Thermal effects in νDM production

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IJCLab, Pôle Théorie

In collaboration with A. Abada, G. Arcadi, M. Lucente & G. Piazza, based on arXiv:2308.01341

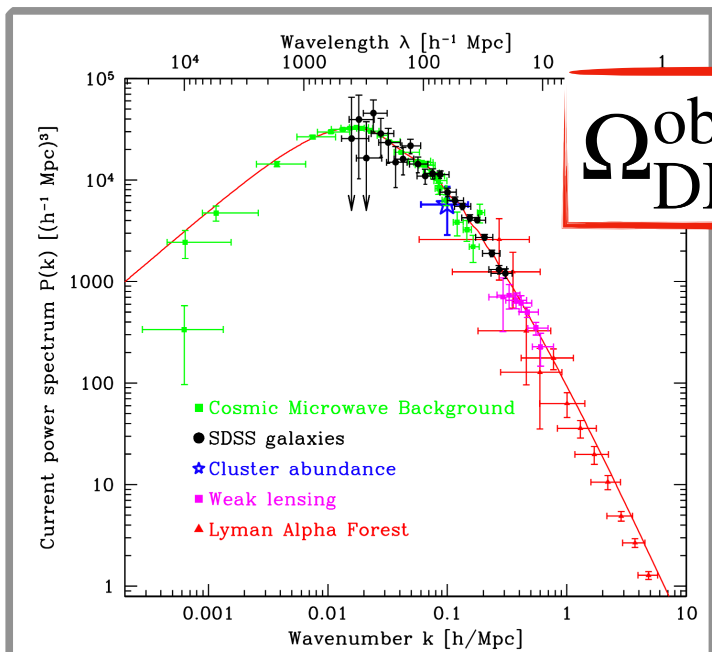
ICHEP 2024, Prague

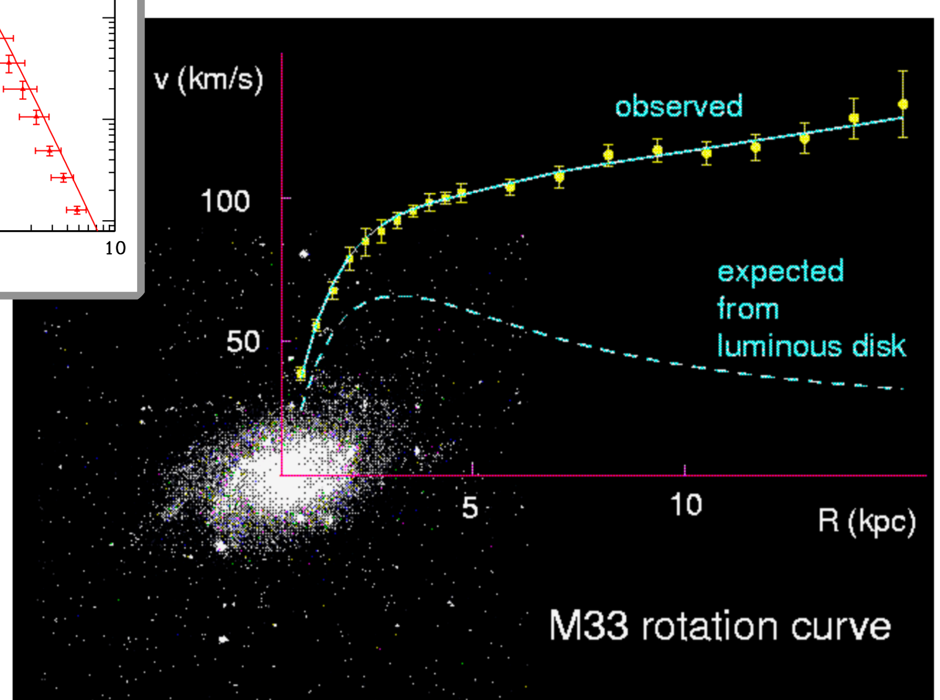
Introduction

Dark matter

Only gravitational probes

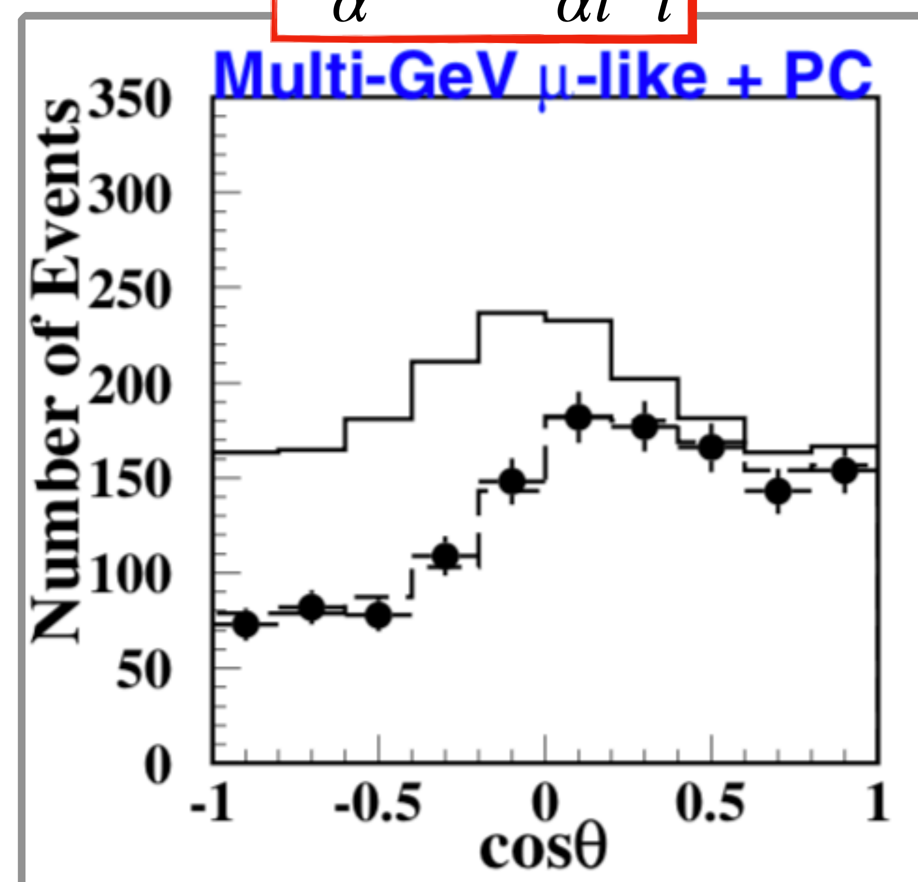
$$\Omega_{\rm DM}^{\rm obs} h^2 \simeq 0.12$$





Massive neutrinos

$$\nu_\alpha = U_{\alpha i}\nu_i$$



Super-Kamiokande Collaboration, arXiv: hep-ex/0105023

Massive neutrinos

Reminder of type-I seesaw

In the **SM** we only have left-handed ν

$$L_L = \begin{pmatrix} \nu_L \\ \ell_L \end{pmatrix}$$

We can just do as for any other SM fermion,
add the right-handed counterpart

N_R

Complete SM singlet!

$$\mathscr{L} \supset -\bar{L}_L Y_\nu \tilde{H} N_R - \frac{1}{2}\bar{N}_R^c M N_R + h.c.$$

