Measurements of A_{LR} and A_{lepton} from SLD

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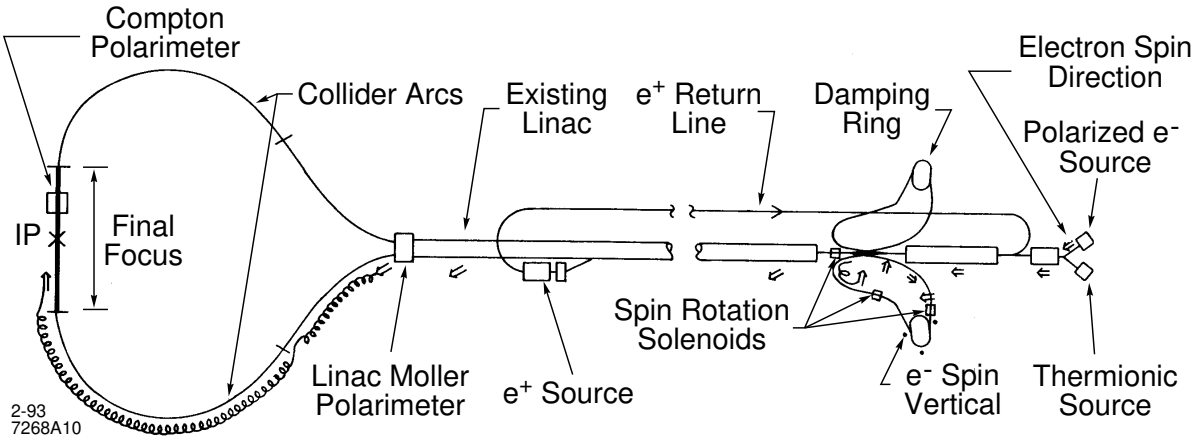
Representing

The SLD Collaboration

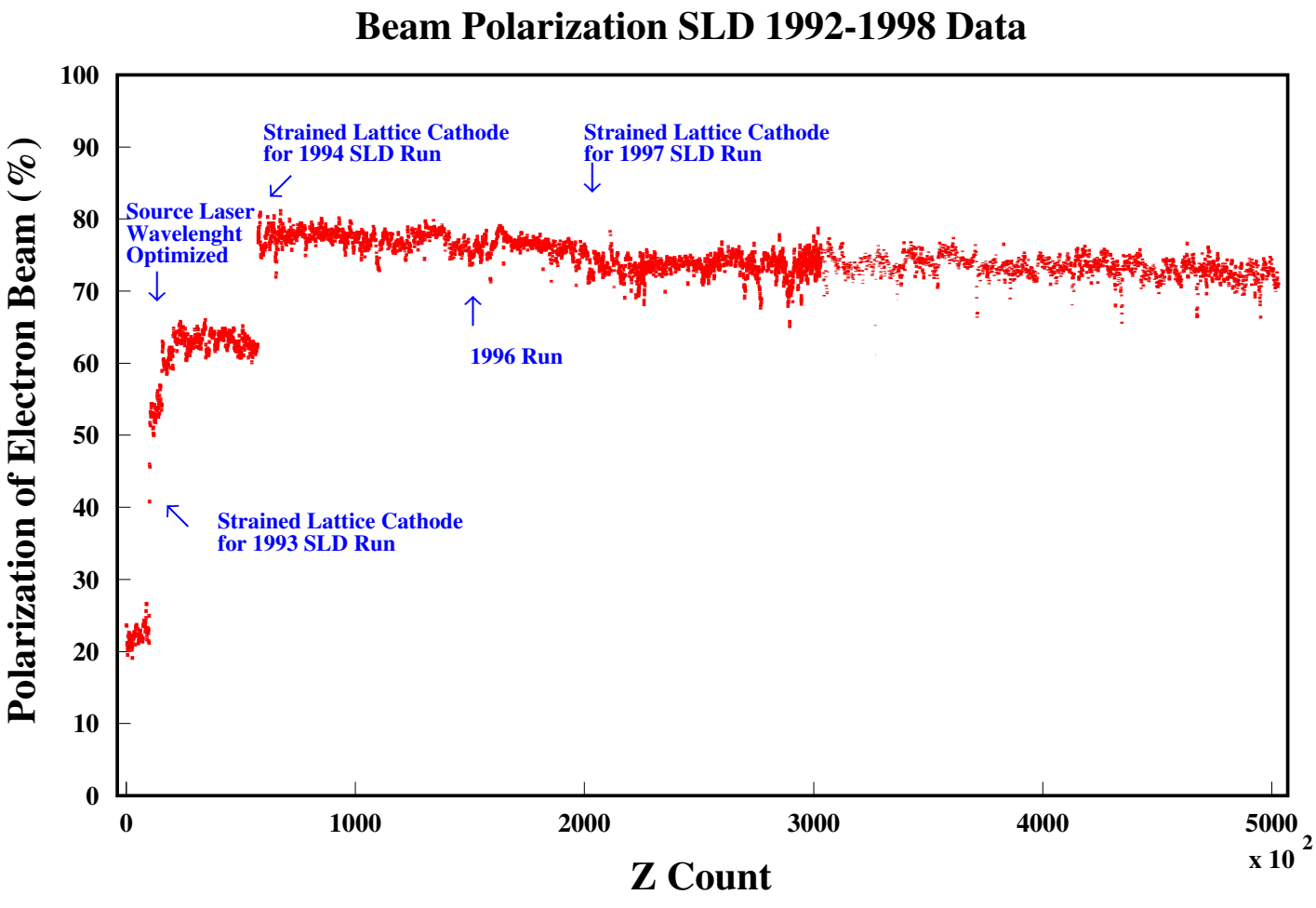
- Introduction to Asymmetries
- Polarization
- A_{LR}
- A_e, A_μ, and A_τ
- Combined Results and Future Prospects

The SLC

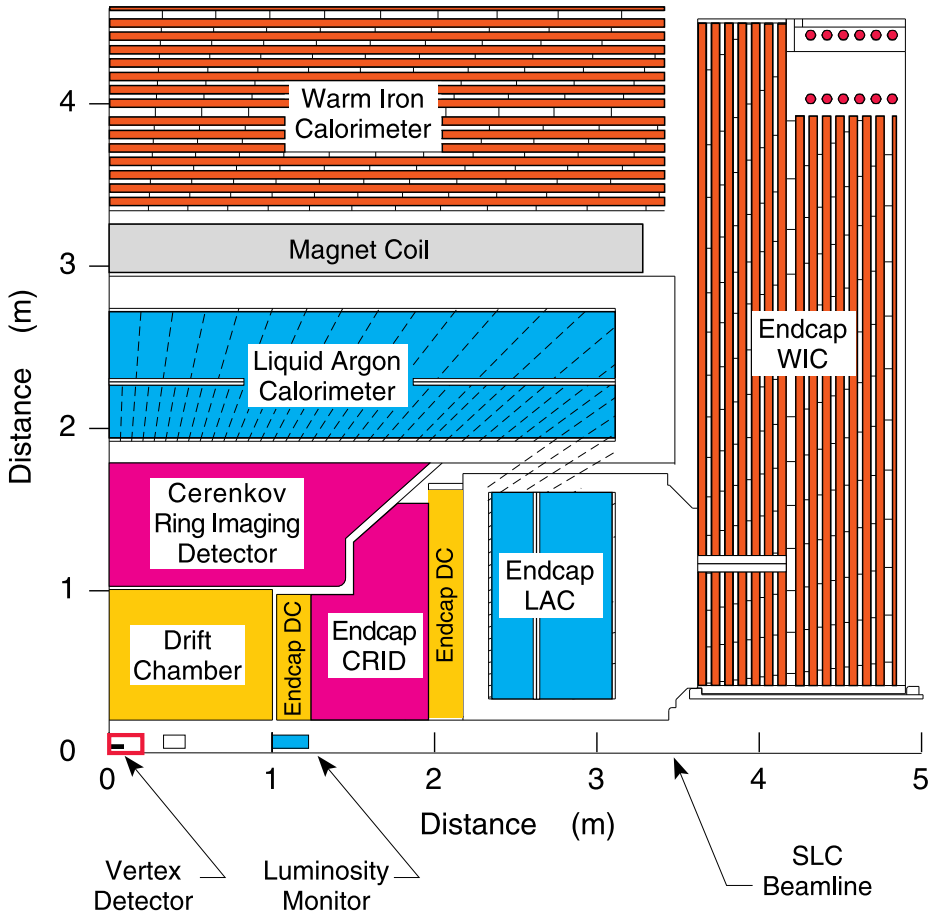


Unique and powerful features of SLC:

- Small Luminous Region: 1.8 x 0.6 x 700 μm^3
- Large Electron Polarization: P_e ~ 0.73 for most recent run



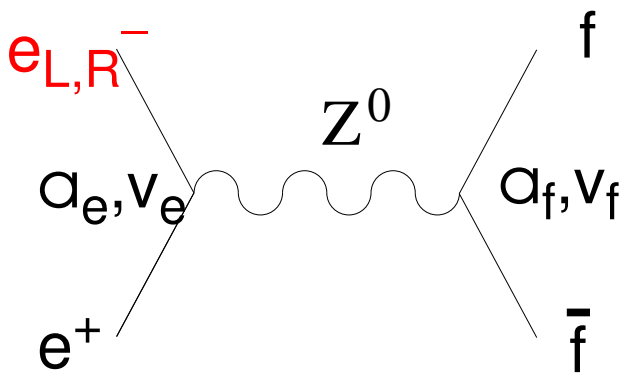
The SLD Detector



Features of SLD:

- CCD Vertex Detector: ~300x10^6 22 x 22 μm^2 pixels (VXD3)
- Cherenkov Ring Imaging Detector: π/K/p separation
- Impact Parameter Resolution: $\sigma_{r\phi} = \frac{76}{p_T \sin\theta} + 11\mu$
- Momentum Resolution: $\frac{\sigma_{p_T}}{p_T} = (0.0095 + 0.0026)\, p_T$
- Energy Resolution: $\frac{\sigma_E}{E} = \frac{0.15}{\sqrt{E}}$ (EM) $\frac{\sigma_E}{E} = \frac{0.60}{\sqrt{E}}$ (HAD)

Polarization Dependent EW Asymmetries



$$a_f = T^3{}_f$$

$$v_f = T^3{}_f - 2Q_f \sin^2\theta_w$$

$$A_f = \frac{2 v_f a_f}{v_f^2 + a_f^2}$$

$$\frac{d\sigma}{dx} \propto (1 - P_e A_e)\,(1 + x^2) + 2\,(A_e - P_e)\,A_f x$$

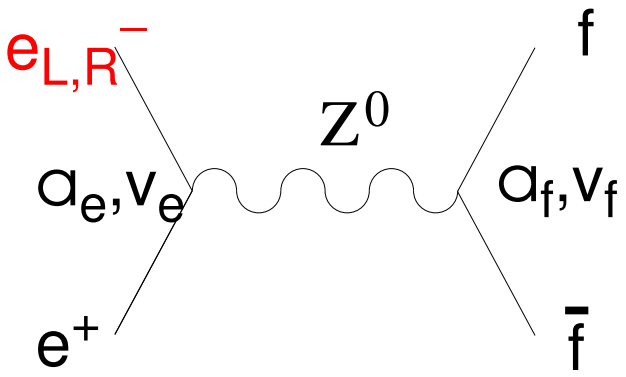
$$x \equiv \cos\theta$$

Left-Right Asymmetry

$$A_{LR} = \frac{\sum_f \int_{-c}^{c} \left(\frac{d\sigma_L}{dx}\right) dx - \sum_f \int_{-c}^{c} \left(\frac{d\sigma_R}{dx}\right) dx}{\sum_f \int_{-c}^{c} \left(\frac{d\sigma_L}{dx}\right) dx + \sum_f \int_{-c}^{c} \left(\frac{d\sigma_R}{dx}\right) dx} \bullet \frac{1}{P_e}$$

$$= A_e \equiv 2\,(1 - 4\sin\theta_w^2)^2 / (1 + (1 - 4\sin\theta_w^2)^2)$$

$\rightarrow$ independent of A_f



$$A_f = \frac{2 v_f a_f}{v_f^2 + a_f^2}$$

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

$$x \equiv \cos\theta$$

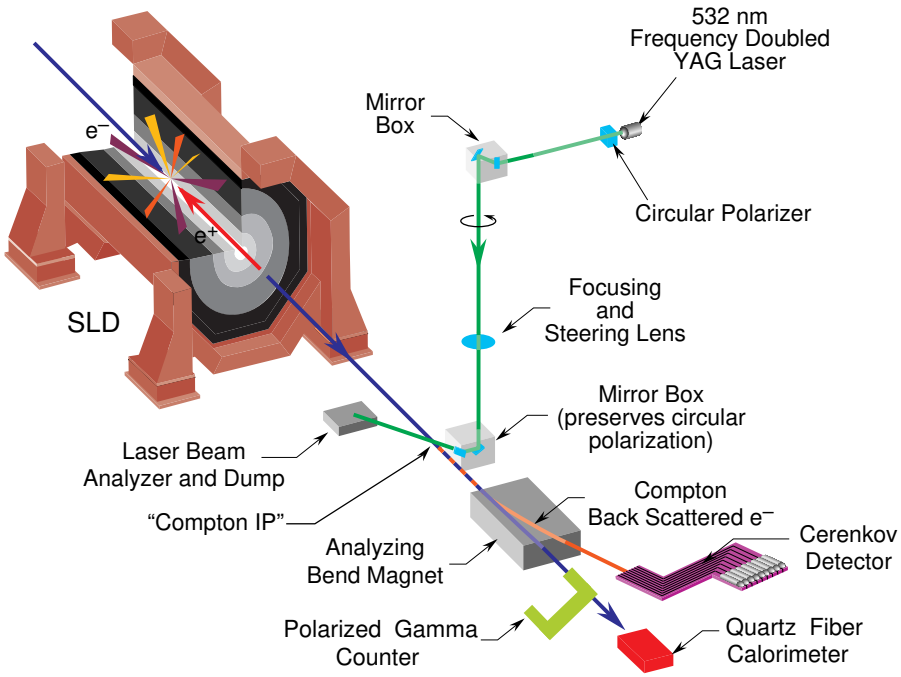
Polarized Forward-Backward Asymmetry

$$\tilde{A}_{FB}(x) = \frac{\left[\frac{d\sigma_f^L(x)}{dx} - \frac{d\sigma_f^L(-x)}{dx}\right] - \left[\frac{d\sigma_f^R(x)}{dx} - \frac{d\sigma_f^R(-x)}{dx}\right]}{\left[\frac{d\sigma_f^L(x)}{dx} + \frac{d\sigma_f^L(-x)}{dx}\right] + \left[\frac{d\sigma_f^R(x)}{dx} + \frac{d\sigma_f^R(-x)}{dx}\right]}$$

$$= \frac{2x}{1 + x^2} A_f \bullet P_e$$

$\rightarrow$ independent of A_e

Polarization Measurement



New polarization developments:

1. A new photocathode in 1997/8 has poorer performance (73%) than the ones used in 1994/5 and 1996 (77%).

2. Two new devices, the Polarized Gamma Counter and the Quartz Fiber Calorimeter measure the beam polarization with backscattered photons and check the backscattered electron measurements of the primary Cerenkov detector.
   $\rightarrow$ Preliminary analyses agree at the $< 1\%$ level.

