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The 50 GeV Program at SLAC *

Charles Y. Prescott
Stanford Linear Accelerator Center
Stanford University, Stanford CA 94309

ABSTRACT

The plans for upgrading the End Station A fixed target beam line and for spin structure experiments using electron beams at energies up to 50 GeV are described.

1. Introduction

SLAC has undertaken a modest program to upgrade the beam energy for fixed target experiments to 50 GeV. This upgrade is possible due to the previous extensive development work on the linac accelerating gradient for the SLC, which has been operational for over five years. The SLC can deliver a beam of energy up to 60 GeV using a pulse compression technique in the rf system which trades pulse length for a higher pulse amplitude. This mode of operation has been reliable and routine for the SLC. However the beam line transport which takes electrons or positrons from the end of the linac to the target in End Station A has not been upgraded from the original design energy of 25 GeV. The 50 GeV upgrade for the fixed target experiments consists in modifying and increasing the number of beam line dipole magnets to reach 50 GeV, plus modernization of the beam line instrumentation and controls.

2. The 50 GeV Upgrade

Figure 1 shows schematically the A-line transport system. It consists of a set of pulse magnets followed by eight dipole magnets and two quadrupoles. Steering magnets at the entrance to the experimental hall allow final position and angle corrections in the beam. The total bending angle from the linac to the target is 24.50 degrees. The upgrade of the A-line system consists in adding four more dipole magnets and new power supplies. The upgraded beam line will then contain four new bending magnets, eight original bending magnets, the original pulsed magnets, a quadrupole, and a single reference magnet, not in the beam line. The reference magnet contains an NMR probe and an automated flipcoil system, which together monitor the magnetic field and the magnetic field integral. This reference magnet is identical in design to the twelve beam line magnets. It is used to make energy adjustments to an accuracy of about 0.1%.

Adding four magnets and raising the beam energy implies an increase in power consumption. To alleviate this unwanted feature, all dipole magnets will be removed,

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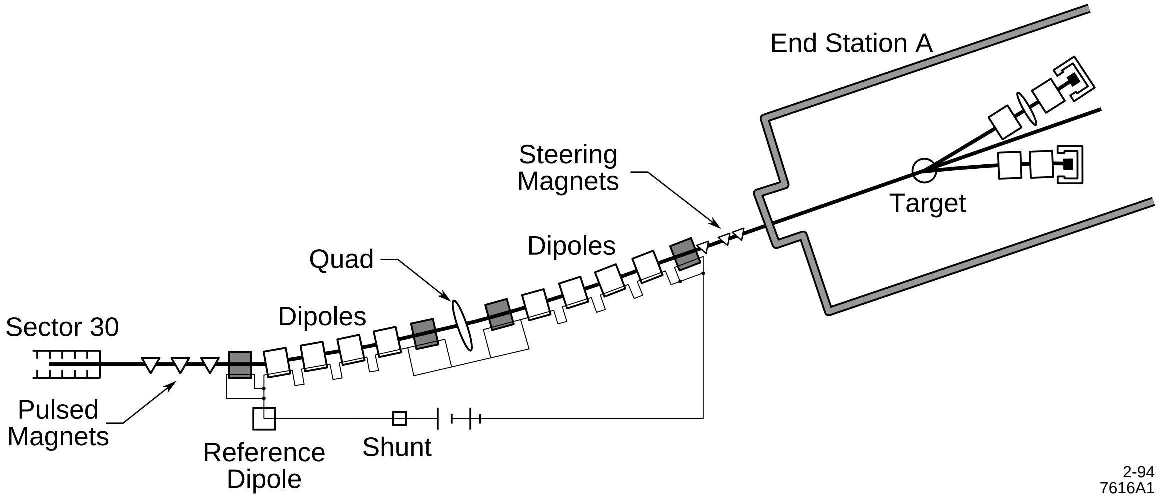

Fig. 1. The beam transport system for the End Station A facility is shown schematically. Pulsed magnets at the end of the linac deflect the beam into the A-line system. Eight dipole magnets, a quadrupole magnet, and focussing and steering magnets comprise the present system. Four additional magnets will be added to augment the system for the 50 GeV energy specification. A new power supply will be added. New controls and instrumentation will also be added.

their gap clearance reduced by one half, and the magnets reinstalled. Even with the addition of four more magnets, this new configuration will have a power consumption lower by more than a factor of 2 than the current configuration. The re-gapping of the magnets will occur between March 1994 and March 1995, at which time the magnets will be reinstalled.

