

The Higgs potential: Vacuum Stability and Higgs Inflation Models

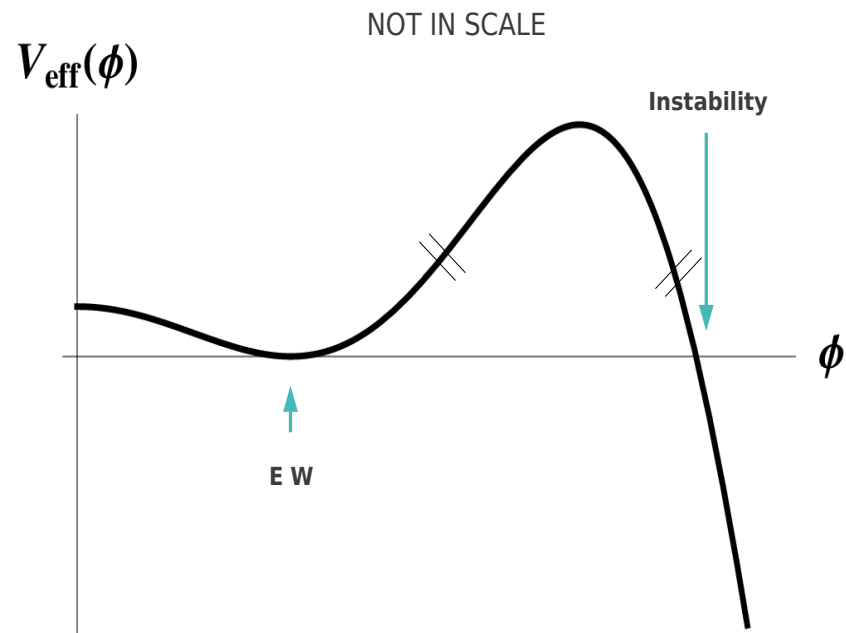
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Roma Tre - December 10, 2014

Top loop-corrections to the Higgs Effective Potential

destabilize the electroweak vacuum...



Some References ... far from being exhaustive

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C.D. Froggatt, H. B. Nielsen, Y. Takanishi (Bohr Inst.), Phys.Rev. **D64** (2001) 113014

G. Isidori, G. Ridolfi, A. Strumia, Nucl. Phys. **B609** (2001) 387.

J. Elias-Miro, J. R. Espinosa, G. F. Giudice, G. Isidori, A. Riotto, A. Strumia, Phys.Lett. **B709** (2012) 222-228

G. Degrassi, S. Di Vita, J. Elias-Miro, J. R. Espinosa, G. F. Giudice, G. Isidori, A. Strumia, JHEP **1208** (2012) 098.

Discovery of the Higgs boson : $M_H = 125 - 126$ GeV

Experimental data consistent with Standard Model predictions

No sign of new physics

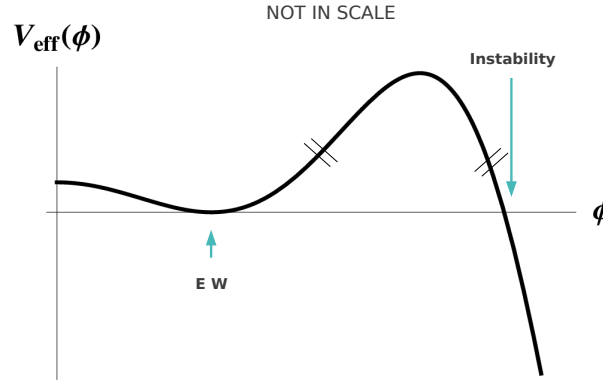
Boost new interest and work on these earlier speculations

Possibility for new physics to show up only at very high energies

Possible scenario: new physics only appears at M_P

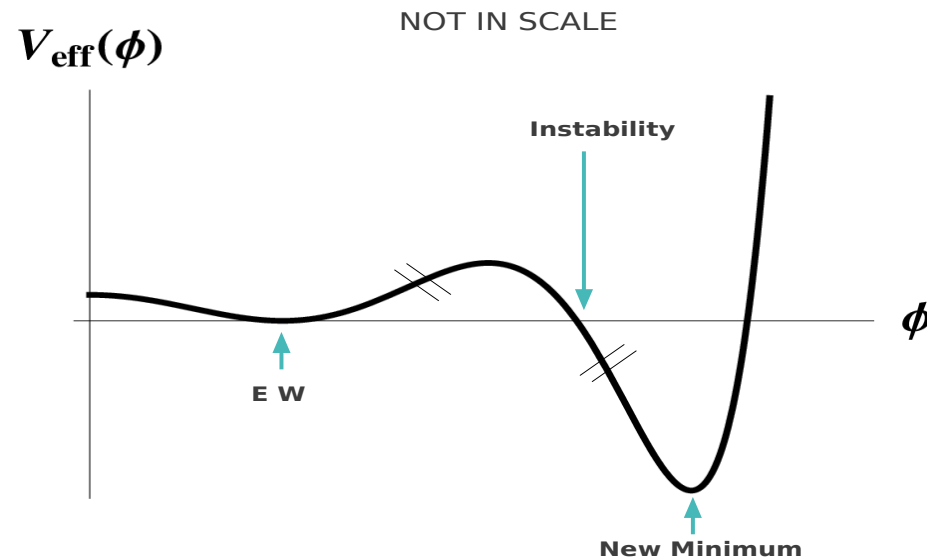
Where do these ideas come from?

Higgs One-Loop Effective Potential $V^{1l}(\phi)$



$$\begin{aligned}
 V^{1l}(\phi) = & \frac{1}{2}m^2\phi^2 + \frac{\lambda}{24}\phi^4 + \frac{1}{64\pi^2} \left[\left(m^2 + \frac{\lambda}{2}\phi^2\right)^2 \left(\ln \left(\frac{m^2 + \frac{\lambda}{2}\phi^2}{\mu^2} \right) - \frac{3}{2} \right) \right. \\
 & + 3 \left(m^2 + \frac{\lambda}{6}\phi^2\right)^2 \left(\ln \left(\frac{m^2 + \frac{\lambda}{6}\phi^2}{\mu^2} \right) - \frac{3}{2} \right) + 6 \frac{g_1^4}{16} \phi^4 \left(\ln \left(\frac{\frac{1}{4}g_1^2\phi^2}{\mu^2} \right) - \frac{5}{6} \right) \\
 & \left. + 3 \frac{(g_1^2 + g_2^2)^2}{16} \phi^4 \left(\ln \left(\frac{\frac{1}{4}(g_1^2 + g_2^2)\phi^2}{\mu^2} \right) - \frac{5}{6} \right) - 12 h_t^4 \phi^4 \left(\ln \frac{g^2\phi^2}{\mu^2} - \frac{3}{2} \right) \right]
 \end{aligned}$$

RG Improved Effective Potential $V_{RGI}(\phi)$



Depending on M_H and M_t , the second minimum can be : (1) **lower** than the EW minimum (as in the figure) ; (2) at the **same level** of the EW minimum ; (3) **higher** than the EW minimum.

Note : $V_{RGI}(\phi)$ is obtained by considering SM interactions only

Note : the instability occurs for **large values** of the field

$\Rightarrow V_{RGI}(\phi)$ well approximated by keeping only the quartic term :

$$V_{RGI}(\phi) \sim \frac{\lambda_{eff}(\phi)}{24} \phi^4$$

and $\lambda_{eff}(\phi)$ depends on ϕ essentially as $\lambda(\mu)$ depends on μ

\Rightarrow we can read the **Effective Potential** from the $\lambda(\mu)$ flow

.... and explore the possibility that

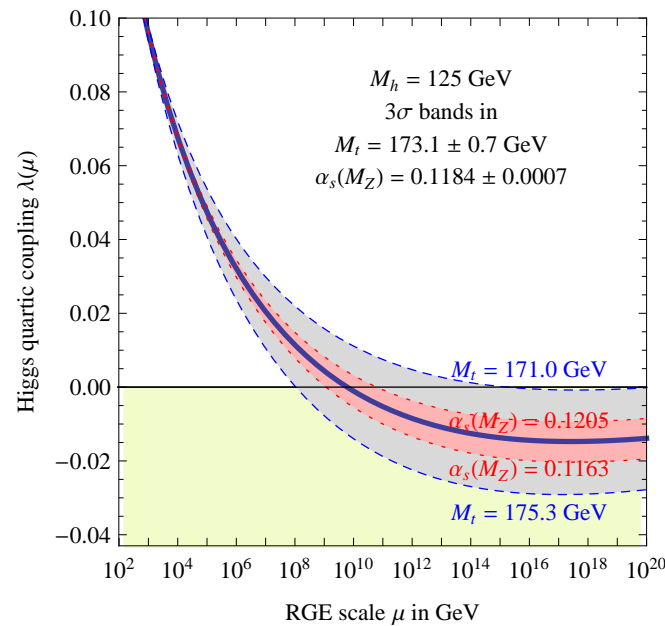
.... SM valid up to very high scales... **Planck scale ???**

... clearly ignoring the Naturalness Problem !!! ...

(... however: interesting connections with the Naturalness problem ...)

Running of $\lambda(\mu)$ in the SM

From: Degrandi, Di Vita, Elias-Miro, Espinosa, Giudice, Isidori, Strumia, JHEP 1208 (2012) 098.



Blue thick line : $M_H = 125 \text{ GeV}$, $m_t = 173.1 \text{ GeV}$; $\lambda(\mu) = 0$ for $\mu \sim 10^{10} \text{ GeV}$

Summary up to now

For large values of ϕ $V_{RGI}^{Higgs}(\phi) \simeq \frac{\lambda_{eff}(\phi)}{24} \phi^4$

at the same time $\lambda_{eff}(\phi) \sim \lambda(\mu)$

\Rightarrow **We are interested in the running of $\lambda(\mu)$**

**more precisely in the running of all of the SM couplings
(coupled RG equations)**

...and this is what people does...

...solving the RG equations for the SM couplings...

