Dark Matter Approach of a Left-Right Symmetric Model

Sanchari Bhattacharyya

University of Calcutta

January 23, 2023

AAPCOS 2023
Saha Institute of Nuclear Physics, Kolkata

Outline

1. **Introduction**
2. **32121 Model**
   - Brief Description
   - Particle Sector
   - Fixing the parameters
   - Masses of the Exotic Particles
3. **Dark Matter in 32121**
   - Direct Detection
   - Relic Density
   - Direct Detection in Two-component DM Scenario
4. **Conclusion**

Introduction

- Standard Model (SM) of particle physics is successful in describing many of the natural phenomena including interactions between elementary particles etc.
- But SM fails to explain some experimentally established phenomena including presence of dark matter (DM) or tiny neutrino mass.
- The incompleteness of SM motivates us to look beyond SM.
- Today we shall investigate such a BSM theory that respects $SU(3)_C \otimes SU(2)_L \otimes U(1)_L \otimes SU(2)_R \otimes U(1)_R$ (32121) local gauge symmetry.
- It is Left-Right (LR) symmetric.
- Its root can be traced back from E_6 GUT.
  $E_6 \longrightarrow 3_C \otimes 3_L \otimes 3_R \longrightarrow 3_C \otimes 2_L \otimes 1_L \otimes 2_R \otimes 1_R \longrightarrow 3_C \otimes 2_L \otimes 1_Y \longrightarrow 3_C \otimes 1_{em}$

32121 Model: Brief Description

Particle Contents

		3_C	2_L	2_R	1_L	1_R
Fermions	L_L	1	2	1	$-1/6$	$-1/3$
	$\bar{L}_R$	1	1	2	$1/3$	$1/6$
	$\bar{L}_B$	1	2	2	$-1/6$	$1/6$
	$\bar{l}_S$	1	1	1	$1/3$	$-1/3$
	Q_L	3	2	1	$1/6$	0
	$\bar{Q}_R$	$\bar{3}$	1	2	0	$-1/6$
	$\bar{Q}_{LS}$	$\bar{3}$	1	1	$-1/3$	0
	Q_{RS}	3	1	1	0	$1/3$
Higgs Bosons	Φ_B	1	2	2	$1/6$	$-1/6$
	Φ_L	1	2	1	$1/4$	$1/4$
	Φ_R	1	1	2	$-1/4$	$-1/4$
	Φ_S	1	1	1	$-1/3$	$1/3$

- Scalars coming from $(\mathbf{1}, \mathbf{3}, \bar{\mathbf{3}})$ representation of $SU(3)^3$.
- Fermions coming from from full **27**-plet of E_6. [Q. Shafi, Phys. Lett. B, 79(3), 301-303]
- The above $U(1)$ hypercharge assignments are anomaly free and follow the symmetry breaking pattern of $SU(3)^3 \longrightarrow 32121$.

32121 Model: Particle Sector

Scalar Sector:

$$\Phi_B = \begin{pmatrix} \frac{1}{\sqrt{2}}(k_1 + h_1^0 + i\xi_1^0) & h_1^+ \\ h_2^- & \frac{1}{\sqrt{2}}(k_2 + h_2^0 + i\xi_2^0) \end{pmatrix},$$

$$\Phi_L = \begin{pmatrix} h_L^+ \\ \frac{1}{\sqrt{2}}(v_L + h_L^0 + i\xi_L^0) \end{pmatrix}, \Phi_R = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_R + h_R^0 + i\xi_R^0) \\ h_R^- \end{pmatrix}, \Phi_S = \frac{1}{\sqrt{2}}(v_S + h_S^0 + i\xi_S^0)$$

Fermion Sector:

$$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}, \; L_R = \begin{pmatrix} \nu_R \\ e_R \end{pmatrix}, \; Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}, \; Q_R = \begin{pmatrix} u_R \\ d_R \end{pmatrix}$$

$$Q_{LS} = q_{SL}, \; Q_{RS} = q_{SR}, \; l_S, \; L_B = \begin{pmatrix} N_1 & E_1 \\ E_2 & N_2 \end{pmatrix} \text{ and } \tilde{L}_B = \begin{pmatrix} N_2^c & E_2^c \\ E_1^c & N_1^c \end{pmatrix}$$

Physical Fields:

Scalars: h^0, h_2^0 (ξ_2^0), h_L^0 (ξ_L^0), H_R^0, H_S^0, $H_1^\pm$, $H_L^\pm$. [$h^0 \longrightarrow$ SM Higgs]

Fermions: ν, N, L_S, e, u, d, E, Q_S. [ν, e, u, $d \longrightarrow$ SM Fermions]

Gauge bosons: Z, γ, Z', A', W, W'. [W, Z, $\gamma \longrightarrow$ SM Gauge Bosons]

32121 Model: Fixing the parameters

- 5 gauge coupling constants, $g_3, g_{2L}, g_{2R}, g_{1L}, g_{1R}$.
  - LR symmetry breaking $\longrightarrow \frac{1}{g_Y^2} = \frac{1}{g_{2R}^2} + \frac{1}{g_{1L}^2} + \frac{1}{g_{1R}^2}$
  - $g_{2L} = g_{2R}$, $g_{1L} = g_{1R}$.
- 5 vacuum expectation values.
  - $k_1 = 246$ GeV (From SM W mass)
  - $v_R > 14.7$ TeV (From direct bound on W' mass)
  - $v_S > 12.61$ TeV (From derived lower mass limit of A' (> 3.5 TeV))
  - $k_2 = 0$ and $v_L = 0$.
- 10 real quartic couplings.
  - The potential must be bounded from below.
  - Accepted only those values who are allowed by the SM Higgs signal strength to $b\bar{b}$ channel.

[**SB** and A. Datta, Phys. Rev. D 105, 075021]

32121 Model: Masses of the Exotic Particles

The lower mass limits of the exotic patricles of 32121 as derived from the LHC data,

- $m_{h_2^0} = m_{\xi_2^0} > 800$ GeV. [1]
- $m_{H_1^\pm} > 720$ GeV. [2]
- $m_{E^\pm} > 1.089$ TeV. [3]
- $m_{A'} > 3.5$ TeV. [4]
- With the lower limit on v_R, $m_{Z'} > 5.089$ TeV.

Throughout our analysis, the masses of the BSM particles have been set at their lowest limits.

[**SB** and A. Datta, Phys. Rev. D 105, 075021]

[1] ATLAS Collaboration, Phys. Rev. D 102, 032004 (2020)
[2] ATLAS Collaboration, JHEP 06 (2021) 145
[3] ATLAS Collaboration, Phys. Rev. D 99 (2019) 092007
[4] ATLAS Collaboration, JHEP10 (2017) 182

Dark Matter in 32121

Consider a similiar variant of the previous set of hypercharge assignments.

	3_C	2_L	2_R	1_L	1_R
Φ_L	1	2	1	1/4	1/4
Φ_R	1	1	2	$-1/4$	$-1/4$

Dark Matter candidates in 32121 model are fermions

Candidates: L_S (a Majorana fermion constructed out of l_S and l_S^c) nd N (a Dirac fermion constructed out of N_1 and N_2^c).

Yukawa Lagrangian

$$\mathcal{L}_{Yukawa} = \mathcal{L}_{Y4} + \mathcal{L}_{Y5} + H.C.$$

$$\begin{aligned} \mathcal{L}_{Y4} &= y_{qij}\ \bar{Q}_{iL}\Phi_B Q_{jR} + \tilde{y}_{qij}\ \bar{Q}_{iR}\tilde{\Phi}_B Q_{jL} + y_{lij}\ \bar{L}_{iL}\Phi_B L_{jR} + \tilde{y}_{lij}\ \bar{L}_{iR}\tilde{\Phi}_B L_{jL} \\ &+ y_{sij}\ \bar{Q}_{iLS}\Phi_S Q_{jRS} + y_{LBij}\ Tr\left[\bar{L}_{iB}\tilde{L}_{jB}\right]\Phi_S^* + y_{BBij}\ Tr\left[\bar{L}_{iB}\tilde{\Phi}_B\right] l_{jS}^c \end{aligned}$$

$$\mathcal{L}_{Y5} = \frac{1}{\Lambda}\left[\, y_{LSij}\ \bar{l}_{iS} l_{jS}^c \Phi_S \Phi_S + y_{SSij}\ Tr\left[\bar{L}_{iB}\Phi_B\right] l_{jS}\Phi_S^* + y_{qSBij}\ \bar{Q}_{iLS}\, Tr\left[\Phi_B^\dagger \tilde{\Phi}_B\right] Q_{jRS}\right]$$

