Ultra-high-energy neutrinos to look for super-heavy dark matter inside the Earth

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Motivation

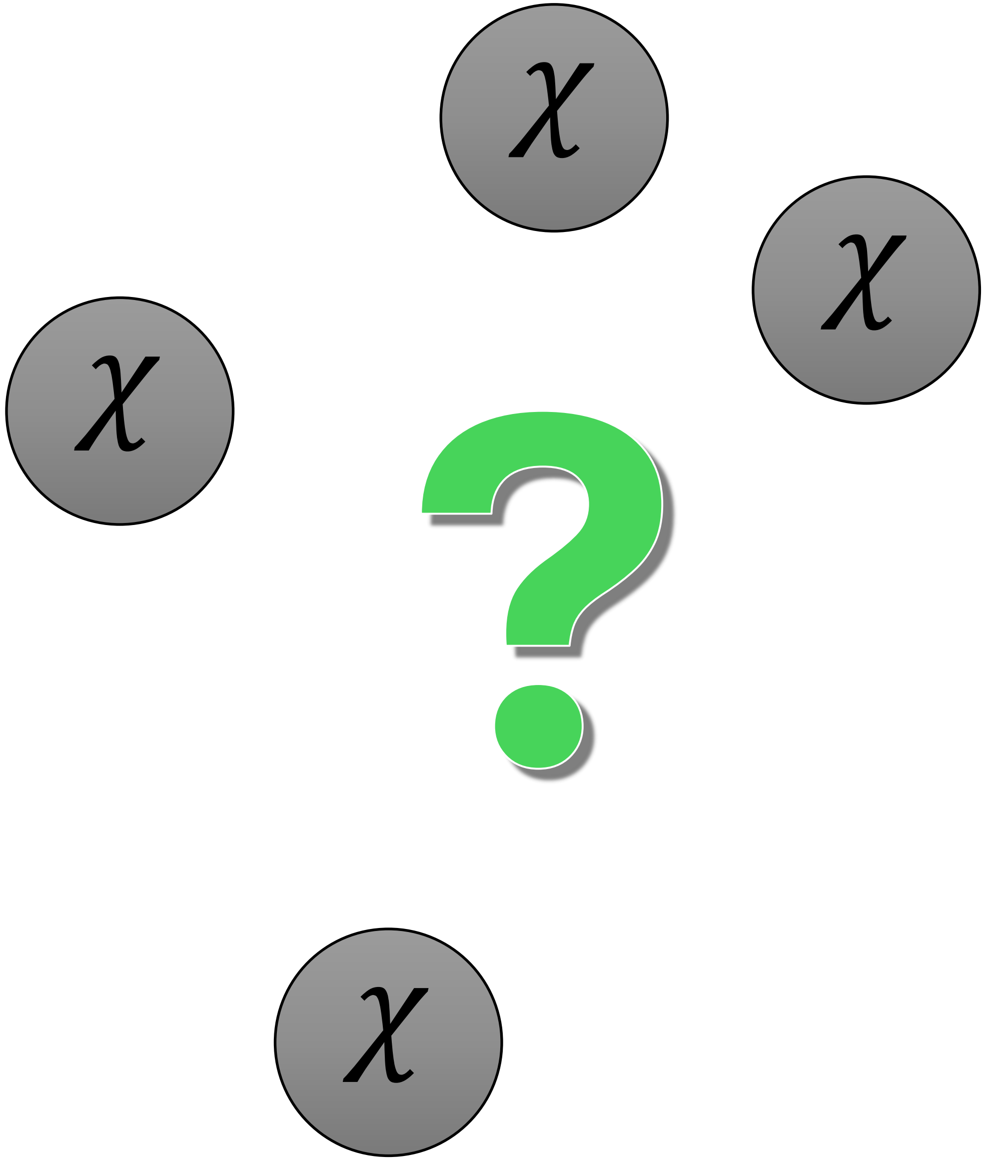
According to ΛCDM ~85% of the matter density of the universe is made up dark matter.

So far, we haven’t been able to determine what it is, the focus has been on GeV scale WIMPs.

