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e^+e^- Collisions at the SLC - the Left-Right Asymmetry

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ABSTRACT

Recent progress with the SLC as a prototype linear collider for high energy e^+e^- collisions is reviewed. Recent advances in the production of high intensity beams of polarized e^-s are also discussed. The SLD Collaboration has embarked on a precision measurement of the left-right polarization asymmetry A_{LR} at the Z pole with polarized electrons. Results and future plans are presented.

1. The SLC Performance

The SLC was proposed in the early 1980s as a major upgrade of the SLAC linear accelerator to develop ideas and techniques for a e^+e^- linear collider and to conduct experiments at the Z pole. This idea, proposed by Burton Richter, was intended to demonstrate the feasibility of high energy e^+e^- colliders using linac technology. In the SLC design, both the electron and positron beams are accelerated in the same linac structure. To bring these bunches into head-on collisions, a dipole magnet at the end of the linac separates the e^+ and e^- beams, and a pair of transport arcs bring the beams to a collision point. The experimental detector sits at the collision point where the arcs meet. The capability for polarized electron beams was incorporated into the SLC design from the beginning. The layout of the linac-to-damping ring paths was chosen to allow for proper spin manipulation by solenoidal fields so that the spin orientation in the damping ring would be normal to the plane of the ring. Space was included for two more solenoidal rotators after the damping rings to permit pointing of the spin vector in any arbitrary direction.

Construction of the SLC commenced in the mid-1980s, and the first beams were delivered to the interaction point (IP) in 1988. The detector at the IP was the upgraded Mark II detector which had been running at PEP in preparation for the SLC run. The Mark II detector collected its first physics data at the SLC in 1989 and in 1990 producing a measurement of the mass and width of the Z° along with some other measurements. The physics results for Mark II were based on a total of about 700 Z° decays.

In 1991 the Mark II was replaced by the SLD, which conducted an engineering run consisting of 400 Z°s produced. By 1992 the performance of the SLC had improved

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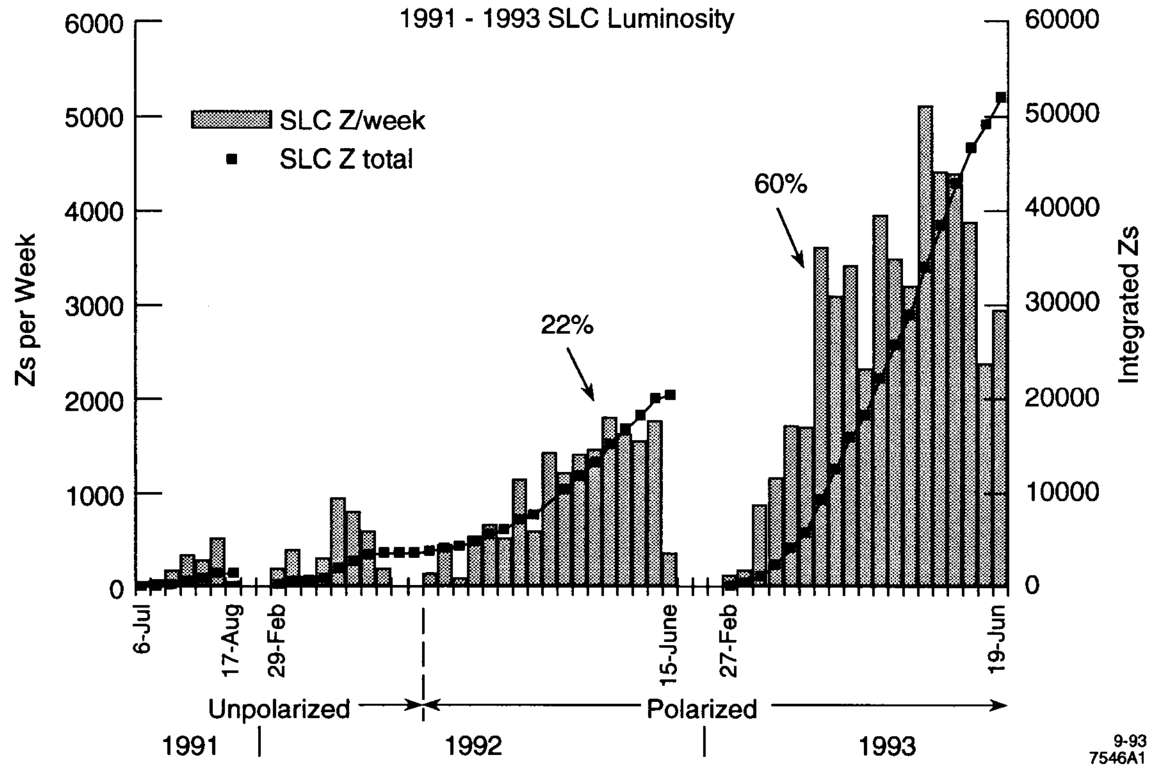

