Electroweak Precision Measurements with Leptons

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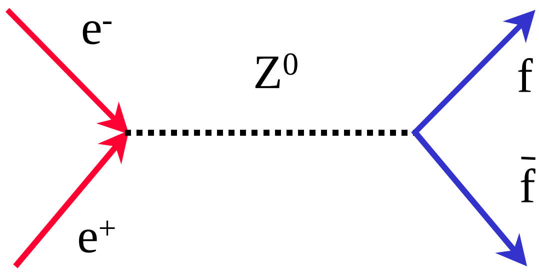
OUTLINE

- SLD Left-Right Asymmetry
  - 1999 update with full data set
- SLD L-R Forward-Backward Asymmetries for e, μ, τ
- τ polarization from LEP
  - updated DELPHI measurement
- Consistency of electroweak lepton measurements

Z° Pole Physics

The Process SLD Tests:



Initial State   Final State

For longitudinally polarized electron beams, we have the polarized cross section (at born level):

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

where; P_e = polarization, $A_{e(f)}$ is initial (final) state coupling asymmetry and θ is the polar angle of the final state fermion to the electron beam.

Note: The final state coupling asymmetry is a measure of the amount of parity violation at the $Zf\bar{f}$ vertex

The coupling asymmetry:

$$A_f \equiv \frac{2v_f a_f}{v_f^2 + a_f^2} \quad \Rightarrow \text{for } e^- \Rightarrow \quad A_e \equiv \frac{2(1 - 4\sin^2\theta_W)}{1 + (1 - 4\sin^2\theta_W)^2}$$

Z° Pole Physics: Asymmetries

Initial State:

- One can define the left-right asymmetry which equals the **initial state** coupling asymmetry A_e ,

$$A_{LR}^{0} \equiv \frac{1}{|P_e|}\frac{s\,(e^{+}e_{L}^{-} \to Z^{0}) - s\,(e^{+}e_{R}^{-} \to Z^{0})}{s\,(e^{+}e_{L}^{-} \to Z^{0}) + s\,(e^{+}e_{R}^{-} \to Z^{0})} = A_e$$

$$\cong \frac{1}{P_e}\frac{N_L - N_R}{N_L + N_R}$$

Note: This becomes a counting experiment with small syst. errors. Also, A_{LR} is very sensitive to the weak mixing angle:

$$\boxed{\frac{dA_{LR}}{d\sin^2 q_W} \approx -7.9}$$

Final State:

- Additionally, one can construct a forward-backward left-right asymmetry and extract the **final state** coupling asymmetry A_f (for say f=τ),

$$\tilde{A}_{FB}^{t} \equiv \frac{(s_{LF} - s_{LB}) - (s_{RF} - s_{RB})}{(s_{LF} + s_{LB}) + (s_{RF} + s_{RB})} = \frac{3}{4}|P_e|A_t$$

$$\boxed{\frac{dA_t}{d\sin^2 q_W} \approx -7.9}$$

Z° Pole Physics: τ Polarization

At LEP, the longitudinal τ polarization, P_τ, of τ pairs produced in Z decays, is

$$P_t = \frac{s_R - s_L}{s_R + s_L}$$

Then, P_τ is a function of the polar scattering angle, so at $\sqrt{s} = m_Z$:

$$P_t(\cos J) = \frac{A_t(1+\cos^2 J) + 2A_e \cos J}{1+\cos^2 J + 2A_t A_e \cos J}$$

(Neglecting γ exchange, γ Z interference, and radiative corrections.)

$$\boxed{\frac{dA_t}{d\sin^2 q_W} \approx -7.9}$$

The LEP experiments do combined fits to determine both A_e and A_τ.

Updated 1999 SLD A_{LR} Measurement

$$\boxed{A^0_{LR} = 0.15108 \pm 0.00218}$$

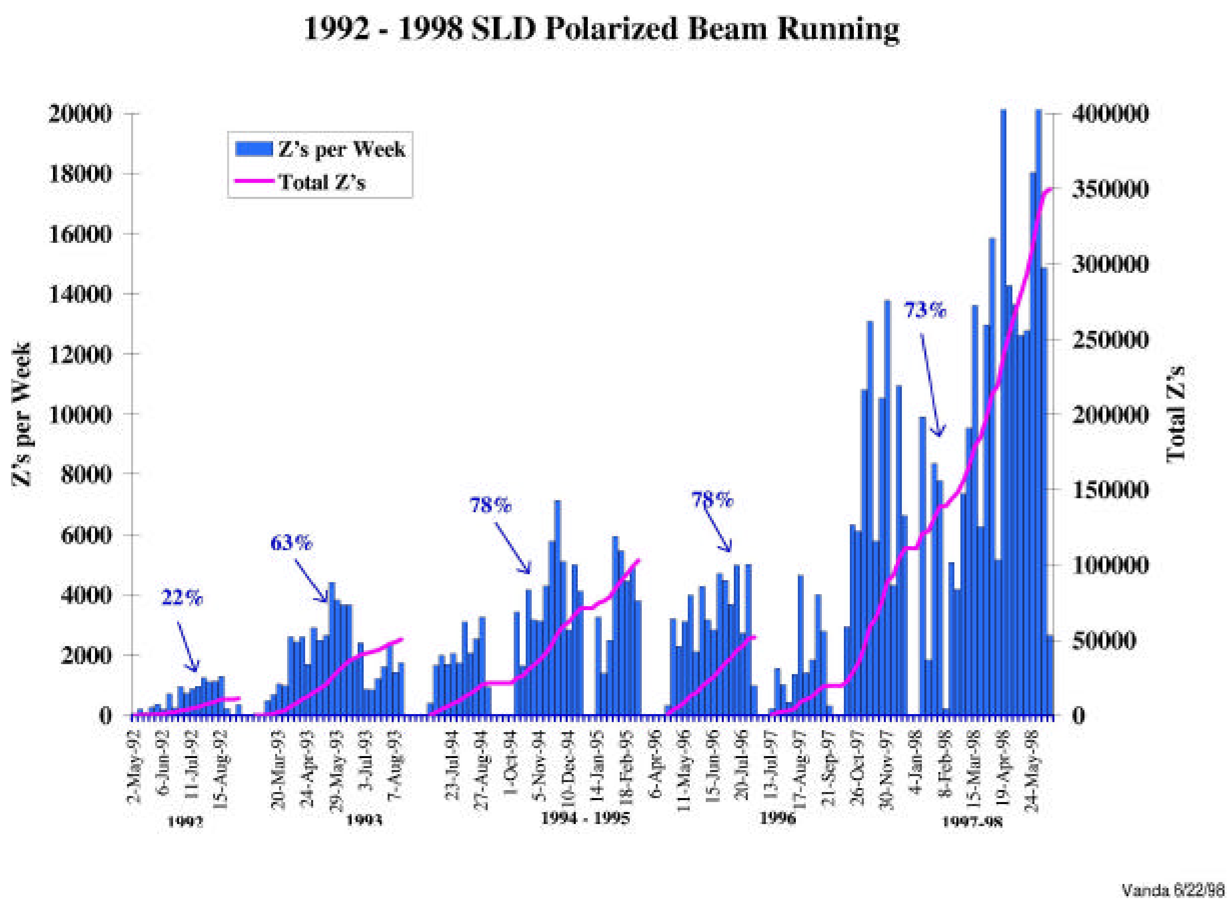
- This is equivalent to an effective weak mixing angle of

