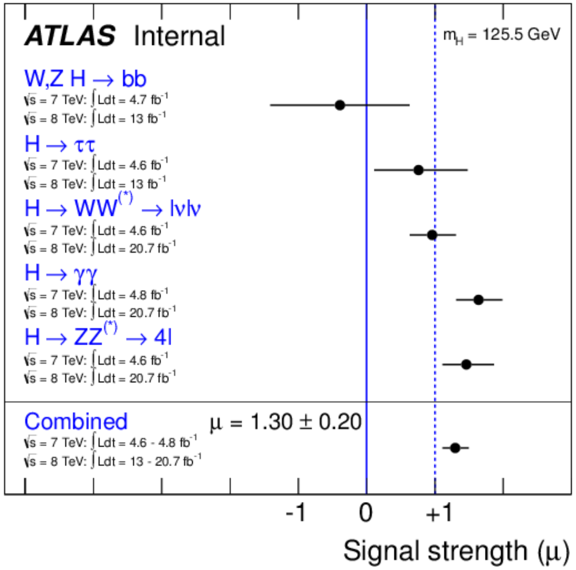
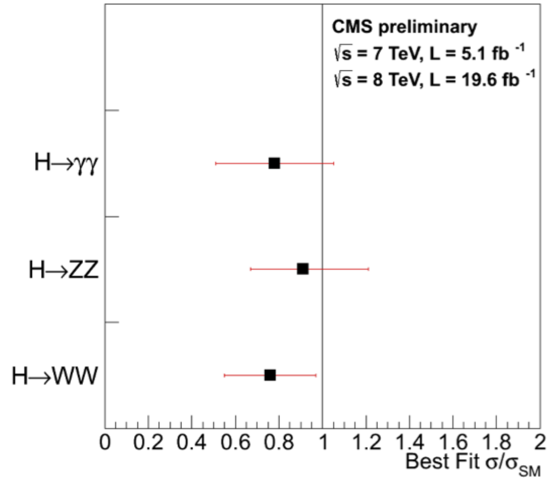
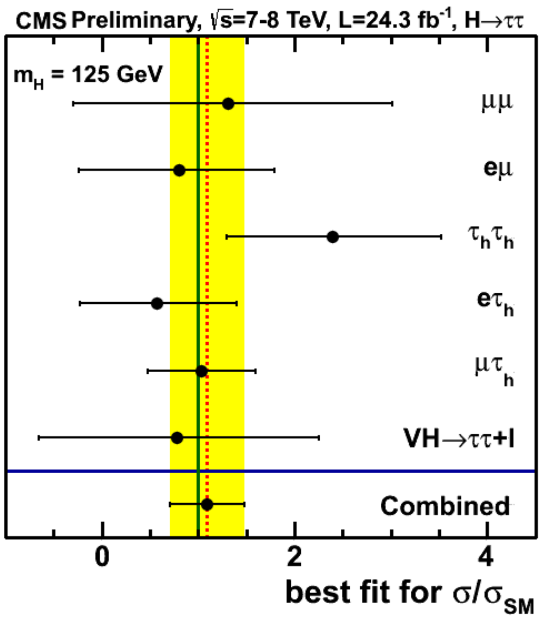
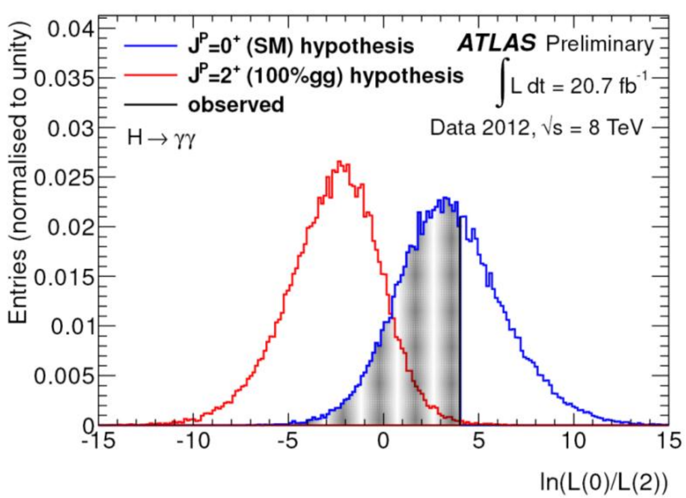
News Higgs results

