Higgs mass implications on the stability of the electroweak vacuum

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joint work with J.R. Espinosa, G.Degrassi, S. Di Vita,
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The Higgs sector of the SM

The Higgs sector of the Standard Model (SM) is the part of the theory from which we have less experimental information.

Interestingly, most of the theoretical problems of the SM arise from the Higgs sector.

The Higgs sector of the SM

- Severe fine tuning
  $m^2 \sim \Lambda^2$

$$V(\Phi) = -m^2\Phi^\dagger\Phi + \lambda(\Phi^\dagger\Phi)^2 + Y^{ij}\Psi_L^i\Psi_R^j\Phi$$

- Instability for $\lambda < 0$ aprox.
  or loss of perturbativity for$\lambda > 16\pi^2$
- Hierarchical structure +
  huge splitting $m_t/m_e = 3 \times 10^5$.

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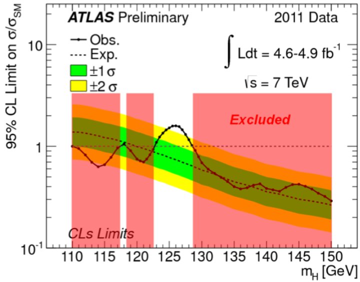
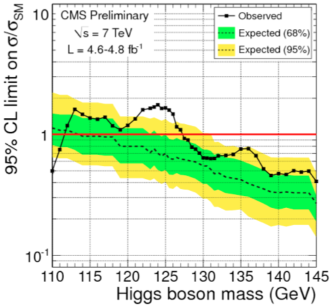




ATLAS excludes a Higgs of mass 110-117.5, 118.5-122.5, 129-539 GeV at 95% CL

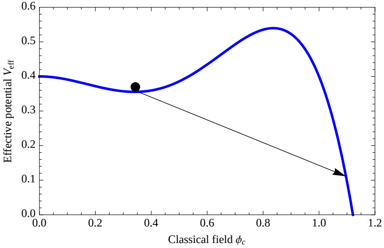
CMS excludes a Higgs of mass 127.5-600 GeV at 95 % CL

$$\text{for } M_h \approx 125 \text{ GeV}, \lambda = \frac{M_h^2}{2v^2} \approx 0.129$$

Assume the SM up to very high energies,
is it a consistent model?

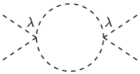
For large field values, $V_{eff} \approx \frac{\lambda_{eff}(\phi)}{4}\phi^4$.

If $\lambda_{eff} \approx \lambda < 0$ at some high energy scale Λ_I, the Electroweak (EW) minimum at $\phi = v \approx 246$ GeV of the Higgs potential is unstable.



But, can λ become negative? Yes, two main competing effects:

$$\mu \frac{d\lambda(\mu)}{d\log(\mu)} = (\ \# \ \lambda^2 \ + \ldots \ -\# \ h_t^4 \ + \ldots) + \ldots$$

- 

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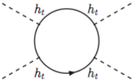
- 

, makes λ decrease.

$h_t(v) = \sqrt{2} M_t / v$ and $\lambda(v) = M_h^2/(2v^2)$.

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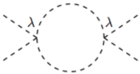
- 

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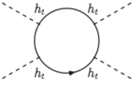
- 

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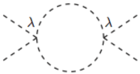
- 

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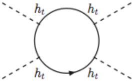
- 

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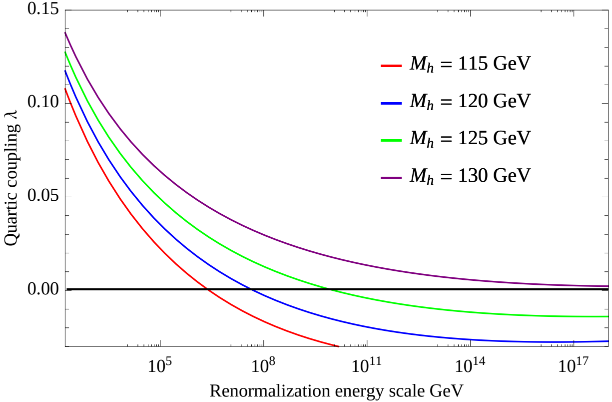
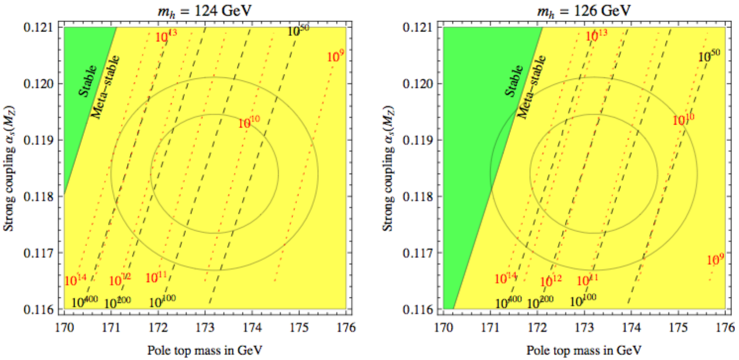
For large field values $V_{eff} \sim \frac{\lambda(\phi)}{4}\phi^4$.

