29 Aug 2013 @ SUSY2013 (Trieste)

Implication of 126 GeV Higgs boson for Planck scale physics - naturalness and stability of SM -

Satoshi Iso (KEK & Sokendai)

based on collaborations

N.Okada (Alabama), Y.Orikasa (Osaka), SI

Phy.Lett.B276(2009)81 & Phys.Rev. D80 (2009) 115007

"Classically conformal B-L extension of the SM"

H.Aoki (Saga), SI *Phys.Rev.D86(2012)013001*

"Revisiting the Naturalness problem"

Y.Orikasa (Osaka), SI

PTEP 2013,023B08 & arXiv:1304.0293

"TeV scale B-L model with a Flat Higgs potential at the Planck scale"

- in view of the Hierarchy problem -

Summary of the talk

UV

M_{PL}

flat potential

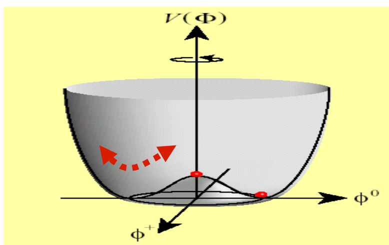
ϕ

$$V(H) = 0 \quad @M_{PL}$$

1. 126 GeV Higgs → λ=0 @ M_{PL}
2. Naturalness → μ^2=0

IR

M_{EW}



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

Two issues:

Is it possible to generate the wine-bottle potential at IR ?

What is the origin of flatness at UV ?

Today I will answer the IR issue in an affirmative way.

Outline

Motivation for V(H)=0 @ M_{PL}

[1] Revisiting the Naturalness Problem

[2] Stability of SM vacuum = 126 GeV M_H

Model realizing the radiative generation of V(H) @M_{EW}

[3] "classically conformal B-L extension of SM"

Today I do not talk about the Phenomenology of the model

[4] Neutrino oscillation, Leptogenesis, etc.

H Aoki, SI : 1201.0857
Y Orikasa, SI : 1210.2848
SI : 1304.0293

[1] Naturalness problem

It is commonly stated that naturalness problem is caused by quadratic divergence of a scalar mass.

Is quadratic divergence physically relevant?

Bardeen (1995)

H Aoki, SI (2012)

3 reasons why I think power divergences are physically irrelevant in the IR effective theory:

(1) they can be always subtracted
unlike multiplicatively renomalized logarithmic divergences

(2) In the Wilsonian RG, power divergences determine the position of the critical surfaces, and have nothing to do with the RG flow.

(3) power divergences are not generally covariant.

ex.) EMT of a massive field on a curved space-time

Energy=$\int dk\, \omega\, k^2$, pressure=$\int dk\, k^4/3\omega$, $\omega^2=(k^2+m^2)$

So Λ^4 term has w=1/3 (so it is not proportional to $g^{\mu\nu}$)

$m^4 \log \Lambda$ term gives the covariant EMT with w=-1 (DE).

Classification of divergences

1. Power divergences Λ^2

   It can be simply subtracted at UV scale, and gives a boundary condition at UV. Once subtracted, no longer appears.

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2. Logarithmic divergences $m^2 \log(\Lambda/m)$

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

3. Logarithmic but quadratic-like: $M^2 \log(\Lambda/M)$

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

m	<<	M
Low energy physics		High energy physics

It is important to distinguish 1 and 3.

