Implications of the Muon Anomalous Magnetic Moment for 3-3-1 models

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Introduction

The Dirac equation predicts at tree level the muon magnetic moment of any charged fermion as follows, $\vec{\mu_\mu} = g_\mu \frac{q}{2m_\mu}\vec{S}$, where $g_\mu = 2$ is the gyromagnetic ratio, m_μ, q and S are the muon mass, the electric charge and the spin respectively. However, through quantum corrections at the loop $g_\mu \neq 2$, leading us to define the **Muon Anomalous Magnetic Moment** as $a_\mu \equiv \frac{g_\mu - 2}{2}$.

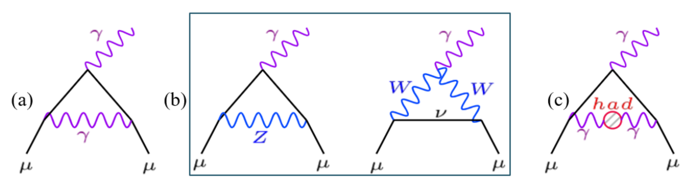


Figure 1: *Feynman diagrams of the corrections to a_μ on SM interactions: (a) 1^{st} order QED; lowest-order (b) weak and (c) hadronic effects.*

The current discrepancy between the experimental and the theoretical values of the a_μ showing that the behavior of muons is in a way not predicted by the Standard Model (SM) ($\Delta a_\mu = 251(59)\times 10^{-11}$ $(4.2\sigma) - 2021$[1]). Therefore, it is of great interest to analyze the effects of new particles contributing to $g_\mu - 2$ through virtual loops. Consequently, we will explore new physics contributions to a_μ in models focused on the $\mathbf{SU(3)_C \times SU(3)_L \times U(1)_X}$ gauge symmetry.

3-3-1 models

There are models based on $\mathcal{G}_{3-3-1} = \mathbf{SU(3)_C \times SU(3)_L \times U(1)_X}$ (3-3-1) gauge symmetry: Minimal [2], with right-handed neutrinos (r.h.n) [3], with neutral lepton(LHN) [4], economical [5] and with exotic leptons [6]. These models are quite popular, because they can explain: neutrino masses, dark matter, meson oscillations, flavor violation, collider physics.

The scalar sector

The 3-3-1 models contain between 2 or 3 scalar triplets (χ, η, ρ) to give the masses of the fermions. The 3-3-1 gauge symmetry experiences the following spontaneous symmetry breaking:

$$\textbf{SSB: } \mathbf{SU(3)_L \times U(1)_X} \xrightarrow{\langle\chi\rangle} \mathbf{SU(2)_L \times U(1)_Y} \xrightarrow{\langle\eta\rangle,\langle\rho\rangle} \mathbf{U(1)_Q}.$$

with VEV different scales: $v_\chi \gg v_\eta, v_\rho$.

The leptonic sector

The 3-3-1 models contain fermionic triplets f_L^a,

Minimal 3-3-1 Model: $f_L^a = \begin{pmatrix} \nu^a \\ \ell^a \\ (\ell^c)^a \end{pmatrix}$, **3-3-1 L.H.N**: $f_L^a = \begin{pmatrix} \nu^a \\ \ell^a \\ N^a \end{pmatrix}; \ell_R \quad N_R^a$,

3-3-1 r.h.n and Economical models: $f_L^a = \begin{pmatrix} \nu^a \\ \ell^a \\ (\nu^c)^a \end{pmatrix}; \ell_R$

3-3-1 with Exotic Leptons:

$$f_{1L} = \begin{pmatrix} \nu_1 \\ \ell_1 \\ E_1^- \end{pmatrix}; l_1^c; f_{2,3L} = \begin{pmatrix} \nu_{2,3} \\ \ell_{2,3} \\ N_{2,3} \end{pmatrix}; l_{2,3}^c \quad f_{4L} = \begin{pmatrix} E_2^- \\ N_3 \\ N_4 \end{pmatrix}; E_2^c; f_{5L} = \begin{pmatrix} N_5 \\ E_3^+ \\ \ell_3^+ \end{pmatrix}; E_3^c$$

Where $a = 1, 2, 3$ is the generation index, ν and ℓ are the SM leptonic particles, ν^c is the r.h.n. In the 3-3-1 L. H. N model, N is the heavy neutral lepton, and in the 3-3-1 with Exotic Leptons model N and E are the exotic neutral and charged leptons, respectively.