$$\boxed{\sin^2\theta_w^{eff} = 0.23101 \pm 0.00028}$$

This results includes ALL of the SLD data,

with many new checks on systematics

SLC Performance



SLD

Evolution of A_{LR} Systematic Errors

Polarimetry errors are approximately
equal to all other systematics combined.

The next largest error is due to the energy spectrometry.

	1992	1993	1995	Now
Polarimetry (fractional error)	**2.7%**	**1.7%**	**0.67%**	**0.5%**
Ecm (fractional error)	**-**	**-**	**-**	**0.4%**
Background (frac.) (correction)	1.4%	0.25%	0.11%	0.044%
SLC asymm (10^{-4}) (correction)	1.8±4.2	0.4±0.5	−1.9±0.3	−1.3±0.7
Total fractional error	**3.6%**	**1.7%**	**0.75%**	**0.65%**

Recent SLD Checks

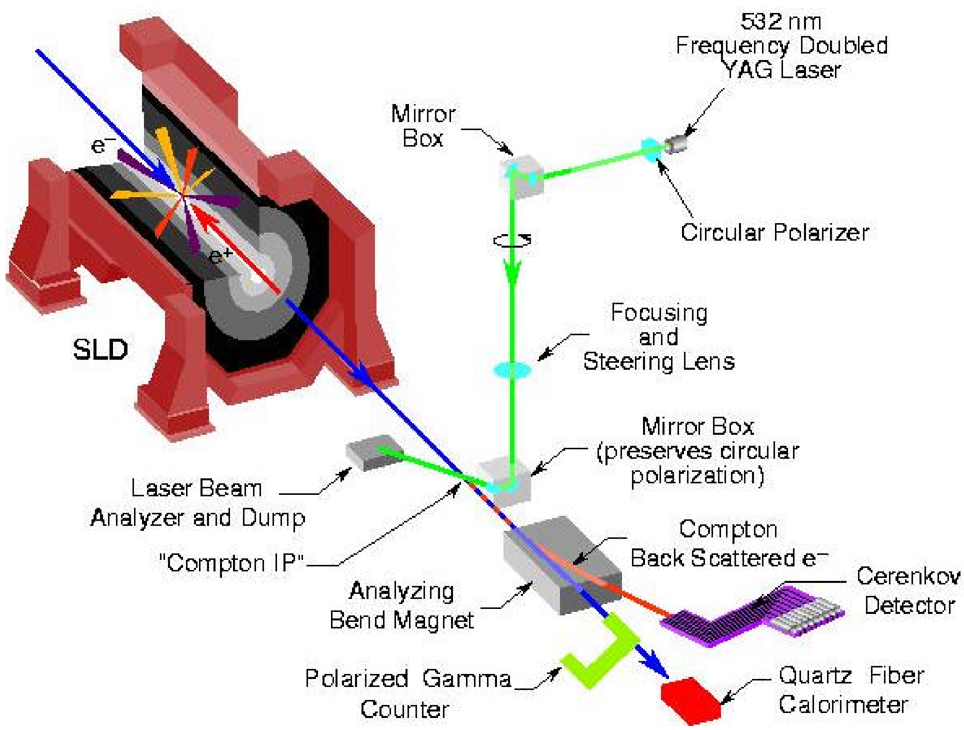
- Electron Polarization
  - two additional independent polarimeters have been employed to confirm the electron polarization measurement
- Center-of-mass Collision Energy
  - Z scan done to confirm the beam energy measurements
- Positron Polarization
  - a measurement of positron polarization was done to confirm its absence
    - P_{e+} = 0.02% +/– 0.07%

SLD Checks: Electron Polarization

Primary Polarimeter:

