Thermal effects in νDM production

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DM & CR Meeting, Napoli

Massive neutrinos

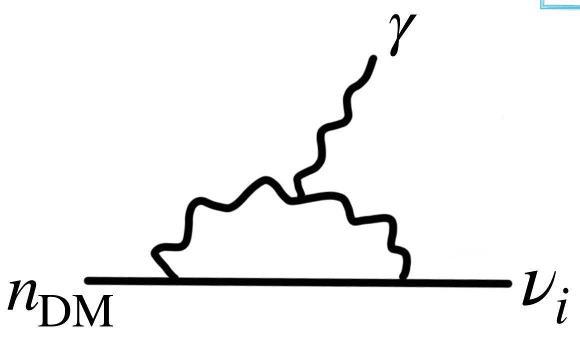
Neutrino dark matter

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

New scale not related to EW symmetry breaking!

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

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



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

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

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

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

A. Merle, A. Schneider & M. Totzauer,
arXiv:1512.05369

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

Irreducible contribution

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Irreducible contribution

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

Freeze-in via 2-body decays

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

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

DM never reaches equilibrium

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

Irreducible contribution

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

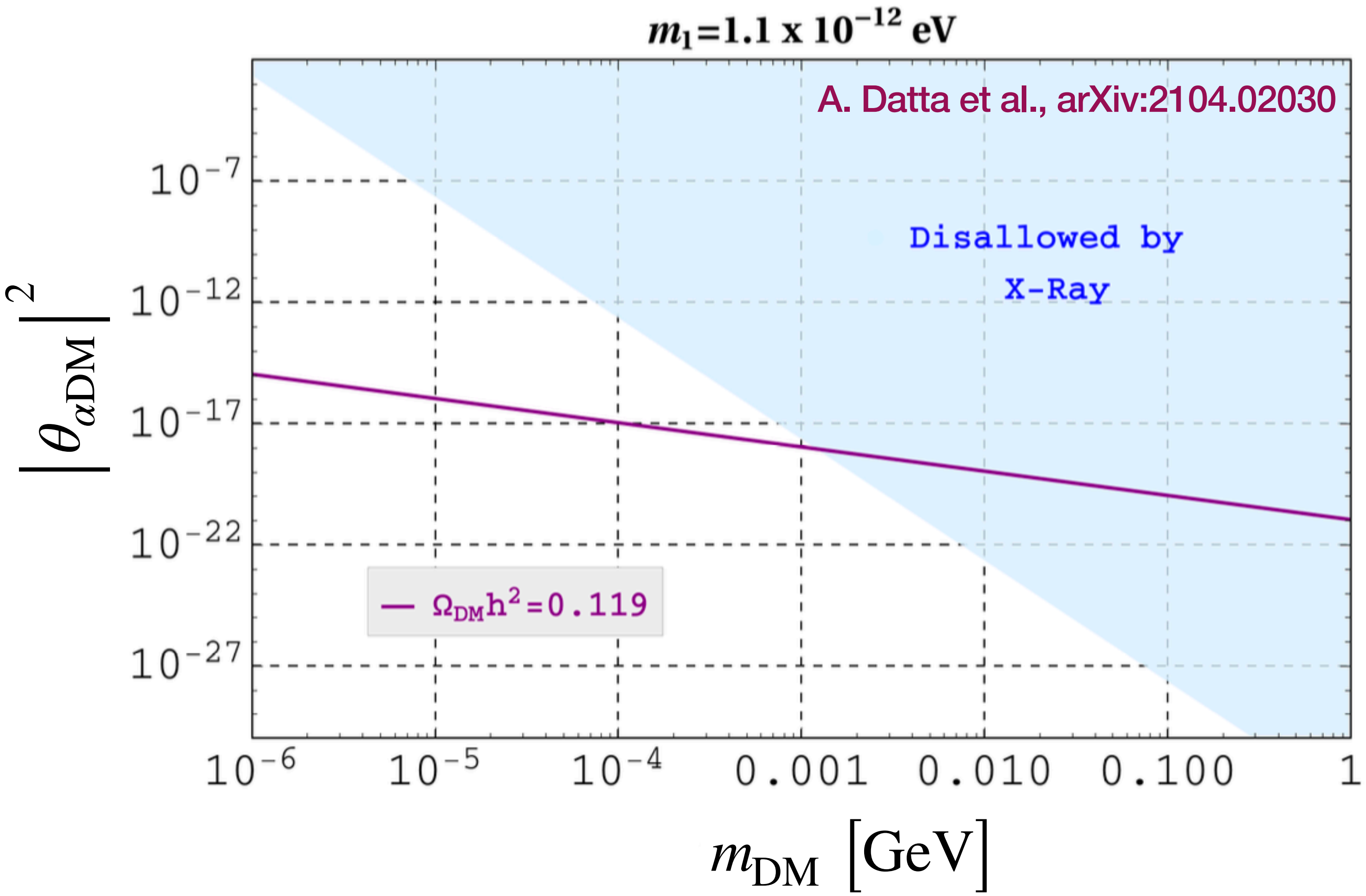
Neutrino dark matter

Freeze-in production: 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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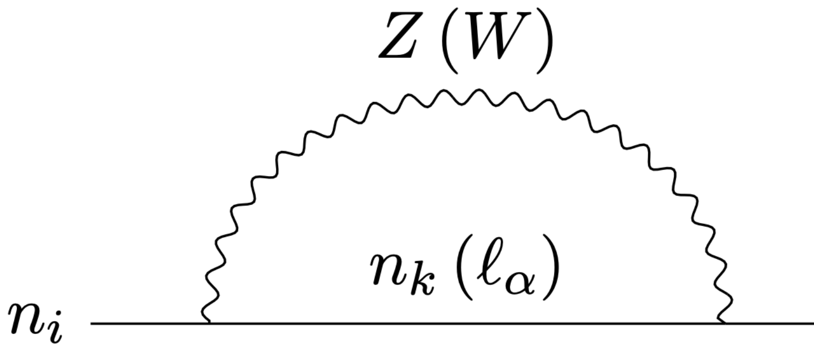
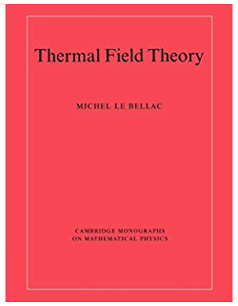
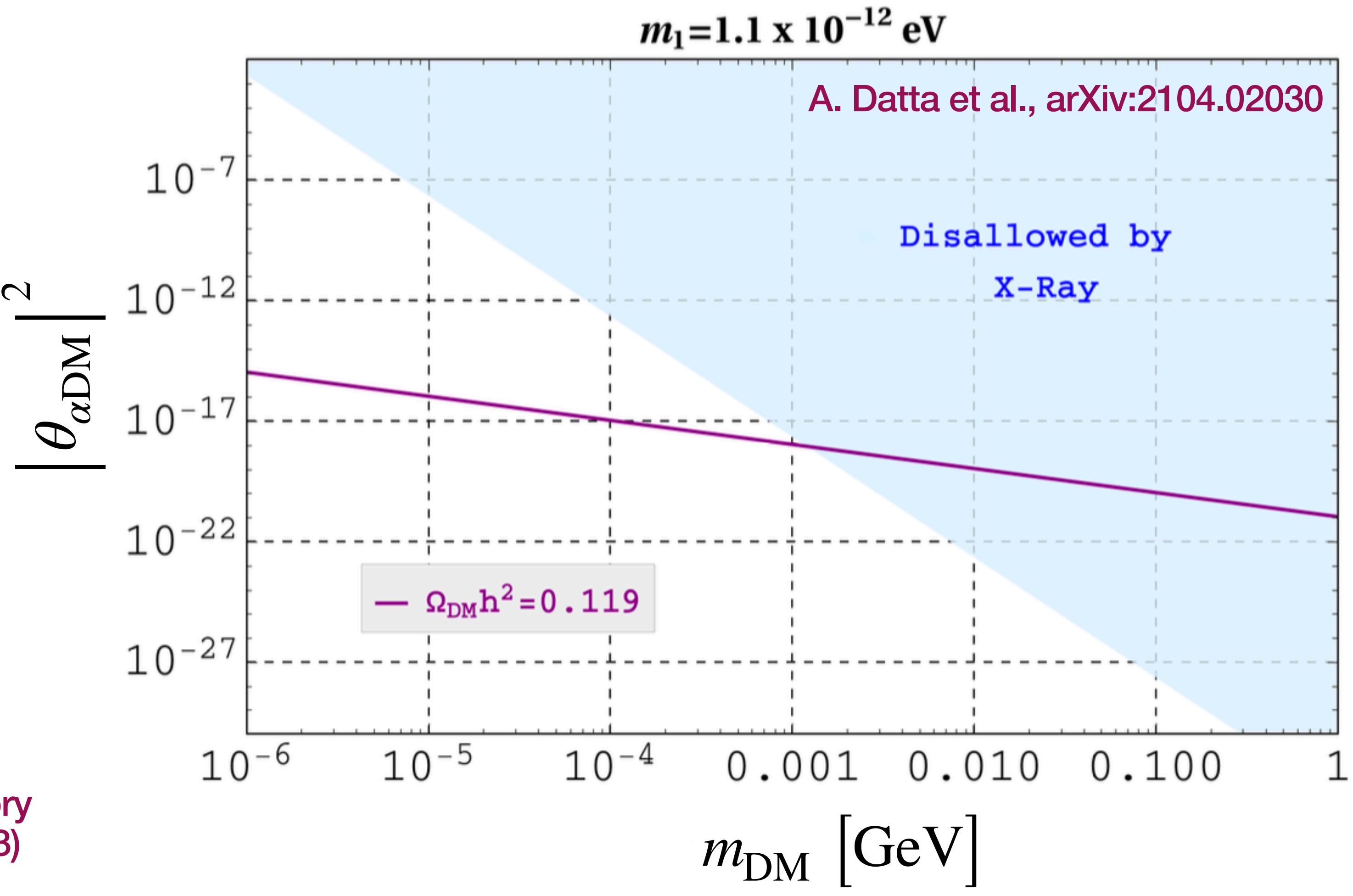
$$\Gamma_s \sim G_F M^3_{Z(W)} \left|\theta_{\alpha \mathrm{DM}}\right|^2$$

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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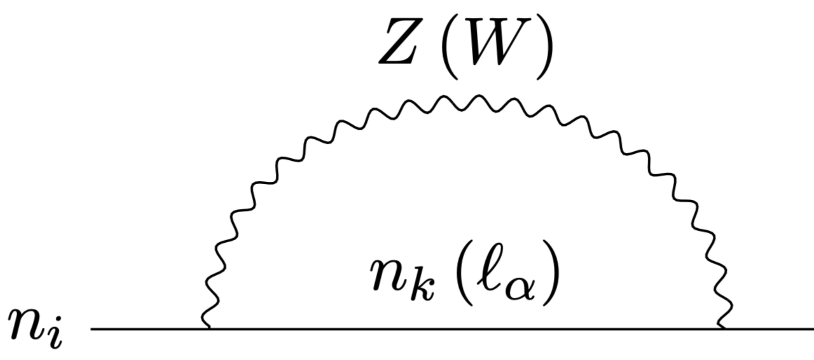

