Sterile Neutrino Dark Matter

and

Neutrino Self-interaction

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Outline

Introduce a SM gauge singlet fermion and mix it with neutrinos

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

ν_4 is the sterile neutrino dark matter. Flavor eigenstates: ν_a active, weakly interacting; ν_s pure singlet. ϑ is vacuum mixing angle.

Relic abundance target (100% of dark matter)

Experimental probes

Non-Thermal Relic

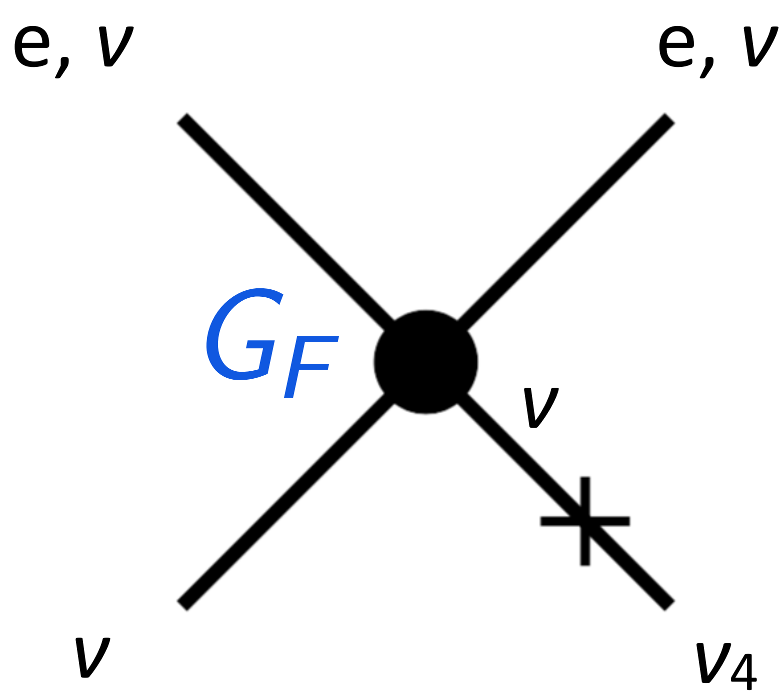
Fully thermalizing ν_4 with SM sector overclose the universe:

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

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

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

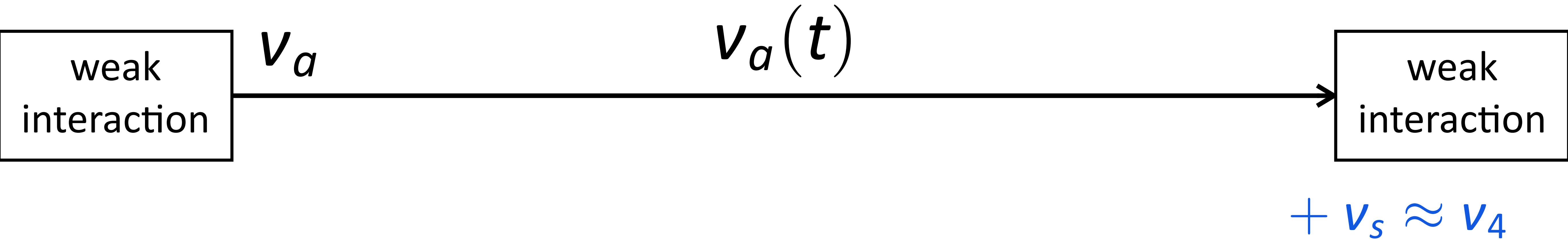
Dodelson-Widrow Mechanism



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.

Key Production Equation

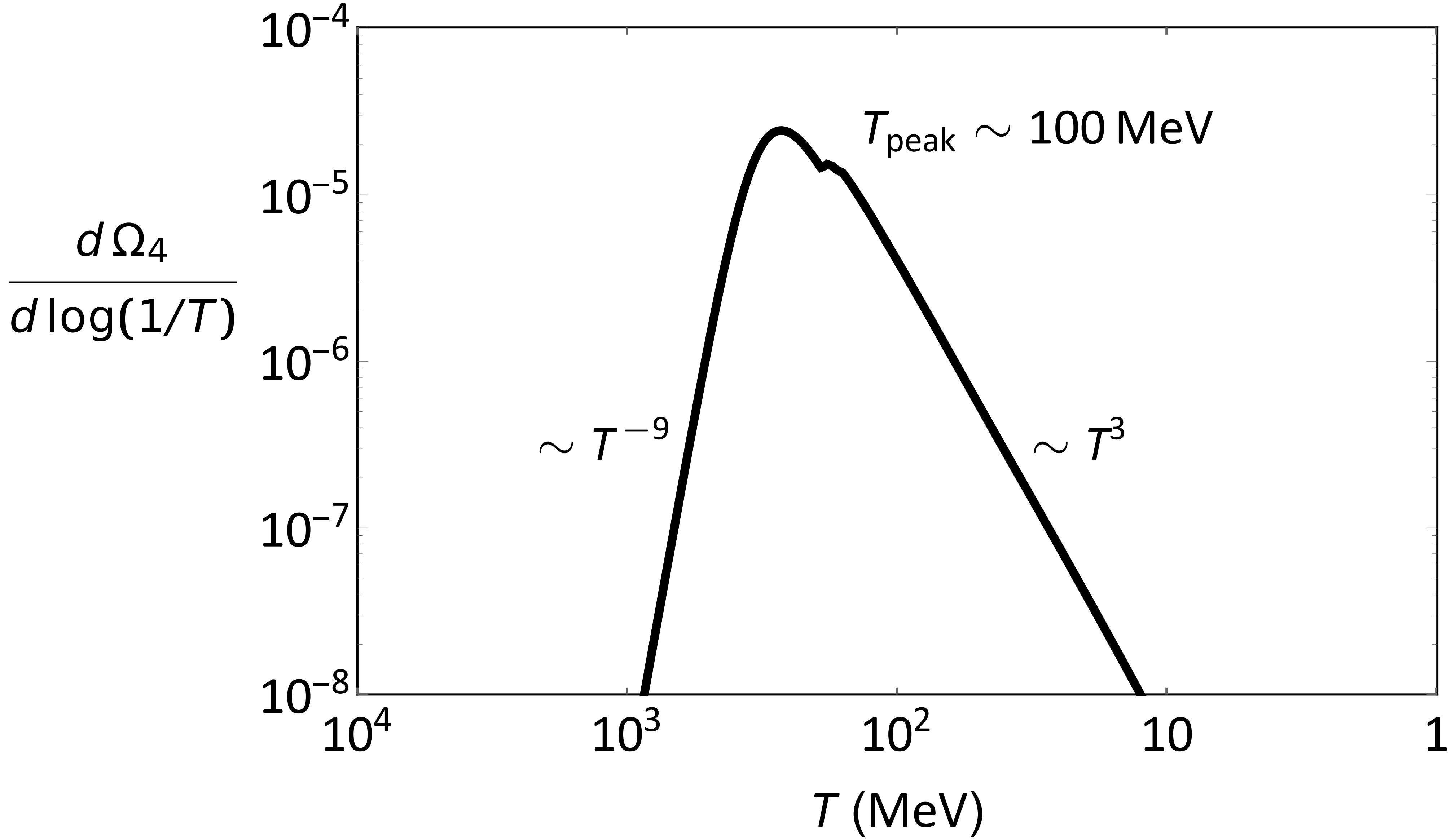
$$\frac{d f_4}{d \log(1/T)} = \frac{\Gamma}{2H} P_{\nu_a \to \nu_4} f_a$$

