# New Target and Probes of Sterile Neutrino Dark Matter

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# Outline

Introduce a gauge singlet fermion, mix it with SM neutrinos

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

Flavor eigenstates: $\nu_a$ active, weakly interacting, $\nu_s$ pure singlet.
$\vartheta$ is vacuum mixing angle.

DM relic abundance target

Experimental probes

# Non-Thermal

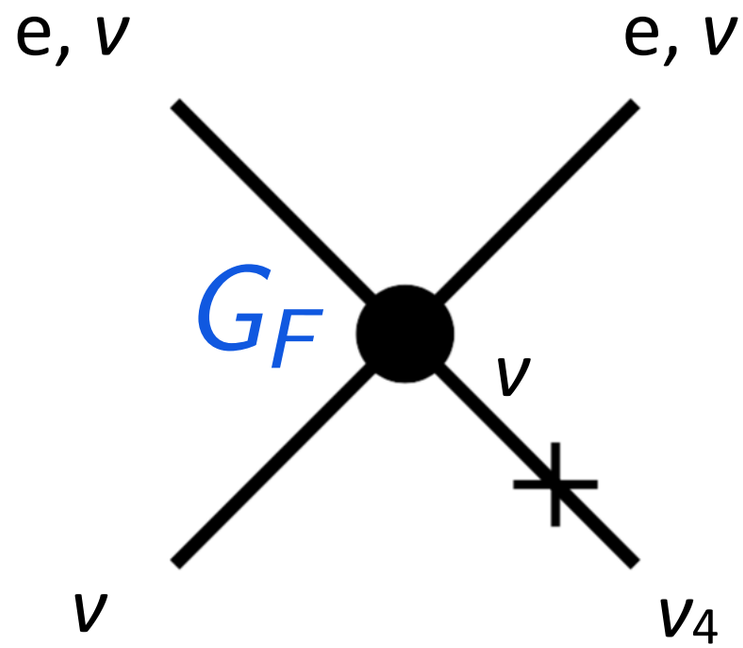
Fully thermalizing $\nu_4$ with SM sector overclose the universe:

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

$\nu_4$ heavier than keV from dwarf galaxies (Tremaine, Gunn 1979).

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

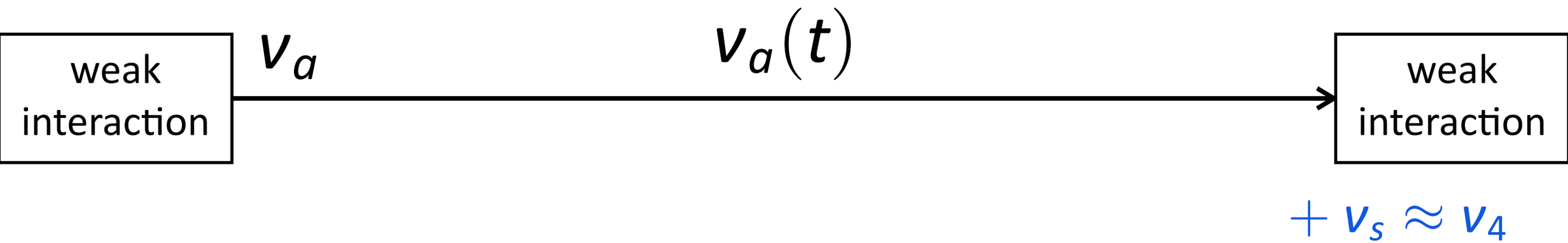
# Dodelson-Widrow Mechanism




Tiny mixing angle $\vartheta$ 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

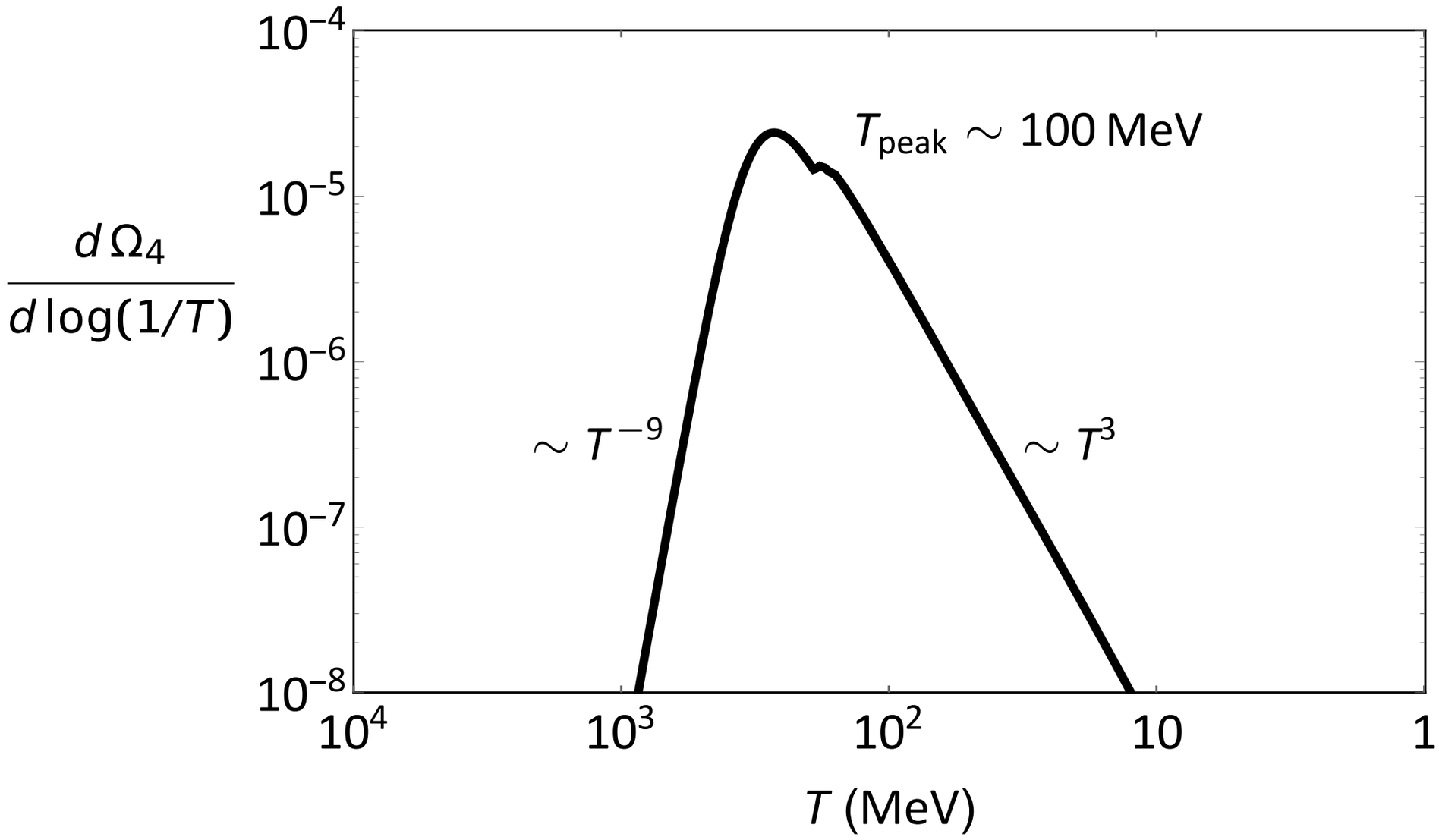
$$\frac{df_4}{d\log(1/T)} = \frac{\Gamma}{2H} P_{\nu_a \to \nu_4} f_a$$