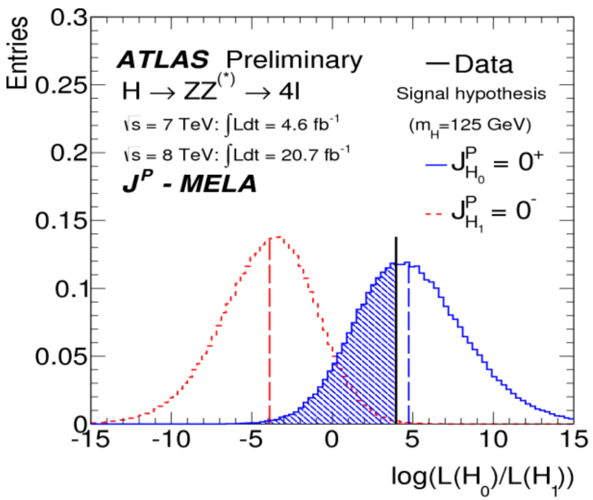






Spin CP





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The universal Higgs fit

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Abstract

We perform a state-of-the-art global fit to all Higgs data. We synthesise them into a 'universal' form, which allows to easily test any desired model. We apply the proposed methodology to extract from data the Higgs branching ratios, production cross sections, couplings and to analyse composite Higgs models, models with extra Higgs doublets, supersymmetry, extra particles in the loops, anomalous top couplings, invisible Higgs decay into Dark Matter. Best fit regions lie around the Standard Model predictions and are well approximated by our 'universal' fit. Latest data exclude the dilaton as an alternative to the Higgs, and disfavour fits with negative Yukawa couplings. We derive for the first time the SM Higgs boson mass from the measured rates, rather than from the peak positions, obtaining $M_h = 124.2 \pm 1.8\,\mathrm{GeV}$.

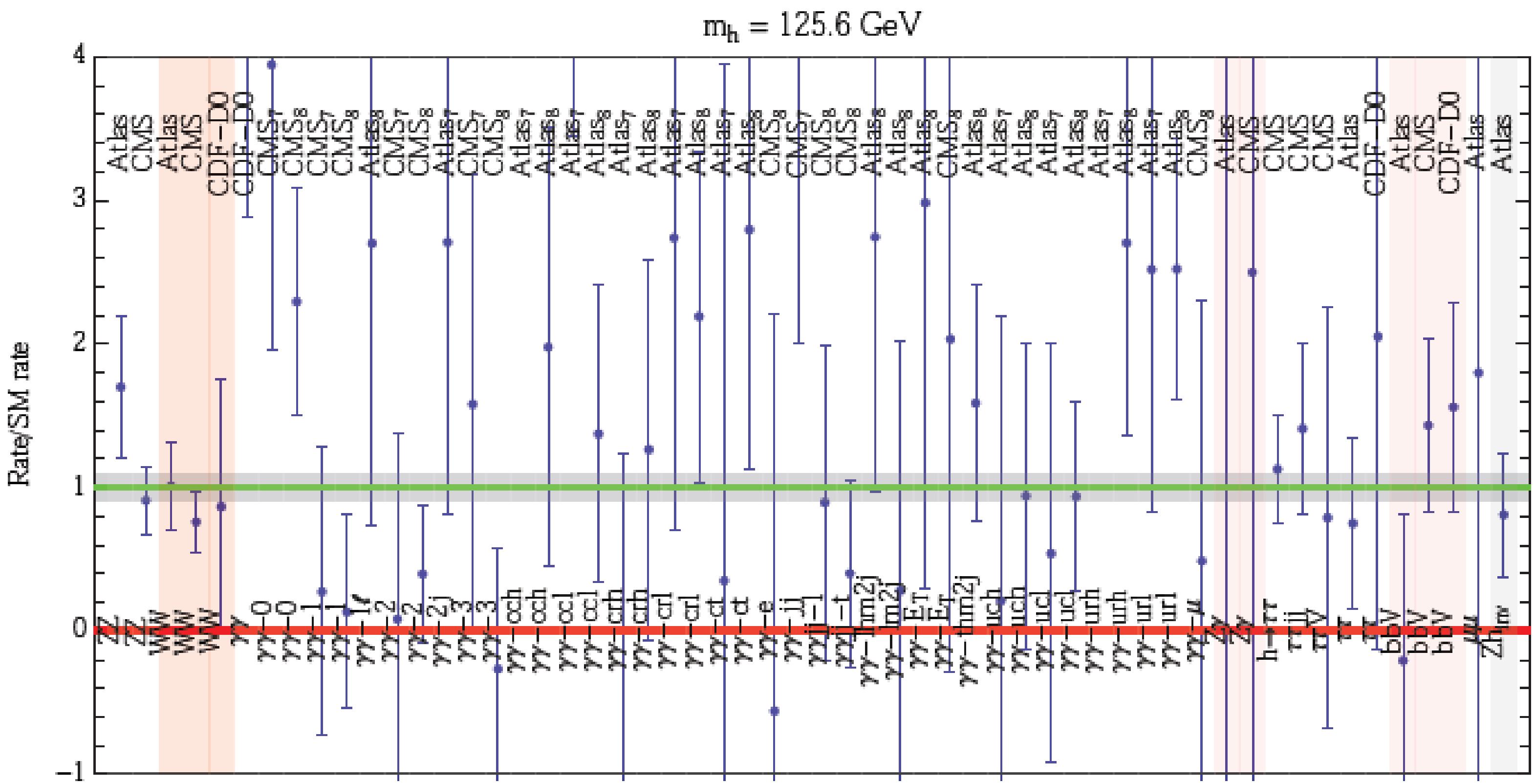


Figure 1: *Measured Higgs boson rates at ATLAS, CMS, CDF, D0 and their average (horizontal gray band at $\pm 1\sigma$). Here 0 (red line) corresponds to no Higgs boson, 1 (green line) to the SM Higgs boson (including the latest data point, which describes the invisible Higgs rate).*

