Jefferson Lab PAC19
Proposal Cover Sheet

This document must be received by close of business Thursday,

December 14, 2000 at:

Jefferson Lab
User Liaison,
Mail Stop 12B
12000 Jefferson Ave.
Newport News, VA
23606

Experimental Hall: C

Days Requested for Approval: 21

❒ **Proposal Title:**
Update: E96-002 Precision measurement of the nucleon spin structure functions in the region of the nucleon resonances

Proposal Physics Goals
Indicate any experiments that have physics goals similar to those in your proposal.

Approved, Conditionally Approved, and/or Deferred Experiment(s) or proposals:

E91-023, E93-009, E94-010, E94-014, E97-101

Contact Person

Name: Oscar A. Rondon
Institution: University of Virginia
Address: Physics Department
Address: P O BOX 400714
City, State, ZIP/Country: Charlottesville VA 22904-4714
Phone: 804-924-6787 **Fax:** 804-924-7909
E-Mail: or@virginia.edu

Jefferson Lab Use Only

Receipt Date:_____

By:_____

Update: TJNAF Exp. 96-002

Precision Measurement of the Nucleon Spin Structure Functions in the Region of the Nucleon Resonances

U. Basel, Florida International U., Hampton U., Kent State U., North Carolina A&T U., Norfolk State U., Old Dominion U., U. of Tel-Aviv, TJNAF, U. of Virginia, C. of William & Mary, Yerevan Physics I. *

Oscar A. Rondon, spokesman

A. Experiment summary

This experiment will make high precision and high resolution measurements of the spin structure of the proton and deuteron in the region of the nucleon resonances, at two values of the four-momentum transfer Q^2, ~ 1.3 GeV^2 and ~ 5.5 GeV^2. Fundamental properties of the nucleon and QCD will be explored with adequate precision to obtain conclusive information.

At $Q^2 \sim 1.3$ GeV^2 we will concentrate on the nucleon spin asymmetries $A_1(\nu, Q^2)$ and $A_2(\nu, Q^2)$; ν is the lepton energy loss. The neutron spin asymmetries will be extracted from the measured proton and deuteron asymmetries. A_1 and A_2 describe the quarks contribution to the nucleon spin, explore the effects of quark-gluon interactions which can be represented by twist-3 matrix elements calculable in lattice QCD, and probe the extension of local duality from the unpolarized scattering regime to spin degrees of freedom. The kinematic region to be covered by the data connects very well with other polarized deep inelastic scattering (DIS) experiments, for direct comparison of extrapolated DIS data with measured resonances data to study local duality. This connection has the additional advantage that the spin structure function $g_1 = F_1(A_1 + QA_2/\nu)/(1+(Q^2/\nu^2))$ measured in our experiment (F_1 is the transverse

---

*Updated list of collaboration membership at end of document.

structure function) can be used to test the extended Gerasimov-Drell-Hearn [1] sum rules with a minimum of interpolations or use of fits to the world data on g_1.

We will measure the inclusive parallel and perpendicular asymmetries $A_{||}$ and $A_{\perp}$, to remove any model dependence when extracting the spin asymmetries $A_1 = \frac{C}{D}\Big(A_{||} - dA_{\perp}\Big)$ and $A_2 = \frac{C}{D}\Big(c'A_{||} + d'A_{\perp}\Big)$where C, c', D, d and d' are only functions of the kinematic variables (D has an additional weak dependence on $R = \sigma_L/\sigma_T$).

At $Q^2 \sim$ 5.5 GeV^2 the focus will be the transverse asymmetry $A_{TT}(\simeq A_1)$ which will provide additional information on polarized local duality and its Q^2 dependence, bridging the low Q^2 data with the 12 GeV upgrade. Higher twists will be studied by combining our data with the numerous DIS results. A_{TT} is also directly related to the resonances' form factors and our measurement will test their Q^2 evolution and the associated pQCD predictions. For this kinematics the contribution of A_2 will be minimized by aligning the target field along the direction of the momentum transfer.

The experiment will use up to 150 nA polarized electron beams of 6 GeV energy incident on 3 cm long ammonia and deuterated ammonia targets (NH_3 and N^2H_3). The beam energy should be as close as possible to 6 GeV consistent with possible polarized beam delivery to three Halls. The scattered electrons will be detected in the Hall C HMS, aligned at $\sim 12.5°$ and 35°, corresponding to the two Q^2 values. The Hall C Møller polarimeter will be used to measure the beam polarization. The existing Hall C beam raster system will be used. The chicane used in E93-026 will be needed when taking $A_{\perp}$ and A_{TT} data.

