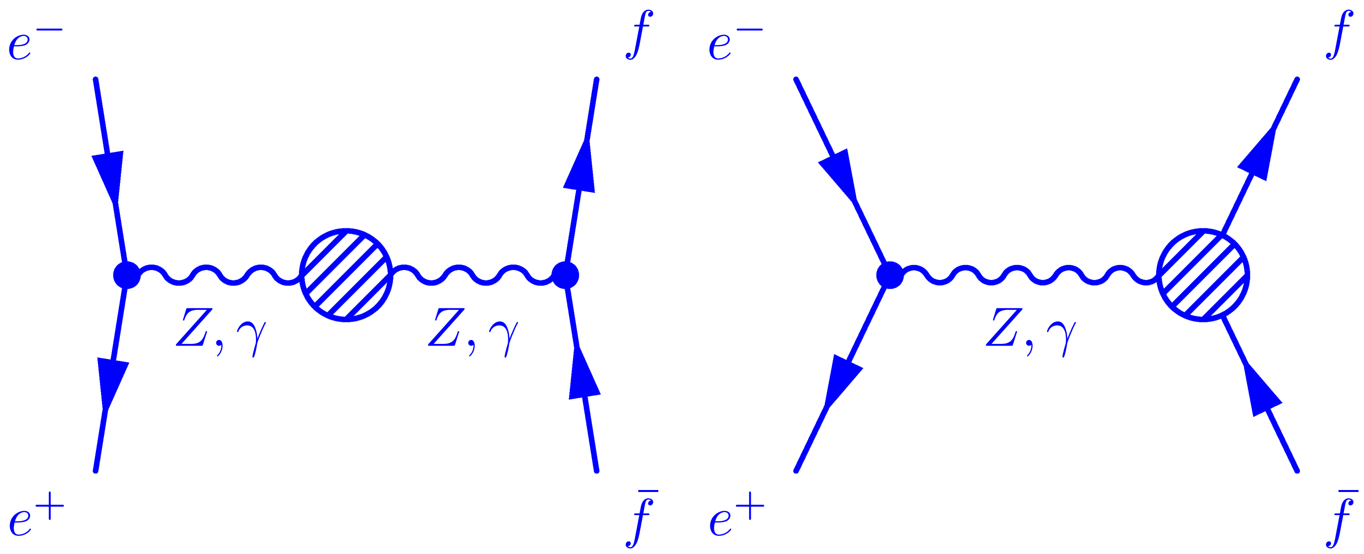
Electroweak Results and Fits to the Standard Model

On behalf of the LEP and SLD Electroweak Working Groups
(Many thanks to Martin Grünewald)

- Introduction
- Electroweak Measurements
- Test of the Standard Model
- Constraint on the Higgs mass
- Conclusions

Electroweak Radiative Corrections



Electroweak Radiative Corrections

Born Level

$$\rho = \frac{m_W^2}{m_Z^2 \cos^2\theta_W} = 1$$

$$\sin^2\theta_W = 1 - \frac{m_W^2}{m_Z^2}$$

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}\sin^2\theta_W G_F}$$

Radiative corrections (non-photonic)

$$\bar{\rho} = 1 + \Delta\rho$$

$$\sin^2\theta_{eff}^{lept} = (1+\Delta\kappa)\sin^2\theta_W$$

$$m_W^2 = \frac{\pi\alpha}{\sqrt{2}\sin^2\theta_W G_F}(1+\Delta r)$$

$$\Delta r = \Delta\alpha - \frac{\cos^2\theta_W}{\sin^2\theta_W}\Delta\rho + \Delta r_{rem}$$

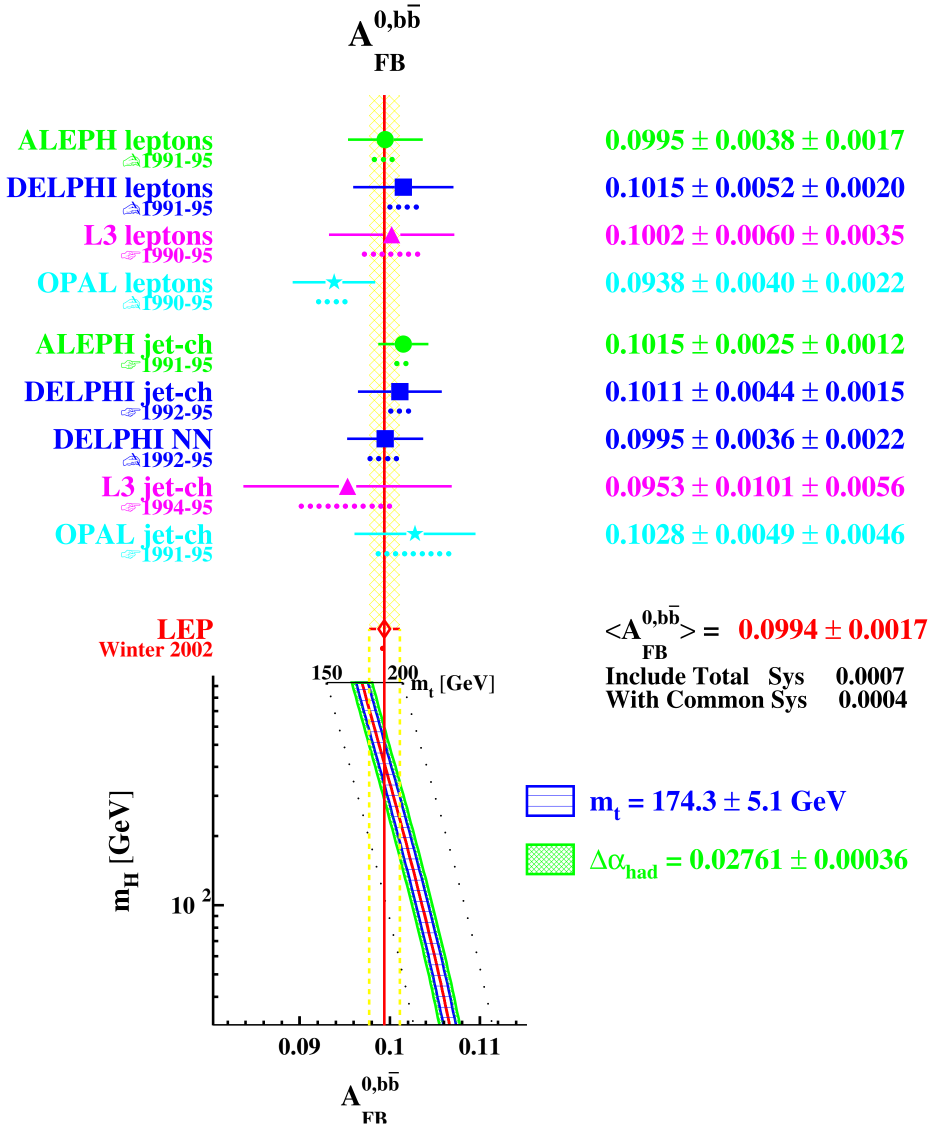
$$\Delta\rho, \Delta\kappa, \Delta r = f\left(m_t^2, \log(m_H)\right)$$

