Detecting Dark Matter through Neutrinos

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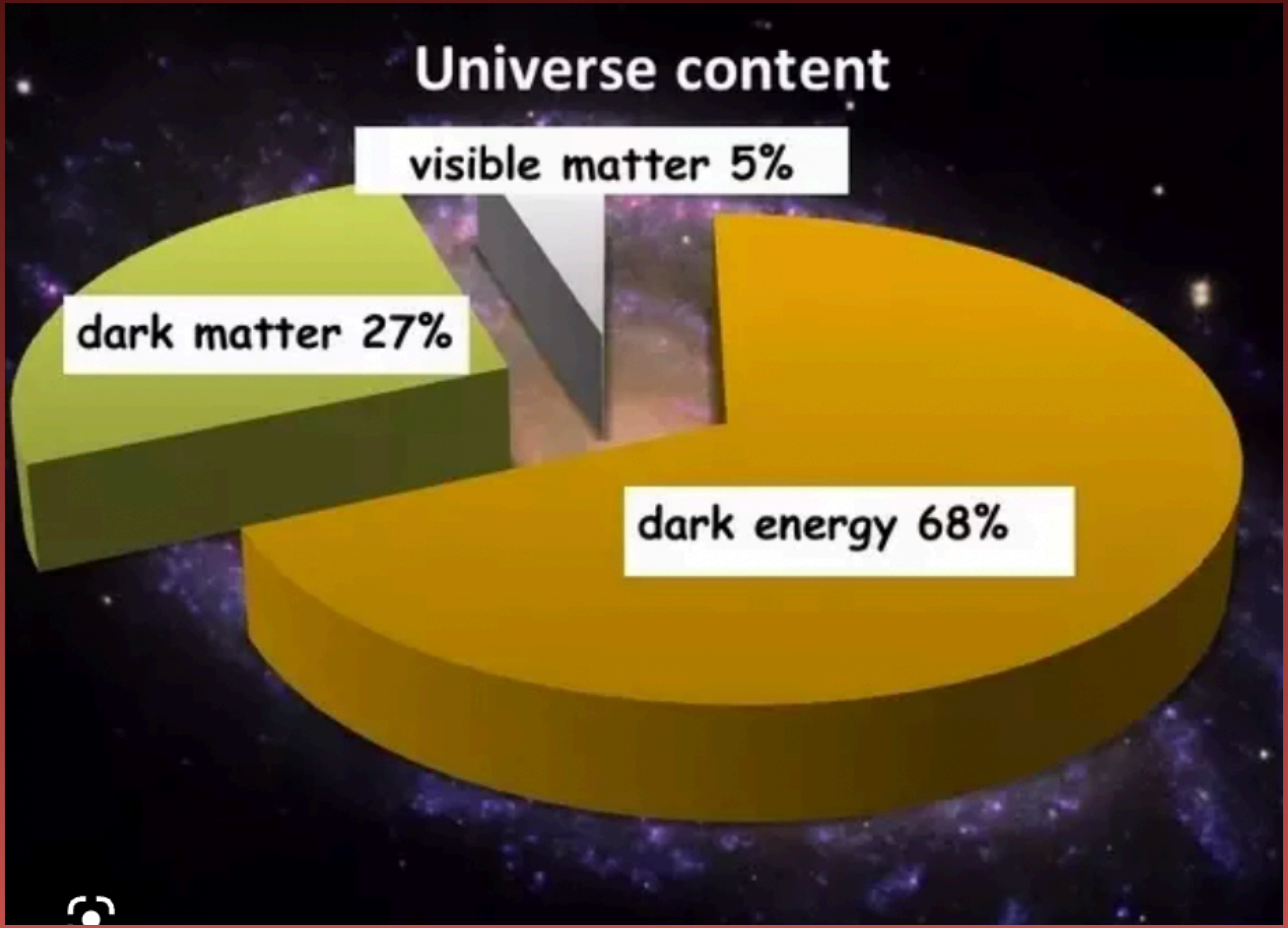
Seminar
May 17th, 2023

Introduction:

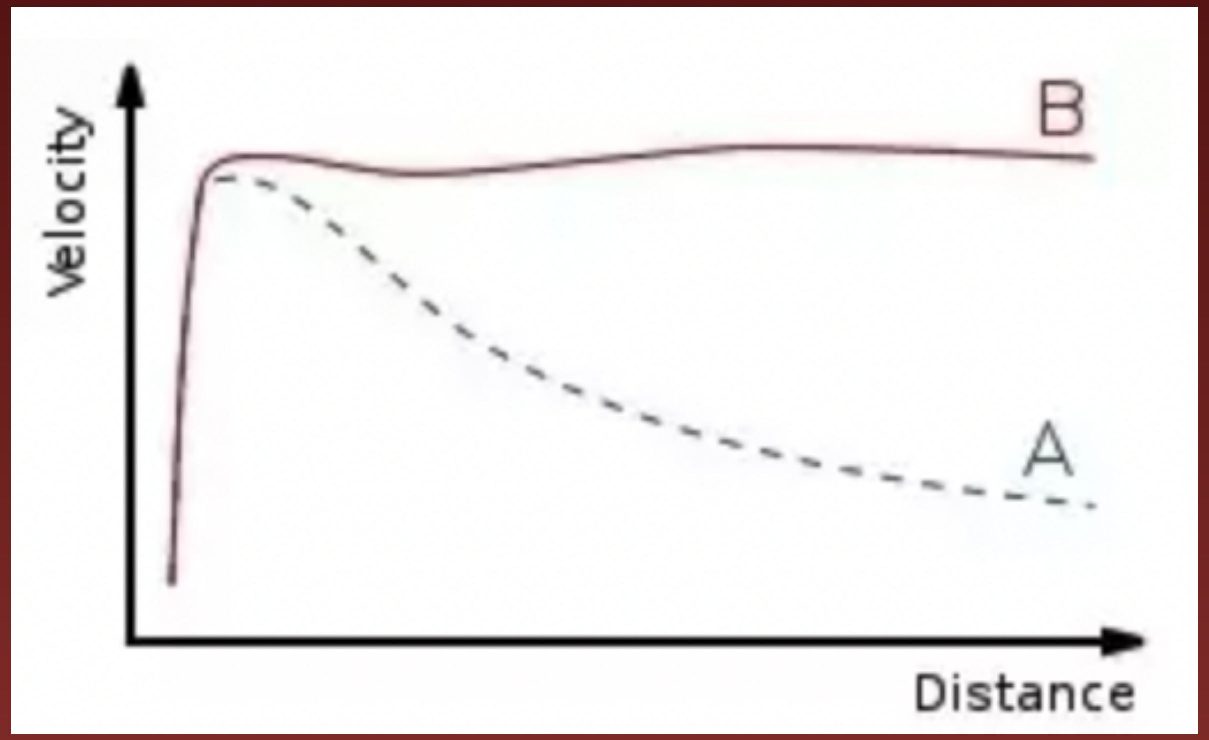
We calculated the KM3NeT's dark matter annihilation sensitivity going to neutrinos (using WIMPs: Weak Interacting Massive Particles), and their implications to selected dark matter models.

Dark Matter?

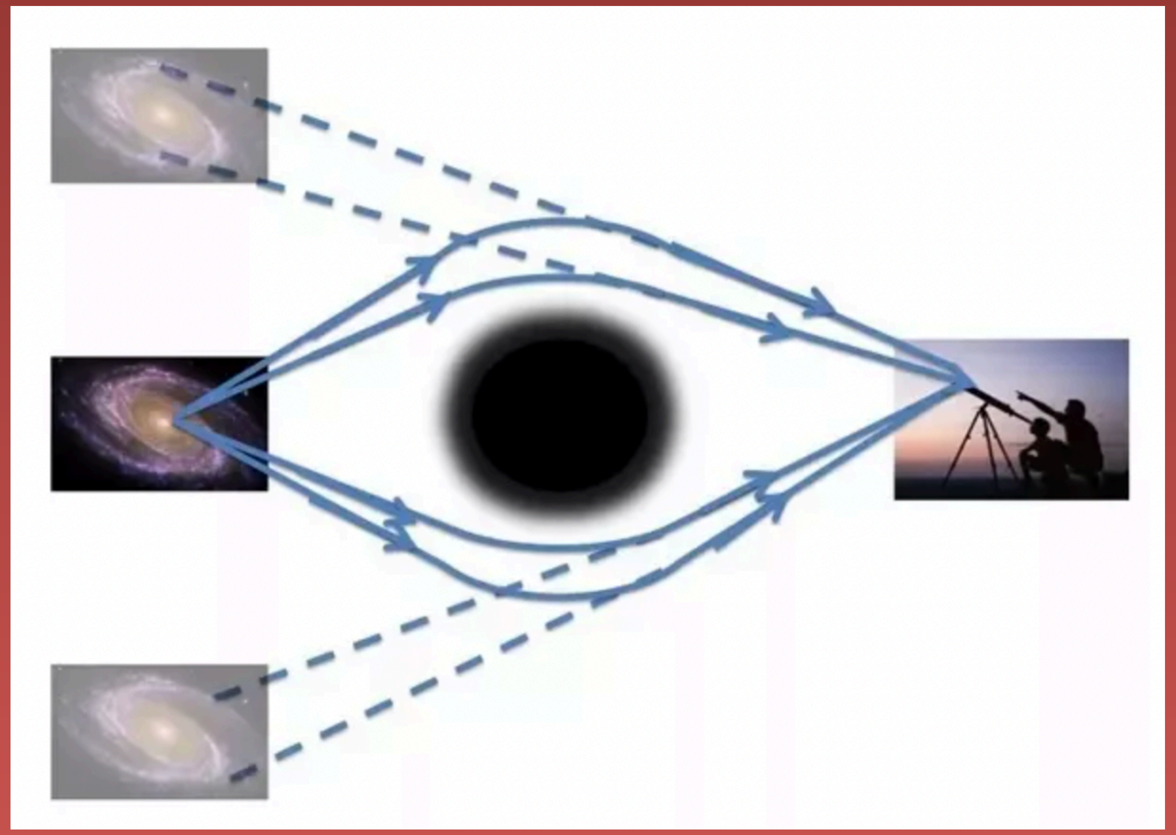

Universe content
visible matter 5%
dark matter 27%
dark energy 68%

a) Galaxy Clusters

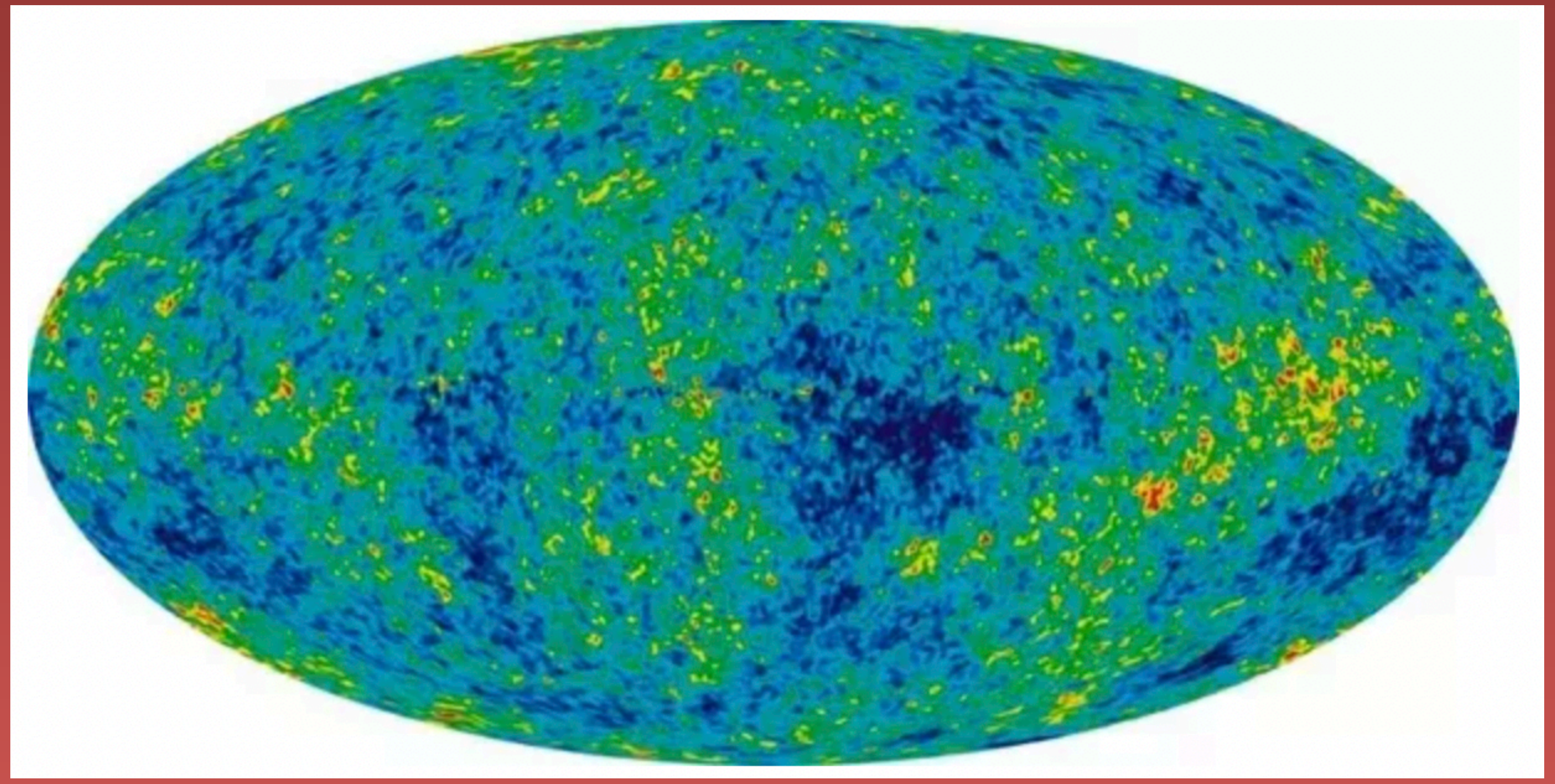
b) Galaxies' rotation speed



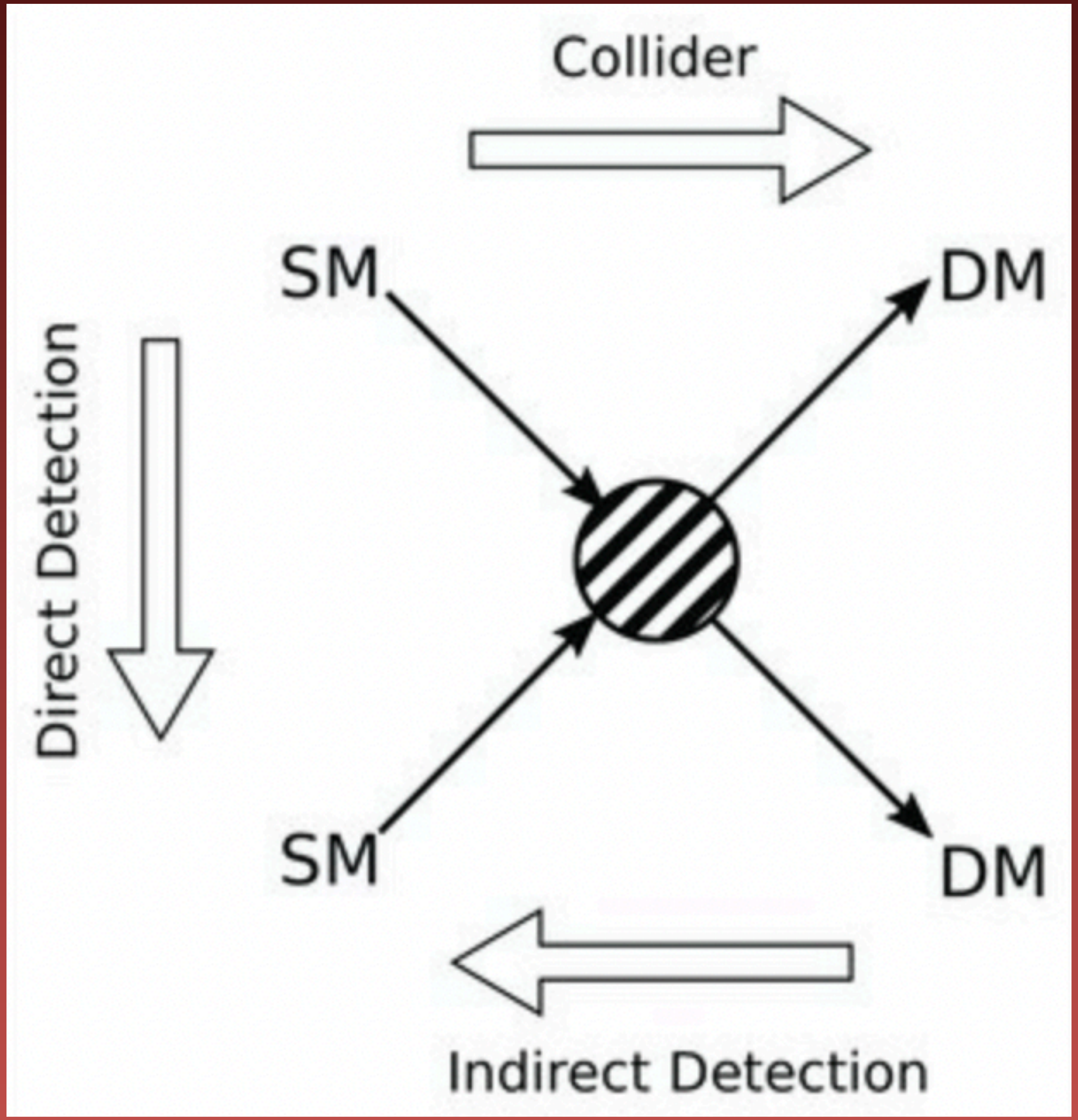
c) Gravitational lenses



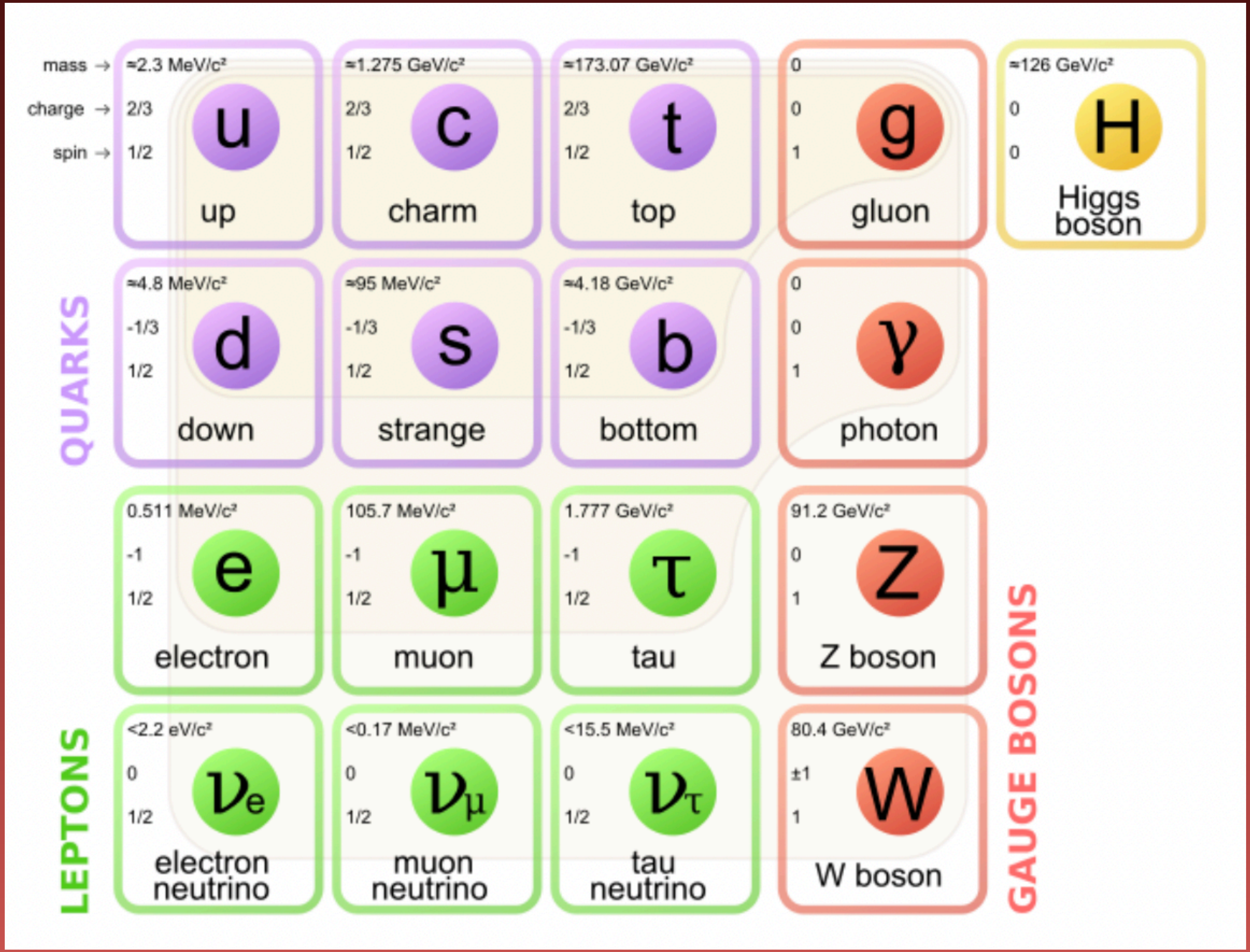
d) CMB



Detection Mechanism



Standard Model



Neutrino Telescopes’ Dark Matter signal

$$\frac{dF_\nu}{dE} = \int d\Omega \frac{dI_\nu}{dE} = \frac{\langle \sigma v \rangle}{8\pi m_\chi^2} \frac{dN_\nu}{dE} \int d\Omega \int_o^{l_{max}} \rho_\chi^2 [r(l)] dl$$

