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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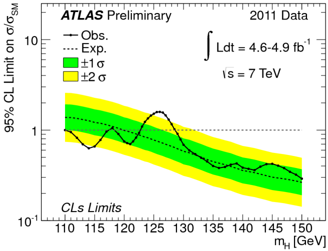
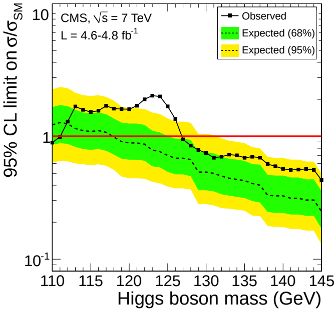
The Higgs sector of the SM

It 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.



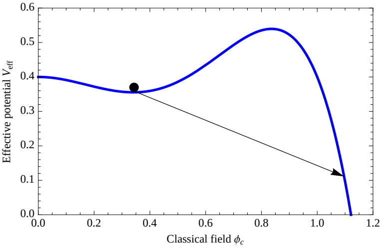


for $M_h \approx 125$ GeV, $\lambda = \frac{M_h^2}{2v^2} \approx 0.129$

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

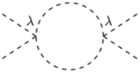
For large field values, $V_{eff} \approx \frac{1}{4}\lambda_{eff}(\phi)\phi^4$.

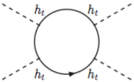
If $\lambda_{eff} \approx \lambda < 0$ at some high energy scale Λ_I, the Electroweak (EW) minimum at $\phi = v \approx 246$ GeV of the Higgs potential is unstable.



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

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

- 

, makes λ grow
- 

, makes λ decrease.

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

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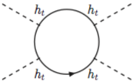
- 

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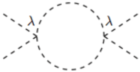
- 

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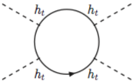
- 

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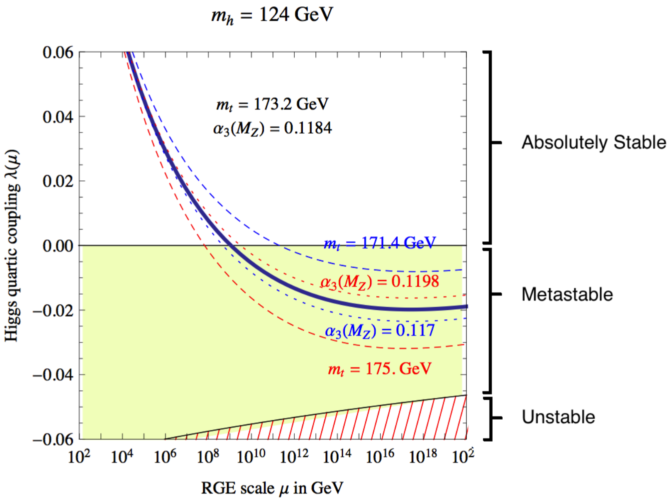
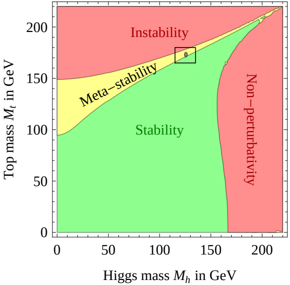
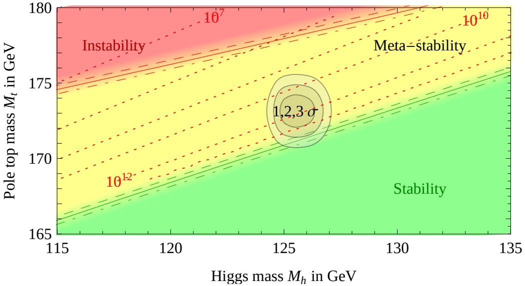


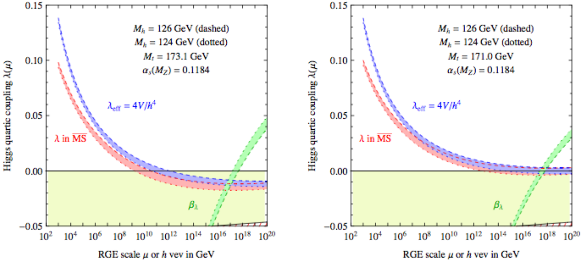
J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Riotto, A. Strumia. [hep/1112.3022]

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. [hep-ph/1205.6497]



Putting all the NNLO ingredients together, we estimate an overall theory error on M_h of ± 1.0 GeV (see section 3). Our final results for the condition of absolute stability up to the Planck scale is

$$M_h\ [\mathrm{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\mathrm{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\rm th}\,. \quad (2)$$

Combining in quadrature the theoretical uncertainty with the experimental errors on M_t and α_s we get

$$M_h > 129.4 \pm 1.8\ \ \mathrm{GeV}. \quad (3)$$

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 $M_h < 126$ GeV.

