections are small. However, it is important that we understand the acceptance of the system to control this possible systematic error.

Detectors

The elastically scattered electrons will be focussed in the spectrometer in a region otherwise free from background. We plan to detect them with an array of lead glass counters. The signals will be integrated for the following three reasons:

1. Integration eliminates problems associated with dead time, which may be severe for a sensitive, high rate experiment.

2. The backgrounds are small, so counting individual particles to reject events is of little value.

3. The rates are sufficiently high that counting individual events would be difficult.

When integrating, it is essential to have a detector that has the same response for each event but that responds linearly to piled up events. In addition, we want a large signal from each good event but at most small pulses from background events. Lead glass meets these requirements. Another option, lucite Čerenkov detectors, would be more sensitive to low energy background. Conventional photomultiplier tubes will be sufficient to detect the light. The geometry of the detectors will be appropriate to intercept only the elastic peak.

The electronics integrating the signals will be new, with special requirements arising from the CW nature of CEBAF.

Polarized Electron Source

The heart of any parity experiment at CEBAF will be the polarized electron source[24]. The quality of the operation of the source will determine the beam polarization, intensity, and duty factor. In addition, and of equal importance, is the fact that the source is the device that creates a large class of possible systematic errors.

The CEBAF source will be based on photoemission from an appropriate crystal. The tried and true crystal, GaAs, provides excellent quantum efficiency (several percent) but has only 40% polarization. Providing a thin, MBE (Molecular Beam Epitaxial) grown crystal can increase the polarization to 50% with modest loss of quantum efficiency. Presently, there is extensive research taking place on promising new crystals which will provide significantly higher polarizations, including chalcopyrites[25],

superlattices[26], and strained crystals[27]. One particularly promising result is with a strained GaAs crystal, which yielded a 86% polarization with a quantum efficiency of 2×10^{-4}. Through private conversations, QE's of more than 10^{-3} are expected.[28] These are very encouraging and suggest that CEBAF might have an 80% polarized beam.

Also encouraging is the development of the Ti:Sapphire laser. It produces about four times the power of the Kr ion laser used at Bates and is more reliable. The usable laser power will be limited by the power density that the crystal can tolerate.

The small phase space required by many CEBAF experiments imposes important constraints on the polarized source. First, the active area of the photocathode must be small. Since there are limits to the power density of the laser light producing the photoemission, relatively high quantum efficiency is needed. Second, beam is lost during injection. The chopper will accept 1/6 of the beam to provide a longitudinally tight beam. Collimators in the injector will accept only 1/4 of the beam to tighten the transverse phase space. Thus the source must provide 24 times more beam than is accelerated, again requiring quantum efficiency. One compromise we would like to explore is relaxing the phase space requirements (parity doesn't require excellent phase space) and gaining back a factor of about 6 in the injection efficiency. That could make the difference between having 50% polarization from high quantum efficiency GaAs and 80% beam polarization from the new materials.

Target

The target will be the same as used for other experiments in Hall A. The power requirement for the full beam, 400W, is substantial. Knowledge of the absolute density is not needed. However, it is essential that the density be uniform over a time scale comparable to the helicity flipping time. If there is boiling, density fluctuations could arise that are larger than the statistical fluctuations. This will require faster flipping times. However, we do not anticipate major problems in this area.

Polarization Reversals

It is traditional in parity experiments at pulsed accelerators to reverse the polarization of the electrons each beam burst. However, in a CW machine like CEBAF, there is no natural time structure, so one must be imposed. In the ideal world, where the beam properties are stable, the details of the method are unimportant. On the other hand, if the accelerator produces a particular kind of noise, careful choice of a flipping pattern may be necessary. Since the noise spectrum of the CEBAF beam is unknown, all we can do here is indicate some of the ideas that are important for dealing with possible problems.

One approach is to flip the beam as rapidly as possible and record the data for each flip. This has the advantage that the statistical error for each point is as large as possible so that other sources of noise are smaller and thus negligible. By reversing

the helicity randomly, any periodic noise becomes effectively random. We believe that this is the most desirable approach. The speed of the flips is then limited only by the data rate. At Bates, we operated at 600 Hz, which was very effective, and there is little reason go faster. The parity experiment at SLAC operated at 120 Hz.

