Probing Flipped Trinification at Colliders

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Outline

- Flipped-trinification (3331) has recently been studied in the literature(2016) [1, 2, 3, 4, 5], these models are based on the $SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_X$ gauge group.
- This class of models can explain the number of families of the Standard Model as 3-3-1 models do [6, 7, 8, 9, 10].
- It is also possible to explain the origin of the violation dynamically, as it occurs in Left-Right models (LR) [11, 12].
- In the simplest realization, neutrino masses arise from a dynamical seesaw mechanism in which the smallness of neutrino masses is correlated with the observed V-A nature of the weak interaction [1].
- An alternative motivation is that it can be achieved from the minimal left-right symmetric model by enlarging the left and right weak isospin groups in order to resolve the number of fermion generations and accommodate dark matter [13, 3].
- The model offers a natural framework for three types of dark matter particles.
- As shown in [2], gauge coupling unification at $\mathcal{O}$(TeV) is possible (which is not possible in 331 models) in the presence of leptonic octets.

Flipped Trinification Models

The so-called Flipped Trinification (FT) models are based on the gauge group $SU(3)_c \otimes SU(3)_L \otimes SU(3)_R \otimes U(1)_X$, was proposed by Reig, W.F. Valle and C.A. Vaquera-Araujo in arXiv:1611.02066. For these models, the most general electric charge operator in the extended electroweak sector is

$$Q = T_{3L} + Y = T_{3L} + T_{3R} + \beta\,(T_{8L} + T_{8R}) + X\mathbf{1}\ , \tag{1}$$

where $T_{L,Ra} = \lambda_a/2$, with $\lambda_a,\ a = 1, 2, \ldots, 8$ are the Gell-Mann matrices for $SU(3)$ normalized as $\mathrm{Tr}(\lambda_a \lambda_b) = 2\delta_{ab}$. In these expresion $\mathbb{1} = \mathrm{Diag}(1, 1, 1)$.

In general, we have for any set of generators T^a of a symmetry $SU(N)$ with $N \leq 3$, a set of generators $-T^{a*}$, which satisfy the exact group algebra. This set of generators spawns the so-called conjugate representation of $SU(N)$.

$$\{T^a, T^b\} = if^{abc}T^c \longrightarrow \{-T^{a*}, -T^{b*}\} = if^{abc}(-T^{c*}) \tag{2}$$

We can obtain the charges of the SM doublets as a linear combination of the generators in the standard representation (i.e, T^a), or as the linear combination of the generators in the conjugated one (i.e, $-T^{a*}$). In each case the value of the X charge is different.

Flipped Trinification Models

- For $\beta = 1/\sqrt{3}$, all the exotic particles have electrical charges like the SM.
- For $\beta = \sqrt{3}$, particles with exotic charges appear in the triplet third component.

Defining $q = -\frac{1+\sqrt{3}\beta}{2}$ we obtain four solution for the hipercharge X of a triplet

$$3_{L,R}\left(X = \frac{q-1}{3}\right) = \begin{pmatrix} \nu^0 \\ e^- \\ E^q \end{pmatrix}, \quad 3^*_{L,R}\left(X = -\frac{q+2}{3}\right) = \begin{pmatrix} e^- \\ \nu^0 \\ E^{-1-q} \end{pmatrix} \tag{3}$$

$$3_{L,R}\left(X = \frac{q+1}{3}\right) = \begin{pmatrix} u^{+\frac{2}{3}} \\ d^{-\frac{1}{3}} \\ Q^{q+\frac{2}{3}} \end{pmatrix}, \quad 3^*_{L,R}\left(X = -\frac{q}{3}\right) = \begin{pmatrix} u^{-\frac{1}{3}} \\ d^{+\frac{2}{3}} \\ Q^{-\frac{1}{3}-q} \end{pmatrix} \tag{4}$$

3-3-3-1 lepton and quark generations.

