Final SLD Results for $A_{LR}$ and $A_{lepton}$

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Representing the SLD collaboration

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Outline of Talk

• Review Key Features of SLD/SLC

• Discuss Important Systematic Checks and Corrections for Final Determination of Asymmetry Parameters

• Review Status of Higgs Mass Predictions
Global Electroweak Fit for \( m_{\text{Higgs}} \)

95% C.L. = 170GeV
- Polarized e⁻ beam
  \( P_e \approx 75\% \)
- Small & stable beamspot
  \( 1.8 \times 0.6 \times 700 \mu m^3 \)
- Peak Luminosity
  \( 3 \times 10^{30} \text{s}^{-1} \text{cm}^{-2} \)
  (300Z's/Hr)
- Compton polarimeter to measure $P_e$
- CCD vertex detector and central tracker
- Čerenkov ring imaging detector
SLD Polarimetry

- 532 nm Frequency Doubled YAG Laser
- Circular Polarizer
- Focusing and Steering Lens
- Mirror Box (preserves circular polarization)
- Compton Back Scattered $e^-$
- Cerenkov Detector
- Quartz Fiber Calorimeter
- Polarized Gamma Counter
- Analyzing Bend Magnet
- "Compton IP"
- Laser Beam Analyzer and Dump
- Mirror Box
- SLD Polarimetry
SLC Performance

1992 - 1998 SLD Polarized Beam Running

~150KZ⁰

~380KZ⁰
Z⁰ Couplings to Fermions

\[ L \propto \bar{\Psi}_f \gamma_\mu (g_L^f P_L + g_R^f P_R) \Psi_f Z^\mu \]

Gives a different coupling strength for left and right handed fermions.
LEP/SLD Asymmetries

n Left-Right Asymmetry

\[ A_{LR}^{\text{meas}} = \left| P_e \right| \left| \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \right| = \left| P_e \right| A_e \quad A_e \text{ at SLD} \]

n Polarized-Forward Backward Asymmetry

\[ A_{FB_{LR}}^f = \left| P_e \right| \left| \frac{(\sigma_{FL}^f - \sigma_{BL}^f) - (\sigma_{FR}^f - \sigma_{BR}^f)}{(\sigma_{FL}^f + \sigma_{BL}^f) + (\sigma_{FR}^f + \sigma_{BR}^f)} \right| = \frac{3}{4} \left| P_e \right| A_f \quad A_f \text{ at SLD} \]

n Unpolarized Forward-Backward Asymmetry and Tau Polarization

\[ A_{FB}^f = \frac{\sigma_F^f - \sigma_B^f}{\sigma_F^f + \sigma_B^f} = \frac{3}{4} A_e A_f \quad A_e, A_f \text{ at LEP} \]

\[ P_\tau = f(\cos \Theta, A_e, A_\tau) \quad A_e, A_{\tau} \text{ at LEP} \]
## SLD Leptonic and Hadronic Asymmetries

<table>
<thead>
<tr>
<th>Final State</th>
<th>Left-Right Asymmetry</th>
<th>Polarized Forward-Backward Asymmetry</th>
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<tbody>
<tr>
<td>qq</td>
<td>$A_e (= A_{LR})$</td>
<td></td>
</tr>
<tr>
<td>$e^+e^-$</td>
<td>$A_e$</td>
<td>$A_e$</td>
</tr>
<tr>
<td>$\mu^+\mu^-$</td>
<td>$A_e$</td>
<td>$A_\mu$</td>
</tr>
<tr>
<td>$\tau^+\tau^-$</td>
<td>$A_e$</td>
<td>$A_\tau$</td>
</tr>
<tr>
<td>$A_e$</td>
<td>$A_\mu$</td>
<td>$A_\tau$</td>
</tr>
</tbody>
</table>

\[
A_{\text{lepton}} = \frac{2(1 - 4 \sin^2 \theta_w \text{eff})}{1 + (1 - 4 \sin^2 \theta_w \text{eff})^2}
\]

