Fermionic dark matter in a Left-Right model with mirror fermions

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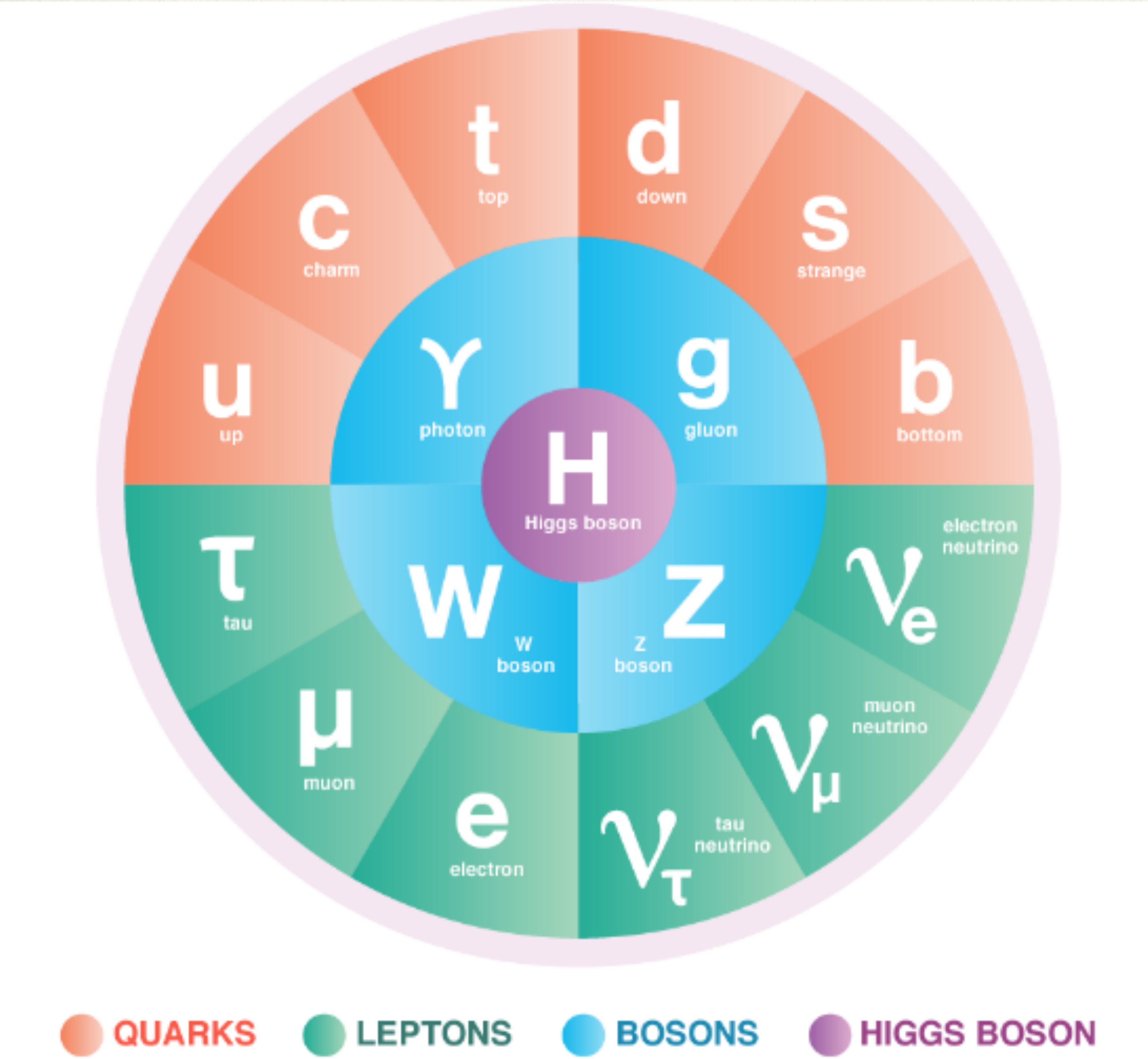
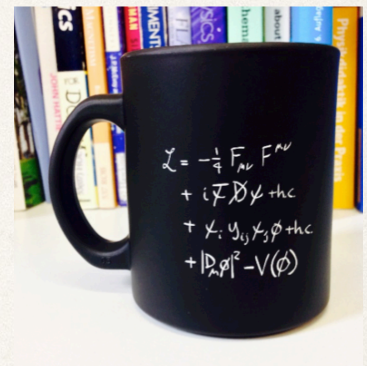
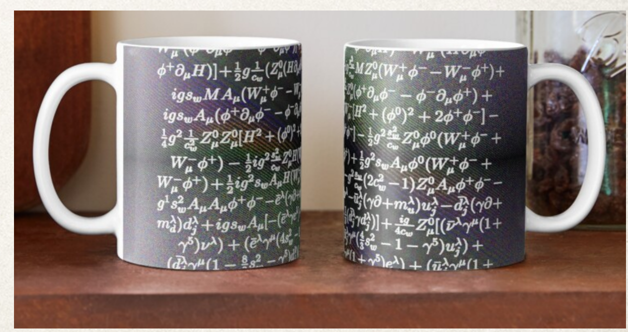
XVIII Mexican Workshop on Particles and Fields
November 24th, Puebla