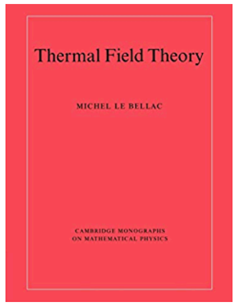

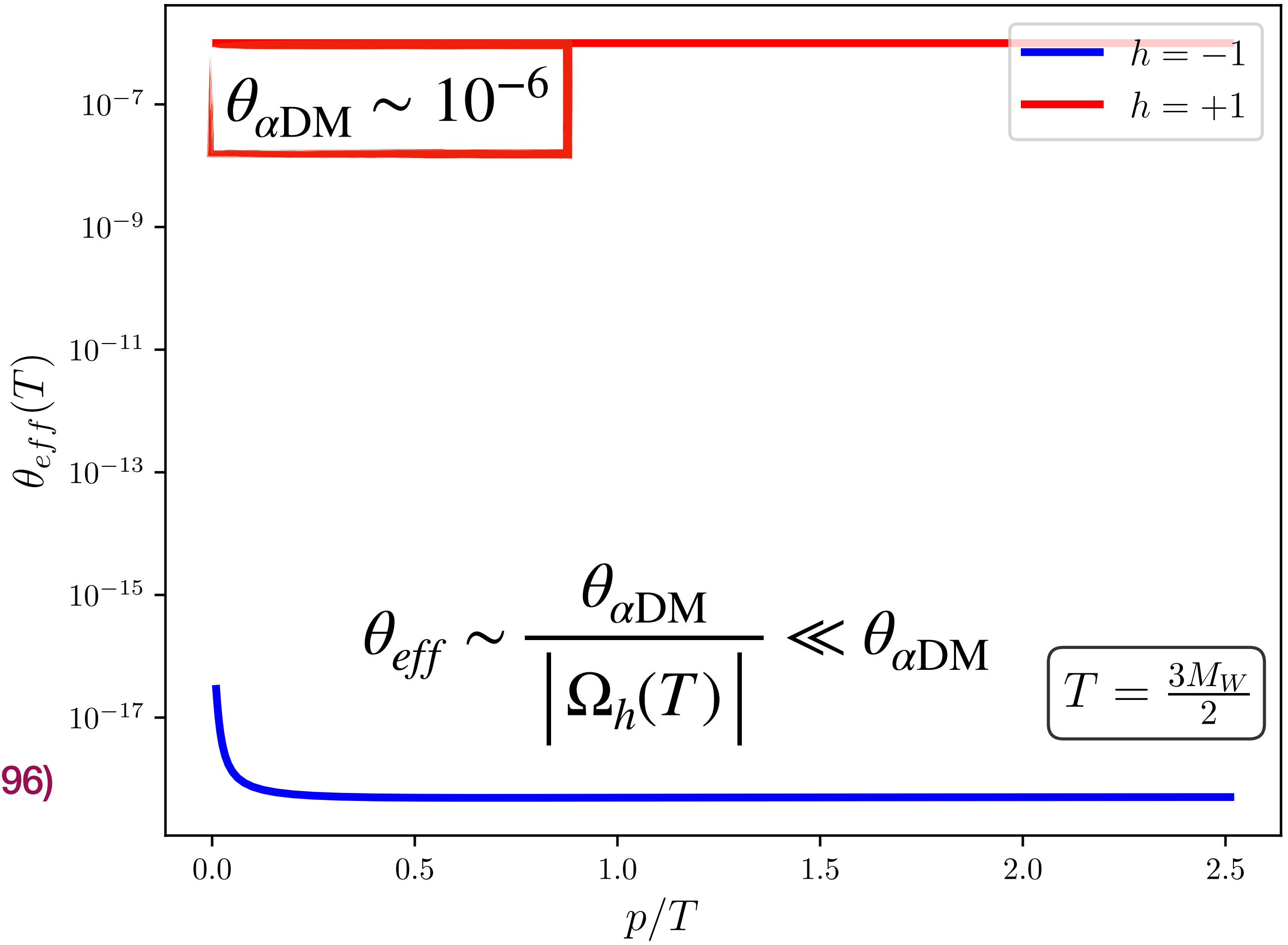

$\theta_{\alpha\mathrm{DM}} \sim 10^{-6}$

$$\theta_{eff} \sim \frac{\theta_{\alpha\mathrm{DM}}}{\left|\Omega_h(T)\right|} \ll \theta_{\alpha\mathrm{DM}}$$