Higgs mass reconstruction:

From the direct measurements:

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

Assuming SM production rates (constraining μ=1):

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

Process X	$h \to WW$	$h \to ZZ$	$h \to \gamma\gamma$	$Vh \to Vbb$	$h \to \tau\tau$
Sensitivity c_X	6.4%/ GeV	7.8%/ GeV	−1.5%/ GeV	−5.4%/ GeV	−4.1%/ 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

$M_h = 124.2 \pm 1.8$ GeV (Higgs mass extracted from the rates, assuming the SM)

Universal Higgs fit

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

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

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

⇒

$$\begin{aligned}
\epsilon_b &= -0.05 \pm 0.34 \\
\epsilon_g &= -0.21 \pm 0.25 \\
\epsilon_{\rm inv} &= -0.25 \pm 0.27 \\
\epsilon_W &= -0.09 \pm 0.15 \\
\epsilon_Z &= +0.02 \pm 0.13 \\
\epsilon_\gamma &= +0.02 \pm 0.16 \\
\epsilon_\tau &= +0.03 \pm 0.19
\end{aligned}$$

We find $\chi^2 = 58.8$ at the best fit (56 data points, 10 free parameters), marginally better than the SM fit, $\chi^2_{\rm SM} = 61.7$ (no free parameters).

Model dependent fits

Assuming the SM predictions for the Higgs decays $r_g = r_t, \quad r_\gamma \approx 1.282 r_W - 0.282 r_t \quad r_{Z\gamma} \approx 1.057 r_W - 0.057 r_t$

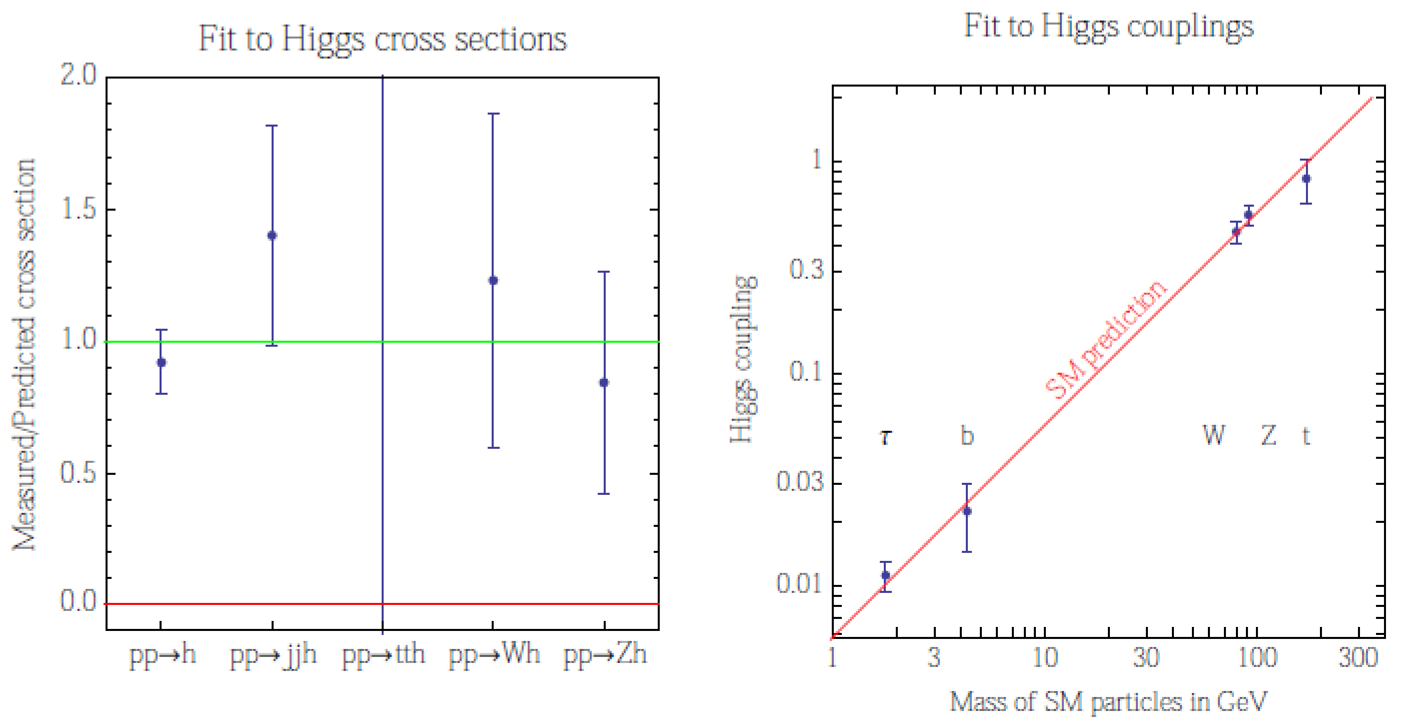


Figure 3: **Left**: *reconstruction of the Higgs production cross sections in units of the SM prediction.* **Right**: *reconstruction of the Higgs couplings to the* t, Z, W, b, τ, *assuming that no new particles exist. The SM predicts that Higgs couplings are proportional to particle masses (diagonal line).*

