Simultaneous detection of boosted dark matter and neutrinos from the semi-annihilation at DUNE

Takashi Toma **Kanazawa University**

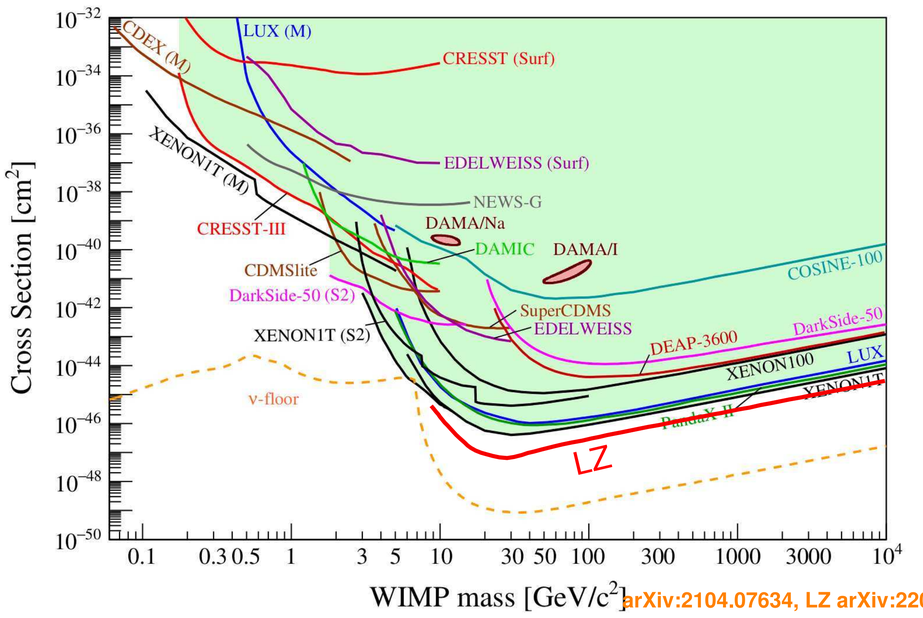
Collaborator: Mayumi Aoki (Kanazawa University)

Based on arXiv:2309.00395 [hep-ph]

KASHIWA DARK MATTER SYMPOSIUM 2023 5–8 December 2023 at IPMU

Introduction

- **Thermal DM models are strongly constrained by direct detection experiments.**

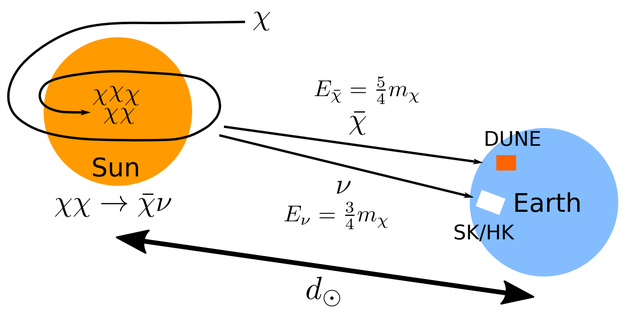


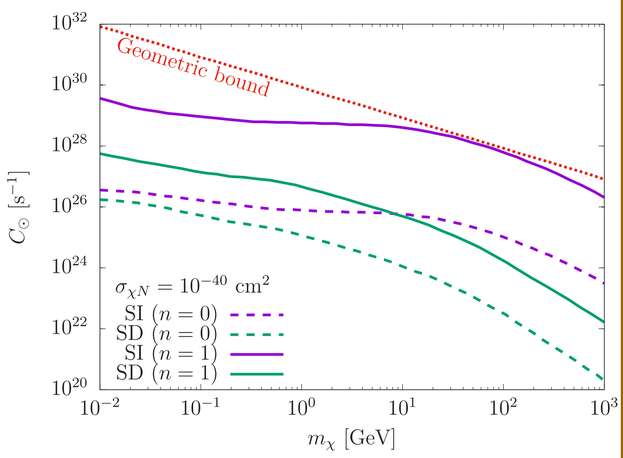
arXiv:2104.07634, LZ arXiv:2207.03764

- **Wayout: a momentum dependent cross section such as pNGB DM ($\sigma \propto Q^2$).** C. Gross, O. Lebedev, TT, PRL (2017) [arXiv:1708.02253]
- **Such a DM candidate can be searched if it is boosted.**

