LABORATÓRIO DE INSTRUMENTAÇÃO
E FÍSICA EXPERIMENTAL DE PARTÍCULAS
partículas e tecnologia

Little Higgs Models Phenomenology

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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 – toy model SU(3)/SU(2)

$$\phi = \phi_0 e^{i\pi/f}$$

Parametrization to get **NBGs interactions**

$$\phi = \exp\left\{\frac{i}{f}\begin{pmatrix} 0 & h \\ h^\dagger & 0 \end{pmatrix}\right\}\begin{pmatrix} 0 \\ f \end{pmatrix} = \begin{pmatrix} 0 \\ f \end{pmatrix} + i\begin{pmatrix} h \\ 0 \end{pmatrix} - \frac{1}{2f}\begin{pmatrix} 0 \\ h^\dagger h \end{pmatrix} + \cdots$$

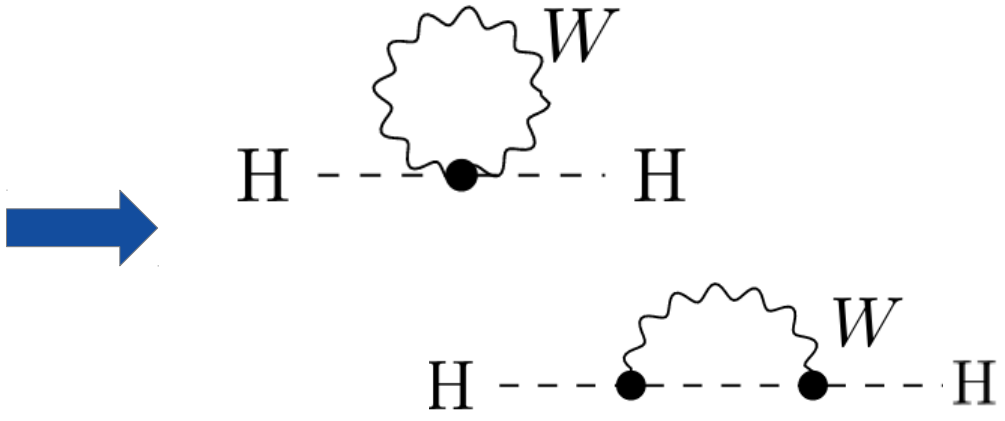
Little Higgs models – toy model SU(3)/SU(2)

By gauging SU(2), we get terms:

$$|g \begin{pmatrix} W_\mu & \\ & 0 \end{pmatrix} \phi|^2$$

$$=$$

$$|gW_\mu h|^2$$



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

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

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

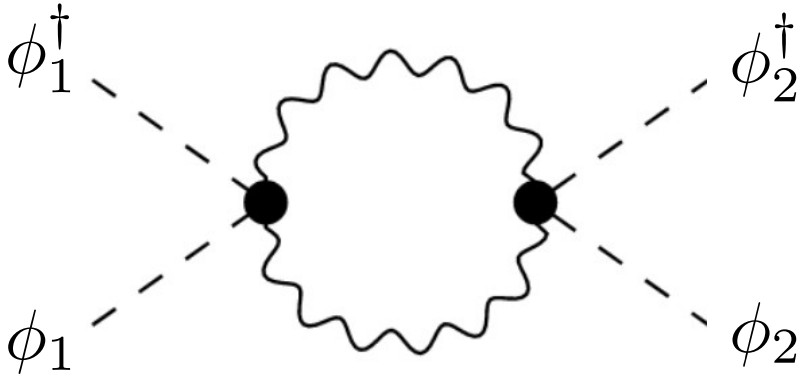
$$A_\mu \to e^{i\alpha_?^a T^a} A_\mu e^{-i\alpha_?^a T^a}$$

Only with both couplings non-zero the symmetry is broken to $SU(3)_D$

(5 eaten NGBs and 5 pseudo NGBs)

