Exploring Left-Right symmetry in the CMB

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Plan of the talk

- Motivation
- Left-Right Symmetric Model (LRSM)
- Left-right (LR) symmetry in the CMB : $\Delta N_{\rm eff}$
- Dark Matter in LR model
- Summary and conclusion

Motivation

- Theoretical predictions of the Standard Model (SM) match experimental search with great accuracy.
- Gauge Structure : $\mathscr{G}_{\text{SM}} \equiv SU(3)_C \times SU(2)_L \times U(1)_Y$.
- There remains unresolved issues within the SM that cannot be adequately addressed.

$$\Downarrow$$

Indicate the existence of the Beyond SM (BSM) frameworks.

- Left-Right Symmetric Model (LRSM) is one of the promising approaches as BSM scenario.
- Our focus has been on the Doublet LR Model (DLRM) featuring Dirac neutrinos. This model can constrain the masses of W_R, Z_R gauge bosons via the precise measurements of ΔN_{eff} from CMB anisotropies.
- In addition, the bounds of ΔN_{eff} can restrict the parameter space of Dark Matter (DM) in DLRM.

Left-Right Symmetric Model (LRSM)

- Gauge Group : $\mathcal{G}_{LR} \equiv SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ (Pati et al.'74, Mohapatra et al.'75).

- Particle Content : $Q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix} : (3,2,1,1/3),\ Q_R \equiv \begin{pmatrix} u_R \\ d_R \end{pmatrix} : (3,1,2,1/3),$

$$\ell_L \equiv \begin{pmatrix} \nu_L \\ e_L \end{pmatrix} : (1,2,1,-1),\ \ell_R \equiv \begin{pmatrix} \nu_R \\ e_R \end{pmatrix} : (1,1,2,-1),$$

$$\Phi \equiv (1,2,2,0),\ \Delta_L \equiv (1,3,1,2),\ \Delta_R \equiv (1,1,3,2).$$

- Triplet LR theories : Majorana masses for light neutrinos can be generated via type-I+II seesaw mechanism.

- In this study, we investigate the DLRM in which the $\Delta_{L,R}$ are replaced by doublet scalars :

$$H_L \equiv (1,2,1,1);\ \ H_R \equiv (1,1,2,1).$$

- No possibility for Majorana mass generation in this minimal scenario.

$$\Downarrow$$

Dirac mass for neutrinos with highly fine-tuned Yukawa couplings.

$\Delta N_{\rm eff}$ in DLRM

- The effective degrees of freedoms (dofs) : $N_{\rm eff} \equiv \frac{8}{7}\left(\frac{11}{4}\right)^{4/3}\left(\frac{\rho_{\rm rad}-\rho_\gamma}{\rho_\gamma}\right)$.

- The effective relativistic dofs for neutrinos:

$$N_{\rm eff}^{\rm SM} = 3.045$$ (Mangano et al.' 2005, Grohs et al.' 2016)

$$N_{\rm eff} = 2.99^{+0.34}_{-0.33} \text{ at } 2\sigma \text{ C.L.}$$ (Planck collaboration' 2018)

$$N_{\rm eff} = 2.99 \pm 0.17 \text{ at } 1\sigma \text{ C.L.}$$

- The deviation from $N_{\rm eff}^{\rm SM}$ i.e., $\Delta N_{\rm eff} \equiv N_{\rm eff} - N_{\rm eff}^{\rm SM}$ $\Rightarrow$ existence of additional dofs beyond SM that can be thermalised in the cosmic plasma due to new interactions/couplings.

- In our scenario, we have additional dofs in the neutrino sector due to Dirac nature of neutrinos.

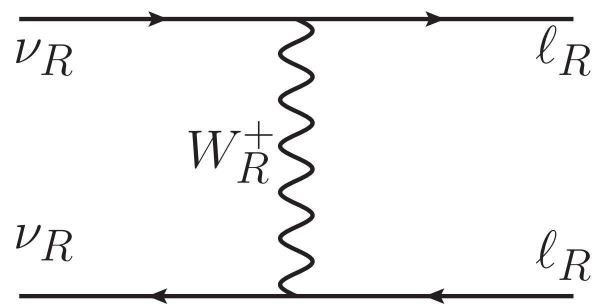
- These extra dofs can be thermalised during the early universe through their gauge interactions with extra gauge bosons (W_R, Z_R) in the theory.

