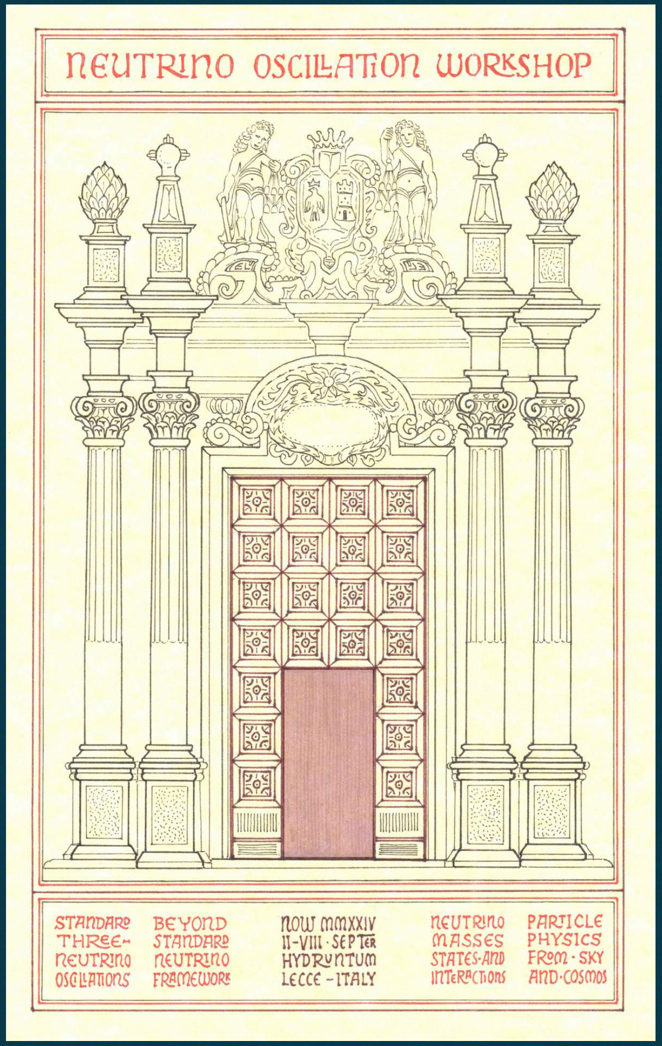


Thermal effects in νDM production

Salvador Rosauro-Alcaraz

IJCLab, Pôle Théorie

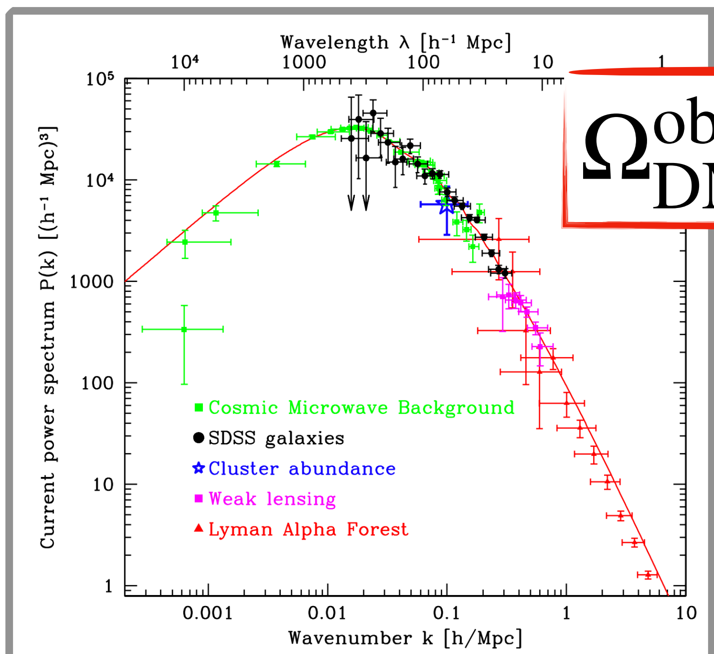
In collaboration with A. Abada, G. Arcadi, M. Lucente & G. Piazza, based on arXiv:2308.01341

