Hidden Sector Searches at DUNE

Kevin Kelly, Fermilab

Hidden Sectors @ Fixed Target Experiments (September 4, 2019)

Based on [1903.10505] with Valentina de Romeri & Pedro A.N. Machado; and forthcoming work

‡ Fermilab

Outline

▸ Semantics

▸ The DUNE Near Detector Complex

▸ Using DUNE-PRISM for Light Dark Matter

▸ Using the DUNE Multi-Purpose Detector for Hidden Sector Decays

Semantics

Symbiosis is a close relationship between two species in which at least one species benefits. For the other species, the relationship may be positive, negative, or neutral. There are three basic types of symbiosis: mutualism, commensalism, and parasitism.

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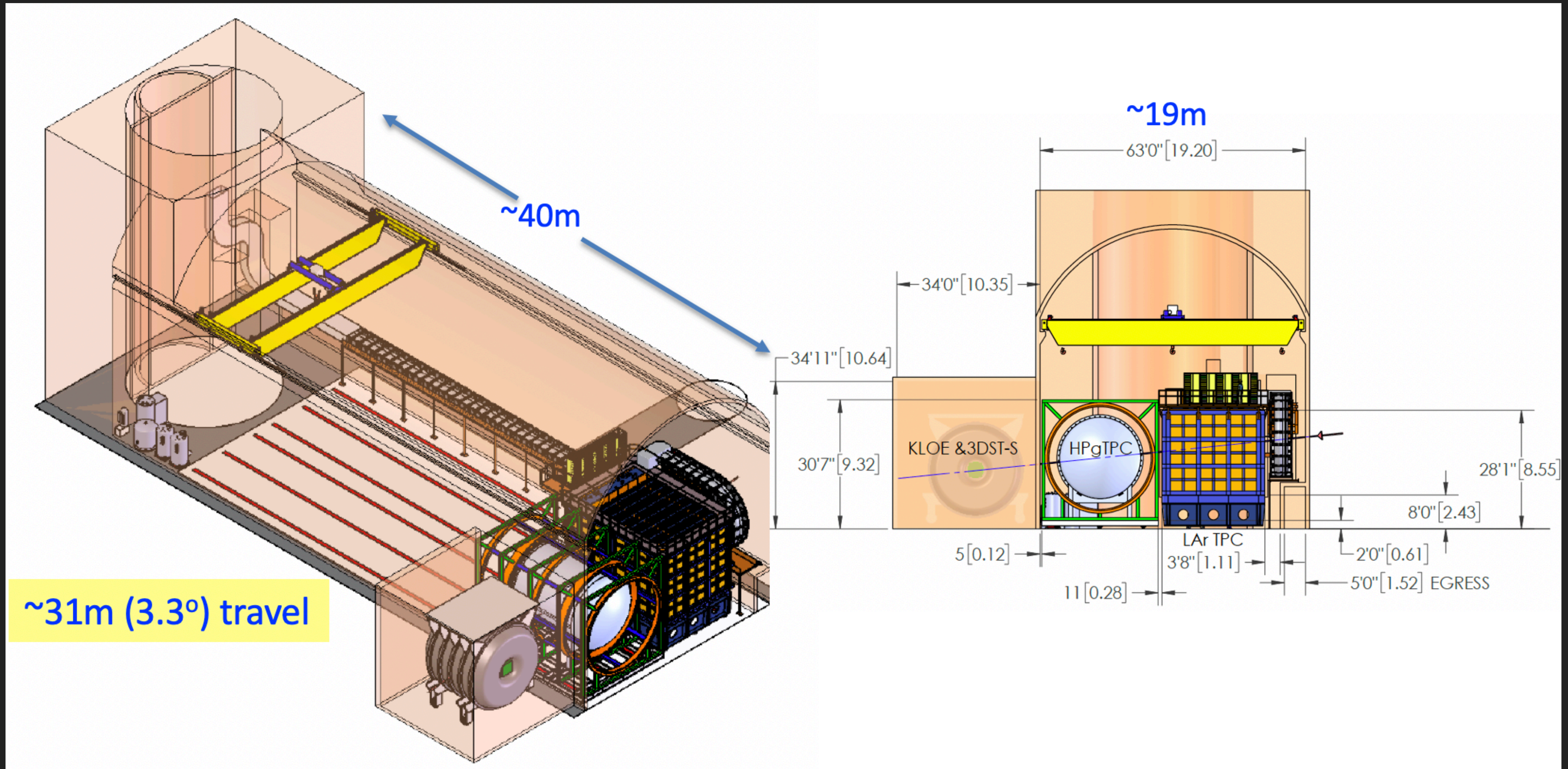

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Parasitism is a symbiotic relationship in which one species (the **parasite**) benefits while the other species (the **host**) is harmed. Many species of animals are parasites, at least during some stage of their life. Most species are also hosts to one or more parasites.
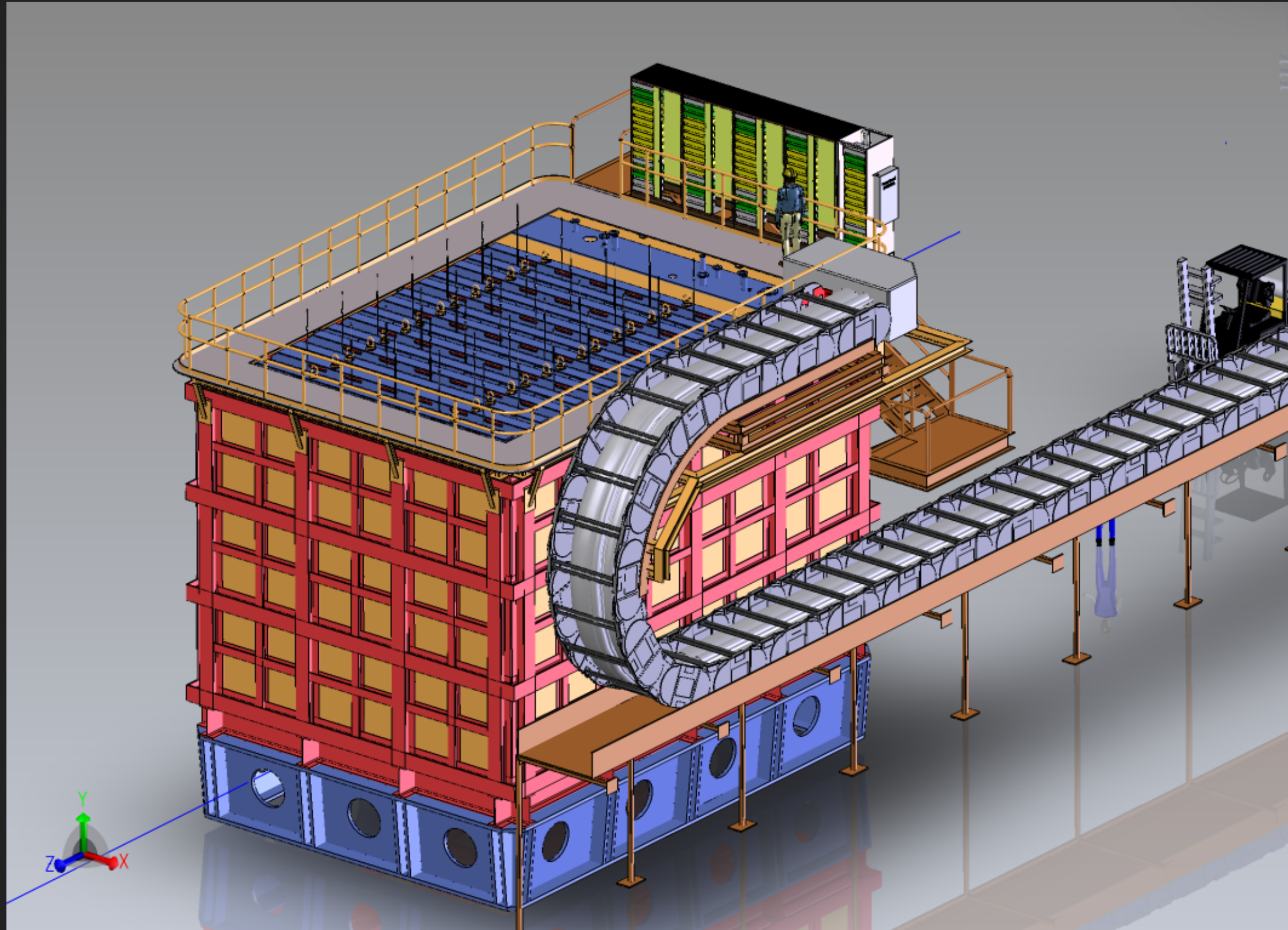
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DUNE Near Detector Complex