3. New calculations of the first-order radiative corrections to polarized Compton scattering by M. Swartz (hep-ph/9711447) and by Dittmaier and Denner (hep-ph/9805443) verify that radiative corrections alter the extracted value of $\mathcal{P}_e$ by -0.1% of itself.

Polarization crosscheck with PGC, QFC

-->these measure energy asymmetry of Compton gammas

(these results still preliminary)

PGC threshold Cherenkov gas counter (ethylene at 1 atm) with variable (1", 1.5", 2") lead preradiator; PMT readout

1996 PGC vs CKV comparison:

PGC: $P = (0.747 \pm 0.005)$
CKV: $P = (0.756 \pm 0.006)$

1998 PGC vs CKV comparison: analysis not complete

QFC quartz fiber (tungsten radiator) calorimeter; PMT readout

1997 QFC vs CKV comparison:

QFC: $P = (0.735 \pm 0.004 \pm 0.007)$
CKV: $P = (0.732 \pm 0.001 \pm 0.008)$

1992-1998 Polarization Summary

The luminosity-weighted average polarization for each run is:

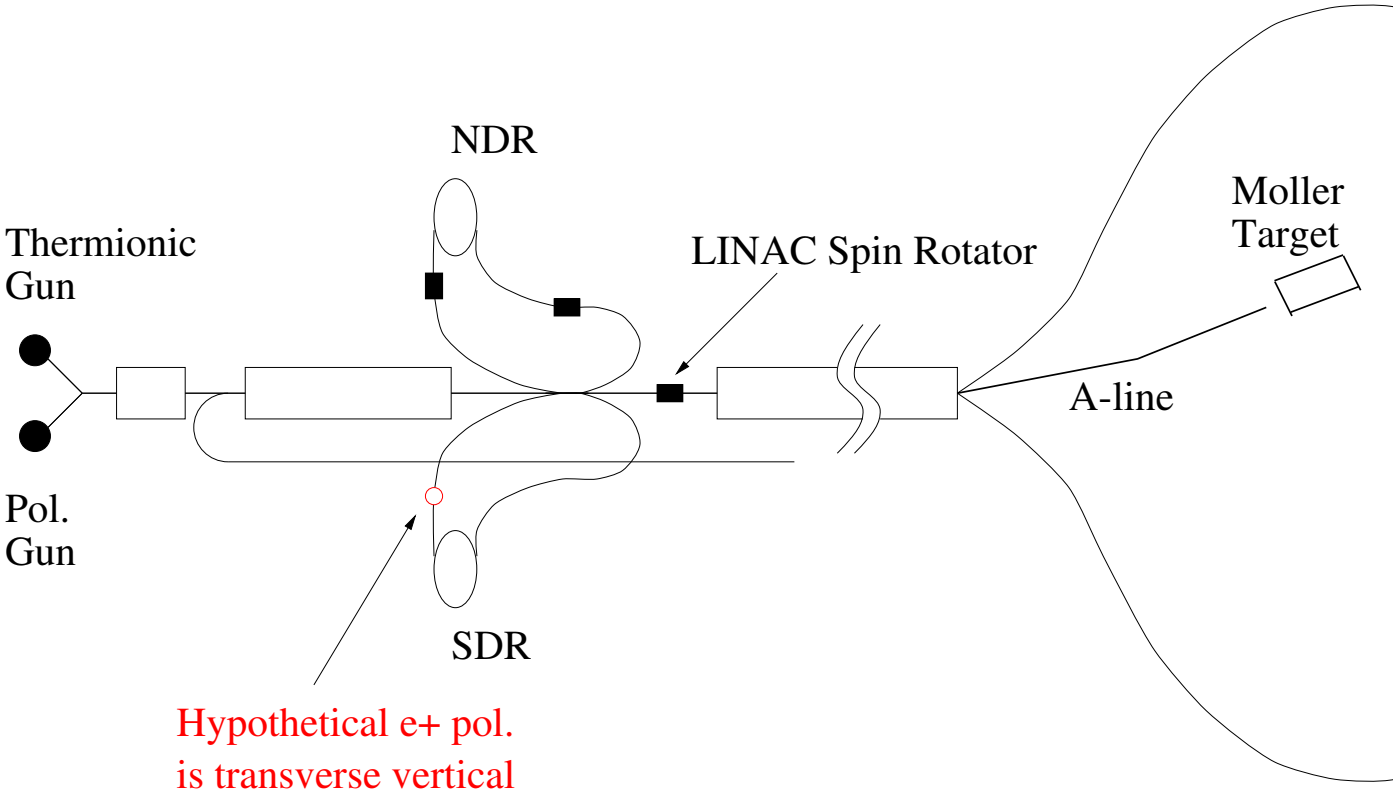
- $\mathcal{P}_e = 0.224 \pm 0.006 \quad (1992)$
- $\mathcal{P}_e = 0.626 \pm 0.012 \quad (1993)$
- $\mathcal{P}_e = 0.772 \pm 0.005 \quad (1994/5)$
- $\mathcal{P}_e = 0.765 \pm 0.005 \quad (1996^*)$
- $\mathcal{P}_e = 0.733 \pm 0.008 \quad (1997^*)$
- $\mathcal{P}_e = 0.731 \pm 0.008 \quad (1998^*)$

Systematic Uncertainties on the Polarization Scale

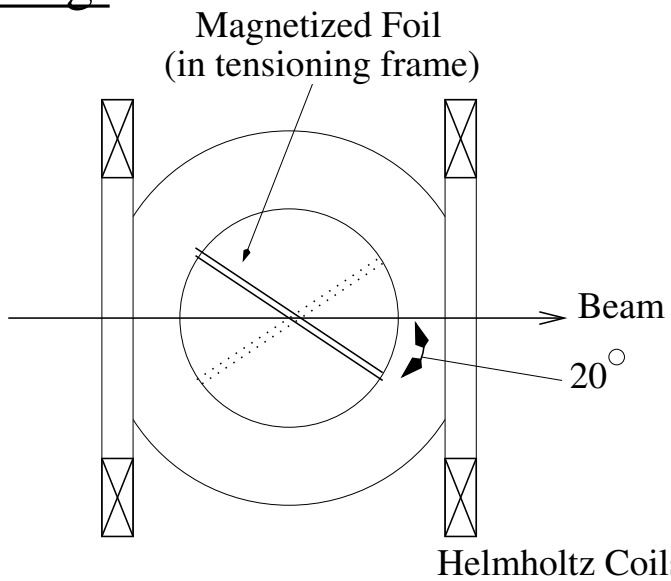
Uncertainty	$\delta\mathcal{P}_e/\mathcal{P}_e$ 1992	$\delta\mathcal{P}_e/\mathcal{P}_e$ 1993	$\delta\mathcal{P}_e/\mathcal{P}_e$ 1994/5	$\delta\mathcal{P}_e/\mathcal{P}_e$ 1996*	$\delta\mathcal{P}_e/\mathcal{P}_e$ 1997*	$\delta\mathcal{P}_e/\mathcal{P}_e$ 1998*
Laser Polarization	2.0%	1.0%	0.20%	0.20%	0.20%	0.10%
Detector Linearity	1.5%	1.0%	0.50%	0.50%	0.50%	0.50%
AP Calibration	0.4%	0.5%	0.29%	0.30%	0.30%	0.30%
Electronic Noise	0.4%	0.2%	0.20%	0.20%	0.20%	0.20%
Interchannel Consistency	0.9%	0.5%	—	—	0.80%	0.80%
Polarimeter Uncertainty	2.7%	1.6%	0.64%	0.64%	1.03%	1.03%
Chromaticity (ξ)	—	1.1%	0.17%	0.18%	0.07%	0.08%
Total $\mathcal{P}_e$ Uncertainty	2.7%	1.9%	0.67%	0.67%	1.03%	1.03%

*1996-8 results are preliminary

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



Moller Target



P_{e^+} = - 0.02 + 0.07% (preliminary)

