LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
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A global approach to Composite Higgs models

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Introduction and motivation – hierarchy problem

Electroweak hierarchy problem: quadratic sensitivity of Higgs boson to larger scales

- **Fermions**:
  when $m \to 0$, recover chiral symmetry.
- **Gauge bosons**:
  when $m \to 0$, recover gauge symmetry.

Contributions to their mass are proportional to the mass itself

Introduction and motivation – hierarchy problem

Electroweak hierarchy problem: quadratic sensitivity of Higgs boson to larger scales

- **Higgs boson:**
  no symmetry is recovered when m$\rightarrow$ 0.

Contributions to its mass are quadratically proportional arbitrarily large scales

Introduction and motivation – hierarchy problem

- **SUSY:** introduce symmetry that ties fermions to bosons
  - Protection to fermions is extended to bosons.
- **Composite Higgs models (CHM)**: Higgs is a bound state and not sensitive to effects above compositeness scale.

↓

We shall focus on Little Higgs models

Higgs as a pseudo-Goldstone boson

Goldstone theorem: NGB's arise when a continuous symmetry is spontaneously broken

NGB's *shift* under the broken symmetry:

$$\theta \to \theta + \alpha$$

We need to explicitly break the symmetry

Little Higgs models – collective symmetry breaking

$$\phi_1 = e^{i\pi_1/f} \begin{pmatrix} 0 \\ f \end{pmatrix} \quad \text{and} \quad \phi_2 = e^{i\pi_2/f} \begin{pmatrix} 0 \\ f \end{pmatrix}$$

Let us take **SU(3)xSU(3) → SU(2)xSU(2):**

#NGBs =16-6=10

Next, we gauge **$SU(3)_D$**

Little Higgs models – collective symmetry breaking

$$\mathcal{L} \sim |g_1 A_\mu \phi_1|^2 + |g_2 A_\mu \phi_2|^2$$

$$\phi_1 \to e^{i\alpha_1^a T^a}\phi_1, \phi_2 \to e^{i\alpha_2^a T^a}\phi_2$$

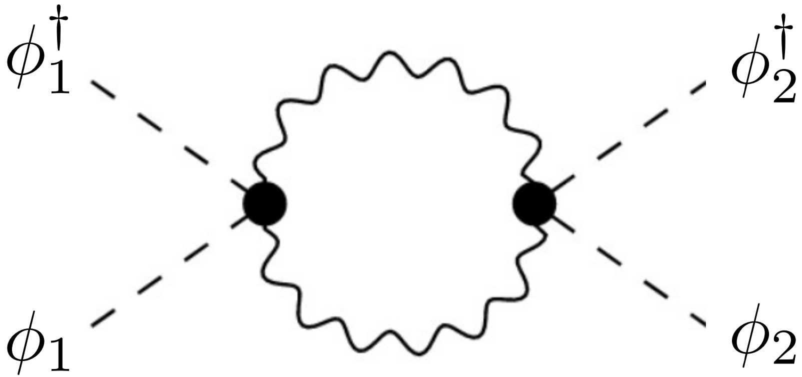
$$A_\mu \to e^{i\alpha^a T^a} A_\mu e^{-i\alpha^a T^a}$$

The symmetry is broken to $SU(3)_D$ only when both couplings are non-zero

(5 eaten NGBs and 5 pseudo NGBs)

Little Higgs models – collective symmetry breaking

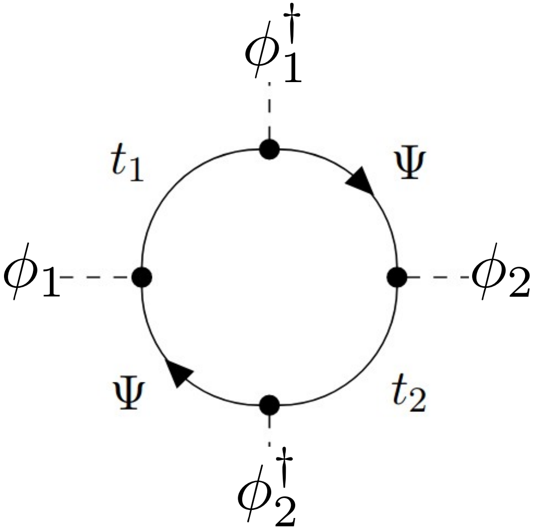
Contributions to pNGBs must involve **both fields:**



$$\propto \left|\phi_1^\dagger \phi_2\right|^2 \frac{g^4}{16\pi^2} \log\left[\frac{\Lambda^2}{\mu^2}\right]$$

