Dark matter in left-right symmetric standard model

triplet scalar dark matter portal

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MOCA

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Focus on
arXiv:1703.08148 (PRD)
In collaboration with
C. Arbeláez (UFSM)& M. Hirsch (IFIC)

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Dark matter and unification

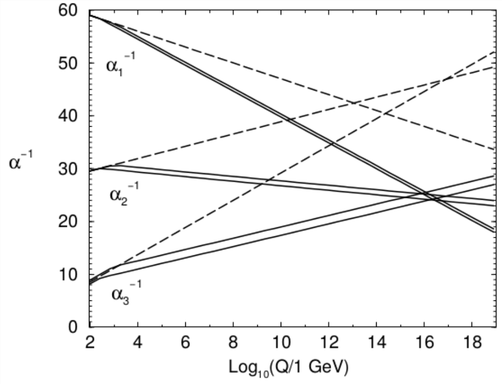
Unification: $SO(10)$

$$16_{F_i} = \begin{pmatrix} {u_R}^\dagger \\ {u_R}^\dagger \\ {u_R}^\dagger \\ u_L \\ u_L \\ u_L \\ d_L \\ d_L \\ d_L \\ {d_R}^\dagger \\ {d_R}^\dagger \\ {d_R}^\dagger \\ \nu_L \\ e_L \\ {e_R}^\dagger \\ N \end{pmatrix}_i \qquad \Rightarrow \mathcal{L}_{SM} \supset h\, \mathbf{16}_F \times \mathbf{16}_F \times \mathbf{10}_S + \text{h.c}$$

Not-susy $SO(10) \to SU(5) \to SU(3)_C \times SU(2)_L \times U(1)_Y \times Z_2$

Standard Model: Z_2**-even**	**New** Z_2**-odd particles**
Fermions: $\mathbf{16}_F$	$\mathbf{10}_F, \mathbf{45}_F, \cdots$
Scalars: $\mathbf{10}_H, \mathbf{45}_H \cdots$	$\mathbf{16}_H, \cdots$

Lightest Odd Particle (LOP) may be a suitable dark matter candidate, and can improve gauge coupling unification



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	fermions	scalars
$SU(2)_L \times U(1)_Y$ representation	even $SO(10)$ representations	odd $SO(10)$ representations
1_0	45, 54, 126, 210	16, 144
$2_{\pm 1/2}$	10, 120, 126, 210, 210$'$	16, 144
3_0	45, 54, 210	144

$SU(3)_C$: 3 (T), 6, 8 (Λ)

$$m_{3_0} = 2.7 \text{ TeV}, \qquad m_\Lambda \sim 10^{10} \text{ TeV}, \qquad m_{\text{GUT}} \sim 10^{16} \text{ GeV}.$$

arXiv:0912.1545 (Frigerio-Hambye)

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Split-SUSY like

arXiv:1509.06313 (C. Arbelaez, R. Longas, D.R, O. Zapata)

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$\boxed{3_0}$	$\boxed{45}$, 54, 210	144

$SU(3)_C$: 3 (T), 6, $\boxed{8\ (\Lambda)}$

Radiative hybrid seesaw (Parida 1106.4137) or 1509.06313

Partial Split-SUSY-like spectrum: bino-higgsino-wino

$+$ $\downarrow$

$\mathbf{10}'_H$ with fermion DM or, $\mathbf{16}_H, \cdots$ with scalar DM

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1509.06313

SUSY-like spectrum: bino-higgsino-wino

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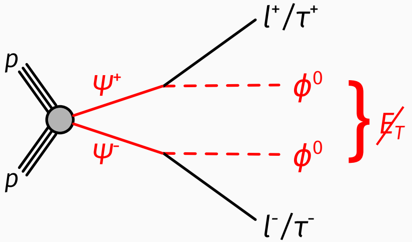
$\mathbf{10}'_H$ with fermion DM or, $\mathbf{16}_H, \cdots$ with scalar DM

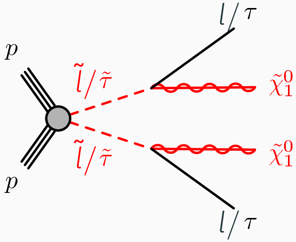
Dilepton plus transverse missing energy signal

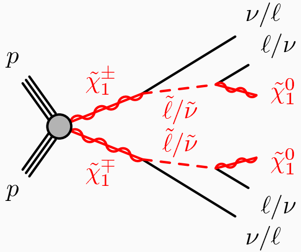


SU(2)$_L$ assignments:

$\Psi = 1, 2(\Psi), 3(\Sigma)$, $\Phi = 1, 2$, with $m_{\mathrm{DM}} \sim m_h/2$.

