Experimental Considerations for NLC-90

SLD Kirkwood 2000 Meeting
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M. Woods, SLAC
(assisted by P. Rowson)

Motivation: precise weak mixing angle, Z-width msmts
- see Marciano's talk
- uncertainty in $\sin^2\theta_W^{eff}$ vs #Zs

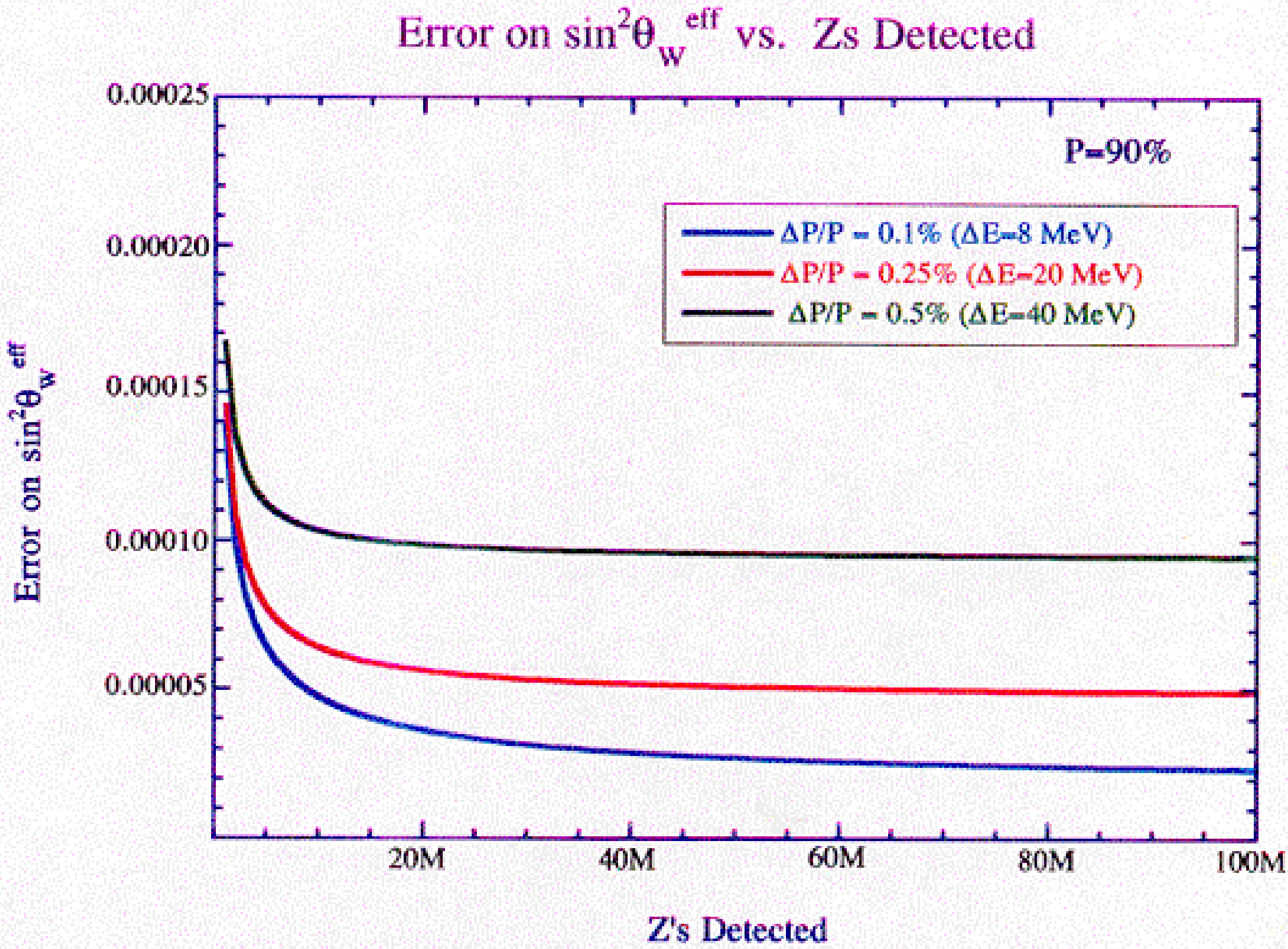
Polarimetry measurements, depolarization effects