To reproduce the SM we account for all the possible lepton S_{L_i} and quark S_{Q_i} families consistent with the SM, i.e.,

- Each family requires one quark doublet q_i and one lepton doublet ℓ_i.
- Three singlets under $SU(2)$ with charges $2/3$ u_i and d_i and e_i correspond to the right-hand components of the doublets of $SU(2)$.
- The $SU(2)$ singlets can correspond to $SU(3)$ singlets or the third component of a $S(3)$ triplet.

$$S_{L1} = 3_L(\text{leptons}) + 3_R(\text{leptons}), \qquad S_{L1} = 3_L(\text{leptons}) + 3^*_R(\text{leptons}) \cup E^q_R \cup E_L^{-q-1}.$$

$$S_{L4} = 3^*_L(\text{leptons}) + 3^*_R(\text{leptons}), \qquad S_{L3} = 3^*_L(\text{leptons}) + 3_R(\text{leptons}) \cup E^q_L \cup E_R^{-q-1}.$$

$$S_{q1} = 3_L(\text{quarks}) + 3_R(\text{quarks}), \qquad S_{L2} = 3_L(\text{quarks}) + 3_R^*(\text{quarks}) \cup E_R^{q+\frac{2}{3}} \cup E_L^{-q-\frac{1}{3}}.$$

$$S_{q4} = 3_L^*(\text{quarks}) + 3_R^*(\text{quarks}), \qquad S_{q3} = 3_L^*(\text{quarks}) + 3_R(\text{quarks}) \cup E_L^{q+\frac{2}{3}} \cup E_R^{-q-\frac{1}{3}}.$$

New 3331 models

Table 1 presents the contribution of each set to the different anomalies.

$$A = \mathrm{Tr}\left[T^a\left\{T^b, T^c\right\}\right] = 0. \quad (5)$$

Anomalies	S_{L1}	S_{L2}	S_{L3}	S_{L4}	S_{Q1}	S_{Q2}	S_{Q3}	S_{Q4}
$[SU(3)_C]^2\otimes\ U(1)_X$	0	0	0	0	0	0	0	0
$[SU(3)_L]^2\otimes\ U(1)_X$	$\frac{q-1}{3}$	$\frac{q-1}{3}$	$-\frac{(q+2)}{3}$	$-\frac{(q+2)}{3}$	$1+q$	$1+q$	$-q$	$-q$
$[SU(3)_R]^2\otimes\ U(1)_X$	$\frac{q-1}{3}$	$-\frac{(q+2)}{3}$	$\frac{q-1}{3}$	$-\frac{(q+2)}{3}$	$1+q$	$-q$	$1+q$	$-q$
$[\mathrm{Grav}]^2\otimes\ U(1)_X$	0	0	0	0	0	0	0	0
$[U(1)_X]^3$	0	$-\frac{2}{9}(1+2q)^3$	$\frac{2}{9}(1+2q)^3$	0	0	$-\frac{2}{3}(1+2q)^3$	$\frac{2}{3}(1+2q)^3$	0
$[SU(3)_{L,R}]^3$	2	0	0	-2	6	0	0	-6

Table: 1 Anomalies for a model with an arbitrary β

3331 Models

The corresponding three-family models are:

$$
\begin{aligned}
M_1 &: 3S_{L4} + S_{Q1} + S_{Q2} + S_{Q3} \ , \\
M_2 &: 3S_{L4} + 2S_{Q1} + S_{Q4} \ , \\
M_3 &: 3S_{L3} + 2S_{Q2} + S_{Q3} \ , \\
M_4 &: 3S_{L3} + S_{Q1} + S_{Q2} + S_{Q4} \ , \\
M_5 &: 3S_{L2} + S_{Q2} + 2S_{Q3} \ , \\
M_6 &: 3S_{L2} + S_{Q1} + S_{Q3} + S_{Q4} \ , \\
M_7 &: 3S_{L1} + S_{Q2} + S_{Q3} + S_{Q4} \ , \\
M_8 &: 3S_{L1} + S_{Q1} + 2S_{Q4} \ .
\end{aligned}
$$

