New Target and Probes of Sterile Neutrino Dark Matter

Yue Zhang

Carleton University

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Sterile Neutrino as Dark Matter

*Not related to recent MicroBooNE or MiniBooNE results.

Outline

Introduce a gauge singlet fermion, mix it with SM neutrinos

$$\nu_4 = \cos\vartheta\, \nu_s + \sin\vartheta\, \nu_a$$

Flavor eigenstates: ν_a active, weakly interacting, ν_s pure singlet.
ϑ is vacuum mixing angle.

DM relic abundance target

Experimental probes

Non-Thermal

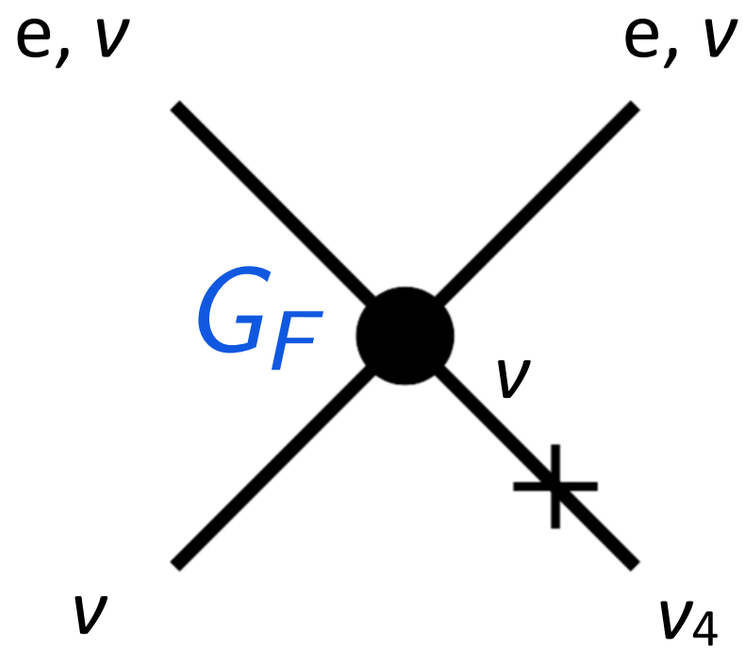
Fully thermalizing ν_4 with SM sector overclose the universe:

$$\Omega_4 \sim 10 \left(\frac{m_4}{\mathrm{keV}} \right)$$

Fermion ν_4 must be heavier than keV scale (Tremaine, Gunn 1979).

Must be produced in a non-thermal way with a small $\vartheta << 1$.

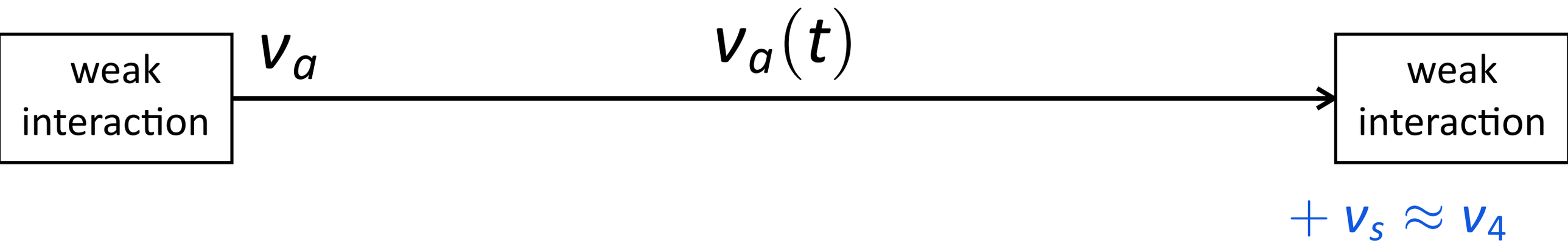
Dodelson-Widrow Mechanism



Tiny mixing angle ϑ controls the relic density.

hep-ph/9303287

Neutrino Oscillation in Early Universe



Two time scales:

In the thermal bath, neutrino after produced remains coherent state until destroyed.

In between, active-sterile neutrino oscillation occurs.

The Key Equation

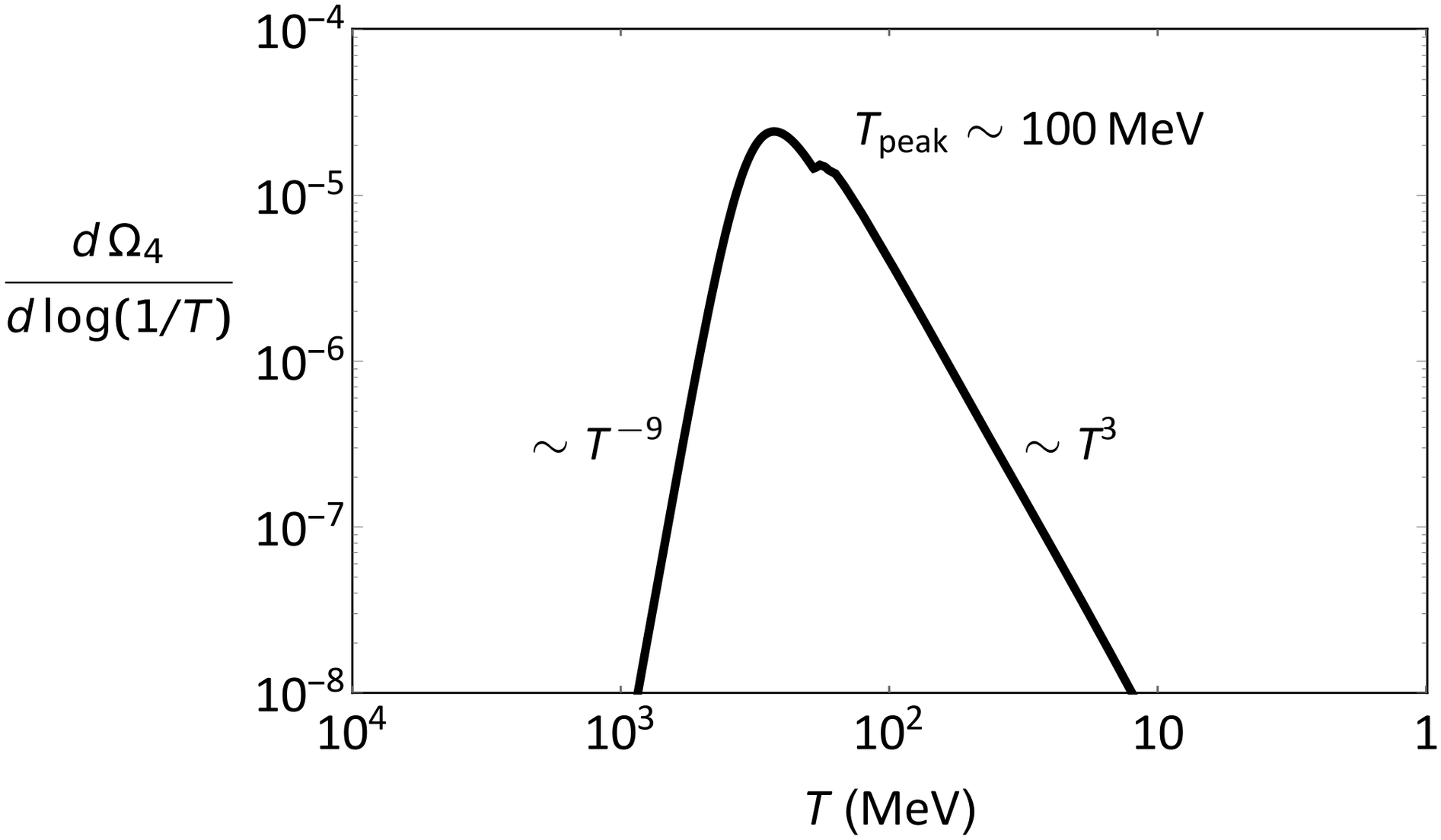
$$\frac{df_4}{d\log(1/T)} = \frac{\Gamma}{2H} P_{\nu_a \to \nu_4} f_a$$

