Nuetrino Portal to Freeze-in Dark Matter

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B. Barman, BD, A. Ghoshal, arXiv:2210.abcde

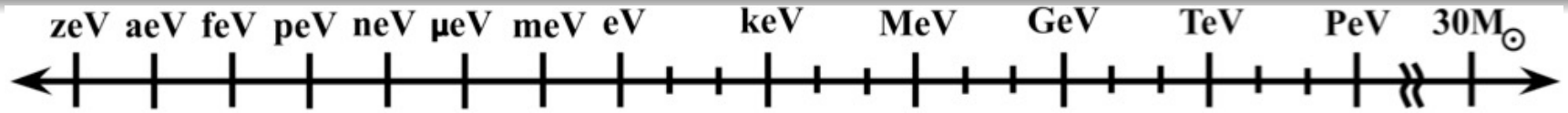
International Conference on Neutrinos and Dark Matter

(NuDM-2022)

Sharm El Sheikh, Egypt

Sept 28, 2022

The Enigmatic Dark Matter



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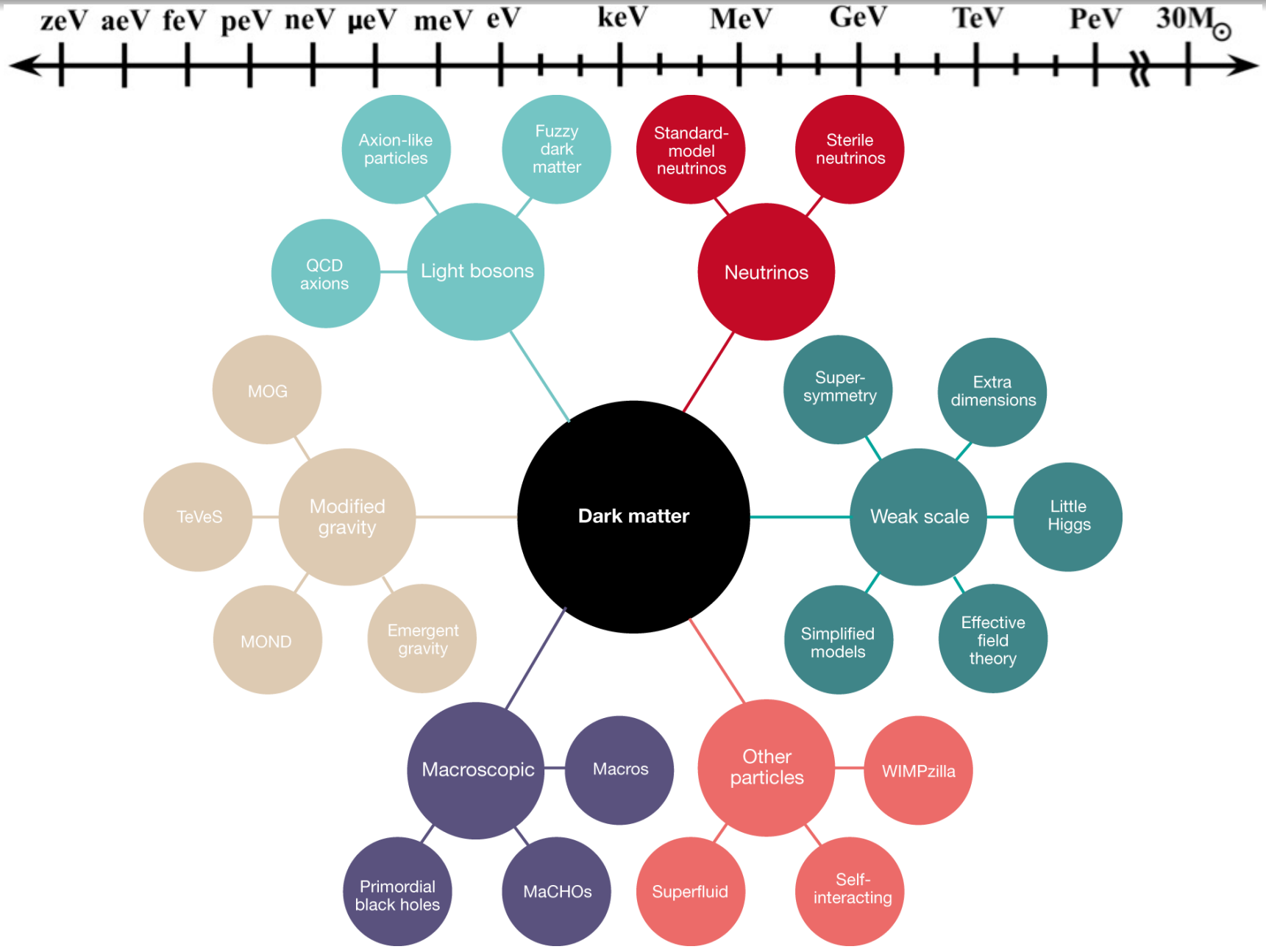
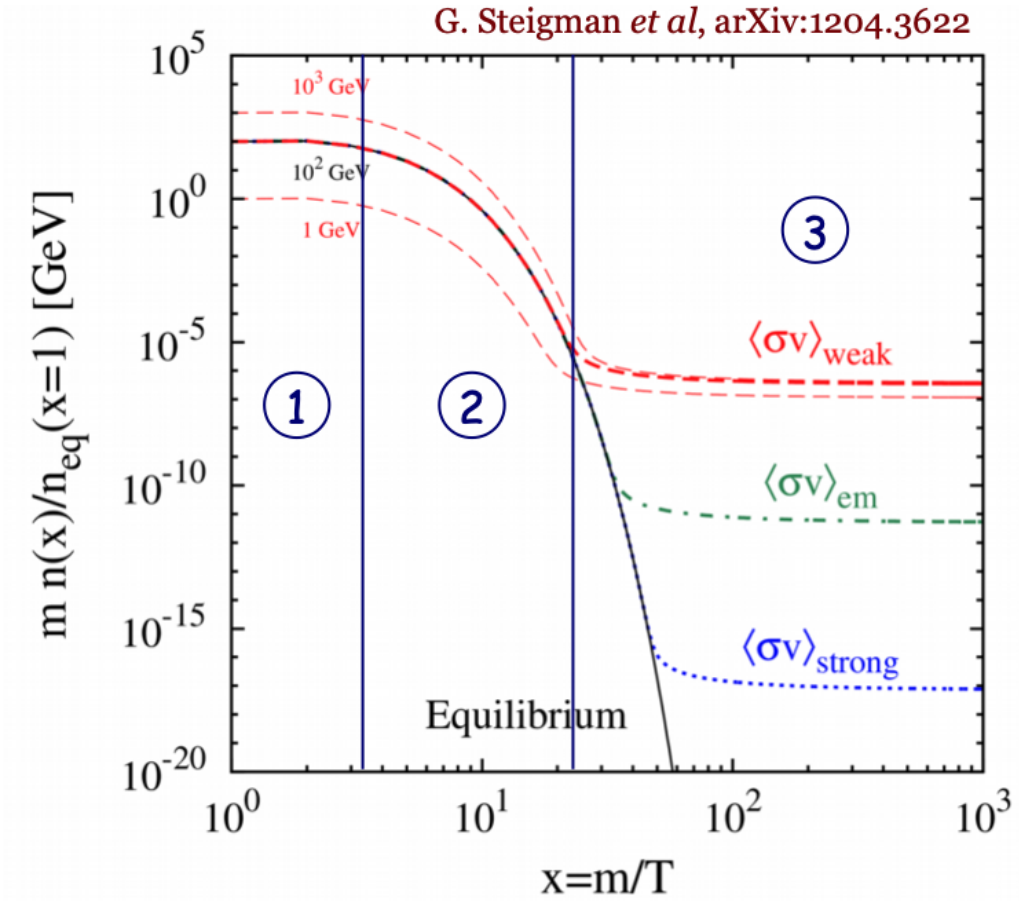


[G. Bertone and T. Tait, *Nature* **562**, 51 (2018)]

Standard Picture: Freeze-out



Physically:

1. DM + DM ↔ SM + SM efficient in both directions.
2. DM + DM ← SM + SM disfavoured.
3. $n_{DM} \langle\sigma v\rangle < H$: Equilibrium lost → Freeze-out.

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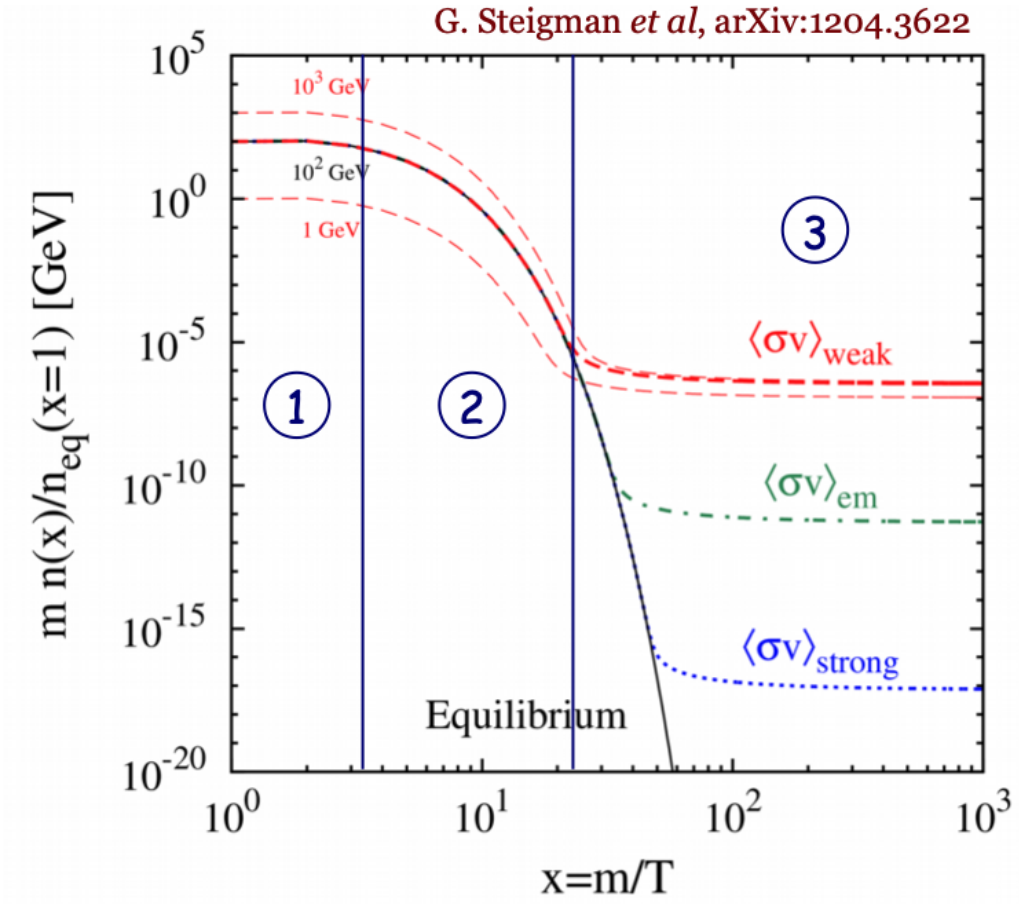