Cerenkov Detector detects Compton electrons

•**measure asymmetry at kinematic edge (70% analyzing power)**



Two new detectors, PGC & QFC, detect Compton gammas

•**measure energy asymmetry**

- •**16-22% analyzing power for PGC**
- •**18% analyzing power for QFC**

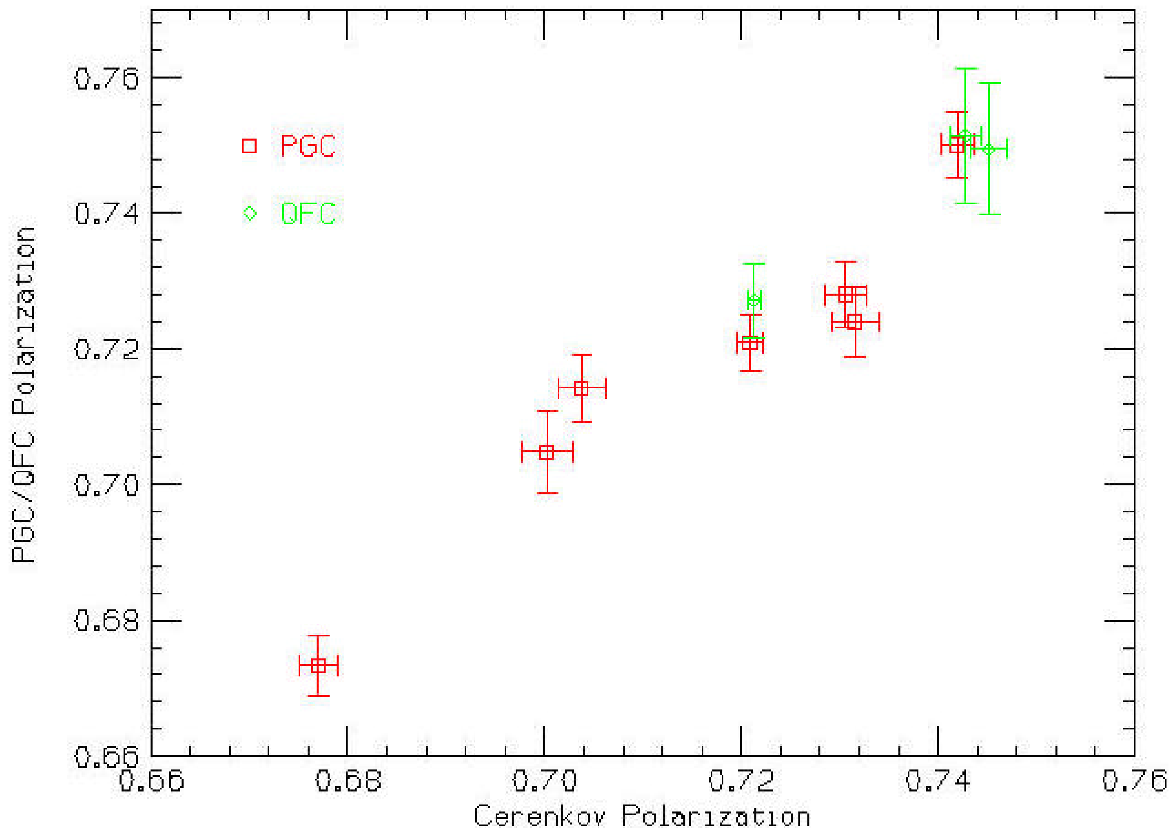
•**measure P during dedicated electron-only runs**

SLD Checks: Electron Polarization

Polarized Gamma Counter and

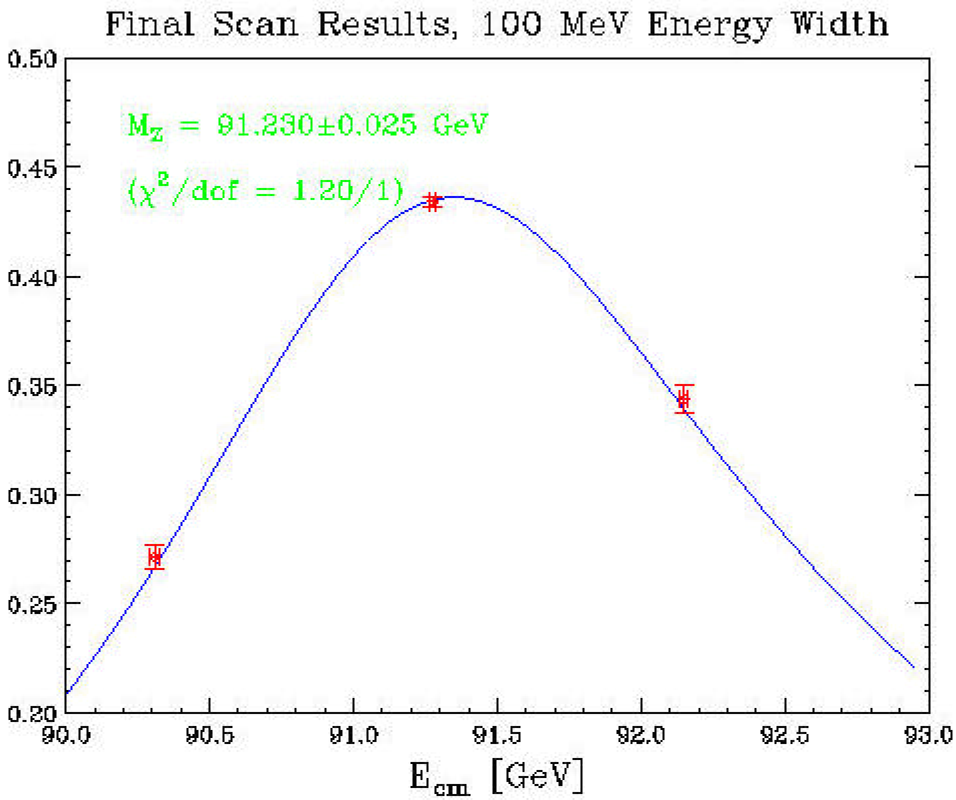
Quartz Fiber Calorimeter

confirm the Cerenkov Detector measurement



PGC: – 0.2% agreement (relative)
QFC: + 0.8% agreement (relative)

