TeV Scale Resonant Leptogenesis with $L_\mu - L_\tau$ Gauge Symmetry in the Light of Muon $(g-2)$

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Debasish Borah, Arnab Dasgupta and D.Mahanta

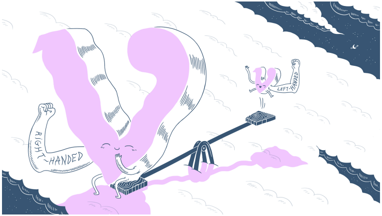
Devabrat Mahanta

Indian Institute of Technology Guwahati

Anomalies 2021

Outline

- Introduction to Baryon asymmetry of the universe
- Connecting BAU to the anomalous magnetic moment of the Muon
- A minimal model
- Results
- The non-minimal model
- Summary



The BAU can be closely related with the existence of small masses for the neutrinos.

The Right handed Majorana neutrinos which are added to give masses to the neutrinos can also lead to lepton number violating decays.

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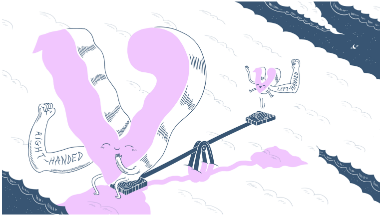

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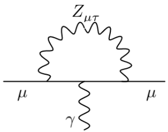
Connecting Muon $(g-2)$ with Leptogenesis

- The recent results on the anomolous magnetic moment of Muon from Fermi Lab put a strong evidence of new physics beyond the standard model [The Muon g-2 collaboration].

$$a_\mu = (g-2)_\mu/2, \Delta a_\mu = 251(59) \times 10^{-11}$$

- We propose a low scale leptogenesis model with $L_\mu - L_\tau$ symmetry which can also be constrained from the muon $(g-2)_\mu$. [X.-G. He et al, 1991]



$$\Delta a_\mu = \frac{g_{\mu\tau}^2}{8\pi^2} \int_0^1 dx \frac{2m_\mu^2 x^2 (1-x)}{x^2 m_\mu^2 + (1-x) M_{Z_{\mu\tau}^2}} = \frac{g_{\mu\tau}^2 m_\mu^2}{12\pi^2 M_{Z_{\mu\tau}}^2}$$

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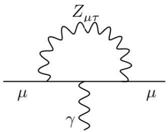

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- The RHNs generating the neutrino masses have the $L_\mu - L_\tau$ gauge interaction which can play a significant role in Leptogenesis.

A Minimal Gauged $L_\mu - L_\tau$ Model

Gauge Group	Fermion Fields			Scalar Field	
	N_e	N_μ	N_τ	Φ_1	Φ_2
$SU(2)_L$	1	1	1	1	1
$U(1)_Y$	0	0	0	0	0
$U(1)_{L_\mu - L_\tau}$	0	1	-1	1	2

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$$\mathcal{L} \supseteq \overline{N_\mu} i\gamma^\mu D_\mu N_\mu - \frac{M_{\mu\tau}}{2} N_\mu N_\tau + \overline{N_\tau} i\gamma^\mu D_\mu N_\tau - \frac{M_{ee}}{2} N_e N_e$$
$$- Y_{e\mu}\Phi_1^\dagger N_e N_\mu - Y_{e\tau}\Phi_1 N_e N_\tau - Y_\mu \Phi_2^\dagger N_\mu N_\mu - Y_{De}\bar{L_e}\tilde{H} N_e$$
$$- Y_{D\mu}\bar{L_\mu}\tilde{H} N_\mu - Y_{D\tau}\bar{L_\tau}\tilde{H} N_\tau - Y_\tau \Phi_2 N_\tau N_\tau - Y_{le}\overline{L_e} H e_R$$
$$+ Y_{l\mu}\overline{L_\mu} H \mu_R + Y_{l\tau}\overline{L_\tau} H \tau_R + \text{h.c.}$$

$$M_R = \begin{pmatrix} M_{ee} & Y_{e\mu}\frac{v_1}{\sqrt{2}} & Y_{e\tau}\frac{v_1}{\sqrt{2}} \\ Y_{e\mu}\frac{v_1}{\sqrt{2}} & \sqrt{2}Y_{\mu}v_2 & \frac{M_{\mu\tau}}{2} \\ Y_{e\tau}\frac{v_1}{\sqrt{2}} & \frac{M_{\mu\tau}}{2} & \sqrt{2}Y_{\tau}v_2 \end{pmatrix} \quad M_D = \begin{pmatrix} Y_{De}\frac{v}{\sqrt{2}} & 0 & 0 \\ 0 & Y_{D\mu}\frac{v}{\sqrt{2}} & 0 \\ 0 & 0 & Y_{D\tau}\frac{v}{\sqrt{2}} \end{pmatrix}$$

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The non-trivial neutrino mixing appear only through the structure of the right handed neutrino mass matrix M_R.

