Fermilab, 12 August '08

The Standard Model confronts the LHC

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This course is designed as an introduction to the School
(for the theoretical courses)

The Standard Model confronts the LHC

QCD
G. Zanderighi

Heavy Flavours
M. Neubert

Higgs
H. Haber

Supersymmetry
S. Martin

Extra Dimensions
E. Ponton

Strong Dynamics
R. S. Chivukula

HEP and Cosmology
R. Kolb

Lecture 1

- Status of the SM EW theory, precision tests
- The Higgs problem

Lecture 2

- Status of QCD
- Top quark

Lecture 3

- Problems of the SM
- Motivation for new physics at the TeV scale
- Avenues for new physics

The LHC physics run will soon start, finally.

2008: 10 TeV   2009: 14 TeV

Physics top priorities at the LHC (ATLAS&CMS):

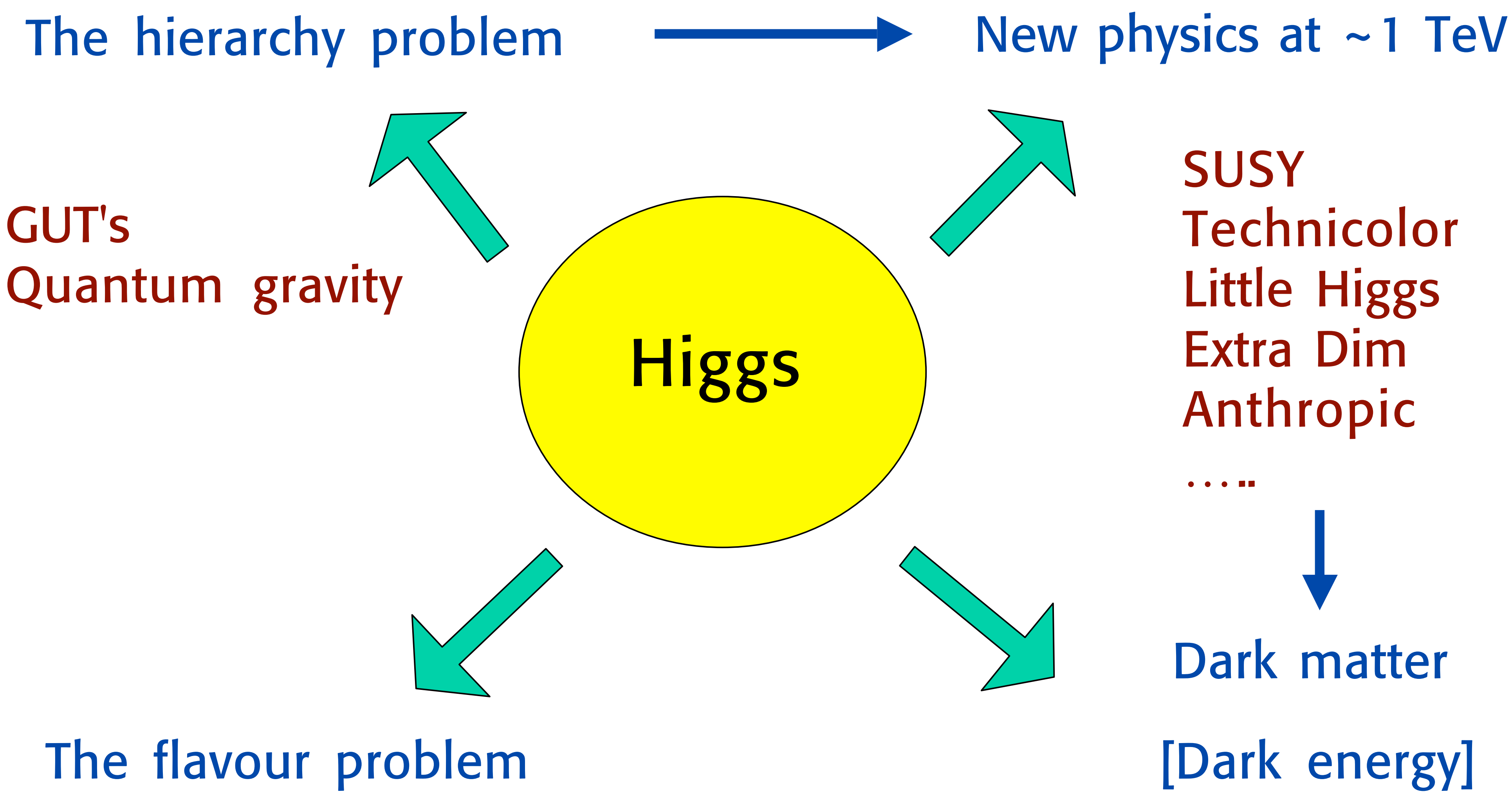
- Clarify the Higgs sector
- Search for new physics at the TeV scale
- Identify the particle(s) that make the Dark Matter in the Universe

Also:

- LHCb: precision B physics (CKM matrix and CP violation)
- ALICE: Heavy ion collisions & QCD phase diagram

At this point, fresh input from experiment is badly needed

The Higgs problem is central in particle physics today



The main problems for the SM show up in the Higgs sector

$$V_{Higgs} = V_0 - \mu^2 \phi^\dagger \phi + \lambda \left(\phi^\dagger \phi\right)^2 + [\bar{\psi}_{Li} Y_{ij} \psi_{Rj} \phi + h.c.]$$

Vacuum energy
$V_{0exp} \sim (2.10^{-3}\ \mathrm{eV})^4$

Origin of quadratic
divergences.
Hierarchy problem

Possible instability
depending on m_H

The flavour problem:
large unexplained ratios
of Y_{ij} Yukawa constants

The Standard EW theory: $\mathcal{L} = \mathcal{L}_{\text{symm}} + \mathcal{L}_{\text{Higgs}}$

$$\mathcal{L}_{symm} = -\frac{1}{4}[\partial_\mu W^A_\nu - \partial_\nu W^A_\mu - ig\varepsilon_{ABC} W^A_\mu W^B_\nu]^2 +$$

$$-\frac{1}{4}[\partial_\mu B_\nu - \partial_\nu B_\mu]^2 +$$

$$+\bar{\psi}\gamma^\mu [i\partial_\mu + gW^A_\mu t^A + g' B_\mu \frac{Y}{2}]\psi$$

$$\mathcal{L}_{Higgs} = |[\partial_\mu - igW^A_\mu t^A - ig' B_\mu \frac{Y}{2}]\phi|^2 +$$

$$+ V[\phi^\dagger \phi] + \bar{\psi}\Gamma\psi\phi + \mathrm{h.c}$$

with $\quad V[\phi^\dagger\phi] = \mu^2(\phi^\dagger\phi)^2 + \lambda(\phi^\dagger\phi)^4$

$\mathcal{L}_{\text{symm}}$: well tested (LEP, SLC, Tevatron…), $\mathcal{L}_{\text{Higgs}}$: ~ untested

All we know from experiment about the SM Higgs:

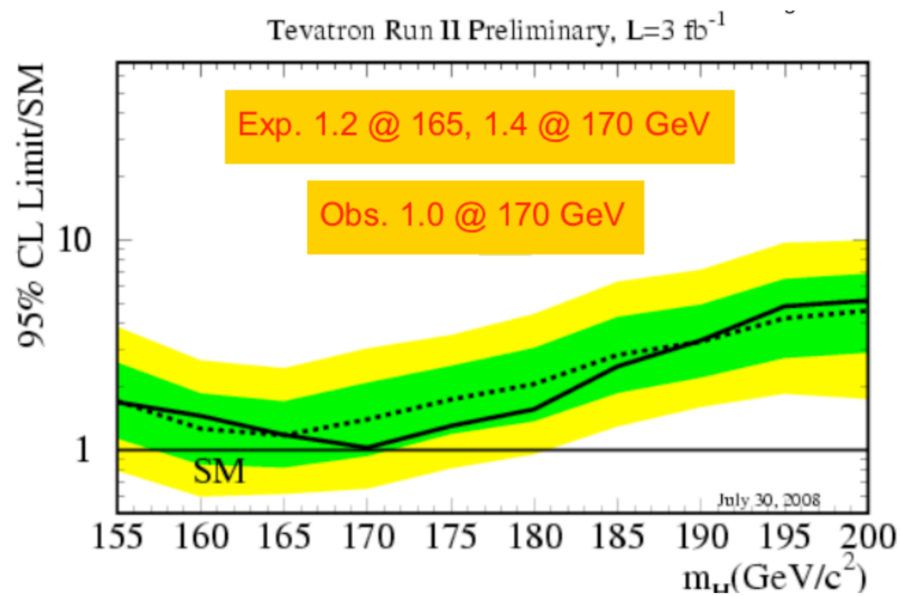
No Higgs seen at LEP2 -> $m_H > 114.4$ GeV (95%cl)

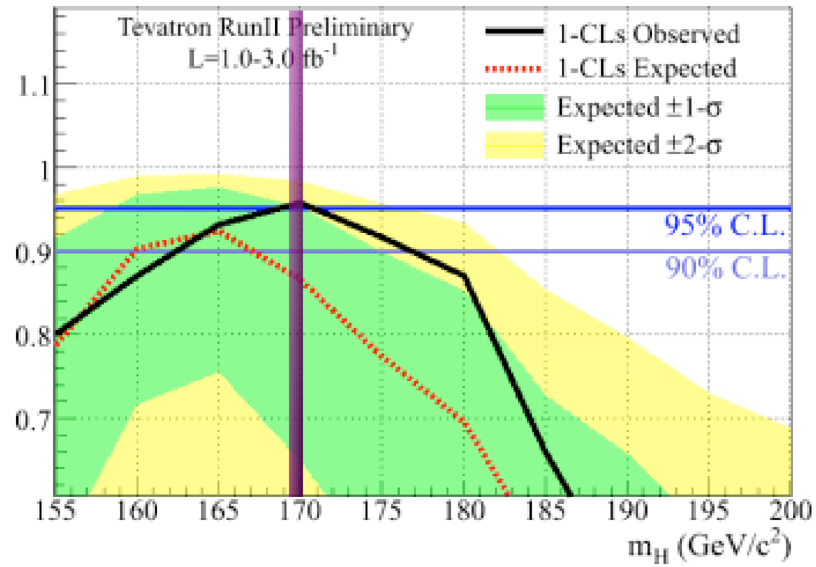
Rad. corr's -> $m_H < 190$ GeV (95%cl, incl. direct search bound)

$v = \langle\phi\rangle = \sim 174$ GeV ; $\quad m_W = m_Z \cos\theta_W$ → doublet Higgs

The Tevatron is reaching the SM sensitivity

Herndon, ICHEP '08





95%CL Limits/SM

M Higgs(GeV)	160	165	170	175
Method 1: Exp	1.3	1.2	1.4	1.7
Method 1: Obs	1.4	1.2	1.0	1.3
Method 2: Exp	1.2	1.1	1.3	1.7
Method 2: Obs	1.3	1.1	0.95	1.2

I quote:

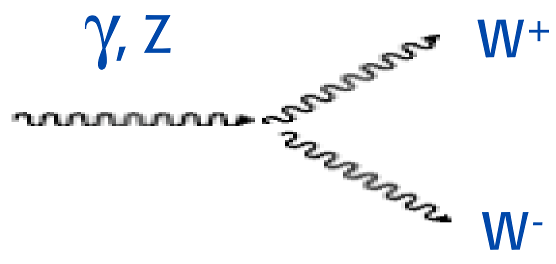
"CDF/D0 exclude at 95% C.L. the production of a SM Higgs boson of 170 GeV"

Experiments prove that all couplings are symmetric

Basic tree level relations: (accuracy few per mil)

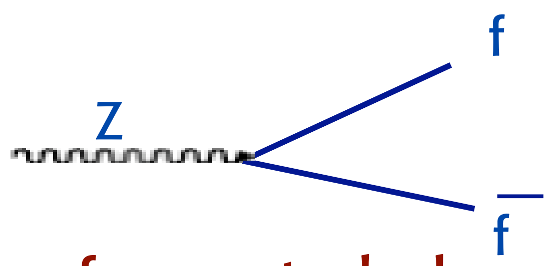
[All corrected by small, computable $f(m_t^2, \log m_H)$ radiative effects]

- $g\sin\theta_W = e$; • $g'/g = tg\theta_W$;
- $\frac{G_F}{\sqrt{2}} = \frac{g^2}{8m_W^2}$;
- $\frac{g_{WW\gamma}}{g_{WWZ}} = tg\theta_W$ →



- $\frac{g}{2\cos\theta_W}\bar{\psi}\gamma_\mu(g_V^f - g_A^f\gamma_5)\psi Z^\mu$

$$\begin{cases} g_A^f = \pm\frac{1}{2} \\ g_V^f/g_A^f = 1-4|Q^f|\sin^2\theta_W \end{cases}$$ →



f = u,c,t, d,s,b, e,μ, τ, ν's

Yet the symmetry is badly broken in the mass spectrum!

Gauge symmetry predicts: All gauge bosons, All fermions } Massless

But $m_W, m_Z >> 0$

In spectrum:
no remnant of even
global SU(2) symmetry!

$m_Z \sim M_{molybdenum\ atom} \sim$ 97 nucleons

Also, for example, m_t (173) and m_b (4.5 GeV) are not 0

Spontaneous symmetry breaking

Currents, charges symmetric. Spectrum totally non symmetric

SSB in gauge theories → Higgs mechanism

That some sort of Higgs mechanism is at work has already been established

The questions are about the nature of the Higgs particle(s)

- One doublet, more doublets, additional singlets?
- SM Higgs or SUSY Higgses
- Fundamental or composite (of fermions, of WW....)
- Pseudo-Goldstone boson of an enlarged symmetry
- A manifestation of extra dimensions (fifth comp. of a gauge boson, an effect of orbifolding or of boundary conditions....)
- Some combination of the above

Suppose we take the gauge symmetric part of the SM and put masses by hand

Gauge invariance is broken explicitly.
We loose understanding of accurate validity of gauge predictions for couplings.

