Standard Model fits to Electroweak data

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Introduction

- Electroweak measurements used as input to SM fits:

LEP I	Z^0 decays
SLD	Z^0 decays; polarised beams
$p\bar{p}$ experiments	m_W, m_t
LEP II	m_W
νN experiments	$1 - m_W^2/m_Z^2$

- Electroweak fits to parametrise and combine these data

- Does the Standard Model work?
  Comparison of direct and indirect measurements of m_W and m_t to test Standard Model relations

- What do the data tell us about the Higgs?
  Fit to all data in the SM framework to extract m_H

Combinations, fits and plots from EWWG - Thanks!

LEP I

Measurements of cross sections of hadrons and lepton pairs and lepton asymmetries at $\sqrt{s} = \mathrm{m_Z}$.

$$\mathrm{e^+e^-} \longrightarrow \mathrm{Z^0} \longrightarrow \mathrm{f\bar{f}}$$

LEP I determines 9 parameters:

$$\sigma^0_{\mathrm{had}} = \frac{12\pi}{m^2_{\mathrm{Z}}}\frac{\Gamma_{\mathrm{e}}\Gamma_{\mathrm{had}}}{\Gamma^2_{\mathrm{Z}}} \qquad R_l = \frac{\Gamma_{\mathrm{had}}}{\Gamma_l}$$

$$A^{0,l}_{\mathrm{FB}} = \frac{3}{4}A_{\mathrm{e}}A_l \qquad A_l = \frac{2\bar{g}_{\mathrm{V}}\bar{g}_{\mathrm{A}}}{(\bar{g}^l_{\mathrm{V}})^2 + (\bar{g}^l_{\mathrm{A}})^2}$$

σ^0_{had}	hadronic pole cross section
$\mathrm{m_Z}$	peak position
Γ_{Z}	peak width
R_l	lepton cross sections
$A^{0,l}_{\mathrm{FB}}$	lepton asymmetries

Deconvolute QED corrections:

$$\sigma_{\mathrm{f\bar{f}}}(s) = \int^1_{4\mathrm{m}^2_{\mathrm{f\bar{f}}}/s} dz R(z,s)\sigma^0_{\mathrm{f\bar{f}}}(zs)$$

LEP I

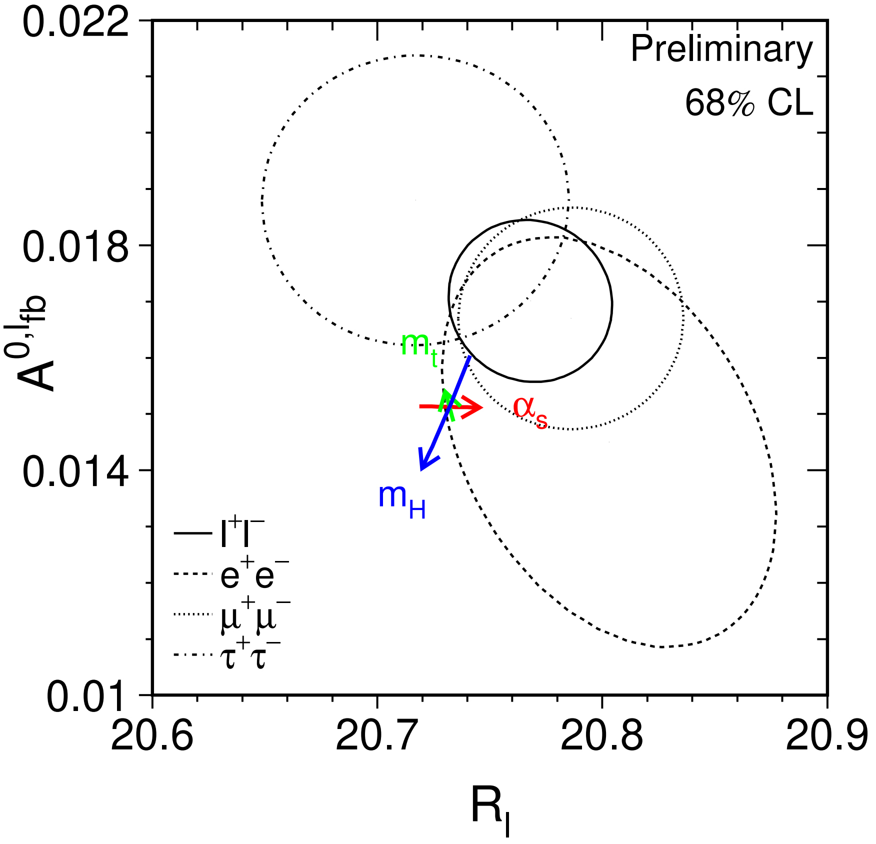
What's new since Moriond 1999:

- Improvements on theoretical calculations $\Rightarrow \mathcal{O}(\alpha^3)$ (ZFITTER 6.23, TOPAZ0 4.4, ALIBABA)
- Reduction of the theoretical error on small angle Bhabha scattering

m_Z	91 187.2 $\pm$ 2.1 MeV
Γ_Z	2 494.4 $\pm$ 2.4 MeV
σ^0_{had}	41.544 $\pm$ 0.037 nb
R_e	20.803 $\pm$ 0.049
R_μ	20.786 $\pm$ 0.033
R_τ	20.764 $\pm$ 0.045
$A^{0,e}_{\text{FB}}$	0.0145 $\pm$ 0.0024
$A^{0,\mu}_{\text{FB}}$	0.0167 $\pm$ 0.0013
$A^{0,\tau}_{\text{FB}}$	0.0188 $\pm$ 0.0017

- Finalising the experimental analyses - 3 LEP experiments have published *FINAL* lineshape results!

Test of Lepton Universality:



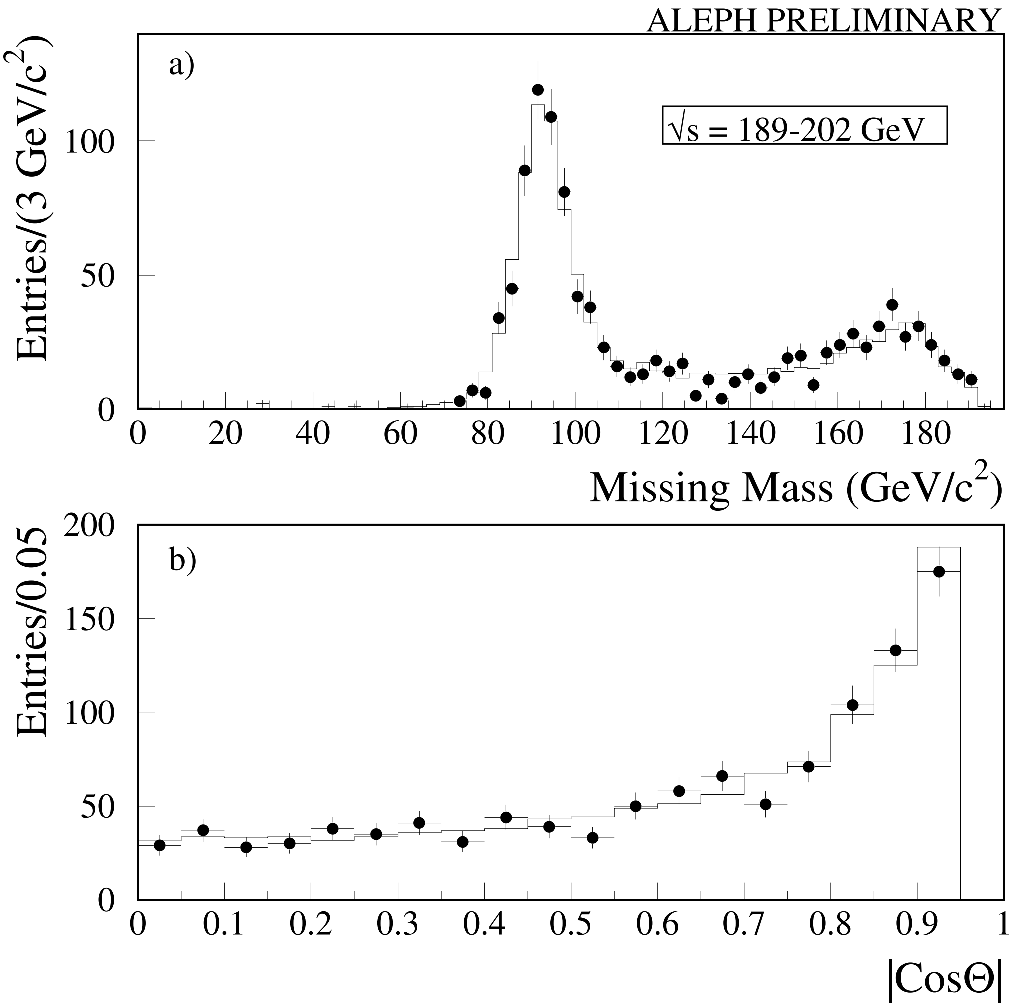
$$R_l = 20.768 \pm 0.024 \qquad A^{0,l}_{\rm FB} = 0.01701 \pm 0.00095$$