Composite Higgs models

$$r_t = r_b = r_\tau = r_\mu = c, \qquad r_W = r_Z = a.$$

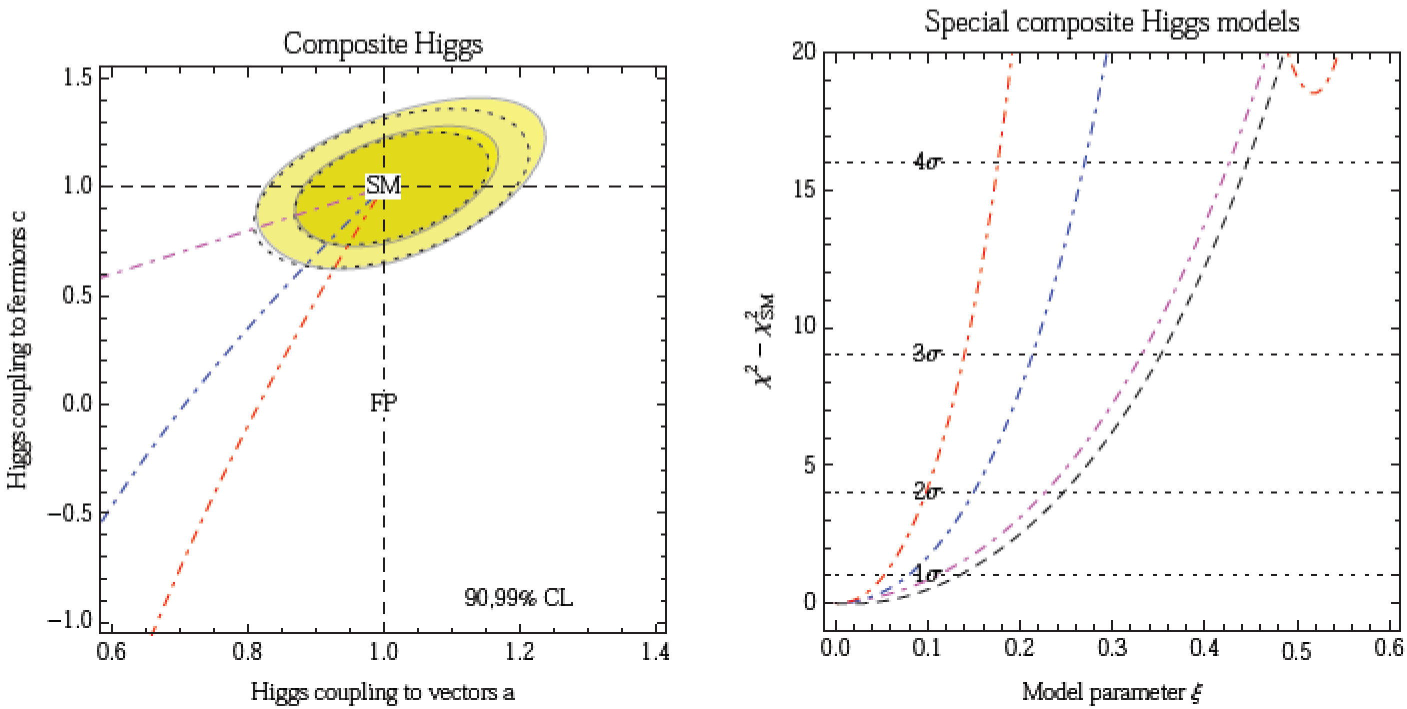


Figure 4: **Left**: *fit of the Higgs boson couplings assuming common rescaling factors a and c with respect to the SM prediction for couplings to vector bosons and fermions, respectively. The two sets of contour lines are our full fit (continuous) and our approximated 'universal' fit (dotted).* **Right**: *values of the χ^2 along the trajectories in the (a, c) plane shown in the left panel, and given by $a = \sqrt{1-\xi}$ and $c = a$ (magenta) $c = (1-2\xi)/a$ (blue) $c = (1-3\xi)/a$ (red), as motivated by composite Higgs models. The black dashed curve corresponds to $a = 1$ and $c = 1 - \xi$.*

$\xi = (V/F_\pi)^2$, where F_π is the scale of global symmetry breaking.

