Higgs Physics at LHC is τ Physics

Pedestrian Seminar

Pablo Roig

$$SM = SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

$$\mathsf{L}_e = \begin{pmatrix} \nu_e \\ e^- \end{pmatrix}_{\mathrm{L}} \quad \mathsf{L}_\mu = \begin{pmatrix} \nu_\mu \\ \mu^- \end{pmatrix}_{\mathrm{L}} \quad \mathsf{L}_\tau = \begin{pmatrix} \nu_\tau \\ \tau^- \end{pmatrix}_{\mathrm{L}} \qquad \mathsf{R}_{e,\mu,\tau} = e_{\mathrm{R}}, \mu_{\mathrm{R}}, \tau_{\mathrm{R}}$$

$$\mathsf{L}_q^{(1)} = \begin{pmatrix} u \\ d' \end{pmatrix}_{\mathrm{L}} \quad \mathsf{L}_q^{(2)} = \begin{pmatrix} c \\ s' \end{pmatrix}_{\mathrm{L}} \quad \mathsf{L}_q^{(3)} = \begin{pmatrix} t \\ b' \end{pmatrix}_{\mathrm{L}} \qquad \mathsf{R}_u^{(1,2,3)} = u_{\mathrm{R}}, c_{\mathrm{R}}, t_{\mathrm{R}} \text{ and } \mathsf{R}_d^{(1,2,3)} = d_{\mathrm{R}}, s_{\mathrm{R}}, b_{\mathrm{R}}$$

$$\begin{pmatrix} d' \\ s' \\ b' \end{pmatrix} = \begin{pmatrix} V_{ud} & V_{us} & V_{ub} \\ V_{cd} & V_{cs} & V_{cb} \\ V_{td} & V_{ts} & V_{tb} \end{pmatrix} \begin{pmatrix} d \\ s \\ b \end{pmatrix} \equiv \mathsf{V} \begin{pmatrix} d \\ s \\ b \end{pmatrix}$$

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$$\mathcal{L} = \mathcal{L}_{\text{gauge}} + \mathcal{L}_{\text{leptons}} + \mathcal{L}_{\text{quarks}}$$

$$\mathcal{L}_{\text{gauge}} = -\tfrac{1}{4}\sum_\ell F^\ell_{\mu\nu} F^{\ell\,\mu\nu} - \tfrac{1}{4} f_{\mu\nu} f^{\mu\nu}$$

$$\begin{aligned}\mathcal{L}_{\text{leptons}} &= \overline{\mathsf{R}}_\ell\, i\gamma^\mu \left(\partial_\mu + i\frac{g'}{2}\mathcal{A}_\mu Y\right)\mathsf{R}_\ell \\ &+ \overline{\mathsf{L}}_\ell\, i\gamma^\mu \left(\partial_\mu + i\frac{g'}{2}\mathcal{A}_\mu Y + i\frac{g}{2}\boldsymbol{\tau}\cdot \boldsymbol{b}_\mu\right)\mathsf{L}_\ell\end{aligned}$$

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Where all particles are **massless**:

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Unless ${\rm SU(2)_L \otimes U(1)_Y}$ is **hidden**…

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Since $U(1)_{em}$ is conserved, we know that the pattern of **S**pontaneous **S**ymmetry **B**reaking must be …

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ESSENTIAL REMARK: IT IS ALL WE KNOW

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GENERAL CONSIDERATION: FIRST TRY THE EASIEST SOLUTION

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$$\phi \equiv \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \quad \mathcal{L}_{\rm scalar} = (\mathcal{D}^\mu \phi)^\dagger (\mathcal{D}_\mu \phi) - V(\phi^\dagger \phi) \qquad V(\phi^\dagger \phi) = \mu^2 (\phi^\dagger \phi) + |\lambda| (\phi^\dagger \phi)^2$$

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After **EWSB**, it will give rise to W and Z masses

$(\mu^2 < 0)$

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After **EWSB**, it will give rise to W and Z masses

Moreover, the following term is also allowed by symmetries:

$\mathcal{L}_{\mathrm{Yukawa}-\ell} = -\zeta_\ell \left[(\overline{\mathsf{L}}_\ell \phi) \mathsf{R}_\ell + \overline{\mathsf{R}}_\ell (\phi^\dagger \mathsf{L}_\ell) \right]$ Giving fermion masses

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$$M_W = gv/2 = ev/2 \sin\theta_W$$

$$v = (G_F\sqrt{2})^{-1/2} = 246 \text{ GeV}$$

$$M_Z = M_W / \cos\theta_W$$

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Giving fermion masses

$$m_e = \zeta_e v / \sqrt{2}$$

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Giving fermion masses

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V-A theory of CC Weak interactions→Fermi theory

Parity Violation

Cabibbo Universality on l, sl.

$$M_Z = \frac{M_W}{\cos\vartheta_W}$$

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Giving fermion masses

$$m_e = \zeta_e v / \sqrt{2}$$

$$M_H^{\ 2} = -2\mu^2 > 0$$

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$$\mathcal{L}_{\text{Yukawa}-\ell} = -\zeta_\ell \left[(\overline{\mathrm{L}}_\ell \phi) \mathrm{R}_\ell + \overline{\mathrm{R}}_\ell (\phi^\dagger \mathrm{L}_\ell) \right]$$

Giving fermion masses

$$m_e = \zeta_e v/\sqrt{2}$$

$$M_H{}^2 = -2\mu^2 > 0$$

$$M_H{}^2 = ?$$

Summing up: The Higgs mechanism is the simplest way of making the $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ Symmetry compatible with the nonvanishing masses of the most of its constituents.

$$SM = SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$$

$$SU(2)_L \otimes U(1)_Y \to U(1)_{em}$$

HIGGS MECHANISM (easiest way)

$$\phi \equiv \begin{pmatrix} \phi^+ \\ \phi^0 \end{pmatrix} \quad \mathcal{L}_{\text{scalar}} = (\mathcal{D}^\mu \phi)^\dagger (\mathcal{D}_\mu \phi) - V(\phi^\dagger \phi) \qquad V(\phi^\dagger \phi) = \mu^2 (\phi^\dagger \phi) + |\lambda| (\phi^\dagger \phi)^2$$

$$\mathcal{D}_\mu = \partial_\mu + i\frac{g'}{2}\mathcal{A}_\mu Y + i\frac{g}{2}\tau \cdot b_\mu$$

After **EWSB**, it will give rise to W and Z masses

$$M_W = gv/2 = ev/2\sin\theta_W$$

$$v = (G_F\sqrt{2})^{-1/2} = 246 \text{ GeV}$$

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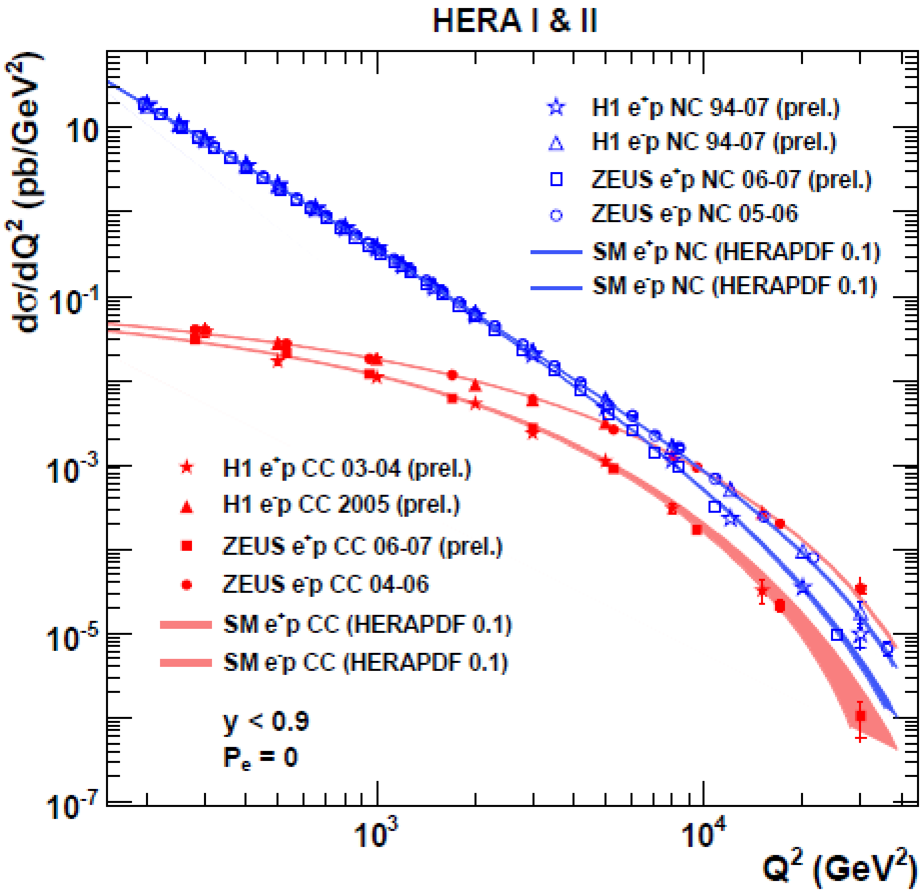
→ But don't forget *there are many others*…

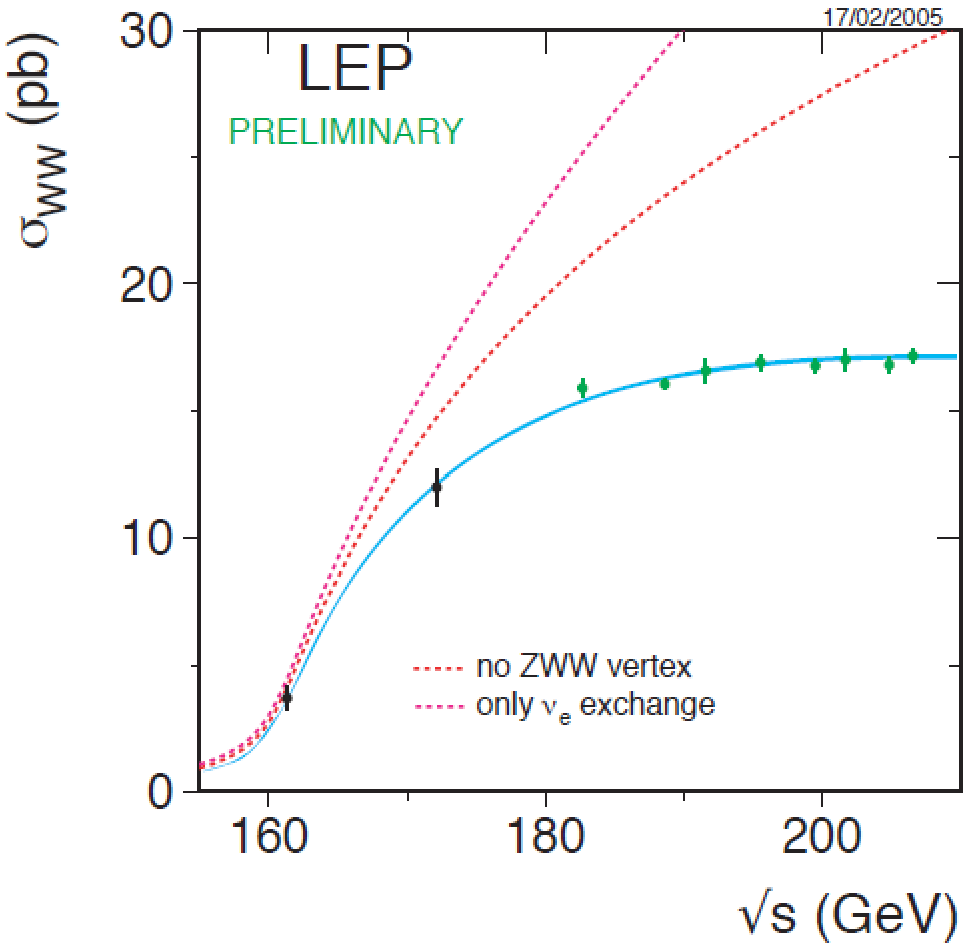
ESSENTIAL REMARK: IT IS ALL WE KNOW

Tests of SM



HERA I & II
dσ/dQ² (pb/GeV²)
H1 e⁺p NC 94-07 (prel.)
H1 e⁻p NC 94-07 (prel.)
ZEUS e⁺p NC 06-07 (prel.)
ZEUS e⁻p NC 05-06
SM e⁺p NC (HERAPDF 0.1)
SM e⁻p NC (HERAPDF 0.1)
H1 e⁺p CC 03-04 (prel.)
H1 e⁻p CC 2005 (prel.)
ZEUS e⁺p CC 06-07 (prel.)
ZEUS e⁻p CC 04-06
SM e⁺p CC (HERAPDF 0.1)
SM e⁻p CC (HERAPDF 0.1)
y < 0.9
Pₑ = 0
Q² (GeV²)

$$e^+e^- \to W^+W^-$$


17/02/2005
LEP
PRELIMINARY
σWW (pb)
30
20
10
0
160
180
200
√s (GeV)
no ZWW vertex
only νe exchange

1989

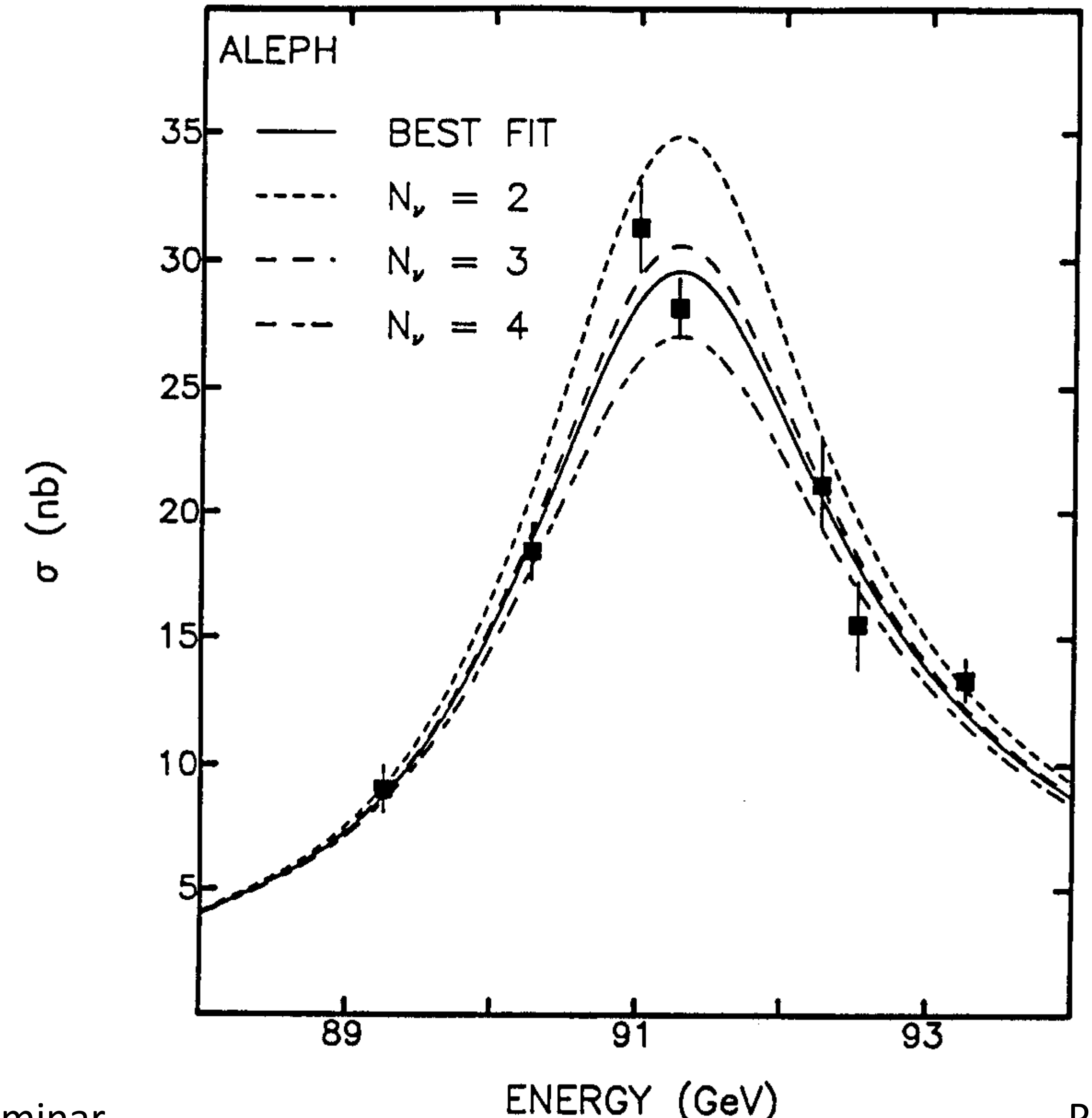


Figure 5: The cross-section for $e^+e^- \to$ hadrons as a function of centre-of-mass energy and result of the three parameter fit.

