VI. PRECISION ELECTROWEAK DATA STUDIES

S. Geer, Chair

VI. PRECISION ELECTROWEAK DATA STUDIES, *S. Geer* (FNAL), Chair

Precision Electroweak Data: Present Status and Future Prospects – *P. Renton* (Oxford, UK)

Physics at the Z^0-Pole: Higher Luminosity with Beam Polarizations – *T. Han* (UC Davis/ UW-Madison)

Precision Electroweak Data:
Present Status and Future Prospects

Pete Renton
University of Oxford

- Precision electroweak data

  Z parameters M_W, R_ν
- Are the data consistent with the Standard Model ?
- Fits to the data: constraints on the Higgs mass etc
- Expected future precision and implications

Data from LEP

- 1989-1995

  LEP I $\Rightarrow\sim 160$ pb^{-1} $(\sim 5 \cdot 10^6\ \mathrm{Z}^0$ decays) / expt

  Precision scan of the Z peak in 1993, 1995

  $\sim$ [illegible] pb^{-1} of data ± 1.8 GeV off peak.
- November 1995

  LEP 1.5 – 130-136 GeV $\Rightarrow \sim 5$ pb^{-1} / experiment
- 1996 LEP2

  161 GeV $\Rightarrow \sim 10$ pb^{-1} / experiment

  172 GeV $\Rightarrow \sim 10$ pb^{-1} / experiment
- 1997

  183 GeV $\Rightarrow \sim 55$ pb^{-1} / experiment

  rerun of 130-136 GeV $\Rightarrow \sim 5$ pb^{-1} / experiment

Data from SLC

- e^+e^- on the Z peak

Up to 1996, ~ 5 pb^{-1}, with $\mathcal{P}_e$ up to 80%.

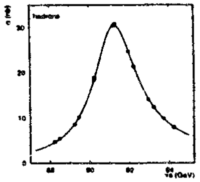
Data from FNAL

- $\overline{\mathrm{p}}\mathrm{p}$ at 1.8 TeV. Run IA+IB ~ 110 pb^{-1}.

Z^0 precision data - formalism

Principal measurements at LEP/SLC

- $\sigma(e^+e^- \to f\bar{f})$ vs. $\sqrt{s} \Rightarrow M_Z, \Gamma_Z$



- $\Gamma_f \equiv \Gamma(Z \to f\bar{f}) \sim (v_f^2 + a_f^2)$ partial widths

  or ratios $R_\ell = \Gamma_{had}/\Gamma_\ell$, $R_b = \Gamma_b/\Gamma_{had}$
- $A_{FB}^f \equiv \frac{\sigma_B - \sigma_F}{\sigma_B + \sigma_F} \sim \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$ Forw.-back. asymmetry

  $\mathcal{A}_f = \frac{2v_f a_f}{v_f^2 + a_f^2}$ Coupling Parameter
- $\mathcal{P}_\tau \sim -\mathcal{A}_\tau$ Average τ polarization
- $A_{FB}^{pol} \sim -\frac{3}{4}\mathcal{A}_e$ τ polarization FB asymmetry

And, specific to SLC, observables related to polarized beams:

- $A_{LR} \equiv \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} \sim -\mathcal{A}_e$ Left-Right asymmetry
- $\tilde{A}_{LR}^f \sim -\frac{3}{4}\mathcal{A}_f$ Left-Right forward-backward asymmetry

In the "Improved Born Approximation", many of the radiative corrections absorbed by using effective couplings in above formulæ, and running α_{em} to M_Z.

Z^0 lineshape + lepton asymmetries

main changes since summer 96:

- LEP Beam energy Probably final beam energy + errors recently released. At present, used by ALEPH/DELPHI; not by OPAL/L3 (correction applied).
- Lineshape + A_{FB}^ℓ Some 1995 data added (DO) Updates (especially $\Delta\sigma_{had}^0$, $A_{FB}^{0,\tau}$) (A)

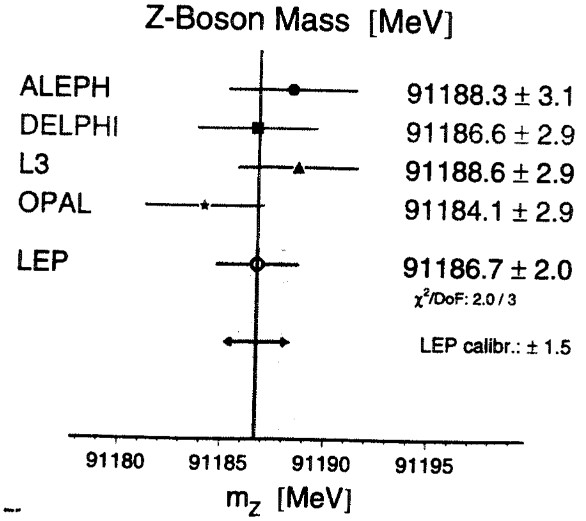
  Final LEP I results awaiting definitive beam energy + errors

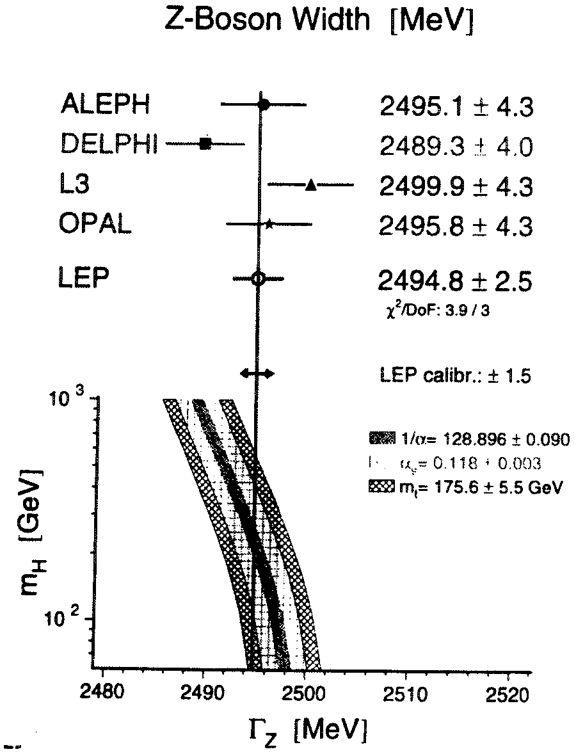
  $\Rightarrow$ PDG'98.
- τ polarization New result (inc. 1995 data) (L)
- A_{LR} (L-R asymmetry) 1996 result available (S)

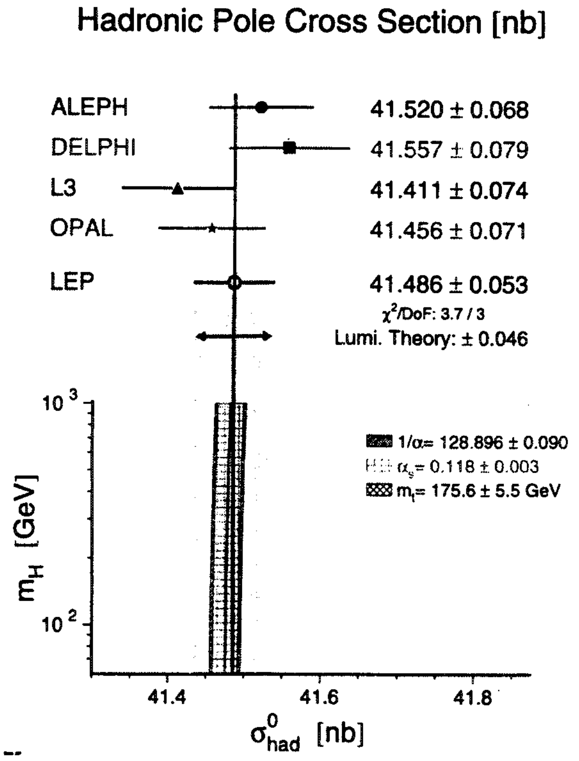
Changes since 1996 quite small. Basic LEP measurements (assuming lepton universality):

