Luminosity Polarization Correlation in the SLC

F.-J. Decker, J.T. Seeman

Stanford Linear Accelerator Center,* *Stanford, California 94309*

Abstract

In this paper we discuss the correlation between low luminosity and low polarization for off-energy particles in the Stanford Linear Collider (SLC). In the arcs of the SLC the spin of the polarized electrons has a net horizontal precession of about 25 turns. For example, a particle off energy by 1 % deviates by 0.25 spin turns or a 90° rotation from the core. It reduces the average polarization measured by a Compton polarimeter near the interaction point (IP). Since the energy acceptance or bandwidth of the final focus optics is limited to a certain range ($\approx \pm 0.5\,\%$), these off-energy particles are not focussed as well at the IP and thus contribute less to luminosity. Therefore, the effective polarization at the IP weighted by the luminosity is higher than the measured polarization. Relative corrections of this measured value by +0.5 to 1 % for the core and another +1 to 2 % for low energy beam tails seems to be necessary for the 1993 run. In 1994, beam shaping with over-compression producing lower energy spreads and smaller tails together with a new arc setup with fewer effective spin turns promise to reduce this effect by an order of magnitude.

1 Introduction

At the Stanford Linear Collider (SLC) highly polarized ($\approx 65\,\%$) electrons collide with positrons at the Z center of mass energy. The measured cross section asymmetry of the left and right handed electrons (A_{LR}) determine important high energy parameters like $\sin^2\theta_W$ and the top mass range [1, 2]. The statistical error of the A_{LR} is about $\pm 6\,\%$, the systematic error is below $\pm 2\,\%$, if the here discussed effect is properly taken into account. Three relevant beam and accelerator set ups are necessary, first a big energy spread of the beam and especially a distribution with long energy tails, second spin rotations in the ARCs [5] where different energy particles precess differently fast and third the final focus optics (FF) where off-energy particles are focussed weaker and contribute less to the luminosity, while the Compton polarimeter measures the spin of all particles. The relevant parameters, measurements and simulations, and the improvements in 1994 are discussed for the three areas.

2 Energy Spread and Distribution

The final energy distribution at the end of the SLC has many contributions from different parts of the accelerator and can be influenced by adjusting parameters in the longitudinal phase space. A detailed description is given elsewhere [3], here we will summarize the effects. In the damping ring the beam has a bunch length of 10 mm (σ). The length is big due potential well distortion and cures for the microwave instability.

Therefore the bunch goes partly over the crest of the rf in the S-band cavity in the ring-to-linac (RTL) compression section. This generates a compressed gaussian bunch (1.3 mm) with additional tails in back and front. In 1994 we are running with an over-compression in the RTL which folds the z-tails of the DR on top of the core generating a more rectangular distribution (less tails than gaussian), which gives a lower energy spread downstream.

In the linac the rf and the longitudinal wakefields shape the energy distribution. Sitting in front of the crest the rf cosine shape will create a long low energy tail in the front of the bunch and also some low energy particles in the back, while the bunch length and phase is adjusted to get a good cancellation of wakefield and rf curvatures resulting in a double-horned core distribution. By adjusting not only the bunch length, but also the bunch distribution the wakefield can cancel the rf in principle perfectly. At the end of the linac in the BSY (beam switch yard) the beams are bend into the ARCs and the energy distribution can be measured at a dispersive point (Fig. 1).