In addition to the magnet work, new power supplies will be added; controls for those supplies will be integrated into the SLC control system; and new beam monitors will be installed. All work is expected to be completed by May 1995, when the system will be commissioned for beam.

Calibration of the beam energy is straightforward. The spin precession is accurately given by the relation

$$\Theta_{prec} = \gamma \, \frac{g-2}{2} \, \Theta_{bend},$$

where $\gamma = E_{beam}/m_e$, and Θ_{prec} is the angle the spin precesses relative to the electron direction. The precession angle can be accurately measured. Figure 2 shows the longitudinal component of the beam polarization as measured by a coincidence Møller system. These data were taken during E143. The horizontal axis is the flipcoil reading of the beam energy in the reference magnet. The solid curve is the expected g-2 precession. The zero crossing at 27.52 GeV (corresponding to $\Theta_{prec} = 8.5\pi$ radians) establishes a flipcoil calibration (the flipcoil is 50 MeV low), and the amplitude of the curve is the magnitude of the polarization at the time of this measurement, $85.6 \pm 0.7\%$.

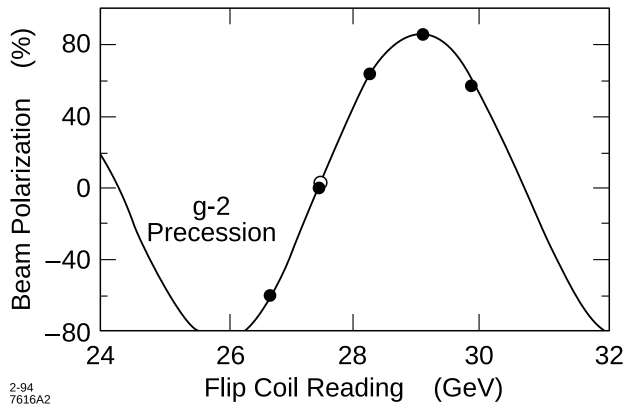

Fig. 2. Calibration of the energy of the beam line in E143 was possible using the precession of spin. The longitudinal component is measured with a Møller polarimeter in the End Station A. The data are shown plotted versus the flipcoil measurement of energy in the reference magnet, and the curve shows the expected g-2 precession. The accuracy of the energy calibration is approximately ±0.1% by this method.

3. The Polarized Electron Beam

Table I gives a list of beam parameters. Two columns are shown, one for the beam before the upgrade, and one for the 50 GeV version. The most significant difference, aside from the increased energy, is the short beam pulse (100 nanoseconds long compared to 2 μsec long for energies below 33 GeV). This shorter pulse will require special attention in the design of the data acquisition system for any spectrometer package to be used in a 50 GeV experiment.

Table 1. Typical Beam Parameters.

Parameter	Now	50 GeV
$E_\circ$ (GeV)	9–32	9–50
Q/pulse (electrons)	$\leq 5 \times 10^{11}$	$\leq 1 \times 10^{11}$
Rate (Hz)	120	120
ΔE (%)	0.1–1.0	0.1–1.0
Pol. (%)	≈ 80	≈ 80
Pulse length (μsec)	2.5	0.10
Norm. Emit. (meter-rad.)	$\leq 20 \times 10^{-5}$	$\leq 20 \times 10^{-5}$
spot size (mm)	≤ 1	≤ 2

Polarized electrons are produced by photoemission from a gallium arsenide (GaAs) surface using a circularly polarized laser beam. Use of GaAs materials for polarized electrons was first proposed in 1974 by E. Garwin, H. C. Seigmann, and D. Pierce.[1] The technique was limited to 50% polarization, but promised to provide