The theory is no more renormalizable, but what is the problem at the LHC scale?

The most immediate disease that needs a solution is the occurrence of unitarity violations in some amplitudes

To avoid this either there is one or more Higgs particles or some new states (e.g. new vector bosons)

Thus something must happen at the few TeV scale!!

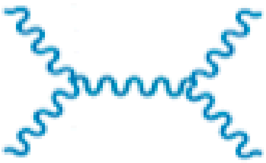
With no Higgs unitarity violations for E_{CM} ~ 1-3 TeV

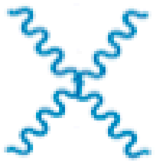
Unitarity implies that scattering amplitudes cannot grow indefinitely with the centre-of-mass energy s

In the SM, the Higgs particle is essential in ensuring that the scattering amplitudes with longitudinal weak bosons (W_L , Z_L) satisfy (tree-level) unitarity constraints
[Veltman, 1977; Lee-Quigg-Thacker, 1977; ...]

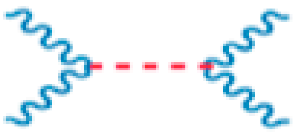
Zwirner

An example: $\mathcal{A}(W_L^+ W_L^- \to Z_L Z_L) \quad (s \gg m_W^2)$





$$i\frac{s}{v^2}$$



$$-i\frac{s^2}{v^2(s-m_h^2)}$$

$$\rightarrow \quad -i\frac{m_h^2}{v^2}\frac{s}{s-m_h^2}$$

If no Higgs then something must happen!

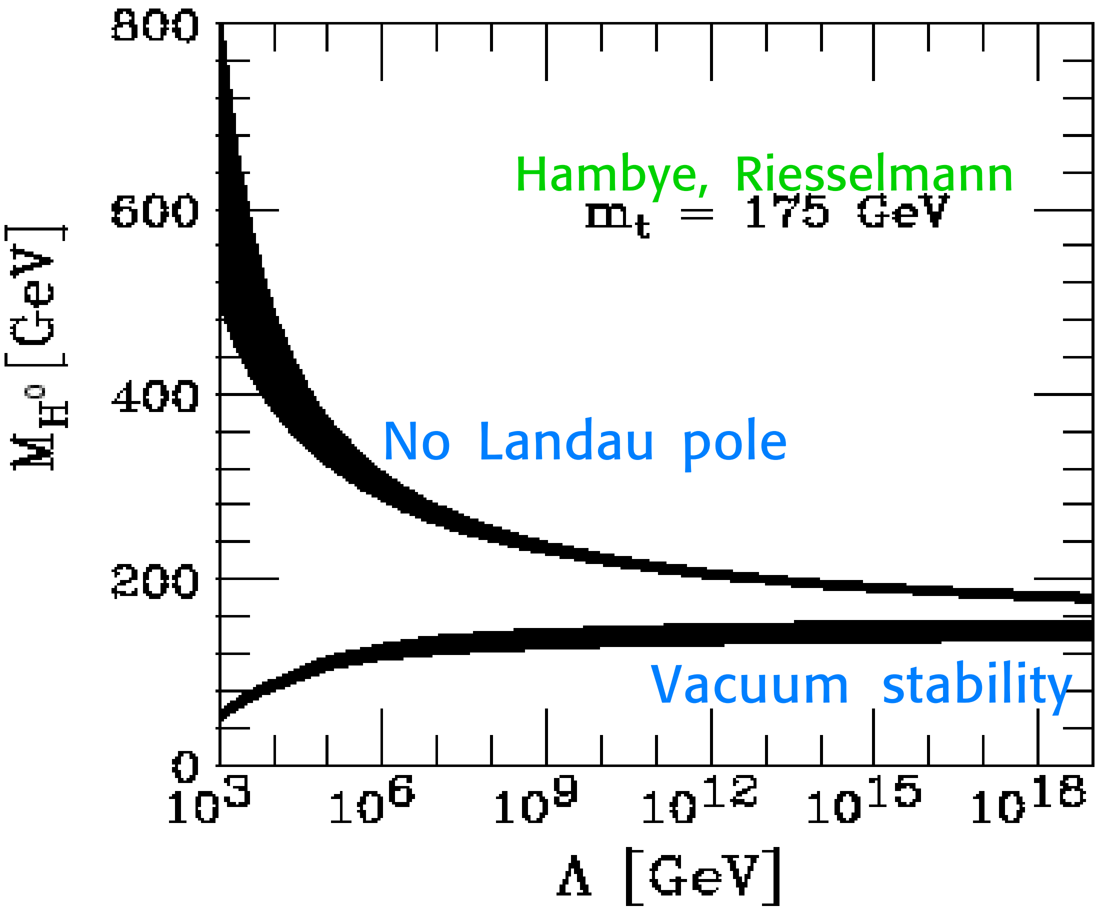
Theoretical bounds on the SM Higgs mass

Λ: scale of new physics beyond the SM

Upper limit: No Landau pole up to Λ

Lower limit: Vacuum (meta)stability

The LHC was designed to cover the whole range



If the SM would be valid up to M_{GUT}, M_{Pl} then m_H would be limited in a small range

Lower now because of m_t → $128\ \text{GeV} < m_H < 180\ \text{GeV}$

Higgs potential

"Wrong" sign

Classic: $V[\phi] = -\mu^2\phi^2 + \lambda\phi^4$ $\quad \mu^2>0,\ \lambda>0$

$$\phi \Rightarrow v + \frac{H}{\sqrt{2}} \quad \Longrightarrow \quad v^2 = \frac{\mu^2}{2\lambda} = \frac{m_H^2}{4\lambda}$$

Quantum loops: $\lambda\phi^4 \Rightarrow \lambda\phi^4\left(1 + \gamma \ln\frac{\phi^2}{\Lambda^2} + \ldots\right) \xrightarrow{\text{RG}} \lambda(\Lambda)\phi'^4(\Lambda)$

(Ren. group improved pert. th)

$$\phi' = [\exp\int\gamma(t)dt]\phi$$

Running coupling

$t = \ln\Lambda/v$ $\quad$ h_t=top Yukawa

$$\frac{d\lambda(t)}{dt} = \beta_\lambda(t) = const[\lambda^2 + 3\lambda h_t^2 - 9h_t^4 + small]$$

Initial conditions (at Λ=v) $\quad \lambda_0 = \frac{m_H^2}{4v^2}$ and $h_{0t} = \frac{m_t}{v}$

Running coupling $t = \ln \Lambda / v$ h_t=top Yukawa

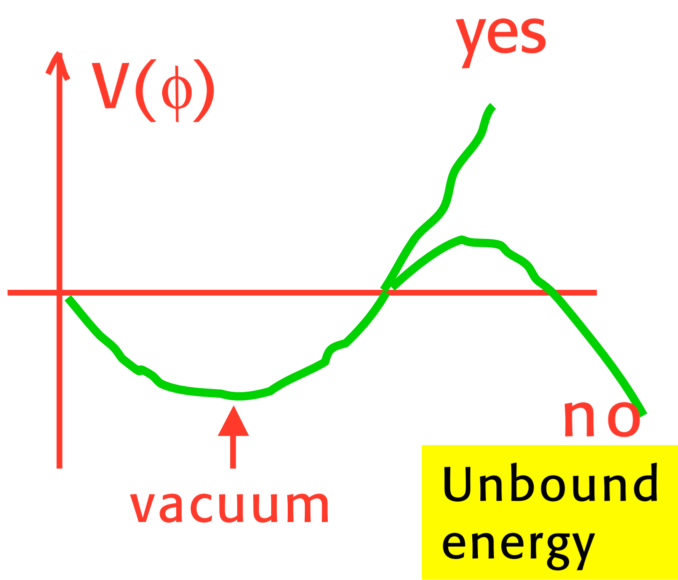
$$\frac{d\lambda(t)}{dt} = \beta_\lambda(t) = const[\lambda^2 + 3\lambda h_t^2 - 9h_t^4 + small]$$

Initial conditions (at Λ=v) $\lambda_0 = \frac{m_H^2}{4v^2}$ and $h_{0t} = \frac{m_t}{v}$

Too small m_H? h_t wins, $\lambda(t)$ decreases.
But $\lambda(t)$ must be >0 below Λ for the vacuum to be stable

⇨ $m_H \geq$ ~130 GeV if $\Lambda \sim M_{GUT}$

(or at least metastable with lifetime $\tau > \tau_{Universe}$)



Cabibbo et al '79.......
Altarelli, Isidori '79

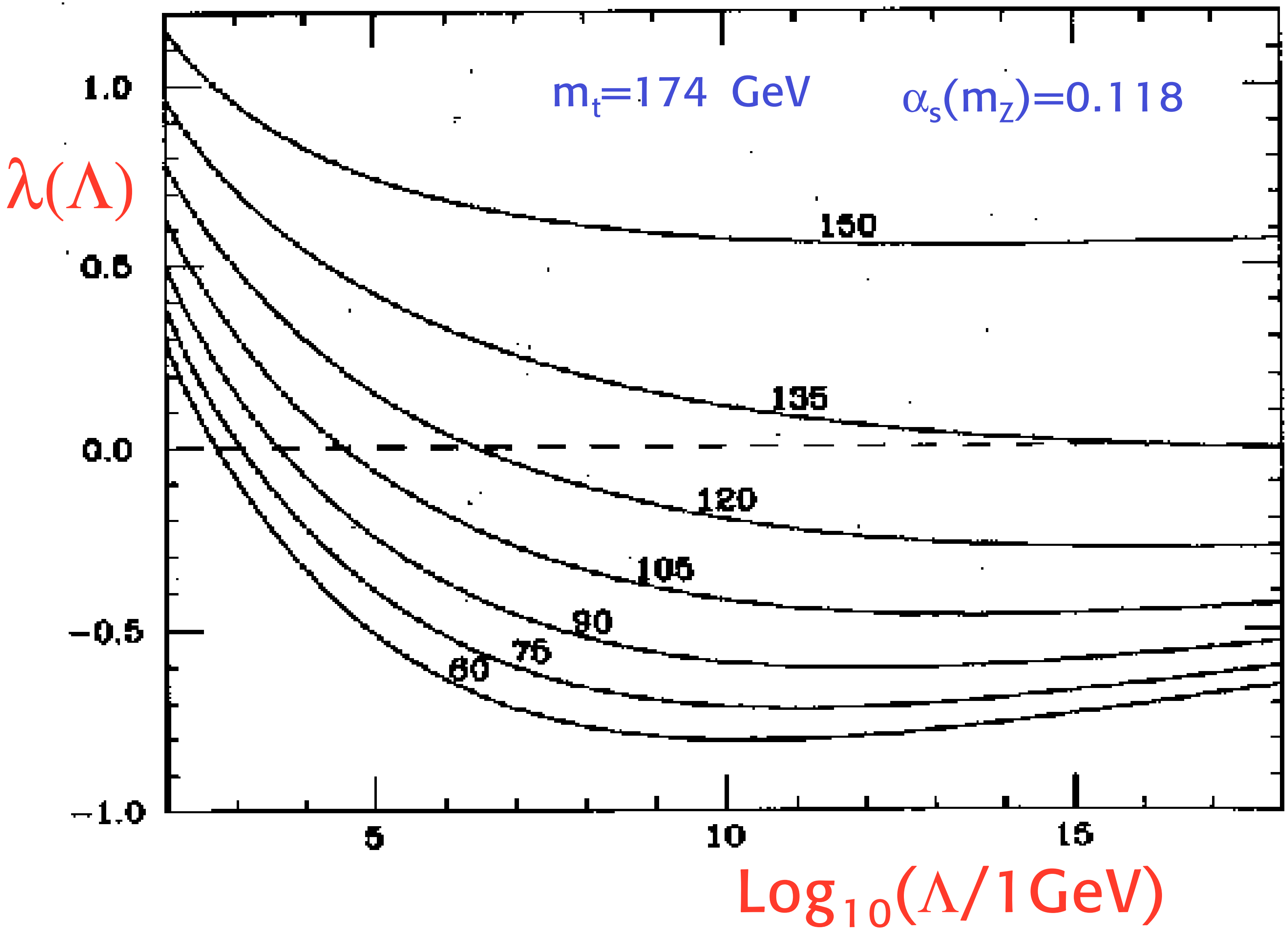
stability $$m_H > 129.5 + 2.1\,[m_t - 171.4] - 4.5\,\frac{\alpha_s(m_Z) - 0.118}{0.006}$$

metastability $$m_H(\mathrm{GeV}) > 117 + 2.9\,[m_t(\mathrm{GeV}) - (175 \pm 2)] - 2.5\left[\frac{\alpha_s(m_Z) - 0.118}{0.002}\right]$$