**Universality**

\[
\sin^2 \theta_w \text{eff}
\]
$A_{LR}$ Measurement

- $A_{LR}$ at $E_{cm}$ is calculated as follows:

$$A_{LR} = A_{LR}^{\text{meas}}/P_e + \delta A_{LR}^{\text{meas}}/P_e$$

$\delta A_{LR}^{\text{meas}} = O(10^{-4})$, it contains background, beam asymmetries, …

- $A_{LR}$ is converted to $A_{LR}^0$ (Z-pole result) as follows:

$$A_{LR}^0 = A_{LR} + \delta A_{EW} (\sim 2\%)$$

$\delta A_{EW}$ contains $\gamma Z$ interference, ISR…
Monitoring Electron Polarization

Total polarimetry systematic error = 0.50%

\[
\text{PGC} \rightarrow \text{QFC}
\]

0.4% calibration cross check

→ Total polarimetry systematic error = 0.50%
Z-pole scan to calibrate $E_{cm}$ for the 1997-98 run

Muon -pair acolinearity used to check modeling of beamstrahlung effects. Also checks beam energy asymmetry from spectrometer data.

$\chi^2$/DOF=1.20/1

$E_{cm}=91.237\pm0.029$ GeV

$\rightarrow$ systematic error 0.39% on $A_{LR^0}$
Positron Polarization

Experimental check that $P_{e^+}=0$

$P_{e^+}=(-0.02\pm0.07)\%$
Final $A_{LR}$ Result

$$n \sin^2 \theta_w^{\text{eff}} = 0.23097 \pm 0.00027 \text{(sys \sim 0.00010)}$$

<table>
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<tr>
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<tbody>
<tr>
<td>Polarimetry</td>
<td>2.7%</td>
<td>1.3%</td>
<td>0.64%</td>
<td>0.50%</td>
<td>0.50%</td>
</tr>
<tr>
<td>Ecm</td>
<td>-</td>
<td>-</td>
<td>0.33%</td>
<td>0.37%</td>
<td>0.39%</td>
</tr>
<tr>
<td>Chromaticity</td>
<td>-</td>
<td>1.1%</td>
<td>0.17%</td>
<td>0.16%</td>
<td>0.15%</td>
</tr>
<tr>
<td>Bkg., detector,…</td>
<td>2.4%</td>
<td>0.1%</td>
<td>0.06%</td>
<td>0.05%</td>
<td>0.07%</td>
</tr>
<tr>
<td>Total sys. error</td>
<td>3.6%</td>
<td>1.7%</td>
<td>0.75%</td>
<td>0.63%</td>
<td>0.64%</td>
</tr>
<tr>
<td>Stat. error</td>
<td>44%</td>
<td>4.3%</td>
<td>2.8%</td>
<td>3.7%</td>
<td>1.6%</td>
</tr>
</tbody>
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A_e, A_μ and A_τ

- **Objectives**
  - Only direct measurement of A_μ
  - Test Lepton Universality
  - Improve sin^2θ_W^{eff} assuming universality

- **Procedure**
  - Select ee, μμ and ττ final states

<table>
<thead>
<tr>
<th>Data Set</th>
<th>ee</th>
<th>μμ</th>
<th>ττ</th>
</tr>
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<tbody>
<tr>
<td>Efficiency</td>
<td>87%</td>
<td>86%</td>
<td>78%</td>
</tr>
<tr>
<td>Purity</td>
<td>99%</td>
<td>99%</td>
<td>95%</td>
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- ML Fit of angular distribution
A_e, A_µ, A_τ Analyses

Maximum likelihood method:

\[ L(A_e, A_µ, \cos\theta) = f_Z \sigma_Z(A_e, A_µ, \cos\theta) + f_{Z\gamma} \sigma_{Z\gamma}(A_e, A_µ, \cos\theta) + f_\gamma \sigma_\gamma(\cos\theta) \]

