# Higgs mass from electroweak data

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**L3 experiment**

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**The data collected by the four LEP collaborations ALEPH, DELPHI, L3, OPAL and by the SLD experiment allow a precise determination of some of the electroweak observables.**

**Using these results as input for the SM and comparing its predictions with $p\bar{p}$, $\nu$ N and LEP-II measurements allows to check the validity of the SM in describing all data.**

**A fit to all EW data allows to determine the Higgs mass.**

**LEP and SLD provide "model independent" observables to the EWWG which combines them.**

**Many thanks**

**higher order corrections affect the couplings**
**they enter the relations which connect:**

- **the effective couplings to the L.O couplings**
  $\bar{g}^f_a = g^f_a \sqrt{\bar{\rho}_f}$
  $\bar{g}^f_v = g^f_a \sqrt{\bar{\rho}_f}(1 - 4 \mid q_f \mid \sin^2 \bar{\theta}_W)$
  **where** $\bar{\rho}_f = \frac{1}{1-\Delta\rho_f}$
  $\sin^2 \bar{\theta}^f_W = \sin^2 \theta_W (1 + \cot^2 \theta_W \Delta\rho_f + \ldots)$
- $G_F$ **to** $m_W$
  $G_F = \frac{\pi\alpha}{\sqrt{2}} \cdot \frac{m_Z^2}{m_W^2(m_Z^2 - m_W^2)} \cdot \frac{1}{1-\Delta r}$
  **where** $\Delta r = (\Delta\alpha - \cot^2 \theta_W \Delta\rho + \ldots$

$$\Delta\rho = \Delta\rho^t + \Delta\rho^H + \ldots$$

$$\textbf{with} \begin{cases} \Delta\rho^t & \propto m_t^2 \\ \Delta\rho^H & \propto log(m_H) \end{cases}$$

**check** $\Delta\rho$ **using** $m_W$ **and** $m_t$
**determine** $m_H$

# Progress

| | 1989-90 LEP data | 1989-95 LEP data |
|---|---|---|
| $\int \mathcal{L}$ $\mathrm{pb}^{-1}$/ exp | $\sim 10$ | $\sim 150$ |
| $\mathrm{M_Z}$ GeV | $91.174 \pm 0.020$ | $91.1863 \pm 0.0020$ |
| $\Gamma_\mathrm{Z}$ GeV | $2.485 \pm 0.010$ | $2.4948 \pm 0.0025$ |
| $\sin^2\theta^\mathrm{l}_\mathrm{eff}$ | $0.2308 \pm 0.019$ | $0.23196 \pm 0.00028$ |
| $\mathrm{m_t}$ GeV | $131^{+27+22}_{-43-14}$ | $158^{+14}_{-11}$ |

**The systematic error arising from the uncertainties in the LEP energy are:**
**20 MeV in 1990**
**1.5 MeV in 1998**

**the top was found in the predicted mass window**

**This unexpected level of accuracy was reached thanks to steady improvements of the:**

- **accelerators:**
  $\nearrow$ L, $\nearrow$ $\epsilon$, $\searrow$ $\Delta$ E, $\nearrow$ $\mathcal{P}$, $\searrow$ $\Delta$ $\mathcal{P}$
- **experiments:**
  **Si detectors:** $\searrow$ $\Delta$ **L, identify h.f**
- **theoretical calculations:**
  **higher order QCD and weak corrections implemented in BHM, TOPAZ0, ZFITTER**

# What has changed since 1997 ?

**Some LEP-I asymmetry measurements were updated**

**SLD left-right asymmetry measurements were updated**

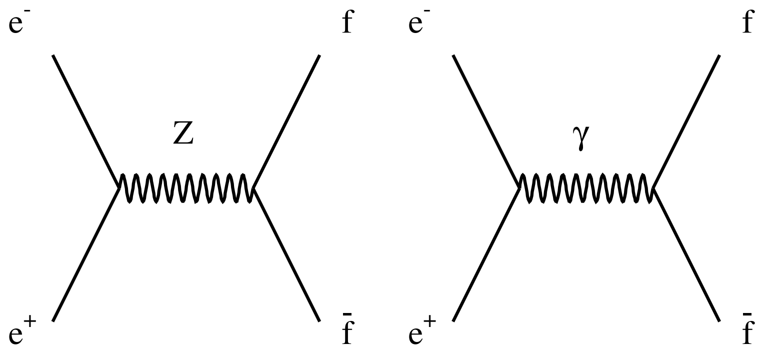
**CDF/D0 $\mathrm{m_t}$ and $\mathrm{m_W}$ measurements were updated**

**LEP-II 183 GeV W data were included**

**There are new calculations of $\alpha(\mathrm{m_Z^2})^{-1}$**

**Two-loop top electroweak corrections computed by Degrassi et al were included in:**
**ZFITTER (Bardin et al)**
**TOPAZ0 (Passarino et al)**

# Cross sections in Standard Model

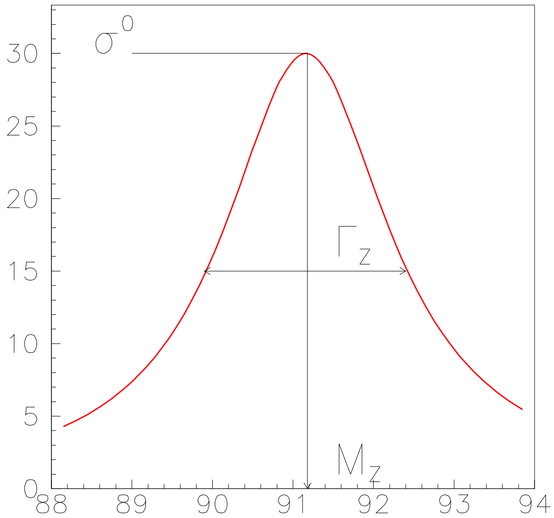



**Lowest order contributions to $e^+e^- \to f\bar{f}$, $f \neq e$**

$\sigma^f(s) = \sigma^f_Z + \sigma^f_\gamma + \sigma^f_{int}$ , $\sigma^f_Z$ **dominant at** $\sqrt{s} \approx M_Z$

$$\sigma^f_Z = \sigma^f_0 \frac{s\Gamma^2_Z}{(s-m^2_Z)^2+s^2\Gamma^2_Z/m^2_Z}$$

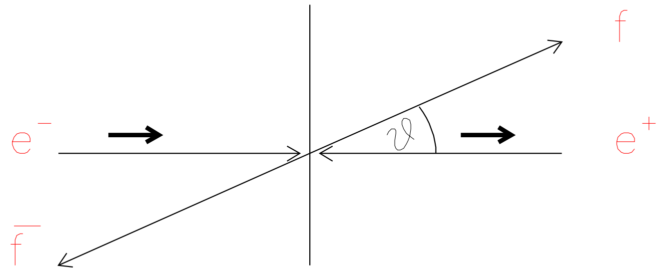
**with** $\sigma^f_0 = \frac{12\pi}{m^2_Z}\frac{\Gamma_e\Gamma_f}{\Gamma^2_Z}$ **and** $\Gamma_f \propto [(g^f_v)^2 + (g^f_a)^2]$