Yuksel et al. Phys.Rev.D 76 (2007) 123506

where:

$$r = \sqrt{R_\oplus^2 + l^2 - 2R_\oplus l cos\psi}$$

$$R_\oplus = 8.5kpc$$

$$l_{max} = R_\oplus cos\psi + \sqrt{R_{vir}^2 - R_\oplus^2 sin^2\psi}$$

$$R_{vir} \approx 200kpc$$

Dark Matter Density profile used - Navarro-Frenk-White (NFW):

$$\rho_\chi(r) = \frac{\rho_S}{(r/r_S)(1+r/r_S)^2}$$

$$r_S = 20kpc$$

$$\rho_\chi(R_\oplus) = 0.4\,GeV\,cm^{-3}$$

And fluxes:

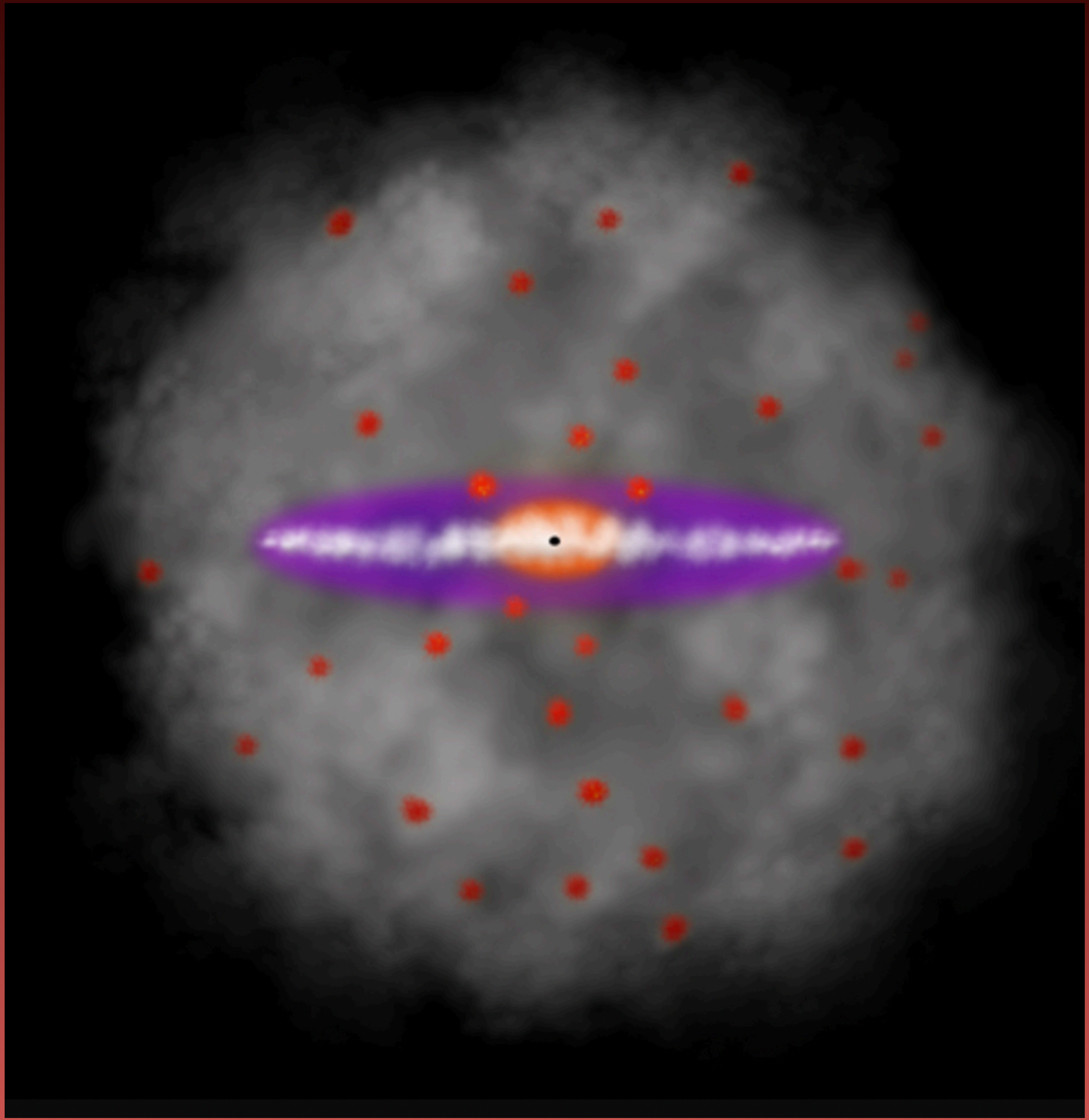
PPPC4DMID $m_\chi < 1\,TeV$

HDMSpectra $m_\chi > 1\,TeV$

$$\chi\chi \longrightarrow \nu\bar{\nu} \qquad \frac{dN_\nu}{dE} = 2\delta(m_x - E_\nu)$$

$$\chi\chi \longrightarrow YY \longrightarrow 2\nu 2\bar{\nu} \qquad \frac{dN_\nu}{dE} = \frac{4H(m_x - E_\nu)}{m_x}$$

Ibarra et al. JCAP 07 (2012) 043



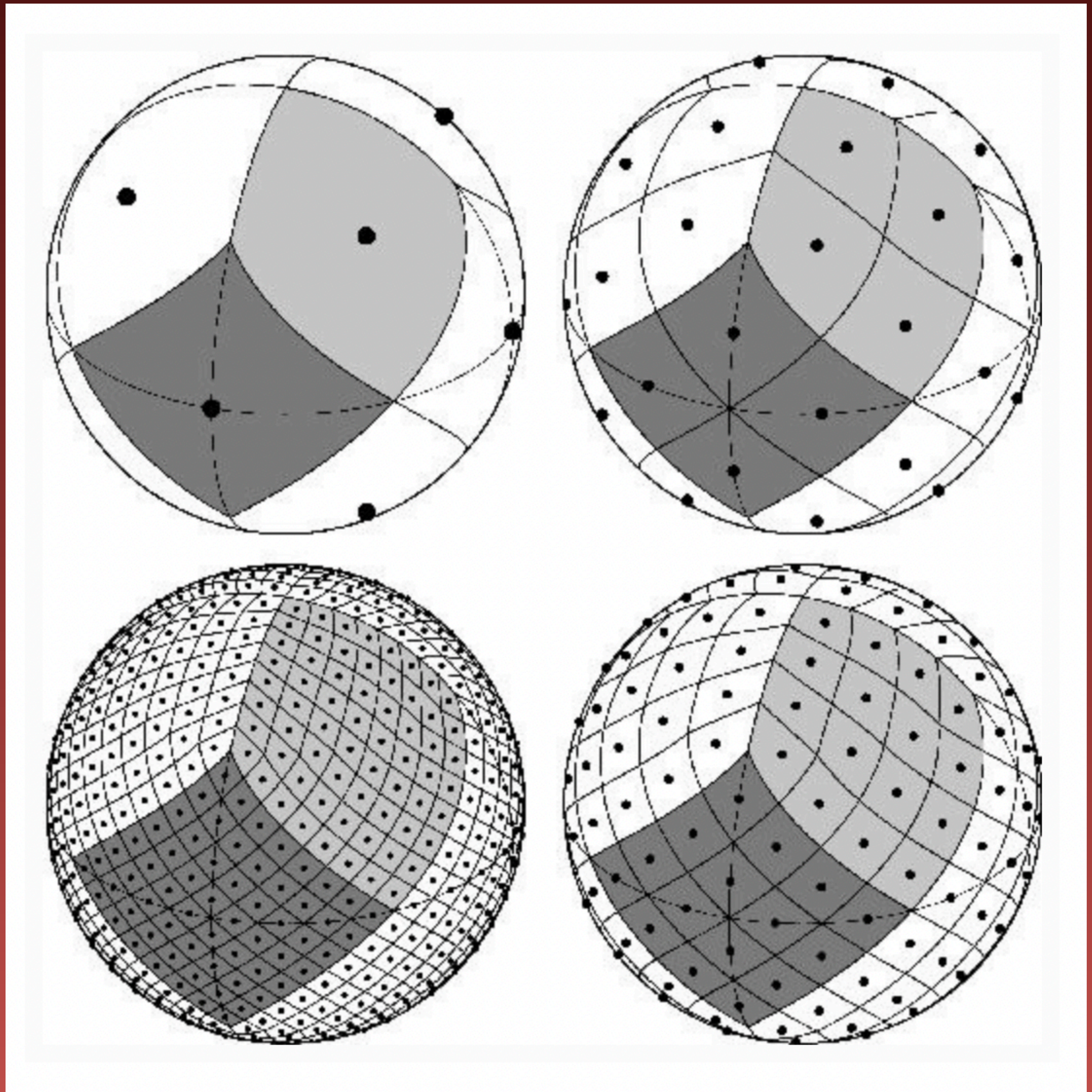
Number of Events

$$n_{ij} = T_{eff} \int_i dE_\nu \int_j vis(\Omega) d\Omega \frac{dI_\nu}{dE} A_{eff} \left\langle e^{-\tau(E_\nu,\Omega)} \right\rangle$$

Healpix and Astropy (Python libraries), help to do the integrations

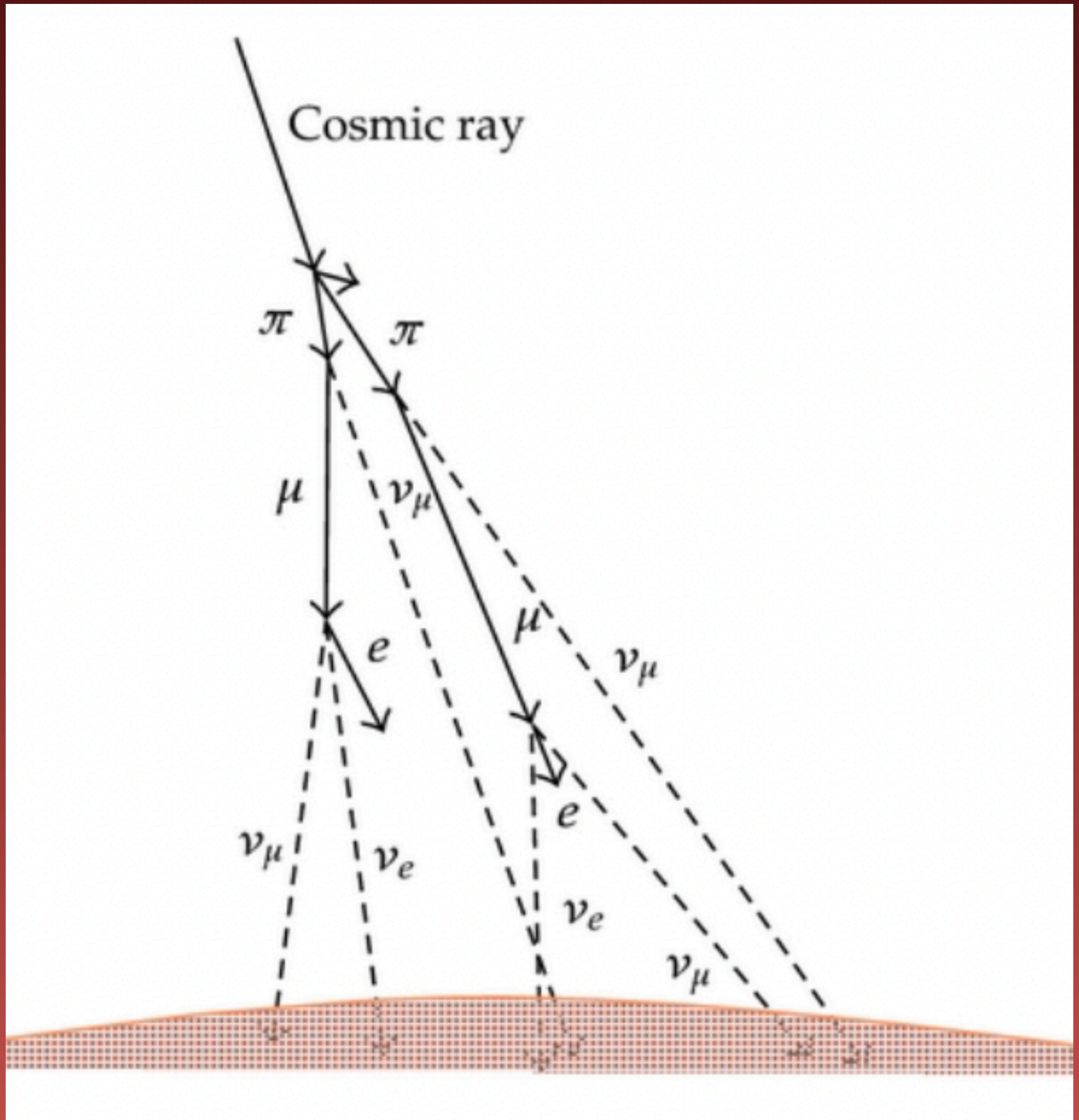
Atmospheric Neutrinos and Astrophysical Neutrinos are the background

