Multi-Higgs aspect of 3-3-1 models

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outline

- Introduction
- 3-3-1 models
- m331 and HL331
  - The scalar sector
  - fermions
    - leptons
    - quarks
  - Gauge fields
- Predictions of the models
- Reduction to the SM
- Phenomenological aspects
- Conclusions

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Almost all the interesting extensions of the standard model (SM) include extra scalar multiplets: a real [Hill 1987, Davoudiasl 2004], or complex [Chikasige 1980] scalar singlet, one or more extra doublets [Branco 2011, this workshop], Hermitian [Brdar 2013] or non-Hermitian triplet [Cheng1980], single charged h^+ [Zee1980,1985] or doubly charged singlet k^{++} [Babu 1988], exotic doublet $(\phi^{++}\,\phi^+)^T$ [Law 2013],

.

Some of them appear in models which extend the electroweak gauge symmetry to $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$, called by short 3-3-1 models

3-3-1 models

- Models with $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ gauge symmetry broken in two steps.
-

$$
\begin{aligned}
SU(3)_C \otimes SU(3)_L \otimes U(1)_X \quad & \xrightarrow{v_\chi} \quad SU(3)_C \otimes SU(2)_L \otimes U(1)_Y \\
& \xrightarrow{v_\eta, v_\rho, v_{\sigma_2}} \quad SU(3)_C \otimes U(1)_{em} \qquad (1)
\end{aligned}
$$

- There are several representation contents

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- There are several representation contents

m331 and HL331

- Two triplets are the minimal number to break the 331 symmetry down to 321 symmetry: χ and one of η, ρ and σ_2. Fermion masses require the other two.
- Three neutral gauge bosons A, Z and Z'
- In addition to $W^{\pm}_{\mu}$ there are dilepton gauge bosons $V^{\pm}_{\mu}$ and $U^{\pm\pm}_{\mu}$ that carry lepton number $L(V^{+}_{\mu}) = L(U^{++}_{\mu}) = -2$

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Two 3-3-1 models

- electric charge operator is given by

$$\frac{Q}{|e|} = T_3 - \sqrt{3}T_8 + X$$

  where e is the electron charge, $T_{3,8} = \lambda_{3,8}/2$, and X is the hypercharge operator associated do the $U(1)_X$ group.
- the minimal 3-3-1 (m331 for short): the lepton sector is the same as in the standard model.
- the model with heavy leptons (HL331 for short) in which heavy leptons are introduced.
- Quarks are the same in both models.

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The scalar sector

$$\eta=\left(\begin{array}{c}\Phi_1\\ \eta_2^+\end{array}\right)\sim(\mathbf{3},0),\ \rho=\left(\begin{array}{c}\Phi_2\\ \rho^{++}\end{array}\right)\sim(\mathbf{3},1),\ \chi=\left(\begin{array}{c}\Phi_C\\ \chi^0\end{array}\right)\sim(\mathbf{3},-1).$$

The triplet η and the sextet S

$$S=\left(\begin{array}{cc}T & \frac{\Phi_3}{\sqrt{2}}\\ \frac{\Phi_3}{\sqrt{2}} & H_2^{--}\end{array}\right),\quad T=\left(\begin{array}{cc}\sigma_1^0 & \frac{h^+}{\sqrt{2}}\\ \frac{h^+}{\sqrt{2}} & H_1^{++}\end{array}\right),$$

couple to leptons. Under $SU(2)\otimes U(1)_Y$:

$$\Phi_1=\left(\begin{array}{c}\eta^0\\ -\eta_1^-\end{array}\right),\ \Phi_2=\left(\begin{array}{c}\rho^+\\ \rho^0\end{array}\right),\ \Phi_3=\left(\begin{array}{c}h^+\\ h^0\end{array}\right),\ \Phi_C=\left(\begin{array}{c}\chi^-\\ \chi^{--}\end{array}\right),$$

$Y=-1,+1,+1,-3$; $\eta_2^+,\rho^{++},\chi^0,H_2^{--}$ are singlet of $SU(2)$ and have $Y=+2,+4,0,+4$, respectively and carry lepton number:

$$L(T,\eta_2^-)=-2\ ,L(\Phi_C,\rho^{--},H_2^{--})=+2,\ L(\Phi_{1,2,3})=0$$

The lepton number

LV explicitly via soft and hard terms. Or, $v_{\sigma_1^0} \neq 0$ inducing spontaneously breaking of L. Three possibilities (Liu& Ng 1993):

1. $\langle\sigma_1^0\rangle = 0$ and no explicit LV. But V_μ^- and U_μ^{--} violate $L_{e,\mu,\tau}$. $\langle\sigma_1^0\rangle = 0$ stable at tree level (Foot et al 1992, Pleitez& Tonasse 1993).
2. No explicit LV but $\langle\sigma_1^0\rangle \neq 0 \to$ a triplet Majoron: ruled out by the Z invisible width.
3. Explicit LV. $\langle\sigma_1^0\rangle = 0$ at tree level, but $\langle\sigma_1^0\rangle \neq 0$ by loop corrections (Pleitez,Tonasse 1993; Framton,Krastev& Liu1994).
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The scalar potential: three triplets

$$V(\eta,\rho,\chi) = V^{(2)} + V^{(3)} + V^{(4)},$$

where

$$\begin{aligned}
V^{(2)} &= \sum_{x=\eta,\rho,\chi} \mu_X^2\, X^\dagger X, \\
V^{(3)} &= \alpha\epsilon\eta\rho\chi \\
V^{(4)} &= a_1(\chi^\dagger\chi)^2 + a_2(\eta^\dagger\eta)^2 + a_3(\rho^\dagger\rho)^2 + \chi^\dagger\chi(a_4\eta^\dagger\eta + a_5\rho^\dagger\rho) \\
&+ a_6(\eta^\dagger\eta)(\rho^\dagger\rho)a_7(\chi^\dagger\eta)(\eta^\dagger\chi) + a_8(\chi^\dagger\rho)(\rho^\dagger\chi) + a_9(\eta^\dagger\rho)(\rho^\dagger\eta) \\
&+ a_{10}[(\chi^\dagger\eta)(\rho^\dagger\eta) + H.c.]
\end{aligned} \tag{2}$$

$a_{10} \neq 0 \Rightarrow$ explicit LV.

three triplets $\to$ 2HDM+1 neutral singlet

$$
\begin{aligned}
V_{2HD+1HS} &= \mu_\eta^2 \Phi_1^\dagger \Phi_1 + \mu_\rho^2 \Phi_2^\dagger \Phi_2 + a_2 (\Phi_1^\dagger \Phi_1)^2 + a_3 (\Phi_2^\dagger \Phi_2)^2 \\
&+ a_6 [(\Phi_1^\dagger \Phi_1)(\Phi_2^\dagger \Phi_2) + (\Phi_1^\dagger \Phi_2)(\Phi_2^\dagger \Phi_1)] \\
&+ \alpha \, [(\Phi_1)_1 (\Phi_2)_2 - (\Phi_1)_2 (\Phi_2)_1] \chi^0 \\
&+ \mu_\chi^2 \chi^{0*} \chi^0 + a_1 (\chi^{0*} \chi^0)^2 + \cdots + H.c.
\end{aligned} \tag{3}
$$

$\cdots$ mean interactions involving χ^0, H_2^{--}, ...

three triplets and the sextet $\rightarrow$ 3HDM

$$V(\eta,\rho,\chi,S) = V^{(2)} + V^{(3)} + V^{(4a)} + \cdots + V^{(4e)},$$

$$\begin{aligned}
V^{(2)} &= \sum_X \mu_X^2 \mathrm{Tr}(X^\dagger X), X = \eta,\rho,\chi,S \\
V^{(3)} &= \alpha_1 \epsilon\eta\rho\chi + \alpha_2 \chi^T S^\dagger \rho + \alpha_3 \eta^T S^\dagger \eta + \alpha_4 \mathrm{Tr}(SSS) \\
&+ \frac{\alpha_5}{3!}\epsilon_{ijk}\epsilon_{mnl}\, S_{im}S_{jn}S_{kl}, \\
V^{(4a)} &= (a_1,\cdots,a_9)(\eta,\rho,\chi) + a_{10}[(\chi^\dagger\eta)(\rho^\dagger\eta) + H.c.], \\
V^{(4b)} &= b_1\chi^\dagger S\chi\eta + b_2\rho^\dagger S\rho\eta + b_3\eta^\dagger S\chi\rho + H.c., \\
V^{(4c)} &= c_1\eta\eta SS + c_2\chi\rho SS + H.c., \\
V^{(4d)} &= d_1(\chi^\dagger\chi)\mathrm{Tr}S^\dagger S + d_2(\chi^\dagger SS^\dagger\chi) + d_3(\eta^\dagger\eta)\mathrm{Tr}(S^\dagger S) \\
&+ d_4(\eta^\dagger SS^\dagger\eta) + d_5(\rho^\dagger\rho)\mathrm{Tr}S^\dagger S + d_6(\rho^\dagger SS^\dagger\rho), \\
V^{(e)} &= e_1(\mathrm{Tr}S^\dagger S)^2 + e_2\mathrm{Tr}(S^\dagger SS^\dagger S). \qquad (4)
\end{aligned}$$