SLD Checks: Z^0 energy scan

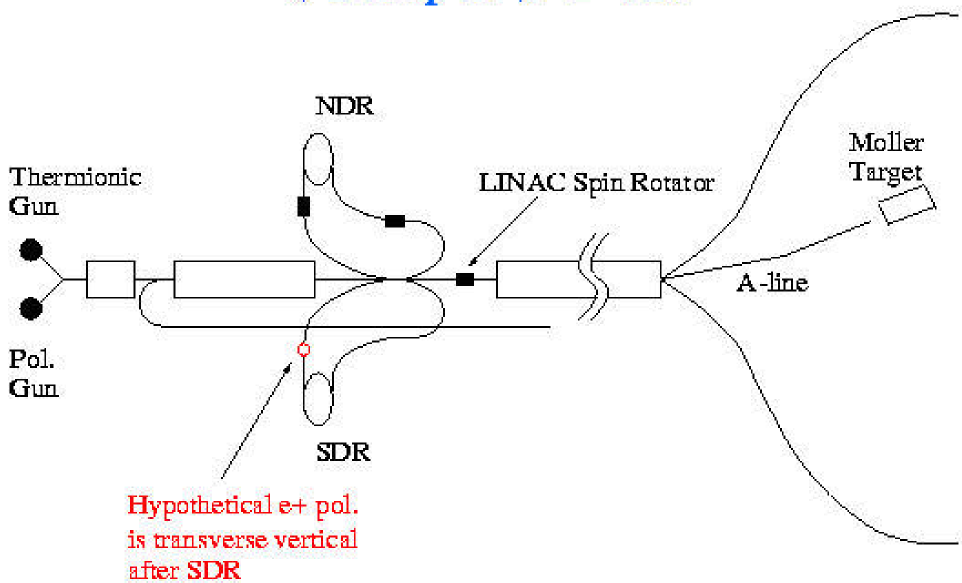


Two off energy points were taken to calibrate the SLD energy spectrometer.

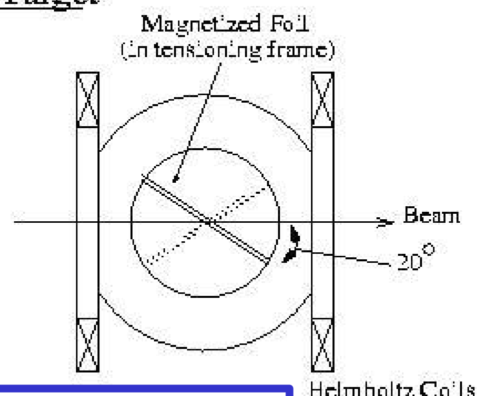
We conclude $\Delta\sqrt{s} = -46 \pm 25$ MeV

SLD Checks: Positron Polarization

Positron Polarization Experiment ("Posipol"): T-419



Moller Target



$$\boxed{P_{e+} = -\,0.02 + 0.07\%}$$

SLD

A_{LR} Numbers

- Table of the time history of SLD's A_{LR} and the luminosty weighted average polarization

Year	A_{LR}^0	P_e (%)
1992	0.100 +/- 0.044 +/- 0.004	22.4 ± 0.6
1993	0.1656 +/- 0.0071 +/- 0.0028	62.6 ± 1.2
1994/5	0.1512 +/- 0.0042 +/- 0.0011	77.2 ± 0.5
1996	0.1570 +/- 0.0057 +/- 0.0011	76.5 ± 0.5
1997/98	0.1490 +/- 0.0024 +/- 0.0010	72.9 ± 0.4
Total	0.15108 +/- 0.00218	

- An EW correction of ~2% is applied to get from A_{LR}^{meas} to A_{LR}^0 (the Z^0 pole)

$$\boxed{A_{LR}^0 = 0.15108 \pm 0.00218}$$

- This is equivalent to the effective weak mixing angle of

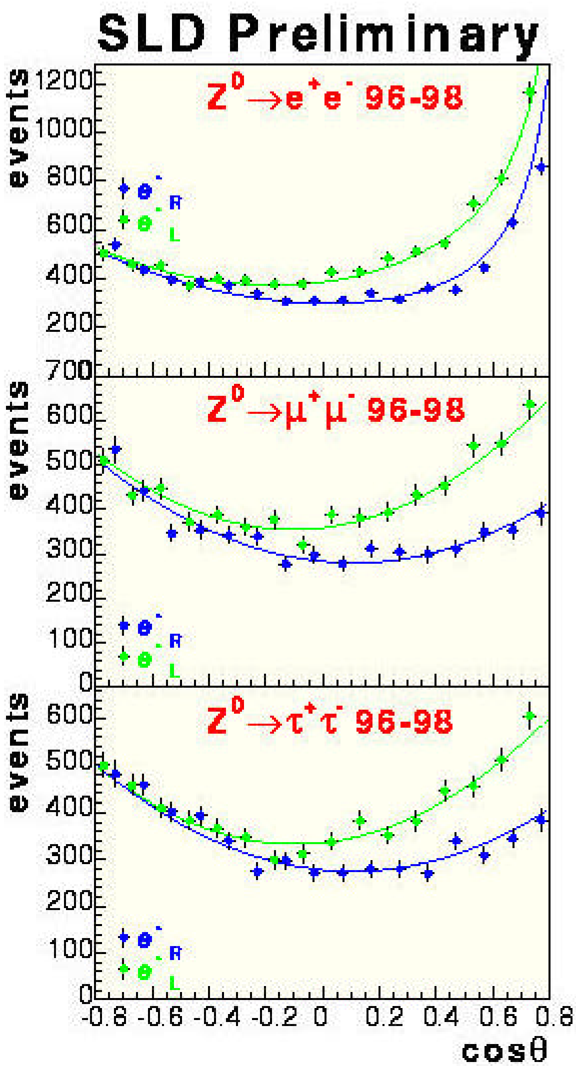
$$\boxed{\sin^2\theta_w^{eff} = 0.23101 \pm 0.00028}$$

