INTRODUCTION TO ELECTROWEAK THEORY AND HIGGS PHYSICS

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Yesterday:

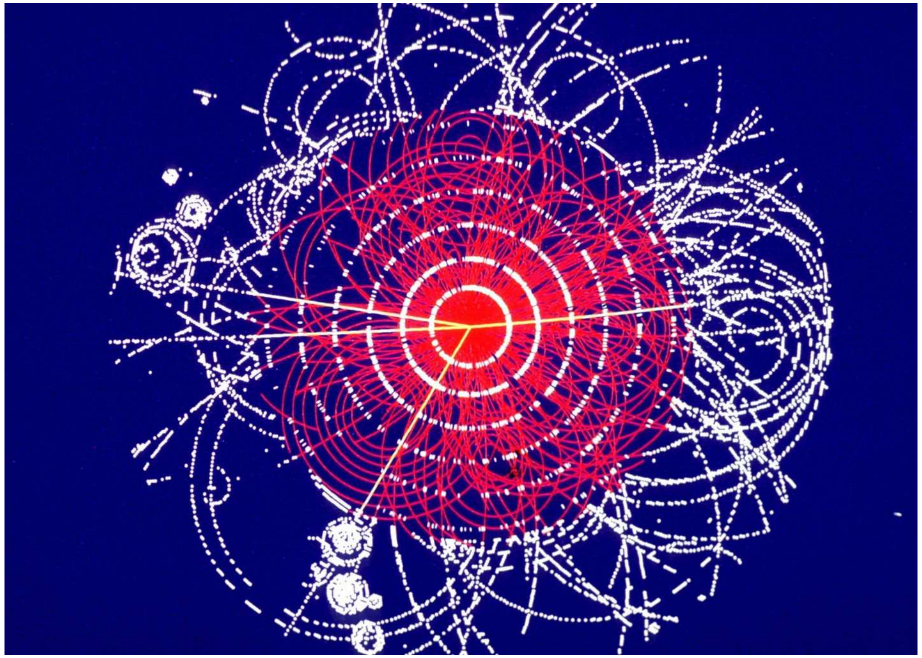
- Theoretical introduction

Today:

- Constraints on the Higgs
- Supersymmetric extension

Tomorrow:

- Higgs boson signals at LHC



Constraints on the Higgs Boson Mass

We had found that the Higgs boson mass is related to the value of the quartic Higgs coupling λ:

$$\mathcal{L} = (D_\mu \Phi)^\dagger (D^\mu \Phi) - \lambda \left(\Phi^\dagger \Phi - \frac{v^2}{2} \right)^2$$

leads to

$$m_H^2 = 2\lambda v^2$$

So far we have measured neither m_H nor $\lambda \Longrightarrow$ no direct experimental information

This raises several questions

- Can we get rid of the Higgs by setting $m_h = \infty$ and $\lambda = \infty$? Can we eliminate the Higgs from the SM?
- Does consistency of the SM as a renormalizable field theory provide constraints?
- Is there indirect information on m_H, e.g. from precision observables and loop effects?

The perturbative unitary bound

A very severe constraint on the Higgs boson mass comes from unitarity of the scattering amplitude.

$$\text{unitarity} \Longleftrightarrow \text{QM probability} < 1$$

Scattering probability bounded from above!

Considering the elastic scattering of longitudinally polarized Z bosons

$$Z_L Z_L \to Z_L Z_L$$

$$\mathcal{M} = -\frac{m_H^2}{v^2}\left[\frac{s}{s-m_H^2} + \frac{t}{t-m_H^2} + \frac{u}{u-m_H^2}\right] \qquad \text{in the } s \gg m_Z^2 \text{ limit}$$

where s, t and u are the usual Mandelstam variables.

The perturbative unitary bound on the $J = 0$ partial amplitude takes the form

$$|\mathcal{M}_0|^2 = \left[\frac{3}{16\pi}\frac{m_H^2}{v^2}\right]^2 < 1 \qquad \Longrightarrow \qquad m_H < \sqrt{\frac{16\pi}{3}}v \approx 1\ \text{TeV}$$

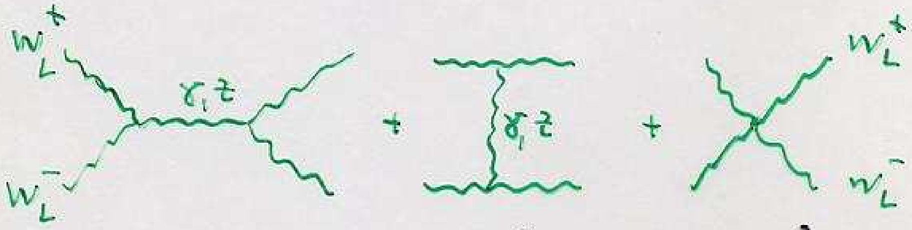
WW scattering and unitarity

Consider longitudinal W's

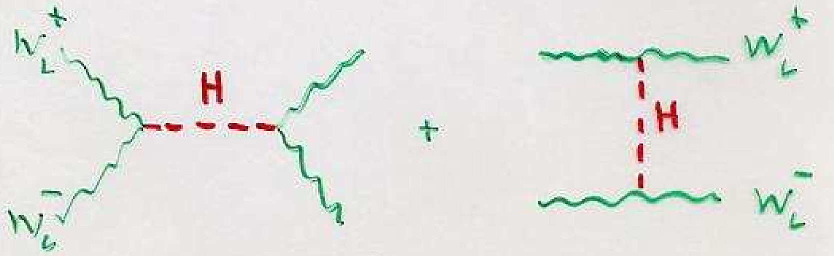
$$W_L^+ W_L^- \to W_L^+ W_L^-$$

Polarisation vector

$$\varepsilon_L^\mu = \frac{p^\mu}{m_W} + O\left(\frac{m_W}{E}\right) \sim \frac{\sqrt{s}}{m_W}$$



$$\mathcal{M} \sim \underbrace{\frac{s^2}{m_W^4} \qquad \frac{s^2}{m_W^4} \qquad \frac{s^2}{m_W^4}}_{s/m_W^2}$$



$$\frac{s}{m_W^2} \qquad \frac{s}{m_W^2}$$

sum $\sim s^0$ for $s \gg m_H^2$

Unitarity of WW scattering

Partial wave amplitudes are bounded by a constant

$\Longrightarrow \quad \mathcal{M} \sim \frac{s}{m_W^2}$ violates unitarity at sufficiently high energy

Without the Higgs contribution, the $J = 0$ partial wave violates unitarity for $\sqrt{s} > 1.2$ TeV

Destructive interference between Higgs exchange amplitudes and gauge boson scattering amplitudes works for $s > m_H^2$ only

$$\Longrightarrow \quad m_H \lesssim 1 \text{ TeV}$$

or new physics at the TeV scale

or both

Running of λ

The one-loop renormalization group equation (RGE) for $\lambda(\mu)$ is

$$\frac{d\lambda(\mu)}{d\log\mu^2} = \frac{1}{16\pi^2}\left[12\lambda^2 + \frac{3}{8}g^4 + \frac{3}{16}\left(g^2 + g'^2\right)^2 - 3h_t^4 - 3\lambda g^2 - \frac{3}{2}\lambda\left(g^2 + g'^2\right) + 6\lambda h_t^2\right]$$

where

$$m_t = \frac{h_t v}{\sqrt{2}} \qquad \text{and} \qquad m_H^2 = 2\lambda v^2$$

This equation must be solved together with the one-loop RGEs for the gauge and Yukawa couplings, which, in the Standard Model, are given by