In order to solve the "naturalness problem", Bardeen (95)
of IR theory embedded in UV completion theory, we need to control

(a) " M_{PL}^2 term" → correct boundary condition at Planck

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

(= classical conformal)

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

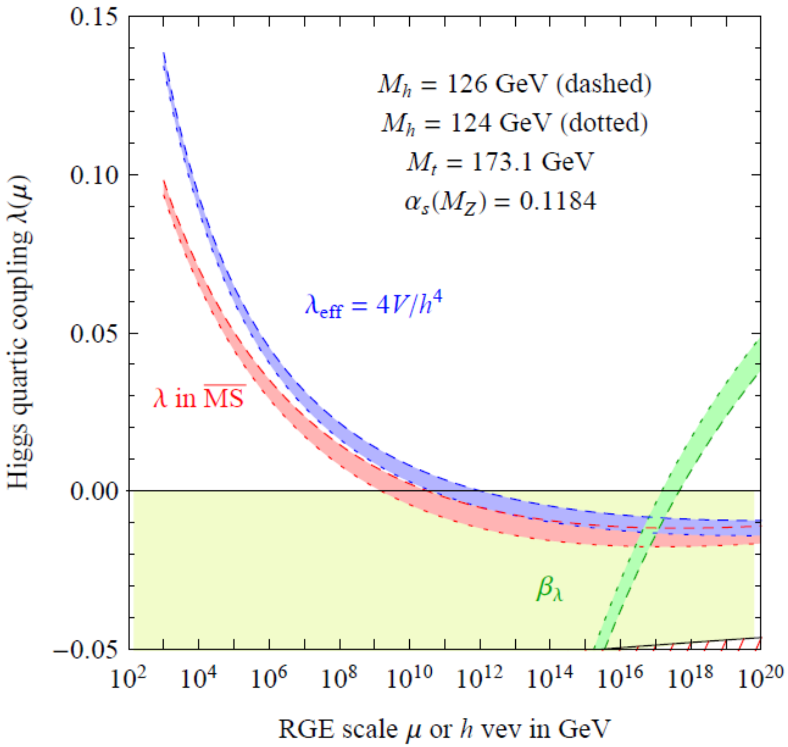
(b) "large logarithmic divergence" by mixing with a large mass M

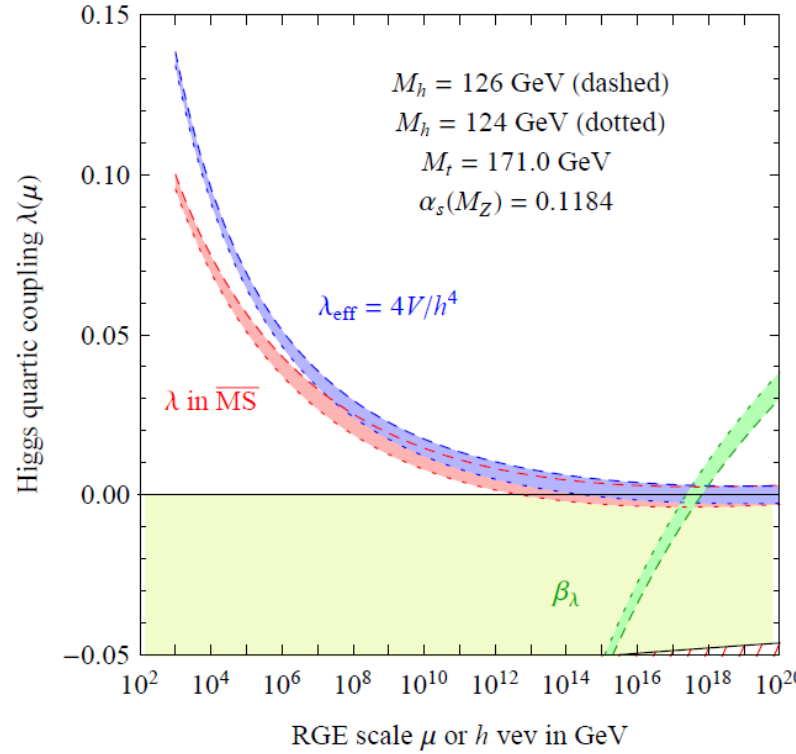
No large intermediate scales beyond EW up to Planck

"Classical conformal theory with no intermediate scale"
can be an alternative solution to the naturalness problem.