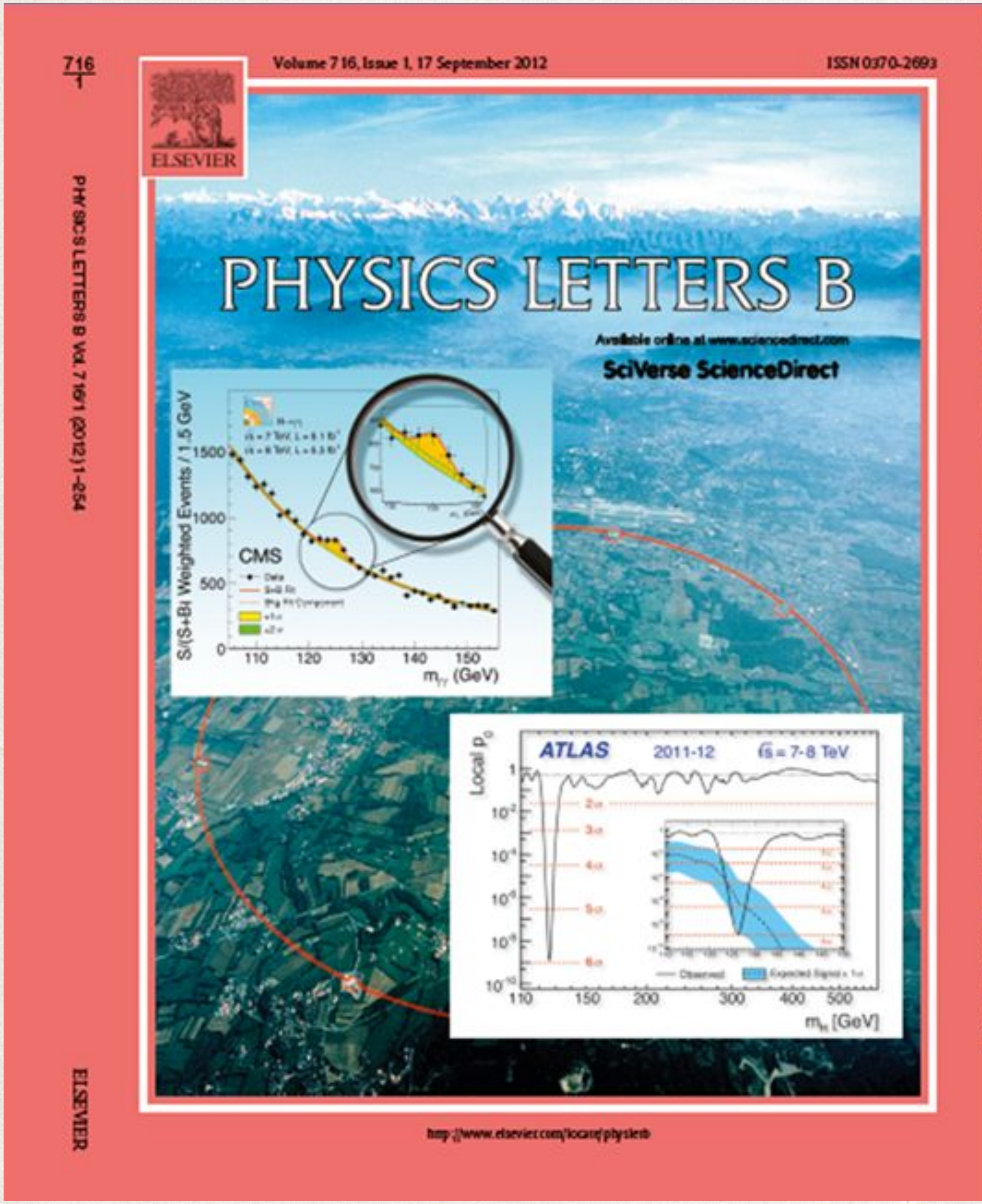
The Standard Model







Experimental search for the SM



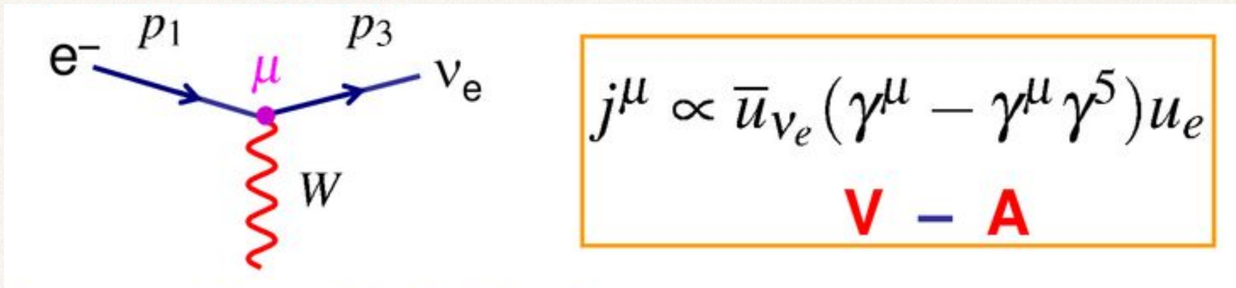
4 Jul 2012, CERN
Francois Englert & Peter Higgs

Some open questions on the SM

- Hierarchy problem
- Neutrino masses
- (Particle) Dark Matter
- CP and P problem in the SM
- Particle - antiparticle asymmetry