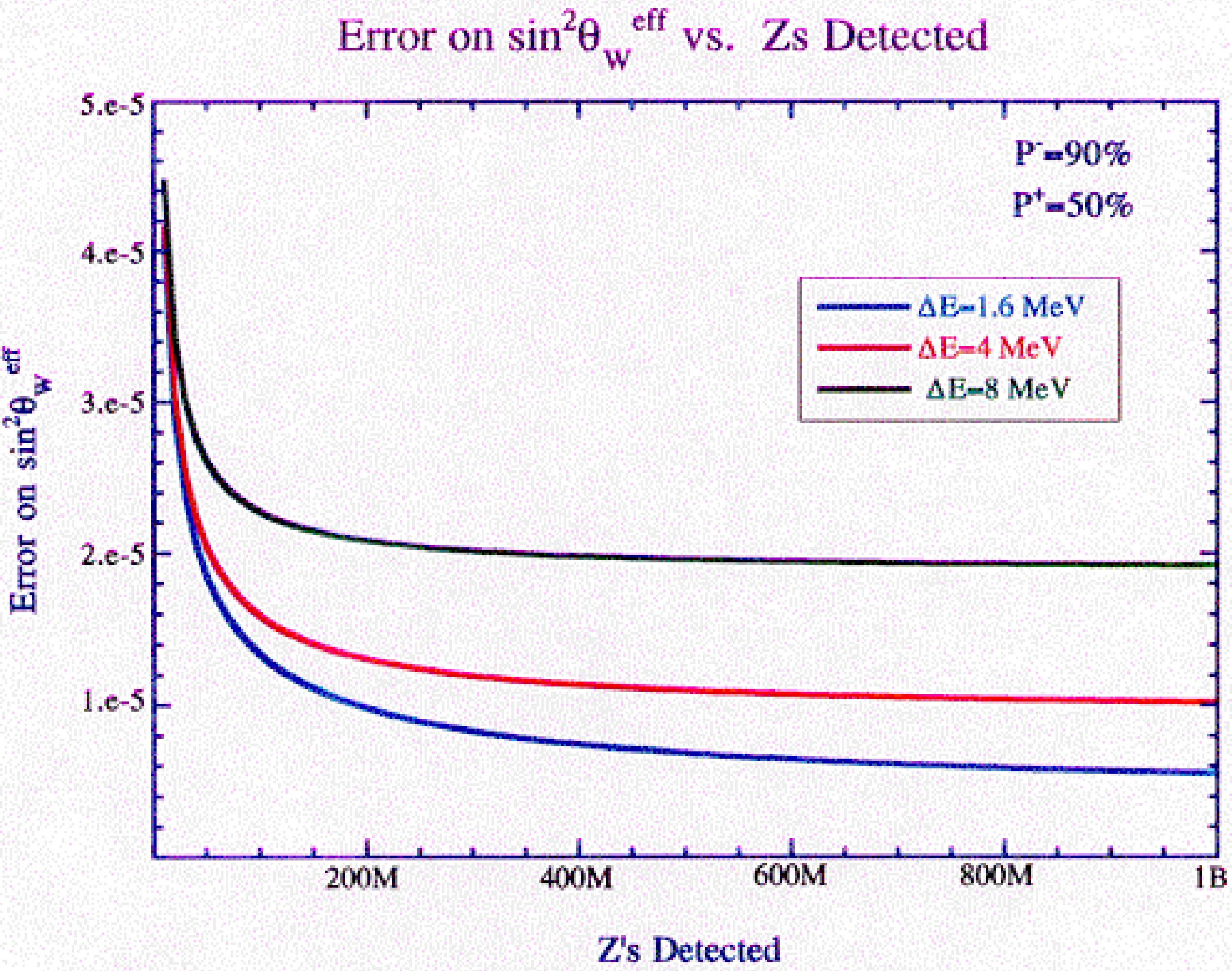
Energy measurements, beamsstrahlung effects

Z-rate effects (multiple Zs per train)

Luminosity measurements, luminosity asymmetries

Extraction Line Design


Error on $\sin^2\theta_W^{eff}$ vs. Zs Detected
P=90%
ΔP/P = 0.1% (ΔE=8 MeV)
ΔP/P = 0.25% (ΔE=20 MeV)
ΔP/P = 0.5% (ΔE=40 MeV)
Error on $\sin^2\theta_W^{eff}$
0.00025
0.00020
0.00015
0.00010
0.00005
20M
40M
60M
80M
100M
Z's Detected



Error on $\sin^2\theta_W^{eff}$ vs. Zs Detected
5.e-5
4.e-5
3.e-5
2.e-5
1.e-5
Error on $\sin^2\theta_W^{eff}$
P^-=90%
P^+=50%
ΔE=1.6 MeV
ΔE=4 MeV
ΔE=8 MeV
200M
400M
600M
800M
1B
Z's Detected