SLD Left-Right Forward-Backward $A_{leptons}$

- This is a final state coupling measurement.
- A_{lepton} is determined from the forward-backward left-right asymmetry:

$$A_l \propto \frac{(N_{LF} - N_{LB}) - (N_{RF} - N_{RB})}{(N_{LF} + N_{LB}) + (N_{RF} + N_{RB})}$$

- A_e and $A_{l=\mu,\tau}$ are simultaneously determined from a maximum likelihood fit to the angular distributions
- This analysis is a test of lepton universality and also, if LU is granted, this analysis precisely measures $\sin^2\theta_W$



$$\frac{d\sigma}{d\cos\theta} \propto (1 - P_e A_e)(1 + \cos^2\theta) + 2A_{\mu,\tau}(A_e - P_e)\cos\theta$$

Measuring $A_{leptons}$

- Sample statistics for 1996-8 data

Channel	Sample size	Efficiency (|cosθ|<0.8)	Purity	Dominant Background(s)
e^+e^-	14803	87.3%	98.6%	$\tau^+\tau^-$ (1.2%)
$\mu^+\mu^-$	11867	85.5%	99.8%	$\tau^+\tau^-$ (0.2%)
$\tau^+\tau^-$	11266	78.1%	94.6%	$\mu^+\mu^-$ (2.0%), 2γ (1.7%)

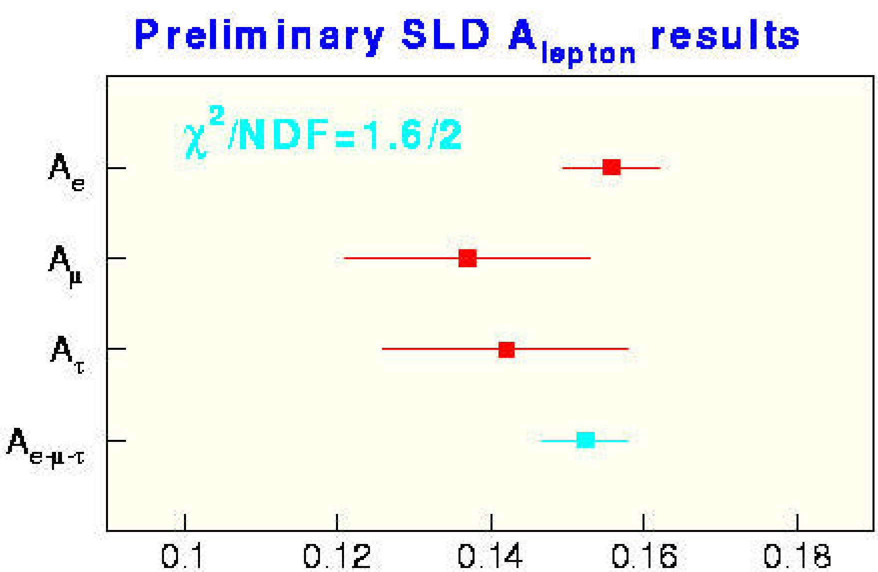
This 1996-98 data has been analyzed to $|\cos\theta| < 0.8$, and will eventually cover to $|\cos\theta| < 0.9$.

- Combined (preliminary) results of the lepton asymmetry for 1993-8 data are consistent with lepton universality:

A_{lepton}	$\sin^2\theta_W^{eff}$
$A_e = 0.1558 \pm 0.0064$	
$A_\mu = 0.137 \pm 0.016$	
$A_\tau = 0.142 \pm 0.016$	
$\mathbf{A_{e\mu\tau} = 0.1523 \pm 0.0057}$	$\mathbf{0.23085 \pm 0.00073}$

Eventual error will be $\pm$ 0.0006

Summarizing the Left-right
Forward-Backward Asymmetry



Summarizing the SLD $\sin^2\theta_W^{eff}$ measurements, using the full SLD data set

1999 A_{LR} update:

$$\boxed{\sin^2\theta_W^{eff}(LR) = 0.23101 \pm 0.00028}$$

Preliminary left-right forward-backward lepton asymmetry

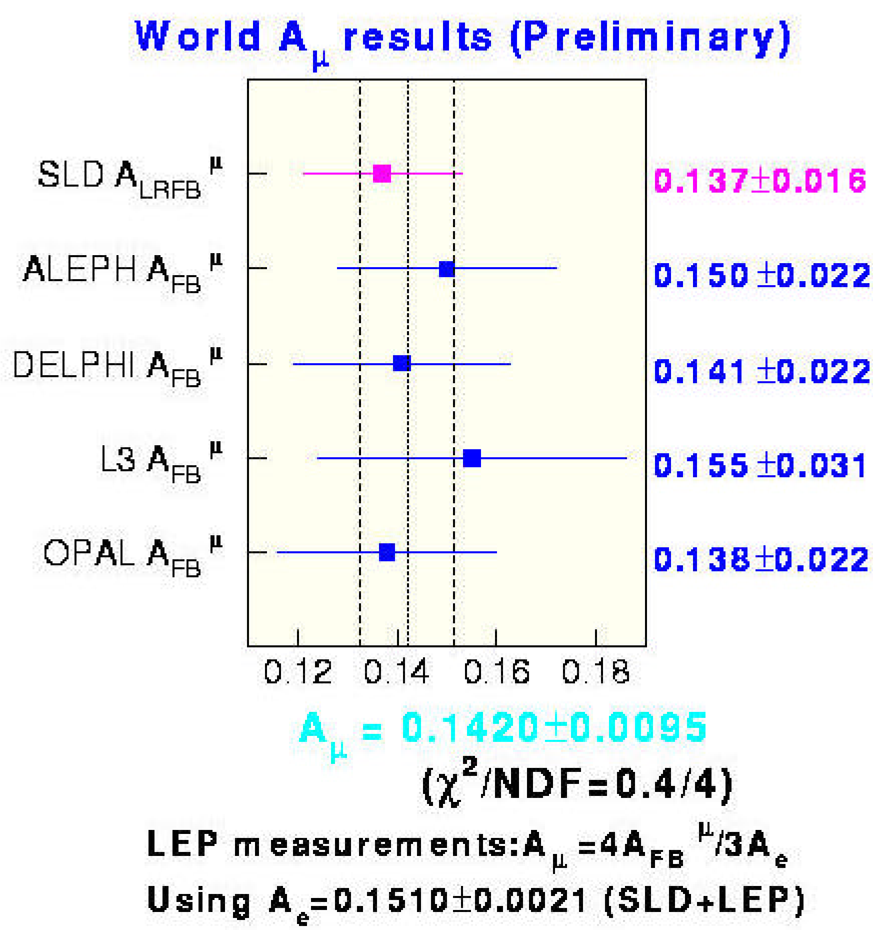
$$\boxed{\sin^2\theta_W^{eff}(LRFB) = 0.23085 \pm 0.00073}$$