$\lambda(\mu)$ for $M_t = 173.1 GeV$:



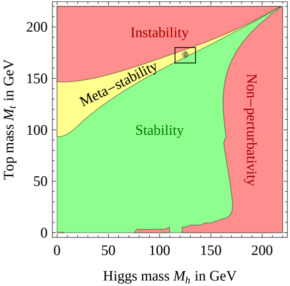
Can the SM be ruled out (and claim that new phisics must come in before the instability scale Λ_I) if there is a minimum depper than the EW minimum at some field value ϕ_I ($\approx \Lambda_I$)?

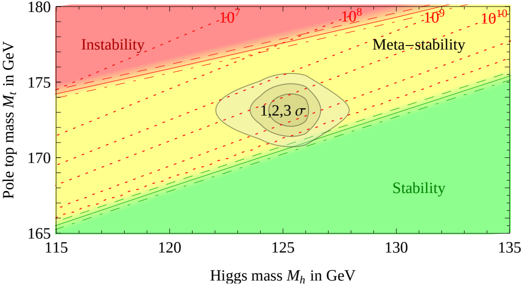
- No, the SM can still be consistent if the lifetime of the unstable EW vacuum is much longer than the age of the universe.



J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Riotto, A. Strumia. (2011)

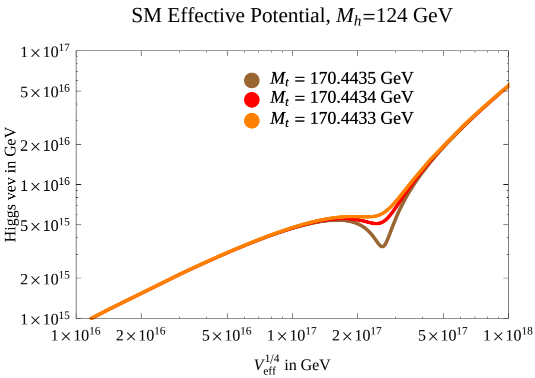
A Higgs mass of ~ 125 GeV is a very special value



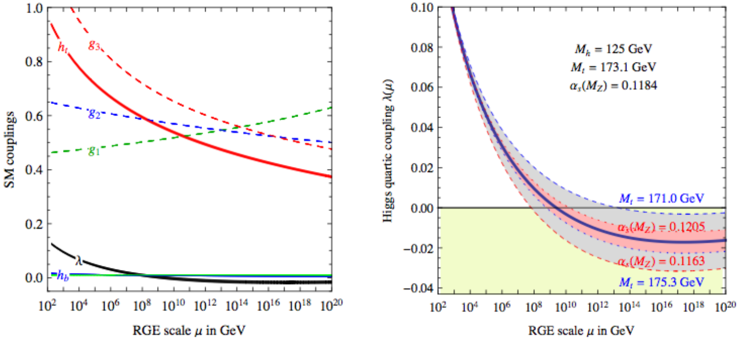


G.Degrassi, S. Di Vita, J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Strumia. (tomorow in arXiv)

In the absence of BSM physics, some people like $\lambda|_{M_{Planck}} = 0$, or doing inflation in the following plateau ($\lambda = \beta_\lambda = 0$)



but...



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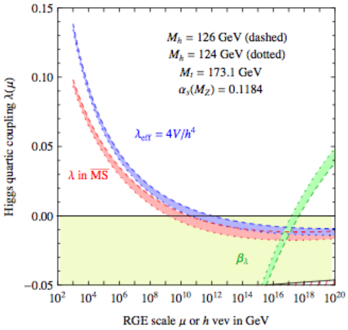

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From this result we conclude that vacuum stability of the SM up to the Planck scale is excluded at 2σ (98% C.L. one sided) for $M_h < 126\,\text{GeV}$.

