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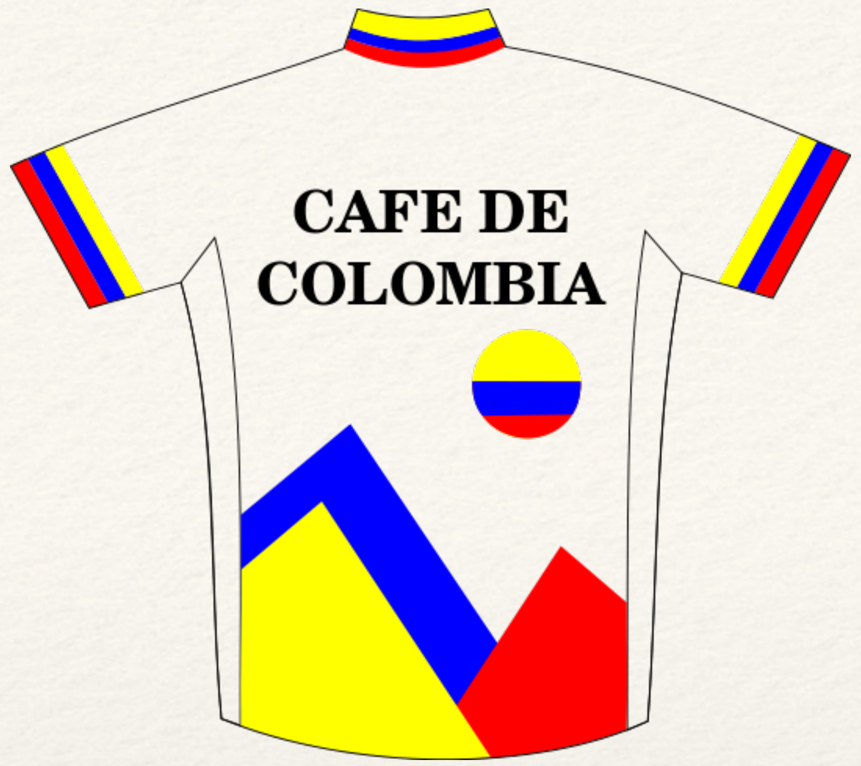

Dynamical Symmetry Breaking and Fermion Mass Hierarchy in the Scale-Invariant 3-3-1 Model

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331 models

$$SU(3)_C \times SU(2)_L \times U(1)_Y \to SU(3)_C \times SU(3)_L \times U(1)_X$$

SM gauge group → 331 gauge group

$$Q = T_3 + \beta T_8 + X,$$

$\beta = 1/\sqrt{3}, \sqrt{3}$

Electric charge operator

Interesting features of the 331 models:

- dark matter,
- neutrino mass generation and mixing,
- the strong CP problem, and
- the number of the fermion families.

Some difficulties in the 331 models

These models:

- Don’t solve the mass hierarchy problem in the SM.
- Have a scalar sector with a much larger number of scalar fields. At least more SU(3) triplets are necessary in the simplest versions.
- Have more arbitrary parameters in the model. This provides less predictability.
- Have more arbitrary energy scale.

A scale-invariant 331 model: matter content

Matter content shared with other 331 models

Charged leptons

$$\psi_{iL} = (\nu_i, e_i, E_i)_L^T \sim (\mathbf{1}, \mathbf{3}, -2/3), \qquad e_{sR} \sim (\mathbf{1}, \mathbf{1}, -1),$$

Quarks

$$Q_{aL} = (d_a, -u_a, U_a)_L^T \sim (\mathbf{3}, \mathbf{3}^*, 1/3),$$
$$Q_{3L} = (u_3, d_3, D)_L^T \sim (\mathbf{3}, \mathbf{3}, 0),$$
$$d_{nR} \sim (\mathbf{3}, \mathbf{1}, -1/3), \qquad u_{mR} \sim (\mathbf{3}, \mathbf{1}, 2/3),$$

Scalar triplets

$$\rho = (\rho_1^0, \rho_2^-, \rho_3^-)^T \sim (\mathbf{1}, \mathbf{3}, -2/3),$$
$$\chi = (\chi_1^+, \chi_2^0, \chi_3^0)^T \sim (\mathbf{1}, \mathbf{3}, 1/3).$$

