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A Parasitic Measurement During E03-004 for Target Single-Spin Asymmetry in Inclusive DIS $n^{\uparrow}(e, e')$ Reaction on a Vertically Polarized ^{3}He Target

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Abstract: We propose a parasitic experiment during the Hall A neutron transversity experiment (E03–04) to measure the target single spin asymmetry A_T^n in inclusive deep-inelastic $n^{\uparrow}(e, e')$ reaction with a vertically polarized ^{3}He target. The goal of this measurement is improve the upper limit of A_T by two orders of magnitude compared with the SLAC proton experiment carried out 35 years ago. A non-zero result would be a sign of chiral symmetry breaking that is beyond the leading twist QCD picture of DIS. This experiment will share the 24 days of 6 GeV beam time with E03-004. One day of dedicated beam time is requested for detector check-out of the Hall A Lumis and a new Big Bite Aerogel Cherenkov detector and to perform systematic studies unique to the single spin asymmetry measurement.

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Contents

1 Introduction

Symmetries have played an important role in our understanding of Physics. The charge (C), parity (P), and time reversal (T) symmetries are important pieces of the Standard Model, and the combined CPT symmetry is one of its key requirements. The discovery [1] of CP violation in 1966 caused an upheaval that led to the search for CP violation or T violation in other systems. It was in this environment that it was first proposed [2] to look for T violation in the target single spin asymmetry. In particular, it was suggested that a non-zero asymmetry from deep inelastic scattering of electrons from a target polarized perpendicular to the scattering plane would be a T-violating reaction. In their paper, Christ and Lee assume that only one photon is exchanged between electron and proton, other particle exchanges are ignored and the quark mass is zero. One experiment was performed at SLAC, which measured A_T^p:

$$A_T = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}}, \tag{1}$$

where $\sigma^{\uparrow(\downarrow)}$ is DIS cross section with target spin up (down) with respect to the electron scattering plane. A_T^p was found to be consistent with zero at the 3.5% level[3]. Subsequent theoretical and experimental results show that the Cabibbo-Kobayashi-Maskawa (CKM) theory [4] accurately describes all know cases of CP violation. This theory does not predict a T-violating electromagnetic reaction. Thus this field has been dormant for over 30 years.

Recent experimental and a theoretical results have created a renewed interest in this field. Much of the theoretical activity has centered on T-odd effects in SIDIS $(e, e'h)$, interaction effects beyond tree-level for strong interactions. Unfortunately these are still T-violating in inclusive DIS.

On the other hand two-photon exchange opens the possibility for asymmetries that are T-odd but not T-violating and do not involve T-odd strong interactions. T-violation would only occur in the T-odd case if positron deep inelastic scattering had a different single spin asymmetry. If the quark mass is non zero, then the asymmetry from two photon exchange would be [6]:

$$A_T = \frac{e_q e^2}{4\pi} \frac{m_q}{2Q} \frac{\sqrt{2\epsilon(1+\epsilon)}}{1 + 4\epsilon m_q^2/Q^2} \frac{Q^2(Q^2 + 4m^2/q)}{\hat{s}\,(\hat{s} - \hat{u})}. \tag{2}$$

While asymmetry from two-photon effects on the quark will be small, in the case of the neutron the net asymmetry must be zero for symmetric u- and d-quark distributions. Besides the quark mass effect, any physics which causes a quark helicity flip, breaks chiral symmetry, can also contribute to this asymmetry. Thus a large measured asymmetry would be a sign of previously unobserved interactions beyond the leading twist QCD picture of DIS.

The previous measurement of A_T in the DIS region was in 1970 at SLAC [3]. This experiment used a vertically polarized butanol target to measure the single spin asymmetry on the proton. The experiment was done with an 18GeV electron beam with much of the data being in the quasi-elastic region. They did collect some DIS data at Q^2 of 1.0 GeV^2 and 0.6 GeV^2 with a W of 2.0 GeV to 2.6 GeV, which when averaged gives for the proton $A_T^p = -1.6 \pm 3.5\%$. No previous experiment has measured the transverse asymmetry on the neutron A_T^n.

The combination of the high beam currents possible at Jefferson Lab, the new large acceptance BigBite spectrometer in Hall A, and the high luminosity polarized ^{3}He targets allow a DIS single spin asymmetry measurement at the 10^{-4} level. A non-zero asymmetry at this level would be a sign of chiral symmetry breaking that is beyond the leading twist QCD picture of DIS.

