SLAC-PUB-6005
November 1992
(N)

POLARIZED ELECTRON BEAMS AT SLAC*

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ABSTRACT

SLAC has successfully accelerated high energy polarized electrons for the Stanford Linear Collider and fixed polarized nuclear target experiments. The polarized electron beams at SLAC use a gallium arsenide (GaAlAs for E-142) photon emission source to provide the beam of polarized electrons with polarization of approximately 28% (41% for E-142). While the beam emittance is reduced in the damping ring for SLC operation a system of bend magnets and superconducting solenoids preserve and orient the spin direction for maximum longitudinal polarization at the collision point. The electron polarization is monitored with a Compton scattering polarimeter, and was typically 22% at the e+e- collision point for the 1992 run. Improvements are discussed to increase the source polarization and to reduce the depolarization effects between the source and the collision point.

1. Introduction

Polarized electron beams at SLAC are used for the Stanford Linear Collider (SLC) to produce Z boson particles in e+e- annihilation and for scattering on fixed polarized targets in End Station A. The SLC is unique among colliding beam facilities in its potential to accelerate longitudinally polarized electrons. The polarization sense is reversible from pulse to pulse, and thereby precise tests of the coupling of fermions through the measurement of the left-right asymmetry

$$A_{LR} = (\sigma_L - \sigma_R)/(\sigma_L + \sigma_R)$$

can be made. Here $\sigma_L(\sigma_R)$ is the cross section for left-handed (right-handed) electrons on unpolarized positrons. In the Standard Model, A_{LR} is uniquely predicted and is independent of the final fermion type.[1] Thus, all visible Z decays can be used. A_{LR} is large and insensitive to initial-state QED radiation and final state mass effects and QCD corrections. It is also very sensitive to the electroweak mixing parameter and to virtual electroweak corrections in the presence of new particles.

Two fixed target experiments have been approved to measure the Nucleon Spin Structure and test the Ellis-Jaffe and the Bjorken sum rules.[2] These experiments will be made using longitudinally polarized electrons on polarized targets in End Station A. The neutron and proton spin structure is extracted from the polarized target data.

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* Work supported by Department of Energy contract DE-AC03-76SF00515

Presented at the 10th International Symposium on High Energy Physics, Nagoya, Japan, November 9-14, 1992.

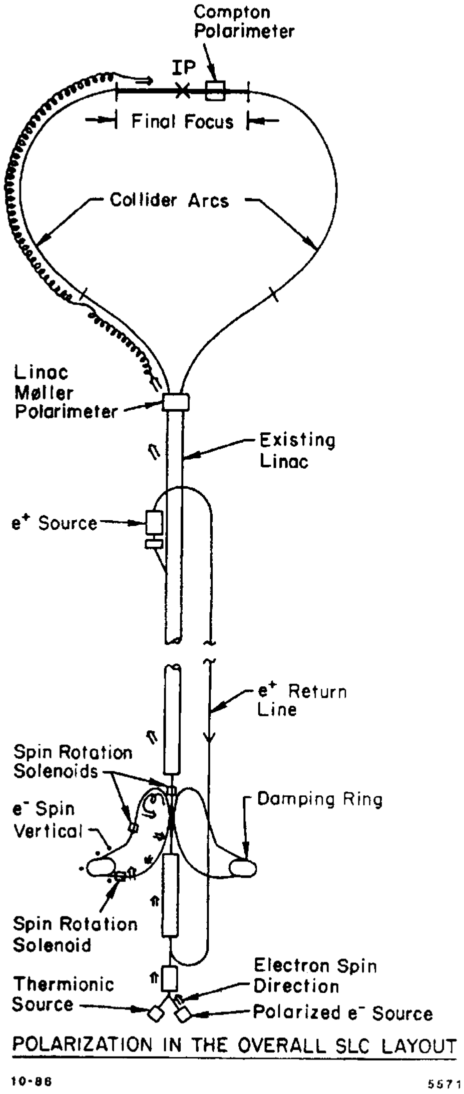

Figure 1. A layout of the SLAC Linear Collider emphasizing polarization. The orientation of an electron spin vector is shown by the double arrow.