Fig. 1. The improving performance of the SLC is shown for the past three years. The rate of Z° production per week is shown on the left hand side, and the total integrated Z°s for each year is shown on the right hand side. The electron beams were unpolarized up to April 1992 when running with polarized beams began. The polarization averaged 22% in 1992 and 60% in 1993.

considerably, and SLD accumulated 11,600K Z°s in tape, with a majority of those from polarized electrons.

In 1993 the SLD has been running smoothly, and at the time of this meeting a sample of 41K Z°s has been collected on tape, all with approximately 60% longitudinal polarization of the incoming electrons (the positrons are unpolarized). The 1993 run has not been completed at the time of this meeting, but the run is progressing successfully toward a goal of 50K Z°s by the end of August 1993.

The SLC is running very well, and the SLD has embarked on a physics program focused primarily on polarization measurements, heavy quark physics using a precision pixel silicon vertex detector, and related subjects.

Figure 1 summarizes the improving SLC performance since 1991, when the SLD detector was installed. Improvements in SLC luminosity have come from a number of factors. An important advance in 1992 came with the commissioning of the "adaptive fast feedback" which refers to an intelligent microprocessor system that stabilizes over 200 parameters in the accelerator systems. This feedback system has led to much improved stability in the accelerator. In addition, the operational efficiency has significantly increased as the hardware reliability has improved. In the 1993 run flat beam geometry has been utilized. Prior to 1993 the SLC ran with round beams generated by running the damping rings on a coupling resonance. In late 1992, tests showed that the damping rings, when uncoupled, produced the expected flat beams, and that these flat beams were accelerated to the end of the linac without loss of emittance. The flat beam geometry offered smaller beam spots in the vertical coordinate and, corresponding to the smaller spot sizes, a higher luminosity.

Plans to upgrade the damping rings and the final focus optics are now underway. In 1994 the SLC should run with higher currents, smaller beam spots at the IP, and higher beam polarization. It may be possible to gain additional luminosity from the long-predicted (but yet to be observed) beam-beam pinch effect. The integrated luminosity should continue to improve in later years. The SLD goals for 1994 are 150K Z°s written to tape, with the beam polarization around 75%. In later years, 250K Z°s per year will be feasible. Tests in the coming running period will help determine whether or not these projections can come to fruition.

2. Polarization

In a high-energy storage ring, the mechanisms which polarize and depolarize the beams compete to establish an equilibrium situation. Time constants for the equilibrium to be established range from tens of minutes to several hours, depending on the running parameters for a ring. In a linear collider these mechanisms are active, but the time a beam spends under the influence of these processes is short.

For the SLC, the beams are in the damping ring for 8 milliseconds (16 milliseconds for the positrons) and in the linac for 13 microseconds. The electrons are born longitudinally polarized, and in the process of accelerating, damping, and transporting the beam to the experiment, the magnitude of the polarization must be preserved, and the orientation rotated to longitudinal at the IP.

The components specific to the polarized electron beam consist of the polarized electron source, the spin rotation solenoids at the e^- damping ring, a Møller polarimeter at the end of the linac, and a Compton polarimeter just after the IP. Figure 2 shows the electron damping ring with its complement of components for polarized beams. Figure 3 shows the two polarimeters used for measurement of the polarization, the Møller polarimeter at the end of the linac, and the Compton polarimeter placed 33 meters after the SLD detector.

