Lecture 2

The gauge sector

The tree level predictions

v, g, g' $\Rightarrow$ the boson masses, M_W, M_Z , their self-interactions and their interactions with matter, all read off (!?) from $\mathcal{L}$

$$gW_\mu^+ J_\mu^- + h.c., \quad J_\mu^- = \bar{u}\gamma_\mu d + \bar{\nu}\gamma_\mu e$$

$$eA_\mu J_\mu^{em}, \quad J_\mu^{em} = 2/3\bar{U}\gamma_\mu U - 1/3\bar{D}\gamma_\mu D - \bar{E}\gamma_\mu E, \quad e = g\sin\theta$$

$$\frac{g}{\cos\theta} Z_\mu J_\mu^Z, \quad J_\mu^Z = \bar{\psi}\gamma_\mu (T_3 - Q\sin^2\theta)\psi$$

$$U = u + (u_c)^C \equiv U_{Dirac}$$

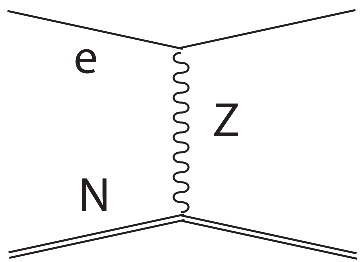
Highly predictive: a great variety of phenomena from

$l_{max} \approx 10^{-8} cm$ (Atomic Parity Violation) to

$l_{min} \approx 10^{-16} \div 10^{-17} cm$ (HERA, LEP, TEVATRON)

[Note, however, that $l_{min} \approx G^{1/2}$]

An example: Atomic Parity Violation

1. From 

to δH_{PV}

δH_{PV} must be local and proportional to G

$\Rightarrow \quad \delta H_{PV} = \frac{G}{\sqrt{2} m_e} Q_W \sigma \cdot \nabla \delta^3(\mathbf{r})$ or $A_{PV} = \frac{G}{\sqrt{2} m_e} Q_W \sigma \cdot \mathbf{q}$

2. From the Z-exchange diagram and $\mathcal{L}$

$$A_{PV} = \frac{G}{\sqrt{2}} (\bar{E} \gamma_\mu \gamma_5 E)(c_u \bar{U} \gamma_\mu U + c_d \bar{D} \gamma_\mu D)$$

