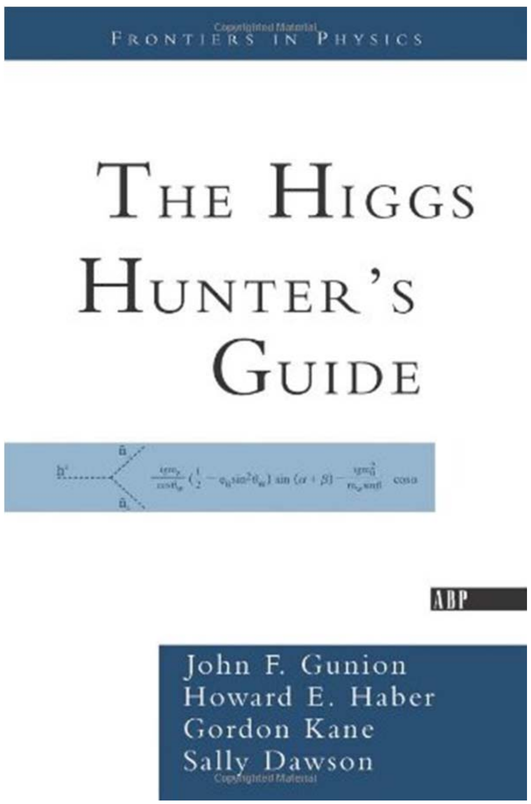
A Higgs Hunter's Perspective

Howard E. Haber
March 11, 2013
Higgs Quo Vadis



Outline

- Properties of the Higgs boson observed by ATLAS and CMS (with a cameo appearance by the Tevatron)

- The decoupling limit of the Higgs sector

    - Heavy mass limit vs. weak coupling limit
    - Tree-level Higgs mixing vs. loop level corrections
    - The decoupling limit of the general 2HDM
    - The decoupling limit of the MSSM Higgs sector
    - Are we approaching the decoupling limit?

- Conclusions

A Higgs boson of mass 126 GeV

A new boson was born on the 4th of July 2012. Its properties seem to be close to the ones predicted for the Standard Model (SM) Higgs boson. As further data comes in, some key questions must be addressed:

1. Is the spin of the new boson 0?

   - It cannot be spin 1, since the $\gamma\gamma$ decay mode is observed. In principle, it could be spin 2 (or higher). Fans of Kaluza-Klein excitations of the graviton would be thrilled if it turned out to be spin 2, although the present data do not favor this spin assignment.

2. Is the new boson CP-even?

   - Ruling out a mixed-CP scalar may take a while.
   - A CP-odd assignment is disfavored by the Higgs data (although it is unlikely anyway in light of its observed couplings to vector boson pairs).

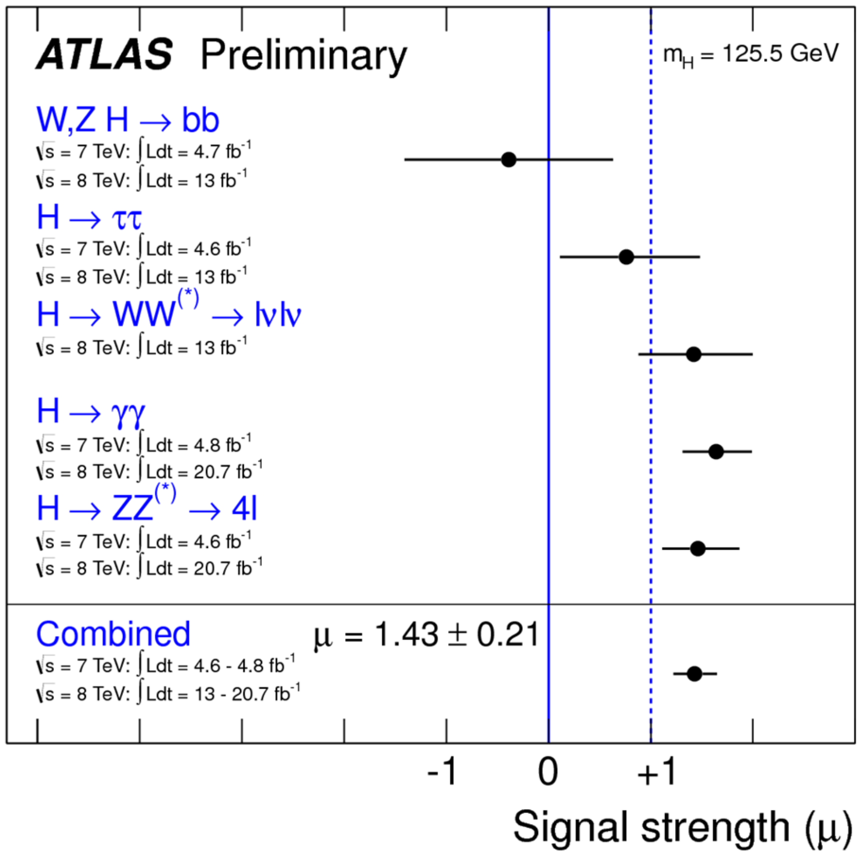
3. Is it a Higgs boson?

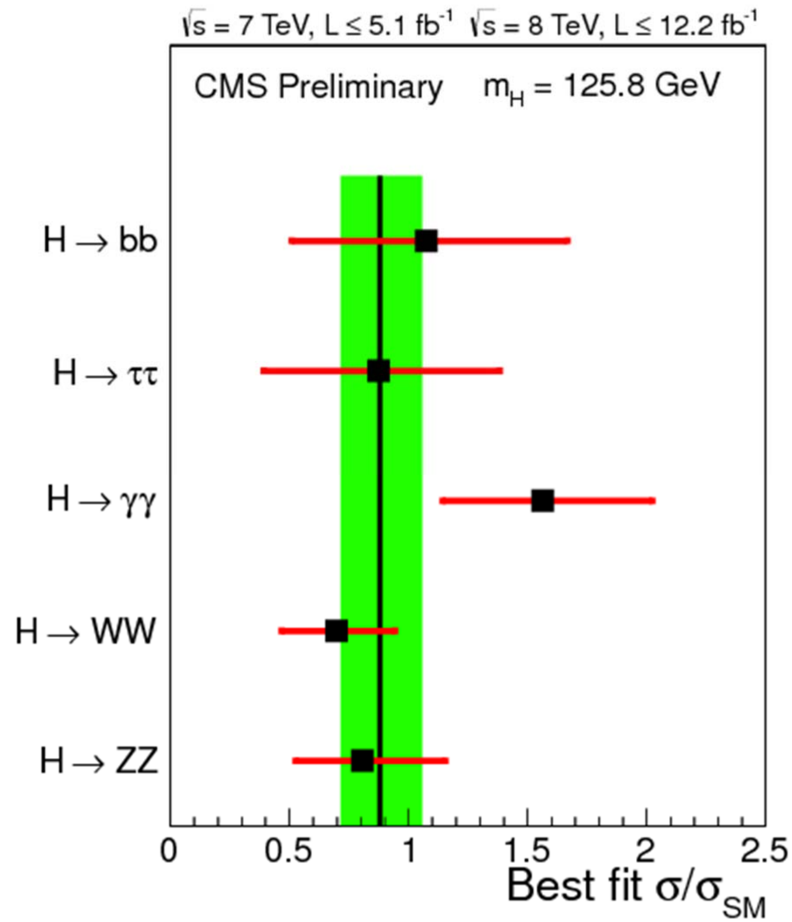
4. Is it *the* Higgs boson?