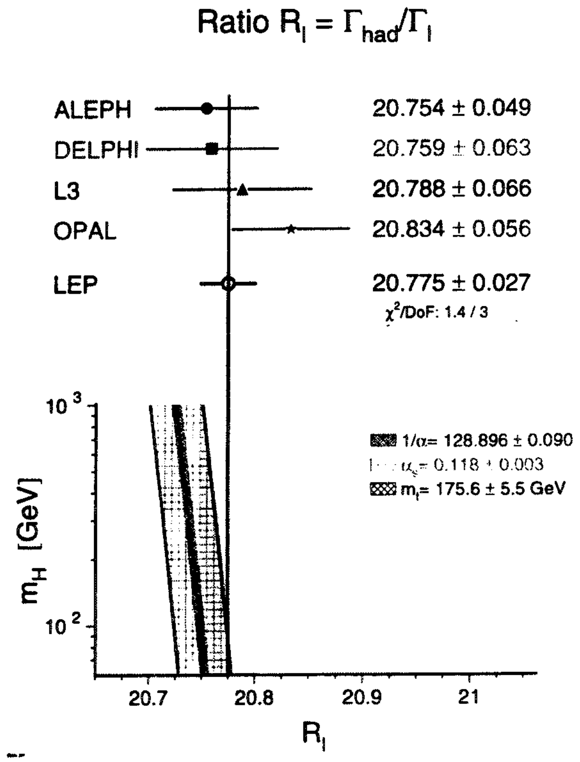
m_Z /GeV	91.1867 ± 0.0020
Γ_Z /GeV	2.4948 ± 0.0025
σ_h^0 /nb	41.486 ± 0.053
R_ℓ	20.775 ± 0.027
$A_{FB}^{0,\ell}$	0.0171 ± 0.0010

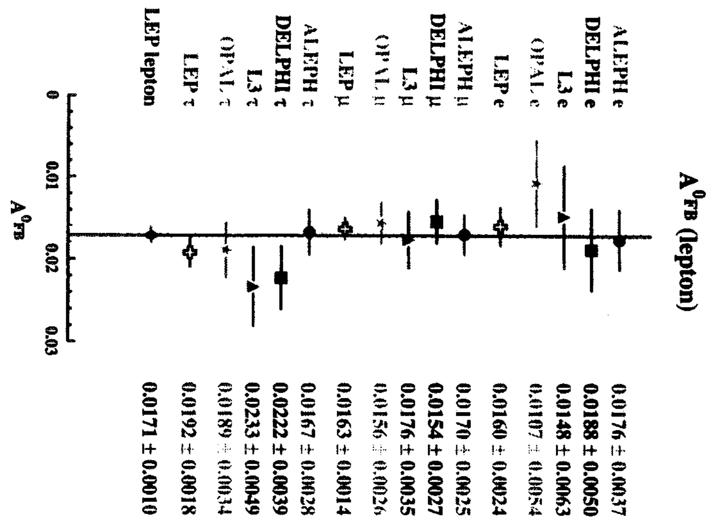
χ^2/dof=22.7/31

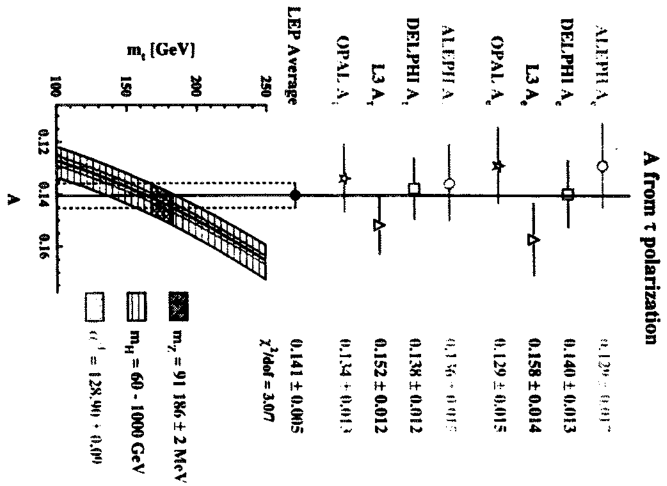

Z-Boson Mass [MeV]
ALEPH
DELPHI
L3
OPAL
LEP
91188.3 ± 3.1
91186.6 ± 2.9
91188.6 ± 2.9
91184.1 ± 2.9
91186.7 ± 2.0
χ^2/DoF: 2.0 / 3
LEP calibr.: ± 1.5
91180
91185
91190
91195
m_Z [MeV]


Z-Boson Width [MeV]
ALEPH
DELPHI
L3
OPAL
LEP
2495.1 ± 4.3
2489.3 ± 4.0
2499.9 ± 4.3
2495.8 ± 4.3
2494.8 ± 2.5
χ^2/DoF: 3.9 / 3
LEP calibr.: ± 1.5
1/α= 128.896 ± 0.090
α_s= 0.118 ± 0.003
m_t= 175.6 ± 5.5 GeV
10^3
10^2
m_H [GeV]
2480
2490
2500
2510
2520
Γ_Z [MeV]


Hadronic Pole Cross Section [nb]
ALEPH
DELPHI
L3
OPAL
LEP
41.520 ± 0.068
41.557 ± 0.079
41.411 ± 0.074
41.456 ± 0.071
41.486 ± 0.053
χ^2/DoF: 3.7 / 3
Lumi. Theory: ± 0.046
1/α= 128.896 ± 0.090
α_s= 0.118 ± 0.003
m_t= 175.6 ± 5.5 GeV
10^3
10^2
m_H [GeV]
41.4
41.6
41.8
σ^0_{had} [nb]

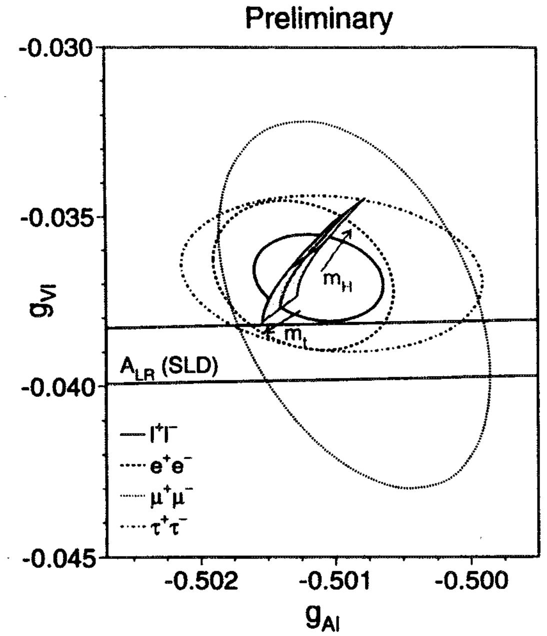

Ratio $R_l = \Gamma_{had}/\Gamma_l$
ALEPH
DELPHI
L3
OPAL
LEP
20.754 ± 0.049
20.759 ± 0.063
20.788 ± 0.066
20.834 ± 0.056
20.775 ± 0.027
χ^2/DoF: 1.4 / 3
1/α= 128.896 ± 0.090
α_s= 0.118 ± 0.003
m_t= 175.6 ± 5.5 GeV
10^3
10^2
m_H [GeV]
20.7
20.8
20.9
21
R_l





Lepton universality

As well as leptonic Z^0 widths and asymmetries, include information from τ polarization to provide best constraints on lepton universality.



Tests universality at the 0.2% level for a_ℓ, 5–10% for v_ℓ .