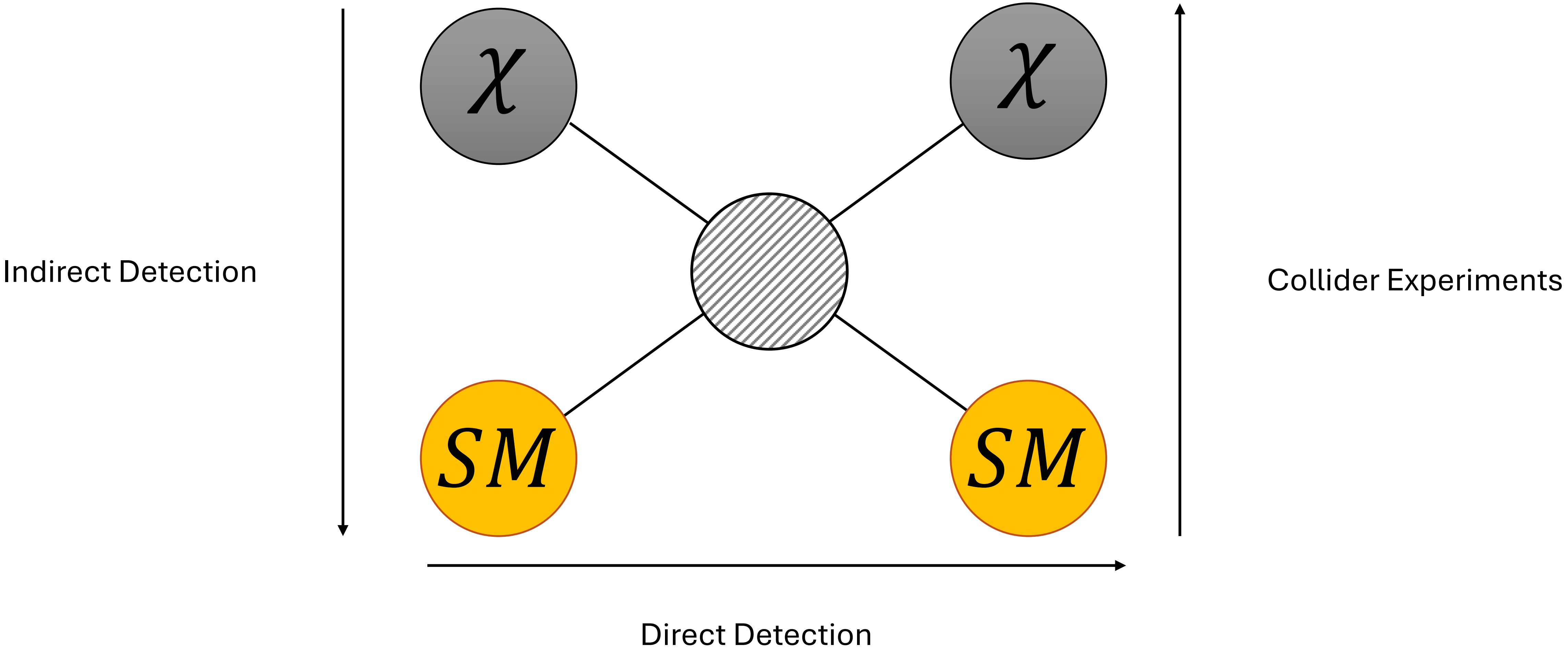
Due to lack of evidence, the search field is being expanded in energy, both up and down.

Ultra-High-Energy neutrinos, can be used for indirect dark matter detection.

$$E_\nu > 10 \text{ PeV}$$



Dark Matter Detection

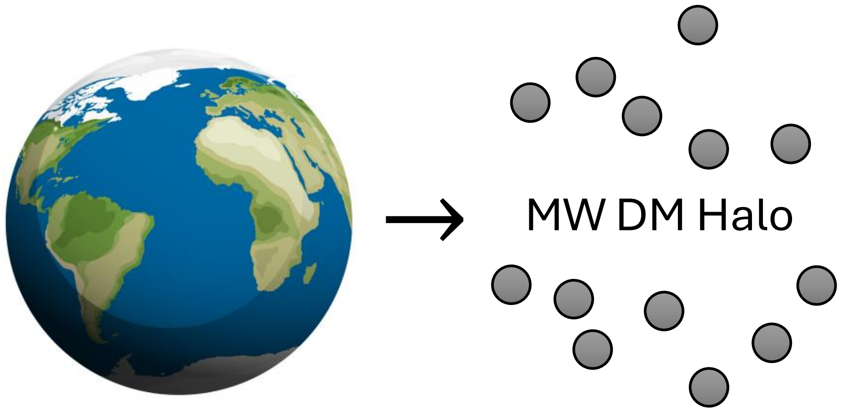


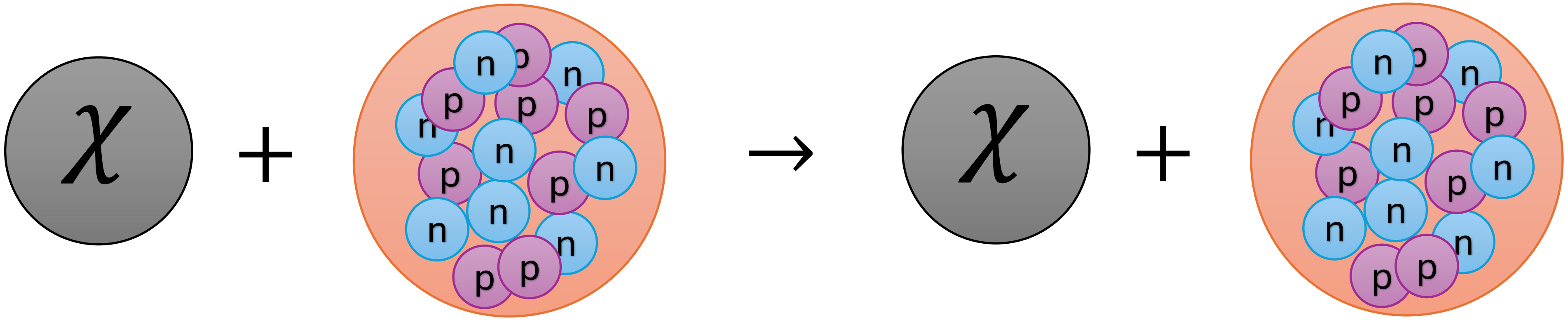
Dark Matter Capture

As the Earth travels through the Milky Way it passes through the galactic halo of dark matter.

Scattering can cause a loss of energy, potentially trapping the DM particle gravitationally.

We focus on the capture coming from dark matter interactions with nuclei.





