Indirect searches of Galactic diffuse dark matter @ MagICAL[a]

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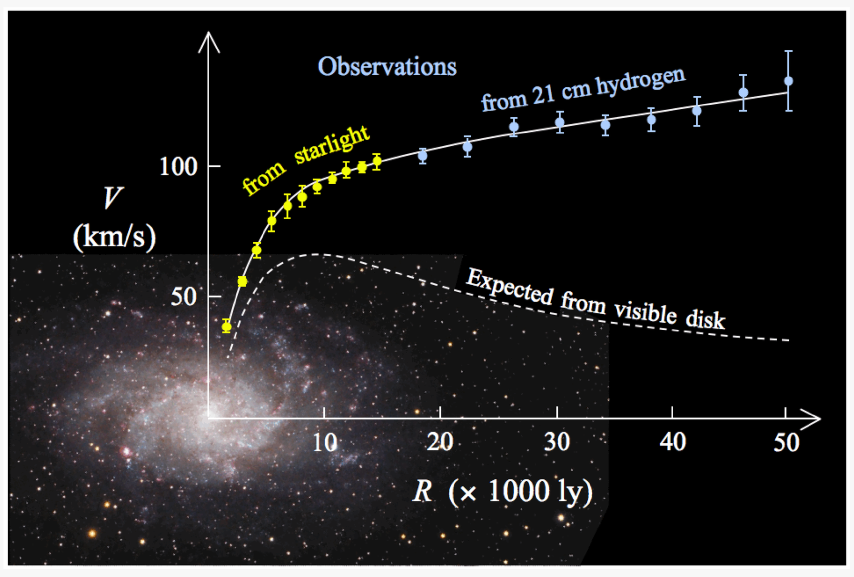
based on JHEP 1706(2017)057 (arXiv:1703.10221)

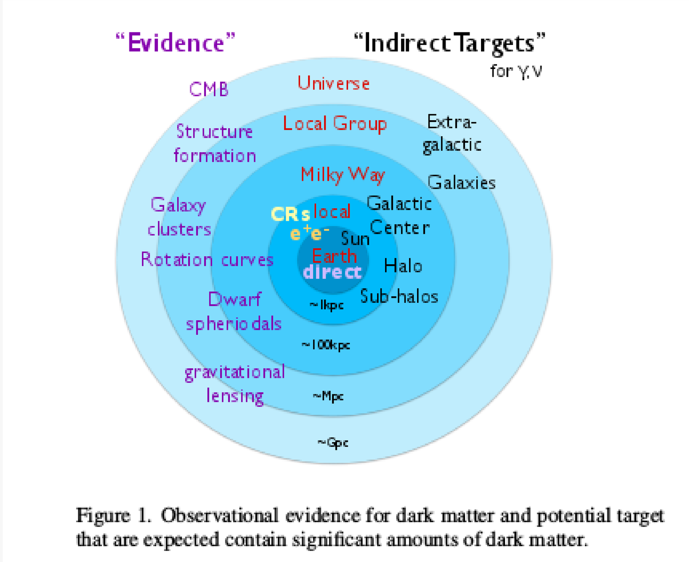
[a]The "MagICAL" name is used here as the abbreviation of Magnetized Iron CALorimeter which is commonly known as ICAL detector at the India-based Neutrino Observatory (INO). We prefer the name MagICAL to emphasize that magnetic field is present in the ICAL detector, which enable us to separate neutrino and anti-neutrino events.

Dark Matter

- Unknown non-baryonic matter, called Dark Matter (DM), contribute $\sim 26\%$ of the total energy density of the Universe
- The astrophysical and cosmological observations confirm the existence of dark matter from the length scales of a few kpc to a few Gpc.

