The ALR analysis

by Jorge Fernandez
Polarization and $A_{LR}$ Measurements for the 1997/98 SLD Run

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Outline

• **Polarization**
  » SLD & Compton Polarimeter
  » Polarization Analysis
  » Preliminary Electron Polarization for
    - 1997
    - 1998
  » Systematic Errors
  » Cross Checks
    - Quartz Fiber Calorimeter
    - Polarized Gamma Counter

• **Left-Right Asymmetry - \( A_{LR} \)**
  » The \( A_{LR} \) Measurement
  » Event Selection
  » Posipol and Peakscan Flash Review
  » Preliminary \( A_{LR} \) Results for
    - 1997
    - 1998
Polarization & $A_{LR}$

**Polarization**

- The SLD and the Compton Polarimeter

![Diagram of the SLD and Compton Polarimeter](image)

- 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
- Compton Detectors

**Compton Detectors**

- Plastic (Scintillator)
- Cerenkov Detector
- Window 2.5 cm Al
- 8 cm Al wall
- 8 cm Aluminum
- 200 AL reflective wall coated
- 1000 Å pure Al
Polarization Analysis

- In 1996, 1997 and some of 1998, 3 minutes of data taking gave us 1-2% statistical precision for Compton Asymmetry.
- From ~March 1998 ‘til the end of the run, SLD saw high luminosity which contributed to high backgrounds in Cherenkov detector → large errors ~ 5%
- For this time, we collected e- only data for Compton Asymmetry measurement.
- At first 3 minutes every hour → error ~ 0.6 %
- later 1 minute every hour → error ~ 1-2 %
- All this effort was to make “good” measurements for the Compton Asymmetry: \( A_{m}^{\text{Compton}} \)
- To get the Polarization, we need to calculate the analyzing powers: \( a_{i} \) where \( i = \text{det. channel} \)

\[
a_{i} = \frac{\int \frac{d\sigma}{dE} A(E)R_{i}(E)dE}{\int \frac{d\sigma}{dE} R_{i}(E)dE} \quad \text{and} \quad P_{e}^{i} = \frac{A_{m}^{\text{Compton}}}{a_{i}P_{\gamma}}
\]

- Need response function \( R_{i} \), Compton asymmetry \( A(E) \), Compton cross section \( \sigma(E) \), and laser polarization \( P_{\gamma} \)
Polarization & $A_{LR}$

Polarization Analysis

- $A_m^{\text{Comp}}$: Compton asymmetry plot

Compton Asymmetry

- Channel positions
- Polarization = 100%
- Polarization = 77%

Energy of Compton backscattered electrons. (Gev)

- Detector response function calibration procedure is in place using tables scans and constructing a modified response function.

Residual plot between MC and data response

Response Function for Ch 7
Polarization Analysis

- Channel to channel consistency (or lack thereof :-)  
  » Bruce has provided a new response function that has significantly reduced Channels 5, 6, 7 discrepancy  
  » A future strategy will be to adopt the cross check detectors (QFC & PGC) into our consistency checks.

- Laser polarization: obtained using the LPOL and EPOL analysis procedures (Pockels cells scans).
  » High luminosity lead to large error bars in EPOL scans - this had the effect of washing out the laser polarization measurement (large errors can only push your measurement in one direction when your near 100%)
Table Scan Polarization

- The graph shows the polarization values across different channels.
- The x-axis represents the channel number, ranging from 1 to 8.
- The y-axis shows the polarization values, ranging from 0.70 to 0.75.
- Data points with error bars indicate the variability in the polarization measurements.

Note: The exact values and error bars are not clearly visible in the image.
Polarization & $A_{LR}$

Polarization Analysis

- "Good" EPOL scan

- "Noisey" EPOL scan
Polarization $\&$ $A_{LR}$

**Polarization Analysis**

- One can cut EPOL scans where error bars are large

\[
P_{\gamma} = 99.9 \pm 0.1\%
\]

- Laser polarization for 1997 and 1998:

\[
P_{\gamma} = 99.9 \pm 0.1\%
\]
Preliminary Electron Polarization Numbers

- Luminosity weighted average Electron Polarization

<table>
<thead>
<tr>
<th>Year</th>
<th>Polarization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1996</td>
<td>$P_e = 76.5 \pm 0.5 %$</td>
</tr>
<tr>
<td>1997</td>
<td>$P_e = 73.3 \pm 0.8 %$</td>
</tr>
<tr>
<td>1998</td>
<td>$P_e = 73.1 \pm 0.8 %$</td>
</tr>
</tbody>
</table>