A scale-invariant 331 model: additional matter

New matter content

New charged leptons

$$\Psi_{iL,R} = (\mathcal{E}_i^+, N_{1i}, N_{2i})_{L,R}^T \sim (\mathbf{1},\mathbf{3},1/3), \qquad \nu_{iR} \sim (\mathbf{1},\mathbf{1},0),$$

New quarks

$$K_{aL,R} = (\mathcal{A}_a^{(5/3)}, \mathcal{U}_{1a}, \mathcal{U}_{2a})_{L,R}^T \sim (\mathbf{3},\mathbf{3},1),$$
$$K_{3L,R} = (\mathcal{B}^{(-4/3)}, -\mathcal{D}_1, \mathcal{D}_2)_{L,R}^T \sim (\mathbf{3},\mathbf{3}^*,-2/3),$$

Scalar singlet

$$\varphi \sim (\mathbf{1},\mathbf{1},0),$$

Gauge symmetry breaking pattern

$$SU(3)_C \otimes SU(3)_L \otimes U(1)_X \xrightarrow{\langle\chi_3^0\rangle = w/\sqrt{2}} SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \xrightarrow{\langle\rho_1^0\rangle = v/\sqrt{2}} SU(3)_C \otimes U(1)_Q,$$

A scale-invariant 331 model: gauge sector

Gauge bosons

Non-hermitian gauge bosons

$$W_\mu^\pm = \frac{W_{1\mu} \mp iW_{2\mu}}{\sqrt{2}}, \qquad V_\mu^\pm = \frac{W_{4\mu} \mp iW_{5\mu}}{\sqrt{2}},$$
$$V_\mu^{0(\dagger)} = \frac{W_{6\mu} \mp iW_{7\mu}}{\sqrt{2}},$$

Masses

$$m_{W^\pm}^2 = \frac{g^2 v^2}{4}, \qquad m_{V^\pm}^2 = \frac{g^2}{4}(v^2 + w^2), \qquad m_{V^0}^2 = \frac{g^2}{4} w^2.$$

Neutral gauge bosons

$$A^\mu = \frac{\sqrt{3}}{\sqrt{3+4t^2}}\left(tW_3^\mu + \frac{t}{\sqrt{3}}W_8^\mu + B^\mu\right),$$
$$Z_1^\mu = N_{Z_2}(-3m_{Z_2}^2 W_3^\mu + \sqrt{3}(3m_{Z_2}^2 - g^2w^2)W_8^\mu + g^2w^2tB^\mu),$$
$$Z_2^\mu = N_{Z_1}(-3m_{Z_1}^2 W_3^\mu + \sqrt{3}(3m_{Z_1}^2 - g^2w^2)W_8^\mu + g^2w^2tB^\mu),$$

$$t^2 = \frac{g_X^2}{g^2} = \frac{\sin^2\theta_W}{1 - \frac{4}{3}\sin^2\theta_W},$$

Masses

$$m_{Z_1}^2 = \frac{g^2 v^2}{4\cos^2\theta_W} + \mathcal{O}\left(\frac{v^2}{w^2}\right),$$
$$m_{Z_2}^2 = \frac{g^2\cos^2\theta_W w^2}{3 - 4\sin^2\theta_W} + \mathcal{O}\left(\frac{v^2}{w^2}\right).$$

Some predictions

$$m_{V^\pm}^2 - m_{V^0}^2 = m_{W^\pm}^2 \quad \text{and}$$
$$\frac{m_{Z_2}^2}{m_{V^0}^2} = \frac{\cos^2\theta_W}{\frac{3}{4} - \sin^2\theta_W} + \mathcal{O}\left(\frac{v^2}{w^2}\right) \approx 1.48,$$

With $\sin^2\theta_W \simeq 0.231.$

A scale-invariant 331 model: extra symmetries

Extra symmetries:

- Scale invariance and,

TABLE I. Field charges under the Z_8 symmetry.

