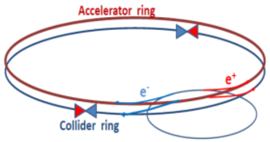
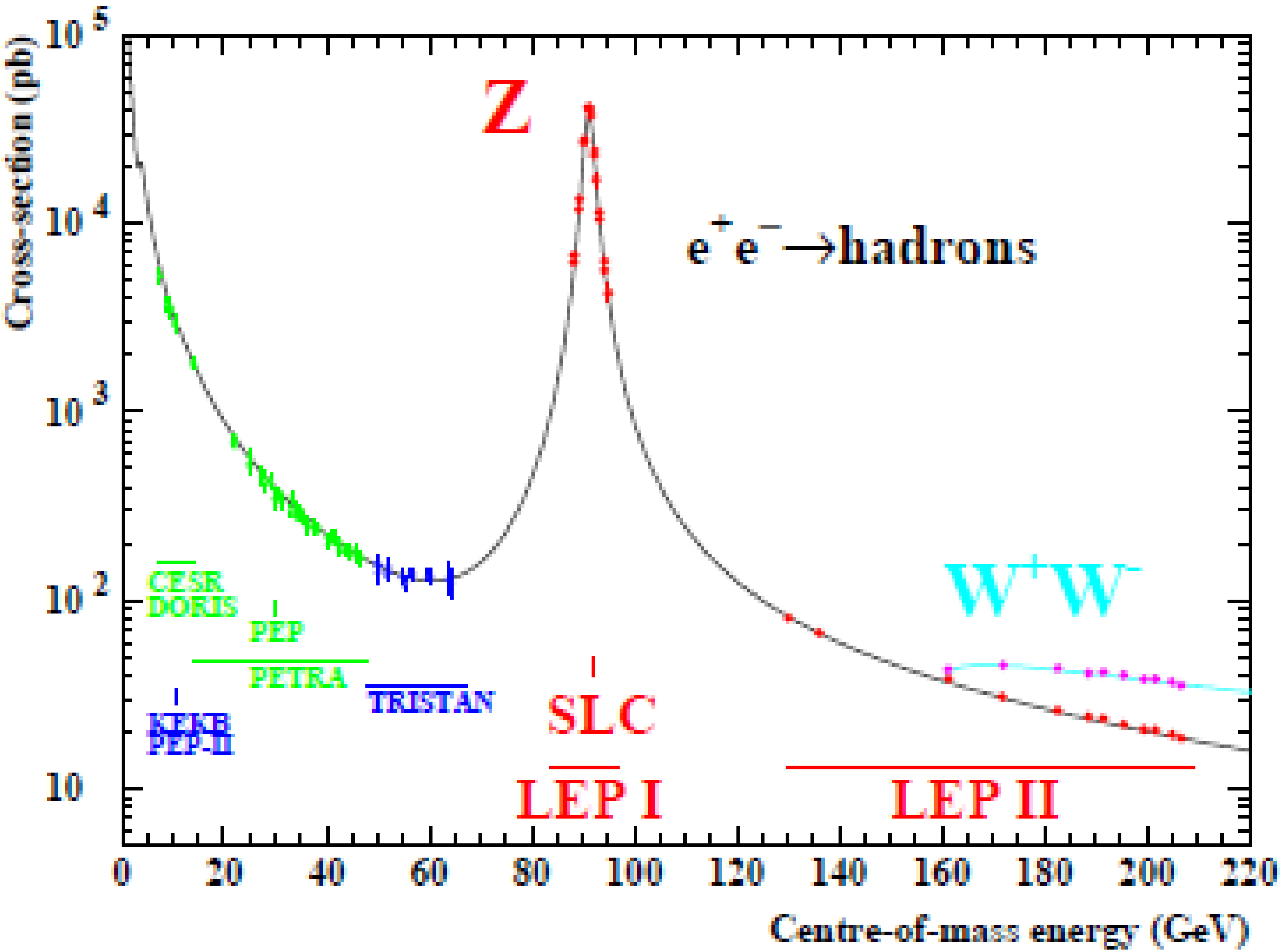


Opportunities and challenges of TLEP as a precision machine for Electroweak Radiative Corrections

‘Will redo te LEP program in a few minutes…. ’


