# The Gravitational Wave Background and Higgs False Vacuum Inflation

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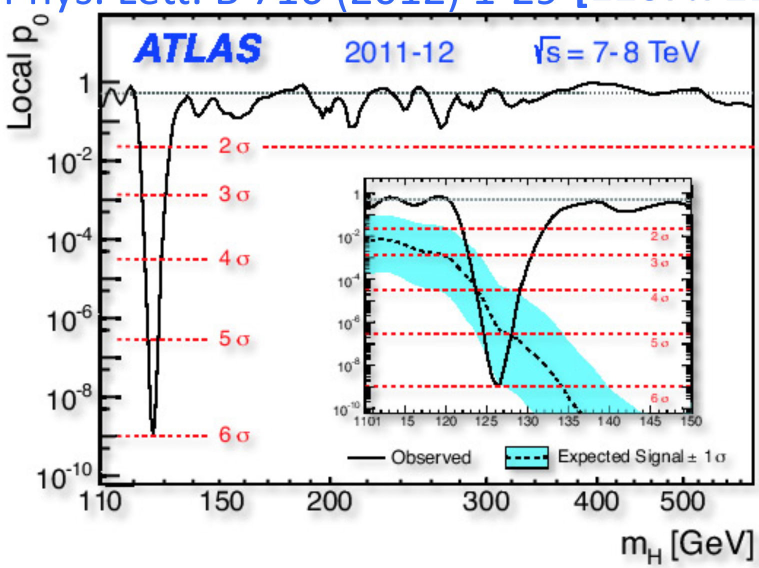
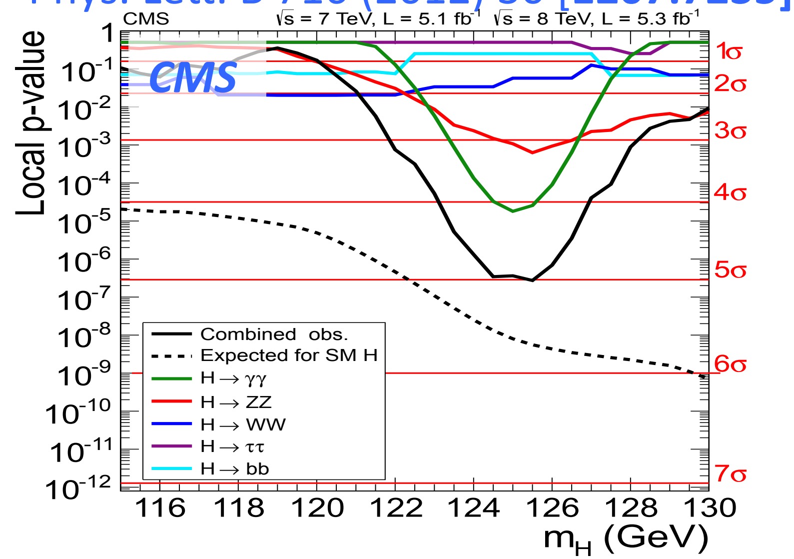
SUSY 2014, Manchester, 22/07/2014

# 4/07/12: A scalar particle has been discovered

Phys. Lett. B 716 (2012) 1-29 **[1207.7214]**




Phys. Lett. B 716 (2012) 30 **[1207.7235]**

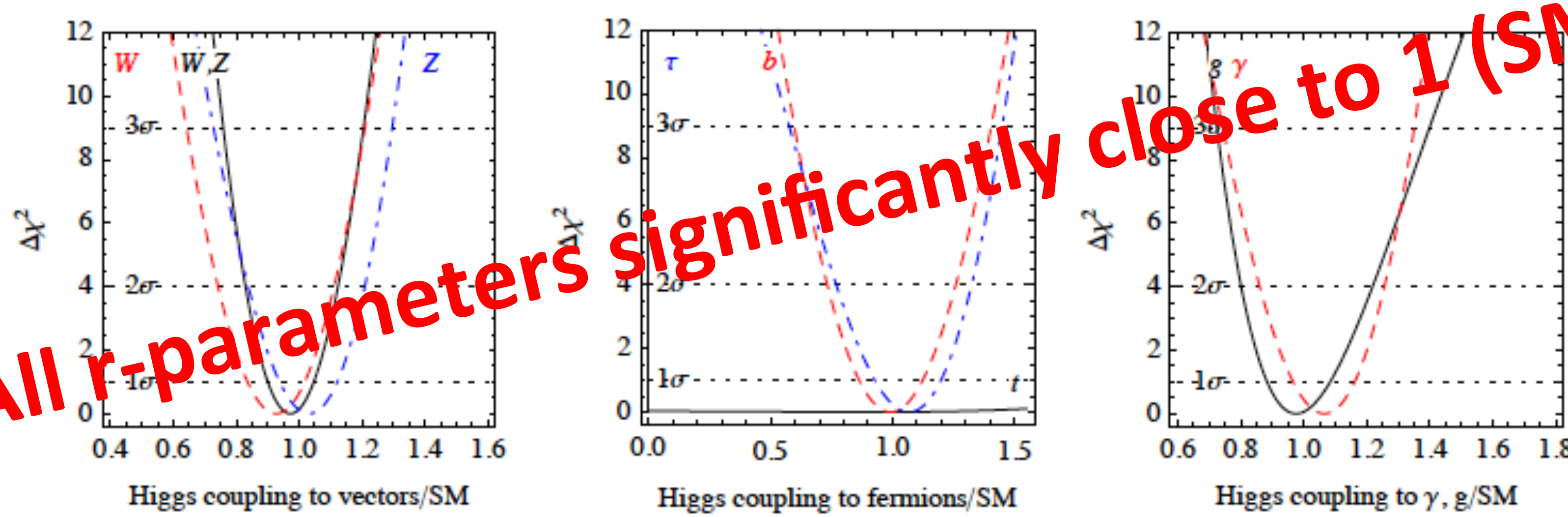



$$m_H \approx 125 - 126\ GeV$$

# Likely it is the SM Higgs boson!

Many combined analysis, see e.g.
Giardino Kannike IM Raidal Strumia, JHEP arXiv:1303.3570

$$\mathcal{L}_h = r_t \frac{m_t}{V} h\bar{t}t + r_b \frac{m_b}{V} h\bar{b}b + r_\tau \frac{m_\tau}{V} h\bar{\tau}\tau + r_\mu \frac{m_\tau}{V} h\bar{\mu}\mu + r_Z \frac{M_Z^2}{V} hZ_\mu^2 + r_W \frac{2M_W^2}{V} hW_\mu^+ W_\mu^- + \\ + r_\gamma c_{\rm SM}^{\gamma\gamma} \frac{\alpha}{\pi V} hF_{\mu\nu}F_{\mu\nu} + r_g c_{\rm SM}^{gg} \frac{\alpha_s}{12\pi V} hG_{\mu\nu}^a G_{\mu\nu}^a + r_{Z\gamma} c_{\rm SM}^{Z\gamma} \frac{\alpha}{\pi V} hF_{\mu\nu}Z_{\mu\nu}.$$




All r-parameters significantly close to 1 (SM)

ATLAS (ZZ, γγ)

$$M_h = 125.5 \pm 0.2_{\rm stat}{}^{+0.5}_{-0.6\,\rm syst}$$

CMS (WW, ZZ, γγ, ττ, bb)

$$M_h = 125.7 \pm 0.3_{\rm stat} \pm 0.3_{\rm syst}$$

$$m_H \approx 125-126\ GeV$$

**SO WHAT?**

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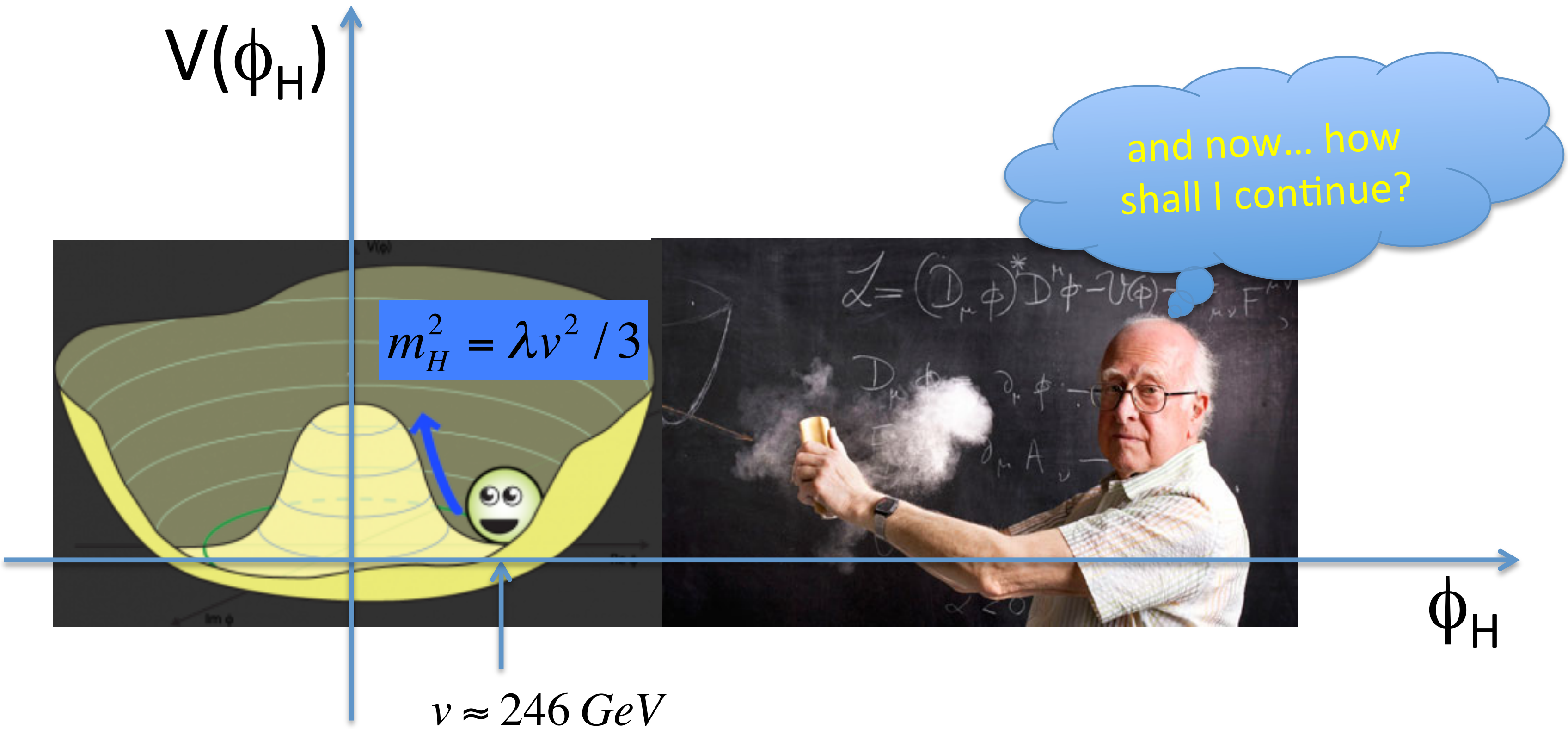
**SO WHAT?**

Finally possible to study the shape of the SM Higgs potential up to the Planck scale!!!

Consider the Higgs doublet $H = (0, (\phi_H + v)/\sqrt{2})$

and the SM Higgs potential: $V(\phi_H) = \frac{\lambda}{6}\left(|H|^2 - \frac{v^2}{2}\right)^2 \approx \frac{\lambda}{24}\phi_H^4$



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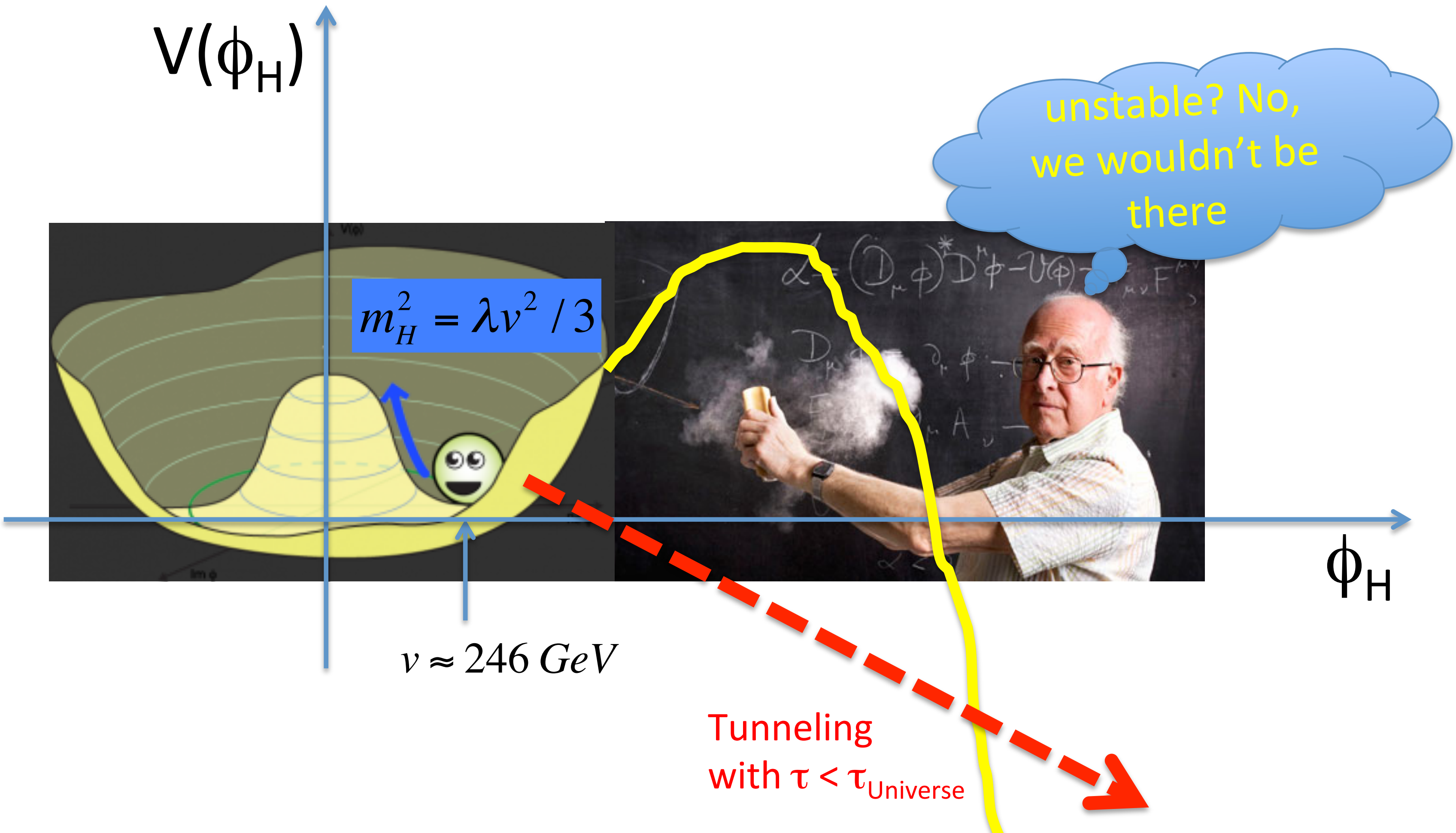

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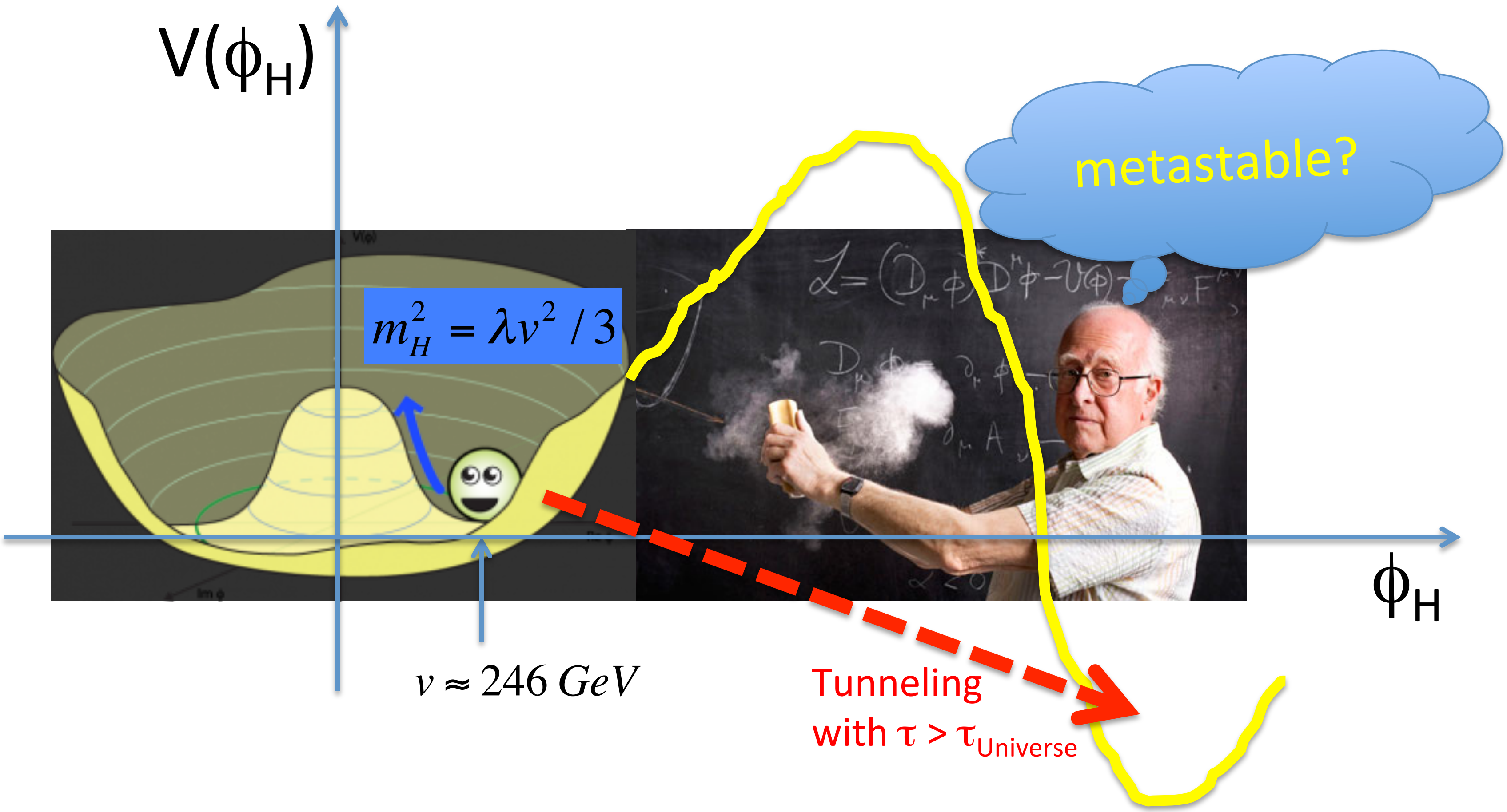

