EW precision tests before the LHC

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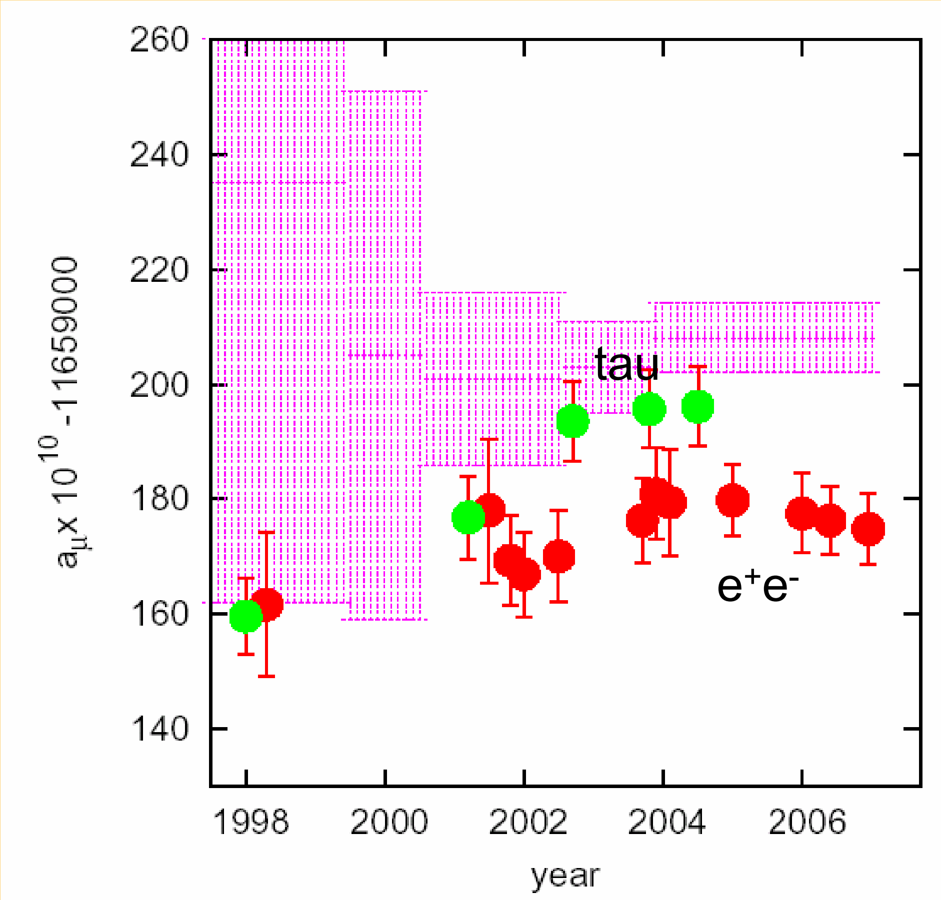
Precision tests in the last few years

- ✓ $(g\text{-}2)_\mu$ remains a puzzle
- ✓ Great improvement in M_t and smaller one in M_W at the Tevatron
- ✓ Small improvements in $\Delta\alpha_h$ determination
- ✓ Most LEP results finalized, final E158 result.
- ✓ Some possible anomalies faded away (weak universality, NuTeV…)
- ✓ ongoing theoretical effort to improve accuracy: important for the future, especially for ILC

Overall the SM performs well, but some cracks in its building have deepened during the last few years.

The ups and downs of $(g-2)_\mu$

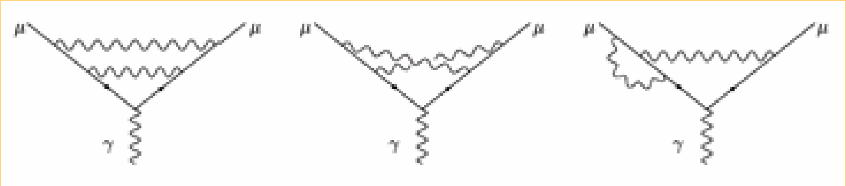


Can we test the SM with $(g-2)_\mu$?

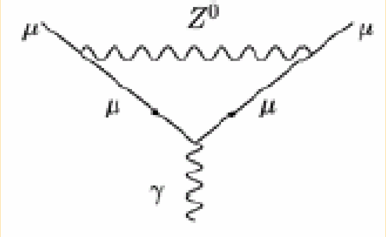
$$a_\mu^{\mathrm{exp}} = 116\,592\,080(60) \times 10^{-11}$$

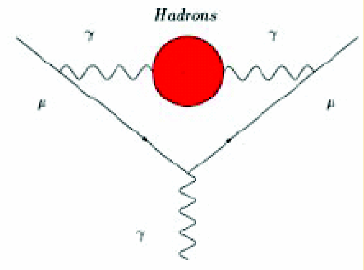
$$a_\mu^{\mathrm{SM}} = [116\,584\,706(3)_{\mathrm{QED}} + 154(2)_{W,Z,H} + 6831(73)_{\mathrm{hadrons}}] \times 10^{-11}$$

~3σ discrepancy: New Physics (Supersymmetry?) or
due to uncalculable strong interaction effects?