All the required experimental equipment has been already used during the 1998 partial run of E93-026 ("Charge Form Factor of the Neutron"), and it will be available again in the 2001 polarized target run period in Hall C. This period is an invaluable opportunity to schedule E96-002 as part of an extended run period, thereby greatly optimizing the use of all participating institutions' resources (JLab and the collaboration).

Experiments 93-026 and 96-002 passed a joint first technical readiness review on January 25, 2000. The review committee determined in their report that "both experiments are on track". This update is submitted to reiterate our interest in preserving the status of E96-

002, approved for 21 days of beam by PAC 11. In addition, the collaboration is convinced that the scientific case for the experiment has been strengthened since its original approval, meriting an improved rating.

B. Developments since 1997

Progress in the following areas has taken place since this experiment was approved:

• Data on the spin structure functions now exist in a very broad kinematic region, $0.003 \leq x \leq 0.9$ and 1 GeV^2 $\leq Q^2 \leq$30 GeV^2 (and for even greater Q^2 at intermediate $x < 0.4$) for DIS, and there are neutron resonances data at $Q^2 <$ 1 GeV^2. Fig. 1 illustrates the coverage for the SLAC [2–5], and DESY (HERMES [6]) experiments for g_1 in the range of interest for TJNAF experiments ($Q^2 \leq$ 10 GeV^2, $x \geq 0.01$). Lines of constant beam energy and central scattering angle are shown; however, the range of Q^2 at every value of x extends significantly about this central value. The SLAC g_1 data are available for both protons and deuterons at all the kinematics shown in the figures, and for neutrons at some values (48.8 GeV; the 22 GeV data [7] are not shown)[1]. The curve of constant invariant mass $W = 2$ GeV, which corresponds to the region of W above which the nucleon resonances cannot be resolved, is displayed as well.

Data for g_2 exist at similar kinematics as those for g_1 (with additional energies of 38.8 and 32.3 GeV). The g_2 data are limited to protons and deuterons.

[1]Not shown either are the earlier $A_1 + \eta A_2$ SLAC-Yale data [8,9], nor the high Q^2 CERN data (EMC [10] and SMC [11]).

FIGURES

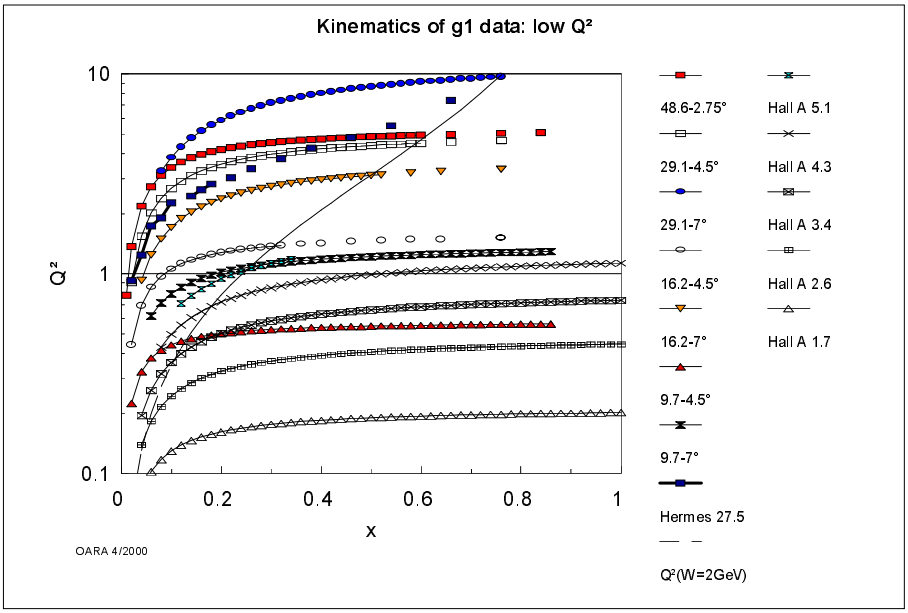

FIG. 1. Kinematic coverage of $g_1(Q^2 < 10\ \mathrm{GeV}^2, x > .01)$. Symbols are only indicative.