2 The Measurement

We purpose to measure the target single spin asymmetry(A_T) in Jefferson Lab Hall A using inclusive deep inelastic scattering (DIS) of a 6 GeV electron beam from a ^{3}He target polarized normal to the scattering plane. This measurement will be preformed parasitically to the neutron transversity experiment, E03-004 [8]. The BigBite spectrometer positioned at 30° relative to the beamline will be used to simultaneously measure A_T at Q^2 of 1.3, 2.0, 2.6, and 3.1 GeV^2. Based on 264 hours of running we expect a statistical uncertainty δA_T^n of 2.4, 3.0, 3.8, and 4.4×10^{-4} for the respective Q^2 bins. The experiment requires the addition of a Aerogel Cherenkov (n=1.03) detector to the BigBite electron detector package for improved online pion rejection. The vertically polarized ^{3}He target will be used. The target will be based on the new potassium/rubidium mixture of alkaloids which has been very successful in providing improved ^{3}He polarization.

The target will be flipped every 10–20 minutes to reduce the effect of systematic bias. To further reduce these effects a quad run structure with target flips of either $\uparrow\downarrow\downarrow\uparrow$ or $\downarrow\uparrow\uparrow\downarrow$ will be used in a randomly determined sequence. The Hall A Lumis located in the beam pipe will be used to monitor the relative luminosity. This will require the use of the Hall A parity DAQ in tandem with the BigBite DAQ. The relative beam charge will be monitored by the Hall A beam charge monitors. One half of the E03-004 running will be done with the target polarized in plane of the scattering angle. This data will give us a clear measure of our false asymmetries.

2.1 Kinematics, rates and statistical uncertainties

The proposed running for E03-004 [8] will be ideal for this measurement. Half of the experiment running time will be with the target in the vertical polarization configuration. The BigBite spectrometer will be placed at a scattering angle of 30 degrees. Expected results assuming 264 hours or running and an average target polarization of 42% are shown in Table 1, where f, the dilution factor, is the fraction of scattered electrons coming from a polarized neutron. The E'-x, W-x and Q^2-x phase space for each x-bin is shown in Fig. 1. The statistical uncertainty δA_T^n will be 2.4, 3.0, 3.8, and 4.4 $\times 10^{-4}$ for the 0.14, 0.23, 0.32, and 0.41 x-bins respectively.

Table 1: Nominal kinematics for x-bin center with a beam energy of $E = 6.0$ GeV. One BigBite setting covers all the kinematics listed. f is the neutron dilution factor.

$E_0 = 6.0$ GeV, ^{3}He(e,e'). 264 hours total, $P_T = 0.42$.

$\langle x \rangle$	E′ GeV	θ_e deg.	Q^2 GeV^2	W GeV	$\Delta E'$ GeV	$d\sigma_{(e,e')}$ nb/GeV/sr	f	Rate Hz	N$_{DIS}$ 10^6	δA_T^n 10^{-4}
0.135	0.815	30.0	1.310	3.050	0.431	29.6	0.350	817.49	776.9	2.44
0.225	1.246	30.0	2.003	2.793	0.398	19.4	0.366	493.42	468.9	3.00
0.315	1.612	30.0	2.592	2.554	0.340	13.0	0.380	281.82	267.8	3.82
0.405	1.925	30.0	3.095	2.331	0.381	8.4	0.391	204.14	194.0	4.37

The other half of E03-004 running time will be taken with the target polarization in the scattering plane of the electron either beam left or beam right. Giving this analysis matching data of similar quality and statistical error. The single spin asymmetry is $\propto (\vec{e} \times \vec{e}') \cdot \vec{S}_T$, which will be uniquely zero for this configuration. Thus any asymmetry will be a direct measure of the systemic bias.

2.2 BigBite: A Large Acceptance electron spectrometer.

E03-004 plans to use the standard BigBite electron detector package that will also be used by the GeN experiment (E02-013)[9]. This package includes three wire chambers, scintillator triggers, and a Lead glass calorimeter for particle identification. While this setup is acceptable for transversity, the factor of 100 pion reduction will not be enough for the single spin asymmetry.

Reduction of pion background is critical to measuring the single spin asymmetry accurately. By adding an Aerogel (n=1.03) Cherenkov box to BigBite detector package, the trigger will be cleaner and pions with $p_\pi < 0.567$ GeV/c can be cleanly removed in the analysis. This Aerogel detector will use the original NIKHEF Aerogel box, which has 12 five-inch Burle-5854 PMT tubes attached, filled with Aerogel material to a volume of 200cm×50cm×9cm. A tentative agreement has been reached with MIT-Bates and Arizona State University to ship parts of MIT-Bates BLAST Aerogel detector to JLab.

We expect the refurbishing and testing of the Aerogel detector will be a straight forward job with minimum cost. The Arizona State University group has expressed an interest of taking the responsibility. This Aerogel box, 30 cm in thickness, will fit between chamber-2 and chamber-3 with chamber-2 shifted 5 cm forward from its current location. The segmentation of the Aerogel will also help in resolving any wire chamber tracking ambiguities.

