BSM theories face Higgs coupling data

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based on
Gupta, Rzehak and Wells (1206.3560)
Gupta, Montull and Riva (1212.5240)
Gupta, Rzehak and Wells (to appear soon)

Part I

- LEP precision data can probe physics up to 3 TeV although LEP Energy was only 209 GeV.

- Can LHC Higgs data also go beyond direct searches?

How well do we *need* to measure Higgs couplings?

- Find maximal allowed deviation if no other EWSB state is accessible at the LHC even in the long run. We will call this the target value.

- Because if such a state is seen we would already know that the Higgs sector is exotic. Higgs couplings will then give only complementary information.

- If no such state is seen, Higgs coupling deviations would be primary evidence of BSM physics.

Gupta, Rzhehak, Wells (2012)

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  Eg.: Heavier Higgses in SUSY, composite resonances

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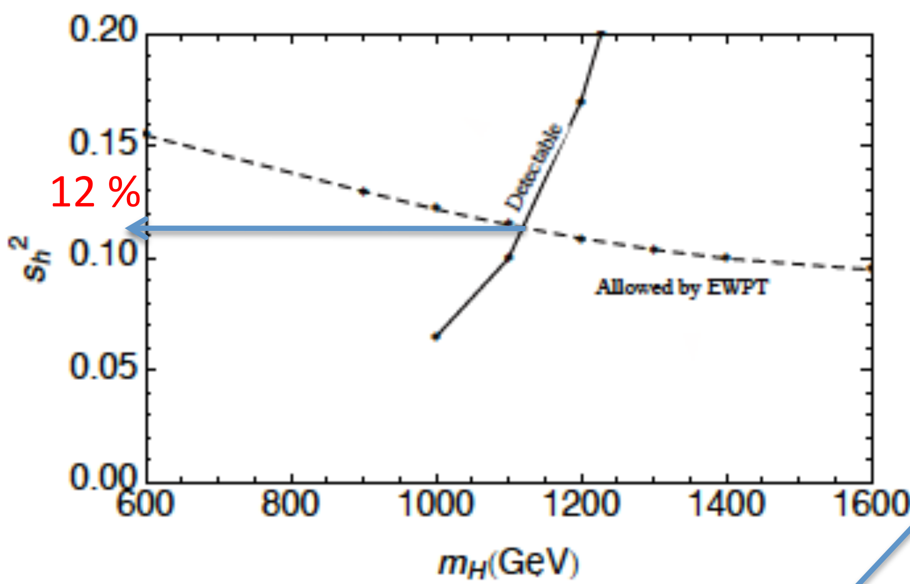
Gupta, Rzhehak, Wells (2012)

Mixed-in singlet



Gives us two Higgs states share SM couplings:

$$g_h^2 = c_h^2 \; g_{SM}^2$$
$$g_H^2 = s_h^2 \; g_{SM}^2 .$$

Precision Observables:

$$S = c_h^2 S_{SM}(m_h) + s_h^2 S_{SM}(m_H)$$
$$T = c_h^2 T_{SM}(m_h) + s_h^2 T_{SM}(m_H)$$

Thus we find target:

$$\Delta g_h / g_{SM} \approx -s_h^2/2 \quad = -6\ \%$$

New term in Lagrangian: $|H_{SM}|^2 |\Phi_S|^2$ → Singlet

Detectability curve based on work of Bowen, Cui and Wells (2007)

Composite PNGB Higgs

- SILH Lagrangian:

(Giudice,Grojean,
Pomarol and Rattazzi (2007))

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

- Coupling deviations of order c_i ξ where $\xi = v^2/f^2$.
- Precision constraints imply $\xi < 0.15$.
- Thus we get coupling deviation targets of order of tens of %.

