Alternative 3-3-1 models with exotic electric charges

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Outline

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- The triangle anomalies must be canceled out only with a number of generations multiple of 3 (For example a 3-3-1 model of E_6 is not interesting in that sense)
- it must contain the standard model (SM).
- There is a lot of literature about 3-3-1 models. Which typically reduces to those models with nonexotic charges.
- By embedding this group in a larger one, it is possible to explain the charge quantization.

3-3-1 models

The so-called 3-3-1 models are based on the gauge group $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$. For the 3-3-1 models, the most general electric charge operator in the extended electroweak sector is

$$Q = T_{L3} + \beta T_{L8} + X\mathbb{1}, \tag{1}$$

where $T_{La} = \lambda_a/2$, with $\lambda_a,\ a = 1, 2, \ldots, 8$ are the Gell-Mann matrices for $SU(3)_L$ normalized as $\mathrm{Tr}(\lambda_a \lambda_b) = 2\delta_{ab}$ and $\mathbb{1} = \mathrm{Diag}(1, 1, 1)$ is the diagonal 3×3 unit matrix.

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.

3-3-1 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.

$$3_L = \begin{pmatrix} 0 \\ -1 \\ -2 \end{pmatrix}, \qquad 3_L^* = \begin{pmatrix} -1 \\ 0 \\ +1 \end{pmatrix} \tag{3}$$

$$3_Q = \begin{pmatrix} +2/3 \\ -1/3 \\ -4/3 \end{pmatrix}, \qquad 3_L^* = \begin{pmatrix} -1/3 \\ +2/3 \\ +5/3 \end{pmatrix} \tag{4}$$

For $\beta = \sqrt{3}$ the electric charges of the triplet and the anti-triplet) are: $Q_{\text{QED}}(3) = \text{Diag}(1 + X, X, -1 + X)$ and $Q_{\text{QED}}(3^\star) = \text{Diag}(-1 + X, X, 1 + X)$, respectively.

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.

Lepton families S_{L_i}

- Lepton generation $S_{L1} = [(\nu_e^0, e^-, E_2^{--}) \oplus e^+ \oplus E_2^{++}]_L$ with quantum numbers $(1, 3, -1); (1, 1, 1)$ and $(1, 1, 2)$ respectively.
- Set $S_{L2} = [(e^-, \nu_e^0, E_1^+) \oplus e^+ \oplus E_1^-]_L$ with quantum numbers $(1, 3^*, 0)$; $(1, 1, 1)$ and $(1, 1, -1)$, respectively.
- Set $S_{L3} = [(e^-, \nu_e^0, e^+)]_L$ with quantum numbers $(1, 3^*, 0)$.

Quark families S_{Q_i}

For $\beta = \sqrt{3}$ the electric charges of a triplet (or anti-triplet) are: $Q_{\text{QED}}(3) = \text{Diag}(1 + X, X, -1 + X)$ and $Q_{\text{QED}}(3^\star) = \text{Diag}(-1 + X, X, 1 + X)$, respectively.

- Set $S_{Q1} = [(d, u, Q_2) \oplus u^c \oplus d^c \oplus Q_2^c]_L$ with quantum numbers $(3, 3^*, 2/3)$; $(3^*, 1, -2/3)$; $(3^*, 1, 1/3)$ and $(3^*, 1, -5/3)$, respectively.
- Set $S_{Q2} = [(u, d, Q_1) \oplus u^c \oplus d^c \oplus Q_1^c]_L$ with quantum numbers $(3, 3, -1/3)$; $(3^*, 1, -2/3)$; $(3^*, 1, 1/3)$ and $(3^*, 1, 4/3)$, respectively.

