E-155 *ext.*

A Proposal for Extension of E155 to Measure the Transverse Spin Structure Functions of the Proton and Deuteron

The E155 Collaboration

Co-spokesmen: R. Arnold, J. McCarthy

R. Arnold, P. Bosted, D. Reyna, S. Rock, L. Sorrell, Z. Szalata, T. Toole

American University, Washington D. C. 20016

I. Sick

Institut für Physik der Universität, CH 4056 Basel, Switzerland

V. Breton, H. Fonvieille, S. Incerti

LPC IN2P3/CNRS, University Blaise Pascal, F-63170 Aubiere Cedex, France

T. Averett, E. W. Hughes, Y. G. Kolomensky

California Institute of Technology, Pasadena, California 91125

H. Borel, R. Lombard-Nelsen, J. Marroncle, F. Sabatie, F. Staley, Y. Terrien

DAPNIA-SPhN, Saclay, F-91191 Gif/Yvette, France

G. G. Petratos, M. Olson

Kent State University, Kent OH 44242

S. Penttila

Los Alamos National Lab, Los Alamos, NM 87545

V. Ghazikhanian, G. Igo, S. Trentalange

University of California, Los Angeles, CA 90021-1547

C. Berisso, R. Hicks, G. Peterson, J. Shaw

University of Massachusetts, Amherst, MA 01003

T. Chupp, K. Coulter, T. Smith, R. Welsh

University of Michigan, Ann Arbor, MI 48109-1120

C. Hyde-Wright, A. Klein, S. Kuhn, L. M. Qin, L. Todor, F. Wesselmann

Old Dominion University, Norfolk, VA 23529

P. Decowski

Smith College, Northampton, MA 01063

P. Anthony, R. Erickson, R. Gearhart, R. Pitthan, C. Prescott, L. Rochester, L. Stuart

S. St. Lorant, W. Meyer, D. Walz C. Young, B. Youngman

Stanford Linear Accelerator Center, Stanford, CA 94309

J. Gomez, J. Mitchell

TJNAF, Newport News, VA 23606

S. Bueltmann, D. Crabb, D. Day, E. Frlez, C. Harris, R. Lindgren, J. McCarthy, P. McKee,

D. Pocanic, O. Rondon-Aramayo, B. Zihlmann, H. Zu

University of Virginia, Charlottesville, VA 22901

K. Griffioen, P. King

College of William and Mary, Williamsburg, VA 23187

H. Band, J. Johnson, G. Mitchell, R. Prepost, T. Wright

University of Wisconsin, Madison, WI 53706

ABSTRACT

This proposal is for an extension of E155 to measure transverse asymmetries for deep inelastic electron scattering of longitudinally polarized electrons from transversely polarized targets of protons and deuterons to determine the virtual photon-nucleon asymmetries A_2^p and A_2^d and the structure functions g_2^p, g_2^d and g_2^n. The expected experimental errors would reduce by a factor of five the errors on measurements of the twist-3 matrix elements, and allow for the first time a test of predictions for g_2 from lattice QCD and the operator product expansion. The proposed measurement would use the same target, spectrometer, and data acquisition systems as were used in E155 with some small modifications. The electron beam energy will be 29 GeV, and with the spectrometers at 2.75°, 5.5°, and 10.5° the kinematic range will be $0.7 < Q^2 < 17$ (GeV/c)^2 and $0.018 < x < 0.8$. We request SLAC resources to reestablish the E155 target setup and to make some small modifications to the beamline and detector systems. We request two calendar weeks of checkout beam at low pulse rate, and two calendar months of high rate (120 hz) data taking.

I. OVERVIEW OF TRANSVERSE STRUCTURE FUNCTIONS AND PREVIOUS RESULTS

The nucleon spin structure functions $g_1(x, Q^2)$ and $g_2(x, Q^2)$ are important tools for testing QCD, models of nucleon structure, and sum rules. Experiments at CERN [1,2] and SLAC [3–8] have measured g_1 and g_2 using deep inelastic scattering (DIS) of longitudinally polarized leptons on polarized nuclear targets. These studies have largely concentrated on g_1^p, g_1^d, and g_1^n, which are dominant when the target is polarized along the beam direction. Their results have established that the quark component of the nucleon helicity is much smaller than the naive quark-parton model predictions [9]. In addition, the Bjorken sum rule [10], a fundamental QCD prediction for the difference of the first moments of g_1^p and g_1^n, has been confirmed within the uncertainties of experiments and theory [2,3,5]. This sum rule has also been used to extract the QCD coupling constant α_s at low Q^2 [11].

Tl is proposal concentrates on $g_2^p(x,Q^2)$ and $g_2^d(x,Q^2)$ which are dominant when longitudinally polarized leptons scatter from transversely polarized nucleons. The g_2 structure function probes both transverse and longitudinal parton polarization distributions inside the nucleon. Properties of g_2 have been established using the operator product expansion (OPE) within QCD [12,13], and the interpretation of g_2 in the light-cone parton model is on firm grounds [14–16]. There are twist-2 (evolves logarithmically in Q^2) and twist-3 (suppressed by an additional $1/\sqrt{Q^2}$) contributions to g_2 which can be written

$$\begin{aligned} g_2(x,Q^2) = &\ g_2^{WW}(x,Q^2) \\ &- \int_x^1 \frac{\partial}{\partial y}\left(\frac{m}{M} h_T(y,Q^2) + \xi(y,Q^2)\right)\frac{dy}{y}. \end{aligned} \tag{1}$$

The twist-2 part comes from $g_2^{WW}(x,Q^2)$ and the quark transverse polarization distribution $h_T(x,Q^2)$, while the twist-3 part $\xi(x,Q^2)$ comes from quark-gluon interactions. The Bjorken scaling variable is denoted by x, $-Q^2$ is the four-momentum transfer squared, m and M are quark and nucleon masses, and y is the x-integration variable. The g_2^{WW} expression of Wandzura-Wilczek [17],

$$g_2^{WW}(x,Q^2) = -g_1(x,Q^2) + \int_x^1 \frac{g_1(y,Q^2)}{y} dy, \tag{2}$$

can be derived from the OPE [12,13] sum rules for g_1 and g_2 at fixed Q^2

$$\begin{aligned} \int_0^1 x^n g_1(x,Q^2)dx &= \frac{a_n}{2}, & n = 0,2,4,... \\ \int_0^1 x^n g_2(x,Q^2)dx &= \frac{1}{2}\frac{n}{n+1}(d_n - a_n), & n = 2,4,... \end{aligned} \tag{3}$$

by keeping a_n (twist-2) and neglecting the d_n (twist-3) matrix elements of the renormalized operators. The quantity $h_T(x,Q^2)$ in Eq. (1) contributes to leading order in quark-quark scattering (e.g., polarized Drell-Yan processes), but is suppressed by m/M [15,16,18] in DIS. This component should not be confused with the twist-3 quark mass term that appears in the OPE, nor with the average transverse spin [18,19] $g_T = g_1 + g_2$ that measures the spin distribution normal to the virtual photon momentum.