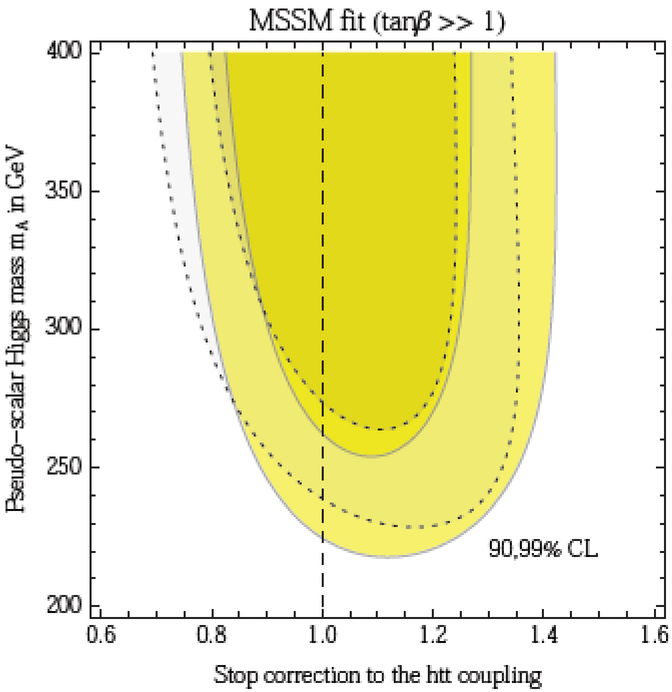
Supersymmetry:

- Stop loops can enhance or reduce the Higgs coupling to the top (and consequently the h->gg, γγ, Zγ rates)
- The type II 2HDM structure of supersymmetric models modifies at tree level the Higgs couplings (large tanβ assumed)

Dilaton vs Higgs:

Dilaton couples to energy momentum tensors

$$\frac{\varphi}{\Lambda}T^{\mu}_{\mu} = \frac{\varphi}{\Lambda}\left(\sum_f m_f \bar{f} f - M_Z^2 Z_\mu^2 - 2M_W^2 W_\mu^2 + b_3 \frac{\alpha_3}{8\pi} G^a_{\mu\nu} G^a_{\mu\nu} + b_\gamma \frac{\alpha_{\rm em}}{8\pi} F_{\mu\nu} F_{\mu\nu}\right)$$



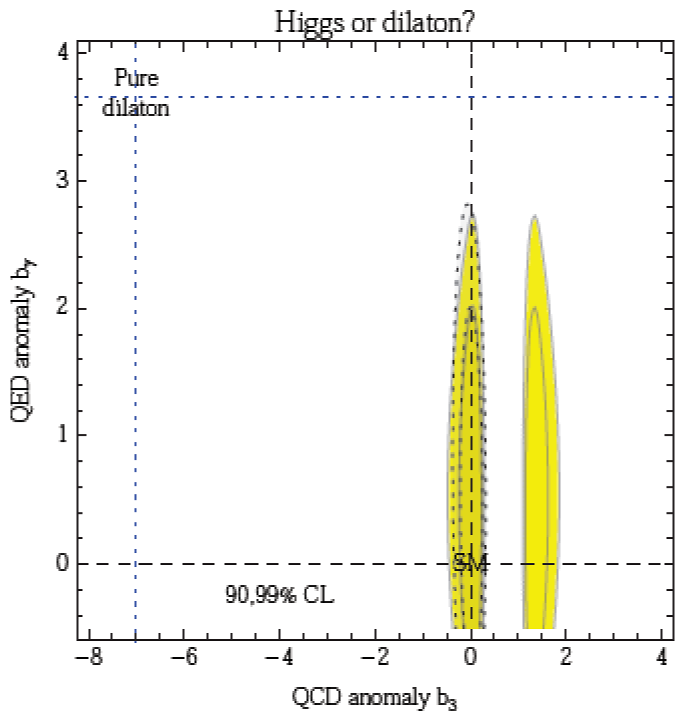


Figure 8: **Left**: *Fit to the two main effects present in supersymmetry: stop loop correction to the $ht\bar{t}$ coupling and tree-level modification of the Higgs couplings due to the two-Higgs doublet structure.* **Right**: *fit as function of the β-function coefficients $b_3 = b_\gamma$ that parameterise dilaton models. The SM Higgs is reproduced at the experimentally favored point $b_3 = b_\gamma = 0$, while the pure dilaton is excluded at more than 5σ.*

5.8 Higgs boson invisible width

Next, we allow for a Higgs boson invisible width, for example into Dark Matter. We perform two fits.

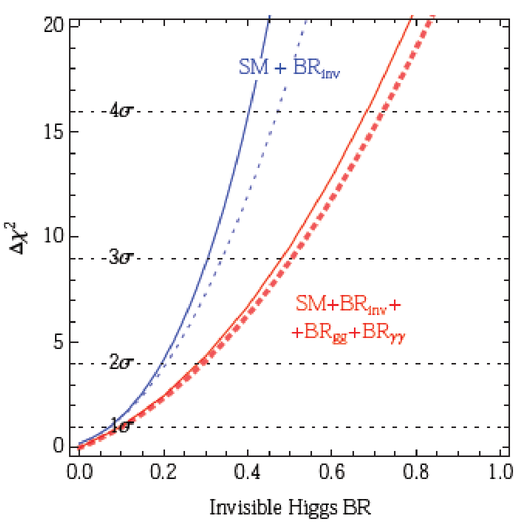
1. In the first fit, the invisible Higgs width is the only new physics. We find (blue curves in fig. 9a) that present data imply

$$\mathrm{BR}_{\mathrm{inv}} = -0.08 \pm 0.16 \qquad \text{i.e.} \qquad \mathrm{BR}_{\mathrm{inv}} < 0.19 \text{ at } 95\% \text{ C.L.}, \tag{25}$$