L is conserved if $\Rightarrow \alpha_3, \alpha_4, \alpha_5, a_{10}, b_3, c_2 = 0$. This is possible if we impose the discrete symmetry

$$\begin{aligned} &\rho \to i\rho,\ \chi \to i\chi,\ \eta \to -\eta,\ S \to -S, \\ &\Psi \to i\Psi,\ Q_{iL} \to -iQ_{iL},\ Q_{3L} \to Q_{3L}, \\ &u_{\alpha R} \to u_{\alpha R},\ d_{\alpha R} \to id_{\alpha R} \end{aligned}$$

$\eta, \rho, \chi, S \Rightarrow$ three-Higgs-Doublet model plus fields T and the singlets χ^0 and H_2^{++}.
However, there are only two quartic non-Hermitian interactions among the three dublets:

$$\begin{aligned} V(\Phi_i)_{3HD} &= \sum_i \mu_i^2 \Phi^\dagger \Phi_i + [\sum_{i<j} m_{ij}^2 (\Phi_i^\dagger \Phi_j) + H.c.] \\ &+ \sum_{i<j} \lambda_{ij} (\Phi_i^\dagger \Phi_j)(\Phi_j^\dagger \Phi_i) + b_2 (\Phi_1^\dagger \Phi_3)(\Phi_1^\dagger \Phi_3) \\ &+ d_4 (\Phi_1^\dagger \Phi_3)(\Phi_1^\dagger \Phi_2) + H.c. \end{aligned}$$

Fermions

Quarks:
two quak generations transform in different way from the third one:

$$Q'_{mL} = (d_m,\ -u_m, j_m)^T_L \sim (\mathbf{3}, \mathbf{3}^*, -1/3);\ m = 1, 2$$
$$Q'_{3L} = (u_3,\ d_3, J)^T_L \sim (\mathbf{3}, \mathbf{3}, 2/3),$$
$$u_{\alpha R} \sim (\mathbf{3}, \mathbf{1}, 2/3), d_{\alpha R} \sim (\mathbf{3}, \mathbf{1}, -1/3),\ \alpha = 1, 2, 3,$$
$$j_{mR} \sim (\mathbf{3}, \mathbf{1}, -4/3), J_R \sim (\mathbf{3}, \mathbf{1}, 5/3).$$

Leptons.
m331: $\Psi_a = (\nu_a\, l_a\, l^c_a)^T_L \sim (1, \mathbf{3}, 0)$.
HL331: $\Psi_{aL} = (\nu_a\, l^-_a\ E^+_a) \sim (1, 3, 0)$,
$l^-_{aR} \sim (1, 1, -1),\ E^+_{aR} \sim (1, 1, 1),\ a = e, \mu, \tau$.
Right-handed neutrinos may be added.

Predicitons of the models

1. The number of generations are three: anomaly cancellation and asymptotic freedom (or at least a multiple of three)
2. The electroweak mixing angle $\sin^2\theta_W < 1/4$
3. A Landau-like pole at energies of the order of few TeVs when $\sin^2\theta_W = 1/4$
4. This pole stabilizes the electroweak scale
5. The asymmetric treatment of the third quark family which may be related to the heaviness of the top quark
6. The electric charge is quantized (anomaly cancellation and the fermion' s masses arisen through the Yukawa interactions independently of the existence of right-handed neutrinos In the SM with three generations this occurs only if neutrinos right-handed and a Majorana mass term is added
7. The models have an almost automatic Peceei-quinn symmetry

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Reduction to the standard model

$v_\chi \to \infty \Rightarrow 331 \to 321$

$$\begin{array}{l} Z_1 \to Z, \quad Z_2 \to Z' \\ g^{Z_1}_{V,A}(s^2_W, \bar{v}^2_\eta, \bar{v}^2_\rho) \to g^Z_{V,A}, \\ f^{Z_2}_{V,A}(s^2_W, \bar{v}^2_\eta, \bar{v}^2_\rho) \to f^{Z'}_{V,A}(s^2_W), \end{array}$$

another non-trivial reduction to SM:

$$\rho_1 = \frac{M_{Z_1}}{c_W M_W} = 1 \Rightarrow$$

$$v^2_\rho = \frac{1-4s^2_W}{2c^2_W} v^2_W \Rightarrow v_\rho \approx 54\,\mathrm{GeV}$$

$$v^2_\eta = \frac{1+2s^2_W}{2c^2_W} v^2_W \Rightarrow v_\rho \approx 240\,\mathrm{GeV}$$

v_χ is a free parameter

Quark masses

$$
\begin{aligned}
-\mathcal{L}_Y &= \bar{Q}'_{mL}[G_{m\alpha}U'_{\alpha R}\rho^* + \tilde{G}_{m\alpha}D'_{\alpha R}\eta^*] \\
&+ \bar{Q}'_{3L}[F_{3\alpha}U'_{\alpha R}\eta + \tilde{F}_{3\alpha}D'_{\alpha R}\rho] + H.c.
\end{aligned}
$$

$$
M^U = \begin{pmatrix} rG_{11} & rG_{12} & rG_{13} \\ rG_{21} & rG_{22} & rG_{23} \\ F_{31} & F_{32} & F_{33} \end{pmatrix} |v_\eta|,
$$

$$
M^D = \begin{pmatrix} r^{-1}\tilde{G}_{11} & r^{-1}\tilde{G}_{12} & r^{-1}\tilde{G}_{13} \\ r^{-1}\tilde{G}_{21} & r^{-1}\tilde{G}_{22} & r^{-1}\tilde{G}_{23} \\ \tilde{F}_{31} & \tilde{F}_{32} & \tilde{F}_{33} \end{pmatrix} |v_\rho|.
$$

$$
V^q_L M^q M^{q\,\dagger} V^{q\dagger}_L = V^q_R M^{q\,\dagger} M^q V^{q\,\dagger}_R = (\hat{M}^q)^2, \quad q = U, D.
$$

Quark masses

$$V_L^U = \begin{pmatrix} -0.00032 & 0.07163 & -0.99743 \\ 0.00433 & -0.99742 & -0.07163 \\ 0.99999 & 0.00434 & -0.00001 \end{pmatrix},$$

$$V_L^D = \begin{pmatrix} 0.00273 \to 0.00562 & (0.03 \to 0.03682) & -(0.9995 \\ -(0.19700 \to 0.22293) & -(0.97436 \to 0.97993) & -0 \\ 0.97483 \to 0.98039 & -(0.19708 \to 0.22291) & -(0.0041 \end{pmatrix}$$

and the CKM matrix

$$|V_{CKM}| = \begin{pmatrix} 0.97385 \to 0.97952 & 0.20134 \to 0.22714 & 0.00021 \to 0.00 \\ 0.20116 \to 0.22679 & 0.97307 \to 0.97869 & 0.04116 \to 0.04 \\ 0.00849 \to 0.01324 & 0.03919 \to 0.04028 & 0.99914 \to 0.99 \end{pmatrix} \quad (6)$$

Similar expressions for $V_R^{U,D}$.

FCNC-Z'

$$\mathcal{L}_{Z'} \quad = \quad -\frac{g}{2\cos\theta_W}\sum_{q=U,D}[\bar{q}_L\gamma^\mu K^q_L q_L + \bar{q}_R\gamma^\mu K^q_R q_R]Z'_\mu, \quad (7)$$

where we have defined

$$K^q_L = V^q_L Y^q_L V^{q\dagger}_L, \quad K^q_R = V^q_R Y^q_R V^{q\dagger}_R, \quad q = U, D; \quad (8)$$

with $V^{U,D}_{L,R}$ given in Eqs. (5) and (**??**) and

$$Y^U_L = Y^D_L = -\frac{1}{2\sqrt{3}h(x)}\text{diag}\,[-2(1-2x), -2(1-2x), 1] \quad (9)$$

and

$$Y^U_R = -\frac{4x}{\sqrt{3}h(x)}\mathbf{1}_{3\times3}, \quad Y^D_R = \frac{2x}{\sqrt{3}h(x)}\mathbf{1}_{3\times3} \quad (10)$$

and $h(x) \equiv (1-4x)^{1/2}$, $x = \sin^2\theta_W$.