$\sigma_h \to M_Z,\ \Gamma_Z,\ \sigma^0_h$ **and** $\sigma_l \to R_l = \Gamma_h/\Gamma_l$

**heavy flavour id** $\to R^0_b = \Gamma_{b\bar{b}}/\Gamma_h,\ R^0_c = \Gamma_{c\bar{c}}/\Gamma_h$

# Asymmetries in Standard Model




**different asymmetries are measured:**

**at LEP (unpolarised beams)**

$$A_{FB}^{f} = \frac{\sigma(\cos\theta>0)-\sigma(\cos\theta<0)}{\sigma(\cos\theta>0)+\sigma(\cos\theta<0)} \qquad A_{fb}^{0,f} = \frac{3}{4}\mathcal{A}_e\mathcal{A}_f$$

$$f = e, \mu, \tau, b, c$$

$$A_{POL}^{\tau} = \frac{\sigma(h_f=+1)-\sigma(h_f=-1)}{\sigma(h_f=+1)+\sigma(h_f=-1)} \qquad A_{POL}^{0,\tau} = -\mathcal{A}_\tau$$

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

**at SLD (polarised beams)**

$$A_{LR}^{e} = \frac{1}{\mathcal{P}}\frac{\sigma_L-\sigma_R}{\sigma_L+\sigma_R} \qquad A_{LR}^{e,0} = -\mathcal{A}_e$$

with $\mathcal{A}_f$ defined as $\mathcal{A}_f = 2\frac{g_v^f g_a^f}{(g_v^f)^2+(g_a^f)^2}$

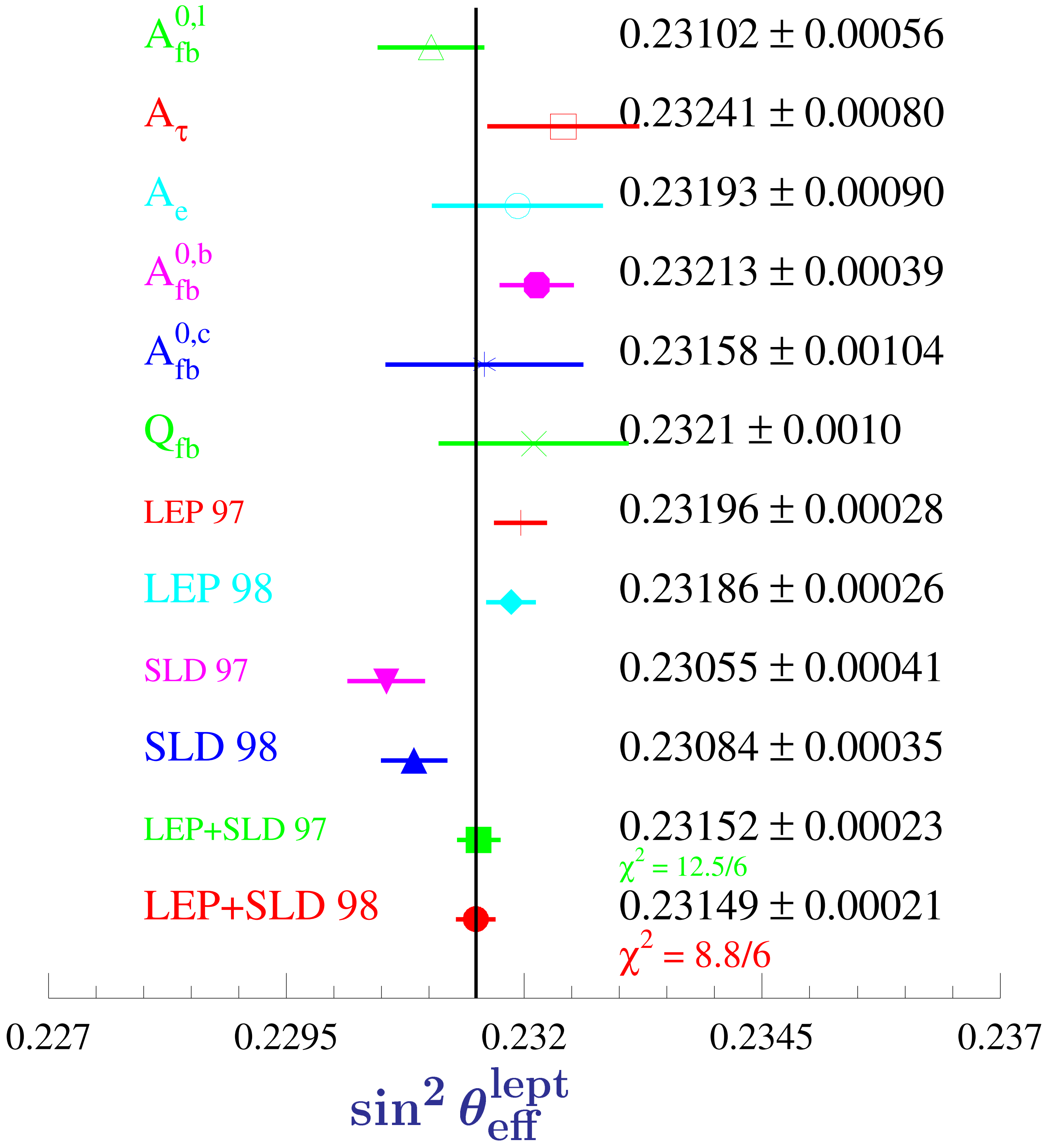
to compare them $\longrightarrow$ $\sin^2\theta_{eff}^{lept} = \frac{1}{4}(1-\frac{g_v^l}{g_a^l})$