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

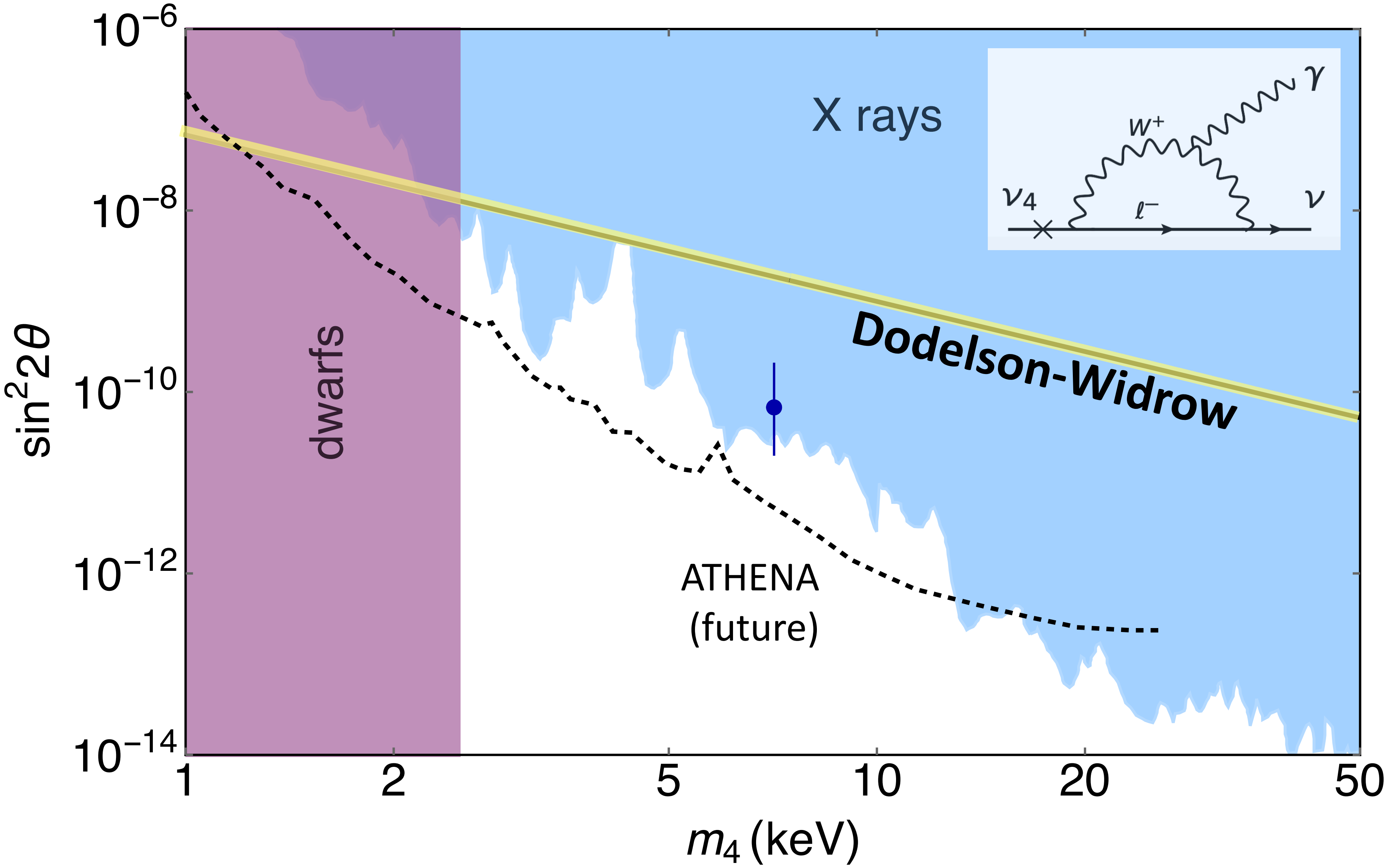
Oscillation probability per cycle:

$$P_{\nu_a \to \nu_4} = \frac{\Delta^2 \sin^2 2\vartheta}{\Delta^2 \sin^2 2\vartheta + \Gamma^2/4 + (\Delta \cos 2\vartheta - V_T)^2}$$

Production Time Window

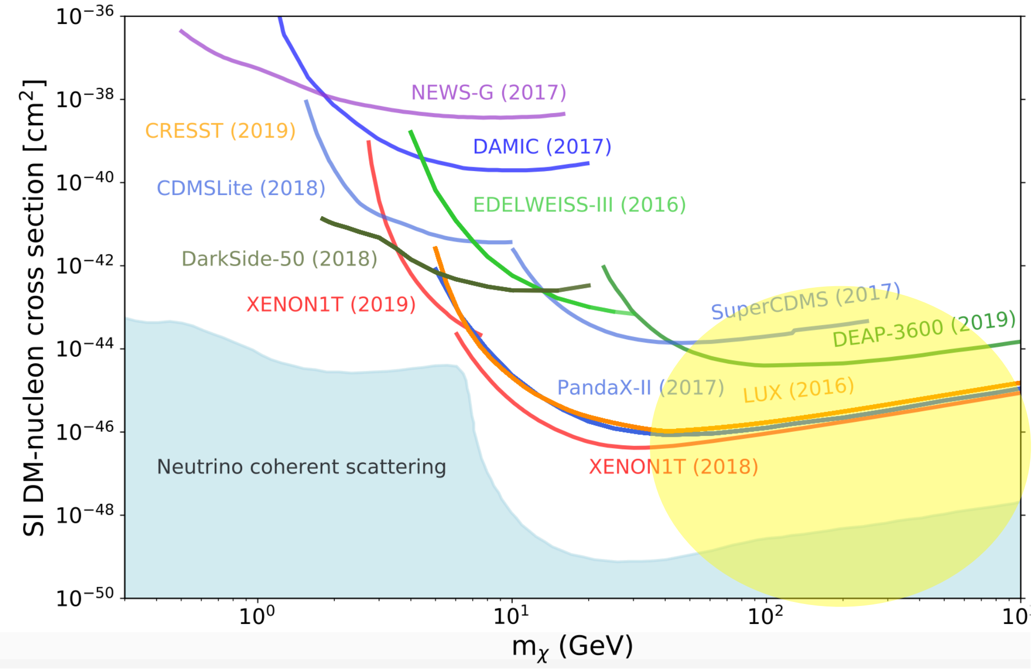


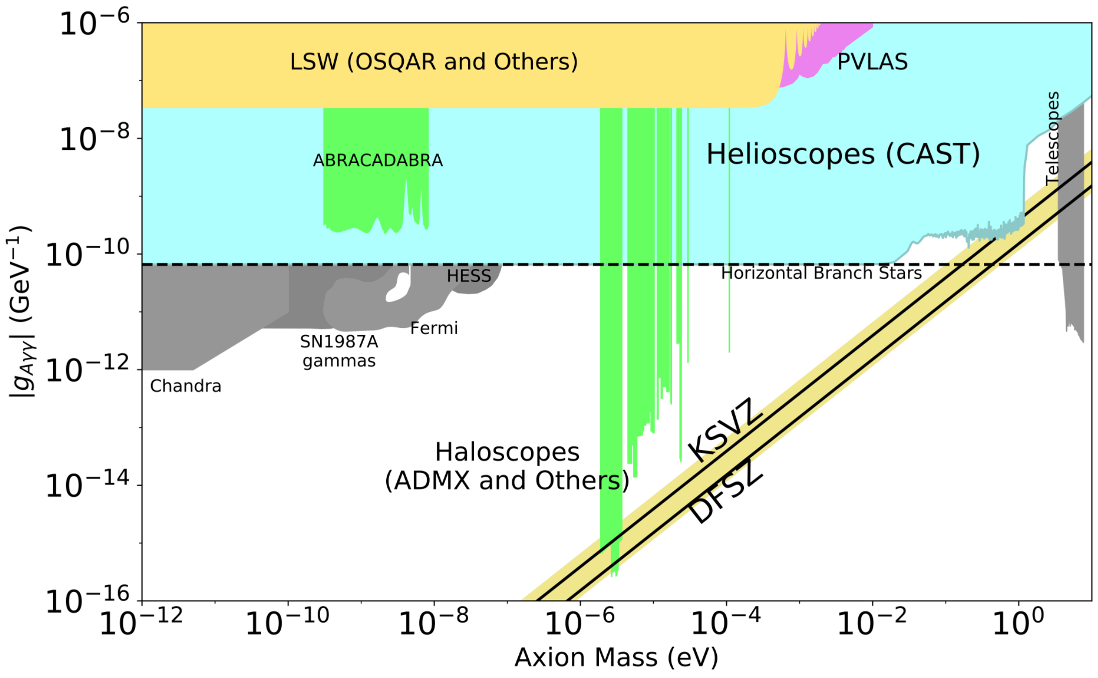
Already Severely Constrained



Abazajian (1705.01837)

