

A realistic model for DM interactions in the neutrino portal paradigm

José I. Illana



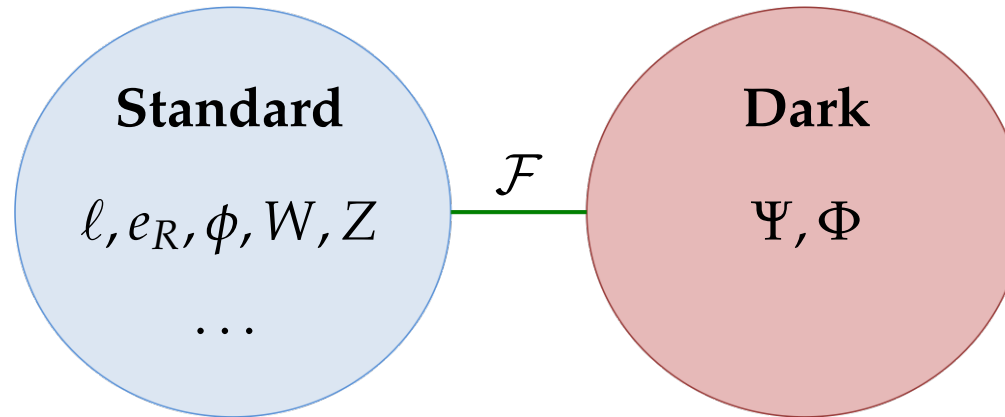
+ Vannia González Macías, José Wudka (*UC Riverside*)

1. Model
2. Constraints
3. Conclusions

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Model

- Simplest realization of the **neutrino portal** paradigm:

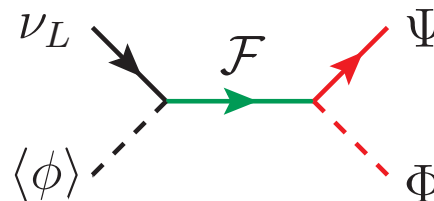


$\mathcal{F}_i$: singlet(s) under $\mathcal{G}_{\text{SM}}$, $\mathcal{G}_{\text{DM}}$, except fermion number

Ψ, Φ : same transformations under $\mathcal{G}_{\text{DM}}$, neutral under $\mathcal{G}_{\text{SM}}$

($m_\Psi < m_\Phi \Rightarrow \Psi$ is the DM candidate)

$$\mathcal{O}^{(5)} = (\tilde{\phi}^\dagger \ell)(\bar{\Psi}\Phi)$$



Model

New fields and parameters

$$\begin{aligned}\mathcal{L} = & \bar{\ell}(\mathrm{i}\not{D})\ell + \bar{e}_R\mathrm{i}\not{D}e_R + \bar{\mathcal{F}}(\mathrm{i}\not{\partial} - M)\mathcal{F} + \bar{\Psi}(\mathrm{i}\not{\partial} - m_\Psi)\Psi + |\partial\Phi|^2 - m_\Phi^2|\Phi|^2 \\ & - (\bar{\ell}\gamma^{(e)}e_R\phi + \bar{\ell}\gamma^{(\nu)}\mathcal{F}\tilde{\phi} + \bar{\Psi}z^\dagger\mathcal{F}\Phi + \text{h.c.}) - \underbrace{\lambda_x|\phi|^2|\Phi|^2}_{\text{Higgs portal} \\ & \quad (m_\Psi > m_\Phi)}\end{aligned}$$

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$$\begin{aligned} 36 &= 18(Y^{(\nu)}) + 9(M) + 6(z) + 3(m_\Psi, m_\Phi, \lambda_x) \\ \text{phys. } 4 + 20 &= \overbrace{4(V) + 3(\eta) + 8(U) + 3(M)} + 3(z) + 3(m_\Psi, m_\Phi, \lambda_x) \\ Y^{(\nu)} &\equiv \frac{\sqrt{2}}{v}V_\eta U M \end{aligned}$$

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$$\text{phys. } 4 + 20 = 4(V) + 3(\eta) + 8(U) + 3(M) + 3(z) + 3(m_\Psi, m_\Phi, \lambda_x)$$

- Light (n_L) and heavy neutrinos ($N_{L,R}$) of masses M_N from mixing of $(\nu_L, \mathcal{F}_L, \mathcal{F}_R)$

$$\begin{aligned} \mathcal{F} &= U^\dagger(\mathcal{C}U_L N_L - \mathcal{S} n_L + U_R N_R) \\ \nu_L &= V(\mathcal{S}U_L N_L + \mathcal{C} n_L) \end{aligned} \quad \mathcal{C} = \frac{1}{\sqrt{1+\eta^2}} \quad \mathcal{S} = \frac{\eta}{\sqrt{1+\eta^2}}$$

$$V = \text{PMNS} \quad \eta = \text{diag}(\eta_i) > 0 \quad U \in SU(3) \quad M \text{ real diagonal}$$

$$U_R^\dagger U M U^\dagger \mathcal{C}^{-1} U_L = M_N = \text{diagonal}$$

Model

New fields and parameters

⇒ Modified Z couplings: $\mathcal{L} \supset -\frac{g}{2c_W} \bar{n}_L \cancel{Z} \mathcal{C}^2 n_L + \dots$

flavor diagonal but **non universal**

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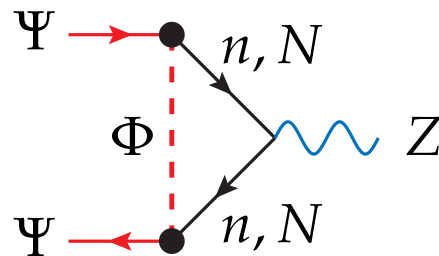
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– One-loop $Z \Psi \Psi$



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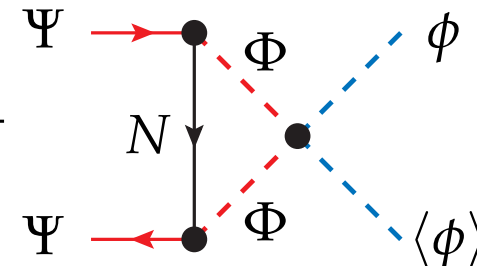
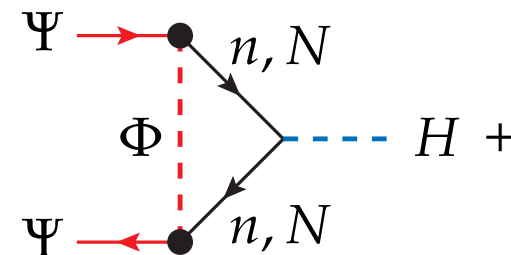
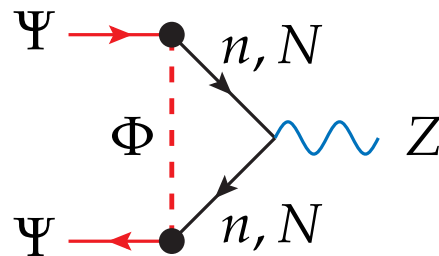
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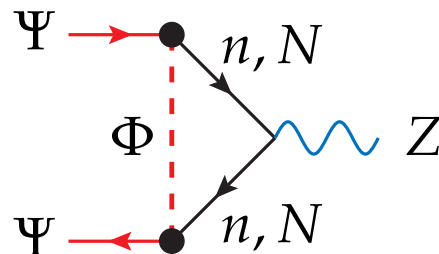
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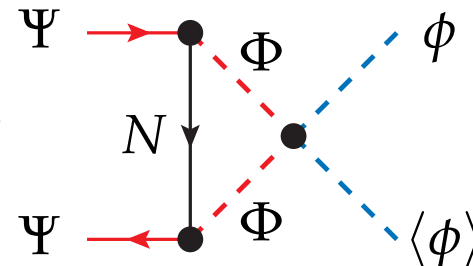
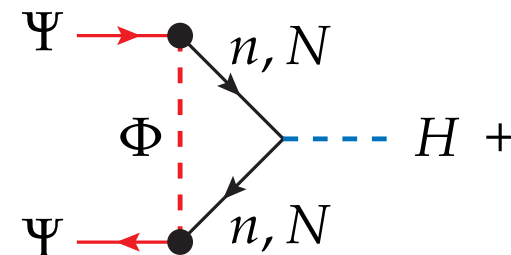
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(neutrino portal)