- Observed deviations from SM (e.g. LUV, muon $g-2$, M_W)

Left-Right symmetry

- V-A structure of the weak interaction



- Enlarging the SM gauge structure by

$$SU(3)_C \times SU(2)_L \times U(1)_Y$$

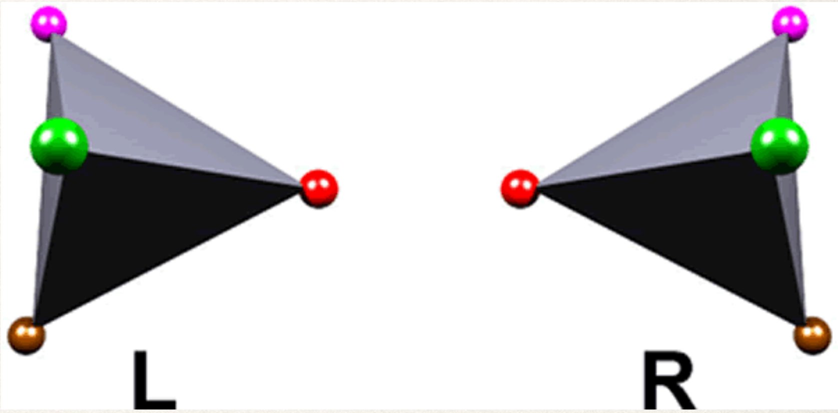
$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_Y$$

- V+A interaction mediated by gauge vector boson W_R heavy enough.

