Dark matter at DUNE near detector

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In collaboration with:
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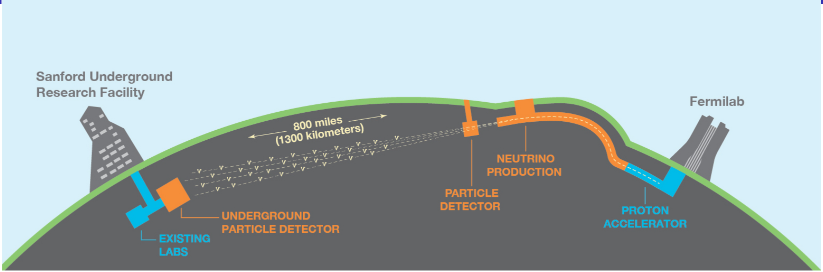
Universidad EIA

Based on:

arXiv:2109.11586
arXiv:22xx.xxxxx

UNIVERSIDAD EIA
Ser, Saber y Servir

DUNE Near Detector

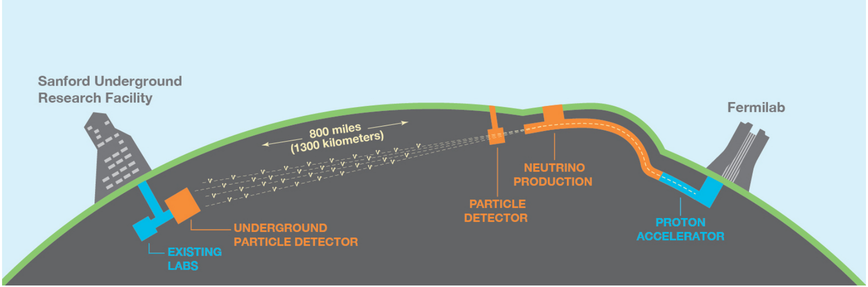


- Protons at 120 GeV collides against a fixed-target made of carbon, then a bunch of particles are created $(\pi^0, \eta, \eta', \omega, \pi^\pm, K^\pm, ...)$.

meson $\mathbf{m}$	meson/POT	$\mathrm{Br}(\mathbf{m}^+ \to \mu^+\nu_\mu)$	$\mathrm{Br}(\mathbf{m}^+ \to e^+\nu_e)$
$\pi^+(\pi^-)$	4.3(4.0)	99.98 %	1.2×10^{-4} %
$\mathrm{K}^+(K^-)$	0.39(0.27)	63.56 %	1.58×10^{-5} %

- Neutrinos are created after the decay of $\pi^\pm, K^\pm, \ldots$
- Muon neutrinos are mostly created in the decays of $\pi^\pm$