Simplified SUSY models

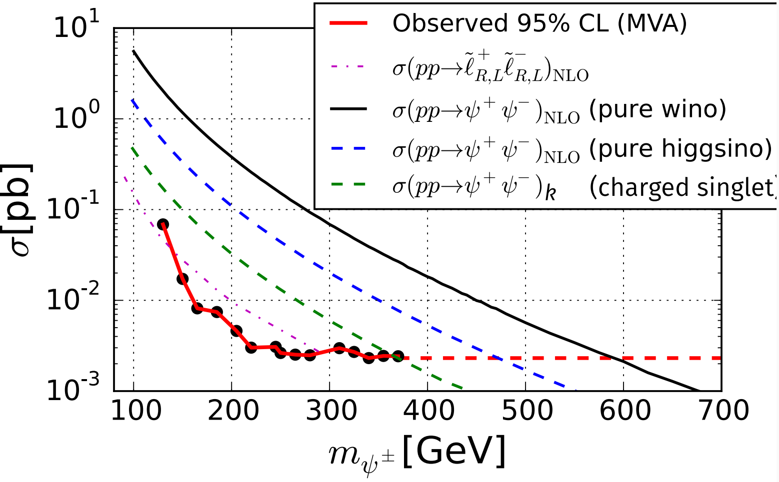




Smaller cross sections.

Intermediate states and smaller lepton $\not{p}_T$

$m_{\phi^0} = 60$ GeV



Full analysis on flavor space: F. von der Pahlen, G. Palacio, DR, O. Zapata arXiv:1605.01129 [PRD]

The most general SO(10) invariant Lagrangian contains the following Yukawa terms

$$-\mathcal{L} \supset Y\mathbf{10}_F\mathbf{45}_F\mathbf{10}_H + M_{\mathbf{45}_F}\mathbf{45}_F\mathbf{45}_F + M_{\mathbf{10}_F}\mathbf{10}_F\mathbf{10}_F$$

Basis $\boldsymbol{\psi}^0 = \left(N, \Sigma^0, \psi_L^0, (\psi_R^0)^\dagger\right)^T$

$$\mathcal{M}_{\boldsymbol{\psi}^0} = \begin{pmatrix} M_N & 0 & -y\,c_\beta v/\sqrt{2} & y\,s_\beta v/\sqrt{2} \\ 0 & M_\Sigma & f\,c_{\beta'} v/\sqrt{2} & -f\,s_{\beta'} v/\sqrt{2} \\ -y\,c_\beta v/\sqrt{2} & f\,c_{\beta'} v/\sqrt{2} & 0 & -M_D \\ y\,s_\beta v/\sqrt{2} & -f\,s_{\beta'} v/\sqrt{2} & -M_D & 0 \end{pmatrix},$$

$\mathbf{10}_F \to \psi_L, (\psi_R)^\dagger$

$\mathbf{45}_F \to \Sigma, \Lambda$

$\mathbf{45}'_F \to N$

arXiv:1511.06495: signals at 100 TeV collider

Singlet-Doublet-Triplet fermion dark-matter

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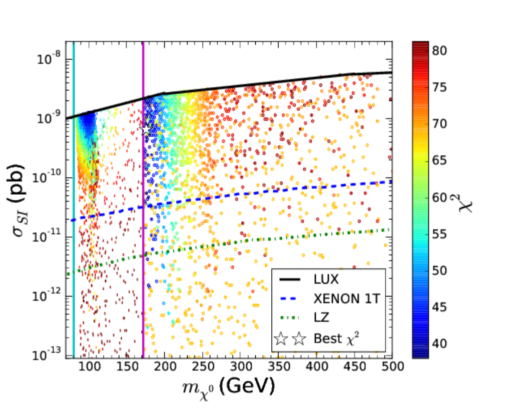