Combined SLD Average:

$$\boxed{\sin^2\theta_W^{eff}(LR + LRFB) = 0.23099 \pm 0.00026}$$

A_μ Measurement

Comparison of the world's A_μ measurements



Tau Polarization

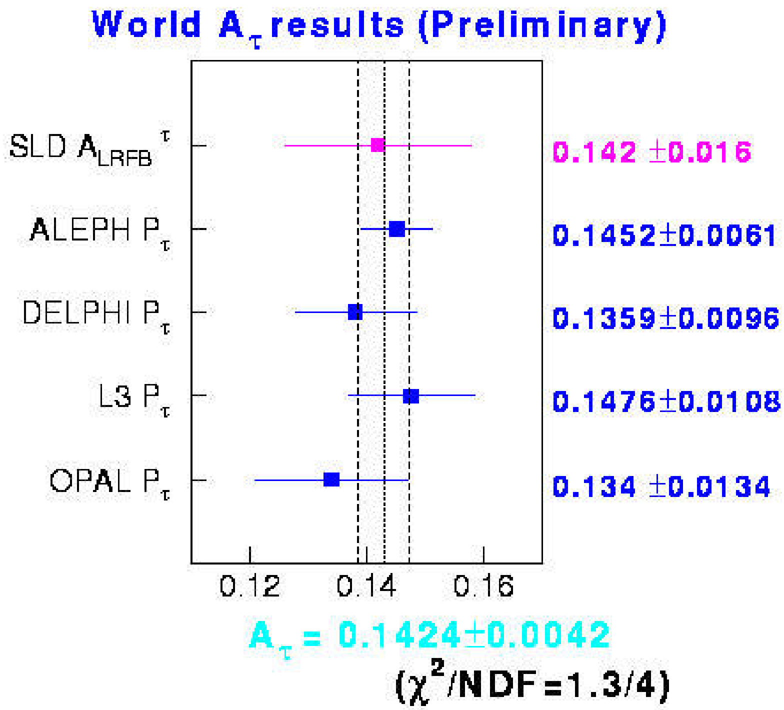
DELPHI has presented a new measurement of the tau polarization

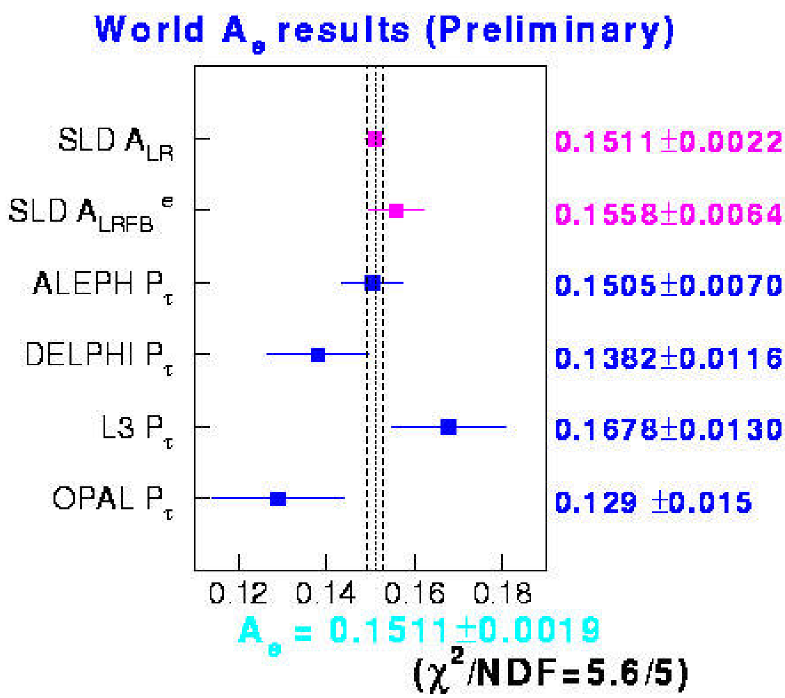
Experiment	A_τ	A_e
ALEPH	0.1452 ± 0.0061	0.1505 ± 0.0069
DELPHI *	0.1359 ± 0.0096 *	0.1382 ± 0.0116 *
L3	0.1476 ± 0.0108	0.1678 ± 0.0130
OPAL	0.1340 ± 0.0134	0.1290 ± 0.0149

* old DELPHI result:

