Two component dark matter model in light of Beam Dump experiments

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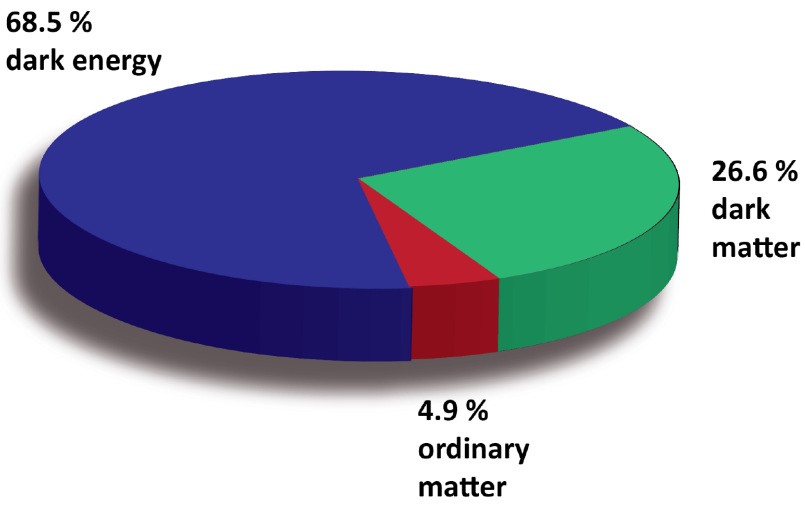
The Dark Matter problem



Universe Content *Credit:NIST*

- Observed motion of stars and galaxies.
- Gravitational lensing.
- The CMB observation and gravitational probes show that the Universe is made of around 25% non-visible matter. The so-called **dark matter**

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 $U(1)_D$

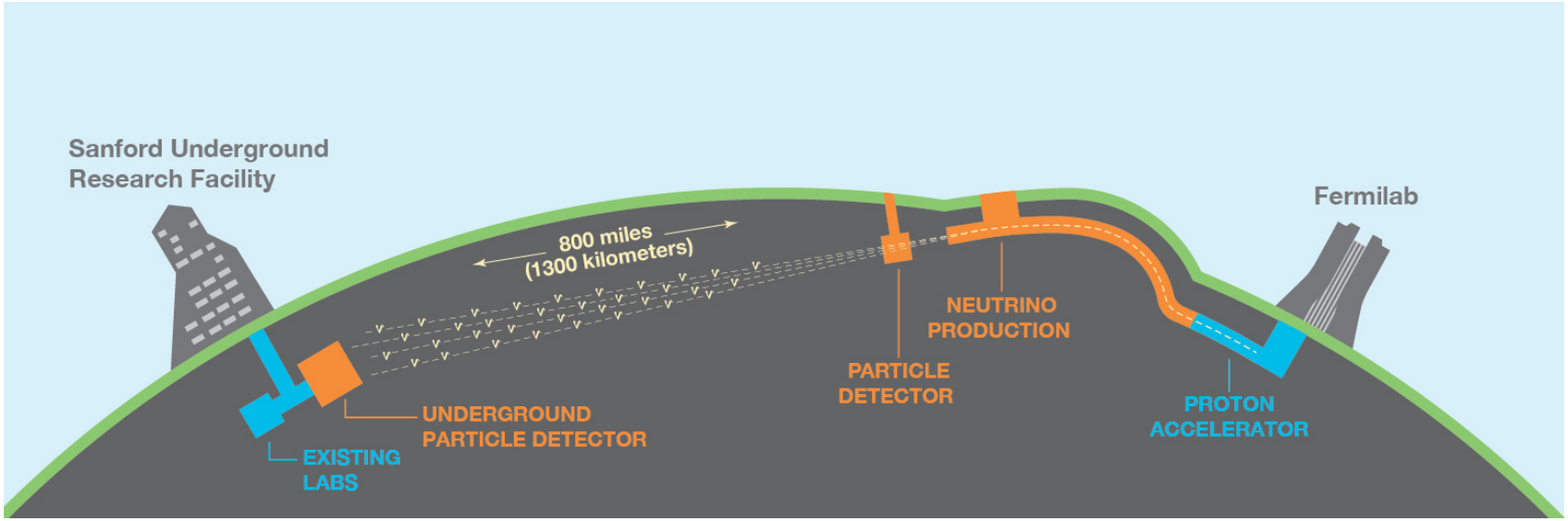
The Lagrangian reads:

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

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

- After EWSB, $G_{SM} \otimes U(1)_D \otimes Z_2 \otimes Z_2' \longrightarrow \text{SU}(3)_C \otimes U(1)_{\text{em}} \otimes Z_2 \otimes Z_2'$ 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 $\gamma_D(A')$.
- The dark photon mixes with the ordinary matter.
- ϕ_1 and ϕ_2 are stable and dark matter candidates.

