Dark Matter and Collider Signals in the Alternative Left Right Model

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Outline

The Alternative Left Right Model

Left Right Symmetric Models

- Left Right Symmetric Models explain parity and neutrino masses
- But to avoid FCNCs the right scale must be high. Also, no natural DM candidate.

Alternative Left Right Symmetric Models

- Based on breaking GUT $E_6 \to SU(3)_c \times SU(3)_L \times SU(3)_H \to SU(3)_c \times SU(2)_L \times SU(2)_H \times U(1)_X$
- Here $SU(2)_H = SU(2)_{R'}$.
- The $SU(2)_{R'}$ partner of the right-handed up-quark u_R is exotic down-type quark d'_R; the $SU(2)_{R'}$ partner of the right-handed charged lepton e_R is a new neutral lepton, the scotino n_R.
- The right-handed neutrino ν_R and down-type quark d_R singlets under both the $SU(2)_L$ and $SU(2)_{R'}$.
- Model includes $SU(2)_L$ singlets n_L scotino and d'_L quark.

ALRM Particle Content

Fields	Repr.	$U(1)_S$
$Q_L = \begin{pmatrix} u_L \\ d_L \end{pmatrix}$	$(3,2,1,\frac{1}{6})$	0
$Q_R = \begin{pmatrix} u_R \\ d'_R \end{pmatrix}$	$(3,1,2,\frac{1}{6})$	$-\frac{1}{2}$
d'_L	$(3,1,1,-\frac{1}{3})$	-1
d_R	$(3,1,1,-\frac{1}{3})$	0
$L_L = \begin{pmatrix} \nu_L \\ e_L \end{pmatrix}$	$(1,2,1,-\frac{1}{2})$	1
$L_R = \begin{pmatrix} n_R \\ e_R \end{pmatrix}$	$(1,1,2,-\frac{1}{2})$	$\frac{3}{2}$
n_L	$(1,1,1,0)$	2
ν_R	$(1,1,1,0)$	1

Fields	Repr.	$U(1)_S$
$\phi = \begin{pmatrix} \phi_1^0 & \phi_2^+ \\ \phi_1^- & \phi_2^0 \end{pmatrix}$	$(1,2,2^*,0)$	$-\frac{1}{2}$
$\chi_L = \begin{pmatrix} \chi_L^+ \\ \chi_L^0 \end{pmatrix}$	$(1,2,1,\frac{1}{2})$	0
$\chi_R = \begin{pmatrix} \chi_R^+ \\ \chi_R^0 \end{pmatrix}$	$(1,1,2,\frac{1}{2})$	$\frac{1}{2}$
G_μ	$(8,1,1,0)$	0
$W_{L\mu}$	$(1,3,1,0)$	0
$W_{R\mu}$	$(1,1,3,0)$	0
B_μ	$(1,1,1,0)$	0

Table: ALRSM particle content, with $SU(3)_c \times SU(2)_L \times SU(2)_{R'} \times U(1)_{B-L}$ and $U(1)_S$ quantum numbers.

Lagrangian and Symmetry Breaking

- Model contains additional $U(1)_S$ symmetry. Through spontaneous breaking of $SU(2)_{R'} \times U(1)_S$, $L = S + T_{3R}$ defined as the **generalised lepton number**, remains unbroken.
- The Yukawa Lagrangian allowed by all symmetries is

$$\begin{aligned} \mathcal{L}_{\rm Y} &= \bar{Q}_L \hat{Y}^u \hat{\tilde{\phi}}^\dagger Q_R - \bar{Q}_L \hat{Y}^d \chi_L d_R - \bar{Q}_R \hat{Y}^{d'} \chi_R d'_L - \bar{L}_L \hat{Y}^e \phi L_R + \bar{L}_L \hat{Y}^\nu \hat{\chi}_L^\dagger \nu_R \\ &+ \bar{L}_R \hat{Y}^n \hat{\chi}_R^\dagger n_L + \mathrm{h.c.}\ , \end{aligned}$$

Breaking the Symmetry to $U(1)_{\rm em}$

$$\langle \phi \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 & 0 \\ 0 & k \end{pmatrix} , \qquad \langle \chi_L \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_L \end{pmatrix} , \qquad \langle \chi_R \rangle = \frac{1}{\sqrt{2}} \begin{pmatrix} 0 \\ v_R \end{pmatrix} .$$

