Higgs boson properties from hadron collider experiments

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Mainly based on
arxiv:1303.3570
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I think you already know that...

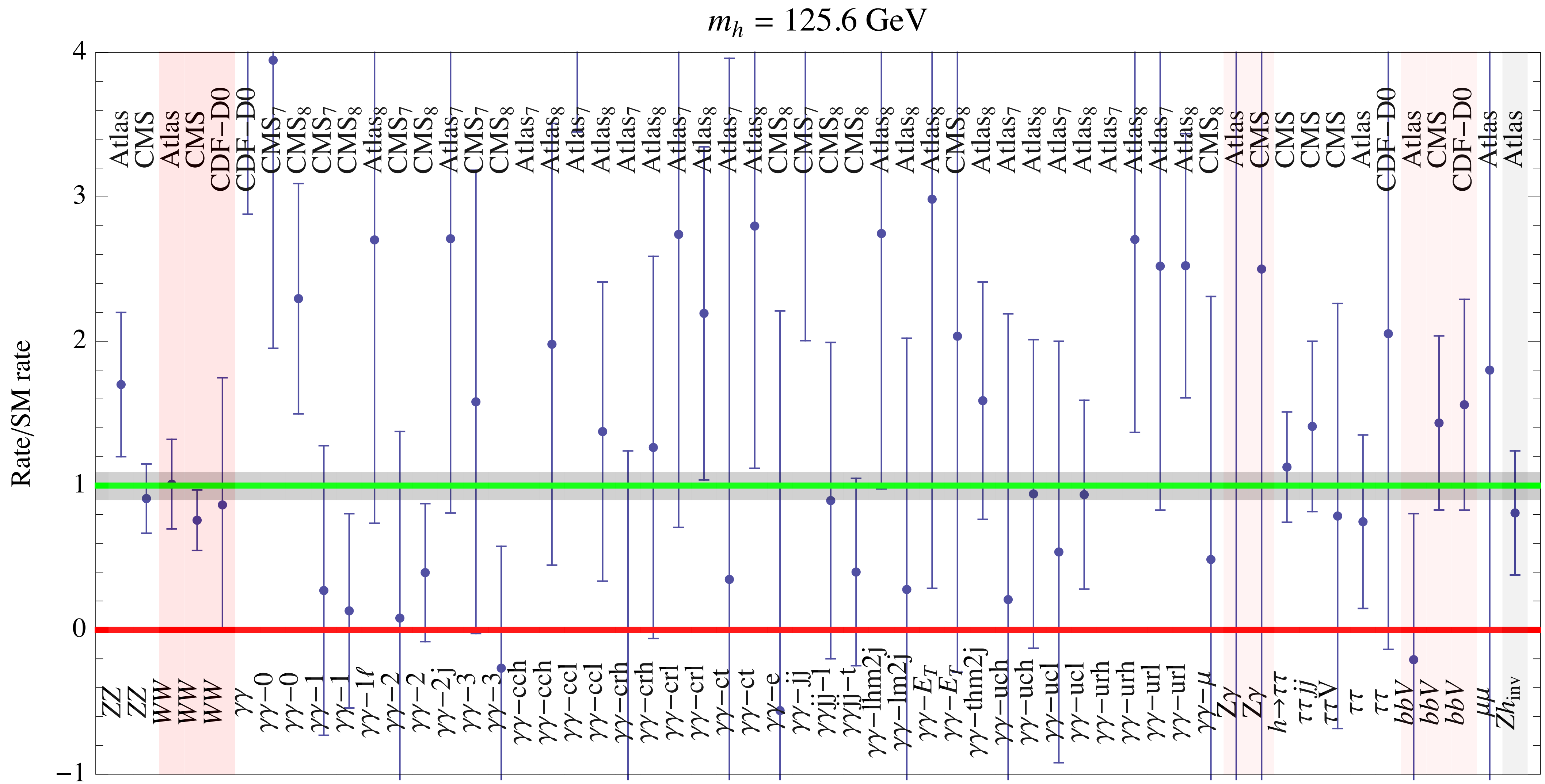
- Recently, the experimental collaborations have found a new particle with a mass of 125.7 GeV (more or less).
- This particle could be the long-waited Higgs boson.
- In order to be sure, we need to investigate thoroughly its properties.

I think you already know that...

- The discrete quantum numbers are interesting, sure...
- but checking if its couplings agree with the SM or other theories is a more significant test.

Data: ATLAS CMS CDF D0

We used all the data available until now: 56 data points.



The grey band shows ±1σ for the average of all rates: 1.00±0.10

The Lagrangian

$$\mathcal{L}_h = r_t \frac{m_t}{V} h\bar{t}t + r_b \frac{m_b}{V} h\bar{b}b + r_\tau \frac{m_\tau}{V} h\bar{\tau}\tau + r_\mu \frac{m_\tau}{V} h\bar{\mu}\mu + r_Z \frac{M_Z^2}{V} hZ_\mu^2 + r_W \frac{2M_W^2}{V} hW_\mu^+ W_\mu^- + \\ + r_\gamma c_{\rm SM}^{\gamma\gamma} \frac{\alpha}{\pi V} hF_{\mu\nu}F_{\mu\nu} + r_g c_{\rm SM}^{gg} \frac{\alpha_s}{12\pi V} hG_{\mu\nu}^a G_{\mu\nu}^a + r_{Z\gamma} c_{\rm SM}^{Z\gamma} \frac{\alpha}{\pi V} hF_{\mu\nu}Z_{\mu\nu}.$$

- We performed the most generic fit in terms of a particle h coupled to pairs of SM particles.
- We also considered the decay $h \to ??$
- We extracted the function

$$\chi^2(r_t, r_b, r_\tau, r_W, r_Z, r_g, r_\gamma, r_{Z\gamma}, r_\mu, \mathrm{BR}_{\rm inv})$$

The universal fit

Higgs data are converging towards the SM predictions with small errors.

$$r_i = 1 + \epsilon_i \qquad \text{with} \qquad \epsilon_i \ll 1$$

The observables are expanded at first order in ε:

$$R_{h\to WW} \;=\; 1 - 1.14\epsilon_b + 1.58\epsilon_g - \epsilon_{\rm inv} - 0.04\epsilon_t + 1.72\epsilon_W + 0.02\epsilon_Z - 0.13\epsilon_\tau$$

and the χ^2 is expanded up to the second order in ε:

$$\chi^2 = \sum_{i,j}(\epsilon_i - \mu_i)(\sigma^2)^{-1}_{ij}(\epsilon_j - \mu_j), \qquad \text{where} \qquad (\sigma^2)_{ij} = \sigma_i\rho_{ij}\sigma_j$$