Earth clip art from www.freepik.com

Capture Rate of Dark Matter in the Earth

The capture of DM can de described by:

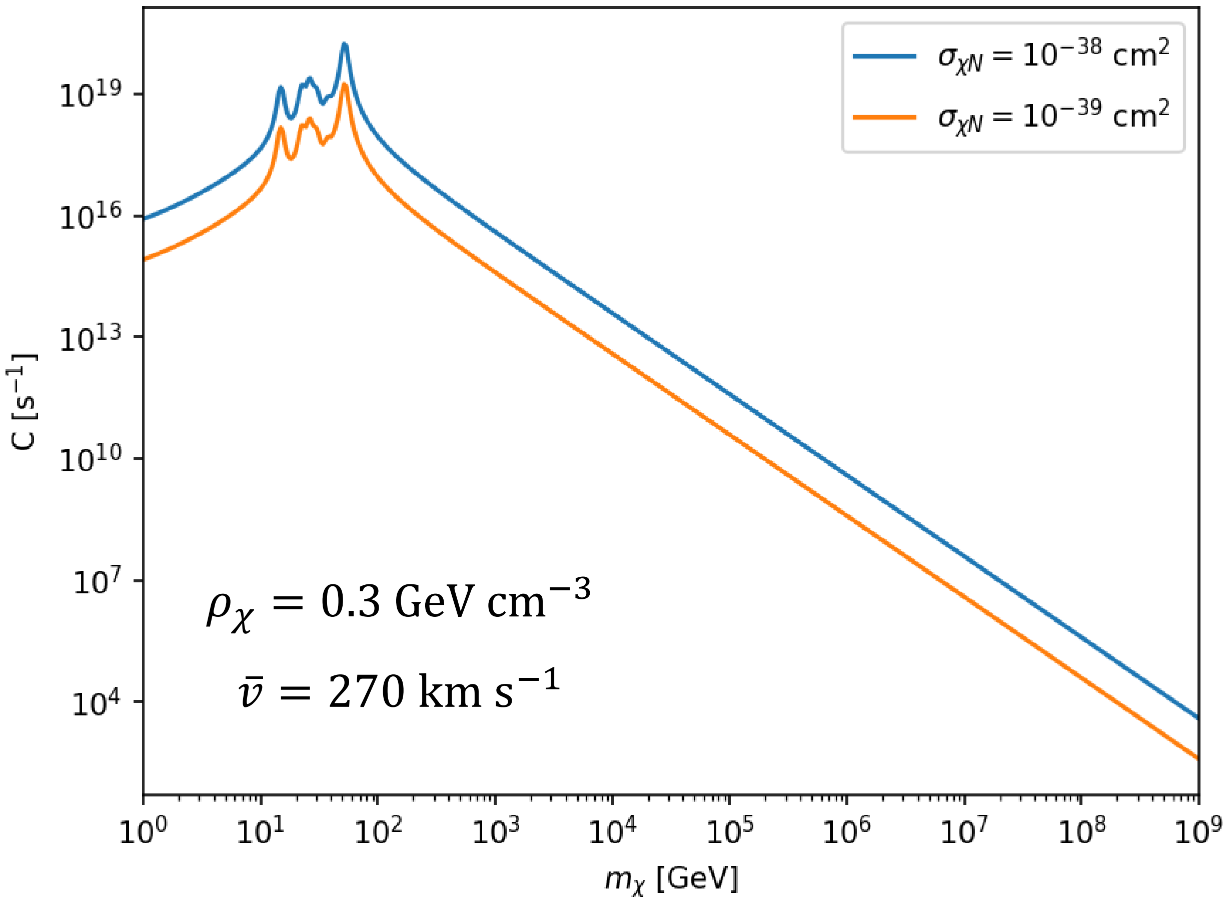
$$\frac{dN_\chi}{dt} = C$$

For nucleon capture, we can define the capture rate as:

$$C = \sum_i C_i$$

Where the capture rate for element i is:

$$C_i = \sqrt{\frac{6}{\pi}}\frac{\rho_\chi \sigma_{\chi i}}{\bar{v} m_\chi}\int_0^R dr\ 4\,\pi\, r^2\,\frac{\rho_i(r)}{m_i} v_{esc}^2(r)\left[1 - \frac{1 - e^{-\mathcal{A}_i^2(r)}}{\mathcal{A}_i^2(r)}\right]$$



Decay and Annihilation Rates

Decay (Annihlation) changes the rate of dark matter accumulation:

Annihilation Constant

$$\frac{dN_\chi}{dt} = \begin{cases} C - A\,N^2 - \cancel{E\,N} \\ C - D\,N - \cancel{E\,N} \end{cases}$$

Decay Rate

At equilibrium we get:

$$\Gamma_{dec}(\tau) = C(\tau)$$

$$\Gamma_{ann}(\tau) = \frac{C(\tau)}{2}$$

$$\tau \equiv \frac{1}{\sqrt{(C_{cap}C_{ann})}}$$

Radial Density of Dark Matter

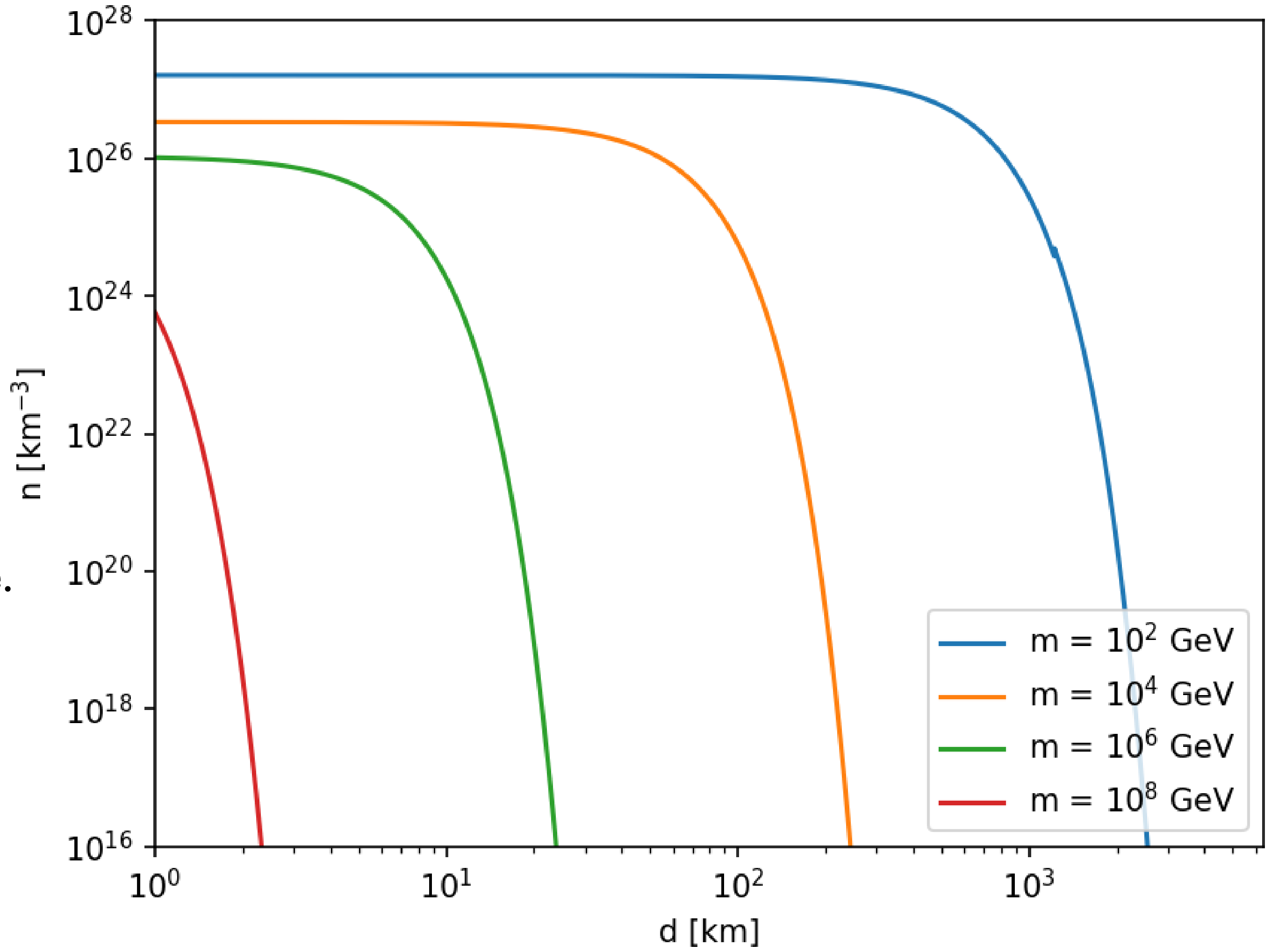
Trapped DM accumulates around the core.

$$n_\chi(r) \propto e^{-\frac{r^2}{2r_0^2}}$$

$$\mathrm{r}_0 \equiv \frac{3kT}{4\pi G m_\chi \rho}$$

Far from the core the amount of DM is negligible.

$$r_s \equiv \frac{\mathrm{n}_\chi(0)}{\mathrm{n}_\chi(\mathrm{r}_s)} < 10^3$$



Neutrino Fluxes from Dark Matter

$$\chi \rightarrow \nu_\ell + \bar{\nu}_\ell$$

Decay

$$\chi + \chi \rightarrow \nu_\ell + \bar{\nu}_\ell$$

Annihilation

Neutrino Flux from Dark Matter Decay

We use HDMSpectra to get the initial neutrino fluxes from DM decay.

$$\chi \to \nu_\ell + \bar{\nu}_\ell$$

Propagation through the Earth attenuates the flux.