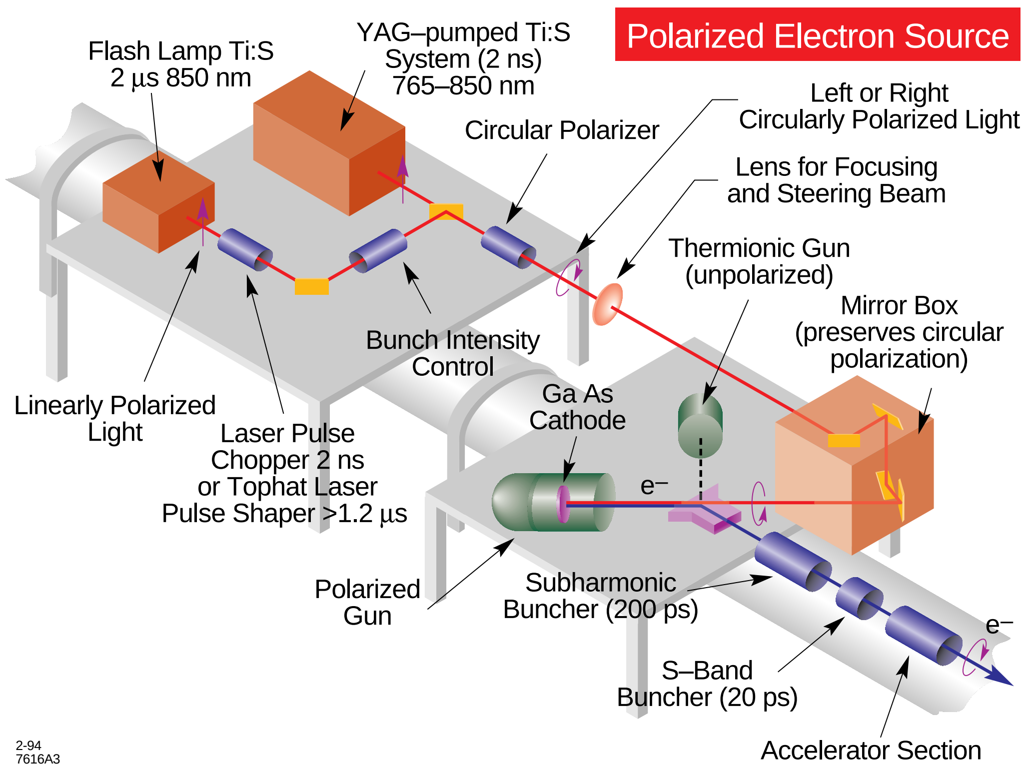

Fig. 3. The layout of the lasers and the polarized gun at the injector is shown schematically. The SLC runs on the YAG-pumped Ti-sapphire laser, while the fixed target experiments use the (long-pulse) flashlamp-pumped Ti-sapphire laser tuned to a wavelength of 845 nm. The laser beam passes through an intensity control, a chopper, a lens box, and mirrors before reaching the gun cathode. The longitudinally polarized photoemitted electrons are deflected by a bend magnet onto the axis of the accelerator.

high currents and low emittances. Experimental demonstration of the polarization of photoemitted electrons from gallium arsenide first occurred at low intensities at Zürich[2] and later at high intensities at SLAC.[3] Recently, increases in the polarization have been possible using MBE (molecular beam epitaxy) and MOCVD (metal organic chemical vapor desposition) processes which allow layered structures to be engineered.[4] By growing the GaAs crystals in thin layers over a gallium-arsenide-phosphide substrate (a material of slightly different lattice spacing), a strain in the GaAs epilayer can be induced. This strain introduces distortions in the surface epilayer lattice that break a degeneracy in the epilayer valence band. The photoemitted electrons when excited by laser wavelengths near the band gap edge are expected to have much higher polarizations.[5] Strained GaAs cathodes are now available which provide high current beams of electrons with polarizations up to 90%.

