DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Boosted Dark Matter in DUNE

A Sensitivity Study

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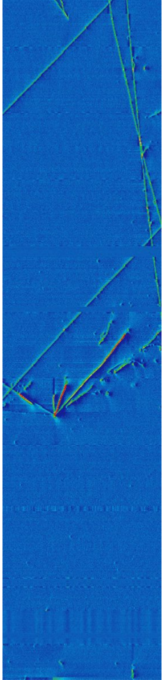

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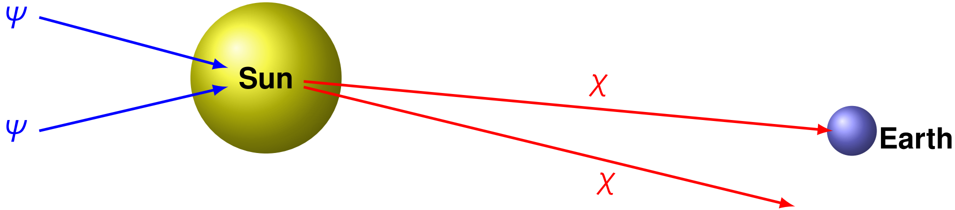
Boosted Dark Matter Model [6] [2] [3]

- Multi-Component Dark Sector.
- Cold DM is captured in concentrated regions of matter (GC or Sun).
- Another component is produced by annihilation or semi-annihilation.
- The DM produced can interact with SM particles.

$$\psi + \psi \rightarrow \chi + \chi$$



Boosted Dark Matter Model

New possibility

A small fraction of DM today is relativistic and is being produced by annihilation in the Sun and interacts with the SM particles.

The interactions with the SM particles are mediated by a spin-1 vector boson, Z' , with a gauge coupling $g_{Z'}$.

$$\mathcal{L} = g_{Z'} Z'_\mu \sum_P J_P^\mu \quad , \quad \gamma = \frac{m_\Psi}{m_\chi}$$

- New way to "seclude" DM from the SM while still maintaining the successes of the thermal freeze-out paradigm of WIMP-type DM.
- Non-minimal dark sectors are quite reasonable, considering the SM.
- Multi-component DM sector is being used to describe anomalies in DM detection experiments. [8] [5] [7]

Boosted DM in DUNE

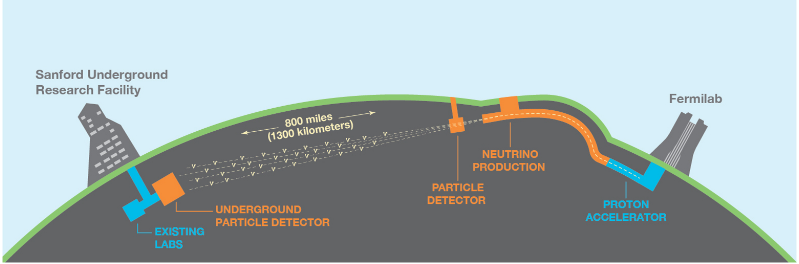


Figure: Cartoon illustrating the configuration of the LBNF beamline at Fermilab, in Illinois, and the DUNE detectors in Illinois and South Dakota, separated by 1300 km.

DUNE is an international experiment with more than 1,000 collaborators from around 180 institutions in 30 countries coordinated by Fermilab.

Boosted DM in DUNE

- LArTPC technology will provide a very good spatial and energy resolution of the events.
- The drift electrons yield a electric pulse in the wires making it possible the spatial reconstruction of the event.
- It will offer great opportunities to study BSM.
- The products of interactions will left a track that can be reconstructed and PID.

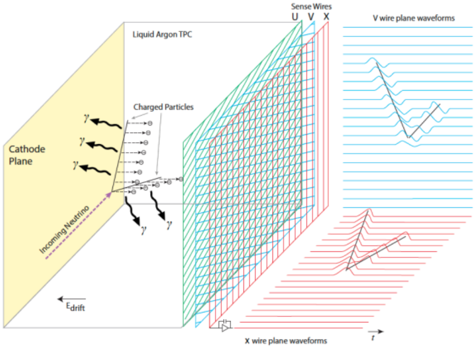


Figure: The general operating principle of the SP LArTPC.