Healpix

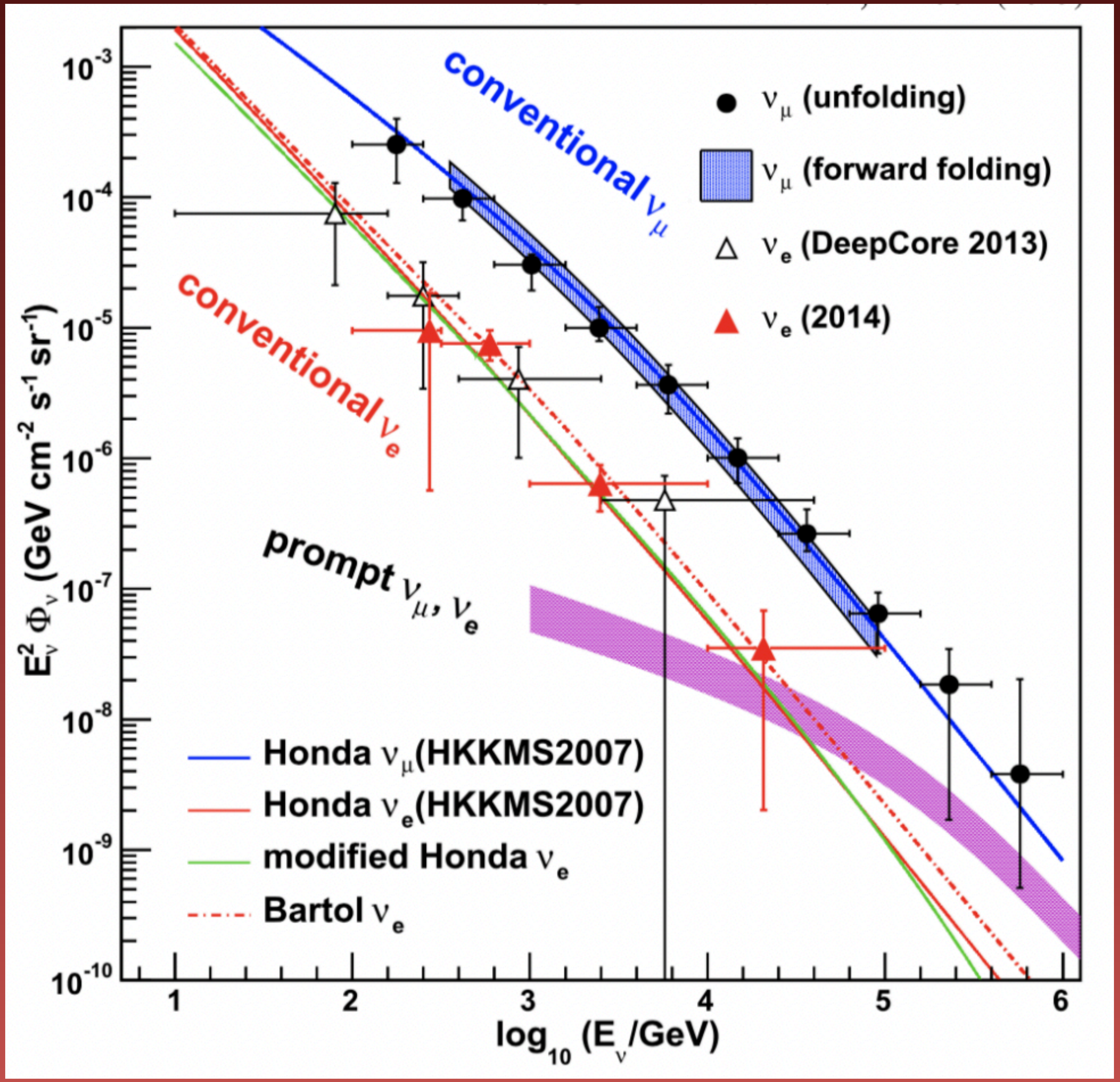


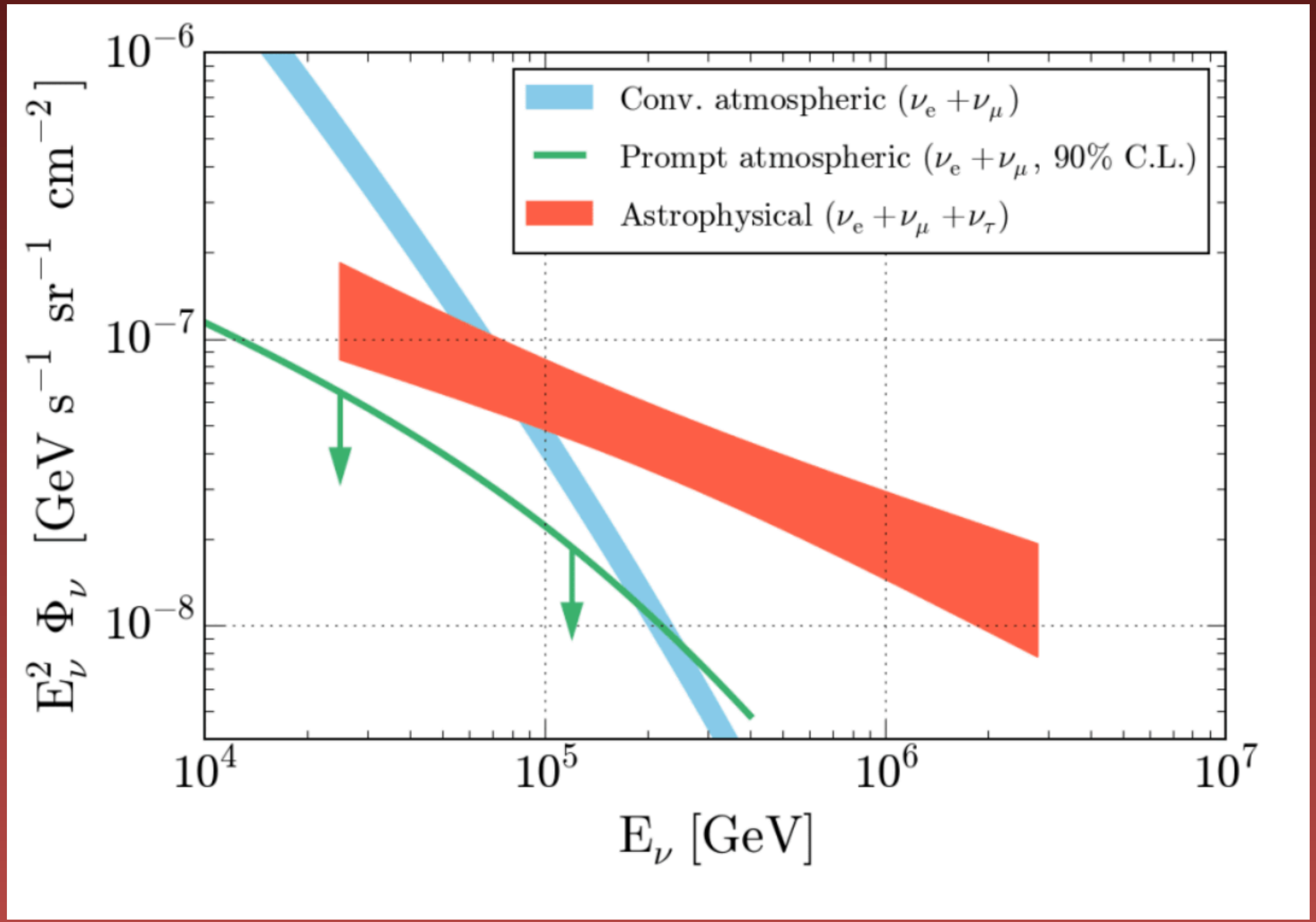
Astropy

Atmospheric Neutrinos

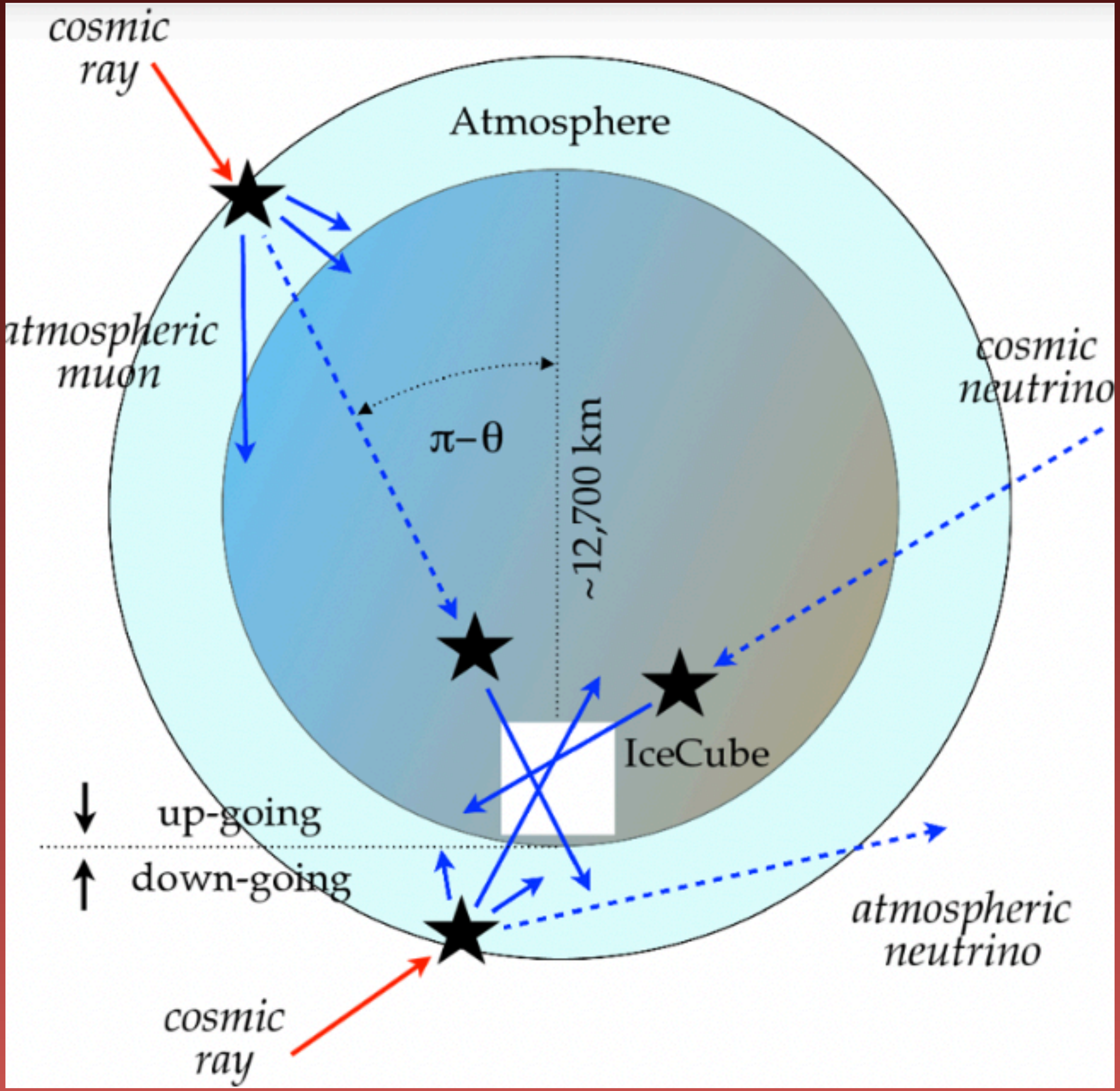


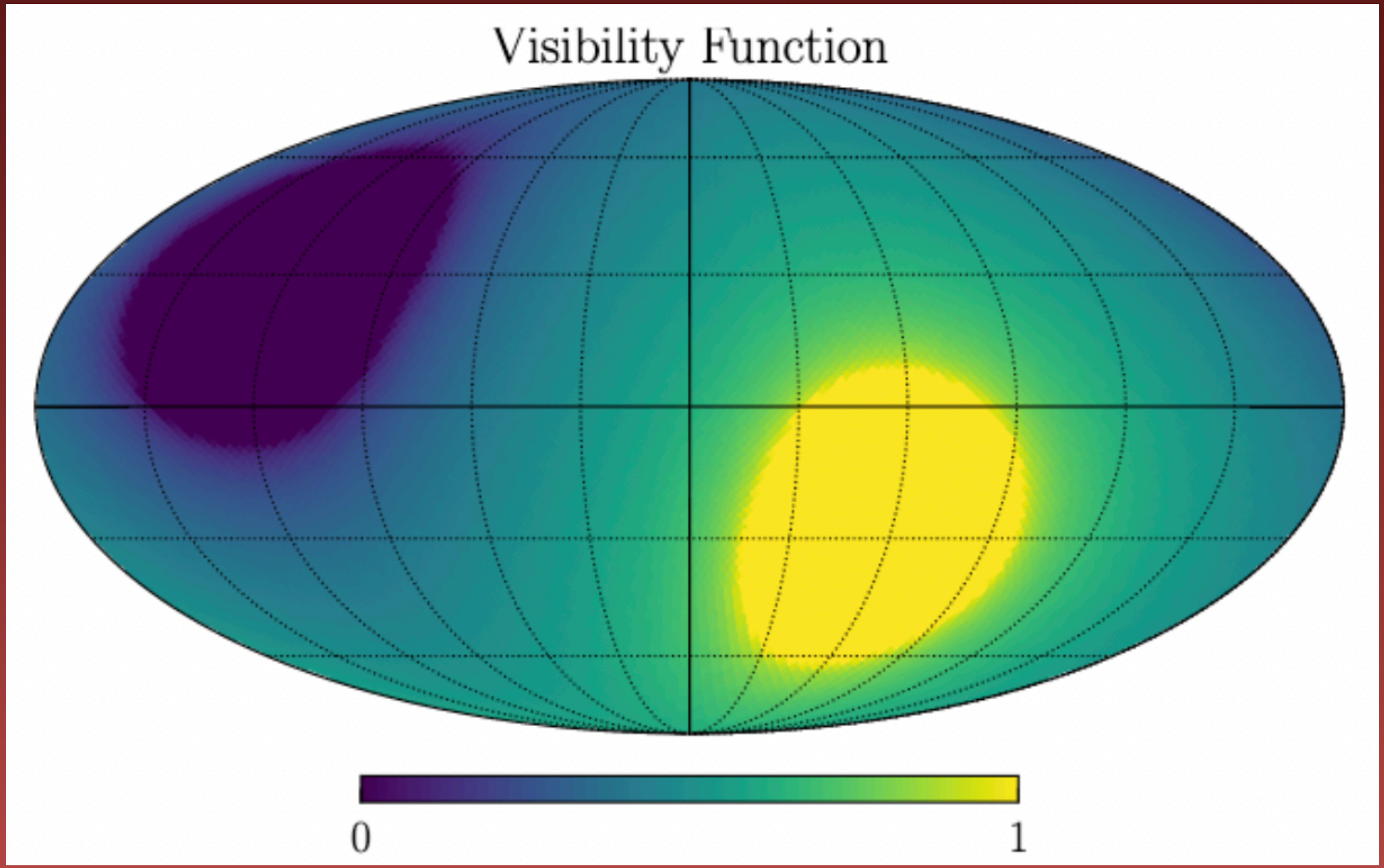
Neutrino Fluxes

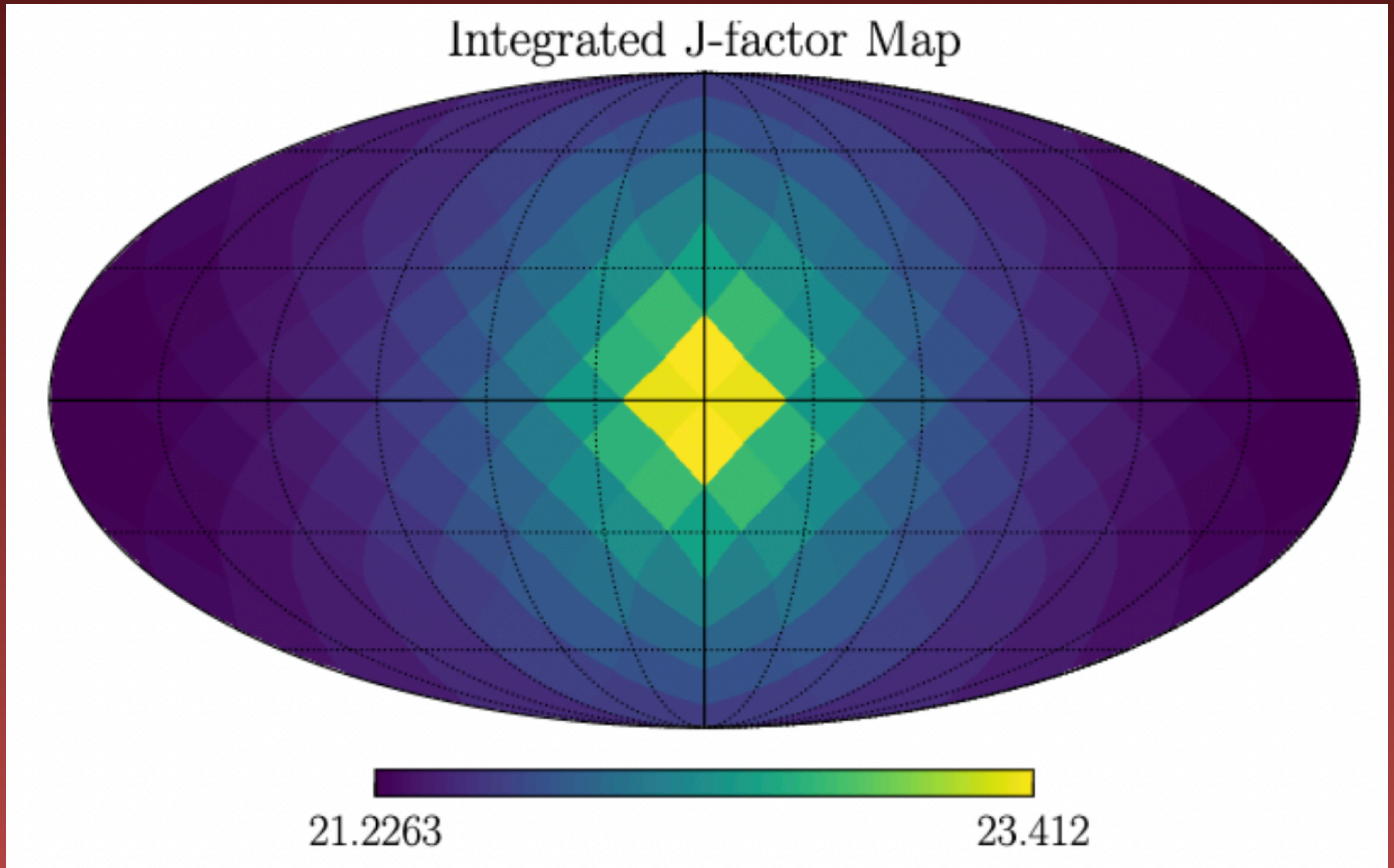




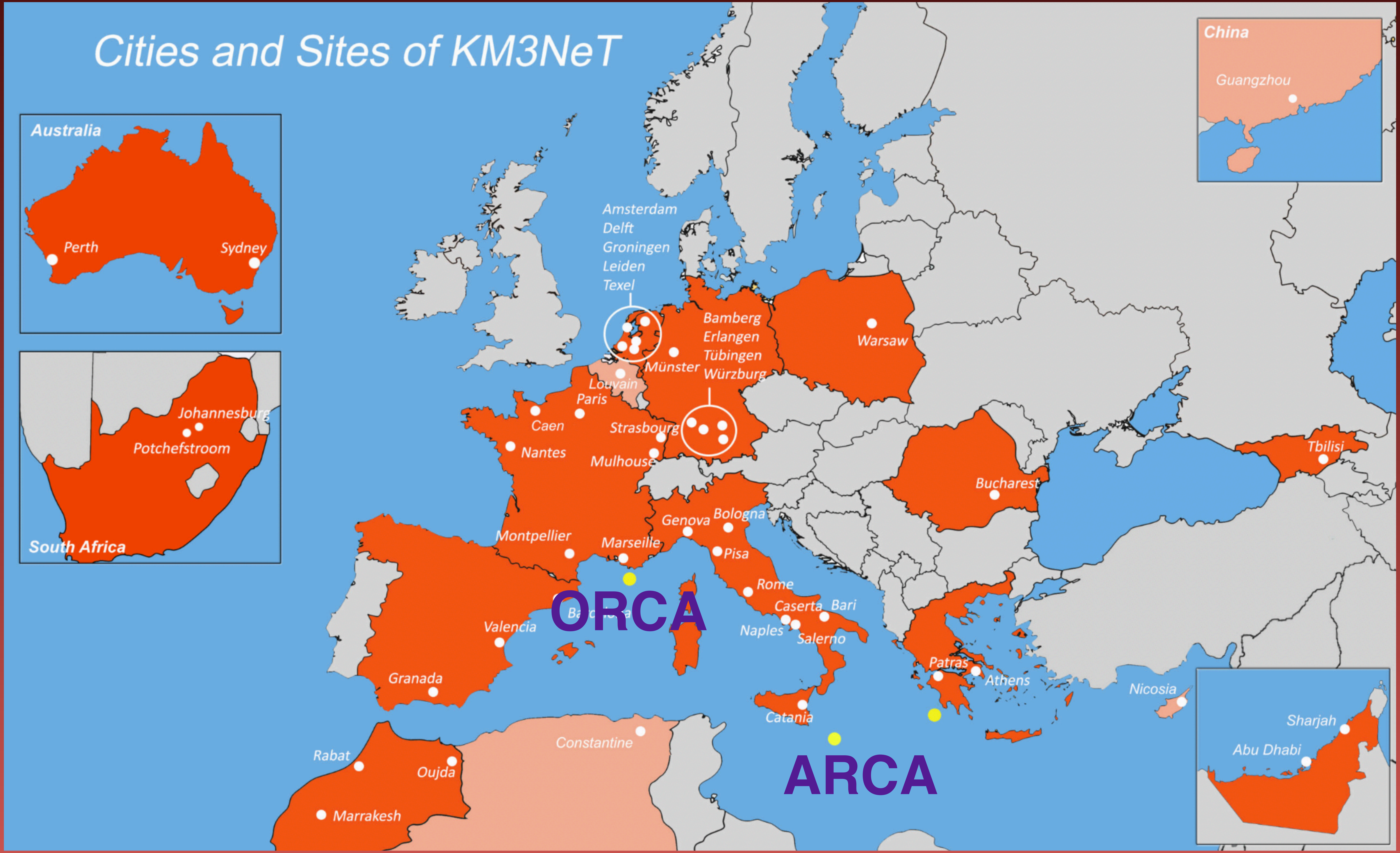
Upgoing and Downgoing neutrinos



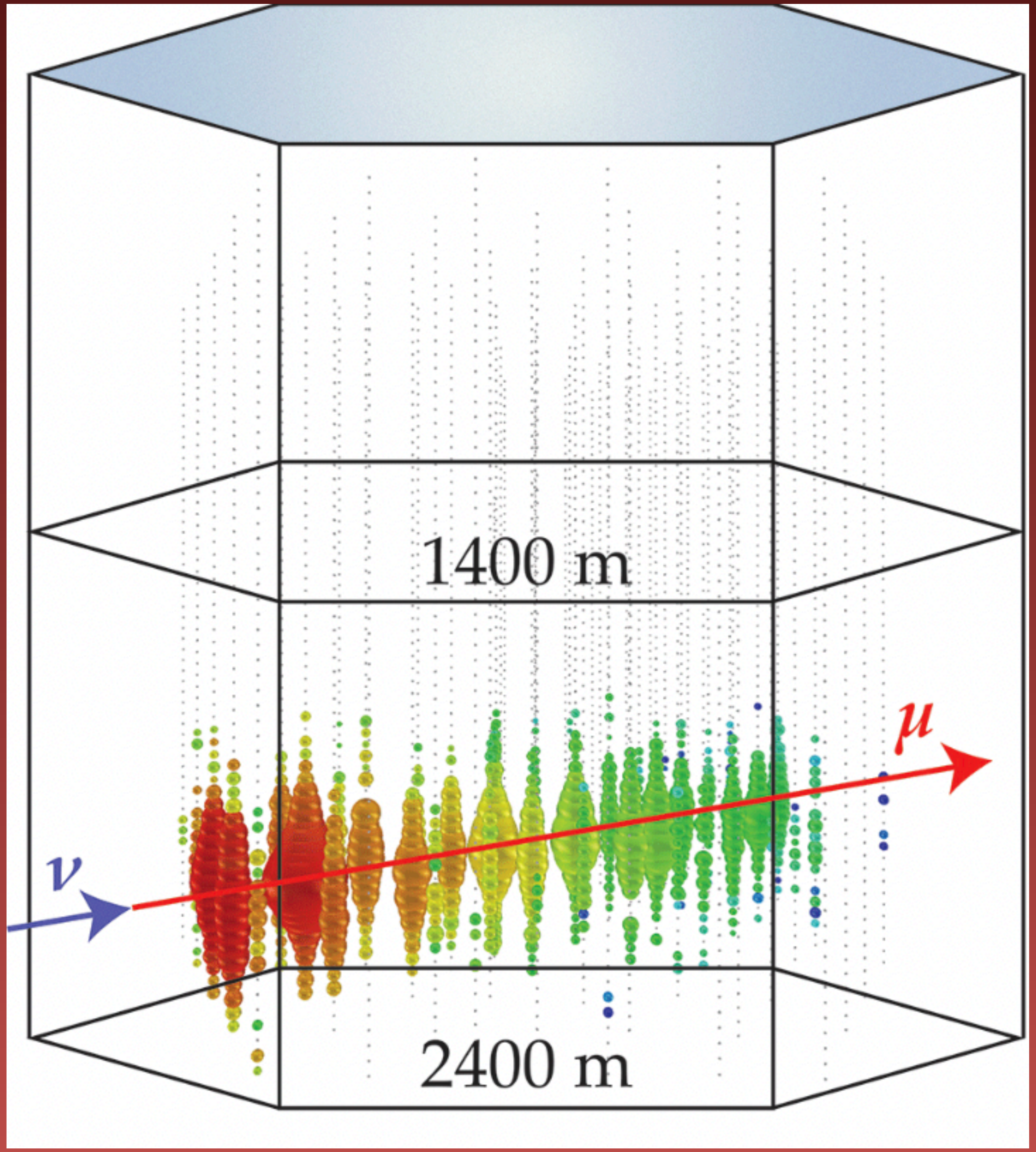

Visibility Function
0
1

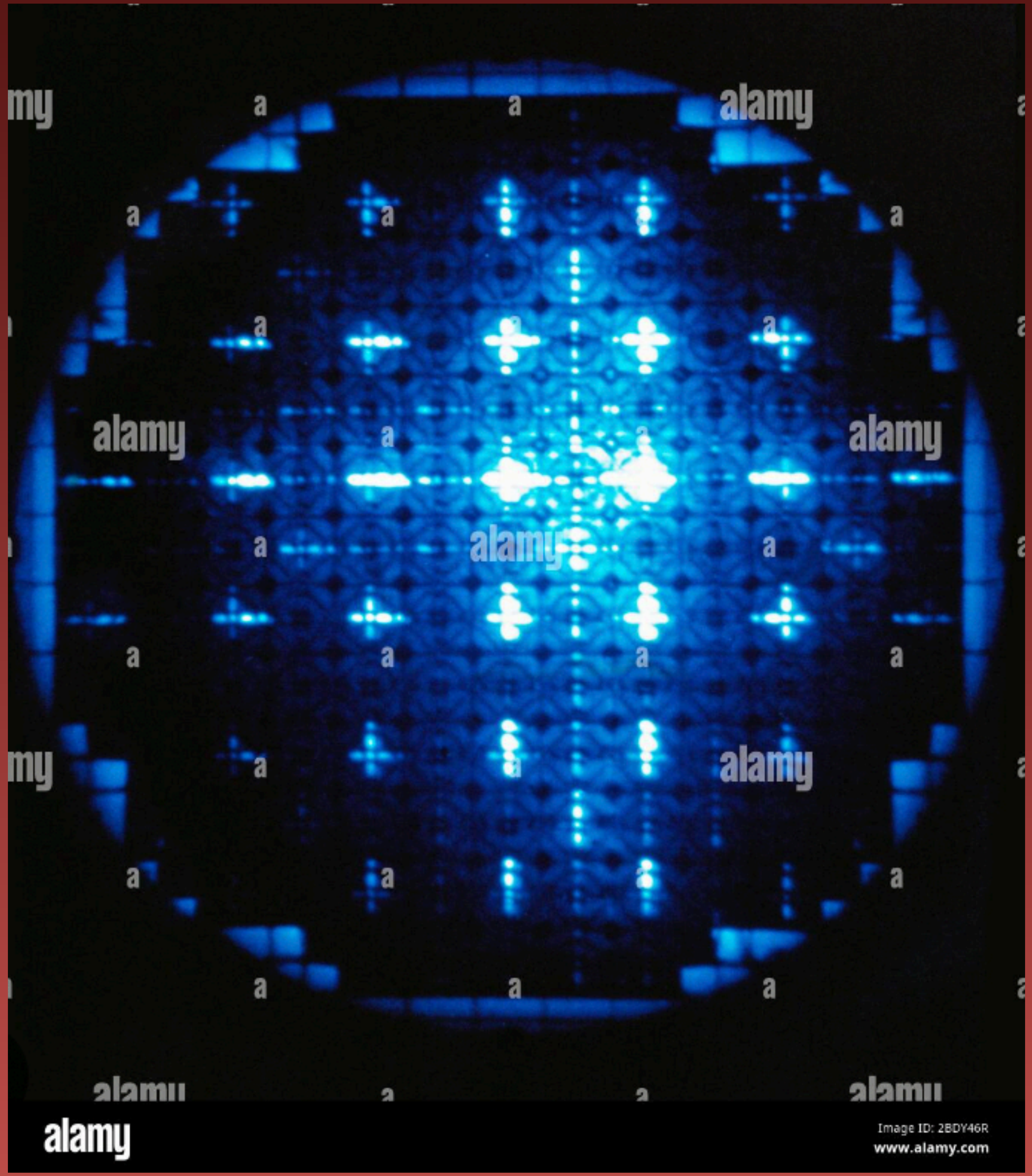

Integrated J-factor Map
21.2263
23.412

ORCA and ARCA (KM3NeT)