Cross-section (pb)
10^5
10^4
10^3
10^2
10
Z
e+e− → hadrons
W+W-
CESR
DORIS
PEP
PETRA
TRISTAN
KEKB
PEP-II
SLC
LEP I
LEP II
0
20
40
60
80
100
120
140
160
180
200
220
Centre-of-mass energy (GeV)

EWRCs

relations to the well measured

$G_F \; m_Z \; \alpha_{QED}$

at first order:

$\Delta\rho$: $\equiv \varepsilon_1$

$$\Gamma_\ell = (1+\Delta\rho)\frac{G_F\, M_Z^3}{24\pi\sqrt{2}}\left(1+\left(\frac{g_{V\ell}}{g_{A\ell}}\right)^2\right)\left(1+\frac{3}{4}\frac{\alpha}{\pi}\right)$$

$\Delta\rho = \alpha/\pi \; (m_{top}/m_Z)^2 - \alpha/4\pi \; \log (m_h/m_Z)^2$

ε_3

$$\sin^2\theta_W^{eff}\cos^2\theta_W^{eff} = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}\, G_F\, m_Z^2}\,\frac{1}{1+\Delta\rho}\,\frac{1}{1-\frac{\varepsilon_3}{\cos^2\theta_W}}$$

$\varepsilon_3 = \cos^2\theta_W \; \alpha/9\pi \; \log (m_h/m_Z)^2$

δ_{vb}

$$\Gamma_b = (1+\delta_{vb})\,\Gamma_d\left(1 - \text{mass corrections } \alpha\, m_b^2/M_Z^2\right)$$

$\delta_{vb} = 20/13 \; \alpha/\pi \; (m_{top}/m_Z)^2$

ε_2

$$M_W^2 = \frac{\pi\alpha(M_Z^2)}{\sqrt{2}\, G_F \sin^2\theta_W^{eff.}}\cdot\frac{1}{(1-\varepsilon_3+\varepsilon_2)}$$

$\sin^2\theta_W^{eff}$ is defined from

$$\sin^2\theta_W^{eff} = \frac{1}{4}\left(1-\frac{g_{V\ell}}{g_{A\ell}}\right) = \sin^2\theta_W^{eff}{}_{lept}$$

obtained from asymmetries at the Z.

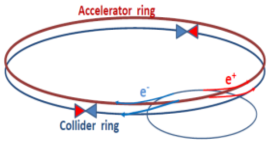
also Δr

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}\, G_F}\cdot\frac{1}{\left(1-\frac{M_W^2}{M_Z^2}\right)}\,\frac{1}{(1-\Delta r)}$$

$$\Delta r = \Delta\alpha - \frac{\cos^2\theta_W}{\sin^2\theta_W}\Delta\rho + 2\frac{\cos^2\theta_W}{\sin^2\theta_W}\varepsilon_3 + \frac{c^2-s^2}{s^2}\varepsilon_2$$

complete formulae at 2d order including strong corrections are available in fitting codes

e.g. ZFITTER



Electroweak precision observables at e+e- collider

comments :

-- most powerful relationships : m_Z vs O_i

-- limitation from uncertainty in $\alpha_{QED}(m_Z)$

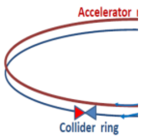
will affect maximally m_Z vs $\sin^2\theta^{eff}_W$ (all Z peak asymmetries) ir

will affect m_Z vs m_W interpretation

will *not* affect such quantities as m_Z vs Γ_{lept} and m_Z vs $R_b= \Gamma$

-- great premium on m_Z and Γ_Z from the line-shape scan

-- Γ_b / Γ_{had} will be obtained from high luminosity at the Z peak.



Number of Events										
	$Z \to q\overline{q}$					$Z \to \ell^+\ell^-$				
Year	A	D	L	O	LEP	A	D	L	O	LEP
1990/91	433	357	416	454	1660	53	36	39	58	186
1992	633	697	678	733	2741	77	70	59	88	294
1993	630	682	646	649	2607	78	75	64	79	296
1994	1640	1310	1359	1601	5910	202	137	127	191	657
1995	735	659	526	659	2579	90	66	54	81	291
Total	4071	3705	3625	4096	15497	500	384	343	497	1724

Table 1.2: The $q\overline{q}$ and $\ell^+\ell^-$ event statistics, in units of 10^3, used for Z analyses by the experiments ALEPH (A), DELPHI (D), L3 (L) and OPAL (O).