P. Minkowski, Phys. Lett. B (1977)
R. N. Mohapatra & G. Senjanovic, Phys. Rev. Lett (1980)
T. Yanagida, Conf. Proc C7902131 (1979)
M. Gell-Mann *et al. Conf. Proc C790927 (1979)*

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Need at least **2** N_R to explain **oscillation data**

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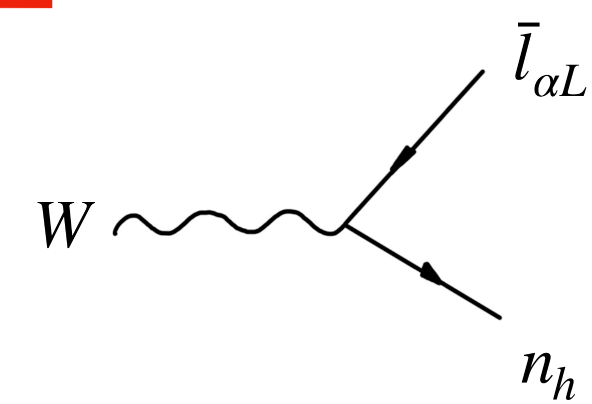
Relation between
flavor and **mass basis**

$$\nu_{\alpha L} = \tilde{U}_{\alpha i} P_L \nu_i + \theta_{\alpha h} P_L n_h$$



Massive neutrinos

Neutrino dark matter

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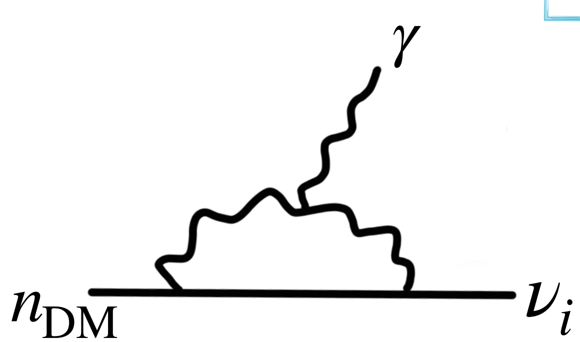


$$\propto \left|\theta_{\alpha \rm DM}\right|^2$$

Unstable DM candidate: $\tau_{\rm DM} > \tau_{\rm Universe}$

Assume $M \sim \mathcal{O}\left(\rm keV\right)$: **Monochromatic X-ray** signal as smoking gun

Not observed→**Set bounds** on $\left|\theta_{\alpha \rm DM}\right|$

Neutrino dark matter

Production mechanism: at $T \lesssim 1\,\mathrm{GeV}$

- Dodelson-Widrow mechanism

S. Dodelson & L. Widrow, arXiv: hep-ph/9303287

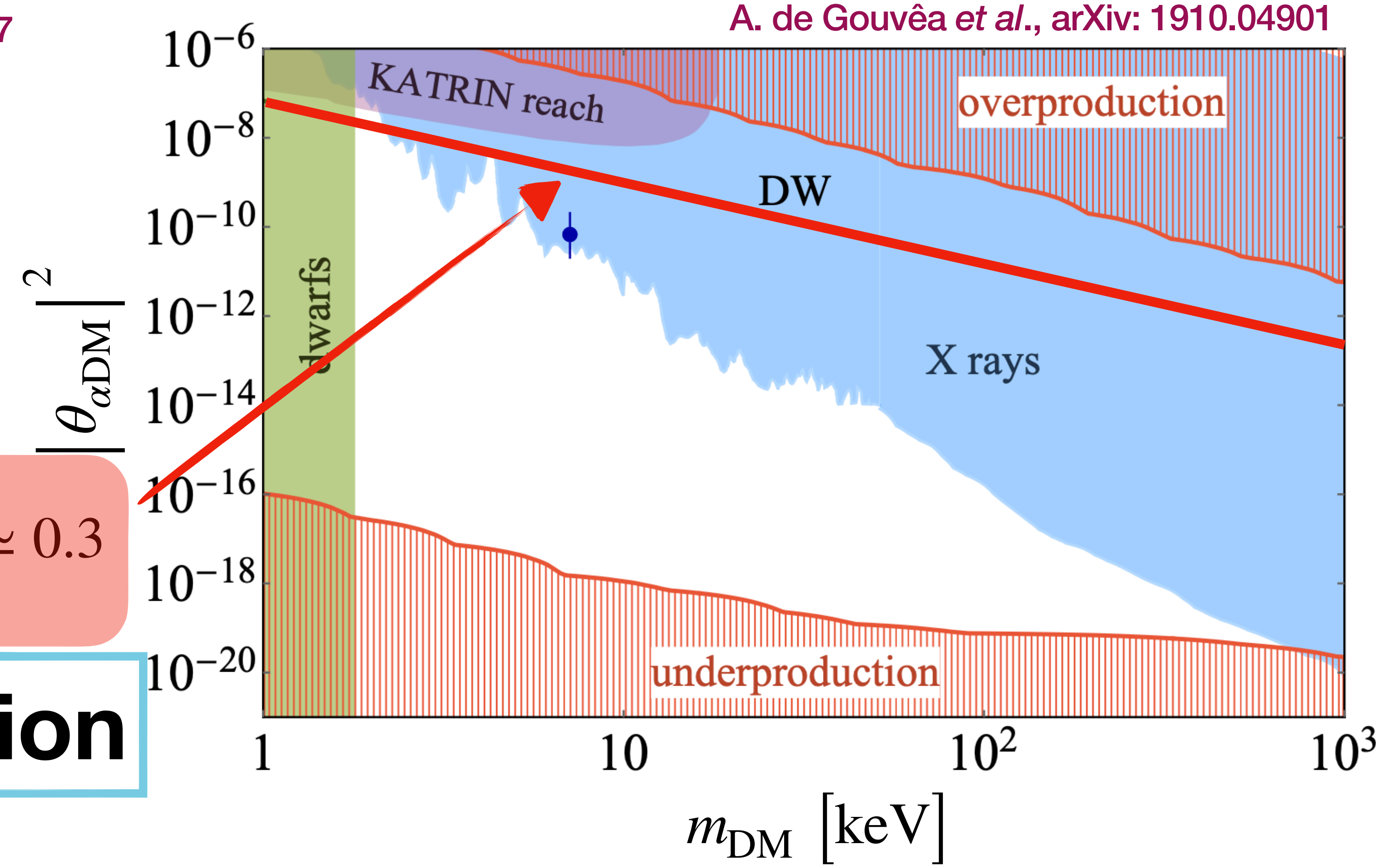
DM abundance from ν oscillations and collisions in the plasma

$$\Omega_{\rm DM}h^2 \propto \left|\theta_{\alpha \rm DM}\right|^2 m_{\rm DM}$$

At most it can produce $f_{\rm DM} = \frac{\Omega_{\rm DM}h^2}{\Omega^{\rm obs}_{\rm DM}h^2} \simeq 0.3$