The measured quantities

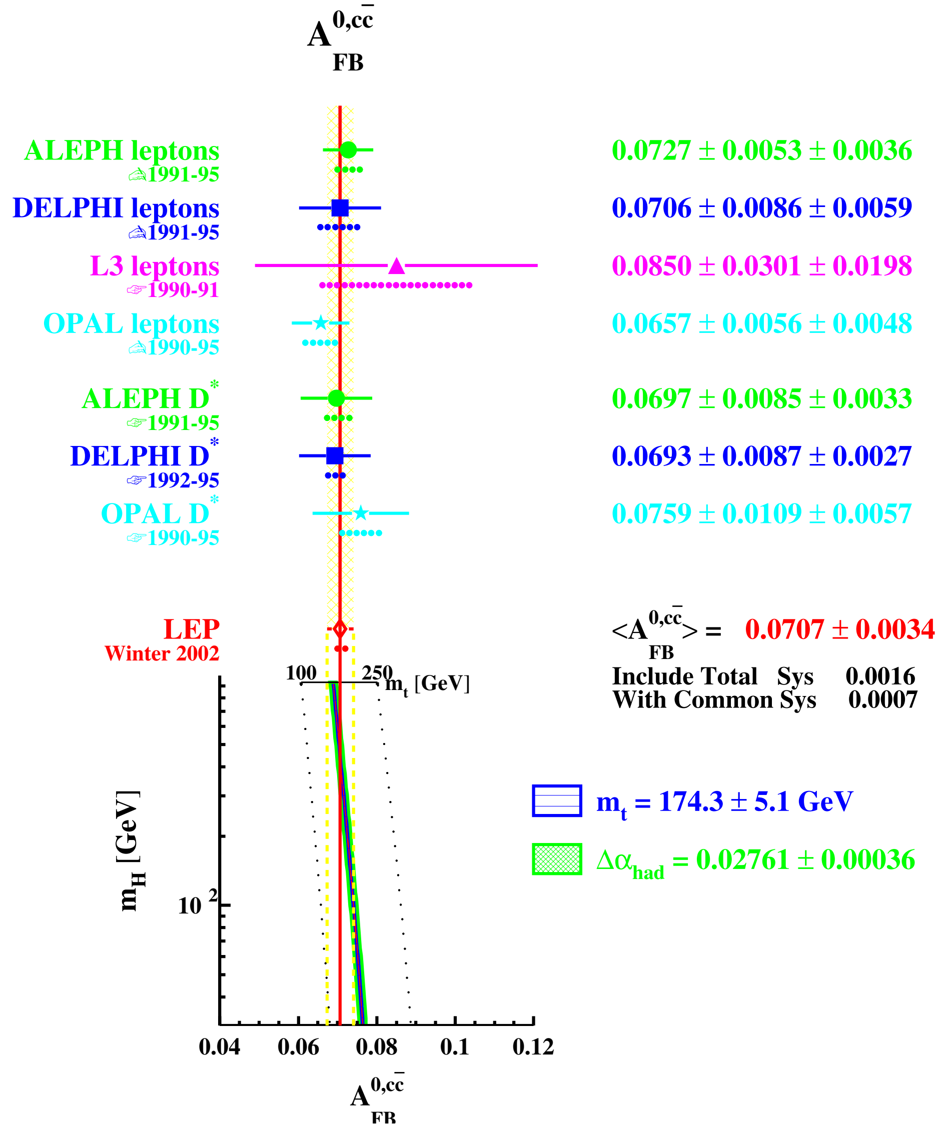
- The Z lineshape parameters
  m_Z, Γ_Z, σ_h^0, R_l, $A_{FB}^{0,l}$
- A_{LR}, A_l from SLD
- The τ polarisation at the Z
- Heavy quark flavours at LEP and SLC
  R_b^0, R_c^0, $A_{FB}^{0,b}$, $A_{FB}^{0,c}$, $< Q_{FB} >$, A_b, A_c
- m_W, Γ_W from LEP and $p\bar{p}$ colliders
- m_t from Tevatron
- Q_W from atomic parity violation
- $\sin^2\theta_W$ from neutrino interactions at the Tevatron
- Experimental determination of $\Delta\alpha_{had}^5$

What is new?