At Bates, there was large periodic noise arising from the 60Hz line noise. To eliminate this, we synchronized our data taking with the line frequency and computed asymmetries for pairs of events occurring at the same line phase. This scheme works well if the only important noise has a single, convenient period.

If there two sources of large noise with different periods, one must flip at a fixed frequency. Implementation of this method is more complex, but must be done on a noisy accelerator. We do not expect CEBAF to be noisy.

IV. SYSTEMATIC ERRORS

Introduction

To many physicists, the idea of measuring a quantity to the level of parts per million is rather intimidating. However, in well designed *asymmetry* experiments, such precision is neither uncommon nor unusually difficult to attain. The reason is that the parameter of interest, such as the spin of one of the particles involved, is rapidly flipped, leaving all other experimental parameters virtually unchanged. Then the numerous systematic errors associated with the other parameters, such as absolute beam energy or position, cancel when the difference is computed. For these experiments, precisions of 100 ppm are almost automatic, and, when special effort is taken, precisions at least as good as 0.02 ppm have been achieved.

For the case of parity experiments with polarized electrons, the major problems in the past have had more to do with attaining sufficient electron intensity and in controlling the beam current than in dealing with systematic errors arising from the small asymmetries. Moreover, in terms of proposing a new experiment at CEBAF, there is much to be learned from previous work at SLAC[29], Mainz[30], and Bates[23] that can be applied to eliminate spurious asymmetries at the required level. Indeed, the achievement at Bates of an uncertainty in the asymmetry of 0.02 ppm is compelling evidence that we can achieve our goals.

At Bates[23], we developed techniques for performing systematic checks simultaneously while obtaining data. This enabled us to use all of the beam time obtaining good data, so our final errors were what we would predict based on the luminosity achieved and counting statistics. We believe that we can ultimately operate at CEBAF with this efficiency.

General Principles

If the polarization of the electron beam can be reversed without changing any

other beam parameter, such as energy, position, or phase space, small experimental asymmetries will be free of systematic error. One major class of systematic error deals with the problem that there are indeed differences in the beam parameters under helicity reversal. They may be minimized by three general methods:

1. Reduce the sensitivity of the apparatus to beam parameters.

2. Minimize the differences in the beam parameters under helicity reversal.

3. Make accurate corrections to the remaining effects of beam differences.

At CEBAF, an additional check is possible. One can repeat the experiment at a nearby energy where the raw parity asymmetry is reversed due to the extra g-2 flip due to the bends in the accelerator. Comparing the results detects the problem, and averaging the result cancels the systematic error.

For electron scattering experiments, there is a large energy dependence on the cross section which cannot be eliminated. Therefore, the apparatus must be sensitive to one of the most important beam parameters, energy (and intensity, which is usually closely related due to beam loading). This effect usually is much greater than any imperfections in the apparatus itself. Therefore, method 1 has limited application for electron experiments.

Method 2, on the other hand, is very powerful for electron scattering. Presumably, all of the helicity correlated beam differences result from differences in the laser beam, which can be minimized by various techniques. For example, at Bates a feedback method greatly reduced the change in beam intensity under helicity reversal, and a similar method could be used at CEBAF. The other laser beam parameters, including position and size, can be controlled by careful design of the optical system.

Method 3 is also very powerful for electron experiments. Very precise position monitors, accurate in position to 10-100μm per measurement, are available. Placed at appropriate positions along the transport line, they are sensitive to differences in the beam position, angle and energy to significantly greater precision than required. Finally, by using a calibration method, the data from the position monitors may be used to accurately correct the asymmetries as was done at Bates.

Beam Monitors

Helicity correlated differences in the first order beam parameters, assumed to be position, angle and energy, are measured by using beam position monitors (BPM's). In the Hall A beam transport line, there will be an XY pair within 0.5 m of the target, an XY pair at least 5 m upstream, and a BPM in the bend where there is substantial dispersion. Ideally, we will have a chicane for energy measurement[31], which will provide an ideal place for the energy monitor. The first four determine position and angle by

tracking, and the fifth gives the energy. The differences in these monitors are denoted δM_i.