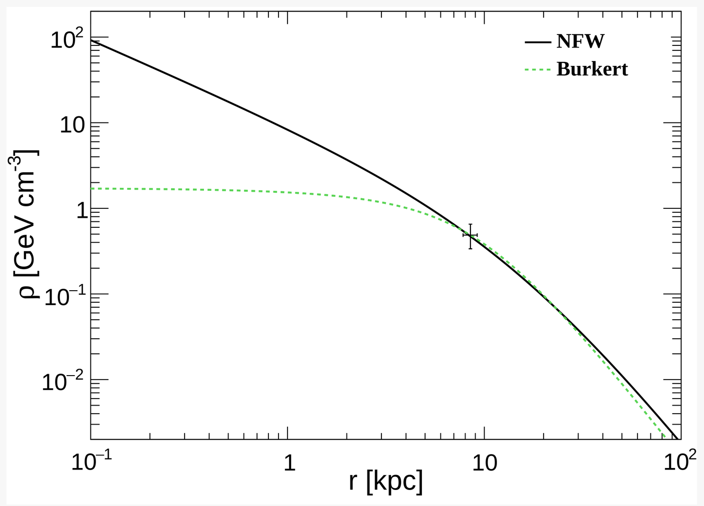


astro-ph/9909252, Corbelli, Salucci



arXiv:1210.4161

Dark Matter Density in the Universe



$$\rho(r) = \frac{\rho_0}{[\delta + r/r_s]^{\gamma} \cdot [1 + (r/r_s)^{\alpha}]^{(\beta-\gamma)/\alpha}} \,. \quad (1)$$

✓Due to large uncertainty in DM density, we produce all the results with two DM profiles

	$(\alpha, \beta, \gamma, \delta)$	ρ_{sc} [GeV cm^{-3}]	r_s [kpc]
NFW	(1, 3, 1, 0)	0.471	16.1
Burkert	(2, 3, 1, 1)	0.487	9.26

These values are taken from M. G. Aartsen et al.(IceCube) Eur.Phys.J.C75, 492 (2015)

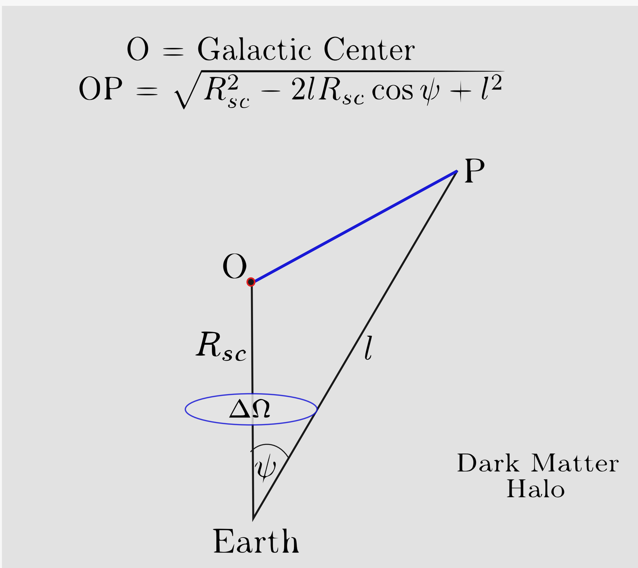
Dark Matter induced $\nu/\bar{\nu}$ Flux

Self Annihilation $(\chi\chi \to \nu\bar{\nu})$:
$$\frac{d^2\Phi^{ann}_{\nu/\bar{\nu}}}{dE\, d\Omega} = \frac{\langle \sigma_A v\rangle}{2} \mathcal{J}^{ann}_{\Delta\Omega} \frac{R_{sc}\rho_{sc}^2}{4\pi\, m_\chi^2} \frac{1}{3}\frac{dN^{ann}}{dE} \,. \qquad \frac{dN^{ann}}{dE} = \delta(E_{\nu/\bar{\nu}} - m_\chi)\,.$$

Decay $(\chi \to \nu\bar{\nu})$:
$$\frac{d^2\Phi^{dec}_{\nu/\bar{\nu}}}{dE\, d\Omega} = \mathcal{J}^{dec}_{\Delta\Omega} \frac{R_{sc}\rho_{sc}}{4\pi\, m_\chi\, \tau} \frac{1}{3}\frac{dN^{dec}}{dE} \,. \qquad \frac{dN^{dec}}{dE} = \delta(E_{\nu/\bar{\nu}} - m_\chi/2)\,.$$

