Standard Model Fits

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QCD and High Energy Hadronic Interactions

- Introduction
- Measurements
- Fit Results
- Summary

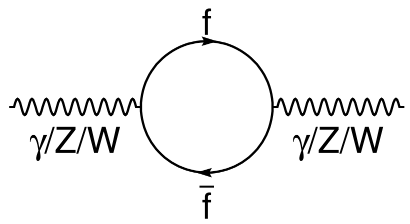
Introduction

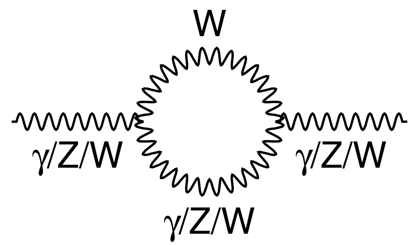
Precision electroweak measurements test the Standard Model at the level of its quantum corrections

Modify tree-level relations:

$$\mathbf{G_F} = \frac{\pi}{\sqrt{2}} \frac{\alpha(0)}{\mathrm{m_W^2} \sin^2\theta_\mathrm{W}} \frac{1}{1-\Delta \mathrm{r}}$$

$$\Delta \mathrm{r} = \Delta\alpha + \Delta \mathrm{r_W}$$



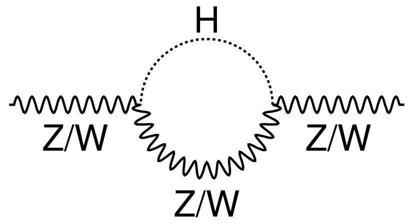


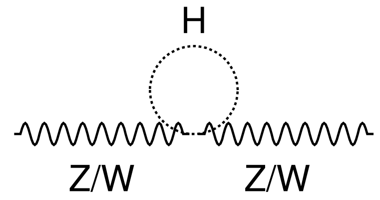
$\Delta\alpha$ absorbed into running of α:

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

Leading electroweak contributions:

$$\Delta \mathrm{r^t} \propto \mathrm{m_t^2} \qquad \Delta \mathrm{r^H} \propto \log \mathrm{m_H}$$





Introduction

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

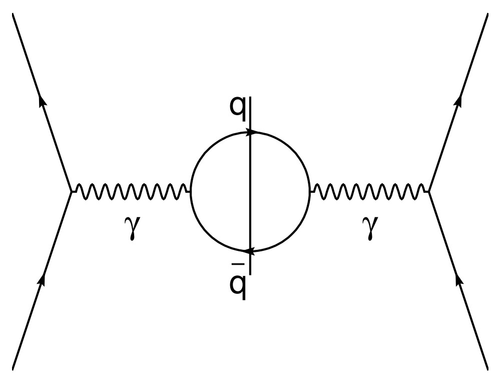
$\Delta\alpha_{\mathrm{lep}}$: leptonic contribution $\longrightarrow$ precisely calculable
$\Delta\alpha_{\mathrm{t}}$: top quark contribution $\longrightarrow$ small due to high top mass
$\Delta\alpha^{(5)}_{\mathrm{had}}$: light quarks involving QCD

obtain $\Delta\alpha^{(5)}_{\mathrm{had}}$ from dispersion integral:

$$\Delta\alpha^{(5)}_{\mathrm{had}} \propto \mathcal{R}e \int_{4m_\pi^2}^{\infty} \frac{R(s')}{s'(s'-s)} ds'$$

$$R(s') = \frac{\sigma(e^+e^- \rightarrow \mathrm{hadrons})}{\sigma(e^+e^- \rightarrow \mu^+\mu^-)}$$

needs data below 5 GeV and perturbative QCD



Burkhardt/Pietrzyk 2001:

$$\Delta\alpha^{(5)}_{\mathrm{had}} = 0.02761 \pm 0.00036$$

Measurements and Input Parameters for the Fits

LEP I:

- m_Z, Γ_Z, σ^0_{had}, ${R_l}^0$, $A^{0,l}_{FB}$
- $P_\tau(\cos\theta) \longrightarrow \mathcal{A}_e$, $\mathcal{A}_\tau$
- R^0_b, R^0_c, $A^{0,b}_{FB}$, $A^{0,c}_{FB}$
- $Q_{FB} \longrightarrow \sin^2\theta^{lept}_{eff}$

SLD:

- L-R asymmetry $\longrightarrow \mathcal{A}_l$, $\mathcal{A}_b$, $\mathcal{A}_c$

$p\bar{p}$/LEP II:

- m_t, m_W

νN:

