1-loop radiative corrections to the $\rho$-parameter in the left–right twin Higgs Model

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Introduction

• Hierarchy problem: one of the main problems in particle physics

• Solution to H.P.: Supersymmetry, ExtraDimensions, Little Higgs models, etc.

• Twin Higgs models:
  Introducing discrete symmetry to protect the Higgs mass from quadratic divergence
• Global U(4)symmetry

\[ V(H) = -m^2 H^\dagger H + \lambda(H^\dagger H)^2 \]

Spontaneous Symmetry breaking, $U(4) \rightarrow U(3)$ with \[ \langle |H| \rangle = \frac{m}{\sqrt{2\lambda}} \equiv f \]

CW effective potential, for $H=(H_A, H_B)$,

\[ \Delta V = \frac{9g_A^2 \Lambda^2}{64\pi^2} H_A^\dagger H_A + \frac{9g_B^2 \Lambda^2}{64\pi^2} H_B^\dagger H_B + \ldots \]
• If we take two gauge couplings equal, i.e. $g_A = g_B = g$, 

$$
\Delta V = \frac{9g^2 \Lambda^2}{64\pi^2} (H_A^\dagger H_A + H_B^\dagger H_B) = \frac{9g^2 \Lambda^2}{64\pi^2} H^\dagger H
$$

which is invariant under $U(4)$, so does not contribute to the mass of Goldstone boson.

$\Rightarrow$ Goldstone boson mass is completely insensitive to the quadratic divergence

$\Rightarrow$ But there exist logarithmic terms which trigger the EWSB
• Coleman-Weinberg Potential,

\[ V_{CW} = \pm \frac{1}{64\pi^2} \sum_i M_i^4 \left( \log \frac{\Lambda^2}{M_i^2} + \frac{3}{2} \right) \]

and with Higgs doublets,

\[ H_A^\dagger H_A = h^\dagger h - \frac{(h^\dagger h)^2}{3f^2} + \ldots \]

\[ H_B^\dagger H_B = f^2 - h^\dagger h + \frac{(h^\dagger h)^2}{3f^2} - \ldots \]
Left Right Twin Higgs Model

- Global $U(4)_1 X U(4)_2$, $SU(2)_L X SU(2)_R X U(1)_{B-L}$ gauged.

\[
H = \begin{pmatrix} H_L \\ H_R \end{pmatrix}, \quad \hat{H} = \begin{pmatrix} \hat{H}_L \\ \hat{H}_R \end{pmatrix}
\]

\[
\langle H \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f \end{pmatrix}, \quad \langle \hat{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \hat{f} \end{pmatrix}
\]

\[
H = f e^{\pi i / f} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}, \quad \pi = \begin{pmatrix} -\frac{N}{2\sqrt{3}} & 0 & 0 & h_1 \\ 0 & -\frac{N}{2\sqrt{3}} & 0 & h_2 \\ 0 & 0 & -\frac{N}{2\sqrt{3}} & C \\ h_1^* & h_2^* & C^* & \frac{\sqrt{3}N}{2} \end{pmatrix}
\]

- SSB,
After EWSB,

\[
\langle H \rangle = \begin{pmatrix} 0 \\ if \sin x \\ 0 \\ f \cos x \end{pmatrix}, \quad \langle \hat{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \hat{f} \end{pmatrix}
\]

where

\[
x = \frac{v}{\sqrt{2}f}
\]

Gauge sector:
Heavy Z & W bosons in addition to SM gauge bosons.
• Fermion Sector

To cancel the top quark contributions, new vector-like partner is introduced

\[ \mathcal{L}_{Yuk} = y_L \bar{Q}_L \tau_2 H^*_L Q_R + y_R \bar{Q}_R \tau_2 H^*_R Q_L - M \bar{Q}_L Q_R + h.c., \]

where \( Q_{L,R} = -i(u_{L,R}, d_{L,R}). \)