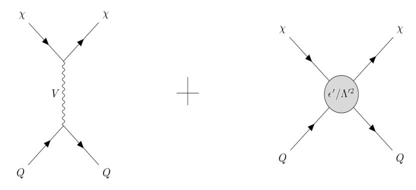
SB and A. Datta, arXiv: [2206.13105]

Fermion Dark Matter: Direct Detection

- When N is DM candidate

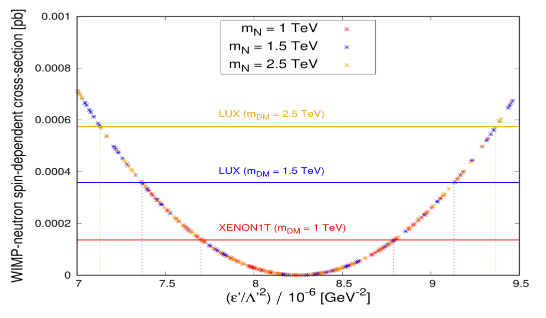
We add a term,

$$\frac{\epsilon'}{\Lambda'^2} Tr[(\bar{L}_B \gamma^\mu \tau_a L_B)] \; (\bar{f}_L \gamma_\mu \tau_a f_L + L \leftrightarrow R)$$



The effect of interference between two diagrams may reduce the total scattering cross-section.

Experimental upper limits on DM-nucleon scattering cross-section from XENON, LUX collaborations helps us to find an allowed range of ϵ'/Λ'^2 for different masses of DM.

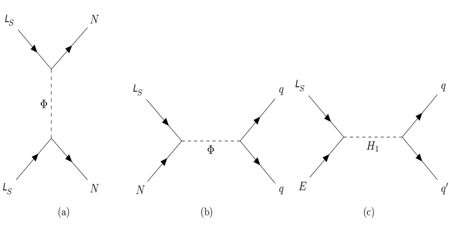


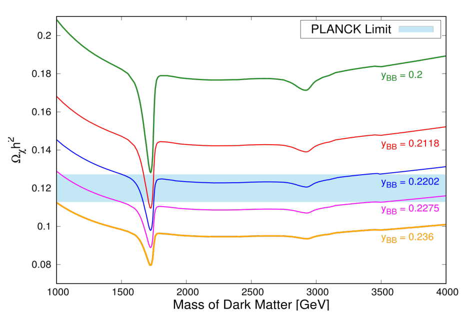
[XENON collab., PRL. 121, 111302 (2018); LUX Collab., PRL. 118, 251302 (2017)]

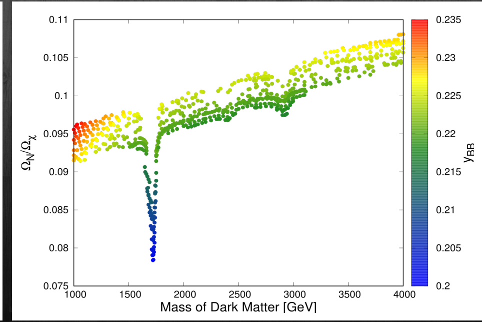
Fermion Dark Matter: Relic Density

y_{BB} is important in this context.

1. We consider the case of $y_{BB} \neq 0$ with N and L_S degenerate in mass.
2. $0.2 < y_{BB} < 0.236$ is allowed by PLANCK experiment for $m_{A'} = 3.5$ TeV and $m_{Z'} = 5.89$ TeV.
   [SB and A. Datta, arXiv: [2206.13105]]







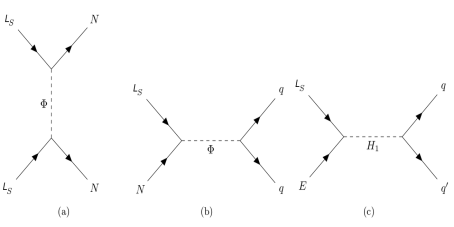
y_{BB} is important in this context.

