Inverse seesaw, g-2 and parity violation in some models for physics beyond the Standard Model

Yohan Mauricio Oviedo Torres
Doutorando

Universidade Federal da Paraíba
Particle and Astroparticle Group (IIP-UFRN)

25 June 2021
PhenoBR2021

Overview

$\mathbf{331}_{\nu RH}$ + Inverse Seesaw Mechanism [10.1016/j.physletb.2020.135931]

Muon g-2 Anomaly in 341 Model [10.1142/S0217751X20501262]

Parity Violation in 2HDM+$U(1)_X$: Some comments

The model: Some essential points

The model structure is based on the gauge group $G = SU(3)_c \times SU(3)_L \times U(1)_N$. The fermions are assigned to the following irreducible representations under G

$$L_{aL} = \begin{pmatrix} \nu_a \\ l_a \\ \nu_a^C \end{pmatrix}_L \sim \left(1, 3, -\frac{1}{3}\right) \tag{1}$$

$$l_R^a \sim (1, 1, -1)\,,\, N_L^a \sim (1, 1, 0) \tag{2}$$

$$Q_{iL} = \begin{pmatrix} d_i \\ -u_i \\ d'_i \end{pmatrix}_L \sim (3, 3^*, 0) \tag{3}$$

$$u_R^i \sim \left(3, 1, \frac{2}{3}\right), d_R^i \sim \left(3, 1, -\frac{1}{3}\right), d'^i_R \sim \left(3, 1, -\frac{1}{3}\right) \tag{4}$$

where $a = 1, 2, 3$ and $i = 1, 2$ while the third family will transform as triplet

$$Q_{3L} = \begin{pmatrix} u_3 \\ d_3 \\ T \end{pmatrix}_L \sim \left(3, 3, \frac{1}{3}\right) \tag{5}$$

$$u_R^3 \sim \left(3, 1, \frac{2}{3}\right), d_R^3 \sim \left(3, 1, \frac{2}{3}\right), T_R \sim \left(3, 1, -\frac{2}{3}\right) \tag{6}$$

The scalar sector is

$$\eta = \begin{pmatrix} \eta^0 \\ \eta^- \\ \eta'^0 \end{pmatrix} \sim \left(1, 3, -\frac{1}{3}\right), \rho = \begin{pmatrix} \rho^+ \\ \rho^0 \\ \rho'^+ \end{pmatrix} \sim \left(1, 3, \frac{2}{3}\right), \chi = \begin{pmatrix} \chi^0 \\ \chi^- \\ \chi'^0 \end{pmatrix} \sim \left(1, 3, -\frac{1}{3}\right) \tag{7}$$

The Yukawa interactions are

$$-\mathcal{L}^Y = f_{ij}\overline{Q_{iL}}\chi^* d'_{jR} + f_{33}\overline{Q_{3L}}\chi T_R + g_{ia}\overline{Q_{iL}}\eta^* d_{aR} + h_{3a}\overline{Q_{3L}}\eta u_{aR} + g_{3a}\overline{Q_{3L}}\rho d_{aR} + h_{ia}\overline{Q_{iL}}\rho^* u_{aR}$$

$$+y_a\overline{L_{aL}}\rho e_{aR} - \frac{1}{2}G_{ab}\epsilon_{lmn}\overline{(L_{aL})^C_l}\rho^*_m (L_{bl})_n + G'_{ab}\overline{(L_{aL})}\chi (N_{bl})^C + \frac{1}{2}\overline{(N_L)^C}\mu N_L + h.c. \tag{8}$$

where $a, b = 1, 2, 3$, $i, j = 1, 2$ and $l, m, n = 1, 2, 3$. We assume that only η^0, ρ^0 and χ'^0 develop vaccum expectation values (VEVs). The last terms in the Yukawa lagrangian above provides the following mass terms for the neutrinos

$$\mathcal{L}_{\nu mass} = \overline{\nu_R} m_D \nu_L + \overline{\nu_R} M N_L + \frac{1}{2}\overline{(N_L)^C}\mu N_L + h.c. \tag{9}$$

where $M_{ab} = v_{\chi'} G'_{ab}/\sqrt{2}$ and $m_{Dab} = v_\rho G_{ab}/\sqrt{2}$. The hierarchy is $\mu << m_D << M$.