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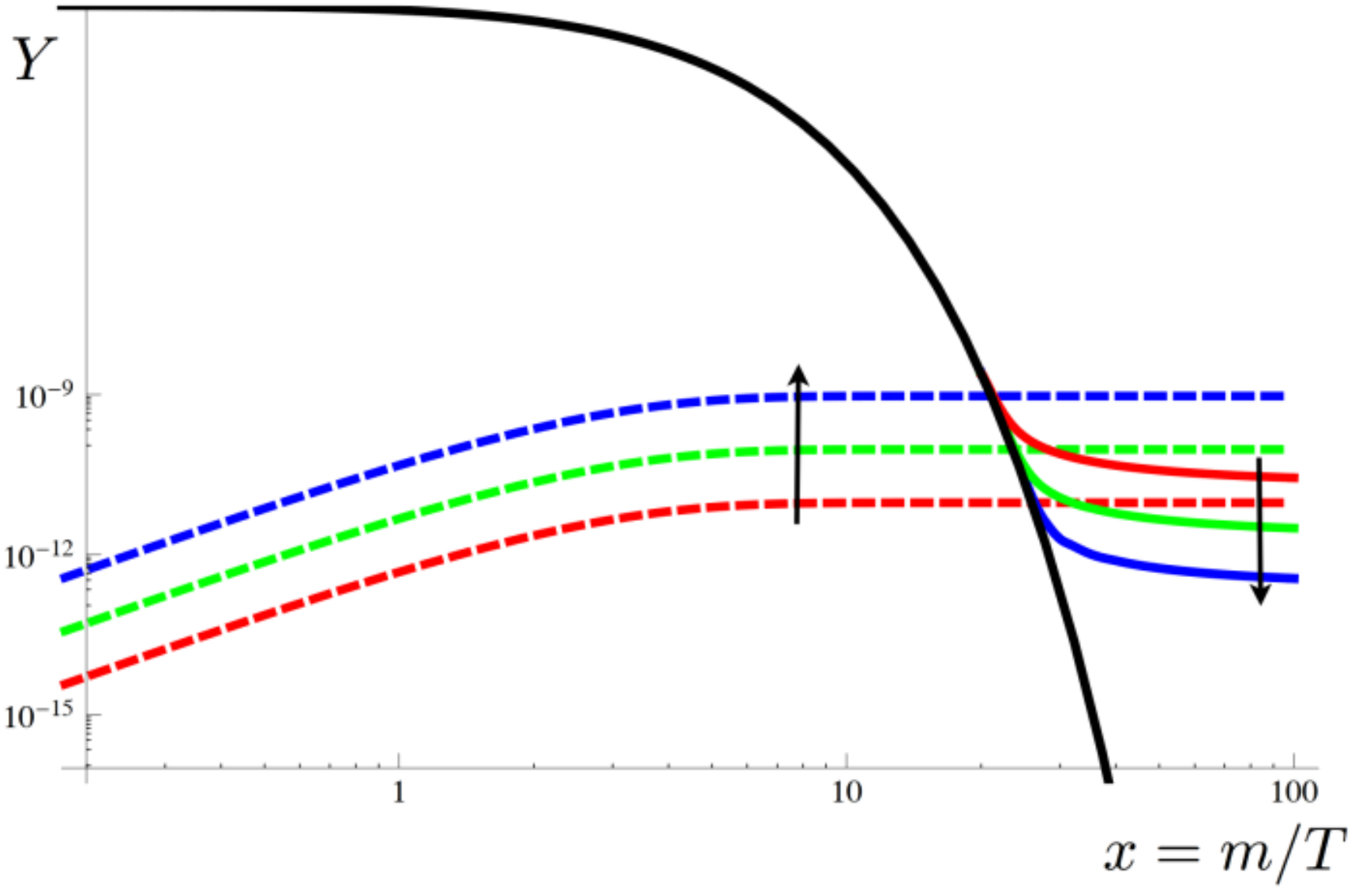
3. n_{DM} <σv> < H : Equilibrium lost → Freeze-out.

$\langle\sigma v\rangle = 2.2 \times 10^{-26}\ \mathrm{cm}^3\mathrm{s}^{-1}$ reproduces the observed $\Omega_\chi h^2 = 0.11$ for a wide range of m_χ.

"WIMP miracle"

Alternative Path: Freeze-in



[L. J. Hall, K. Jedamzik, J. March-Russell and S. M. West, 0911.1120]

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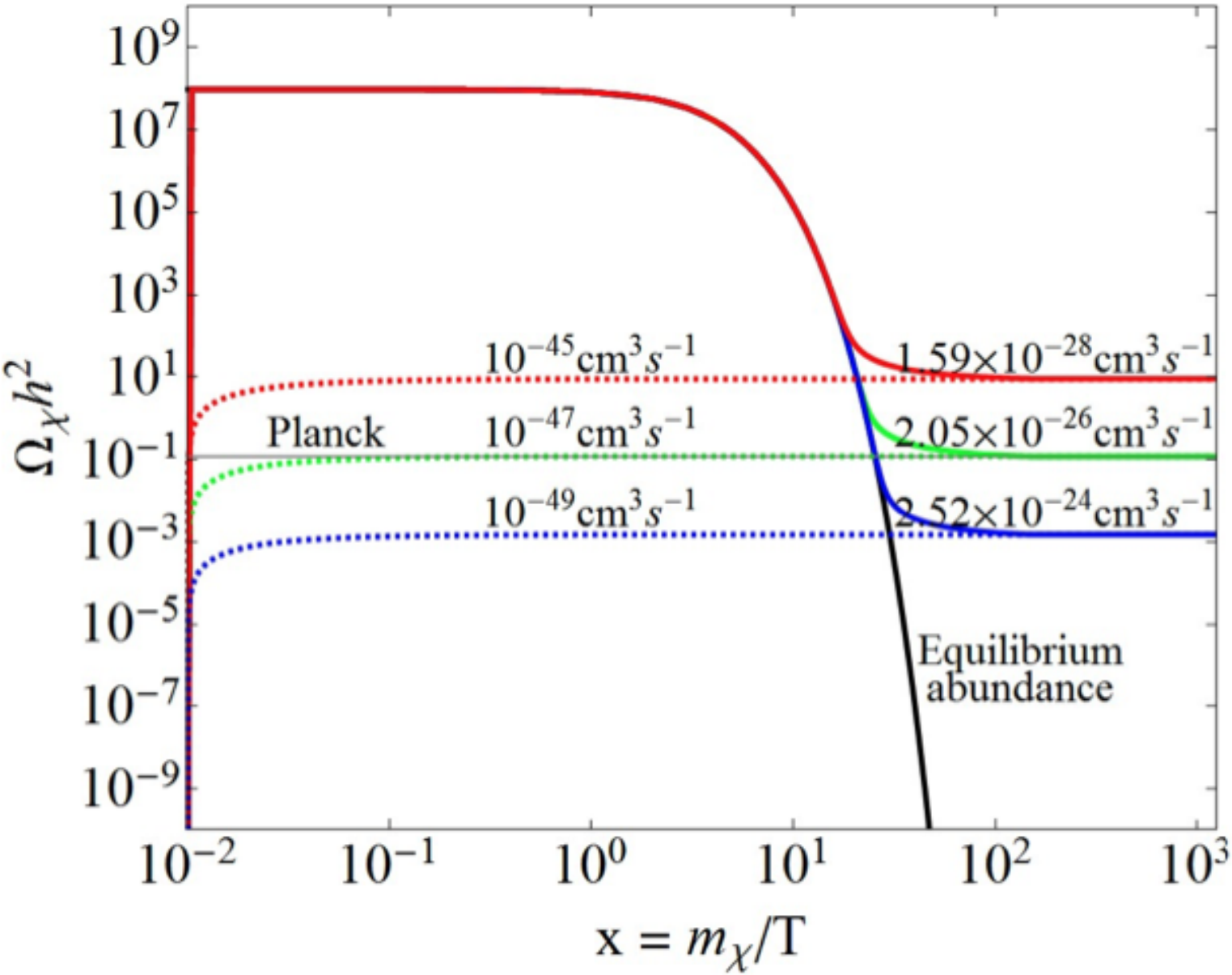
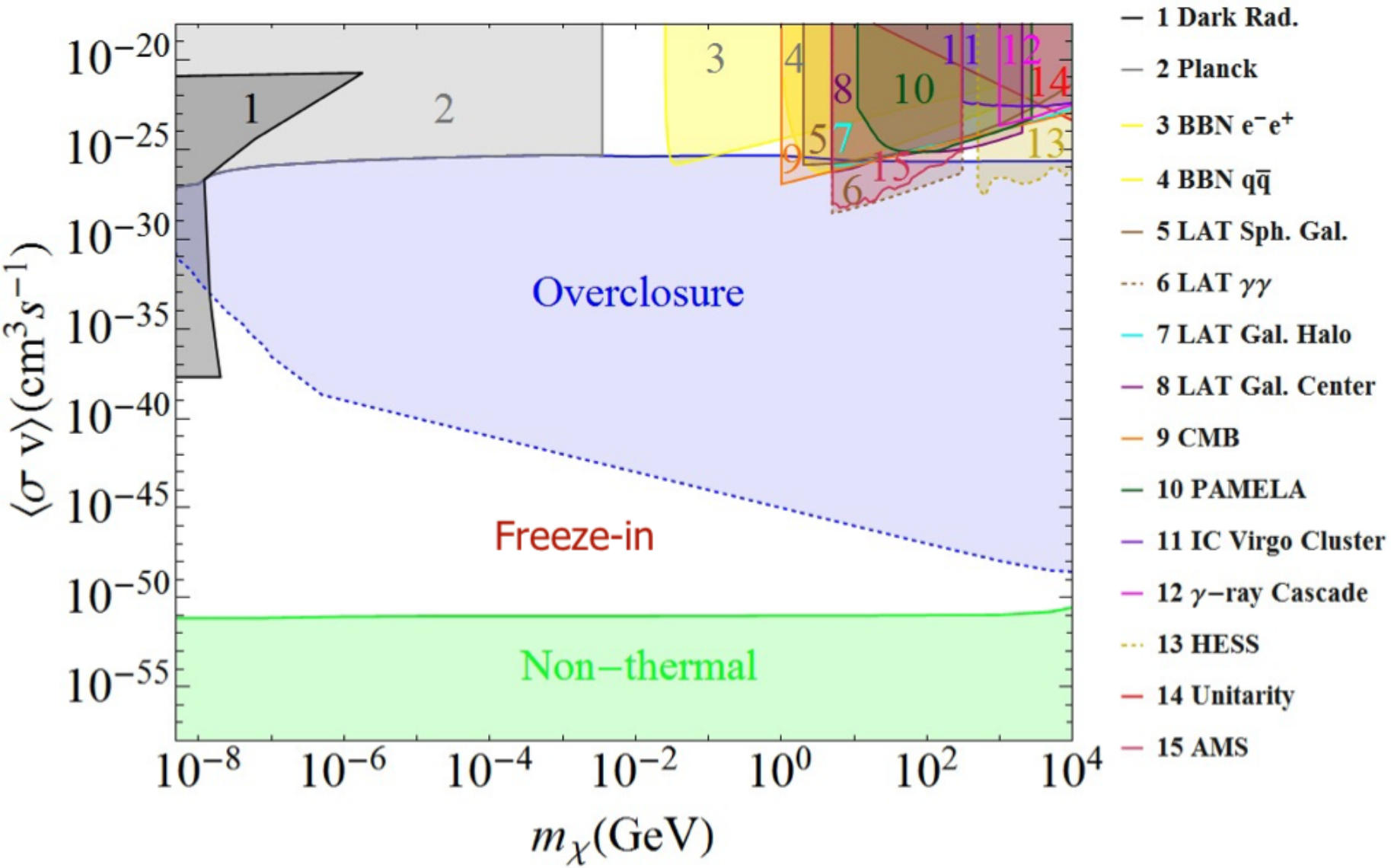