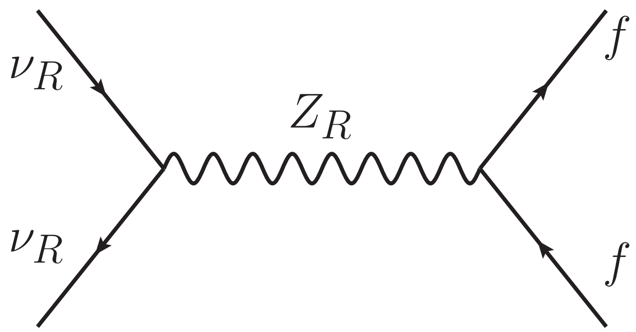
Constraining new gauge boson masses

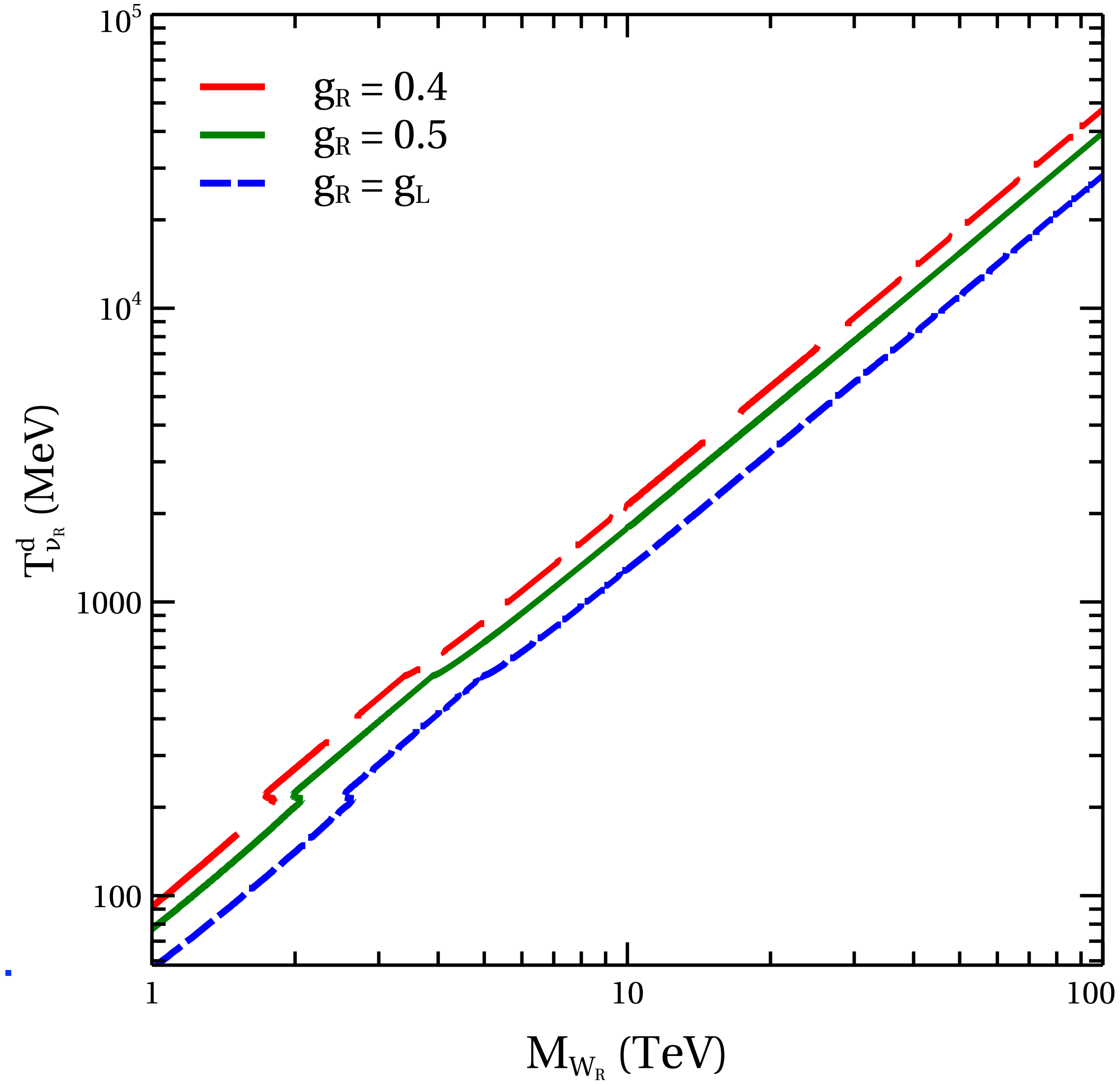
- Negligible mixing between left and right sector of the gauge bosons ⇒ no $\nu_R \bar{\nu}_L, \bar{\nu}_R \nu_L \to f\bar{f}$ diagrams.

