# Left-Right Twin Higgs Model in CalcHEP

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http://www.physics.arizona.edu/~shufang/twinhiggs.html

Code Writer: Hock-Seng Goh, Ethan Dolle, Shufang Su

# Outline

## Will not discuss (in detail)

- CalcHEP
  - http://www.ifh.de/~pukhov/calchep.html
- Left-Right Twin Higgs Model (LRTH)
  - Chacko, Goh, Harnik, hep-ph/0512088
  - H. Goh, SS, hep-ph/0611015

## Will discuss

- New particles and model parameters
- CalcHEP model files
- A few words about usage in MicrOMEGAs

# CalcHEP

A simple tool for simple-minded theorists

- Advantages:
  - ➡ easy to add new physics model
  - ➡ good for decay branching ratios, production cross sections
  - ➡ easy to use without program coding
- Disadvantages:
  - ➡ only good for $1 \to 5$, $2 \to 4$
  - ➡ can not handle long cascade decay chain
    (can generate events, sent to other program for cascade decay and hadronization)

# Twin Higgs Mechanism

Higgs as pseudo-Goldstone boson of a global symmetry

Its mass is protected against radiative corrections

- Little Higgs mechanism: collective symmetry breaking
- Twin Higgs mechanism: discrete symmetry

## Mirror symmetry

Type IA TH: Chacko, Goh, Harnik, hep-ph/0506256
Type IB TH: Chacko, Nomura, Papucci, Perez, hep-ph/0510273
phenomenology: R. Barbieri, T. Gregoire and L. Hall, hep-ph/0509242

## Left-right symmetry

Type II TH: Chacko, Goh, Harnik, hep-ph/0512088

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## → Left-right symmetry

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# Left-right Twin Higgs Model

- $U(4) \times U(4)$, with gauged $SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ + LR symmetry

Couple to gauge boson only

SM Higgs doublet

↓ EWSB

SM neutral Higgs: H

$SU(2)_L$ Higgs doublet

$\hat{H}_1^{\pm}$, $\hat{H}_2^0$

$$H = \begin{pmatrix} H_L \\ H_R \end{pmatrix} \qquad \hat{H} = \begin{pmatrix} \hat{H}_L \\ \hat{H}_R \end{pmatrix}$$

3 eaten by heavy gauge bosons

Left 3 Higgses:

neutral Higgs $\phi^0$, charged Higgs $\phi^{\pm}$

$U(4) \times U(4) \rightarrow U(3) \times U(3)$

$$\langle H \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ f \end{pmatrix} \qquad \langle \hat{H} \rangle = \begin{pmatrix} 0 \\ 0 \\ 0 \\ \hat{f} \end{pmatrix}$$

$SU(2)_L \times SU(2)_R \times U(1)_{B-L} \rightarrow SU(2)_L \times U(1)_Y$

7 GB

7 GB

$\hat{f} > f$

# Left-right Twin Higgs Model

**Fermion sector:**

$$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix} : (\mathbf{3}, \mathbf{2}, \mathbf{1}, 1/3), \qquad L_L = \begin{pmatrix} \nu_L \\ l_{L\alpha} \end{pmatrix} : (\mathbf{1}, \mathbf{2}, \mathbf{1}, -1),$$

$$Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix} : (\mathbf{3}, \mathbf{1}, \mathbf{2}, 1/3), \qquad L_R = \begin{pmatrix} \nu_R \\ l_R \end{pmatrix} : (\mathbf{1}, \mathbf{1}, \mathbf{2}, -1),$$

**Top quark mass:**

$$T_L = [1, 1, 4/3]\,, \quad T_R = [1, 1, 4/3]\,,$$

$$y H_R^\dagger Q_R T_L + y H_L^\dagger Q_L T_R + M \bar{T}_L T_R + h.c.$$

**Top quark mass eigenstates:** SM top and $t_H$

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# New Particles

- **Heavy gauge bosons:** $W_H$, $Z_H$ $\quad m^2_{WH,ZH} \sim g^2(f^2+\hat{f}^2)$
- **Heavy top:** $t_H$ $\quad m^2_{TH} \sim M^2+y^2f^2$
- **Other $SU(2)_R$ Higgses:** $\phi^\pm$ $\quad m^2_{\phi\pm} \sim g^4/(16\pi^2)\hat{f}^2 \log(\Lambda/g\hat{f})$

  $\phi^0$ $\quad m^2_{\phi 0} \sim \mu_R^2\ (\hat{f}/f)$ $\quad \boxed{\mu_R^2 H_R^\dagger \hat{H}_R}$

  $\mu_R^2$: small, $(50\text{-}100\ \text{GeV})^2$

- **Other $SU(2)_L$ Higgs** $\hat{H}_1^\pm$ $\quad m^2_{H1^\pm,\ H2^0} \sim \hat{\mu}^2$

  $\hat{H}_{20}$ $\quad \hat{\mu}$: soft symmetry breaking, O(f)