Current DUNE ND Plan

~40m

~31m (3.3°) travel

~19m

63'0"[19.20]

34'0"[10.35]

34'11"[10.64]

30'7"[9.32]

KLOE &3DST-S

HPgTPC

LAr TPC

5[0.12]

3'8"[1.11]

11[0.28]

28'1"[8.55]

8'0"[2.43]

2'0"[0.61]

5'0"[1.52] EGRESS

[Alan Bross's talk at NuFact 2019]

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Liquid Argon TPC

[Alan Bross's talk at NuFact 2019]

- ‣ Active Volume: 5m (beam direction), 3m (tall), 7m (transverse)
- ‣ Active mass: 150t
- ‣ Fiducial mass: 50t
- ‣ 35 separate (1m x 1m x 3.5 m) modules
- ‣ Pixelated charged readout
- ‣ Movable off-axis (up to ~30 m)

Multi-purpose Detector

[Alan Bross's talk at NuFact 2019]
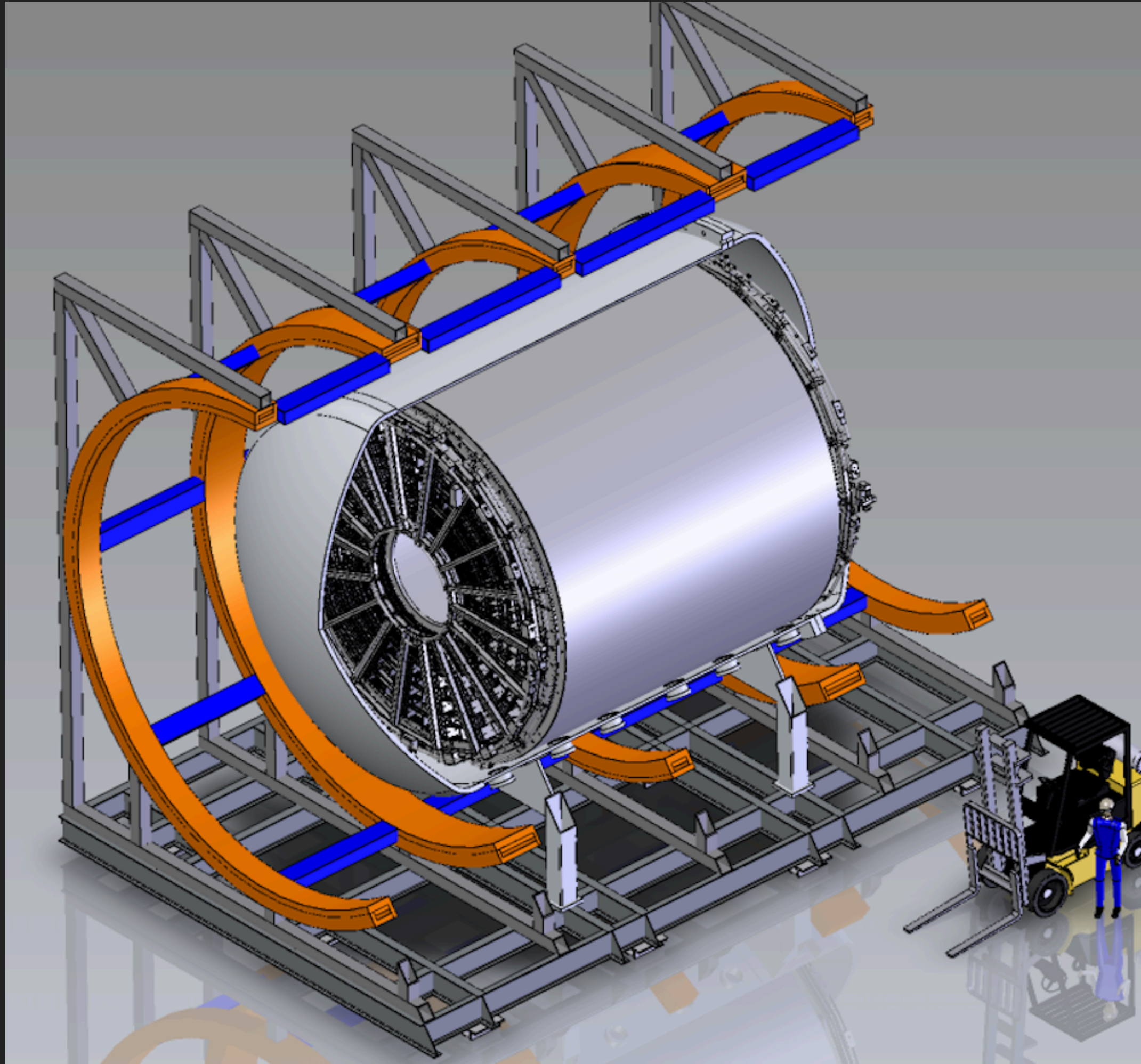
‣ High-pressure Gas TPC (10 bar)

‣ ECAL Surrounding Gas TPC

‣ Magnet surrounding ECAL

‣ Spectrometer for particles that exit Liquid Argon TPC

‣ Low thresholds, fine-grained tracking

‣ Moveable off-axis with LAr TPC

3D Scintillator Tracker–Spectrometer (3DST–S)

[Alan Bross's talk at NuFact 2019]
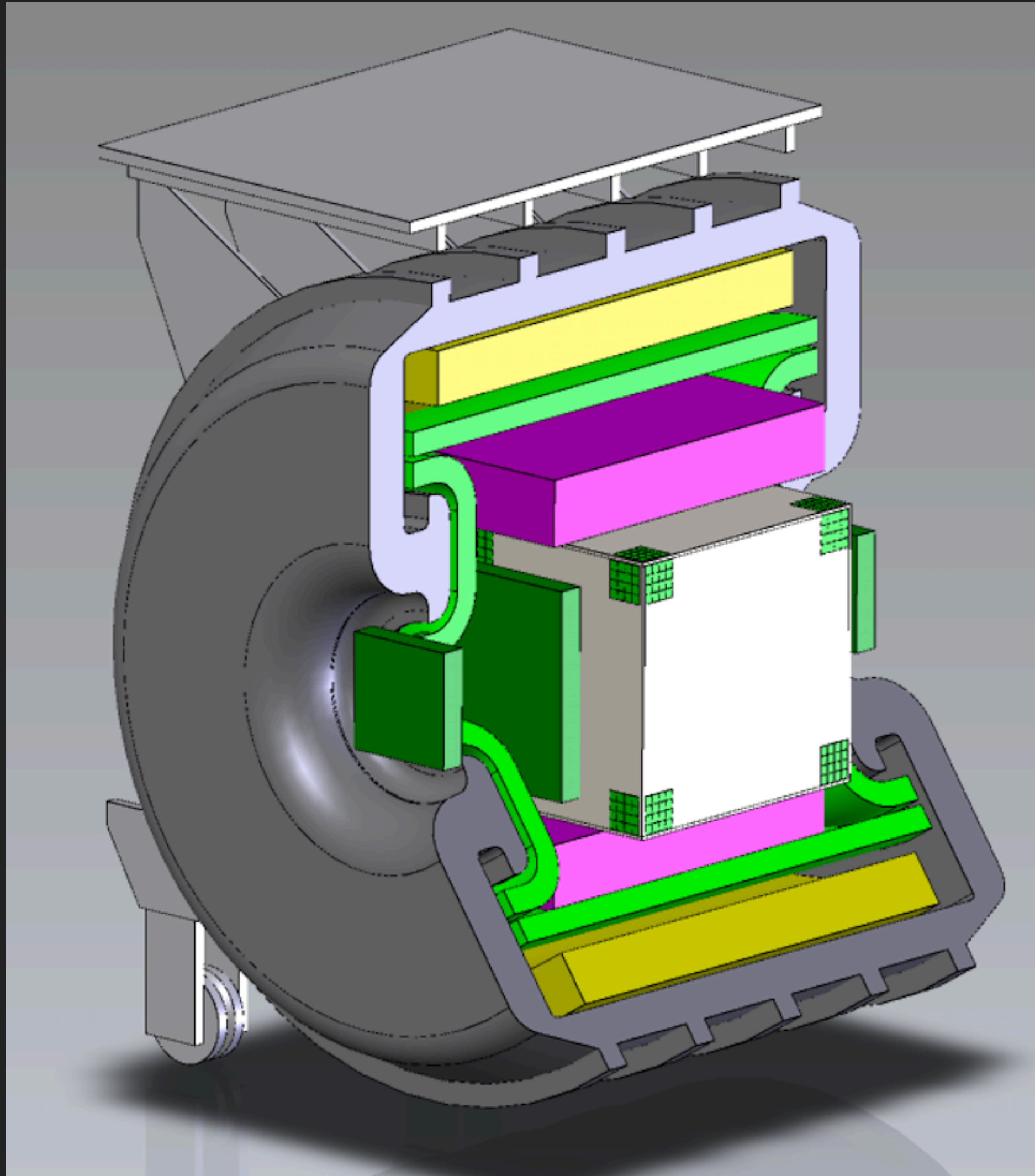
- ‣ Active target of scintillator tracker (8 t)
- ‣ Gas tracking chambers (1 atm)
- ‣ 1x1x1 cc cubes (total volume 2.4 m x 2.4 m x 2 m)
- ‣ Independent program for cross sections on CH.
- ‣ Remains on-axis to monitor flux