Considering the basis $S_L = \left(\nu_L, \overline{\nu^C}, N_L\right)^T = (\nu_L, \zeta_L)^T$, we can write

$$\mathcal{L}_{\nu mass} = \frac{1}{2}\overline{(S_L)^C} M_\nu S_L + h.c. \tag{10}$$

where

$$M_{\nu 9\times 9} = \begin{pmatrix} 0_{3\times 3} & \mathcal{M}_{D3\times 6}^T \\ \mathcal{M}_{D6\times 3} & \mathcal{M}_{R6\times 6} \end{pmatrix} \tag{11}$$

and

$$\mathcal{M}_{D6\times 3} = \begin{pmatrix} m_{D3\times 3} \\ 0_{3\times 3} \end{pmatrix}, \mathcal{M}_{R6\times 6} = \begin{pmatrix} 0_{3\times 3} & M_{3\times 3}^T \\ M_{3\times 3} & \mu_{3\times 3} \end{pmatrix} \tag{12}$$

We need to diagonalize $\mathcal{M}_D$. For this purpose we use the matrix W (first diagonalization)

$$W \simeq \begin{pmatrix} 1 - \frac{1}{2}(\mathcal{M}_D)^\dagger \left[\mathcal{M}_R(\mathcal{M}_R)^\dagger\right]^{-1} \mathcal{M}_D & (\mathcal{M}_D)^\dagger \left[(\mathcal{M}_R)^\dagger\right]^{-1} \\ -(\mathcal{M}_R)^{-1}\mathcal{M}_D & 1 - \frac{1}{2}(\mathcal{M}_R)^{-1}\mathcal{M}_D(\mathcal{M}_D)^\dagger \left[(\mathcal{M}_R)^\dagger\right]^{-1} \end{pmatrix} \tag{13}$$

$$W^T M_\nu W \approx \begin{pmatrix} m_{light} & 0 \\ 0 & m_{heavy} \end{pmatrix} \tag{14}$$

where $m_{light} = -\mathcal{M}_D^T \mathcal{M}_R^{-1} \mathcal{M}_D$ and $m_{heavy} = \mathcal{M}_R$. Then we use the matrix U for a second diagonalization

$$U = \begin{pmatrix} U_{PMNS} & 0 \\ 0 & U_R \end{pmatrix} \tag{15}$$

Then we finally have $V = WU$, so

$$U^T W^T M_\nu W U = \begin{pmatrix} m_\nu & 0 \\ 0 & m_R \end{pmatrix} \tag{16}$$

with $m_\nu = diag\,(m_1, m_2, m_3)$ and $m_R = diag\,(m_4, ..., m_9)$. The matrix V connects the flavor basis $S_L = \left(\nu_L, \overline{\nu^C}, N_L\right)^T$ = $(\nu_L, \zeta_L)^T$ with the physical one which we call $n_L = \left(n^0_{iL}, n^1_{kL}\right)^T$ where $i = 1, 2, 3$ and $k = 1, ..., 6$.

So the relation between flavor and mass eigenstates, $S_L = Vn_L$ is

$$\nu_{aL} = \left\{ U_{PMNS} - \frac{1}{2}(\mathcal{M}_D)^\dagger \left[\mathcal{M}_R(\mathcal{M}_R)^\dagger\right]^{-1} \mathcal{M}_D U_{PMNS} \right\}_{ai} n^0_{iL} + \left\{ (\mathcal{M}_D)^\dagger \left[(\mathcal{M}_R)^\dagger\right]^{-1} U_R \right\}_{ak} n^1_{kL} \quad (17)$$

$$\zeta_{bL} = \left\{ \left[-(\mathcal{M}_R)^{-1}\mathcal{M}_D\right] U_{PMNS} \right\}_{bi} n^0_{iL} + \left\{ U_R - \frac{1}{2}(\mathcal{M}_R)^{-1}\mathcal{M}_D(\mathcal{M}_D)^\dagger \left[(\mathcal{M}_R)^\dagger\right]^{-1} U_R \right\}_{bk} n^1_{kL} \quad (18)$$

So, How do we get the values of the mass matrices that appear in the currents that involve neutrinos? We know that $M_{ab} = v_{\chi'} G'_{ab}/\sqrt{2}$, $m_{Dab} = v_\rho G_{ab}/\sqrt{2}$ and $m_{light} = m_D^T M^{-1} \mu \left(M^T\right)^{-1} m_D$, so

$$m_{light} = a\left(\frac{v_\rho}{v_{\chi'}}\right)^2 G^T G'^{-1} \left(G'^T\right)^{-1} G \quad (19)$$