– One-loop $Z\Psi\Psi$



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$Z \rightarrow \text{inv}$

$H \rightarrow \text{inv}$

π, τ decays

Relic abundance

Direct detection

Indirect detection

Collider searches

Model

Quasidegenerate heavy neutrinos

$$\boxed{M_N = \Lambda \mathbb{1} \quad \eta \ll 1} \quad \Rightarrow \quad \mathcal{C} \approx \mathbb{1} - \frac{1}{2}\eta^2 \quad \mathcal{S} \approx \eta \quad M \approx \Lambda(\mathbb{1} - \frac{1}{2}U^\dagger \eta^2 U)$$

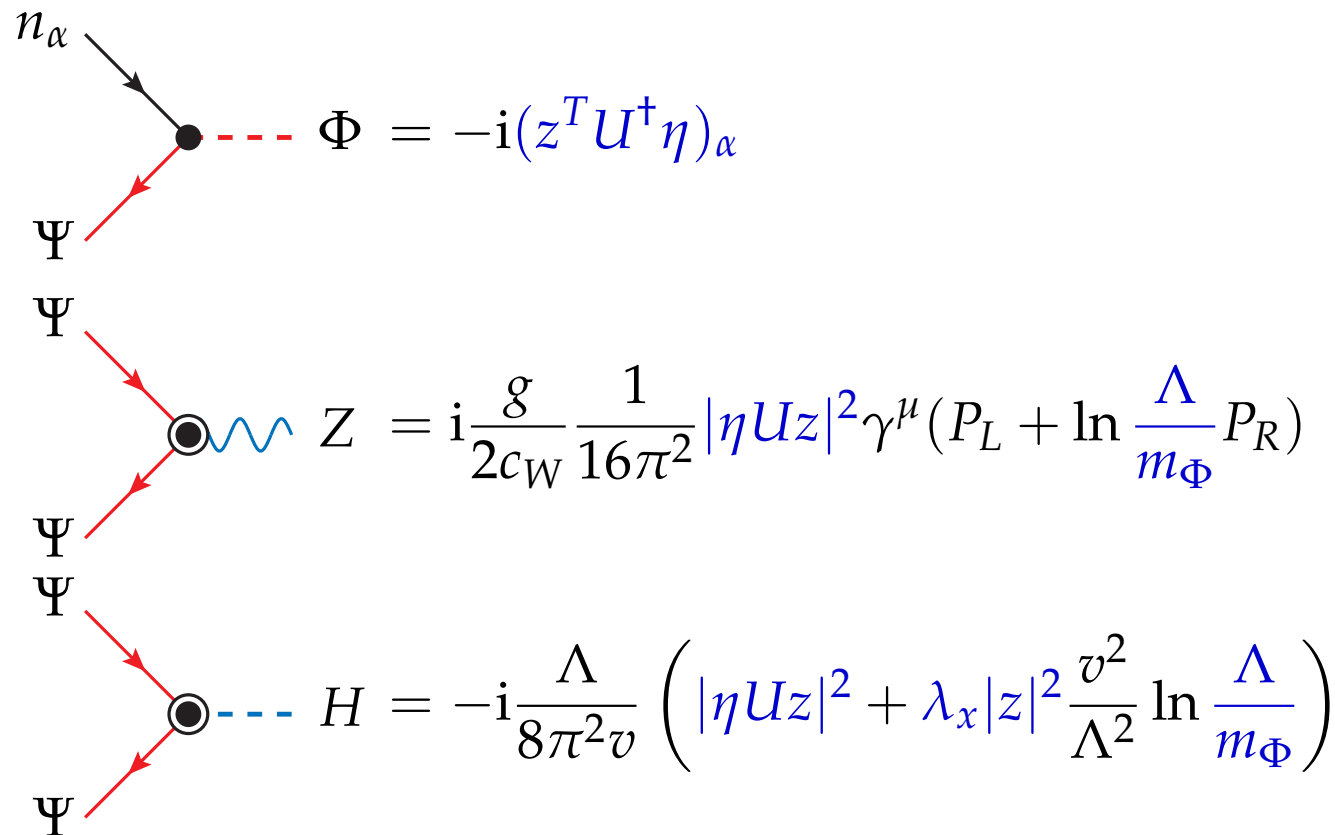
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- Just the following 5 parameter combinations appear in DM observables:

$$\Lambda \quad m_\Psi \quad m_\Phi \quad |\eta U z|^2 \quad \lambda_x |z|^2$$



Constraints

Electroweak

- Z: $\Gamma(Z \rightarrow \text{inv}) = \frac{1}{3} \text{Tr}(\mathcal{C}^4) \Gamma_{\text{SM}}(Z \rightarrow \text{inv}) \Rightarrow \sum \eta_i^2 < 0.014$ [LEP] (3σ)

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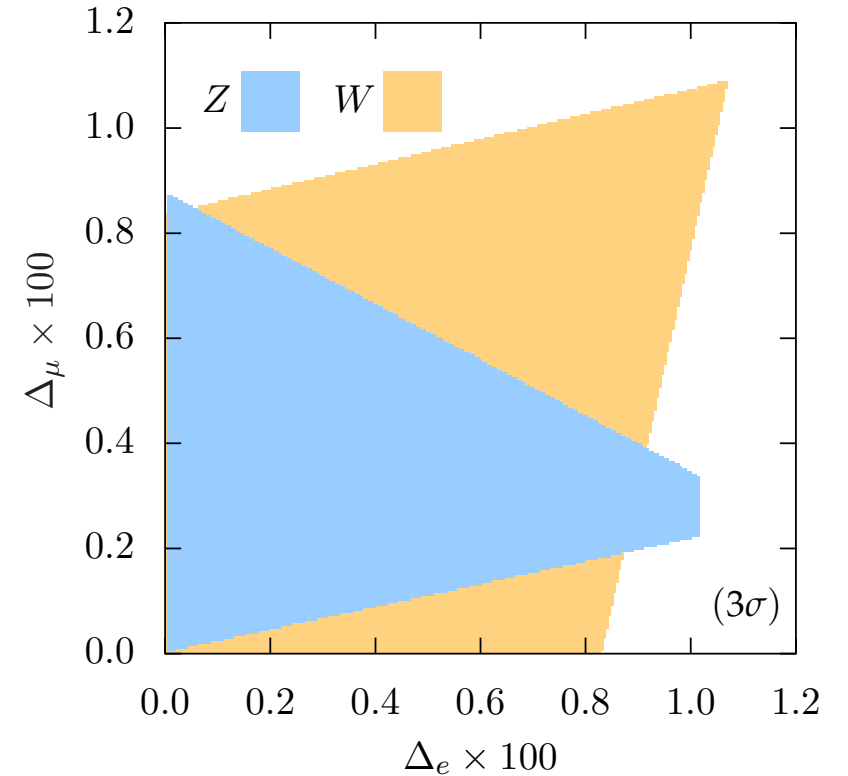
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$$\Gamma(\pi \rightarrow \ell_\alpha \bar{\nu}_\alpha) = (1 - \Delta_\alpha) \Gamma_{\text{SM}}$$

$$\Gamma(\ell_\alpha \rightarrow \ell_\beta \bar{\nu}_\alpha \nu_\beta) = (1 - \Delta_\alpha - \Delta_\beta) \Gamma_{\text{SM}}$$