$$c_u = -1/2 + 4/3 \sin^2 \theta$$
$$c_d = 1/2 - 2/3 \sin^2 \theta$$

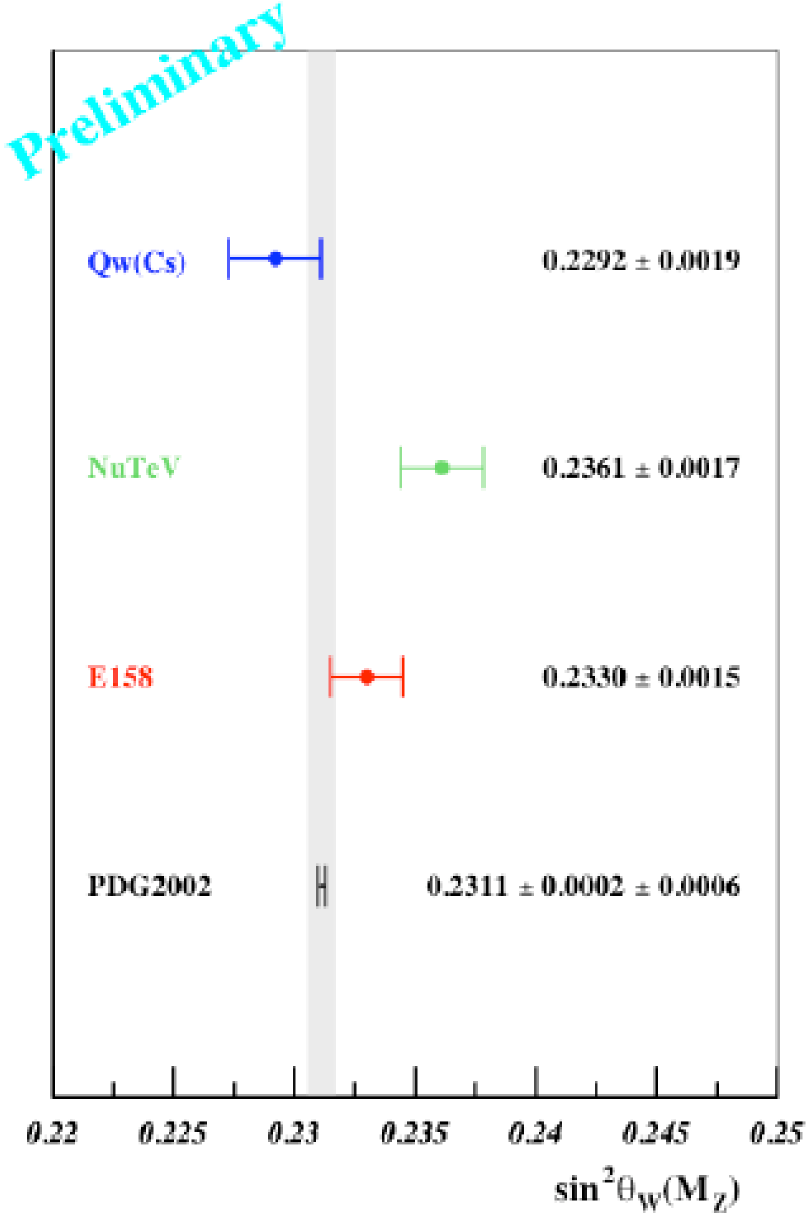
so that, by comparison, in the NRL (!?)

$$Q_W = -2(c_u n_u + c_d n_d) = (2 - 4 \sin^2 \theta) Z - A$$

3. From the measured S-P mixing in Ce^{133}_{55} induced by δH_{PV}

$Q_W|_{exp} = 72.69(48)$ $\qquad$ $Q_W|_{th} = 73.19(3)$

3 low-energy neutral-current measurements



APV

νN-scattering

Moller scattering

(Langacker)

Radiative effects

The prototype examples:

- $$\frac{(g-2)_e}{2} \equiv a_e = a_e(QED) + a_e(had) + a_e(EW)$$ (the terms $a_e(had)$ and $a_e(EW)$ are crossed out)

$$a_e(QED) = \sum_n C_n^e \left(\frac{\alpha}{\pi}\right)^n$$

From $\alpha^{-1}(at.int.) = 137.03600030(100)$ $\quad \frac{\delta\alpha}{\alpha} = 7.4 \cdot 10^{-9}$

$$a_e(th) = 1159652182.3(8.5) \cdot 10^{-12}$$ versus

$$a_e(exp) = 1159652185.9(3.8) \cdot 10^{-12}$$

Remarkable, but a pure QED effect (contained in $\mathcal{L}$)

Radiative effects

The prototype examples (continued):

2 $\frac{(g-2)_\mu}{2} \equiv a_\mu$ probes distances $\frac{m_e}{m_\mu}$ smaller than a_e so that $\frac{\square a_e}{\square a_\mu}|_{univ} = (\frac{m_e}{m_\mu})^2$

$$a_\mu = a_\mu(QED) + a_\mu(had) + a_\mu(EW)$$

$$a_\mu(exp) = 116592080(60) \cdot 10^{-11}$$

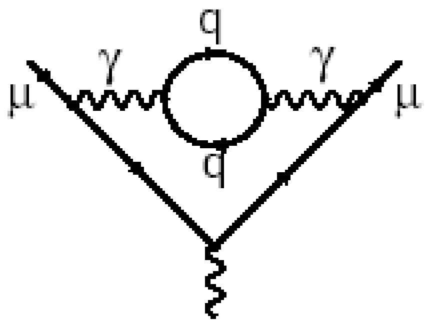
$$\frac{\square a_\mu}{a_\mu} = 5 \cdot 10^{-7}$$