Light dark matter at DUNE



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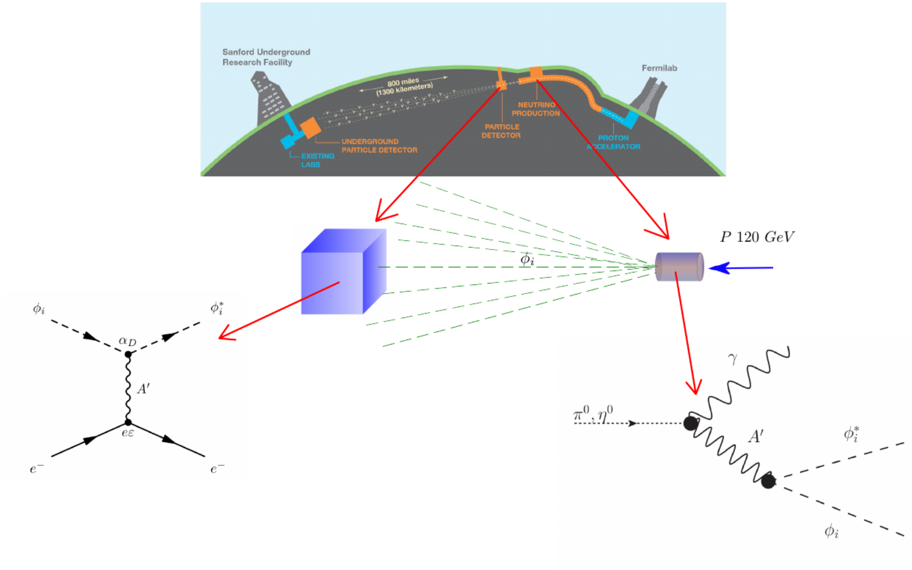
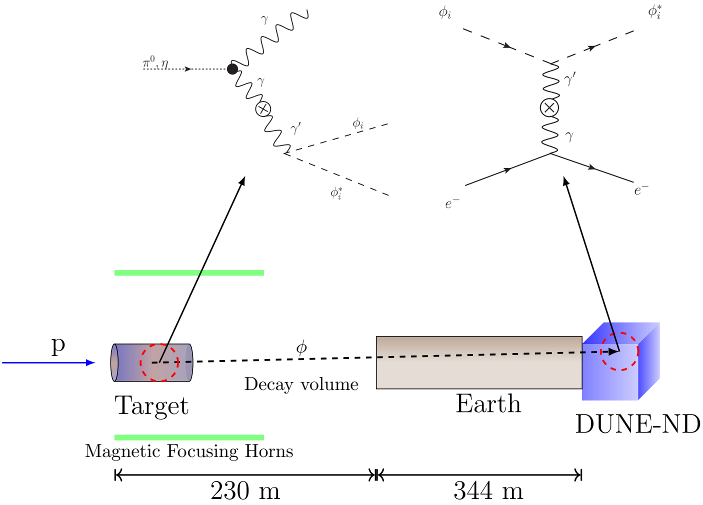
meson **m**	meson/POT	Br(**m** $\to \gamma\gamma$)
π^0	4.8	99.82 %
η	0.5	39.41 %

- LDM could be produced thanks to the mixing between γ-γ'

DUNE Near Detector



DUNE Near Detector



The Model

The SM is extended with:

- $G_{SM} \otimes U(1)_D \otimes Z_2 \otimes Z_2'$
- Two complex scalar singlets, $\phi_1 \sim (-1, +, -)$ and $\phi_2 \sim (-1, -, +)$
- One complex scalar singlet, $s \sim (2, -, -)$, which develops **VEV** and breaks $U(1)_D$

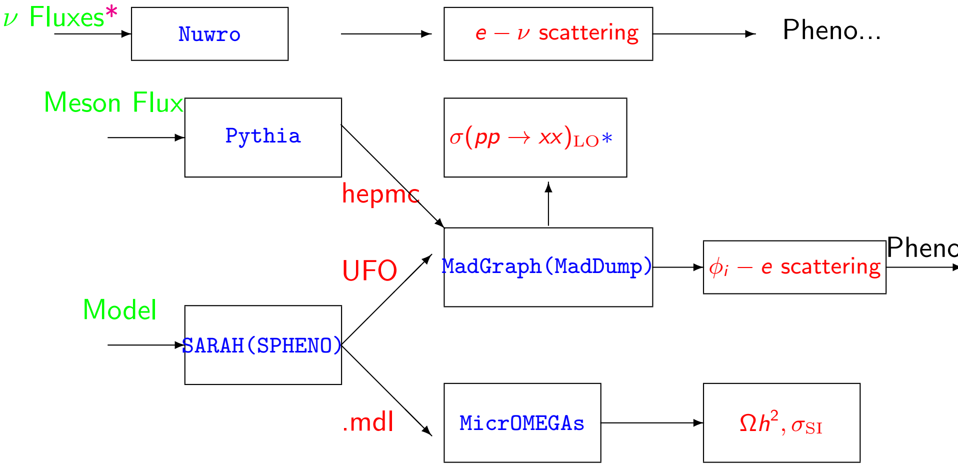
The Lagrangian reads:

$$\mathcal{L}_{\rm new} \supset -\frac{\varepsilon}{2} F_{\mu\nu} F'^{\mu\nu} + \sum_{i=1}^{2} |D_\mu \phi_i|^2 + V(H, s, \phi_1, \phi_2)$$

$$\mathcal{L}_\phi = \frac{i g_D}{2} \gamma'^\mu \sum_{i=1}^{2} \left[\partial_\mu(\phi_i^\dagger)\phi_i - \phi_i^\dagger(\partial_\mu \phi_i) \right]$$

- After EWSB, $G_{SM} \otimes U(1)_D \otimes Z_2 \otimes Z_2' \longrightarrow \mathrm{SU}(3)_C \otimes U(1)_{\rm em} \otimes Z_2 \otimes Z_2'$ the mixing of the fields (B_3^μ, A^μ, A'^μ) give rises to the boson Z, the photon γ and the dark photon $\gamma_D(\gamma')$.
- The dark photon mixes with the ordinary matter.
- ϕ_1 and ϕ_2 are stable and dark matter candidates.

