Littlest Higgs in Sherpa

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Outline

- Littlest Higgs with T-parity
- Implementation of the model into Sherpa
- Phenomenology
- Future Plans

Littlest Higgs model with T-parity

The Littlest Higgs model

- The breaking of the $SU(5)$ global symmetry $\Rightarrow SO(5)$ is parameterized by a non-linear sigma model.
- Σ_0 breaks $[SU(2) \times U(1)]^2 \Rightarrow SU(2)_L \times U(1)_Y$
- The vev $\langle h \rangle = (0, v/\sqrt{2})^T$ breaks $SU(2)_L \times U(1)_Y \Rightarrow U(1)_{EM}$.

$$\Sigma = e^{2i\Pi/f}\Sigma_0 \,, \qquad \Sigma_0 = \begin{pmatrix} 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \end{pmatrix} \tag{1}$$

$$\Pi = \begin{pmatrix} \mathbf{0}_{2\times 2} & \frac{h^\dagger}{\sqrt{2}} & \phi \\ \frac{h}{\sqrt{2}} & 0 & \frac{h^*}{\sqrt{2}} \\ \phi^\dagger & \frac{h^T}{\sqrt{2}} & \mathbf{0}_{2\times 2} \end{pmatrix} \tag{2}$$

Arkani-Hamed, Cohen, Katz, Nelson hep-ph/0206021

Littlest Higgs model with T-parity

T-parity

- There are strict EWP bounds on the original Littlest Higgs model
  - The scale f is required to be as ~ 5 TeV. [hep-ph/0303236]
  - Reintroduction of a fine-tuning between the cut off scale and the weak scale.
- A new discrete symmetry, called T–parity, is introduced. [Cheng and Low]
  - T–parity is a symmetry which exchanges the gauge boson fields of the two gauged $SU(2) \times U(1)$ groups, $[SU(2) \times U(1)]_1 \Longleftrightarrow [SU(2) \times U(1)]_2$.
  - Under T–parity SM fields are T–even while the new heavy partners are T–odd. (T–odd partners can only be pair produced)
  - Mixing between the SM gauge bosons, $(W^{\pm}, Z, A)$, and the heavy gauge bosons, $(W_H^{\pm}, Z_H, A_H)$ is absent. $\Rightarrow f \sim 500$ GeV.
  - A_H,the *lightest T–odd Particle*(LHT), is a good candidate for cold dark matter. [JHEP 01 (2005) 135]

The event generator: SHERPA

[hep-ph/0311263]

- Exact matrix elements in the helicity method. [hep-ph/0109036]
- Parton showers matched with hard matrix elements via CKKW. [hep-ph/0109231]
- Hadronization.
- Decays

LHTM in Sherpa

Particle Spectrum

Gauge and fermion sector:

T–even	$Z_{L\,\mu}$	$A_{L\,\mu}$	$W^{\pm}_{L\,\mu}$	T_+	t	d	u	ν_e	e
T–odd	$Z_{H\,\mu}$	$A_{H\,\mu}$	$W^{\pm}_{H\,\mu}$	T_-	t_-	d_-	u_-	ν_{e-}	e_-

Higgs sector:

T–even	H^0			
T–odd	Φ^0	Φ^P	$\Phi^{\pm}$	$\Phi^{\pm\pm}$

Littlest Higgs model with T-parity

Particle Mass Spectrum

	m_H(GeV)	κ_l	κ_q	f (GeV)	M (GeV)	Γ (GeV)
W_H	120	0.5	1.0	500	312.17	0.1451
Z_H					312.17	0.0464
A_H					64.890	stable
u_H					684.78	13.174
d_H					707.11	13.339
e_H					352.55	0.7113
$\nu_{e,H}$					342.39	0.4289

A new feature in SHERPA is the automatic generation of decay tables for new physics objects.

```
 Decay table for : KK_W_1, total width is now 5.14326 GeV,
   (instead of -1 GeV), calculated by
-----------------------------------------------------------------
KK_W_1 -> KK_B1_1 W+  : 0.145178 GeV.
KK_W_1 -> anti-KK_dL_1 u  : 0.945125 GeV.
KK_W_1 -> KK_uL_1 anti-d  : 1.03635 GeV.
KK_W_1 -> anti-KK_sL_1 c  : 0.945025 GeV.
KK_W_1 -> KK_cL_1 anti-s  : 1.03635 GeV.
KK_W_1 -> KK_t2_2 anti-b  : 1.03523 GeV.
```