Γ/H : Counts number of cycles for the above oscillation process to repeat before neutrino decoupling.

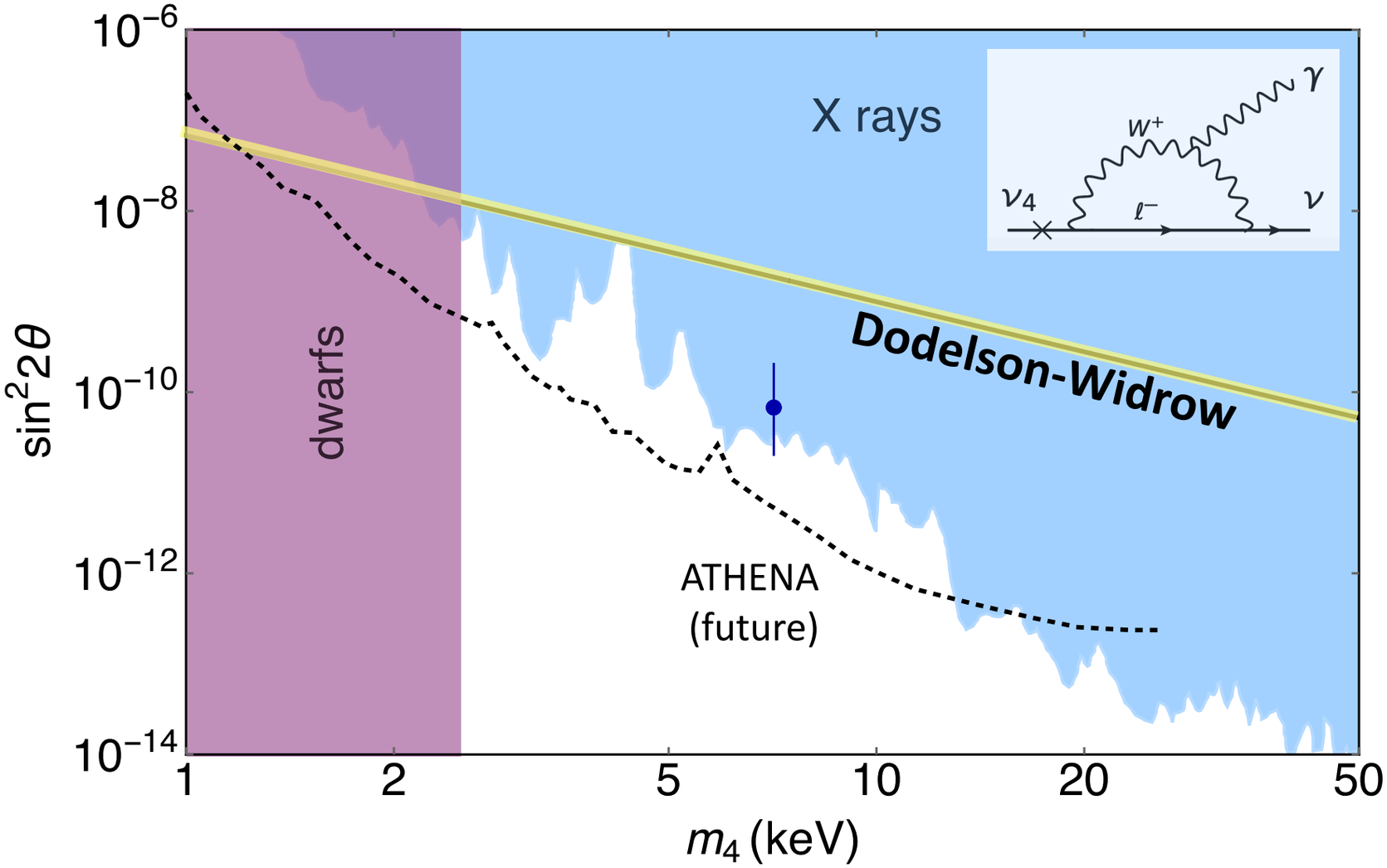
Quantum Zeno effect: $P_{\nu_a \to \nu_4}$ highly suppressed for very large Γ

At low temperatures $P_{\nu_a \to \nu_4} \sim sin^2 2\theta$

Production Time Window



Severely Constrained



Abazajian (1705.01837)

A Simple Idea

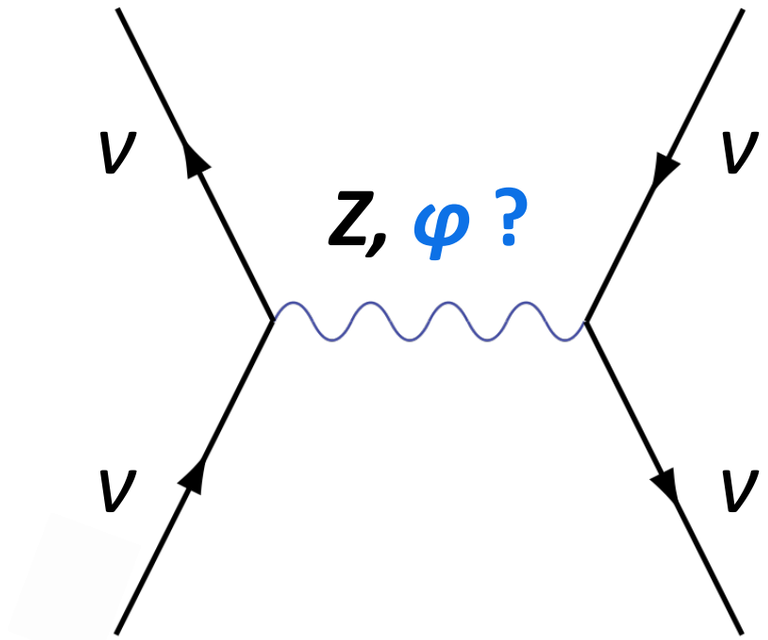
$$\Omega_4 \propto [\text{weak interaction rate}] \times \sin^2 2\theta$$

total

Intuition: compensate smaller mixing with larger reaction rate.

