Little Higgs M-theory

Hsin-Chia Cheng
UC Davis

SUSY06, Irvine, California

W/ Jesse Thaler and Lian-Tao Wang, to appear
Introduction

- LHC is expected to discover new physics which explains electroweak symmetry breaking and addresses the hierarchy problem.

- Most of the collider studies focused on SUSY, which is the most popular scenario.

- There have been many alternatives proposed (technicolor, extra dimensions, little Higgs,...). Within each class, there are many variants. Which models deserve more detailed studies?

- It would be nice if there is a model which interpolates among various models and covers most of the features of the non-SUSY theories.
In fact, most of the known non-SUSY models can be represented or approximated by **moose diagrams**.

**Technicolor:**

Global: \[ SU(2)_L \to SU(2)_R \]

Gauged: \[ SU(2) \to SU(N_c) \]

**Extra dimensions: by deconstruction**

Global: \[ SU(2)_1 \to SU(2)_2 \to \cdots \to SU(2)_N \]

Gauged: \[ SU(2) \to SU(2) \to \cdots \to SU(2) \]

Warp factor can be represented by different Goldstone decay constant on the links.

**Little Higgs:**

Global: \[ SU(3) \to SU(3) \]

Gauged: \[ SU(2)_1 \to SU(2)_2 \]
• Precision EW constraints indicate that the scale of strong dynamics is probably out of the reach of the LHC, and in the case of extra dimensions, LHC will be able to discover only a few KK modes at most.

• At low energies (accessible to LHC), most non-SUSY models can be well represented by some simple moose models, and many models can be described by the same moose diagram.
Little Higgs Theories

- Higgs field(s) are **pseudo-Nambu-Goldstone bosons** (PNGBs) of a spontaneously broken global symmetry $G \rightarrow H$.

- Higgs mass is protected from one-loop quadratic divergence so that the cutoff can be pushed up to $\sim 10$ TeV.

- The quadratic divergences are cancelled by new particles which are **partners of the SM top quark, gauge bosons and Higgs**. Unlike SUSY, they have the **same spins** as the SM particles.
Many different little Higgs models bases on various $G/H$ and the gauged subgroup $F \subset G$.

(The unbroken gauge group: $I = F \cap H$ ( =SM))

**Minimal moose:**

$$F = (SU(2) \times U(1))^2$$

**Littlest Higgs:**

$$F = (SU(2) \times U(1))^2$$

**Simple little Higgs:**

$$F = SU(3) (\times U(1))$$

Arkani-Hamed et al, hep-ph/0206020

Arkani-Hamed et al, hep-ph/0206021

Kaplan & Schmaltz, hep-ph/0302049
Using CCWZ (Callan, Coleman, Wess & Zumino, 1969) and/or related ideas such as hidden local symmetry, AdS/CFT, they can all be converted into moose models.

Number of uneaten PNGBs: \((G - H) - (F - I)\)
CCWZ

# of PNGBs: \((G + H - H) - (F + H - I)\)

HC & Low, hep-ph/0405243
Low, hep-ph/0409025
Thaler, hep-ph/0502175
Thaler & Cheung, hep-ph/0604259

# of PNGBs: \((G + G - G) - (F + H - I)\)
AdS/CFT Construction

Global symmetry of CFT $\rightarrow$ Gauge symmetry in AdS bulk

Put gauged $G$ in the bulk

Weakly gauging $F$ in CFT $\rightarrow$ Gauge fields on UV brane

Put gauged $F$ on UV brane

Spontaneous symmetry breaking $\rightarrow$ BC on IR brane

Put gauged $H$ on IR brane

\[
\begin{align*}
F & \quad G & \quad H \\
\text{UV Brane} & \quad \text{Bulk} & \quad \text{IR Brane} \\
\end{align*}
\]

CFT with global $G$ symmetry $+$ $F \subset G$ gauged $+$ $G/H$ symmetry breaking
AdS/CFT Construction

![Diagram of AdS/CFT Construction]

Deconstruction

Global: $G$ $G$ $G$ $G$ $G$

Gauged: $F$ $G$ $G$ $G$ $H$

To the extreme limit:

Global: $G$ $\xi$ $G$

Gauged: $F$ $H$
Examples:
Littlest Higgs model

\[ G = SU(5), \ H = SO(5), \]
\[ F = SU(2)^2 \times U(1), \ I = SU(2) \times U(1) \]

Global :
\[ SU(5)_L \quad \psi \quad SU(5)_R \]

Gauged :
\[ SU(2)^2 \times U(1)_Y \quad SU(N_c) \quad SO(5) \]