Determination of α_s from R_l:

$$\alpha_s = 0.1229 \pm 0.0036 \pm 0.0033$$
$$(\mathrm{m_t} = 174.3 \pm 5.1\ \mathbf{GeV},\ 100 < \mathrm{m_H} < 900\ \mathbf{GeV})$$

Invisible width and number of neutrino families in the SM:

$$\Gamma_{\rm inv} = \Gamma_{\rm Z} - \Gamma_{\rm had} - 3\Gamma_l = 498.80 \pm 1.5\ \mathbf{MeV}$$
$$N_\nu = \frac{\Gamma_{\rm inv}}{\Gamma_l}\left(\frac{\Gamma_l}{\Gamma_\nu}\right)_{\rm SM} = 2.9835 \pm 0.0083$$



	N_{obs}/N_{exp}	N_ν	up to $\sqrt{s}$
Aleph	0.990 ± 0.030		202 GeV
Delphi	0.969 ± 0.042	2.82 ± 0.17	202 GeV
L3	0.992 ± 0.044	3.05 ± 0.12	189 GeV
Opal	0.918 ± 0.039		189 GeV

Leptons at SLD

From left-right asymmetry $A_{\rm LR}$ at SLD (polarised beam):

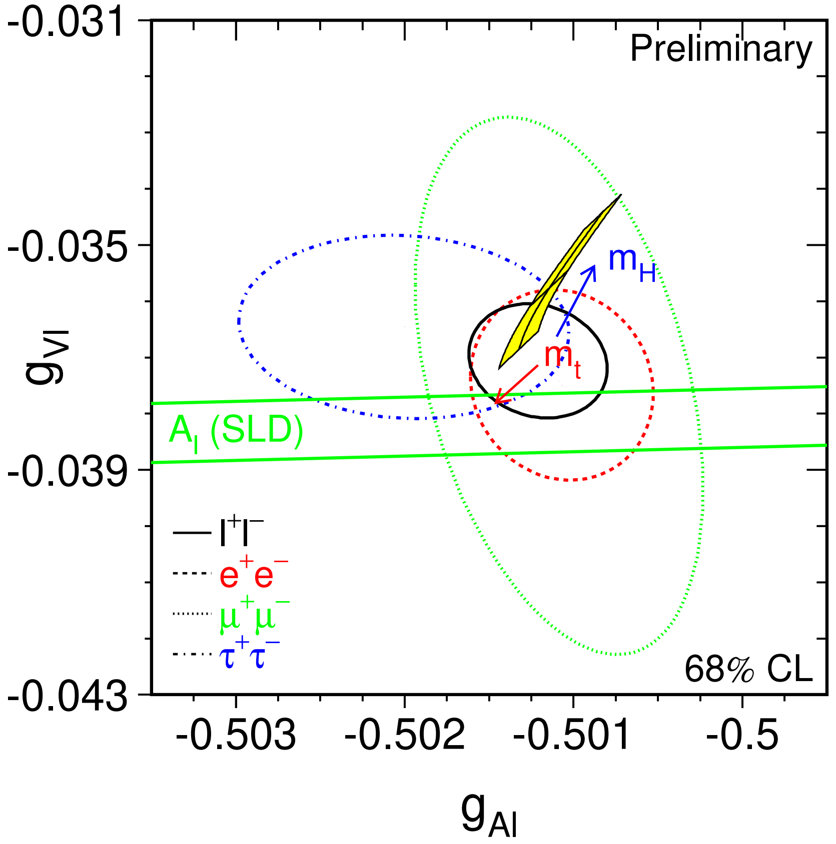
$$A^0_{\rm LR} = A_{\rm e} = 0.1514 \pm 0.0022 \text{ *FINAL*}$$

From the forward-backward asymmetries:

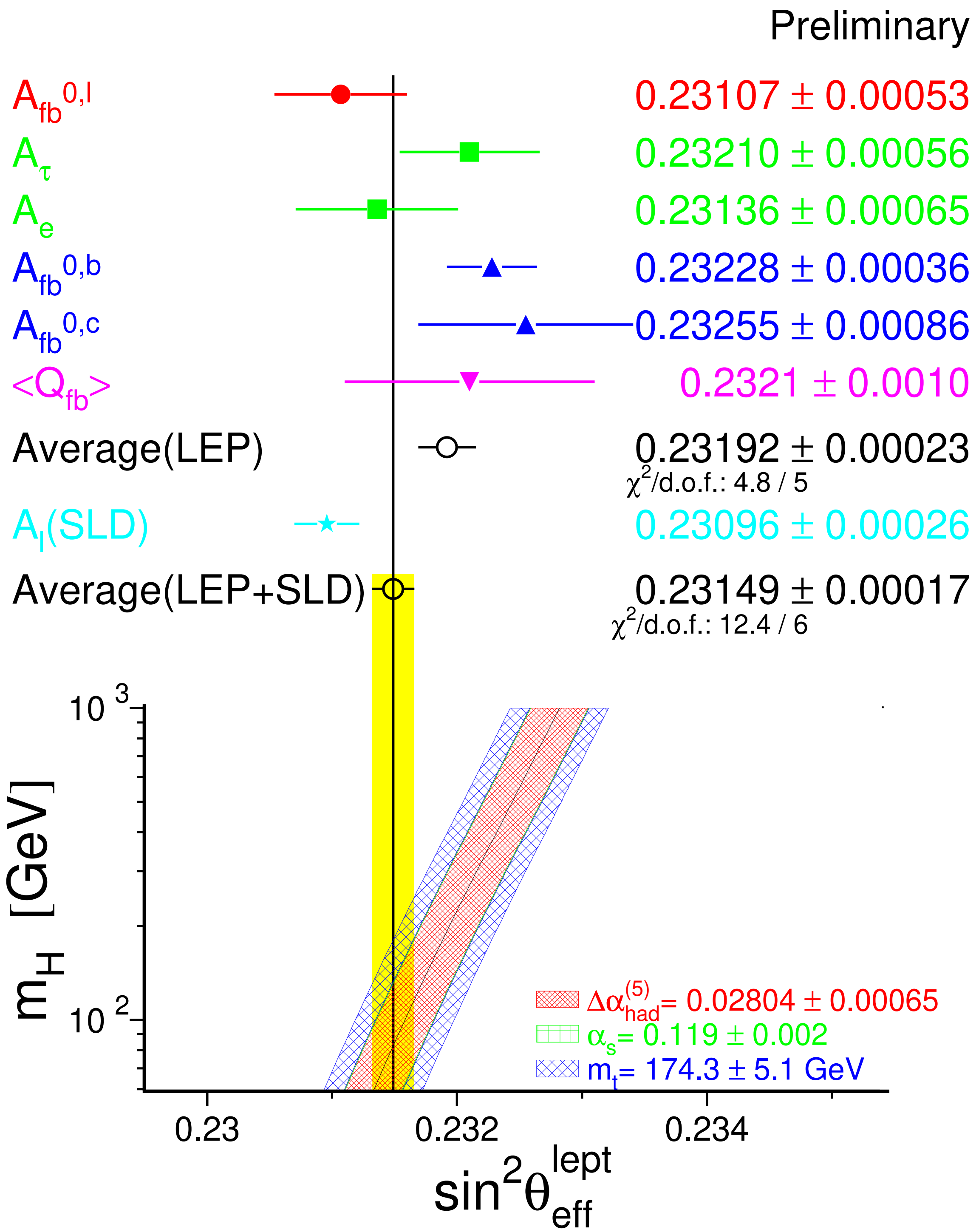
$$\begin{aligned} A_{\rm e} &= 0.1548 \pm 0.0058 \\ A_\mu &= 0.142 \pm 0.015 \\ A_\tau &= 0.140 \pm 0.015 \end{aligned}$$

Combination gives $\sin^2\overline{\theta}_{lep}$ from SLD:

$$\sin^2\overline{\theta}_{lep} = \frac{1}{4}\left(1 - \frac{\overline{g}^l_{\rm V}}{\overline{g}^l_{\rm A}}\right) = 0.23096 \pm 0.00026$$