Fact: beyond Standard Model neutrino interactions with known particles (e.g. electron) already tightly constrained
— resort to neutrino self-interactions.

Neutrino Self Interaction

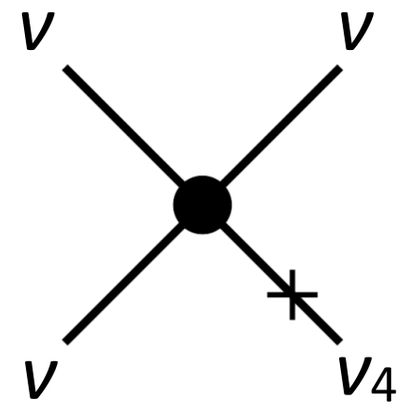


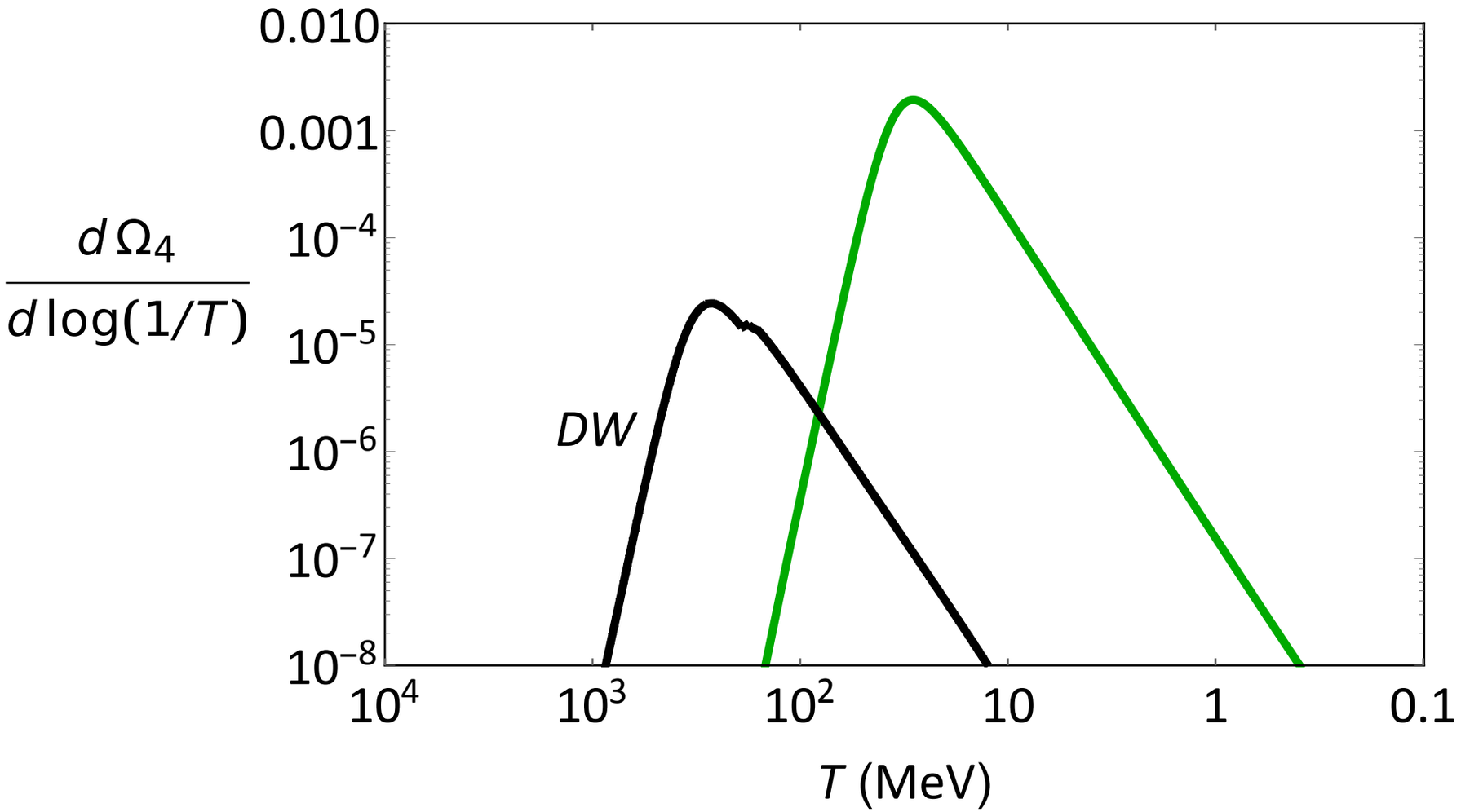
Never directly measured. Allowed to be much stronger.

