General Solutions for minimal non-universal Z' gauge bosons

Eduardo Rojas Peña

Collaborators: R. Benavides, L. Muñoz, O. Rodriguez, W.A. Ponce.

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Universidad de Nariño

Outline

- Minimal Models
- solutions to the anomaly equations
- Phenomenological issues in non-universal Z' models.
- Collider and Low energy constraints
- Conclusions

Mínimal Models

- Mínimal Z' models are anomaly free electroweak extensions of the standard model associated with an extra gauge U(1) symmetry, with the same fermion content as the standard model plus three right handed neutrinos.

particle content

particles	spin	$SU(3)_C$	$SU(2)_L$	$U(1)_Y$	$U(1)'$
l_{Li}	1/2	1	2	-1/2	l_i
e_{Ri}	1/2	1	1	-1	e_i
ν_{Ri}	1/2	1	1	0	n_i
q_{Li}	1/2	3	2	+1/6	q_i
u_{Ri}	1/2	3	1	+2/3	u_i
d_{Ri}	1/2	3	1	-1/3	d_i
ϕ_i	0	1	2	1/2	Y_{ϕ_i}

General anomaly equations for a minimal non-universal Z' model.

$$[SU(2)]^2 U(1)' : \; 0 = \Sigma q + \frac{1}{3}\Sigma l,$$

$$[SU(3)]^2 U(1)' : \; 0 = 2\Sigma q - \Sigma u - \Sigma d,$$

$$[\mathrm{grav}]^2 U(1)' : \; 0 = 6\Sigma q - 3(\Sigma u + \Sigma d) + 2\Sigma l - \Sigma n - \Sigma e$$

$$[U(1)]^2 U(1)' : \; 0 = \frac{1}{3}\Sigma q - \frac{8}{3}\Sigma u - \frac{2}{3}\Sigma d + \Sigma l - 2\Sigma e$$

$$U(1)[U(1)']^2 : \; 0 = \Sigma q^2 - 2\Sigma u^2 + \Sigma d^2 - \Sigma l^2 + \Sigma e^2,$$

$$[U(1)']^3 : \; 0 = 6\Sigma q^3 - 3(\Sigma u^3 + \Sigma d^3) + 2\Sigma l^3 - \Sigma n^3 - \Sigma e^3 \; .$$

$$\Sigma f = f_1 + f_2 + f_3.$$

Yukawa interaction terms.

$$\mathcal{L}_Y \supset \bar{l}_{1_L}\tilde{\phi}_1\nu_{1_R} + \bar{l}_{1L}\phi_1 e_{1_R} + \bar{q}_{1_L}\tilde{\phi}_1 u_{1_R} + \bar{q}_{1_L}\phi_1 d_{1_R} +$$
$$\bar{l}_{2_L}\tilde{\phi}_2\nu_{2_R} + \bar{l}_{2L}\phi_2 e_{2_R} + \bar{q}_{2_L}\tilde{\phi}_2 u_{2_R} + \bar{q}_{2_L}\phi_2 d_{2_R} +$$
$$\bar{l}_{3_L}\tilde{\phi}_3\nu_{3_R} + \bar{l}_{3_L}\phi_3 e_{3_R} + \bar{q}_{3_L}\tilde{\phi}_3 u_{3_R} + \bar{q}_{3_L}\phi_3 d_{3_R} + \text{h.c.}$$

Yukawa constraints on the fermion and Higgs charges.

$$
\begin{aligned}
+\phi_i + e_i - l_i &= 0, \\
-\phi_i + n_i - l_i &= 0, \\
+\phi_i + d_i - q_i &= 0, \\
-\phi_i + u_i - q_i &= 0,
\end{aligned}
$$

Anomaly cancellation between fermions in the same family. Type I Solutions. (e.g., B-L)

f	$\epsilon^A(f)$
l_i	$-3q_i$
e_i	$-n_i - 6q_i$
u_i	$n_i + 4q_i$
d_i	$-n_i - 2q_i$

$$\phi_i = n_i + 3q_i .$$

Type II Solutions. (e.g., B-3L_τ)

z

f	$\epsilon^B(f)$
l_i	$+n_i - \Sigma q - \frac{1}{3}\Sigma n$
e_i	$+n_i - 2\Sigma q - \frac{2}{3}\Sigma n$
u_i	$+q_i + \Sigma q + \frac{1}{3}\Sigma n$
d_i	$+q_i - \Sigma q - \frac{1}{3}\Sigma n$

$$Y_{\phi_{123}} = q_1 + q_2 + q_3 + \tfrac{1}{3}(n_1 + n_2 + n_3),$$

Type III Solutions. (e.g., L_i-L_j)