QED diagrams

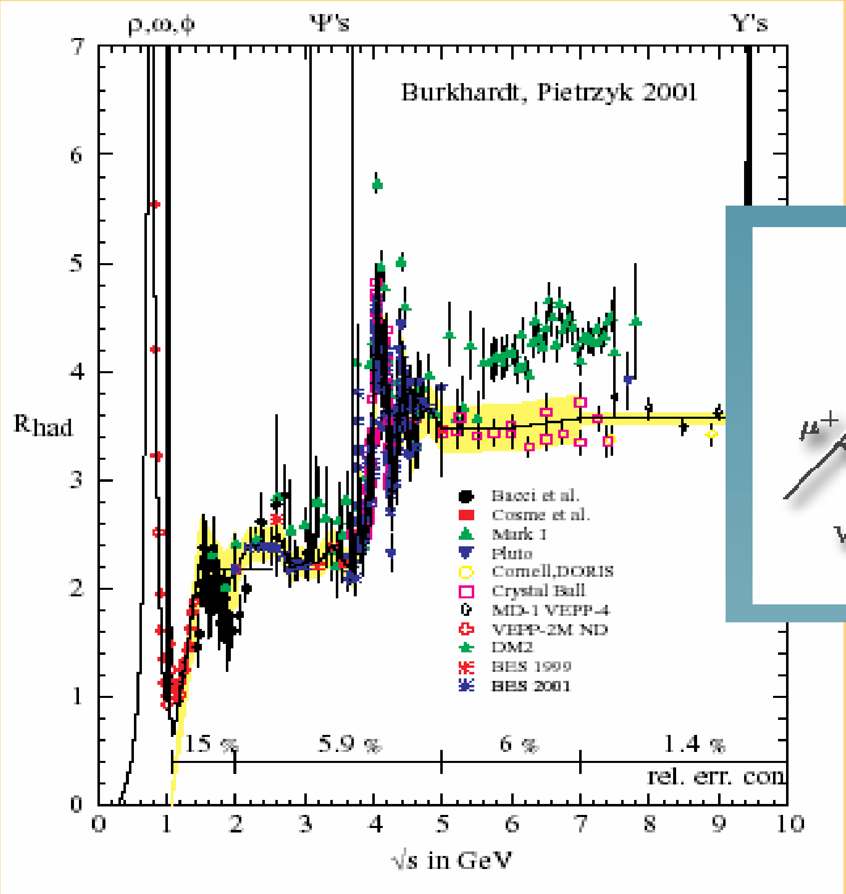


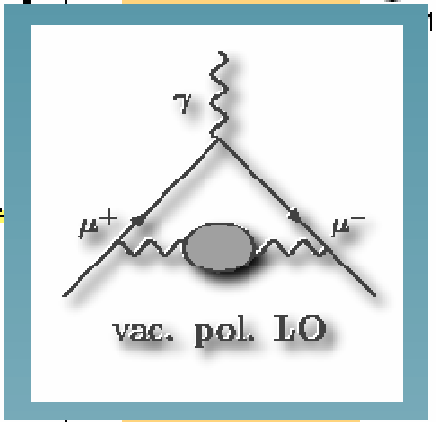


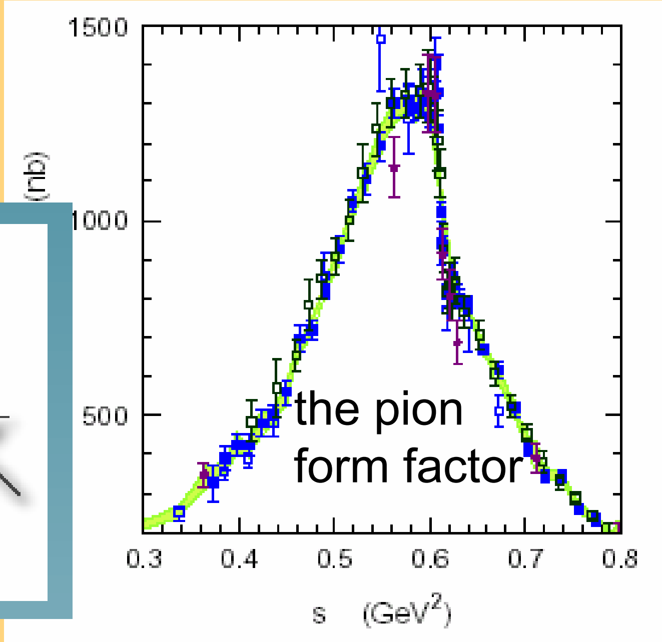
Non-QED effects are suppressed by m_μ^2/Λ^2 but starting at 2loops Λ can also be the scale of strong interactions $\Lambda \sim M_\rho \sim 700$MeV !

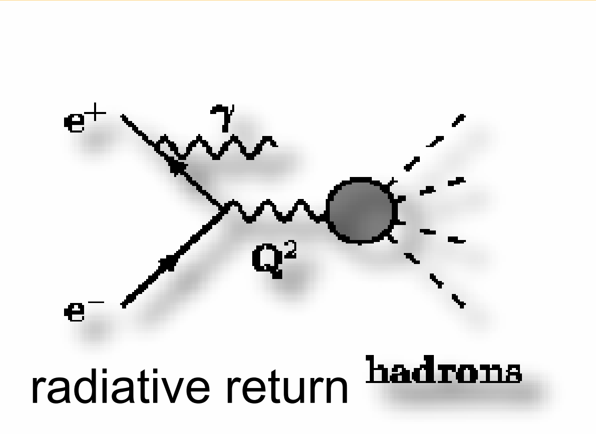
Excellent place for new physics, no M_H sensitivity: loop effects $\sim m^2_\mu/\Lambda^2$ but needs *chiral* enhancement: SUSY natural candidate at moderate/large tanβ

The spectral function





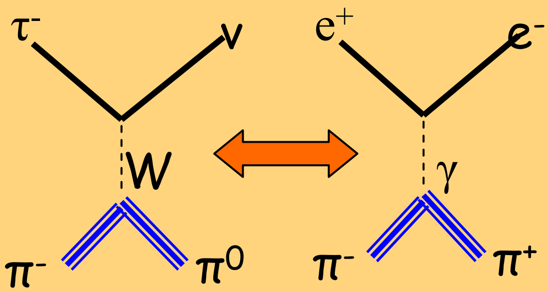




The spectral function can be measured in
$e^+ e^- \to$ hadr, in τ decays, and with radiative return

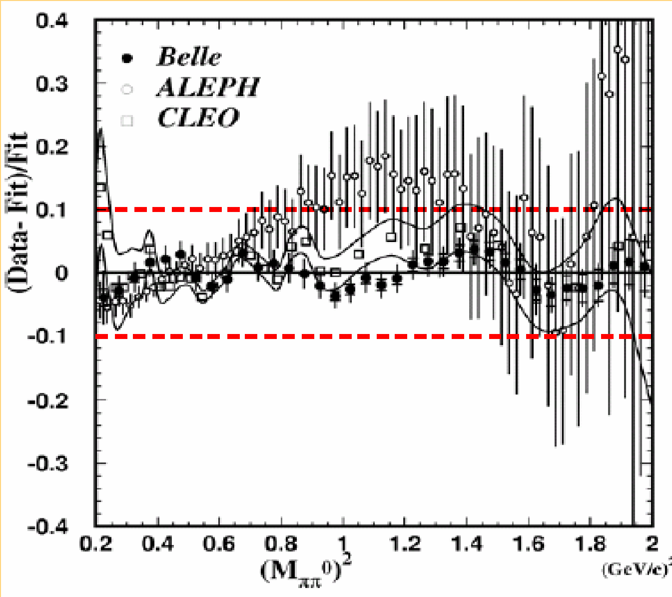
The main open problems

Spectral function from tau decays implies extra theory input



CVC + isospin symmetry

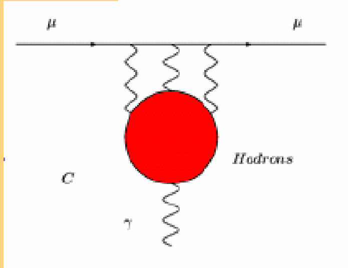
Corrections by Cirigliano et al 02



Experimental situation is improving but tau data must be understood (experimental or theoretical problem?)