- We really want to know whether this state is completely responsible for repairing unitarity in the scattering of longitudinal gauge bosons, or whether it is one of a number of scalar states.

- We would also like to clarify the role of the new boson in the fermion mass mechanism.

The limited Higgs data set (as of March 2013) does not permit us to answer any of these questions definitively. Nevertheless, let us see what the present data indicates for the properties of the new boson, normalized to the corresponding properties of the SM Higgs boson.



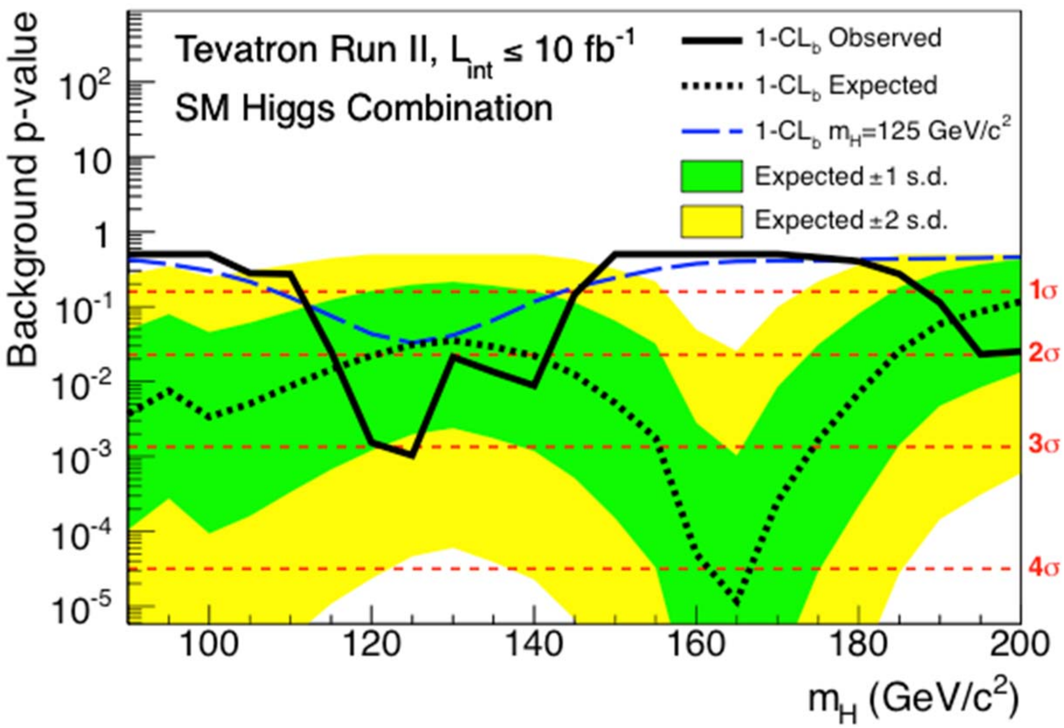


Summary of the individual and combined best-fit values of the strength parameter for a Higgs boson mass hypothesis of 125.5 GeV. Taken from ATLAS-CONF-2013-014, 6 March 2013.

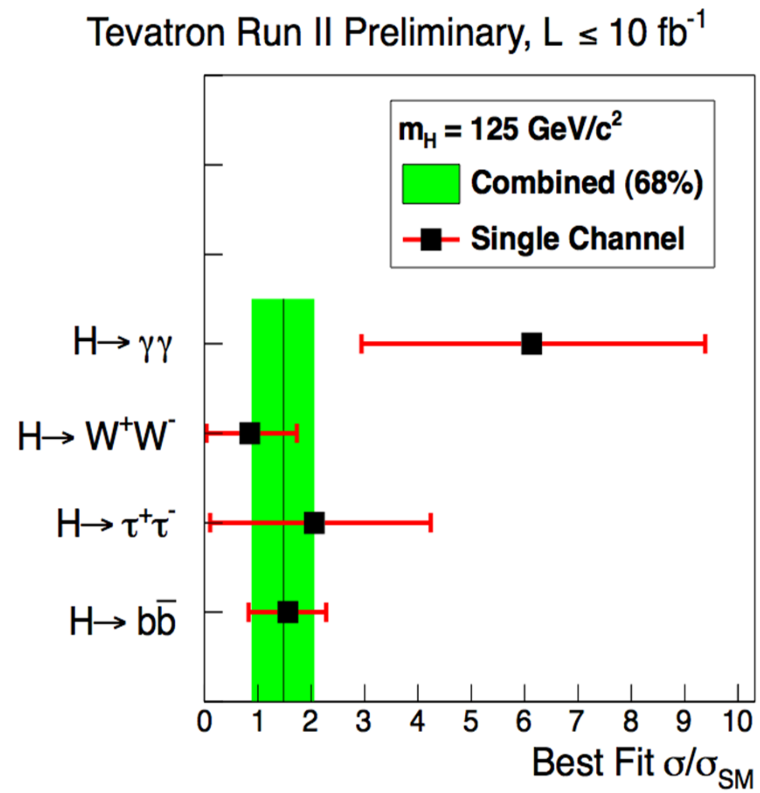
The ATLAS γγ signal strength deviates from the Standard Model prediction by 2.3 σ.

Values of $\hat{\mu} = \sigma/\sigma_{SM}$ for the combination (solid vertical line) and for sub-combinations grouped by decay mode (points). The vertical band shows the overall $\hat{\mu}$ value 0.88 ± 0.21. The horizontal bars indicate the ±1σ uncertainties (both statistical and systematic) on the $\hat{\mu}$ values for individual channels. Taken from CMS-PAS-HIG-12-045, 16 November 2012.

Even the Tevatron has something to contribute



The local p-value distribution for background-only hypothesis, for the combination of the CDF and D0 analyses. The green and yellow bands correspond to the regions enclosing 1 σ and 2σ fluctuations around the median predicted value in the background-only hypothesis, respectively.

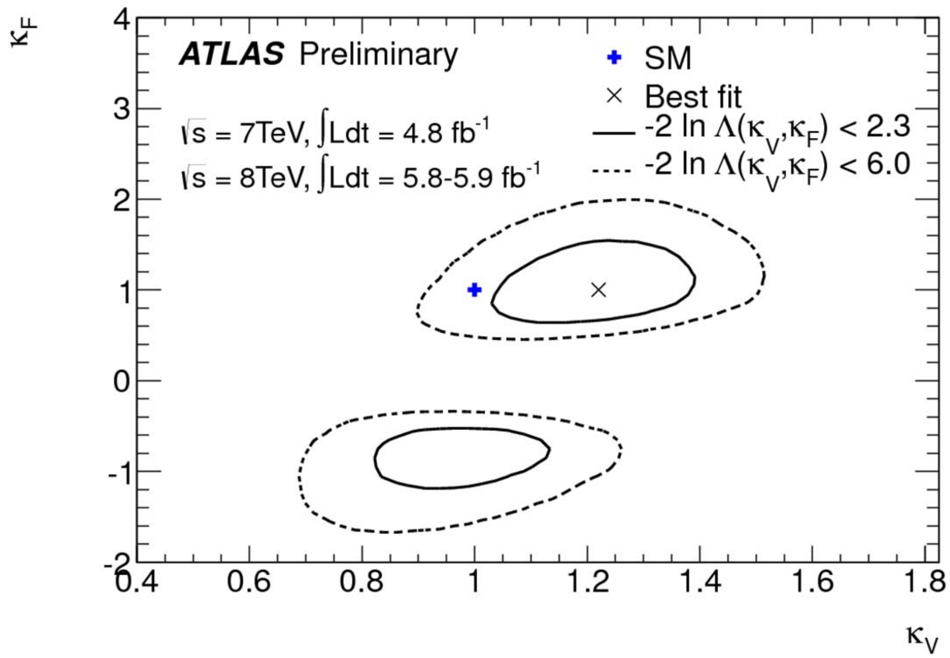


Best fit signal strength for a hypothesized Higgs boson mass of 125 GeV for the combination (black line) and for the three sub-combinations. The band corresponds to the ± 1σ uncertainties on the full combination.