FCNC-Higgs

$$-\mathcal{L}_{qqh} = \sum_{q=U,D} \overline{q}_L \mathcal{K}^q q_R + \text{mass terms} + H.c.,$$

$$\mathcal{K}^D \approx$$

$$\begin{pmatrix} 10^{-4}\rho^0 - 10^{-6}\eta^0 & 10^{-4}\rho^0 - 10^{-5}\eta^0 & -10^{-4}\rho^0 + 10^{-5}\eta^0 \\ 10^{-6}\rho^0 + 10^{-4}\eta^0 & 10^{-5}\rho^0 + 10^{-3}\eta^0 & -10^{-6}\rho^0 + 10^{-2}\eta^0 \\ 10^{-6}\rho^0 - 10^{-5}\eta^0 & 10^{-6}\rho^0 - 10^{-3}\eta^0 & -10^{-6}\rho^0 + 0.011\eta^0 \end{pmatrix},$$

$$\mathcal{K}^U \approx$$

$$\begin{pmatrix} 0.0099\rho^0 - 10^{-6}\eta^0 & 0.00340\rho^0 - 10^{-5}\eta^0 & 0.0109\rho^0 - 10^{-5}\eta^0 \\ -0.13846\rho^0 + 10^{-7}\eta^0 & 0.0556\rho^0 + 10^{-6}\eta^0 & -0.1521\rho^0 - 10^{-6}\eta^0 \\ 1.9228\rho^0 - 10^{-11}\eta^0 & 0.8656\rho^0 - 10^{-10}\eta^0 & 2.3569\rho^0 - 10^{-10}\eta^0 \end{pmatrix}$$

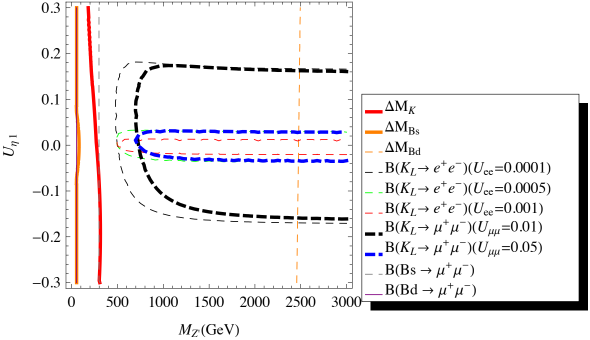

Figure: Allowed regions for $U_{\eta 1}$ and $M_{Z'}$. Taking into account the 125 GeV neutral scalar.

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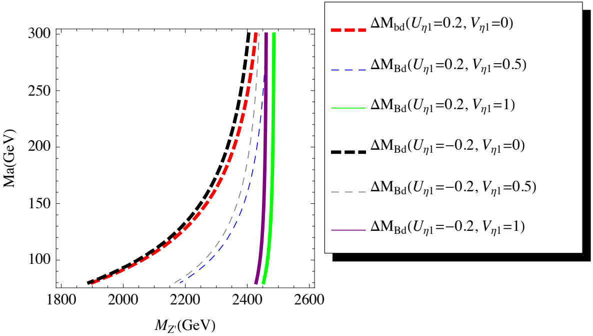

Figure: Allowed region for $M_{Z'}$ and M_A.

CP Violation

$$
\begin{aligned}
V(\eta,\rho,\chi) &= \sum_{x=\eta,\rho,\chi} \mu_X^2\, X^\dagger X + \alpha\epsilon\eta\rho\chi + a_1(\chi^\dagger\chi)^2 + a_2(\eta^\dagger\eta)^2 \\
&+ a_3(\rho^\dagger\rho)^2 + \chi^\dagger\chi(a_4\eta^\dagger\eta + a_5\rho^\dagger\rho) + a_6(\eta^\dagger\eta)(\rho^\dagger\rho) \\
&+ a_7(\chi^\dagger\eta)(\eta^\dagger\chi) + a_8(\chi^\dagger\rho)(\rho^\dagger\chi) + a_9(\eta^\dagger\rho)(\rho^\dagger\eta)
\end{aligned}
$$

HL331: three VEVs and α complex: four phases, one survives.
m331: four VEVs complex
The electric dipole moment of electron and neutron have been calculated in the contex of the HL331 G. de Conto and Pleiez arXiv:1408.6551
More hard violating phases in $V_L^{U,D}$ nine phases plus the constrain $V_L^U V_L^{D\dagger} = V_{CKM}$ (Promberger)

Lepton masses

$\langle S \rangle = 0$ at tree level (but there is a divergent contribution to $\langle \sigma_2^0 \rangle$ at one loop level),

$$\mathcal{L}_\nu = \bar{\Psi}_{aL} G^{\nu\eta}_{ab} \nu_{aR} \eta + \overline{(\nu_{aR})^c} (M_R)_{ab} \nu_{bR}$$

M_R is diagonal, and $M_R^{-1} = (1/M)\bar{M}_R$ where
$\bar{M} = \mathrm{diag}(M/m_{R1}, M/m_{R2}, 1)$ and $M \equiv m_{R3} > m_{R1}, m_{R2}$.

$$M^\nu_{ab} \approx -\frac{v_\eta^2}{2M} G^{\nu\eta}_{ab} \bar{M}_R (G^{\nu\eta})^T, \quad M^l_{ab} = G^{l\eta}_{ab} \frac{v_\eta}{\sqrt{2}} + \frac{1}{\Lambda} G^S_{ab} v_\rho v_\chi .$$

$$|V_{PMNS}| \approx \begin{pmatrix} 0.826 & 0.548 & 0.130 \\ 0.506 & 0.618 & 0.602 \\ 0.249 & 0.563 & 0.788 \end{pmatrix} . \qquad (11)$$

3-3-1 models have interesting features: FCNC in both quarks and lepton sectors, (partially) explain the number of generation, but many parameters have to be known before more realistic phenomenological studies are done: it is mandatory to considered vector, scalar and exotic charged fields altogether in order to have a realistic phenomenology. Until now most of the articcles consider only one these particles in a a given processes. As can be seen from Fig. 1 and 2, there constructive and destructive interference between the Z' and the SM-like scalar h and one of the pseudoscalar A.

THANKS!

(below you can find some references)

References

- A. Hill and J. J. van der Bij, Strongly Interacting Singlet - Doublet Higgs Model, Phys. Rev. D **36**, 3463 (1987).
- H. Davoudiasl, R. Kitano, T. Li and H. Murayama, The New minimal standard model, Phys. Lett. B **609**, 117 (2005) [hep-ph/0405097].
- Y. Chikashige, R. N. Mohapatra and R. D. Peccei, Are There Real Goldstone Bosons Associated with Broken Lepton Number ?, Phys. Lett. B **98**, 265 (1981).
- G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516**, 1 (2012) [arXiv:1106.0034 [hep-ph]].
- V. Brdar, I. Picek and B. Radovcic, Radiative Neutrino Mass with Scotogenic Scalar Triplet, Phys. Lett. B **728**, 198 (2014) [arXiv:1310.3183 [hep-ph]].
- T. P. Cheng and L. -F. Li, Neutrino Masses, Mixings and Oscillations in SU(2) x U(1) Models of Electroweak

References

- A. Hill and J. J. van der Bij, Strongly Interacting Singlet - Doublet Higgs Model, Phys. Rev. D **36**, 3463 (1987).
- H. Davoudiasl, R. Kitano, T. Li and H. Murayama, The New minimal standard model, Phys. Lett. B **609**, 117 (2005) [hep-ph/0405097].
- Y. Chikashige, R. N. Mohapatra and R. D. Peccei, Are There Real Goldstone Bosons Associated with Broken Lepton Number ?, Phys. Lett. B **98**, 265 (1981).
- G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516**, 1 (2012) [arXiv:1106.0034 [hep-ph]].
- V. Brdar, I. Picek and B. Radovcic, Radiative Neutrino Mass with Scotogenic Scalar Triplet, Phys. Lett. B **728**, 198 (2014) [arXiv:1310.3183 [hep-ph]].
- T. P. Cheng and L. -F. Li, Neutrino Masses, Mixings and Oscillations in SU(2) x U(1) Models of Electroweak