The expected performance [12] of the detector is shown in Fig. 2, the Aerogel Cherenkov will preform the best at our lowest momentum where the pion background is highest. With the ADC sum of the Aerogel Cherenkov added to the BigBite singles trigger, the singles trigger rate is expected to be below 5 kHz level.

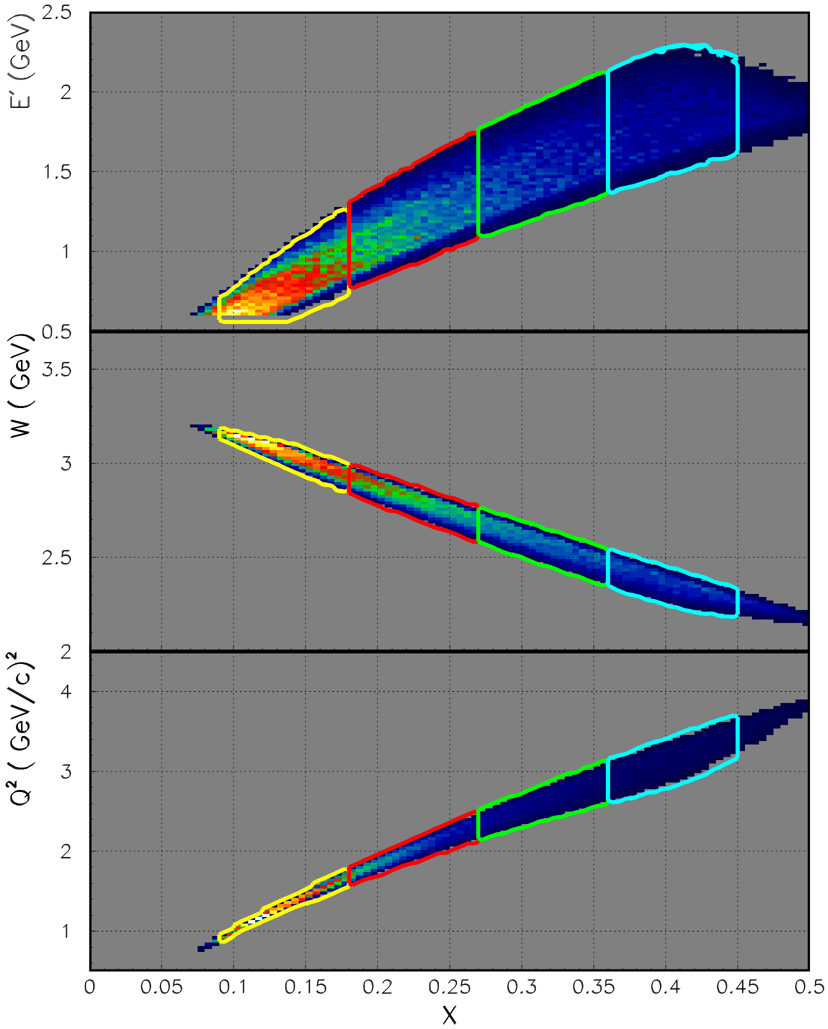

Figure 1: Available phase space in the (E', x), (Q^2, x), and (W, x) planes with each x-bin in different colors.

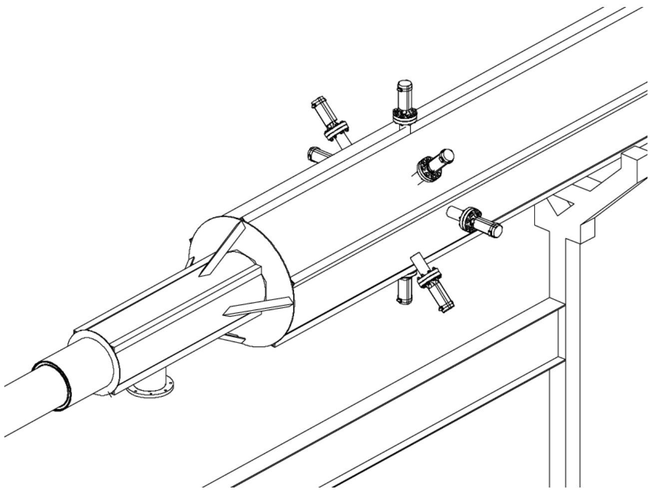

Figure 2: The average number of photons for electrons (triangles) and pions (squares) in the Aerogel Cherenkov

The GeN experiment [9] will run spring 2006 in Hall A using the BigBite spectrometer. This data will allow us to test two-chamber tracking in the BigBite. If the resolution is good enough for E03-004, then one option is to remove the second wire chamber from the detector stack. This will allow us to insert a gas Cherenkov detector between the first and third wire chamber. The gas Cherenkov would allow pion rejection at all of our kinematics, and would be the ideal PID choice if the two-chamber tracking is acceptable.