PS: other dark matter candidates





those still live well

A Simple Idea

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

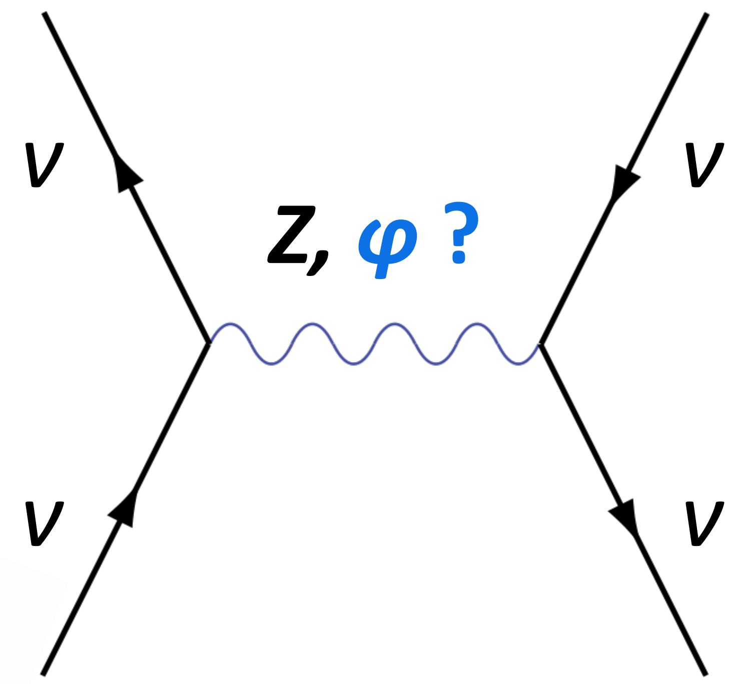
(~~weak~~) total

Intuition: compensate smaller mixing with larger reaction rate.

Requirement: new physics enhances Γ but does not introduce additional radiative decay mode.

Particles in early universe plasma T~100 MeV: $e, \mu, u, d, \gamma, \nu$

Neutrino Self Interaction

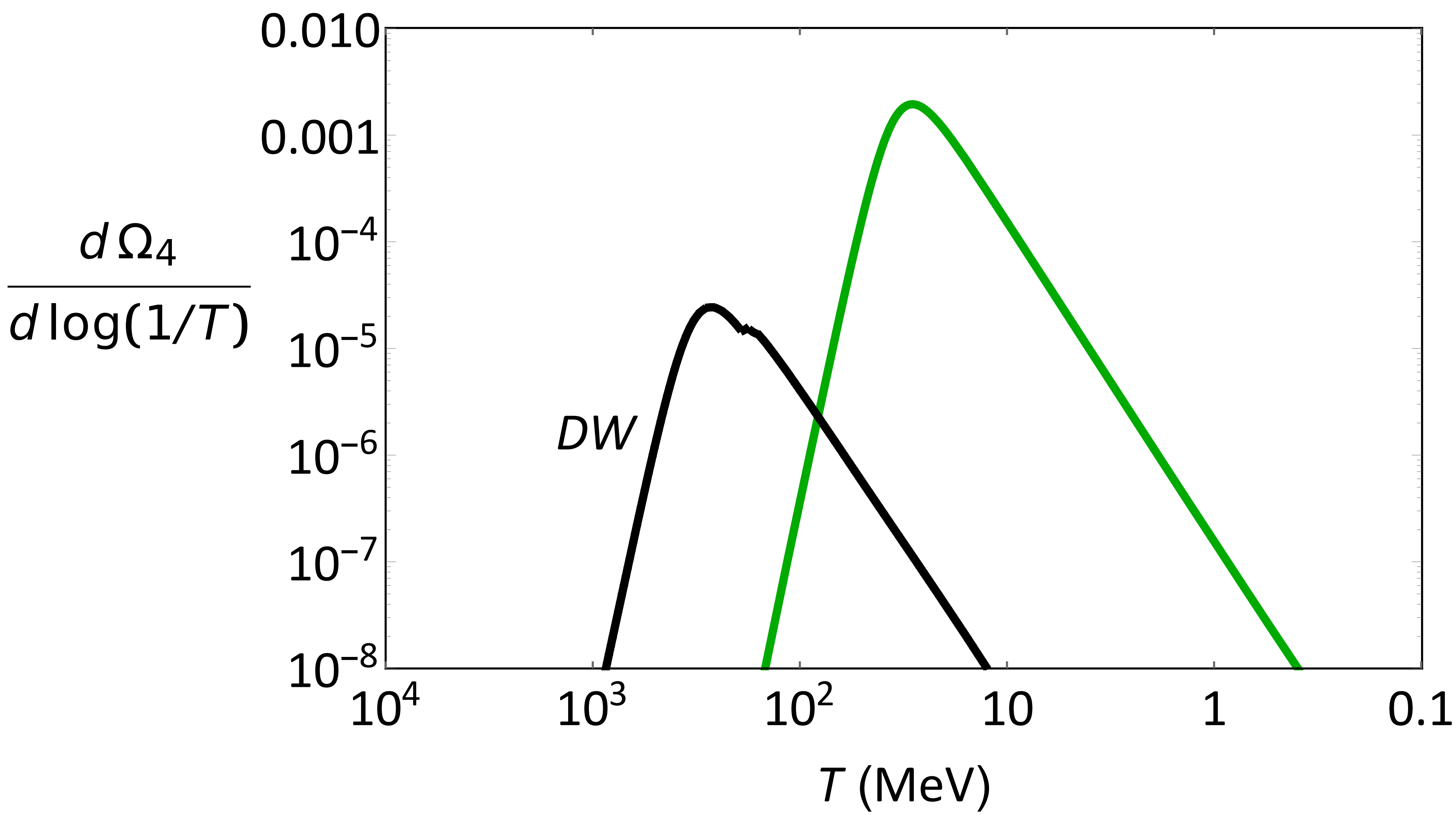


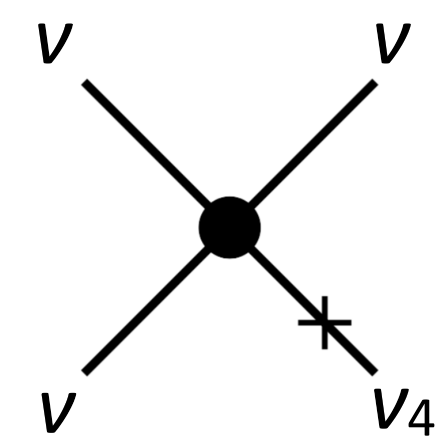
Never directly measured in labs. Allowed to be much stronger.