Little Higgs models – collective symmetry in fermionic sector

By introducing SU(3) symmetry: $\Psi \equiv (t, b, T)$



$$\mathcal{L}_{\text{yuk}} = \lambda_1 \phi_1^\dagger \Psi t_1^c + \lambda_2 \phi_2^\dagger \Psi t_2^c$$

$$\propto \left| \phi_1^\dagger \phi_2 \right|^2 \frac{\lambda^4}{16\pi^2} \log \left[\frac{\Lambda^2}{\mu^2} \right]$$

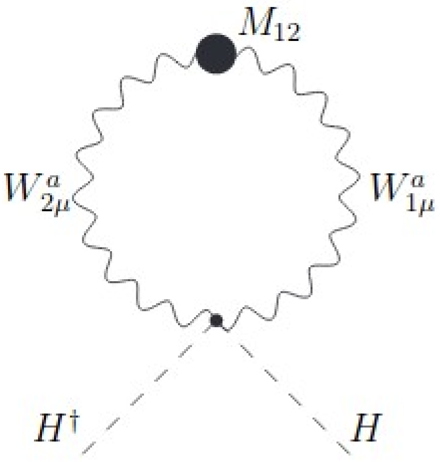
Littlest Higgs model:

$$\mathbf{SU(5)} \rightarrow \mathbf{SO(5)}$$

Unbroken	**Broken**	
$Q_1^a + Q_2^a$	$Q_1^a - Q_2^a$	$[SU(2) \times U(1)]^2$
$Y_1 + Y_2$	$Y_1 - Y_2$	$\downarrow$ $SU(2) \times U(1)$
$SU(2)_W$ $U(1)_Y$	**Heavy gauge bosons**	**4 eaten goldstones**

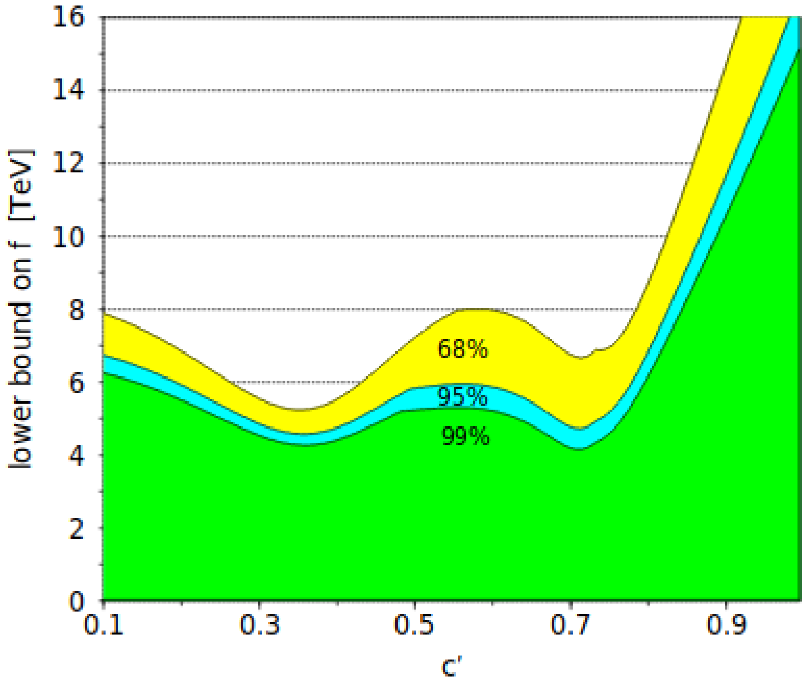
Littlest Higgs model – collective symmetry

$$\frac{1}{4}H^\dagger H\left(g_1 g_2 W_1^{\mu a} W_{2\mu}^a + g_1' g_2' B_1^\mu B_{2\mu}\right)$$



Both couplings ***always*** present

Littlest Higgs model - constraints



Taken from: *hep-ph/0211124v2*

Scale of new physics severely constrained by EWPO

Littlest Higgs with T-parity – gauge sector

$$G_1 \overset{\mathrm{T}}{\longleftrightarrow} G_2 \qquad g_1 = g_2, g_1^{'} = g_2^{'}$$

T-even

$$W^{\pm} = \frac{1}{2}\left[\left(W_1^1 + W_2^1\right) \mp i\left(W_1^2 + W_2^2\right)\right], \quad W^3 = \frac{W_1^3 + W_2^3}{\sqrt{2}}, \quad B = \frac{B_1 + B_2}{\sqrt{2}}$$