The OPE analysis does not yield a sum rule for the first moment of g_2 ($n = 0$). However, Burkhardt and Cottingham [20] have derived the sum rule $\int_0^1 g_2(x)dx = 0$ in the $Q^2 \to \infty$ limit from virtual Compton scattering dispersion relations. It has been suggested [21,22] that g_2 might possibly diverge at low x due to couplings of Regge poles to multi-pomeron cuts. This divergence would invalidate the BC sum rule. More recently a calculation [23] in the double logarithmic approximation suggests that g_2 and g_1 should have the same convergent behavior at small-x. A measurement of g_2 at low x could shed light on which low-x theories are more reliable.

The spin asymmetries A_1 and A_2 for virtual Compton scattering are directly related to the spin structure functions. From the virtual photon transverse cross section σ_T and the transverse-longitudinal interference cross section σ^{TL} one can form the transverse asymmetry

$$A_2(x, Q^2) = \frac{\sigma^{TL}}{\sigma^T} = \frac{(Q/\nu)[g_1(x, Q^2) + g_2(x, Q^2)]}{F_1(x, Q^2)}, \tag{4}$$

where E and E' are the incident and scattered lepton energies, $\nu = E - E'$, and $F_1(x, Q^2)$ is a spin-averaged DIS structure function. The SMC has measured A_2^p [2] at four values of x in the range $0.006 \leq x \leq 0.6$ and $1 < Q^2 < 30$ (GeV/c)^2. These results are much closer to zero than the positivity condition $|A_2(x, Q^2)| \leq \sqrt{R(x, Q^2)}$, where $R(x, Q^2)$ is the ratio of longitudinal to transverse virtual photon absorption cross sections. E143 [6] also found A_2^p and A_2^d to be much smaller than the positivity limit, with a hint that A_2^p is slightly positive in the region $0.2 > x$.

Both A_2 and g_2 can be expressed in terms of the experimental asymmetries as:

$$\begin{aligned} A_2(x, Q^2) &= \frac{\gamma(2-y)}{2d} \left[A_\perp \frac{y(1+xM/E)}{(1-y)\sin\theta} + A_\parallel\right], \\ g_2(x, Q^2) &= \frac{yF_1(x, Q^2)}{2d} \quad \left[\frac{E + E'\cos\theta}{E'\sin\theta} A_\perp - A_\parallel\right], \end{aligned} \tag{5}$$

where $\gamma = 2Mx/\sqrt{Q^2}$, θ is the scattering angle, $y = (E - E')/E$, $d = [(1-\epsilon)(2-y)]/[y(1 + \epsilon R(x, Q^2))]$, and $\epsilon^{-1} = 1 + 2[1 + \gamma^{-2}]\tan^2(\theta/2)$. For $F_1(x, Q^2) = F_2(x, Q^2)(1 + \gamma^2)/[2x(1 + R(x, Q^2))]$ we use fits to data for F_2 [26] and for R [27] which was extrapolated to unmeasured regions for $x < 0.08$.

The previous results for xg_2^p and xg_2^d from SLAC experiment E143 [6] are shown in Fig. 1. The error bars are statistical only. Systematic errors, dominated by radiative correction uncertainties, are indicated by bands. For a given x, the Q^2 probed by the two spectrometers at 4.5° and 7.0° differs by nearly a factor of two. Also shown is the g_2^{WW} curve evaluated using Eq. (2) at $E = 29$ GeV and $\theta = 4.5°$. The g_2^{WW} was determined using $g_1(x, Q^2)$ evaluated from a fit to world data of A_1 [29] and assuming negligible higher-twist contributions. Also shown are bag model predictions [19,31] which include twist-2 and twist-3 contributions for $Q^2 = 5$ (GeV/c)^2. At high x the results for g_2^p indicate a negative trend consistent with the expectations for g_2^{WW}. The deuteron results are less conclusive because of the larger errors.

By extracting the quantity $\overline{g_2}(x, Q^2) = g_2(x, Q^2) - g_2^{WW}(x, Q^2)$, we can look for possible quark mass and higher twist effects. If the term in Eq. (1) which depends on quark masses can be neglected then $\overline{g_2}(x, Q^2)$ is entirely twist-3. Possible contributions beyond twist-2 would be seen from the difference between the data and the solid line in Fig. 1. Within the experimental uncertainty the data are consistent with $\overline{g_2}$ being zero but also with $\overline{g_2}$ being of the same order of magnitude as g_2^{WW}.

Possible contributions to g_2 from higher twist effects can also be searched for by looking at the first few moments of the OPE sum rules and then solving for the twist-3 matrix elements d_n using Eq. 3. E143 reported [6] values for the first three moments for p and d and compared to theoretical predictions [19,31–33] for d_2^p and d_2^d. The results for d_n are consistent with zero, but the errors are large. The precision of the data is insufficient to distinguish between model predictions. E154 reported [8] a measurement of g_2^n and there also the errors were too large to distinguish a difference from g_2^{WW}.

During the recently completed E155 experiment, a small amount of data were taken with both proton and deuteron targets polarized in the transverse direction and with beam energy of 38 GeV, mainly for the purpose of extracting g_1 from the measured $A_{||}$. These results are not yet available, but the feasibility of transverse measurements using the E155 arrangement was clearly demonstrated. These data provide the information on signal and background rates under realistic experimental conditions that is the baseline for the assumptions used in the present proposal.