Consider a new scalar that dominantly couples to neutrinos

$$\mathcal{L}_{\text{int}} = \lambda \nu \nu \varphi + \text{h.c.}$$

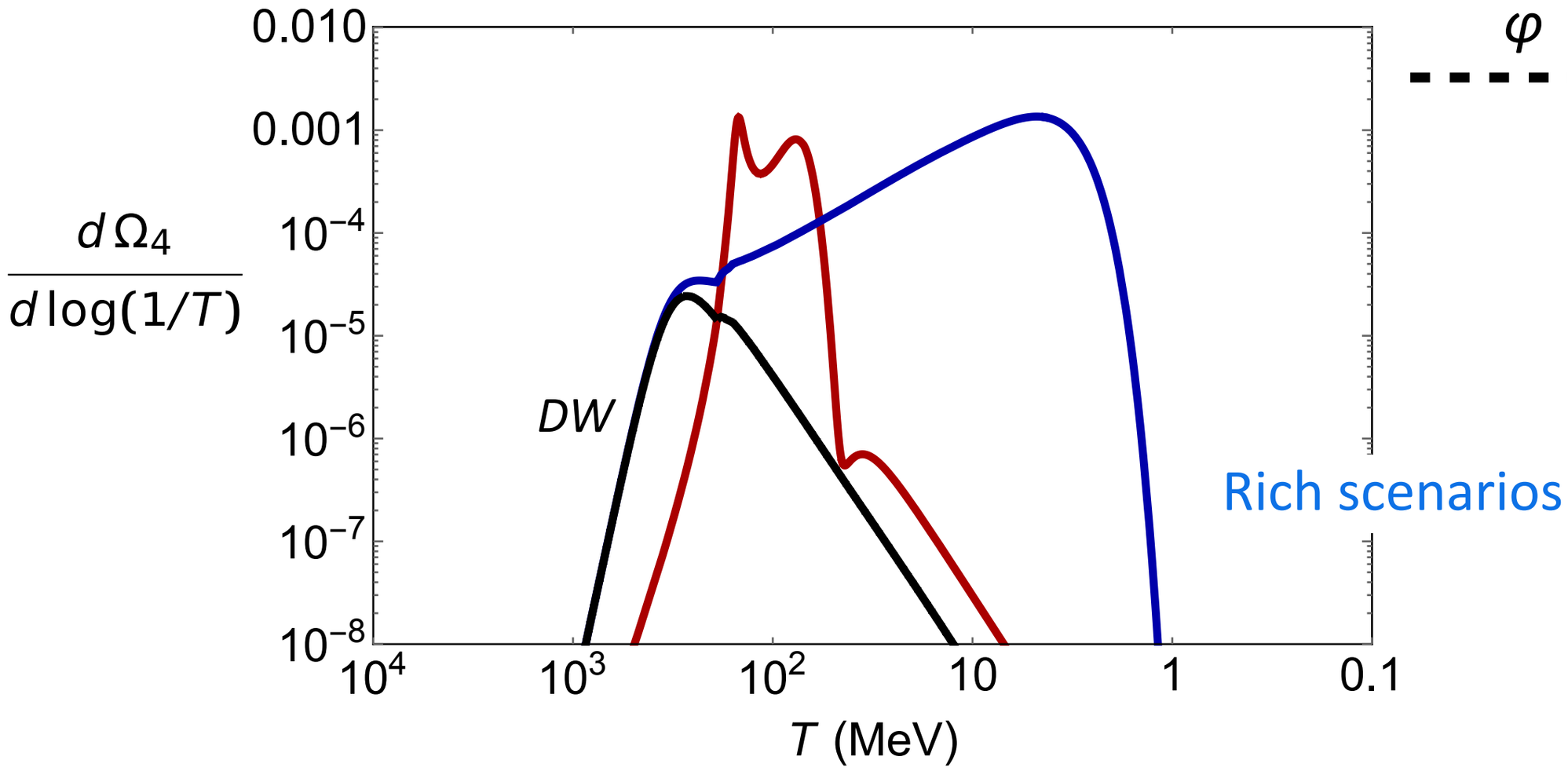
Production with a Heavy Mediator

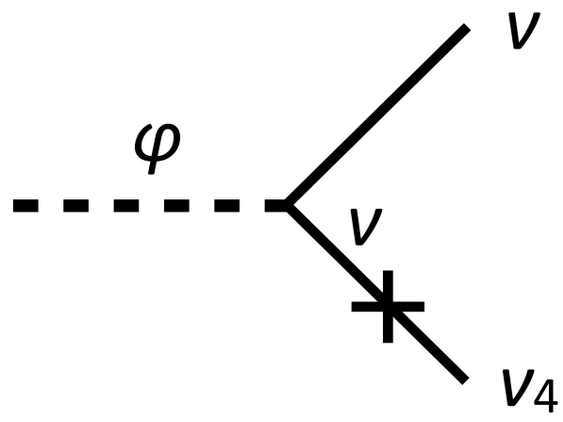




Final relic density: $\Omega_4 \propto \frac{\lambda^3}{m_\varphi^2} \gg \frac{g^3}{M_W^2}$

Production with a Light Mediator

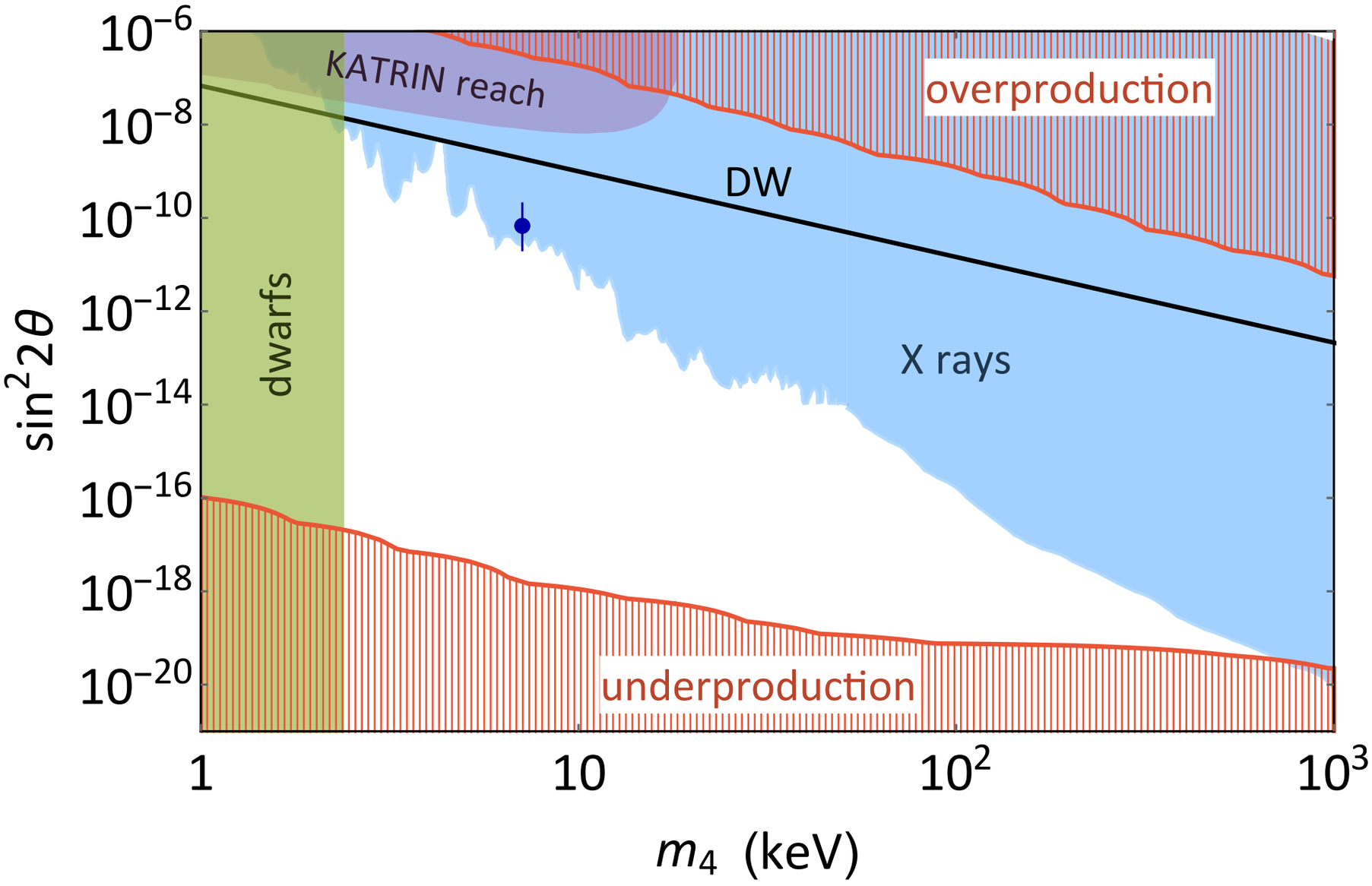




When $T>m_\varphi$, φ exists in thermal bath, decays to ν_4.