Neutrino Trident Scattering for New Physics

Recent, DUNE-focused work:

[1902.06765] W. Altmansshofer, S. Gori, J. Martín-Albo, A. Sousa, and M. Wallbank

[1902.08579] P. Ballett, M. Hostert, S. Pascoli, Y. Perez-Gonzalez, Z. Tabrizi, R. Zukanovich Funchal

New Physics Contribution (via interference) to SM Trident Production

$L_\mu - L_\tau$, DUNE ND, 75 tonnes, 5 y ν-mode + 5 y $\bar\nu$-mode, 120 GeV p^+, $\sigma_{\rm norm} = 5\%$

$$\varepsilon = \frac{eg'}{12\pi^2} \ln \frac{m_\mu^2}{m_\tau^2}$$

LHC

Borexino

CCFR

BaBar 4μ

$(g-2)_\mu \pm 2\sigma$

$\Delta N_{\rm eff} > 0.5$

DUNE 90% C.L.
$\mu^+\mu^-$ trident
$\nu - e$ scattering

g'

$M_{Z'}$ (GeV)
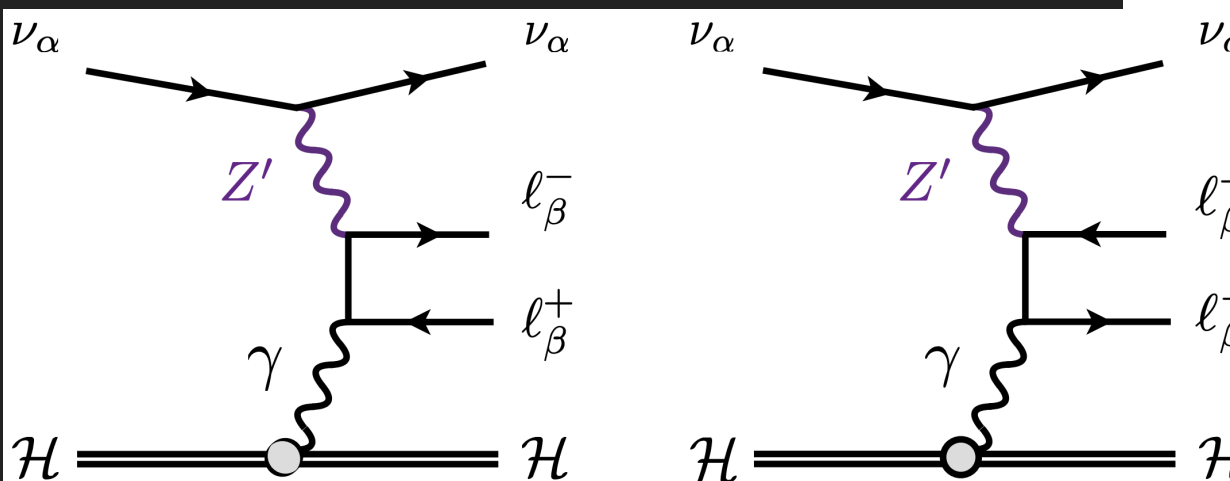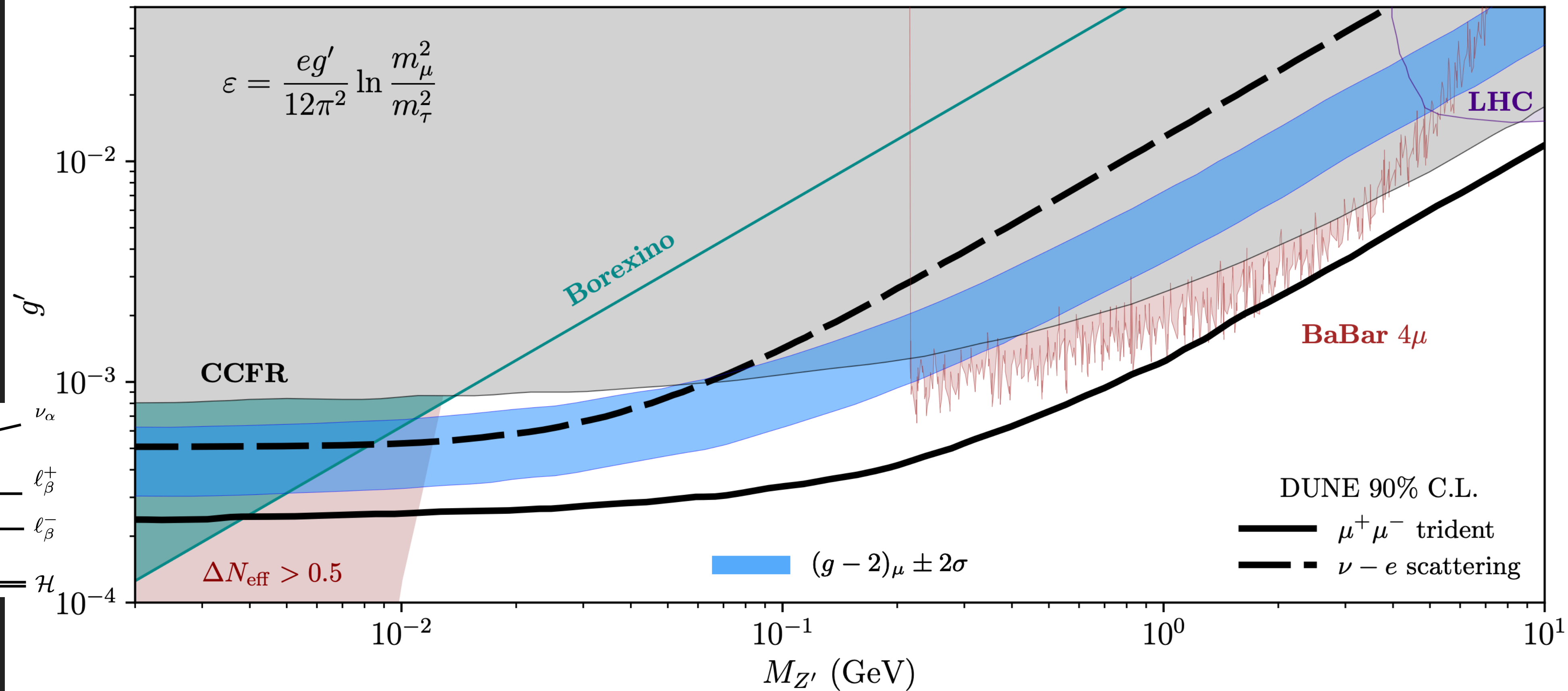
[1902.08579]

