Title
e+e- Collisions at the SLC - The Left-Right Asymmetry

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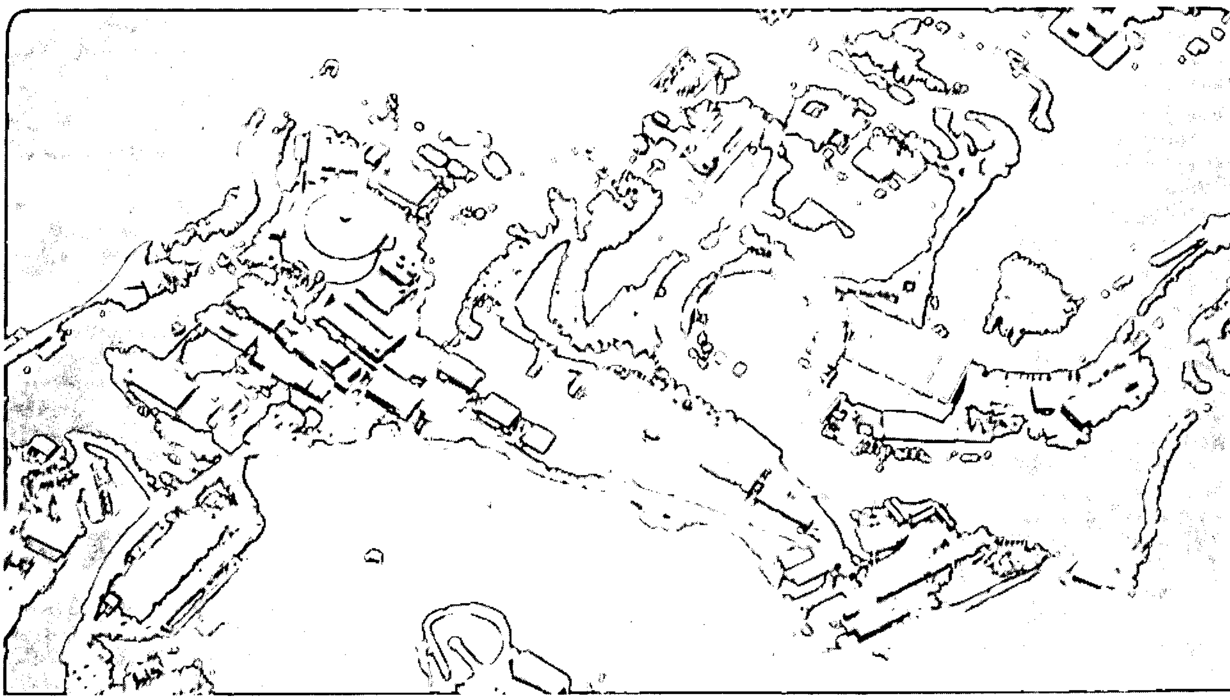
The SLD Collaboration

September 1993



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

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ABSTRACT

The Stanford Linear Collider has operated successfully to produce over 50,000 Z^0's with polarized electron beams. The asymmetry in the production of Z^0's with respect to left and right handed electron beams has been measured, and a preliminary result is presented.

1. THE SLC PERFORMANCE

The SLC was proposed in the early 1980's as a major upgrade of the SLAC linear accelerator to develop ideas and techniques for an 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, shown in Figure 1. 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 SLD detector was installed into the interaction point in 1991, following an earlier run by the Mark II detector. There was an engineering run that year that produced 400 Z^0's with unpolarized beams. In 1992 the SLC began to accelerate polarized electrons. That year the SLD recorded over 11,000 Z^0's, with an average electron polarization of 22%. The results of the first A_{LR} measurement, using that data, have already been published [1].

In 1993 the SLD recorded nearly 50,000 Z^0's, with an average longitudinal polarization of 62% for the electrons at the intercation point. The positrons are unpolarized.

Figure 2 summarizes the improving SLC performance since 1991. The peak luminosity so far, achieved in May 1993, was as high as 50 calculated Z^0's per hour. The cross–section at the Z pole is 30 nanobarns. So the best luminosity, averaged over several seconds at 120 Hertz accelerator repetition rate, would amount to 5×10^{29} per square centimeter per second.

2. POLARIZATION

The components specific to the polarized electron beam consist of the polarized electron source, the spin rotation solenoids at the e^- damping rings, a Møller polarimeter at the end of the linac, and the Compton polarimeter placed 33 meters after the SLD detector.

