E12-06-112: Measurement of neutron spin asymmetry A_1^n in the valence quark region using 8.8 GeV and 6.6 GeV beam energies and Bigbite spectrometer in Hall A

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A Hall A Collaboration Proposal

1 Introduction

This document provides an update for experiment E12-06-122 [1]: a precision measurement of the virtual photon asymmetry A_1^n of the neutron in the Deep Inelastic Scattering (DIS) region ($W^2 > 4$ GeV^2) using the Hall A polarized ^{3}He target and the Hall A Bigbite spectrometer up to $x_{_{Bj}} \approx 0.71$.

Since the approval of this experiment, the hall A d2 [2] experiment, a DIS experiment, and the hall A transversity experiment [3], a SIDIS experiment, have successfully run using the polarized ^{3}He target and the Bigbite spectrometer. These two experiments have clearly demonstrated the feasibility of using this setup for DIS studies. We have also been able to determine which parts of the setup need to be improved. Most notably, the need for a Cerenkov detector better designed to operate in a high rate enviorenment. In section 3 of this update we present the plans for the design and construction of a high rate Cerenkov detector for Bigbite.

While the experiment can be performed with impresssive statistical accuracy within 550 hours using the existing configuration of the polarized ^{3}He target and the Bigbite spectrometer, as originally proposed four years ago, several important advances in polarized ^{3}He target technology and in the availability of detectors in Hall A make it possible to improve the experiment even further. These changes are also described in section 3 of this update. The improved setup will allow us to reduce statistical errors, so that they are comparable to the systematic errors, and complete the experiment within 480 hours.

2 Scientific Case

The spin asymmetry A_1 provides important insight into the wave function of the nucleon. Within the quark parton model, it provides a direct measurement of the polarization of the parton distribution functions. At high values of $x_{_{Bj}}$, it is also one of the rare quantities describing nucleon structure that is calculable within the framework of pQCD. As such, it provides a valuable opportunity to compare theory with experiment.

The quantity A_1^n of the neutron is sensitive to quark orbital angular momentum (OAM), and the polarization of specific quark flavors (for the d quark in particular) is even more so. It is probably not unfair to point to the now well known measurements of G_E^p/G_M^p in Hall A [6] as the discovery of the importance that quark OAM plays in the structure of the nucleon. The subsequent measurement of A_1^n from E99-117 provided early support for this

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notion[4], a fact that was a key motivation for this proposal. Since our original proposal for this experiment, evidence for quark OAM was also published by the HERMES collaboration in the form of the observation of a non-zero Sivers effect in single-spin asymmetries in DIS[7]. It is also notable that measurements at SPIN RHIC of the fraction of spin carried by gluons, ΔG, is significantly smaller than had earlier been anticipated. Taken together, the motivation for E12-06-122 is even stronger today than it was when first proposed in 2006.

The virtual photon asymmetry A_1 is defined as

$$A_1(x,Q^2) \equiv \frac{\sigma_{1/2}-\sigma_{3/2}}{\sigma_{1/2}+\sigma_{3/2}}$$

where $\sigma_{1/2(3/2)}$ is the nucleon's virtual photo-absorption cross section with total helicity of the $\gamma^* - N$ system being 1/2(3/2). A_1 can be related to the unpolarized and the polarized structure functions F_1 and g_1 by

$$A_1(x,Q^2) = \frac{g_1(x,Q^2)-\gamma^2 g_2(x,Q^2)}{F_1(x,Q^2)} \tag{1}$$

where $\gamma^2 \equiv \frac{Q^2}{\nu^2} = \frac{(2Mx)^2}{Q^2}$ and at large Q^2 one has $A_1 \approx g_1/F_1$. The structure functions F_1 and g_1 have explicit implications in the quark-parton model:

$$F_1(x,Q^2) = \frac{1}{2}\sum_i e_i^2 q_i(x,Q^2) \quad \text{and} \quad g_1(x,Q^2) = \frac{1}{2}\sum_i e_i^2 \Delta q_i(x,Q^2)\ , \tag{2}$$

where $q_i(x,Q^2)$ is the probability that a struck quark carries momentum fraction x for a particular value of Q^2, and $\Delta q_i(x,Q^2)$ is the difference in the probability that a struck quark is polarized parallel to the nucleon spin as opposed to antiparallel to the nucleon spin. At high values of x_{Bj}, where the sea quarks make a minimal contribution, knowledge of A_1 for both the neutron and proton, together with the assumption of isospin symmetry, provides a flavor separation of the polarized parton distribution functions. Of tremendous interest is that in the high x_{Bj} region A_1 can be calculated using perturbative QCD (pQCD). Such calculations can be performed for the proton and neutron, or alternatively, for u quarks and d quarks. These calculations are quite sensitive to the manner in which quark orbital angular momentum (OAM) is handled.