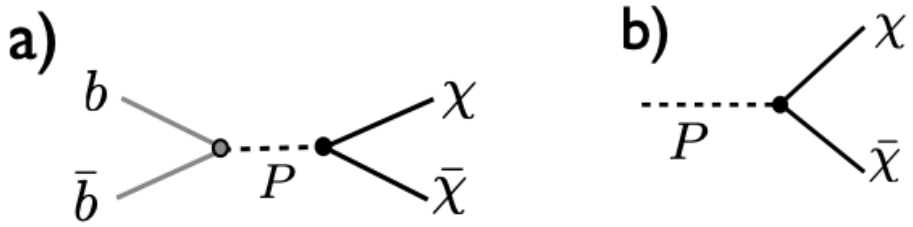
[BD, A. Mazumdar and S. Qutub, 1311.5297]

Can we probe Freeze-in?



[BD, A. Mazumdar and S. Qutub, 1311.5297]

Freeze-in through Portals

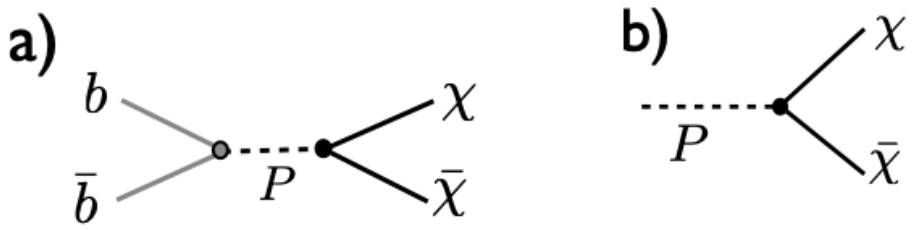


[M. Blennow, E. Fernandez-Martinez, B. Zaldivar, 1309.7348]

Three portals:

- Higgs portal [Silveira, Zee '85; De Romeri, Karamitros, Lebedev, Toma '20; Arcadi, Djouadi, Kado '21;...]
- Vector portal [Galison, Manohar '84; Holdom '86; Fitzpatrick, Liu, Slatyer, Tsai '20; ...]
- **Neutrino portal** [Pospelov, Ritz, Voloshin '07; Escudero, Rius, Sanz '16; Batell, Han, McKeen, Shams Es Haghi '17; Becker '18; Blennow et al '19; ...]

Freeze-in through Portals



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We will consider a **heavy neutrino portal**. Connects to several other phenomena:

- Neutrino mass
- Leptogenesis
- Charged lepton flavor violation

A Simple Model

Standard Model plus

- SM gauge-singlet RHNs N_i. Need at least two for neutrino mass generation at tree level.
- A gauge-singlet Majorana fermion χ, which is the dark matter candidate.
- A real singlet scalar φ which connects the DM to the RHN portal.

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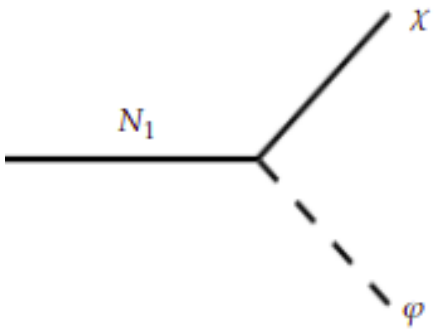
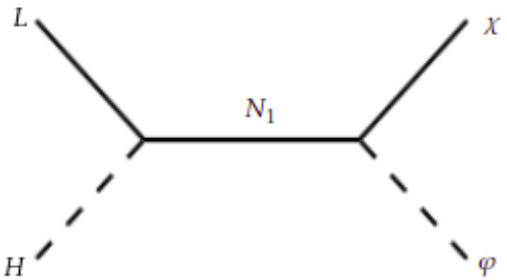
$$-\mathcal{L}_\nu = (Y_D)_{\alpha j}\, \overline{L}_\alpha\, H\, N_j + \frac{1}{2}(M_N)_{ij}\, \overline{N_i^c}\, N_j + \text{H.c.}$$

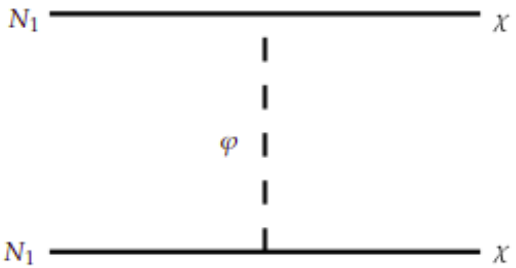
$$-\mathcal{L}_{\text{dark}} = y_\chi\, \overline{N^c}\, \varphi\, \chi + m_\chi\, \overline{\chi^c}\, \chi + \text{H.c.} + V(H, \varphi)$$

$$V(H,\varphi) = -\mu_H^2\, (H^\dagger H) + \lambda_H\, (H^\dagger H)^2 + \mu_\varphi^2\, \varphi^2 + \lambda_\varphi\, \varphi^4 + \lambda_{H\varphi}\, \varphi^2\, (H^\dagger H)\,.$$

Freeze-in Production of Dark Matter







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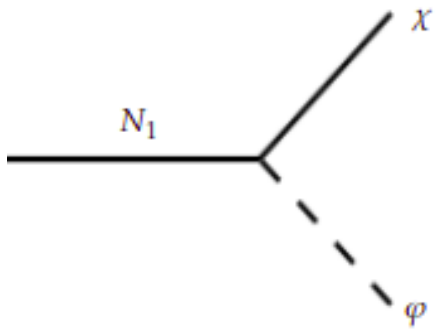
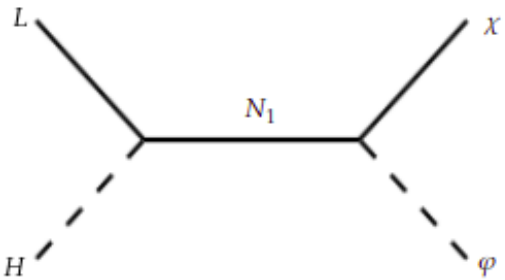