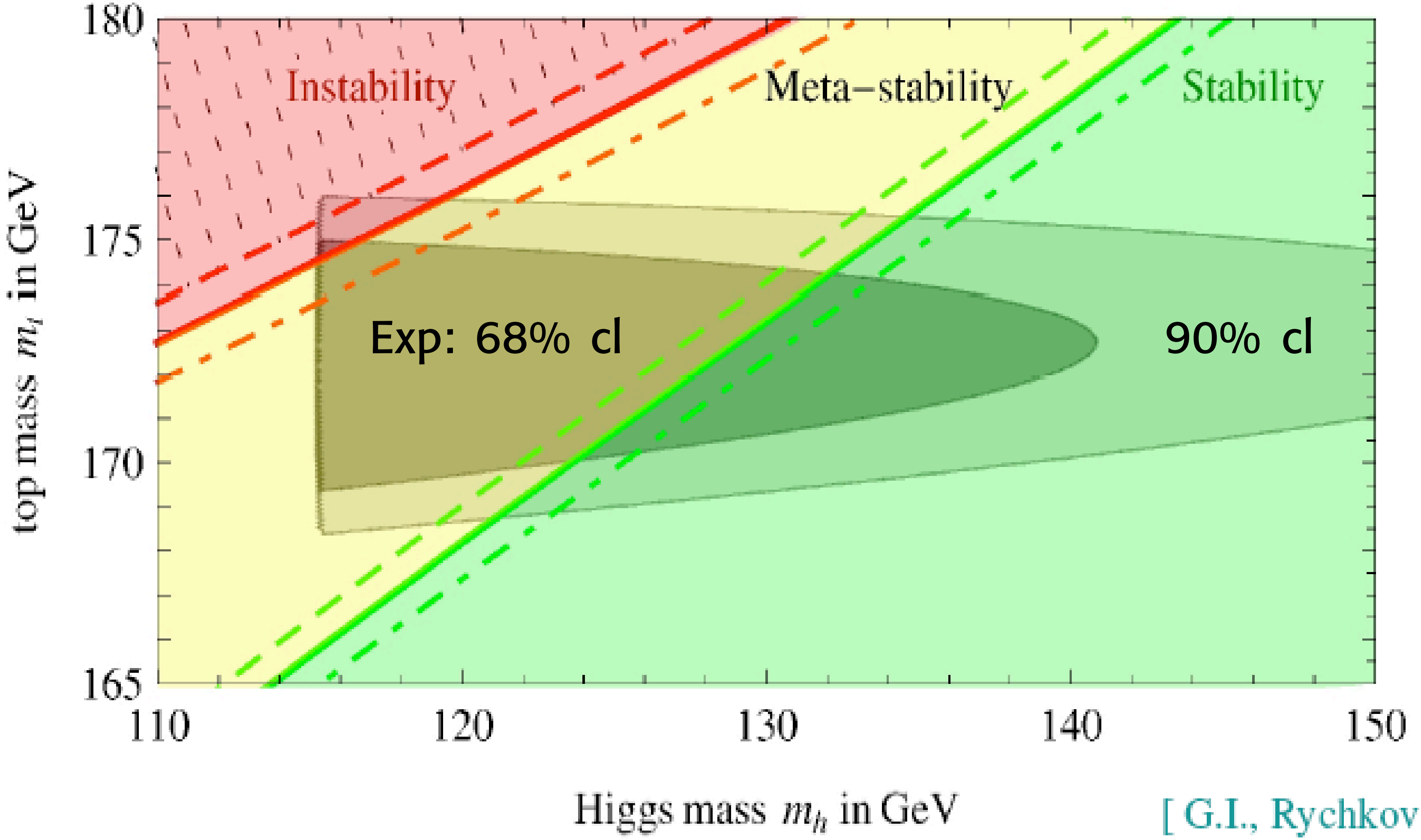
Isidori, Ridolfi, Strumia '01

Condition for stability

Altarelli, Isidori '94



Adding the metastable possibility: Isidori, Ridolfi, Strumia '01



[G.I., Rychkov, Strumia, Tetradis '08]

- The unstable region is almost ruled out

Upper bound (more interesting for the LHC)

h_t=top Yukawa

t=ln Λ/v

$$\frac{d\lambda(t)}{dt} = \beta_\lambda(t) = const[\lambda^2 + 3\lambda h_t^2 - 9h_t^4 + small]$$

b

Initial conditions (at Λ=v) $\lambda_0 = \frac{m_H^2}{4v^2}$ and $h_{0t} = \frac{m_t}{v}$

Too large m_H? λ^2 wins, λ(t) increases.

$$\lambda(t) \sim \frac{\lambda_0}{1 - b\lambda_0 t}$$

Landau pole

The upper limit on m_H is obtained by requiring that no Landau pole occurs below Λ

$m_H \leq$ ~180 GeV if Λ~M_{GUT}

~ 600-800 GeV if Λ~o(TeV)

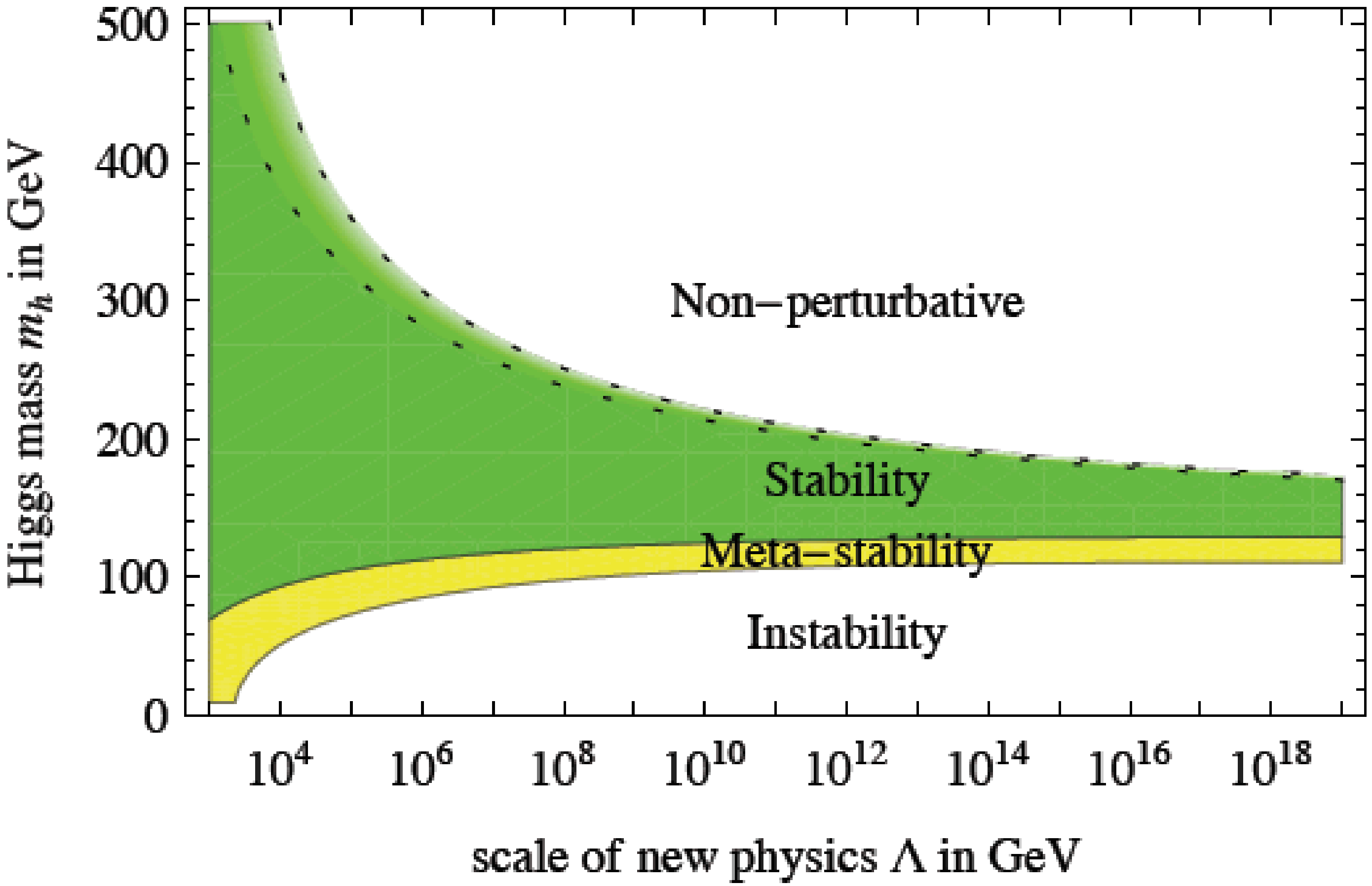
Rather than a bound says where non pert effects are important

Caution: near the pole pert. theory inadequate.
Simulations on the lattice appear to confirm the bound

Kuti et al, Hasenfratz et al, Heller et al

Summarising: in the SM

Isidori, Rychkov, Strumia, Tetradis '08



Precision Tests of SM

The only recent development in this domain is the decrease of the experimental value of m_t from CDF& D0 Run II

The error went also much down!

(Run I value: 178.0±4.3 GeV)

March '08

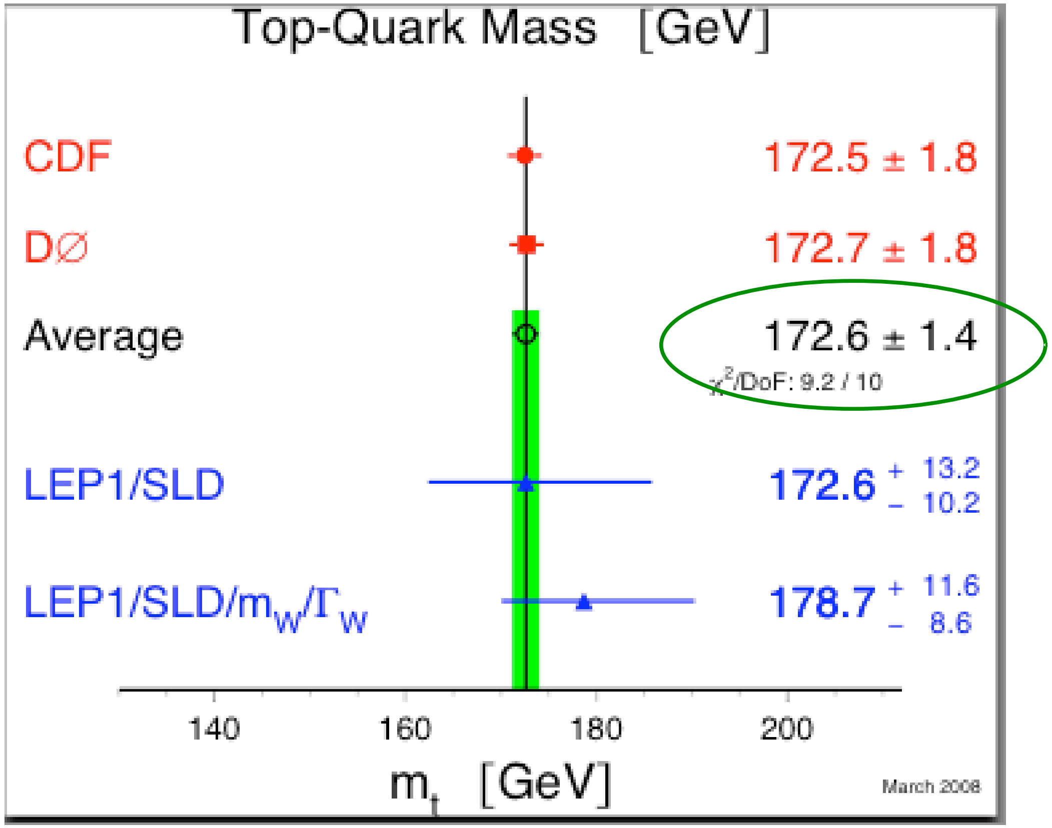
This has a small effect on the quality of the SM fit and on the m_H bounds

m_t ⇓ : m_H ⇓

quality ⇓

Summer'08

ICHEP'08: 172.4±1.2 GeV



Overall the EW precision tests support the SM and a light Higgs.

The χ^2 is reasonable:

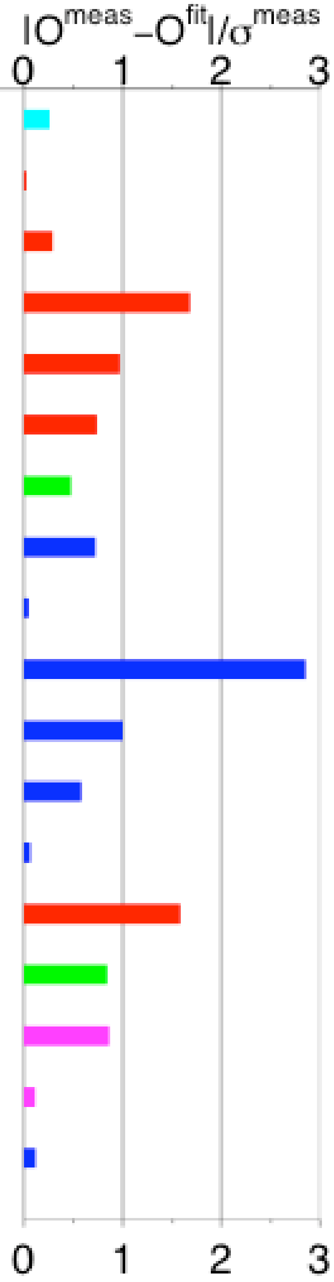
χ^2/ndof~17.2/13 (~19%)

Note: does not include NuTeV, APV, Moeller and $(g\text{-}2)_\mu$

a_μ ~3σ deviation?

