(A New Proposal to Jefferson Lab PAC19)
Measurement of neutron (^{3}He) spin structure functions in the resonance region.

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A Hall A Collaboration Proposal

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Abstract

We propose a precision extraction of the neutron spin structure function g_1^n and the virtual photon asymmetry A_1^n in the resonance region over a moderate Q^2 range (up to $Q^2 = 5.4(\mathrm{GeV/c})^2$) using a polarized ^{3}He target. The Bloom-Gilman duality has been experimentally demonstrated for the spin independent structure functions of the proton down to small values of Q^2. The proposed experiment combined with Deep-Inelastic-Scattering data will provide a precision test of quark-hadron duality predictions for neutron spin structure functions. The demonstration of duality for spin structure functions will enable the use of resonance data as a powerful tool to study the nucleon spin structure in the very high x region.

1 Introduction

We are proposing a precision extraction of neutron spin structure function g_1 and the virtual photon asymmetry A_1 in the resonance region using the Hall A polarized ^{3}He target. The quantities g_1 and A_1 carry valuable information about the spin content of the nucleon, in terms of polarized parton distributions. At low values of x, g_1 and A_1 are sensitive to the sea of $q\bar{q}$ pairs whereas at high x they can be used to study the valence quark spin structure.

A large amount of spin structure data [1] in the Deep Inelastic Scattering (DIS) region has become available over the last two decades. The precision of DIS spin structure data continues to improve with advancements in polarized beam and polarized target technologies. However, very little spin structure data are available in the resonance region. This is especially true for the neutron. Due to the lack of a free neutron target, experiments have been performed with polarized deuteron and ^{3}He targets to extract neutron spin information. Using polarized ND_3 and NH_3 targets SLAC experiment E-143 [2] extracted neutron spin structure functions (SSF) in the resonance region for $Q^2 < 1.2$ (GeV/c)^2. Jefferson lab experiment E94-010 [4] used a polarized ^{3}He target to do a high precision extraction of resonance spin structure functions for the neutron for $Q^2 < 1.0$ (GeV/c)^2. The results from this experiment are expected soon. However, in the moderate Q^2 region of $1.5 < Q^2 < 10$ (GeV/c)^2, there is no SSF data in the resonance region available at present.

Some neutron SSF data in the resonance region are expected to become available in the near future from two Jefferson Lab experiments [5]. Both these experiments will be using polarized ND_3 and NH_3 targets to extract neutron information. This proposal discusses a high precision extraction of the neutron spin structure functions g_1 and the virtual photon asymmetry A_1^n in the resonance region using a polarized ^{3}He target as an effective neutron target for $1 < Q^2 < 5.4$ (GeV/c)^2. Hall C experiment 96-002 will obtain neutron (ND_3) data only at $Q^2 = 1.3$ GeV^2. While hall B EG1/EG2000 group of experiments will have neutron (ND_3) data up to $Q^2 \sim 5$ GeV^2, the statistical uncertainty of the neutron spin structure functions extracted from this data will be about a factor of five larger than the statistical uncertainties for the proposed measurement. Further, the Hall A ^{3}He target setup allows for a direct measurement of the transverse asymmetry ($A_\perp$). This allows us to separate g_1 and g_2 (and A_1 and A_2) in a model independent way. It is not possible to measure $A_\perp$ directly in the Hall B setup requiring model assumptions to separate g_1 and g_2 (and A_1 and A_2) [28]. Thus the proposed measurement will be complementary to the neutron data extracted using polarized ND_3 and NH_3 targets in Halls B and C. These data combined with the precision high x spin structure function data in the DIS region from experiment 99-117 [6] can be used for a stringent test of quark-hadron duality for spin structure functions.

Thirty years ago Bloom and Gilman [7] made the observation that the scaling curve seen at high momentum transfer is an accurate average over the resonance bumps at lower momentum transfer but at the same value of x. This duality between the resonance region, which is best described by constituent quark models, and the scaling region, which is well described by pQCD, hints a common origin for both regions. Several years after the observation of duality, De Rujula, Georgi and Politzer [8] suggested a framework based on the QCD operator product expansion (OPE) within which the averaging of the resonance bumps to the scaling curve can be interpreted in terms of the role of higher twists in DIS. In the OPE, the contributions to the QCD moments of the structure functions are organized according to the powers of $1/Q^2$. The leading terms are associated with free quark scattering and are responsible for the scaling of the structure functions. The $1/Q^2$ terms (higher twist terms) involve interactions between quarks and gluons and hence reflect elements of confinement dynamics. The experimental observation of duality for the unpolarized structure function F_2 of the proton indicates that the higher twist contributions to the proton F_2 moments are small or canceling on average, even in the low Q^2 regime where they should be maximized due to the $1/Q^2$ behavior.

More recently Carlson and Mukhopadhyay [9] have done a further QCD analysis of duality that includes the treatment of background under the resonance peaks. Ji and Unrau [10] have also examined QCD implications of duality. As one of the applications of duality, Ji and Melnitchouk [11] illustrated that higher twist matrix elements could be extracted from resonance data. Recent data from Jefferson Lab Hall C [12] have further confirmed that Bloom-Gilman duality holds to a few percent level down to small values of Q^2. The striking agreement shown by these data for unpolarized structure functions between the resonance and the scaling regions raises the question whether duality holds for polarized structure functions as well. Recently Carlson and Mukhopadhyay [13] have predicted quark-hadron duality for Spin Structure Functions.