($\delta(P_{e^+})$= 0.07% --> $\delta(\sin^2\theta_w^{eff})$ = 0.00009)

A_{LR} Measurement

$$A_{LR} = \frac{1}{\mathcal{P}_e} \frac{N_Z(L) - N_Z(R)}{N_Z(L) - N_Z(R)} = \frac{1}{\mathcal{P}_e} A_m$$

Helicity of the SLC e^- beam chosen pseudo-randomly pulse-to-pulse (to excellent approximation, $\mathcal{L}_L = \mathcal{L}_R$). To measure A_{LR}:

1. Count hadronic Z events produced with left- and right-handed beams (excluding final state e^+e^- pairs), form asymmetry A_m.
2. Measure the beam polarization $\mathcal{P}_i$ associated with each Z and form the luminosity-weighted average,

   $$\mathcal{P}_e = (1 + \xi) \frac{1}{N_Z} \sum_i^{N_Z} \mathcal{P}_i$$

   where ξ is a small correction (0.001-0.002) for chromatic and beam transport effects.
3. Correct for residual background to Z sample and for residual left-right asymmetries in luminosity, polarization, beam energy, etc.
4. Correct for electroweak interference to extract $A_{LR}^0 = A_e$.

A_{LR} Calculation

The left-right asymmetry at E_{cm} is calculated as follows:

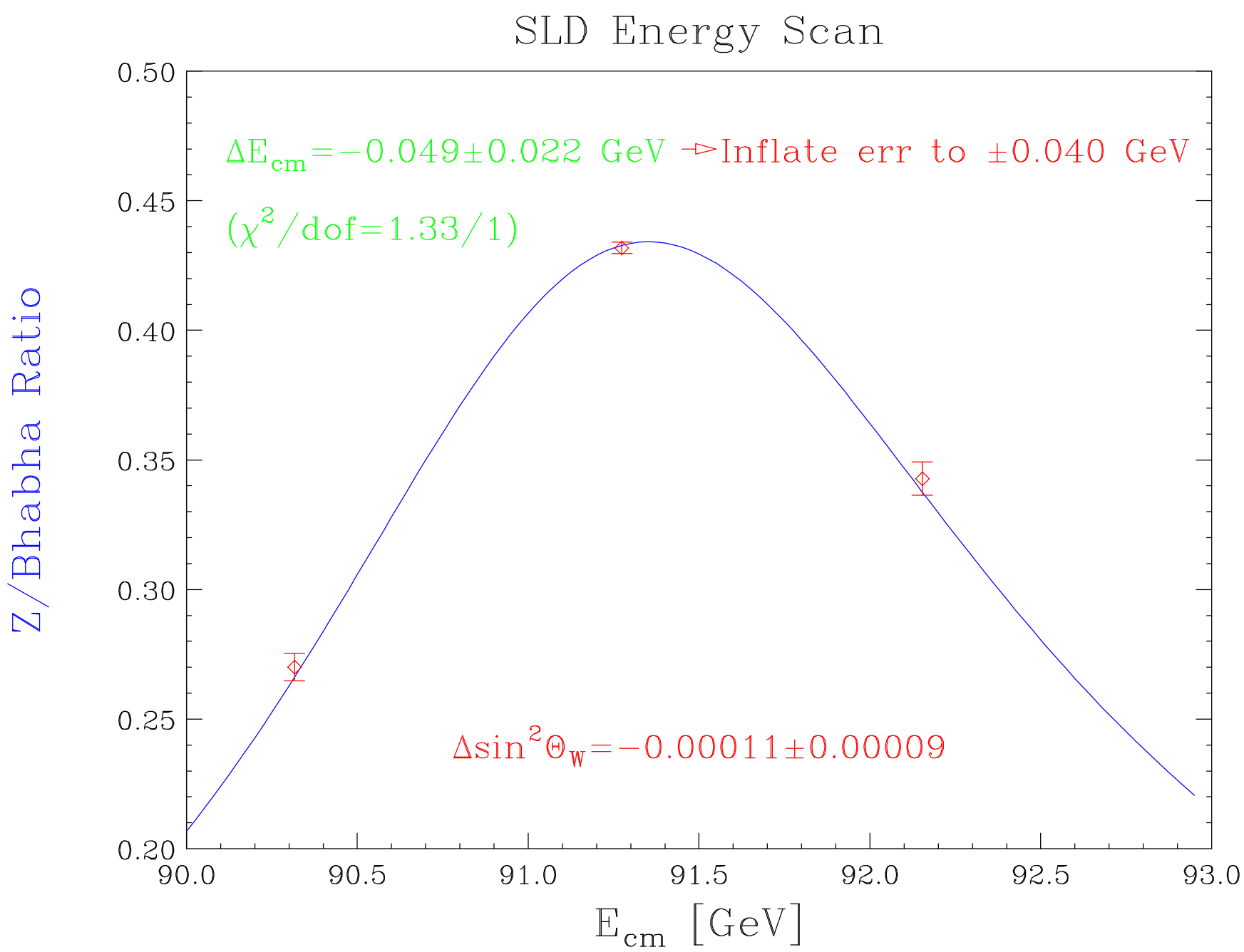
$$A_{LR} = \frac{A_m}{\langle \mathcal{P}_e \rangle} + \frac{1}{\langle \mathcal{P}_e \rangle}\Big[f_b(A_m - A_b) - A_{\mathcal{L}} + A_m^2 A_{\mathcal{P}} - E_{cm}\frac{\sigma'(E_{cm})}{\sigma(E_{cm})}A_E - A_\varepsilon + \langle \mathcal{P}_e \rangle \mathcal{P}_p\Big]$$

where the various quantities (in units of 10^{-4}) are:

Quantity	1992	1993	1994/5	1996*	1997*	1998*
A_m	223 ± 99	1031 ± 46	1144 ± 32	1178 ± 44	1061 ± 31	1060 ± 22
$f_b(A_m - A_b)$	4.7 ± 1.6	1.75 ± 0.72	0.65 ± 0.55	0.65 ± 0.55	0.56 ± 0.55	0.56 ± 0.55
$A_{\mathcal{L}}$	1.8 ± 4.2	0.38 ± 0.50	-1.9 ± 0.3	0.0 ± 0.5	-0.4 ± 0.5	-0.4 ± 0.5
$A_m^2 A_{\mathcal{P}}$	—	-0.35 ± 0.01	0.31 ± 0.13	0.10 ± 0.13	—	—
$E_{cm}\frac{\sigma'(E_{cm})}{\sigma(E_{cm})}A_E$	—	—	—	—	—	—
A_ε	—	—	—	—	—	—
$\langle \mathcal{P}_e \rangle \mathcal{P}_p$	—	—	—	—	—	—
Corr. to A_m	0 ± 4.5	1.0 ± 0.8	2.75 ± 0.79	0.76 ± 0.75	0.22 ± 1.01	0.22 ± 1.01

- **1992** $A_{LR}(91.55\ \text{GeV}) = 0.100 \pm 0.044(\text{stat}) \pm 0.004(\textbf{sys})$
- **1993** $A_{LR}(91.26\ \text{GeV}) = 0.1628 \pm 0.0071(\text{stat}) \pm 0.0028(\textbf{sys})$
- **1994** $A_{LR}(91.28\ \text{GeV}) = 0.1485 \pm 0.0042(\text{stat}) \pm 0.0010(\textbf{sys})$
- **1996** $A_{LR}(91.26\ \text{GeV}) = 0.1541 \pm 0.0057(\text{stat}) \pm 0.0010(\textbf{sys})^*$
- **1997** $A_{LR}(91.26\ \text{GeV}) = 0.1449 \pm 0.0042(\text{stat}) \pm 0.0015(\textbf{sys})^*$
- **1998** $A_{LR}(91.23\ \text{GeV}) = 0.1450 \pm 0.0030(\text{stat}) \pm 0.0015(\textbf{sys})^*$