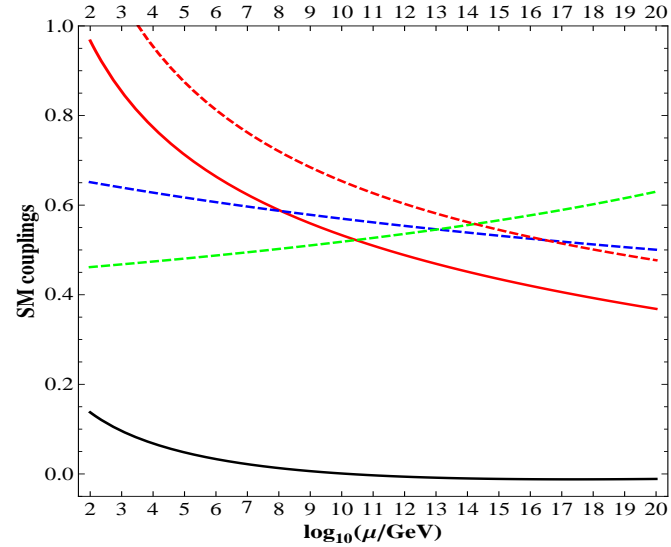
$$\mu \frac{d}{d\mu} \lambda(\mu) = \beta_\lambda (\lambda, h_t, \{g_i\})$$

$$\mu \frac{d}{d\mu} h_t(\mu) = \beta_{h_t} (\lambda, h_t, \{g_i\})$$

$$\mu \frac{d}{d\mu} g_i(\mu) = \beta_{g_i} (\lambda, h_t, \{g_i\})$$

with $i = 1, 2, 3$ and $g_i = \{g', g, g_s\}$

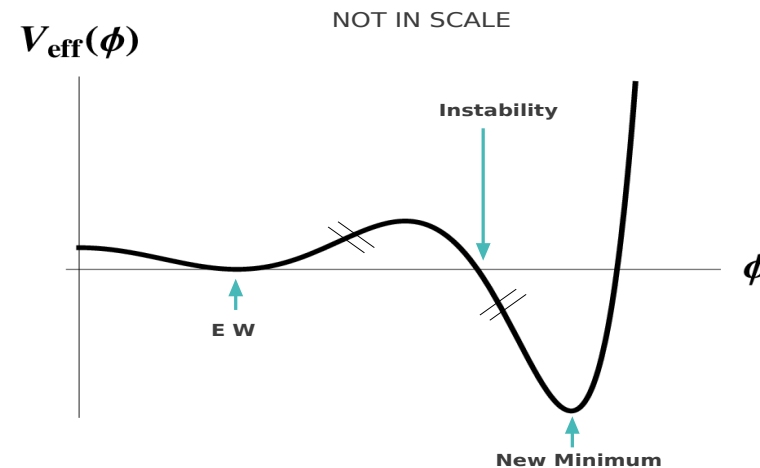
Running of the SM couplings



$M_t = 173.1 \text{ GeV}$, $M_H = 125 \text{ GeV}$, $M_Z = 91.45 \text{ GeV}$, $\lambda(M_t) = 4.53$,
 $h_t(M_t) = 0.936$, $g'(M_Z) = 0.652$, $\sqrt{5/3}g(M_Z) = 0.46$, $g_s(M_Z) = 1.22$.

$\lambda(\mu)$ (black line), $h_t(\mu)$ (red, solid line), $g'(\mu)$ (blue line), $g(\mu)$ (greenline) $g_s(\mu)$ (red, dashed line).

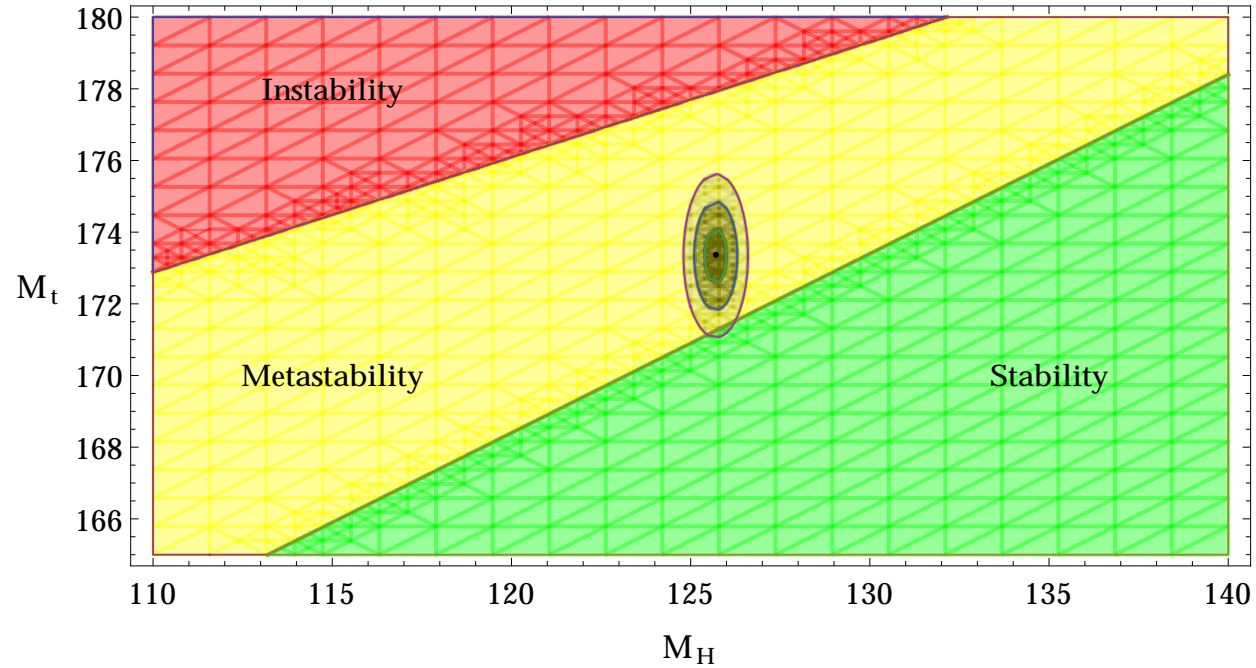
Then we have all the ingredients
...to cook up the RGI Higgs effective potential $V_{RGI}(\phi)$...



As already pointed out, depending on M_H and M_t , the second minimum can be : (1) **lower** (as in figure), (2) at the **same level**, or (3) **higher** than the EW minimum. If the New Minimum is lower than the EW minimum, the latter is a **false vacuum**... and we have to consider its **lifetime** τ ...

... we can then draw the stability diagram \Rightarrow

Stability Diagram in the $M_H - M_t$ plane

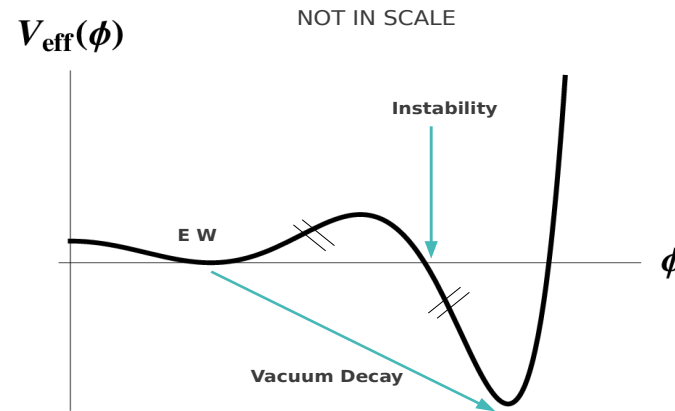


Stability region : $V_{eff}(v) < V_{eff}(\phi_{min}^{(2)})$. **Meta-stability** region : $\tau > T_U$.

Instability region : $\tau < T_U$. Stability line : $V_{eff}(v) = V_{eff}(\phi_{min}^{(2)})$. Instability line : M_H and M_t such that $\tau = T_U$.

Metastability Scenario

When the second minimum is lower than EW



Tunnelling between the Metastable EW Vacuum and the True Vacuum.

As long as EW vacuum lifetime larger than the age of the Universe ...

.... we may well live in the Meta-Stable (EW) Vacuum

How do we compute the tunneling time ?

How do we compute the tunneling time ?

Semiclassical calculation - WKB - instantons

EW vacuum lifetime (= Tunneling Time τ)

$$\Gamma = \frac{1}{\tau} = T_U^3 \frac{S[\phi_b]^2}{4\pi^2} \left| \frac{\det' [-\partial^2 + V''(\phi_b)]}{\det [-\partial^2 + V''(v)]} \right|^{-1/2} e^{-S[\phi_b]}$$

$\phi_b(r)$: **Bounce Solution**

Solution to the Euclidean Equation of Motion with appropriate boundary conditions

S. Coleman, Phys. Rev. D 15 (1977) 2929

C.G.Callan, S.Coleman, Phys. Rev. D 16 (1977) 1762

Tunneling and bounces

Bounce : solution to Euclidean equations of motion

$$-\partial_\mu\partial_\mu\phi + \frac{dV(\phi)}{d\phi} = -\frac{d^2\phi}{dr^2} - \frac{3}{r}\frac{d\phi}{dr} + \frac{dV(\phi)}{d\phi} = 0 ,$$

Boundary conditions : $\phi'(0) = 0$, $\phi(\infty) = v \rightarrow 0$.

