SLAC-PUB-10246
DPNU-96-03

PRECISION TEST AT SLC/SLD

SLD Collaboration
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Taking advantage of the linear collider, SLD has determined the most precise *Weak Mixing Angle* by polarization experiment.

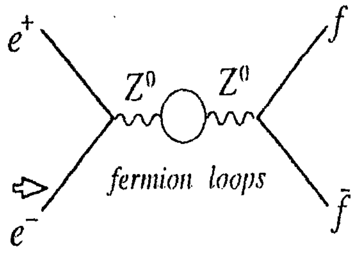
1. Left-Right Asymmetry

Z^0 boson production by the collision of polarized electrons and unpolarized positrons have the left-right symmetry A_{LR},

$$A_{LR} = \frac{\sigma_L(Z^0) - \sigma_R(Z^0)}{\sigma_L(Z^0) + \sigma_R(Z^0)} = \frac{1}{P_e}\frac{N_L - N_R}{N_L + N_R} = \frac{2(1-4\sin^2\theta_W^{eff})}{1+(1-4\sin^2\theta_W^{eff})^2}$$

where N_L and N_R are numbers of Z^0 counts obtained by the left- and right-handed polarized beams, respectively, and P_e is the magnitude of beam polarization. A_{LR} measurement uses no double scattering technique, and is statistically powerful since all Z^0 decay samples are available in analysis.

A_{LR} is sensitive to the electroweak mixing angle, namely $\delta A_{LR} = 7.84\delta\sin^2\theta_W$, and is insensitive to the possible systematics of experiment, i.e. detector inefficiencies and cuts applied in data analysis. To obtain an equal statistical precision with A_{LR}, numbers of Z^0 samples required in the forward-backward asymmetries are 250 and 100 times larger for leptons (A^l_{FB}) and for b-quarks (A^b_{FB}), respectively, and 320 times for τ-lepton polarization (P_τ).



Since Z^0 production amplitude have contributions from the fermion loops of t-quark and/or new particles in the propagator, A_{LR} measurement is the most sensitive *Electroweak* test.

Beside the polarization, SLD has a unique vertex determination capability with the advantages of stable IP point and a small beam cross section ($\sigma_x \times \sigma_y \approx 2.5 \times 0.6\ \mu m$ with a flat beam configuration) and the 3 layers of CCD vertex detectors surrounding

Work supported by the Department of Energy contract DE-AC03-76SF00515.
Stanford Linear Accelerator Center, Stanford University, Stanford, CA 94309
Presented at the 2nd Rencontres du Vietnam (Consisting of 2 parallel conferences):
Astrophysics Meeting: From the Sun and Beyond and Particle Physics Meeting:
Physics at the Frontiers of the Standard Model, 10/21/1995 - 10/28/1995, Ho Chi Minh City, Vietnam

a beam pipe of small radius (30 mm) at the Interaction Point (IP).

SLC luminosity was remarkably improved since the first experiment in 1991, and the peak of Z^0 production rate per week were recorded as 1,200, 4,500 and 7,000 in 1992, 1993 and 1994-95, respectively.

In 1994-95 experiment, SLD accumulated ~100,000 Z^0 samples at the energy of 91.270(20) GeV, slightly off Z^0 pole, with an average electron polarization of ~80%. In combining samples obtained in 1992 and 1993 with beam polarization of 22% and 63%, respectively, 170,000 Z^0 samples are available for analysis.

2. Polarized Electron Beam

The SLC used the Polarized Electron Source (PES) with a strained GaAs cathode irradiated by a circular polarized laser light of wave length 765-850 nm. Parameters of the strained GaAs cathode are: phosphorus fraction x in $GaAs_{1-x}P_x$ (E_g=1.75 eV) with $0.24 \leq x \leq 0.3$ (a larger x gives a larger strain), GaAs (E_g=1.50 eV) active layer thickness t with $0.1 \leq t \leq 0.5$ μm.

The electron helicity was randomized throughout the data acquisition runs to minimize systematics in the experiment.

Polarization orientations in the overall SLC layout is shown in Fig. 1. The electron polarization in the North Dumping Ring is set vertical to avoid depolarization, and the two solenoids installed in the transportation line from NDR to the main linac can control direction of polarization arbitrarily.

