Vectorlike Leptons and Inert Scalar Triplet: Lepton Flavor Violation, g-2 and Collider Searches

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Álvaro Santos de Jesus
Advisor: Farinaldo da Silva Queiroz

Department of Theoretical and Experimental Physics

Federal University of Rio Grande do Norte, Brazil

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Vectorlike leptons and inert scalar triplet: Lepton flavor violation, $g-2$, and collider searches

A. S. de Jesus,[1,*] S. Kovalenko,[2,†] F. S. Queiroz,[1,‡] C. Siqueira,[1,§] and K. Sinha[3,‖]

[1]*International Institute of Physics, Universidade Federal do Rio Grande do Norte, Campus Universitário, Lagoa Nova, Natal-RN 59078-970, Brazil*

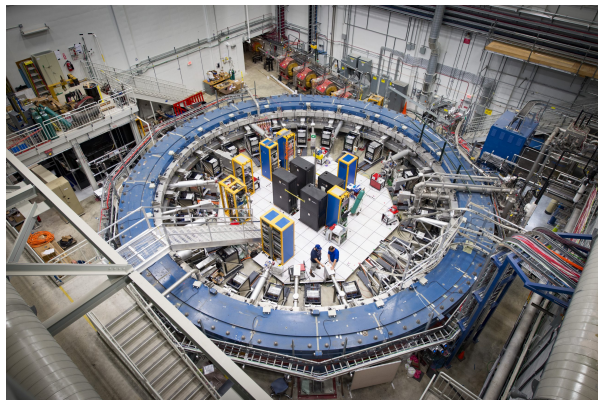
[2]*Departamento de Ciencias Físicas, Universidad Andres Bello, Sazié 2212, Santiago, Chile*

[3]*Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma 73019, USA*

Muon $g-2$

There is a persistent discrepancy between the theoretical prediction and the measured value of the muon magnetic moment, which is an important clue about physics beyond the SM. A historical review of the measured discrepancies is given below:

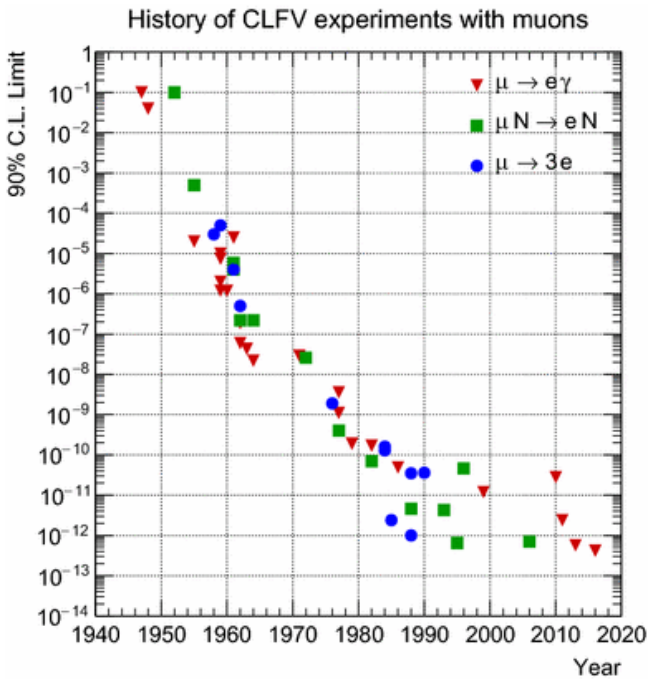
$$\Delta a_\mu = (261 \pm 78) \times 10^{-11} \ (3.3\sigma) \ \ [1, 2] \text{ - (2009)};$$
$$\Delta a_\mu = (325 \pm 80) \times 10^{-11} \ (4.05\sigma) \ \ [3] \text{ - (2012)};$$
$$\Delta a_\mu = (287 \pm 80) \times 10^{-11} \ (3.6\sigma) \ \ [4] \text{ - (2013)};$$
$$\Delta a_\mu = (377 \pm 75) \times 10^{-11} \ (5.02\sigma) \ \ [5] \text{ - (2015)};$$
$$\Delta a_\mu = (313 \pm 77) \times 10^{-11} \ (4.1\sigma) \ \ [6] \text{- (2017)};$$
$$\Delta a_\mu = (270 \pm 36) \times 10^{-11} \ (3.7\sigma) \ \ [7] \text{ - (2018)}.$$