II. THE PROPOSED EXPERIMENT

In this proposal we plan to make measurements of the proton and deuteron asymmetries $A_\perp^p$ and $A_\perp^d$ using longitudinally polarized electrons with energy 29.1 GeV and polarization of about 80% scattered from polarized protons and deuterons in cryogenic ammonia ($^{15}NH_3$) and ^{6}LiD and the three-spectrometer and detector complex used for E155. This data together with previous data for $A_{\parallel}$ will be used to extract the transverse asymmetries A_2^p and A_2^d and the structure functions g_2^p and g_2^d over the range $0.7 < Q^2 < 17$ (GeV/c)^2 and $0.018 < x < 0.8$. The beam energy of 29 GeV is chosen to optimize the physics yield for transverse asymmetry measurements over a wide x and Q^2 range given the E155 spectrometers at 2.75°, 5.5°, and 10.5°. For this proposal we have assumed 225 hours of 100% efficiency data taking for both the proton and deuteron target. The beam and target parameters are similar to E155, with beam polarization average 80%, proton average polarization of 70% (it could be as high as 80%), and deuteron polarization of 22% in ^{6}LiD. The beam current is assumed to be 2×10^9 electrons per beam pulse at 120 Hz.

A comparison of the possible results from measurements at 29 and 38 GeV is given in Fig. 2. The precision of the data is increased at 29 GeV because of the increase in cross section at lower energy. With the 29 GeV beam energy most of the data are at Q^2 above 1 (GeV/c)^2, except for a few of the lowest x bins of the 2.75° spectrometer where the lowest Q^2 is 0.7 (GeV/c)^2.

In Figs. 3 and 4 we show the possible results for proton and deuteron targets from each of the three spectrometers with the beam energy at 29 GeV. In these and the following plots we have used the beam and target parameters listed above, and have plotted the results assuming $g_2 = g_2^{WW}$. These plots show the overlapping kinematic range of the three instruments that provide wide coverage in x and yields measurements at three values of Q^2 for several bins above $x = 0.2$. This wide kinematic coverage is important for looking for the possible presence of higher-twist contributions to the g_2 structure functions.

The targets will be the same cryogenic complex · sed for E155, and will be polarized transversely relative to the beam by physically rotating the polarizing magnet to put the 5T target field perpendicular to the beam direction. The proton material will be $^{15}NH_3$ which yields maximum proton polarization above 90% and average proton polarization as high as 80%. The deuteron material will be the same ^{6}LiD material used in E155. This material is favored over deuterated ammonia because the ^{6}Li nucleus is polarizable and behaves to the 90% level as a polarized deuteron with an unpolarized ^{4}He core. This results in a larger fraction of target nucleons that are polarized. Experience in E155 shows that deuteron polarization average around 22% is readily achievable. The ^{6}LiD material is robust and more resistant to radiation damage than deuterated ammonia, which improves the overall efficiency of the data taking.

The E155 spectrometer, detector, and data acquisition systems will be used essentially as they were for E155, with the exception of a few small modifications and improvements described below. Running in transverse mode with beam energy of 29 GeV will necessitate a few small adjustments to the beam pipe and collimator system downstream of the target due to the larger excursion of beam in the target/chicane system than for the higher energy beam used in E155. The beam polarization will be measured with the single-arm and double-arm Møller systems used in E155.

For this experiment we request two calendar months of data taking at high pulse rate after a checkout period of two weeks at low rate. For counting rate estimates we have assumed a beam current of 2.0×10^9 electrons per beam pulse. This is to be compared to the 4×10^9 e/pulse used in E155 for longitudinal measurements at beam energy of 45 GeV, and 1.5×10^9 e/pulse at 38 GeV in transverse mode. It was necessary in E155 to reduce the current while in transverse mode to reduce the instantaneous counting rates in the detector systems and the overall total data rate into the DAQ system to acceptable levels. In transverse mode there is an increase in background into the detectors, both from direct spray into the spectrometer apertures, and leakage through the shielding from the large flux of particles deflected by the target field transverse to the beam. This proposed experiment will be run at lower beam energy of 29 GeV compared to the 38 GeV used in E155 transverse. This reduces the beam power that goes into background spray at a given luminosity. We also plan to make a few small but important improvements to the beam pipe and shielding arrangement that should help reduce the background into the detectors. These factors should permit operation at 2×10^9 e/pulse.

III. POSSIBLE RESULTS OF THIS EXPERIMENT

The possible results for measurements of the g_2 structure functions of the proton, deuteron, and extracted for the neutron are shown in Figs. 5 to 7. The E155x data points represent the statistical error that would be achieved by averaging the measurements in the three spectrometers assuming 225 hours of 100% efficiency data to tape for each of the proton and deuteron targets and with beam and target parameters given above. The final total error for g_2 will also contain relatively small contributions from the systematic errors on the measurements, and from the errors on g_1 from the previous experiments. The errors on g_2 will be dominated by the statistical errors of this proposed measurement.

To show the sensitivity of this proposed measurement to the possible physics content of the structure functions, the possible data points are plotted at values of $g_2 = g_2^{WW}$. Also shown are the previous data for g_2^p and g_2^d from E143 [6], and the recent results from E154 [8] for g_2^n obtained from a small amount of data taken on a polarized ^{3}He target. Deviations of the measured values from g_2^{WW} that would reveal the higher twist contributions were not discernible in previous data, given the errors on the data. This experiment will be able to distinguish higher-twist contributions as small as 15% to 20% of g_2 in the region $x > 0.2$. The x dependence of the g_2 structure function will be important for discriminating the various models which predict different shapes for g_2 versus x (See Fig. 1).

The possible presence of higher twist contributions may also be detected from integrals over the g_2 data. Indicated in Figs. 5 to 7 are the values of the possible error on the twist-3 matrix element d_2 that would be obtained from such measurements compared to the values from the previous experiments. The following table shows a comparison of the proposed errors on the d_2 matrix elements with errors from the previous data, and with values from various model calculations. This experiment would improve the precision on the d_2 contributions by factors of 4 to 5 compared to the previous data, and would be able to distinguish between the model predictions.