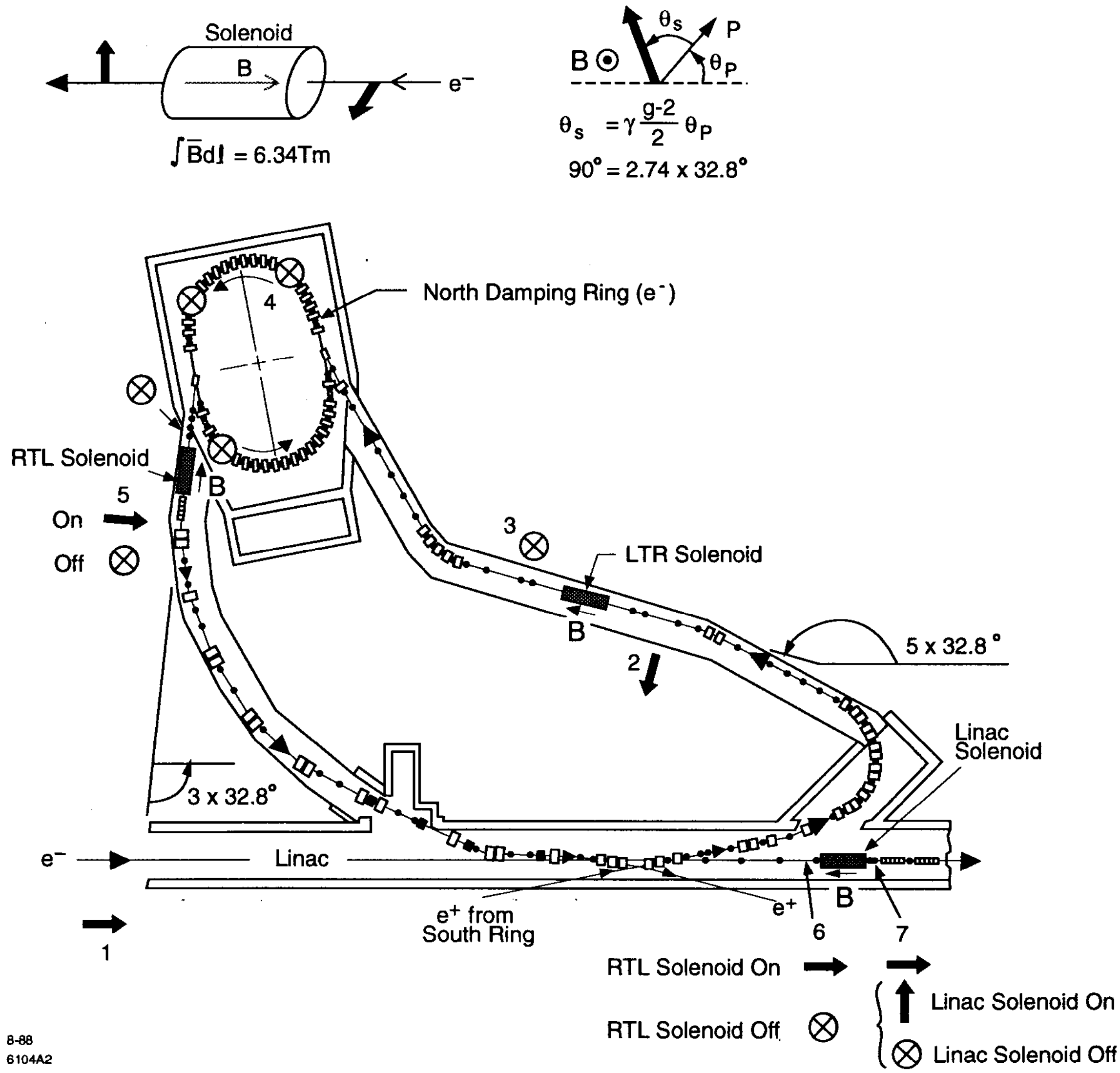

Fig. 2. Spin rotation at the electron damping ring is shown in this figure. The electrons from the 1.2 GeV point of the linac are extracted and sent to the damping ring for emittance reduction. In the transport line at the input and output of the ring, solenoidal rotators manipulate the spin to preserve polarization and to orient in it a direction to give longitudinal spin at the experimental IP.