Tor's NLC-90 Parameters

	Preliminary! IP Parameters for low energy IR						TESLA-90	
	90 GeV			250 GeV				
	Nominal	Semi-High	Round	Nominal	Semi-High	Round	Nominal	Low
Luminosity (10^{33})	1.3	1.7	4.1	2.7	4.4	7.7	6.5	2.0
Pinch Enhancement	1.3	1.4	4.4	1.4	1.4	3.9		
Repetition Rate (Hz)	60	60	60	60	60	60	5	5
Bunch Charge (10^{10})	1	0.75	0.7	1	0.75	0.7	2.	1.2
Bunches/RF Pulse	95	190	190	95	190	190	2820	2820
Bunch Separation (ns)	2.8	1.4	1.4	2.8	1.4	1.4	337	337
Injected $\gamma\varepsilon_x$ / $\gamma\varepsilon_y$ (10^{-8})	300 / 3	300 / 2	300 / 3	300 / 3	300 / 2	300 / 3		
$\gamma\varepsilon_x$ at IP (10^{-8} m-rad)	400	360	360	400	360	360	1000	1000
$\gamma\varepsilon_y$ at IP (10^{-8} m-rad)	6	3.5	5	7	4	5	3	3
Tolerances	10	10	13	9	9	10		
β_x / β_y at IP (mm)	10 / 0.10	10 / 0.10	1 / 1	10 / 0.12	10 / 0.10	1.3 / 1.3	15/0.4	15/0.4
σ_x / σ_y at IP (nm)	670 / 8	632 / 6	200 / 24	400 / 6	384 / 4	140 / 16	1300/12	1300/12
σ_z at IP (um)	125	100	125	125	100	125	400	400
L0 / Ltotal (%)	55	62	13	40	48	9		
Yave	0.01	0.01	0.03	0.06	0.06	0.12		
Beamstrahlung δB (%)	0.28	0.22	4.2	1.7	1.3	13.9	0.10	0.03
Photons per e+/e-	0.6	0.5	2.5	1	0.8	3.1		
Polarization loss (%) ??	0.1	0.1	0.6	0.3	0.2	1.7		

Polarization Measurements

Two Possibilities at NLC-90: Compton polarimetry and ‘Blondel scheme’

1. Only electron beam is polarized.

Use Compton Polarimetry:

Uncertainty	SLC-90 δP/P	NLC-90 Goal δP/P
Laser Pol.	0.1%	0.1%
Linearity	0.2%	0.1%
Electr. Noise	0.2%	0.05%
Anal. Pwr. Cal.	0.4%	0.2%
Total	0.50%	0.25%

- use multichannel electron spectrometer (and if possible, Compton gamma detector in dedicated electron-only runs)
- check calibration against W-pair asymmetry when operate above W-pair threshold!
- correct for any depolarization effect (expected to be <0.1%) by comparing polarization measurement with and without collisions

2. Both electron and positron beams are polarized.

$$P^- = 90\%, P^+ = 50\%$$
$$\frac{\delta P^-}{P^-} = 0.25\%, \frac{\delta P^+}{P^+} = 0.25\%$$

$$P_{eff} = \frac{P^- + P^+}{1 + P^- P^+} = 96.55\%$$
$$\frac{\delta P_{eff}}{P_{eff}} = 0.10\%$$
$$\frac{N_{LR} - N_{RL}}{N_{LR} + N_{RL}} = P_{eff} A_{LR}$$

Can also use 'Blondel scheme' to determine beam polarizations directly:

$$\frac{N_{LL} + N_{LR} - N_{RL} - N_{RR}}{N_{LL} + N_{LR} + N_{RL} + N_{RR}} = P^- A_{LR}$$
$$\frac{N_{RR} + N_{LR} - N_{RL} - N_{LL}}{N_{RR} + N_{LR} + N_{RL} + N_{LL}} = P^+ A_{LR}$$

- using Blondel technique, just need Compton polarimeters for measuring polarization differences between L,R states; and only need to spend approx. 10% of running time in N_{RR}, N_{LL} states
- this technique directly measures lum-wted polarizations (any depolarization effect properly taken into account)

Polarized Positrons?

$$\frac{N_{LR} - N_{RL}}{N_{LR} + N_{RL}} = P_{eff} A_{LR}$$

$\Rightarrow$

Need to understand relative detector efficiency for 'RL' and 'LR' modes at level of 10^{-4}

Need to measure polarization difference, $P_R^+ - P_L^+$, at level of 10^{-3}

This will be difficult unless can measure these modes simultaneously, ie. can switch positron polarization randomly pulse-to-pulse, as is done for electrons.

Note: even if positrons are nominally unpolarized, need to verify this!

$$\boxed{\delta(A_{LR}) = P^+}$$

For $\delta(A_{LR})=4 \times 10^{-4}$, want $\delta(P^+)<2\times10^{-4}$. SLD's 'posipol' measurement achieved $\delta(P^+)=7\times10^{-4}$. (This is relevant for electron-only A_{LR} measurement, which is a factor 5 better than SLD's result.)

Beam Energy/Spectrum Measurements and Luminosity Spectra Measurements

The Lum-wted E_{CM} needs to be accurately determined. This requires an accurate measurement of the undisrupted beam energy and a correction for beamstrahlung effects. To correct for the beamstrahlung, there are 2 approaches:

Method 1 uses beam energy and beam spectrum diagnostics for measuring both the disrupted and undisrupted beam. (SLD approach)

Method 2 uses a beam energy measurement for the undisrupted beam, and a luminosity spectrum measurement -- ex. small angle Bhabhas. (proposed approach for top threshold scan)

1. Beam Energy/Spectrum Measurements
   - i) SLC-style Synchrotron Spectrometer
   - ii) LEP2-style BPM Spectrometer
   - iii) Moller/Bhabha Scattering from a hydrogen gas jet target (was proposed but not built for LEP2)
   - iv) wire scans at a high dispersion point

   - for absolute calibration of these devices, can cross-calibrate to Z Mass with a Z-peak scan
     (what will be time stability of these calibrations -- hours? days?)