The required relative precision of the beam monitors is estimated as follows. The cross section for electron scattering is very sensitive to energy; with $\sigma \sim E^n$ where n is 5 or more. If we assume that $n < 10$ for our reactions, then we require $\Delta E/E < 0.1\Delta\sigma/\sigma \sim 0.1$ ppm to be totally negligible. With a dispersion of 1 cm/%, this corresponds to a position of 0.01 μm. However, this is the average over a whole run (typically at least 100 hr), and for this type of difference measurement where systematic errors cancel, the error precision increases as the square root of the running time. Thus, the requirement is a precision of 600 μm for a 100 μsec measuring gate. The CEBAF BPM's are specified to have 100 μm precision (electronic noise) with a 5 μsec gate, more than an order of magnitude better than needed. Of course, any measurement of *absolute* position or energy will not be limited by statistics but rather by the ability to measure the location of the devices, slow drifts, etc., and much lower precision results.

The situation for beam angle and position is similar. The scattering angle is 0.22 radians, so $\Delta\theta/\theta < 0.1\,\Delta\sigma/\sigma \sim 0.1$ ppm requires 2×10^{-9} rad or 0.01 μm position resolution at 5 m. This is the same requirement as for energy. Differences in beam position may have two effects. First, the beam position at the target influences the average scattering angle. Second, the thickness of the target may depend on position. If a 10 cm target varies in thickness 1 mm for a 1 cm transverse displacement, 0.01 μm position sensitivity is again appropriate.

It is also possible that there are helicity correlated differences in second order beam parameters such as phase space. We expect these effects to be small for our experiment. First, the response of the detector is very sensitive to the first order beam parameters in a linear way, so only very large second order effects would be important. Second, the known systematic errors in the beam are linear, and one would expect the residual higher order effects to be small. Making corrections for higher order effects in beam properties is difficult because there are so many possible parameters. Instead, we can cleanly measure and cancel any such possible effect by running the experiment at a slightly lower energy so that there is an extra g-2 spin flip which reverses the parity asymmetry but leaves the systematic error unchanged.

Calibration

Having sufficiently sensitive monitors is a necessary requirement. If the helicity correlated monitor differences are negligible, then it is sufficient. However, if these monitor differences are nonzero, a calibration method is required to accurately convert the monitor data into cross section corrections. This is achieved by varying the beam parameters in a controlled way by ramping steering coils and the beam energy. This method was effectively demonstrated for the ^{12}C parity experiment at Bates, and a similar method should work well at CEBAF.

To correct the raw asymmetries, we use the equation

$$A_{exp} = A_{raw} - \Sigma a_i \delta M_i,$$

where A_{raw} is the uncorrected asymmetry, δM_i are the differences in the beam monitors correlated with helicity, and the a_i are correction coefficients. Data obtained while the steering coils in the beam line are ramped are used to compute the correction coefficients involving the position and angle of the beam.

The coefficients a_i, which are really $\partial\sigma/\partial M_i$, are computed by first measuring the response of the spectrometer and the monitors to the coils C_i: $\partial\sigma/\partial C_i$ and $\partial M_j/\partial C_i$. Then the equation

$$\frac{\partial\sigma}{\partial C_j} = \frac{\partial\sigma}{\partial M_i}\frac{\partial M_i}{\partial C_j} = a_i \frac{\partial M_i}{\partial C_j}$$

is solved by matrix inversion to obtain the a_i. The key of the method is to ramp under computer control a complete set of parameters with devices (steering coils and an energy vernier) placed upstream of all of the monitors. Steering coils upstream of the most upstream monitor, the energy monitor, serve to control the position and angle. There are important dynamic range criteria here. First, the coils must vary position and angle with ample independence so that the matrix $\frac{\partial M_i}{\partial C_j}$ is far from being singular. The amplitude of the ramping must be large enough so that it exceeds the size of the normal beam jitter, yet small enough so that the effect of the ramping is small compared to the statistical error on the cross section. Achieving these requirements simultaneously was accomplished at Bates and should be easier at CEBAF because the beam should be quieter and we know the relevant criteria prior to establishing the design of the beam transport system. This method is key to simultaneously taking production data and studying systematic errors.

