How well do we need to measure the Higgs boson couplings?

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in coll. with Rick S. Gupta and James D. Wells

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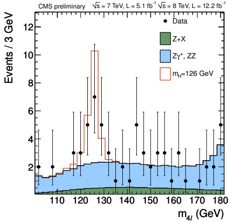
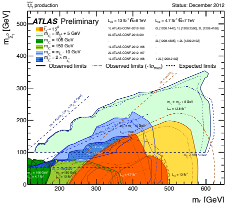
Status

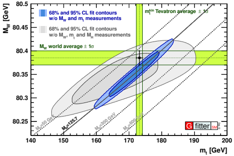
- Discovery of
  a Standard Model Higgs like particle



- No hint of beyond Standard Model physics



- Precision measurements of W mass,. . .



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If no beyond Standard Model physics is seen at the LHC:

How large can deviations from
the Standard Model Higgs couplings be?

$\Rightarrow$ How well do we need to know these couplings?

How large can the deviations be?

No totally model independent answer possible:

3 type of models:

- Mixed-in singlet Higgs boson
- Composite Higgs model
- Minimal Supersymmetric Standard Model (MSSM)

Higgs Couplings in a Mixed-in Singlet Model

Standard Model (SM) + exotic Higgs boson singlet:

Higgs fields mix via operator $|H_{SM}|^2 |S|^2$

[Schabinger, Wells, hep-ph/0509209; Bowen, Cui, Wells, hep-ph/0701035]

$\Rightarrow$ 2 CP-even mass eigenstates h, H
with couplings^2

$$g_h^2 = c_h^2 \, g_{SM}^2 \qquad c_h = \cos\theta_h \qquad \theta_h = \text{mixing angle}$$

$$g_H^2 = s_h^2 \, g_{SM}^2 \qquad s_h = \sin\theta_h$$

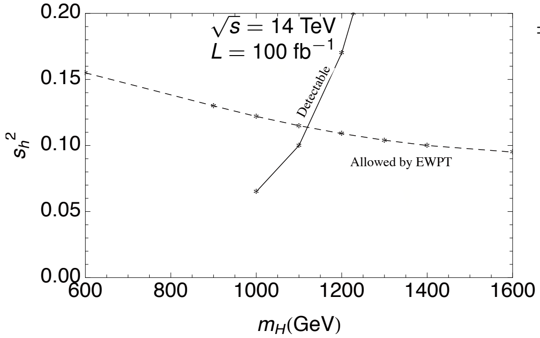
Here: h the SM like one

H the heavier Higgs boson – detectable at the LHC
if light enough

Higgs Couplings in a Mixed-in Singlet Model

[Gupta, H.R., Wells, arXiv:1206.3560]

Region of possible LHC detection of the heavy Higgs boson and region allowed by electroweak precision tests in the s_h^2-m_H plane:



$\Rightarrow$ max. deviation of Higgs couplings to other particles:

$$\frac{\Delta g_h}{g_{SM}} \approx -\frac{s_h^2}{2} \approx -6\%$$

detectability region based on: [Bowen, Cui, Wells, hep-ph/0701035; Iordanidis, Zeppenfeld, hep-ph/9709506]

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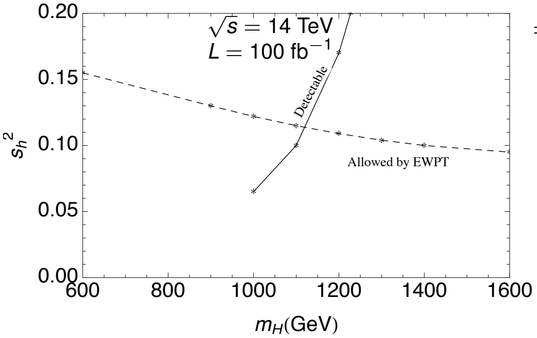


$\Rightarrow$ max. deviation of the triple Higgs coupling:

$$\frac{\Delta g_{hhh}}{g_{hhh}^{SM}} = (c_h^3 - 1) - s_h^3 \frac{v}{v'}$$

$$\approx -18\%$$

detectability region based on: [Bowen, Cui, Wells, hep-ph/0701035; Iordanidis, Zeppenfeld, hep-ph/9709506]

