Standard Model and beyond after the Higgs discovery

Gino Isidori
[ INFN, Frascati & CERN ]

Introduction
The Higgs potential at high energies
Stability and metastability bounds
Vacuum stability at NNLO
Speculations on Planck-scale dynamics
Conclusions
Introduction

All known phenomena in particle physics (leaving aside a few cosmological observations) can be described with good accuracy by a remarkably simple (effective) theory:

\[
\mathcal{L}_{SM} = \mathcal{L}_{\text{gauge}} (A_a, \psi_i) + \mathcal{L}_{\text{Symm. Break.}} (\phi, A_a, \psi_i)
\]

- **Natural**
- Experimentally tested with high accuracy
- Stable with respect to quantum corrections (UV insensitive)
- Highly symmetric

\[
\mathcal{L}_{\text{gauge}} = \sum_a - \frac{1}{4g_a^2} (F_{\mu\nu}^a)^2 + \sum_\psi \sum_i \bar{\psi}_i i\gamma^\mu \partial_\mu \psi_i
\]

- \(\mathcal{L}_{\text{gauge}}\) \(\times\)SU(3)\(c\) x SU(2)\(L\) x U(1)\(_Y\) local symmetry
- \(\mathcal{L}_{\text{gauge}}\) \(\times\) Global flavor symmetry
**Introduction**

All known phenomena in particle physics (*leaving aside a few cosmological observations*) can be described with good accuracy by a **remarkably simple** (effective) theory:

\[ \mathcal{L}_{SM} = \mathcal{L}_{gauge} (A_a, \psi_i) + \mathcal{L}_{Symm. Break.} (\phi, A_a, \psi_i) \]

- **Natural**
  - Experimentally tested with high accuracy
  - Stable with respect to quantum corrections (UV insensitive)
  - Highly symmetric [*gauge + flavor symmetries*]

- **Ad hoc**
  - Necessary to describe data [*the electroweak symmetry forbid masses for all the elementary particles observed so far...*]
  - Not stable with respect to quantum corrections (UV sensitive)
  - Origin of the flavor structure of the model [*and of all the problems of the model...*]
**Introduction**

All known phenomena in particle physics (*leaving aside a few cosmological observations*) can be described with good accuracy by a remarkably simple (effective) theory:

\[
\mathcal{L}_{SM} = \mathcal{L}_{\text{gauge}}(A_a, \psi_i) + \mathcal{L}_{\text{Symm. Break.}}(\phi, A_a, \psi_i)
\]

- **Natural**
  - Experimentally tested with high accuracy

- **Ad hoc**
  - Necessary to describe data
    
    [*we couldn't live in a fully symmetric world...*]

**Elegant & stable, but also a bit boring...**

**Ugly & unstable, but is what makes nature interesting...!**
Introduction

LHC experiments have confirmed once more that we understand very well gauge interactions...
Introduction

LHC experiments have confirmed once more that we understand very well gauge interactions, but the “breaking-news” announced the 4th of July 2012 is about the symmetry breaking sector of the theory:

Clear evidence of a new particle compatible with the properties of the Higgs boson.
Introduction

The more we a look at it, the more this particle looks like the “standard” Higgs boson:

\[ \sigma / \sigma_{SM} = 0.91^{+0.30}_{-0.24} \quad (m_H = 125.8 \text{ GeV}) \]
The SM Higgs sector

\[ (D_{\mu}\phi)^* D_{\mu} \phi - U(\phi) - \frac{1}{4} F_{\mu\nu} F^{\mu\nu} \]

\[ \partial_{\mu} \phi - i e A_\mu \phi \]

\[ \chi = \partial_{\mu} A_{\mu} - D_{\mu} A_{\mu} \]

\[ \chi = \lambda \phi^* \phi + \beta (\phi^* \phi)^2 \]

\[ \chi < 0, \quad \beta > 0 \]
The SM Higgs sector

The Higgs mechanism, namely the introduction of an elementary SU(2)\textsubscript{L} scalar doublet, with $\phi^4$ potential, is the most economical & simple choice to achieve the spontaneous symmetry breaking of both gauge $[\text{SU}(2)\textsubscript{L} \times \text{U}(1)\textsubscript{Y} \rightarrow \text{U}(1)\textsubscript{Q}]$ and flavor symmetries that we observe in nature.
The SM Higgs sector