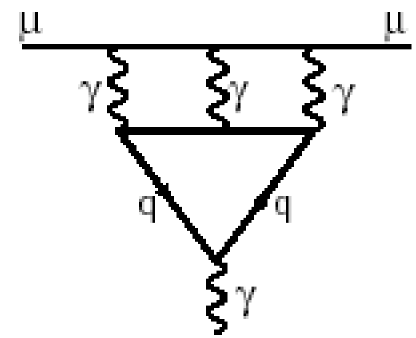
$$a_\mu(EW) = 154(3) \cdot 10^{-11}$$

$$a_\mu(exp) - a_\mu(th) = \begin{bmatrix} 208 \pm 100 \\ 61 \pm 100 \end{bmatrix} \cdot 10^{-11}$$

depending on which data one infers $a_\mu(had)$ from: upper (e+e-), lower (□-decays)

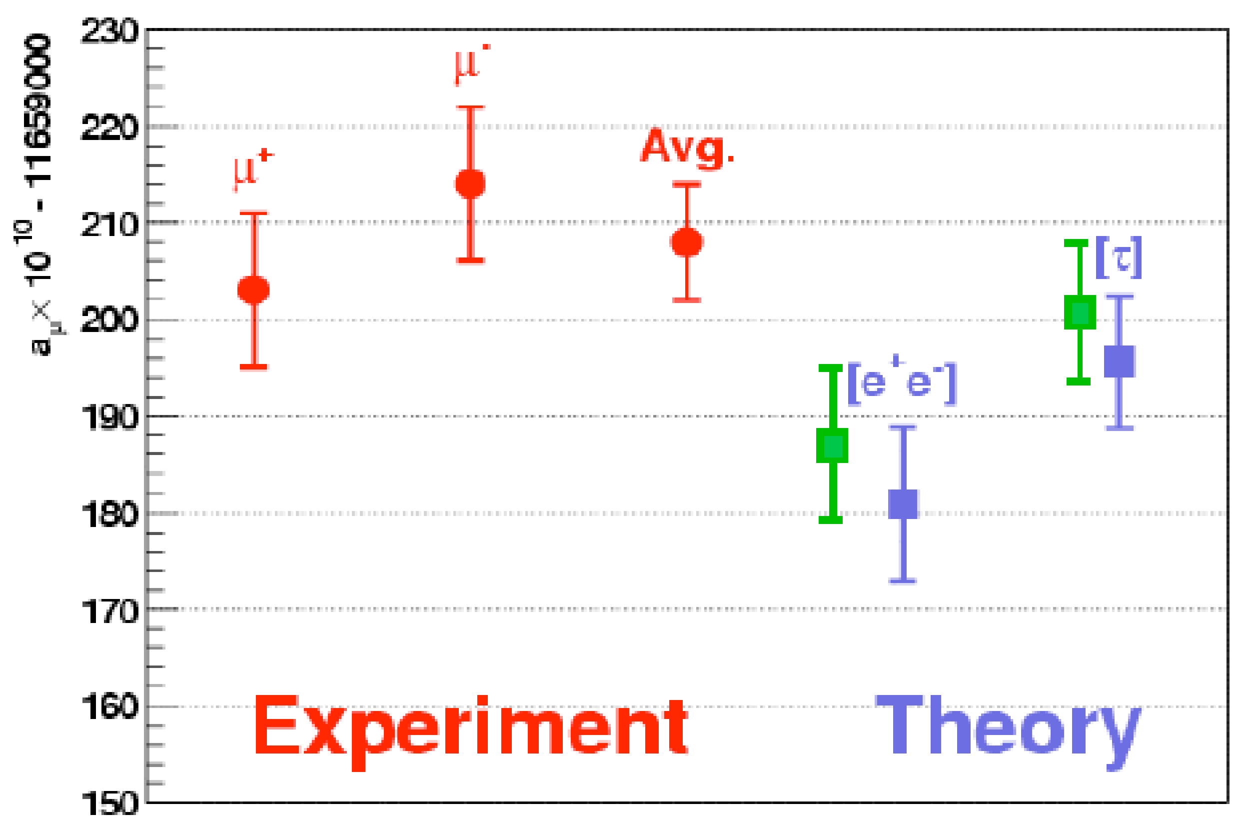
More sensitive, yes, but also more uncertain even apart from the □/ e+e- problem





