Signatures of T-odd Heavy Gauge Bosons and Heavy Quarks of The Littlest Higgs Model at The LHC

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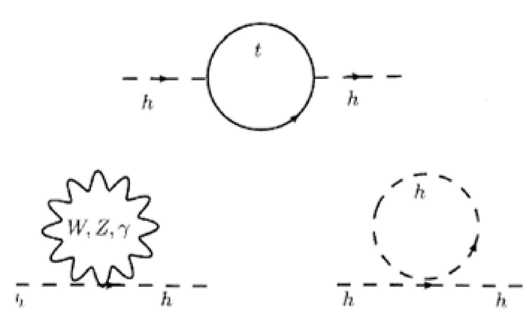
Why Beyond Standard Model

The Standard Model describes physics at low energy ($\leq 1TeV$) very well but it suffers from some serious problems. A few of those unanswered question are as follows which motivate to search for Beyond Standard Model physics.

- Why Weak Scale $\ll$ Planck 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: $V(\phi) = -\mu^2\phi^2 + \lambda\phi^4$.
The Vacuum expectation value : $< \phi >= \mu/\sqrt{(2\lambda)}$.



These are the quadratically divergent diagrams in the SM which contributes to the Higgs Mass.
$\Delta m_H^2(f) = -y_f^2/16\pi^2 * 2\Lambda^2$
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).

- μ^2 has the following form,

$$\begin{aligned} \mu^2 &= \mu_{bare}^2 + \Lambda^2(y_f^2 C_1 + g^2 C_2 + \lambda_s C_3 + H.O) \\ \mu &= 2\lambda < \phi > \\ < \phi > &= 250GeV \end{aligned} \quad (1)$$

Hence, at a scale of $\Lambda = 10^{14}GeV$
$\mu^2/\Lambda^2 = 10^{-24} = \mu_b^2/\Lambda^2 + (y_f^2 C_1 + g^2 C_2 + \lambda_s C_3 + H.O)$
which implies, Unnatural Fine Tuning.

Little Hierarchy Problem

- As Λ 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, Electrweak 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 ~ 10 higher is the so called *'Little Hierarchy Problem'*.

Little Higgs Model

- A good alternative of Supersymmetry.
- Higgs as a pseudo-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 cancells 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 brakes down to SO(5). SU(5) containes two copies of $[SU(2)XU(1)]^2$ that are diagonally broken down to one copy of SU(2)XU(1). In terms of groups,

$$\begin{aligned} SU(5) &\rightarrow SO(5) \\ U &\quad\; U \\ [SU(2)\ X\ U(1)]^2 &\rightarrow [SU(2)_w\ X\ U(1)_Y] \rightarrow [U(1)_{EW}] \end{aligned} \quad (2)$$

- The first breaking happens at scale f and the second one at EW scale. Due to EWPT the scale f is required to be ≥ 5 TeV.
- Introduce a discrete symmetry T-Parity (Similar to R-parity in MSSM). It lowers the scale to atleast 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_H, Z_H and A_H. Similarly, Q_Hs 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.
- The neutral weakly interacting lightest T-odd particle (A_H) arising due to the conservation of T-parity, is a good candidate for a dark matter.

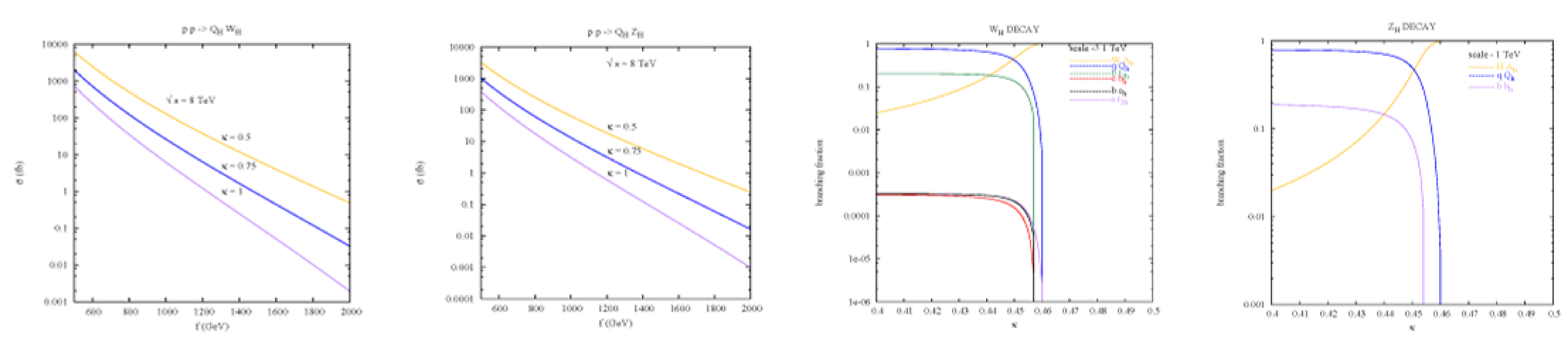
Collider Analysis

- Associative production of T-odd heavy gauge bosons(W_H/Z_H) and heavy quarks(Q_H) yield $jets + \not{E}_T$ channel.