Irreducible contribution

A. de Gouvêa *et al.*, arXiv: 1910.04901



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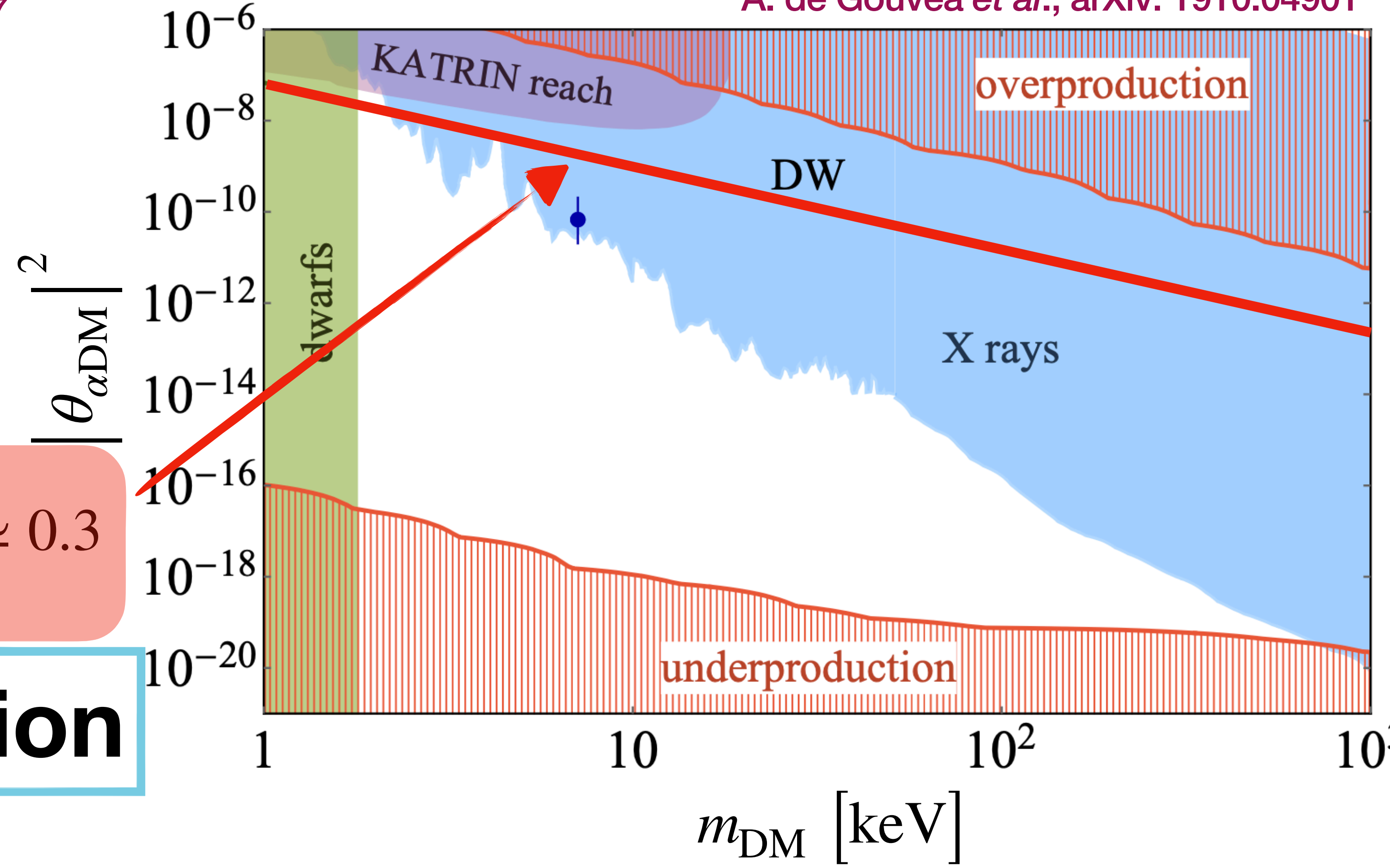

Irreducible contribution

- Shi-Fuller mechanism

X. Shi & G. Fuller, arXiv: astro-ph/9810076

Rely on a large lepton asymmetry to resonantly produce DM

Neutrino dark matter

Production mechanism: at $T \simeq 100\,\mathrm{GeV}$

Consider two body decays

$$\left.\begin{array}{l} Z(W) \to \nu_i(\ell_\alpha) + n_{\mathrm{DM}} \\ h \to \nu_i + n_{\mathrm{DM}} \\ n_h \to h(Z) + n_{\mathrm{DM}} \end{array}\right\} \quad \Gamma_s \propto \left|\theta_{\alpha\mathrm{DM}}\right|^2 \ll H$$

Heavy neutrino necessary to account for oscillation data

A. Abada et al., arXiv:1406.6556
D. Boyanovsky & L. Lello, arXiv:1508.04077
M. Lucente, arXiv:2103.03253
A. Datta et al., arXiv:2104.02030
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Freeze-in production

DM never reaches equilibrium

$$\frac{df_{\mathrm{DM}}}{dt} = \Gamma_s(p,t)\left[f^{\mathrm{eq}}_{\mathrm{DM}}(p,t) - f_{\mathrm{DM}}(p,t)\right]$$

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$$
\Omega_{\rm DM} h^2 \propto \frac{m_{\rm DM}\Gamma_s(A \to B + DM)}{m_A^2}
$$