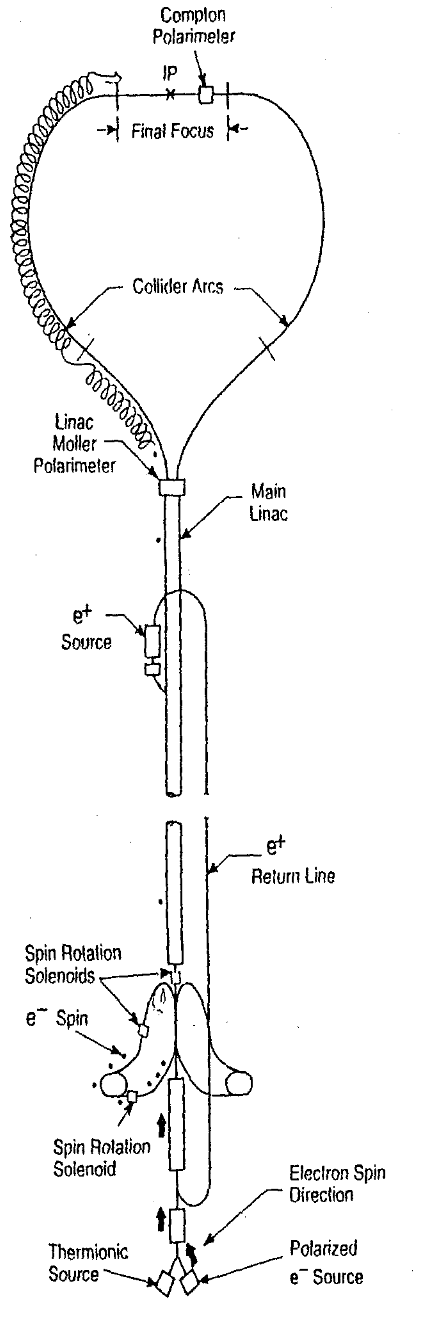


Fig. 1 Polarzation in the Overall SLC Layout

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The spin precession in the Collider Arc is nearly resonant with the vertical betatron oscillation, i.e. betatron phase advance of 1080° and spin procession of 1085°. By making use of this feature, SLC installed two orthogonal beam bumps in the North Arc for arbitrary control of spin direction at IP. By injecting electrons with spin oriented vertical into the North Arc, these beam bumps were tuned to minimize total precession in the arc and thus reducing the polarization dependence on energy.

A Møller polarimeter at the entrance of North Arc provides polarization measurement at linac, and a Compton polarimeter installed at the downstream of SLD measures the polarization at IP.

In 1994-95 runs, precise polarization data was made available in every 10 minutes. Three major improvements were applied for the Compton polarimeter error analysis; (1) the phase shift induced in laser transport line was continuously monitored, (2) a frequent Compton edge scans were made in the detector for back scattered electrons (3 times per week), and drifts were monitored by the channel asymmetry ratio, (3) photo-tube voltages of Cerenkov counters were scanned frequently.

Table 1. Corrections and uncertainties to polarization measurement

Item	Correction (%)	Uncertainty ($\delta P/P$ in %)
Laser polarization	+0.38	0.2
Detector / Spectrometer		
laser pickup	-0.19	0.1
cross talk		0.2
linearity		0.5
Analyzing-power calibration	0.71	0.29
Internal consistency		0.40
Beam divergence and chromatic correction	0.1	0.2
Total		0.80

With SLC flat beam configuration, chromatic aberrations at IP could correlate the energy and luminosity. Since the Compton polarimeter $<P_c>$ measures the average electron polarization across the entire beam profile, the net beam polarization relevant for Z^0 production is the luminosity weighted polarization $<P_e>$. To calibrate this chromatic effect, frequent wire scans were made for beam profile n(E), and infrequent energy scans for polarization P(E), and 120 Hz operation data on

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ıminosity spectrum L(E). The final beam focus system causes a small spin precession ıd is corrected for the typical beam divergence $\theta_x \times \theta_y$=300 × 200 mrad. The other eam related effects are negligibly small. Corrections and uncertainties in the olarization measurement are summarized in the Table 1.

The preliminary result of polarization in 1994-95 run was:

$$\langle P_e \rangle = 77.34 \pm 0.61 \text{ (systematic)}\%.$$

Comparing to the 1993 data, $\langle P_e \rangle = 63.0 \pm 1.1$ (systematic)%, improvements in olarization and uncertainty are remarkable. Since the precise polarization is a key of xperiment, a further improvement (~0.3 %) is expected in the next experiment.