S. Horiuchi, O. Macias, DR, A. Rivera, O. Zapata, 1602.04788 (JCAP)

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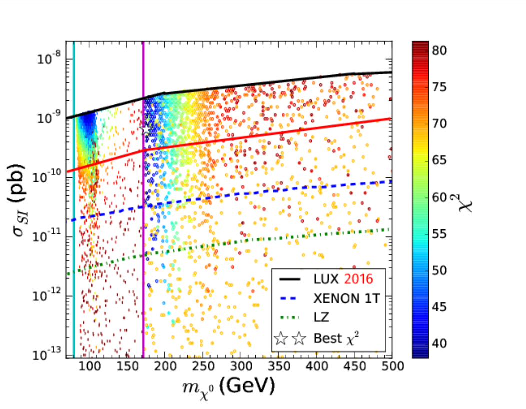

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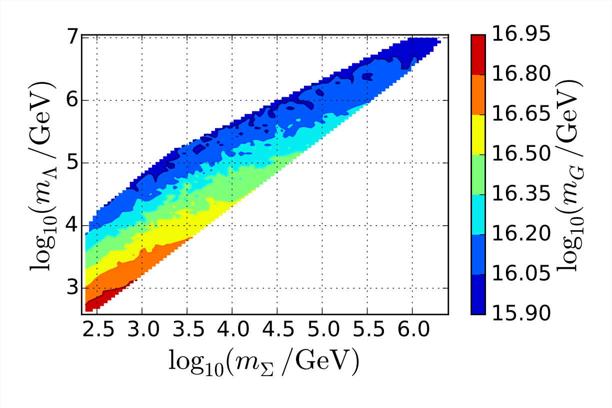
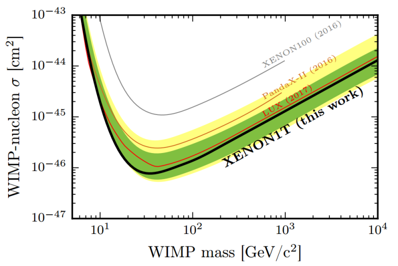


Split-SUSY: like $M_\Phi = 2$ TeV

Is the glass half empty or half full?

Tree-level SM-portal could be fully excluded in the near future

- Singlet scalar dark matter
- Inert doublet model
- Tree-level SM-portal dark matter $\cdots$



In this talk we explore

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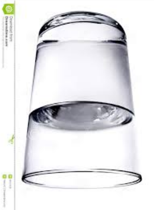

In this talk we explore

- Recover SM-portals in LR models

Is the glass half empty or half full?

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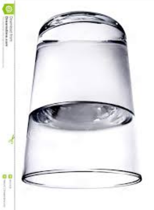

In this talk we explore

- Recover SM-portals in LR models
- New portals in LR models

Left-Right symmetric realization

Singlet-doublet fermion dark matter

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Φ	1	$(1, 2, 2, 0)$	0	10
χ, χ^c	1	$(1, 2, 2, 0)$	$1/2$	10
N	1	$(1, 1, 1, 0)$	$1/2$	45

Table 1: The relevant part of the field content. Note that, the two fermion doublets χ and χ^c come from an only fermionic LR bidoublet. In the third column the relevant fields are characterized by their $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$ quantum numbers while their SO(10) origin is specified in the fourth column.

Unification

m_{LR} (GeV)	$3_c 2_L 2_R 1_{B-L}$	m_G (GeV)
2×10^3	$\Phi_{1,2,2,0} + 2\Phi_{1,1,3,-2} + \Psi_{1,1,3,0} + \Phi_{1,1,3,0} + \Phi_{8,1,1,0}$	1.65×10^{16}
$\vdots$	$\vdots$	$\vdots$

Table 2: $\Delta_{L,R} = 2\Phi_{1,1,3,-2}$. m_{LR} and m_G are given in GeV.