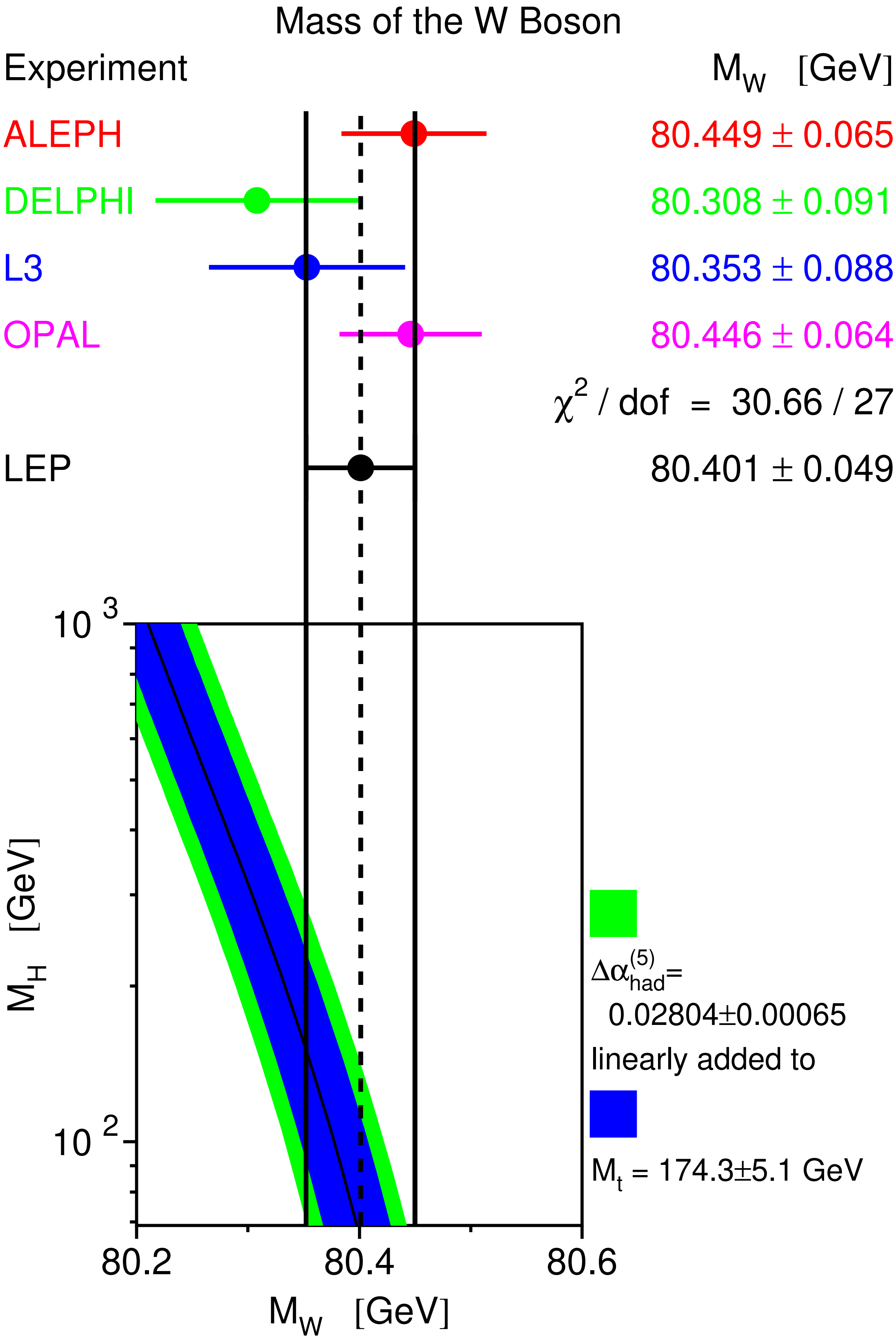


Leptons at LEP I and SLD



LEP I and SLD measurements still disagree

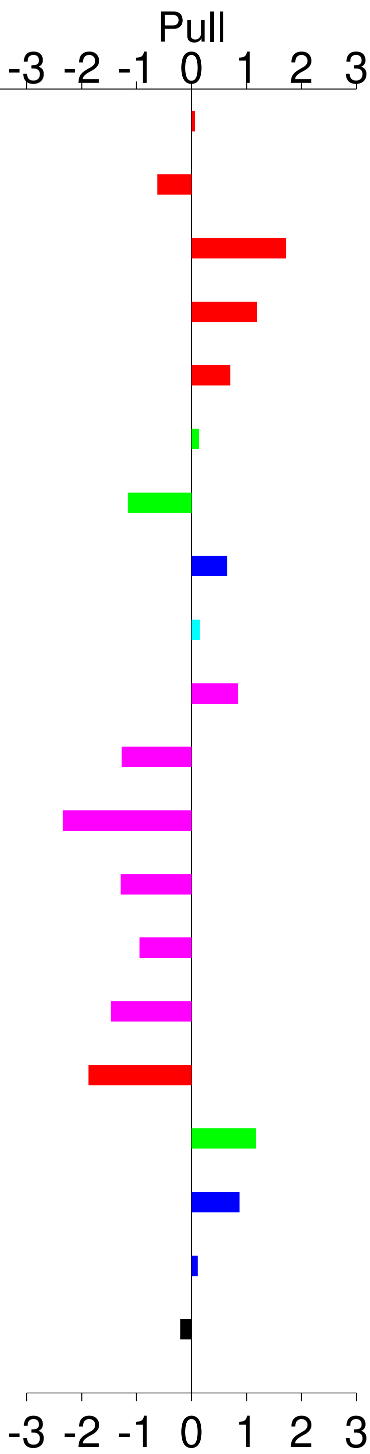
W-mass at LEP II



Comparison of data and SM fit

Moriond 2000

	Measurement	Pull
m_Z [GeV]	91.1871 ± 0.0021	.07
Γ_Z [GeV]	2.4944 ± 0.0024	-.62
σ^0_{hadr} [nb]	41.544 ± 0.037	1.72
R_e	20.768 ± 0.024	1.19
$A^{0,e}_{fb}$	0.01701 ± 0.00095	.70
A_e	0.1483 ± 0.0051	.13
A_τ	0.1425 ± 0.0044	-1.16
$\sin^2\theta^{lept}_{eff}$	0.2321 ± 0.0010	.65
m_W [GeV]	80.401 ± 0.048	.15
R_b	0.21642 ± 0.00073	.85
R_c	0.1674 ± 0.0038	-1.27
$A^{0,b}_{fb}$	0.0988 ± 0.0020	-2.34
$A^{0,c}_{fb}$	0.0692 ± 0.0037	-1.29
A_b	0.911 ± 0.025	-.95
A_c	0.630 ± 0.026	-1.47
$\sin^2\theta^{lept}_{eff}$	0.23096 ± 0.00026	-1.87
$\sin^2\theta_W$	0.2255 ± 0.0021	1.17
m_W [GeV]	80.448 ± 0.062	.88
m_t [GeV]	174.3 ± 5.1	.11
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02804 ± 0.00065	-.20



SM parametrisation

α, α_s	QED and QCD couplings
$\mathrm{m_Z}, \mathrm{m_W}, \mathrm{m_H}$	boson masses
$\mathrm{m_f}, V_{\mathrm{CKM}}$	fermion masses and CKM matrix