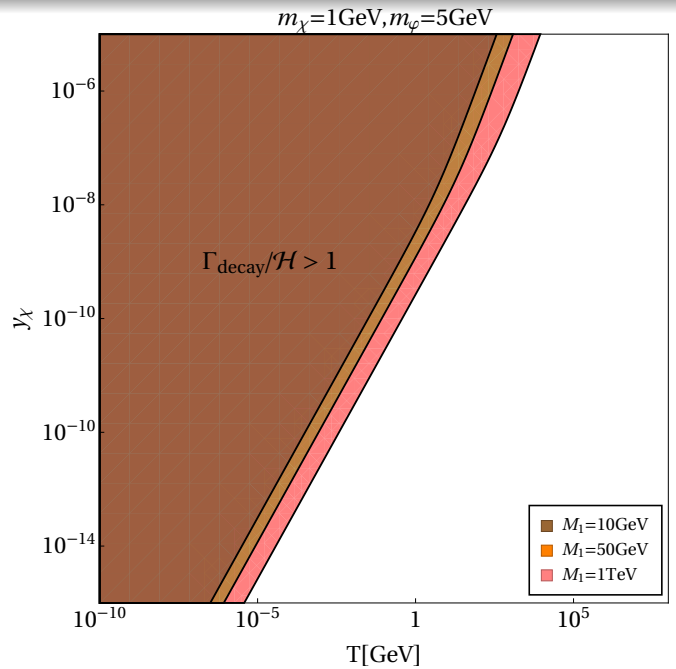


$$\boxed{x\,H\,s\,\frac{dY_\chi}{dx} = \gamma_{\text{ann}} + \gamma_{\text{decay}}}\,.$$

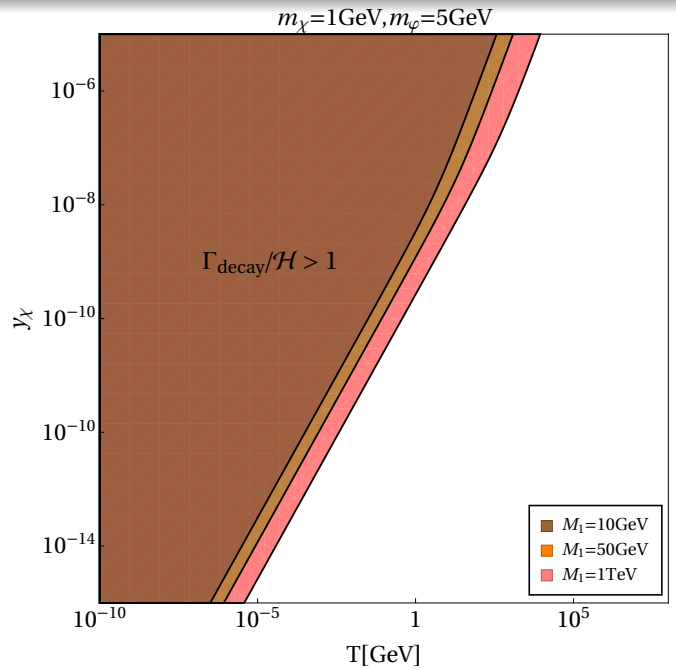
$$\gamma_{\text{decay}} = \frac{g_a}{2\,\pi^2}\,m_a^2\,\Gamma_{a\to 1,2}\,T\,K_1\left(\frac{m_a}{T}\right)$$

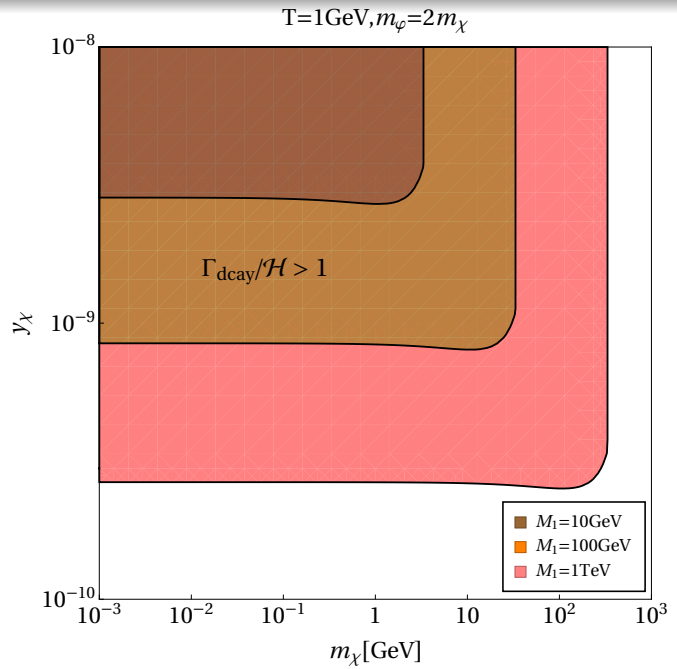
$$\gamma_{\text{ann}} = \frac{T}{32\pi^4}\,g_a g_b \int_{s_{\min}}^{\infty} ds\,\frac{\left[\left(s-m_a^2-m_b^2\right)^2 - 4m_a^2 m_b^2\right]}{\sqrt{s}}\,\sigma\left(s\right)_{a,b\to 1,2}\,K_1\left(\frac{\sqrt{s}}{T}\right)$$

Decay Case

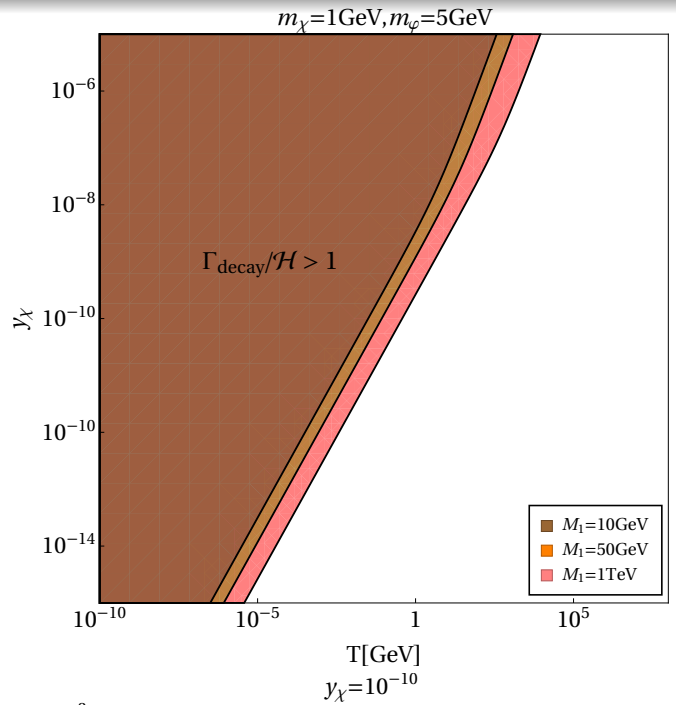

m_χ=1GeV, m_φ=5GeV
10^{-6}
10^{-8}
10^{-10}
10^{-10}
10^{-14}
Y_χ
$\Gamma_{\text{decay}}/\mathcal{H} > 1$
M_1=10GeV
M_1=50GeV
M_1=1TeV
10^{-10}
10^{-5}
1
10^{5}
T[GeV]

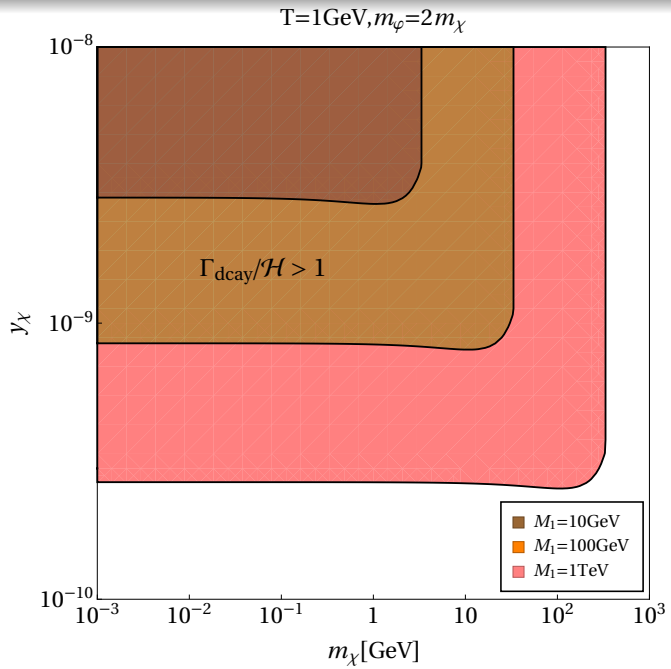
Decay Case

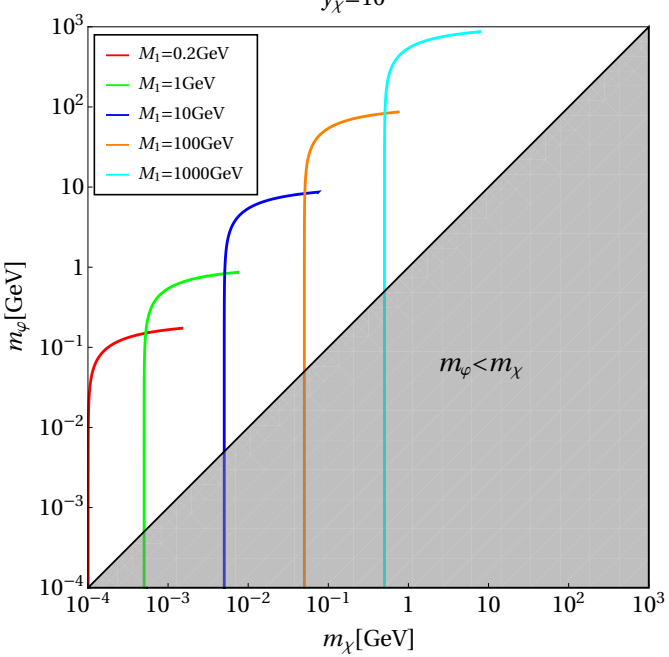

m_χ=1GeV, m_φ=5GeV
$\Gamma_{\rm decay}/\mathcal{H} > 1$
M_1=10GeV
M_1=50GeV
M_1=1TeV
y_χ
T[GeV]


T=1GeV, m_φ=2m_χ
$\Gamma_{\rm dcay}/\mathcal{H} > 1$
M_1=10GeV
M_1=100GeV
M_1=1TeV
y_χ
m_χ[GeV]