March '08

	Measurement	Fit
$\Delta\alpha_{had}^{(5)}(m_Z)$	0.02758 ± 0.00035	0.02767
m_Z [GeV]	91.1875 ± 0.0021	91.1874
Γ_Z [GeV]	2.4952 ± 0.0023	2.4959
σ_{had}^0 [nb]	41.540 ± 0.037	41.478
R_l	20.767 ± 0.025	20.743
$A_{fb}^{0,l}$	0.01714 ± 0.00095	0.01643
$A_l(P_\tau)$	0.1465 ± 0.0032	0.1480
R_b	0.21629 ± 0.00066	0.21581
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	0.1480
$\sin^2\theta_{eff}^{lept}(Q_{fb})$	0.2324 ± 0.0012	0.2314
m_W [GeV]	80.398 ± 0.025	80.377
Γ_W [GeV]	2.097 ± 0.048	2.092
m_t [GeV]	172.6 ± 1.4	172.8



March 2008

Electron g-2: A recent measurement

Odom, Hanneke, D'Urso, Gabrielse '06

$a_e = (g-2)/2 = 11596521808.5(7.6)\ 10^{-13}$

$$\frac{g}{2} = 1 + C_2\left(\frac{\alpha}{\pi}\right) + C_4\left(\frac{\alpha}{\pi}\right)^2 + C_6\left(\frac{\alpha}{\pi}\right)^3 + C_8\left(\frac{\alpha}{\pi}\right)^4 + \ldots$$

$$+ a_{\mu\tau} + a_{\text{hadronic}} + a_{\text{weak}},$$

δa_h small

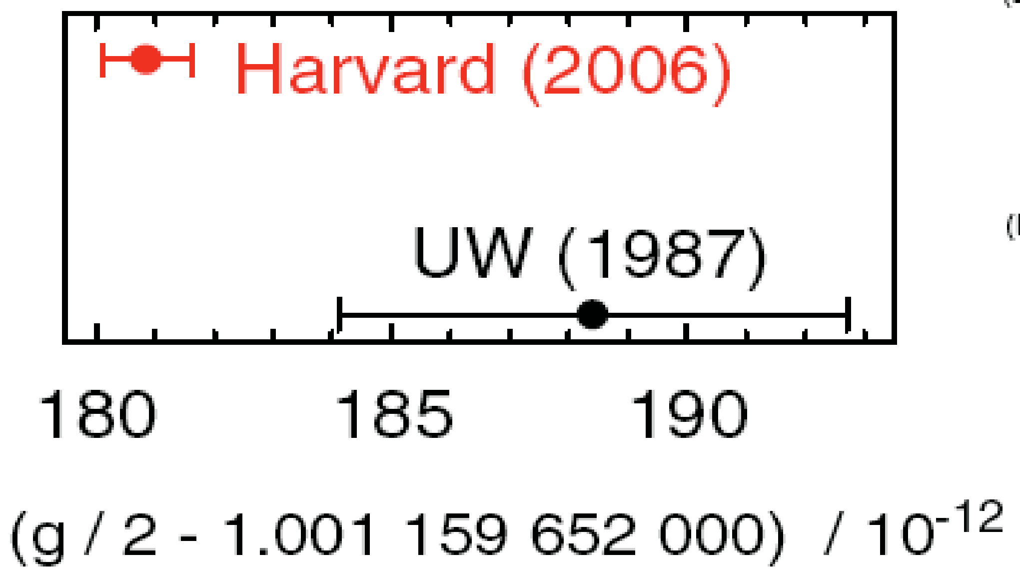
Best determination of α_{QED}

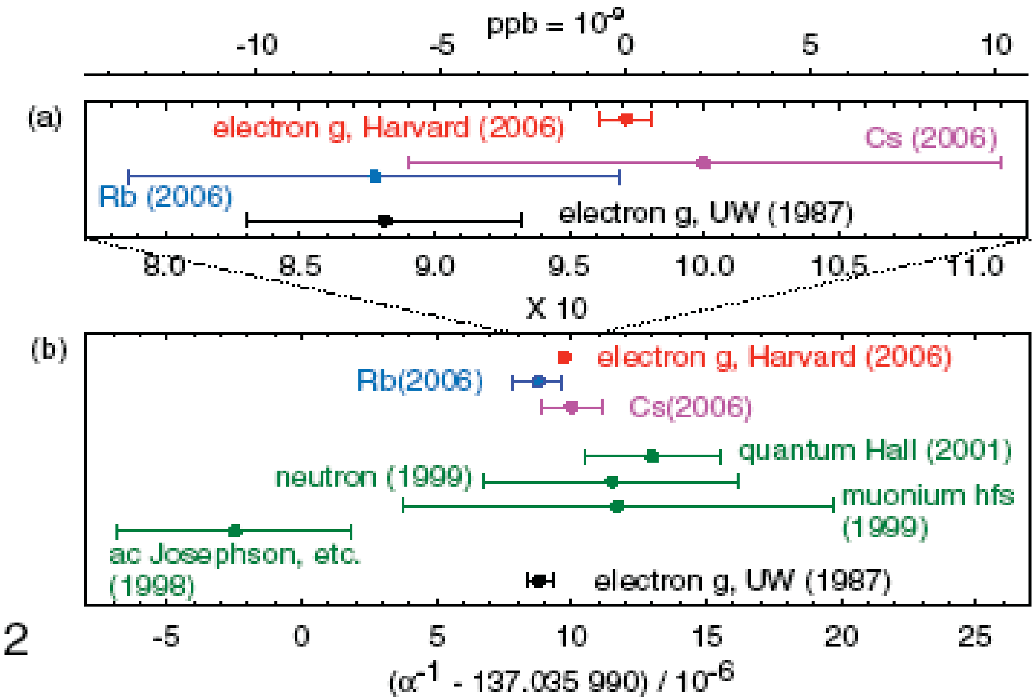
$\alpha^{-1} = 137.035999070(98)$

Value given in Aoyama et al '07, after a theory error was corrected

$$a(\text{hadron}) = 1.671\,(19) \times 10^{-12}$$

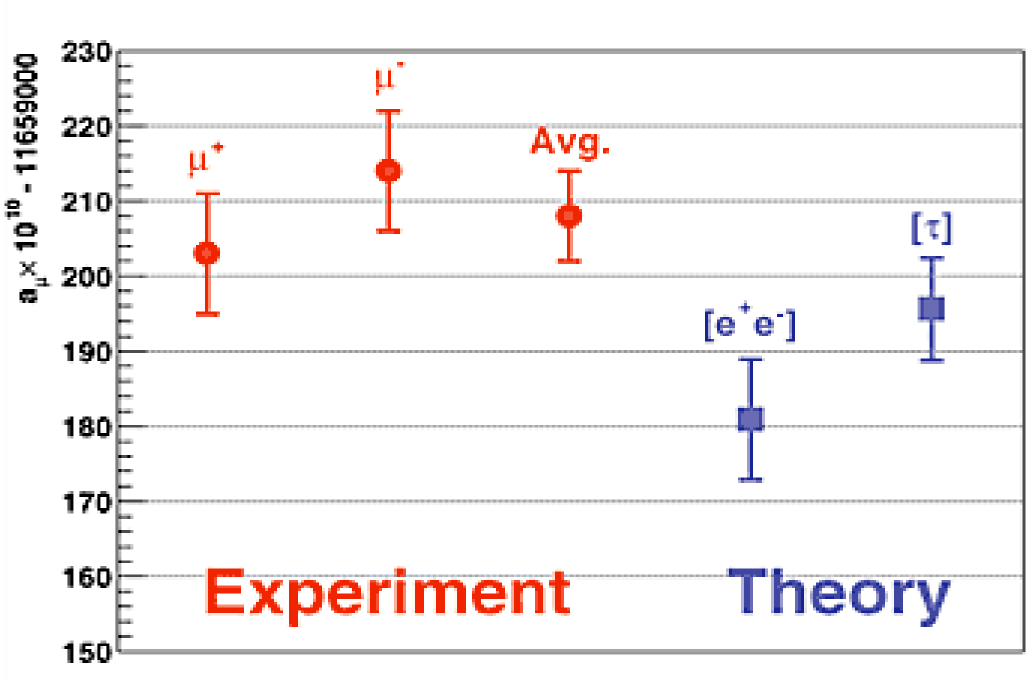
$$a(\text{weak}) = 0.030\,(01) \times 10^{-12}$$



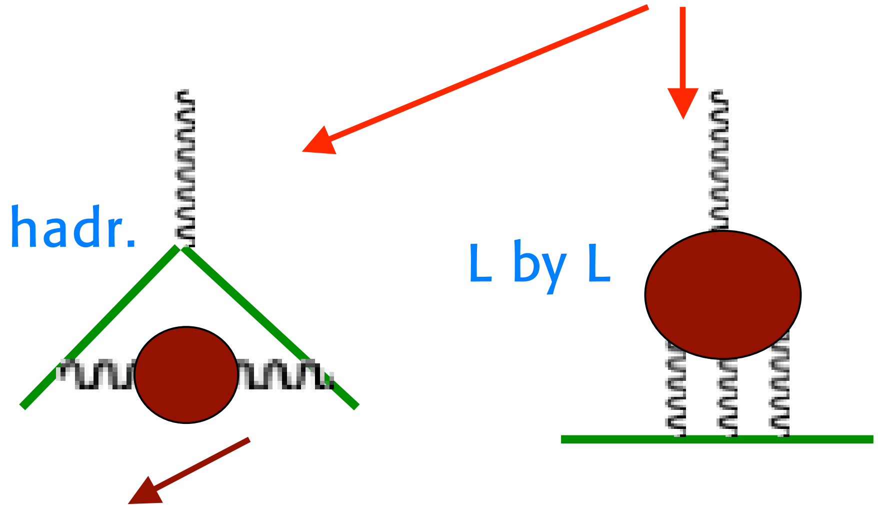


Muon g-2: more sensitive to new physics by $(m_\mu/m_e)^2 \sim 2\ 10^4$

BNL '04-'06: $a_\mu = (11659208.0 \pm 6.3)\ 10^{-10}$



$$a_\mu^{\mathrm{SM}} = a_\mu^{\mathrm{QED}} + a_\mu^{\mathrm{EW}} + a_\mu^{\mathrm{had}}$$



$$a_\mu^{\mathrm{had,LO}} = \left(\frac{\alpha m_\mu}{3\pi}\right)^2 \int_{4m_\pi^2}^{\infty} ds\, \frac{R(s)\, K(s)}{s^2},$$

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

From the latest value of a_e (G. Gabrielse et al., 2006):
$\alpha^{-1} = 137.035999710(96)$,
$a_\mu^{\rm QED} = (116584718.09 \pm 0.14 \pm 0.08) \cdot 10^{-11}$.

Eidelmann, ICHEP'06

Contribution	$a_\mu, 10^{-10}$
Experiment	11659208.0 ± 6.3
QED	11658471.94 ± 0.14
Electroweak	$15.4 \pm 0.1 \pm 0.2$
Hadronic	693.1 ± 5.6
Theory	11659180.5 ± 5.6
Exp.–Theory	27.5 ± 8.4 (3.3σ)

Mostly VP-LO
VP-NLO = -9.8±0.1
LbyL = 12.0±3.5

Knecht, Nyffeler'02
Melnikov, Veinshtein'04
Davier, Marciano '04

'07: 29.5±8.8 (3.4σ) Hertzog et al '07

New e^+e^- Data Based Calculation of $a_\mu^{\rm had,LO}$

$\sqrt{s}$, GeV	$a_\mu^{\rm had,LO}, 10^{-10}$	$\delta a_\mu^{\rm had,LO}$, %
2π	$504.6 \pm 3.1 \pm 1.0$	73.0
ω	$38.0 \pm 1.0 \pm 0.3$	5.5
ϕ	$35.7 \pm 0.8 \pm 0.2$	5.2
$0.6 - 1.8$	$54.2 \pm 1.9 \pm 0.4$	7.8
$1.8 - 5.0$	$41.1 \pm 0.6 \pm 0.0$	6.0
$J/\psi, \psi'$	$7.4 \pm 0.4 \pm 0.0$	1.1
> 5.0	$9.9 \pm 0.2 \pm 0.0$	1.4
Total	$690.9 \pm 3.9_{\rm exp} \pm 1.9_{\rm rad} \pm 0.7_{\rm QCD}$	100.0

Higher accuracy of e^+e^- data: the $a_\mu^{\rm had,LO}$ error is 4.4 (0.63%) compared to 15.3 of EJ, 1995 and 7.2 of DEHZ, 2003!