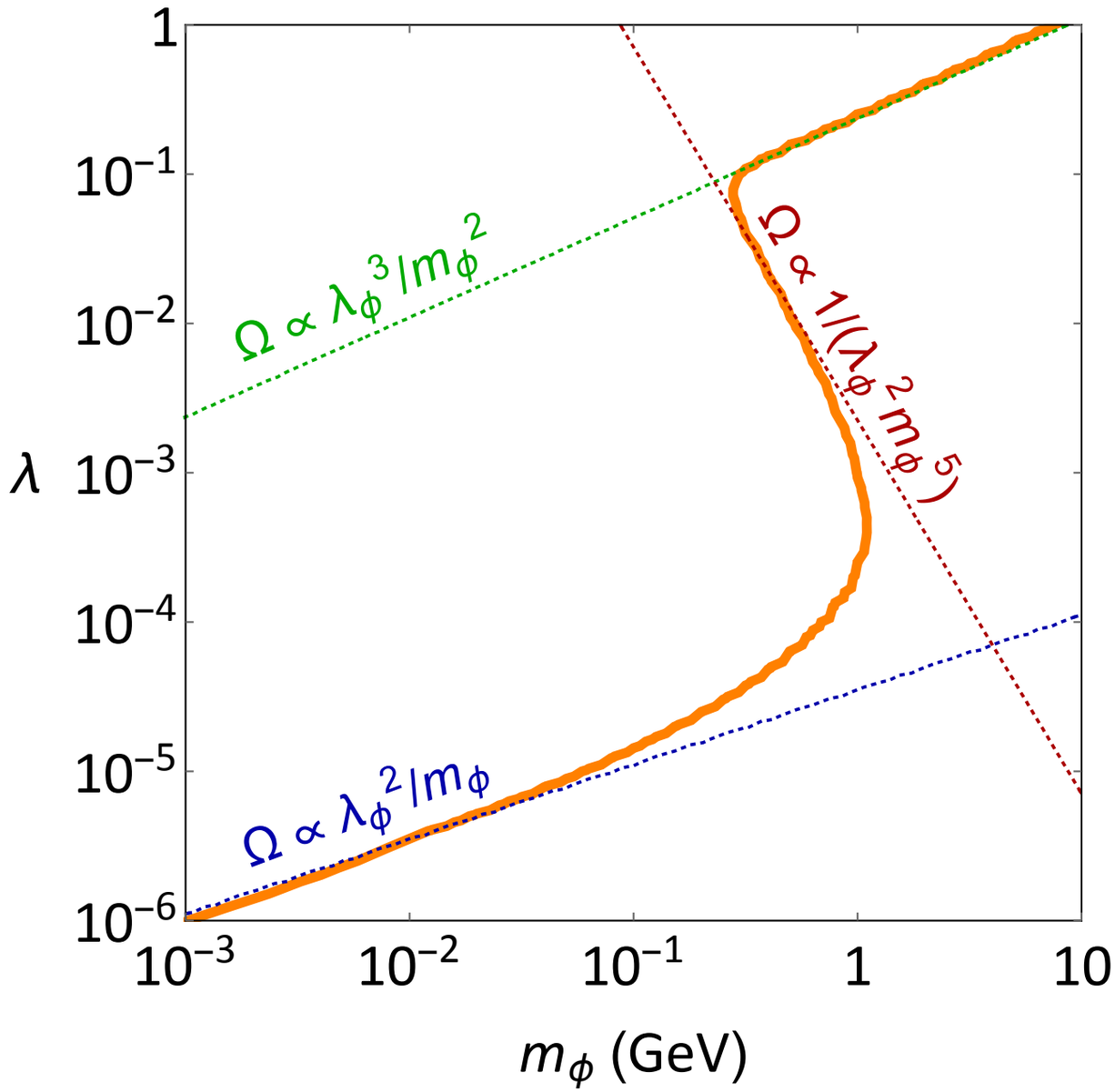
$\Gamma_{\text{decay}} \sim \lambda^2$, more important than scattering for $\lambda << 1$.

Opens Up Wide Window



de Gouvêa, Sen, Tangarife, YZ (1910.04901)

Scalar Mass and Coupling

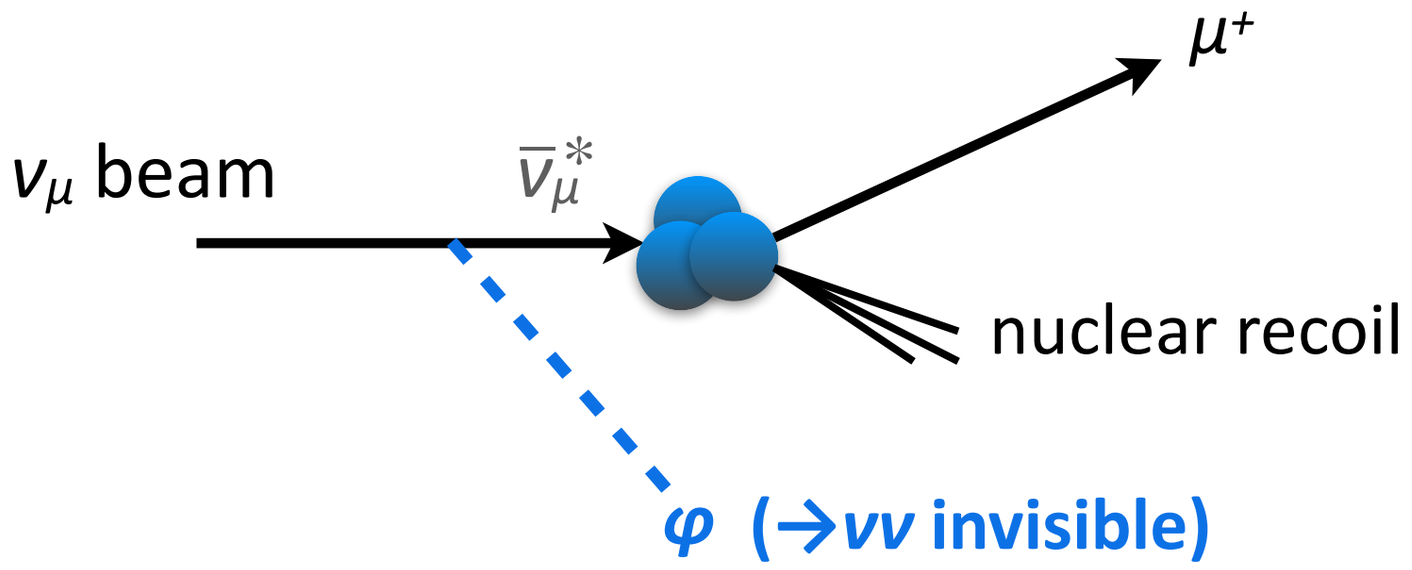


$\sin^2 2\vartheta = 7\text{x}10^{-11}$

m_4=7.1 keV

de Gouvêa, Sen, Tangarife, YZ (1910.04901)