Mixing in the charged sector, with $\tan\beta = \frac{k}{v_L}$ and $\tan\zeta = \frac{k}{v_R}$:

$$\begin{pmatrix} \phi_2^\pm \\ \chi_L^\pm \end{pmatrix} = \begin{pmatrix} \cos\beta & \sin\beta \\ -\sin\beta & \cos\beta \end{pmatrix} \begin{pmatrix} H_1^\pm \\ G_1^\pm \end{pmatrix} , \quad \begin{pmatrix} \phi_1^\pm \\ \chi_R^\pm \end{pmatrix} = \begin{pmatrix} \cos\zeta & \sin\zeta \\ -\sin\zeta & \cos\zeta \end{pmatrix} \begin{pmatrix} H_2^\pm \\ G_2^\pm \end{pmatrix} .$$

Scalar and Pseudoscalar Mixing

$$\begin{pmatrix} \Im\{\phi_1^0\} \\ \Im\{\phi_2^0\} \\ \Im\{\chi_L^0\} \\ \Im\{\chi_R^0\} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & U^{\mathrm{A}}_{3\times 3} & \\ 0 & & & \end{pmatrix} \begin{pmatrix} A_1^0 \\ G_1^0 \\ G_2^0 \\ A_2^0 \end{pmatrix} \quad \text{and} \quad \begin{pmatrix} \Re\{\phi_1^0\} \\ \Re\{\phi_2^0\} \\ \Re\{\chi_L^0\} \\ \Re\{\chi_R^0\} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & & & \\ 0 & & U^{\mathrm{H}}_{3\times 3} & \\ 0 & & & \end{pmatrix} \begin{pmatrix} H_1^0 \\ H_0^0 \\ H_2^0 \\ H_3^0 \end{pmatrix} .$$

Gauge Bosons Masses and Mixing

$W = W_L$ and $W' = W_R$ do not mix as $\langle \phi_1^0 \rangle = 0$, and their masses are

$$M_W = \frac{1}{2} g_L \sqrt{k^2 + v_L^2} \equiv \frac{1}{2} g_L v \qquad \text{and} \qquad M_{W'} = \frac{1}{2} g_R \sqrt{k^2 + v_R^2} \equiv \frac{1}{2} g_R v' . \tag{2}$$

The neutral gauge boson squared mass matrix in the $(B_\mu, W^3_{L\mu}, W^3_{R\mu})$ basis is

$$(\mathcal{M}_V^0)^2 = \frac{1}{4} \begin{pmatrix} g_{B-L}^2 \ (v_L^2 + v_R^2) & -g_{B-L} \ g_L \ v_L^2 & -g_{B-L} \ g_R \ v_R^2 \\ -g_{B-L} \ g_L \ v_L^2 & g_L^2 \ v^2 & -g_L \ g_R \ k^2 \\ -g_{B-L} \ g_R \ v_R^2 & -g_L \ g_R \ k^2 & g_R^2 \ v'^2 \end{pmatrix} . \tag{3}$$

The Z, Z' masses are, with $\sin_{\phi_W} = \frac{g_{B-L}}{\sqrt{g_{B-L}^2 + g_R^2}} = \frac{g_Y}{g_R}$, $\sin_{\theta_W} = \frac{g_Y}{\sqrt{g_L^2 + g_Y^2}} = \frac{e}{g_L}$

$$M_Z = \frac{g_L}{2 \cos_{\theta_W}} \ v \quad \text{and} \quad M_{Z'} = \frac{1}{2} \sqrt{g_{B-L}^2 \sin^2_{\phi_W} \ v_L^2 + \frac{g_R^2 \cos^4_{\phi_W} \ k^2 + v_R^2)}{\cos^2_{\phi_W}}} .$$

Fermion Masses

$$m_u = \frac{1}{\sqrt{2}} Y^u v_2 \sin\beta\,, \quad m_d = \frac{1}{\sqrt{2}} Y_L^d v_2 \cos\beta\,, \quad m_{d'} = \frac{1}{\sqrt{2}} Y_R^{d'} v_R\,,$$

$$m_e = \frac{1}{\sqrt{2}} Y^e v_2 \sin\beta\,, \quad m_n = \frac{1}{\sqrt{2}} Y_R^n v_R\,, \qquad tan\beta = v_2/v_L\,.$$