Mirror fermions

- Doubling the fermion content of the SM with opposite chirality

SM			Mirror
	ℓ_L	L_R	
	ν_R	N_L	
	ℓ_R	L_L	
	q_L	Q_R	
	u_R	U_L	
	d_R	D_L	



Particle content

	Field	$SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{Y'}$
Leptons	ℓ_{iL}	$(\mathbf{1},\ \mathbf{2},\ \mathbf{1},\ -1)$
	ν_{iR}	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ 0)$
	e_{iR}	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ -2)$
	$\hat{\nu}_{iL}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ 0)$
	$\hat{e}_{iL}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ -2)$
	$\hat{l}_{iR}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{2},\ -1)$
Quarks	u_{iR}	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 4/3)$
	d_{iR}	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 2/3)$
	$\hat{u}_{iL}$	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 4/3)$
	$\hat{d}_{iL}$	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 2/3)$
	q^o_{iL}	$(\mathbf{3},\ \mathbf{2},\ \mathbf{1},\ 1/3)$
	$\hat{q}_{iR}$	$(\mathbf{3},\ \mathbf{1},\ \mathbf{2},\ 1/3)$
Scalars	Φ	$(\mathbf{1},\ \mathbf{2},\ \mathbf{1},\ -1)$
	$\hat{\Phi}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{2},\ -1)$

Particle content

SM fermions

Scalars

Field	$SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{Y'}$
ℓ_{iL}	$(\mathbf{1},\ \mathbf{2},\ \mathbf{1},\ -1)$
ν_{iR}	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ 0)$
e_{iR}	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ -2)$
$\hat{\nu}_{iL}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ 0)$
$\hat{e}_{iL}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ -2)$
$\hat{l}_{iR}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{2},\ -1)$
u_{iR}	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 4/3)$
d_{iR}	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 2/3)$
$\hat{u}_{iL}$	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 4/3)$
d_{iL}	$(\mathbf{3},\ \mathbf{1},\ \mathbf{1},\ 2/3)$
q^o_{iL}	$(\mathbf{3},\ \mathbf{2},\ \mathbf{1},\ 1/3)$
$\hat{q}_{iR}$	$(\mathbf{3},\ \mathbf{1},\ \mathbf{2},\ 1/3)$
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$\hat{\Phi}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{2},\ -1)$

Particle content

Mirror fermions

Scalars

Field	$SU(3)_C \otimes SU(2)_L \otimes SU(2)_R \otimes U(1)_{Y'}$
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Particle content

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e_{iR}	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ -2)$
$\hat{\nu}_{iL}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ 0)$
$\hat{e}_{iL}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{1},\ -2)$
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Φ	$(\mathbf{1},\ \mathbf{2},\ \mathbf{1},\ -1)$
$\hat{\Phi}$	$(\mathbf{1},\ \mathbf{1},\ \mathbf{2},\ -1)$

$\mathbb{Z}_2$ charge assigned to mirror neutrinos & heavy higgs

Symmetry breaking scheme

$$SU(3)_C \times SU(2)_L \times SU(2)_R \times U(1)_Y \times \mathbb{Z}_2$$

$$\downarrow \quad \langle \phi_2 \rangle = v_2$$

$$SU(3)_C \times SU(2)_L \times U(1)_Y \times \mathbb{Z}_2$$

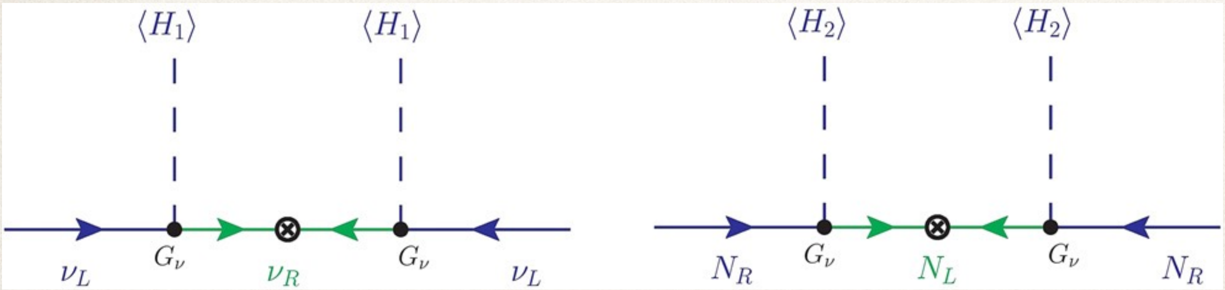
$$\downarrow \quad \langle \phi_1 \rangle = v_1$$

$$SU(3)_C \times U(1)_Q \times \mathbb{Z}_2$$

Neutrino masses

- Left-handed neutrino masses generated via type-1 seesaw mechanism

$$M_\nu^{light} = \frac{v^2 y^2}{2m} SD$$



[I S Alam, 2022]