The polarized e^- source 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 photo- cathode of the gun structure. The polarized electron gun operates at −120 KV potential on the cathode. The photo-emitting 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). Several variations on the type of GaAs material have been used in recent accelerator runs. Figure 3 shows the polarization versus laser wavelength for three such materials [2]. The most recent runs (1993) used strained GaAs material. In a fixed-target run (not SLD) in late 1993, beams in excess of 80% polarization have been reliably delivered to the experimental area.

Figure 4 shows the measured polarization at the SLD detector during the runs of 1992 and 1993. The horizontal coordinate is the ordinal number of the detected Z^0 events. The marked improvement in the polarization with the introduction of the strained GaAs photo-cathode at the beginning of 1993 is seen after event number 11,000. Soon thereafter, after an additional 5,000 events, the wavelength of the laser was optimized at 865 nm. For the rest of the 1993 run the beam polarization averaged 62%.

The Compton polarimeter, the principle instrument with which the electron beam polarization was measured, is described in another talk by the same speaker at this conference [3]. A discrepancy between the polarization measured by the Compton polarimeter, which is close to the e^+e^- interaction point, and the Møller polarimeter, at the end of the linac before the beams enter the arcs, has now been resolved by correcting a systematic error in Møller polarimeters pointed out by L. G. Levchuk [4]. There is a small loss in polarization, under 3%, as the beam goes around the arcs.

TABLE I: COMPTON POLARIMETER SYSTEMATIC ERROR

Source	At Present	After Complete Analysis 1993 Run	Expected For 1994
Laser Polarization	1.0 %	0.8 %	0.5 %
Detector Linearity	1.0	0.7	0.5
Interchannel Consistency	0.5	0.5	0.3
Electronic Cross-talk	0.2	0.2	0.2
Analyzing Power Calibration	0.5	0.5	0.2
TOTAL	1.6 %	1.3 %	0.8 %

3. THE LEFT–RIGHT ASYMMETRY

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

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

where σ_L (σ_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 $e^+e^- \to Z^0 \to e^+e^-$. Forward Bhabha scattering, dominated by the t–channel, being mostly an electromagnetic process, is expected to be parity–conserving, and thus to exhibit not asymmetry. Observation of the small asymmetry in the forward Bhabha channel is in fact a systematic check that no false asymmetries are introduced by the beam or the apparatus.

The experiment consists of reversing the electron helicity frequently, randomly on a 120 Hz basis, counting the Z^0's produced, and forming the asymmetry

$$A_{meas} = \frac{1}{P_e}\frac{N_L - N_R}{N_L + N_R}$$

This measured asymmetry A_{meas} is, within small corrections, equal to A_{LR} provided P_e, the electron beam polarization, is well measured, and the integrated luminosity in each helicity is equal.

A_{LR} is a sensitive electroweak parameter. It is sensitive to the heavy masses of the top quark and the Higgs boson, plus any new objects which couple couple to the photon or the Z^0, such as those in supersymmetric models.

A_{LR} can be measured using any Z^0 decay channel, except Bhabhas. 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 frequent 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.

TABLE II: PRELIMINARY CORRECTIONS TO A_{LR}

ERROR SOURCE	CORRECTION	$d(A_{LR})/A_{LR}$
Background Fraction	$0.6 \pm 0.3\%$	$+0.4 \pm 0.2$ %
Polarization Asymmetry	0.5%	+0.02%
Energy Asymmetry	6×10^{-6}	−0.01 %
Efficiency Asymmetry	0	0
Luminosity Asymmetry	$(-1.0 \pm 0.2) \times 10^{-4}$	$+0.10 \pm 0.2$ %
TOTAL		$+0.5 \pm 0.2$ %

Event selection for the Z^0 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, that the sum of the energy vectors in the towers must be less than 0.8 of the total energy seen. These cuts cuts remove most of the two-gamma events and beam-related backgrounds. The remaining sample contains 92 ± 2 % of the hadrons, 30% of the tau pairs that are produced, beam backgrounds < 0.3%, two-gamma events < 0.1%, and Bhabha 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 I lists the systematic errors in the polarization measurement for the 1993 running, and those expected for next year. Table II lists the preliminary systematic errors from sources other than the polarization measurement. Table III gives the preliminary results. For the 1993 running the center of mass energy was 91.26 +/- .02 GeV, compared to the cross section peak at 91.28 GeV.

