Little Higgs with T-parity measurements at the ILC

LCWS11
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There are 2 predictions on where the energy scale of new physics should emerge.

1. Fine tuning of Higgs mass

\[ m^2_{Higgs} = m^2_0 + \delta m^2 \]

- Measured Higgs mass
- Bare mass
- Correction term

\[ \delta m^2 \approx (0.27\Lambda)^2 \]

\( \Lambda < 1 \text{ TeV} \)

2. Electroweak precision measurement

\( \Lambda > 10 \text{ TeV} \)

Conflict between the 2 energy scales.

Little Higgs model was proposed!
The Little Higgs model addresses the Little hierarchy problem by introducing a new symmetry, SU(5), which is a subgroup of SO(5). The Higgs mass contribution is given by:

$$f \sim 1 \text{ TeV} \quad \text{SO}(5) \quad v \sim \langle h \rangle$$

The global symmetry SU(5) is reduced to SU(2)_L \times U(1)_Y via a symmetry breaking pattern.

### Quadratic divergent terms cancel at 1-loop order

$$\sum \frac{W_i W_j}{2} = 0 \Lambda^2$$

This cancellation solves the Little hierarchy problem.

**Features of Little Higgs Model**

- Prediction of top partner
- Prediction of gauge boson partner
- Definite relation between model parameters (little higgs mechanism)
LHT masses in gauge & lepton sector can be described in 2 parameters

\[ f(VEV): \text{energy scale of global symmetry breaking} \]

\[ K : \text{lepton Yukawa coupling} \]

Important parameters which describe how LHT particles obtain masses & solve little hierarchy problem.
Aim of study

Evaluate ILC’s sensitivity on ...

- **1st aim**: extracting model parameters ($f$ & $\kappa$)
- **2nd aim**: completing the mass spectrum and checking consistency with parameters
- **3rd aim**: meas. coupling check consistency with parameters

Strong proof that discovered particles are indeed LHT.

$E_{cm} = 1 \text{ TeV}$, Luminosity $= 500 \text{ fb}^{-1}$

<table>
<thead>
<tr>
<th>$\kappa$</th>
<th>$f$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5</td>
<td>580(GeV)</td>
</tr>
</tbody>
</table>
Analysis

1. First signal of LHT!
   
   - $e^- \rightarrow A_H \rightarrow e^+_H Z_H$

2. Precision measurement on $f$.
   
   - $e^- \rightarrow \gamma, Z \rightarrow W_H W_H$

3. Complete mass spectrum in gauge sector.
   
   - $e^- \rightarrow Z_H \rightarrow e^+_H Z_H$

4. Precision measurement on $\kappa$.
   
   - $e^- \rightarrow \gamma, Z \rightarrow e^+_H e_H$

5. Complete mass spectrum in lepton sector.
   
   - $e^- \rightarrow Z \rightarrow \nu_H \nu_H$
Analysis procedure

1. T-Parity new particles are produced in pairs
2. produced new particles decay into SM and LHT particles.
3. Extract LHT mass information by recognizing end point of SM energy.
4. Extract model parameters, using the fact that LHT masses are expressed with them.

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<thead>
<tr>
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<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td><img src="image2.png" alt="Diagram" /></td>
<td><img src="image3.png" alt="Diagram" /></td>
<td><img src="image4.png" alt="Diagram" /></td>
<td><img src="image5.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

- $A_H$
- $W_H^-$
- $W_H^+$
- $W$ energy (GeV)
- $m_{W_H}$
- $W_{H,A_H}$
- $m_{A_H}$
- $g f$
- $\sqrt{0.2 g' f}$

\[ m_A H \approx 0.2 g f \]
results show that ILC is capable of highly accurate precision measurements on LHT masses and parameters.

- This is extremely important in studying LHT’s mass generation mechanism.
- Shows how likely it is actually it is LHT.