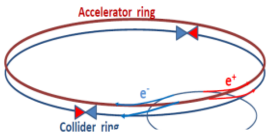
LEP = 16 Million hadronic Z decays, 1.7 Million leptonic decays,

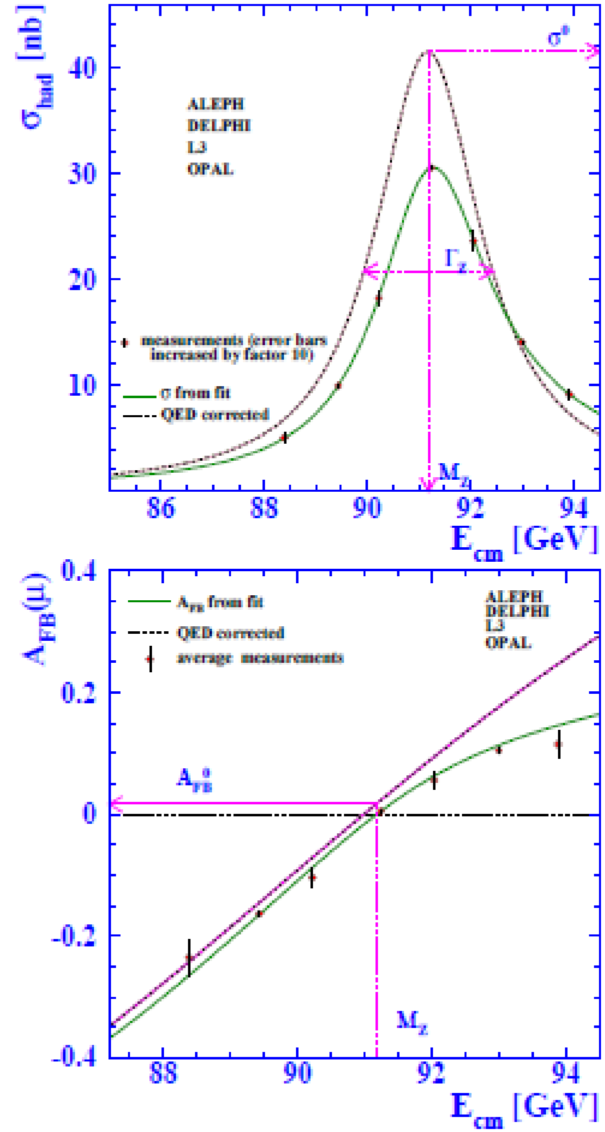
10^{31} /cm^2/s → 3 Z events per second + 4 times that rate in Bhabhas = 15 events per second.

10^{36} /cm^2/s → 1’500’000 events per second **1.5MHz** …. 10^7 seconds → 3 10^{12} Z decays. TeraZ

CHALLENGE I design of detector and DAQ system to keep high precision in cross-section measurement

Small angle e+e- is necessary for luminosity determination as large angle e+e- is dominated by Z decays themselves