Assuming universality:

	LEP	LEP+SLD
v_ℓ	-0.03681 ± 0.00085	-0.03793 ± 0.00058
a_ℓ	-0.50112 ± 0.00032	-0.50103 ± 0.00031
v_ν	$+0.50125 \pm 0.00092$	$+0.50125 \pm 0.00092$

Heavy Flavour Electroweak

main changes since summer 96:

- $R_{\rm b}$ Recent preliminary results published (AOS), new results (DLS)
- $R_{\rm c}$ Recent preliminary result published (O)New results (AS)
- $A_{\rm FB}^{\rm b}$ New results (LO); withdrawn result (A)
- $\mathcal{A}_{\rm b}$, $\mathcal{A}_{\rm c}$ (L-R asymmetries) updated (S)

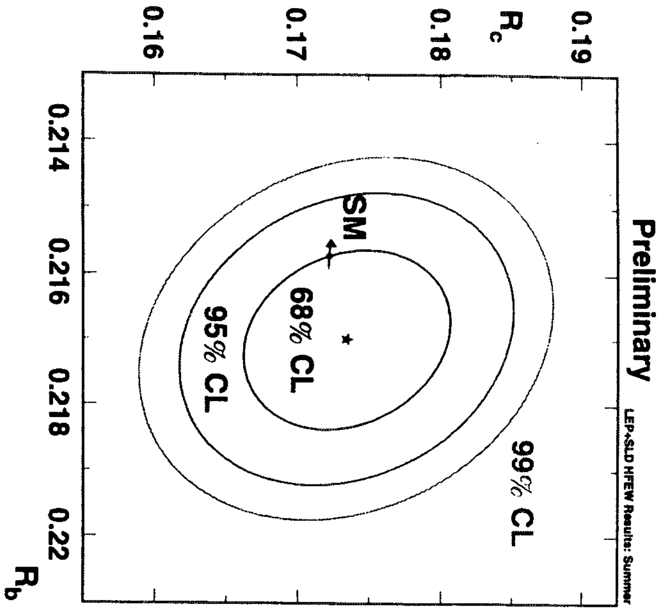
Summary of results (fit to all heavy flavour electroweak data):

$R_{\rm b}$	0.2170 ± 0.0009
$R_{\rm c}$	0.1734 ± 0.0048
$A_{\rm FB}^{0,\rm b}$	0.0984 ± 0.0024
$A_{\rm FB}^{0,\rm c}$	0.0741 ± 0.0048
$\mathcal{A}_{\rm b}$	0.900 ± 0.050
$\mathcal{A}_{\rm c}$	0.650 ± 0.058

Main improvements since last year are $R_{\rm b}$, $R_{\rm c}$, $\mathcal{A}_{\rm c}$.

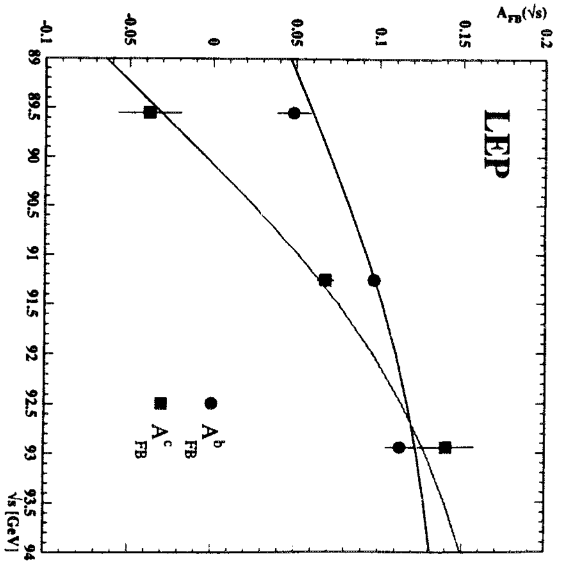
$R_{\rm b}$ vs. $R_{\rm c}$

Preliminary



Errors improved by factor ~ 3 in the 4 years since 1993 and R_b by factor ~ 2 since 1995.

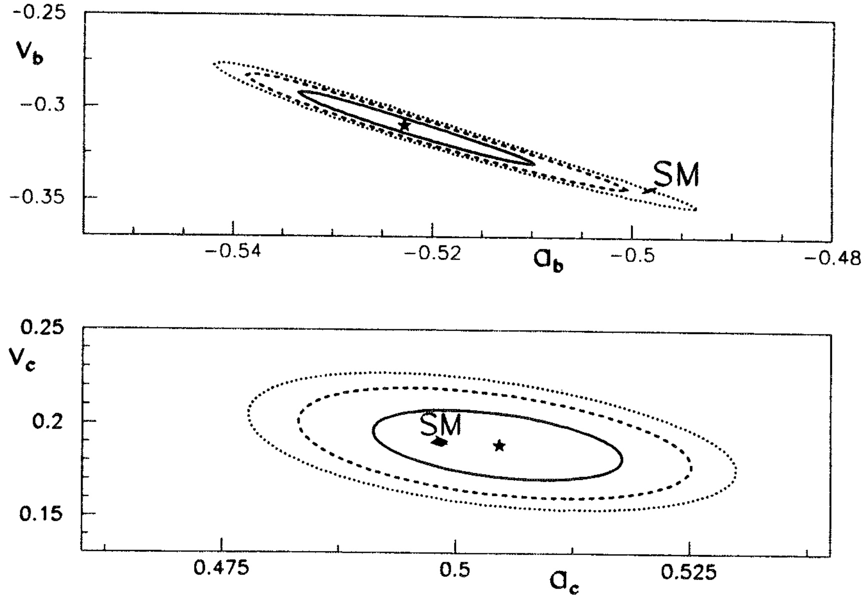
$A_{\rm FB}^{\rm 0b}$ and $A_{\rm FB}^{\rm 0c}$



extraction of heavy quark couplings

- using $R_b = \Gamma_b/\Gamma_{had}$ with Γ_{had} from lineshape $\Longrightarrow v_b^2 + a_b^2$
- using $R_c = \Gamma_c/\Gamma_{had}$ with Γ_{had} from lineshape $\Longrightarrow v_c^2 + a_c^2$
- A_e from LEP/SLD $\Longrightarrow v_e/a_e$
- $A_{FB}^b, A_b \Longrightarrow v_b/a_b$ $A_{FB}^c, A_c \Longrightarrow v_c/a_c$
- plus constraint $\alpha_s = 0.120 \pm 0.005$