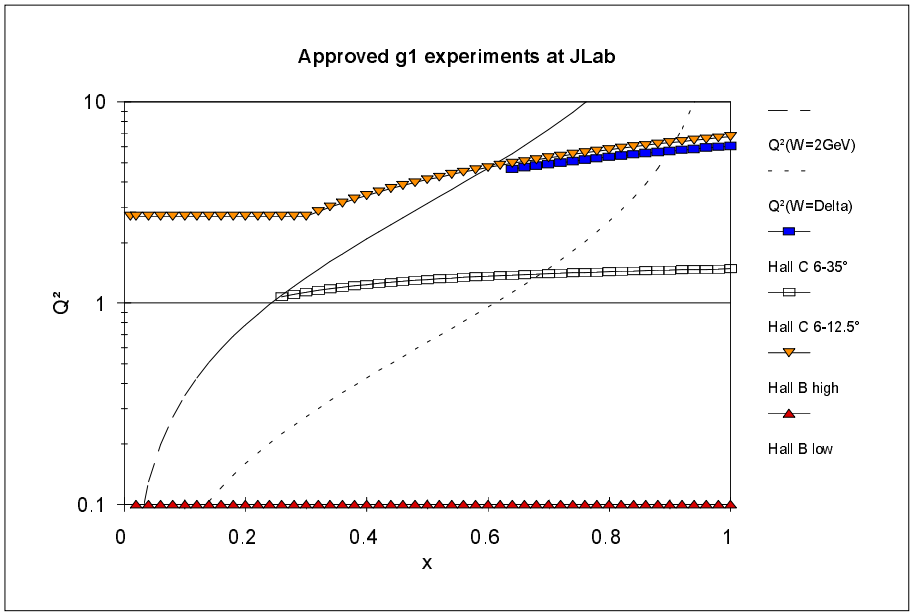

FIG. 2. Kinematic coverage of g_1 by current or planned JLab proton and deuteron experiments. Symbols are only indicative.

From fig. 1 it can also be seen that the region below invariant mass W= 2 GeV, corresponding to the nucleon resonances, is still poorly covered above Q^2=1 GeV^2. Data below

this value of the four-momentum transfer are limited to the neutron (Hall A E94-010 [12]). Fig. 2 shows the additional coverage expected from current and planned JLab experiments (eg1 in Hall B [13,14], and E96-002 in Hall C). The curve of constant invariant mass $W = 1.232$ GeV, which corresponds to the $\Delta(1232)$ resonances is also shown (short dashes).

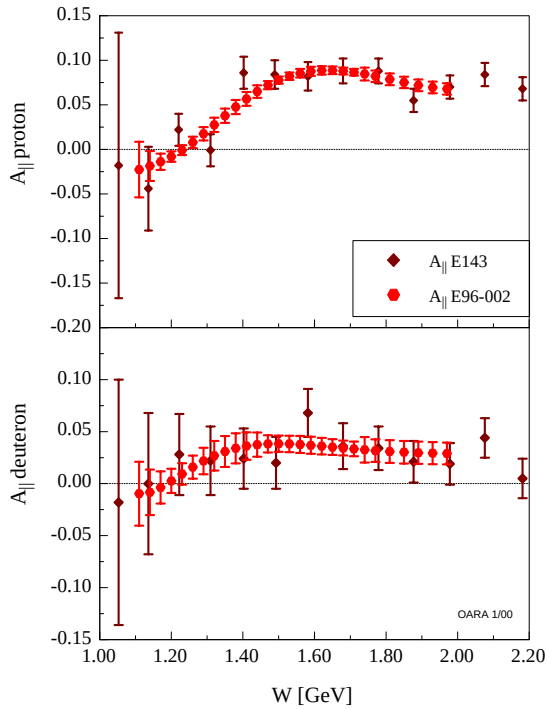

FIG. 3. $A\|$ for protons and deuterons in the nucleon resonances region. Diamonds: SLAC E143; hexagons: expected errors.

• SLAC experiment 143 has published its final results on the spin structure in the resonances region [2]. E143 measured $A_{\|}$ for protons and deuterons with a 9.7 GeV beam at 4.5° and 7°. From these data, the longitudinal spin structure g_1 was extracted, under the assumption $A_2 = 0$. The E143 results for $A_{\|}$ at 7° are shown along with our expected results in fig. 3, based on 100 nA, ∼70% polarized beams and ∼80% proton (30% deuteron) target polarization. The kinematics of the E143 7° data is very similar to our proposed low Q^2 measurement. Factors of ∼3 improvements in both W resolution and statistical precision

are expected for both targets in E96-002.