HEP Tools implementation for Signal and Background

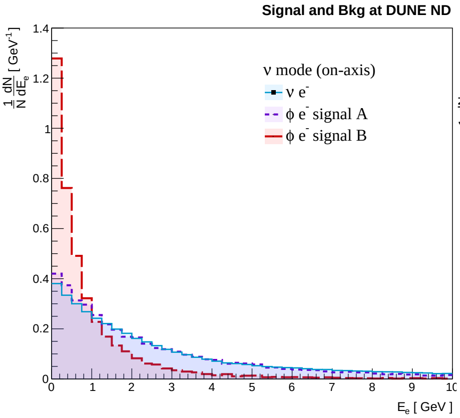


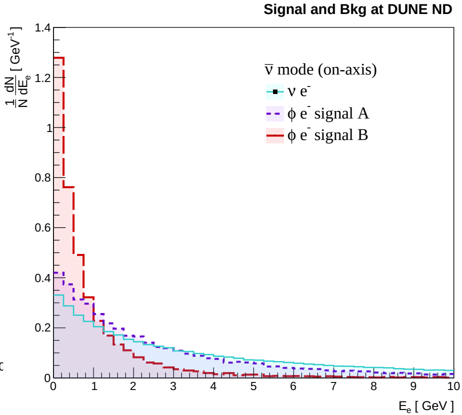
https://home.fnal.gov/ljf26/DUNEFluxes/

Signal and Background on-axis

Benchmark Points

- BPA $\rightarrow m_{\gamma'} = 30$ MeV, $m_{\phi 1} = 20$ MeV, $m_{\phi 2} = 1.7$ GeV, $\alpha_D \varepsilon^4 = 10^{-13}$
- BPB $\rightarrow m_{\gamma'} = 90$ MeV, $m_{\phi 1} = 30$ MeV, $m_{\phi 2} = 1.7$ GeV, $\alpha_D \varepsilon^4 = 10^{-13}$





Benchmark Point

$m_{\gamma'} = M_{A'} = 3m_{\phi 1}, m_{\phi 2} = 1.7 \text{ GeV}, \ \alpha_D = 0.1,$