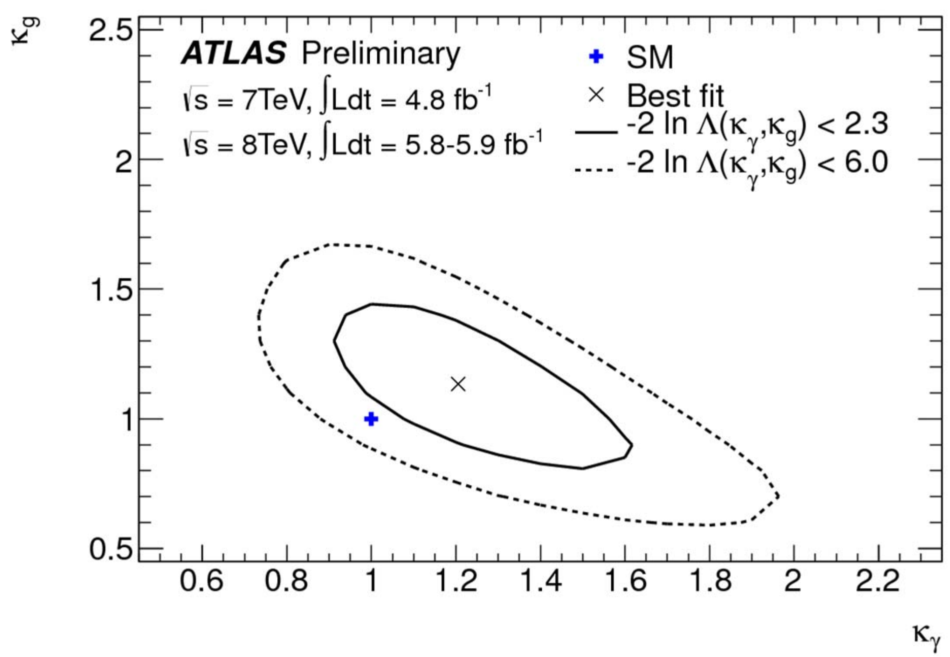
Reference: Aurelio Juste, presentation at the HCP Symposium in Kyoto, Japan, November 15, 2012.

How well does ATLAS Higgs data fit the Standard Model expectations for Higgs couplings?

Top figure: Fits for 2-parameter benchmark models probing different Higgs coupling strength scale factors for fermions and vector bosons, under the assumption that there is a single coupling for all fermions t, b, τ (κ_F) and a single coupling for vector bosons (κ_V).



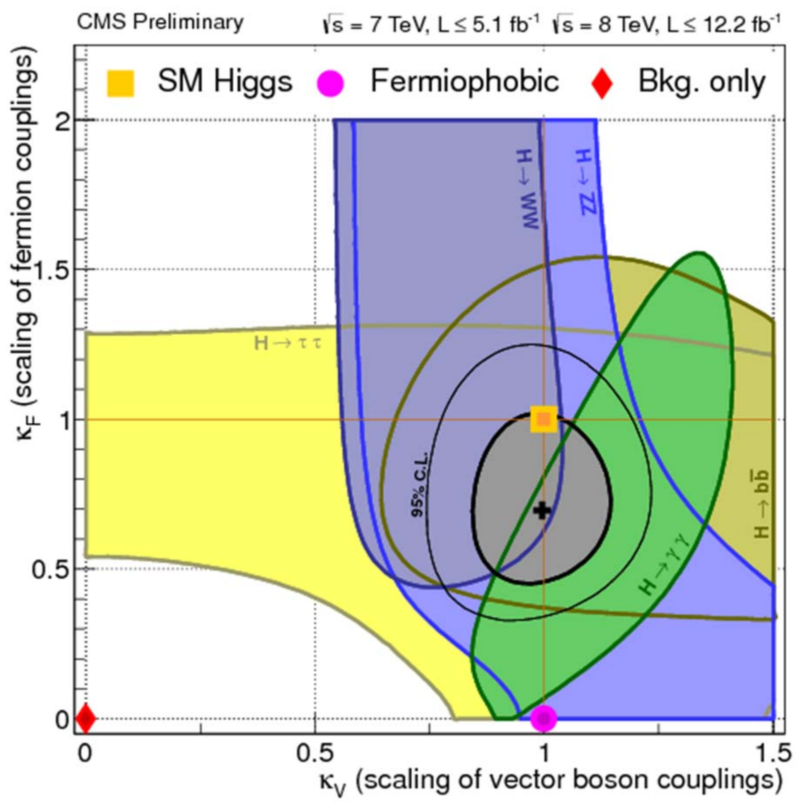
Bottom figure: Fits for benchmark models probing for contributions from non-Standard Model particles: probing only the gg → H and H→ γγ loops, assuming no sizable extra contribution to the total width. The magnitudes of the ggH and γγH couplings relative to their Standard Model values are denoted by κ_g and κ_γ.



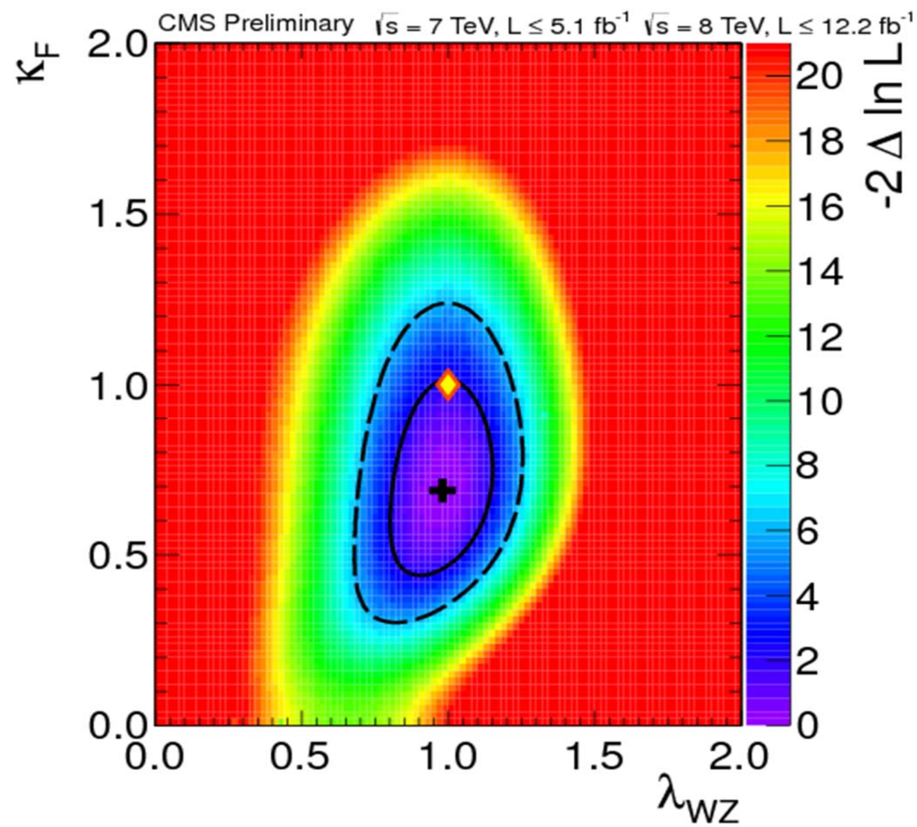
<u>Reference</u>:

ATLAS-CONF-2012-127 (September 9, 2012)

How well does CMS Higgs data fit the Standard Model expectations for Higgs couplings?