Systematic Errors:

- The chromaticity effect is the difference between the luminosity weighted convolution integral for the polarization at the SLC IP (SIP) and that at the Compton IP (CIP)

\[
P_{\text{SIP}} = \frac{\int n(E) L(E) P(E) dE}{\int n(E) L(E) dE}
\]

\[
P_{\text{CIP}} = \frac{\int n(E) P(E) dE}{\int n(E) dE}
\]

\[
\Delta_{\text{chrom}} = P_{\text{SIP}} - P_{\text{CIP}}
\]
Polarization & $A_{LR}$

Polarization: Systematic Errors

**Chromaticity (cont.)**

- For the chromaticity analysis we need energy profile $n(E)$, polarization dependence on energy $P(E)$ and Luminosity dependence on energy $L(E)$.

**Energy Profile - There is an issue:**

- We used WS22 (until it broke in 3/98) and CA11-62 to determine $n(E)$. (These were consistent.)

<table>
<thead>
<tr>
<th>Wire Scanner</th>
<th>Energy Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>WS22</td>
<td>$\sigma(E) = 0.1149 \pm 0.0245$</td>
</tr>
<tr>
<td>CA11-62</td>
<td>$\sigma(E) = 0.1189 \pm 0.0198$</td>
</tr>
</tbody>
</table>

- For 1997 and most of 1998, energy profiles were well behaved and this resulted in a low chromaticity effect.
- The issue: The last 6 weeks of the run saw high luminosity which we expect will cause a bump (ie, higher chrom effect).

**Polarization Dependence on Energy:**

- Three energy scans were taken throughout the run and all were consistent with 17 turns.

**Luminosity Dependence on Energy:**

- We are still using the old conservative model using new beam parameters.
- We want to fold in random trigger info.
  \[ L(E) = \frac{Z(E)}{N_{RT}(E)} \]
- We want to update the model by talking with the accelerator boys and girls.

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Polarization & $A_{LR}$

**Polarization: Systematic Errors**

- *Future issue:* with higher lum, we’ll have to more carefully monitor this effect and make sure that we maintain wires.

- The Chromaticity Effect combines with B-B Disrupt. (0.0 +/- 0.1 %) and Beam Transport Effects (0.11 +/- 0.01 %) to give total Compton/SLC IP Correction...

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>chrom</td>
<td>1.7 %</td>
<td>0.2 %</td>
<td>0.15 %</td>
<td>0.05 %</td>
<td>0.128 %</td>
</tr>
<tr>
<td>C/S IP</td>
<td>-</td>
<td>-</td>
<td>0.04 %</td>
<td>-0.06 %</td>
<td>0.018 %</td>
</tr>
<tr>
<td>Uncert</td>
<td>-</td>
<td>-</td>
<td>0.16 %</td>
<td>0.11 %</td>
<td>0.16 %</td>
</tr>
</tbody>
</table>

- **Total Systematic Errors:** ($\%$)

<table>
<thead>
<tr>
<th>Uncertainty</th>
<th>92</th>
<th>93</th>
<th>94/95</th>
<th>96</th>
<th>97</th>
<th>98</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser Polarization</td>
<td>2.0</td>
<td>1.0</td>
<td>0.20</td>
<td>0.20</td>
<td>0.10</td>
<td>0.10</td>
</tr>
<tr>
<td>Detector Linearity</td>
<td>1.5</td>
<td>1.0</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Detector Calibration</td>
<td>0.4</td>
<td>0.5</td>
<td>0.29</td>
<td>0.30</td>
<td>0.30</td>
<td>0.30</td>
</tr>
<tr>
<td>Electronic Noise</td>
<td>0.4</td>
<td>0.2</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Interch. Consist</td>
<td>0.9</td>
<td>0.5</td>
<td>-</td>
<td>-</td>
<td>0.80</td>
<td>0.80</td>
</tr>
<tr>
<td>Polarimeter Unc</td>
<td>2.7</td>
<td>1.6</td>
<td>0.64</td>
<td>0.64</td>
<td>1.01</td>
<td>1.01</td>
</tr>
<tr>
<td>Compt/SLC IP Corr</td>
<td>-</td>
<td>1.1</td>
<td>0.17</td>
<td>0.16</td>
<td>0.11</td>
<td>0.16</td>
</tr>
<tr>
<td><strong>Total P. Uncert</strong></td>
<td>2.7</td>
<td>1.9</td>
<td>0.67</td>
<td>0.67</td>
<td>1.02</td>
<td>1.03</td>
</tr>
</tbody>
</table>

