Based on the paper 2106.xxxx

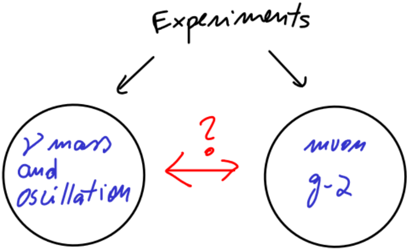
Is there a way to accommodate $g-2$ anomaly in Inverse Seesaw models?

João Paulo Pinheiro
(C. A. de S. Pires, Farinaldo S. Queiroz, Yoxara S. Villamizar)

João Pessoa
2021

Our main goal in this research

Our main goal in this work is to understand if we can connect a TeV mechanism for neutrino generation and muon $g-2$ results.



Muon g-2

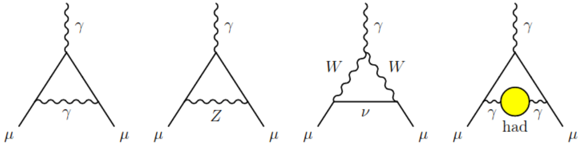
Actual muon $g-2$ experimental results implies a 4.2σ discrepancy from the standard model (SM) (*B. Abi et al. 2104.03281*)

$$\Delta a_\mu = a_\mu^{\text{exp}} - a_\mu^{\text{SM}} = (251 \pm 59) \times 10^{-11}.$$

If the SM cannot explain this difference, we must extent it or develop a model that encompasses it in order to accommodate this new experimental fact. There are many complete models that accommodate this result, as Left-Right and $U(1)_{B-L}$ models.

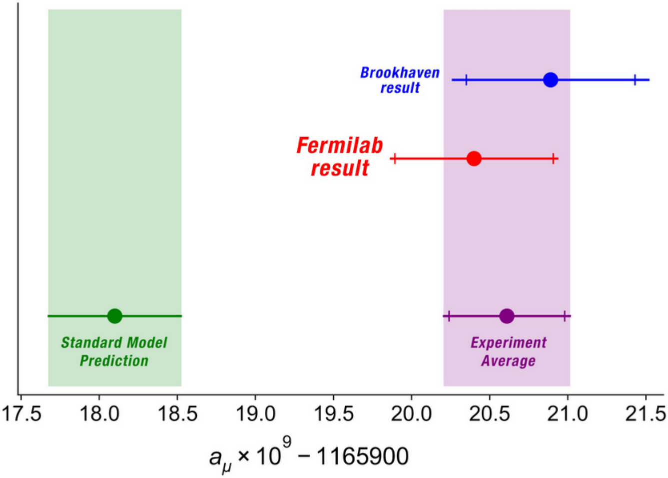
Muon $g-2$

A very precise test of the Standard Model. Any deviation of this value ($a_\mu^{SM} = 116591830(1)(40)(26) \times 10^{-11}$)(*PDG*) indicates physics beyond Standard Model (BSM).



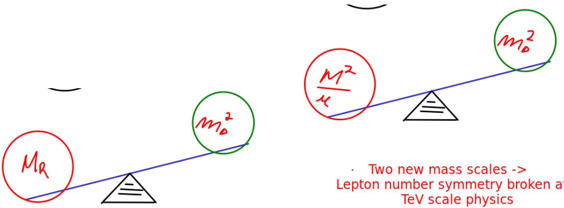
Diagrams that contributes for a_μ^{SM} (PDG).

Muon $g-2$



B. Abi *et al.* 2104.03281

Inverse Seesaw Mechanism



Two new mass scales ->
Lepton number symmetry broken at low energies->
TeV scale physics

ISS mechanism is a natural way to generate neutrino masses at TeV scales (*R. N. Mohapatra et al. Phys. Rev. D* ***34***, *Phys. Rev. Lett.* ***56***).

After the minimal extension of the SM that accommodates the SM, is there a way to accommodate $\Delta a_\mu \sim 10^{-9}$?

The most logical way to study this dependence is considering variable masses for the heavy neutrinos. The main question now is: Is there a neutrino mass m_N that accommodate the muon $g-2$ anomaly?