G.Degrassi, S. Di Vita, J.EM, J. Espinosa, G.F. Giudice, G. Isidori, A. Strumia. [hep-ph/1205.6497]

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.

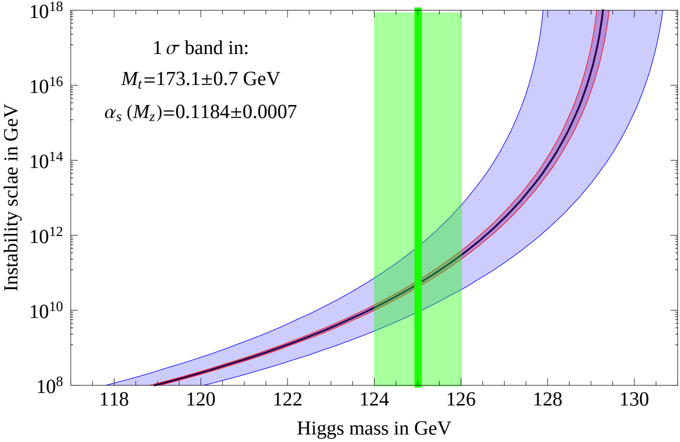
- The Higgs quartic coupling becomes very small. Very unlikely becomes zero at the Planck scale. However $\lambda(M_{Planck}) \approx 0$

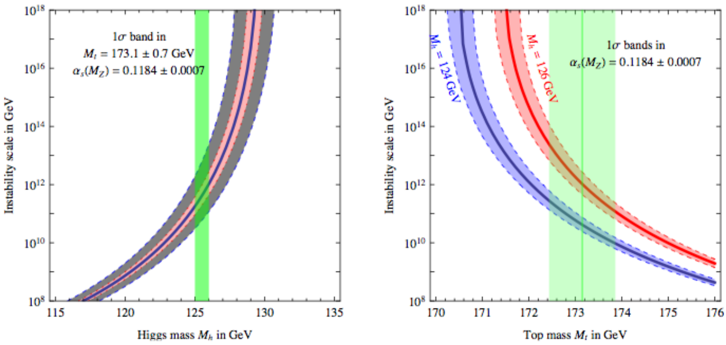
The SM is such a good model that admits a theoretical extrapolation up to M_{Planck} without any consistency problem.

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!

$$
\begin{aligned}
(4\pi)^2 \frac{d\lambda_H}{d\ln\mu} &= \left(12y_t^2 - 3g'^2 - 9g^2\right)\lambda_H - 6y_t^4 \\
&\quad + \frac{3}{8}\left[2g^4 + (g'^2 + g^2)^2\right] + 24\lambda_H^2 + 4\lambda_{HS}^2\ , \\
(4\pi)^2 \frac{d\lambda_{HS}}{d\ln\mu} &= \lambda_{HS}[\frac{1}{2}\left(12y_t^2 - 3g'^2 - 9g^2\right) \\
&\quad + 4\left(3\lambda_H + 2\lambda_S\right) + 8\lambda_{HS}]\ , \\
(4\pi)^2 \frac{d\lambda_S}{d\ln\mu} &= 8\lambda_{HS}^2 + 20\lambda_S^2\ .
\end{aligned}
\tag{1}
$$


1 σ band in:
M_t=173.1±0.7 GeV
α_s (M_z)=0.1184±0.0007
Instability sclae in GeV
10^{18}
10^{16}
10^{14}
10^{12}
10^{10}
10^{8}
118
120
122
124
126
128
130
Higgs mass in GeV



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

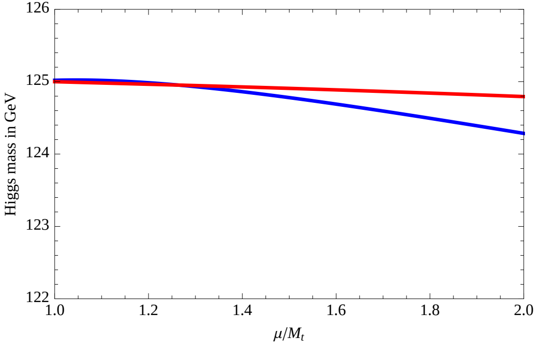
$$+$$

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

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

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

and so on.


126
125
124
123
122
Higgs mass in GeV
1.0
1.2
1.4
1.6
1.8
2.0
μ/M_t