$\Gamma/H$ : Counts number of cycles for the above process to repeat before neutrino decoupling.

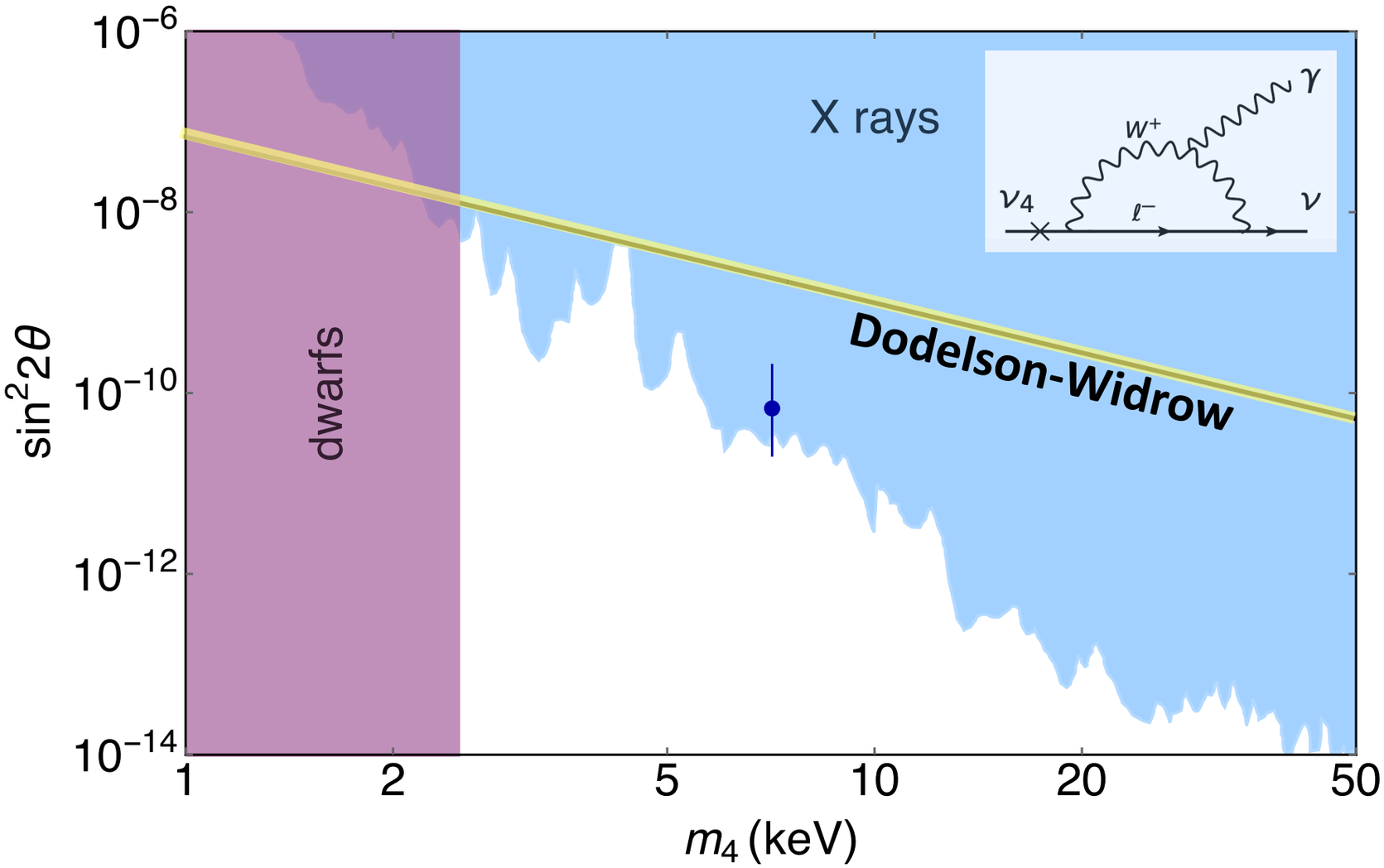
Roughly $P_{\nu_a \to \nu_4} \sim sin^2 2\theta$

Subtlety, $P_{\nu_a \to \nu_4} \sim sin^2 2\theta$ is highly suppressed for very large $\Gamma$.

