IMPLICATIONS OF M_t (AND M_h) FOR VACUUM STABILITY

Top2015, Ischia
17 Sept. 2015

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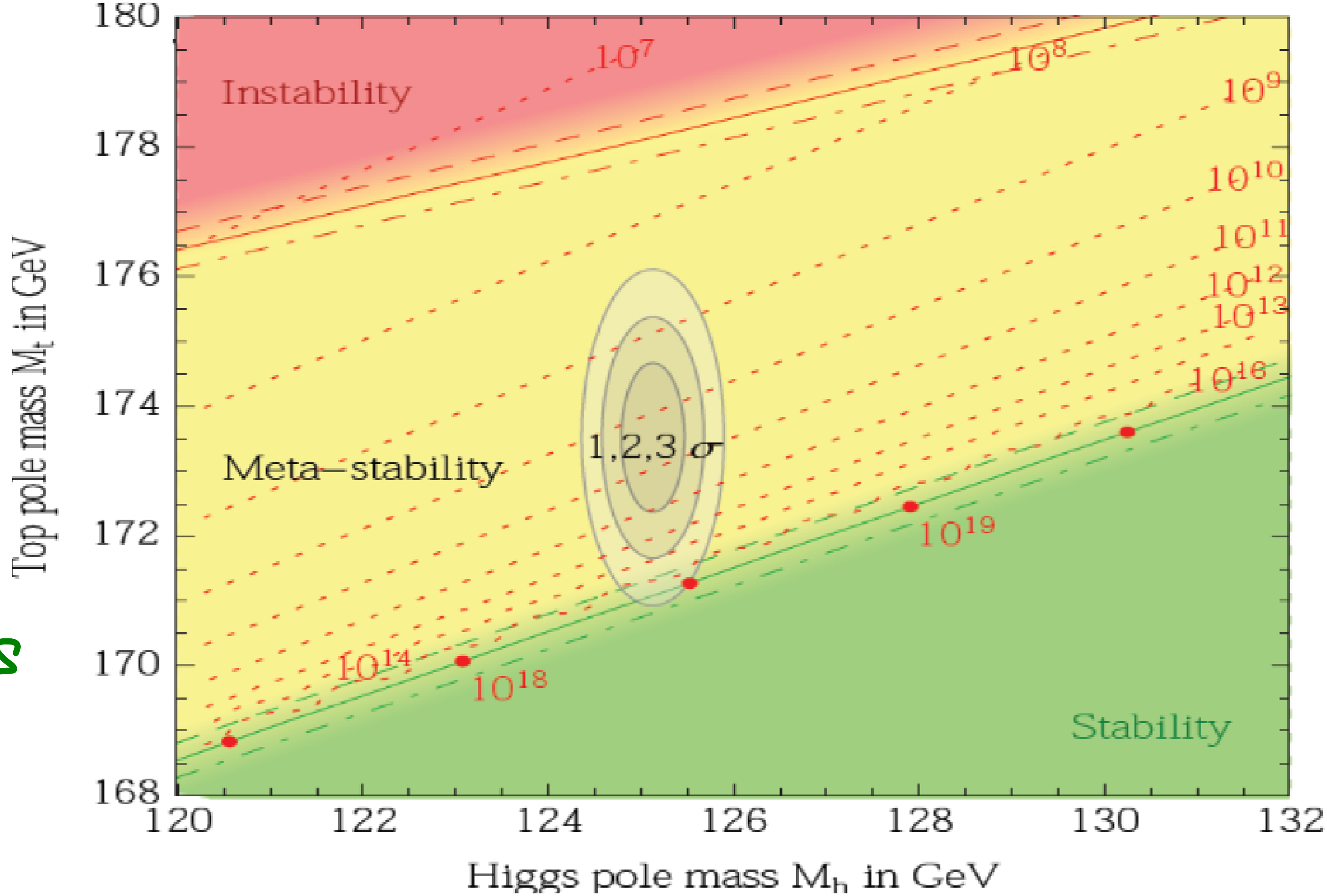
AiM OF THE TALK

Degrassi et al '12, Buttazzo et al.'13

Explain this plot →

- Ingredients
- Assumptions
- Implications



With emphasis on the crucial role of Mtop

(B) SM STATUS AFTER LHC 1

- Higgs discovered, close to SM-like

+

- No trace of BSM so far ⇒ $\Lambda >$ few TeV ?

+

- Holding on to naturalness

$$V = \frac{1}{2} m^2 h^2 + \frac{1}{4} \lambda h^4 \Rightarrow \langle h \rangle^2 \sim \frac{m^2}{\lambda} \sim \text{EW}$$

$m^2 \sim \frac{1}{(4\pi)^2} \Lambda^2$

(B) SM STATUS AFTER LHC 1

- Higgs discovered, close to SM-like

+

- No trace of BSM so far ⇨ $\Lambda >$ few TeV ?

+

- Holding on to naturalness

⇩

$\Lambda \sim$ few TeV

IN THIS TALK

- Higgs discovered, close to SM-like

+

- No trace of BSM so far ⇨ $\Lambda \gg$ few TeV ?

+

- Disregarding naturalness

⇩

$\Lambda \sim M_{Pl}$?

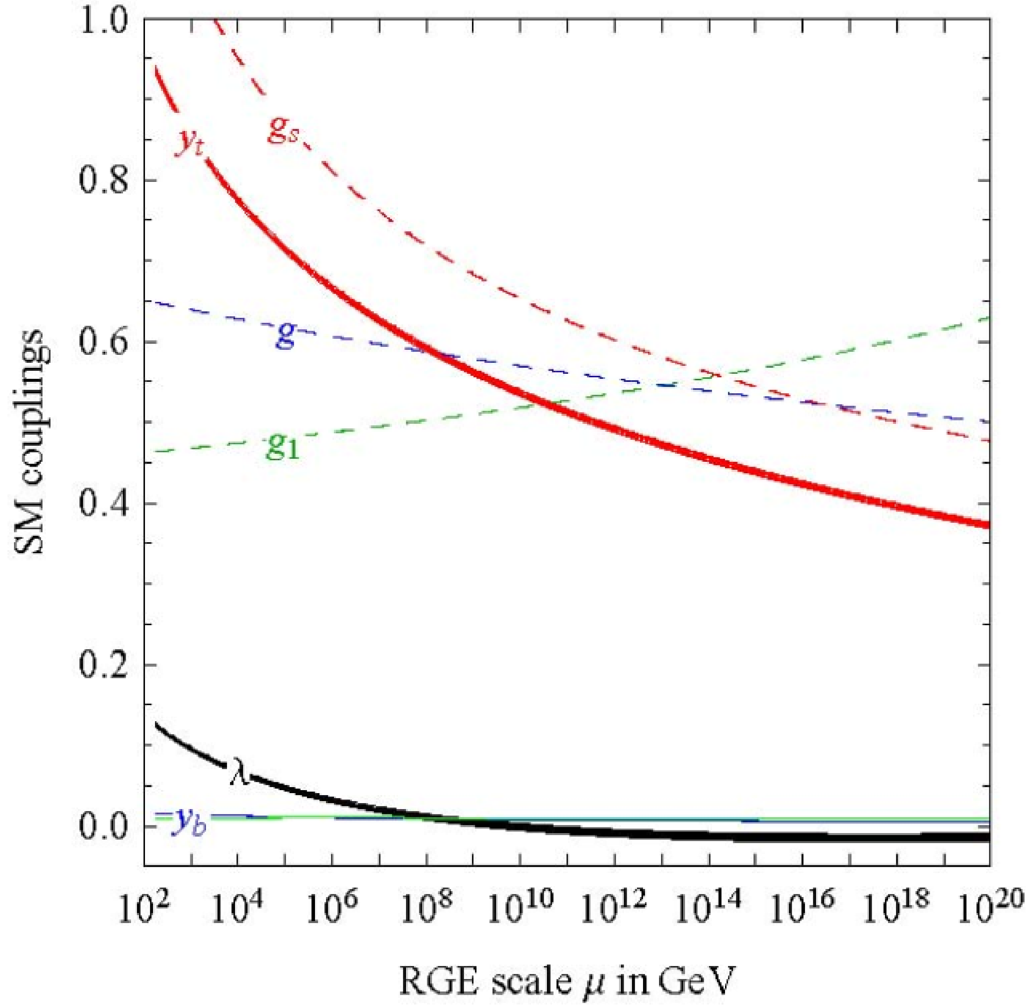
Assume Higgs has SM props. and no BSM Physics

SM EXTRAPOLATION

Can the SM be valid up to M_{Pl}?

All SM parameters known

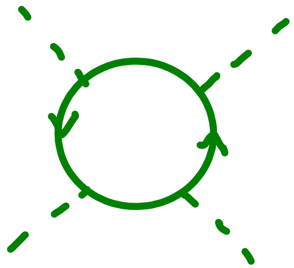
$M_h \Rightarrow \lambda(EW)$

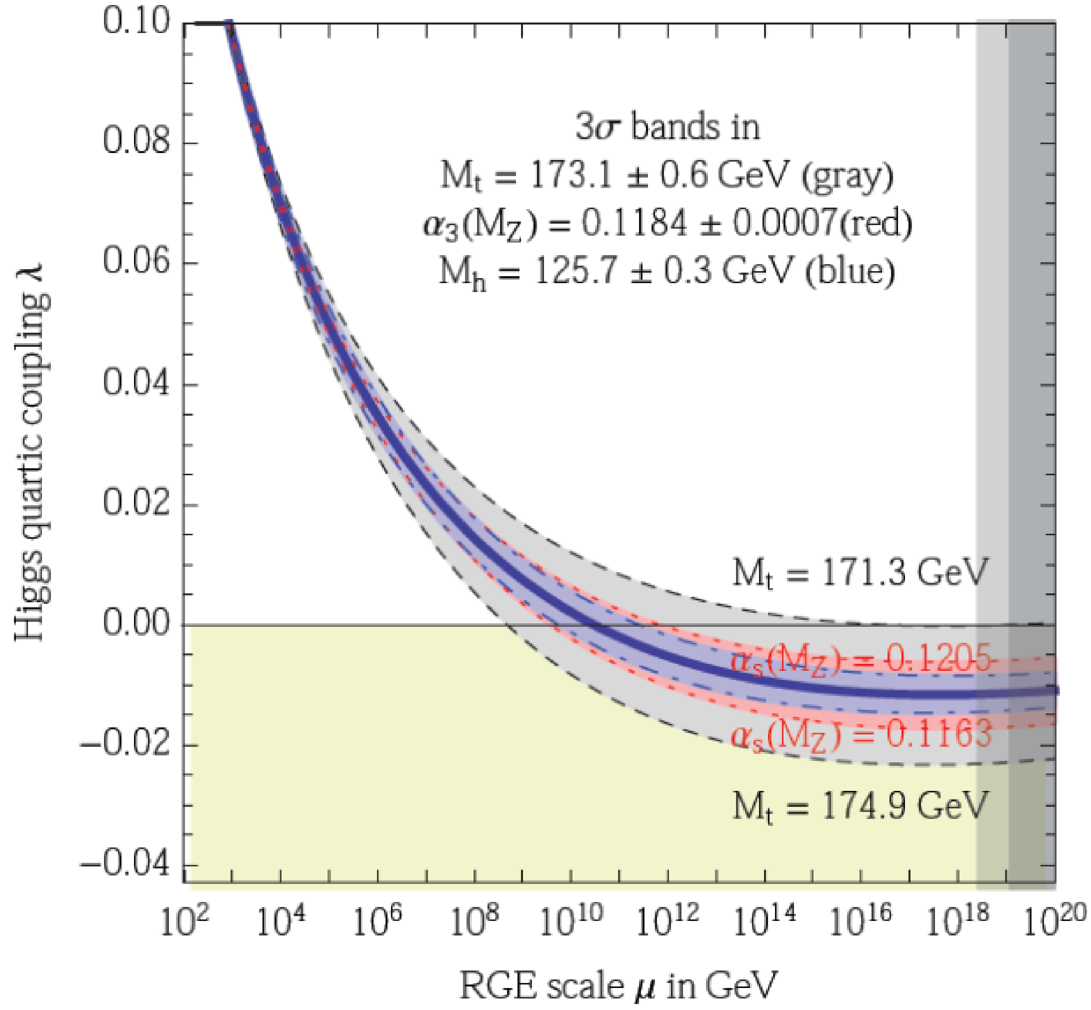


Weakly coupled up to M_{Pl}

VACUUM INSTABILITY

$$\frac{d\lambda}{d\ln\mu} \sim -\frac{h_t^4}{16\pi^2}$$





$\lambda < 0$ at $\Lambda_I \sim 10^{10}$ GeV

⇓

Higgs potential instability

$$V(h \gg M_t) \simeq \frac{1}{4}\lambda(\mu \simeq h)\, h^4$$

Buttazzo et al '13

VACUUM INSTABILITY

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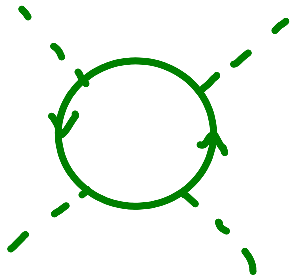