Feynman Rules for LHT

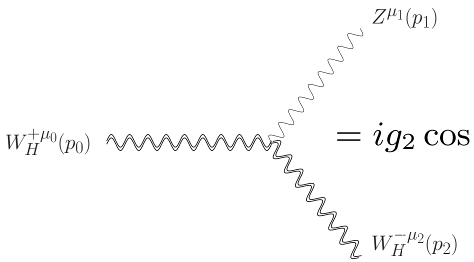
- There are several papers for the which the Feynman rules have been presented:
  - "Phenomenology of the Little Higgs Model" [hep-ph/0301040]
  - "Phenomenology of the littlest Higgs model with T–parity" [hep-ph/0411264]
  - "Phenomenology of a littlest Higgs model with T–parity: Including effect of T–odd fermions" [hep-ph/0609179]
- A complete set can be obtained by taking advantage of tools like LanHEP [hep-ph/0208011].

As of today there is no tool that automatically writes model files for Sherpa. However, this will soon change.

Fields in the vertex	Variational derivative of Lagrangian by fields
$A_{H\,\mu}$ $A_{H\,\nu}$ $W^-_{L\,\rho}$ $W^+_{L\,\sigma}$	$-\frac{i\cdot e^2\cdot s_H{}^2}{s_w{}^2}\left(2g^{\mu\nu}g^{\rho\sigma}-g^{\mu\sigma}g^{\nu\rho}-g^{\mu\rho}g^{\nu\sigma}\right)$
$A_{H\,\mu}$ $A_{L\,\nu}$ $W^-_{H\,\rho}$ $W^+_{L\,\sigma}$	$\frac{i\cdot e^2\cdot s_H}{s_w}\left(2g^{\mu\nu}g^{\rho\sigma}-g^{\mu\sigma}g^{\nu\rho}-g^{\mu\rho}g^{\nu\sigma}\right)$
$A_{H\,\mu}$ $A_{L\,\nu}$ $W^+_{H\,\rho}$ $W^-_{L\,\sigma}$	$\frac{i\cdot e^2\cdot s_H}{s_w}\left(2g^{\mu\nu}g^{\rho\sigma}-g^{\mu\sigma}g^{\nu\rho}-g^{\mu\rho}g^{\nu\sigma}\right)$
$A_{H\,\mu}$ $W^-_{H\,\nu}$ $W^+_{H\,\rho}$ $Z_{H\,\sigma}$	$\frac{i\cdot c_H\cdot e^2\cdot s_H}{s_w{}^2}\left(2g^{\mu\sigma}g^{\nu\rho}-g^{\mu\rho}g^{\nu\sigma}-g^{\mu\nu}g^{\rho\sigma}\right)$
$A_{H\,\mu}$ $W^-_{H\,\nu}$ $W^+_{L\,\rho}$ $Z_{L\,\sigma}$	$\frac{i\cdot c_w\cdot e^2\cdot s_H}{s_w{}^2}\left(2g^{\mu\sigma}g^{\nu\rho}-g^{\mu\rho}g^{\nu\sigma}-g^{\mu\nu}g^{\rho\sigma}\right)$

In the mean time, you build the model files by hand.