Neutrinos mass terms

$$\begin{pmatrix} \overline{\Psi}_{\nu L}, & \overline{\Psi^c}_{\nu L} \end{pmatrix} \begin{pmatrix} M_L & M_D \\ M_D & M_R \end{pmatrix} \begin{pmatrix} \Psi_{\nu R} \\ \Psi^c_{\nu R} \end{pmatrix}$$

with

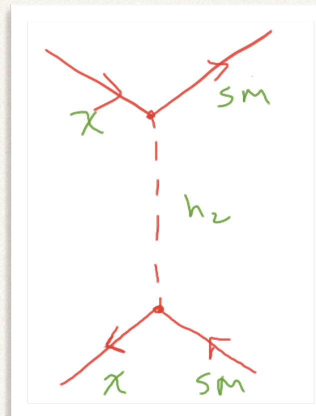
$$M_L = \begin{pmatrix} 0 & \frac{v}{\sqrt{2}}\sigma_{ij} \\ \frac{v}{\sqrt{2}}\sigma^T_{ij} & \hat{\chi}_{ij} \end{pmatrix}$$

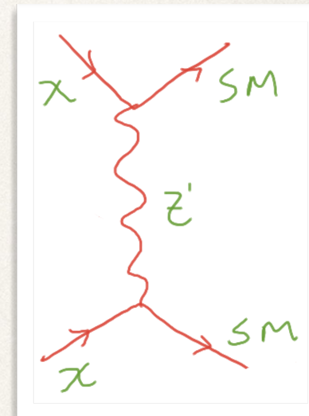
$$M_R = \begin{pmatrix} \chi_{ij} & \frac{\hat{v}}{\sqrt{2}}\hat{\sigma}_{ij} \\ \frac{\hat{v}}{\sqrt{2}}\hat{\sigma}^T_{ij} & 0 \end{pmatrix}$$

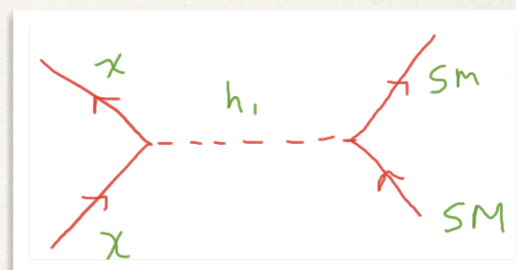
$$M_D = \begin{pmatrix} \frac{v}{\sqrt{2}}\lambda_{ij} & 0 \\ h_{ij} & \frac{\hat{v}}{\sqrt{2}}\hat{\lambda}_{ij} \end{pmatrix}$$

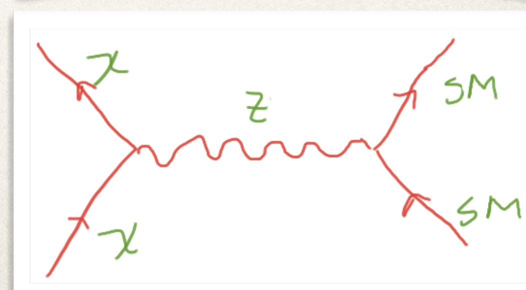
DM Phenomenology

- The $\mathbb{Z}_2$ stabilises the DM (χ), which is a ν_R & N_L mixing.
- We have performed a parameter region scan consistent with
  - Scalar potential copositivity constraints
  - LH neutrino masses $m_\nu \sim 1eV$
  - DM direct detection constrains
  - Higgs invisible decay ($\Gamma(h \to \text{inv}) < 20\,\%$)
  - Previous collider data (small mixings)