Dark Matter

- Introduce a generalized R-parity, defined as $(-1)^{3B+L+2s}$.
- The odd R-parity particles are: *scalars* $\chi_R^{\pm}$, $\phi_1^{\pm}$, $\Re(\phi_1^0)$ and $\Im(\phi_1^0)$, *fermions* scotinos n_L, n_R, and exotic quarks d'_L, d'_R, *gauge bosons*, W_R.
- All the rest of the particles, including all SM quarks, leptons and SM gauge bosons are R-parity even.
- A dark matter sector arises from R-parity odd particles: only the neutral Higgs, the pseudoscalar Higgs or the scotino can be DM candidates.
- Investigate the possibility that the DM is either the R-parity odd Higgs boson (scalar or pseudoscalar), or the scotino(s), or both.

R-parity odd states: physical H_1^0 and A_1 eigenstates (from $\Re(\phi_1^0)$ and $\Im(\phi_1^0)$), degenerate in mass and possible scalar DM:

$$M^2_{H_1^0} = M^2_{A_1} = 2v_2^2\lambda_2 - (\alpha_2 - \alpha_3)\left(v_L^2 + v_R^2\right) - \frac{\mu_3 v_L v_R}{\sqrt{2}v_2}.$$

Charged Higgs bosons masses by diagonalizing the 2×2 matrices:

$$m^2_{H_1^\pm} = -\left[v_2 v_L\left(\alpha_2 - \alpha_3\right) + \frac{\mu_3 v_R}{\sqrt{2}}\right]\frac{v^2}{v_2 v_L},\ R\text{-parity even}$$

$$m^2_{H_2^\pm} = -\left[v_2 v_R\left(\alpha_2 - \alpha_3\right) + \frac{\mu_3 v_L}{\sqrt{2}}\right]\frac{v'^2}{v_2 v_R},\ R\text{-parity odd.}$$

$M_{H_1^0}$ (GeV)	Annihilation Channels
$M_{H_1^0} < M_h$	$H_1^0 H_1^0 \to WW,\ ZZ,\ GG,\ \gamma\gamma,\ b\bar{b}$
$M_h < M_{H_1^0} < m_t$	$H_1^0 H_1^0 \to WW,\ ZZ,\ GG,\ \gamma\gamma, b\bar{b},\ hh$
$m_t < M_{H_1^0} < M_{H_1^\pm}$	$H_1^0 H_1^0 \to WW, ZZ, GG, \gamma\gamma,\ b\bar{b},\ hh,\ t\bar{t}$
$(M_{H_1^\pm} + M_W) < 2M_{H_1^0}$	$H_1^0 H_1^0 \to WW, ZZ, GG, \gamma\gamma,\ b\bar{b},\ hh,\ t\bar{t},\ W^\pm H_1^\mp$

TABLE: Annihilation channels for H_1^0 for different scalar dark matter masses.

Scalar Dark Matter: Parameter Ranges and Scenarios Considered

Numerical study: $\tan\beta = 2.0$, $\lambda_2 = -0.1$, $\alpha_1 = 0.1$, $\alpha_2 = \alpha_3 = 0.1$

Parameter	Range
$M_{H_1^0} = M_{A_1}$	$(100 - 2000)$ GeV
$M_{H_2^\pm} - M_{H_1^0}$	$(10 - 60)$ GeV
$m_{q'} - M_{H_1^0}$	$(200 - 500)$ GeV
$m_{n_\tau} - M_{H_1^0}$	$(0.001 - 1)$ GeV
λ_3	$(1.0 - 2.0)$
v'	$(1.9 - 35)$ TeV
$\|\mu_3\|$	$(100 - 2000)$ GeV

Case (i) (degenerate)	$m_{n_e} = m_{n_\mu} = m_{n_\tau}$
Case (ii) (small splitting)	$(m_{n_e} = m_{n_\mu}) - m_{n_\tau} =$ Range (10 keV - 20 MeV)
Case (iii) (large splitting)	$(m_{n_e} = m_{n_\mu}) - m_{n_\tau} =$ Range (100 MeV - 10 GeV)

Table: Range of masses considered for the scan in the scalar dark matter case, for three different cases of neutrino mass hierarchy.

