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# The Compton Polarimeter for SLC*

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## ABSTRACT

We report on the use of a Compton scattering based polarimeter to measure beam polarization near the $e^+e^-$ interaction point at the SLAC Linear Collider (SLC). Measurement of the beam polarization to a statistical precision of $\delta P/P = \pm 3\%$ requires approximately three minutes under normal conditions. An average beam polarization of $22.4 \pm 0.7\%$(syst.) was measured over the course of the 1992 polarized beam run.

## 1. Introduction

The SLC began running with polarized electron beams on April 19th, 1992. The first $Z$ bosons produced with polarized beam were collected by the SLD detector a few days later. Over the course of the run, the SLD collected over 11,000 $Z$ events with polarized beam[1].

The Compton polarimeter is used for continuous measurements of the beam polarization near the $e^+e^-$ interaction point. The polarimeter is based on Compton scattering of the electron beam off circularly polarized photons. A schematic of the polarimeter is shown in Fig. 1. The outgoing 45.7 GeV electron beam collides with a 2.33 eV circularly polarized photon beam at a $\gamma e^-$ collision point 33 meters downstream from the SLC $e^+e^-$ interaction point. Since the Compton electron scattering angles are smaller than the angular divergence of the incident beam, the scattered and unscattered beams remain unseparated until they pass through a pair of SLC dipole magnets of field integral 3.05 T-m. The scattered electrons are dispersed horizontally and exit the vacuum system through a thin window. Electrons in the energy interval 17-30 GeV are detected and their momentum analyzed by a pair of multichannel detectors located 3.57 m and 3.87 m downstream of the effective bend center of the dipole pair. The differential cross section for the Compton scattering of longitudinally polarized electrons and circularly polarized photons is given by[2],

$$\frac{d\sigma_p}{dE_s} = \frac{d\sigma_u}{dE_s}\left[1 + \mathcal{P}_\gamma \mathcal{P}_e A(E_s)\right], \tag{1}$$

where $\sigma_p$ is the polarized cross section, $E_s$ is the energy of the scattered electron, $\sigma_u$ is the unpolarized Compton scattering cross section, $\mathcal{P}_\gamma$ is the photon spin polarization in the helicity basis, $\mathcal{P}_e$ is the longitudinal polarization of the electron, and $A(E_s)$ is the Compton asymmetry for $\gamma e^-$ spins parallel vs anti-parallel. The unpolarized cross section and the asymmetry function depend on the energies of the electron and photon beams.

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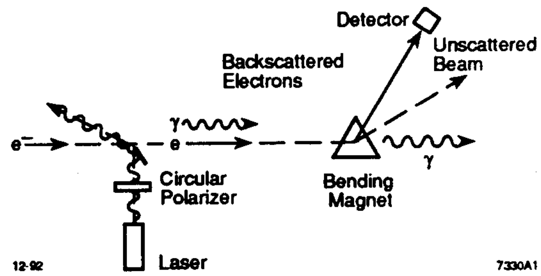


Fig. 1. Compton Polarimeter Schematic.

The largest cross section and asymmetry occur at the kinematic limit $E_s = 17.4$ GeV, corresponding to a scattering angle of 180 degrees in the electron rest frame. The asymmetry is zero at $E_s = 25.2$ GeV and becomes negative for larger energies. We measure the counting rates in the detectors for anti-parallel and parallel beam helicities, $R(\mathcal{P}_\gamma \mathcal{P}_e > 0)$ and $R(\mathcal{P}_\gamma \mathcal{P}_e < 0)$, respectively. It follows from Eq. (1) that the asymmetry formed from these rates determines the electron beam polarization,

$$\mathcal{P}_e = \frac{1}{\mathcal{P}_\gamma \langle A \rangle} \left[ \frac{R(\mathcal{P}_\gamma \mathcal{P}_e > 0) - R(\mathcal{P}_\gamma \mathcal{P}_e < 0)}{R(\mathcal{P}_\gamma \mathcal{P}_e > 0) + R(\mathcal{P}_\gamma \mathcal{P}_e < 0)} \right] = \frac{A_{Compton}^{measured}}{\mathcal{P}_\gamma \langle A \rangle}, \tag{3}$$

where $\langle A \rangle$ is the average Compton asymmetry for the energy interval subtended by the detector channel used to measure the rate asymmetry.