We use μ diagonal ($\mu = aI$) with $a = 0.3keV$, $v_\rho = 174GeV$ and $v_{\chi'} = 5TeV$. We known

$$U^T_{PMNS} m_{light} U_{PMNS} = m_\nu = a\left(\frac{v_\rho}{v_{\chi'}}\right)^2 U^T_{PMNS} G^T G'^{-1} \left(G'^T\right)^{-1} G U_{PMNS} \quad (20)$$

If

$$G' = \begin{pmatrix} g'_{11} & 0 & 0 \\ 0 & g'_{22} & 0 \\ 0 & 0 & {g'}_{33} \end{pmatrix} \tag{21}$$

$$G = \begin{pmatrix} 0 & g_{12} & g_{13} \\ -g_{12} & 0 & g_{23} \\ -g_{13} & -g_{23} & 0 \end{pmatrix} \tag{22}$$

we have

$$F = G^T G'^{-1} \left(G'^T \right)^{-1} G = \begin{pmatrix} \frac{g_{12}{}^2}{g'_{22}{}^2} + \frac{g_{13}{}^2}{g'_{33}{}^2} & \frac{g_{13} g_{23}}{g'_{33}{}^2} & -\frac{g_{12} g_{23}}{{g'}_{22}{}^2} \\ \frac{g_{13} g_{23}}{g'_{33}{}^2} & \frac{g_{12}{}^2}{g'_{11}{}^2} + \frac{g_{23}{}^2}{g'_{33}{}^2} & \frac{g_{12} g_{13}}{{g'}_{11}{}^2} \\ -\frac{g_{12} g_{23}}{{g'}_{22}{}^2} & \frac{g_{12} g_{13}}{{g'}_{11}{}^2} & \frac{g_{13}{}^2}{g'_{11}{}^2} + \frac{g_{23}{}^2}{g'_{22}{}^2} \end{pmatrix} = \begin{pmatrix} 0.0101 & 0.0186 & 0.0026 \\ 0.0186 & 0.0716 & 0.0573 \\ 0.0026 & 0.0573 & 0.0744 \end{pmatrix} \tag{23}$$

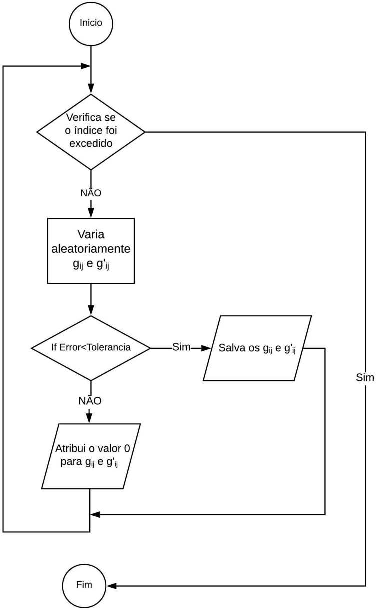

FIGURE 1: Monte Carlo Algorithm for the problem.

Results:

$$G' = \begin{pmatrix} 0.019 & 0 & 0 \\ 0 & 0.07 & 0 \\ 0 & 0 & 0.04 \end{pmatrix} \tag{24}$$

$$G = \begin{pmatrix} 0 & 4.26 \times 10^{-3} & 4.97 \times 10^{-3} \\ -4.26 \times 10^{-3} & 0 & 6.62 \times 10^{-3} \\ -4.97 \times 10^{-3} & -6.62 \times 10^{-3} & 0 \end{pmatrix} \tag{25}$$

Finally, we can calculate all the mixing matrices and the masses of the six heavy neutrinos (degenerates)!
$m\left(n^1_{1L}, n^1_{6L}\right) \approx 373.28 GeV$, $m\left(n^1_{2L}, n^1_{5L}\right) \approx 220.84 GeV$ and $m\left(n^1_{3L}, n^1_{4L}\right) \approx 96.32 GeV$

The 3-4-1 Model is an electroweak extension of the SM, which is based on $SU(3)_C \times SU(4)_L \times U(1)_X$ gauge symmetry. This 3-4-1 model is a natural extenion of the $SU(3)_C \times SU(3)_L \times U(1)_X$ symmetry. 3-4-1 models embed these 3-3-1 models and therefore, we naturally inherit these features. The most general expression for the electric charge operator in the case of the $SU(4)_L \times U(1)_X$ symmetry is given by:

$$Q = aT_{3L} + \frac{b}{\sqrt{3}} T_{8L} + \frac{c}{\sqrt{6}} T_{15L} + XI_4 \tag{26}$$

The different values of a, b, c allow us to set the fermion and scalar multiplets as well as the gauge boson content. We explore three models.