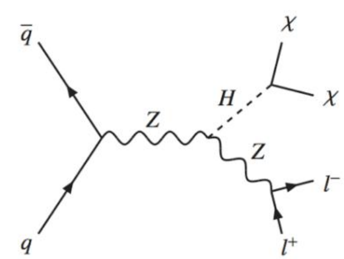
2. In addition to the invisible width we also allow for non-standard values of $h \to \gamma\gamma$ and $h \to gg$, finding a weaker constraint on $\mathrm{BR}_{\mathrm{inv}}$ (red curves in fig. 9a)

$$\mathrm{BR}_{\mathrm{inv}} < 0.28 \text{ at } 95\% \text{ C.L.} \tag{26}$$

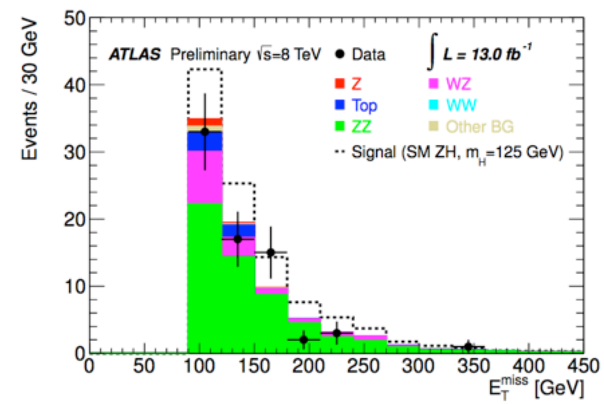
Notice that the main constraint con $\mathrm{BR}_{\mathrm{inv}}$ does not come from the direct search for $pp \to Zh \to \ell\ell\not{E}_T$ (included in our data-set) but from the global fit [8, 33].



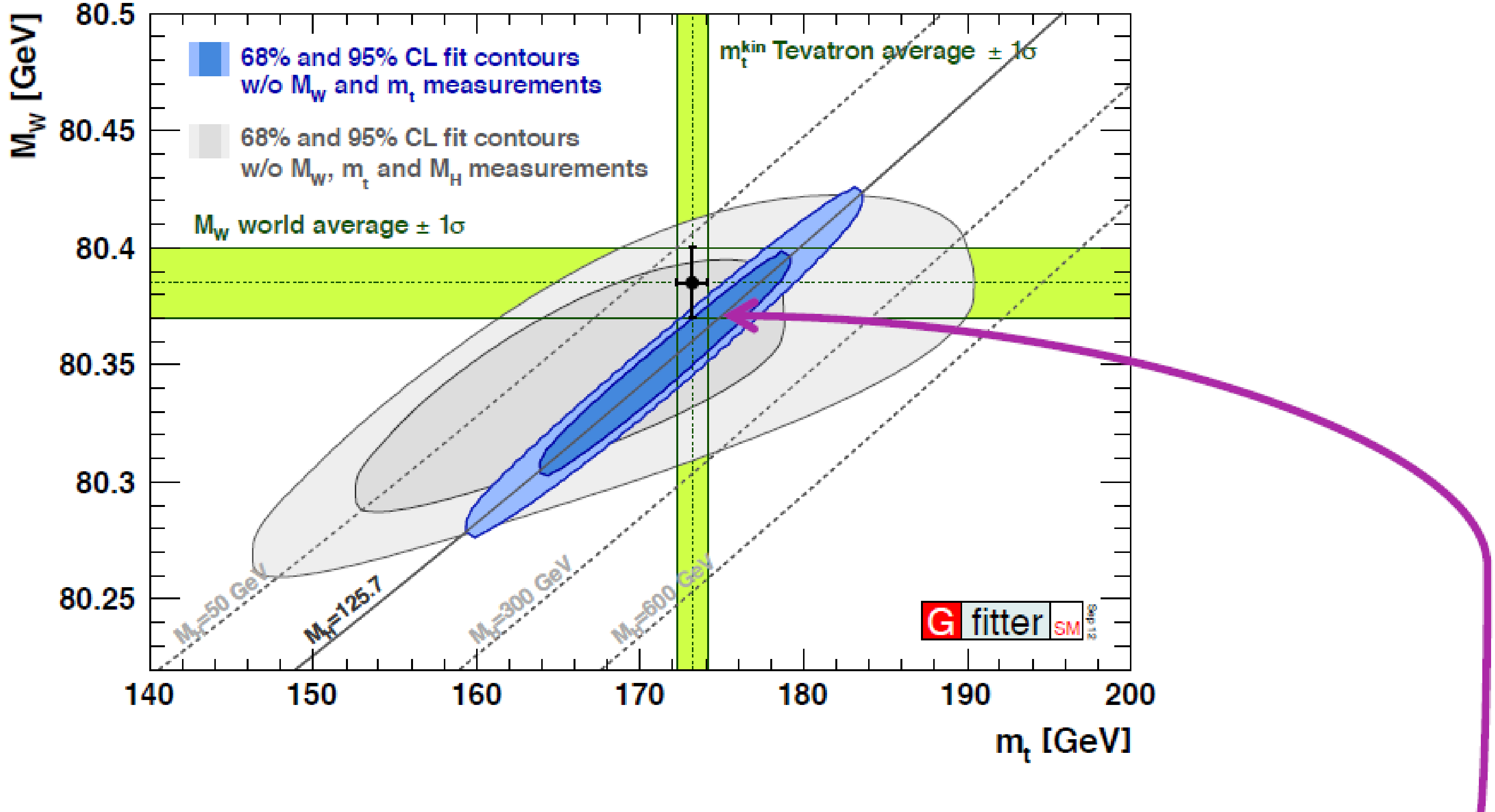
ATLAS result:



BR(H→inv) <0.65 at 95% CL.