- $\longrightarrow \sin^2\theta_W$

Theory

$$R^0_l = \Gamma_{had}/\Gamma_l$$

$$R^0_q = \Gamma_q/\Gamma_{had}$$

$$P_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta)+2\mathcal{A}_e\cos\theta}{1+\cos^2\theta+2\mathcal{A}_\tau\mathcal{A}_e\cos\theta}$$

$$A^{0,f}_{FB} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

$$\mathcal{A}_f = \frac{2g^f_V g^f_A}{(g^f_V)^2+(g^f_A)^2}$$

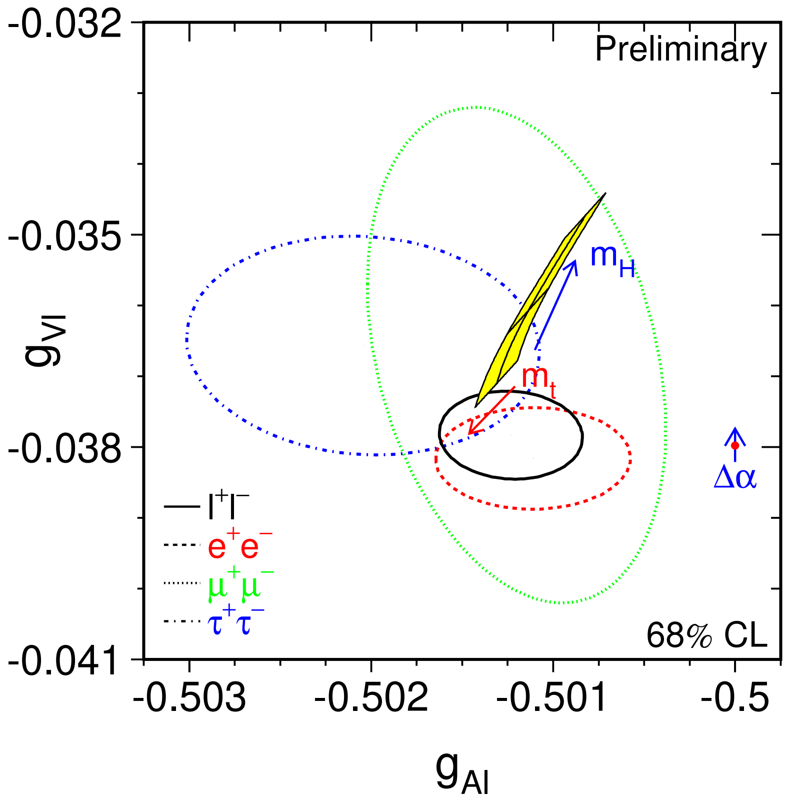
$$g^l_V/g^l_A = 1-4\sin^2\theta^{lept}_{eff}$$

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

Lepton Universality

Final Z lineshape from LEP

m_Z	91187.5 ± 2.1 GeV
Γ_Z	2495.2 ± 2.3 GeV
σ^0_{had}	$41.540 \pm 0.037 nb$
R^0_l	20.767 ± 0.025
$A^{0,l}_{FB}$	0.0171 ± 0.0010



$+P_\tau(\cos\theta)$ **final:**

$$\mathcal{A}_l{}^{LEP} = 0.1482 \pm 0.0026$$

SLD final:

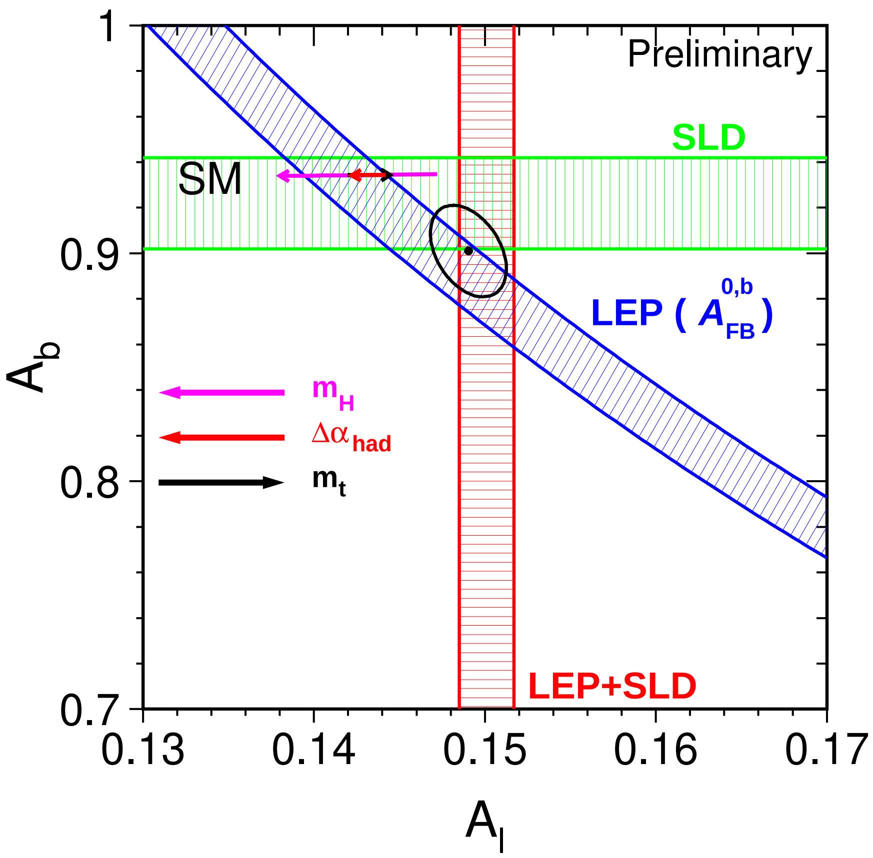
$$\mathcal{A}_l{}^{SLD} = 0.1513 \pm 0.0021$$

