Implication of 126 GeV Higgs for Planck scale physics

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Higgs was discovered at
M_H =126 GeV

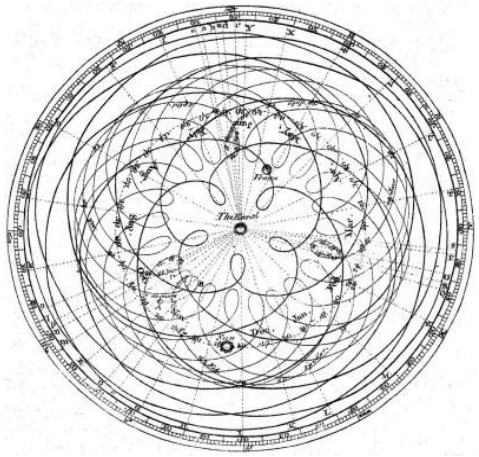
No evidence
of "new" physics
@ ATLAS,CMS & LHCb

What is the implication of these two?
together with some phenomena beyond SM
(ν oscillation, Baryon asymmetry, Dark matter)

Higgs (production, decay)
B rare decays
are all consistent with SM.

→ Stringent constraints on TeV SUSY

Mathematically sophisticated,
but far from being simple!



Planetary orbits by Ptolemy

↓

We may need to reconsider Hierarchy problem

Hierarchy problem

Is quadratic divergence the issue of hierarchy problem?

NO

Bardeen(1995)

H Aoki, SI PRD(2012)]

There are 3 different types of divergences

1. Quadratic divergences Λ^2
2. Logarithmic divergences $m^2 \log \Lambda$
3. Logarithmic but looks like quadratic $M^2 \log \Lambda$

(1) Quadratic divergence can be simply subtracted,
so it gives a boundary condition at UV cut off Λ.

→ If massless at Λ, it continues to be so in the IR theory.

(2) No Higgs mass term is generated in SM through RGE
(multiplicatively renormalized)

$$\frac{dm^2}{dt} = \frac{m^2}{16\pi^2}\left(12\lambda + 6Y_t^2 - \frac{9}{2}g^2 - \frac{3}{2}g_1^2\right) + \frac{M^2}{8\pi^2}\lambda_{mix}$$

(3) If SM is coupled with a massive particle with mass M,
logarithmic divergences give a correction to m as

$$\delta m^2 = \frac{\lambda_{mix} M^2}{16\pi^2}\log(M^2/m^2)$$

In order to solve the "hierarchy problem" without a special cancellation like supersymmetry, we need to control

(a) "quadratic divergence" → correct boundary condition at Planck

The most natural b.c. is NO MASS TERMS at Planck

(= classical conformal invariance)

(b) "radiative corrections" by mixing with other relevant operators

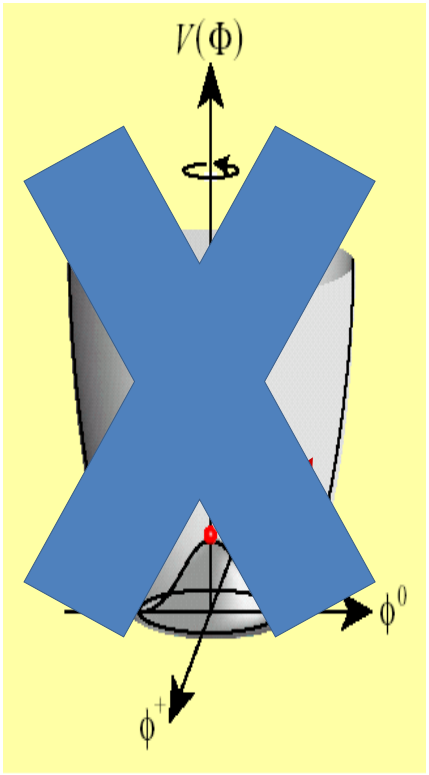
No intermediate scales between EW (or TeV) and Planck

"Classical conformal theory with no intermediate scale"