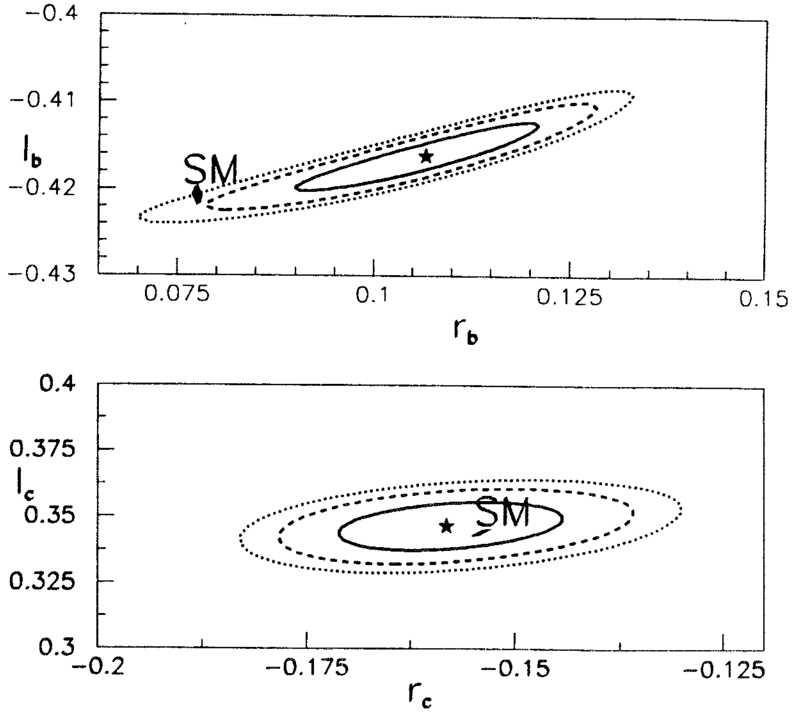
70, 95 and 99% contours



left and right handed heavy quark couplings

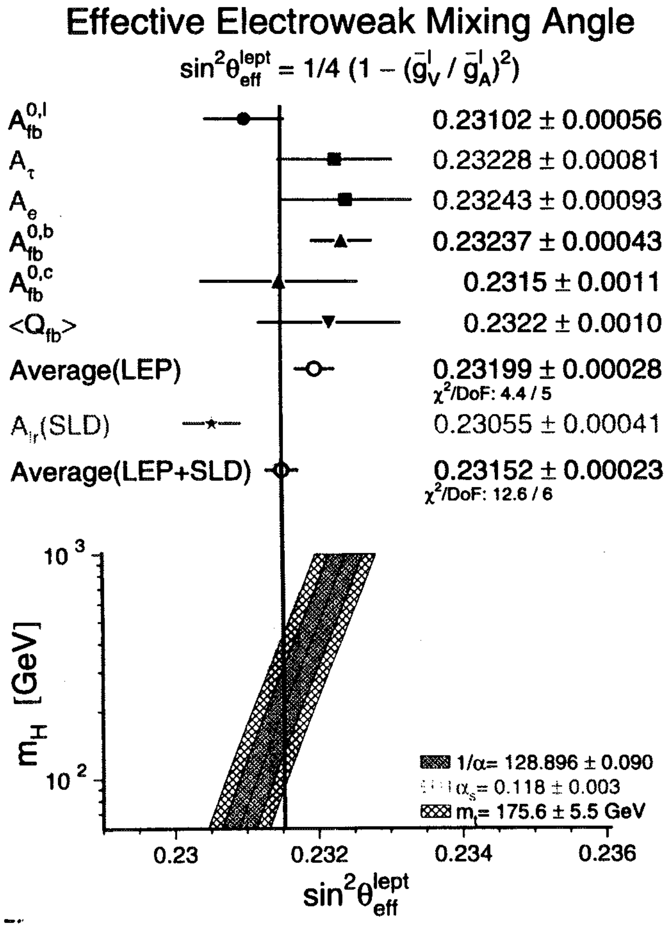
$l_b = (v_b + a_b)/2$ $r_b = (v_b - a_b)/2$

70, 95 and 99% contours

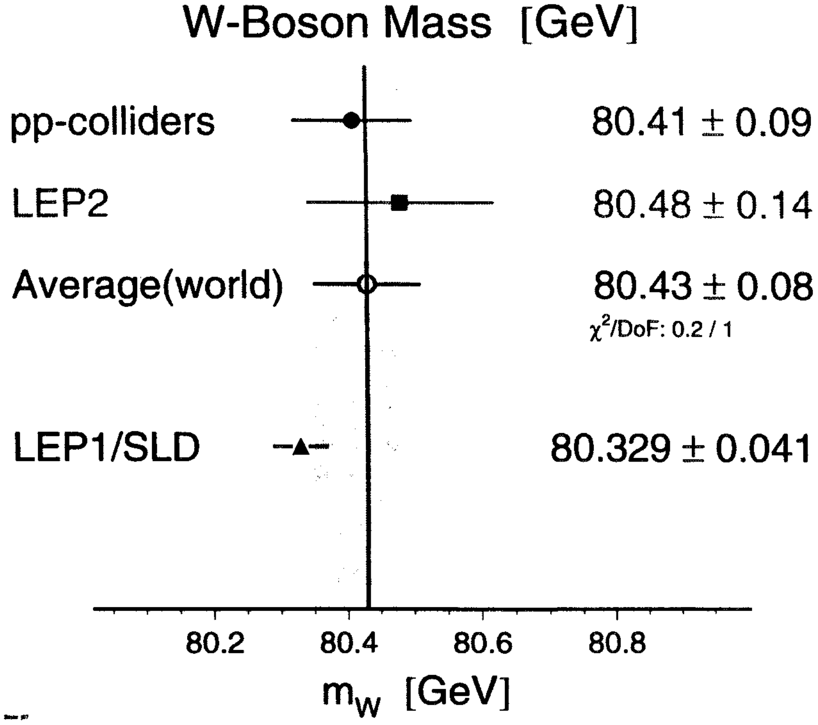


$\sin^2 \theta_{\text{lept}}^{\text{eff}}$

The various asymmetry measurements all effectively measure $\sin^2 \theta_{\text{lept}}^{\text{eff}}$ → check consistency.



W Mass – world compilation



- LEP delivered ~ 55 pb^{-1}/expt at 183 GeV in 1997, so LEP error should reduce to ~ 80 MeV.
- By the end of LEP2 and Tevatron Run 2, both expect to achieve error on M_W ~ 30–40 MeV.

SM fit to LEP/SLD/$\mathrm{p\overline{p}}/\nu\mathrm{p}$ data

Perform global electroweak fits to the SM using as inputs:

- Z^0 measurements from LEP/SLC
- M_W from LEP 2/Tevatron
- $m_\mathrm{t} = 175.6 \pm 5.5$ GeV CDF/D0
- $1 - M_\mathrm{W}^2/M_\mathrm{Z}^2 = 0.2254 \pm 0.0037$ from νN scattering (includes new result from CCFR)
- $1/\alpha(M_\mathrm{Z}) = 128.894 \pm 0.090$

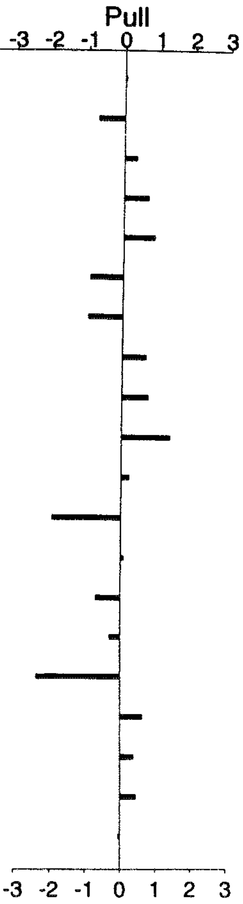
Treating m_H, $\alpha_\mathrm{s}(M_\mathrm{Z})$ and optionally m_t, M_W, as free parameters.

	LEP (inc. M_W)	All but M_W, m_t	All data
m_t / GeV	158^{+14}_{-11}	157^{+10}_{-9}	173.1 ± 5.4
m_H / GeV	83^{+168}_{-49}	41^{+64}_{-21}	115^{+116}_{-66}
$\log m_\mathrm{H}$	$1.92^{+0.48}_{-0.39}$	$1.62^{+0.41}_{-0.31}$	$2.06^{+0.30}_{-0.37}$
$\alpha_\mathrm{s}(M_\mathrm{Z})$	0.121±0.003	0.120±0.003	0.120±0.003
χ^2/dof	8/9	14/12	17/15
m_W / GeV	80.298±0.043	80.329±0.041	80.375±0.030

SM fit to LEP/SLD/$\mathrm{p\overline{p}}/\nu\mathrm{p}$ data

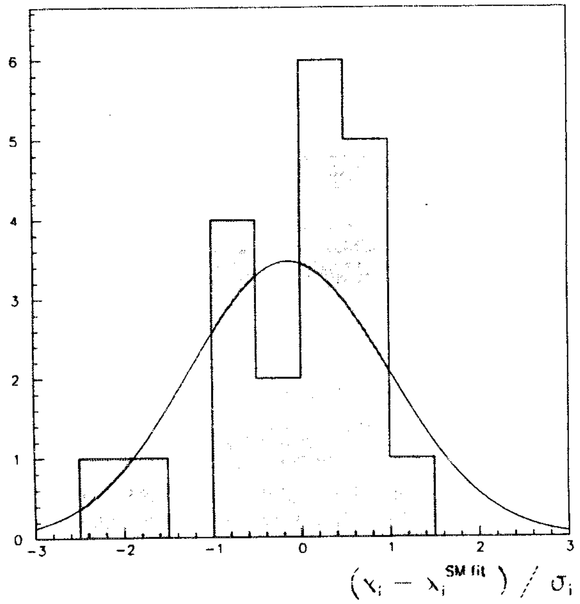
Jerusalem 1997

	Measurement	Pull
m_Z [GeV]	91.1867 ± 0.0020	.04
Γ_Z [GeV]	2.4948 ± 0.0025	-.73
σ^0_{hadr} [nb]	41.486 ± 0.053	.36
R_l	20.775 ± 0.027	.71
$A^{0,l}_{fb}$	0.0171 ± 0.0010	.89
A_τ	0.1411 ± 0.0064	-.93
A_e	0.1399 ± 0.0073	-.98
$\sin^2\theta^{lept}_{eff}$	0.2322 ± 0.0010	.68
m_W [GeV]	80.48 ± 0.14	.75
R_b	0.2170 ± 0.0009	1.38
R_c	0.1734 ± 0.0048	.24
$A^{0,b}_{fb}$	0.0984 ± 0.0024	-1.95
$A^{0,c}_{fb}$	0.0741 ± 0.0048	.09
A_b	0.900 ± 0.050	-.69
A_c	0.650 ± 0.058	-.31
$\sin^2\theta^{lept}_{eff}$	0.23055 ± 0.00041	-2.37
$1-m_W^2/m_Z^2$	0.2254 ± 0.0037	.63
m_W [GeV]	80.41 ± 0.09	.39
m_t [GeV]	175.6 ± 5.5	.45
$1/\alpha$	128.896 ± 0.090	-.05