NOW 2024, Otranto

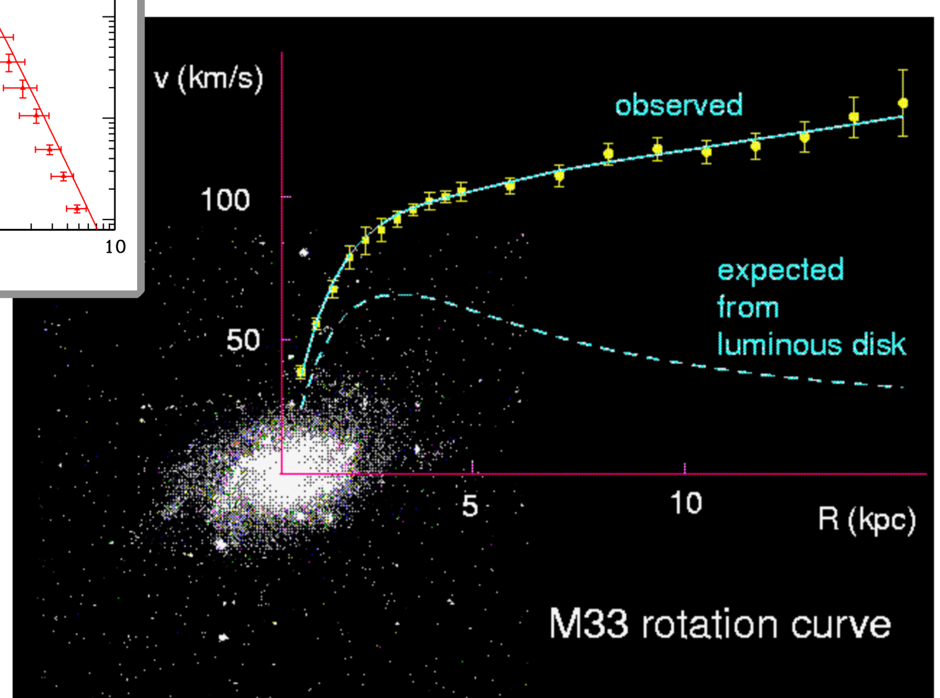
Introduction

Dark matter

Only gravitational probes

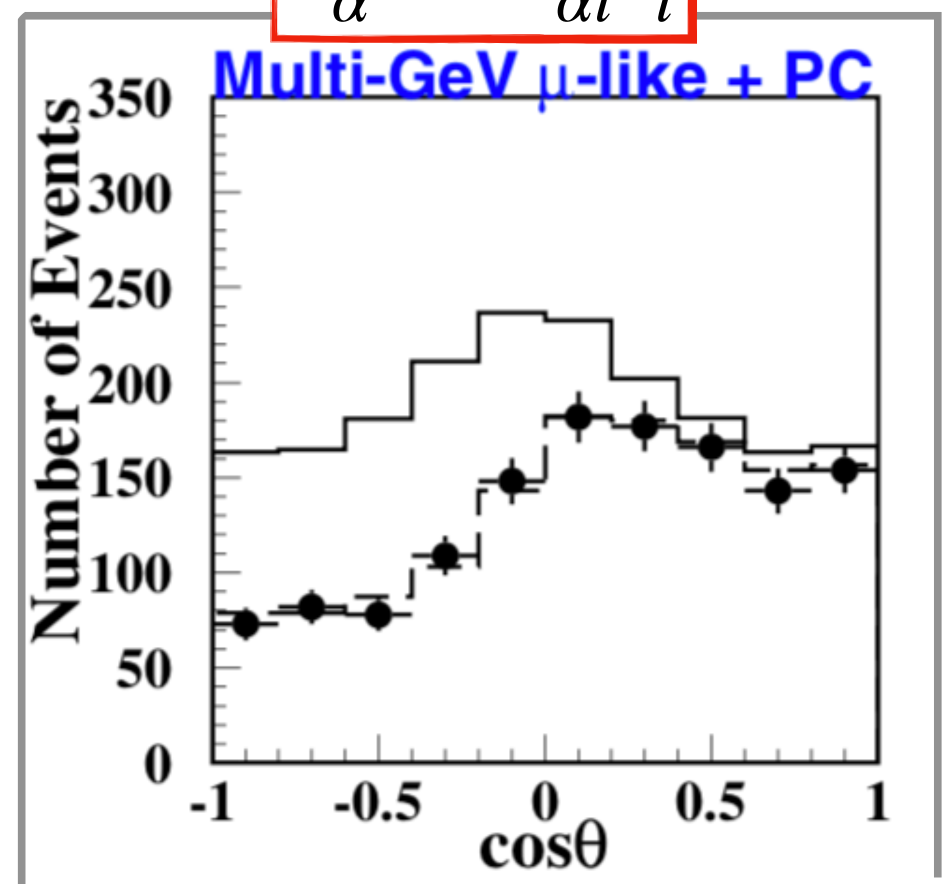


$$\Omega_{\rm DM}^{\rm obs} h^2 \simeq 0.12$$



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

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

New scale not related to EW symmetry breaking

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**

A. Ibarra & G. Ross, arXiv:hep-ph/0312138

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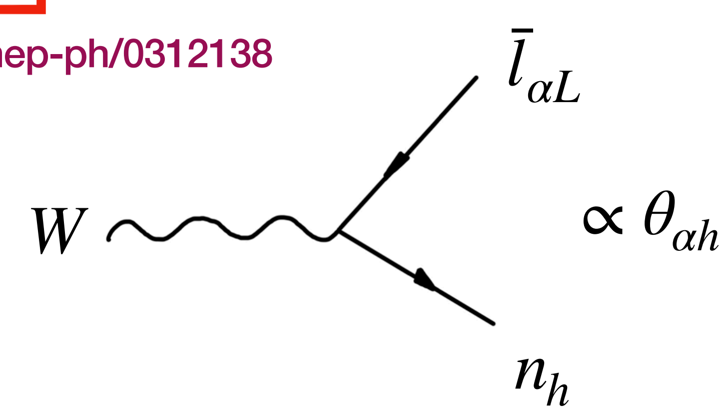
Relation between
flavor and **mass basis**

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



Massive neutrinos

Neutrino dark matter

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

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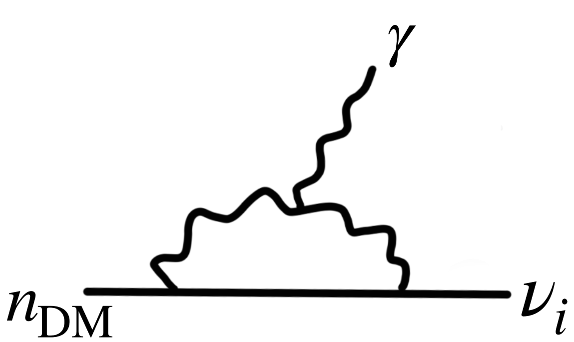
Assume $M \sim \mathcal{O}\left(\mathrm{keV}\right)$: **Monochromatic X-ray** signal as smoking gun

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



$$\propto G_F^2 \left|\theta_{\alpha \mathrm{DM}}\right|^2 m_{\mathrm{DM}}^5$$

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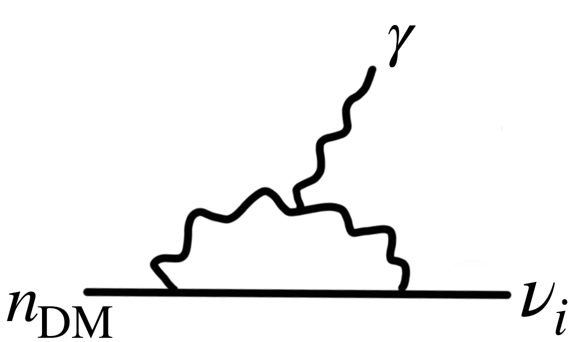

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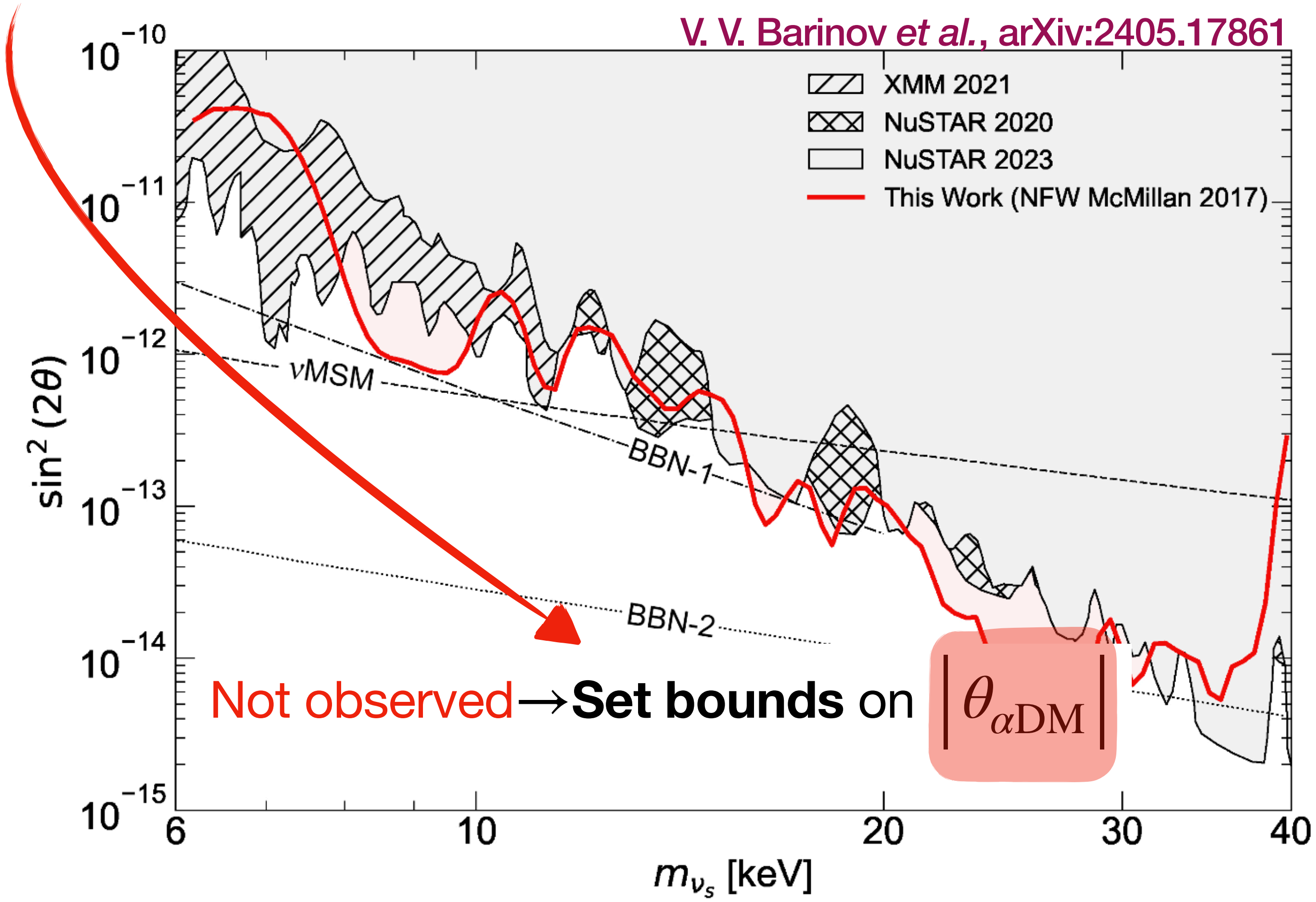

Not observed → **Set bounds** on $\left|\theta_{\alpha\mathrm{DM}}\right|$

Neutrino dark matter

Production mechanism

Temperatures $T \lesssim 1\,\mathrm{GeV}$

Dodelson-Widrow mechanism

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

DM abundance from ν **oscillations** and **collisions** in the plasma

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

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

Irreducible contribution

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$$\left.\begin{aligned} Z(h) &\leftrightarrow \nu_i + n_{\rm DM} \\ W &\leftrightarrow \ell_\alpha + n_{\rm DM} \\ n_h &\leftrightarrow h(Z) + n_{\rm DM} \end{aligned}\right\}$$

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

DM never reaches equilibrium

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

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How much DM is produced?