2005

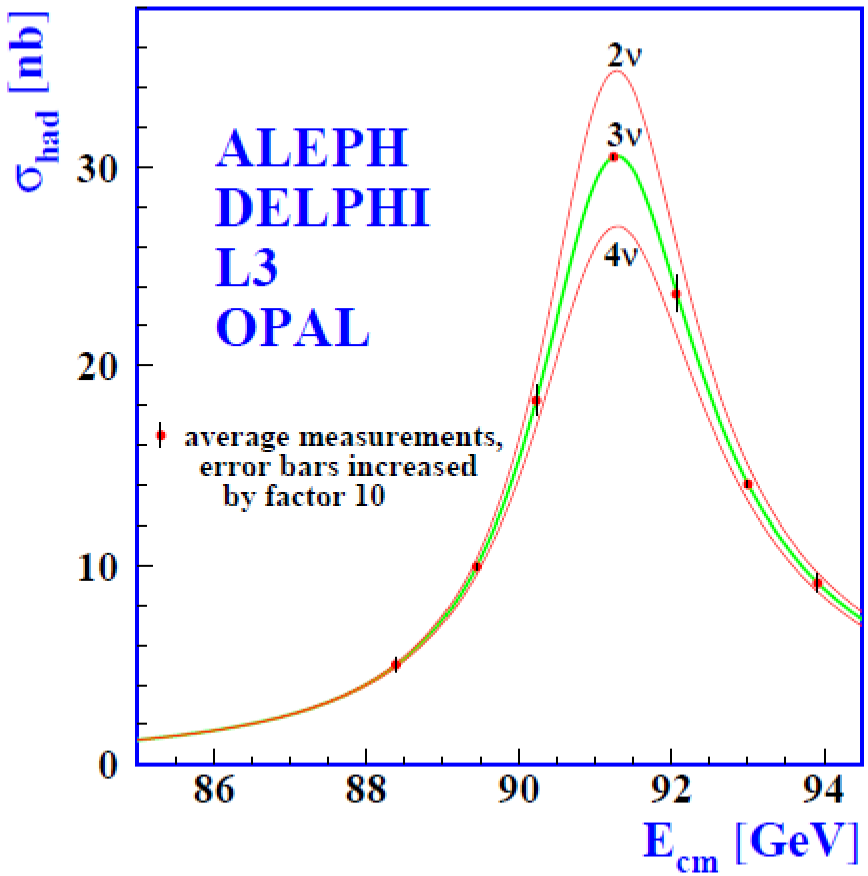


Figure 1.13: Measurements of the hadron production cross-section around the Z resonance. The curves indicate the predicted cross-section for two, three and four neutrino species with SM couplings and negligible mass.

Tests of SM

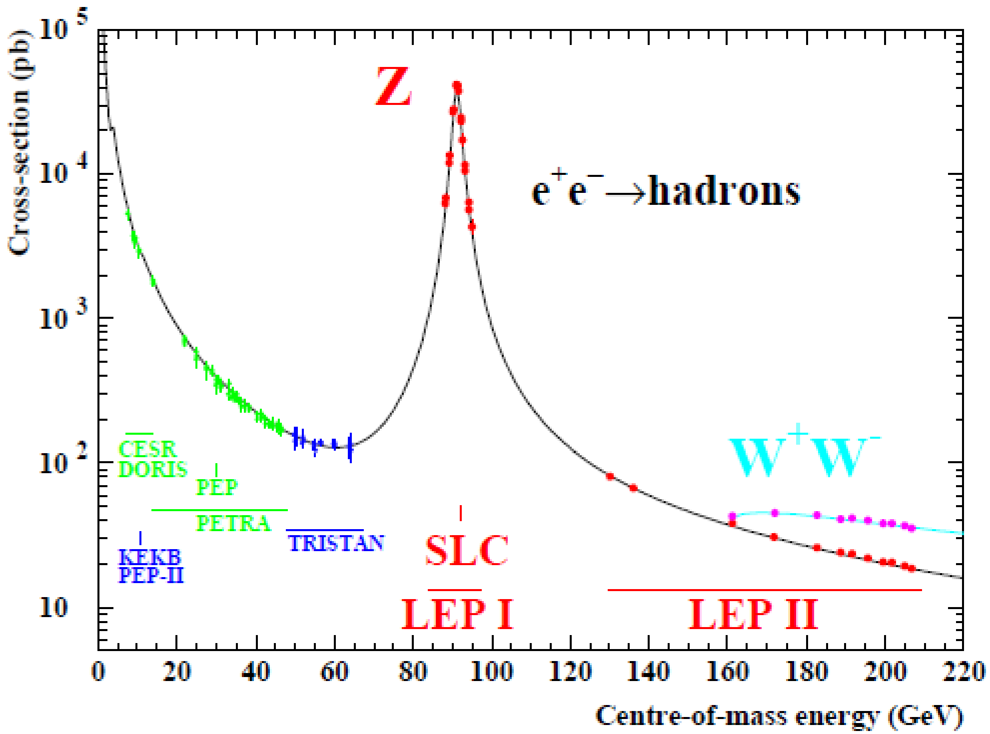
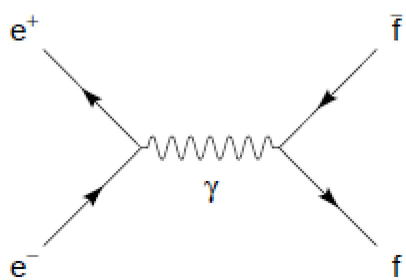
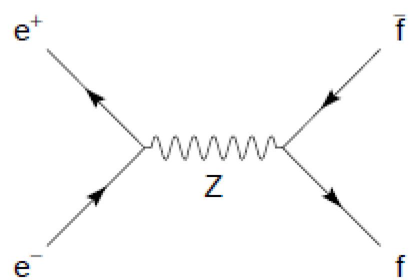


Figure 1.2: The hadronic cross-section as a function of centre-of-mass energy. The solid line is the prediction of the SM, and the points are the experimental measurements. Also indicated are the energy ranges of various e^+e^- accelerators. The cross-sections have been corrected for the effects of photon radiation.





Smallness of FCNC processes
Test of Cabibbo picture (CKM)

$$M_W^2 = M_Z^2 \left(1 - \sin^2\theta_{\mathrm{W}}\right)\left(1 + \Delta\rho\right)$$

$$\Delta\rho \approx \Delta\rho^{(\mathrm{quarks})} = \frac{3G_{\mathrm{F}} m_t^2}{8\pi^2\sqrt{2}}$$

Tests of SM

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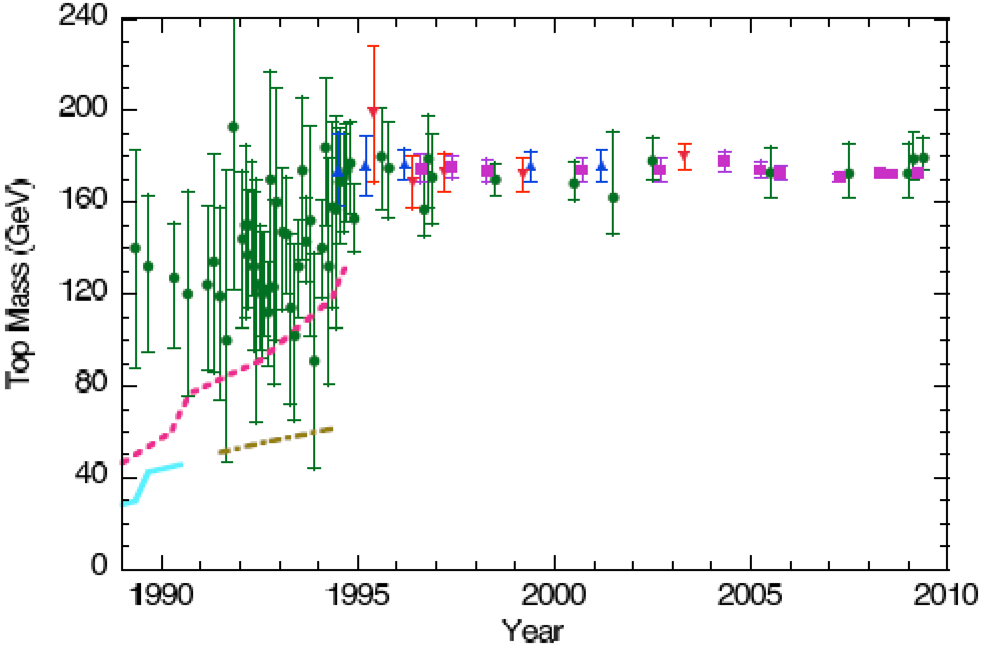
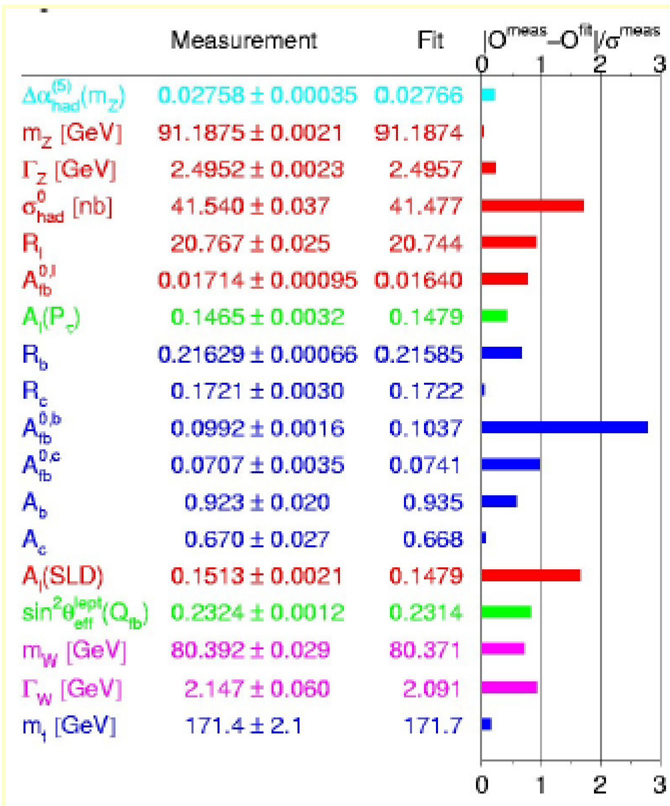
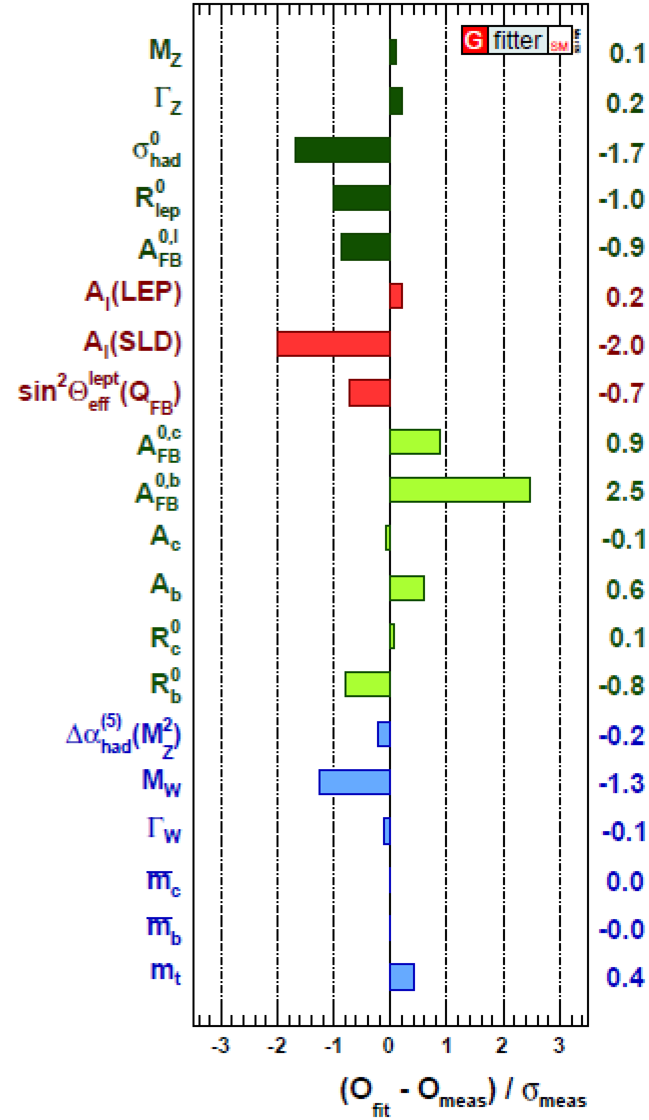