Little Technicolor, Thaler, hep-ph/0502175
Simple little Higgs model:

\[ G = SU(3)^2, \quad H = SU(2)^2, \quad F = SU(3), \quad I = SU(2) \]

Global: \[ SU(3)^2 \quad \quad SU(3)^2 \]

Gauged: \[ SU(3)_V \quad \quad SU(2)^2 \]

Global: \[ SU(3) \quad \quad SU(3) \quad \quad SU(3) \]

Gauged: \[ SU(2) \quad \quad SU(3)_V \quad \quad SU(2) \]

Global: \[ SU(3) \quad \quad \Sigma_1 \quad \quad \Sigma_2 \quad \quad SU(3) \]

Gauged: \[ SU(2)_1 \quad \quad SU(3)_m \quad \quad SU(2)_2 \]
The moose diagram can describe several very different looking models by taking various limits.

- **Simple little Higgs:** \( g_{1,2} \) of \( SU(2)_{1,2} \to \infty \)
- **Minimal moose:** \( g_m \) of \( SU(3)_m \to \infty \)

The middle site can be integrated out.

- **T-parity:** \( g_1 = g_2 \), \( \langle \Sigma_1 \rangle = \langle \Sigma_2 \rangle \)

HC & Low, hep-ph/0308199

- **Holographic PNGB Higgs:**

Contino, Nomura & Pomarol, hep-ph/0306259
Little M-theory

Holographic Higgs

Simple little Higgs

Minimal moose

T-parity

RS

UEDs

M=Moose
Little M-theory

In practice, we need to make some compromises between versatility and simplicity.

We construct a model based on the following goals:

1. **Perturbative** below the cutoff \( \sim 10 \text{TeV} \)
2. **No large quadratic divergence** to Higgs mass-squared
3. Containing a **custodial SU(2)** symmetry
4. **Minimal flavor violation** can be implemented
5. “**KK partners**” for SM fermions to mimic extra dims
6. Having a **T-symmetric** limit
7. Lots of dials providing rich phenomenology
**Little M-theory**

**A representative model: Sp(4)/SO(4) moose**

Gauged: \( SU(2)_L \times U(1)_R \) \( \rightarrow \) \( Sp(4) \) \( \rightarrow \) \( SU(2)_R \times U(1)_R \)

Quarks: \( Q_1, Q_1^c \) \( \rightarrow \) \( Q_m \) \( \rightarrow \) \( Q_2, Q_2^c \)

Leptons: \( L_1, L_1^c \) \( \rightarrow \) \( L_m \) \( \rightarrow \) \( L_2, L_2^c \)

\[
Q_i = \begin{pmatrix} q_i \\ 0 \\ 0 \end{pmatrix}, \quad Q_i^c = \begin{pmatrix} q_i^c \\ t_i^c \\ b_i^c \end{pmatrix}, \quad Q_m = \begin{pmatrix} q_m \\ t_m \\ b_m \end{pmatrix}, \quad Q' = \begin{pmatrix} 0 \\ t' \\ b' \end{pmatrix}, \quad Q'^c = \begin{pmatrix} 0 \\ t'^c \\ b'^c \end{pmatrix},
\]

\[
L_i = \begin{pmatrix} l_i \\ 0 \\ 0 \end{pmatrix}, \quad L_i^c = \begin{pmatrix} l_i^c \\ \nu_i^c \\ \tau_i^c \end{pmatrix}, \quad L_m = \begin{pmatrix} l_m \\ \nu_m \\ \tau_m \end{pmatrix}, \quad L' = \begin{pmatrix} 0 \\ \nu' \\ \tau' \end{pmatrix}, \quad L'^c = \begin{pmatrix} 0 \\ \nu'^c \\ \tau'^c \end{pmatrix}.
\]
Little M-theory

Rich phenomenology:

- $W', Z'$
- $W_R, X$ (off-diagonal) gauge bosons
- “KK” quarks and leptons
- Extra PNGB scalars
- T-parity, SUSY (UED) faking collider signals, dark matter

If some of such states are discovered at the LHC, it’s easy to construct a moose model to describe them, with appropriate couplings and parameters to fit the experimental measurements.
Summary

• Most of the non-SUSY models at the LHC energies can be described by moose diagrams, allowing them to be treated in a unified way.

• Little M-theory serves a good framework for collider studies of non-SUSY models, as it covers a wide range of possible new physics to be discovered.

• To tell the real underlying model may require experimental explorations to higher energies where one can see strong dynamics or more KK modes.