# Summary of measurements

| | 1997 | | 1998 | |
|---|---|---|---|---|
| **LEP-I** | | | | |
| $m_Z$ $GeV$ | 91.1863 | $\pm$ 0.0019 | 91.1867 | $\pm$ 0.0020 |
| $\Gamma_Z$ $GeV$ | 2.4947 | $\pm$ 0.0026 | 2.4948 | $\pm$ 0.0025 |
| $\sigma^0_{had}$ $nb$ | 41.489 | $\pm$ 0.055 | 41.486 | $\pm$ 0.053 |
| $R_l$ | 20.783 | $\pm$ 0.029 | 20.775 | $\pm$ 0.027 |
| $A^{0,l}_{FB}$ | 0.00177 | $\pm$ 0.0010 | 0.00171 | $\pm$ 0.0010 |
| $A_\tau$ | 0.1401 | $\pm$ 0.0067 | 0.1400 | $\pm$ 0.0063 |
| $A_e$ | 0.1382 | $\pm$ 0.0076 | 0.1438 | $\pm$ 0.0071 |
| $R_b$ | 0.2179 | $\pm$ 0.0011 | 0.2175 | $\pm$ 0.0009 |
| $R_c$ | 0.1720 | $\pm$ 0.0056 | 0.1720 | $\pm$ 0.0048 |
| $A^{0,b}_{FB}$ | 0.0985 | $\pm$ 0.0023 | 0.0997 | $\pm$ 0.0022 |
| $A^{0,c}_{FB}$ | 0.0734 | $\pm$ 0.0048 | 0.0733 | $\pm$ 0.0045 |
| $sin^2\theta^l_{eff}$ $(Q_{FB})$ | 0.2322 | $\pm$ 0.0010 | 0.2321 | $\pm$ 0.0010 |
| **LEP-II** | | | | |
| $m_W$ $GeV$ | 80.48 | $\pm$ 0.14 | 80.35 | $\pm$ 0.09 |
| **SLD** | | | | |
| $sin^2\theta^l_{eff}$ $(ALR)$ | 0.23055 | $\pm$ 0.00041 | 0.23084 | $\pm$ 0.00035 |
| $R_b$ | 0.2149 | $\pm$ 0.0038 | 0.2158 | $\pm$ 0.0022 |
| $R_c$ | 0.1756 | $\pm$ 0.0181 | 0.1790 | $\pm$ 0.0105 |
| $A_b$ | 0.877 | $\pm$ 0.050 | 0.901 | $\pm$ 0.049 |
| $A_c$ | 0.623 | $\pm$ 0.085 | 0.643 | $\pm$ 0.049 |
| $p\bar{p}$ | | | | |
| $m_W$ $GeV$ | 80.37 | $\pm$ 0.10 | 80.40 | $\pm$ 0.09 |
| $m_t$ $GeV$ | 175.6 | $\pm$ 5.5 | 173.5 | $\pm$ 5.2 |
| $\nu$N | | | | |
| $1 - \frac{m^2_W}{m^2_Z}$ | 0.2244 | $\pm$ 0.0042 | 0.2254 | $\pm$ 0.0037 |