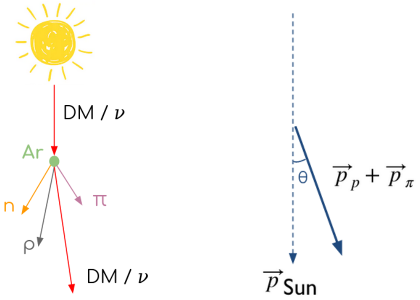
Boosted DM in DUNE

Signal

NC-like event: Total Momentum of the events loosely aligned with Sun direction.

Background

Atmospheric Neutrinos: Isotropic with respect to Sun Direction.

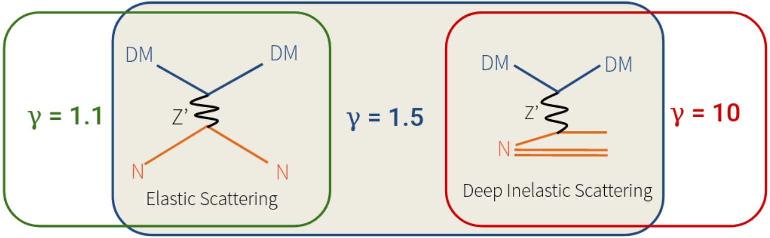


A phenomenological study[3] made by collaborators showed that DUNE will be competitive to potential detection.

Boosted DM in DUNE

- A full simulation and reconstruction of the detector capabilities was done and analyzed.

$$m_\chi = 10 \text{ GeV}$$



- No resonance scattering was simulated, it was left for further studies. In this scenario, the study is conservative bounds.

Monte Carlo Samples

GENIE Tunes: Bodek-Ritchie Fermi Gas model and hA model. [1]

Signal: Boosted DM $\gamma = 1.1, 1.5, 10$

- 10,000 events for each Lorentz factor.

Background: Atmospheric Neutrinos

- 28,500 events.

In this current analysis strategy, the kinematics are basically determined by gamma. Only contained tracks were analyzed.

From truth table #1:

Select only NC interactions, resulting in 11,853 events from atmospheric neutrinos.

*More Information about the samples can be found in our wiki page .

Reconstruction using Pandora

Pandora[4] is a Multi-Algorithm Pattern Recognition.

Only used the contained particles recognized as tracks by Pandora.

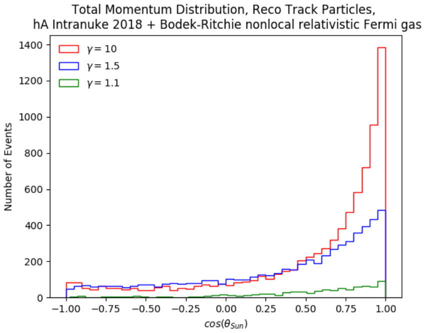
From truth table #2

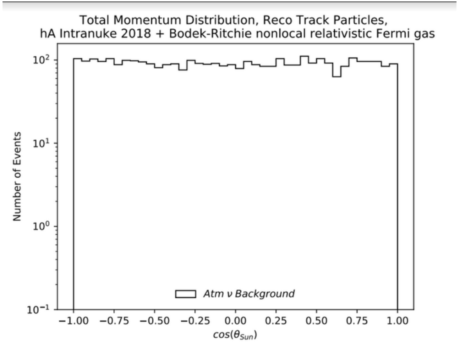
Flip the reconstructed track direction based on the True Vertex.

- Momentum estimation range method based on protons and muons, which are used for charged pions in this analysis.
- Particle identification: χ^2-based particle ID (standard in LArSoft), if returns a proton. Then, estimate the track momentum as a proton, otherwise as a muon (in a real case pions).

