T-parity in UV complete Little Higgs models

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Work in progress with Claudia Frugiuele

Little Higgs models

Higgs is a pseudo-Goldstone boson

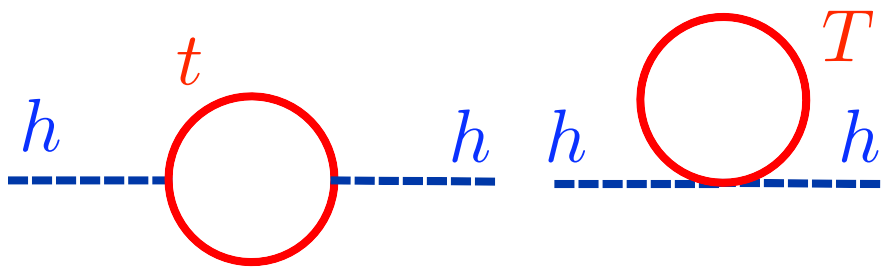
Described by a non-linear Sigma model at low energy

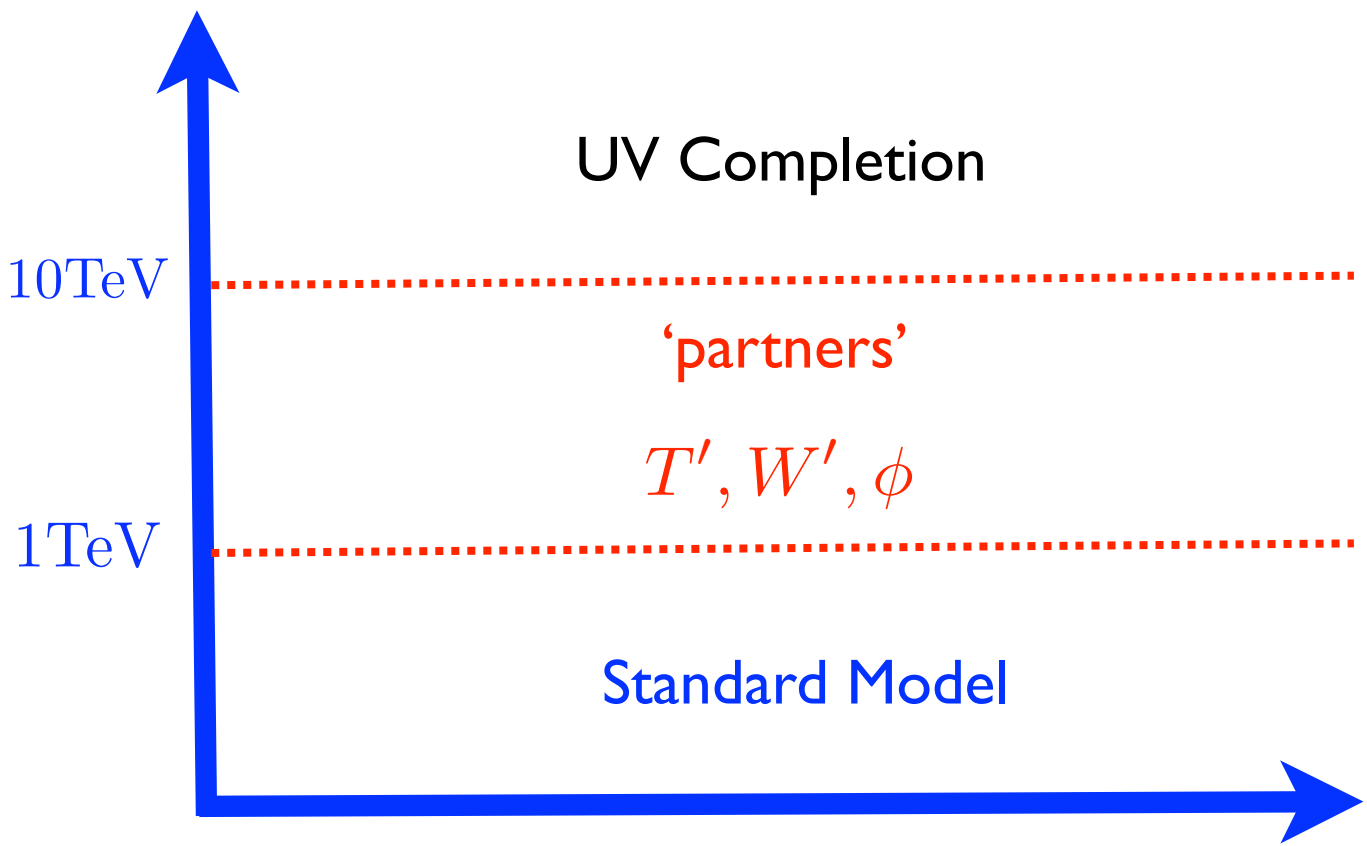
$$E < \Lambda \sim 10\mathrm{TeV}$$

mass of the Higgs protected by collective symmetry breaking

$$m_h^2 \sim \frac{g_1^2}{16\pi^2}\frac{g_2^2}{16\pi^2}\Lambda^2$$

Quadratic divergences cancelled by 'partners' of the same spin

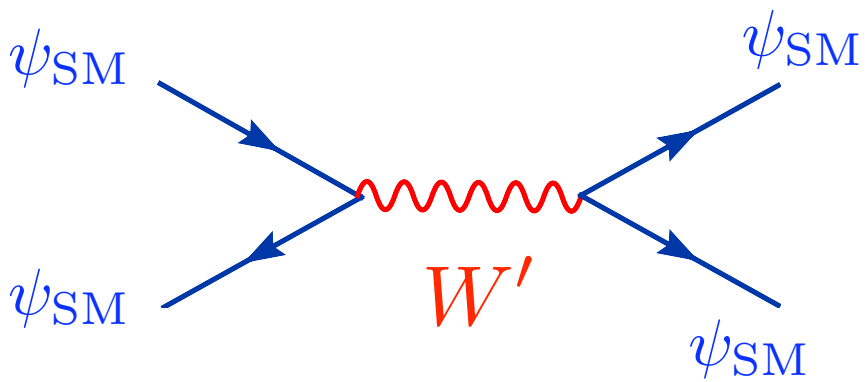




Problems:

- Electroweak precision measurements

Higher dimensional operators at tree level



$$\frac{\Psi_{\rm SM}\Psi_{\rm SM}\Psi_{\rm SM}^{\dagger}\Psi_{\rm SM}^{\dagger}}{f^2} + \text{others}$$

Possible solution:

T-parity

Cheng,Low

Low

$$\phi_{\rm SM} \to \phi_{\rm SM}$$

$$\phi_{\rm partner} \to -\phi_{\rm partner}$$

- Dark matter candidate
- LHC phenomenology more similar to SUSY

Littlest Higgs

$$SU(5)/SO(5)$$

transformation law:

$$\Sigma \to V \Sigma V^T \qquad V \in SU(5)$$

vev:

$$\langle \Sigma \rangle = \Sigma_0 = \begin{pmatrix} \mathbf{0} & 0 & \mathbf{1} \\ 0 & 1 & 0 \\ \mathbf{1} & 0 & \mathbf{0} \end{pmatrix}$$

5×5

2×2

pions:

$$\Sigma = e^{i\pi/f} \Sigma_0 e^{i\pi^T/f} \qquad \pi = \begin{pmatrix} \alpha & h & \phi \\ h^\dagger & 0 & h^T \\ \phi^\dagger & h^* & \alpha^T \end{pmatrix}$$

gauged subgroup:

$$Q_1^a = \begin{pmatrix} \sigma^a & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{pmatrix} \qquad Q_2^a = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & -\sigma^{a*} \end{pmatrix}$$

T-parity definition

$$\Sigma \to \Omega \Sigma^\dagger \Omega \qquad \Omega = \begin{pmatrix} 0 & 0 & \mathbf{1} \\ 0 & -1 & 0 \\ \mathbf{1} & 0 & 0 \end{pmatrix} \in SO(5)$$

$$A^1_\mu \to A^\mu_2$$

$$W'_\mu \to -W'_\mu$$

$$\phi \to -\phi$$

$$W_{\mathrm{SM}\,\mu} \to W_{\mathrm{SM}\,\mu}$$

$$h \to h$$

Strongly coupled UV completion

Strong $SO(N)$

5 flavour charged under this $SO(N)$

$$\begin{pmatrix}\psi_2\\ \psi_0\\ \psi_2'\end{pmatrix} \rightarrow \langle \Psi_5 \Psi_5 \rangle = \begin{pmatrix}\mathbf{0} & 0 & \mathbf{1}\\ 0 & 1 & 0\\ \mathbf{1} & 0 & \mathbf{0}\end{pmatrix}$$

What about the top sector?

Could be a composite too: a baryon

How can we impose T-parity in the UV completion?

$$\begin{pmatrix}\psi_2\\ \psi_0\\ \psi_2'\end{pmatrix} \rightarrow \Sigma \rightarrow \Omega\Sigma^\dagger\Omega \qquad \Omega = \begin{pmatrix}0 & 0 & \mathbf{1}\\ 0 & -1 & 0\\ \mathbf{1} & 0 & 0\end{pmatrix}$$

$$\psi_2 \rightarrow {\psi_2'}^\dagger$$

$$\psi_0 \rightarrow -{\psi_0}^\dagger$$

not a symmetry

need $\mathbf{x} \rightarrow -\mathbf{x}$

Analogy to QCD

In the chiral Lagrangian $\Sigma \to \Sigma^\dagger$

$$\pi \to -\pi$$

could be a symmetry

Not a symmetry of QCD

$$\pi F_{\mu\nu} \tilde{F}_{\mu\nu}$$

Similar terms exist in Little Higgs models

WZW terms: fixed by anomaly structure

Make the dark matter candidate unstable

Do not contribute to EWPO

problem is deeper: what symmetry to impose in the UV?