References

- A. Hill and J. J. van der Bij, Strongly Interacting Singlet - Doublet Higgs Model, Phys. Rev. D **36**, 3463 (1987).
- H. Davoudiasl, R. Kitano, T. Li and H. Murayama, The New minimal standard model, Phys. Lett. B **609**, 117 (2005) [hep-ph/0405097].
- Y. Chikashige, R. N. Mohapatra and R. D. Peccei, Are There Real Goldstone Bosons Associated with Broken Lepton Number ?, Phys. Lett. B **98**, 265 (1981).
- G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516**, 1 (2012) [arXiv:1106.0034 [hep-ph]].
- V. Brdar, I. Picek and B. Radovcic, Radiative Neutrino Mass with Scotogenic Scalar Triplet, Phys. Lett. B **728**, 198 (2014) [arXiv:1310.3183 [hep-ph]].
- T. P. Cheng and L. -F. Li, Neutrino Masses, Mixings and Oscillations in SU(2) x U(1) Models of Electroweak

References

- A. Hill and J. J. van der Bij, Strongly Interacting Singlet - Doublet Higgs Model, Phys. Rev. D **36**, 3463 (1987).
- H. Davoudiasl, R. Kitano, T. Li and H. Murayama, The New minimal standard model, Phys. Lett. B **609**, 117 (2005) [hep-ph/0405097].
- Y. Chikashige, R. N. Mohapatra and R. D. Peccei, Are There Real Goldstone Bosons Associated with Broken Lepton Number ?, Phys. Lett. B **98**, 265 (1981).
- G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516**, 1 (2012) [arXiv:1106.0034 [hep-ph]].
- V. Brdar, I. Picek and B. Radovcic, Radiative Neutrino Mass with Scotogenic Scalar Triplet, Phys. Lett. B **728**, 198 (2014) [arXiv:1310.3183 [hep-ph]].
- T. P. Cheng and L. -F. Li, Neutrino Masses, Mixings and Oscillations in SU(2) x U(1) Models of Electroweak

References

- A. Hill and J. J. van der Bij, Strongly Interacting Singlet - Doublet Higgs Model, Phys. Rev. D **36**, 3463 (1987).
- H. Davoudiasl, R. Kitano, T. Li and H. Murayama, The New minimal standard model, Phys. Lett. B **609**, 117 (2005) [hep-ph/0405097].
- Y. Chikashige, R. N. Mohapatra and R. D. Peccei, Are There Real Goldstone Bosons Associated with Broken Lepton Number ?, Phys. Lett. B **98**, 265 (1981).
- G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516**, 1 (2012) [arXiv:1106.0034 [hep-ph]].
- V. Brdar, I. Picek and B. Radovcic, Radiative Neutrino Mass with Scotogenic Scalar Triplet, Phys. Lett. B **728**, 198 (2014) [arXiv:1310.3183 [hep-ph]].
- T. P. Cheng and L. -F. Li, Neutrino Masses, Mixings and Oscillations in SU(2) x U(1) Models of Electroweak

References

- A. Hill and J. J. van der Bij, Strongly Interacting Singlet - Doublet Higgs Model, Phys. Rev. D **36**, 3463 (1987).
- H. Davoudiasl, R. Kitano, T. Li and H. Murayama, The New minimal standard model, Phys. Lett. B **609**, 117 (2005) [hep-ph/0405097].
- Y. Chikashige, R. N. Mohapatra and R. D. Peccei, Are There Real Goldstone Bosons Associated with Broken Lepton Number ?, Phys. Lett. B **98**, 265 (1981).
- G. C. Branco, P. M. Ferreira, L. Lavoura, M. N. Rebelo, M. Sher and J. P. Silva, Theory and phenomenology of two-Higgs-doublet models, Phys. Rept. **516**, 1 (2012) [arXiv:1106.0034 [hep-ph]].
- V. Brdar, I. Picek and B. Radovcic, Radiative Neutrino Mass with Scotogenic Scalar Triplet, Phys. Lett. B **728**, 198 (2014) [arXiv:1310.3183 [hep-ph]].
- T. P. Cheng and L. -F. Li, Neutrino Masses, Mixings and Oscillations in SU(2) x U(1) Models of Electroweak

References

- A. Zee, Quantum Numbers of Majorana Neutrino Masses, Nucl. Phys. B **264**, 99 (1986).
- A. Zee, A Theory of Lepton Number Violation, Neutrino Majorana Mass, and Oscillation, Phys. Lett. B **93**, 389 (1980) [Erratum-ibid. B **95**, 461 (1980)].
- K. S. Babu, Model of 'Calculable' Majorana Neutrino Masses, Phys. Lett. B **203**, 132 (1988).
- S. S. C. Law and K. L. McDonald, The simplest models of radiative neutrino mass, Int. J. Mod. Phys. A **29**, 1450064 (2014) [arXiv:1303.6384 [hep-ph]].

References

- A. Zee, Quantum Numbers of Majorana Neutrino Masses, Nucl. Phys. B **264**, 99 (1986).
- A. Zee, A Theory of Lepton Number Violation, Neutrino Majorana Mass, and Oscillation, Phys. Lett. B **93**, 389 (1980) [Erratum-ibid. B **95**, 461 (1980)].
- K. S. Babu, Model of 'Calculable' Majorana Neutrino Masses, Phys. Lett. B **203**, 132 (1988).
- S. S. C. Law and K. L. McDonald, The simplest models of radiative neutrino mass, Int. J. Mod. Phys. A **29**, 1450064 (2014) [arXiv:1303.6384 [hep-ph]].

References

- A. Zee, Quantum Numbers of Majorana Neutrino Masses, Nucl. Phys. B **264**, 99 (1986).
- A. Zee, A Theory of Lepton Number Violation, Neutrino Majorana Mass, and Oscillation, Phys. Lett. B **93**, 389 (1980) [Erratum-ibid. B **95**, 461 (1980)].
- K. S. Babu, Model of 'Calculable' Majorana Neutrino Masses, Phys. Lett. B **203**, 132 (1988).
- S. S. C. Law and K. L. McDonald, The simplest models of radiative neutrino mass, Int. J. Mod. Phys. A **29**, 1450064 (2014) [arXiv:1303.6384 [hep-ph]].

References

- A. Zee, Quantum Numbers of Majorana Neutrino Masses, Nucl. Phys. B **264**, 99 (1986).
- A. Zee, A Theory of Lepton Number Violation, Neutrino Majorana Mass, and Oscillation, Phys. Lett. B **93**, 389 (1980) [Erratum-ibid. B **95**, 461 (1980)].
- K. S. Babu, Model of 'Calculable' Majorana Neutrino Masses, Phys. Lett. B **203**, 132 (1988).
- S. S. C. Law and K. L. McDonald, The simplest models of radiative neutrino mass, Int. J. Mod. Phys. A **29**, 1450064 (2014) [arXiv:1303.6384 [hep-ph]].

Refrences

- F. Pisano and V. Pleitez, $SU(3)_L \otimes U(1)_N$ model for electroweak interactions, Phys. Rev. D **46**, 410 (1992)
- P. H. Frampton, Chiral dilepton model and the flavor question, Phys. Rev. Lett. **69**, 2889 (1992).
- R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3)-L x U(1)-N gauge model, Phys. Rev. D **47**, 4158 (1993)
- V. Pleitez and M. D. Tonasse, Neutrinoless double beta decay in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 5274 (1993) [hep-ph/9302201].
- P. H. Frampton, P. I. Krastev and J. T. Liu, Cubic mass relation in $SU(3) \otimes U(1)$ electroweak theory, Mod. Phys. Lett. A **9**, 761 (1994) [hep-ph/9308275].
- V. Pleitez and M. D. Tonasse, 0Heavy charged leptons in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 2353 (1993) [hep-ph/9301232].

Refrences

- F. Pisano and V. Pleitez, $SU(3)_L \otimes U(1)_N$ model for electroweak interactions, Phys. Rev. D **46**, 410 (1992)
- P. H. Frampton, Chiral dilepton model and the flavor question, Phys. Rev. Lett. **69**, 2889 (1992).
- R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3)-L x U(1)-N gauge model, Phys. Rev. D **47**, 4158 (1993)
- V. Pleitez and M. D. Tonasse, Neutrinoless double beta decay in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 5274 (1993) [hep-ph/9302201].
- P. H. Frampton, P. I. Krastev and J. T. Liu, Cubic mass relation in $SU(3) \otimes U(1)$ electroweak theory, Mod. Phys. Lett. A **9**, 761 (1994) [hep-ph/9308275].
- V. Pleitez and M. D. Tonasse, 0Heavy charged leptons in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 2353 (1993) [hep-ph/9301232].

Refrences

- F. Pisano and V. Pleitez, $SU(3)_L \otimes U(1)_N$ model for electroweak interactions, Phys. Rev. D **46**, 410 (1992)
- P. H. Frampton, Chiral dilepton model and the flavor question, Phys. Rev. Lett. **69**, 2889 (1992).
- R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3)-L x U(1)-N gauge model, Phys. Rev. D **47**, 4158 (1993)
- V. Pleitez and M. D. Tonasse, Neutrinoless double beta decay in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 5274 (1993) [hep-ph/9302201].
- P. H. Frampton, P. I. Krastev and J. T. Liu, Cubic mass relation in $SU(3) \otimes U(1)$ electroweak theory, Mod. Phys. Lett. A **9**, 761 (1994) [hep-ph/9308275].
- V. Pleitez and M. D. Tonasse, 0Heavy charged leptons in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 2353 (1993) [hep-ph/9301232].