The Higgs mechanism, namely the introduction of an elementary SU(2)\_L scalar doublet, with \( \phi^4 \) potential, is the most economical & simple choice to achieve the spontaneous symmetry breaking of both gauge \([ SU(2)_L \times U(1)_Y \rightarrow U(1)_Q ]\) and flavor symmetries that we observe in nature.

\[
\mathcal{L}_{\text{higgs}} (\phi, A_a, \psi_i) = D\phi^+ D\phi - V(\phi) \\
V(\phi) = -\mu^2 \phi^+\phi + \lambda(\phi^+\phi)^2 + Y^{ij}_{\psi} \psi_L^i \psi_R^j \phi
\]

Before the start of the LHC only the ground state determined by this potential (and the corresponding Goldstone boson structure) was tested with good accuracy:

\[
v = \langle \phi^+\phi \rangle^{1/2} \sim 246 \text{ GeV} \quad [ m_W = \frac{1}{2} g v ]
\]
**The SM Higgs sector**

The Higgs mechanism, namely the introduction of an elementary SU(2)_L scalar doublet, with $\phi^4$ potential, is the most economical & simple choice to achieve the spontaneous symmetry breaking of both gauge [SU(2)_L × U(1)_Y → U(1)_Q] and flavor symmetries that we observe in nature.

$$\mathcal{L}_{\text{higgs}}(\phi, A_a, \psi_i) = D\phi^+ D\phi - V(\phi)$$

$$V(\phi) = -\mu^2 \phi^+ \phi + \lambda (\phi^+ \phi)^2 + Y^{ij} \psi^i_L \psi^j_R \phi$$

Before the start of the LHC only the ground state determined by this potential (and the corresponding Goldstone boson structure) was tested with good accuracy:

$$v = \langle \phi^+ \phi \rangle^{1/2} \sim 246 \text{ GeV} \quad [m_W = \frac{1}{2} g v]$$

The situation has substantially changed a few months ago, with the observation of the 4th degree of freedom of the Higgs field (or its massive excitation):

$$\lambda_{(\text{tree})} = \frac{1}{2} m_h^2 / v^2 \sim 0.13$$
The SM Higgs sector

Actually some information about the Higgs mass was already present in the e.w. precision tests (assuming the validity of the SM up to high scales):
The SM Higgs sector

Actually some information about the Higgs mass was already present in the e.w. precision tests (assuming the validity of the SM up to high scales):

Message n.1: The observation of the physical Higgs boson with $m_h$ well consistent with the (indirect) prediction of the e.w. precision tests is a great success of the SM!
The SM Higgs sector

Actually some information about the Higgs mass was already present in the e.w. precision tests (assuming the validity of the SM up to high scales):

More generally, we have a strong indication that the symmetry breaking sector of the theory has a minimal and weakly coupled structure (at least around the TeV scale) as in the SM.
Still, the SM Higgs potential is “ugly” and hides the most serious theoretical problems of this highly successful theory:

\[ V(\phi) = -\mu^2 \phi^+\phi + \lambda (\phi^+\phi)^2 + Y^{ij}_{\psi_L} \psi^i_L \psi^j_R \phi \]

**The SM Higgs sector**

- Quadratic sensitivity to the cut-off
  \[ \Delta \mu^2 \sim \Delta m_h^2 \sim \Lambda^2 \]
  (indication of *new physics* close to the electroweak scale ?)

- Vacuum instability
  possible internal inconsistency of the model \((\lambda < 0)\) at large energies
  \([key dependence on m_h]\)

- SM flavor problem
  (unexplained span over several orders of magnitude and strongly hierarchical structure of the Yukawa coupl.)
Still, the SM Higgs potential is “ugly” and hides the most serious theoretical problems of this highly successful theory:

\[ V(\phi) = \Lambda^4 - \mu^2 \phi^*\phi + \lambda (\phi^*\phi)^2 + Y^{ij} \psi_L^i \psi_R^j \phi + \frac{g^{ij}}{\Lambda} \psi_L^i \psi_L^T \phi \phi^T \]

- **Cosmological constant prob.**
- **vacuum instability**
- **possible internal inconsistency** of the model ($\lambda < 0$) at large energies
  - key dependence on $m_h$
- **Quadratic sensitivity to the cut-off**
  - $\Delta \mu^2 \sim \Delta m_h^2 \sim \Lambda^2$
- **SM flavor problem**
  - (unexplained span over several orders of magnitude and strongly hierarchical structure of the Yukawa coupl.)