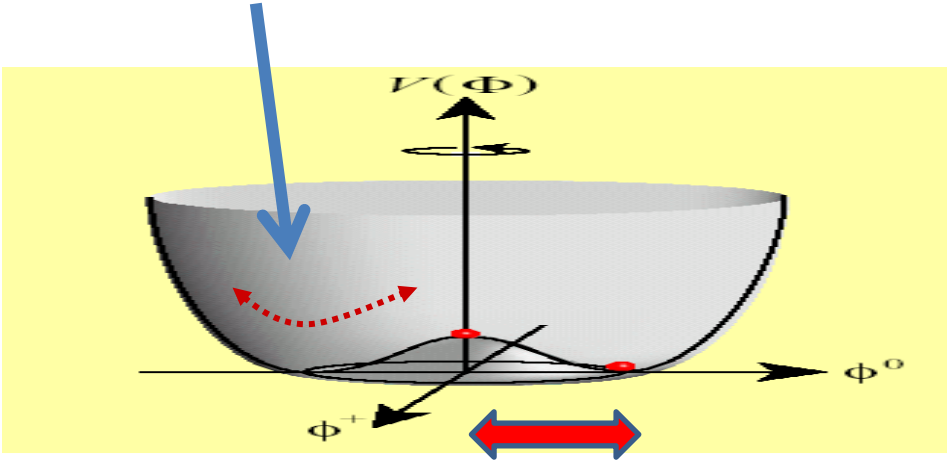
can be an alternative solution to hierarchy problem.

Bardeen (95)
Shaposhnikov (07)
Meissner Nicolai (07)
SI, Okada,Orikasa (09)

Another Hint of 126 GeV Higgs mass is
Stability bound of the Higgs quartic coupling