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
A. Abada, G. Arcadi, G. Piazza, M. Lucente & **SRA**, arXiv:2308.01341

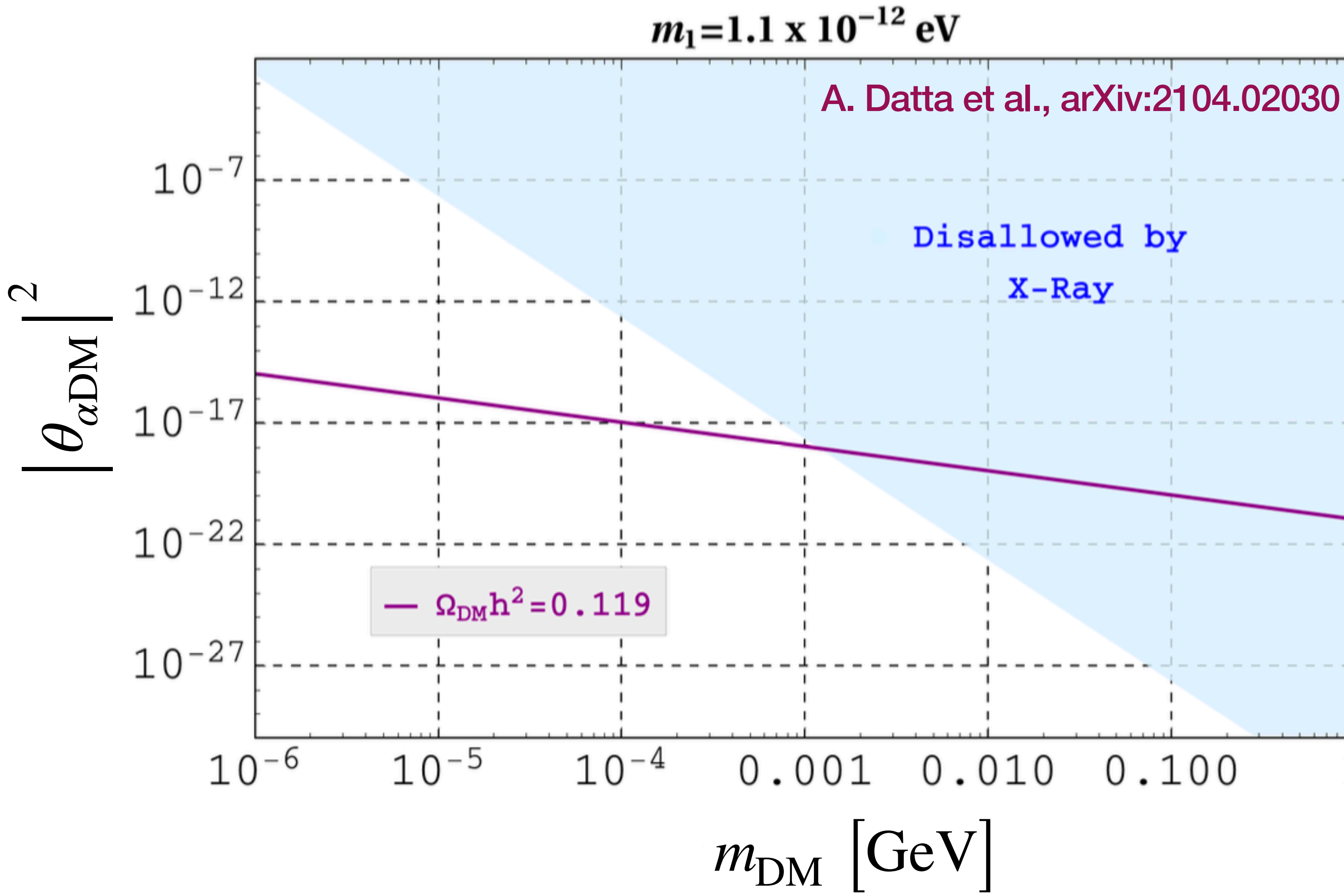
Neutrino dark matter

Freeze-in production: $W(Z) \leftrightarrow \ell_\alpha (\nu_i) + n_{\rm DM}$

Consider the production through gauge boson decays

In vacuum

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



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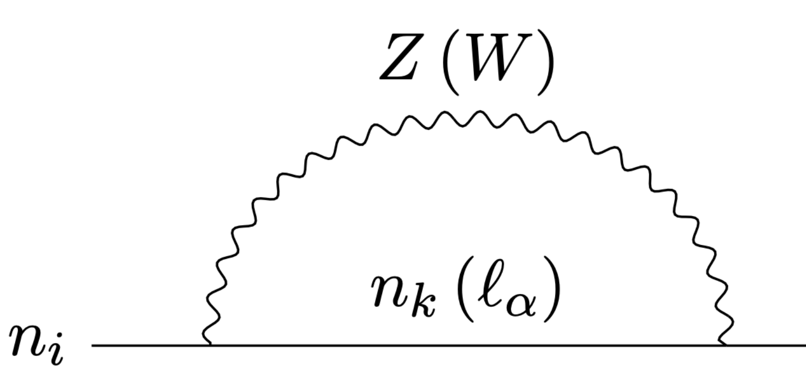
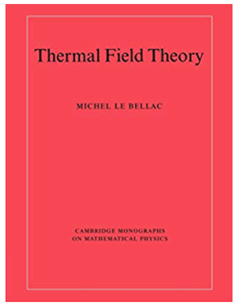
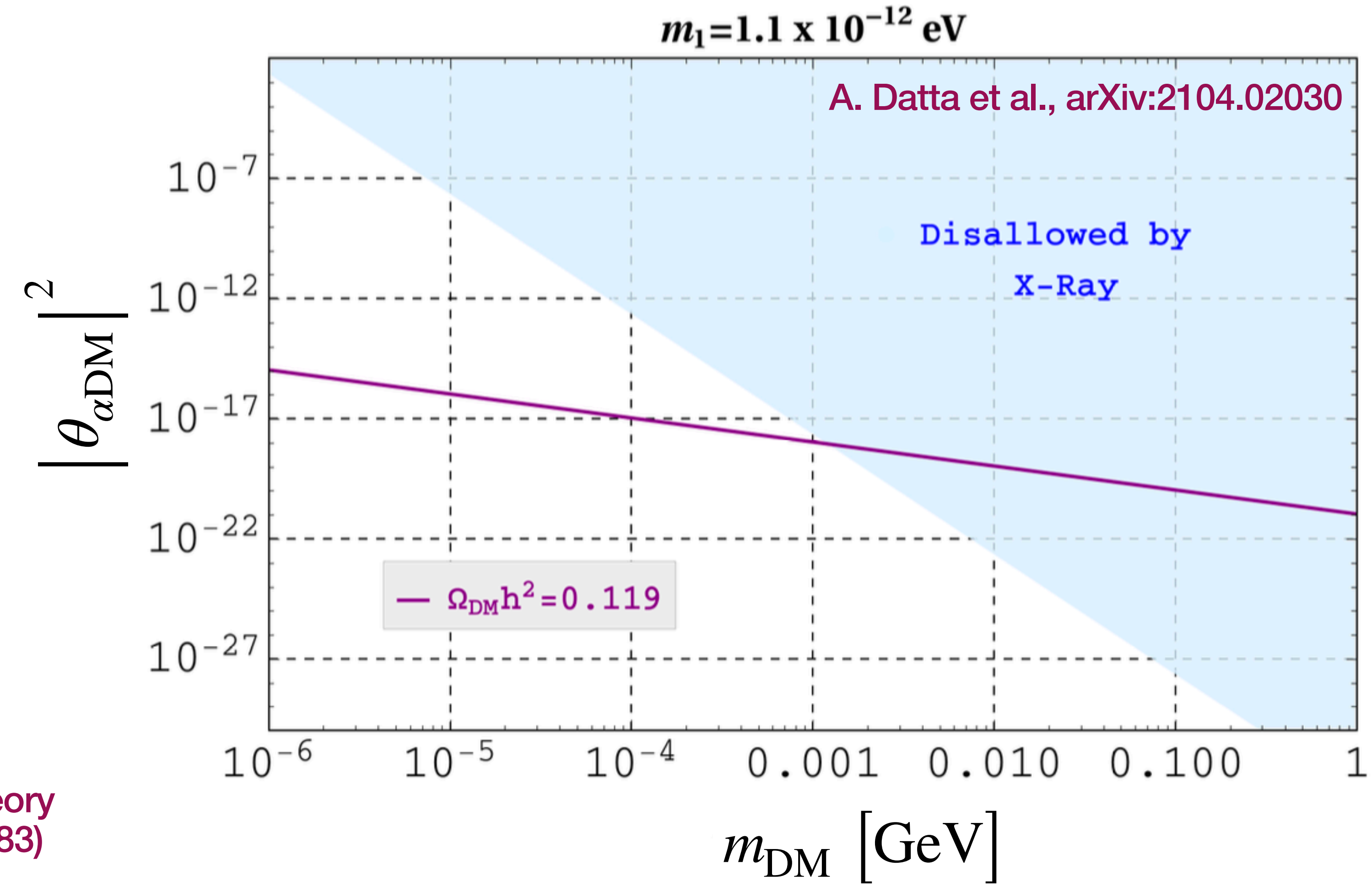
Le Bellac, Thermal Field Theory
H. Weldon, Phys. Rev. D (1983)