low m_H preferred

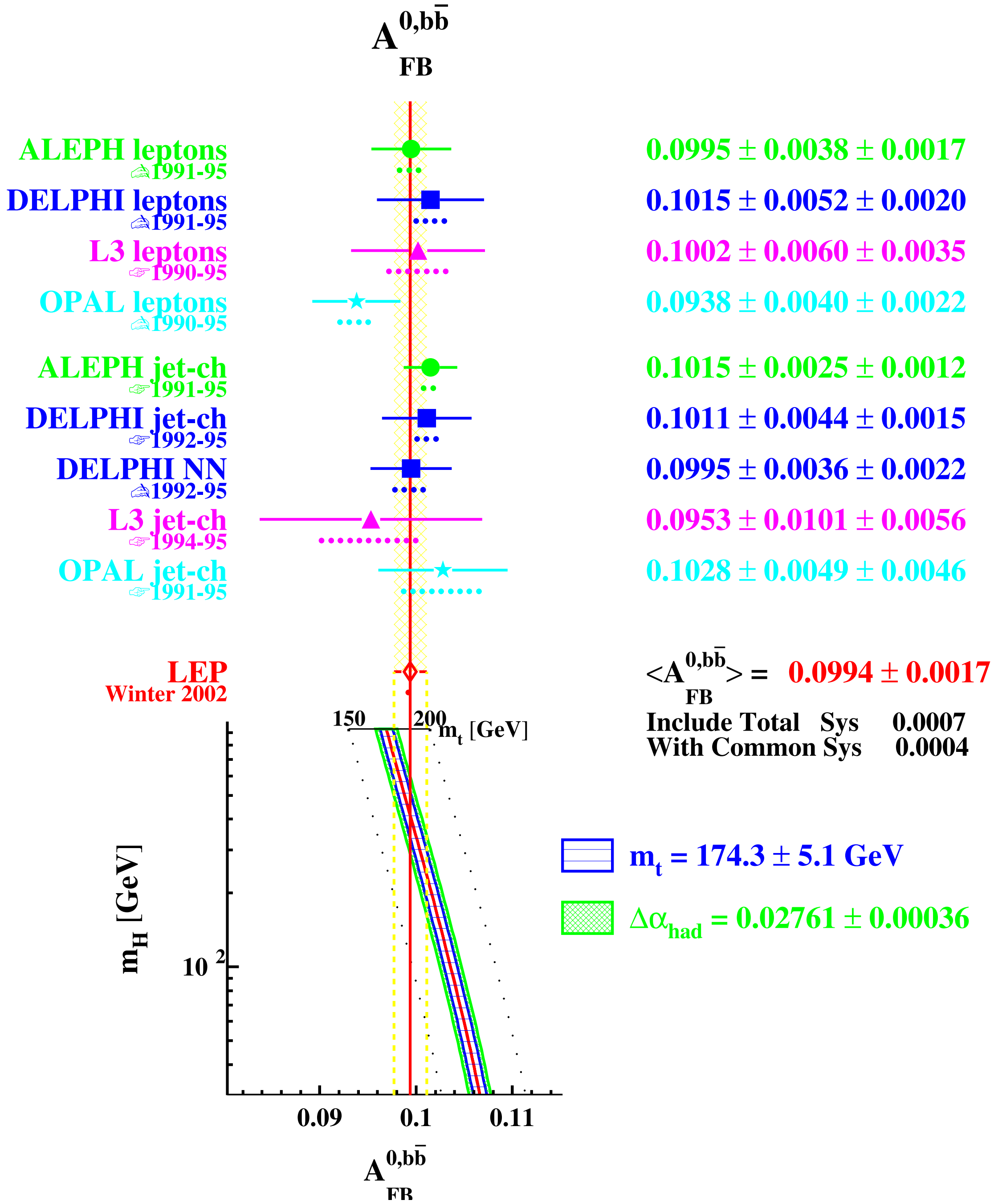
Measurements: Heavy Flavour

Final results from Z peak

LEP I	R_b^0	0.21646 ± 0.00065
	R_c^0	0.1719 ± 0.0031
	$A_{FB}^{0,b}$	0.0994 ± 0.0017
	$A_{FB}^{0,c}$	0.0685 ± 0.0034
SLD	$\mathcal{A}_b$	0.922 ± 0.020
LEP+SLD	$\mathcal{A}_l$	0.1501 ± 0.0016