Light by light

The contribution of the hadronic l-b-l diagrams had a troubled life. The latest values vary between:



$a_\mu^{HHO}(lbl) = +80\ (40) \times 10^{-11}$	Knecht & Nyffeler '02
$a_\mu^{HHO}(lbl) = +136\ (25) \times 10^{-11}$	Melnikov & Vainshtein '03

based on Hayakawa & Kinoshita '98 & '02; Bijnens, Pallante and Prades '96 & '02; Knecht, Nyffeler, Perrottet & de Rafael '02.

Passera Tau

Status of $(g\text{-}2)_\mu$

LxL: Melnikov Vainshtein

a_μ: Standard Model vs. measurement.

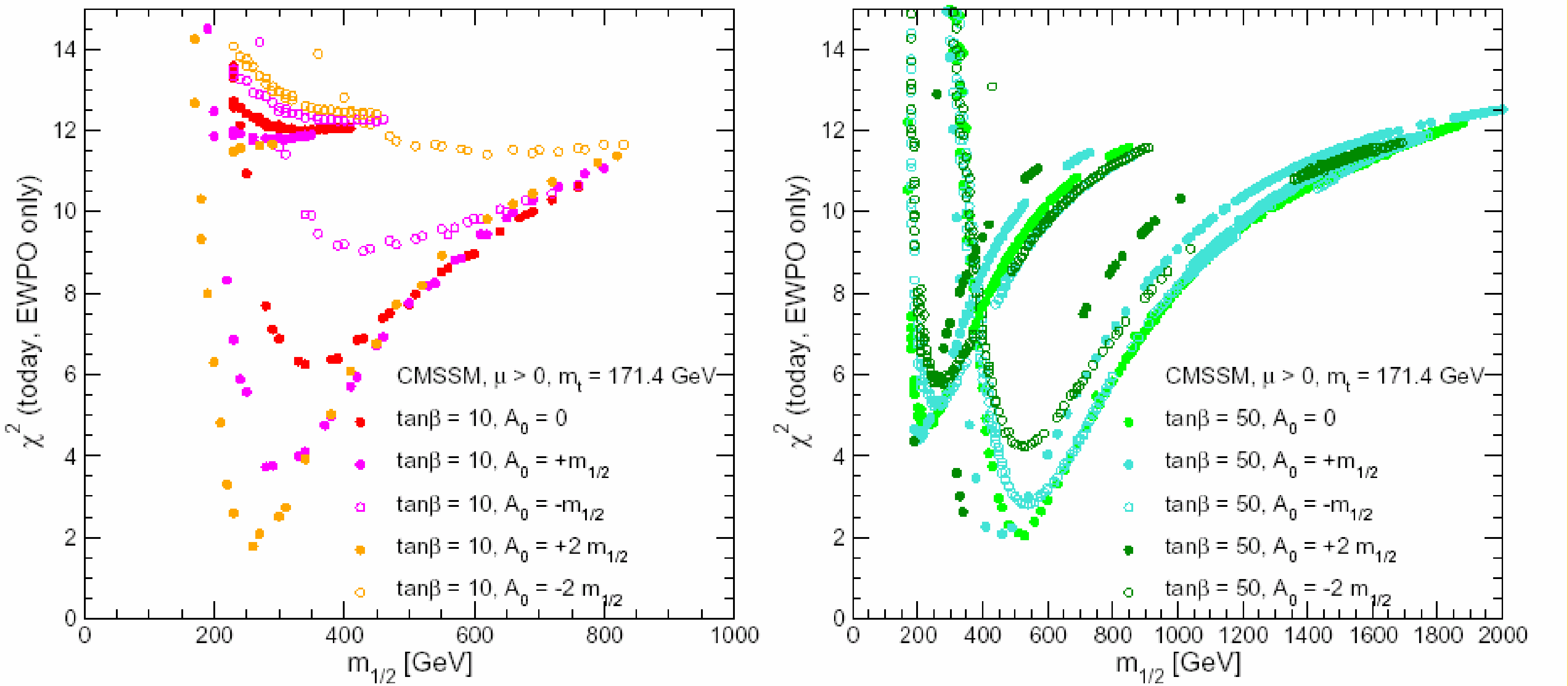
	$a_\mu^{SM} \times 10^{11}$	$\Delta \times 10^{11}$	σ
[68]	116 591 763 (60)	317 (87)	3.7 $\langle 3.2 \rangle$
[69]	116 591 748 (61)	332 (88)	3.8 $\langle 3.4 \rangle$
[70]	116 591 775 (69)	305 (93)	3.3 $\langle 2.8 \rangle$
[71]	116 591 798 (63)	282 (89)	3.2 $\langle 2.7 \rangle$
[73]	116 591 961 (70)	119 (95)	1.3 $\langle 0.7 \rangle$

e^+e^- (rows [68]–[71]); Aleph τ (row [73])

Passera, hep-ph/0702027

At present still problematic. Exp problems will be solved in the near future.
LxL eventual bottleneck, but has the *wrong* sign and theory evolves.
The proposed new experiments at Brookhaven and JLab should be funded