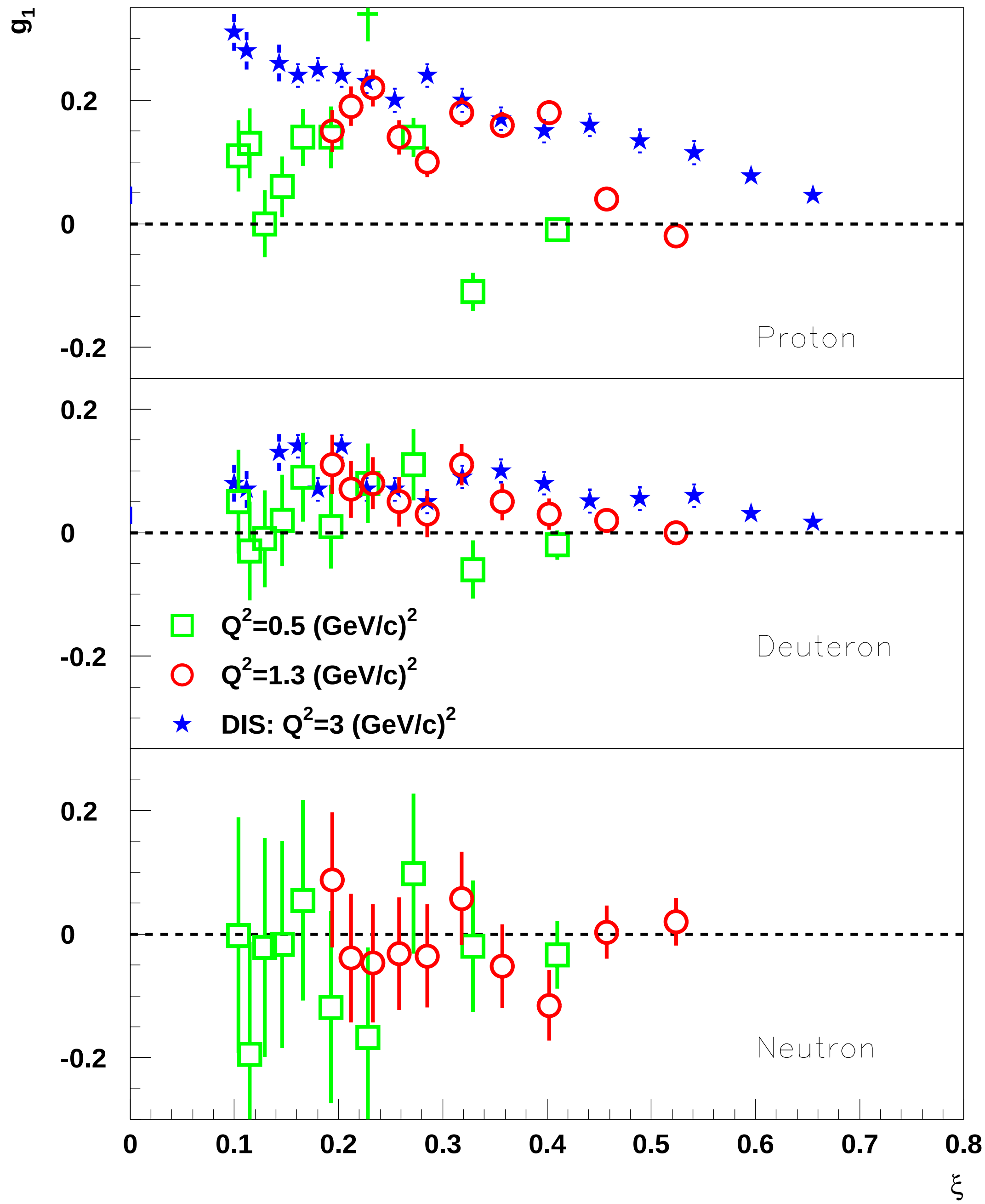

Figure 1: g_1^p and g_1^D measured by SLAC experiment E143 [2] in DIS and resonance regions. The bottom plot shows g_1^n extracted from g_1^p and g_1^D using the equation, $g_1^n(x,Q^2) = \frac{2g_1^D(x,Q^2)}{1-1.5w_D} - g_1^p(x,Q^2)$ where $W_D = 0.05$.

Figure 1 shows g_1^p and g_1^D measured by SLAC experiment E143 [2] in DIS and resonance regions plotted as a function of the Nachtmann scaling variable $\xi = 2x/(1+\sqrt{1+4M^2x^2/Q^2})^1$. For the case of the proton the g_1 resonance data at very low Q^2 ($Q^2 = 0.5$ (GeV/c)^2) differ

[1]The Nachtmann scaling variable takes into account the target mass corrections which become important at low values of Q^2. Note that for high Q^2, $\xi \to x$.

significantly from g_1 data measured in the DIS region. For the $Q^2 = 1.2$ (GeV/c)^2 case the resonance data seem to approach the DIS data indicating the possible onset of duality. It is not possible to draw any conclusion about the g_1^n in DIS and resonance regions because of the large statistical uncertainties that result from the subtraction of g_1^p from g_1^D. Hall A experiment E94-010 [4] is expected to produce g_1^n with high statistical accuracy for $Q^2 < 1.2$ (GeV/c)^2. The measurement we are proposing here will allow us to extend this data to $Q^2 < 5.4$ (GeV/c)^2.

Except for the hint of duality for spin structure functions from E143 data, all the evidence of duality for the nucleon structure functions have only been from the proton F_2 data. The measurement proposed here would provide a study of spin and flavor dependence of duality. This will help answer the question whether the quark-hadron duality observed in one structure function of the proton is due to an accidental cancellation of the higher twist terms (as organized in the OPE formalism) or whether it due to a more fundamental connection between the resonance and scaling regions.

While it is interesting in its own right to test duality predictions for spin structure functions, such a test can lead to very important applications. The measurement of the spin structure functions and the virtual photon asymmetry (A_1) remains crucial to the understanding of the valence quark structure of the nucleon. Different theories and models provide dramatically different predictions for $A_1^{n,p}$ in the high x region. Exact SU(6) symmetry requires that $A_1^n = 0$ and $A_1^p = 5/9$. Quark models with broken SU(6) symmetry predict that both $A_1^p \to 1$ and $A_1^n \to 1$ as $x \to 1$ [14] [15] [16]. pQCD calculations [17] [18] also show that $A_1^p \to 1$ and $A_1^n \to 1$ as $x \to 1$. A recent approach [19] that uses instantons as an important degree of freedom predicts that A_1^n remains negative or close to zero.

Although much more spin structure data exist for the DIS region than for the resonance region, most of these data are limited to the lower x region. This is mainly due to kinematic restrictions in the DIS region that make it difficult to access the high x region. As shown in Figures 3 and 2, this situation is even worse for the neutron due to lack of a free neutron target. Jefferson lab experiment 99-117 intends to measure A_1^n in the DIS region up to $x = 0.63$ with high precision. The availability of 12 GeV beam at Jefferson lab would allow extending this measurement to $x = 0.75$. However, going to higher x in the DIS region requires going to higher Q^2 which reduces the cross section. This makes it almost impossible to measure A_1^n and spin structure functions in the DIS region above $x \approx 0.75$ with a reasonable statistical accuracy. These kinematic restrictions do not apply to the resonance region data. With the availability of 12 GeV beam, it will be relatively easy to measure A_1 and g_1 in the resonance region up to x values as high as 0.95. Therefore if duality is established between the resonance region and the DIS region in the overlap range of $x < 0.75$, the resonance data can be used as a very powerful tool to infer the DIS behavior up to very high values of x.

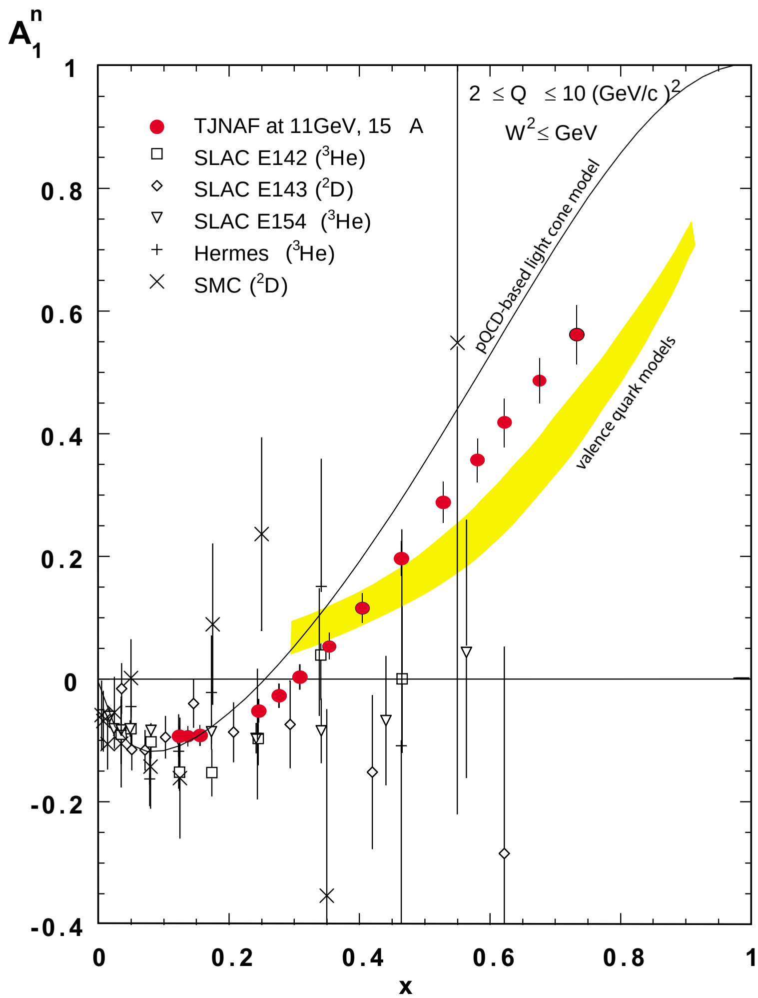

Figure 2: Available DIS A_1^n data. The solid circles show the projected DIS data with 11 GeV beam at Jefferson lab. The solid band indicates the quark model prediction by Isgur [16]. While SLAC E155 data will improve A_1^p at high x, it will not improve A_1^n significantly.