2. Luminosity Spectra Measurements

- use small angle Bhabha event kinematics (energies, angles) to deduce beamstrahlung effect given undisrupted beam energy measurement and ISR calculations
  - this has been studied for top threshold scans to determine energy scale uncertainty at level of 100 MeV
- Panvini is using SLD mu-pair events in a similar way; in progress

both Method 1 and Method 2 need a detailed study to determine if can reach desired energy-sensitivity for $\delta(E_{CM}^{lum\text{-}wt})$ of 1-10 MeV

Next, some Guinea-Pig simulations of beamstrahlung effects for

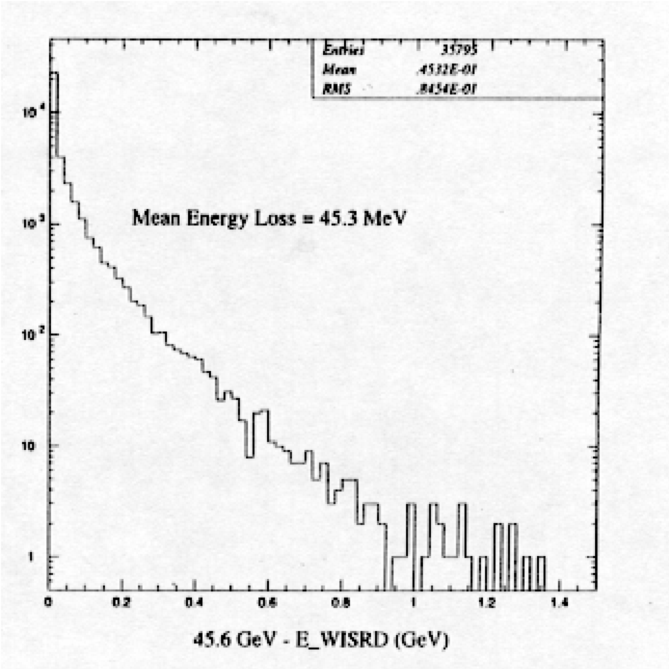
i) SLC-90

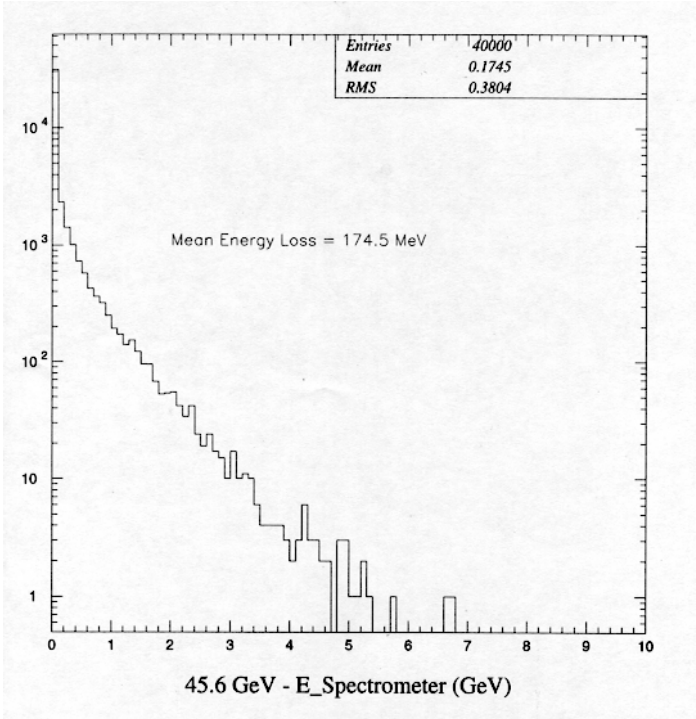
ii) NLC-90

iii) TESLA-90 (Nominal and Low)

These will illustrate the size of the beamstrahlung corrections needed.
(my feeling is it will be hard, but perhaps possible, to understand such corrections with 10% accuracy -- I’m very skeptical of achieving 1% accuracy in these corrections; SLD estimate was 33%)