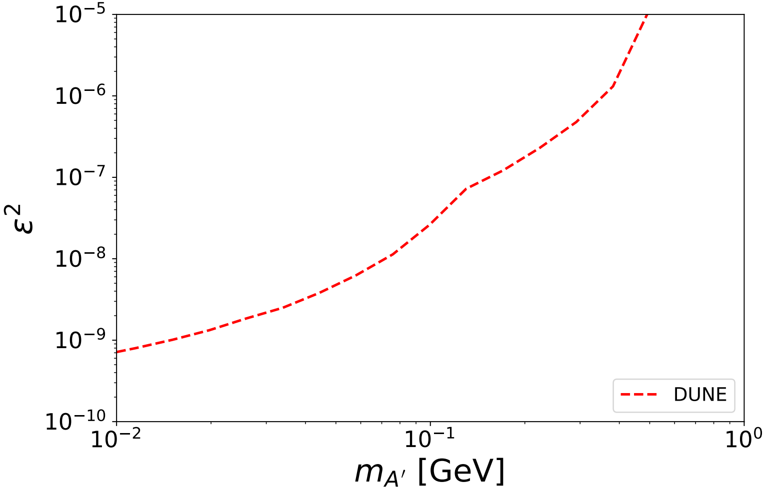


Figure 1: Expected sensitivity at 90% CL

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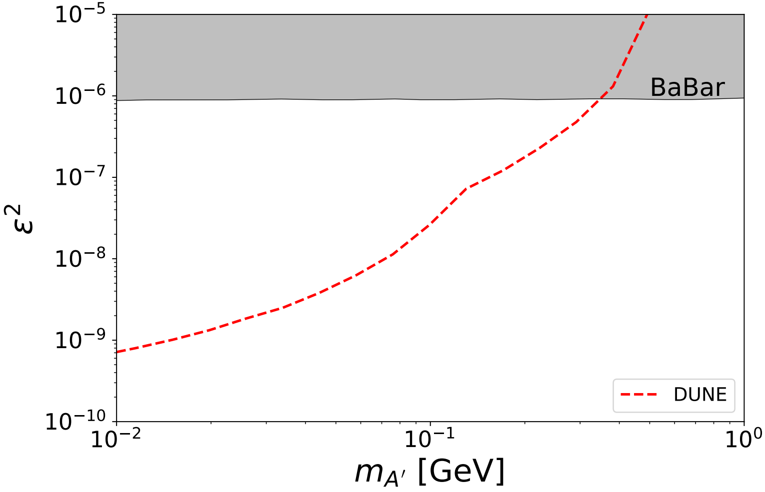

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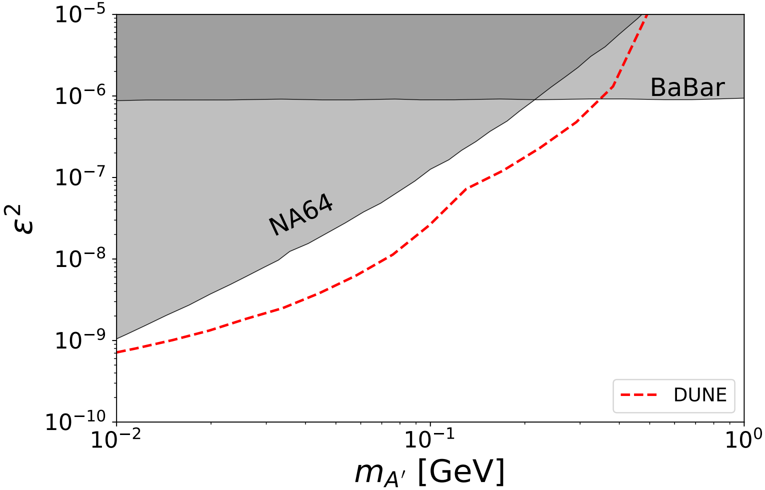

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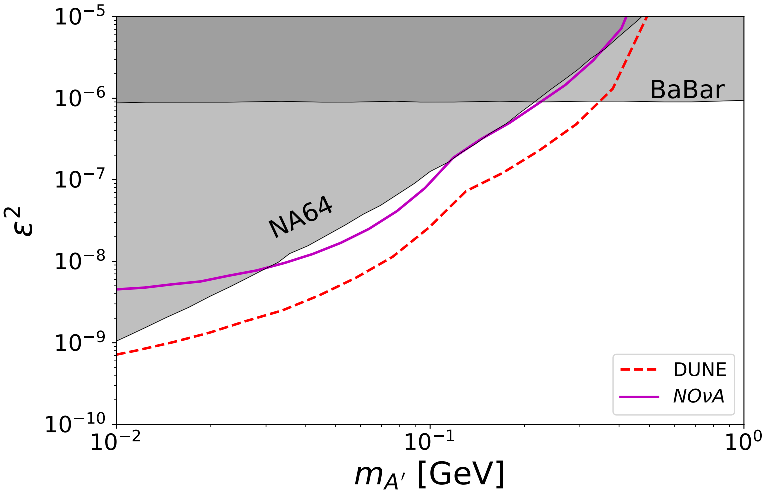

