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Flipped models in Trinification

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Anomalies

$$\sum_{\text{left}} \text{Tr}\left(T^a\{T^b, T^c\}\right) - \sum_{\text{right}} \text{Tr}\left(T^a\{T^b, T^c\}\right) = 0 \qquad (1)$$

- $SU(3)_c^2 U(1)_{z'}$ $\quad$ $SU(2)_w^2 U(1)_{z'}$
- $U(1)_Y^2 U(1)_{z'}$ $\quad$ $U(1)_Y U(1)_{z'}^2$
- $U(1)_{z'}^3$
- $1^2 U(1)_{z'}$

For SM fermions only a $U(1)_{z'}$ proportional to the SM hypercharge is consistent with anomaly cancellation [Appelquist,Bogdan,Dobrescu and Hopper: 2002]

In general, intrincate models are not appealing, a way to look for new models with a moderate content of fermions is to consider flipped versions of the known models in the literature. //
In ER and Jens Erler 2015 all the possible alternative subgroup chains in E_6 were enumerated, however, many of them are equivalent from phenomenological grounds. //
In the present talk we will present a thorough study of the alternative chains of subgroups for

$$SU(3)_C \otimes SU(3)_L \otimes SU(3)_R \rightarrow \tag{2}$$

$$\rightarrow \begin{cases} SU(3)_C \otimes SU(3)_L \otimes U(1)_{331} \otimes U(1)_I, & \text{331 universal model} \\ SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{B-L}, & \text{LR symmetric model} \end{cases} \tag{3}$$

The Trinification fundamental representation have a dimension 27

$$27 = (3,3,1) \oplus (1,\bar{3},3) \oplus (\bar{3},1,\bar{3}) \; ,$$

the particle content of each term is:

$$\begin{aligned}
(3,3,1) &= (u,d,D)_L^T \; , \\
(\bar{3},1,\bar{3}) &= (u^c,d^c,D^c)_L^T \; , \\
(1,\bar{3},3) &= \begin{pmatrix} N^0 & E^- & e^- \\ E^+ & N^{0c} & \nu_e \\ e^+ & \overline{\nu} & M^0 \end{pmatrix}_L \; ,
\end{aligned}$$

which corresponds to the 27 states in the fundamental representation of E_6.

under $SU(2)$ a triplet goes into a doublet and a singlet

$$3_R \xrightarrow{SU(2)_a} (2, g) + (1, -2g) \ , \tag{4}$$

$$\begin{aligned}(\bar{3}, 1, \bar{3}) =& (u^c, d^c, D^c)_L \longrightarrow (\bar{3}, 1, \bar{2}, -1/6) \oplus (\bar{3}, 1, 1, 1/3) \\ =& \begin{cases} (u^c, d^c)_L \oplus D^c_L \ , & X = I \ , \\ (D^c, d^c)_L \oplus u^c_L \ , & X = U \ , \\ (u^c, D^c)_L \oplus d^c_L \ , & X = V \ . \end{cases}\end{aligned}$$

The 331 flipped models

For the $[SU(3)]^3$ group the interaction Lagrangian is

$$
\begin{aligned}
-\mathcal{L}_I =& g_L J^I_{L3\mu} A^{I\mu}_{L3} + g_L J^I_{L8\mu} A^{I\mu}_{L8} + g_R J^X_{R3\mu} A^{X\mu}_{R3} + g_R J^X_{R8\mu} A^{X\mu}_{R8} \\
=& g_L J^I_{L3\mu} A^{I\mu}_{L3} + g' J_{Y\mu} B^{\mu} + g_2 J_{2\mu} Z'^{\mu} + g_3 J_{3\mu} Z''^{\mu} \ . \qquad (5)
\end{aligned}
$$

$$
\begin{pmatrix} A_\mu \\ Z_\mu \\ Z'_\mu \\ Z''_\mu \end{pmatrix} = \mathcal{W} \cdot \mathcal{O}^T \begin{pmatrix} A^I_{L3\mu} \\ A^I_{L8\mu} \\ A^X_{R8\mu} \\ A^X_{R3\mu} \end{pmatrix} , \qquad (6)
$$

For these lagrangians we found identical electroweak charges for the three flipped models. As we showed in our work this result is a consequence of the equivalence of the Lagrangians under a $SU(3)_R$ rotation.