The answer for this question is: **YES!**

Review - Inverse Seesaw Mechanism

(R. N. Mohapatra et al. Phys. Rev. D ***34****, Phys. Rev. Lett.* ***56*** *)*

$$\mathcal{L}_\nu \supset -\bar{\nu_L} M_D S'_R - \bar{S_L} M S'_R - \frac{1}{2}\bar{S_L}\mu S_L^C + H.c., \qquad (1)$$

where M_D, M and μ are generic 3×3 mass matrices. These masses can be represented as a 9×9 matrix in the basis $(\nu_L, S_R'^C, S_L)$:

$$M_\nu = \begin{pmatrix} 0 & M_D^T & 0 \\ M_D & 0 & M^T \\ 0 & M & \mu \end{pmatrix}. \qquad (2)$$

On considering the hierarchy $\mu << M_D << M$, we can diagonalize this matrix as

$$m_{light} = -m_{light} = M_D^T M^{-1}\mu M^{-1} M_D, \quad m_{heavy} = \mathcal{M}_\mathcal{R},$$

in such a way that $\mathcal{M}_\mathcal{R}$ is

$$\mathcal{M}_\mathcal{R} = \begin{pmatrix} 0 & M^T \\ M & \mu \end{pmatrix}, \quad \mathcal{M}_\mathcal{D} = \begin{pmatrix} M_D \\ 0 \end{pmatrix} \qquad (3)$$

Minimal ISS

More explicitly, the three active neutrino masses are given by

$$m_{active} \approx \mu \frac{M_D^2}{M^2}$$

such that μ is a explicitly $B-L$ symmetry breaking energy scale $\rightarrow$ by t'Hooft naturalness principle μ should be small and $M_D \sim$ EW scales $\rightarrow M \sim \ TeV$ scales.

Minimal ISS

It can be shown that the mixing between active and sterile neutrinos is given by (*D. Cogollo et al Phys. Lett. B **811***)

$$\nu \approx U_{PMNS}(1 - \frac{1}{2}F^{\dagger}F)\, n + \mathcal{M_D}\mathcal{M_R}^{-1} U_R\, N \tag{4}$$

such that $F = M_D M^{-1}$ and U_R diagonalize six pseudo-Dirac neutrinos N_j.

This means that the mix between active and pseudo-Dirac neutrinos is proportional to $M_D M^{-1}$. Since $M \sim TeV$ and $M_D \sim GeV$, then $M_D M^{-1} \sim 10^{-3}$ is **huge!**

Minimal ISS

This huge mixing can induce a considerable interaction between these six pseudo-Dirac neutrinos and standard W boson!

$$\mathcal{L}_{\nu}^{CC} = -\frac{g}{2\sqrt{2}}(\bar{\nu}\gamma^{\mu}(1-\gamma_5)\bar{\mu}W_{\mu}^{-}) + H.c.$$

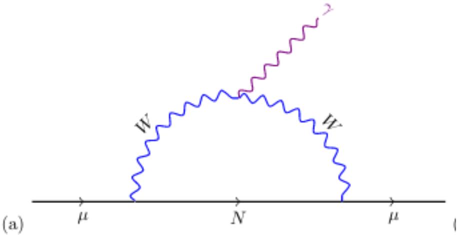


Figura: New contribution for the muon $g-2$ due N.

Pseudo-Dirac Mixing

Estimation of the new contribution for the $g - 2$ of the muon can be obtained if we discover who is U_R. Then, we must find out a way to calculate this mixing matrix.

Is it possible to find U_R without fixing benchmark points for the neutrino masses?

WE DID IT!

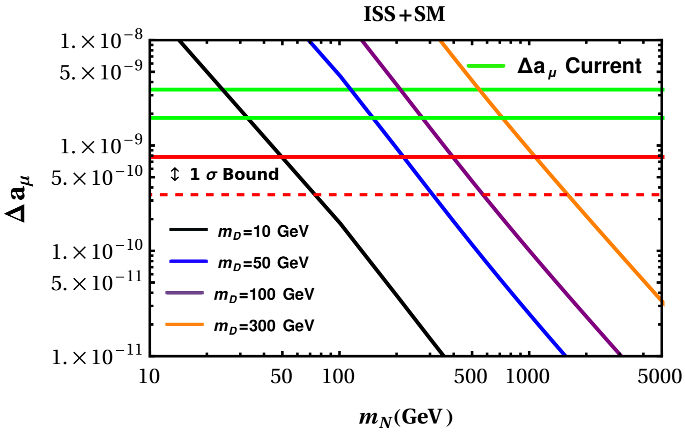
Charged Current contribution

And now it is possible to calculate the contributions for the $g-2$ of the muon depending on the parameter m_N (for simple SM realization).