Potential : $V(\phi) = \frac{\lambda}{4}\phi^4$

with negative λ

Bounce solutions :

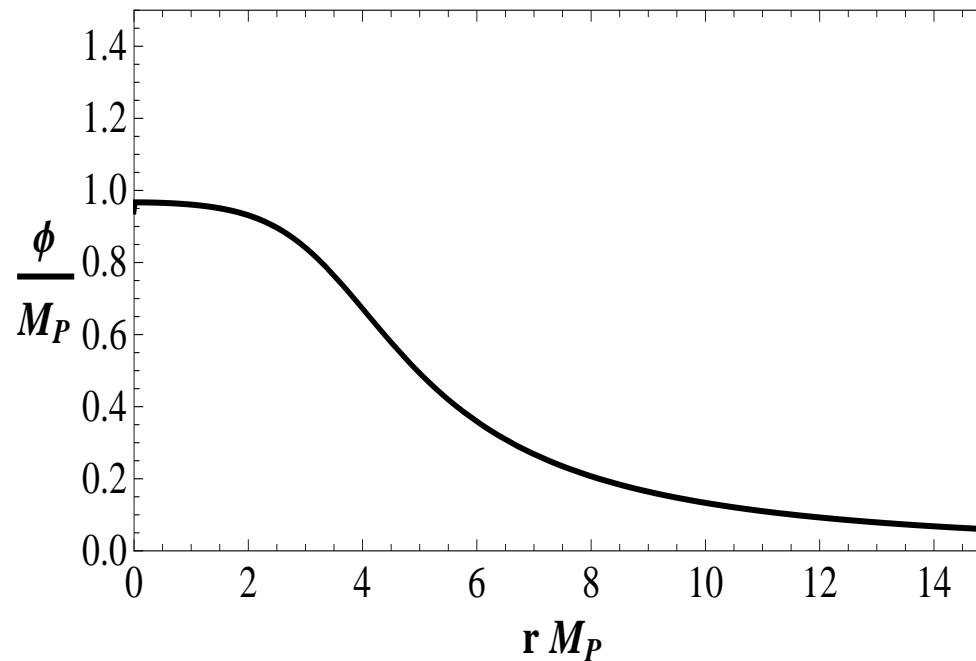
$$\phi_b(r) = \sqrt{\frac{2}{|\lambda|}} \frac{2R}{r^2 + R^2}$$

R is the size of the bounce

Bounces :

$$\phi_b(r) = \sqrt{\frac{2}{|\lambda|}} \frac{2R}{r^2 + R^2}$$

R = bounce size – Classical degeneracy : $S[\phi_b] = \frac{8\pi^2}{3|\lambda|}$

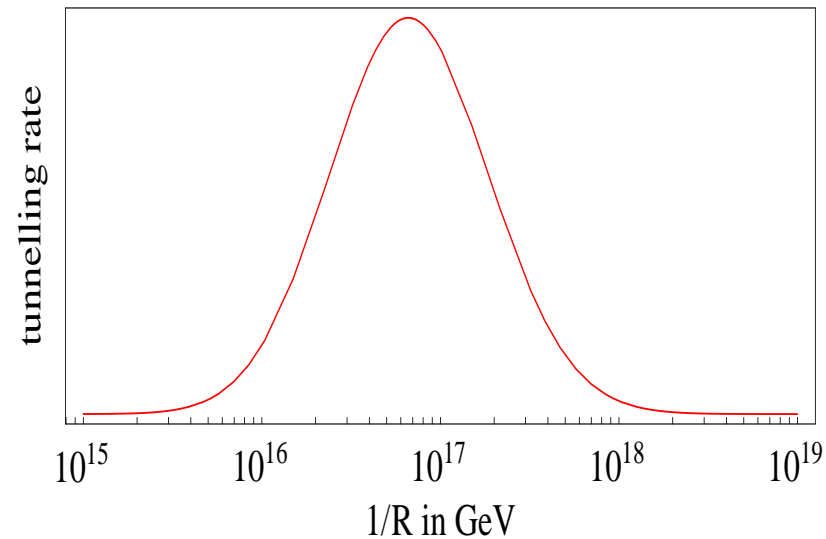


Degeneracy removed at the Quantum Level

Degeneracy removed at the Quantum Level

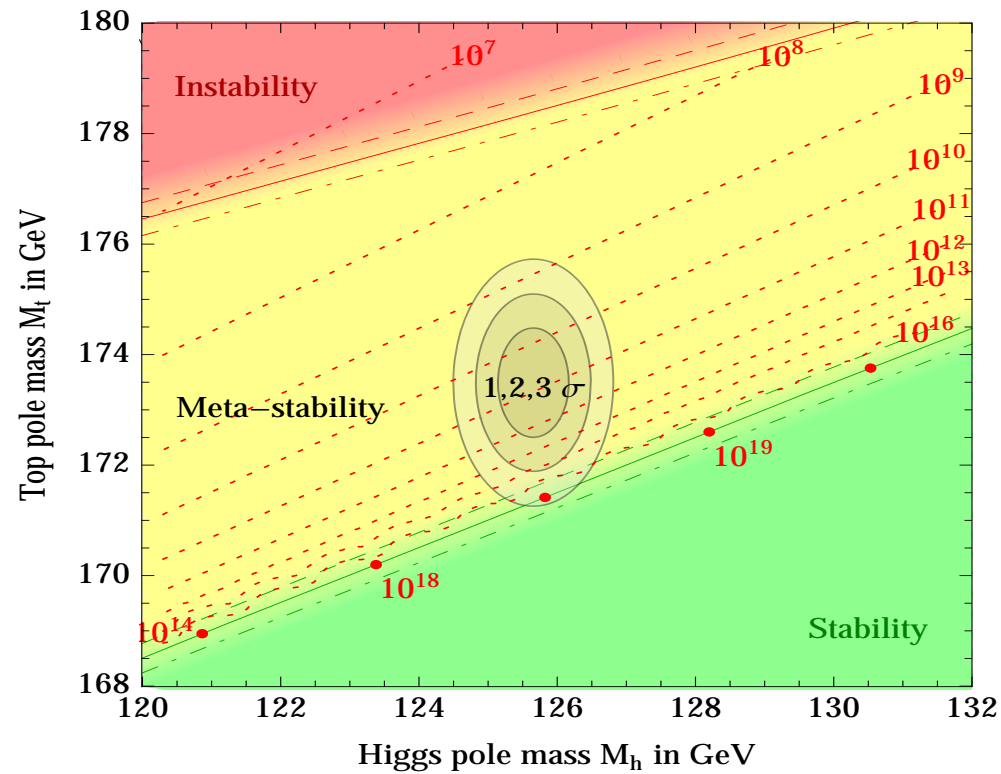
Transition rate as a function of R : ($\mu \sim \frac{1}{R}$)

$$p = \max_R \frac{V_U}{R^4} \exp \left[-\frac{8\pi^2}{3|\lambda(\mu)|} - \Delta S \right]$$



from : G. Isidori, G. Ridolfi, A. Strumia, Nucl.Phys.B 609 (2001) 387

With this Heavy Artillery \Rightarrow Stability Diagram



Buttazzo, Degrandi, Giardino, Giudice, Sala, Salvio, Strumia, JHEP 1312 (2013) 089.

Summary up to now

The scenario that we are considering is the following:

New Physics shows up only at the Planck scale

Within this scenario we study the stability of the EW vacuum

.....

.... Let's take a Little Tour on

Higgs Inflation and Stability

Higgs Inflation and Stability

Flatness, homogeneity , isotropy , generation of scale invariant spectrum of perturbations (structure formation) \Leftarrow Inflation (Starobinsky , Mukhanov , Guth , Linde , Albrecht)

Usually : introduction of an **additional scalar field (particle) - Inflaton**.

Appears in different extensions of SM (GUTs, SUSY, strings, extra dimensions,...)

Higgs Inflation :

The SM itself can give rise to Inflation

1. Higgs inflation from **non-minimal coupling to gravity**
2. Higgs inflation from **false vacuum**

1. Higgs inflation from nonminimal coupling to gravity

$$\mathcal{L}_{\text{tot}} = \mathcal{L}_{\text{SM}} - \frac{M_P^2}{2}R - \xi H^\dagger H R$$

Scalar sector (unitary gauge $H = h/\sqrt{2}$) :

$$S = \int d^4x \sqrt{-g} \left\{ -\frac{M_P^2}{2}R + \frac{\xi h^2}{2}R + \frac{\partial_\mu h \partial^\mu h}{2} - \frac{\lambda}{4}(h^2 - v^2)^2 \right\}$$

ξ : new coupling constant fixing the **strength of the non-minimal interaction** (nonminimal coupling required for consistency of the SM in curved space-time). The value of ξ cannot be fixed theoretically within the SM.

$\xi = 0$: minimal coupling.... **Good particle physics phenomenology ... Bad Inflation** (self-coupling of the Higgs field too large and matter fluctuations are many orders of magnitude larger than those observed)

This interaction **flattens the Higgs potential above the scale $M_{\text{Pl}}/\xi^{\frac{1}{2}}$... slow-roll inflation** ... correct inflationary indexes n_s and r .

From the **spectrum of primordial fluctuations** \Rightarrow extract the value of ξ .

Using the **tree-level potential** : $\xi \approx 4.7 \times 10^4 \sqrt{\lambda}$.

Classical Potential → Effective Potential

We have seen that : **quantum fluctuations change the form of the potential.**

We do not want radiative corrections ruin the **flatness of the scalar potential at high energies** ... This leads to ...

⇒ Higgs inflation can only take place if

$$M_H > M_H^{\text{crit}}$$

... Higgs coupling constant must be **positive** at **energies up to the inflationary scale** ...

$$M_H^{\text{crit}} = \left[129.6 + \frac{y_t - 0.9361}{0.0058} \times 2.0 - \frac{\alpha_s - 0.1184}{0.0007} \times 0.5 \right]$$

Two-loops - three-loop beta functions ... small theoretical error : 0.07 GeV

Main uncertainty in M_H^{crit} : experimental and theoretical errors in y_t ...