$$\Gamma \sim \frac{g_R^4 T^5}{M_{W_R}^4}, \quad H \sim T^2$$

- Yukawa couplings are very small ⇒ No Higgs mediated diagrams.

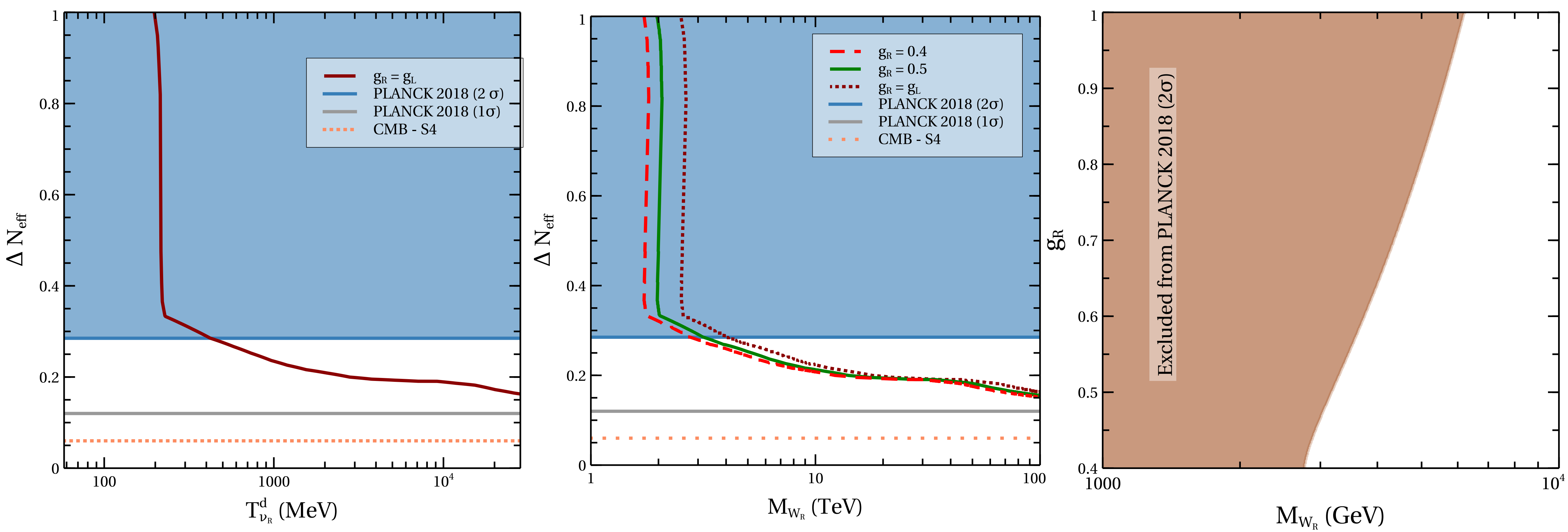






- For larger (smaller) values of M_{W_R} (g_R), $T^d_{\nu_R}$ increases.

