The sterile neutrino portal to Dark Matter: The Global $U(1)_{B-L}$ symmetry breaking scenario

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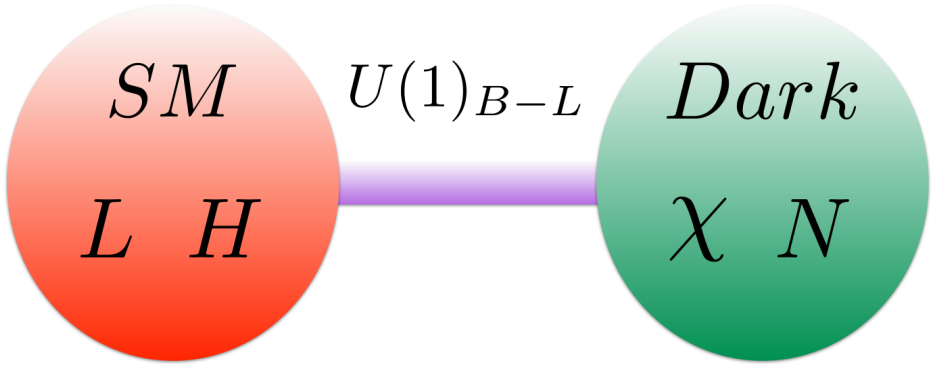
Global $U(1)_{B-L}$

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

- **Local**
  - Massive, Z'_{B-L}
  - Strong constraints from LEP and LHC
  - Dark matter only if $m_{\rm DM} \gtrsim 2$ TeV or $m_{DM} \simeq m_{Z'_{B-L}}/2$
- **Global**
  - Goldstone Boson, the Majoron, η
  - Very feebly interacting with SM fermions
  - 1loop and m_ν suppressed: $\mathcal{L} \sim 10^{-20} \eta \bar{f}_{\rm SM} \gamma^5 f_{\rm SM}$

Chikashige, Mohapatra & Peccei Phys. Lett. B98 (1981).

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



	$\mathrm{U}(1)_{B-L}$	Z_2
ϕ	$+2$	$+$
N_{aR}	-1	$+$
χ_R	-1	-

$$\begin{aligned}
\mathcal{L} \supset\ & \mu_H^2 H^\dagger H - \lambda_H (H^\dagger H)^2 + \mu_\phi^2 \phi^\dagger \phi - \lambda_\phi (\phi^\dagger \phi)^2 - \lambda_{H\phi} (H^\dagger H)\,(\phi^\dagger \phi) \\
-\ & \left(\frac{\lambda_{Nab}}{\sqrt{2}} \phi^\dagger\, \overline{N}_{Ra} N^c_{Rb} + h.c. \right) - (Y_{\alpha a} \overline{L}^\alpha_L H N_{Ra} + h.c.) \\
-\ & \left(\frac{\lambda_\chi}{\sqrt{2}} \phi^\dagger\, \overline{\chi}_R \chi^c_R + h.c. \right)
\end{aligned}$$

Phenomenology Summary

$$\phi = \frac{1}{\sqrt{2}}\left(v_{B-L} + \tilde{\rho} + i\eta\right)$$

$$\begin{aligned}\mathcal{L} \supset & -\frac{m_N}{2}\overline{N}N - \frac{\lambda_N}{2}\left[(-h\,\sin\theta + \rho\cos\theta)\overline{N}N - i\eta\overline{N}\gamma_5 N\right] - (Y\overline{L}HP_R N + h.c.) \\ & -\frac{m_\chi}{2}\overline{\chi}\chi - \frac{\lambda_\chi}{2}\left[(-h\,\sin\theta + \rho\cos\theta)\overline{\chi}\chi - i\eta\overline{\chi}\gamma_5\chi\right]\end{aligned}$$

1) Type-I seesaw $\quad \mathcal{M}_\nu = \begin{pmatrix} 0 & m_D \\ m_D^T & m_N \end{pmatrix}$

2) Higgs portal mixing $\begin{pmatrix}\tilde{h}\\ \tilde{\rho}\end{pmatrix} = \begin{pmatrix}\cos\theta & -\sin\theta \\ \sin\theta & \cos\theta\end{pmatrix}\begin{pmatrix}h\\ \rho\end{pmatrix}$, $\tan 2\theta = \frac{\lambda_{H\phi} v_H v_{B-L}}{\lambda_\phi v_{B-L}^2 - \lambda_H v_H^2}$