Consider a new scalar that dominantly couples to neutrinos

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

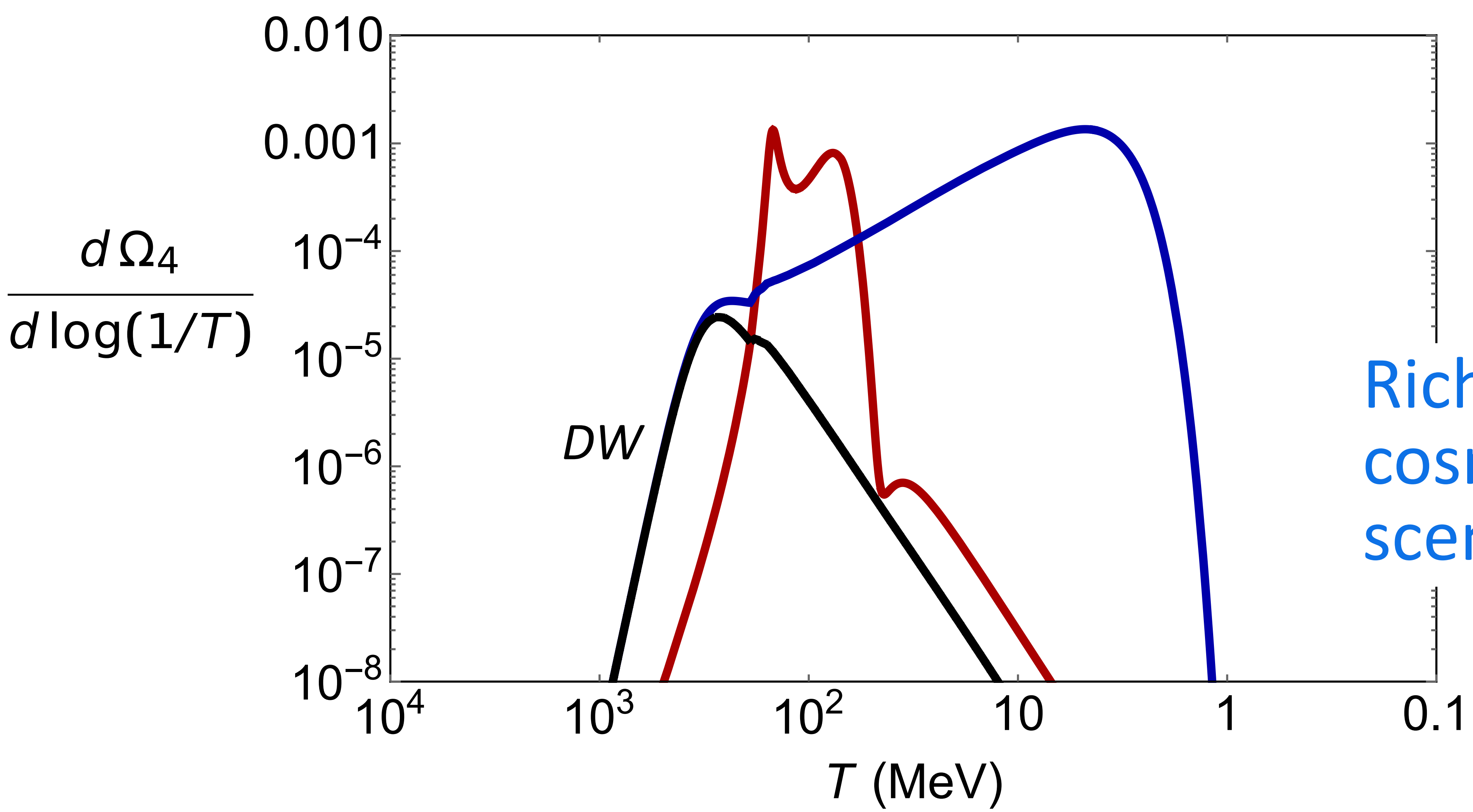
Production via a Heavy Mediator

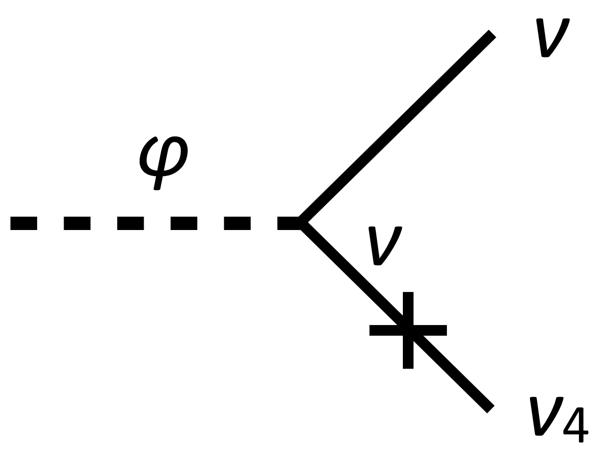




Final relic density: $\Omega_4 \propto \frac{\lambda^3}{m_\varphi^2} \gg \frac{g^3}{M_W^2}$