Lepton Flavor Violation

Many extensions of the SM predict the existence of processes that violate lepton flavor. We focus in particular on the rare muon decay $\mu \rightarrow e\gamma$, on which the MEG collaboration [8] currently imposes the bound

$$BR(\mu \rightarrow e\gamma) < 4.2 \times 10^{-13}.$$



3-3-1 Models

There is a class of models known as 3-3-1 models, where there is an extension of the SM gauge group, with $SU(2)_L \times U(1)_Y \to SU(3)_L \times U(1)_N$. So, we have the following gauge structure:

$$SU(3)_C \times SU(3)_L \times U(1)_N - [9, 10, 11],$$

where the leptonic and quark sectors are enlarged to triplets, with:

$$f_L^a = \begin{pmatrix} \nu^a \\ l^a \\ N^a \end{pmatrix}_L , \; l_R^a, N_R^a; \; Q_L^a = \begin{pmatrix} u^a \\ d^a \\ J^a \end{pmatrix}_L , \; u_R^a, d_R^a, J_R^a. \tag{1}$$

The scalar sector is extended as well, being necessary (at least) 2 scalar triplets to provide the masses of the fermions.

3-3-1 Models

3-3-1 models are appealing, being able to provide plausible answers for a few problems in particle physics. This class of models has been used in different subjects in the literature, such as:

i) Generations of fermions;
ii) Dark matter;
iii) Neutrino masses;
iv) Flavor physics;
v) Collider physics.

Collider bounds on 3-3-1 models

The extension in the gauge sector introduce 5 new gauge bosons to the model, such as a Z' and $W^{\pm\prime}$. However, those gauge bosons are constrained by experiments, especially collider searches. The most constraining bound comes from the Z', where we can have the conservative limits of:

$$\text{LHC 13 TeV: } M_{Z'} > 2\,\text{TeV};\ v_\chi > 5\,\text{TeV[12]}.$$

Using the code described in [13] to determine the HL-LHC and HE-LHC reach, we conclude that:

$$\text{HL-LHC: } M_{Z'} > 4.5\,\text{TeV};\ v_\chi > 11.4\,\text{TeV},$$
$$\text{HE-LHC: } M_{Z'} > 8.9\,\text{TeV};\ v_\chi > 22.5\,\text{TeV}.$$

Inert Scalar Triplet

Since the relevant symmetry is $SU(3)_L$, an inert scalar triplet can be trivially added. Its contribution to $g-2$ is proportional to the mass of the muon, which would imply a suppressed correction to $g-2$. Thus, we can add

$$\mathcal{L} = \lambda_{ab}\bar{f}_{aL}\phi e_{bR}. \tag{2}$$

The inert scalar triplet acquires a mass term from the quartic scalar potential term that goes as $\lambda\chi^{\dagger}\chi\phi\phi$. Therefore, $M_{\phi} \sim \lambda v_{\chi}$, where v_{χ} is the vacuum expectation value of the symmetry breaking.

Inert Scalar contribution to g-2 and lepton flavor violation

The inert scalar can contribute to the muon g-2 as well as for the rare decay $\mu \to e\gamma$ by the following expressions:

$$\Delta a_\mu = \frac{m_\mu^2}{8\pi^2 M_\phi^2} \int_0^1 dx \sum_b \frac{\lambda_{2b}^2 x^2 (1 - x + \epsilon_b)}{(1-x)(1-\lambda^2 x) + x\epsilon_b \lambda^2} \tag{3}$$

where $\epsilon_b = m_b/m_\mu$ and $\lambda = m_\mu/M_\phi$. and

$$BR(\mu \to e\gamma) = \frac{3(4\pi)^3 \alpha_{em}}{4G_F^2} |A_{e\mu}^M|^2 \tag{4}$$

where A^M is a form factor that accounts for the loop correction and carries information about the couplings and masses.

Inert Scalar with Exotic Leptons

There are a few possible ways to tackle the muon g-2 with vector-like leptons in the context of 3-3-1 models, one of them given by the following lagrangian:

$$\mathcal{L} = \lambda_{ab} \bar{E}_{aL} \phi e_{bR}, \tag{5}$$

where ϕ is a scalar singlet and E_{aL} represent the vector-like exotic charged lepton. As the inert scalar triplet, the scalar singlet mass depends on the scale of symmetry breaking. Therefore, we can use the same expressions for the muon g-2 and $\mu \to e\gamma$ for this case with $\epsilon_b = m_E/m_\mu$, m_E being a free parameter.