(indication of new physics close to the electroweak scale ?)
Still, the SM Higgs potential is “ugly” and hides the most serious theoretical problems of this highly successful theory:

\[
V(\phi) = \Lambda^4 - \mu^2 \phi^+\phi + \lambda (\phi^+\phi)^2 + Y^{ij} \psi_L^i \psi_R^j \phi + \frac{g^{ij}}{\Lambda} \psi_L^i \psi_L^j T_j \phi \phi^T
\]

- Vacuum instability possible internal inconsistency of the model ($\lambda < 0$) at large energies [key dependence on $m_h$]
- Quadratic sensitivity to the cut-off $\Delta\mu^2 \sim \Delta m_h^2 \sim \Lambda^2$ (indication of new physics close to the electroweak scale?)
- SM flavour problem (unexplained span over several orders of magnitude and strongly hierarchical structure of the Yukawa coupl.)

Cosmological constant prob.

Effective neutrino mass term
Stability and metastability bounds
Stability and metastability bounds

At large field values the shape of the Higgs potential is determined by the RGE evolution of the Higgs self coupling:

\[ V_{\text{eff}}( |\phi| \gg v ) \approx \lambda(|\phi|) \times |\phi|^4 + O(v^2|\phi|^2) \]

The evolution of \( \lambda \) is determined by two main effects:

- Growing \( \lambda \) at large energies
- Decreasing \( \lambda \)

\[ \lambda(v) \propto \frac{m_h^2}{v^2} \]

\[ y_t(v) \propto \frac{m_t}{v} \]

Given the large value of \( y_t \), the destabilization due to top-quark loops is quite relevant.
**Stability and metastability bounds**

At large field values:
\[ V_{\text{eff}}(|\phi|) \approx \lambda(|\phi|) \times |\phi|^4 \]

The problem was well-known since a long time, but now for the first time we can “quantify it”, knowing the Higgs mass.
Can we rule out the model (and determine an upper bound on the new-physics scale $\Lambda$) if there is a second (deeper) minimum at large field values?

**Not really:** The model could still be consistent if the lifetime of the (unstable) e.w. minimum is sufficiently long (i.e. longer than the age of the Universe)
Can we rule out the model (and determine an upper bound on the new-physics scale $\Lambda$) if there is a second (deeper) minimum at large field values? 

**Not really:** The model could still be consistent if the lifetime of the (unstable) e.w. minimum is sufficiently long (i.e. longer than the age of the Universe)

The e.w. minimum is destabilized by:

- quantum fluctuations (at $T=0$)
  - computable in a model-independent way
- thermal fluctuations
  - the probability depends on the thermal history of the universe & competes with the quantum tunneling only for very high $T$

The most conservative bound is obtained by considering the stability under quantum fluctuations at zero temperature
The quantum tunneling occurs via bubble formation in the homogeneous background of the false (e.w.) minimum.

At the semi-classical level, the tunneling probability can be written as:

\[ p \approx K e^{-S_0[h]} \]

Volume factor

\[ K \propto T_U^4 \] not exactly calculable within the semi-classical approx.

Euclidean action

\[ \int \frac{1}{2} (\partial_\mu h)^2 + V(h) \]

solution of the e.o.m. that interpolates between the false and the true vacuum

**Bounce**

N.B.: within a QFT (system with infinite d.o.f.) the tunneling is suppressed even in absence of a potential barrier (kinematic barrier due to the boundary conditions)
The quantum-tunneling rate:

If we neglect the mass term, the tree-level Higgs potential is scale invariant & its bounces have a rather simple form:

\[ h(r) = \left( \frac{2}{|\lambda|} \right)^{1/2} \frac{2R}{r^2 + R^2} \]

\[ r = x_\mu x_\mu \quad \text{O(4) invariant bounces minimize the action} \]

\[ R = \text{arbitrary scale parameter} \]

\[ S_0[h] = \frac{8\pi^2}{3|\lambda|} \quad \Rightarrow \quad p_{\text{semicl.}} \propto e^{-8\pi^2/3|\lambda|} \]

If \(|\lambda|\) remains sufficiently small, the tunneling rate can be very suppressed.