TABLE III: PRELIMINARY RESULTS FOR A_{LR}

Number Events		Left Beam	Right Beam	Raw Asymmetry
BHABHAS:	125375	62656	62719	-.0005 +/- .0028
Z^0's:	47492	26195	21297	+.1031 ± .0046

POLARIZATION OF BEAM P_e: .626 ± .012

A_{LR} (1993 data only) = .1656 ±.0073 (stat) ± .0032 (sys)

A_{LR} (combined 92–93) = .1635 ± .0072 (stat) ± .0032 (sys)

From the combined preliminary value of A_{LR}, we can calculate a value of the weak mixing angle:

$$\sin^2\theta_W = .2290 \pm .0010.$$

The errors will continue to diminish in future SLC runs, and A_{LR} will likely become the most precise single asymmetry measurement bearing on the electroweak theory parameters. The 1994 run is expected to produce 100,000 to 150,000 Z^0's with beam polarization exceeding 75%. Further runs to bring the Z^0 total close to one million events are planned for the succeeding years.

REFERENCES

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[2] T. Maruyama et al., Phys.Rev.Lett. 66,2351 (1991)

[3] G. Shapiro, "The Compton Polarimeter at the SLC," paper presented at SPIN–93, Protvino, Russia.

[4] L. G. Levchuk, "The Intra–Atomic Motion of Bound Electrons as a Possible Source of a Systematic Error in Electron Beam Polarization Measurements by Means of a Møller Polarimeter," Kharkov Institute of Physics and Technology, KFTI–92–32

FIGURE CAPTIONS

Figure 1. Polarization in the Overall SLC Layout

Figure 2. The improving performance of the SLC is shown for the past three years. The rate of Z^0 production per week is shown on the left hand side, and the total integrated Z^0's for each year is shown on the right hand side. The electron beams were unpolarized up to April 1992.

Figure 3. The polarization versus wavelength for three cathode materials used on the accelerator.

Figure 4. Electron beam polarization versus time, measured in ordinal number of detected Z^0.