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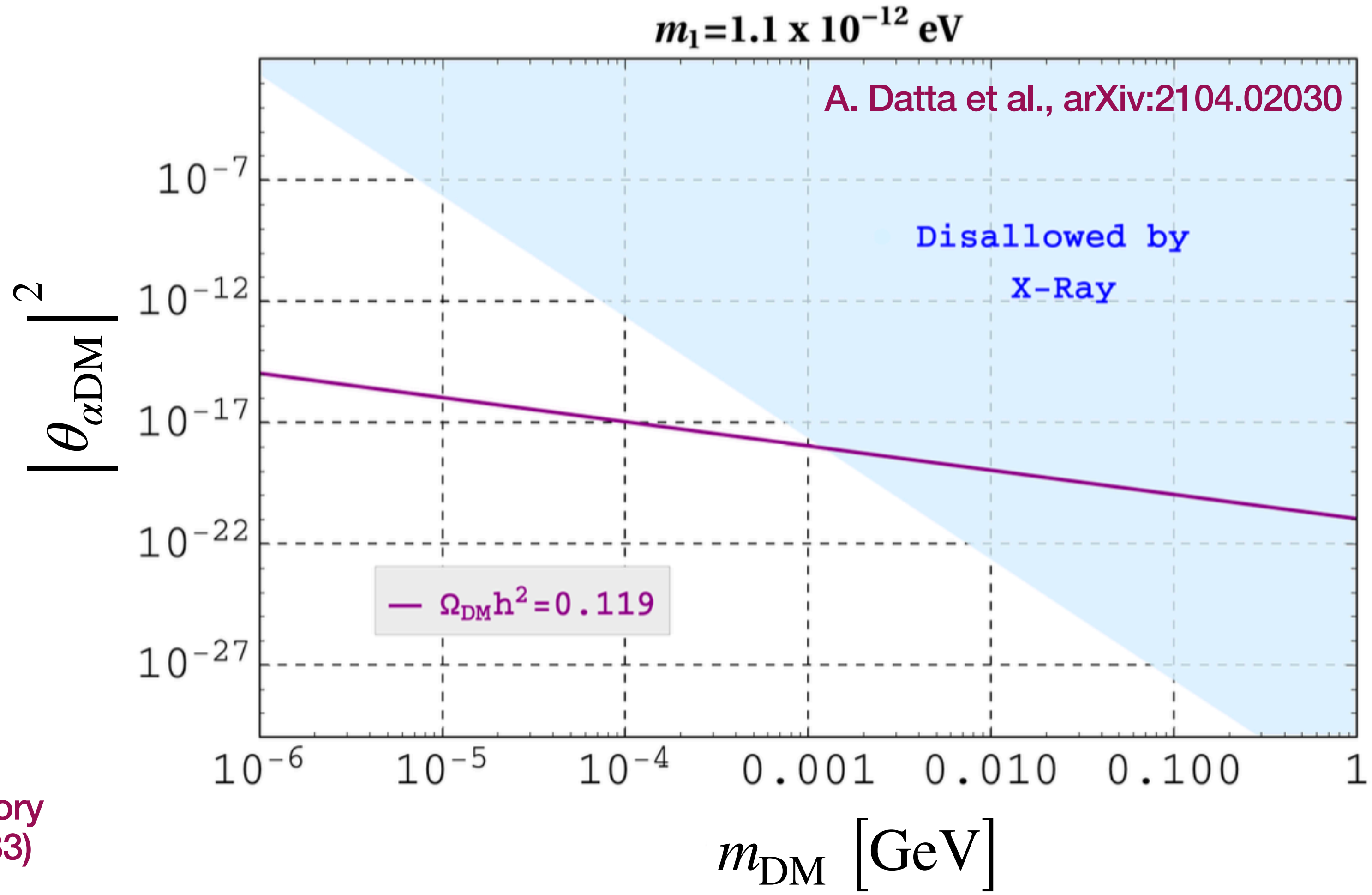

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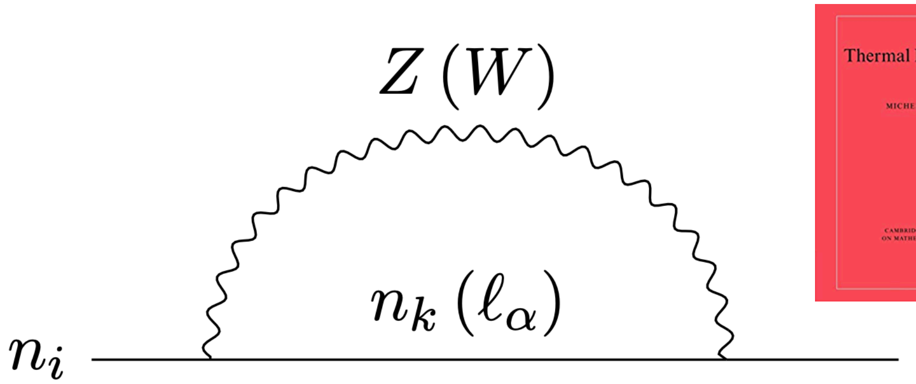

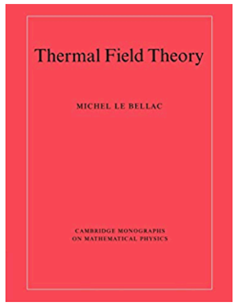

$$\mathcal{M}^2 = \begin{pmatrix} \Omega^h(T) - \frac{m^2_{DM}}{4}\tan^2 2\theta_{\alpha \rm DM} & -\frac{m^2_{DM}}{2}\tan 2\theta_{\alpha \rm DM} \\ -\frac{m^2_{DM}}{2}\tan 2\theta_{\alpha \rm DM} & -m^2_{DM}\left[1 + \frac{1}{4\alpha^h}\tan^2 2\theta_{\alpha \rm DM}\right] \end{pmatrix}$$

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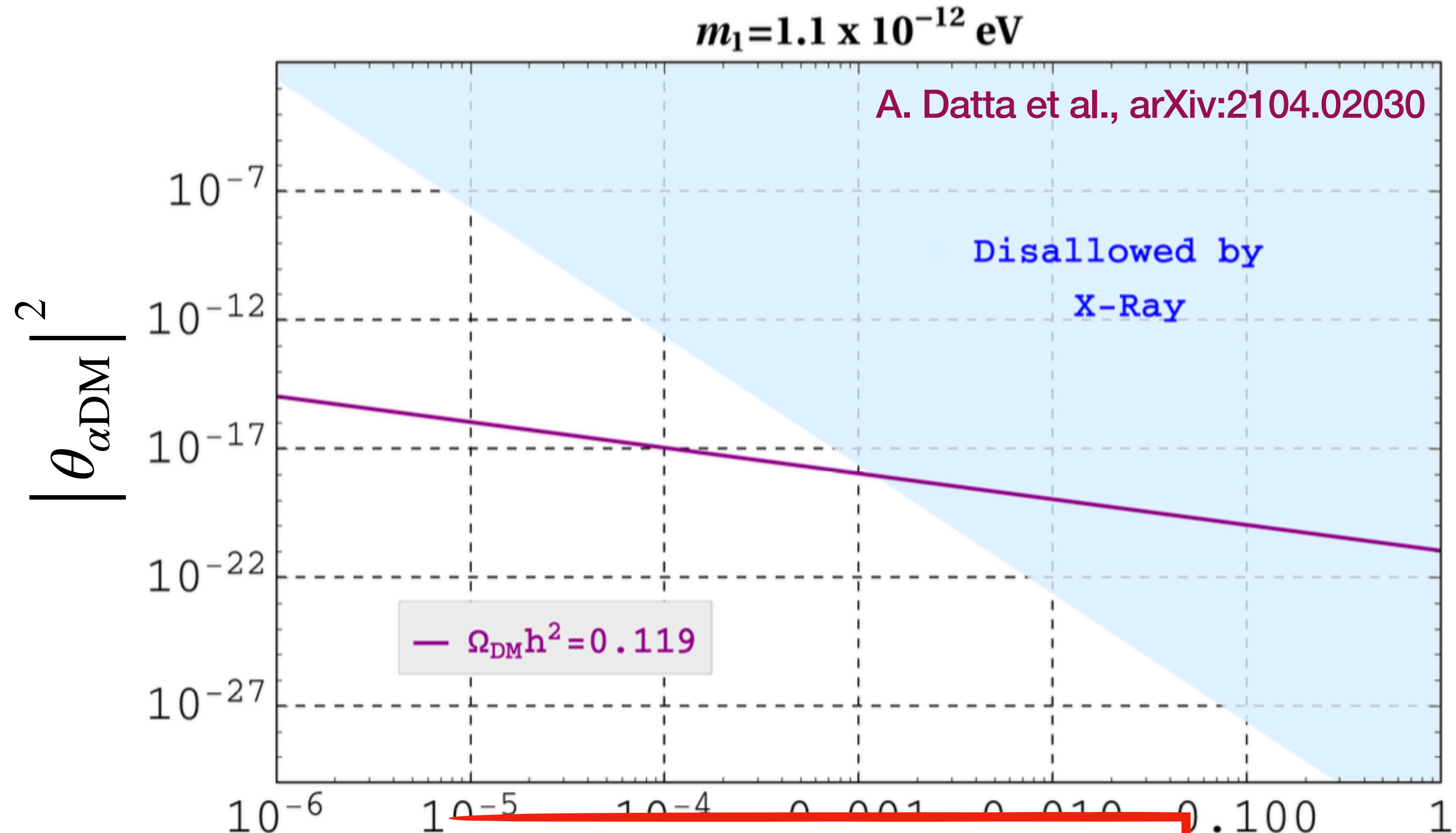