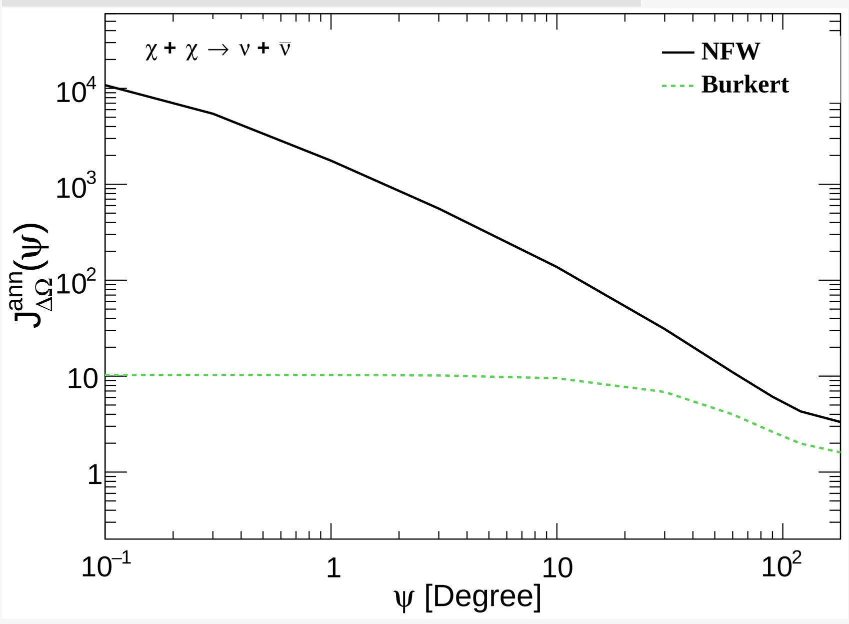
- Flavor ratio of $\nu/\bar{\nu}$ at the source and also at the surface of the Earth is 1:1:1.

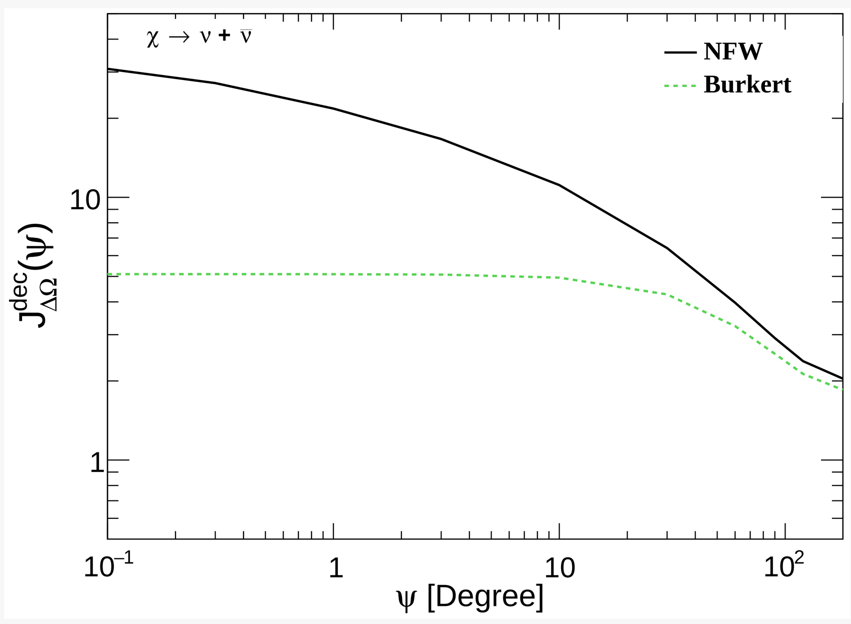
Here, m_χ : mass, $\langle\sigma_A v\rangle$: self-annihilation cross-section, and τ : decay life time of dark matter.