Higgs Couplings in Composite Higgs Models

Model where the SM Higgs like particle is a pseudo-Goldstone:

SM vector bosons and fermions + strong sector with Higgs multiplet

in terms of an effective field theory

for a strong interacting light Higgs (SILH) boson

[Guidice, Grojean, Pomarol, Rattazzi, hep-ph/0703164]

two independent parameters: mass of new resonance m_ρ

decay constant f with $m_\rho = g_\rho f$

g_ρ = coupling of the new resonance

Lagrangian:

$$\mathcal{L}_{\text{SILH}} = \left(\frac{c_y y_f}{f^2} H_{SM}^\dagger H_{SM} \bar{f}_L H_{SM} f_R + \frac{c_S g g'}{4 m_\rho^2} (H_{SM}^\dagger \sigma_I H_{SM}) B_{\mu\nu} W^{I\mu\nu} + h.c. \right)$$

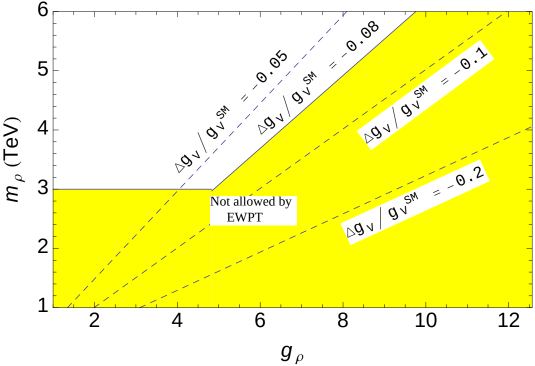
$$+ \frac{c_H}{2f^2} \partial^\mu (H_{SM}^\dagger H_{SM}) \partial_\mu (H_{SM}^\dagger H_{SM}) + \frac{c_6 \lambda}{f^2} (H_{SM}^\dagger H_{SM})^3 + \ldots$$

Naive Dimensional Analysis: c_H, c_y, c_S, c_6: $\mathcal{O}(1)$ numbers

Higgs Couplings in Composite Higgs Models

[Gupta, H.R., Wells, arXiv:1206.3560]

region allowed by electroweak precision tests in the m_ρ-g_ρ plane:



max. deviation:

coupling to vector bosons:

$$\frac{\Delta g_V}{g_V^{\rm SM}} = -\frac{c_H \xi}{2} + \ldots$$
$$\approx -8\%$$

coupling to fermions:

$$\frac{\Delta g_f}{g_f^{\rm SM}} = -\frac{c_H \xi}{2} + c_y \xi + \ldots$$
$$\approx -8\% - 15\% \frac{c_y}{c_H}$$

$\xi = \frac{v^2 g_\rho^2}{m_\rho^2}$, m_ρ and g_ρ mass and coupling of the new resonance

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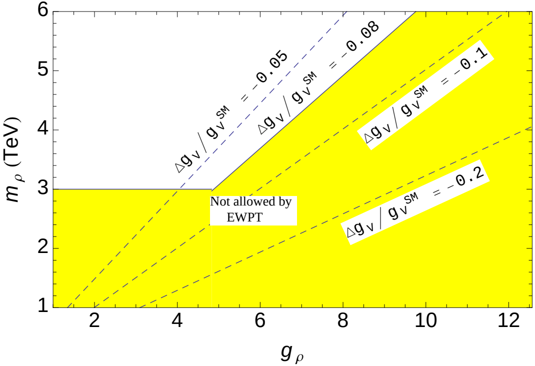

max. deviation:

coupling to gluons:

$$\frac{\Delta g_g}{g_g^{SM}} = -\frac{c_H \xi}{2} + c_y \xi + \ldots$$

$$\approx -8\% - 15\% \frac{c_y}{c_H}$$

coupling to photons:

$$\frac{\Delta g_\gamma}{g_\gamma^{SM}} = -\frac{c_H \xi}{2} + 0.3 c_y \xi + \ldots$$