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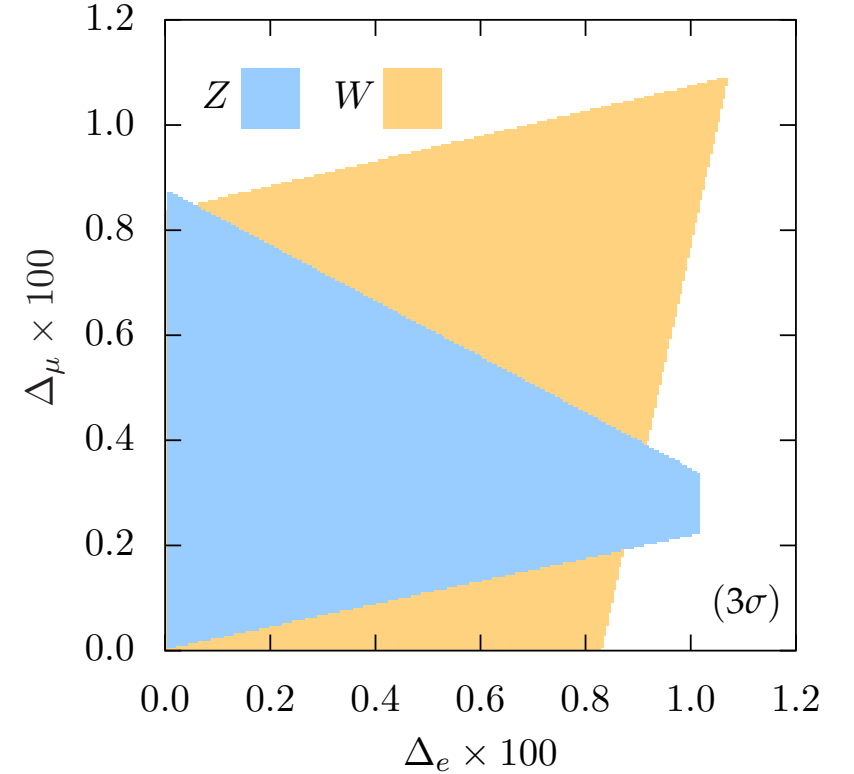
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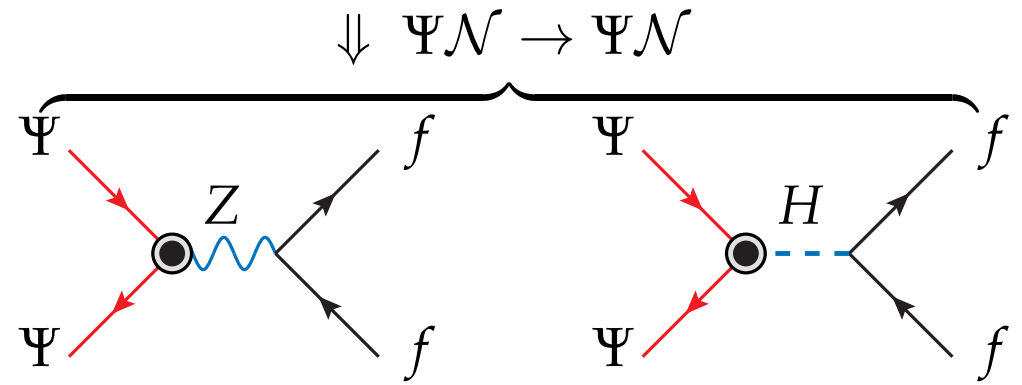
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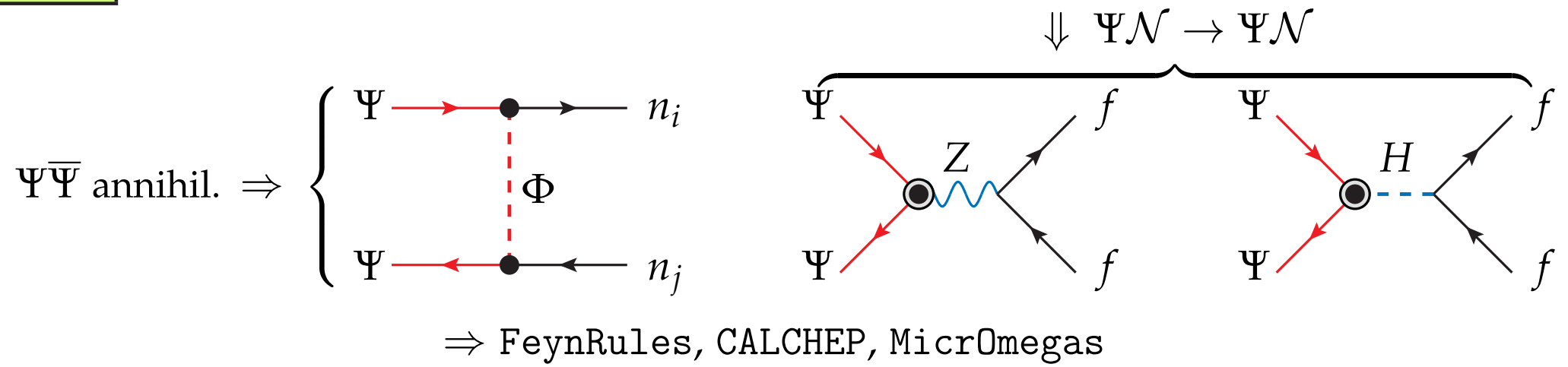
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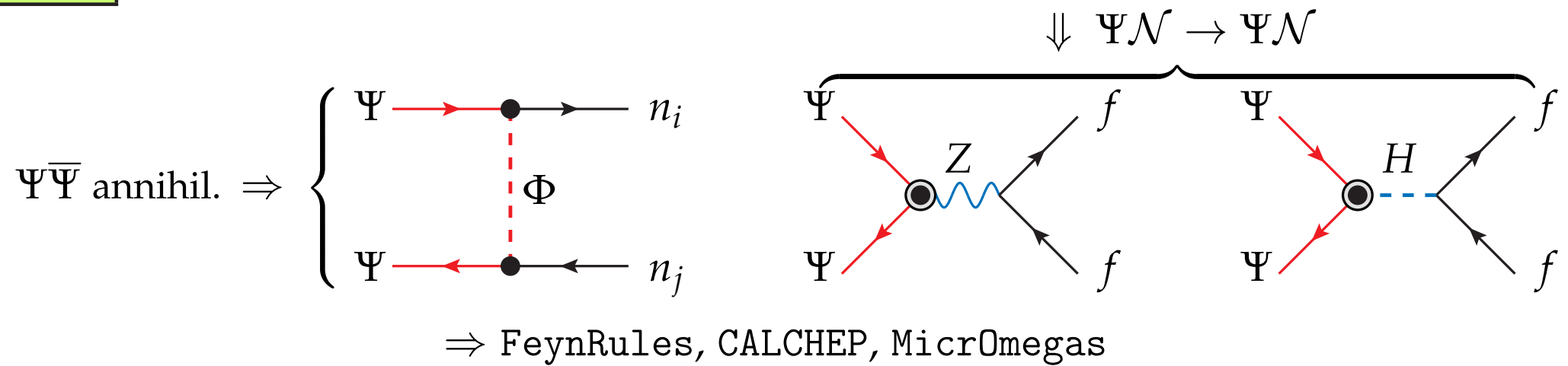