The computer steering control system might also be used to keep the average beam parameters at values minimizing the sensitivity of the apparatus to systematic errors. Hitting the precise center of the target is one possibly important example.

Transverse Polarizations

If the electron spins have a transverse component, there will be an asymmetry given in the high energy, low angle limit by

$$A_{Mott} = \frac{\alpha Z \theta^3}{4\gamma} P_t \sin\phi$$

where P_t is the transverse component of the beam polarization and ϕ is the angle between the transverse spin component and the normal to the scattering plane. For typical kinematics for this proposal, $A_{Mott} \approx 10^{-8}$ and is totally negligible. This is without using the symmetry of the apparatus and taking into account the small

magnitude of the transverse beam polarization, which would reduce the effect two further orders of magnitude.

Electronics

Imperfections in the electronics can induce systematic errors. A convenient feature of this class of error is that it may be studied extensively without using any beam.

This first problem is cross-talk between the signals controlling the beam helicity and the detector electronics. There are two methods for reducing this effect. The first is to avoid having signals present, such as gate generators, which are correlated with helicity. Instead, we can use preset patterns of spin reversal and apply the information to the data only off line. A major potential problem is other users at CEBAF creating in time signals based on helicity. Adequate communication throughout the lab will be required.

Detector linearity is another problem. The relevant criteria is the ratio of the largest asymmetry present relative to the desired error. For experiments where there is a large helicity correlated difference in intensity and/or large background in the detectors, this can impose stringent requirements. However, if ample care is taken at CEBAF, the largest asymmetry in the experiment will be caused by parity violation! Linearity at the 1% level will then be ample.

Beam Polarization

Ideally, we will have a precision Compton polarimeter to measure the beam polarization. It will measure the polarization simultaneously with data taking, eliminating errors due to time variation in the polarization. The precision will be a few percent or better. Of course, implementation of this device is a significant challenge.

If the Compton polarimeter is not available for our earlier work, we can use the simpler, well tested method of Møller scattering. This will require the interruption of data taking for polarization measurement, which is annoying. In addition, the precision will be limited to about 5%. However, even with these limitations, we can learn a lot about the weak current of the nucleon.

Absolute Calibration

In order to perform a 3 ppm parity measurement where the asymmetry is 100 ppm, (a 3% measurement), one must know the absolute beam energy and angle since the asymmetries depend strongly on the kinematics of the points. Thus these absolute quantities should be known to ~0.3%. This is crude by Hall A standards. However, these errors still must not be ignored.

Magnetized Iron

Polarized electrons striking magnetized iron can produce an asymmetric background because of the spin dependence of the interaction with the polarized electrons in the iron. These effects are small: the electron polarization in iron is 7%, the maximum analyzing power is 5/9, only a few percent of the energy loss is due to interaction with the electrons (.02), the magnetization of most of the iron is perpendicular to the beam (.05), and the true signals in the detector swamp the background (0.001). Putting these factors together gives an error of $\sim 10^{-8}$, which is comfortable.

The most serious feature of this systematic error is that there is no simple method, such as changing the beam energy to induce an extra g-2 flip, to cancel the effect. Thus care special care must be taken to assure that the above effects are indeed small. On the other hand, there isn't too much iron that beam should strike. The small phase space of the beam and lack of halo eliminates scraping in transport elements. The Hall A spectrometers have iron-free quadrupoles at the front. The only iron is in the dipoles, where there are few background electrons.

There are three categories of iron in the apparatus:

1. Iron in the beam transport.

2. Iron in the spectrometer dipole pole faces serving as an aperture.

3. Iron in the dipole which stops the inelastic tails.

Background from halo striking iron in the transport magnets is expected to be negligible and can be measured by observing the background levels in the spectrometer with the target out. If the target empty background is negligible, the spin-dependent part of it must be negligible.

