SLAC–PUB–7878
ICHEP–PA01 #362
July 1998

An Improved Direct Measurement of Leptonic Coupling Asymmetries with Polarized Z^0's *

The SLD Collaboration**

Abstract

The SLD experiment at the Stanford Linear Collider reports new measurements of leptonic asymmetry parameters with polarized Z^0's. We study the reaction $e^-_{L,R} + e^+ \to Z^0 \to e^+e^-, \mu^-\mu^+$ and $\tau^-\tau^+$, where L and R denote left- and right-handed polarized electron beams. The 1996, 1997 and winter 1998 SLD runs are included in this analysis and combined with published data from the 1993-95 runs. Preliminary results are as follows: $A_e = 0.1504 \pm 0.0072$, $A_\mu = 0.120 \pm 0.019$ and $A_\tau = 0.142 \pm 0.019$. If lepton universality is assumed, a combined asymmetry parameter $A_{e\mu\tau} = 0.1459 \pm 0.0063$ results. This translates into an effective value of the weak mixing angle $\sin^2\theta_W^{eff} = 0.2317 \pm 0.0008$ at the Z^0 pole.

Paper Contributed to the XXIXth International Conference on High Energy Physics, July 23-29, 1998, Vancouver, Canada.

*Work supported in part by the Department of Energy contract DE–AC03–76SF00515.

INTRODUCTION

We report new results on polarization-dependent asymmetries at the Z^0 pole with data collected by the SLD experiment at the SLAC Linear Collider (SLC). The data taken during SLD's 1996-98 runs with the upgraded vertex detector (VXD3) are combined earlier published results [1]. This study is based on the leptonic Z^0 decays in the reactions $e^-_{L,R} + e^+ \rightarrow Z^0 \rightarrow e^+e^-, \mu^+\mu^-$ and $\tau^+\tau^-$, where L (R) refers to the left (right)-handed electron beam polarization.

Polarized Z^0 boson production and decay exhibits parity violation through asymmetrical polarization-dependent cross sections and final state angular distributions. The magnitudes of the asymmetries are characterized by the asymmetry parameters; A_e, A_μ and A_τ. Each parameter is a simple function of the leptonic neutral current vector- and axial-vector couplings for that lepton's species. Alternately, for some applications, right- and left-handed couplings may be used instead. The standard model assumes lepton universality, so that all three species of leptonic asymmetry parameters are expected to be identical and directly related to a single value of the effective weak mixing angle, $\sin^2\theta_W^{eff}$, at the Z^0 pole. Moreover, the leptonic asymmetry parameters sensitively measure the weak mixing angle, i.e., the errors are related by $\delta\sin^2\theta_W^{eff} \sim \delta A_e/8$.

There are two principle goals of this study. One is to test lepton universality by comparing the magnitudes of the three asymmetry parameters. The other purpose is to add additional precision to SLD's determination of $\sin^2\theta_W^{eff}$ which is based mostly on the left-right cross section asymmetry of the hadronic event sample.

We conclude this report with a summary of our latest leptonic asymmetry results and compare these data with the SLD hadronic asymmetry (A_{LR}) and the LEP I electroweak measurements.

THE SLC AND THE SLD

Details about the SLC, the polarized electron source, and the measurements of the electron-beam polarization with the Compton polarimeter, can be found in SLD Polarization Group reports and web pages [2]. Relevant details about the SLD detector are described in recent SLD publications [3]. This analysis relies on tracking by the central drift chamber and by the Liquid Argon Calorimeter (LAC). High energy muons are cleanly separated from high energy electrons by noting the strong showering of electrons contrasted with the nearly undeflected passage of muons. Tau pairs selected for this study rely on tracking provided by the central drift chamber and on energy measurements with the LAC.

THEORY

A_{LR} and $\widetilde{A}^l_{FB}$

Polarization-dependent asymmetries are easily computed from the tree-level differential cross section for the dominant process $e^-_{L,R} + e^+ \rightarrow Z^0 \rightarrow l^- + l^+$, where l represents either a μ-

or a τ-lepton.

$$\frac{d\sigma}{d(\cos\theta)} \propto (1 - PA_e\delta_{LR}) \left(1 + \cos^2\theta\right) + 2\,(A_e - P\delta_{LR})\,A_l \cos\theta. \tag{1}$$

The direction between the electron beam and the outgoing lepton is given by $\cos\theta$. The leptonic asymmetry parameter which refers to the final state lepton appears in this expression as A_l. Note that the first term, symmetric in $\cos\theta$, exhibits initial state coupling to the electron by its dependence on A_e. The second term, asymmetric in $\cos\theta$, is mostly influenced by A_l. P is the magnitude of the effective longitudinal polarization of the electron beam and δ_{LR} is -1 for a left-handed and +1 for right-handed electron beams.