$$\mathcal{L}_{N,\mu,W} = -\frac{g}{2\sqrt{2}}\bar{\mu}(1-\gamma_5)\gamma^{\mu}[(\mathcal{M_D}^{\dagger})[\mathcal{M_R}^{\dagger}]^{-1}U_R]_{1k}N_k W^{-}_{\mu} + H.c. \tag{5}$$

such that $(\mathcal{M_D}^{\dagger})[\mathcal{M_R}^{\dagger}]^{-1}U_R$ is

$$(\mathcal{M_D}^{\dagger})[\mathcal{M_R}^{\dagger}]^{-1}U_R \approx \frac{m_D}{M_R}\begin{pmatrix} -1 & 1 & 0 & -1 & 1 & 0 \\ -1 & -1 & -1 & 1 & 1 & 1 \\ 1 & 1 & 1 & 1 & 1 & 1 \end{pmatrix} \tag{6}$$


ISS+SM
Δa_μ Current
1 σ Bound
m_D=10 GeV
m_D=50 GeV
m_D=100 GeV
m_D=300 GeV
Δa_μ
$1.\times10^{-8}$
$5.\times10^{-9}$
$1.\times10^{-9}$
$5.\times10^{-10}$
$1.\times10^{-10}$
$5.\times10^{-11}$
$1.\times10^{-11}$
10
50
100
500
1000
5000
m_N(GeV)

Clearly, there are values for pseudo-Dirac neutrino masses that accommodate muon $g-2$. They depend on m_D parameter, too. Great, right?

IS THIS ALL?

Origin of the parameter η

We can look at this expression

$$\nu_{\alpha L} = [U_{PMNS} - \frac{1}{2}(F^\dagger F) U_{PMNS}]_{\alpha i} n_{iL} + [\mathcal{M_D}^\dagger (\mathcal{M_R}^\dagger)^{-1} U_R]_{\alpha k} N_{kL}, \tag{7}$$

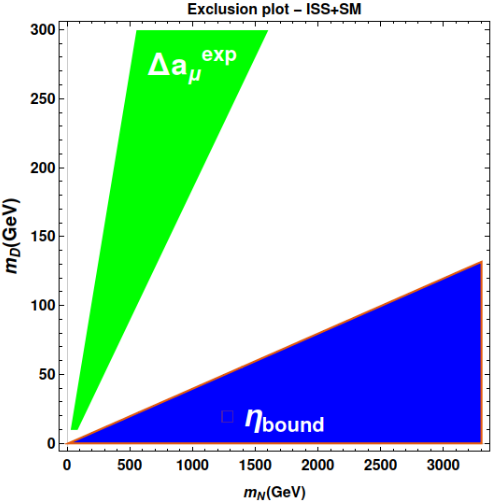
and see that there is a perturbation of the unitarity of the U_{PMNS} matrix, such that $F = M_D M^{-1}$. Then, we must define the parameter $\eta \equiv \frac{1}{2}(F^\dagger F)$, that has the following superior limit(S. Antusch, et al. Nucl. Phys. B**810**; P. S. Bhupal Dev et al. Phys. Rev.D**81**)

$$| \eta_{bound} | < \begin{pmatrix} 2 \times 10^{-3} & 3.5 \times 10^{-5} & 8.0 \times 10^{-3} \\ 3.5 \times 10^{-5} & 8.0 \times 10^{-4} & 5.1 \times 10^{-3} \\ 8.0 \times 10^{-3} & 5.1 \times 10^{-3} & 2.7 \times 10^{-3} \end{pmatrix} \tag{8}$$

Is there a way to accommodate η parameter and $g-2$ anomaly at the same time

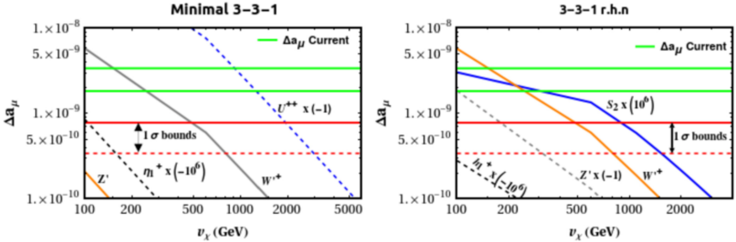
The answer is: ???