Fermions $\frac{Q_1 \Psi \Psi Q_1^c}{\Lambda^2} + \frac{Q_2 \Psi^\dagger \Psi^\dagger Q_2^c}{\Lambda^2}$

Possible solutions

Look for new UV completions

Look for a new definition of T-parity

Add a new field:

$$\Sigma_1 \to \Sigma_2$$

$$\Sigma_1 \to L\Sigma_1 L^T \qquad \Sigma_2 \to R^*\Sigma_2 R^\dagger$$

The number of fields is doubled: even and odd

Give mass to the unwanted combination:

$$\Lambda^2 f^2 \Sigma_1 \Sigma_2$$

break the enlarged gobal symmetry to the diagonal

Could come from 4-Fermi interactions in the UV theory, but might be hard to engineer.

SUSY UV completion
Csaki, Heinonen, Perelstein, Spethman

Other possibility:

change global symmetry structure

we want: $A_1 \to A_2$

why not: $\psi_2 \to \psi_2'$?

$$\begin{pmatrix} \psi_2 \\ \psi_0 \\ \psi_2' \end{pmatrix}$$

2 of $SU(2)_1$ $\quad$ 2^* of $SU(2)$

$$Y = \frac{1}{2} \qquad Y = -\frac{1}{2}$$

Add a new flavour

		$SU(2)_1$	$SU(2)_2$	$U(1)_Y$
$SU(6)$	Ψ_2	2	1	0
	Ψ_0	1	1	$1/2$
	Ψ'_0	1	1	$-1/2$
	Ψ'_2	1	2^*	0

$$\Psi_2 \to \epsilon \Psi_2'$$

$$\Psi_0 \to \Psi_0$$

$$\Psi_0' \to \Psi_0'$$

$$\Psi_2' \to -\epsilon \Psi_2$$

Global symmetry

$$SU(6)/Sp(6)$$

Low,Skiba,Smith

$$\Sigma_0 = \begin{pmatrix} \mathbf{0} & 0 & 0 & \mathbf{1} \\ 0 & 0 & 1 & 0 \\ 0 & -1 & 0 & 0 \\ \mathbf{-1} & 0 & 0 & \mathbf{0} \end{pmatrix}$$

2×2 2×1 2×1 2×2 2×2 2×2

$$Q_1^a = \begin{pmatrix} \sigma^a & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} \qquad Q_2^a = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\sigma^{a*} \end{pmatrix}$$

$$Y = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1/2 & 0 & 0 \\ 0 & 0 & -1/2 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

$$\pi = \begin{pmatrix} \alpha - \eta/2 & h_1 & h_2 & s \\ h_1^\dagger & \eta & 0 & h_2^T \\ h_2^\dagger & 0 & \eta & h_1^T \\ s^\dagger & -h_2^* & h_1^* & \alpha^T - \eta/2 \end{pmatrix}$$

2 Higgs doublet

1 light real singlet

1 TeV complex singlet

top sector

$$\lambda_1 f Q \Sigma^\dagger Q^c$$

$$+\lambda_2 f (q_1^c K_1 q_3 + q_2^c K_2 q_3) + \lambda_3 u \tilde{u}^c$$

$$Q = \begin{pmatrix} q_1 \\ u \\ d \\ q_2 \end{pmatrix} \qquad Q^c = \begin{pmatrix} q_2^c \\ d^c \\ u^c \\ q_1^c \end{pmatrix}$$

$q_1 + q_2$ is even and massless

spectrum of top sector

1 even doublet

1 odd doublet

2 even singlets

Radiative corrections

The gauge and top sector contribute small mass terms

The gauge sector generates order one quartic couplings

$$\mathrm{Tr}\Sigma Q_1^a \Sigma^* Q_1^{aT} + \mathrm{Tr}\Sigma Q_2^a \Sigma^* Q_2^{aT}$$

At leading order the Higgs potential is

$$V(h_1, h_2) = \mu^2(|h_1|^2 + |h_2|^2) + b(h_2^\dagger h_1 + hc) + \lambda h_2^\dagger h_1 h_1^\dagger h_2$$

Inert Higgs doublet model

Barbieri,Hall,Rychkov

$$\langle h_+ \rangle = \begin{pmatrix} 0 \\ v \end{pmatrix} \qquad \langle h_- \rangle = \begin{pmatrix} 0 \\ 0 \end{pmatrix}$$

$h_1 + h_2$

$h_1 - h_2$

$$m_{h_0} < m_{H_0} = m_{H^+} < m_A$$

custodial symmetry

Corrections to S and T from the 2 Higgs doublet model are small

Dark Matter

The neutral, odd, CP even Higgs is the dark matter candidate

The correct relic abundance can be achieved for low masses

Dolle, Su

$$m_H \sim 80\mathrm{GeV} \quad m_{H^\pm} \sim 90\mathrm{GeV}$$

Phenomenology

Similarity with SUSY

Odd top partner	stop
charged Higgs	chargino

$$m_{H^\pm} > 70\mathrm{GeV}$$

Conclusions

- Little Higgs model try to realize the Higgs as a pseudo-Goldstone boson
- UV completion change the phenomenology and structure of the low energy theory
- The SU(6)/Sp(6) model is well suited for a different implementation of T-parity