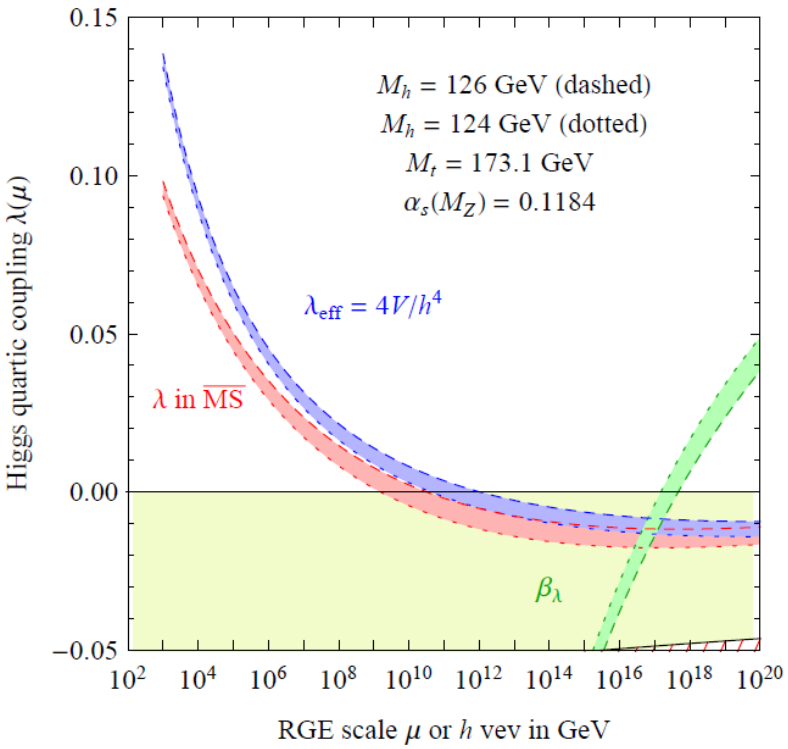


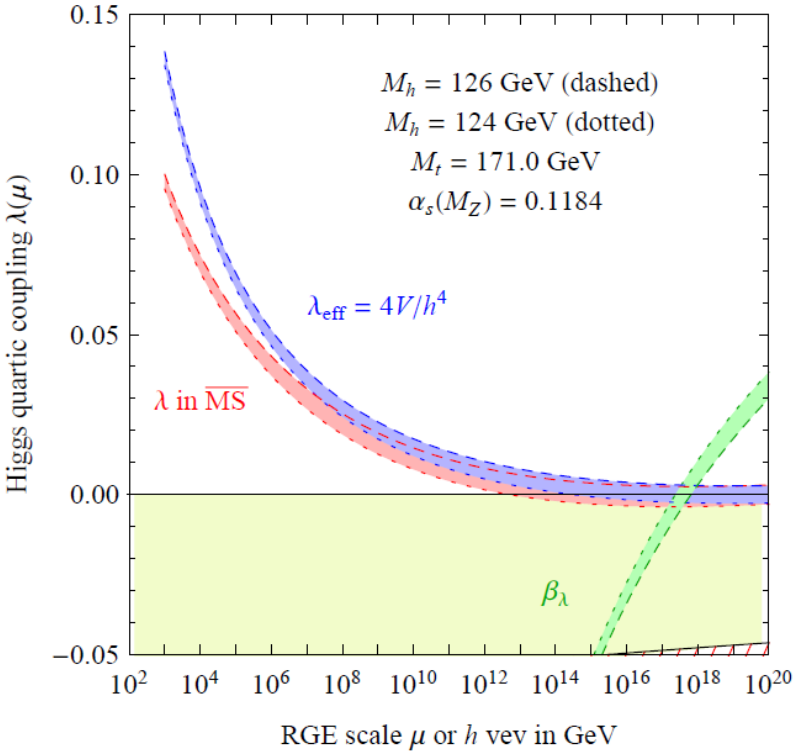
$$m_H = 126 \text{ GeV}$$



$$v = 246\text{GeV}$$

Why stability bound is important for Planck scale physics?





New physics at 10^{12} GeV
is necessary to stabilize the vacuum

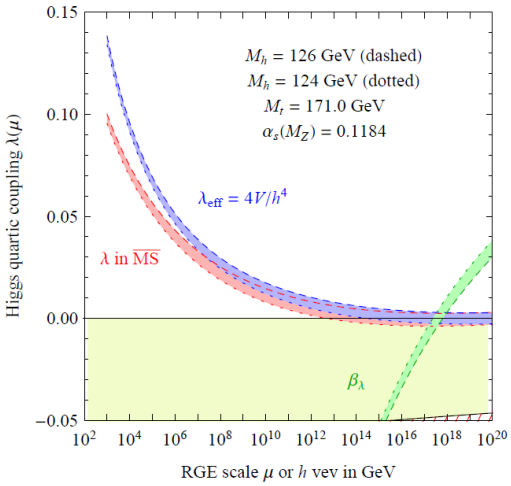
Flat Higgs potential
at Planck scale

$$M_h\ [\mathrm{GeV}] > 129.4 + 1.4\left(\frac{M_t\ [\mathrm{GeV}] - 173.1}{0.7}\right) - 0.5\left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007}\right) \pm 1.0_{\rm th}$$

very sensitive to top quark mass

Elias-Miro et.al.(12)
Shaposhnikov et.al. (12)

If this



is the case ?

$$\lambda(\Lambda_0) = \beta_\lambda(\Lambda_0) = 0$$

Direct window to Planck scale

M.Shaposhnikov (07)

Indication of LHC on Higgs potential

$$V = -\mu^2|H|^2 + \lambda(|H|^2)^2$$

Hierarchy
(classical conformality)

Stability
Vanishing at Planck

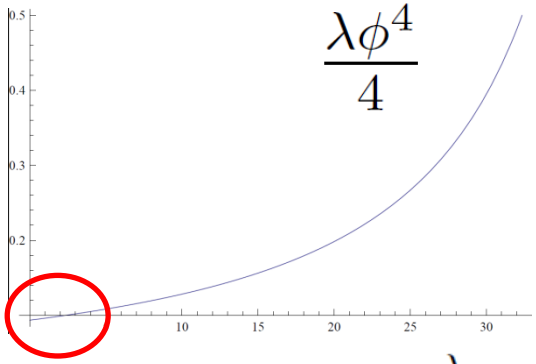
LHC experiment implies that
Higgs has a flat potential V(H)=0 at Planck.

How can we realize EW symmetry breaking from V(H)=0 potential at Planck?

Everything should be radiative

Coleman-Weinberg radiative breaking

λ



Symmetry is broken near the scale where the coupling crosses zero.

$$M_{CW} = M_{UV} \exp(-\frac{\lambda_{UV}}{b} - \frac{1}{4})$$

Dimensional transmutation

But CW does not work in SM.

the **large top Yukawa** coupling **invalidates the CW** mechanism

↓

Extension of SM is necessary !