- The deviation from $N_{\rm eff}^{\rm SM}$: $\Delta N_{\rm eff} = N_{\nu_R}\left(\frac{g_{*s}(T^d_{\nu_L})}{g_{*s}(T^d_{\nu_R})}\right)^{4/3}$

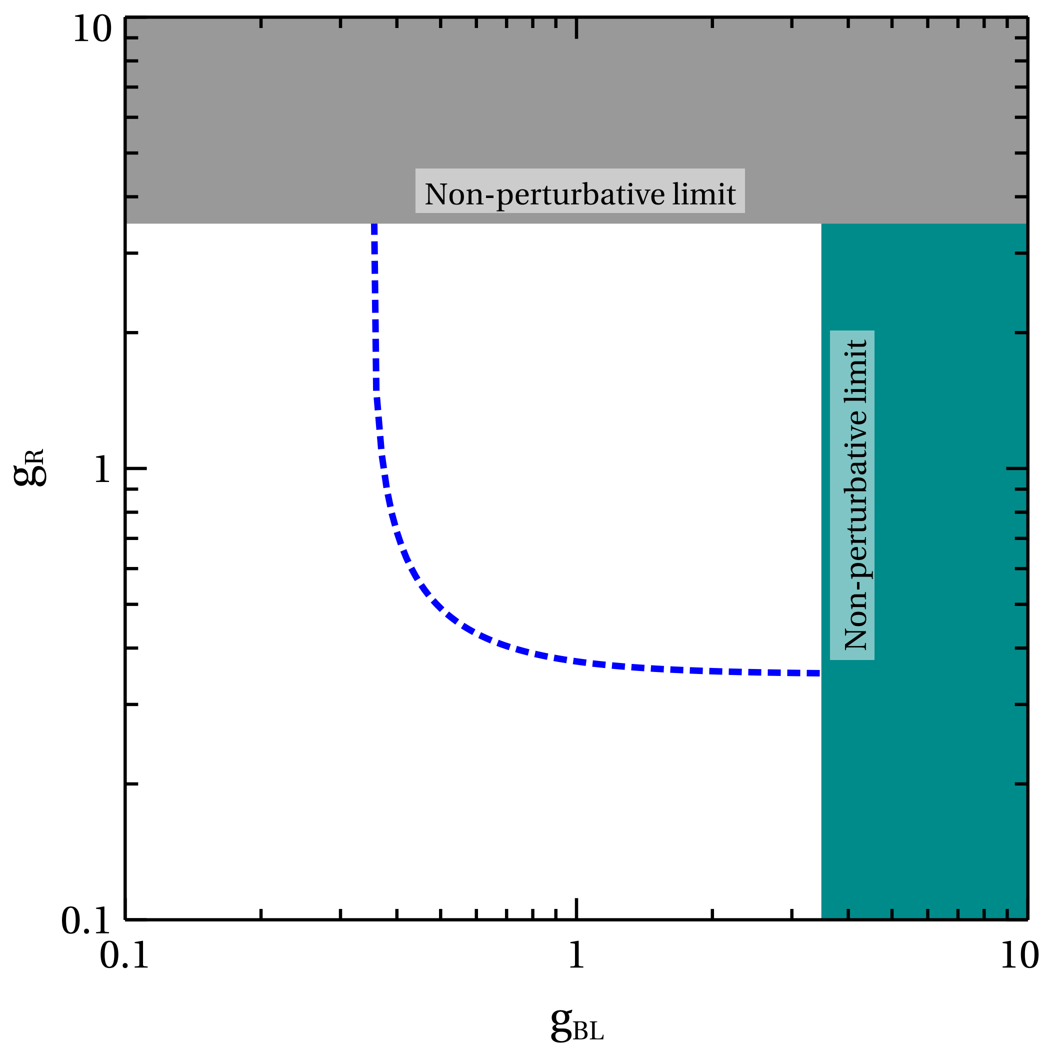


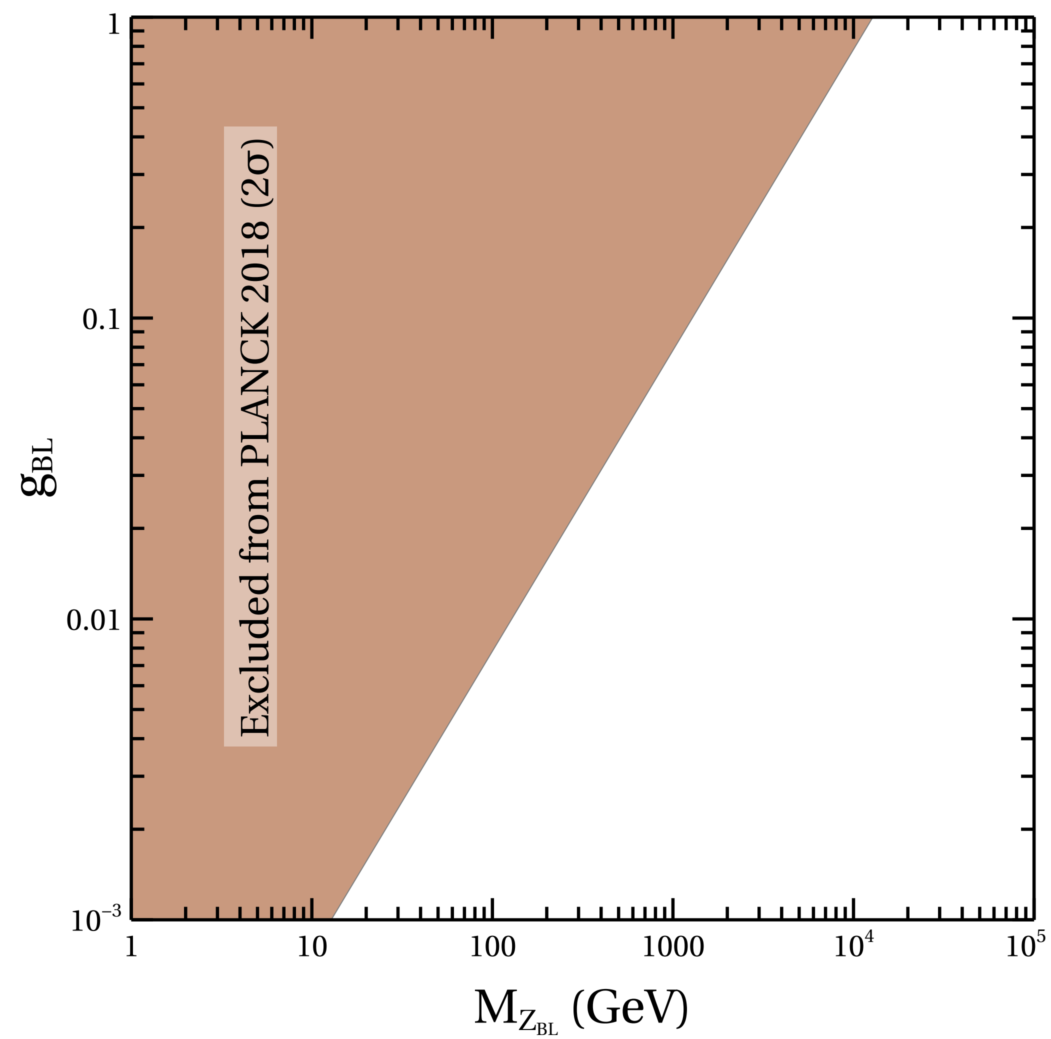
- For symmetric LR case i.e., $g_L = g_R$: $M_{W_R} \sim 4.06$ TeV can saturate Planck 2σ bound on $\Delta N_{\rm eff}$.
- Higher values of g_R as compared to g_L results in a more stringent lower limit on M_{W_R} .

Comparison with gauged $U(1)_{B-L}$ models

- In DLRM the g_R, g_{BL} are well constrained by g_Y : $\dfrac{1}{g_R^2} + \dfrac{1}{g_{BL}^2} = \dfrac{1}{g_Y^2} \Rightarrow M_{W_R}, M_{Z_R}$ are well constrained.