$(g-2)_\mu$ in the MSSM



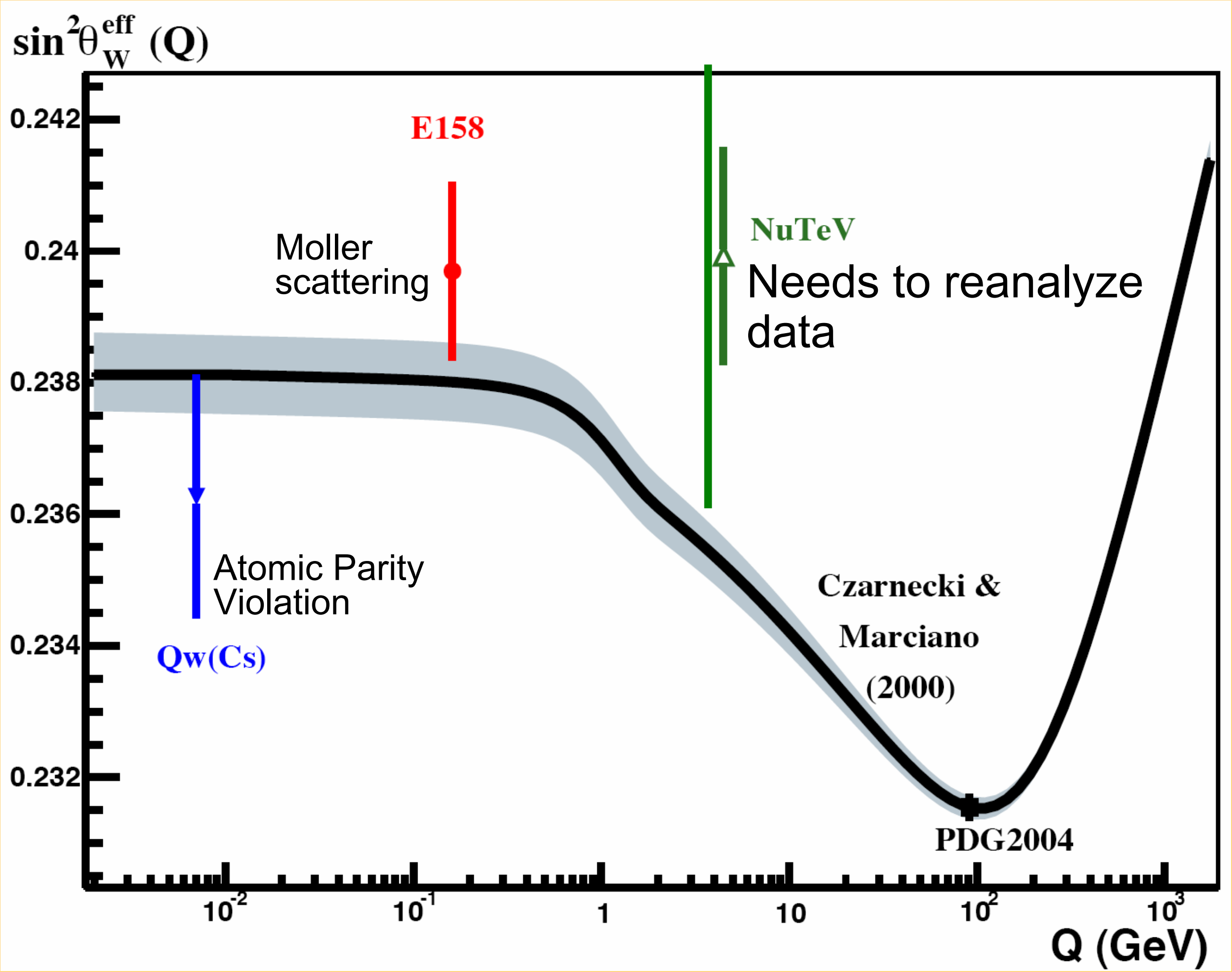
Ellis et al, arXiv:0706.0652

EW fit in the CMSSM: the existence of the dip (preference for light superpartners) in χ^2 rests almost exclusively on this piece of data

Low energy tests of NC couplings

Low energy measurements of $\sin^2\theta_W$ can be presented as tests of its running

NuTeV uncertainty from PDFs, implementation of NLO and EW corrections



Indirect determination of M_H

Best known EW observables: $G_\mu (0.9\ 10^{-5})$ $M_Z (2\ 10^{-5})$ $\alpha(M_Z) (3\ 10^{-4})$
$M_W (4\ 10^{-3})$ $\sin^2\theta_{eff}^{lept} (0.8\ 10^{-3})$ $\Gamma_l (10^{-3})$

$\alpha(M_z), G_\mu, M_w \rightarrow f(M_t, M_H)$

or $\alpha(M_z), G_\mu, \sin^2\theta_{eff}^{lept} \rightarrow g(M_t, M_H)$

Since M_t is now known to 1% → M_H

$$G_\mu = \frac{\pi\alpha(M_Z)}{\sqrt{2}M_W^2(1-\frac{M_W^2}{M_Z^2})}\frac{1}{(1-\Delta r)}$$

EW loops

Δr is an observable quadratic (logarithmic) function of M_t (M_H), known with theory precision close to 10^{-4}. Analogous relations hold for $\sin^2\theta_{eff}^{lept}$ etc.

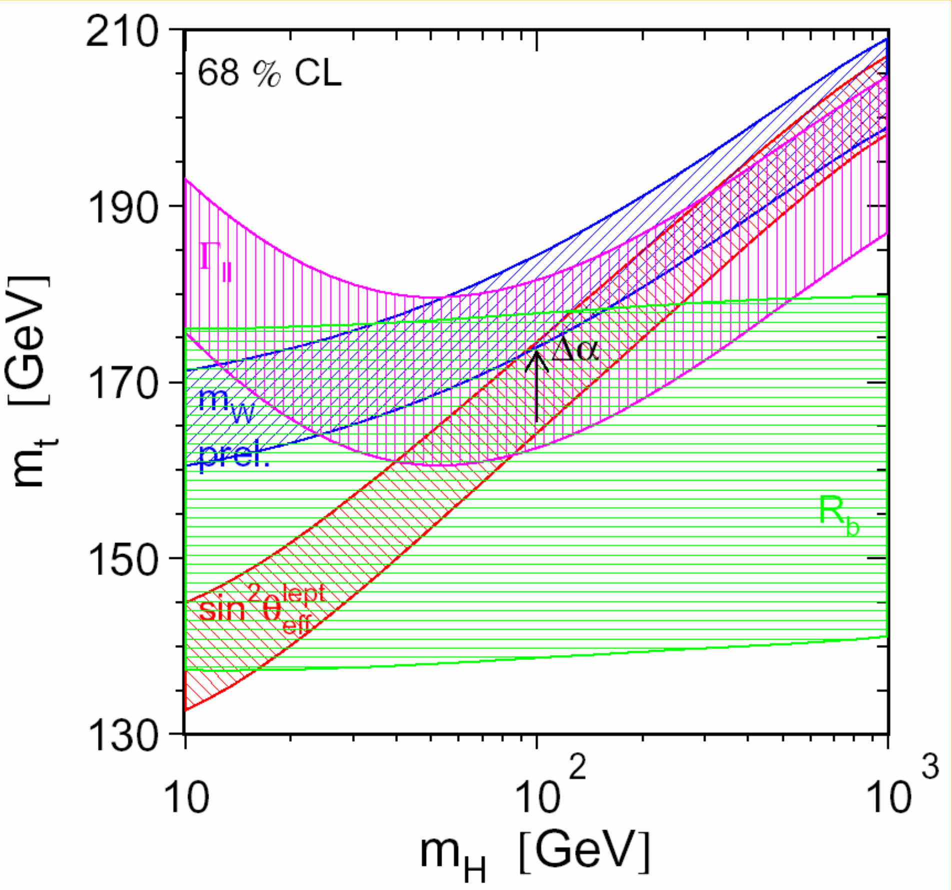
Recent calculations: complete 2loop EW, leading 3 and 4 loop effects

Awramik,Czakon,Freitas,Feisst,Uccirati,Sturm, Weiglein,Boughezal,Van der Bij,Tausk,Chetyrkin,Kuehn,Meier,Hollik...