. Event selection

'ollowing selection criteria were applied for events having significant visible nergies in the Liquid Argon Calorimeter (LAC) ,

$E_{observed}$ > 22 GeV

$E_{inbalance}$ < 0.6 $E_{observed}$

$N_{cluster}$ > 9 (12 if $|\cos\theta_{thrust}| > 0.8$)

Vith these selection criteria, e^+e^- pairs were excluded, and the hadron detection :fficiency was estimated to be 93%, τ-pairs about 30%, μ-pairs negligibly small and ıon-Z^0 background events was 0.23 ± 0.10%.

I. Corrections to A_{LR} and Results

Measured asymmetry A_{meas} was corrected for various sources of asymmetry by lefining the correction term δ as,

$$A_{LR} = \frac{1}{\langle P_e \rangle} (1 + \delta)\, A_{meas}.$$

Corrections and uncertainties for each items are summarized as follows:

(1) Background asymmetry: (+ 0.23 ± 0.08)%

- Bhabha events have t-channel interference effect
- Beam related backgrounds have no asymmetry

(2) Luminosity asymmetry: (+ 0.087 ± 0.043)%

- Measured with beam current monitors and luminosity monitors.

(3) Polarization asymmetry: (+ 0.011 ± 0.024)%

- Directly measured with Compton polarimeter

(4) Energy asymmetry: (− 0.0010 ± 0.0004)%

- Well measured with energy spectrometer

(5) Efficiency asymmetry: 0

- No dead time or overflow inefficiencies in detectors.

(6) Positron polarization: < 0.01% (estimated)

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- Damping ring storage time 16.6 ms is much smaller than 960 s, buildup time of possible polarization due to Sokolov-Ternov effect

Total correction to A_{meas} is estimated to be (+ 0.327 ± 0.094)%.

5. New Results from 1994-95 Experiment

In 1994-95 experiment, SLD collected Z^0 boson samples:

$$N_L = 51{,}446, \quad N_R = 40{,}815.$$

The average beam polarization is:

$$\langle P_e \rangle = 77.34 \pm 0.62 \text{ (systematic)\%} \quad \text{(preliminary)},$$
$$\delta A_{LR} = 0.327 \pm 0.094 \text{ (systematic)\%}.$$

Using these data, A_{LR} is:

$$A_{LR} = 0.1495 \pm 0.0042 \pm 0.0012 \text{ (measured at 91.270(20) GeV)}.$$

Correcting to the "pole" value:

$$A^0_{LR} = 0.1524 \pm 0.0042 \pm 0.0012 \text{ (SLD 95, preliminary)}.$$

The weak mixing angle is determined as:

$$\sin^2\theta^{eff}_W = 0.23084 \pm 0.00054 \pm 0.00015 \text{ (SLD 95, preliminary)}.$$

Combining all 1992-1995 SLD samples:

$$A^0_{LR} = 0.1551 \pm 0.0040 \quad \text{(SLD 1992-95, preliminary)},$$
$$\sin^2\theta^{eff}_W = 0.23049 \pm 0.00050 \text{ (SLD 1992-95, preliminary)}.$$

The LEP average presented at Moriond 1995 is:

$$\sin^2\theta^{eff}_W = 0.2318 \pm 0.0004 \text{ (LEP 1995)}.$$

New SLD weak mixing angle is plotted in Fig. 2 with results form each LEP experiments. Fig. shows SLD gives the most precise measurement of $\sin^2\theta_W$.

SLD-LEP Weak Mixing Angle Results

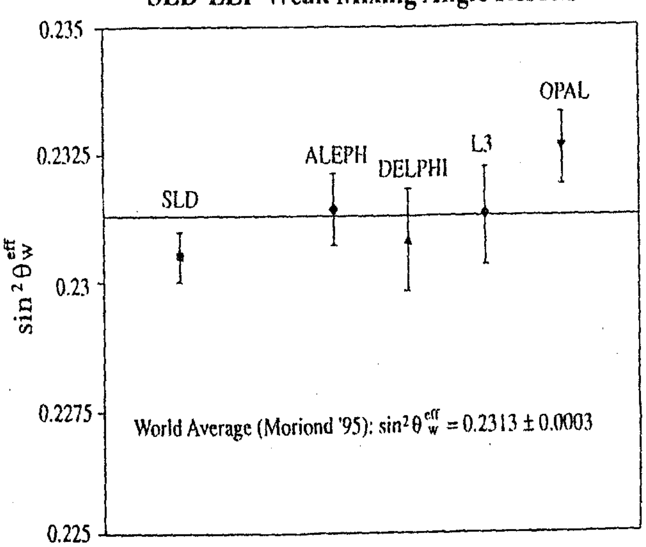

Fig2. New SLD weak mixing angle and LEP data.