Scalar Relic Density and Direct Detection

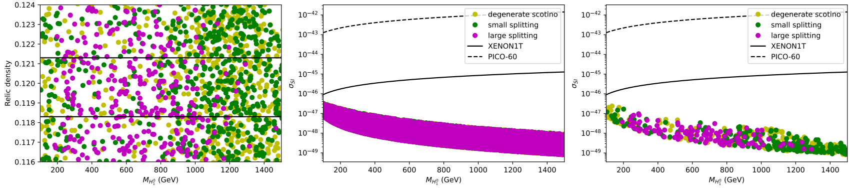

FIGURE: (L): Relic density with 1σ range $\Omega_{DM}^{obs}h^2$. (M): Direct detection cross section. (R): Direct detection cross section also satisfied by Ω_{obs} within 1σ.
Case (i) (greenish yellow), Case (ii) (green) and Case (iii) (magenta).

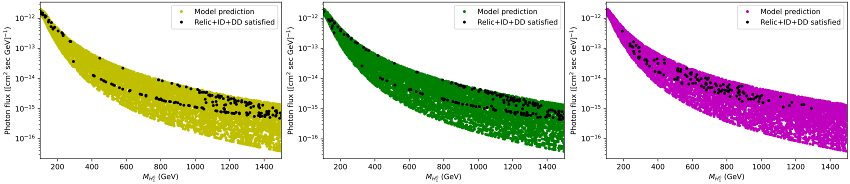

FIGURE: Indirect detection restrictions with the photon flux (L) Case (i), (M) Case (ii), (R) Case (iii). All points satisfy Fermi-LAT, while black dots are also consistent with relic density + DD restrictions.

Scotino Dark Matter: Parameter Ranges and Annihilation Channels

Annihilation Channels for n_τ
$n_\tau \bar{n}_\tau \to \ell\bar{\ell},\ \nu\bar{\nu},\ q\bar{q},\ WW,\ ZZ,\ Zh,\ ZH_1^0,\ ZA_1^0,\ hh$

Parameter	Range (GeV)
m_{n_τ}	(100 – 2000)
$m_{q'} - m_{n_\tau}$	(200 – 500)
$M_{H_2^\pm} - M_{H_1^0}$	(10 – 70)
v'	(1900 – 35000)

m_{n_e} and m_{n_μ}	
Case (i) (degenerate)	$m_{n_e} = m_{n_\mu} = m_{n_\tau}$
Case (ii) (small splitting)	$(m_{n_e} = m_{n_\mu}) - m_{n_\tau} =$ Range (10 keV - 20 MeV)
Case (iii) (large splitting)	$(m_{n_e} = m_{n_\mu}) - m_{n_\tau} =$ Range (100 MeV - 10 GeV)

$\tan\beta = 2.0,\ \lambda_2 = -0.1,\ \lambda_3 = 1.6,\ \alpha_1 = \alpha_2 = \alpha_3 = 0.1,\ v_L = 5$ GeV, $\mu_3 = -320$ GeV

Table: Mass ranges for the scan for tau scotino DM, with $q' = d',\ s',\ b'$, with three different cases of neutrino mass hierarchy.

Scotino Relic Density and Direct Detection

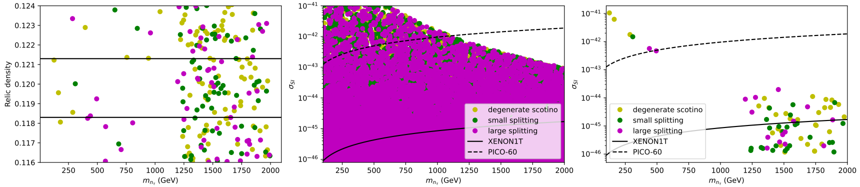

FIGURE: (L): Relic density with 1σ range $\Omega^{obs}_{DM}h^2$. (M): Direct detection cross section. (R): Direct detection cross section also satisfied by Ω_{obs} within 1σ.
Case (i) (greenish yellow), Case (ii) (green) and Case (iii) (magenta).