- ALEPH final results for $A_{FB}^{0,b}$, $A_{FB}^{0,c}$ from leptons
- Final NuTeV results for $\sin^2\theta_W$
- New evaluation of Q_W in atomic parity violation in cesium
- Inclusion of Γ_W measurements from LEP and the Tevatron



$A_{FB}^{0,b\bar{b}}$
ALEPH leptons 1991-95 — 0.0995 ± 0.0038 ± 0.0017
DELPHI leptons 1991-95 — 0.1015 ± 0.0052 ± 0.0020
L3 leptons 1990-95 — 0.1002 ± 0.0060 ± 0.0035
OPAL leptons 1990-95 — 0.0938 ± 0.0040 ± 0.0022
ALEPH jet-ch 1991-95 — 0.1015 ± 0.0025 ± 0.0012
DELPHI jet-ch 1992-95 — 0.1011 ± 0.0044 ± 0.0015
DELPHI NN 1992-95 — 0.0995 ± 0.0036 ± 0.0022
L3 jet-ch 1994-95 — 0.0953 ± 0.0101 ± 0.0056
OPAL jet-ch 1991-95 — 0.1028 ± 0.0049 ± 0.0046
LEP Winter 2002
$<A_{FB}^{0,b\bar{b}}>$ = 0.0994 ± 0.0017
Include Total Sys 0.0007
With Common Sys 0.0004
150 200 m_t [GeV]
m_t = 174.3 ± 5.1 GeV
$\Delta\alpha_{had}$ = 0.02761 ± 0.00036
m_H [GeV]
10^2
0.09 0.1 0.11
$A_{FB}^{0,b\bar{b}}$



$A_{FB}^{0,c\bar{c}}$
ALEPH leptons 1991-95 — 0.0727 ± 0.0053 ± 0.0036
DELPHI leptons 1991-95 — 0.0706 ± 0.0086 ± 0.0059
L3 leptons 1990-91 — 0.0850 ± 0.0301 ± 0.0198
OPAL leptons 1990-95 — 0.0657 ± 0.0056 ± 0.0048
ALEPH D* 1991-95 — 0.0697 ± 0.0085 ± 0.0033
DELPHI D* 1992-95 — 0.0693 ± 0.0087 ± 0.0027
OPAL D* 1990-95 — 0.0759 ± 0.0109 ± 0.0057
LEP Winter 2002
$<A_{FB}^{0,c\bar{c}}>$ = 0.0707 ± 0.0034
Include Total Sys 0.0016
With Common Sys 0.0007
100 250 m_t [GeV]
m_t = 174.3 ± 5.1 GeV
$\Delta\alpha_{had}$ = 0.02761 ± 0.00036
m_H [GeV]
10^2
0.04 0.06 0.08 0.1 0.12
$A_{FB}^{0,c\bar{c}}$

The final NuTeV result

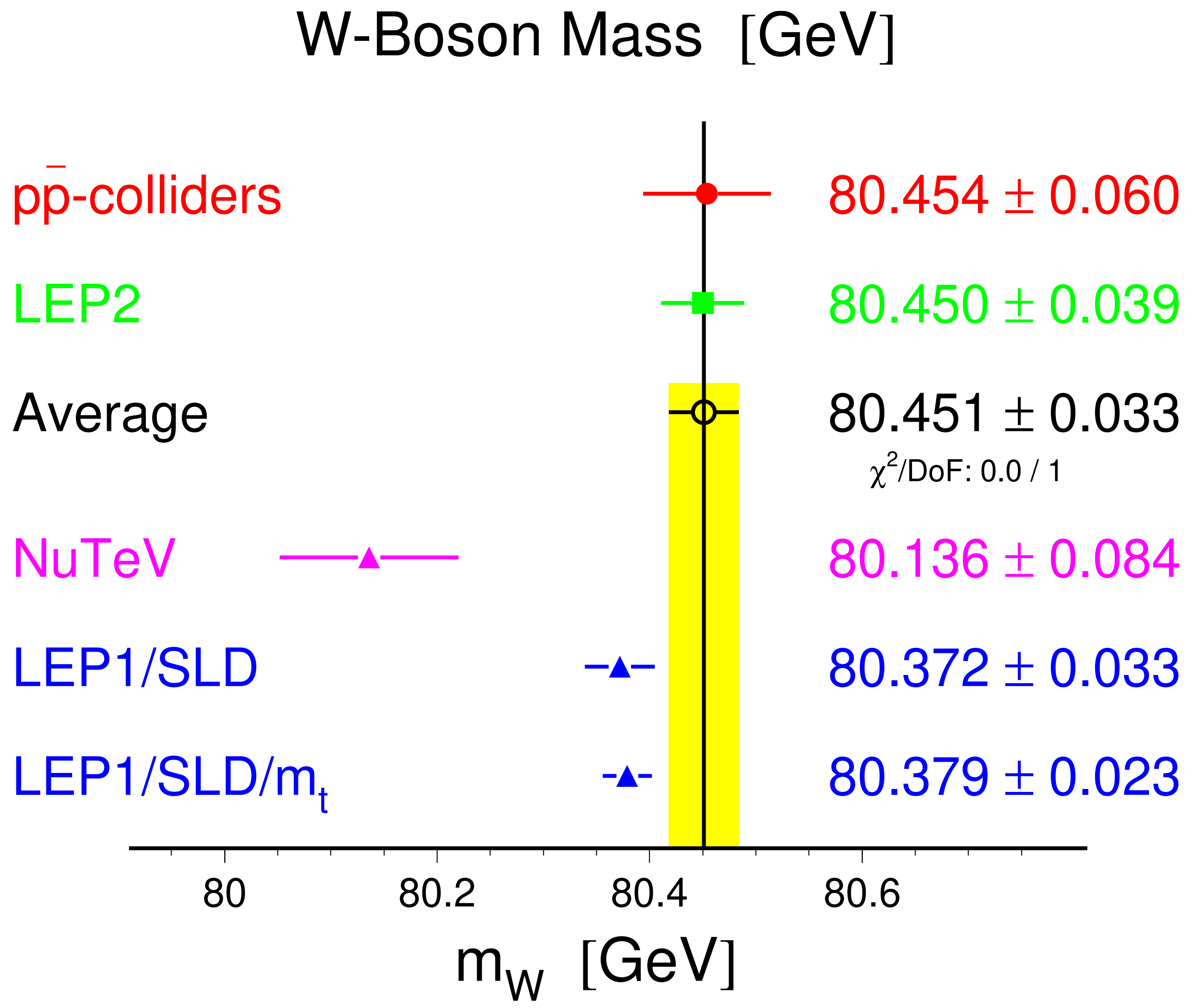
$$R^{\nu(\bar{\nu})} = \frac{\sigma(\overset{(-)}{\nu}\ N \rightarrow \overset{(-)}{\nu}\ X)}{\sigma(\overset{(-)}{\nu}\ N \rightarrow l^{-(+)} X)} = (g_L^2 + r^{(-1)} g_R^2)$$