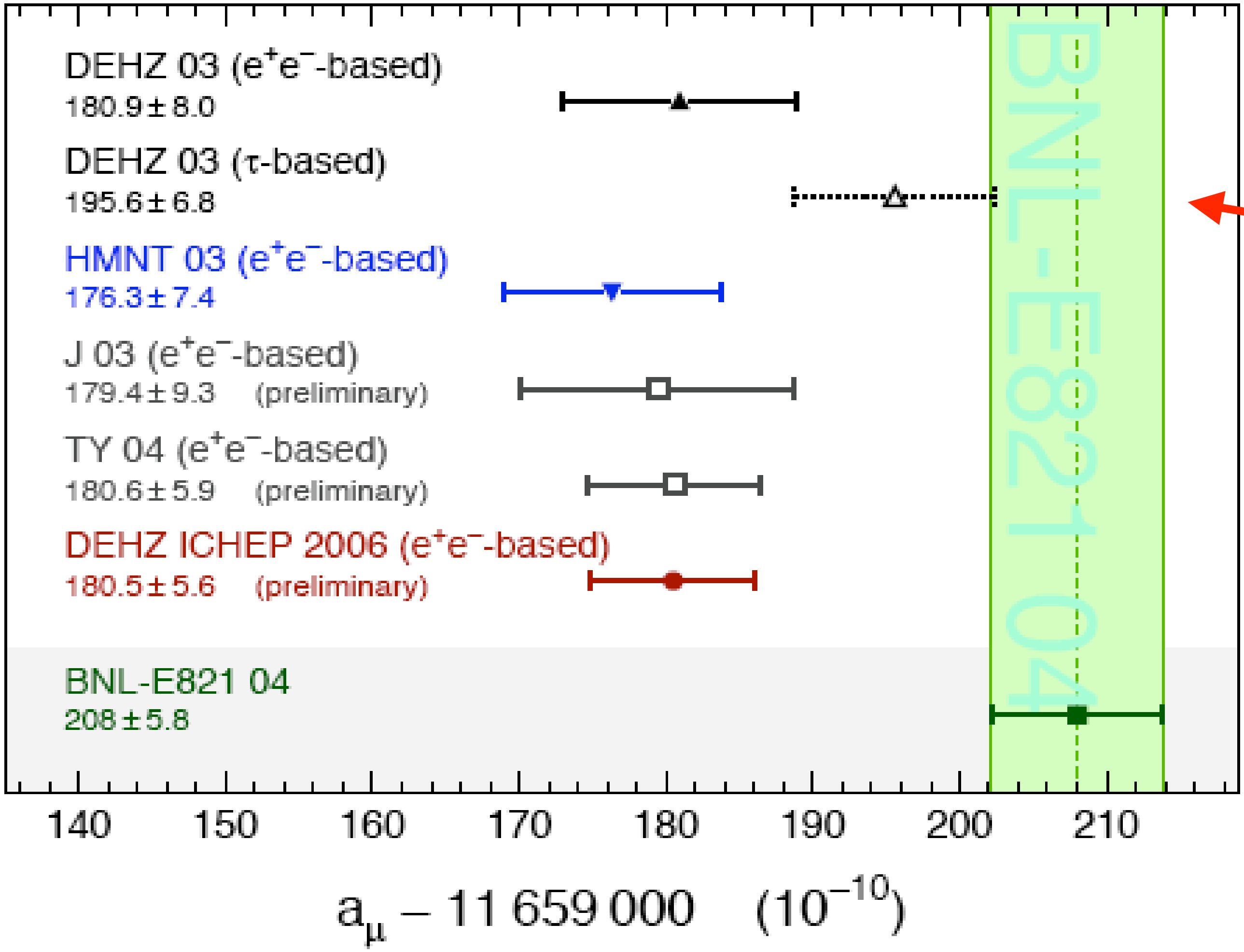
From e+e- data: ~3.3 σ

Observed Difference with Experiment:

$$a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (27.5 \pm 8.4) \times 10^{-10}$$

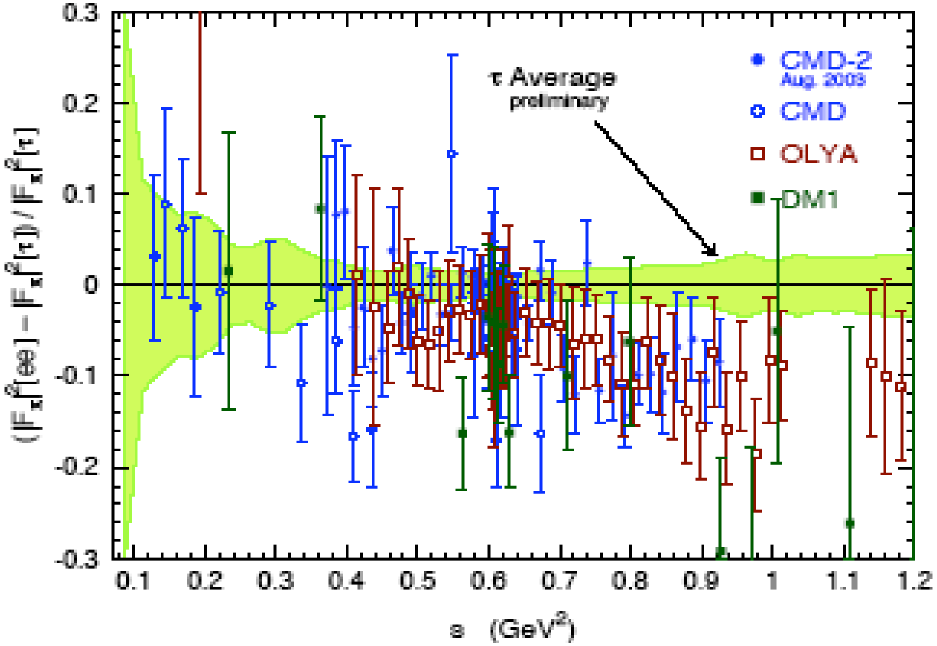
➡ 3.3 "standard deviations"

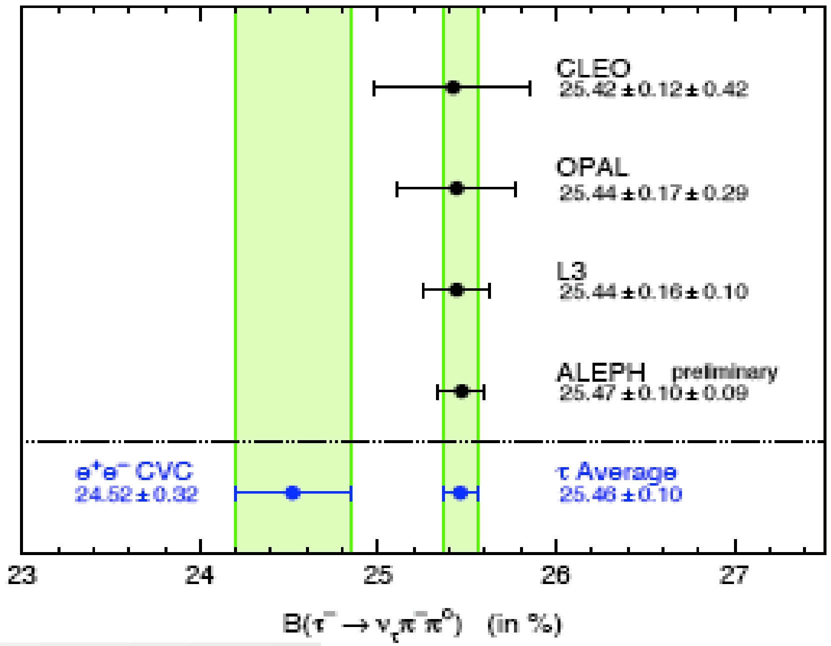
Davier/Hocker



Hadronic contr. from data.
τ vs e+e- discrepancy

CVC in the 2π Channel. e^+e^- vs. τ





Difference: BR[τ] – BR[e^+e^- (cvc)]:

Mode	$\Delta(\tau - e^+e^-)$	"Sigma"
$\tau^- \to \pi^- \pi^0 \nu_\tau$	$+0.92 \pm 0.21$	4.5
$\tau^- \to \pi^- 3\pi^0 \nu_\tau$	-0.08 ± 0.11	0.7
$\tau^- \to 2\pi^- \pi^+ \pi^0 \nu_\tau$	$+0.91 \pm 0.25$	3.6

e^+e^- data on $\pi^-\pi^+\pi^0\pi^0$ not satisfactory

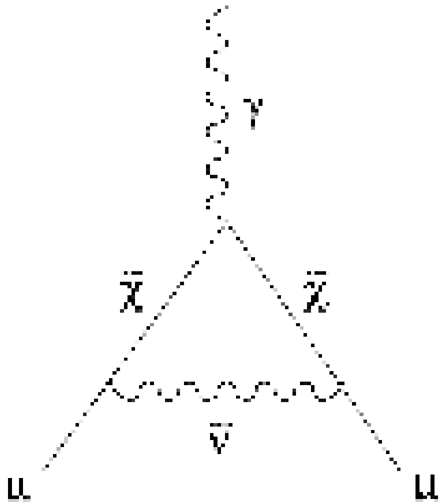
Observed Difference with Experiment:

$$a_\mu^{exp} - a_\mu^{SM} = (27.5 \pm 8.4) \times 10^{-10}$$

➡ 3.3 "standard deviations"

Could be new physics
eg light SUSY

$$\delta a_\mu = 13 \cdot 10^{-10} \left(\frac{100 GeV}{M_{SUSY}} \right)^2 tg\beta$$



a_μ is a plausible
location for a
new physics signal!!

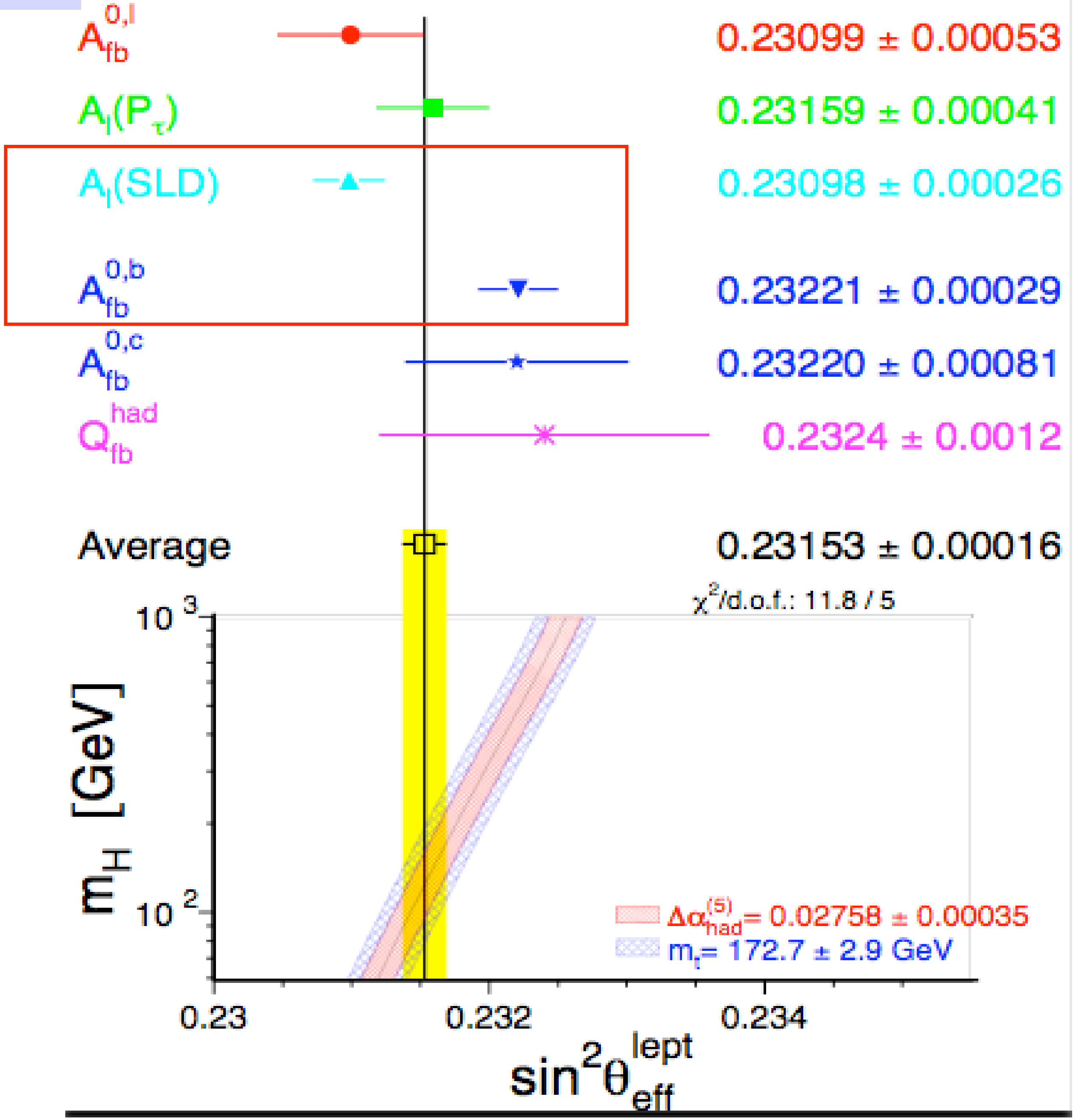
But the e-τ discrepancy is not understood:
theoretical errors underestimated?

Large Q^2 precision tests

$\sin^2\theta_W$

The two most precise measurements
do not really match!

This unfortunate fact makes the interpretation of precision tests less sharp.