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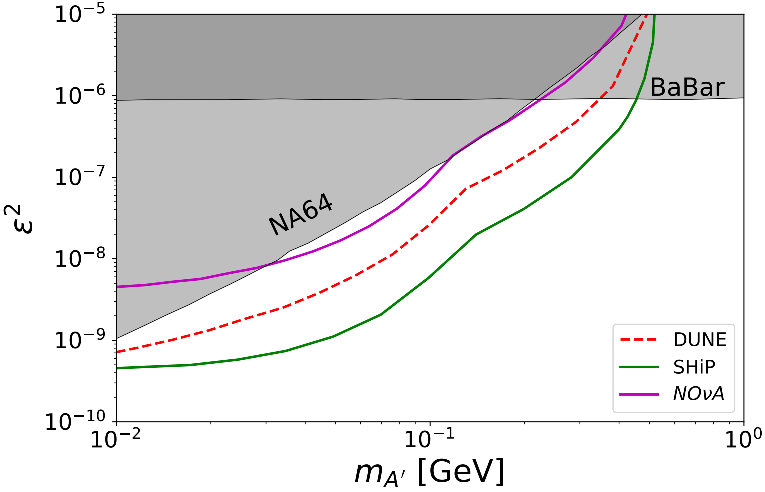

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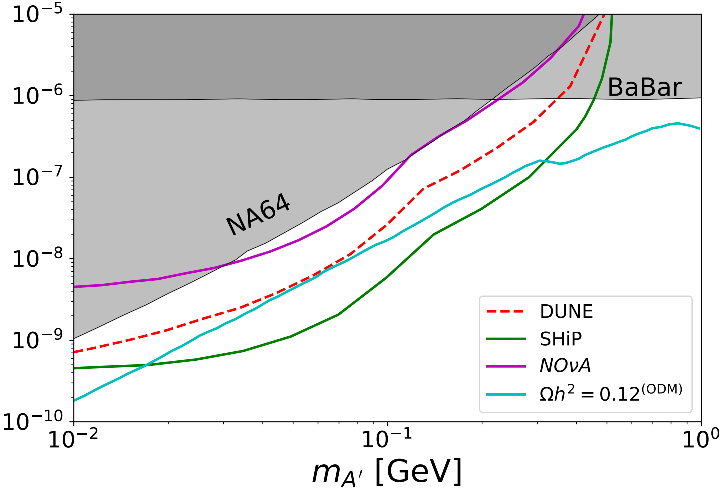

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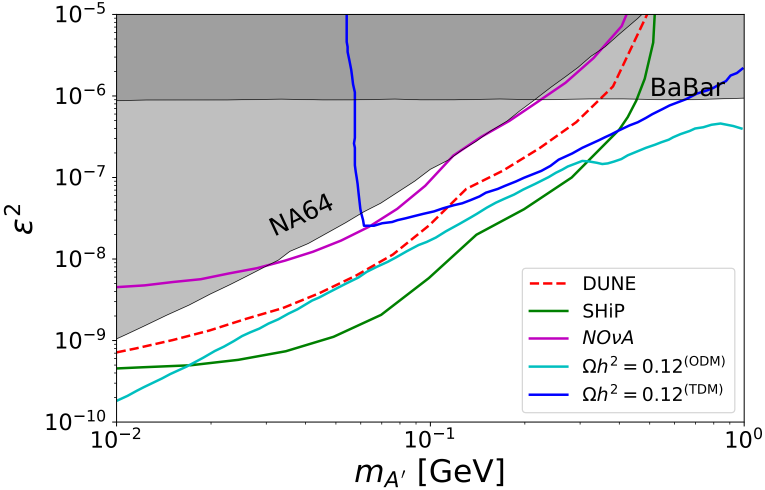

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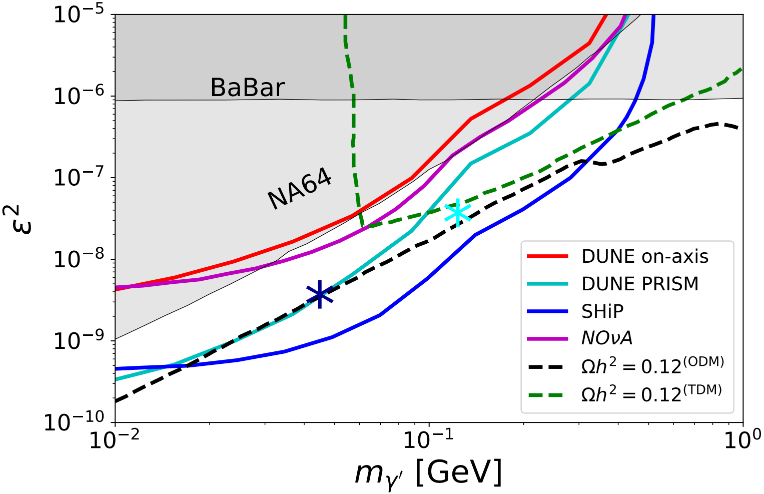


Figure 1: Expected sensitivity at 90% CL

How to distinguish Signal from Background?