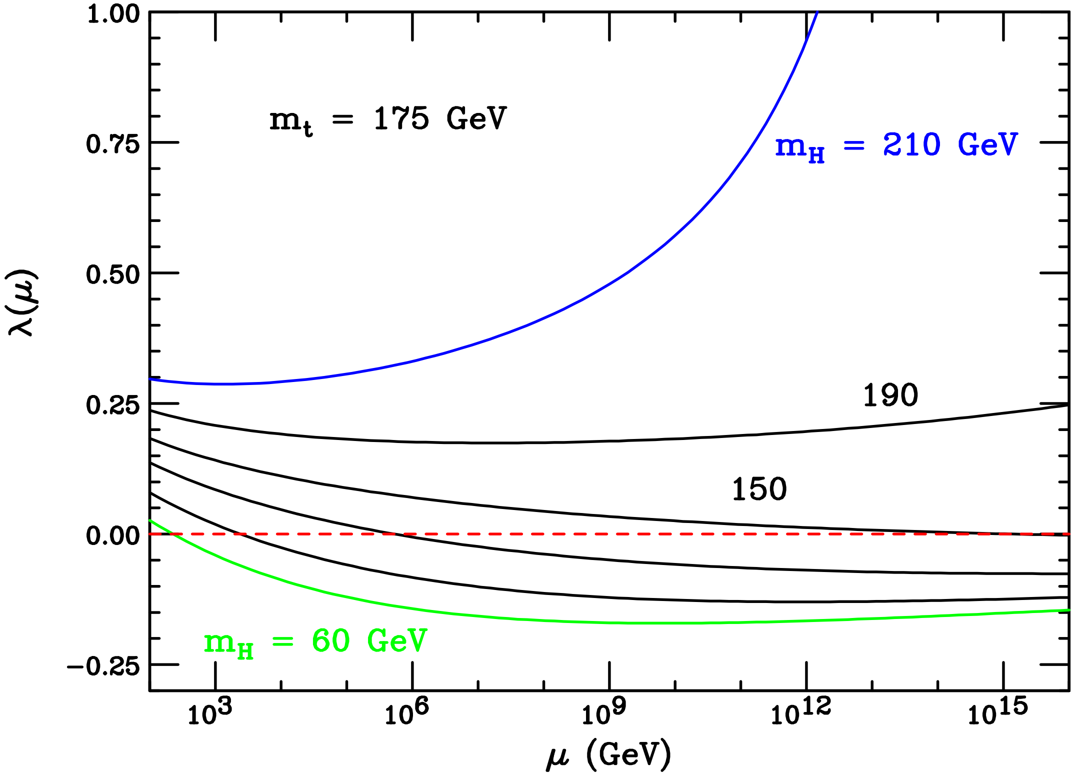
$$\begin{aligned}
\frac{dg(\mu)}{d\log\mu^2} &= \frac{1}{32\pi^2}\left(-\frac{19}{6}g^3\right) \\
\frac{dg'(\mu)}{d\log\mu^2} &= \frac{1}{32\pi^2}\frac{41}{6}g'^3 \\
\frac{dg_s(\mu)}{d\log\mu^2} &= \frac{1}{32\pi^2}\left(-7g_s^3\right) = \frac{1}{32\pi^2}\left(-(11 - \frac{2}{3}n_f)g_s^3\right) \\
\frac{dh_t(\mu)}{d\log\mu^2} &= \frac{1}{32\pi^2}\left[\frac{9}{2}h_t^3 - \left(8g_s^2 + \frac{9}{4}g^2 + \frac{17}{12}g'^2\right)h_t\right]
\end{aligned}$$

here g_s is the strong interaction coupling constant, and the $\overline{\text{MS}}$ scheme is adopted.

Solutions for $\lambda(\mu)$

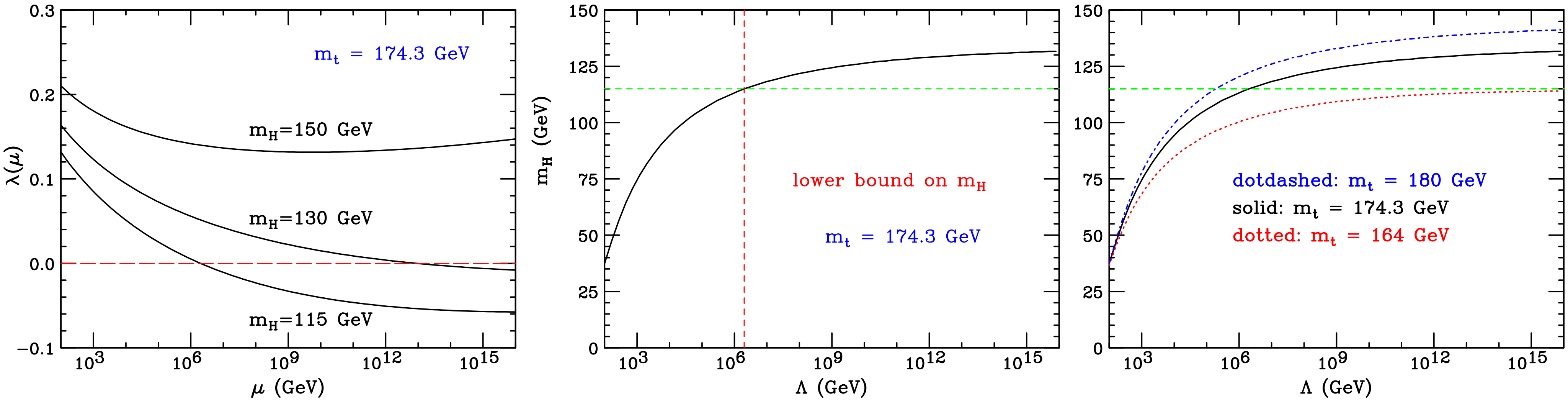
Solving this system of coupled equations with the initial condition

$$\lambda\left(m_H\right) = \frac{m_H^2}{2v^2}$$



Lower bound for m_H: vacuum stability

It can be shown that the requirement that the Higgs potential be bounded from below, even after the inclusion of radiative corrections, is fulfilled if $\lambda(\mu)$ stays positive, at least up to a certain scale $\mu \approx \Lambda$, the maximum energy scale at which the theory can be considered reliable.



✗ This limit is extremely sensitive to the top-quark mass.

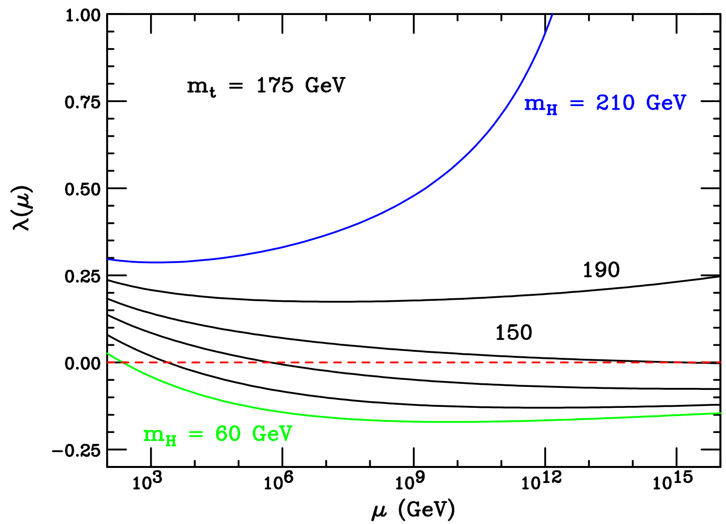
✓ The stability lower bound can be relaxed by allowing metastability

Upper bound for m_H: triviality bound

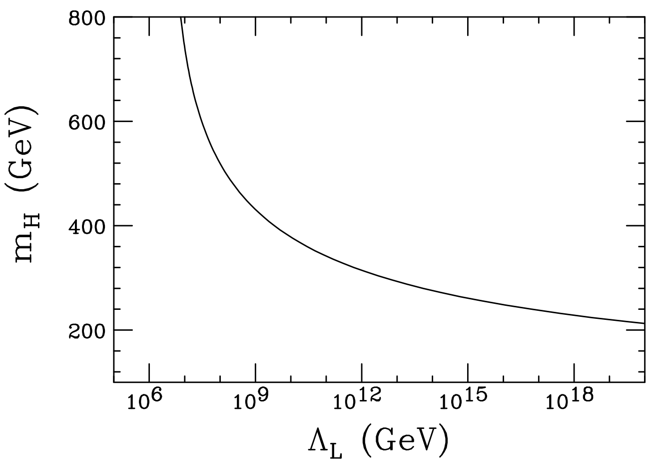
For large values of the Higgs boson mass, the coupling $\lambda(\mu)$ grows with increasing μ, and eventually leaves the perturbative domain ($\lambda \lesssim 1$): the solution has a singularity in μ , known as the Landau pole.

For the theory to make sense up to a scale Λ, we must ask $\lambda(\mu) \lesssim 1$ (or something similar), for $\mu \leq \Lambda$.