Meissner Nicolai (07)

(B-L) extension of SM with flat Higgs potential at Planck

SM + B-L sector
- U(1)B-L gauge
- SM singlet scalar ϕ
- Right-handed ν

N Okada, Y Orikasa, & SI
0902.4050 (PLB)
0909.0128 (PRD)
1011.4769 (PRD)
1210.2848

"Occam's razor" scenario

that can explain
- 126 GeV Higgs
- hierarchy problem
- ν oscillation, baryon asymmetry

Flat Higgs potential at Planck scale

$$\cancel{m_H^2 H^2} + \cancel{\lambda_H H^4} + \cancel{\lambda_{H\Phi} H^2 \Phi^2}$$

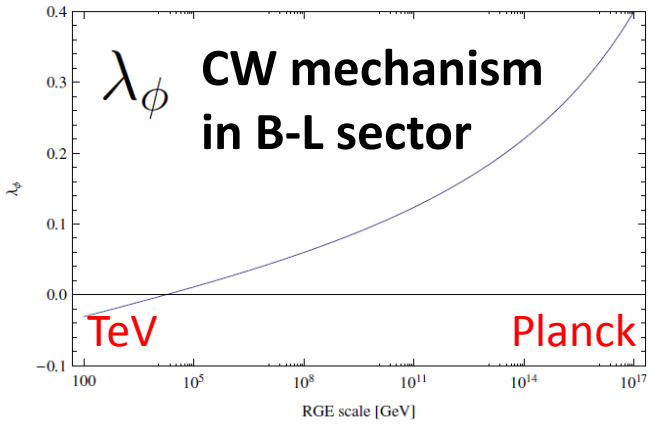
classically conformal

126 GeV

key to relate EW and TeV

$$V(\Phi, H)|_{UV} = \lambda_\Phi (\Phi^\dagger \Phi)^2$$

$$M_{B-L} \sim M_{Planck} \exp(-\frac{\lambda_\phi}{b})$$



B-L can be broken by CW mechanism at TeV.

How about EWSB ?

Can the small scalar mixing be realized naturally?

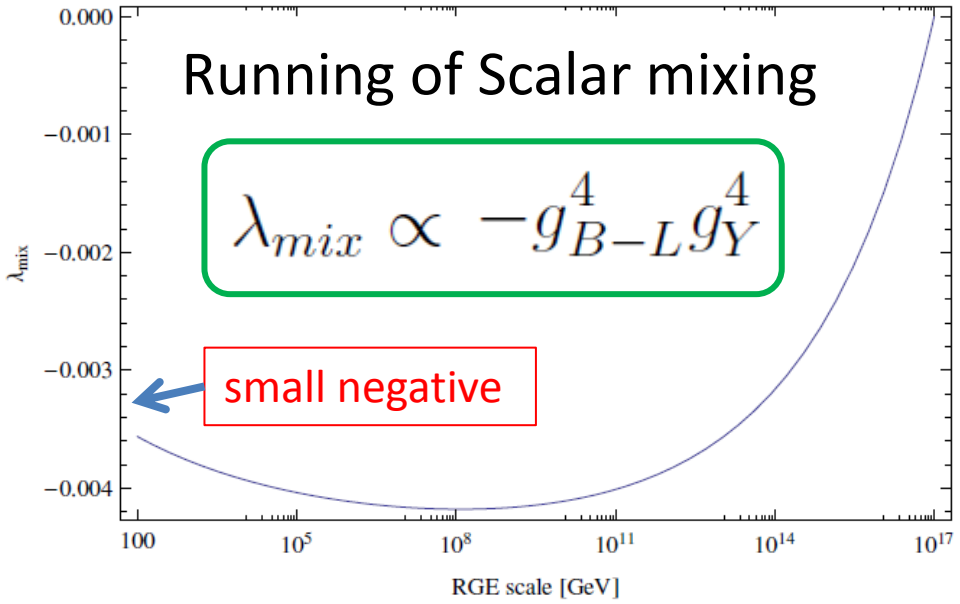
YES

Radiatively generated scalar mixing in V(H)