DUNE Near Detector

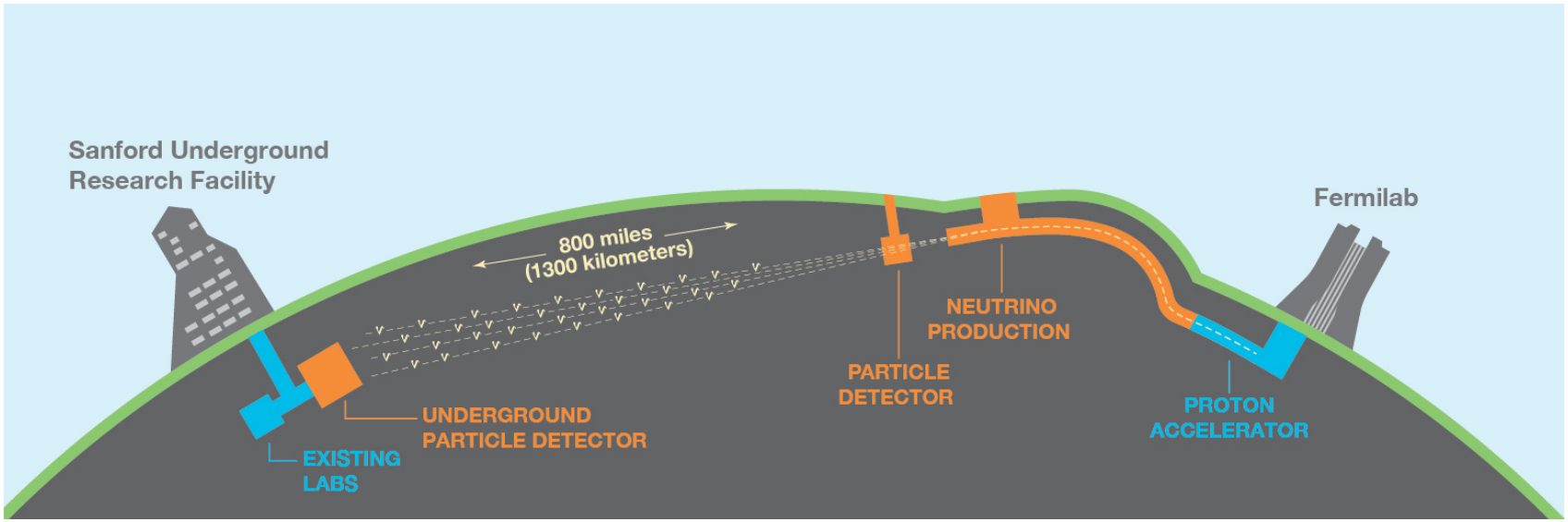


- Protons at 120 GeV collides against a fixed-target made of carbon, then a bunch of particles are created ($\pi^0, \eta, \eta', \omega, \pi^\pm, K^\pm, ...$).

meson **m**	meson/POT	Br($\mathbf{m}^+ \to \mu^+\nu_\mu$)	Br($\mathbf{m}^+ \to e^+\nu_e$)
$\pi^+(\pi^-)$	4.3(4.0)	99.98 %	1.2×10^{-4} %
$K^+(K^-)$	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 $\pi^\pm$