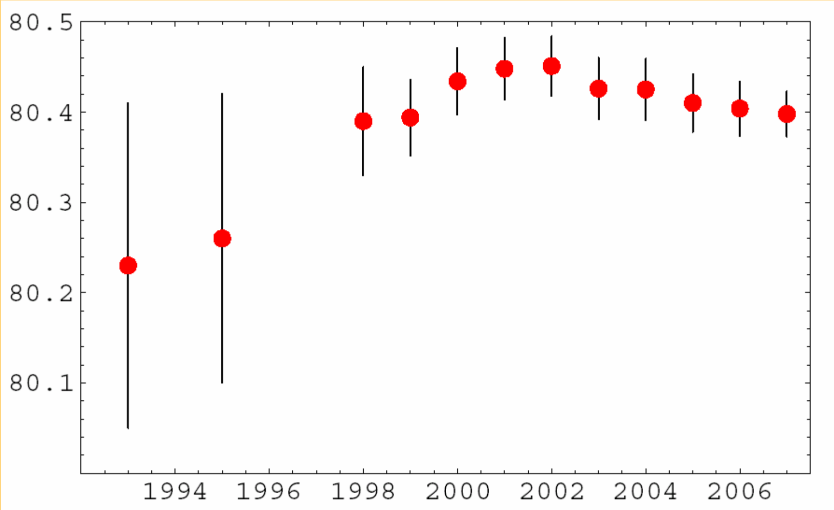
M_{top}-M_H correlations

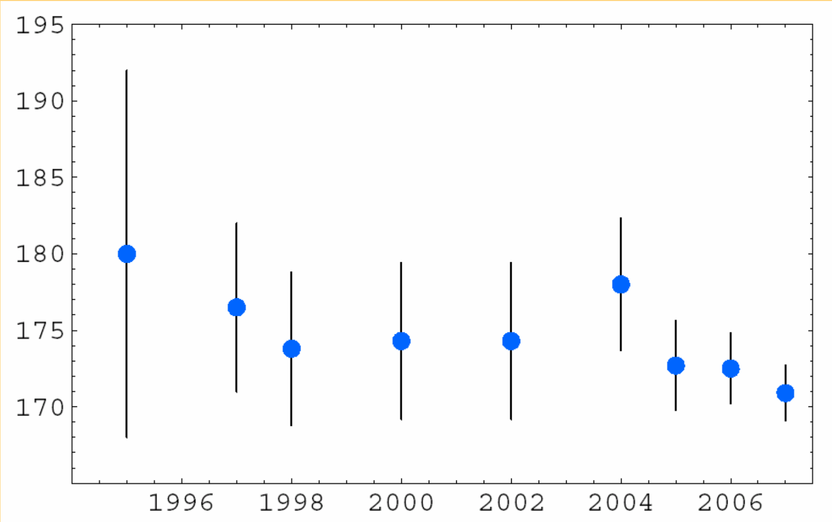
Strong correlation because they enter the same loops
Positive correlation:
higher M_t → higher M_H

The constraining power of M_W and $\sin^2\theta_{eff}$ is similar at current precision



M_W and M_{top} history





The low value of M_{top} implies a preference for lower M_H

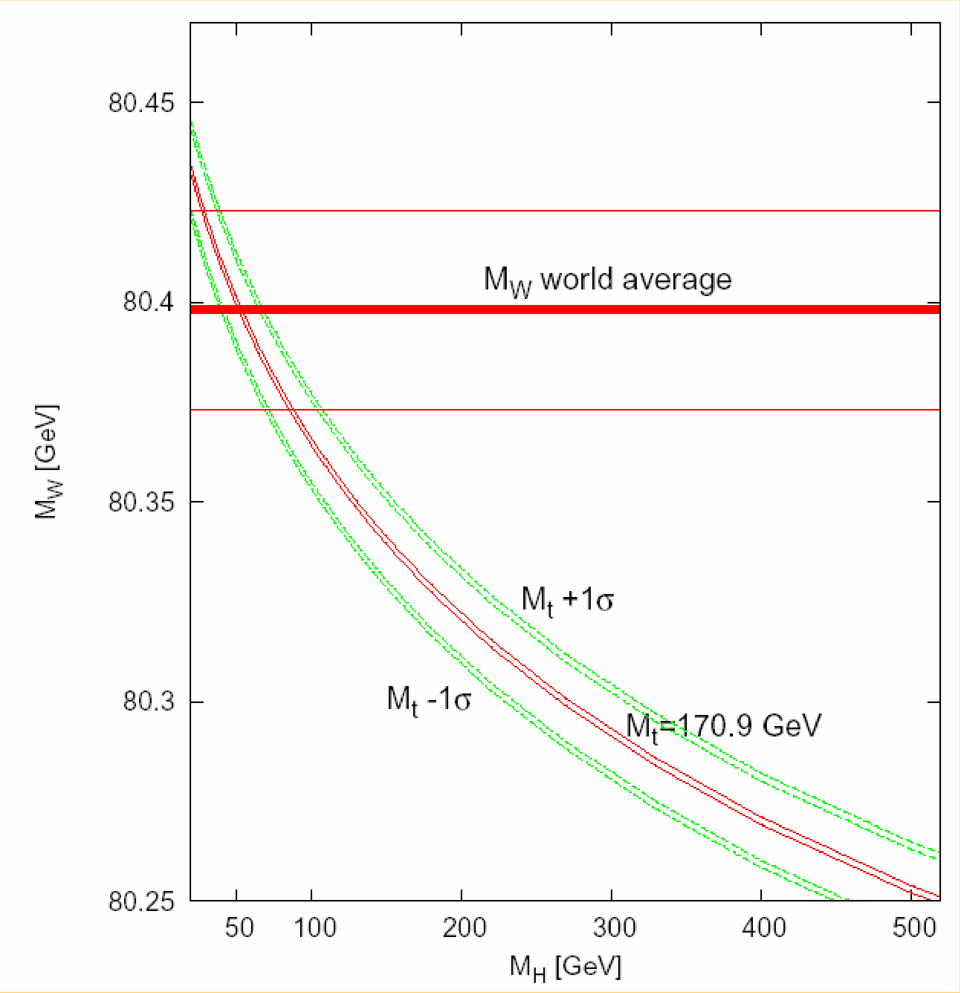
Which mass is being measured? It's time to go to NLO and adopt a well-defined mass that induces small radiative corrections, eg MS $m_t(m_t)$

Pointing to a light Higgs

M_W likes a very light Higgs
Almost too light...