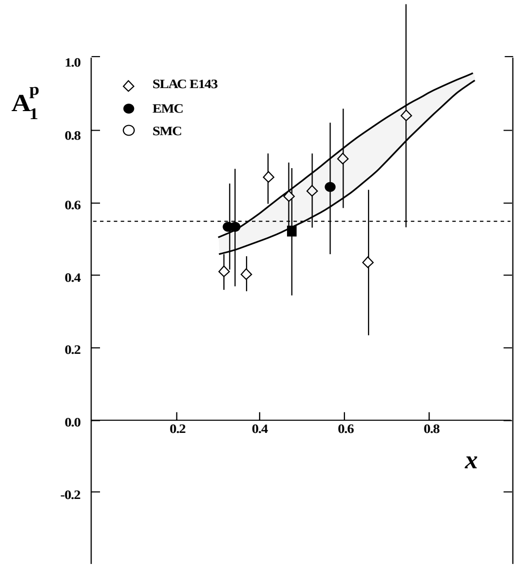

Figure 3: Available DIS A_1^p data in the high x region. The solid band indicates the quark model prediction by Isgur [16].

2 Spin Structure Functions in the Resonance Regions

The exclusive process, $e + p \to e + R$ where R is the final baryon, is described by helicity amplitudes [13]

$$G_m = \frac{1}{2m_N}\langle R, \lambda' = m - \frac{1}{2} \mid \epsilon^{(m)} \cdot j^\mu(0) \mid N, \lambda = \frac{1}{2}\rangle, \tag{1}$$

where $m = \pm 1, 0$, and the polarization vectors are

$$\epsilon^{(\pm)} = (0, \mp 1, -i, 0)/\sqrt{2} \tag{2}$$

$$\epsilon^{(0)} = (\mid q \mid, 0, 0, \nu)/Q. \tag{3}$$

For a single sharp resonance R the relation between the spin structure functions and the helicity amplitudes are

$$\left(1 + \frac{Q^2}{\nu^2}\right) g_1 = m_N^2 \delta(W^2 - m_R^2)\left[\mid G_+ \mid^2 - \mid G_- \mid^2 + (-1)^{s_R - 1/2}\eta_R \frac{Q\sqrt{2}}{\nu} G_0^* G_+\right], \tag{4}$$

$$\left(1 + \frac{Q^2}{\nu^2}\right) g_2 = m_N^2 \delta(W^2 - m_R^2)\left[\mid G_+ \mid^2 - \mid G_- \mid^2 + (-1)^{s_R - 1/2}\eta_R \frac{\nu\sqrt{2}}{Q} G_0^* G_+\right], \tag{5}$$

where $W^2 = (q + p)^2$, the total hadronic mass squared (p is the momentum of the target nucleon and q is the momentum transfer), and s_R and η_R are the spin and parity of the resonance. The delta function for the sharp resonance can be approximated by

$$\delta(W^2 - m_R^2) \approx \frac{1}{2m_R}\frac{\Gamma_R/2\pi}{(W - m_R)^2 + \Gamma_R^2/4} \rightarrow \frac{1}{\pi m_R \Gamma_R}. \tag{6}$$

where Γ_R is the width of the resonance.

3 Bloom-Gilman Duality and Spin Structure Functions

Recently Carlson and Mukhopadhyay [13] have shown that pQCD arguments lead to duality predictions for spin structure functions measured in DIS and resonance regions. These arguments are summarized in this section.

pQCD counting rules [17] give the high Q^2 behavior of helicity amplitudes as,

$$G_+ = \frac{g_+}{Q^3}, \tag{7}$$

$$G_0 = m_N \frac{g_0}{Q^4}, \tag{8}$$

$$G_- = m_N^2 \frac{g_-}{Q^5}, \tag{9}$$

where $g_{\pm,0}$ are constants. These relationships combined with equations 2-6 yield the high Q^2 behavior of g_1 at the resonance peak,

$$g_1 = \frac{m_N^2}{\pi m_R \Gamma_R}\frac{g_+^2}{Q^6} = \frac{m_N^2}{\pi m_R \Gamma_R}\frac{g_+^2}{(m_R^2 - m_N^2)^3}(1-x)^3. \tag{10}$$

The second result requires

$$\frac{1}{Q^2} = \frac{1}{W^2 - m_N^2}\frac{1-x}{x} \approx \frac{1}{(m_R^2 - m_N^2)}(1-x) \tag{11}$$

for $x \rightarrow 1$ and $W \approx m_R$. Similarly,

$$g_2 = \frac{m_N^2}{\pi m_R \Gamma_R}\frac{(1-x)^3}{(m_R^2 - m_N^2)^3} g_+ \left(g_+ - \frac{\eta_R (-1)^{s_R - 1/2}}{\sqrt{2}} g_0 \right). \tag{12}$$

In the deep inelastic region g_1 and F_1 are similarly related to quark distributions except for one sign,

$$g_1 = \frac{1}{2}\sum e_q^2 \left[q_\uparrow(x, Q^2) - q_\downarrow(x, Q^2) \right], \tag{13}$$

$$F_1 = \frac{1}{2}\sum e_q^2 \left[q_\uparrow(x, Q^2) + q_\downarrow(x, Q^2) \right], \tag{14}$$

where the $\uparrow$ ($\downarrow$) refers to quark spin parallel (anti-parallel) to the spin of the parent nucleon. pQCD arguments show that $q_\uparrow$ dominates as $x \rightarrow 1$ [18]. Given this condition both F_1 and

g_1 can be expected to behave similarly at high x. Since $F_1 \propto (1-x)^3$ as $x \rightarrow 1$ one can expect that

$$\lim_{x \rightarrow 1} \; g_1(x) \propto (1-x)^3 \tag{15}$$

in the DIS region. Equations 10 and 15 show that the x evolution of g_1 is the same in DIS and resonance regions indicating duality for g_1.

The virtual photon asymmetry (A_1) is related to spin structure functions by

$$A_1 \equiv \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1 - \frac{Q^2}{\nu^2} g_2}{F_1}, \tag{16}$$

where $\sigma_{1/2}$ and $\sigma_{3/2}$ are cross sections for photo absorption with total initial state spins of 1/2 and 3/2 respectively. For a resonance,

$$A_1 = \frac{\mid G_+ \mid^2 - \mid G_- \mid^2}{\mid G_+ \mid^2 + \mid G_- \mid^2}. \tag{17}$$

Since pQCD arguments show that $\mid G_+ \mid \gg \mid G_- \mid$ at high Q^2, A_1 can be expected to go to 1 as $x \rightarrow 1$ for the resonance data.