$$V(H) = \lambda_H H^4 + \lambda_{mix}\Phi^2 H^2$$ triggers EWSB

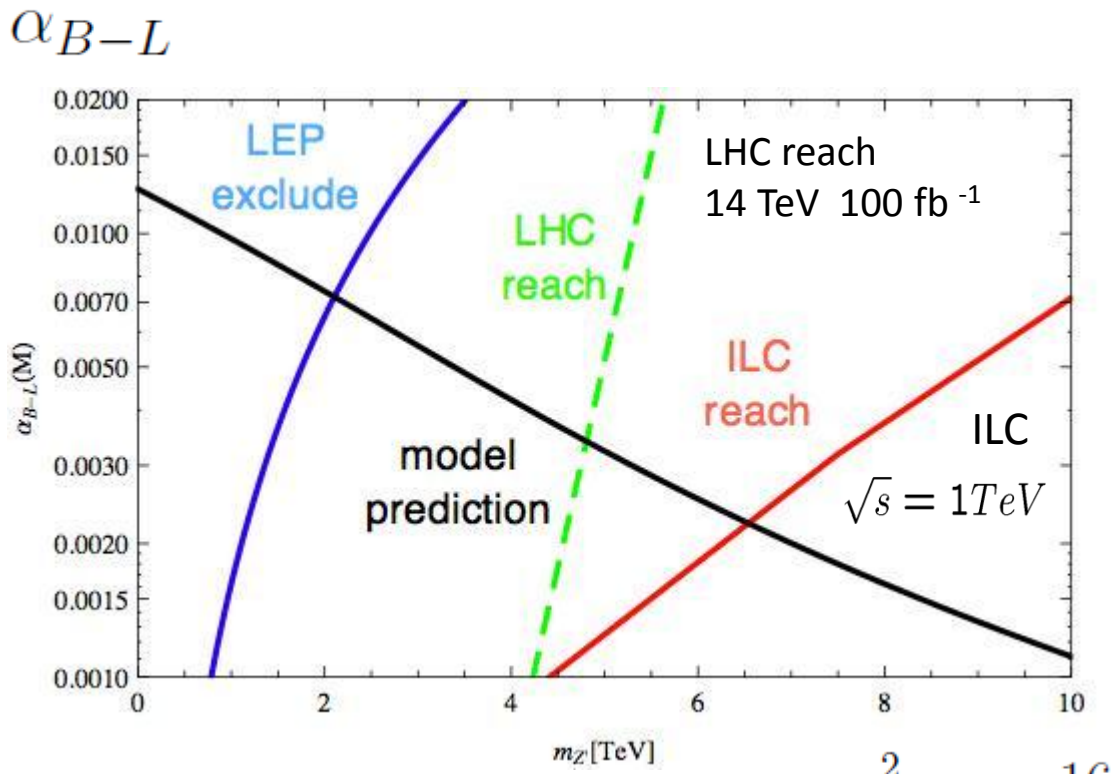
$$\langle H \rangle = \sqrt{\frac{-\lambda_{mix}}{\lambda_H}} M_{B-L}$$

$$\sim c\frac{\alpha_{B-L}\alpha_Y}{\sqrt{\lambda_H}} M_{B-L}$$



Prediction of the model

In order to realize EWSB at 246 GeV,
B-L scale must be around TeV (for a typical value of $\alpha_{B\text{-}L}$).