Neglecting gauge and Yukawa coupling, we have



$$\lambda(\mu^2) = \frac{\lambda(m_H^2)}{1 - \frac{3}{4\pi^2}\lambda(m_H^2)\log\frac{\mu^2}{m_H^2}} \qquad \text{singular when} \qquad \mu^2 \approx \Lambda_L^2 \equiv m_H^2 \exp\left[\frac{4\pi^2}{3\lambda(m_H^2)}\right]$$



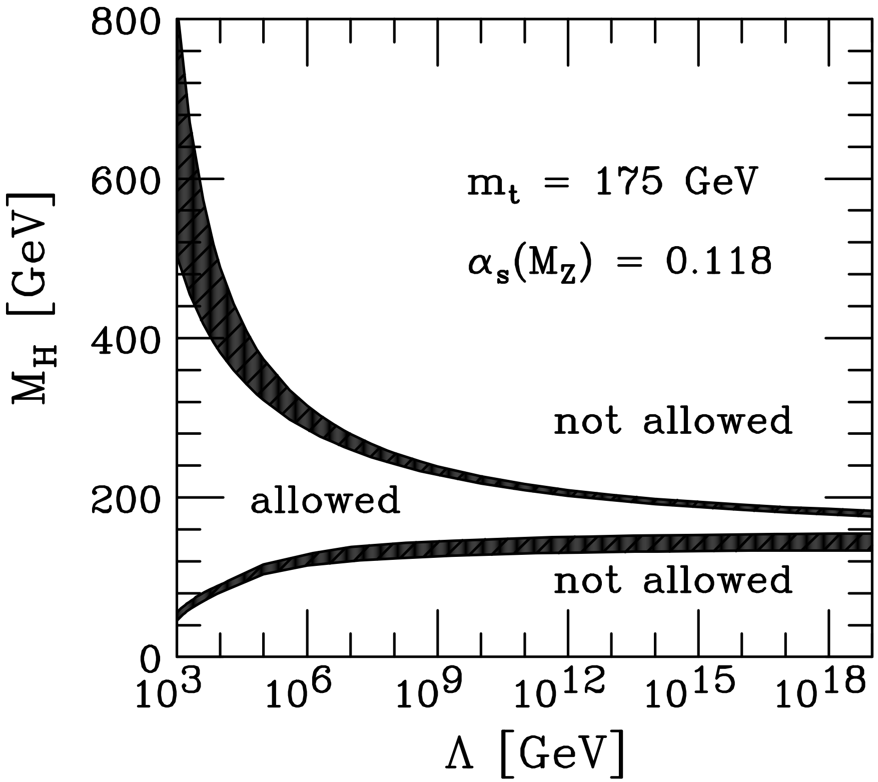
For any value of $\lambda\left(m_H^2\right)$ the theory has an upper scale Λ of validity.

$\Lambda \to \infty$ for pure scalar theory possible only if $\lambda(\mu) \equiv 0$, i.e. no scalar self-coupling $\Longrightarrow$ free or trivial theory

Higgs boson mass bounds

Renormalization group constraints on the Higgs boson mass, $m_H = \sqrt{2\lambda}v$

Riesselmann, hep-ph/9711456



Notice the small window 140 GeV $< m_H <$ 180 GeV, where the theory is valid up to the Planck scale $M_{\text{Planck}} = (\hbar c / G_{\text{Newton}})^{1/2} \approx 1.22 \times 10^{19}$ GeV.

For a cutoff scale of $\Lambda >$ 1000 TeV the Higgs boson should lie in the mass window 110 GeV $< m_H <$ 300 GeV

Constraints from precision data

$$\alpha = \frac{1}{4\pi}\frac{g^2 g'^2}{g^2+g'^2} = \frac{1}{137.03599976(50)}$$

$$G_F = \frac{1}{\sqrt{2}v^2} = 1.16637(1)\times 10^{-5}\ \mathrm{GeV}^{-2}$$

$$m_Z = \frac{1}{2}\sqrt{g^2+g'^2}\,v = 91.1875(21)\ \mathrm{GeV}\ ,$$

where the uncertainty is given in parentheses. The value of α is extracted from low-energy experiments, G_F is extracted from the muon lifetime, and m_Z is measured from e^+e^- annihilation near the Z mass.

We can express m_W as

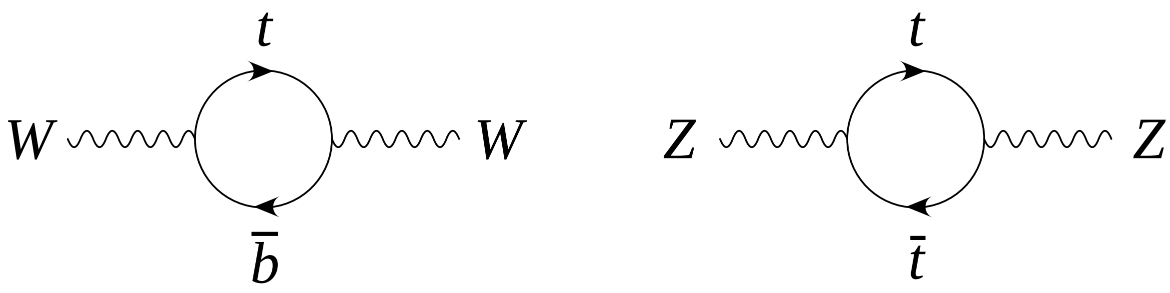
$$m_W^2 = \frac{1}{\sin^2\theta_W}\frac{\pi\alpha}{\sqrt{2}G_F}$$

where

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

Clues to the Higgs boson mass

From the sensitivity of electroweak observables to the mass of the top, we are able to measure its mass, even without directly producing it

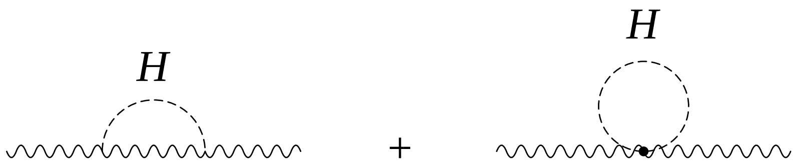


These quantum corrections alter the link between W and Z boson masses

$$m_W^2 = \frac{1}{\sin^2\theta_W\,(1-\Delta\rho)}\frac{\pi\alpha}{\sqrt{2}G_F} \qquad \Delta\rho_{(\text{top})} \approx -\frac{3G_F}{8\pi^2\sqrt{2}}\frac{1}{\tan^2\theta_W}m_t^2$$

The strong dependence on m_t^2 accounts for the precision of the top-quark mass estimates derived from electroweak observables.

The Higgs boson quantum corrections are typically smaller than the top-quark corrections, and exhibit a more subtle dependence on m_H than the m_t^2 dependence of the top-quark corrections.



$$\Delta\rho_{(\text{Higgs})} = \frac{11 G_F m_Z^2 \cos^2\theta_W}{24\sqrt{2}\pi^2} \log\left(\frac{m_H^2}{m_W^2}\right)$$

Since m_Z has been determined at LEP to 23 ppm, it is interesting to examine the dependence of m_W upon m_t and m_H.