As previously noted there are many different predictions for the high x behavior of A_1^n in the deep inelastic region. SU(6) symmetry breaking quark models and pQCD predict that $A_1^n \rightarrow 1$ as $x \rightarrow 1$. If this is the case duality can be expected to hold for A_1 as well.

4 Extraction of g_1 and A_1

g_1 and A_1 can be extracted from helicity asymmetry measurements. Longitudinally polarized electrons are scattered from a target that is polarized either longitudinally or transversely to the beam polarization. The longitudinal ($A_{||}$) and transverse ($A_{\perp}$) asymmetries are formed by combining data obtained with opposite beam helicity;

$$A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}}, \tag{18}$$

$$A_{\perp} = \frac{\sigma^{\downarrow\rightarrow} - \sigma^{\uparrow\rightarrow}}{\sigma^{\downarrow\rightarrow} + \sigma^{\uparrow\rightarrow}}. \tag{19}$$

The spin structure functions can be extracted from these asymmetries by using,

$$g_1(x, Q^2) = \frac{F_1(x, Q^2)}{d'} [A_{||} + \tan(\theta/2) A_{\perp}] \tag{20}$$

$$g_2(x, Q^2) = \frac{y F_1(x, Q^2)}{2d'} \left[\frac{E + E' \cos(\theta)}{E' \sin(\theta)} A_{\perp} - A_{||} \right], \tag{21}$$

where E is the beam energy, E' is the scattered electron energy, θ is the scattering angle, $y = (E - E')/E$, $d' = [(1-\epsilon)(2-y)] / [y(1 + \epsilon R(x, Q^2))]$, $\epsilon = 1/(1 + 2 [1 + \gamma^{-2}] \tan^2(\theta/2), \gamma =$

$2Mx/\sqrt{Q^2})$, M is the nucleon mass and $R(x,Q^2)$ is the ratio of longitudinal to transverse cross sections.

A_1 and A_2 are related to the measured asymmetries by,

$$A_1 = \frac{A_{\parallel}}{D(1+\eta\zeta)} - \frac{\eta A_{\perp}}{d(1+\eta\zeta)} \tag{22}$$

$$A_2 = \frac{\zeta A_{\parallel}}{D(1+\eta\zeta)} + \frac{A_{\perp}}{d(1+\eta\zeta)} \tag{23}$$

where $D = (1 - E'\epsilon/E)/(1+\epsilon R), \eta = \epsilon\sqrt{Q^2}/(E - E'\epsilon), d = D\sqrt{2\epsilon/(1+\epsilon)}$, and $\zeta = \eta(1+\epsilon)/2\epsilon$.

5 The Experiment

We are proposing to measure g_1^{3He} and A_1^{3He} in the resonance region and then use this data to extract g_1^n and A_1^n with high precision up to $x = 0.87$. The lower x range ($x < 0.65$) that overlaps with the DIS data from E99-117 can be used to test duality between the resonance and DIS regions for g_1^n and A_1^n. Longitudinally polarized CEBAF beam up to 6 GeV will be used with the Hall A polarized ^{3}He high pressure gas target. At beam energies of 3.0 GeV, 4.0, GeV 5.0 GeV and 6.0 GeV, both Hall A High Resolution spectrometers (HRS) will be used in a symmetric configuration in electron detection mode. A beam current of 15 μA combined with a target density of about 7×10^{21} atoms/cm^2 provides a luminosity of about 6.5×10^{35} cm^{-2}s^{-1} allowing this experiment to be completed in only 24 days.

5.1 The CEBAF Polarized Beam

In our rate calculations we have assumed 15 μA of beam with 80% polarization. Currents in excess of 15μA with beam polarization as high as 80% have already been delivered over long periods of time using the strained GaAs source at Jefferson lab. The beam polarization will be measured with the Hall A Møller and Compton polarimeters.

5.2 The polarized ^{3}He target

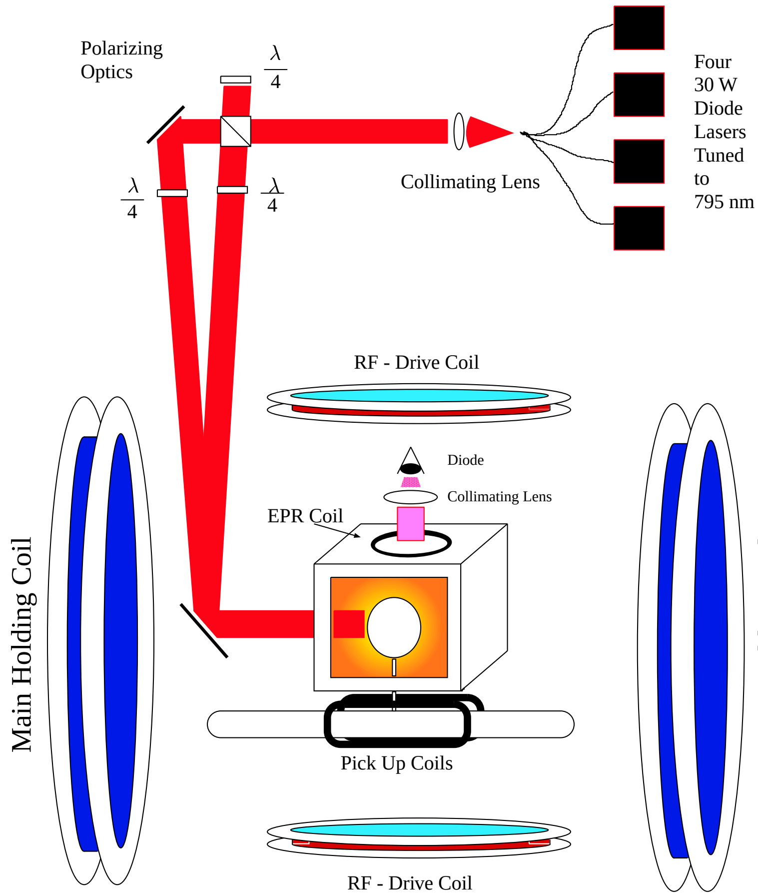

Figure 4: A schematic diagram of the Hall A polarized ^{3}He target

The Hall A polarized ^{3}He target is based on the principal of spin exchange between optically pumped alkali-metal vapor and noble-gas nuclei [23]. This target was successfully used for Jefferson Lab experiments E94-010 and E95-001.

The main feature of the target is the sealed glass cell, which under operating conditions contains ^{3}He at about 10 atmospheres. As shown in Figure 4 the cell consists of two chambers; an upper chamber where the spin exchange takes place and a lower chamber through which the electron beam passes. The appropriate number density of the alkali-metal Rubidium in the upper chamber is maintained by keeping it at a temperature of 200 °C.

The main coils shown in Figure 4 are large Helmholtz coils used to apply a static magnetic field of about 25 Gauss. Also shown are the components for the NMR and EPR polarimetry. The optics system includes three diode lasers for longitudinal pumping and three for transverse pumping. A polarizing beam splitter lens system and quarter wave plates are required to condition each laser beam line and provide circular polarization. For the proposed measurement 25 cm target cells will be used instead of the 40 cm cells used for experiments 94-010 and 95-001. The average target polarization for these two experiments were about 35%. The increased pumping cell volume to target cell volume ratio will help increase the average polarization to the 40% level projected for the proposed measurement.