Reconstruction using Pandora

Angle of the Total Momentum in a event w.r.t to Sun Direction





Single Variate Analysis $cos(\theta)$ cut

Find the angular cut of the smallest signal strength (s') for which the sensitivity to BDM signal can be obtained at 5 standard deviations.

$$\frac{\epsilon_{Ar} s'}{\sqrt{\epsilon_{Ar} s' + b}} = 5$$

After obtain the efficiency ($\epsilon_{Ar} s'$) for signal models, count the expected number of events for background, and calculate the sensitivity to $g^4_{Z'}$ at 2 standard deviations.

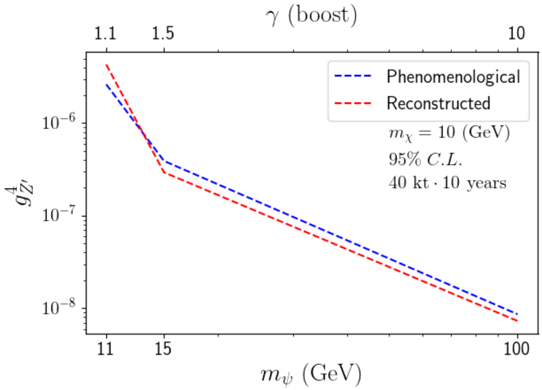
$$Z \approx \sqrt{2\left[(s+b)\log\left(1+\frac{s}{b}\right) - s\right]}$$

Results

Lorentz Factor (γ)	1.1	1.5	10
Flux / $(g_{Z'})^4$ (cm^{-2} s^{-1})	303.6	203.4	7521
Ar Cross Section/ $(g_{Z'})^4$ (cm^2)	1.063×10^{-30}	5.609×10^{-29}	1.377×10^{-27}
Optimal Cos(θ) Cut	0.360	0.295	0.590
Signal Efficiency (ε_{Ar})	0.060	0.381	0.515
Expected Signal Events (s) / $(g_{Z'})^8$	4.305×10^{12}	9.600×10^{14}	1.322×10^{18}
Background counts (b)*	1125 ± 32	1238 ± 34	7012 ± 26

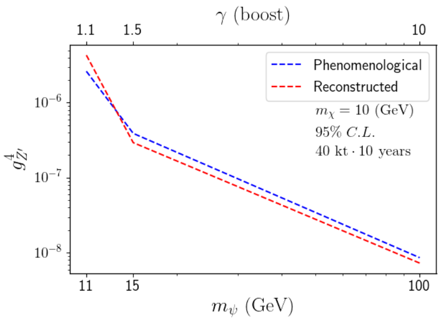
*Statistical uncertainty for background.

Results



γ (boost)
1.1
1.5
10
Phenomenological
Reconstructed
$m_\chi = 10$ (GeV)
95% C.L.
40 kt · 10 years
$g_{Z'}^4$
10^{-6}
10^{-7}
10^{-8}
11
15
100
m_ψ (GeV)

Summary and Outlook



From truth table

1. Pure NC Background Sample
2. Reco Tracks with directions based on the True Vertex

- Phenomenological study also used truth information for the background and vertex location.
- Relevant quantities: NC/CC neutrino interaction identification and vertex reconstruction.

Summary and Outlook

$m_\chi = 10$ GeV

Other samples are being producing right now $m_\chi = 5,\ 20,\ 40$ GeV.
Most relevant step forward is to include different BDM mass.
It will be possible to cover the range (5.5 – 400 GeV) for the abundant component (ψ).

- This work was done in collaboration with Yun-Tse Tsai (SLAC), Gianluca Petrillo (SLAC) and João de Mello Neto (UFRJ).
- Sample production made by Josh Barrow and Ken Herner.
- Special thanks to Joshua Berger and Dom Brailsford.

FAPERJ CAPES CNPq

Obrigado!!!

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