\( \sigma \): tree level cross section
\( f \): relative size of cross sections taking initial state radiation into account
Backgrounds and Systematic Uncertainties in Leptonic Analyses

- Electron-Pairs: largest background is from tau-pairs, largest systematic error from radiative corrections
- Muon-Pairs: Small background from Tau-Pairs
- Tau-Pairs: backgrounds from electrons, muons and hadrons; largest correction due to V-A asymmetry from weak decay of Tau
- Systematic/statistical errors in 1997-98 data: electrons (1.3/6.6); muons (1/16); taus (3/17)
SLD $A_e, A_\mu, A_\tau$ results

\[ \chi^2/\text{NDF}=1.7/3 \]

- $A_{LR}^0$: 0.15138±0.00216
- $A_e$: 0.1544±0.0060
- $A_\mu$: 0.142±0.015
- $A_\tau$: 0.136±0.015
- $A_{e-\mu-\tau}$: 0.15130±0.00207

SLD grand average: $\sin^2\theta_w^{\text{eff}}=0.23098\pm0.00026$
Using $\theta = 0.1510 \pm 0.0021$ (SLD+LEP)

LEP measurements: $A_{\eta} = 0.49^{+0.08}_{-0.09}$

$\chi^2_{\text{NDF}=0.4/4} = 0.1420 \pm 0.0095$

$A_{\eta} = 0.1420 \pm 0.0095$

- OPAL $A_{\eta}^{FB}$
- L3 $A_{\eta}^{FB}$
- DELPHI $A_{\eta}^{FB}$
- ALEPH $A_{\eta}^{FB}$
- SLD $A_{\eta}^{FB}$
World $\sin^2 \theta_w^{\text{eff}}$ results

SLD-LEP Weak Mixing Angle Results

- World Avg: $\sin^2 \theta_w = 0.23147 \pm 0.00017$
  \[\chi^2/\text{NDF}=12.9/7\]

- Leptons Only: $\sin^2 \theta_w = 0.23113 \pm 0.00020$
  \[\chi^2/\text{NDF}=2.6/4\]

- Hadrons Only: $\sin^2 \theta_w = 0.23231 \pm 0.00031$
  \[\chi^2/\text{NDF}=0.2/2\]
Test of the MSM: the S-T plot

\[ U=0 \text{ Constraint} \]
\[ S = -0.02 \pm 0.10 \]
\[ T = -0.02 \pm 0.10 \]
\[ M_H < 196 \text{ GEV (95\%)} \]

\[ m_t \]
\[ m_H \]
\[ m_t^{\text{ref}} = 175 \text{ GeV} \]
\[ m_H^{\text{ref}} = 100 \text{ GeV} \]
Global Electroweak Fit for $m_{\text{Higgs}}$

95% C.L. = 170GeV
$\Delta \alpha_{\text{had}} = 0.02784 \pm 0.00026$
Higgs Mass Limits, 95% CL

- 170 GeV, 120 GeV and 149 GeV, respectively for (1) all EW data, including $A_{FB}^b$, (2) with $A_{FB}^b$ excluded, (3) with new BES data included in fit.

- Using Kuhn-Steinhauser value of $\alpha(M_z)$ instead of data, $M_z < 174.4$ GeV or $< 120.8$ GeV, for $A_{FB}^b$ included or excluded, respectively. Consistent with $M_z < 113.3$ GeV from direct measurements at 24% and 6.4%, respectively.
SLD has finalized its very precise measurement of the weak mixing angle

$$\sin^2\theta_{ew}^{\text{eff}} = 0.23098 \pm 0.00026$$

$$A_{LR} + A_e = 0.1516 \pm 0.0021$$

$$A_\mu = 0.142 \pm 0.015$$

$$A_\tau = 0.136 \pm 0.015$$

This result includes ALL of the SLD data, with many checks on systematics and is still statistics limited.

The SLD/LEP lepton electroweak measurements are in good agreement.

In the context of the Standard Model, our data prefer a light Higgs mass.

See PRL 84:5945-5949,2000 for final $A_{LR}$