Compare Beamstrahlung Energy Losses at SLC-90 and NLC-90



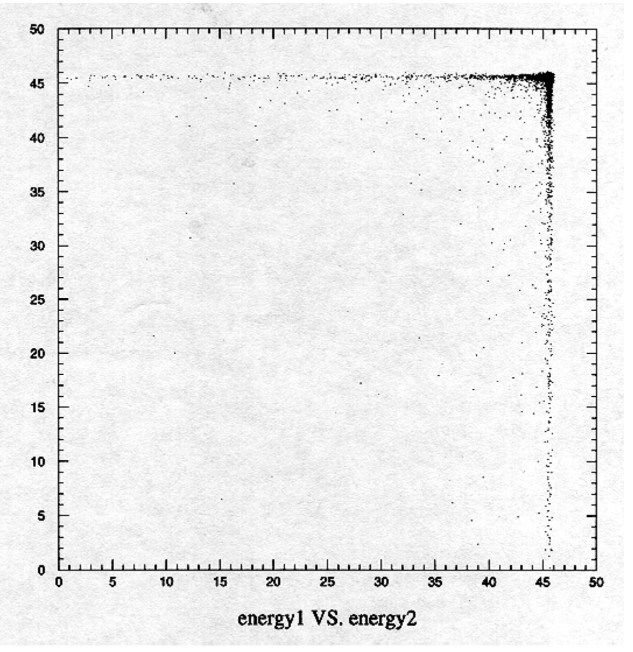


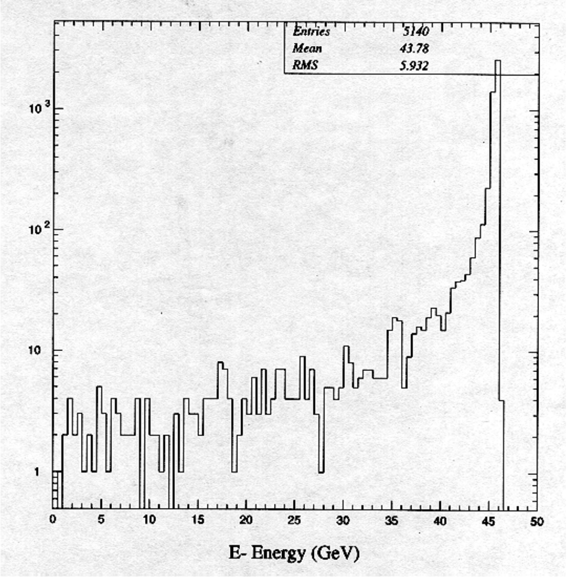
SLC: $L = 2.0 \cdot 10^{30} cm^{-2} s^{-1}$