- $H: \Gamma(H \rightarrow \text{inv}) \Rightarrow \frac{v}{\Lambda} \left| |\eta U z|^2 \frac{\Lambda^2}{v^2} + \lambda_x |z|^2 \frac{\Lambda}{m_\Phi} \right| < 1.7 \quad [\text{ATLAS}] (90\% \text{ C.L.})$
(if $m_\Psi < m_H/2$)

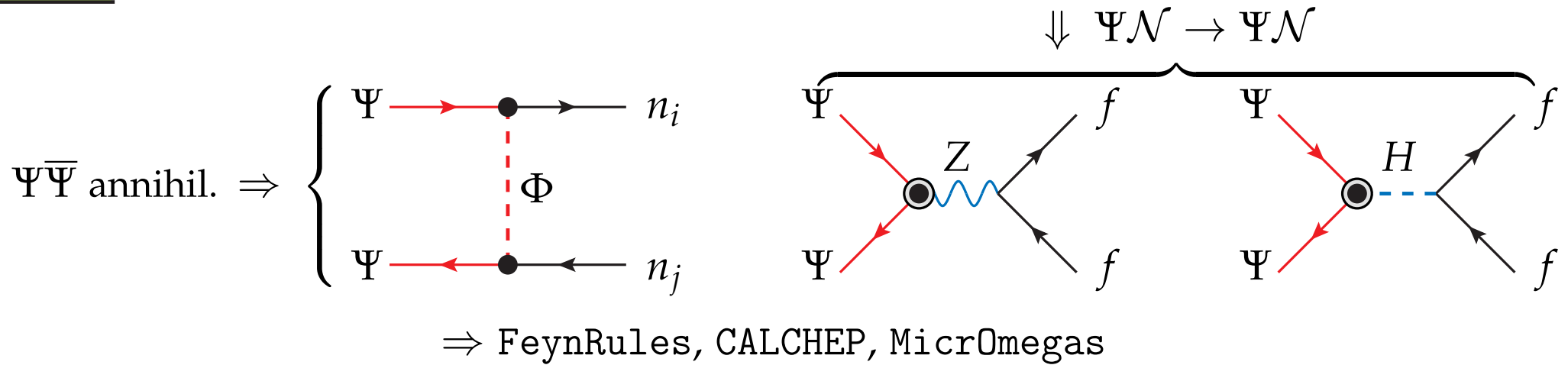
$$\Psi\bar{\Psi} \text{ annihil.} \Rightarrow \left\{ \begin{array}{l} \Psi \xrightarrow{\text{red}} \bullet \xrightarrow{\text{black}} n_i \\ \Psi \xleftarrow{\text{red}} \bullet \xleftarrow{\text{black}} n_j \end{array} \right. \quad \Phi$$







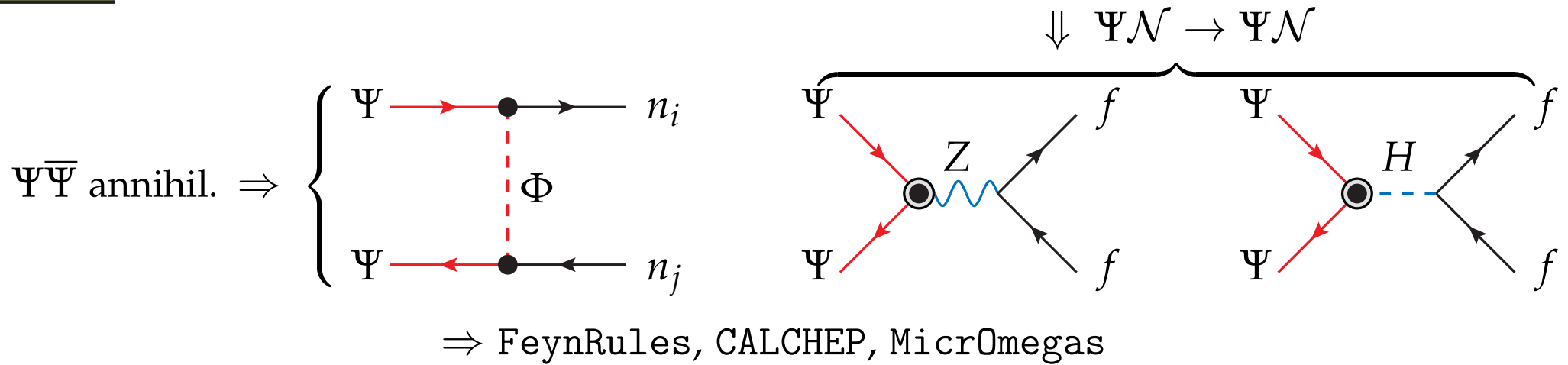
Parameter scan: Λ m_Ψ m_Φ $|\eta U z|^2$ $\lambda_x |z|^2$



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$$200 \text{ GeV} \leq \Lambda \leq 10 \text{ TeV} \quad (\text{heavy neutrinos})$$