$$r = \frac{\sigma(\bar{\nu}N \rightarrow l^+ X)}{\sigma(\nu N \rightarrow l^- X)}$$

$$R^{\nu}_{exp} = 0.3916 \pm 0.0007, R^{\bar{\nu}}_{exp} = 0.4050 \pm 0.0016$$

yielding $\sin^2\theta_W^{on-shell}$ with explicit m_t and m_H dependences:

$$\begin{aligned} \sin^2\theta_W^{on-shell} &= 0.2277 \pm 0.0013\ (stat) \pm 0.0009\ (syst) \\ &-0.00022 \times \left(\frac{m_t^2 - (175\ \text{GeV})^2}{(50\ \text{GeV})^2}\right) \\ &+0.00032 \times \ln\left(\frac{m_H}{150\ \text{GeV}}\right) \end{aligned}$$


W-Boson Mass [GeV]
p$\bar{p}$-colliders
80.454 ± 0.060
LEP2
80.450 ± 0.039
Average
80.451 ± 0.033
χ^2/DoF: 0.0 / 1
NuTeV
80.136 ± 0.084
LEP1/SLD
80.372 ± 0.033
LEP1/SLD/m_t
80.379 ± 0.023
80
80.2
80.4
80.6
m_W [GeV]

Atomic parity violation in cesium

The weak interaction of an electron with the nucleus is

$$H = \frac{G_F}{2\sqrt{2}} \rho(r) Q_W \gamma_5$$

where

$$Q_W = -2\left[C_{1u}(2Z+N) + C_{1d}(Z+2N)\right]$$

and to leading order

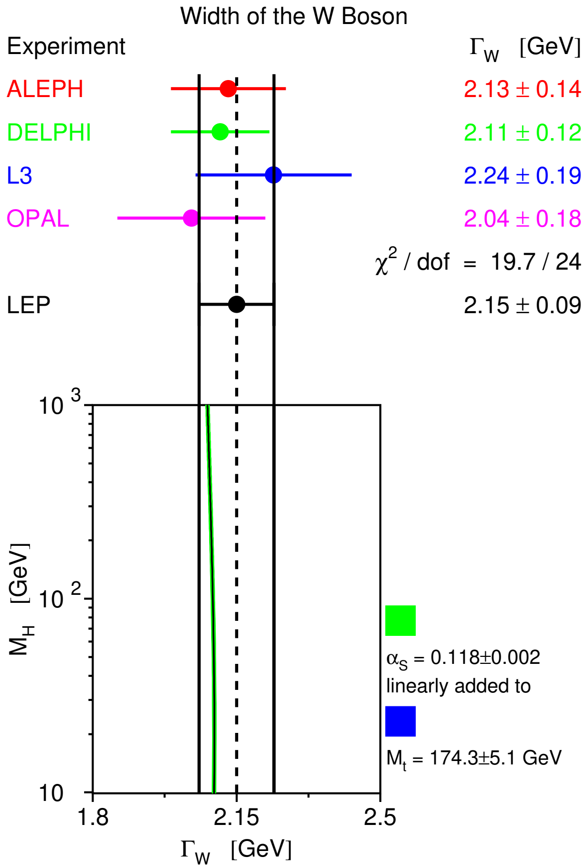
$$C_{1u} = \rho\left[-\frac{1}{2} + \frac{4}{3}\sin^2\theta_W\right], C_{1d} = \rho\left[\frac{1}{2} - \frac{2}{3}\sin^2\theta_W\right]$$