Fit SM to all data ⇒ χ^2/dof = 17/15 (prob = 32 %)

distribution of pulls

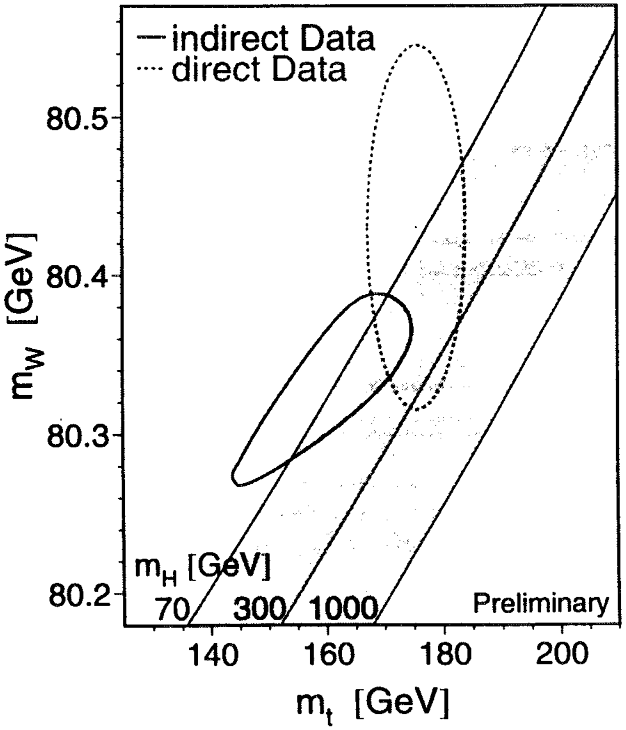


mean = -0.1 ± 0.4

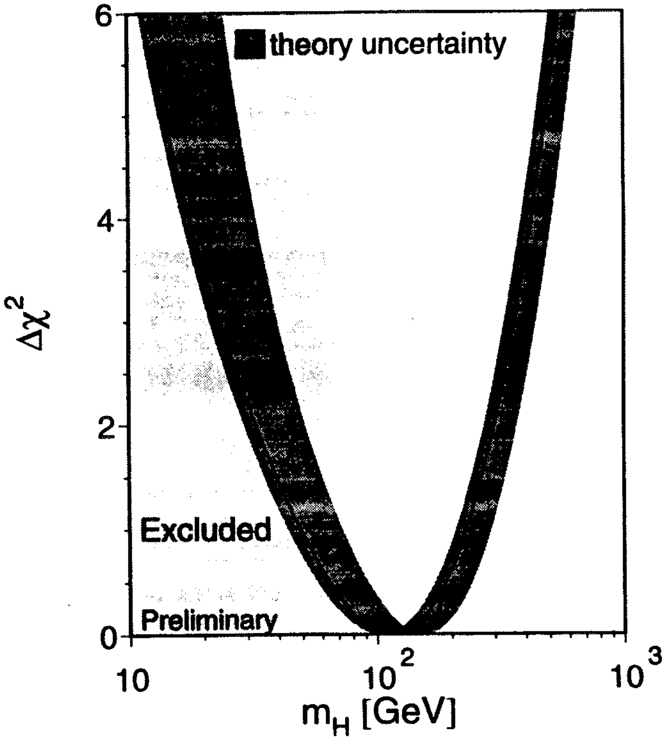
rms = 1.1 ± 0.3

Consistency of $M_{\mathrm{W}}, m_{\mathrm{t}}$?

Compare the indirect determination with direct measurements.



Implications for M_H?



$\Rightarrow M_H = 115^{+116}_{-66}$ GeV

$M_H < 420$ GeV (95% c.l.)

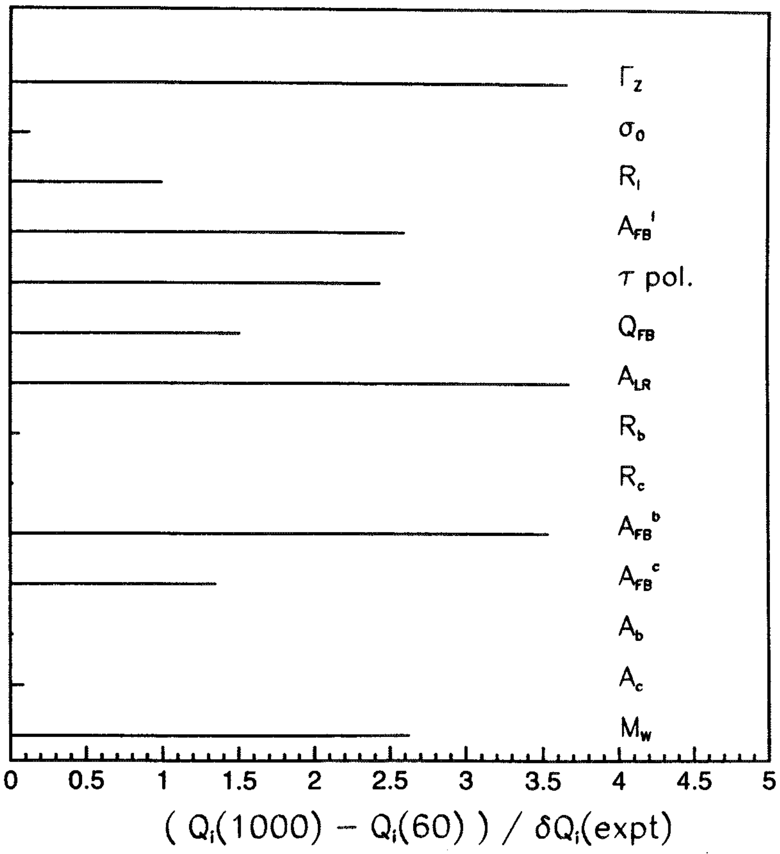
Direct search results not taken into account in 95% c.l. limit.

Theory uncertainty has been allowed for.

Electroweak Higgsometer

for m_t = 175 GeV and α_s = 0.120 (fixed)

plot **($Q_i(m_H{=}1000) - Q_i(m_H{=}60)$) / δQ_i(expt)**



Statistics (like beauty)

lies in the eye

of the beholder

What can we deduce about M_H ?

two points of view

1) the overall χ^2 = 17 / 15 d.f. is OK

expect statistically to see some $\sim 2\ \sigma$ effects

even if all measurements are reliable

so take data at face value

2) it is the quantities most sensitive to M_H which

show the largest χ^2

quantity	pull
A_{LR}	-2.4
Γ_Z	-0.7
A^b_{FB}	-2.0
M_W	+0.7
A^ℓ_{FB}	+0.9
τ pol	-1.3

these give a contribution of χ^2 of 13.3

so should scale errors by $\sqrt{(\chi^2/(n-1))}$?

Are we sure the Higgs is 'light'

fit to all electroweak data

- standard fit

  $M_{\rm H} = 115\,^{+116}_{-66}$ GeV $M_{\rm H} \lesssim 420$ GeV 95% cl

- if exclude SLAC A_{LR} measurement

  $M_{\rm H} = 220\,^{+185}_{-109}$ GeV $M_{\rm H} \lesssim 715$ GeV 95% cl

- scale errors on Higgs sensitive quantities by 1.5

  $M_{\rm H} = 188\,^{+152}_{-91}$ GeV $M_{\rm H} \lesssim 590$ GeV 95% cl

- CONCLUSIONS:

  best estimate for $M_{\rm H}$ is relatively light

  but data not fully compatible, so some caution !