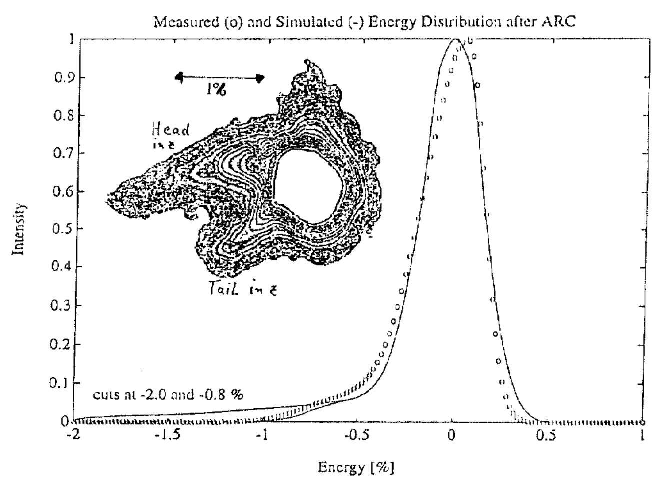

Figure 1: Beam Distributions at Dispersive Points

A profile monitor in the BSY (insert) shows the full energy distribution. Here the core is saturated, but tails down to -2 % are visible. The measured energy distribution in the Chromatic Correction Section (o) shows a part of the low energy tail and an asymmetry which can be compared to the simulation results for different cuts (-2 % and -0.8 %).

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

In the BSY there are energy collimators which were clipping the beam differently during the 1993 run. This resulted in a correlation between the measured polarization and the position of the low energy jaw of the collimator [4] (stars in Fig. 5).

In the ARCs there is a small (0.07 %) energy spread increase due to synchrotron radiation. At the end in the chromatic correction section (CCS) of the FF another energy spread measurement was done. This can be compared with a simulation which includes the long tails, the longitudinal wakefields in the linac, the cut in the collimator and the energy spread increase in the ARC (compare Fig. 1). A skewness of the core can be generated by higher order and non-linear effects (skewness in DR distribution, T_{566} and/or phase offset in RTL, not optimal phase in linac phase).

3 Spin Turns in the Arc

The arcs bend the beams out by nearly 90° and then back by about 180°. The spin of an electron will rotate and make about −25 turns in the first part and back +50 turns in the second part, resulting in an overall value of 25 turns. Since these turns depend linearly on energy, an electron with an energy offset of 1 % will rotate 0.25 turns differently. In other words, the spin of this electron has an angle of 90° compared to the on-energy electrons. 2 % off-energy particles will have the opposite spin direction.

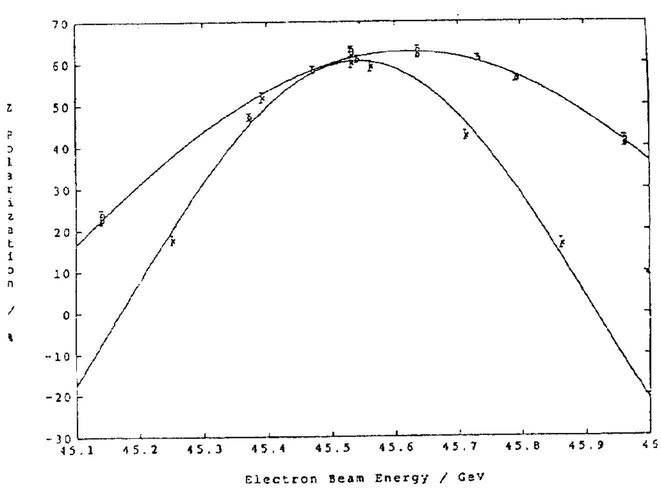

Figure 2: Polarization versus Energy

The polarization shows a 17 turn (or 29 turn) dependence for vertical (horizontal) spin launch.

Due to the vertical spin resonance a vertically oriented spin can tilt to the horizontal and/or back depending on the vertical orbit. This is helpful for orienting the spin at the IP with vertical orbit bumps which have two advantages: First, it made it possible to turn off the RTL and linac solenoids, which were incompatible with the flat beam (low vertical emittance) running in 1993. Second, since the spin is now not launched horizontally, but vertically, the spin of different energy electrons will stay the same (vertical) till it is rotated into the horizontal (and longitudinal at the IP), where it will experience only a small amount of energy dependence [5]. Instead of the original 25 turns, a 17 turn dependence was measured for the vertical launch (Fig. 2). A further reduction with different local bumps (front, middle, back arc) might help to reduce the energy dependence even further.