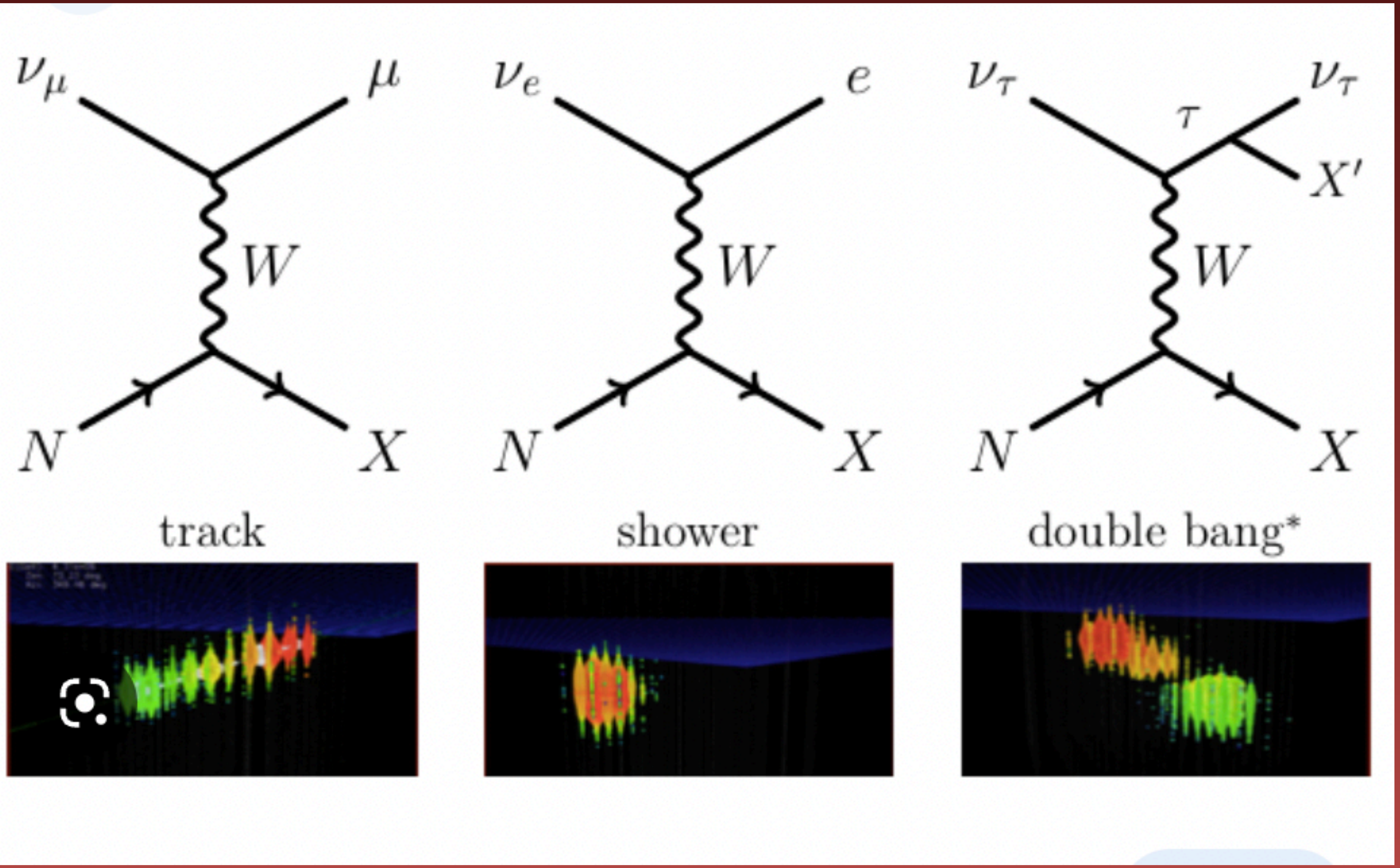
Cherenkov Radiation

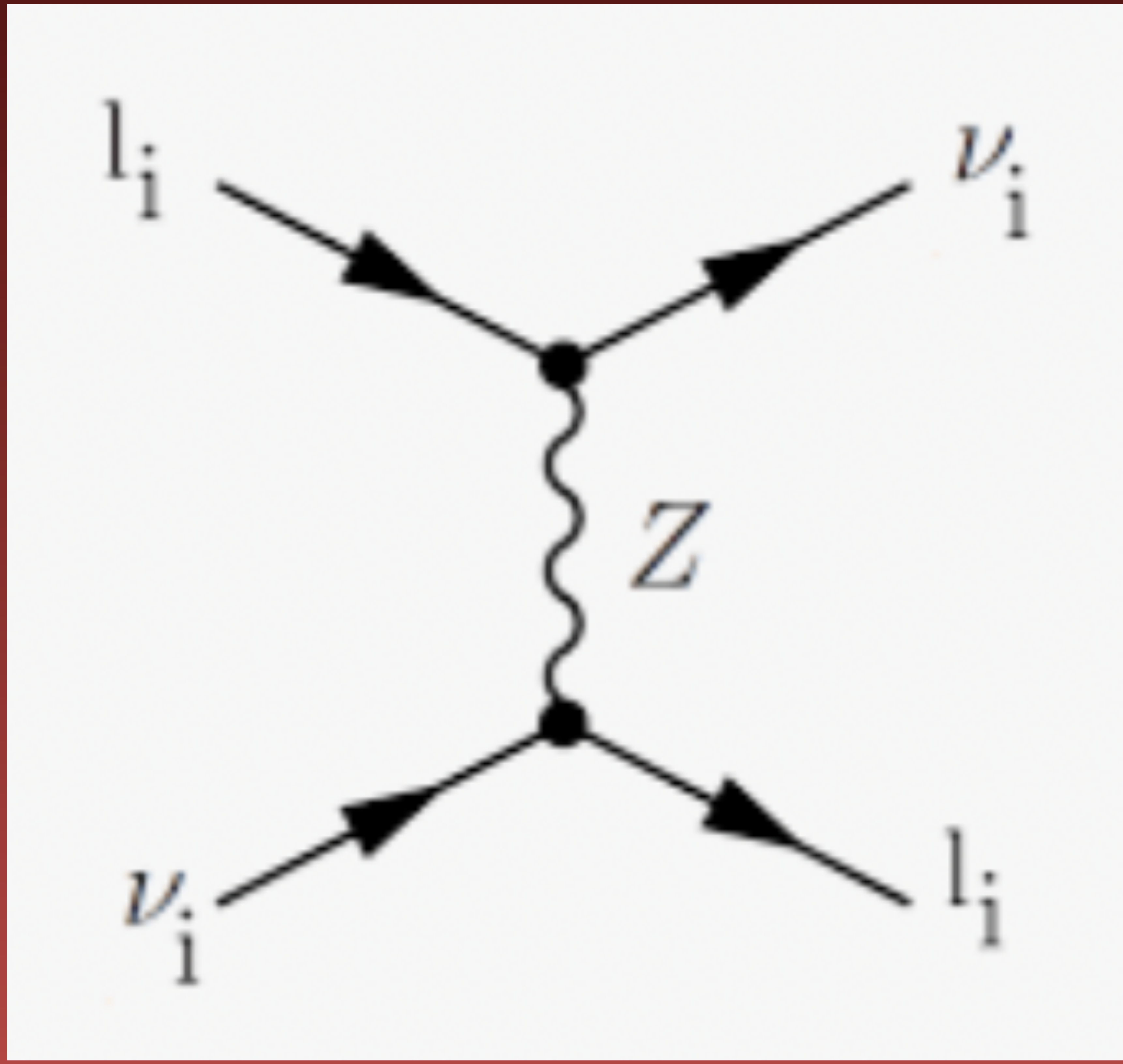




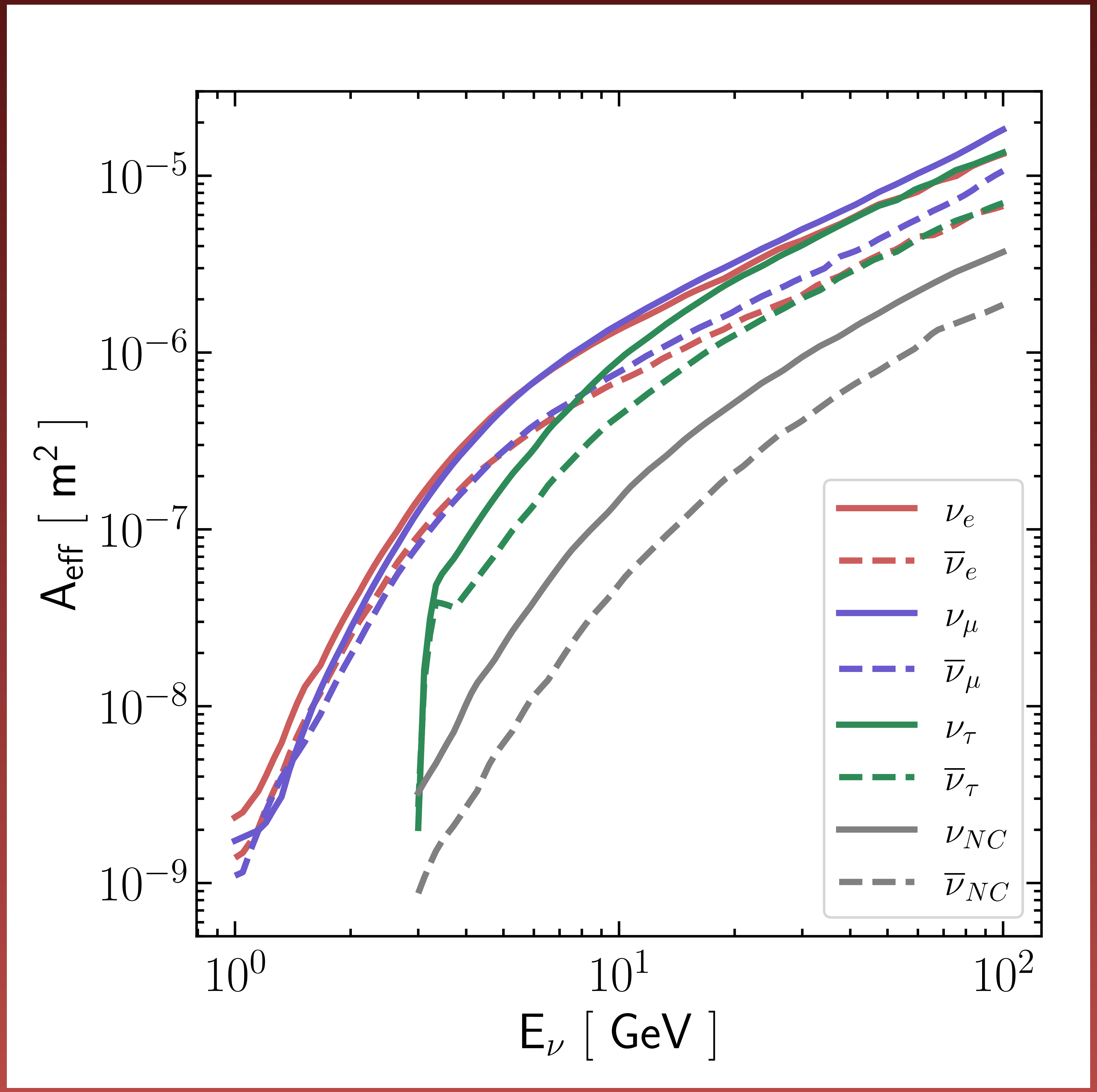
Charged Currents

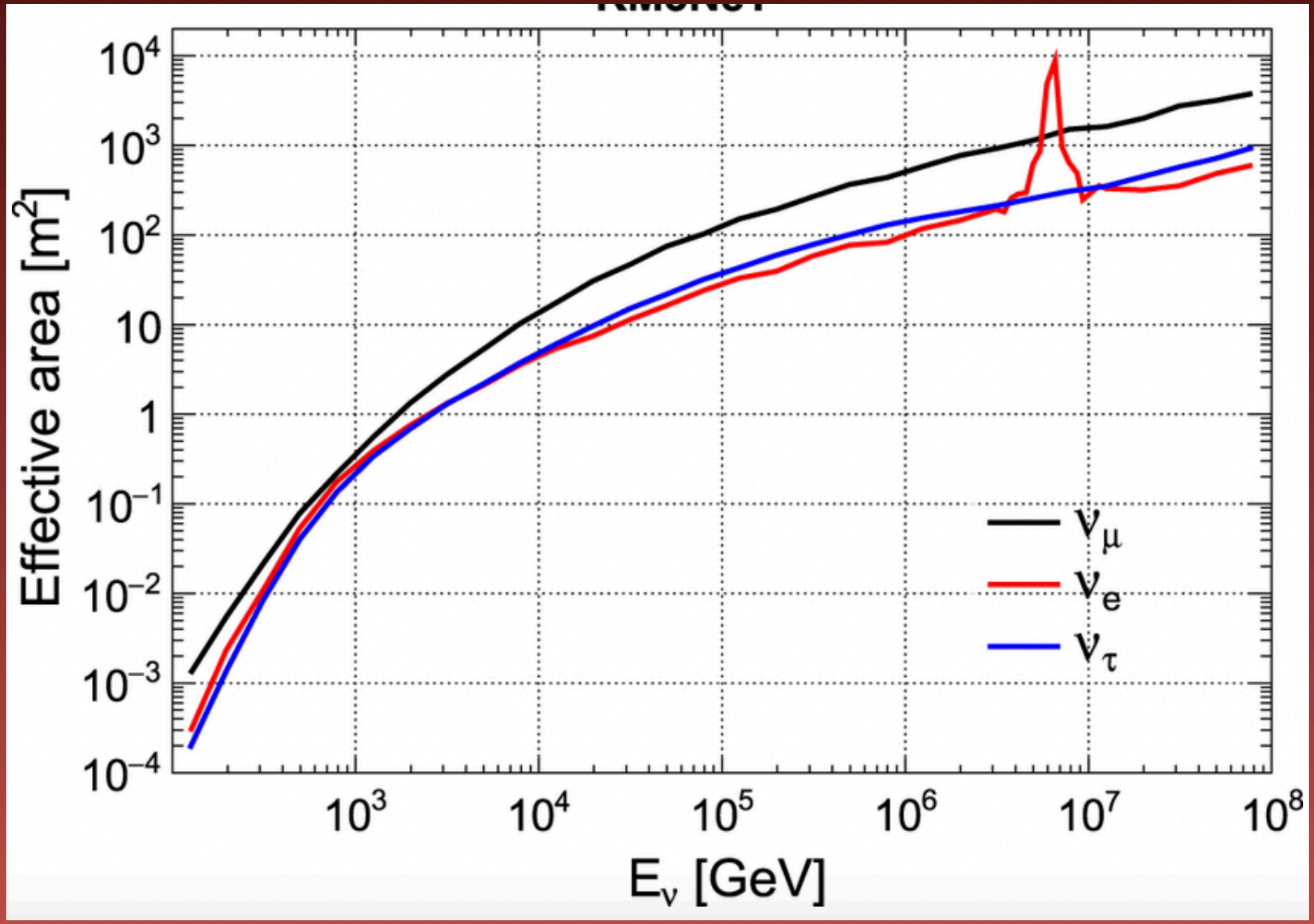
Neutral Currents





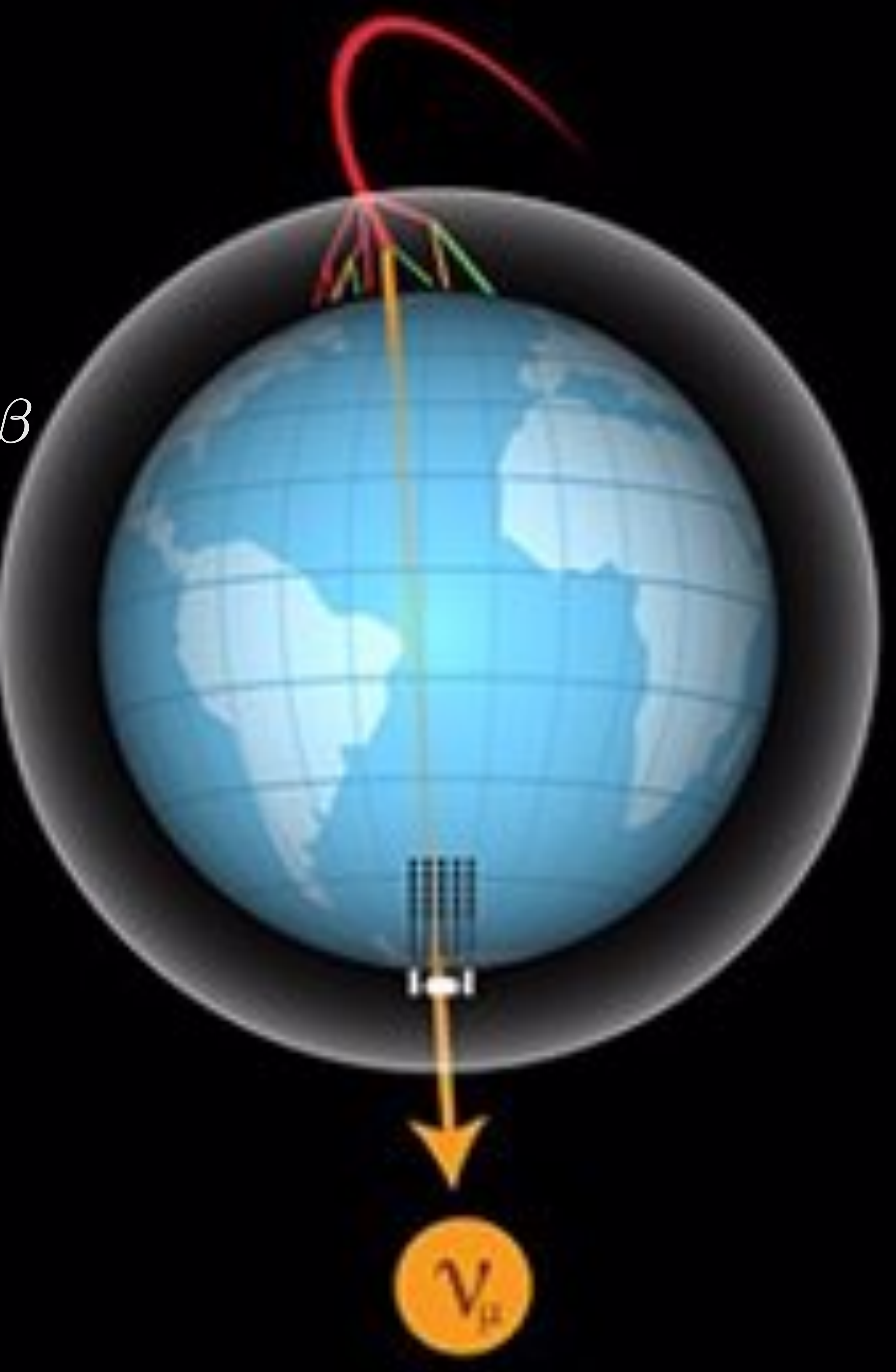
Effective Areas





Neutrino Oscillations

$$\left(\frac{dN}{dE}\right)_\beta = \sum_\alpha \left(\frac{dN}{dE}\right)_\alpha^{src} P_{\alpha\beta}$$



a) ORCA background Neutrino Oscillations

Schrödinger Equation

$$H_f = \frac{1}{2E} U_f M U_f^T + V_f \,.$$