Ok, these are preliminary
Quartz Fiber Calorimeter

cross check of the polarization measurement at the SLD at sub-1% level

532 nm Frequency Doubled YAG Laser

Circular Polarizer

Focusing and Steering Lens

Mirror Box (preserves circular polarization)

Compton Back Scattered e−

Cerenkov Detector

Laser Beam Analyzer and Dump

“Compton IP”

Analyzing Bend Magnet

Polarized Gamma Counter

Quartz Fiber Calorimeter

QFC signal distributions

QFC vs CKV

Each point corresponds to a single polrun (3 min)
Polarization & $A_{LR}$

**Polarization: Cross Checks**

*Quartz Fiber Calorimeter*:
- The QFC is a completely independent polarimeter with its own set of systematics.
- The QFC was calibrated on the test beam at the end of the 97/98 run.
- The device shows excellent linearity over the entire energy range.
- Analysis is in progress but initial estimations suggest $\sim 0.7\%$ relative systematic error - this is the error that the Compton provides, however Compton provides it continually over the course of the run and during actual collisions.
- This points to the hope that it may be possible to get the Compton error down to the 0.5% level by comparing QFC and Cherenkov data.
**Beam Test**

**Objectives:**
- energy response function
- electronics linearity check
- effect of misalignments
- tuning Monte Carlo

---

*Residuals to response function*

*Fractional residual:* $\frac{\text{Data}}{\text{MC}}$

*Energy, GeV*
Polarized Gamma Counter
C. Field, R. Frey, M. Woods

- PGC Goal: Check Polarization scale at < 1\% level

- Use Cherenkov threshold of 14 MeV (ethene at 1 atm) to get above synchrotron bkgd. \(E_C \approx 1\) MeV

- Three remotely actuated Pb radiators:
  1" analyzing power = 0.163; largest signal
  1.5" 0.198
  2" 0.216
  ⇒ provide critical consistency check

- Response measured in test beam

PGC Systematics

- Systematic effects are functions of Pb thickness
  ⇒ Each thickness must give same Polarization
  ⇒ use to constrain/measure systematics

- Biggest effect: Acceptance at first mirror ("effective aperture")

\[
\begin{align*}
\text{Effective Aperature (sq inch)} & \\
\text{Anal. Power/Araw (≡|/Pol|)} & \\
1.5 & \\
1.4 & \\
1.3 & \\
1.2 & \\
1.1 & \\
0.6 & \hline
0.8 & \\
1 & \\
\end{align*}
\]

- 0.2% for 1 inch Pb
- 0.6% for 1.5 inch Pb
- 0.7% for 2 inch Pb

- Other systematics: 0.3% geometry uncertainty
  + Same laser and chromaticity errors as CKV
PGC 1996 Run Result

![Graph showing POL vs. Pb Thickness (inch)]

<table>
<thead>
<tr>
<th>Pb Thickness (inch)</th>
<th>CKV(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.00</td>
<td>0.7561 ± 0.0058 [0.77%]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PGC Thickness (Pb)</th>
<th>PGC Value</th>
<th>CKV(7) Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&quot; Pb</td>
<td>0.7578 ± 0.0082(stat) ± 0.0029(sys)</td>
<td></td>
</tr>
<tr>
<td>1.5&quot; Pb</td>
<td>0.7390 ± 0.0048(stat) ± 0.0053(sys)</td>
<td></td>
</tr>
<tr>
<td>2&quot; Pb</td>
<td>0.7478 ± 0.0069(stat) ± 0.0058(sys)</td>
<td></td>
</tr>
<tr>
<td>PGC-AVG</td>
<td>0.7470 ± 0.0047 [0.63%]</td>
<td></td>
</tr>
</tbody>
</table>

- PGC and CKV(7) agree to within 1.2% (1.2σ).
- Good agreement between Pb thicknesses
  \[\Rightarrow\] determines size of systematic error
Data of April 29-30

\[ \langle A \rangle = 0.1402 \pm 0.0007 \quad (0.5\%) \]

\[ \langle A \rangle = 0.1183 \pm 0.00035 \text{(stat)} \quad (0.3\%) \]

\[ \langle A \rangle = 0.0875 \pm 0.0007 \quad (0.8\%) \]

\[ P = 0.724 \pm 0.004 \text{(stat)} \pm \sim 2\% \]

\[ \text{TBD} \rightarrow \sim 0.5\% \]

\[ \text{\sim 50\% of data} \]
Beam off

Entries 29434
Mean 75.00

Laser off

Entries 837383
Mean 98.17

j = 1/2

Entries 68177
Mean 397.3

j = 3/2

Entries 68346
Mean 475.2

S/B = 13

S/B = 16

1'' Pb
-1370 V on PMT

PGC 4/29/98
- Excellent 1998 data
- From prelim. analysis, expect Polarization results with systematic errors 0.5-1.0% (stat. errors < 0.5%)
- Still waiting for standard polarimeter results (circa 1971) to make comparisons
- Expect overall P&C error to be NO.5%
Polarization & $A_{LR}$