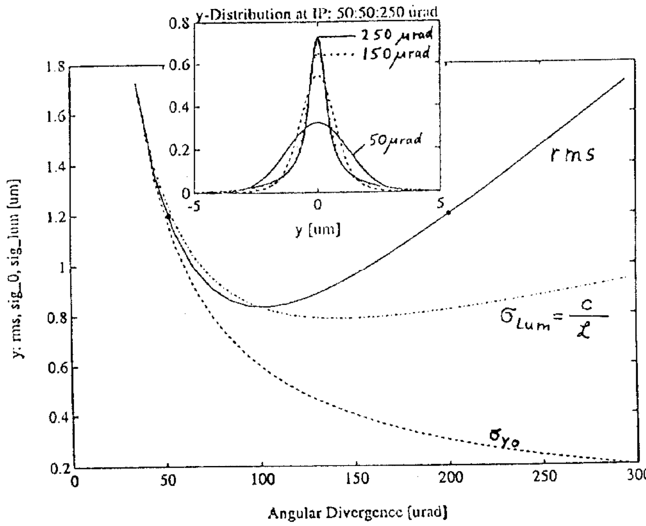

Figure 3: Vertical Spot Size vs Angular Divergence

The effective spot size (lum) can be overestimated by using the rms value when higher chromatic abberation are present.

4 Final Focus Optics

In the final focus system the beam is reduced down to micron-sized beam spots. Since the very low y-emittance of the flat beam running the spot size in y is even below 1 μm and starts to get dominated by higher order abberations. In the content of this paper mainly the chromatic effects are of interest, since off-energy particles will be somewhat away from the IP and therefore contribute less to luminosity, but will be measured at the Compton polarimeter together with the other particles as an average polarization.

The chromatic effects can consist of dispersion R_{36} and higher order effects: T_{366}, U_{3466}. The dispersion is generally minimized during beam-beam scans. T_{366} is assumed to be small. The $U_{3466} = 230\,\text{m}$ is the biggest term for the 1993 run and is eliminated with the final focus upgrade. The spot size σ_y is calculated for a certain angular divergence and energy offset as

$$\sigma_y \;=\; \sqrt{\sigma_{y_0}^2 \frac{\theta_{y_0}^2}{\theta_y^2} + 4\,\theta_y^2 \cdot U_{3466}^2 \cdot (\Delta E/E)^4}. \qquad (1)$$

For a given energy distribution $(\Delta E/E)^4$ has to be replaced by the forth moment of that distribution $\langle\delta_E^4\rangle$ which is $\langle\delta_E^4\rangle = 3\,\delta_{rms}^4$ for a Gaussian and $\langle\delta_E^4\rangle = 1.8\,\delta_{rms}^4$ for a rectangular distribution. This will give the rms-value $\sigma_{y,rms}$ of the vertical distribution at the IP. Since the distribution is not at all Gaussian, the luminosity can not be derived by simply taking

$$L = \frac{const}{4\pi\sigma_{y,rms}}, \tag{2}$$

where the 4π is a form factor for Gaussian distributions. Instead of changing the form factor, the distribution is convoluted with the same distribution (like collided with the positron beam) and the luminosity calculated directly. From there an effective Gaussian beam size is extracted by simply taking $\sigma_{y,lum} = c/L$. Fig. 3 shows the rms, luminosity and linear optics spot sizes as functions of the angular divergence. The luminosity can not be improved by changing the angular divergence from 150 to 100 μrad, as experimentally found, but expected from the simple rms picture.

The spot size dependence at the final focus versus energy or the bandwidth can only be measured with a single round beam on the FF-wires. Extrapolating this result to flat beams is consistent with the assumed value for U_{3466} (Fig. 4).