LDM @ DUNE



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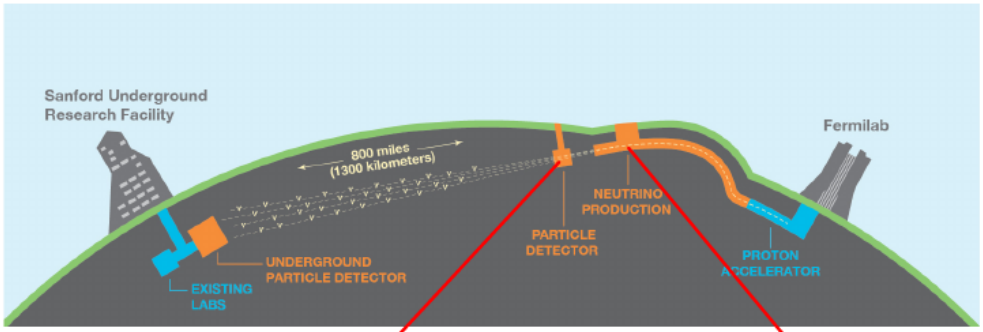
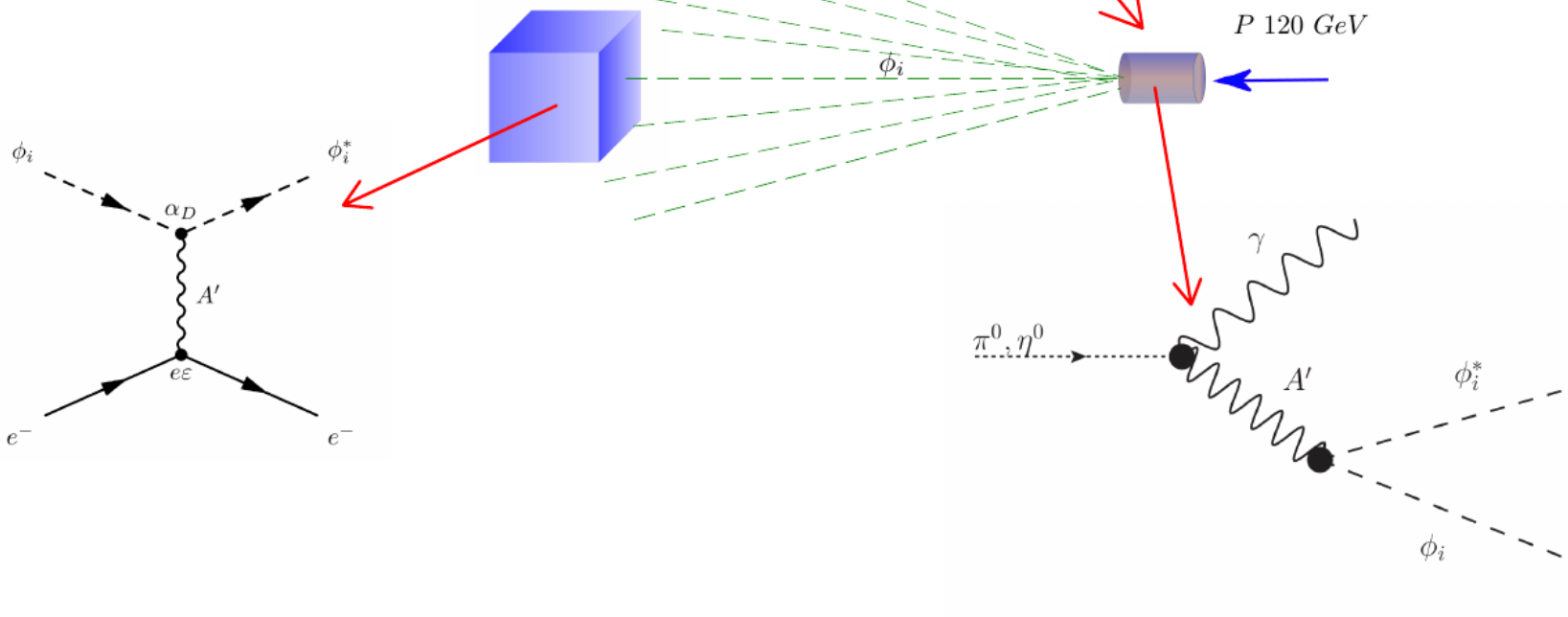
meson **m**	meson/POT	Br(**m** $\to \gamma\gamma$)
π^0	4.8	99.82 %
η	0.5	39.41 %

