Unity of elementary particles and forces for the 3rd family[1]

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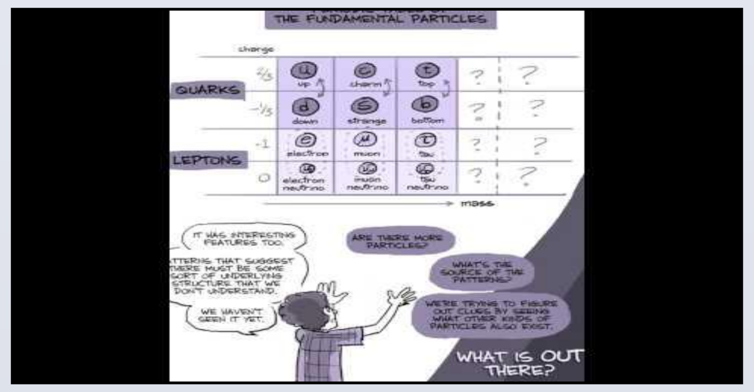
Abstract:

- We propose a non-supersymmetric $SU(5)\times SU(3)'_C\times SU(2)'_L\times U(1)'_Y$ model in which only the 3rd family of fermions are unified in the SU(5) while the first two families belong to $SU(3)'_C\times SU(2)'_L\times U(1)'_Y$. 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: $\frac{1}{g_j^2}=\frac{1}{g_5^2}+\frac{1}{(g_j')^2},\ \frac{1}{g_Y^2}=\frac{1}{(g_5^Y)^2}+\frac{1}{(g_Y')^2}$,with j = 1; 2; 3.
- Thus no unification of the SM couplings.
- $SU(5)\times SU(3)'_C\times SU(2)'_L\times U(1)'_Y$ 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 :



Particles	Quantum Numbers	Particles	Quantum Numbers
Q_i	$(\mathbf{1};\mathbf{3},\mathbf{2},\mathbf{1/6})$	L_i	$(\mathbf{1};\mathbf{1},\mathbf{2},-\mathbf{1/2})$
U_i^c	$(\mathbf{1};\bar{\mathbf{3}},\mathbf{1},-\mathbf{2/3})$	N_k^c	$(\mathbf{1};\mathbf{1},\mathbf{1},\mathbf{0})$
D_i^c	$(\mathbf{1};\bar{\mathbf{3}},\mathbf{1},\mathbf{1/3})$	E_i^c	$(\mathbf{1};\mathbf{1},\mathbf{1},\mathbf{1})$
F_3	$(\mathbf{10};\mathbf{1},\mathbf{1},\mathbf{0})$	$\bar{f}_3$	$(\bar{\mathbf{5}};\mathbf{1},\mathbf{1},\mathbf{0})$
H	$(\mathbf{1};\mathbf{1},\mathbf{2},-\mathbf{1/2})$	Φ	$(\bar{\mathbf{5}};\mathbf{1},\mathbf{1},\mathbf{0})$
U_T	$(\mathbf{5};\bar{\mathbf{3}},\mathbf{1},\mathbf{1/3})$	U_D	$(\mathbf{5};\mathbf{1},\mathbf{2},-\mathbf{1/2})$
XT	$(\mathbf{1};\bar{\mathbf{3}},\mathbf{1},\mathbf{1/3})$	XU	$(\mathbf{10};\mathbf{1},\mathbf{1},-\mathbf{1})$
Xf	$(\mathbf{5};\mathbf{1},\mathbf{1},\mathbf{0})$	$\overline{Xf}$	$(\bar{\mathbf{5}};\mathbf{1},\mathbf{1},\mathbf{0})$
XD	$(\mathbf{1};\mathbf{3},\mathbf{1},-\mathbf{1/3})$	$\overline{XD}$	$(\mathbf{1};\bar{\mathbf{3}},\mathbf{1},\mathbf{1/3})$
XL	$(\mathbf{1};\mathbf{1},\mathbf{2},-\mathbf{1/2})$	$\overline{XL}$	$(\mathbf{1};\mathbf{1},\mathbf{2},\mathbf{1/2})$

Table: The complete particle content and the particle quantum numbers under $SU(5)\times SU(3)'_C\times SU(2)'_L\times U(1)'_Y$ gauge symmetry in the top $SU(5)$ model. Here, $i=1,2$ and $k=1,2,3$.