***1996-8 results are preliminary**

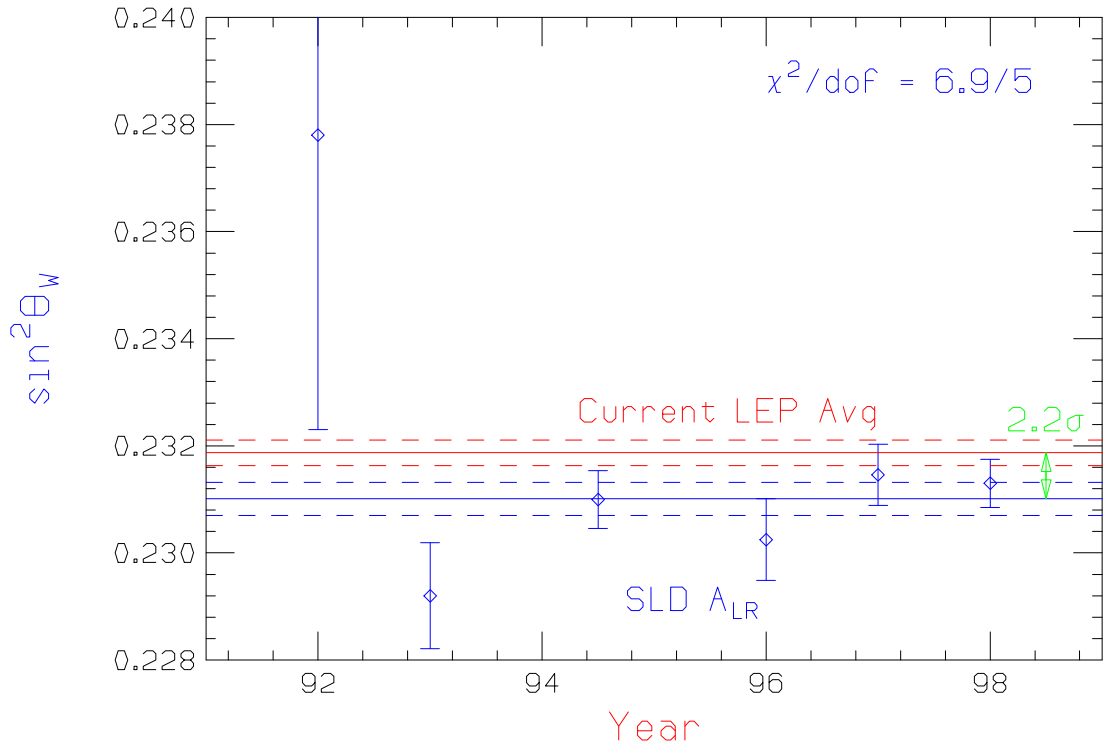

SLD Energy Scan
$\Delta E_{cm} = -0.049 \pm 0.022$ GeV → Inflate err to ±0.040 GeV
(χ^2/dof = 1.33/1)
$\Delta \sin^2\Theta_W = -0.00011 \pm 0.00009$
Z/Bhabha Ratio
E_{cm} [GeV]
0.50
0.45
0.40
0.35
0.30
0.25
0.20
90.0
90.5
91.0
91.5
92.0
92.5
93.0

The Z-Pole Results

After application of the interference corrections, the following results are obtained:

Year	A_{LR}^0	$\sin^2\theta_W^{\rm eff}$
1992	$0.100 \pm 0.044 \pm 0.004$	$0.2378 \pm 0.0056 \pm 0.0005$
1993	$0.1656 \pm 0.0071 \pm 0.0028$	$0.2292 \pm 0.0009 \pm 0.0004$
1994/5	$0.1512 \pm 0.0042 \pm 0.0011$	$0.23100 \pm 0.00054 \pm 0.00014$
1996*	$0.1570 \pm 0.0057 \pm 0.0011$	$0.23025 \pm 0.00073 \pm 0.00014$
1997*(New)	$0.1475 \pm 0.0042 \pm 0.0016$	$0.23146 \pm 0.00054 \pm 0.00020$
1998*(New)	$0.1487 \pm 0.0031 \pm 0.0017$	$0.23130 \pm 0.00039 \pm 0.00022$
Total	0.1510 ± 0.0025	0.23101 ± 0.00031

*1996/8 results are preliminary



Measurement of A_e, A_μ, A_τ from Polarized $Z^0 \rightarrow e^+e^-, \mu^+\mu^-, \tau^+\tau^-$

(i) Direct Measurement of A_μ, A_τ

(ii) Test Universality: $A_e \stackrel{?}{=} A_\mu \stackrel{?}{=} A_\tau$

(iii) Assuming Universality, what is $\sin^2\theta_W^{eff}$?

Analysis Outline

1. Select e^+e^-, $\mu^+\mu^-$, $\tau^+\tau^-$ decay modes

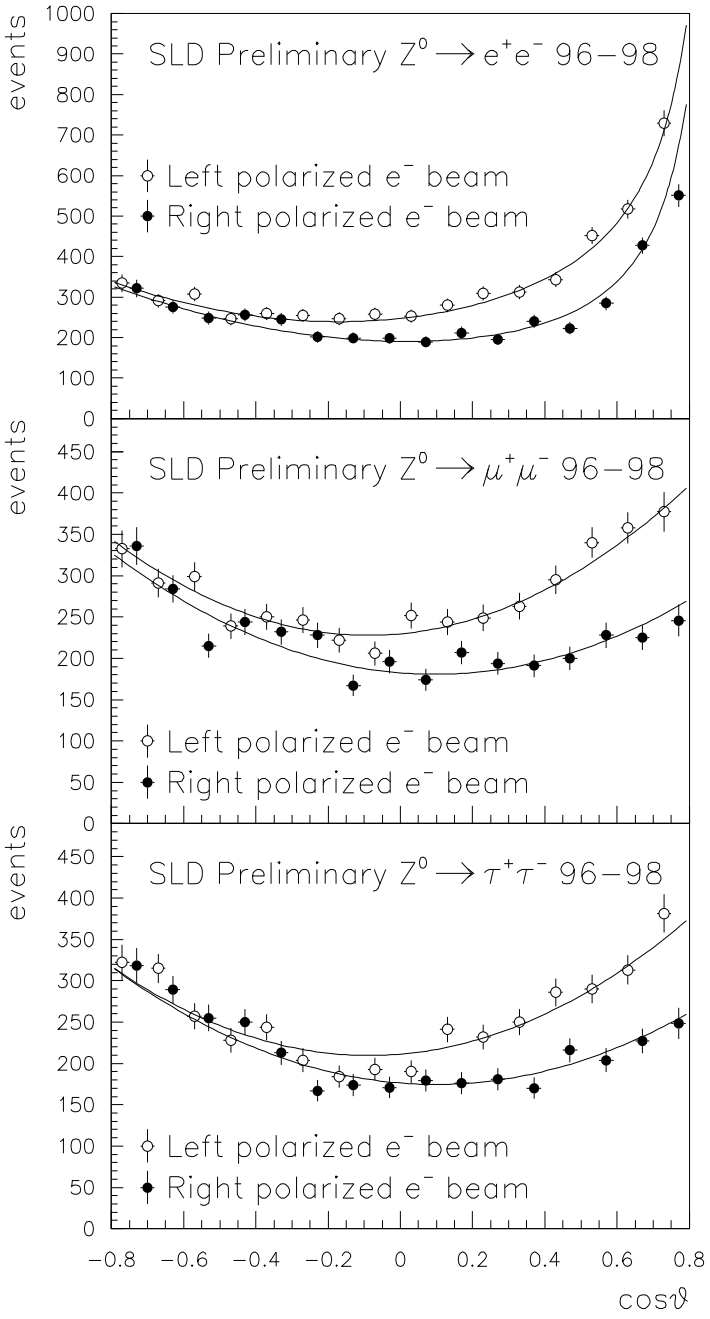
$1 < N_{tracks} < 9$ $\qquad\qquad$ $|\cos\theta| < 0.8$

$\Sigma Q_{hemi1} \times \Sigma Q_{hemi2} = -1$ $\qquad\qquad$ For at least one track, $P > 1$ GeV

e^+e^- Selection	$\mu^+\mu^-$ selection	$\tau^+\tau^-$ selection
$E_{LAC}(p1) + E_{LAC}(p2) > 45$ GeV	Event Mass > 70 GeV	Event Mass < 70 GeV
	$0 < \max E_{LAC}(trk) < 10$	$0 < \max E_{LAC}(trk) < 27.5$ ($\lvert\cos\theta\rvert<0.7$) $0 < \max E_{LAC}(trk) < 20.0$ ($\lvert\cos\theta\rvert>0.7$)
		$\max M_{hemi} < 1.8$GeV
		max(p)>3GeV
		$\theta_{acollinearity}$>160 deg.

