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Precision Electroweak Measurements at the SLC : Overview and Perspective.*

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Abstract

Preliminary SLD electroweak results based on essentially the complete 550K Z dataset are presented and interpreted, and some historical background is provided.

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1 Introduction

The recent run (1997-98) of the Stanford Linear Collider (SLC) was the most productive to date : approximately 350K Z bosons were detected, compared to 210K for the entire program from 1992-96, at peak luminosities of $3 \times 10^{30}\mathrm{cm}^{-2}\mathrm{s}^{-1}$, nearly a factor of three improvement compared to the best previous results. Nevertheless, LEP enjoys a 28 : 1 advantage in statistics, and it is only due to the unique features of SLC operation that the SLD experiment is able to contribute several state-of-the-art electroweak and b-physics measurements. These well-known features are :

- High (75%), precisely measured ($\frac{\delta\mathcal{P}}{\mathcal{P}} \sim 0.5\%$) longitudinal e- polarization.
- A small and stable e^+e^- luminous region (1.5 by 0.8 by 700 μm) and a uniquely precise CCD-based vertex detector (I.P. determined to 4 by 4 by 30 μm).

In what follows, recent electroweak results will be summarized, some historical background provided, and implications of the data will be discussed.

2 The Electroweak Observables

The polarized differential cross section at the Z pole is given by :

$$\frac{d\sigma}{dcos\theta} \sim (1 - \mathcal{P}_e A_e)(1 + cos^2\theta) + 2A_f(A_e - \mathcal{P}_e)cos\theta,$$

where the parity violating asymmetries in terms of the vector and axial vector NC couplings for fermion flavor f are $A_f = \frac{2v_f a_f}{v_f^2 + a_f^2}$. The polarized e^- beam at the SLC allows for the isolation of the initial state (A_e) and final state (A_f) asymmetries. The initial state couplings are determined most precisely via the left-right Z production asymmetry

$$A_{LR}^0 = \frac{1}{\mathcal{P}_e}\frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = A_e,$$

while the left-right-forward-backward asymmetry for the final state flavor $f = b, c, s, e, \mu, \tau$

$$A_{LRFB} = \frac{(\sigma_{LF} - \sigma_{LB}) - (\sigma_{RF} - \sigma_{RB})}{(\sigma_{LF} + \sigma_{LB}) + (\sigma_{RF} + \sigma_{RB})} = \frac{3}{4}\mathcal{P}_e A_f,$$

determines the final state couplings.

The A_{LR} measurement is unique among all electroweak precision measurements in that no efficiency or acceptance effects enter, and no significant final state identification is required. Due to the extensively crosschecked high precision polarimetry, the total systematic error ($\sim 0.75\%$) ensures that the result is statistically dominated (stat. error $\sim 1.3\%$). The quantity A_{LR}^0 provides by far the most precise determination of $sin^2\theta_W^{eff}$ presently available, and rivals the 4 experiment CERN average, without recourse to the assumption of lepton/hadron universality inherent in the most precise technique from LEP ($A_{FB}(b)$).

The significance of the A_{LRFB} measurement, while not as precise as A_{LR}, is that it provides the only direct measurement of the important parameter A_b (and the charm, strange and muon analogs as well), which can only be obtained indirectly from unpolarized asymmetries. While the weak mixing angle measurements are particularly sensitive to vacuum polarization loop effects (and hence to the Higgs mass), A_b is instead affected by corrections at the Zb$\overline{\text{b}}$ vertex. In the context of the Minimal Standard Model (MSM), these vertex corrections are insensitive to M_{Higgs} and hence A_b has an unambiguous predicted value (compared to experimental precision). The combination of independent measurements of A_e and A_b is therefore a powerful test of the MSM.

In addition, measurements of the hadronic partial width ratios R_b and R_c, which are best measured at LEP and SLD, respectively, have become precisely known. In particular, R_b is interesting due to high precision (0.4% in the world average), and the fact that it provides a nicely complimentary measurement to A_b : A_b is primarily sensitive to *right*-handed NC b couplings, while R_b is most sensitive to the *left*-handed sector.