Refrences

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- P. H. Frampton, Chiral dilepton model and the flavor question, Phys. Rev. Lett. **69**, 2889 (1992).
- R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3)-L x U(1)-N gauge model, Phys. Rev. D **47**, 4158 (1993)
- V. Pleitez and M. D. Tonasse, Neutrinoless double beta decay in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 5274 (1993) [hep-ph/9302201].
- P. H. Frampton, P. I. Krastev and J. T. Liu, Cubic mass relation in $SU(3) \otimes U(1)$ electroweak theory, Mod. Phys. Lett. A **9**, 761 (1994) [hep-ph/9308275].
- V. Pleitez and M. D. Tonasse, 0Heavy charged leptons in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 2353 (1993) [hep-ph/9301232].

Refrences

- F. Pisano and V. Pleitez, $SU(3)_L \otimes U(1)_N$ model for electroweak interactions, Phys. Rev. D **46**, 410 (1992)
- P. H. Frampton, Chiral dilepton model and the flavor question, Phys. Rev. Lett. **69**, 2889 (1992).
- R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3)-L x U(1)-N gauge model, Phys. Rev. D **47**, 4158 (1993)
- V. Pleitez and M. D. Tonasse, Neutrinoless double beta decay in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 5274 (1993) [hep-ph/9302201].
- P. H. Frampton, P. I. Krastev and J. T. Liu, Cubic mass relation in $SU(3) \otimes U(1)$ electroweak theory, Mod. Phys. Lett. A **9**, 761 (1994) [hep-ph/9308275].
- V. Pleitez and M. D. Tonasse, 0Heavy charged leptons in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 2353 (1993) [hep-ph/9301232].

Refrences

- F. Pisano and V. Pleitez, $SU(3)_L \otimes U(1)_N$ model for electroweak interactions, Phys. Rev. D **46**, 410 (1992)
- P. H. Frampton, Chiral dilepton model and the flavor question, Phys. Rev. Lett. **69**, 2889 (1992).
- R. Foot, O. F. Hernandez, F. Pisano and V. Pleitez, Lepton masses in an SU(3)-L x U(1)-N gauge model, Phys. Rev. D **47**, 4158 (1993)
- V. Pleitez and M. D. Tonasse, Neutrinoless double beta decay in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 5274 (1993) [hep-ph/9302201].
- P. H. Frampton, P. I. Krastev and J. T. Liu, Cubic mass relation in $SU(3) \otimes U(1)$ electroweak theory, Mod. Phys. Lett. A **9**, 761 (1994) [hep-ph/9308275].
- V. Pleitez and M. D. Tonasse, 0Heavy charged leptons in an $SU(3)_L \otimes U(1)_N$ model, Phys. Rev. D **48**, 2353 (1993) [hep-ph/9301232].

References

- P. B. Pal, The Strong CP question in $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models, Phys. Rev. D **52**, 1659 (1995) [hep-ph/9411406].
- A. G. Dias and V. Pleitez, Stabilizing the invisible axion in 3-3-1 models, Phys. Rev. D **69**, 077702 (2004) [hep-ph/0308037].
- J. C. Montero, V. Pleitez and O. Ravinez, Soft superweak CP violation in a 331 model, Phys. Rev. D **60**, 076003 (1999) [hep-ph/9811280].
- J. T. Liu and D. Ng, Lepton flavor changing processes and CP violation in the 331 model, Phys. Rev. D **50**, 548 (1994) [hep-ph/9401228].
- J. C. Montero, C. A. de S. Pires and V. Pleitez, Lepton masses from a TeV scale in a 3-3-1 model, Phys. Rev. D **66**, 113003 (2002) [hep-ph/0112203].
- J. C. Montero, C. A. De S. Pires and V. Pleitez, Neutrino masses through the seesaw mechanism in 3-3-1 models,

References

- P. B. Pal, The Strong CP question in $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models, Phys. Rev. D **52**, 1659 (1995) [hep-ph/9411406].
- A. G. Dias and V. Pleitez, Stabilizing the invisible axion in 3-3-1 models, Phys. Rev. D **69**, 077702 (2004) [hep-ph/0308037].
- J. C. Montero, V. Pleitez and O. Ravinez, Soft superweak CP violation in a 331 model, Phys. Rev. D **60**, 076003 (1999) [hep-ph/9811280].
- J. T. Liu and D. Ng, Lepton flavor changing processes and CP violation in the 331 model, Phys. Rev. D **50**, 548 (1994) [hep-ph/9401228].
- J. C. Montero, C. A. de S. Pires and V. Pleitez, Lepton masses from a TeV scale in a 3-3-1 model, Phys. Rev. D **66**, 113003 (2002) [hep-ph/0112203].
- J. C. Montero, C. A. De S. Pires and V. Pleitez, Neutrino masses through the seesaw mechanism in 3-3-1 models,

References

- P. B. Pal, The Strong CP question in $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models, Phys. Rev. D **52**, 1659 (1995) [hep-ph/9411406].
- A. G. Dias and V. Pleitez, Stabilizing the invisible axion in 3-3-1 models, Phys. Rev. D **69**, 077702 (2004) [hep-ph/0308037].
- J. C. Montero, V. Pleitez and O. Ravinez, Soft superweak CP violation in a 331 model, Phys. Rev. D **60**, 076003 (1999) [hep-ph/9811280].
- J. T. Liu and D. Ng, Lepton flavor changing processes and CP violation in the 331 model, Phys. Rev. D **50**, 548 (1994) [hep-ph/9401228].
- J. C. Montero, C. A. de S. Pires and V. Pleitez, Lepton masses from a TeV scale in a 3-3-1 model, Phys. Rev. D **66**, 113003 (2002) [hep-ph/0112203].
- J. C. Montero, C. A. De S. Pires and V. Pleitez, Neutrino masses through the seesaw mechanism in 3-3-1 models,

References

- P. B. Pal, The Strong CP question in $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models, Phys. Rev. D **52**, 1659 (1995) [hep-ph/9411406].
- A. G. Dias and V. Pleitez, Stabilizing the invisible axion in 3-3-1 models, Phys. Rev. D **69**, 077702 (2004) [hep-ph/0308037].
- J. C. Montero, V. Pleitez and O. Ravinez, Soft superweak CP violation in a 331 model, Phys. Rev. D **60**, 076003 (1999) [hep-ph/9811280].
- J. T. Liu and D. Ng, Lepton flavor changing processes and CP violation in the 331 model, Phys. Rev. D **50**, 548 (1994) [hep-ph/9401228].
- J. C. Montero, C. A. de S. Pires and V. Pleitez, Lepton masses from a TeV scale in a 3-3-1 model, Phys. Rev. D **66**, 113003 (2002) [hep-ph/0112203].
- J. C. Montero, C. A. De S. Pires and V. Pleitez, Neutrino masses through the seesaw mechanism in 3-3-1 models,

References

- P. B. Pal, The Strong CP question in $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models, Phys. Rev. D **52**, 1659 (1995) [hep-ph/9411406].
- A. G. Dias and V. Pleitez, Stabilizing the invisible axion in 3-3-1 models, Phys. Rev. D **69**, 077702 (2004) [hep-ph/0308037].
- J. C. Montero, V. Pleitez and O. Ravinez, Soft superweak CP violation in a 331 model, Phys. Rev. D **60**, 076003 (1999) [hep-ph/9811280].
- J. T. Liu and D. Ng, Lepton flavor changing processes and CP violation in the 331 model, Phys. Rev. D **50**, 548 (1994) [hep-ph/9401228].
- J. C. Montero, C. A. de S. Pires and V. Pleitez, Lepton masses from a TeV scale in a 3-3-1 model, Phys. Rev. D **66**, 113003 (2002) [hep-ph/0112203].
- J. C. Montero, C. A. De S. Pires and V. Pleitez, Neutrino masses through the seesaw mechanism in 3-3-1 models,

