A suppressed Higgs coupling in a classically conformal extension of the Standard Model

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Coleman-Weinberg Mechanism

Radiative Symmetry breaking as origin of SM Higgs potential

$$V = -m^2(H^\dagger H) + \lambda(H^\dagger H)^2 \tag{1}$$

- Scalar particle with $-m^2$ term displays spontaneous symmetry breaking.
- Negative mass-squared term may arise from quantum corrections via the Coleman-Weinberg mechanism (Coleman & Weinberg, 1973).
- Extend SM minimally with a new hidden $U(1)$ gauge group containing a Higgs scalar Φ.
- Implement CW mechanism for SM-extended Φ sector by imposing classical conformality (Iso, Okada, & Orikasa, 2009).

Coleman-Weinberg Mechanism

Radiative Symmetry breaking as origin of SM Higgs potential

- Hidden $U(1)$ sector scalar potential of the form

$$V_\phi = \lambda_\phi \left(\Phi^\dagger \Phi\right)^2 + V_{1-loop}$$
$$= \frac{1}{4}\lambda_\phi \phi^4 + \frac{\beta_\phi}{8}\phi^4 \left(ln\left[\frac{\phi^2}{v_\phi^2}\right] - \frac{25}{6}\right), \text{ where } \phi = \sqrt{2}\mathrm{Re}\left[\Phi\right] \tag{2}$$

- Radiative symmetry breaking occurs at $\langle \phi \rangle = v_\phi$
- Combined Higgs and Φ potential is

$$V = \lambda_h \left(H^\dagger H\right)^2 - \lambda_{mix}\left(H^\dagger H\right)\left(\Phi^\dagger \Phi\right) + V_\phi \tag{3}$$

- With $\lambda_{mix} > 0$, $\langle \phi \rangle = v_\phi$ generates SM Higgs VEV, driving EW symmetry breaking.

Potentials

Conventional: $V = \frac{\lambda_h}{4}(h^2 - v_h^2)^2 + \frac{\lambda_\phi}{4}(\phi^2 - v_\phi^2)^2 - \frac{\lambda_{mix}}{4}(h^2 - v_h^2)(\phi^2 - v_\phi^2)$

CW system: $V = \frac{\lambda_h}{4} h^4 + \frac{\lambda_\phi}{4}\phi^4 + \frac{\beta_\phi}{8}\phi^4 \left(\ln\left[\frac{\phi^2}{v_\phi^2}\right] - \frac{25}{6} \right) - \frac{\lambda_{mix} h^2 \phi^2}{4}$

- Mass-squared matrices defined as

$$M_{sq} = \begin{pmatrix} \partial_h^2 V & \partial_h \partial_\phi V \\ \partial_\phi \partial_h V & \partial_\phi^2 V \end{pmatrix} \Bigg|_{h=v_h, \phi=v_\phi} = \begin{pmatrix} m_h^2 & M^2 \\ M^2 & m_\phi^2 \end{pmatrix}$$

- Diagonalize M_{sq} to find mixing of eigenstates:

$$h = h_1 \cos(\theta) - h_2 \sin(\theta)$$
$$\phi = -h_1 \sin(\theta) + h_2 \cos(\theta)$$

Coupling Analysis

- We consider $\theta \ll 1$, so $h_1 \sim h$, $h_2 \sim \phi$.
- Obtain couplings by taking appropriate derivatives of h_1 and h_2.

Using $M_{h_1} = 125$ GeV, $v_h = 246$ GeV, sample values $M_{h_2} = 10$ GeV, $v_\phi = 10^4$ GeV, $\theta = 0.1$:

$$\text{Conventional system:} \quad g_{h\phi\phi} \simeq 0.79436$$
$$\text{CW system:} \quad g_{h\phi\phi,CW} \simeq -0.00396683$$

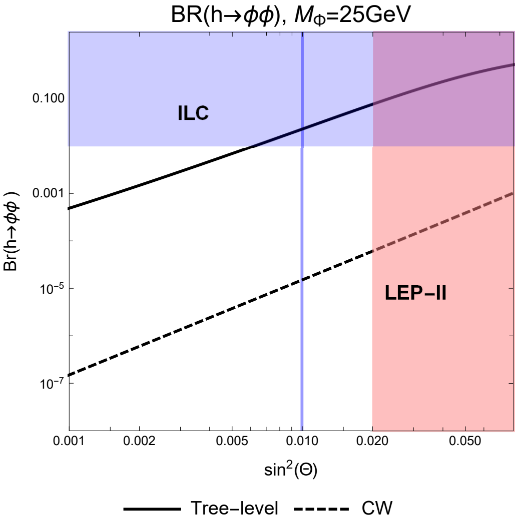
- To investigate origin of the suppression, we look at the forms of the couplings expanding θ:

  - Conventional system yields: $g_{h\phi\phi} \simeq \frac{M^2}{v_h} \cos(\theta) \sin(\theta)$
  - Coleman-Weinberg system: $g_{h\phi\phi,CW} \simeq -\frac{M^2}{v_h} \sin^3(\theta)$

- Cancellation of lower order θ terms leads to coupling suppression for CW system.

$\mathrm{Br}(h \to \phi\phi)$

- Using benchmark values of $M_\phi = 25$ GeV, $v_\phi = 10^4$ GeV, relative suppression seen across a range of small θ for light ϕ.
- Vertical blue line indicates benchmark value $\theta = 0.1$, as well as prospective ILC search reach.



General bounds: LEP-II

- LEP bounds on exotic Higgs decays provide more general constraints on θ for light ϕ (Abbiendi, et. al., 2003).
- Masses below $M_\Phi \sim 10$ GeV more strongly constrained by B-physics.

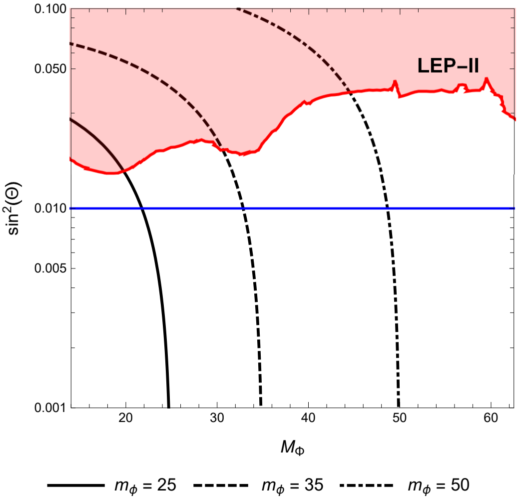


Figure: Dependence of $\sin^2(\theta)$ on M_ϕ for given values of the parameter m_ϕ.

Summary

- Classical conformal structure & Coleman-Weinberg mechanism as origin of SM Higgs mass-squared term
- One-loop corrected coupling displays marked suppression versus the naive tree-level expectation.
- Future experiments may be able to probe further parameter space. Higgs anomalous coupling measurements could reach down to $\sin^2(\theta) \sim \mathcal{O}(0.01)$
- $g_{h\phi\phi}$ dictates $h \to \phi\phi$ process which can be used to probe conformal structure via (non-)observation of $h \to \phi\phi$ after measurement of nonzero mixing angle θ.
- Simple to implement in more general SM extensions.