$A = Z, W, h, n_h$

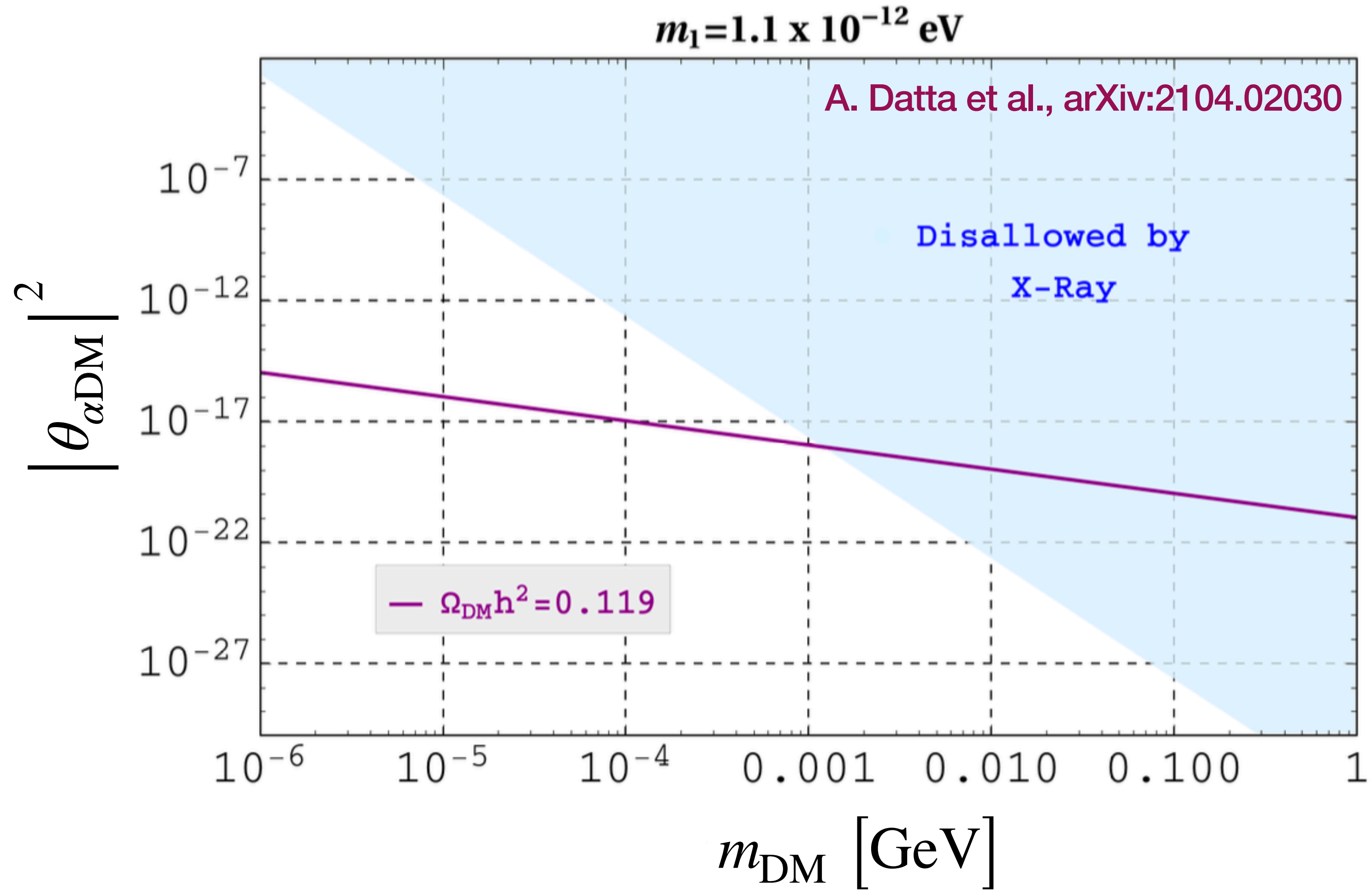
Neutrino dark matter

Freeze-in production: Gauge boson decay

Consider the production through gauge boson decays

In vacuum

$$\Gamma_s \sim G_F M_{Z(W)}^3 \left|\theta_{\alpha \mathrm{DM}}\right|^2$$



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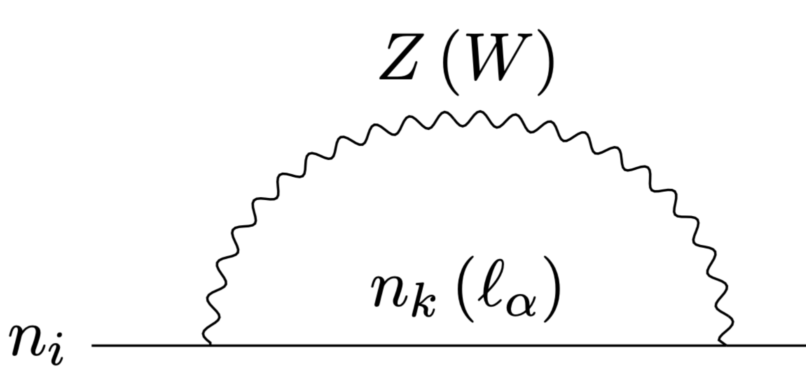
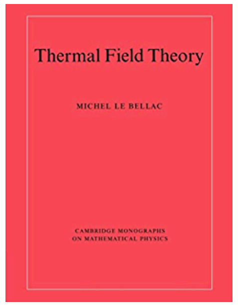
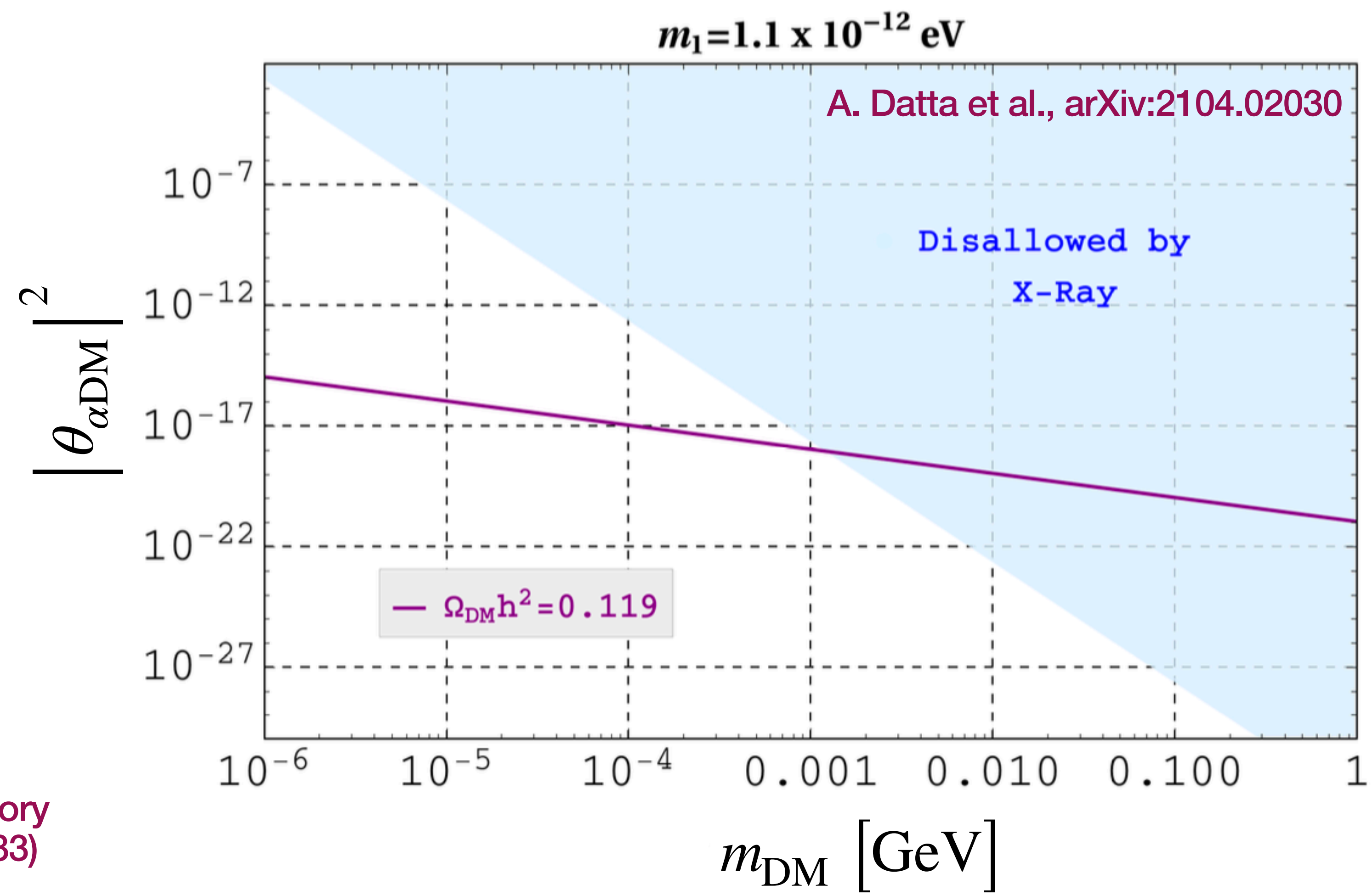
However at $T \sim 100\,\mathrm{GeV}$ thermal effects need to be taken into account