- In the previous result no cuts were implemented at all, and the test-statistic used for the sensitivity was based in the whole number of events for signal and background energy histograms. The sensitivity at 90% was computing using

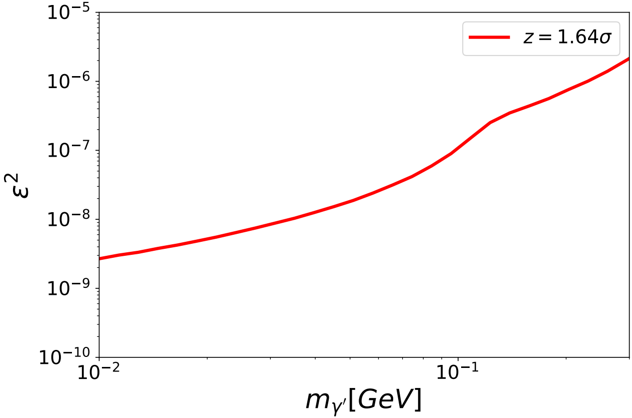
$$Z = \frac{N^{\phi}}{\sqrt{N^{\nu} + \sum_{i \in (\nu_e, \nu_\mu, \overline{\nu}_e, \overline{\nu}_\mu)} (k_i N_i^{\nu})^2}} \geq 1.64 \ ,$$

- Our new study is based on the exploration of ML techniques to distinguish signal from background and improve the potential exclusion reach of DUNE.
- Machine Learning (ML) can be used as supervised learning to perform classification.

Basic idea and preliminary results: Sensitivity for DUNE-ND: One year running

Benchmark Points

$m_{\gamma'} = 0.11\ GeV,\ \varepsilon^2 = 1.5 \times 10^{-7} \rightarrow \varepsilon^2 = 4.5 \times 10^{-8}$



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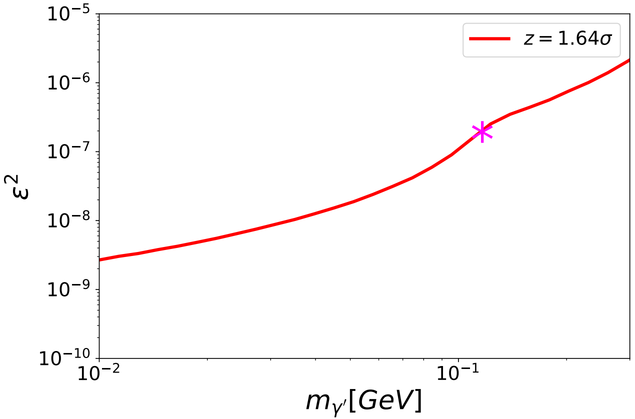

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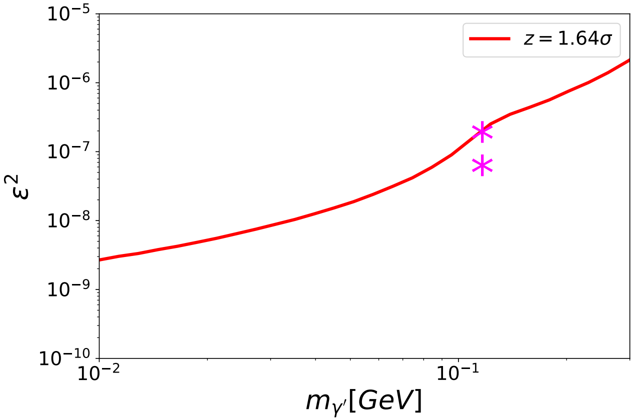