	$d_2^p \times 10^2$	$d_2^d \times 10^2$	$d_2^n \times 10^2$	Ref.
This Prop.	$\pm.12$	$\pm.14$	$\pm.31$	
World Avg.	$.54 \pm .50$	$.39 \pm .92$	-1.0 ± 1.5	
Bag Models	1.76	.68	.25	[19]
	.6	.29	.03	[31]
QCD Sum	$-.6 \pm .3$	$-1.7 \pm .5$	3 ± 1	[32]
Rules	$-.3 \pm .3$	$-1.3 \pm .5$	2.5 ± 1	[33]
Lattice	$-4.8 \pm .5$	$-2.6 \pm .92$	$-.39 \pm .27$	[34]

This proposed measurement would also yield significantly more precise results for the virtual photon-nucleon asymmetries $A_2(x, Q^2)$. It would be very interesting to see if the hint that A_2^p is non zero for $x > 0.2$ seen in E143 is confirmed by more precise data. Data from this experiment could be used to look for the Q^2 dependence of A_2 predicted to fall with Q^2 like $1/\sqrt{Q^2}$.

Finally, the precision of this proposed data at various values of Q^2 in the three spectrometers will permit a search for the possible Q^2 dependent shape of the g_2 structure functions. To indicate the potential sensitivity to twist-3 components, which are predicted to fall with increasing Q^2 like $1/\sqrt{Q^2}$, we show one example in Fig. 8 of the data plotted versus Q^2 for the x bin around $x = 0.45$ where we might expect the sensitivity to twist-3 terms to be significant (See Fig. 1.). For pure g_2^{WW} we expect the values of $\overline{g_2}(x, Q^2) = g_2(x, Q^2) - g_2^{WW}(x, Q^2)$ to be centered around zero within errors. Higher twist contributions could show up as an offset from zero (of either sign). If the extra contributions followed the form $1/\sqrt{Q^2}$, then the values of $\overline{g_2}(x, Q^2)$ could have the shapes of the curves shown in Fig. 8, where the curves correspond to different amounts of possible twist-3 contribution. At $x = 0.45$ the value of g_2^{pWW} is about 0.08. So for example, a value for $\overline{g_2}(x, Q^2) = C/Q$ with $C = 0.01$ as shown in Fig. 8 corresponds to a 12% twist-3 contribution at $Q^2 = 1$ (Gev/c)^2. This proposed experiment should be able to discern contributions beyond twist-2 of 15% to 20% or more from the Q^2 dependence in the bins $x > 0.2$.

IV. PROPOSED IMPROVEMENTS AND RUN PLAN

This proposal assumes that the E155 target complex will be returned to SLAC from TJNAF and reinstalled in End Station A. For this proposed experiment we plan to use the E155 target, spectrometers, and data acquisition systems essentially as they were for E155, with a few small improvements necessary for running in transverse mode at 29 GeV and to improve the background rejection in the detectors of the 10.5° spectrometer.

During E155 we found that the detector package of the 10.5° spectrometer could be improved with some minor additions to the detectors and electronics that would significantly enhance the background rejection in that instrument. The signal of deep inelastic scattered electrons into the 10.5° spectrometer is small (about 0.01 e/pulse) while the flux of pions and low energy spray particles is fairly large, due mainly to the shallow bend angle and the relatively open geometry of the magnet system. The primary method for signal detection is by identification of hits in coincidence in the Cherenkov, shower counter, and a set of front hodoscopes. The proposed plan for improving this device is to increase the number of hits in TDC's that can be used for identifying good scattered electrons amid the background. This can be achieved by adding a second layer of discriminators and TDC's to the shower counter blocks, similar to the scheme that is employed in the other two spectrometers. The two levels of discriminators are operated with different thresholds, which gives some energy sensitivity to the TDC hits. This information is very useful for identifying electrons which typically generate larger pulse heights than the background.

Another improvement would be to increase the granularity of the front hodoscope package to permit the tracking system to function adequately in the expected background situation for transverse running. For this we would use a combination of existing PMT's and scintillators that would be refurbished by the collaboration. Some new discriminator and TDC electronics and cabling would be required.

Another feature of the 10.5° spectrometer system that needs to be fixed is the sensitivity of the shower counter photo tubes to the stray magnetic fields (in the 5 to 10 gauss range) from the spectrometer and target magnets. This sensitivity interferes with the operation of the experiment with different magnet configurations (e.g. when running the spectrometers in opposite polarity to detect positrons for subtraction of the pair-symmetric backgrounds). This shielding could easily be accomplished with an iron box around the entire shower counter.

In summary the proposed improvements are:

1. Modifications to the beamline and the collimator 3C6 just downstream of the target to permit beam at 29 GeV to pass on to Beam Dump East with the offsets created by the transverse magnetic field of the target and the chicane magnets.

2. Minor improvements to the shielding in the area downstream of the target to reduce the impact of the spray flux from the target on the detectors of the 5.5° and 10.5° spectrometers.

3. Addition of about 50 channels of variable width discriminators and TDC's to the 10.5° shower counter, plus addition of about 70 channels of discriminators and TDC's to the front hodoscope package.

4. Addition of a magnetic shield around the 10.5° shower counter.

The basic run plan for the data taking portion of this experiment requires two calendar months. We have estimated the expected statistical errors using counting rate for signal and backgrounds based on experience from E155 and using the beam and target parameters described above. The two months (2×720 hours) would be apportioned roughly as: SLAC linac and lab efficiency = 0.7, E155 efficiency = 0.7 yielding a 100% efficiency for data to tape of about 0.5 of the calendar time. The 720 hours at 100% efficiency would be divided into three approximately equal portions, with about 225 hours each devoted to the proton and deuteron targets in transverse mode. The other third of the beam hours will be spent spent on a) measuring pair symmetric backgrounds with the spectrometer magnetic fields reversed, b) spectrometer and detector calibrations, c) empty target and solid (carbon) target runs for determination of the target dilution factor (fraction of polarized nucleons), and d) Møller runs to measure the beam polarization. This plan is completely consistent with the actual data taking efficiencies and overheads achieved during E155.

V. REQUEST TO THE LABORATORY

Our request to SLAC for this proposed measurement is:

1. Resources to reinstall the E155 target and make it operational.

2. Resources to make the modifications and improvements to the experimental equipment itemized above.

3. Checkout run time at low pulse rate of approximately two weeks prior to the full rate data taking to commission the target, spectrometers, and data acquisition systems.

4. Full rate (120 pps equivalent) running for two calendar months to measure transverse asymmetries for proton and deuteron targets.