A new evaluation of the $6s - 7s$ transition gives for the amplitude:

$$E_{PNC} = (0.902 \pm 0.006) \times 10^{-11} iea_B \left(\frac{-Q_W}{N}\right)$$

$$\text{and} \quad Q_W = -72.39 \pm 0.29\ (exp) \pm 0.51\ (th)$$

Measurements of Γ_W



- Tevatron measurement is $\Gamma_W = 2.11 \pm 0.11$ GeV

The derived parameters

The leptonic partial widths from fits to LEP data:

$$\Gamma_{ee} = 83.92 \pm 0.12 \text{ MeV}$$
$$\Gamma_{\mu\mu} = 83.99 \pm 0.18 \text{ MeV}$$
$$\Gamma_{\tau\tau} = 84.08 \pm 0.22 \text{ MeV}$$

in good agreement with lepton universality, hence:

$$\Gamma_{ll} = 83.985 \pm 0.086 \text{ MeV}$$

We can obtain values for α_s from R_l:

$$\alpha_s = 0.1224 \pm 0.0038^{+0.0033}_{-0.0000}(m_H\ 100 + 900 - 0 \text{ GeV})$$

or from the pole hadronic cross-section σ_h^0:

$$\alpha_s = 0.1180 \pm 0.0030^{+0.0026}_{-0.0000}(m_H\ 100 + 900 - 0 \text{ GeV})$$

The coupling parameters

In terms of the effective vector and axial-vector neutral current couplings of the leptons:

$$A_l = 2\frac{g_{Vl}g_{Al}}{g_{Vl}^2 + g_{Al}^2}$$

and the fermion forward-backward asymmetries at the pole can be expressed as:

$$A_{FB}^{0,l} = \frac{3}{4}A_e A_l$$

The coupling parameters

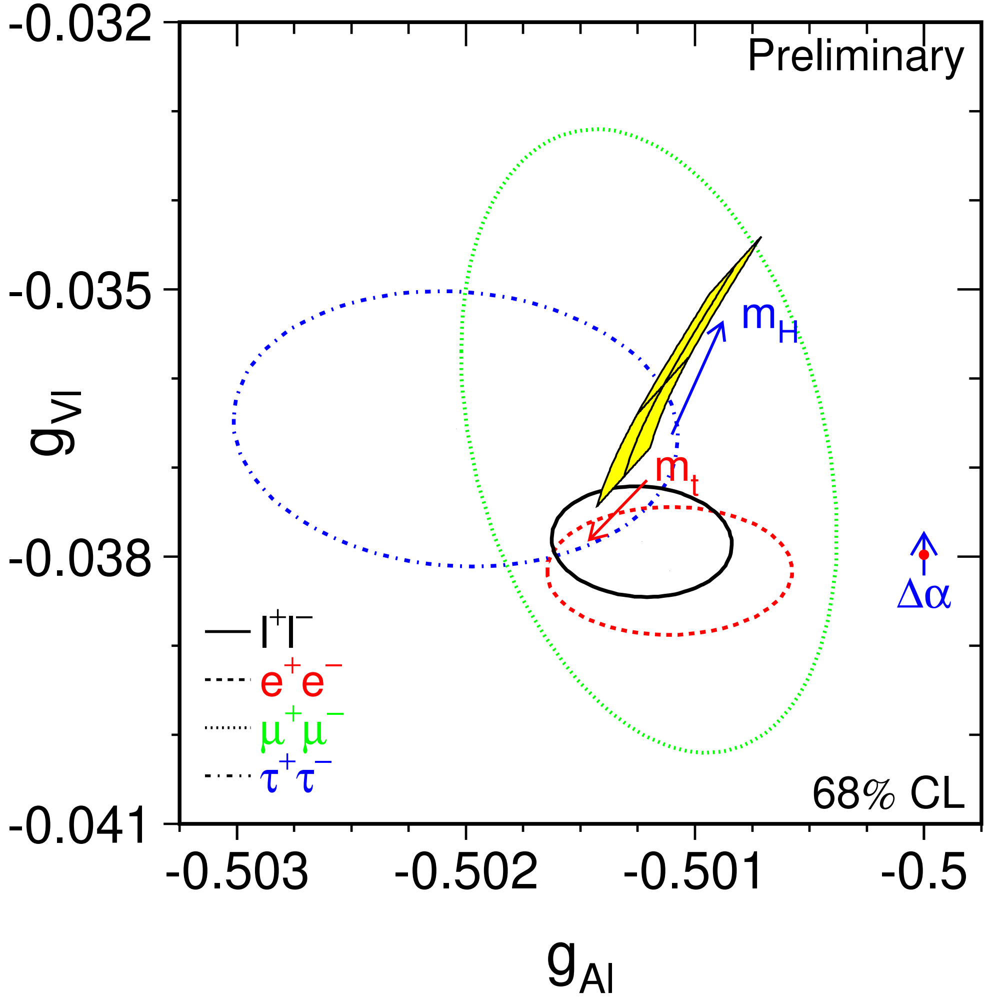
Using LEP lineshape, forward-backward asymmetries and τ polarisation measurements, and the A_l from SLD the following values are found:

$$
\begin{aligned}
A_e &= 0.1514 \pm 0.0019 \\
A_\mu &= 0.1456 \pm 0.0091 \\
A_\tau &= 0.1449 \pm 0.0040
\end{aligned}
$$

Or assuming lepton universality:

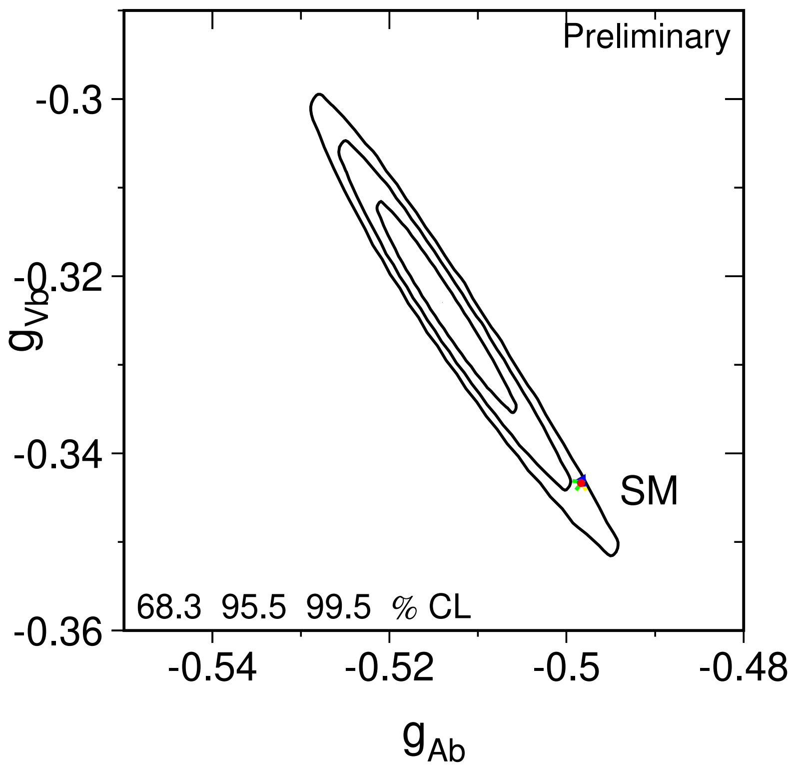
$$A_l = 0.1501 \pm 0.0016$$

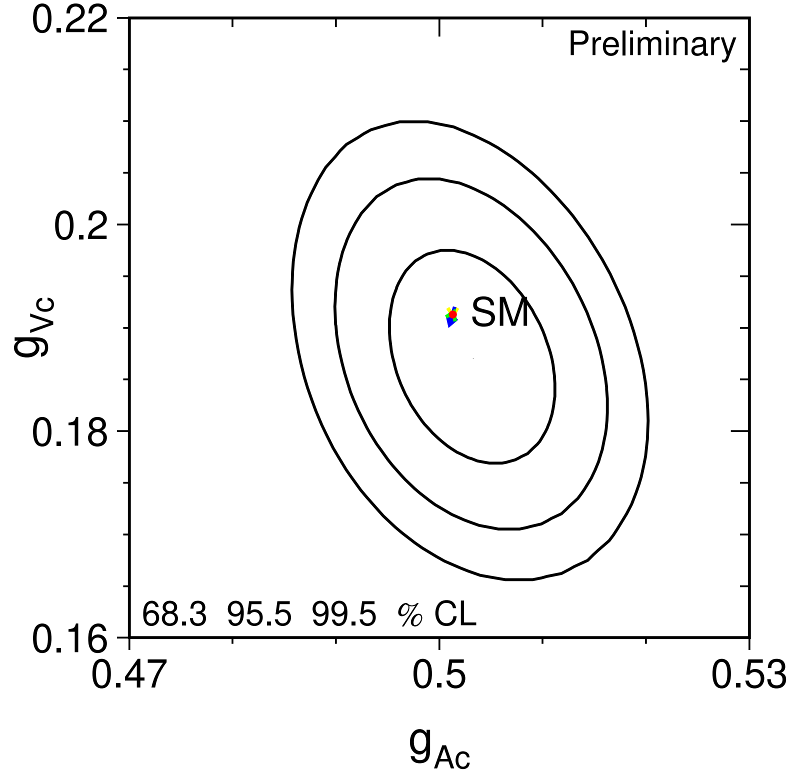
These results can also be expressed in terms of the effective couplings g_{Vl} and g_{Al}



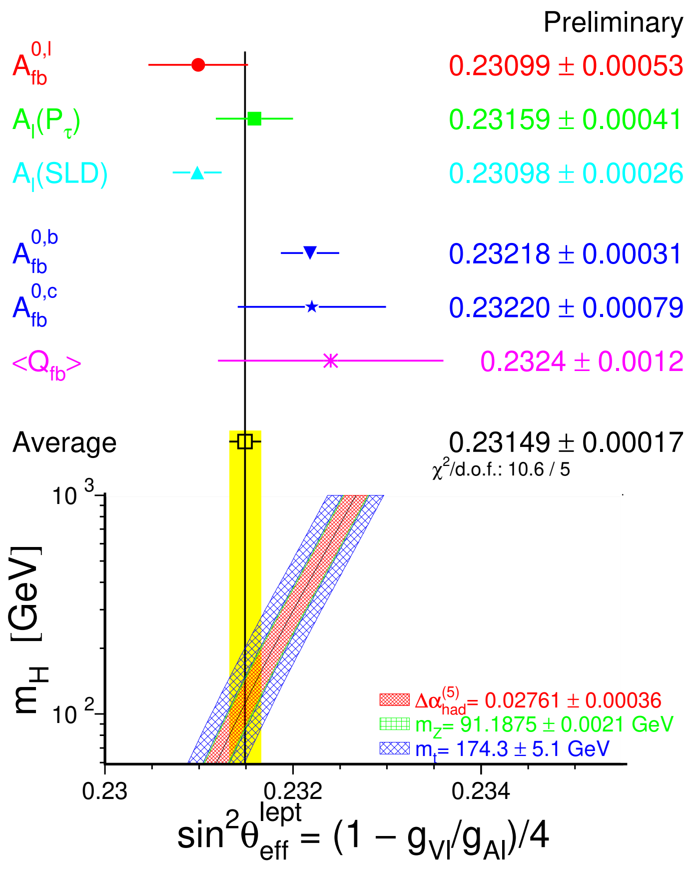
Preliminary
68% CL
g_{Vl}
g_{Al}
-0.032
-0.035
-0.038
-0.041
-0.503
-0.502
-0.501
-0.5
m_H
m_t
$\Delta\alpha$
l^+l^-
e^+e^-
$\mu^+\mu^-$
$\tau^+\tau^-$

