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Final Results on Electroweak Asymmetries from SLD [a]

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Abstract

I present the final measurements of the Z boson-lepton coupling asymmetry parameters A_e, A_μ, and A_τ, obtained from the complete sample of polarized Z bosons collected by the SLD detector at the SLAC Linear Collider. The measurements use leptonic Z decays and the results are $A_e = 0.1544 \pm 0.0060$, $A_\mu = 0.142 \pm 0.015$, and $A_\tau = 0.136 \pm 0.015$. The A_e result is combined with the left-right asymmetry using Z decays to hadrons, $A^0_{LR} (\equiv A_e)$, and is found to be $A_e = 0.1516 \pm 0.0021$. Assuming lepton universality, a combined effective weak mixing angle of $\sin^2 \theta_W^{eff} = 0.23098 \pm 0.00026$ is obtained. Using additional Standard-Model parameters an upper limit on the Higgs mass is given.

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FINAL RESULTS ON ELECTROWEAK ASYMMETRIES FROM SLD

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I present the final measurements of the Z boson-lepton coupling asymmetry parameters A_e, A_μ, and A_τ, obtained from the complete sample of polarized Z bosons collected by the SLD detector at the SLAC Linear Collider. The measurements use leptonic Z decays and the results are $A_e = 0.1544 \pm 0.0060$, $A_\mu = 0.142 \pm 0.015$, and $A_\tau = 0.136 \pm 0.015$. The A_e result is combined with the left-right asymmetry using Z decays to hadrons, $A^0_{LR} (\equiv A_e)$, and is found to be $A_e = 0.1516 \pm 0.0021$. Assuming lepton universality, a combined effective weak mixing angle of $\sin^2 \theta_W^{eff} = 0.23098 \pm 0.00026$ is obtained. Using additional Standard-Model parameters an upper limit on the Higgs mass is given.

1 Introduction

Parity violation in the electroweak interaction can be probed in the production and decay of polarized Z bosons generated by e^+e^- annihilation. Parity violation in Z production ($e^+e^- \rightarrow Z$) and decay into charged lepton pairs ($Z \rightarrow e^+e^-, \mu^+\mu^-, \tau^+\tau^-$) is characterized by the Z boson-lepton coupling asymmetry parameters A_e, A_μ, and A_τ. The asymmetry parameter is defined as $A_l = 2v_l a_l/(v_l^2 + a_l^2)$, where v_l and a_l are the effective vector and axial-vector couplings of the Z boson to the lepton (of flavor "l") current, respectively. The Standard Model assumes lepton universality, so that all three species of leptonic asymmetry parameters are expected to be identical and directly related to the effective electroweak mixing angle θ_W^{eff}. The effective electroweak mixing angle depends on virtual electroweak radiative corrections including those which involve the Higgs boson and those arising from new phenomena outside of the scope of the Standard Model. Presently, the most stringent upper bounds on the Standard Model Higgs mass are provided by measurements of $\sin^2 \theta_W^{eff}$.

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2 Asymmetries in Polarized e^+e^- Collisions

As the SLAC Linear Collider (SLC) delivers a longitudinally-polarized electron beam, the initial- and final-state asymmetry parameters can be extracted separately as shown here. The Born-level differential cross section for $e^+e^- \to Z^0 \to f\bar{f}$, for longitudinally polarized electrons and unpolarized positrons, is

$$\frac{d\sigma}{d\cos\theta} \sim (1 - P_e A_e)(1 + \cos^2\theta) + 2(A_e - P_e)A_f \cos\theta$$

where θ is the polar angle of the outgoing fermion of flavor f (with respect of the incoming electron beam) and P_e is the electron beam polarization; A_e and A_f are the initial- and final-state asymmetry parameters, respectively. A_e can now be isolated by taking the left-right asymmetry, A_{LR}:

$$A_{LR} = \frac{1}{|P_e|} \cdot \frac{\sigma_L - \sigma_R}{\sigma_L - \sigma_R} = A_e$$