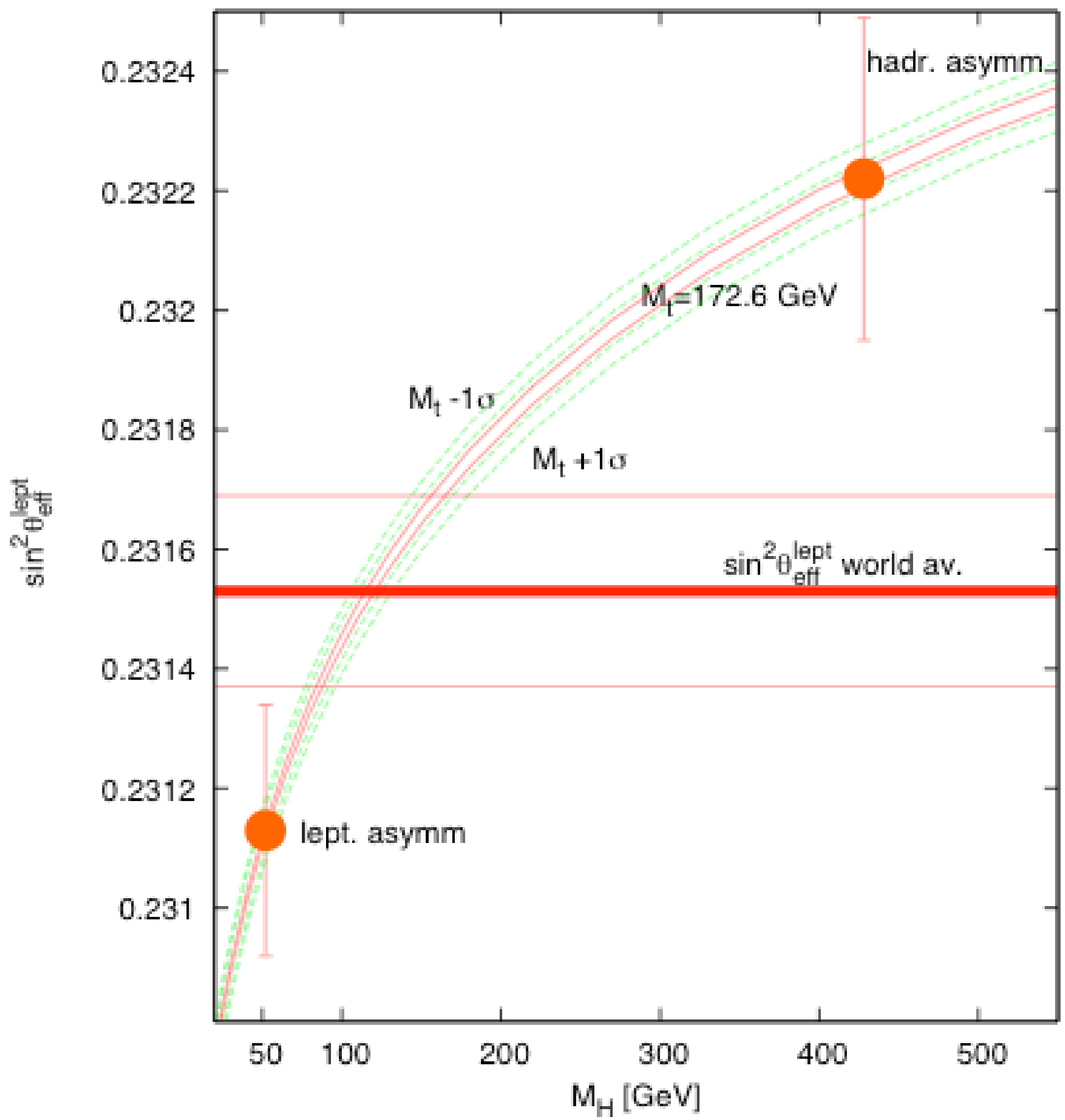
P. Gambino

Plot $\sin^2\theta_{eff}$ vs m_H

Exp. values are plotted at the m_H point that better fits given m_{texp}

Clearly leptonic and hadronic asymm.s push m_H towards different values

$\sin^2\theta_{eff}$



A^b_{FB} vs $[\sin^2\theta]_{lept}$: New physics in Zbb vertex?

After all the 3rd generation is somewhat special

The difficulty is that:

- No deviations are seen in A_b (SLD) and R_b
- A quite large shift in g_R, the Zbb right-handed coupling is needed (by ~30%: a tree level effect)

$$A^b_{FB} = \frac{3}{4} A_e A_b \qquad A_f = \frac{g_L^2 - g_R^2}{g_L^2 + g_R^2}$$

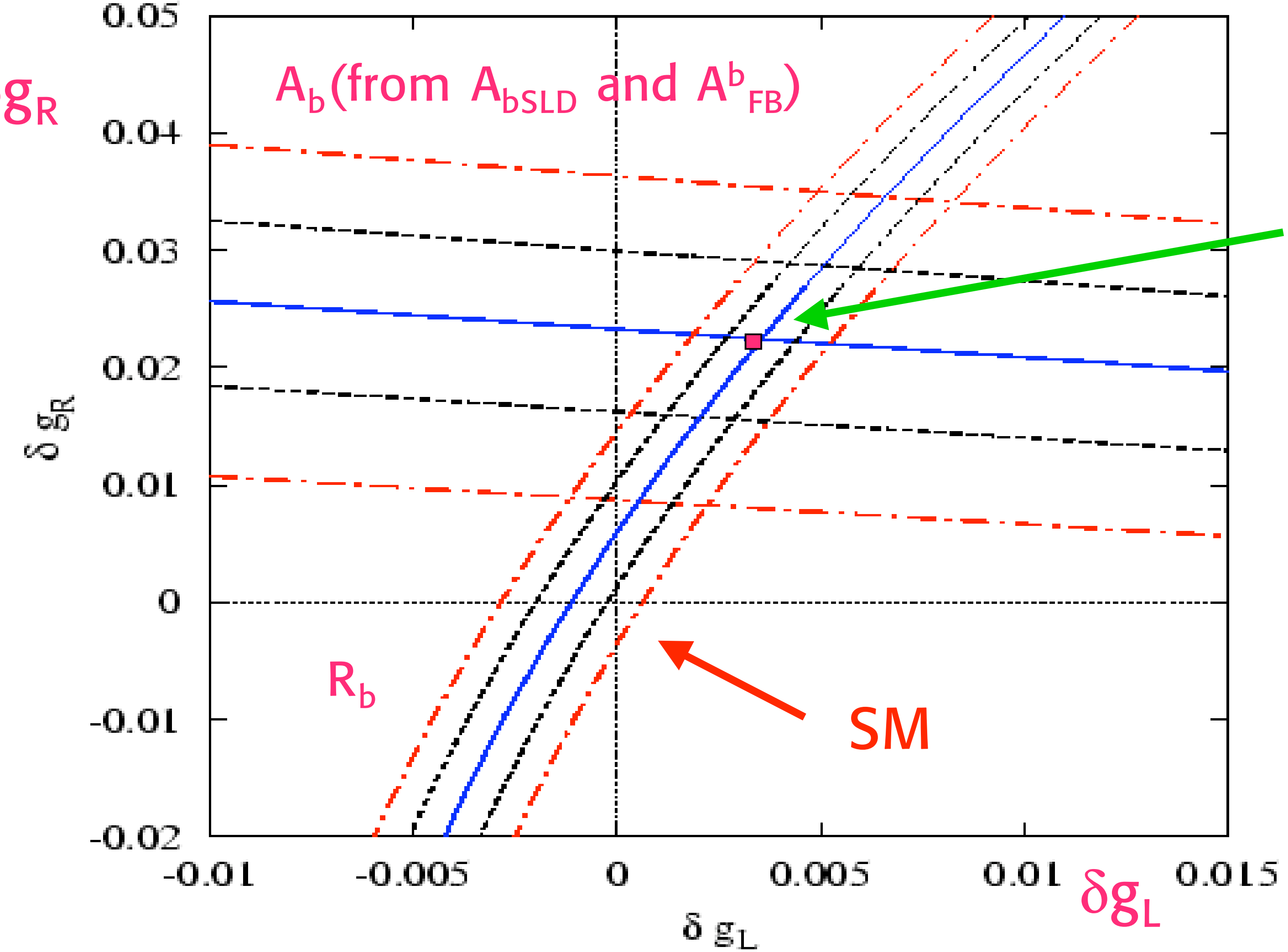
SM: $g_L^2 \approx 0.72 >> g_R^2 \approx 0.02$

$$(A_b)_{SM} \approx 0.936$$

from A^b_{FB} → $(A_b)_{SM} - A_b = 0.055 \pm 0.018$ -> ~3 σ

But note: $(A_b)_{SLD} = 0.923 \pm 0.020$,

also $R_b = 0.21629 \pm 0.00066$ ($R_{bSM} \sim 0.2157$) ← $R_b \sim g_L^2 + g_R^2$



Choudhury, Tait, Wagner '01

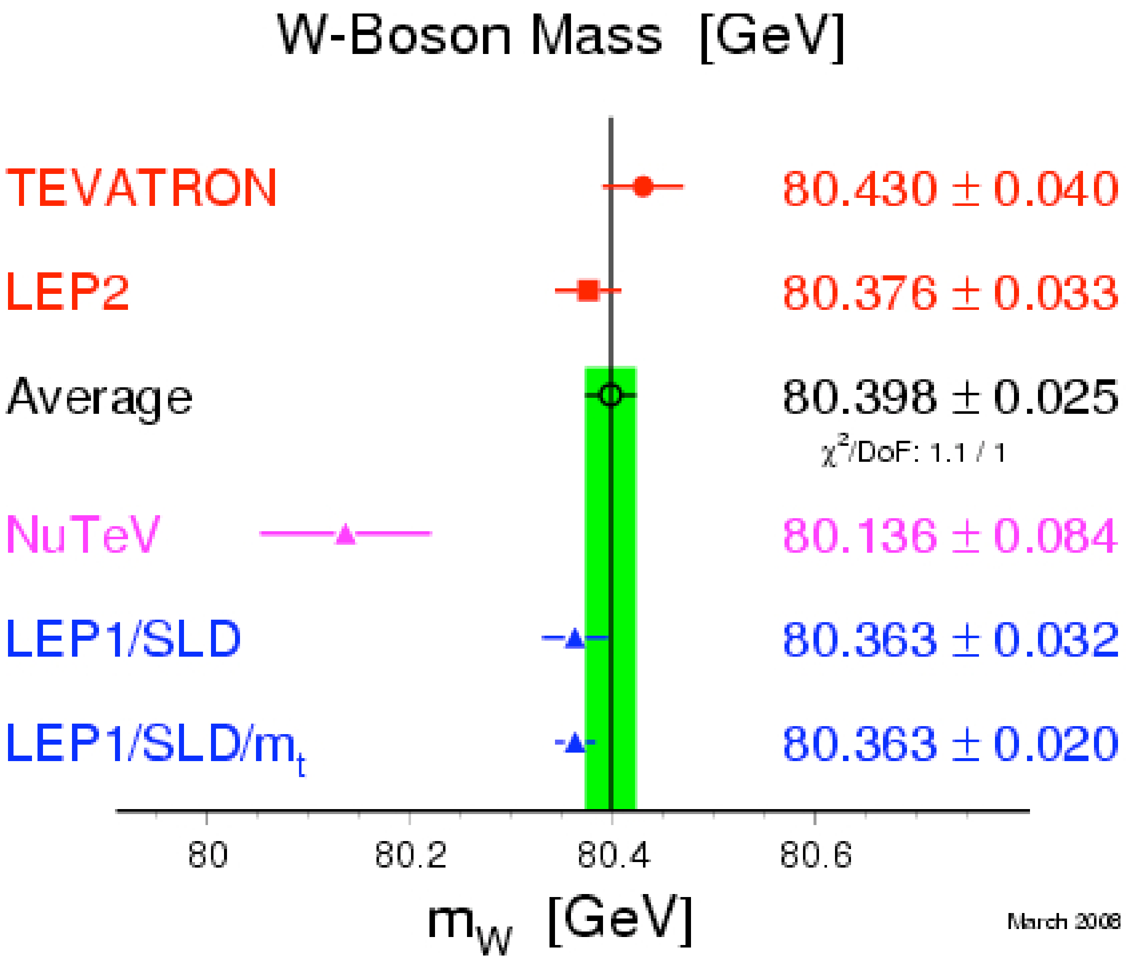
0.992 g_L(SM), 1.26 g_R(SM)

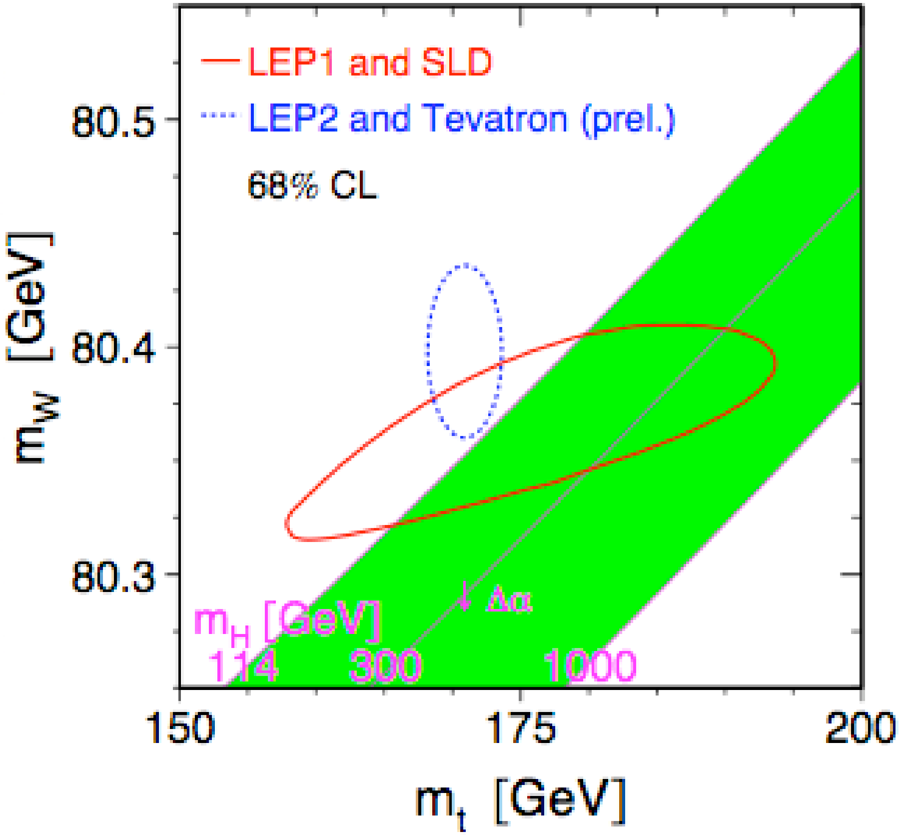
Too large for a loop effect. Needs a ad hoc tree level effect

Mixing of the b quark with a vectorlike doublet (ω,χ) with charges (2/3, -1/3) or (-1/3, -4/3)? CTW'01
Or mixing of Z with Z' and KK recurrences in extra dim models? Agashe, Contino, Pomarol '06; Djouadi, Moreau, Richard '06

• The measured value of m_W is a bit high (given m_t)
(now came a little bit down from 80.420 -> 80.398)