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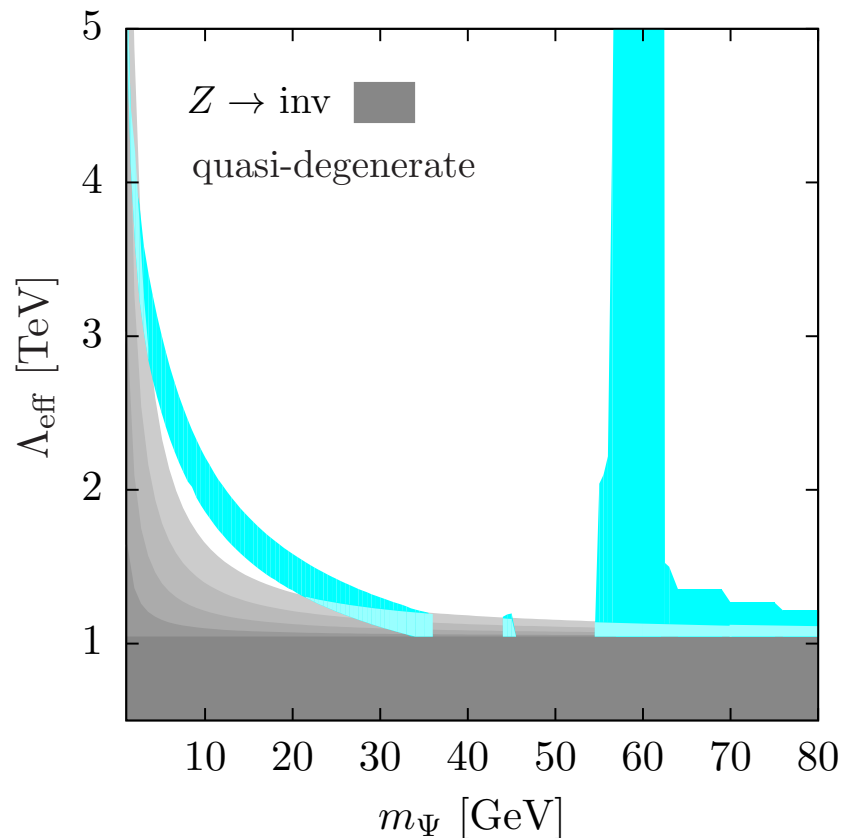
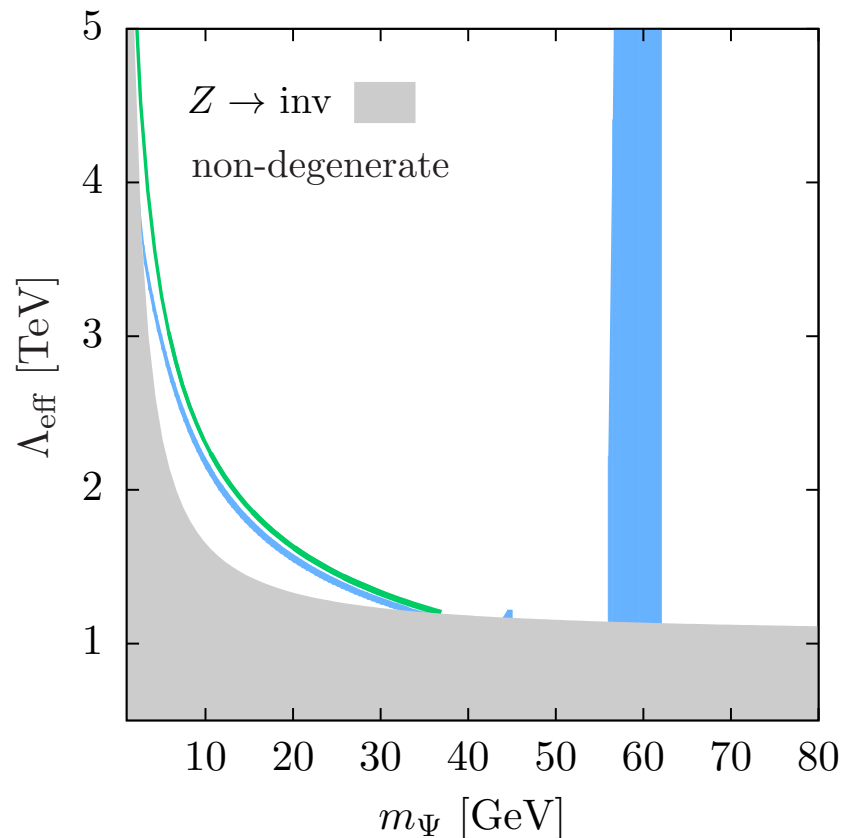
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- non-degenerate: $m_\Psi + 10 \text{ GeV} \leq m_\Phi$
- quasi-degenerate: $m_\Psi < m_\Phi < m_\Psi + 10 \text{ GeV}$

DM**Relic abundance**

$$\Omega_\Psi h^2 = 0.1198 \pm 0.026 \text{ (3}\sigma\text{) [Planck]}$$

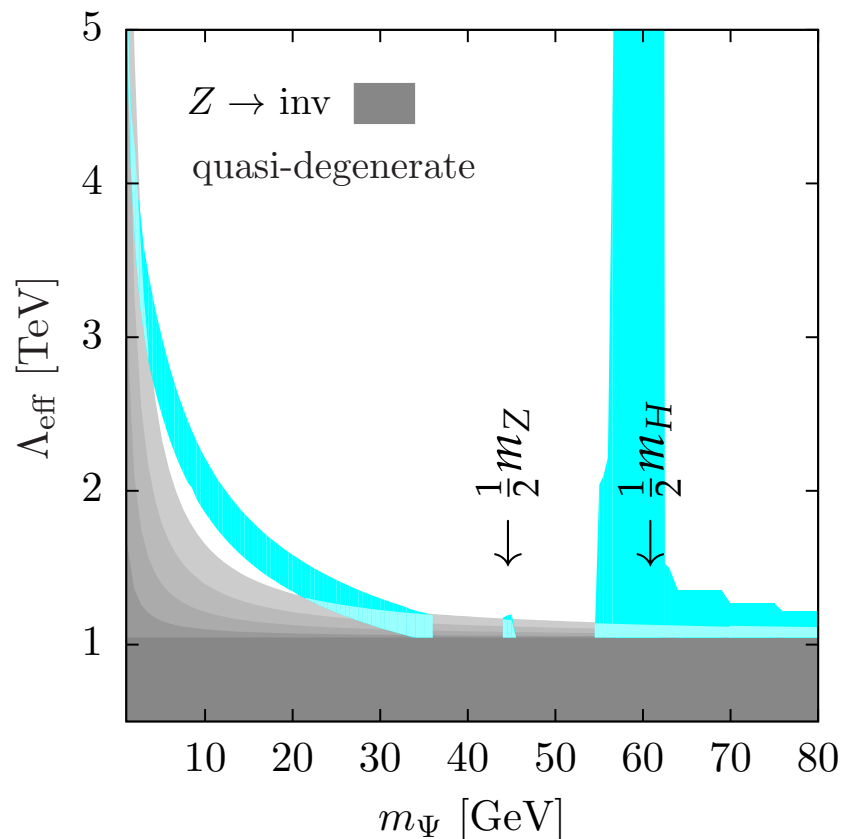
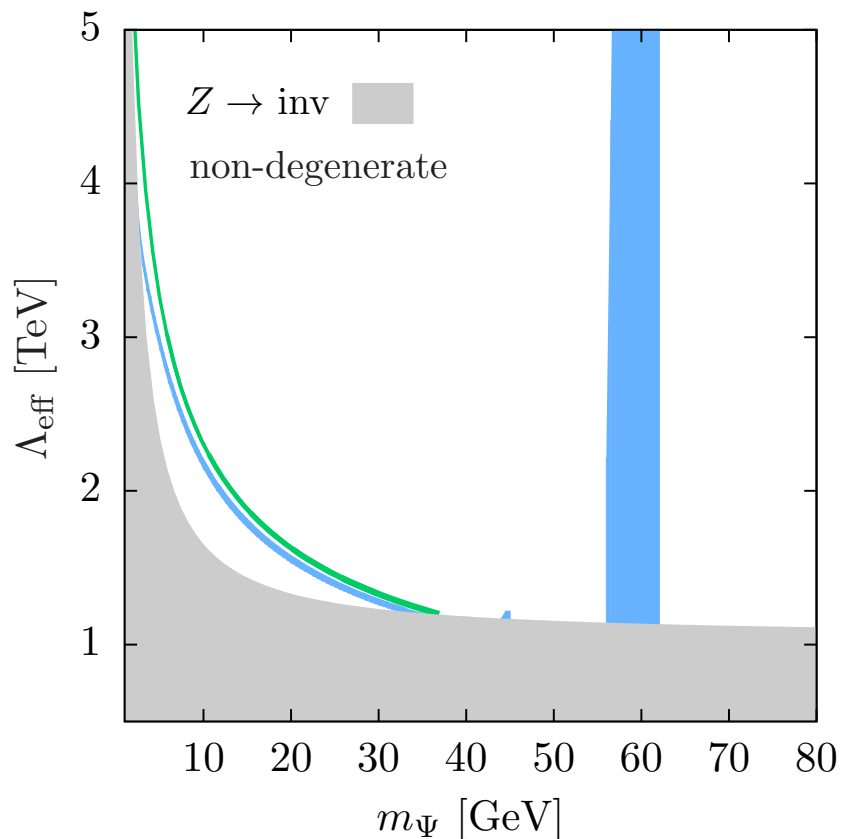


