

COMPTON POLARIMETRY AT A 1 TEV COLLIDER*

M. WOODS

Stanford Linear Accelerator Center
Stanford University, Stanford, CA 94309

Abstract

An electron beam polarization of 80% or greater will be a key feature of a 1 TeV Linear Collider. Accurate measurements of the beam polarization will therefore be needed. We discuss design considerations and capabilities for a Compton-scattering polarimeter located in the extraction line from the Interaction Point. Polarization measurements with 1% accuracy taken parasitic to collision data look feasible, but detailed simulations are needed. Polarimeter design issues are similar for both electron-positron and electron-electron collider modes, though beam disruption creates more difficulties for the electron-electron mode.

Presented at

e^-e^-97

2nd International Workshop on Electron-Electron Interactions at TEV Energies
September 22-24, 1997
UC Santa Cruz, Santa Cruz, CA, USA

and

LC97

VII International Workshop on Linear Colliders
September 29 - October 3, 1997
Zvenigorod, Russia

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

1. Introduction

A Compton polarimeter analyzes either the scattered beam electrons or the back-scattered gamma rays from the collision of a longitudinally polarized electron beam with a circularly polarized laser beam. The cross-section for this process¹ is given by:

$$\sigma_C = \sigma_C^0 + \mathcal{P}_e \mathcal{P}_\gamma \sigma_C^1 \quad (1)$$

where σ_C^0 is the unpolarized cross-section and σ_C^1 is the polarized cross-section; \mathcal{P}_e is the electron linear polarization and \mathcal{P}_γ is the laser circular polarization. The electron beam polarization can then be deduced from measurements of the relative Compton-scattering rates for the J=3/2 (electron and photon spins parallel) and J=1/2 (electron and photon spins anti-parallel) initial states, given accurate determinations of the laser polarization and the detector analyzing power. This is reflected in Equation (2):

$$A^{meas} = \frac{R(\rightarrow\rightarrow) - R(\rightarrow\leftarrow)}{R(\rightarrow\rightarrow) + R(\rightarrow\leftarrow)} = \mathcal{P}_e \mathcal{P}_\gamma A_C^{det} \quad (2)$$

where A_C^{det} is the detector analyzing power determined from Equation (1) and the detector acceptance.

A^{meas} is maximal at the kinematic edge corresponding to 180° backscatter in the center of mass frame,^a and is zero for 90° scattering. An electron polarimeter typically determines the beam polarization from asymmetry measurements at the kinematic edge, while a gamma polarimeter measures the energy flow asymmetry integrated over the full gamma spectrum.

2. The Compton Polarimeter at the SLAC Linear Collider (SLC)

We begin by considering the performance of the Compton polarimeter for the SLC, and the experience from its operations during the SLD experiment. This polarimeter,² shown in Figure 1, detects both Compton-scattered electrons and Compton-backscattered gammas from the collision of the longitudinally polarized 45.6 GeV electron beam³ with a circularly polarized photon beam. The photon beam is produced from a pulsed Nd:YAG laser with a wavelength of 532 nm. The laser is pulsed once for every 7 electron beam pulses.^b Laser off pulses are used to measure backgrounds in the polarimeter detectors. After the Compton Interaction Point (CIP), the electrons and backscattered gammas pass through a dipole spectrometer. A nine-channel threshold Cherenkov detector (CKV) measures electrons in the range 17 to 30 GeV.^c Two detectors, a single-channel Polarized Gamma

^aThe energy of the Compton-scattered electron has a minimum in the laboratory frame at the kinematic edge.

^bOnce every 7 seconds, the laser is pulsed on the 6th electron pulse rather than the 7th electron pulse to avoid any synching of the laser pulse with instabilities in the electron beam. The electron beam pulse rate is 120 Hz.

^cThe kinematic edge with maximal asymmetry is at an electron energy of 17.4 GeV, and the zero-asymmetry point is at 25.2 GeV.

Counter (PGC)⁴ and a multi-channel Quartz Fiber Calorimeter (QFC),⁵ are located in the neutral beamline to measure the counting rates of the Compton-scattered gammas.