Mono-Neutrino Signal

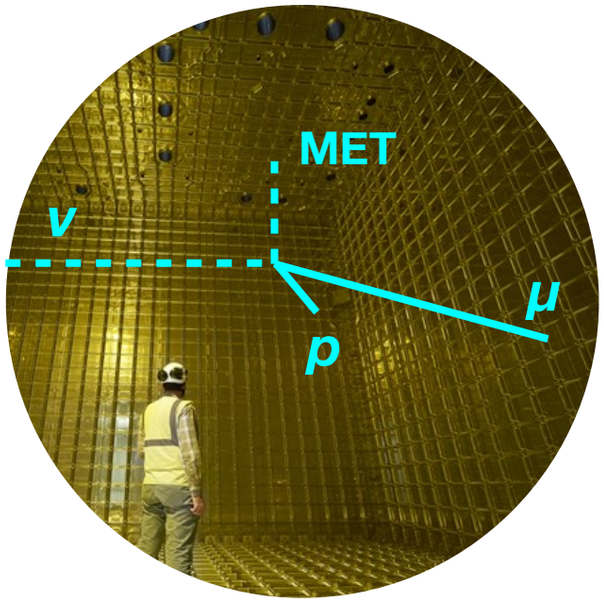


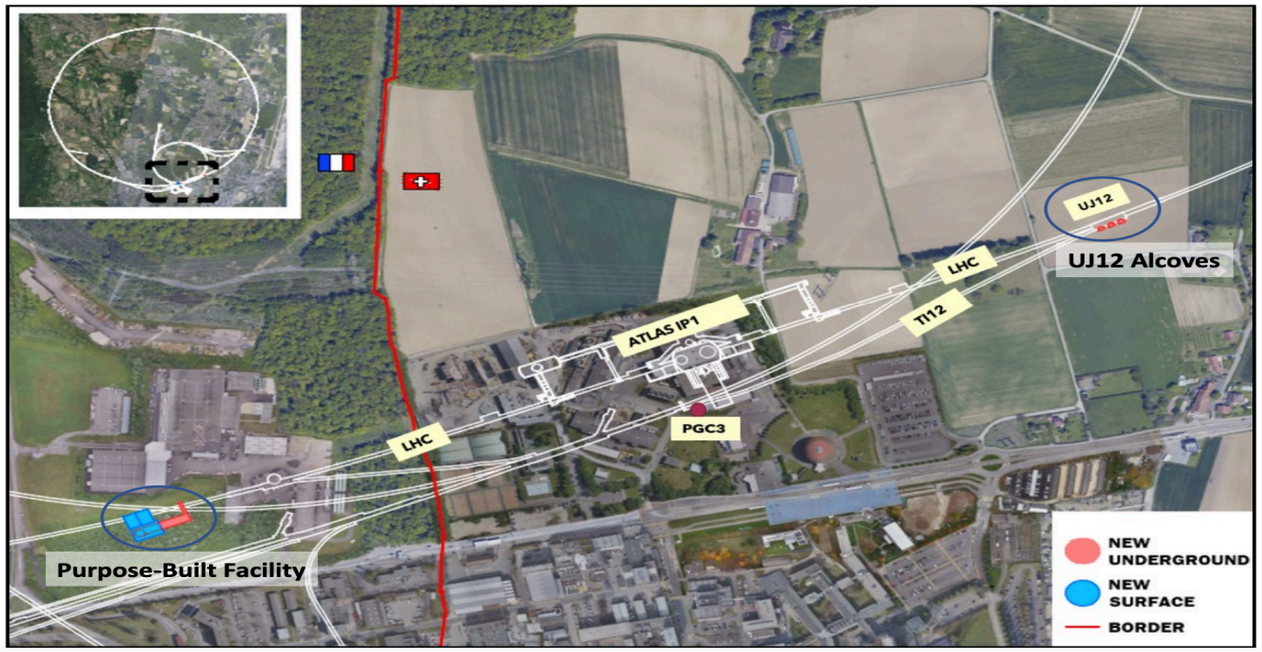
Signatures:

- "Wrong-sign" outgoing muon
- Missing transverse momentum p_T

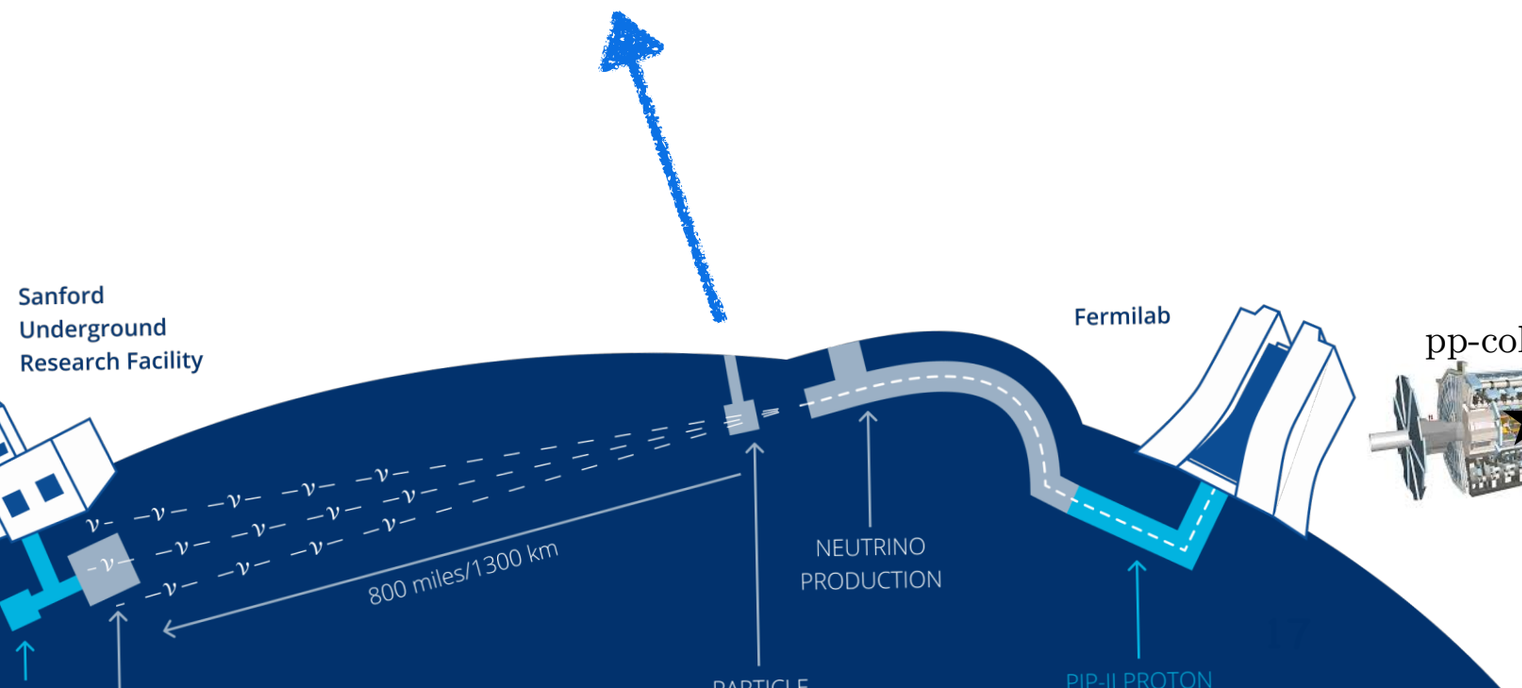
Kelly, YZ (1901.01259)