REFERENCES

[1] EMC, J. Ashman *et al.*, Phys. Lett. **B206**, 364 (1988); Nucl. Phys. **B328**, 1 (1989).

[2] SMC, B. Adeva *et al.*, Phys. Lett. **B302**, 533 (1993); D. Adams *et al.*, Phys. Lett. **B329**, 399 (1994); **B336**, 125 (1994); **B357**, 248 (1995).

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

[4] E143, K. Abe *et al.*, Phys. Rev. Lett. **74**, 346 (1995).

[5] E143, K. Abe *et al.*, Phys. Rev. Lett. **75**, 25 (1995).

[6] E143, K. Abe *et al.*, Phys. Rev. Lett. **76**, 587 (1996).

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

[8] E154, K. Abe *et al.*, SLAC PUB 7460 (May 1997), Phys. Lett. bf B404, 377 (1997).

[9] J. Ellis and R. Jaffe, Phys. Rev. **D9**, 1444 (1974); **D10**, 1669 (1974).

[10] J. D. Bjorken, Phys. Rev. **148**, 1467 (1966); Phys. Rev. **D1**, 1376 (1970).

[11] J. Ellis and M. Karliner, Phys. Lett. **B341**, 397 (1995).

[12] R. L. Jaffe and X. Ji, Phys. Rev. **D43**, 724 (1991).

[13] E. V. Shuryak and A. I. Vainshtein, Nucl. Phys. **B201**, 141 (1982).

[14] L. Mankiewicz and Z. Rysak, Phys. Rev. **D43**, 733 (1991).

[15] X. Artru and M. Mekfi, Z. Phys. **C45**, 669, (1990).

[16] J. L. Cortes, B. Pire and J. P. Ralston, Z. Phys. **C55**, 409 (1992).

[17] S. Wandzura and F. Wilczek, Phys. Lett. **B72**, 195 (1977).

[18] R. L. Jaffe and X. Ji, Phys. Rev. Lett. **67**, 552 (1991).

[19] X. Song and J. S. McCarthy, Phys. Rev. **D49**, 3169 (1994), **D50**, 4718, (1994), X. Song, INPP-UVA-95/04 (1995).

[20] H. Burkhardt and W. N. Cottingham, Ann. Phys. **56**, 453 (1970).

[21] M. Anselmino, A. Efremov and E. Leader, Phys. Rep. **262**, 1 (1995).

[22] R. L. Heimann, Nucl. Phys. **B64**, 429 (1973).

[23] B. I. Ermolaev and S. I. Troyan, hep-ph/9703384 (1997), hep-ph/9706324.

[24] T. V. Kukhto and N. M. Shumeiko, Nucl. Phys. **B219**, 412 (1983); I. V. Akusevich and N. M. Shumeiko, J. Phys. **G20**, 513 (1994).

[25] Y. S. Tsai, Report No. SLAC-PUB-848 (1971); Rev. Mod. Phys. **46**, 815 (1974).

[26] NMC, P. Amaudruz *et al.,* Phys. Lett. **B295**, 159 (1992).

[27] L. W. Whitlow *et al.,* Phys. Lett. **B250**, 193 (1990).

[28] B. Ehrnsperger and A. Schafer, Phys. Rev. **D52**, 2709 (1995).

[29] E143 K. Abe *et al.,* Phys. Lett. **B364**, 61 (1995).

[30] A. Ali, V. M. Braun, and G. Hiller, Phys. Lett. **B266**, 117 (1991).

[31] M. Stratmann, Z. Phys. **C60**, 763 (1993), and private communication for values at $Q^2 = 5$ (GeV/c)^2.

[32] E. Stein *et al.*, Phys. Lett. **B343**, 369 (1995).

[33] I. I. Balitsky, V. M. Braun and A. V. Kolesnichenko, Phys. Lett. **B242**, 245 (1990); **B318**, 648 (1993).

[34] M. Gőckeler *et al.*, Phys. Rev. **D53**, 2317 (1996).