	ψ_{iL}	e_{iR}	E_{iR}	ν_{iR}	Q_{aL}	Q_{3L}	u_{iR}	U_{aR}	d_{iR}	D_R	Ψ_{iL}	Ψ_{iR}	K_{aL}	K_{aR}	K_{3L}	K_{3R}	ρ	χ	φ
Z_8	1	6	0	7	2	3	1	3	4	2	6	4	2	0	3	5	2	1	2

This discrete symmetry allows that fermion mass matrices have a see-saw texture

Why are the extra fermions necessary?

Without them we have that:

$$M_{\mathbf{E}} = \frac{w}{\sqrt{2}}\begin{pmatrix} 0 & 0 \\ y^e & y^E \end{pmatrix},$$

Charged lepton mass matrix.

Up-quark mass matrix.

$$M_{\mathbf{U}} = \frac{1}{\sqrt{2}}\begin{pmatrix} 0_{[2\times2]} & 0_{[2\times1]} & 0_{[2\times2]} \\ h^u_{[1\times2]}v & h^{u_3}v & h^U_{[1\times2]}v \\ y^a_{[2\times2]}w & y^{u_3}_{[2\times1]}w & y^U_{[2\times2]}w \end{pmatrix},$$

Down-quark mass matrix.

$$M_{\mathbf{D}} = \frac{1}{\sqrt{2}}\begin{pmatrix} h^d_{[2\times2]}v & h^{d_3}_{[2\times1]}v & h^D_{[2\times1]}v \\ 0_{[1\times2]} & 0 & 0 \\ y^d_{[1\times2]}w & y^{d_3}w & y^D w \end{pmatrix},$$

These fermions are massless at all order of the perturbation theory because their masses are protected by accidental symmetries.

The introduction of the extra fermion fields break these symmetries because of the operators such as

$$\overline{\Psi^c_R}\rho^* e_R,\ \overline{\psi_L}\Psi^c_L\chi^*,\ \overline{Q_L}K_R\rho, \qquad \overline{Q_{3L}}K_{3R}\rho^*,$$

Scalar sector

With the scalar

$$\rho^T = \left(\frac{S_1 + iA_1}{\sqrt{2}}, \rho_2^-, \rho_3^-\right);$$

$$\chi^T = \left(\chi_1^+, \frac{S_2 + iA_2}{\sqrt{2}}, \frac{S_3 + iA_3}{\sqrt{2}}\right); \qquad \varphi = \frac{S_\varphi + iA_\varphi}{\sqrt{2}}.$$

Tree-level scalar potential

$$\begin{aligned} V_0 = {} & \lambda_\rho(\rho^\dagger\rho)^2 + \lambda_\chi(\chi^\dagger\chi)^2 + \lambda_{\rho\chi}\rho^\dagger\rho\chi^\dagger\chi \\ & + \lambda'_{\rho\chi}\rho^\dagger\chi\chi^\dagger\rho + \lambda_{\rho\varphi}\rho^\dagger\rho\varphi^*\varphi + \lambda_{\chi\varphi}\chi^\dagger\chi\varphi^*\varphi \\ & + \lambda_\varphi(\varphi^*\varphi)^2 - |\lambda'_\varphi|(\varphi^4 + \varphi^{*4}). \end{aligned}$$

Applying the copositivity criterium, the positivity of the hermitian matrix and the scalar masses we have

$$\lambda_\rho \geq 0, \qquad \lambda_\chi \geq 0, \qquad \lambda_\varphi - 2|\lambda'_\varphi| \geq 0, \qquad \det \mathbf{\Lambda}_0 \geq 0,$$

$$-2\sqrt{\lambda_\rho\lambda_\chi} \leq \lambda_{\rho\chi} \leq 2\sqrt{\lambda_\rho\lambda_\chi}, \qquad -2\sqrt{\lambda_\rho(\lambda_\varphi - 2|\lambda'_\varphi|)} \leq \lambda_{\rho\varphi} \leq 2\sqrt{\lambda_\rho(\lambda_\varphi - 2|\lambda'_\varphi|)},$$

$$-2\sqrt{\lambda_\chi(\lambda_\varphi - 2|\lambda'_\varphi|)} \leq \lambda_{\chi\varphi} \leq 2\sqrt{\lambda_\chi(\lambda_\varphi - 2|\lambda'_\varphi|)}.$$