Both pQCD and relativistic constituent quark models (RCQMs) predict that as $x_{Bj} \rightarrow 1$ both A_1^p and A_1^n asymptotically approach unity. Hall A experiment E99-117 showed for the first fime that A_1^n becomes positive above roughly x_{Bj}=0.5 [4]. The value measured was consistent with expectations from RQPMs, but not with pQCD calculations in which "hadron helicity conservation" or HHC is assumed. The assumption of HHC essentially precludes a contribution to A_1^n from quark OAM. The apparent disagreement between the measurement of ref. [4] and the earlier pQCD calculations is the reason that the earlier Hall A measurement of A_1^n is seen as evidence for non-zero quark OAM. Interestingly, more recent pQCD calculations that explicitly include effects corresponding to non-zero quark OAM show greatly improved agreement [5].

No A_1^n data exist for $x_{Bj} > 0.6$. Furthermore, most of the theoretical predictions for A_1^n have been made in the Bjorken limit. The naive expectation has been that since A_1 is roughly the ratio of the structure functions g_1 and F_1, both of which show similar scaling violations due to gluon radiation, A_1 should show little or no Q^2 dependence. However, we have no understanding of the Q^2 dependence of A_1 that might arise from quark OAM effects and higher twist effects. Therefore if we are to understand the behavior of A_1^n approaching the Bjorken limit, we need to measure it not only at a single set of Q^2 values, but over a range of Q^2 values. The experiment proposed herein makes this possible.

The large acceptance of the Bigbite spectrometer, the higher beam energies that will be available after the upgrade and the high-luminosity Hall A polarized ^{3}He target make it possible to measure A_1^n accurately over a range of Q^2 values at high $x_{_{Bj}}$. Despite the rapid drop-off in event rate with increasing $x_{_{Bj}}$, an accurate measurement of A_1^n up to $x_{_{Bj}}= 0.71$ is achievable even under fairly conservative assumptions. Based on the trend observed during E99-117, A_1^n should nearly double in comparison to its value at $x_{_{Bj}}= 0.6$. Furthermore, the statistical accuracy with which A_1^n will be known at values of $x_{_{Bj}}$less than 0.71 will be improved by more than a factor of four. Information on the Q^2 dependence will also be obtained for all but the highest $x_{_{Bj}}$bin. In short, the data will seriously constrain theory, thus shedding light on a host of issues ranging from quark OAM to higher-twist effects.

Finally, we note that the proposed experiment also provides us with two parasitic datasets in the resonance region covering the high $x_{_{Bj}}$ and high Q^2 region. This is due to the large momentum acceptance of the Bigbite spectrometer, and does not require compromising our chosen kinematic settings. Altogether, the proposed measurement provides a comprehensive mapping of A_1^n in the DIS and resonance regions up to $x_{_{Bj}}\approx 0.83$ and $Q^2 \approx 10$ GeV^2.

3 Technical Progress toward realizing the experiment

We are proposing to use an 8.8 GeV and 6.6 GeV longitudinally polarized ($P_e = 0.8$) CEBAF electron beam and the Hall A polarized ^{3}He target. The BigBite spectrometer, located at 30.0° will be used to detect scattered electrons in the range of 1.6 GeV to 3.3 GeV. With the target polarization direction set parallel and perpendicular to the electron beam, the experiment will measure the parallel asymmetry $A_{\parallel}^{^3He}$ and the perpendicular asymmetry $A_{\perp}^{^3He}$. One magnetic field setting of the Bigbite spectrometer with, B= 1.2 Tesla, covers the entire kinematic range of $0.20 \leq x \leq 0.71$ of this proposal. The beam helicity will be reversed at a rate of 30 Hz. A beam current of 30 μA combined with a target density of $3.2{\times}10^{20}$ atoms/cm^3 provides an $e-\vec{n}$ luminosity of 2.0 $\times 10^{36}$ cm^{-2}s^{-1} over a 50 cm effective target length.

