Maximal deviations of the scalar boson couplings if no further particle is seen

Heidi Rzehak

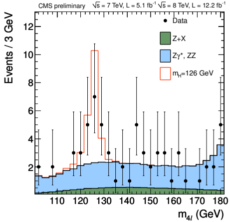
CERN

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

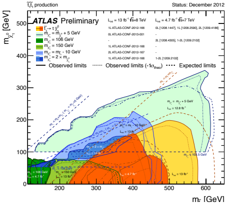
Rencontres de Moriond EW, 6 March 2013

Status

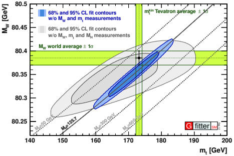
- Discovery of
  a Standard Model scalar like particle



- No hint of beyond Standard Model physics



- Precision measurements of W mass,…



Properties of the discovered particle?

Measurements of the discovered particle's properties needed to make sure it is the Standard Model scalar

Properties of the discovered particle?

Measurements of the discovered particle's properties needed to make sure it is the Standard Model scalar – or a Standard Model like one?

Properties of the discovered particle?

Measurements of the discovered particle's properties needed
to make sure it is the Standard Model scalar
– or a Standard Model like one?

Can the particle's couplings give hints about
the underlying model?

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

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

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)

Couplings in a Mixed-in Singlet Model

Standard Model (SM) + exotic Higgs boson singlet:

Scalar 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

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

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

Here: h the SM like one

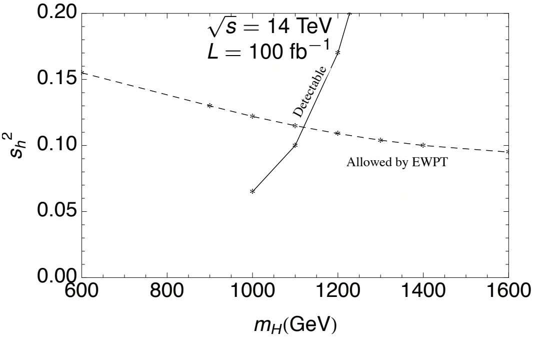
H the heavier scalar – detectable at the LHC

if light enough

Couplings in a Mixed-in Singlet Model

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

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



$\Rightarrow$ max. deviation:

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

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

Couplings in Composite Higgs Models

Model where the SM scalar 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:

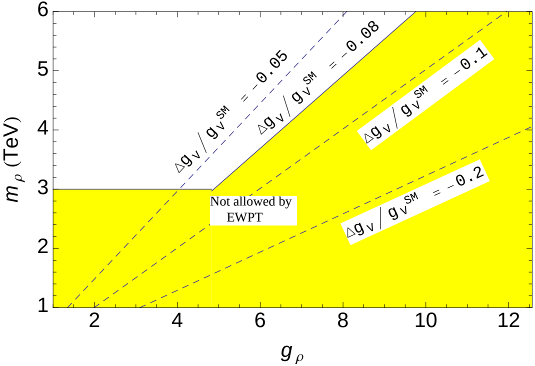
$$\mathcal{L}_{\rm SILH} = \frac{c_H}{2f^2}\partial^\mu(H^\dagger_{SM}H_{SM})\partial_\mu(H^\dagger_{SM}H_{SM}) + \frac{c_y y_f}{f^2}H^\dagger_{SM}H_{SM}\bar{f}_L H_{SM} f_R$$
$$+\frac{c_S g g'}{4m_\rho^2}(H^\dagger_{SM}\sigma_I H_{SM})B_{\mu\nu}W^{I\mu\nu} + h.c. + \ldots$$

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

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:

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

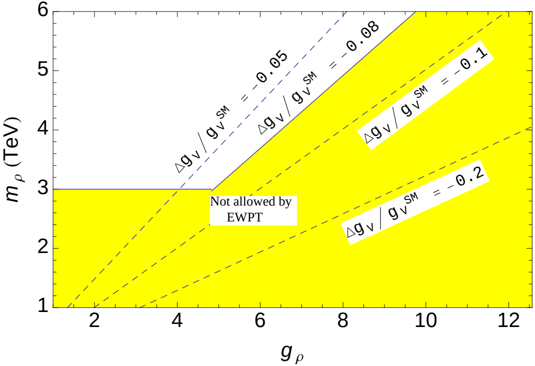
$$\approx -8\% - 15\% \frac{c_y}{c_H}$$

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

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 gluons:

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

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

coupling to photons:

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

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

g_g^{SM}, g_γ^{SM}: loop-induced

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 scalar

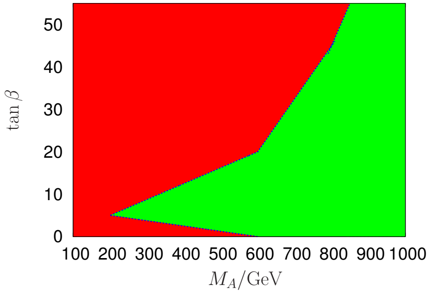
otherwise (i.e. $H =$ SM like scalar):

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

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])



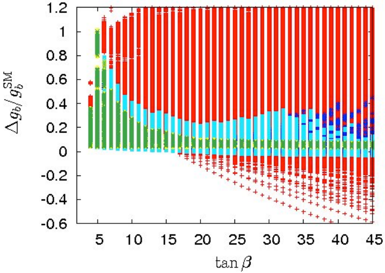
red region: Several of *h*, *H*, *A*, $H^{\pm}$ can be discovered

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

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

Couplings in the MSSM

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



Legend:

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

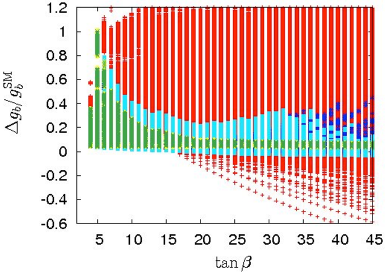
only h is discovered:

- 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]

Couplings in the MSSM

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



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

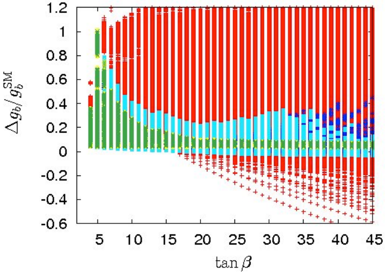
stops heavier than 1.5 TeV

- biggest deviation of the SM scalar 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%.

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

Couplings in the MSSM

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



Legend:

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

only h is discovered:

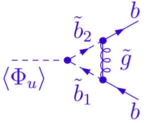
exluded by $Br(b \to s\gamma)$

also stop quarks lighter than a 1 TeV

stops heavier 1 TeV, but not all heavier than 1.5 TeV

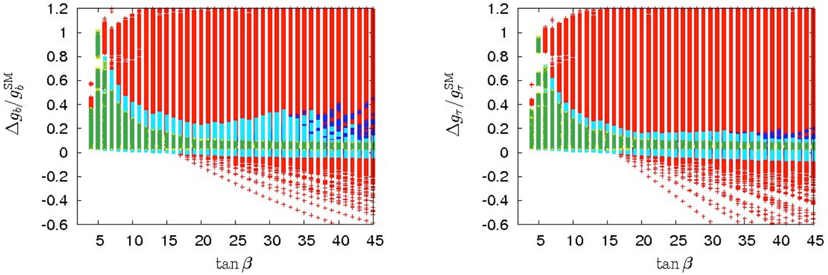
stops heavier than 1.5 TeV

- 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]

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: $\Delta g_t/g_t^{\rm SM} \approx 3$ %

Conclusion

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

The answer in the context of 3 different models:

	ΔhVV	$\Delta h\bar{t}t$	$\Delta h\bar{b}b$
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	$< 1\%$	3%	10%, 100%

↑ 10%: $\tan\beta > 20$, no superpartners; 100%: all other cases