March '08





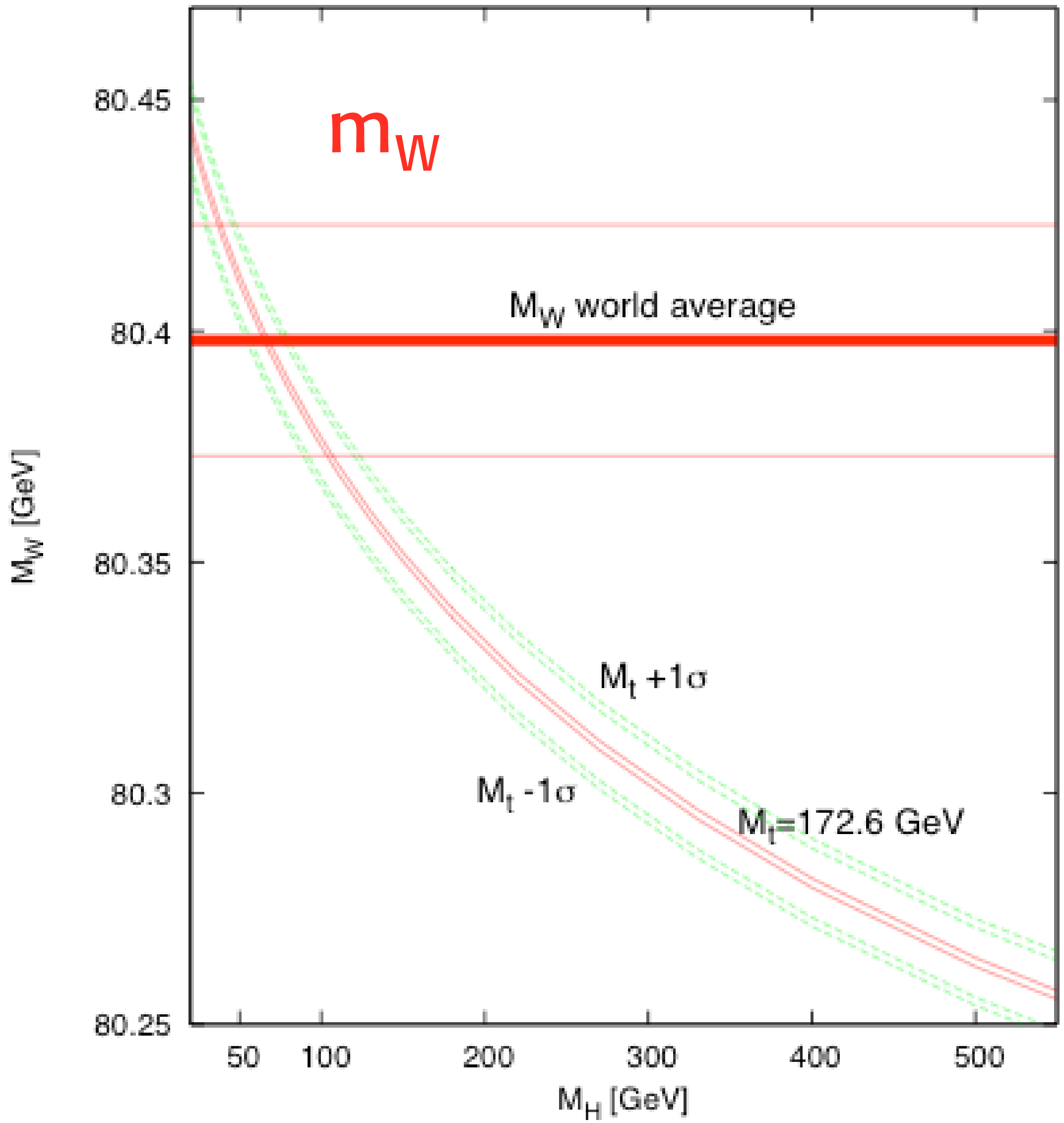
Plot m_W vs m_H

P. Gambino

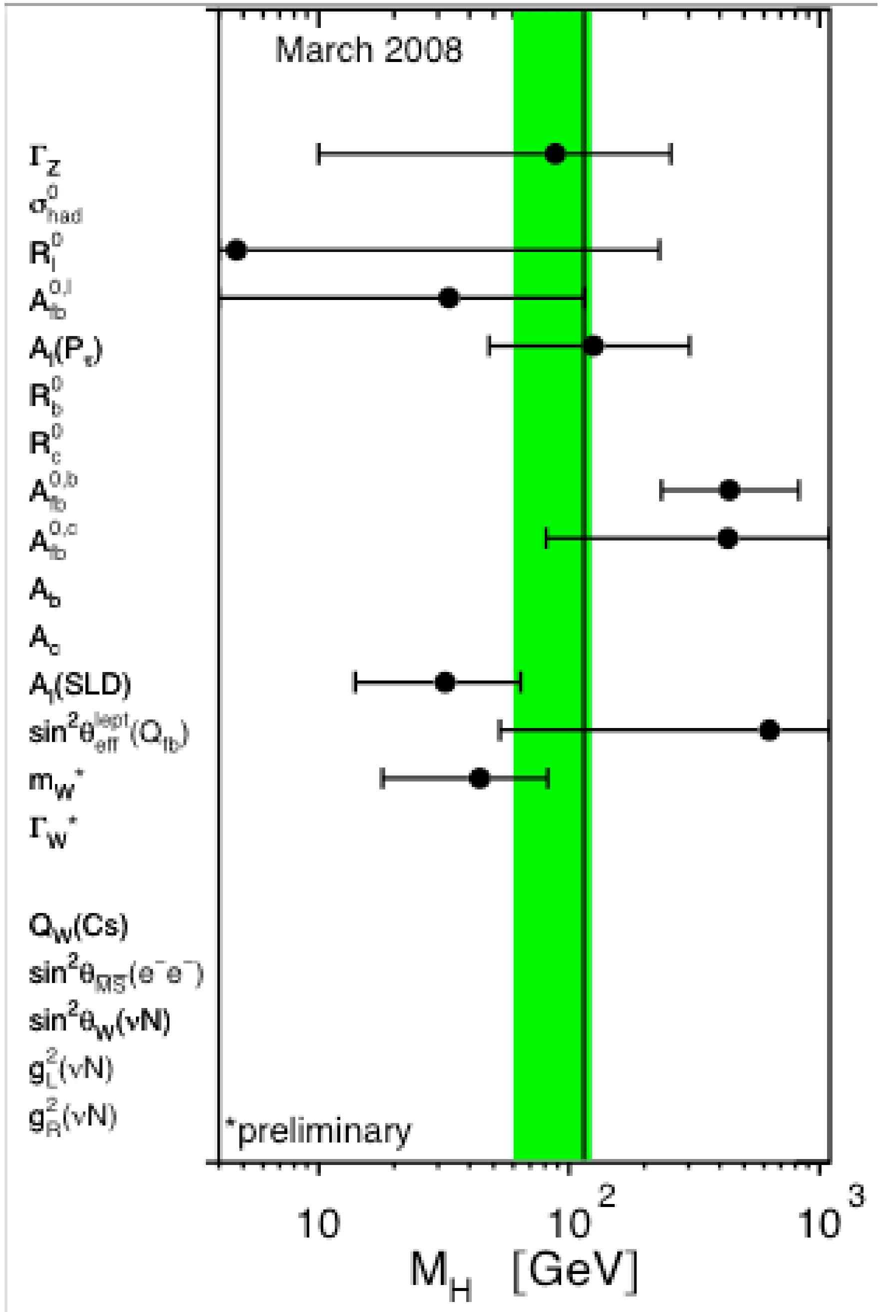
March '08

m_W points to a light Higgs!

Like $[\sin^2\theta_{eff}]_l$



Sensitivity to m_H



Fit results

Here only m_W and not m_t is used: shows m_t from rad. corr.s

March '08

	only m_W	only m_t	m_W, m_t
m_t(GeV)	178.7+12-9	172.6±1.4	172.8±1.4
m_H(GeV)	143+236-80	111+56-39	87+36-27
log[m_H(GeV)]	2.16±0.39	2.05 ± 0.18	1.94± 0.16
$\alpha_s(m_Z)$	0.1190(28)	0.1190 (27)	0.1185 (26)
χ^2/dof	16.8/12	16.0/11	17.2/13
m_W(MeV)	80385(19)	80363(20)	80377(15)

WA: m_W=80398(25)

Rad. corr.'s predict m_t and m_W very well. May be also m_H!

Status of the SM Higgs fit

Winter '07

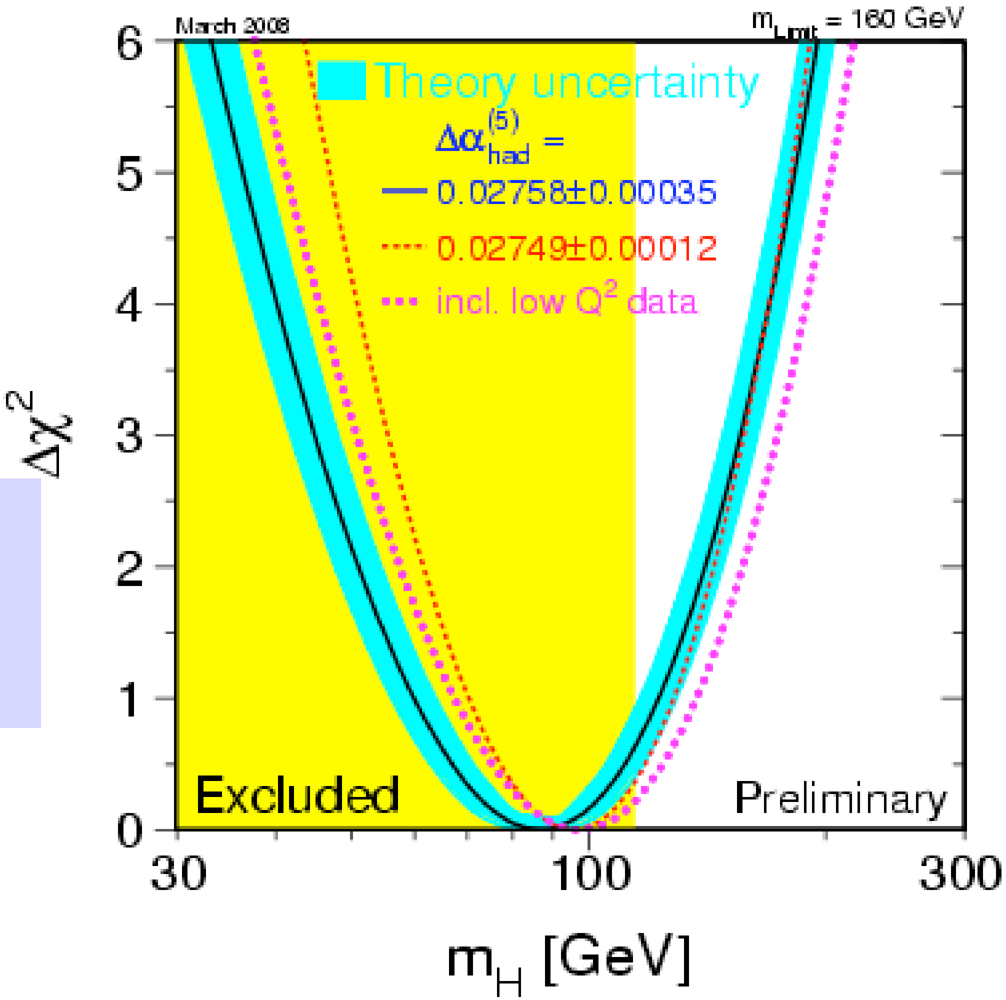
Rad Corr.s -> ← Sensitive to log m_H

$\log_{10} m_H(\text{GeV}) = 1.94 \pm 0.16$

$m_H = 87 + 36 - 27$ GeV

This is a great triumph for the SM: ~right in the narrow allowed range $\log_{10} m_H \sim 2 - 3$

Direct search: $m_H > 114.4$ GeV



At 95 % cl

$m_H < 160$ GeV (rad corr.'s)

$m_H < 190$ GeV (incl. direct search bound)

$\log_{10} m_H \sim 2$ is a very important result!!

Drop H from SM -> renorm. lost -> divergences -> cut-off Λ

$$\log m_H \to \log\Lambda + \text{const}$$

Any alternative mechanism amounts to identify the physics of Λ and the prediction of finite terms.