Example: $W_H^+ W_H^- Z$



$$= ig_2 \cos\theta_w \left(g^{\mu_1\mu_2}(p_1 - p_2)^{\mu_0} + g^{\mu_0\mu_2}(p_2 - p_0)^{\mu_1} + g^{\mu_1\mu_0}(p_0 - p_1)^{\mu_2}\right) \quad (3)$$

```
Flavour flZ(kf::Z);
Flavour flWh(kf::KK_W_1); //Heavy boson wh+
Kabbala kcpl0,kcpl1;

if (flWh.IsOn() && flZ.IsOn()) {
  //Wh Wh Z
  kcpl0 = M_I*g2*costW;
  kcpl1 = kcpl0;

  vertex[vanz].in[0] = flWh;
  vertex[vanz].in[1] = Flavour(kf::Z);
  vertex[vanz].in[2] = flWh;
  vertex[vanz].cpl[0]  = kcpl0;
  vertex[vanz].cpl[1]  = kcpl1;
  vertex[vanz].Str     = (kcpl0*PR+kcpl1*PL).String();
  vertex[vanz].ncf   = 1;
  vertex[vanz].Color = new Color_Function(cf::None);
  vertex[vanz].nlf     = 1;
  vertex[vanz].Lorentz = new Lorentz_Function(lf::Gauge3);
  vertex[vanz].Lorentz->SetParticleArg(0,1,2);
  vertex[vanz].on      = 1;
  vertex.push_back(Single_Vertex());vanz++;
  }
```

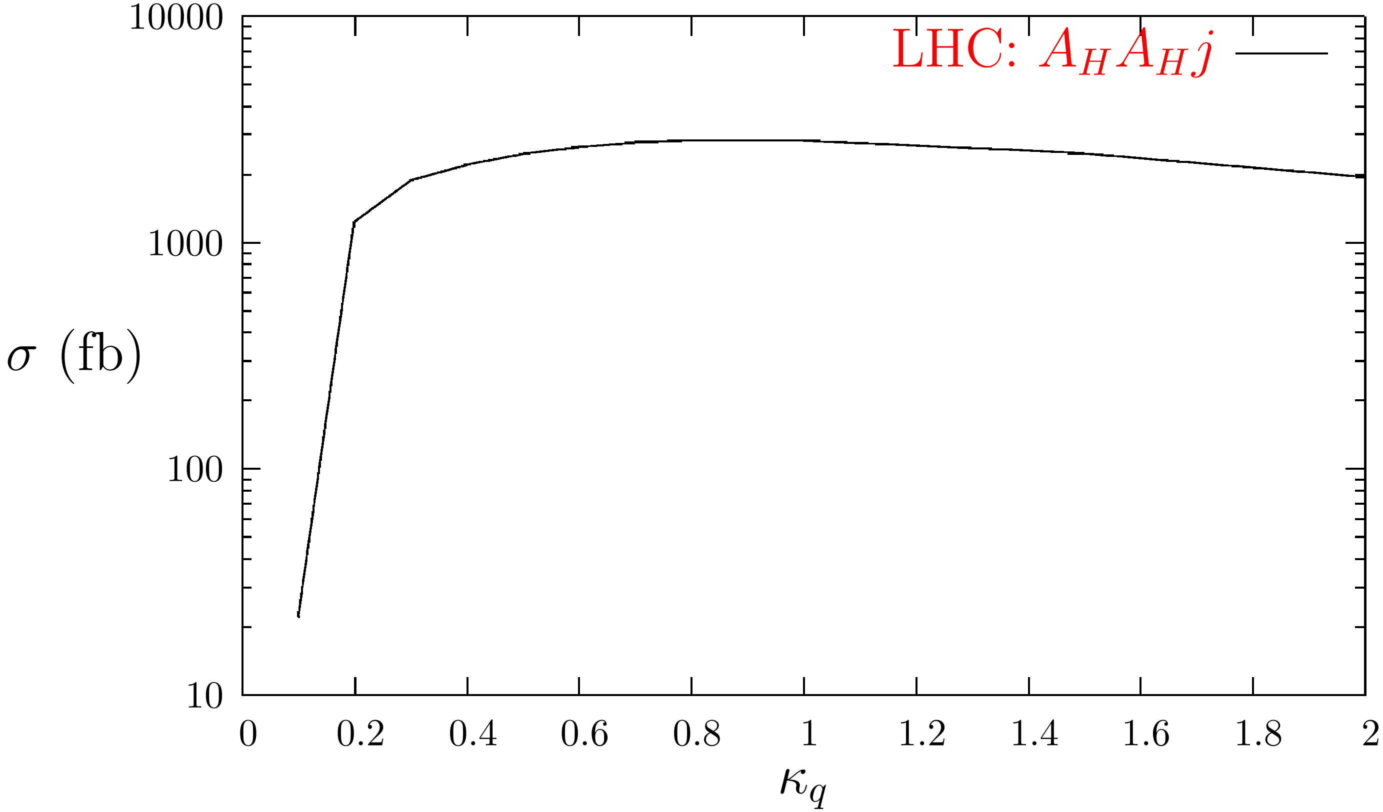
Doing LHT Phenomenology with Sherpa: monojets