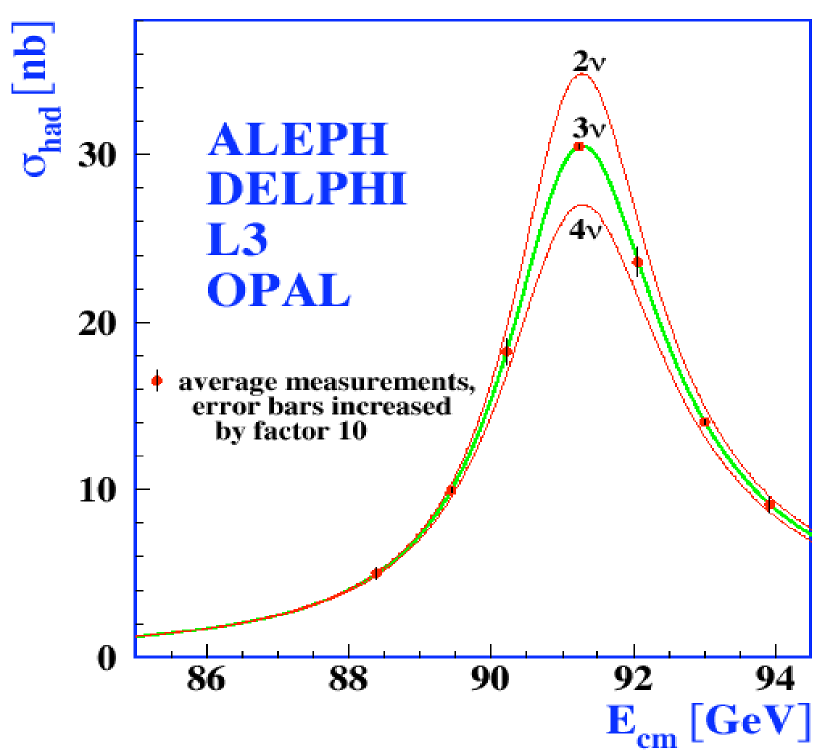


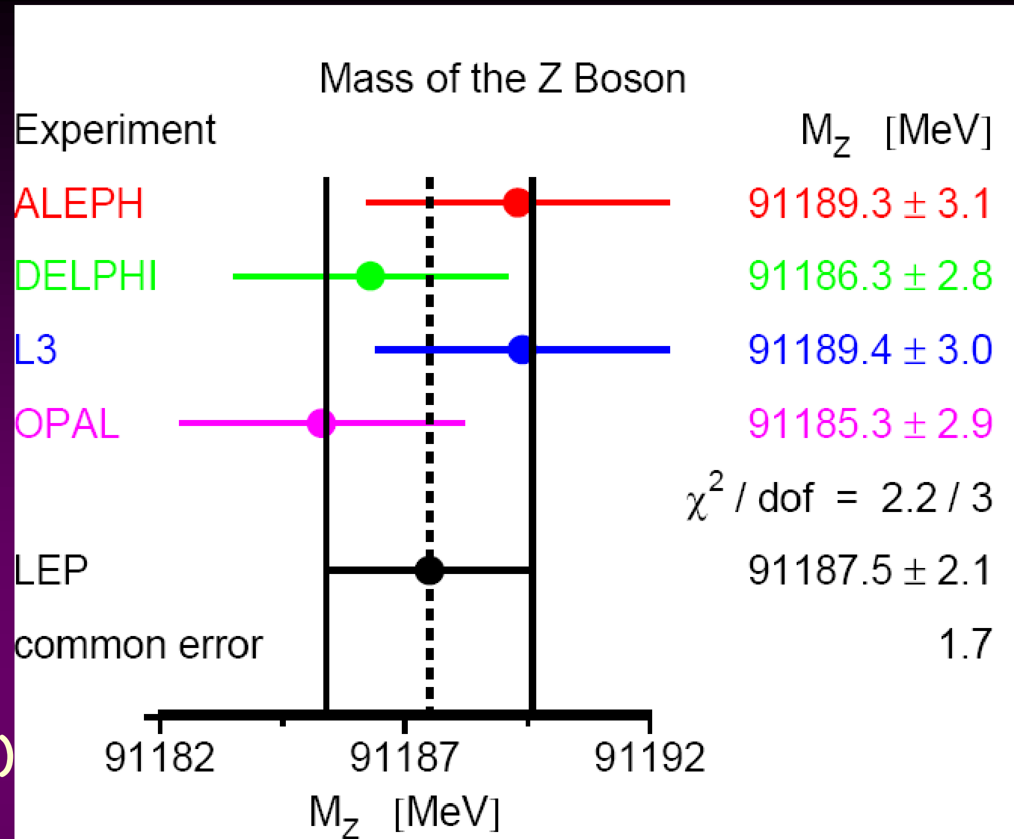


Statistical errors will reduce nicely
can we reduce systematics also?