2.3 Luminosity monitoring

The HAPPEX experiments e99-115 [10] and e00-114 [11] have recently completed an extended run. These experiments built 8 luminosity monitors called the Lumis. Each detector is made of Quartz with an air light guide. The monitors are placed downstream of the target within the beam pipe at a scattering angle of $7mrad$, see Fig. 3. The Lumis have performed very well during HAPPEX, monitoring the Luminosity to a very high precision for 30 Hz beam helicity flips.

Vertically polarized single spin ^{3}He experiments will flip the target spin in a time period of ten to twenty minutes. To study the systematic effects of the Lumis in this time window, the HAPPEX data slug 30 was examined. This slug consisted of fourteen runs, each of 56 minutes in length. The data for each run was divided into four equal length time periods. The results from all eight Lumis were summed to remove Physics effects. Each sum was divided by the value from the Hall A beam charge monitor (BCM) to cancel beam jitter. The average result was determined for each 14 minute time window. The only cut used required a non-zero beam current. The basic asymmetry assuming an ABAB sequence for all is 5×10^{-6}. To get a better handle on the systematic error a random number generator was used to randomly determine either an ABBA or BAAB pattern for each run. The 14 sequences were

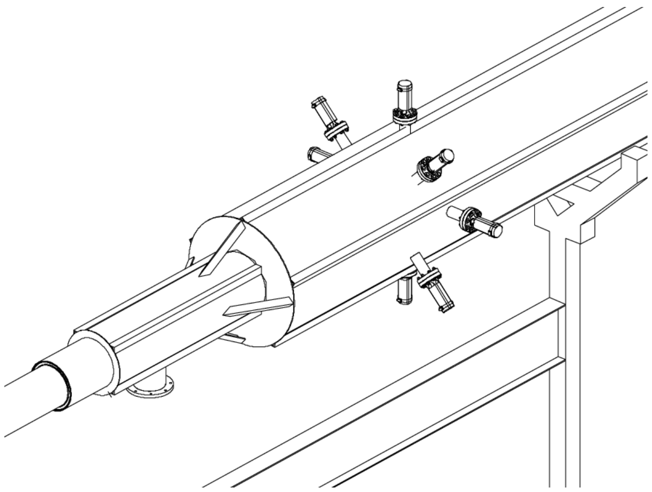

Figure 3: The Hall A Lumis in the beam pipe downstream of the target

randomly determined 1000 times giving a root mean square of 5×10^{-5} as shown in Fig. 4. The HAPPEX data has a very large data rate so all errors should be systematic. This test has shown that the Lumis should be able to monitor the luminosity differences between target spin up and target spin down for a vertically polarized single spin ^{3}He experiments to the 5×10^{-5} level.

2.4 Trigger, data acquisition and offline event selection

The trigger used will be the same single arm electron trigger as E03-004. The addition of the Aerogel Cherenkov should greatly reduce the trigger rate and our deadtime corrections, which should enable running with a very low prescale factor on the trigger. The goal will be a deadtime of less then 5% to minimize our effect on E03-004. The coincidence trigger rate is only a few hertz. We will require both the BigBite DAQ and the Hall A parity DAQ to run. The parity DAQ will be used to monitor the Lumis, BCMs and position differences.

2.5 The polarized ^{3}He target and density fluctuations.

The vertically polarized ^{3}He target used by E03-004 is ideal for our measurement. The target will be an optically pumped Rubidium/Potassium hybrid mixture which has shown in tests to have a higher polarization then standard Rubidium only targets. This is due to the larger rate of spin exchange between Potassium and ^{3}He. To minimize systematics the target spin will be flipped frequently. The extra requirement that this experiment imposes is a strict control of target density between the spin states. While the Hall A Lumis should be able to monitor small fluctuations, we want to try to keep the Lumi asymmetry small. Since the target volume is fixed we only need to control the temperature to control density. The use of the small pumping chamber cells should keep density gradients reasonable. During the Spin

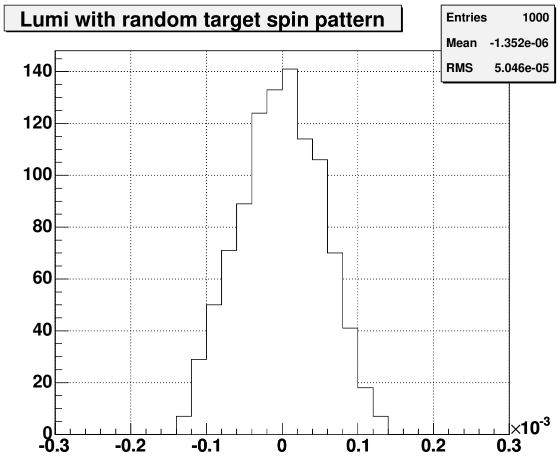

Figure 4: The Asymmetries of the Hall A Lumi sum divided by the BCM with 14 minute time windows for HAPPEX slug 30, using 1000 different random combinations of ABBA or BAAB. The very high rate of HAPPEX experiments means that the RMS is related only to the Lumi systematic error for 14 minute time windows.

