Classically Conformal Left-Right Model and Higgs Vacuum Stability

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(A work in progress)

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Talk Outline

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  - Particle contents
  - Conformal scalar potential and Yukawa interactions
- Coleman-Weinberg mechanism
- Electro-Weak symmetry breaking
- Higgs Vacuum Stability
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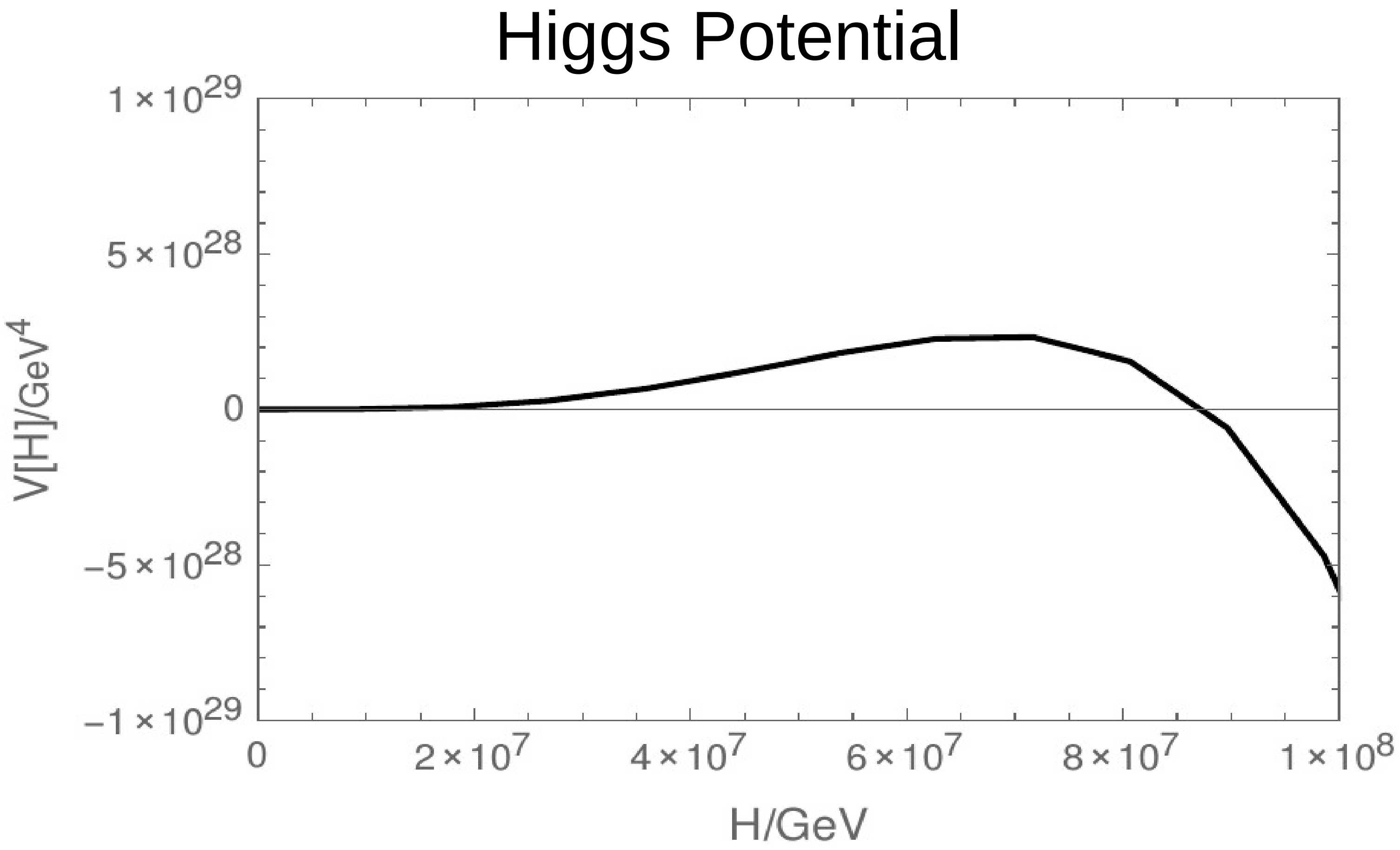
- Conclusions