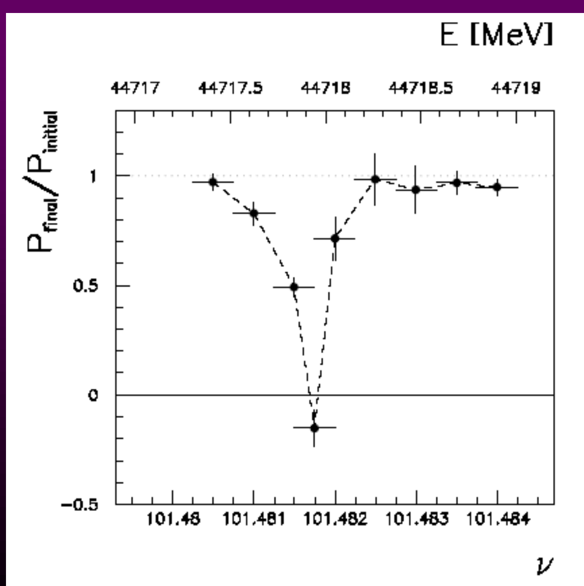
$$\Delta m_Z \approx \frac{1}{2} \cdot \Delta(E_{+2} + E_{-2}) \text{ and}$$
$$\Delta \Gamma_Z \approx \frac{\Gamma_Z}{E_{+2} - E_{-2}} \Delta(E_{+2} - E_{-2}) \,.$$

-- Energy calibration
-- Luminosity measurements
-- Cross-section measurements





energy resolution (resonant depolarization) +-200 keV! variations due to tides, trains, rain, etc..

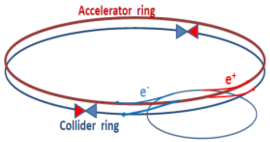


m_Z= 91187.5 +-2.1 MeV

Energy calibration systematics was 10 times that the measurement itself because .. measurement was not performed continuously.

End of fills – systematically shifted

55% transverse polarization was achieved



Beam Polarization at TLEP-Z

I do not consider here the possibility of injectig polarized electrons and positrons. A discouraging parameter against this is the spin tune $\nu_s = E_{beam}$ [GeV]/0.4406486 =103.5 at the Z peak. Crossing all these resonances in the acceleration will kill polarization for sure.

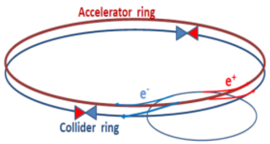
➔ Build up polarization by Sokolov Ternov effect at high energy.

$$\tau = A\frac{\hbar^2}{mce^2}\left(\frac{mc^2}{E}\right)^2\left(\frac{H_0}{H}\right)^3$$

where A is the limiting degree of polarization (92.4%) and τ is the polarization time.

The polarization time at the Z peak was **300 minutes in LEPI**
It will be 300x(80/27) ~ 9'000 minutes or **150 hours at TLEP-Z – ouch.**

we can use wigglers and we must be patient.



Polarization Wigglers as they were designed for LEP I
(A.B and John Jowett, in Polarization at LEP, CERN Yellow report 88-06)

Asymmetric B- B+ B- 12 magnets in straight sections ➔ 65 m total

$$\max B_+ \simeq 1.3\,\mathrm{T}, \qquad L_+ = 0.65\,\mathrm{m}, \qquad L_- = 4.0\,\mathrm{m}, \qquad L_g = 0.25\,\mathrm{m}.$$

3 kW of SR locally per mA ➔ 4 MW extra power at the Z.

40 minutes polarization time.

need to check many things such as energy spread etc…

LEP3/TLEP parameters -1

soon at SuperKEKB:
β_x^*=0.03 m, β_Y^*=0.03 cm

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
beam energy E_b [GeV]	104.5	60	120	45.5	120	175
circumference [km]	26.7	26.7	26.7	80	80	80
beam current [mA]	4	100	7.2	1180	24.3	5.4
#bunches/beam	4	2808	4	2625	80	12
#e−/beam [10^{12}]	2.3	56	4.0	2000	40.5	9.0
horizontal emittance [nm]	48	5	25	30.8	9.4	20
vertical emittance [nm]	0.25	2.5	0.10	0.15	0.05	0.1
bending radius [km]	3.1	2.6	2.6	9.0	9.0	9.0
partition number J_ε	1.1	1.5	1.5	1.0	1.0	1.0
momentum comp. α_c [10^{-5}]	18.5	8.1	8.1	9.0	1.0	1.0
SR power/beam [MW]	11	44	50	50	50	50
β^*_x [m]	1.5	0.18	0.2	0.2	0.2	0.2
β^*_y [cm]	5	10	0.1	0.1	0.1	0.1
σ^*_x [µm]	270	30	71	78	43	63
σ^*_y [µm]	3.5	16	0.32	0.39	0.22	0.32
hourglass F_{hg}	0.98	0.99	0.59	0.71	0.75	0.65
ΔE^{SR}_{loss}/turn [GeV]	3.41	0.44	6.99	0.04	2.1	9.3