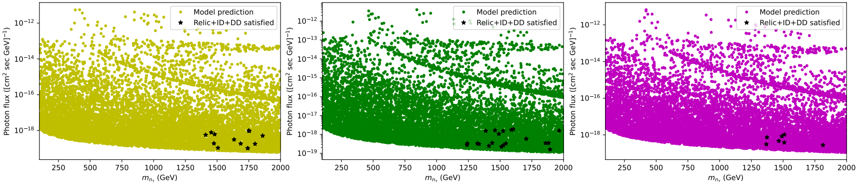

FIGURE: Indirect detection restrictions for scotino dark matter. The photon flux for Case (i) (L), Case (ii) (M), and Case (iii) (R). All points satisfy constraints from Fermi-LAT, while the black asterisks are also consistent with relic density + direct detection restrictions.

Top Flavour Changing Decays

- In LRSM, the Higgs sector could lead to non-acceptable tree-level FCNC requiring the $SU(2)_R \times U(1)_{B-L}$ symmetry to be broken at very high energy scale.
- This can be avoided in ALRSM, as the Higgs couples to one ordinary and one exotic fermion, so the Higgs and W_R bosons can be light.
- In ALRM top FCNC are absent at tree-level, but appear at one loop.

Ranges of parameters used for numerical evaluation

Parameter	Scanned range	Parameter	Scanned range
$\tan\beta$	$[0.7, 50]$	θ'_{12}	$[0, \frac{\pi}{4}]$
g_R	$[0.37, 0.768]$	θ'_{13}	$[0, \frac{\pi}{4}]$
v'	$[6.5, 20]$ TeV	θ'_{23}	$[0, \frac{\pi}{4}]$
λ_2	0.	$m_{d'}$	$[100, 10000]$ GeV
λ_3	$[0.01, 0.09]$	$m_{s'}$	$[100, 10000]$ GeV
κ	$[-1000, -1]$ GeV	$m_{b'}$	$[100, 10000]$ GeV
$\alpha_1 = \alpha_2 = \alpha_3$	$[0.01, 0.5]$		

Maximum Branching Ratio for Rare Top Decays

Branching Ratio		
Channel	SM value	Max. BR in ALRM
$t \to c\gamma$	1.0×10^{-13}	3.4×10^{-11}
$t \to u\gamma$	8.1×10^{-16}	7.1×10^{-12}
$t \to cZ$	2.4×10^{-14}	1.1×10^{-10}
$t \to uZ$	1.9×10^{-16}	7.9×10^{-11}
$t \to cH$	1.8×10^{-13}	7.8×10^{-9}
$t \to uH$	1.4×10^{-15}	8.3×10^{-9}
$t \to cg$	8.5×10^{-12}	2.9×10^{-10}
$t \to ug$	6.6×10^{-14}	4.3×10^{-11}

- Maximum enhancement is $\mathcal{O}(10^6)$ in $t \to uZ$ and $t \to uH$ channel. For all other modes, it is $\mathcal{O}(10^3 - 10^{4)}$.
- For $\tan\beta > 5$, $M_{H_2}^{+} < 500$ GeV, otherwise no restrictions.
- Enhancements favour large θ'_{13} in V_R^{CKM} matrix, while somewhat insensitive to the other two angles.

BENCHMARKS

BP's	$\tan\beta$	v_R (TeV)	λ_2	λ_3	α_1	$\alpha_2 = \alpha_3$	μ_3	Masses in GeV						
								$M_{H_1^0} = M_{A_1^0}$	m_{n_τ}	m_{n_μ}	m_{n_e}	$m_{d'}$	$m_{s'}$	$m_{b'}$
BP1	2	12.9	-0.1	1.2	0.1	0.1	-100	1230	1230.004	1230	1230.5	1465	1704	1712
BP2	3	14.4	-0.1	1.4	0.01	0.1	-340	1428	1428.	1428.5	1428.9	1764	1877	1902
BP3	2	14	-0.001	1.6	0.1	0.1	-320	1258.51	1210	1215	1220	1600	1700	1800
BP4	10	13	-0.01	1.6	0.1	0.1	-2800	1604	1395	1399	1402	1600	1700	1800

TABLE: Benchmark points for scalar (BP1 and BP2) and scotino (BP3 and BP4) DM.