N.B.: the tunneling rate is a pure non-perturbative phenomenon - cannot be computed to any finite order in “ordinary” perturbation theory [wrong choice of the vacuum]
To go beyond the semi-classical level we need to take into account the quantum fluctuations around the (non-constant) bounce solution.

Non-trivial problem which has been solved (semi-analytically) in the SM case:

- Quantum corrections break scale invariance + the functional integral provides an unambiguous estimate of the volume factor.
- The tunneling is dominated by bounces of size $R$, such that $\lambda(1/R)$ reaches its minimum value:

$$p = \max_R \frac{V_U}{R^4} \exp \left[ - \frac{8 \pi^2}{3 |\lambda(1/R)|} + \text{tiny higher-order terms} \right]$$

*The quantum-tunneling rate:*
The metastability condition:

\[ p \approx \max_R \frac{V}{R^4} \exp \left[ -\frac{8\pi^2}{3|\lambda(1/R)|} \right] \]

\( \lambda \) can become negative, provided it remains small in absolute magnitude:
Message n.2: For $m_h \approx 125-126$ GeV and the present central value of $m_{\text{top}}$, the SM vacuum is unstable but sufficiently long-lived, compared to the age of the Universe.

$m_h = 125$ GeV
$m_t = 173.2 \pm 0.9$ GeV
Vacuum stability at NNLO (for $m_h \sim 125$ GeV)

How “precise” is our estimate of the evolution of $\lambda$ (and the corresponding conclusion that the SM potential is unstable)?

A full NNLO analysis has recently become possible:

- Two-loop potential
  - Ford, Jack, Jones '92, '01

- Three-loop beta functions
  - Mihaila, Salomon, Steinhauser 1201.5868
  - Chetyrkin, Zoller, 1205.2892

- Two-loop threshold corrections in relating $\lambda(\nu)$ to the Higgs mass:
  \[
  \lambda(\mu) = \frac{G_F m_h^2}{\sqrt{2}} + \Delta \lambda(\mu)
  \]
  - Yukawa×QCD
  - Bezrukov, Kalmykov, Kniehl, Shaposhnikov, 1205.2893
  - Yukawa×QCD • Yuk.×Yuk.
  - Degrassi, Di Vita, Elias-Miro', Espinosa, Giudice, G.I., Strumia 1205.6497

(dominate uncertainty)
Given the fast running of $\lambda$ close to the e.w. scale, the dominant uncertainty comes from threshold (non-log enhanced) corrections at the electroweak scale (or in the precise evaluation of the initial condition).

While the smallness of $\lambda$ (and the other couplings) at high energies imply that the 3-loop terms in the beta functions play a very minor role (useful to control the error).
With the NNLO calculation we are able to derive a very precise relation between Higgs and top masses from vacuum stability:

\[ M_h \text{ [GeV]} > 129.4 + 2.0 \left( \frac{M_t \text{ [GeV]} - 173.1}{1.0} \right) - 0.5 \left( \frac{\alpha_s(M_Z) - 0.1184}{0.0007} \right) \pm 1.0_{\text{th}} \]

Conservative th. error given the size of the shifts from NLO to NNLO:

+ 0.6 GeV due to the QCD threshold corrections to \( \lambda \)
+ 0.2 GeV due to the Yukawa threshold corrections to \( \lambda \)
− 0.2 GeV from RG equation at 3 loops
− 0.1 GeV from the effective potential at 2 loops.
With the NNLO calculation we are able to derive a very precise relation between Higgs and top masses from vacuum stability:

![Graph showing the relationship between Higgs mass and pole top mass](image)
With the NNLO calculation we are able to derive a very precise relation between Higgs and top masses from vacuum stability:

Assuming a precise determination of $m_h$ by ATLAS & CMS in a short time, the main uncertainty will remain the top mass. Note also that the $m_t$ measured by Tevatron is not really the pole mass (possible larger error... Alekhin, Djouadi, Moch '12, Hoang & Stewart, '07-'08)
Two additional remarks about the instability of the SM potential:

I. What about the instability because of thermal fluctuations?

II. What about adding to the model heavy right-handed neutrinos?
Two additional remarks about the instability of the SM potential:

I. What about the instability because of thermal fluctuations?

- The instability occurs at very high energies

- The Higgs mass is quite close to the stability border

  Thermal corrections do not destabilize further the potential.
Two additional remarks about the instability of the SM potential:

I. What about the instability because of thermal fluctuations?

- The instability occurs at very high energies
- The Higgs mass is quite close to the stability border

Thermal corrections do not destabilize further the potential.
Two additional remarks about the instability of the SM potential:

**I.** What about the instability because of thermal fluctuations?

Since the instability occurs at very high energies, thermal corrections do not play a significant role in destabilizing the potential.