Constraints from independent measurements:

From muon decay:

$$G_{\mathrm{F}} = \frac{\pi\alpha(0)}{\sqrt{2}} \cdot \frac{m_{\mathrm{Z}}^2}{m_{\mathrm{W}}^2(m_{\mathrm{Z}}^2 - m_{\mathrm{W}}^2)} \cdot \frac{1}{1-\Delta r}$$

$$G_{\mathrm{F}} = (1.16639 \pm 0.00001) \cdot 10^{-5}\ \mathrm{GeV}^{-2}$$

From low energy measurements:

$$\alpha(\mathrm{m_Z^2}) = \frac{\alpha(0)}{1-\Delta\alpha(\mathrm{m_Z^2})}$$

$$\Delta\alpha(\mathrm{m_Z^2}) = \Delta\alpha_{\mathrm{lep}} + \Delta\alpha^5_{\mathrm{had}}$$

$$\alpha(\mathrm{m_Z^2})^{-1} = 128.896 \pm 0.090$$

$\Delta\alpha^5_{\mathrm{had}} = 0.02804 \pm 0.00065$ Jegherlehner et al.

$\Delta\alpha^5_{\mathrm{had}} = 0.02784 \pm 0.00026$ 'theory driven'

New results coming from BES:
Hadronic cross sections between
$2\ \mathrm{GeV} \leq \sqrt{s} \leq 5\ \mathrm{GeV}$.

Radiative corrections in SM

Higher order corrections to couplings introduce sensitivity to top quark mass and Higgs boson mass:

$$m_t^2 \qquad\qquad \log m_H$$

Fit to all electroweak measurements
except direct measurements of m_W and m_t:

$$m_W = 80.368 \pm 0.034 \text{ GeV} \qquad m_t = 167.3 \pm 8.8 \text{ GeV}$$

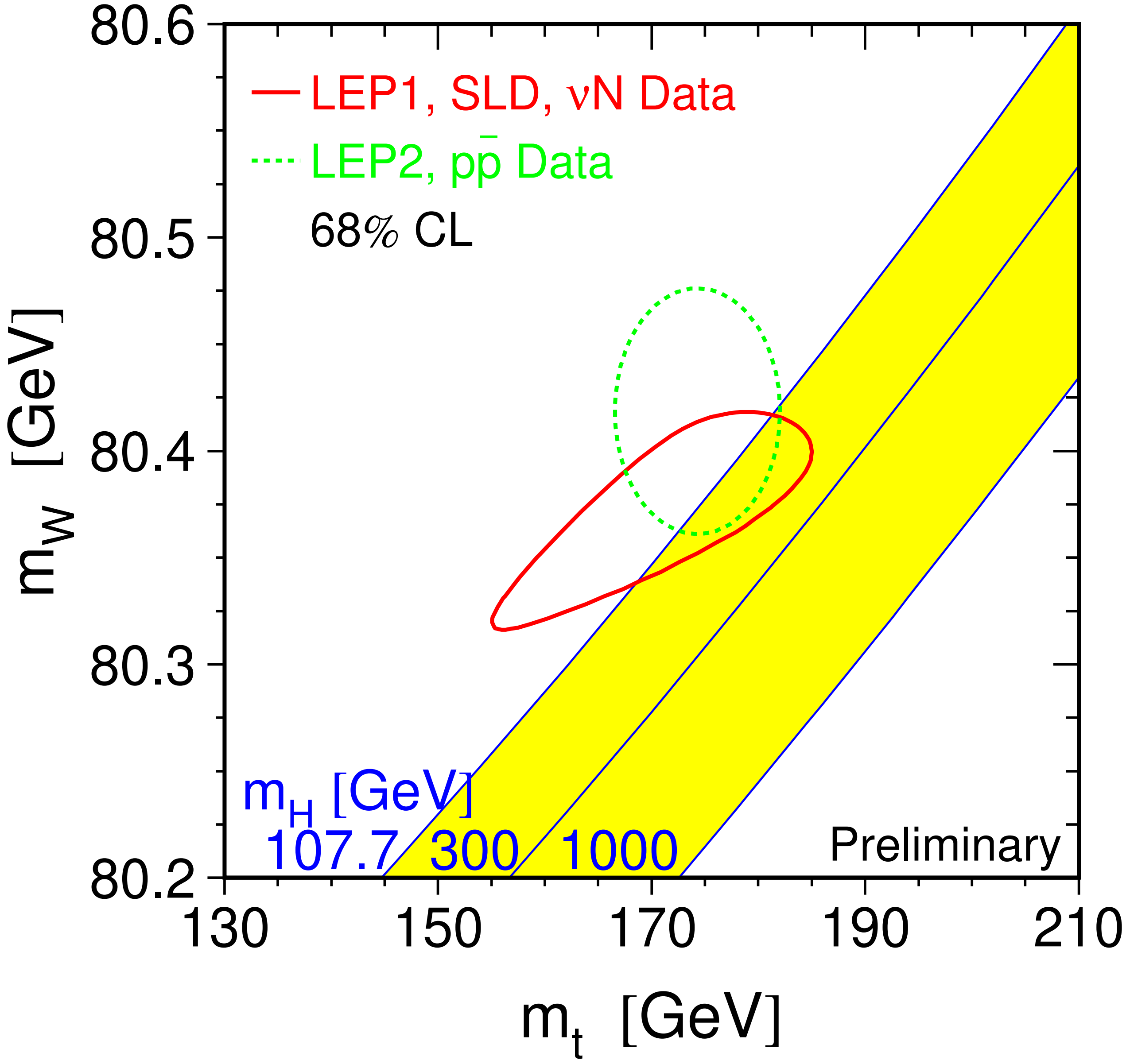
Direct LEP II m_W and TEVATRON m_t:

$$\begin{aligned} m_W &= 80.401 \pm 0.049 \quad \text{(LEPII)} \\ m_W &= 80.448 \pm 0.062 \quad \text{(Tevatron)} \\ m_t &= 174.3 \pm 5.1 \quad \text{(Tevatron)} \end{aligned}$$

GOOD AGREEMENT direct measurements and SM fits

Next step: include all data in SM fit
(LEP I, SLD, νN, LEP II and Tevatron)

