Alternative 3-3-1 models: a comprehensive analysis

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Systematic study of the $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ local gauge symmetry

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Abstract

We review in a systematic way how anomaly free $SU(3)_c \otimes SU(3)_L \otimes U(1)_x$ models without exotic electric charges can be constructed, using as basis closed sets of fermions which includes each one the particles and antiparticles of all the electrically charged fields. Our analysis reproduces not only the known models in the literature, but also shows the existence of several more independent

Overview

Abstract

- We review in a systematic way how anomaly free $SU(3)_c \otimes SU(3)_L \otimes U(1)_x$ models without exotic electric charges can be constructed, using as basis closed sets of fermions which includes each one the particles and antiparticles of all the electrically charged fields.
- Our analysis reproduces not only the known models in the literature, but also shows the existence of several more independent models for one and three families not considered so far.
- A phenomenological analysis of the new models is done, where the lowest limits at a 95 % CL on the gauge boson masses are presented.

Introduction

- The impressive success of the Standard Model (SM) based on the local gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$, has not been able enough to provide explanation for several fundamental issues.
- Minimal extensions of the SM arise either by adding new fields, or by enlarging the local gauge group (adding a right handed neutrino field constitute its simples extension). The electroweak gauge group is $SU(3)_c \otimes SU(3)_L \otimes U(1)_X$ (3-3-1 for short) in which the electroweak sector of the standard model $SU(2)_L \otimes U(1)_Y$ is extended to $SU(3)_L \otimes U(1)_X$.
- Our analysis is to obtain the alternative embeddings for some of the well-known 3-3-1 models in the literature.

3-3-1 Models

Two classes of models will show up: universal one family models where the anomalies cancel in each family as in the SM, and family models where the anomalies cancel by an interplay between the several families.

For the 3-3-1 models, the most general electric charge operator in the extended electroweak sector is

$$Q = a\lambda_3 + \frac{1}{\sqrt{3}} b\lambda_8 + XI_3, \tag{1}$$

where $\lambda_\alpha, \ \alpha = 1, 2, \ldots, 8$ are the Gell-Mann matrices for $SU(3)_L$ normalized as $\mathrm{Tr}(\lambda_\alpha \lambda_\beta) = 2\delta_{\alpha\beta}$ and $I_3 = Dg(1, 1, 1)$ is the diagonal 3×3 unit matrix. $a = 1/2$, the isospin $SU(2)_L$ of the SM is entirely embedded in $SU(3)_L$ and if one wishes to avoid exotic electric charges in the fermion and boson sectors as the ones present in the minimal (3-3-1) model, one must choose $b = 1/2$.