Production via a Light Mediator



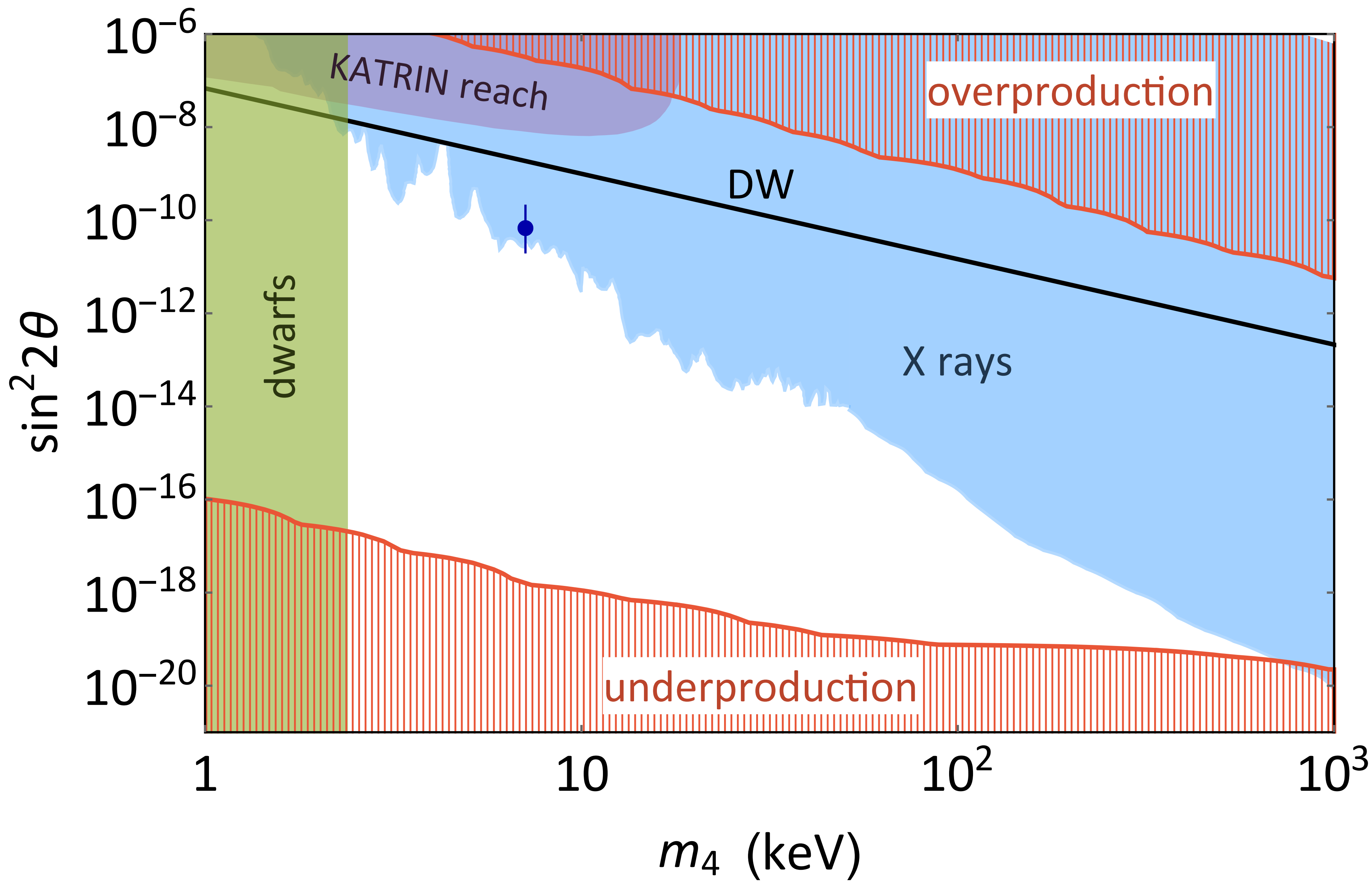


Rich cosmological scenarios

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

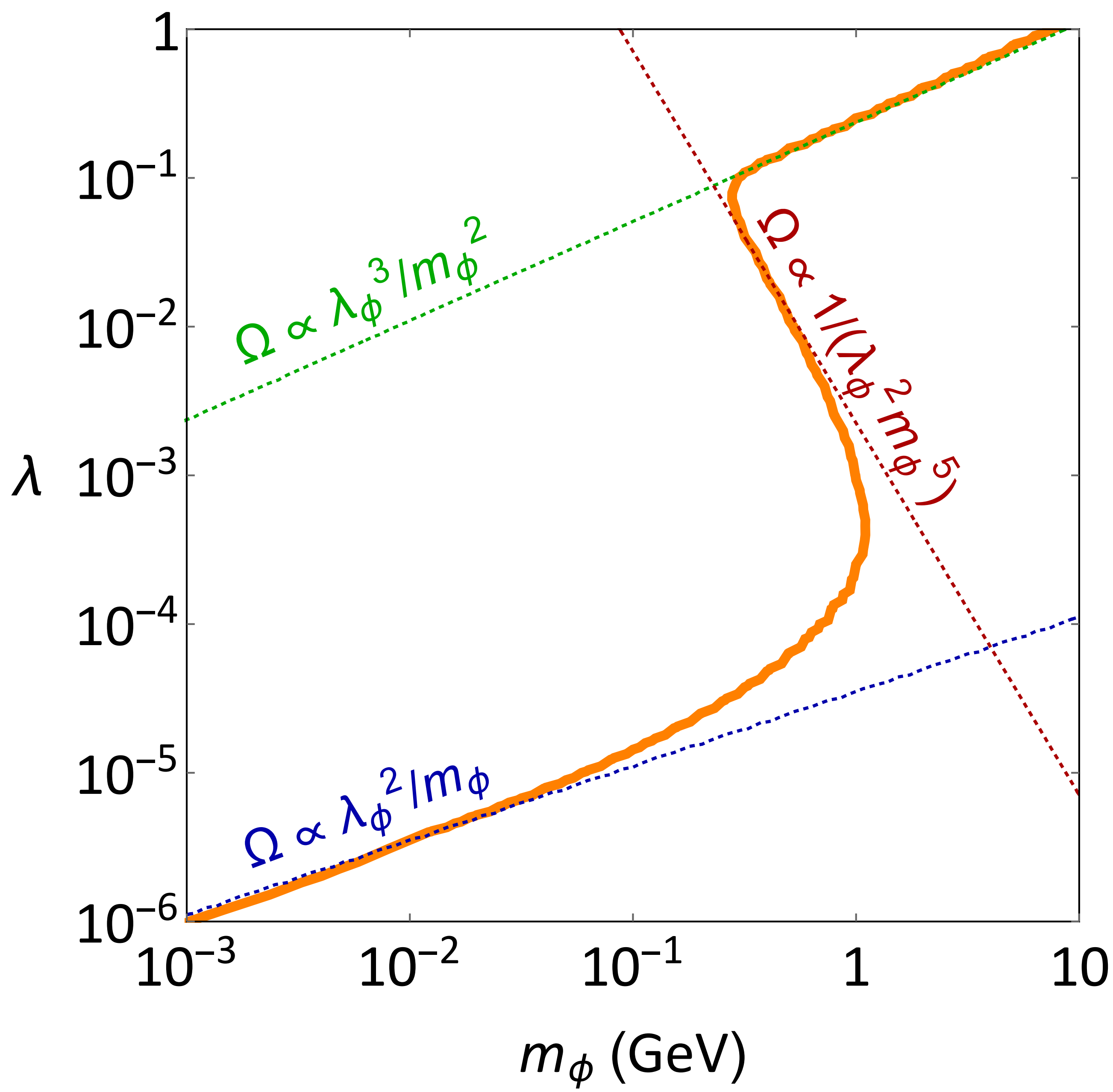
$\Gamma_{\rm decay} \sim \lambda^2$, more important than scattering for $\lambda << 1$.

Opens Up Wide Window



de Gouvêa, Sen, Tangarife, YZ (1910.04901)

Dark Matter Relic Target

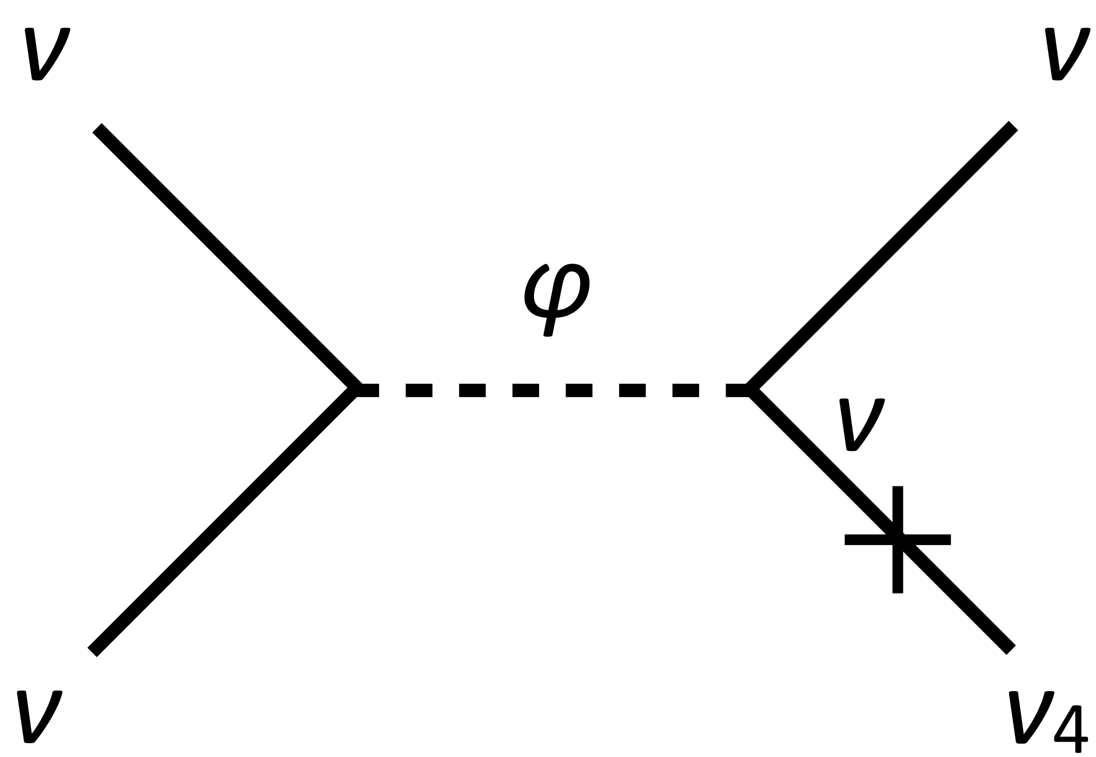


$\sin^2 2\vartheta = 7\text{x}10^{-11}$

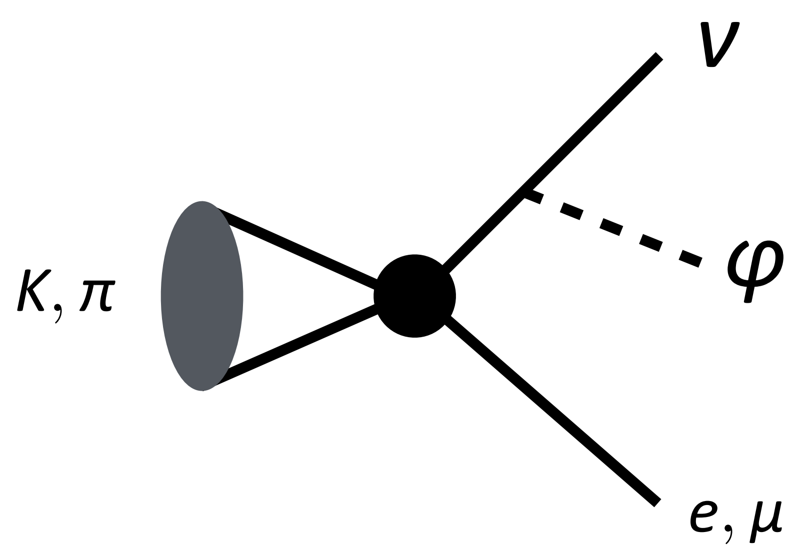
m_4=7.1 keV

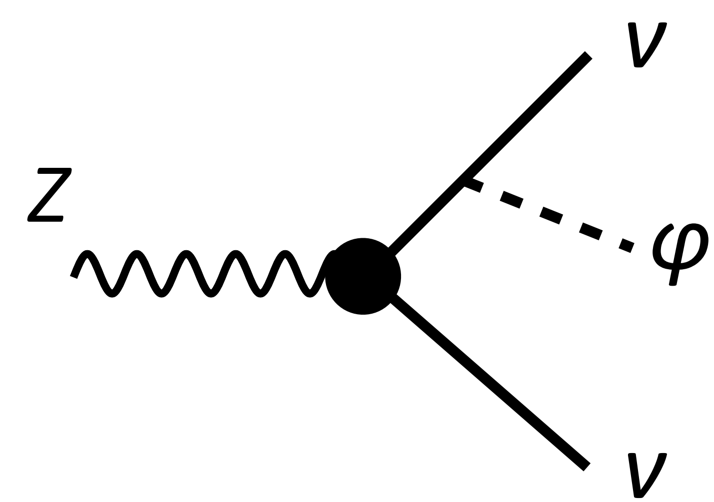
de Gouvêa, Sen, Tangarife, YZ (1910.04901)