Here σ_L, σ_R refer to left- and right-handed incoming electrons, respectively. With a polarized electron beam one can also isolate the final-state asymmetry parameter by the polarized forward-backward asymmetry,

$$A^f_{FBLR} = \frac{4}{3}\frac{1}{|P_e|} \cdot \frac{(\sigma^f_{FL} - \sigma^f_{BL}) - (\sigma^f_{FR} - \sigma^f_{BR})}{(\sigma^f_{FL} + \sigma^f_{BL}) + (\sigma^f_{FR} + \sigma^f_{BR})} = A_f.$$

Here the subscripts F and B refer to $\cos\theta > 0$ and < 0, respectively, and f to the flavor of the produced lepton.

By comparison, in unpolarized e^+e^- collisions the forward-backward asymmetry gives only the product of the initial- and final-state asymmetries, $A_e A_f$.

Thus the initial-state asymmetry, A_e, is obtained from A_{LR} in hadronic (as well as leptonic) final states; from A^f_{FBLR} for lepton final states ($f = e, \mu, \tau$) one obtains A_e, A_μ and A_τ.

Comparing the latter three asymmetries provides also a test of lepton universality; assuming that, one can combine them to form a 'lepton asymmetry,' A_{lepton}, which in turn may be combined with A_{LR} to derive a value for the effective weak mixing angle, θ_W^{eff} from

$$A = \frac{2(1 - 4\sin^2\theta_W^{eff})}{1 + (1 - 4\sin^2\theta_W^{eff})^2}$$

3 The SLD Measurement

SLD has collected polarized Z^0 data from 1992 to 1998; results from the 1992-95 data of about 150,000 Z^0 decays have already been published.[12] In 1996 to 1998, about 380,000 more Z^0 decay events were collected.

For the A_{LR} measurement one selects hadronic final states and excludes beam background and two-photon events as well as e^+e^- final states (the t-channel contribution of which would dilute the asymmetry). The selection efficiency is about 91%, with a small amount of $\tau^+\tau^-$ final states (not a background); the background fraction is only 0.042%. Using these selected events, one forms the measured asymmetry, A_m,

$$A_m = \frac{N_L - N_R}{N_L + N_R}$$

by taking the difference of events created by left- and right-handed electrons over their sum. This measured asymmetry needs to be divided by the average polarization $< P_e >$, and corrected for background and machine-related asymmetries, which are small, to obtain A_{LR}:

$$A_{LR} = A_m / < P_e > + \delta A_m / < P_e > = A_m / < P_e > + O(10^{-4}).$$

Then A_{LR} is converted to the Z=pole result, A^0_{LR} by applying γZ^0 interference and initial-state radiation corrections the relative size of which is about 2%:

$$A^0_{LR} = A_{LR} + \delta A_{EW}$$

The electron polarization plays an important role in this measurement; it is measured by Compton scattering of the electron beam (after it has passed through SLD) with a cicularly-polarized laser beam. The asymmetry in the Compton electron spectrum is then measured with a Cerenkov spectrometer. For a cross-check, the Compton-scattered photon spectrum was also measured with a quartz-fibre calorimeter and a threshold Cerenkov detector. The measurements of the electron polarization with these detectors are consistent. The total systematic uncertainty is 0.5% relative.

Two additional systematic error checks have been performed during the 1997-98 run. The average center-of-mass energy must be well-understood; it is needed for the energy-dependent corrections (δA_{EW}), which are the second-biggest contribution to the systematic error. Thus a Z-pole energy scan has been performed with two off-peak points. (The remaining systematic error is then 0.39% in A_{LR}.) While there is no reason to assume a non-zero positron polarization, we also measured it with a Møller polarimeter and found it to be consistent with zero.

Combining the 1996-1998 data with those of SLD's previous measurements [1] one obtains[3]

$$A^0_{LR} = 0.15138 \pm 0.00216 \qquad \sin^2\theta_W^{eff} == 0.23097 \pm 0.00027$$

Note that the systematic error is only 0.0001 (in $\sin^2\theta_W^{eff}$). This is the most precise determination of $\sin^2\theta_W^{eff}$ presently available from a single measurement.