The $A_{LR}$ Measurement

- The equations:

$$A_{LR}^0 \equiv \frac{\sigma(e_L^- e^+ \rightarrow Z) - \sigma(e_R^- e^+ \rightarrow Z)}{\sigma(e_L^- e^+ \rightarrow Z) + \sigma(e_R^- e^+ \rightarrow Z)}$$

- This defines the effective mixing angle

$$A_{LR}^0 = \frac{2(1 - \sin^2 \theta_w^{\text{eff}})}{1 + (1 - \sin^2 \theta_w^{\text{eff}})^2}$$

Event Selection:

- We use to use Kal, now we use TaKal event selection which means 1) sum clusters, 2) form imbalance and 3) count tracks.

- Track must be close to SLD IP ($R \leq 5 \text{ cm}$, $Z \leq 10 \text{ cm}$). $P_t \geq 100 \text{ MeV}$ and $\cos \theta \leq 0.866$

$$E_{\text{tot}} = \sum_{\text{clusters}} E_i$$

$$\text{Imb} = \left| \sum_{\text{clusters}} E_{i} \hat{r}_{i} \right| / E_{\text{tot}}$$

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Polarization & $A_{LR}$

The $A_{LR}$ Measurement

**Kal**
- Pass 1, Eitl
- Pass 2 $E_{tot} > 15$ GeV, $\text{Imb} < 0.6$
  - Clusters $> 8$ Barrel
  - Clusters $> 12$ Endcap

**TaKal**
- Pass 1, Eitl or Tau1
- Pass 2 $E_{tot} > 15$ GeV, $\text{Imb} < 0.6$
  - We demand $\geq 3$ tracks, except ...
  - We toss the "3 vs. 1" topology.

Polmatching (associate a pol meas. for each Z):
- TaKal (95.5% Pol Eff)

<table>
<thead>
<tr>
<th>Year</th>
<th>$N$</th>
<th>$N_t$</th>
<th>$N_R$</th>
<th>$A_m$</th>
<th>$P_F(\text{uncor})$</th>
<th>$A_{LR}(\text{uncor})$</th>
</tr>
</thead>
<tbody>
<tr>
<td>97 Pre</td>
<td>104,396</td>
<td>57,643</td>
<td>46,753</td>
<td>0.1043</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>97 Post</td>
<td>99,320</td>
<td>54,930</td>
<td>44,390</td>
<td>0.1061</td>
<td>73.5%</td>
<td>0.1444</td>
</tr>
<tr>
<td>98 Pre</td>
<td>230,690</td>
<td>127,583</td>
<td>103,107</td>
<td>0.1061</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>98 Post</td>
<td>224,962</td>
<td>124,395</td>
<td>100,607</td>
<td>0.1056</td>
<td>73.3%</td>
<td>0.1440</td>
</tr>
</tbody>
</table>

**Not!** The last line is missing 20K Z's.
Beam Polarization SLD 1992-1998 Data

Polarization of Electron Beam (%) vs. Z Count

- Strained Lattice Cathode for 1993 SLD Run
- Strained Lattice Cathode for 1994 SLD Run
- Strained Lattice Cathode for 1997 SLD Run
- Source Laser Wavelength Optimized
- 1996 Run

Some plots...
Posipol:
- A 1% positron polarization corresponds to a 6% shift in $A_{LR}^*$ so a measurement would be very useful.
- We made the measurement (Møller Target).
- We expected 0.0%.
- We got: $P_p = -0.02 \pm 0.07\%$
- Our strategy for interpreting this number is to apply NO CHANGE on the systematics.

Peakscan:
- We deduce a $40 \pm 40$ MeV energy offset.
- This corresponds to a relative correction of 0.5% to $A_{LR}^*$. 