The universal fit

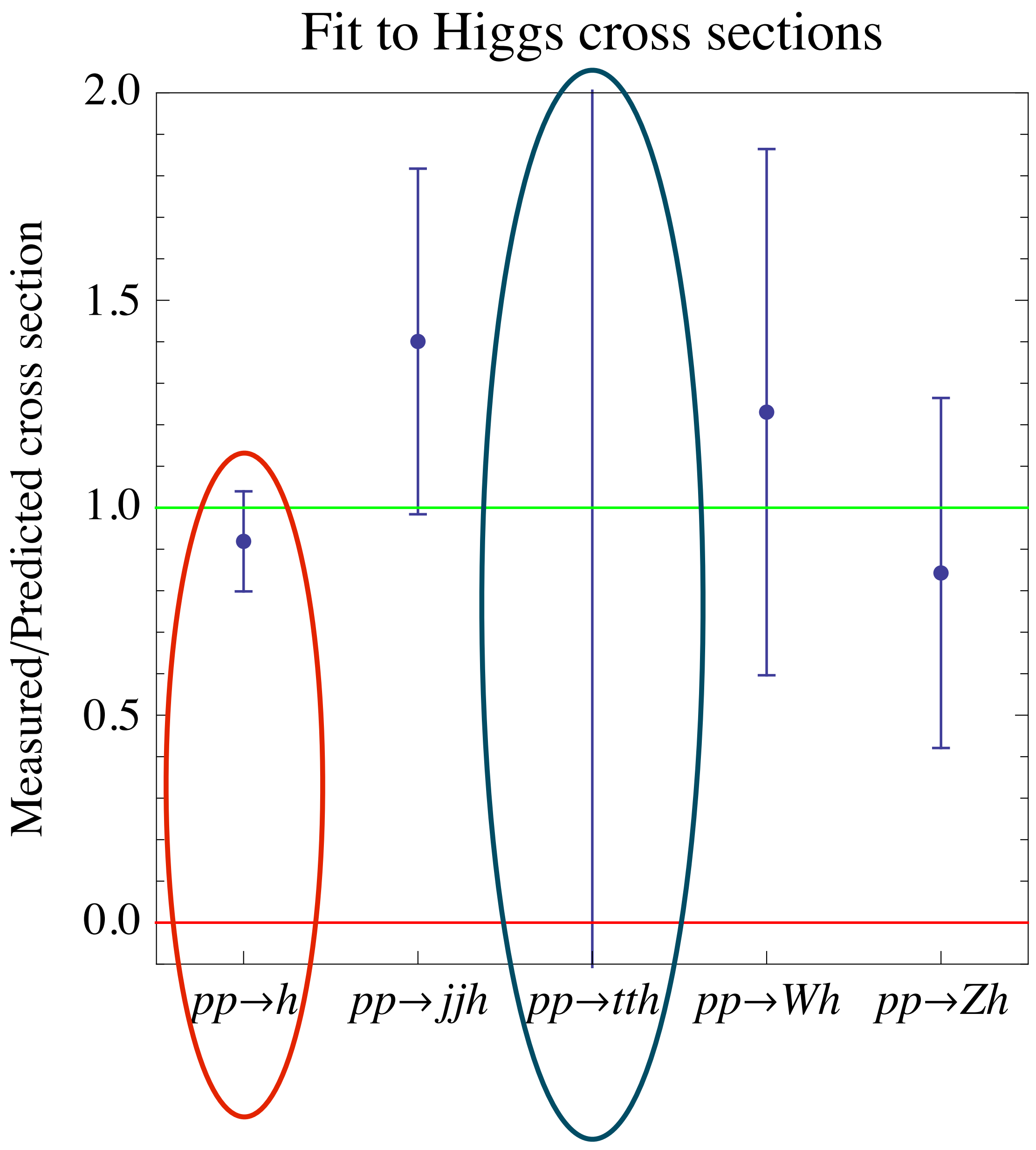
- We believe that this is the most useful form in which the experimental collaborations can report their results.

- From our approximated analysis we obtain:

$$\begin{aligned}
\epsilon_b &= -0.05 \pm 0.34 \\
\epsilon_g &= -0.21 \pm 0.25 \\
\epsilon_{\rm inv} &= -0.25 \pm 0.27 \\
\epsilon_W &= -0.09 \pm 0.15 \\
\epsilon_Z &= +0.02 \pm 0.13 \\
\epsilon_\gamma &= +0.02 \pm 0.16 \\
\epsilon_\tau &= +0.03 \pm 0.19
\end{aligned}
\qquad
\rho = \begin{pmatrix}
1 & 0.73 & 0.06 & 0.48 & 0.43 & 0.56 & 0.48 \\
0.73 & 1 & 0.47 & 0.34 & 0.20 & 0.40 & 0.34 \\
0.06 & 0.47 & 1 & 0.49 & 0.31 & 0.45 & 0.36 \\
0.48 & 0.34 & 0.49 & 1 & 0.64 & 0.70 & 0.61 \\
0.43 & 0.20 & 0.31 & 0.64 & 1 & 0.59 & 0.54 \\
0.56 & 0.40 & 0.45 & 0.70 & 0.59 & 1 & 0.60 \\
0.48 & 0.34 & 0.36 & 0.61 & 0.54 & 0.60 & 1
\end{pmatrix}$$

A standard Higgs?

- Assuming the SM, we extract the Higgs production cross sections,
- they agree with the SM predictions.



A standard Higgs?