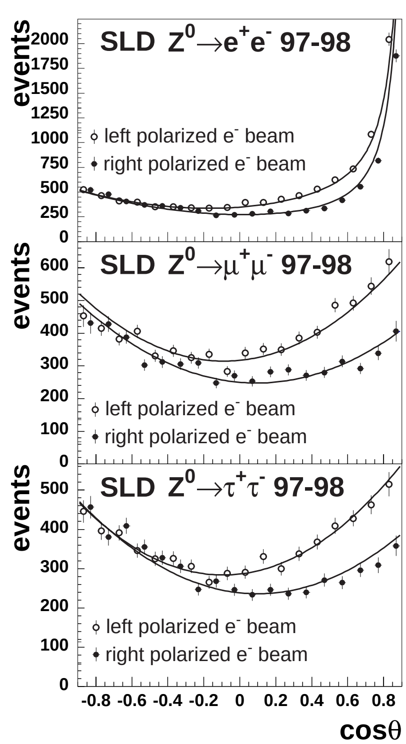

Figure 1: Polar-angle distributions for Z decays to e, μ and τ pairs for the 1997-98 SLD run.

Figure 1 here shows the angular distributions of selected leptonic final states for left- and right-handed electrons. An asymmetry is clearly visible. For $|\cos\theta| > 0.7$, the data are corrected for a decrease in the detection efficiency with increasing $|\cos\theta|$. The asymmetries in the 1996 data look similar but have smaller acceptance ($|\cos\theta| \leq 0.8$).

Using these events A_e, A_μ and A_τ are determined from an unbinned maximum likelihood method rather than just counting events.[4] The maximum-likelihood function contains tree-level cross sections for Z exchange, photon exchange, and photon-Z interference for $\mu^+\mu^-$ and $\tau^+\tau^-$ final states, and also all the relevant t-channel Z and photon exchanges for e^+e^- final states, and takes into account initial-state radiation. This method is less sensitive to detector acceptance as function of polar angle (θ) and has more statistical power.

These results are combined with our previous leptonic asymmetry measurements [2], accounting for small effects due to correlations in systematic uncertainties (polarization and average SLD center-of-mass energy). From purely leptonic final states, one obtains $A_e = 0.1544 \pm 0.0060$. Combining the A_e result with the left-right asymmetry measurement using Z decays to hadrons ($A^0_{LR} \equiv A_e$) [3] and one obtains:[4]

$$\begin{array}{lllll} A_e & = & 0.1516 & \pm & 0.0021 \text{ (with } A^0_{LR}) \quad ; \\ A_\mu & = & 0.142 & \pm & 0.015 \quad ; \text{and} \\ A_\tau & = & 0.136 & \pm & 0.015. \end{array}$$

These results are consistent with lepton universality. Assuming universality, we combine these results into A_{lepton} which in the context of the standard model is simply related to the electroweak mixing angle, and obtain

$$A_{lepton} = 0.15130 \pm 0.00207 \qquad \sin^2\theta_W^{eff} = 0.23098 \pm 0.00026.$$

as the final SLD results for these quantities. This is presently the most precise available determination of this quantity. Within the context of the SM, the result above can be used to constrain the mass of the Higgs boson. With the measured Z boson [5] and top quark masses [6], a determination of $\alpha(M_Z^2)$ [7], and the ZFITTER 6.23 program [8] one obtains a 95% confidence level upper bound of 147 GeV/c^2 on the Standard Model Higgs mass..

In conclusion, direct measurements of the Z boson-lepton coupling asymmetries A_e, A_μ, and A_τ using $e^+e^- \to e^+e^-$, $\mu^+\mu^-$, $\tau^+\tau^-$ events produced with a longitudinally polarized electron beam during the 1996-98 SLD runs were presented here. These results were combined with our previously published results, yielding SLD's final result for the weak mixing angle.

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