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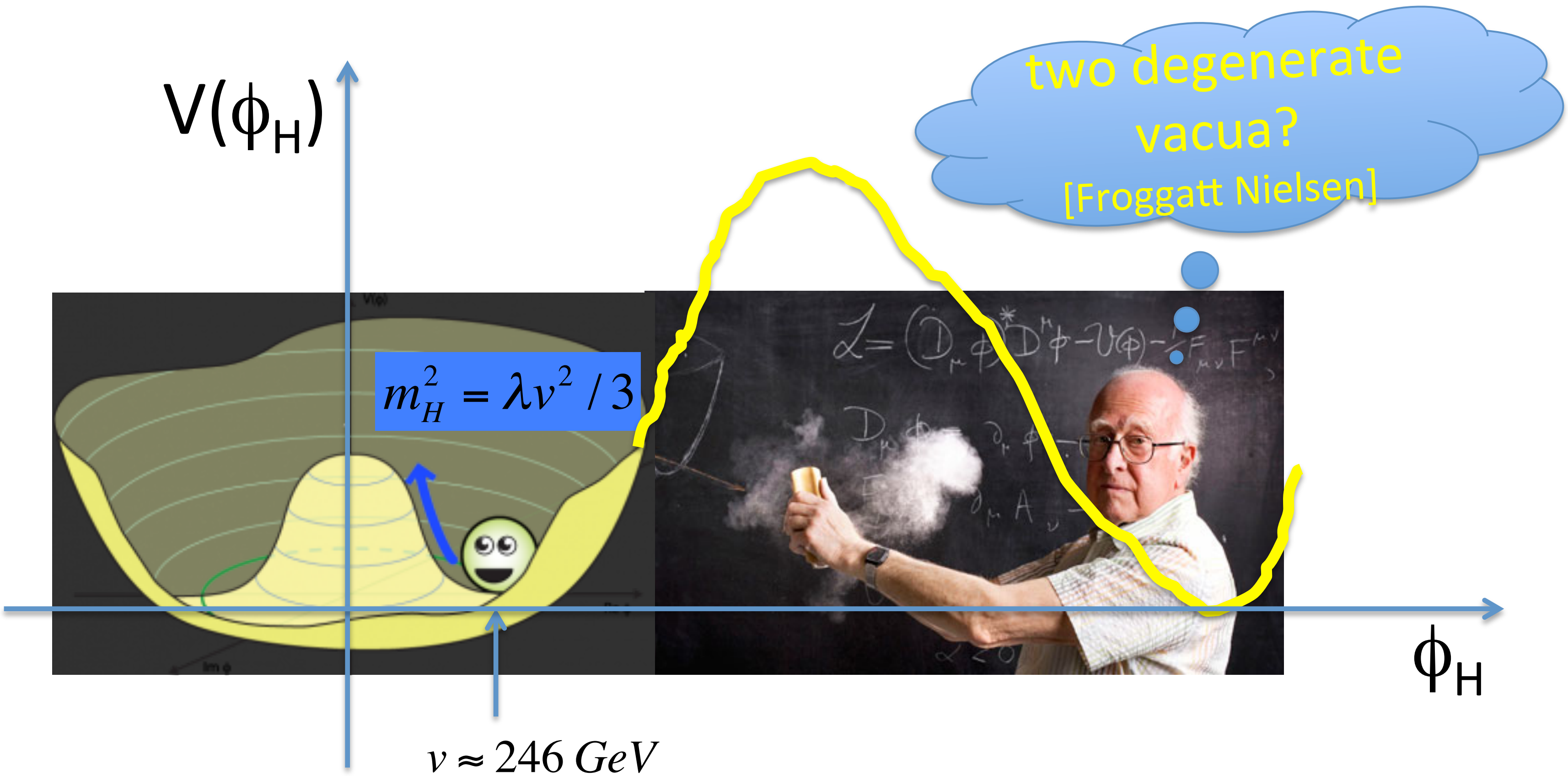

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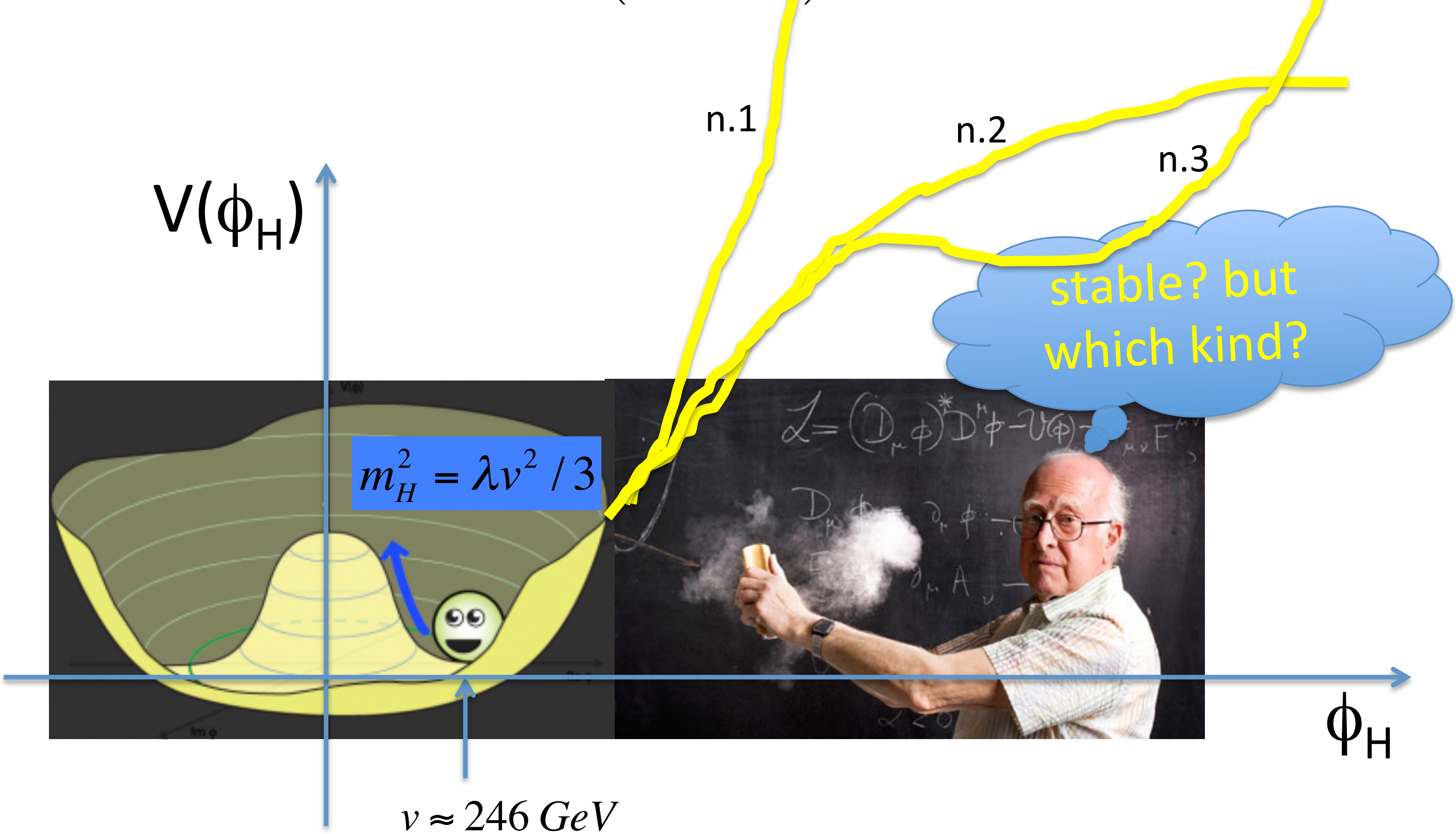

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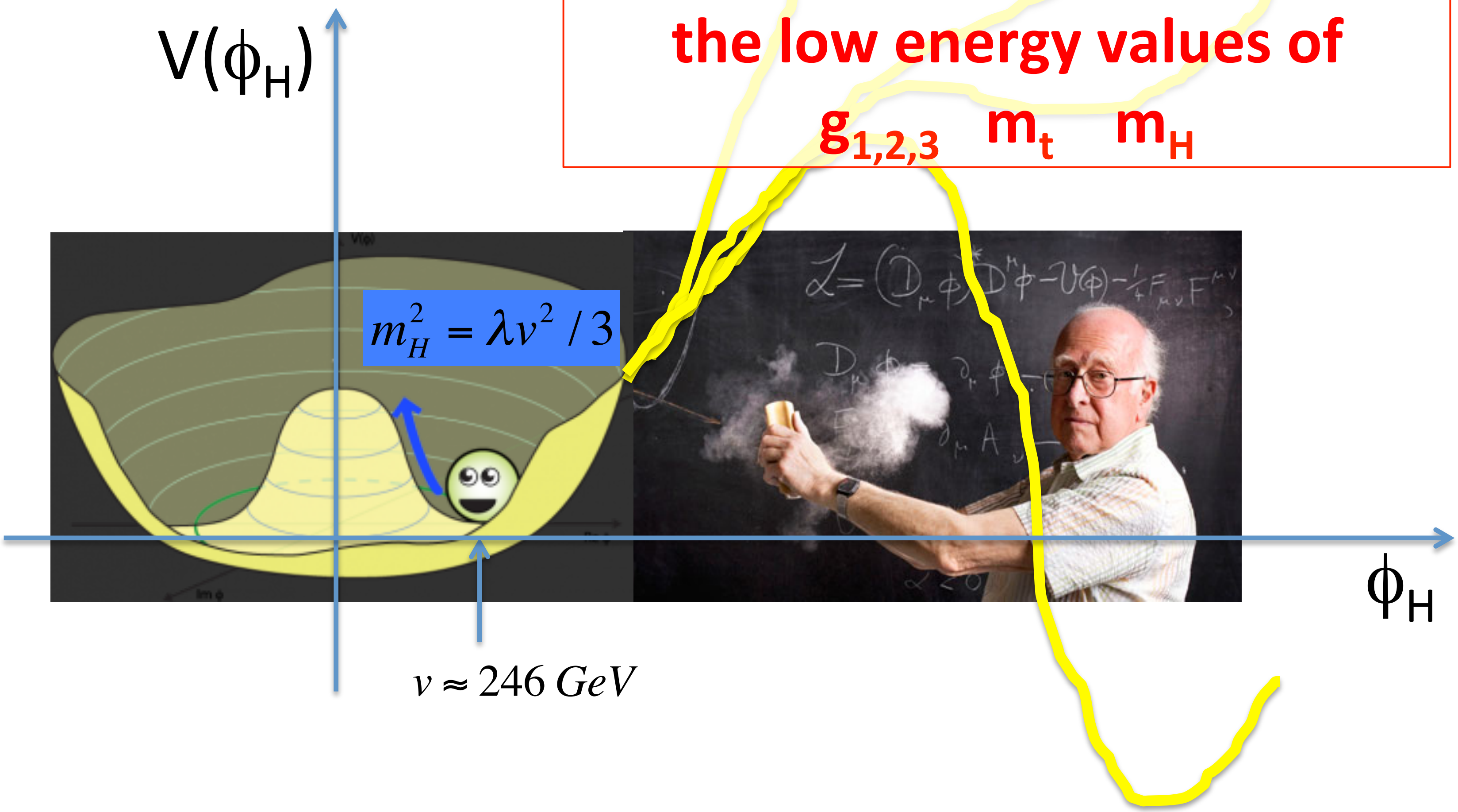
**To study $\lambda(\mu)$ one needs the low energy values of $g_{1,2,3}$ $m_t$ $m_H$**



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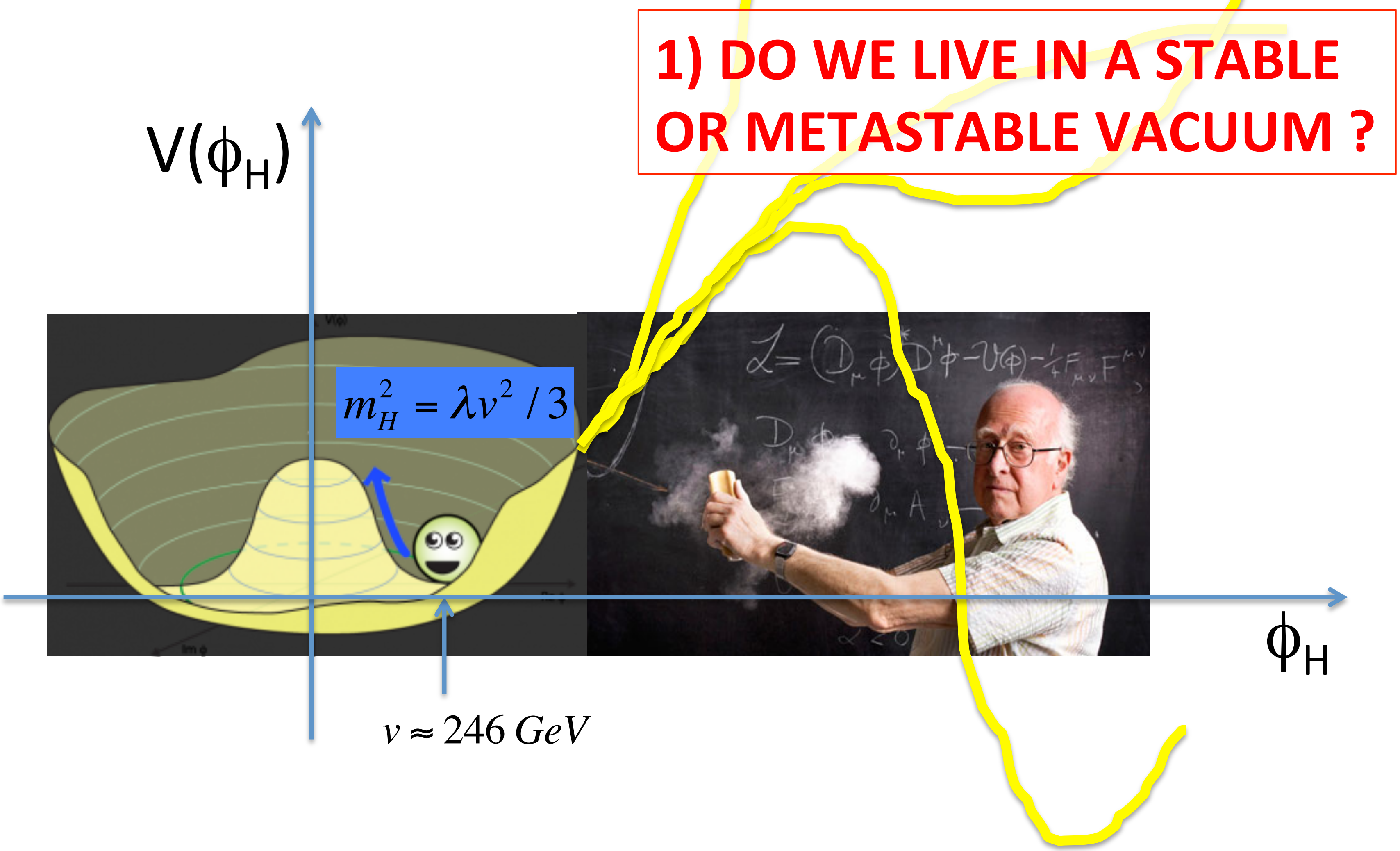

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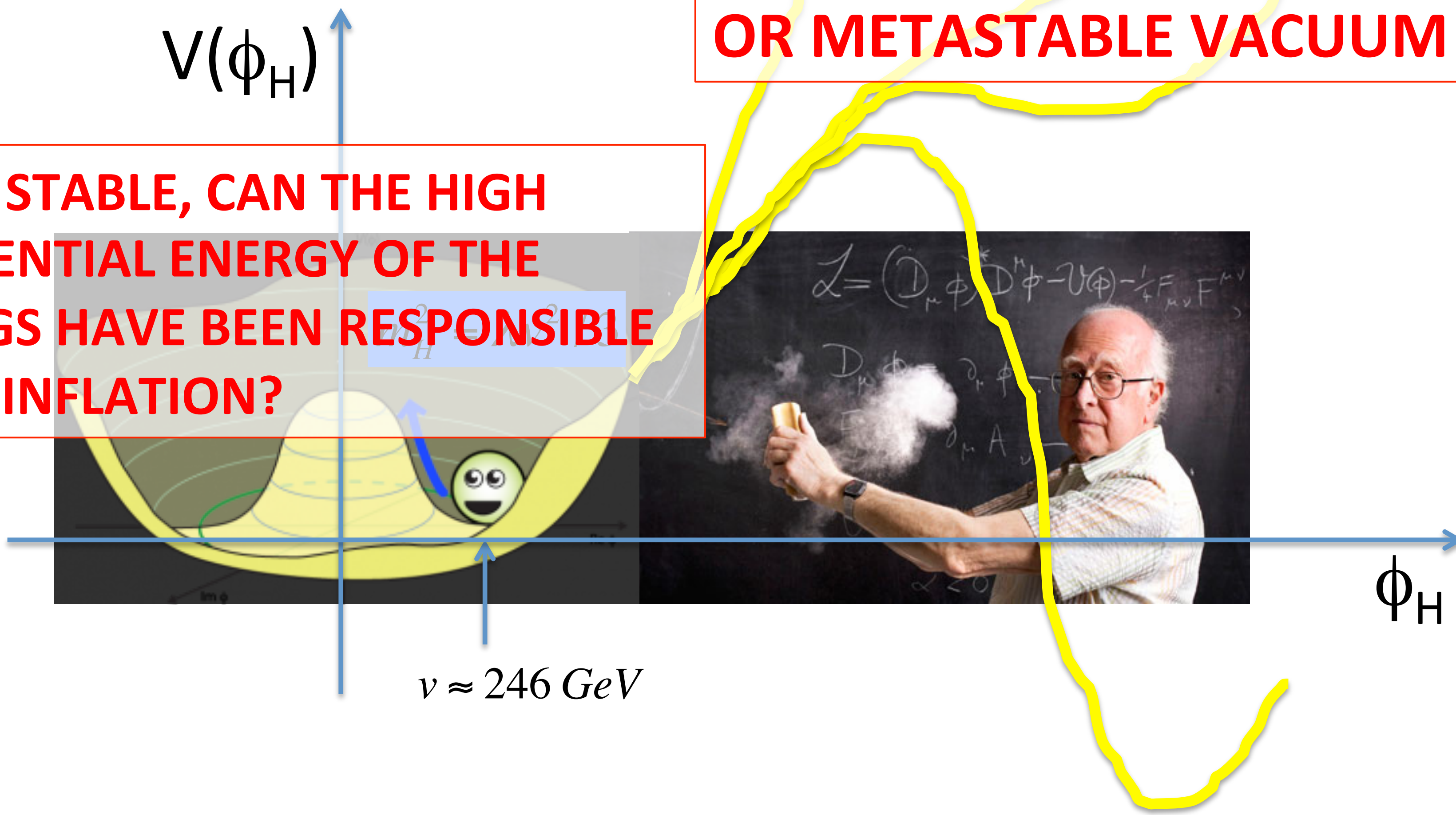
**1) DO WE LIVE IN A STABLE OR METASTABLE VACUUM ?**

**2) IF STABLE, CAN THE HIGH POTENTIAL ENERGY OF THE HIGGS HAVE BEEN RESPONSIBLE FOR INFLATION?**



1)