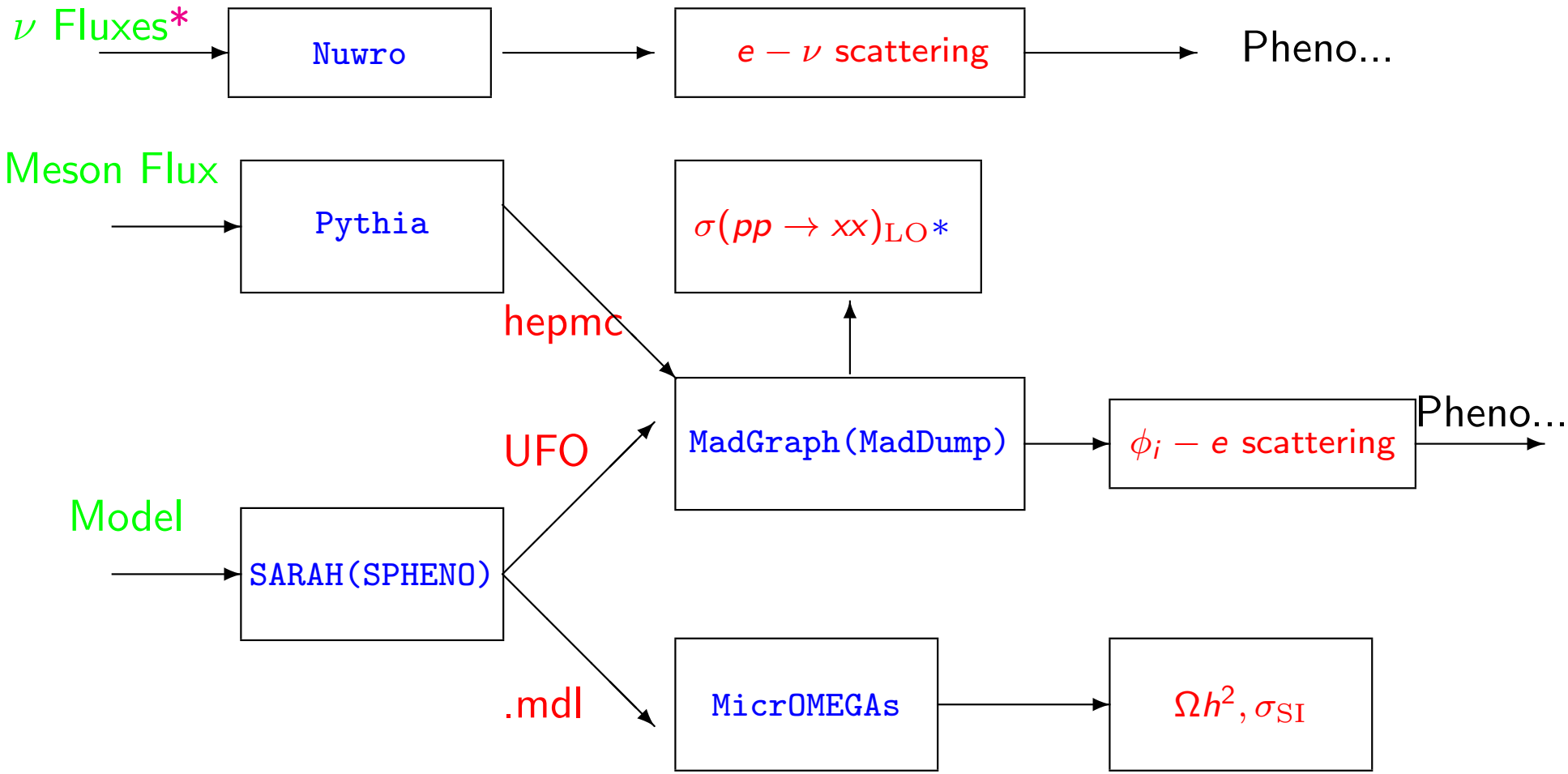
- LDM could be produced thanks to the mixing between γ-A'