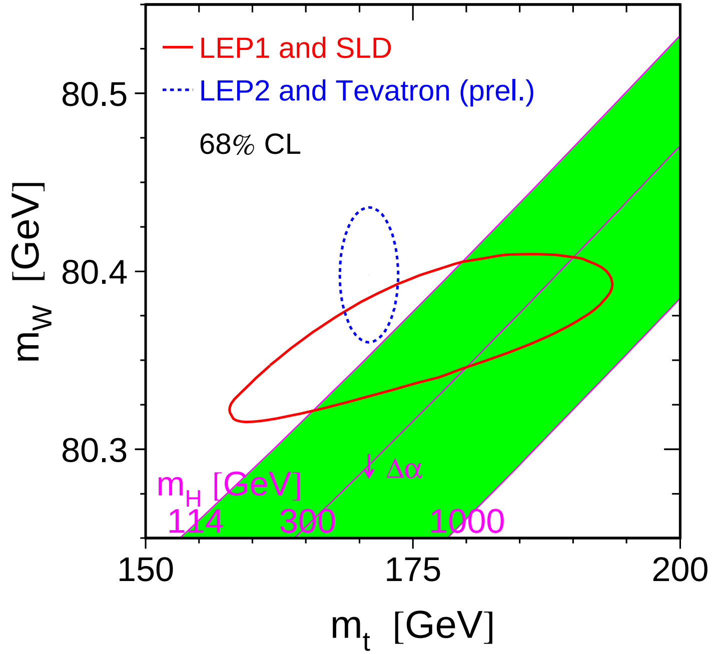
Indirect measurements of m_W and m_t (solid line)

Direct measurements of m_W and m_t (dotted line)

$m_t = 170.9 \pm 1.8$ GeV

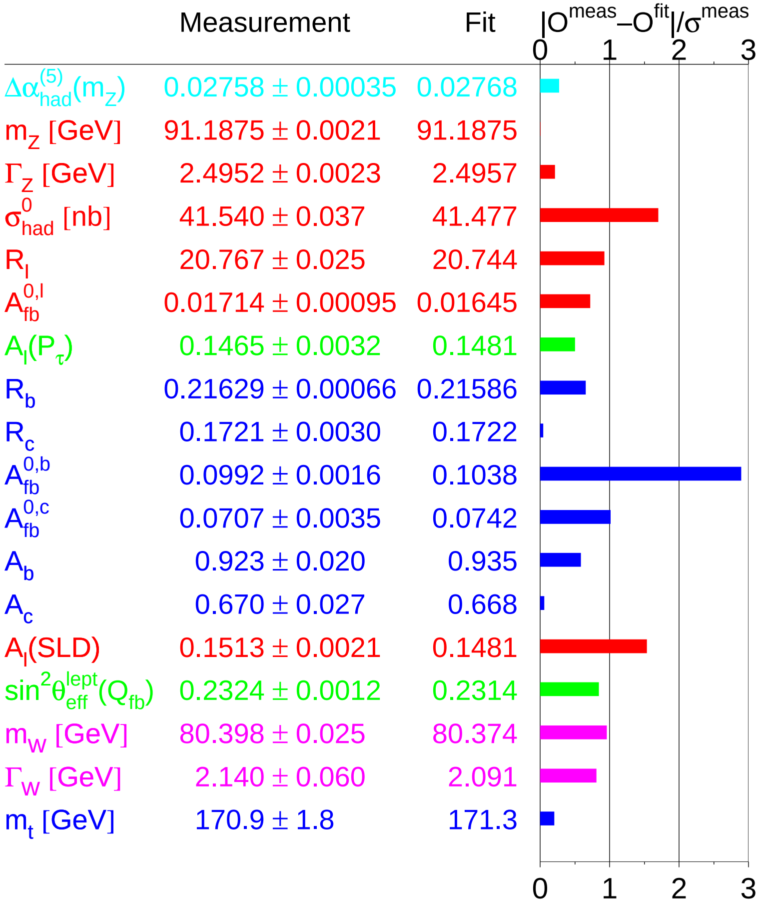
$m_W = 80.398 \pm 0.025$ GeV

both shown as one-standard-deviation regions.



The indirect and direct determinations are in reasonable agreement and both favor a light Higgs boson, within the framework of the SM.

Summary of EW precision data



Better estimates of the SM Higgs boson mass are obtained by combining all available data:

Summary of electroweak precision measurements (status winter 2007) as given on LEP-EWWG page:
http://lepewwg.web.cern.ch/LEPEWWG/

SM Higgs mass fit to EW precision data

$$m_H = 76^{+33}_{-24} \text{ GeV}$$

Including theory uncertainty

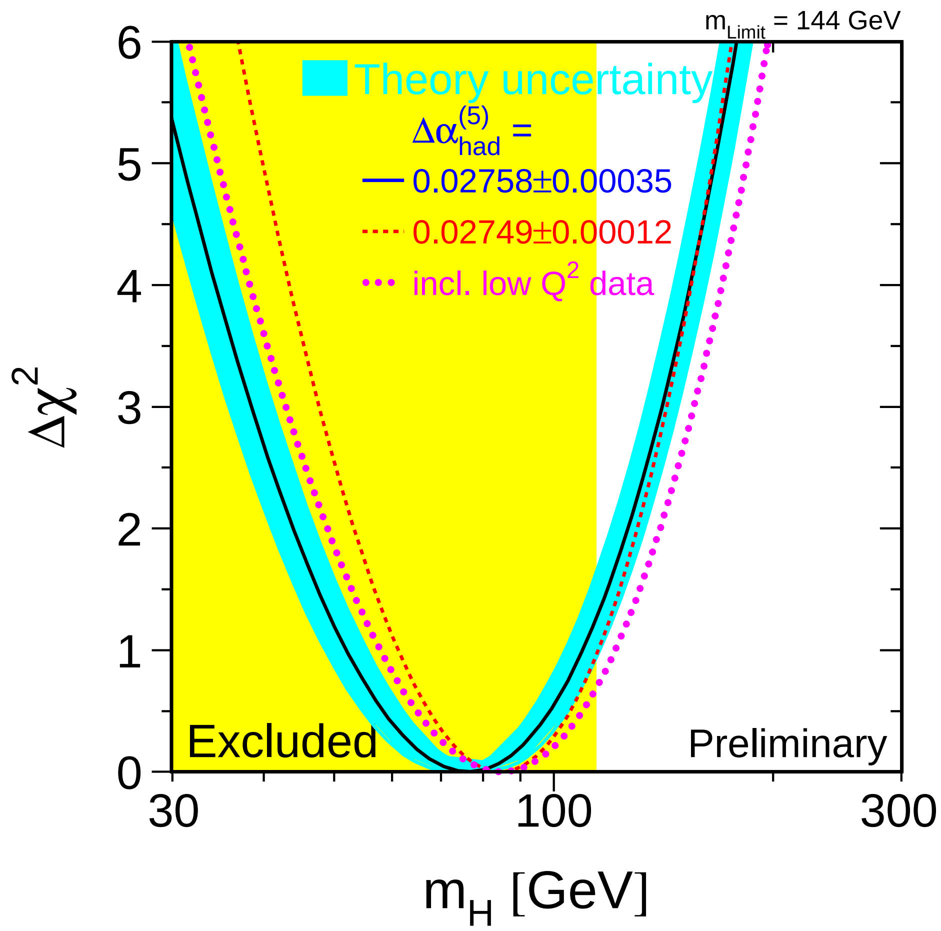
$$m_H < 144 \text{ GeV} \quad (95\% \text{ CL})$$

Does not include
Direct search limit from LEP

$$m_H > 114 \text{ GeV} \quad (95\% \text{ CL})$$

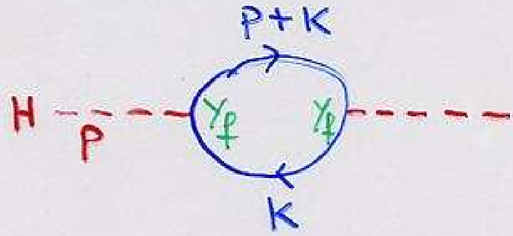
Renormalize probability for
$m_H > 114$ GeV to 100%:

$$m_H < 182 \text{ GeV} \quad (95\% \text{ CL})$$



A SM problem: Higgs self energy

a) Fermionic 1-loop contribution to $\Pi_H(p^2)$ [...]



$$y_f = \frac{m_f}{v}$$

$$-i\,\Pi_H^f(p^2) = -\int \frac{d^4k}{(2\pi)^4}\, \mathrm{tr}\,(-iy_f)\frac{i}{\not p+\not k-m_f}(-iy_f)\frac{i}{\not k-m_f}$$

$$= -2y_f^2 \int \frac{d^4k}{(2\pi)^4} \frac{k^2-m_f^2 + (k+p)^2-m_f^2 + 4m_f^2-p^2}{[k^2-m_f^2][(k+p)^2-m_f^2]}$$

$$\Pi_H^f(p^2) = -\frac{y_f^2}{16\pi^2}\left[4\,A(m_f^2) + 2(p^2-4m_f^2)\,B_0(p,m_f)\right]$$ [...]

