Perturbativity constraints on $U(1)_{B-L}$ and Left-Right Models

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In collaboration with
P.S.B Dev, R.N Mohapatra & Y. Zhang (arXiv: 1811.08789)

Outline

- Introduction & Motivation
- Theoretical Constraints
- Bounds in $U(1)_{B \quad L}$ model
- Bounds in Minimal LRSM
- Conclusions

Introduction & Motivation

- The Standard Model(SM) has been highly successful but needs extension to include new physics such as tiny neutrino masses, DM and baryon asymmetry.

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- Many TeV scale extensions introduce extended gauge groups like extra $U(1)$'s or $SU(2) \times U(1)$.
- Our results apply to a subclass of these gauge extensions of SM, where the generators of the extra gauge groups contribute to the electric charge.

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- The motivation is to embed the TeV-scale gauge extension into a larger gauge symmetry at GUT scale.
- We'll specifically focus on $U(1)_{B\ \ L}$ & minimal LRSM, and discuss the implications for gauge boson searches.

Theoretical Constraint on Gauge Couplings

- Consider a SM extension: $SU(2)_L \times U(1)_X \times U(1)_Z$ such that:

$$Q = I_{3L} + I_X + \frac{Q_Z}{2}$$

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- Then requiring that coupling g_Z is perturbative at breaking scale,

$$\Rightarrow \quad \boxed{r_g \equiv \frac{g_X}{g_L} > \tan\theta_W \left(1 - \frac{4\pi}{g_Z^2}\frac{\alpha_{EM}}{\cos^2\theta_W}\right)^{1=2}}$$

$U(1)_{B-L}$ model

- Particle content of the $SU(2)_L \times U(1)_{I_{3R}} \times U(1)_{B\ \ L}$ model:

	$SU(2)_L$	$U(1)_{I_{3R}}$	$U(1)_{B\ \ L}$
Q	$\mathbf{2}$	0	$\frac{1}{3}$
u_R	$\mathbf{1}$	$+\frac{1}{2}$	$\frac{1}{3}$
d_R	$\mathbf{1}$	$-\frac{1}{2}$	$\frac{1}{3}$
L	$\mathbf{2}$	0	-1
N	$\mathbf{1}$	$+\frac{1}{2}$	-1
e_R	$\mathbf{1}$	$-\frac{1}{2}$	-1
H	$\mathbf{2}$	$-\frac{1}{2}$	0
$_R$	$\mathbf{1}$	-1	2

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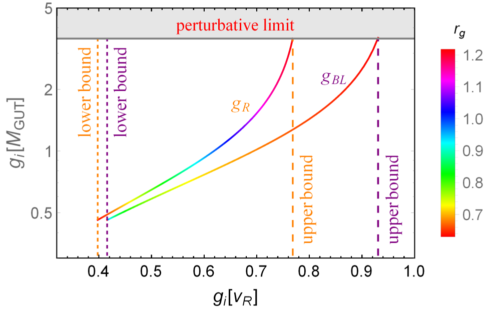
N	$\mathbf{1}$	$+\frac{1}{2}$	-1
e_R	$\mathbf{1}$	$-\frac{1}{2}$	-1
H	$\mathbf{2}$	$-\frac{1}{2}$	0
$_R$	$\mathbf{1}$	-1	2

- The RGEs for the gauge couplings of the two $U(1)$'s are respectively

$$16\pi^2\beta(g_{I_{3R}}) \;=\; \frac{9}{2}\, g_{I_{3R}}^3 \,, \quad 16\pi^2\beta(g_{B\,L}) \;=\; 3\, g_{B\,L}^3 \,.$$

$SU(2)_L \times U(1)_{I3R} \times U(1)_{B-L}$ (Gauge Couplings)