The CKV, PGC and QFC are all threshold Cherenkov detectors, which are readout by photomultiplier tubes and charge-sensitive ADCs. The CKV detector uses propane as the Cherenkov radiator, while the PGC uses ethylene and the QFC uses quartz fibers. Table 1 summarizes the index of refraction and Cherenkov threshold energy for each of these detectors. A high threshold energy is desirable to discriminate against background sources of gammas from synchrotron radiation produced in

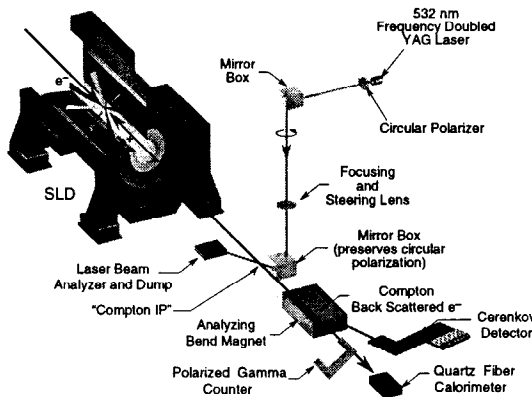


Fig. 1. Compton Polarimeter for the SLD Experiment

the dipole spectrometer and beamstrahlung produced in the collision process. In fact, the PGC and QFC located in the neutral beamline only make polarization measurements when the beams are not in collision due to the large beamstrahlung backgrounds. Typical signal and background sources of gammas are summarized in Table 2.^d The dipole spectrometer is composed of a soft bend (1 mrad bend angle) and a hard bend (17 mrad bend angle), and the synchrotron radiation from each is listed separately. The soft bend magnet does not produce a significant background source, but the hard bend magnet does and especially so for the QFC detector. There is a separation at the QFC, however, between the swath of hard bend synchrotron radiation and the Compton gammas due to the presence of the soft bend. The geometry of the detector takes advantage of this, and with careful work on shielding against scattered hard bend gammas from flanges and beampipes, acceptable backgrounds can be achieved in the QFC. Shielding against gammas scattered from beampipes, flanges and apertures is also important for the PGC and CKV detectors. Additionally, the CKV detector makes polarization measurements during beam collisions; it must be shielded against beamstrahlung radiation and tails of the disrupted electron beam which can hit apertures near the detector. It is necessary to heavily shield these detectors and their phototubes with lead. Typical Compton signal:background levels in the polarimeter detectors are 2:1 in the CKV detector during collisions, 10:1 in the PGC detector during electron-only running, and 1:1 in the QFC detector during electron-only running.

Because the CKV detector is the only one which can make polarization measurements during beam collisions, it is the primary detector and the most carefully

^dThese rates correspond to running conditions during the 1997 SLD run with beam intensities of $4.0 \cdot 10^{10}$ per pulse and luminosities of $1.5 \cdot 10^{30} \text{ cm}^{-2} \text{ s}^{-1}$.

Table 1. Threshold Cherenkov Counters

Detector	Material	Index of Refraction	Threshold Energy
CKV	Propane	1.0011	11 MeV
PGC	Ethylene	1.0007	14 MeV
QFC	Quartz	1.5	0.2 MeV

Table 2. Neutral Beam Gammas

Gamma Source	Gammas/Pulse	$\langle E_\gamma \rangle$	E_{TOTAL}
Compton	1000	15 GeV	15 TeV
Soft Bend	$4 \cdot 10^{10}$	15 keV	600 TeV
Hard Bend	$6.7 \cdot 10^{11}$	0.5 MeV	$3.3 \cdot 10^5$ TeV
Beamstrahlung	$3.6 \cdot 10^{10}$	30 MeV	$1.1 \cdot 10^6$ TeV

analyzed. A summary of the systematic errors associated with its polarization measurement is given in Table 3. The error noted for the SLC IP vs Compton IP reflects that the luminosity-weighted polarization at the SLC IP can differ from the average polarization measured at the Compton IP. This includes the effects of depolarization from the beam-beam interaction, chromatic effects, and steering effects.³ Analysis of data from the PGC and QFC detectors is not yet complete, but preliminary results are consistent with the CKV result to within 1%. Typical beam polarizations for the SLD experiment have been in the range 74 – 78%.

3. Polarimetry at a 1 TeV Linear Collider (TLC)

The primary polarimeter at a TLC should be a Compton polarimeter in the extraction line from the IP. Additionally, there should be a Mott polarimeter at the polarized electron source and a polarimeter at or following the Damping Ring.