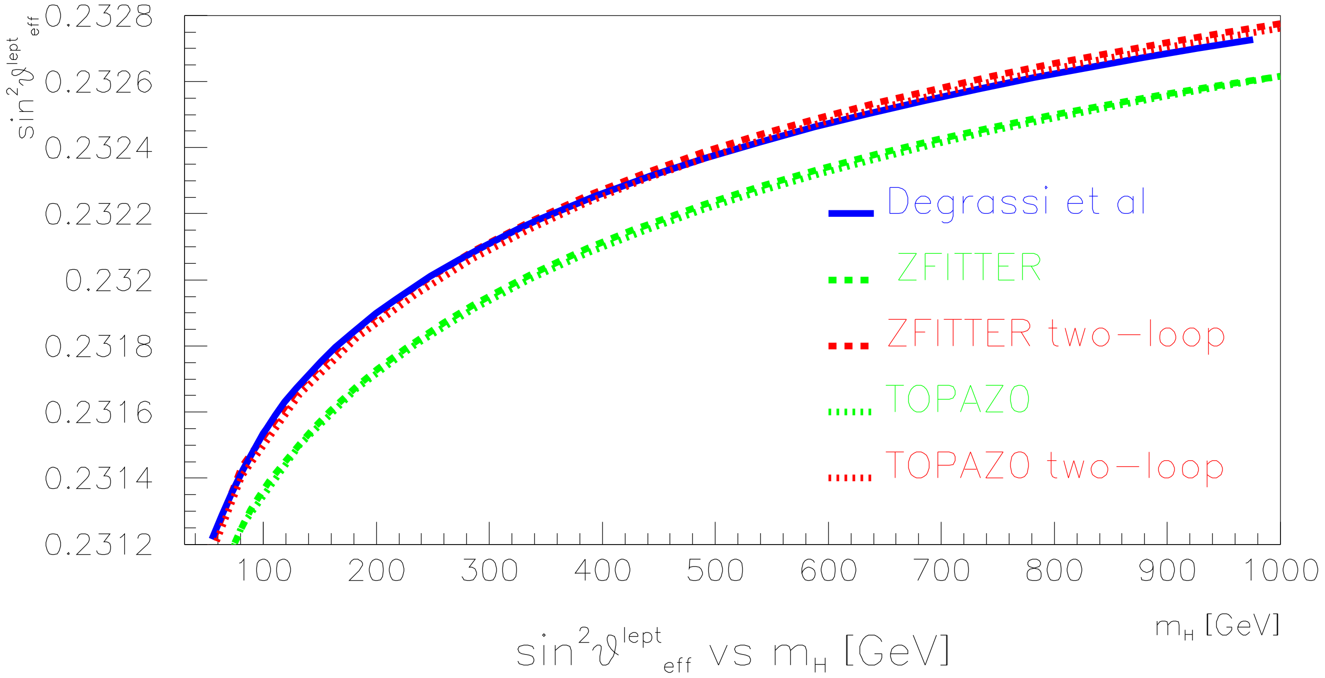
# Effective Electroweak Mixing angle

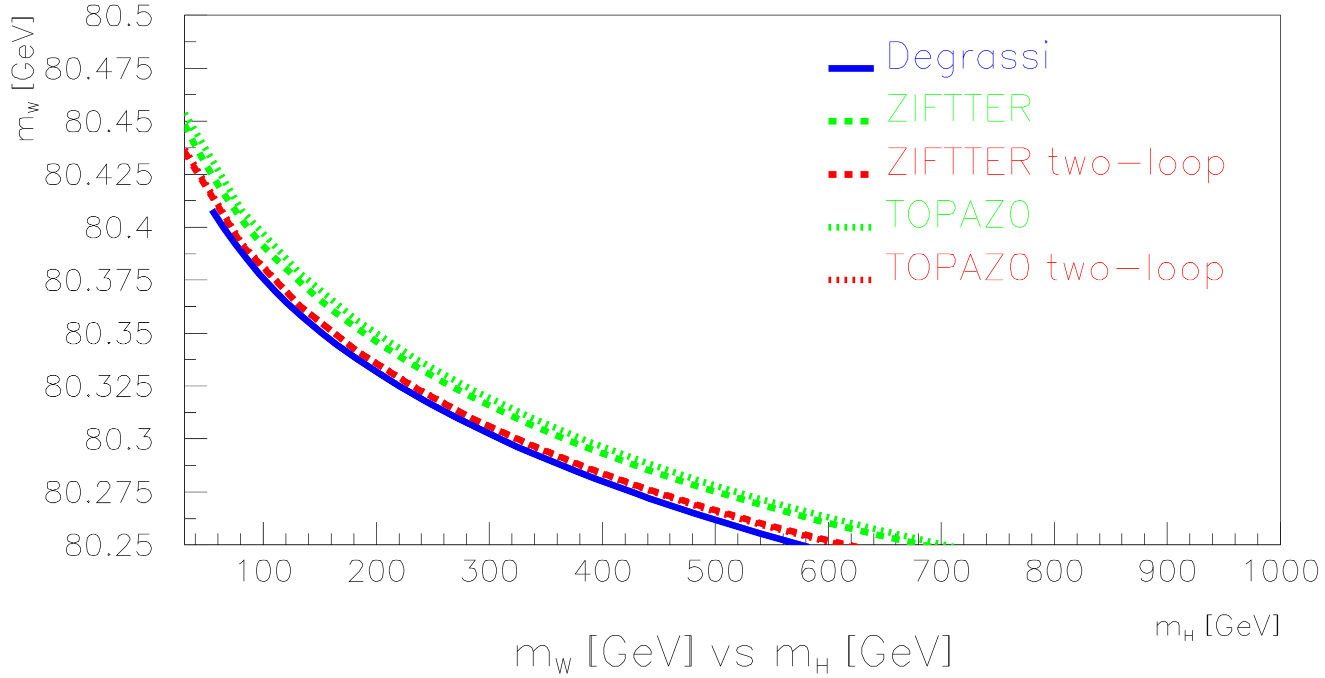
$$\sin^2\theta^{\mathrm{lept}}_{\mathrm{eff}} = \frac{1}{4}\left(1 - \frac{\bar{g}^{l}_{V}}{\bar{g}^{l}_{a}}\right)$$



# Degrassi, TOPAZ0 and ZFITTER comparison

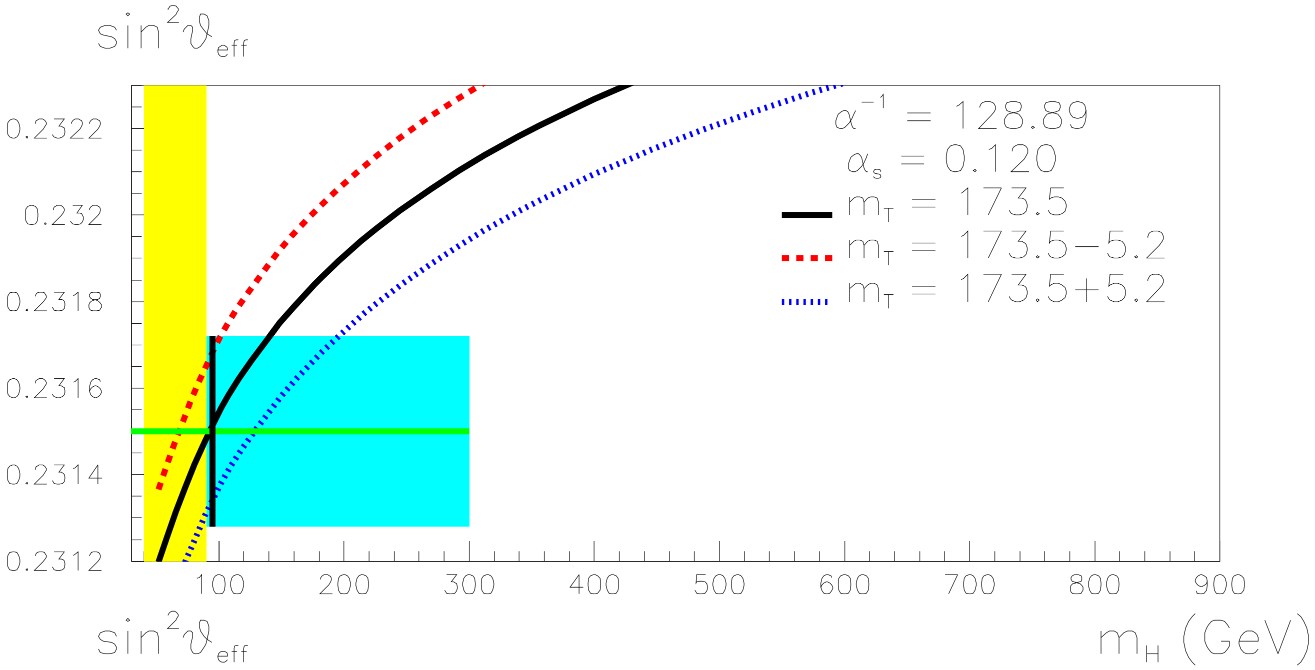
$$\mathbf{m_Z = 91.186,\ m_t = 175.3,\ \alpha^{-1} = 128.90,\ \alpha_s = 0.120}$$