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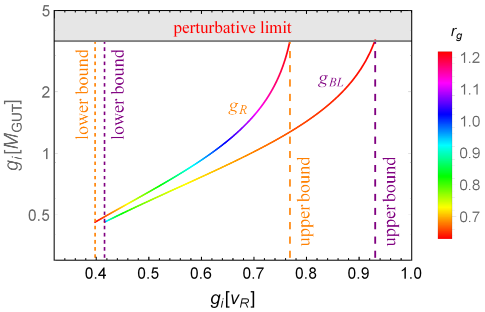
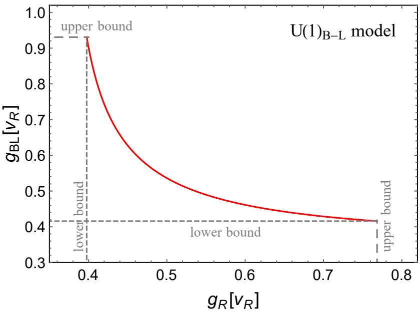
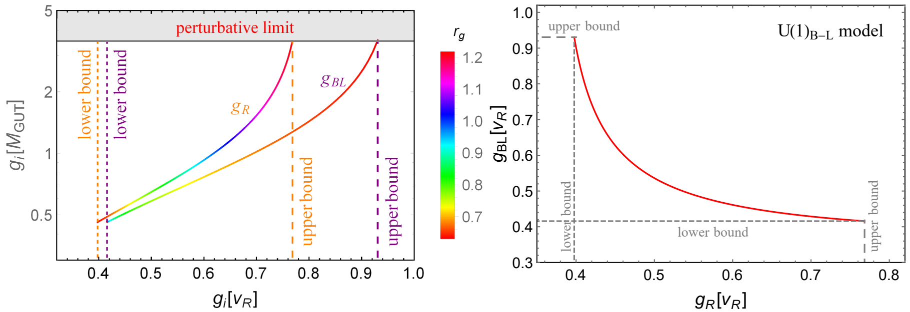


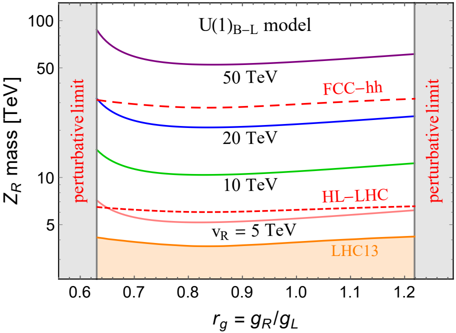




$0.398 < g_R < 0.768; \quad 0.416 < g_{BL} < 0.931$, with $0.631 < r_g < 1.218$

at v_R = 5 TeV

$SU(2)_L \times U(1)_{I3R} \times U(1)_{B-L}$ (Z_R searches)



(ATLAS-CONF-2016-045)
(CMS-PAS-EXO-16-031)

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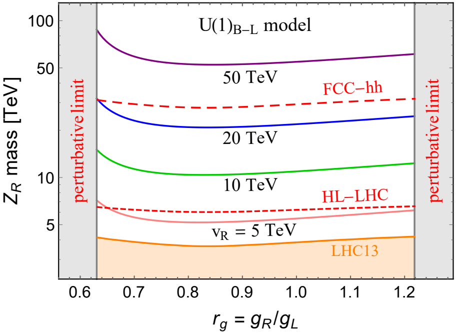

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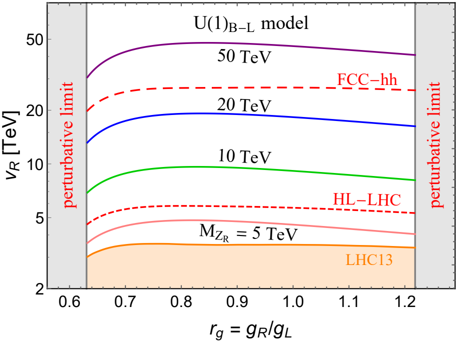

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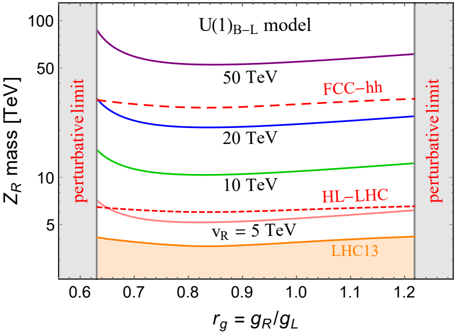
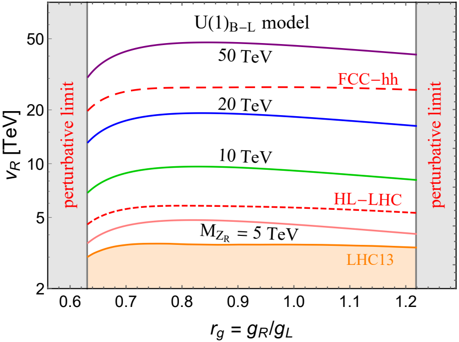




collider	M_{Z_R} [TeV]	v_R [TeV]
LHC13	[3.6, 4.2]	[3.02, 3.57]
HL-LHC	[6.0, 6.6]	[4.60, 5.82]
FCC-hh	[27.9, 31.8]	[19.9, 26.8]