$$\text{dominant } \langle \sigma v \rangle_{\Psi\bar{\Psi} \rightarrow \nu\bar{\nu}} = \frac{(v/\Lambda_{\text{eff}})^4}{256\pi m_\Psi^2} \quad \Lambda_{\text{eff}} = \frac{v/\sqrt{2}}{|\eta U z|} \sqrt{\frac{m_\Psi^2 + m_\Phi^2}{m_\Psi^2}}$$

$$\langle \sigma v \rangle_{\Psi\bar{\Psi} \rightarrow f\bar{f}} = \underbrace{(\sigma_0)_Z}_{S\text{-wave}} + \frac{T}{m_\Psi} \underbrace{(\sigma_0)_H}_{P\text{-wave}} \quad \langle v \rangle \sim T^{1/2}$$

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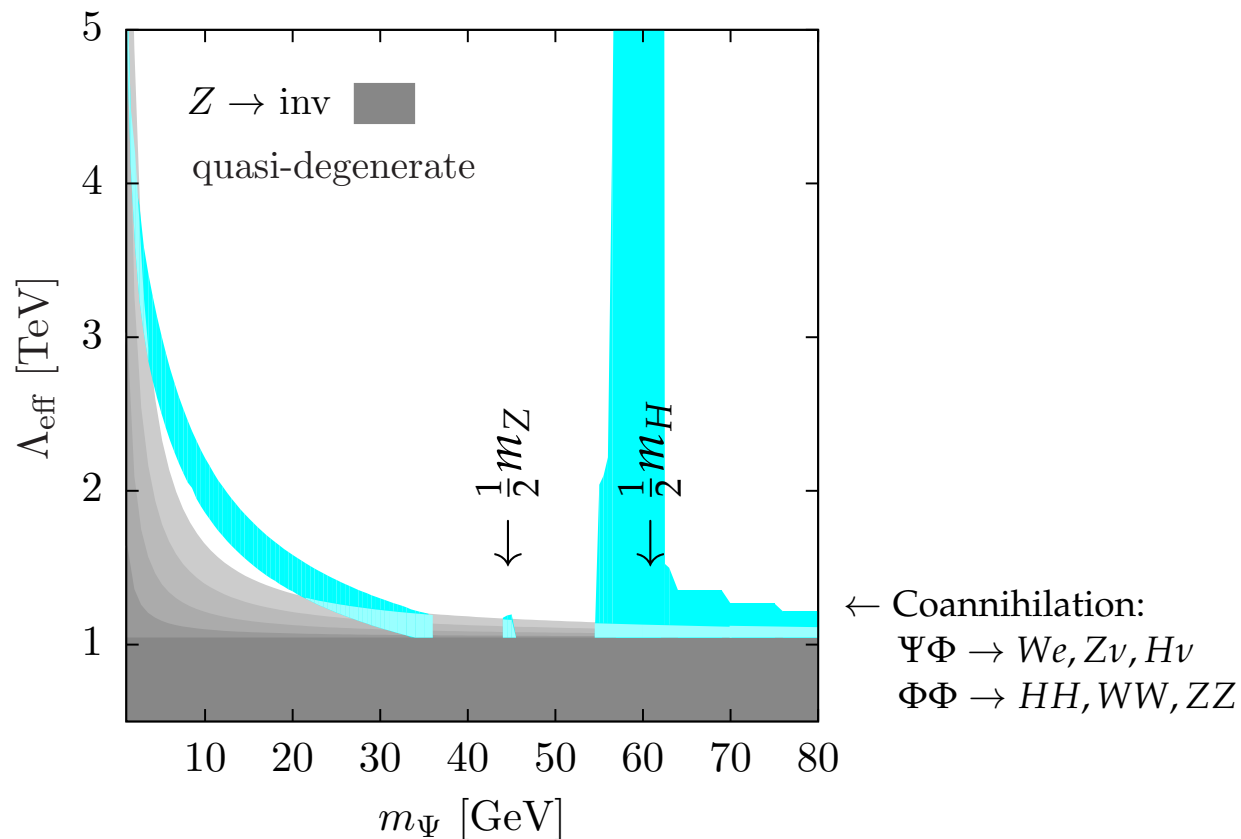
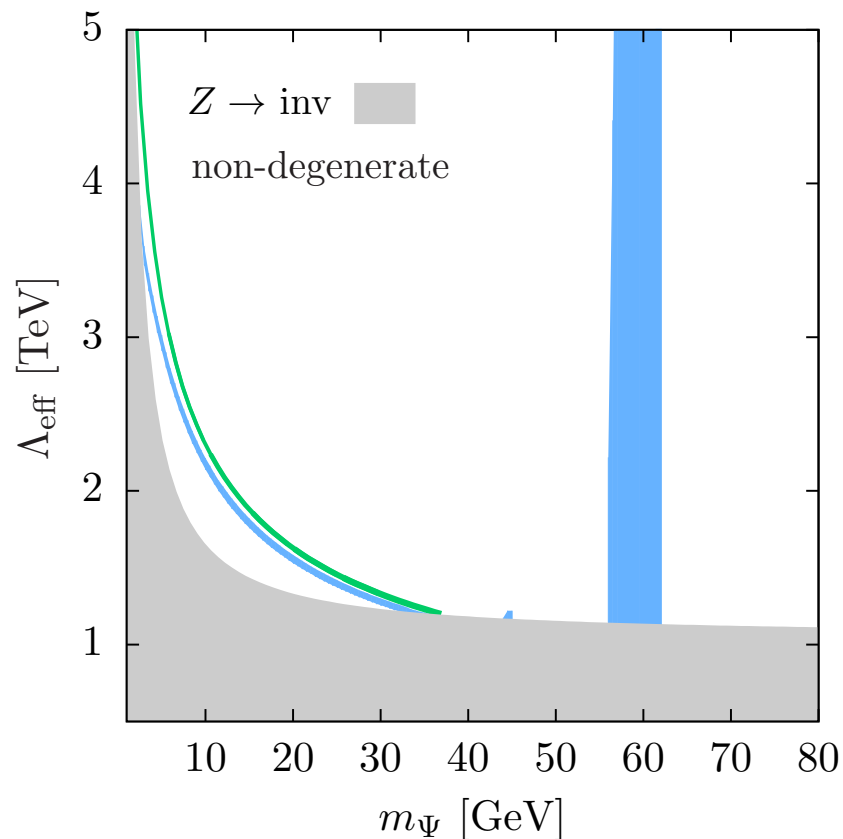