- The Higgs potential breaking gauge symmetry is given by:

$$\mathbf{V}=-\mathbf{m}_T^2|U_T^2|-\mathbf{m}_D^2|U_D^2|+\lambda_T|U_T^2|^2+\lambda_D|U_D^2|^2+\lambda_{TD}|U_T^2|\ |U_D^2|\ +[A_T\Phi U_T XT^\dagger+A_D\Phi U_D H^\dagger+\frac{y_{TD}}{M_*}U_T^3U_D^2+H.C]$$

Where, $\langle U_D\rangle=v_D\begin{pmatrix}\mathbf{0}_{3\times2}\\ \mathbf{I}_{2\times2}\end{pmatrix},\ \langle U_D\rangle=v_D\begin{pmatrix}\mathbf{0}_{3\times2}\\ \mathbf{I}_{2\times2}\end{pmatrix}$

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

$$\sum_{i=T,D}\left\langle(D_\mu U_i)^\dagger D^\mu U_i\right\rangle=\frac{1}{2}v_T^2(g_5\hat{A}_\mu^{a3}-g_3'\tilde{A}_\mu^{a3})^2+\frac{1}{2}v_D^2(g_5\hat{A}_\mu^{a2}-g_2'\tilde{A}_\mu^{a2})^2+(\frac{v_T^2}{3}+\frac{v_D^2}{2})(g_5^Y\hat{A}_\mu^{a1}-g_Y'\tilde{A}_\mu^{a1})^2+\frac{1}{2}g_5^2(v_T^2+v_D^2)(X_\mu\bar{X}_\mu+Y_\mu\bar{Y}_\mu).$$

Yukawa Coupling:

$$-L=y_{ij}^uU_i^cQ_j\tilde{H}+y_{kj}^\nu N_k^cL_j\tilde{H}+y_{ij}^dD_i^cQ_jH+y_{ij}^eE_i^cL_jH+y_{33}^uF_3F_3\Phi^\dagger+y_{33}^{d,e}F_3\bar{f}_3\Phi+y_{k3}^\nu N_k^c\bar{f}_3\Phi^\dagger+m_{kl}^NN_k^cN_l^c+H.C$$

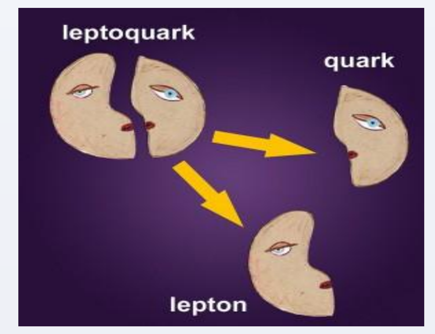
- Choose a basis in which up quark mass matrix is diagonal.. So no mixing between u, c, t.
- CKM mixing arises from purely down quark sector. The mixing between the first two families and the 3rd family is done by using dimension 5 operators generated by the fields in the model via renormalizable interaction.
- CKM Mixings: The dimension 5 interactions are generated at the renormalizable level by using the vector-like fermions (Xf, XD, XL) with masses ~1; 000TeV . This gives M * to be 1,000 TeV.