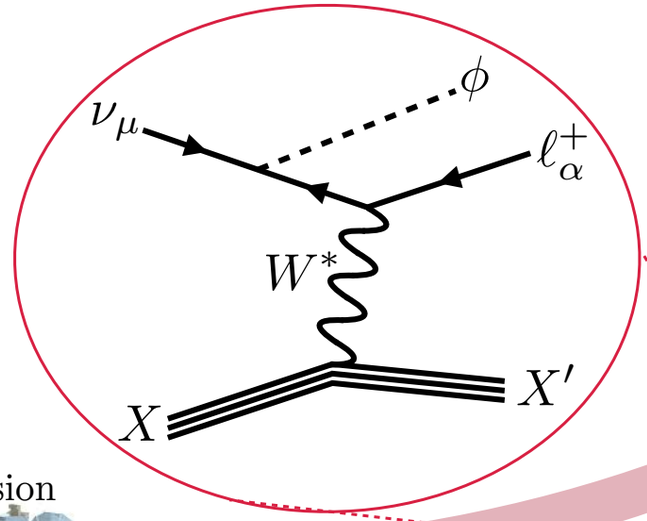
DUNE & Forward Physics Facility

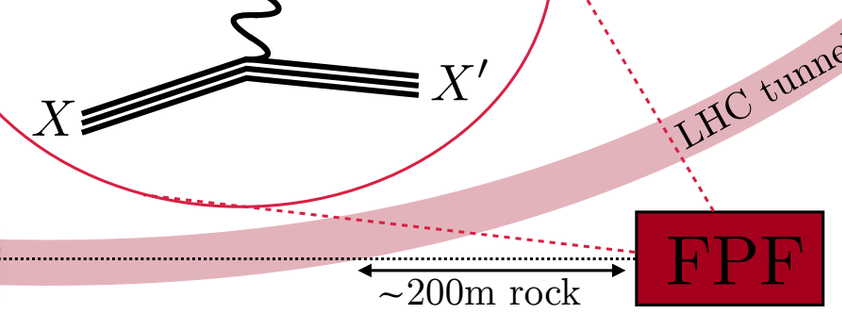




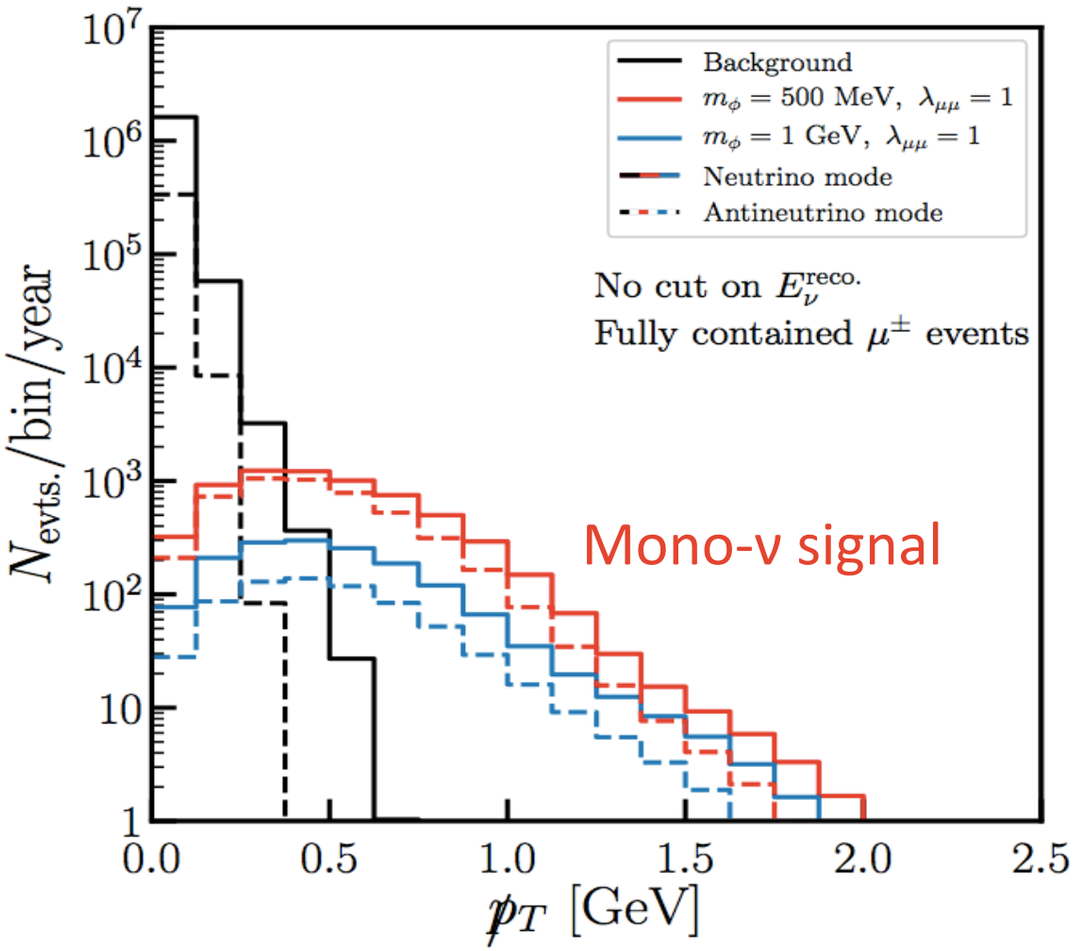
(Near detector)