- Scan of M_W vs m_t, with the direct measurements excluded from the fit.
- Results from Higgs measurement significantly reduces allowed indirect parameter space → corners the SM!

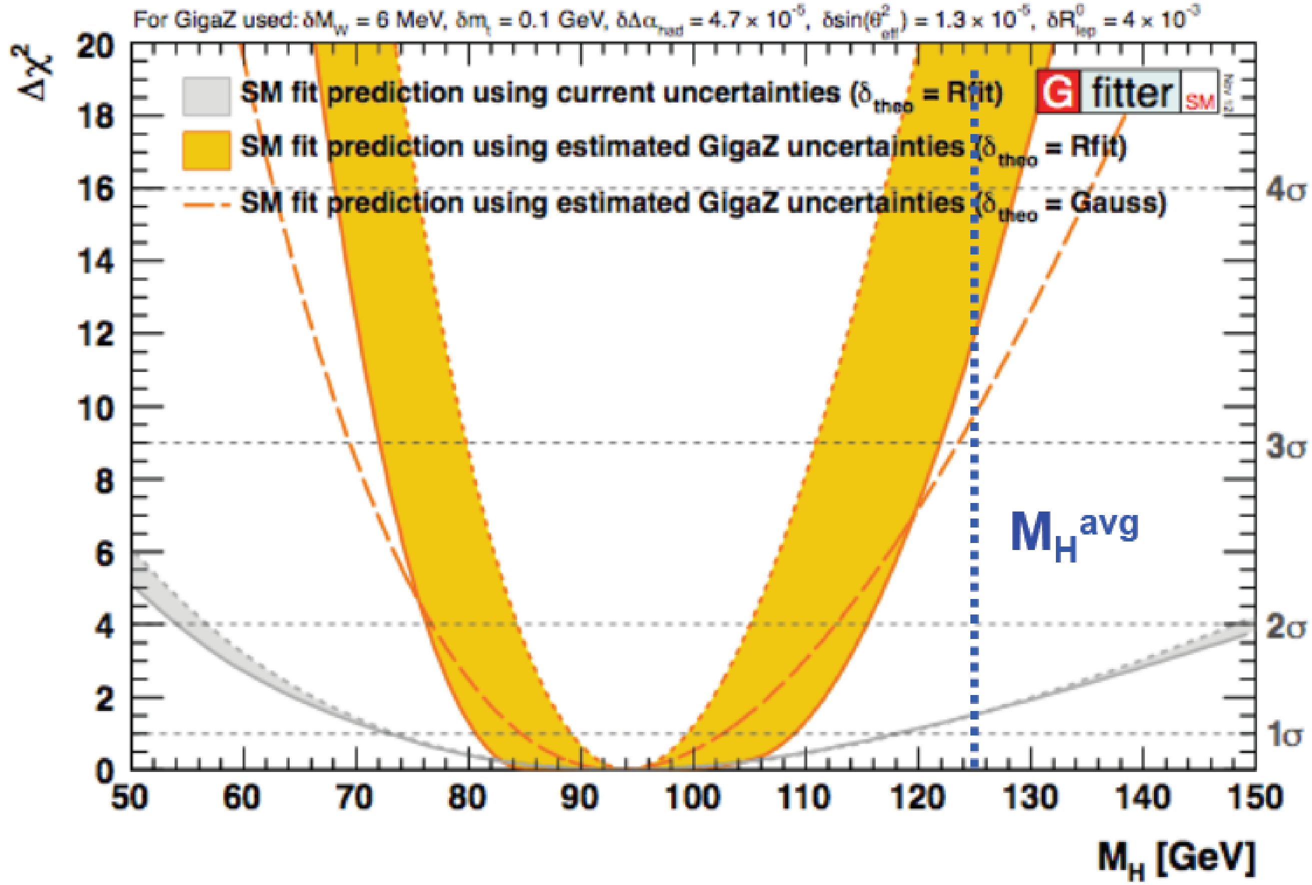


- Observed agreement demonstrates impressive consistency of the SM!