Exclusion Plot - *ISS+SM*



Minimal 3-3-1 and 3-3-1 with RHNs

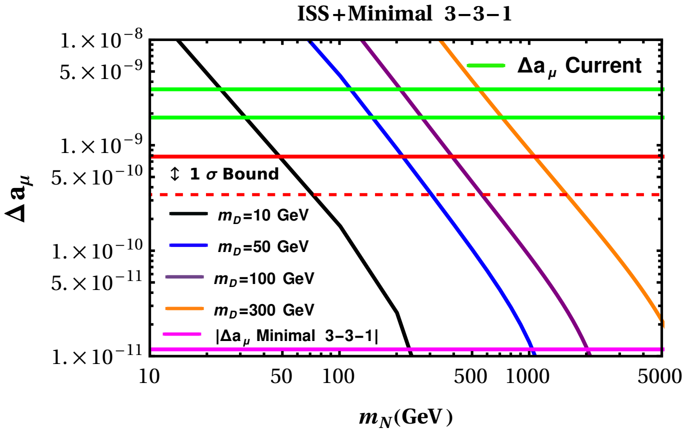
Following (*Á. S. de Jesus et al Phys. Lett. B* ***809***) we studied if 3-3-1 models can accommodate $g-2$. Their conclusion is that 3-3-1 cannot explain muon magnetic moment anomaly for high v_χ. We did the same analysis for different heavy neutrino masses.



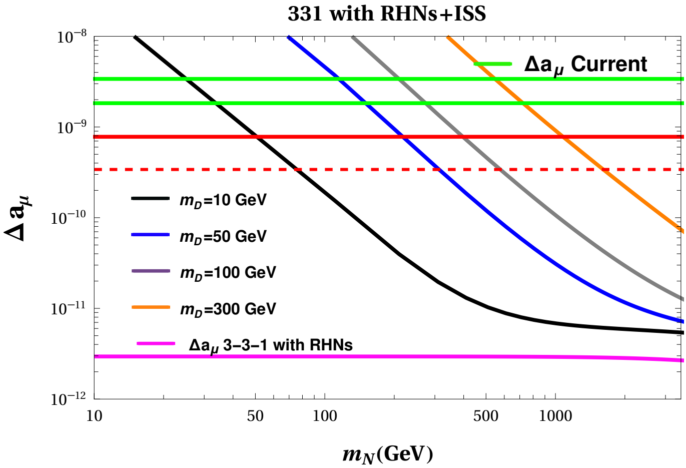
Á. S. de Jesus et al Phys. Lett. B **809**

Minimal 331 + ISS

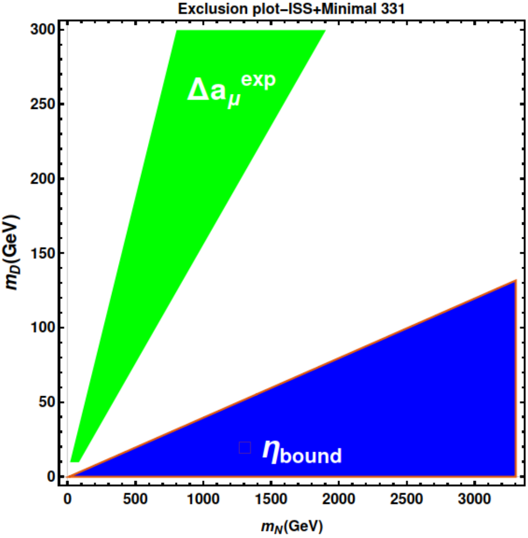
Then, we have the same structure as the SM+ISS case and we found that



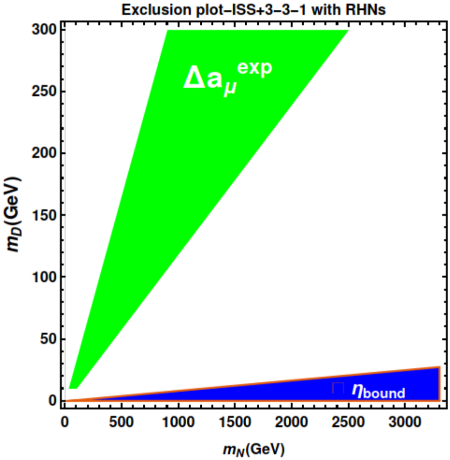
331 with RHNs + ISS



Exclusion Plot - *ISS+minimal 3-3-1*



Exclusion Plot - *ISS+3-3-1 with RHNs*



Is there a way to accommodate η parameter and $g-2$ anomaly at the same time

The answer is: **NO!** (There is a more general proof...)

The End

- Thanks!