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A Higgs mass fit based on the minimal standard model was made by M. Swartz (SLAC) with inputs from SLD and LEP data (Fig. 3).

Results of fit are: $M_{HIGGS} = 91^{+179}_{-63}$ GeV, $\alpha_S = 0.122 \pm 0.004$, $M_{top} = 169^{+12}_{-10}$ GeV, $\alpha^{-1}(M_Z^2) = 128.96 \pm 0.06$, and $M_Z = 91.189 \pm 0.002$ GeV.

In Fig. 4, a S–T plot after Peskin-Takeuchi (Phys.Rev.D 46,381,1992) is shown for a comprehensive comparison between experiments and the MSM. SLD and LEP agree to the range of standard model prediction ($167 < m_t < 192$ GeV, $60 < m_H < 1000$ GeV) within their errors.

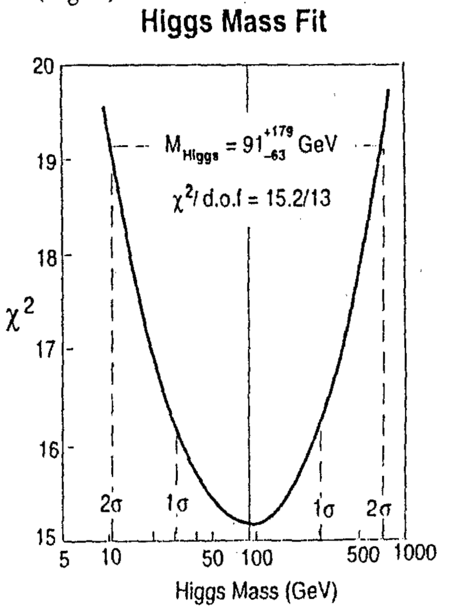

Fig.3. Higgs mass fit with new SLD and LEP data.

6. Conclusion

SLD has made the most precise determination of Weak Mixing Angle by the left-right asymmetry measurements. The combined 1992–1995 result is:

$$\sin^2\theta_W^{eff} = 0.23049 \pm 0.00050 \text{ (SLD 1992-95, preliminary)},$$

where error is dominated by statistics.

The precise test of *Electroweak* shows no significant disagreement with the *Minimal Standard Model*. There are 2σ difference between SLD and the LEP average, however, we can not find any particular meaning from this disagreement considering their systematic errors at this moment. It is interesting to look for the new physics from the independent precision experiments, typically the SLD and the LEP, with different observables and/or systematics.

With a half Million Z^0 samples and $\delta P/P < 0.3\%$ accuracy in polarization measurement, SLD can determine $\sin^2\theta_W^{eff}$ with an errors of ± 0.0003 which could distinguish additional contributions from non-standard objects to Z^0 amplitude. A rapid increase of Z^0 samples in SLD experiment is expected.

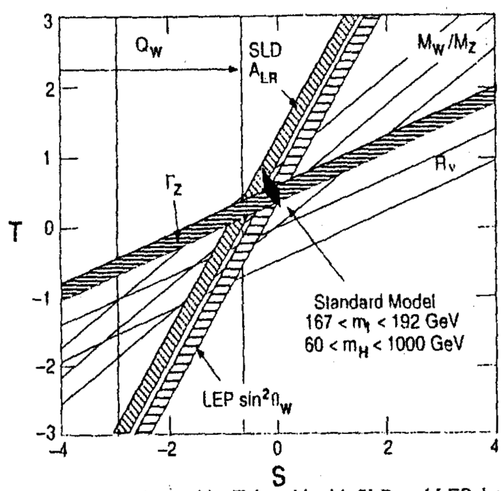

Fig. 4. S–T plot by Peskin–Takeuchi with SLD and LEP data.

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