Duality experiment E01-012 [17] the density asymmetry between target spin 0° and 180° with respect to the beam was found to be 8×10^{-4}. The behavior of the Lumis at various target densities will be closely monitored.

3 Expected Results

Based on full statistics we expect to improve the measurement of the DIS single spin asymmetry A_T by over two order of magnitude. We plot our results with the previous measurements versus W and x in Fig. 5 and Fig. 6. Our expected result versus x is plotted with the average of the SLAC results in Fig. 7. The systematic uncertainty should be dominated by the uncertainty in the luminosity ratio for the three highest x bins, with errors similar to statistical uncertainty of δA_{phys}. The lowest x bin will have large backgrounds from both pions and the quasi-elastic tail.

3.1 Relative Luminosities

Control of systematics will be extremely important for this experiment. In particular for this measurement is knowledge of the relative luminosity. The measured asymmetry depends not only on the counting rate but also the relative luminosity as below:

$$A_{meas} = \frac{N_{\uparrow} - N_{\downarrow} \cdot \dfrac{\mathcal{L}_{\uparrow}}{\mathcal{L}_{\downarrow}}}{N_{\uparrow} + N_{\downarrow} \cdot \dfrac{\mathcal{L}_{\uparrow}}{\mathcal{L}_{\downarrow}}}, \tag{3}$$

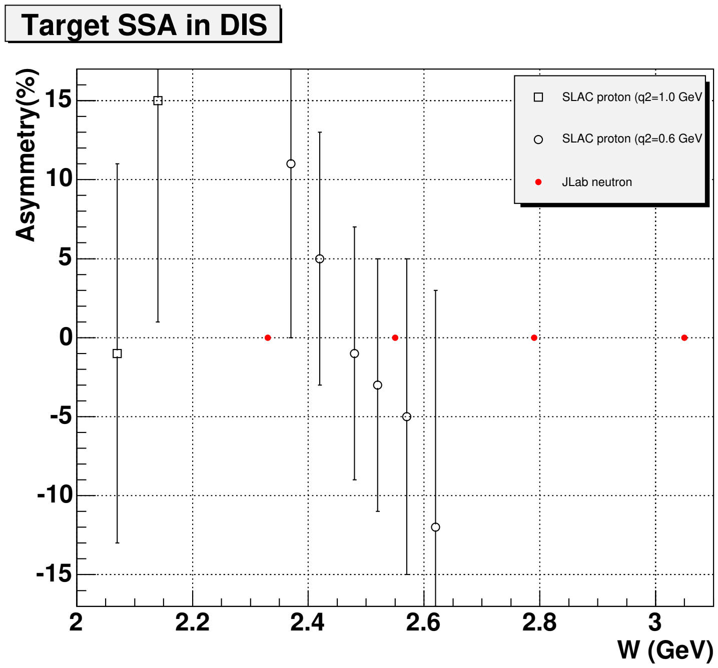

Figure 5: The transverse single spin asymmetry for DIS scattering as a function of W. The open squares and circles are SLAC data on the proton at Q^2 of 1.0 GeV^2 and 0.6 GeV^2. Our expected results with a two order of magnitude improvement in statistics are shown as the solid circle.