The relevant interactions to Muon Anomalous Magnetic Moment

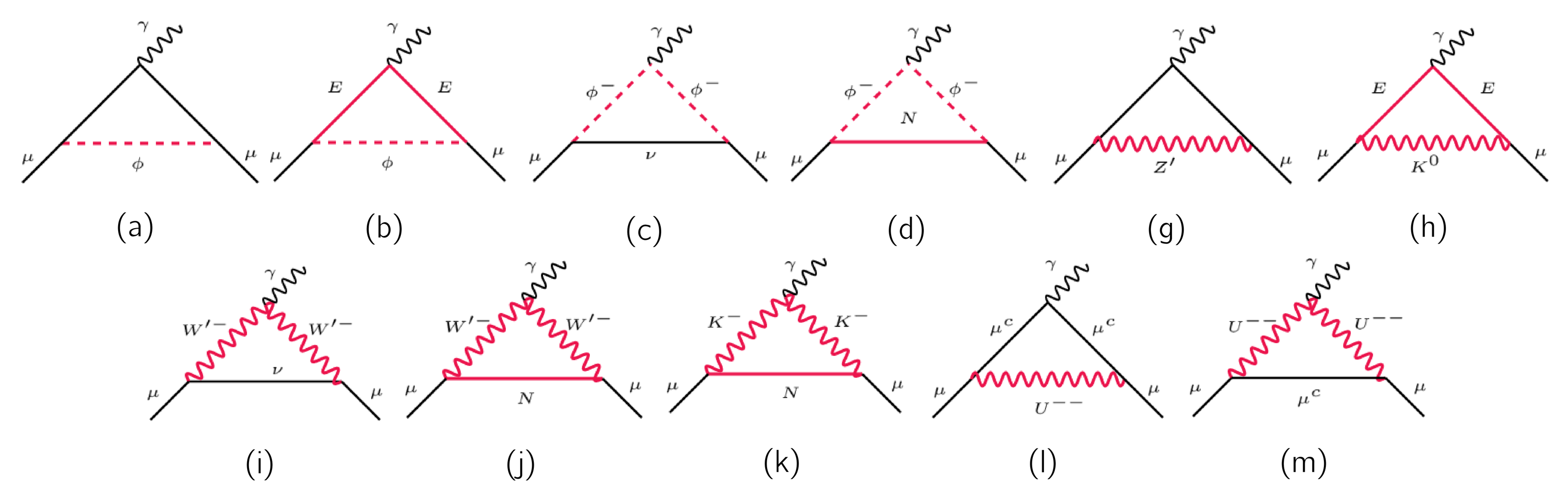


Figure 2: *Feynman diagrams that illustrate the new gauge boson and new scalar field interactions with leptons that contribute to the $g_\mu - 2$ in the 3-3-1 models investigated in this work. Where $U^{\pm\pm}$, W'^-, K^-, K^0 and Z' are new gauge bosons, and ϕ and ϕ^- stand for the new neutral and singly charged scalar fields in the 3-3-1 models.*

Results

We make our *Mathematica numerical codes* of the analytical expressions to Δa_μ corresponding to the 3-3-1 models available at `https://bit.ly/2vFZLnG`.