Missing Transverse Momentum

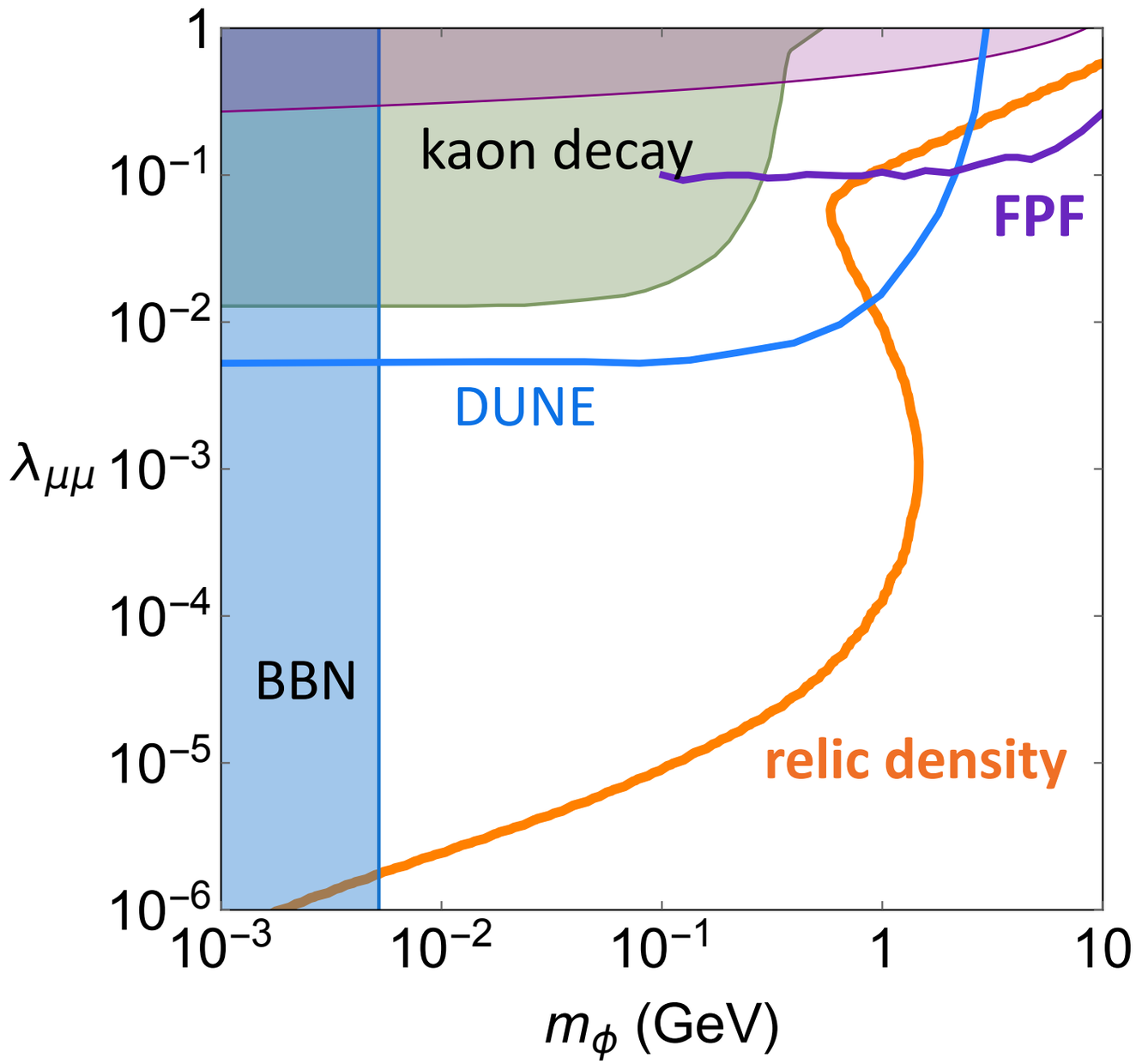


Kelly, YZ (1901.01259)

Theorists' estimate: nucleon level simulation, final state energy smearing based on DUNE CDR (2015)

$$3\%/\sqrt{E_{\text{muon}}[\text{GeV}]},\ 20\%/\sqrt{E_{\text{proton}}[\text{GeV}]},\ 40\%/\sqrt{E_{\text{neutron}}[\text{GeV}]}$$

Coverage



Kelly, YZ (1901.01259)

Kelly, Kling, Tuckler, YZ (2111.xxxxx)

Conclusion

This talk discussed a novel neutrino-dark matter connection.

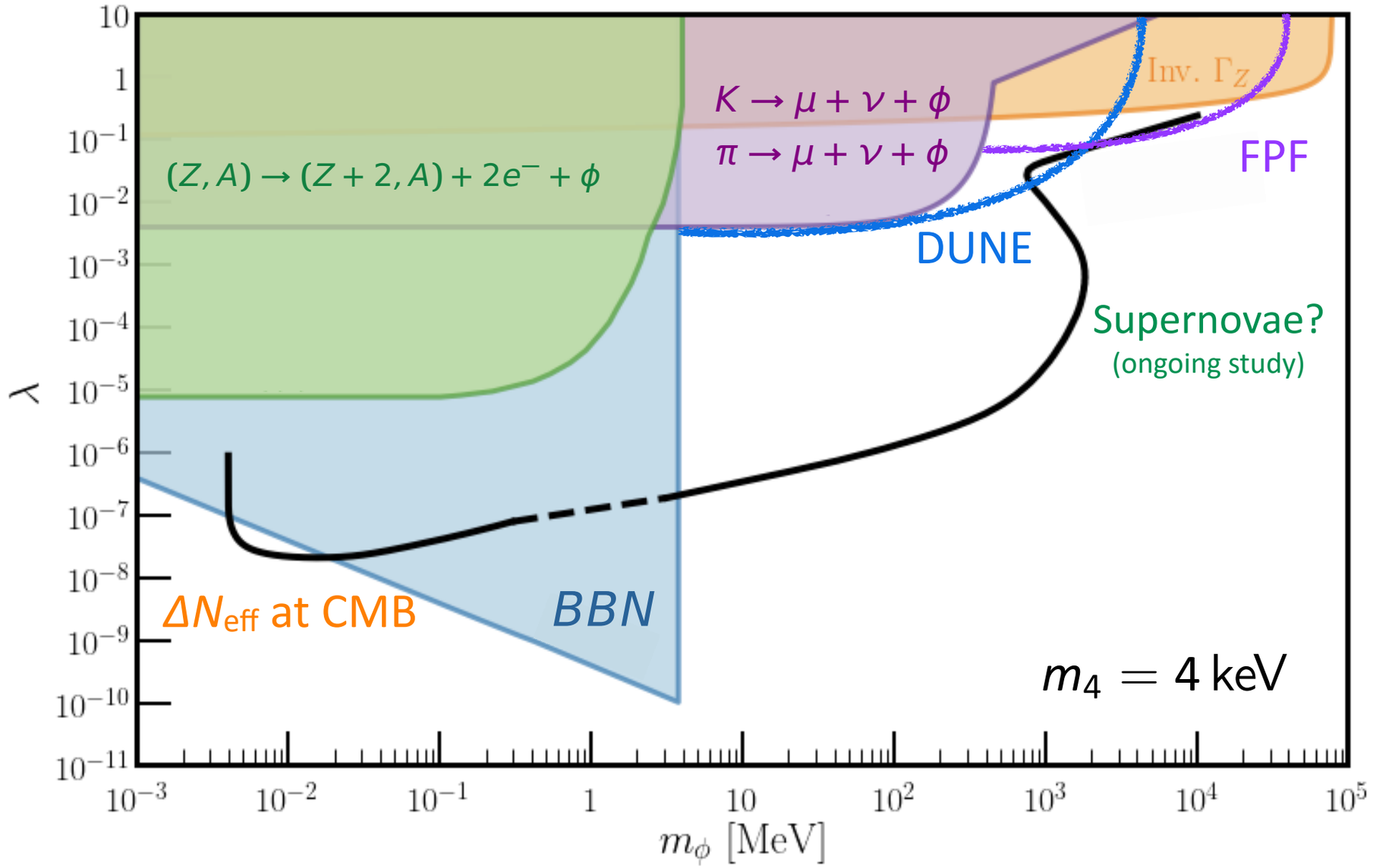
Active neutrino self-interaction via a light mediator can play instrumental role in the origin of sterile neutrino dark matter.

A number upcoming particle and astro (see also 2011.02487) experiments can probe such a target.

thanks!

deleted scene

Broad Mass Window



Kelly, Sen, YZ (2011.02487)