The Hall A left HRS spectrometer, will be located at $-30.0°$, in a symmetric configuration to Bigbite. The data from HRS, while at a lower statistical precision than the data from Bigbite, will provide an important cross check of every aspect of the data accumulated on Bigbite. The left HRS momentum will be stepped across to cover the kinematic range $0.20 \leq x \leq 0.71$.

3.1 Update on the polarized ^{3}He target

In our original proposal we assumed a 50% polarization for our ^{3}He target when using a $10\,\mu$A beam, parameters that were demonstrated during the Hall A G_E^n experiment (E02-013). Since that time, the Hall A polarized ^{3}He target has been successfully run with a 65+% polarization in $15\,\mu$A of beam, a factor of 2.5 improvement in the appropriate figure-of-merit (FOM) over our original proposal. Furthermore, it is quite clear that the performance of that target was limited by the fact that the movement of gas between the two chambers of the glass target cell was limited by diffusion. The two chambers include the "pumping chamber" where the gas is polarized and the "target chamber" through which the electron beam passes. Subsequent to our original proposal in 2006, the UVa group has developed (and demonstrated) a new target-cell design in which gas is transferred between the two chambers by convection instead of by diffusion. A target utilizing this design can easily provide 65% polarization in a $30\,\mu$A beam with a longer target cell, a factor of 8.4 improvement in FOM over our original proposal. This is what we have assumed in our update.

We note that a second-generation measurement of G_E^n [9] in Hall A has already been approved and assigned beam time that will utilize apparatus from the Super Bigbite project, as well as a target with a polarization of 62% in $60\,\mu$A of beam. The new GEN target will utilize a metal target chamber to accommodate the higher beam currents, as well as the above-mentioned gas transfer using convection. This development project is well underway, and will likely be complete when this experiment runs. We have assumed a slightly more modest target design, however, because E12-06-122 requires only Bigbite and not Super Bigbite, and may well run quite early in the 12 GeV era, perhaps toward the end of 2013. It seems conservative to associate the full-performance of the next-generation polarized ^{3}He target with the time-scale of Super Bigbite, which may come slightly later than our new A_1^n experiment.

In summary, the FOM of the Hall A polarized ^{3}He target has already demonstrated a FOM that is 2.5 times better than what we assumed in our original proposal. We assume, for what we present here, an improvement in FOM of 8.4 over our original proposal. And finally, we note that the next-generation measurement of G_E^n in Hall A has already been approved under the assumption of a target with an even larger improvement in FOM (15.4 over our original proposal), and the only reason we do not assume this higher value here is because we want E12-06-122 be ready to run as soon as possible.

3.2 The BigBite spectrometer

BigBite is a non-focusing large momentum and angular acceptance spectrometer that was installed in hall A in 2006 with a new detector package for the hall A Gen experiment. Since then many experiments (E04-007, E05-009, E05-015 (d2), and hall A transversity) have successfully used Bigbite. When Bigbite has been used for electron detection, its detector package has included the following components:

- Three Multi-wire Drift Chambers (MWDC) for tracking.
- A Gas Cerenkov counter for pion rejection (installed for the d2 experiment).

- A double layer lead glass calorimeter for triggering on high energy electrons and for further pion rejection.
- A plane of scintillators.

The luminosity we are proposing for this experiment is a factor of ~ 4.5 higher compared to the luminosities used for hall A transversity and d2 experiments. In order to handle this increased luminosity we will replace the first Bigbite MWDC with two Gas Electron Multiplier (GEM) chambers from the Super-BigBite spectrometer, and will improve the design of the Bigbite Cerenkov detector, as described in the next section.

The electron identification in our case will be provided by the proposed Cerenkov counter in combination with the electromagnetic calorimeter. The latter is composed of two subpackages. The first is a preshower detector made out of blocks of TF-5 lead glass spanning an active area of 210×74 cm^2 with 10 cm depth (3 r.l.) along the particle direction. This is followed by a shower detector composed with total absorption blocks of TF-5 lead glass covering an area of 221×85 cm^2 with 34 cm depth which should contain showers with energies up to 10 GeV. The resolution of the calorimeter is about $8\%/\sqrt{E}$[GeV] leading to an expected pion rejection of 100:1 (after offline analysis).