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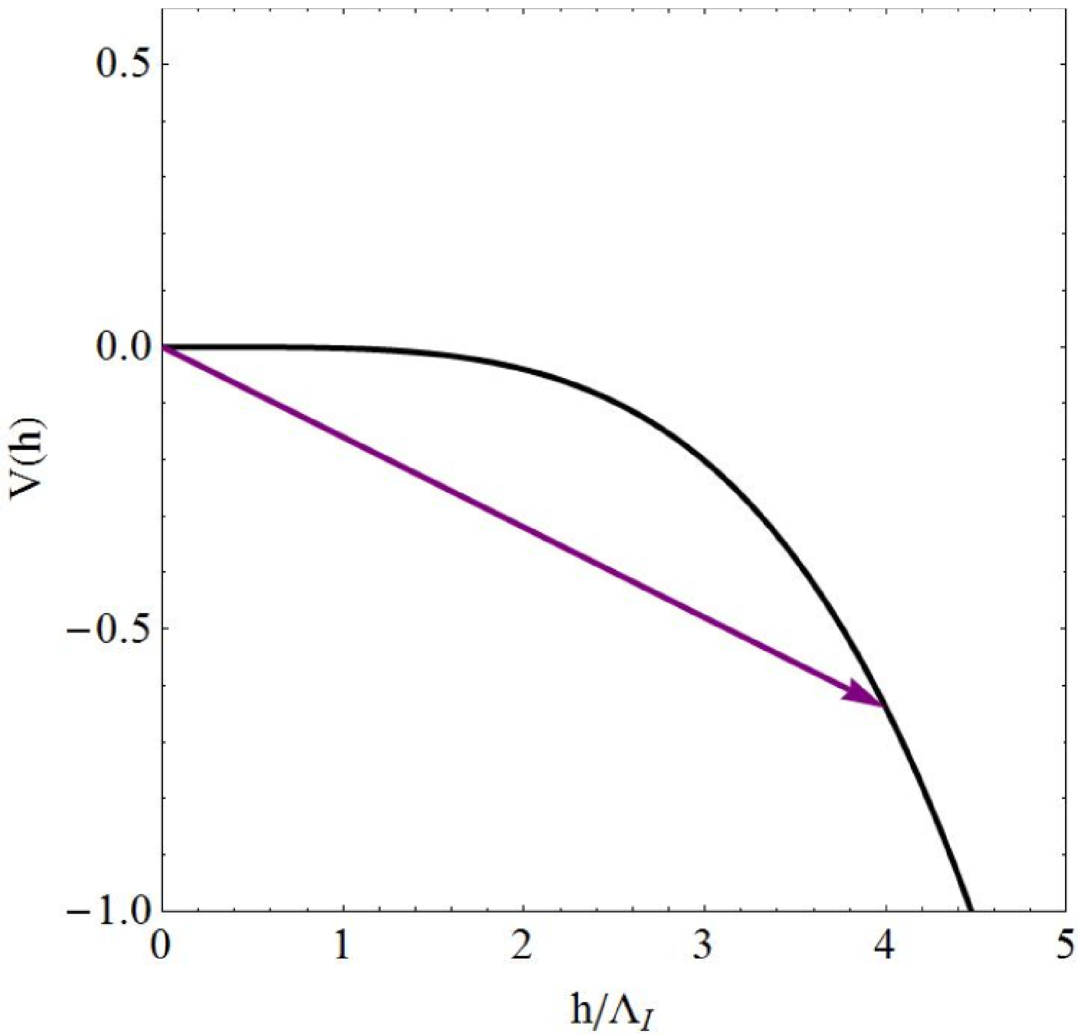

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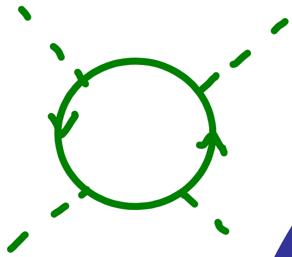

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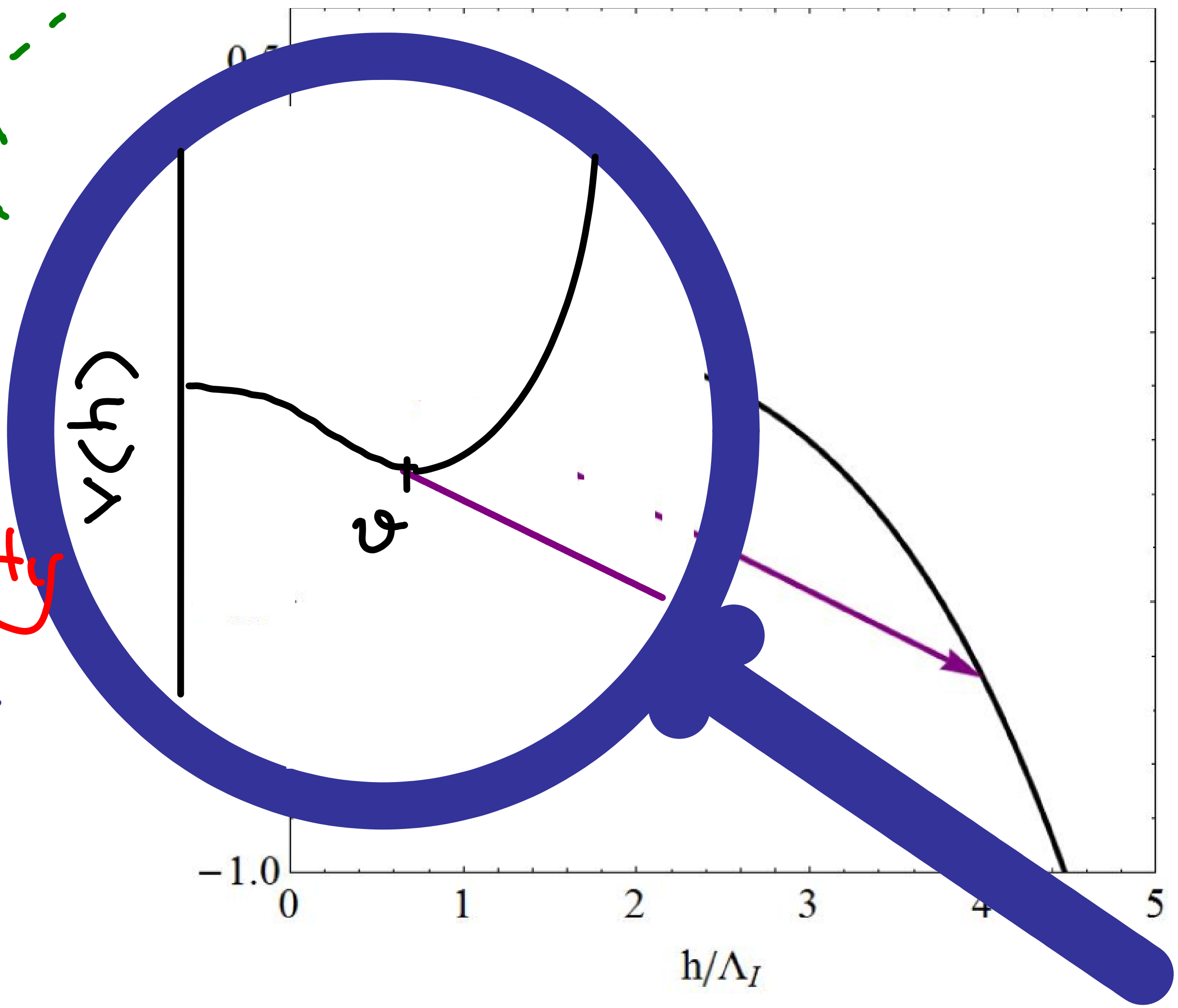
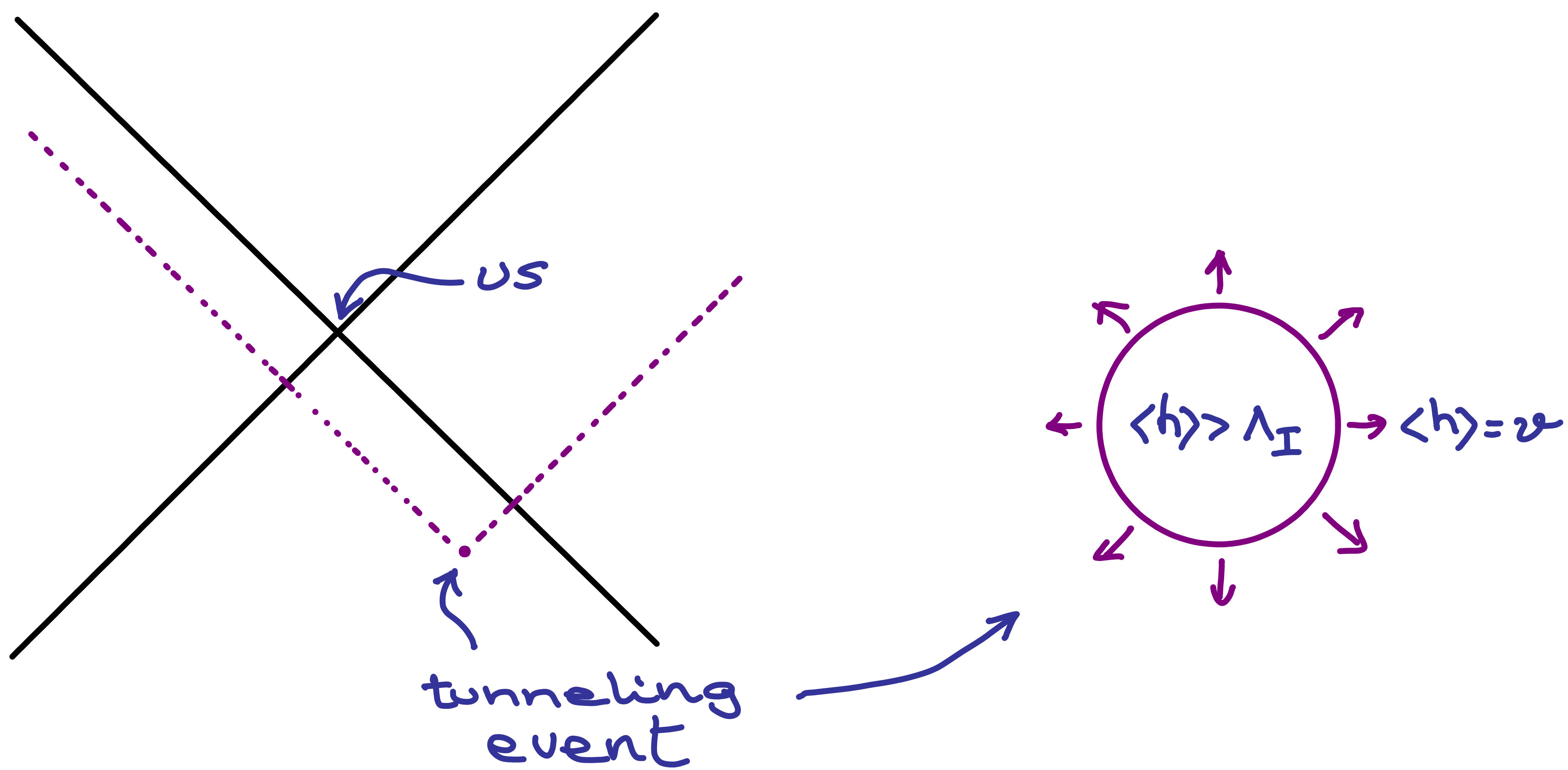


LIFE IN A METASTABLE VACUUM

$$p = \text{Decay prob.} = \frac{\text{Decay rate}}{\Delta t \cdot \Delta V}\, \tau_U^4 \quad \text{with} \quad \tau_U^4 \sim \left(e^{140}/M_{Pl}\right)^4$$



LIFE IN A METASTABLE VACUUM

$$p = \text{Decay prob.} = \underbrace{\frac{\text{Decay rate}}{\Delta t \cdot \Delta V}}_{h^4 e^{-S_4}} \tau_U^4 \quad \text{with} \quad \tau_U^4 \sim \left(e^{140}/M_{Pl}\right)^4$$