BP's	Masses in GeV							DM Relic Ωh^2
	$M_{H_1^\pm}$	$M_{H_2^\pm}$	$M_{A_2^0}$	$M_{H_2^0}$	$M_{H_3^0}$	$M_{W_R^\pm}$	$M_{Z'}$	
BP1	1515.839	1277	1515.882	1517.035	20137.437	4212	5054.39	0.119
BP2	1520.740	1471	1520.912	1520.042	21750.899	4687.23	5624.63	0.121
BP3	2814.18	1258.67	2814.24	19799.5	2814.72	4571.56	5485.88	0.120
BP4	16123.30	1604.60	16123.30	23255.30	16123.10	4245.22	5094.27	0.119

TABLE: Masses of the gauge bosons and scalars corresponding to the four BPs above.

	Cross section (fb)			
Processes	BP1	BP2	BP3	BP4
$pp \to \bar{d}' d'$	32.1	6.3	–	–
$pp \to \bar{s}' s'$	8.7	3.5	–	–
$pp \to \bar{b}' b'$	8.3	3.1	–	–
$pp \to H_2^+ H_2^-$	–	–	8.341	0.7918
$pp \to W_R^+ W_R^-$	–	–	9.64×10^{-7}	4.96×10^{-8}

TABLE: Cross sections at the 14 TeV LHC for the four different BP's.

BP1: SCALAR DM

Selection criteria (BP1)	Fiducial Cross section (fb)		Significance S
	Signal	Background	14 TeV @ 300 fb^{-1}
Initial (no cut)	20.3	2046.6	7.7
reject : $E_T < 200$ GeV	19.6	1175.6	9.8
reject : $E_T(b) < 100$ GeV	18.1	777.5	11.1
reject : $\not{E}_T < 100$ GeV	16.2	464.6	12.8
reject : $-1.5 < y(b) < 1.5$	15.1	341.4	13.8

TABLE: Cross section ($pp \to d'd' \to bb\ H_1^0 H_1^0 / A_1 A_1$) and background ($pp \to bb\nu\nu$) for BP1.

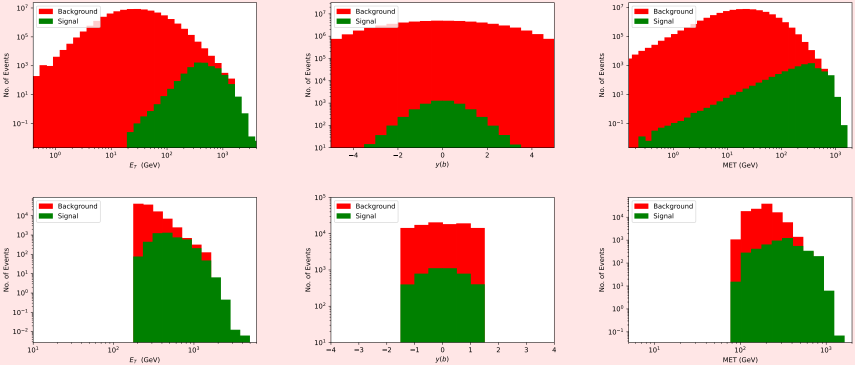

FIGURE: Parton level event distributions for $pp \to \bar{q}'q' \to \bar{b}bH_1^0 H_1^0 / A_1^0 A_1^0$ for BP1: the total transverse energy E_T, the rapidity y, $E_T(b)$, and the missing transverse energy $\not{E}_T$. (Top) before cuts; (Bottom) after cuts.

BP2: SCALAR DM

Selection criteria (BP2)	Fiducial Cross section (fb) Signal	Background	Significance S 14 TeV @ 300 fb^{-1}
Initial (no cut)	3.7	2046.6	1.4
reject : $E_T < 200$ GeV	3.3	79.4	6.3
reject : $\not{E}_T < 200$ GeV	2.8	29.5	8.4
reject : $E_T(b) < 200$ GeV	2.4	16.4	9.4

TABLE: Cross section for the signal ($pp \to d'd' \to bb\ H_1^0 H_1^0/A_1 A_1$) and the background ($pp \to bb\nu\nu$) for BP2 at 14 TeV LHC.