Flat direction

Following the Gildener-Weinberg method, we find, first, the flat direction

Condition for the flat direction

(i) $\nabla_{\mathbf{N}} V_0(\mathbf{N})|_{\mathbf{N}=\mathbf{n}} = 0$

(ii) $V_0(\mathbf{n}) = 0.$

$\mathrm{P}|_{\mathbf{N}=\mathbf{n}} = \nabla_{\mathbf{N}} \nabla_{\mathbf{N}}^T V_0(\mathbf{N})|_{\mathbf{N}=\mathbf{n}}$

$$\lambda_{\chi\varphi}|_{\mu_0} = \frac{\lambda_{\rho\varphi}\lambda_{\rho\chi} \pm \sqrt{(\lambda_{\rho\varphi}^2 - 4\lambda_\rho(\lambda_\varphi - 2|\lambda'_\varphi|))(\lambda_{\rho\chi}^2 - 4\lambda_\rho\lambda_\chi)}}{2\lambda_\rho}.$$

Flat directions

$$n_\rho^2 = \frac{-\lambda_{\chi\varphi}(\lambda_{\rho\varphi} + \lambda_{\rho\chi}) + 2\lambda_\chi(\lambda_{\rho\varphi} - 2(\lambda_\varphi - 2|\lambda'_\varphi|)) + 2\lambda_{\rho\chi}(\lambda_\varphi - 2|\lambda'_\varphi|) + \lambda_{\chi\varphi}^2}{\mathrm{den}},$$

$$n_\chi^2 = \frac{2\lambda_\rho(\lambda_{\chi\varphi} - 2(\lambda_\varphi - 2|\lambda'_\varphi|)) - \lambda_{\rho\varphi}(\lambda_{\rho\chi} + \lambda_{\chi\varphi}) + 2\lambda_{\rho\chi}(\lambda_\varphi - 2|\lambda'_\varphi|) + \lambda_{\rho\varphi}^2}{\mathrm{den}},$$

$$n_\varphi^2 = \frac{2\lambda_\rho(\lambda_{\chi\varphi} - 2\lambda_\chi) - \lambda_{\rho\chi}(\lambda_{\rho\varphi} + \lambda_{\chi\varphi}) + 2\lambda_{\rho\varphi}\lambda_\chi + \lambda_{\rho\chi}^2}{\mathrm{den}},$$

Where

$$\begin{aligned}\mathrm{den} \equiv &-4\lambda_\rho(\lambda_\varphi + \lambda_\chi - \lambda_{\chi\varphi} - 2|\lambda'_\varphi|) - 2\lambda_{\rho\chi}(\lambda_{\rho\varphi} + \lambda_{\chi\varphi} + 4|\lambda'_\varphi|) \\ &- 4\lambda_\chi(-\lambda_{\rho\varphi} + \lambda_\varphi - 2|\lambda'_\varphi|) + (\lambda_{\rho\varphi} - \lambda_{\chi\varphi})^2 + \lambda_{\rho\chi}^2 + 4\lambda_{\rho\chi}\lambda_\varphi.\end{aligned}$$

Scalar sector

Charged scalar

$$H^{\pm} = \frac{1}{\sqrt{v^2 + w^2}}(w\rho_3^{\pm} + v\chi_1^{\pm}),$$

$$m_{H^{\pm}}^2 = \frac{\lambda'_{\rho\chi}}{2}(v^2 + w^2),$$

CP-odd

$$m_{A_\varphi}^2 = 8|\lambda'_\varphi| v_\varphi^2.$$

CP -even scalars

$$h \simeq \frac{1}{N_h}\left[S_1 + \frac{\lambda_{\rho\varphi}}{\lambda_{\rho\chi} - \lambda_{\rho\varphi}}\frac{v}{w}S_3 - \frac{v}{v_\varphi}S_\varphi\right],$$

$$H \simeq \frac{1}{N_H}\left[\frac{\lambda_\chi}{\lambda_{\rho\chi} - \lambda_{\rho\varphi}}\frac{v}{w}S_1 + S_3 - \frac{w}{v_\varphi}S_\varphi\right],$$

$$m_h^2 = \lambda_\rho v^2 + (\lambda_\varphi - 2|\lambda'_\varphi|)v_\varphi^2 + \lambda_\chi w^2 - m_\Delta^2,$$

$$m_H^2 = \lambda_\rho v^2 + (\lambda_\varphi - 2|\lambda'_\varphi|)v_\varphi^2 + \lambda_\chi w^2 + m_\Delta^2,$$

