THE STANDARD SUSY HIGGS IN DISGUISE

Marcela Carena
Theoretical Physics Dept.
Fermilab

Aspen Winter Conference, February 3-9, 2002.

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Plays Peekaboo

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The Standard SUSY Higgs Plays Peekaboo

- Introduction
  - Indirect constraints on the Higgs mass
  - LEP bounds/hint of a Higgs?
  - Theory bounds on the SM Higgs mass

- Beyond the SM $\Longrightarrow$ Higgs and Supersymmetry

  - MSSM Higgs Sector at tree Level

  $\Longrightarrow$ masses, couplings and approach to decoupling

  - radiative corrections

  $\Longrightarrow$ masses, couplings and the decoupling limit revisited

- Precision Higgs physics at future colliders

- CP Violation and Supersymmetry
  - The MSSM Higgs sector with CP violation

  $\Longrightarrow$ implications for collider phenomenology

- Overview

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At present:

excellent understanding of fundamental physics

$\Longrightarrow$ effective description: SM of electroweak and strong interactions

SM predictions verified at the loop level of accuracy

but, SM not complete: essential mechanism giving mass to all known particles not understood

SM postulates existence of scalar Higgs field which acquires v.e.v $\Longrightarrow$ spontaneous electroweak symmetry breakdown $\equiv$ vacuum becomes source of energy

particles acquire mass via their couplings to the Higgs

success of precision electroweak fits

+ failure of new physics at LEP

$\Longrightarrow$ motivates to assume that new physics beyond the SM makes negligible contributions

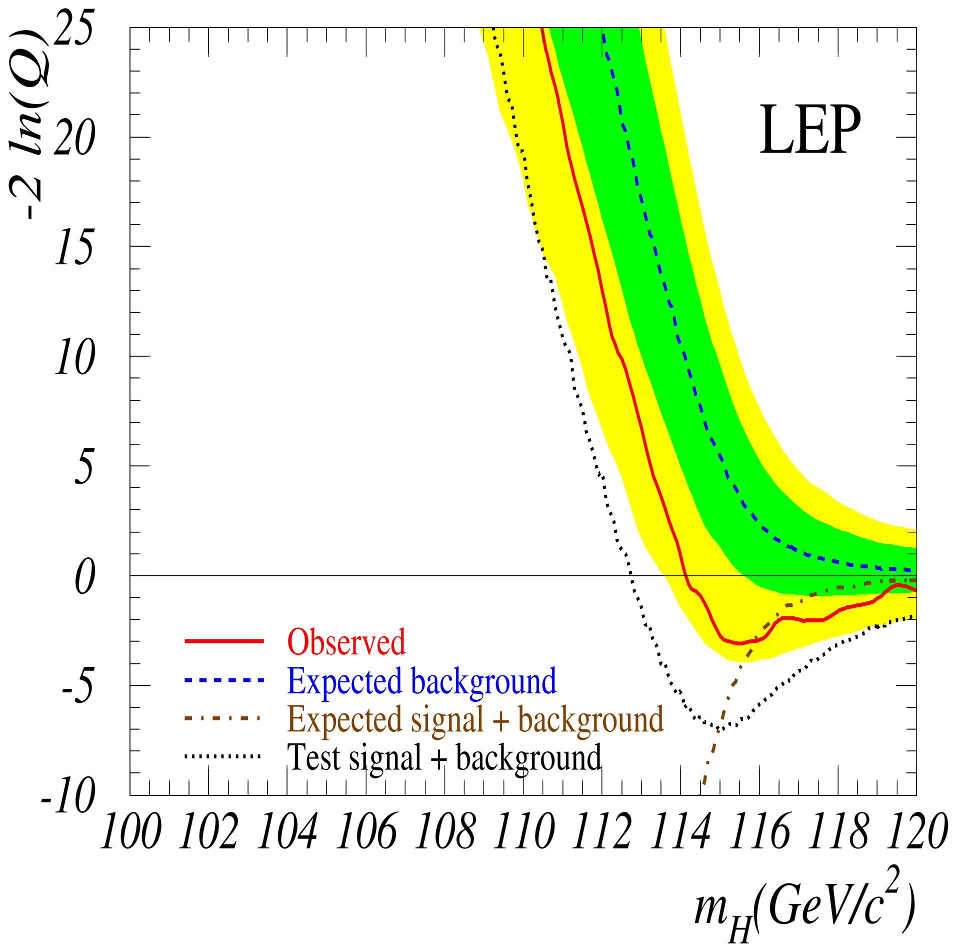
SM Higgs mass $\Longrightarrow$ indirectly contrained by loop corrections to electroweak observables