M_H^{crit} **about 2-3 σ from M_H^{exp}** (ATLAS , CMS)

Summary

Important points for Higgs Inflation scenario from nonminimal coupling to gravity :

Flattening of the potential (then flattening in the running of the quartic coupling constant) at high (\sim Planck) scales (generated by nonminimal coupling to gravity)

Stability of the potential up to high (\sim Planck) scales

... This boils up to

\Rightarrow

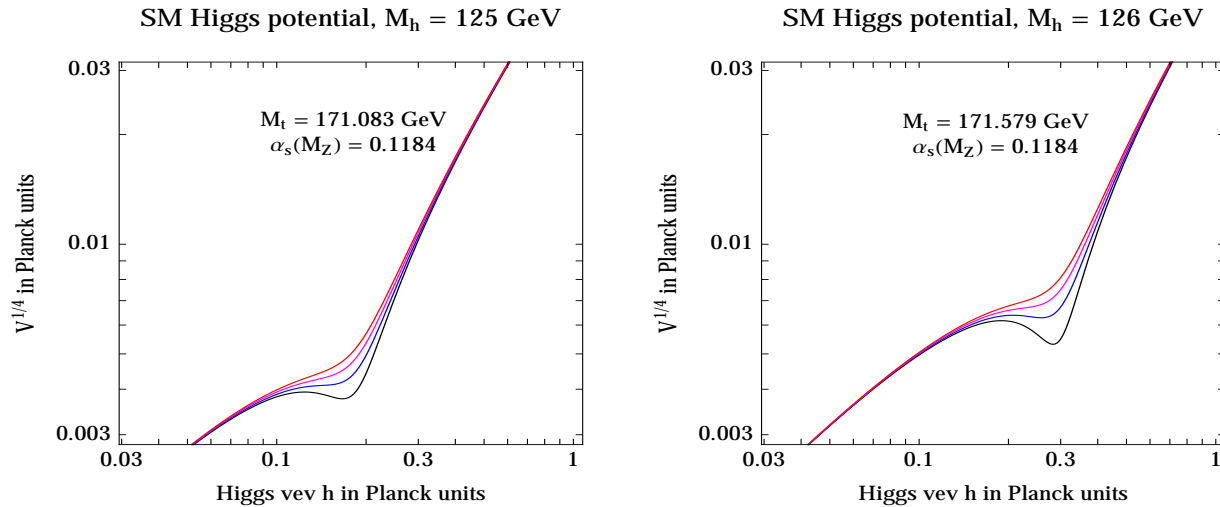
$$\lambda(M_P) \sim 0 \quad \text{and} \quad \beta(\lambda(M_P)) = \left(\mu \frac{d\lambda(\mu)}{d\mu} \right)_{\mu=M_P} \sim 0$$

2. Higgs inflation from false vacuum

Alternative proposal based on the existence of a **second minimum** $\phi_{min}^{(2)}$ of $V(\phi)$ at **large Higgs field values** ... for special choices of M_H and M_t $V(\phi_{min}^{(2)}) > V(v_{EW})$

... Inflation could have started at $\phi_{min}^{(2)} \sim 10^{15} - 10^{17}$ GeV. This minimum with $\phi_{min}^{(2)}$ in this range exists for a narrow band of values of M_H and M_t .

Needed : additional degree of freedom for transition to the radiation era.



... Ingredients ... Scenario

- False vacuum of $V(\phi)$ that can source exponential expansion in the early Universe
- Graceful exit ... from Inflation to Radiation era.
- Consider the Standard Model Higgs potential (including running of λ)

$$V_{\text{Higgs}}(\phi) = \frac{\lambda}{24} \phi^4$$

- For certain values of M_H and M_t :

New minimum at $\phi_{\min}^{(2)} \sim 10^{16} \text{ GeV}$; $V_{\text{Higgs}}(\phi_{\min}^{(2)}) > V_{\text{Higgs}}(v_{EW})$

- Assume that ϕ starts trapped in this false vacuum \Rightarrow Universe dominated by the potential energy $V_{\text{Higgs}}(\phi_{\min}^{(2)})$ and can inflate

To end Inflation and have a transition to Radiation dominated era

- Introduce a new scalar field Φ weakly coupled to the Standard Model Higgs
the field Φ evolves with time and makes the barrier in $V_{\text{Higgs}}(\phi)$ disappear...

[[[Note: similar to hybrid inflation scenarios, where a “waterfall” field (not the Higgs) is trapped at zero and suddenly starts to evolve when another field (in this case Φ) reaches some critical value. In this Higgs Inflation model the trapped field is the SM Higgs and it is stuck at a large value $\phi_{min}^{(2)}$ (rather than being trapped in zero)]]]

- The additional field Φ is coupled to the Higgs field ϕ in such a way that when it reaches a critical value Φ_{cr} , **the false vacuum $\phi_{min}^{(2)}$ disappears** and the Higgs can start **rolling down its potential**

Full scalar potential :

$$V(\phi, \Phi) = V_{\text{Higgs}}(\phi) + V_{\text{int}} + V_{\Phi}(\Phi) = \frac{\lambda}{24}(\phi^2 - v^2)^2 + \frac{\alpha}{2}(\Phi^2 - v_{\Phi}^2)\phi^2 + \frac{\sigma}{24}(\Phi^2 - v_{\Phi}^2)^2$$

Tunneling rate Γ assumed to be **initially very small** ($\Gamma \ll H^4 \dots H$ Hubble rate) :
obtained by **tuning the barrier in V_{Higgs} varying M_H and M_t** \Rightarrow during Inflation :
 $\phi = \phi_{min}^{(2)}$

Some warnings

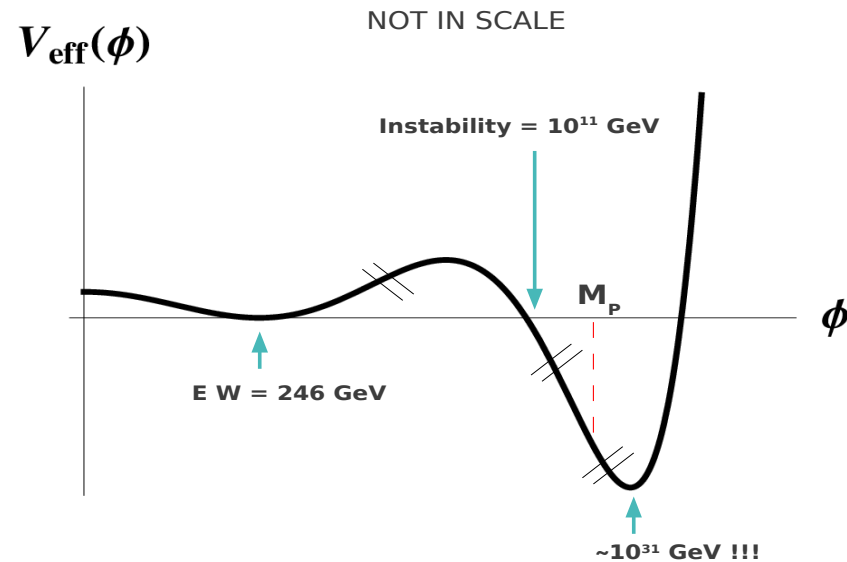
V. Branchina, E. Messina, Phys.Rev.Lett.111, 241801 (2013) (arXiv:1307.5193)

V. Branchina, arXiv:1405.7864, Moriond 2014

V. Branchina, E. Messina, A. Platania JHEP 1409 (2014) 182 (arXiv:1407.4112)

V. Branchina, E. Messina, M. Sher, e-Print: arXiv:1408.5302, in print Phys. Rev. D

Probably worth to know : $M_H \sim 126 \text{ GeV}$ and $M_t \sim 173 \text{ GeV}$



New minimum at $\phi_{\min}^{(2)} \sim 10^{30} \text{ GeV} !!!!$

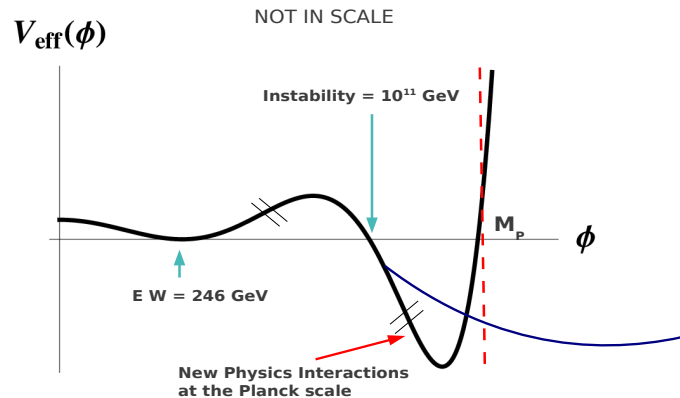
SM Effective Potential extrapolated well above M_P !!!

(you normally hear : assume SM valid up to M_P)

Does it make any sense ??? Is this a problem or not ???

To make sense out of this potential, people have (had?) arguments ...

1. New Physics Interactions that appear at the Planck scale M_P eventually stabilize the potential around M_P ...



... meaning that if you take into account the presence of these new physics interactions, given in terms of higher order operators as

$$\frac{\phi^6}{M_P^2} \quad , \quad \frac{\phi^8}{M_P^4} \quad , \dots$$

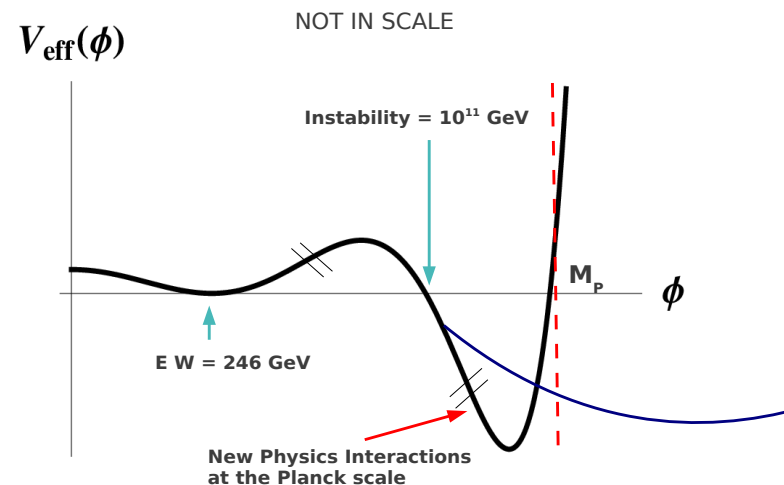
the potential should be stabilized by these terms around M_P ...