matrix in the flavor basis, $V_f = \mathrm{diag}(V_e, 0, 0)$, ta

$$V_e = \sqrt{2} G_F N_e \approx 3.78 \times 10^{-14} \left(\frac{\rho}{\mathrm{g/cm^3}} \right) \mathrm{eV} \,,$$

$$a)\; P_{\alpha\beta} = P^{\oplus}_{\alpha\beta}$$

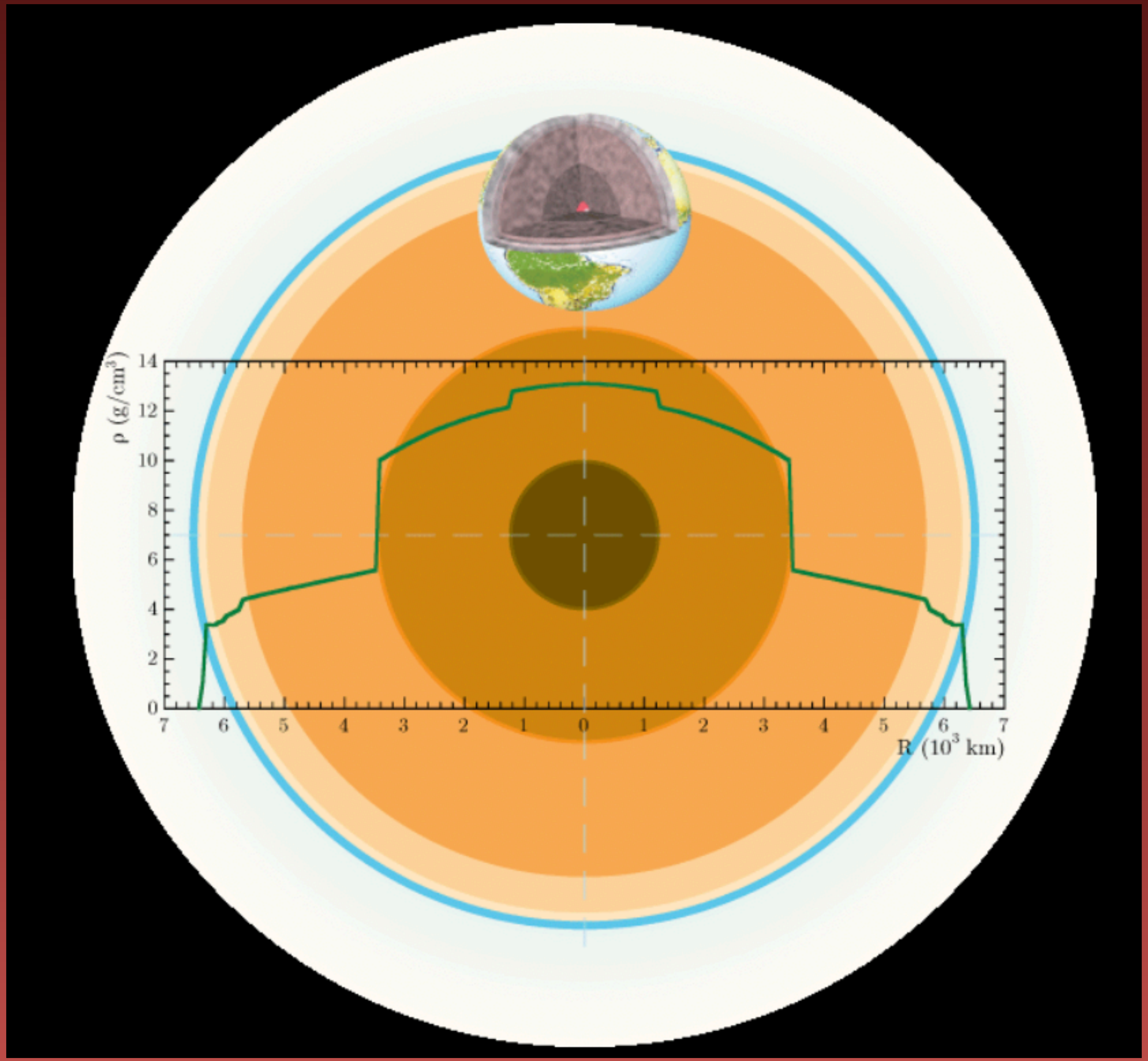
b) Dark Matter ORCA Neutrino Oscillations

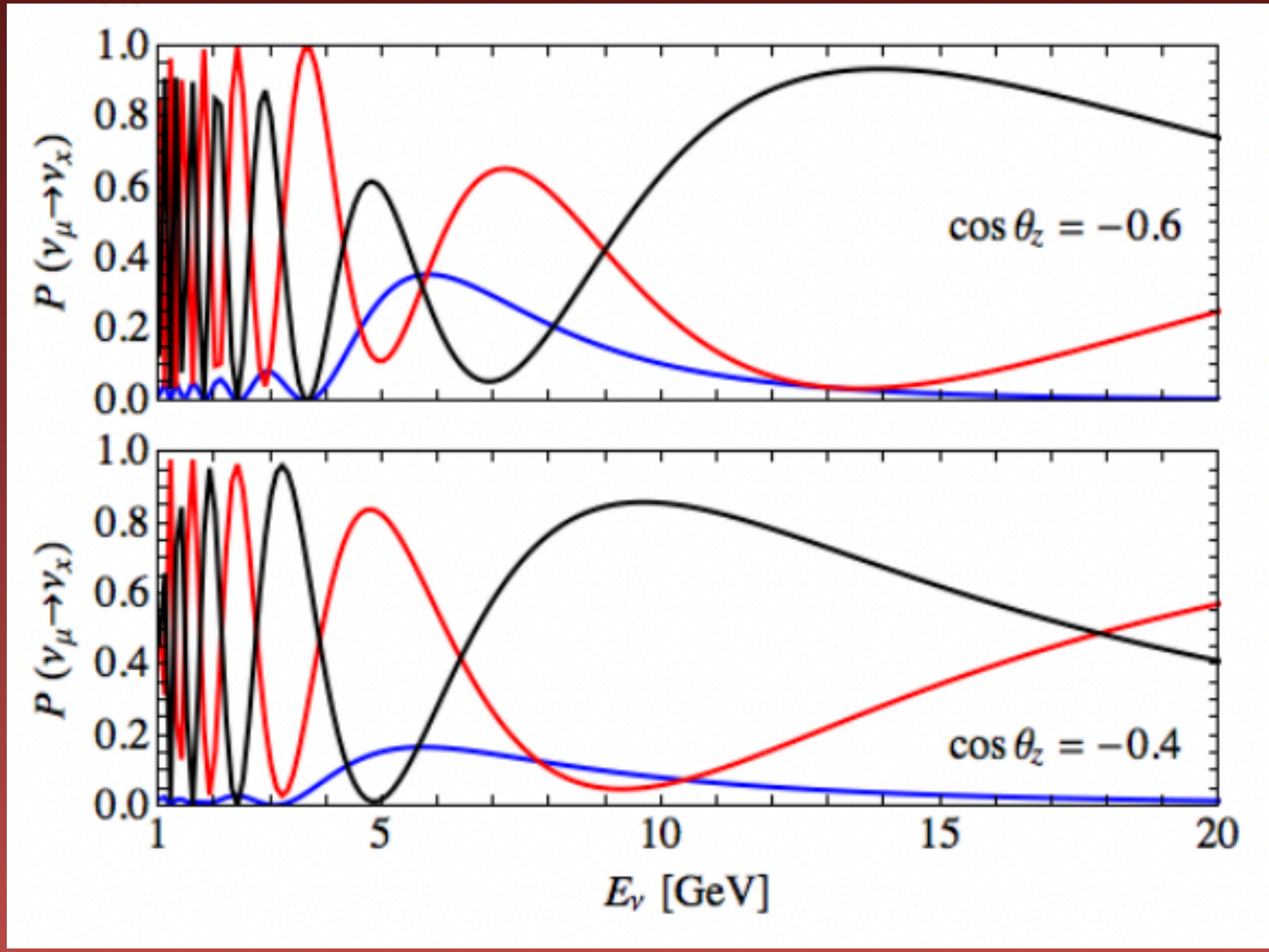
$$b)\; P_{\alpha\beta} = \sum_i |U_{\alpha i}|^2 |\sum_\eta A^{\oplus}_{\beta\eta} U_{ni}|^2$$

c) ARCA Neutrinos

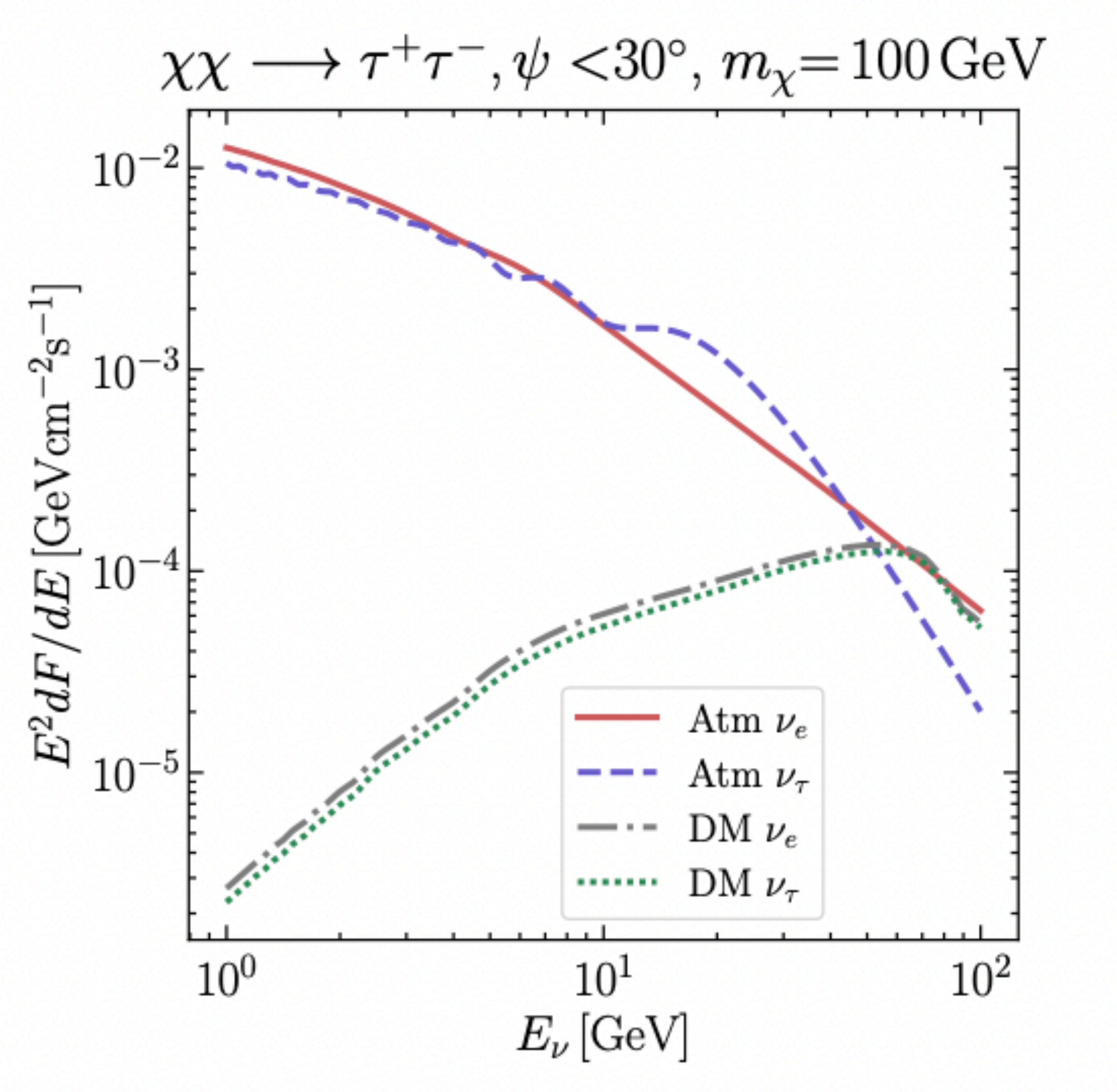
$$c)\; P_{\alpha\beta} = \sum_i |U_{\alpha i}|^2 |U_{\beta i}|$$