The spectrometers will be baffled with lead collimators so that no good particles will scrape the pole faces. The effectiveness of this scheme can be determined during the spectrometer tune-up phase by studying the trajectories of the events using the standard detector package.

Baffles will be used to reduce the number of inelastic electrons striking iron. The effectiveness of this can be measured by taking data where the spectrometer is tuned so that the elastic peak is dumped in a suspicious place.

Polarized Electron Source

The source is also central to the issue of systematic errors. Flipping the helicity must not change the beam intensity, which can cause many types of problems due to beam loading, which may be further complicated by the various feedback systems used at CEBAF. There are two approaches to make both helicities have the same intensity. The first is to have a perfectly aligned optics system. If the light is truly circular everywhere, only the helicity changes. In many realistic systems, the light becomes

slightly elliptical, and optical elements in the transport induce an intensity asymmetry (PITA effect[32]). At Bates, we developed an effective feedback system to control the PITA effect, and a similar method, if needed, can be used at CEBAF.

Another problem is that the Pockels cell that reverses the helicity of the laser light can also deflect the beam. At Bates, we used a lens system to image the Pockels cell onto the crystal to reduce this effect. With care, such problems can also be reduced at CEBAF.

Some of the preliminary work on controlling source-related systematic errors can be done in combination with early studies of the the low energy end of the accelerator. The rest of the accelerator simply passes on the systematic effects generated at the injector.

Errors in Evaluating the Theoretical Prediction

To evaluate the theoretical expression for the parity asymmetry in hydrogen, the following expression is useful:

$$
\begin{aligned}
A_{ep}^{PV} = 3.167 \times 10^{-4}\tau \Bigg[& (3\tilde{\gamma} - \tilde{\alpha}) \left(\frac{\varepsilon G_{Ep} G_{En} + \tau G_{Mp} G_{Mn}}{\varepsilon G_{Ep}^2 + \tau G_{Mp}^2} \right) \\
& + (3\tilde{\gamma} + \tilde{\alpha}) \left(\quad 1 \quad \right) \\
& + (\tilde{\beta} - \frac{3}{5}\tilde{\delta}) \left(\frac{\sqrt{1-\varepsilon^2}\sqrt{\tau(\tau+1)} G_{Mp} G_A}{\varepsilon G_{Ep}^2 + \tau G_{Mp}^2} \right) \\
& + 2(\tilde{\gamma} + \epsilon_{av}^{es}) \left(\frac{\varepsilon G_{Ep} G_{Es} + \tau G_{Mp} G_{Ms}}{\varepsilon G_{Ep}^2 + \tau G_{Mp}^2} \right) \Bigg]
\end{aligned}
$$

where $\tau = Q^2/4M_p$ and $\varepsilon = \left(1 + 2(1+\tau)\tan^2(\frac{\theta}{2})\right)^{-1}$. G_{Ep}, G_{En}, G_{Mp} and G_{Mn} are the usual electromagnetic form factors for the proton and neutron. The values of the

coupling constants in the Standard Model are given by:

	Standard Model	$\sin^2\theta_W = 0.23$
$\tilde{\alpha}$	$-\rho(1-2\sin^2\theta_W)$	-0.54
$\tilde{\beta}$	$-\rho(1-4\sin^2\theta_W)$	-0.08
$\tilde{\gamma}$	$\frac{2}{3}\rho\sin^2\theta_W$	0.15
$\tilde{\delta}$	0.	0.00
ϵ_{av}^{es}	$\frac{1}{2}\rho(1-\frac{4}{3}\sin^2\theta_W)$	0.35

where the numerical value for $\sin^2\theta_W$=0.23. Thus the coefficients to the first $(3\tilde{\gamma}-\tilde{\alpha})$ and fourth $(\tilde{\gamma}+\epsilon_{av}^{es})$ terms are unity, and those of the second and third are < 0.1.

There are a number of problems involved in evaluating the above prediction for the parity asymmetry in hydrogen. Most of the asymmetry comes from the first term, which is proportional to the neutron form factors. The size of the errors on these form factors is a somewhat controversial issue, both in terms of the present limits to our knowledge and in terms of what will be learned in the near future from experiments at Bates, Mainz, and CEBAF.