# Production Time Window



# Severely Constrained




Abazajian (1705.01837)

# A Simple Idea

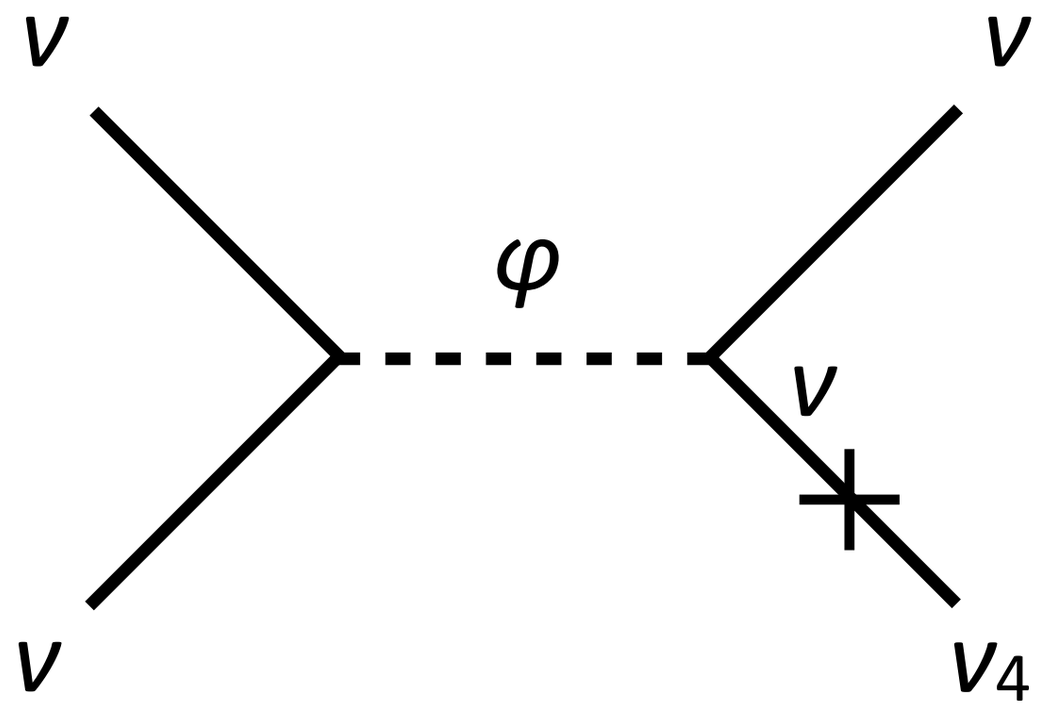
$$\Omega_4\,[\mathrm{DW}] \sim \Gamma_w \times \sin^2 2\vartheta$$

$\Gamma_w$ given by weak interaction; *X*-ray constrains $\vartheta$.

Intuition: compensate smaller mixing with larger reaction rate.

BSM neutrino interactions with known particles (e.g. electron, photon) tightly constrained. Resort to neutrino self interaction: never directly measured, allowed to be much stronger.