The relationships between the asymmetry parameters and between vector- and axial-vector, or left-right couplings, is given as follows: $g^l_L = g^l_A + g^l_V$ and $g^l_R = g^l_A - g^l_V$.

$$A_l = \frac{2g^l_V g^l_A}{{g^l_V}^2 + {g^l_A}^2} = \frac{{g^l_L}^2 - {g^l_R}^2}{{g^l_L}^2 + {g^l_R}^2}. \tag{2}$$

The Standard Model relates the Weak Mixing angle to the couplings by the expressions $g^l_A = -\frac{1}{2}$ and $g^l_V = -\frac{1}{2} + 2\sin^2\theta^{eff}_W$.

The left- and right-handed cross sections are obtained by integrating equation 1 over all $\cos\theta$ giving σ^l_L or σ^l_R for left- and right-handed beams, respectively. (For convenience, we drop the superscript in the following discussions since the meaning of the expressions will be clear enough in context.) Parity violation causes σ_L and σ_R to be different. Hence, we define the left-right cross section asymmetry, A_{LR}.

$$A_{LR} = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R}. \tag{3}$$

Four cross sections are obtained by integrating forward (F) and backward (B) hemispheres separately, along with left- and right-handed polarization. Based on these four possibilities, we define the polarized forward backward asymmetry, $\tilde{A}^l_{FB}$.

$$\tilde{A}^l_{FB} = \frac{(\sigma_{LF} - \sigma_{LB}) - (\sigma_{RF} - \sigma_{RB})}{(\sigma_{LF} + \sigma_{LB}) + (\sigma_{RF} + \sigma_{RB})} \tag{4}$$

Leptonic Asymmetry Parameters: A_e, A_μ and A_τ

With equal luminosities for left- and right-handed electron beams, the cross sections (σ) in equation 3 may be replaced with the numbers of events: N_L and N_R. After integrating equation 1 over all angles to get expressions for N_L and N_R in terms of P, δ_{LR}, A_e and A_l, and after substituting in equation 3 for both signs of polarization (δ_{LR}), what remains is given by

$$A_e = A_{LR}/P. \tag{5}$$

In a similar fashion, integrating over foward or backward hemispheres, and substituting both signs of polarization in equation 4, gives the expression

$$A_l = (\widetilde{A}^l_{FB}/P)(1 + \frac{x^2_{max}}{3})/x_{max}, \tag{6}$$

where $x_{max} = \cos\theta_{max}$ is the maximum value of the magnitude of the polar angle accepted by the lepton event trigger.

γ-exchange and $Z\gamma$-interference:

The expressions giving A_e and A_l, equations 5 and 6, are based on the tree level formula, equation 1, where only Z^0 exchange in the direct channel is considered. This is the major contribution, but non-negligible contributions from direct channel γ-exchange, as well as from $Z^0\gamma$ interference, must be considered too. Matters are further complicated by the fact that the three terms have different energy dependences. While the Z^0- and γ-exchange terms change slowly with energy, the interference term has a strong energy dependence away from the Z^0 pole. The energy-dependence must be considered because initial state photon emission smears the center-of-mass (cm) energy. While most events occur with a cm energy near twice the beam energies, initial state radiation creates a long low energy tail in the energy distribution. To correct for γ-exchange, A_e obtained via A_{LR} and A_l from $\widetilde{A}^l_{FB}$ must each be increased by about 0.001. The correction for the $Z^0\gamma$ interference term is approximately 0.003. The net effect is that the values obtained from equations (5) and (6) must be increased by 0.004 to account for γ-exchange and $Z\gamma$-interference.

The effect of t-channel exchange for $e^+e^- \rightarrow e^+e^-$:

Including both s-channel and t-channel Z^0 and photon exchange, as required for the e^+e^- final state, gives four amplitudes and ten cross section terms. All ten terms are energy-dependent, but some terms vary much more rapidly with energy than do others.