$A(m^2)$ is quadratically divergent

$$A(m^2) = \frac{1}{i\pi^2}\int^R d^4k\,\frac{1}{-k^2+m^2-i\varepsilon}$$

$$= \frac{1}{i\pi^2}\underbrace{\int d^3\Omega}_{2\pi^2}\; i\int_0^\Lambda dk_E\,\frac{k_E^3}{k_E^2+m^2}$$

$$= \Lambda^2 - m^2\log\left(1+\frac{\Lambda^2}{m^2}\right)$$

Fine tuning problem

$$\delta m_H^2 = \Pi_H(m_H^2) = -4\sum_f \frac{y_f^2}{16\pi^2}\Lambda^2 + O(\log\Lambda)$$

mass shift is quadratically divergent

$$|\delta m_H^2| \gg m_H^2 \quad \text{for } \Lambda \to M_{Planck}$$

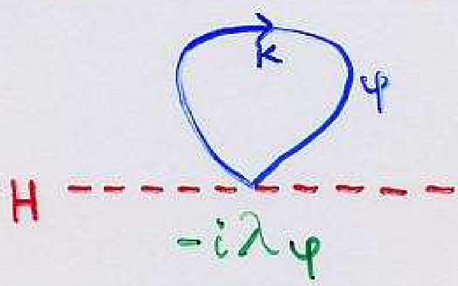
we need

$$\underbrace{m_H^2}_{\sim 10^4\,\mathrm{GeV}^2} = m_{0H}^2 + \underbrace{\delta m_H^2}_{\sim 10^{38}\,\mathrm{GeV}^2} \ll \Lambda^2$$

Keeping $m_H \ll m_{Planck}$ in spite of radiative shift of order $\Lambda \approx m_{Planck}$ requires incredible

Fine tuning in SM

b) Suppose there are scalars φ with quartic couplings λ_φ to the Higgs



$$-i\Pi_H^\varphi(p^2) = -i\lambda_\varphi \int \frac{d^4k}{(2\pi)^4} \frac{i}{k^2 - m_\varphi^2}$$

$$= -i\lambda_\varphi \frac{1}{16\pi^2} A(m_\varphi^2)$$

Overall mass shift

$$\delta m_H^2 = \frac{1}{16\pi^2}\left[\sum_\varphi \lambda_\varphi - \sum_f 4 y_f^2\right]\Lambda^2 + \ldots$$

$\Rightarrow$ cancellation of quadratic divergenc[e] provided Higgs couplings λ_φ and y_f to scalars and fermions are matched precisely.

Ex.: MSSM in the decoupling limit:

For each Dirac fermion $f = \begin{pmatrix} f_L \\ f_R \end{pmatrix}$ there are two sfermions $\tilde{f}_L, \tilde{f}_R$ with quartic couplings

$$\lambda_{\tilde{f}_{L,R}} = 2 y_f^2 + \ldots$$

... extra terms cancel between L,R scalars of given SU(2) multiplet

$$\delta m_H^2 \Big|_{f's} \approx -\frac{y_t^2}{4\pi^2} M_{SUSY}^2 \log \frac{\Lambda^2}{M_{SUSY}^2}$$

$$M_{SUSY} \sim m_{\tilde{t}} \lesssim O(1\,\text{TeV})$$

Fine tuning problem is solved in supersymmetric models with SUSY scale of order 1 TeV

The MSSM Higgs sector

The SM uses the conjugate field $\Phi_c = i\sigma_2\Phi^*$ to generate down quark and lepton masses. In supersymmetric models this must be an independent field

$$\begin{aligned} \mathcal{L}_{\text{Yukawa}} &= -\Gamma_d \bar{Q}_L \Phi_1 d_R - \Gamma_e \bar{L}_L \Phi_1 e_R + \text{h.c.} \\ &\quad -\Gamma_u \bar{Q}_L \Phi_2 u_R + \text{h.c.} \end{aligned}$$

Two complex Higgs doublet fields Φ_1 and Φ_2 receive mass and VEVs v_1, v_2 from generalized Higgs potential. Mass eigenstates constructed out of these 8 real fields are

Neutral sector:

2 CP even Higgs bosons: h and H

1 CP odd Higgs boson: A

1 Goldstone boson: χ_0

Charged sector:

charged Higgs bosons: $H^\pm$

charged Goldstone boson: $\chi^\pm$

Higgs mixing and MSSM parameters

The Higgs potential leads to general mixing of the 2 doublet fields

$$\Phi_1 = \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2}[H^- \sin\beta - \chi^- \cos\beta] \\ v_1 + [H \cos\alpha - h \sin\alpha] + i[A \sin\beta + \chi_0 \cos\beta] \end{pmatrix} \to \frac{1}{\sqrt{2}} \begin{pmatrix} \sqrt{2} H^- \sin\beta \\ v_1 + \varphi_1 + iA \sin\beta \end{pmatrix}$$

$$\Phi_2 = \frac{1}{\sqrt{2}} \begin{pmatrix} v_2 + [H \sin\alpha + h \cos\alpha] + i[A \cos\beta - \chi_0 \sin\beta] \\ \sqrt{2}[H^+ \cos\beta + \chi^+ \sin\beta] \end{pmatrix} \to \frac{1}{\sqrt{2}} \begin{pmatrix} v_2 + \varphi_2 + iA \cos\beta \\ \sqrt{2} H^+ \cos\beta \end{pmatrix}$$

The angle β is determined by the VEVs:

$$v_1 = v \cos\beta\,, \qquad v_2 = v \sin\beta\,, \qquad \Longrightarrow \qquad \frac{v_2}{v_1} = \tan\beta$$

The mixing angle α between the 2 CP even scalars and the masses are determined by

$$\tan\beta\,, \qquad m_A\,, \qquad v = \sqrt{v_1^2 + v_2^2} = 246\ \text{GeV}$$

SUSY Higgs mass relations

Higgs potential in the MSSM produces distinct mass relations at tree level

$$
\begin{aligned}
m_h^2, m_H^2 &= \frac{1}{2}\left[m_A^2 + m_Z^2 \pm \sqrt{\left(m_A^2 + m_Z^2\right)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta}\right] \\
m_{H^\pm} &= \sqrt{m_A^2 + m_W^2} > m_W
\end{aligned}
$$

Pseudoscalar mass m_A sets scale for H and $H^\pm$ mass, but h must be light

$$
m_h^2 = \frac{2m_A^2 m_Z^2 \cos^2 2\beta}{m_A^2 + m_Z^2 + \sqrt{\left(m_A^2 + m_Z^2\right)^2 - 4m_A^2 m_Z^2 \cos^2 2\beta}} < m_Z^2 \cos^2 2\beta
$$

because quartic coupling is proportional to g^2, g'^2

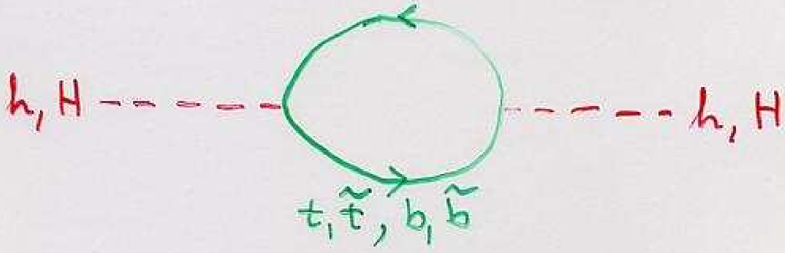
Problem: $m_h < m_Z$ is ruled out by LEP data! $\Longrightarrow$ need to include radiative corrections

Behaviour for $m_A \gg m_Z$:

$$
m_H^\pm \approx m_A \approx m_H\,, \qquad\qquad m_h = m_Z|\cos 2\beta|
$$

m_h is largest for $\tan\beta \to 0, \infty$.
Later: h has SM couplings in $m_A \to \infty$ limit (decoupling limit)

Include radiative corrections



Change h/H mass matrix

$$m^2_{H/h} = m^2_0 + \delta m^2$$

diagonalize $\Rightarrow m^2_h, m^2_H$, mixing angle α

Consider special case: $m_A \gg m_Z, \tan\beta \gg 1$

Lowest order: $m_h = m_Z$ (= upper bound)

h has SM couplings

$\Rightarrow t, \tilde{t}_1, \tilde{t}_2$ loops dominate

strong dependence on stop mixing:

$$X_t = A_t - \mu \cot\beta$$

governs $\tilde{t}_L, \tilde{t}_R \Longleftrightarrow \tilde{t}_1, \tilde{t}_2$ mass eigenstate