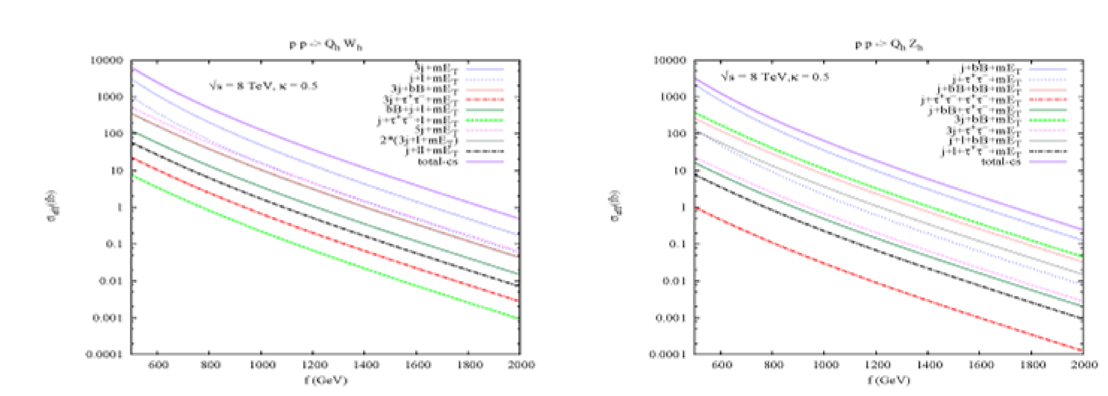
$$\begin{aligned} pp &\rightarrow Q_H W_H \;\text{ and, }\; pp \rightarrow Q_H Z_H \\ Q_H &\rightarrow qA_H/qZ_H, \quad W_H \rightarrow qq'A_H \\ Z_H &\rightarrow H_{SM}A_H/qQ_H \rightarrow (b\bar{b}/\tau^+\tau^- A_H)/(qq'A_H) + A_H \end{aligned} \quad (3)$$

giving rise to the signal : $pp \rightarrow jets + \not{E}_T$ or $pp \rightarrow jets + \tau + \not{E}_T$.

- It is interesting to note that the Higgs boson(H_{SM}) mass can be reconstructed from the tagged heavy flavoured b/τ jet invariant mass.
- .The cross-sections are calculated with CalcHep v3.2. The cross-section for $pp \rightarrow Q_H W_H$ and $pp \rightarrow Q_H Z_H$ are calculated varying the scale f from 500 GeV to 2000 GeV for different values of κ.



- The branching fractions of W_H and Z_H for the value of $f = 1TeV$ are shown as above. Here, qQ_H is the sum of all quark contribution.
- We studied the effective cross-section for possible signals at $\kappa = 0.5$.



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.
- α_T cut (> 0.51) helps to reduce QCD backgrounds. For jet multiplicity greater than 2, Pseudo-jets are formed to calculate $\alpha_T = p_{T2}/M_{jj}$
- To reduce background events for $t\bar{t}$, $W+jets$ or $Z+jets$, a large $\not{E}_T$ cut > 450 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 $> 600GeV$.

Results

- Till now we have only analyzed $pp \rightarrow Q_H W_H$ process. We will also search for the other process.
- Whole analysis done for three different f values but for a fixed value of $\kappa =$ 0.45.
- Results obtained from our simulation for LHC at 8 TeV centre of mass energy for the channel $njet \geq 3 + \not{E}_T$.

	Signal (fb)				SM background (fb)		
	f (TeV)						
σ_{eff}	0.75	0.85	1.0	1.25	$t\bar{t}$	$W+jets$	$Z+jets$
$= N_{pass}/N * \sigma$	5.62	5.60	4.66	2.10	0	20.12	17.1

Scale(f)	S at $\mathcal{L} = 20fb^{-1}$	S at $\mathcal{L} = 30fb^{-1}$
0.75TeV	4.41	5.06
0.85TeV	4.12	5.04
1.0TeV	3.43	4.20
1.25TeV	1.54	1.89

We define Significance as $S = N_{eff}|_{sig}/\sqrt{N_{eff}}|_B$.

- We are trying to do the analysis for LHC c.o.m energy 14 TeV.

References

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