3 Remarks on High Precision

The unique precision of A_{LR} is a centerpiece of the SLD program, but the extensive crosschecks which have bolstered our confidence in this measurement are not so well known and are briefly reviewed here.

In the early years (1992-95), a number of dedicated accelerator experiments were performed to establish the integrity of the polarimetry, in particular 1) the e^- bunch helicity transmission was verified by setting up a current/helicity correlation in the SLC, 2) medium precision Møller and Mott polarimeters confirmed the high precision Compton polarimeter result to $\sim 3\%$. In addition, the advent of spin manipulation via "spin bumps" in the SLC arcs allowed us to minimize the spin chromaticity ($d\mathcal{P}/dE$) which helped reduce a resulting polarization correction from $> 1\%$ in 1993 to $< 0.2\%$ by 1995.

Since 1997, two additional detectors of the Compton scattered photons (the Compton e^- are seen in the primary device), with rather different systematics, presently confirm our overall polarization scale to within 0.5%. Most recently, two longstanding questions were answered : 1) A dedicated experiment using the End Station A fixed target polarimeter confirmed that accidental e^+ polarization is consistent with zero ($-0.02 \pm 0.07\%$), 2) A short resonance scan was used to calibrate the SLC energy spectrometers against M_Z, verifying their accuracy on E_{cm} to about 40 MeV and leading to an estimate of induced systematic error of $\sim 0.5\%$. [a]

In summary, several years of instrumental work and crosschecks, supplemented by extensive accelerator based tests, have answered a large number of detailed questions, from the most fundamental to the fairly obscure. The high precision of A_{LR} is now very well established.

4 Results and Interpretation

The preliminary results are given below (with the exception of kaon tagging for A_b, and the latest $\sim 100K$ events for R_b, these results are based on the entire 1992-1998 SLD data set). [1]

Table 1: SLD electroweak results.

Observable	Prelim. Result	$sin^2\theta_W$	comments
A_{LR}	0.1504 ± 0.0023	0.23109 ± 0.00029	Incl. SLD leptonic result
A_e	0.1504 ± 0.0072		(The LEP leptons only
A_μ	0.120 ± 0.019	(0.2317 ± 0.0008)	result for $sin^2\theta_W$:
A_τ	0.142 ± 0.019		0.23153 ± 0.00034)
A_c	0.634 ± 0.027		(LEP : 0.634 ± 0.040)
A_b	0.898 ± 0.029		(LEP : 0.887 ± 0.021)
R_c	0.169 ± 0.006		These observables are
R_b	0.2159 ± 0.0020		consistent with the MSM.

[a] This result was somewhat inflated by instrumental problems during the scan, compared to our prior estimate of $\sim 0.4\%$, but remains at or below the polarimeter uncertainty.

A few comments are in order :

- Final errors will be $\sim \pm 0.00025$ for $sin^2\theta_W^{eff}$, and $\sim \pm 0.022$ for A_b, mainly due to improved systematics.

- Additional $sin^2\theta_W^{eff}$ information derives from the left-right asymmetry in the lepton sample (the dominant A_{LR} result is from a hadronic sample).

- The A_b result is just over one sigma away from the SM prediction (0.935), but if A_b is deduced from the LEP $A_{FB}(b)$ measurement, the SLD/LEP combined result is 2.6 sigma low.

- The SLD $sin^2\theta_W^{eff}$ result is nicely consistent with lepton-based results from LEP (0.8 sigma), a situation that has held stably since 1995, while the $A_{FB}(b)$ dominated LEP hadronic average differs from the lepton based result by 2.2 sigma.

The difficulty seen with the b-flavor results may be a statistical fluctuation or due to analysis bias, or may point to the intruiging possibility of an anamoly in b-NC couplings, in particular, the right-handed coupling, a situation which is difficult to motivate theoretically (the R_b world average is consistent with the MSM). In either of the later two cases, the b-hadron based $sin^2\theta_W^{eff}$ result is called into question - for now we feel it is reasonable to perform our electroweak fits using the lepton-based weak mixing angle average.