Tests of fermion and vector boson couplings of the Higgs boson. The Standard Model (SM) expectation is (κ_V , κ_F)=(1,1).



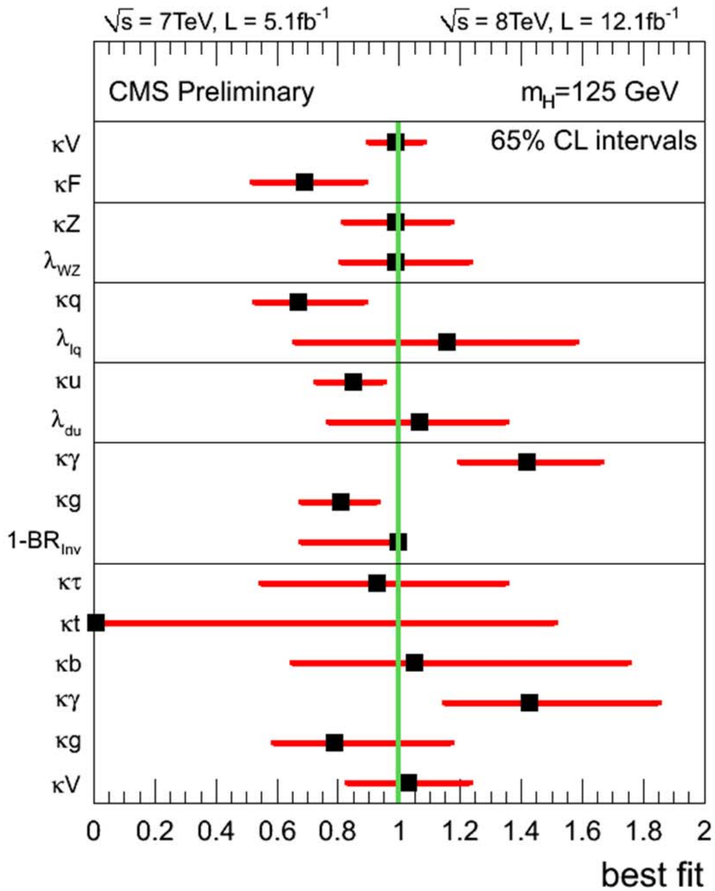
Test of custodial symmetry: the Standard Model expectation is $\lambda_{WZ} = \kappa_W / \kappa_Z = 1$.

Taken from: CMS-PAS-HIG-12-045, 16 November 2012.

CMS Higgs couplings summary

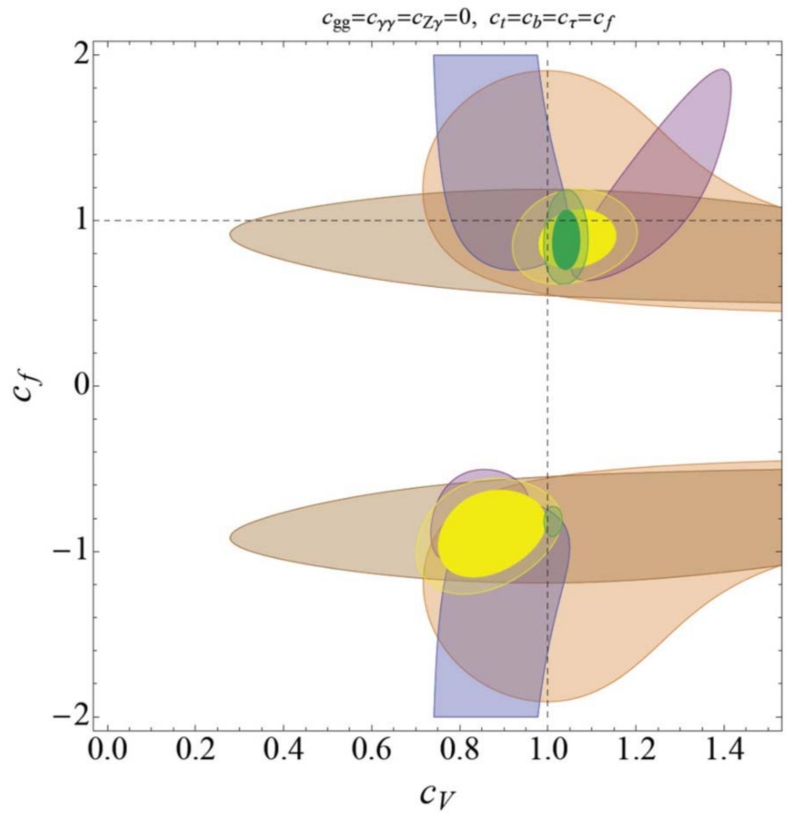
- Overall good compatibility with SM predictions
- Still limited precision