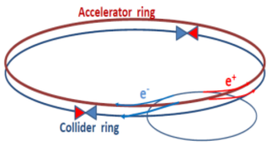
SuperKEKB: $\varepsilon_y/\varepsilon_x$=0.25%

LEP3/TLEP parameters -2

LEP2 was not beam-beam limited

	LEP2	LHeC	LEP3	TLEP-Z	TLEP-H	TLEP-t
$V_{RF,tot}$ [GV]	3.64	0.5	12.0	2.0	6.0	12.0
$\delta_{max,RF}$ [%]	0.77	0.66	5.7	4.0	9.4	4.9
ξ_x/IP	0.025	N/A	0.09	0.12	0.10	0.05
ξ_y/IP	0.065	N/A	0.08	0.12	0.10	0.05
f_s [kHz]	1.6	0.65	2.19	1.29	0.44	0.43
E_{acc} [MV/m]	7.5	11.9	20	20	20	20
eff. RF length [m]	485	42	600	100	300	600
f_{RF} [MHz]	352	721	700	700	700	700
δ^{SR}_{rms} [%]	0.22	0.12	0.23	0.06	0.15	0.22
$\sigma^{SR}_{z,rms}$ [cm]	1.61	0.69	0.31	0.19	0.17	0.25
L/IP[10^{32}cm^{-2}s^{-1}]	1.25	N/A	94	10335	490	65
number of IPs	4	1	2	2	2	2
Rad.Bhabha b.lifetime [min]	360	N/A	18	74	32	54
Υ_{BS} [10^{-4}]	0.2	0.05	9	4	15	15
n_γ/collision	0.08	0.16	0.60	0.41	0.50	0.51
$\Delta\delta^{BS}$/collision [MeV]	0.1	0.02	31	3.6	42	61
$\Delta\delta^{BS}_{rms}$/collision [MeV]	0.3	0.07	44	6.2	65	95

LEP data for 94.5 - 101 GeV consistently suggest a beam-beam limit of ~0.115 (R.Assmann, K. C.)



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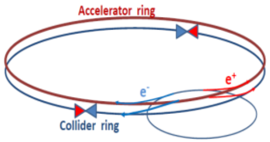
3 kW of SR locally per mA ➔ 4 MW extra power at the Z.

40 minutes polarization time at LEPI would be 120 minutes

need to check many things such as energy spread etc…



Operation mode

operation mode probably different for the Z line shape measurement,
for high intensity peak measurements and for
longitudinal polarization measurements

Proposed for line shape measurement
it is important to keep a number of bunches transversally polarized to perform the calibration continuously. ***These bunches need not be colliding.*** Thanks to synchrotron oscillations the average energy of colliding beams cannot be different to that of circulating beams (this can be checked by beam position in dispersion zones)
Spin matching techniques of LEP can be used (low beta, solenoids, imperfections, etc..)
hopefully easier if we have careful thought ahead of time.

This should allow the systematic error to be reduced below the 100 keV/beam level per measurement , with improvement expected as 1/sqrt(N_{meas})

Keep some fraction of the 2625 bunches not colliding and measure continuously.