Future expectations

- estimate final errors from LEP 1

  Z lineshape results ~ final

  some improvements expected in τ polarisation

  and heavy flavour results

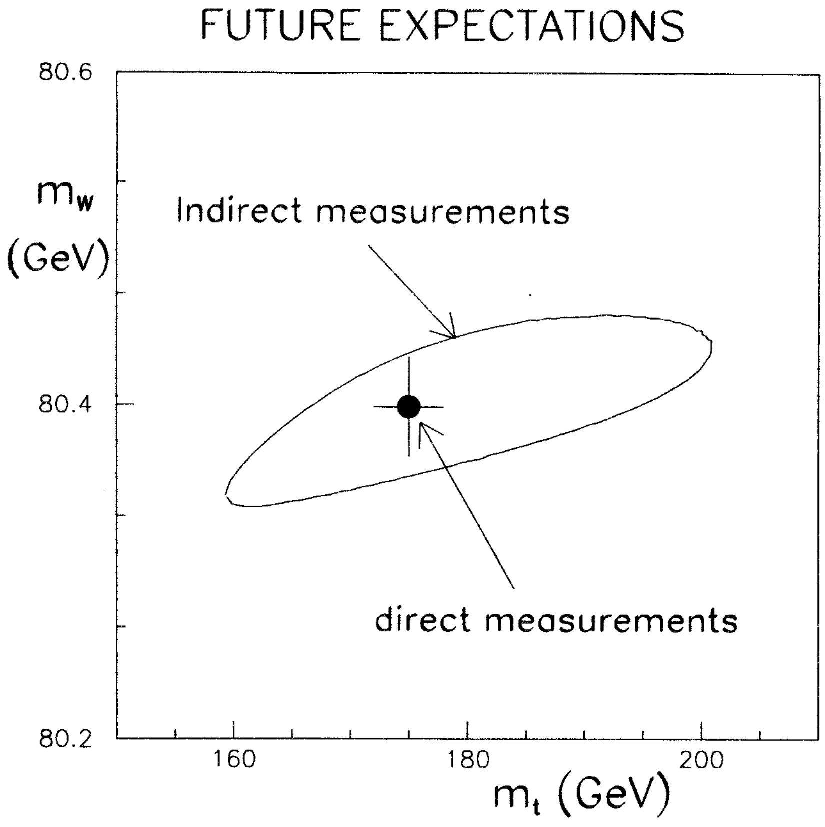
- for SLD assume $\delta \sin^2\theta^{\rm lept}_{\rm eff} \rightarrow .00025$ (from .00041)
- assume $\delta M_{\rm W} \rightarrow 30$ MeV (LEP2 + Tevatron)

  (present error 76 MeV)

- assume $\delta M_{\rm t} \rightarrow 3$ GeV (from 5.5 GeV)
- $\delta\alpha^{-1} \rightarrow 0.05$
- all quantities at SM values for $M_{\rm t}$ = 175 GeV, α_s = 0.120

	$M_{\rm H}$ = 100 GeV	= 300 GeV	= 500 GeV
Stand. assump.	100^{+49}_{-35}	300^{+122}_{-89}	500^{+199}_{-143}
$\delta M_{\rm W}$ = 20 MeV	100^{+46}_{-34}	300^{+108}_{-83}	500^{+175}_{-131}
$\delta \sin^2\theta^{\rm lept}_{\rm eff}$ (A_{LR}) = 0.00015	100^{+45}_{-33}	300^{+111}_{-83}	500^{+182}_{-134}
$\delta M_{\rm t}$ = 0.5 GeV	100^{+39}_{-30}	300^{+90}_{-71}	500^{+146}_{-114}
$\delta\alpha^{-1}$ = 0.09	100^{+62}_{-42}	300^{+141}_{-101}	500^{+229}_{-159}

m_t v m_W direct and indirect

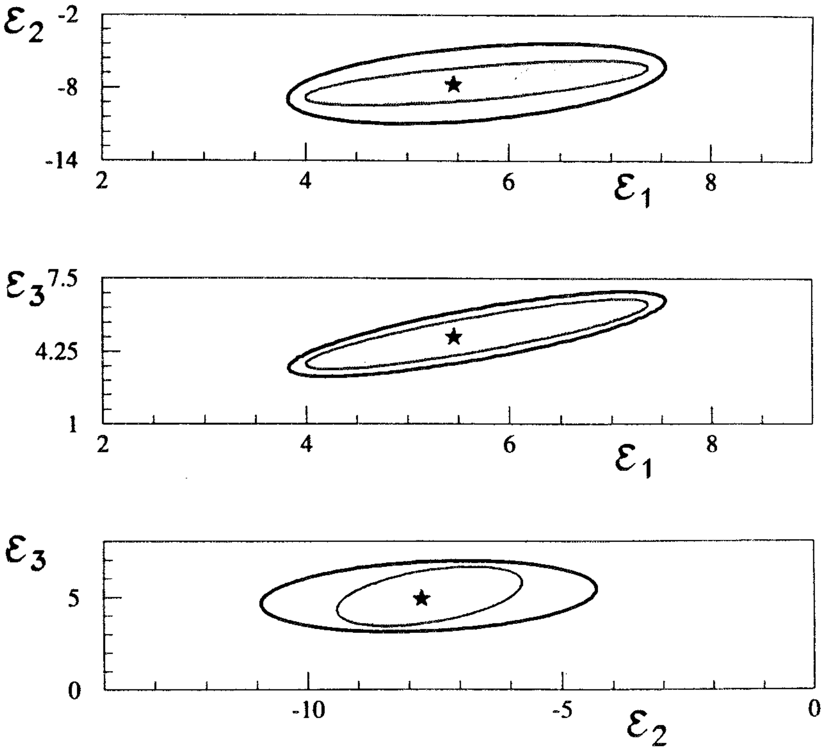


Future expectations for ϵ's

compare summer 1997 with future expectations

central values correspond to

m_t = 175 GeV, m_H = 100 GeV, $\alpha_s(M_Z)$ = 0.120



Summary and Conclusions

- Existing data from LEP, SLAC and FNAL provide stringent tests of the SM

  some possible discrepancies in extracted $\sin^2\theta_{\mathrm{eff}}^{\mathrm{lept}}$ from LEP and SLD data

  b-quark couplings, in particular the right-handed, show largest deviations from SM

- In fits to SM data favour a light Higgs

  but limits very sensitive to measurements which are themselves not very consistent

  hence caution in the interpretation !

- tests will become more stringent with future data

  SLAC measurement of A_{LR}

  FNAL and LEP measurements of M_{W}

  FNAL measurement of M_{t}

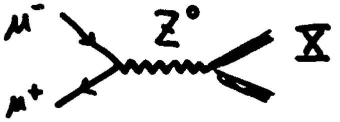
  plus future Colliders (LHC, $\mathrm{e}^+\mathrm{e}^-$, $\mu^+\mu^-$)

- indirect tests will be still important when new physics is discovered

Physics at the Z°-pole

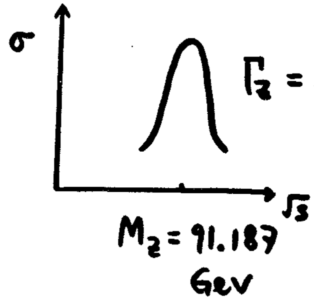
— higher luminosity w/ beam polarizations

T. Han @ UC - Davis
UW - Madison



$$\sigma_{Z\text{-peak}} = \frac{12\pi}{M_Z^2} BR(\mu^+\mu^-) BR(X)$$

$$\simeq 60 \cdot 10^6 \, BR(X) \quad fb$$



$\Gamma_Z = 2.5$ Gev $\gg \sigma_{\text{beam resl'n}}$

present:

	# of Z's:	Eff. Pol. $P_{eff} = \frac{P_{\ell^+} - P_{\ell^-}}{1 - P_{\ell^+} P_{\ell^-}}$	
LEP-I	4 × 4M	0	
SLD	300 K	77%	($P_{\ell^-} = -77\%$)

proposals:

	Z's/Yr:		
SLC/SLD 2000	3M	80% (?)	
FMC (R=0.12%)	70M (1.2 fb^{-1})	40%	($P_{\ell^+} = -P_{\ell^-} = 20\%$)
	18M (0.3 fb^{-1})	80%	($P_{\ell^+} = -P_{\ell^-} = 50\%$)
[JLC (M_Z):	600 M (10 fb^{-1})	85% (?)	($P_{e^-} = -85\%$)]

1. More precise measurements on SM Parameters:

... ...