(1996-1998)	e^+e^-	$\mu^+\mu^-$	$\tau^+\tau^-$
Events	9419	7564	7088
Efficiency	87.3%	85.5%	78.1%
Purity	98.6%	99.8%	94.6%
Background Source	$\tau^+\tau^-$ (1.2%)	$\tau^+\tau^-$ (0.2%)	e^+e^-(0.7%), 2γ(1.7%), Hadron(0.8%)

Polar Angle Distributions for Left- and Right-Handed e^- beams



2. Perform Maximum Likelihood Fit to extract

$$A_e^{(e)},\ A_e^{(\mu)},\ A_\mu^{(\mu)},\ A_e^{(\tau)},\ A_\tau^{(\tau)}$$

3. Correct for ang. dists. of bkgs, V-A effect:

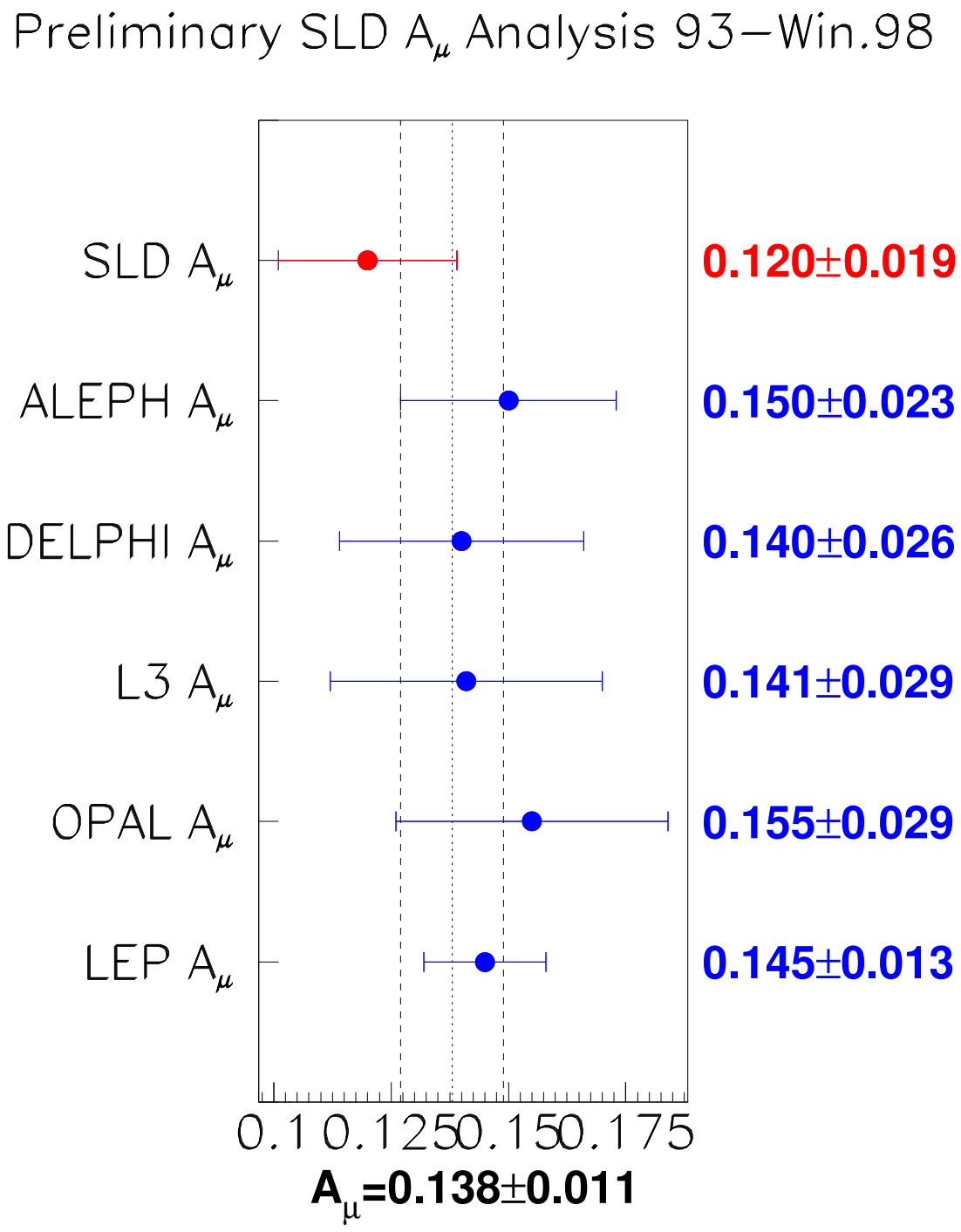
Signal	Source	ΔA_e (x 10^{-4})	ΔA_τ (x 10^{-4})
e^+e^-	$\tau^+\tau^-$ bkg.	4.0 ± 4.0	
$\tau^+\tau^-$	e^+e^- bkg.	0 ± 0	–2 ± 2
	$\gamma\gamma$ bkg.	25 ± 25	18 ± 18
	Had bkg.	0 ± 0	13 ± 13
	V-A		– 130 ± 29
	Total:	25 ± 25	–101 ± 37

A_{lepton} Systematics:

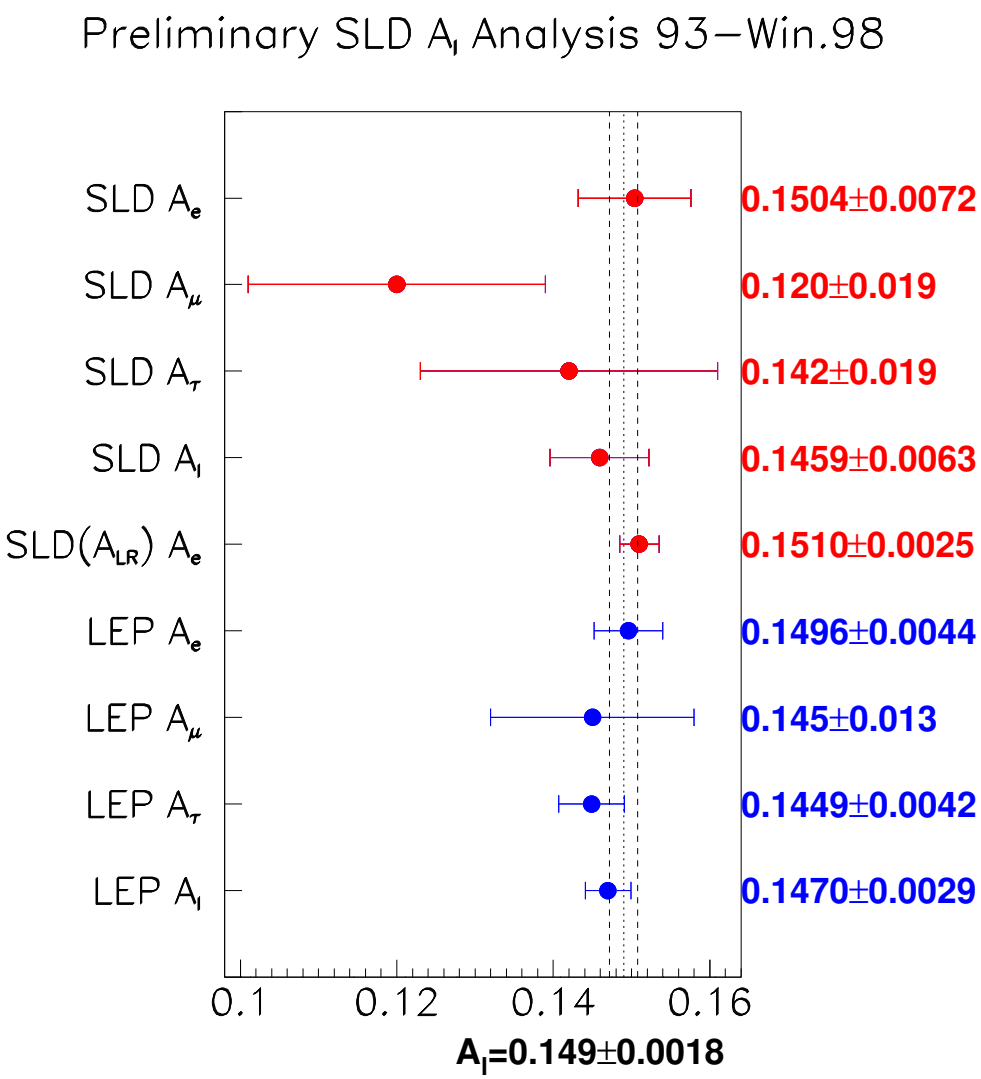
	A_e^e	A_e^μ	A_e^τ	A_μ^μ	A_τ^τ
Pol.	16	16	16	16	16
BKG.	4		25		22
Rad.Corr.	30	3	3	4	3
V-A					29
Thrust					
Total	34	16	30	16	40

A_{lepton} Results (1993-1998):

A_e	0.1504 ± 0.0072
A_μ	0.120 ± 0.019
A_τ	0.142 ± 0.019
$A_{e\text{-}\mu\text{-}\tau}$	0.1459 ± 0.0063


Preliminary SLD A_μ Analysis 93–Win.98
SLD A_μ
ALEPH A_μ
DELPHI A_μ
L3 A_μ
OPAL A_μ
LEP A_μ
0.120±0.019
0.150±0.023
0.140±0.026
0.141±0.029
0.155±0.029
0.145±0.013
0.1 0.125 0.15 0.175
A_μ=0.138±0.011