$SU(4)_L \times U(1)_X$: Model A

$$f_{aL} = \begin{pmatrix} \nu_\alpha \\ l_\alpha \\ \nu_\alpha^C \\ l_\alpha^C \end{pmatrix}_L \sim (1, 4, 0)\, , Q_{1L} = \begin{pmatrix} u_1 \\ d_1 \\ u' \\ J \end{pmatrix}_L \sim (3, 4, 2/3)\, , Q_{iL} = \begin{pmatrix} j_i \\ d'_i \\ u_i \\ d_i \end{pmatrix}_L \sim (4, 4^*, -1/3) \tag{27}$$

where $\alpha = 1, 2, 3$ and $i = 1, 2$. In this model is necessary the introduction of four scalar multiplets transforming as **4** and one scalar multiplet transforming as 10^*. After the diagonalization procedure we can define the physical charged gauge boson and then writte the charged and neutral current parts of the lagrangian as

$$\mathcal{L}^{CC} \supset -\frac{g}{2\sqrt{2}}[\overline{\nu}\gamma^{\mu}\left(1-\gamma_5\right)\mu W^{+}_{\mu} + \overline{\nu^{C}}\gamma^{\mu}\left(1-\gamma_5\right)\mu V^{+}_{1\mu} + \overline{\mu^{C}}\gamma^{\mu}\left(1-\gamma_5\right)\nu V^{+}_{2\mu}$$

$$+\overline{\mu^{C}}\gamma^{\mu}\left(1-\gamma_5\right)\nu^{C} V^{+}_{3\mu} + \overline{\mu^{C}}\gamma^{\mu}\left(1-\gamma_5\right)\mu U^{++}_{\mu} + h.c.] \tag{28}$$

$$\mathcal{L}^{NC} \supset -\frac{g}{2C_w}\left(\overline{l_L}\gamma^{\mu} l_L \alpha + \overline{l_R}\gamma^{\mu} l_R \beta\right) Z_{n\mu} \tag{29}$$

Exist other contributions to g-2 coming from charged and neutral scalars that would be derived from the Yukawa Lagrangian

$$-\mathcal{L}_{Yuk} \supset \frac{1}{2} G_{ab}\overline{f^{C}_{aL}} f_{bL} H \tag{30}$$

This mean that the scalars couple to leptons proportionally to their masses. Their contributions to $g-2$ is suppressed.

$$M_n^2 = \frac{g^2}{4}\lambda_n V_\chi^2, M_W^2 = \frac{g^2}{4}\left(4v_1^2\right), M_{V_{1,2}}^2 = \frac{g^2}{4}\left(3v_1^2 + V_\chi^2\right)$$

$$M_{V_3}^2 = \frac{g^2}{4}\left(2v_1^2 + 2V_\chi^2\right), M_{U^{++}}^2 = \frac{g^2}{4}\left(9v_1^2 + V_\chi^2\right) \tag{31}$$

$SU(4)_L \times U(1)_X$: Model B

$$f_{\alpha L} = \begin{pmatrix} l_\alpha \\ \nu_\alpha \\ N_\alpha \\ {N'}_\alpha \end{pmatrix}_L \sim (1, 4^*, -1/2), Q_{iL} = \begin{pmatrix} u_i \\ d_i \\ D_i \\ {D'}_i \end{pmatrix}_L \sim (3, 4, -1/6), Q_{3L} = \begin{pmatrix} d_3 \\ u_3 \\ U \\ U' \end{pmatrix}_L \sim (3, 4^*, 5/6) \tag{32}$$

where $\alpha = 1, 2, 3$ and $i = 1, 2$. The interactions that contribute to the anomaly in this model are

$$\mathcal{L}_l^{CC} \supset -\frac{g}{\sqrt{2}}\left(\overline{N_L^0}\gamma^\mu \mu_L K_\mu^+ + \overline{{N'}_L^0}\gamma^\mu \mu_L X_\mu^+ + h.c.\right) \tag{33}$$

$$\mathcal{L}^{NC} \supset \overline{\mu}\gamma^\mu\left(g_v - g_A\gamma^5\right)\mu {Z'}_\mu \tag{34}$$

where

$$g_V = -\frac{g}{2C_w}\frac{1-3S_w^2}{\sqrt{3C_w^2-1}}, g_A = -\frac{g}{2C_w}\frac{C_w^2}{\sqrt{3C_w^2-1}} \tag{35}$$

The mass eigenvalues of the gauge bosons we are interested here are:

$$M^2_{K^\pm} = \frac{g^2}{2}\left(V^2 + v'^2\right), M^2_{X^\pm} = \frac{g^2}{2}\left(V'^2 + v'^2\right), M^2_{Z'} = \frac{g^2}{4}V^2 \tag{36}$$