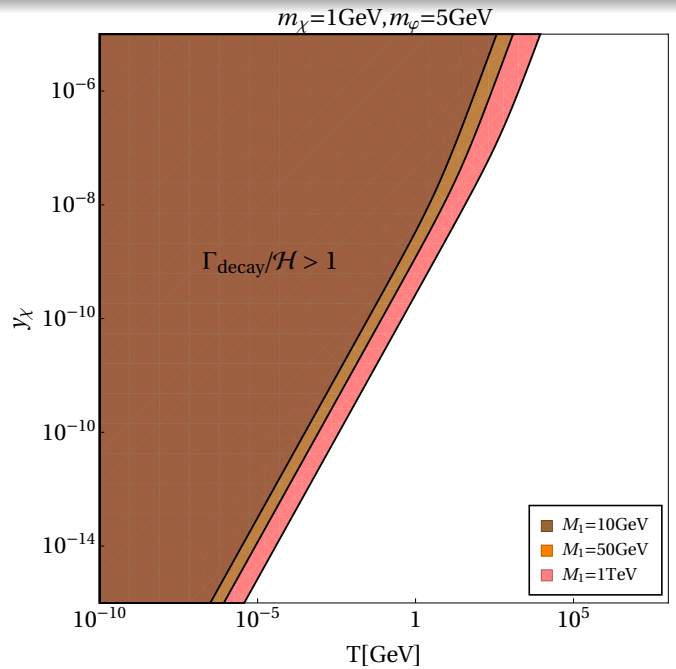
Decay Case

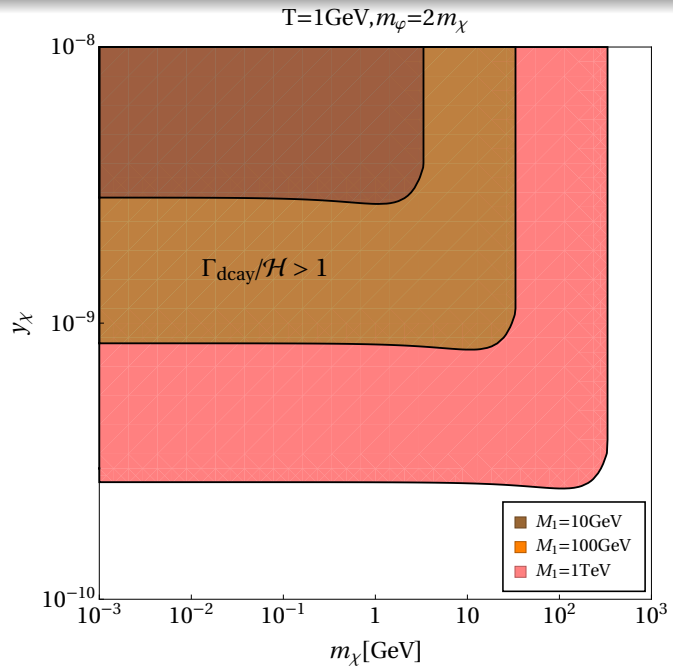

m_χ=1GeV, m_φ=5GeV
$\Gamma_{decay}/\mathcal{H} > 1$
M_1=10GeV
M_1=50GeV
M_1=1TeV
y_χ
T[GeV]

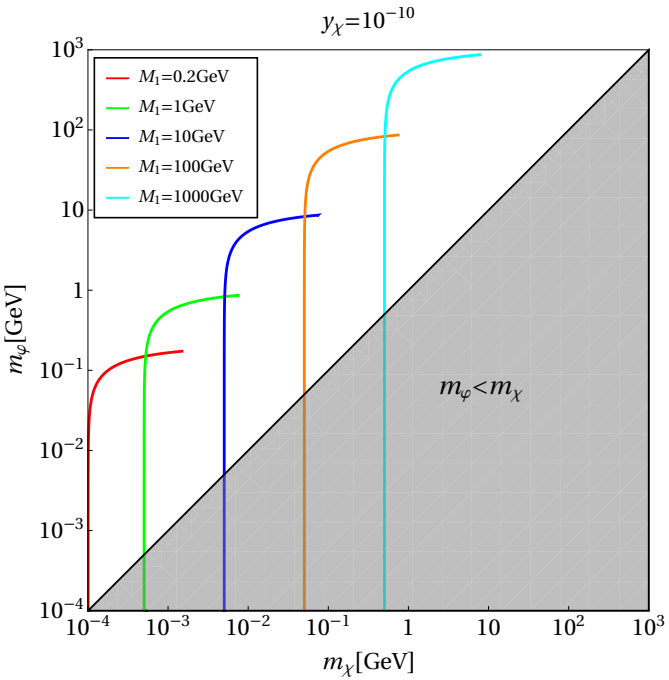

T=1GeV, m_φ=2m_χ
$\Gamma_{dcay}/\mathcal{H} > 1$
M_1=10GeV
M_1=100GeV
M_1=1TeV
y_χ
m_χ[GeV]

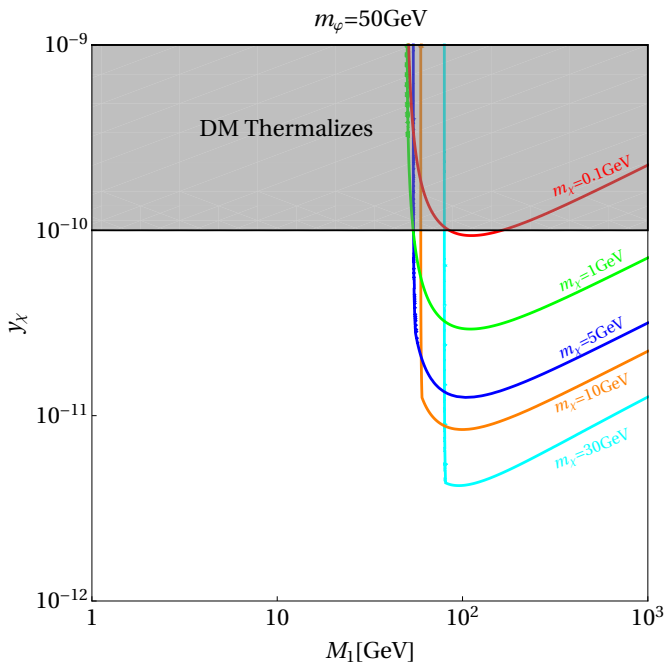

y_χ=10^{-10}
M_1=0.2GeV
M_1=1GeV
M_1=10GeV
M_1=100GeV
M_1=1000GeV
$m_\varphi < m_\chi$
m_φ[GeV]
m_χ[GeV]

Decay Case

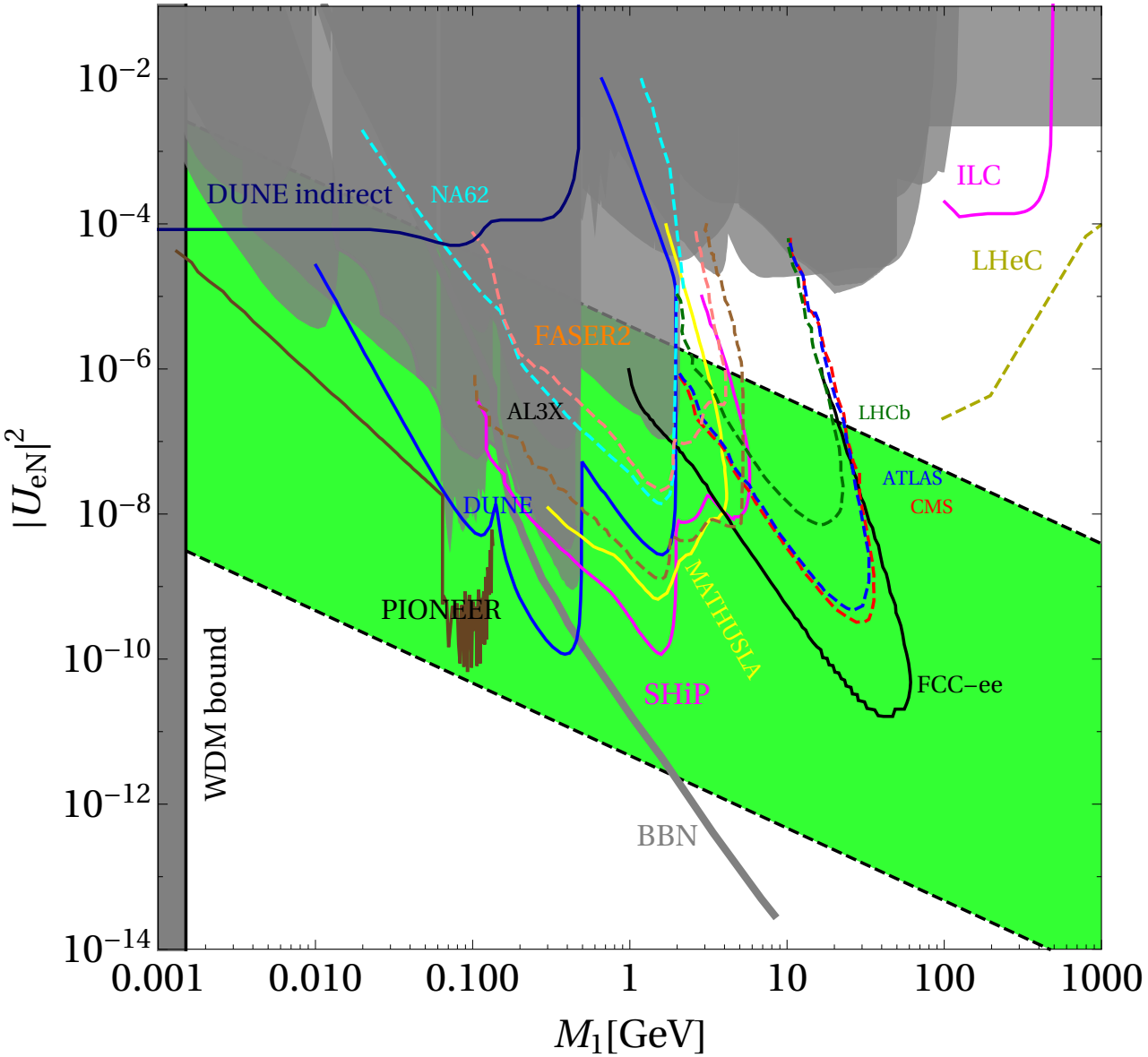

m_χ=1GeV, m_φ=5GeV
$\Gamma_{decay}/\mathcal{H} > 1$
M_1=10GeV
M_1=50GeV
M_1=1TeV
y_χ
T[GeV]