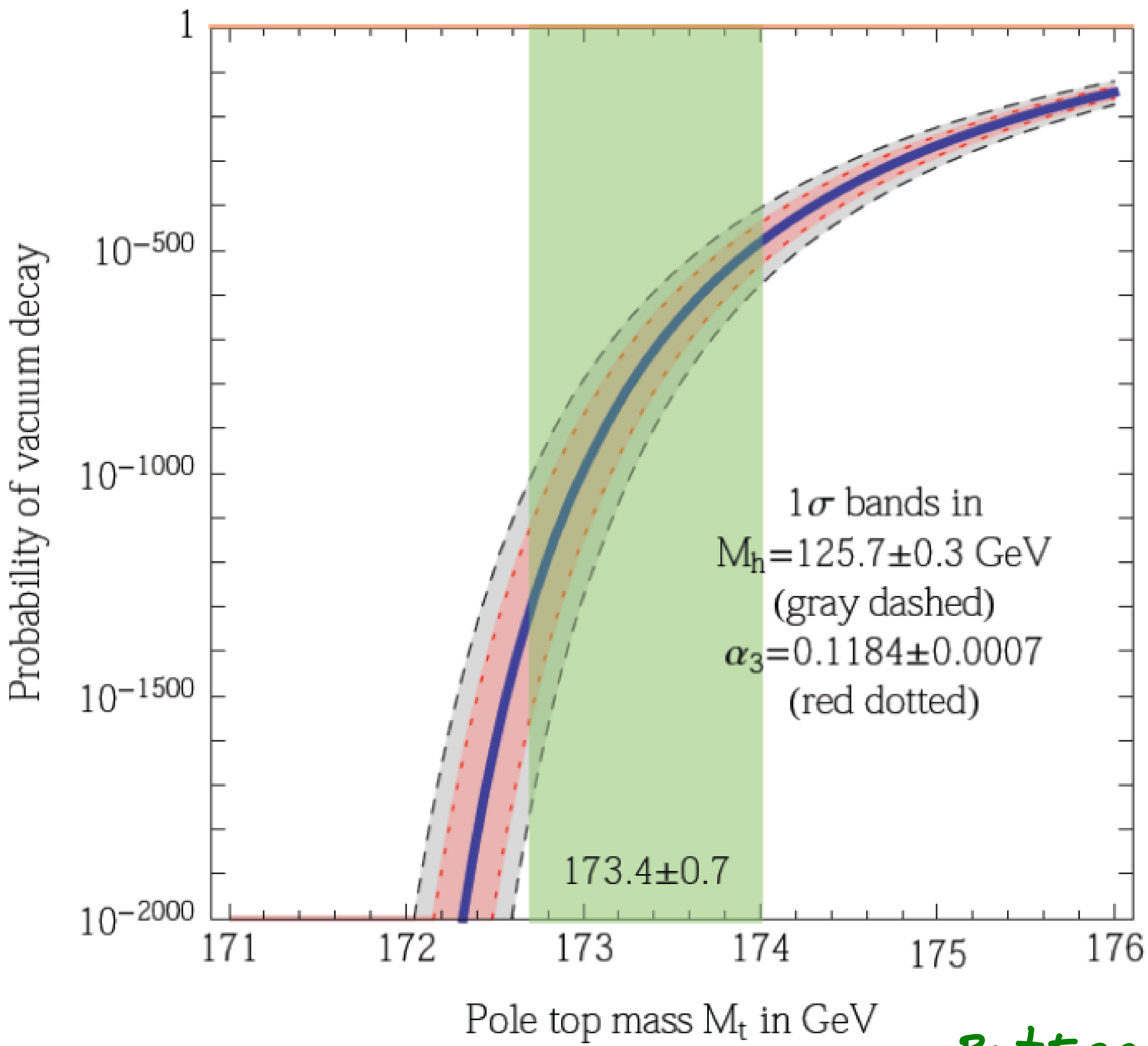
$$h^4 e^{-S_4} \sim h^4 \exp\left(-\frac{8\pi^2}{3|\lambda(h)|}\right) \sim h^4 \exp\left[-\frac{1700}{|\lambda|/0.015}\right]$$

(Isidori, Ridolfi, Strumia '01)

easily wins over τ_U^4

$p \lll 1$: Lifetime of EW vacuum much longer than τ_U

PROBABILITY OF VACUUM DECAY



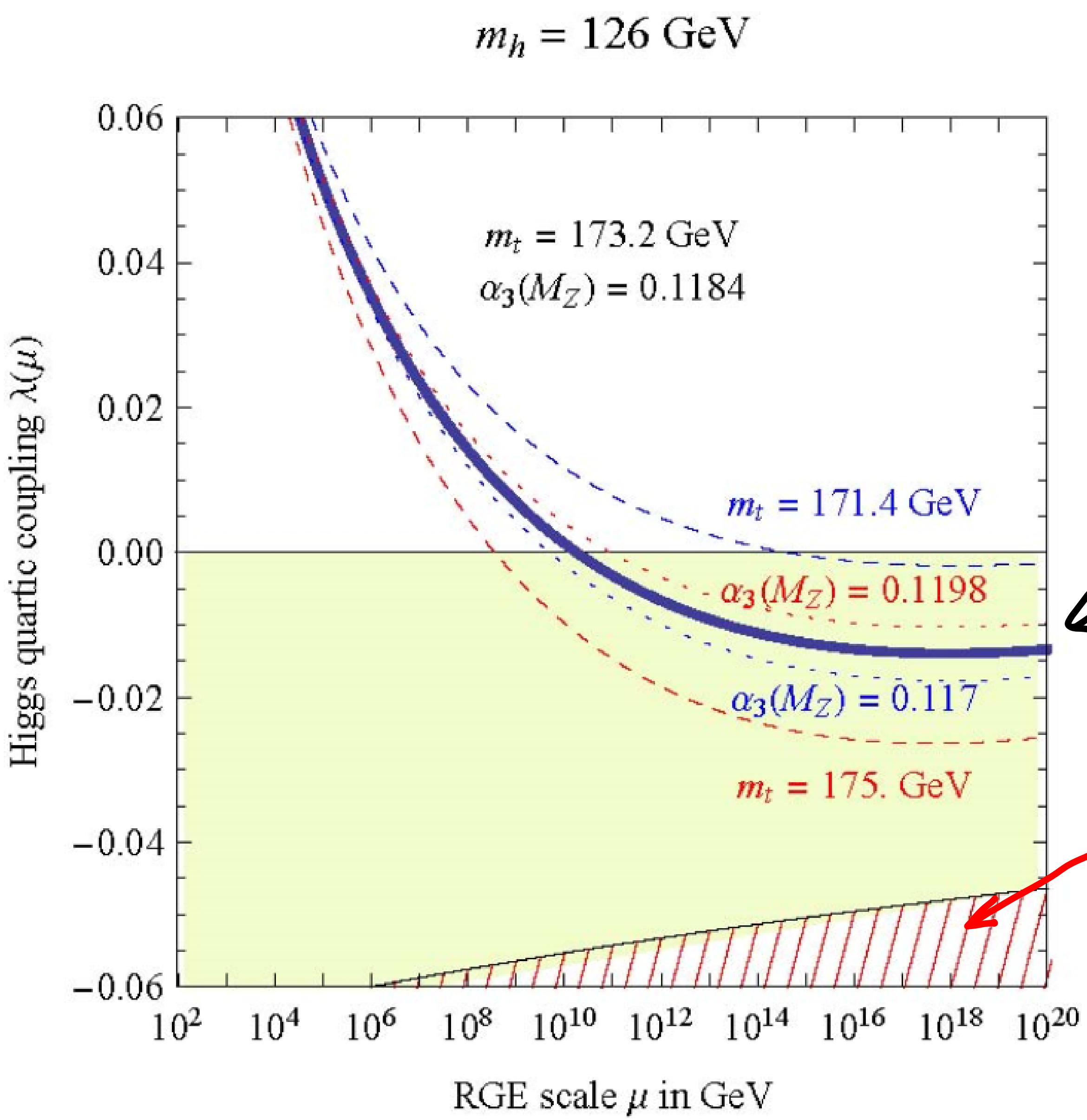
Buttazzo et al '13

PROBABILITY OF VACUUM DECAY

Q: Is BSM below M_{Pl} required to cure the metastability of the EW vacuum?

A: No!