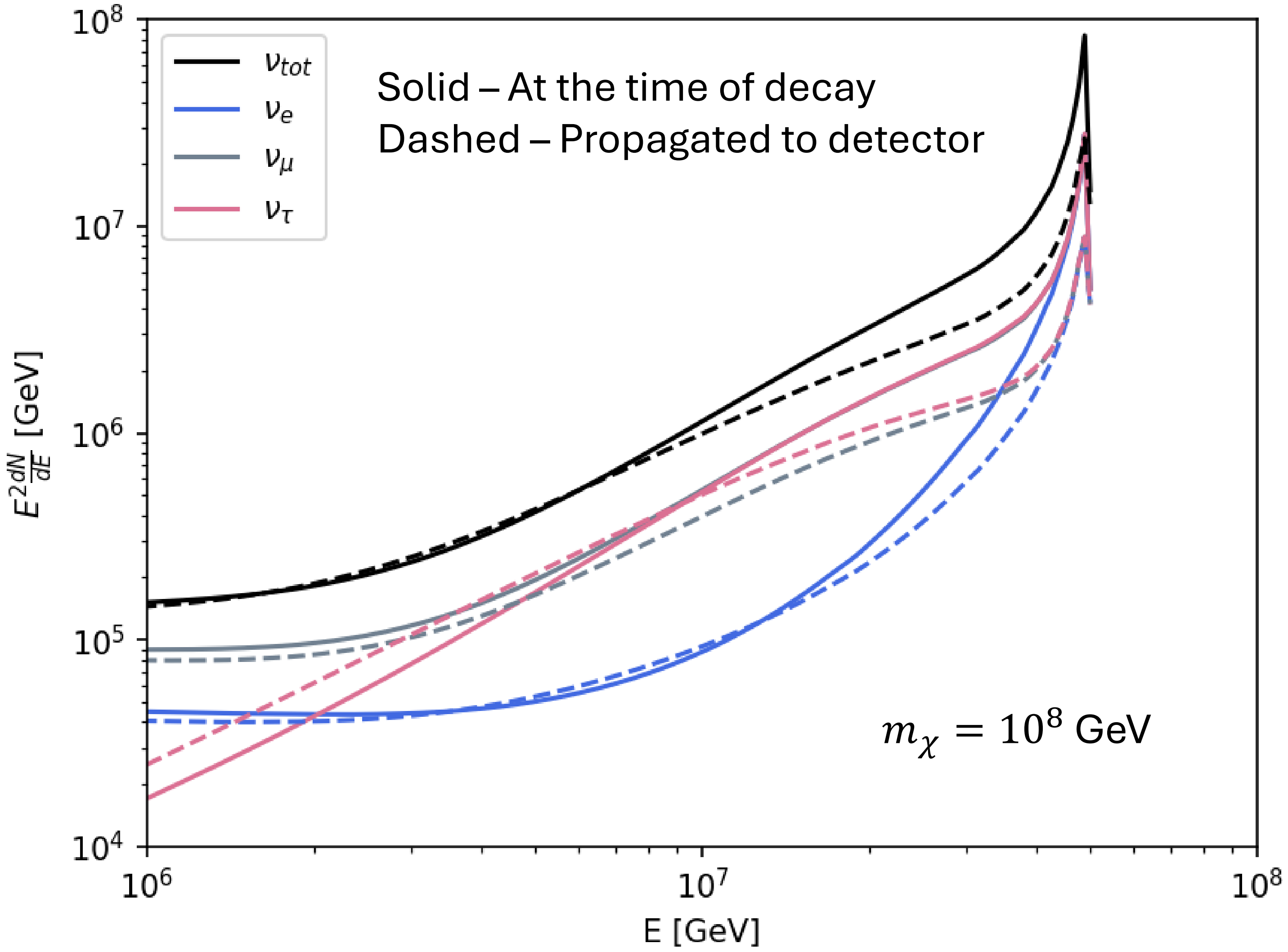
$$\nu_\ell + N \to \ell^- + X$$

$$\bar{\nu}_\ell + N \to \ell^+ + X$$

$$\nu_\ell + N \to \nu_\ell + X'$$

ν_τ flux enhanced by τ-regeneration.

HDMSpectra arXiv: 2007.15001



UHE Neutrino Background Fluxes

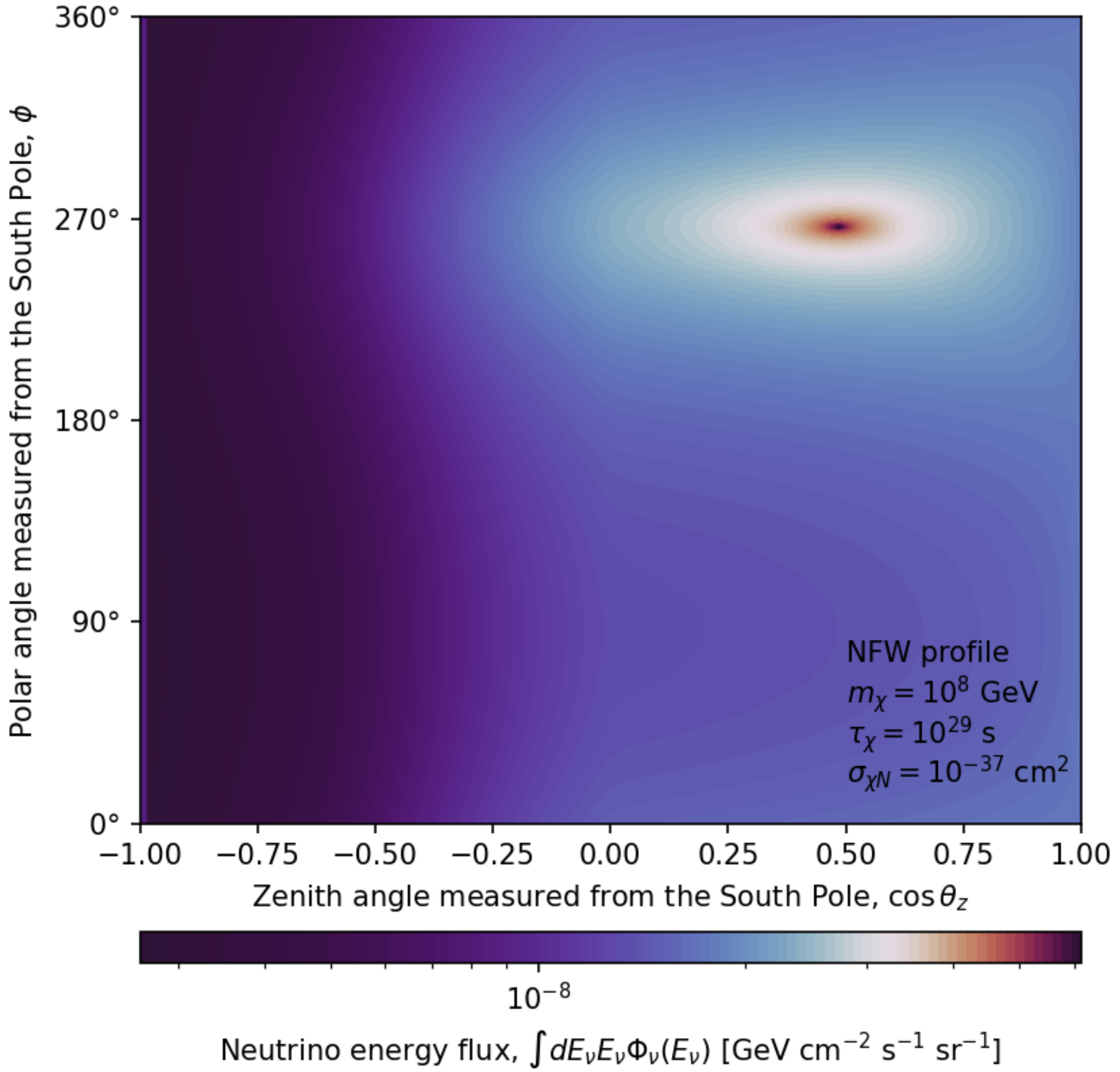
The UHE looked for in other searches becomes a background to our signal. Along with background from other DM decays.