Q^2-DEPENDENCE OF A_2

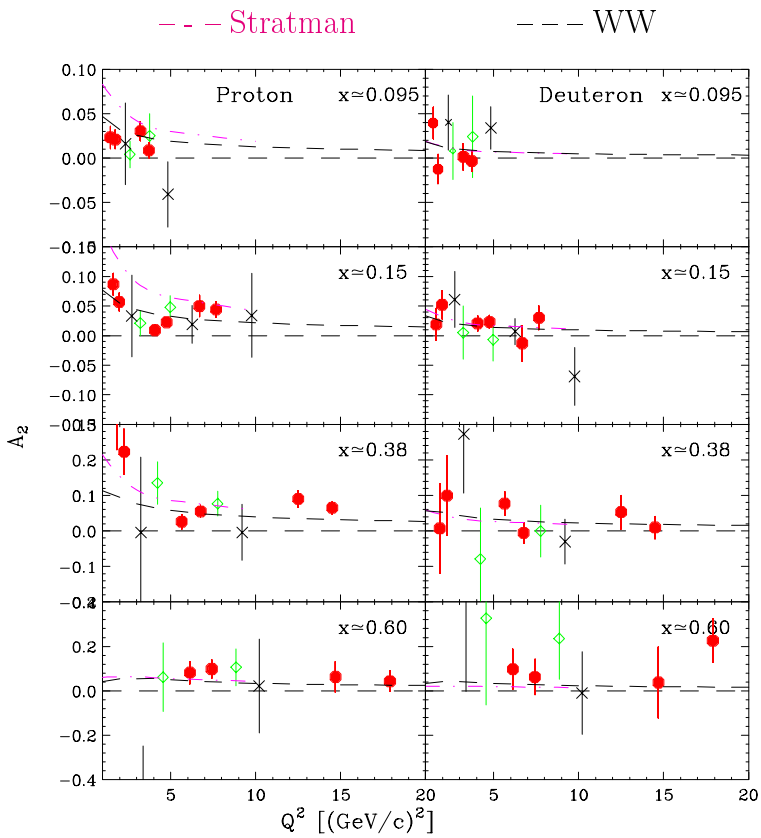

FIG. 4. Preliminary A_2 results from E155x (solid circles) along with the previous measurements from SMC ($\times$), E143 (open diamonds, proton) and E155 (open diamonds, deuteron). Results from the three spectrometers are averaged together. The dashed curve is A_2^{WW}.

• The transverse asymmetry A_2 has been measured in the deep inelastic scattering region in three SLAC experiments [2,4,5]. The results, including preliminary results from E155x are shown in fig. 4, and clearly show a positive $A_2 \sim 0.1$ for much of the x and Q^2 ranges. Therefore, the expectation that A_2 may be zero or very small in the resonances is now quite unlikely, since A_2 shows also a clear tendency to increase with decreasing Q^2, up to the limit $A_2 \leq \sqrt{R}$. R is not yet well known in the resonances (the recent JLab E94-110 [15] is

being analyzed), but existing data indicate $R \simeq 0.2$. This puts a very serious constraint on extracting A_1 from measurements of $A_{||}$ only, under the assumption of a small or zero A_2, and highlights the unique advantage of E96-002 with its $A_{||}$ plus $A_{\perp}$ technique.

• Substantial theoretical interest on the question of local duality for the polarized structure functions has developed after being first mentioned in the original proposal for this experiment [16–20]. The white paper for the 12 GeV upgrade explicitly mentions duality in polarized and unpolarized structure functions among the scientific issues driving the upgrade.