Testing the Idea



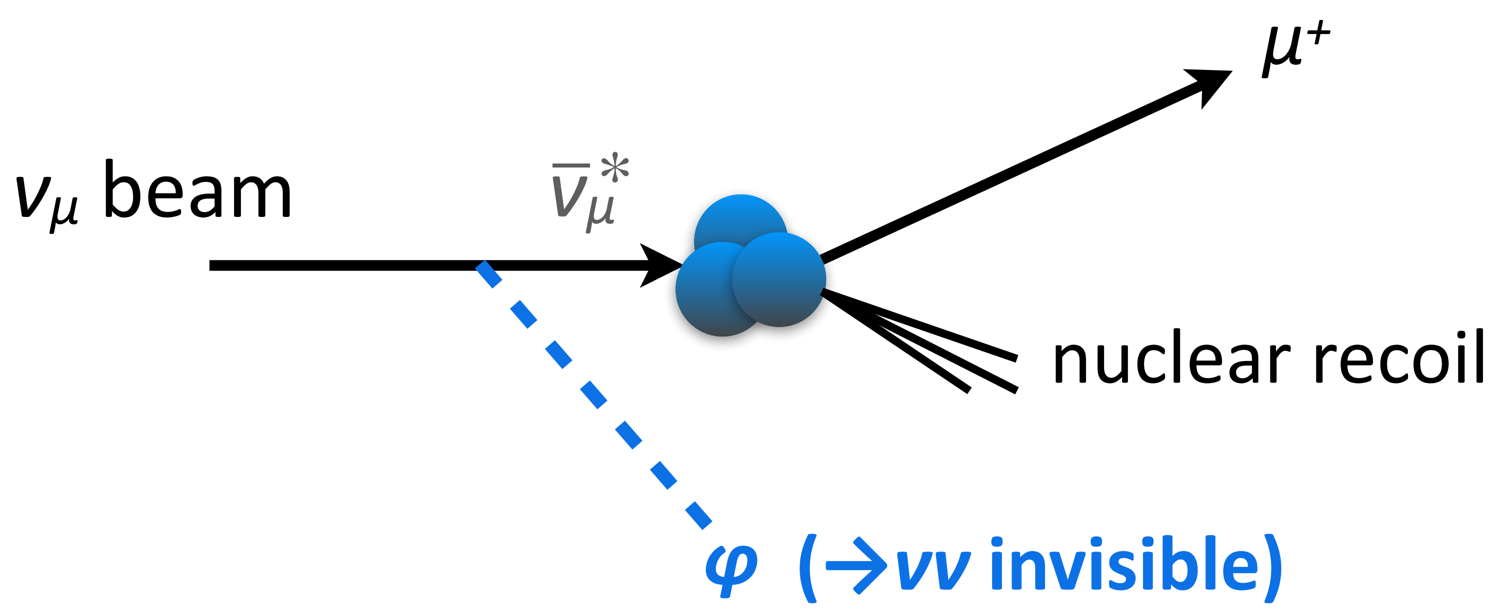
Particle Decays





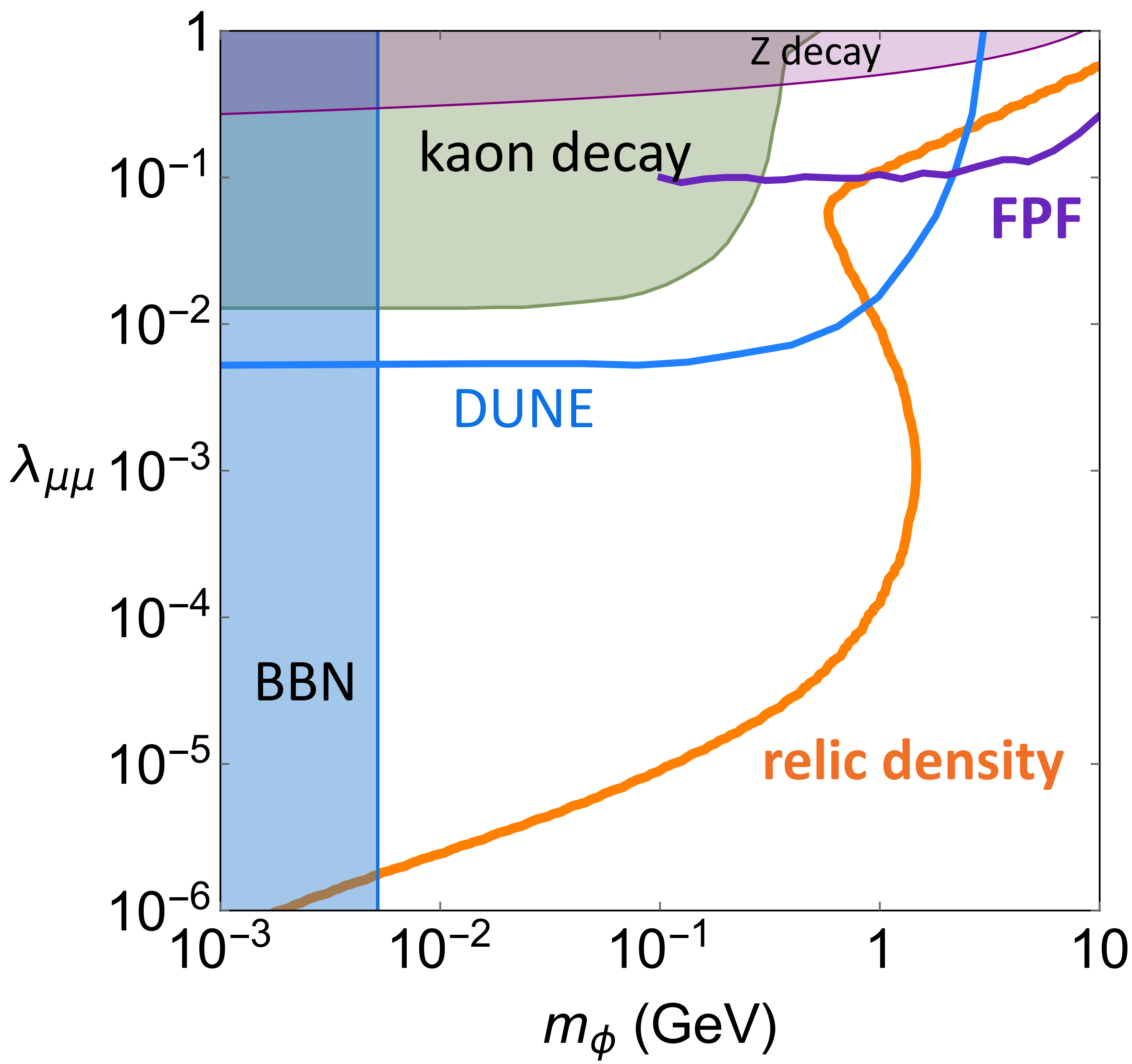
Barger, Keung, Pakvasa (1982)
Berryman, de Gouvêa, Kelly, YZ (1802.00009)
Brdar, Lindner, Vogl, Xu (2003.05339)

Mono-Neutrino Signal



Missing energy signature can be searched for at the upcoming DUNE (near detector) and Forward physics facility at LHC.