LIFE IN A METASTABLE VACUUM

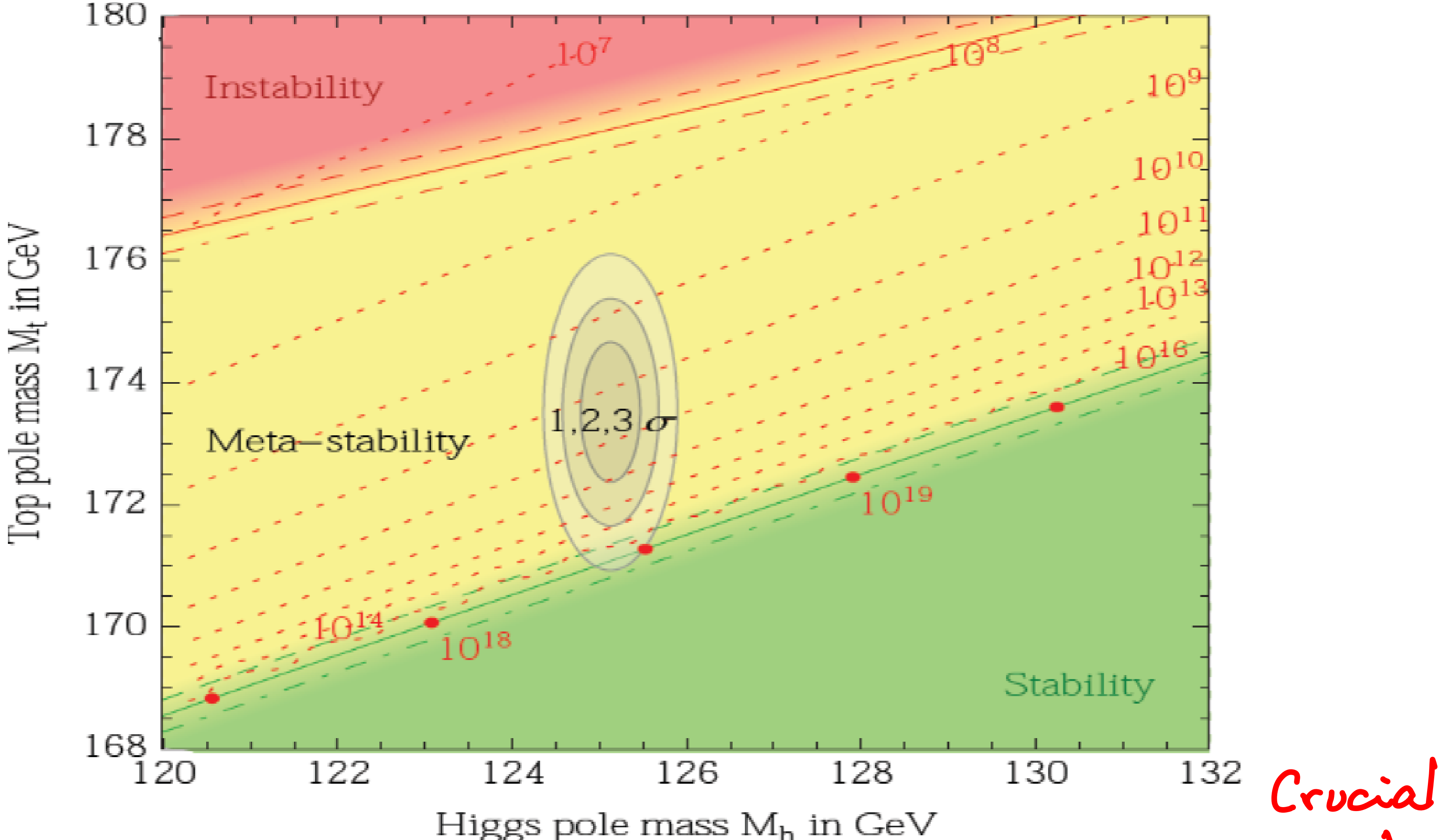


Lifetime $\propto \exp \frac{1}{|\lambda|}$

$\gg$ age of Universe

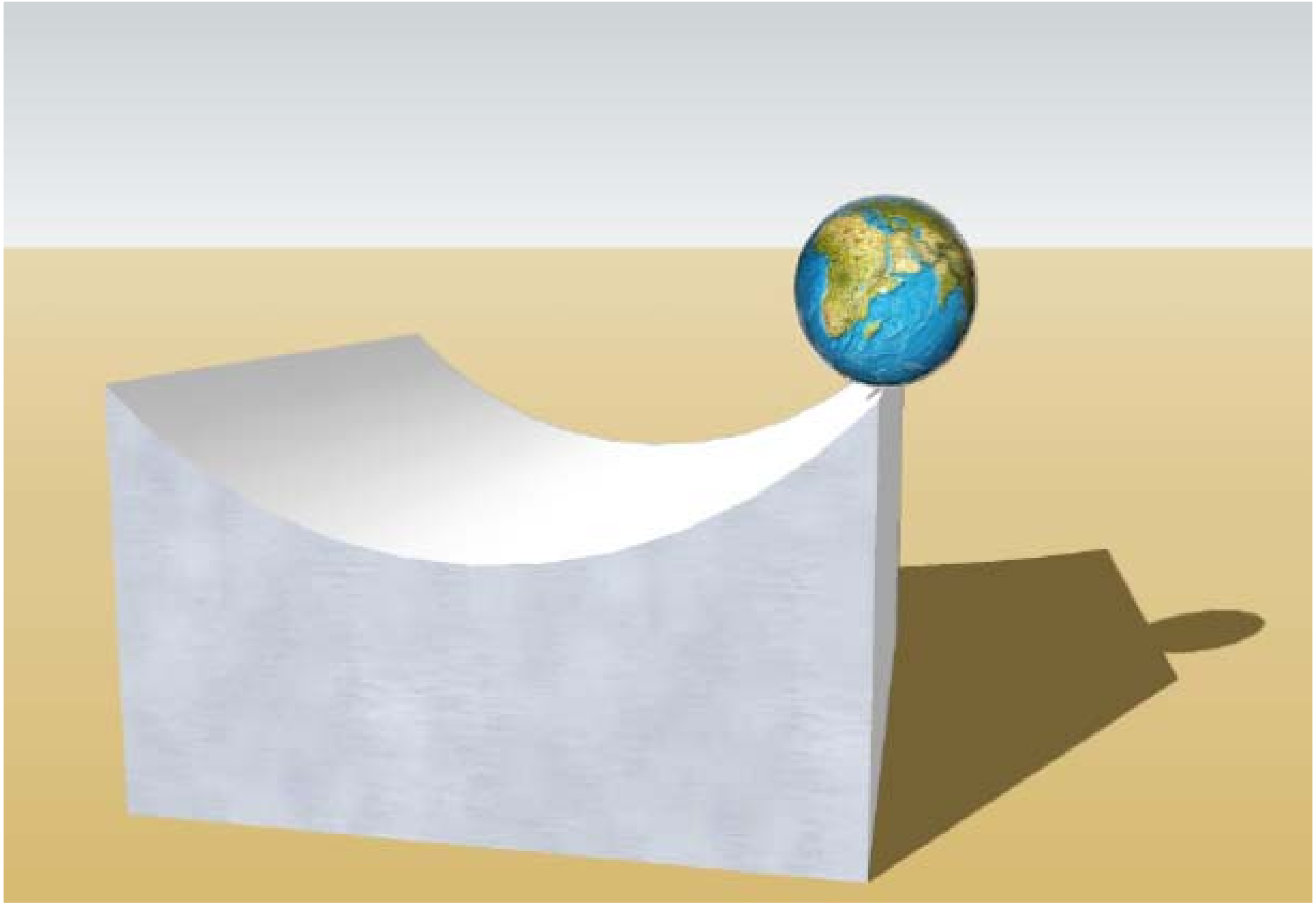
$P > 1$
Unstable vacuum
($M_h \downarrow$)

LIVING AT THE EDGE



$M_h = 125.13 \pm 0.23$ GeV $\quad M_t = 173.34 \pm 0.76$ GeV

LIVING AT THE EDGE



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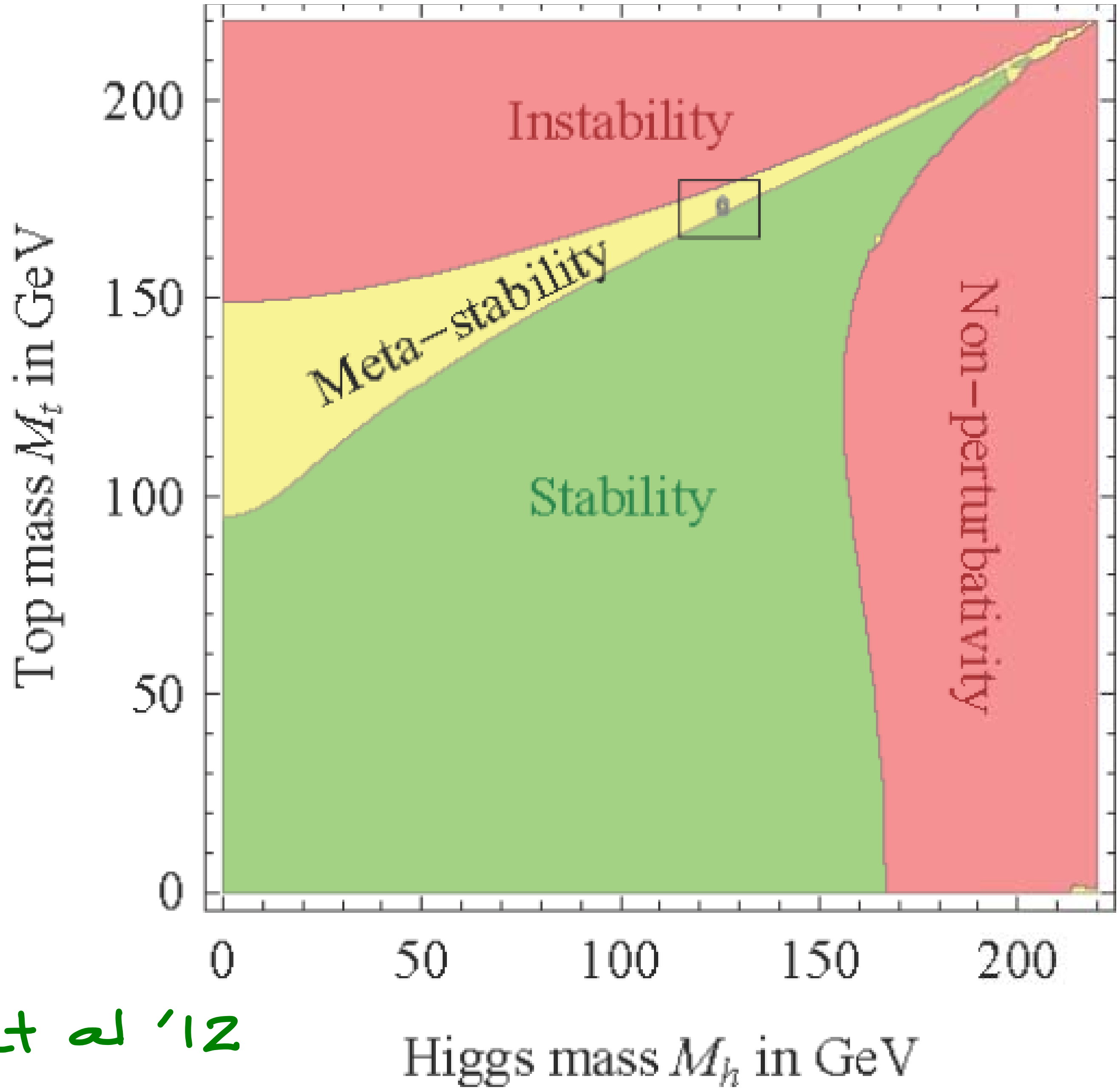
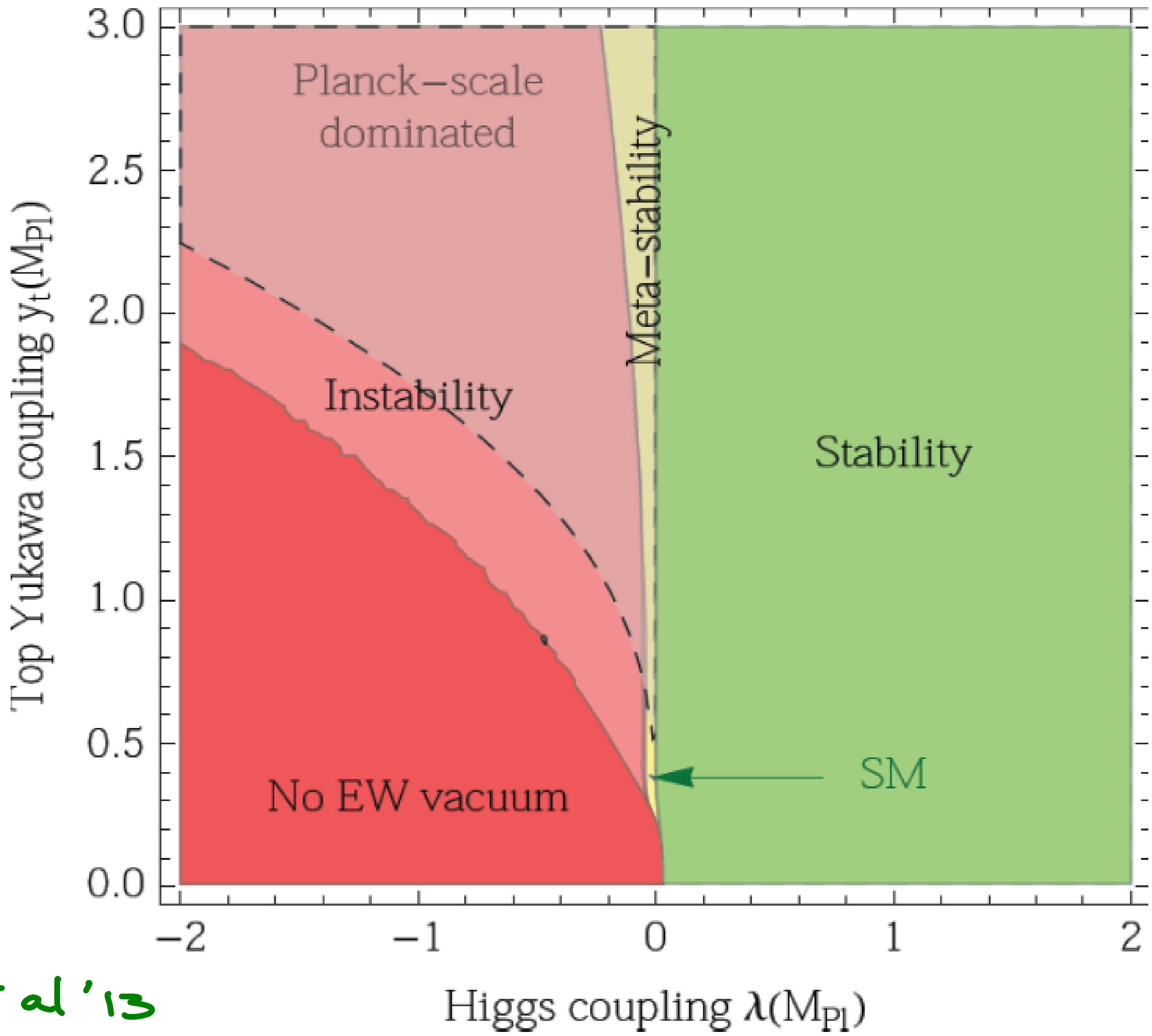


Degrassi et al '12

LIVING AT THE EDGE



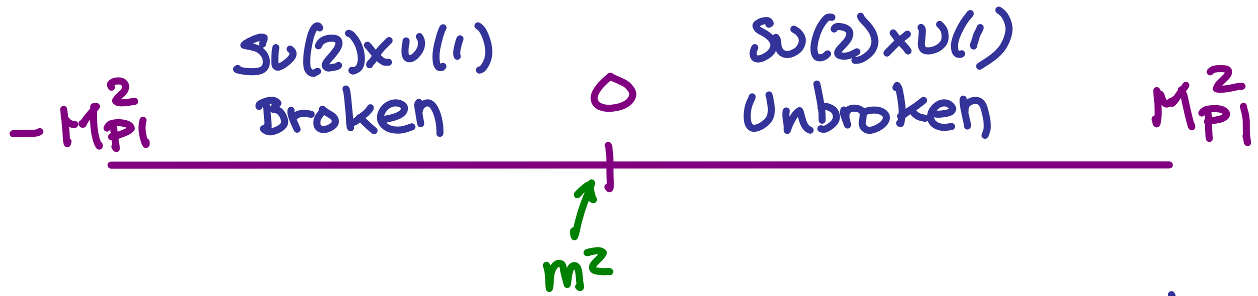
Buttazzo et al '13

NEW KNOWLEDGE BRINGS NEW QUESTIONS

- ★ Why do we live near the critical boundary for stability?

$$\lambda(M_{Pl}) \simeq 0$$

- ★ Is this related to our living near the phase boundary $m^2/M_{Pl}^2 \simeq 0$?