Summary of Results

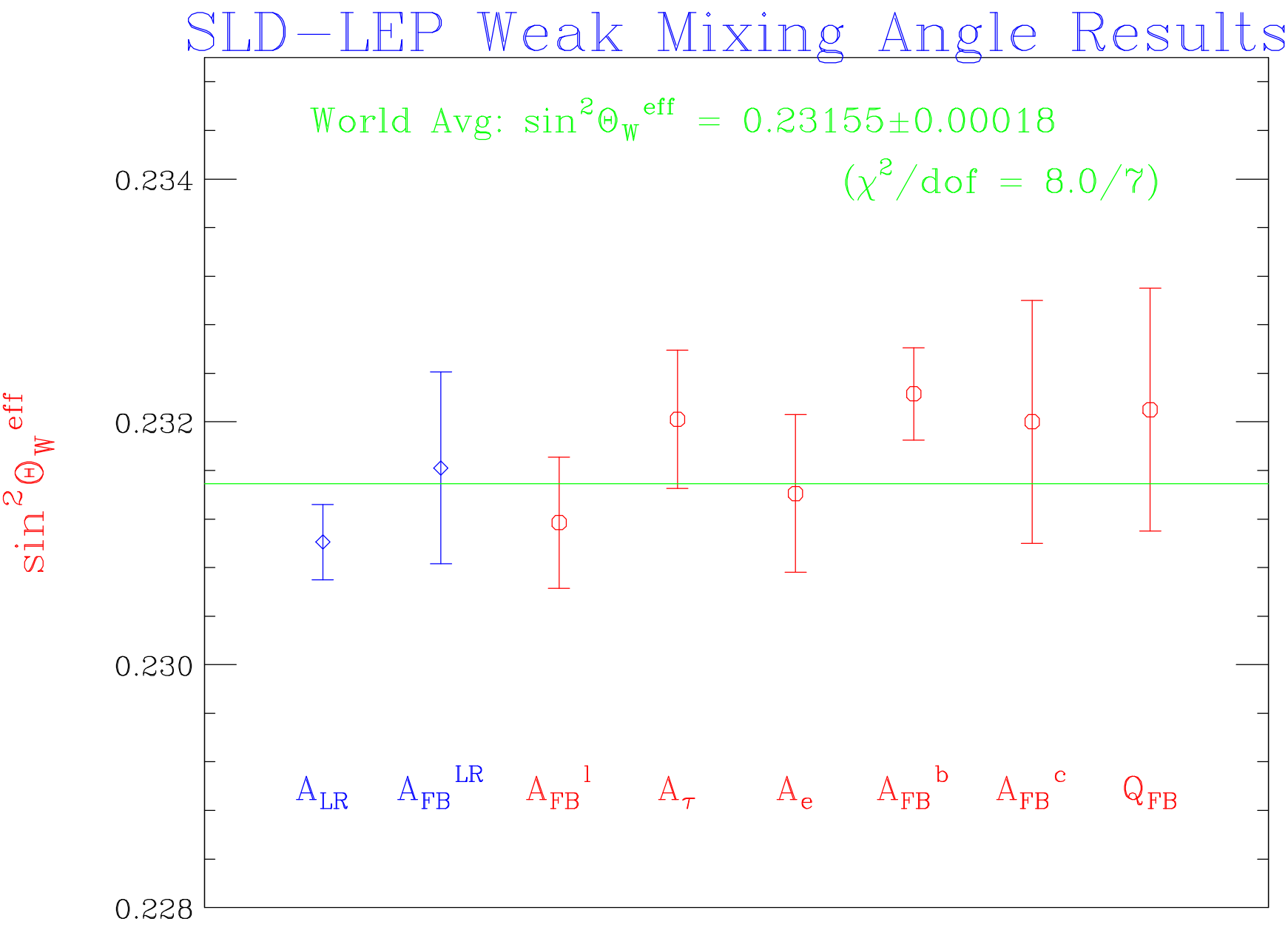


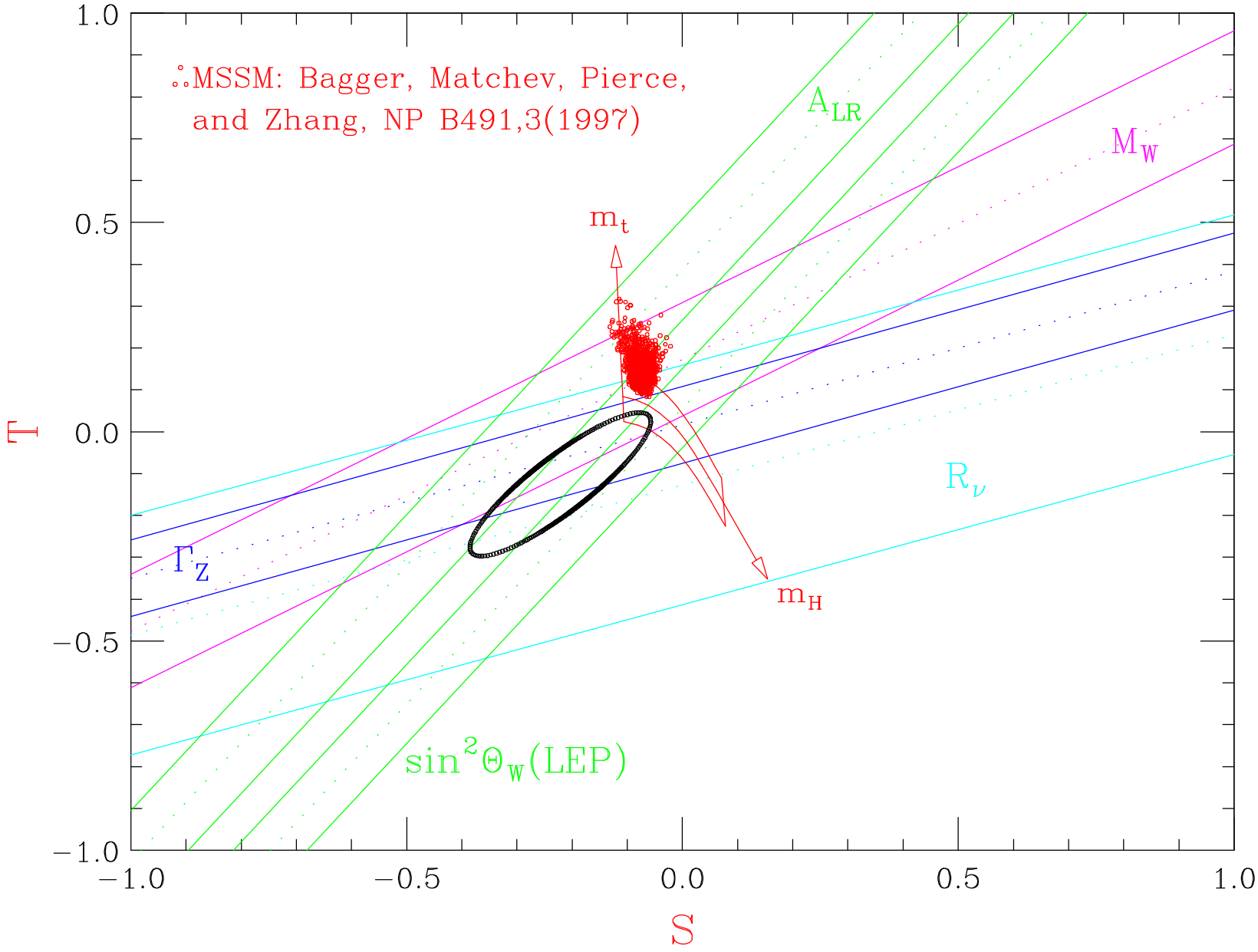
SLD $\sin^2\theta_w^{eff}$(leptons) = 0.2317 ± 0.0008

combined w/A_{LR} results (0.23101± 0.00031)

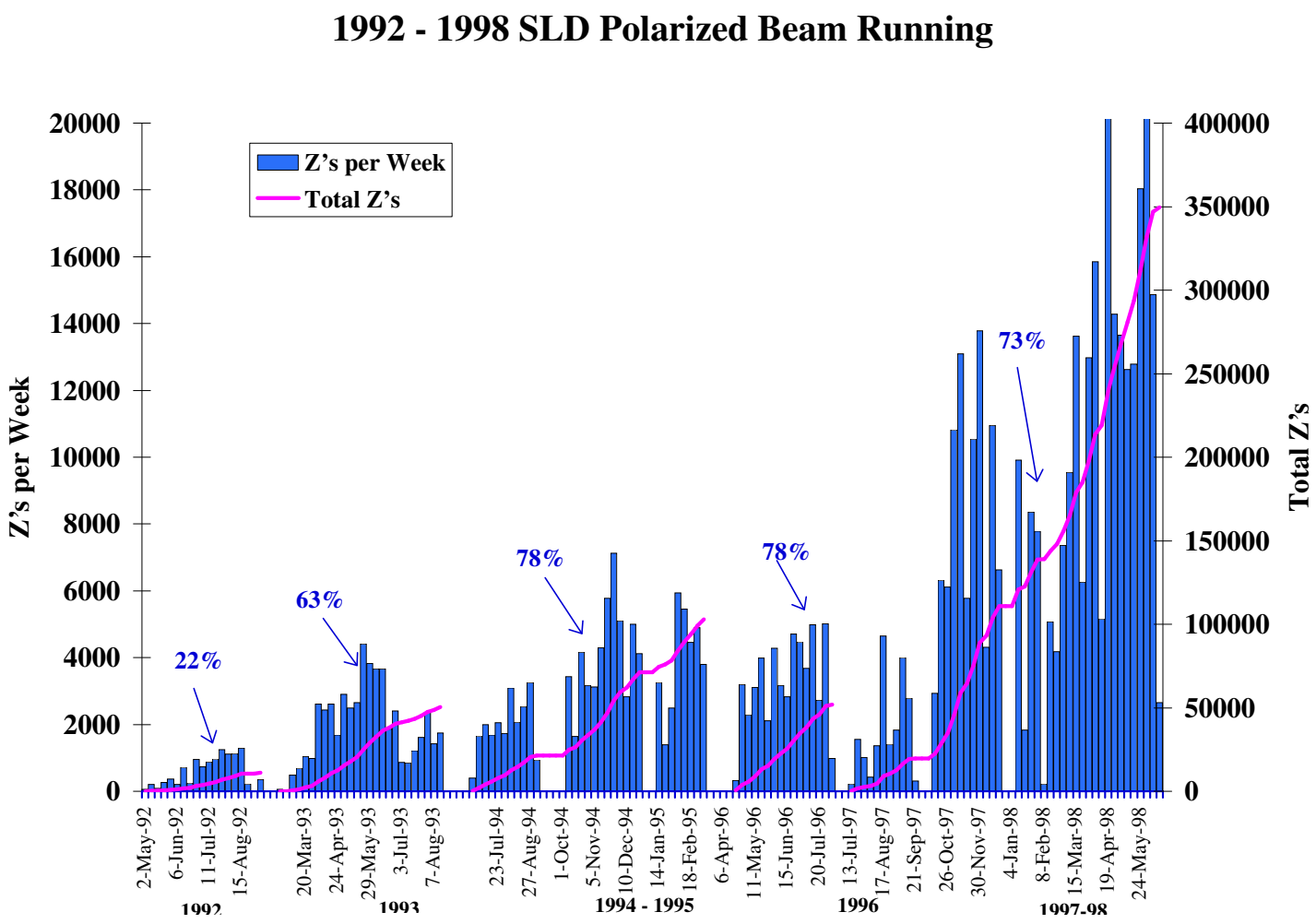
→ SLD Combined $\sin^2\theta_w^{eff}$ = 0.23110 ± 0.00029

(preliminary 1993-98)


SLD−LEP Weak Mixing Angle Results
World Avg: sin²Θ_W^eff = 0.23155±0.00018
(χ²/dof = 8.0/7)
sin²Θ_W^eff
0.234
0.232
0.230
0.228
A_LR
A_FB^LR
A_FB^l
A_τ
A_e
A_FB^b
A_FB^c
Q_FB


∴MSSM: Bagger, Matchev, Pierce,
and Zhang, NP B491,3(1997)
A_LR
M_W
m_t
R_ν
Γ_Z
m_H
sin²Θ_W(LEP)
1.0
0.5
0.0
−0.5
−1.0
T
S

Future Plans



In light of the excellent 1997-1998 run, the SLD Collaboration has asked for a run extension with the goal of obtaining >700K additional Z^0's (double overall dataset, triple VXD3 dataset).

- A_{LR} and A_{lepton} measurements still statistically limited (and will be for another 2+ Million Z^0's)!
- Many other precision measurements to make!