Setup

- **Consider a semi-annihilation $\chi\chi \to \nu\overline{\chi}$ (Boost factor: $E_\chi/m_\chi = 1.25$)**
- **Discuss how to detect the boosted DM coming from the Sun**





- **DM capture rate in the Sun** $\Rightarrow$
- **ν and DM fluxes:**

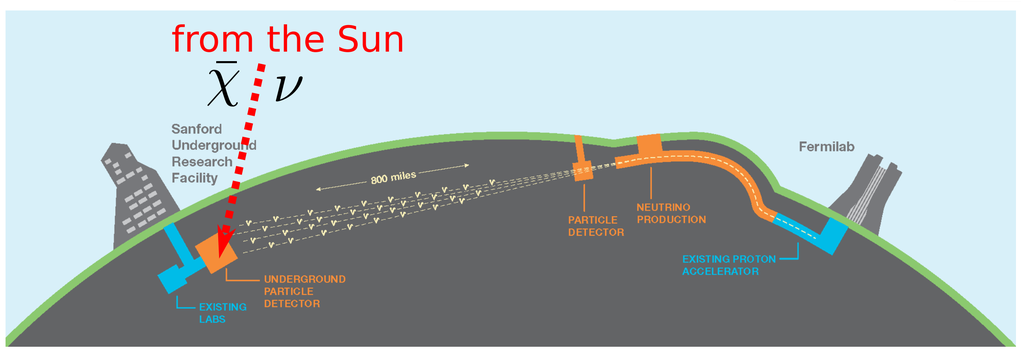
$$\frac{d^2\Phi_\nu}{dE_\nu d\Omega} = \frac{\Gamma_{\rm ann}}{4\pi d_\odot^2}\delta\left(E_\nu - \frac{3}{4}m_\chi\right)\delta\left(\Omega - \Omega_\odot\right)$$

$$\frac{d^2\Phi_\chi}{dE_\nu d\Omega} = \frac{\Gamma_{\rm ann}}{4\pi d_\odot^2}\delta\left(E_\chi - \frac{5}{4}m_\chi\right)\delta\left(\Omega - \Omega_\odot\right)$$

where $\Gamma_{\rm ann} = C_\odot/2 \propto \sigma_{\chi N}$

- **Two simultaneous signals could be found at DUNE ($\chi N \to \chi N$)**

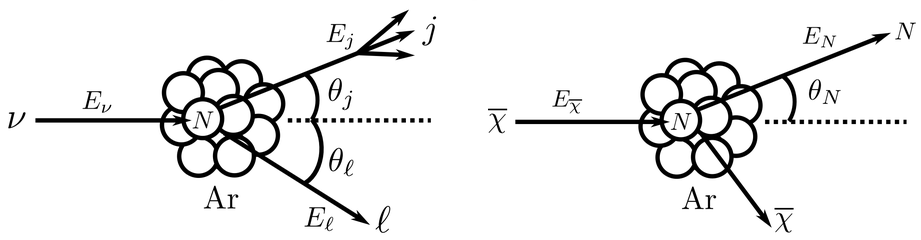
Signal and background



- **DUNE experiment will start in 2029 (upgrade 40 kton Ar in 2035)**
- **Take into account energy thresholds, energy/angular resolutions (1° for charged leptons, 5° for nucleons)**
- **Use `GENIE` to generate events**

UNIVERSAL NEUTRINO GENERATOR & GLOBAL FIT

- $\dfrac{d\sigma_{\chi N}}{dQ^2} = \dfrac{\sigma_0 s}{4m_N^2|\boldsymbol{p}_\chi|^2}\left(\dfrac{Q^2}{m_N^2 v_0^2}\right)^n |F(Q^2)|^2 \ (n=0,1,2)$ **($\sigma_{\chi N} \propto$ const, Q^2, Q^4)**
- **Number of events:** $N_\nu \sim N_N T \sigma_{\nu N}\Phi_\nu, \quad N_\chi \sim N_N T \sigma_{\chi N}\Phi_\chi$
- **Main background: atmospheric ν $\Rightarrow$ HAKKM model** arXiv: 1502.03916



