We propose a non-supersymmetric $SU(5) \times SU(3)_L \times SU(2)_L \times U(1)'$ model in which only the third family of fermions are unified in the $SU(5)$ while the first two families belong to $SU(3)_L \times SU(2)_L \times U(1)'$. We call it a top $SU(5)$ model.

The Model remedies the non-unification of the three Standard Model couplings in non-supersymmetric $SU(5)$.

It also provides a mechanism of baryon number violation which is needed for the baryon asymmetry of the universe and not present in the Standard Model.

Current experimental constraints on the leptoquark and diquark gauge bosons, mediating such baryon and lepton violating interactions, allow their masses to be at the TeV scale.

These can be searched for as a (b tau) or (t t) resonance at the Large Hadron Collider.

**Our Model and Formalism:**

First two families of the SM fermions are charged under SM and singlet under the SU(5), while the third family is charged under SU(5) and singlet under SM.

The SM gauge couplings are given by: $\frac{1}{\sqrt{2}} \frac{1}{\sqrt{3}} \frac{1}{\sqrt{2}} \frac{1}{\sqrt{3}}$, with $j = 1; 2; 3$.

Thus no unification of the SM couplings.

$SU(5) \times SU(3)_L \times SU(2)_L \times U(1)'$ is broken to the SM gauge symmetry $SU(3)_c \times SU(2)_L \times U(1)_Y$ via Higgs mechanism.

**Particle content of the model:**

The Higgs potential breaking gauge symmetry is given by:

$$V = -m_i |U_i|^2 - m_{ij} |U_{ij}|^2 + A_{ij} |U_{ij}|^2 + A_{H} |U_{H}|^2 + A_{H} |U_{H}|^2 + \sum_{i} \sum_{m} Y_{i}^{m} |U_{m}^{i}|^2 + H.C.$$ 

Where,

$$U_{m}^{i} = \left( \begin{array}{c} 0 \nu_{m}^{i} \\ \{ \nu_{m}^{i} \} \{ \nu_{m}^{i} \} \end{array} \right) ; \{ \nu_{m}^{i} \} = \left( \begin{array}{c} 0 \nu_{m}^{i} \\ \{ \nu_{m}^{i} \} \{ \nu_{m}^{i} \} \end{array} \right)$$

We assume that VT and VD are in the TeV scale. The masses of the gauge bosons are,

$$\sum_{i} (D_{ij})^{2} D_{ij} = \frac{1}{2} (y_{i}^{j} y_{i}^{j} + y_{j}^{i} y_{j}^{i}) + \frac{1}{2} (y_{i}^{j} y_{i}^{j} + y_{j}^{i} y_{j}^{i}) + \frac{1}{3} (y_{i}^{j} y_{i}^{j} + y_{j}^{i} y_{j}^{i}) + \frac{1}{2} (y_{i}^{j} y_{i}^{j} + y_{j}^{i} y_{j}^{i}) + \frac{1}{2} (y_{i}^{j} y_{i}^{j} + y_{j}^{i} y_{j}^{i})$$

Yukawa Coupling:

$$-L = y_{i}^{j} U_{i}^{j} L_{i} H + y_{j}^{i} U_{j}^{i} H + y_{i}^{j} D_{i}^{j} H + y_{j}^{i} D_{j}^{i} H + y_{i}^{j} F_{i}^{j} F_{j}^{i} + y_{j}^{i} F_{j}^{i} F_{i}^{j} + y_{i}^{j} \Phi_{i}^{j} \Phi_{j}^{i} + y_{j}^{i} \Phi_{j}^{i} \Phi_{i}^{j} + m_{i}^{j} N_{i} N_{j} + H.C.$$ 

Choose a basis in which up quark mass matrix is diagonal. So no mixing between u, c, t.

CKM mixing arises from purely down quark sector. The mixing between the first two families and the 3rd family is done by using dimension 5 operators generated by the fields in the model via renormalization interaction.

**CKM Mixings:** The dimension 5 interactions are generated at the renormalizable level by using the vector-like fermions (Xi, Xd, XL) with masses ~1 TeV. This gives $M^5 \sim 1000$ TeV.

$$-L = \frac{1}{M^5} (y_{i}^{j} D_{i}^{j} F_{i}^{j} + y_{j}^{i} D_{j}^{i} F_{j}^{i} + y_{i}^{j} H_{i}^{j} + y_{j}^{i} H_{j}^{i} + y_{i}^{j} F_{i}^{j} H_{i}^{j} + y_{j}^{i} F_{j}^{i} H_{j}^{i} + y_{i}^{j} F_{i}^{j} \Phi_{i}^{j} + y_{j}^{i} F_{j}^{i} \Phi_{j}^{i}) + H.C.$$ 

Correct CKM mixing is generated by using $M^5 \sim 1000$ TeV.

**Phenomenological Implications:**

- Leptoquark gauge bosons X and Y can be pair produced at the LHC via QCD strong interactions.
- $gg \rightarrow X \bar{X}, t \bar{t} \rightarrow X \bar{X}$
- X and Y subsequently decays to $X \rightarrow f \bar{f}, Y \rightarrow f \bar{f}$.
- Consider signal for production: $gg \rightarrow b \bar{b} t \bar{t}$
- Both b and tau can be tagged, so the resonance X in the b tau mode can be reconstructed in Fig.
- Dominant SM background: $pp \rightarrow 2b 2\tau h 2j 2j 4a 4j di di$ which can be easily eliminated using suitable cuts.

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**Abstract:**

- Leptoquark gauge bosons X and Y can be pair produced at the LHC via QCD strong interactions.
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- Dominant SM background: $pp \rightarrow 2b 2\tau h 2j 2j 4a 4j di di$ which can be easily eliminated using suitable cuts.

**Leptoquark Signal at LHC:**

- To prove baryon and lepton violation, X need to be reconstructed also in the (t t) mode in addition to the (b t) mode to show that it is a leptoquark as well as a diquark and hence baryon and lepton number violating.
- For heavier leptoquark, one can look for the final state $bb t \bar{t}$ signal.
- For 7 TeV LHC, our model gives 5 sigma reach for mass as high as 750 GeV with 5 fb$^{-1}$ luminosity.

**Conclusions:**

- Presented TeV scale model for quark lepton unification in 4 Dimensions.
- Has leptoquark gauge bosons X and Y coupling only to the 3rd family of fermions, and hence produces B and L violation only involving the 3rd family.
- Can be observed as $b \tau$ and (t t) resonance at the LHC at the 7 TeV LHC, with 5 fb$^{-1}$ luminosity, the discovery reach is 750 GeV.

**Further Works on this model:**

- Motivated by our model, CMS collaboration has searched third generation leptosquarks with integrated luminosity of 4.8 fb$^{-1}$ as a resonance in the (b t) mode and has set a limit of exclusion of SU(5) vector leptoquarks with masses below 760 GeV at 95% CL.

*Further theoretical work for X, Y on the other modes at 8 TeV and 14 TeV LHC are in progress.*

**References:**


*Presenter: S. Nandi (Advisor)*