MSSM

- MSSM Higgs coupling deviations:

$$g_{huu} \xrightarrow{M_A \gg M_Z} 1 + \frac{M_Z^2}{2M_A^2}\frac{\sin 4\beta}{\tan\beta} \xrightarrow{\tan\beta \gg 1} 1 - \frac{2M_Z^2}{M_A^2 \tan^2\beta} \to 1$$

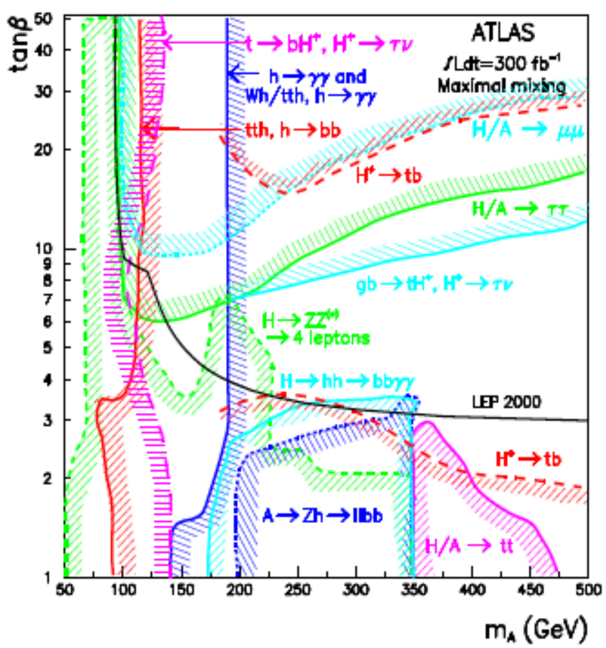
$$g_{hdd} \xrightarrow{M_A \gg M_Z} 1 - \frac{M_Z^2}{2M_A^2}\sin 4\beta \tan\beta \xrightarrow{\tan\beta \gg 1} 1 + \frac{2M_Z^2}{M_A^2} \to 1$$

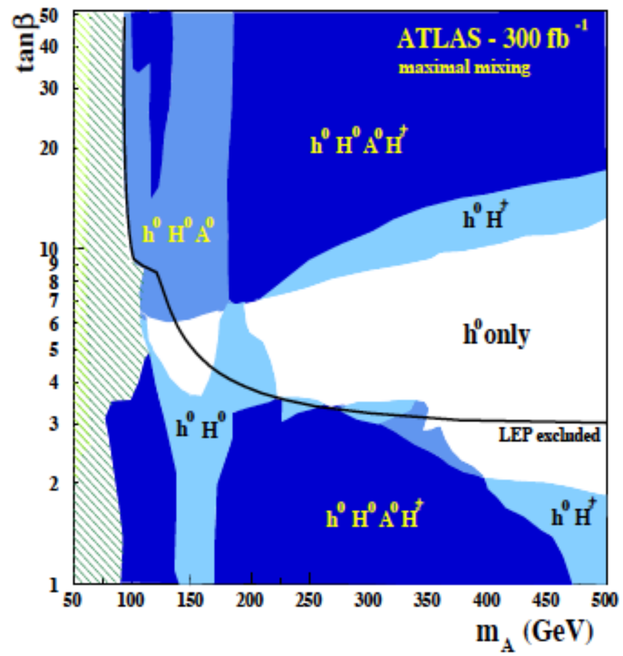
$$g_{hVV} = \sin(\beta - \alpha) \xrightarrow{M_A \gg M_Z} 1 - \frac{M_Z^4}{8M_A^4}\sin^2 4\beta \xrightarrow{\tan\beta \gg 1} 1 - \frac{2M_Z^4}{M_A^4 \tan^2\beta} \to 1$$

Suppression

- *hdd* coupling deviations most important.
- Region near tan β=5 and m_A=200 GeV, inaccessible to direct searches. Higgs coupling deviation measurements are more sensitive here.
- Targets large in this region.

MSSM





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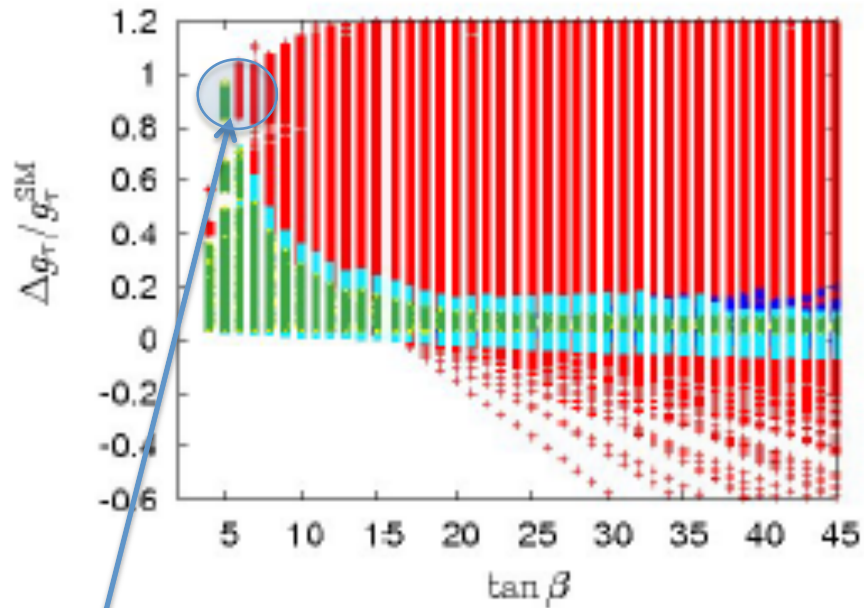