Quadratic divergencies cancel at scal

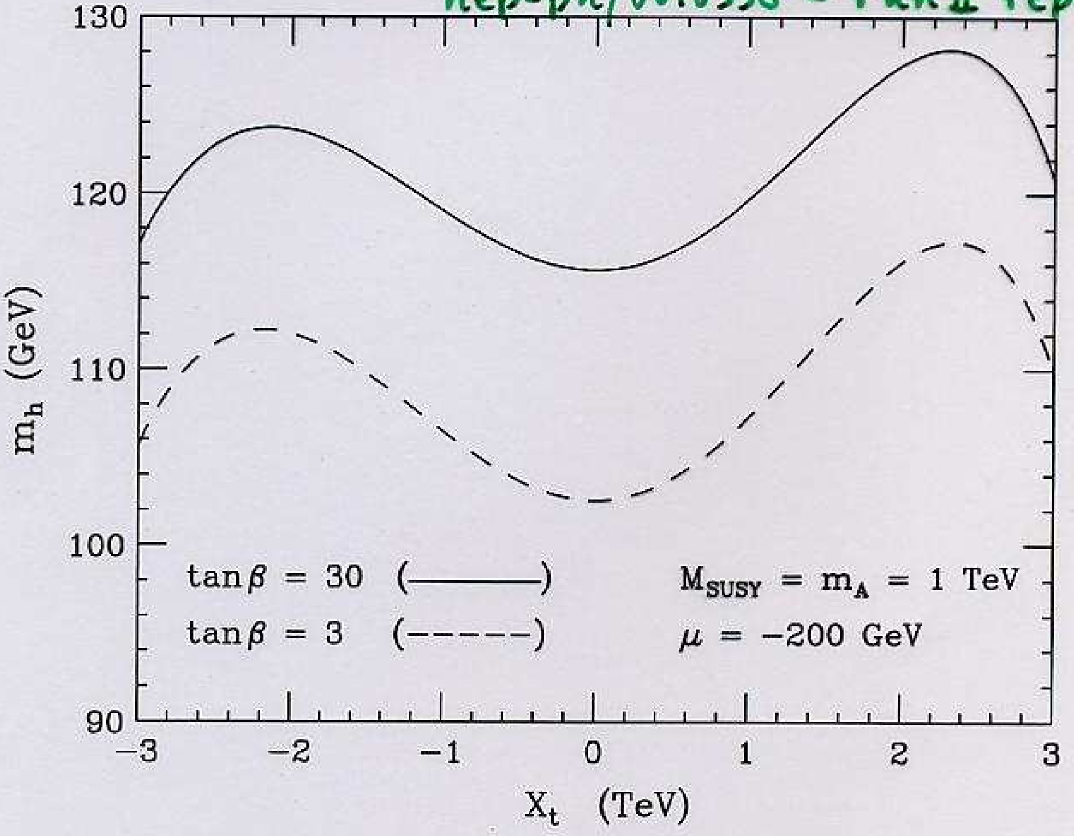
$$M_S^2 = \frac{1}{2}\left(m^2_{\tilde{t}_1} + m^2_{\tilde{t}_2}\right)$$

upper bound (reached for large $\tan\beta$)

$$m_h^2 \leq m_Z^2 + \frac{3 m_t^4}{2\pi^2 v^2}\left[\ln\frac{M_S^2}{m_t^2} + \frac{X_t^2}{M_S^2}\left(1 - \frac{X_t^2}{12 M_S^2}\right)\right]$$

include all 1-loop + leading 2-loop corrections:

hep-ph/0010338 = run II report

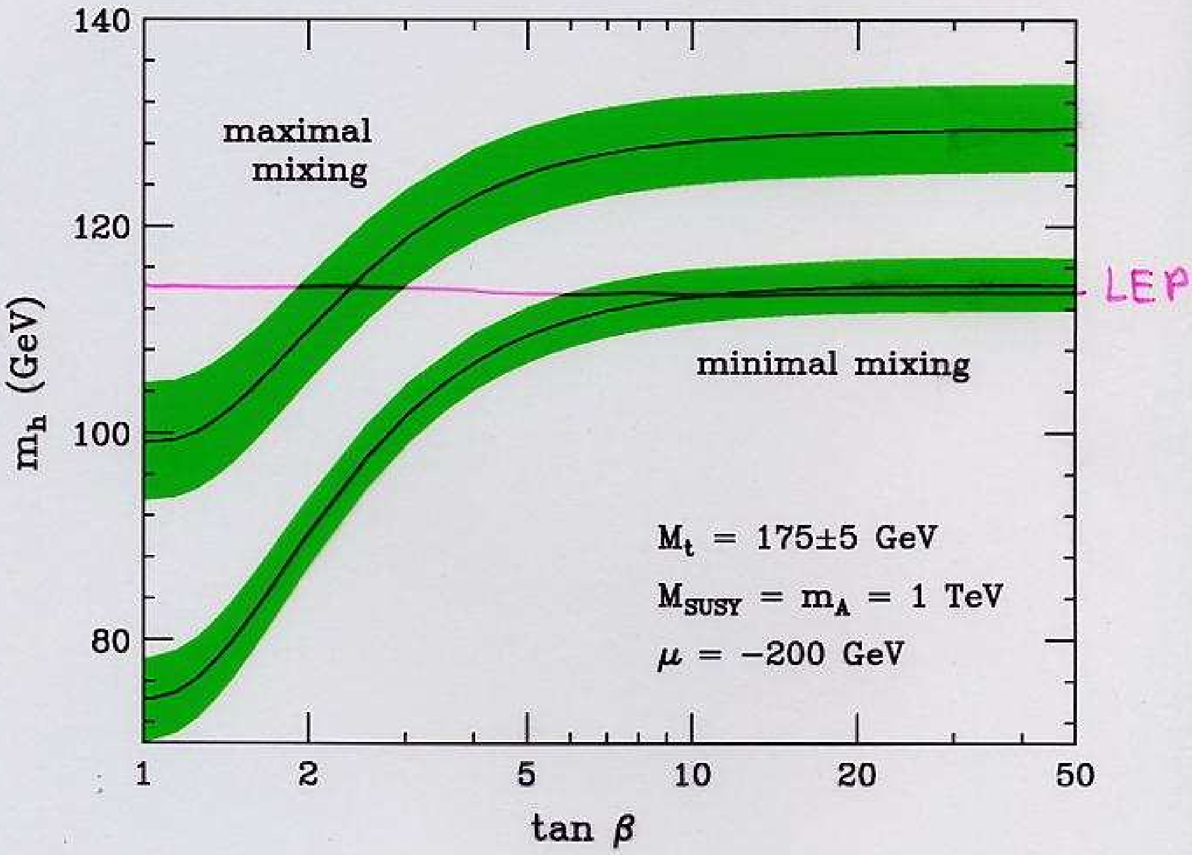


maximal mixing: $X_t = \sqrt{6}\, M_S$

minimal mixing: $X_t = 0$

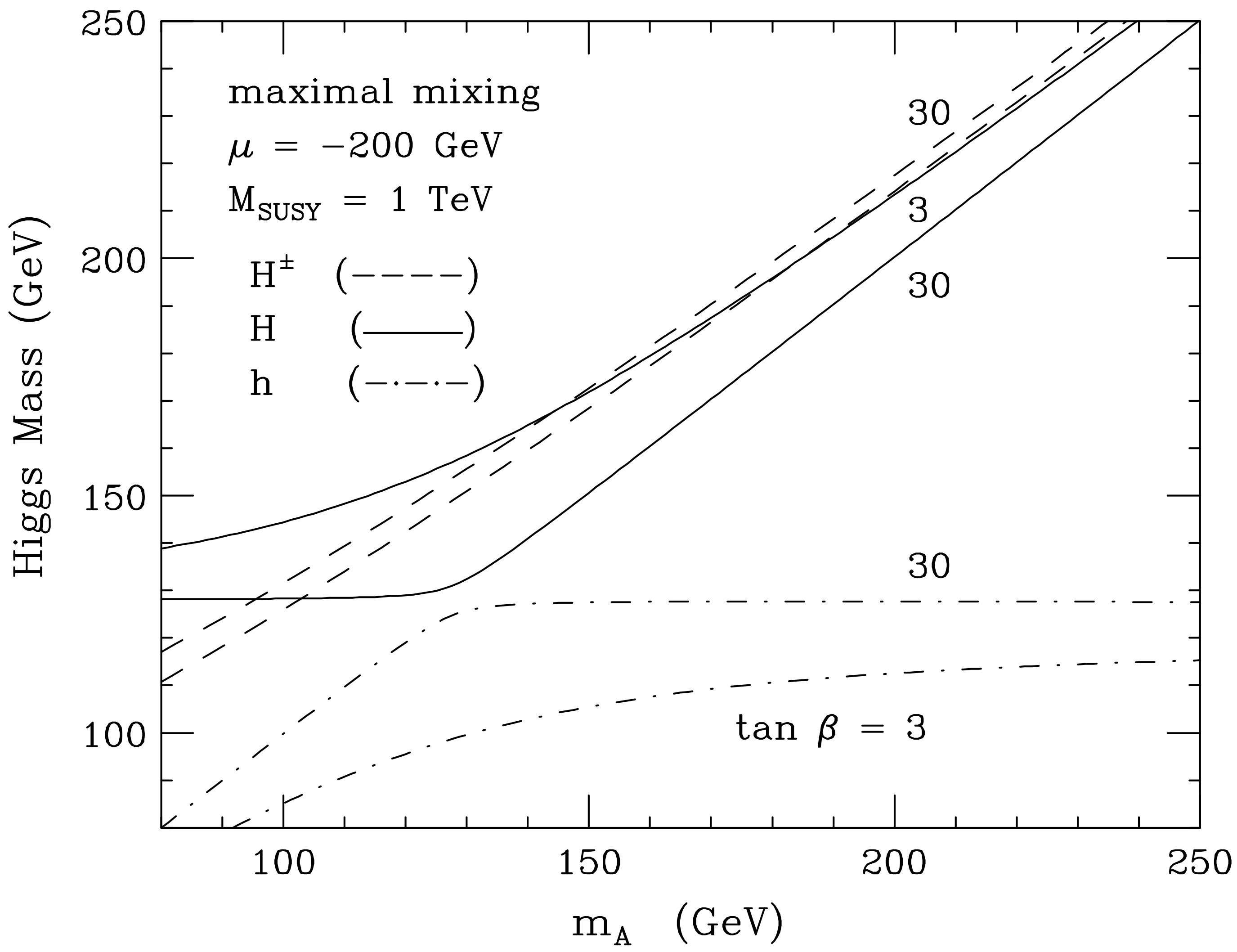
tan β dependence of m_h

green band: m_t = 170 .... 180 GeV



LEP limit of $m_h > 114$ GeV for SM Higgs

- rules out $\tan\beta \approx 1$
- favors large stop mixing



Lightest Higgs mass $m_h \lesssim 135$ GeV since quartic coupling is given by gauge couplings,

$$V_{quartic} = (g^2 + g'^2)/8 \left(\Phi_1^\dagger \Phi_1 - \Phi_2^\dagger \Phi_2\right)^2 + g^2/2\ \Phi_1^\dagger \Phi_2 \Phi_2^\dagger \Phi_1$$

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Coupling to gauge bosons

$$\begin{aligned}\mathcal{L} &= (D^\mu\Phi_1)^\dagger D_\mu\Phi_1 + (D^\mu\Phi_2)^\dagger D_\mu\Phi_2 \\ &= \frac{1}{2}|\partial_\mu\phi_1|^2 + \frac{1}{2}|\partial_\mu\phi_2|^2 + \left(\frac{g_Z^2}{8}Z_\mu Z^\mu + \frac{g^2}{4}W_\mu^+ W^{-\mu}\right)\left[(v_1+\varphi_1)^2 + (v_2+\varphi_2)^2\right]\end{aligned}$$

The $v_1^2 + v_2^2 = v^2$ term gives same masses to W, Z as in the SM

$$m_W^2 = \frac{g^2 v^2}{4} \qquad m_Z^2 = \frac{(g^2 + g'^2)\, v^2}{4} = \frac{m_W^2}{\cos^2\theta_W}$$

The couplings to the gauge bosons arise from

$$2v_1\varphi_1 + 2v_2\varphi_2 = 2v\,[\, H\cos(\beta-\alpha) + h\sin(\beta-\alpha)\,]$$

$\Longrightarrow$ extra coupling factors for hVV and HVV couplings as compared to SM

$$hVV \sim \sin(\beta-\alpha) \qquad HVV \sim \cos(\beta-\alpha)$$

At tree level

$$\cos^2(\beta-\alpha) = \frac{m_h^2\,(m_Z^2 - m_h^2)}{m_A^2\,(m_H^2 - m_h^2)}$$

$$\longrightarrow \frac{m_Z^4 \sin^2 4\beta}{4\, m_A^4} \quad \text{for large } m_A$$

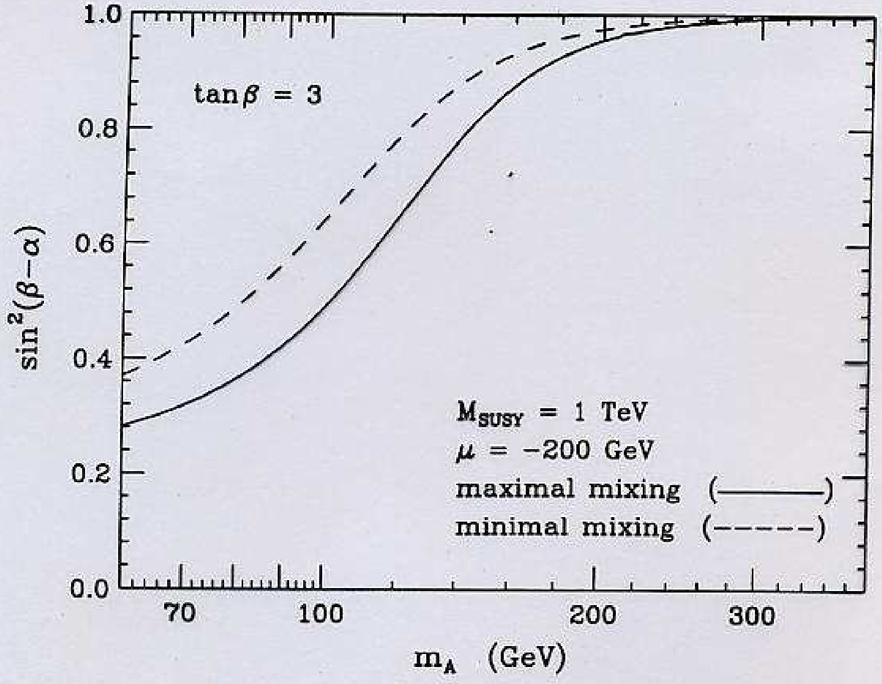
$$\Rightarrow \left.\begin{array}{l} \cos(\beta-\alpha) \to 0 \\ \sin(\beta-\alpha) \to 1 \end{array}\right\} \text{ for large } m_A$$

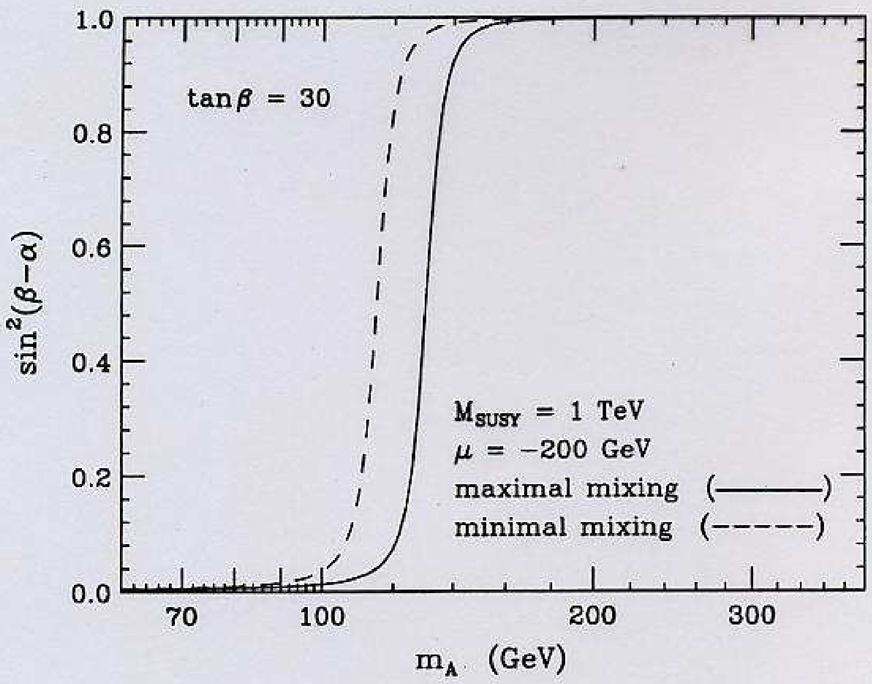
H decouples from W, Z }
h couples like SM } as $m_A \to \infty$