- Particle content of the minimal LRSM based on the gauge group $SU(2)_L \times SU(2)_R \times U(1)_{B\ \ L}$:

	$SU(2)_L$	$SU(2)_R$	$U(1)_{B\ \ L}$
$Q_L \equiv \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$\mathbf{2}$	$\mathbf{1}$	$\frac{1}{3}$
$Q_R \equiv \begin{pmatrix} u_R \\ d_R \end{pmatrix}$	$\mathbf{1}$	$\mathbf{2}$	$\frac{1}{3}$
$\psi_L \equiv \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$\mathbf{2}$	$\mathbf{1}$	-1
$\psi_R \equiv \begin{pmatrix} N \\ e_R \end{pmatrix}$	$\mathbf{1}$	$\mathbf{2}$	-1
$= \begin{pmatrix} \phi_1^0 & \phi_2^+ \\ \phi_1 & \phi_2^0 \end{pmatrix}$	$\mathbf{2}$	$\mathbf{2}$	0
${}_R = \begin{pmatrix} \frac{1}{\sqrt{2}}\,{}^{+}_{R} & {}^{++}_{R} \\ {}^{0}_{R} & -\frac{1}{\sqrt{2}}\,{}^{+}_{R} \end{pmatrix}$	$\mathbf{1}$	$\mathbf{3}$	2

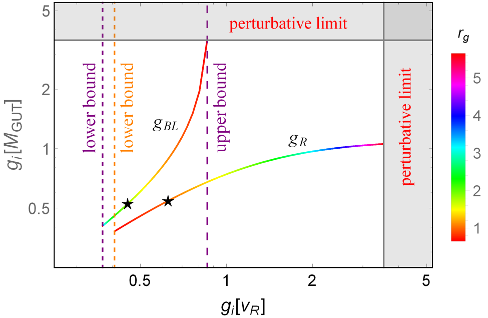
Minimal LRSM

- The RGEs for the gauge couplings in the minimal LRSM are [1]

$$
\begin{aligned}
16\pi^2\beta(g_L) &= -3\, g_L^3\,,\\
16\pi^2\beta(g_R) &= -\frac{7}{3}\, g_R^3\,,\\
16\pi^2\beta(g_{BL}) &= \frac{11}{3}\, g_{BL}^3
\end{aligned}
$$

[1] I. Z. Rothstein, Nucl. Phys. B358, 181 (1991)

$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ (Gauge Couplings)



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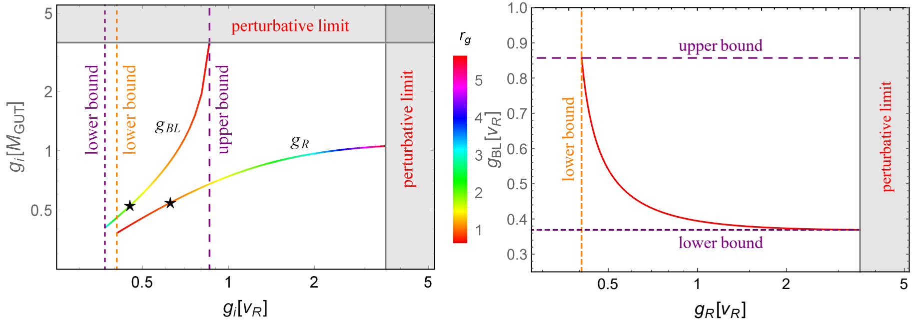