Scalon: NG boson of the scale-invariance symmetry

$$S = \frac{1}{\sqrt{v^2 + w^2 + v_\varphi^2}}[vS_1 + wS_3 + v_\varphi S_\varphi].$$

$$m_S^2 = 8B\langle\phi_r\rangle^2,$$

One-loop mass

One-loop effective potential

$$V_{1-\text{loop}}(\phi_r \mathbf{n}) = A\phi_r^4 + B\phi_r^4 \ln\left(\frac{\phi_r^2}{\mu_0^2}\right),$$

$$A = \frac{1}{64\pi^2\langle\phi_r\rangle^4}\left[\sum_{\mathcal{S}} n_{\mathcal{S}} m_{\mathcal{S}}^4\left(\ln\frac{m_{\mathcal{S}}^2}{\langle\phi_r\rangle^2} - \frac{3}{2}\right) + 3\sum_{\mathcal{V}} n_{\mathcal{V}} m_{\mathcal{V}}^4\left(\ln\frac{m_{\mathcal{V}}^2}{\langle\phi_r\rangle^2} - \frac{5}{6}\right) - 4\sum_{\mathcal{F}} n_{\mathcal{C}} n_{\mathcal{M}} \mathrm{Tr}\left[M_{\mathcal{F}}^4\left(\ln\frac{M_{\mathcal{F}}^2}{\langle\phi_r\rangle^2} - 1\right)\right]\right],$$

$$B = \frac{1}{64\pi^2\langle\phi_r\rangle^4}\left[\sum_{\mathcal{S}} n_{\mathcal{S}} m_{\mathcal{S}}^4 + 3\sum_{\mathcal{V}} n_{\mathcal{V}} m_{\mathcal{V}}^4 - 4\sum_{\mathcal{F}} n_{\mathcal{C}} n_{\mathcal{M}} \mathrm{Tr}[M_{\mathcal{F}}^4]\right],$$

One-loop effective potential

Using

$$0 = \left[\frac{\partial V_{1-\text{loop}}(\phi_r \mathbf{n})}{\partial \phi_r}\right]_{\langle\phi_r\rangle}.$$

→

$$\langle\phi_r\rangle = \mu_0 \exp\left[-\frac{1}{4} - \frac{A}{2B}\right],$$

$$V_{1-\text{loop}}(\phi_r \mathbf{n}) = B\phi_r^4\left[\ln\left(\frac{\phi_r^2}{\langle\phi_r\rangle^2}\right) - \frac{1}{2}\right],$$

→

$$B > 0$$

$$B = \frac{1}{64\pi^2\langle\phi_r\rangle^4}\left[\sum_{\mathcal{S}} n_{\mathcal{S}} m_{\mathcal{S}}^4 + 3\sum_{\mathcal{V}} n_{\mathcal{V}} m_{\mathcal{V}}^4 - 4\sum_{\mathcal{F}} n_{\mathcal{C}} n_{\mathcal{M}} \mathrm{Tr}[M_{\mathcal{F}}^4]\right],$$

Working in the approximation

$$v \ll w \ll v_\varphi (\simeq \langle\phi_r\rangle).$$

Fermion spectrum: neutrinos

Yukawa Lagrangian of the leptons

$$\mathcal{L}_l = y^E_{ij}\overline{\psi_{iL}}\chi E_{jR} + h^\nu_{ij}\overline{\psi_{iL}}\rho\nu_{jR} + h^e_{ij}\overline{\Psi^c_{iR}}\rho^* e_{jR} + y_{ij}\overline{\psi_{iL}}\Psi^c_{jL}\chi^* + \frac{f^\nu_{ij}}{2}\varphi\overline{\nu^c_{iR}}\nu_{jR} + f^\Psi_{ij}\varphi\overline{\Psi_{iL}}\Psi_{jR} + \text{H.c.}, \tag{38}$$