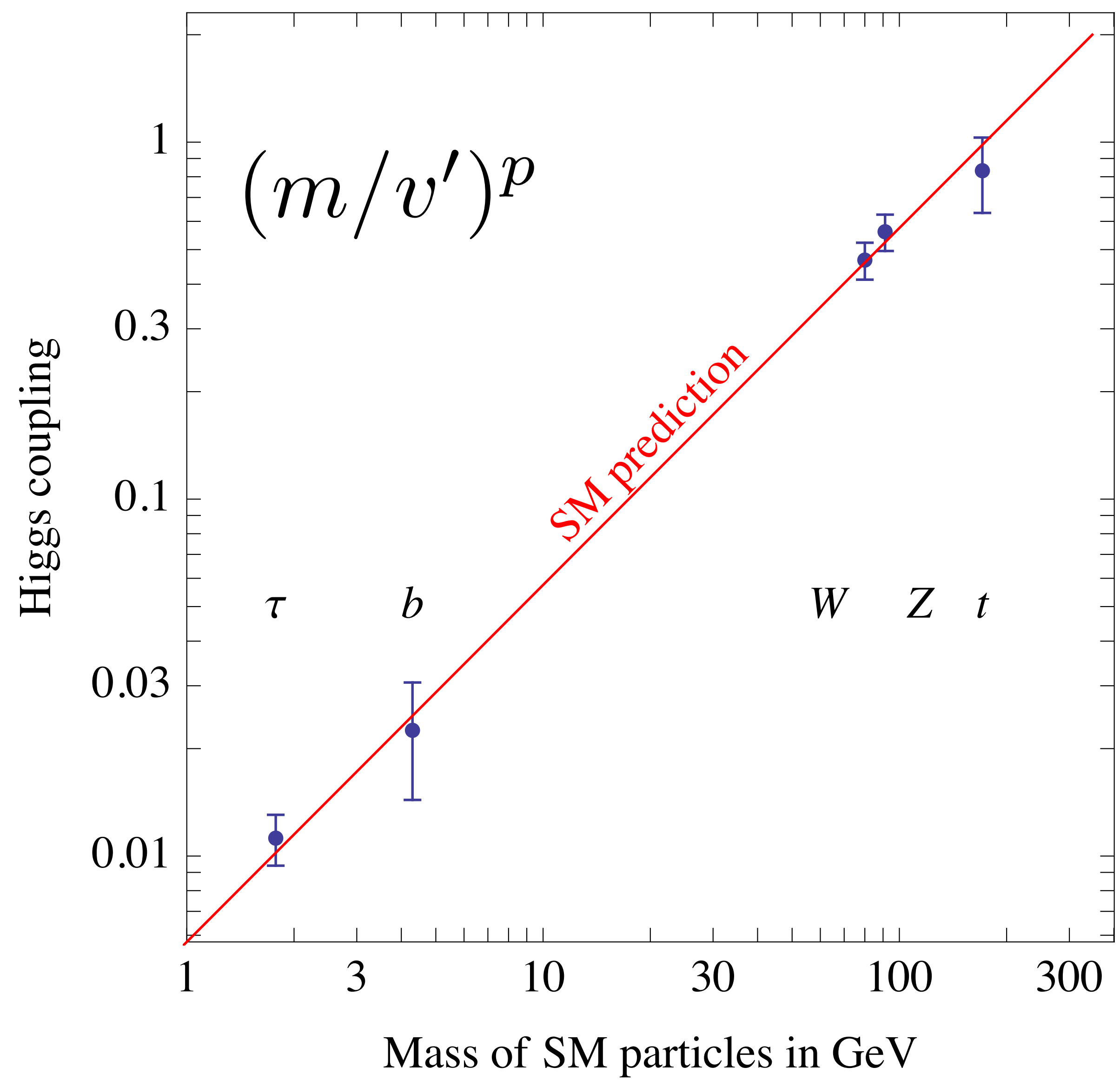
- We set

$$r_g = r_t$$
$$r_\gamma \approx 1.282 r_W - 0.282 r_t$$
$$r_{Z\gamma} \approx 1.057 r_W - 0.057 r_t$$

- We allow for the position and slope to vary:

$$p = 0.98 \pm 0.02$$
$$v' = v(0.98 \pm 0.07)$$

Fit to Higgs couplings



A standard Higgs?

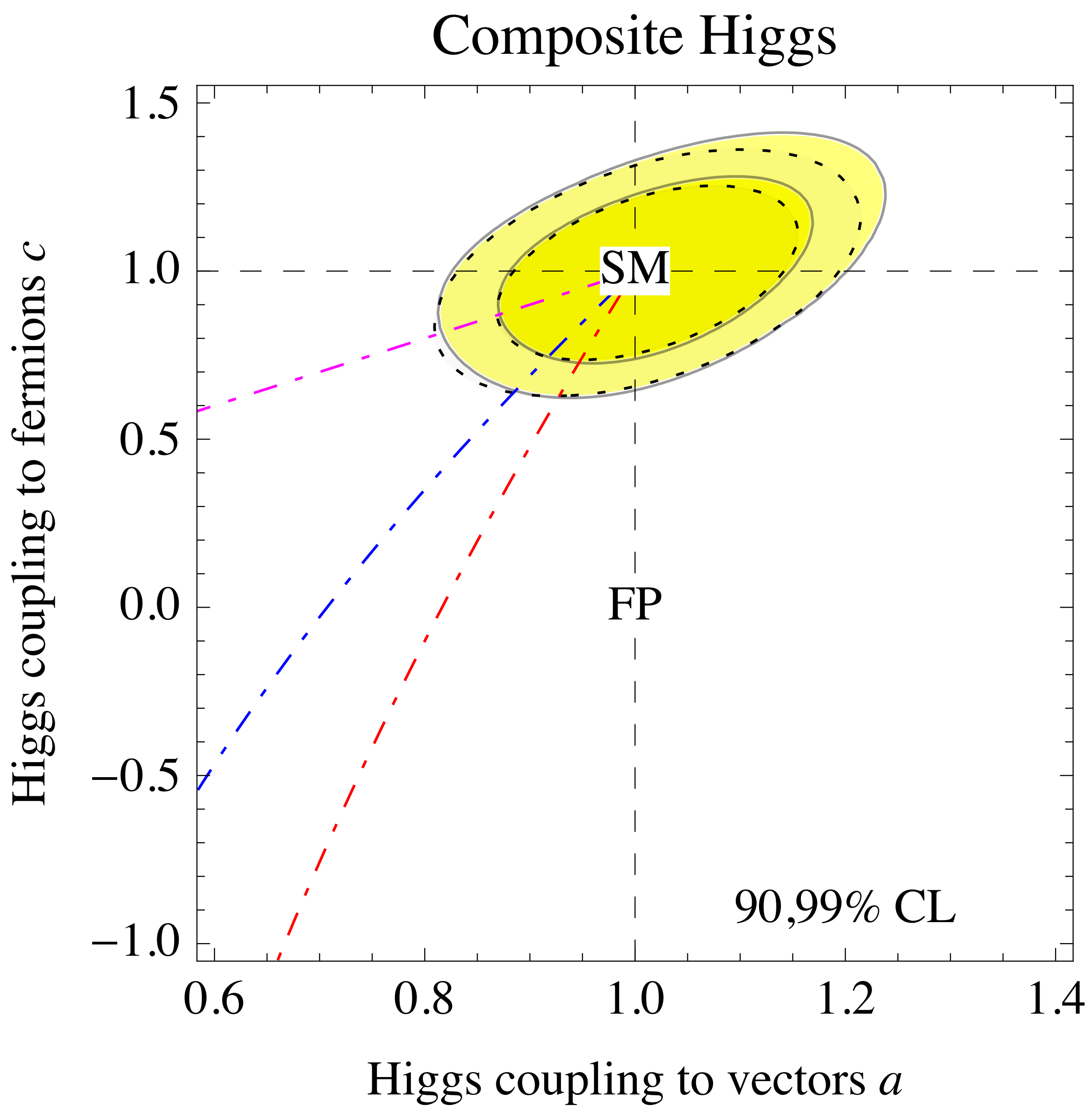
$$M_h = 125.66 \pm 0.34 \text{ GeV} = \begin{cases} 125.4 \pm 0.5_{\text{stat}} \pm 0.6_{\text{syst}} \text{ GeV} & \text{CMS } \gamma\gamma \\ 125.8 \pm 0.5_{\text{stat}} \pm 0.2_{\text{syst}} \text{ GeV} & \text{CMS } ZZ \\ 126.8 \pm 0.2_{\text{stat}} \pm 0.7_{\text{syst}} \text{ GeV} & \text{ATLAS } \gamma\gamma \\ 124.3 \pm 0.6_{\text{stat}} \pm 0.5_{\text{syst}} \text{ GeV} & \text{ATLAS } ZZ \end{cases}$$

- The experimental collaborations found the Higgs mass from the peaks,
- If we require that the measured rates agree with their SM predictions we find