Tests of SM

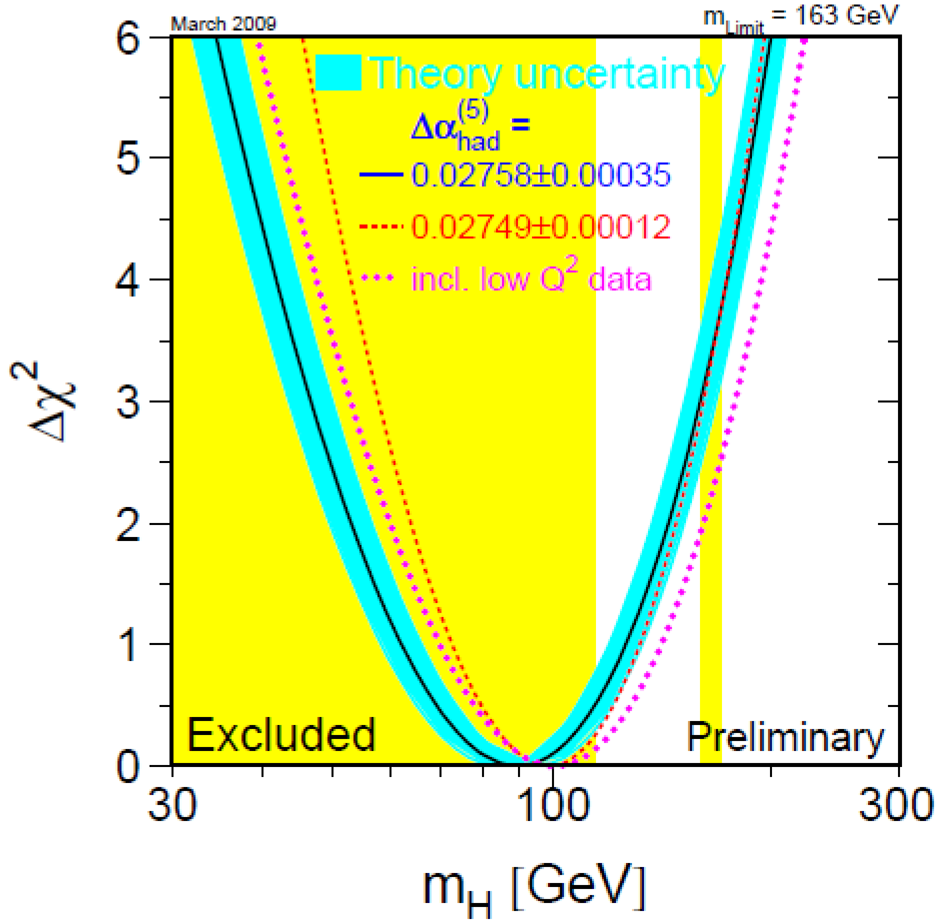


Measurement
Fit
|O^meas−O^fit|/σ^meas
0 1 2 3
Δα_had^(5)(m_Z) 0.02758 ± 0.00035 0.02766
m_Z [GeV] 91.1875 ± 0.0021 91.1874
Γ_Z [GeV] 2.4952 ± 0.0023 2.4957
σ_had^0 [nb] 41.540 ± 0.037 41.477
R_l 20.767 ± 0.025 20.744
A_fb^0,l 0.01714 ± 0.00095 0.01640
A_l(P_τ) 0.1465 ± 0.0032 0.1479
R_b 0.21629 ± 0.00066 0.21585
R_c 0.1721 ± 0.0030 0.1722
A_fb^0,b 0.0992 ± 0.0016 0.1037
A_fb^0,c 0.0707 ± 0.0035 0.0741
A_b 0.923 ± 0.020 0.935
A_c 0.670 ± 0.027 0.668
A_l(SLD) 0.1513 ± 0.0021 0.1479
sin²θ_eff^lept(Q_fb) 0.2324 ± 0.0012 0.2314
m_W [GeV] 80.392 ± 0.029 80.371
Γ_W [GeV] 2.147 ± 0.060 2.091
m_t [GeV] 171.4 ± 2.1 171.7
0 1 2 3



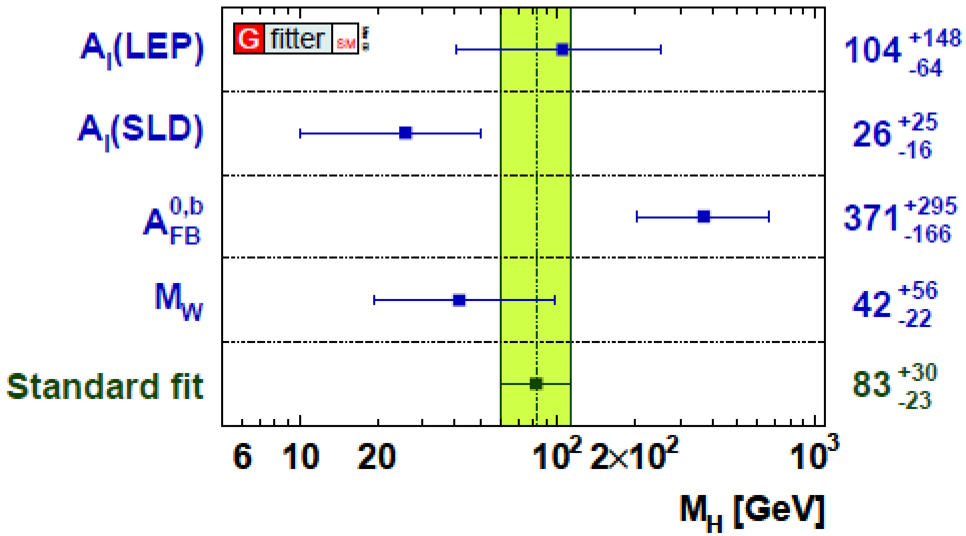
G fitter SM
M_Z 0.1
Γ_Z 0.2
σ_had^0 -1.7
R_lep^0 -1.0
A_FB^0,l -0.9
A_l(LEP) 0.2
A_l(SLD) -2.0
sin²Θ_eff^lept(Q_FB) -0.7
A_FB^0,c 0.9
A_FB^0,b 2.5
A_c -0.1
A_b 0.6
R_c^0 0.1
R_b^0 -0.8
Δα_had^(5)(M_Z^2) -0.2
M_W -1.3
Γ_W -0.1
m̄_c 0.0
m̄_b -0.0
m_t 0.4
-3 -2 -1 0 1 2 3
(O_fit - O_meas) / σ_meas

Tests of SM



The Higgs-boson masses favored by the global fits of the LEP Electroweak Working Group, $M_H = 90^{+36}_{-27}$ GeV [53], Gfitter, 83^{+30}_{-23} GeV [108], or Particle Data Group, 70^{+28}_{-22} GeV [36], lie in the region excluded by direct searches at LEP.

Tests of SM



fitter
A_l(LEP)
A_l(SLD)
$A_{FB}^{0,b}$
M_W
Standard fit
104^{+148}_{-64}
26^{+25}_{-16}
371^{+295}_{-166}
42^{+56}_{-22}
83^{+30}_{-23}
6
10
20
10^2
2×10^2
10^3
M_H [GeV]

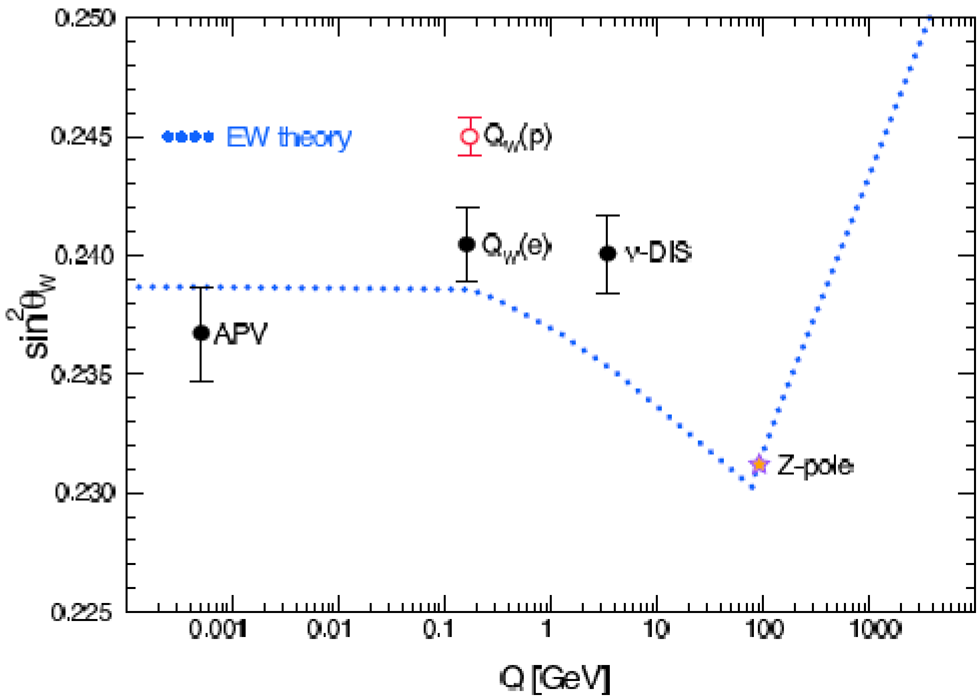


FIG. 8: Evolution of the weak mixing parameter $\sin^2\theta_W$ in the $\overline{\rm MS}$ scheme [125] (dotted curve). The minimum occurs at $Q = M_W$, where the β-function for the weak mixing parameter changes sign as the influence of weak-boson loops drops out. The selected data are from atomic parity violation [126] (APV), Møller scattering [127] ($Q_W(e)$), and deeply inelastic νN scallering [128, 129]. Also indicated (open circle) is the uncertainty projected for the $Q_{\rm weak}$ experiment [130].

Tests of SM

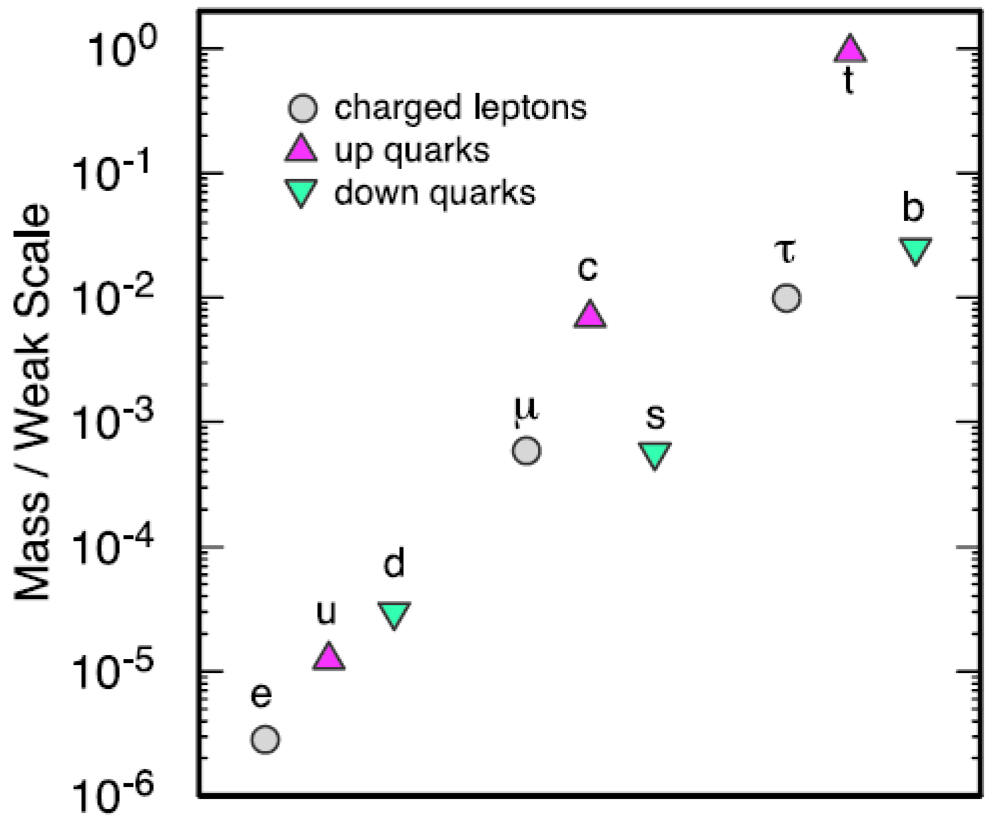


FIG. 9: Yukawa couplings $\zeta_i = m_i/(v/\sqrt{2})$ inferred from the masses of the quarks and charged leptons [49].

EWSB

Two-body collisions $W_0^+ W_0^-$ $\frac{Z_0 Z_0}{\sqrt{2}}$ $\frac{HH}{\sqrt{2}}$ HZ_0

For $s \gg M_H^2, M_W^2, M_Z^2,$

$$(a_0) \to \frac{-G_F M_H^2}{4\pi\sqrt{2}} \cdot \begin{bmatrix} 1 & 1/\sqrt{8} & 1/\sqrt{8} & 0 \\ 1/\sqrt{8} & 3/4 & 1/4 & 0 \\ 1/\sqrt{8} & 1/4 & 3/4 & 0 \\ 0 & 0 & 0 & 1/2 \end{bmatrix}$$

$$|a_0| \leq 1 \Rightarrow \quad M_H \leq \left(\frac{8\pi\sqrt{2}}{3G_F}\right)^{1/2} \approx 1 \text{ TeV}$$

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The other way out is to have a strongly interacting theory at this energy scale (χPT-like)

EWSB

Two body collisions among EW gauge bosons and Higgs

if weak interactions are to be always weak, then $M_H \leq 1$ TeV

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$$V(\phi^\dagger\phi) = \mu^2(\phi^\dagger\phi) + |\lambda|\,(\phi^\dagger\phi)^2$$

Stability of V: existence of lower bound for H $\rightarrow \lambda > 0$

When considering Quantum corrections → Limits on M_H as a function of Λ^{NP}

$$M_H|_{\Lambda=1\mathrm{TeV}} \gtrsim 50.8\ \mathrm{GeV} + 0.64(m_t - 173.1\ \mathrm{GeV})$$

$$M_H|_{\Lambda=M_{\mathrm{Planck}}} \gtrsim 134\ \mathrm{GeV}$$

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(Meta)Stability of V against Quantum corrections:

$$M_H|_{\Lambda=M_{\mathrm{Planck}}} \lesssim 180\ \mathrm{GeV}$$
$$M_H|_{\Lambda=1\,\mathrm{TeV}} \lesssim 700\ \mathrm{GeV}$$

EWSB

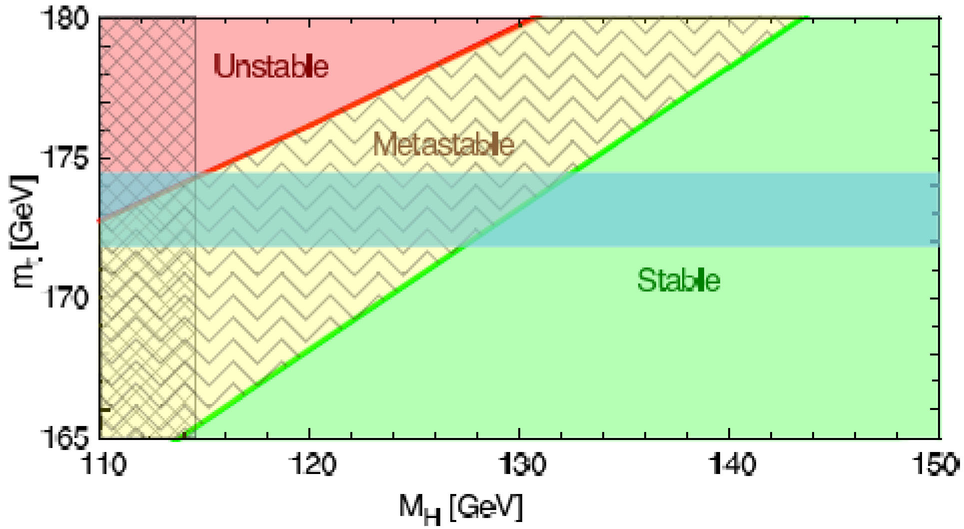

FIG. 10: Metastability region of the standard-model vacuum in the (M_H, m_t) plane [158]. The hatched region at left indicates the LEP lower bound, $M_H > 114.4$ GeV. The horizontal band shows the measured top-quark mass, $m_t = (173.1 \pm 1.3)$ GeV [106].

EWSB

Two body collisions among EW gauge bosons and Higgs

if weak interactions are to be always weak, then $M_H \lesssim 1$ TeV

The other way out is to have a strongly interacting theory at this energy scale (χPT-like)

$V(\phi^\dagger\phi) = \mu^2(\phi^\dagger\phi) + |\lambda|\,(\phi^\dagger\phi)^2$ Lower bound for H → $\lambda>0$ $M_H|_{\Lambda=1\mathrm{TeV}} \gtrsim 50.8\ \mathrm{GeV} + 0.64(m_t - 173.1\ \mathrm{GeV})$

$M_H|_{\Lambda=M_{\mathrm{Planck}}} \gtrsim 134\ \mathrm{GeV}$

(Meta)Stability of V_{min}

$M_H|_{\Lambda=M_{\mathrm{Planck}}} \lesssim 180\ \mathrm{GeV}$

$M_H|_{\Lambda=1\mathrm{TeV}} \lesssim 700\ \mathrm{GeV}$

Does this mean that 134 GeV$\lesssim M_H \lesssim$180 GeV?