$$\sin\theta^{\rm eff}_{\alpha\rm DM} \sim \frac{m^2_{\rm DM}}{\Omega^h(T)} \sin 2\theta_{\alpha\rm DM}$$

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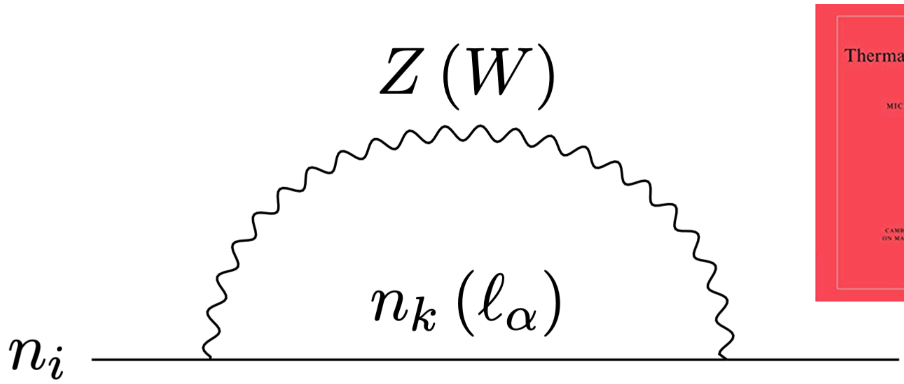

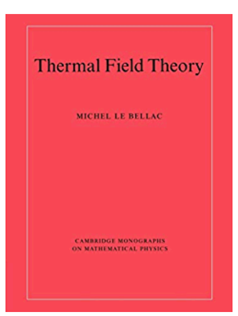

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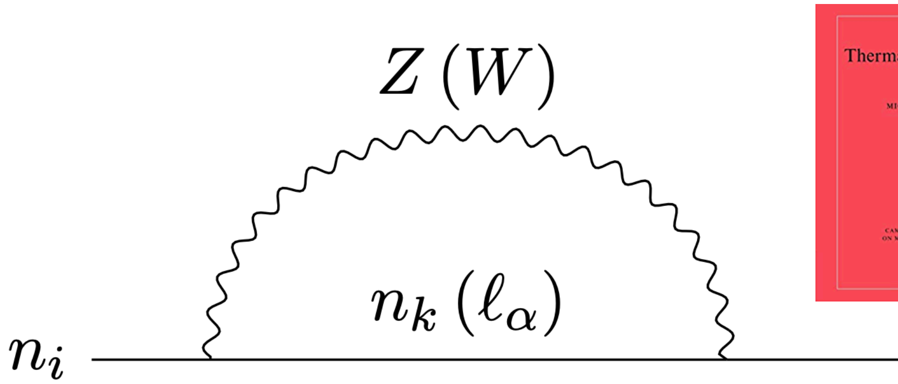