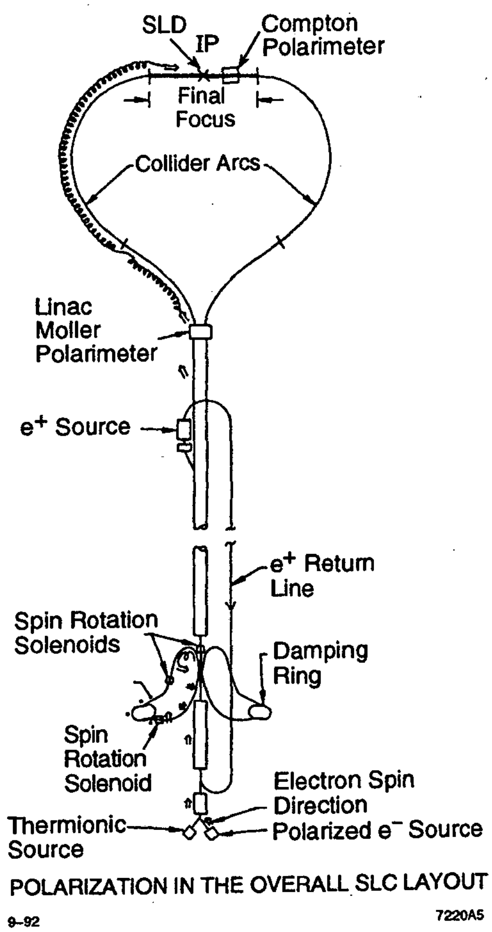
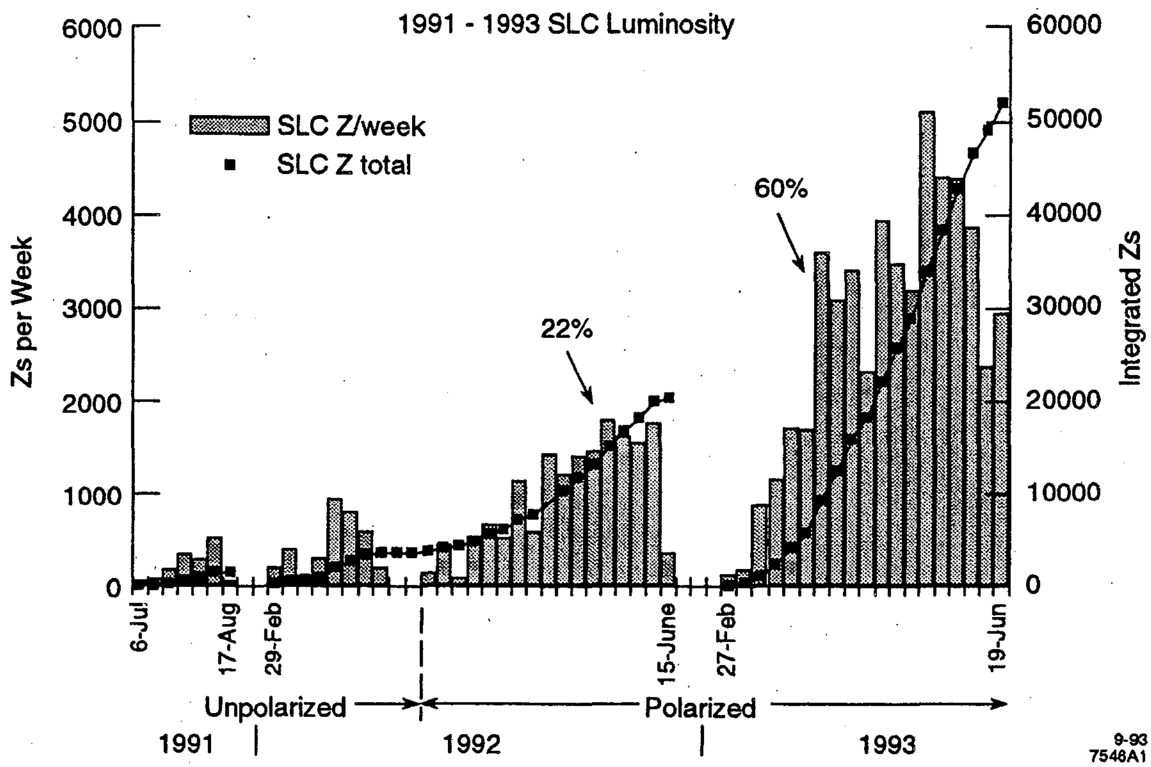
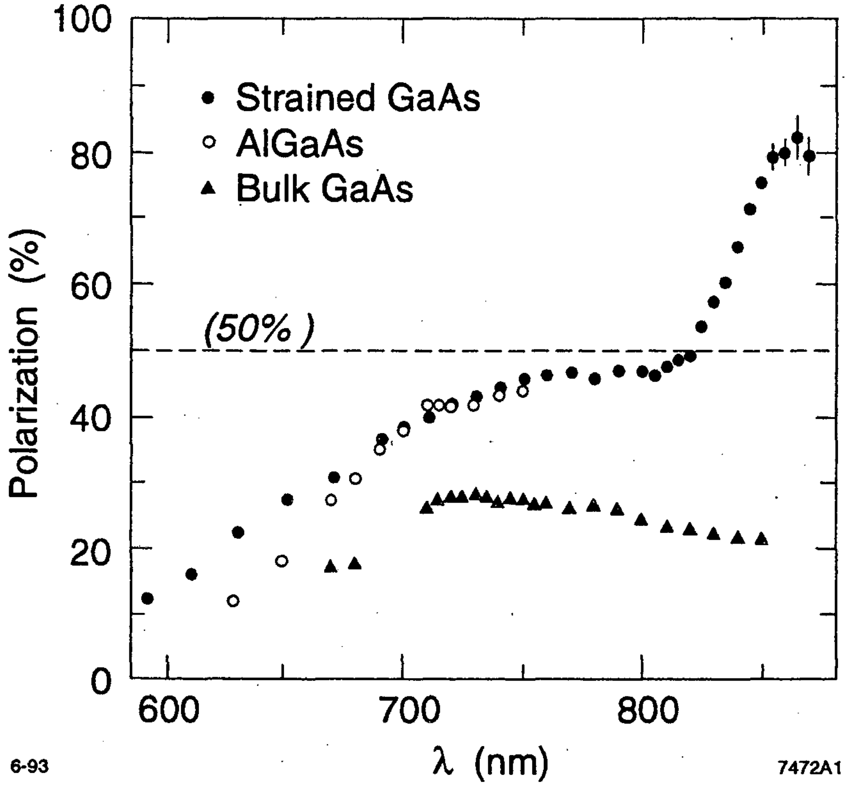

SLD
IP
Compton
Polarimeter
Final
Focus
Collider Arcs
Linac
Moller
Polarimeter
e+ Source
e+ Return
Line
Spin Rotation
Solenoids
Damping
Ring
Spin
Rotation
Solenoid
Electron Spin
Direction
Thermionic
Source
Polarized e⁻ Source
POLARIZATION IN THE OVERALL SLC LAYOUT
9-92
7220A5