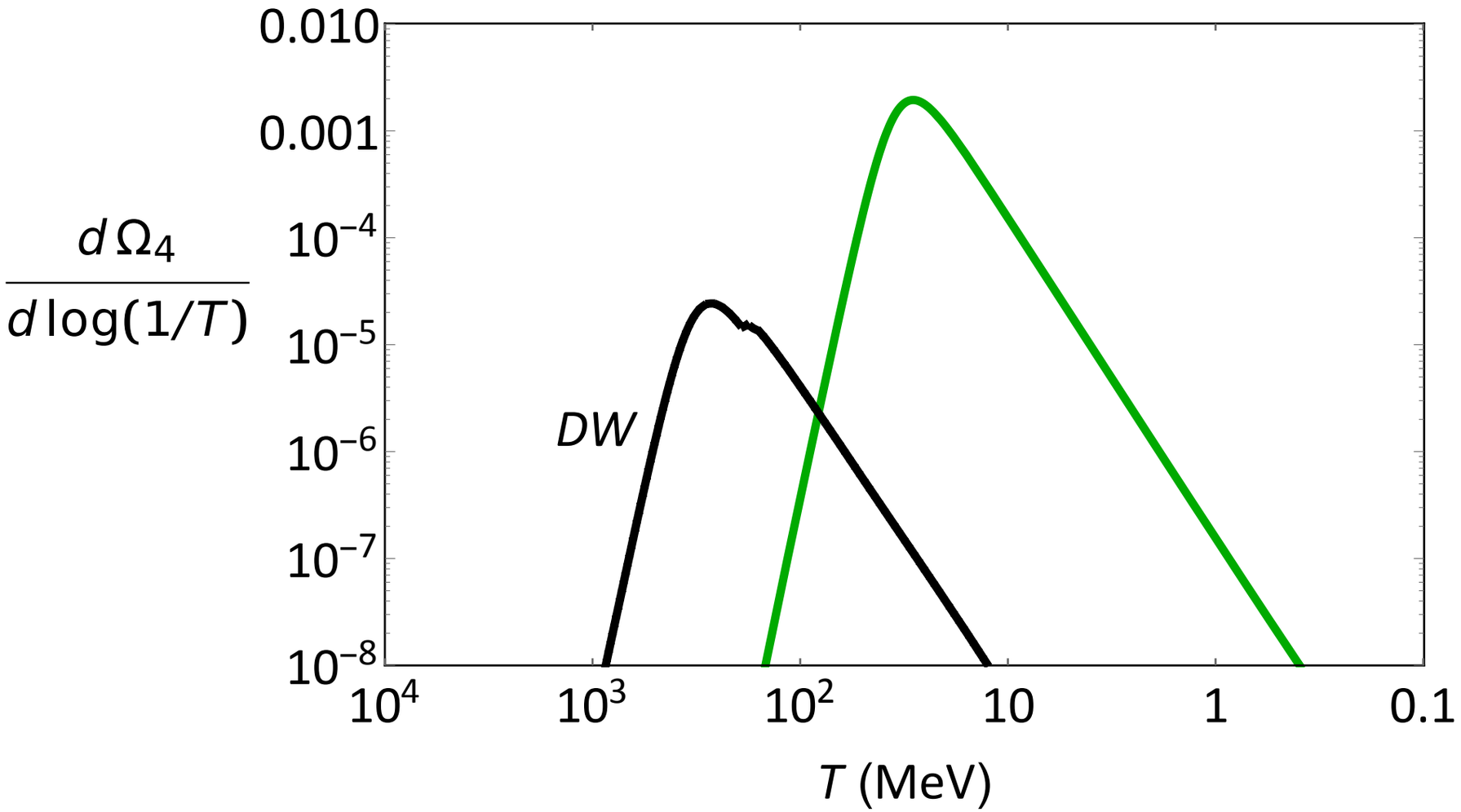
# Majoron-like Scalar Mediator




New dark matter production model

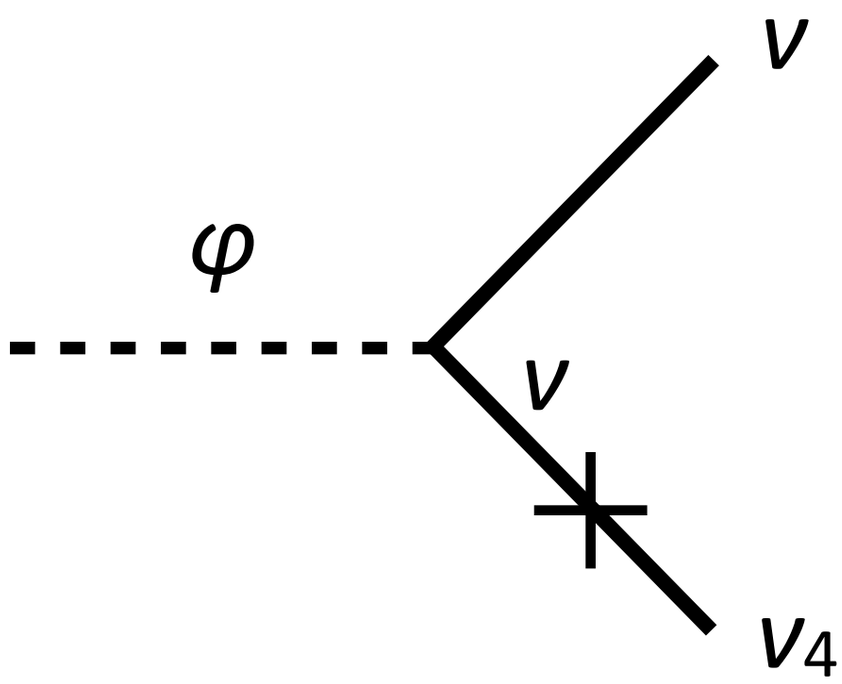
de Gouvêa, Sen, Tangarife, YZ (1910.04901)

# Case of Heavy Mediator




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

# Case of Light Mediator

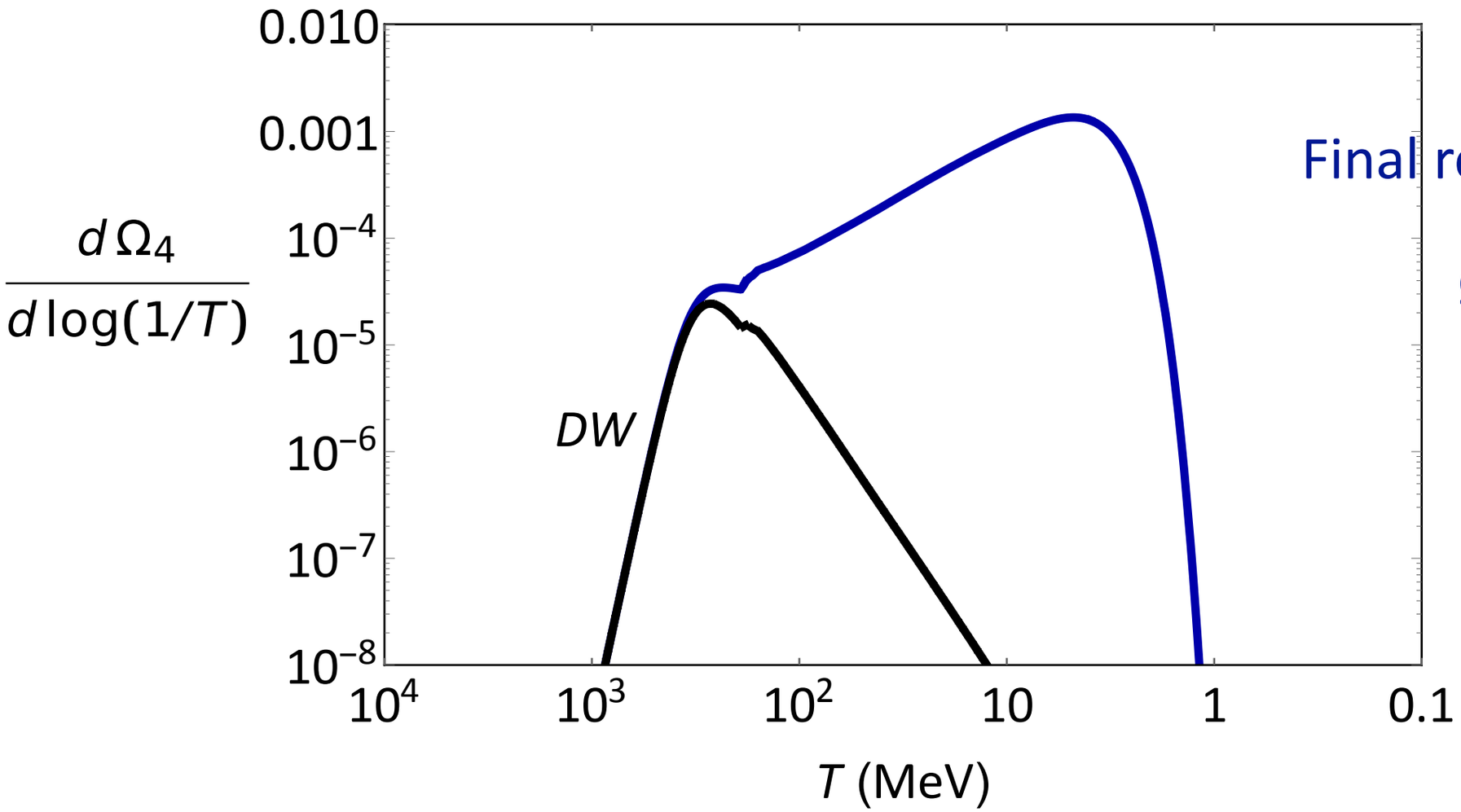



When $T > m_\varphi$, $\varphi$ exists in thermal bath, decays to $\nu_4$.