Motivation



- Self coupling corrections chiefly due to the Top quark drives Electro-Weak vacuum instability at high energies

Left-Right Model: Particle Contents

Gauge Group: $SU(3)_C$ X $SU(2)_L$ X $SU(2)_R$ X $U(1)_{B-L}$

Particle Contents:

	$SU(1)_C$	$SU(2)_L$	$SU(2)_R$	$U(1)_{B-L}$
Q_L	3	2	1	1/3
Q_R	3	1	2	1/3
ℓ_L	1	2	1	-1
ℓ_R	1	1	2	-1
H	1	2	2	0
Φ	1	1	2	1

Left-Right Model: Interactions

Conformal Scalar Potential

i) $V = \lambda_1 \left(tr\{ H^\dagger H \} \right)^2 + \lambda_2 tr\{ H^\dagger H \} \left(\Phi^\dagger \Phi \right) + \lambda_3 \left(\Phi^\dagger \Phi \right)^2$

Where,

$$\Phi = \begin{bmatrix} \varphi_+ \\ \varphi \end{bmatrix}, \ \langle \Phi \rangle = \begin{bmatrix} 0 \\ M \end{bmatrix}$$

and we assume, $\lambda_2 \ll \lambda_3$

(Note: Our model thus far utilizes this form as other terms contribute negligibly to the main focus of our discussion. In the future we will consider a more generalized potential)

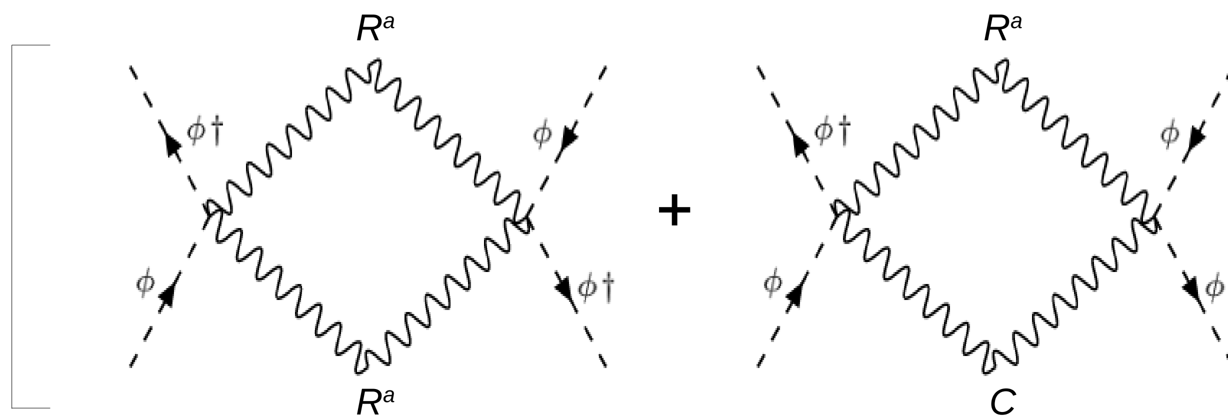
Yukawa Interactions

ii) $L_{Yukawa} \supset \{ \overline{Q_L} \left(Y_q H + \tilde{Y}_q \tilde{H} \right) Q_R + h.c. \} + \{ \overline{l_L} \left(Y_l H + \tilde{Y}_l \tilde{H} \right) l_R + h.c. \}$

Coleman-Weinberg Mechanism

i) $V_{eff} \supset \lambda_3 (\varphi^\dagger \varphi)^2 + \frac{B(\varphi^\dagger\varphi)^2}{2}\left(\ln\left[\frac{\varphi^\dagger\varphi}{M}\right]^2 - \frac{25}{6}\right)$ where, $\lambda_3 \sim B$

