Explanation of neutrino mass and muon $(g-2)$ anomaly in an $U(1)_{L_\mu - L_\tau}$ extended left-right theory

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Outline

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- Motivation
- The model and Neutrino mass Generation
- Model prediction on muon $(g-2)$ anomaly
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Introduction: Left-Right Symmetric Model (LRSM)

- In the framework of LRSM (Pati et al.'74, Mohapatra et al.'75), these questions receive a satisfactory answer pointing to unification,
  (a) The origin of parity violation in low-energy weak-interaction processes.
  (b) The origin of neutrino masses, for which now there is evidence from neutrino oscillation searches.
- The LRSMs are based on the gauge group,

$$G_{LR} \equiv SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C \tag{1}$$

- The right-handed massive neutrino is the natural outcome of LRSM.

Introduction: Generation of Neutrino mass

- In manifest LRSM neutrino mass can be explained by seesaw mechanism.

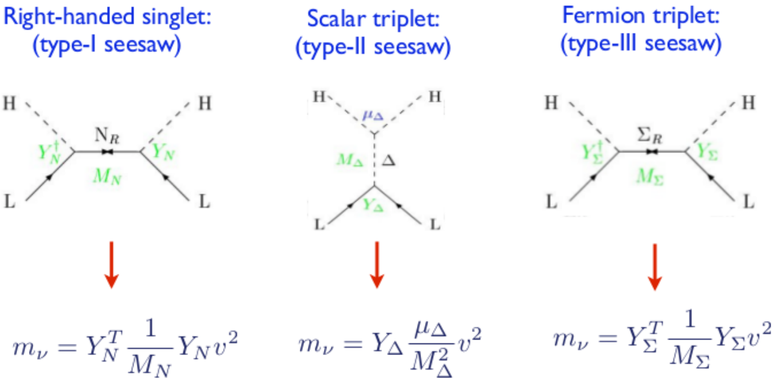

Figure: Three types of see-saw mechanism (Picture Credit: Wikipedia).

Continued ...

- The usual seesaw mechanism provides a very high right-handed breaking scale (>10^{14} GeV).
- The inverse seesaw(ISS) mechanism (Mohapatra et al.'86) is another way of generation of neutrino mass at low scale.
- This offers right-handed breaking scale at around some TeV scale and also allows large light-heavy neutrino mixing.
- ISS scenario requires the addition of three extra sterile neutrinos S_i.
- The neutrino mass formula for this mechanism is given by

$$m_\nu = M_D M^{-1} \mu M_D^T (M^{-1})^T. \tag{2}$$

Introduction: Muon $(g-2)$ Anomaly (a_μ)

- The muon anomalous magnetic moment $(g-2)$ is a prime example of the success of theoretical advancements in quantum field theory.
- There lies a wide gap between Standard model(SM)'s prediction of muon anomalous magnetic moment, a_μ and its measurement.
- This indicates the existence of new physics beyond Standard Model (BSM).
- The corrections are parametrized in terms of $a_\mu = (g_\mu - 2)/2$ where g is the gyromagnetic ratio.

- In principle the a_μ predicted by SM is given by

$$a_\mu^{\text{SM}} = a_\mu^{\text{QED}} + a_\mu^{\text{electroweak}} + a_\mu^{\text{hadronic}}$$

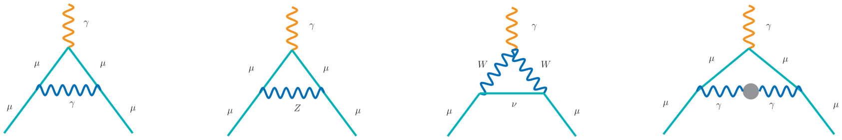

Figure: Lowest-order SM corrections to Δa_μ.

- The theoretical prediction of a_μ (PDG'18) is

$$a_\mu^{\text{SM}} = (11659183.0 \pm 4.8) \times 10^{-10}. \quad (3)$$

Continued: Experimental frontier of a_μ

- The most recent measurement by BNL (2006) data (G. W. Bennett et al.'06) with a 3.3σ deviation,

$$a_\mu^{\text{exp}} = (11659209.1 \pm 6.3) \times 10^{-10} \tag{4}$$

with $\Delta a_\mu = (26.1 \pm 7.9) \times 10^{-10}$ (Bhupal Dev et al.'20).