Basis

$$\tilde{\mathbf{N}}_L \equiv (\nu_L, \nu^c_R, N_{1L}, N^c_{1R})^T$$

Type-I See-saw texture

$$M_{\tilde{\mathbf{N}}} = \begin{pmatrix} 0 & M_D^T \\ M_D & M_\varphi \end{pmatrix}$$

With

$$M_D = \frac{1}{\sqrt{2}}\begin{pmatrix} h^\nu v & yw & 0 \end{pmatrix}^T \quad \text{and}$$

$$M_\varphi = \frac{v_\varphi}{\sqrt{2}}\begin{pmatrix} f^\nu & 0 & 0 \\ 0 & 0 & f^\Psi \\ 0 & f^{\Psi T} & 0 \end{pmatrix}.$$

$$M_{N_2} = \frac{v_\varphi}{\sqrt{2}} f^\Psi.$$

Fermion spectrum: charged leptons

Basis

$(e, \mathcal{E}^{+c})^T_{L(R)}$

Type-I See-saw texture

$$M_{\tilde{\mathbf{E}}} = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & -yw \\ h^e v & f^\Psi v_\varphi \end{pmatrix},$$

Masses

$$M_E = \frac{w}{\sqrt{2}} y^E,$$

$$M^2_{E'} \simeq \frac{v^2_\varphi}{2} f^\Psi f^{\Psi\dagger}$$

$$M^2_{e'} \simeq \frac{v^2 w^2}{2 v^2_\varphi} y (f^\Psi)^{-1} h^e [y (f^\Psi)^{-1} h^e]^\dagger$$

All of the fermion mass matrices have the same type-I see-saw texture

RESIDUAL SYMMETRY AND PHENOMENOLOGICAL IMPLICATIONS

U(1) generator

$$\mathcal{G} = -4T_3 + 2\sqrt{3}T_8 + N,$$

TABLE II. Field charges under the $U(1)_N$ and $U(1)_{\mathcal{G}}$ symmetries. The fields not shown above do not carry charges under these symmetries.

	ψ_{iL}	e_{iR}	E_{iR}	Q_{aL}	Q_{3L}	u_{iR}	U_{aR}	d_{iR}	D_R	$\Psi_{iL,R}$	$K_{aL,R}$	$K_{3L,R}$	ρ	χ	W^+_μ	V^+_μ	V^0_μ
$U(1)_N$	1	4	−1	2	0	−1	4	3	−2	−3	1	1	1	2	0	0	0
$U(1)_{\mathcal{G}}$	$\begin{pmatrix}0\\4\\-1\end{pmatrix}$	4	−1	$\begin{pmatrix}3\\-1\\4\end{pmatrix}$	$\begin{pmatrix}-1\\3\\-2\end{pmatrix}$	−1	4	3	−2	$\begin{pmatrix}-4\\0\\-5\end{pmatrix}$	$\begin{pmatrix}0\\4\\-1\end{pmatrix}$	$\begin{pmatrix}2\\-2\\3\end{pmatrix}$	$\begin{pmatrix}0\\4\\-1\end{pmatrix}$	$\begin{pmatrix}1\\5\\0\end{pmatrix}$	−4	1	5

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TABLE III. Field charges under $U(1)_{\mathcal{G}'}$ and its parity subgroup $\mathcal{P} = (-1)^{\mathcal{G}'}$. The fields not displayed here transform trivially under these symmetries.