5.3 The Spectrometer setup

We plan to use both Hall A High Resolution spectrometers (HRS) in a symmetric configuration in electron detection mode. The spectrometer detector packages will be similar to those to be used for experiment E99-117. Each detector package will consist of:

- A Vertical Drift Chamber (VDC) pair for tracking.
- A pair of trigger scintillator planes.
- Gas Cerenkov counter for pion rejection.
- A lead glass calorimeter for additional pion rejection.

As shown in Figure 5 the worst case e/π ratio for this experiment is about 1:100. Thus the combined pion rejection factor of 2×10^{-4} with Gas Cerenkov and lead glass calorimeter, already achieved by E94-010, is sufficient for this experiment.

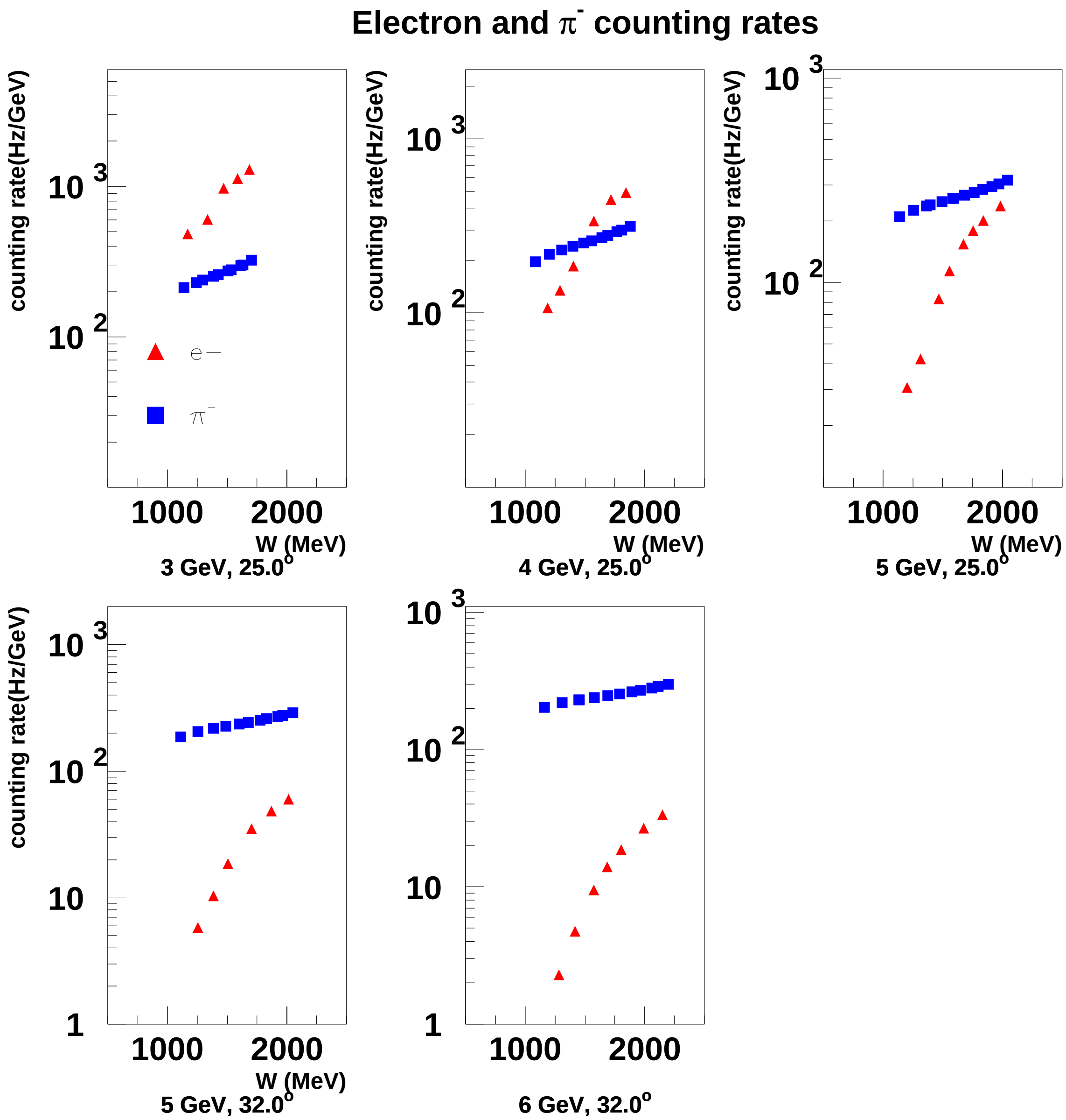

Figure 5: Estimated electron and π^- counting rates.

5.4 Proposed Measurement and Data Analysis

The measurement consists of collecting $^3\vec{\mathrm{He}}(\vec{\mathrm{e}}, \mathrm{e}')$ data at a scattering angle of 25.0° with 3.0 GeV and 4.0 GeV beam energies and at 25.0 ° and 32.0° with 5 GeV and 6 GeV beam energies. Each of these settings will consist of several sub settings with different spectrometer momenta to cover the full resonance region.

The raw measured ^{3}He counting asymmetries are converted to the experimental asymmetry using the relation,

$$A_{\parallel}^{^3He} = \frac{\Delta_{\parallel}}{P_b P_t f} \tag{24}$$

$$A_{\perp}^{^3He} = \frac{\Delta_{\perp}}{P_b P_t f} \tag{25}$$

$$\Delta_{\parallel} = \frac{(N^{\uparrow\downarrow} - N^{\uparrow\uparrow})}{(N^{\uparrow\downarrow} + N^{\uparrow\uparrow})} \tag{26}$$

$$\Delta_{\perp} = \frac{(N^{\downarrow\rightarrow} - N^{\uparrow\rightarrow})}{(N^{\downarrow\rightarrow} + N^{\uparrow\rightarrow})} \tag{27}$$

where $N^{\uparrow\uparrow}$ ($N^{\uparrow\downarrow}$) represents the rate of scattered electrons for each bin in W and Q^2 when the helicity of the incoming electron beam is parallel (anti-parallel) to the target spin. $N^{\downarrow\rightarrow}$ and $N^{\uparrow\rightarrow}$ correspond to the case where the target spin is perpendicular to the beam helicity. $P_b = 0.8$ and $P_t = 0.4$ are the beam and target polarizations respectively. f is the dilution factor that corresponds to the fraction of events that originated from scattering off ^{3}He. At the scattering angles of this experiment, the target cell windows will be outside the spectrometer acceptance, so that there is little or no dilution of asymmetry due to glass windows. Further, the excellent position resolution of the HRS pair would allow the removal of target wall events with software cuts. Reference target runs at each beam energy will be used to calculate the dilution factor. The analysis of E94010 data has indicated that the dilution factor for ^3He due to N_2 present in the target cell is about 95% and it can be calculated to better than 1%. Note that the calculation of A_1^n from $A_1^{^3He}$ involves an extra dilution factor of about $\frac{1}{3}$. The extraction of A_1^n from $A_1^{^3He}$ is discussed in the next section.