LHC Constraints

We consider the ATLAS search for high-mass dilepton resonances in the mass range of 250 GeV to 6 TeV in proton-proton collisions at a center-of-mass energy of $\sqrt{s} = 13$ TeV during Run 2 of the LHC with an integrated luminosity of 139 fb^{-1} [14]. This data was collected from searches of Z' bosons decaying dileptons. We obtain the mass lower limit from the intersection of the theoretical predictions with the upper limit on the cross-section at a 95% confidence level. We use the expressions given in Ref. [15, 16, 17] to calculate the theoretical

Upper limit on the cross-section at a 95% confidence level [14].

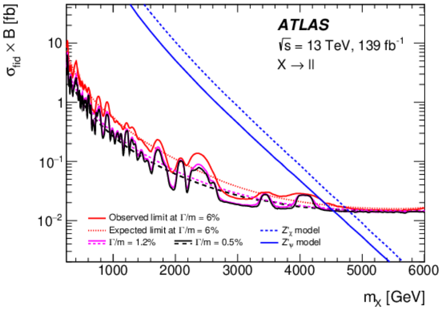

Figure: Mass lower limit from the intersection of the theoretical predictions with the upper limit on the cross-section at a 95% confidence level [14].

Frame Title

the Z' chiral charges:

$$g_{Z'}\epsilon_{L,R}^{Z'} = \quad A_{L,R}\cos\theta + B_{L,R}\sin\theta \ , \tag{6}$$
$$g_{Z''}\epsilon_{L,R}^{Z''} = - A_{L,R}\sin\theta + B_{L,R}\cos\theta \ , \tag{7}$$

and θ is a mixing angle which can take any value between $-\pi$ and π and For exact left-right symmetry we have $g_L = g_R$, replacing these identities in $A_{L,R}$ and $B_{L,R}$ we obtain the following.

$$A_{L,R} = \quad \frac{g_L}{\hat{\alpha}_R}\left[\left(\frac{1}{z} + z\right)X_{L,R} - \frac{z}{2}(B-L)\right] , \tag{8}$$
$$B_L = - g_Y \frac{B-L}{2\hat{\alpha}_R} \ , \tag{9}$$
$$B_R = g_Y\left(-\frac{B-L}{2\hat{\alpha}_R} + \hat{\alpha}_R\epsilon_R^3\right) \ . \tag{10}$$

Here $z = \frac{g_L}{\beta g_X} = \frac{1}{\beta}\sqrt{\cot^2\theta_W - \beta^2 - 1} = \frac{1}{\beta}\sqrt{\hat{\alpha}_R^2 - \beta^2}$. Under the previous assumptions with $\sin^2\theta_W = 0.23120$ (here, we use the value for the weak mixing angle in the $\overline{\text{MS}}$ scheme) we get $\hat{\alpha}_R = \sqrt{\cot^2\theta_W - 1}$. To avoid imaginary couplings, we require: $\beta < \hat{\alpha}_R \approx 1.525$, this condition rules out the notable case $\beta = \sqrt{3}$.