References

- P. B. Pal, The Strong CP question in $SU(3)_C \otimes SU(3)_L \otimes U(1)_N$ models, Phys. Rev. D **52**, 1659 (1995) [hep-ph/9411406].
- A. G. Dias and V. Pleitez, Stabilizing the invisible axion in 3-3-1 models, Phys. Rev. D **69**, 077702 (2004) [hep-ph/0308037].
- J. C. Montero, V. Pleitez and O. Ravinez, Soft superweak CP violation in a 331 model, Phys. Rev. D **60**, 076003 (1999) [hep-ph/9811280].
- J. T. Liu and D. Ng, Lepton flavor changing processes and CP violation in the 331 model, Phys. Rev. D **50**, 548 (1994) [hep-ph/9401228].
- J. C. Montero, C. A. de S. Pires and V. Pleitez, Lepton masses from a TeV scale in a 3-3-1 model, Phys. Rev. D **66**, 113003 (2002) [hep-ph/0112203].
- J. C. Montero, C. A. De S. Pires and V. Pleitez, Neutrino masses through the seesaw mechanism in 3-3-1 models,

- A. G. Dias, R. Martinez and V. Pleitez, Concerning the Landau pole in 3-3-1 models, Eur. Phys. J. C **39**, 101 (2005) [hep-ph/0407141].
- A. G. Dias and V. Pleitez, Stabilization of the Electroweak Scale in 3-3-1 Models, Phys. Rev. D **80**, 056007 (2009) [arXiv:0908.2472 [hep-ph]].
- C. A. de Sousa Pires and O. P. Ravinez, Charge quantization in a chiral bilepton gauge model, Phys. Rev. D **58**, 035008 (1998) [hep-ph/9803409].
- C. Q. Geng and R. E. Marshak, Uniqueness of Quark and Lepton Representations in the Standard Model From the Anomalies Viewpoint, Phys. Rev. D **39**, 693 (1989).
- K. S. Babu and R. N. Mohapatra, Quantization of Electric Charge From Anomaly Constraints and a Majorana Neutrino, Phys. Rev. D **41**, 271 (1990).
- R. Foot, Electric Charge Quantization And Vector Like Fermions, Mod. Phys. Lett. A **5**, 1947 (1990).

- A. G. Dias, R. Martinez and V. Pleitez, Concerning the Landau pole in 3-3-1 models, Eur. Phys. J. C **39**, 101 (2005) [hep-ph/0407141].
- A. G. Dias and V. Pleitez, Stabilization of the Electroweak Scale in 3-3-1 Models, Phys. Rev. D **80**, 056007 (2009) [arXiv:0908.2472 [hep-ph]].
- C. A. de Sousa Pires and O. P. Ravinez, Charge quantization in a chiral bilepton gauge model, Phys. Rev. D **58**, 035008 (1998) [hep-ph/9803409].
- C. Q. Geng and R. E. Marshak, Uniqueness of Quark and Lepton Representations in the Standard Model From the Anomalies Viewpoint, Phys. Rev. D **39**, 693 (1989).
- K. S. Babu and R. N. Mohapatra, Quantization of Electric Charge From Anomaly Constraints and a Majorana Neutrino, Phys. Rev. D **41**, 271 (1990).
- R. Foot, Electric Charge Quantization And Vector Like Fermions, Mod. Phys. Lett. A **5**, 1947 (1990).

- A. G. Dias, R. Martinez and V. Pleitez, Concerning the Landau pole in 3-3-1 models, Eur. Phys. J. C **39**, 101 (2005) [hep-ph/0407141].
- A. G. Dias and V. Pleitez, Stabilization of the Electroweak Scale in 3-3-1 Models, Phys. Rev. D **80**, 056007 (2009) [arXiv:0908.2472 [hep-ph]].
- C. A. de Sousa Pires and O. P. Ravinez, Charge quantization in a chiral bilepton gauge model, Phys. Rev. D **58**, 035008 (1998) [hep-ph/9803409].
- C. Q. Geng and R. E. Marshak, Uniqueness of Quark and Lepton Representations in the Standard Model From the Anomalies Viewpoint, Phys. Rev. D **39**, 693 (1989).
- K. S. Babu and R. N. Mohapatra, Quantization of Electric Charge From Anomaly Constraints and a Majorana Neutrino, Phys. Rev. D **41**, 271 (1990).
- R. Foot, Electric Charge Quantization And Vector Like Fermions, Mod. Phys. Lett. A **5**, 1947 (1990).

- A. G. Dias, R. Martinez and V. Pleitez, Concerning the Landau pole in 3-3-1 models, Eur. Phys. J. C **39**, 101 (2005) [hep-ph/0407141].
- A. G. Dias and V. Pleitez, Stabilization of the Electroweak Scale in 3-3-1 Models, Phys. Rev. D **80**, 056007 (2009) [arXiv:0908.2472 [hep-ph]].
- C. A. de Sousa Pires and O. P. Ravinez, Charge quantization in a chiral bilepton gauge model, Phys. Rev. D **58**, 035008 (1998) [hep-ph/9803409].
- C. Q. Geng and R. E. Marshak, Uniqueness of Quark and Lepton Representations in the Standard Model From the Anomalies Viewpoint, Phys. Rev. D **39**, 693 (1989).
- K. S. Babu and R. N. Mohapatra, Quantization of Electric Charge From Anomaly Constraints and a Majorana Neutrino, Phys. Rev. D **41**, 271 (1990).
- R. Foot, Electric Charge Quantization And Vector Like Fermions, Mod. Phys. Lett. A **5**, 1947 (1990).

- A. G. Dias, R. Martinez and V. Pleitez, Concerning the Landau pole in 3-3-1 models, Eur. Phys. J. C **39**, 101 (2005) [hep-ph/0407141].
- A. G. Dias and V. Pleitez, Stabilization of the Electroweak Scale in 3-3-1 Models, Phys. Rev. D **80**, 056007 (2009) [arXiv:0908.2472 [hep-ph]].
- C. A. de Sousa Pires and O. P. Ravinez, Charge quantization in a chiral bilepton gauge model, Phys. Rev. D **58**, 035008 (1998) [hep-ph/9803409].
- C. Q. Geng and R. E. Marshak, Uniqueness of Quark and Lepton Representations in the Standard Model From the Anomalies Viewpoint, Phys. Rev. D **39**, 693 (1989).
- K. S. Babu and R. N. Mohapatra, Quantization of Electric Charge From Anomaly Constraints and a Majorana Neutrino, Phys. Rev. D **41**, 271 (1990).
- R. Foot, Electric Charge Quantization And Vector Like Fermions, Mod. Phys. Lett. A **5**, 1947 (1990).

- A. G. Dias, R. Martinez and V. Pleitez, Concerning the Landau pole in 3-3-1 models, Eur. Phys. J. C **39**, 101 (2005) [hep-ph/0407141].
- A. G. Dias and V. Pleitez, Stabilization of the Electroweak Scale in 3-3-1 Models, Phys. Rev. D **80**, 056007 (2009) [arXiv:0908.2472 [hep-ph]].
- C. A. de Sousa Pires and O. P. Ravinez, Charge quantization in a chiral bilepton gauge model, Phys. Rev. D **58**, 035008 (1998) [hep-ph/9803409].
- C. Q. Geng and R. E. Marshak, Uniqueness of Quark and Lepton Representations in the Standard Model From the Anomalies Viewpoint, Phys. Rev. D **39**, 693 (1989).
- K. S. Babu and R. N. Mohapatra, Quantization of Electric Charge From Anomaly Constraints and a Majorana Neutrino, Phys. Rev. D **41**, 271 (1990).
- R. Foot, Electric Charge Quantization And Vector Like Fermions, Mod. Phys. Lett. A **5**, 1947 (1990).

- R. Foot, G. C. Joshi, H. Lew and R. R. Volkas, Charge quantization in the standard model and some of its extensions, Mod. Phys. Lett. A **5**, 2721 (1990).
- R. Foot, New Physics From Electric Charge Quantization?, Mod. Phys. Lett. A **6**, 527 (1991).
- J. Sladkowski and M. Zralek, Charge quantization in the standard model with the three generations of fermions, Phys. Rev. D **45**, 1701 (1992).
- M. Nowakowski and A. Pilaftsis, A Note on charge quantization through anomaly cancellation, Phys. Rev. D **48**, 259 (1993) [hep-ph/9304312].
- R. Foot, H. Lew and R. R. Volkas, Electric charge quantization, J. Phys. G **19**, 361 (1993) [Erratum-ibid. G **19**, 1067 (1993)] [hep-ph/9209259].
- A. G. Dias, J. C. Montero and V. Pleitez, Closing the $SU(3)_L \otimes U(1))X$ symmetry at electroweak scale, Phys. Rev. D **73**, 113004 (2006) [hep-ph/0605051].