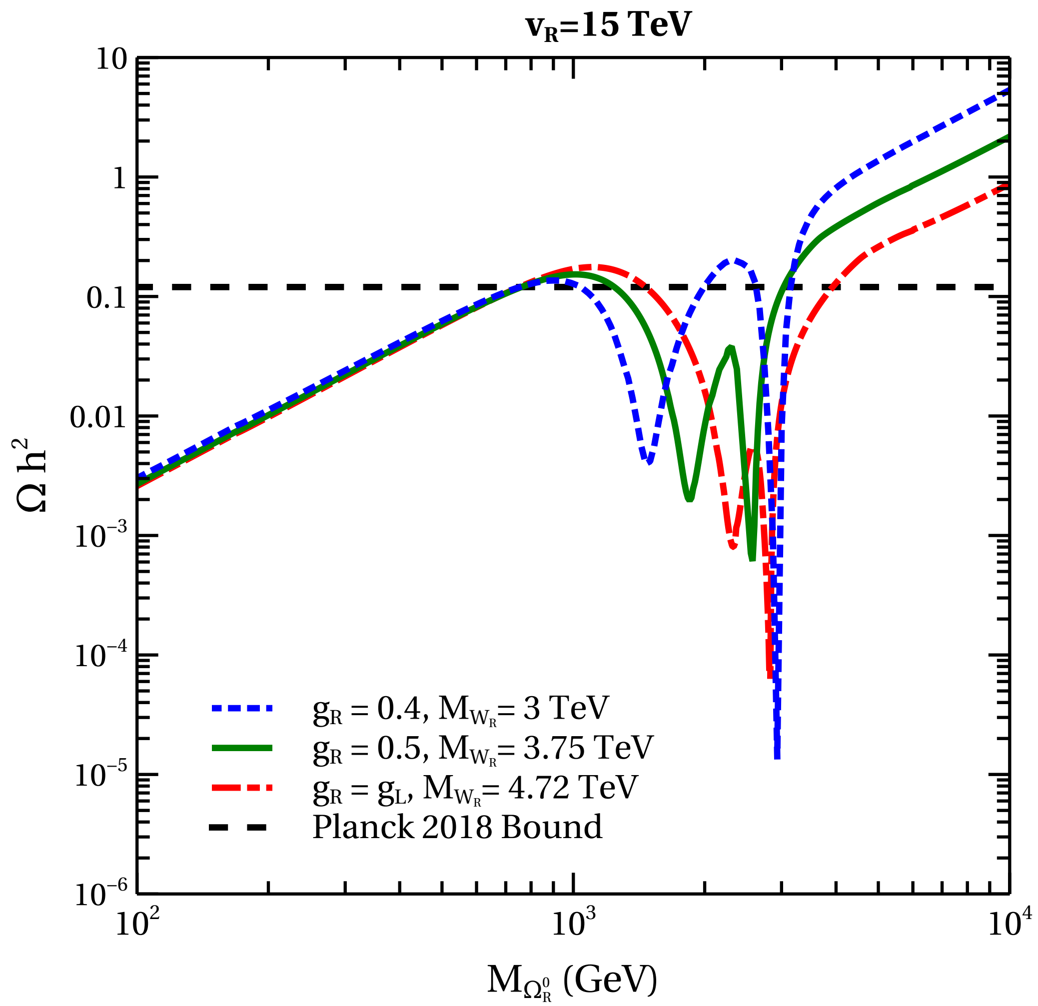
- Conversely, in gauged $U(1)_{B-L}$ models : g_{BL} is not constrained in any way, allowing Z_{BL} to be extremely light.