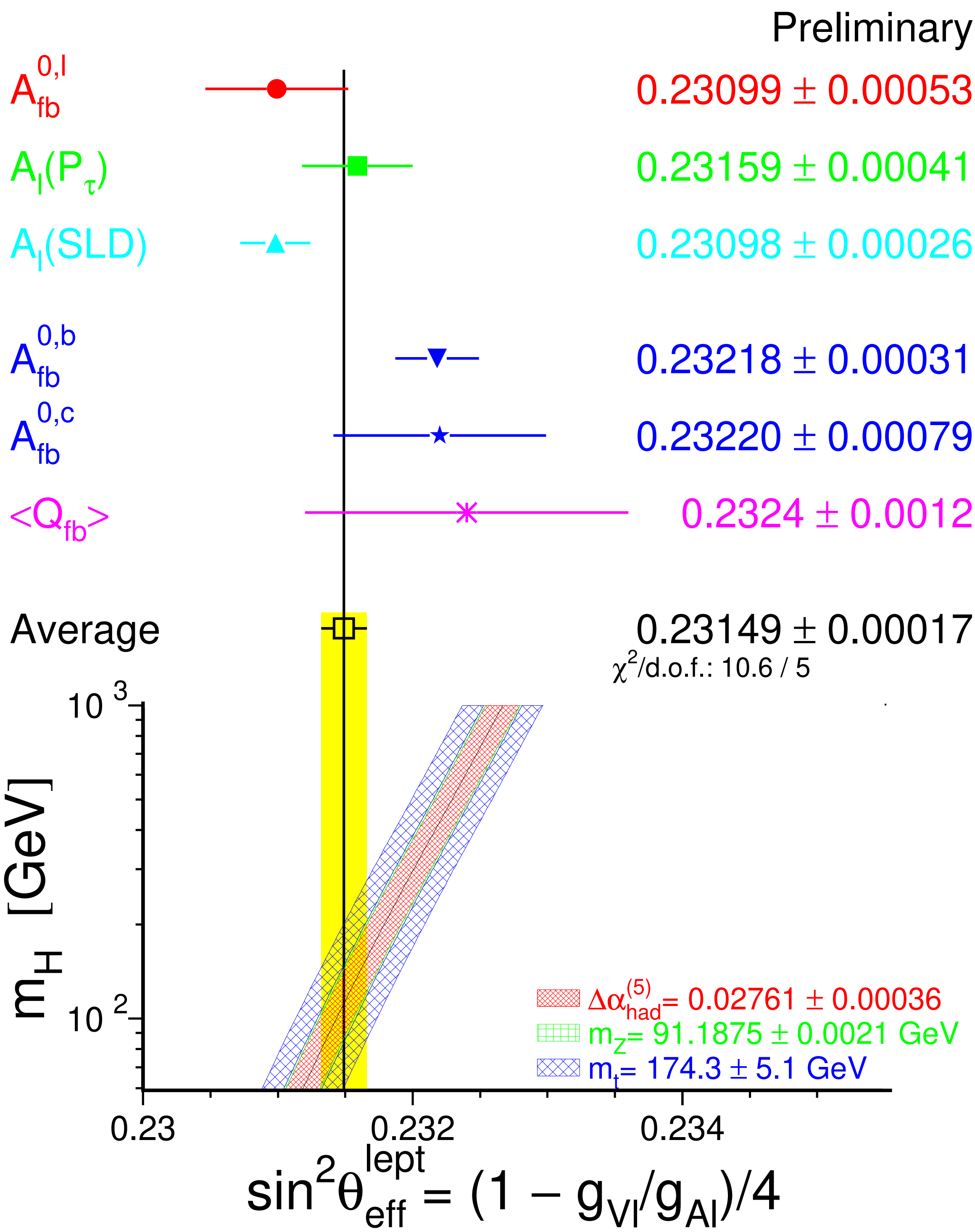


Measurements: Heavy Flavour



favours high m_H

Measurements: $\sin^2\theta_{\rm eff}^{\rm lept}$



Leptons vs. Hadrons: 3σ difference

Determination of SM Parameters

LEP I:

- m_Z, Γ_Z, σ^0_{had}, $R_l{}^0$, $A_{FB}^{0,l}$
- $P_\tau(\cos\theta) \longrightarrow \mathcal{A}_e$, $\mathcal{A}_\tau$
- R^0_b, R^0_c, $A_{FB}^{0,b}$, $A_{FB}^{0,c}$
- $Q_{FB} \longrightarrow \sin^2\theta_{eff}^{lept}$

SLD:

- L-R asymmetry $\longrightarrow \mathcal{A}_l$, $\mathcal{A}_b$, $\mathcal{A}_c$

$p\bar{p}$/LEP II:

- m_t, m_W

νN:

- $\longrightarrow \sin^2\theta_W$

Theory

$$R^0_l = \Gamma_{had}/\Gamma_l$$

$$R^0_q = \Gamma_q/\Gamma_{had}$$

$$P_\tau(\cos\theta) = -\frac{\mathcal{A}_\tau(1+\cos^2\theta)+2\mathcal{A}_e\cos\theta}{1+\cos^2\theta+2\mathcal{A}_\tau\mathcal{A}_e\cos\theta}$$

$$A_{FB}^{0,f} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

$$\mathcal{A}_f = \frac{2g_V^f g_A^f}{(g_V^f)^2+(g_A^f)^2}$$

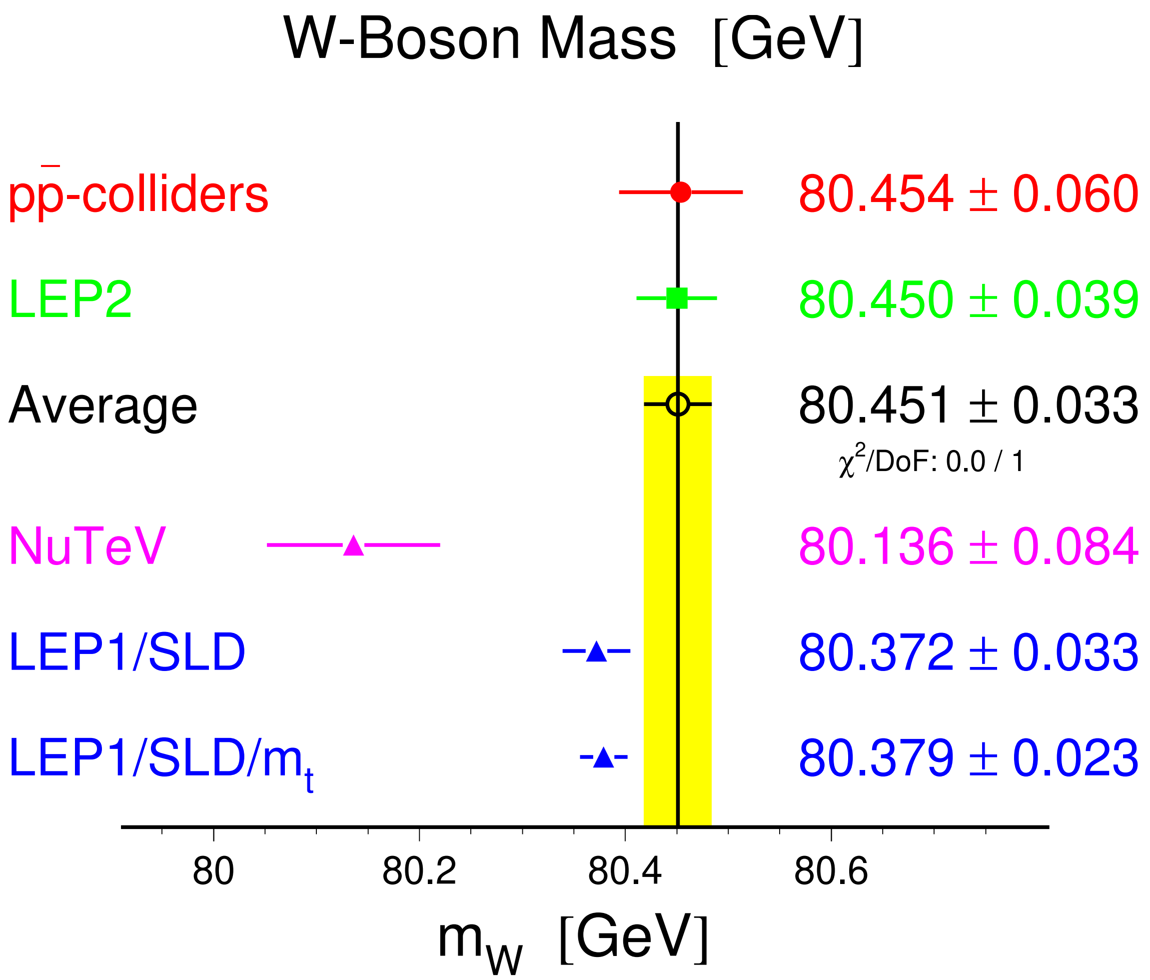
$$g_V^l/g_A^l = 1-4\sin^2\theta_{eff}^{lept}$$