FIGURES

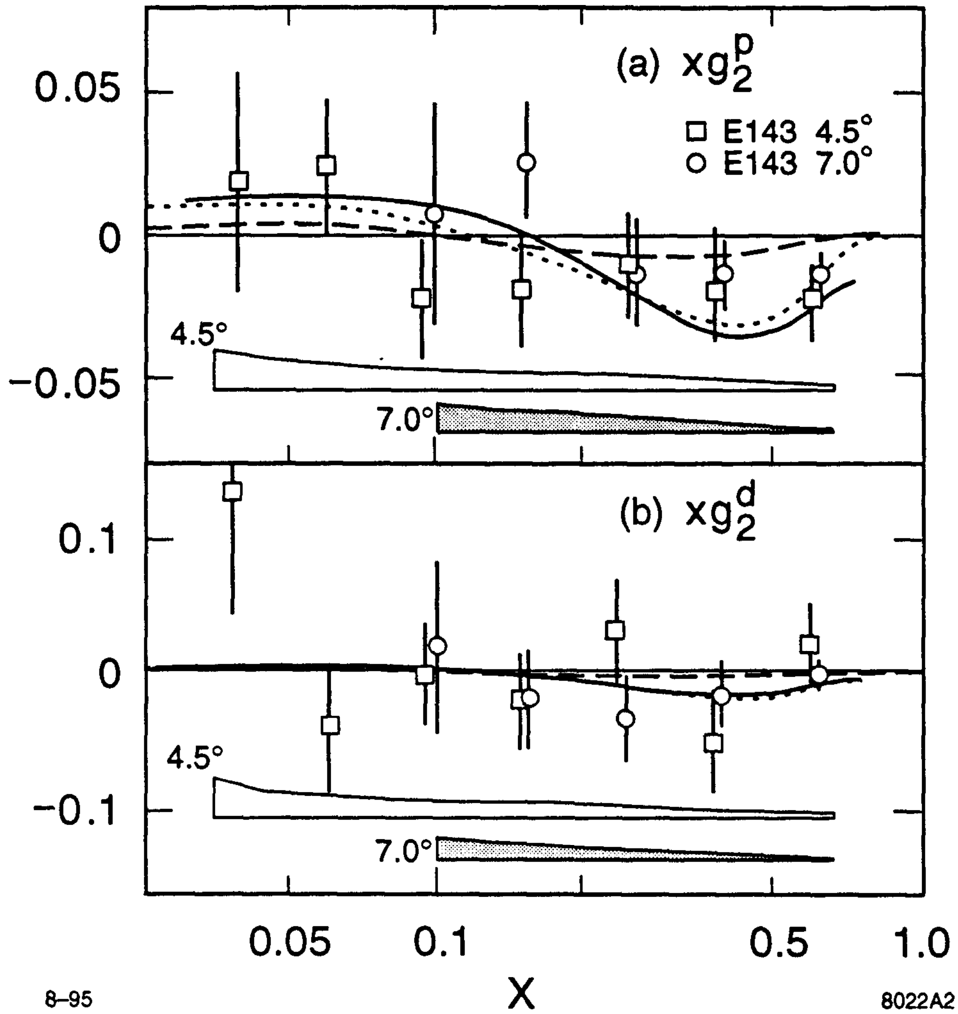

FIG. 1. Measurement for (a) xg_2^p and (b) xg_2^d from E143. Systematic Errors are indicated by bands. The solid curve shows the twist-2 g_2^{WW} calculations for $E = 29.1$ GeV and $\theta = 4.5°$. Bag model calculations at $Q^2 = 5.0$ (GeV/c)^2 by Stratmann [31] (dotted) and Song and McCarthy [19] (dashed) are indicated.

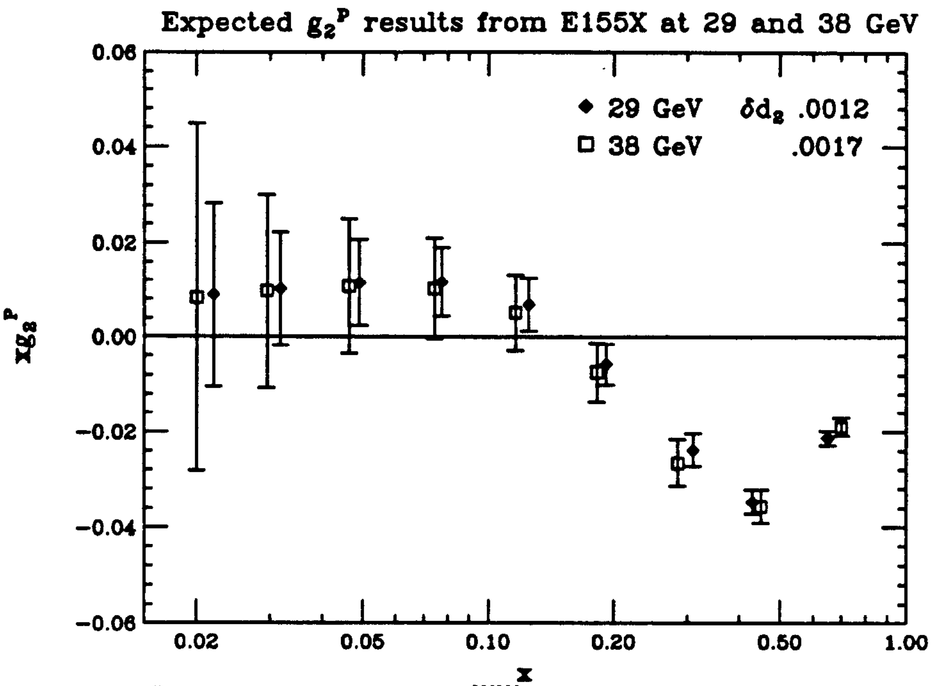

FIG. 2. Expected xg_2^p results assuming $g_2 = g_2^{WW}$ from E155x at 29 and 38 GeV for 225 hours of data. Results from three spectrometers at 2.75°, 5.5°, and 10.5° are averaged together. The δd_2 values are the expected errors on the twist-3 matrix elements d_2^p.

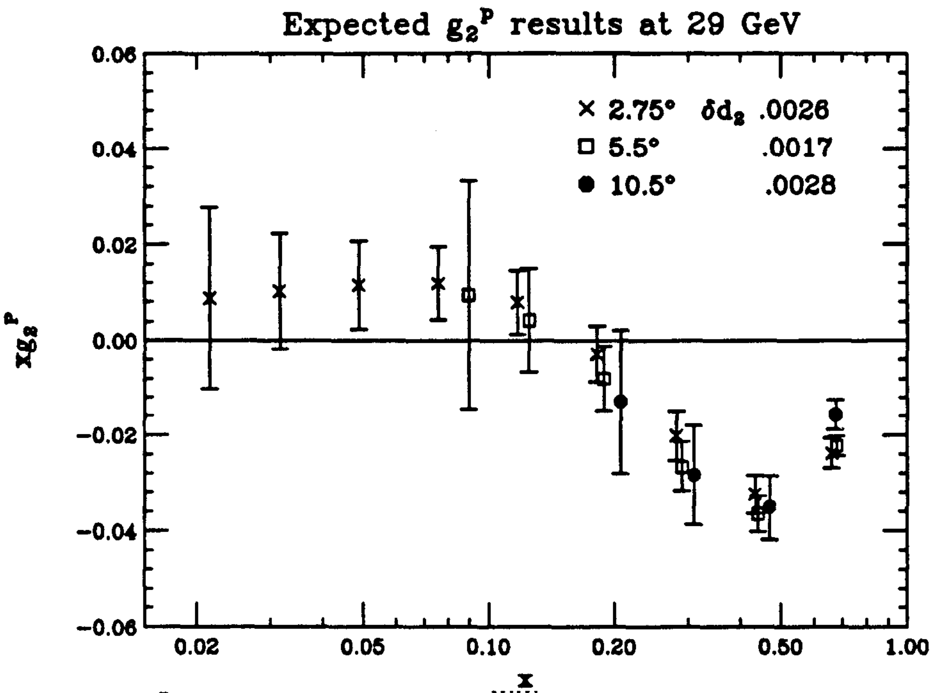

FIG. 3. Expected xg_2^p results assuming $g_2 = g_2^{WW}$ from E155x at 29 GeV in the three spectrometers at 2.75°, 5.5°, and 10.5° The δd_2 values are the expected errors on the twist-3 matrix elements d_2^p.