Following the experience of the SLD Compton polarimeter, we expect to measure the beam polarization primarily from measurements of the Compton rate asymmetry of the Compton-scattered electrons at the kinematic endpoint. The endpoint

Table 3. Systematic Errors for CKV Polarization Measurement

Item	Error
Analyzing Power	0.3%
Detector Linearity	0.5%
Electronics Linearity	0.2%
Laser Polarization	0.2%
SLC IP vs Compton IP	0.2%
Total	0.7%

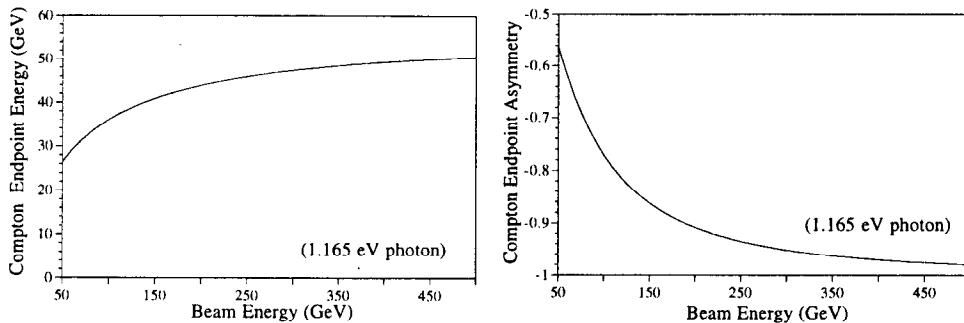


Fig. 2. Compton endpoint energy and endpoint asymmetry vs beam energy

and endpoint asymmetry are given by the following equations:

$$y = \left(1 + \frac{4E_e E_\gamma}{m_e^2}\right)^{-1}$$

$$E_C(\text{endpoint}) = E_e \cdot y$$

$$A_C(\text{endpoint}) = \frac{y^2 - 1}{y^2 + 1}$$

They are plotted versus the beam energy in Figure 2 for a laser photon energy of 1.165eV (corresponding to a 1064nm Nd:YAG laser). At high beam energies, the Compton endpoint is well separated from the beam energy; this is important and helps allow a layout of the extraction line that achieves a good suppression of background to Compton signal. The Compton asymmetry is also very large, facilitating quick and accurate polarization measurements. For the example of a 1.165eV laser photon scattering from a 500 GeV beam electron, the Compton cross-sections for the J=3/2 and J=1/2 polarization states are plotted in Figure 3.

The primary backgrounds to contend with are collision-related. The outgoing beams from the IP are severely disrupted and there is a large flux of beamstrahlung. To illustrate this, we reproduce two plots from SLAC's Zeroth-order Design Report (ZDR)⁶ for the NLC in Figure 4. The average energy loss per incident beam particle is about 10%, significantly greater than the 0.1% loss at the SLC.

At a TLC, the beam power is roughly 10 MW with a corresponding beamstrahlung-power of 1 MW to be compared with 30 kW beam power and 30 W beamstrahlung power at the SLC. This imposes a challenging environment for beam diagnostics at the TLC. Very careful design and simulation of the extraction lines

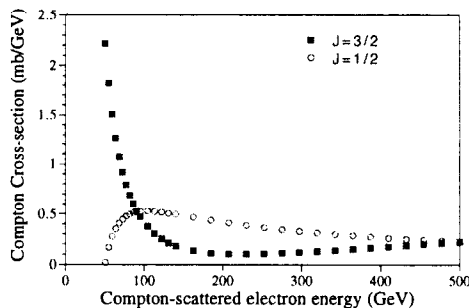


Fig. 3. Compton scattering cross-sections for the J=3/2 and J=1/2 polarization states

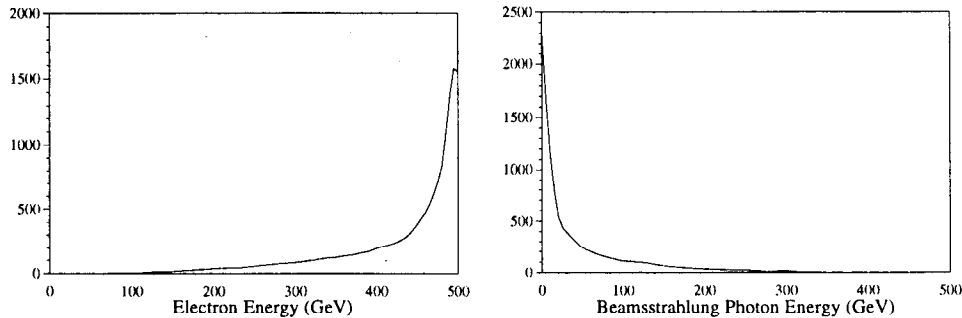


Fig. 4. Disrupted electron energy and beamstrahlung energy distributions at a TLC

from the IP to the beam dumps is needed to transport both the disrupted incident beam and the beamstrahlung with minimal losses, while allowing for sufficient beam diagnostics. For SLAC's ZDR a proposed layout for the extraction line was developed, which is shown in Figure 5.