The Maximum Likelihood Method

To incorporate the contributions of all the terms in the cross section and to include the effect of initial state radiation, a Maximum Likelihood Method (MLM) is used to estimate the asymmetry parameters. The probability density function used in the MLM is formed by convoluting the energy dependence in the cross section with the effective cm energy distribution that results from initial state radiation and the spread in the beam energies. By incorporating this information into the procedure of estimating parameters, no further correction of the parameters for the effective cm energy smearing is required. The details of this procedure are discussed elsewhere [1].

Advantages of Highly Polarized Z^0's

SLD's measurement of the asymmetry parameter A_e is proportional to the measured left-right cross section asymmetry, A_{LR}, as given by 5. This measurement is possible only with polarized Z^0's. A_{LR} is an inclusive measurment that depends solely on the initial state electron couplings and the magnitude of the beam polarization. Because essentially all of the data may be used, a high precision determination of A_e results. SLD's A_μ and A_τ, are proportional to the polarized, or left-right, forward-backward asymmetry, $\widetilde{A}^l_{FB}$. The accuracy of A_μ and A_τ is limited by the number of final state lepton pairs. The forward-backward component of the e^+e^- final state also makes a small contribution to A_e. With SLD's beam polarization, A_μ and A_τ are determined with the same precision from $\widetilde{A}^{\mu,\tau}_{FB}$ as is obtained with $(P/A_e)^2$ times as many events (about a factor of 25) with no beam polarization and the simple forward-backward asymmetry, $A^{\mu,\tau}_{FB}$. However, the LEP I determination of A_τ takes advantage of the final state tau polarization and with their large data sample are able to achieve a high precision A_τ measurement.

Hence, the SLD experiment determines A_e best of all via A_{LR}. SLD's A_μ is also a world's-best measurement. A_τ is determined most accurately at LEP I by combining information from the final states of all four experiments. SLD's A_τ is determined with a statistical accuracy of one LEP I experiment. The LEP I measurements of forward-backward asymmetries are proportional to the product $A_l A_e$ while SLD's asymmetries directly measure the parameters. There is no direct comparison to be made with SLD's unique A_{LR} except to note that the error on A_e is approximately given by $\frac{1}{P\sqrt{N}}$, and N is essentially the total number of Z^0's irrespective of the final state.

ANALYSIS

Data Sample

This study includes the data obtained during the 1996 and 1997-98 SLD runs. Results are combined with published analyses from data taken during the 1993 SLD run and the 1994-95 run. The 1993 data sample consists of approximately 50,000 Z^0's with an electron beam polarization of 63% while the 1994-95 data set consists of about 100,000 Z^0 events with the beam polarization increased to 77%. The 1996 data set consisted of about 50,000 Z^0's with about 77% polarization. The 1997 data sample contains about 110,000 Z^0's and the winter 1998 sample, an additional 90,000 Z^0's. The beam polarization for the 1997-98 runs averaged about 73%. The data were recorded at a mean center-of-mass energy of 91.28 ± 0.02 GeV. The analysis of the leptonic decays from about 140,000 Z^0's gathered during spring of 1998 is not yet ready for this study. The branching ratio $Z^0 \to l^+l^- = 3.4\%$ so that the total branching ratio into all three lepton species combined is about 10%.

Event Selection

Leptonic Z^0 decays are characterized by their low multiplicity and high momentum charged tracks. Muons and electrons are particularly distinctive as they emerge back-to-back with little curvature from the primary interaction vertex, and tau pairs form two tightly collimated cones directed in well-defined opposite hemispheres. Lepton pair candidates are chosen on the basis of the momentum of the charged tracks as well as from energy deposited in the calorimeter. The criteria used for the event selection give a high efficiency for finding the signal events while the backgrounds remain sufficiently low as to be almost entirely negligible.

Lepton-pair candidates are initially selected by restricting the charged multiplicity to lie between two and eight charged tracks to reduce background from hadronic Z^0 decays. The product of the sums of the charges of the tracks in each hemisphere must be -1. This insures a correct determination of the sign of the scattering angle. Requiring that at least one track have at least 1 GeV momentum reduces two-photon background while capturing candidate events with a high efficiency.

After the preselection, additional conditions are applied. The lepton's angle is computed from the the momentum sums of the tracks in the two hemispheres with respect to the beamline; it is equivalent to the thrust axis.