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

**Opens up new parameter space.**

# Case of Light Mediator

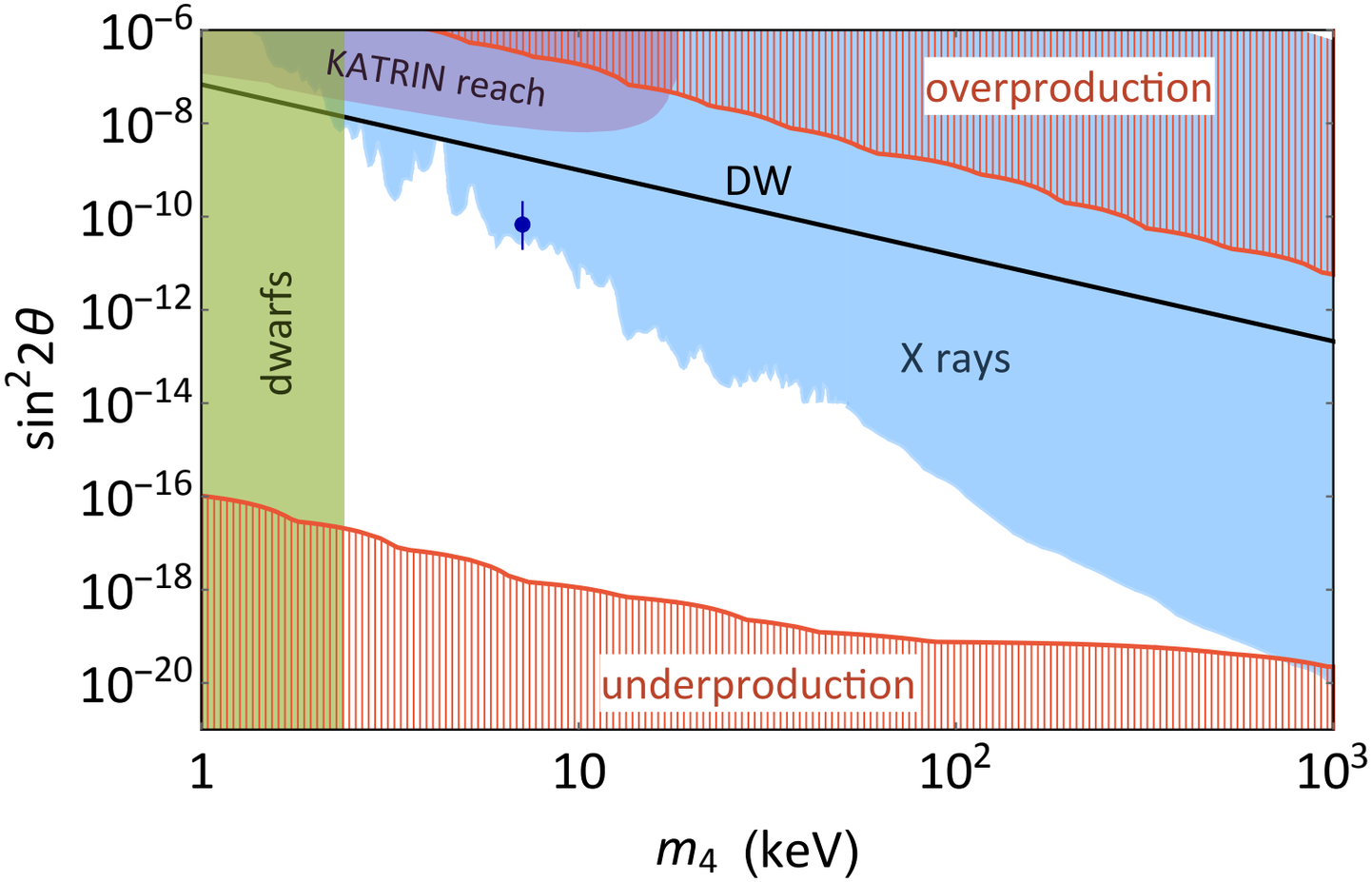



Final relic density:

$\Omega_4 \propto \lambda^2/m_\varphi$

Additional scenario: new interaction can also impact mixing angle

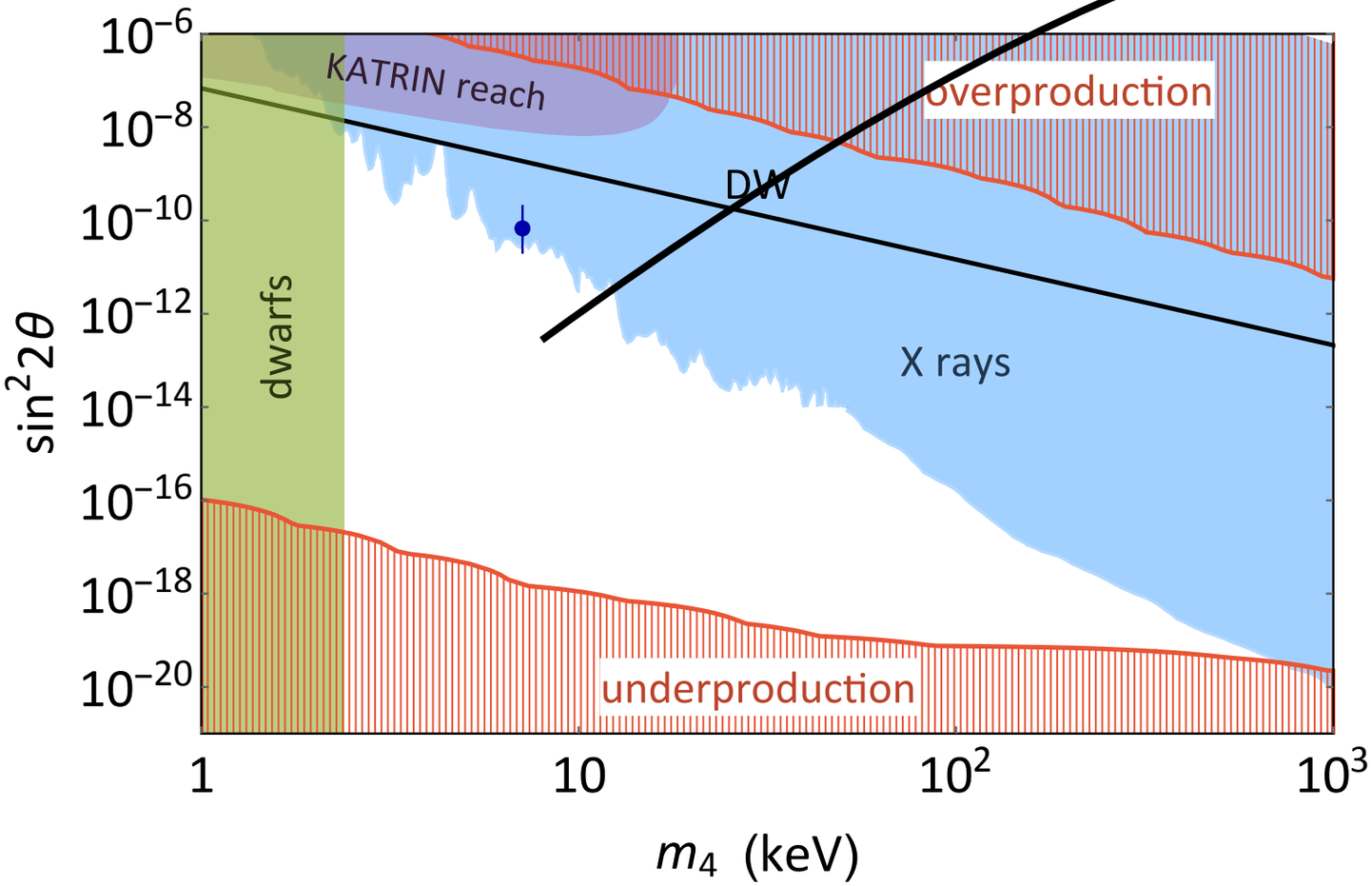
# Wide Window for Relic Density

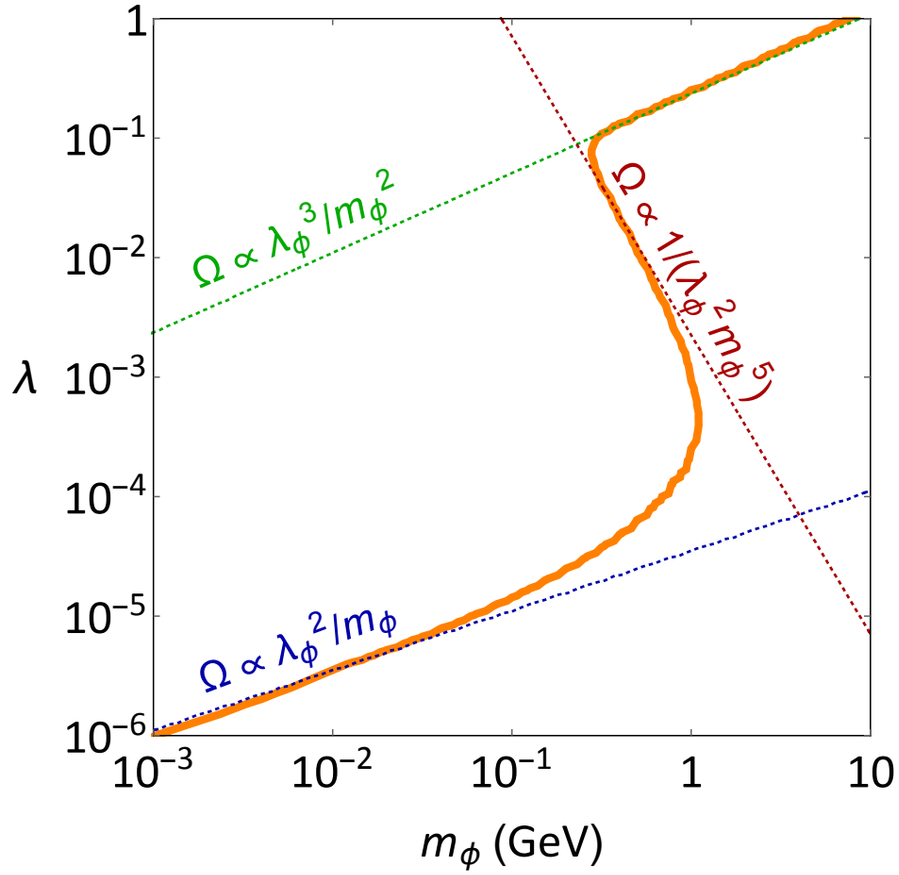



de Gouvêa, Sen, Tangarife, YZ (1910.04901)

# Wide Window for Relic Density

Take any point from the left figure

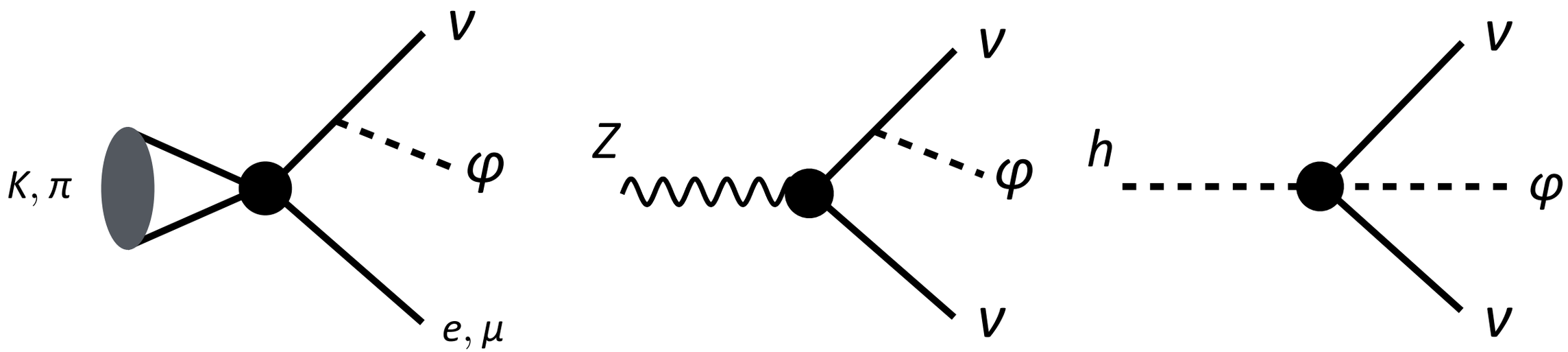



de Gouvêa, Sen, Tangarife, YZ (1910.04901)