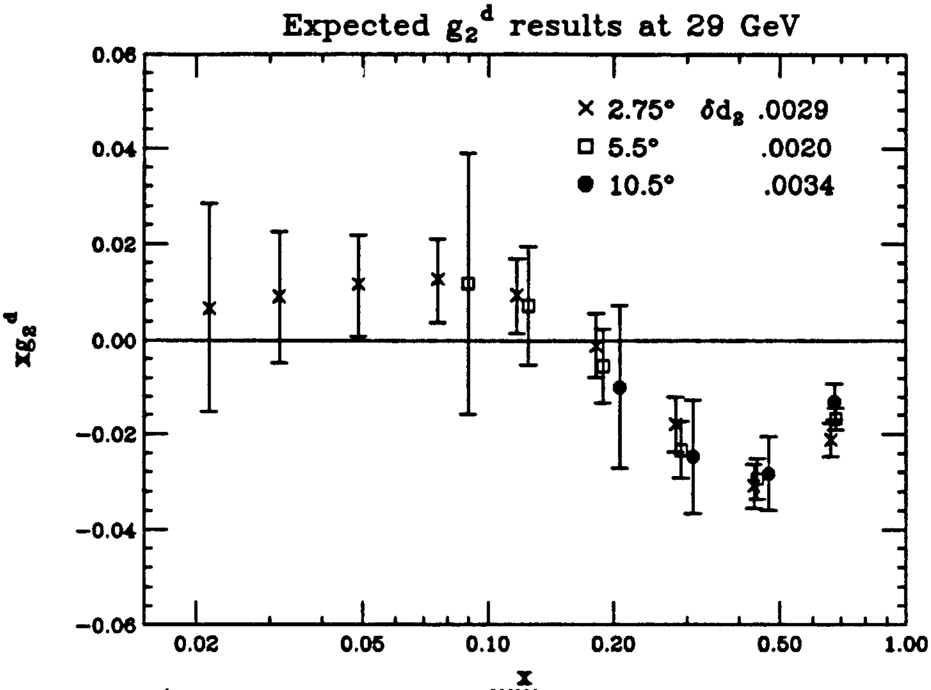

FIG. 4. Expected xg_2^d results assuming $g_2 = g_2^{WW}$ from E155x at 29 GeV in the three spectrometers at 2.75°, 5.5°, and 10.5° The δd_2 values are the expected errors on the twist-3 matrix elements d_2^d.

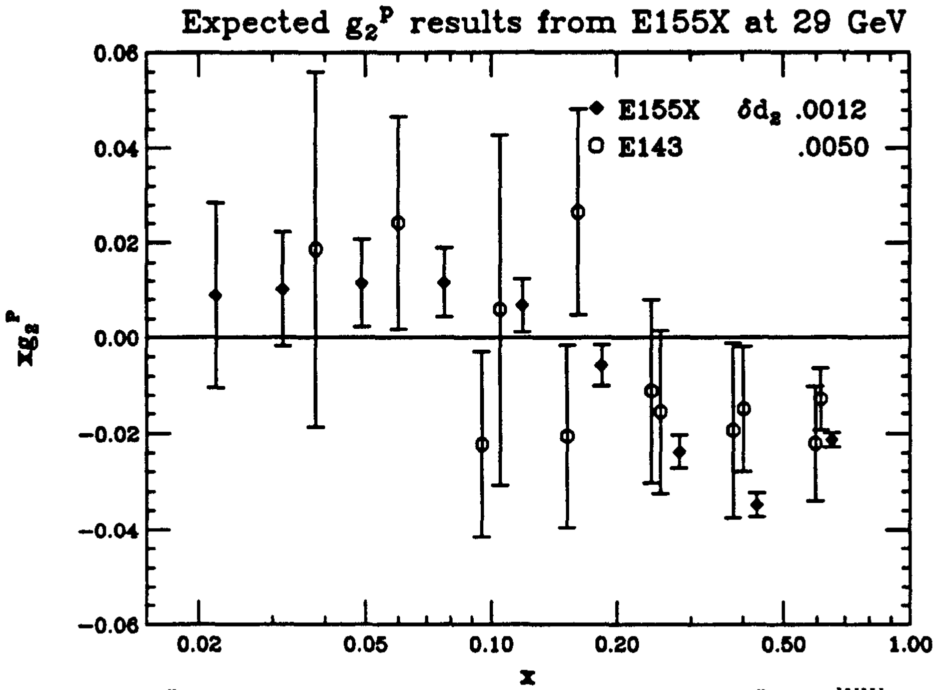

FIG. 5. Expected xg_2^p results from E155x at 29 GeV assuming $g_2^p = g_2^{WW}$ along with the previous measurements from E143. Results from three spectrometers at 2.75°, 5.5°, and 10.5° are averaged together. The δd_2 values are the corresponding errors on the twist-3 matrix elements d_2^p.

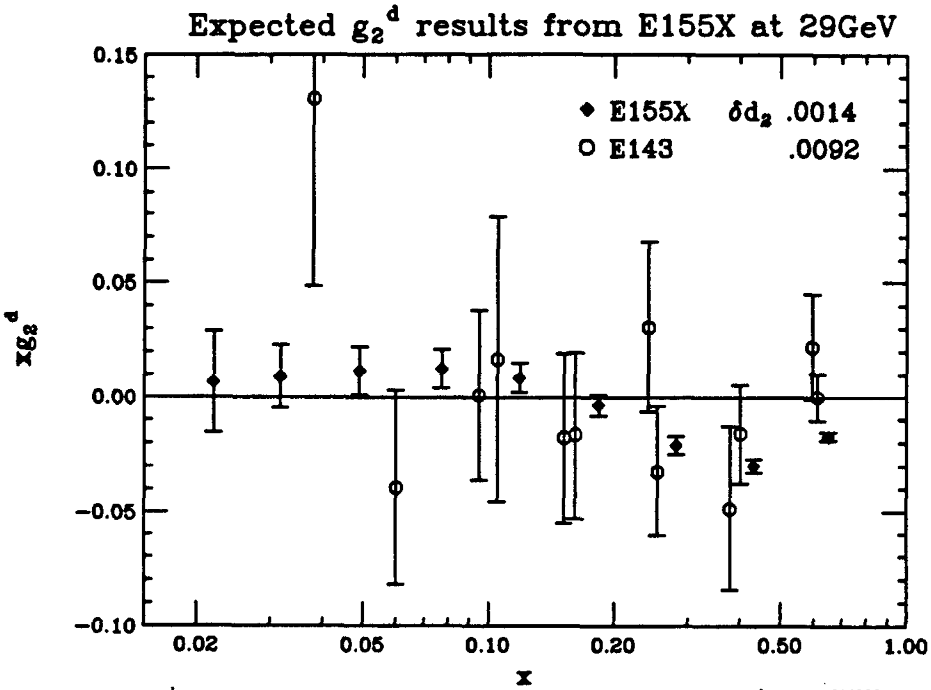

FIG. 6. Expected xg_2^d results from E155x at 29 GeV assuming $g_2^d = g_2^{WW}$ along with the previous measurements from E143. Results from three spectrometers at 2.75°, 5.5°, and 10.5° are averaged together. The δd_2 values are the corresponding errors on the twist-3 matrix elements d_2^d.