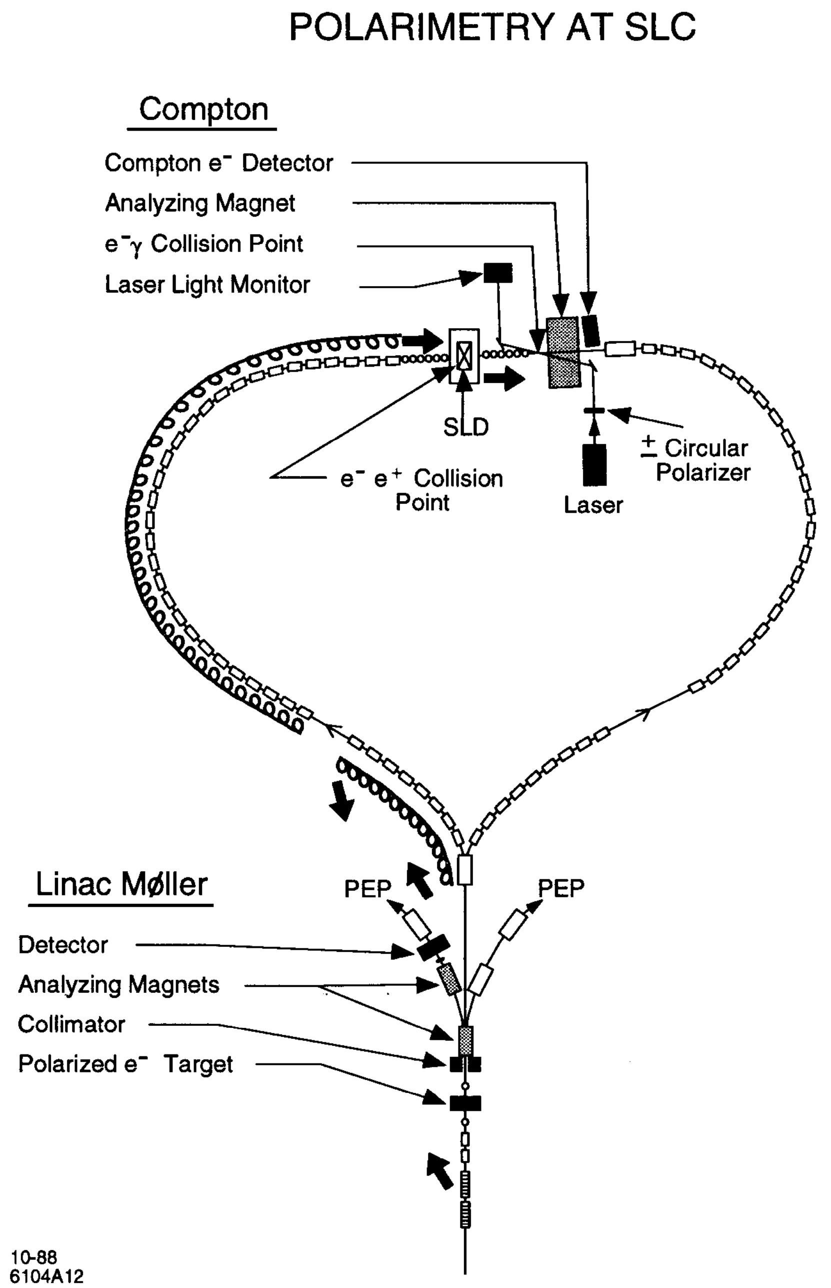

Figure 3. Two polarimeters serve to determine the beam polarization, a Møller polarimeter at the end of the linac and a Compton polarimeter at the experiment 33 meters after the IP.

Figure 4 shows the layout of the polarized e^- source. It consists of a YAG-pumped Ti:Sapphire laser operating at 865 nm, a series of optical elements to control the intensity, pulse length, circular polarization, and steering. The laser beam passes through a mirror box and onto the photocathode of the gun structure. The polarized electron gun has been developed over the past several years at SLAC.[1] It is based on the design of the SLAC thermionic gun. The gun operates at -120 KV