- ★ Is the EW scale determined by Planck scale physics?
- ★ Or is this just a coincidence? BSM...

BSM & STABILITY

Even without naturalness, BSM must exist...

- Neutrino masses
- Matter-antimatter asymmetry
- Dark Matter
- Dark Energy

BSM & STABILITY

Even without naturalness, BSM must exist...

Its impact on the Higgs instability can be

IRRELEVANT

MAKE iT WORSE

CURE iT

BSM & STABILITY

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Example

IRRELEVANT

See-saw neutrinos

MAKE IT WORSE

CURE IT

BSM & STABILITY

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	Example
IRRELEVANT	See-saw neutrinos
MAKE IT WORSE	See-saw neutrinos
CURE IT	

BSM & STABILITY

Even without naturalness, BSM must exist...

Its impact on the Higgs instability can be

	Example
IRRELEVANT	See-saw neutrinos
MAKE IT WORSE	See-saw neutrinos
CURE IT	See-saw neutrinos (& SUSY!)

BSM & STABILITY

Even without naturalness, BSM must exist...

Its impact on the Higgs instability can be

Example

IRRELEVANT — See-saw neutrinos $M_R \lesssim 10^{13}$ GeV

MAKE IT WORSE — See-saw neutrinos $M_R \gtrsim 10^{13}$ GeV

CURE IT — See-saw neutrinos $M_R \sim \langle S \rangle$ & $\lambda_{HS} |H|^2 |S|^2$

Lebedev '12, Elias-Miro et al. '12

BSM IMPLICATIONS

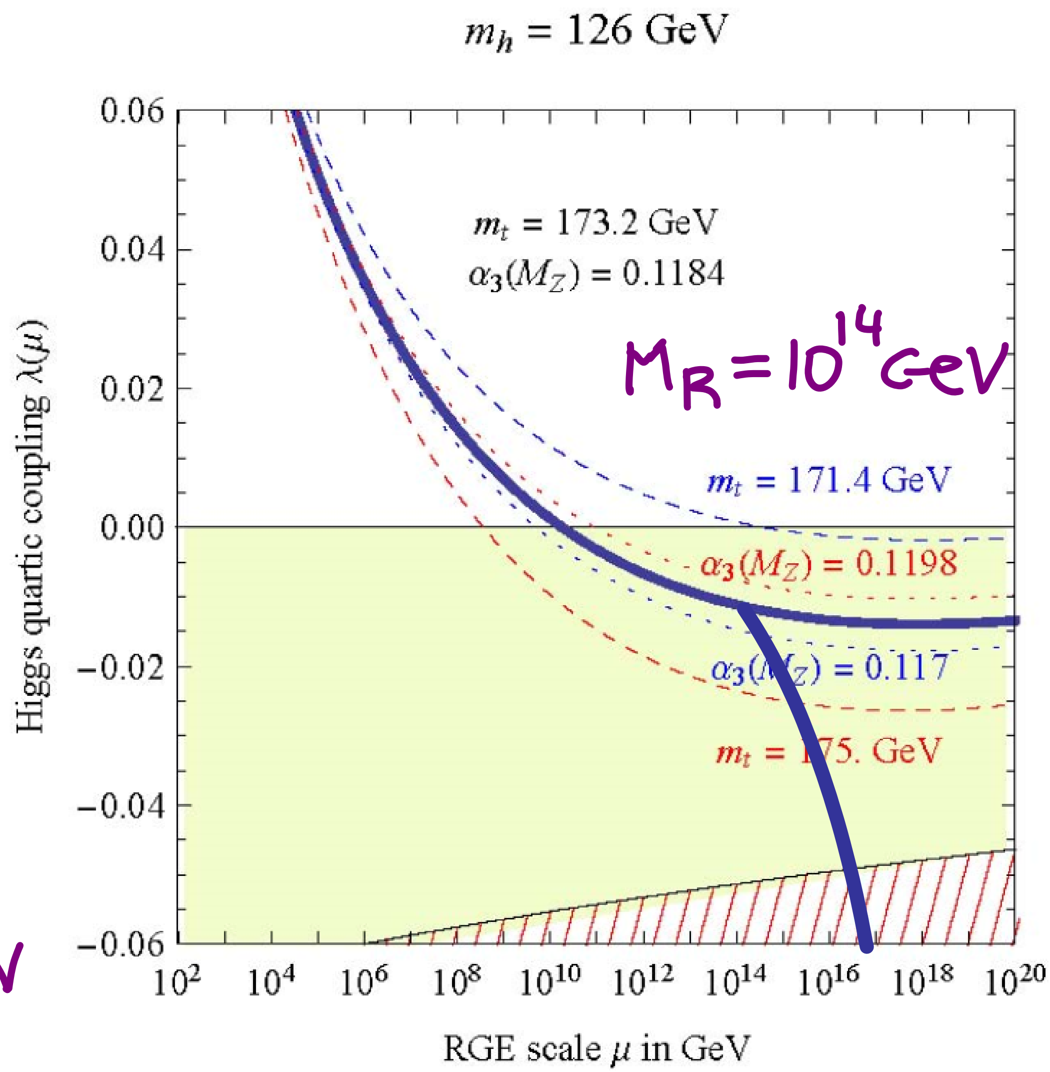
- See-saw neutrinos: Impact on $\beta_\lambda \supset -y_\nu^4/(16\pi^2)$ *

$m_\nu \sim \frac{y_\nu^2 v^2}{M_R}$

$M_R \uparrow \Rightarrow y_\nu \uparrow$

Adds to the top destabilizing effect

Important for $M_R \gtrsim 10^{13-14}$ GeV

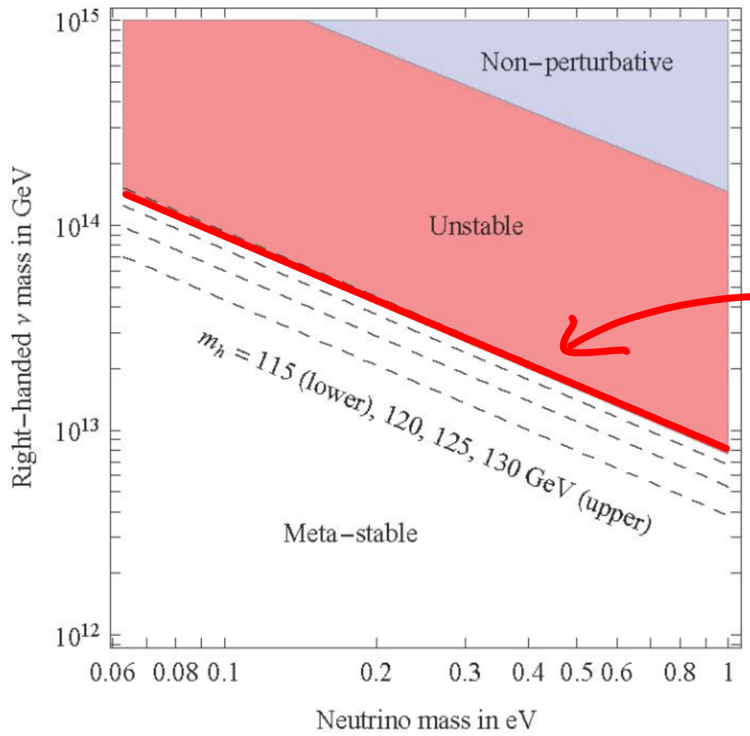


Elias-Miro et al. '11

BSM IMPLICATIONS

- See-saw neutrinos: Bound on M_{ν_R}

M_R



$M_h = 125$ GeV

m_ν

Elias-Miro et al. '11

Useful to bound additional sources of instability.

PLANCKIAN EFFECTS ?

Analysis relies on SM as effective QFT valid below

$$M_{Pl} \simeq 1.2 \times 10^{19}\,\mathrm{GeV}$$

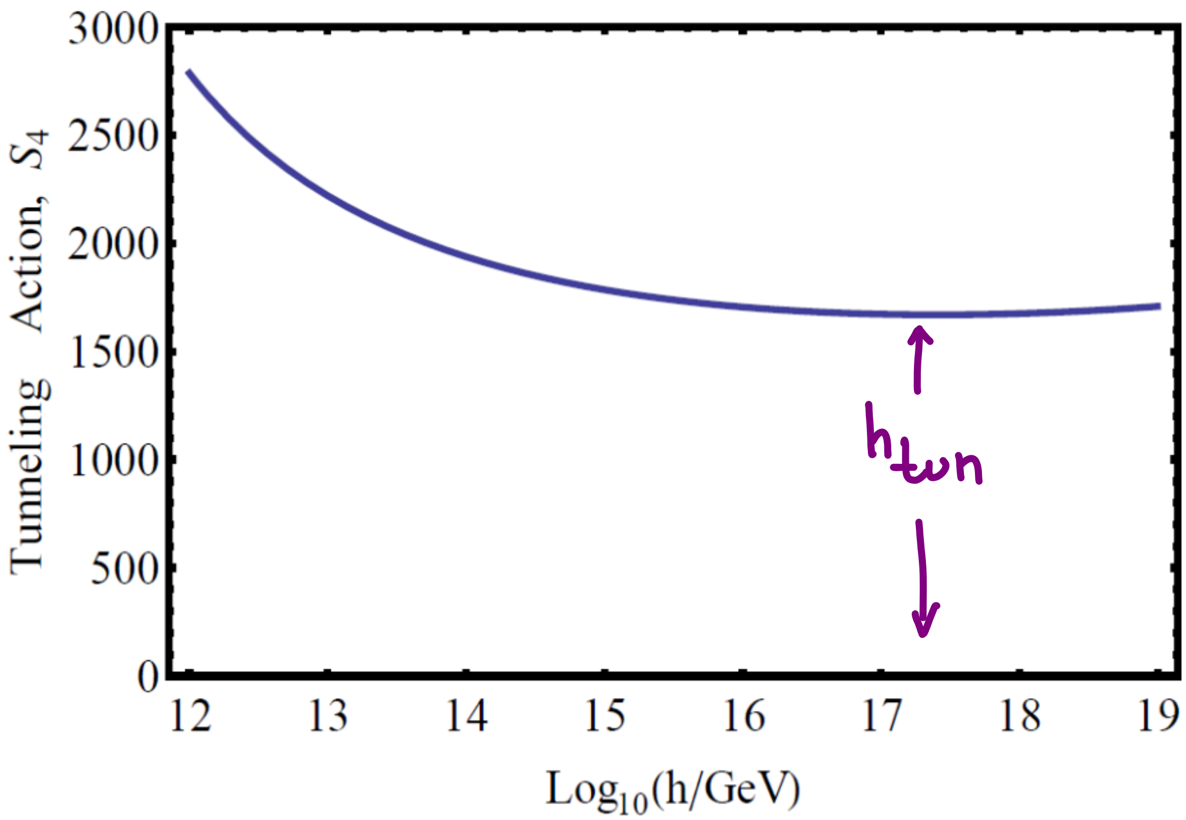
Field values or energy densities never become $\sim M_{Pl}^{(4)}$