$$a_\mu^{\rm had,LO} = \begin{cases} 6963(62)(36)\times 10^{-11} & e^+e^- \text{ based} \\ 7110(50)(8)(28)\times 10^{-11} & \tau \text{ based} \end{cases}$$

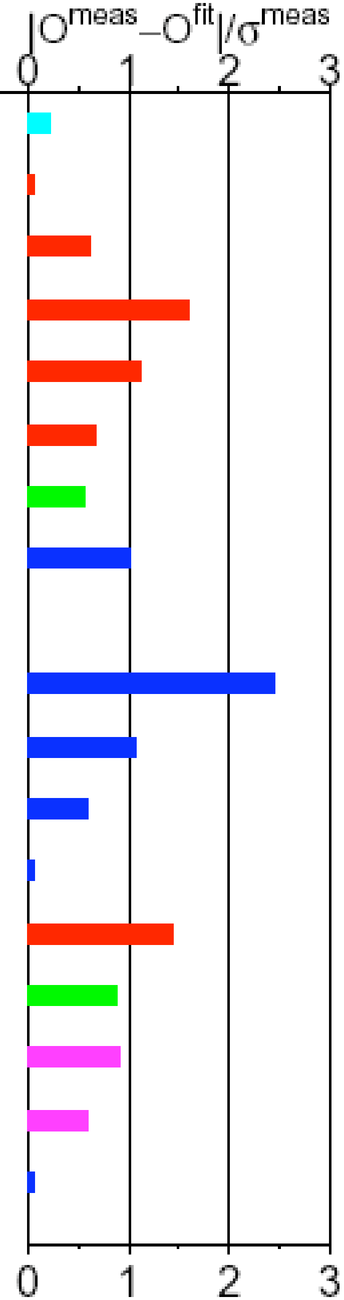
$$a_\mu^{\rm LbL} = 136(25) \times 10^{-11}$$



(Vainshtein)

The ElectroWeak Precision Tests (Z and W prop.s)

	Measurement	Fit
$\Delta\alpha^{(5)}_{had}(m_Z)$	0.02761 ± 0.00036	0.02769
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4966
σ^0_{had} [nb]	41.540 ± 0.037	41.481
R_l	20.767 ± 0.025	20.739
$A^{0,l}_{fb}$	0.01714 ± 0.00095	0.01650
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1483
R_b	0.21630 ± 0.00066	0.21562
R_c	0.1723 ± 0.0031	0.1723
$A^{0,b}_{fb}$	0.0998 ± 0.0017	0.1040
$A^{0,c}_{fb}$	0.0706 ± 0.0035	0.0744
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.026	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1483
$\sin^2\theta^{lept}_{eff}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.425 ± 0.034	80.394
Γ_W [GeV]	2.133 ± 0.069	2.093
m_t [GeV]	178.0 ± 4.3	178.2
$G[GeV^{-2}]$	$(1.16637 \pm 1)10^{-5}$	



parameters:

v, g, g' (at tree level)

m_t, m_h (from 1 loop on)

precision often better than 10^{-3}

LEPEWWG 2004

Infact the EWPT bring together:

A. The gauge sector $\left(\frac{g^2}{4\pi}, \frac{g'^2}{4\pi}\right)$

B. The flavor sector, through $\lambda_t Q_3 t \Box$ $\left(\frac{\lambda_t^2}{4\pi} = \frac{G m_t^2}{8\pi^2\sqrt{2}}\right)$

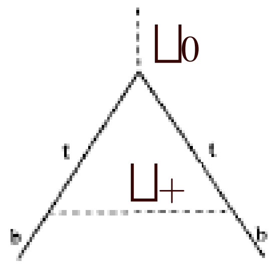
C. The EWSB sector, mostly through $\frac{g^2}{4\pi}\log m_h$

About A - In principle not different from the standard $\frac{e^2}{4\pi}$ expansion of QED, but with exchanged W's and Z's

About B - In fact, these effects (the dominant part) can be most easily computed with g = g' =0, hence in a theory of top/bottom quarks, the Higgs h and the (unphysical) Goldstones (π's)

The leading corrections of type B(!?)

$$\Rightarrow \quad \frac{M_W^2}{M_Z^2\cos^2\theta} \equiv \rho = \frac{Z_2^+}{Z_2^0} = 1+3x$$

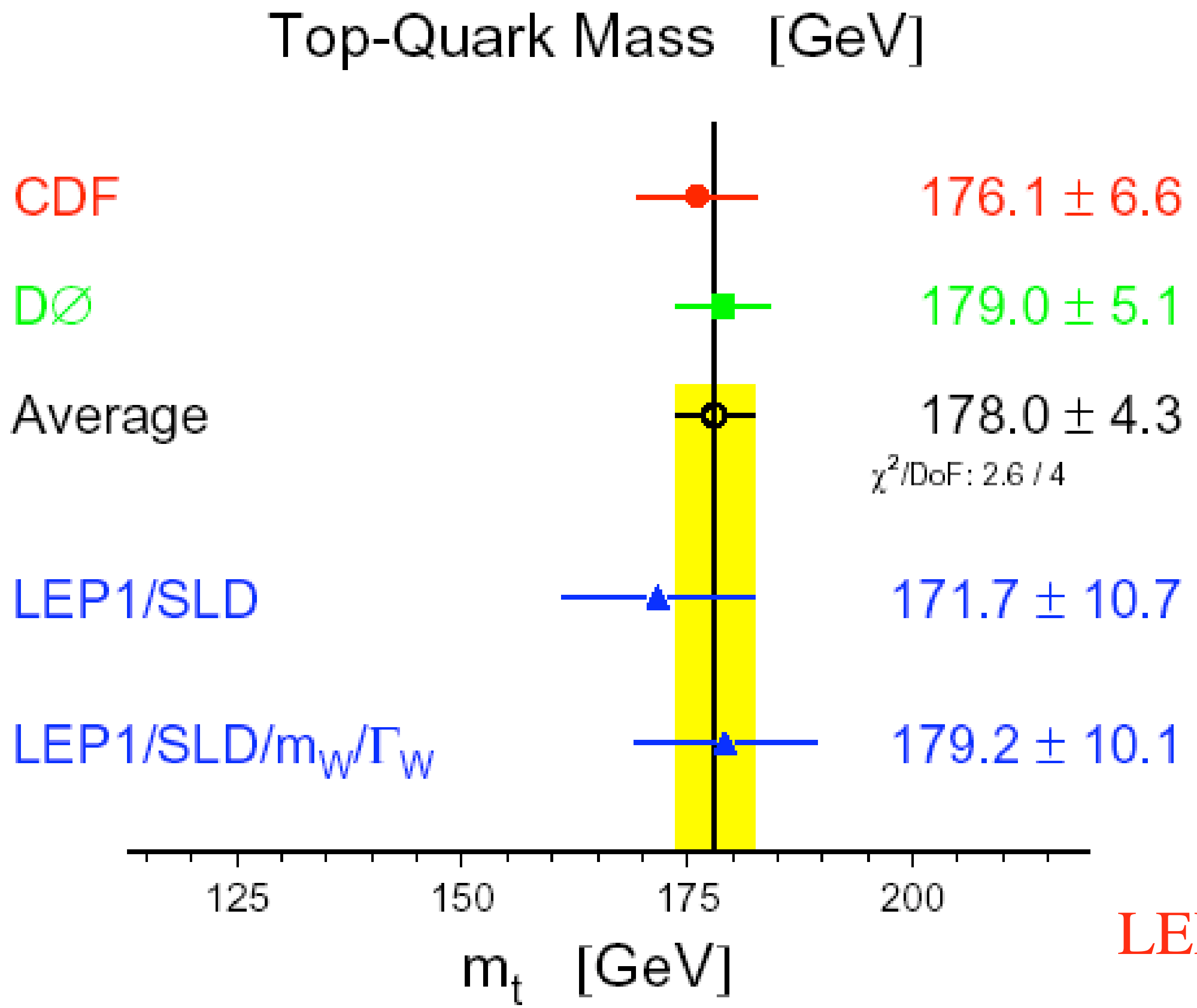


$$\Rightarrow \quad \delta V_\mu(Z \to b\bar{b}) \equiv \frac{g}{2\cos\theta}\epsilon\gamma_\mu\frac{1+\gamma_5}{2} \qquad \epsilon = \frac{Z_1}{Z_2^b} = -2x$$