# To be or not to be (stable), that is the (first) question…

(Assuming desert)

extrapolate the SM Higgs potential at renormalization scale $\mu$ via RGE

[Hung, Cabibbo et al '79, Lindner, Sher, Casas, Espinosa, Quiros, Giudice, Riotto, Isidori, Strumia, etc etc etc]

**This can now be done at NNLO!!**

3-loop running & 2-loop matching of

$g(\mu)$, $g'(\mu)$, $g_3(\mu)$, $\lambda(\mu)$, $y_t(\mu)$

in $\overline{MS}$ scheme

# Matching

$g(\mu)$, $g'(\mu)$, $g_3(\mu)$, $\lambda(\mu)$, $y_t(\mu)$

matched directly at $m_Z$

According to PDG,
the larger exp error is in:

$$\alpha_3(m_Z) = 0.1196 \pm 0.0017$$

# Running

g(μ), g' (μ), $g_3$(μ), λ(μ), $y_t$(μ)

$$\frac{41}{6}g'(t)^3$$

$$-\frac{19}{6}g(t)^3$$

$$-7g_3(t)^3$$

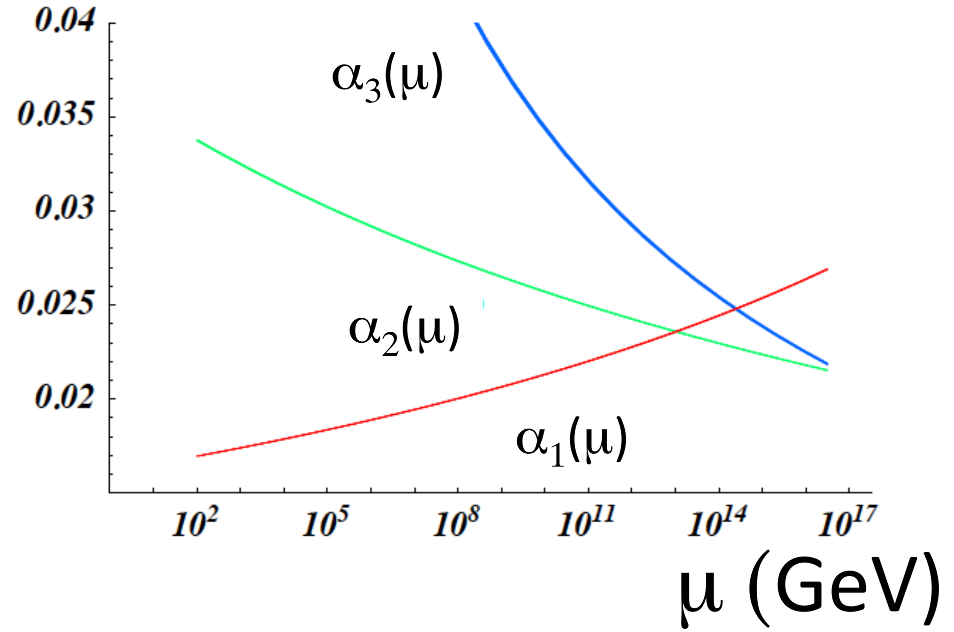
$$\frac{d}{dt}g(t) = \kappa\beta_g^{(1)} + \kappa^2\beta_g^{(2)} + \kappa^3\beta_g^{(3)},$$

$$\frac{d}{dt}g'(t) = \kappa\beta_{g'}^{(1)} + \kappa^2\beta_{g'}^{(2)} + \kappa^3\beta_{g'}^{(3)},$$

$$\frac{d}{dt}g_3(t) = \kappa\beta_{g_3}^{(1)} + \kappa^2\beta_{g_3}^{(2)} + \kappa^3\beta_{g_3}^{(3)},$$

$$t = \log \mu/m_Z$$

$$\kappa = 1/(16\pi^2)$$




Mihaila Salomon Steinhauser,
PRL, arXiv:1201.5868

# Matching

$g(\mu)$, $g'(\mu)$, $g_3(\mu)$, $\lambda(\mu)$, $y_t(\mu)$

Need to know $m_H$:

$$\lambda(\mu) = 3\frac{m_H^2}{v^2}\left(1 + \delta_H^{(1)}(\mu) + \delta_H^{(2)}(\mu) + \dots\right)$$

**1-loop by**

Sirlin Zucchini NPB '86

$$\frac{G_\mu m_Z^2}{8\sqrt{2}\pi^2}\left(\xi f_1(\mu) + f_0(\mu) + \frac{f_{-1}(\mu)}{\xi}\right)$$

**2-loop by**

Bezrukov Kalmykov Kniehl Shaposhnikov
JHEP, arXiv:1205.2893

Degrassi Di Vita Elias-Miro Espinosa Giudice Isidori Strumia
JHEP, arXiv:1205.6497

# Matching

$g(\mu)$, $g'(\mu)$, $g_3(\mu)$, $\lambda(\mu)$, $y_t(\mu)$

Need to know top mass:

running $\overline{\text{MS}}$ top mass — pole top mass

$$y_t(\mu)\frac{v}{\sqrt{2}} = \overline{m_t}(\mu) = m_t\Big(1 + \delta_t(\mu)\Big)$$

$\delta_t(\mu)$ known at 2-loop

Analyses use (2-loop) matching via "Tevatron" $m_t$ pole mass
(corresponding to a non-perturbative parameter of a MonteCarlo):

$$m_t^{exp} = 173.2 \pm 0.9\,\text{GeV}$$

This method introduces an unavoidable theoretical error associated to 2-loop matching

# Matching

$g(\mu)$, $g'(\mu)$, $g_3(\mu)$, $\lambda(\mu)$, $y_t(\mu)$

Need to know top mass:

running $\overline{\text{MS}}$ top mass — pole top mass

$$y_t(\mu)\frac{v}{\sqrt{2}} = \overline{m_t}(\mu) = m_t\left(1+\delta_t(\mu)\right)$$

known at 2-loop

Alekhin Djouadi Moch, PLB arXiv:1207.0980

say it is not meaningful to use Tevatron measure: could underestimate error!

BETTER to match directly with running $\overline{\text{MS}}$: $\overline{m_t}(m_t) = 163.3 \pm 2.7\ \text{GeV}$
as it can also be experimentally extracted from the total cross section for top quark pair production at hadron colliders $p\bar{p} \to t\bar{t} + X$

In this way one avoids the theoretical error due to matching

Method followed in: IM, PRD arXiv:1209.0393

…essentially agrees with results obtained via the other method for: $m_t = \overline{m_t} + 10$ GeV

# Running

$g(\mu)$, $g'(\mu)$, $g_3(\mu)$, $\lambda(\mu)$, $y_t(\mu)$

$$\frac{27}{4}g(t)^4 + \frac{9}{2}g'(t)^2 g(t)^2 - 9\lambda(t)g(t)^2 + \frac{9}{4}g'(t)^4 - 36h_t(t)^4 + 4\lambda(t)^2 - 3g'(t)^2\lambda(t) + 12h_t(t)^2\lambda(t)$$

$$\frac{9}{2}h_t(t)^3 - \frac{9}{4}g(t)^2 h_t(t) - 8g_3(t)^2 h_t(t) - \frac{17}{12}g'(t)^2 h_t(t)$$

$$\frac{d}{dt}\lambda(t) = \kappa\beta_\lambda^{(1)} + \kappa^2\beta_\lambda^{(2)} + \kappa^3\beta_\lambda^{(3)},$$
$$\frac{d}{dt}h_t(t) = \kappa\beta_{h_t}^{(1)} + \kappa^2\beta_{h_t}^{(2)} + \kappa^3\beta_{h_t}^{(3)},$$

Chetyrkin Zoller, JHEP arXiv:1205.2892, 1303.2890

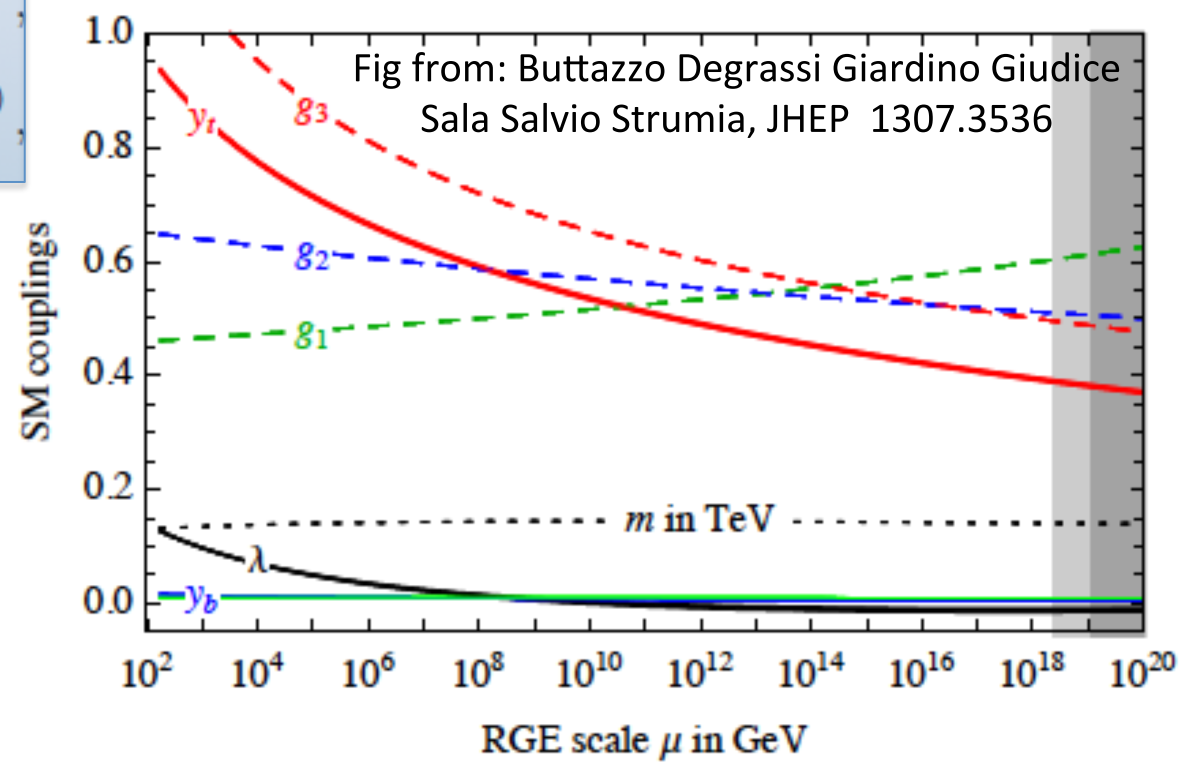
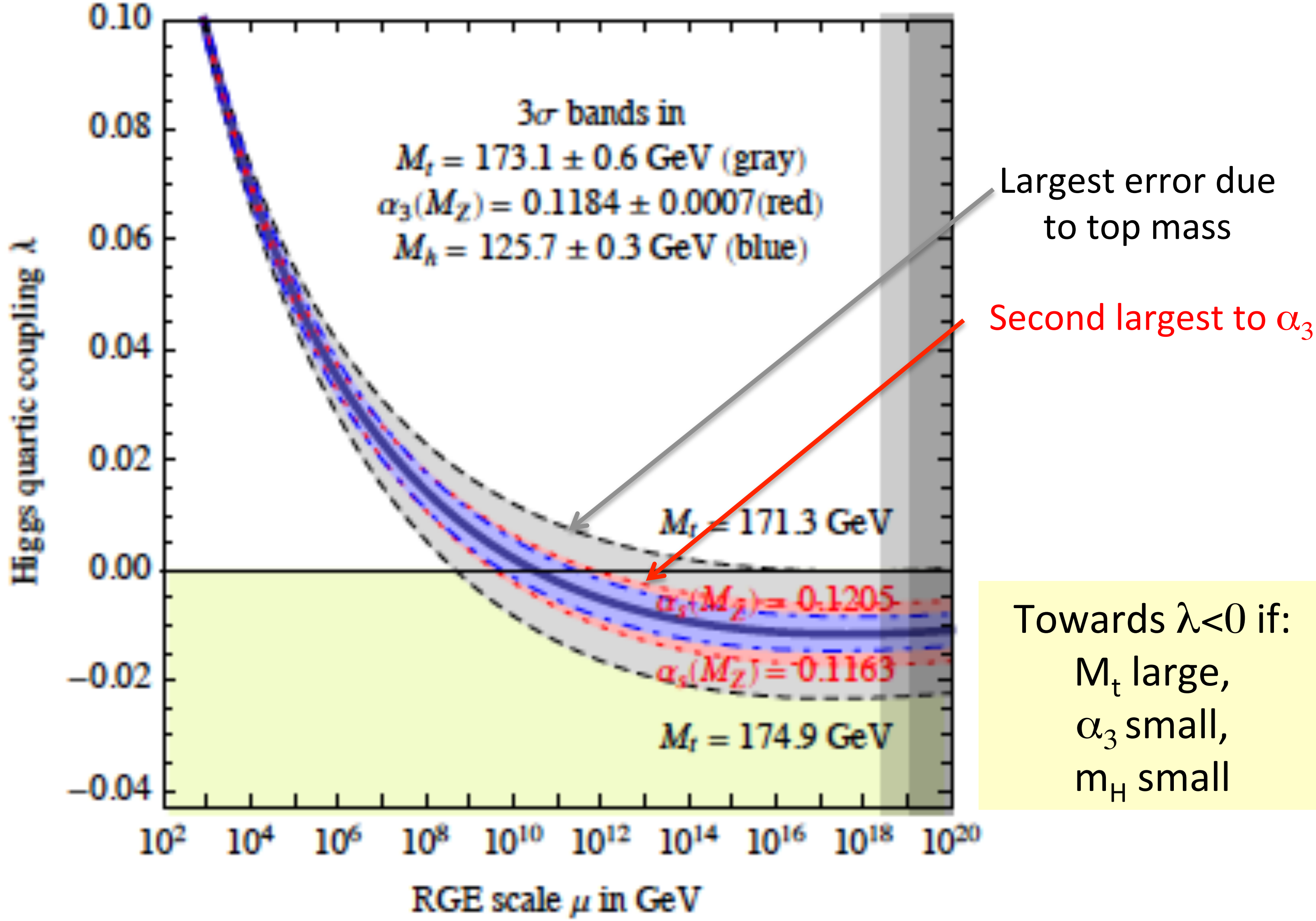