G.Degrassi, S. Di Vita, J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Strumia. (tomorrow in arXiv)

Conclusions

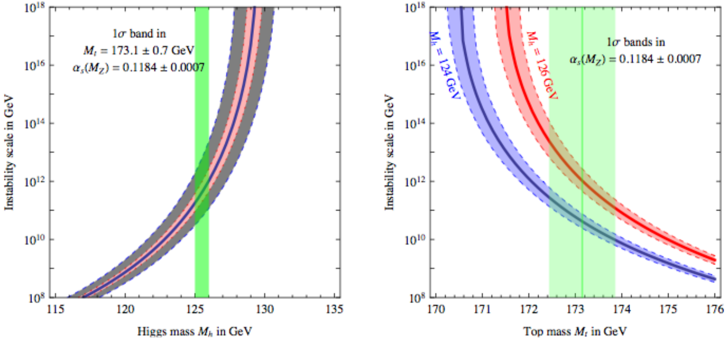
- From metastabilty considerations, a SM Higgs with $M_h \sim 125$ GeV does not imply an strict upper bound on the scale of new physics.

- The Higgs quartic coupling becomes very small. However, very unlikely becomes zero at the Planck scale.

The SM is such a good model that admits a theoretical extrapolation up to M_{Planck} without any consistency problem.

I hope this analysis will be soon invalidated by nature, due to new physics coming in close to the EW scale...

Thank you for your attention!



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$$\lambda_{\rm eff}(h) = e^{4\Gamma(h)}\left\{\lambda(h) + \frac{1}{(4\pi)^2}\sum_p N_p \kappa_p^2 \left(r_p - C_p\right)\right.$$

$$+$$

$$
\begin{aligned}
\delta\lambda_{\rm eff} &= \kappa^2 \Big\{ \frac{g^6}{48}\left[-30r_w^2 - 18r_{t/w}r_{(t-w)^2/(tw)} + 532r_w + 144r_{z/w} - 598 + 12\pi^2\right) \\
&+ \frac{g^4G^2}{96}\left[397 - 32r_{t/z}^2 + 126r_{z/w}^2 + 66r_z^2 + 27r_w^2 - 232r_z - 138r_w + 160\frac{\pi^2}{3}\right] \\
&+ \frac{g^4y_t^2}{24}\left(-27r_w^2 + 27r_{t/w}r_{(t-w)^2/(tw)} - 100r_t - 128r_z + 36r_w + 333 + 9\pi^2\right) \\
&- \frac{g^2G^4}{96}\left[219r_z^2 - 40r_{t/z}^2 + 21r_{w/z}^2 - 730r_z + 6r_w + 715 + 200\frac{\pi^2}{3}\right] \\
&+ \frac{2}{3}G^2y_t^4\left(3r_t^2 - 8r_t + 9\right) - \frac{G^6}{192}\left(34r_{t/z}^2 - 273r_z^2 + 3r_{w/z}^2 + 940r_z - 961 - 206\frac{\pi^2}{3}\right) \\
&+ \frac{G^4y_t^2}{48}\left[27\left(r_{t/z}^2 - r_z^2\right) - 68r_t - 28r_z + 189\right] + \frac{5}{3}g^2G^2y_t^2\left(2r_t + 4r_z - 9\right) \\
&- \frac{3y_t^6}{2}\left(3r_t^2 + 2r_{t/w}r_{(t-w)/t} - 16r_t + 23 + \frac{\pi^2}{3}\right) + \frac{3}{4}\left(g^6 - 3g^4y_t^2 + 4y_t^6\right)\mathrm{Li}_2[w/t] \\
&+ \frac{y_t^2}{48}\left[\left(14G^2 - 160g^2 + 128\frac{g^4}{G^2}\right)y_t^2 + 17G^4 - 40g^2G^2 + 32g^4\right]\xi_{11zt} \\
&+ \frac{g^2}{192}\left[3G^4 + 4\left(12G^2 - 51g^2 - 36\frac{g^4}{G^2}\right)g^2\right]\xi_{11zw}\Big\} \ ,
\end{aligned}
$$

where $\xi_{11xy} = \xi(1,1,x/y)$,

$$
r_p \equiv \ln[\kappa_p e^{2\gamma(h)}] \ , \quad r_{t/w} \equiv \ln[\kappa_t/\kappa_w] \ , \quad r_{(t-w)/t} \equiv \ln[(\kappa_t - \kappa_w)/\kappa_w] \ ,
$$