Foot Kobakhidze Macdonald Volkas (07), Shaposhnikov (07), Meissner Nicolai (07),
SI, Okada,Orikasa (09), Holthausen Lindner Schmidt (09), Nunneley Pilaftsis (10), Iwashita(11),
Lee Pilaftsis(12), Englert Jaekel Khoze Spannovski (13), Chun Jun Lee (13), Carone Ramos(13), , , ,

[2] Stability of Vacuum





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

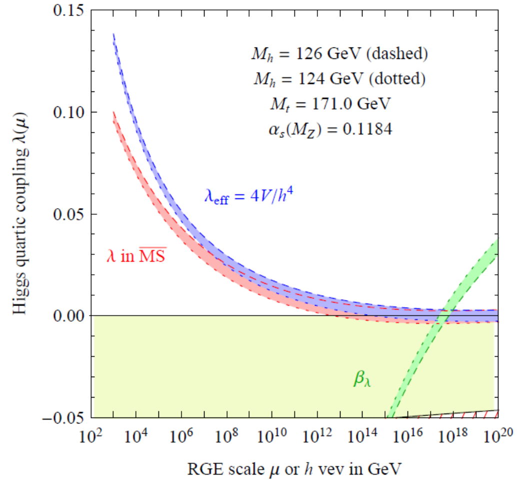
Flat Higgs potential
at Planck scale

$$M_H \geqslant 129.2 + 1.8 \times \left(\frac{m_t^{\rm pole} - 173.2\ {\rm GeV}}{0.9\ {\rm GeV}} \right) - 0.5 \times \left(\frac{\alpha_s(M_Z) - 0.1184}{0.0007} \right) \pm 1.0\ {\rm GeV}.$$

Elias-Miro et.al.(12)
Alkhin, Djouadi, Moch (12)

very sensitive to top quark mass

(Also sensitive to higher dim op. and nonperturbative behavior of RG)

If this 

is the case ?

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

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

Direct window to Planck scale

Frogatt Nielsen (96)
M.Shaposhnikov (07)

[3] “classically conformal B-L model”

N Okada, Y Orikasa, SI
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0909.0128 (PRD)
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1210.2848 (PTEP)

Indication on the Higgs potential

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

flat potential

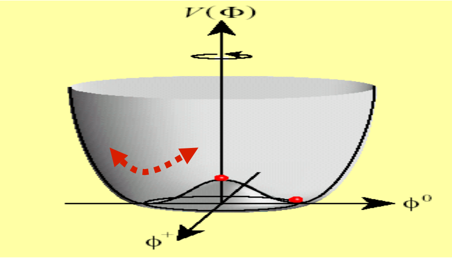
ϕ

flat potential V(H)=0 at Planck.

M_{PL}

Radiatively generate

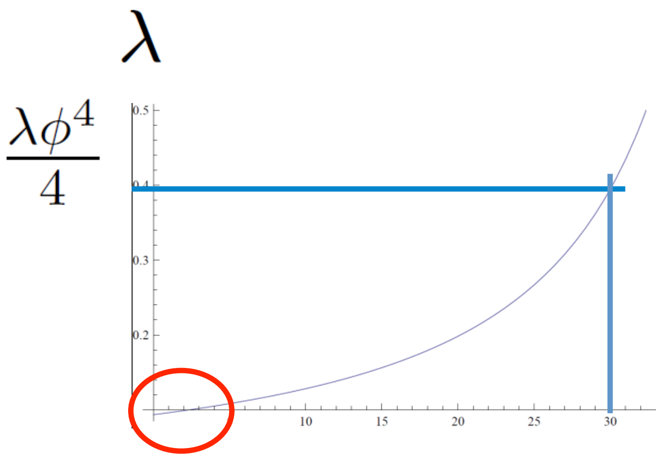
Coleman-Weinberg mechanism



EWSB @ M_{EW}

CW mechanisms = dimensional transmutation

Coleman-Weinberg radiative breaking



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

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

Positive beta function in IR region

cf. Dimensional transmutation in QCD

$$\Lambda_{QCD} = M_{UV} \exp\left(-\frac{2\pi}{b_0 \alpha_s(M_{UV})}\right)$$

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
- $U(1)_{B\text{-}L}$ gauge
- SM singlet scalar ϕ
- Right-handed ν

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

"Occam's razor" scenario

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

B-L is broken through the Coleman-Weinberg mechanism.