No, this means that if the SM is selfconsistent (complete) up to M_{Pl} → 134 GeV$\lesssim M_H \lesssim$180 GeV

The other way out is to have some kind of NP in between the EW and Pl scales

EWSB

Two body collisions among EW gauge bosons and Higgs

if weak interactions are to be always weak, then $M_H \leq 1$ TeV

The other way out is to have a strongly interacting theory at this energy scale (χPT-like)

LEP lower bound, $M_H > 114.4$ GeV

Potential bounded and its (meta)stability

If the SM is selfconsistent (complete) up to M_{Pl} $\rightarrow$ 134 GeV $\leq M_H \leq$ 180 GeV

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And again: The Higgs mechanism is the simplest way of making the $SU(3)_C \otimes SU(2)_L \otimes U(1)_Y$ Symmetry compatible with the nonvanishing masses of the most of its constituents.

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EWSB

Two body collisions among EW gauge bosons and Higgs

if weak interactions are to be always weak, then $M_H \leq 1$ TeV

CDF & D0 at Tevatron **excludes**:
170GeV<M_H<180GeV

The other way out is to have a strongly interacting theory at this energy scale (χPT-like)

$$\text{LEP lower bound, } M_H > 114.4 \text{ GeV}$$

Potential bounded and its (meta)stability

If the SM is selfconsistent (complete) up to M_{Pl}
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Search for the SM Higgs

$$\Gamma(H \to f\bar{f}) = \frac{G_F m_f^2 M_H}{4\pi\sqrt{2}} \cdot N_c \cdot \left(1 - \frac{4m_f^2}{M_H^2}\right)^{3/2}$$

$$\Gamma(H \to W^+W^-) = \frac{G_F M_H^3}{32\pi\sqrt{2}}(1-x)^{1/2}(4-4x+3x^2) \qquad x \equiv 4M_W^2/M_H^2$$

$$\Gamma(H \to Z^0Z^0) = \frac{G_F M_H^3}{64\pi\sqrt{2}}(1-x')^{1/2}(4-4x'+3x'^2)$$

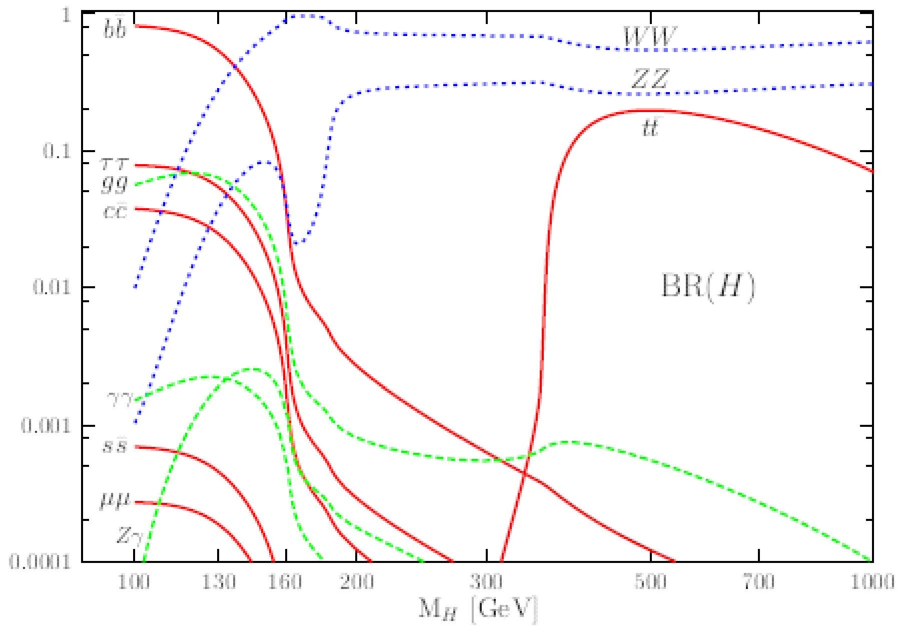

FIG. 12: Branching fractions for prominent decay modes of the standard-model Higgs boson, from [170].

Search for the SM Higgs

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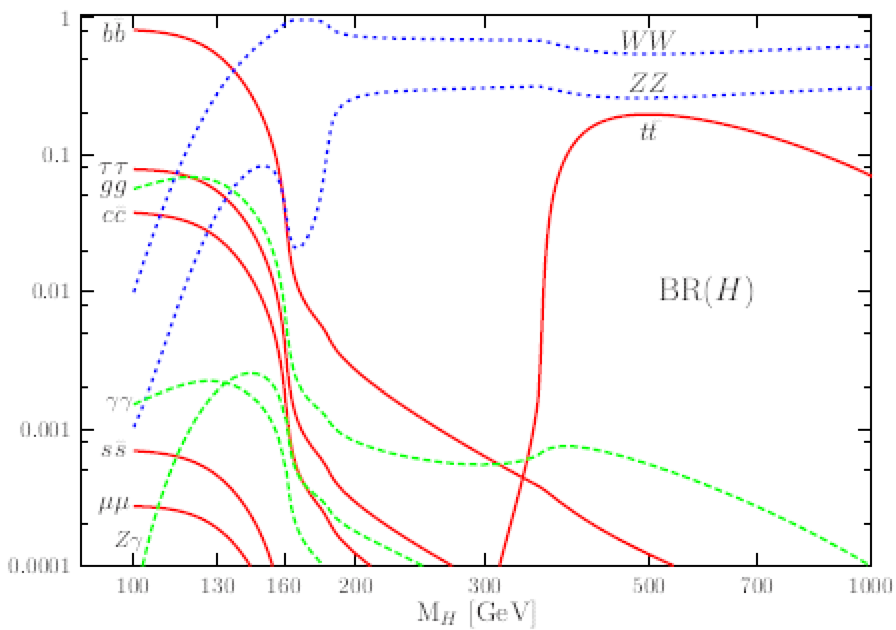

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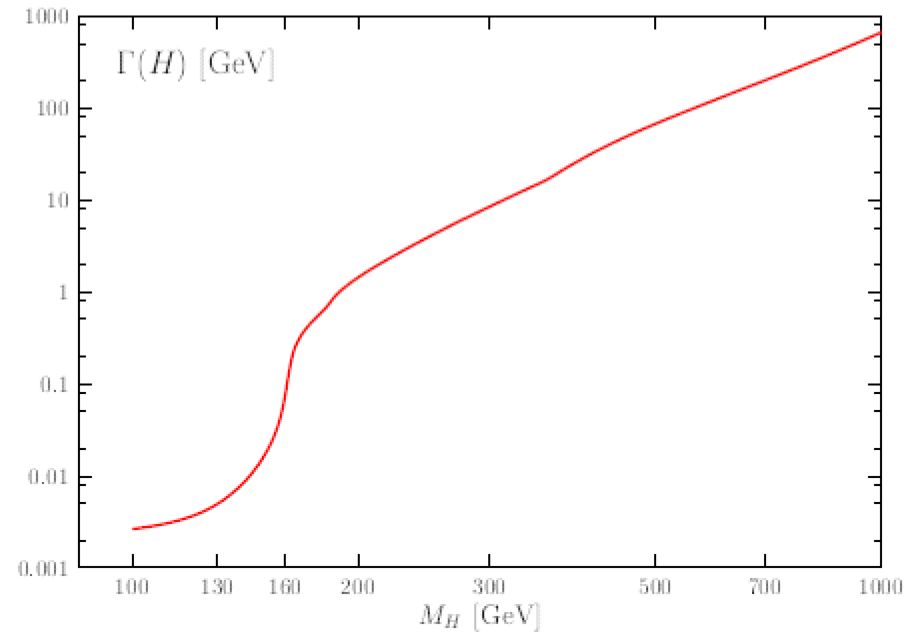
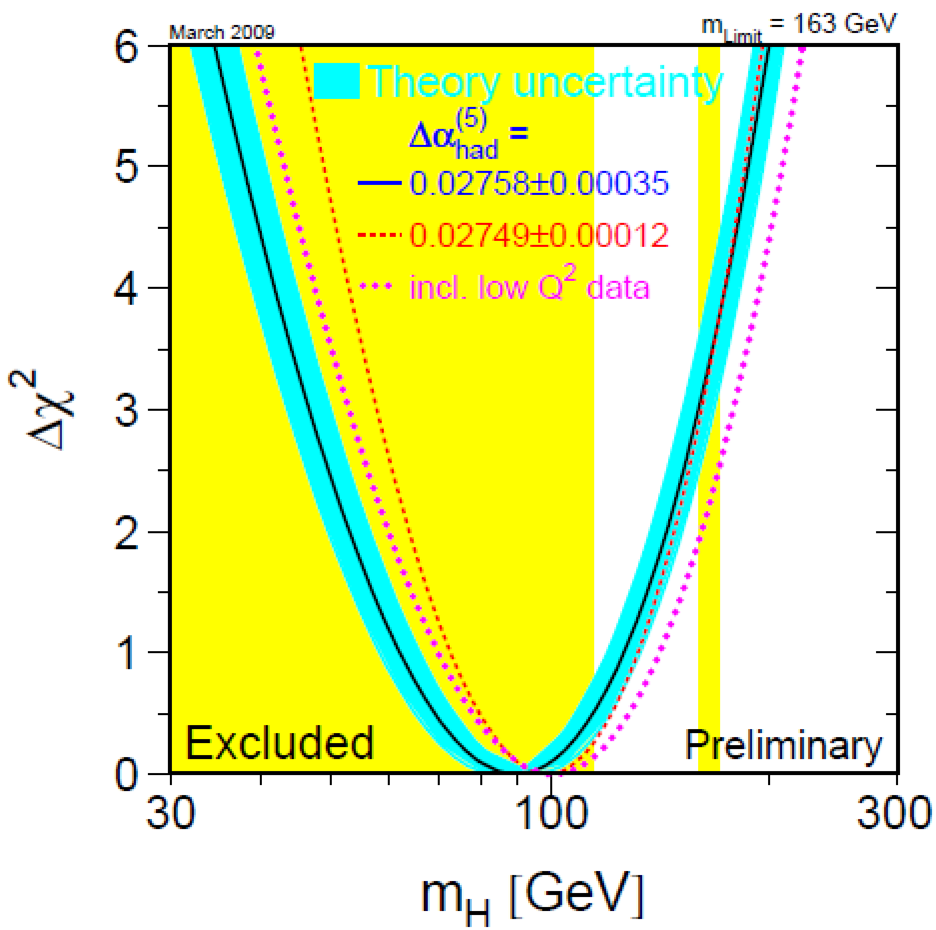


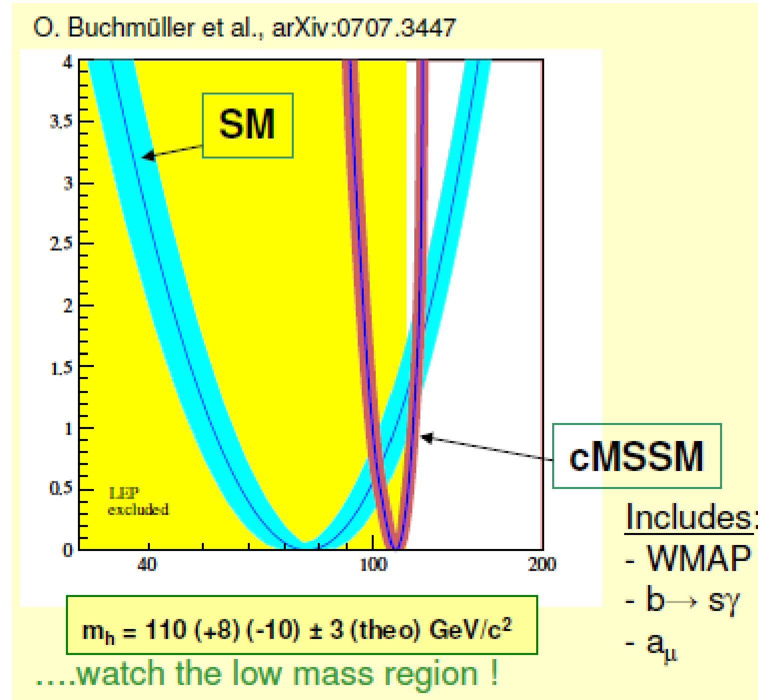
FIG. 13: Total width of the standard-model Higgs boson vs. mass, from [170].

No Higgs: Alternatives

•Technicolor-like: à la QCD. Technifermion condensates produce the masses for W and Z.
•Little Higgs: The Higgs is as a pseudo-Goldstone of a spontaneously broken global sym.
•Boundary conditions on extra-dim yield EWSB. Consequence: KK particles.
•EW theory itself in more than 4D.
•EWSB arises from strong interactions among the weak gauge bosons.
•…

Where to search for the Higgs





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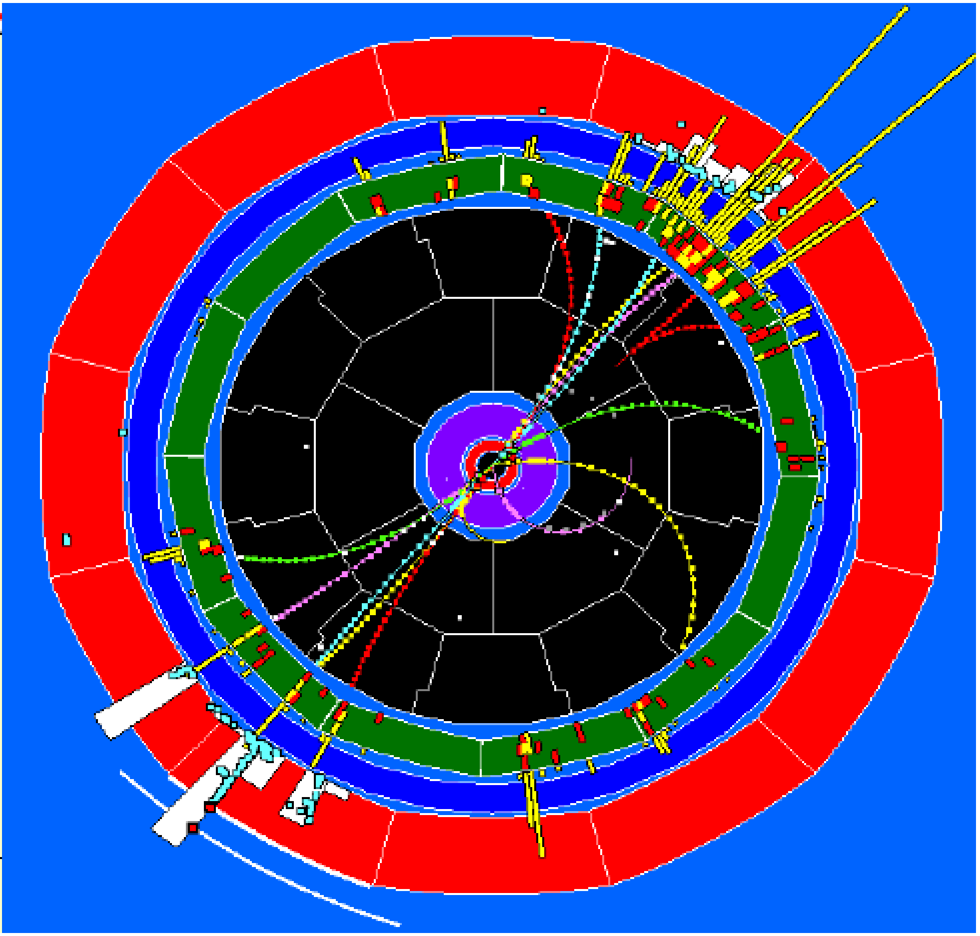
Leptonic collider