A heavy Higgs can be accomodated by many types of New Physics, ex: 4th generation.
It needs an accidental cancellation we cannot exclude

NB further improvements on m_t will have a more limited effect on M_H constraints



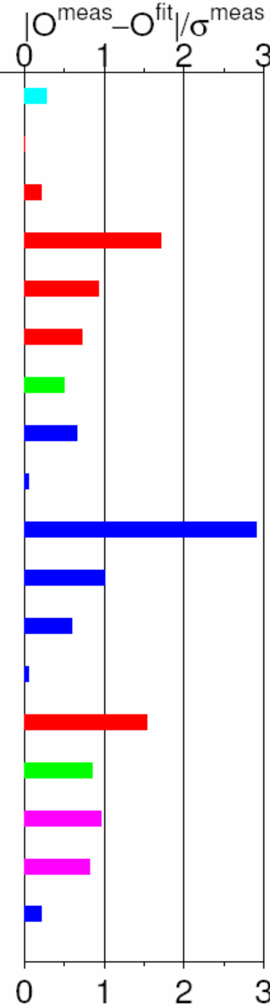
The “global” EWWG fit

M_H^{fit}=76 GeV, M_H<144 GeV at 95%CL
χ^2/dof=18.2/13 15.1% prob

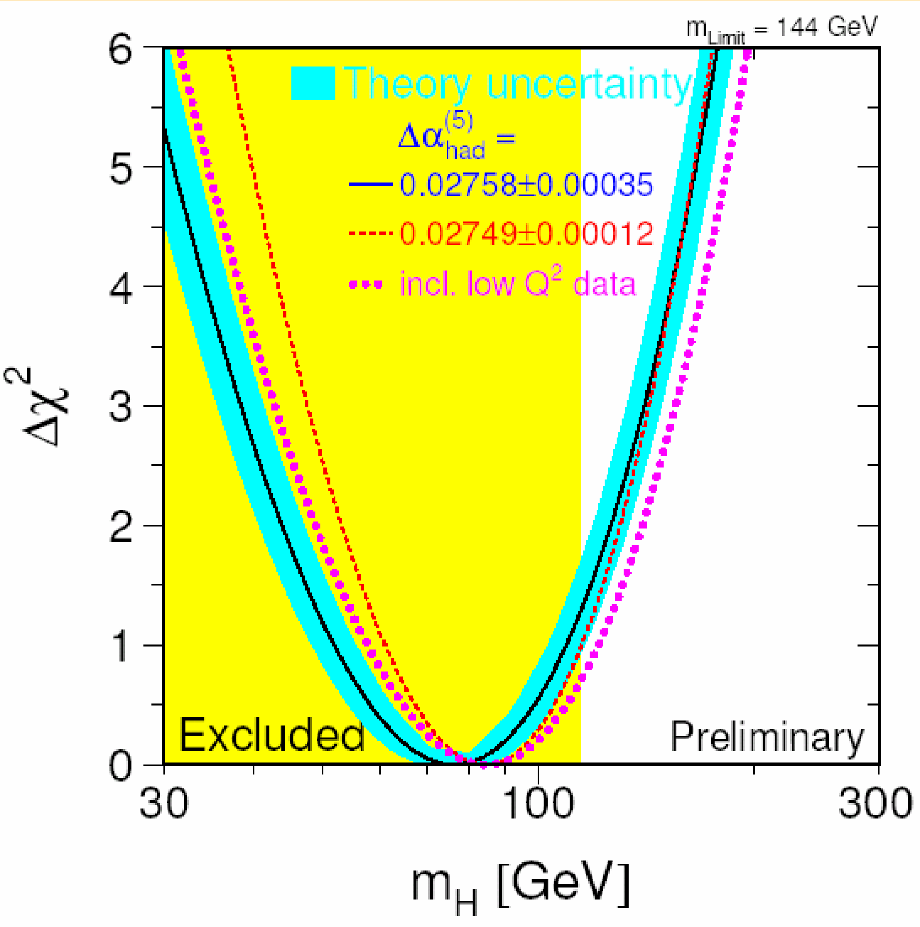
Strong preference for light Higgs, below 150 GeV, even including info from direct searches

OVERALL, SM fares well
(does not include NuTeV, APV, g-2)

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02768
m_Z [GeV]	91.1875 ± 0.0021	91.1875
Γ_Z [GeV]	2.4952 ± 0.0023	2.4957
σ_{had}^0 [nb]	41.540 ± 0.037	41.477
R_l	20.767 ± 0.025	20.744
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01645
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1481
R_b	0.21629 ± 0.00066	0.21586
R_c	0.1721 ± 0.0030	0.1722
$A_{fb}^{0,b}$	0.0992 ± 0.0016	0.1038
$A_{fb}^{0,c}$	0.0707 ± 0.0035	0.0742
A_b	0.923 ± 0.020	0.935
A_c	0.670 ± 0.027	0.668
A_l(SLD)	0.1513 ± 0.0021	0.1481
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.374
Γ_W [GeV]	2.140 ± 0.060	2.091
m_t [GeV]	170.9 ± 1.8	171.3