  $\boxed{\hat{\mu}^2 \hat{H}_L^\dagger \hat{H}_L}$

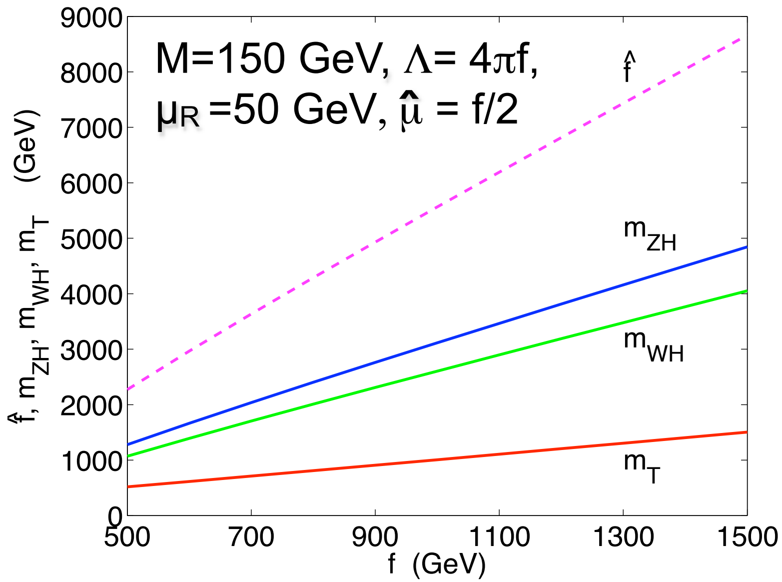
# Model Parameters and Mass Spectrum

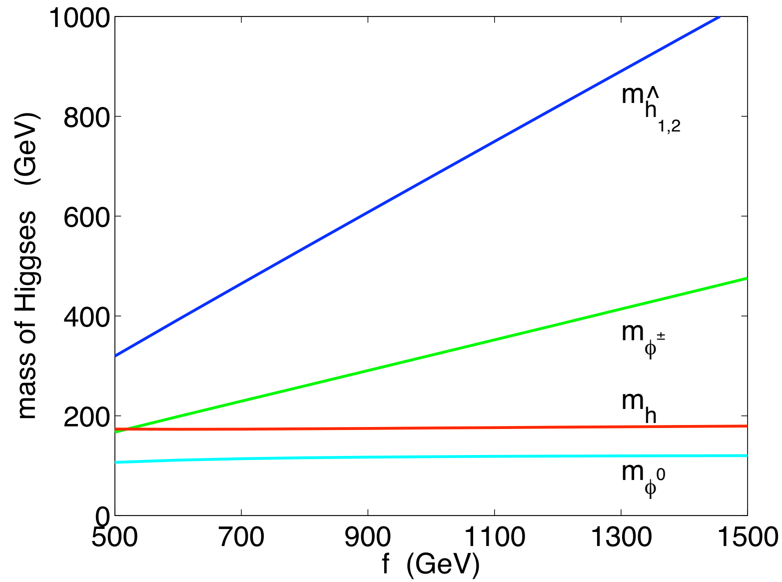
$\langle H_L \rangle = v = 246$ GeV

f, M , Λ → $\hat{f}$

$\mu_R$, $\hat{\mu}$

} Determine particle masses and interactions




- $\hat{f}$ as a function of f (for given M, Λ) : para.data
- mass spectrum as a function of f (for given M, Λ, $\mu_R$, $\hat{\mu}$): mass.data

formulae for mass spectrum also available in hep-ph/0611015

# CalcHEP Model Files

- Particles (parcls.mdl): define particles
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Full  name      | P   |aP  |number|2*spin| mass |width  |color|aux|> LaTeX(A)<|>LaTeX(A+)<|

Heavy W         |Wp |Wn |92       |2       |MWH  |!wWH |1      |      |W_H^+       |W_H^-
Heavy t-quark|tH   |TH  |93       |1       |MtH   |!wtH   |3      |      |T                 |\bar{T}
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automatically calculate decay width

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**Model parameters**

$f$, $M$, $\Lambda$ } $\hat{f}$

$\mu_R$

$\hat{\mu}$

**Interactions:** $f, \hat{f}, M$

**Mass:** $f, \hat{f}, M, \mu_R, \hat{\mu}$

**CalcHEP parameters**

| | | |
|---|---|---|
| f1 | \|800 | \|f |
| f2 | \|4288.2 | \|fhat |
| MMp | \|150 | \|M |
| MZH | \|2407.44 | \|mass for ZH |
| MWH | \|2013.13 | \|mass for WH |
| MtH | \|812.188 | \|mass for tH |
| Mh1 | \|536.828 | \|mass for h1pm |
| Mh2 | \|536.028 | \|mass for h20 |
| MAx | \|115.868 | \|mass for phi0 |
| MHR | \|260.225 | \|mass for phipm |
| MH | \|175.46 | \|mass of Higgs |

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$$\left.\begin{matrix} f \\ M \\ \Lambda \end{matrix}\right\} \hat{f}$$

**CalcHEP parameters**

```
f1    |800     |f
f2    |4288.2  |fhat
MMp   |150     |M
```

Advantage: easy/straightforward to implement.

Disadvantage: need to change all parameters at once

➡ there is an easy way to do this using batch mode **set_param**

➡ values for typical choice of ($f$, $M$, $\Lambda$, $\mu_R$, $\hat{\mu}$) can be found at para.data and mass.data (download from LRTH in CalcHEP website)

# Examples

- Heavy top partner decay
- Heavy top partner pair production
- Use batch mode

# A Few Words about using it in MicrOMEGAs

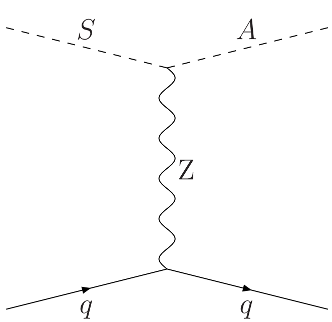
## MicrOMEGAs:

- calculation of dark matter relic density using CalcHEP model file
- calculation of fragmentation photon from dark matter annihilation into W/Z

http://lappweb.in2p3.fr/lapth/micromegas/index.html

$\hat{H}_2^0 = (S+iA)/\sqrt{2}$

- $|m_S - m_A| >$ a few GeV to avoid constraints from DM direct detection
- such mass splitting can be generated by $\frac{\lambda}{2}[(H_L^\dagger \hat{H}_L)^2 + \text{h.c.}]$




**Model files to be used in MicrOMEGAs will be ready in a couple of days.**