T=1GeV, $m_\varphi = 2m_\chi$
$\Gamma_{dcay}/\mathcal{H} > 1$
M_1=10GeV
M_1=100GeV
M_1=1TeV
y_χ
m_χ[GeV]


$y_\chi = 10^{-10}$
M_1=0.2GeV
M_1=1GeV
M_1=10GeV
M_1=100GeV
M_1=1000GeV
$m_\varphi < m_\chi$
m_φ[GeV]
m_χ[GeV]

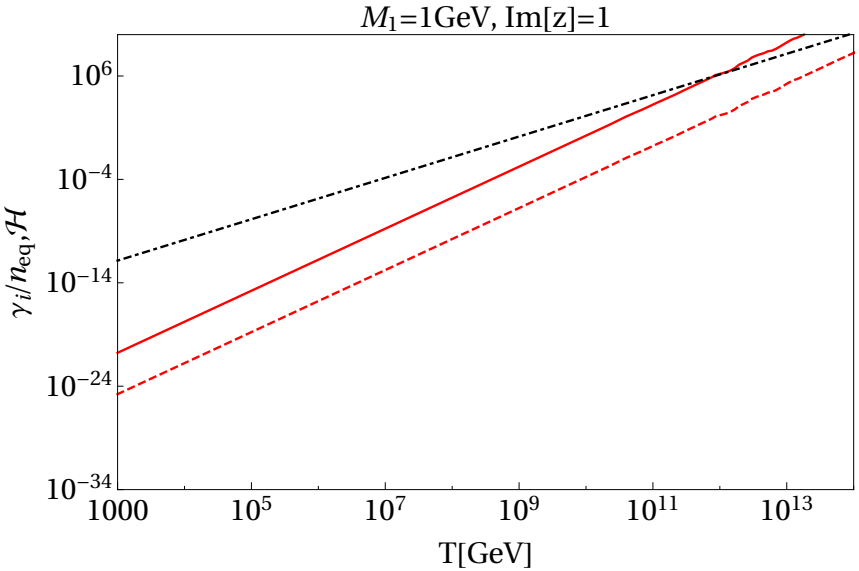

m_φ=50GeV
DM Thermalizes
m_χ=0.1GeV
m_χ=1GeV
m_χ=5GeV
m_χ=10GeV
m_χ=30GeV
y_χ
M_1[GeV]

Experimental Prospect



[For details of RHN experimental constraints and sensitivities, see e.g. 2203.08039 and 2206.01140]

Scattering Case



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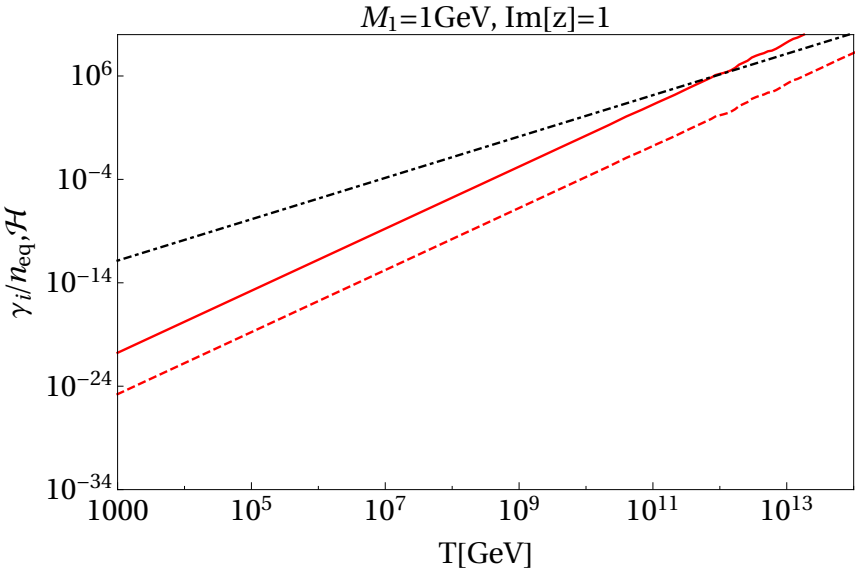