The importance of the beam polarization measurement is best seen in relation to the measurement of the left-right electroweak asymmetry. To lowest order, the following simple relationship exists between the weak mixing angle $\sin^2 \theta_W^{\rm lept}$, the measured asymmetry for $Z$ boson production by left vs right handed electron beam, $A_{LR}^{measured}$, and the longitudinal component of the electron beam polarization $\mathcal{P}_e$,

$$\frac{1 - 4\sin^2 \theta_W^{\rm lept}}{1 - 4\sin^2 \theta_W^{\rm lept} + 8\sin^4 \theta_W^{\rm lept}} = \frac{A_{LR}^{measured}}{\mathcal{P}_e}. \tag{4}$$

The beam polarization in turn, is related to the Compton photon beam polarization and the polarimeter analyzing power by Eq. (3). The error on the measurement of the weak mixing angle in the limit of large statistics thus depends directly on the error in the beam polarization measurement in the following way for $\sin^2 \theta_W^{\rm lept} = 0.23$,

$$\delta \sin^2 \theta_W^{\rm lept} \sim \frac{1}{7.8} \cdot \sqrt{A_{LR}^2 \left( \frac{\delta \mathcal{P}_e}{\mathcal{P}_e} \right)^2 + \frac{1}{\mathcal{P}_e^2 N_Z}}. \tag{5}$$

Our goal for the polarization measurement is that it contribute a neglegible amount to the overall error in a high precision measurement of the weak mixing angle angle ($\delta \sin^2 \theta_W^{\rm lept} < 0.001$).

## 2. The Compton Light Source

The Compton Light Source (CLS) consists of the laser, the evacuated transport line, and hardware and optics for laser beam circular polarization, steering, focusing and diagnostics. The Laser is a commercially available Spectra Physics GCR-11 frequency doubled Nd:YAG laser (532 nm). The laser pulse width is 7 ns (FWHM), and has a pulse energy of about 45 mJ/pulse. The laser is pulsed once every 11 SLC machine cycles (the SLC operates at 120 Hz), giving an effective repetition rate of about 11 Hz. The laser beam passes through a prism polarizer and Pockels cell combination to circularly polarize the beam. The sign of the circular polarization is determined by the polarity of the high voltage applied to the Pockels cell. Under normal running conditions, the polarity of the cell is set pulse to pulse following a pseudo-random pattern. Before exiting the laser room and entering the evacuated transport line, the beam diameter is expanded to 2 cm in order to maintain collimation over the long (40 m) pathlength to the Compton interaction point. A small portion of the beam is sampled just after the Pockels cell for the purpose of monitoring the beam polarization. The beam transport line between the Pockels cell and the Compton interaction point consists of evacuated straight sections connected by 4 sets of phase compensated mirror pairs, 4 windows and a focusing lens. The compensated mirror pairs preserve the circular polarization of the photon beam upon reflection. The transport line windows were measured to have negligible birefringence. The 5 meter focal length lens focuses and steers the laser beam onto the electron beam. After leaving the SLC vacuum, the beam is monitored for intensity, steering and polarization. The electron and photon beams cross at an angle of 10 milliradians. At the Compton interaction point, the approximate RMS beam sizes are 350 $\mu$m for the electron beam and 500 $\mu$m for the photon beam.

## 3. The Compton Electron Detectors

The Compton Cerenkov detector consists of a nine-cell threshold gas Cerenkov counter viewing a retractable 1.4-radiation-length lead radiator. Each $1\times1.5\times20$ cm mirrorized Cerenkov channel is filled with non-scintillating gas ($\beta$-butylene) at a pressure of 1.0 atm and is viewed by a 1 cm-diameter phototube. The mirrorized Al walls dividing the Cerenkov channels are thin (250$\mu$) in order to minimize showering in the scattering plane. The Cerenkov light collection efficiency is estimated to be over 50%. The electron energy threshold for producing Cerenkov light is approximately 10 MeV, providing good immunity to low energy backgrounds. The phototubes are operated at low gain ($\sim10^5$) to ensure a linear response function.