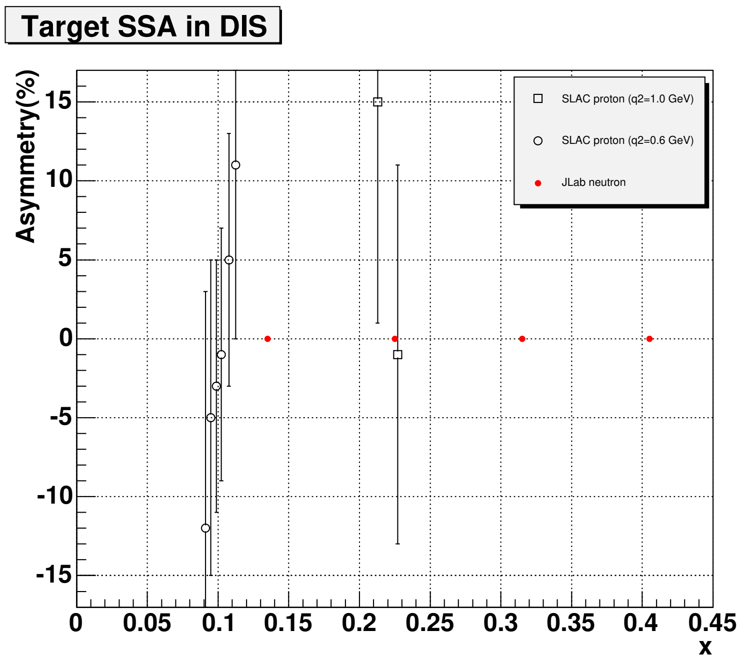

Figure 6: The transverse single spin asymmetry for DIS scattering as a function of x. The open squares and circles are SLAC data on the proton at Q^2 of 1.0 GeV^2 and 0.6 GeV^2. Our expected results with a two order of magnitude improvement in statistics are shown as the solid circle.

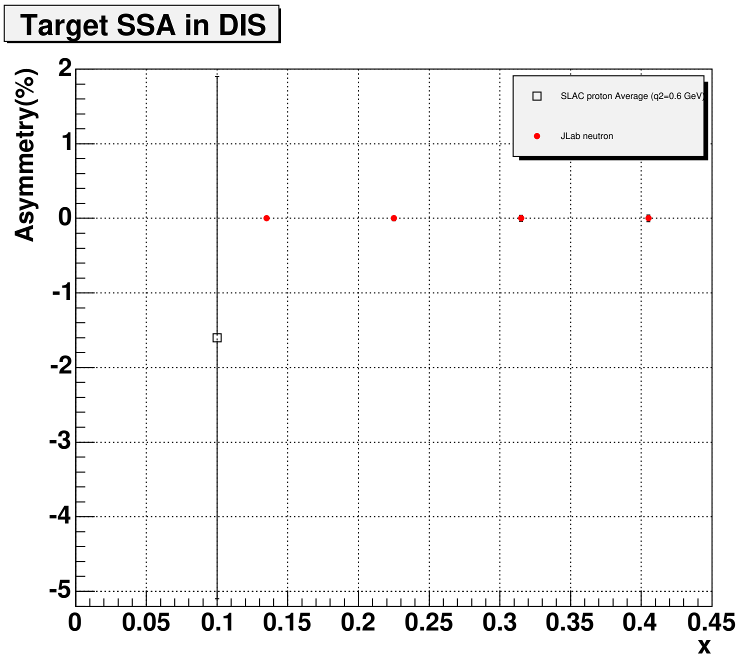

Figure 7: The transverse single spin asymmetry for DIS scattering as a function of x. The open square is the average of all SLAC data on the proton at Q^2 0.6 GeV^2. Our expected results with a two order of magnitude improvement in statistics are shown as the solid circle.

where $N_\uparrow$ and $N_\downarrow$ are the target spin up and down counting rates and $\frac{\mathcal{L}_\uparrow}{\mathcal{L}_\downarrow}$ is the relative luminosity. The uncertainty in the luminosity ratio contributes to the asymmetry systematic by:

$$(\delta A_{meas})_{sys} = \frac{N_\downarrow \cdot \delta\left(\frac{\mathcal{L}_\uparrow}{\mathcal{L}_\downarrow}\right)}{N_\uparrow + N_\downarrow \cdot \frac{\mathcal{L}_\uparrow}{\mathcal{L}_\downarrow}} \cdot (1 + A_{meas}). \tag{4}$$

If we assume that that asymmetry is small, than $N_\uparrow/\mathcal{L}_\uparrow \approx \mathcal{N}_\downarrow/\mathcal{L}_\downarrow$, which leads to:

$$(\delta A_{meas})_{sys} \approx \frac{1}{2} \cdot \frac{\delta\left(\frac{\mathcal{L}_\uparrow}{\mathcal{L}_\downarrow}\right)}{\frac{\mathcal{L}_\uparrow}{\mathcal{L}_\downarrow}}. \tag{5}$$

These equations show that uncertainty of the luminosity is directly related to the final systematic uncertainty, and that we need to control the relative uncertainty. The systematic uncertainty of the HALL A Lumis is shown in Sec. 2.3 to be at the 5×10^{-5} level. Correcting for dilution and polarization leads to $(\delta A_{phys})_{sys}$ for the Luminosity to be 3.4×10^{-4}.

3.2 Target Polarization Differences

It is also possible that the polarization of the ^{3}He target will be different for spin up($\uparrow$) and spin down($\downarrow$). This difference is easy to correct, since this will be a monitored by both EPR and NMR and should be a small asymmetry.