$f_{\mathrm{DM}} \sim 0$ 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 through $n_h \to h + n_{\rm DM}$

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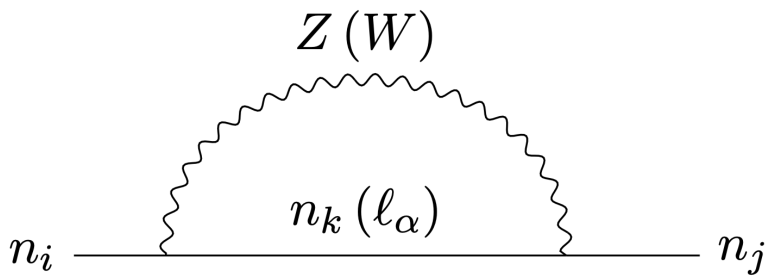

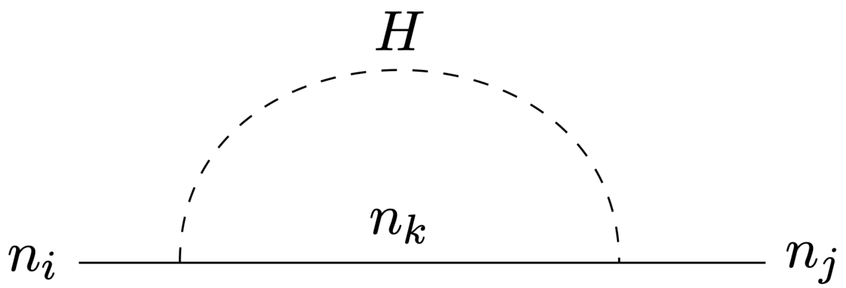