3) Fixed couplings $\quad \lambda_\chi = m_\chi / v_{B-L},\ \lambda_N = m_N / v_{B-L}$

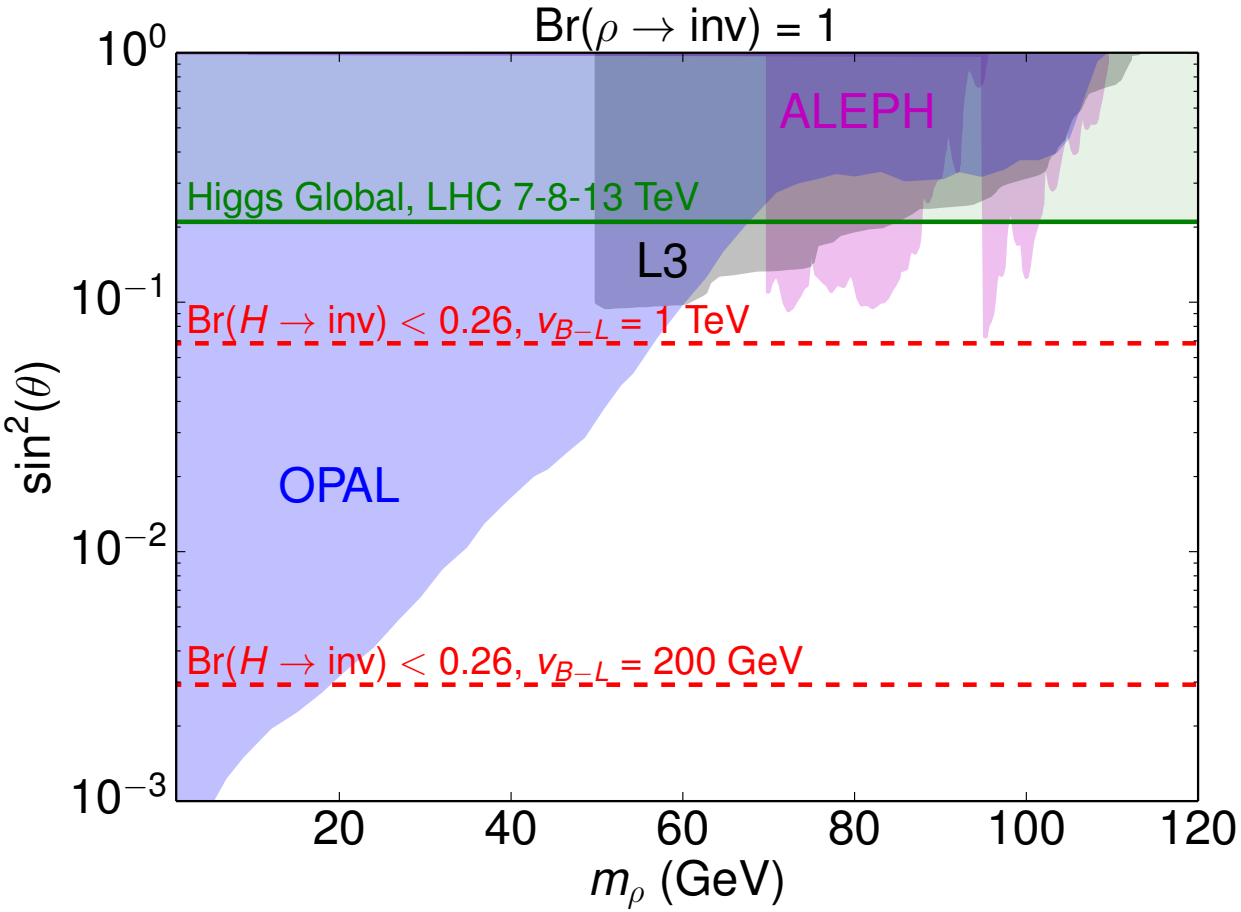
Particle	Description	Properties/Constraints
χ	Dark matter	Right relic abundance, DD and ID
η	The *Majoron*	Very feebly interacting with SM: $\mathcal{L} \sim 10^{-20}\eta \bar{f}_{\rm SM}\gamma^5 f_{\rm SM}$
ρ	CP-even scalar	Direct searches, Higgs decays and DD
N	Sterile Neutrino	New invisible decay modes