$$\frac{d\phi_{\nu_\alpha}^{BG}}{dE_\nu d\Omega_\nu} = \frac{d\phi_{\nu_\alpha}^{Gal}}{dE_\nu d\Omega_\nu} + \frac{d\phi_{\nu_\alpha}^{EG}}{dE_\nu d\Omega_\nu} + \frac{d\phi_{\nu_\alpha}^{Ast}}{dE_\nu d\Omega_\nu}$$

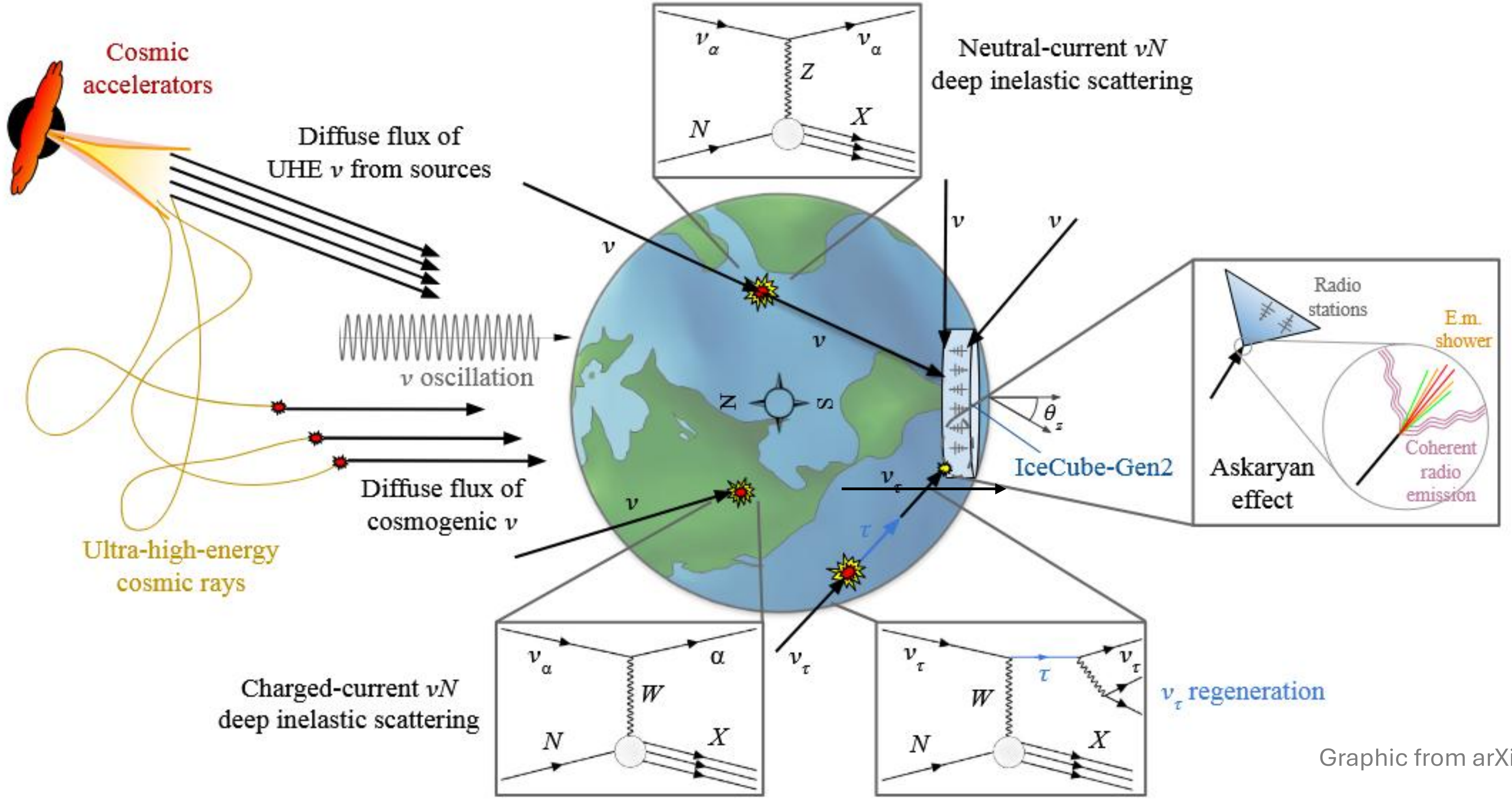
Galactic DM

Extra-Galactic DM

Astrophysical

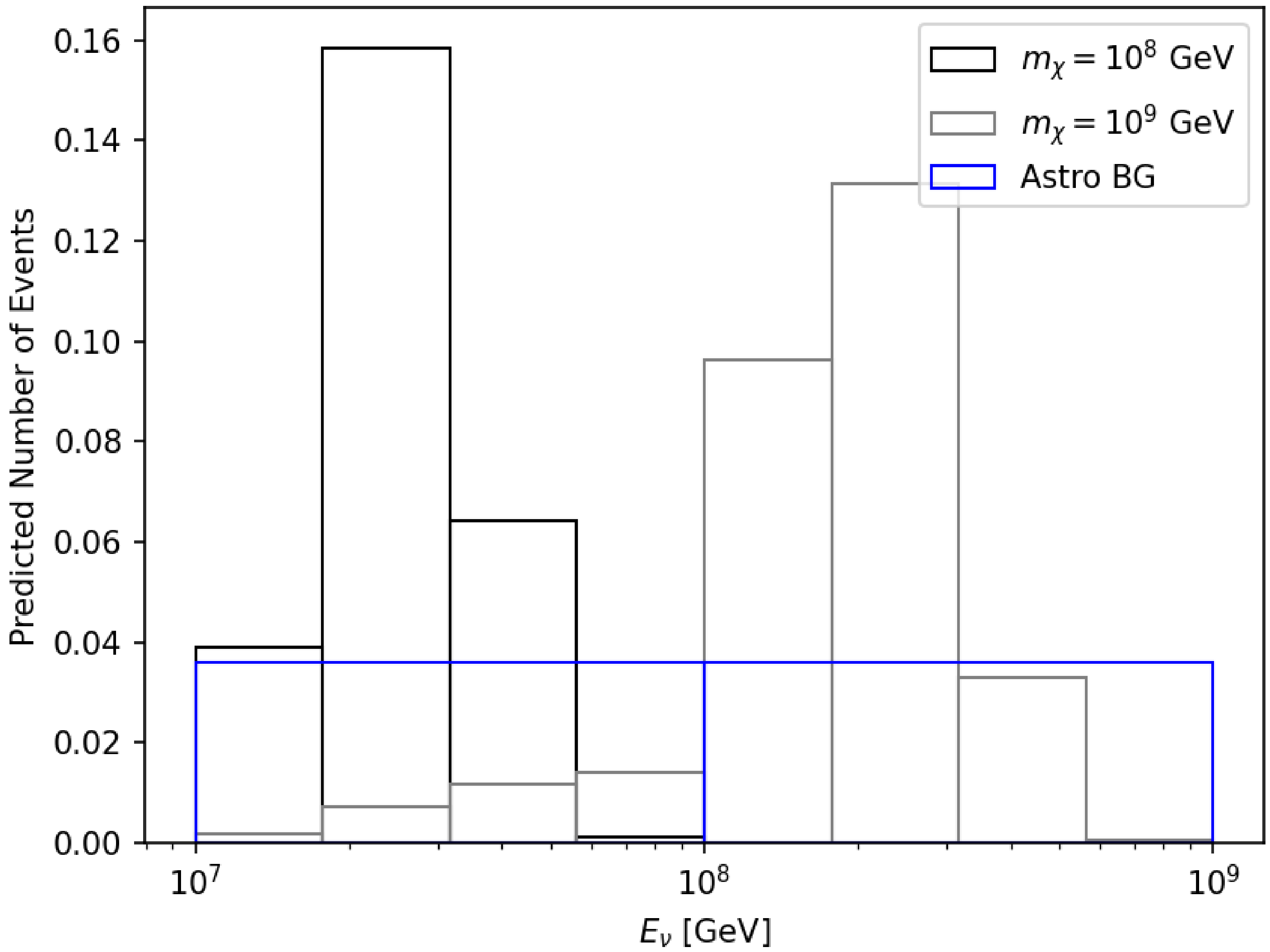


Detection at IceCube-Gen2 Radio