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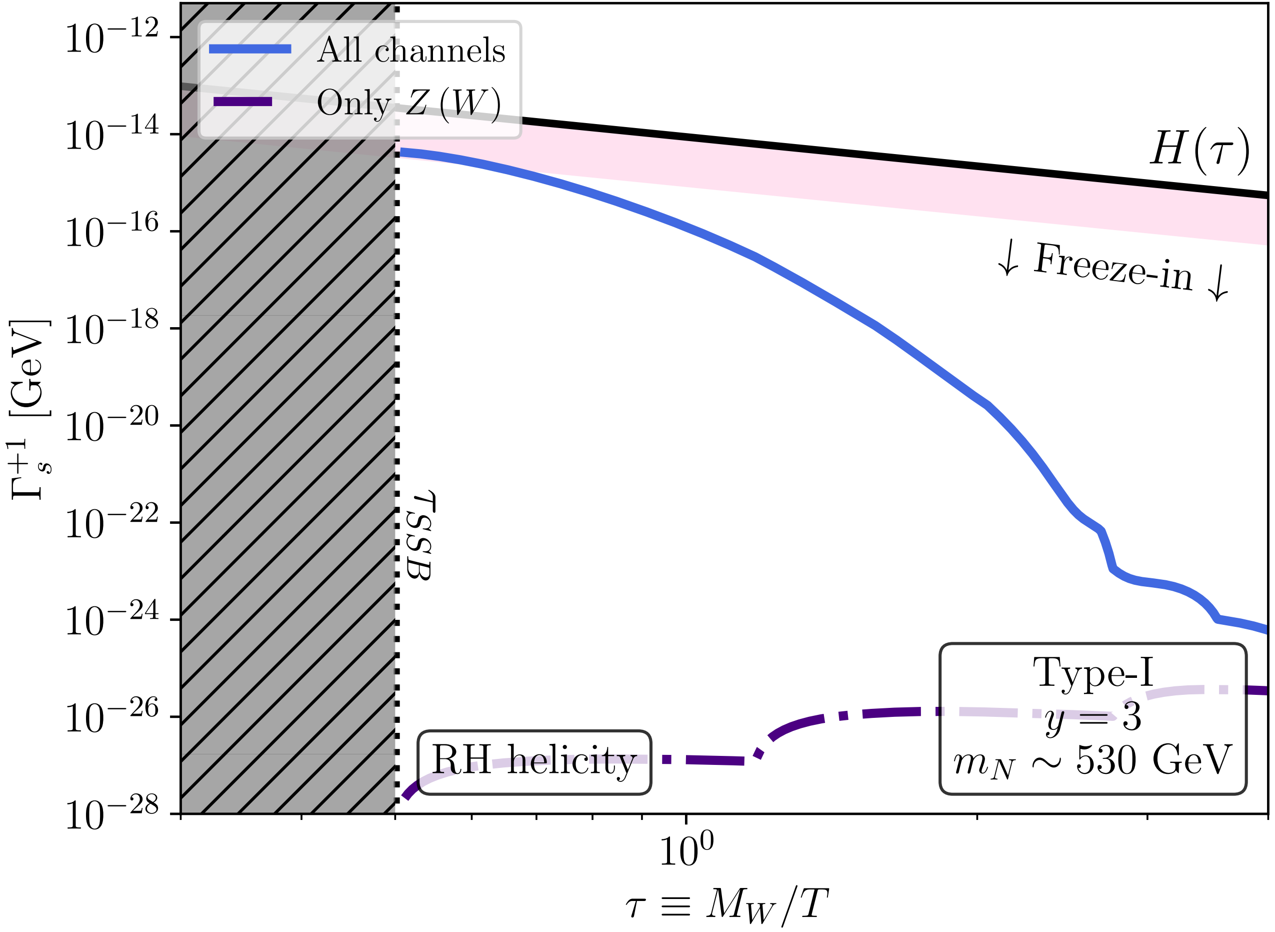
Active-heavy neutrino mixing

Benchmark point

$$\theta_{\alpha\rm DM} \sim 10^{-5}, \theta_{\alpha h} \sim 10^{-3}$$
$$m_{\rm DM} \sim 5\,\mathrm{keV}, m_N \sim 530\,\mathrm{GeV}$$