- The Muon $g - 2$ Experiment at Fermilab (FNAL) (J. Grange et al.'15) aims to improve the statistical error by a factor of four, reaching a similar precision by J-PARC (M. Abe et al.'19).
- A proposed experiment, namely MUonE (G. Abbiendi et al.'16) aspires to reduce this theoretical uncertainty by determining the hadronic vacuum polarization more precisely.

Our Work

Neutrino masses, mixing and muon $(g-2)$ anomaly in $U(1)_{L_\mu - L_\tau}$ extension of left-right theories [JHEP09(2020)010]
(CM, SP, PP, SS and UAY)

Motivation

- The $U(1)_{L_\mu - L_\tau}$ extension of SM has been extensively studied but same extension of LRSM has been less studied.
- Also LRSM offers wider possibilities of explaining different phenomenological aspects.
- Thus with the motivation of explaining neutrino mass and muon $(g-2)$ anomaly within a single framework we reach for the LRSM and augment it with the $U(1)_{L_\mu - L_\tau}$ symmetry.

Building the model

- The model is governed by the gauge group,
$$G_{LR}^{\mu\tau} \equiv SU(2)_L \times SU(2)_R \times U(1)_{B-L} \times SU(3)_C \times U(1)_{L_\mu - L_\tau}.$$
- Let us begin with the usual particle content of LRSM i.e. quarks ($q_{L,R}$), leptons ($\ell_{L,R}$), Higgs bidoublet Φ and triplets $\Delta_{L,R}$.
- In this scenario the light neutrino mass can be generated via type-I+II seesaw formula.
- The obtained degenerate eigenvalues imply disagreement with the neutrino oscillation experiment data.
- This degeneracy can be avoided by introducing another pair of triplet scalars with non-zero $L_\mu - L_\tau$ charge.
- The model no more remains minimal !!

Continued...

- So we have replaced the triplets $\Delta_{L,R}$ with doublet scalars $H_{L,R}$.
- To break the $U(1)_{L_\mu - L_\tau}$ symmetry we have added another scalar χ which has non-zero $L_\mu - L_\tau$ charge.
- For implementing LRSM inverse seesaw(LISS) mechanism to generate neutrino masses in this model we need to add left handed sterile neutrinos(S_L), one per each generation to the usual particle contents of LRSM.
- This also allows large light-heavy neutrino mixing which will be an important feature for explaining muon anomaly (will see later).
- The model is minimal and the degeneracy eigenvalues problems are no more in this model.

Model Prediction on Muon $(g-2)$ anomaly

In our model, the contributions to muon $(g-2)$ anomaly arise from the interactions of;

- singly charged gauge bosons with heavy neutral fermions,
- neutral vector boson with singly charged fermions,
- singly charged scalars with neutral fermion,
- neutral scalars with muons,
- light new gauge boson $Z_{\mu\tau}$ with muons.

Singly charged gauge bosons contributions: Theoretical Estimation:

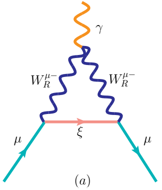

Figure: Feynman diagrams for the interaction of singly charged vector bosons.

$$(a)\ \Delta a_\mu(W_R) \simeq \frac{1}{4\pi^2}\frac{m_\mu^2}{m_{W_R}^2}\left[|g_v^\mu|^2\left(\frac{5}{6}\right)+|g_a^\mu|^2\left(\frac{5}{6}\right)\right]. \quad (5)$$

$$(b)\ \Delta a_\mu(W_L) \simeq 9.06\times 10^{-9}\, g_L^2 \sum_{i=1,..,6} |V_{\mu i}^{\nu\xi}|^2 \quad (6)$$

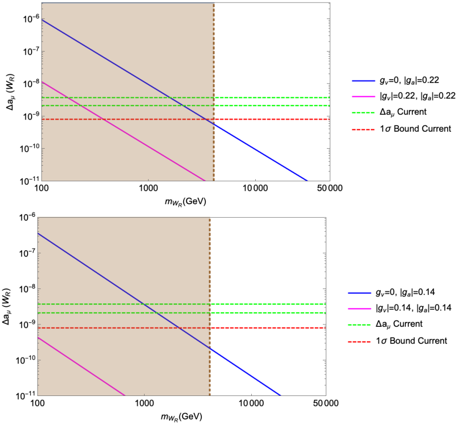

Figure: Plot showing the contribution of charged vector boson W_R to Δa_μ for the cases $g_L = g_R$ and $g_L \neq g_R$.