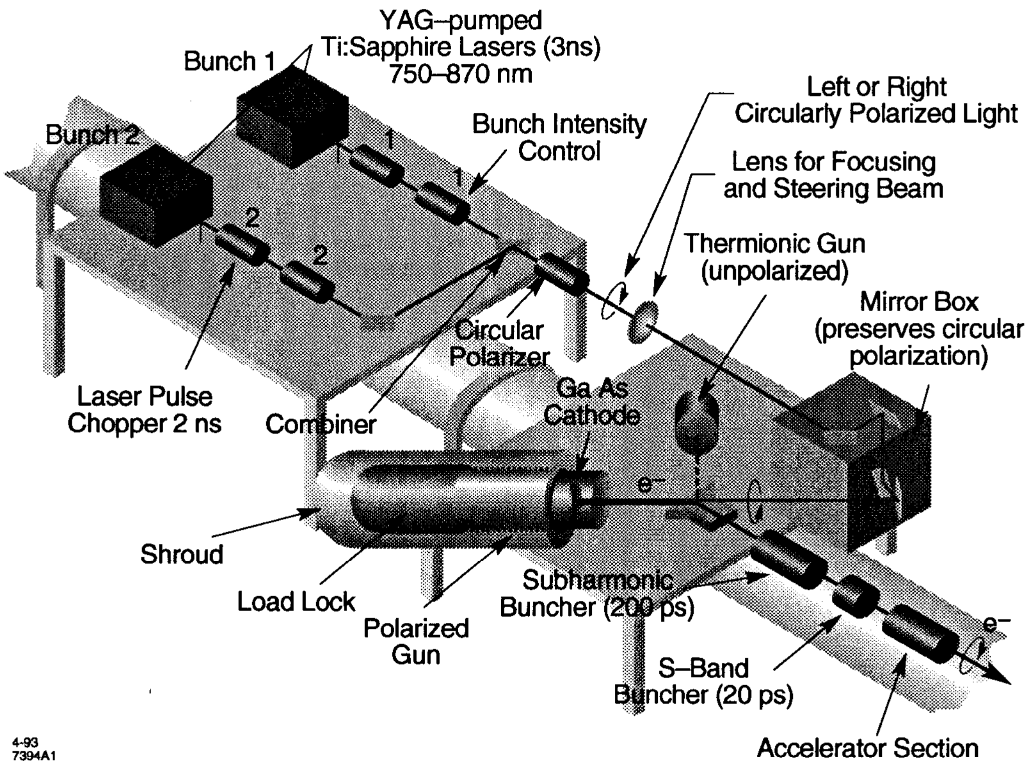

Fig. 4. The layout of the lasers and the polarized gun at the SLC injector is shown schematically. The SLC runs on the YAG-pumped Ti-sapphire laser tuned to a wavelength of 865 nm. The laser beam passes through an intensity control, a chopper, a lens box, and mirrors before reaching the gun cathode. The longitudinally polarized photoemitted electrons are deflected by a bend magnet onto the axis of the accelerator.

potential on the cathode. The photoemitting surface consists of a 14 mm diameter wafer of gallium arsenide (GaAs) which has been prepared with a clean surface by heating, and then coating with cesium and fluorine (approximately one atomic layer in thickness). The preparation of photoactive cathodes follows closely procedures which have been discussed extensively in the literature.

The SLAC gun is designed for easy insertion and removal of the GaAs cathode without disturbing the gun electrodes or the gun vacuum.[2] Several variations on the type of GaAs material have been used in recent accelerator runs. Figure 5 shows the polarization versus laser wavelength λ for three such materials. The most recent run (1993) uses the strained GaAs material, producing nearly 80% polarization.[3]

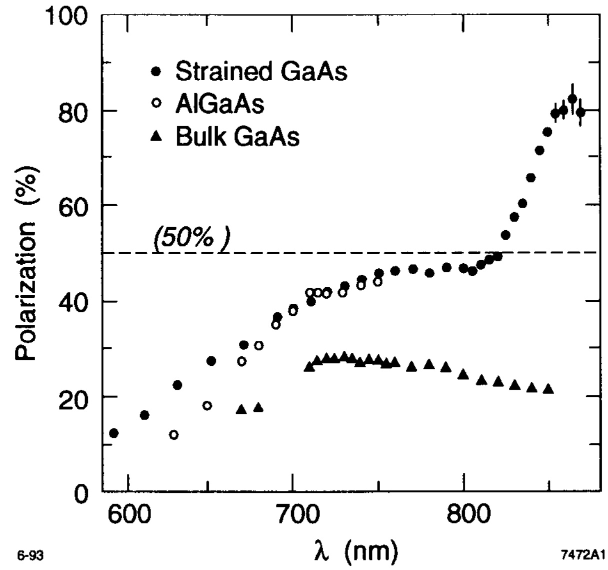

Figure 5. The polarization versus wavelength for three cathode materials used on the accelerator. The strained GaAs cathode operating at 865 nm delivered approximately 80% polarization during the 1993 running.

Optimization of the polarization from the strained GaAs surface has been studied at SLAC. Cathodes now exist that achieve polarization values up to 90%.[4] These improvements in polarization are expected to be transferred to the source operating on the SLC in the near future.

Figure 6 shows the measured polarization at the SLD detector during a 15 day period in March and April 1993. The value of the polarization, rising to 62%, is a major improvement from the previous year, when it averaged 22%. This increase resulted from the use of the strained GaAs material. However not all of the polarization from the source survives. Some depolarization occurs due to energy spread in the beam, and when coupled to the rapid precession of spin in the arcs, leads to diffusion of the spin.

3. The Left-Right Asymmetry

The left-right asymmetry A_{LR} is an important electroweak parameter. A_{LR} is defined as

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \tag{1}$$

where $\sigma_L(\sigma_R)$ is the visible cross section for the left-handed (right-handed) incident electrons. Simply stated, A_{LR} is the spin-flip asymmetry in the total cross section. It is independent of the final state detected, so all final states are used (except $e^+e^- \rightarrow Z^\circ \rightarrow e^+e^-$).