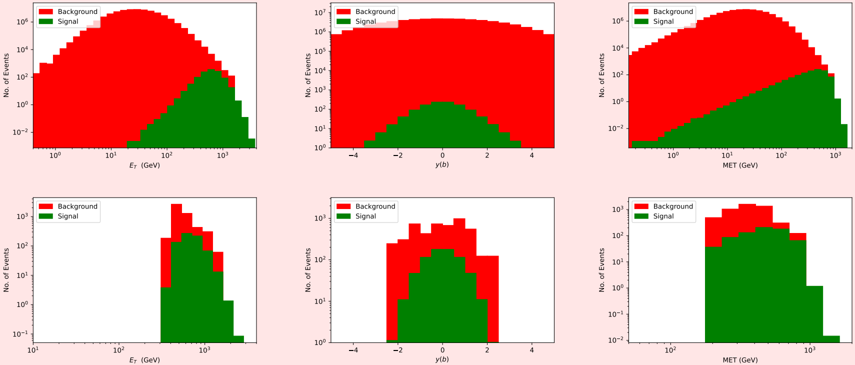

FIGURE: Parton level event distributions for $pp \to \bar{q}'q' \to \bar{b}bH_1^0 H_1^0/A_1^0 A_1^0$ for BP2 : the total transverse energy E_T, the rapidity y, and the missing transverse energy $\not{E}_T$. (Top) before cuts, (Bottom) after cuts.

BP3: SCOTINO DM

Selection criteria (BP3)	Fiducial Cross section (fb) Signal	Background	Significance, S at integrated luminosity 300 fb^{-1}	14 TeV @ 3000 fb^{-1}
Initial (no cut)	5.52	506.11		
reject : $\|y(\tau)\| < 2.5$	0.096	0	5.39	16.98

TABLE: Cross section of the signal ($pp \to H_2^+ H_2^- \to \nu_\tau \nu_\tau \tau^+ \tau^-$) and the background ($pp \to \nu\nu\tau^+\tau^-$) for BP3.

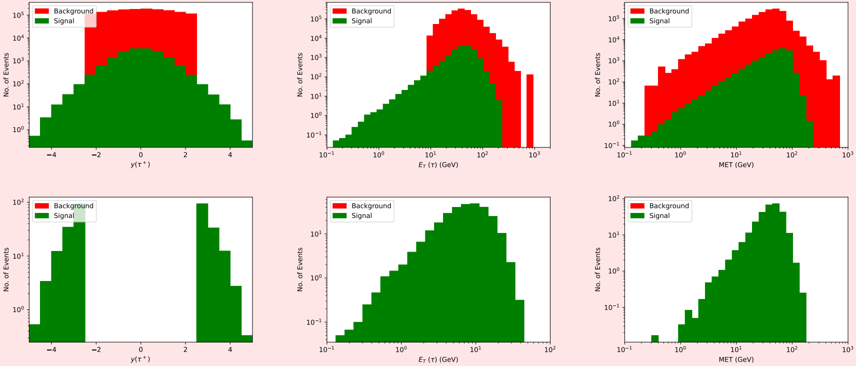

FIGURE: Parton level event distributions for $pp \to \bar{q}' q' \to \bar{b} b H_1^0 H_1^0 / A_1^0 A_1^0$ for BP3: the rapidity y, the total transverse energy E_T, and the missing transverse energy $\not{E}_T$. (Top) before cuts, (Bottom) after cuts.

BP4: SCOTINO DM

Selection criteria (BP4)	Fiducial Cross section (fb)		Significance, S at integrated luminosity	
	Signal	Background	300 fb^{-1}	3000 fb^{-1}
Initial (no cut)	0.58	506.11		
reject : $\lvert y(\tau)\rvert < 2.5$	0.009	0	1.73	5.22
reject : $E_T < 400$ GeV	0.198	1.945	2.3	7.41

TABLE: Cross section of the signal ($pp \to H_2^+ H_2^- \to \nu_\tau \nu_\tau \tau^+ \tau^-$) and the background ($pp \to \nu\nu\tau^+\tau^-$) for BP4.