Scalar Constraints: LEP & LHC

Direct Searches: $\Gamma_\rho \simeq \Gamma(\rho \to \eta\eta) + \sin^2\theta \Gamma_H^{\rm SM}(m_\rho)$

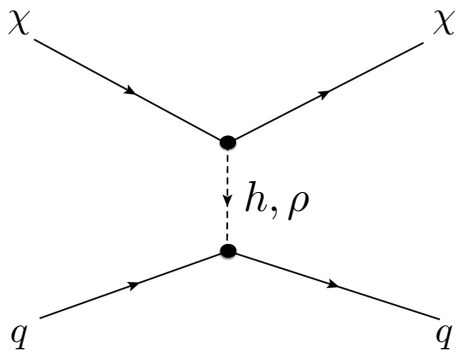
New Higgs decay channels: $\Gamma(H \to \eta\eta) = \frac{m_H^3}{32\pi v_{B-L}^2} \sin^2\theta$

Global Higgs rates: $7 + 8 + 13\,\text{TeV} \to \sin^2\theta < 0.2,\ \text{Br}(H \to \text{inv}) < 0.26,\ \forall m_\rho$

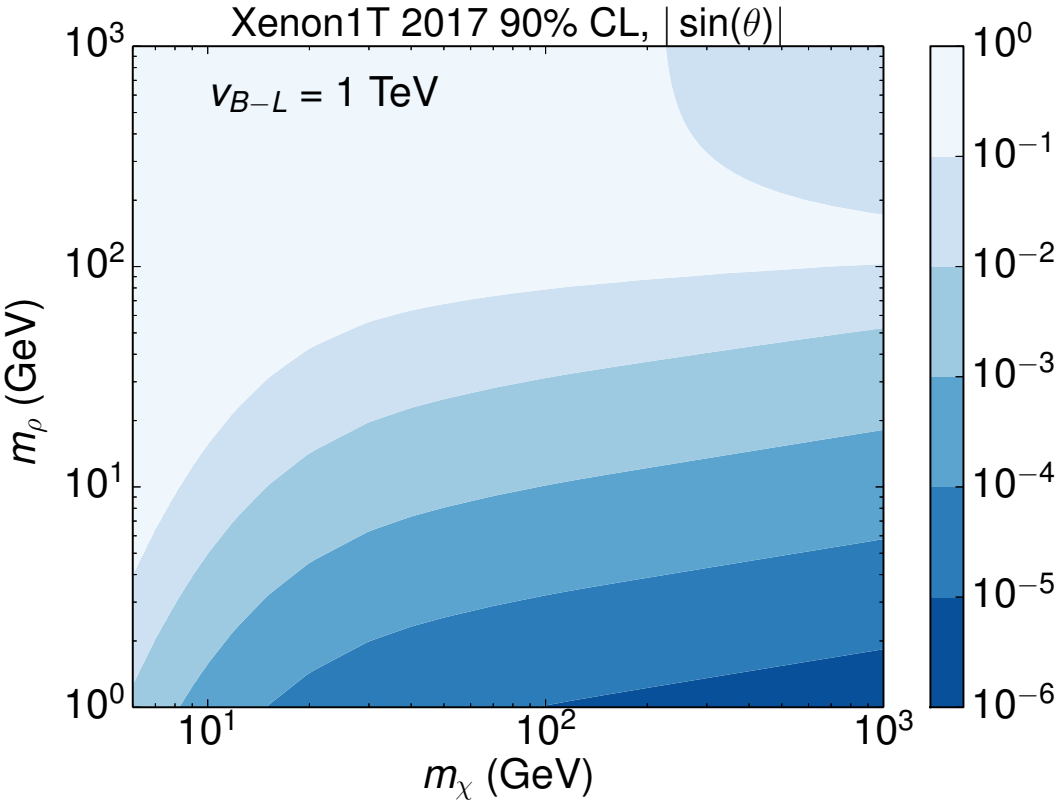


LHC direct searches for $m_\rho > m_h$ inefficient if $\text{Br}(\rho \to \text{inv}) \sim 1$