NLC: $L = 1.3 \cdot 10^{33} cm^{-2} s^{-1}$

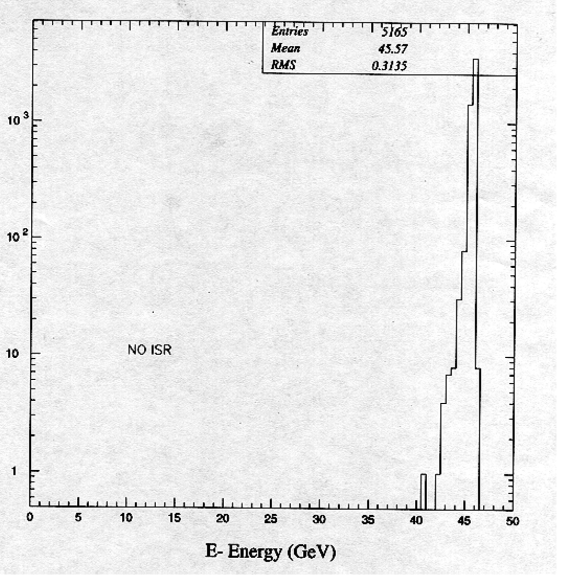
'Guinea-Pig' Simulation

Luminosity Spectra with and without ISR



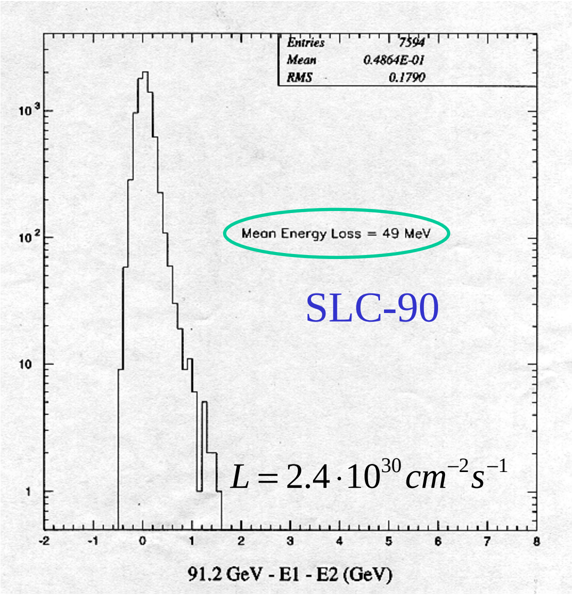


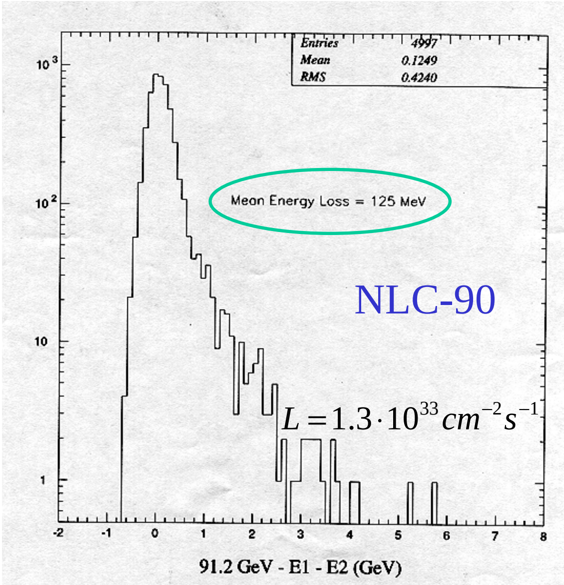
ISR + Beamstrahlung

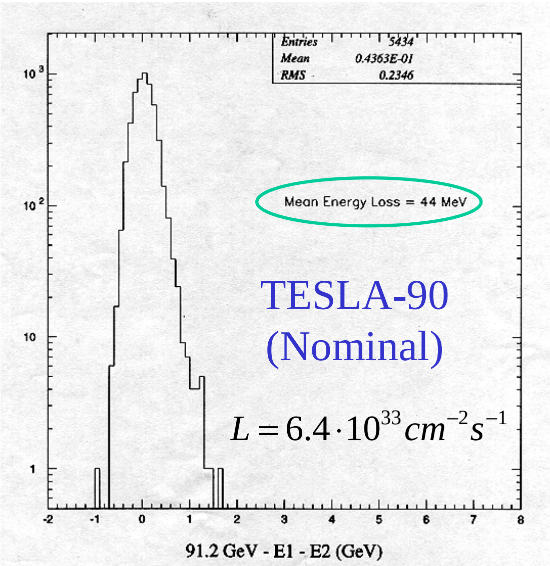


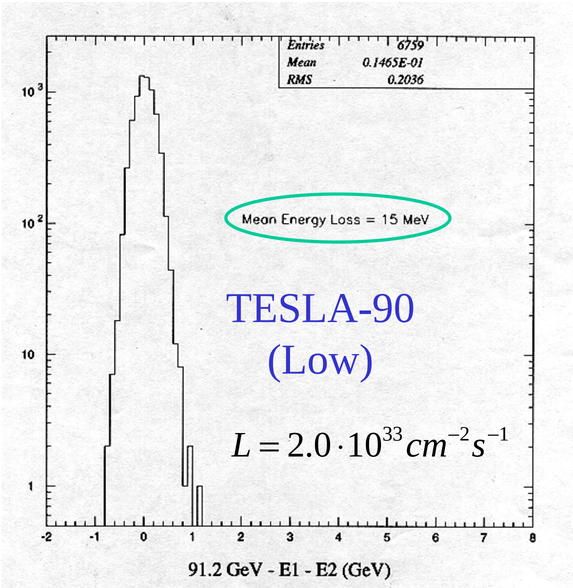
Beamstrahlung Only

Lum-wted E_{CM} Corrections

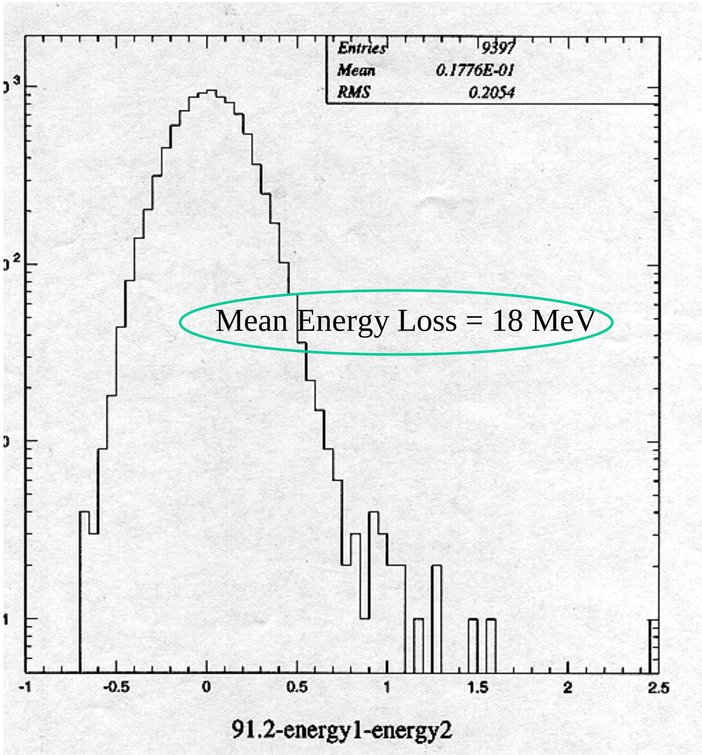




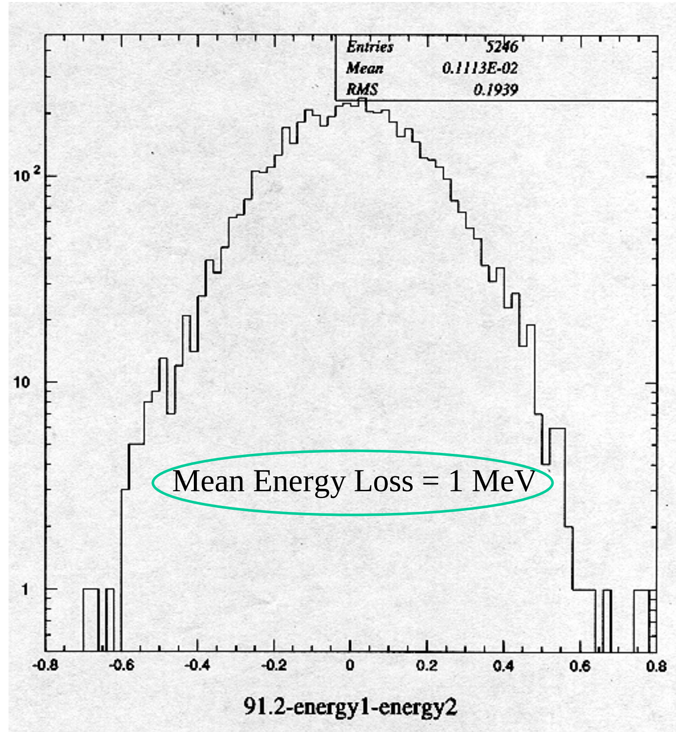




Using NLC-90 Nominal and Tesla-90 Nominal, but increasing β_x by x9.



NLC-90



TESLA-90

$L = 2.9 \cdot 10^{32} cm^{-2} s^{-1}$ @60Hz

$L = 8.6 \cdot 10^{32} cm^{-2} s^{-1}$ @180Hz

$L = 1.5 \cdot 10^{33} cm^{-2} s^{-1}$

Z-Rate Effects
(Multiple Zs per train)

Z Cross-section: $\sigma^Z = 30$ nb,
NLC-90 Luminosity: $L = 1.3 \times 10^{33}\ cm^{-2}s^{-1}$

Z Rate: $R = \sigma^Z \times L = 39$ Z/s

Rep rate = 60Hz, so Z Rate = 0.65 Z/train

=> **52% probability for 0 Zs in a given train**
34% probability for 1 Z in a given train
14% probability for 2 or more Zs in a given train!!

With a data sample of $>10^8$ Zs, need to understand
Z multiplicity distribution with better than 0.02% accuracy

For TESLA-90 (Low) , R= 60 Z/s = 0.0043Z/bunch
=> 99.57% probability for 0 Zs in a given bunch
0.43% probability for 1 Z in a given bunch
9.2e-6 probability for 2 or more Zs in a given bunch