$SU(4)_L \times U(1)_X$: Model C

$$f_{\alpha L} = \begin{pmatrix} \nu_\alpha \\ l_\alpha \\ E^-_\alpha \\ E'^-_\alpha \end{pmatrix}_L \sim (1, 4, -3/4), Q_{iL} = \begin{pmatrix} d'_i \\ u_i \\ U_i \\ U'_i \end{pmatrix}_L \sim (3, 4^*, 5/12), Q_{3L} = \begin{pmatrix} u_3 \\ d_3 \\ D_3 \\ D'_3 \end{pmatrix}_L \sim (3, 4, -1/12) \tag{37}$$

$$\mathcal{L}^{CC} \supset -\frac{g}{2\sqrt{2}}\left(\overline{\mu}\gamma^\mu\left(1-\gamma^5\right)EK^0_\mu + \overline{\mu}\gamma^\mu\left(1-\gamma^5\right)E'X^0_\mu\right) + h.c. \tag{38}$$

$$\mathcal{L}^{NC} \supset \bar{l}\gamma^\mu\left(g'_V - g'_A\gamma^5\right)lZ'_\mu \tag{39}$$

where

$$g'_V = \frac{g}{2C_W}\frac{1/2 + S_W^2}{\sqrt{2-3S_W^2}}, g'_A = -\frac{g}{2C_W}\frac{C_{2W}}{2\sqrt{2-3S_W^2}} \tag{40}$$

and

$$M_{W^\pm}^2 = \frac{g^2}{2}\left(v_3^2 + v'^2\right), M_{K^0}^2 = \frac{g^2}{2}\left(v_3^2 + V^2\right), M_{X^0}^2 = \frac{g^2}{2}\left(v_3^2 + V_\chi^2\right) \tag{41}$$

Contributions to g-2

[10.1016/j.physrep.2017.12.001]

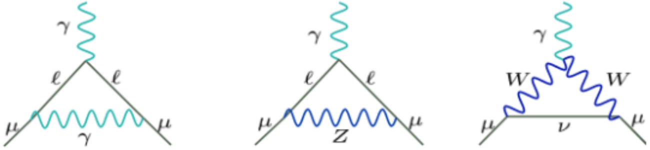

FIGURE 2: Feynman diagrams of the corrections to g-2 on SMEW interactions.

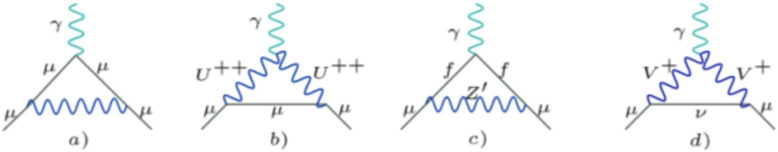

FIGURE 3: Feynman diagrams of the corrections to g-2 on 341 interactions

Neutral Scalar

$$\frac{1}{2}(g-2)=\Delta a_\mu(\phi)=\frac{1}{8\pi^2}\frac{m_\mu^2}{m_\phi^2}\int_0^1 dx\sum_f\frac{\left(g_{s1}^{f\mu}\right)^2 P_1^+(x)+\left(g_{p1}^{f\mu}\right)^2 P_1^-(x)}{(1-x)\left(1-x\lambda^2\right)+x\epsilon_f^2\lambda^2} \tag{42}$$

where

$$P_1^{\pm}(x)=x^2\left(1-x\pm\epsilon_f\right),\epsilon_f=\frac{m_f}{m_\mu},\lambda=\frac{m_\mu}{m_\phi} \tag{43}$$

Singly Charged Scalar

$$\frac{1}{2}(g-2)=\Delta a_\mu\left(\phi^+\right)=-\frac{1}{8\pi^2}\frac{m_\mu^2}{m_{\phi^+}^2}\int_0^1 dx\sum_f\frac{\left(g_{s2}^{f\mu}\right)^2 P_2^+(x)+\left(g_{p2}^{f\mu}\right)^2 P_2^-(x)}{\epsilon_f^2\lambda^2(1-x)\left(1-x\epsilon_f^{-2}\right)+x} \quad (44)$$

where

$$P_2^\pm(x)=x(1-x)\left(x\pm\epsilon_f\right),\ \epsilon_f=\frac{m_{\nu_f}}{m_\mu},\ \lambda=\frac{m_\mu}{m_{\phi^+}} \quad (45)$$

