Twin Higgs from Left-Right Symmetry

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June 13, 2006

Outline

- Introduction: Little Hierarchy Problem
- Twin Mechanism
- Twin Higgs from Left-Right Symmetry
- Phenomenology
- Summary

Recipe

- SU(4) Global symmetry in Higgs potential
- $H = (H_A, H_B)$ transforms as a fundamental
- Twin symmetry $A \leftrightarrow B$
- $< H >= (0, 0, 0, f)$ break $SU(4)$ to $SU(3)$ $\Rightarrow$ 7 Goldstone bosons
- Gauge $SU(2)_A \times SU(2)_B \subset SU(4)$
- Promote top Yukawa to preserve Twin symmetry

Left-Right Models

[Chacko,HSG,Harnik hep-ph/0512088]

$$SU(2)_A \times SU(2)_B \quad \rightsquigarrow \quad SU(2)_L \times SU(2)_R$$

$$Twin \quad \rightsquigarrow \quad L - R$$

$$\underline{SU(2)_L} \quad \oplus \quad \underline{SU(2)_R}$$

$$Q_L \quad \leftrightarrow \quad Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$Z_2$$

$$\vdots \qquad \vdots$$

$$\underbrace{H_L \qquad H_R}_{H}$$

$$SU(4)$$

Higgs Sector

– Focus on effective theory below the scale $\Lambda \sim 4\pi f$

– H is Non-linearly realized

– Transforms under SU(4) as a fundamental

non-linear representation

$$\begin{pmatrix} H_L \\ H_R \end{pmatrix} = H \;=\; f e^{i\frac{\pi}{f}} \begin{pmatrix} 0 \\ 0 \\ 0 \\ 1 \end{pmatrix} \quad ; \pi = \begin{pmatrix} 0 & 0 & 0 & h_1 \\ 0 & 0 & 0 & h_2 \\ 0 & 0 & 0 & C \\ h_1^* & h_2^* & C^* & \phi \end{pmatrix}$$

– Potential of π is zero at tree level

– EW symmetry breaking is induced dynamically
—via SU(4) violating interactions

Gauge Sector

Gauge symmetry

$$SU(2)_L \times \underbrace{SU(2)_R \times U(1)_{B-L}}_{\texttt{<H>=f}}$$
$$\Downarrow$$
$$U(1)_Y$$

left-right symmetry $\Rightarrow g_L = g_R = g_2$

Massive gauge bosons : $W_H^\pm$ and Z_H with masses

$$m_{Z_H}^2 \sim \frac{g_1^2 + g_2^2}{g_2^2} m_{w_H^\pm}^2$$
$$m_{W_H^\pm}^2 = \frac{1}{2} g_2^2 f^2 \cos^2 \frac{v}{f}$$

Z' searches $\Rightarrow f \gtrsim 2$ TeV

Fermion Sector

Light fermion masses come from terms

$$\frac{(\bar{Q}_R H_R)(H_L^\dagger Q_L)}{\Lambda} \quad and \quad \frac{(\bar{Q}_R H_R^\dagger)(H_L Q_L)}{\Lambda}$$

for down and up type respectively. Too small for top quark

introduce one vector-like pair of quarks T_L and T_R

We can write

$$y\bar{Q}_R H_R^\dagger T_L + y\bar{Q}_L H_L^\dagger T_R + M T_L T_R$$

$$m_T^2 \sim M^2 + y^2 f^2$$

– Preserve L-R symmetry

– M can be arbitrarily small

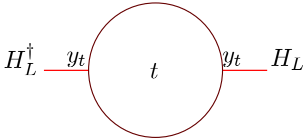
Cancellations

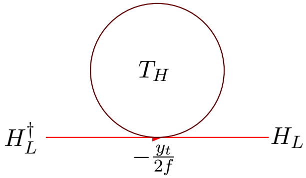
To see explicitly how are the quadratic divergent m^2 of h_L cancelled, go to the non-linear representation

$$\begin{pmatrix} H_L \\ H_R \end{pmatrix} = H \ \sim \ \begin{pmatrix} ih_L \\ 0 \\ f - \frac{1}{2}\frac{h_L^\dagger h_L}{f} \end{pmatrix}$$

for top sector

$$\bar{Q}_L H_L t_R + \bar{Q}_R H_R T_L = i\bar{Q}_L h_L t_R - \frac{1}{2}\frac{h_L^\dagger h_L}{f}\bar{T}_L T_R + f\bar{T}_L T_R + ...$$

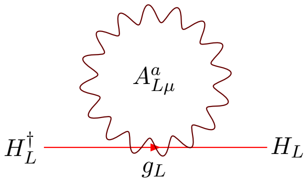

$H_L^\dagger$
y_t
t
y_t
H_L

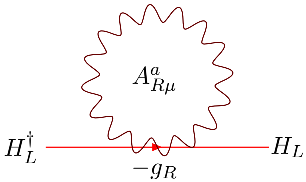

T_H
$H_L^\dagger$
H_L
$-\frac{y_t}{2f}$

$$\begin{pmatrix} H_L \\ H_R \end{pmatrix} = H \sim \begin{pmatrix} ih_L \\ 0 \\ f - \frac{1}{2}\frac{h_L^\dagger h_L}{f} \end{pmatrix}$$

for the gauge sector

$$|D_L H_L|^2 + |D_R H_R|^2 = h_L^\dagger A^\dagger A h_L - h_L^\dagger h_L (A^\dagger A)_{22}$$


$A^a_{L\mu}$
$H_L^\dagger$
H_L
g_L


$A^a_{R\mu}$
$H_L^\dagger$
H_L
$-g_R$

EW Symmetry Breaking

The mass of the Higgs doublet get a one loop correction from the top sector

$$m^2 \;=\; -\frac{3}{8\pi^2} y^2 f^2 \ln(\frac{\Lambda^2}{f^2}) \tag{1}$$

large f required by Z' searches reintroduced certain amount of fine tuning. To decouple this constraint from the tuning problem,

– Order an extra scalar $\hat{H}$

– Impose $\hat{H} \rightarrow -\hat{H}$ symmetry
so $\hat{H}$ does not couple to fermions.