Fig from: Buttazzo Degrassi Giardino Giudice Sala Salvio Strumia, JHEP 1307.3536

# Let focus on the running of λ




Towards $\lambda<0$ if:
$M_t$ large,
$\alpha_3$ small,
$m_H$ small

Fig from: Buttazzo Degrassi Giardino Giudice Sala Salvio Strumia, JHEP 1307.3536

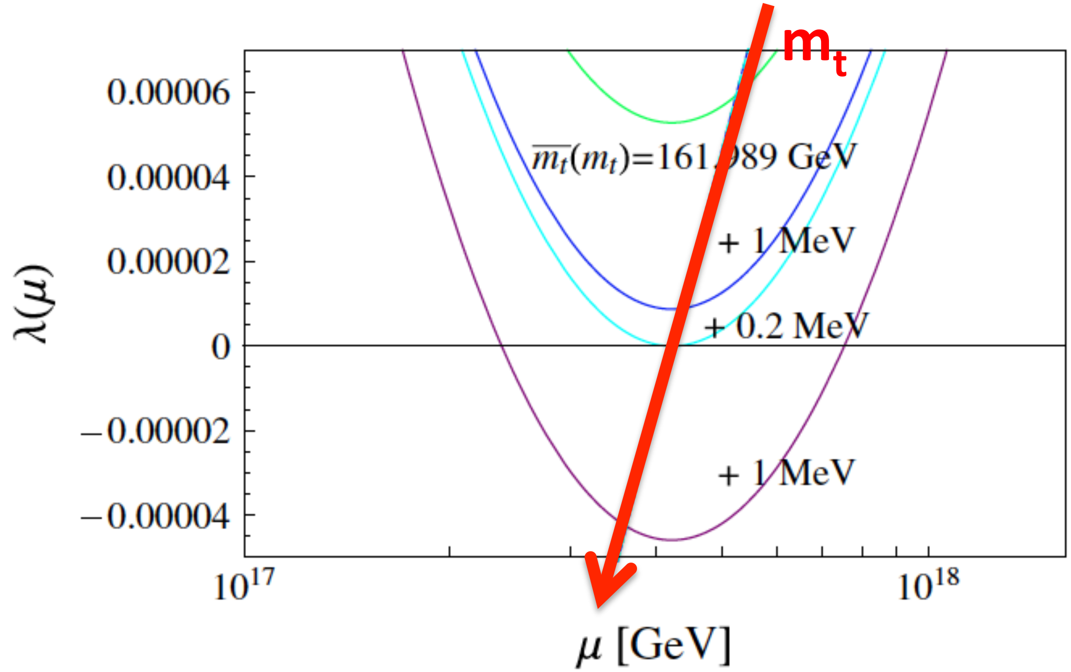
Fix $m_H$ = 126 GeV and $\alpha_3(m_Z)$

**Increasing $m_t$**
**$\lambda$ goes negative…**

$$V(\phi_H) \approx \frac{\lambda(\mu)}{24}\phi_H^4$$

- $\lambda(\mu) > 0$ stability
- $\lambda(\mu) < 0$ metastability

**… and V is destabilized**



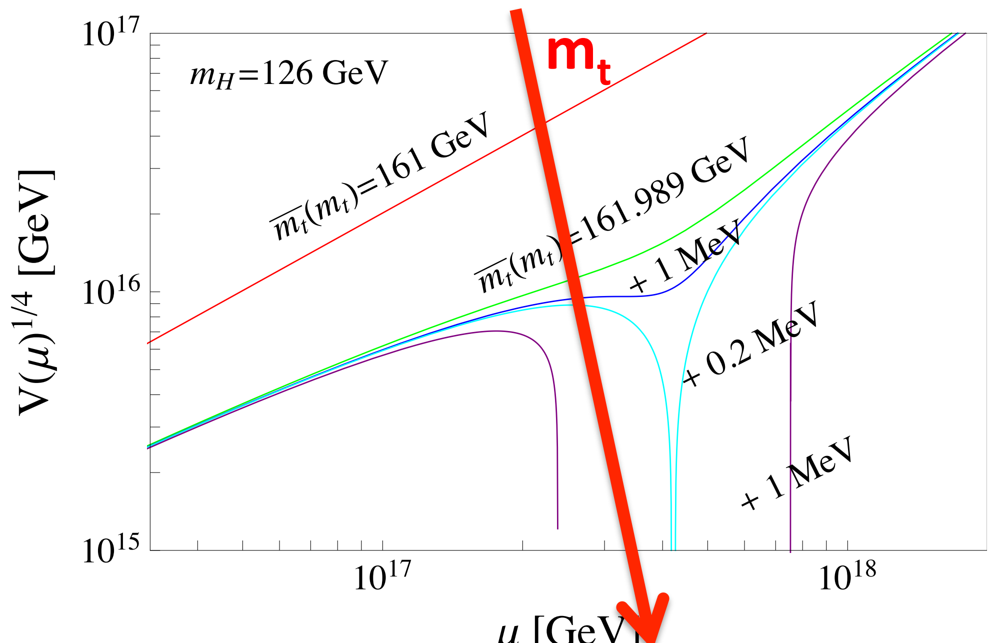




Fig from: IM, PRD 1209.0393

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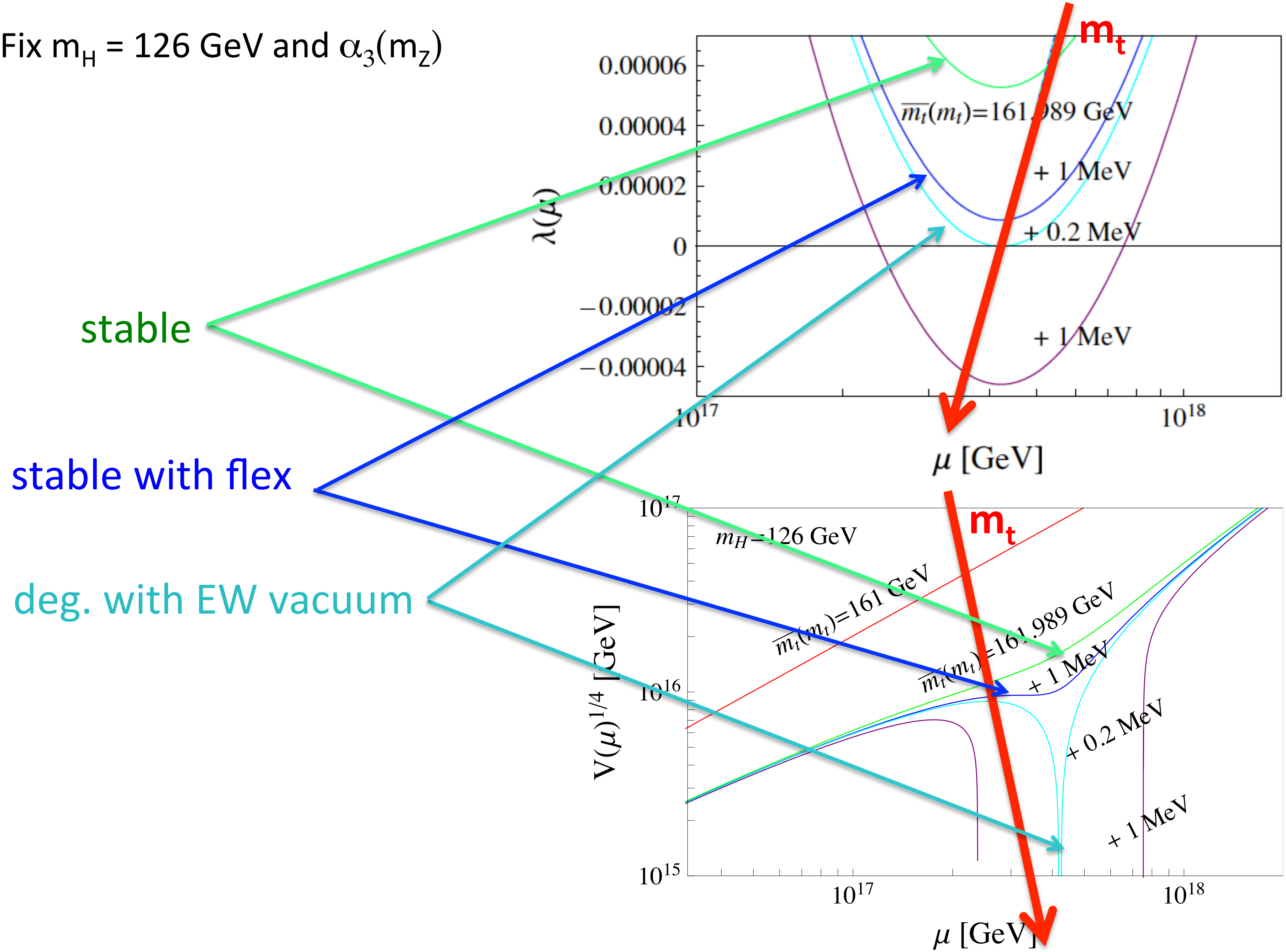


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Fix $m_H$ = 126 GeV and $\alpha_3(m_Z)$

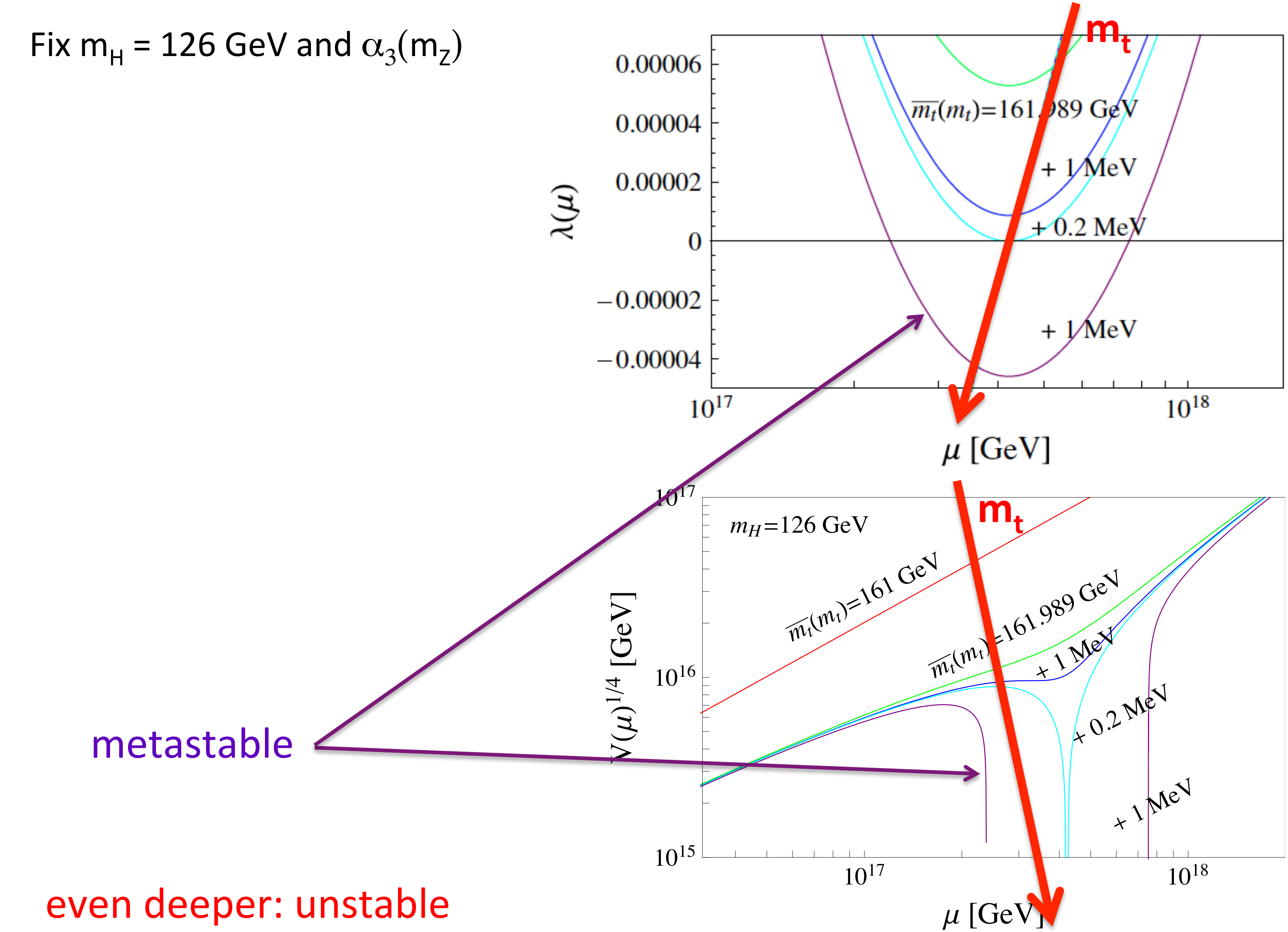
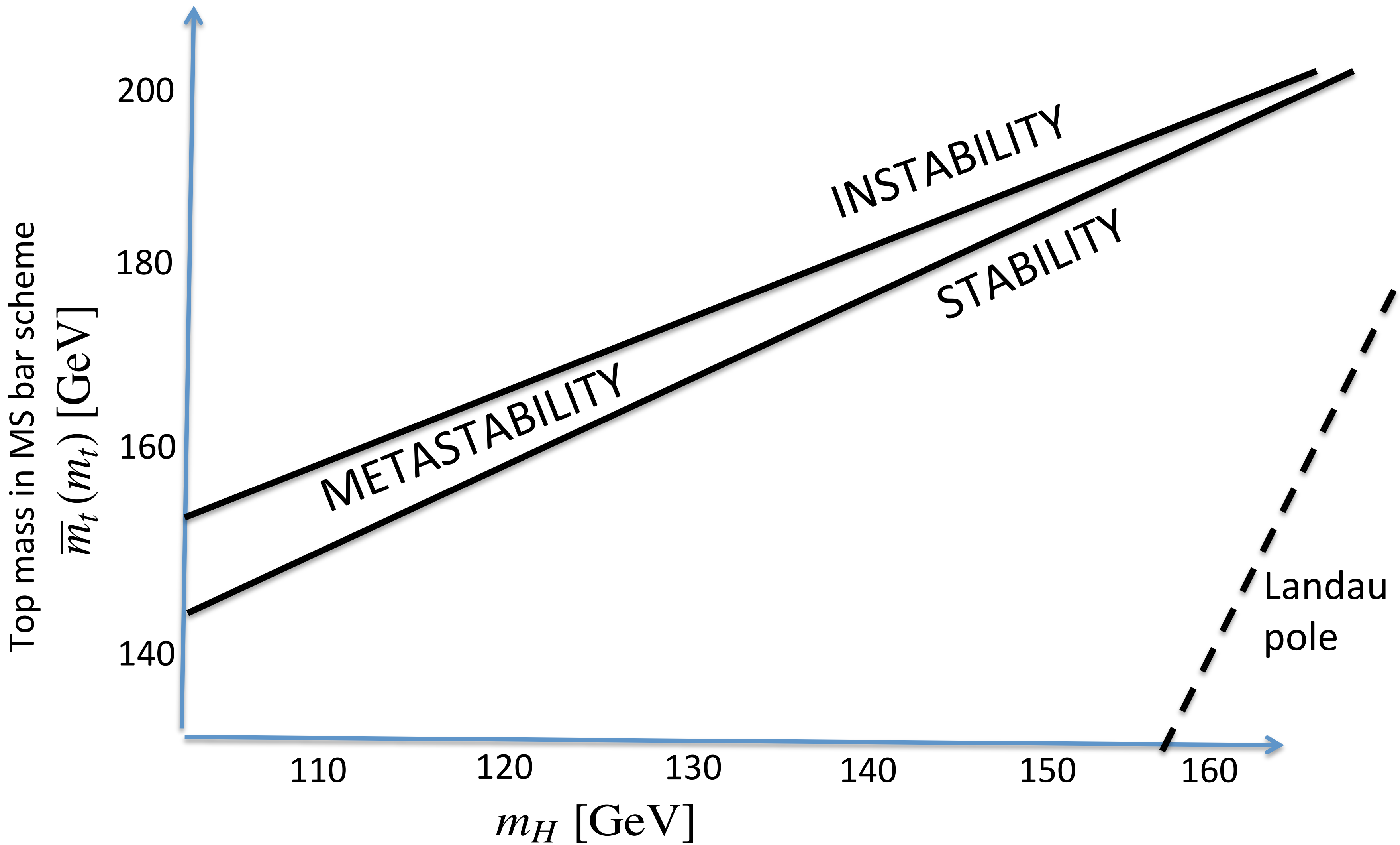
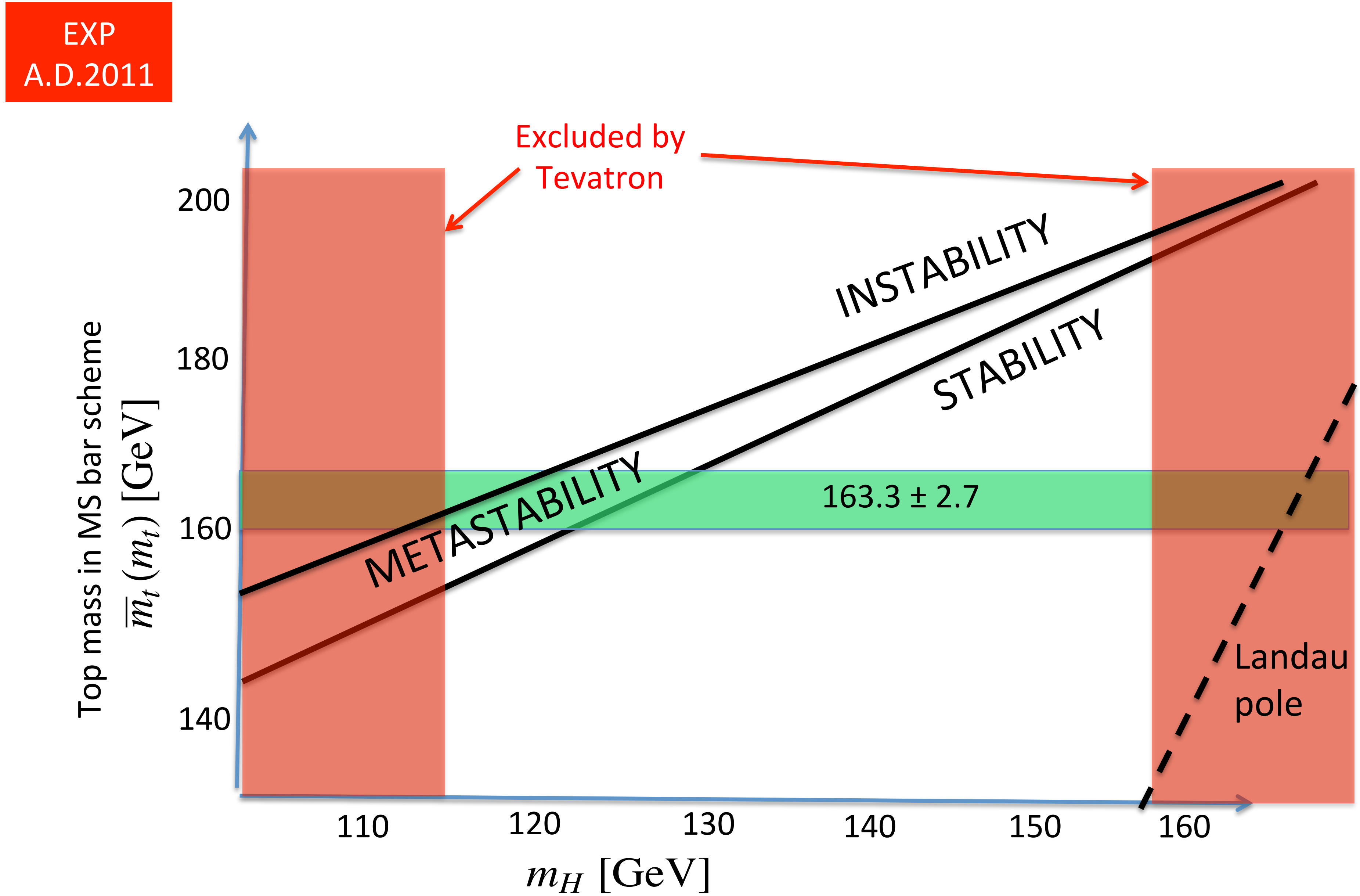



Fig from: IM, PRD 1209.0393

# RESULTS



Top mass in MS bar scheme
$\overline{m}_t(m_t)$ [GeV]
200
180
160
140
INSTABILITY
METASTABILITY
STABILITY
Landau
pole
110
120
130
140
150
160
$m_H$ [GeV]