$$\mathcal{J}^{ann}_{\Delta\Omega}(\psi) = \frac{1}{R_{sc}\rho_{sc}^2} \frac{1}{2\pi(1-\cos\psi)} \int_{\cos\psi}^{1} 2\pi\, d(\cos\psi') \int_0^{l_{max}} dl\; \rho^2 \left(\sqrt{R_{sc}^2 - 2lR_{sc}\cos\psi' + l^2}\right) .$$

$$\mathcal{J}^{dec}_{\Delta\Omega}(\psi) = \frac{1}{R_{sc}\rho_{sc}} \frac{1}{2\pi(1-\cos\psi)} \int_{\cos\psi}^{1} 2\pi\, d(\cos\psi') \int_0^{l_{max}} dl\; \rho \left(\sqrt{R_{sc}^2 - 2lR_{sc}\cos\psi + l^2}\right) .$$





✓We use $\mathcal{J}^{dec}_{\Delta\Omega}$ $(\psi = 180°)$ in our analysis which is 2.04 (1.85) for the NFW (Burkert) profile.
✓We take $\mathcal{J}^{ann}_{\Delta\Omega}(\psi = 180°)$ = 3.33 (1.6) for the NFW (Burkert) profile.

The MagICAL detector at INO

- The proposed MagICAL detector consists of 50 kt iron as target and glass Resistive Plate Chambers as active detector elements.
- Iron plates will be magnetized with an uniform magnetic field of strength around 1.5 Tesla.
- In the detector, μ^- and μ^+ will be separated.

Energy resolution (σ_E) (GeV)	$0.1 \times (E/\text{GeV})$
Angular resolution $(\Delta\theta)$	$10°$
Detection efficiency $(\mathcal{E})$	80%
CID efficiency $(\mathcal{C})$	90%

Table 2: *The detector characteristics for μ^- and μ^+ events as used in the analysis.*

✓These representative choices of detector response produce similar results for oscillation studies as obtained by the INO simulation code.

Event Distributions in MagICAL

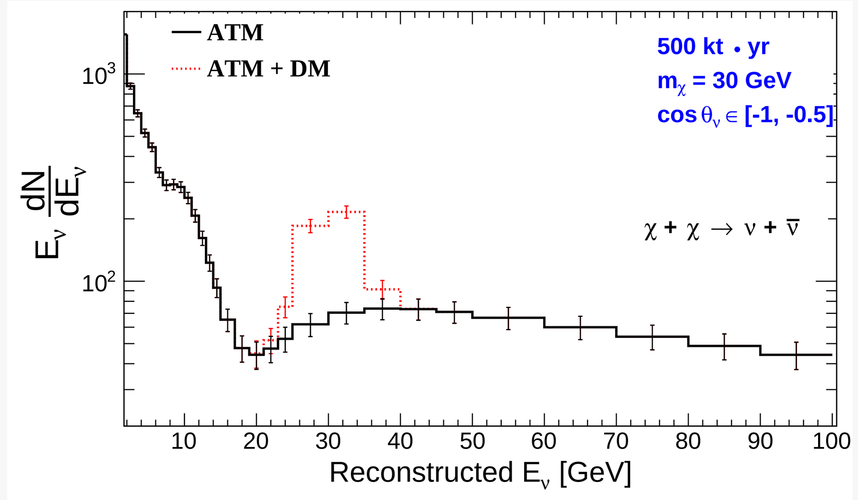
$$\frac{d^2N^{ATM}(\mu^-)}{d\cos\theta\, dE} = N_t\, \mathcal{T} \sigma^{CC}_{\nu_\mu}(E) \left\{ \frac{d^2\Phi_{\nu_\mu}}{d\cos\theta\, dE} P_{\mu\mu} + \frac{d^2\Phi_{\nu_e}}{d\cos\theta\, dE} P_{e\mu} \right\} . \quad (2)$$