The cross sections of the two states can be related as:

$$\sigma_\uparrow = \sigma_0 + P_\uparrow \sigma_1, \tag{6}$$

$$\sigma_\downarrow = \sigma_0 - P_\downarrow \sigma_1, \tag{7}$$

where σ_0 is the target spin independent cross section, σ_1 is the target spin dependent cross section, and $P_\uparrow$ and $P_\downarrow$ are two polarizations.

Ignoring radiative effects, the measured asymmetry is:

$$A_{meas} = \frac{\sigma_\uparrow - \sigma_\downarrow}{\sigma_\uparrow + \sigma_\downarrow} = \frac{P_\uparrow + P_\downarrow}{2} \cdot \frac{\sigma_1}{\sigma_0}. \tag{8}$$

Target polarization differences only affect the size of the asymmetry, they don't create an asymmetry. The systematic will be on the order of $A_{meas} \cdot \delta P_{\uparrow(\downarrow)}/P_{\uparrow(\downarrow)}$. Typically for ^{3}He experiments $\delta P/P \approx 4\%$, thus we will not be systematics limited from Target Polarization differences for any $A_{meas} < 6 \times 10^{-3}$.

3.3 Backgrounds

In an inclusive scattering experiment all final states are integrated over. One possible source of backgrounds come from the quasi-elastic tail. To estimate the size of the inelastic tail the unpolarized cross sections are estimated using a modified QFS program [13,14] which fits the world data and recent Jefferson Lab data. Quasi-elastic scattering (QE), the Δ resonance, the second and third resonance, two-nucleon processes (2N), elastic scattering, and deep inelastic scattering (DIS) are all simulated by the program. The cross-section versus ν is shown in Fig 8. The background from quasi-elastic rises with larger ν. For our two high x bins it is clear that the backgrounds are less then 1%, the third bin should see a background of about 5%, and the lowest x bin will have an average background of 10%. The modified Regge GPD model [15] predicts quasi-elastic single spin asymmetry A_y should have a value of 5×10^{-3} at our kinematics with 30% uncertainty. Thus we expect a correction of 5×10^{-4} for the lowest x bin, with a systematic $\delta(A_T^n) = 2 \times 10^{-4}$. The Ay experiment [16] E05-015 should test this model and could provide an improvement to these numbers.

Another source of background is pions that pass the PID cuts. We expect a pion rejection factor of 100 for the lead glass calorimeter, and a factor of 10 from the Aerogel Cherenkov for the lowest x bin. The π/e ratio should be less then 10:1 for our two highest x bins. Our lowest x bin will have a π/e ratio of 100. Thus we expect a pion background less then 10%. To correct for this background, we will measure the pion asymmetry by selecting a clean pion signal from our data. These events will

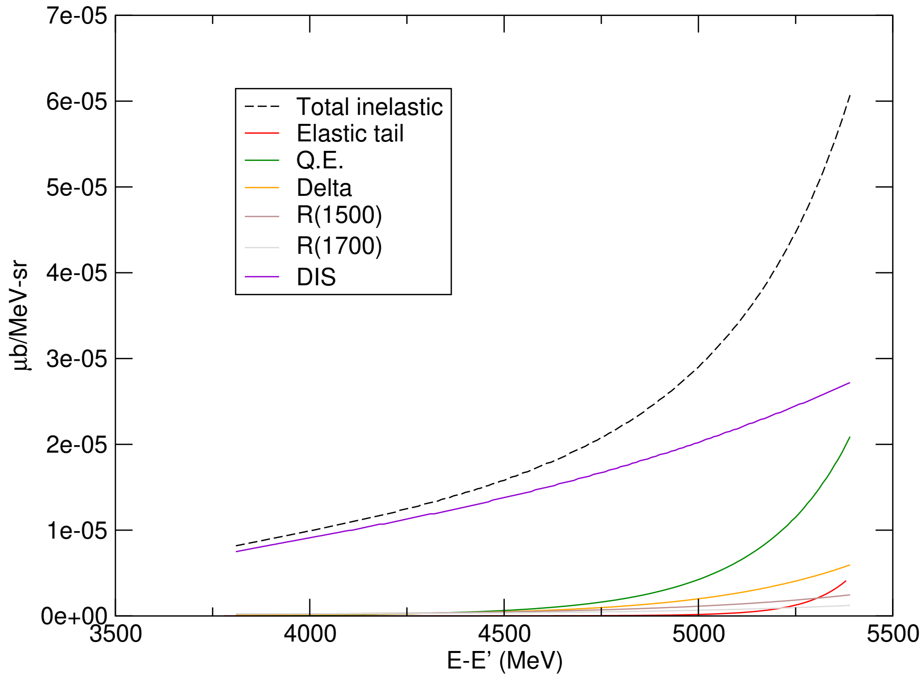

Figure 8: Radiative contributions to the total unpolarized cross-sections versus ν at $E_0 = 6.0$ GeV and $\theta = 30°$ from elastic, quasi-elastic, delta resonance, second resonance, third resonance, and deep inelastic.