T-odd

$$W_H^{\pm} = \frac{1}{2}\left[\left(W_1^1 - W_2^1\right) \mp i\left(W_1^2 - W_2^2\right)\right], \quad W_H^3 = \frac{W_1^3 - W_2^3}{\sqrt{2}}, \quad B_H = \frac{B_1 - B_2}{\sqrt{2}}$$

$$A, Z, Z_H, A_H$$

Littlest Higgs with T-parity – fermionic sector

$$\mathcal{Q}_1 = \begin{pmatrix} q_1 \\ U_{L1} \\ 0 \end{pmatrix}, \quad \mathcal{Q}_2 = \begin{pmatrix} 0 \\ U_{L2} \\ q_2 \end{pmatrix}$$

The physical particles now read:

$$q_\pm = \frac{1}{\sqrt{2}}(q_1 \mp q_2), \quad U_{L\pm} = \frac{1}{\sqrt{2}}(U_{L1} \mp U_{L2}), \quad U_{R\pm} = \frac{1}{\sqrt{2}}(U_{R1} \mp U_{R2})$$

Littlest Higgs with T-parity – collider phenomenology

- **Several new pair produced heavy particles**
  - Such as VLLs and VLQs
- **Two top partners, T-even and T-odd**
  - A mass hierarchy between them allows for new decays
- **Missing energy signature from lightest T-odd particle**
  - Dark matter candidate

Littlest Higgs with T-parity – dark matter observables

Since A_H is a dark matter candidate, **astrophysical observables** can be used to constrain LHT, such as:

- **Relic density** $\Omega h^2 = 0.12 \pm 0.0012$
- **Direct detection**
- **Indirect detection** – gamma rays

Littlest Higgs with T-parity – dark matter observables

- Consider regime in which new particles have **similar mass**

- This allows for **coannihalation**:

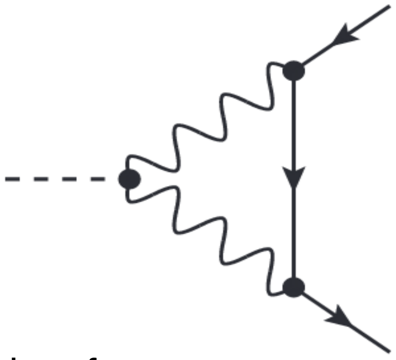
$$A_H A_H \rightarrow SMSM$$

$$A_H \ell_H \rightarrow SMSM$$

Freedom to evade relic density constraints

Littlest Higgs with T-parity – lepton flavour violation

- **The observation of LFV would be a sign of new physics**
  - LHT introduces LFV processes:



- **The misalignment between heavy leptons and SM leptons is the source of LFV**

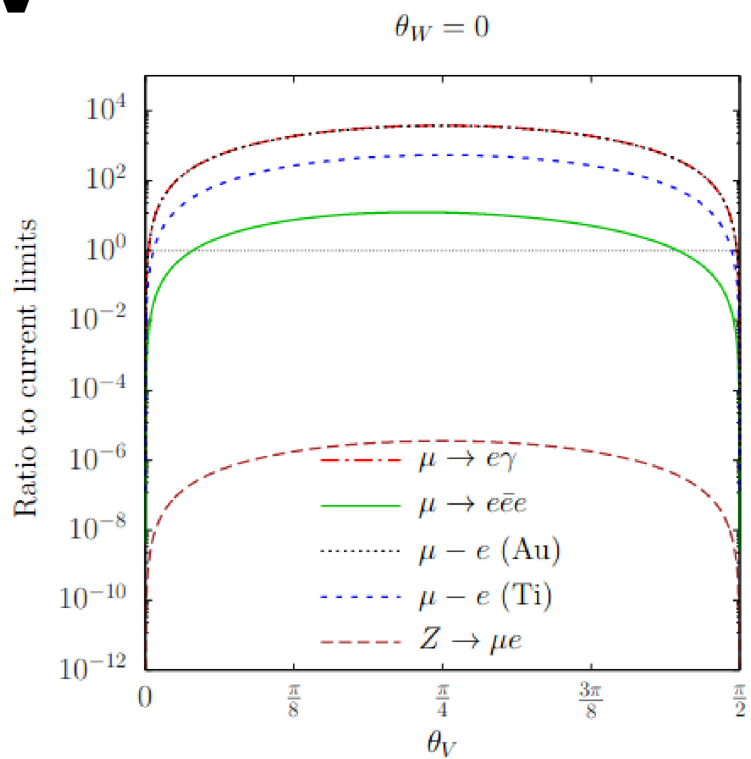
Taken from: *arxiv.org/pdf/1705.08827.pdf*

Littlest Higgs with T-parity – current results on LFV

- **The LHT is still allowed by current constraints** – misaligment must be very small

- Future experiments are expected to push the LHT to limits of viability.

Flavour symmetries?



Taken from: *arxiv.org/abs/1901.07058*

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