W_R is not a good candidate !

Numerical Results for W_L

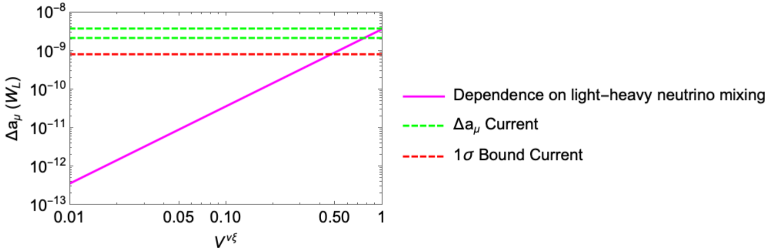

Figure: Plot showing the variation of Δa_μ coming from purely left-handed currents via W_L mediation vs. the light-heavy mixing parameter $V^{\nu\xi}$.

For $V^{\nu\xi} \sim \mathcal{O}(0.3 - 1), W_L$ is a good candidate to explain muon anomaly.

Neutral vector boson contribution: Theoretical Estimation:

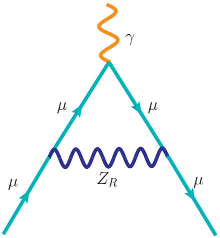

Figure: Feynman diagrams for the interaction of neutral vector boson.

- $$\Delta a_\mu(Z_R) \simeq -\frac{1}{4\pi^2}\frac{m_\mu^2}{m_{Z_R}^2}\left[\left(-\frac{1}{3}\right)|g_v^\mu|^2 + \left(\frac{5}{3}\right)|g_a^\mu|^2\right]. \quad (7)$$

Numerical Estimation for Z_R

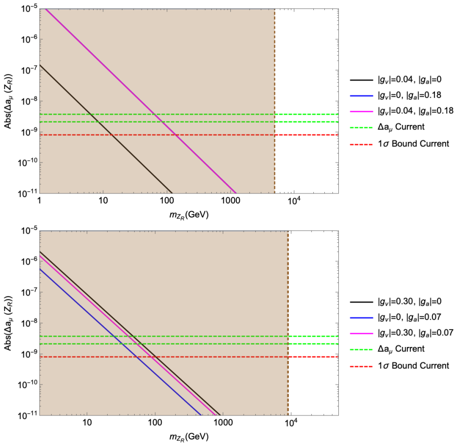

Figure: Plot showing the contribution of charged vector boson Z_R to Δa_μ for the cases $g_L = g_R$ and $g_L \neq g_R$.

Z_R is also not a good candidate !

Singly charged scalars contributions: Theoretical Estimation:

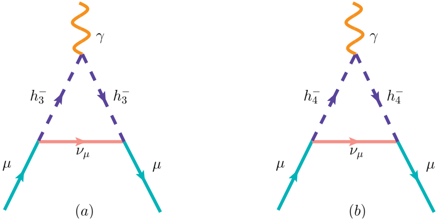

Figure: Feynman diagrams for the interaction of singly charged scalars.

- $$\Delta a_\mu(h_i^+) \simeq -\frac{1}{4\pi^2}\frac{m_\mu^2}{m_{h_i^+}^2}\left[|g_s^\mu|^2\left(\frac{1}{12}\right)+|g_p^\mu|^2\left(\frac{1}{12}\right)\right]. \qquad (8)$$

Numerical estimation for charged scalars

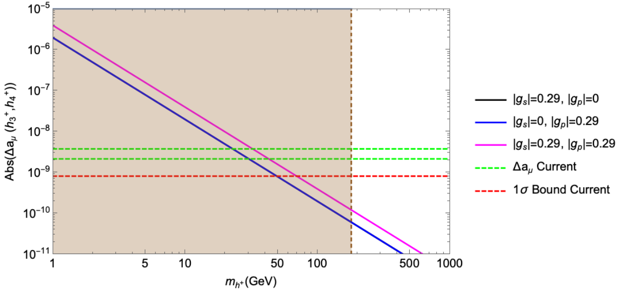

Figure: Plot showing the contribution of charged scalars to Δa_μ.

Singly charged scalars are not good candidates !

Neutral scalars contributions: Theoretical Estimation of CP-even scalars:

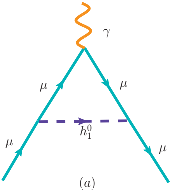

Figure: Feynman diagrams for the interaction of CP-even neutral scalars.