$$\approx -8\% - 5\% \frac{c_y}{c_H}$$

g_g^{SM}, g_γ^{SM}: loop-induced

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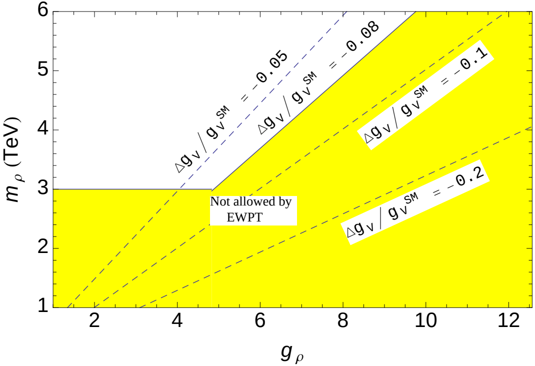


max. deviation:

triple Higgs coupling:

$$\frac{\Delta g_{hhh}}{g_{hhh}^{SM}} = -\frac{3}{2} c_H \xi + c_6 \xi + \ldots$$

$$\approx -23\% + 15\% \frac{c_6}{c_H}$$

Higgs Couplings in the MSSM

Standard Model + 2nd Higgs doublet + superpartners:

Particles to be fully identified or discovered:

2 CP-even h, H 1 CP-odd A 2 charged $H^{\pm}$ lots of superpartners	} might be discovered at the LHC depending on parameters

in our case: h is always the SM like Higgs boson

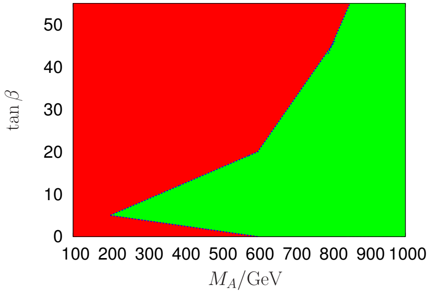
otherwise (i.e. $H =$ SM like Higgs boson):

h, A or $H^{\pm}$ should be discovered at the LHC

Higgs Couplings in the MSSM

[Gupta, H.R., Wells, arXiv:1206.3560]

h, H, A, $H^{\pm}$
discovery potential
for $\sqrt{s} = 14$ TeV, $L = 300$ fb^{-1}
(modeled after figure of
[CLIC Conceptual Design Report (2012);
ATLAS collaboration, CERN-LHCC-99-15])



red region: Several of h, H, A, $H^{\pm}$ can be discovered

green region: Only a single one, h, can be discovered

$\tan\beta$ = ratio of the Higgs vacuum expectation values

Higgs Couplings in the MSSM

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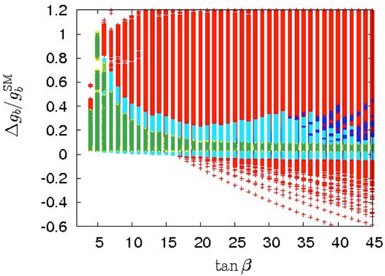

Legend:

several h, H, A, $H^{\pm}$ discovered

only h is discovered:

- exluded by $Br(b \to s\gamma)$
- also stop quarks lighter than a 1 TeV
- stops heavier 1 TeV, but not all heavier than 1.5 TeV
- stops heavier than 1.5 TeV

Scan done using FeynHiggs [Hahn, Heinemeyer, Hollik, H.R., Weiglein]

Higgs Couplings in the MSSM

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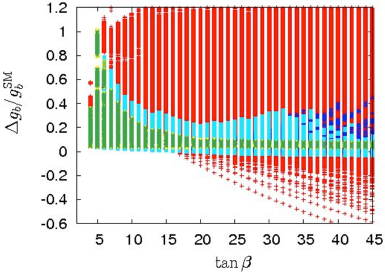

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- biggest deviation of the SM Higgs coupling to bottom quarks $\Delta g_b/g_b^{\rm SM}$ with $\Delta g_b = g_b^{\rm MSSM} - g_b^{\rm SM}$ for $\tan\beta = 5$, up to a 100%.