Doubly Charged Scalar

$$\frac{1}{2}(g-2)=\Delta a_\mu\left(\phi^{++}\right)=-\frac{1}{\pi^2}\frac{m_\mu^2}{m_{\phi^{++}}^2}\int_0^1 dx\sum_f\frac{\left(g_{s3}^{f\mu}\right)^2 P_2^+(x)+\left(g_{p3}^{f\mu}\right)^2 P_2^-(x)}{\epsilon_f^2\lambda^2(1-x)\left(1-x\epsilon_f^{-2}\right)+x}-$$

$$-\frac{1}{2\pi^2}\frac{m_\mu^2}{m_{\phi^{++}}^2}\int_0^1 dx\sum_f\frac{\left(g_{s3}^{f\mu}\right)^2 P_1^+(x)+\left(g_{p1}^{f\mu}\right)^2 P_1^-(x)}{(1-x)\left(1-x\lambda^2\right)+x\epsilon_f^2\lambda^2} \quad (46)$$

where

$$\epsilon_f = \frac{m_f}{m_\mu}, \lambda = \frac{m_\mu}{m_{\phi^{++}}} \tag{47}$$

Neutral Fermion - Charged Gauge Boson

$$\frac{1}{2}(g-2) = \Delta a_\mu \left(N, W'\right) = -\frac{1}{8\pi^2}\frac{m_\mu^2}{m_{W'}^2}\int_0^1 dx \sum_f \frac{\left(g_{v1}^{f\mu}\right)^2 P_3^+(x) + \left(g_{a1}^{f\mu}\right)^2 P_3^-(x)}{\epsilon_f^2\lambda^2(1-x)\left(1-x\epsilon_f^{-2}\right)+x} \tag{48}$$

$$P_3^\pm(x) = -2x^2\left(1+x\mp 2\epsilon_f\right) + \lambda^2 x\,(1-x)\left(1\mp\epsilon_f\right)^2\left(x\pm\epsilon_f\right) \tag{49}$$

with

$$\epsilon_f = \frac{m_{N_f}}{m_\mu}, \lambda = \frac{m_\mu}{m_{W'}} \tag{50}$$

Singly Charged Fermion - Neutral Gauge Boson

$$\frac{1}{2}(g-2)=\Delta a_\mu\left(E,Z'\right)=\frac{1}{8\pi^2}\frac{m_\mu^2}{m_{Z'}^2}\int_0^1 dx\sum_f\frac{\left(g_{v2}^{f\mu}\right)^2 P_4^+(x)+\left(g_{a2}^{f\mu}\right)^2 P_4^-(x)}{(1-x)\left(1-x\lambda^2\right)+x\epsilon_f^2\lambda^2} \tag{51}$$

$$P_4^\pm(x)=2x(1-x)\left(x-2\pm 2\epsilon_f\right)+\lambda^2x^2\left(1\mp\epsilon_f\right)^2\left(1-x\pm\epsilon_f\right) \tag{52}$$

$$\epsilon_f=\frac{m_{E_f}}{m_\mu},\lambda=\frac{m_\mu}{m_{Z'}} \tag{53}$$

Charged Fermion - Doubly Charged Vector Boson

$$\frac{1}{2}(g-2)=\Delta a_\mu\left(U^{++}\right)=\frac{1}{\pi^2}\frac{m_\mu^2}{m_{U^{++}}^2}\int_0^1 dx\sum_f\frac{\left(g_{v4}^{f\mu}\right)^2 P_3^+(x)+\left(g_{a4}^{f\mu}\right)^2 P_3^-(x)}{\epsilon_f^2\lambda^2(1-x)\left(1-x\epsilon_f^{-2}\right)+x}-$$

$$-\frac{1}{2\pi^2}\frac{m_\mu^2}{m_{U^{++}}^2}\int_0^1 dx\sum_f\frac{\left(g_{v4}^{f\mu}\right)^2 P_4^+(x)+\left(g_{a4}^{f\mu}\right)^2 P_4^-(x)}{(1-x)\left(1-x\lambda^2\right)+x\epsilon_f^2\lambda^2} \tag{54}$$