so with data sample of $>10^8$ Zs, need to understand Z multiplicity distribution
with better than 5% accuracy

Luminosity Measurements and Backgrounds

SLD achieved luminosity asymmetries approx. 10^{-4}.

SLAC E158 is working to achieve luminosity asymmetries << 10^{-6}

Can measure luminosity asymmetries with small angle Bhabha detectors. For data samples of >10^{8} Zs, need to understand luminosity asymmetries to better than 10^{-4}. This should be achievable (though could be difficult of different polarization modes are not taken simultaneously).

Need to understand non-Z backgrounds at level of 10^{-4}.
SLD result was 3 x 10^{-4}.

Extraction Line Design

For precise NLC-90 measurements, the extraction line design may not be compatible with high luminosity running of the low energy IR!

May need to reconfigure some aspects of the extraction line between different running modes.

Z Linewidth Measurement

LEP1 Result: 5M Z peak scan gives $\delta(\Gamma_Z)$ = 2.1 MeV (stat); $\delta(\Gamma_Z)$ = 2.4 MeV (stat+syst)

Systematic errors:

i) Beam Energy measurement: 1.2 MeV

ii) Uncertainty in center-of-mass energy spread

$$\delta(E_{CM}^{rms}) = 1MeV \Rightarrow \delta(\Gamma_Z) = 0.2MeV$$

(At LEP1, beam energy spread = 37 MeV; 0.08%)

Could NLC-90 or TESLA-90 achieve $\delta(\Gamma_Z)$ = 1.0 MeV (stat+syst)??