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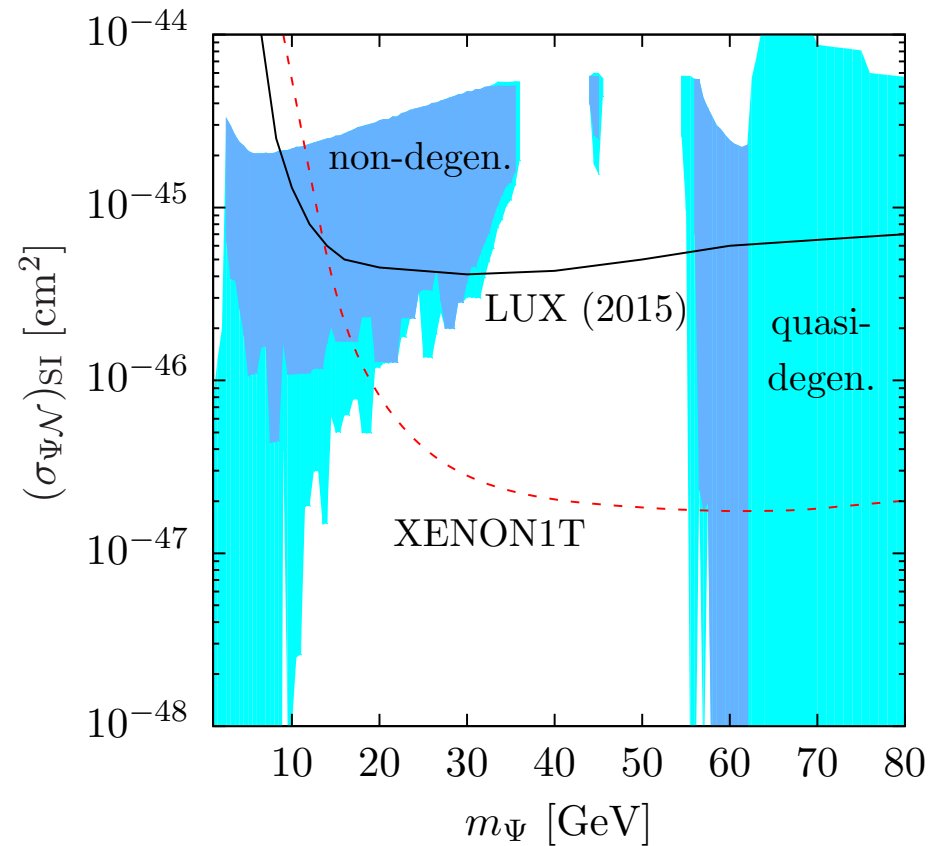
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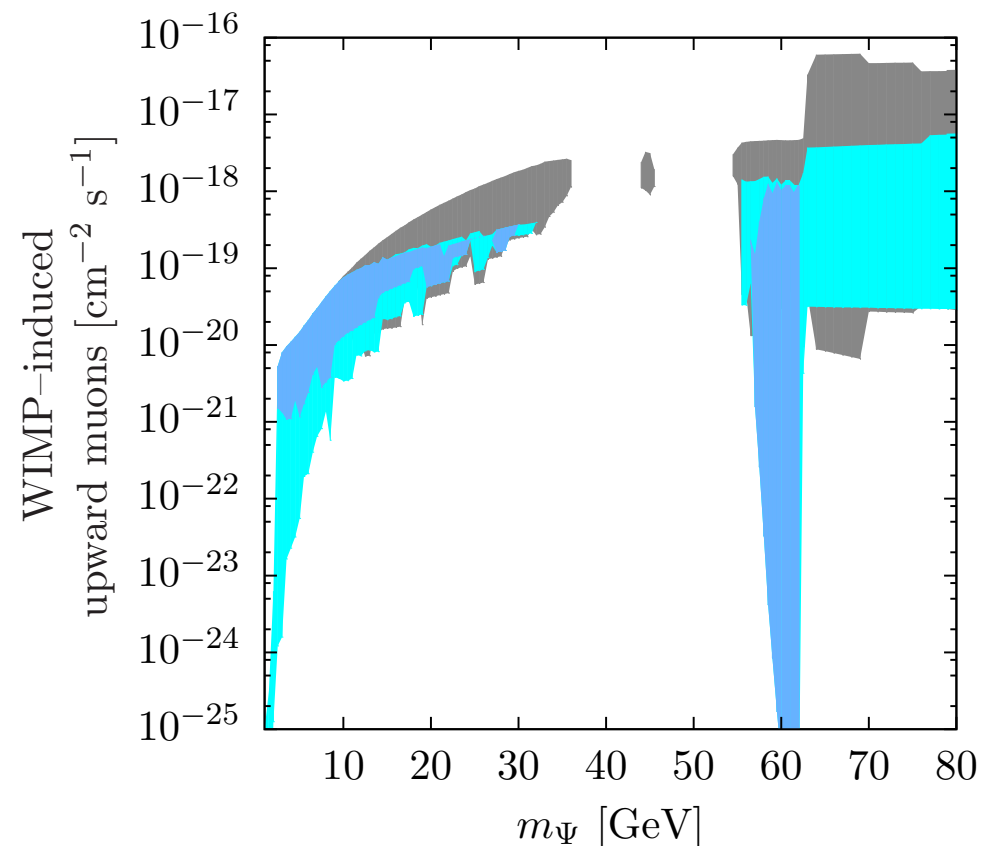
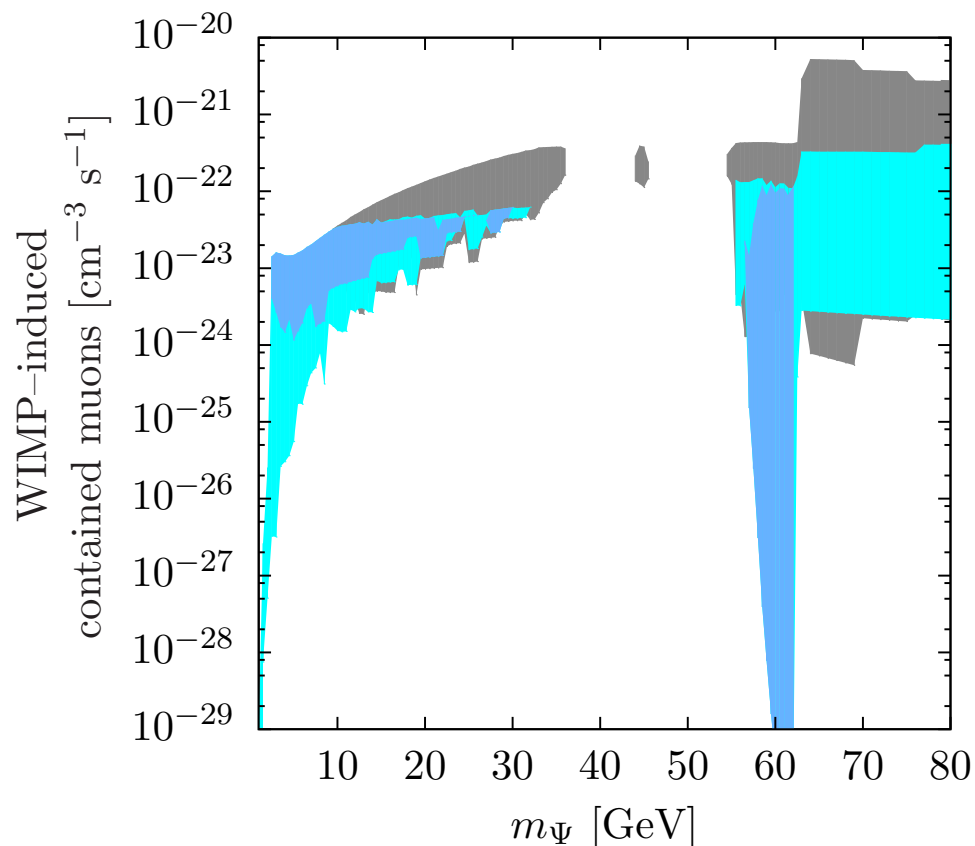
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$$\Psi\mathcal{N} \rightarrow \Psi\mathcal{N}$$