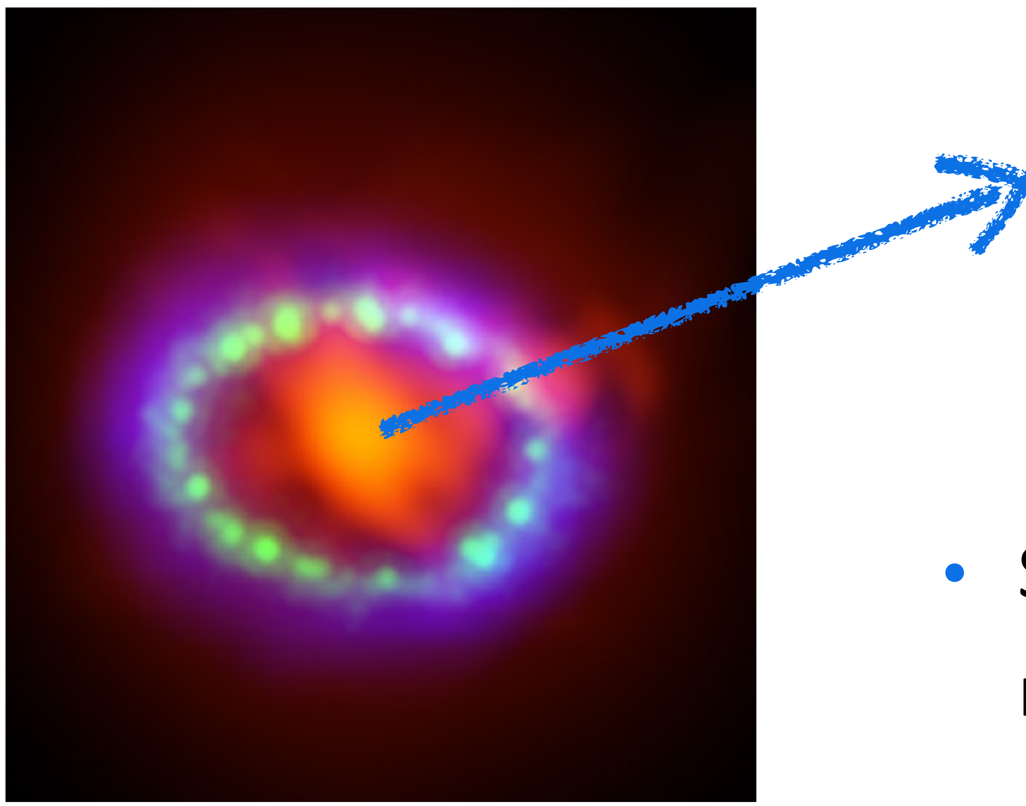
Neutrino Experiments Coverage

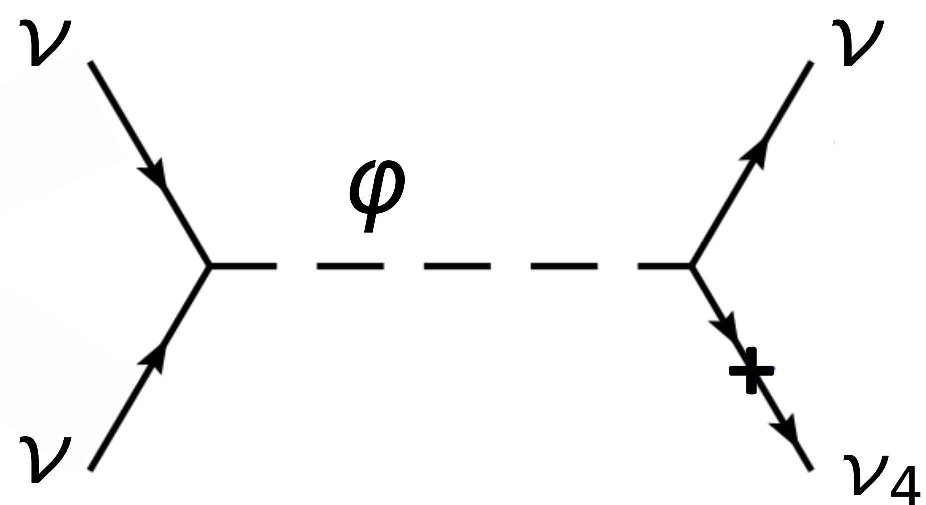


Beam neutrinos most useful for constraining ν_μ self interaction, along with ν_s-ν_μ mixing.

Kelly, YZ (1901.01259); Kelly, Kling, Tuckler, YZ (2111.05868)

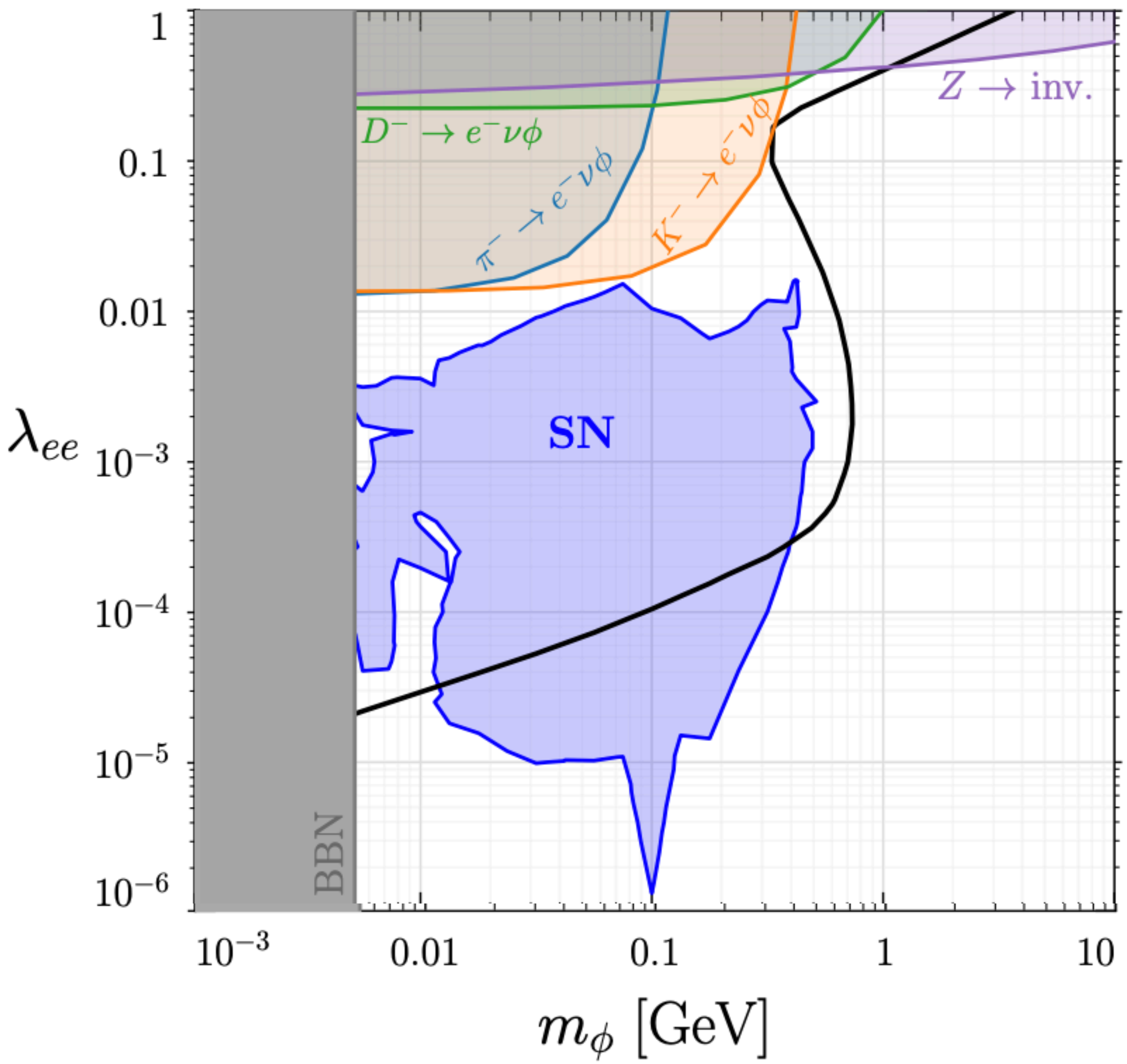
Core-collapse Supernova





- Same fundamental process as dark matter production in early universe.
- Similar environment.
- Excessive cooling due to $\varphi \to \nu\nu_4$ decay below the “neutrino sphere”.