be numerous so statistical error on the pion asymmetry should be very small. To accurately understand pion behavior in the PID detectors we will take a short two hour run with looking for coincidence events between π^+ in the BigBite and electrons in the L-HRS at the delta. This run will involve four hours of preparation, two hours to switch BigBite polarity and two hours to switch it back. This should allow us to understand the PID behavior to 0.5%. The systematic uncertainty due to the pion background will be $\delta(A_T)_{\pi back} \approx A_\pi \cdot \delta(\pi/e)$. If $A_\pi < 1\%$, then $\delta(A_T)_{\pi back} < 5 \times 10^{-5}$. If it is possible to use the gas Cherenkov detector, then this systematic should be reduced by factor of ten.

3.4 Extra Systematic Studies

A series of studies will be done periodically through the run to monitor our systematics. Runs will be taken with the beam moved off center in both x_{beam} and y_{beam} to get a good understanding of position differences in the Lumis and the BigBite spectrometer. This data will be correlated with natural position differences seen during normal running. Other runs will be taken with one or two of the target pumping lasers off. This will change the density of the target and allow us to correlate density differences with response of the Lumi. Finally data will be taken at different beam currents to understand the linearity of the Lumis. Understanding of these conditions will allow us to better control small deviations that will occur naturally during production.

3.5 Overall Systematic Cancellation

To help reduce the overall systematic uncertainties we will use a random ↑↓↓↑ or ↓↑↑↓ quad run structure for the target spin, where the first run in a quad will have its spin determined by a random number generator. This sequence will be blinded in the single spin asymmetry data analysis to reduce the chance for bias. The overall systematic will also be checked by analysis of the $P_{\leftarrow}$ and $P_{\rightarrow}$ data. A full analysis will be done to measure the false asymmetry and cross check our corrections.

4 Relation with other experiments

Jefferson Lab is uniquely suited for performing this experiment. The high luminosities accessible in Hall A with the polarized ^{3}He target coupled with large acceptance of the BigBite spectrometer create a unique Physics reach. HERMES has a lot of data with the target spin normal to the scattering angle, so there is also potential to do this measurement there. Unfortunately, HERMES typically only makes beam polarization flips a few times a year [7], which leads to large systematic errors in measuring A_T. HERMES did take one year of data with unpolarized beam, but in private communications with Steve Rock he suggested that this data quality was not good enough for this type of measurement.

This experiment will make a long term contribution to Jefferson Lab as the corner stone target single-spin asymmetry experiment. The new 12 GeV upgrade will allow parity violating DIS single spin asymmetry experiments where the target is polarized longitudinal to the beam. The DIS parity signal is expected to be $\approx 10^{-4} \times Q^2$. Follow on experiments to probe A_T at larger x will also be of interest. If positron beams were developed at Jefferson Lab, time reversal violation tests could be performed on transversely polarized targets. These experiments will be sensitive to Physics beyond the Standard Model.

5 Beam Time Request

Our beam time requirements are outlined in Table 2. Most of the time will be shared with E03-004, but we do request 24 hours of beam time for three separate tasks: commissioning of the new BigBite Aerogel Cherenkov, testing of the Hall A Lumis, and special systematic studies unique to the measurement of the single spin asymmetry A_T. These special systematic studies include large position difference runs, target temperature tests, and short run with the polarity of the BigBite reversed to study the PID response to a clean pion signal.

Table 2: Beam time request.

	Time (Hour)
Production on Pol. ^{3}He	**528 (shared with E03-004)**
Reference cell runs, optics and detector check	16 (shared with E03-004)
Target Overhead: spin rotation, polarization measurement	32 (shared with E03-004)
Extra systematic check, luminosity monitor checks	24
Total Time Request	**1 day (24 hours)**

6 Summary

We purpose to measure the transverse target single spin asymmetry A_T^n, In addition to the 24 days requested by E03-004 we request one additional day of beamtime for: detector commissioning and systematics studies. Our measurement is mostly parasitic to E03-004 requiring only the instillation of the new Aerogel Cherenkov detector in the BigBite and a small increase in deadtime. A measurement at the 10^{-4} sensitivity is a two order of magnitude improvement on all previous results. This measurement will be uniquely able to study two photon effects at the quark level. A large asymmetry would be a signal for a new physical process involving chiral symmetry breaking beyond the leading twist QCD picture of DIS. This experiment can be the corner stone experiment for a target single-spin asymmetry program with a bright future at 12 GeV.

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