Triplets

Minimal Left-Right Symmetric Standard Model

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
Q^c	3	$(\bar{3}, 1, 2, -\frac{1}{3})$	1/2	16
L	3	$(1, 2, 1, -1)$	1/2	16
L^c	3	$(1, 1, 2, +1)$	1/2	16
Φ	1	$(1, 2, 2, 0)$	0	10
Δ_R	1	$(1, 1, 3, -2)$	0	126

Left-singlet right-triplet DM

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Q	3	$(3, 2, 1, +\frac{1}{3})$	1/2	16
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Φ	1	$(1, 2, 2, 0)$	0	10
Δ_R	1	$(1, 1, 3, -2)$	0	126
Ψ_{1130}	1	$(1, 1, 3, 0)$	1/2	45

$\Omega h^2 = 0.1199 \pm 0.0027$ at 3σ

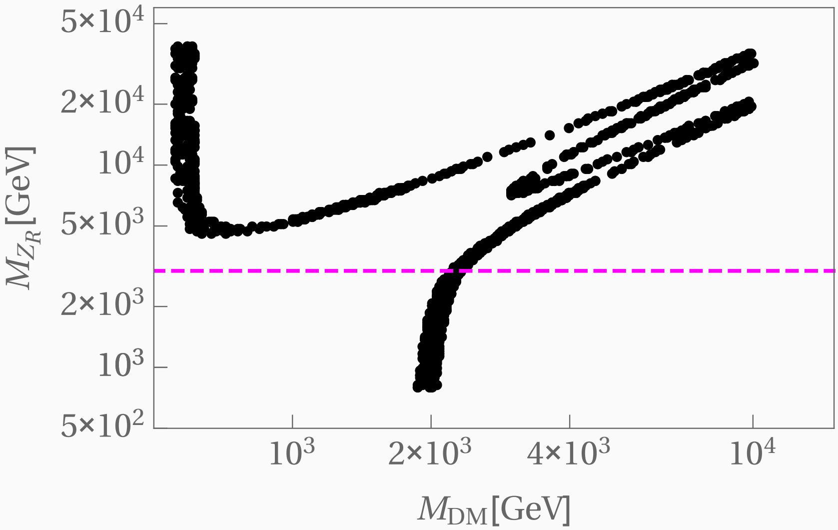

Figure 1: Proper relic density scan: $0.5 < v_R/\mathrm{TeV} < 50$

Mixed Left-singlet right-triplet DM

Field	Multiplicity	$3_c 2_L 2_R 1_{B-L}$	Spin	SO(10) origin
Q	3	$(3, 2, 1, +\frac{1}{3})$	$1/2$	16
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Ψ_{1132}	1	$(1, 1, 3, 2)$	1/2	126
Ψ_{113-2}	1	$(1, 1, 3, -2)$	1/2	$\overline{126}$

Setup

$$\Psi_{1132} = \begin{pmatrix} \Psi^{+}/\sqrt{2} & \Psi^{++} \\ \Psi^{0} & -\Psi^{+}/\sqrt{2} \end{pmatrix}, \qquad \bar{\Psi}_{113-2} = \begin{pmatrix} \Psi^{-}/\sqrt{2} & \overline{\Psi}^{0} \\ \Psi^{--} & -\Psi^{-}/\sqrt{2} \end{pmatrix}. \tag{1}$$

$$\begin{aligned} L \supset & M_{11}\,\mathrm{Tr}(\Psi_{1130}\Psi_{1130}) + M_{23}\,\mathrm{Tr}(\Psi_{1132}\bar{\Psi}_{113-2}) \\ & + \lambda_{13}\,\mathrm{Tr}(\Delta_R\bar{\Psi}_{113-2}\Psi_{1130}) + \lambda_{12}\,\mathrm{Tr}(\Delta_R^{\dagger}\Psi_{1132}\Psi_{1130}), \end{aligned} \tag{2}$$

$$\tan\gamma = \frac{\lambda_{13}}{\lambda_{12}}, \qquad \lambda = \sqrt{\lambda_{12}^2 + \lambda_{13}^2}. \tag{3}$$