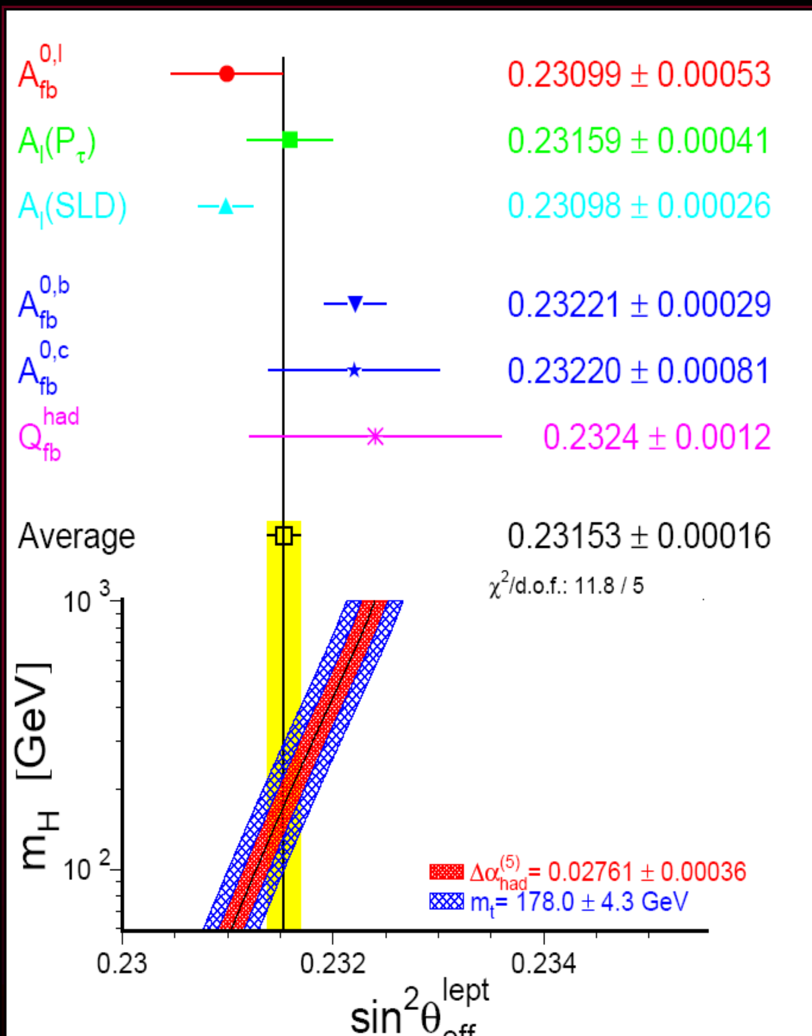
Can we keep full luminosity while doing this? (some reduction would not kill us)

Measuring $\sin^2\theta_W^{eff}\ (m_Z)$

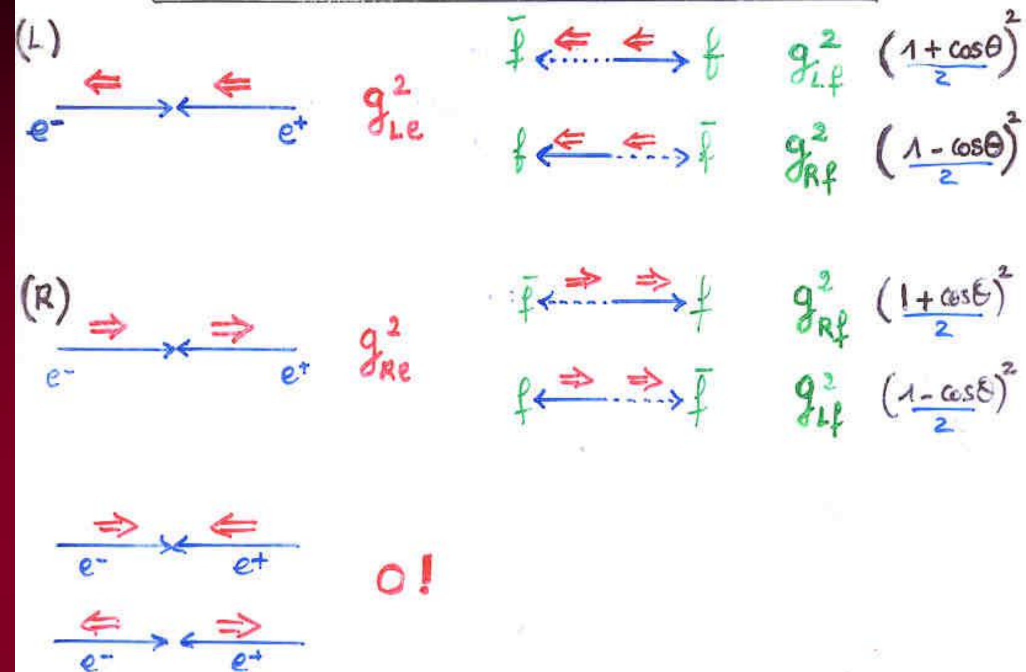
$$\sin^2\theta_W^{eff} \equiv \frac{1}{4}\left(1 - g_V/g_A\right)$$