and, $B \approx$ [



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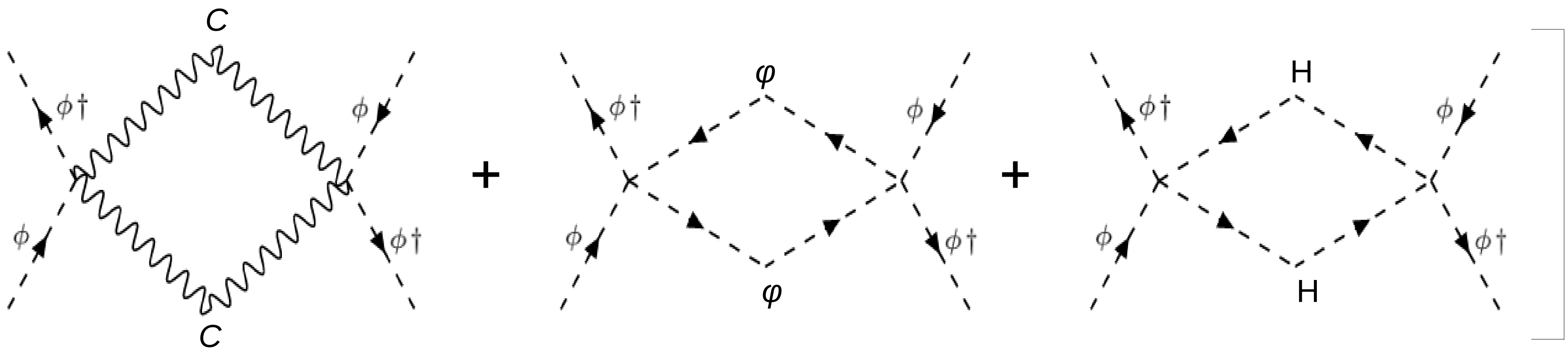

]

- R^a and C are the $SU(2)_R$ and $U(1)_{B-L}$ gauge bosons respectively

Coleman-Weinberg Mechanism

ii) $$\frac{dV_{eff}}{d\varphi}\Big|_{\varphi=M} = 0 \;\rightarrow\; \lambda_3 = \frac{11B}{6}$$ (Dimensional Transmutation)

iii) $$\frac{d^2 V_{eff}}{d\varphi^2}\Big|_{\varphi=M} = m_\Phi^2 \;\rightarrow\; m_\Phi^2 = 4BM^2$$ (Radiative Breaking)

*S.R. Coleman and E.J. Weinberg, Phys. Rev. D7, 1888 (1973)

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- The C-W mechanism radiatively breaks **$SU(2)_R$ X $U(1)_{B-L}$** to **$U(1)_Y$**

iv) $$M_{W_R^{\pm}} = g_R\,M\,,\;\; M_{Z'} = \sqrt{g_R^2 + g_{B-L}^2}\left(\frac{M_{W_R^{\pm}}}{g_R}\right),\;\; g_Y = \frac{g_R\,g_{B-L}}{\sqrt{g_R^2 + g_{B-L}^2}}$$

v) $$\alpha_R = \frac{(g_R)^2}{4\pi}\,,\;\; \alpha_{B-L} = \frac{(g_{B-L})^2}{4\pi}$$ ($SU(2)_R$ X $U(1)_{B-L}$ couplings)

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Electro-Weak Symmetry Breaking

- After Φ develops a non-zero VEV, this creates a negative mass^2 to the potential and breaks $\mathbf{SU(2)_L \times U(1)_Y}$ to $\mathbf{U(1)_{EM}}$

i) $$V_{eff} \supset \lambda_1 \left(tr\{H^\dagger H\}\right)^2 + \lambda_2\, tr\{H^\dagger H\}(M)^2$$

where, $$\lambda_2 < 0,\ diag(\langle H \rangle) = (v_1, v_2),$$
$$v_{SM}^2 = (v_1)^2 + (v_2)^2 = (125)^2\, GeV^2$$