Marco Zanetti, presentation at HCP 2012, Kyoto

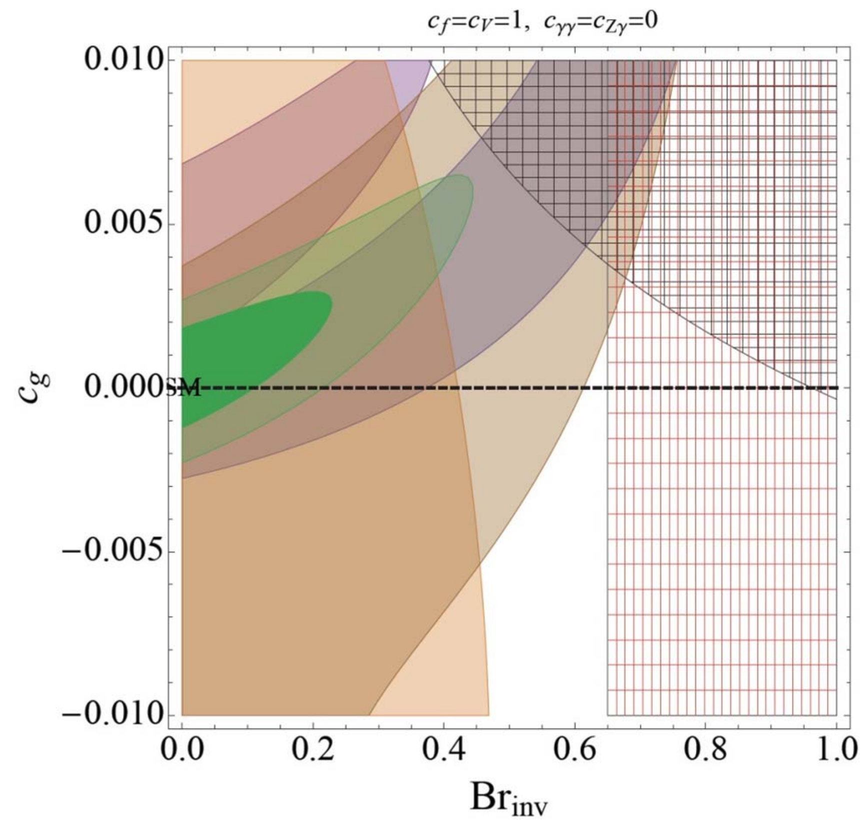


Model parameters	Assessed scaling factors (95% CL intervals)	
λ_{WZ}, κ_Z	λ_{WZ}	[0.57–1.65]
$\lambda_{WZ}, \kappa_Z, \kappa_f$	λ_{WZ}	[0.67–1.55]
κ_V	κ_V	[0.78–1.19]
κ_f	κ_f	[0.40–1.12]
κ_γ, κ_g	κ_γ	[0.98–1.92]
	κ_g	[0.55–1.07]
$\mathcal{B}(H \to BSM), \kappa_\gamma, \kappa_g$	$\mathcal{B}(H \to BSM)$	[0.00–0.62]
$\lambda_{du}, \kappa_V, \kappa_u$	λ_{du}	[0.45–1.66]
$\lambda_{\ell q}, \kappa_V, \kappa_q$	$\lambda_{\ell q}$	[0.00–2.11]
$\kappa_V, \kappa_b, \kappa_\tau, \kappa_t, \kappa_g, \kappa_\gamma$	κ_V	[0.58–1.41]
	κ_b	[not constrained]
	κ_τ	[0.00–1.80]
	κ_t	[not constrained]
	κ_g	[0.43–1.92]
	κ_γ	[0.81–2.27]

From A. Falkowski, F. Riva and A. Urbano, arXiv 1303.1812 based on Higgs data through March 6, 2013. "Overall, the data are well consistent with the Standard Model Higgs boson, except for the slight excess in the h→ γγ channel." Moreover, Falkowski et al. assert that the Higgs couplings to VV (V=W or Z) relative to the Standard Model are "constrained in the range [0.97,1.07] at 95% confidence level."



The 68% (darker green) and 95% (lighter green) CL best fit regions in the c_V–c_f parameter space. The yellow regions are fits without the electroweak data. The color bands are the 1σ regions preferred by the Higgs data in the γγ (purple), VV (blue), ττ (brown), and bb (mauve) channels.



The 68% CL (light green) and 95% CL (dark green) best fit regions to the combined LHC Higgs data. The color bands are the 1σ regions preferred by the Higgs data in the γγ (purple), VV (blue), ττ (brown), and bb (mauve) channels. The meshed regions are excluded by the ATLAS Z+h→invisible search (red) and the monojet constraints (black).

The Decoupling Limit of the Higgs sector

The Higgs boson serves as a window to physics beyond the Standard Model (SM) only if one can experimentally establish deviations of Higgs couplings from their SM values, or discover new scalar degrees of freedom beyond the SM-like Higgs boson. The prospects to achieve this are challenging in general due to the decoupling limit.

In extended Higgs models (as well as in some alternative models of electroweak symmetry breaking), regions of the parameter space exist in which one of the neutral scalars resembles the SM Higgs boson. That is, the lightest neutral scalar is (approximately) CP-even with SM-like Higgs tree-level couplings.

Mechanisms of decoupling

➢ The effective one-doublet Higgs theory

Much of the parameter space of extended Higgs models consists of a scalar mass spectrum in which all but one of the scalars are somewhat heavier in mass (of order Λ_H) with small mass splittings of order $(m_Z/\Lambda_H)m_Z$. Below the scale Λ_H, the effective Higgs theory is the SM. Thus, the lightest neutral scalar resembles the SM Higgs boson.

➢ Weak couplings to the Higgs portal

Since $H^\dagger H$ is an singlet with respect to the electroweak gauge group, the effective Lagrangian

$$\mathscr{L}_{\text{int}} = \lambda H^\dagger H f(\phi, \psi, A_\mu)$$

provides for the possibility of Higgs boson interactions with electroweak gauge singlet combinations of the fields ϕ, ψ and A_μ. In the limit of weak coupling ($\lambda \to 0$), H resembles the SM Higgs boson.

Two aspects of decoupling via heavy mass states

- It is important to distinguish two energy scales:
  - Λ_H : the scale of the heavy non-minimal Higgs bosons.
  - Λ_{NP} : the scale of new physics beyond the Higgs-extended SM.

- The departure from the decoupling limit can receive contributions from both the heavy Higgs states via tree-level mixing and from new physics via one-loop radiative correction effects.

  - Separating out these two effects if deviations from SM Higgs couplings are confirmed will be important (and challenging).

Note: new invisible decays of the Higgs boson (e.g. via the Higgs portal) can complicate further the interpretation of deviations from SM Higgs couplings.

The two-Higgs doublet model (2HDM) provides a laboratory for studying the phenomenology of an extended Higgs sector and possible departures from the decoupling limit.

- It is often motivated by the MSSM, which requires a second Higgs doublet in order to cancel anomalies that arise from Higgsino partners.

- The MSSM also provides a scale of new physics beyond the Higgs-extended Standard Model that can also generate deviations from SM-like Higgs behavior.

- In addition, the MSSM allows for a possible invisible Higgs decay channel, $h^0 \rightarrow \chi^0 \chi^0$.

Theoretical structure of the 2HDM

Start with the 2HDM scalar doublet, hypercharge-one fields, Φ_1 and Φ_2, in a generic basis, where $\langle\Phi_i\rangle = v_i$, and $v^2 \equiv |v_1|^2 + |v_2|^2 = (246\ \text{GeV})^2$. It is convenient to define new Higgs doublet fields:

$$H_1 = \begin{pmatrix} H_1^+ \\ H_1^0 \end{pmatrix} \equiv \frac{v_1^* \Phi_1 + v_2^* \Phi_2}{v}\,, \qquad H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix} \equiv \frac{-v_2 \Phi_1 + v_1 \Phi_2}{v}\,.$$

It follows that $\langle H_1^0\rangle = v/\sqrt{2}$ and $\langle H_2^0\rangle = 0$. This is the *Higgs basis*, which is uniquely defined up to an overall rephasing, $H_2 \to e^{i\chi} H_2$. In the Higgs basis, the scalar potential is given by:

$$\begin{aligned}
\mathcal{V} = {} & Y_1 H_1^\dagger H_1 + Y_2 H_2^\dagger H_2 + [Y_3 H_1^\dagger H_2 + \text{h.c.}] + \tfrac{1}{2} Z_1 (H_1^\dagger H_1)^2 \\
& + \tfrac{1}{2} Z_2 (H_2^\dagger H_2)^2 + Z_3 (H_1^\dagger H_1)(H_2^\dagger H_2) + Z_4 (H_1^\dagger H_2)(H_2^\dagger H_1) \\
& + \left\{ \tfrac{1}{2} Z_5 (H_1^\dagger H_2)^2 + \left[Z_6 (H_1^\dagger H_1) + Z_7 (H_2^\dagger H_2)\right] H_1^\dagger H_2 + \text{h.c.} \right\}\,,
\end{aligned}$$

where Y_1, Y_2 and $Z_1, \ldots, Z_4$ are real and uniquely defined, whereas Y_3, Z_5, Z_6 and Z_7 are complex and transform under the rephasing of H_2,

$$[Y_3, Z_6, Z_7] \to e^{-i\chi}[Y_3, Z_6, Z_7] \quad \text{and} \quad Z_5 \to e^{-2i\chi} Z_5\,.$$

The Higgs mass-eigenstate basis

The physical charged Higgs boson is the charged component of the Higgs-basis doublet H_2, and its mass is given by $m^2_{H^\pm} = Y_2 + \frac{1}{2}Z_3 v^2$.