Little Higgs models – collective symmetry breaking

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

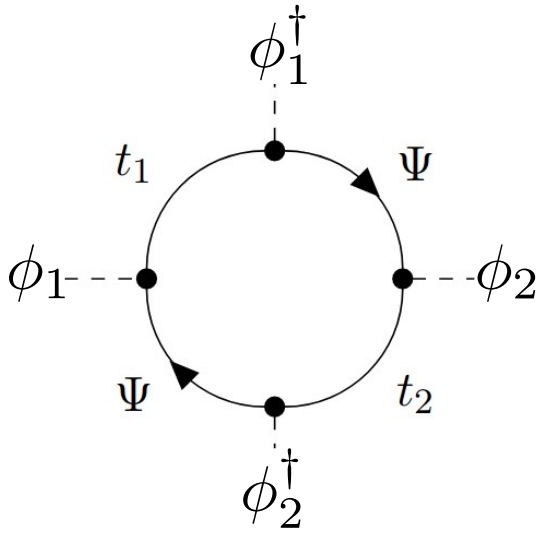


$$\propto \left|\phi_1^\dagger \phi_2\right|^2 \frac{g^4}{16\pi^2} \log\left[\frac{\Lambda^2}{\mu^2}\right]$$

$$\left|\phi_1^\dagger \phi_2\right|^2 \sim f^2 - 2H^\dagger H + \ldots$$

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: $\mathbf{SU(5) \to SO(5)}$

Unbroken

$$Q_1^a + Q_2^a$$

$$Y_1 + Y_2$$

$$SU(2)_W$$

$$U(1)_Y$$

Broken

$$Q_1^a - Q_2^a$$

$$Y_1 - Y_2$$

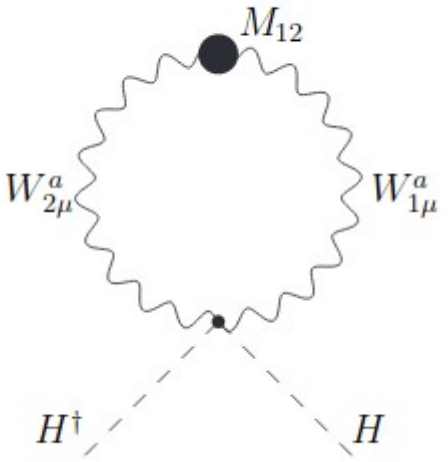
Heavy gauge bosons

$$[SU(2) \times U(1)]^2 \downarrow SU(2) \times U(1)$$

4 eaten goldstones

Littlest Higgs model – collective symmetry

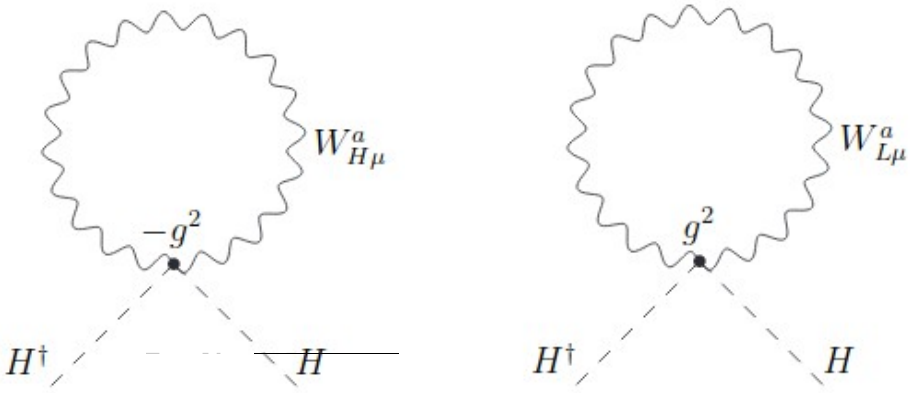
$$\frac{1}{4} H^\dagger H \left(g_1 g_2 W_1^{\mu a} W_{2\mu}^a + g_1' g_2' B_1^\mu B_{2\mu} \right)$$