Le Bellac, Thermal Field Theory
H. Weldon, Phys. Rev. D (1983)







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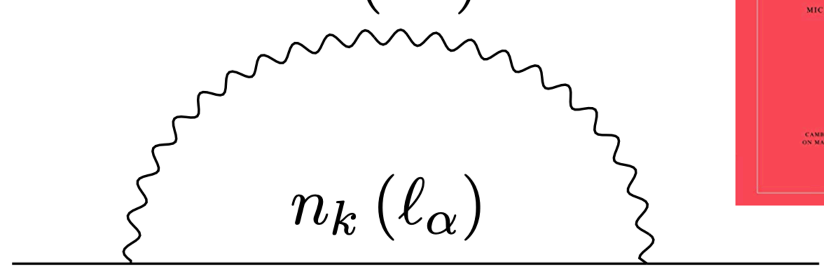

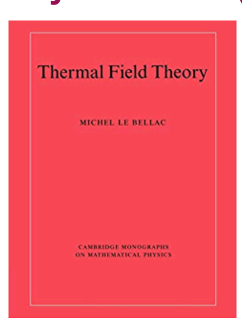

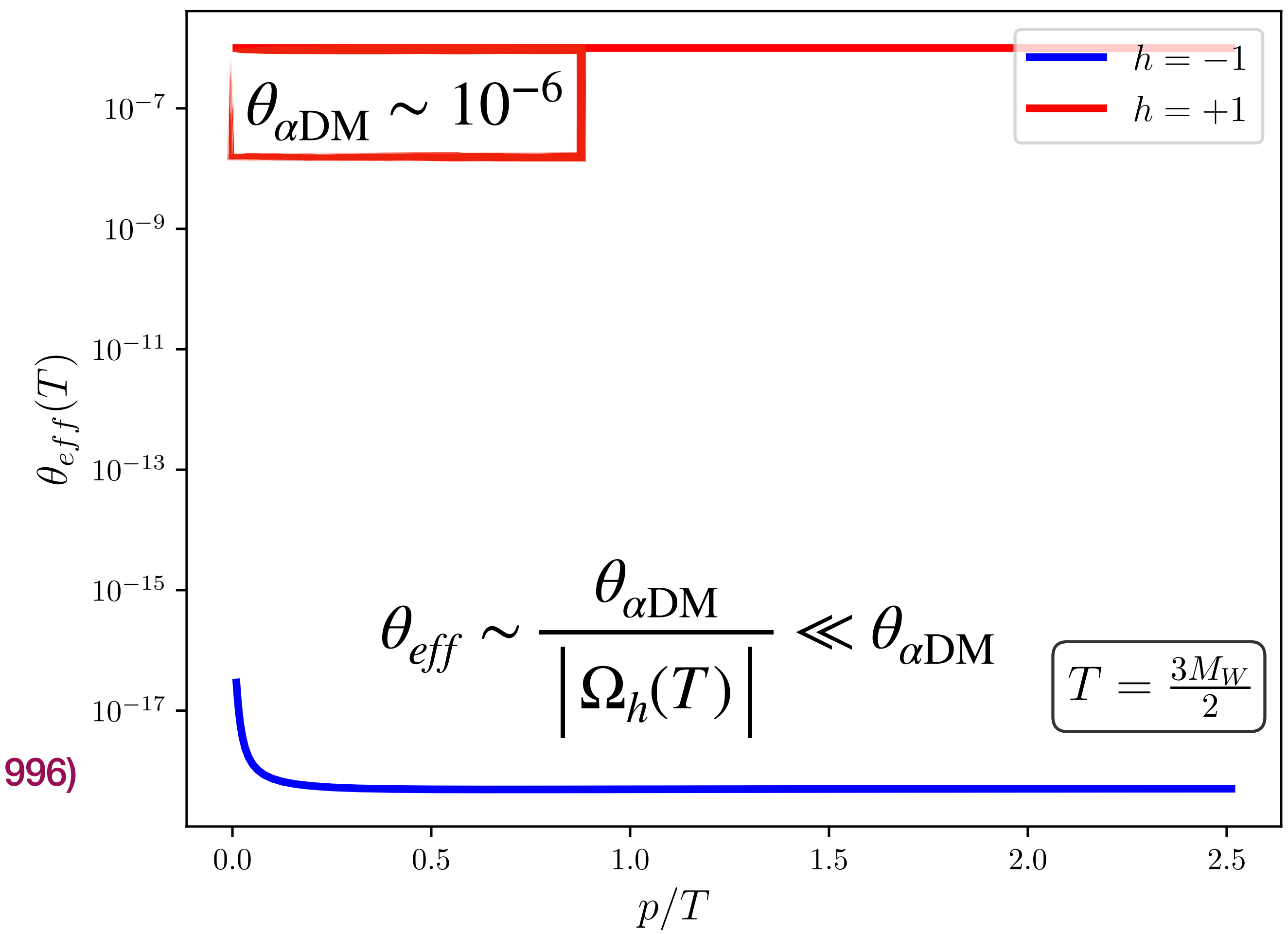

$f_{\mathrm{DM}} \sim 0$ from $Z\,(W)$ decays

D. Boyanovsky et al., arXiv:1609.07647
A. Abada, G. Arcadi, G. Piazza, M. Lucente & **SRA**, arXiv:2308.01341

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Freeze-in production: Heavy neutrino decay

Consider the production through $n_h \to h + n_{\rm DM}$

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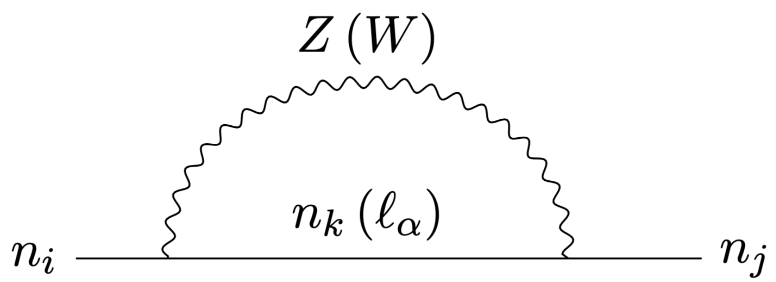