Results for the inert scalar triplet

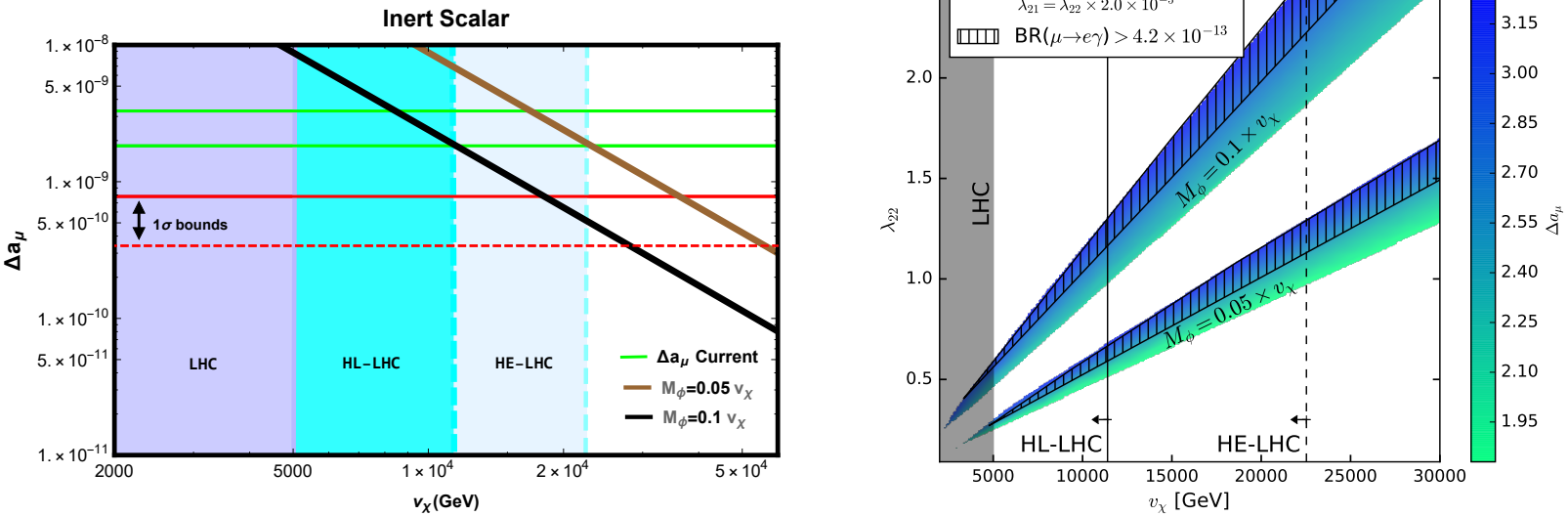


Figure: Plots of the results for the inert scalar triplet for the muon $g-2$ (left) and its complementarity with CLFV (right). It is possible to see the restraints in the Yukawa couplings from CLFV, which excludes the hatched area.