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We screwed up the calculation?

The vector boson masses came from

$$\mathcal{L}_K = \sum_{i=1,2} \mathrm{Tr}\left[D_\mu \Phi_i (D^\mu \Phi_i)^\dagger\right] |_{\Phi_i = \langle \Phi_i \rangle} \ ,$$

$$= \frac{1}{2}\mathcal{A}^T \cdot \mathcal{M} \cdot \mathcal{A}; \tag{7}$$

which is invariant under gauge transformations. The covariant derivative is given by:

$$D_\mu \Phi = \partial_\mu \Phi - \frac{i}{2}\left(g_L \lambda^a A^a_{\mu L}\Phi - g_R \Phi \lambda^a A^a_{\mu R}\right) \ , \tag{8}$$

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The null space of the mass matrix $\mathcal{M}$ is

$$\mathcal{A}^{\mu}_{\text{null}} = \mathcal{N}\left(\frac{1}{g_L}, \quad \frac{1}{\sqrt{3}g_L}, \quad \frac{1}{\sqrt{3}g_R}, \quad \frac{1}{g_R}\right) A^{\mu}(x) \ , \tag{9}$$

where $A^{\mu}(x)$ is an arbitrary vector field which, as we will see later, corresponds to the photon, and $\mathcal{N}$ is an arbitrary normalization. An important cross-check is to verify that

$$\left(\mathcal{W}\cdot\mathcal{O}^{T}\right)^{-1}\begin{pmatrix} A_\mu \\ 0 \\ 0 \\ 0 \end{pmatrix} = \mathcal{N}\begin{pmatrix} \frac{1}{g_L} \\ \frac{1}{\sqrt{3}g_L} \\ \frac{1}{\sqrt{3}g_R} \\ \frac{1}{g_R} \end{pmatrix} A_\mu, \tag{10}$$

it works for all the vector fields,i.e., Z_μ,Z'_μ and Z''_μ,

an extra bonus

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For any Higgs potential and any $SU(N) \otimes SU(M) \otimes SU(P) \cdots$ gauge group there is a null vector for the mass matrix M^{ab} of the neutral gauge vector bosons, with components

$$A^a_\mu = \frac{c^a}{g^a} A(x)_\mu \tag{11}$$

where the c^a are the coefficients of the group generators in the charge operator, *i*.e.,

$$Q = c^a T^a, \tag{12}$$

the g^a is the coupling strength associated with the A^a_μ vector field and $A(x)_\mu$ must be identified with the photon field.

Flipped versions for the left-right symmetric model

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The neutral current Lagrangians for these models are

$$
\begin{aligned}
-\mathcal{L}_{NC} =& g_L J^I_{L3\mu} A^{I\mu}_{L3} + g_R J^X_{R3\mu} A^{X\mu}_{R3} + g^X_{BL} J^X_{BL\mu} A^{X\mu}_{BL} \\
=& g_L J^I_{L3\mu} A^{I\mu}_{L3} + g' J_{Y\mu} B^{\mu} + g_2 J_{2\mu} Z'^{\mu}, \; X = I, V \; , \qquad (13) \\
-\mathcal{L}_{NC} =& g_L J^I_{L3\mu} A^{I\mu}_{L3} + g_R J^U_{R8\mu} A^{U\mu}_{R8} + g^U_{BL} J^U_{BL\mu} A^{U\mu}_{BL} \\
=& g_L J^I_{L3\mu} A^{I\mu}_{L3} + g' J_{Y\mu} B^{\mu} + g_2 J_{2\mu} Z'^{\mu} \; , \quad X = U \; . \qquad (14)
\end{aligned}
$$