Exotic families and fermionic dark matter candidates

It is advantageous to cancel anomalies by introducing triplets and anti-triplets of exotic leptons, for example:

- First exotic lepton set, $S_{E1} = [(N_1^0, E_4^+, E_3^{++}) \oplus E_4^- \oplus E_3^{--}]_L$ with quantum numbers $(1, 3^*, 1)$; $(1, 1, -1)$ and $(1, 1, -2)$, respectively.
- Second exotic lepton set, $S_{E2} = [(E_5^+, N_2^0, E_6^-) \oplus E_5^- \oplus E_6^+]_L$ with quantum numbers $(1, 3, 0)$; $(1, 1, -1)$ and $(1, 1, 1)$, respectively.

In these triplets, it is possible to identify fermionic dark matter candidates.

Anomalies

Table 1 shows the contribution of the sets to each of the anomalies.

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

Anomalías	S_{L1}	S_{L2}	S_{L3}	S_{Q1}	S_{Q2}	S_{E1}	S_{E2}
$[SU(3)_C]^2 \otimes U(1)_X$	0	0	0	0	0	0	0
$[SU(3)_L]^2 \otimes U(1)_X$	-1	0	0	2	-1	1	0
$[\text{Grav}]^2 \otimes U(1)_X$	0	0	0	0	0	0	0
$[U(1)_X]^3$	6	0	0	-12	6	-6	0
$[SU(3)_L]^3$	1	-1	-1	-3	3	-1	1

Table: Anomalías para campos fermiónicos del modelo 331 con $\beta = \sqrt{3}$

New 3-3-1 models

i	Just lepton families S_{Lj}	one quark family S_{Qj}	two quark families S_{Qj}	three quark families S_{Qj}
	$S_{E2}+S_{L2}$	$S_{E2}+2S_{L1}+S_{Q1}$	$S_{L1}+S_{L2}+S_{Q1}+S_{Q2}$	$3S_{L1}+2S_{Q1}+1S_{Q2}$
	$S_{E1}+S_{L1}$	$S_{E1}+2S_{L2}+S_{Q2}$	$S_{L1}+S_{L3}+S_{Q1}+S_{Q2}$	$3S_{L2}+1S_{Q1}+2S_{Q2}$
	$S_{E2}+S_{L3}$	$S_{E1}+S_{L2}+S_{L3}+S_{Q2}$		$3S_{L3}+1S_{Q1}+2S_{Q2}$
		$S_{E1}+2S_{L3}+S_{Q2}$		$2S_{L2}+1S_{L3}+1S_{Q1}+2S_{Q2}$
				$1S_{L2}+2S_{L3}+1S_{Q1}+2S_{Q2}$

Table: Anomaly free sets (AFS) for $\beta=\sqrt{3}$.

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} [1]. This data was collected from searches of Z' bosons decaying dileptons. We obtain the upper 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. [2, 3, 4] to calculate the theoretical

Particle content first generation	LHC-Lower limit in TeV
$S_{L3} + S_{Q1}$	7.3
$S_{L3} + S_{Q2}$	6.4

Table: The lepton families S_{L_1} and S_{L_2} are strongly coupled (For S_{L_1} and S_2 the lehf-handed doubled ℓ and the right-handed charged singled e have couplings larger than 1, respectively). Therefore only S_{L_3} is phenomenologically viable for the first family. Depending on the quark content, i.e., S_{Q_1} or S_{Q_2}, we have two different constraints.

Conclusions

- Several $SU(3)_L$ generations have been proposed.
- We report the list of the minimal anomaly-free sets for 3-3-1 models with $\beta = \sqrt{3}$
- We have given a full account of the possible 3-3-1 models with $\beta = \sqrt{3}$ and their corresponding LHC constraints.

Frame Title

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- J. Erler, P. Langacker, S. Munir, and E. Rojas, "Z' Bosons at Colliders: a Bayesian Viewpoint," *JHEP*, vol. 11, p. 076, 2011.
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- R. H. Benavides, L. Muñoz, W. A. Ponce, O. Rodríguez, and E. Rojas, "Electroweak couplings and LHC constraints on alternative Z' models in E_6," *Int. J. Mod. Phys. A*, vol. 33, no. 35, p. 1850206, 2018.