$$\epsilon_f=\frac{m_f}{m_\mu},\lambda=\frac{m_\mu}{m_U} \tag{55}$$

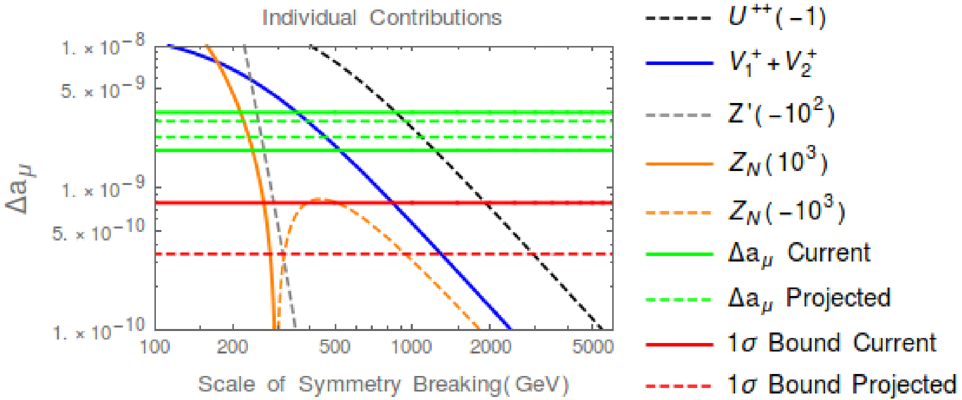

FIGURE 4: Individual contributions (Model A)

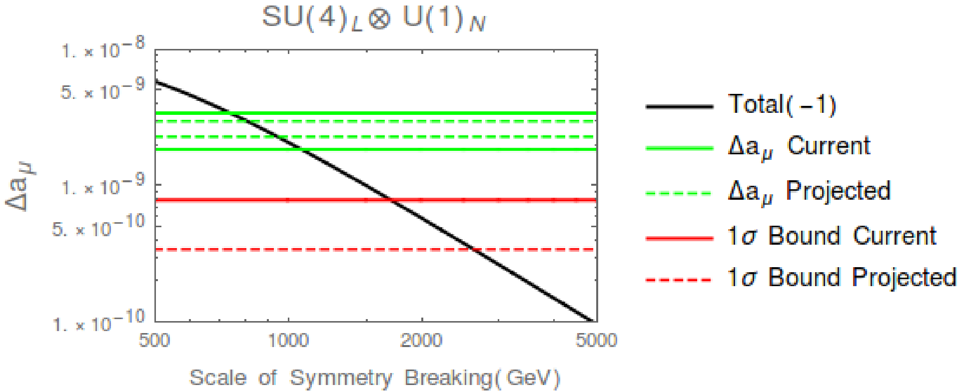

FIGURE 5: Total contributions (Model A)

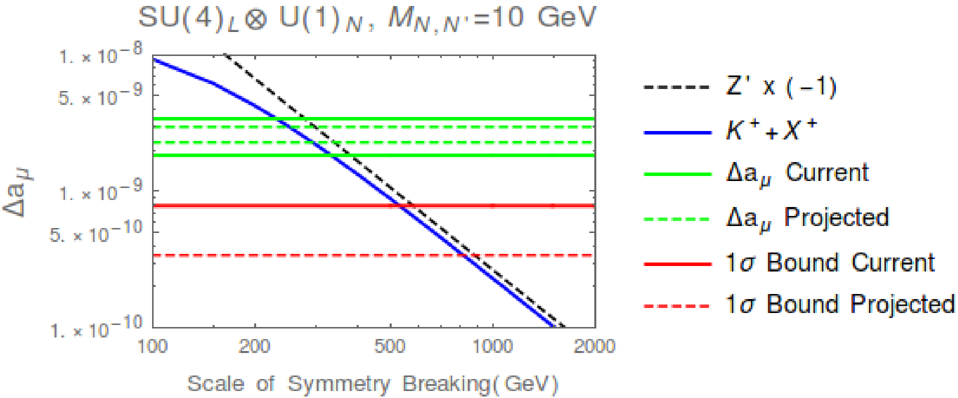

FIGURE 6: Individual contributions (Model B)

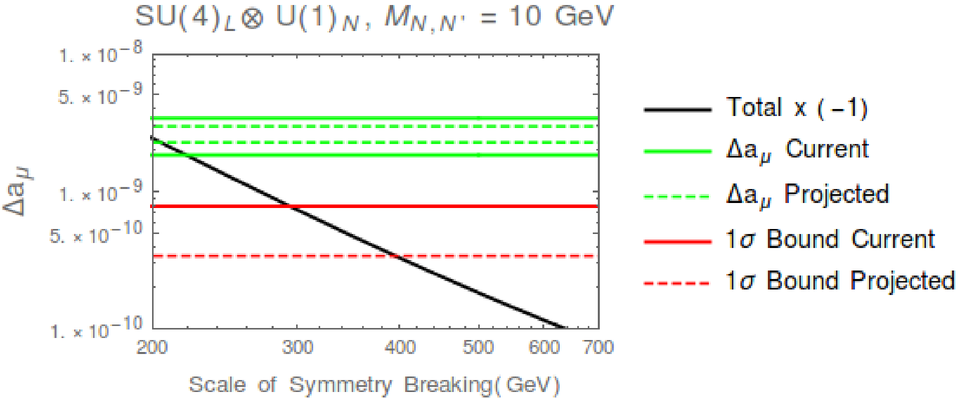

FIGURE 7: Total contributions (Model B)