	ψ_{iL}	e_{iR}	E_{iR}	Q_{aL}	Q_{3L}	u_{iR}	U_{aR}	d_{iR}	D_R	$\Psi_{iL,R}$	$K_{aL,R}$	$K_{3L,R}$	ρ	χ	W^+_μ	V^+_μ	V^0_μ
$U(1)_{\mathcal{G}'}$	$\begin{pmatrix} 0 \\ 4 \\ -1 \end{pmatrix}$	4	−1	$\begin{pmatrix} 2 \\ -2 \\ 3 \end{pmatrix}$	$\begin{pmatrix} -2 \\ 2 \\ -3 \end{pmatrix}$	−2	3	2	−3	$\begin{pmatrix} -4 \\ 0 \\ -5 \end{pmatrix}$	$\begin{pmatrix} -1 \\ 3 \\ -2 \end{pmatrix}$	$\begin{pmatrix} 1 \\ -3 \\ 2 \end{pmatrix}$	$\begin{pmatrix} 0 \\ 4 \\ -1 \end{pmatrix}$	$\begin{pmatrix} 1 \\ 5 \\ 0 \end{pmatrix}$	−4	1	5
$\mathcal{P}$	$\begin{pmatrix} + \\ + \\ - \end{pmatrix}$	+	−	$\begin{pmatrix} + \\ + \\ - \end{pmatrix}$	$\begin{pmatrix} + \\ + \\ - \end{pmatrix}$	+	−	+	−	$\begin{pmatrix} + \\ + \\ - \end{pmatrix}$	$\begin{pmatrix} - \\ - \\ + \end{pmatrix}$	$\begin{pmatrix} - \\ - \\ + \end{pmatrix}$	$\begin{pmatrix} + \\ + \\ - \end{pmatrix}$	$\begin{pmatrix} - \\ - \\ + \end{pmatrix}$	+	−	−

Generators

$$\mathcal{G}' = \mathcal{G} - 3\mathbf{B},$$

$$\mathcal{P} = (-1)^{\mathcal{G}'}$$

RESIDUAL SYMMETRY AND PHENOMENOLOGICAL IMPLICATIONS

Dark matter candidates

N_2 and V^0

But,

$$m_{N_2}(v_\varphi) \gg m_{V^0}(w)$$

So, V^0 is the lightest $\mathscr{P}$-odd particle.

$$\langle \sigma v_{\rm rel} \rangle_{v\to 0} \simeq \frac{5\alpha^2 m_X^2}{8 s_W^4 m_W^4}.$$

$$\Omega_X h^2 \simeq \frac{0.1 \text{ pb}}{\langle \sigma_{\rm tot} v_{\rm rel} \rangle} < \frac{0.1 \text{ pb}}{\langle \sigma v_{\rm rel} \rangle}$$
$$\simeq 0.0024 \times \left(\frac{m_W}{m_X}\right)^2 < 0.00008,$$

RESIDUAL SYMMETRY AND PHENOMENOLOGICAL IMPLICATIONS

Some signal in colliders

$$
\begin{aligned}
pp \to D\bar{D} &\to bV^0\bar{b}V^{0\dagger}, \\
&\to bV^0\bar{t}V^+ \to bV^0\bar{t}t\bar{b}V^{0\dagger}, \\
&\to tV^-\bar{b}V^{0\dagger} \to t\bar{t}bV^0\bar{b}V^{0\dagger}, \\
&\to tV^-\bar{t}V^+ \to t\bar{t}bV^0\bar{t}t\bar{b}V^{0\dagger},
\end{aligned}
$$

RESIDUAL SYMMETRY AND PHENOMENOLOGICAL IMPLICATIONS

TABLE IV. Mass benchmarks for the particles at the 3-3-1 scale $w = 10$ TeV. See the text for details.

	H	$H^\pm$	V^0_μ	$V^\pm_\mu$	$Z_{2\mu}$	E_i, U_a, D
Mass (GeV)	800	3500	3264	3265	3974	3535

Conclusions

- We have proposed the minimal scale invariant 3-3-1 model, based on the $SU(3)_C \times SU(3)_L \times U(1)_X$ symmetry and scale invariance with the simplest scalar potential for this type of models.

- Together with the gauge and scale symmetries, the Z_8 symmetry makes evident the seesaw texture in most of the fermion mass matrices provided that $v_\varphi >> w >> v$. This point is useful to mitigate possible phenomenological issues associated with flavor changing neutral currents because, in this case, the suppressed mixing between light and heavy fermions are proportional to $v/v_\varphi, w * v/v_\varphi^2$.

- Interestingly, once the seesaw mechanism takes place, the heavy masses of the extra fermions, proportional to v_φ, suppress the masses of some of the standard ones providing thus an explanation for the mass hierarchy between the third and first two families.