Hadronic collider

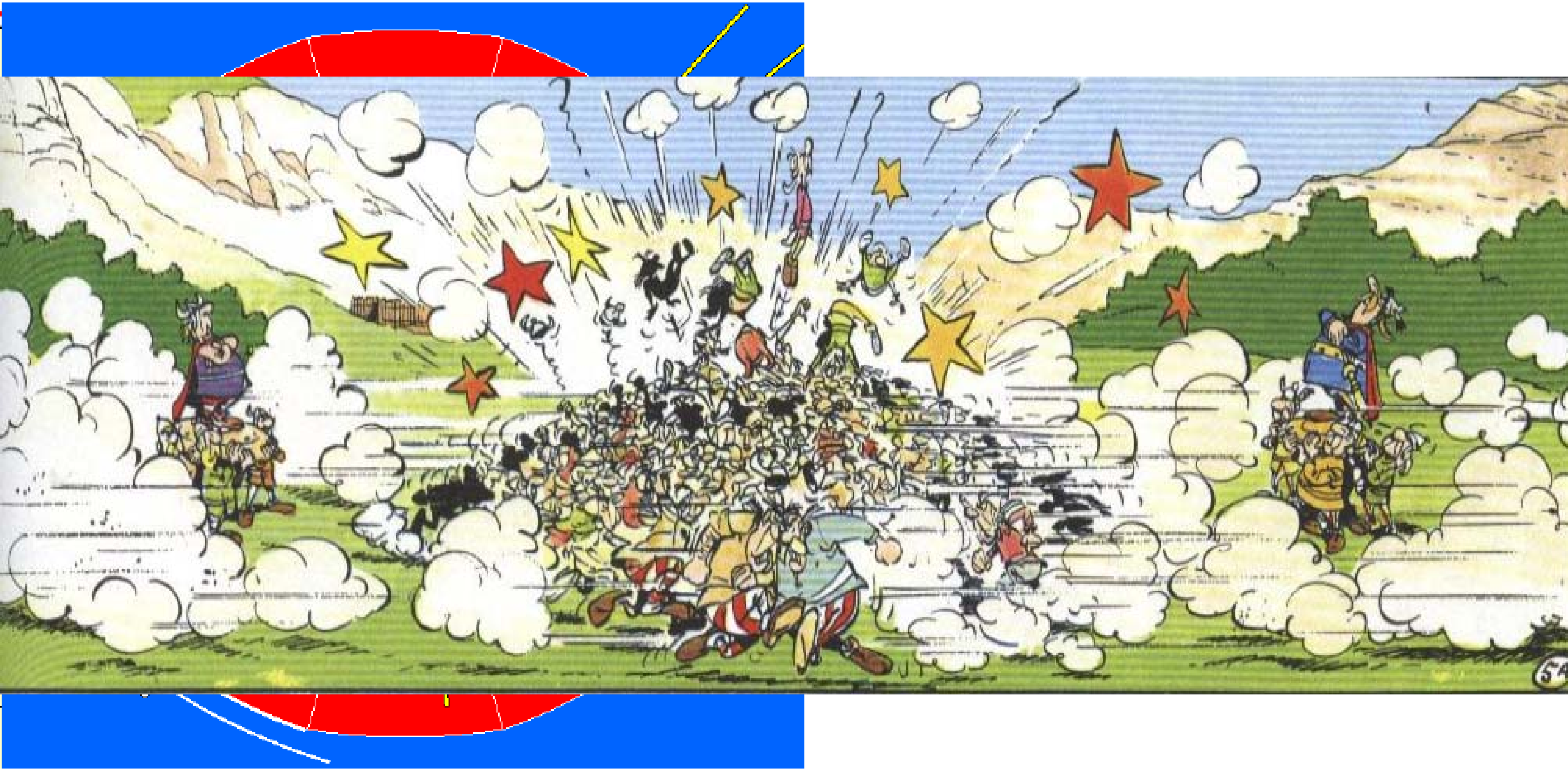


Pedestrian Seminar

Pablo Roig

Leptonic collider

Hadronic collider



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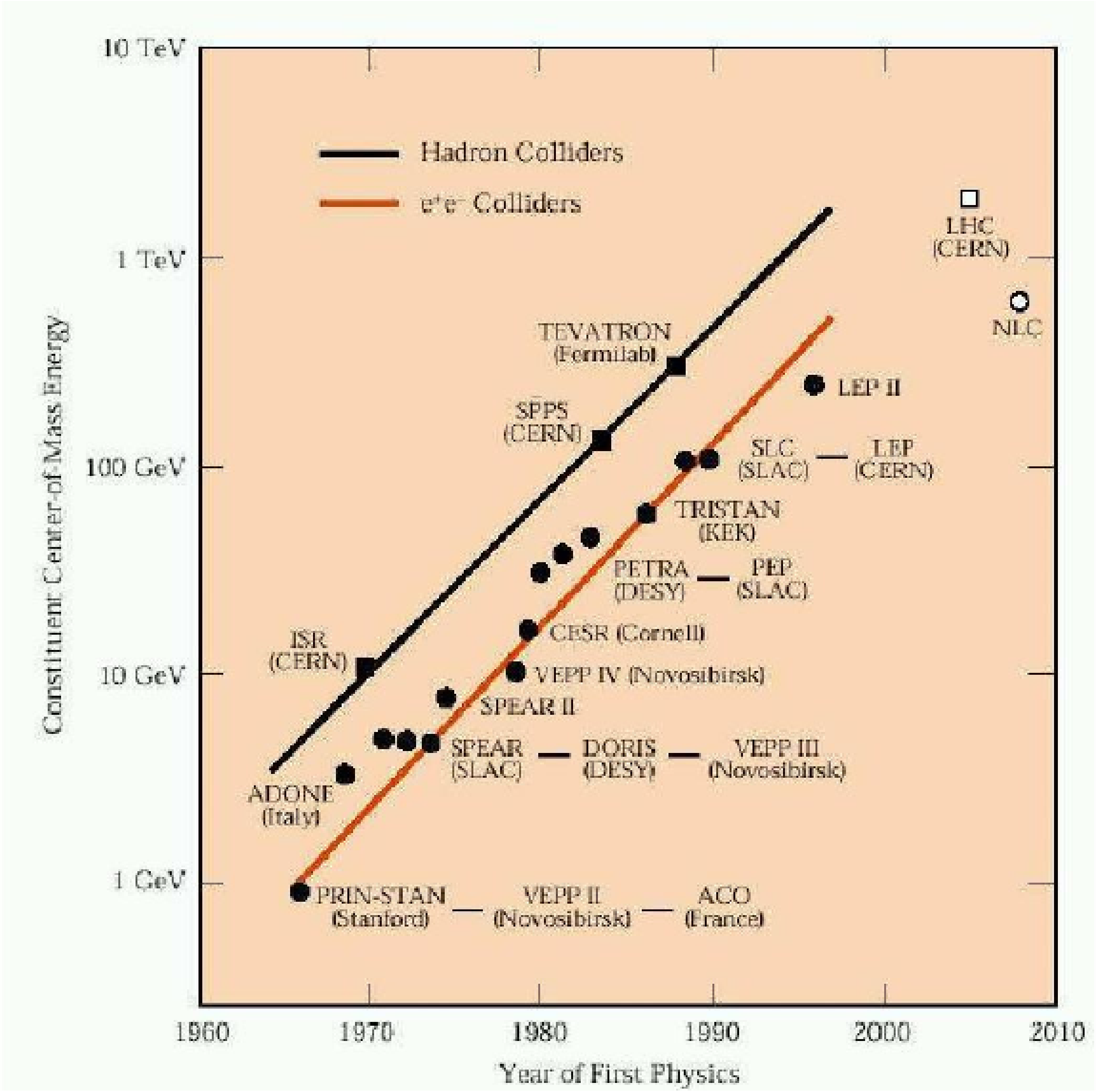
Leptonic vs hadronic colliders



Towards Physics:

some aspects of reconstruction of physics objects

- As discussed before, key signatures at Hadron Colliders are

Leptons: e (tracking + very good electromagnetic calorimetry)
μ (dedicated muon systems, combination of inner tracking and muon spectrometers)
τ hadronic decays: $\tau \rightarrow \pi^{+} + n\,\pi^{0} + \nu$ (1 prong)
$\rightarrow \pi^{+}\pi^{-}\pi^{+} + n\,\pi^{0} + \nu$ (3 prong)

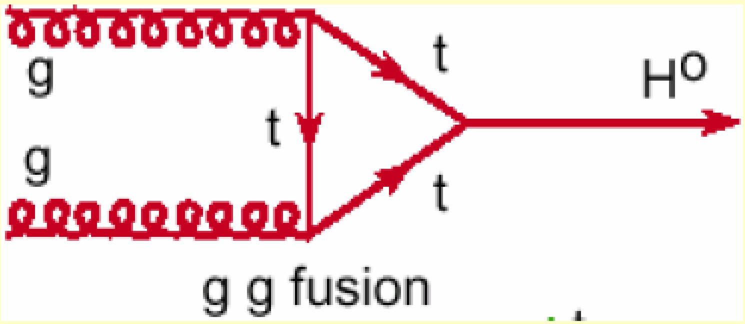
Photons: γ (tracking + very good electromagnetic calorimetry)

Jets: electromagnetic and hadronic calorimeters
b-jets identification of b-jets (b-tagging) important for many physics studies

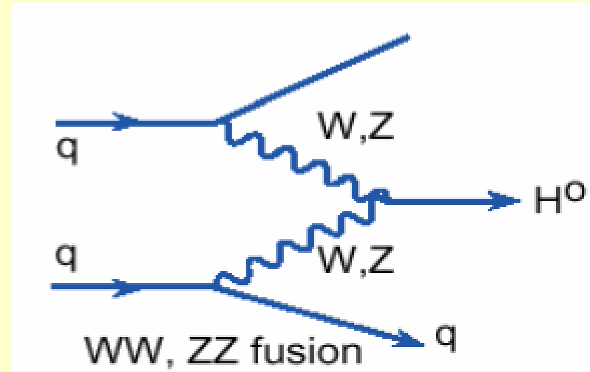
Missing transverse energy: inferred from the measurement of the total energy in the calorimeters; needs understanding of all components… response of the calorimeter to low energy particles

Higgs Boson Production at Hadron Colliders

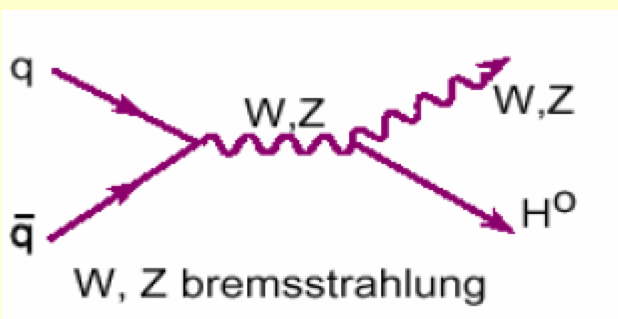
(i) Gluon fusion

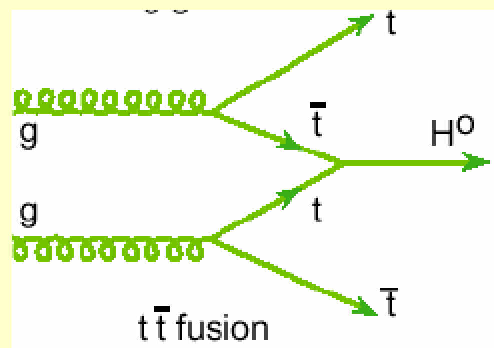


(ii) Vector boson fusion

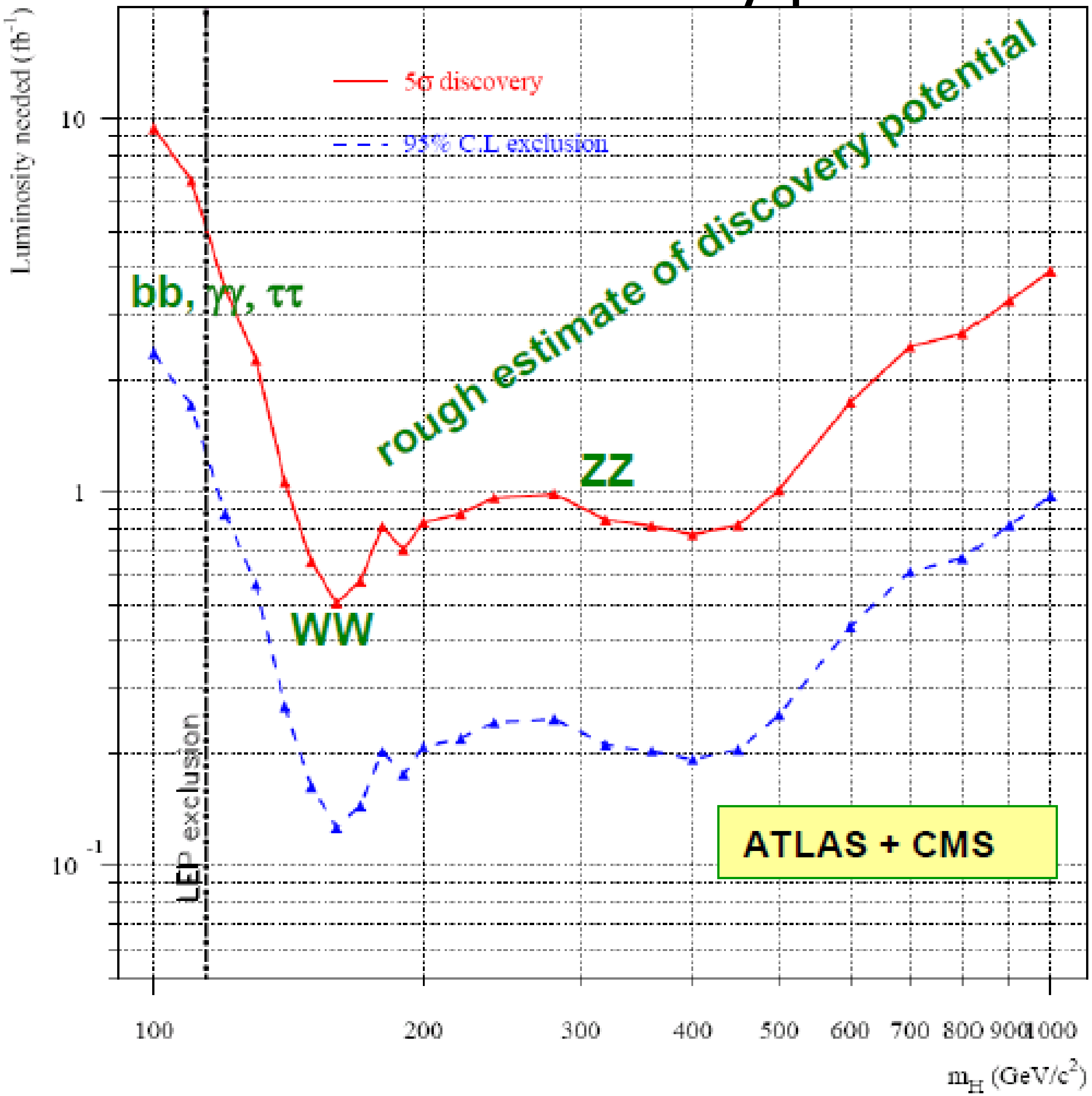


(iii) Associated production (W/Z, tt)