The observation of local duality for the structure functions $F_2^{p,d}$ by Bloom and Gilman [21] can be summarized as the averaging out of the magnitude of the structure functions in the region of the resonances to the extrapolation of their DIS counterparts. The local character of duality is reflected in the fact that the averaging applies to individual resonances, not just to the region as a whole. The question of whether the polarized structure functions would exhibit local duality as well remains unresolved to date, as it can be seen from fig. 5 which shows the E143 9.7 GeV, 7° proton data plotted as a function of the Nachtmann scaling variable

$$\xi = \frac{2x}{1 + \sqrt{1 + 4x^2 M^2/Q^2}} \tag{1}$$

Although the W resolution of the data is poor, it is hard to see from the figure any averaging effect, either local or global. Since the data are at almost constant Q^2 (points with the solid X symbols near $Q^2 = 1$ GeV^2 in fig. 1,) it is valid to calculate directly the integral of the measured structure function $\int_{015}^{0.6} d\xi g_1(\xi)$= 0.40±0.09, and compare it to that of the fit = 0.56, i.e. more than 30% larger than the data's.

The polarized local duality studies to be carried by E96-002 represent an important and unique advance in answering this question, bridging the low Q^2 results that will come out of the current experiments with those of future ones at even higher momentum transfer than that of our measurements at 1.3 and 5.5 GeV^2.

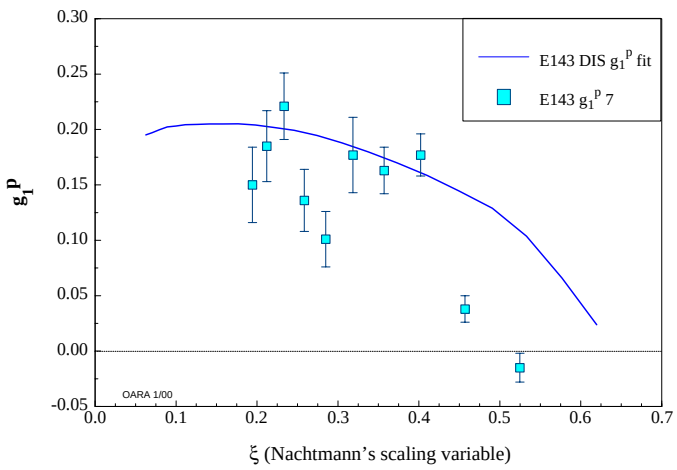

FIG. 5. g_1 in the resonances from SLACs' E143 and extrapolation of E143's global fit to g_1/F_1.

C. Related TJNAF experiments and unique advantages of E96-002

Experiments 91-023 [13] (ammonia targets) and 94-010 [12] (^{3}He target) recently carried out in Hall B and Hall A have made initial measurements of these asymmetries at TJNAF. The Hall B measurements are continuing at the time of this update's writing, with the designation eg1 (E91-023 and E93-009 [14]).

E96-002 is the only experiment capable of measuring A_2 for the proton and the deuteron for the foreseeable future, and of extracting both A_2 and A_1 without assumptions, thanks to our technique of measuring both $A_{||}$ and $A_{\perp}$. The extraction of $A_2(Q^2,\nu)$ from two measurements of $A_{||}$ is severely limited by the magnification of the uncertainties in $A_{||}$, which effectively prevent any significant measurement for most of the kinematic ranges accessible at JLab.

$A_{||}$ depends on the combination of A_1 and A_2

$$A_1(Q^2,\nu) + \eta(E,E',\theta)A_2(Q^2,\nu) = \frac{A_{||}(E,E',\theta)}{D(E,E',\theta,R)} \tag{2}$$

so that two measurements of $A_{||}(E,E',\theta)$ at the (Q^2,ν) intersection of two lines of constant beam energy and scattering angle E_a,θ_a and E_b,θ_b in the Q^2,ν plane can in principle be

used to separate A_1 and A_2. E' is the energy of the scattered electron, $\eta = \epsilon\sqrt{Q^2}/(E - \epsilon E')$, $\epsilon^{-1} = 1 + 2[1 + (\nu^2/Q^2)]\tan^2(\theta/2)$ is the longitudinal polarization of the virtual photon and $D = (1 - \epsilon E'/E/)/(1 + \epsilon R)$ is the virtual photon depolarization. However, for

$$A_2(Q^2, \nu) = \frac{1}{\eta(E_a, E'_a, \theta_a) - \eta(E_b, E'_b, \theta_b)}\Big(\frac{A_{\|}(E_a, E'_a, \theta_a)}{D(E_a, E'_a, \theta_a, R)} - \frac{A_{\|}(E_b, E'_b, \theta_b)}{D(E_b, E'_b, \theta_b, R)}\Big)$$

$$= \frac{1}{\eta_a - \eta_b}\Big(\frac{A_{\|}(a)}{D_a} - \frac{A_{\|}(b)}{D_b}\Big) \tag{3}$$

the uncertainties in $A_{\|}$ are magnified by the factors $1/((\eta_a - \eta_b)D_{a(b)})$

$$\delta^2 A_2 = \frac{1}{D_a^2(\eta_a - \eta_b)^2}\delta^2 A_{\|}(a) + \frac{1}{D_b^2(\eta_a - \eta_b)^2}\delta^2 A_{\|}(b). \tag{4}$$