The expressions for the neutral current associated with the Z' are:

$$\begin{aligned} g_2 J_{2\mu} =& - g_{BL}^X J_{BL\mu}^X \cos\gamma + g_R J_{R3\mu}^X \sin\gamma \\ =& g_L \tan_W \left(\alpha_X J_{R3\mu}^X - \frac{c_X J_{BL\mu}^X}{\alpha_X} \right), \; X = I, V \,, \\ g_2 J_{2\mu} =& - g_{BL}^X J_{BL\mu}^X \cos\delta + g_R J_{R8\mu}^X \sin\delta \\ =& g_L \tan_W \left(\alpha_U J_{R8\mu}^X + \frac{\sqrt{3} J_{BL\mu}^X}{\alpha_U} \right), \; X = U \,, \end{aligned} \tag{15}$$

where

$$\begin{aligned} \alpha_X =& \sqrt{\left(\frac{g_R}{g_L}\right)^2 \cot^2\theta_W - c_X^2} \xrightarrow{[SU(3)]^3} \\ & \frac{1}{\sqrt{4\cos^2\theta_W - 1}} \,, \qquad X = I, V \,, \\ \alpha_U =& \sqrt{\left(\frac{g_R}{g_L}\right)^2 \cot^2\theta_W - 3} \,, \qquad X = U \,. \end{aligned} \tag{16}$$

Z'	$M_{Z'}$ [GeV]		$\sin\theta_{ZZ'}$		
	LHC	EW	$\sin\theta_{ZZ'}$	$\sin\theta_{ZZ'}^{\min}$	$\sin\theta_{ZZ'}^{\max}$
Z_{331G}	2,925	958	-0.00007	-0.0012	0.0009
Z_I^{Tri}	2,492	1,134	0.0003	-0.0006	0.0013
Z_I	2,525	1,204	0.0003	-0.0005	0.0012
Z_{LR}^{Tri}	2,693	1,182	-0.0004	-0.0015	0.0006
Z_{LR}	2,682	998	-0.0004	-0.0013	0.0006
Z_{LRU}	2.588	935	-0.00001	-0.0011	0.0008
Z_{ALR}^{Tri}	2,532	447	-0.0004	-0.0014	0.0007

Table : 95% C.L. lower mass limits on extra Z' bosons for various models from EW precision data and constraints on $\sin\theta_{ZZ'}$ from GAPP package (J. Erler 2009) . For comparison, we show in the second column the 95% LHC constraints at 8 TeV, with a luminosity of 20 fb^{-1}, which have been calculated according to Salazar-Benavides-Ponce and E.R.. In the following columns we give, respectively, the central value and the 95% C.L. lower and upper limits for $\sin\theta_{ZZ'}$.

conclusions

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- In this work we analyzed all the possible embeddings of the 3-3-1 and 3-2-2-1 models present in the $[SU(3)]^3$ gauge group. By considering the weak-U-spin and weak-V-spin symmetries in $SU(3)_R$ besides the usual weak-I-spin symmetry [best known as $SU(2)_R$] we found two flipped versions of the 3-3-1 model, with the particularity that the Z' axial and vector charges are identical for the three spin symmetries; hence, they are not a new source of phenomenological results.
- For the left-right symmetric model we also found two flipped versions one of them not reported in the literature as far as we know. This new model is denoted as Z_{RLU} and it corresponds to a second alternative model of the left-right model Z_{LR} (the first alternative model is Z_{ALR} which is well known in the literature E.Ma 1986). In several respects the Z_{LRU} model is different of Z_{LR} and Z_{ALR}; for example, it is not viable as a low energy effective theory, unless we make it left-right symmetric, which is a typical assumption of the Z_{LR} and Z_{ALR} models.
- By using the LHC experimental results and EW precision data, new limits on the Z' mass $M_{Z'}$ and the mixing angle $\theta_{Z-Z'}$ were imposed.