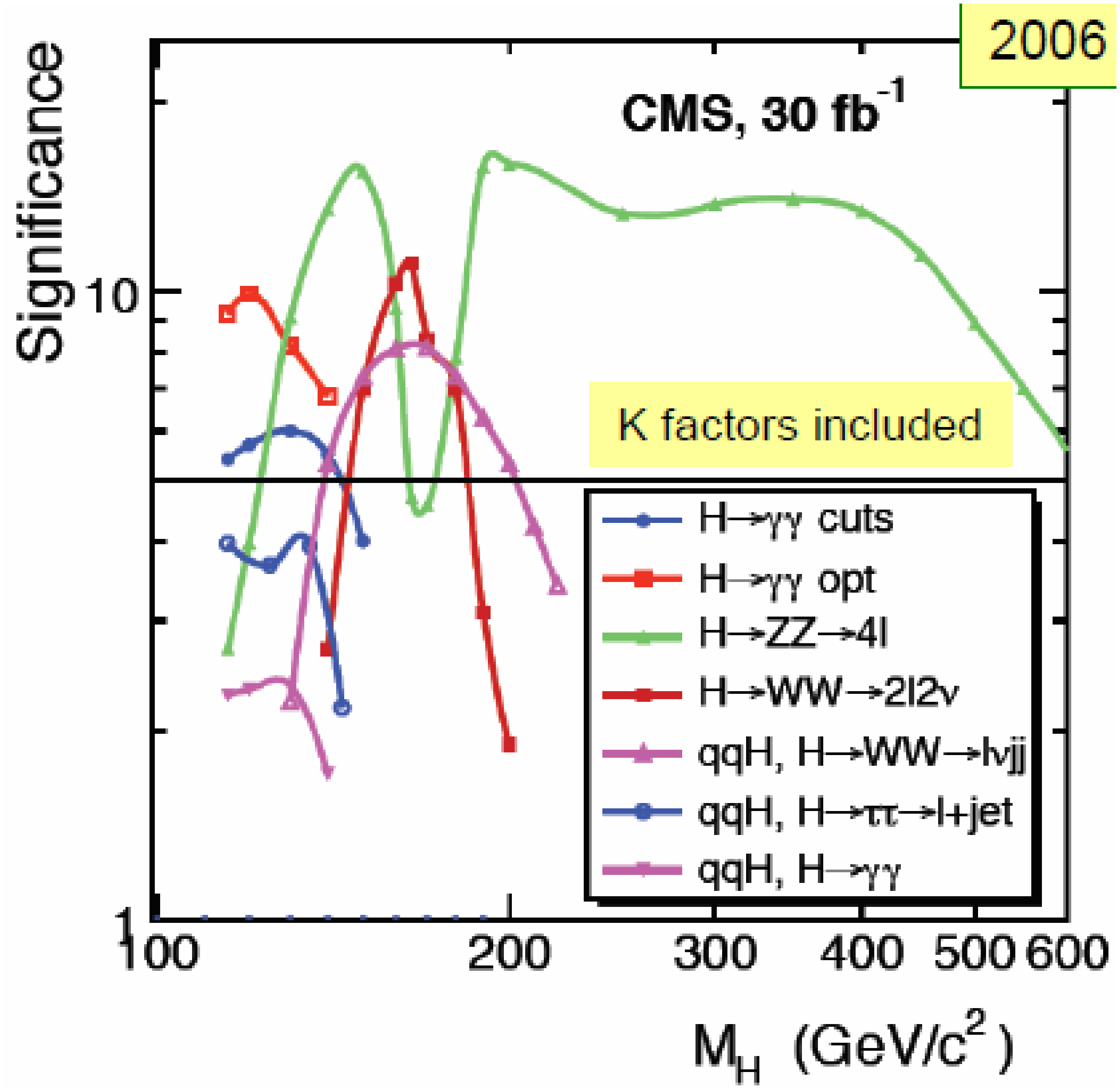




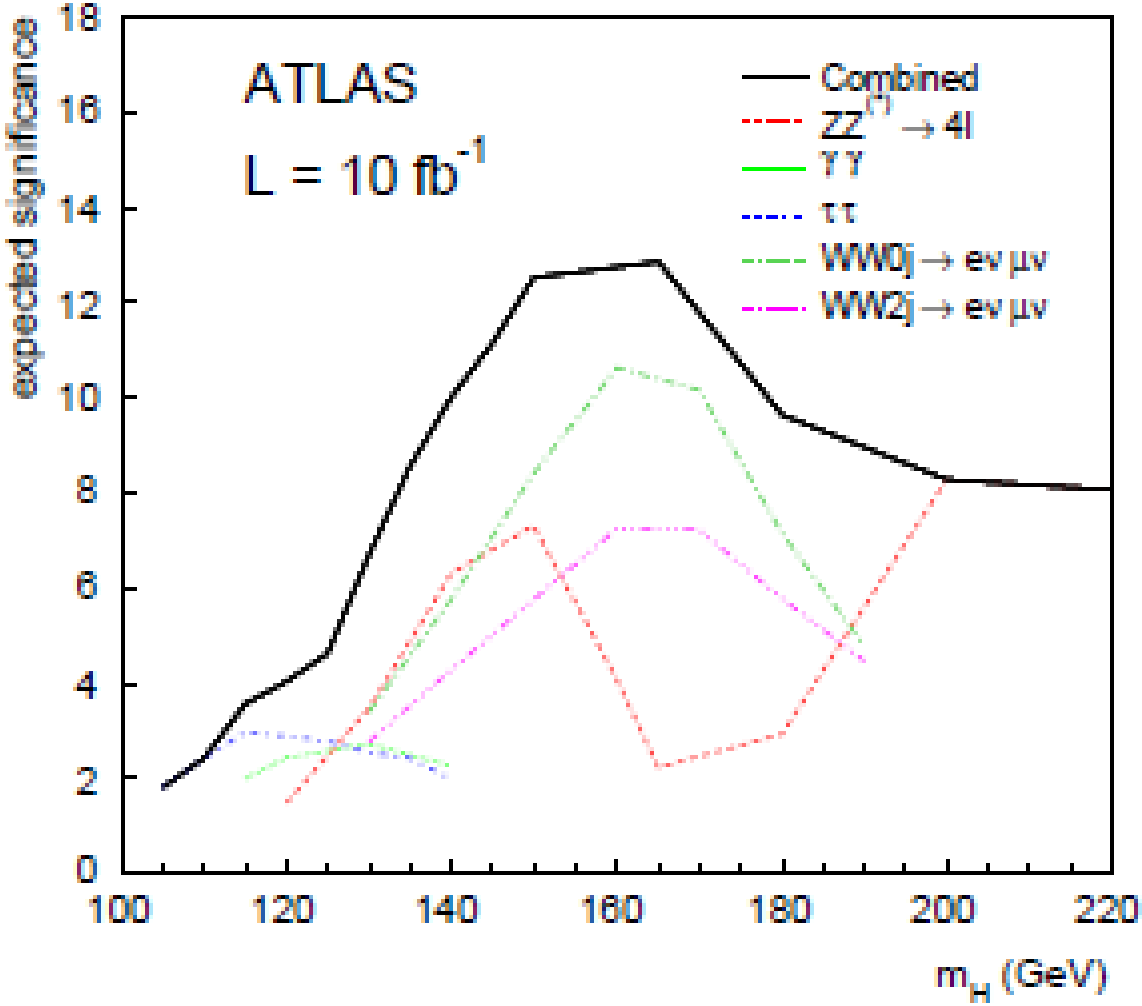
ATLAS + CMS discovery potential



CMS (~ATLAS) discovery potential



ATLAS (~CMS) discovery potential



The Higgs Sector in the MSSM

Two Higgs doublets: 5 Higgs particles **H, h, A**
H^+, H^-

Determined by two parameters: m_A, $\tan\beta$

Fixed mass relations at tree level:
(Higgs self coupling in MSSM fixed by gauge couplings)

$$m^2_{H,h} = \frac{1}{2}\left(m_A^2 + m_Z^2 \pm \sqrt{(m_A^2+m_Z^2)^2 - 4m_Z^2 m_A^2\cos^2 2\beta}\right)$$

$$m_h^2 \leq m_Z^2 \cos^2 2\beta \leq m_Z^2$$

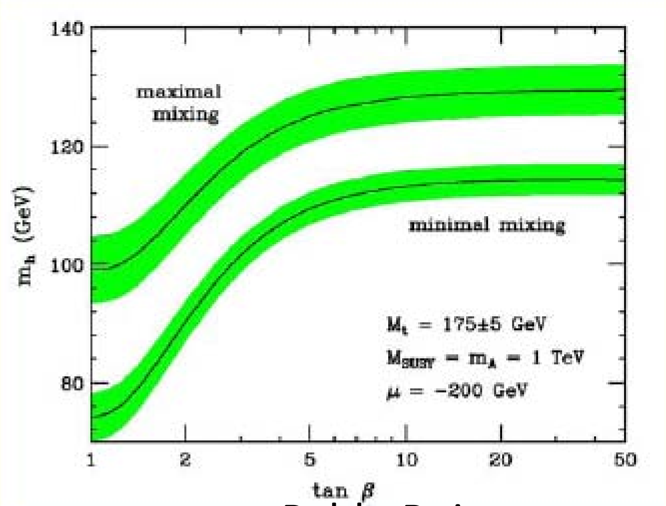
Important radiative corrections !! (tree level relations are significantly modified)
→ upper mass bound depends on top mass and mixing in the stop sector

$$m_h^2 \leq m_Z^2 + \frac{3g^2 m_t^4}{8\pi^2 m_W^2}\left[\ln\left(\frac{M_S^2}{m_t^2}\right) + x_t^2\left(1 - \frac{x_t^2}{12}\right)\right]$$

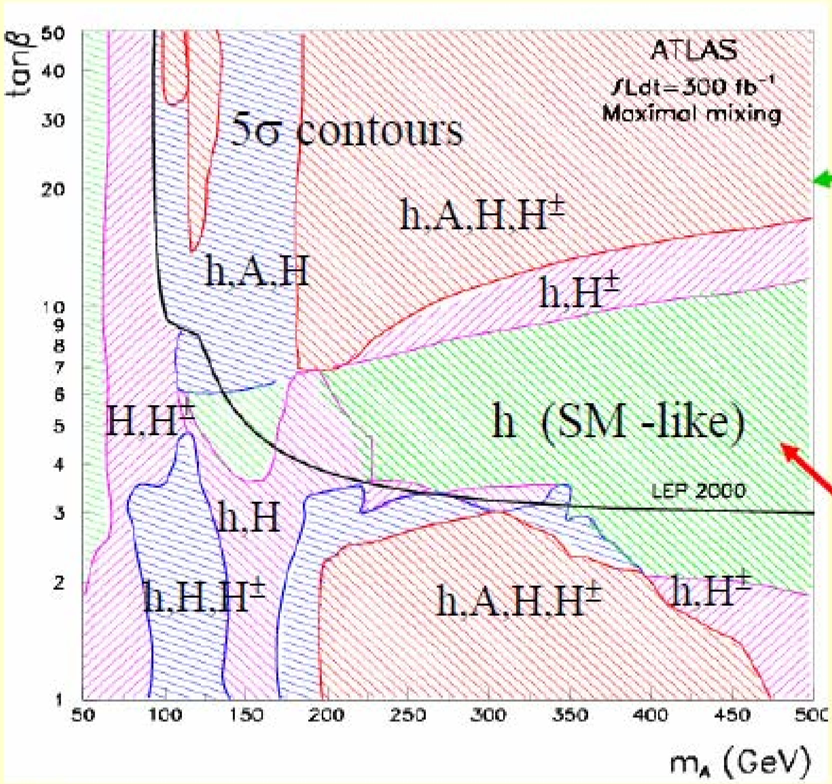
where: $M_S^2 = \frac{1}{2}\left(M_{\tilde{t}_1}^2 + M_{\tilde{t}_2}^2\right)$ and $x_t = (A_t - \mu\cot\beta)\ /\ M_S$

→ m_h < 115 GeV for no mixing
→ m_h < 135 GeV for maximal mixing

i.e., no mixing scenario: in LEP reach
max. mixing: easier to address at the LHC



LHC discovery potential for SUSY Higgs bosons



4 Higgs observable
3 Higgs observable
2 Higgs observable
1 Higgs observable

A, H, H± cross-sections ~ $\tan^2\beta$

- best sensitivity from A/H → ττ, H± → τν
  (not easy the first year ....)

- A/H → μμ experimentally easier
  (esp. at the beginning)

Here only SM-like h observable if SUSY particles neglected.

CONCLUSIONS

- We only know the pattern of EWSB, not the agent behind. $SU(2)_L \otimes U(1)_Y \to U(1)_{em}$
- Theory suggests that the SM cannot be complete up to arbitrarily large energies.
- There is lower bound (LEP) and a exclusion band (CDF+D0) on M_H.
- LHC's motivation is to find the/a Higgs.
- Every time Higgs Physics seems to need more τ Physics.

CONCLUSIONS

- We only know the pattern of EWSB, not the agent behind. $SU(2)_L \otimes U(1)_Y \to U(1)_{em}$
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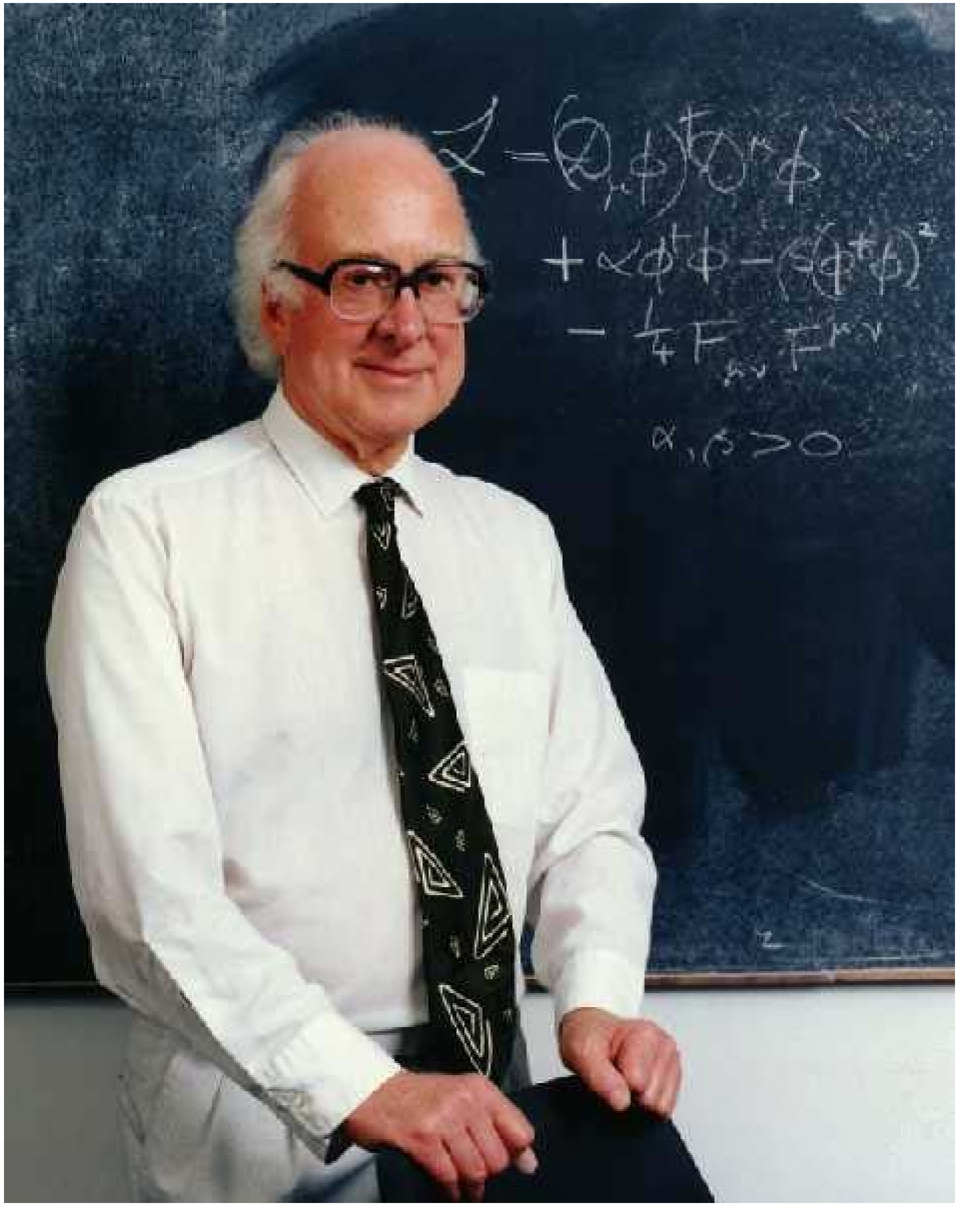
- LHC's motivation is to find the/a Higgs.
- Every time Higgs Physics seems to need more τ Physics.