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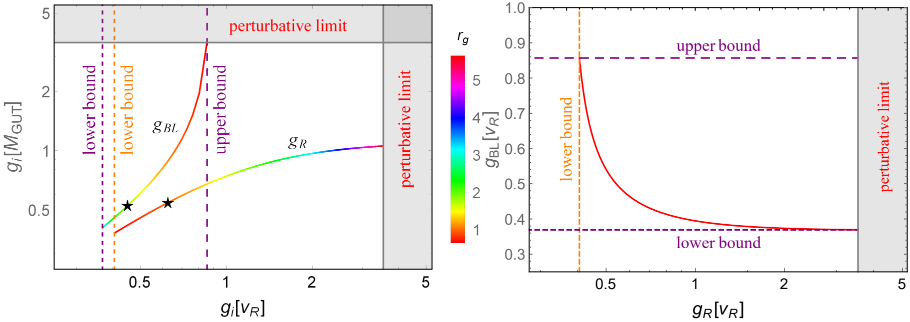
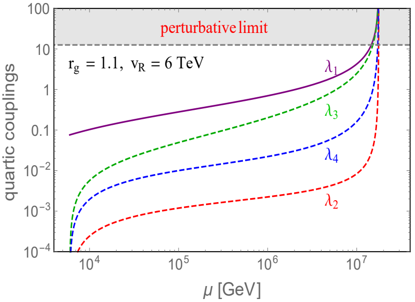
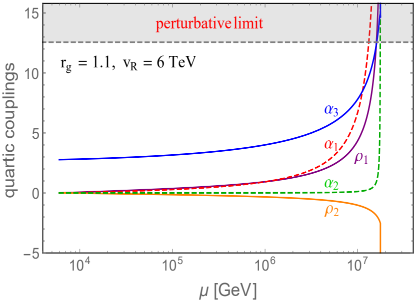


$0.406 < g_R < \sqrt{4\pi}$; $\quad 0.369 < g_{BL} < 0.857$, with $0.648 < r_g < 5.65$

at v_R = 10 TeV

$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ (Scalar sector)





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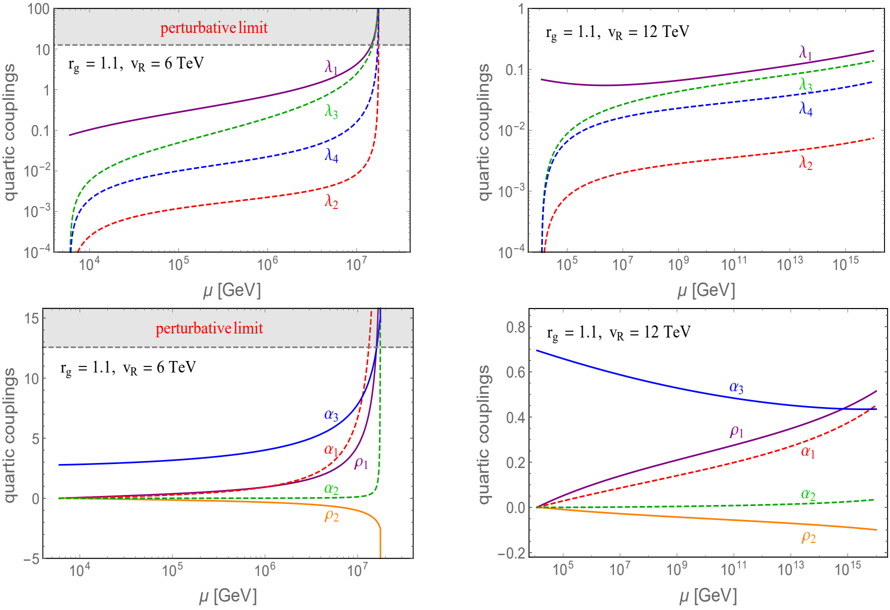
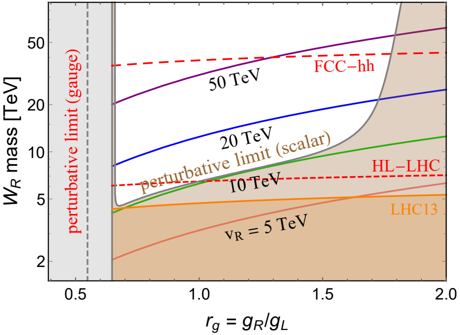


$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ (Z_R and W_R searches)