2. The Polarized Electron Source

The layout of the polarized SLC is shown in Figure 1. The electrons are produced longitudinally polarized by irradiating a GaAs crystal with a circularly polarized laser beam of wavelength 715 nm. A diagram of the Polarized Electron Source is shown in Figure 2. During each of the 120 Hz SLC machine cycles, the polarized electron source produces two pulses of approximately $6X10^{10}$ electrons with a duration (full width at half maximum) of 2 ns and a separation of 61 ns. This control is done by modulating the laser light. During the Spring and Summer 1992 run a cathode of bulk GaAs was used at a temperature of $0^{o}C$ giving a polarization of about 28%. Operating the source cathode at the lower temperature improved the cathode lifetime so that sufficient beam intensity could be maintained for five days between cesiations. We found that the maximum yield of electrons from the gun at the operating voltage of 120 KV depended strongly on quantum efficiency. At lower quantum efficiencies the charge limit was much lower than the space charge limit for the gun. A discussion of this new phenomena was presented at the Workshop on Polarized Electron

Sources and Electron Spin Polarimeters (hereafter called the Workshop) by Mike Woods.[3] More details of the operational experience of the source which delivered beam to SLC more that 93% of the time can be found in the Workshop report of Dave Schultz.[4]

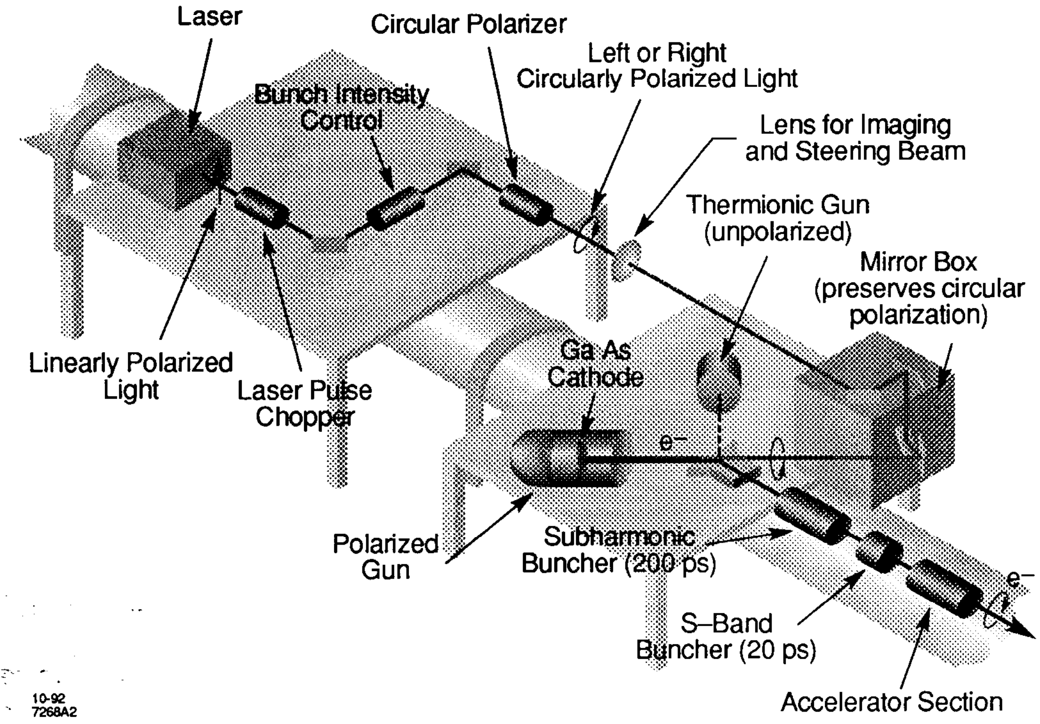

Figure 2. A schematic diagram of the Polarized Electron Source at SLAC.

Presently, the experiment E-142 is taking data with a thin GaAlAs cathode. The wavelength dependence of the polarization for different cathodes is shown in Figure 3.[5] The data labeled bulk GaAs was taken from the same material sample used for the 1992 SLC run. The polarization is higher for the GaAlAs cathode presumably due to the thinness of the active layer. The aluminum has the effect of shifting the band gap so that the highest polarization is reached at the operating wavelength of 715 nm. A Møller polarimeter located in End Station A measures a longitudinal polarization of about 41% which is in agreement with the results shown in Fig. 3..

Improvements to the Polarized Electron Source to reach higher polarization are expected for the 1993 SLC run (the goal is for polarization above 40% at the collision point). A vigorous research and development program to develop higher polarization cathodes has taken place at SLAC. Thin GaAs cathodes have been developed giving polarization close to the maximum value of 50% for unstrained GaAs cathodes.[5] Takashi Maruyama reported the results from strained lattice cathodes at the Workshop which give polarization above 80%.[5] Longer wavelength light sources are required to reach polarizations of 50% or higher. The development of a Ti-Sapphire laser which is tunable between 750 and 900 nm was reported by Mike Woods in the Workshop.[6] Investigation of the charge limit phenomena must be done before choosing a cathode for the upcoming run since the quantum efficiencies are low at the longer wavelengths. Other improvements to the gun were presented by Jim Clendenin in the Workshop, and they include a load-lock cathode transfer system and an inverted gun geometry.[7]