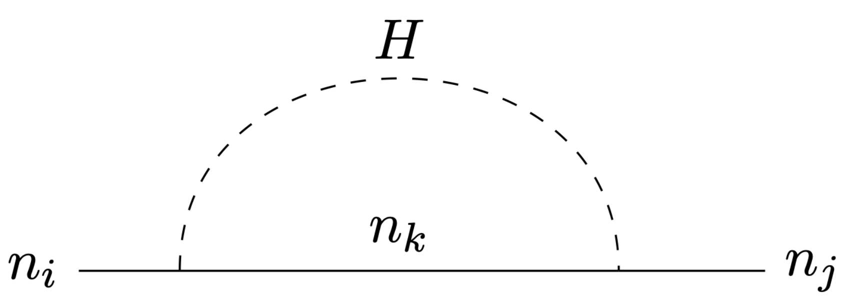

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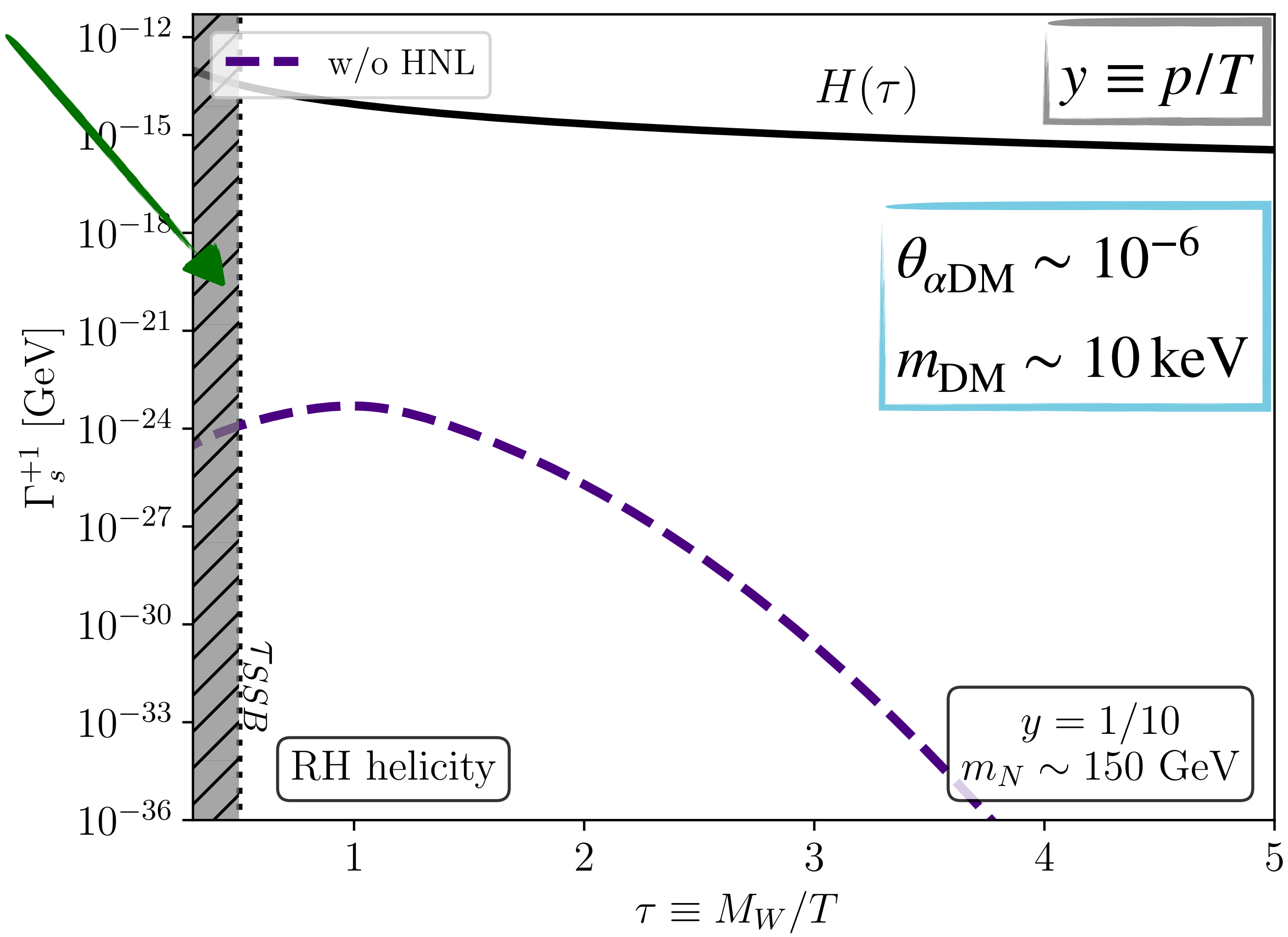
This channel is only viable if $v_H \neq 0 \to T \lesssim 160\,\mathrm{GeV}$



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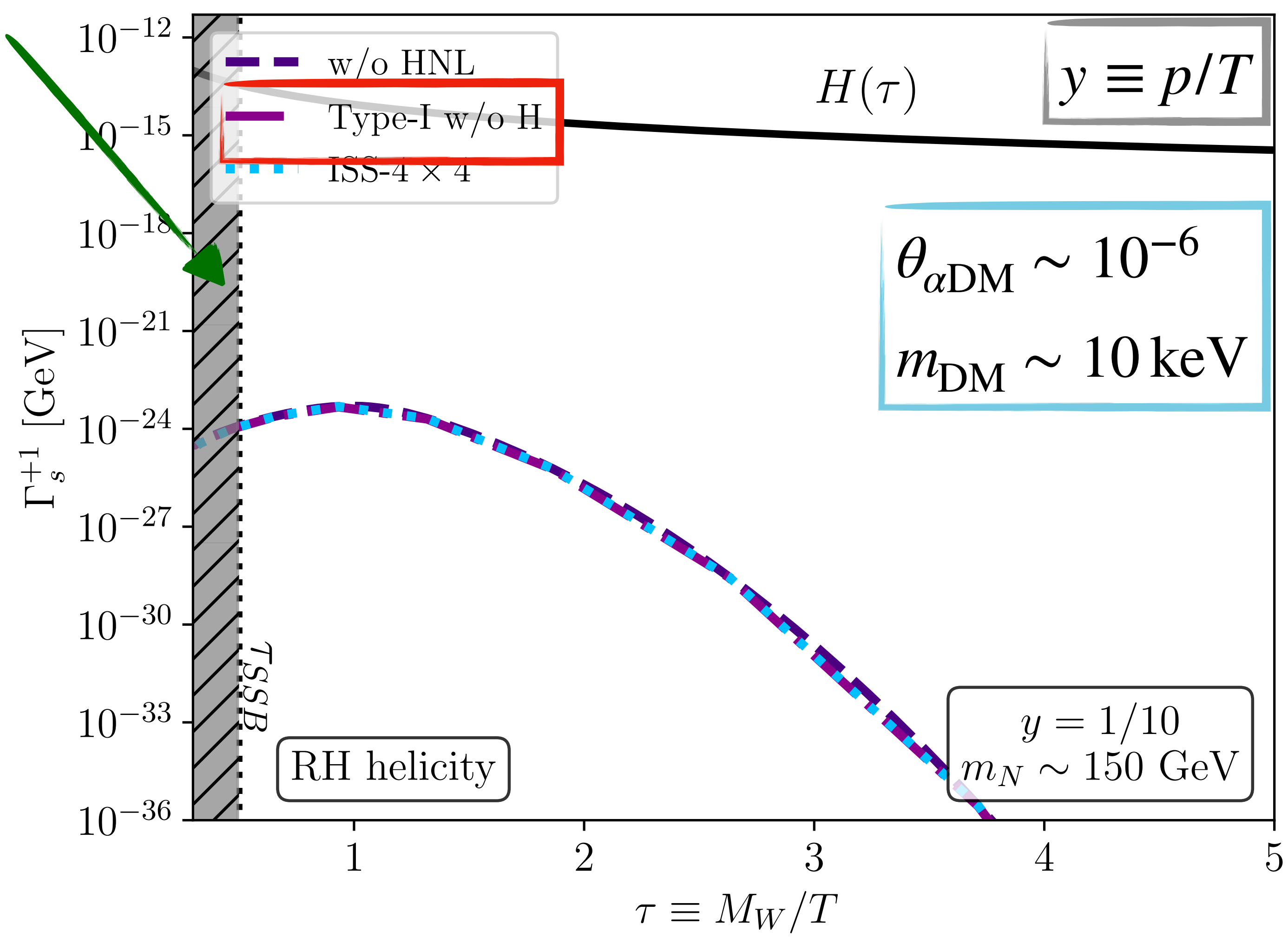
No additional production from $n_h \to Z + n_{\rm DM}$