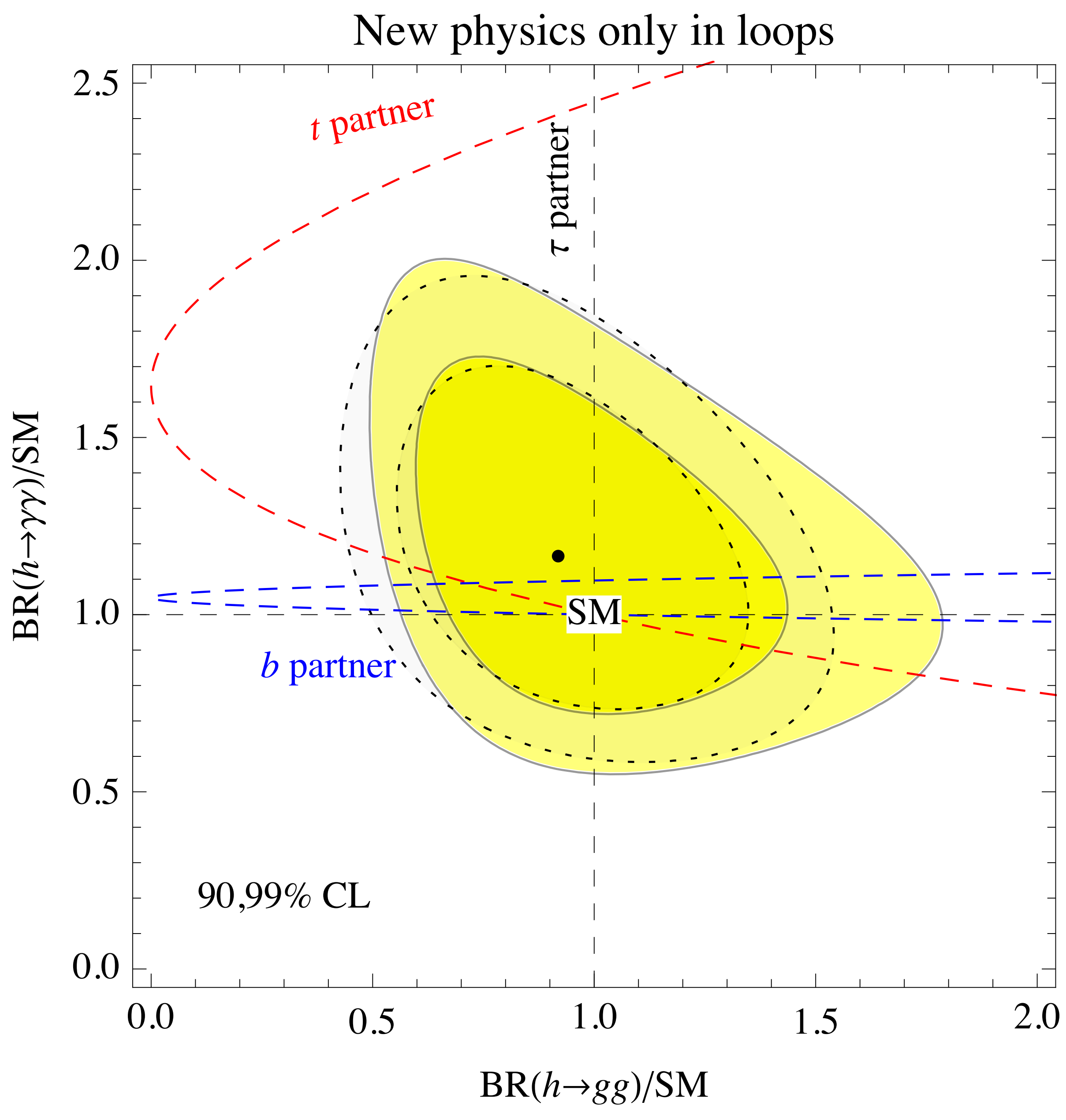
$$M_h = 124.2 \pm 1.8 \text{ GeV}$$

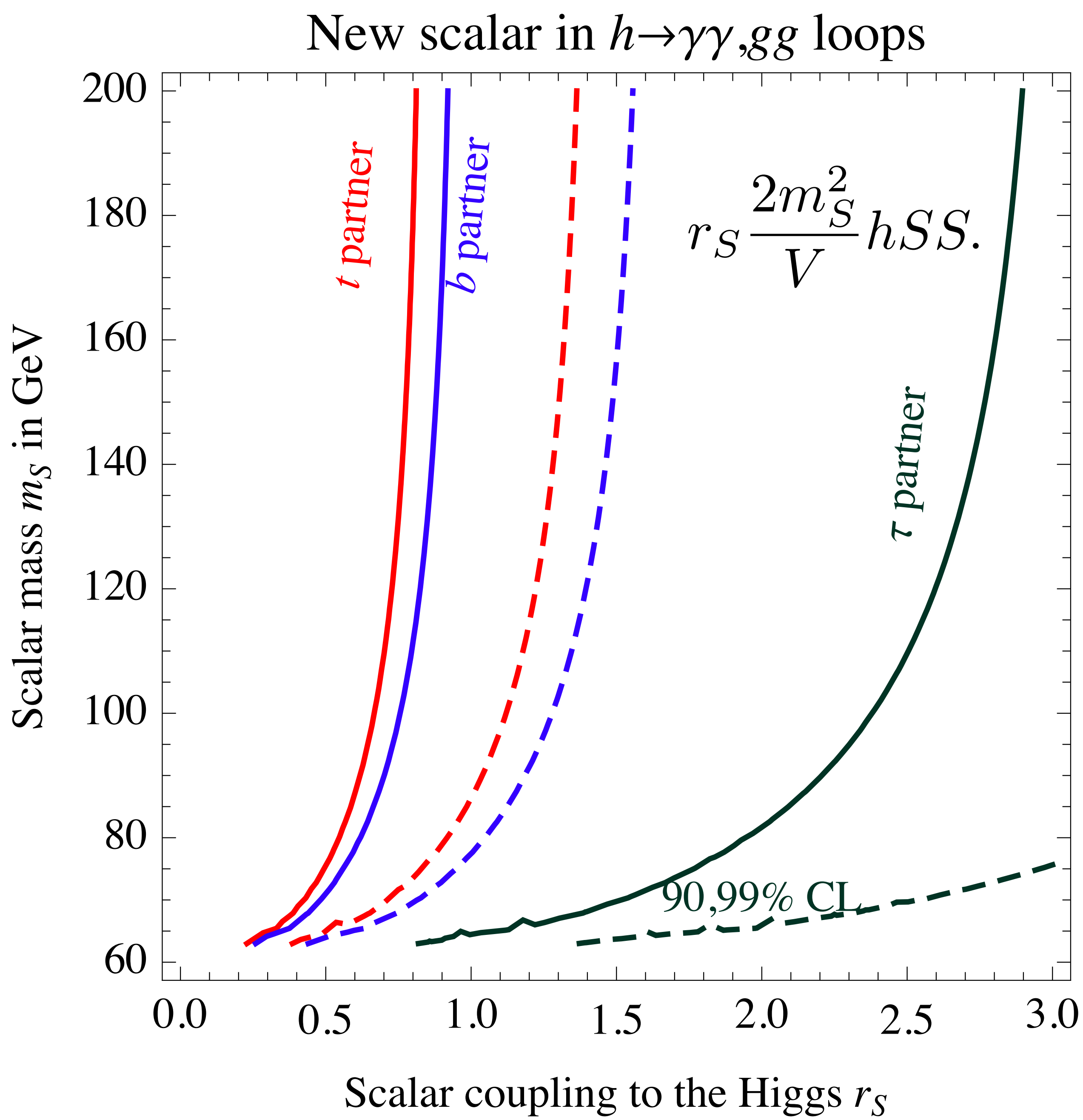
Composite Higgs

- The r coefficients for a Composite Higgs are:
$r_W = r_Z = a,$
$r_t = r_b = r_\tau = r_\mu = c$
- The "universal" fit (dotted line) reproduces the full fit.
- No more "dysfermiophilia".



NP only in loops