EXP
A.D.2011
Excluded by
Tevatron
200
180
160
140
Top mass in MS bar scheme
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INSTABILITY
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METASTABILITY
163.3 ± 2.7
Landau
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110
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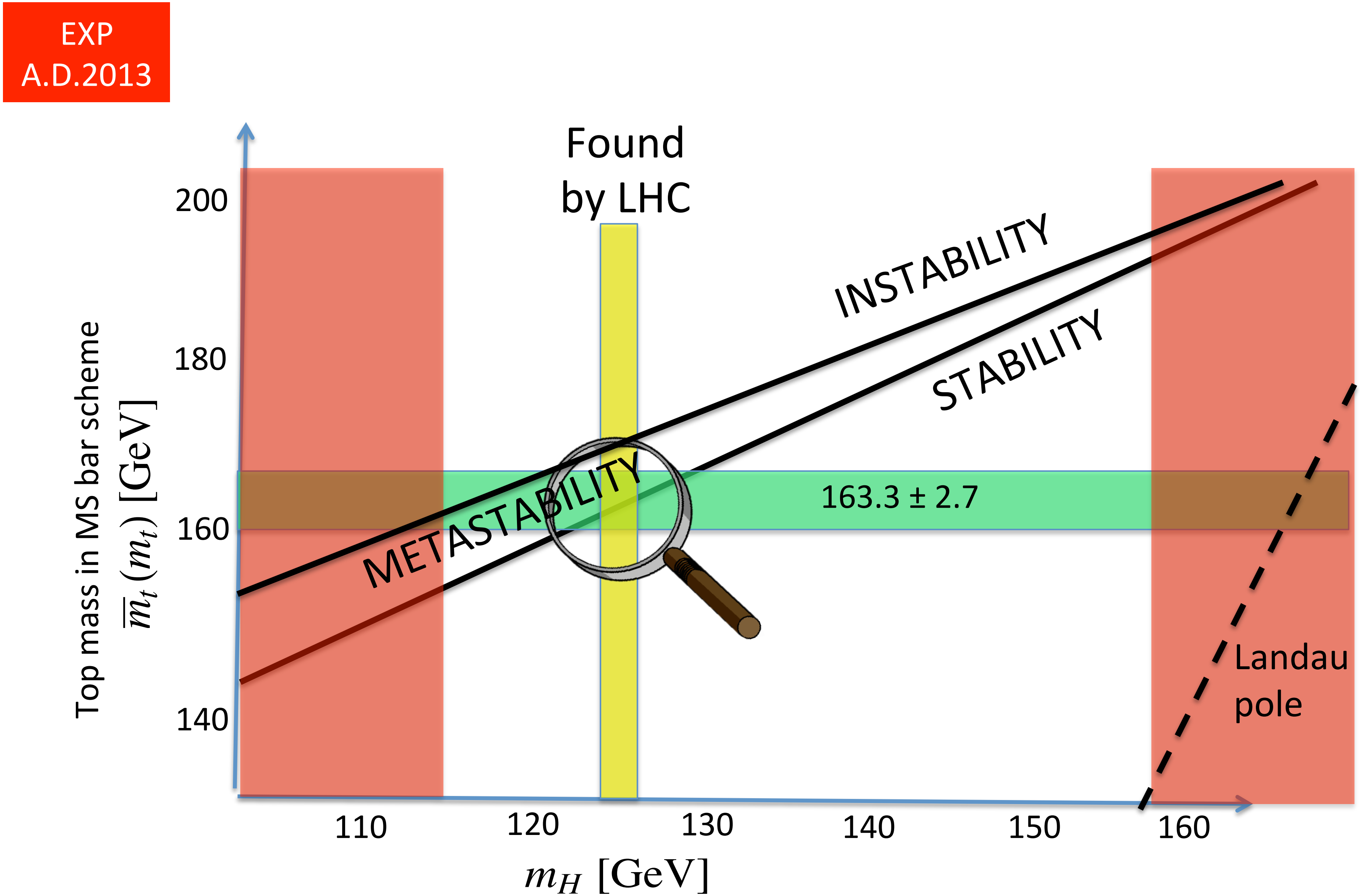
EXP
A.D.2013
Found
by LHC
200
180
160
140
Top mass in MS bar scheme
$\overline{m}_t(m_t)$ [GeV]
INSTABILITY
STABILITY
METASTABILITY
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Landau
pole
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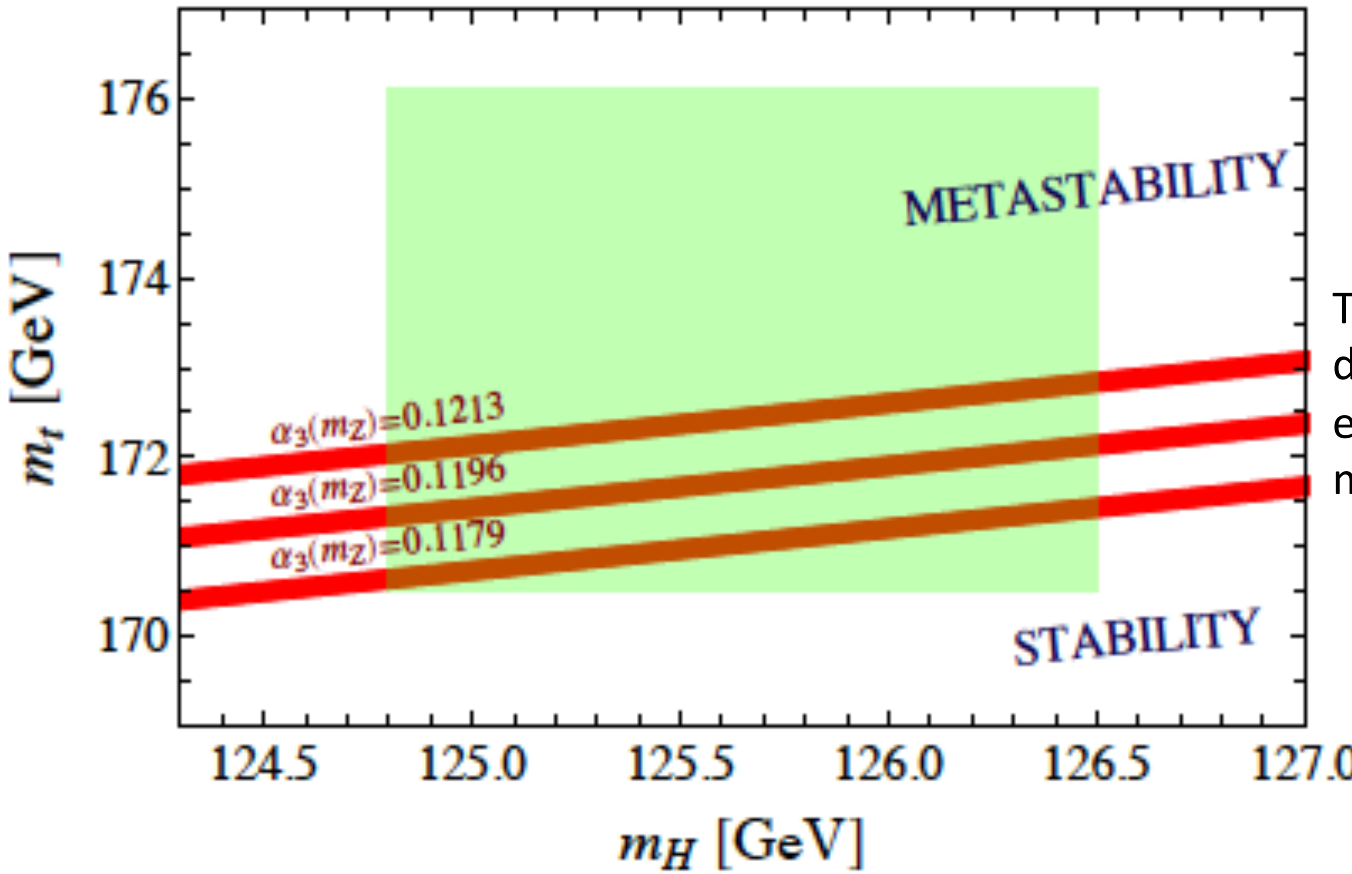
$m_H$ [GeV]

IM, PRD arXiv:1209.0393



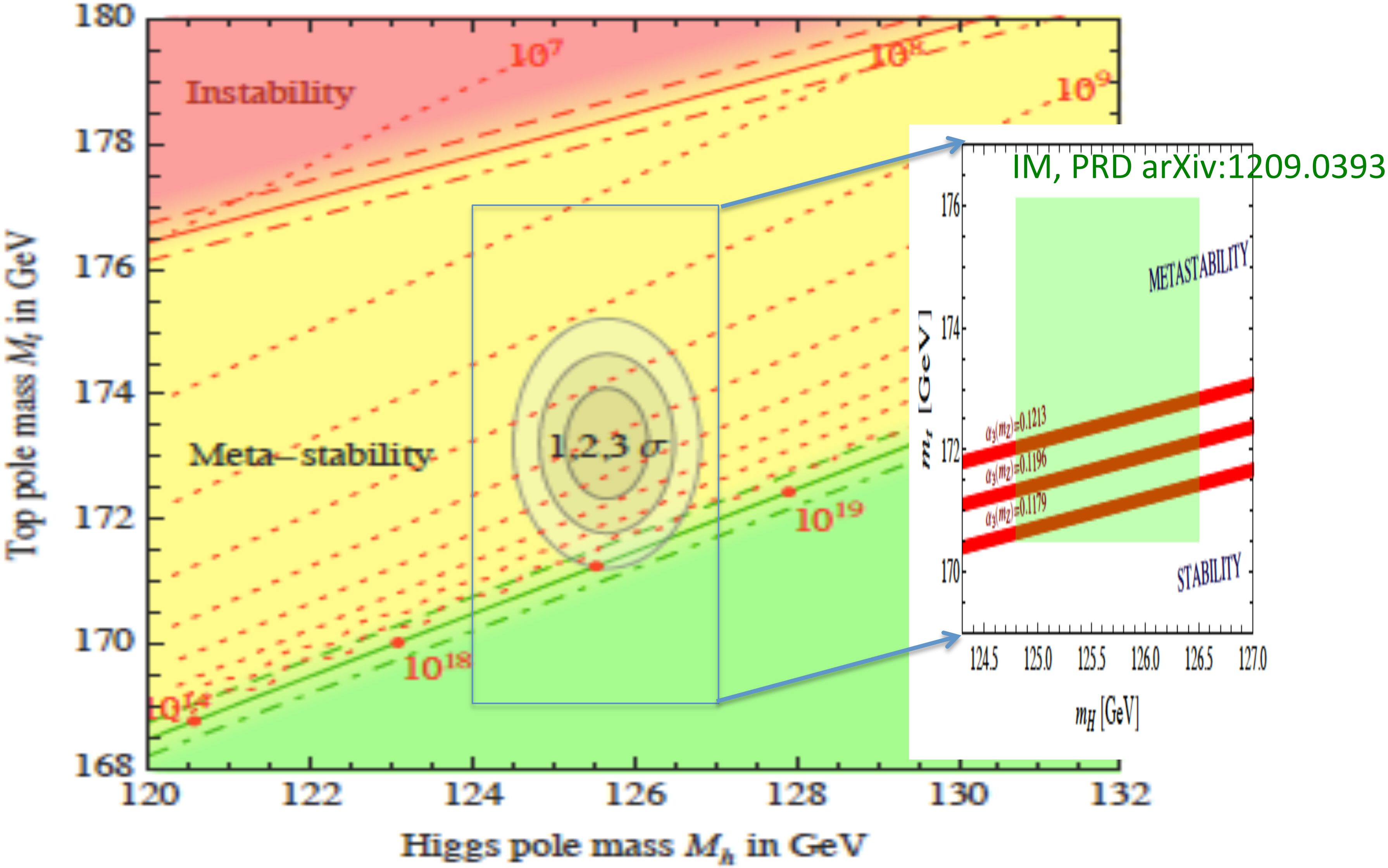

Thickness dominated by error due to matching of λ

STABILITY BOUND

$$\overline{m_t}(m_t)[\text{GeV}] \leq 162.0 + 0.47\,(m_H[\text{GeV}] - 126) + 0.7\left(\frac{\alpha_3(m_Z) - 0.1196}{0.0017}\right) - 0.2^{(\mu_\lambda)}_{th}$$

…essentially agrees with results obtained via the other method for: $m_t = \overline{m_t} + 10$ GeV

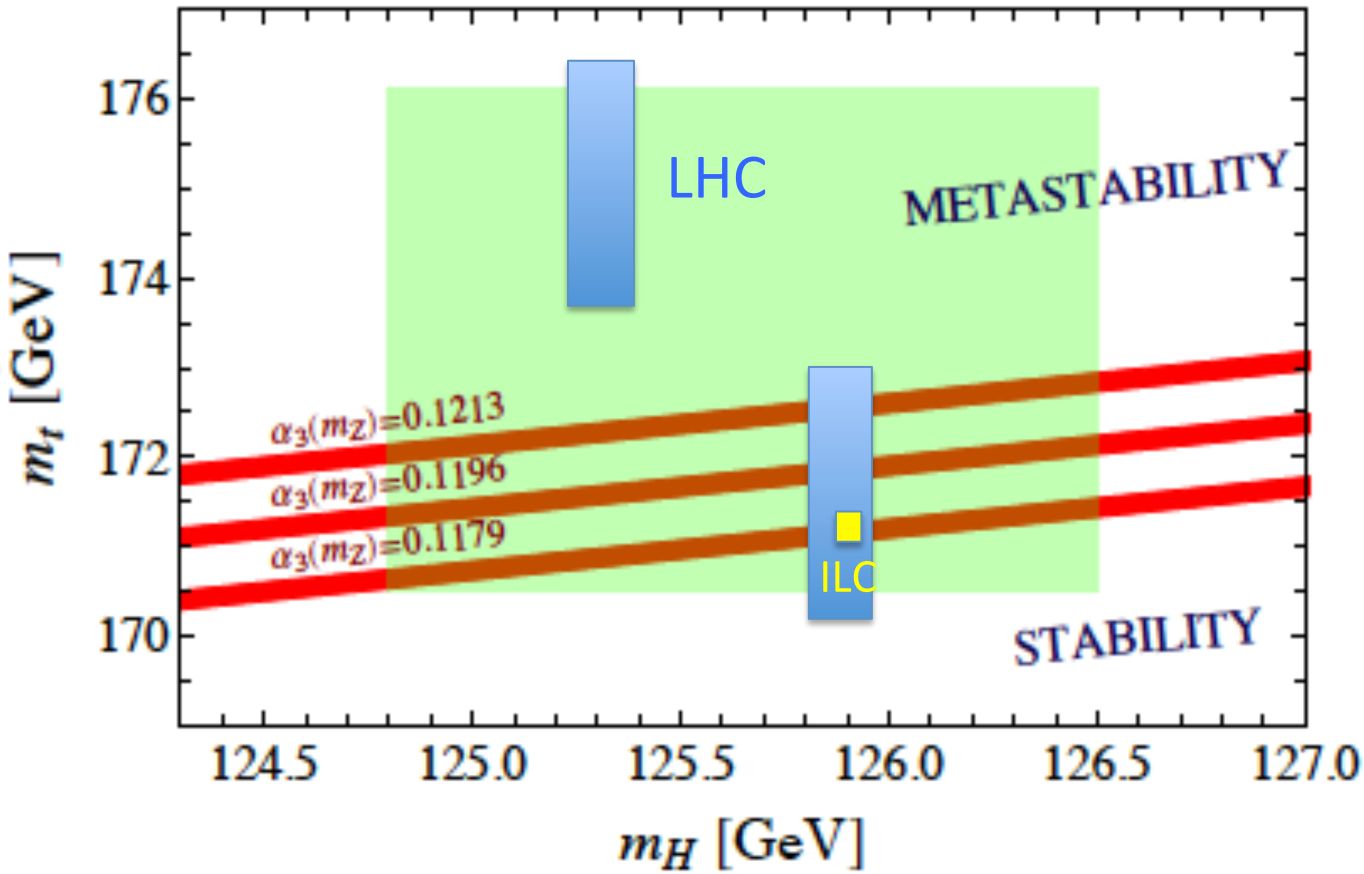
Fig from: Buttazzo Degrassi Giardino Giudice Sala Salvio Strumia, JHEP 1307.3536




… anyway results are essentially the same!

PROSPECTS

NEED MORE PRECISE MEASURE




For a recent paper on the determination of $m_t$ see e.g. S. Frixione 1407.2763

Possible to **stabilize** the Higgs potential
in case it will turn out that the SM one is metastable?

YES! e.g. extend the SM by including scalar

[J.Elias-Miro, J.R.Espinosa, G.F.Giudice, H.M.Lee , 1203. 0237]

…instead seesaw neutrinos could destabilize!

# 2) Higgs inflation

Now that we have some idea of the shape of SM Higgs potential "hill",
is it possible to exploit it for inflation?

YES! If, for some reason, there has been a period in which the Hubble rate was dominated by a nearly constant $V_H > 0$

$$\left(\frac{\dot{a}(t)}{a(t)}\right)^2 \equiv H(t)^2 \cong \frac{V_H(\mu_0)}{3M_{Pl}^2}$$

$V_H$ acts as cosmological constant term

$$a(t) \propto e^{H\,t}$$

EXPONENTIAL EXPANSION

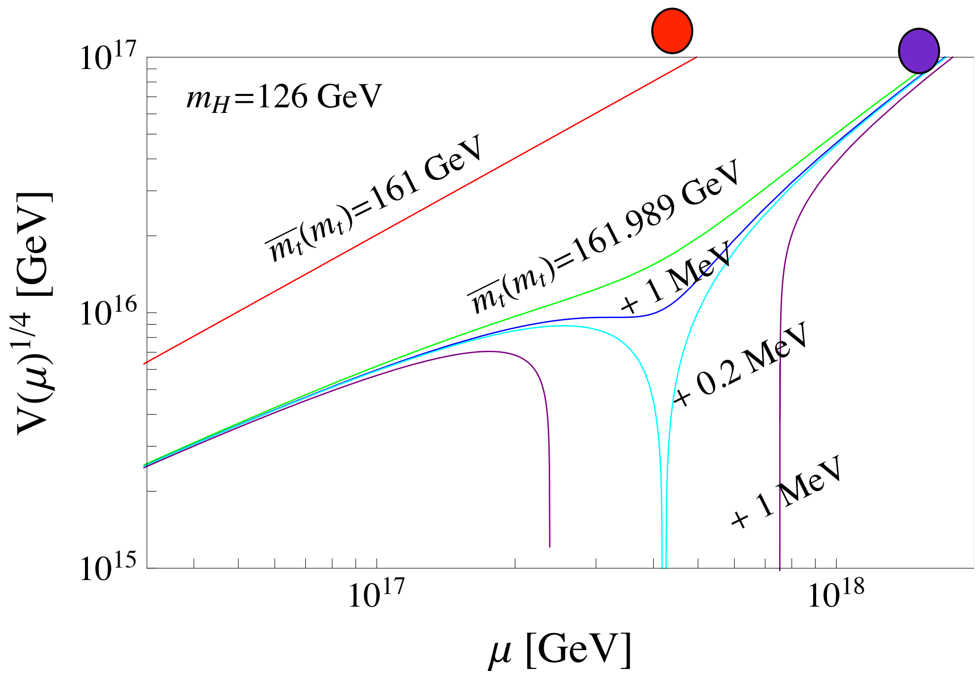
$(\phi < M_{Pl})$

# Small field:

does not work in the "pure" SM (without any addition)

because

there is **no slow roll** in general



$(\phi < M_{Pl})$

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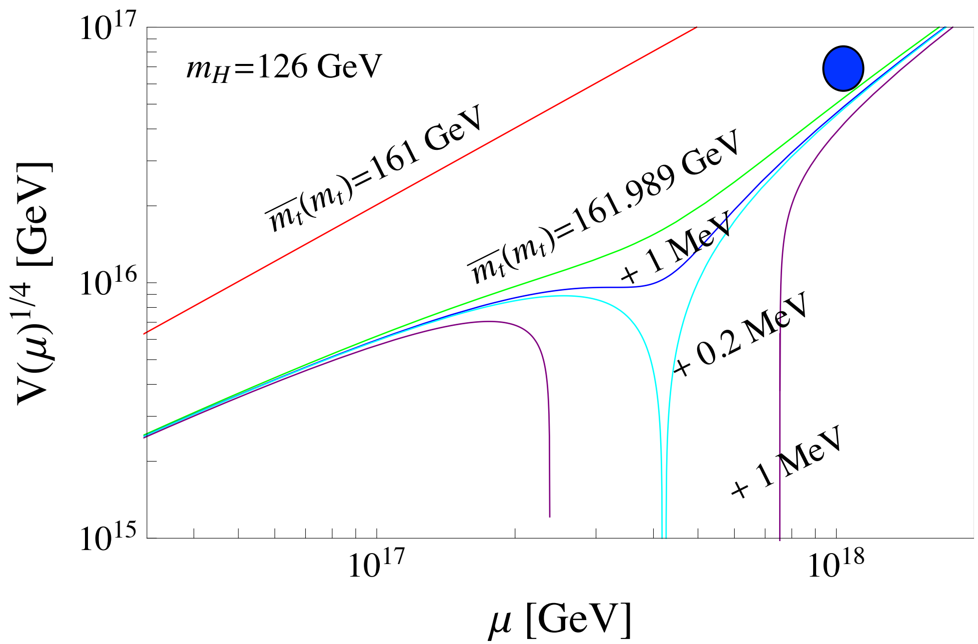


With an **inflection point slow roll** can occur …

…but there are not enough e-folds for inflation

[see e.g. G.Isidori V.Rychkov A.Strumia N.Tetradis, 0712.0242]

These conclusions holds for a **rolling** Higgs having
**canonical kinetic term** and **minimal coupling to gravity**

$$S = \int d^4x \sqrt{-g} \left( \frac{M^2}{2} R - \frac{1}{2} (\partial h)^2 - \frac{\lambda}{4} (h^2 - v^2)^2 \right)$$

There would arise possibilities that the SM Higgs field is the inflaton
if we loose the above assumptions

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**canonical kinetic term** and **minimal coupling to gravity**

$$S = \int d^4x \sqrt{-g} \left( \frac{M^2}{2} R - \frac{1}{2} (\partial h)^2 - \frac{\lambda}{4} (h^2 - v^2)^2 \right)$$

$+\xi\, h^2$

There would arise possibilities that the SM Higgs field is the inflaton
if we loose the above assumptions

1

Flatten the Higgs potential:
e.g. via **non-minimal** gravitational coupling
(new inflation = slow roll)