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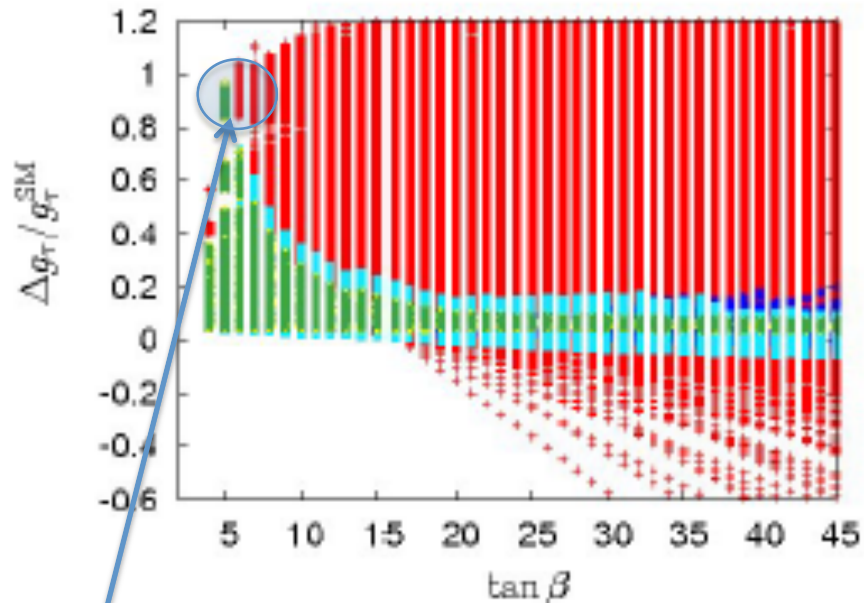

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Higgs coupling Targets

	ΔhVV	$\Delta h\bar{t}t$	Δhbb
Mixed-in Singlet	6%	6%	6%
Composite Higgs	8%	tens of %	tens of %
Minimal Supersymmetry	< 1%	3%	10%[a], 100%[b]
LHC 14 TeV, 3 ab^{-1}	8%	10%	15%

(*a* refers to tan β >20, *b* to all other cases)

Higgs couplings need to be measured to at least about 10 % accuracy in different models. As LHC does not have this precision this is the strongest argument for linear colliders.

Self-Coupling Targets

Model	Δhhh
Mixed-in Singlet	-18%
Composite Higgs	tens of %
Minimal Supersymmetry	-2%[a] – 15%[b]
NMSSM	-25 %
LHC 3 ab^{-1}	-30 %, +20 %

(*a* refers to tan β >10, *b* to all other cases)

Self-coupling targets ~ 20 %.

Gupta, Rzhehak, Wells (to appear soon)

Part-2

- To show that any SUSY modification to raise the Higgs mass would necessarily change Higgs couplings in a correlated way.
- Find bounds on SUSY models (MSSM and beyond) from *present Higgs data.*
- Showing that Higgs coupling data more sensitive than direct search data in certain regions of the parameter space.

Gupta, Montull and Riva (2012)

MSSM

- MSSM Higgs coupling deviations:

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Suppression

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- Targets large in this region.