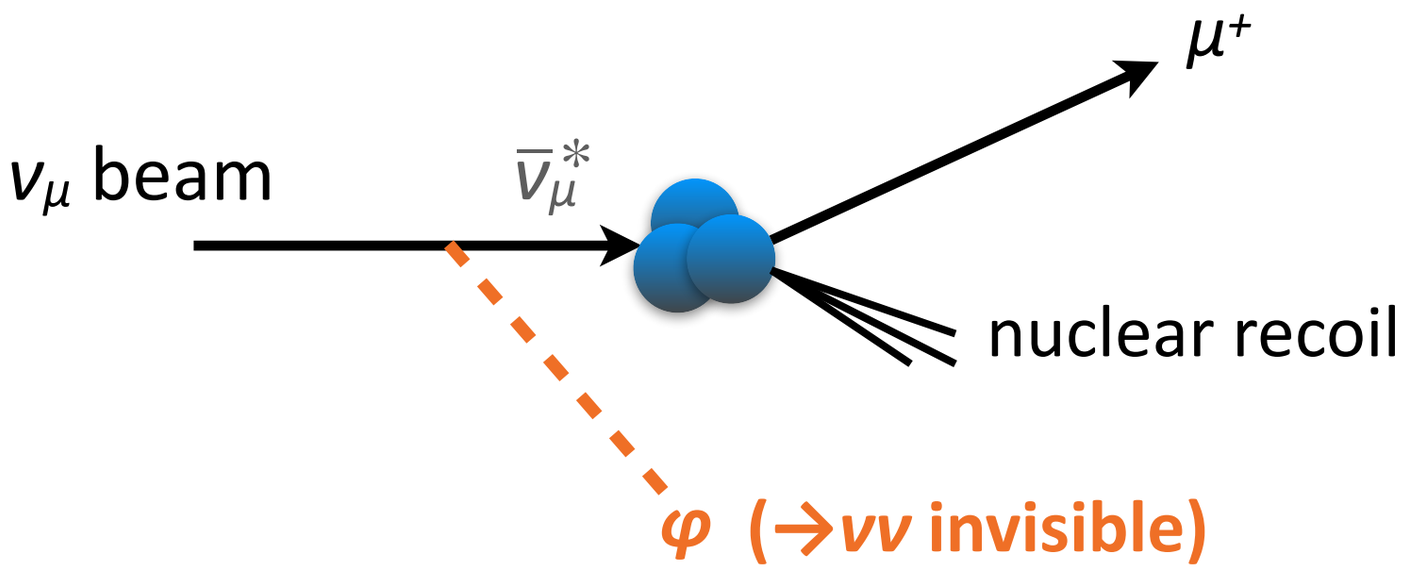
# Probing Neutrino Self Interaction

# Meson, *Z*, Higgs Invisible Decays




Berryman, de Gouvêa, Kelly, YZ (1802.00009)
Brdar, Lindner, Vogl, Xu (2003.05339)
Pasquini, Perez (1511.01811)
Barger, Keung, Pakvasa (PRD 1982)