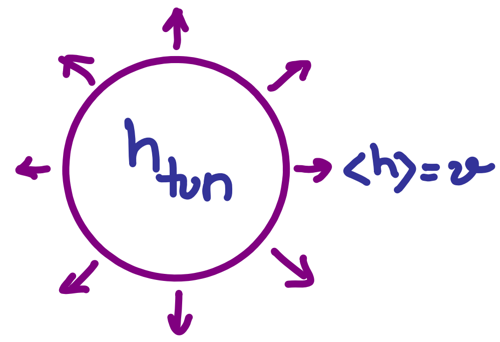
TUNNELING BUBBLE

Remember: tunneling action $S_4 \simeq \frac{8\pi^2}{3|\lambda(h)|}$

⇨ Tunneling dominated by field value h_{tun} where $|\lambda(h)|$ maximal

Arnold '89



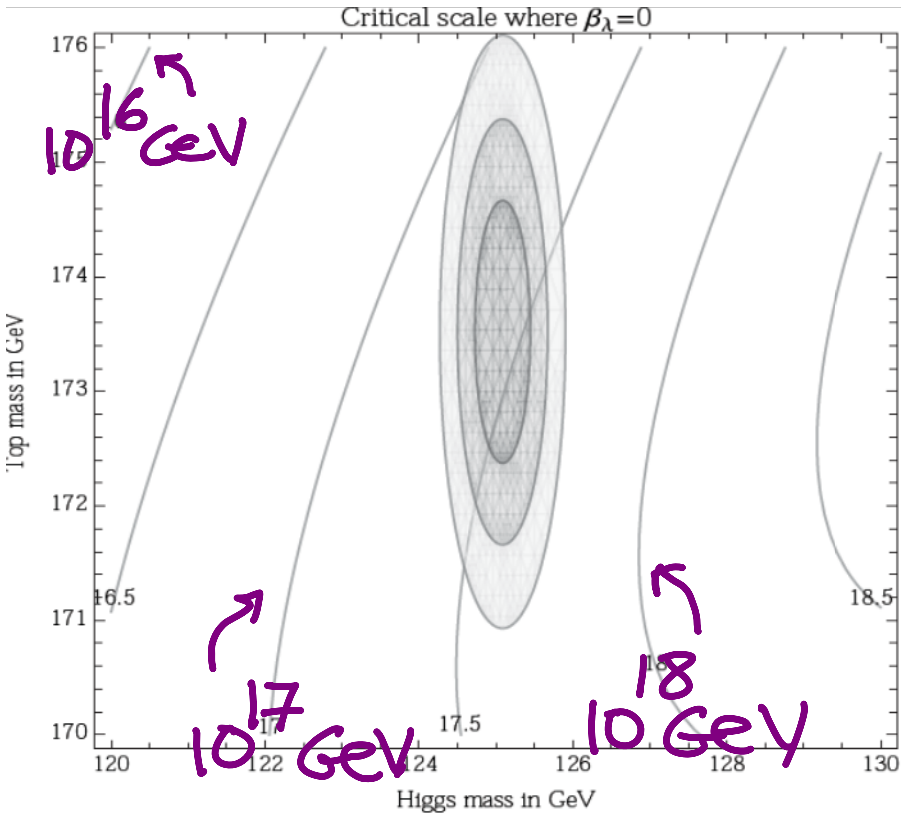


Although $h_{tun} \gg \Lambda_I$

Luckily $h_{tun} < M_{Pl}$

TUNNELING BUBBLE

However, h_{tun} is not so far from $M_{Pl} = 1.2 \times 10^{19}$ GeV



A. Strumia

Tunneling might be sensitive to Planckian effects.

PLANCKIAN EFFECTS ?

Possible Planckian effects

- Gravitational effects on tunneling process
  Coleman, de Luccia '80
  Included, suppress decay.

- Modifications of $V(h)$ below M_{Pl}

PLANCKIAN EFFECTS ON V(h)?

This can be studied in h/M_{Pl} expansion.

$$V = \frac{\lambda}{4} h^4 + \underbrace{\frac{\lambda_6}{6}\frac{h^6}{M_{Pl}^2} + \frac{\lambda_8}{8}\frac{h^8}{M_{Pl}^4}}_{\Delta V} + \ldots$$

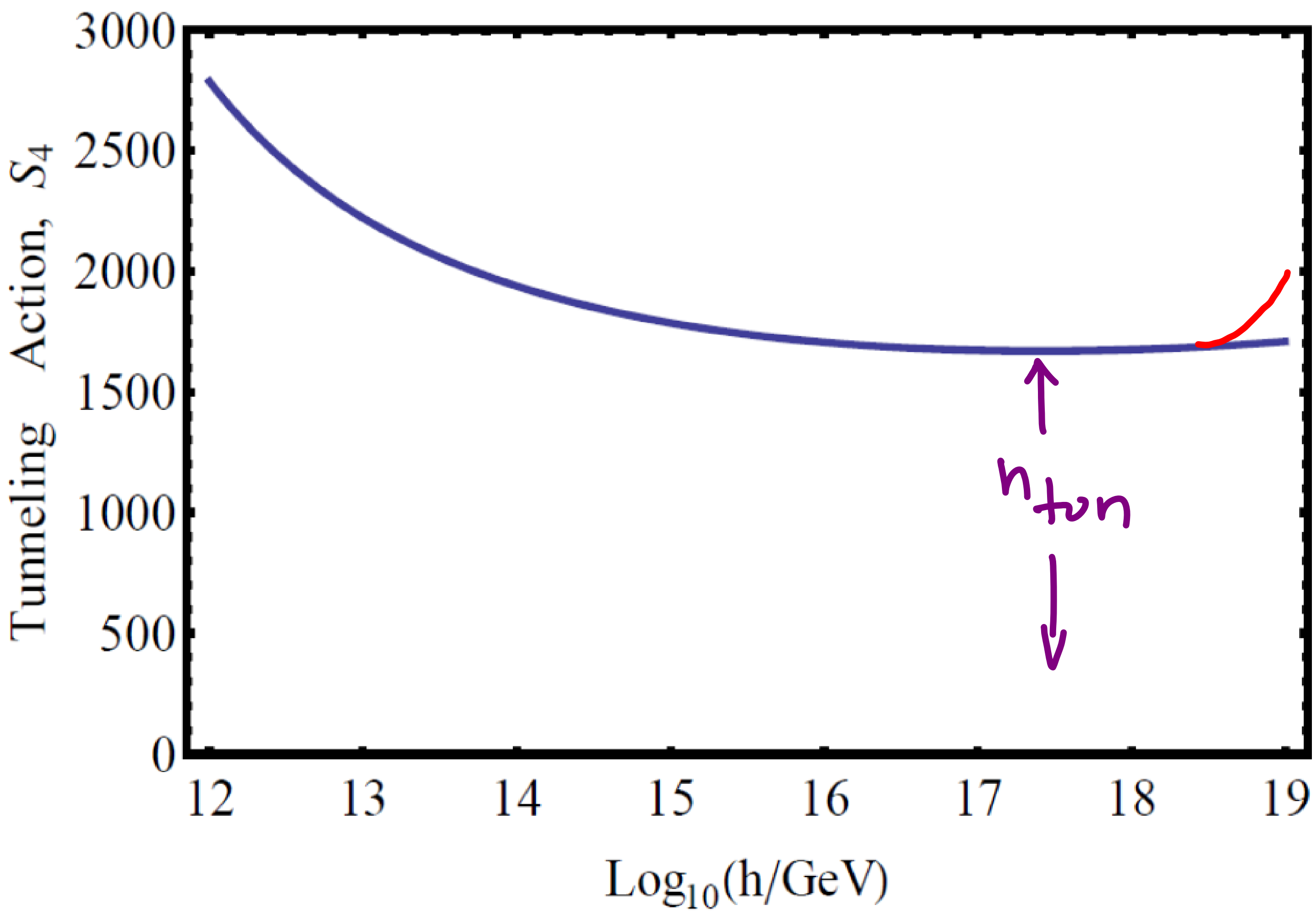
Expansion parameter h^2/M_{Pl}^2 should be small.

Q: Can M_P physics make the potential stable?
(eg. shifting the stability line towards the experimental values of M_h & M_t?)

A: No.

PLANCKIAN EFFECTS ON V(h)?

Effect on tunneling action $\Delta V > 0$ eg. $\lambda_6 > 0$

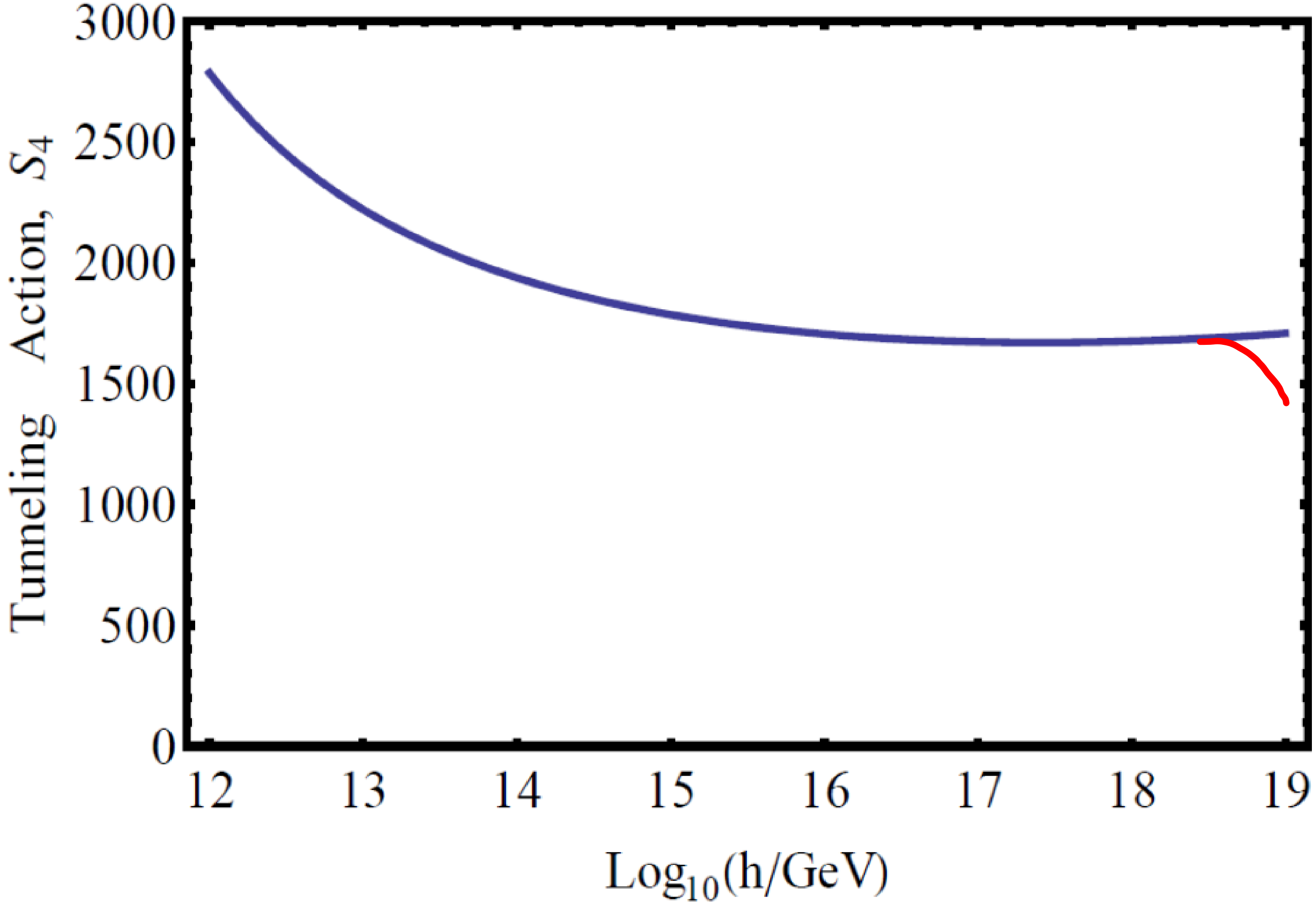


Tunneling action (and h_{tun}) unchanged

PLANCKIAN EFFECTS ON V(h)?

Effect on tunneling action $\Delta V < 0$ $\lambda_6 < 0, \lambda_8 > 0$

Branchina et al.



Potential more unstable (unmotivated)

PLANCKIAN EFFECTS ON V(h)?

Q: Can Planckian physics spoil criticality?

A1: Of course!