**II.** What about adding to the model heavy right-handed neutrinos?

On general ground, adding new fermions may induce a further destabilization of the potential. However, the effect depends on the size of the new Yukawa couplings:

\[ m_{\nu} \sim Y^T_n \frac{\nu^2}{M_R} Y_n \]

Requiring a sufficiently stable Higgs potential allows us to derive an upper bound on \( M_R \).
$m_\nu \sim Y_n^T \frac{\nu^2}{M_R} Y_n$

Still enough room for leptogenesis to take place.

Elias-Miro et al. '11
Speculations on Planck-scale dynamics
Looking at the plane from a more distant perspective, it appears more clearly that “we live” in a quite “peculiar” region...

Moving $m_t$ down by $\sim 2$ GeV, we reach the even more peculiar configuration where $\lambda(M_{pl})=0$

Froggatt, Nielsen, Takanishi, '01
Arkani-Hamed et al., '08
Shaposhnikov, Wetterich, '10
...

Speculations on Planck-scale dynamics
Speculations on Planck-scale dynamics

Looking at the plane from a more distant perspective, it appears more clearly that “we live” in a quite “peculiar” region...

Moving $m_t$ down by $\sim 2$ GeV, we reach the even more peculiar configuration where $\lambda(M_{pl})=0$

Froggatt, Nielsen, Takanishi, '01
Arkani-Hamed et al., '08
Shaposhnikov, Wetterich, '10
...

Elias-Miro et al. '11

G. Isidori – Standard Model and beyond after the Higgs discovery

UCL, May 2013
Speculations on Planck-scale dynamics

It seems that the Higgs potential is “doubly tuned” around two “critical values”:

$$V(\phi) = -\mu^2 \phi^2 + \lambda (\phi^* \phi)^2$$
Speculations on Planck-scale dynamics

What's special about $\lambda(M_{\text{pl}}) = 0$?
Despite also the beta function vanishes, is not a true fixed point (other coupl. ≠ 0)

$M_h = 125$ GeV
3σ bands in
$M_t = 173.1 \pm 0.7$ GeV
$\alpha_s(M_Z) = 0.1184 \pm 0.0007$

$M_t = 171.0$ GeV
$\alpha_s(M_Z) = 0.1205$

$M_t = 175.3$ GeV
$\alpha_s(M_Z) = 0.1163$


**Speculations on Planck-scale dynamics**

What's special about $\lambda(M_{pl})=0$?

Despite also the beta function vanishes, is not a true fixed point (other coupl. $\neq 0$). Maybe more interesting the overall smallness of $\lambda$ compared to the other couplings. At a scale $\Lambda \gtrsim 10^8$ GeV $\lambda$ becomes of the same order of its typical e.w. quantum corrections: *hints of a radiatively generated coupling?*
Speculations on Planck-scale dynamics

What's special about $\lambda(M_{pl}) = 0$?

Despite also the beta function vanishes, is not a true fixed point (other coupl. $\neq 0$). Maybe more interesting the overall smallness of $\lambda$ compared to the other couplings.

At a scale $\Lambda \gtrsim 10^8$ GeV $\lambda$ becomes of the same order of its typical e.w. quantum corrections: hints of a radiatively generated coupling?
Speculations on Planck-scale dynamics

The smallness of $\lambda$ certainly fits well with the possibility of a high-scale matching with a weakly coupled theory.

Giudice & Strumia '11-'12

[Graph showing Higgs mass versus supersymmetry breaking scale with different tan$\beta$ values and regions labeled as Split SUSY and High-Scale SUSY, and an experimentally favored region.]

G. Isidori – Standard Model and beyond after the Higgs discovery

UCL, May 2013
Speculations on Planck-scale dynamics
Speculations on Planck-scale dynamics

- **INSTABILITY**
  - Low-scale instability ($\lambda < 0$ below 1 TeV)

- **STABILITY**
  - MSSM regime $M_{\text{SUSY}} \geq 1$ TeV
  - Non-MSSM regime (too large $\lambda$)
  - Non-perturb. regime ($\lambda > 4\pi$) before $M_{\text{Pl}}$

G. Isidori – Standard Model and beyond after the Higgs discovery

G.I. et al. - work in prog.
Speculations on Planck-scale dynamics

![Diagram showing regions of instability and stability based on values of $m_t$ and $m_h$.]