2. These New Physics Interactions present at the Planck scale do not affect the EW vacuum lifetime τ (can be neglected when computing τ)

(a) - Instability scale much lower than Planck scale \Rightarrow

$$\Rightarrow \text{suppression } \left(\frac{\Lambda_{inst}}{M_P} \right)^n$$

(b) - For tunnelling, only height of the barrier and turning points matter



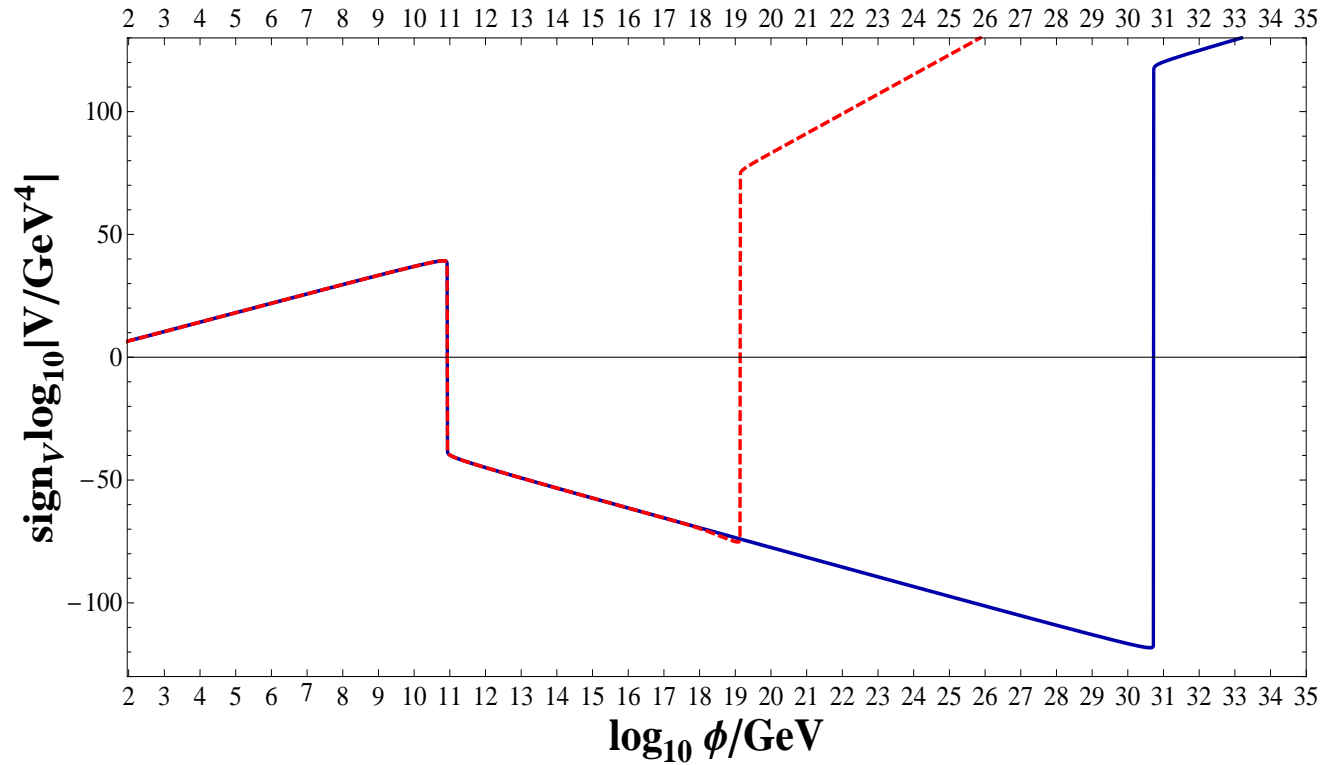
Let us consider New Physics at M_P

Add ϕ^6 and ϕ^8 in such a way to implement the stabilization of the SM Higgs potential at M_P :

$$V(\phi) = \frac{\lambda}{4}\phi^4 + \frac{\lambda_6}{6} \frac{\phi^6}{M_P^2} + \frac{\lambda_8}{8} \frac{\phi^8}{M_P^4}$$

$$V_{eff}^{new}(\phi) = V_{eff}(\phi) + \frac{\lambda_6(\phi)}{6M_P^2} \xi(\phi)^6 \phi^6 + \frac{\lambda_8(\phi)}{8M_P^4} \xi(\phi)^8 \phi^8$$

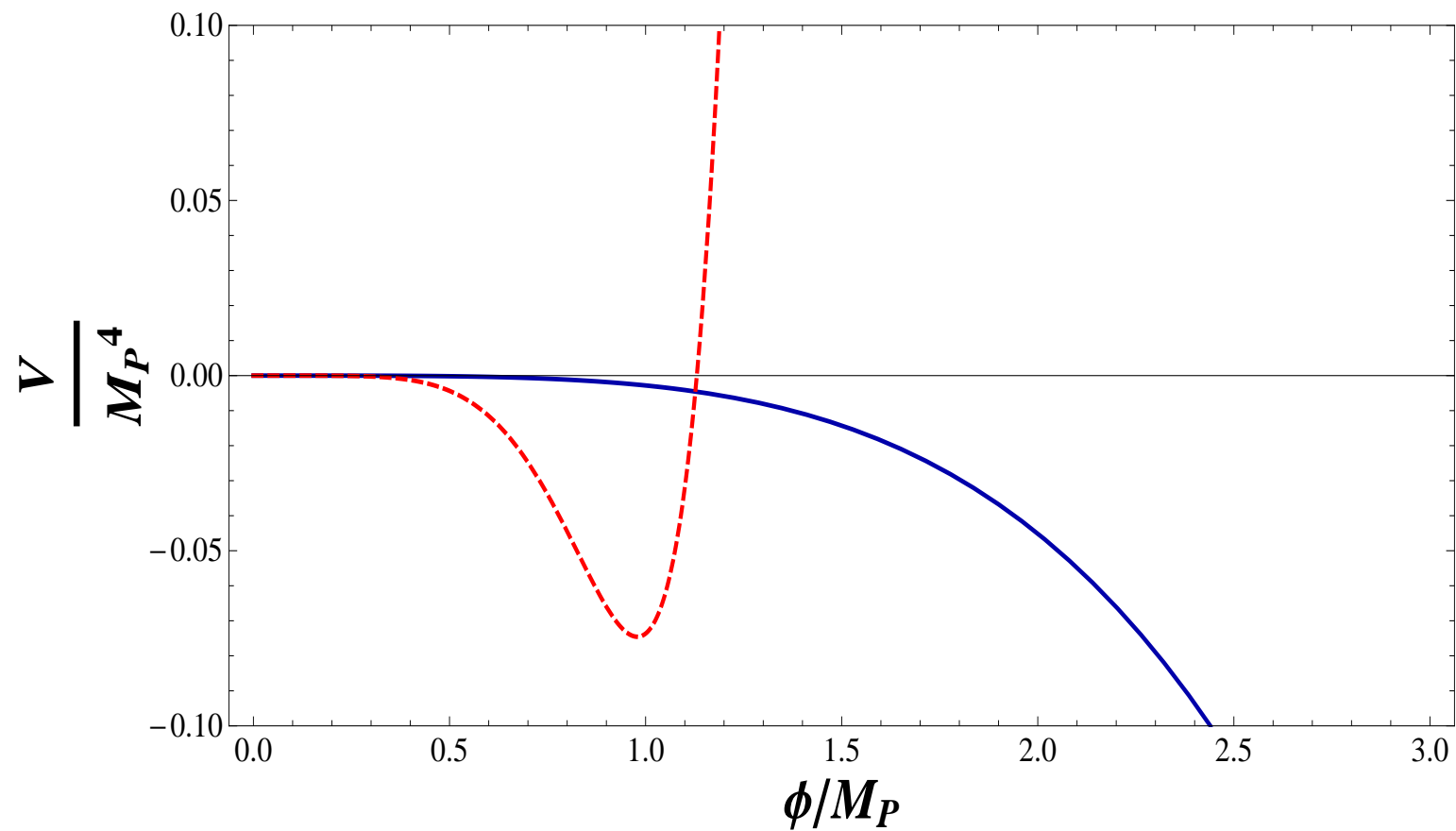
Effective Potential $M_H \sim 126$ $M_t \sim 173$ Log-Log Plot



Blue line : $V_{eff}(\phi)$ no higher order terms

Red line : $V_{eff}^{new}(\phi)$ with $\lambda_6(M_P) = -2$ $\lambda_8(M_P) = 2.1$

Zoom around the Planck scale



Blue line : $V_{eff}(\phi)$ no higher order terms
Red line : $V_{eff}^{new}(\phi)$ with $\lambda_6(M_P) = -2$ $\lambda_8(M_P) = 2.1$

We have a New Potential \Rightarrow we have to consider new bounce configurations for the computation of the tunnelling time

$$V(\phi) = \frac{\lambda}{4}\phi^4 + \frac{\lambda_6}{6}\frac{\phi^6}{M_P^2} + \frac{\lambda_8}{8}\frac{\phi^8}{M_P^4}$$

In the computation of the EW vacuum lifetime :

Competition between

Old Bounce $\phi_b^{(Old)}(r)$ and the New Bounce $\phi_b^{(New)}(r)$

New Physics not included : Only $\phi_b^{(old)}$ (Literature case)

$$\Gamma = \frac{1}{\tau} = \frac{1}{T_U} \left[\frac{S[\phi_b^{(old)}]^2}{4\pi^2} \frac{T_U^4}{R_M^4} e^{-S[\phi_b^{(old)}]} \right] \times [e^{-\Delta S_1}]$$

New Physics included : $\phi_b^{(new)}$ and $\phi_b^{(old)}$ (Our case)

$$\begin{aligned} \Gamma = \Gamma_1 + \Gamma_2 = \frac{1}{\tau_1} + \frac{1}{\tau_2} &= \frac{1}{T_U} \left[\frac{S[\phi_b^{(old)}]^2}{4\pi^2} \frac{T_U^4}{R_M^4} e^{-S[\phi_b^{(old)}]} \right] \times [e^{-\Delta S_1}] \\ &+ \frac{1}{T_U} \left[\frac{S[\phi_b^{(new)}]^2}{4\pi^2} \frac{T_U^4}{R^4} e^{-S[\phi_b^{(new)}]} \right] \times [e^{-\Delta S_2}] \end{aligned}$$

Neglecting for a moment the ΔS (quantum) contributions

Literature : $S[\phi_b^{(old)}] \sim 1833 \Rightarrow \tau \sim 10^{555} T_U$

Our case : $S[\phi_b^{(new)}] \sim 82 \Rightarrow \tau \sim 10^{-208} T_U$

Contribution from $\phi_b^{(old)}$ exponentially suppressed !