Graphic from arXiv 2204.04237

Predicted Event Rates



$\tau_\chi = 10^{29}\text{s}$

$\sigma_{\chi N} = 10^{-37}\text{cm}^2$

$T = 10$ years

$0.99 < \cos(\theta_z) \leq 1$

Conclusions

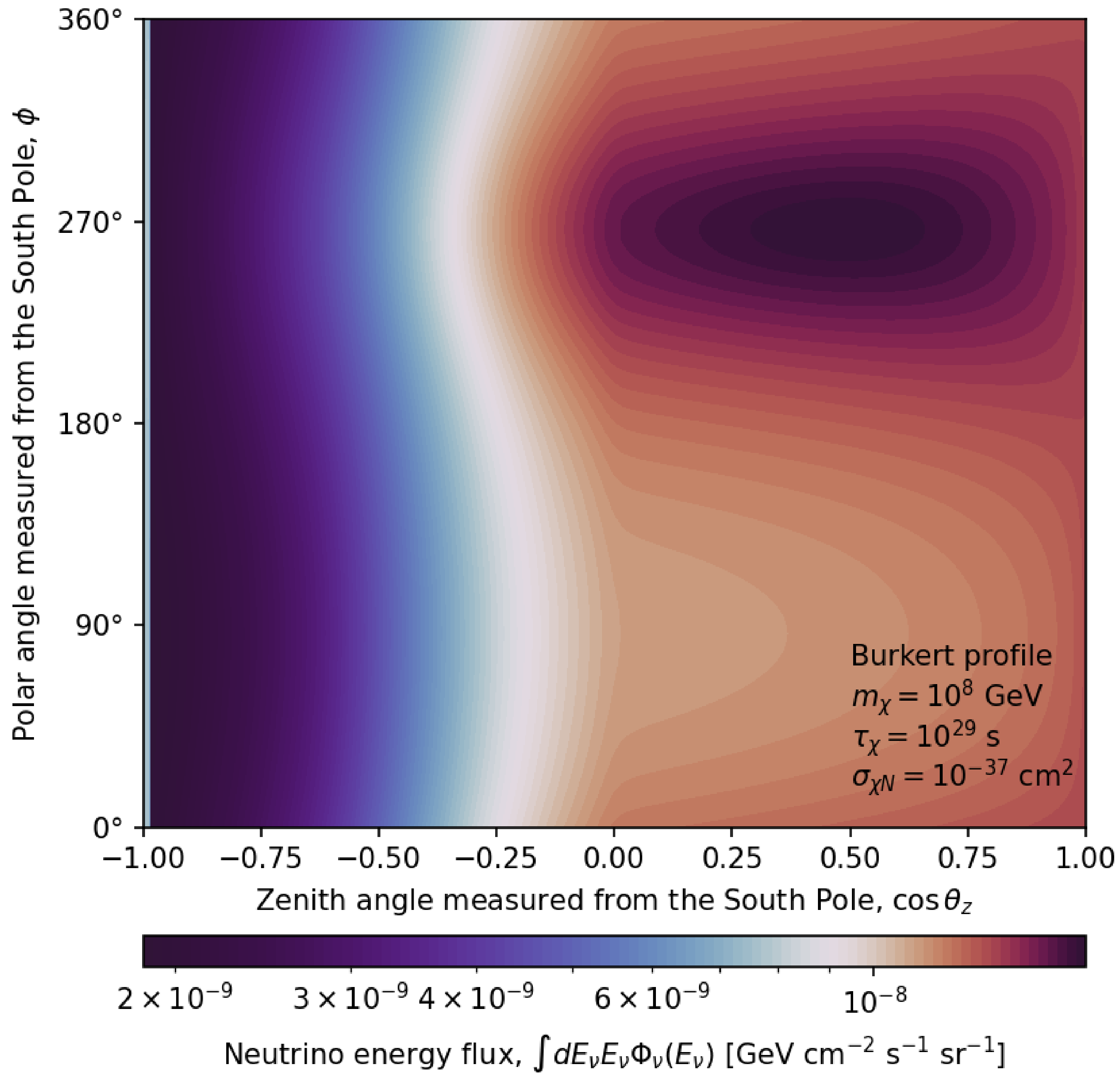
Currently working on producing potential limits of τ_χ vs m_χ

Low event rates – Higher than the expected backgrounds

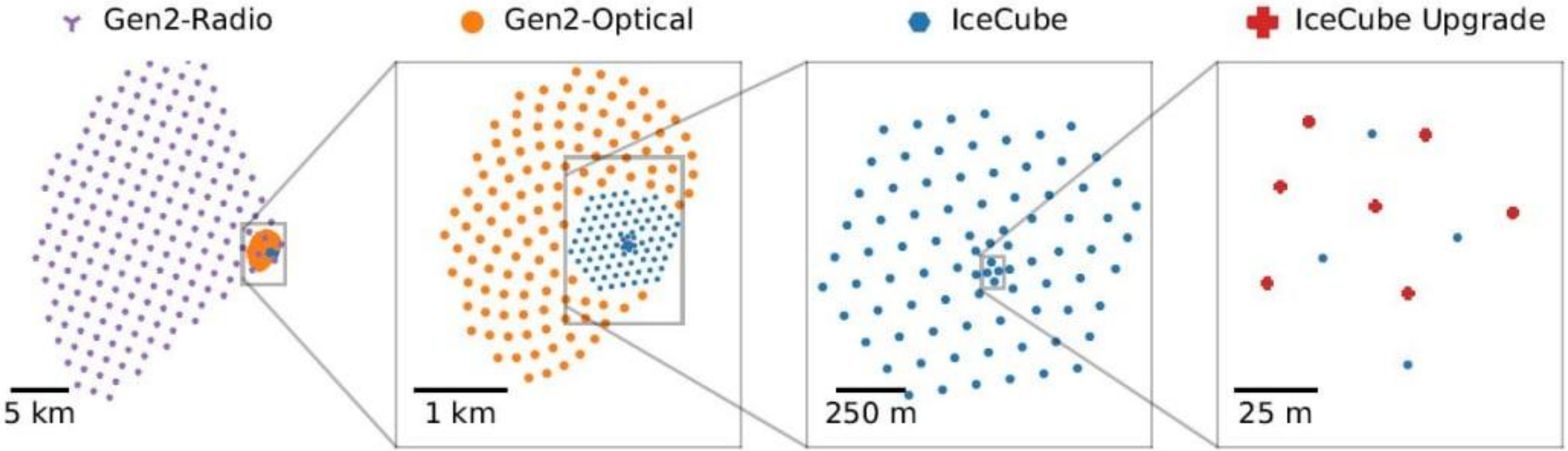
The End

$$\frac{d\phi_{\nu_\alpha}^{Gal}}{dE_\nu d\Omega_\nu} = \frac{dN_{\nu_\alpha}}{dE_\nu} \int_0^\infty \frac{\rho_\chi(s,b,l)}{4\,\pi\,\tau_\chi\,m_\chi} ds$$

$$\frac{d\phi_{\nu_\alpha}^{EG}}{dE_\nu d\Omega_\nu} = \frac{\Omega_{DM}\,\rho_c}{4\,\pi\,\tau_\chi\,m_\chi} \int_0^\infty \frac{dz}{H(z)} \frac{dN_{\nu_\alpha}}{dE_\nu}\bigg|_{E_\nu(1+z)}$$



IceCube Gen2 Radio



Official IceCube graphic