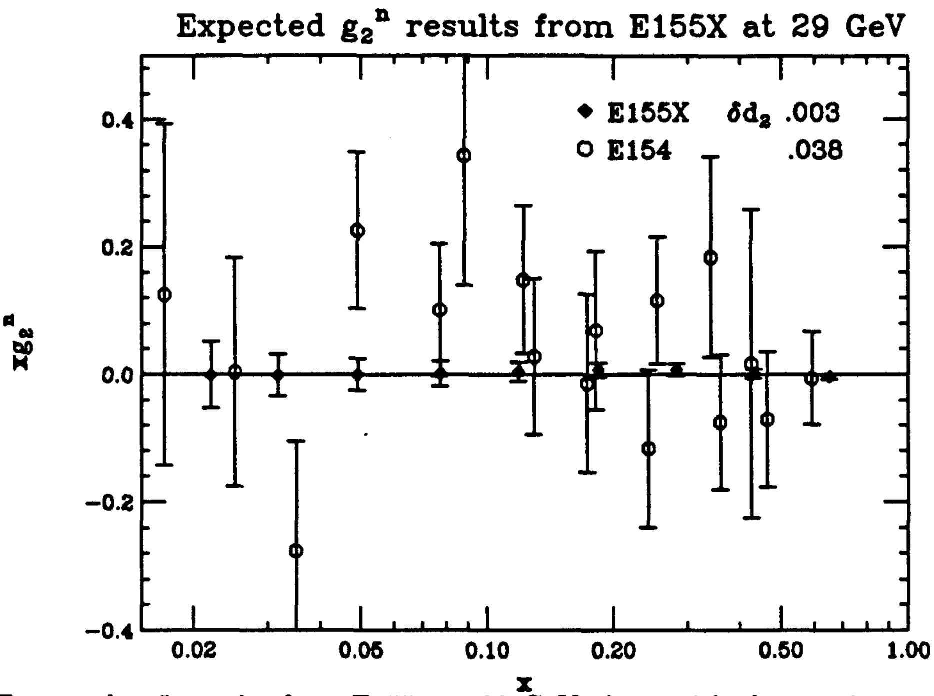

FIG. 7. Expected xg_2^n results from E155x at 29 GeV along with the previous measurements from E154. Results from three spectrometers at 2.75°, 5.5°, and 10.5° are averaged together. The δd_2 values are the corresponding errors on the twist-3 matrix elements d_2^n.

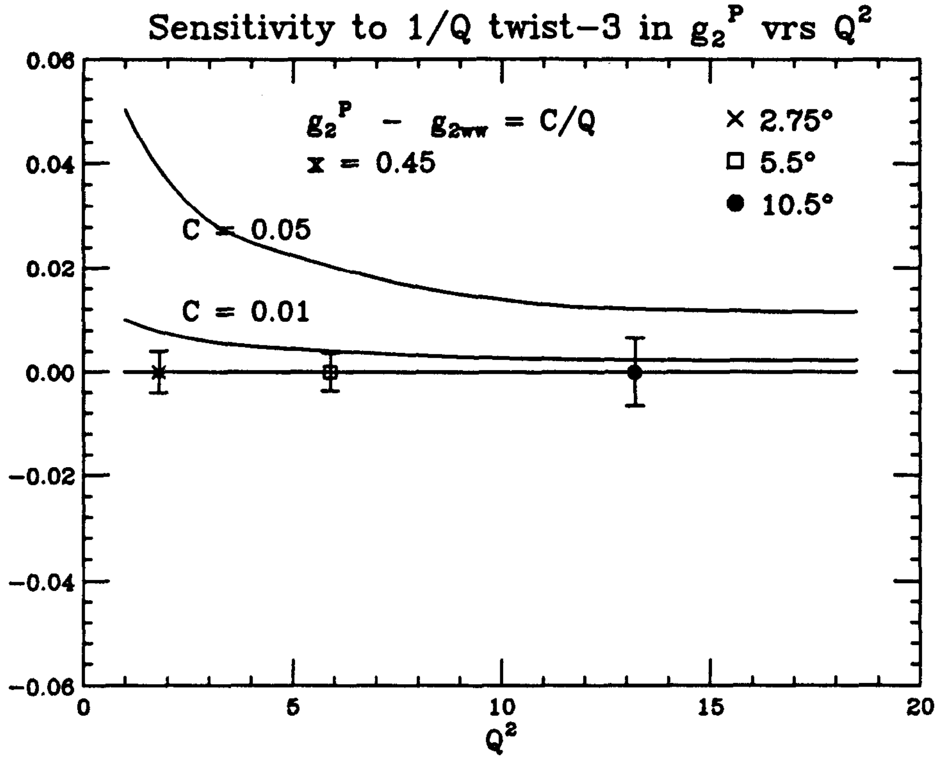

FIG. 8. Sensitivity of E155x to the possible presence of twist-3 components in g_2^p. The three points, one from each spectrometer, indicates the error bars achievable on the quantity $\overline{g_2} = g_2^p - g_2^{WW}$ at $x = 0.45$ versus Q^2. If there are no twist-three components in g_2^p then the values will be centered at 0.0. If there are significant twist-3 components (i.e. $c \neq 0.0$), the values of $\overline{g_2}$ could be shifted from zero and could display a $1/Q$ dependence expected of twist-3 terms. A coefficient $c = 0.01$ corresponds to twist-3 contributions about 12% of the g_2^{WW} twist-2 values at that x.