Light Dark Matter and DUNE-PRISM

[1903.10505] with Valentina de Romeri & Pedro Machado

Model of Interest + Production Mechanism

$$\mathcal{L} \supset -\frac{\varepsilon}{2}F^{\mu\nu}F'_{\mu\nu} + \frac{M_{A'}^2}{2}A'_\mu A'^\mu + \bar{\chi}i\gamma^\mu\left(\partial_\mu - ig_D A'_\mu\right)\chi - M_\chi\bar{\chi}\chi.$$
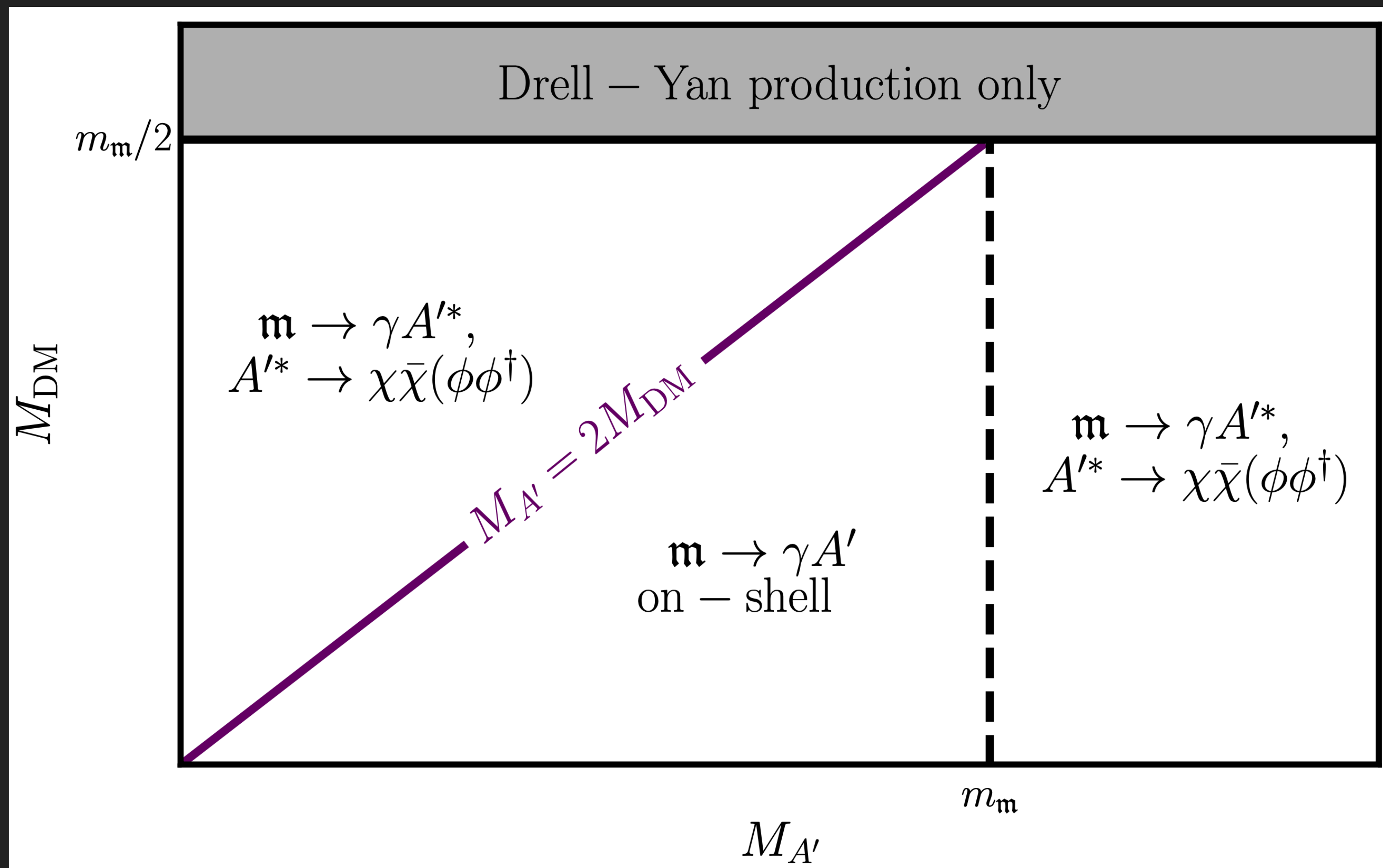
(or similar with scalar DM)

In a fixed-target environment, many neutral mesons that can decay $\mathfrak{m} \to \gamma\gamma$ are produced. With suitable masses, they can decay instead by


Or
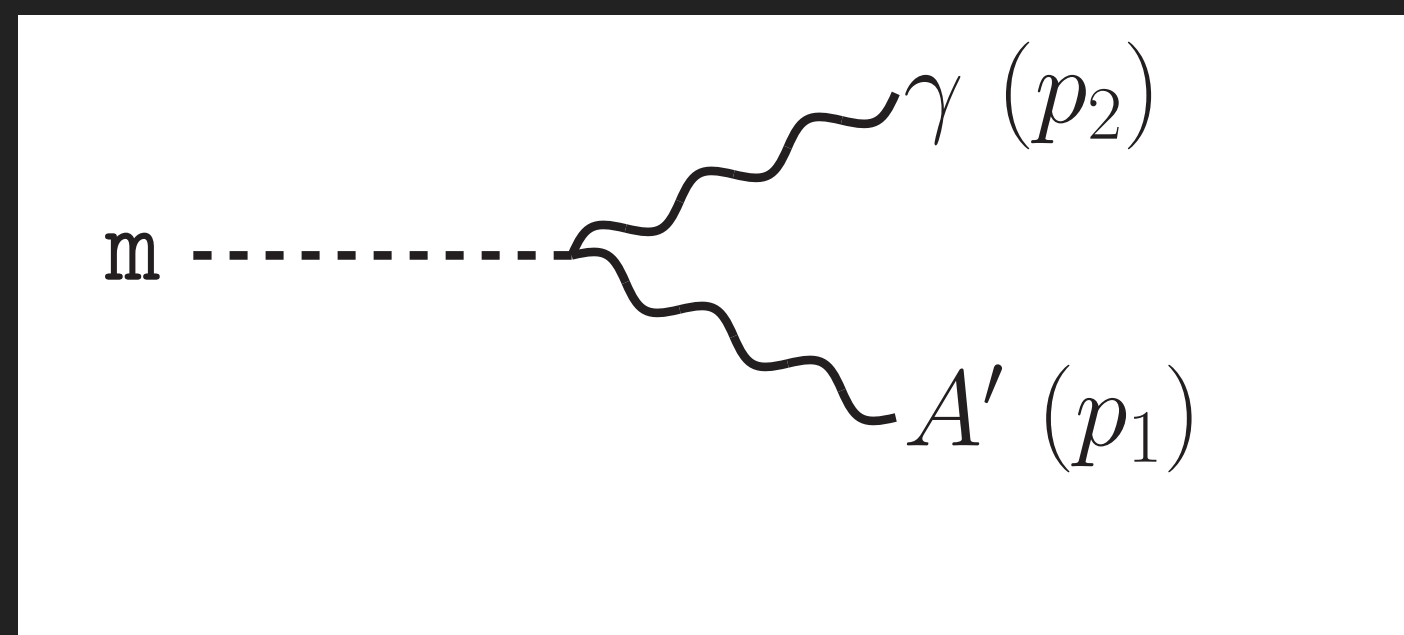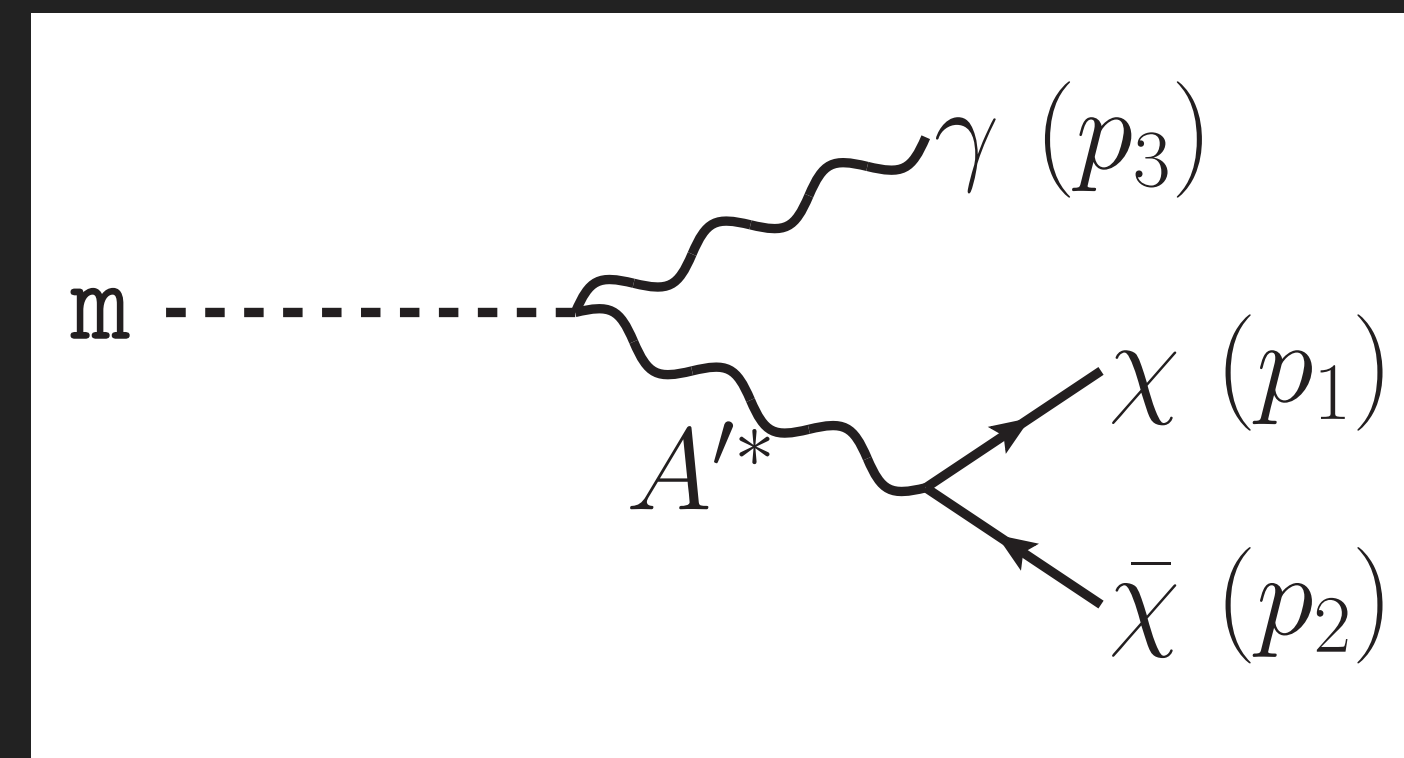
Backgrounds and Neutrino Focusing