The systematic uncertainties are dominated by the measurements of beam and target polarizations. To evaluate the systematic uncertainties for the proposed measurement, we used $\Delta P_b/P_b = 0.03$ as presently achieved by the Hall A Møller and Compton polarimeters and $\Delta P_t/P_t = 0.04$, which is the achieved uncertainty of E94-010. The systematic uncertainties for the proposed measurement are smaller than or comparable to the statistical uncertainties.

The radiative corrections will be applied in two steps. The external corrections will be evaluated using the Mo and Tsai prescription [21]. The internal corrections will be evaluated and corrected for by using the prescription by Kukhto and Shumeiko [22]. A set of low beam energy (3 GeV) measurements at the same angles as the measurements at the two higher beam energies has been selected especially for use in the radiative corrections of the higher beam energy settings.

5.5 Extraction of Neutron Information from ^{3}He

In the DIS region, an effective neutron spin structure response can be extracted from that of ^{3}He using the following procedure, where spin contributions from S, S′ and D states of ^{3}He are considered [24]:

$$\tilde{g_1}^n = \frac{1}{\rho_n}(g_1^{^3He} - 2\rho_p g_1^p) \tag{28}$$

$$\tilde{A_1}^n = \frac{W_1^{^3He}}{W_1^n}\frac{1}{\rho_n}(A_1^{^3He} - 2\frac{W_1^p}{W_1^{^3He}}\rho_p A_1^p), \tag{29}$$

where $\tilde{g_1}^n$, g_1^p and $g_1^{^3He}$ are the spin structure functions for an effective free neutron, a free proton and ^{3}He respectively. The $\tilde{A_1}^n$, A_1^p, and $A_1^{^3He}$ terms give the virtual photon asymmetries for the three particles while W_1^n, W_1^p and $W_1^{^3He}$ give the unpolarized structure functions for the three particles. Because of the pairing of the two protons of ^{3}He mainly in the S state, ^{3}He polarization is dominated by the neutron polarization. $\rho_n = (87 \pm 2)\%$ and $\rho_p = (-2.7 \pm 0.3)\%$ are the polarization values of the neutron and the proton in ^{3}He due to the S, S$'$ and D states of the wave function.

This approach has been shown to work in the DIS region at a few percent level [25]. However, this approach does not include Fermi motion effects or binding effects of the neutron inside ^{3}He. Fermi motion is expected to affect the extraction of the neutron response especially in the resonance region, because of the smearing of the resonance peaks. For the proposed test of duality in this experiment, the important quantity is neither the values of g_1 nor that of A_1 at a certain point of energy transfer but rather the integrated value of these quantities over a resonance region including the contributions from the background [13]. Thus the effects due to Fermi motion will have little effect on the results of this experiment.

A convolution approach to extract the neutron response using a realistic ^{3}He wave function including the full treatment of Fermi motion and binding energy effects has been developed over the last ten years [25]. Currently the development of this method continues especially in the resonance region. Soon this method will be applied to the resonance region spin structure function data from experiment 94-010. This method will also be used by several future polarized ^{3}He experiments in Hall A. Thus, by the time this experiment runs this method will be well tested and we believe that we will be able to use this method to extract the neutron spin response from this experiment at a few percent level.

5.6 Kinematics and rate estimates

Tables 1 gives the kinematics, electron rates and expected uncertainties. For the rate calculations we have assumed a beam current of 15 μA, the combined angular acceptance of the HRS pair (2×6 msr) and the flat region of the HRS momentum acceptance ($\pm$ 4.5%). 15μA of beam combined with a target density of about 7×10^{21} atoms/cm^2 provides a luminosity of about 6.5×10^{35}cm^{-2}s^{-1}. The cross sections were calculated by using the code QFS [26] of Lightbody and O'Connell.

E_0 (GeV)	θ_e (degrees)	E′ (GeV)	Q^2 $(GeV)^2$	$\bar{W}$ (GeV)	$\bar{x}$	Rate Hz	ΔA_1^n	Time Hours
3.0	25.0	2.21	1.24	1.19	0.69	53	0.04	12
		2.04	1.15	1.34	0.54	66	0.04	5
		1.88	1.06	1.47	0.44	107	0.03	5
		1.60	0.98	1.57	0.37	124	0.03	4
		1.48	0.90	1.67	0.31	143	0.03	3
		1.37	0.83	1.75	0.27	145	0.03	3
		1.74	0.77	1.85	0.23	144	0.03	2
4.0	25.0	2.76	2.01	1.20	0.79	12	0.04	15
		2.55	1.91	1.44	0.60	21	0.03	14
		2.35	1.76	1.60	0.50	37	0.03	7
		2.17	1.63	1.73	0.42	49	0.03	4
		2.00	1.50	1.84	0.36	54	0.03	3
		1.84	1.37	1.94	0.31	59	0.03	3
5.0	25.0	3.20	3.03	1.20	0.81	3.4	0.04	45
		2.98	2.80	1.50	0.67	9.2	0.03	18
		2.76	2.58	1.68	0.56	17	0.03	11
		2.54	2.38	1.87	0.46	22	0.03	8
		2.35	2.20	2.12	0.40	26	0.03	6
5.0	32.0	2.66	4.05	1.22	0.85	0.7	0.05	76
		2.46	3.74	1.54	0.70	2.2	0.03	60
		2.10	3.44	1.73	0.61	4.2	0.03	18
		1.93	3.18	1.88	0.53	5.8	0.03	13
		1.78	2.94	2.12	0.42	7.2	0.03	10
6.0	32.0	2.94	5.40	1.25	0.87	0.3	0.08	65
		2.72	5.00	1.58	0.75	1.1	0.04	56
		2.51	4.57	1.84	0.63	2.2	0.04	25
		2.32	4.22	2.01	0.56	3.2	0.04	16

Table 1: Kinematics, rates and statistical uncertainties for the proposed measurement. A 50 MeV momentum bin was used for the rate calculations for the 3 GeV setting while a 100 MeV momentum bin was used for the rest of the settings. Due to the HRS momentum acceptance of $\sim \pm 4.5\%$, each momentum setting considered here contains about four 50 MeV bin (for the 3 GeV case) or 2-3 100 MeV bins. The rates and the uncertainties given are for the bin with the lowest rate of a given momentum setting.

The Q^2/W phase-space covered by this experiment is given in Figure 6. Figure 8 shows the expected data for the three resonance regions compared to the available world data and projected E99-117 data.