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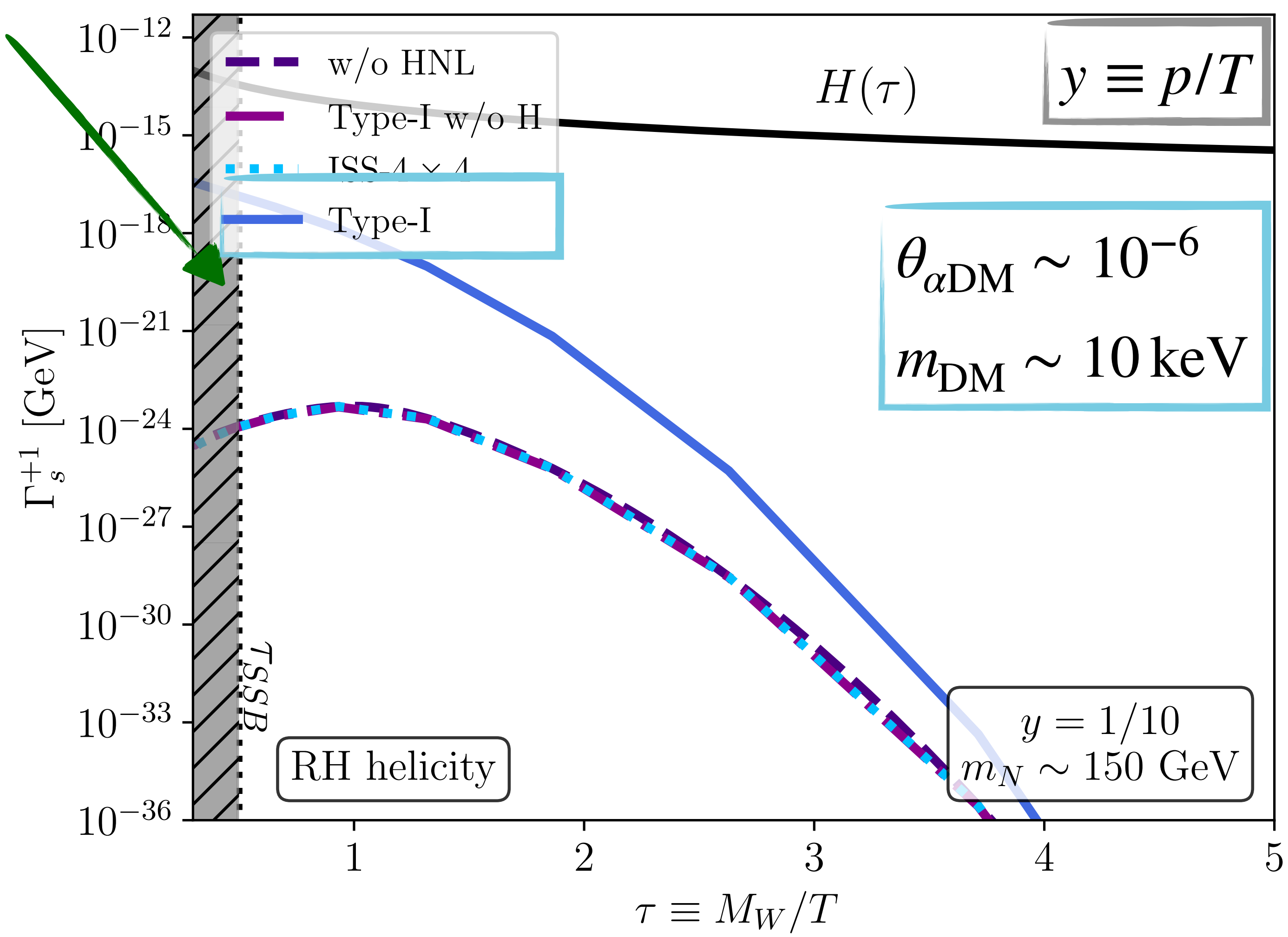
$n_h \to h + n_{\rm DM}$ enhances the DM production



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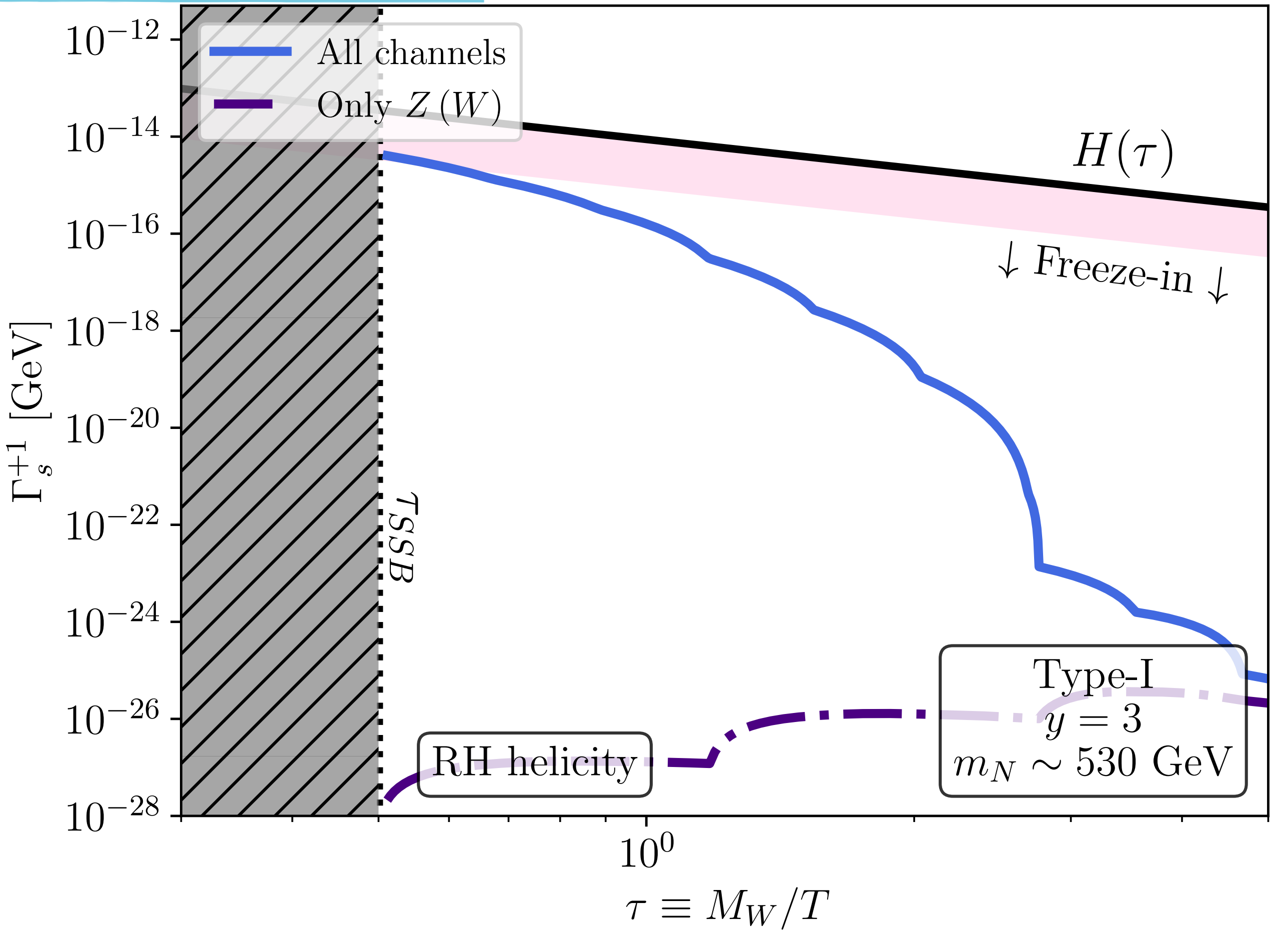
Active-heavy neutrino mixing