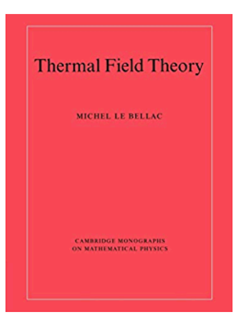

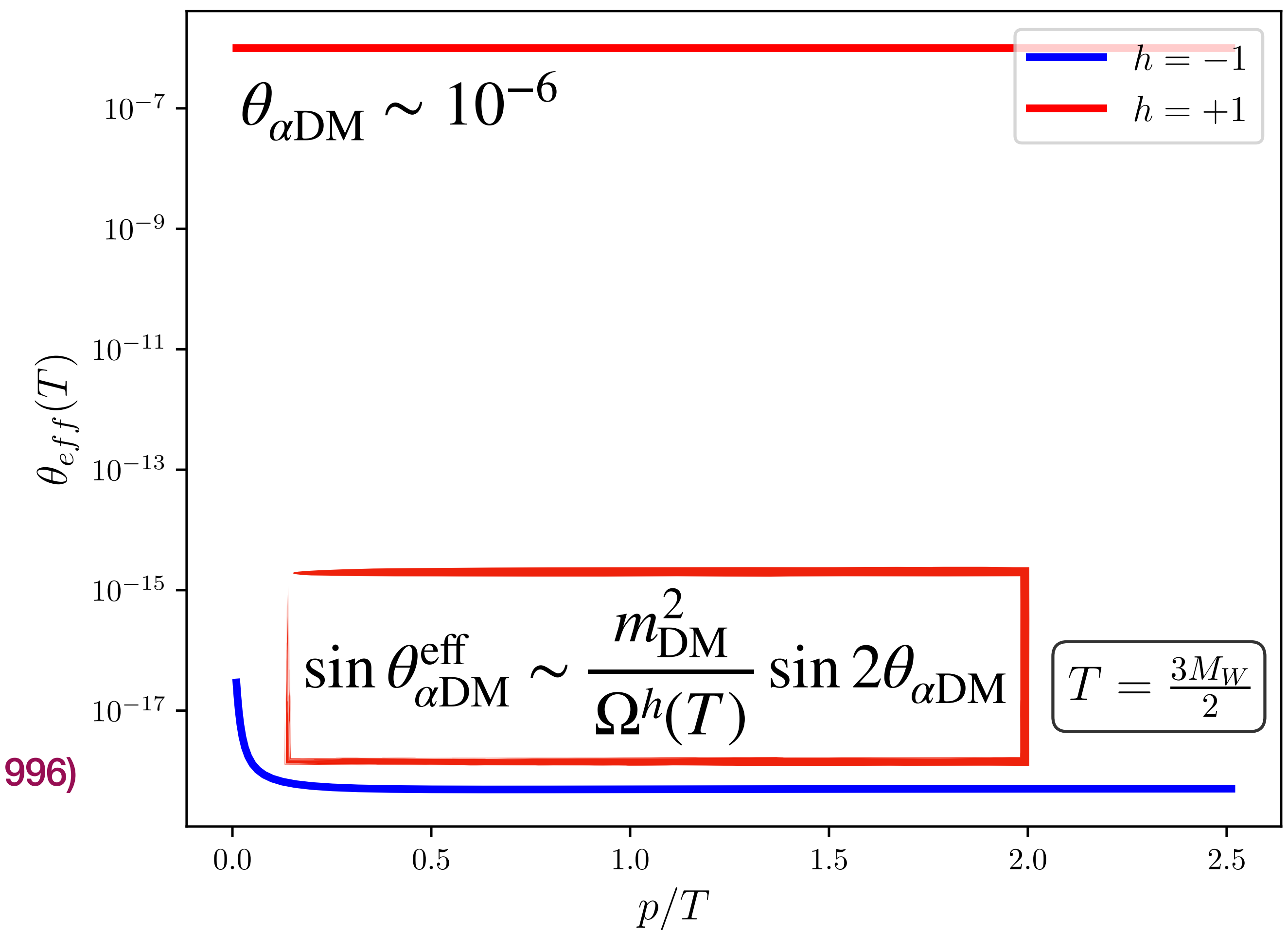

$f_{\mathrm{DM}} \sim 0$ from $Z\,(W)$ decays

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

Neutrino dark matter

Freeze-in production: Heavy neutrino decay

Consider the production
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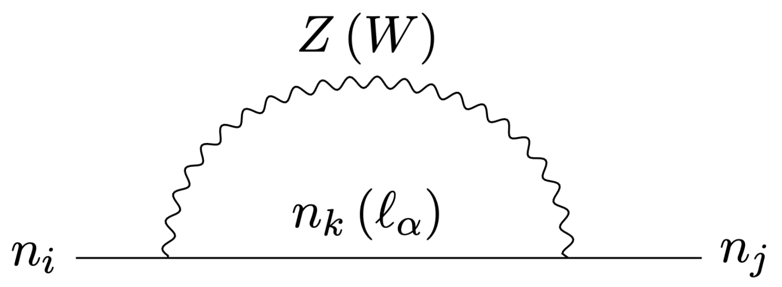
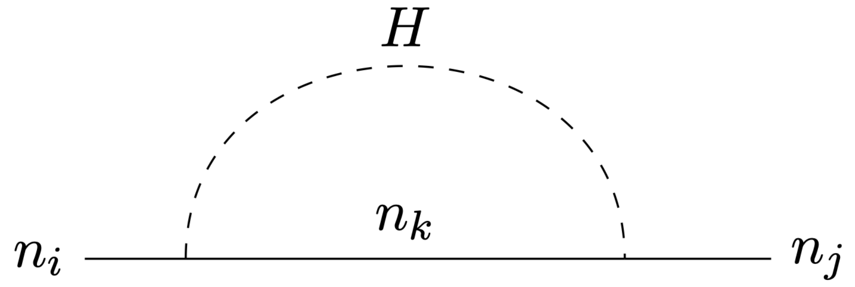
A. Abada, G. Arcadi, G. Piazza, M. Lucente & **SRA**, arXiv:2308.01341





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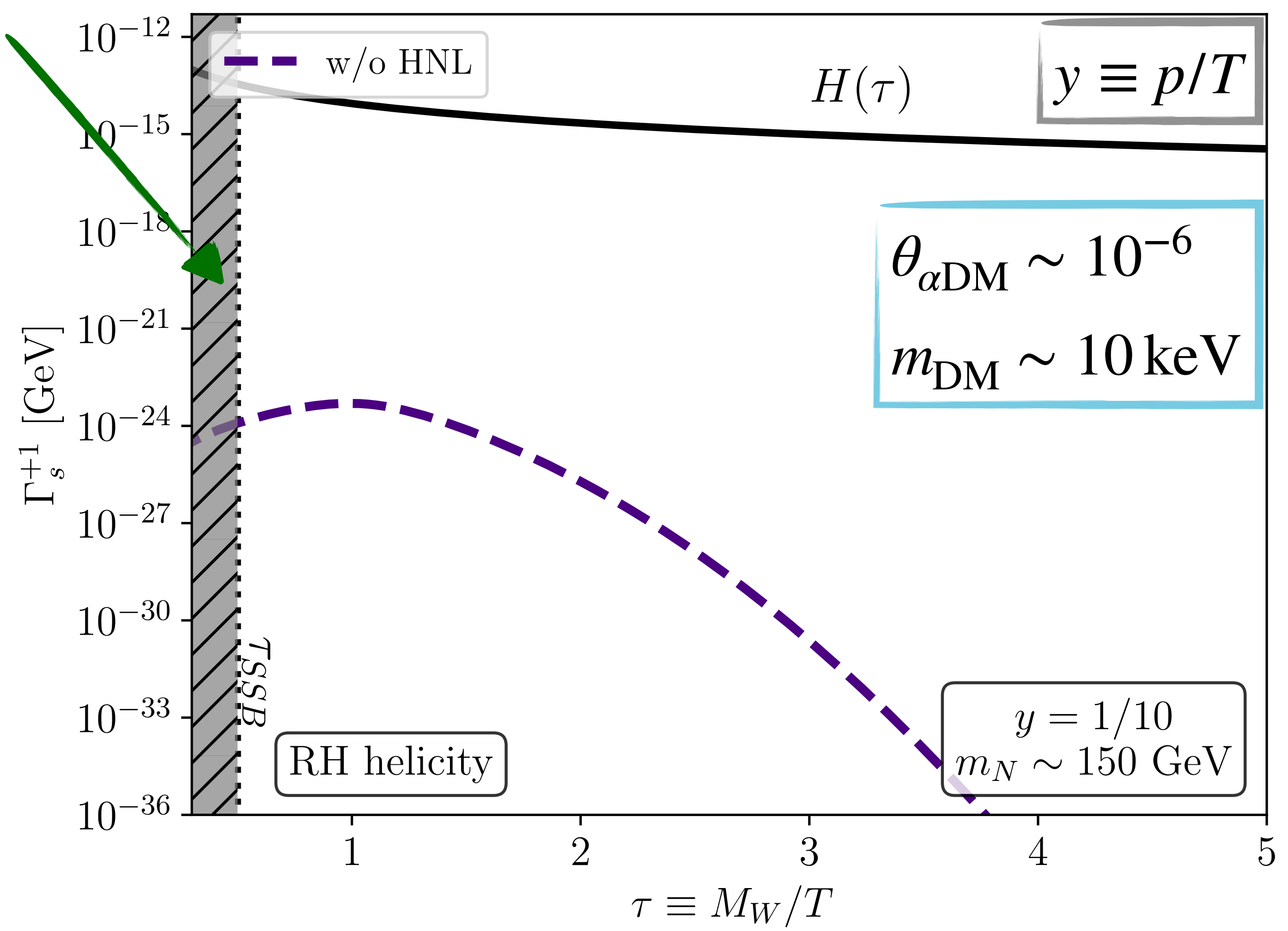
This channel is only viable if $v_H \neq 0 \to T \lesssim 160\,\mathrm{GeV}$



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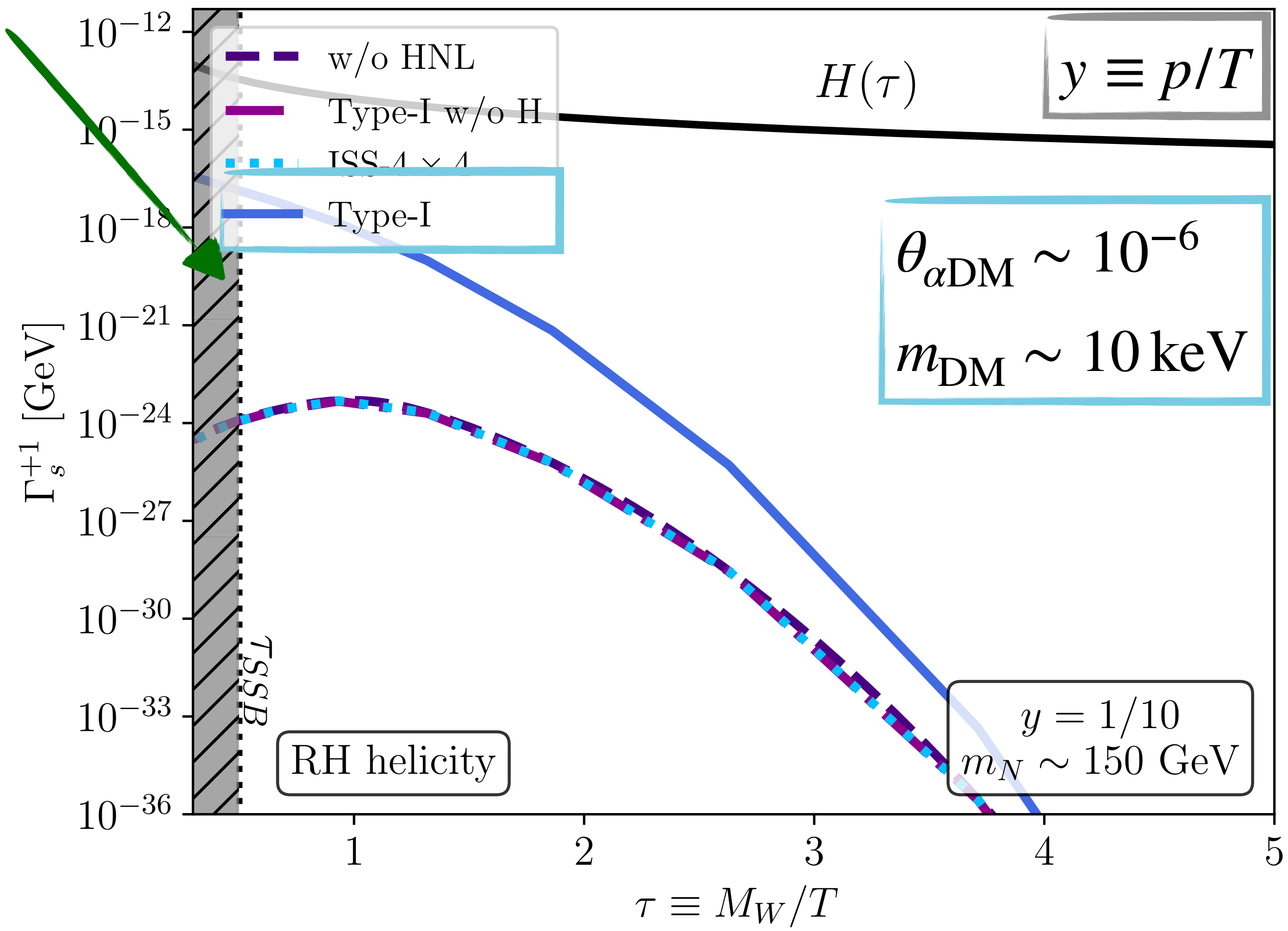