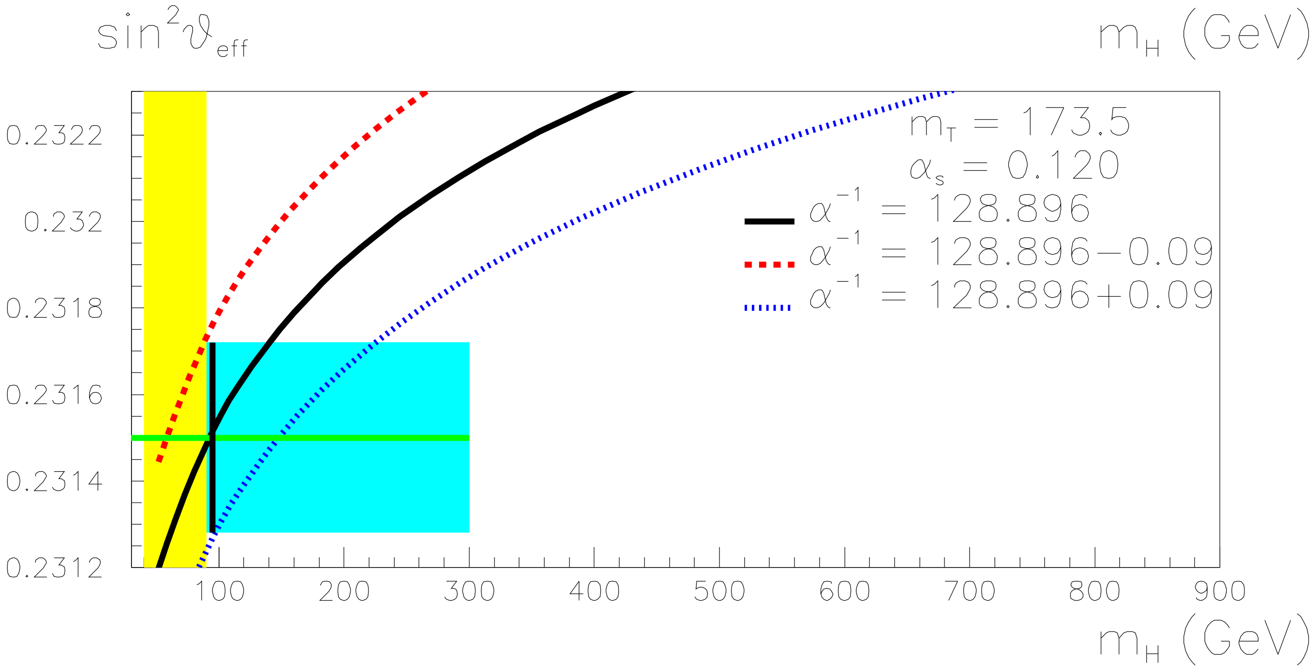


# Effective Electroweak Mixing angle

$$\sin^2\theta_{\rm eff}^{\rm lept} = F(m_H, m_t, \alpha^{-1}, \alpha_s) \text{ (Degrassi et al.)}$$

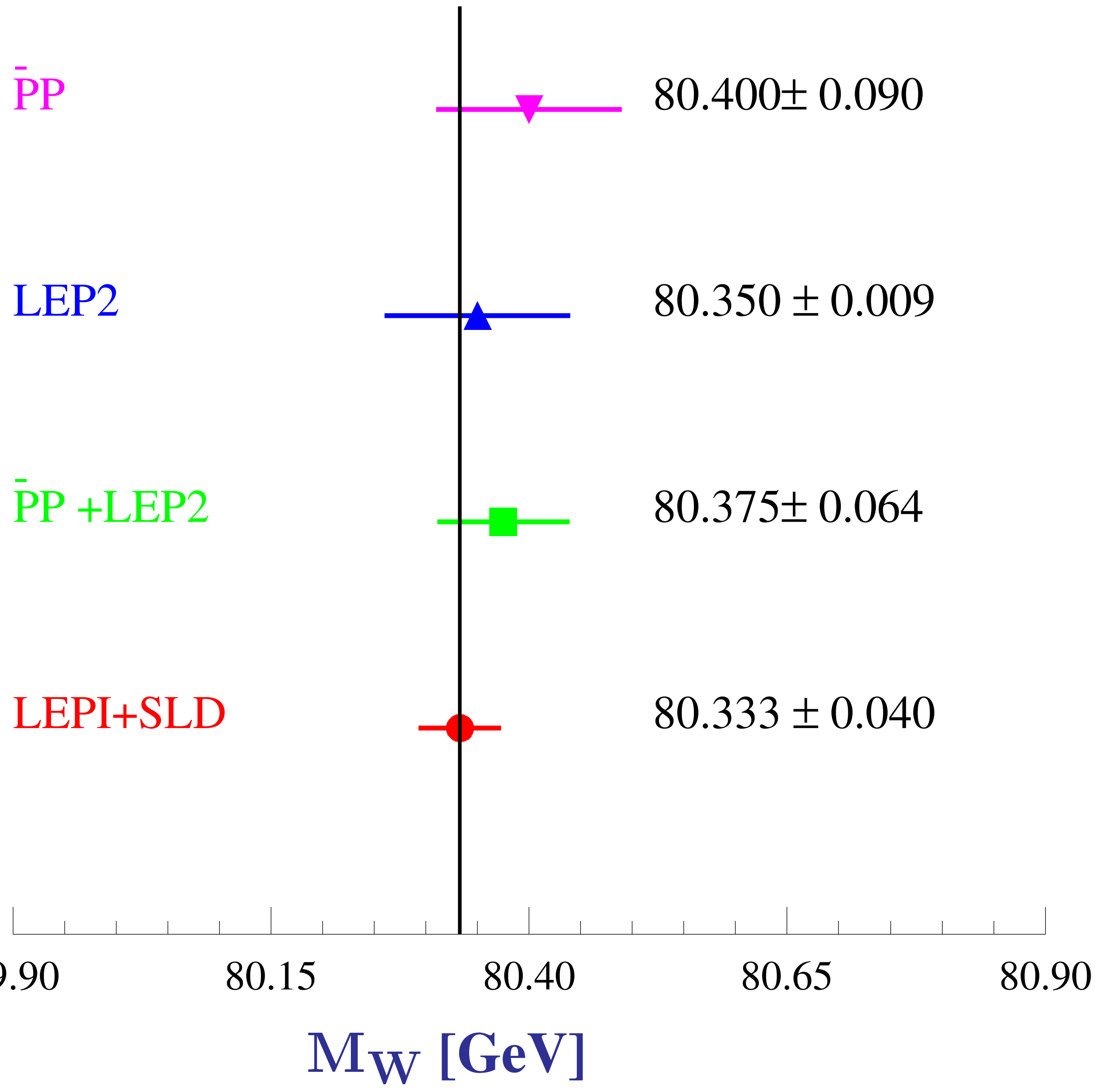



$$\Delta \sin^2\theta_{\rm eff}^{\rm lept}(\exp),\ \Delta m_t,\ \Delta\alpha^{-1}$$