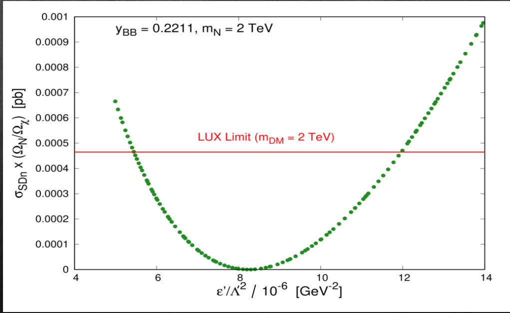
1. We consider the case of $y_{BB} \neq 0$ with N and L_S degenerate in mass.
2. $0.2 < y_{BB} < 0.236$ is allowed by PLANCK experiment for $m_{A'} = 3.5$ TeV and $m_{Z'} = 5.89$ TeV.
   [**SB** and A. Datta, arXiv: [2206.13105]]

- In case of a two-component DM model, the direct detection cross-section,

$$\sigma = \left(\frac{\Omega_N}{\Omega_\chi}\right)\sigma_N + \left(\frac{\Omega_{l_S}}{\Omega_\chi}\right)\sigma_{l_S}$$

- A new wider range of ϵ'/Λ'^2 we obtain.





[LUX Collaboration, PRL. 118, 251302 (2017)]

Conclusion

- We investigate a LR symmetric gauge model that respects $SU(3)_C \otimes SU(2)_L \otimes U(1)_L \otimes SU(2)_R \otimes U(1)_R$ local gauge symmetry.
- A few assumptions we considered to simplify the large parameter space.
- Using the recent LHC results we could derive lower limits on the masses of some BSM particles.
- Some of them may generate interesting signature at 14 and 27 TeV HL-LHC run.
- 32121 model contains fermion Dark Matter candiates.
- We study a two-component fermion DM scenario.
- We find parameter spaces allowed by PLANCK experiment.
- We also derive limits on the coefficient of effective four-fermi operator from Direct Detection Experiments.
- We are hopeful to explore more with this model.

Thank You

Back Ups

Scalar potential:

$$\mathcal{V} = \mathcal{V}_1 + \mathcal{V}_2$$

where,

$$\begin{aligned}
\mathcal{V}_1 = & - \mu_1^2 \, Tr\left(\Phi_B{}^\dagger \Phi_B\right) - \mu_3^2 \left(\Phi_L{}^\dagger \Phi_L + \Phi_R{}^\dagger \Phi_R\right) - \mu_4^2 \Phi_S{}^\dagger \Phi_S \\
& + \lambda_1 \, Tr\left[(\Phi_B{}^\dagger \Phi_B)^2\right] + \lambda_3 \left(Tr\left[\Phi_B{}^\dagger \tilde{\Phi}_B\right] Tr\left[\tilde{\Phi}_B^\dagger \Phi_B\right]\right) \\
& + \alpha_1 (\Phi_S^\dagger \Phi_S)^2 + \beta_1 \, Tr\left[\Phi_B{}^\dagger \Phi_B\right](\Phi_S^\dagger \Phi_S) + \gamma_1 \left[(\Phi_L^\dagger \Phi_L) + (\Phi_R^\dagger \Phi_R)\right](\Phi_S^\dagger \Phi_S) \\
& + \rho_1 \left[(\Phi_L^\dagger \Phi_L)^2 + (\Phi_R^\dagger \Phi_R)^2\right] + \rho_3 \left[(\Phi_L^\dagger \Phi_L)(\Phi_R^\dagger \Phi_R)\right] + c_1 \, Tr\left[\Phi_B{}^\dagger \Phi_B\right]\left[(\Phi_L^\dagger \Phi_L) + (\Phi_R^\dagger \Phi_R)\right] \\
& + c_3 \left[(\Phi_L^\dagger \Phi_B \Phi_B^\dagger \Phi_L) + (\Phi_R^\dagger \Phi_B^\dagger \Phi_B \Phi_R)\right] + c_4 \left[(\Phi_L^\dagger \tilde{\Phi}_B \tilde{\Phi}_B^\dagger \Phi_L) + (\Phi_R^\dagger \tilde{\Phi}_B^\dagger \tilde{\Phi}_B \Phi_R)\right]
\end{aligned}$$

and,

$$\mathcal{V}_2 = \mu_{BS} \, Tr\left[\Phi_B^\dagger \tilde{\Phi}_B\right] \Phi_S^* + h.c.$$

Parameters in $\mathcal{V}$ are real.