$$f_{\rm DM} \sim 1.2$$

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



Outlook

Origin of ν masses

Seesaw-mechanism

Sterile ν DM

We look for it through its mixing with SM neutrinos

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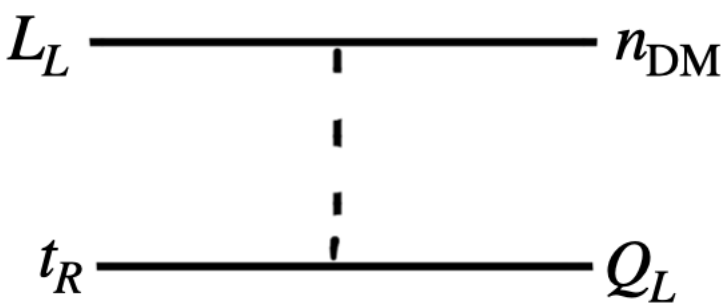
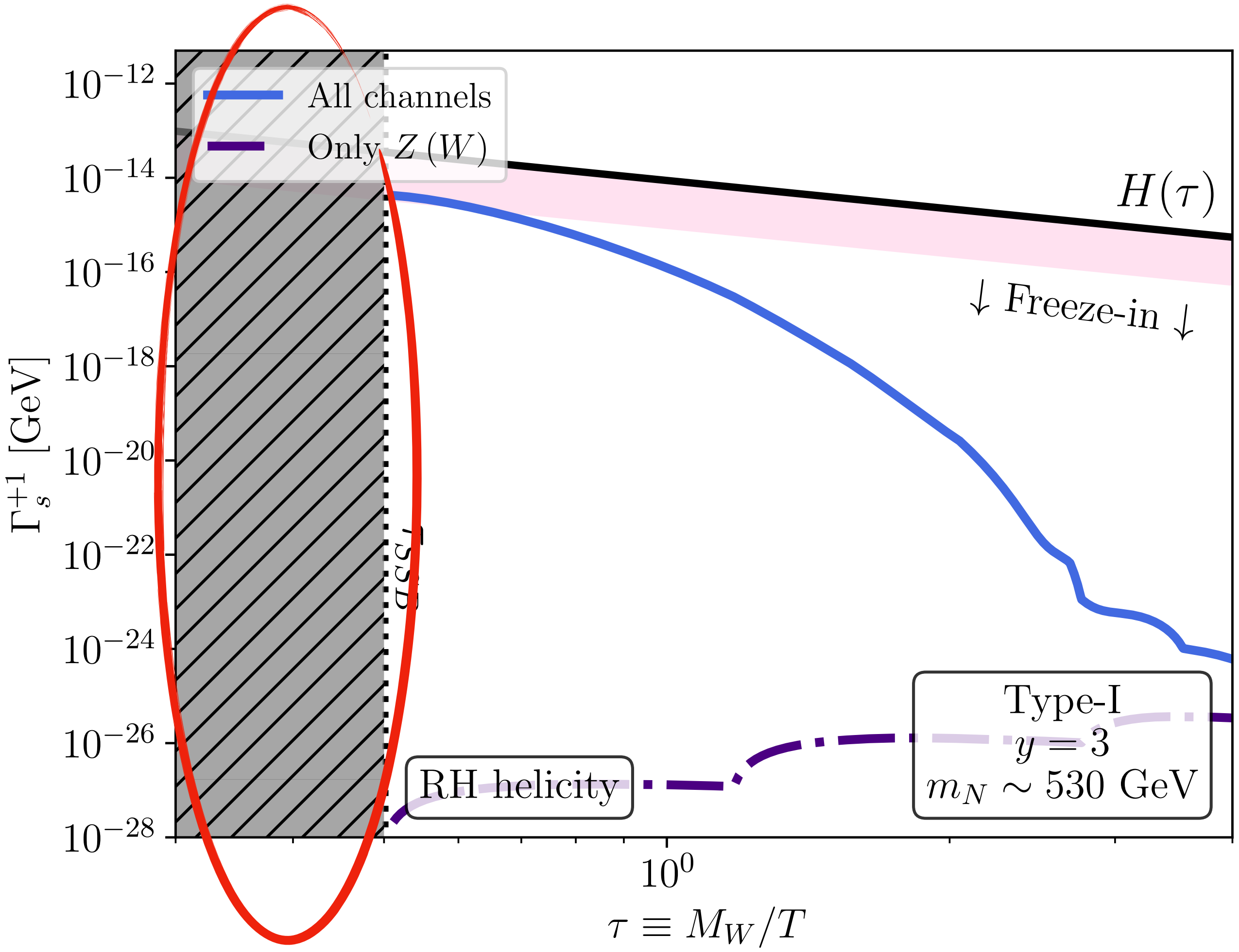
What happens for $T > T_{\rm SSB}$?

