DUNE potential for direct detection of sub-GeV dark matter

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Introduction

The existance of dark matter is strongly suggested by various gravitational phenomena in astrophysics and cosmology. The simplest realization of dark matter particles is in form of new stable weakly interacting non-baryonic elementry particles. The presence of such particles has motivated experimentalist to design experiments capable of capturing dark matter (DM) signal. The three main experimental approaches which are used to probe the dark matter particles are indirect detection experiments, direct detection experiments and detection of dark matter particles produced with collider detection technique. Many possible candidates of DM have been postulated and their mass varies from 10^{-31} to 10^{20} GeV which further can be divided on the basis of detection technique and the type of its interaction with DM i.e. axions (below 1 MeV), light DM (1 MeV-1 GeV) and WIMPs (above 1 GeV). These weak-scale (low mass mediator) parameter characteristics offer a hope for direct detection of non-gravitational DM interactions in laboratory under Lee-Weinberg bounds [3]. In this paper, we have checked the sensitivity of Deep underground neutrino experiment (DUNE) [1] for light scalar dark matter detection which is generated through vector portal. Different channels in beam dump mode at fixed target are analysed to improve the sensitivity for DM.

Portals and Dark Matter Production Channels:

The applicable low energy lagrangian is a sum of the dark sector lagrangian and SM lagrangian given as,

$$L_{DM} = L_{\gamma_D} + L_\chi \qquad (1)$$

where,

$$L_{\gamma_D} = -\frac{1}{4}F_{D\mu\nu}F_D^{\mu\nu} + \frac{1}{2}m^2_{\gamma_D}\gamma_{D\mu}\gamma_D^\mu - \frac{1}{2}\epsilon F_{D\mu\nu}F^{\mu\nu} \qquad (2)$$

$$L_\chi = \frac{ig_D}{2}\gamma_D^\mu J_\mu^\chi + \frac{1}{2}\partial_\mu\chi^\dagger\partial_\mu\chi - m_\chi^2\chi^\dagger\chi \qquad (3)$$

where, ϵ is kinetic mixing of dark photon with SM photon, J_μ^χ is DM current density and g_D is treated as gauge coupling constant between DM current density and a new massive dark photon field $\gamma_{D\mu}$, originated from broken gauge symmetry $U(1)_D$.
The model contains four parameters, dark matter mass (m_χ), dark photon mass (m_{γ_D}), gauge coupling parameter (g_D) and kinetic mixing parameter (ϵ).

We have to summarize three production mode used in our work by keeping in mind that beam energy (120 GeV) of DUNE flux is high.
1) π^0/η mesons decay in flight is relevant for low mass of dark photon.

$$p+p(n) \to X+\pi^0, \eta \to X+\gamma+\gamma_D \to \gamma+\chi+\chi^\dagger$$

2) Resonant vector mesons (Bremsstrahlung) decay is relevant for intermediate mass of dark photon.

$$p + p(n) \to p + p(n) + \gamma_D$$

3) Direct or parton-level production from quarks and gluon constituents is relevant for higher mass of dark photon (m_{γ_D}>1).

$$p + p(n) \to X + \gamma_D \to X + \chi\chi^\dagger$$

Simulation and Results:

We present the outcome for DUNE experiment in below figures by using Monte Carlo BdNMC [2] simulation tool from elastic nucleon scattering and elastic electron scattering. We have used $E_R \in [0.1, 2]$ GeV cuts on the recoil energy of nucleons and electrons. We have to also applied the forward angle cuts on the scattered electrons $\theta_e \in [0.01, 0.02]$ to reduce the neutrino background. Fig(1&2) shows the sensitivity contours plot in ϵ and m_{γ_D} plane, and Fig(3&4) shows the yield in Y and m_χ plane corresponding to 1 (blue), 100 (green) and 1000 (red) events while black line is showing thermal relic dark matter (freezout). The simulation tool uses cuts on the recoil energy of nucleons and electrons and cuts

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on the forward angle of electron scattering to ruduce the neutrino background and then we expect true sensitivity should be absolutely good, likley at the order of few events level. It is observed that dark matter signal events from nucleon scattering is slightly weaker than from electron scattering on account of corresponds kinematics. Nucleon scattering dark matter events becomes stronger around resonance regime (for higher m_{γ_D}).

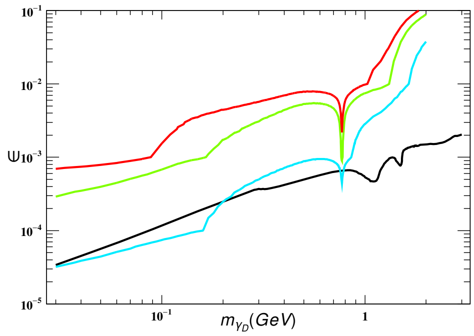

FIG. 1: The DM sensitivity of elastic scattering off nucleons. We have taken $m_\chi = 0.01$ GeV, $\alpha_D = 0.5$ and POT $= 1.1 \times 10^{21}$.

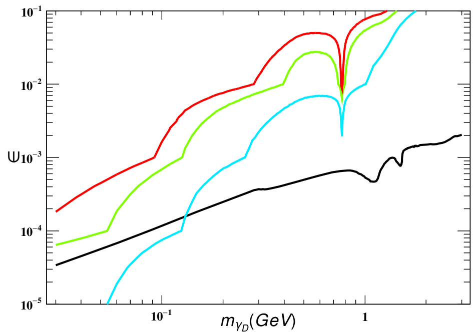

FIG. 2: The DM sensitivity of elastic scattering off electrons. We have taken $m_\chi = 0.01$ GeV, $\alpha_D = 0.5$ and POT $= 1.1 \times 10^{21}$.

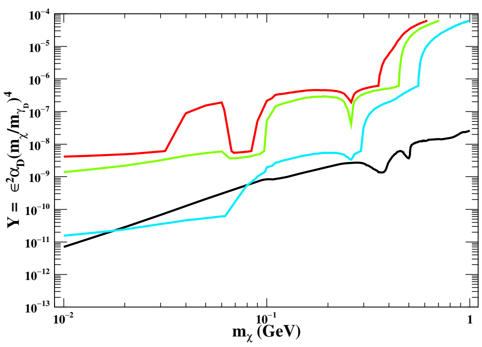

FIG. 3: The DM yield of elastic scattering off nucleons. We have taken $m_{\gamma_D} = 3m_\chi$, $\alpha_D = 0.5$ and POT $= 1.1 \times 10^{21}$.

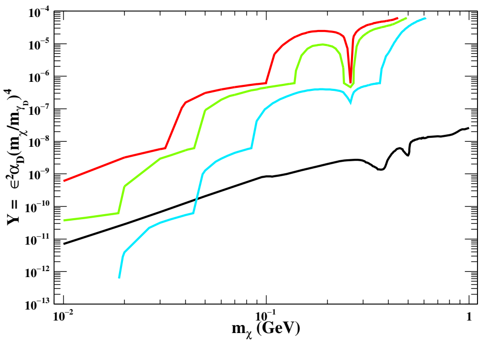

FIG. 4: The DM yield of elastic scattering off electrons. We have taken $m_{\gamma_D} = 3m_\chi$, $\alpha_D = 0.5$ and POT $= 1.1 \times 10^{21}$.

Conclusion:

This study exposes the DUNE sensitivity for light DM particles.

Acknowledgments

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