Blind spot at

$$M_{23}\sin 2\gamma - M_{\mathrm{DM}} = 0 \tag{4}$$

Proper relic density scan

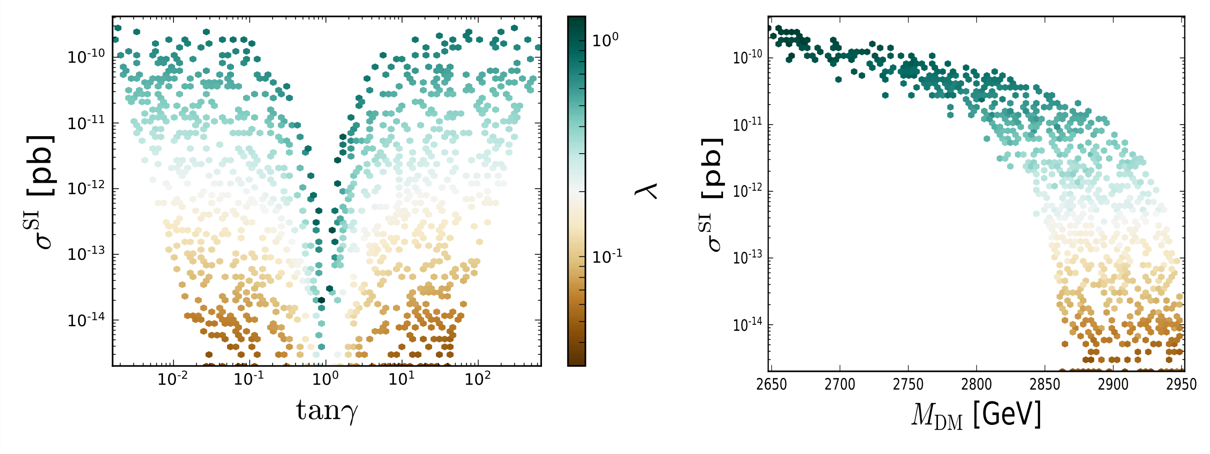

Figure 2: $M_{11} = 50$ TeV $2.7 < M_{23}/\text{TeV} < 3.1$ (Right: $\tan\gamma > 5$)

$\Omega h^2 = 0.1199 \pm 0.0027$ at 3σ

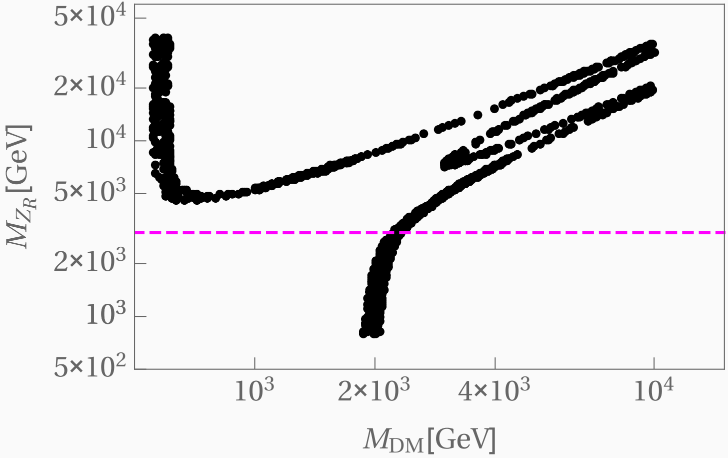

Figure 3:

$\Omega h^2 = 0.1199 \pm 0.0027$ at 3σ

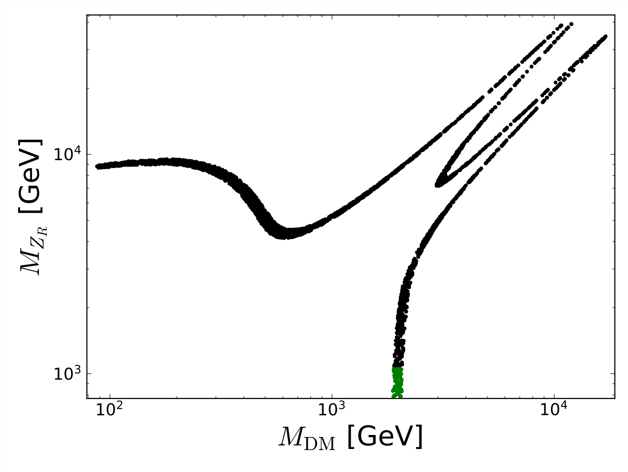

Figure 3: Proper relic density scan: v_R : $[2, 50]$ TeV, M_{23} : $[0.2, 50]$ TeV, M_{11} : 50 TeV, $\tan\gamma = -1$ and $\lambda = 0.14$.