The three physical neutral Higgs boson mass-eigenstates are determined by diagonalizing a 3×3 real symmetric squared-mass matrix that is defined in the Higgs basis

$$\mathcal{M}^2 = v^2 \begin{pmatrix} Z_1 & \mathrm{Re}(Z_6) & -\mathrm{Im}(Z_6) \\ \mathrm{Re}(Z_6) & \frac{1}{2}Z_{345} + Y_2/v^2 & -\frac{1}{2}\mathrm{Im}(Z_5) \\ -\mathrm{Im}(Z_6) & -\frac{1}{2}\mathrm{Im}(Z_5) & \frac{1}{2}Z_{345} - \mathrm{Re}(Z_5) + Y_2/v^2 \end{pmatrix},$$

where $Z_{345} \equiv Z_3 + Z_4 + \mathrm{Re}(Z_5)$.The diagonalizing matrix is a 3×3 real orthogonal matrix that depends on three angles: θ_{12}, θ_{13} and θ_{23}. Under the rephasing $H_2 \to e^{i\chi} H_2$,

$$\theta_{12}\,,\ \theta_{13} \text{ are invariant, and } \quad \theta_{23} \to \theta_{23} - \chi\,.$$

The Decoupling Limit of the 2HDM

In the decoupling limit, the following conditions are neccesary and sufficient for achieving a SM-like neutral scalar state, h_1:

$$|\sin\theta_{12}|\,,\ |\sin\theta_{13}|\,,\ |\mathrm{Im}(Z_5\,e^{-2i\theta_{23}})|\ \ll 1\,.$$

This decoupling can be achieved in two ways:

- Heavy mass decoupling. In this case, $m_1\,,\,v \ll m_2, m_3, m_{H^\pm}$, and

  $$|\sin\theta_{12}| \sim \mathcal{O}\left(\frac{v^2}{m_2^2}\right)\,,\qquad |\sin\theta_{13}|\,,\ |\mathrm{Im}(Z_5\,e^{-2i\theta_{23}})| \sim \mathcal{O}\left(\frac{v^2}{m_3^2}\right)\,.$$

  In particular, the properties of h_1 coincide with the SM Higgs boson with $m_1^2 = Z_1 v^2$ up to corrections of $\mathcal{O}(v^4/m_{2,3}^2)$, and the heavy scalars are nearly mass-degenerate, $m_2 \simeq m_3 \simeq m_{H^\pm}$, with squared-mass splittings of $\mathcal{O}(v^2)$.

- Weak-coupling to the Higgs portal. In this case, the Higgs basis field H_1 is identified as the SM-like Higgs boson, with weak coupling to the Higgs portal field H_2 (which need not be heavy).

Decoupling limit without heavy Higgs masses

The case of Z_6=0 is special (since it forbids H_1–H_2 mixing). It leads to one scalar state with exact SM tree-level couplings. Choosing this state to be h_1, then $\sin\theta_{12} = \sin\theta_{13} = \mathrm{Im}(Z_5 e^{-2i\theta_{23}}) = 0.$

In light of the scalar potential mimimum conditions,

$$Y_1 = -\tfrac{1}{2} Z_1 v^2 \text{ and } Y_3 = -\tfrac{1}{2} Z_6 v^2,$$

we have Y_3= Z_6=0. This condition is not natural unless Z_7=0 as well, in which case we have a $\mathbf{Z_2}$ symmetry in the Higgs basis. The 2HDM with Y_3= Z_6=Z_7=0 is called the inert 2HDM. In this model, the Higgs basis field H_1 is identical to the SM Higgs boson. The lightest neutral scalar inside H_2 is absolutely stable (and provides a possible candidate for dark matter).

However, even in the inert 2HDM, there are some clues to distinguish h_1 from the SM Higgs boson. In particular the $h_1H^+H^-$, h_1AA and h_1HH couplings are nonzero (H.E. Haber and D. O'Neil):

$$
\begin{aligned}
g_{h_1H^+H^-} &= Z_3 v\,,\\
g_{h_1AA} &= \left[Z_3 + Z_4 - \mathrm{Re}(Z_5 e^{-2i\theta_{23}})\right] v\,,\\
g_{h_1HH} &= \left[Z_3 + Z_4 + \mathrm{Re}(Z_5 e^{-2i\theta_{23}})\right] v\,.
\end{aligned}
$$

Hence, even without detecting the non-minimal Higgs states, the properties of h_1 can be shifted:

- The tri-linear Higgs couplings can introduce new radiative corrections. For example, a charged Higgs loop would (slightly) modify the rate for $h_1 \to \gamma\gamma$.

- If any of the non-minimal Higgs states were lighter than $\frac{1}{2}m_{h_1}$, then new h_1 decay channels would open up. In the inert 2HDM, this would lead to invisible Higgs decays (e.g. $h_1 \to AA$).

Scenarios of this type can also arise in Higgs portal models.

Higgs Yukawa couplings in the 2HDM

In the Higgs basis, $\kappa^{U,D}$ and $\rho^{U,D}$, are the 3×3 Yukawa coupling matrices,

$$-\mathscr{L}_{\rm Y} = \overline{U}_L(\kappa^U H_1^{0\,\dagger} + \rho^U H_2^{0\,\dagger})U_R - \overline{D}_L K^\dagger(\kappa^U H_1^- + \rho^U H_2^-)U_R$$
$$+\overline{U}_L K(\kappa^{D\,\dagger} H_1^+ + \rho^{D\,\dagger} H_2^+)D_R + \overline{D}_L(\kappa^{D\,\dagger} H_1^0 + \rho^{D\,\dagger} H_2^0)D_R + \text{h.c.},$$

where $U = (u, c, t)$ and $D = (d, s, b)$ are the physical quark fields and K is the CKM mixing matrix. (Repeat for the leptons.)

By setting $H_1^0 = v/\sqrt{2}$ and $H_2^0 = 0$, one obtains the quark mass terms. Hence, κ^U and κ^D are proportional to the diagonal quark mass matrices M_U and M_D, respectively,

$$M_U = \frac{v}{\sqrt{2}}\kappa^U = \text{diag}(m_u\,, m_c\,, m_t)\,, \qquad M_D = \frac{v}{\sqrt{2}}\kappa^{D\,\dagger} = \text{diag}(m_d\,, m_s\,, m_b)\,.$$

Note that $\rho^Q \to e^{-i\chi}\rho^Q$ under the rephasing $H_2 \to e^{i\chi}H_2$, (for $Q = U, D$).

In general ρ^Q is a complex non-digaonal matrix. As a result, the most general 2HDM exhibits tree-level Higgs-mediated FCNCs and new sources of CP-violation in the interactions of the neutral Higgs bosons.

In the decoupling limit where $m_1 \ll m_{2,3}$, CP-violating and tree-level Higgs-mediated FCNCs are suppreseed by factors of $\mathcal{O}(v^2/m^2_{2,3})$. In contrast, the interactions of the heavy neutral Higgs bosons (h_2 and h_3) and the charge Higgs bosons ($H^{\pm}$) in the decoupling limit can exhibit both CP-violating and quark flavor non-diagonal couplings (proportional to ρ^Q).

How to avoid tree-level Higgs-mediated FCNCs

- Arbitrarily declare ρ^U and ρ^D to be diagonal matrices. This is an unnaturally fine-tuned solution.

- Impose a discrete symmetry or supersymmetry (e.g.“Type-I” or “Type-II” Higgs-fermion interactions), which selects out a special basis of the 2HDM scalar fields. In this case, ρ^Q is automatically proportional to M_Q (for $Q = U, D, L$), and is hence diagonal.

- Impose alignment without a symmetry: $\rho^Q = \alpha^Q \kappa^Q$, $(Q = U, D, L)$, where the α^Q are complex scalar parameters [e.g. see Pich and Tuzon (2009)].