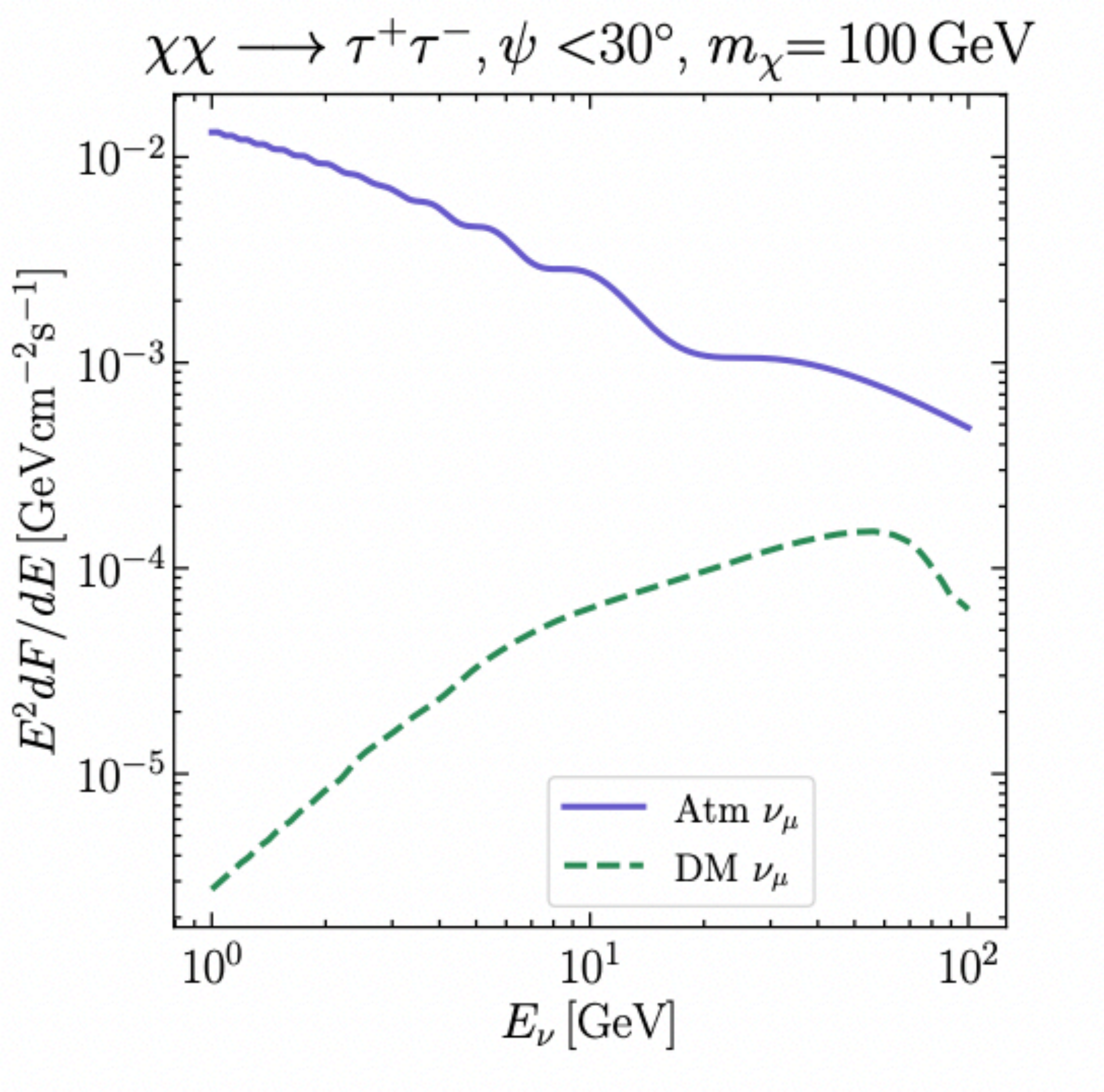
Neutrino Oscillations through Mantle's Earth

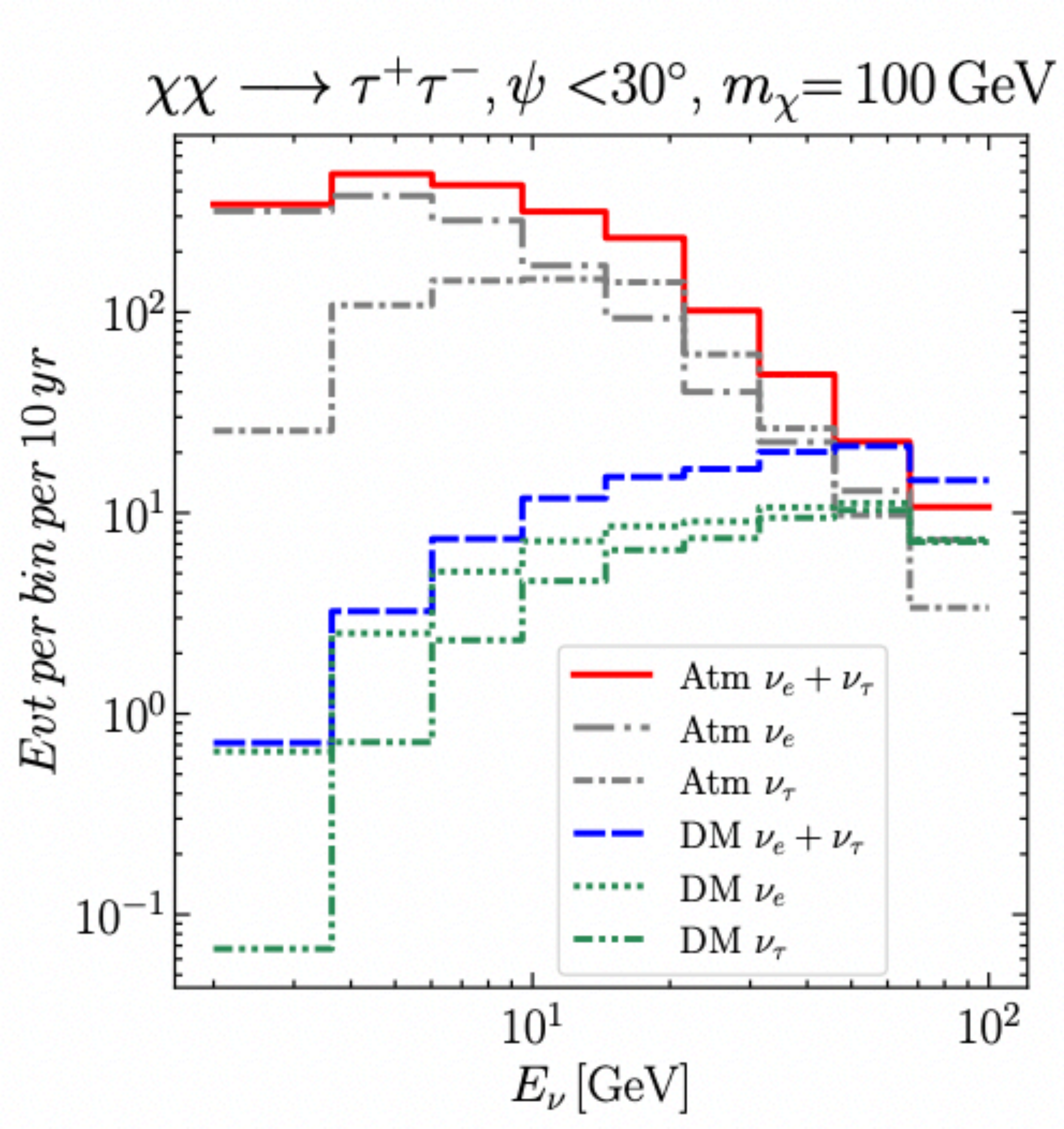




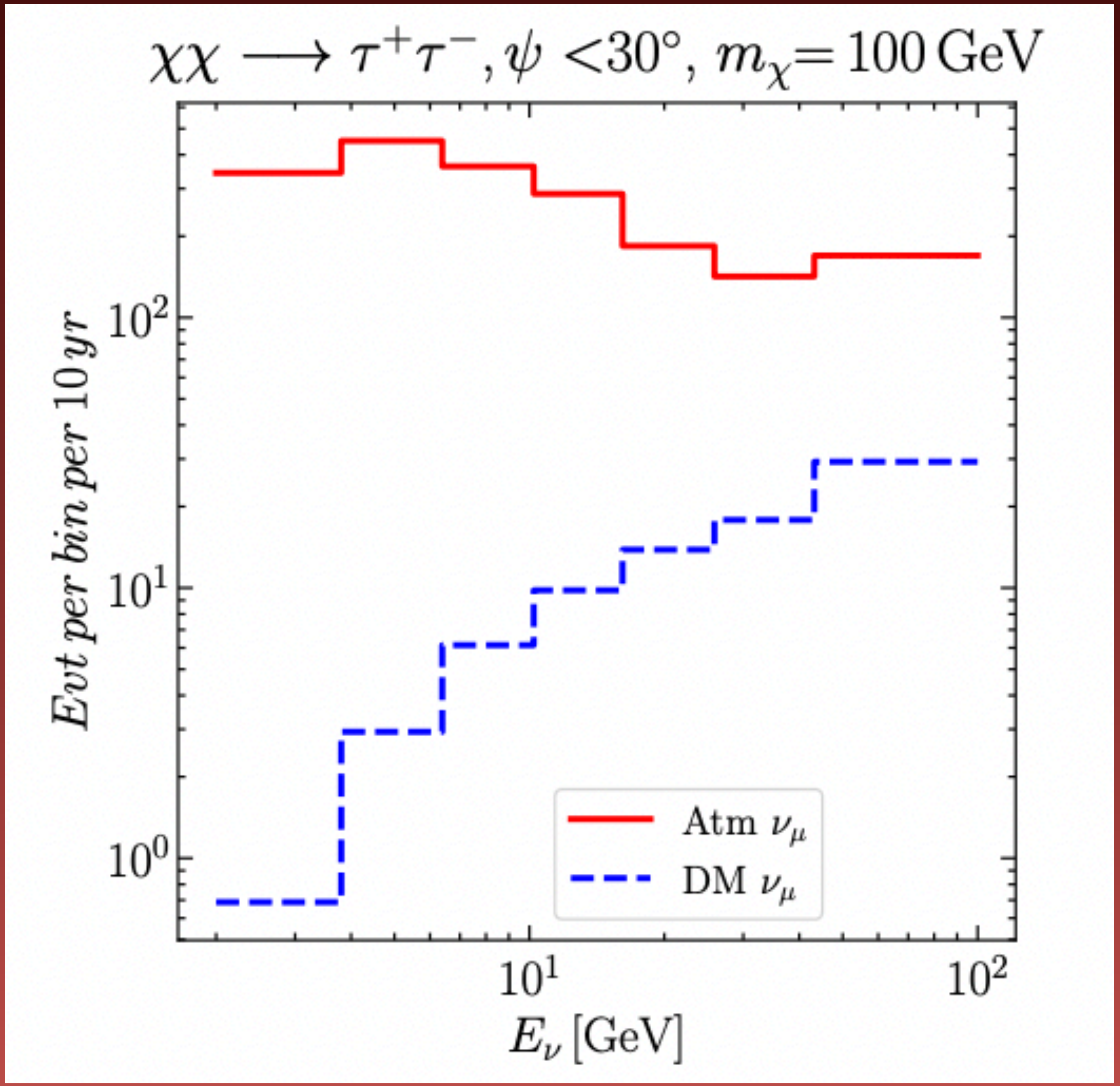
ORCA fluxes and number of events





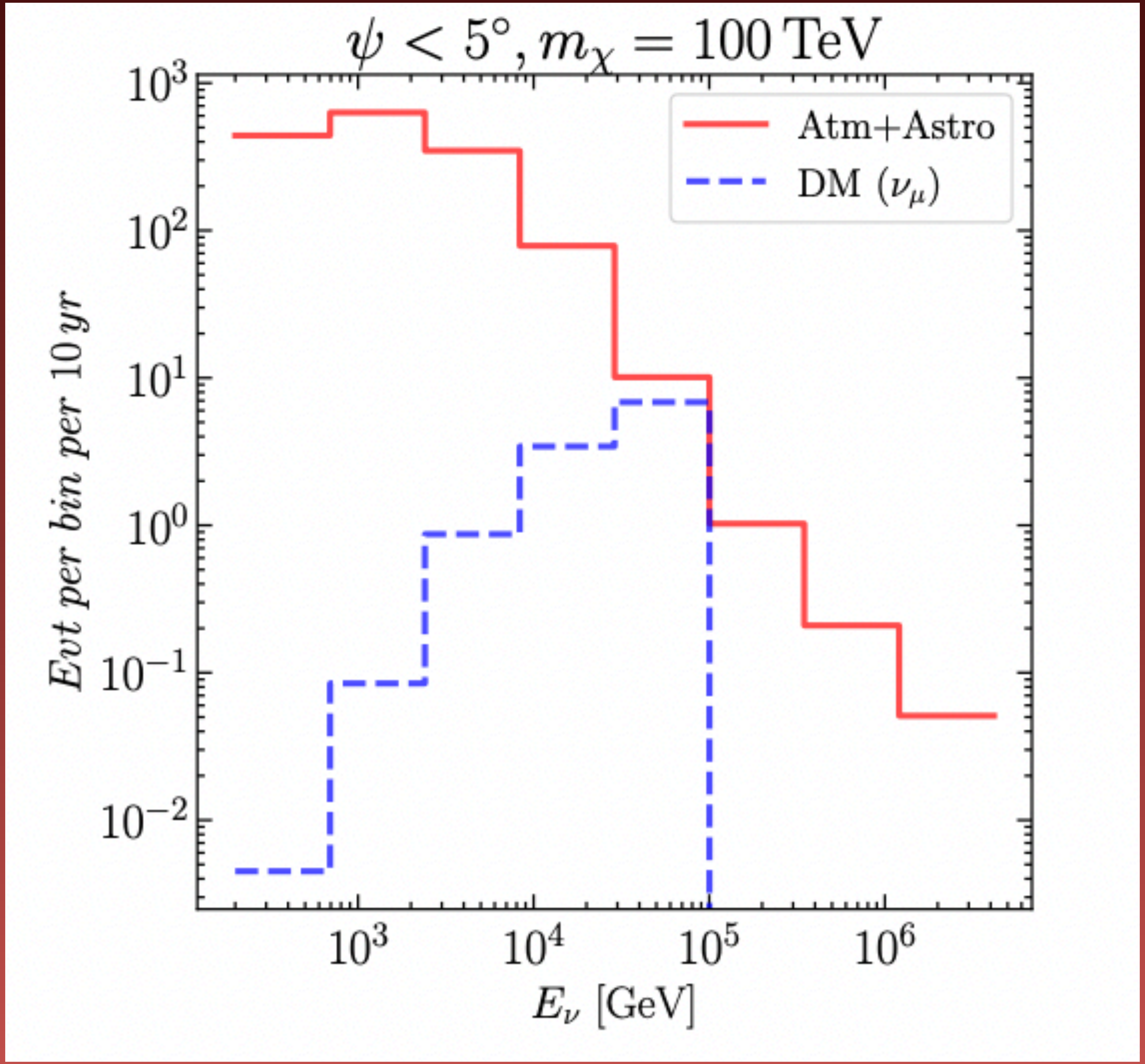


$\chi\chi \longrightarrow \tau^+\tau^-, \psi < 30°, m_\chi = 100\,\mathrm{GeV}$
Evt per bin per 10 yr
E_ν [GeV]
Atm $\nu_e + \nu_\tau$
Atm ν_e
Atm ν_τ
DM $\nu_e + \nu_\tau$
DM ν_e
DM ν_τ



$\chi\chi \longrightarrow \tau^+\tau^-, \psi < 30°, m_\chi = 100\,\mathrm{GeV}$
Evt per bin per 10 yr
E_ν [GeV]
Atm ν_μ
DM ν_μ

ARCA number of events



Maximum Likelihood ratio analysis

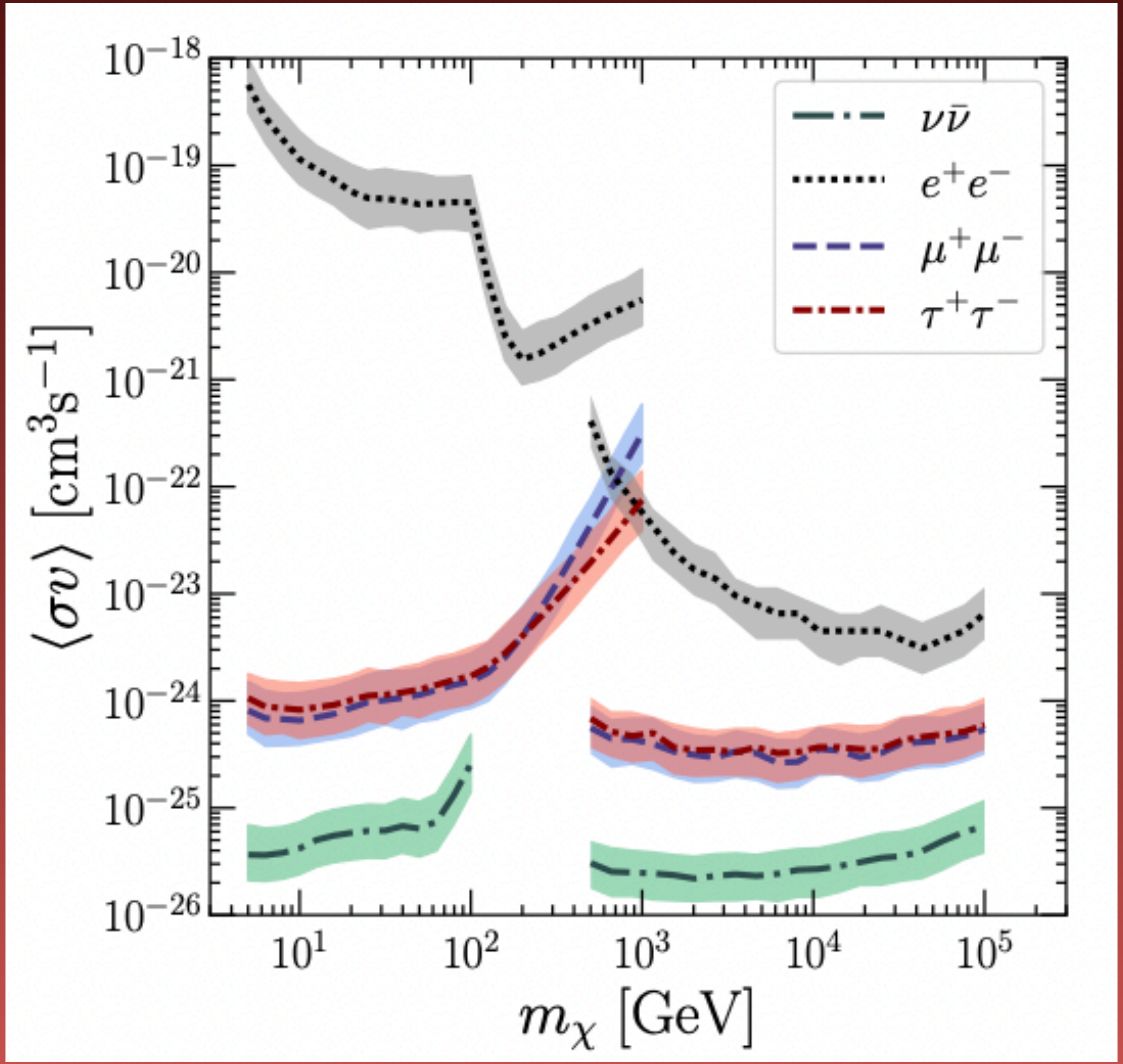
$$L(\langle \sigma v \rangle) = \Pi_{ij} \left[\frac{\mu_{ij}^{n_{ij}} e^{-\mu_{ij}}}{n_{ij}!} \right]$$

Number of events include background and expected number of events include background plus signal events.