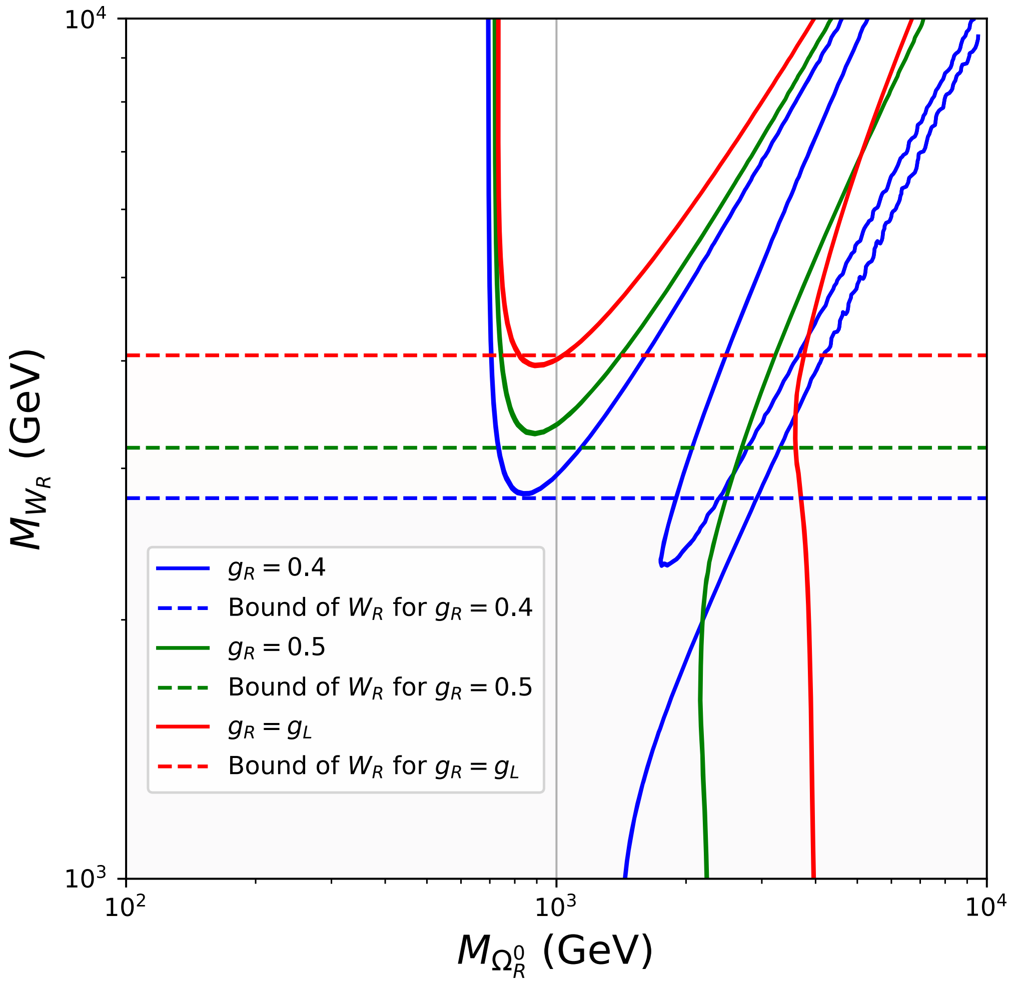




Dark Matter in DLRM

- No stabilising symmetry as $(-1)^{B-L}$ in DLRM since the LR symmetry breaks via the vevs of H_R with B-L charge 1.
- Need higher dimensional multiplet which does not have any renormalisable coupling to SM particles $\Rightarrow$ real fermion quintuplet with B-L charge 0.
- The bounds on ΔN_{eff} constrain the DM parameter space considerably.
- DLRM with three RH Dirac neutrinos + real fermion quintuplet $\Rightarrow$ can saturate Planck 1σ bound on ΔN_{eff}.





Summary

- LR theories have emerged as a promising class of BSM scenarios that offer viable explanations for various unresolved problems in the SM.

- This study has focused on the Doublet LR Model (DLRM), which produces Dirac masses for neutrinos.

- The Dirac nature of neutrinos introduces additional degrees of freedom in the neutrino sector, which can couple through interactions with new gauge bosons. This, in turn, offers an explanation for any deviation of $N_{\rm eff}$ from $N_{\rm eff}^{\rm SM}$ value.

- Using Planck data (including BAO data), we have put lower limits on the masses of new gauge bosons. These limits are just as competitive as the limits derived from di-jet resonance searches at the LHC.

- The parameter space of Dark Matter has been constrained based on the $\Delta N_{\rm eff}$ bounds.

Thank you!

Comments, questions, Suggestions!!!

Saturation of Planck 1σ bound

- Require additional dofs to be present in the theory to saturate Planck 1σ bound.
- Real fermion quintuplet + DLRM with right-handed Dirac neutrinos effectively accomplishes the task.
- Higher decoupling temperature constrain the parameter space more stringently.