Figure 3 shows schematically the laser and polarized gun layout at the SLAC injector. The flashlamp-pumped Ti-sapphire laser provides a pulsed beam of light at 120 Hz. That beam passes through a light chopper which produces a 2-μsec-long pulse,

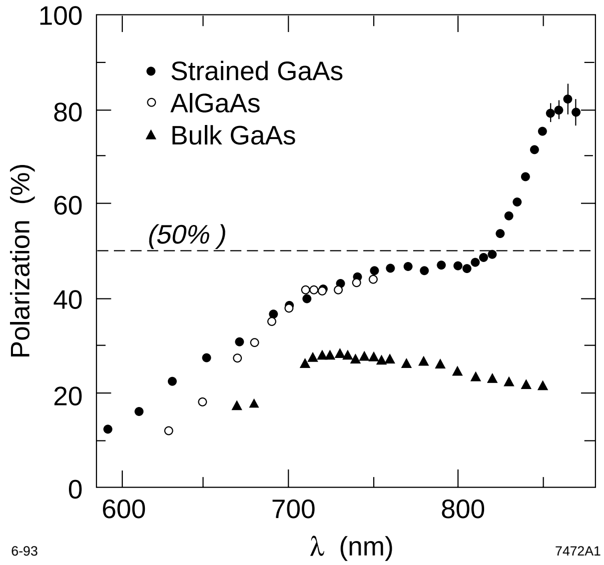

Fig. 4. The polarization versus wavelength for three cathode materials used on the accelerator is shown. The strained GaAs cathode operating at 865 nm delivered approximately 70% polarization during the 1993 running for SLC. The AlGaAs material, illuminated with a laser tuned to a wavelength of 720 nm, was used for E142, delivering 40% polarization.

then through polarizers, a steering and focussing lens, and onto a gallium arsenide cathode in a gun structure sitting at -120 KV. Longitudinally polarized electrons are photoemitted and transported to the accelerator. Acceleration occurs without depolarization. Polarization is easily reversed by reversing the laser circular polarization with a Pockels cell. The sign of polarization is reversed between pulses of the linac in a random pattern at the linac rate of 120 Hz.

Figure 4 shows the polarization versus wavelength λ. Several variations of gallium arsenide have been used in past experiments at SLAC. The bulk GaAs cathode material and the AlGaAs cathode material are two versions of GaAs materials which have been used, the first for the SLC run in 1992, and the second for E142. They were excited by laser light at a wavelength of 720 nm. A third material, the strained GaAs material, was used for SLC running in 1993, at $\lambda = 850$ nm.

Figure 5 shows recent measurements of some samples of strained GaAs. In these samples, the epilayer thickness has been varied, and the degree of strain was varied by adjusting the amount of phosphorus in the substrate material upon which the epilayer was grown. The optimum polarization is seen to reach 90% in one sample. The E143 experiment presently is operating with one such sample for the cathode material, giving an average polarization of 85% at $\lambda = 845$ nm.

4. Spin Structure Experiments at 50 GeV

The present SLAC fixed target program is focussed on deep inelastic polarized structure function measurements. We have two experiments approved for 50 GeV, E154 and E155. These two experiments are extensions of E142 and E143, respectively, and