Understanding SUSY Higgs coupling deviations

- Write potential in terms of *h* and *H*, where:

raises Higgs mass

gets full VEV

changes Higgs couplings

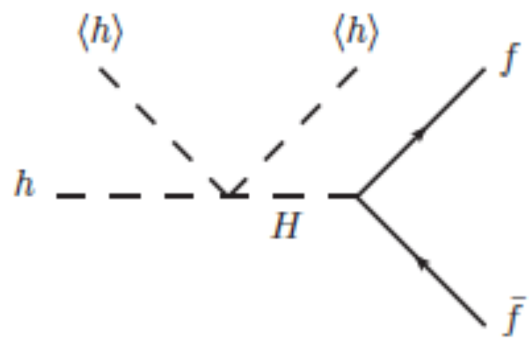
$$
\begin{aligned}
h_1^0 &= \cos\beta h + \sin\beta H \\
h_2^0 &= \sin\beta h - \cos\beta H
\end{aligned}
$$

$$\Delta V(H_1, H_2) = +\delta_\lambda h^4 + \delta h^3 H + \delta_2 h^2 H^2 + \delta_3 h H^3 + \delta_4 H^4$$

- *H* and *h* almost mass eigenstates if $m_A \gg m_Z$ ($m_A > 350$ GeV).

Understanding SUSY Higgs coupling deviations

- Integrate out *H* to obtain:



$$c_{b,\tau} \approx 1 - 4\tan\beta\,\delta\frac{v^2}{m_H^2}$$
$$c_t \approx 1 + 4\cot\beta\,\delta\frac{v^2}{m_H^2}$$

MSSM + Stops

$$\delta_\lambda = \frac{m_Z^2}{16v^2}(c_\beta^2 - s_\beta^2)^2, \qquad \delta = \frac{m_Z^2}{2v^2}s_\beta c_\beta(c_\beta^2 - s_\beta^2)$$

+

$$\delta_\lambda = s_\beta^4\frac{\lambda_2}{8}, \qquad \delta = -4s_\beta^3 c_\beta\frac{\lambda_2}{8}.$$

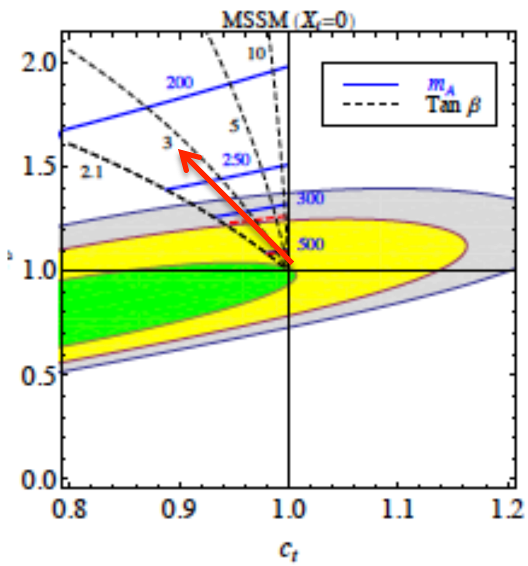
$$c_b \approx 1 + \frac{m_h^2 - m_Z^2\cos 2\beta}{m_H^2},$$
$$c_t \approx 1 - (\cot\beta)^2\frac{m_h^2 - m_Z^2\cos 2\beta}{m_H^2}.$$

D-terms

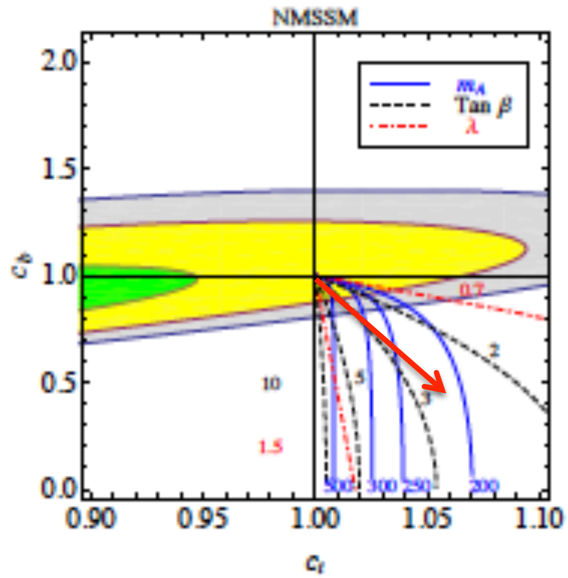
$$\delta_\lambda = \frac{m_Z^2}{16v^2}(c_\beta^2 - s_\beta^2)^2,$$
$$\delta = \frac{m_Z^2}{2v^2}s_\beta c_\beta(c_\beta^2 - s_\beta^2)$$
$$m_Z^2/v^2 \to 4\kappa$$
$$c_b \approx 1 + 2\frac{m_h^2}{m_H^2}\frac{t_\beta^2}{t_\beta^2 - 1}$$
$$c_t \approx 1 - 2\frac{m_h^2}{m_H^2}\frac{1}{t_\beta^2 - 1}$$