3.2.1 Bigbite background rates and improvements to the BigBite detector package

Two GEANT Monte-Carlo Simulations [11, 10] and real data [3] were used to estimate background rates on BigBite detectors at the proposed new luminosity. The BigBite magnet deflects charged particles with momenta below 300 MeV/c out of the detector acceptance, so the majority of the background hits are due to low energy photons.

For the Hall A transversity experiment, the Bigbite spectrometer was located at the setting proposed for the A_1^n measurement here (30°, 1.5 m from the target). In the transversity experiment, with a 12 μA, 5.7 GeV beam, and a 40 cm ^{3}He target cell, the rate per 140 cm × 35 cm MWDC plane was 41 MHz. A MC simulation normalized to this data shows that for our conditions (30 μA, on a 50 cm ^{3}He cell) the rate will increase by a factor of ~ 4. Estimating that the Bigbite MWDC photon detection efficiency will be at most a factor of 5 smaller than that of GEM chambers, we can expect an overall increase of factor of 20, or a rate of 1.7 kHz/mm^2. This is well below the rate at which GEM chambers have been demonstrated to operate.

In September 2007 the Italian institute INFN approved the development and construction of the front tracker for the Super Bigbite spectrometer for the total amount of 720k Euro. This GEM tracker will consist of 6 triple GEM chambers, each with an active area of 150 cm × 40 cm. (A full description of these GEM chambers and their readout system is given in the Super-Bigbite CDR [8]) We will use two of these six chambers to replace the first (of three) sets of MWDC planes in the Bigbite tracker. These two GEM chambers are expected to be ready by the end of 2011. The first prototype GEM chamber of this GEM tracker is currently under construction in Rome. With two planes of GEM chambers, and two full sets of MWDC planes, we will have excellent redundancy in our tracker system.

The hall A d2 experiment used a Cerenkov detector for pion rejection. While this detector worked, it faced some difficulties due to high background rates in Bigbite. The following reasons may have contributed to these difficulties [12]:

- The photo-tubes used for this detector were large 5-inch tubes, each presenting a substantial area for background hits. A test conducted with a 3-inch PMT showed that the background went down by about a factor of 10 compared to 5-inch PMT. This reduction is significantly larger than the naive reduction factor of $(5/3)^2 = 2.8$ due to the photo-cathode surface area ratio alone.
- PMTs were located symmetrically on both side of the detector; the background rate on PMTs on the small scattering angle side was more than a factor of 4 higher than on the larger scattering angle side.

One of the spokespersons of this experiment, Todd Averett, will design and construct a new gas Cerenkov for Bigbite. In this new detector, the above issues will be corrected as follows:

- Explore the advantages in using 0.75-inch PMTs instead of the 5-inch PMTs used earlier. A large set (2500) 0.75-inch PMTs (including their housings) is available from the HERMES RICH detector, which is currently in storage at UVa.
- The mirror design will be modified so that the PMTs are located only on the large angle side of the detector. On this side the tubes are shielded from the beam-dump and the down-stream beam pipe by the Bigbite magnet.

We expect a pion rejection ratio of at least 50:1 from the Cerenkov and, when coupled with cuts on the shower/pre-shower, we expect to achieve a total pion rejection of 5×10^3. This is quite adequate for the proposed measurement (the worst case π:e ratio we expect is 20:1). The pion asymmetry will also be measured during the same experiment.