A single cut effectively selects e^+e^- final states: the sum of the energies associated with the two highest momentum tracks in the event must be greater than 45 GeV as measured in the electromagnetic calorimeter.

Muon final state selection starts by demanding that the invariant mass of the event, based on charged tracks, be greater than 70 GeV. Tau final states usually fail this selection. Since muons deposit little energy as they traverse the calorimeters, we require also that the largest energy recorded in the calorimeter by a charged track in each hemisphere be greater than zero and less than 10 GeV. Electron pairs are removed by this requirement.

Tau selection requires that the largest calorimeter energy associated with a charged track in each hemisphere is less than 27.5 GeV and 20.0 GeV for the magnitude of $\cos\theta$ less than or greater than 0.7, respectively, to distinguish them from e^+e^- pairs. We take the compliment of the muon event mass cut and require the event mass to be less than 70 GeV. At least one track must have momentum above 3 GeV to reduce backgrounds from two-photon events. We define the event acollinearity from the vector sums of the momenta of the tracks in the seperate hemispheres and angle between the resultant momentum vectors must be greater than 160 degrees; this also removes two-photon events. Finally, the invariant mass of charged tracks in each hemisphere is restricted to less than 1.8 GeV to further restrict hadronic backgrounds.

The results from the event selections are summarized in Table 1. The events in the 1996-98 data set are restricted to the polar angle range $|\cos\theta| < 0.8$. Our published results based on the 1993-95 data used the more restricted range, $|\cos\theta| < 0.7$ [1].

Table 1: Backgrounds and Efficiencies (1996-98 data).

Sample	% Background	Efficiency for $\lvert\cos\theta\rvert < 0.8$	# Evemts
Electrons	1.2% $\tau^+\tau^-$	87.3%	9419
Muons	0.2% $\tau^+\tau^-$	85.5%	7564
Taus	0.7% e^+e^- 2% $\mu^+\mu^-$ 1.7% 2γ 0.8% hadrons	78.1%	7088

Backgrounds

Muon-pair samples are relatively background-free but tau-pair candidates are contaminated by electron-pairs, or from two-photon and hadronic events. A small percentage of tau-pairs are identified as electron-pairs. Beam-gas and cosmic ray backgrounds have been estimated and found negligible. Estimates of backgrounds are given in Table 1. These estimates have been derived from detailed Monte Carlo simulations as well as from studying the effect of cuts in background-rich samples of real data. Tau pairs are the only non-negligible backgrounds in the electron and muon pair samples. However, unless lepton universality is badly violated, no noticable change in the parameter estimates for these final states will occur because of tau pair backgrounds. The t-channel electron pair background, the two photon background, and the hadronic background, cause significant corrections that must be applied to A_τ. The next section deals with the technique that is applied for correcting the asymmetry parameters for background contributions.

Corrections to Asymmetry Parameters

The maximum likelihood procedure gives an excellent first estimate of the asymmetry parameters and the statistical error on each parameter. However, the central value of each parameter must be corrected for backgrounds and biases. Finally, we must estimate the systematic errors on these corrections. We discuss these corrections in this section and summarize the numerical values in Table 2 and Table 3.

Table 2: Corrections to Estimated Values of A_e and A_τ.

Final State	Background	δA_e ($\times 10^{-4}$)	δA_τ ($\times 10^{-4}$)
e^+e^-	$\tau^+\tau^-$	4 ± 4	–
$\tau^+\tau^-$	e^+e^-	–	-2 ± 2
	two photon	25 ± 25	18 ± 18
	hadron	–	13 ± 13
	V-A	–	-130 ± 29
$\tau^+\tau^-$ Totals		25 ± 25	-101 ± 37

Effect of Backgrounds:

We estimate how the backgrounds discussed above affect each asymmetry parameter by creating an ensemble of "toy Monte Carlo experiments." Each individual "experiment" consists of the number of events in a typical data set of real events, with each event consisting of a $\cos\theta$ value for either a left- or a right-handed beam polarization. The distribution is generated from the same formula for the cross-section used to fit the real data. Trial backgrounds are then superimposed on each toy data set, where the shape of the background has been obtained from the shape of the data that forms the particular background. Each background is normalized relative to the signal according to detailed Monte Carlo estimates.

The effect of each background on each asymmetry parameter is determined from the differences between the averages of the fitted parameter values before and after inclusion of the backgrounds in the set of toy experiments. The net corrections that must be made due to backgrounds is given in Table 2.