$$\Longrightarrow m_H^{exp} \leq 222 \ \text{GeV} \qquad 95\% \text{ C.L. (LEPEWWG)}$$

LEP bound/hint of a SM Higgs

Exclusion limit, 95% C.L. $\Longrightarrow m_H > 114.1$ GeV

Comparison of observed signal with expected background and expected signal + background:



Excess at $m_H \simeq 115.6$ GeV : Significance 2.1 σ

in good agreement with SM Higgs production for $m_H = 115.6 \pm 1$ GeV

Theoretical Bounds on the SM Higgs

MSSM Higgs sector at Tree-Level

H_1, H_2 doublets $\Longrightarrow$ 2 CP-even Higgs h, H
1 CP-odd state A   2 charged Higgs $H^{\pm}$

Higgs masses and couplings given in terms of two parameters: m_A and $\tan\beta \equiv v_2/v_1$

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

Couplings to gauge bosons and fermions (norm. to SM)

hZZ, hWW, ZhA, $WH^{\pm}h$ $\longrightarrow \sin(\beta-\alpha)$
HZZ, HWW, ZHA, $WH^{\pm}H$ $\longrightarrow \cos(\beta-\alpha)$

(h,H,A) $u\bar{u} \longrightarrow \cos\alpha/\sin\beta, \quad \sin\alpha/\sin\beta, \quad 1/\tan\beta$
(h,H,A) $b\bar{b} \longrightarrow -\sin\alpha/\cos\beta, \quad \cos\alpha/\cos\beta, \quad \tan\beta$

If $m_A \gg M_Z \rightarrow$ decoupling limit

- $\cos(\beta-\alpha)=0$ up to correc. $\mathcal{O}(m_Z^2/m_A^2)$
- lightest Higgs has SM-like couplings and mass
$m_h^2 \simeq m_Z^2 \cos^2 2\beta$

- other Higgs bosons: heavy and roughly degenerate
$m_A \simeq m_H \simeq m_H^{\pm}$ up to correc. $\mathcal{O}(m_Z^2/m_A)$

Radiative Corrections to Higgs Masses and Couplings

important quantum corrections due to loop of particles and their superpartners: incomplete cancellation due to SUSY breaking

main effect $\Longrightarrow$ top and stop loops, bottom, sbottom loops in large $\tan\beta$ regime

$$\begin{aligned} m_h^2 &\simeq M_Z^2 \cos^2 2\beta + \frac{3 m_t^4}{8\pi^2 v^2} \left[\log\left(\frac{m_{\tilde{t}_1}^2 m_{\tilde{t}_2}^2}{m_t^4} \right) \right. \\ &+ \left. 2 \frac{|X_t|^2}{m_Q^2} \log\left(\frac{m_{\tilde{t}_1}^2}{m_{\tilde{t}_2}^2} \right) + \mathcal{O}\left(\frac{|X_t|^4}{m_Q^4} \right) \right] \end{aligned}$$