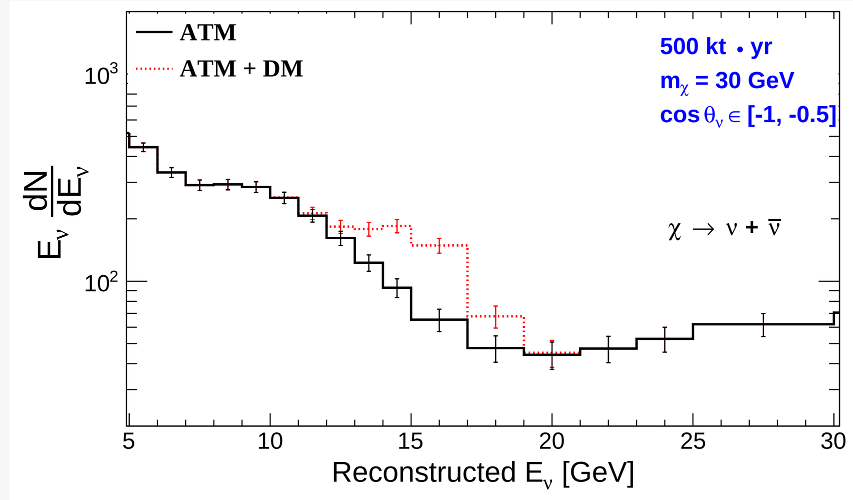
$$\frac{d^2N^{DM}(\mu^-)}{d\cos\theta\, dE} = N_t\, \mathcal{T} \sigma^{CC}_{\nu_\mu}(E) \frac{d^2\Phi^{dm}}{d\cos\theta\, dE} \left\{ P_{e\mu} + P_{\mu\mu} + P_{\tau\mu} \right\} . \quad (3)$$

Here, $P_{\alpha\beta}$ is oscillation probability of $\nu_\alpha \to \nu_\beta$, $\mathcal{T}$ is time of exposure, and N_t is the number of target nuclei in the detector.

- Dark matter induced neutrino fluxes are contributed from ν_e, ν_μ, as well as ν_τ, whereas atmospheric neutrinos contain only ν_e and ν_μ at the source. Same is true for antineutrino.

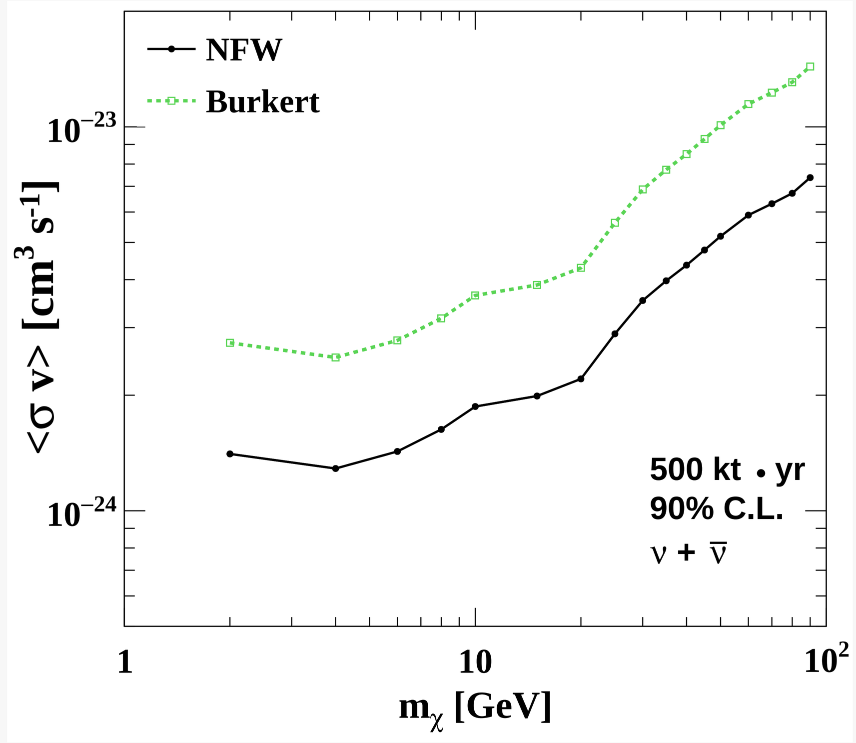
✓We fold events with the detector properties properly and show the event distributions in MagICAL bellow in absence (ATM) and in presence (ATM+DM) of dark matter induced neutrinos using arbitrary choice of self-annihilation cross-section and decay lifetime.