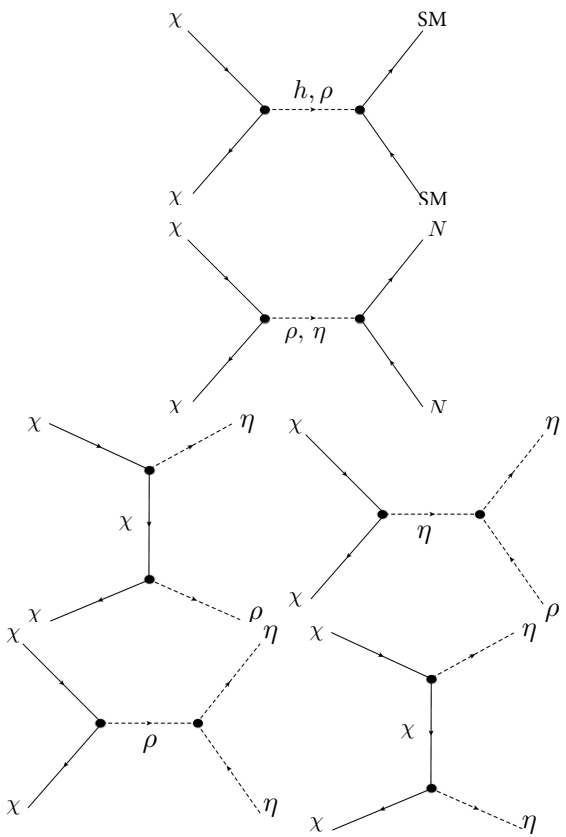
Dark Matter: Direct Detection



$$\sigma^{\rm SI}_{\chi n} = f_n^2 \, \frac{(\lambda_\chi \sin 2\theta)^2}{4\pi v_H^2} \, \frac{m_n^4 m_\chi^2}{(m_n + m_\chi)^2} \left(\frac{1}{m_h^2} - \frac{1}{m_\rho^2} \right)^2$$