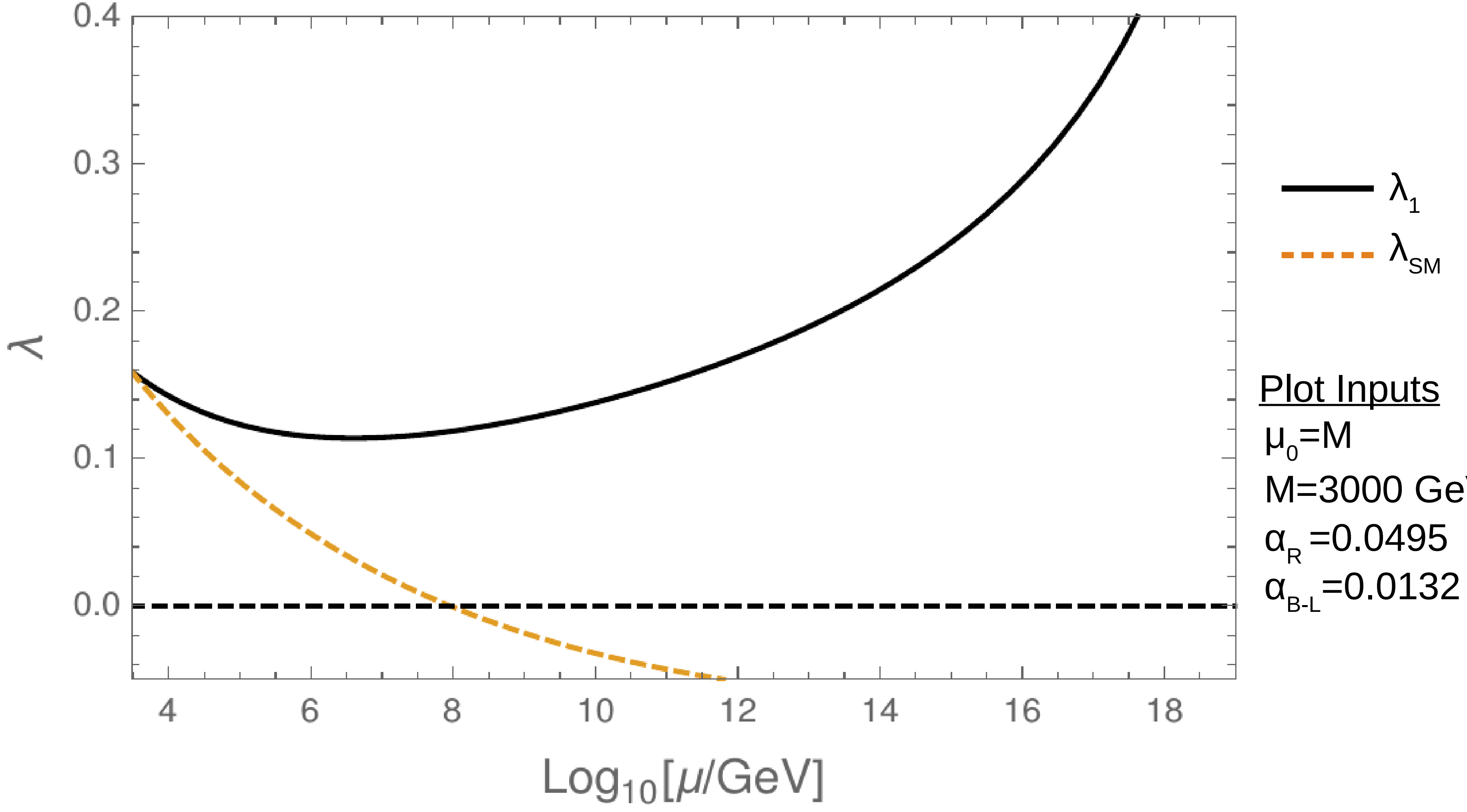
and,

ii) $$V_{eff}'\Big|_{h=\frac{v_{SM}}{\sqrt{2}}} = 0 \rightarrow \lambda_2 = \lambda_1 \left(\frac{v_{SM}}{M}\right)^2 \ll \lambda_1\ \&\ \lambda_3$$

(This verifies our earlier assumption)

iii) $$V_{eff}''\Big|_{h=\frac{v_{SM}}{\sqrt{2}}} \rightarrow m_h^2 = 2\lambda_1 v_{SM}{}^2$$