DUNE Near Detector





HEP Tools implementation for Signal and Background

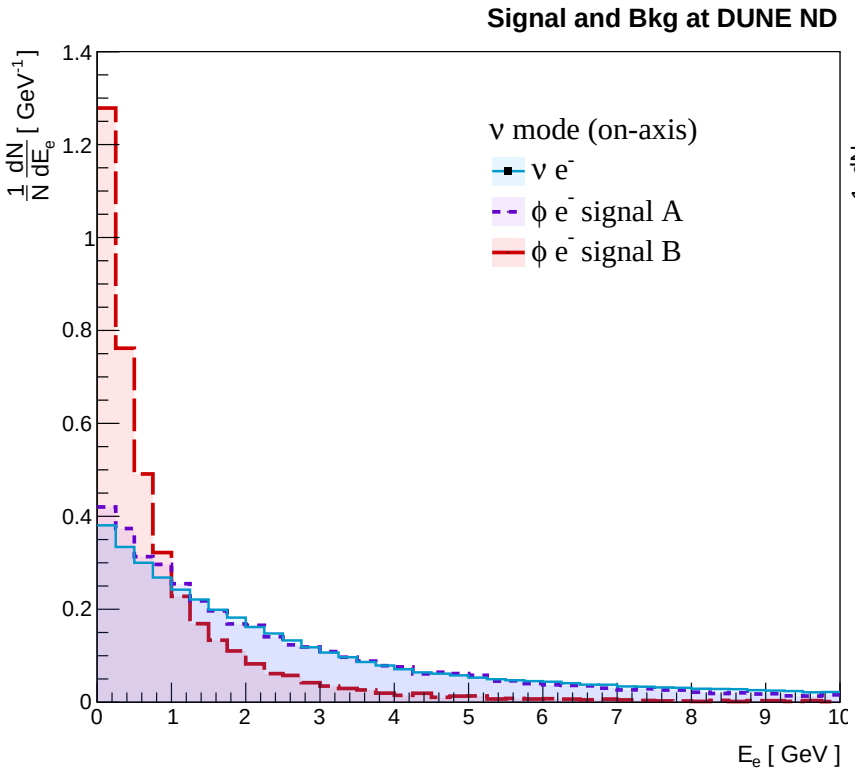


https://home.fnal.gov/ljf26/DUNEFluxes/

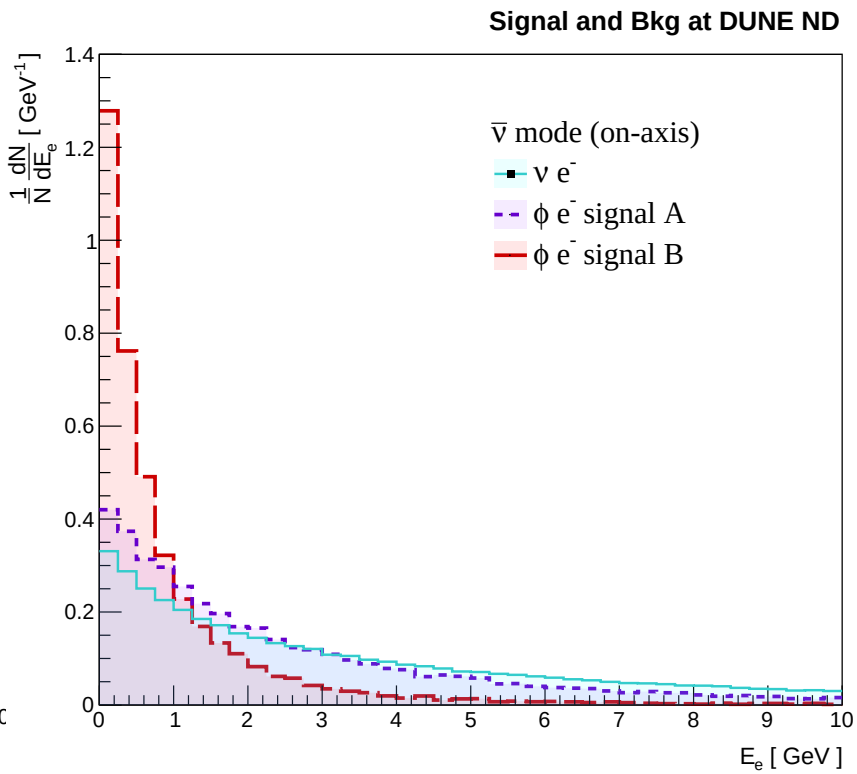
Signal and Background on-axis

Benchmark Points

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



$e - \nu\ (\phi_1 - \nu)$ scattering

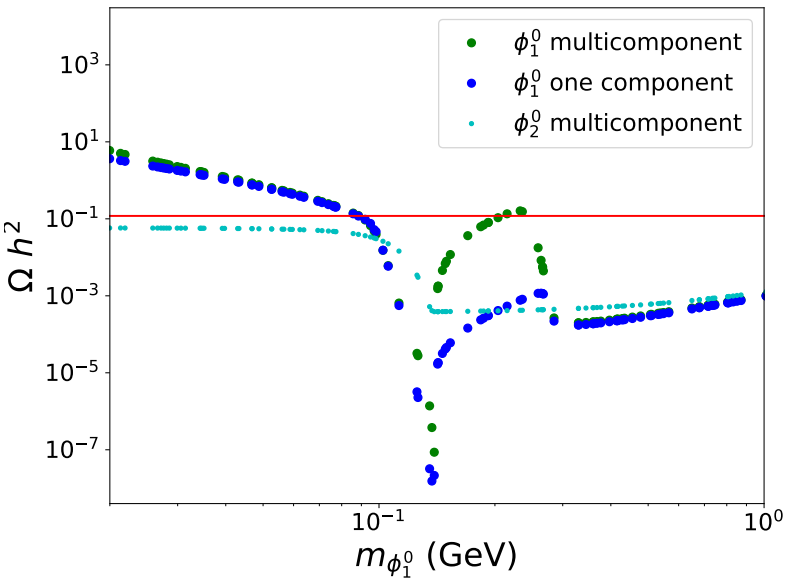


$e - \overline{\nu}\ (\phi_1 - \overline{\nu})$ scattering

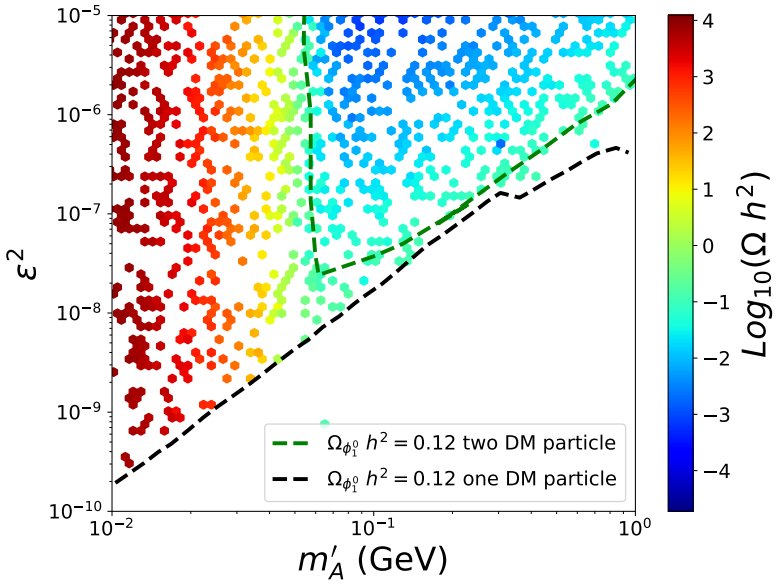
Dark Matter Results

Benchmark Points