Radiative corrections: no significant change of tree level result for decoupling.

radiative corrections included

run II
report





Coupling to fermions

$$\mathcal{L}_{\text{Yuk.}} = -\Gamma_b \bar{b}_L \Phi_1^0 b_R - \Gamma_t \bar{t}_L \Phi_2^0 u_R + \text{h.c.}$$

$$= -\Gamma_b \bar{b}_L \frac{v_1 + H\cos\alpha - h\sin\alpha + iA\ \sin\beta}{\sqrt{2}} b_R - \Gamma_t \bar{t}_L \frac{v_2 + H\sin\alpha + h\cos\alpha + iA\ \cos\beta}{\sqrt{2}} t_R + \text{h.c.}$$

The v_1, v_2 terms are the fermion masses

$$m_b = \frac{\Gamma_b v_1}{\sqrt{2}} \qquad m_t = \frac{\Gamma_t v_2}{\sqrt{2}} \qquad \Longrightarrow \qquad \frac{\Gamma_b}{\sqrt{2}} = \frac{m_b}{v\cos\beta} \qquad \frac{\Gamma_t}{\sqrt{2}} = \frac{m_t}{v\sin\beta}$$

Expressed in terms of masses the Yukawa Lagrangian is

$$\mathcal{L}_{\text{Yuk.}} = -\frac{m_b}{v}\bar{b}\left(v + H\frac{\cos\alpha}{\cos\beta} - h\frac{\sin\alpha}{\cos\beta} - i\gamma_5 A\ \tan\beta\right) b - \frac{m_t}{v}\bar{t}\left(v + H\frac{\sin\alpha}{\sin\beta} + h\frac{\cos\alpha}{\sin\beta} - i\gamma_5 A\ \cot\beta\right) t$$

$\Longrightarrow$ coupling factors compared to SM hff coupling $-i\ m_f/v$

Decoupling limit for fermions

$h\bar{b}b, h\tau\tau$: $-\frac{\sin\alpha}{\cos\beta} = \underbrace{\sin(\beta-\alpha)}_{\to 1} - \tan\beta \underbrace{\cos(\beta-\alpha)}_{\to 0} \to 1$

$h\bar{t}t$: $\frac{\cos\alpha}{\sin\beta} = \sin(\beta-\alpha) + \frac{\cos(\beta-\alpha)}{\tan\beta} \to 1$

$Hb\bar{b}, H\tau\tau$: $\frac{\cos\alpha}{\cos\beta} = \cos(\beta-\alpha) + \tan\beta \sin(\beta-\alpha)$

$\to \tan\beta$

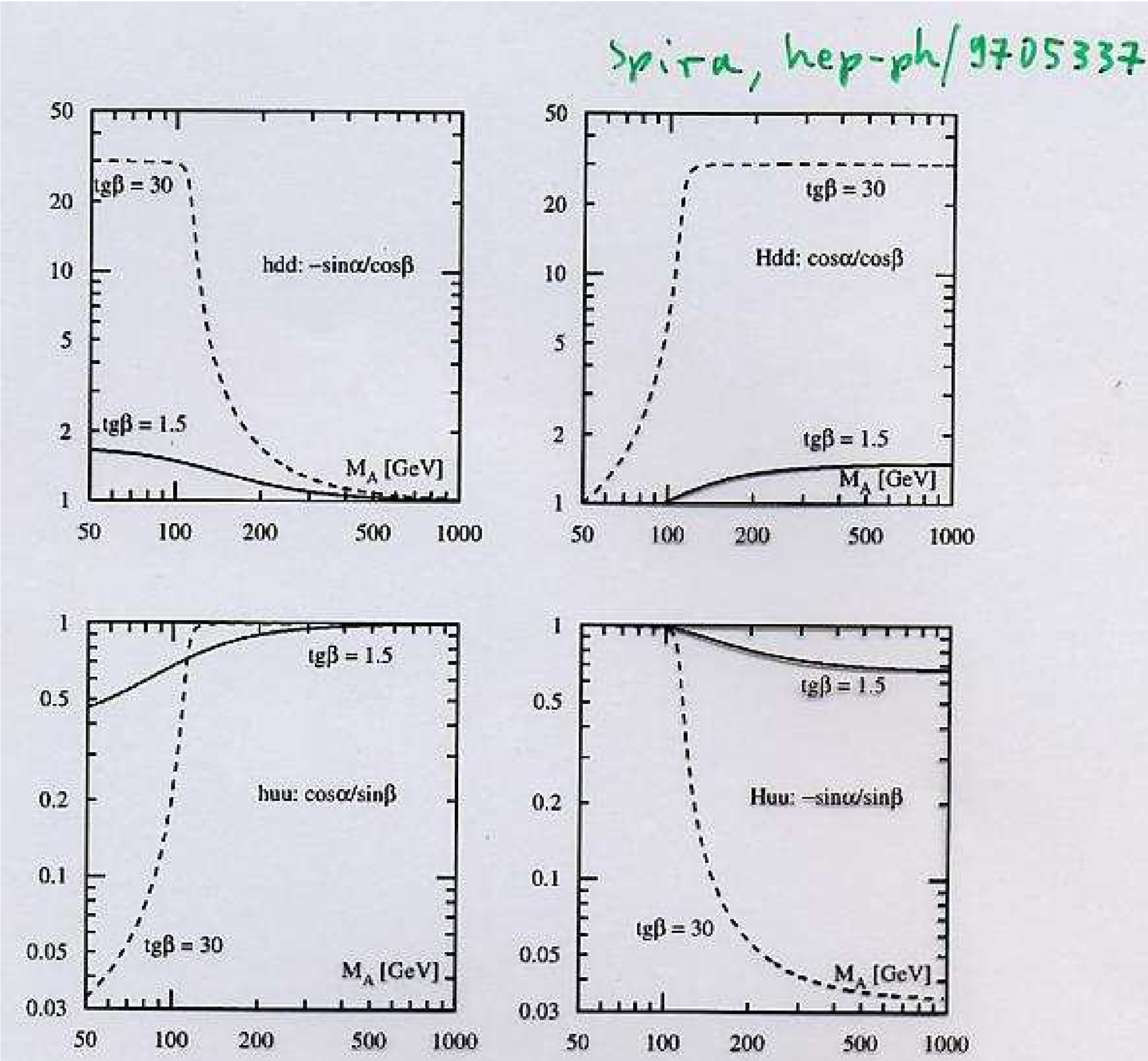
$Ht\bar{t}$: $\frac{\sin\alpha}{\sin\beta} = \cos(\beta-\alpha) - \frac{\sin(\beta-\alpha)}{\tan\beta}$

$\to \frac{-1}{\tan\beta}$

In the large m_A regime

- light h couplings to fermions approach SM values
- $H\bar{b}b$ (and $Ab\bar{b}$, $H(A\tau\tau)$ couplings are enhanced $\sim \tan\beta$

  $\Rightarrow$ large cross sections at LHC


Spira, hep-ph/9705337
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tgβ = 1.5
M_A [GeV]
Hdd: cosα/cosβ
tgβ = 30
tgβ = 1.5
M_A [GeV]
huu: cosα/sinβ
tgβ = 1.5
tgβ = 30
M_A [GeV]
Huu: −sinα/sinβ
tgβ = 1.5
tgβ = 30
M_A [GeV]
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.03
50 100 200 500 1000