– Require $< \hat{H} >= \hat{f} >> f$

So Far ....

$$
\begin{aligned}
m_{Z_H}^2 &\sim \frac{g_1^2+g_2^2}{2}(\hat{f}^2+f^2) \\
m_T^2 &\sim M^2+y^2 f^2
\end{aligned}
$$

and

$$
\Delta m^2 = -\frac{3}{8\pi^2} y^2 f^2 \ln(\frac{\Lambda^2}{f^2})
$$

f is now allowed to be $<$ TeV $\Rightarrow$ fine tuning is milder

Higgs Potential and Fine Tuning

- Higgs m^2 get a negative contribution from top loop
- Positive contribution from gauge loop
- Tuning these two terms to get correct EW symmetry breaking fix $\hat{f}$ with f
- Fine tuning is $\sim 11\%$ for f=800 GeV and 27% for f=500 GeV with the best case scenario $\Lambda = 4\pi f$

μ Terms

- With 2 Higgs, Global symmetry is $U(4) \times U(4)$
- There are separate global U(1) factors for H and $\hat{H}$
- They are broken by f and $\hat{f} \Rightarrow$ 2 Goldstone bosons
- One is eaten by Z_H, The other left uneaten, it is the ϕ^0
- This global U(1) is exact $\Rightarrow \phi^0$ remain massless

Add a mass term

$$B H_R^\dagger \hat{H}_R + \mu^2 \hat{H}_L^\dagger \hat{H}_L$$

These are technically natural. $\hat{H}_L \longrightarrow -\hat{H}_L \Rightarrow$ dark matter

Summary

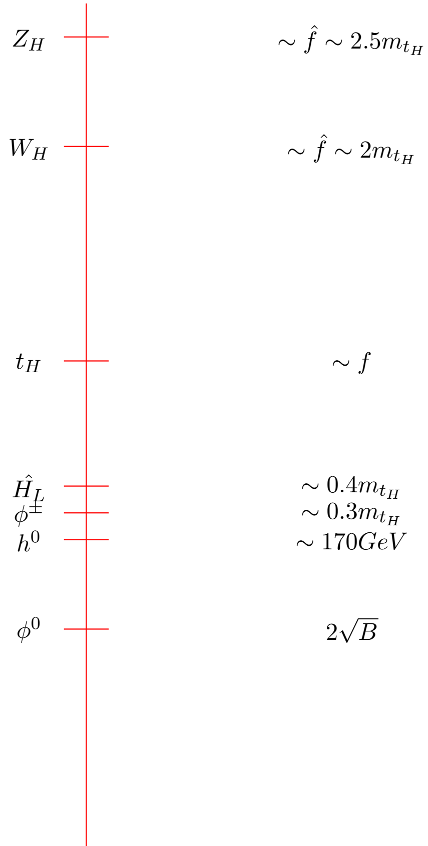
new parameters : f, $\hat{f}$, y, M, $\sqrt{B}$ and μ (very few)

- $\hat{f}$ is fixed by f to get m_W
- y is fixed by m_t
- M is arbitrary. It can even be zero
- Free parameters μ and $\sqrt{B}$

new particles :

- $W_H^{\pm}$, Z_H
- T_H
- 14-6=8 : h^0, $\hat{h}_L$, $\phi_R^{\pm}$ and ϕ_R^0

Generic Spectrum



"Linearize" Non-Linear Representation

$$
\begin{aligned}
H &= i\frac{\sin\sqrt{\chi}}{\sqrt{\chi}}e^{i\frac{\phi}{f}}\begin{pmatrix} h_1 \\ h_2 \\ C \\ \phi - if\sqrt{\chi}\cot\sqrt{\chi} \end{pmatrix} \\
\phi &\to \frac{\hat{f}}{\sqrt{2}F(\cos x + \frac{\sin x}{x})}\phi \\
h_1 &\to 0 \\
h_2 &\to \frac{v+h}{\sqrt{2}} - i\frac{x\hat{f}}{\sqrt{2}F(\cos x + \frac{\sin x}{x})}\phi \\
C &\to -\frac{x\hat{f}}{F\sin x}C
\end{aligned}
$$

Conclusion

– Left-right model

- Both gauge and Yukawa couplings break SU(4) but preserve the Z_2 symmetry
- Predict :
  - Extra gauge bosons $W_H^{\pm}$ and Z_H with mass few TeV
  - Extra top quarks of mass $\sim f$
  - Scalar fields h_L,$\hat{h}_L$, $\phi^{\pm}$ and ϕ^0 which are relatively lighter
- Dark matter candidate
- Solve the fine tuning up to 10 TeV
- Very few parameters : f, $\hat{f}$, M, μ and $\sqrt{B}$
- Expect LHC to see these exotic particles and test the model