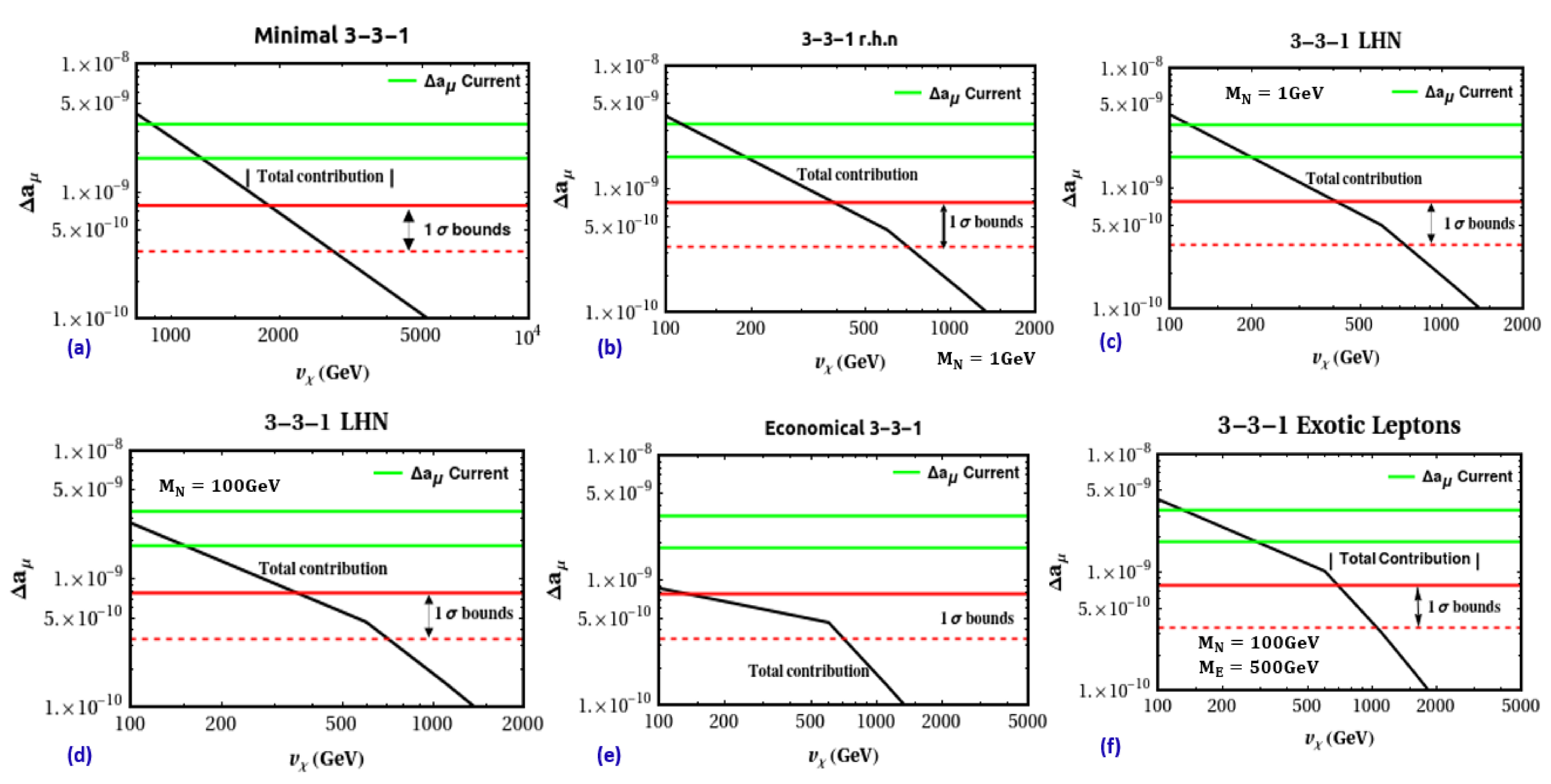


Figure 3: *Overall contribution to Δa_μ from the 3-3-1 models: (a) Minimal 3-3-1, (b) 3-3-1 r.h.n, (c) and (d) 3-3-1 L.H.N for $M_N = 1GeV$ and $M_N = 100GeV$ respectively, (e) Economical 3-3-1 and (f) 3-3-1 with exotic leptons for $M_N = 100GeV$ and $M_E = 500GeV$. The green bands are delimited by $\Delta a_\mu = (261 \pm 78)\times 10^{-11}$ (3.3σ)[7, 8]. The projected 1σ bound is found by requiring $\Delta a_\mu < 78 \times 10^{-11}$ while the bound is obtained for $\Delta a_\mu < 34 \times 10^{-11}$.*

Table 1: Summary of the lower bounds of the gauge bosons masses based on our calculations.

Model	LHC-13 TeV	$g-2$ current [GeV]	$g-2$ projected [GeV]
Minimal 3-3-1	$M_{Z'} > 3.7$TeV [9] $M_{W'} > 3.2$TeV [9]	$M_{Z'} > 434.5$ $M_{W'} > 646$	$M_{Z'} > 632$ $M_{W'} > 996.1$
3-3-1 r.h.n	$M_{Z'} > 2.64$TeV [10] -	$M_{Z'} > 158$ $M_{W'} > 133$	$M_{Z'} > 276.5$ $M_{W'} > 239$
3-3-1 LHN ($M_N = 1GeV$)	$M_{Z'} > 2$ TeV [10] -	$M_{Z'} > 160$ $M_{W'} > 134.3$	$M_{Z'} > 285$ $M_{W'} > 238.3$
3-3-1 LHN ($M_N = 100GeV$)	$M_{Z'} > 2$ TeV [10] -	$M_{Z'} > 136.7$ $M_{W'} > 114.2$	$M_{Z'} > 276.5$ $M_{W'} > 231$
Economical 3-3-1	$M_{Z'} > 2.64$TeV [10] -	$M_{Z'} > 59.3$ $M_{W'} > 49.5$	$M_{Z'} > 271.4$ $M_{W'} > 226.7$
3-3-1 with exotic leptons $M_N\,(M_E) = 10\,(150)\,GeV$	$M_{Z'} > 2.91$TeV[11] -	$M_{Z'} > 429$ $M_{W'} > 359$	$M_{Z'} > 693$ $M_{W'} > 579.6$
3-3-1 with exotic leptons $M_N\,(M_E) = 100\,(150)\,GeV$	$M_{Z'} > 2.91$TeV[11] -	$M_{Z'} > 369$ $M_{W'} > 309.1$	$M_{Z'} > 600$ $M_{W'} > 501.4$