$$r_t = r_b = r_\tau = r_\mu = r_W = r_Z = 1, \qquad \frac{\Gamma(h \leftrightarrow gg)}{\Gamma(h \leftrightarrow gg)_{\rm SM}} = r_g^2, \qquad \frac{\Gamma(h \to \gamma\gamma)}{\Gamma(h \to \gamma\gamma)_{\rm SM}} = r_\gamma^2$$

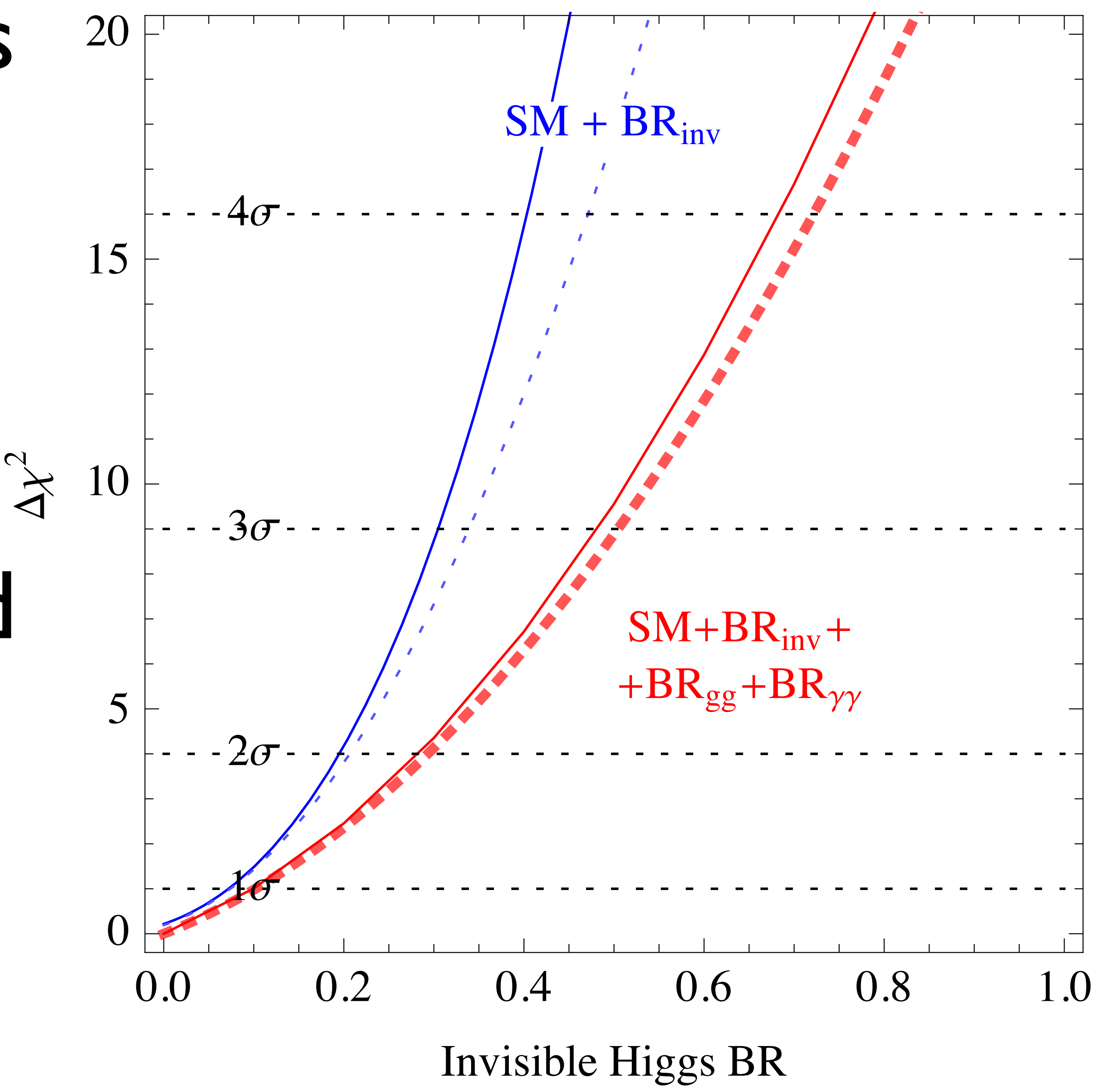
Invisible width

- If the invisible Higgs width is the only new physics, data imply

  $BR_{inv}<0.19$ at 95% C.L.