▸ Signal looks identical to neutrino nucleus neutral current scattering, or neutrino-electron scattering.

▸ If performing a counting experiment, this means we will be background-dominated.

▸ Going beyond a counting experiment is difficult - shape of the neutrino flux (in terms of energy) is typically constrained by measurements of neutrino-electron scattering.
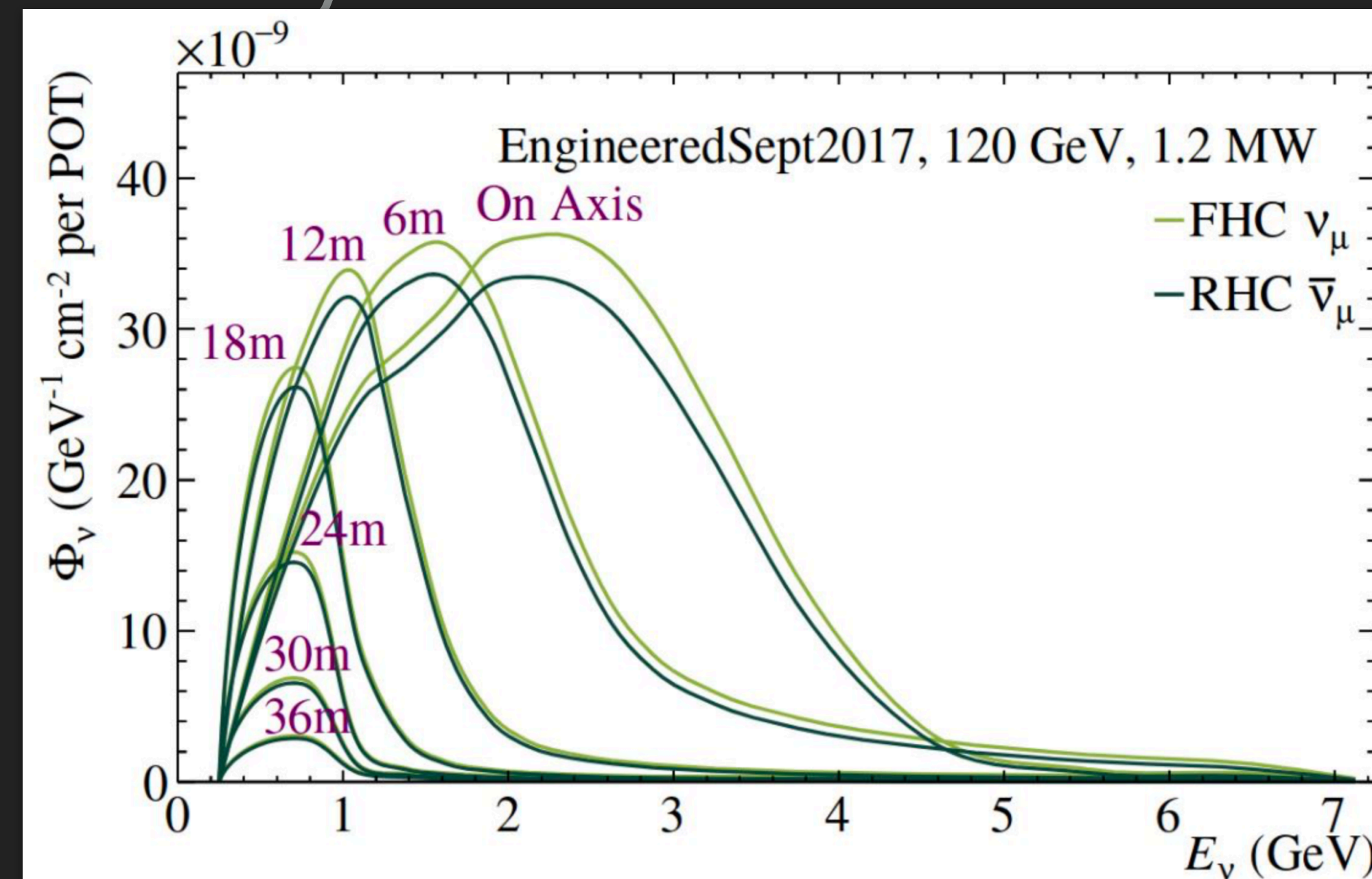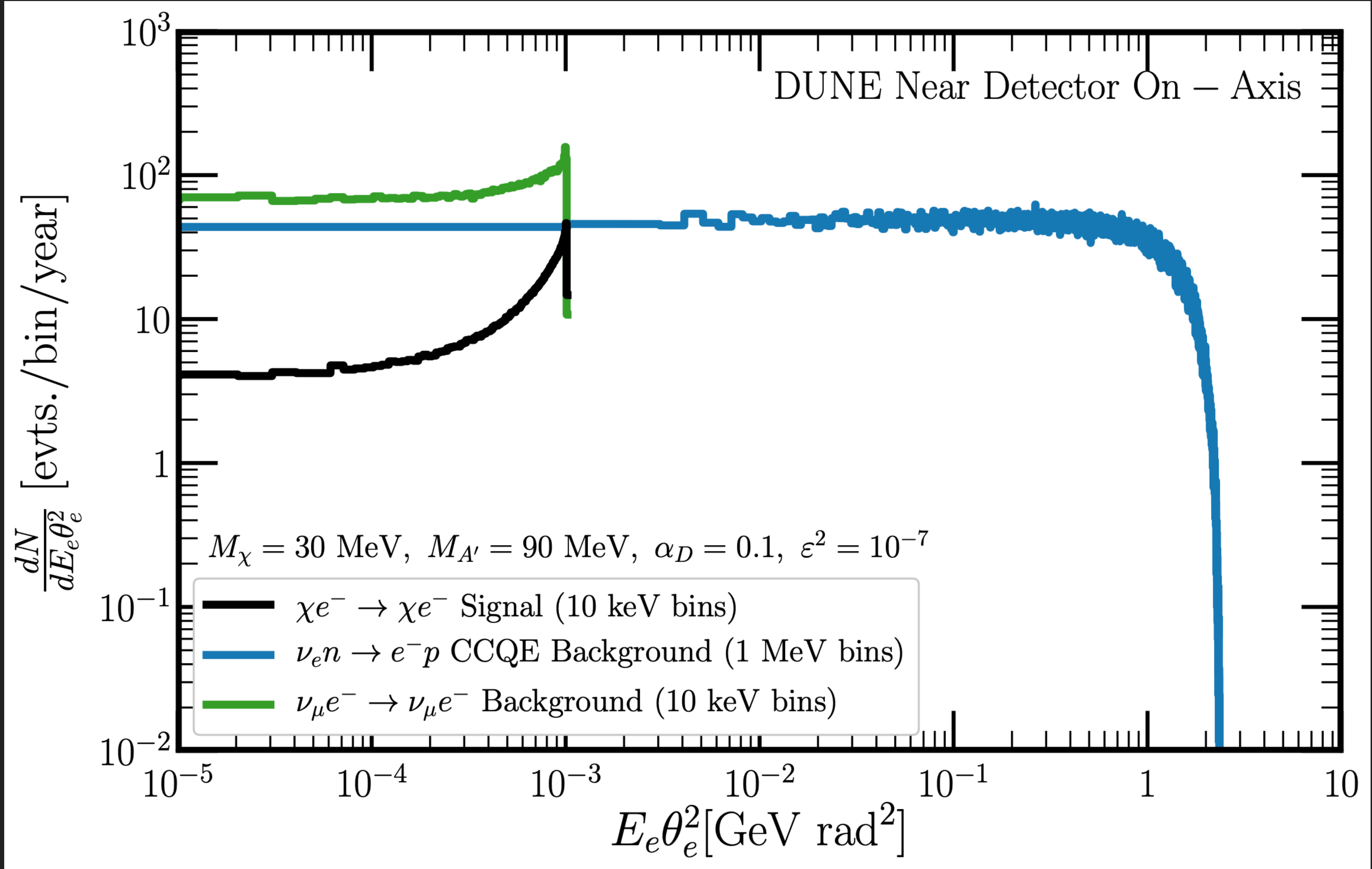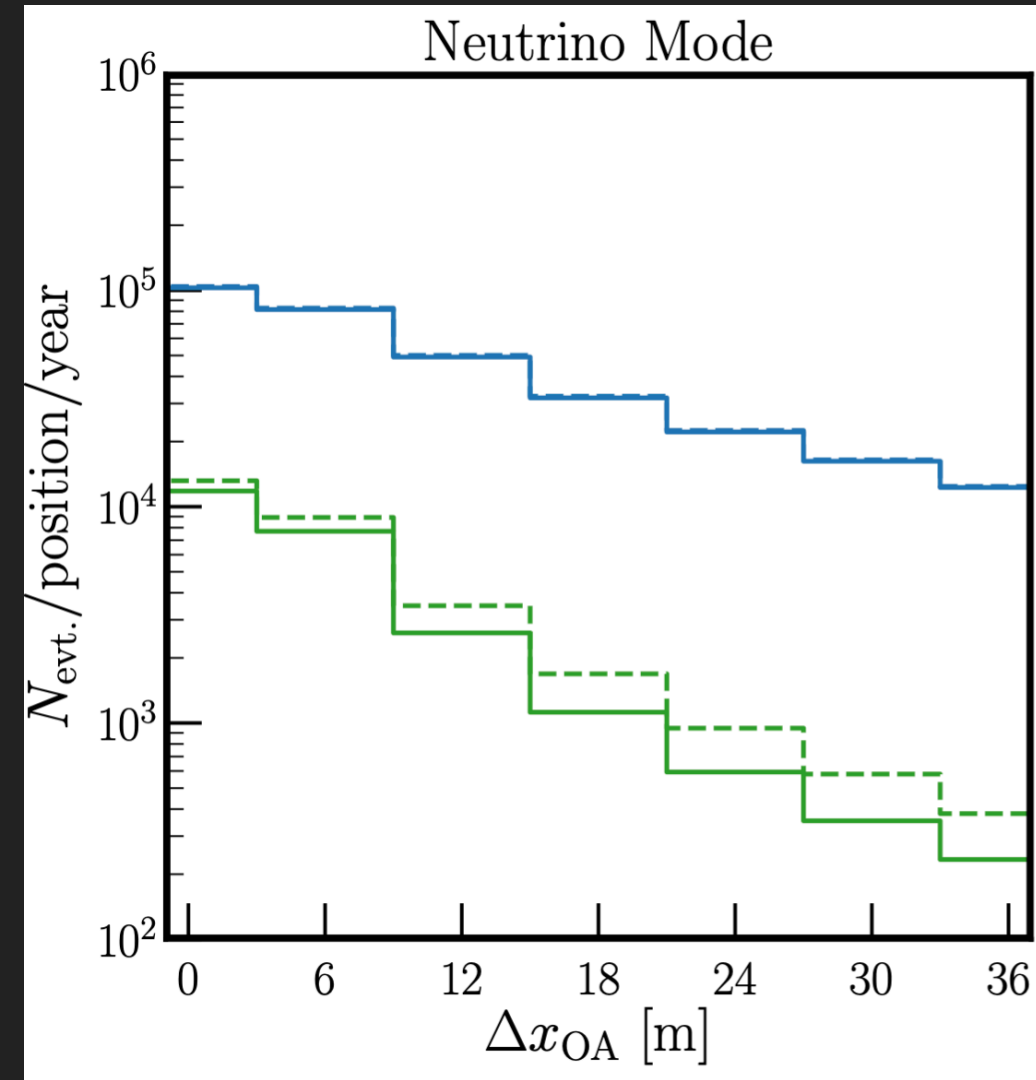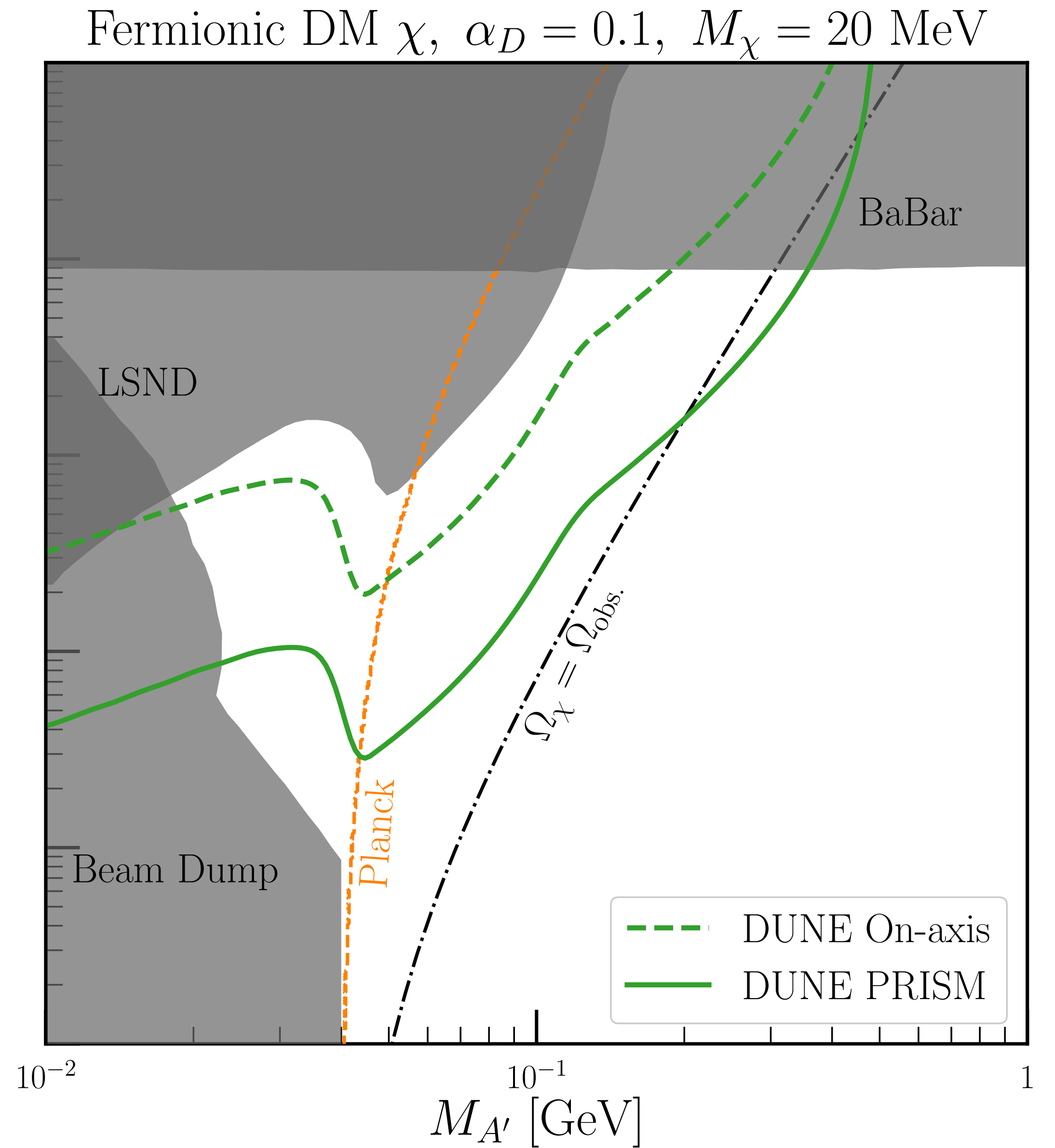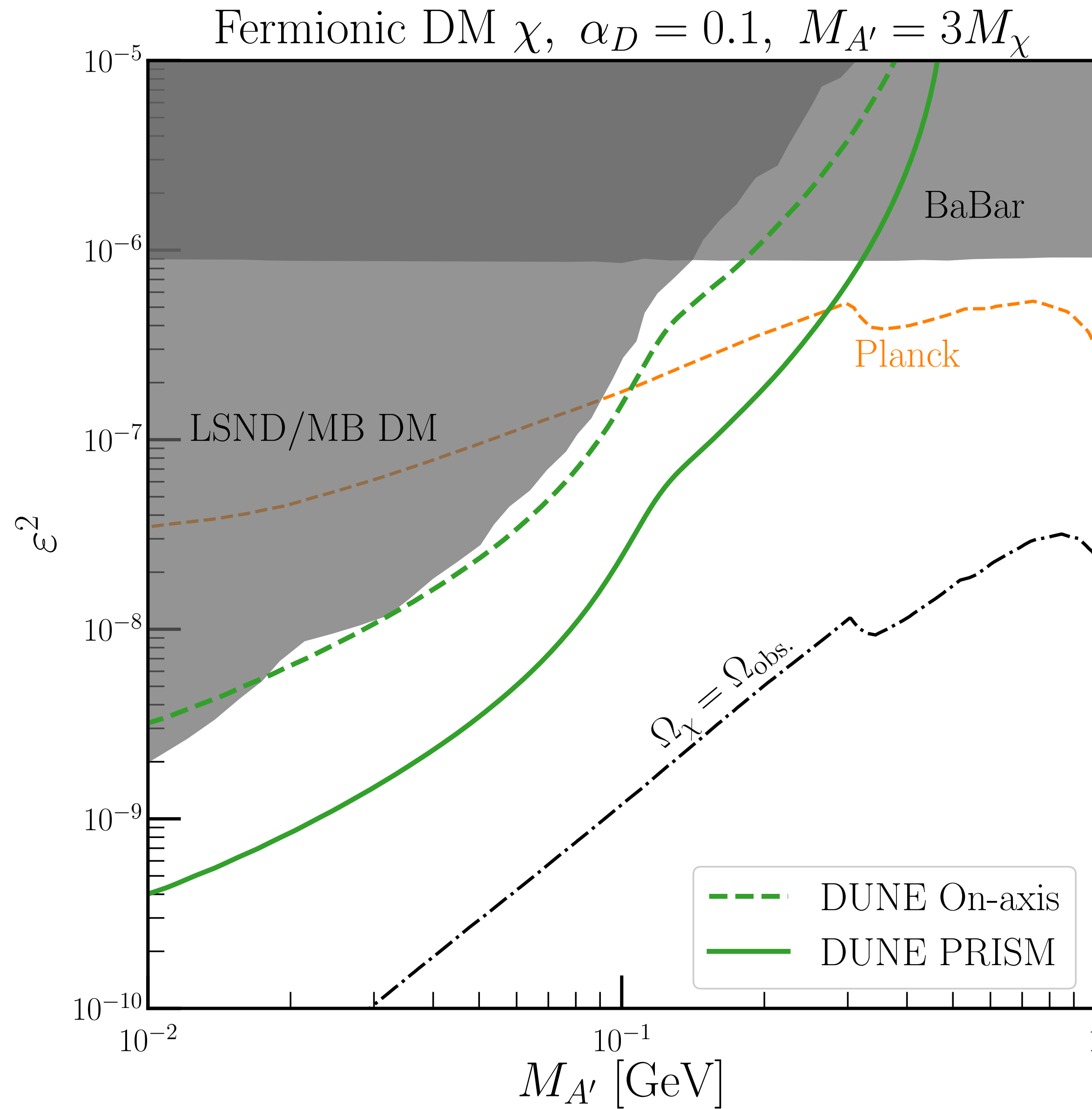