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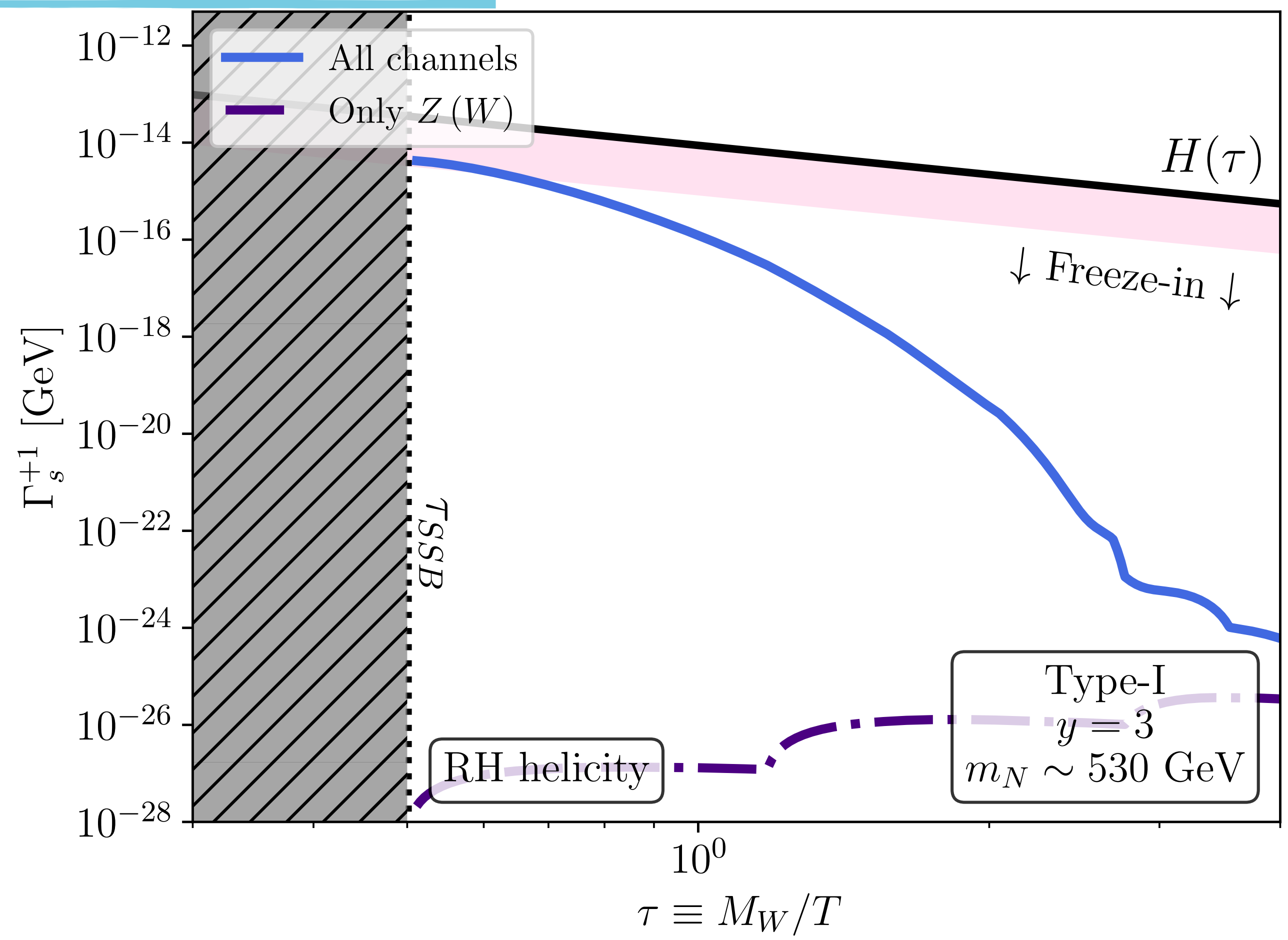
Active-heavy neutrino mixing

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

$$f_{\rm DM} = \Omega_{n_{\rm DM}}/\Omega_{\rm DM}^{\rm obs} \sim 1.2$$

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



Conclusions

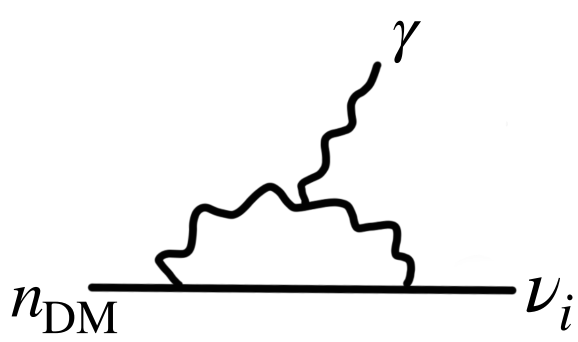
Origin of ν masses

Seesaw-mechanism

Leptogenesis

See talk by A. Granelli

Sterile ν DM



We look for it through its mixing with SM neutrinos

Can we produce enough DM only relying on neutrino mixing?

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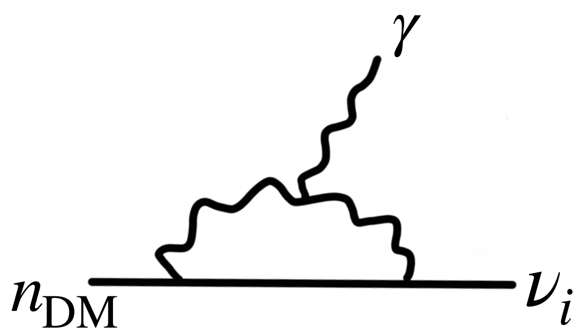

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$T \sim 1\,\mathrm{GeV}$

Can only produce up to 30% of DM

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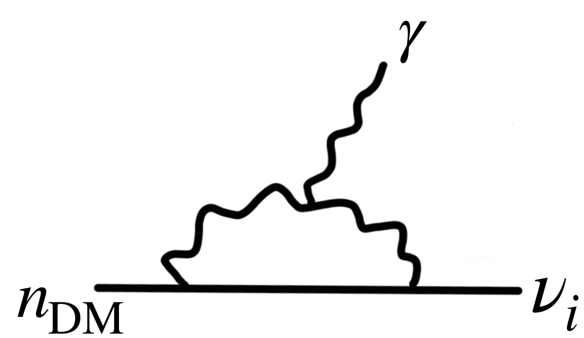

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Freeze-in production

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

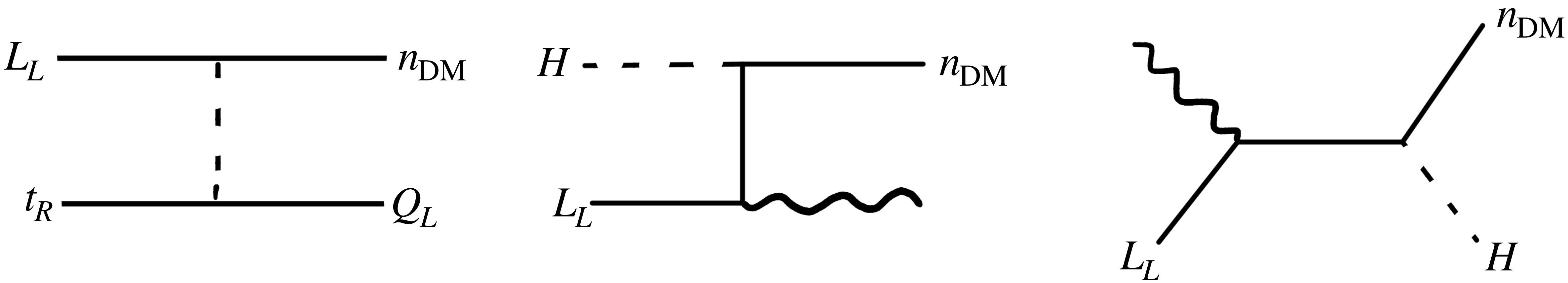
Decays involving $Z\,(W)$ do not produce DM