$$M_{A'} = 3M_{\phi 1},\ M_{\phi 2} = 1.7\ \text{GeV},\ \alpha_D = \frac{g_D^2}{4\pi} = 0.1$$



Ωh^2 for one and two DM components



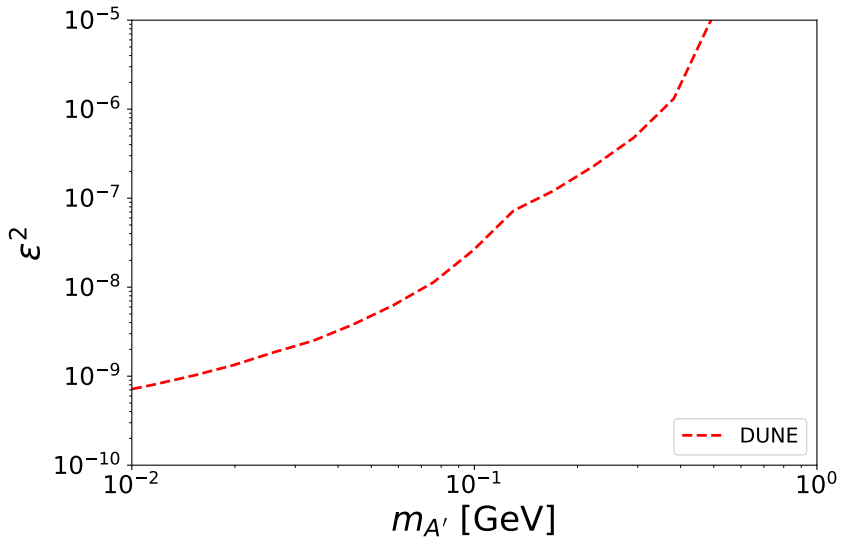
ε^2 vs $m_{A'}$

Potential exclusion reach of beam dump experiments

Benchmark Point

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

For the sensitivity analysis we consider the figure of merit $Z = \dfrac{N_s}{\sqrt{N_B}}$, and $Z = 1.64$ will correspond to a 90% CL. N_s is the number of events for the signal ($\mathrm{DM} - e$ scattering) and N_B is the number of events for the background ($\nu - e$ scattering)