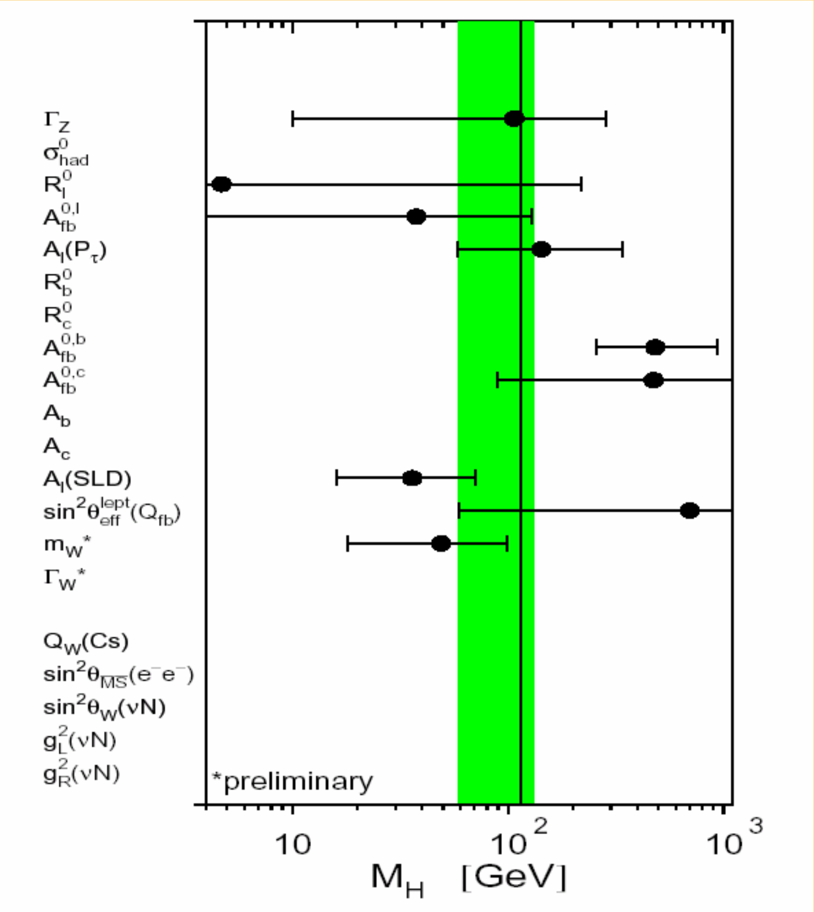


The blue band



LEP-SLD EW Working Group http://lepewwg.web.cern.ch/LEPEWWG

The M_H fit

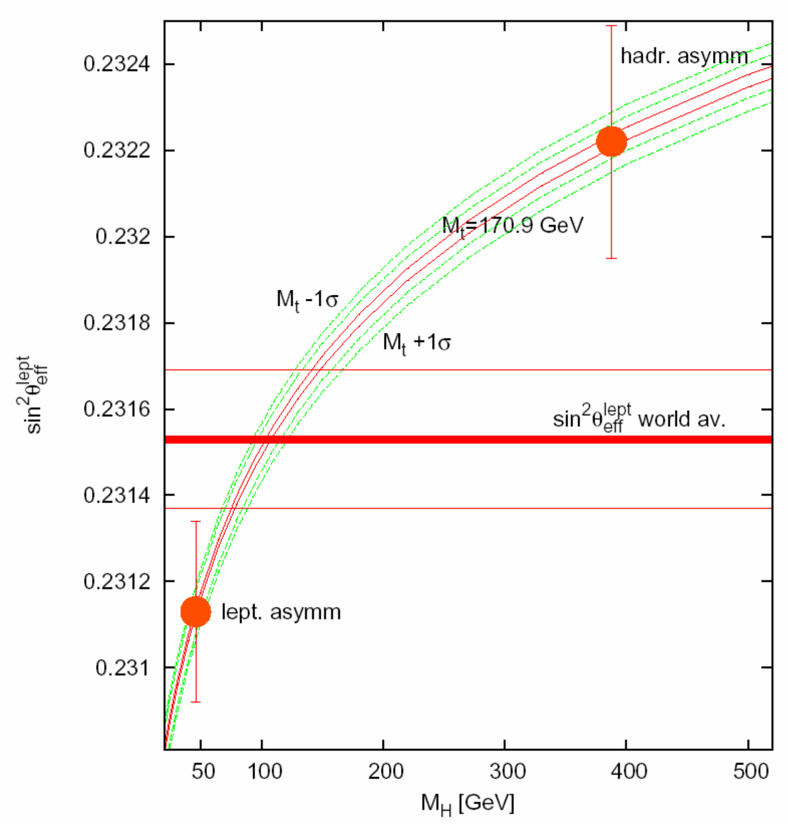


EWWG fits an arbitrary set
no $(g-2)_\mu$, no universality, no $b \to s\gamma$

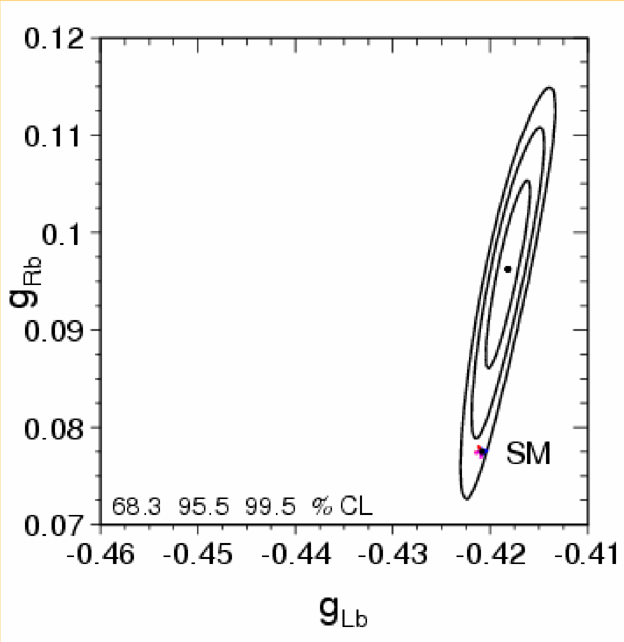
Only a subset of observables
is sensitive to M_H

A fit only to the observables
sensitive to M_H has the
same central value
and much LOWER probability
of about 2%

New physics in the b couplings?



Root of the problem: old ~3σ discrepancy between LR asymmetry of SLD and FB b asymmetry of LEP: in SM they measure the same quantity, $\sin^2\theta^{eff}$ (A_b is practically fixed in SM)



New Physics in the b couplings could explain it, but it should be tree level and such that $|\delta g_R^b| >> |\delta g_L^b|$ Problematic and ad-hoc

Choudhury et al, He-Valencia

The Chanowitz argument

2 possibilities, both involving new physics:

a) $A_{FB}(b)$ points to new physics

b) it's a fluctuation or is due to unknown systematics

without $A_{FB}(b)$, the M_H fit is very good, but in conflict with direct lower bound M_H>114.4 GeV

M_H^{fit}=48 GeV, M_H<97 GeV at 95%CL

with Hagiwara et al for $\Delta\alpha_h$ M_H=44 GeV, M_H<87 GeV at 95%CL

Even worse if $\alpha(M_Z)$ from tau is used

If true, not difficult to find NP that mimics a light Higgs.
Non-trivially, SUSY can do that with light sleptons, tanβ>4

Altarelli et al

Statistically not very strong (<3 σ) but quite intriguing

Precision tests and LHC

* Higgs discovery or disproval remains the first task of LHC. We have growing evidence that the SM Higgs must be <u>very close to the LEP exclusion bound</u>, if it exists. A heavy H can describe data only with new physics (and a *conspiracy)*

* Whatever LHC observes will need to be *understood*: is this the SM Higgs or not? are these heavy charged scalars squarks o KK excitations? The constraints from EWPT enhance significantly the analyzing power for LHC results.