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

Conclusions

To do list

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



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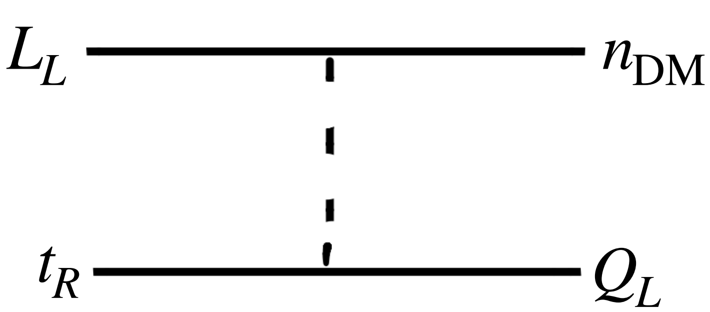

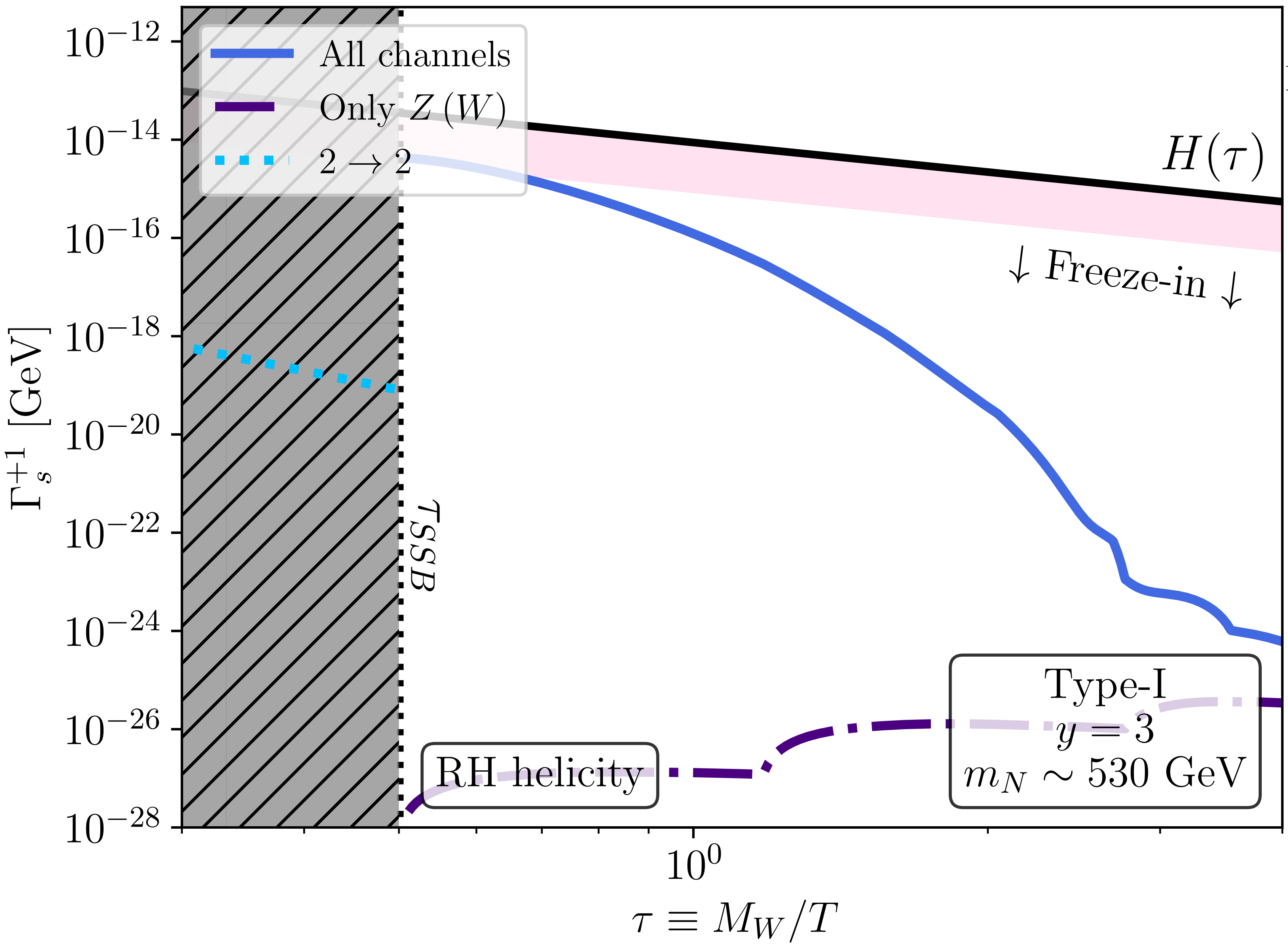

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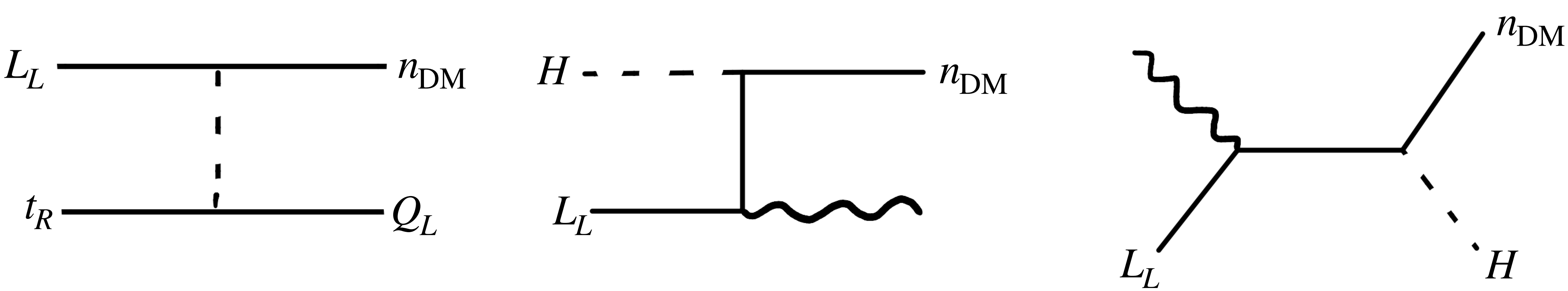

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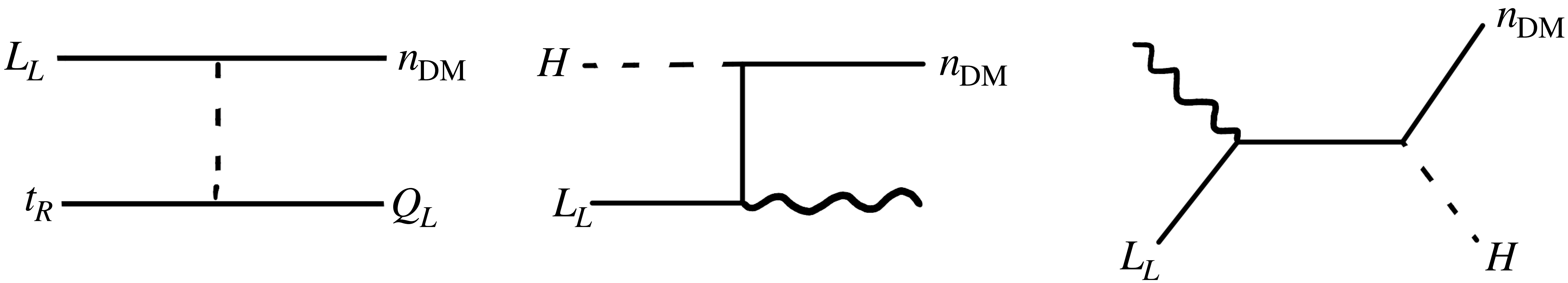

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Thank you!