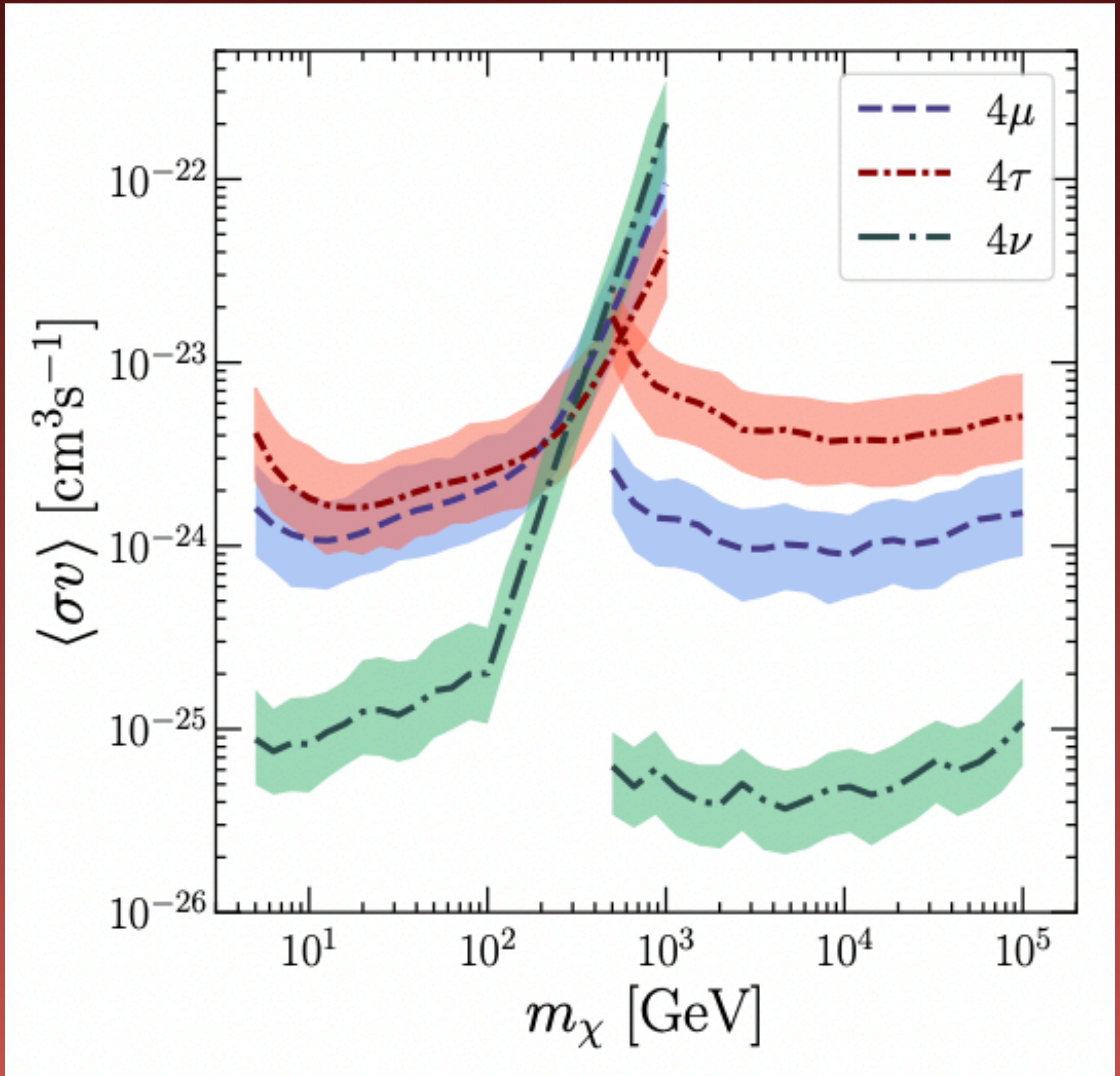
Confidence level to 95% one sided and one variable, takes the limit value TS = 2.71, for any annihilation channel.

$$TS(\langle \sigma v \rangle) = -2In \left[\frac{L(\langle \sigma v \rangle)}{L(0)} \right]$$

Results

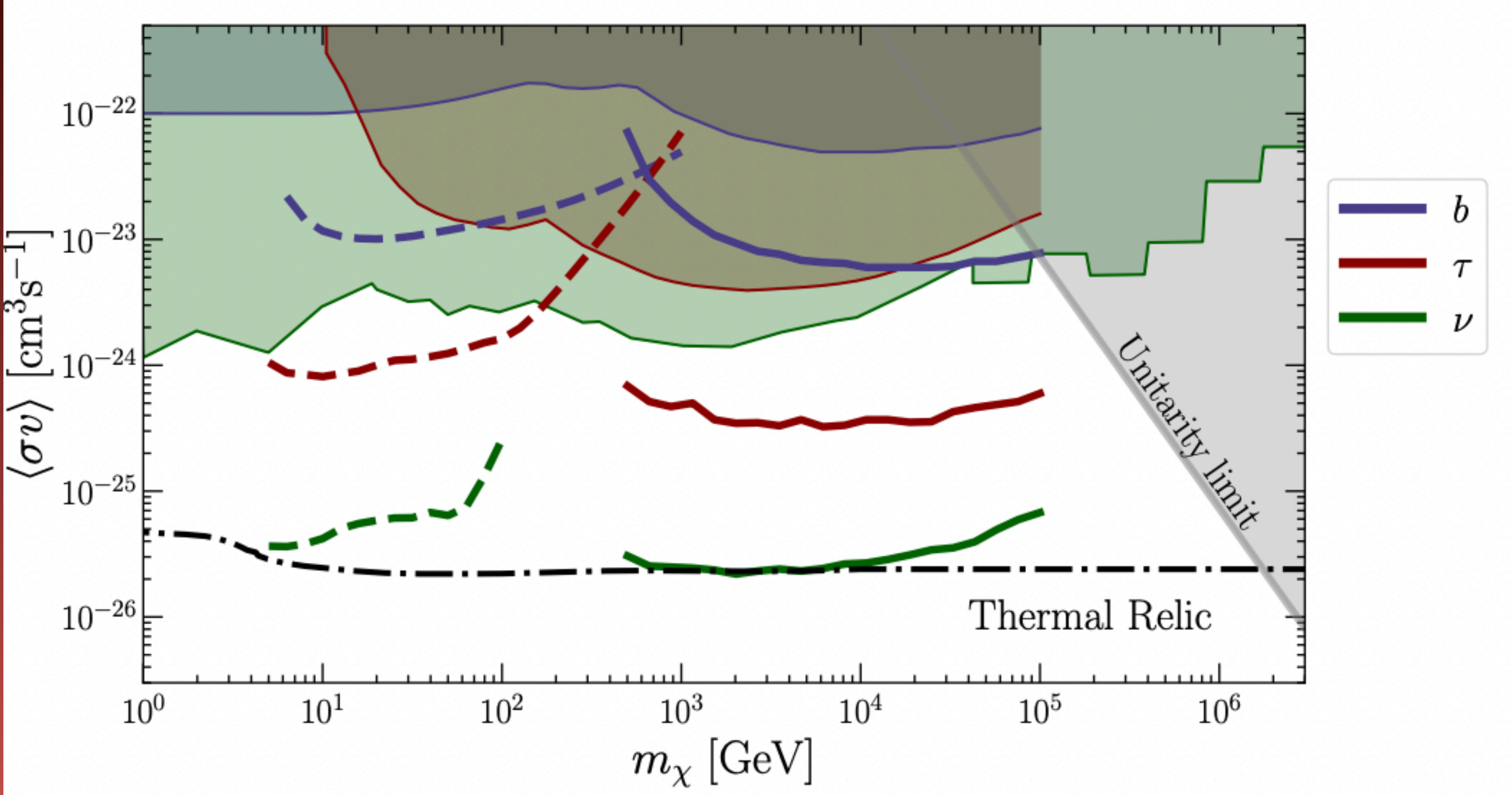


10^{-18}
10^{-19}
10^{-20}
10^{-21}
10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
$\langle \sigma v \rangle$ [cm^{3}s^{-1}]
$\nu\bar{\nu}$
e^+e^-
$\mu^+\mu^-$
$\tau^+\tau^-$
10^1
10^2
10^3
10^4
10^5
m_χ [GeV]



10^{-22}
10^{-23}
10^{-24}
10^{-25}
10^{-26}
$\langle \sigma v \rangle$ [cm^{3}s^{-1}]
4μ
4τ
4ν
10^1
10^2
10^3
10^4
10^5
m_χ [GeV]

Arguelles et al. Rev. Mod. Phys. 93 (2021) 3, 035007



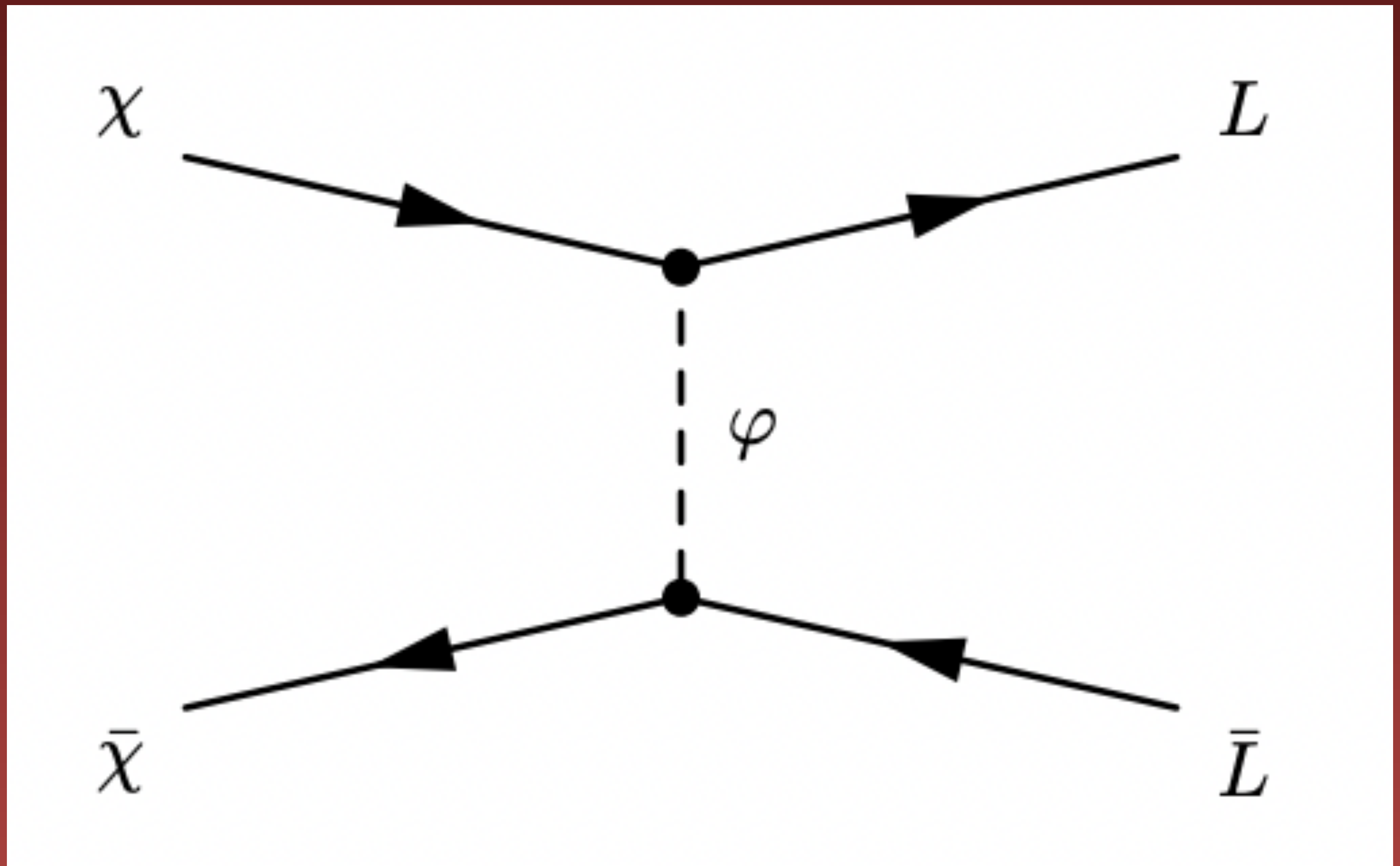
Implications for simple dark matter models

Basegmez du Pree et al. JCAP 05(2021) 054

a) Scalar mediator case:

$$\mathcal{L}^{\varphi} = y_{\alpha}\bar{\chi}L_{\alpha}\phi^{\dagger} + h.c.$$

$\mathcal{L}^{\varphi} = y_{\alpha}\bar{\chi}L_{\alpha}\phi^{\dagger} + h.c.$

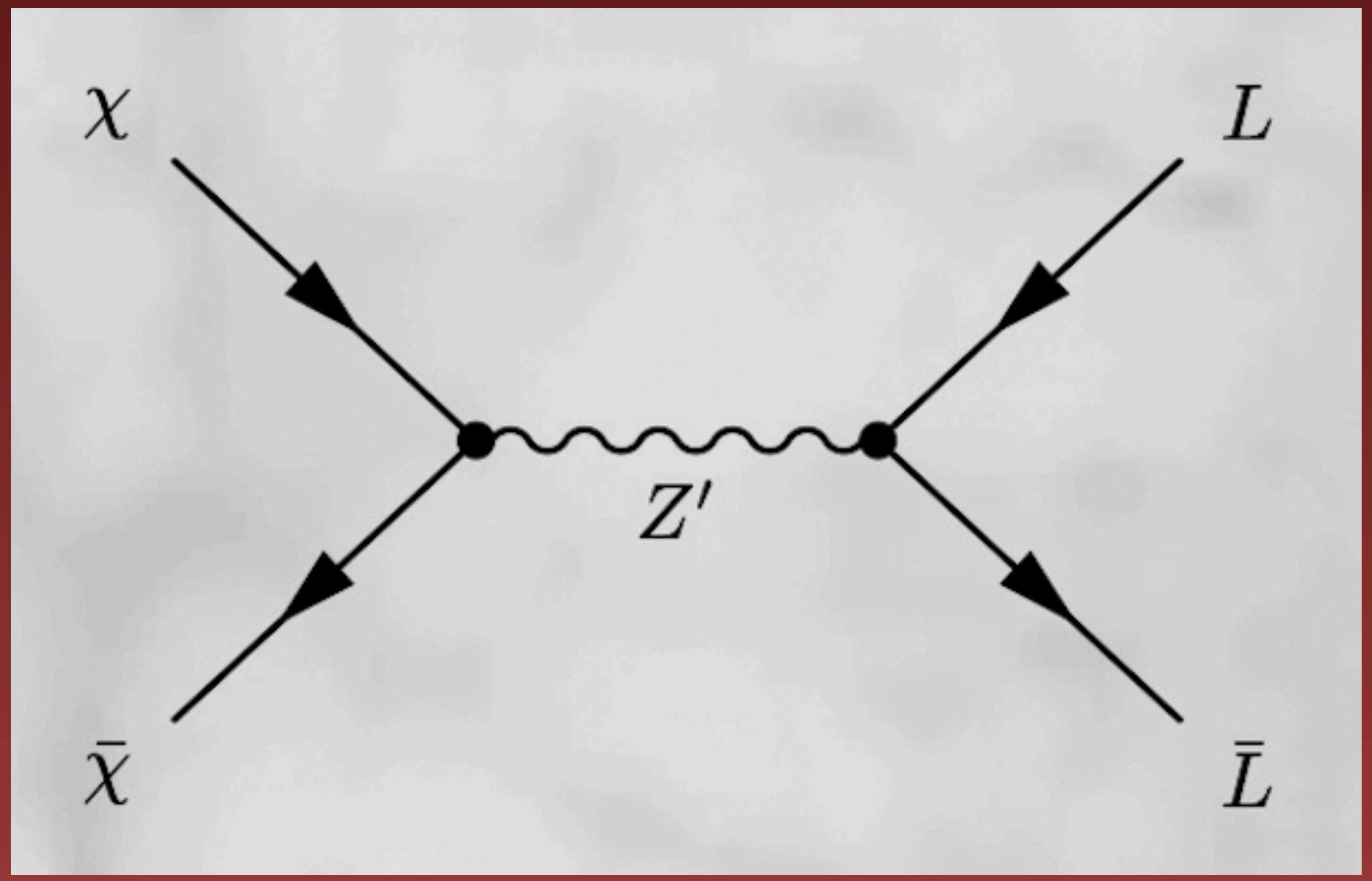


There parameters for this model:

$$\{m_{\chi}, m_{\varphi}, y_{\tau}\}$$

b) Gauged $U(1)_{L_\mu - L_\tau}$

$$\mathcal{L} = g_\chi \bar{\chi}\gamma_\alpha \chi Z'^\alpha + g_{\mu-\tau}(\bar{\mu}_R \gamma_\alpha \mu_R Z'^\alpha - \bar{\tau}_R \gamma_\alpha \tau_R Z'^\alpha + \bar{L}\gamma_\alpha L_\mu Z'^\alpha - L_\tau \gamma_\alpha L_\tau Z'^\alpha)$$