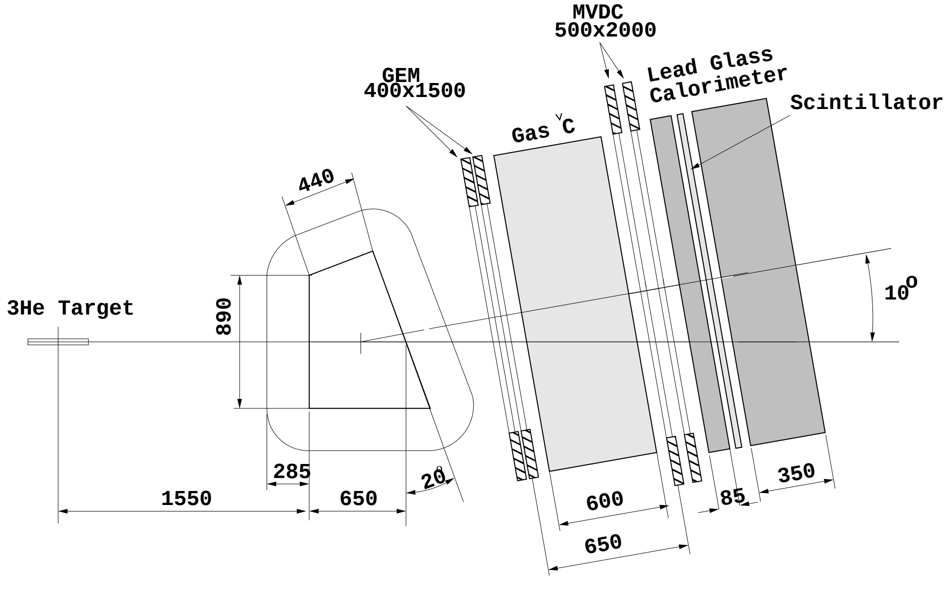

Figure 1: The side view of the BigBite experimental setup in the MC simulation.

4 Proposed Measurement

The measurement consists of collecting $^3\overrightarrow{\mathrm{He}}(\overrightarrow{e}, \mathrm{e}')$ data at a scattering angle of 30.0° with 8.8 GeV and 6.6 GeV polarized electron beams. The calculation of $A_1^{3\mathrm{He}}$ from raw data and the extraction of neutron information from ^{3}He were described in our original proposal. Thus, here we only present the revised beam time estimates and rate calculations for the updated beam and target conditions: an 80% polarized beam current of 30 μA, on a 65% polarized target with a 50 cm effective length (after cuts to remove target end windows).

4.1 Kinematics and rate estimates

Table 1 gives the beam time estimates for $E_0 = 8.8$ GeV production data and calibration running while table 3 provides the central values for scattered electron energy, Q^2 and W^2 for each x_{Bj} bin followed by the ^{3}He(e,e′) rate and the expected uncertainties. The cross sections were calculated by using the MRST [14] parametrization. The calculated beam times were increased to account for an assumed 90% DAQ life-time and a 75% tracking efficiency.

Table 2 gives the beam time estimates for $E_0 = 6.6$ GeV production running, while table 4 provides the expected uncertainties for x_{Bj} bins for the $E_0 = 6.6$ GeV run.

Task	Time (hours)
Production data; parallel asymmetry	220
Production data; perpendicular asymmetry	60
N2 dilution runs	10
^{3}He elastic asymmetry runs (2.2 GeV on HRS)	15
^{3}He delta asymmetry runs (2.2 GeV on HRS)	10
Bigbite optics calibration runs using H(e,e′p) data	50
Beam and target polarization measurements	25
Total	390

Table 1: Beam time estimates for $E_0 = 8.8$ GeV production data and calibration running.

Task	Time (hours)
Production data ; parallel asymmetry	70
Production data; perpendicular asymmetry	20
Total	90

Table 2: Beam time estimates for $E_0 = 6.6$ GeV production data.

x	E' (GeV)	Q2 (GeV^2)	W2 (GeV^2)	rate (Hz)	dA1n (Stat)	dA1n (Syst)
0.71	3.175	7.758	4.1	2.5	0.019	0.030
0.66	3.025	7.133	4.6	8.5	0.009	0.022
0.61	2.875	6.779	5.2	15	0.006	0.017
0.56	2.725	6.425	5.9	20	0.005	0.015
0.52	2.575	6.072	6.5	32	0.004	0.013
0.48	2.425	5.718	7.1	41	0.003	0.012
0.44	2.275	5.364	7.8	44	0.003	0.010
0.40	2.125	5.011	8.4	31	0.004	0.009

Table 3: Rate, Statistical uncertainty and Systematic uncertainty for the Bigbite data for each $x_{_{Bj}}$ bin for the $E_0 = 8.8$ GeV run.

x	E' (GeV)	Q2 (GeV^2)	W2 (GeV^2)	rate (Hz)	dA1n (Stat)	dA1n (Syst)
0.61	2.587	4.576	3.8	6.5	0.025	0.022
0.56	2.462	4.355	4.2	40	0.008	0.017
0.52	2.337	4.134	4.7	60	0.006	0.015
0.48	2.212	3.913	5.2	85	0.005	0.013
0.44	2.087	3.692	5.6	115	0.004	0.012
0.40	1.962	3.471	6.1	150	0.004	0.012
0.36	1.837	3.250	6.5	150	0.004	0.010
0.32	1.712	3.028	7.0	85	0.005	0.009

Table 4: Rate, Statistical uncertainty and Systematic uncertainty for the Bigbite data for each $x_{_{Bj}}$ bin for the $E_0 = 6.6$ GeV run.