- R. Foot, G. C. Joshi, H. Lew and R. R. Volkas, Charge quantization in the standard model and some of its extensions, Mod. Phys. Lett. A **5**, 2721 (1990).
- R. Foot, New Physics From Electric Charge Quantization?, Mod. Phys. Lett. A **6**, 527 (1991).
- J. Sladkowski and M. Zralek, Charge quantization in the standard model with the three generations of fermions, Phys. Rev. D **45**, 1701 (1992).
- M. Nowakowski and A. Pilaftsis, A Note on charge quantization through anomaly cancellation, Phys. Rev. D **48**, 259 (1993) [hep-ph/9304312].
- R. Foot, H. Lew and R. R. Volkas, Electric charge quantization, J. Phys. G **19**, 361 (1993) [Erratum-ibid. G **19**, 1067 (1993)] [hep-ph/9209259].
- A. G. Dias, J. C. Montero and V. Pleitez, Closing the $SU(3)_L \otimes U(1))X$ symmetry at electroweak scale, Phys. Rev. D **73**, 113004 (2006) [hep-ph/0605051].

- R. Foot, G. C. Joshi, H. Lew and R. R. Volkas, Charge quantization in the standard model and some of its extensions, Mod. Phys. Lett. A **5**, 2721 (1990).
- R. Foot, New Physics From Electric Charge Quantization?, Mod. Phys. Lett. A **6**, 527 (1991).
- J. Sladkowski and M. Zralek, Charge quantization in the standard model with the three generations of fermions, Phys. Rev. D **45**, 1701 (1992).
- M. Nowakowski and A. Pilaftsis, A Note on charge quantization through anomaly cancellation, Phys. Rev. D **48**, 259 (1993) [hep-ph/9304312].
- R. Foot, H. Lew and R. R. Volkas, Electric charge quantization, J. Phys. G **19**, 361 (1993) [Erratum-ibid. G **19**, 1067 (1993)] [hep-ph/9209259].
- A. G. Dias, J. C. Montero and V. Pleitez, Closing the $SU(3)_L \otimes U(1))X$ symmetry at electroweak scale, Phys. Rev. D **73**, 113004 (2006) [hep-ph/0605051].

- R. Foot, G. C. Joshi, H. Lew and R. R. Volkas, Charge quantization in the standard model and some of its extensions, Mod. Phys. Lett. A **5**, 2721 (1990).
- R. Foot, New Physics From Electric Charge Quantization?, Mod. Phys. Lett. A **6**, 527 (1991).
- J. Sladkowski and M. Zralek, Charge quantization in the standard model with the three generations of fermions, Phys. Rev. D **45**, 1701 (1992).
- M. Nowakowski and A. Pilaftsis, A Note on charge quantization through anomaly cancellation, Phys. Rev. D **48**, 259 (1993) [hep-ph/9304312].
- R. Foot, H. Lew and R. R. Volkas, Electric charge quantization, J. Phys. G **19**, 361 (1993) [Erratum-ibid. G **19**, 1067 (1993)] [hep-ph/9209259].
- A. G. Dias, J. C. Montero and V. Pleitez, Closing the $SU(3)_L \otimes U(1))X$ symmetry at electroweak scale, Phys. Rev. D **73**, 113004 (2006) [hep-ph/0605051].

- R. Foot, G. C. Joshi, H. Lew and R. R. Volkas, Charge quantization in the standard model and some of its extensions, Mod. Phys. Lett. A **5**, 2721 (1990).
- R. Foot, New Physics From Electric Charge Quantization?, Mod. Phys. Lett. A **6**, 527 (1991).
- J. Sladkowski and M. Zralek, Charge quantization in the standard model with the three generations of fermions, Phys. Rev. D **45**, 1701 (1992).
- M. Nowakowski and A. Pilaftsis, A Note on charge quantization through anomaly cancellation, Phys. Rev. D **48**, 259 (1993) [hep-ph/9304312].
- R. Foot, H. Lew and R. R. Volkas, Electric charge quantization, J. Phys. G **19**, 361 (1993) [Erratum-ibid. G **19**, 1067 (1993)] [hep-ph/9209259].
- A. G. Dias, J. C. Montero and V. Pleitez, Closing the $SU(3)_L \otimes U(1))X$ symmetry at electroweak scale, Phys. Rev. D **73**, 113004 (2006) [hep-ph/0605051].

- R. Foot, G. C. Joshi, H. Lew and R. R. Volkas, Charge quantization in the standard model and some of its extensions, Mod. Phys. Lett. A **5**, 2721 (1990).
- R. Foot, New Physics From Electric Charge Quantization?, Mod. Phys. Lett. A **6**, 527 (1991).
- J. Sladkowski and M. Zralek, Charge quantization in the standard model with the three generations of fermions, Phys. Rev. D **45**, 1701 (1992).
- M. Nowakowski and A. Pilaftsis, A Note on charge quantization through anomaly cancellation, Phys. Rev. D **48**, 259 (1993) [hep-ph/9304312].
- R. Foot, H. Lew and R. R. Volkas, Electric charge quantization, J. Phys. G **19**, 361 (1993) [Erratum-ibid. G **19**, 1067 (1993)] [hep-ph/9209259].
- A. G. Dias, J. C. Montero and V. Pleitez, Closing the $SU(3)_L \otimes U(1))X$ symmetry at electroweak scale, Phys. Rev. D **73**, 113004 (2006) [hep-ph/0605051].

- A. C. B. Machado, J. C. Montero and V. Pleitez, Flavor-changing neutral currents in the minimal 3-3-1 model revisited, Phys. Rev. D **88**, 113002 (2013) [arXiv:1305.1921 [hep-ph]].
- C. Promberger, S. Schatt and F. Schwab, Flavor Changing Neutral Current Effects and CP Violation in the Minimal 3-3-1 Model, Phys. Rev. D **75**, 115007 (2007) [hep-ph/0702169 [HEP-PH]].
- A. J. Buras, F. De Fazio, J. Girrbach and M. V. Carlucci, The Anatomy of Quark Flavour Observables in 331 Models in the Flavour Precision Era, JHEP **1302**, 023 (2013) [arXiv:1211.1237 [hep-ph]].
- K. S. Babu, A. Patra and S. K. Rai, New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider, Phys. Rev. D **88**, 055006 (2013) [arXiv:1306.2066 [hep-ph]].
- A. J. Buras and J. Girrbach, Towards the Identification of

- A. C. B. Machado, J. C. Montero and V. Pleitez, Flavor-changing neutral currents in the minimal 3-3-1 model revisited, Phys. Rev. D **88**, 113002 (2013) [arXiv:1305.1921 [hep-ph]].
- C. Promberger, S. Schatt and F. Schwab, Flavor Changing Neutral Current Effects and CP Violation in the Minimal 3-3-1 Model, Phys. Rev. D **75**, 115007 (2007) [hep-ph/0702169 [HEP-PH]].
- A. J. Buras, F. De Fazio, J. Girrbach and M. V. Carlucci, The Anatomy of Quark Flavour Observables in 331 Models in the Flavour Precision Era, JHEP **1302**, 023 (2013) [arXiv:1211.1237 [hep-ph]].
- K. S. Babu, A. Patra and S. K. Rai, New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider, Phys. Rev. D **88**, 055006 (2013) [arXiv:1306.2066 [hep-ph]].
- A. J. Buras and J. Girrbach, Towards the Identification of

- A. C. B. Machado, J. C. Montero and V. Pleitez, Flavor-changing neutral currents in the minimal 3-3-1 model revisited, Phys. Rev. D **88**, 113002 (2013) [arXiv:1305.1921 [hep-ph]].
- C. Promberger, S. Schatt and F. Schwab, Flavor Changing Neutral Current Effects and CP Violation in the Minimal 3-3-1 Model, Phys. Rev. D **75**, 115007 (2007) [hep-ph/0702169 [HEP-PH]].
- A. J. Buras, F. De Fazio, J. Girrbach and M. V. Carlucci, The Anatomy of Quark Flavour Observables in 331 Models in the Flavour Precision Era, JHEP **1302**, 023 (2013) [arXiv:1211.1237 [hep-ph]].
- K. S. Babu, A. Patra and S. K. Rai, New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider, Phys. Rev. D **88**, 055006 (2013) [arXiv:1306.2066 [hep-ph]].
- A. J. Buras and J. Girrbach, Towards the Identification of

- A. C. B. Machado, J. C. Montero and V. Pleitez, Flavor-changing neutral currents in the minimal 3-3-1 model revisited, Phys. Rev. D **88**, 113002 (2013) [arXiv:1305.1921 [hep-ph]].
- C. Promberger, S. Schatt and F. Schwab, Flavor Changing Neutral Current Effects and CP Violation in the Minimal 3-3-1 Model, Phys. Rev. D **75**, 115007 (2007) [hep-ph/0702169 [HEP-PH]].
- A. J. Buras, F. De Fazio, J. Girrbach and M. V. Carlucci, The Anatomy of Quark Flavour Observables in 331 Models in the Flavour Precision Era, JHEP **1302**, 023 (2013) [arXiv:1211.1237 [hep-ph]].
- K. S. Babu, A. Patra and S. K. Rai, New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider, Phys. Rev. D **88**, 055006 (2013) [arXiv:1306.2066 [hep-ph]].
- A. J. Buras and J. Girrbach, Towards the Identification of