  $M_A \gg M_Z$: $\dfrac{\Delta g_b}{g_b^{\rm SM}} \propto \dfrac{1}{M_A^2}$

Higgs Couplings in the MSSM

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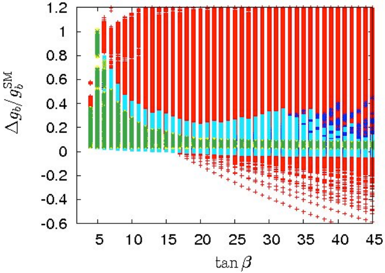

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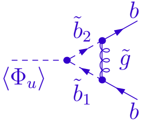
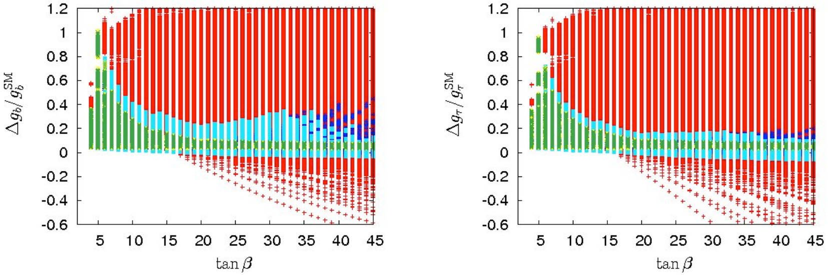
- for large $\tan\beta$ and light stops, enhancement by Δ_b contributions
  Δ_b: $\tan\beta$ enhanced contribution due to



[Carena, Garcia, Nierste,Wagner, hep-ph/9912516]

Higgs Couplings in the MSSM



- overall behaviour similar for $\Delta g_\tau/g_\tau^{\rm SM}$, no Δ_τ contributions included
- for $\tan\beta > 20$ and heavy stops: maximal deviation of ~ 10 %.
- Maximal deviations for coupling to Z or W: $\Delta g_V/g_V^{\rm SM} < 1$ %
- Maximal deviations for coupling to top quarks: $\Delta g_t/g_t^{\rm SM} \approx 3$ %

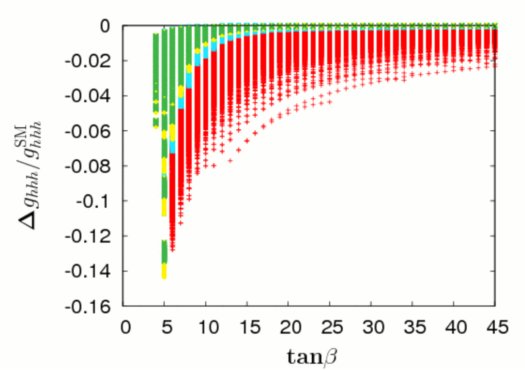
Higgs Couplings in the MSSM

[Gupta, H.R., Wells, arXiv:1305.preview]

Devation of the triple Higgs coupling in the MSSM:

Use same approximation for Higgs boson mass and triple coupling!

Here: renormalization-group improved corrections of the eff. potential, incl. some 2-loop terms [Carena, Espinosa, Quiros, Wagner, hep-ph/9504316]



relaxed Higgs mass constraint:

$|\Delta g_{hhh}/g_{hhh}^{SM}| \lesssim 15\%$

strict Higgs mass constraint:

$|\Delta g_{hhh}/g_{hhh}^{SM}| \lesssim 4\%$

$m_{\tilde{t}_1} < 1.0$ TeV

1.0 TeV $\leq m_{\tilde{t}_1} < 2.5$ TeV

lighter stop mass $m_{\tilde{t}_1} \geq 2.5$ TeV

Conclusion

How large can the maximal deviations from the SM Higgs couplings be if no new physics is discovered by the LHC?

The answer in the context of 3 different models:

	$\lvert\Delta hVV\rvert$	$\lvert\Delta h\bar{t}t\rvert$	$\lvert\Delta h\bar{b}b\rvert$	$\lvert\Delta hhh\rvert$
Mixed-in Singlet	6%	6%	6%	18%
Composite Higgs	8%	tens of %	tens of %	tens of %
MSSM	$< 1\%$	3%	10%, 100%	2%, 15%

$\tan\beta > 20$ no superpartners (10% and 2%); all other cases (100% and 15%)