where $\quad x = \dfrac{Gm_t^2}{8\pi^2\sqrt{2}} \approx 0.5\%$

$\Rightarrow$ clearly visible effects, used to get a range of top masses before the actual discovery (in 1993 $m_t = 120 \div 160 GeV$), now almost a background

Current comparison (2004)



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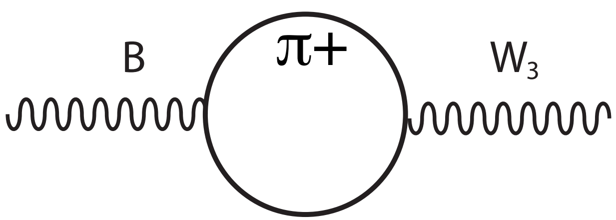
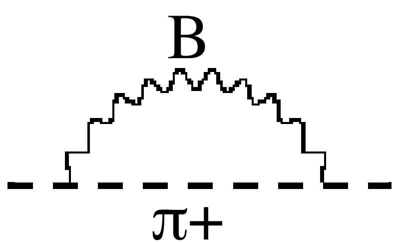
About the Higgs mass dependence

In the limit of infinite Higgs mass, $(m_h^2 = 4\square v^2 : \quad \square \to \quad)$ divergences appear: log's at 1 loop, quadratic at 2 loops. In the perturbative regime ($\square\square 4\square$ or m_h $\square$ 1-2 TeV) the log's dominate, with 2 effects only (!?):



$$= \square_{W_3B}(p^2)\, g_{\mu\square} + p_\mu p_\square - terms$$

$$\Rightarrow \hat{S} \equiv \square'_{W_3B}(0) = \frac{\square}{24\square \sin^2\square} \log\square$$



$$= \square_+(p^2)$$

$$\Rightarrow \hat{T} \equiv \square'_+(0) = -\frac{3\square}{8\square \sin^2\square} \log\square$$