Both couplings ***always*** present

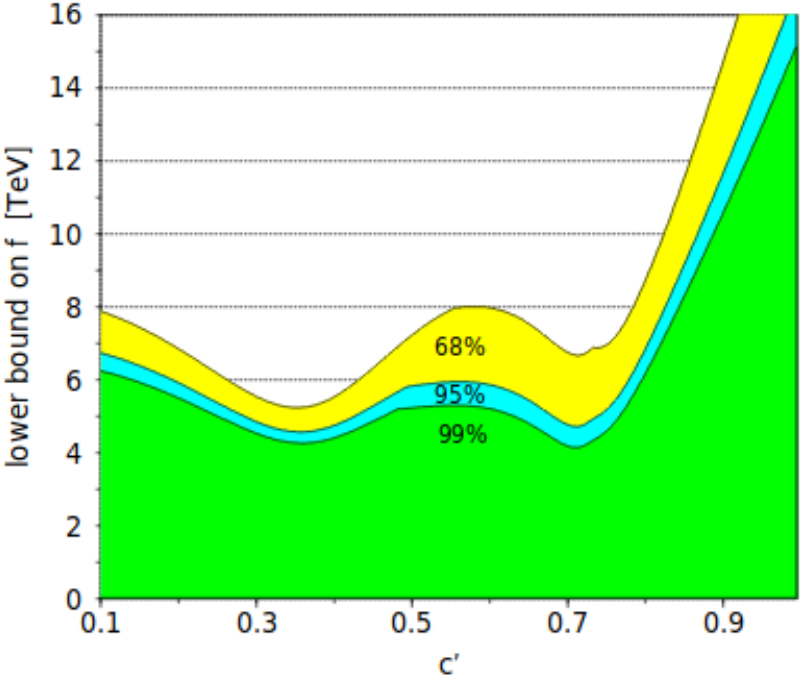
Littlest Higgs model – collective symmetry

Heavy – light bosons cancellation:



$$\frac{1}{4}H^\dagger H\left(g^2\left(W^a_{L\mu}W^{\mu a}_L - W^a_{H\mu}W^{\mu a}_H - 2\cot 2\psi W^a_{H\mu}W^{\mu a}_L\right) + g'^2\left(B_{L\mu}B^\mu_L - B_{H\mu}B^\mu_H - 2\cot 2\psi' B_{H\mu}B^\mu_L\right)\right.$$

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:

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

Littlest Higgs with T-parity – phenomenology

- **Pair production for T-odd particles**
- **Stable DM candidate (no T-violation)**
- **No contribution to EWPO at tree level**