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

χ^2- fit

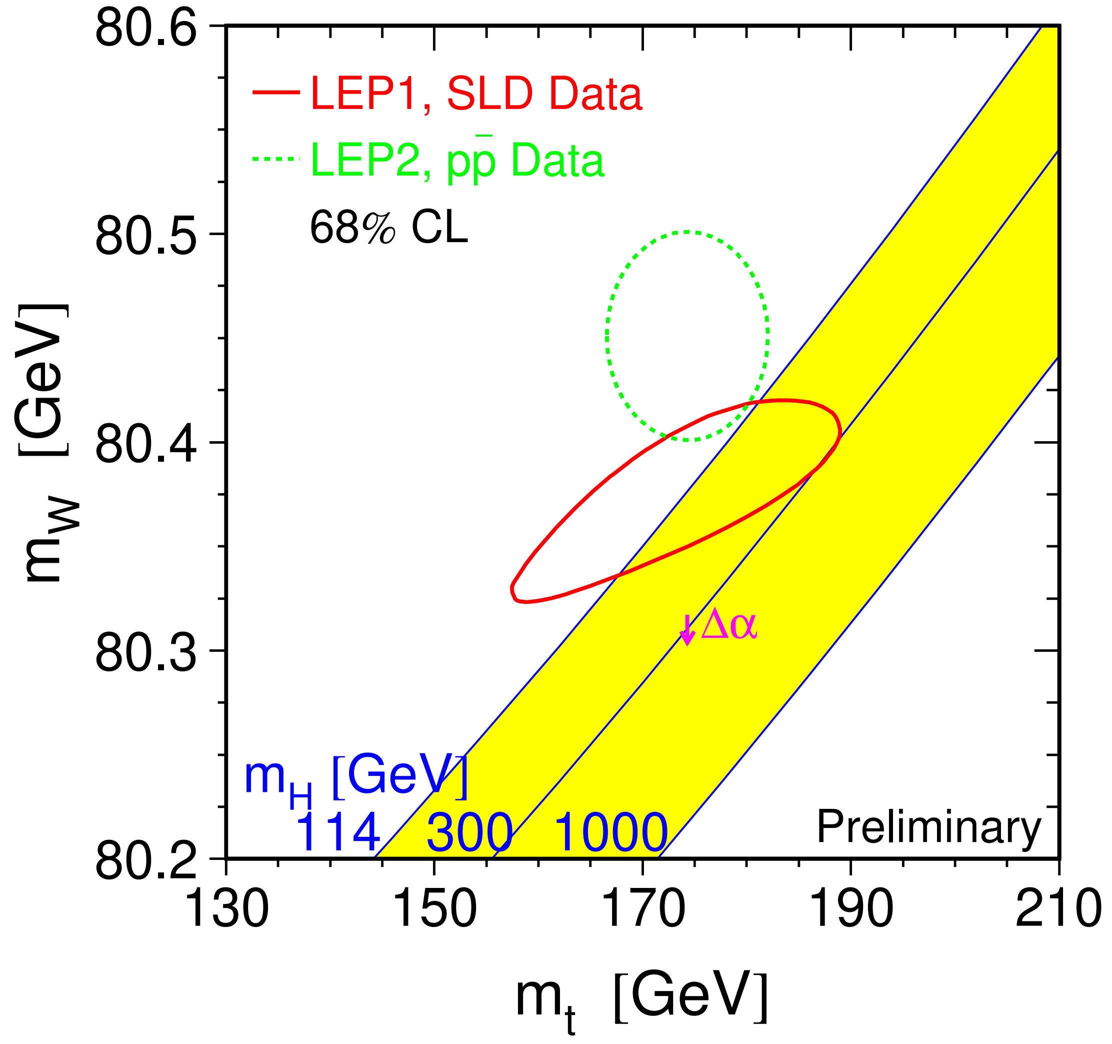
m_Z m_t m_H $\alpha(m_Z^2)$ $\alpha_s(m_Z^2)$

Direct Measurement $m_W \leftrightarrow$ SM Prediction



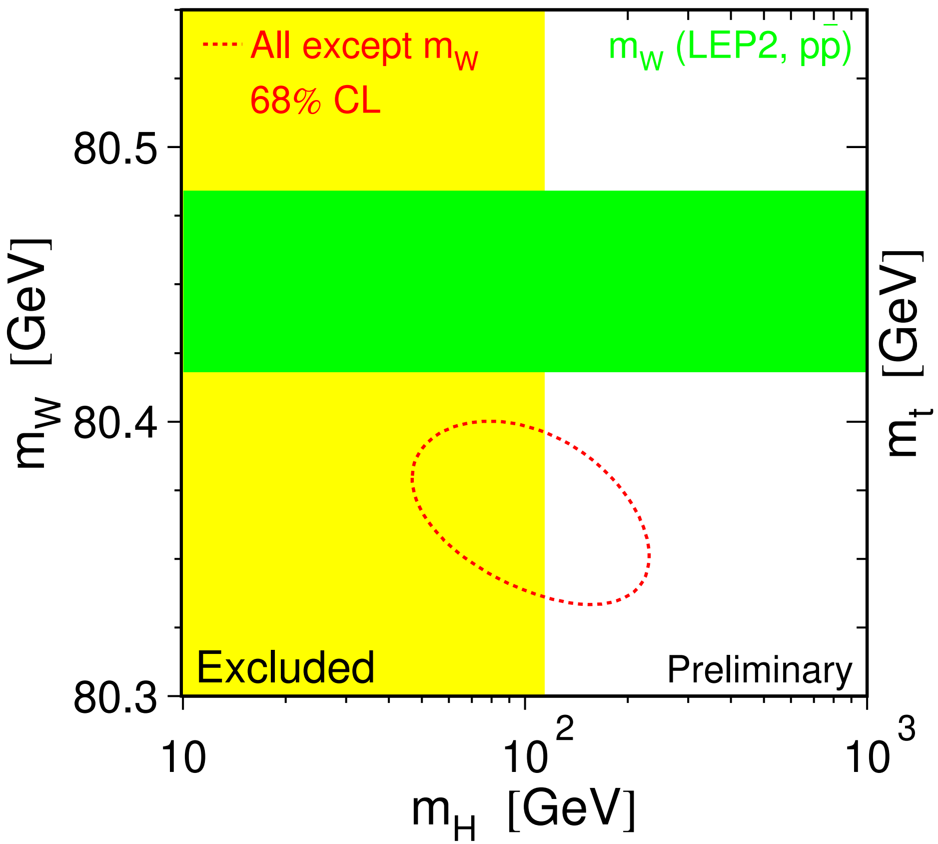
indirect and direct measurement consistent within 1.7σ