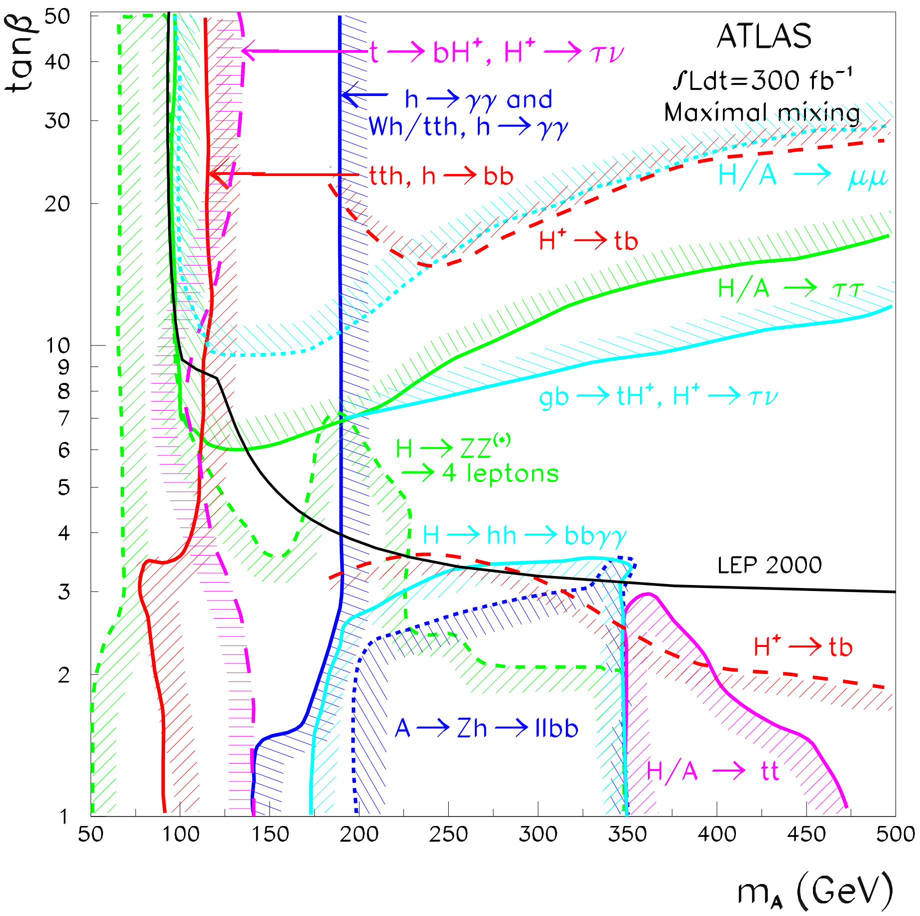
important quantum correc. to Higgs masses and couplings

After radiative corrections:

$$m_h \leq 135 \text{ GeV}$$

Precision Higgs Boson Measurements

The LHC will provide many Higgs boson measurements, and will achieve some degree of accuracy.



In the decoupling regime, only h will be discovered for moderate values of $\tan\beta$.

CP violating phases and Supersymmetry

- Mechanism of SUSY breaking unknown
- Soft SUSY breaking parameters MAY BE COMPLEX and take any value allowed by phenomenological constraints

➖ Complex parameters may induce large values of the electron and neutron EDM's

at one loop $\rightarrow$ resolve the CP crisis by

- heavy 1. and 2. generation sfermions
- cancellations between different EDM's

at two loops $\rightarrow$ effects of 3. generation sfermions relevant to Higgs sector as well as to the generation of the observed Baryon Asymmetry

- either strong constraint on large $\tan\beta$ values ($\tan\beta \leq 10$)
- or cancellations of some type

CP violation in the Higgs Sector

- at tree level $\Longrightarrow$ MSSM Higgs potential invariant under CP
- After radiative corrections: CP violation induced through loop effects via 3. generation sfermion and gaugino mass parameters

– Many possible relevant phases to Higgs sector

$m_{\tilde{g}}$ (one phase if Univ. gaugino masses)
A_f μ and m_{12}^2

Due to U(1) symm.of the conformal inv. sector:
$\rightarrow$ one can redefine fields and absorbe two phases

rephasing inv. combinations

$\rightarrow$ if $\quad \mathrm{Im}\ ((m_{12}^2)^* A_f \mu) \neq 0$ and/or

$$\mathrm{Im}\ ((m_{12}^2)^* m_{\tilde{g}} \mu) \neq 0$$

$\Longrightarrow$ CP violating effects will be present in the MSSM

in practice m_{12}^2 and μ real and leave phases in A_f and $m_{\tilde{g}}$

Higgs Potential → Quantum Corrections

Minimization should be performed with respect to real and imaginary parts of Higgs fluctuations