f	$\epsilon^C(f) = Q_{ijk}(f)$
l_i	$-3q_i$
e_i	$-n_i - 6q_i$
u_i	$+n_i + 4q_i$
d_i	$-n_i - 2q_i$
l_j	$+\frac{1}{2}[n_j - n_k - 3(q_j + q_k)]$
e_j	$-n_k - 3(q_j + q_k)$
u_j	$+\frac{1}{2}(n_j + n_k + 5q_j + 3q_k)$
d_j	$-\frac{1}{2}(n_j + n_k + q_j + 3q_k)$
l_k	$+\frac{1}{2}[-n_j + n_k - 3(q_j + q_k)]$
e_k	$-n_j - 3(q_j + q_k)$
u_k	$+\frac{1}{2}(n_j + n_k + 3q_j + 5q_k)$
d_k	$-\frac{1}{2}(n_j + n_k + 3q_j + q_k)$

$$Y_{\phi_1} = n_i + 3q_i \text{ and } Y_{\phi_2} = Y_{\phi_3} = \frac{1}{2}[n_j + n_k + 3(q_j + q_k)],$$

Frequent phenomenological issues:

- Flavor changing Neutral currents.
- Generation of CKM and PMNS mixing matrices.
- Collider and low energy constraints.

Collider constraints.

- In order to avoid collider constraints, it is possible to build a model with zero couplings to the up and down quarks and in general to the fermions of the first family
- That is a lucky choice since it avoids contributions of new physics to the Wilson coefficients C_9 (e) and C_10 (e), which are non-anomalous.

FCNC

- For the flavor violating Z' charges of the left-handed up and down quarks, these constraints can be avoided by choosing the left-handed coupling q 1 of the quark doublet of the first generation (u_L , d_L) to be identical to the corresponding charge q_2 of the doublet in the second generation (c_L , s_L)
- It is possible to solve to avoid Flavor Changing Neutral Currents Constraints by setting the Z-Z' mixing angle equal to zero.

there is a contribution to the Z-Z' mixing angle from the Higgs sector.

$$\theta_{Z-Z'} = C g_2 M_Z^2 / (g_1 M_{Z'}^2).$$

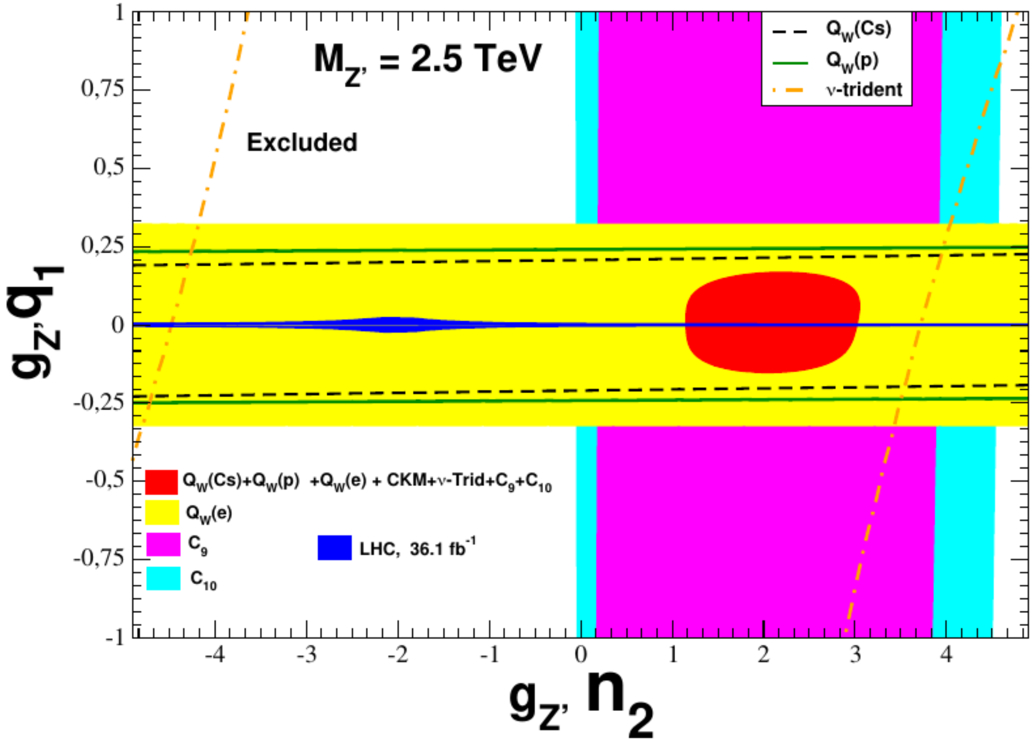
$$C = + \frac{0.03975(v_{23}^2)}{2(v_1^2 + v_{23}^2)},$$