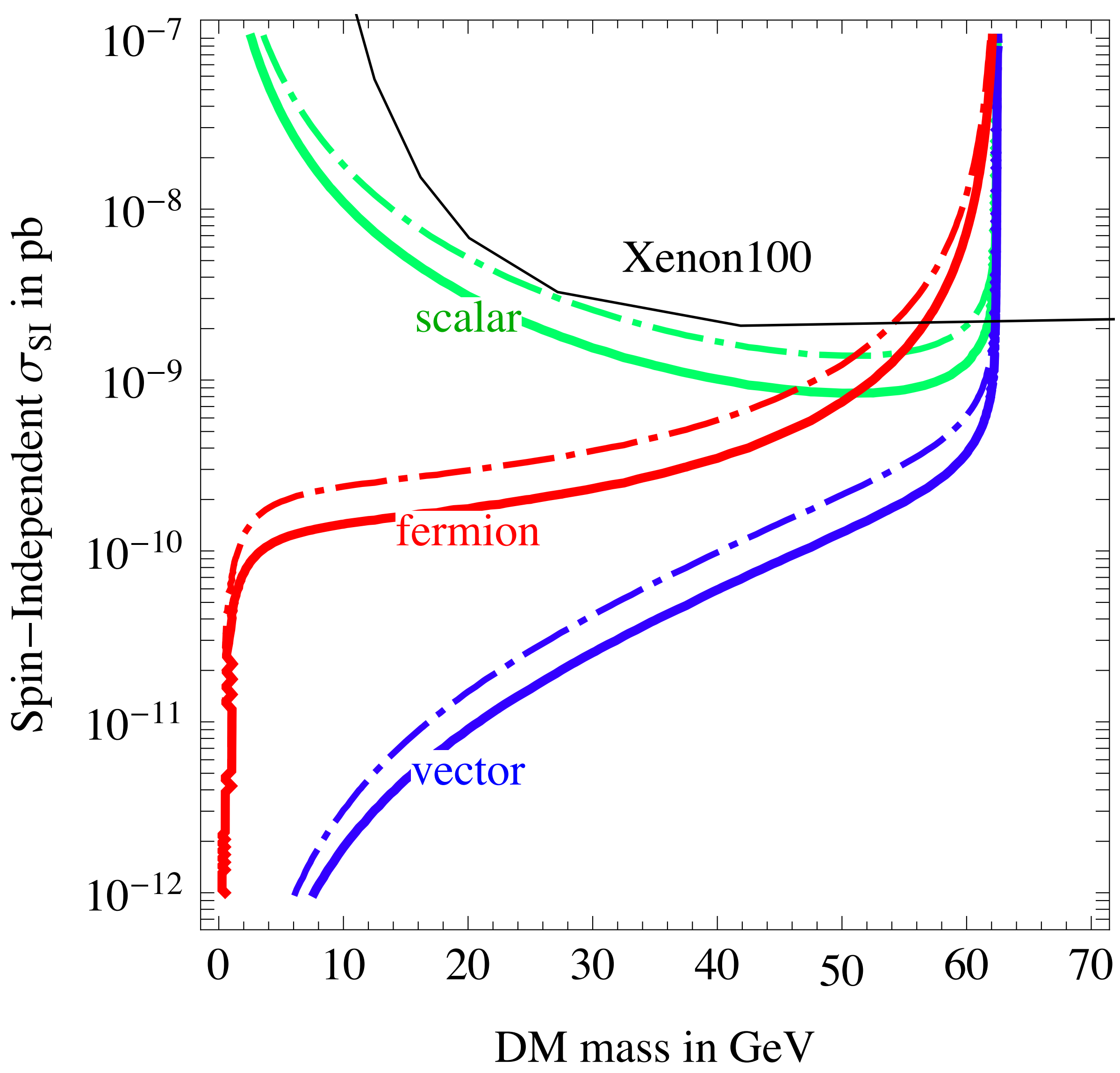
- If we allow for non-standard values of r_γ and r_g than

  $BR_{inv}<0.28$ at 95% C.L.



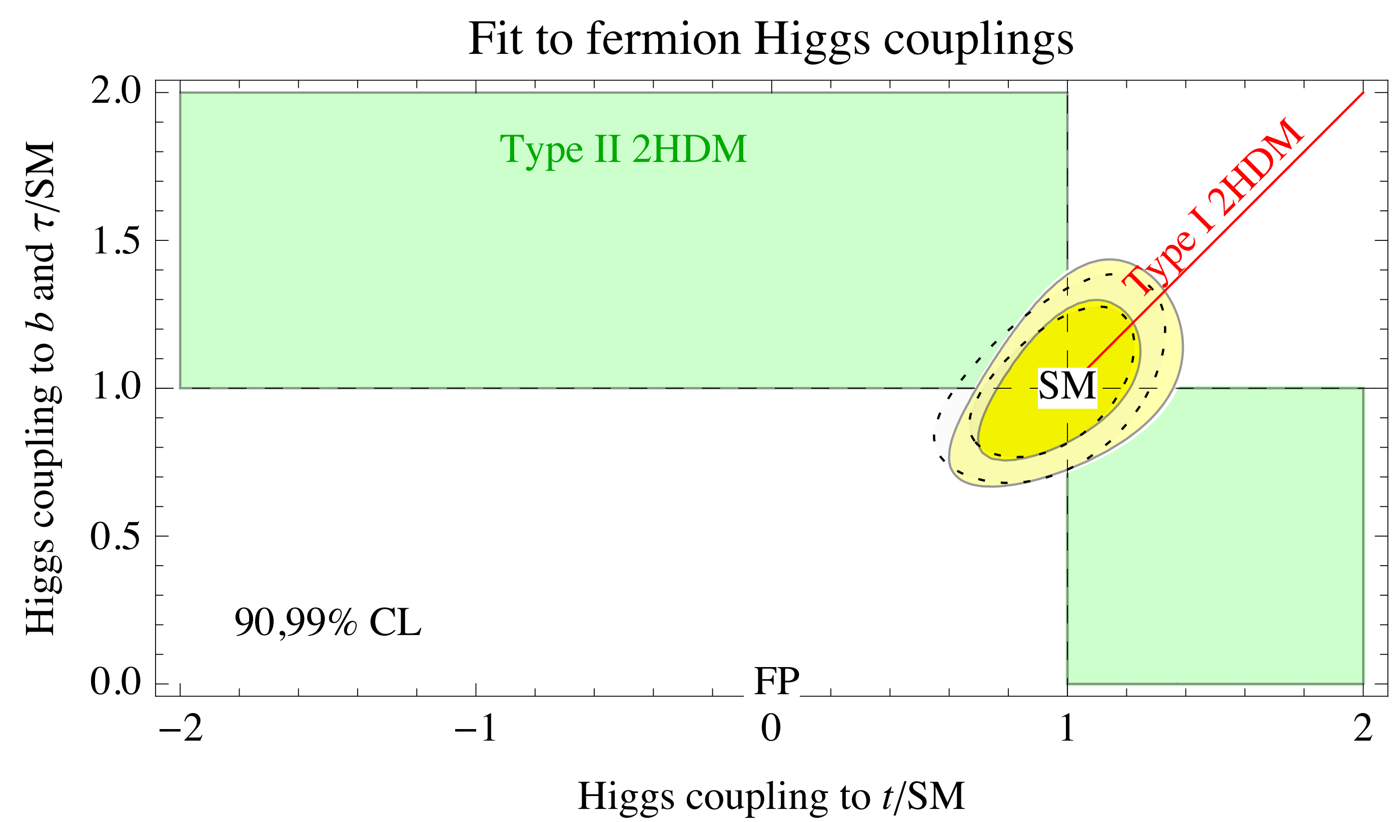
Dark matter

- The bound on BR_{inv} can be used to constrain the DM mass and its elastic cross section on nucleons.
- Imposing the upper bounds on BR_{inv} we found the upper limits on σ_{SI}.