Neutrino Phenomenology and Resonant Leptogenesis

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- In presence of only one scalar singlet ϕ_1 the model predicts zeros at $\mu\mu$ and $\tau\tau$ of M_R. Satisfying neutrino oscillation data with almost two degenerate RHNs becomes difficult.
- With two singlet scalars ϕ_1, ϕ_2 we can have two degenerate RHNs satisfying the neutrino oscillation data.

Boltzmann Equations

- Decay term for N_i , Annihilations of N_i

$$\frac{dn_i}{dz} = -D_i(n_i - n_i^{eq}) - \frac{s}{Hz} < \sigma v >_{N_i N_i \longrightarrow XX} (n_i^2 - (n_i^{eq})^2)$$

$$\frac{dn_{B-L}}{dz} = -\epsilon_i D_i(n_i - n_i^{eq}) - (W_{ID_i} + \Delta W)n_{B-L}$$

In our model we have two kinds of annihilation for the RHNs and they are $N_i N_i \longrightarrow f\bar{f}, Z_{\mu\tau} Z_{\mu\tau}$. The washout term consist of inverse decays (WID) and scattering washouts (ΔW).

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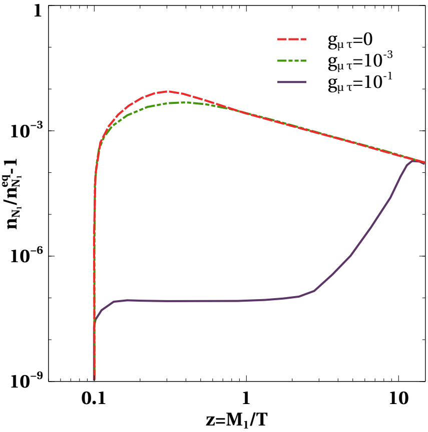
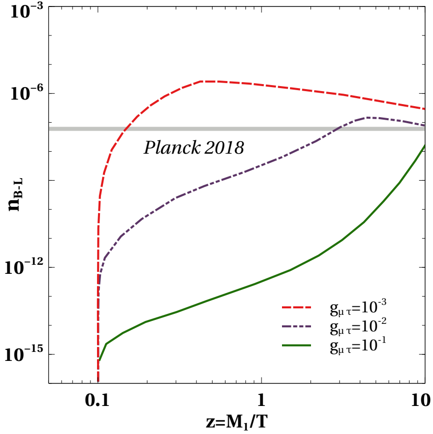
Results



$g_{\mu\tau}$=0
$g_{\mu\tau}$=10^{-3}
$g_{\mu\tau}$=10^{-1}
1
10^{-3}
10^{-6}
10^{-9}
$n_{N_1}/n^{eq}_{N_1}$-1
0.1
1
10
z=M_1/T



10^{-3}
10^{-6}
10^{-12}
10^{-15}
n_{B-L}
Planck 2018
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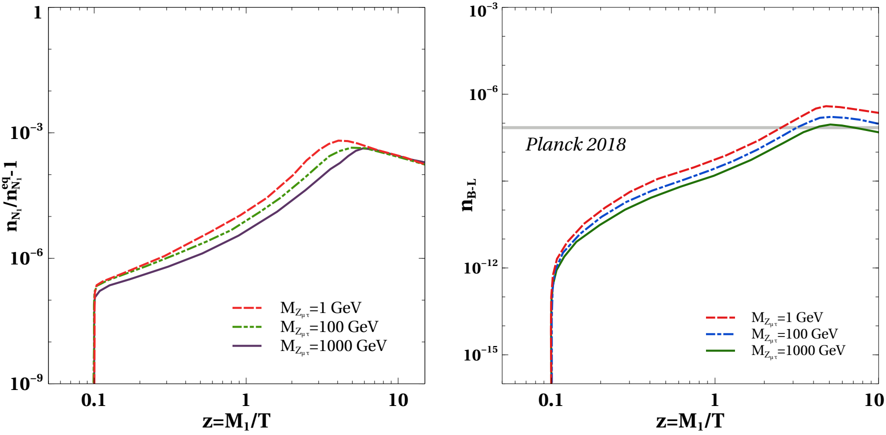
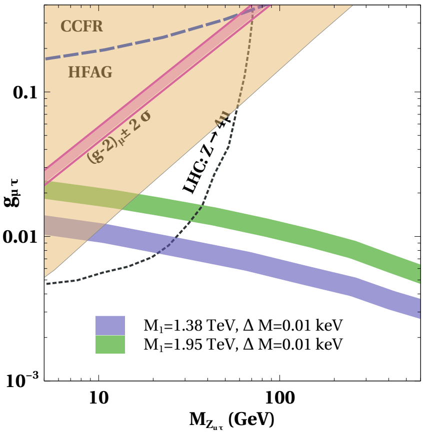


For $M_1 > 2M_{Z_{\mu\tau}}$ with the increase in $M_{Z_{\mu\tau}}$, the annihilation cross-section for the process $N_iN_i \longrightarrow f\bar{f}$ increases.