Direct detection cross section

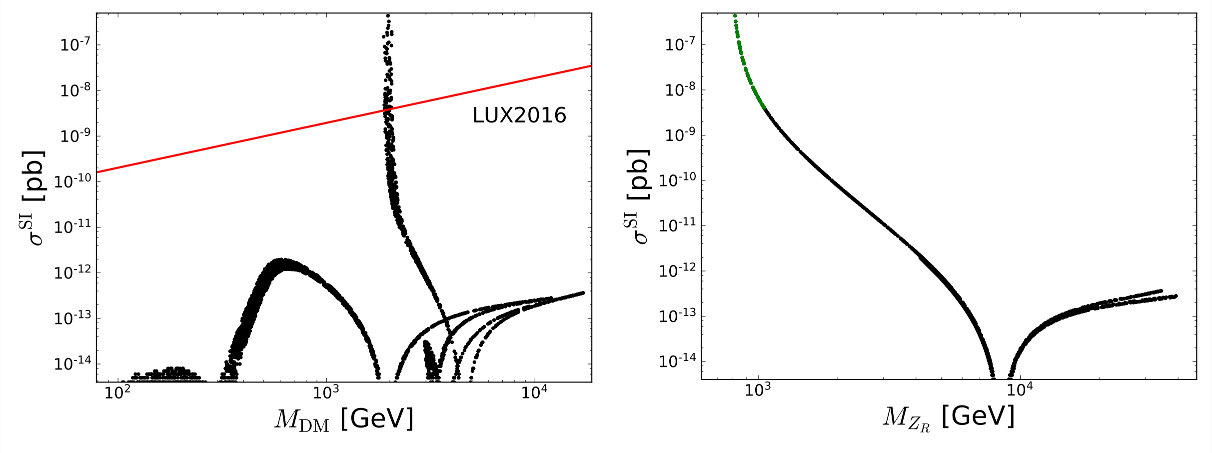

Figure 4: v_R : [2, 50] TeV, M_{23} : [0.2, 50] TeV, M_{11} : 50 TeV, $\tan\gamma = -1$ and $\lambda = 0.14$.

Unification

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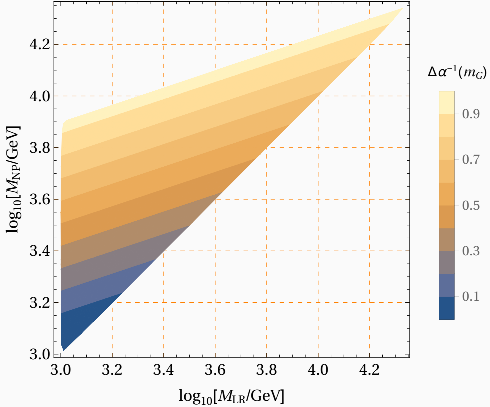
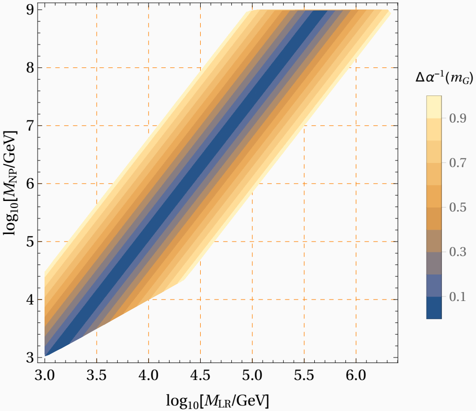
Ψ_{1132}	1	$(1, 1, 3, 2)$	1/2	126
Ψ_{113-2}	1	$(1, 1, 3, -2)$	1/2	$\overline{126}$
Ψ_{1310}	1	$(1, 3, 1, 0)$	1/2	45
Ψ_{8110}	1	$(1, 1, 8, 0)$	1/2	45
$\Psi_{321\frac{1}{3}}$	1	$(3, 2, 1, 1/3)$	1/2	16
$\Psi_{321-\frac{1}{3}}$	1	$(1, 2, 3, -1/3)$	1/2	$\overline{16}$