And I will stop here, because you know what my preferences are…

(P. Higgs, Univ. Edinburgh)



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SKIPPED SLIDES

Some figures on FCNC: Theory vs experiment

$$B\left(K_L{}^0 \to \mu^+\mu^-\right) = \left(6.84 \pm 0.11\right)\cdot 10^{-9} \cong SM$$

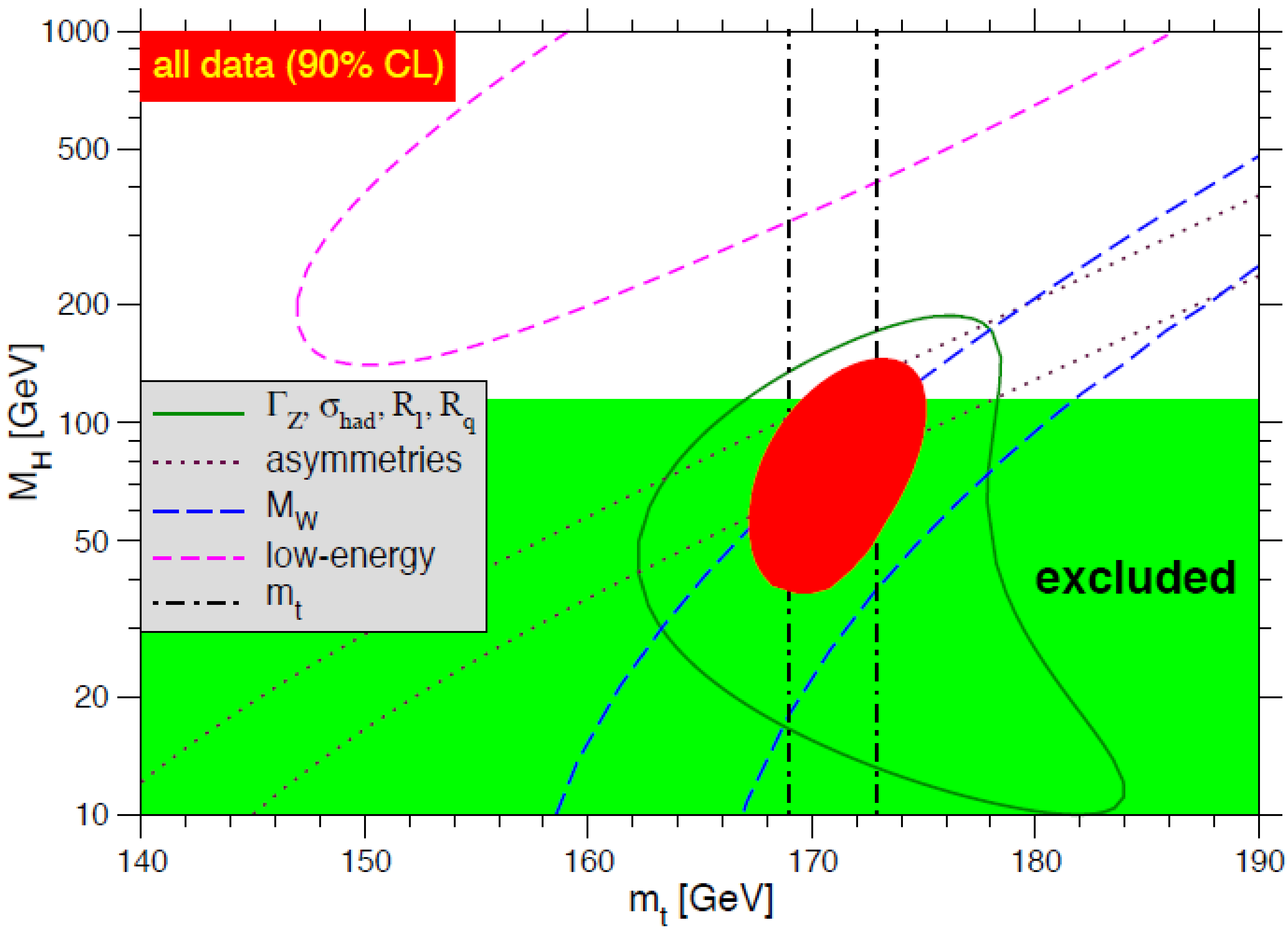
$$B\left(K^+ \to \pi^-\nu\overline{\nu}\right) = \left(1.73^{+1.15}_{-1.05}\right)\cdot 10^{-10} \leftrightarrow SM = \left(0.85 \pm 0.07\right)\cdot 10^{-10}$$

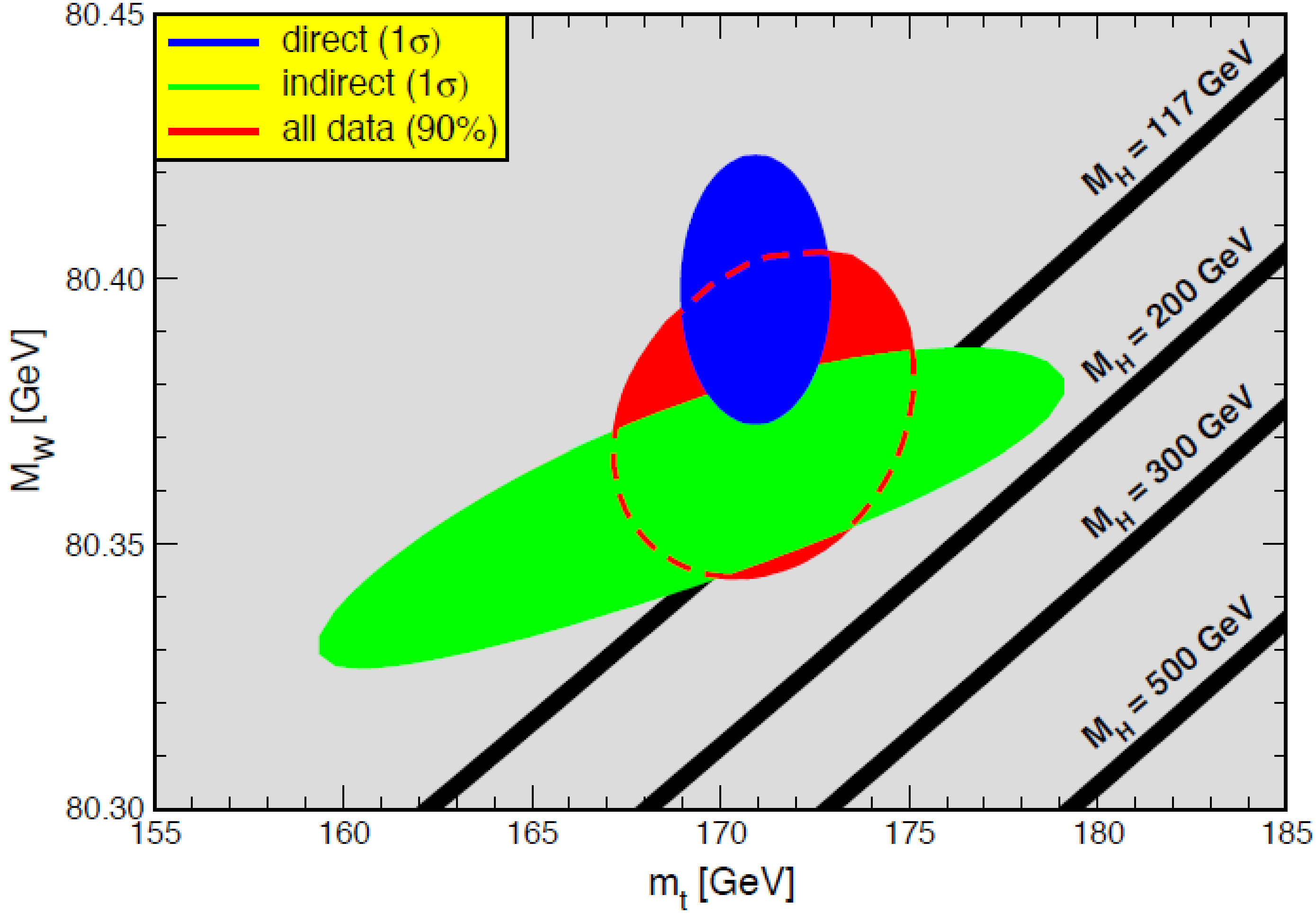
$$B\left(D^0 \to \mu^+\mu^-\right) \leq 5.3\cdot 10^{-7} \leftrightarrow SM \approx 4\cdot 10^{-13}$$

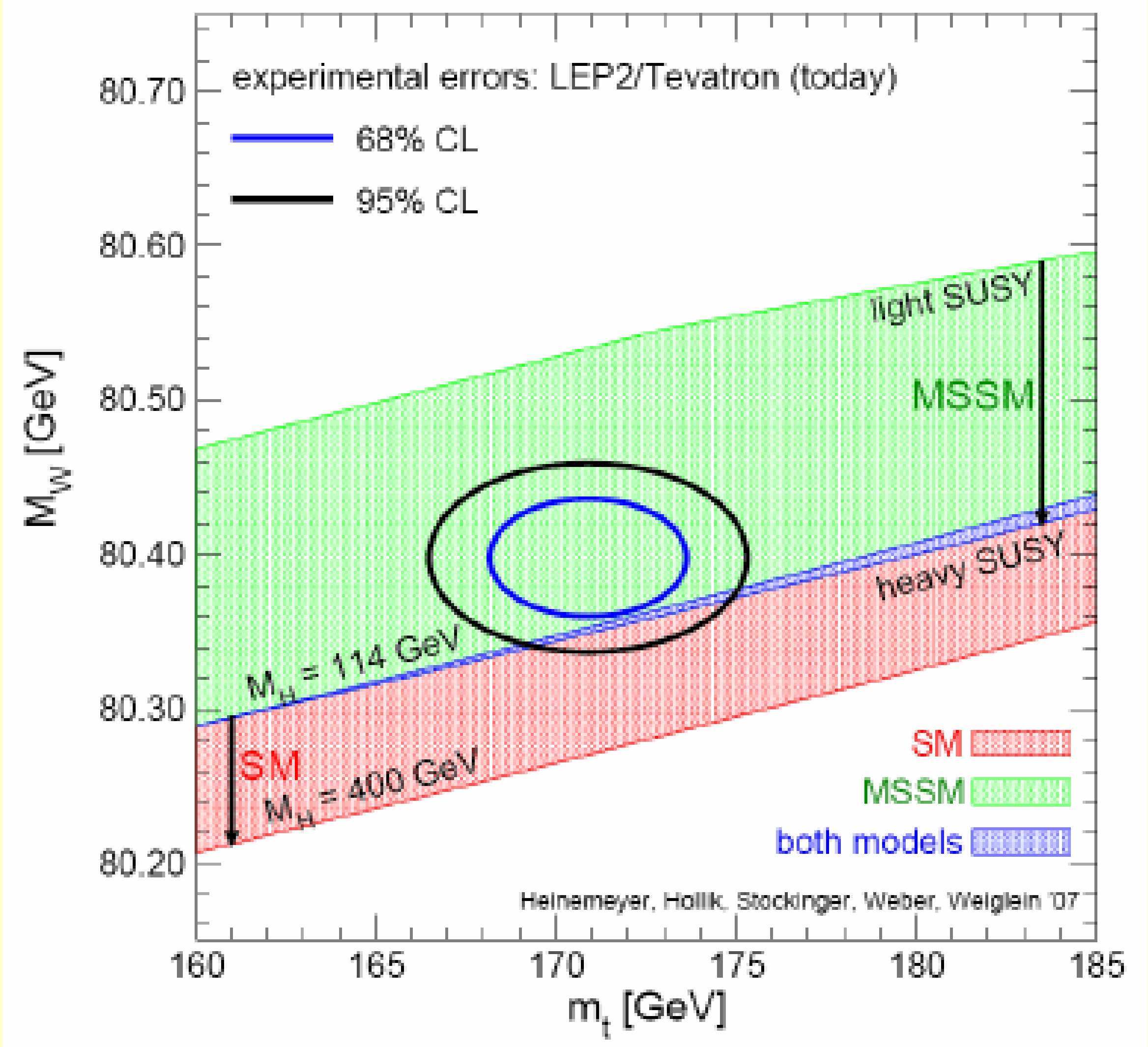
$$B\left(B_s \to \mu^+\mu^-\right) \leq 5.8\cdot 10^{-8} \leftrightarrow SM = \left(3.6 \pm 0.3\right)\cdot 10^{-9}$$

$$B\left(B_d \to \mu^+\mu^-\right) < 1.8\cdot 10^{-8} \leftrightarrow SM = \left(1.1 \pm 0.1\right)\cdot 10^{-10}$$

$$B\left(t \to cg\right) < 5.7\cdot 10^{-3} \leftrightarrow SM \approx 10^{-10}$$


all data (90% CL)
1000
500
200
100
50
20
10
M_H [GeV]
140
150
160
170
180
190
m_t [GeV]
Γ_Z, σ_{had}, R_l, R_q
asymmetries
M_W
low-energy
m_t
excluded


direct (1σ)
indirect (1σ)
all data (90%)
M_H = 117 GeV
M_H = 200 GeV
M_H = 300 GeV
M_H = 500 GeV
80.45
80.40
80.35
80.30
M_W [GeV]
155
160
165
170
175
180
185
m_t [GeV]



experimental errors: LEP2/Tevatron (today)
68% CL
95% CL
light SUSY
MSSM
heavy SUSY
M_H = 114 GeV
SM
M_H = 400 GeV
SM
MSSM
both models
Heinemeyer, Hollik, Stockinger, Weber, Weiglein '07
80.70
80.60
80.50
80.40
80.30
80.20
M_W [GeV]
160
165
170
175
180
185
m_t [GeV]