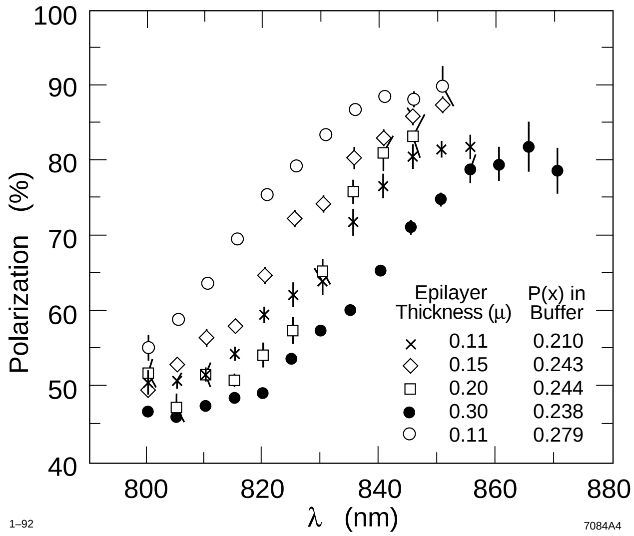

Fig. 5. Polarization can be enhanced by varying the thickness of the surface epilayer and the phosphorus concentration of the sublayer. Shown here are measurements made in GaAs materials with these parameters varied. E143 has been operating with a 0.1μ and 28% phosphorus concentration, giving an average polarization of 85%.

will use the same spectrometers and collect data at the same kinematic points. E154 will utilize the polarized ^{3}He target in essentially the same form as for E142. E155 will use the $^{15}NH_3$ and $^{15}ND_3$ targets similar to those of E143.

The two spectrometers for E154 and E155 will be similar to those used in E142 and E143. The two spectrometers, each consisting of two dipoles in opposite polarity, will be set at 2.75 and 5.5 degrees scattering angle. The higher beam energy for E154 and E155 implies higher spectrometer E' energies, on average. The gas Čerenkov counters, which are used for π/e separation (two per spectrometer), will be lengthened to allow efficient operation at reduced pressures. In addition to the Čerenkov counters, the scintillator hodoscopes, which are used for tracking of the charged particles, will be augmented. The data acquisition system will be expanded and modified to accommodate the short (100 nsec) beam pulse. These modifications are expected to take approximately one year to complete, and the entire system will be ready for a run in the latter half of 1995.

One of the main objectives of the 50 GeV run will be to study the Q^2 dependence of the spin structure functions. Figure 6 shows the expected statistical errors on A_1^n (in the figure, the values for A_1^n are plotted at 0, and the errors are those from the E154 proposal) over a range of Q^2 from 1 to 10 GeV/c^2 for three bins in x. Figure 7 shows the expected errors on A_1^n versus x from the E154 proposal for the two spectrometers and compares them to the E142 results.[6] Figure 8 shows expected errors for the proton from the E155 proposal and compares them to the published EMC results.[7] In this figure, xg_1^p is plotted against a logarithmic scale for x. Figure 9 shows the same for xg_1^d from the E155 proposal and compares the results to published SMC results.[8] Figure 10 shows xg_1^n from the E155 proposal and compares them to the E142 results.

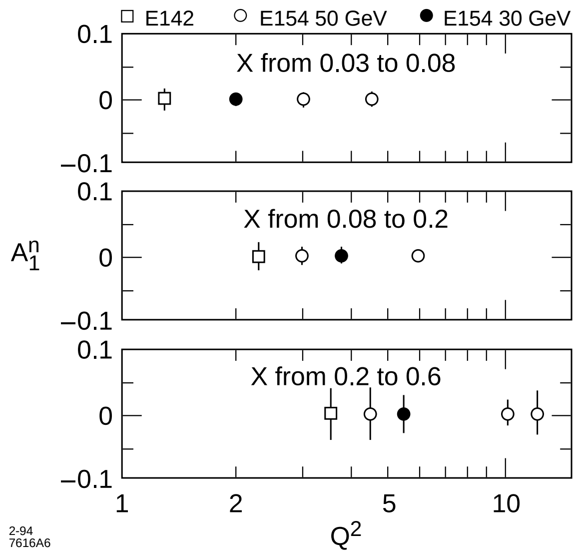

Fig. 6. A calculation of the expected statistical errors in A_1^n versus Q^2 for three x bins, from the 50 GeV E154 proposal, *Precision Measurement of the Neutron Spin Structure Function using a Polarized Helium-3 Target.* Data at 50 GeV and 30 GeV will augment to E142 data taken at 22.66 GeV (ref. 6).