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Polarization & $A_{LR}$

**Preliminary $A_{LR}$ Numbers**

- Corrections to $A_{LR}$ (in units of $10^{-4}$)

\[
A_{LR} = \frac{A_m}{\langle P_e \rangle} + \frac{1}{\langle P_e \rangle} (other\_asymmetries)
\]

<table>
<thead>
<tr>
<th>Asymmetry</th>
<th>Quantity</th>
<th>1996*</th>
<th>1997*</th>
<th>1998*</th>
</tr>
</thead>
<tbody>
<tr>
<td>background</td>
<td>$f_b(A_m - A_n)$</td>
<td>0.65 +/- 0.55</td>
<td>0.56 +/- 0.55</td>
<td>0.56 +/- 0.55</td>
</tr>
<tr>
<td>luminosity</td>
<td>$A_L$</td>
<td>0.0 +/- 0.5</td>
<td>-0.4 +/- 0.5</td>
<td>-0.4 +/- 0.5</td>
</tr>
<tr>
<td>polarization</td>
<td>$A_m^2 A_p$</td>
<td>0.10 +/- 0.13</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>energy</td>
<td>$E_m \sigma(E_m) A_k$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>efficiency</td>
<td>$A_e$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>posipol</td>
<td>$\langle P_e \rangle P_p$</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Corr. to $A_m$</td>
<td>0.76 +/- 0.75</td>
<td>0.22 +/- 1.01</td>
<td>0.22 +/- 1.01</td>
<td></td>
</tr>
</tbody>
</table>

- To get from $A_{LR}$ to $A_{LR}^0$, E-W interference terms must be calculated ($\sim 2 \%$ correction).

- Put it all together (1996-1998 results are Preliminary)

<table>
<thead>
<tr>
<th>Year</th>
<th>$A_{LR}^0$</th>
<th>$\sin^2 \theta_{w\text{eff}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>0.100 +/- 0.044 +/- 0.004</td>
<td>0.2378 +/- 0.0056 +/- 0.0005</td>
</tr>
<tr>
<td>1993</td>
<td>0.1656 +/- 0.0071 +/- 0.0028</td>
<td>0.2292 +/- 0.0009 +/- 0.0004</td>
</tr>
<tr>
<td>1994/5</td>
<td>0.1512 +/- 0.0042 +/- 0.0011</td>
<td>0.23100 +/- 0.00054 +/- 0.00014</td>
</tr>
<tr>
<td>1996</td>
<td>0.1570 +/- 0.0057 +/- 0.0011</td>
<td>0.23025 +/- 0.000730 +/- 0.00014</td>
</tr>
<tr>
<td>1997</td>
<td>0.1475 +/- 0.0042 +/- 0.0016</td>
<td>0.23146 +/- 0.00054 +/- 0.00020</td>
</tr>
<tr>
<td>1998</td>
<td>0.1487 +/- 0.0031 +/- 0.0016</td>
<td>0.23130 +/- 0.00039 +/- 0.00022</td>
</tr>
<tr>
<td>Total</td>
<td><strong>0.1510 +/- 0.0025</strong></td>
<td><strong>0.23101 +/- 0.00031</strong></td>
</tr>
</tbody>
</table>

\[
\sin^2 \theta_{w\text{eff}} = 0.23101 \pm 0.00031
\]

SLD
Preliminary $A_{LR}$ Numbers

- How the numbers stack: 2.2σ difference between LEP and SLD. (for leptons only $\Rightarrow 0.8\sigma$ diff)

\[
\sin^2\Theta_w \text{ from } A_{LR}
\]

\[
\chi^2 = 6.9/5 \text{ (SLD)}
\]

- We expect the final numbers by the winter holidays - that is, for the winter conferences (DPF, etc...)
We would have no ethical difficulties with 1,000,000 $Z'$s

$1 \times 10^6 \ Z'$

would be

OK!

1,000,000 Hadronic $Z'$s

$\sigma_{A_L} (\text{stat}) = 0.00133 \quad \sigma_{A_L} (\text{syst}) = 0.00075$

$\sigma_{\sin^2 \theta_W} (\text{stat}) = 0.00017 \quad \sigma_{\sin^2 \theta_W} (\text{syst}) = 0.00010$

$\Delta \sin^2 \theta_W^{\text{eff}} = 0.000197$

1,100,000 Leptonic $Z'$s (< perfect efficiency)

$\sigma_{A_L} (\text{stat}) = 0.00127 \quad \sigma_{A_L} (\text{syst}) \text{ same as above}$

$\sigma_{\sin^2 \theta_W} (\text{stat}) = 0.000163$

$\Delta \sin^2 \theta_W^{\text{eff}} = 0.000191$