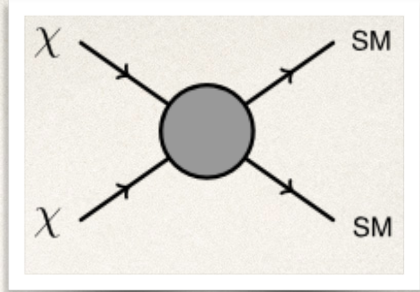


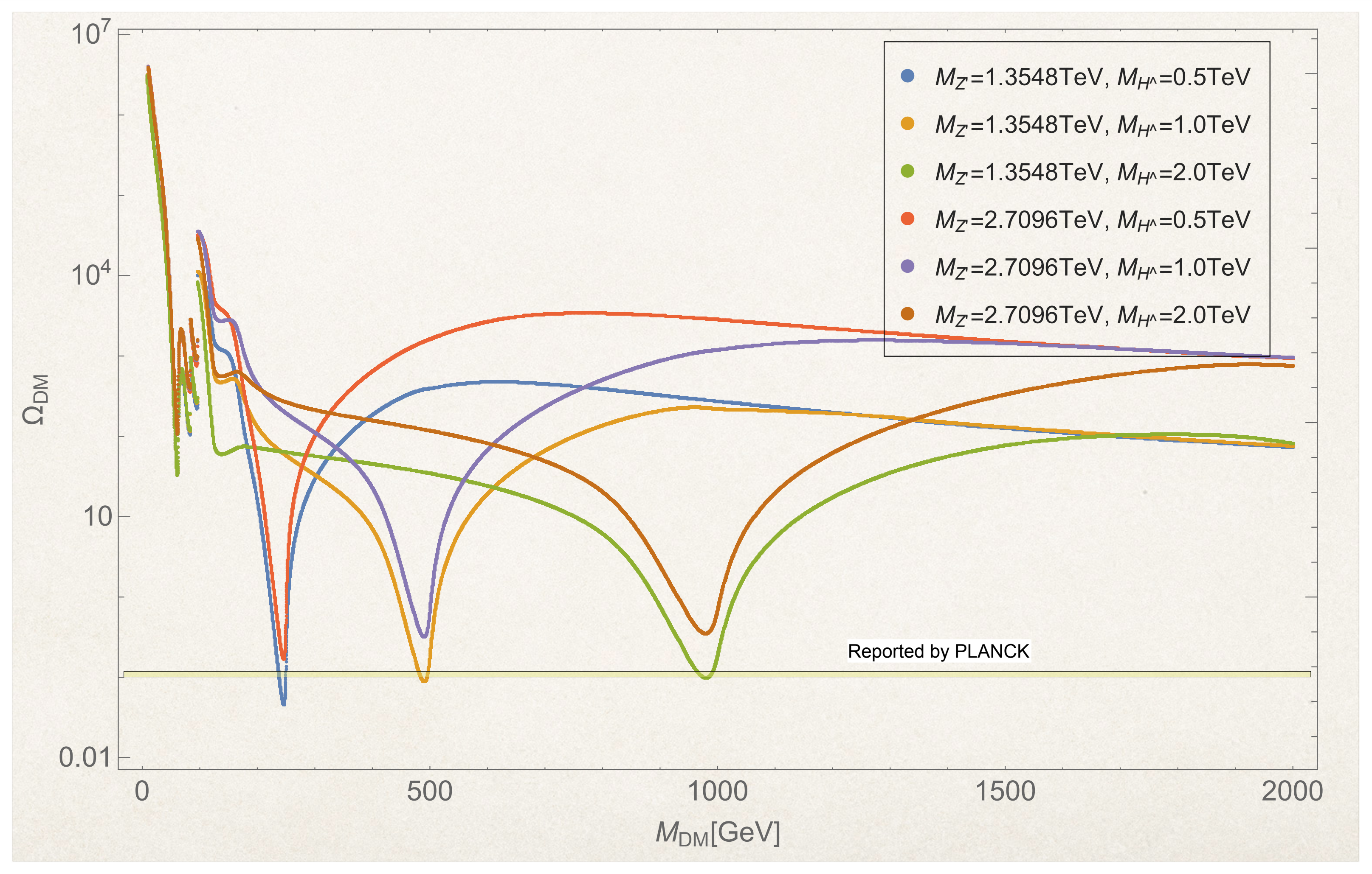




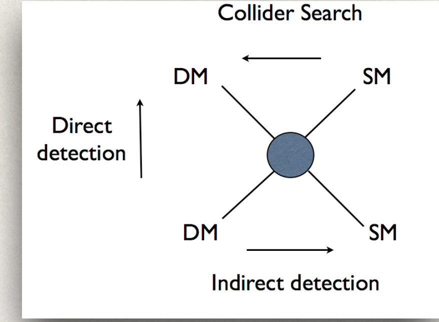


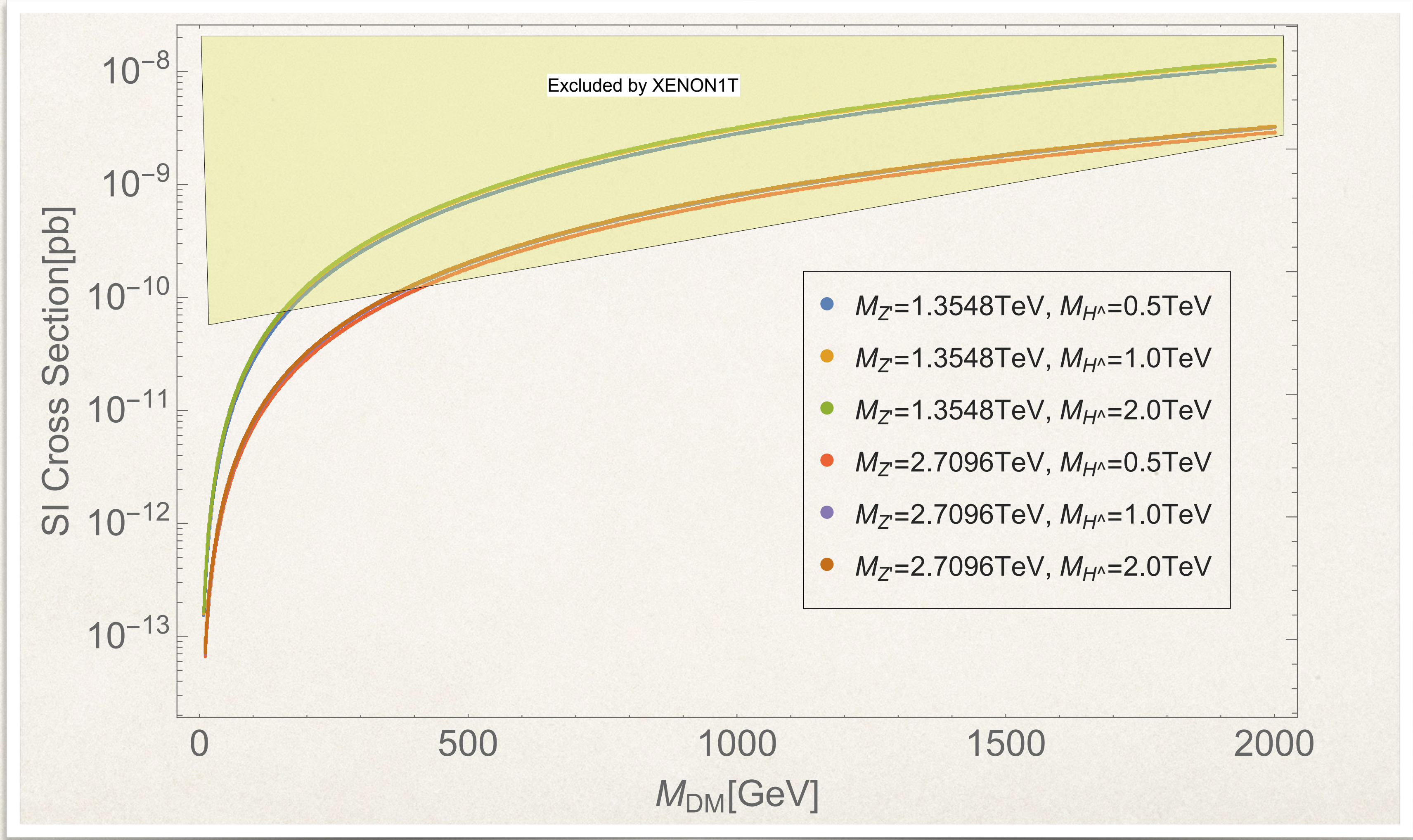
DM Relic density





DM Direct Detection





Summary and final remarks

- We have showed a minimal Left-Right model with mirror fermions which is able to induce small neutrino masses and having a viable DM candidate.
- We still have to explore the scenario where matter-antimatter asymmetry could be generated by the decay of heavy mirror neutrinos (N_R).
- Further constraint the allowed parameter region of the model with the inclusion of LFV processes & collider data (e.g. $N_{2,3} \to N_1\ \gamma$).

Thank you for your attention.