Expected sensitivity at 90% CL

Potential exclusion reach of beam dump experiments

Benchmark Point

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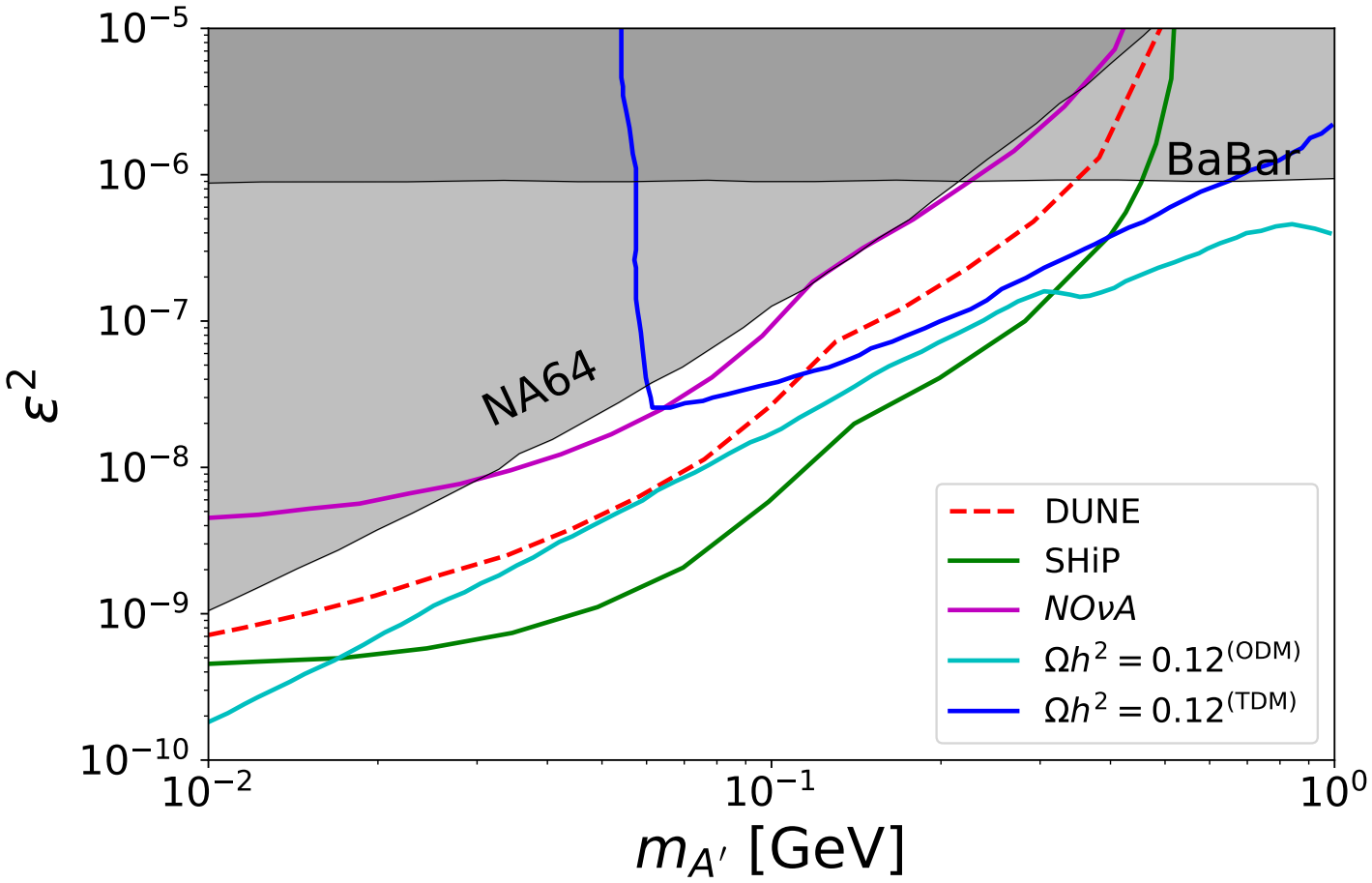

Expected sensitivity at 90% CL

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 and multi-component dark matter pheno still a work in progress.
- Detector response is not implemented in the analysis.