$$\theta_{Z'-Z} \sim 4 \times 10^{-5}.$$

Low energy observables

$\mathcal{O}$	Value [63, 67, 71]	SM prediction $\mathcal{O}_{\rm SM}$ [63]	$\Delta\mathcal{O} = \mathcal{O} - \mathcal{O}_{\rm SM}$
$Q_W(p)$	0.0719 ± 0.0045	0.0708 ± 0.0003	$4\left(\frac{M_Z}{g_1 M_{Z'}}\right)^2 \Delta_A^{ee}\left(2\Delta_V^{uu} + \Delta_V^{dd}\right)$
$Q_W(\mathrm{Cs})$	-72.62 ± 0.43	-73.25 ± 0.02	$Z\Delta Q_W(p) + N\Delta Q_W(n)$
$Q_W(e)$	-0.0403 ± 0.0053	-0.0473 ± 0.0003	$4\left(\frac{M_Z}{g_1 M_{Z'}}\right)^2 \Delta_A^{ee}\Delta_V^{ee}$
$1 - \sum_{q=d,s,b} \|V_{uq}\|^2$	$1 - 0.9999(6)$	0	$\frac{3}{4\pi^2}\frac{M_W^2}{M_{Z'}^2}\left(\ln\frac{M_{Z'}^2}{M_W^2}\right)\Delta_L^{\mu\mu}\left(\Delta_L^{\mu\mu} - \Delta_L^{dd}\right)$
$C_9^{\rm NP}(\mu)$	$-1.29^{+0.21}_{-0.20}$	0	$-\frac{1}{g_1^2 M_{Z'}^2}\frac{\Delta_L^{sb}\Delta_V^{\mu\bar{\mu}}}{V_{ts}^* V_{tb}\sin^2\theta_W}$
$C_{10}^{\rm NP}(\mu)$	$+0.79^{+0.26}_{-0.24}$	0	$-\frac{1}{g_1^2 M_{Z'}^2}\frac{\Delta_L^{sb}\Delta_A^{\mu\bar{\mu}}}{V_{ts}^* V_{tb}\sin^2\theta_W}$
$\frac{\sigma^{\rm SM+Z'}}{\sigma_{SM}}$	0.83 ± 0.18	1	$\frac{1+\left(1+4s_W^2+\Delta_V^{\mu\mu}\Delta_L^{\nu\nu}v^2/M_{Z'}^2\right)^2}{1+(1+4s_W^2)^2} - 1$

95% allowed regions



particular solution consistent with the LHC and Low energy constraints.

$M_{Z'} = 2.5$ TeV	$i = 1$	$i = 2$	$i = 3$
$g_{Z'} l_i$	0	1.1875	-2.9875
$g_{Z'} e_i$	0	0.3749	-3.8001
$g_{Z'} n_i$	0	2.0001	-2.1749
$g_{Z'} q_i$	0	0	0.6000
$g_{Z'} u_i$	0	0.8126	1.4126
$g_{Z'} d_i$	0	-0.8126	-0.2126
$g_{Z'} \phi_i$	0	0.8126	

	$\mathrm{Pull}^i = \frac{\mathcal{O}^i_{\mathrm{exp}} - \mathcal{O}^i_{\mathrm{th}}}{\sqrt{\sigma^{i2}_{\mathrm{exp}} + \sigma^{i2}_{\mathrm{th}}}}$							
$\mathcal{O}^i$	$Q_W(p)$	$Q_W(\mathrm{Cs})$	$Q_W(e)$	CKM	C_9	C_{10}	ν-Trident	χ^2_{min}
	0.244	1.46	1.38	-1.10	-0.575	0.700	-1.00	7.13

Conclusions

- In this work we presented an anomaly-free non-universal Z' family of models, which only includes SM fermions plus right-handed neutrinos and two Higgs doublets.
- Our solutions have three families with different charges for every family, \ie the model is non-universal; however, a priori it is not possible to identify one of them with a particular family in the SM; hence, it is necessary a study of the phenomenology of all the possibilities.
- By means of an explicit example, we show that it is possible to build a model with zero couplings to the up and down quarks and in general to the fermions of the first family, in such a way that the model evades collider constraints and does not contribute to the corresponding the Wilson coefficients $C_9(e)$ and $C_{10}(e)$. Simultaneously, our solution is flexible enough to accommodate the flavor anomalies in the Wilson coefficients $C_9(\mu)$ and $C_{10}(\mu)$. By requiring that the left-handed couplings of the down and strange couplings be identical it is possible to avoid FCNC.