Dark Matter: Relic Abundance

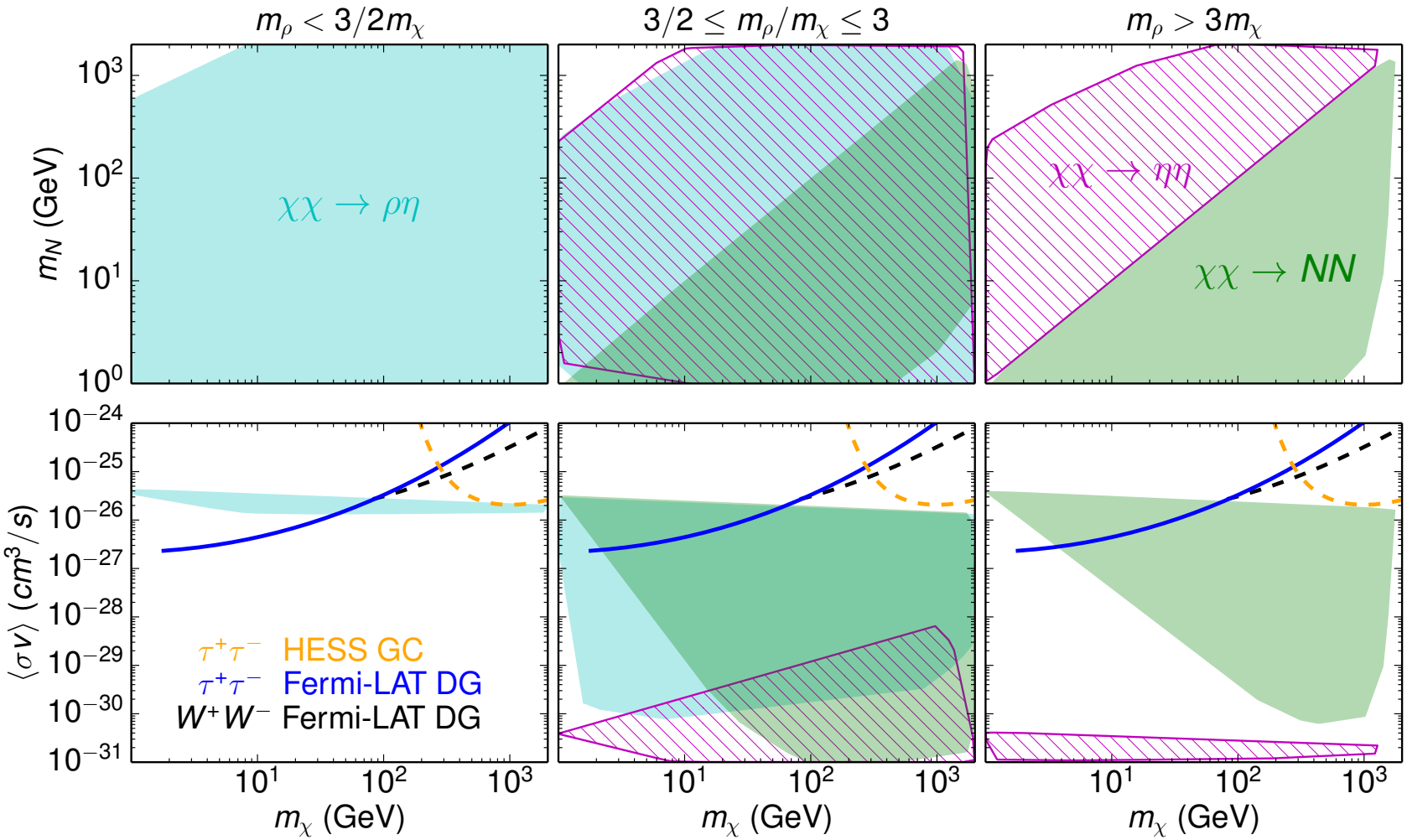
Channel	Comment	Final state
	DD and collider searches imply $\ll 1$ unless $m_\chi \sim m_h/2$	$H \to$ SM SM (Visible)
	s-wave but Yukawa suppressed $\propto m_N^2/v_{B-L}^2$	$m_N < m_W$: $NN \to 2\eta 2\nu$ (Invisible) / $m_N > m_W$: $NN \to 4$SM (Visible)
	s-wave	$\rho\eta \to 3\eta$, (Invisible)
	p-wave	2η, (Invisible)

New sterile neutrino invisible decay mode: $\dfrac{\Gamma(N \to 2\,\mathrm{SM})}{\Gamma(N \to \nu\eta)} \sim \left(\dfrac{v_{B-L}}{v_H}\right)^2$, $\dfrac{\Gamma(N \to 3\,\mathrm{SM})}{\Gamma(N \to \nu\eta)} \lesssim 10^{-2}\left(\dfrac{v_{B-L}}{v_H}\right)^2$

Parameter space scanned with micrOMEGAs. Relic abundance achieved with:

$$\lambda_\chi = \frac{m_\chi}{v_{B-L}} \lesssim \sqrt{\frac{m_\chi}{1\,\mathrm{TeV}}}$$

Dark Matter: Indirect Searches



1702.06145 Campos, Queiroz, Yaguna, & Weniger

Detailed analysis: 1704.08708 Batell, Han & Es Haghi

170X.XXXXX Folgado, Rius & Ruiz de Austri

Conclusions

1. Global $U(1)_{B-L}$: Dark matter-sterile neutrino connection with minimal particle content and outside resonances.
2. New invisible decay mode of the sterile: $N \to \nu\eta$.
3. Collider and direct detection bounds heavily restrict Higgs portal mixing. They imply $\chi\chi \to \text{SM SM} \lesssim 7\%$ unless $m_\chi \simeq m_h/2$.
4. Relic abundance sets $\lambda_\chi = \frac{m_\chi}{v_{B-L}} \lesssim \sqrt{\frac{m_\chi}{1\,\text{TeV}}}$.
5. Annihilation dominated by $\chi\chi \to NN$ if $m_\rho > 3m_\chi$.
6. Invisible decay modes preclude constraints from indirect detection searches for $m_N \lesssim 80$ GeV.

Thank you!