contribute $\sim$ to $\Delta m_H$

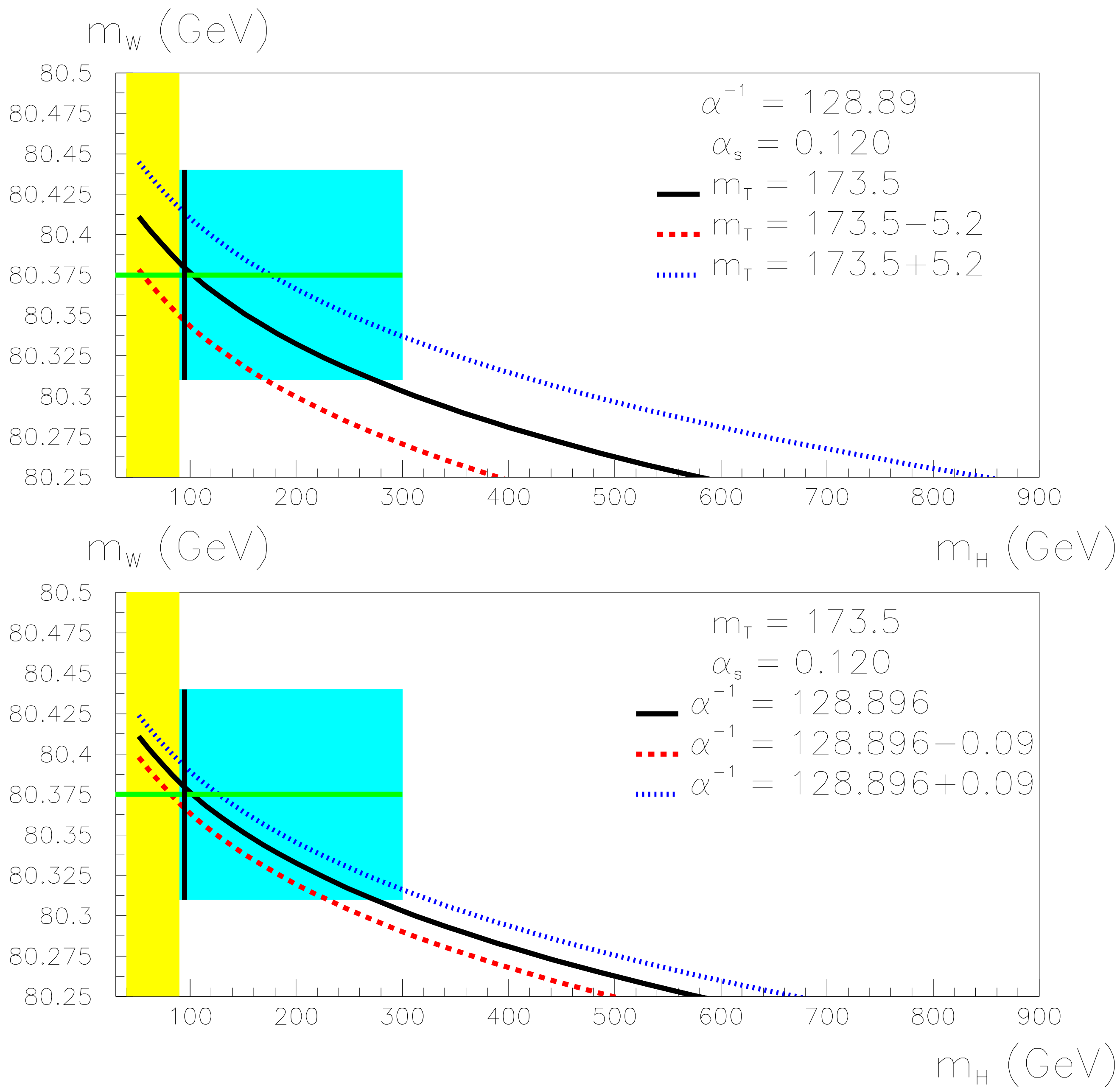
# W-Boson Mass



$\bar{P}P$
80.400± 0.090
LEP2
80.350 ± 0.009
$\bar{P}P$ +LEP2
80.375± 0.064
LEPI+SLD
80.333 ± 0.040
79.90
80.15
80.40
80.65
80.90
$M_W$ [GeV]

# MW

$$\mathbf{m_W = F(m_H, m_t, \alpha^{-1}, \alpha_s)} \text{ (Degrassi et al.)}$$




## $\mathbf{m_H}$ from $\mathbf{m_W}$ is less sensitive to $\mathbf{\Delta\alpha^{-1}}$

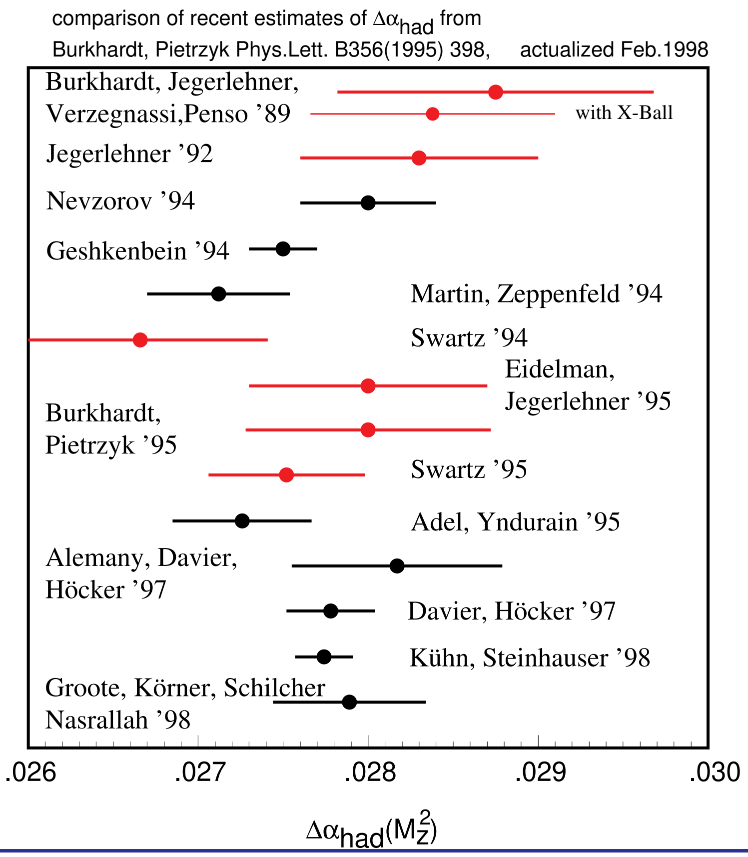
## $\mathbf{\Delta m_W}$ will $\searrow$