Prospects for ILC with Giga Z

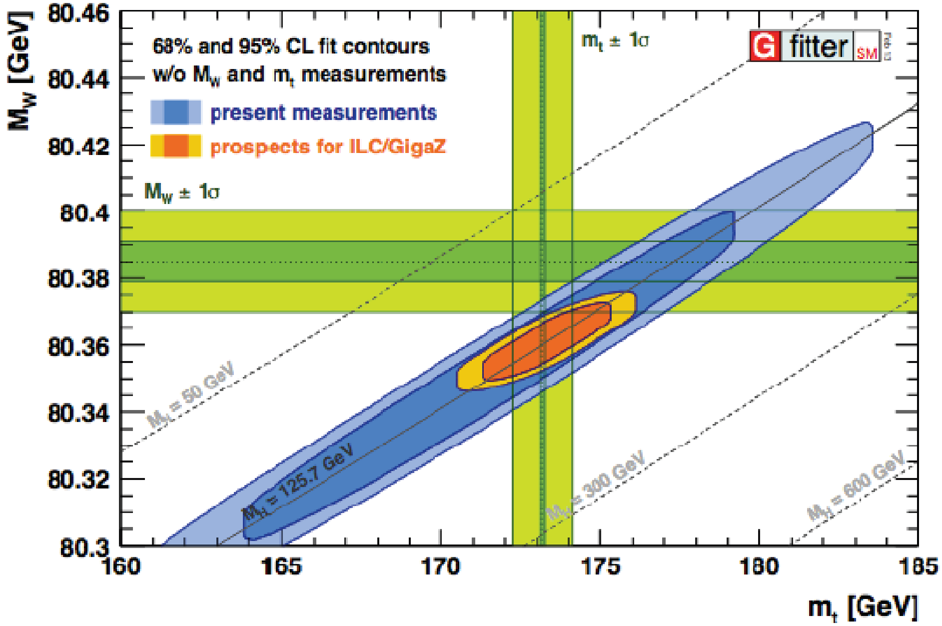
- Future Linear Collider could improve precision of EW observables tremendously.
  - *WW threshold, to obtain M_W*
    - from threshold scan: δM_W : 15 → 6 MeV
  - *ttbar threshold, to obtain m_t*
    - obtain m_t indirectly from production cross section: δm_t : 0.9 → 0.1 GeV
  - *Z pole measurements*
    - High statistics: 10^9 Z decays: δR^0_{lep} : $2.5 \cdot 10^{-2} \rightarrow 4 \cdot 10^{-3}$
    - With polarized beams, uncertainty on $\delta A^{0,f}_{LR}$: $10^{-3} \rightarrow 10^{-4}$, which translates to $\delta \sin^2\theta^l_{eff}$: $1.6 \cdot 10^{-4} \rightarrow 1.3 \cdot 10^{-5}$

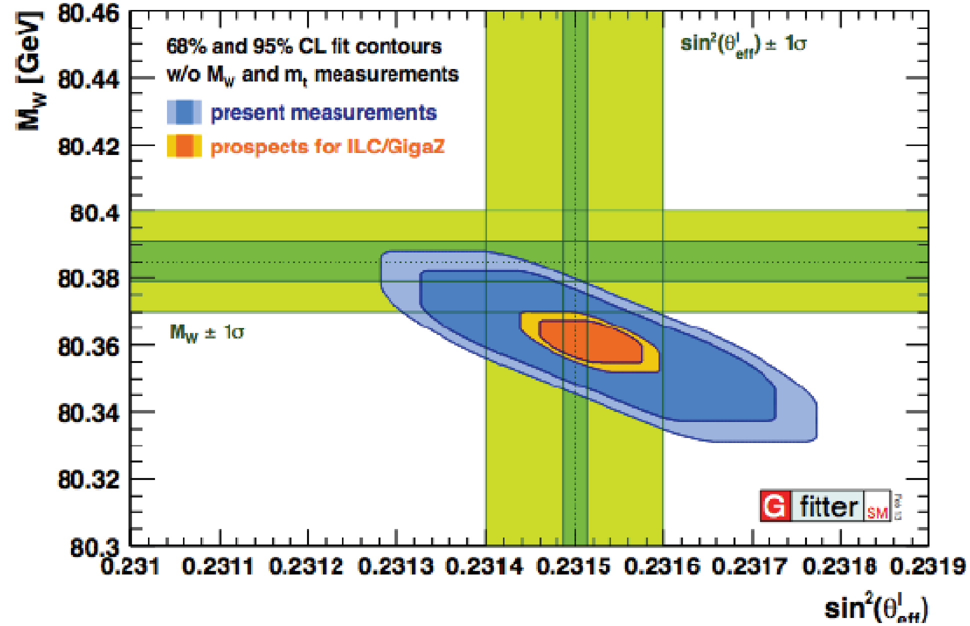
Prospects for ILC with Giga Z



- Logarithmic dependency on M_H → cannot compete with direct M_H meas.
- Indirect prediction M_H dominated by theory uncertainties.
  - No theory uncertainty: $M_H = 94.2^{+5.3}_{-5.0}$ GeV
  - Rfit scheme: $M_H = 92.3^{+16.6}_{-11.6}$ GeV

Prospects for ILC with Giga Z





- current precision
- prospects for direct ILC measurements

- *Assuming also 50% of today's theoretical uncertainties*
  - Implies three-loop EW calculations!
- Huge reduction of uncertainty on indirect determinations
- Also strong constraints on S, T, U