Results for the Inert Scalar with Exotic Leptons

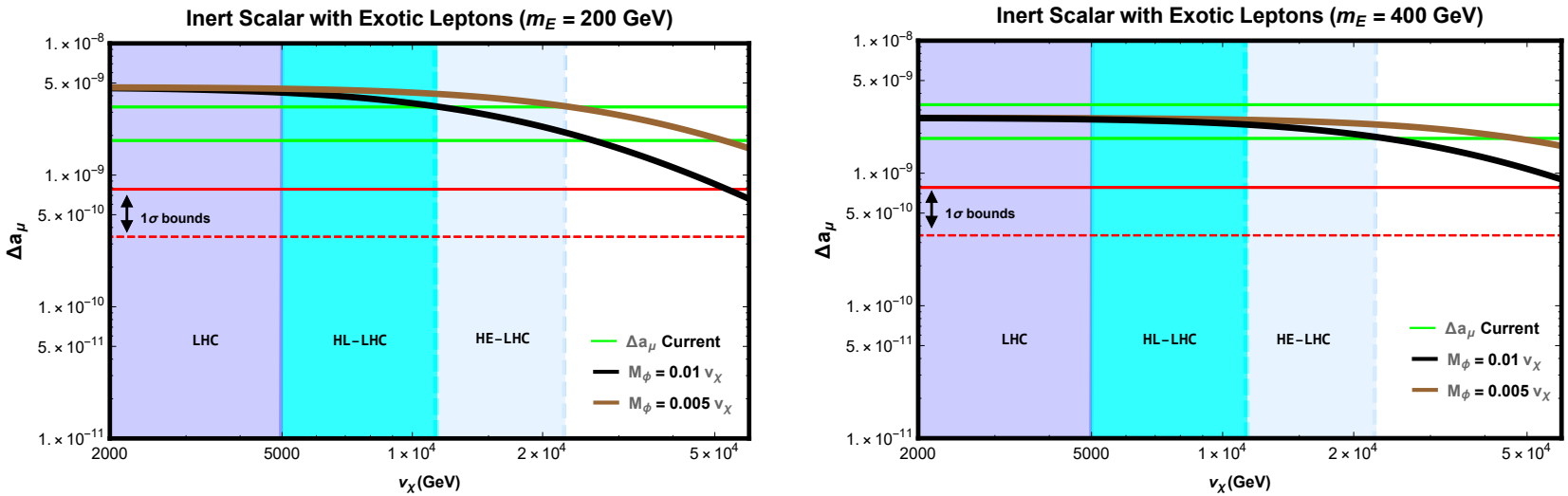


Figure: Results for the inert scalar with exotic leptons with $m_E = 200$GeV (left) and $m_E = 400$GeV (right).

Results for the Inert Scalar with Exotic Leptons

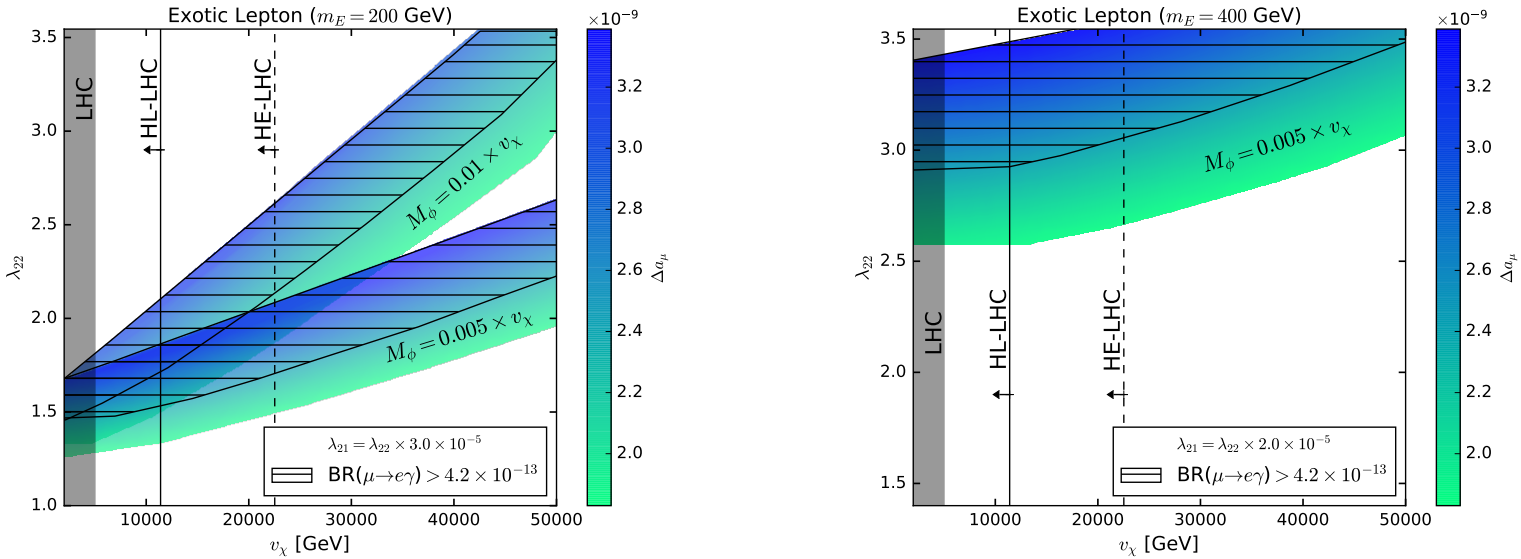


Figure: Plot of the relationship between the Yukawa coupling λ_{22} and the scale of symmetry breaking v_χ for the model with exotic leptons. We considered the cases of $m_E = 200$GeV (left) and $m_E = 400$GeV (right).

Conclusions

In this work, we provided simplified scenarios that accommodate the muon $g-2$ anomaly while in accord with the collider bounds coming from the Z' and $W^{\pm\prime}$ gauge bosons. We analyzed the possibility to accommodate CLFV processes within the same model. However, this feature depends on the choice of the Yukawa couplings, resulting in very restrictive limits.

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