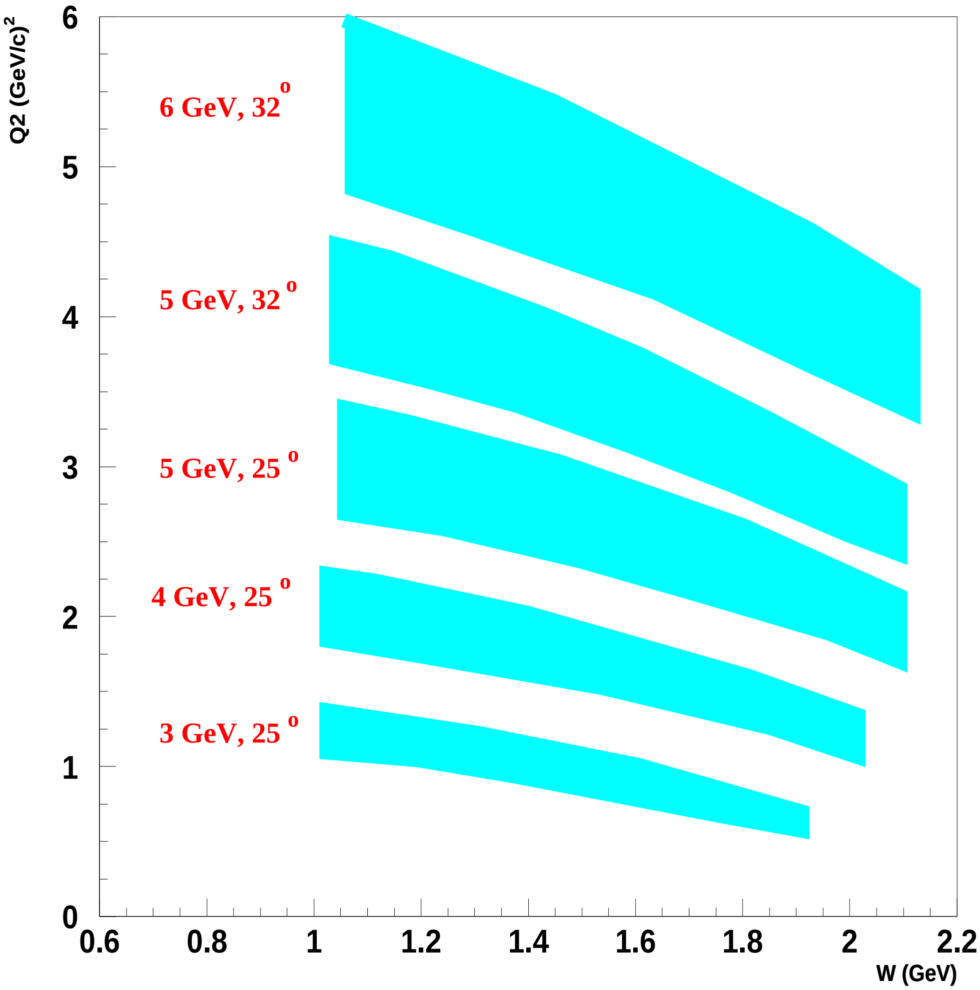

Figure 6: The proposed Q^2 and W coverage

The total measurement time as given in table 1 is 507 hours. This beam time allows for almost complete coverage of the resonance region in Q^2 ($1 < Q^2 < 5.4$ (GeV/c)^2), in x ($0.2 < x < 0.87$), and in W ($1.0 < W < 2.1$ GeV). In addition to this time 12 hours for momentum changes, 8 hours for four Møller measurements, 18 hours for beam energy changes, 8 hours for beam energy measurements 20 hours for calibration and 4 hours for the reference cell running will be required.

The expected uncertainties for g_1 were estimated using the code **ao** [27] of Burkert and Li. Figure 7 compares the projected uncertainties for the $Q^2 \sim 1.3$ GeV^2 setting of the proposed experiment with those for SLAC experiments E143 [2] (resonance region) and E154 [3] (DIS region). E143 g_1^n results shown have been extracted from the proton and deuteron g_1 using the equation [2]:

$$g_1^n(x, Q^2) = \frac{2g_1^d(x, Q^2)}{1 - 1.5w_D} - g_1^p(x, Q^2) \tag{30}$$

where w_D is the probability that the deuteron will be in a D-state. $w_D = 0.05$ was used here as given by N-N potential calculations

Past measurements have indicated that g_1^p is about 5 to 10 times larger than g_1^n in the $0.1 < x < 0.6$ region. As a result, the subtraction of g_1^p from g_1^d generates a large fractional uncertainty for g_1^n as shown for the E143 resonance data in figure 7. For the polarized ^{3}He case, the statistical uncertainty of g_1^n and $g_1^{^3He}$ are similar due the cancellation of the proton spins to first order.

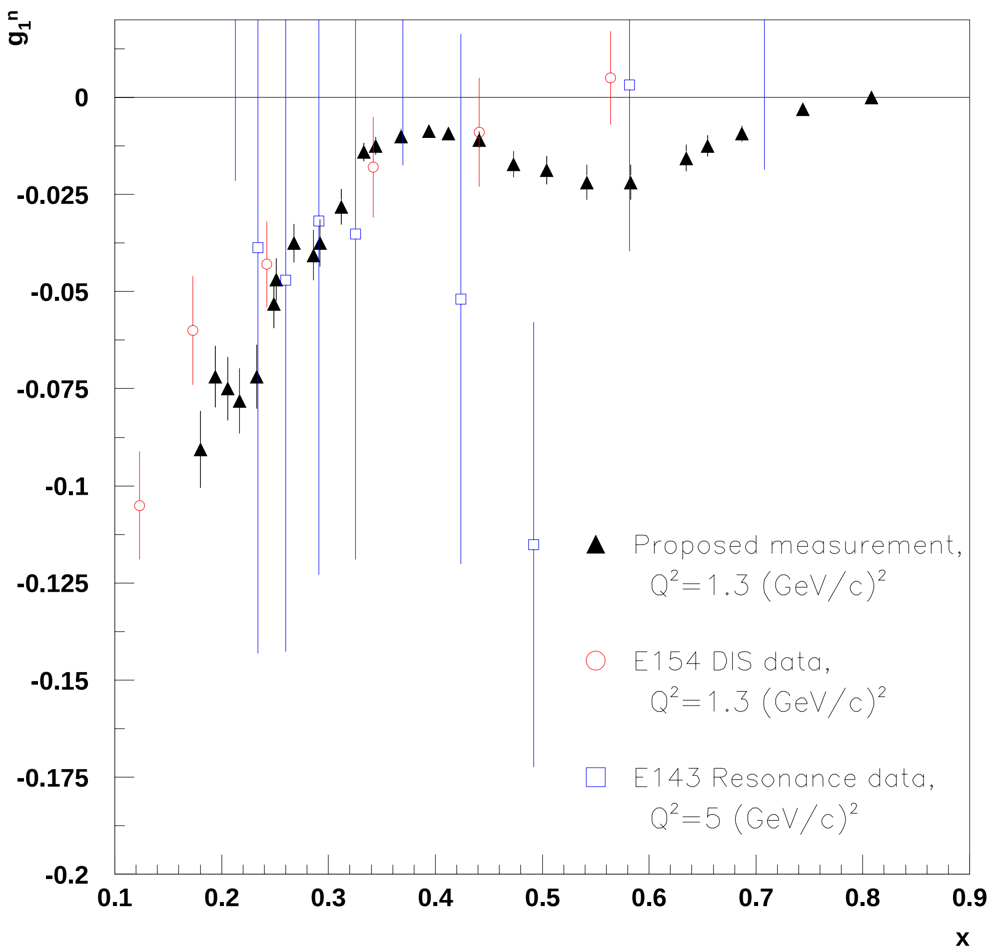

Figure 7: The estimated uncertainties for g_1 at one of the eight proposed settings ($Q^2 = 1.3$ GeV^2), compared with the results from SLAC E143 and E154 experiments

EG1/EG2000 group of experiments in Hall B are currently taking data on NH_3 and ND_3 targets to extract spin structure functions for the proton and the neutron. The statistical uncertainty for A_1^p from EG2000 is expected to be comparable to the uncertainty of A_1^n for the proposed measurement while the uncertainty of A_1^D is going to be about 50% larger than for the proposed measurement. Thus, EG1/EG2000 data will soon allow a precision test of duality for spin structure functions of the proton and the deuteron. However, since g_1^p is many times larger than g_1^n, the deuteron spin structure is dominated by the proton.