which spread in the various observables with $\log\square \to \log m_h$

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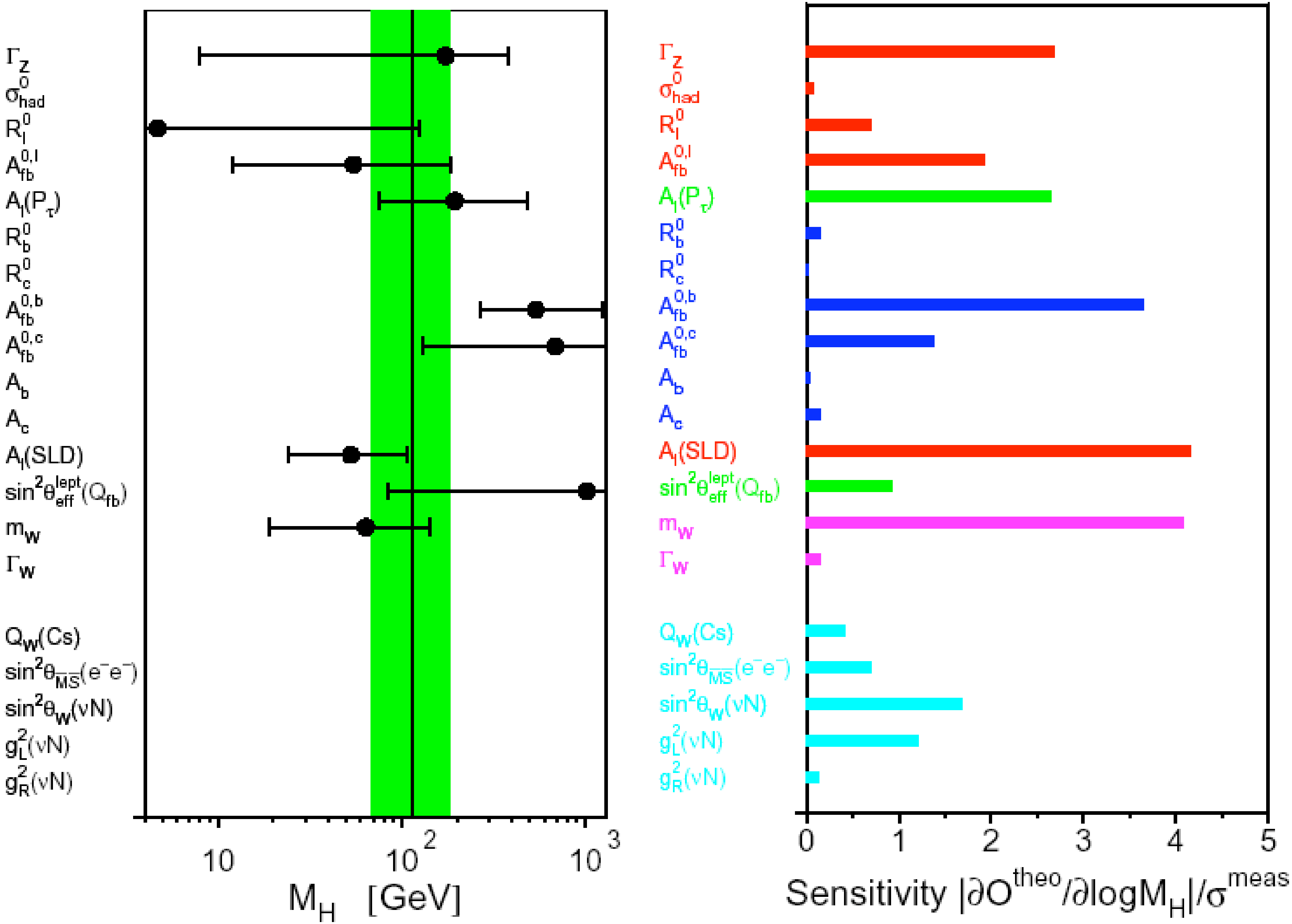
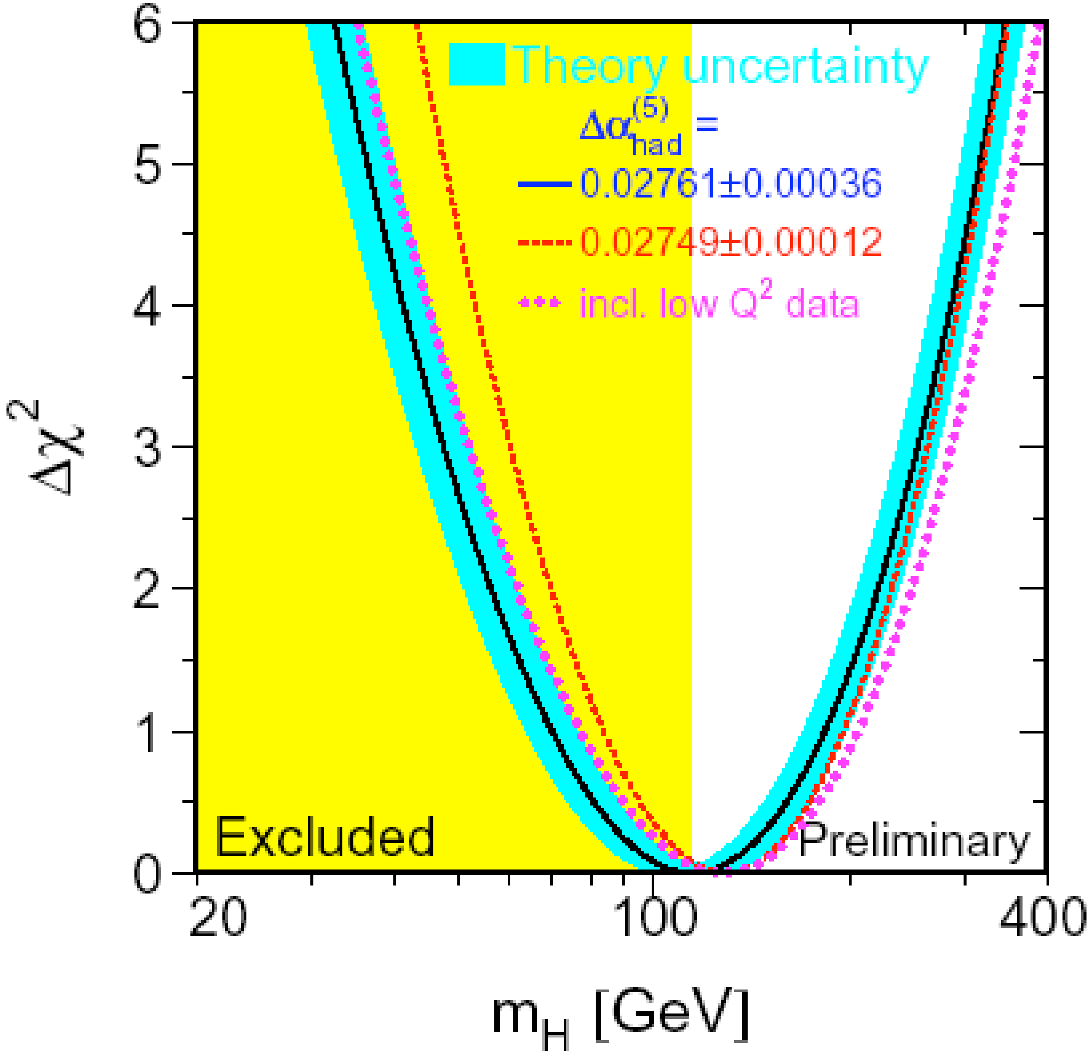
Current comparison (2004)



The Higgs mass indirect determination in the SM



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(more on this later in Lecture 5)

The foreseeable (?) future in EWPT

At present 3 main (relatively) uncertain parameters: $m_t, m_h, \alpha(M_Z)$

$\Rightarrow$ 4 more precise measurements needed for a better test

	now	LHC	LC	Giga-Z
$\delta \sin^2\theta_{eff}(10^{-5})$	16 (?)	15	?	1.3
$\delta M_W [MeV]$	34	15	10	7
$\delta M_t [GeV]$	4.3	1.0	0.2	0.1
$\Rightarrow \frac{\delta m_h}{m_h}$	60%	15-20%	10-15%	5-10%

(A future improved $\alpha(M_Z)$?)