The Compton proportional tube detector (PTD) consists of 16 proportional tubes of inside diameter 3.9 mm embedded in a 5-radiation-length lead radiator. The sensitive area of the detector is 60 mm in the horizontal plane by 6 mm in the vertical plane. In order to maintain a linear response function, they are operated at very low gain (50-100). The detector is heavily shielded except for a narrow region in the scattering plane. This reduces susceptibility to beam related backgrounds.

Since the laser is pulsed once in 11 machine pulses, the 10 intervening pulses provide an accurate measurement of the background. The background in both detectors is due principally to beamstrahlung photons produced at the SLC interaction point[3]. The signal-to-noise ratio is typically 5-10 for the Cerenkov detector and 1-2 for the PTD detector.

## 4. Polarization Measurements

Any channel in either of the two detectors with large analyzing power can be used to measure the beam polarization assuming that the analyzing power for that channel is well understood. The beam polarization measurements thus far have been made with the two highest analyzing power (sixth and seventh) channels of the Cerenkov detector. The sixth and seventh channels detect electrons in the energy intervals 18.4-19.6 GeV and 17.3-18.4 GeV, respectively. The average Compton scattering asymmetries (analyzing powers) for these intervals are 0.6154 and 0.7027, respectively. The channel-by-channel polarization asymmetry as measured by the Cerenkov detector is shown in Fig. 2. The mean electron energy E for each channel includes a small correction for showering in the pre-radiator and channel walls. The detector position and spectrometer momentum scale are determined from measurements of the minimum electron energy point and the zero-asymmetry point. The theoretical asymmetry function $A(E_s)$ is shown as a continuous line in the figure, with absolute normalization adjusted to provide the best fit to the data[4].

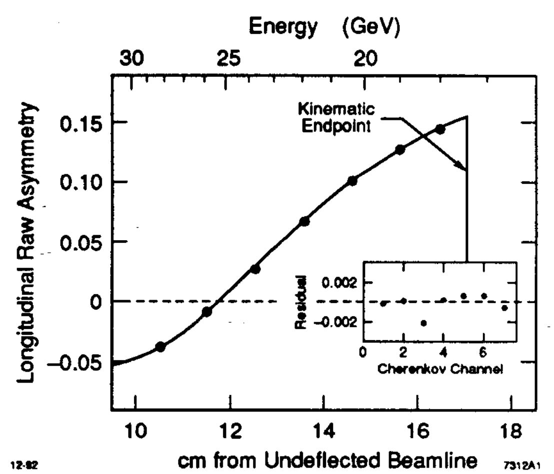


Fig. 2. The polarization asymmetry measured by seven channelsof the Cerenkov detector. The solid histogram represents the best fit to the data.

Limits have been placed on systematic effects such as the linearity of the phototube/ADC detection system, stability of the calibration, electronic cross talk, and biases in the measurement of the background. The total systematic error arising from these sources is estimated to be 1.8%. The laser beam polarization was monitored continuously throughout the run and was measured directly at the Compton interaction point both before and after the run. A plane polarizer was rotated in the beam and maximum and minimum transmitted intensity were recorded with a photodiode. The circular polarization is calculated using $\mathcal{P}_\gamma = 2\sqrt{I_{min} I_{max}}/(I_{min}+I_{max})$. From the direct measurements and the spread in monitored photon polarization, we measure a photon polarization of 93±2%. A determination of the absolute electron beam helicity was made by exploiting the known cross section difference between the J=1/2 and J=3/2 $\gamma e^-$ interactions[5]. The total systematic error on the measurement is estimated to be 3%, dominated by the error on the laser beam polariztion at the Compton interaction point. This error should drop below 1% in the next run with the installation of new laser beamline hardware.