V-A structure in tau decays:

The largest systematic effect for the tau analysis, indicated in Table 2, comes about because we measure not the taus themselves, but their decay products. Some explanation of this effect is warranted.

The longitudinal spin projections of the two taus from Z^0 decay are 100% anti-correlated: one will be left-handed and the other right-handed. So, given the V-A structure of tau decay, the decay products from the τ^+ and the τ^- from a particular Z^0 decay will take their energies from the same set of spectra. For example, if both taus decay to $\pi\nu$, then both pions will generally be low in energy (in the case of a left handed τ^- and right handed τ^+) or both will be generally higher in energy. The effect is strong at SLD because the high beam polarization induces very high tau polarization as a function of polar production angle. And, most importantly, the sign of the polarization is basically opposite for left and right beam events. So a cut on event mass, say, may cause polar angle dependence in selection efficiency for taus which has the opposite effect for taus from events produced with the left and right polarized electron beam. Taking all tau decay modes into account, using Monte Carlo simulation, we find an overall shift of $+0.0130 \pm 0.0029$ on A_τ, (the value extracted from the fit must be reduced by this amount). A_e is not affected since the overall relative efficiencies for left-beam and right-beam events are not changed much (only the polar angle dependence of the efficiencies are changed).

Other Corrections

The above-mentioned corrections are non-negligible, although small compared with current statistical errors. Other potential corrections are discussed below. Their effect on the asymmetry parameters is deemed negligible for the current measurements.

Effect of polarization asymmetries:

SLD's asymmetry measurements rely critically on the time-dependent polarization values and the polarization is measured during the run at least once an hour. Details on the polarization measurements are discussed in connection with SLD's latest report on A_{LR} that includes the 1994-95 data [3]. The current estimate of the error on the polarization is given by $\delta P/P = 0.67\%$. The preliminary estimate of $\delta P/P = 0.67\%$ for the 1997-98 data is 1.08%.

Effect of detector asymmetries:

Electron and muon pairs are characterized by two back-to-back tracks with little curvature in the drift chamber. Since there will generally be no bias in the fit as long the the efficiency is symmetric in $\cos\theta$, there will be a problem only if the efficiency for detecting positive tracks is different from that of negative tracks. Tau pairs are mostly one-pronged, and similar to electrons and muons in this respect. Those tau decays which result in three or more prongs can be more complex, but unless there is an inherent bias that favors one sign of charge over the other, the symmetry in $\cos\theta$ will be preserved. We estimate this effect by examining the relative numbers of opposite sign back-to-back tracks with positive-positive and negative negative pairs. The latter will occur whenever one of the two back-to-back tracks in a two-pronged event has a wrong sign of measured charge. Double charge mismeasurement is less likely. The correction for biases due to charge mismeasurement is found to be negligible.

Final state thrust angle resolution:

We have studied the effect of imprecise measurements of the thrust axis by smearing the directions of outgoing tracks. The results depend on the final state with muons measured best of all and taus least well measured. Final state QED radiation can affect the determination of the track angle particularly for electrons, although we find the angle to be well-determined in that case as well. The result depends somewhat on how final pairs are selected but this source of correction is also deemed negligible from our studies.

Table 3: Systematic Errors ($\times 10^{-4}$).

Source	A_e^e	A_e^μ	A_e^τ	A_μ^μ	A_τ^τ
Polarization	16	16	16	16	16
Backgrounds	4	–	25	–	22
Rad. Corr.	30	3	3	4	3
V-A	–	–	–	–	29
Totals	34	16	30	16	40

Systematic errors:

Table 3 summarizes the systematic errors on the asymmetry parameters due to the contributing factors discussed above. The superscript on each parameter indicates the lepton species from which that particular parameter was determined. For example, A_e^μ refers to the estimate of A_e obtained through the dependence expressed in equation 1 by analyzing the muon pairs.

RESULTS

Results from fits to the 1996-98 data are summarized in Table 4 with statistical and systematic errors combined. The numbers in this table have been corrected for the effect of backgrounds and the "V-A effect" for taus. The estimates for A_e, A_μ and A_τ were obtained by fitting each lepton sample separately, for both signs of polarization, by the maximum likelihood procedure. A comprehensive value of A_e is obtained from all lepton species combined.