- Cross sections for TOQ pair production can be as large at 100 pb and lead to dijet plus missing E_T signatures [PRD **75**, 092701(R) (2007)]
- Why not monojets plus missing E_T? (See hep-ex/0005033)

$$pp \to q_H A_H \to q A_H A_H$$

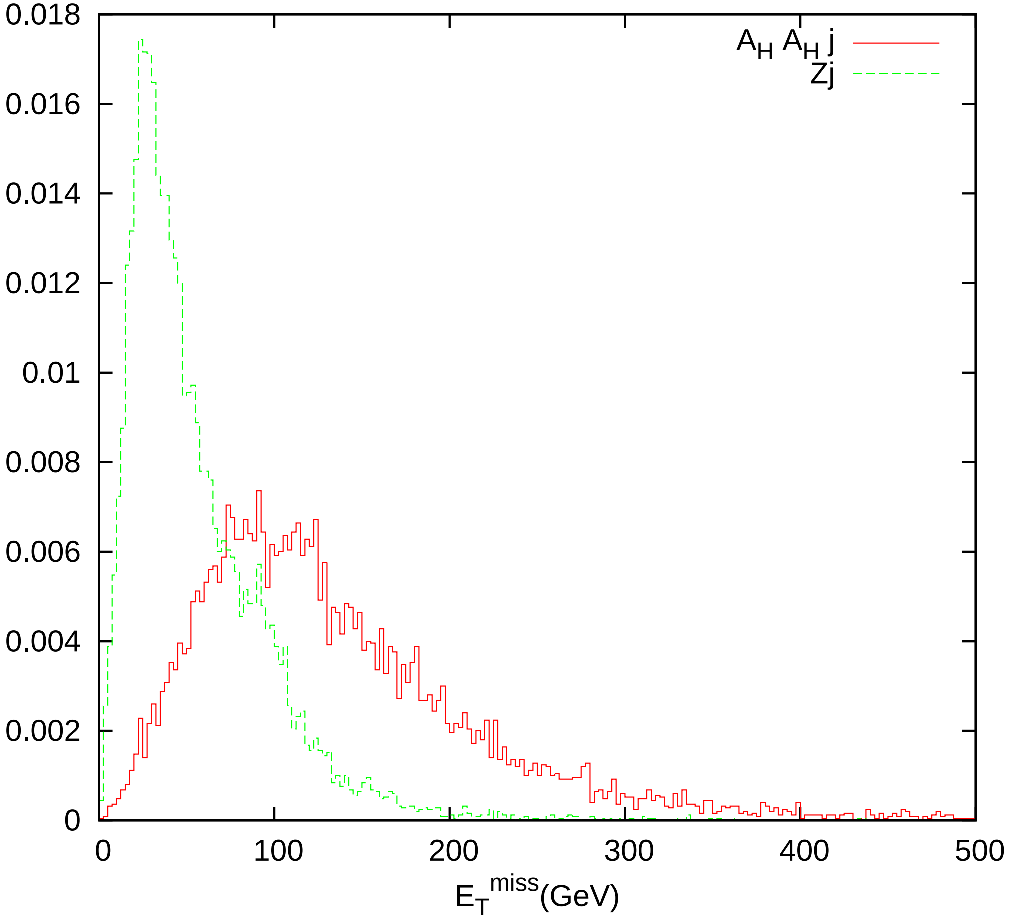
$f = 500$ GeV and

$$M_{u_-} = \sqrt{2}\kappa_q f(1 - \frac{v^2}{8f^2}) + \dots\ , \qquad M_{d_-} = \sqrt{2}\kappa_q f \tag{4}$$



The Signal and Backgrounds

Need to consider $W^{\pm}jj$.
Research is in progress.



Future Plans

- Implement several models for the top sector in LHT.
- Implement T–parity violating interactions, i.e., $A_H \rightarrow VV$. (see arXiv:0705.0697,arXiv:0707.3648)
- Use Sherpa to study other new physics models.