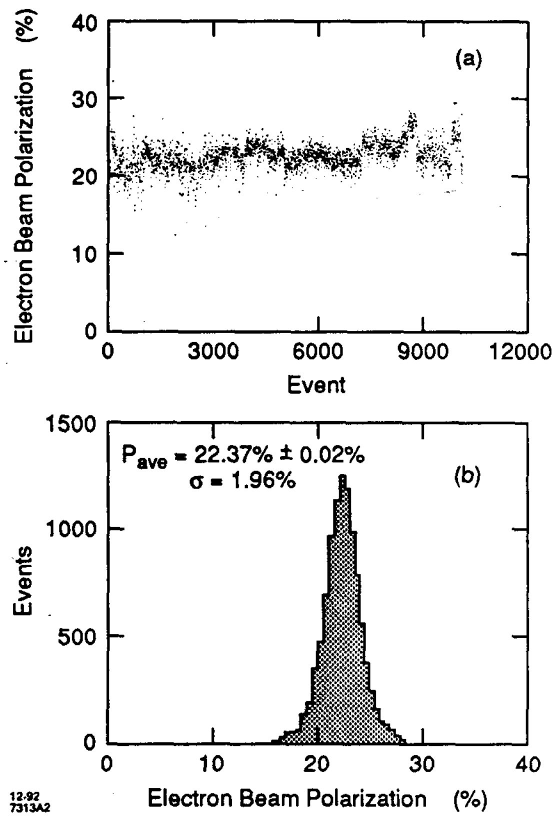


Fig. 3. Beam polarization measurement for each $Z$ selected by the SLD detector. b) The average beam polarization measurement for this set of $Z$ data.

We have performed a number of checks of the polarization measurement. The polarimeter measures the electron scattering rate for two helicity states of electrons and two helicity states of photons. We therefore measure two independent nonzero asymmetries and two independent null asymmetries. We verify that the nonzero asymmetries are consistent and that the null asymmetries are consistent with zero. The polarimeter provides a beam polarization measurement for each $Z$ selected with the SLD detector. The time history of polarization measurements associated with Z events is shown in Fig. 3. The average beam polarization for this set of $Z$ data is $22.4 \pm 0.7\%$(syst.).

## 5. Conclusions

We have designed, built and operated a Compton scattering based polarimeter for use at the SLC, and we are now using it as a physics tool for the measurement of the left-right electroweak asymmetry and other polarization related quantities. Assuming future higher beam polarizations of up to 70% at the SLD interaction point[6], our present 3% relative systematic error on the beam polarization measurement ensures a statistics limited measurement of the left-right electroweak asymmetry until over 115,000 $Z$'s are logged by SLD. Nevertheless, through recent improvements in the laser beam transport line, and upgrades of our electron detectors, we expect to improve our beam polarization measurement for the 1993 running period so that the relative systematic error on the beam polarization measurement will be less than 1%.

## 6. References


1. Details about the operation and performance of the SLC Polarized Electron Source can be found in the workshop proceedings, see M. Woods, D. Schultz, J. Clendenin. Details about the performance of the Polarized SLC as whole and the measurement of the left-right electroweak asymmetry can be found in the main conference proceedings, see K. Moffeit, M. Swartz.
2. See S.B. Gunst and L.A. Page, *Phys. Rev.* **92**, 970 (1953), F.W. Lipps and H.A. Tolhoek, *Physica* **20**, 395 (1954) or H. A. Olsen, *Applications of QED, Springer Tracts in Modern Physics,* Vol. 44, p. 83 (1968).
3. R. Sah, SLAC-AATF/80/19, March 1980.
4. For details about the beam polarization measurement using the Cerenkov detector, including details about detector contributions to the overall systematic error, see B. Schumm and R. Elia, SLD Note 222, November 1992.
5. For details about the laser beam polarization measurement, including details about the absolute handedness determination, see M. Fero *et al.,* SLD Note 221, October 1992.
6. See T. Maruyama in the Workshop proceedings.