The quark effective couplings





$\sin^2\theta_{eff}^{lept}$ from quarks and leptons



- Overall fit probability 5.9%

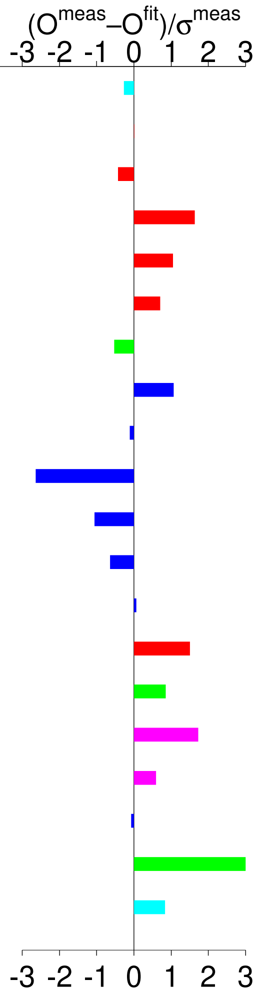
Standard Model Fits

	LEP1 + LEP2	All High Q^2	All data
m_t (GeV)	185^{+13}_{-11}	176.0 ± 4.3	174.7 ± 4.4
m_H (GeV)	238^{+373}_{-141}	83^{+50}_{-33}	85^{+54}_{-34}
$\log(m_H/\mathrm{GeV})$	$2.38^{+0.41}_{-0.39}$	$1.92^{+0.20}_{-0.22}$	$1.93^{+0.21}_{-0.23}$
$\alpha_s(m_Z^2)$	$0.1199^{+0.0032}_{-0.0030}$	0.1182 ± 0.0027	0.1183 ± 0.0027
$\chi^2/d.o.f$	14/9	19/13	29/15
$\sin^2\theta^{lept}_{eff}$	0.23159 ± 0.00018	$0.23133^{+0.00014}_{-0.00015}$	$0.23137^{+0.00014}_{-0.00015}$
$\sin^2\theta_W$	0.22276 ± 0.00051	0.22255 ± 0.00036	0.22272 ± 0.00036
m_W (GeV)	80.392 ± 0.026	80.403 ± 0.019	80.394 ± 0.018

- Using ZFITTER and TOPAZ0
- $\Delta\alpha^5_{had}(m_Z) = 0.02761 \pm 0.00036$
- Using Z-pole plus direct m_t, $m_W = 80.379 \pm 0.023$ GeV
- Using Z-pole plus direct m_W, $m_t = 181^{+11}_{-9}$ GeV

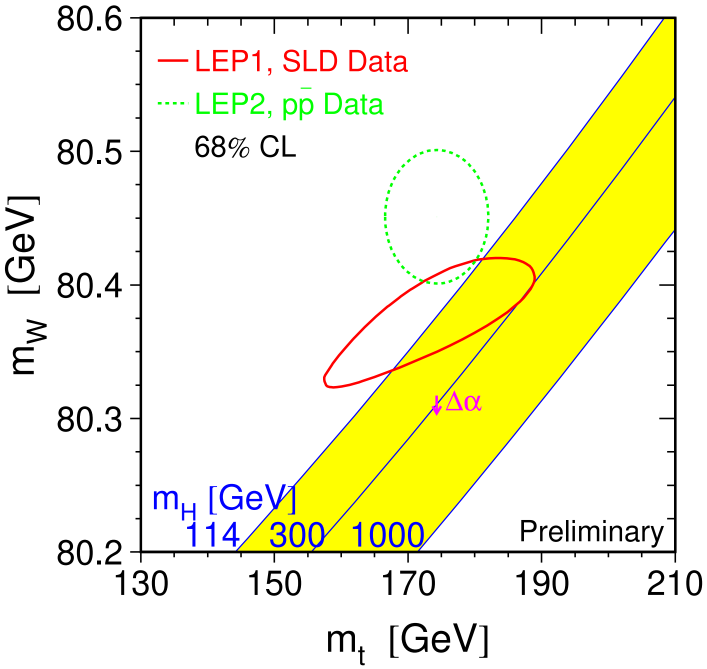
Winter 2002

	Measurement	Pull
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	-.27
m_Z [GeV]	91.1875 ± 0.0021	.01
Γ_Z [GeV]	2.4952 ± 0.0023	-.42
σ^0_{had} [nb]	41.540 ± 0.037	1.63
R_l	20.767 ± 0.025	1.05
$A^{0,l}_{fb}$	0.01714 ± 0.00095	.70
$A_l(P_\tau)$	0.1465 ± 0.0033	-.53
R_b	0.21646 ± 0.00065	1.06
R_c	0.1719 ± 0.0031	-.11
$A^{0,b}_{fb}$	0.0994 ± 0.0017	-2.64
$A^{0,c}_{fb}$	0.0707 ± 0.0034	-1.05
A_b	0.922 ± 0.020	-.64
A_c	0.670 ± 0.026	.06
A_l(SLD)	0.1513 ± 0.0021	1.50
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	.86
m_W [GeV]	80.451 ± 0.033	1.73
Γ_W [GeV]	2.134 ± 0.069	.59
m_t [GeV]	174.3 ± 5.1	-.08
$\sin^2\theta_W(\nu N)$	0.2277 ± 0.0016	3.00
$Q_W(Cs)$	-72.39 ± 0.59	.84



