The role of the top quark mass in the vacuum stability of the Standard Model (SM)

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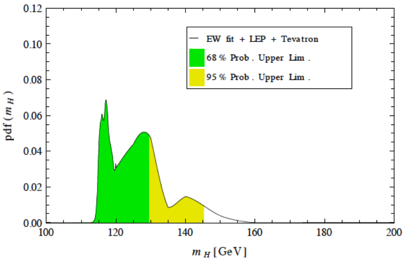
Outline

New Physics (NP) decoupled at LHC

- No physics beyond the Standard Model has been discovered in the first run of LHC.
- The Higgs boson was found where predicted by the SM.

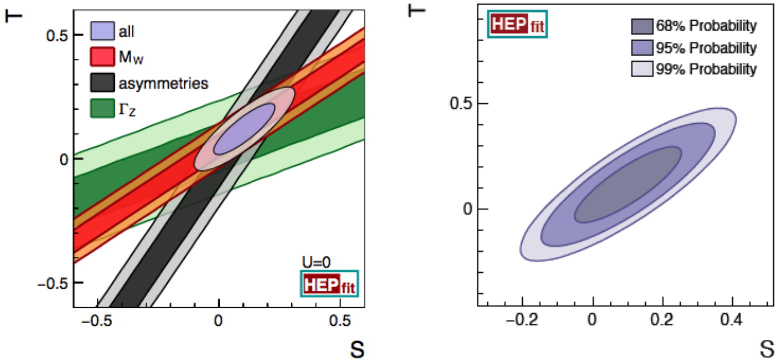
Precision measurements and accurate calculations **within the SM**, combined with the results of the Higgs search experiments at LEP and Tevatron → probability density function of the Higgs mass m_H

$$\mathrm{pdf}(\mathrm{m_H}) \propto \frac{\mathrm{Q}(\mathrm{m_H})}{\mathrm{m_H}} \exp\left(-\frac{\chi^2}{2}\right)$$



New Physics (NP) if there seems to be of decoupling type.

In scenarios in which NP only modifies the electroweak gauge bosons propagators, very precise measurements of electroweak precise observables can be described only by the **oblique** three parameters S, T, U



$$\mathbf{S} = 0.10 \pm 0.08 \quad \mathbf{T} = 0.12 \pm 0.07.$$

(Meta) Stability regime

Quantum corrections to the classical Higgs potential in the SM can modify its shape

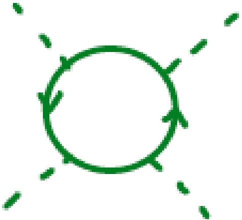
$$V_{\mathrm{class}} = -\frac{1}{2}m^2\phi^2 + \lambda\phi^4 \to V_{eff} \sim -\frac{1}{2}m^2(\mu)\phi^2(\mu) + \lambda(\mu)\phi^4(\mu)$$

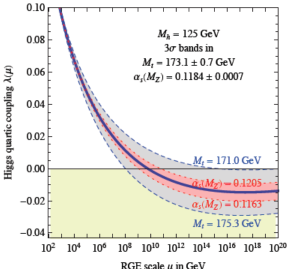
$$\phi \sim \mu >> v = (\sqrt{2}G_F)^{-\frac{1}{2}} \sim 246\,GeV \to V_{eff} \sim \lambda(\mu)\phi^4(\mu)$$

λ runs

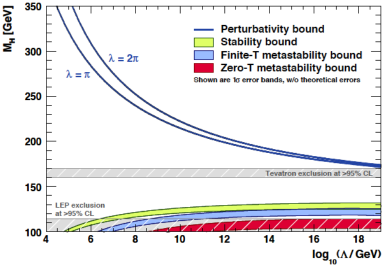
$$\frac{d\lambda}{d\log\mu} = +\frac{3\lambda^2}{2\pi^2} - \frac{3}{8\pi^2}Y_t^4 \ldots$$

Y_t it the top Yukawa coupling: $M_t = \frac{Y_t v}{\sqrt{2}}$ and $\lambda = \frac{M_H^2}{2v^2}$.