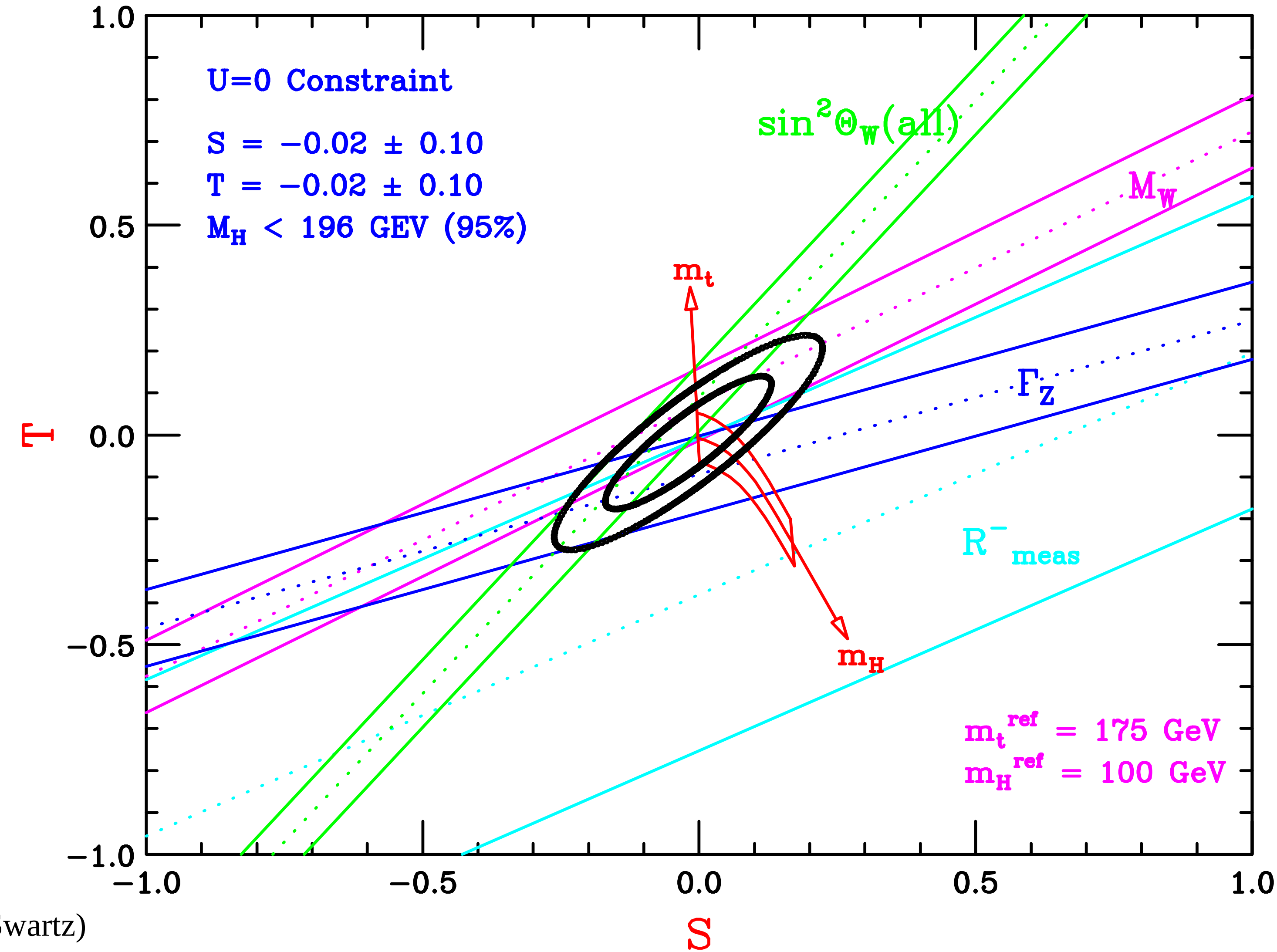
Very unlikely (though easier at TESLA)

- don't have resonant depolarization; need very detailed study to demonstrate feasibility of alternate technique achieving < 1MeV
- want beamsstrahlung correction on $E_{CM}^{lum\text{-}wt}$ < 10 MeV so only need to know correction to 5-10%; but want luminosity high so scan can be done quickly
- need to understand E_{CM} energy spread to < 3-5 MeV
  (NLC-90 0.3% beam energy spread gives E_{CM} energy spread = 190 MeV)

A better electroweak measurement is to improve W mass msmt to $\delta(M_W)$=5-10 MeV

- current uncertainty is 38 MeV (expected to improve to 25 MeV with LEP2 and Tevatron Run 2)
- 5-10 MeV should be achievable at NLC-180, TESLA-180

S-T Plot for All Electroweak Data



(from M. Swartz)

SUMMARY

With only the electron beam polarized, 90%,

→ can improve SLD's A_{LR} measurement by x5 with 0.25% polarimetry and with modest luminosity (use $L=4 \times 10^{32}\ cm^{-2}\ s^{-1}$) to accumulate 50M Zs in 0.4 Snowmass-years. Beamstrahlung correction for $E_{CM}^{lum\text{-}wt}$ should only be about 40 MeV and need to know this with 10 MeV accuracy. **But still need to study problem of understanding the Z multiplicity (to approx 0.2%)**. (This measurement is much easier at TESLA-90.)

With $P^- = 90\%$ and $P^+ = 50\%$,

→ to improve SLD's A_{LR} measurement by x10 or more, need to understand $E_{CM}^{lum\text{-}wt}$ at 5 MeV level and to understand Z multiplicity at level of 0.02% at NLC (5% at TESLA-90).

This measurement probably only makes sense at TESLA-90.

To measure Z width to 1 MeV,

Too hard at NLC-90. Possible, but unlikely, at TESLA-90.

(But improving W mass measurement to 5-10 MeV should be achievable at NLC-180, TESLA-180.)