These conclusions holds for a **rolling** Higgs having **canonical kinetic term** and **minimal coupling to gravity**

+curvaton

$$S = \int d^4x \sqrt{-g} \left( \frac{M^2}{2} R - \frac{1}{2} (\partial h)^2 - \frac{\lambda}{4} (h^2 - v^2)^2 \right)$$

There would arise possibilities that the SM Higgs field is the inflaton if we loose the above assumptions

**2**

The Higgs is **not rolling** but is trapped in a **false vacuum** (=old inflation); another slow rolling field acts as curvaton and as a clock to end inflation

# The NEW DATA from BICEP2

17 March 2014: **arXiv:1403.3985**

detected B-modes (curl component) of the polarization of the CMB at the level of

tensor-to-scalar
ratio of amplitudes

$$r = 0.20^{+0.07}_{-0.05}$$

disfavouring $r = 0$ at the level of $7\sigma$ ($5.9\sigma$ after foreground subtraction)

In a model were slow-roll is applicable

$(2.20 \pm 0.05) \times 10^{-9}$ at $k_0 = 0.002\,\mathrm{Mpc}^{-1}$

$$\Delta_R^2 = \frac{2}{3\pi^2}\frac{1}{r}\frac{V(\chi_0)}{M_{Pl}^4}$$

$0.20^{+0.07}_{-0.05}$

$\Rightarrow$ $V^{1/4} \approx 2 \times 10^{16}$ GeV

EXAMPLE 1

Non-minimal coupling Higgs Inflation
(new inflation type)

# BIBLIOGRAPHY

**F.Bezrukov M.Shaposhnikov, 0710.3755**

**"The Standard Model Higgs boson as the inflaton" Phys.Lett. B659 (2008) 703**

Following papers also in collaboration with **Gorbunov, Magnin, Sibiryakov, Kalmykov, Kniehl**
**0812.4950, 0904.1537,1008.5157, 1111.4397, 1205.2893**

**A.O.Barvinsky A.Kamenshchik C.Kiefer A.Starobinsky C.Steinwachs**
**0809.2104, 0910.1041**

**A. De Simone, M.P. Hertzberg F. Wilczek, 0812.4946**

**L.A. Popa, N. Mandolesi, A. Caramete, C. Burigana, 0907.5558, 0910.5312, 1009.1293**

**H.M. Lee G.Giudice O. Lebedev, 1010.1417, 1105.2284**

**H.M. Lee 1301.1787**

etc

**After BICEP2, see e.g.**

**F.Bezrukov M.Shaposhnikov, 1403.6078**
**Y.Hamada H.Kawai K.Oda S.C.Park 1403.5043**

SM Higgs potential

Non minimal coupling of Higgs with gravity

$$1 + \frac{\xi h^2}{M^2}$$

$$\frac{\lambda}{4}(h^2 - v^2)^2$$

$$S = \int d^4x \sqrt{-g} \left( -\frac{M^2}{2} f(h) R + \frac{1}{2} \partial_\mu h \partial^\mu h - V(h) \right)$$

Non minimal coupling of Higgs with gravity

$$1+\frac{\xi h^2}{M^2}$$

SM Higgs potential

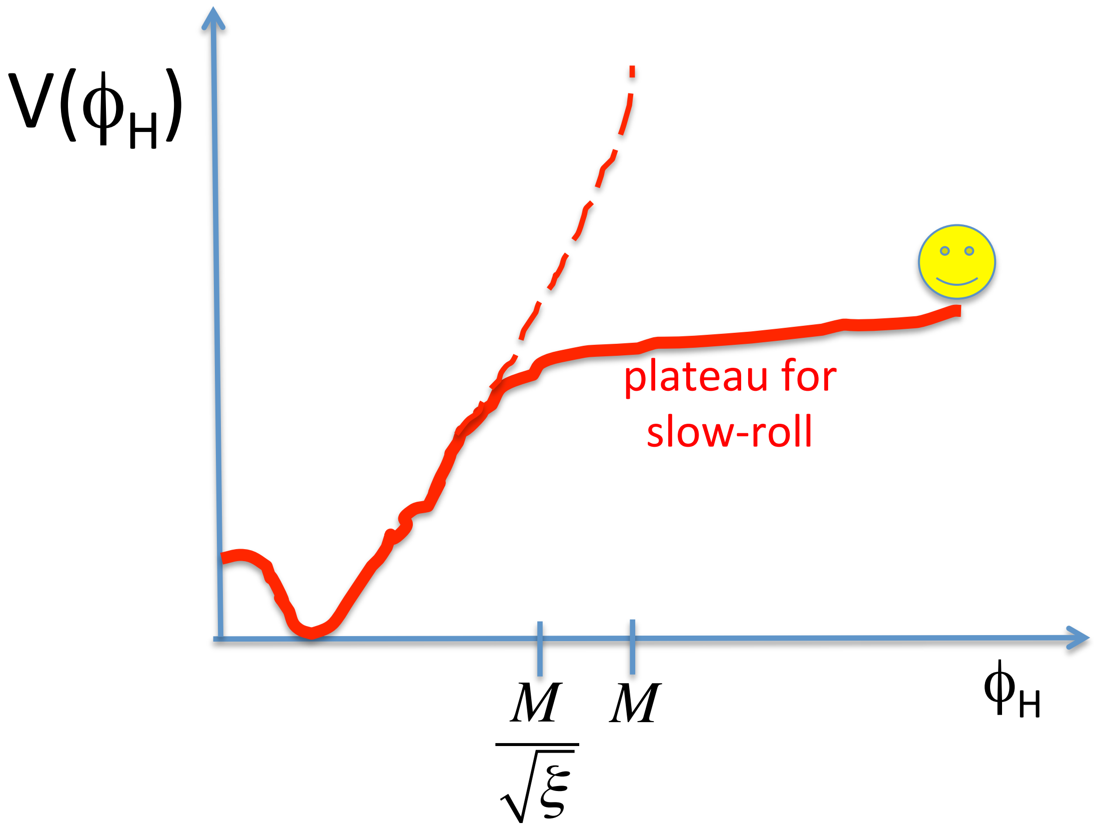
$$\frac{\lambda}{4}(h^2-v^2)^2$$

$$S=\int d^4x\sqrt{-g}\left(-\frac{M^2}{2}f(h)R+\frac{1}{2}\partial_\mu h\partial^\mu h-V(h)\right)$$

Upon conformal transformation to Einstein frame and redefinition of Higgs field to have canonical kinetic term

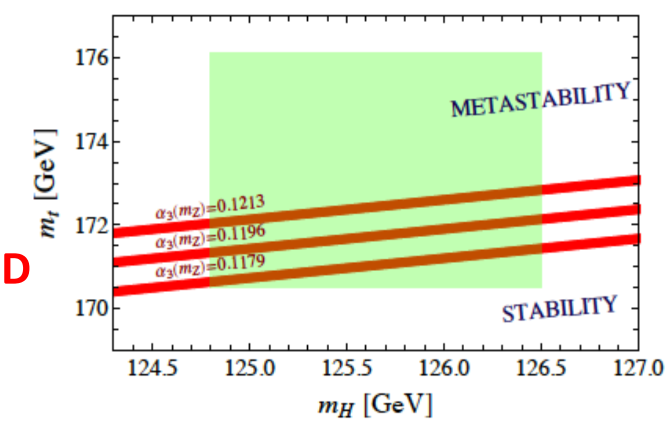
Higgs potential flattened below Planck scale

$$S_E=\int d^4x\sqrt{-\hat{g}}\left(-\frac{M^2}{2}\hat{R}+\frac{\partial_\mu\chi\partial^\mu\chi}{2}-\frac{\frac{\lambda}{4}h^4}{(1+\frac{\xi h^2}{M^2})^2}\right)$$



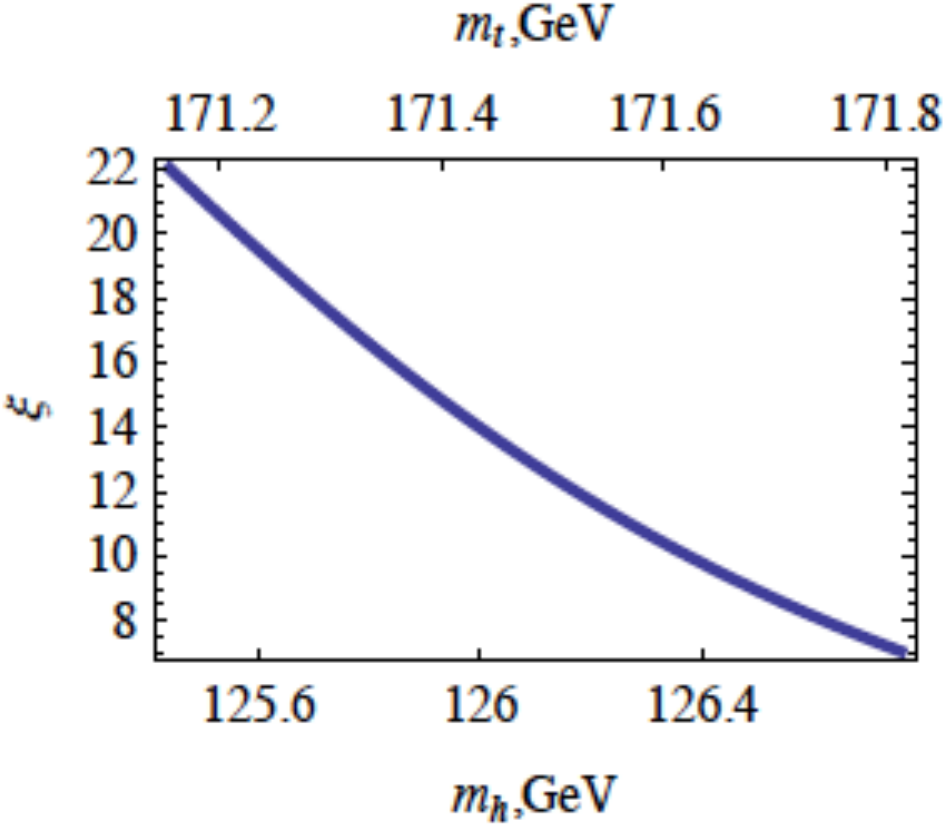

A configuration more (or as stable as) an inflection point is necessary for Higgs inflation via non-minimal gravitation couplings

**stay on RED BAND**



# A non-minimal coupling of about 10 might do the job

(for quite low $m_t$ and quite high $m_H$ )




F.Bezrukov M.Shaposhnikov, 1403.6078

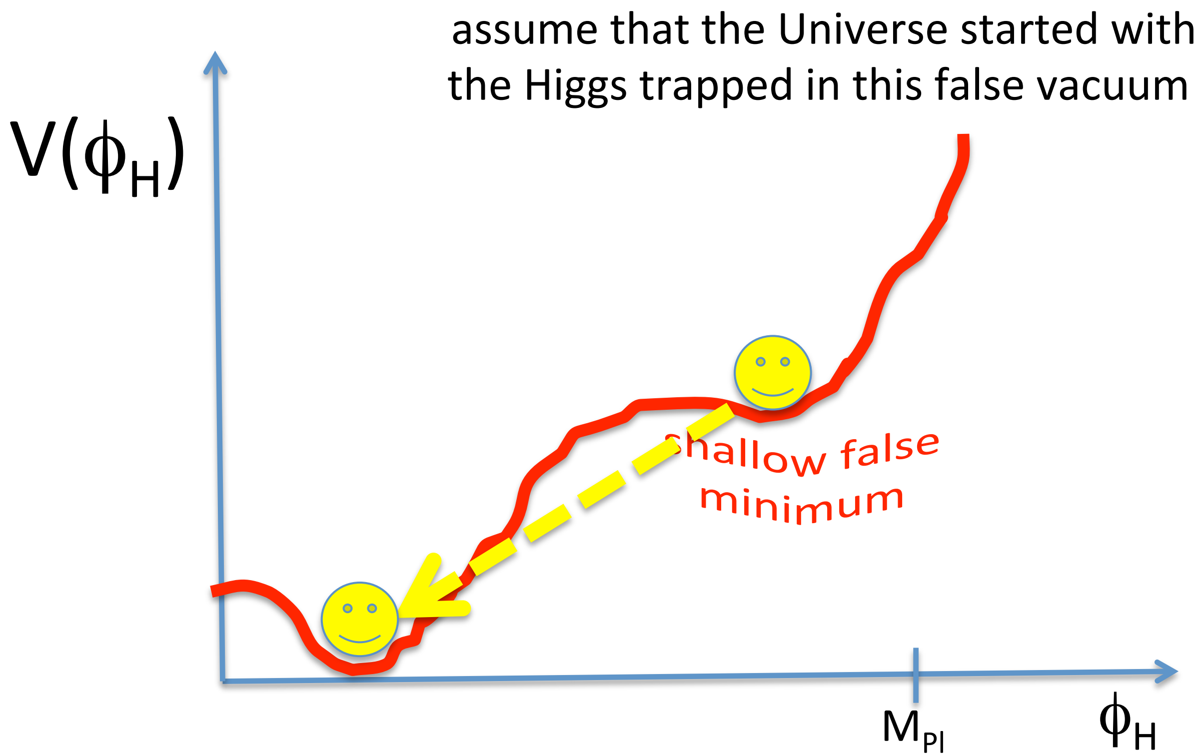
EXAMPLE 2

Shallow false minimum
(old inflation type revisited)

**BIBLIOGRAPHY**

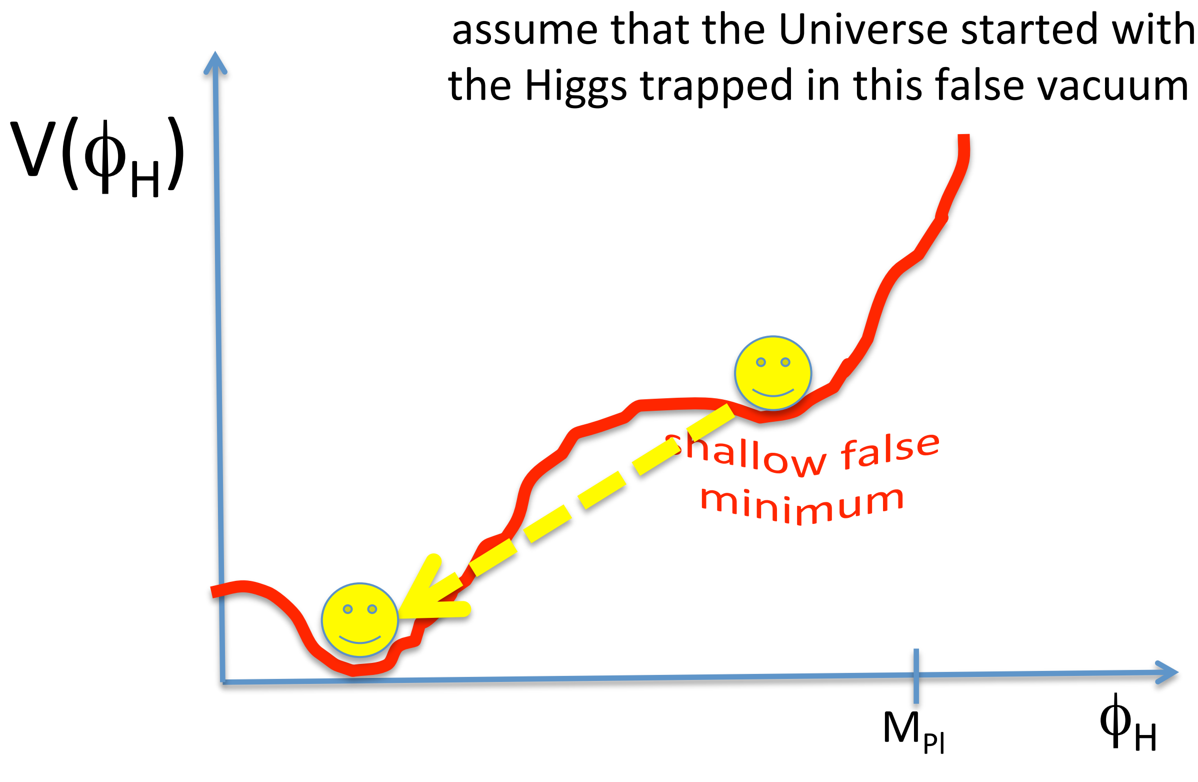
**I.M. A.Notari,** Phys.Rev. D85 (2012) 123506 [1112.2659],
Phys.Rev.Lett. 108 (2012) 191302 [1112.5430],
JCAP 1211 (2012) 031 [1204.4155]