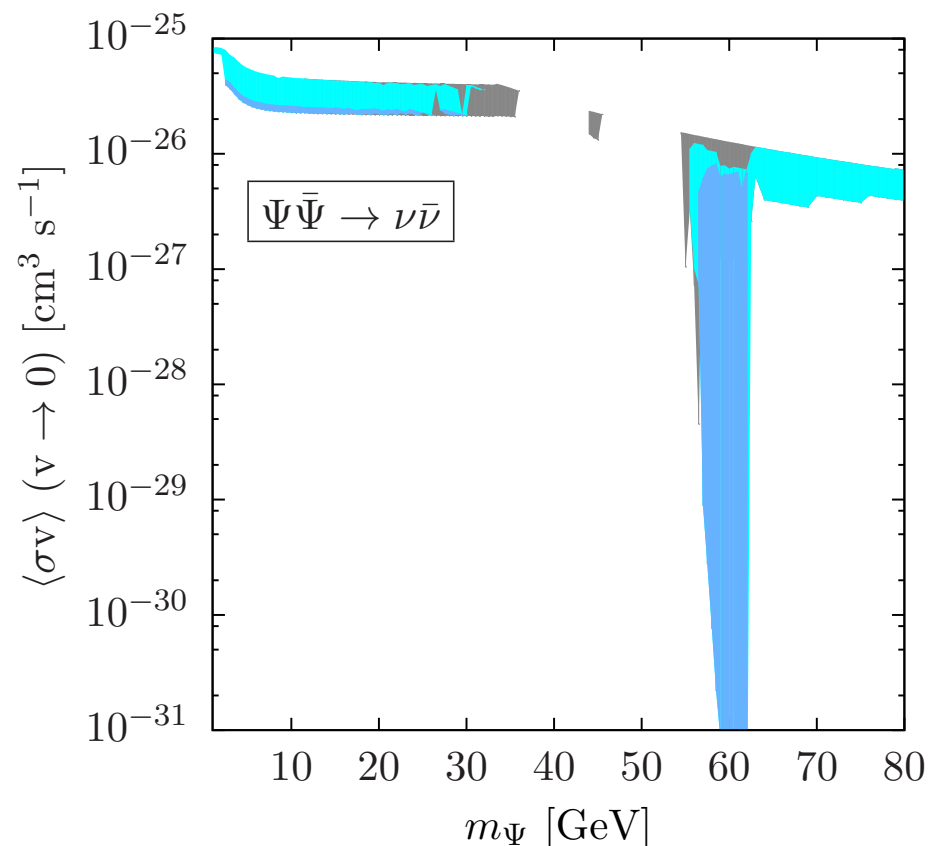
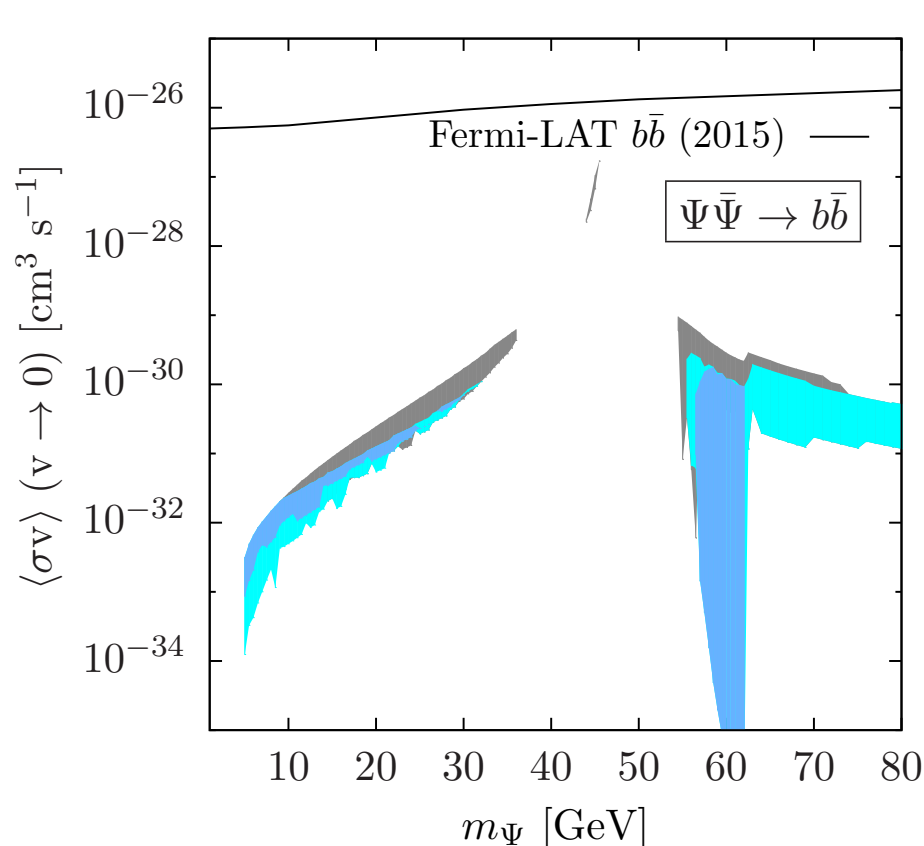
- LUX excludes Z resonance region
- Non-degenerate: Cross sections larger than 10^{-46} cm^2 unless $m_\Psi \sim m_H/2$
- Quasi-degenerate: large parameter space available



- **Neutrino line** $E_\nu = m_\Psi$:

$$dN/E_{\nu_i} \sim \frac{1}{2} C_\Psi \delta(E_{\nu_i} - m_\Psi) \quad C_\Psi \sim \sigma_{\Psi\mathcal{N}} \times \rho_{\text{local}}^{\text{DM}}$$

[exp sensitivity: IceCube ($E_\nu > 100$ GeV) Super-K (up-muons $\gtrsim 10^{-14}$ cm⁻² s⁻¹)]



- Into charged fermions (1-loop):
 H -mediated is P -wave, suppressed
w.r.t. Z -mediated (S -wave)
(safe from Fermi-LAT)

- Into neutrinos (tree-level):
Poorly measured
(Super-K?)

Conclusions

- A realization of the neutrino-portal scenario:
 - Multicomponent DM: Ψ, Φ ($m_\Psi < m_\Phi$)
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 - Quasi-degenerate $\Rightarrow$ also heavier (coannihilation)
- Cleanest **signature**: **neutrino line** ($E_\nu = m_\Psi$)