2 Higgs doublets

	Type I	Type II
r_t	$\frac{\cos\alpha}{\sin\beta}$	$\frac{\cos\alpha}{\sin\beta}$
$r_b,\ r_\tau$	$\frac{\cos\alpha}{\sin\beta}$	$-\frac{\sin\alpha}{\cos\beta}$



$$r_W = r_Z = \sin(\beta-\alpha) = (1+r_t r_b)/(r_t+r_b) \simeq 1+\epsilon_t\epsilon_b/2$$

We did fit of other 2 Higgs models, with similar results

Supersymmetry

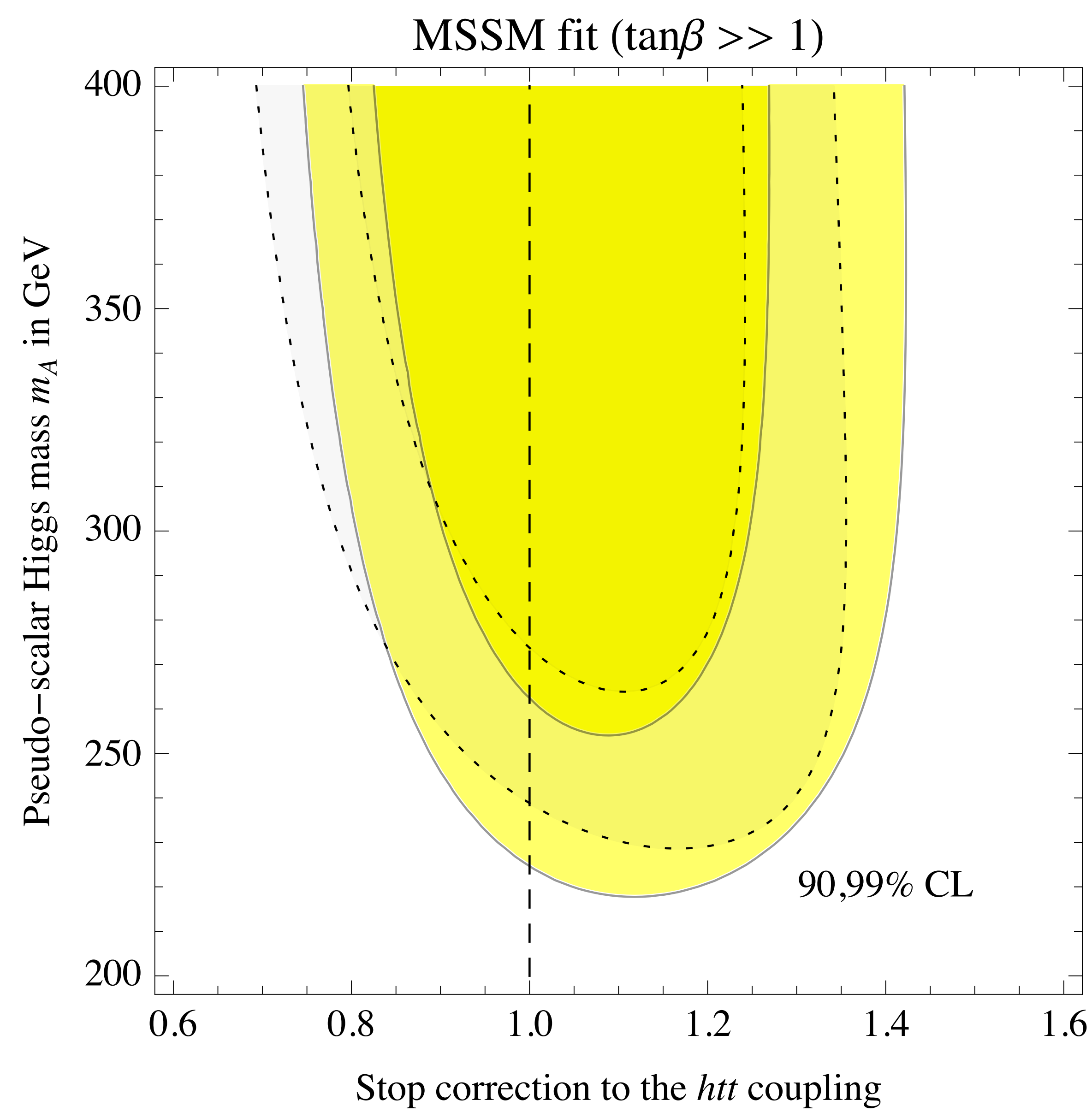
The form of r parameters is the one of Type II, but the top coupling receive a correction from the stop:

$$r_t = R_{\tilde{t}} \frac{\cos\alpha}{\sin\beta},$$

$$r_b = r_\tau = r_\mu = -\frac{\sin\alpha}{\cos\beta},$$

$$r_W = r_Z = \sin(\beta - \alpha)$$

Obviously, supersymmetry can manifest in extra ways.

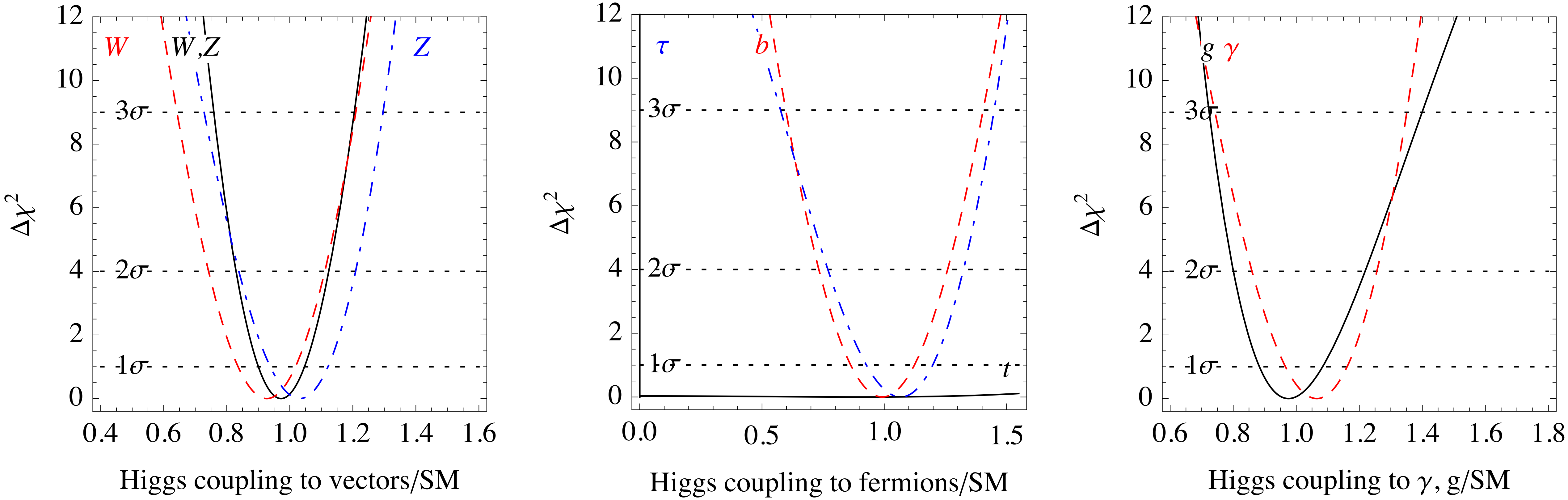


Summary

- We performed a state-of-the-art global fit to the Higgs boson data.
- We found a very healthy Standard Model.
- Best fit regions lie along SM predictions.
- Our simple "universal" approximation is adequate.