- Impose the heavy Higgs mass decoupling limit. Tree-level Higgs-mediated FCNCs will be suppressed by factors of squared-masses of heavy Higgs states. (How heavy is sufficient?)

The CP-conserving 2HDM with Type I or II Yukawa couplings

The scalar potential exhibits a $\mathbb{Z}_2$ symmetry that is at most softly broken,

$$V = m_{11}^2 \Phi_1^\dagger \Phi_1 + m_{22}^2 \Phi_2^\dagger \Phi_2 - \left(m_{12}^2 \Phi_1^\dagger \Phi_2 + \text{h.c.} \right) + \tfrac{1}{2}\lambda_1 \left(\Phi_1^\dagger \Phi_1 \right)^2 + \tfrac{1}{2}\lambda_2 \left(\Phi_2^\dagger \Phi_2 \right)^2$$
$$+ \lambda_3 \Phi_1^\dagger \Phi_1 \Phi_2^\dagger \Phi_2 + \lambda_4 \Phi_1^\dagger \Phi_2 \Phi_2^\dagger \Phi_1 + \left[\tfrac{1}{2}\lambda_5 \left(\Phi_1^\dagger \Phi_2 \right)^2 + \text{h.c.} \right],$$

where m_{12}^2 and λ_5 are real. The most general Yukawa Lagrangian, in terms of the quark mass-eigenstate fields, is:

$$-\mathscr{L}_{\rm Y} = \overline{U}_L \widetilde{\Phi}_a^0 \eta_a^U U_R + \overline{D}_L K^\dagger \widetilde{\Phi}_a^- \eta_a^U U_R + \overline{U}_L K \Phi_a^+ \eta_a^{D\,\dagger} D_R + \overline{D}_L \Phi_a^0 \eta_a^{D\,\dagger} D_R + \text{h.c.}\,,$$

where $a = 1, 2$, $\widetilde{\Phi}_a \equiv (\widetilde{\Phi}^0\,,\,\widetilde{\Phi}^-) = i\sigma_2 \Phi_a^*$ and K is the CKM mixing matrix. The $\eta^{U,D}$ are 3×3 Yukawa coupling matrices.

Type-I Yukawa couplings: $\eta_1^U = \eta_1^D = 0$.

	h^0	A^0	H^0
up-type quarks	$\cos\alpha/\sin\beta$	$\cot\beta$	$\sin\alpha/\sin\beta$
down-type quarks and leptons	$\cos\alpha/\sin\beta$	$-\cot\beta$	$\sin\alpha/\sin\beta$

Type-II Yukawa couplings: $\eta_1^U = \eta_2^D = 0$ [employed by the MSSM].

	h^0	A^0	H^0
up-type quarks	$\cos\alpha/\sin\beta$	$\cot\beta$	$\sin\alpha/\sin\beta$
down-type quarks and leptons	$-\sin\alpha/\cos\beta$	$\tan\beta$	$\cos\alpha/\cos\beta$

Here, α is the CP-even Higgs mixing angle and $\tan\beta = v_u/v_d$. The h^0 and H^0 are CP-even neutral Higgs bosons with $m_{h^0} \leq m_{H^0}$ and A^0 is a CP-odd neutral Higgs boson.

Example: decoupling of the non-minimal Higgs bosons of the MSSM Higgs sector (tree-level analysis)

The MSSM employs a type-II Higgs-fermion Yukawa coupling scheme. In addition, supersymmetry restricts the Higgs potential parameters,

$$\lambda_1 = \lambda_2 = -(\lambda_3 + \lambda_4) = \tfrac{1}{4}(g^2 + g'^2)\,, \qquad \lambda_4 = -\tfrac{1}{2}g^2\,, \qquad \lambda_5 = 0\,.$$

In the limit of $m_A \gg m_Z$, the tree-level expressions for the MSSM Higgs masses and mixings are:

$$m_h^2 \simeq m_Z^2 \cos^2 2\beta\,, \qquad m_H^2 \simeq m_A^2 + m_Z^2 \sin^2 2\beta\,,$$

$$m_{H^\pm}^2 = m_A^2 + m_W^2\,, \qquad \cos^2(\beta - \alpha) \simeq \frac{m_Z^4 \sin^2 4\beta}{4m_A^4}\,.$$

Indeed, $m_A \simeq m_H \simeq m_{H^\pm}$, up to corrections of $\mathcal{O}(m_Z^2/m_A)$, and $\cos(\beta - \alpha) = 0$ up to corrections of $\mathcal{O}(m_Z^2/m_A^2)$, as expected. This is the decoupling limit of the MSSM Higgs sector.

To connect with previous notation, $\sin\theta_{12} = -\cos(\beta - \alpha)$, $\theta_{23} = 0$ and $\sin\theta_{13} = \mathrm{Im}(Z_5 e^{-2i\theta_{23}}) = 0$.

In general, in the limit of $\cos(\beta-\alpha)\to 0$, all the h^0 couplings to SM particles approach their SM limits. In particular, if λ_V is a Higgs coupling to vector bosons and λ_f is a Higgs couplings to fermions, then

$$\frac{\lambda_V}{[\lambda_V]_{\rm SM}} = \sin(\beta-\alpha) = 1 + \mathcal{O}\left(m_Z^4/m_A^4\right)\,, \qquad\qquad \frac{\lambda_f}{[\lambda_f]_{\rm SM}} = 1 + \mathcal{O}\left(m_Z^2/m_A^2\right)\,.$$

The behavior of the $h^0 ff$ coupling is:

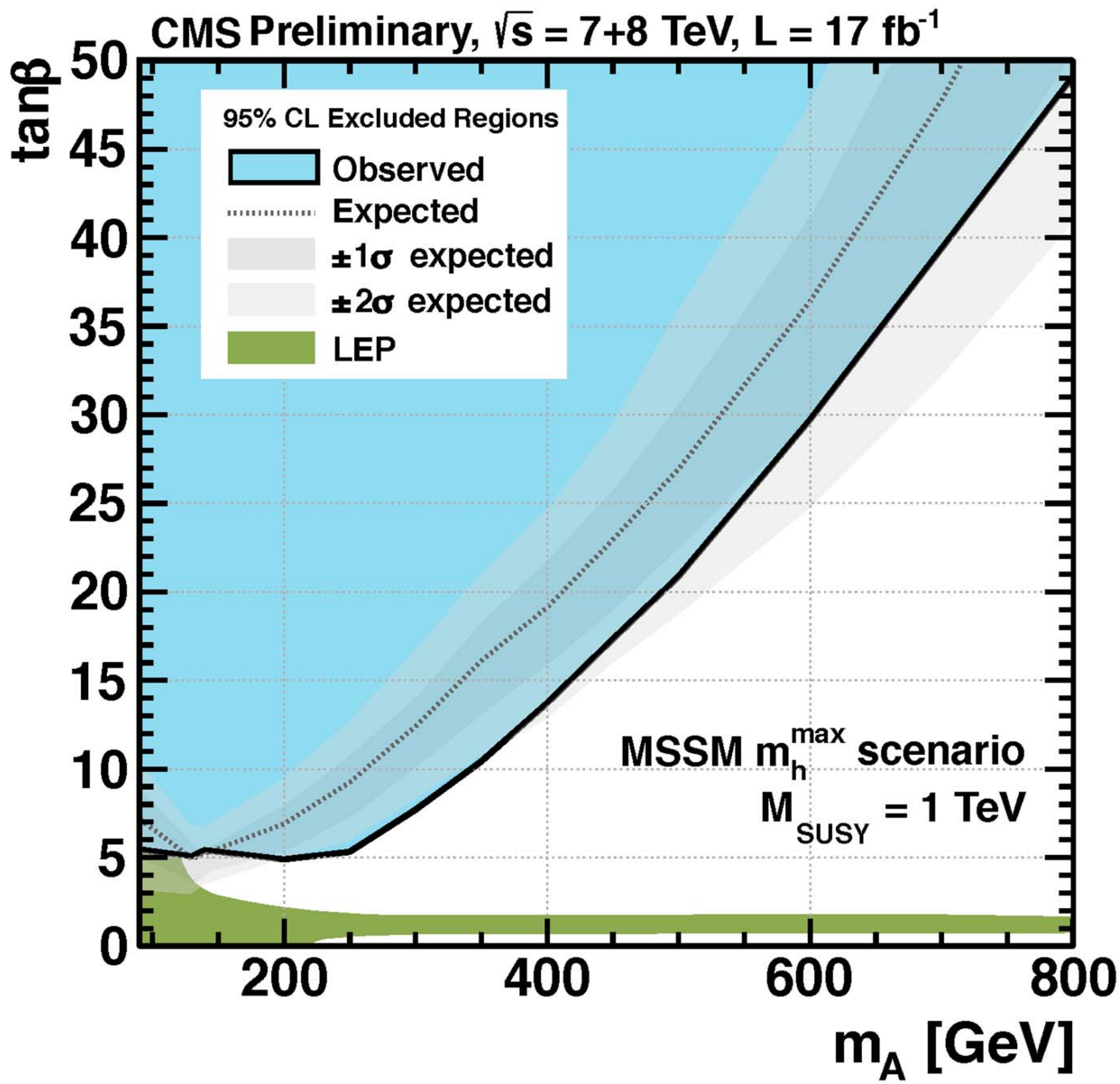
$$h^0 b\bar{b} \quad (\text{or } h^0\tau^+\tau^-): \qquad -\frac{\sin\alpha}{\cos\beta} = \sin(\beta-\alpha) - \tan\beta\,\cos(\beta-\alpha)\,,$$