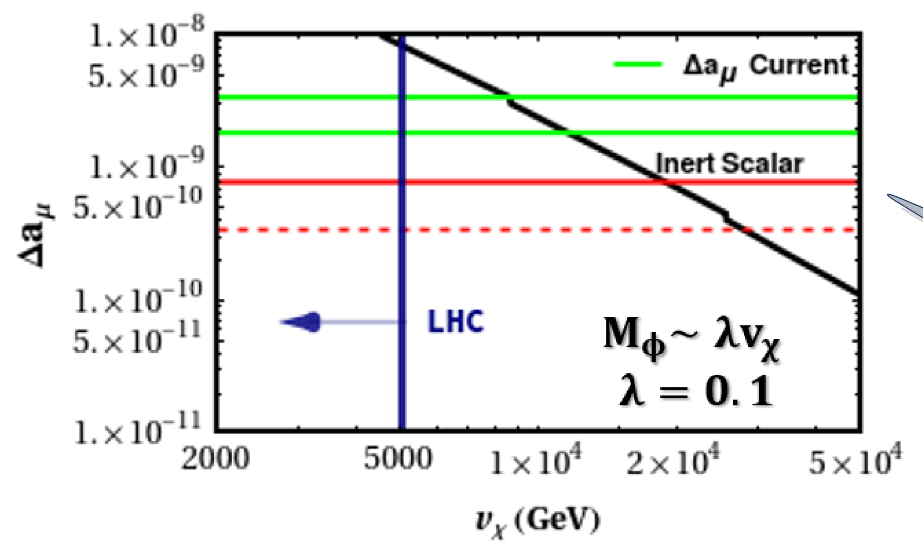
In the Table 1 the lower bounds can be seen on masses of the gauge bosons, derived for the 3-3-1 model, where the LHC bounds are based on either $36fb^{-1}$ or $139fb^{-1}$ of the data. The lower mass bounds on the Z' and W' bosons from the *3-3-1 r.h.n* model are also applicable to the *Economical 3-3-1* model as they have the same interactions.

None of the five models investigated here can accommodate the anomaly in agreement with existing bounds.

Extended version of the 3-3-1 LHN Model

The 3-3-1 LHN model augmented by an inert scalar triplet

The inert scalar triplet allows us to include $\mathcal{L} \supset y_{ab}\bar{f}_a\phi e_{bR}$, taking $y_{22} = 1$. Such scalar triplet gets a mass from the quartic coupling in the scalar potential ($\lambda\phi^\dagger\phi\chi^\dagger\chi$), after the scalar triplet χ acquires a vev.



The extended version of the 3-3-1 LHN Model successfully accommodates the a_μ anomaly for $v_\chi \sim 10$ TeV, while being consistent with LHC constraint.

Figure 4: Overall contribution of the 3-3-1 LHN Model augmented by an inert scalar triplet ϕ. The green and red bands are delimited by the current and projected discrepancy, respectively.

We have conclusively presented a solution to the muon anomalous magnetic moment in the context of 3-3-1 models.

Conclusions

1. We concluded that none of the five models investigated here can accommodate the anomaly.
2. We derived robust and complementary 1σ lower mass bounds on the masses of the new gauge bosons, namely the Z' and W' bosons, that contribute to muon anomalous magnetic moment assuming the anomaly is otherwise resolved.
3. The 3-3-1 models must be extended to explain the anomaly observed in the muon anomalous magnetic moment.
4. Solution: we presented a plausible extension to the 3-3-1 LHN model, which features an inert scalar triplet.

Acknowledgement

To the funding organizations, for the support received for the development of this work and the participation in this event:

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