Models Without Exotic Electric Charges

- $S_1 = [(\nu_e^0, e^-, E_1^-) \oplus e^+ \oplus E_1^+]_L$ with quantum numbers $(1, 3, -2/3)$; $(1, 1, 1)$ and $(1, 1, 1)$ respectively.
- $S_2 = [(e^-, \nu_e^0, N_1^0) \oplus e^+]_L$ with quantum numbers $(1, 3^*, -1/3)$ and $(1, 1, 1)$ respectively.
- $S_3 = [(d, u, U) \oplus u^c \oplus d^c \oplus U^c]_L$ with quantum numbers $(3, 3^*, 1/3)$; $(3^*, 1, -2/3)$; $(3^*, 1, 1/3)$ and $(3^*, 1, -2/3)$ respectively.
- $S_4 = [(u, d, D) \oplus u^c \oplus d^c \oplus D^c]_L$ with quantum numbers $(3, 3, 0)$; $(3^*, 1, -2/3)$; $(3^*, 1, 1/3)$ and $(3^*, 1, 1/3)$ respectively.
- $S_5 = [(N_2^0, E_2^+, e^+) \oplus E_2^- \oplus e^-]_L$ with quantum numbers $(1, 3^*, 2/3)$ $(1, 1, -1)$, and $(1, 1, -1)$ respectively.
- $S_6 = [(E_3^+, N_3^0, N_4^0) \oplus E_3^-]_L$ with quantum numbers $(1, 3, 1/3)$ and $(1, 1, -1)$ respectively,
- $S_7 = [(e^-, \nu_e^0, N_1^0) \oplus (N_2^0, E^+, e^+) \oplus E^-]_L$ with quantum numbers $(1, 3^*, -1/3)$; $(1, 3^*, 2/3)$ and $(1, 1, -1)$ respectively.
- $S_8 = [(\nu_e^0, e^-, E^-) \oplus (E^+, N_1^0, N_2^0) \oplus e^+]_L$ with quantum numbers $(1, 3, -2/3)$, $(1, 3, 1/3)$ and $(1, 1, 1)$ respectively.
- $S_9 = [(e^-, \nu_e, N_1^0) \oplus (E^-, N_2^0, N_3^0) \oplus (N_4^0, E^+, e^+)]_L$ with quantum numbers $(1, 3^*, -1/3)$;$(1, 3^*, -1/3)$ and $(1, 3^*, 2/3)$ respectively.
- $S_{10} = [(\nu_e, e^-, E_1^-) \oplus (E_2^+, N_1^0, N_2^0) \oplus e^+ \oplus (N_3^0, E_2^-, E_3^-) \oplus E_1^+ \oplus E_3^+]_L$ with quantum numbers $(1, 3, -2/3)$; $(1, 3, 1/3)$; $(1, 1, 1)$; $(1, 3, -2/3)$; $(1, 1, 1)$, and $(1, 1, 1)$ respectively.
- $S_{11} = [(e^-, \nu_e, N_1^0) \oplus (N_2^0, E_1^+, e^+) \oplus (N_3^0, E_2^+, E_3^+) \oplus E_1^- \oplus E_2^- \oplus E_3^-]_L$ with quantum numbers $(1, 3^*, -1/3)$; $(1, 3^*, 2/3)$; $(1, 3^*, 2/3)$; $(1, 1, -1)$; $(1, 1, -1)$, and $(1, 1, -1)$ respectively.
- $S_{12} = [(\nu_e^0, e^-, E_1^-) \oplus (E_1^+, N_1^0, N_2^0) \oplus (E_2^+, N_3^0, N_4^0) \oplus e^+ \oplus E_2^-]_L$ with quantum numbers $(1, 3, -2/3)$; $(1, 3, 1/3)$; $(1, 3, 1/3)$; $(1, 1, 1)$, and $(1, 1, -1)$; respectively.

Irreducible anomaly free sets

i	Vector-like lepton sets (L_i)	One quark set (Q_i^I)	Two quark sets (Q_i^{II})	Three quark sets (Q_i^{III})
1	$S_1 + S_5$	$S_4 + S_9$	$S_1 + S_2 + S_3 + S_4$	$3S_2 + S_3 + 2S_4$
2	$S_2 + S_6$	$S_3 + S_{10}$	$2S_1 + S_3 + S_4 + S_7$	$3S_1 + 2S_3 + S_4$
3	$S_7 + S_8$	$S_2 + S_4 + S_7$	$2S_2 + S_3 + S_4 + S_8$	
4	$S_{10} + S_{11}$	$S_1 + S_3 + S_8$	$3S_2 + S_3 + S_4 + S_{12}$	
5	$S_9 + S_{12}$	$2S_1 + S_3 + S_6$	$3S_1 + 2S_3 + S_{12}$	
6	$S_1 + S_6 + S_7$	$2S_2 + S_4 + S_5$	$3S_2 + 2S_4 + S_{11}$	
7	$S_6 + S_8 + S_9$	$S_1 + S_4 + 2S_7$	$3S_1 + S_3 + S_4 + S_{11}$	
8	$S_2 + S_5 + S_8$	$S_2 + S_3 + 2S_8$		
9	$S_5 + S_7 + S_{10}$	$S_1 + S_2 + S_3 + S_{12}$		
10	$S_2 + S_7 + S_{12}$	$S_1 + S_2 + S_4 + S_{11}$		
11	$S_1 + S_8 + S_{11}$	$S_4 + 3S_7 + S_{10}$		
12	$S_1 + 2S_6 + S_9$	$S_3 + 3S_8 + S_9$		
13	$S_6 + 2S_7 + S_{10}$	$2S_1 + S_3 + S_7 + S_{12}$		
14	$S_5 + 2S_8 + S_9$	$2S_1 + S_4 + S_7 + S_{11}$		
15	$S_5 + S_6 + S_9 + S_{10}$	$2S_2 + S_3 + S_8 + S_{12}$		
16	$S_2 + 2S_5 + S_{10}$	$2S_2 + S_4 + S_8 + S_{11}$		
17	$S_1 + 2S_7 + S_{12}$	$3S_2 + S_3 + 2S_{12}$		
18	$S_1 + S_2 + S_{11} + S_{12}$	$3S_2 + S_4 + S_{11} + S_{12}$		
19	$S_2 + 2S_8 + S_{11}$	$3S_1 + S_3 + S_{11} + S_{12}$		
20	$2S_1 + S_6 + S_{11}$	$3S_1 + S_4 + 2S_{11}$		
21	$2S_2 + S_5 + S_{12}$			