**After BICEP2, see e.g.** **I.M., PRD 1403.5244**



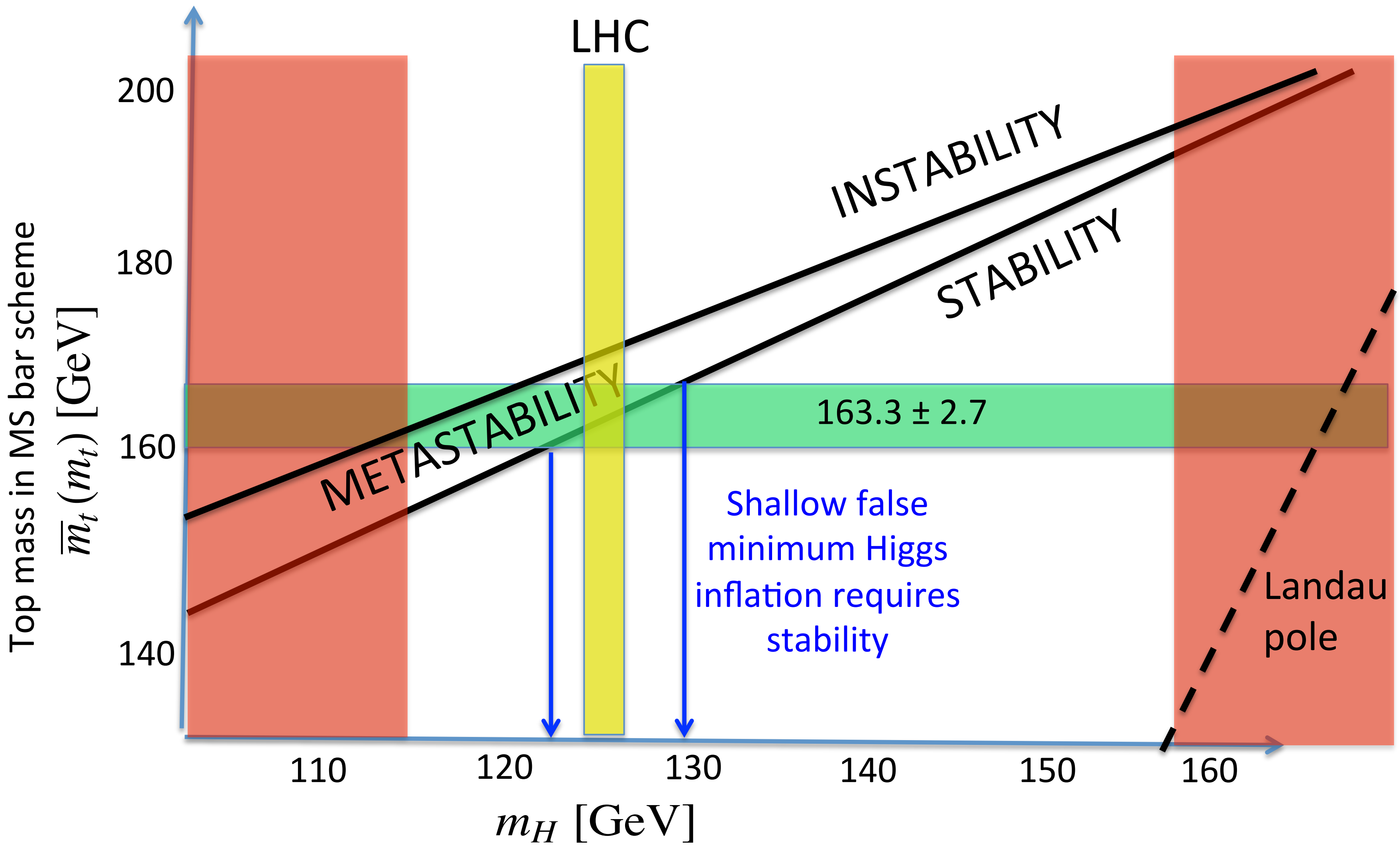

Inflation ends thanks to some other mechanism

In this scenario the Higgs cannot be the curvaton

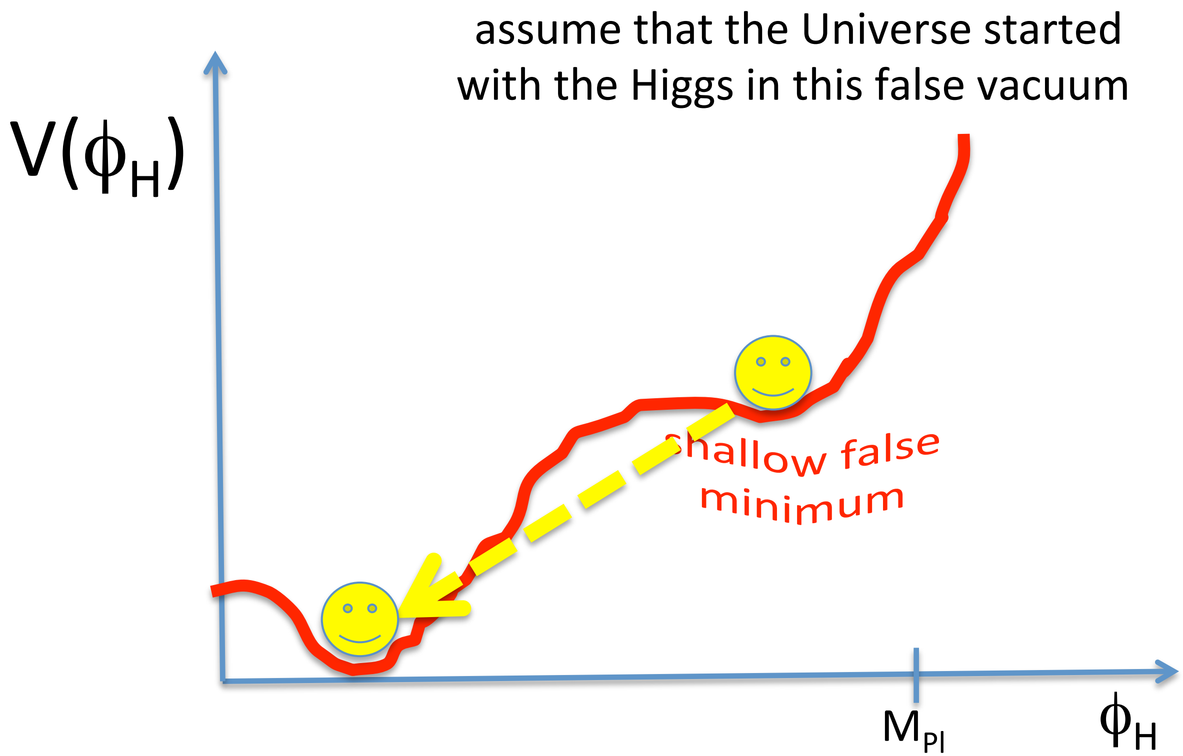



NB 1. This scenario required $m_H$ = 123-130 GeV (before Higgs discovery)

Before LHC…




Prediction that $m_H$ is in the range 123-130 GeV appeared on the arXiv before LHC 3σ announcement [I.M. A.Notari 1112.2659]



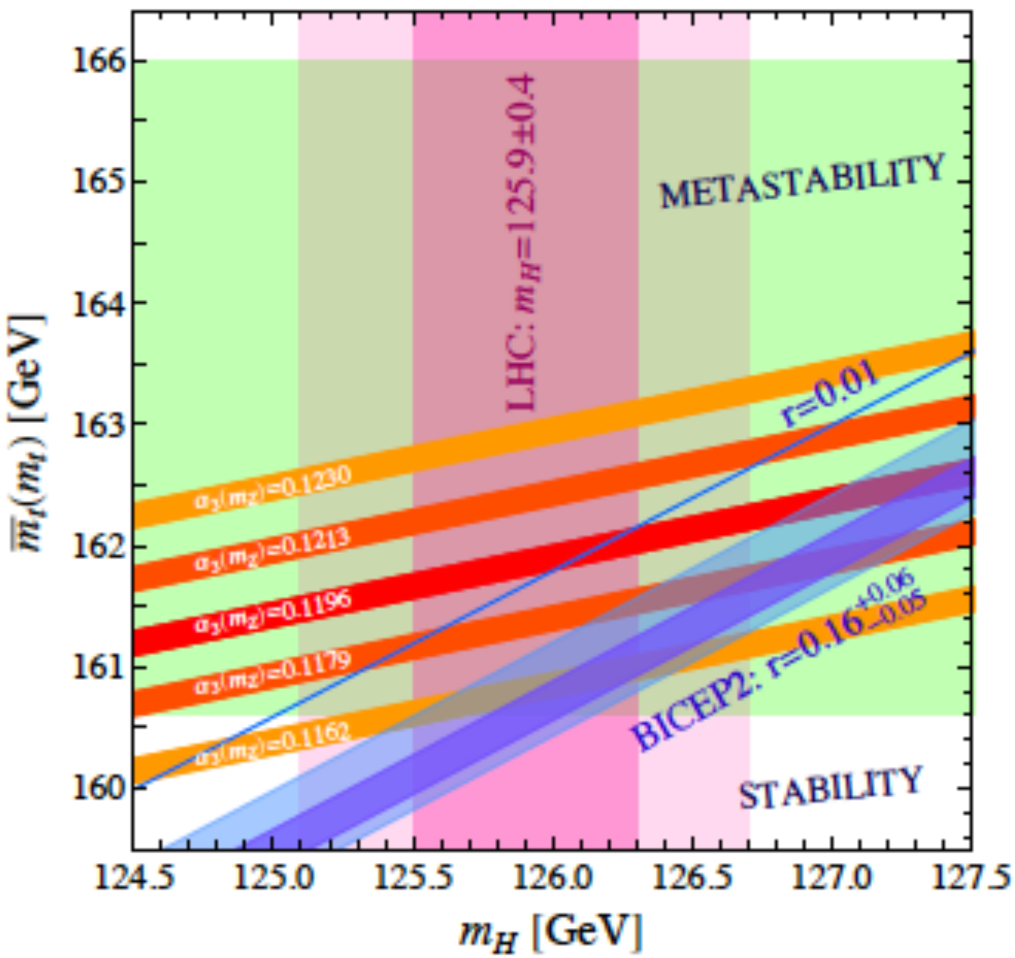

NB 1. This scenario required $m_H$ = 123-130 GeV (before Higgs discovery)

NB 2. Clean prediction for r ($n_s$ is instead model dependent)

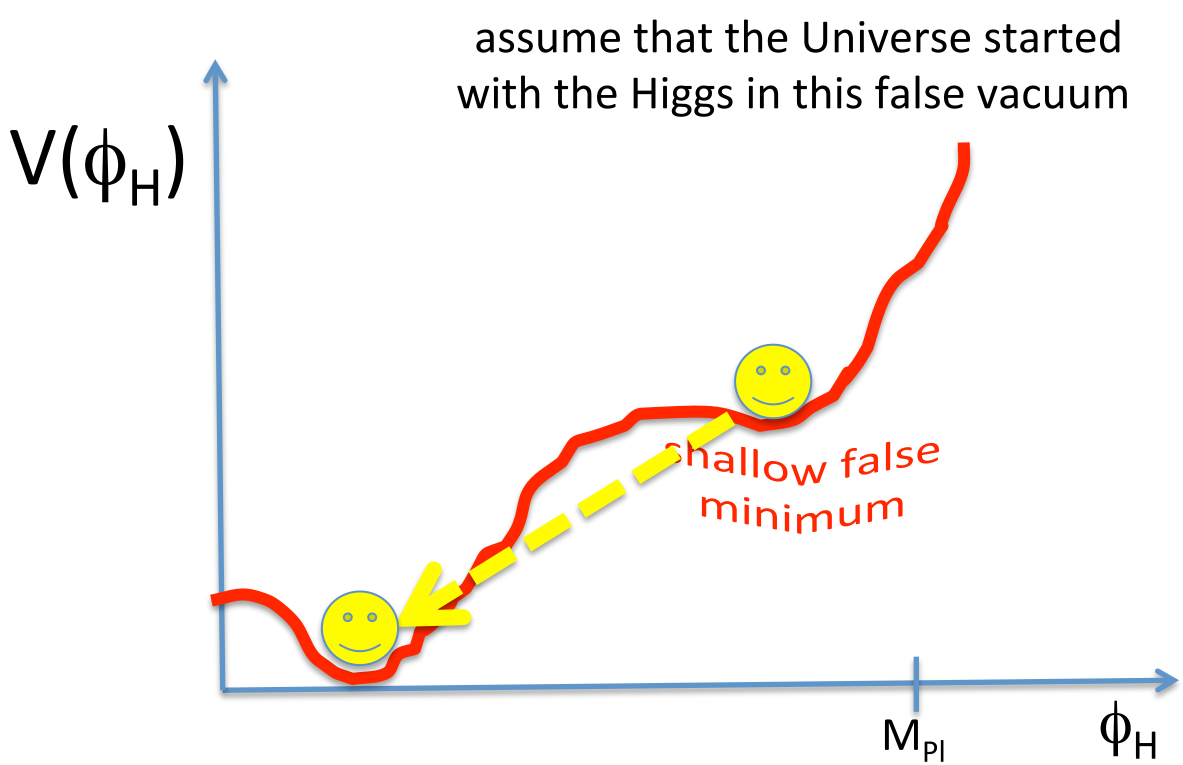
$$2 \times 10^{-9} \approx \Delta_R^2 = \frac{2}{3\pi^2} \frac{1}{r} \frac{V_H(\mu_0)}{M^4}$$

determined by $m_H$
($m_t$ choosen in order to have false minimum)

IM, PRD 1403.5244




BICEP2 can be accomodated within $2\sigma$:
large $m_H$
small $m_t$
small $\alpha_3(m_Z)$




**Realizations of the scenario:**

A model in scalar-tensor gravity & a model with hybrid inflation

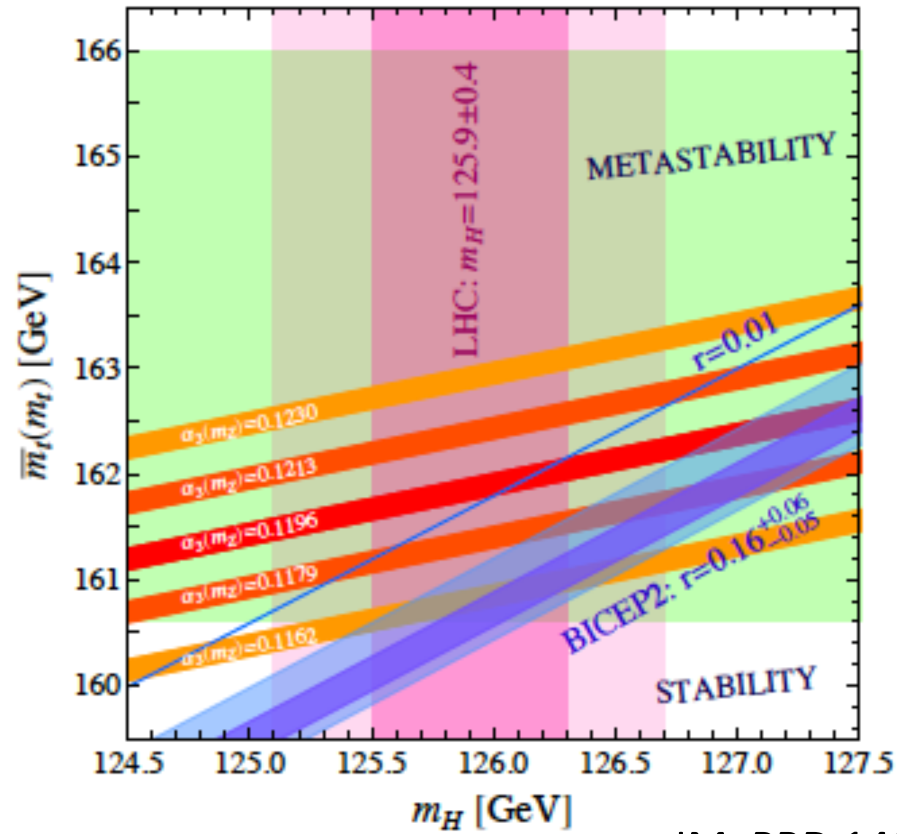
IM Notari, arXiv:1112.2659, ~~1204.4155~~

Not satisfactory but maybe…

KO because or r and $n_s$
[see e.g. Fairbairn et al 1403.7483]

Anyway…

the numerical concordance is so intriguing




IM, PRD 1403.5244

→ worth to develop more models to better explore the idea of shallow false minimum Higgs inflation

# CONCLUSIONS

1) Stability/Metastability of the Higgs potential in the SM: calls for more precise measurement of top mass

2) SM Higgs inflation models:
   seem promising and calls for confirmation of r

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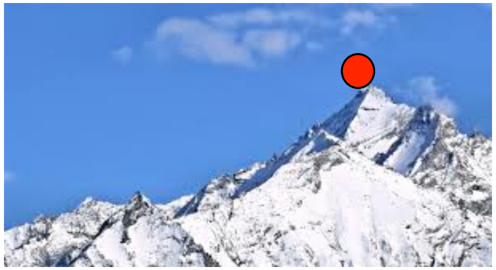
1) Stability/Metastability of the Higgs potential in the SM: calls for more precise measurement of top mass

2) SM Higgs inflation models: seem promising and calls for confirmation of r



**The measured value of the Higgs boson mass is intriguing!!**

# backup

## Main difficulty of the false vacuum scenario: provide a **graceful exit** from inflation

To end inflation the field have to tunnel by nucleating bubbles which eventually collide and reheat the Universe.
If

$$H^4 >> \Gamma$$

nucleation rate per unit time and volume

There are enough e-folds of inflation
…but an insufficient number of bubbles is produced inside a Hubble horizon…

A graceful exit would require that after some time

$$H^4 \leq \Gamma$$

But in standard gravity as both are time-independent:
That's why old inflation [Guth '80] was abandoned

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A graceful exit would require that after some time $H^4 \leq \Gamma$

Time dependent H is possible e.g. in a scalar-tensor theory of gravity

For power-low expansion
(extended or hyperextended inflation)

C.Mathiazhagan V.B.Johri, 1984
D.La P.J.Steinhardt, 1989
P.J.Steinhardt F.S.Accetta, 1990

For exponential expansion followed by power-low

T.Biswas F.Di Marco A.Notari, 2006

# Higgs false vacuum inflation via scalar-tensor gravity

[IM Notari, arXiv:1112.2659]

A new scalar ϕ decoupled from the SM but coupled to gravity

$$1+\gamma_n\left(\frac{\phi}{M}\right)^n$$

n=2,4,6,8,...

$$-S=\int d^4x\sqrt{-g}\left[\mathcal{L}_{SM}+\frac{(\partial_\mu\phi\partial^\mu\phi)}{2}-\frac{M^2}{2}f(\phi)R\right]$$

# Higgs false vacuum inflation via scalar-tensor gravity

[IM Notari, arXiv:1112.2659]

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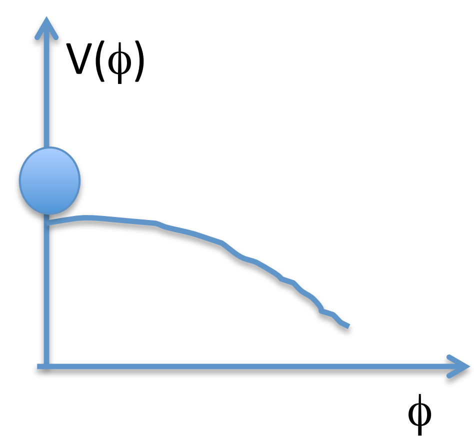
$$-S=\int d^4x\sqrt{-g}\left[\mathcal{L}_{SM}+\frac{(\partial_\mu\phi\partial^\mu\phi)}{2}-\frac{M^2}{2}f(\phi)R\right]$$

Einstein frame potential is dominated by the Higgs field

$$\bar{V}(\Phi)=V_H(\chi_0)\left(1-2\gamma_n\left(\frac{\Phi}{M}\right)^n+\ldots\right)$$

→ exponential inflation until $\phi$ becomes large and H decreases. Power low inflation stage then allows Higgs tunnelling with efficient bubble production and collisions