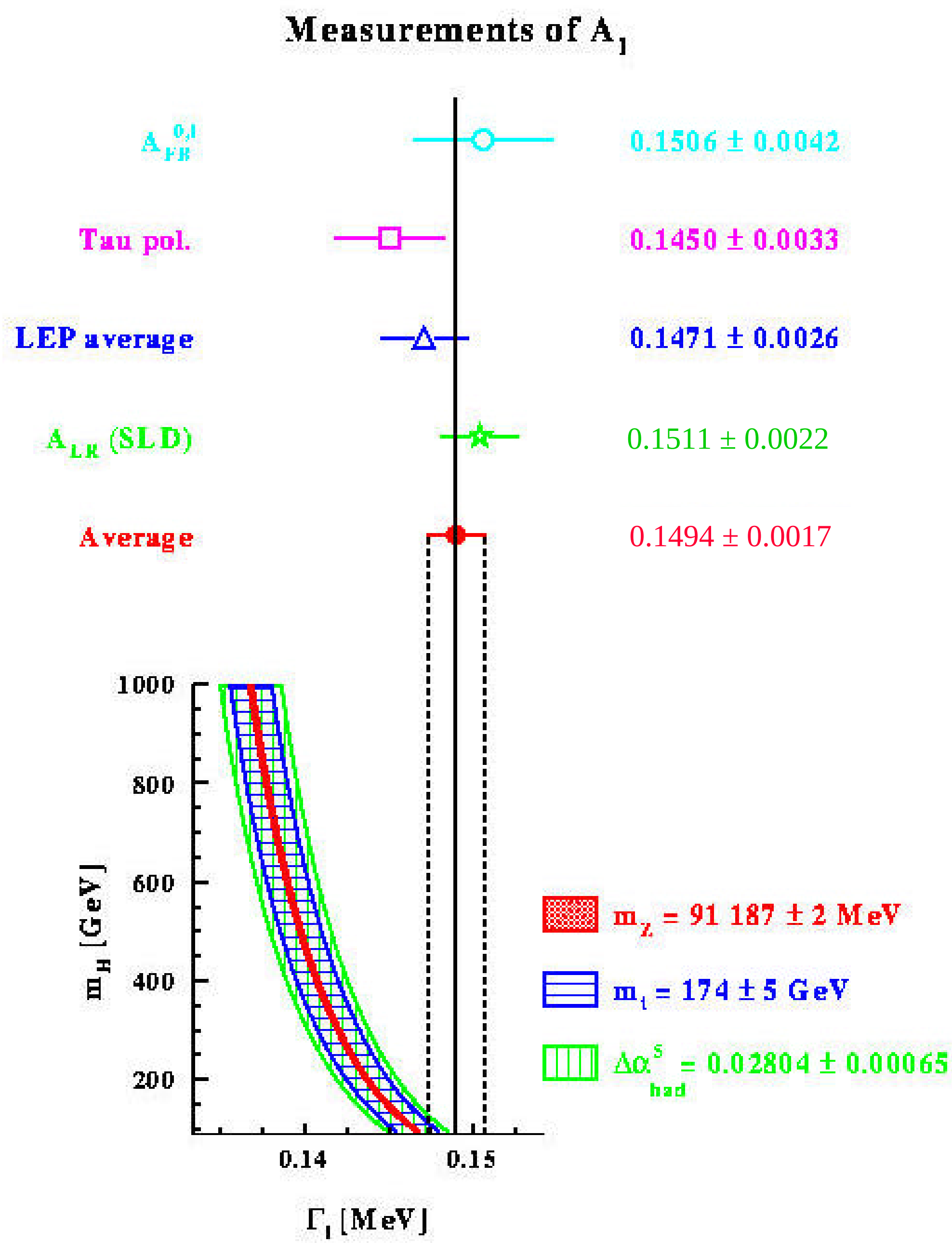
$$A_\tau = 0.1381 \pm 0.0104$$
$$A_e = 0.1353 \pm 0.0121$$