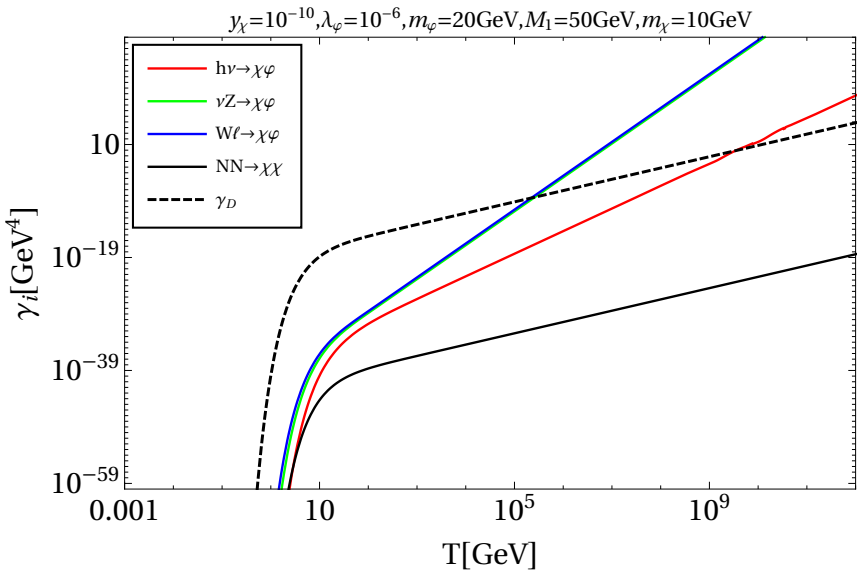

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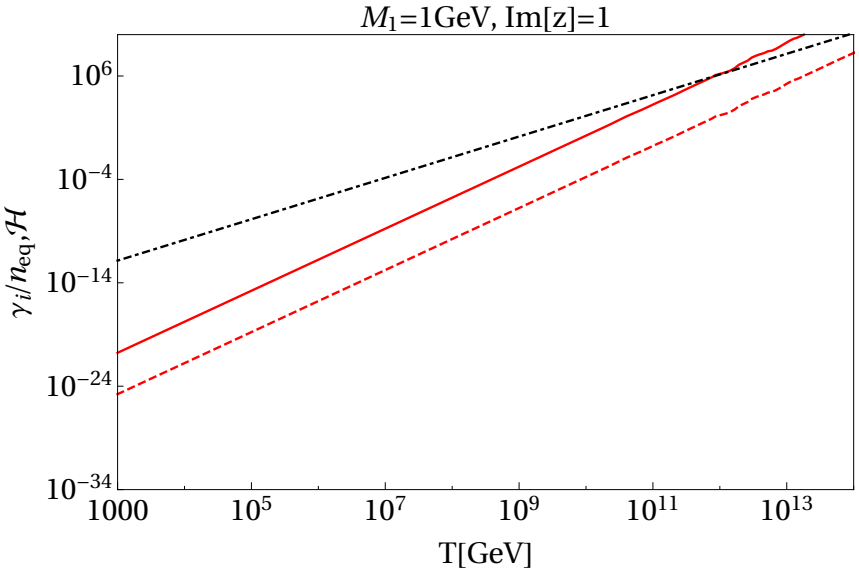
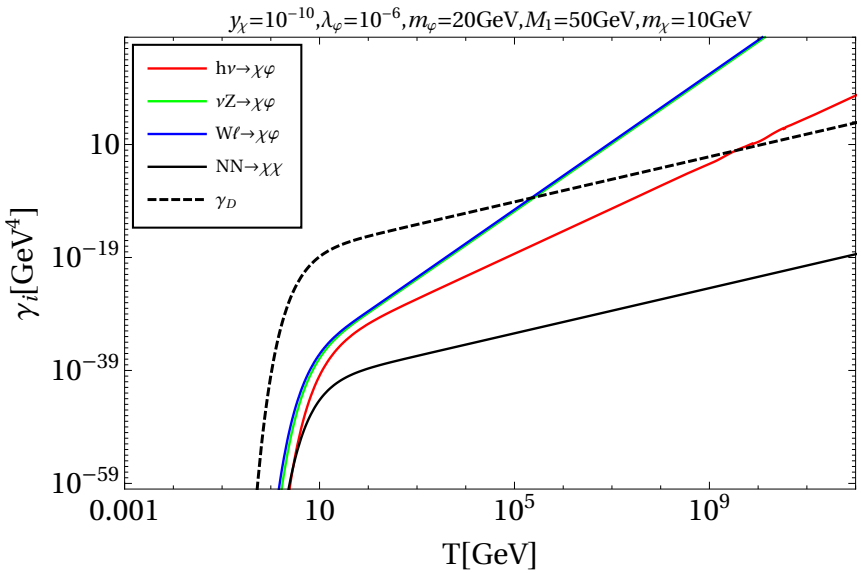
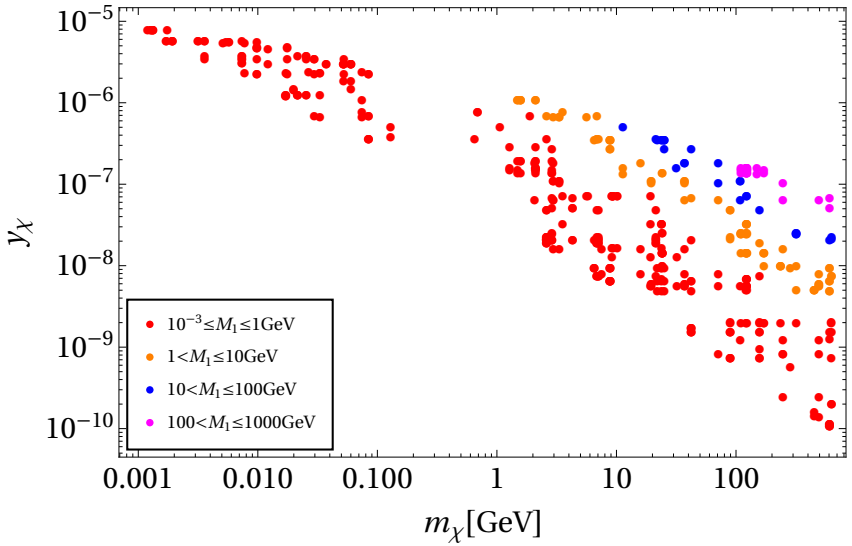
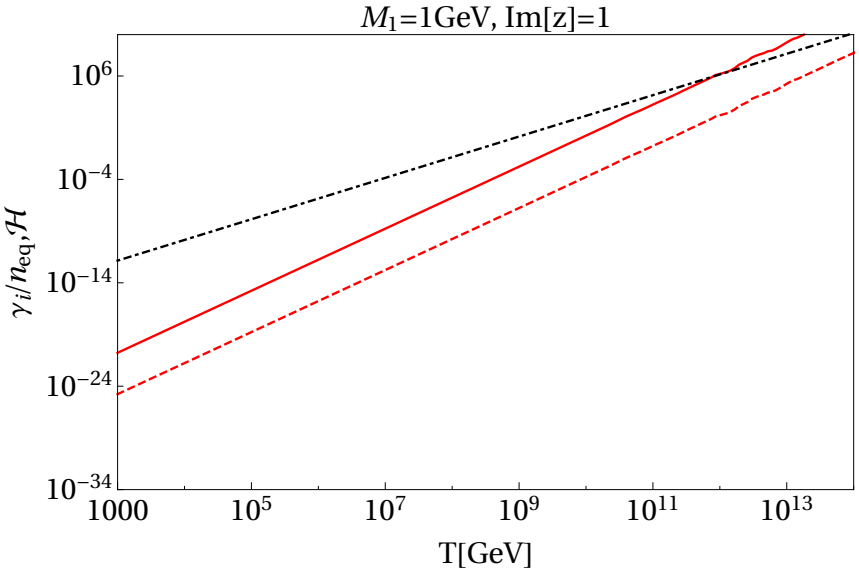
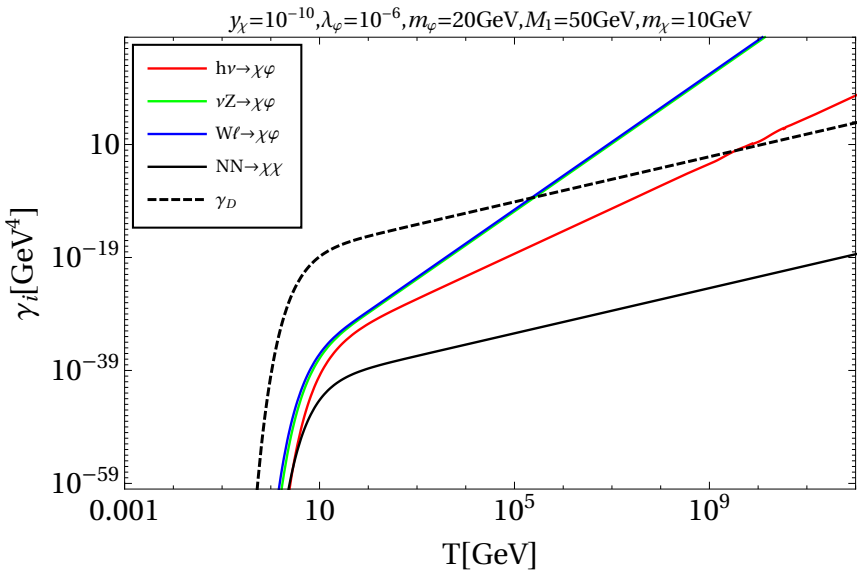