NMSSM

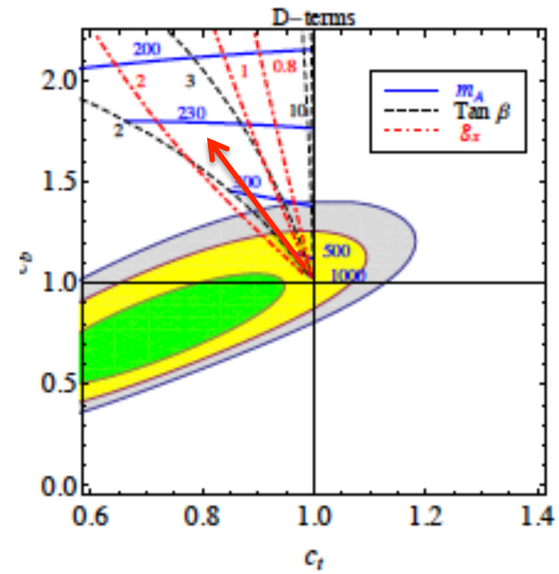
$$\delta_\lambda = \frac{\lambda^2}{16}\sin^2 2\beta\,.$$
$$\delta = -\frac{\lambda^2}{8}\sin 4\beta$$
$$c_b \approx 1 - \frac{t_\beta^2 - 1}{2}\frac{m_h^2 - m_Z^2}{m_H^2}$$
$$c_t \approx 1 + \frac{t_\beta^2 - 1}{2t_\beta^2}\frac{m_h^2 - m_Z^2}{m_H^2},$$



MSSM



NMSSM



D-terms

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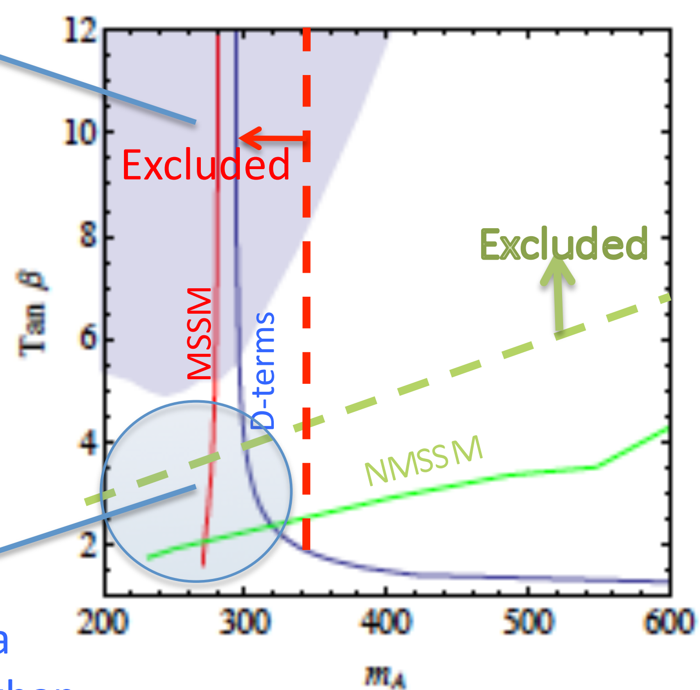
Exclusions

CMS h->ττ



Dashed: Barbieri et al (2012)
with latest data
Solid lines: our bounds

Higgs coupling data
more competitive than
direct searches in
low tan β region

Summary

- Higgs couplings need to be measured to at least about 10 % accuracy in different models. As LHC does not have this precision this is the strongest argument for linear colliders.

- In the MSSM Higgs coupling measurements surpass direct searches in the low tan β region.

- SUSY modifications to raise the Higgs mass would necessarily change Higgs couplings in a correlated way.