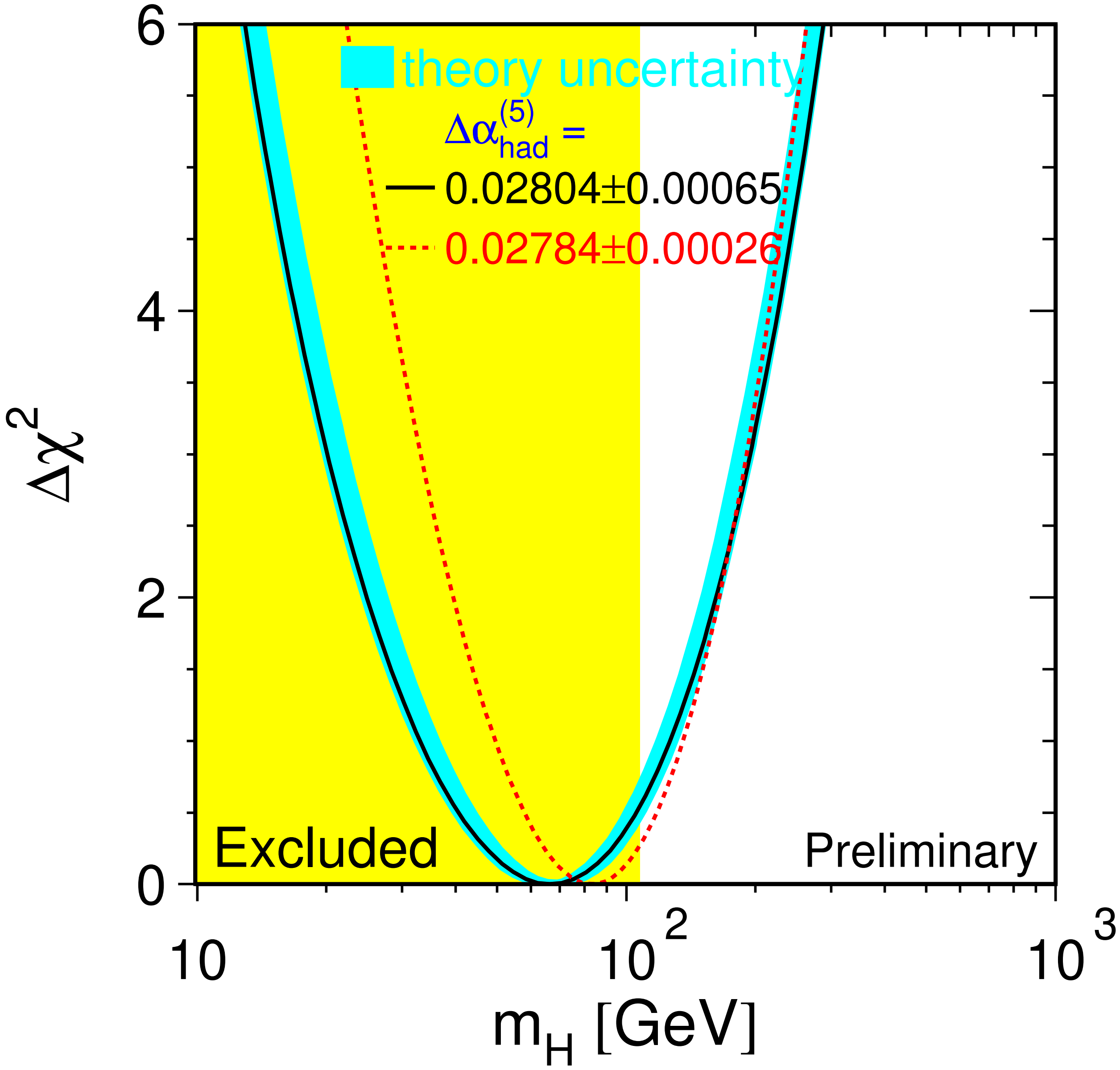
Direct and indirect measurements



68 % C.L. Contours

Data prefer a light Higgs boson

Higgs mass



$m_H = 66.5\,^{+60.0}_{-33.4}$ $\log m_H = 1.82\,^{+0.28}_{-0.30}$

From direct searches at LEP II:

$m_H > 107.7$ GeV at 95 % C.L.

From SM fits to electroweak data:

$m_H < 188$ GeV at 95 % C.L.

Conclusion

- High precision electroweak measurements provide a strong test to the Standard Model. Direct and indirect measurements of m_W and m_t are in excellent agreement.
- Data prefers a light Higgs boson!

$$m_H < 188\ \mathrm{GeV}\ \ \text{at } 95\%\ \text{C.L.}$$

And for the future...

- *FINAL* LEPI and SLD electroweak results soon
- Results from BES to improve on $\Delta\alpha^5_{\mathrm{had}}$
- One more year of data taking at LEPII
  About 100 pb^{-1} additional luminosity $\Rightarrow$
  Final total error $\Delta m_W < 35$ MeV
- Higgs boson is light $\Rightarrow$ Higgs boson at LEP II?
  LEP energy in 2000 > 202 GeV
- Next year: new measurements from Tevatron
  on m_W and m_t