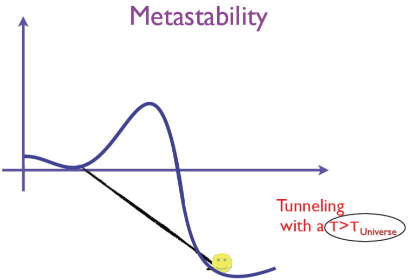


$M_H >> 200 GeV$: λ^2 wins: $\lambda(M_t) \to \lambda(\mu) >> 1$
$M_H << 200 GeV$: $-Y_t^4$ wins: $\lambda(M_t) \to \lambda(\mu) << 1$
The running depends on $M_t, \alpha_s \ldots$



$M_H \sim 125 \div 126 GeV$: $-Y_t^4$ wins $\lambda(M_t) \sim 0.14$ runs toward smaller values and can eventually become negative. If so the potential is either unbounded from below or can develop a second (deeper) minimum at large field values.

The problem

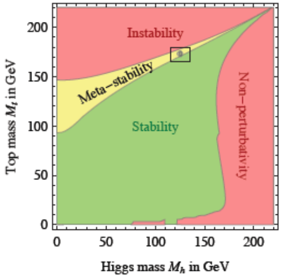


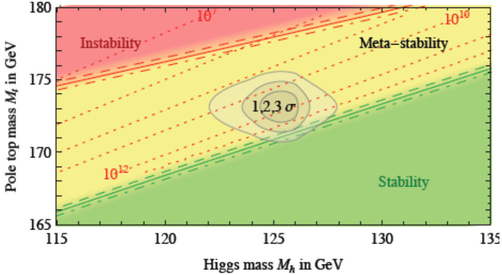
The SM vacuum is unstable but sufficiently long-lived compared to the age of the Universe.

Transition probability: $e^{\frac{8\pi^2}{3|\lambda|}}$

Living at the edge

The measured values of M_H and M_T place the SM vacuum at the border between stability and metastability.





Since the experimental error on the Higgs mass is already fairly small and will be further reduced by future LHC analyses, it is becoming more appropriate to express the stability condition in terms of the pole top mass M_t.

What is the Top Mass M_t?

- The M_t of the stability analysis is the pole mass of the top quark. For some asymptotic state $|p, \sigma>$

$$p^2 = M_t^2$$

There is confinement: what does mean asymptotic state?

- Monte Carlo are used to reconstruct the top pole mass from its decays products that contain jets, missing energy and initial state radiation.

$$M_t = M_t^{MC} + \Delta \quad \delta M_t^{MC} = \pm 0.7 GeV \quad \Delta = ?$$

- By taking M_t as a scale-dependent parameter of the SM Lagrangean

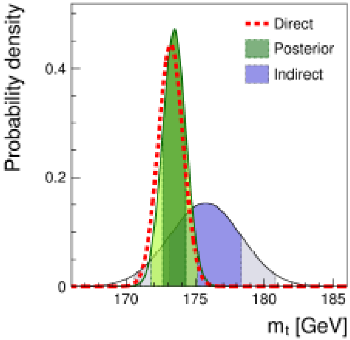
$$M_t^{\overline{MS}}(M_t) = (163.3 \pm 2.7) GeV \rightarrow M_t = (173.3 \pm 2.8) GeV$$

consistent with the Tevatron number albeit with a larger error ($\Delta = 0?$).

- In the SM the Higgs boson gives mass to matter fields via Higgs-Yukawa coupling (Y_t).
- For quantum chromodynamics QCD quark masses are gauge invariant.
- In the SM the $M_t^{\overline{MS}}$ are not gauge invariant, Yukawa couplings are. The vev v is not a parameter of the SM.

1. v minimum of the tree level potential $\rightarrow$ $M_t^{\overline{MS}}$ is gauge invariant but large electro-weak corrections in the relation between $M_t^{\overline{MS}}$ and M_t.
2. v of the radiatively corrected effective potential $\rightarrow$ $M_t^{\overline{MS}}$ is not gauge invariant (problem? $\overline{MS}$ mass is not a physical quantity). No large EW correction in the relation between $M_t^{\overline{MS}}$ and M_t.

Is $M_t \sim 171 GeV$ compatible with the pole mass?



The stability range for M_T is only at the tail of the distribution, with a probability of few percents, as extracted from the EW fits.

Conclusions and prespectives

- The value of the Higgs mass found by ATLAS and CMS causes the SM potential to be at the border of the stability region.
- The exact value of the top mass plays the central role between the full stability or the metastability.
- The possibility of $\lambda > 0$ up to M_{Planck} requires a top mass value around 171 GeV, a number not preferred by the EW fit.
- We plan to make an analysis of the vacuum stability with other definition of the short distance top quark mass, like those coming from the so called *MSR* schemes.

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