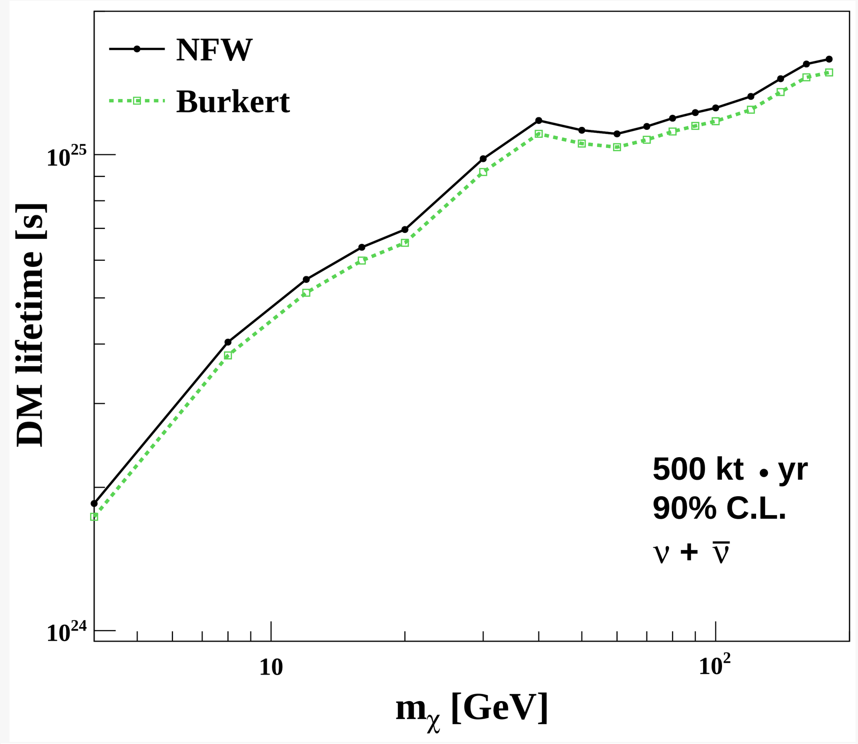


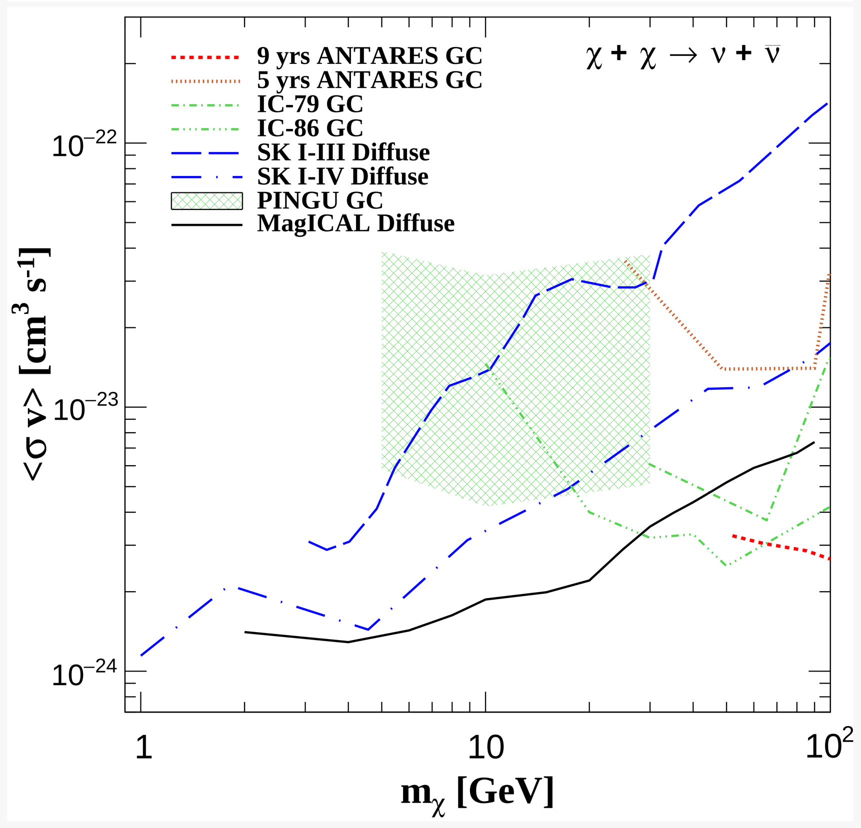


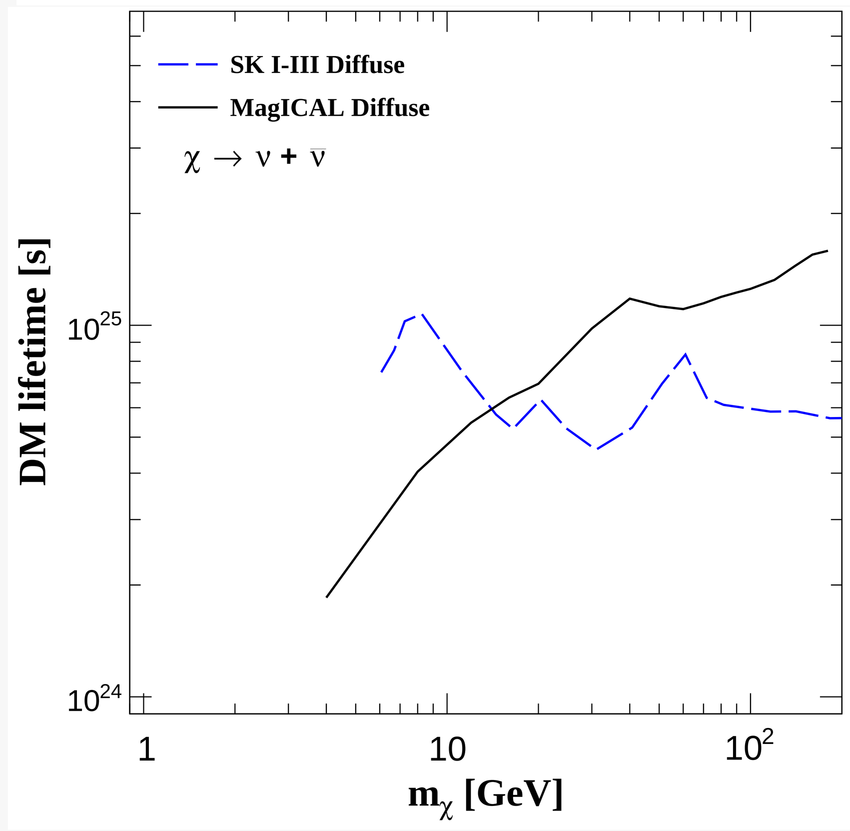
Expected Bound on $\langle\sigma v\rangle$ and τ

Using χ^2 method, we obtain upper limit on self-annihilation cross-section and lower limit on decay life time of dark matter.