Constraint from SN 1987A

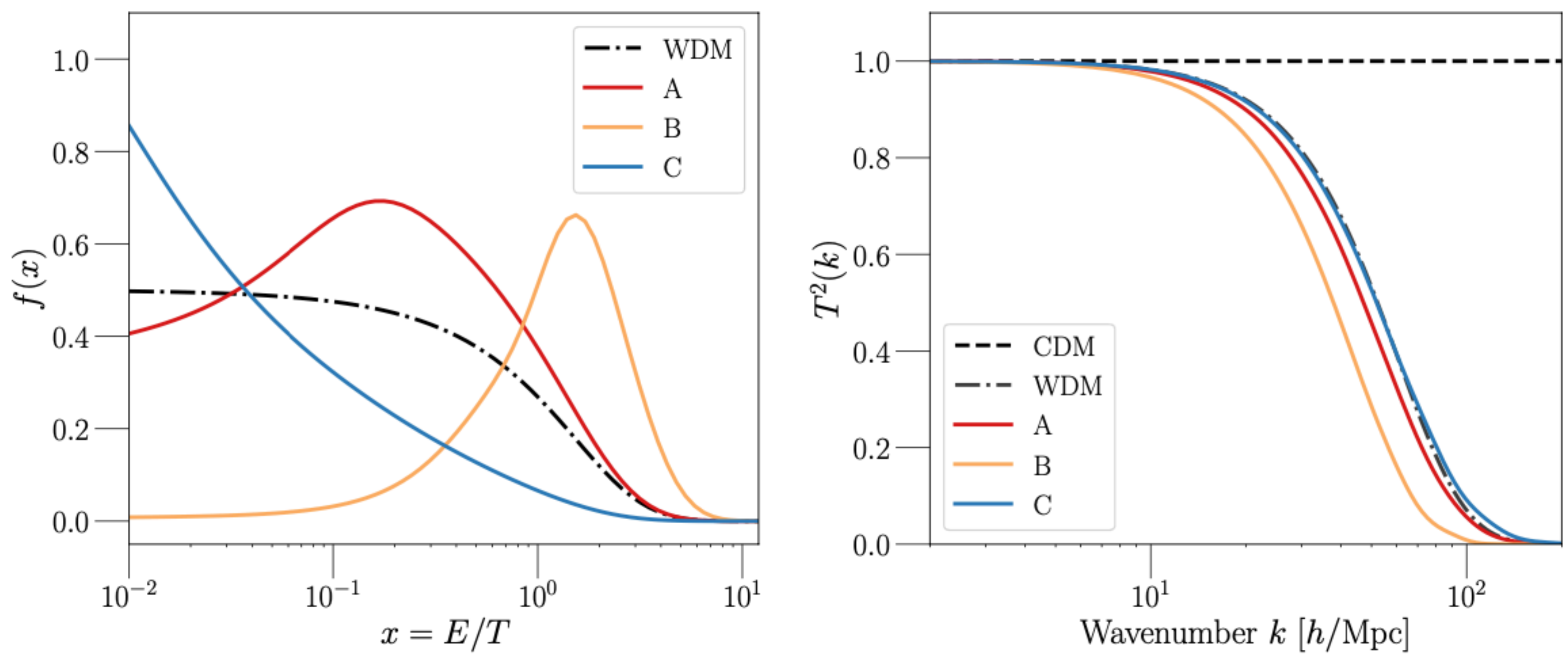


SN most useful for constraining ν_e self interaction, along with ν_s-ν_e mixing.

Chen, Sen, Tangarife, Tuckler, YZ (2207.14300)

Milky Satellite Galaxies

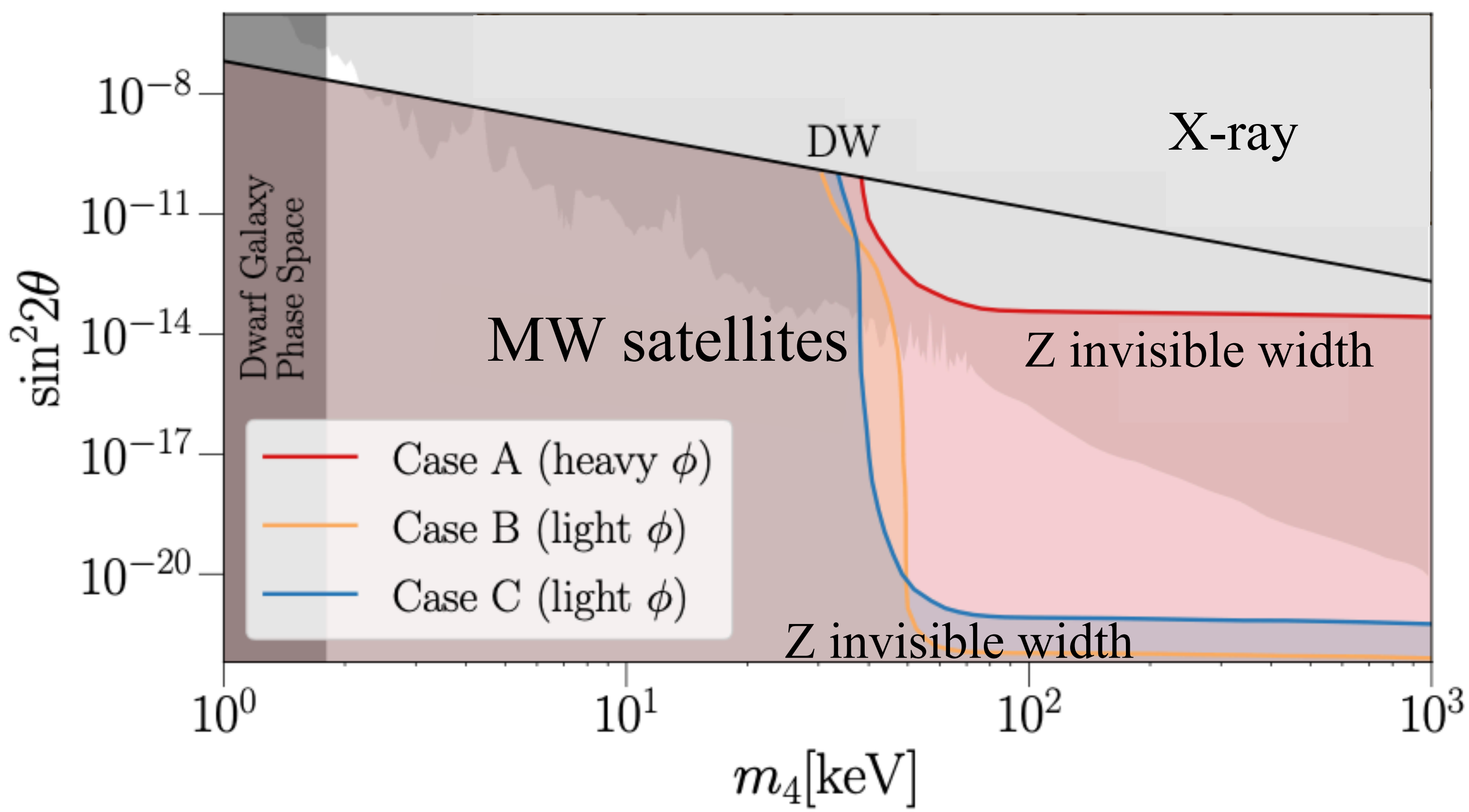
DM production mechanism not only predicts a number (Ω), but also a phase space distribution *f*(q) — matter power spectrum.

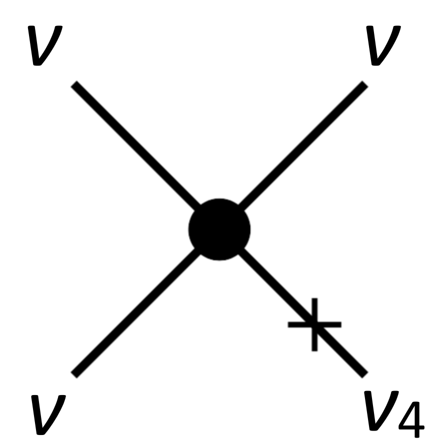


DES experiment set WDM mass > 6.5 keV. (arXiv:2008.00022)

Stronger limit expected here (~30 keV) because here $T_{\nu 4} \gg T_{WDM}$.

Flavour Independent Constraint





(case A)

A remarkable finding: MW satellites, X-ray, and Z decay together exclude strong neutrino self-interaction scenario (case A: heavy mediator).

An, Gluscevic, Nadler, YZ (to appear soon)

Conclusion

This talk discusses 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, astrophysical and cosmological experiments can be used to probe such a nice target.

Thanks!