The most sensitive to $\log m_H$ are $\varepsilon_1 \sim \Delta\rho$ and ε_3 (or T&S):

$\log_{10} m_H \sim 2$ means that $f_{1,3}$ are compatible with the SM prediction

$$\varepsilon_1 = -\underbrace{\frac{3 G_F m_W^2}{4\pi^2\sqrt{2}}\mathrm{tg}^2\theta_W}_{-1.2\ 10^{-3}}\left[\log\frac{m_H}{m_Z} + f_1\right]$$

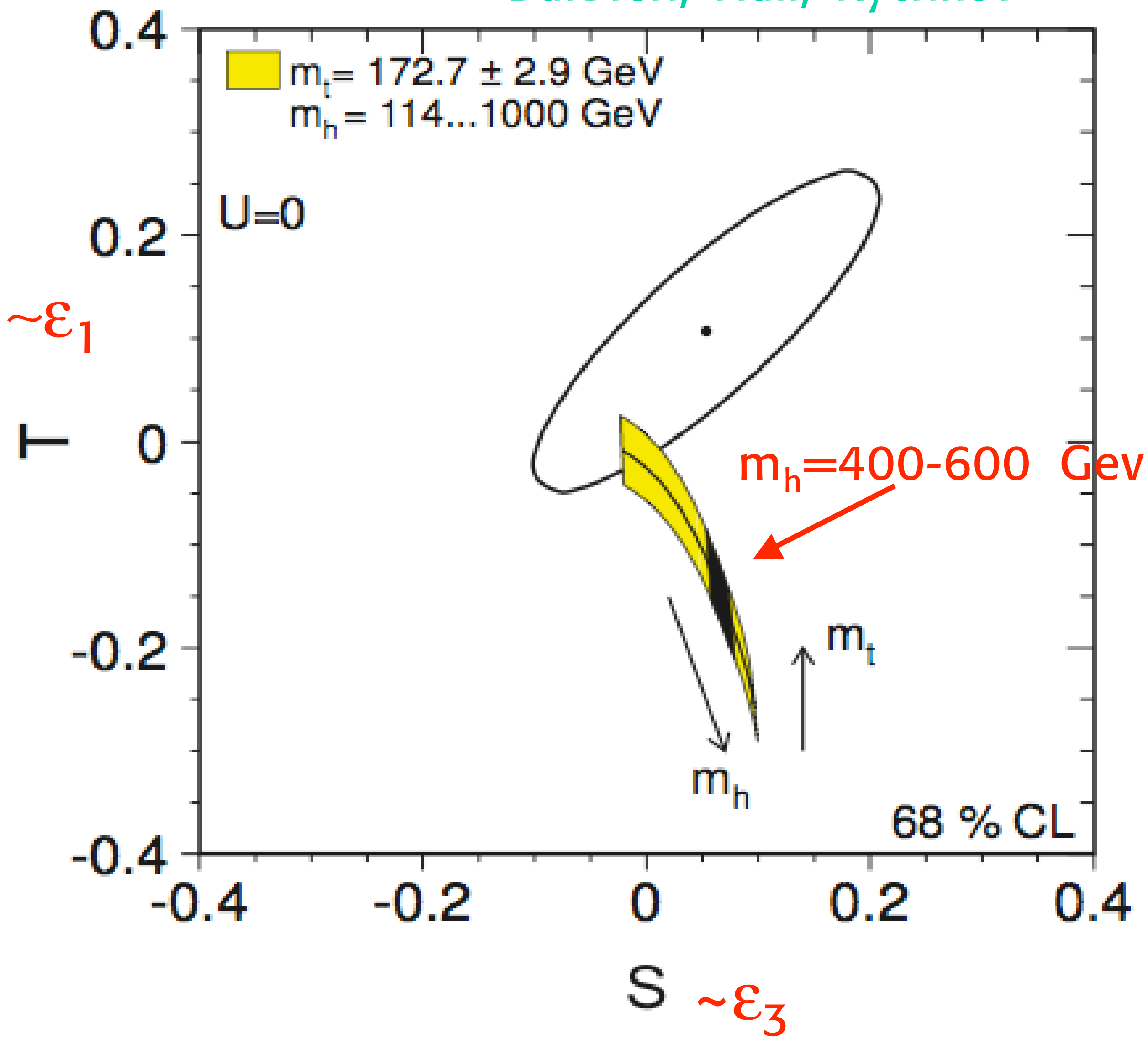
New physics can change the bound on m_H (different $f_{1,2}$): well possible!

Some conspiracy is needed to simulate a light Higgs

$$\varepsilon_3 = \underbrace{\frac{G_F m_W^2}{12\pi^2\sqrt{2}}}_{0.45\ 10^{-3}}\left[\log\frac{m_H}{m_Z} + f_3\right]$$

We see that to shift m_h up we need a new physics effect that mainly pushes T up

Barbieri, Hall, Rychkov



Here "Higgs" means the "the EW symmetry breaking mechanism"

Is it possible that the Higgs is not found at the LHC?

Looks pretty unlikely!!

The LHC range is large enough:
$m_H < \sim 1$ TeV
the Higgs should be really heavy!

Rad. corr's indicate a light Higgs (whatever its nature)

Such a heavy Higgs would make perturbation theory to collapse nearby (violations of unitarity for $m_H > 0.8$ TeV)

e.g. strongly interacting WW or WZ scattering

Such nearby collapse of pert. th. is very difficult to reconcile with EW precision tests plus simulating a light Higgs

The SM perfect agreement with the data favours forms of new physics that keep at least some Higgs light

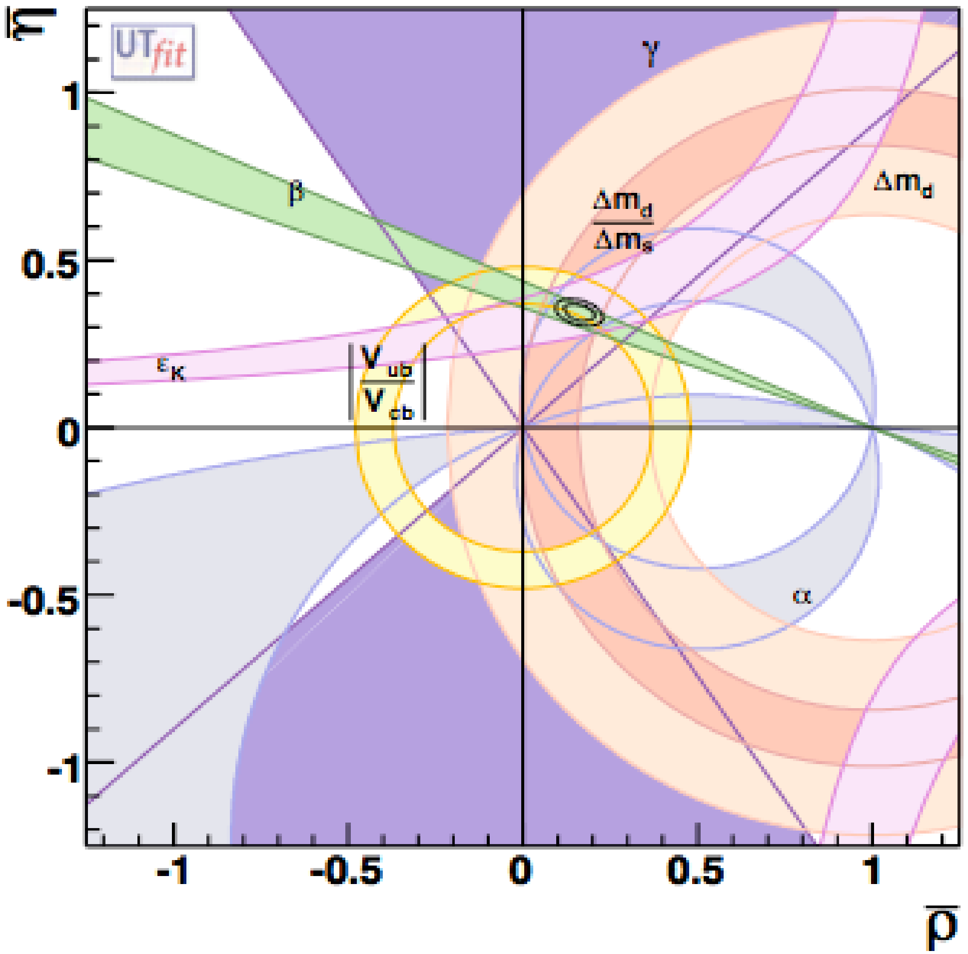
Precision Flavour Physics

Another area where the SM is good, too good.....

- Light Higgs -> New physics at ~ few TeV
- But all effective non rinorm. vertices for FCNC have bounds above a few TeV

Apparently the SM suppression of FCNC and the CKM mechanism for CP violation is only mildly modified by new physics:
an intriguing mystery and a major challenge for models of new physics

The study of B decays (BaBar, Belle, CDF...) has revealed no signs of new physics



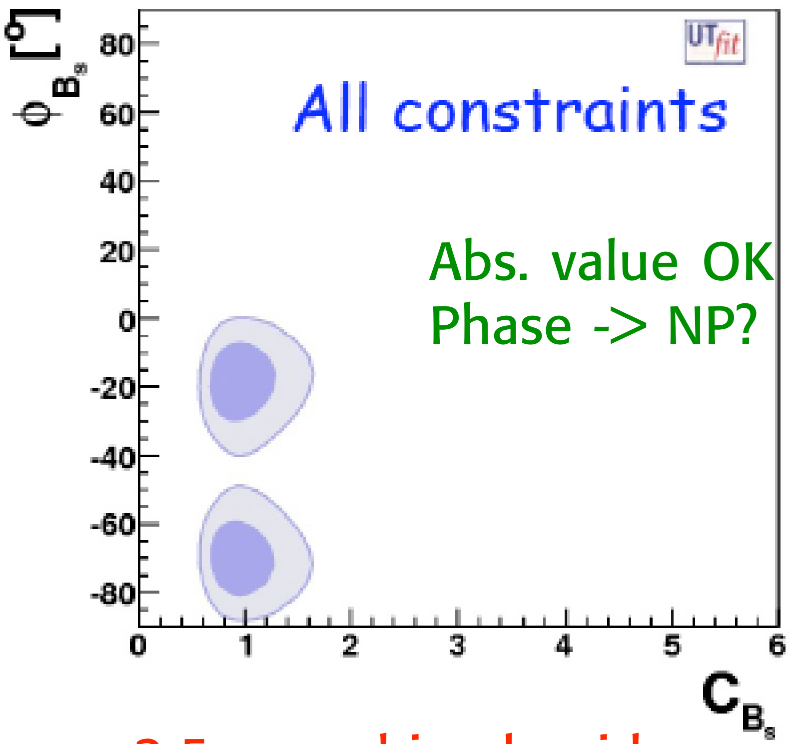
The LHCb experiment at the LHC will go further in this direction

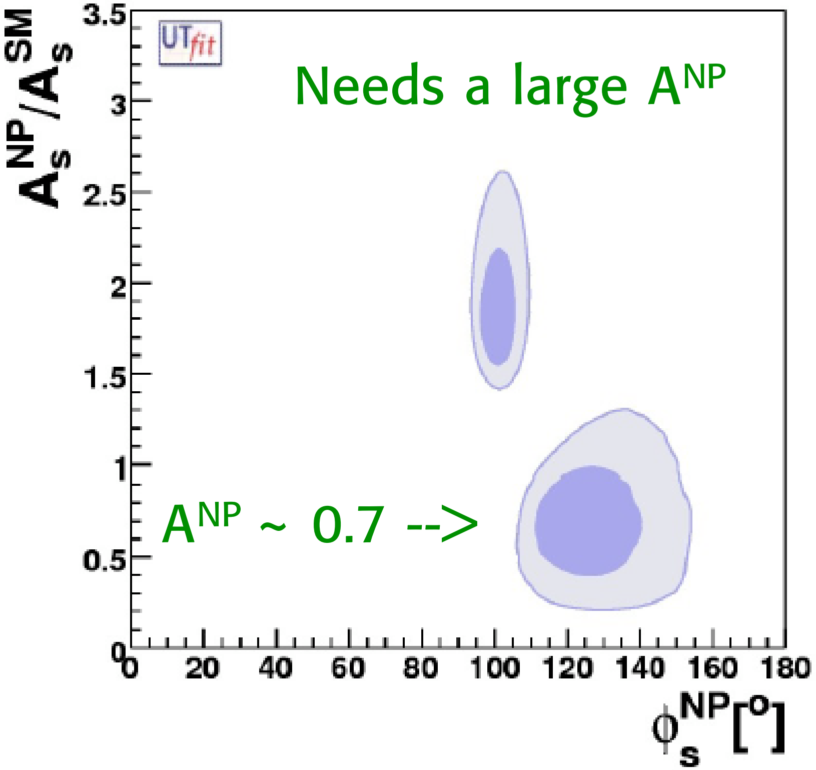
A hint for new physics in B_s mixing (CDF&D0 data)

UTfit analysis

Mixing amplitude = SM contribution + NP contribution

$$C_{B_s}\, e^{2i\phi_{B_s}} = \frac{A_s^{\rm SM} e^{-2i\beta_s} + A_s^{\rm NP} e^{2i(\phi_s^{\rm NP}-\beta_s)}}{A_s^{\rm SM} e^{-2i\beta_s}} = \frac{\langle B_s | H_{\rm eff}^{\rm full} | \bar{B}_s \rangle}{\langle B_s | H_{\rm eff}^{\rm SM} | \bar{B}_s \rangle}$$





~2.5σ combined evidence

Adding effective operators to SM generally leads to very large Λ

$$M(B_d\text{-}\bar{B}_d) \sim \frac{(y_t V_{tb}{}^* V_{td})^2}{16\,\pi^2 M_W{}^2} + c_{NP}\frac{1}{\Lambda^2}$$

Isidori

c_{NP}:

- ~ 1 — tree/strong + generic flavour → $\Lambda \gtrsim 2\times 10^4$ TeV [K]
- $\sim 1/(16\,\pi^2)$ — loop + generic flavour → $\Lambda \gtrsim 2\times 10^3$ TeV [K]
- $\sim (y_t V_{ti}{}^* V_{tj})^2$ — tree/strong + MFV → $\Lambda \gtrsim 5$ TeV [K & B]
- $\sim (y_t V_{ti}{}^* V_{tj})^2/(16\,\pi^2)$ — loop + MFV → $\Lambda \gtrsim 0.5$ TeV [K & B]

But the hierarchy problem demands Λ in the few TeV range

only assuming $c_{NP} \sim (y_t V_{tb}{}^* V_{td})^2$ (or anyway small)

we get a bound on Λ in the TeV range

eg in Minimal Flavour Violation (MFV) models

D'Ambrosio, Giudice, Isidori, Strumia'02

B-factories, CDF, D0..... have severely tested the CKM picture (in the particularly dangerous 3rd generation sector).

The CKM picture is confirmed as the main source of CPV

This poses strong constraints for models BSM

Not only one needs small NP contributions at the weak scale.
But also to control feedback from high scales thru RGE

In particular additional constraints on SUSY models.