To set the context of the scale of errors, we will consider predictions about the contributions of the strange quarks to the charge form factor. If the predictions of Jaffe are right, strange quarks change the asymmetry by more than 50%, and will overwhelm most other errors. One of the Skyrme model predictions gives 20% contributions, and determining if this is true is a reasonable goal for a first round experiment. The Skyrme model prediction of 8% will be more challenging to establish; this might represent the ultimate goal of the program.

The question that has received the most attention in the literature is the value of G_{En}, the neutron electric form factor. The difference in the parity asymmetry between G_{En} being its nominal value[34] and zero is about 15% for all of the points in Table II. In addition, the error in G_{Mn}, on the order of 10%, is important because the parity asymmetry is approximately proportional to that quantity. Modest improvements in our knowledge will be sufficient for our first round goals.

Another issue is radiative corrections.[11,12] Due to the excellent resolution (compared to SAMPLE) of the spectrometers, most of the radiative tail will be rejected, simplifying that part of the calculation. The more difficult problem is the electroweak radiative corrections related to the composite nature of the nucleon. These effects are often described in terms of percent corrections, which can become very confusing because the effects under consideration are often small or zero; some have a factor of

$1 - 4\sin^2\theta_W \approx 0.08$ and others are strictly zero. Indeed, at low Q^2 and forward angles, the first term in the above equation, which is small, dominates. For our kinematics, however, the second term, involving G_{Mn}, is largest. Its coefficient is 1 instead of 0.008. Moreover, the radiative corrections are multiplied by $1 - 4\sin^2\theta_W$, reducing their importance. The calculated corrections should be reliable to at least a few percent (ignoring top quark mass problems) and uncalculated box diagrams which are the analog to two photon exchange diagrams should also be tractable.

Table V presents a summary of expected experimental errors. Since important parameters for the experiment, including beam polarization, electron polarimetry, accelerator noise are not well established, it is especially hard to estimate the errors. Consequently, we have quoted a range. The large errors we regard as extremely conservative. The small errors represent design goals.

Table V. Estimated Errors

SOURCE	ERROR
Statistics	3-10%
Energy and position monitors	1-3%
Electronics	1%
Magnetized iron	1-3%
Background	1-3%
Beam Polarization	1-5%
Radiative Corrections	1-5%
Total	4-14%
Form Factors (neutron G_E and G_M)	3-18%

V. RUN PLAN

Choice of Kinematics

Our physics goal is to measure the weak form factors of the proton with as much kinematic range and precision as practical. Ideally, we would like to measure all of the points in Table II to the listed precision. In addition, if the contribution of the strange quarks is significant, we would like to verify the effect in the cleaner but less sensitive ^{4}He system at a Q^2 of 0.1 (GeV/c)^2. However, this is too ambitious a program for a first round experiment. Thus we must choose what we can do in 800 hours that will

have the most significance. This of course will depend upon the state of the field at the time that we perform the experiment; knowledge of the nucleon form factors, results of other parity experiments, and even the polarization and intensity of the available beam.

If we were to run today, our first priority would be to search for the large strange quark contribution predicted by Jaffe. We would run at a Q^2 of ~ 0.5 and achieve a precision of at least 15%. This is a rather modest goal, yet its implications for physics are immense. The result of this measurement would determine the priorities for the remaining beam time. For example, ^{4}He would be very attractive if the design rates and polarization are achieved and also the predicted contribution of the strange quarks from the first hydrogen point is in the 10-15% range. If the data taking is slow, the high rates of the deuterium experiment may make it the choice for a second point.

Interaction with the Existing Program in Hall A

An important issue is whether a parity violation experiment can co-exist with the existing program in Hall A. We believe the answer to this question is a qualified "yes". Initial work will emphasize understanding the central beam parameters. Much of this work is necessary to carry out other aspects of the Hall A program, such as polarization transfer studies on D and ^{16}O which make demanding requirements on knowledge of the polarization, energy and orientation of the beam. Clearly the demands of the parity violation program will serve to improve knowledge of the beam parameters which are also needed for other experiments. The detectors needed for parity violation measurements could be made interchangeable with existing Čerenkov detectors. The Hall A electronics can either be turned off and left in place, or could conceivably be used as a parasitic monitor of the beam profile in the spectrometer.