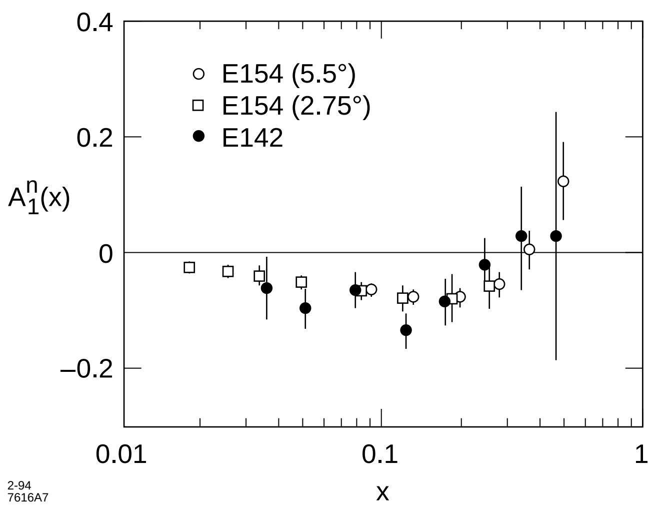

Fig. 7. The comparison of expected errors on $A_1^n(x)$ from the 50 GeV experiment E154 against those for E142 (ref. 6). This graph is taken from the E154 proposal.

Table II summarizes the expected errors on the various integrals for the experiments E142, E143, E154, and E155. The E142 errors are the published ones. All other errors are taken from the respective proposal documents. E143 is presently collecting data, and the run progress is going well. It is expected that the final errors for E143 will be approximately those values that were proposed.

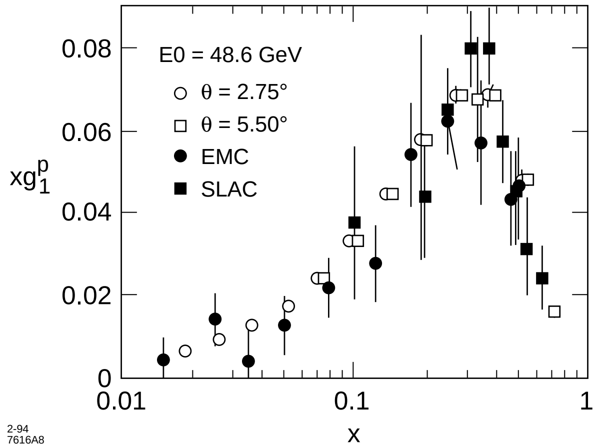

Fig. 8. The expected statistical errors on $xg_1^p(x)$ from the 50 GeV experiment E155 proposal is compared to existing EMC/SLAC data (ref. 7).

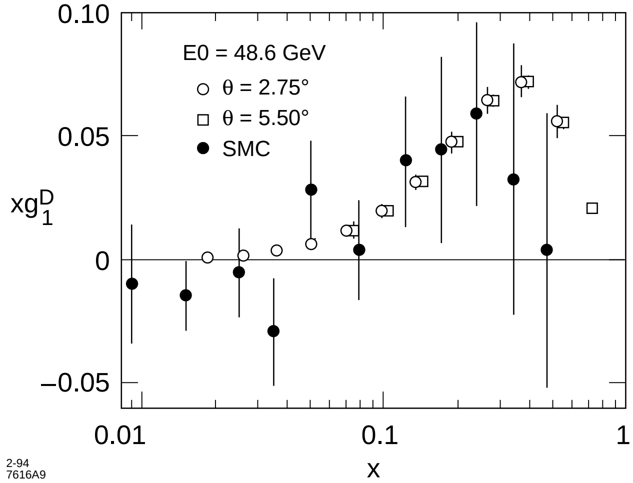

Fig. 9. The expected statistical errors on $xg_1^d(x)$ from the 50 GeV experiment E155 proposal is compared to existing SMC data (ref. 8).