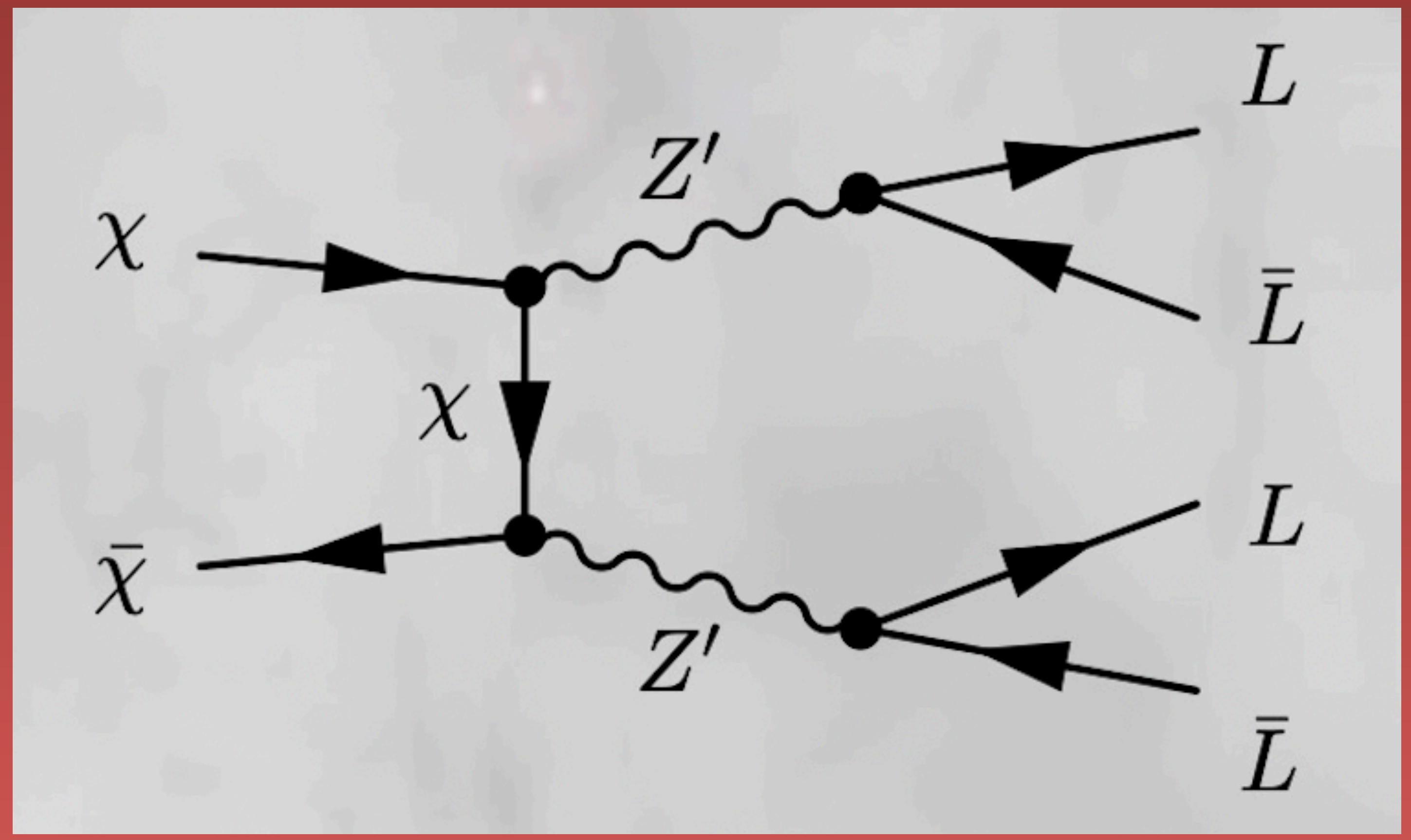
Parameters:

$$\{m_\chi, m_{Z'}, g_\chi, g_{\mu-\tau}\}$$

Cases:

$g_\chi \sim g_{\mu-\tau} \sim 1$

$g_\chi >> g_{\mu-\tau}$ Secluded case



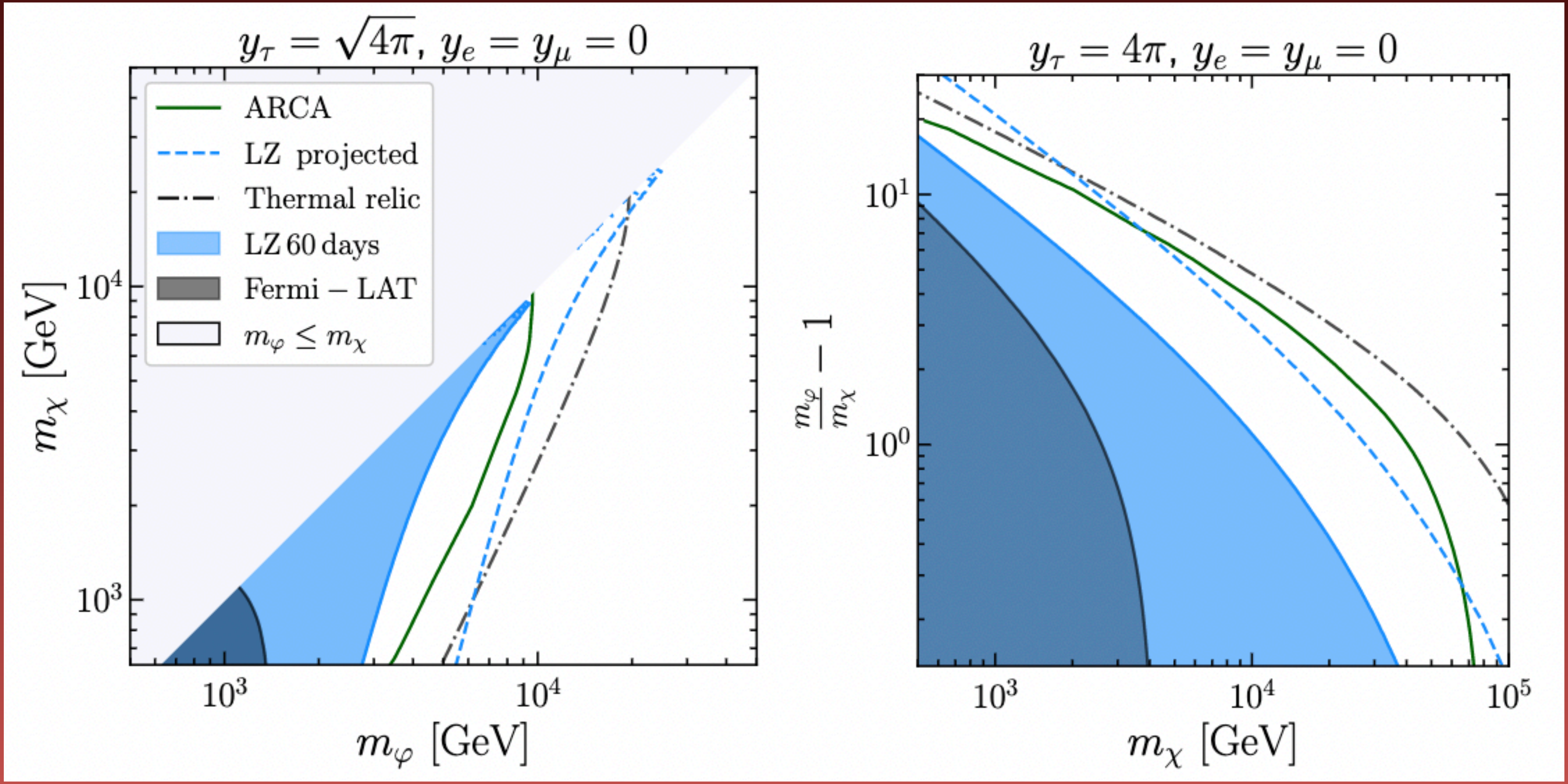
Results

a) We compared results using MadDM tool

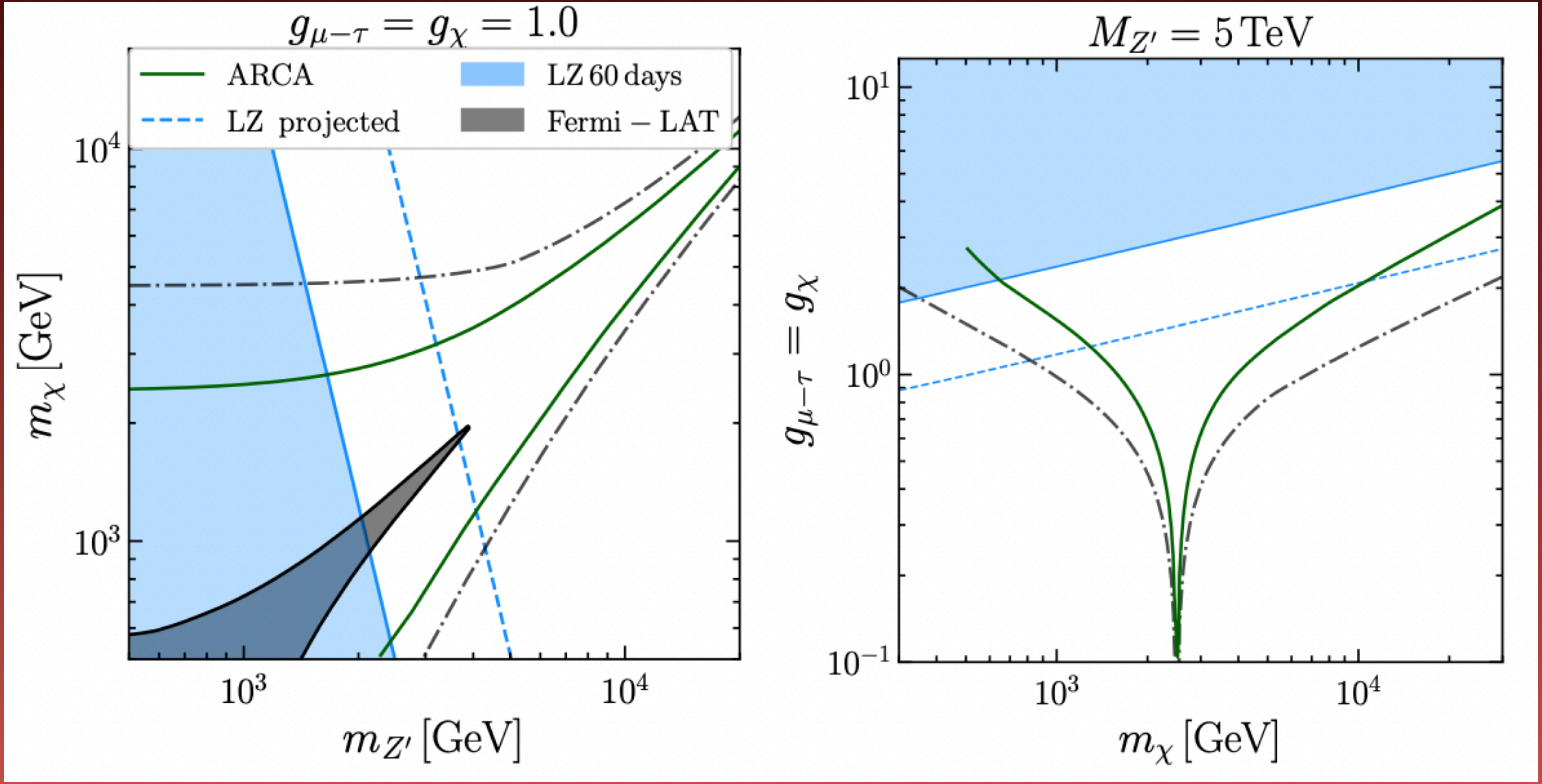
Ambrogi et al. Physics of the dark Universe 24 (2019) 100249

b) We campared them with photons and directs dark matter Experiments tool

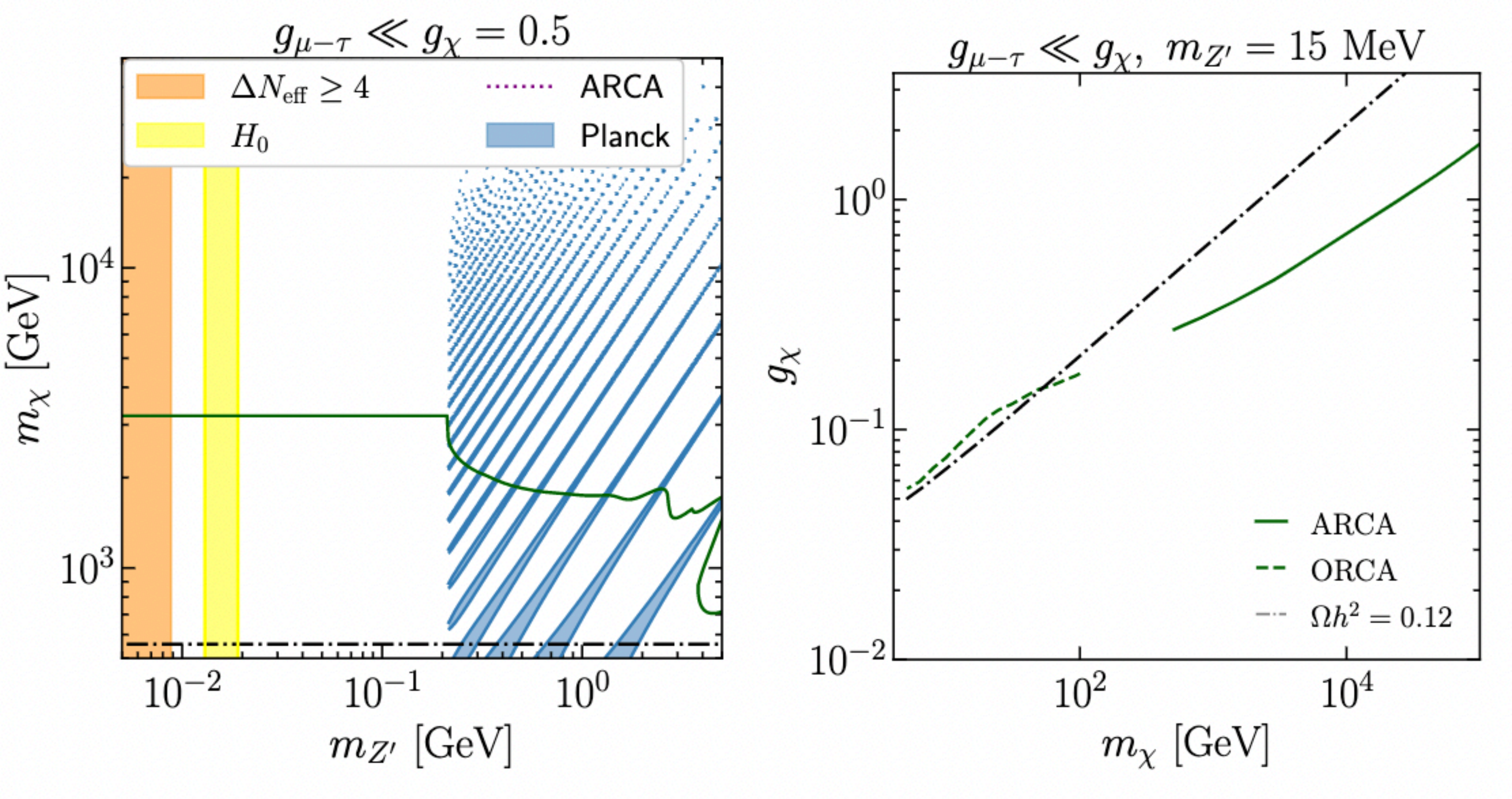
a) Scalar Mediator Case



b) Gauged $U(1)_{L_\mu - L_\tau}$ $g_\chi \sim g_{\mu-\tau} \sim 1$



c) Gauged $U(1)_{L_\mu - L_\tau}$ Secluded case



Conclusions:

1. Dark matter density profile is the calculation's main uncertainty variable

2. Sensitivity to dark matter detection covers from 5 GeV a 10^5 GeV, and more promising channels are 2 and 4 leptones for KM3NeT telescope.

3. Neutrino telescopes will be able to test WIMPs dark matter mass energy range.

4. We selected simple models where dark matter anihilates through s and t channels

Referencia: 2212.09795

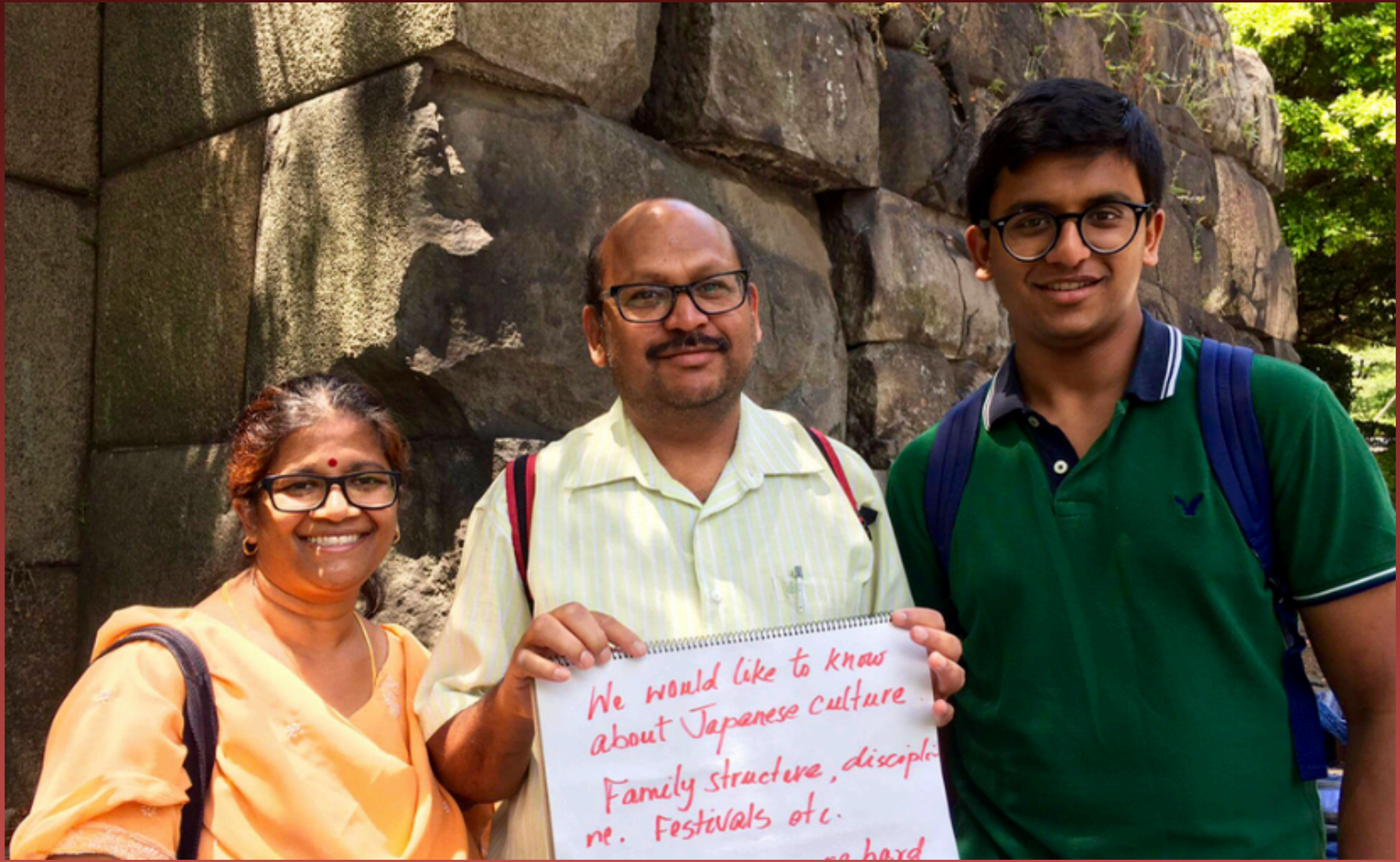
Let me introduce myself:

a) Master adviser (IFUAP, BUAP)

Alfonso Rosado

Olga G. Félix Beltrán

b) PhD (ICN, UNAM. Astroparticles)



Sarira Sahu

c) 2 Postdoctoral Jobs

Soebur Razzaque (UJ, Johanesburgo , South Africa)

Kenny C. Y. Ng (CUHK, Hong Kong, China)


Thanks !!!