Off–Axis Signal vs. Background
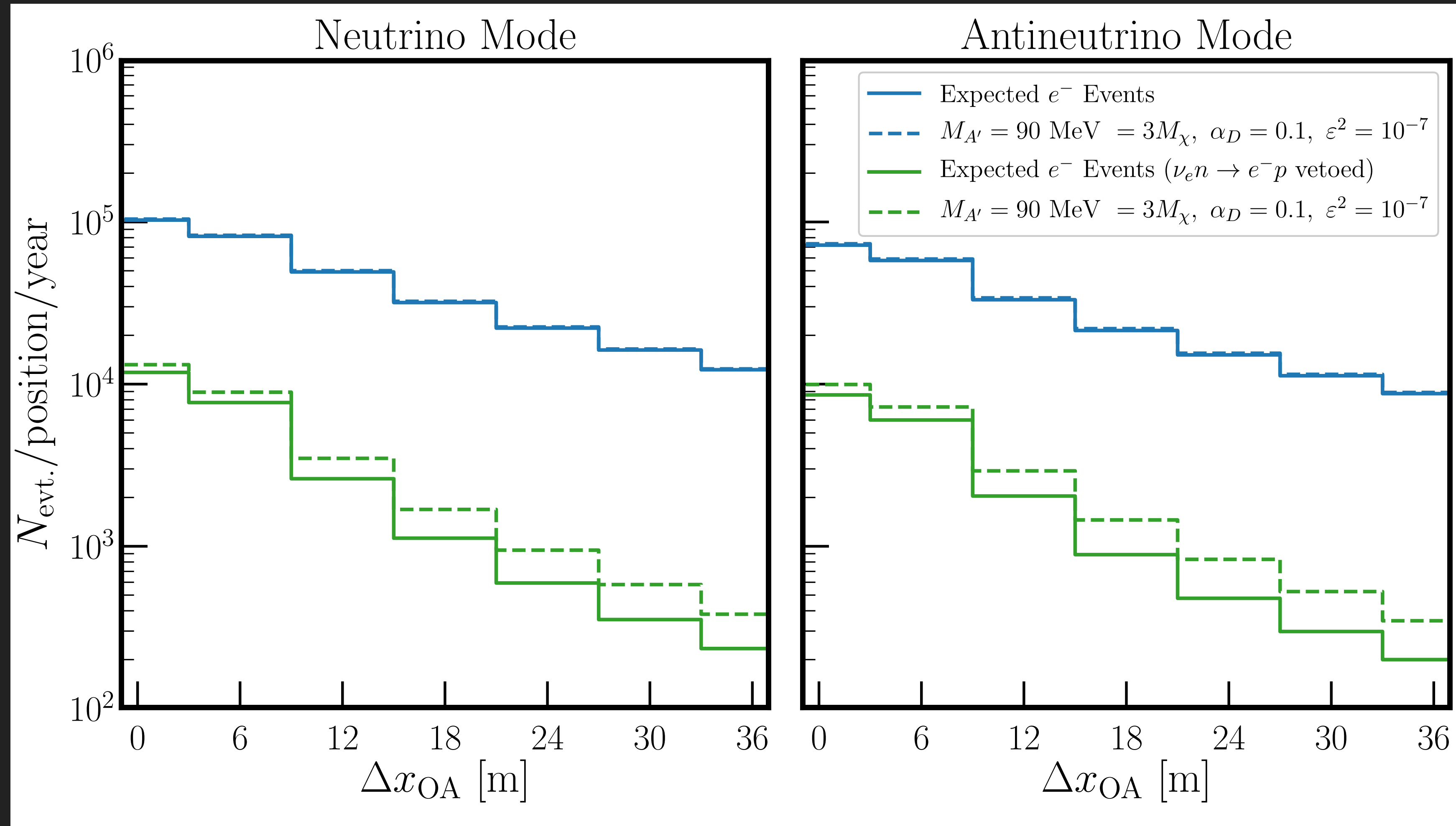
This shape, in contrast to energy distributions, is well-predicted by meson decay kinematics.
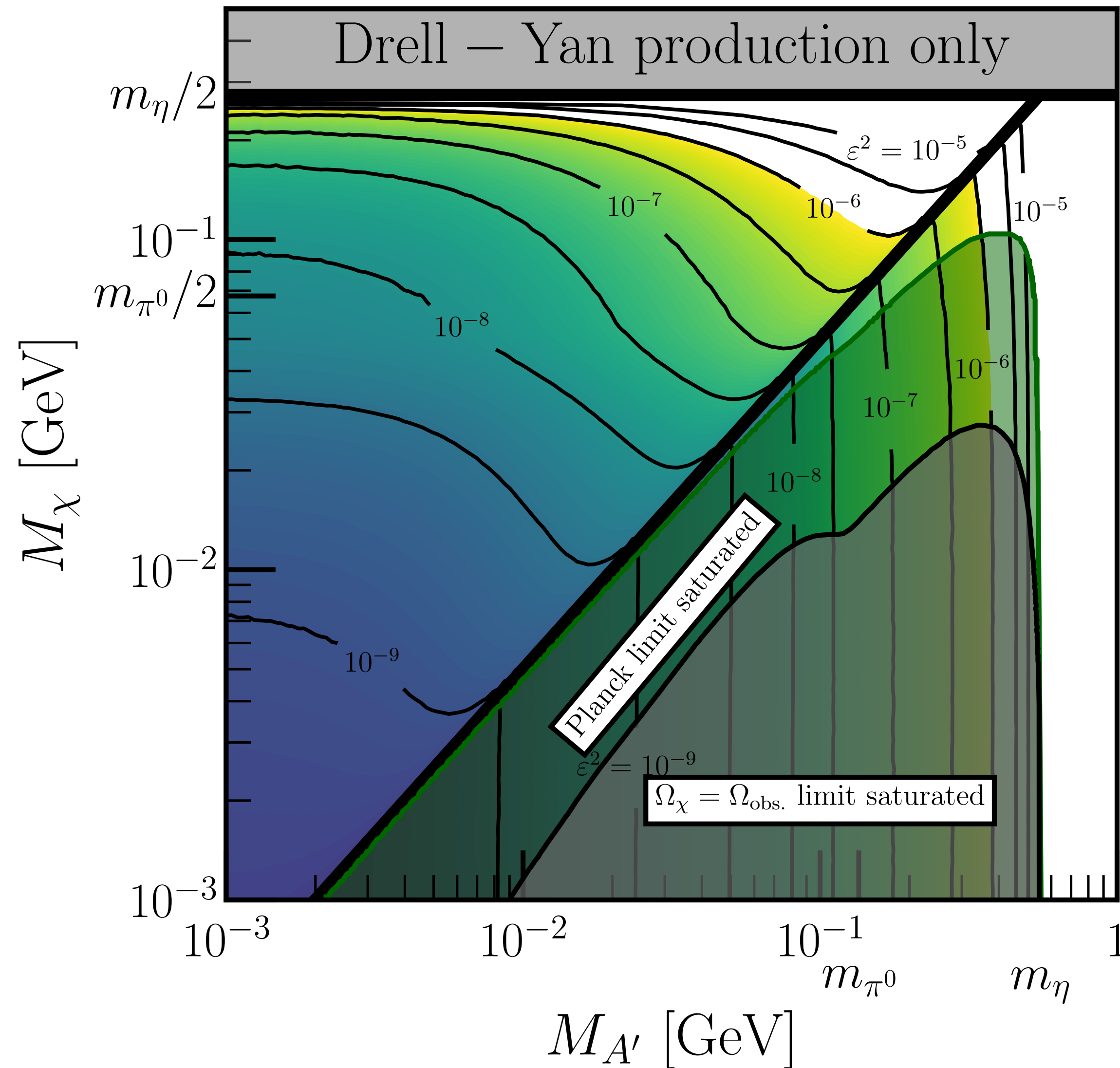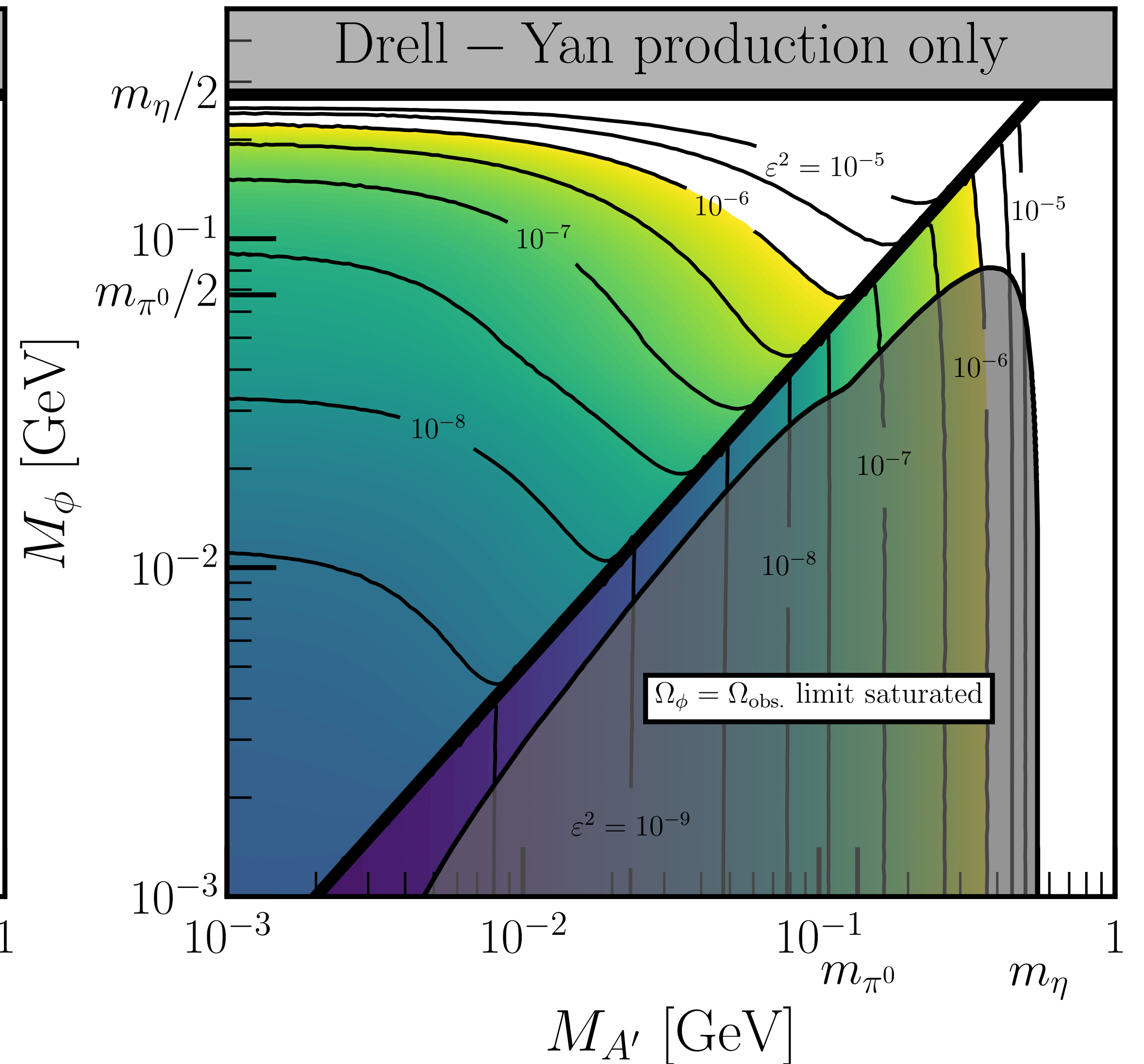
CCQE Vetoing