Littlest Higgs with T-parity – phenomenology

Implementation of model in Feynrules

UFO model

Generating events with Madgraph

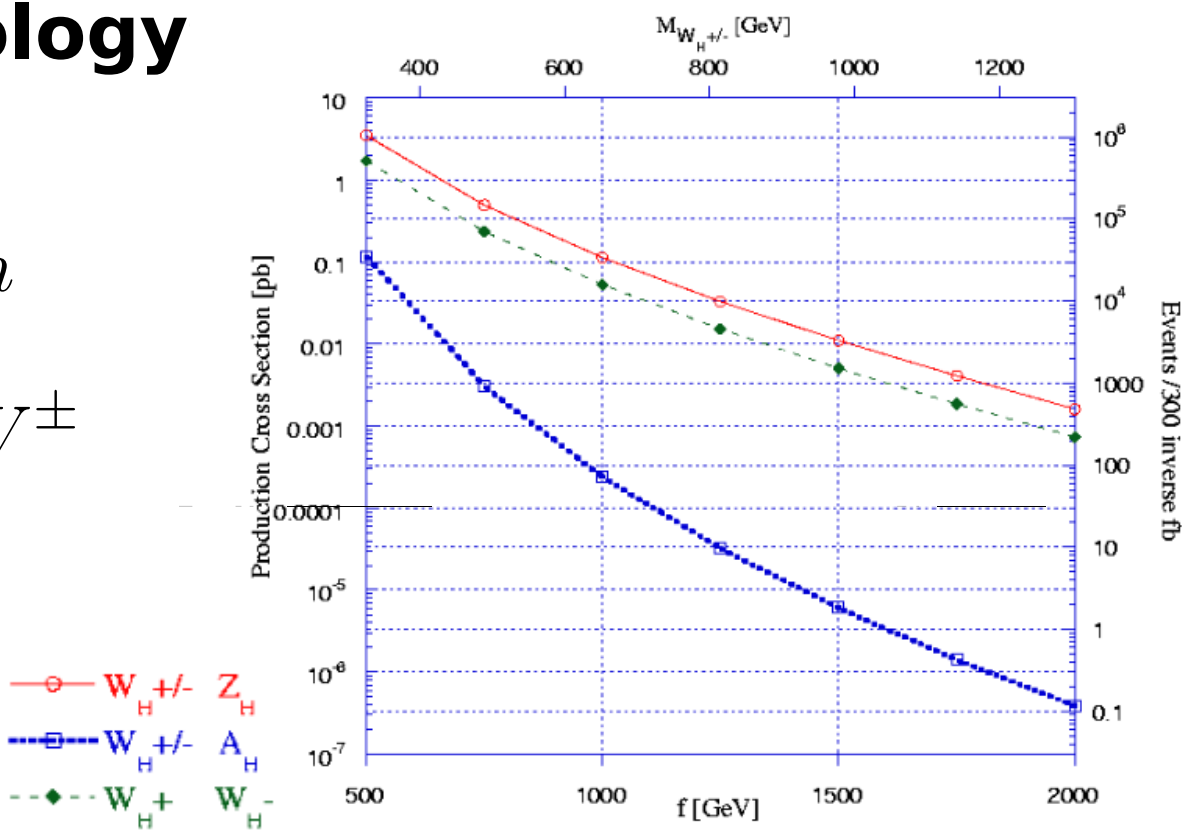
Developing analysis with Madanalysis

Littlest Higgs with T-parity – phenomenology

$$Z_H \to A_H h$$

$$W_H^{\pm} \to A_H W^{\pm}$$

Missing energy



Littlest Higgs with T-parity – phenomenology

Heavy Lepton Sector

- Not yet thoroughly studied
- Possible source of Lepton Flavour Violation
  - Further constraints on model

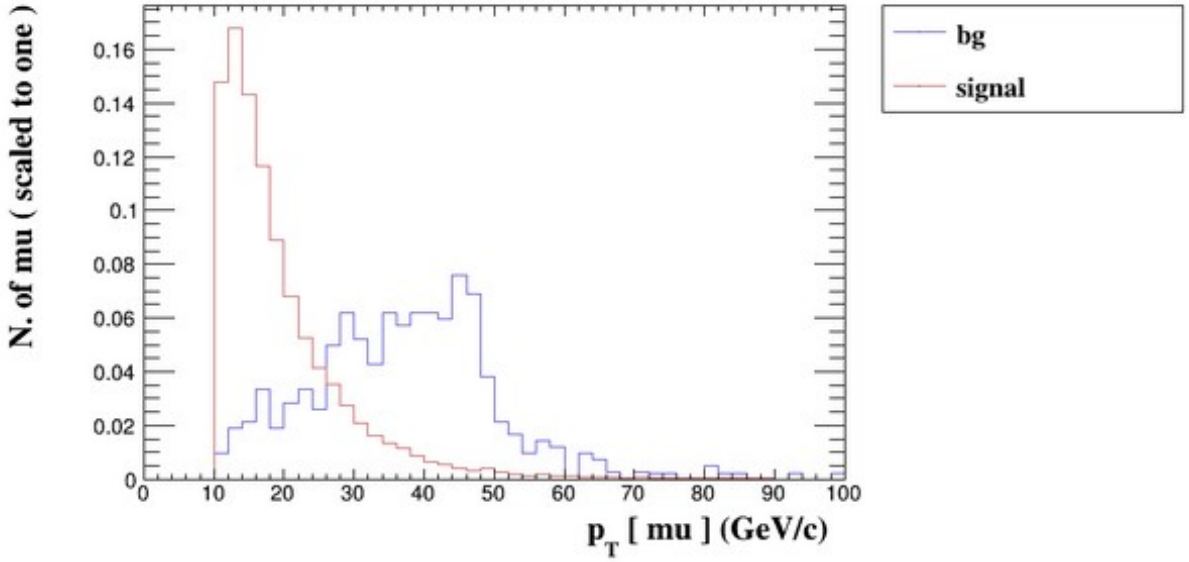
Littlest Higgs with T-parity – phenomenology