- A. C. B. Machado, J. C. Montero and V. Pleitez, Flavor-changing neutral currents in the minimal 3-3-1 model revisited, Phys. Rev. D **88**, 113002 (2013) [arXiv:1305.1921 [hep-ph]].
- C. Promberger, S. Schatt and F. Schwab, Flavor Changing Neutral Current Effects and CP Violation in the Minimal 3-3-1 Model, Phys. Rev. D **75**, 115007 (2007) [hep-ph/0702169 [HEP-PH]].
- A. J. Buras, F. De Fazio, J. Girrbach and M. V. Carlucci, The Anatomy of Quark Flavour Observables in 331 Models in the Flavour Precision Era, JHEP **1302**, 023 (2013) [arXiv:1211.1237 [hep-ph]].
- K. S. Babu, A. Patra and S. K. Rai, New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider, Phys. Rev. D **88**, 055006 (2013) [arXiv:1306.2066 [hep-ph]].
- A. J. Buras and J. Girrbach, Towards the Identification of

- A. C. B. Machado, J. C. Montero and V. Pleitez, Flavor-changing neutral currents in the minimal 3-3-1 model revisited, Phys. Rev. D **88**, 113002 (2013) [arXiv:1305.1921 [hep-ph]].
- C. Promberger, S. Schatt and F. Schwab, Flavor Changing Neutral Current Effects and CP Violation in the Minimal 3-3-1 Model, Phys. Rev. D **75**, 115007 (2007) [hep-ph/0702169 [HEP-PH]].
- A. J. Buras, F. De Fazio, J. Girrbach and M. V. Carlucci, The Anatomy of Quark Flavour Observables in 331 Models in the Flavour Precision Era, JHEP **1302**, 023 (2013) [arXiv:1211.1237 [hep-ph]].
- K. S. Babu, A. Patra and S. K. Rai, New Signals for Doubly-Charged Scalars and Fermions at the Large Hadron Collider, Phys. Rev. D **88**, 055006 (2013) [arXiv:1306.2066 [hep-ph]].
- A. J. Buras and J. Girrbach, Towards the Identification of

- R. Gauld, F. Goertz and U. Haisch, An explicit Z'-boson explanation of the $B \to K^* \mu^+ \mu^-$ anomaly, JHEP **1401**, 069 (2014) [arXiv:1310.1082 [hep-ph]].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, arXiv:1310.4614 [hep-ph].
- A. J. Buras, F. De Fazio and J. Girrbach, 331 models facing new $b \to s\mu^+\mu^-$ data, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
- F. Richard, A Z-prime interpretation of $B_d \to K * mu^+ mu^-$ data and consequences for high energy colliders, arXiv:1312.2467 [hep-ph].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, PoS EPS **-HEP2013**, 339 (2013).
- A. J. Buras, F. De Fazio and J. Girrbach-Noe, $Z - Z'$ Mixing and Z-Mediated FCNCs in $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ Models, arXiv:1405.3850 [hep-ph].

- R. Gauld, F. Goertz and U. Haisch, An explicit Z'-boson explanation of the $B \to K^* \mu^+ \mu^-$ anomaly, JHEP **1401**, 069 (2014) [arXiv:1310.1082 [hep-ph]].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, arXiv:1310.4614 [hep-ph].
- A. J. Buras, F. De Fazio and J. Girrbach, 331 models facing new $b \to s\mu^+\mu^-$ data, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
- F. Richard, A Z-prime interpretation of $B_d \to K * mu^+ mu^-$ data and consequences for high energy colliders, arXiv:1312.2467 [hep-ph].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, PoS EPS **-HEP2013**, 339 (2013).
- A. J. Buras, F. De Fazio and J. Girrbach-Noe, $Z - Z'$ Mixing and Z-Mediated FCNCs in $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ Models, arXiv:1405.3850 [hep-ph].

- R. Gauld, F. Goertz and U. Haisch, An explicit Z'-boson explanation of the $B \to K^* \mu^+ \mu^-$ anomaly, JHEP **1401**, 069 (2014) [arXiv:1310.1082 [hep-ph]].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, arXiv:1310.4614 [hep-ph].
- A. J. Buras, F. De Fazio and J. Girrbach, 331 models facing new $b \to s\mu^+\mu^-$ data, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
- F. Richard, A Z-prime interpretation of $B_d \to K * mu^+ mu^-$ data and consequences for high energy colliders, arXiv:1312.2467 [hep-ph].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, PoS EPS **-HEP2013**, 339 (2013).
- A. J. Buras, F. De Fazio and J. Girrbach-Noe, $Z - Z'$ Mixing and Z-Mediated FCNCs in $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ Models, arXiv:1405.3850 [hep-ph].

- R. Gauld, F. Goertz and U. Haisch, An explicit Z'-boson explanation of the $B \to K^* \mu^+ \mu^-$ anomaly, JHEP **1401**, 069 (2014) [arXiv:1310.1082 [hep-ph]].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, arXiv:1310.4614 [hep-ph].
- A. J. Buras, F. De Fazio and J. Girrbach, 331 models facing new $b \to s\mu^+\mu^-$ data, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
- F. Richard, A Z-prime interpretation of $B_d \to K * mu^+ mu^-$ data and consequences for high energy colliders, arXiv:1312.2467 [hep-ph].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, PoS EPS **-HEP2013**, 339 (2013).
- A. J. Buras, F. De Fazio and J. Girrbach-Noe, $Z - Z'$ Mixing and Z-Mediated FCNCs in $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ Models, arXiv:1405.3850 [hep-ph].

- R. Gauld, F. Goertz and U. Haisch, An explicit Z'-boson explanation of the $B \to K^* \mu^+ \mu^-$ anomaly, JHEP **1401**, 069 (2014) [arXiv:1310.1082 [hep-ph]].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, arXiv:1310.4614 [hep-ph].
- A. J. Buras, F. De Fazio and J. Girrbach, 331 models facing new $b \to s\mu^+ \mu^-$ data, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
- F. Richard, A Z-prime interpretation of $B_d \to K * mu^+ mu^-$ data and consequences for high energy colliders, arXiv:1312.2467 [hep-ph].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, PoS EPS **-HEP2013**, 339 (2013).
- A. J. Buras, F. De Fazio and J. Girrbach-Noe, $Z - Z'$ Mixing and Z-Mediated FCNCs in $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ Models, arXiv:1405.3850 [hep-ph].

- R. Gauld, F. Goertz and U. Haisch, An explicit Z'-boson explanation of the $B \to K^* \mu^+ \mu^-$ anomaly, JHEP **1401**, 069 (2014) [arXiv:1310.1082 [hep-ph]].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, arXiv:1310.4614 [hep-ph].
- A. J. Buras, F. De Fazio and J. Girrbach, 331 models facing new $b \to s\mu^+\mu^-$ data, JHEP **1402**, 112 (2014) [arXiv:1311.6729 [hep-ph], arXiv:1311.6729].
- F. Richard, A Z-prime interpretation of $B_d \to K * mu^+ mu^-$ data and consequences for high energy colliders, arXiv:1312.2467 [hep-ph].
- F. De Fazio, Quark flavour observables in 331 models in the flavour precision era, PoS EPS **-HEP2013**, 339 (2013).
- A. J. Buras, F. De Fazio and J. Girrbach-Noe, $Z - Z'$ Mixing and Z-Mediated FCNCs in $SU(3)_C \otimes SU(3)_L \otimes U(1)_X$ Models, arXiv:1405.3850 [hep-ph].

- S. M. Boucenna, S. Morisi and J. W. F. Valle, Radiative neutrino mass in 331 scheme, Phys. Rev. D **90**, 013005 (2014) [arXiv:1405.2332 [hep-ph]].
- B. Acharya *et al.* [MoEDAL Collaboration], The Physics Programme Of The MoEDAL Experiment At The LHC arXiv:1405.7662 [hep-ph].

- S. M. Boucenna, S. Morisi and J. W. F. Valle, Radiative neutrino mass in 331 scheme, Phys. Rev. D **90**, 013005 (2014) [arXiv:1405.2332 [hep-ph]].
- B. Acharya *et al.* [MoEDAL Collaboration], The Physics Programme Of The MoEDAL Experiment At The LHC arXiv:1405.7662 [hep-ph].