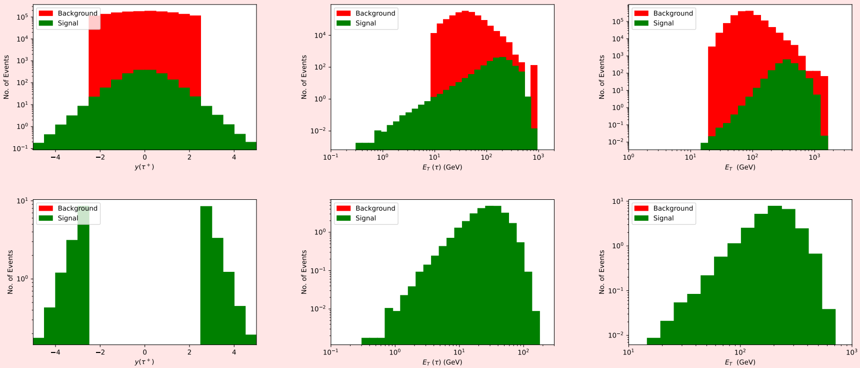

FIGURE: Parton level event distributions for $pp \to \bar{q}'q' \to \bar{b}bH_1^0H_1^0/A_1^0A_1^0$ for BP4: the rapidity y, the total transverse energy of the τ^+ lepton, the total transverse energy E_T,. (Top) before cuts, (Bottom) after cuts.

Signals of W_R at Colliders

$M_{W_R} < m_{d'}, m_{s'}, m_{b'}$ – leptonic decays

λ_2	λ_3	$\alpha_1 = \alpha_2 = \alpha_3$	μ_3	$\tan\beta$	g_R	v'
0.5	1.6	0.01	-400 GeV	50	0.37	6.2 TeV

M_{W_R}	$M_{Z'}$	$M_{H_2^-}$	m_{n_e}	m_{n_μ}	m_{n_τ}
1.15 TeV	4.55 TeV	187 GeV	140 GeV	135 GeV	130 GeV

$BR(W_R \to \tau n_\tau)$	$BR(H_2^- \to \tau n_\tau)$	cross section $\times$ BR
17.0 %	59.6 %	108.7 fb

Possible production modes: $pp \to W_R W_R,\ H_2^+ H_2^-,\ W_R H_2^\pm \to 2\tau + \not{E}_T$.

Signals and Significance

Selection	Signal Events	Background Events	Significance
no cut: @ $\int \mathcal{L} = 3$ fb $^{-1}$	326	5580	4.0
$\lvert\cos(\theta^\nu)\rvert < 0.9$, $p_T^\nu >$350 GeV	251	2	171.7

Table: Cuts on the backgrounds and signal for processes for 27 TeV @ 3 fb^{-1}.

Signals of W_R at Colliders

Signal and Background for $pp \to 2\tau + \not{E}_T$

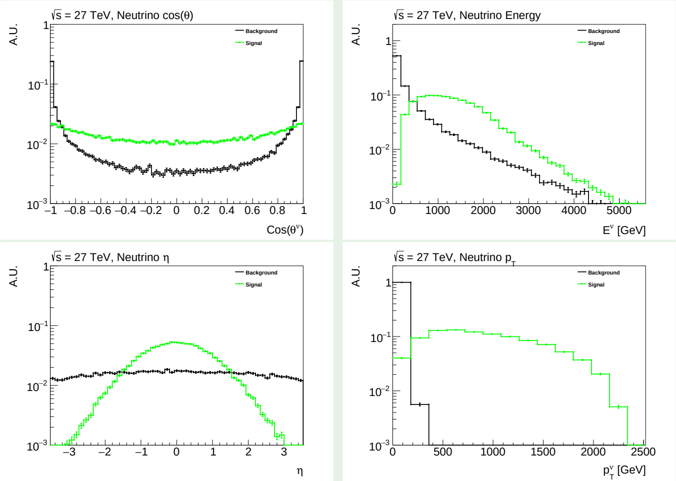

FIGURE: Angular separation tau-missing energy (top left), the scotino energy (top right), the pseudorapidity (bottom left) and the scotino transverse momentum (bottom right), with signal (green) and background (black).

Conclusion

Advantages of ALRM

- It protects against low energy flavour violation, allowing the additional Higgs and W_R bosons to be relatively light;
- It allows R-parity symmetry without SUSY and provides a natural DM candidate (scalar/pseudoscalar Higgs or fermion–scotino);
- Consistent with relic and direct/indirect bounds: light DM masses for scalars, $\mathcal{O}(1)$ TeV for the scotino;
- Scenarios with degenerate, or small and larger mass splittings among the scotinos can be accommodated;
- It provides testable signals at colliders:
  - For scalar DM, signals at 300 fb^{-1}, could indicate exotic d' quarks in the TeV range.
  - For fermionic DM, signals at 300 or at 3000 fb^{-1}, could indicate charged Higgs bosons in the TeV region.
  - Signals for light W_R could be visible at 27 TeV.
- The model can yield enhanced top flavour changing branching ratios.