$$pp \to \mu_H \mu_H$$

focusing on

$$\mu_H \to \mu A_H$$

Preliminary work



$$M_{\mu_H} = 150\text{GeV}; M_{A_H} = 140\text{GeV}$$

Littlest Higgs with T-parity – phenomenology

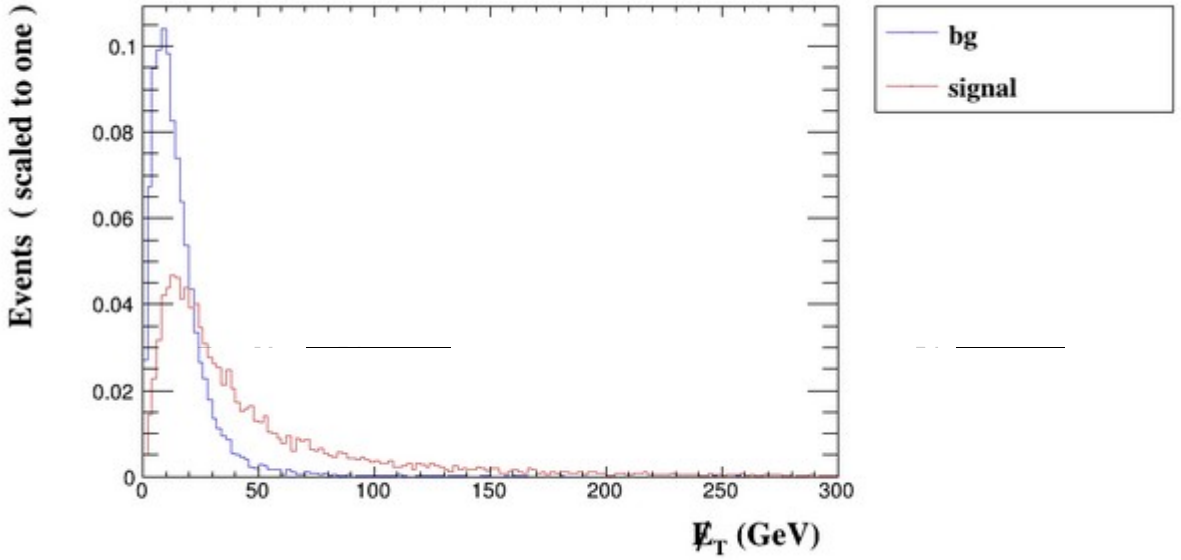
Possible dicriminating variables?

$$pp \to \mu_H \mu_H$$

focusing on

$$\mu_H \to \mu A_H$$

Preliminary work



$$M_{\mu_H} = 150\text{GeV}; M_{A_H} = 140\text{GeV}$$

Littlest Higgs with T-parity – prospects

A global approach:

- Collider phenomenology
- Flavour experiments
- Astrophysical constraints – DM candidate

Thanks