How does it trigger the EWSB ?

$$V(H) = \lambda_H H^4 + \boxed{\lambda_{mix}\Phi^2 H^2} \quad @\ M_{EW}$$

Radiatively generated $\downarrow$ key to relate EW and TeV

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

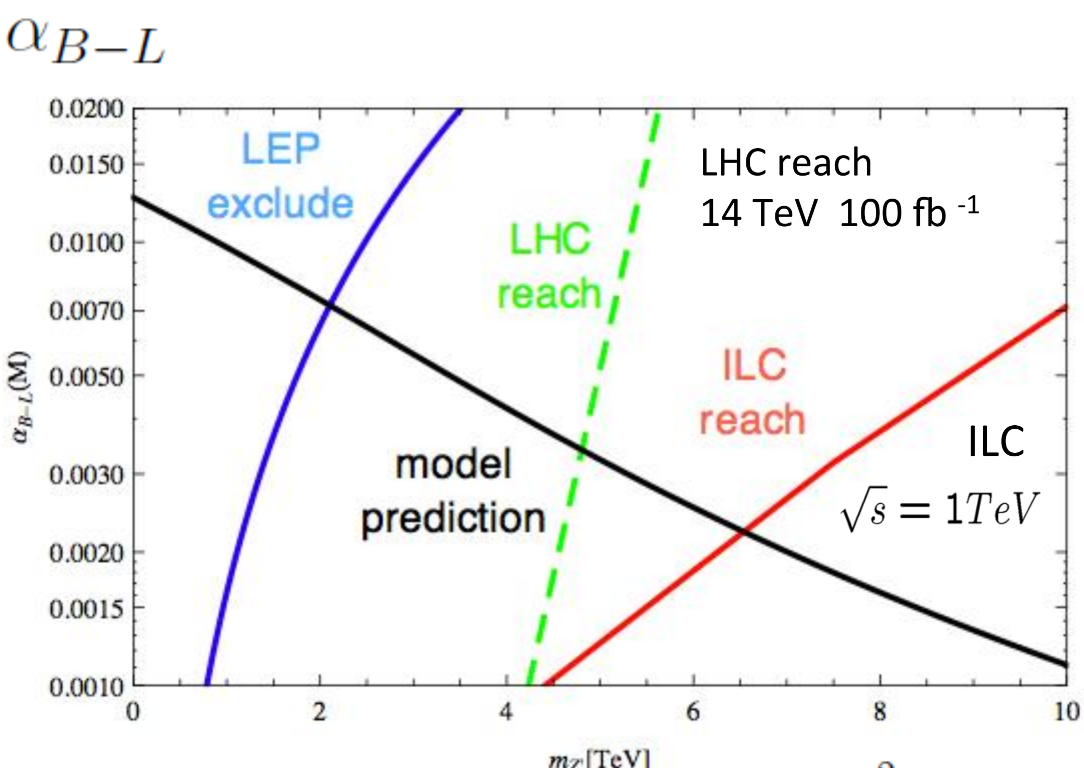
A small negative scalar mixing is radiatively generated though the mixing of $U(1)_Y$ and $U(1)_{B-L}$

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

→ EW and B-L scales are related in terms of gauge couplings.

Prediction of the model

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



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

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

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

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

Y Orikasa, SI; 1210.2848(PTEP)

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 solves naturalness problem

(2) it explains why B-L breaking scale is around TeV.

(3) phenomenologically viable

Neutrino oscillation, resonant leptogenesis

(4) Prediction

Z' around several TeV, $M_\phi < M_{Z'}$, Leptogenesis at TeV

Grazie mille !