$$2 \rightarrow 2,\ 1 \rightarrow 3\ldots$$





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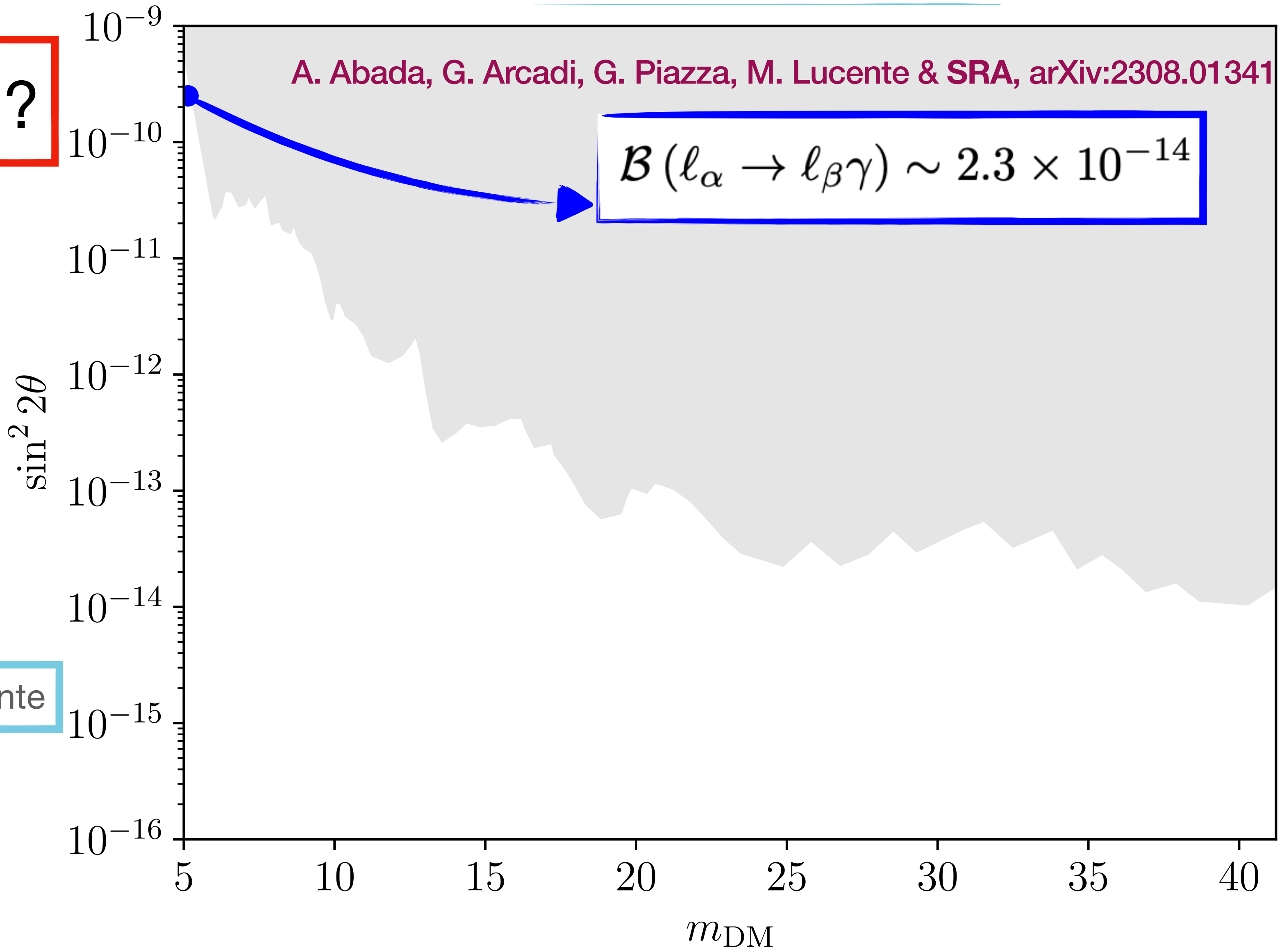
$2 \to 2,\ 1 \to 3 \ldots$

What is the allowed parameter space?

Work in progress with A. Abada, G. Arcadi & M. Lucente



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$\mathcal{B}\left(\ell_\alpha \to \ell_\beta \gamma\right) \sim 2.3 \times 10^{-14}$