- $$\Delta a_\mu(h_i^0) \simeq \frac{1}{4\pi^2}\frac{m_\mu^2}{m_{h_i^0}^2}\left[|g_s^\mu|^2\left(-\frac{7}{12}-\log\frac{m_\mu}{m_{h_i^0}}\right)+|g_p^\mu|^2\left(\frac{11}{12}+\log\frac{m_\mu}{m_{h_i^0}}\right)\right] \tag{9}$$

Continued...: Theoretical Estimation of CP-odd scalars:

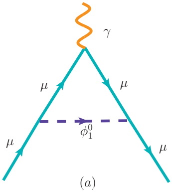

Figure: Feynman diagrams for the interaction of CP-odd neutral scalars.

- $$\Delta a_\mu(\phi_i^0) \simeq \frac{1}{4\pi^2}\frac{m_\mu^2}{m_{\phi_i^0}^2}\left[|g_s^\mu|^2\left(-\frac{7}{12}-\log\frac{m_\mu}{m_{\phi_i^0}}\right)+|g_p^\mu|^2\left(\frac{11}{12}+\log\frac{m_\mu}{m_{\phi_i^0}}\right)\right] \tag{10}$$

Numerical Estimation for Neutral Scalars

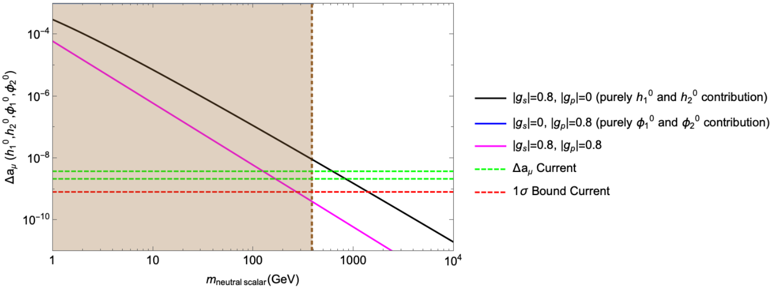

Figure: Plot showing the contribution of neutral scalars to Δa_μ.

CP-even scalars are good candidates for explaining muon $(g-2)$ anomaly.

New gauge boson $Z_{\mu\tau}$ contribution: Theoretical Estimation:

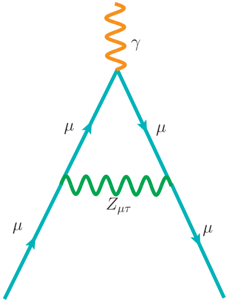

Figure: Feynman diagrams for the interaction of gauge boson $Z_{\mu\tau}$.

- $$\Delta a_\mu(Z_{\mu\tau}) = \frac{g_{\mu\tau}^2}{12\pi^2}\frac{m_\mu^2}{m_{Z_{\mu\tau}}^2}. \tag{11}$$

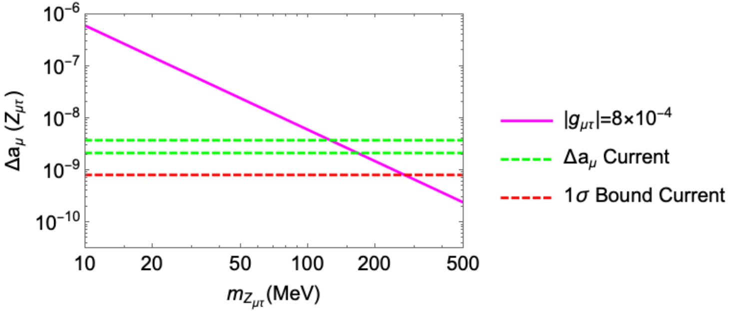

Figure: Plot showing the contribution of $Z_{\mu\tau}$ to Δa_μ.

$Z_{\mu\tau}$ with mass around 150 MeV is a good candidate to explain the muon anomaly.

Summary and Conclusion

- We have constructed an extended left-right model which can explain non-zero neutrino mass and muon anomalous magnetic moment within a single framework.
- Neutrino mass is generated in the model through inverse seesaw mechanism that allows large light-heavy neutrino mixing.
- Within this scenario we have three potential candidates (CP-even scalars, W_L, $Z_{\mu\tau}$) which can explain the entire anomaly.
- Overall we have found that inverse seesaw mechanism influences the results on muon anomaly to a large extent.
- For more details one can refer to JHEP09(2020)010.


Thank You!