**SIGNATURES OF T-ODD HEAVY GAUGE BOSONS AND HEAVY QUARKS OF THE LITTLEST HIGGS MODEL AT THE LHC**

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**Why Beyond Standard Model**

The Standard Model describes physics at low energy (≤ 1 TeV) very well but it suffers from some serious problems. A few of those unanswered questions are as follows which motivates to search for Beyond Standard Model physics:

- **Why Weak Scale o Planet Scale ?**
- **What is the solution of the Hierarchy Problem ?**
- **What is the symmetry that hold Particle Physics at TeV Scale ?**
- **What are Dark Matter, Dark Energy ?**
- **What is the origin of Neutrino mass ?** etc...

**Hierarchy Problem**

- Higgs Potential: $V(φ) = m_h^2 φ^2 + λφ^4$.
  - The Vacuum expectation $v < φ > = ρ / 4(2)$.

These are the quadratically divergent diagrams in the SM which contributes to the Higgs Mass. $2 m_{W^±}^2 j / 4(2) = \rho^2 + \lambda φ^4$.

There is nothing which can protect the Higgs mass and so, new physics is needed. Supersymmetry resolves this problem by invoking a new symmetry (sfermion loop cancels the boson loop).

$\rho^2$ has the following form.

\[ \rho^2 = \rho_{loop}^2 + \lambda (\rho C_1 + \rho C_2 + \lambda C_3 + H.O) \]

\[ ρ = \frac{2A}{\sqrt{2}} \rho > > 2 \text{ TeV} \]

Hence, at a scale $\lambda = 10^4 \text{ TeV}$

$\rho^2 (\rho/\sqrt{2})^2 + \rho_{loop}^2 (\rho/\sqrt{2})^2 + \lambda (\rho C_1 + \rho C_2 + \lambda C_3 + H.O)$

which implies, Unnatural Fine Tuning.

**Little Hierarchy Problem**

As $\lambda$ increases, the level of fine tuning also increases. However, if the cut-off is 1 TeV, there is no need for fine tuning.

- So, it is to be expected that new particles exist and those have masses of approximately 2 TeV.
- However, Electroweak Precision measurement typically favor the scale of new physics to be $\sim 5 - 10$ TeV.

This tension between having to introduce new physics at the TeV scale for naturalness, and EWPT preferring it to be a factor of $\sim 10$ higher is the so called 'Little Hierarchy Problem'.

**Little Higgs Model**

A good alternative of Supersymmetry.

Higgs as pseud Goldstone Boson arises due to some spontaneously broken global symmetry at a high energy scale.

- It acquires mass via (collective) symmetry breaking at the EW scale. No mass term at tree level.
- One-loop quadratic divergence cancels by the new gauge bosons, scalars and fermions.
- Still, no solution to little hierarchy problem.

**Littlest Higgs with T-Parity**

This Model was introduced by Arkani-Hamed[2].

- A global symmetry group SU(5) spontaneously breaks down to SO(5). SU(5) contains two copies of SU(3) X U(1) that are diagonally broken down to one copy of SU2 X U(1).
- In terms of groups,
  \[ SU(5) \rightarrow SO(5) \]

\[ U \rightarrow \text{SU}(2) \times U(1) \]

\[ SU(2) \times U(1) \rightarrow [SU(2) \times U(1)] \rightarrow SU(2)[U(1)] \]

- The first breaking happens at scale $f$ and the second one at EW scale. Due to EWPT the scale $f$ is required to be $\geq 7$ TeV.
- Introduce a discrete symmetry T-Parity (Similar to R-parity in MSSM). It lowers the scale to around 500 GeV. Most constraints from EWPT come from tree level mixing of heavy and light mass eigenstates which T-Parity forbids. It, therefore, solves the little hierarchy problem.
- Standard Model gauge bosons W,Z and photon has its own heavy T-odd partner $W_T$, $Z_T$ and $A_T$. Similarly, $Q_T$ are partners of quarks. These heavy particles acquire mass due to the global symmetry breaking at scale $f$. The SM particles are even under T-parity and exotic particles are T-odd.

**Collider Analysis**

- Associative production of T-odd heavy gauge bosons($W_T/Z_T$) and heavy quark($Q_T$) yield jets + BY channel:
  \[ pp \rightarrow Q_T W_T \text{ and; } pp \rightarrow Q_T Z_T \]
  \[ Q_T \rightarrow q q / q g / q g \text{, } W_T \rightarrow q / g / q g \text{, } Z_T \rightarrow H_0 g g / H_0 q q / \bar{c} b \]
  \[ \text{giving rise to the signal: } pp \rightarrow jets + BY \text{ or } pp \rightarrow jets + \gamma + BY \]

It is interesting to note that the Higgs boson($H_{(33)}$) can be reconstructed from the tagger heavy flavoured $b / t$ jet invariant mass.

- The cross-sections are calculated with CalcHep v2.2. The cross-section for $pp \rightarrow Q_T W_T$ and $pp \rightarrow Q_T Z_T$ are calculated varying the scale $f$ from 500 GeV to 2000 GeV for different values of $\kappa$.

**Background Estimation**

- Dominant background comes from $t \bar{t}$, W + jets and Z + jets events. MLM or CKKW matching can not be done for QCD events in PYTHIA.

- $t \bar{t}$ cut (3.5) helps to reduce QCD backgrounds. For jet multiplicity greater than 2, Pseudo-jets are formed to calculate $\sum_{j = 1}^{3} \eta_j$. 

- To reduce background events for $W$ + jets or $Z$ + jets , a large $p_T$ cut > 60 GeV and large $p_T$ cut > 200 GeV is applied and the sum of the $p_T$ of first three leading jet is required to be > 6000 GeV.

- We studied the effective cross-section for possible signals at $\kappa = 0.5$.

**Results**

- Till now we have only analyzed $pp \rightarrow Q_T W_T$ process. We will also search for the other process.

- Whole analysis done for three different $f$ values but for a fixed value of $\kappa = 0.5$.

- Results obtained from our simulation for LHC at 8 TeV centre of mass energy for the channel $n jet \geq 3 + BY$.

**References**