Adding our published results from the 1993-95 data give our current best estimates for SLD's leptonic asymmetry parameter in Table 5. The most precise value of A_e from

Table 4: Summary of A_e, A_μ and A_τ with 1996 to winter 1998 data.

Final States	Asymmetry Parameter
$\mu^+\mu^-$	$A_\mu = 0.128 \pm 0.022$
$\tau^+\tau^-$	$A_\tau = 0.117 \pm 0.023$
e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$	$A_e = 0.1497 \pm 0.0088$

Table 5: Summary of A_e, A_μ, A_τ and $\sin^2\theta_W^{eff}$ with all data (1993 to winter 1998).

Final States	Asymmetry Parameter	$\sin^2\theta_W^{eff}$
$\mu^+\mu^-$	$A_\mu = 0.120 \pm 0.019$	
$\tau^+\tau^-$	$A_\tau = 0.142 \pm 0.019$	
e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$	$A_e = 0.1504 \pm 0.0072$	
	$A_{e\mu\tau} = 0.1459 \pm 0.0063$	0.2317 ± 0.0008

these data is obtained by assuming lepton universality. This global asymmetry parameter is referred to as $A_{e\mu\tau}$. The value of the weak mixing angle, $\sin^2\theta_W^{eff}$, which corresponds to $A_{e\mu\tau}$ is also given in Table 5.

Binned angular distributions for electron-, muon- and tau-pair final states from the 1996 through winter 1998 data sets are shown in Figures 1. The left-right cross section asymmetries and forward-backward angular distribution asymmetries are clearly seen. The acceptance in $\cos\theta$ out to ± 0.7 is uniform, but falls off at larger $\cos\theta$. Since the data are plotted out to values of $\cos\theta$ ± 0.8, it was necessary to correct the data for the acceptance efficiency in order that the fitted curve could be compared with the data. Similar fits were done for the 1993 and 1994-95 data sets. In all cases the curves fit the data well.

SUMMARY AND CONCLUSIONS

We report measurements of the leptonic asymmetry parameters, A_e, A_μ and A_τ from SLD data collected from 1993 through winter of 1998. The spring 1998 data with about 140,000 more Z^0's is still being processed.

Maximum likelihood fits to the reactions $e^-_{L,R} + e^+ \rightarrow Z^0 \rightarrow e^+e^-, \mu^+\mu^-$ and $\tau^+\tau^-$ were used to estimate the parameters. The probability density function used in the fit incorporates all three s-channel terms required from the tree-level calculations for the muon- and tau-pair final states. The electron-pair final states are described by both s- and t-channel Z^0 and photon exchange requiring ten cross section terms, all of which are included in the probability density function. Whether three or ten terms, the probability density function used in the fit results from convoluting the energy-dependent cross section formulas with a spectral function that incorporates initial state QED radiation, the intrinsic beam energy spread, and the effect of energy-dependent selection criteria. The parameters estimated from these fits require no further corrections for these effects. However, A_τ is corrected for a bias that results from the V-A structure of tau decays and both tau and electron pair events require additional small corrections due to backgrounds. Results are summarized in Table 4 and Table 5.

Comparing the values of A_e, A_μ and A_τ to test lepton universality reveals that A_μ is barely one standard deviation below A_e while A_τ closely agrees with A_e. Hence no statistically signicant differences are seen in these data.

Assuming lepton universality, the value of the weak mixing angle from leptonic Z^0 decays gives

$$\sin^2\theta_W^{eff} = 0.2317 \pm 0.0008. \tag{7}$$

SLD's estimate for the weak mixing angle from A_{LR} using hadrons gives

$$\sin^2\theta_W^{eff} = 0.23101 \pm 0.00031 \tag{8}$$

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The combined **preliminary** value of the weak mixing angle with leptonic and hadronic events combined gives

$$\sin^2\theta_W^{eff} = 0.23110 \pm 0.00029. \tag{9}$$

SLD's value of the weak mixing angle is now about 2.1σ lower than that of the most recent combined LEP I value [4]. The Minimum Standard Model (MSM) predictions for $\sin^2\theta_W^{eff} \pm 0.00025$ are 0.2310, 0.2312 and 0.2318 for input Higgs boson masses of 65, 100 and 300 GeV, respectively [5]. SLD's data favors a light MSM Higgs.