$$M_{B-L} \sim \frac{1}{\alpha_{B-L}} \times 35 \text{ GeV}$$

$$m_{Z'} \sim \frac{1}{\sqrt{\alpha_{B-L}}} \times 250 \text{ GeV}$$

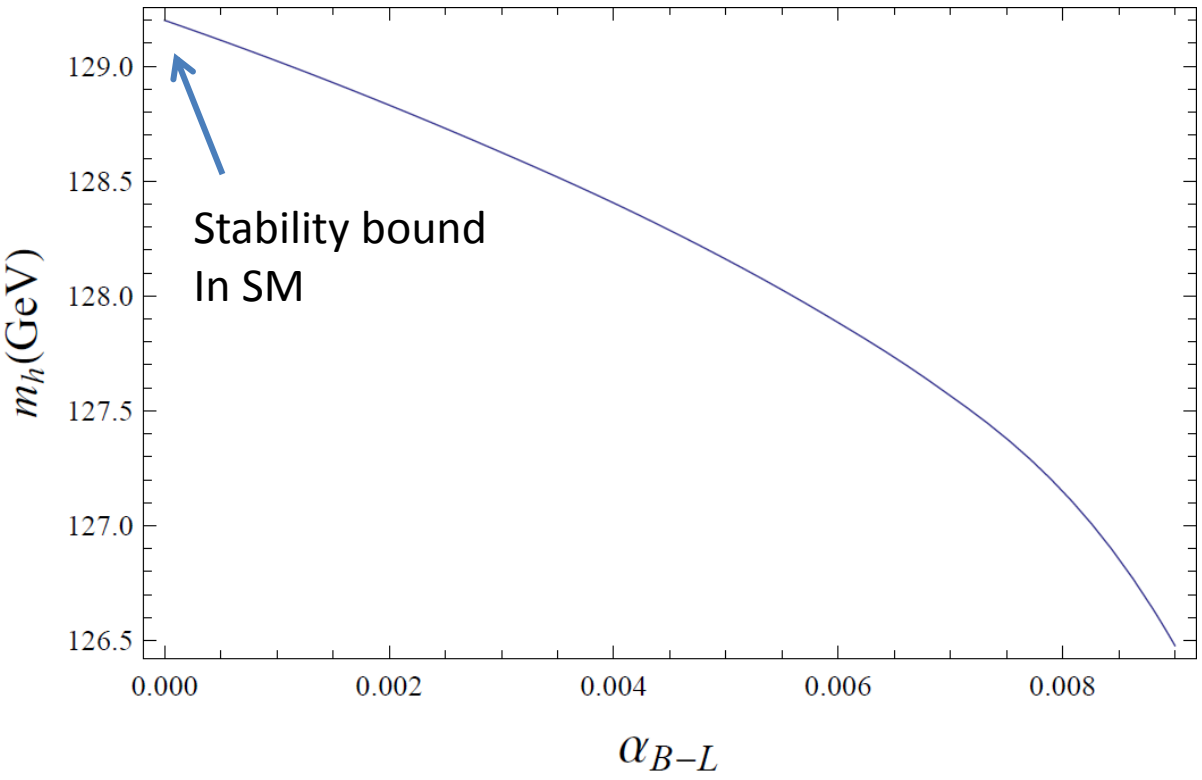
$$m_{\phi} \sim 0.1\, m_{Z'}$$

$$m_{Z'}^2 = 16\pi\alpha_{B-L}(0)M_{B-L}^2$$

Stability bound in TeV scale B-L model

$$\frac{d\lambda_H}{dt} = \frac{1}{16\pi}\left(24\lambda^2 - 6Y_t^4 + \frac{9}{8}g^4 + \frac{3}{8}g_1^4 + \frac{3}{4}g^2g_1^2 + \boxed{\frac{3}{4}(g^2+g_1^2)g_{mix}^2} + \cdots\right)$$

An extra positive term is added



Lower the stability bound

Summary

- 126 GeV Higgs = border of the stability bound of SM vacuum.
  → Direct window to Planck scale → Flat Higgs potential @Planck
  Hint for the origin of Higgs in string theory
- Occam's razor scenario beyond SM
  "Classically conformal B-L model" is proposed

(1) it can solve hierarchy problem
(2) it can explain why B-L breaking scale is around TeV.
(3) Stability bound can be lowered about 1 GeV
  M_H ~ 128 GeV
(4) phenomenologically viable
  Neutrino oscillation, resonant leptogenesis
(5) Highly predictive (or excludable)
  Prediction
  Z' around a few TeV, $M_\phi < M_{Z'}$, Leptogenesis at TeV

Future perspectives

- Origin of flat Higgs potential at Planck

  Hierarchy problem & M_H =126 GeV

  → PNGB ? Moduli ? Gauge/Higgs ? .....

  Non-susy vacua of superstring with flat V(H)

- Resonant leptogenesis Garny, Kartavsev, Hohenegger (11)

  Kadanoff-Baym equation (quantum Boltzman)

- Non-susy GUT at Planck SO(10) or E6 type

  Gravity or string threshold correction to RGE

LHC gave us a big hint for Planck scale physics.