Experimental Plan

A tentative assignment of experimental responsibilities is presented in Appendix I. Appendix II summarizes parity specific costs and needs. The experimental plan can be conceptualized as comprising the following three stages of development:

Construction Phase: It is important that the needs of future parity experiments be incorporated into the basic Hall A program during the construction and commissioning phases of the Hall A development. Baffling studies of the spectrometer must be carried out this year(1991-1992) and appropriate beam line monitoring devices installed by late 1994 or early 1995. The plans for a beam line polarimeter should be accelerated to be available concurrently with the polarized source. The Hall A parity collaboration will participate in the development of this instrumentation much of which is also needed for the general Hall A program. Specialized parity detectors will also be built in this period and appropriate diagnostic techniques developed.

Systematic Errors Studies: As soon as a polarized source becomes available we will

begin studying and reducing sources of systematic errors. Some work can begin at the level of the injector. Early work in Hall A can begin with a low energy, unrecirculated beam and may use solid targets like ^{12}C. As soon as the cyrogenic targets become available and the first spectrometer fully instrumented, we will explore the spectrometer phase space, instrumental backgrounds and other extended target effects in the focal plane. Such work would be of mutual benefit to and involve other parties in the Hall A collaboration.

Data Acquisition Phase: Once systematic errors are under control we plan to carry out an initial set of measurements involving one or two points on hydrogen. Measurements on deuterium may be done as well since they would add only a 25% overhead on the necessary run time. We are explicitly asking for 800 hours to carry out the initial measurements, with the number of points and accuracy being determined by the beam polarization and current available to us at that time. After successfully analyzing these data, we plan to submit additional requests to the PAC to carry out the extended program that we have outlined in this proposal. In our most optimistic scenario, assuming a 80% beam polarization, about 10 high quality experimental points could be acquired over a two year period, running about two months per year, leading to a number of Ph.D. Theses.

VI. BEAM TIME REQUEST AND SUMMARY

We are requesting 800 hours of beam time to initiate a precision program of parity measurements using the CEBAF Hall A HRS^2 spectrometer pair. Depending on beam current and polarization available at run time, this will allow us to measure one or two points on hydrogen with about 5% statistical precision. Accurate measurement of the neutral weak form factors of the nucleon over a range of Q^2 would represent a major advance in the field and, as such, presents an important opportunity for the CEBAF community.

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* SLAC is not sponsoring this initiative as an Institution, given its policy of only supporting research activities at SLAC. The participation of G.G. Petratos is possible because of his fixed term research appointment at SLAC.

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Appendix I

Tentative Responsibilities of Participants

- CEBAF: J Mougey et al.–Spectrometer and beam line optics and baffling.
- CSULA: Epstein et al.–Cryogenic Targets.
- CUNY: M. Lubell–Beam diagnostics, Source.
- Harvard: R. Wilson–Electronics
- MIT/Bates: W. Bertozzi et al.–Spectrometer calibrations.
- Princeton: G. D. Cates et al.–Lasers, Polarimetry.
- Stanford: Z. Meziani et al.–Polarimetry.
- Syracuse: P. A. Souder et al.–Detectors, Analysis.
- UVA: R. Lourie et al.–Spectrometer calibrations.
- William and Mary: J. M. Finn et al.– Data acquisition software, Analysis.

Appendix II

Special Experimental Equipment

Shared equipment with the general Hall A program includes the two HRS spectrometers, high powered cyrogenic targets, a beam line polarimeter and standard beam line monitors. Additional equipment that is required especially for the parity experiment are listed below with some cost estimates based on our experience at Bates:

1. Lead glass detectors with phototubes ($50k).

2. Integrating electronics for the detectors ($30k).

3. Control electronics for the source, beam steering, and beam monitors ($50k).

4. User supplied software.