We first work within the framework of the MSM - Figure 1 shows the result of separate fits to the Higgs mass using the lepton-based $sin^2\theta_W^{eff}$ results from SLD and LEP, the M_W results from LEP II and the Tevatron, and for comparison the result using the $A_{FB}(b)$ based weak mixing angle measurement from LEP. [b] The M_W measurements seem to be confirming the very low Higgs mass favored by A_{LR}. It is also noteworthy that even when M_W precision reaches ± 30 MeV (presently ± 44 MeV), the strongest contraints will still be coming from $sin^2\theta_W^{eff}$. The key to this enterprise is that improved $\alpha(M_Z^2)$ determinations are becoming available [2], with further improvements expected from new low energy R data [c]. To fully exploit higher precision in $\alpha(M_Z^2)$ will also require the expected FNAL Run II improvements in δm_{top}, from the present 5 GeV to below 3 GeV.

[b] The $\alpha(M_Z^2)$ of Kuhn etal. is used for the fits discussed here - the Jegerlehner etal. value used by the LEP EWWG yields a χ^2 minimum about 30 GeV lower, but due to larger errors, provides about the same 95% confidence upper bound.[2]

[c] Improved data for the critical 2-5 GeV region is already available from BES, with an eventual factor of two improvement in precision expected in this region. [3]

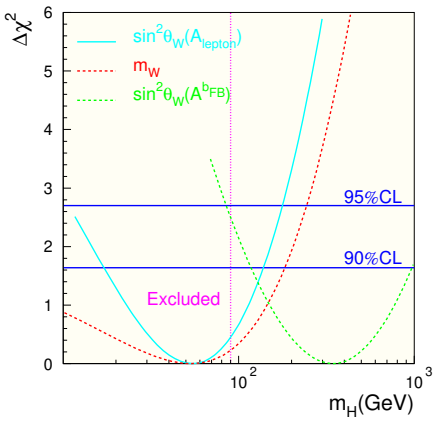

Figure 1: Selected MSM fits.

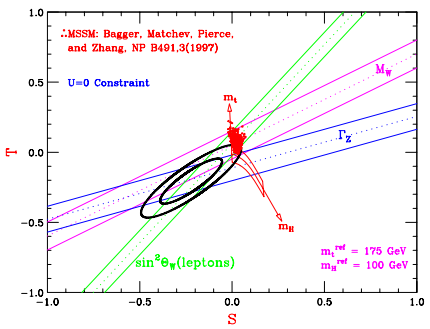

Figure 2: Global S,T fit.

A more general approach employs a fit to the S,T,U parameters[4], which encompass a broad class of models dominated by oblique radiative effects, including supersymmetric models. We perform a global fit to all the world's electroweak data, including $sin^2\theta_W^{eff}$, M_W, Z-width and leptonic BRs, DIS-ν scattering, and atomic parity violation, but excluding the heavy quark results from LEP and SLD (as these may be showing significant vertex corrections). Figure 2 shows the 68% and 90% fit ellipses and the contributions from the three most precise inputs to the fit. The MSM allows the banana-shaped shaped region, whose size is limited by the present FNAL top mass errors, and the LEP II direct Higgs search bounds (a value of 98 GeV for the combined result is used here). Also shown are a collection of points sampled from the 5-parameter space of the Minimal Supersymetric Model (MSSM). It is evident how light Higgs masses, and hence the MSSM, are presently favored (in particular by $sin^2\theta_W^{eff}$ and M_W). It is also intriguiging how $sin^2\theta_W^{eff}$ has begun to place limits on MSSM parameters, and with improved precision could play a role in untangling ambiguous Higgs observations at the LHC.

References

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3. D. Kong, DFP'99, January 5-9, 1999.
4. M. Peskin and T. Takeuchi, *Phys.Rev.*D46:381-409,1992.