# Standard Model parameters

- $\mathrm{m_f}, \mathrm{V_{CKM}}$ **fermion masses and Quark mixing parameters**
- $\alpha^{-1}, \alpha_s$ **QED and QCD coupling**
- $\mathrm{m_Z}, \mathrm{m_W}, \mathrm{m_H}$ **boson masses**

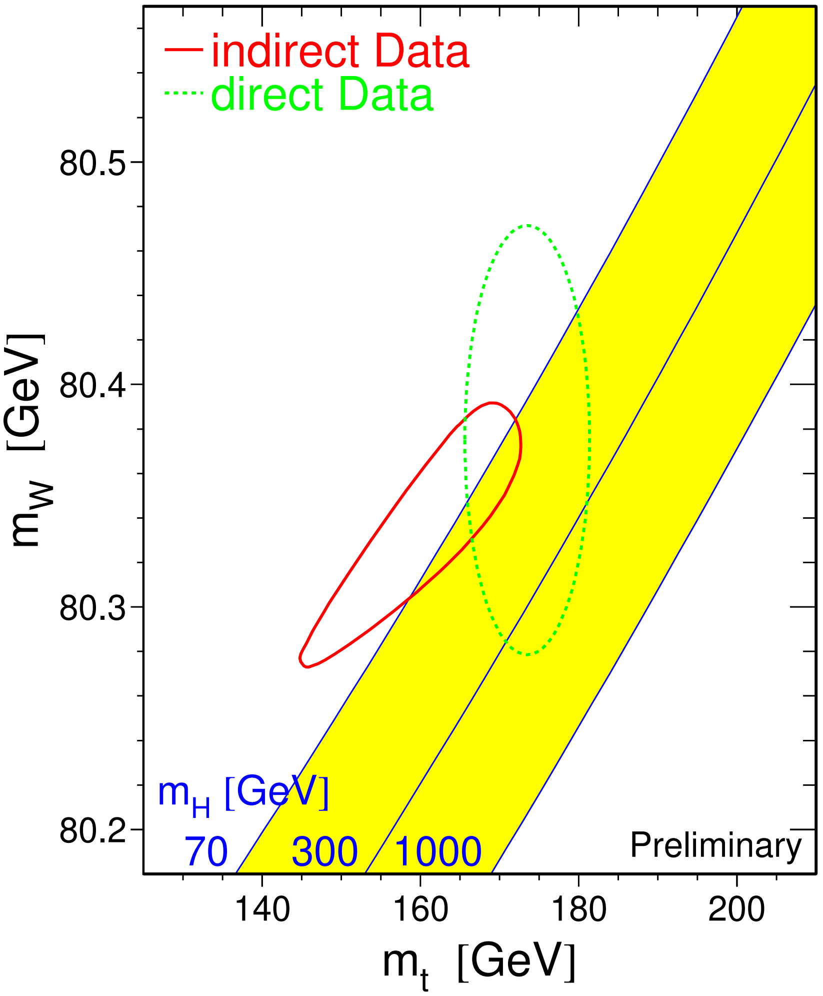
- $\mathrm{G_F} = (1.16639 \pm 0.00002) \cdot 10^{-5}\ \mathrm{GeV}^{-2}$
  **Fermi coupling constant measured in muon decay**
- $\alpha(\mathrm{m_Z^2})^{-1} = 128.896 \pm 0.090$

| | $\Delta\alpha_{\mathrm{had}}(\mathrm{m_Z^2})$ | $\alpha(\mathrm{m_Z^2})^{-1}$ |
|---|---|---|
| **Jegerlehner et al** | $0.0280 \pm 0.0007$ | $128.896 \pm 0.090$ |
| **Davier et al** | $0.02778 \pm 0.00026$ | $128.923 \pm 0.036$ |