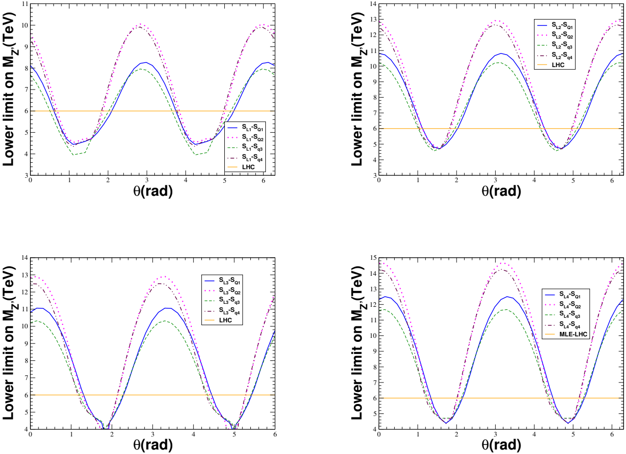

Figure: Lower limit on the Z' mass. We obtain these limits from the 95% CL upper limits on the fiducial Z' production cross section times the $Z' \to \ell^+\ell^-$ branching [14]. Restrictions for Z' masses above 6 TeV are assumed to be projected limits. They are obtained assuming that the projected upper limit for the cross section in this region cannot exceed the ATLAS limit at 6 TeV

contribution

Model	Lepton content	SM Quark Embeddings	$2+1$	FCNC	LHC-Lower limit (TeV)
M_1	$3S_{L4}$	$S_{Q_1}+S_{Q_2}+S_{Q_3}$	$\times$	✓	ED
M_2	$3S_{L4}$	$2S_{Q_1}^{ud,cs}+S_{Q_4}^{tb}$	✓	$\times$	4.3
M_3	$3S_{L3}$	$2S_{Q_2}^{ud,cs}+S_{Q_3}^{tb}$	✓	$\times$	4
M_4	$3S_{L3}$	$S_{Q_1}+S_{Q_2}+S_{Q_4}$	$\times$	✓	ED
M_5	$3S_{L2}$	$2S_{Q_3}^{ud,cs}+S_{Q_2}^{tb}$	✓	$\times$	4.5
M_6	$3S_{L2}$	$S_{Q_1}+S_{Q_3}+S_{Q_4}$	$\times$	✓	ED
M_7	$3S_{L1}$	$S_{Q_2}+S_{Q_3}+S_{Q_4}$	$\times$	✓	ED
M_8	$3S_{L1}$	$2S_{Q_4}^{ud,cs}+S_{Q_1}^{tb}$	✓	$\times$	4.3

Table: Embeddings of the Standard Model quarks within each family are shown. The superscript denotes the quark content of each family. The lepton sector is universal and does not require an explicit embedding. A check mark indicates that a configuration with at least two families (2+1) sharing identical Z' charges is possible. LHC constraints are reported only for embeddings where identical Z' charges can be assigned to the first two families. In models with three non-universal quark families, Flavor-Changing Neutral Currents (FCNC) arise between the first two generations, in conflict with experimental constraints. In all cases, the models exhibit universality in the lepton sector. ED stands for Embedding Dependent. In these cases, the lower limit depends on which families are identified with the first generation of the SM.

¿ Why could these models be attractive?

Even the Universal embeddings are capable of having clear signatures.

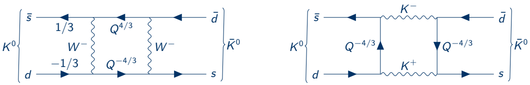

Figure: Exotic quark contribution to the $K^0 - \bar{K}^0$ mixing.

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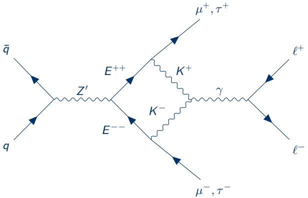

Figure: Doubly charged exotic lepton contribution to the process $q\bar{q} \rightarrow Z' \rightarrow E^{++}E^{--} \rightarrow \ell^+\ell^-\gamma \rightarrow \ell^+\ell^-\mu^+\mu^-(\tau^+\tau^-)$.

Conclusions

- Several anomaly free realizations of the $SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \otimes U_X$ gauge symmetry have been proposed.
- We report the list of minimal anomaly-free sets for 3331 models for an arbitrary β
- We have fully accounted for the possible 3331 models with $\beta = \sqrt{3}$ and their corresponding LHC constraints.
- These models are suitable for studying flavor physics and strongly coupled extension models.

Frame Title

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