Γ_Z, Γ_ℓ,

$$A_f = \frac{2g_V g_A}{g_V^2+g_A^2} = \frac{g_L^2-g_R^2}{g_L^2+g_R^2}$$

Comp. SM fit:

a). $A^e_{LR} = A_e \Rightarrow \sin^2\theta_W^{eff}|_{SLD} = 0.23055(41)$ -2.4σ

$\sin^2\theta_W^{eff}|_{LEP} = 0.23199(28)$ $+1.7\sigma$

[while $\sin^2\theta_W^{eff}|_{SM\,fit} = 0.23152$] $m_{h^0}\downarrow$!

Note:

$\Delta\sin^2\theta_W^{eff}|_{SLD} = \pm 0.00073(\text{stat.}) \pm 0.00021\ (\text{syst.})$

⇒ more than 10 × Z's needed (a few M pol. Z's) to bring $\Delta_{stat} \sim \Delta_{syst}$.

More over:

$$\Delta\sin^2\theta_W^{eff}|_{SLD} \propto \underset{\nearrow\ \text{Stat.+Syst}}{\frac{1}{\sqrt{N_Z}\,P_{eff}}} \oplus A_{LR}\underset{\nearrow\ \text{Syst}}{\frac{\Delta P_{eff}}{P_{eff}}}$$

Provided that:

$\frac{\Delta \ell}{\ell} \lesssim 0.1\%$ (LEP)

And:

JLC

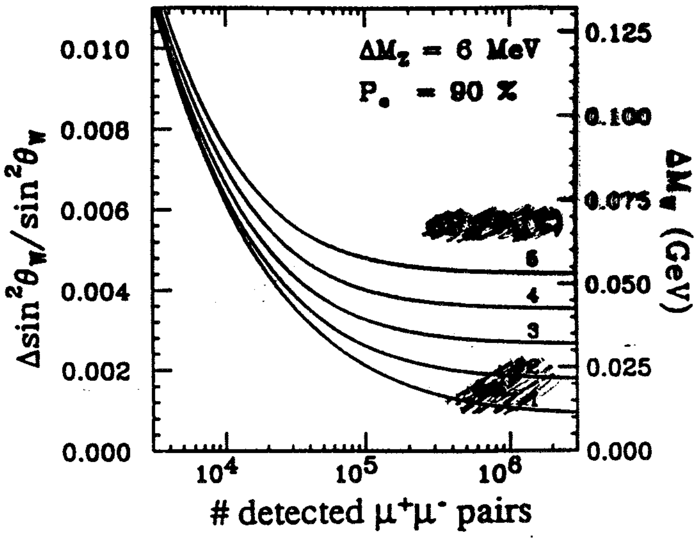


Figure 6: The error on $\sin^2\theta W$ as a function of the number of muon pairs.

b). $R_{had} = \frac{\Gamma_{had}}{\Gamma_\ell} = 20.775 \pm 0.0025$

$$\Rightarrow \alpha_s(M_Z) = 0.124 \underbrace{\pm 0.004}_{\text{exp.}} \underbrace{\pm 0.002}_{\text{Theo. } m_h \ldots}$$

While $\alpha_s^{\text{world}}(M_Z) = 0.118 \pm 0.003$

DIS, τ-decay,
Lattice ($c\bar{c}$, $b\bar{b}$), $R(e^+e^-)$...

an effect on Unification !

For a better Direct measurement:

10x Z's, $\Delta\alpha_s(M_Z) \lesssim 0.001$ (100 M Z's)

but again: $\frac{\Delta\ell}{\ell} \lesssim 0.1\%$

c). A_{FB}^b at LEP: 0.0983(24) -2σ
SM fit: 0.1031

R_b: 0.2170(9) $+1.4\sigma$
SM fit: 0.2158

error dominated by b-tagging/impurity

d). Michel parameters in τ- decays

$$\frac{d\Gamma(\tau\to\ell\nu\bar{\nu})}{d\cos\theta_\ell\, dx} \propto x^2 \Big\{ 12(1-x) + \rho_\tau\left(\frac{32}{3}x-8\right) + \eta_\tau \frac{24m_\ell}{m_\tau}\cdot\frac{1-x}{x} - P^\tau \xi_\tau \cos\theta_\ell \left[4(1-x) + \delta_\tau\left(\frac{32}{3}x-8\right)\right] \Big\}$$

where $P^\tau = \frac{d\sigma_R/d\cos\theta_{\tau^-} - d\sigma_L/d\cos\theta_{\tau^-}}{\text{"} + \text{"}}$, $x = \frac{2E_\ell}{m_\tau}$

Currently

		SM: (V-A)	exp.	Comp. w/ μ
	ρ_τ	0.75	0.742 ± 0.027	0.7518 ± 0.0026
	η_τ	0	-0.01 ± 0.14	-0.007 ± 0.013
Need Pol. P^τ!	ξ_τ	1	1.04 ± 0.07	1.003 ± 0.008
	δ_τ	0.75	0.76 ± 0.11	0.749 ± 0.004

Need 100 - 1000x τ's (>100 M Z's)
to reach an accuracy in μ's

2. $\not{CP}$ with $Z \to B_d \bar{B}_d$

- Copious production

  $BR(Z \to b\bar{b}) \simeq 15\%$

  $70\,M\ Z\text{'s}/Yr \Rightarrow 10\,M \left\{ \begin{matrix} B^+B^- \\ B_d\bar{B}_d \\ B_s\bar{B}_s \end{matrix} \right. /Yr$

- highly boosted system.

  $\beta\gamma = P/m \sim 9 \Rightarrow l = \beta\gamma c\overset{468\mu m}{\tau} \simeq 4.2\ mm$

- rich modes

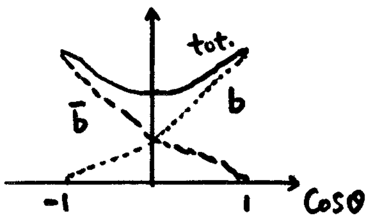
$B_d(\bar{B}_d) \to$		probe:	BR's:
$(c\bar{c}s)$	$J/\psi\, K_S^0$ $J/\psi\, K_L^0$ $J/\psi\, K^{0*}$	β	$\sim 10^{-3}$
$(c\bar{c}d)$	D^+D^- $D^{+*}D^{-*}$ $D^{\pm *}D^{\mp}$	β	$\lesssim 10^{-3}$
$(u\bar{u}d$ $d\bar{d}d)$	$\pi^+\pi^-$ $\rho^{\pm}\pi^{\mp}$ $a^{\pm}\pi^{\mp}$	α	$\sim 10^{-5}$
$(c\bar{u}s)$	D^0K^*	$\Rightarrow \gamma$	$\lesssim 10^{-5}$
...	...		

- CP Asymmetry in Charged $B^{\pm}$ decays.

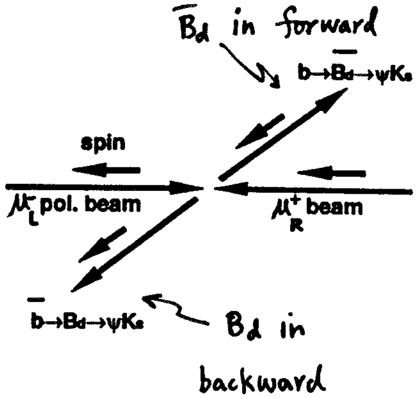
  (direct $\not{CP}$ violation only)

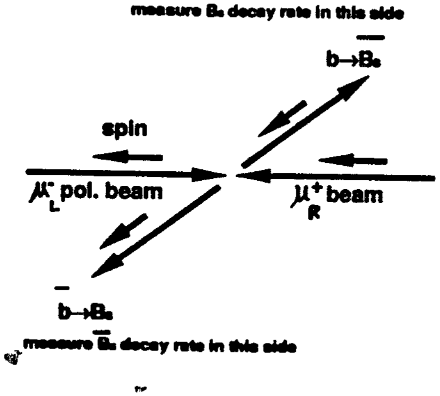
	BR's	$a_{asym.}$
$B^+ \to K^+\pi^0$	$< 1\%$	$\sim 1\%$
$\pi^+\pi^0$		
$K^+\phi$	$\sim 10^{-5}$	$\sim 1\%$
...		