Higgs Vacuum Stability at 1-loop



Plot Inputs

μ_0=M

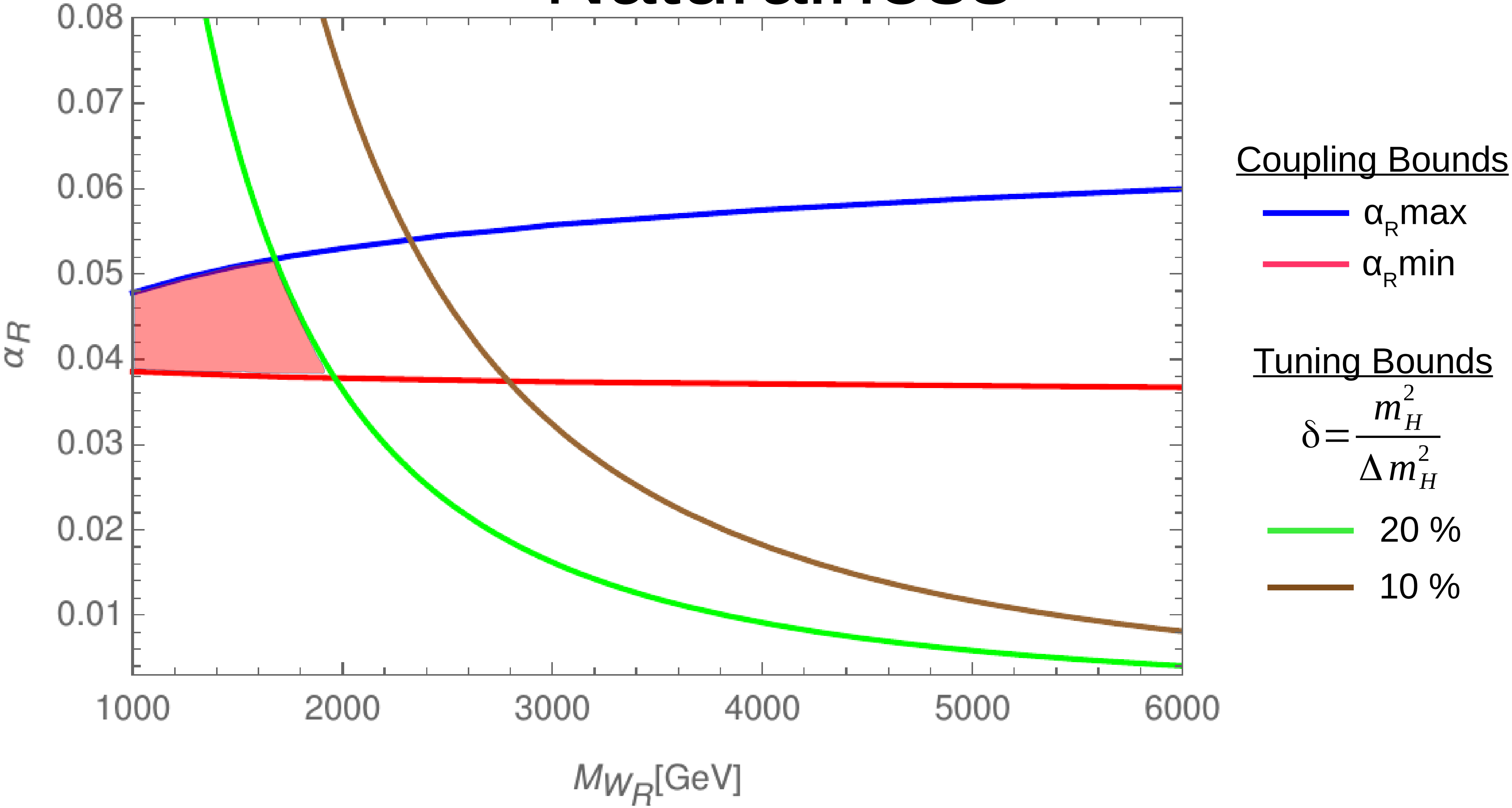
M=3000 GeV

α_R =0.0495

α_{B-L}=0.0132

- For various parameter values of M and α_R the Higgs self coupling constant, λ_1 remains positive

Naturalness



- Red/Blue lines are the maximum/minimum bounds that prevent couplings from diverging below Planck Scale
- Highlighted area shows permissible region below Naturalness bound (< 20%)
- These bounds confine the parameter region to be ~TeV

Conclusions

- Conformal L-R model with $SU(2)_R$ x $U(1)_{B-L}$ and $SU(2)_R$ scalar doublet(Φ), provides a means to avoid the Higgs Instability problem
- Radiative corrections break $\mathbf{SU(2)_R \times U(1)_{B-L} \rightarrow U(1)_Y}$ and induce $\mathbf{SU(2)_L \times U(1)_Y \rightarrow U(1)_{EM}}$ (EWSB)
- Naturalness constraints and convergence bounds place model in range accessible to LHC Run 2