Fig. 1



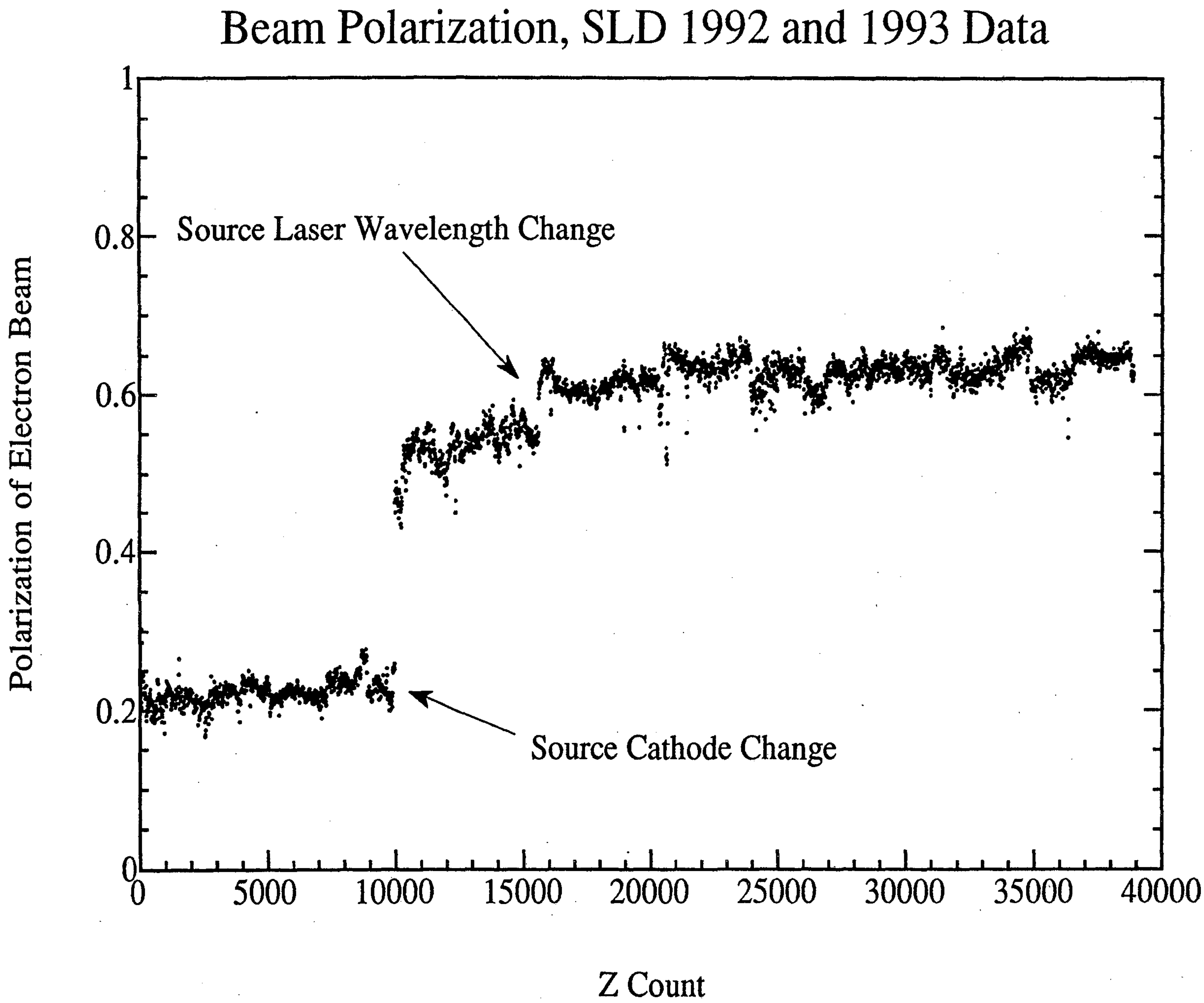
1991 - 1993 SLC Luminosity
6000
5000
4000
3000
2000
1000
0
Zs per Week
SLC Z/week
SLC Z total
60%
22%
60000
50000
40000
30000
20000
10000
0
Integrated Zs
6-Jul
17-Aug
29-Feb
15-June
27-Feb
19-Jun
Unpolarized
Polarized
1991
1992
1993
9-93
7546A1

Fig. 2



100
80
60
40
20
0
Strained GaAs
AlGaAs
Bulk GaAs
(50%)
Polarization (%)
600
700
800
λ (nm)
6-93
7472A1

Fig. 3


Beam Polarization, SLD 1992 and 1993 Data
Source Laser Wavelength Change
Source Cathode Change
Polarization of Electron Beam
Z Count
1
0.8
0.6
0.4
0.2
0
0
5000
10000
15000
20000
25000
30000
35000
40000

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