Since both $D < 1$ and $\eta < 1$, the magnification factors are quite large at the beam energies and angles of interest, as shown in Table 1, for the case of the $P_{33}(1232)$ resonance for two realistic values of the energies and angles, the last one corresponding to our low Q^2 settings. The situation does not change significantly for other values of W because as the η factors increase, the D factors decrease.

Table 1.

W GeV	Q^2 GeV^2	E_a GeV	θ_a	E_b GeV	θ_b	Magnification for E_a, θ_a	Magnification for E_b, θ_b
1.23	0.63	4	12.5°	1.2	60°	11	2.5
1.23	1.4	6	12.5°	3	28.55°	26	11

The value of A_2 has been measured at higher Q^2 values than those contemplated at JLab, as pointed out earlier, and found to be on the order of 0.1. The precision of the $\delta A_{\|}$ measurement that is required to measure $A_2 \sim 0.1$ can be easily estimated from the magnification factors. For the optimized condition in which both the E_a and E_b data contribute equal uncertainties one has

$$\delta A_{\|}(Q^2 = 1.4\text{GeV}^2, W = 1.232\text{GeV}) \leq 0.1/(\sqrt{2} * 26) = 2.7 \times 10^{-3}, \tag{5}$$

which requires a better than 3.3×10^{-4} statistical precision in the counts asymmetry, or equivalently 9 million counts in a $\sim$ 60 MeV bin at 6 GeV plus 1.6 million at 3 GeV.[2]

With a beam current of 10 nA in Hall B's CLAS and a favorable rate of 5 Hz at the bin of interest, the time needed for the measurement of $A_2\sim 0.1 \pm 0.1$ (which is the precision considered in the E91-023 proposal extension [22]) is 500 h at 6 GeV plus 90 h at 3 GeV. On the other hand, with the E96-002 method and for the same ΔW bin width, we get the uncertainties shown in Table 2, in 30 hours $A_\perp$ plus 60 h $A_{||}$ for the proton and 45 h plus 90 h for the deuteron, which clearly constitute a reasonable, albeit not optimum, measurement of A_2.

Table 2.

Resonance	W	Q^2	δA_2	δA_2
	GeV	GeV^2	proton	deuteron
$P_{33}\Delta(1232)$	1.230	1.40	0.03	0.06
$S_{11}N(1535) - D_{13}N(1520)$	1.535	1.29	0.02	0.04
$F_{15}N(1680)$	1.680	1.23	0.02	0.03

Our extraction of A_1 has an even better level of precision (and 30 MeV resolution in W) than that for A_2, as shown in detail in the experiment's proposal.

Experiment 94-014 [23] has explored the $\Delta(1232)$ form factors up to 4 GeV^2, and the $S_{11}(1535)$ up to 3.6 GeV^2, using unpolarized reactions. E97-101 [24] proposes to extend these measurements up to 7.5 GeV^2. The present experiment can extend our knowledge to almost 6 GeV^2 for all the resonances, using polarized scattering to measure the transverse asymmetry A_{TT}. A sample of the expected precision and resolution of those data is shown in fig. 6, based on the same assumptions as the low Q^2 data.

[2] A favorable dilution factor of 0.22 at $W = 1.23$ GeV, beam polarization of 0.7 and target polarization of 0.8 have been assumed for this estimate.