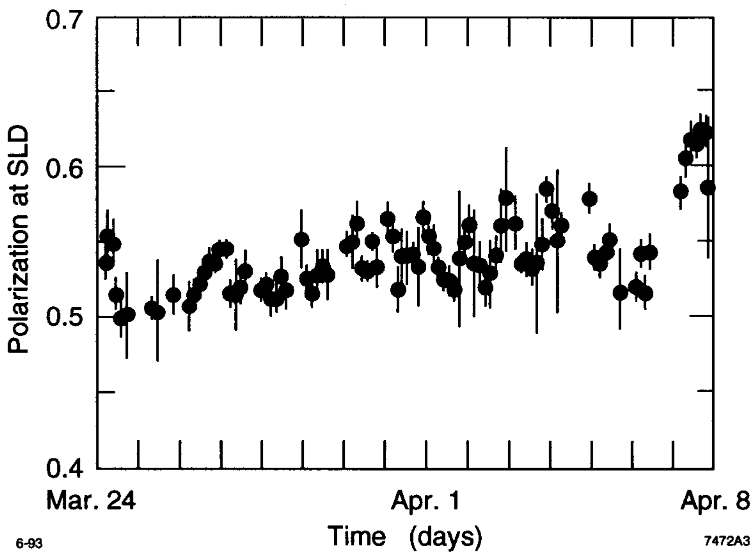

Fig. 6. Measurements of beam polarization from the Compton polarimeter at the SLD detector show short term and long term variations. The period shown covers March 24, 1993 to April 8, 1993, a period of 15 days. During this period steady improvement in the SLC running conditions contributed to an increasing polarization. An intentional change of laser wavelength from 855 nm to 865 nm on April 6 led to a jump in polarization to 62%, as seen in the data.

The experiment consists of reversing the electron helicity frequently, counting the Z°s produced, and forming the asymmetry

$$A_{meas} = [\frac{N_L - N_R}{N_L + N_R}]/P_e. \tag{2}$$

This measured asymmetry A_{meas} is, within small corrections, equal to A_{LR} provided P_e is well measured, and the integrated luminosity in each helicity is equal. Luminosity must be measured carefully to assure this equality is achieved.

A_{LR} is a sensitive electroweak parameter. It is sensitive to the heavy masses M_{top} and M_{Higgs}, plus any new objects which couple to the photon or the Z° (such as those in supersymmetric models).

A_{LR} can be measured using any Z° decay channel (except $e^+e^- \to Z^\circ \to e^+e^-$). The strategy is to use all visible decays since the value measured is independent of the decay channel and the statistical error will decrease in proportion to the inverse square root of the total number of decays. In addition, A_{LR} is insensitive to initial state radiation, and independent of QCD corrections. Because of the rapid spin reversals at the source, drifts in the detector efficiencies cancel in the asymmetry. The only significant systematic error in A_{LR} lies in the measurement of P_e.

The polarization is measured by a Compton scattering polarimeter near the IP. Figure 7 shows the layout of the Compton polarimeter. The laser beam is circularly polarized, and when it collides against the outgoing e^- beam, backscattered e^-s are