Unification quality





Ernest Ma, D.R, Óscar Zapata: arXiv:706.08240

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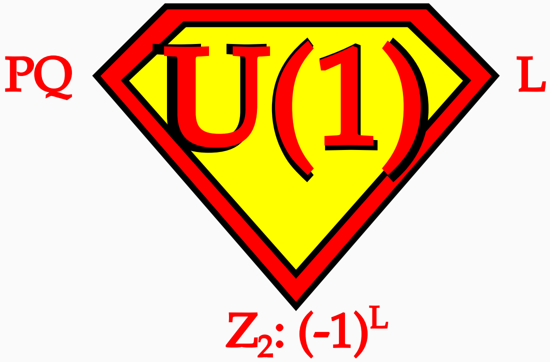
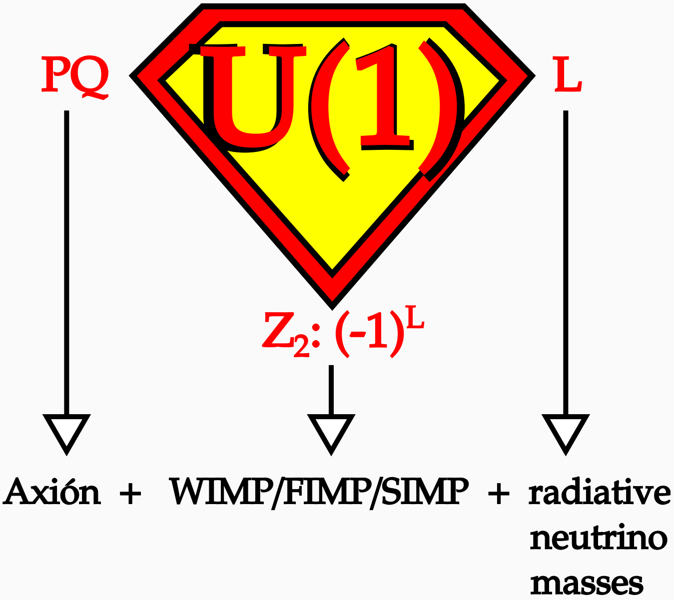
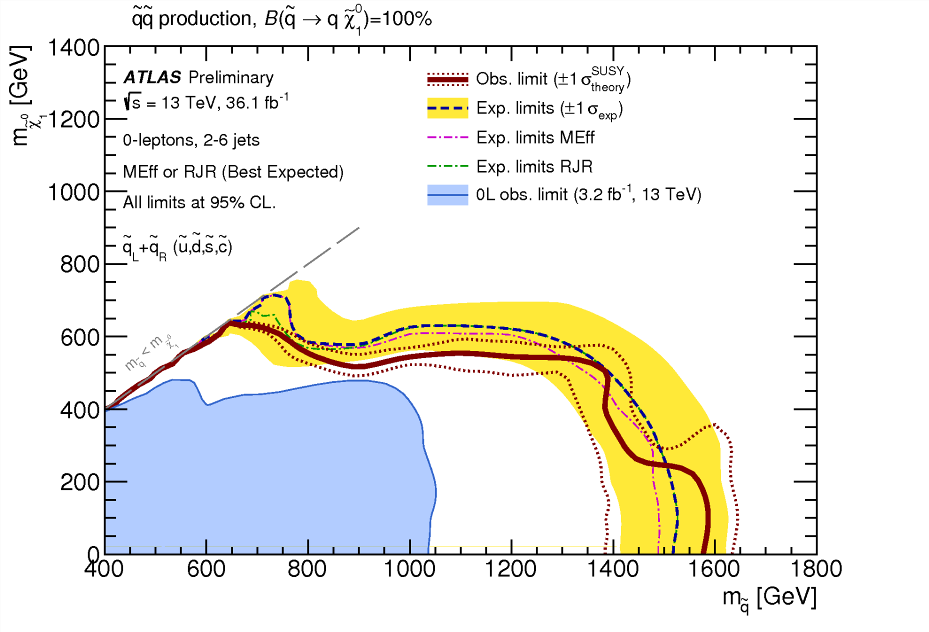
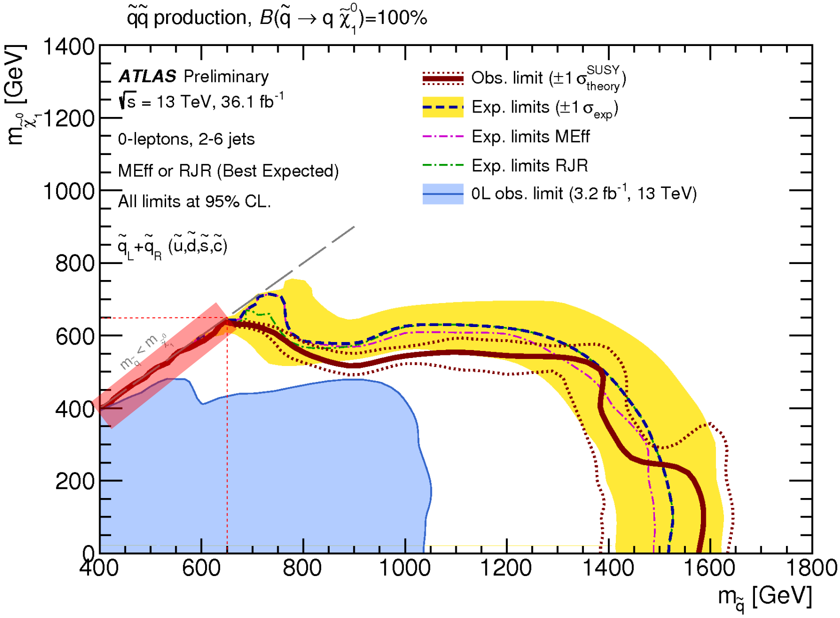