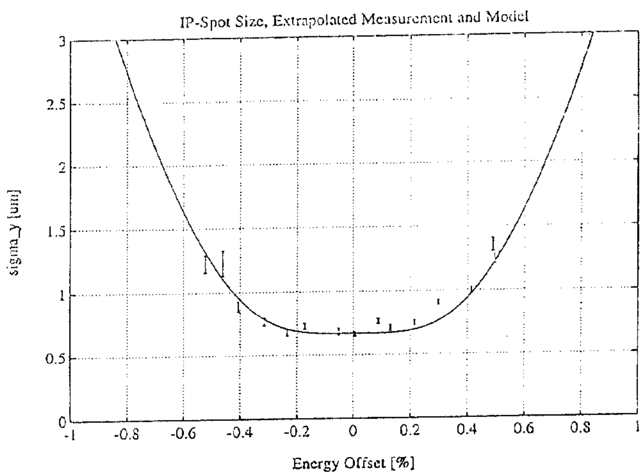

Figure 4: Energy Bandwidth

The vertical spot size is measured for different energies and extrapolated to an emittance of about $\gamma\epsilon = 0.5\cdot10^{-5}$ *m-rad. The assumed* U_{3466} *term shows a good agreement.*

The Compton polarimeter is down stream of the IP and it is assumed that it measures the average polarization of all particles. At particular times different polarizations were measured for certain energy spreads [6].

5 Conclusion

Simulating the three effects (energy distribution, ARC depolarization and bandwidth limitation in the final focus optics), a higher polarization at the IP of 2 %±0.5 % compared to the Compton average is predicted and agrees with the measured slope (Fig. 5).

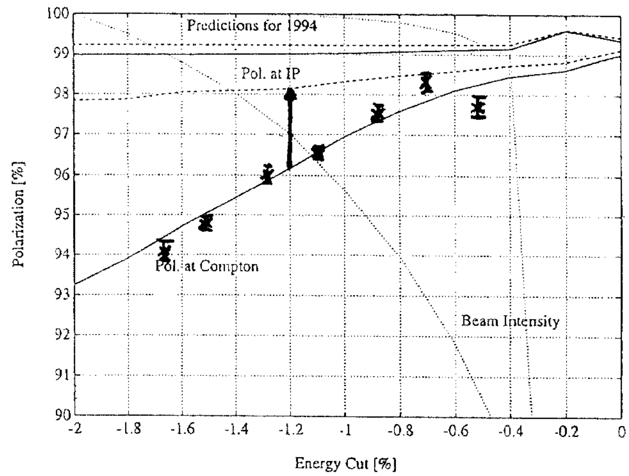

Figure 5: Correlation of Polarization versus Collimator Position.

The collimators were moved many times during the run and there is a correlation with the polarization visible (, scaled). Simulations show that the low energy tail reduces the measured polarization (Compton), but changes the effective IP polarization only a little bit, making a correction necessary.*

Acknowledgement

I would like to thank the whole Compton Polarimeter Group and many of the Accelerator Department for helpful discussions and the interest in this "small" effect.

References

[1] SLD Collaboration, *First Measurement of the Left-Right Cross Section Asymmetry in Z Boson Production by e^+e^- Collisions*, Phys. Rev. Letters, 26 April 1993, Vol. 70, Number 17, p. 2515.

[2] SLD Collaboration, *Precise Measurement of the Left-Right Cross Section Asymmetry in Z Boson Production by e^+e^- Collisions*, SLAC-PUB-6456, March 94, submitted to Phys. Rev. Letters.

[3] F.-J. Decker, *Luminosity Weighted Polarization Correction*, SLAC, SLC Collider Note 399, March, 1994.

[4] B. Schumm, *A Systematic Study of the Behavior of the SLC Electron Beam Polarization with the Compton Polarimeter*, SLD Note 234, Oct. 93.

[5] P. Emma, T. Limberg, R. Rossmanith, *Depolarization in the SLC Collider Arcs*, EPAC, London, June 94.

[6] F.-J. Decker et al., *Arc Spin Transport Studies*, SLD Note 238, Jan. 94.