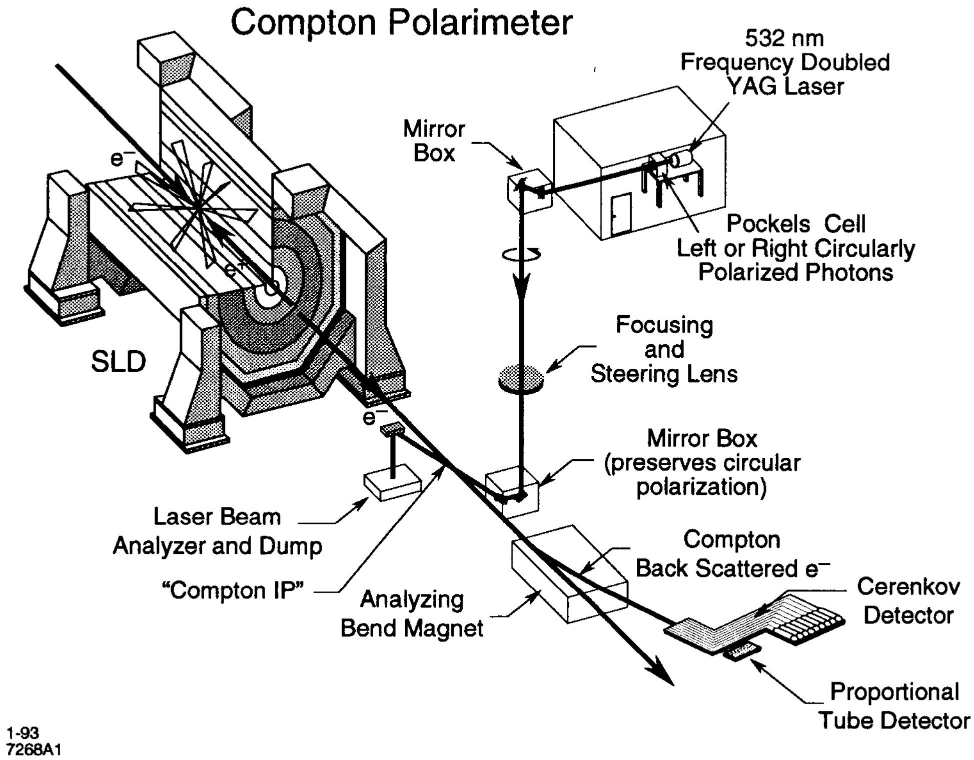

Fig. 7. The Compton polarimeter is shown schematically. A frequency doubled YAG laser delivers circularly polarized pulses of laser light to the SLC beam line at a point 33 meters after the SLD collision point. Backscattered photons and backscattered electrons degraded in energy travel down the beam pipe along with the outgoing electron beam. The electrons are deflected out of the unscattered beam by bending magnets. Two detectors measure the flux of scattered Compton electrons, a gas-filled Cerenkov counter and a lead-proportional tube detector.

detected in a multi-channel gas Cerenkov counter after passing through a bending magnet. The Compton process is accurately described in QED, and the geometry and beam related backgrounds can be well controlled or measured. The counting rate asymmetry is measured as a function of the detector channels in two independent detectors. The data, shown in Fig. 8, fall onto the theoretical curve which is fit by adjusting a single scale factor to determine the value of P_e.

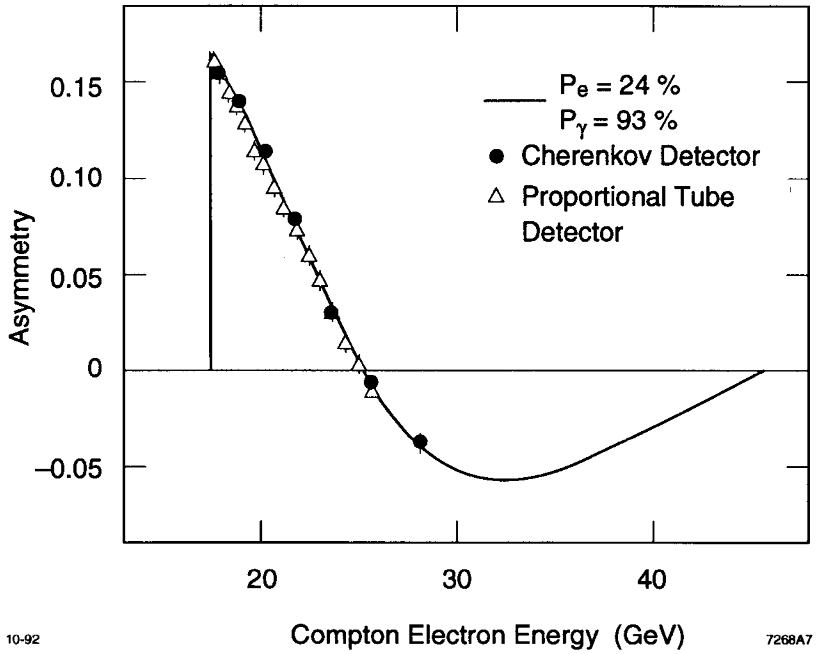

Fig. 8. The asymmetry measured in both the Cerenkov detector and the lead-proportional detector is shown versus the scattered energy. The curve shows the theoretical fit to the data for a beam polarization of 24%.

TABLE I. The Compton Polarimeter: Error on P_e

Source	1992	1993 goal	1993 achieved
	%	%	%
Laser Polarization	2.0	≤ 1.0	2.2
Detector Linearity	1.5	0.7	0.7
Interchannel Consistency	0.9	0.5	0.5
Electronic cross-talk	0.4	0.4	0.4
Analyzing Power Calibration	0.4	0.4	0.4
TOTAL	2.7	1.4	2.4

Table I summarizes the systematic errors associated with the Compton polarimeter for the two years of SLD running. The goal for future runs is to improve the present errors on the measurement of P_e to 1% or less.