# A fit to all the data except LEP-II $m_W$ measurement and Tevatron $m_W$, $m_t$ measurement

$m_t = 158^{+9}_{-8}$, $m_W = 80.333 \pm 0.040$ GeV




**68 % C.L contours**

**Good agreement with the direct measurements**

$m_t = 173.5 \pm 5.2$ GeV and $m_W = 80.40 \pm 0.09$ GeV CDF/D0

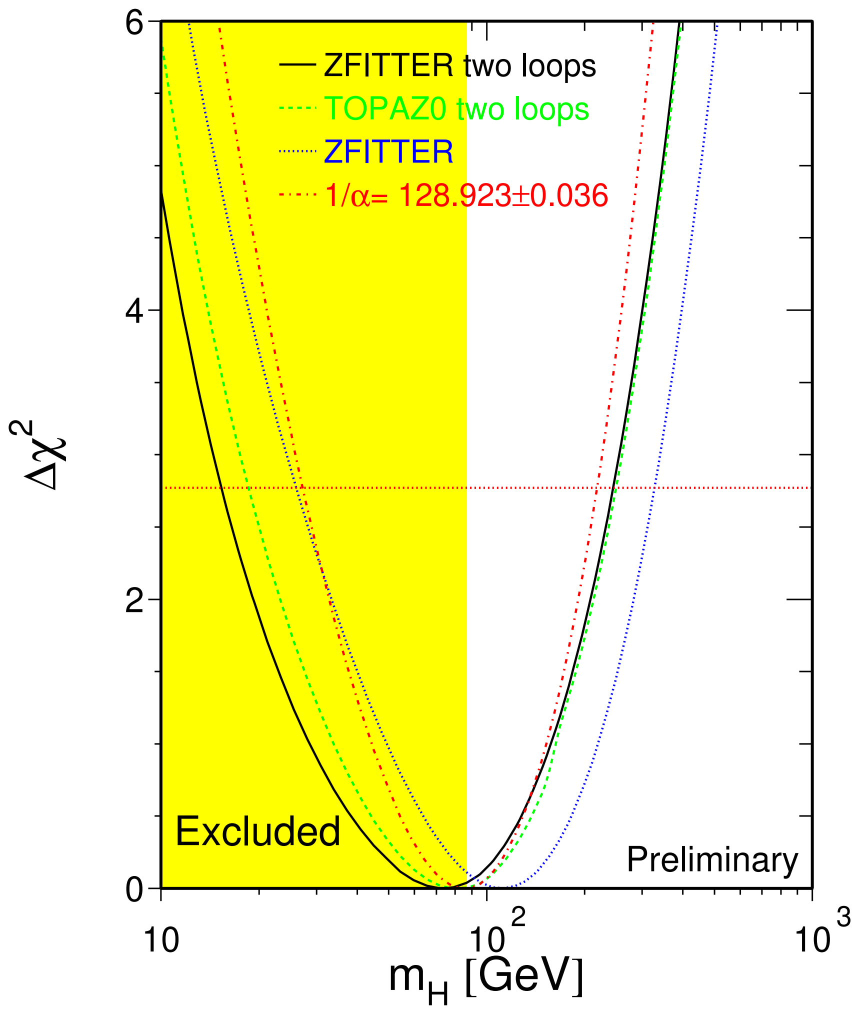
$m_W = 80.35 \pm 0.09$ GeV LEP2

# SM Fits

## A fit to all data, including LEP-II $m_W$ measurement and CDF/D0 $m_t$, $m_W$ measurements

| Computer code | Two-loop corrections | $\alpha^{-1}$ | $m_H$ GeV | 95% CL U.L GeV |
|---|---|---|---|---|
| ZFITTER | Yes | $128.896 \pm 0.090$ | 74 | 240 |
| ZFITTER | No | $128.896 \pm 0.090$ | 105 | 325 |
| TOPAZ0 | Yes | $128.896 \pm 0.090$ | 80 | 250 |
| ZFITTER | Yes | $128.923 \pm 0.036$ | 86 | 220 |

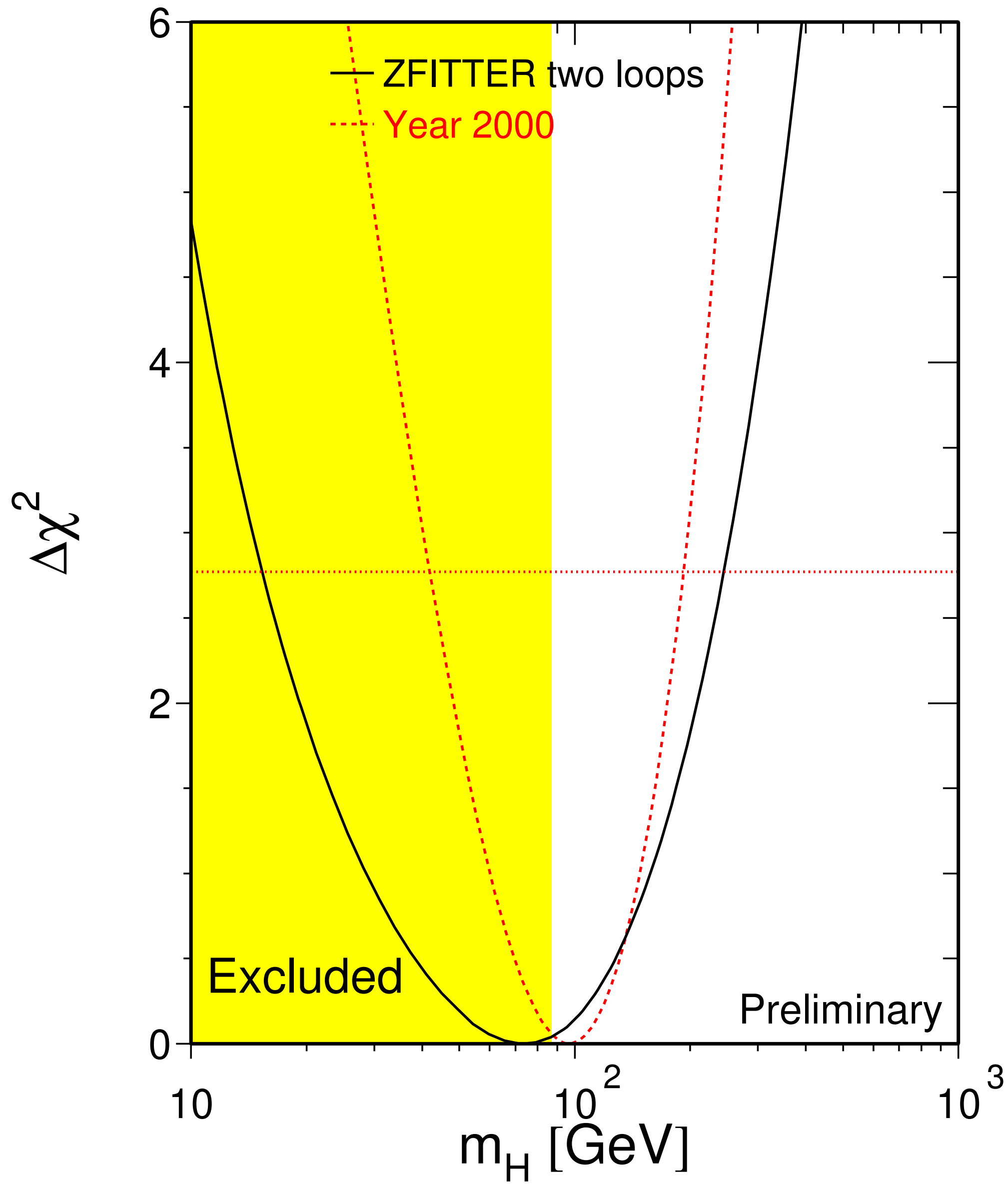
**$\Delta m_H(\text{theory})$ not included**



# Prospects

**In 1998**

$$\mathbf{88\ GeV\ < m_H < 250\ GeV}$$




**End Year 2000**

$$\mathbf{\Delta(m_W) \sim 40\ MeV,\ \Delta(m_t) \sim 3\ GeV,\ \Delta(\alpha^{-1}) = 0.036}$$

$\mathbf{m_H < 200 GeV}$ **at 95% confidence level**

# Conclusions

- **the good agreement between indirect and direct measurements of $m_W$ and $m_t$ is a clear evidence of the validity of the radiative correction calculations.**
- **the SM fit to all electroweak data gives:**
  $m_H = 74^{+84}_{-45}$ GeV , $\log(m_H) = 1.87^{+.33}_{-.41}$
  88 GeV $< m_H <$ 250 GeV
- **the uncertainty on the Higgs mass will decrease with the improvements expected on:**
  **$\sin^2\theta_{eff}$ at SLD**
  **$M_W$, $M_t$ at LEP-II and Tevatron**
  **$\alpha$ at BES/CMD .**
- **raising the LEP-II energy to $\sim$ 200 GeV in 1999 and running in 2000 increases significantly the discovery potential for "a" Higgs boson.**