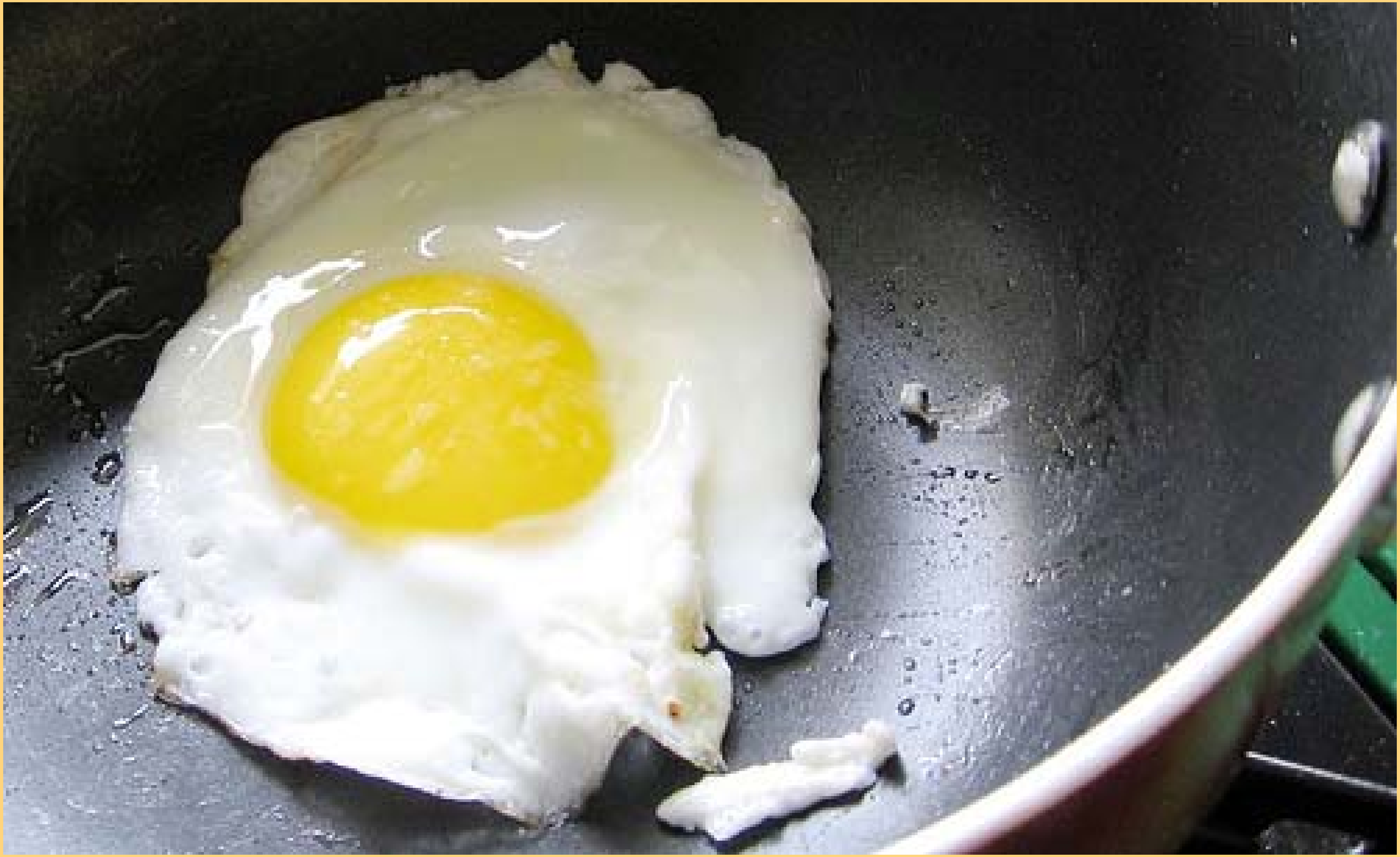
* LHC will also have its own EW program, including the study of Higgs properties (mass, width, couplings), W mass (goal 10 MeV) and width, top mass (probably th limited) and properties, $\sin^2\theta_{eff}^{lept}$ from FB asymmetries, triple gauge couplings.

* Muon g-2 and $A_{FB}(b)$ are puzzling (3σ!) anomalies. Had $A_{FB}(b)$ not been measured, we would face a similar puzzle, with the conflict of direct and indirect M_H determinations.

Cracks in the egg?

Possibility n.1

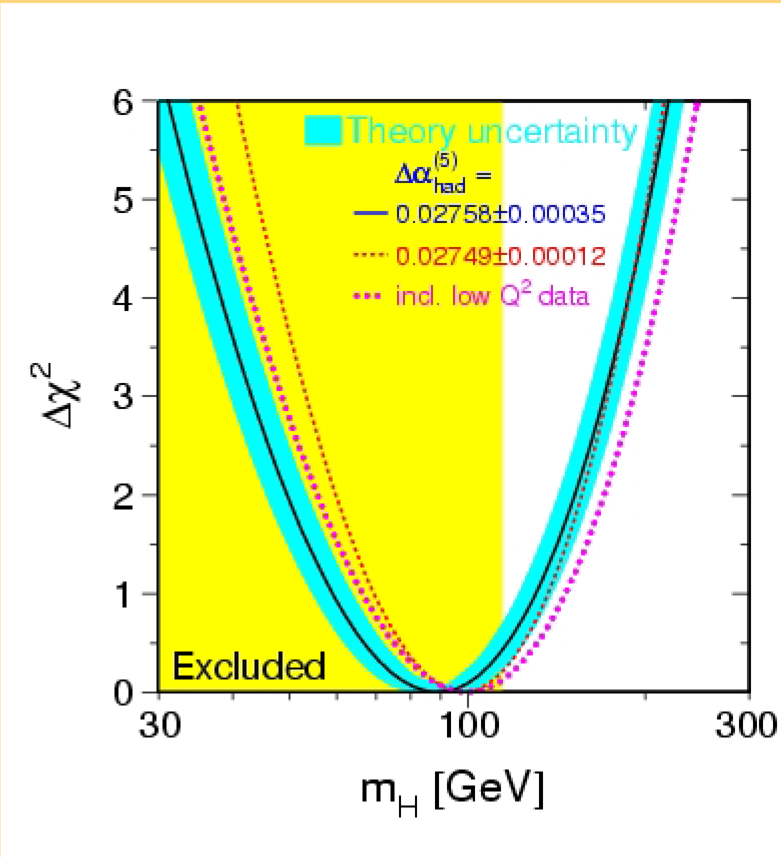
Possibility n.2



We won’t need to wait long for an answer

Overview of precision tests

<u>EWSB</u>: O(0.1%), Λ > 5 TeV (roughly)



<u>Flavor</u>: O(2-10%), Λ > 2 TeV (roughly)

The modern version of Weak Universality