New Physics Interactions at the Planck scale do matter !!!

Quantum fluctuations do not change significantly these “classical” results

Literature : Loop contributions to τ

$e^{\Delta S_H}$	2.87185
$e^{\Delta S_t}$	1.20708×10^{-18}
$e^{\Delta S_{gg}}$	1.26746×10^{50}

$$\Rightarrow \quad \tau_{cl} \sim 10^{555} T_U \quad \rightarrow \quad \tau \sim 10^{588} T_U$$

Our case : Loop contributions to τ

$e^{\Delta S_H}$	2.82295×10^{10}
$e^{\Delta S_t}$	8.62404×10^{-5}
$e^{\Delta S_{gg}}$	4.97869×10^9

$$\Rightarrow \quad \tau_{cl} \sim 10^{-208} T_U \quad \rightarrow \quad \tau \sim 10^{-189} T_U$$

How comes that new physics can have such an impact on τ ?

Why the arguments on the suppression of new physics do not apply ?

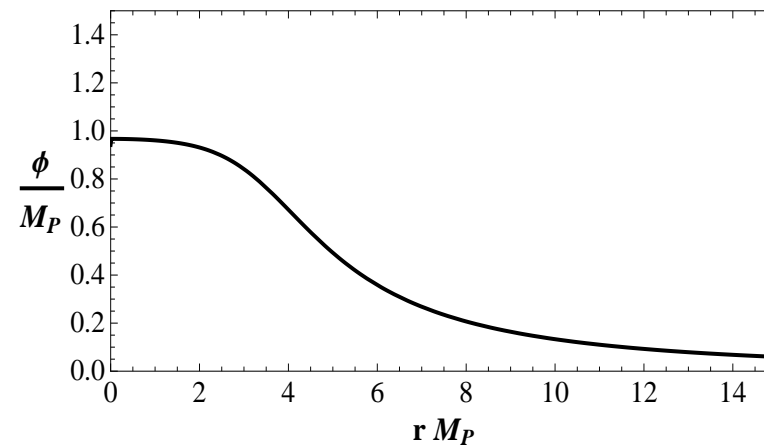
1. **New physics** appears in terms of **higher dimension operators**, and people expected their contribution to be **suppressed** as $(\frac{\Lambda_{inst}}{M_P})^n$

But: **Tunnelling** is a **non-perturbative** phenomenon. We first select the **saddle point**, i.e. compute the **bounce** (**tree level**), and then compute the quantum fluctuations (**loop corrections**) on the top of it.

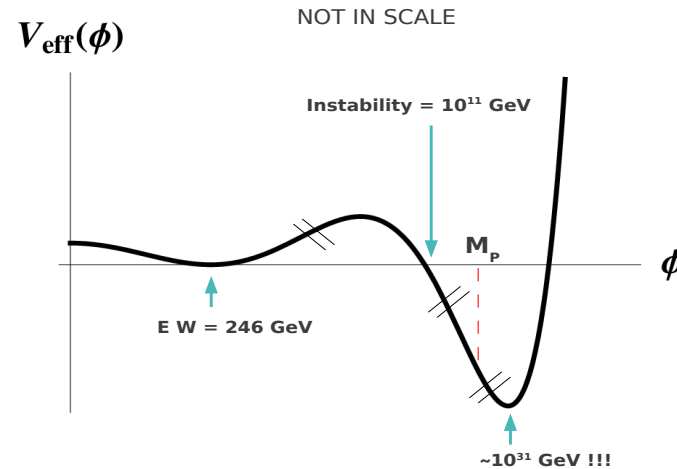
Suppression in terms of **inverse powers of M_P** (**power counting theorem**) concerns the **loop corrections**, not the saddle point (**tree level**).

Remember : $\tau \sim e^{S[\phi_b]}$

New bounce $\phi_b^{(2)}(r)$, New action $S[\phi_b^{(2)}]$, New τ



2. Height of the barrier and turning points...



This is QFT with “very many” dof, not 1 dof QM \Rightarrow the potential is not $V(\phi)$ in figure with 1 dof, but...

$$\mathcal{L} = \frac{1}{2} \partial_\mu \phi \partial^\mu \phi - V(\phi) = \frac{1}{2} \dot{\phi}^2 - \frac{1}{2} (\vec{\nabla} \phi)^2 - V(\phi) = \frac{1}{2} \dot{\phi}(\vec{x}, t)^2 - U(\phi(\vec{x}, t))$$

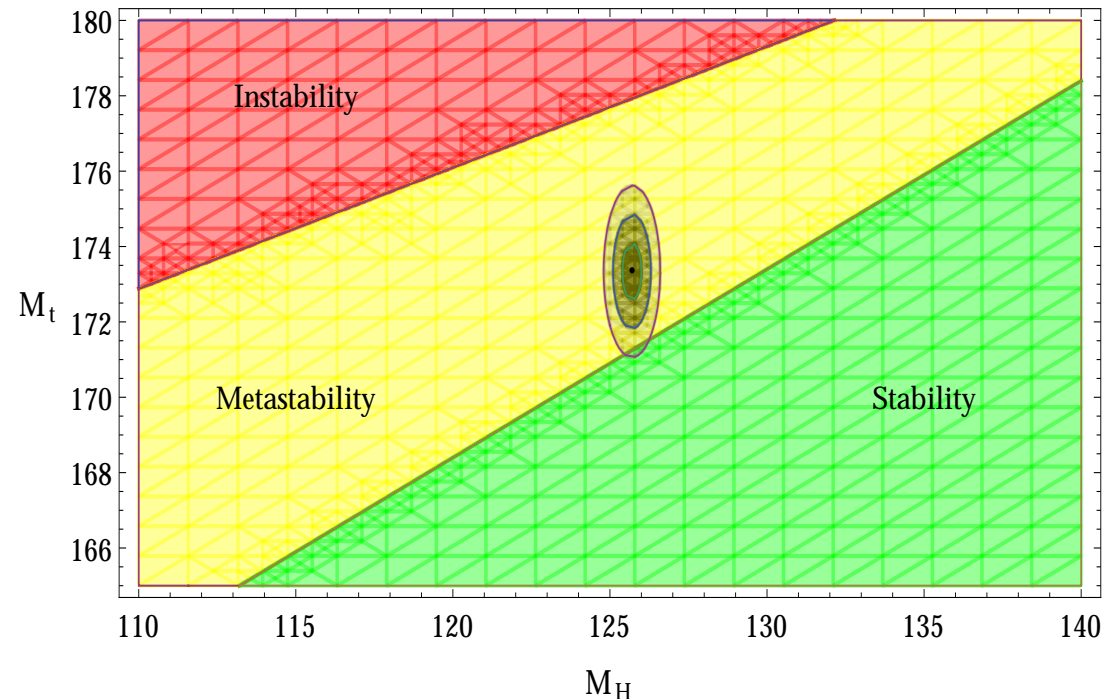
where $U(\phi(\vec{x}, t))$ is : $U(\phi(\vec{x}, t)) = V(\phi(\vec{x}, t)) + \frac{1}{2} (\vec{\nabla} \phi(\vec{x}, t))^2$

Very many dof, not 1 dof... The Potential is : $\sum_{\vec{x}} U(\phi(\vec{x}, t))$

The bounce is **not a constant configuration** ... **Gradients** do matter a lot!

Let us move now to Phase Diagrams...

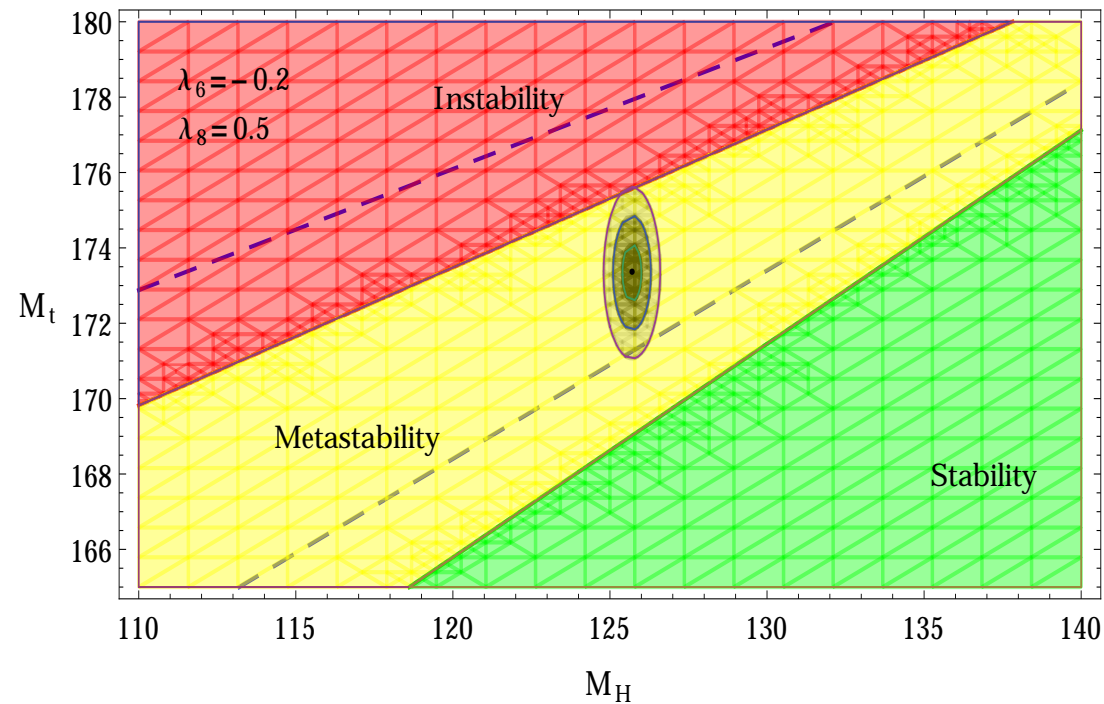
Phase diagram with $\lambda_6 = 0$ and $\lambda_8 = 0$ - Literature case



This is the well known Phase Diagram... Accordingly : (1) For $M_H \sim 125 - 126$ GeV and $M_t \sim 173$ we live in a metastable state ; (2) 3σ close to the stability line (**Criticality**) ; (3) Precision measurements of the top mass should allow to discriminate between stable, metastable, or critical EW vacuum ...