Energy reconstruction

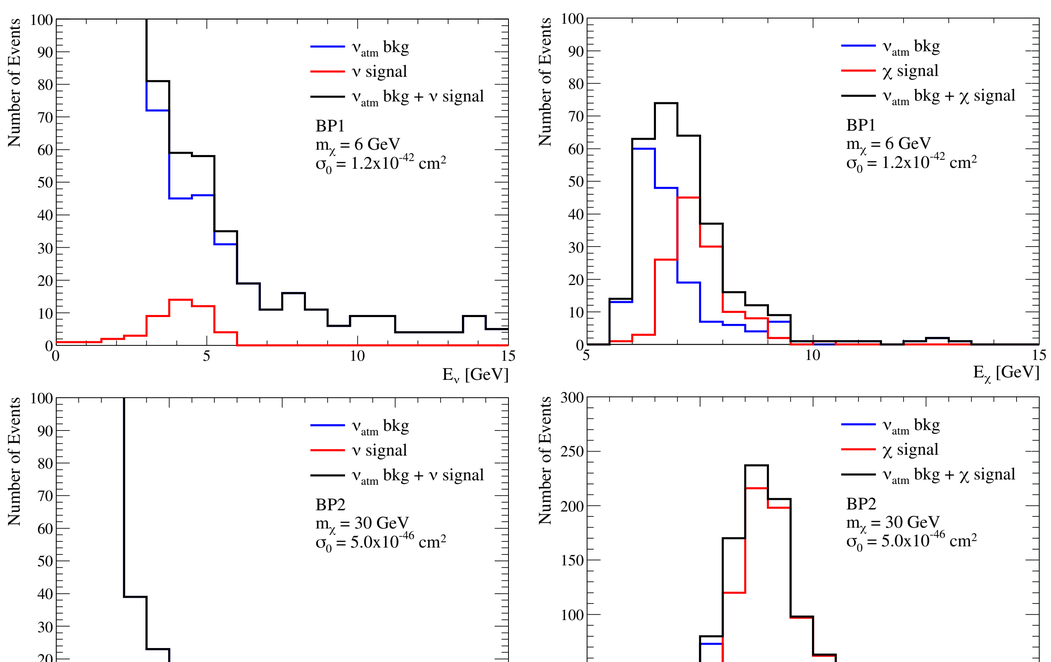
$$E_\nu = \frac{1}{2}\frac{\sin\theta_j(1+\cos\theta_\ell)+\sin\theta_\ell(1+\cos\theta_j)}{\sin\theta_j}E_\ell$$

$$E_\chi = m_N\frac{1+\alpha\cos\theta_N\sqrt{1-\beta+\alpha^2\beta\cos^2\theta_N}}{-1+\alpha^2\cos^2\theta_N}$$

where $\alpha = \sqrt{(E_N+m_N)/(E_N-m_N)} > 1$ **and** $\beta = m_\chi^2/m_N^2 > 1$

Energy reconstruction

	model	m_χ [GeV]	σ_0 [cm^2]	# of ν events	# of χ events
BP1	SD $(n=1)$	6	1.2×10^{-42}	$N^{\rm CC}_{{\rm atm}\,\nu} = 54/2070$ $N^{\rm CC}_{\nu} = 18/47$	$N^{\rm NC}_{{\rm atm}\,\nu} = 98/994$ $N_\chi = 113/372$
BP2	SD $(n=2)$	30	5.0×10^{-46}	$N^{\rm CC}_{{\rm atm}\,\nu} = 1/2070$ $N^{\rm CC}_{\nu} = 0/0$	$N^{\rm NC}_{{\rm atm}\,\nu} = 18/994$ $N_\chi = 405/2117$



- **Observed/Expected**
- **True energies**
  BP1: $E_\nu = 4.5$ **GeV**
  $E_\chi = 7.5$ **GeV**
  BP2: $E_\nu = 22.5$ **GeV**
  $E_\chi = 37.5$ **GeV**
- **Simultaneous detection of two signals is possible for BP1**
- **A large number of DM events for BP2. But no signal for ν.**

$\Rightarrow$ **HK, IceCube/DeepCore**

Summary

- **DUNE has sensitivity for moderately boosted DM ($v_\chi = 0.6$)**
- **Simultaneous detection of neutrinos and boosted DM signals at DUNE is possible if DM mass is below** 8 GeV**.**
- **Event for larger DM mass, it is possible to detect two signals separately combining with the other experiments such as HK.**