There exits extra heavy top quark which gives large logarithmic term to the SM Higgs masses.
• Higgs Sector

14-6 = 8 Nambu-Goldstone bosons get masses through quantum effects and soft symmetry breaking terms.

\[ V_\mu = -\mu_r^2(H_R^\dagger \hat{H}_R + c.c.) + \mu_t^2 \hat{H}_L^\dagger \hat{H}_L \]

In addition to the SM Higgs, there are

\[ \phi^\pm, \phi^0, \hat{h}_1^\pm \text{ and } \hat{h}_2^0 \]
\[ \rho - \text{parameter} \]

- Tree level

  \[ \rho \equiv \frac{M_W^2}{M_Z^2 c_\theta^2} \]

- Loop level

  With \( M_W \) predicted from the model,

  \[ M_W^2 = \frac{1}{2} \left[ a(1 + \Delta \hat{r}) + \sqrt{a^2(1 + \Delta \hat{r})^2 + 4a \Pi^{WW}(0)} \right], \]

  \[ \Delta \hat{r} = -\frac{\Delta s_\theta^2}{s_\theta^2} - \frac{Re(\Pi^{ZZ}(M_Z^2))}{M_Z^2} + \Pi^{\gamma'}(0) + \frac{2(g_V^e - g_A^e)}{Q_e} \frac{\Pi^{ZZ}(0)}{M_Z^2} - \frac{c_\theta^2 - s_\theta^2}{c_\theta s_\theta} \frac{Re(\Pi^{\gamma Z}(M_Z^2))}{M_Z^2} \]

  \[ a \equiv \frac{\pi \alpha(M_Z)}{\sqrt{2} G_F s_\theta^2} \]
Relevant diagrams

\[
\begin{align*}
\gamma &\rightarrow t & \gamma &\rightarrow b & \gamma &\rightarrow \bar{T} \\
\gamma &\rightarrow \phi^+ & \gamma &\rightarrow \phi^- & \gamma &\rightarrow \phi^+ \\
\gamma &\rightarrow h_1^+ & \gamma &\rightarrow h_1^- & \gamma &\rightarrow h_1^+ \\
\end{align*}
\]
Numerical Results

- Input parameters

\[ G_F = 1.16637(1) \times 10^{-5} \text{ GeV}^{-2}, \]
\[ M_Z = 91.1876(21) \text{ GeV}, \]
\[ \alpha(M_Z)^{-1} = 127.918(18), \]
\[ s_\theta^2 = 0.23153(16). \]

- Experimental bound (PDG)

\[ 1.00989 \leq \rho^{exp} \leq 1.01026. \]
• Free Parameters of LRTH

\[ f, \ M, \ \mu_r, \ \hat{\mu} \]

- Mass of the heavy top is solely determined by \( f \) and \( M \).
- Masses of the scalar particles largely depend on all of them.
- \( \hat{f} \) determined from the EWSB conditions.
- Negative mass squared, \( v = 246 \text{ GeV} \).
• Numerical range

\[ 500 \text{ GeV} \leq f \leq 2500 \text{ GeV}, \quad 0 \leq M, \mu_r, \hat{\mu} \leq f. \]
• Division of the allowed parameter space to two regions, less than **670 GeV** or larger than **1.1 TeV**.

• Constraint for f from heavy W and Z boson masses

• If we accept the lower bound for heavy W is roughly **1.6 TeV** from LR model with $K_L-K_s$ mixing, then small f region will be excluded.
Summary and Conclusion

• We have calculated 1-loop corrected $\rho$ parameter in the LRTH model.

• With the constraints for heavy particles we can give a serious bound on the $f$ and masses of the non-SM particles.

• We also gives a typical mass range for Higgs boson. (maybe upper bound.)
• Our numerical results significantly reduce the parameter space which are favorably accessible to the LHC

• More study on the precision variables, Peskin-Takeuchi STU analysis.

• Flavor and CP structure of the LRTH model wait for you attentions.