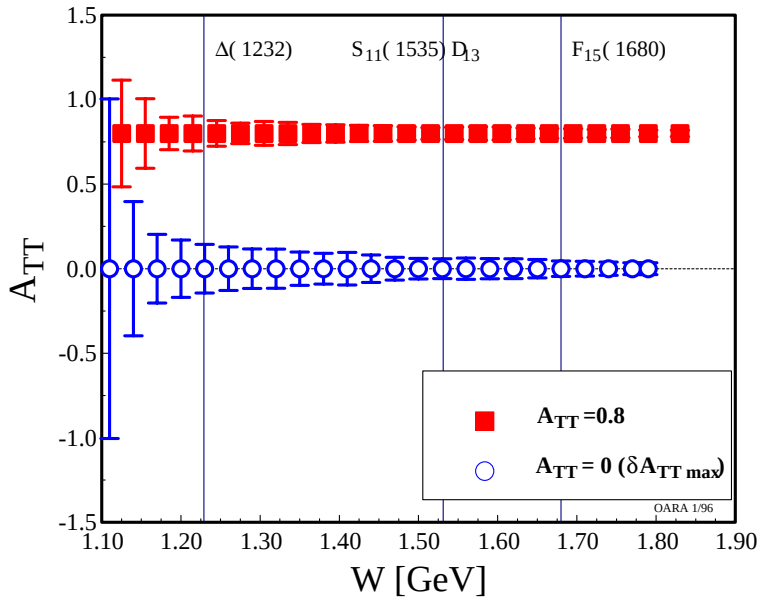

FIG. 6. Expected results for A_{TT} vs invariant mass W

These data and the lower Q^2 data will be used in combination with the abundant body of DIS data to test polarized local duality. The good 30 to 45 MeV expected W resolution, and Q^2 constant to better than 15%, will play a decisive role in reaching definitive conclusions regarding the level of locality of any observed duality. Only E96-002 is capable of this resolution.

D. Proposal and beam request documents

The following documents are on file at TJNAF:

Lab Resources Requirements List,

Hazard Identification Checklist

Beam Time and Requirements List.

The cover sheet and Computing Requirements List have been submitted on-line.

In addition, an up-to-date Beam Request set of forms, with the concurrent signatures, is on file.

E96-002 passed its first Readiness Review, jointly with E93-026, on Jan. 25, 2000.

An updated list of collaborators who have explicitly expressed interest in participating is attached to this update. This satisfies the requirement regarding "Miscellaneous Manpower" mentioned in the Review Committee's Report.

E. Summary

The availability of close to 6 GeV beams with 75% polarization completes all the requirements to carry out this experiment in optimum conditions. The experience gained with the use of the systems involved in this type of measurements during the partial run of E93-026 (G_E^n) will significantly enhance the effective utilization of the approved 21 days of beam time. The demand on the laboratory's resources represented by the installation of the polarized target can be optimized by scheduling this experiment in conjunction with the other scheduled experiment that use the polarized target (continuation of E93-026).

REFERENCES

[1] V.D. Burkert and B.L. Ioffe, Phys. Lett. **B296**, 223 (1992).

[2] K. Abe *et al.* [E143 Collaboration], Phys. Rev. **D58** 112003 (1998).

[3] K. Abe *et al.* , [E154 Collaboration] Phys. Rev Lett. 79 (1997) 26.

[4] P. L. Anthony *et al.* [E155 Collaboration], Phys. Lett. **B493**, 19 (2000).

[5] R. Arnold *et al.* [E155x Collaboration] *A proposal for Extension of E155 to Measure the Transverse Spin Structure Functions of the Proton and Deuteron*, SLAC E155x, September 1997.

[6] A. Airapetian *et al.* [HERMES Collaboration], Phys. Lett. **B442**, 484 (1998).

[7] SLAC E142, P. L. Anthony *et al.,* Phys. Rev. Lett. **71**, 959 (1993).

[8] SLAC E80, M. J. Alguard *et al.,* Phys. Rev. Lett. **37**, 1261 (1976); **41**, 70 (1978).

[9] SLAC E130, G. Baum *et al.,* Phys. Rev. Lett. **51**, 1135 (1983).

[10] EMC, J. Ashman *et al.*, Nucl. Phys. **B328**, 1 (1989)

[11] SMC, B. Adeva *et al.*, Phys. Rev. D **58** 112001-1 (1998).

[12] G. Cates and Z-E. Meziani, spokespersons *Measurement of the Neutron (3He) Spin Structure Function at Low Q^2: a Connection between the Bjorken and Drell- Hearn-Gerasimov Sum Rules*, CEBAF experiment 94-010.

[13] V. Burkert, D. Crabb, R. Minehart, spokespersons, *Measurement of Polarized Structure Functions in Inelastic Electron Proton Scattering using CLAS*, CEBAF Experiment 91-023.