$H_1^0 = \phi_1 + iA_1$ $\qquad\qquad$ $H_2^0 = \phi_2 + iA_2$

Performing a rotation: A_1, A_2 $\quad \Longrightarrow$ A, G^0 (Goldstone)

Main Effect of CP-Violation is the mixing between the three neutral Higgs boson states

$$\begin{pmatrix} A \\ \Phi_1 \\ \Phi_2 \end{pmatrix} = \mathcal{O} \begin{pmatrix} H_1 \\ H_2 \\ H_3 \end{pmatrix} \tag{1}$$

In the base (A, ϕ_1, ϕ_2):

$$\mathcal{M}_N^2 = \begin{bmatrix} m_A^2 & \left(M_{SP}^2\right)^T \\ M_{SP}^2 & M_{SS}^2 \end{bmatrix}$$

where $M_{SP}^2 \propto \mathrm{Im}(\mu A_t)$

M_{SS}^2 similar to the mass matrix in CP conserving case

and M_A^2 is the mass of the would be CP-odd Higgs

m_A^2 no longer a physical parameter, but the charged Higgs mass $M_{H^\pm}$ can be used as a physical parameter, together with M_S, $|\mu|$, $|A_t|$, $\arg(A_t)$ and $\arg(M_{\tilde{g}})$.

Yukawa Couplings

$$-\mathcal{L}_{\phi b\bar{b}} = \left(h_b H_1^0 + \Delta h_b H_2^0\right) \bar{b}_L b_R + h.c. \qquad (2)$$

Coupling Δh_b generated by SUSY breaking effects

$$\Delta h_b \simeq \frac{\alpha_3}{3\pi} \frac{M_3^* \mu^*}{M_S^2}$$

The one loop corrections to the Yukawa couplings introduce CP-violating effects which are independent of Higgs mixing (like ϵ and $\epsilon^{'}$).

$$\begin{aligned} g^S_{H_i dd} &= \frac{1}{h_d \cos\beta + \Delta h_d \sin\beta} \left[Re(h_d) O_{1i} + Re(\Delta h_d) O_{2i} \right. \\ &+ \left. \left(Im(h_d) \sin\beta - Im(\Delta h_d) \cos\beta \right) O_{3i} \right] \qquad (3) \end{aligned}$$

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where we have defined the phase of the superfield b_R

$$m_b^2 \propto h_b + \delta h_b + \Delta h_b \tan\beta$$

to be real and positive

Overview

Tevatron Run 2 $\Longrightarrow$ very rich and broad physics potential

- Starting from the first few hundred pb^{-1}:

• B Physics: CP Violation

$\Longrightarrow \sin(2\beta_{\psi K}) \rightarrow$ tests new physics

- With increasing integrated Luminosity ($\geq 2\ \text{fb}^{-1}$):

• precise meas. of M_t & M_W

$\Longrightarrow$ indirect meas. of m_H

• *Furthermore*, search for new physics via top physics.

• SUSY particle Searches:

$m_{\tilde{t}} \sim 160 - 200$ GeV, $m_{\tilde{b}} \sim 200 - 270$ GeV,
$m_{\tilde{\chi}^{\pm}} \sim 100 - 200$ GeV, $m_{\tilde{g}} \sim 400 - 600$ GeV

test many different scenarios

• Search for Exotic Physics and Extra Dimensions

- Maximal demand on total integrated luminosity and detectors performance:

• Higgs Physics:

SM $\Longrightarrow$ test Higgs mass region preferred by precision data
Probe MSSM through its Higgs sector

High integrated Luminosity $\Longrightarrow\ \geq 15\ \text{fb}^{-1}$
top priority for Higgs search at the Tevatron.