IAFSs. Any general Anomaly Free-Set (AFS) containing quarks, must be a combination of IAFSs (i.e., L_i, Q^I, Q^{II} and Q^{III}) even for more than three families. For leptons, the second column (L) is not exhaustive and it was not possible to account for all the possibilities.

Collider Constraints

Model	j	SM Lepton Embeddings	Universal	2+1	Lepton Configuration	LHC-Lower limit (TeV)
A	-	$3S_2^{\bar{\ell}+e^+}$	✓	×	$3C_2$	4.87
B	-	$3S_1^{\ell+e^+}$	✓	×	$3C_1$	5.53
C^j	1	$S_1^{\ell+e^+} + S_2^{\bar{\ell}+e^+} + S_9^{\bar{\ell}+e'^+}$	×	×	$C_1 + C_2 + C_3$	
	2	$(S_1^{\ell} + S_9^{e'^+}) + S_2^{\bar{\ell}+e^+} + (S_9^{\bar{\ell}} + S_1^{e^+})$	×	✓	$2C_2 + C_4$	4.87
D^j	1	$S_1^{\ell+e^+} + S_2^{\bar{\ell}+e^+} + S_{10}^{\ell+e^+}$	×	✓	$2C_1 + C_2$	5.53
	2	$S_1^{\ell+e^+} + S_{10}^{2\ell+2e^+}$	✓	×	$3C_1$	5.53

Alternative embeddings for the classical AFSs. The superscripts correspond to the particle content of the SM, where ℓ ($\bar{\ell}$) stands for a left-handed lepton doublet embedded in a $SU(3)_L$ triplet (anti-triplet), and e'^+ (e^+) is the right-handed charged lepton embedded in a $SU(3)_L$ triplet (singlet). The check mark ✓ means that at least two families (2+1) or three families (universal) have the same charges under the gauge symmetry, the cross × stands for the opposite. LHC constraints are obtained for embeddings for which we can choose the same Z' charges for the first two families, otherwise we leave the space blank.

Conclusions

The main conclusions of this work are:

1. Restricting ourselves to models without exotic electric charges, we have built 12 sets of particles S_i from triplets, antitriplets and singlets of $SU(3)_L \otimes U(1)_X$. These sets are constructed in such a way that they contain the charged particles and their respective antiparticles.
2. With these sets, we built the IAFSs L_i, Q_i^{I}, Q_i^{II} and Q_i^{III} depending on their quark content. From the IAFSs it is possible to systematically build 3-3-1 models. It is important to realize that if we restrict the AFSs to a minimum content of vector-like structures (i.e, L_i), having a lepton and quark sector consistent with the SM, our analysis is reduced to the AFSs that contain the classical 3-3-1 models.
3. If we allow alternative embeddings for SM particles within S_i, we get new phenomenological distinguishable model.
4. We found 1682 models which could be of phenomenological interest.
5. We can see that, independent of the model, the mass value of the new neutral gauge boson for all the 3-3-1 models without exotic electric charges is above 4.87 TeV.

THANK YOU!