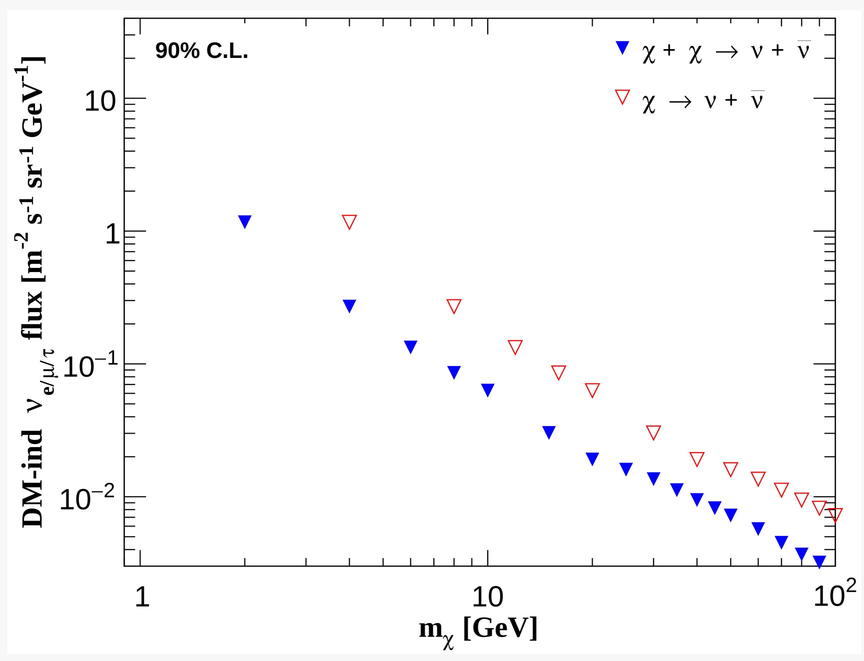


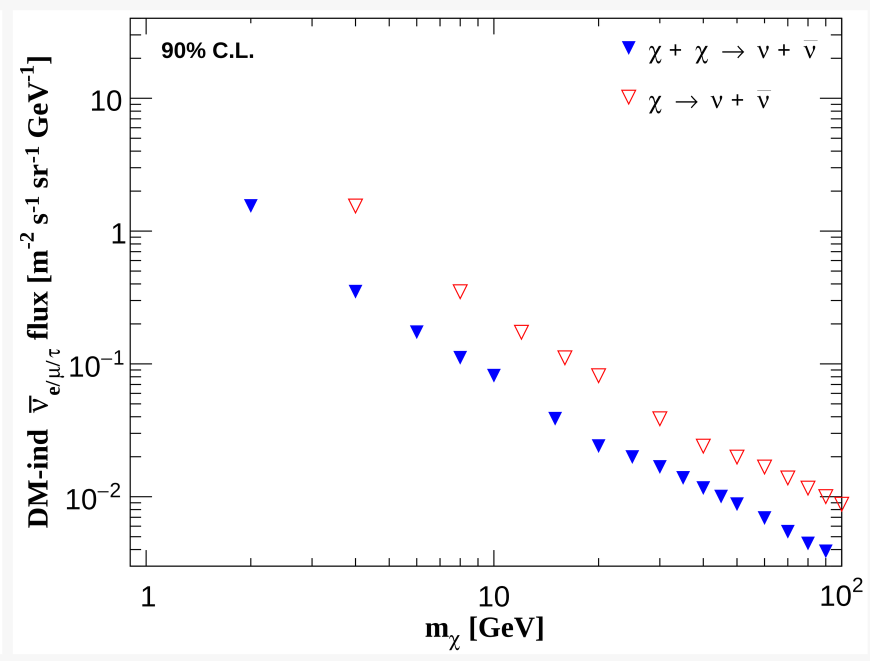






Expected Bound on dark matter induced $\nu/\bar{\nu}$ Flux





Concluding remarks

- At low energy (2-30 GeV), MagICAL will be able to place most stringent bound on $\langle\sigma v\rangle$. For decay, MagICAL is better than Super-Kamiokande at high energy.
- Using 500 kt·yr exposure of the MagICAL detector, the expected limits on $\langle\sigma v\rangle$ and τ are $\leq$ 1.87 $\times 10^{-24}$ cm^3 s^{-1} and $\geq$ 4.8 $\times 10^{24}$ s respectively at 90% C.L. (1 d.o.f.) for m_χ = 10 GeV assuming the NFW profile.
- Data of the MagICAL can also give constraints on exotic lepton number violating dark matter interactions.
- For details, please see our paper JHEP 1706(2017)057 (arXiv:1703.10221).