- Stronger annihilations of N_is keep their abundance close to their equilibrium abundance which lead to a decrease in asymmetry.
- A higher value of $g_{\mu\tau}$ requires a smaller value of $M_{Z_{\mu\tau}}$ to satisfy the correct asymmetry.
- The $(g-2)_\mu$ favoured region is ruled out from the results by CCFR collaboration [W. Altmannshofer el at 2014].
- The LHC bounds on searches for multi-lepton final states signatures also rule out some part of the parameter space.
- Can leptogenesis and $(g-2)_\mu$ have a common parameter space with sub-GeV $Z_{\mu\tau}$?

The Non-Minimal Model

- In the sub-GeV mass region of the $Z_{\mu\tau}$ the region favoured by $(g-2)$ lies in $M_{Z_{\mu\tau}} \simeq 10 - 100$ MeV and $g_{\mu\tau} \simeq 10^{-4} - 10^{-3} \longrightarrow \mu - \tau$ symmetry breaking scale lies below the sphaleron freeze out temperature.

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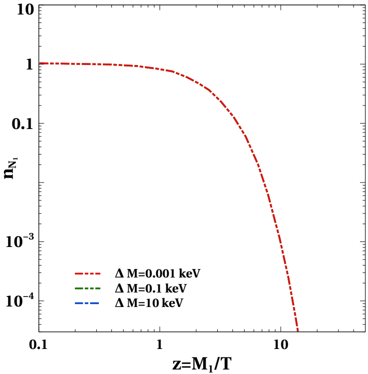
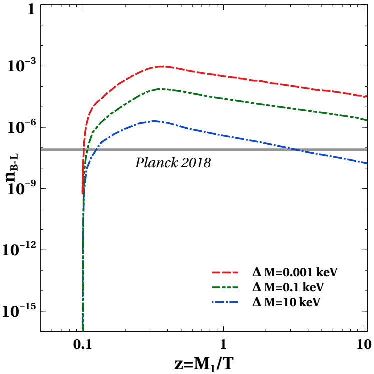
$$-\mathcal{L} \supset Y_{De}\bar{L}_e N_e \tilde{H}_1 + Y_{D\mu}\bar{L}_\mu N_\mu \tilde{H}_2 + Y_{D\tau}\bar{L}_\tau N_\tau \tilde{H}_3 + \text{h.c.}$$

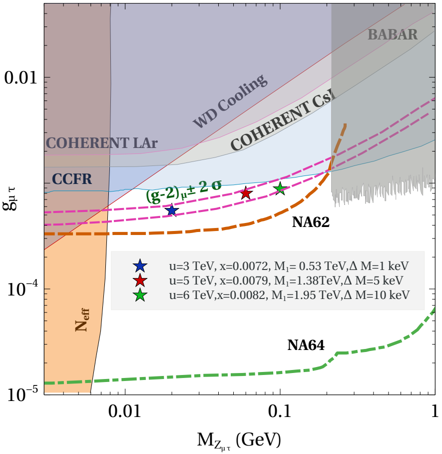
- $\mu\tau$ symmetry breaking leads to $Z_{\mu\tau}$ mass $M_{Z_{\mu\tau}} = \sqrt{5}xg_{\mu\tau}u$.
- The Majorana mass matrix M_R takes the same form.
- The $SU(2)_L$ breaking generate the Dirac mass matrix for the neutrinos $m_D = diag(Y_{De}v_1, Y_{Dm}v_1 tan\beta, Y_{Dt}v_1 tan\beta)$. Here $tan\beta = v_2/v_1 = v_3/v_1$.

The chosen VEV structure give $v_1\sqrt{1+2tan\beta^2} = 246$





Summary



- Due to the feeble gauge interaction of the N_is, no strong correlation has been seen in the gauge sector from Leptogenesis.
- We show that successful TeV scale leptogenesis is possible in the muon $(g-2)$ favored parameter space evading the current experimental bounds on sub-GeV leptophillic gauge sector.
- The presence of additional Higgs doublets can give rise to interesting phenomenology.

Thank You

For Your Attention!

Any Questions

Backup slides

- The CP asymmetry formula for resonant leptogenesis

$$\epsilon_i = \frac{\Gamma_{(N_i \longrightarrow \sum_\alpha L_\alpha H)} - \Gamma_{(N_i \longrightarrow \sum_\alpha L^c_\alpha H)}}{\Gamma_{(N_i \longrightarrow \sum_\alpha L_\alpha H)} + \Gamma_{(N_i \longrightarrow \sum_i L^c_\alpha H)}} = \frac{\mathrm{Im}[(h^\dagger h)^2_{ij}]}{(h^\dagger h)_{ii}(h^\dagger h)_{jj}} \frac{(M_i^2 - M_j^2) M_i \Gamma_j}{(M_i^2 - M_j^2)^2 + M_i^2 \Gamma_j^2}. \quad (1)$$

- The scattering washouts in our model are $lW^\pm(Z) \longrightarrow N_{1,2}H$, $lZ_{\mu\tau} \longrightarrow N_1 H$, $ql \longrightarrow qN_{1,2}$, $lN_{1,2} \longrightarrow qq^c$, $lH \longrightarrow l^c H^*$, $lH \longrightarrow N_{1,2}W^\pm(Z)$ and $lN_{1,2} \longrightarrow Z_{\mu\tau}, H$