$$g_V = g_L + g_R$$

$$g_A = g_L - g_R$$



Helicity effects in $e^+e^- \to f\bar{f}$



Pol'd BEAM $\Rightarrow$

$$A_{LR} = \frac{\sigma_L^{tot} - \sigma_R^{tot}}{\sigma_L^{tot} + \sigma_R^{tot}} = \frac{g_{Le}^2 - g_{Re}^2}{g_{Le}^2 + g_{Re}^2} \equiv \mathcal{A}_e = \frac{2\, g_{Ve}\, g_{Ae}}{g_{Ve}^2 + g_{Ae}^2}$$

$$A_{FB}^{Pol\,f} = \frac{\sigma_L^{Ff} - \sigma_L^{Bf} - (\sigma_R^{Ff} - \sigma_R^{Bf})}{\sigma_L^{Ff} + \sigma_L^{Bf} + \sigma_R^{Ff} + \sigma_R^{Bf}} = \frac{3}{4}\mathcal{A}_f$$

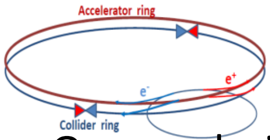
no Pol available:

$$A_{FB} = \frac{\sigma_U^{Ff} - \sigma_U^{Bf}}{\sigma_U^{Ff} + \sigma_U^{Bf}} = \frac{3}{4}\mathcal{A}_e \mathcal{A}_f$$

Pol'n analyses τ

$$\langle P_f \rangle = \frac{\sigma_U^R - \sigma_U^L}{\sigma_U^R + \sigma_U^L} = -\mathcal{A}_f$$

$$A_{FB}^{Pol} = \frac{\sigma_U^{RF} - \sigma_U^{LF} - (\sigma_U^{RB} - \sigma_U^{LB})}{\sigma_U^{RF} + \sigma_U^{LF} + \sigma_U^{RB} + \sigma_U^{LB}} = -\frac{3}{4}\mathcal{A}_e$$



Longitudinal polarization

Once polarization is transverse it needs to be rotated in the direction of the beam to become longitudinal in the IP region and again the same transverse in the next arcs

➔ **the art of spin rotators** (there have been many proposals, probably best are the Hera rotators)

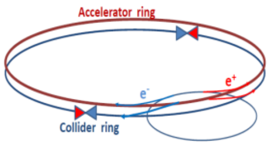
For longitudinal polarization experiments we need to keep the beam **polarized while in collisions. This is the main unknown.** Top up mode should provide stable operation which is essential for the exquisite orbit corrections, but will dilute the beam polarization as $P = (1/\tau_P) / (1/\tau_P + 1/\tau_{lumi})$ (or something like that). This is not solid science, but can be tested with transerse polarization before deciding on the spin rotators.

We had some limited MD experience at LEP, which showed some polarization in collision but this was only once. We should dig-out this result.

It may mean that the luminosity should remain at a few % of the maximal unpolarized luminosity. Still 10^{34}/cm^2/s will provide 3.10^{10} detected Z decays per year.

➔ towards $\Delta\sin^2\theta_W^{eff}$ = few 10^{-6} this is two order manitude better than the present 0.00016

Unlike the Z line shape re-measurement which could be a few weeks of running this is more likely to be **a one year affair.**



Outlook

I have **begun** to investigate the possibility of improving the EWRC sensitive observables at TLEP (aka EWPT) around the Z resonance. Not m_W yet.

-- Z peak observables can be measured with fantastic statistics.
b and hadron width, tau polarization, forward backward asymmetries

-- Beam polarization is critical for line shape and polarized asymmetry.
At TLEP, polarization time is 150 hours. Polarization wigglers are necessary,
also, polarimeters and spin rotators, etc…

-- new measurements of the Z mass and widths (electron and neutrino) require line shape precision scan – unique to a circular machine. **precision aim: 0.1 MeV on m_Z, Γ_Z**

-- Longitudinal polarization requires dedicated study to understand what polarization level can be maintained in collision for a given luminosity. Top-up injection should help a lot. This is a more important endeavour. (year) aim $\Delta\sin^2\theta_W^{eff}$ = few 10^{-6} .

-- there are other systematic errors related to luminosity measurement and detection uncertainties which need to be addressed as well.

-- suggest a workshop/working group for this.