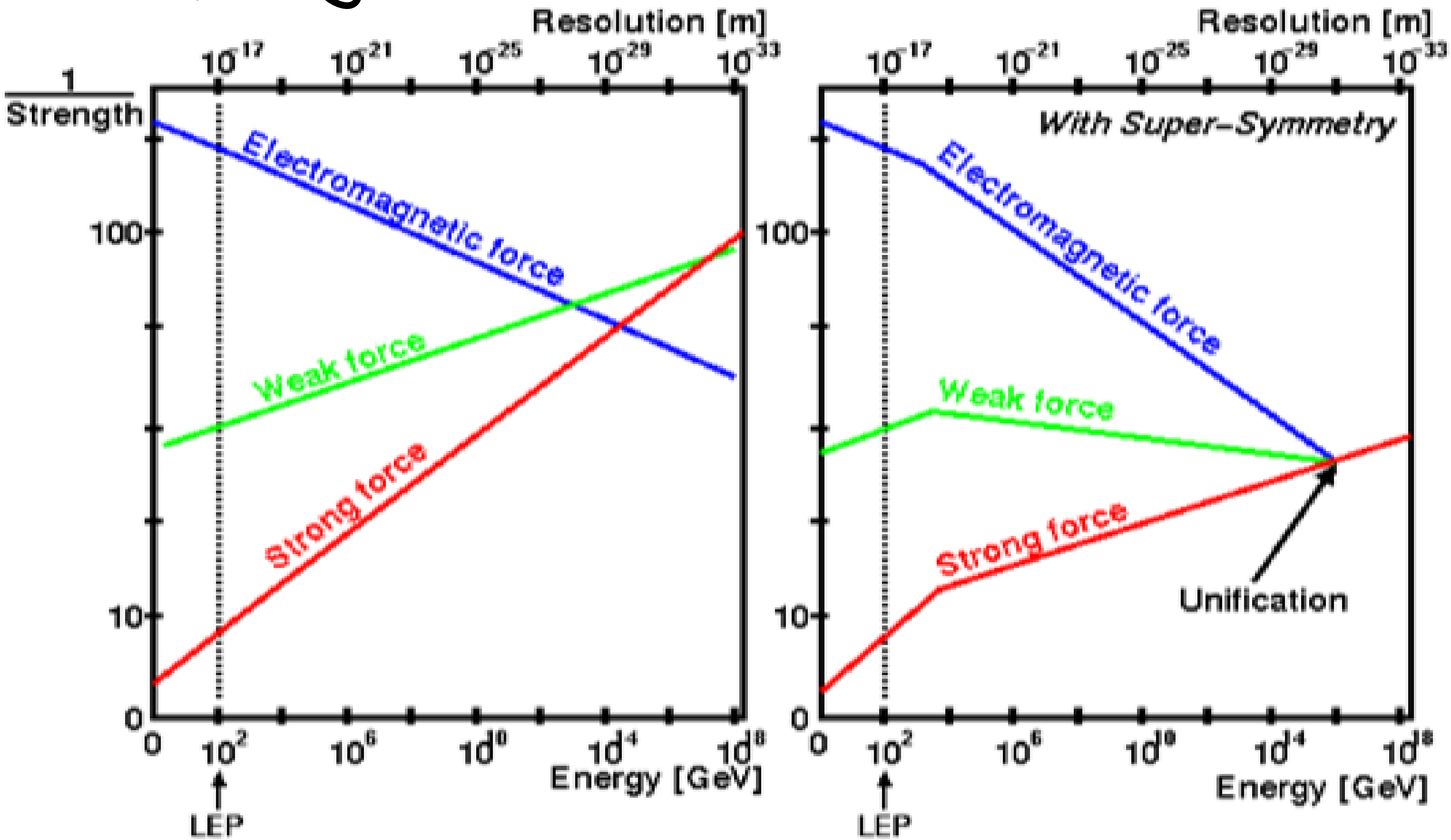
Even modest see-saw neutrinos could.

A2: That's the wrong question to ask!

Criticality ⟷ Gauge Coupling Unification

AN INTRIGUING HINT FROM LEP

Gauge coupling unification :

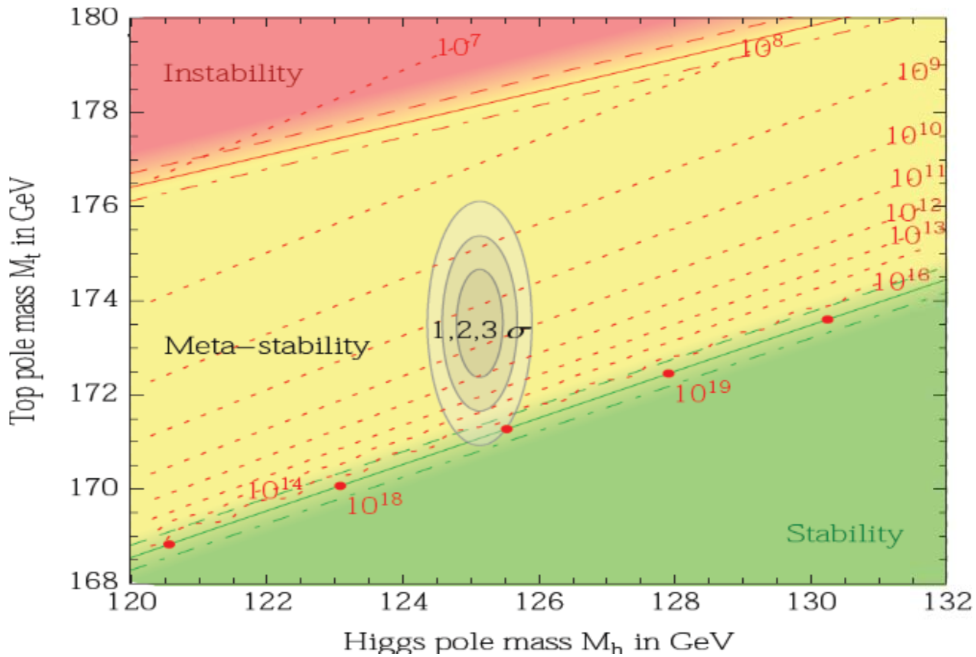


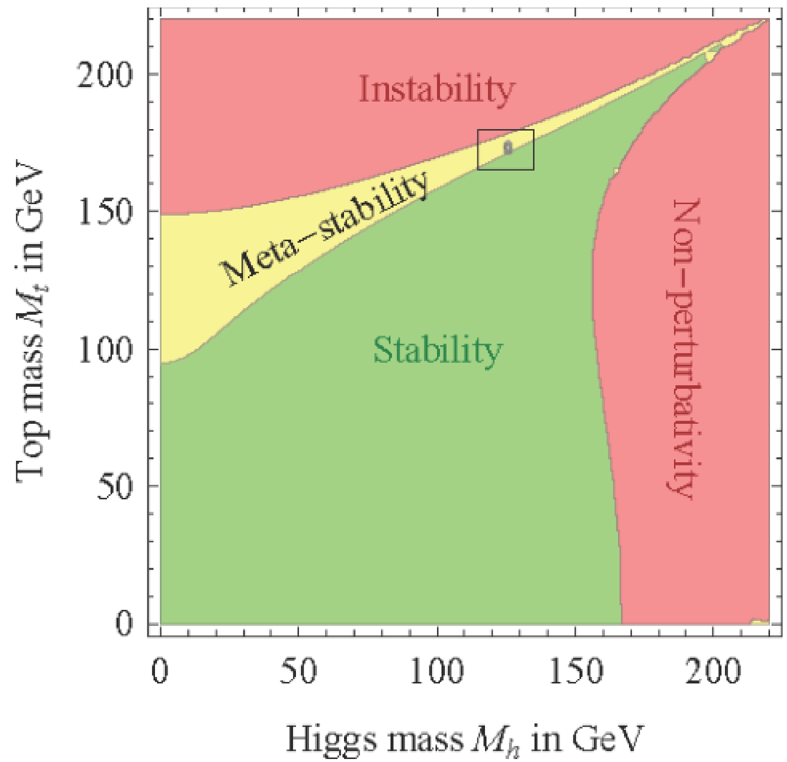
Many effects can upset it, including huge corrections from physics at the unification scale.

Yet, it might be telling us something important

AN INTRIGUING HINT FROM LHC

Living close to the stability boundary:





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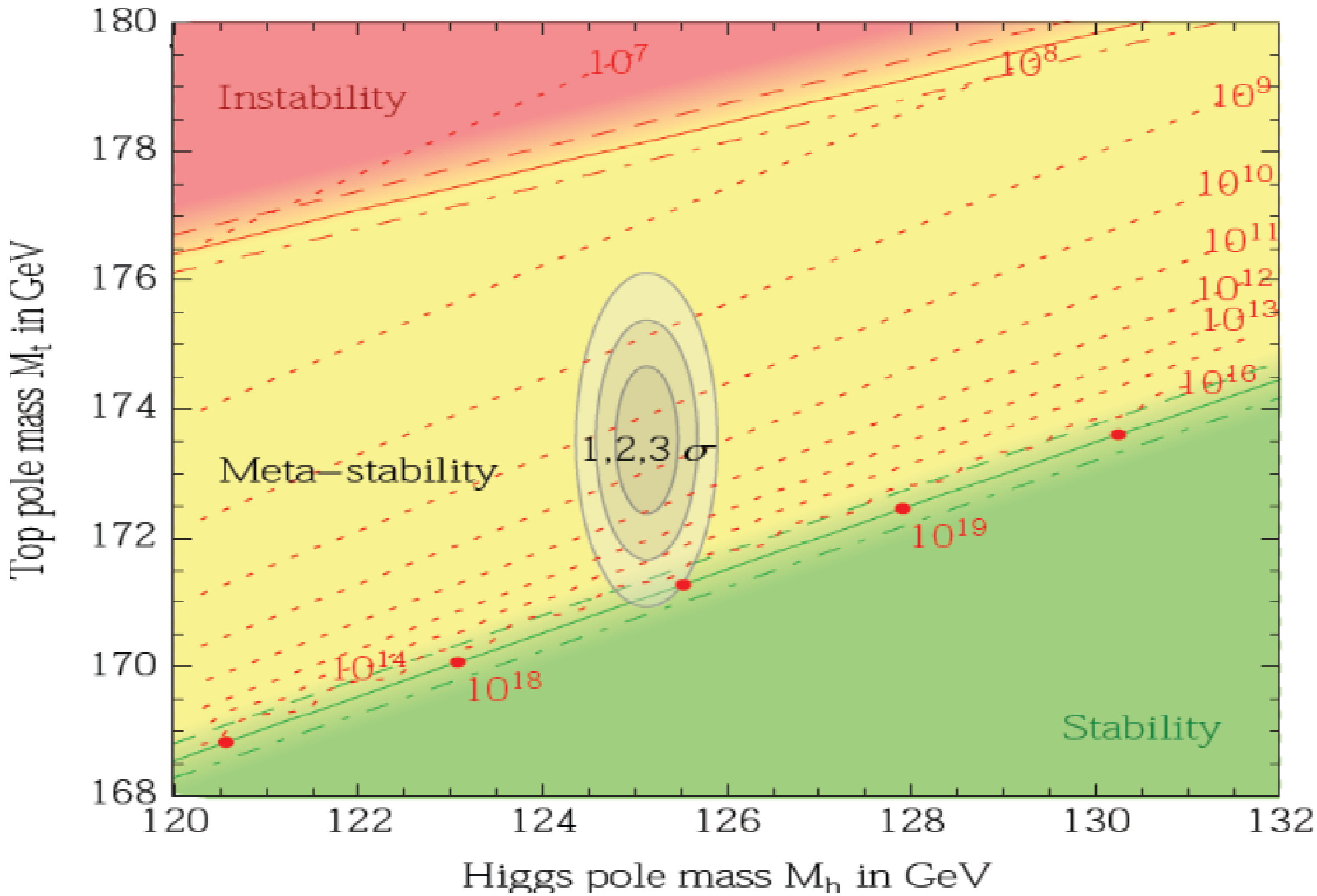
Yet, it might be telling us something important

CONCLUSION



Good motivation to improve Mtop determination !

BACK-UP SLIDES

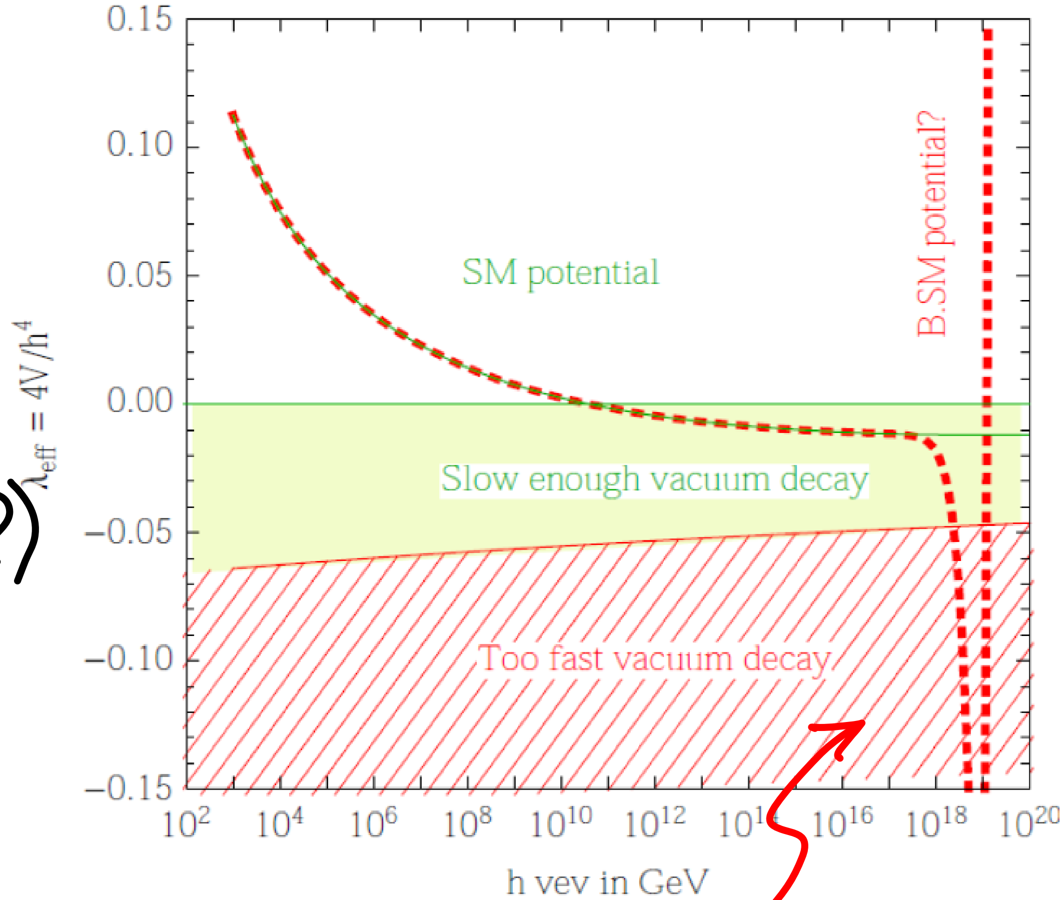
PLANCKIAN EFFECTS ON V(h)?