The errors should decrease by about 10% after a better understanding of the systematic errors on the latest data, and after the spring 98 data sample is included in the leptonic analysis.

References

[1] K. Abe et al, *Direct Measurement of Leptonic Coupling Asymmetries with Polarized Z's,* Phys.Rev.Lett.79:804-808,1997; see also Michael B. Smy, *Measurement of Z^0 Lepton Coupling Asymmetries*, SLAC Report-R-515, PhD Thesis, Colorado State University, July 1997.

[2] See, for example, M. Woods, *The Polarized Electron Beam for the SLAC Linear Collider*, SLAC-PUB-7320 (1996); see 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] K. Abe et al, *An Improved Measurement of the Left-Right Z^0 Cross Section Asymmetry,* Phys. Rev. Lett.78:2075-2079, 1997.

[4] For recent electroweak results from LEP I, see D. Abbaneo (CERN), A^b_{FB} *measurements at LEP*, XXXIIIrd Recontre Di Moriond, March 1998 and LEP Electroweak Working Group, *A Combination of Preliminary Electroweak Measurements and Constraints on the Standard Model,* CERN-PPE/97-154, 2 Dec. 1997.

[5] Theoretical estimates from lecture by W. Marciano, *Electroweak Physics (In Search of Hidden Symmetries),* Proceedings of Frontiers in Contemporary Physics – Fundamental Particles and Interactions, Eds. R.S. Panvini and T.J. Weiler, Nashville, TN, May 11-16, 1997, AIP Conference Proceedings 423, pp. 176-185 (1998).

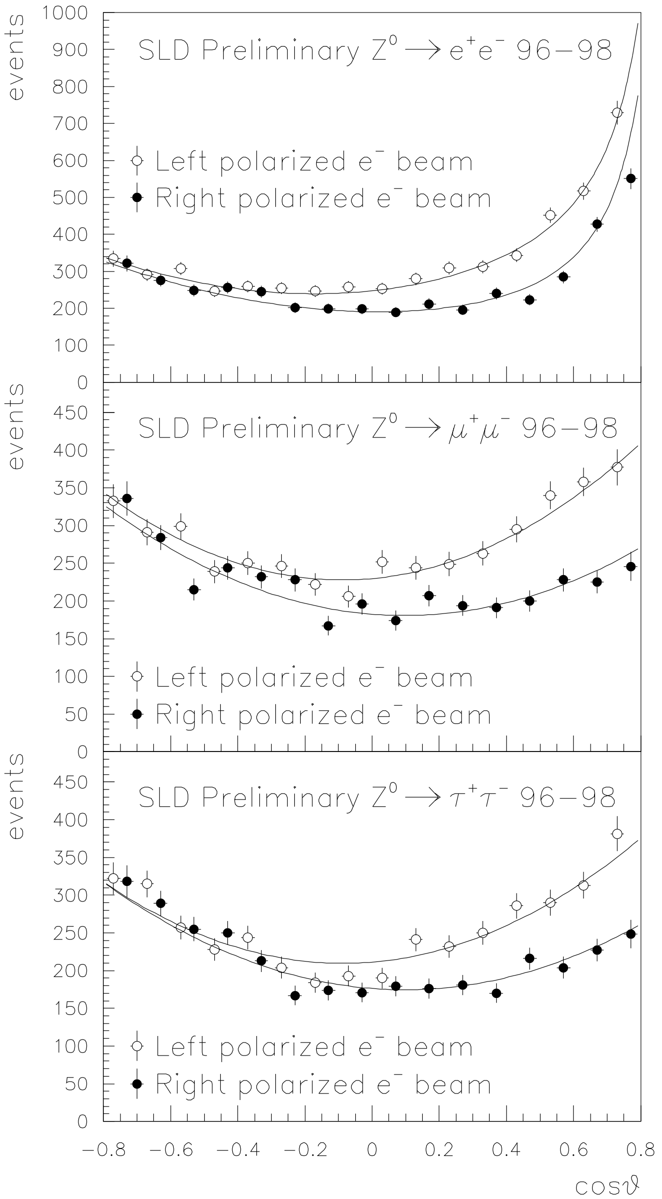

Figure 1: Polar angular distributions for both left- and right-handed polarization from SLD's 1996 to winter 98 data sets. The data are corrected for $|\cos\theta| > 0.7$ where the detection efficiency drops with increasing $|\cos\theta|$.

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