$$h^0 t\bar{t}: \qquad \frac{\cos\alpha}{\sin\beta} = \sin(\beta-\alpha) + \cot\beta\,\cos(\beta-\alpha)\,.$$

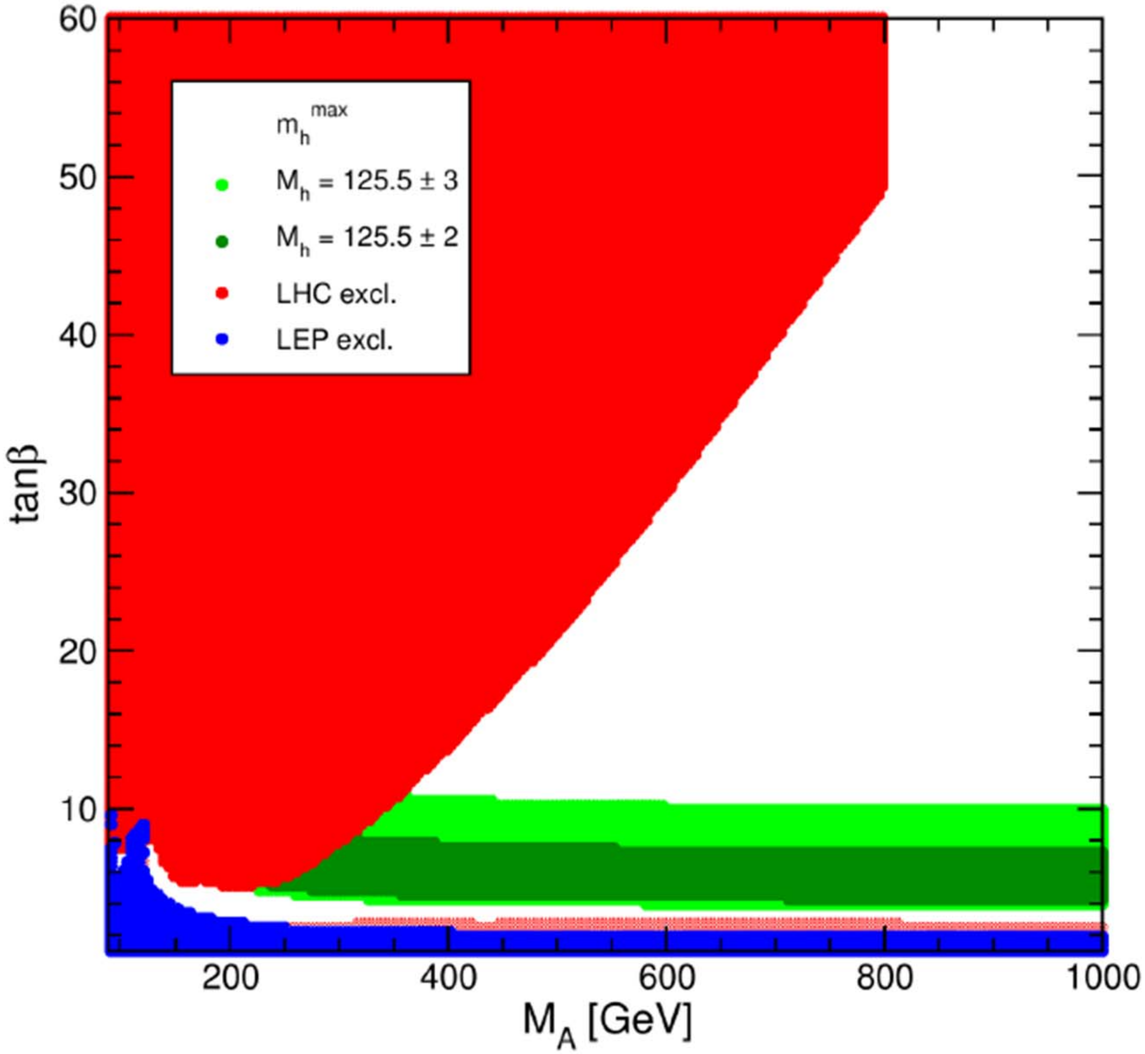
Note the extra $\tan\beta$ enhancement in the deviation of λ_{hbb} from $[\lambda_{hbb}]_{\rm SM}$.

Thus, the approach to decoupling is fastest for the h^0VV couplings, and slowest for the couplings of h^0 to down-type quarks and leptons (if $\tan\beta$ is large).

More evidence for the decoupling limit?



If you also impose the constraint of the observed Higgs mass, the lower bound on m_A is raised above 200 GeV, which is approaching the Higgs decoupling regime.



Taken from M. Carena et al., arXiv:1302.7033

Conclusions

- The current LHC Higgs data sets are limited in statistics. Despite some intriguing variations, the present data is consistent with a SM-like Higgs boson.
- If further data reveals no statistically significant deviations from SM Higgs behavior, then we are in the domain of the decoupling limit.
- The decoupling limit can be achieved in two different ways:
  1. an extended Higgs sector in which all scalar states (save one) are heavy
  2. weak coupling to Higgs portal states (these may include new singlet states with respect to the SM or new states with electroweak quantum numbers)
- The interpretation of small deviations from SM-like Higgs behavior is both theoretically and experimentally challenging.
- The LHC has the capability of exploring Higgs couplings with $\mathcal{O}(10\%)$ accuracy. However, in the decoupling regime, we will require a precision Higgs factory with $\mathcal{O}(1\%)$ accuracy in order to elucidate the possibility of new Higgs physics beyond the Standard Model.