Backup

The universal fit



The chi squared are approximately parabolic. This suggest that our "universal" approximation is reasonably good.

A standard Higgs?

The SM predictions of the measured rates depend on the Higgs mass and can be approximated as

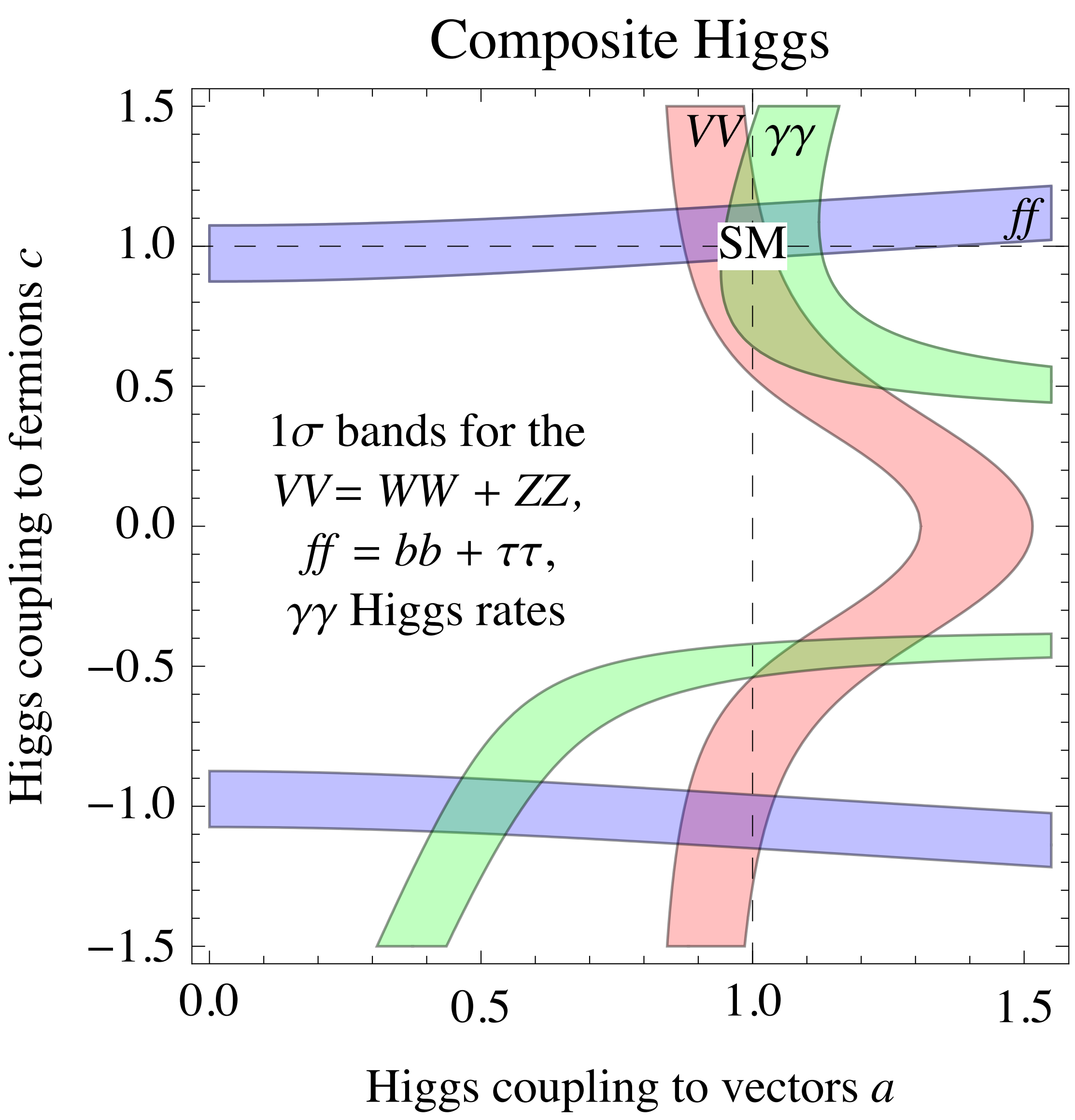
$$\sigma(pp \to X) \approx \sigma(pp \to X)_{M_h = 125\,\text{GeV}} \times [1 + c_X \times (M_h - 125\,\text{GeV})]$$

where

Process X	$h \to WW$	$h \to ZZ$	$h \to \gamma\gamma$	$Vh \to Vbb$	$h \to \tau\tau$
Sensitivity c_X	$6.4\%/\,\text{GeV}$	$7.8\%/\,\text{GeV}$	$-1.5\%/\,\text{GeV}$	$-5.4\%/\,\text{GeV}$	$-4.1\%/\,\text{GeV}$
Measured rate/SM	0.84 ± 0.17	1.06 ± 0.22	1.07 ± 0.19	1.19 ± 0.42	1.11 ± 0.28
Higgs mass in GeV	123.0 ± 3.0	126.2 ± 2.7	121 ± 12	122 ± 8	123 ± 7

Composite Higgs

This plot shows the bands favoured by the overall rates for Higgs decay into heavy vectors, fermions and photons.
These bands cross only around the SM point: no "dysfermiophilic" Higgs.



Invisible width

One partial decay width can be reconstructed by data, because gg→h and hh→g are related by

$$\sigma(gg \to h) = \frac{\pi}{8} \frac{\Gamma(h \to gg)\Gamma(h)}{(s - m_h^2)^2 + m_h^2 \Gamma(h)^2}$$

$$\overset{\Gamma(h) \ll m_h}{\simeq} \frac{\pi^2}{8 m_h} \Gamma(h \to gg) \delta(s - m_h^2)$$

Performing a global fit to the Higgs boson branching ratios we can reconstruct the total Higgs boson width.

Dark matter

$$r_S \frac{2m_S^2}{V} hSS + r_f \frac{m_f}{V} h\bar{f}f + r_V \frac{2m_V^2}{V} hV_\mu V_\mu \ .$$

$\Gamma(h \to \mathrm{DM\,DM})$ and σ_{SI} are proportional to the square of the DM-Higgs coupling, so the ratio $\mu \equiv \sigma_{\mathrm{SI}}/\Gamma(h \to \mathrm{DM\,DM})$ depends only on the the unknown DM mass and on the known masses and couplings of the relevant SM particles.

This allows us to relate the invisible Higgs branching fraction to the DM direct detection cross section:

$$\mathrm{BR}_{\mathrm{inv}} \equiv \frac{\Gamma(h \to \mathrm{DM\,DM})}{\Gamma_h^{\mathrm{SM}} + \Gamma(h \to \mathrm{DM\,DM})} = \frac{\sigma_{\mathrm{SI}}}{\mu\Gamma_h^{\mathrm{SM}} + \sigma_{\mathrm{SI}}}$$

where $\Gamma_h^{\mathrm{SM}} = 4.1\mathrm{GeV}$ is the total Higgs decay width into all SM particles, that we fix to its SM prediction.