Branchina et al.

Studied with

$\lambda_6 < 0 \quad \lambda_8 > 0$

Tailored to create a minimum below M_{Pl} (why?) by $\lambda_6 \leftrightarrow \lambda_8$ interplay



Potential made much more unstable

Instability would be there even for $\lambda > 0$

ISSUES

- At the new minimum the expansion parameter $h/M_{Pl} \sim 0.8$ ⇒ EFT breaks down.
- Stability plot claimed to be non-universal
  Of course : like for see-saw neutrinos.
  But why should gravity introduce a new source of instability ($\lambda_6 < 0$) ?
- No Coleman-de Luccia effects considered (M_P just as any other QFT threshold)
- Criticism of criticality misses the point
  (see analogy with gauge coupling unification)

OTHER IMPLICATIONS

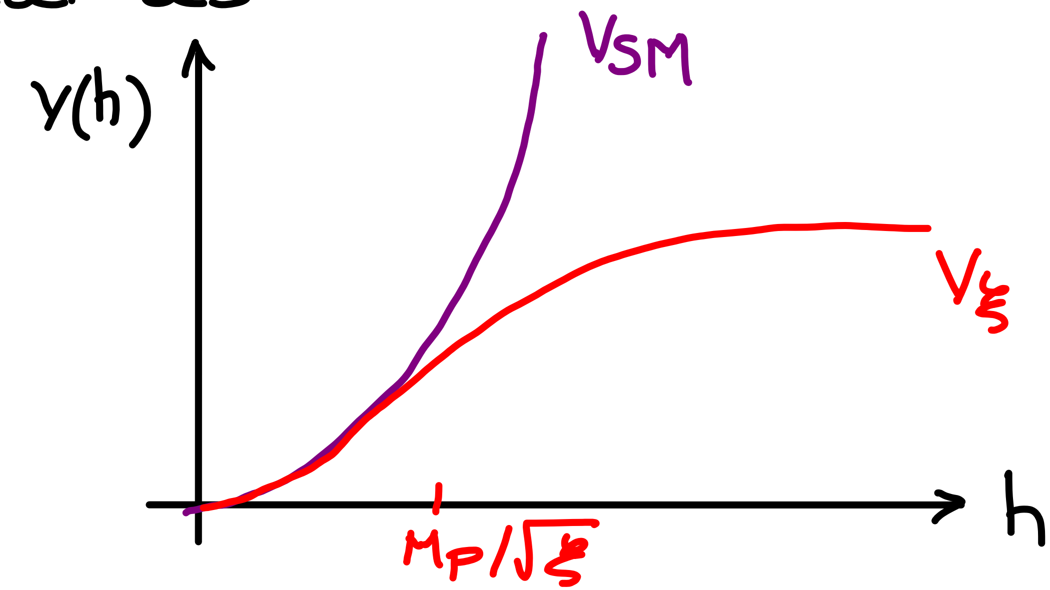
- Cosmology: Higgs inflation Bezrukov, Shaposhnikov '07

Higgs coupled to gravity as $\mathcal{L} \supset \int \sqrt{-g}\, \xi |H|^2 R$

coupling removed by $g_{\mu\nu} \to g_{\mu\nu} \left(1 + \xi h^2/M_P^2\right)^{-1}$

rescales the potential as

$$V(h) \Rightarrow \frac{V(h)}{\left(1 + \xi h^2/M_P^2\right)^2}$$



Requires $\xi \sim 10^4$ to give the right spectrum of primordial fluctuations.

(MORE) TROUBLE FOR HIGGS INFLATION

※1 Effective theory with cutoff

$$\Lambda \sim \frac{M_P}{\xi} \ll \Lambda_{HI} \sim \frac{M_P}{\sqrt{\xi}}$$

Can't trust the plateau region

Burgess, Lee, Trott '09. Barbón et al. '09 '15

※2 Stability up to $\sim 10\Lambda_{HI}$ is a must.

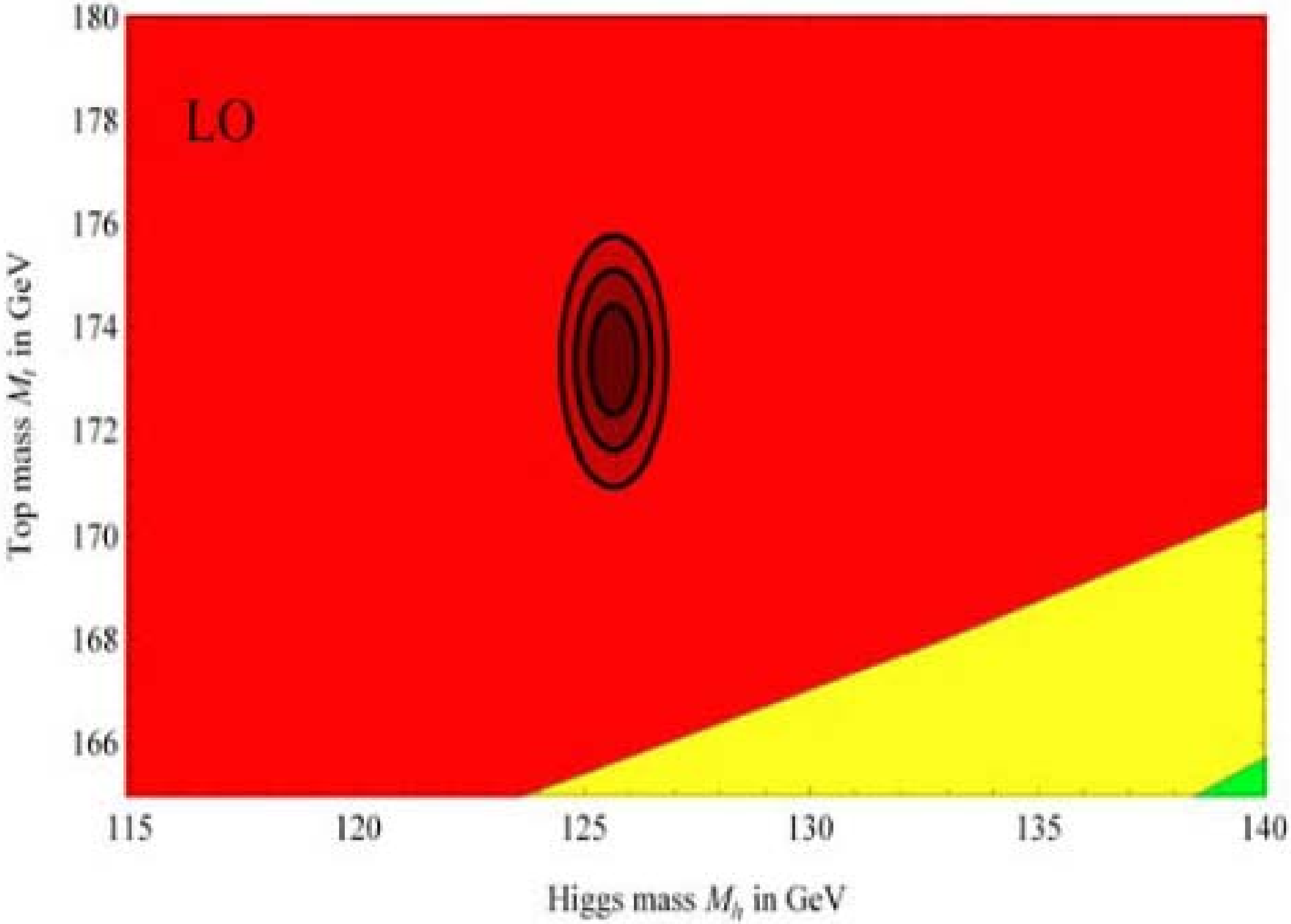
Requires marginal values of M_h & M_t

※3 Additional scalar can solve ※1

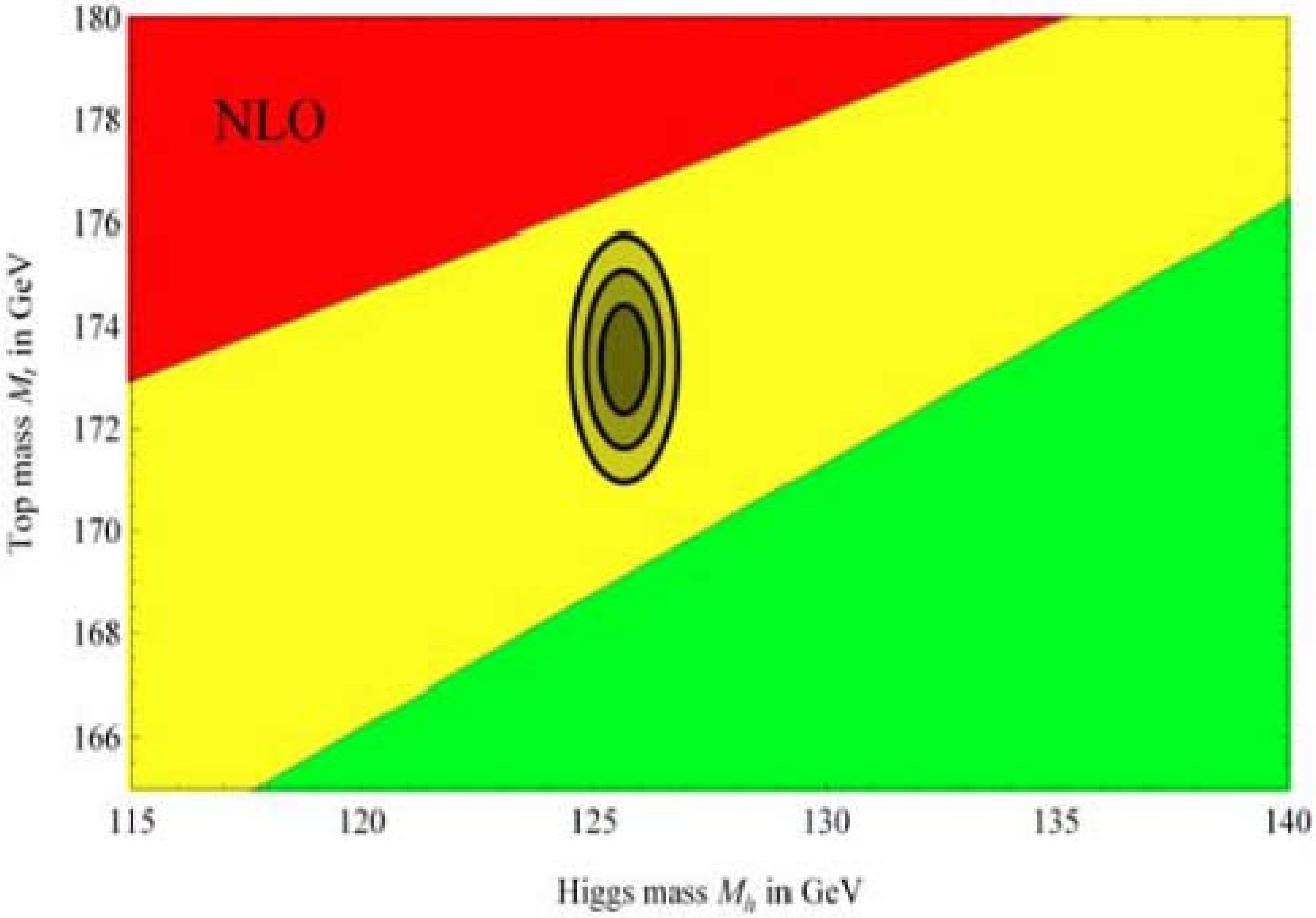
But then that scalar plays inflaton role

Giudice, Lee '11 Barbón et al '15

PROGRESS IN STABILITY CALCULATION



PROGRESS IN STABILITY CALCULATION



PROGRESS IN STABILITY CALCULATION