Quantum fluctuations in $\phi$ generate the spectrum of density perturbations with

$$n_S \approx 1 - \frac{n-1}{n-2}\frac{2}{\bar{N}}$$

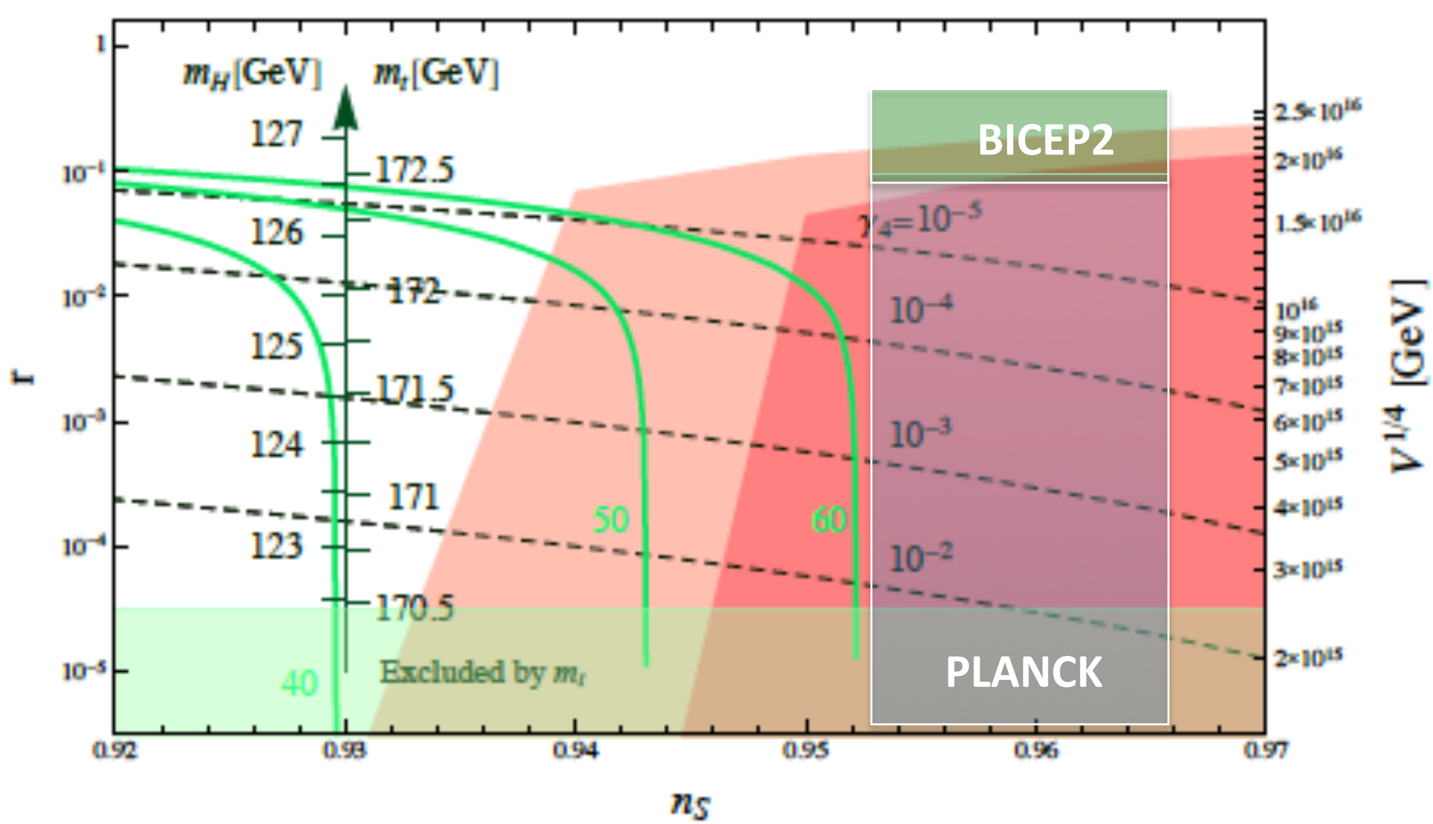
Number of efolds

Quantum fluctuations in φ generate the spectrum of density perturbations with

$$n_S \approx 1 - \frac{n-1}{n-2}\frac{2}{\bar{N}}$$

Number of efolds

n=4

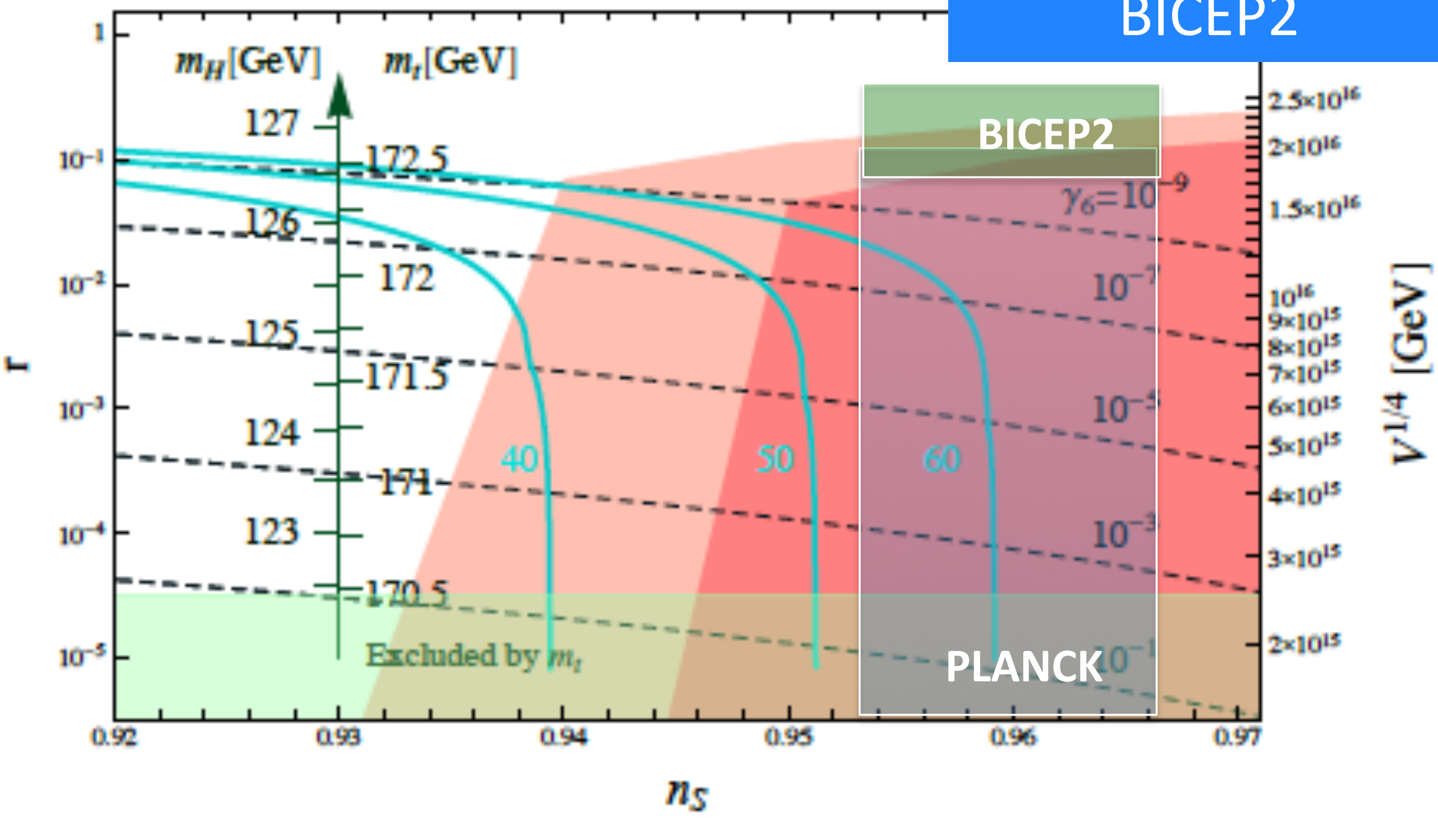


Quantum fluctuations in ϕ generate the spectrum of density perturbations with

$$n_S \approx 1 - \frac{n-1}{n-2}\frac{2}{\bar{N}}$$

Marginally consistent with BICEP2

n=6

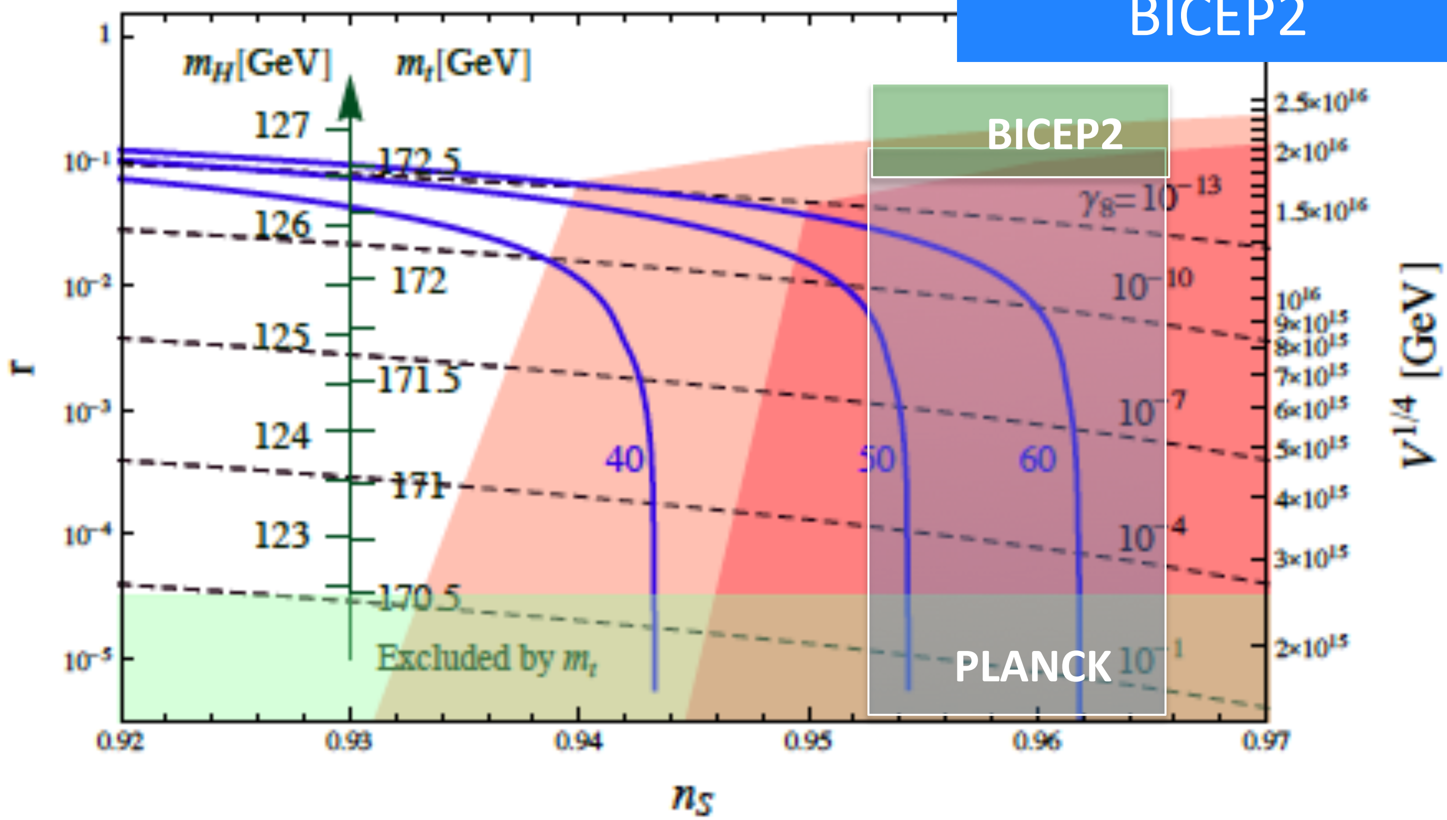


Quantum fluctuations in ϕ generate the spectrum of density perturbations with

$$n_S \approx 1 - \frac{n-1}{n-2}\frac{2}{\bar{N}}$$

n=8

Marginally consistent with BICEP2



# 3) Effect of neutrinos on the shape of the Higgs potential

# Type I seesaw Dirac Yukawa interactions neutrinos could destabilize V…

[Casas Ibarra Quiros, Okada Shafi, Giudice Strumia Riotto, Rodejohann Zhang, etc ]

# Type I seesaw Dirac Yukawa interactions neutrinos could destabilize V…

[Casas Ibarra Quiros, Okada Shafi, Giudice Strumia Riotto, Rodejohann Zhang, etc ]

$\mu > M_\nu$

$$\frac{dh_\nu(t)}{dt} = \kappa\, h_\nu(t)\left(\frac{5}{4}h_\nu(t)^2 + \frac{3}{2}h_t(t)^2 - \frac{3}{4}g'(t)^2 - \frac{9}{4}g(t)^2\right)$$

$$\delta\beta_\lambda^{(1)} = -3h_\nu(t)^4 + 2\lambda(t)h_\nu(t)^2 \ , \ \delta\beta_{h_t}^{(1)} = \frac{1}{2}h_\nu(t)^2$$

$\mu = M_\nu$

$$h_\nu(M_\nu) = 2\sqrt{\frac{m_\nu(M_\nu)\, M_\nu}{v^2}}$$

The larger is $h_\nu$
the larger is $M_\nu$

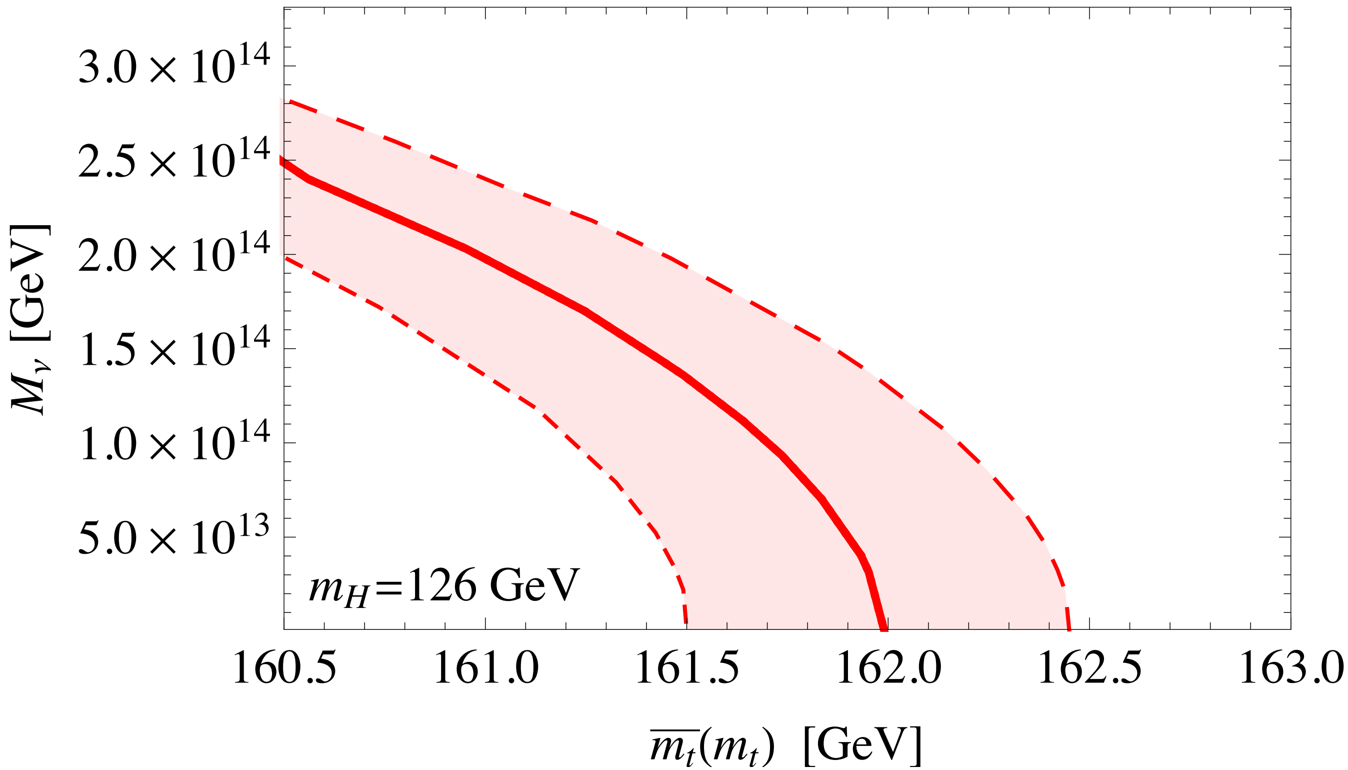
$\mu < M_\nu$

$$\frac{dm_\nu(t)}{dt} = \kappa\left(-3g_2(t)^2 + 6h_t(t)^2 + \frac{\lambda(t)}{6}\right)m_\nu(t)\ .$$

so that one matches with light neutrino masses

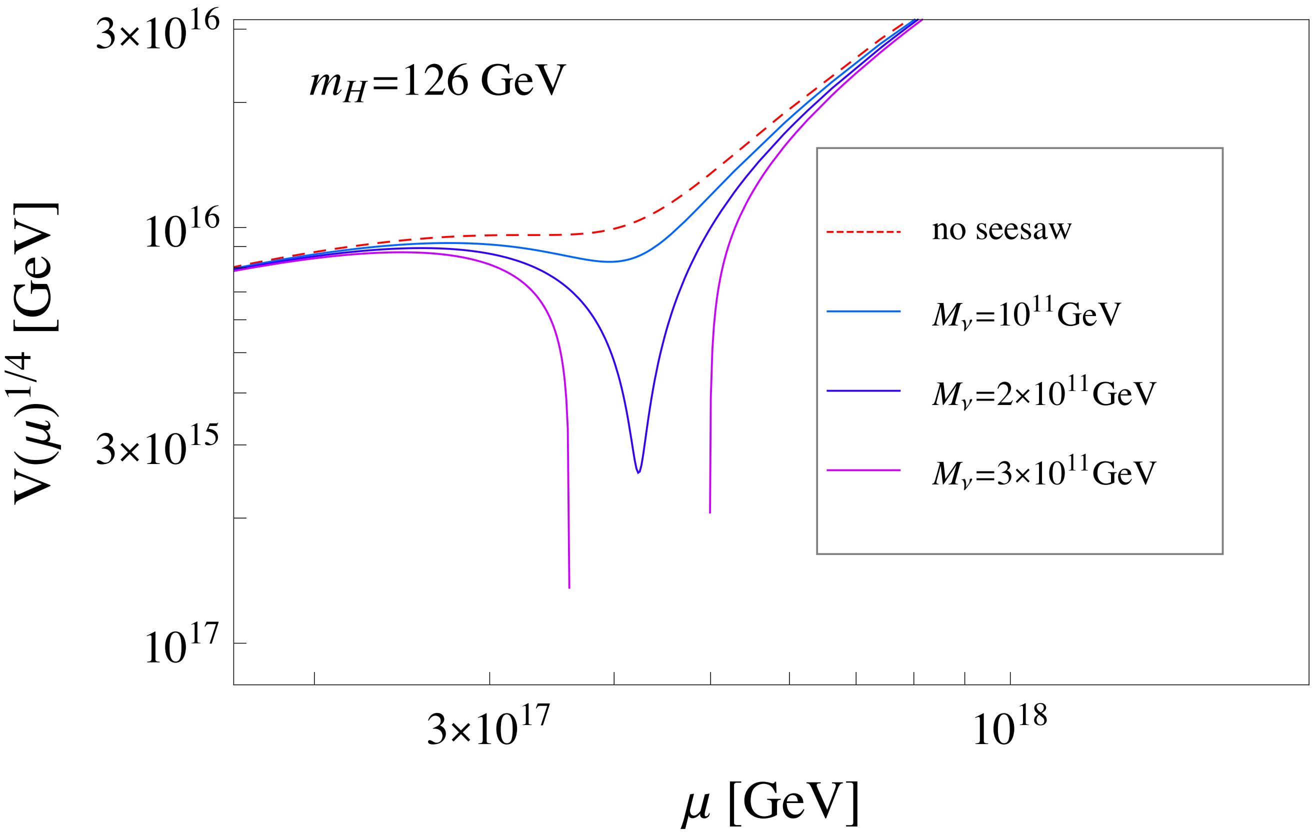
Requirement of stability of the Higgs potential
→ $h_\nu$ not too large → "upper bound" on $M_\nu$

E.g. : assume one generation giving $m_\nu$=0.06 eV




IM arXiv:1209.0393

The "upper bound" is even more stringent if one does not want to waste an inflection point configuration (interesting for inflation)




IM arXiv:1209.0393