# Mono-Neutrino Signal

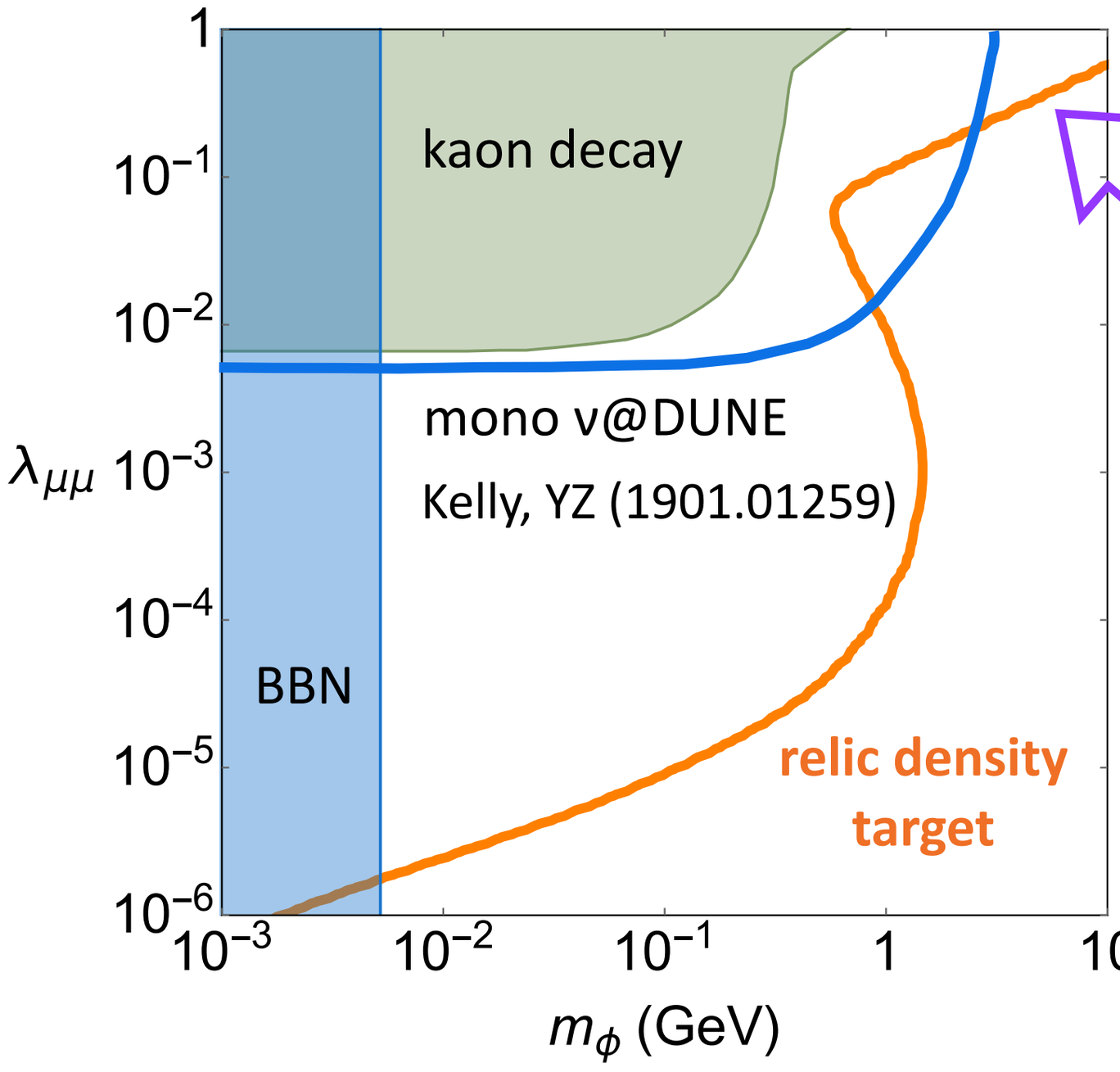



Beamstrahlung process: $\nu_\mu + N \to \mu^+ + N' + \varphi$, features

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

Kelly, YZ (1901.01259)

# Coverage

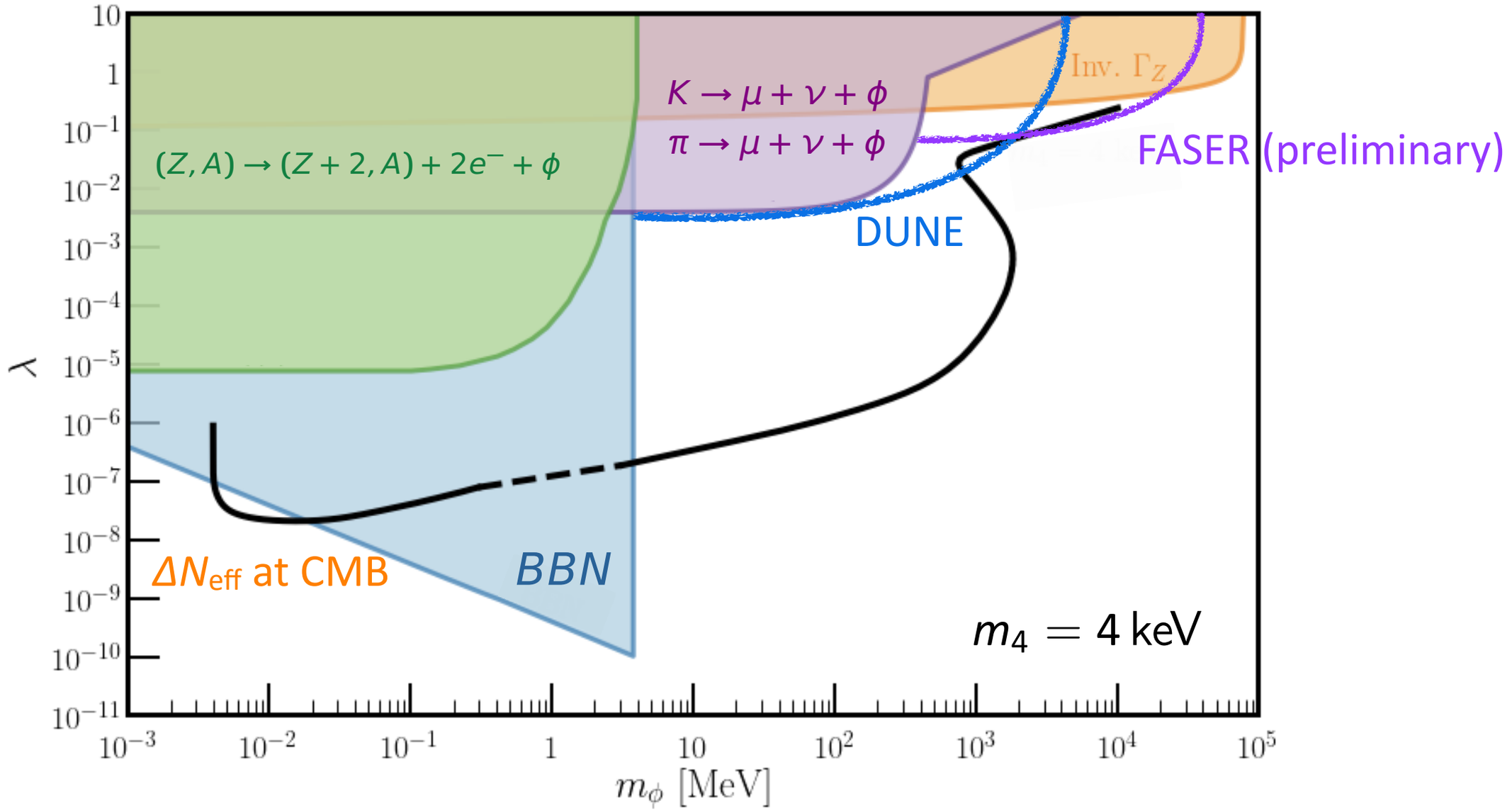



**FASERν**

Sensitive to $\varphi$ coupling to $\nu_\mu\nu_\mu$ and $\nu_\mu\nu_\tau$ flavors

Kelly, Kling, Tuckler, YZ (in preparation)

# The Big Picture




Kelly, Sen, YZ (2011.02487)

# Conclusion

Neutrino self interactions can have a novel impact on the origin of sterile neutrino dark matter.

Broad open parameter space relevant for DM relic density.

Excitingly, there are a number of ways to test this scenario with upcoming experiments.

**thanks!**