The total measurement time as given in table 1 includes time for the following calibration tasks:

- reference cell running to determine the N_2 dilution factor.
- ^{3}He elastic asymmetry and delta asymmetry runs to cross check the product of beam and target polarization for longitudinal and transverse polarization running. These runs will be taken with one pass beam ($E_0 = 2.2$ GeV). The scattered electrons will be detected on HRS-L.
- Bigbite optics calibration runs using H(e,e′p) data, with Bigbite set to positive polarity detecting the proton in coincidence with a high energy electron detected in a small calorimeter.
- Beam polarization measurements with the Moller polarimeter (beam polarization will also be measured in-situ using the Compton polarimeter), and target polarization measurements using NMR and EPR methods.

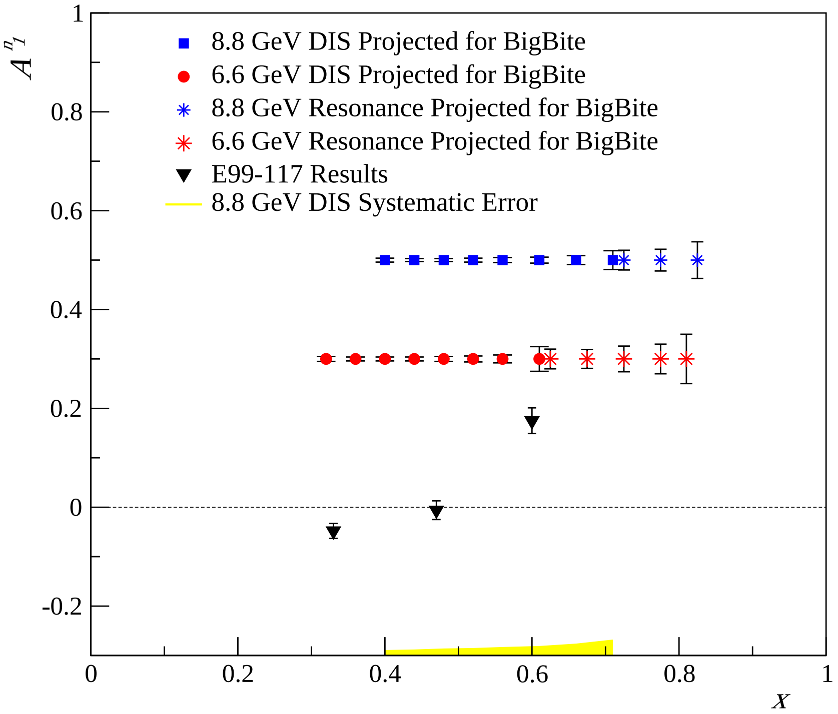

Figure 2: The projected data for the proposed measurement The solid triangles show the published data from E99-117. The error bars shown are statistical. The estimated systematic error for each point is comparable to the statistical error as shown in tables 3 and 4. The yellow band at the bottom shows the estimated systematic error for 8.8 GeV DIS data

Figure 2 shows the expected uncertainties for the DIS data, compared to the results from Jefferson lab experiment 99-117, which has provided the most accurate A_1^n data to date. Although this proposal is optimized to study the DIS region, the large momentum acceptance of Bigbite provides us with the opportunity to gather two precision datasets in the resonance region at no extra cost. The stars in the figure show the expected accuracies for the resonance data.

5 Summary

In summary, we are requesting 20 days of beam for a precision measurement of the virtual photon asymmetry A_1^n of the neutron in the DIS region up to $x_{Bj}= 0.71$. The experiment will utilize beam energies of 8.8 GeV and 6.6 GeV, a beam current of 30 μA, the Bigbite spectrometer and the Hall A polarized ^{3}He target. The results of the experiment will represent a spectacular improvement in our knowledge of A_1^n, adding greatly to our knowledge of the nuclear wave function in the valence region. If the observed trend persists, A_1^n is likely to nearly double between $x_{Bj}= 0.60$ (the highest value of x_{Bj} for which A_1^n is currently known) and $x_{Bj}= 0.71$. The experiment will greatly reduce the errors with which A_1^n is known at lower values of x_{Bj}, improving over E99-117 by more than a factor of four in statistics. And finally, the experiment will begin the important task of understanding the Q^2 dependence of

A_1^n, an issue that is critical to the interpretation of the results. The data obtained, together with corresponding data on A_1^p, will permit a significantly improved understanding of the flavor-separated polarization of the parton distribution functions. And finally, the data will enable detailed comparisons with pQCD calculations, which among other things is likely to improve our understanding of the role of quark OAM in the nucleon wave function.