The Compton IP is chosen to be at a location of high dispersion with $\eta = 20\text{mm}$. This assists separating the Compton signal from backgrounds at the polarimeter detector. It also allows studying the dependence of the beam polarization on the disrupted electron energy by varying the targeting of the laser beam on the dispersed electron beam. This requires a good measurement of the disrupted energy distribution, which should be achievable with a conventional wire scanner.

The polarization of the incident electron beam prior to colliding is easily determined from measurements where the opposing colliding beam is absent. At the TLC there can be significant depolarization at the level of a few percent in the collision process.⁷ Though this can be calculated given a good knowledge of the beam parameters, it is important to measure the depolarization directly. By comparing polarization measurements with and without collisions and under differing luminosity configurations, it should be possible to understand the depolarization loss to better than 1%.

A new feature of the TLC compared to the SLC is the use of bunch trains, with typically 90 bunches per train and an interbunch spacing of 2.8ns. It is of interest to measure how the polarization varies within the train. This can be done by colliding a short ($< 2\text{ns}$) laser pulse with an individual electron bunch. A fast photomultiplier tube and readout gate can then be used to minimize background from other bunches in the train. The laser and gate timing can be adjusted to map out the polarization within the train.

4. Conclusions

A Compton polarimeter located in the extraction line from the IP should achieve 1% accuracy at a TLC. It is important to take polarization measurements parasitic to beam collisions and detector data logging. The outgoing beams from the IP are highly disrupted from the collision process. This and the high power beamstrahlung

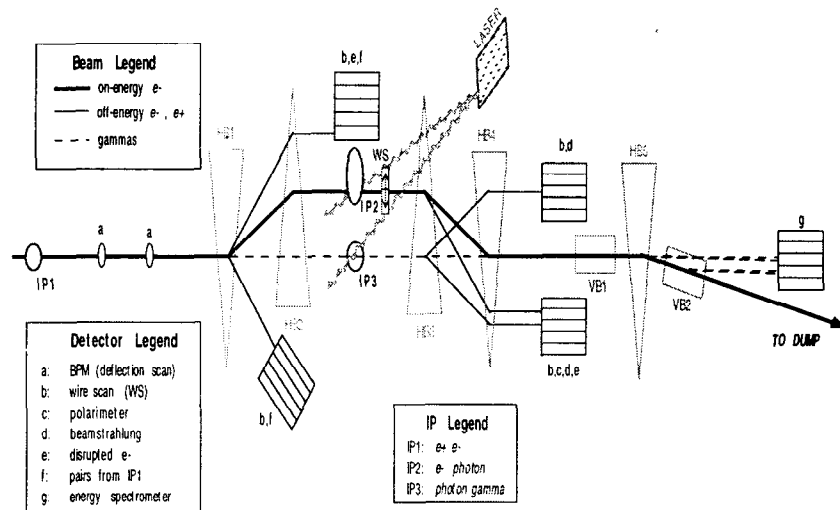


Fig. 5. Extraction Line from IP to Beam Dump

produced provide significant challenges to designing the extraction line. This is a more difficult problem for the electron-electron collider than for the electron-positron collider. Detailed system design and simulations are needed to ensure adequate signal to background in the polarimeter detector. Detailed studies are also needed to evaluate how well the luminosity-weighted polarization for a given collision process can be determined from the Compton polarization measurements.

References

1. S.B. Gunst and L.A. Page, *Phys. Rev.* **92**, 970 (1953).
2. M. Woods, SLAC-PUB-7319, (1996). Refer also to the theses by E. Torrence, SLAC-Report-509 (1997); R. King, SLAC-Report-452 (1994); A. Lath, SLAC-Report-454 (1994); and R. Elia, SLAC-Report-429 (1994).
3. M. Woods, SLAC-PUB-7320, (1996); and M. Woods, SLAC-PUB-6694 (1995).
4. R.C. Field et al., OREXP 97-04 (1997).
5. D. Onoprienko et al., UTKHEP-97-20 (1997).
6. NLC Design Group (C. Adolphsen et al.), *Zeroth-Order Design Report for the Next Linear Collider*, SLAC Report 474, (1996).
7. K. Yokoya and P. Chen, SLAC-PUB-4692, (1988).