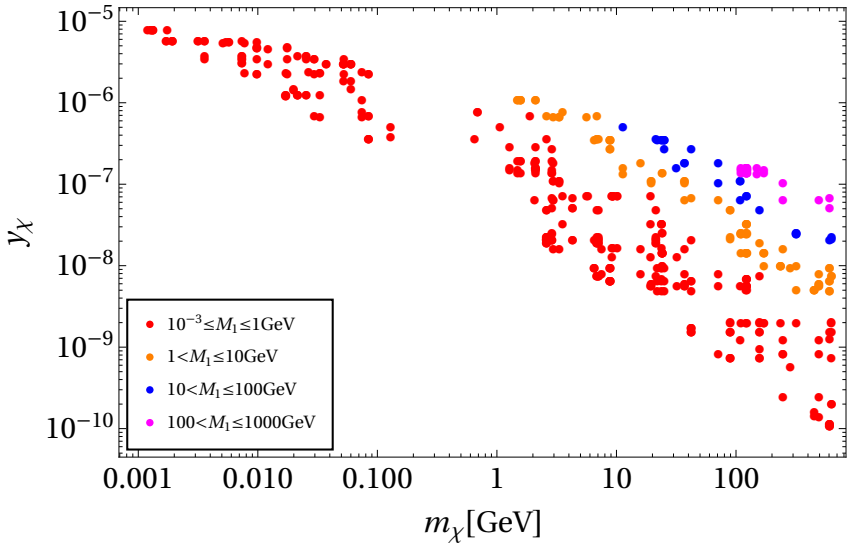


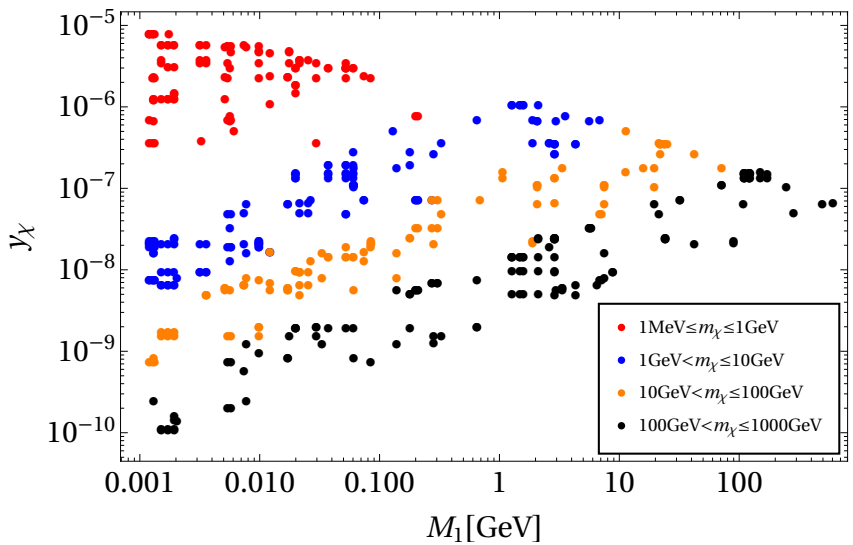


Scattering Case

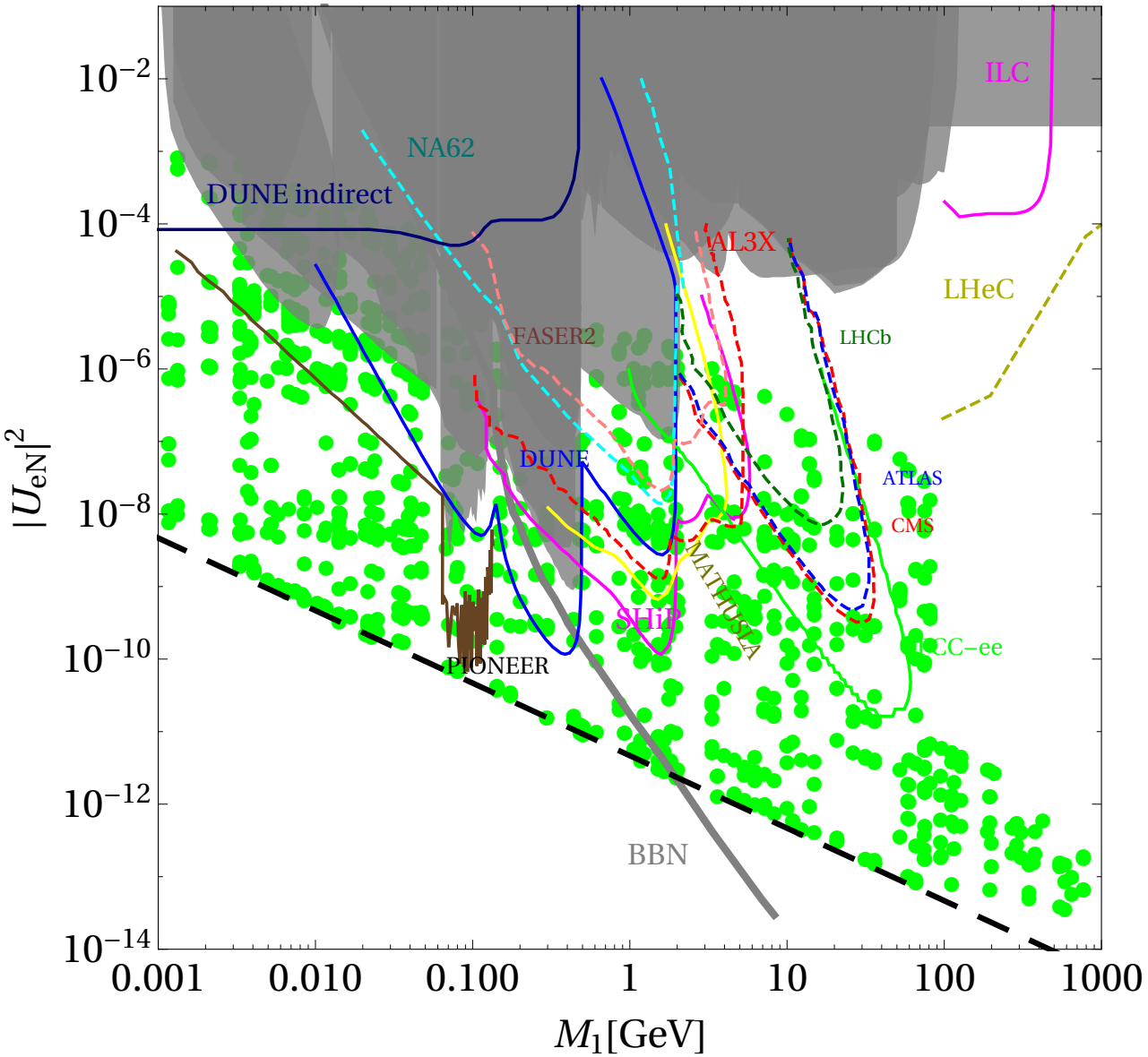






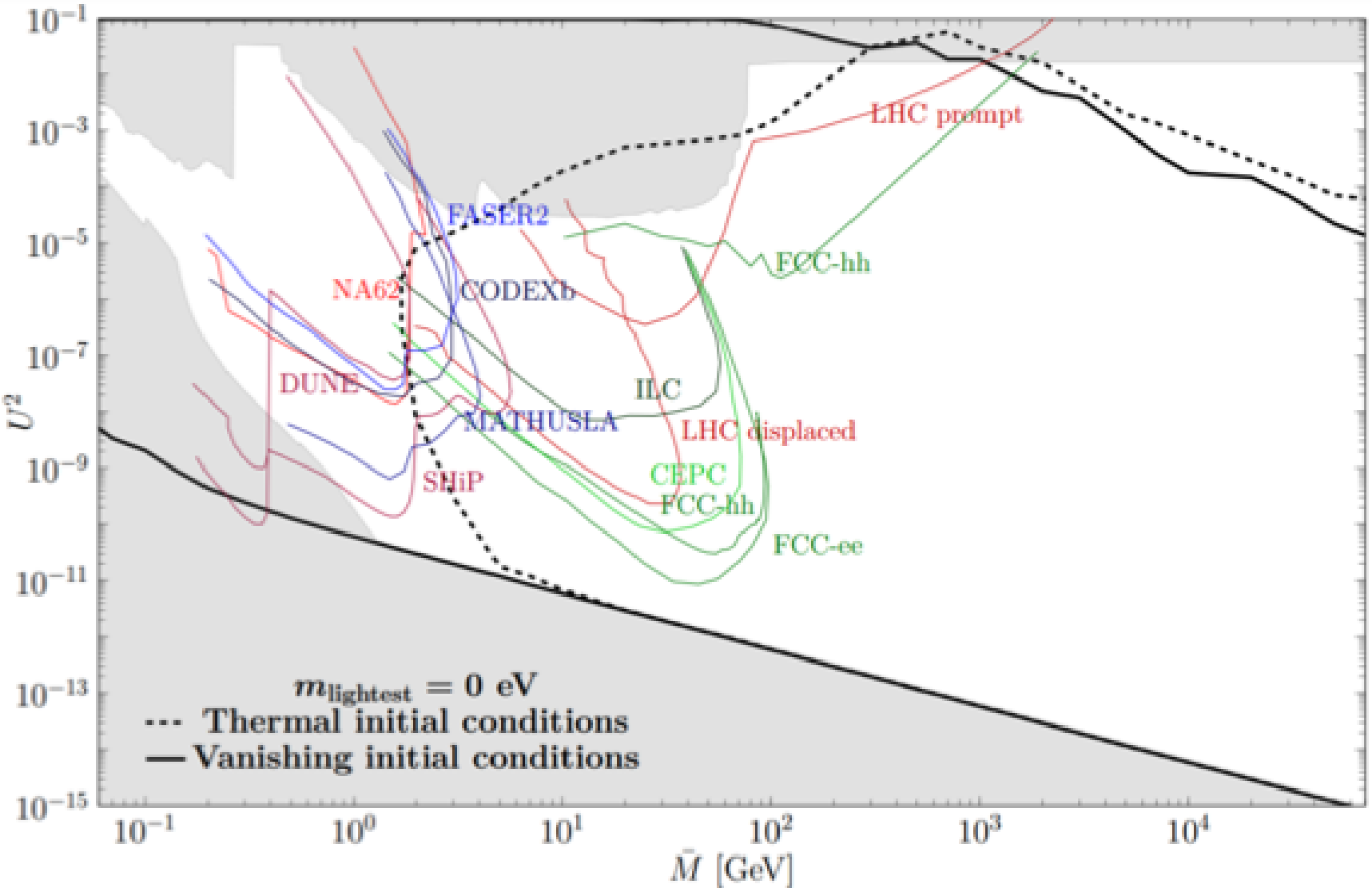


Experimental Prospect



[For details of RHN experimental constraints and sensitivities, see e.g. 2203.08039 and 2206.01140]

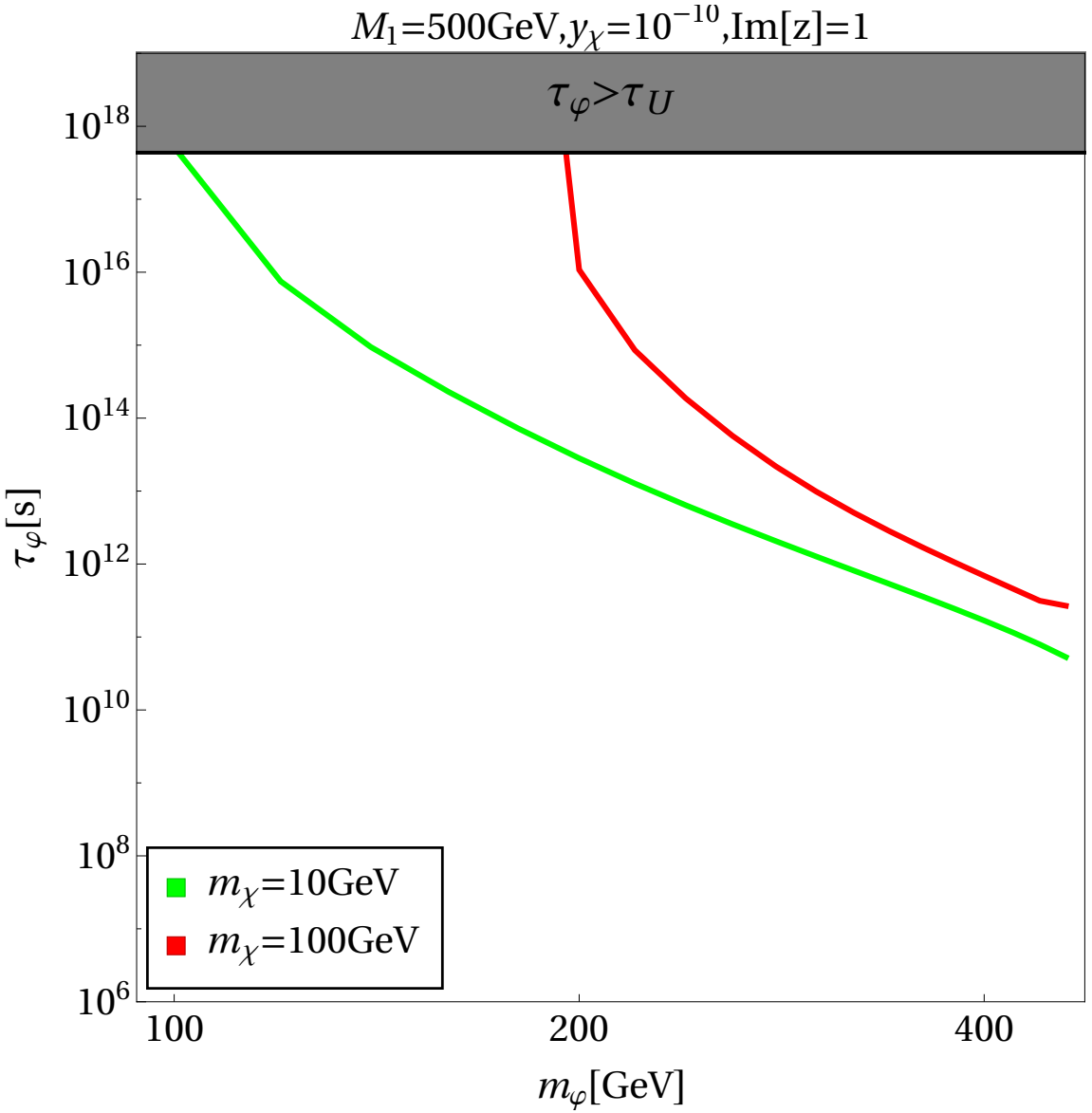
Leptogenesis



[M. Drewes, Y. Georis, and J. Klaric, 2106.16226]

What Happens to φ

$$\varphi \to N^* \chi \to L H^{(*)} \chi$$



Conclusion

- Freeze-in dark matter can be tested experimentally via its portal interactions.
- We studied a heavy neutrino portal scenario.
- Two possibilities for DM production: Decay and Scattering of heavy neutrinos.
- In the decay case, the DM Yukawa coupling $y_\chi \lesssim 10^{-10}$ for freeze-in to work.
- In the scattering case, $y_\chi \lesssim 10^{-7}$.
- In both cases, the correct relic density region falls within the future sensitivity for RHN searches.
- Also compatible with successful leptogenesis.