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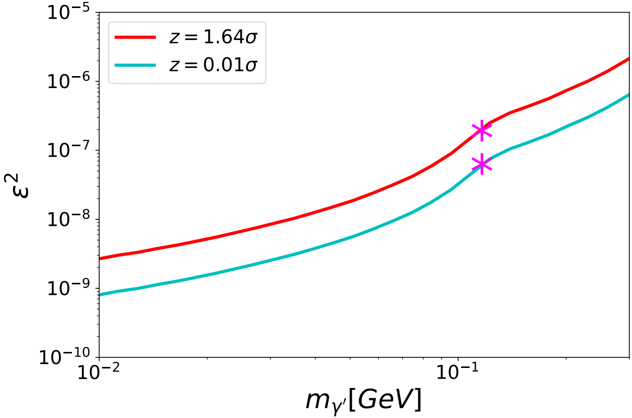

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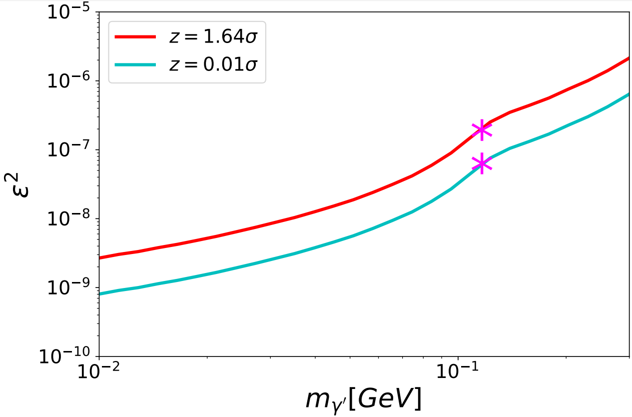

For the new point (in cyan line) the expected sensitivity using ML (xgboost) is of 1.68σ

Log-Likelihood ratio for two hypothesis

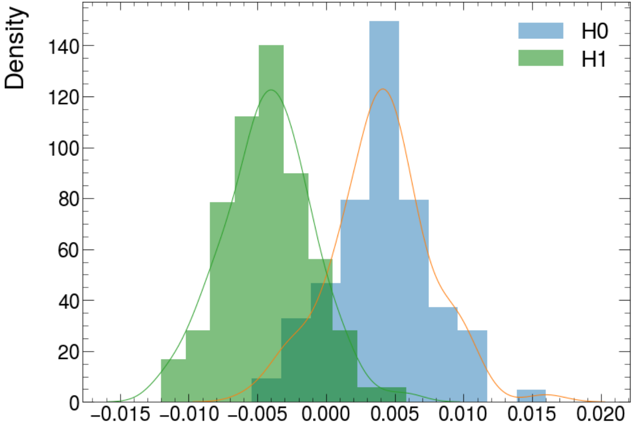

Figure 2: LLR for two hypothesis

Preliminary Results

Benchmark Points

$M_{\gamma'} = 0.11\ GeV, \varepsilon^2 = 1.5 \times 10^{-7}$[*Left*] $\varepsilon^2 = 4.5 \times 10^{-8}$[*Right*]

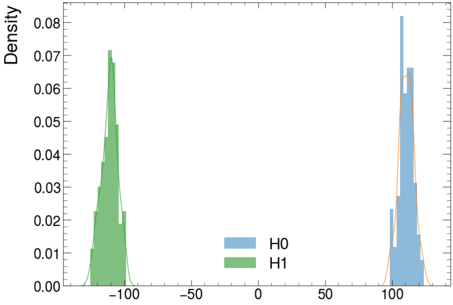

Figure 3: LLR Benchmark point 1 (up)

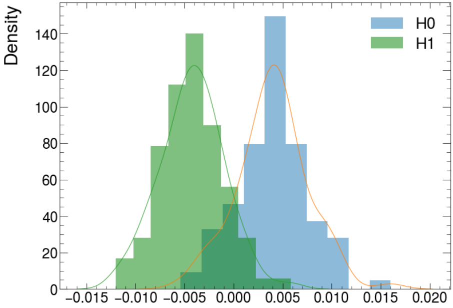

Figure 4: LLR Benchmark point (down)

Conclusions

- Beam Dump experiments has the potential to explore a big portion of the parameter space of the model.
- The correct relic density can be explained in regions that Beam Dump experiments will soon probe.
- Off-axis analysis implemented.
- ML techniques has the potential to increase the exploratory reach of DUNE
- A full analysis is under way

Thanks for your attention