The schedule for running E154 and E155 is not yet fixed. Draft schedules do exist which include E154 and E155. The upgrade of the A-line magnets and beam monitors will commence immediately following the shutdown of E143, in February 1994. Magnets will be removed in February and March 1994 and will go to the shops for modifications. The SLC will run for SLD physics from June 1994 to March 1995. The magnets will be reinstalled beginning March 1995, and the beam line will be commissioned in May 1995. The next window for End Station A experiments is presently shown on the draft schedule to begin in June 1995. All long range schedules at SLAC are subject to revisions, depending on budgets and other issues.

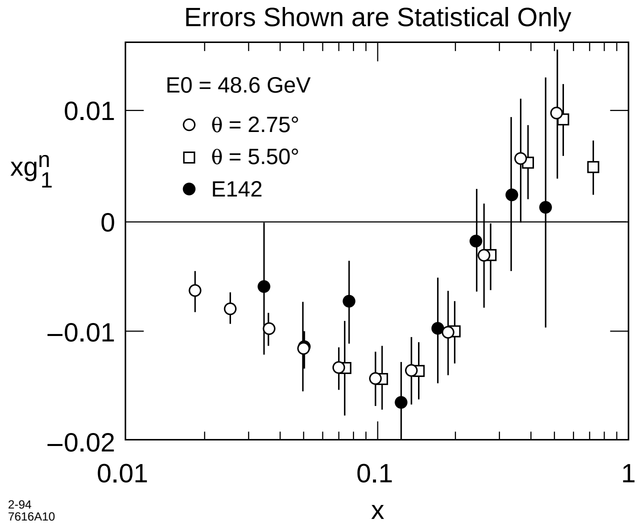

Fig. 10. The expected statistical errors on $xg_1^n(x)$ from the 50 GeV experiment E155 proposal is compared to existing E142 data (ref. 6).

Table 2. Summary of expected errors from the SLAC fixed target experiments.[a]
stat. (sys.) [extrapolation]

Exp (target)	$\Delta \int g_1^p dx$	$\Delta \int g_1^d dx$	$\Delta \int g_1^n dx$	$\Delta \int (g_1^p - g_1^n) dx$
E142 (^{3}He)	——	——	.007(.006)[.007]	——
			53%	
E143 ($^{15}NH_3/^{15}ND_3$)	.003(.010)[.002]	.005(.011)[.004]	.006(.012)[.004]	.007(.023)[.006]
	8.4%	12%	64%	14%
E154 (^{3}He)	——	——	.003(.004)[.003]	——
			27%	
E155 ($^{15}NH_3/^{15}ND_3$)	.001(.008)[.001]	.002(.008)[.002]	.002(.006)[.002]	.003(.012)[.003]
	6.4%	7.7%	30%	7.1%

[a]assumes $\int g_1^p dx = 0.126$ and $\int g_1^n dx = -0.022$

5. Summary

The 50 GeV upgrade for fixed target experiments is underway and will be completed in 1995. Experiments currently planned utilize the good polarized electron beams to study the spin structure of protons, neutrons, and ^{3}He. The 50 GeV data will expand the Q^2 range of the data, and errors resulting form these data will reduce the uncertainties on the Bjorken and Ellis-Jaffe sum rules by a factor of 2 relative to the earlier experiments E142 and E143. The 50 GeV data should be available by the end of 1995.

References

1. E. L. Garwin et al., Helv. Phys. Acta **47**, 393 (1974).

2. D. T. Pierce and F. Meier, Phys. Rev. **B13**, 5484 (1976).
3. C. K. Sinclair et al., in High Energy Physics with Polarized Beams and Polarized Targets, AIP Conference Proceedings No. 51, Particles and Fields Subseries No. 17, G. H. Thomas, editor (Argonne 1976).
4. see for example A. Y. Chao and J. R. Arthur, Progress in Solid-State Chemistry **10**, 157 (1975).
5. T. Maruyama et al., Phys. Rev. Lett. **66**, 2351 (1991).
6. P. L. Anthony et al., Phys. Rev. Lett. **71**, 959 (1993).
7. J. Ashman et al., Phys. Lett. **B206**, 364 (1988).
8. B. Adeva et al., Phys. Lett. **B302**, 533 (1993).