Higgs production

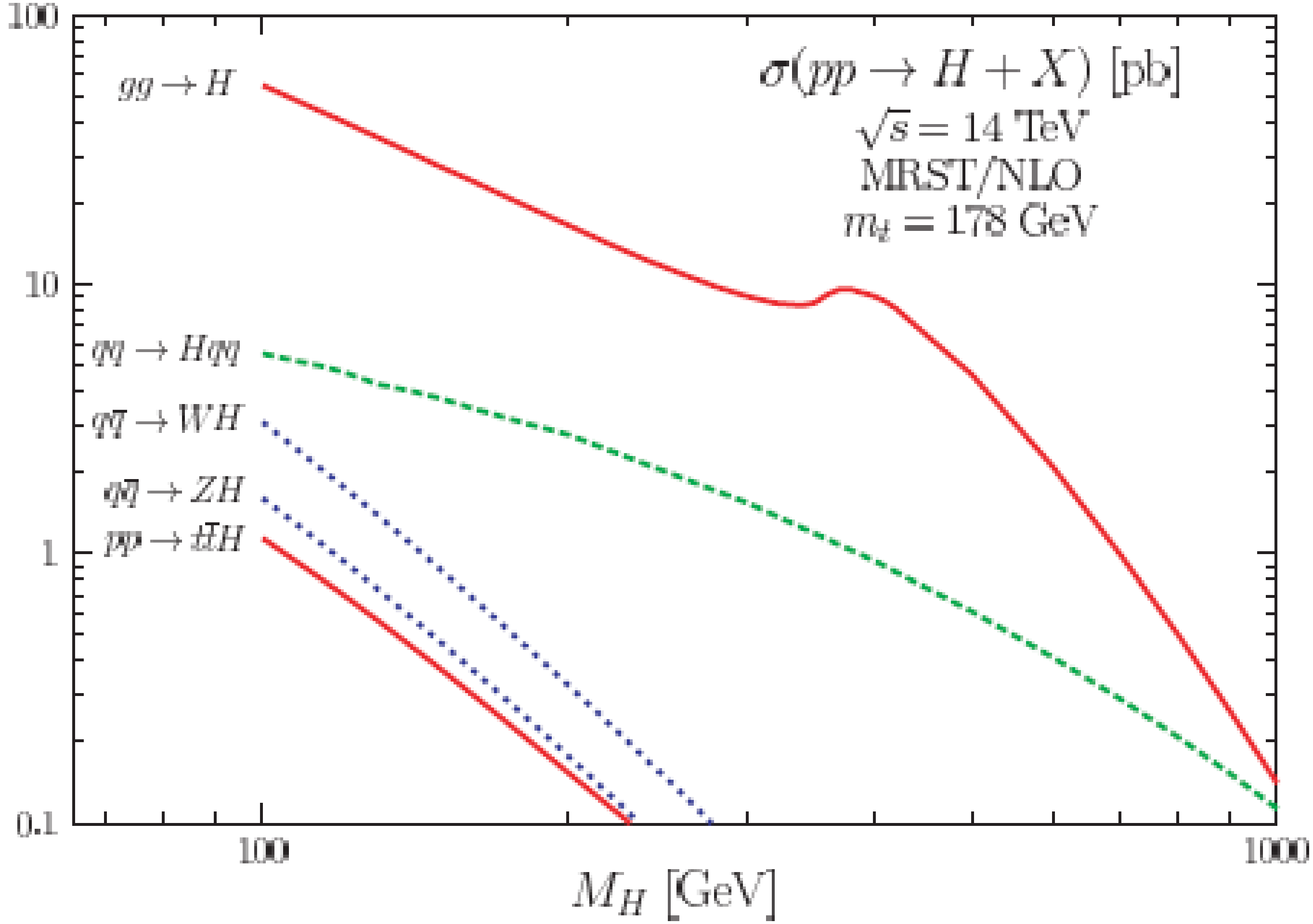
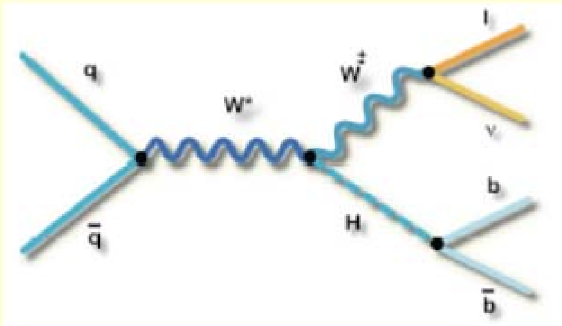
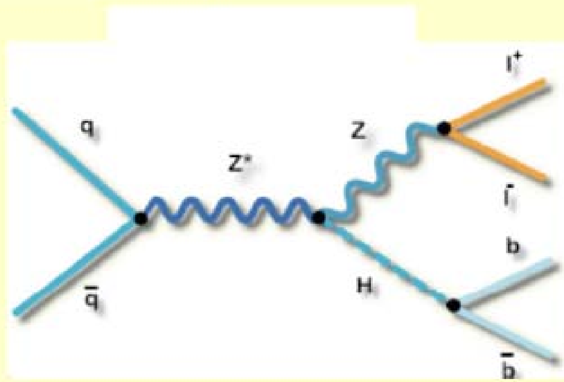


FIG. 14: Higgs-boson production cross sections in pp collisions at $\sqrt{s} = 14$ TeV, computed at next-to-leading order using the MRST parton distributions [171]; from [170]

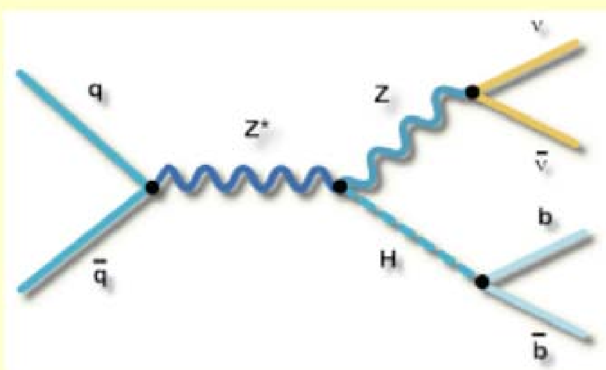
Main low mass search channels



ℓ + E_T^{miss} + bb: $WH \to \ell \nu bb$
Largest *VH* production cross section
More backgrounds than $ZH \to \ell\ell bb$

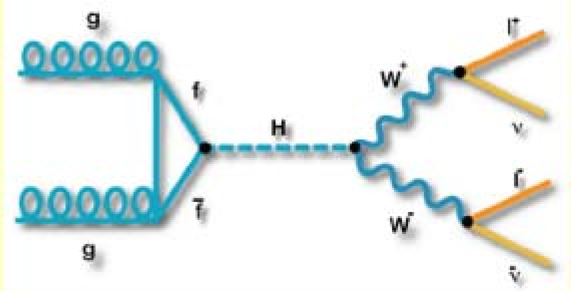


$\ell\ell$+bb: $ZH \to \ell\ell bb$
Less backgrounds
Fully constrained
Smallest Higgs signal

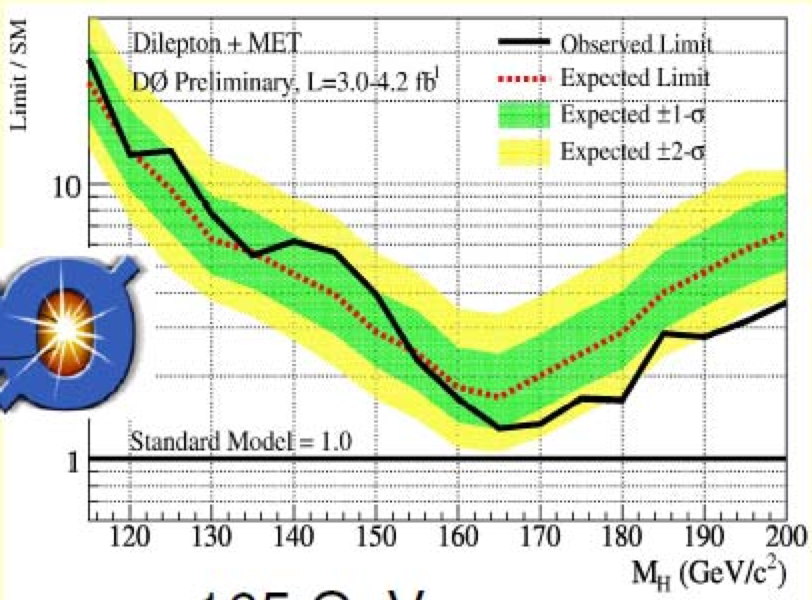


E_T^{miss} + bb: $ZH \to \nu\nu bb$
3x more signal than $ZH \to \ell\ell\ bb$
($+WH \to \ell\nu\ bb$ when lepton missing)
Large backgrounds which are difficult to handle

$H \rightarrow l^+l^- \nu\nu$

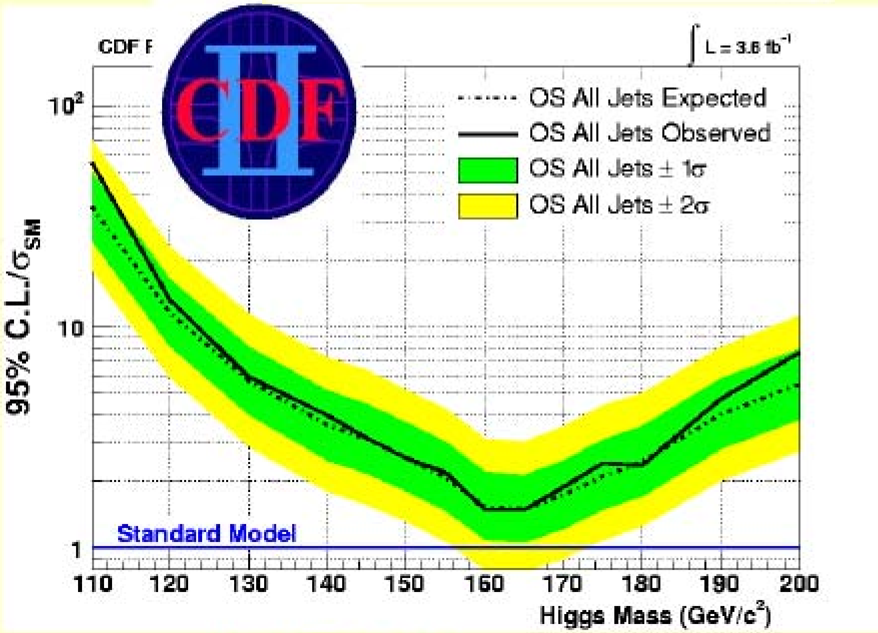


Exclusion limits per experiment:



m_H=165 GeV

Exp(Obs): 1.7(1.3) x σ_{SM}



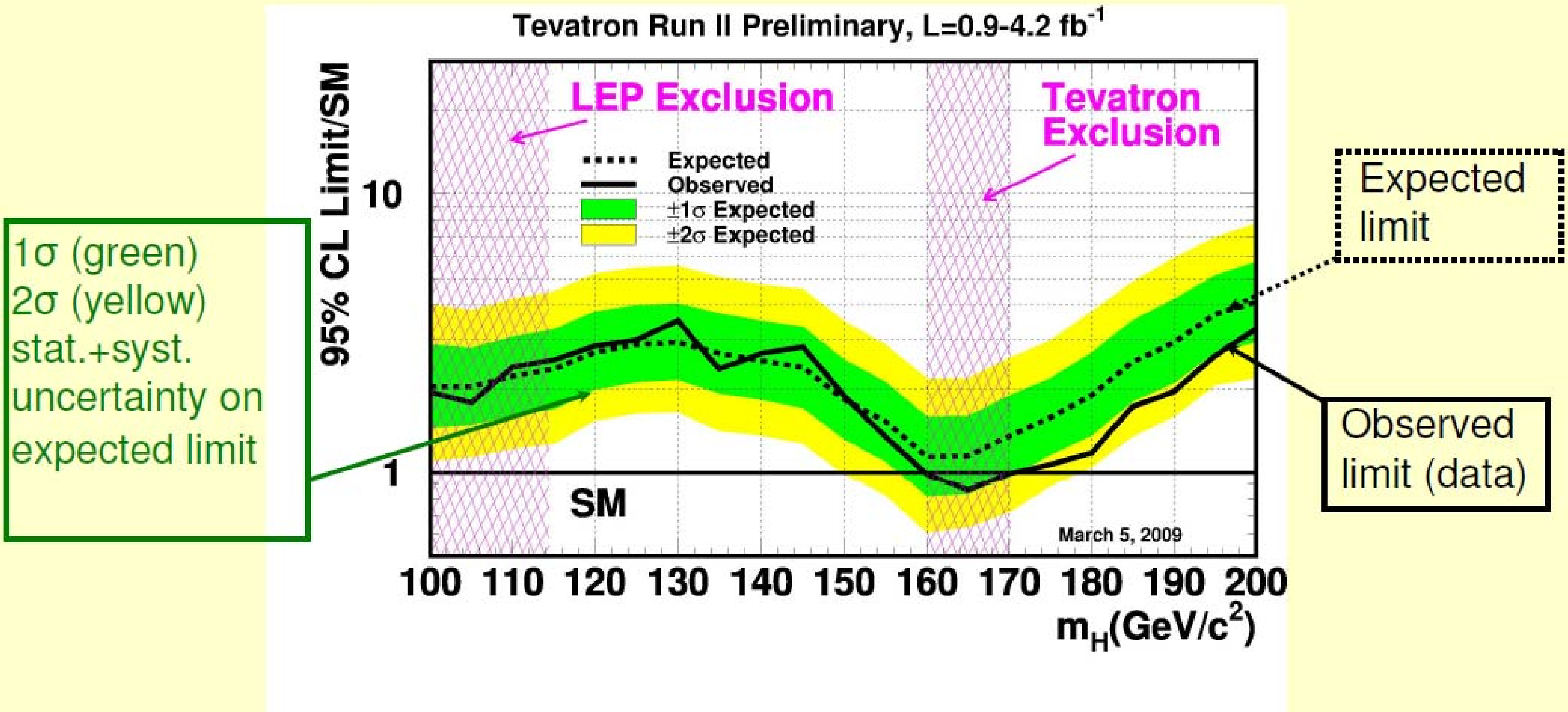
m_H=165 GeV

Exp(Obs): 1.4(1.5) x σ_{SM}

With additional luminosity expect single experiment exclusion around m_H = 165 GeV

CDF & D0 at Tevatron **excludes**: 170GeV<M_H<180GeV

Combined Tevatron limits



A fluctuation in the data allows the Tevatron to set a 95% CL exclusion of a SM Higgs boson in the mass region around 160–170 GeV (first direct exclusion since LEP)

At m_H=115 GeV Expected limit: 2.4 x σ_{SM}

Observed limit: 2.5 x σSM

No Higgs: QCD chiral symmetry breaks also EWS

$$\mathcal{M}^2 = \begin{pmatrix} g^2 & 0 & 0 & 0 \\ 0 & g^2 & 0 & 0 \\ 0 & 0 & g^2 & gg' \\ 0 & 0 & gg' & g'^2 \end{pmatrix} \frac{f_\pi^2}{4}$$

$$M_Z^2/M_W^2 = (g^2 + g'^2)/g^2 = 1/\cos^2\theta_\mathrm{W}$$

$$\cancel{M_W \approx 30\ \mathrm{MeV}}$$

INCOMPLETENESS OF THE EW THEORY

- Problem of identity
- The hierarchy problem
- The “LEP paradox”
- The vacuum energy problem
- Dark matter
- Baryon asymmetry of the Universe
- Quantization of electric charge
- Absence of Gravity