Benchmark point
$\theta_{\alpha \rm DM} \sim 10^{-6}, \theta_{\alpha h} \sim 10^{-3}$
$m_{\rm DM} \sim 6\,\text{keV}, m_N \sim 530\,\text{GeV}$

$f_{\rm DM} \sim 1.2$

Using production rates in vacuum one finds $f_{\rm DM}^{T=0} \sim 100 f_{\rm DM}$



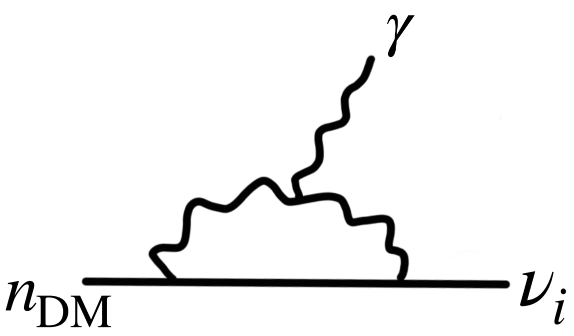
Conclusions

Origin of ν masses

Seesaw-mechanism

Leptogenesis

Sterile ν DM



We look for it through its mixing with SM neutrinos

Can we produce enough DM only relying on neutrino mixing?

If not, we need extra new physics to account for DM!

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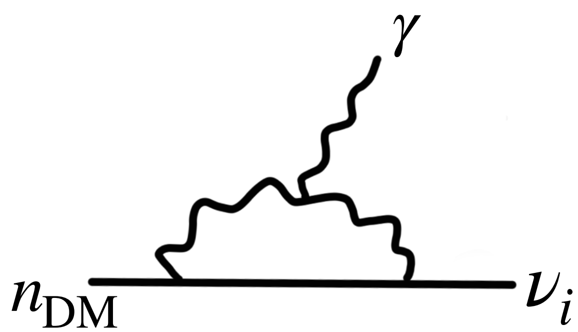

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$T \sim 1\,\mathrm{GeV}$

Can only produce up to 30% of DM

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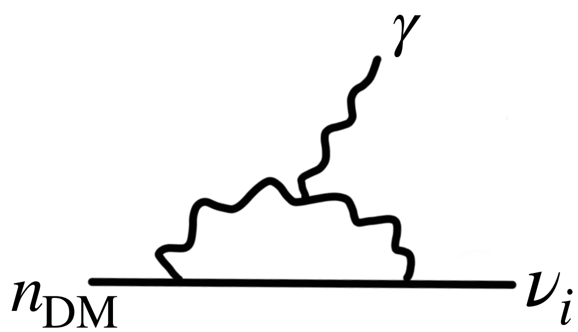

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DW mechanism

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Freeze-in production

$T \sim 100\,\mathrm{GeV}$

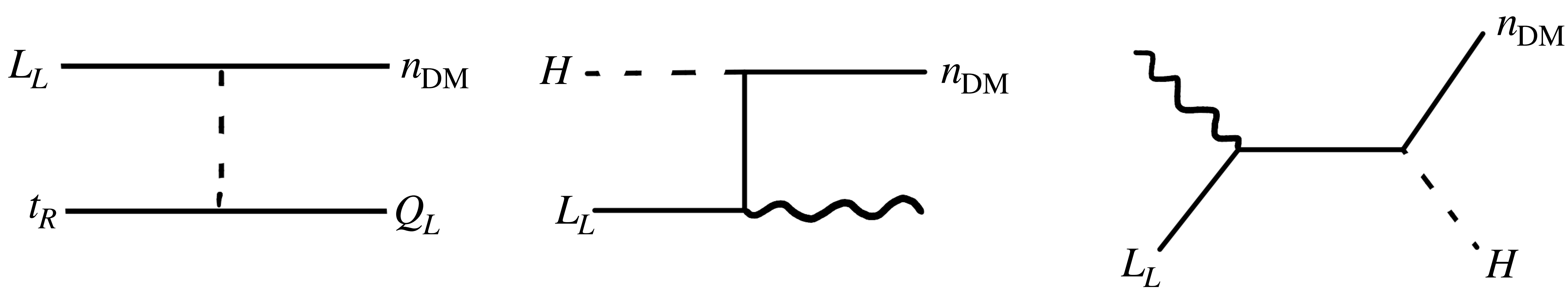
Decays involving $Z\,(W)$ do not produce DM

$n_h \to h + n_{\rm DM}$ promising production channel!

Conclusions

To do list

- Account for production at $T > 160\,\mathrm{GeV}$: $2 \to 2$ processes



- Include other thermal effects
- Phenomenology: if this mechanisms accounts DM, what are the **consequences** for **flavor probes** and **EWPO**?

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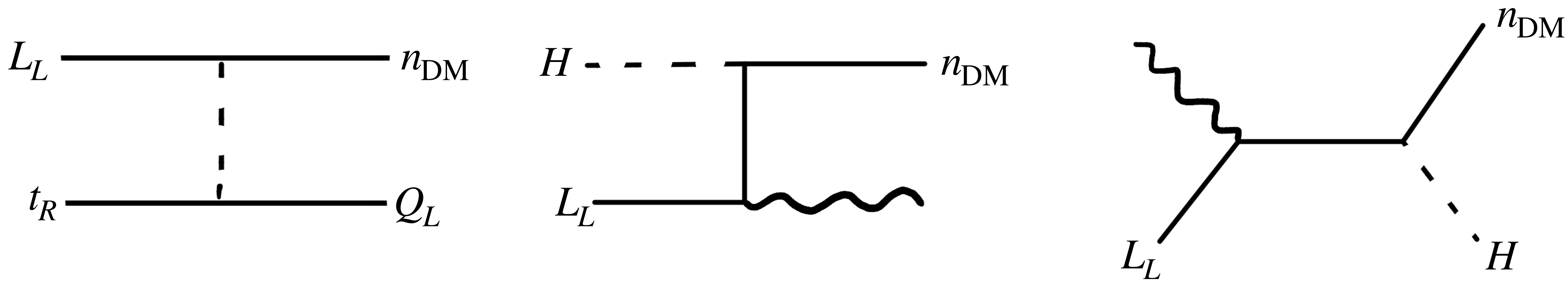

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