Ernest Ma, D.R, Óscar Zapata: $\Longrightarrow R = (-1)^{2s+3B+L}$ arXiv:706.08240





$\tilde{q}\tilde{q}$ production, $B(\tilde{q} \to q\,\tilde{\chi}_1^0)$=100%
ATLAS Preliminary
$\sqrt{s}$ = 13 TeV, 36.1 fb^{-1}
0-leptons, 2-6 jets
MEff or RJR (Best Expected)
All limits at 95% CL.
$\tilde{q}_L+\tilde{q}_R$ ($\tilde{u},\tilde{d},\tilde{s},\tilde{c}$)
Obs. limit ($\pm1\,\sigma_{theory}^{SUSY}$)
Exp. limits ($\pm1\,\sigma_{exp}$)
Exp. limits MEff
Exp. limits RJR
0L obs. limit (3.2 fb^{-1}, 13 TeV)
$m_{\tilde{q}} < m_{\tilde{\chi}_1^0}$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{q}}$ [GeV]



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$\tilde{q}_L+\tilde{q}_R$ ($\tilde{u},\tilde{d},\tilde{s},\tilde{c}$)
Obs. limit ($\pm 1\,\sigma_{theory}^{SUSY}$)
Exp. limits ($\pm 1\,\sigma_{exp}$)
Exp. limits MEff
Exp. limits RJR
0L obs. limit (3.2 fb^{-1}, 13 TeV)
$m_{\tilde{q}} < m_{\tilde{\chi}_1^0}$
$m_{\tilde{\chi}_1^0}$ [GeV]
$m_{\tilde{q}}$ [GeV]
0
200
400
600
800
1000
1200
1400
1600
1800

Conclusions

In addition to accommodate usual simplified dark matter models, Left-right symmetric standard models have additional DM portals:

New Δ_R portal for direct detection of left-singlet right-triplet mixed dark matter, in companion with left-singlets charged and doubly charged fermions.

Next: Search for them in compressed spectra scenarios at the LHC

Thanks!