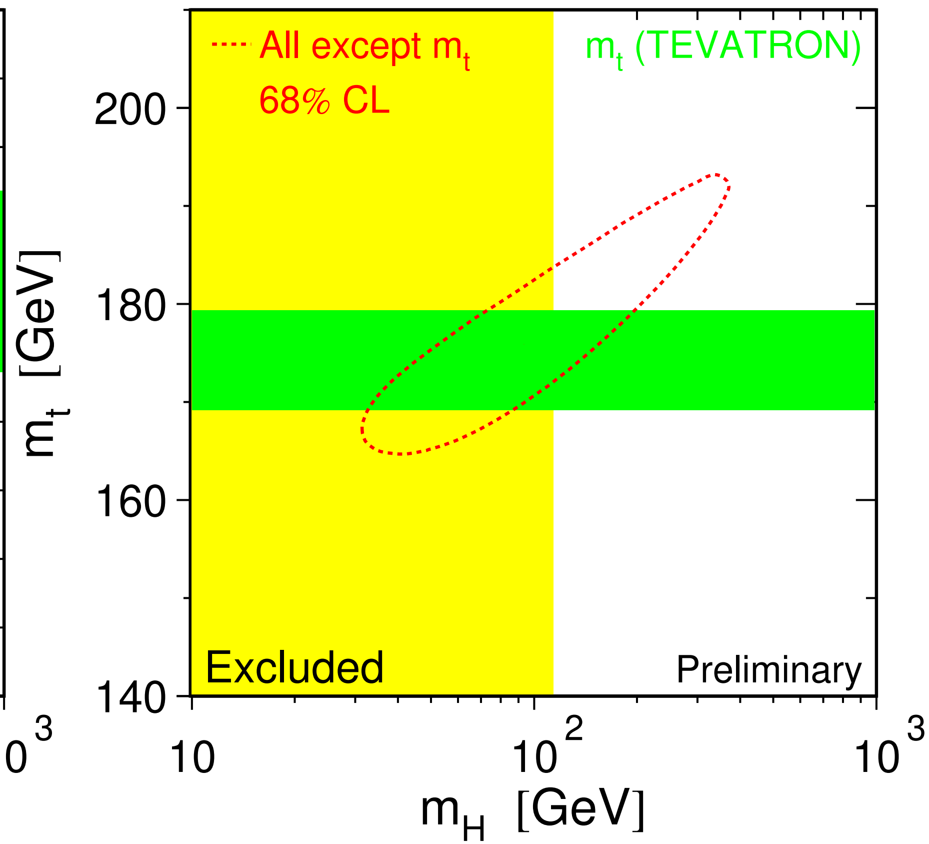
Fit Results: m_t and m_W



favours low m_H

Results: m_t, m_W and m_H

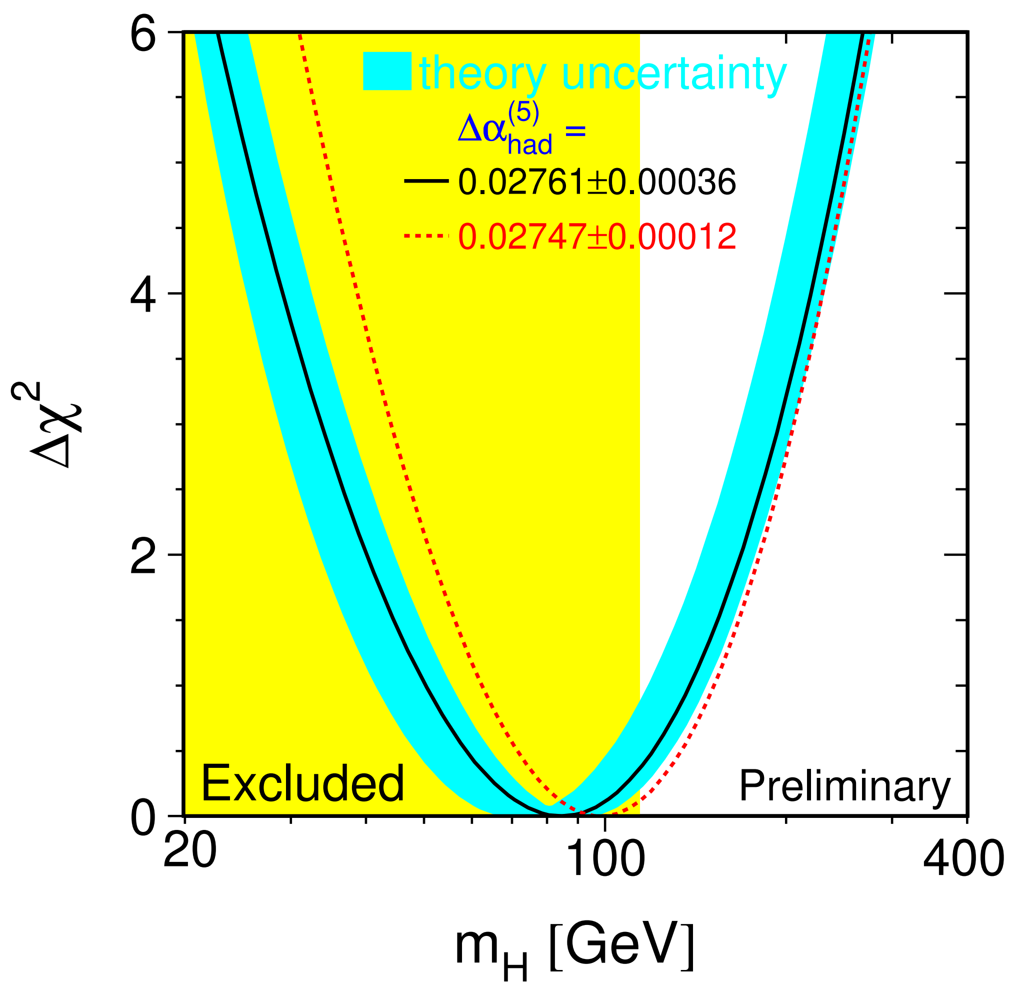




prefer low m_H

Fit Results: m_H

$$m_H = 85^{+54}_{-34}\ \mathrm{GeV}$$

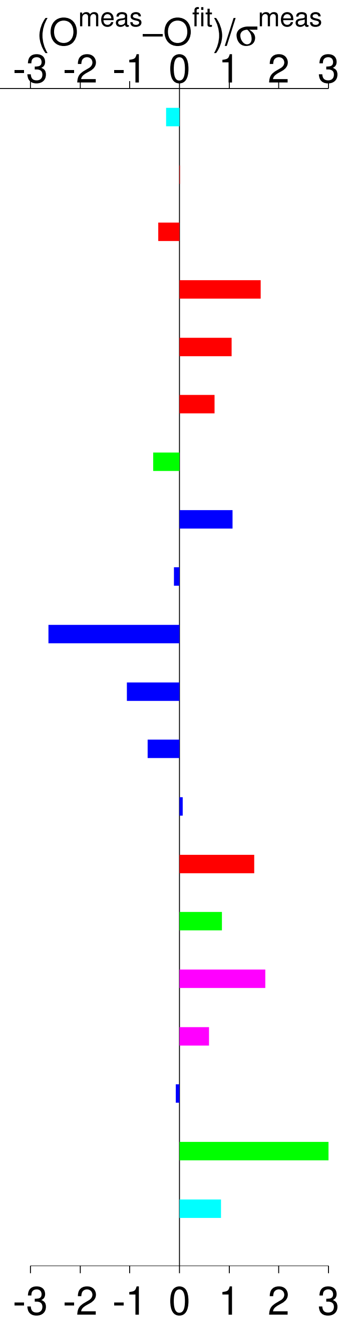


Direct searches $m_H > 114.1$ GeV
$m_H < 196$ GeV at 95% C.L.

Fit Results: Global

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



$$\text{Pull} = \frac{\mathcal{O}^{meas} - \mathcal{O}^{fit}}{\sigma\mathcal{O}^{meas}}$$

Summary

- the Standard Model describes the data well
- most measurements favour a low Higgs mass (but no Higgs found)
- need precise measurement of $\Delta\alpha^{(5)}_{\mathrm{had}}$ and $\mathrm{m_t}$
- $\sin^2\theta_{\mathrm{W}}$ from NuTeV deviates by 3.0σ

Thanks to the LEPEWWG for the numbers and plots