Therefore g_1^n and A_1^n extracted from the EG2000 data will suffer from the large increase in uncertainty due to the subtraction of proton data from the deuteron data. As a result, the statistical uncertainties in g_1^n and A_1^n for EG1/EG2000 experiments will be about 5 times larger than the statistical uncertainties for the proposed experiment. Further, the Hall A ^{3}He target setup allows for a direct measurement of the transverse asymmetry ($A_\perp$). This allows us to separate g_1 and g_2 (and A_1 and A_2) in a model independent way. It is not possible to measure $A_\perp$ directly in the Hall B setup requiring model assumptions to separate g_1 and g_2 (and A_1 and A_2) [28].

6 Summary and Request

In summary, we propose a precision measurement of the spin structure function g_1^n and the virtual photon asymmetry A_1^n of the neutron in the resonance region up to $Q^2 = 5.4$ (GeV/c)^2. For the Δ resonance this covers the x range up to $x = 0.87$. For $x < 0.65$ resonance data from this experiment and DIS data from E99-117 overlap enabling a precision test of duality predictions for spin structure functions. When 12 GeV beam becomes available at Jefferson Lab, the DIS measurements could be extended to $x \approx 0.75$, These high x DIS data combined with the data from this proposed measurement will provide a complete test of duality up to $Q^2 = 8$ (GeV/c)^2 and $x = 0.75$. The demonstration of quark-hadron duality for spin structure functions will enable the use of resonance data as a very powerful tool to study the very high x range ($0.8 < x < 0.95$).

The proposed measurement requires 507 hours of data taking along with 12 hours for momentum changes, 8 hours for four Møller measurements, 18 hours for beam energy changes, 8 hours for beam energy measurements 20 hours for calibration and 84hours for the reference cell running. We therefore request a total of 577 hours (24 days) of beam time.

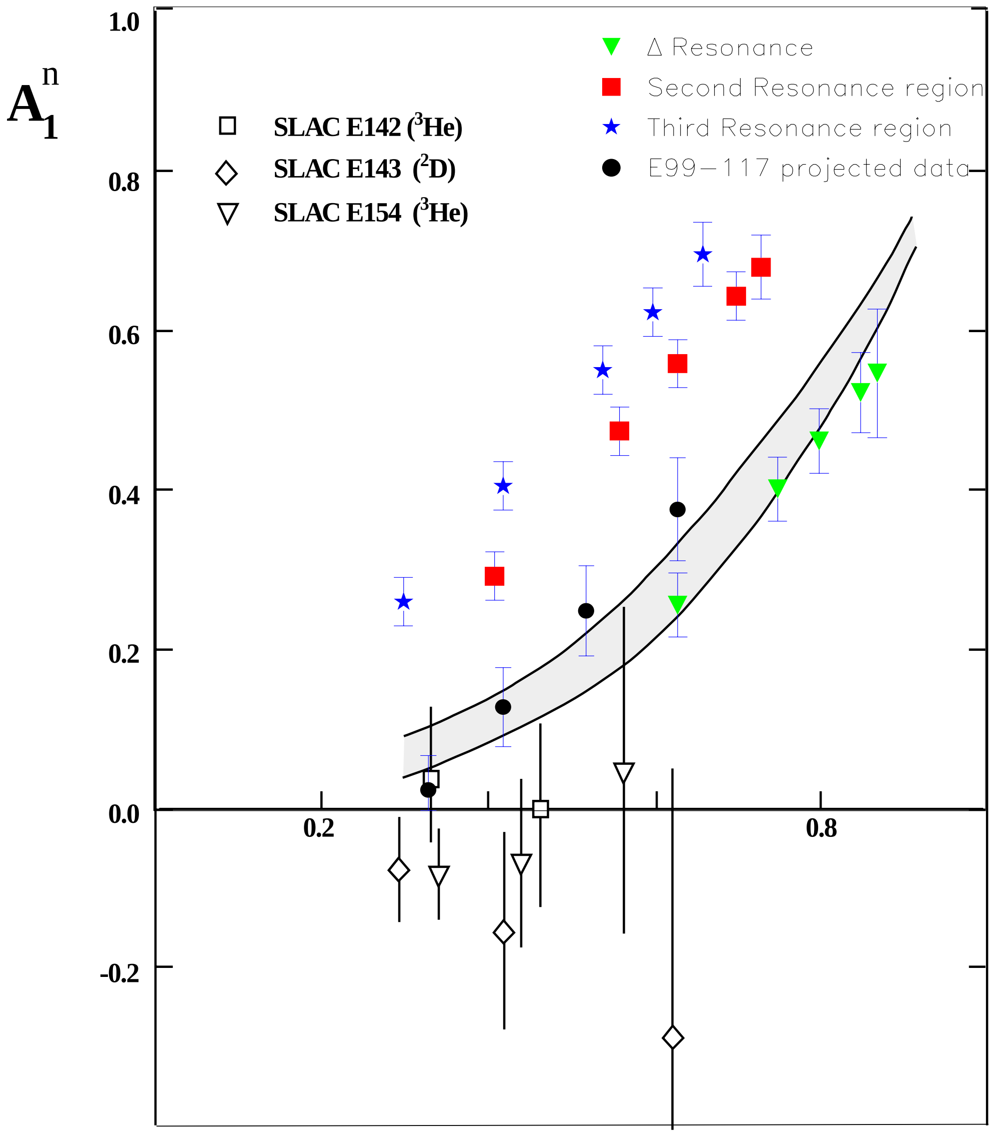

Figure 8: The projected data for the proposed measurement in the three resonance regions. Only 1/5 of the proposed data points are shown here. Note that the values of A_1^n for the three resonance regions have been shifted by different offsets to ensure clarity. The solid circles show the projected data for E99-117

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Appendix: PAC 18 comments on this proposal

Individual Proposal Report

Proposal: PR-00-113

Scientific Rating: N/A

Title: Measurement of neutron (^{3}He) spin structure functions in the resonance region.

Spokesperson: J.P. Chen, N. Liyanage and S. Choi

Motivation: A precise extraction of g_1^n and A_1^n in the resonance region, using a polarized ^{3}He target, will provide a precision test of quark-hadron duality for the spin structure functions.

Measurement and Feasibility: The proposed experiment intends to measure the neutron spin structure function g_1 in the resonance region, for $1.5 < Q^2 < 10$ GeV^2, where no data exist. The experiment will use a polarized ^{3}He target. These data, combined with the soon to be available precise high-x data in the DIS region from Jlab experiment E-99-117, will provide a test of quark-hadron duality in a new sector, the spin structure functions. The neutron g_1^n and A_1^n data will extend up to x=0.84 (for the Δ resonance). The x values between 0.2 and 0.65 will be used to test duality. A beam of 15 µA, 80% polarization will scatter on a pressurized 10 atmosphere, polarized ^{3}He target expected to have at least 35% target polarization.

Issues: The PAC considers that the neutron spin structure is a very important place to study duality, and underlines the relevance of Δ resonance data because of its negative contribution to the neutron g_1. The PAC sees this experiment as one facet in a comparison of neutron and proton spin structure functions to study duality. However, due to the heavy pressure for beam time in Hall A, approval could not be recommended at this time.

Recommendation: Defer