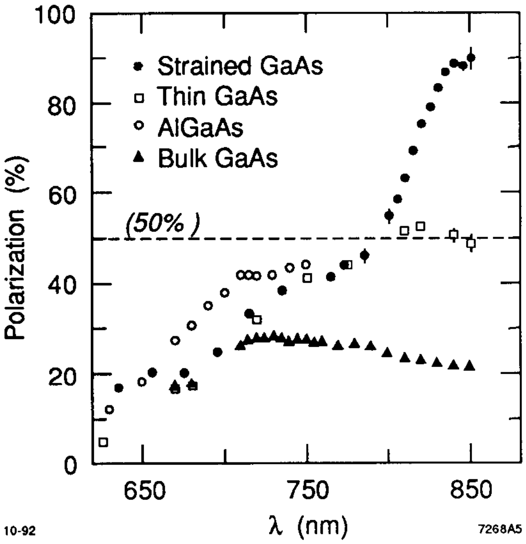

Figure 3. Polarization versus wavelength for different cathode materials. Data from Reference 5 .

The requirements for the fixed target program are less severe than for the SLC. The peak electron current is only 80 mA for E-142 (0.2 mA for E-143) instead of the 5-8 amps at SLC. As a result the higher polarization cathodes can be expected to deliver the required beam intensity for these experiments because the effects of the charge limit may not be felt. The experiment E-143 plans to run with a strained lattice cathode delivering the low current beam with polarization in excess of 80%.

3. Spin Rotation System

The pair of electron pulses is accelerated to 1.16 GeV and stored in the North Damping Ring of the SLC. A system composed of the dipole magnets of the Linac-To-Ring (LTR) transfer line and a superconducting solenoid magnet is used to rotate the longitudinal polarization of the beam into the vertical direction for storage in the damping ring. A system composed of two superconducting solenoids and the dipole magnets of the Ring-To-Linac transfer line is used to reorient the polarization vector upon extraction from the damping ring. This system has the ability to provide nearly all polarization orientation in the linac.

The LTR spin rotation system was designed to operate at the damping design energy of 1.21 GeV. Since the damping ring is currently operated at 1.16 GeV, the net spin precession in the LTR dipole magnets is less that the 90^0 design value. The resulting polarization direction of the electron beam at injection into the damping ring is not perfectly aligned with the vertical magnetic guide fields and some depolarization results. The expected net spin transmission of the system was 95% for the 1992 run. The damping ring will run closer to the design value for future runs, and we expect to increase the net spin transmission to above 98%.

The electron beam for the fixed target experiments does not use the damping ring. The longitudinally polarized electron beam is accelerated to an energy of 22.66 GeV. At the end of the linac it is deflected into End Station A. The energy is chosen so that the electron beam is longitudinally polarized when it intercepts the polarized target.

The leading electron pulse for SLC is accelerated in the linac to 46.7 GeV before the beam enters the North Arc of the SLC for transport to the Final Focus systems to the interaction point of the machine. As it traverses the North Arc, the electron bunch undergoes a total bend angle of 236^{0} and an average energy loss of 1.0 GeV due to the emission of synchrotron radiation.

The spin precession frequency is 1085 degrees for each of the 23 achromats in the Arc and is almost equal to the betatron oscillation phase advance of 1080 degrees. Depending on the relative phase of spin and betatron oscillation either the initial horizontal or longitudinal component will couple into the vertical component of spin. Even though the effect is small in each achromat the accumulation in the 23 can be large. Monte Carlo studies have shown that betatron oscillations of the order of 25 microns are sufficient to cause significant spin rotation in the arcs.[8] Knowledge of the arc orbit is not adequate to allow prediction of the spin direction at the end of the arc. The net spin rotation of the arc system is sensitive to the parameters of the orbit and is measured empirically. The spin rotation system is adjusted to maximize the longitudinal polarization at the IP. Feedback on the launch angle into the Arc maintains the orbit. As a result, spin transmission was normally about 85% where with a perfect Arc 95% would be expected due to the energy spread of the electron beam.

4. Polarimeters

A Møller polarimeter located at the end of the linear accelerator is used to measure the longitudinal and transverse polarization components of the electron beam before the beam enters the North Arc of the SLC. (A second Møller polarimeter is located in End Station A for the fixed target experiments.) Polarization measurements with both damped and undamped electron beams verify the expected polarization transmission of 0.95 in the damping ring.[9]

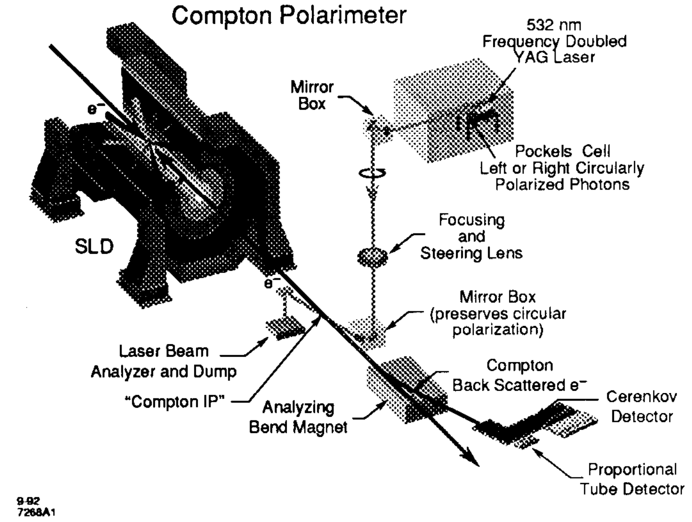

Figure 4. A schematic diagram of the Compton Polarimeter.