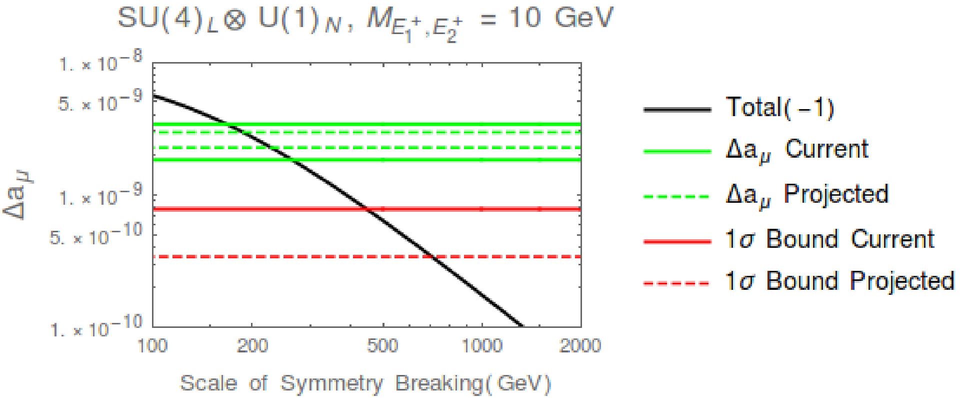

FIGURE 8: Individual contributions (Model C)

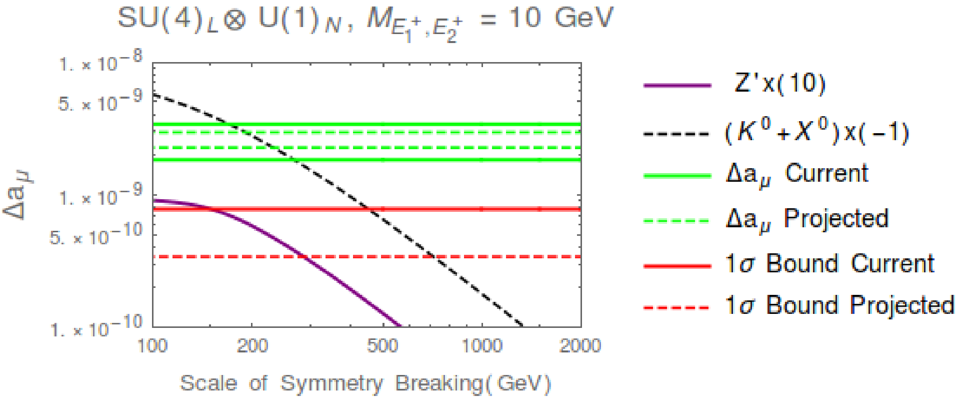

FIGURE 9: Total contributions (Model C)

$$2HDM + U(1)_X$$

$$\Downarrow$$

$$Q_W^{Exp} \neq Q_W^{SM}$$

$$\Downarrow$$

$$Q_W^{Exp} = Q_W^{SM} + Q_W^{BSM}$$

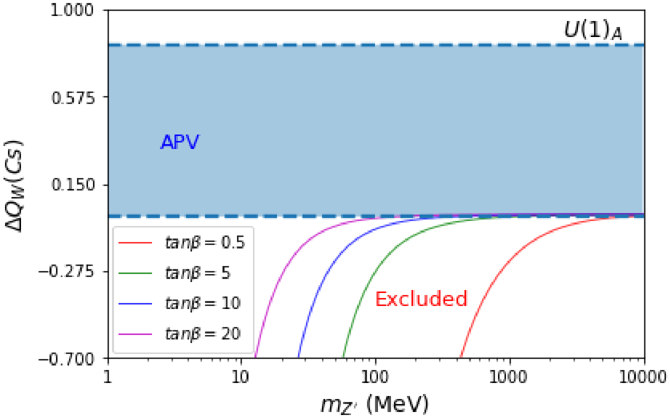

FIGURE 10: APV in 2HDM+$U(1)_A$

Thank You!