- **INSTABILITY**
  - Low-scale instability ($\lambda < 0$ below 1 TeV)
  - Non-perturbative regime ($\lambda > 4\pi$) before $M_{Pl}$

- **STABILITY**
  - MSSM regime
    - “quasi-natural” SUSY $M_{SUSY} = 1$ TeV
  - Non-MSSM regime (too large $\lambda$)

G. Isidori – Standard Model and beyond after the Higgs discovery

UCL, May 2013
Speculations on Planck-scale dynamics

\[ m (GeV) \]

INSTABILITY

- Low-scale instability \( (\lambda < 0 \text{ below } 1 \text{ TeV}) \)

Meta-stability

MSSM regime
- “high-scale” SUSY \( M_{\text{SUSY}} = 10^{10} \text{ TeV} \)

STABILITY

- Non-MSSM regime (too large \( \lambda \))
- Non-perturbative regime \( (\lambda > 4\pi) \) before \( M_{\text{Pl}} \)

G. Isidori – Standard Model and beyond after the Higgs discovery
Speculations on Planck-scale dynamics

An attractive feature of having $\lambda=0$ close to $M_{\text{pl}}$ (assuming no new physics below such scale) is the possibility that the Higgs field has played some role in the early Universe, during inflation.

\begin{align*}
\log[V(|\phi|)]
\end{align*}

```
New non-trivial feature in the potential that occurs if $\lambda=\beta_{\lambda}=0$
```

Bezrukov & Shaposhnikov, '08
Notari & Masina '11-'12
De Simone & Riotto, '12

```
“our minimum”
```

Bennett, Nielsen,Picek, '88
Froggatt, Nielsen, '96
G.I., Rychkov, Strumia, Tetradis '08
**Speculations on Planck-scale dynamics**

An attractive feature of having $\lambda=0$ close to $M_{\text{pl}}$ (assuming no new physics below such scale) is the possibility that the Higgs field has played some role in the early Universe, during inflation.

The minimal set-up (SM only) does not work (field trapped into the new minimum or too large fluctuations)  

---

![Graph showing variations in $M_t$ and $\alpha_s(M_Z)$](image)

$M_t = 170.981 \text{ GeV}$  
$\alpha_s(M_Z) = 0.1184$

Variations of 0.1 MeV (!) in $M_t$
**Speculations on Planck-scale dynamics**

An attractive feature of having $\lambda=0$ close to $M_{pl}$ (assuming no new physics below such scale) is the possibility that the Higgs field has played some role in the early Universe, during inflation.

The minimal set-up (SM only) does not work (field trapped into the new minimum or too large fluctuations)  

G.I. et al. '08

The problem can be solved with non-minimal couplings of the Higgs field to gravity and/or introducing other fields  

Bezrukov & Shaposhnikov, '08  
Notari & Masina '11-'12

The minimality of the scheme is lost, but it remains an intriguing possibility  

Maybe even with some observable (cosmological) consequences  

De Simone & Riotto, '12
Conclusions

• A SM-like Higgs with $m_h \sim 125$ GeV does not allow us to derive model-independent conclusions about the scale of New Physics: the Higgs potential is most likely unstable, but the e.w. vacuum is certainly sufficiently long-lived.
Conclusions

- A SM-like Higgs with $m_h \sim 125$ GeV does not allow us to derive model-independent conclusions about the scale of New Physics: the Higgs potential is most likely unstable, but the e.w. vacuum is certainly sufficiently long-lived.

- Clear indication of a small $\lambda$ at high energies: if the SM is only an effective theory, we have to match it into a model where the Higgs is a weakly interacting particle - if the matching occurs close to the e.w. scale [as indicated by naturalness]

- has a vanishing intrinsic self-coupling - if the matching occurs above $\sim 10^8$ GeV

- The peculiar “doubly-critical” structure of the Higgs potential may be an indication some (non-understood yet) phenomenon at high scales

- In absence of direct NP signals, more precise determinations of both $m_h$ & $m_t$ would be very useful to better investigate this problem.