<table>
<thead>
<tr>
<th>particle</th>
<th>mass</th>
<th>sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_H$</td>
<td>81.9(GeV)</td>
<td>1.3%</td>
</tr>
<tr>
<td>$W_H$</td>
<td>369(GeV)</td>
<td>0.20%</td>
</tr>
<tr>
<td>$Z_H$</td>
<td>368(GeV)</td>
<td>0.56%</td>
</tr>
<tr>
<td>$e_H$</td>
<td>410(GeV)</td>
<td>0.46%</td>
</tr>
<tr>
<td>$v_H$</td>
<td>400(GeV)</td>
<td>0.10%</td>
</tr>
</tbody>
</table>

For details, ILD work shop talk
It will be extremely important to measure couplings between LHT particles and SM particles in order to know how particles interact with each other.
• With the method I am going to introduce we can derive the couplings in the vertices shown above.
Observables for coupling extraction

- Cross section
  - Assume $W_H, Z_H$ decays 100% to $A_H$
  - Derive coupling

- However....
  - We don’t know $Br$ of particles which have several decay modes.
  - We need an additional observable.

Ex)

$\begin{align*}
\text{Input coupling} & \quad \text{Derived coupling} \\
\text{Vertex structure (spin, ratio between Left right coupling)} & \quad \text{will be assumed}
\end{align*}$
Observables for coupling extraction

- Differential cross section
  - We know masses of LHT particles.
  - Angular distribution of pair produced LHT particle can be derived by solving kinematics.
    - Derive coupling from angular distribution
    - Coupling sign can also be derived (s-channel contribution destructive/constructive)

※ Vertex structure (spin, ratio between Left right coupling) will be assumed

From differential cross section we can derive Coupling ratio and sign Between vertices

From cross section we can derive Coupling

<table>
<thead>
<tr>
<th>Total cross section</th>
<th>Decay branch</th>
</tr>
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<td><img src="image1.png" alt="Diagram" /></td>
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Deriving coupling

Observable:
cross section (CS)
differential cross section (DCS)

CS & DCS

Total of 8 coupling measurements!!
Cross section meas.

- Fit standard energy distribution used before and measure cross section

![Diagram with reactions]

- Higgs energy
- $W^\pm$ energy
- Electron energy
- Missed $P_T$ (event selection)
Cross section measurement

<table>
<thead>
<tr>
<th>Mode</th>
<th>vertex</th>
<th>Xsec Meas. accuracy</th>
<th>Coupling meas. Accuracy</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AHZ_H$</td>
<td>C1</td>
<td>7.70%</td>
<td>3.90%</td>
</tr>
<tr>
<td>$ZZ_H$</td>
<td>C2</td>
<td>0.859%</td>
<td>0.219%</td>
</tr>
<tr>
<td>$e_He_H$</td>
<td>C3</td>
<td>2.72%</td>
<td>1.49%</td>
</tr>
<tr>
<td>$\nu_H\nu_H$</td>
<td>C4</td>
<td>0.949%</td>
<td>0.648%</td>
</tr>
<tr>
<td>$WW_H$</td>
<td>C5</td>
<td>0.401%</td>
<td>0.174%</td>
</tr>
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Center value of the coupling can be estimated using the previously derived parameter $f$ & $\kappa$. 

Contour of Meas. Coupling
Summary/plan

- High precision in parameter extraction, mass measurement & coupling extraction through cross section meas. is possible. Which is extremely important in verifying the LHT.

- All of the other couplings will be derived using template fitting of decay angle distribution.

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<table>
<thead>
<tr>
<th>parameter</th>
<th>True value</th>
<th>Measurement accuracy</th>
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<tbody>
<tr>
<td>$f$</td>
<td>580(GeV)</td>
<td>0.16%</td>
</tr>
<tr>
<td>$K$</td>
<td>0.5</td>
<td>0.01%</td>
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Coupling extracted from xsec

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<td>$\nu_H\nu_H$</td>
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</tr>
<tr>
<td>$W_HW_H$</td>
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