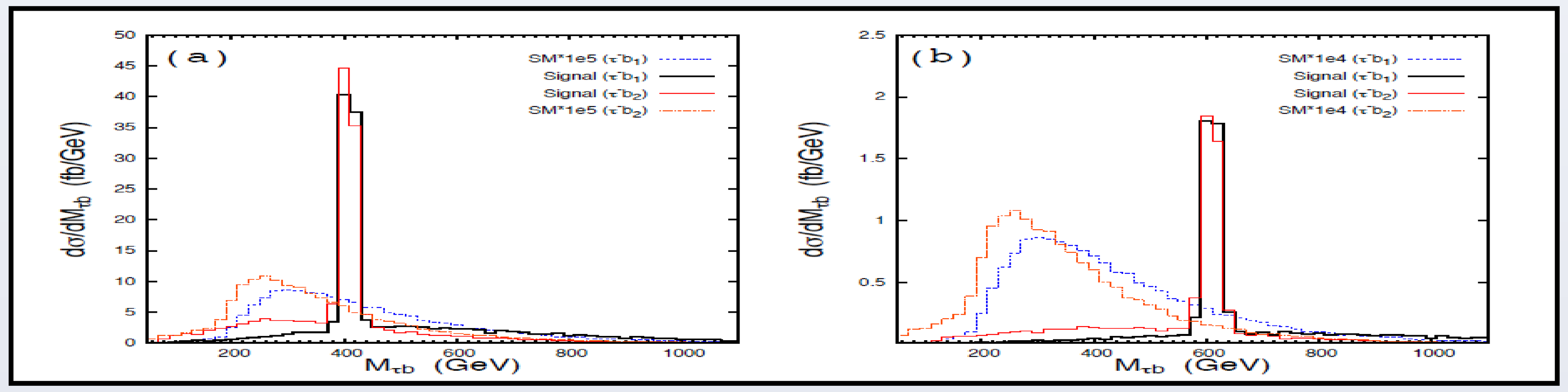
$$-L=\frac{1}{M_*}(y_{i3}^dD_i^cF_3\Phi U_T^\dagger+y_{i3}^eE_i^c\bar{f}_3HU_D+y_{3i}^d\bar{f}_3Q_iHU_T+y_{3i}^eF_3L_i\Phi U_D^\dagger)+H.C$$

- Correct CKM mixing is generated by using M* ~ 1,000 TeV.

Phenomenological Implications:

- Leptoquark gauge bosons X and Y can be pair produced at the LHC via QCD strong interactions.
  $gg\to X\bar{X},Y\bar{Y},\quad q\bar{q}\to X\bar{X},Y\bar{Y}$
- X and Y subsequently decays to:
  $X\to\bar{b}\tau^+,tt;\bar{X}\to b\tau^-,\bar{t}\bar{t}.\quad Y\to\bar{b}\nu_\tau,Y\to\bar{t}\tau^+,tb.$
- Consider signal for production : $\Rightarrow(\bar{b}\tau^+)(b\tau^-)$
- Both b and tau can be tagged, so the resonance X in the b tau mode can be reconstructed in Fig.
- Dominant SM background : $pp\to 2b2\tau;4b;2j2b;4j;t\bar{t}$,which can be easily eliminated using suitable cuts.





X resonance in the $b\tau$ mode at 7 TeV LHC

- Invariant mass distribution for the b channel for M_X = 400 GeV and M_X = 600 GeV.
- Cuts used: p_T > 80GeV; η < 2:5;ΔR > 0:2 Also used efficiency for b and τ tagging to be 0.5, mistag rate for light quark 1%, for charmed quark 10%.
- Background has been multiplied by 10^5 in (a) and 10^4 in (b).

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 $(b\tau)$ 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 $bb\tau\tau$ signal.
- **For 7 TeV LHC, our model gives 5 sigma reach for mass as high as 750 GeV with 5fb^{-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 5fb^{-1} luminosity, the discovery reach is 750 GeV.

Further Works on this model:

- Motivated by our model, CMS collaboration has searched for third generation leptoquarks with integrated luminosity of **4.8 fb^{-1}** as a resonance in the $(b\tau)$ 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 8TeV and 14TeV LHC are in progress.[3]**

References:

[1] S.Chakdar, T.Li, S.Nandi and S.K Rai,arXiv:1206.0409v1.

[2] CMS Physics Analysis Summary: CMS PAS EXO-12-002.

[3] S.Chakdar,T.Li ,S.Nandi and S.K.Rai (in preparation).

[4]T.Li and S.Nandi, Phys.Lett B 617,112(2005)

***Presenter and S.Nandi (Advisor)**