Indirect determination of m_t and m_W

Use electroweak measurements at LEP1 and SLD to obtain indirect determinations of m_t and m_W

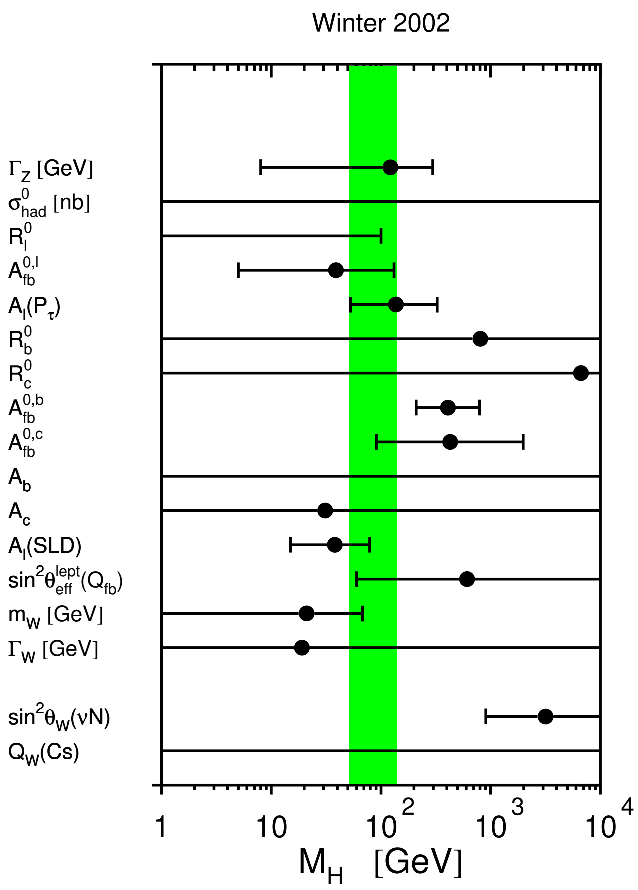


$$m_H = 82^{+109}_{-41}\ \text{GeV}$$
$$m_t = 170.6^{+11.4}_{-9.0}\ \text{GeV}$$
$$m_W = 80.372 \pm 0.033\ \text{GeV}$$

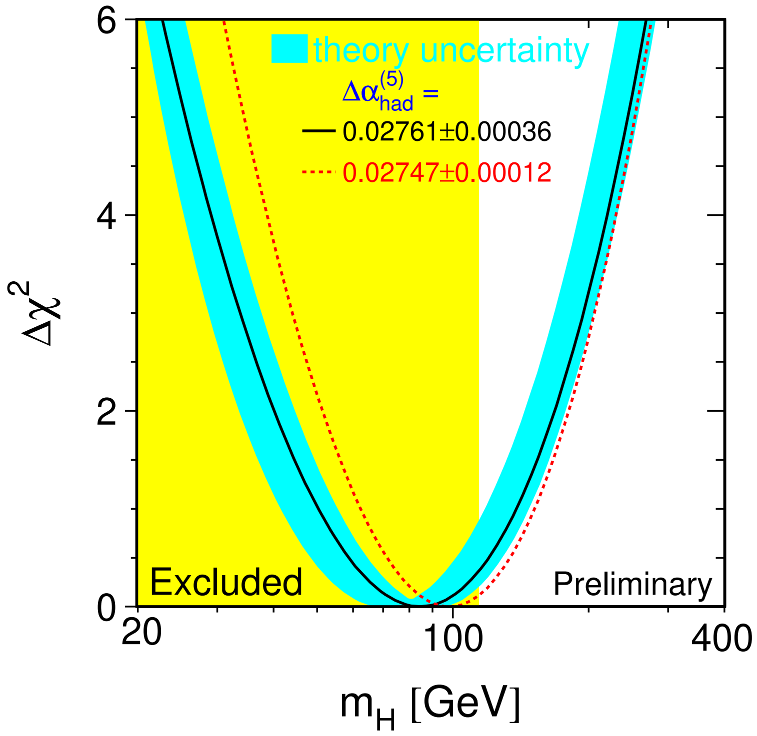
cf direct measurements at LEP and $p\bar{p}$ colliders:

$$m_t = 174.3 \pm 5.1\ \text{GeV}$$
$$m_W = 80.451 \pm 0.033\ \text{GeV}$$

Sensitivity of different quantities to Higgs mass



Limits on the Higgs boson mass



- One-sided 95% Confidence Limit $m_H < 196$ GeV

Conclusions

- With inclusion of new data overall fit probability falls to 1.7%
- The largest pulls are for $A_{FB}^{0,b}$ and $\sin^2\theta_W$
- However values of fitted parameters do not change much
- Light Higgs boson still preferred
- Many input measurements are still preliminary, so much work still to be done