[14] S.E. Kuhn, spokesperson, *The Polarized Structure Function g_l^n and the Q^2 dependence of the Gerasimov-Drell-Hearn Sum Rule for the Neutron*, CEBAF Experiment 93-009.

[15] C. Keppel, spokesperson, *Measurement of R= Sigma L/Sigma T in the Nucleon Resonance Region*, CEBAF Experiment 94-110.

[16] W. Melnitchouk, hep-ph/0010311.

[17] C. E. Carlson and N. C. Mukhopadhyay, Phys. Rev. **D58**, 094029 (1998).

[18] C. E. Carlson and N. C. Mukhopadhyay, hep-ph/9801205.

[19] C. E. Carlson, hep-ph/0005169.

[20] A. Radyushkin, *Duality for Polarized and Unpolarized Structure Functions*, talk at *Quark-Hadron Transition in Structure and Fragmentation Functions Workshop* TJNAF, April 2000.

[21] E. Bloom and F. Gilman, Phys. Rev. D **4**, 2901 (1970).

[22] V. Burkert, D. Crabb, R. Minehart, spokespersons, *Measurement of Polarized Structure Functions in Inelastic Electron Proton Scattering using CLAS*, Extension of Experiment 91-023 to 6 GeV.

[23] J. Napolitano, P. Stoler, spokespersons, *The delta(1232) form Factor at High Momentum Transfer*, CEBAF Experiment 94-014.

[24] P. Stoler, contact person, *Baryon Resonance Electroproduction at High Momentum Transfer*, CEBAF Experiment 97-101.

E96-002 Collaboration
Manpower Resources

Name		Institution
Markus	Hauger	Basel
Adriann	Honegger	Basel
Juerg	Jourdan	Basel
Martin	Kaufmann	Basel
Gunther	Kubon	Basel
Thomas	Petitjean	Basel
Daniela	Rohe	Basel
Ingo	Sick	Basel
Michael	Steinacher	Basel
Glenn	Warren	Basel
Harmut	Woehrle	Basel
Werner	Boeglin	FIU
Pete	Markowitz	FIU
Brian	Raue	FIU
Joerg	Reinhold	FIU
Cynthia	Keppel	Hampton
Keith	Baker	Hampton
Liguang	Tang	Hampton
Ashot	Gasparian	Hampton
Paul	Gueye	Hampton
Michael	Christy	Hampton
Hu	Bitao	Hampton
Liping	Gan	Hampton
Steven	Avery	Hampton
Y.	Liang	Hampton
Anthony	Cochran	Hampton
Alicia	Uzzle	Hampton
Lulin	Yuan	Hampton
Leon	Cole	Hampton
Mina	Katramatou	KSU
Makis	Petratos	KSU
Abdellah	Ahmidouch	NCAT
Sam	Danagoulian	NCAT
Mahbub	Khandaker	NSU
Gail	Dodge	ODU
Andi	Klein	ODU
Jechiel	Lichtenstadt	Tel Aviv

Name		Institution
Chris	Armstrong	TJNAF
Roger	Carlini	TJNAF
Jian-Ping	Chen	TJNAF
Rolf	Ent	TJNAF
Ken	Garrow	TJNAF
Javier	Gomez	TJNAF
Nilanga	Liyanage	TJNAF
Dave	Mack	TJNAF
Joe	Mitchell	TJNAF
Greg	Smith	TJNAF
Bill	Vulcan	TJNAF
Chen	Yan	TJNAF
Jim	Dunne	UMiss/TJNAF
Donald	Crabb	UVA
Donal	Day	UVA
Renee	Hutchins	UVA
Changwu	Li	UVA
Richard	Lindgren	UVA
Dustin	McNulty	UVA
Blaine	Norum	UVA
Yelena	Prok	UVA
Oscar	Rondon	UVA
Cole	Smith	UVA
Kebin	Wang	UVA
Frank	Wesselman	UVA
Marko	Zeier	UVA
Hongguo	Zhu	UVA
Mark	Pitt	VTU
Keith	Griffioen	W&M
Hamlet	Mkrtchyan	Yerevan
Sam	Stepanyan	Yerevan
Vardan	Tadevosyan	Yerevan

Number of collaborators	69
Available shift-persons @10/person	690
Number of beam days	42
Number of run-shifts-persons	378
Number of maintenance days	4
Number of maintenance-shift-persons	12
Total shift-persons	390
Minimum shifts/person	6

12/15/00