We have been very conservative in projecting our results. We are proposing this experiment at half the luminosity achievable from the fully upgraded polarized ^{3}He target, despite the fact that the higher luminosity is compatible with the rate-handling capabilities of the BigBite spectrometer when equipped with the new GEM chambers. Furthermore, in predicting the rates that we will see, we have normalized our background-rate simulations to the actual rates measured during the Hall A transversity experiment. Despite this conservative approach, E12-06-122 has a figure of merit that is roughly 3 times higher than what can be achieved with the combination of the SHMS and the HMS combined.

Finally, we wish to emphasize three points. First, the proposed experiment will compliment nicely the kinematics being proposed for the A_1^n experiment in Hall C [13]. Second, because the proposed experiment will use only existing equipment (or in the case of the Cerenkov counter, apparatus that can be constructed with equipment at hand), and will not require the full performance of the upgraded CEBAF, E12-06-122 will make an excellent commissioning experiment. And third, based on event rates alone, the comparison of Bigbite's FOM with other spectrometers continues to be impressive even at $x_{_{Bj}}$= 0.8 with an 11 GeV beam.

Continuing on this last point, the proposed experiment, in addition to providing an accurate measurement of A_1^n up to $x_{Bj} = 0.71$, will teach us more about backgrounds and issues related to particle ID. As such, E12-06-122 will set the stage for using BigBite to achieve even more kinematic reach than we conservatively propose here. If combined with the future Super Bigbite apparatus, the potential is quite impressive. Furthermore, the careful comparison of data from E12-06-122 with data from PR12-06-110 (the Hall C A_1^n experiment using HMS+SHMS), which will occur under very different conditions using focusing spectrometers, will provide a powerful check of the technique of using open-geometry (BigBite style) spectrometers as a powerful tool to do inclusive physics during the 12 GeV era. E12-06-112 and PR12-06-110 thus not only compliment one another in kinematic coverage, they also collectively help to open new opportunities for a wide variety of inclusive measurements.

References

[1] Jefferson Lab experiment E12-06-112, T. Averett, G. Cates, N. Liyanage, G. Rosner, B. Wojtsekhowski, X. Zheng, spokespersons.

[2] Jefferson lab experiment E06-014, S. Choi, X. Jiang, Z. E. Meziani, B. Sawatzky, spokespersons.

[3] Jefferson lab experiment E06-010, J. P. Chen, X. Jiang, J. C. Peng, spokespersons; Jefferson lab experiment E06-011, X. Jiang, H. Gao,, E. Cisbani, spokespersons.

[4] X. Zheng *et al.*, Phys. Rev. Lett., **92**, 012004 (2004); Phys. Rev. C **70**, 065207 (2004).

[5] H. Avakian *et al.*, Phys. Rev. Lett., **99**, 082001 (2007);

[6] M.K. Jones *et al.*,Phys. Rev. Lett. **84**, 1398 (2000); O. Gayou *et al.*, Phys. Rev. Lett. **88**, 092301 (2002).

[7] A. Airapetian *et al.*, Phys. Rev. Lett. **103**, 152002 (2009).

[8] Super-Bigbite Conceptual Design Report, available at `http://hallaweb.jlab.org/12GeV/SuperBigBite`

[9] Jefferson Lab experiment E12-09-016, G. Cates, S. Riordan and B. Wojtsekhowski, spokespersons.

[10] V. Nelyubin, private communication.

[11] P. V. Degtyarenko, private communication.

[12] B . Sawatzky, private communication.

[13] G.D. Cates, J.-P. Chen, Z.-E. Meziani and X. Zheng, Conditionally approved experiment E12-06-110: Measurement of Neutron Spin Asymmetry A_1^n in the Valence Quark Region Using an 11 GeV Beam and a Polarized ^{3}He Target in Hall C.

[14] A.D. Martin, R.G. Roberts, W.J. Stirling and R.S. Thorne, Eur. Phys. J. C **23**, 73 (2002).