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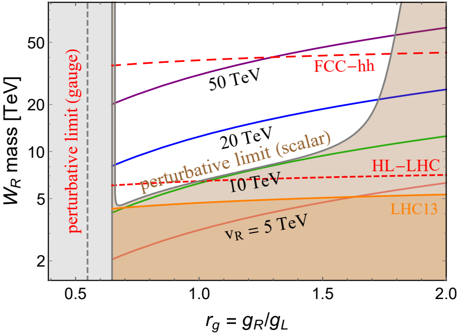

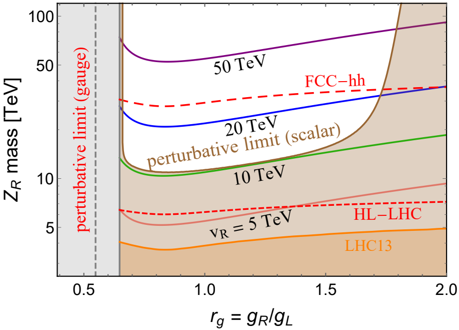

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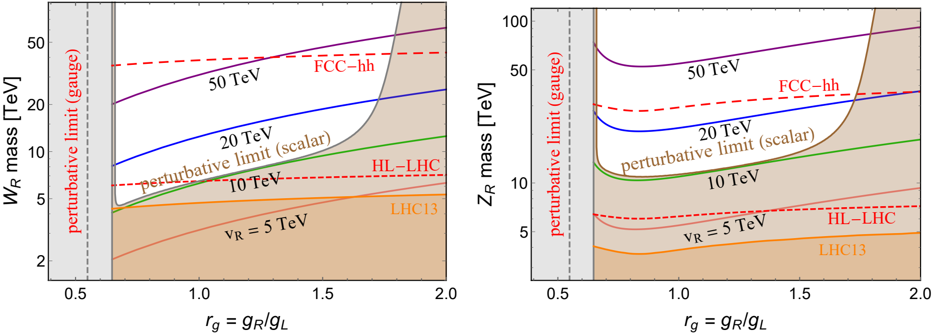
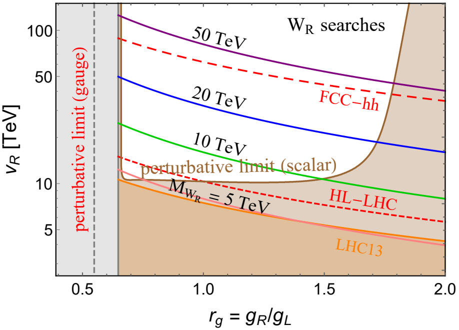


collider	W_R searches		Z_R searches	
	M_{W_R} [TeV]	v_R [TeV]	M_{Z_R} [TeV]	v_R [TeV]
LHC13	–	–	–	–
HL-LHC	[6.09, 6.47]	[10.3, 14.8]	–	–
FCC-hh	[35.6, 42.2]	[38.3, 87.5]	[27.9, 35.4]	[21.8, 26.8]

$SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ (v_R bound)



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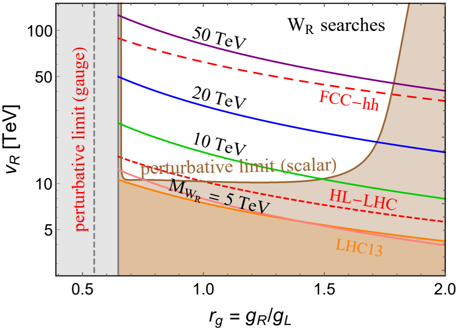

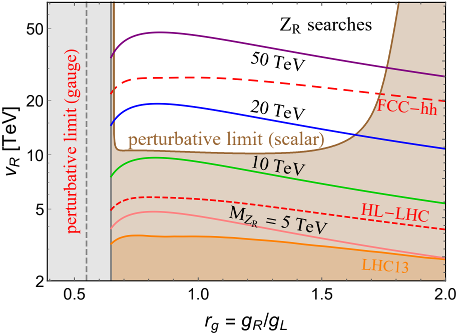

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- For minimal LRSM, we found W_R and Z_R couldn't have been seen at LHC13.
- In case, Z_R is found in HL-LHC run then couldn't be from minimal LRSM.
    - The results can be generalized to other gauge group extensions.

Thank you! Questions?