Table II. Systematic Errors on $\Delta A_{LR}/A_{LR}$

Source	1992	1993 status
	%	%
Compton Polarimetry	2.7	2.4
Δ Luminosity (left-right)	1.9	0.1
Background fraction	1.4	0.6
Δ Polarization (l-r)	.006	.006
Δ Beam energy (l-r)	.07	.07
TOTAL	3.6	2.5

Event selection for the Z° candidates is currently based on SLD's calorimeters only. The analysis requires the total energy deposited to exceed 20 GeV. Events with energy greater than 12 GeV in the calorimeter end caps are excluded to remove machine generated backgrounds. An energy imbalance cut is imposed ($\Sigma_{\rm towers}\vec{E}_i/\Sigma|\vec{E}_i| < 0.8$). These cuts remove most of the 2γ events and beam-related backgrounds. Separately $e^+e^- \to Z^\circ \to e^+e^-$ are removed. The remaining sample contains $92 \pm 2\%$ of the hadrons, 30% of the τ pairs that are produced, beam backgrounds $< 0.3\%$, 2γ events $< 0.1\%$, and e^+e^- contamination $< 0.3\%$. In addition, a valid Compton polarimeter measurement is required within one hour of the event candidate if it is to be used.

Table II lists the systematic errors in ΔA_{LR} for the 1992 data sample, and for the 1993 run in progress. These 1993 numbers are preliminary. For 1992, the event sample contained 10,224 events of which 5,226 were produced with left-handed helicity and the remaining 4,998 events with right-handed electrons. The average polarization was $P_e = 0.224 \pm .006(\text{stat.}) \pm .027(\text{sys.})$. This resulted in

$$A_{LR} = 0.100 \pm 0.044(\text{stat.}) \pm 0.004(\text{sys.}) \quad (3)$$

and a derived value

$$\sin^2\theta_W = 0.237 \pm 0.056 \pm 0.0005 \quad (4)$$

which has been published.[5]

In these data 25,615 small-angle Bhabha events were recorded, and a value

$$A_{\rm Bhabha} = 0.0085 \pm 0.028 \quad (5)$$

consistent with 0 as expected. The value of $A_{\rm Bhabha} \approx 0$ confirms that a known null asymmetry can be measured by the experiment and that false asymmetries are not being introduced by the procedures used.

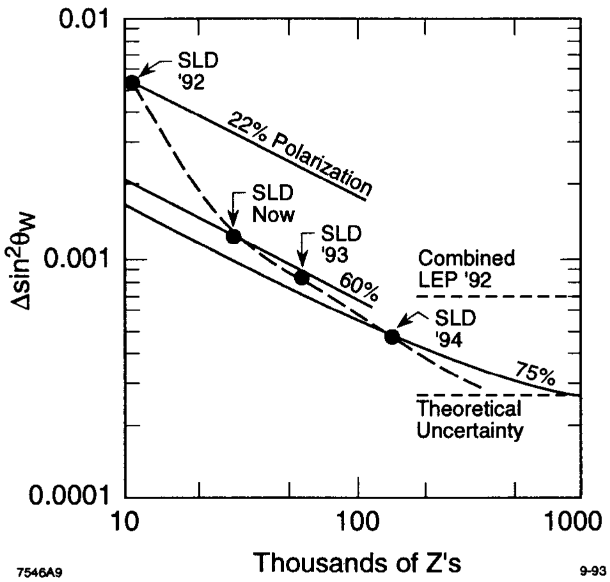

Fig. 9. The error in $\sin^2\theta_W$ versus the accumulated total of Z°s counted. The points show the past, present, and expected future accuracy for the SLD measurements.

For 1993, the work is still in progress. At the time of this conference, over 40K Z°s have been logged to tape, with an average polarization $P_e \approx 60\%$. Analysis is underway and preliminary results should be available by the end of the summer.

The errors on A_{LR} will continue to improve significantly for these current results as the data sample expands. The combined error on A_{LR} is expected to be $\Delta A_{LR} = 0.006$ and $\Delta\sin^2\theta_W = 0.0008$ by the end of the 1993 running.

Figure 9 shows the expected improvement in $\Delta\sin^2\theta_W$ as the data sample increases and as the beam polarization increases. The errors will continue to diminish in future SLC runs, and A_{LR} will likely become the most precise single asymmetry measurement. Soon after, by the end of 1994, it is expected to become as precise as the combined LEP data.

References

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