The polarimeter based on Compton scattering continually monitors the longitudinal polarization of the electron beam after it has passed through the IP and before it is deflected by dipole magnets. Polarimeter data are acquired continually for intervals of about three minutes and are logged in summary form onto data tapes as well as into history files used to monitor changes in the longitudinal polarization. A diagram of the polarimeter is shown in Figure 4. A circularly polarized laser beam intercepts the electron beam downstream of the interaction point. Recoiling Compton electrons emerge forward in the laboratory with momentum much less than that of the beam, from which they are separated in the field of the soft and hard bend magnets. Electrons in the energy interval 15-30 GeV are detected and momentum analyzed by a pair of redundant multichannel detectors (a Cherenkov detector and a proportional tube detector). The asymmetry is formed from the rates for parallel photon/electron and anti-parallel photon/electron helicities. The laser beam is circularly polarized in the laser room and is transported to the Compton IP with four sets of mirror pairs that approximately preserve the circular polarization. The circular polarization of the laser beam at the Compton IP was measured to be 93+-2%. In order to avoid systematic effects, the sign of the circular polarization is changed randomly on sequential laser pulses. The laser runs at eleven hertz, and therefore samples all machine cycles. The data acquisition reads data at 120 hertz and collects laser off cycles for background subtraction. In Figure 5, the asymmetry data for one run from the multichannel detectors is shown along with the expected curve for the indicated electron and laser beam polarizations. The systematic error on the polarization measurement is presently +-2.7%. The determination of the laser beam circular polarization is the largest systematic error and we expect to reduce its uncertainty to less than 1%. However, the present systematic error is far below the statistical error we expect from the final data sample. More details of the Compton polarimeter can be found in the Workshop report of Mike Fero.[10] First measurement of the left-right cross section asymmetry in Z boson production has been made at SLC, and is reported in the paper by Morris Swartz in these proceedings.[11]

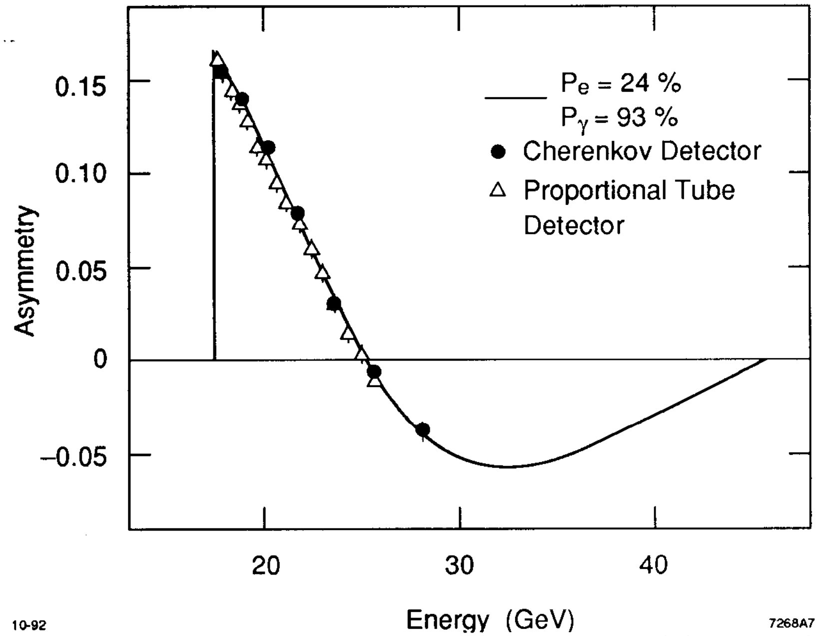

Figure 5. The polarization asymmetry measured by the multichannel detectors. The solid curve gives the theoretical asymmetry expected for the indicated electron and laser beam polarizations.

5. Conclusions

The polarized electron beams at SLAC work well and a precision measurement of the electroweak mixing parameter can be expected. The program to measure the nucleon spin structure is in progress using longitudinally polarized electrons on polarized targets in End Station A. In the future, we expect to increase the electron polarization to a level above

40%. It may be possible to make use of the recent development of strained lattice cathodes to achieve source polarizations in excess of 80%.

6. References

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