Phase diagram with $\lambda_6 = -0.2$ and $\lambda_8 = 0.5$

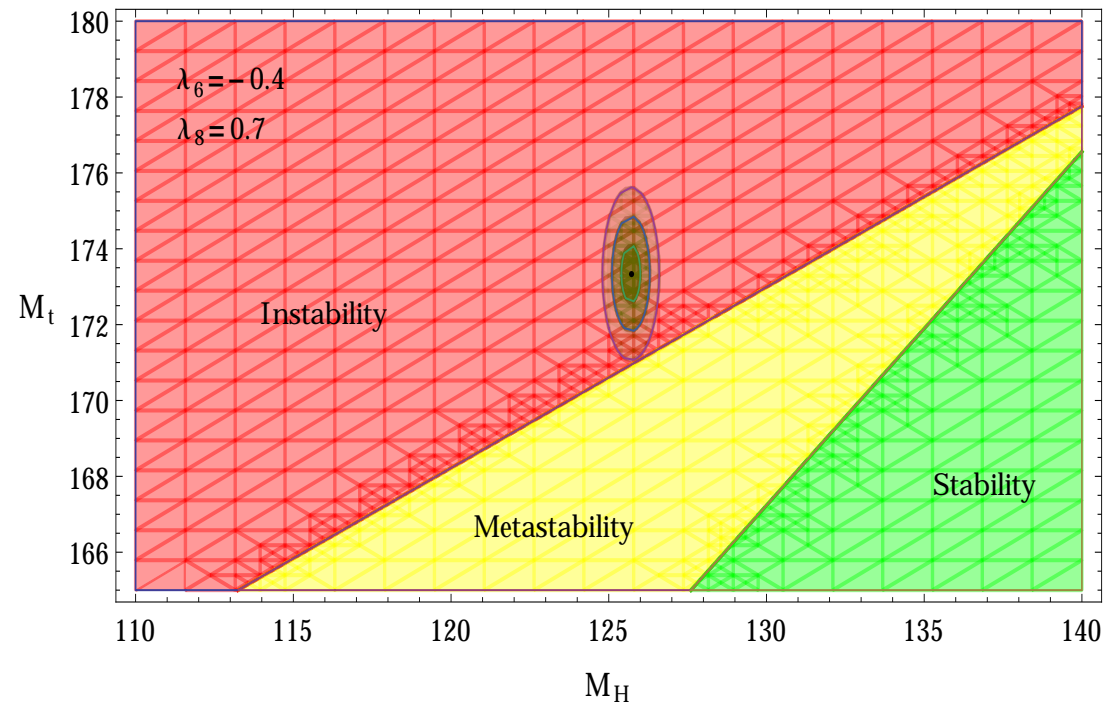
(Please note : Natural values for the coupling constants)



The strips move downwards ... The Experimental Point no longer at 3σ from the stability line !!! ...

Phase diagram with $\lambda_6 = -0.4$ and $\lambda_8 = 0.7$

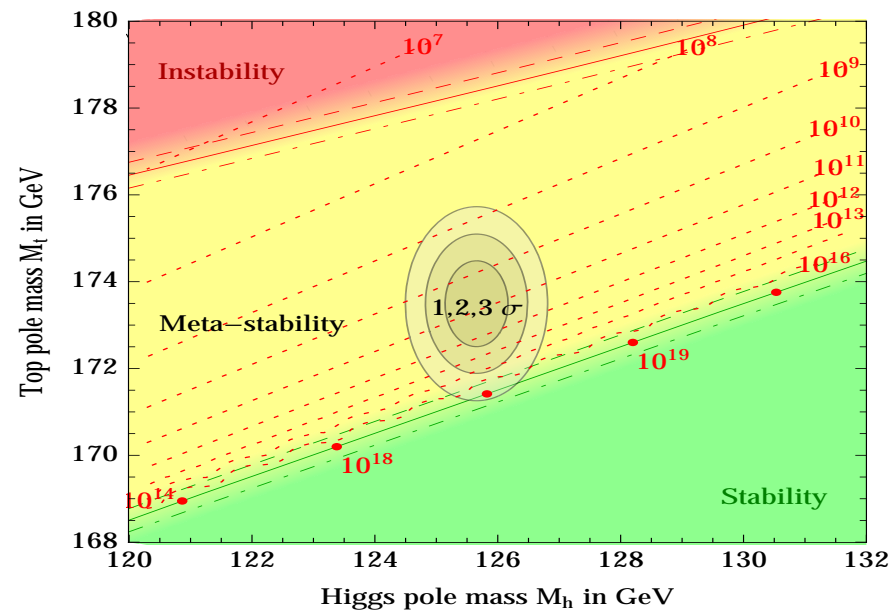
(Please note : Natural values for the coupling constants)



Even worse !

Lessons

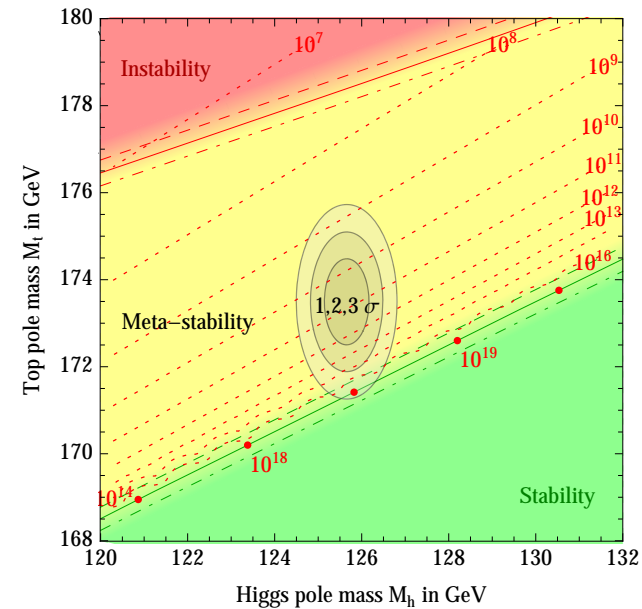
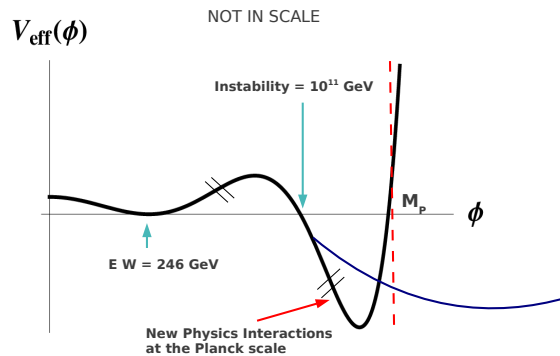
The Phase Diagram



in not Universal
... one out of different possibilities

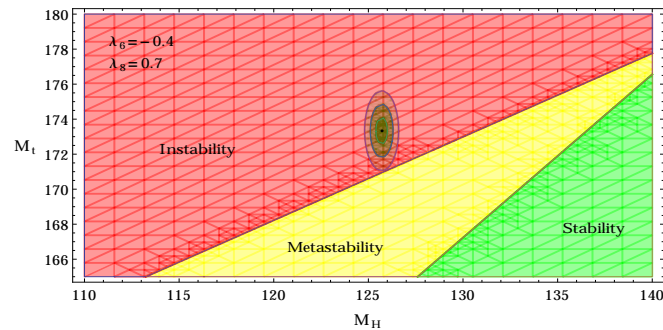
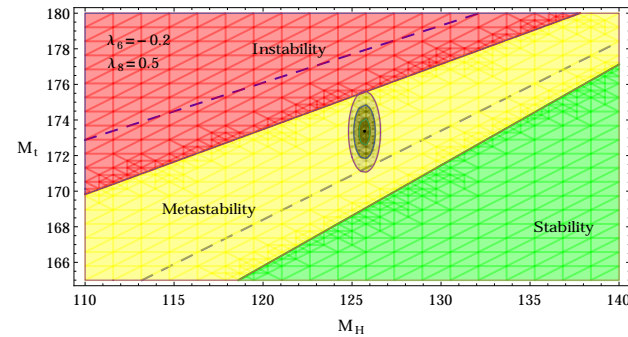
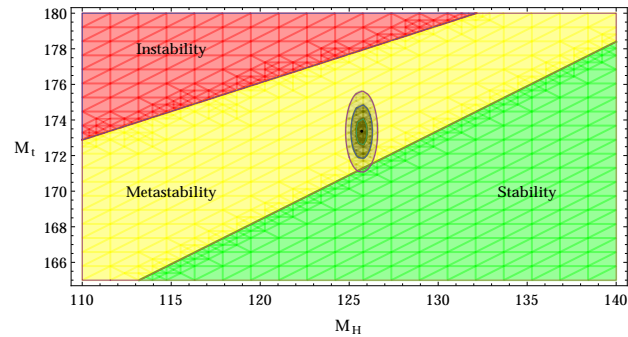
These two statements :

(1) - There should be new physics at the Planck scale that stabilizes the potential