EW Precision Measurements

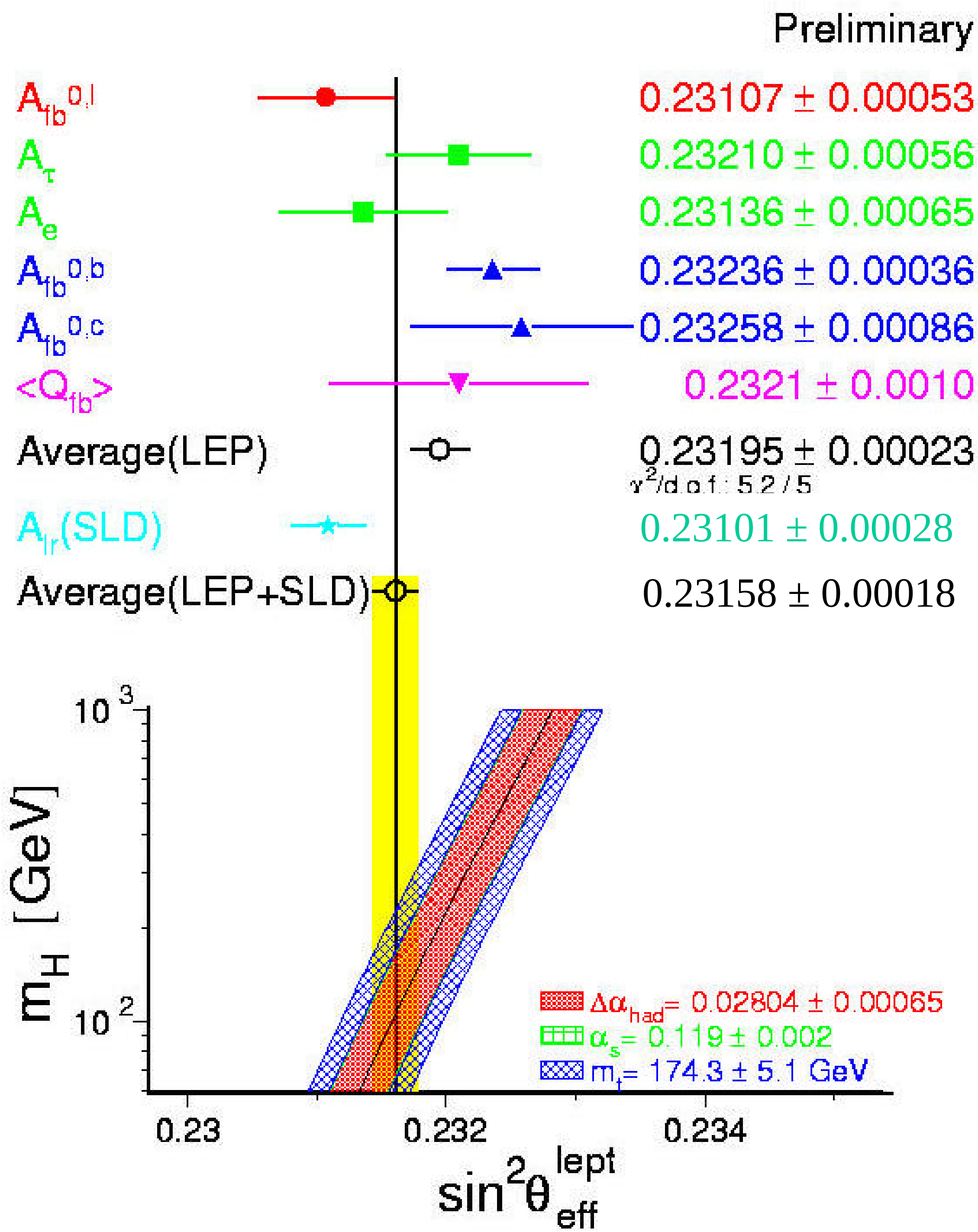




EW Precision Measurements



EW Precision Measurements



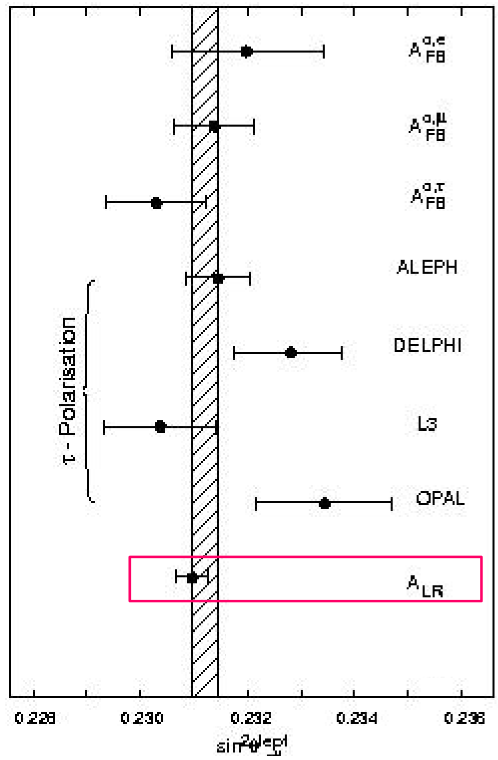
SLD/LEP weak mixing angle Results

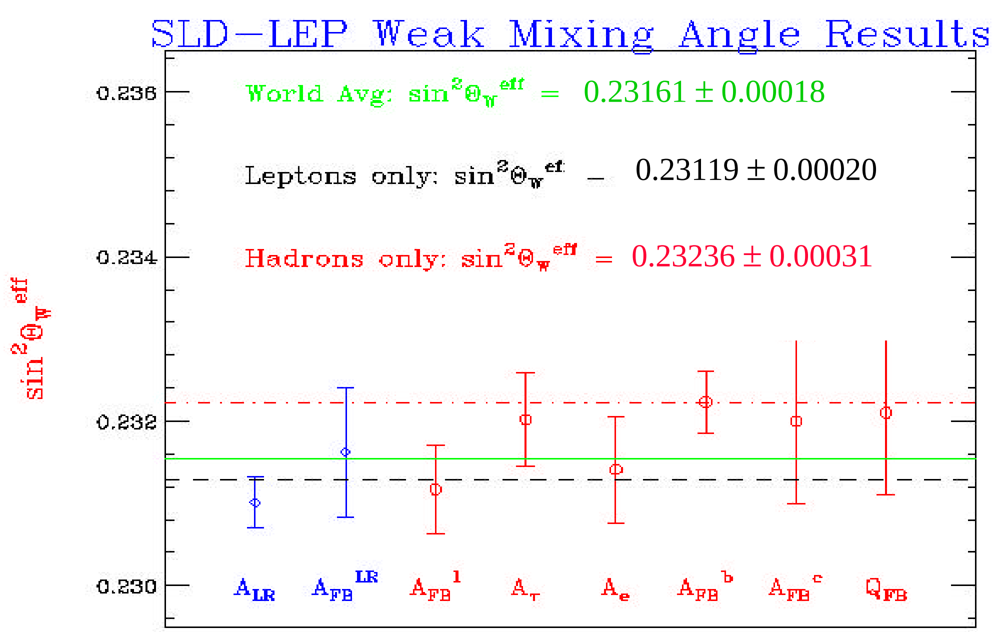
Lepton based results are nicely consistent (LEP includes results from lepton FB asyms. and tau polarization).

SLD : 0.23099(26)

LEP : 0.23151(33)

average : 0.23119(20)





The LEP hadronic methods differ from the lepton average by 3 σ

The dominant LEP contributor here derives from A_{FB}(b) :

Any concerns about b-couplings are also relevant here.

Conclusions

SLD now has an updated measurement of the weak mixing angle from A_{LR} and the left-right forward-backward lepton asymmetries:

$$\boxed{\sin^2 \theta_W^{eff}(LR + LRFB) = 0.23099 \pm 0.00026}$$

This result includes ALL of the SLD data,

with many new checks on systematics

The SLD/LEP lepton electroweak measurements are self-consistent.

A modest difference exists between the lepton and hadron parameters.