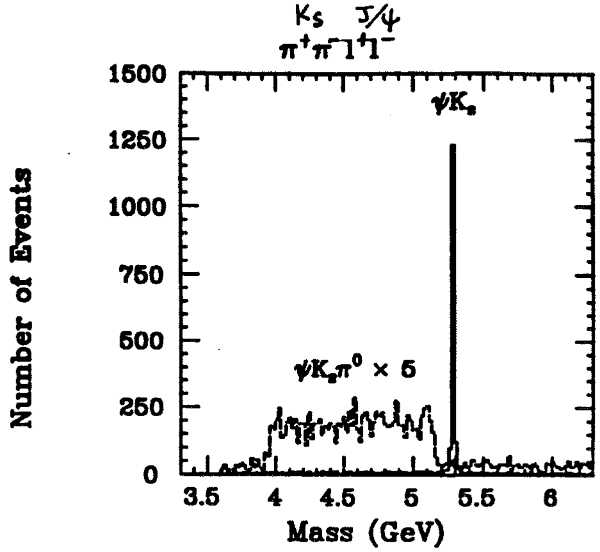
at least a few M b's $\Rightarrow$ 10M Z's



- flavor tagging by Kinematics w/ polarized beam.







JLC Study

Figure 2.60: Invariant mass distributions of $\pi^+\pi^-l^+l^-$. The solid histogram shows ψK_s deca and the dotted one shows $\psi K_s\pi^0$ decay.

1~2 Yr of FMC: 100M Z's

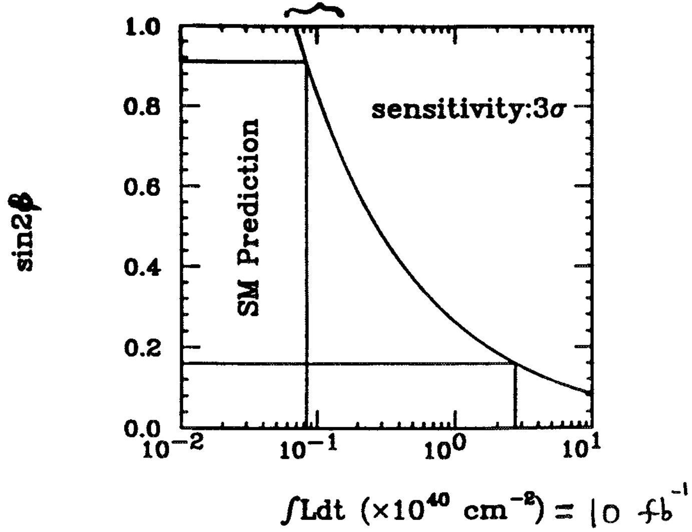


Figure 2.61: The required luminosity to measure $sin2\beta_1$ with three standard deviation.

$B_s^0 - \bar{B}_s^0$ Mixing Measurement:

JLC

$B_s^0 \; \bar{B}_s^0 \rightarrow \ell^+ \nu D_s^- , \; \ell^- \nu D_s^+$

$(\bar{b}s) \; (b\bar{s})$

- Mixing: $\dfrac{N(\ell^+\ell^+) + N(\ell^-\ell^-)}{N(\ell^+\ell^-) + N(\ell^-\ell^+)}$

- time-dependent oscillation

  $P(t) = \frac{1}{2} e^{-t/\tau} (1 - \cos x_s \frac{t}{\tau}) = \frac{1}{2} e^{-t/\tau} (1 - \cos \Delta m_s t)$

  where $x_s = \dfrac{\Delta m_s}{\Gamma} \leftarrow m_{heav} - m_{light}$

  expected $x_s \gg 1$. $x_d = 0.73 \pm 0.05$

- Current limit:

  $\Delta m_s > 10.2 \text{ ps}^{-1}$ or $x_s > 16.5$

$$\frac{\Delta m_d}{\Delta m_s} \propto \left| \frac{V_{td}}{V_{ts}} \right|^2$$

SLD expectation w/ 0.5 M Z's:

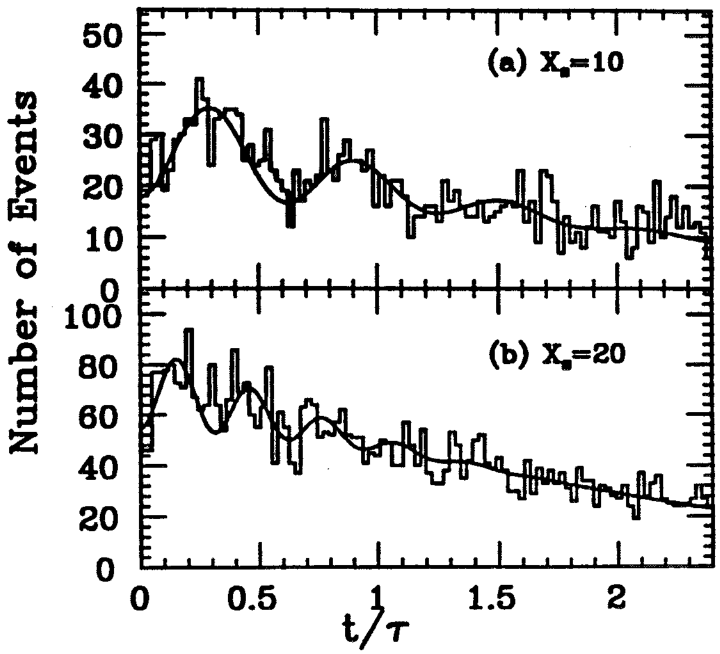
$\Delta m_s > 16 \text{ ps}^{-1}$ or $x_s > 26$

$\tau_{B_s} = 1.61$ ps

$\Gamma_{B_s} = 0.62 \text{ ps}^{-1}$

$x_s = \Delta m / \Gamma \geq 16.5$

$B_s - \bar{B}_s$ oscillation: $\ell^\pm \nu D_s^\mp$



2 M Z's (excluded by LEP)

4 M Z's.

Figure 2.62: The decay proper time distribution for (a) $X_s = 10$ and (b) $X_s = 20$.

3. Rare & forbidden Processes:

$Z \to e^- \mu^+ \ldots$ $BR(\ell \bar{\ell}') < 10^{-6}$

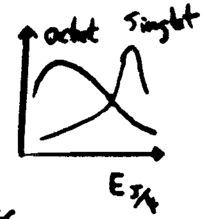
$\gamma\gamma(\gamma)$ $BR(\gamma\gamma(\gamma)) < 10^{-5}$

$\pi^0 \gamma$

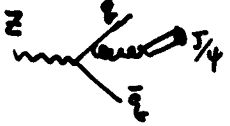
$\rho^0 \gamma$

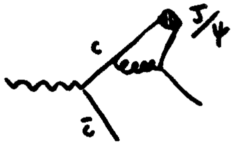
… …

$Z \to J/\psi\ X$



Cheung, Keung, Yuan; Cho.





Conclusions:

A FMC w/

	annual $\mathcal{L}$	(Z's)	Pol_{eff}
(i)	1.2 fb^{-1}	(70M)	40%
(ii)	0.3 fb^{-1}	(18M)	80%

- Case (i) Significantly improve LEP I both statistically & in polarizat.

•• Case (ii) Significantly improve SLC/SLD Statistically

provided: $\Delta\mathcal{L}/\mathcal{L}$, $\Delta P_\mu / P_\mu < 0.1\%$, b-tagging …

∴ $\gtrsim 100$ M Z's needed to do

* CP better than b-factories

* observe $B_s - \bar{B}_s$ oscillat.