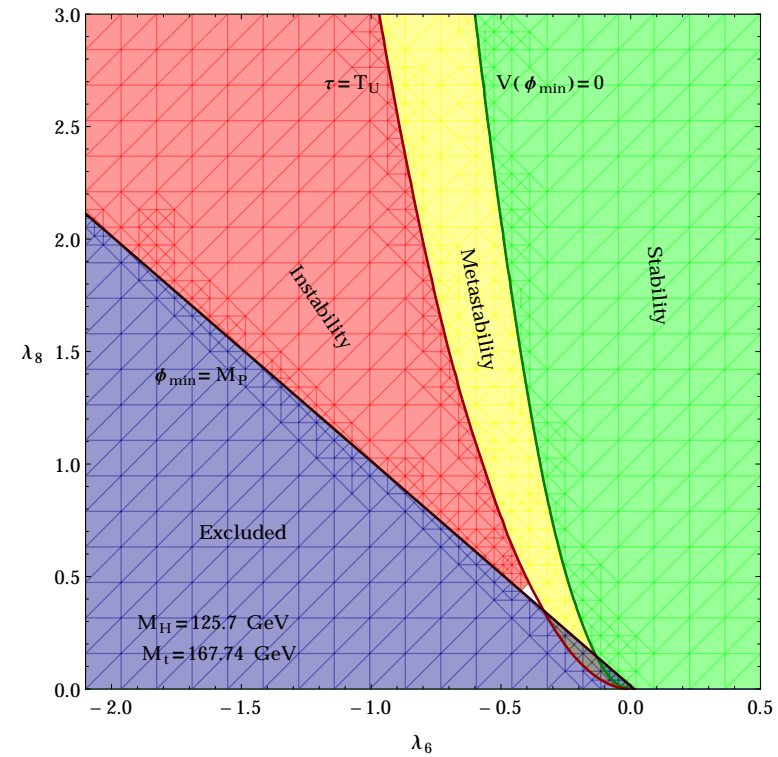
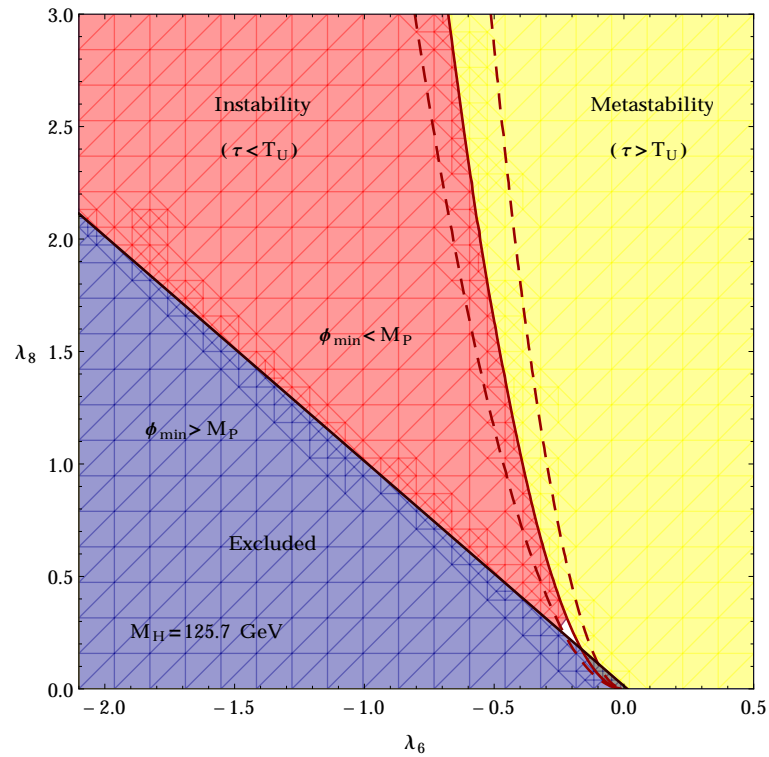
(2) - The stability phase diagram is independent on this new physics

Cannot be true at the same time



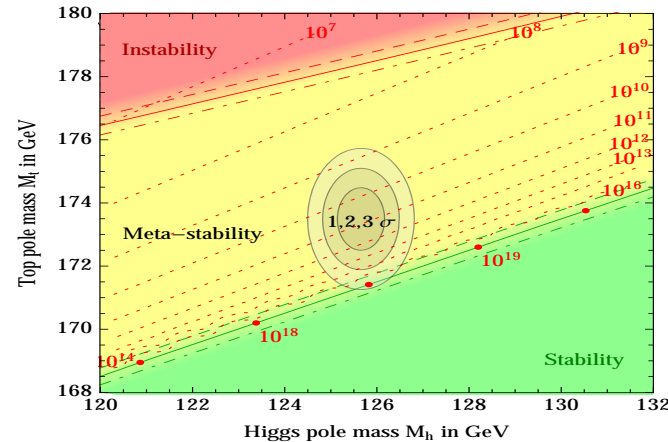
Precision measurements of M_t (and/or M_H) cannot discriminate between **stability, metastability or criticality** ... The knowledge of M_t and M_H alone is not sufficient to decide of the **EW vacuum stability condition**. We need informations on **NEW PHYSICS** in order to asses this question ...

“Precision Measurements of M_t ”



Constraining allowed region in theory space - **BSM “Stability Test”**

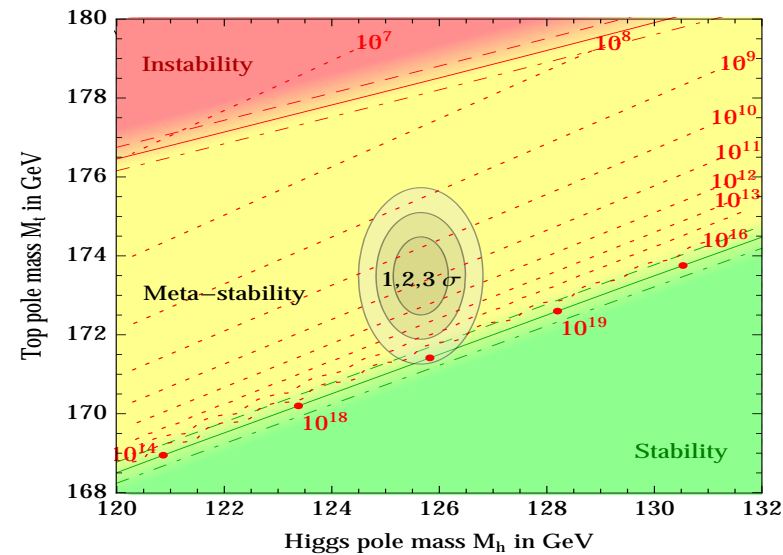
“Near-Criticality”



Somebody considers this near-criticality of the SM vacuum as the most important message so far from experimental data on the Higgs boson

But : This “near-criticality” picture (technically $\lambda(M_P) \sim 0$ and $\beta(\lambda(M_P)) \sim 0$) can be easily screwed up by even small seeds of new physics ... Strong sensitivity to new physics, No Universality.

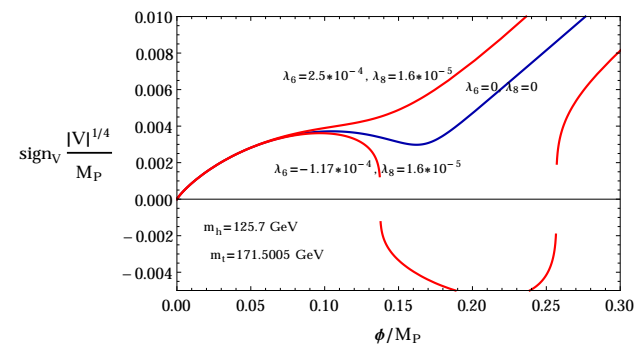
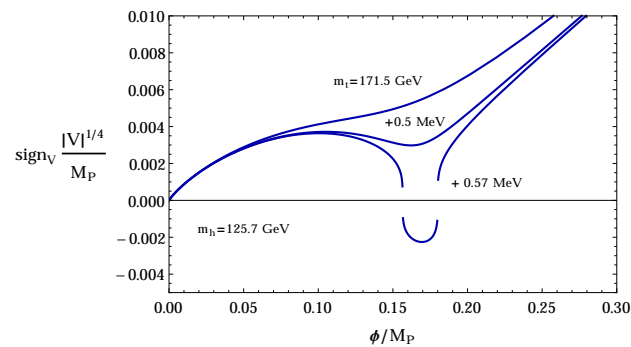
Higgs Inflation “1”



The Higgs inflation scenario of Shaposhnikov - Bezrukov strongly relies on the realization of the criticality picture ($\lambda(M_P) \sim 0$ and $\beta(\lambda(M_P)) \sim 0$). As we have just said, even a little seed of new physics can easily screw up this picture

Higgs Inflation “2” (Masina - Notari)

For a **narrow band of values of the top quark and Higgs boson masses**, the Standard Model Higgs potential develops a shallow local minimum higher than the EW minimum, where primordial inflation could have started



Again : Strong sensitivity to new physics !

Summary and Conclusions

- The **Stability Phase Diagram** of the EW vacuum **strongly depends** on New Physics ...
- **Precision Measurements** of the **Top Mass** will not allow to **discriminate** between **stability, metastability or criticality** of the EW vacuum. Phase Diagram too sensitive to New Physics ...
- **Higgs Inflation ??** ... **Any small seed** of new physics screws up the picture

$$\lambda(M_P) \sim 0 \quad \text{and} \quad \beta(\lambda(M_P)) = \left(\mu \frac{d\lambda(\mu)}{d\mu} \right)_{\mu=M_P} \sim 0$$

- Our results provide a “**BSM stability test**”. A BSM is acceptable if it provides either a **stable** EW vacuum or a **metastable** one, with lifetime larger than the age of the universe (**No** $\tau \ll T_U$!!).
- This analysis can be repeated even if the new physics scale lies **below the Planck scale**, say, for instance, **GUT scale**, or ...