Results

Fermionic DM χ, $\alpha_D = 0.1$, $M_{A'} = 3M_\chi$

Fermionic DM χ, $\alpha_D = 0.1$, $M_\chi = 20$ MeV

BaBar

LSND/MB DM

Planck

$\Omega_\chi = \Omega_{\text{obs.}}$

DUNE On-axis

DUNE PRISM

$M_{A'}$ [GeV]

ε^2

LSND

BaBar

Beam Dump

Planck

$\Omega_\chi = \Omega_{\text{obs.}}$

DUNE On-axis

DUNE PRISM

$M_{A'}$ [GeV]

Broader, Two–Parameter Search

Decaying Portal Particles in the DUNE MPD

Forthcoming Work

New Physics Models of Interest

▸ Augmenting the Standard Model to accommodate interactions with dark matter, if focusing on renormalizable operators, we have three options:

    ▸ Vector Portal

        ▸ Kinematic mixing with SM Photon

        ▸ Leptophilic Gauge Bosons

        ▸ etc.

    ▸ Higgs Portal

        ▸ Mixing with the SM Higgs

    ▸ Neutrino Portal

        ▸ Predicts heavy neutral leptons

        ▸ Could explain light neutrino masses

ECAL/Magnets

Proton Beam 80 GeV · Target · π^0 · π^+ · Decay Volume · η · π^- · earth · DUNE LArTPC (75 t) · DUNE MPD (1 t)

Magnetic Focusing Horns
(Clearly, Preliminary)
Xxx m · Xxx m · 574 m · 579 m · 579 m

Distance from Target (not to scale)

▸ Each of these options relies on a new mediator or "portal" particle to allow for DM/SM interactions.

▸ Depending on the scenario of interest, DUNE can produce metastable portal particles that may travel and decay in the near detector(s).
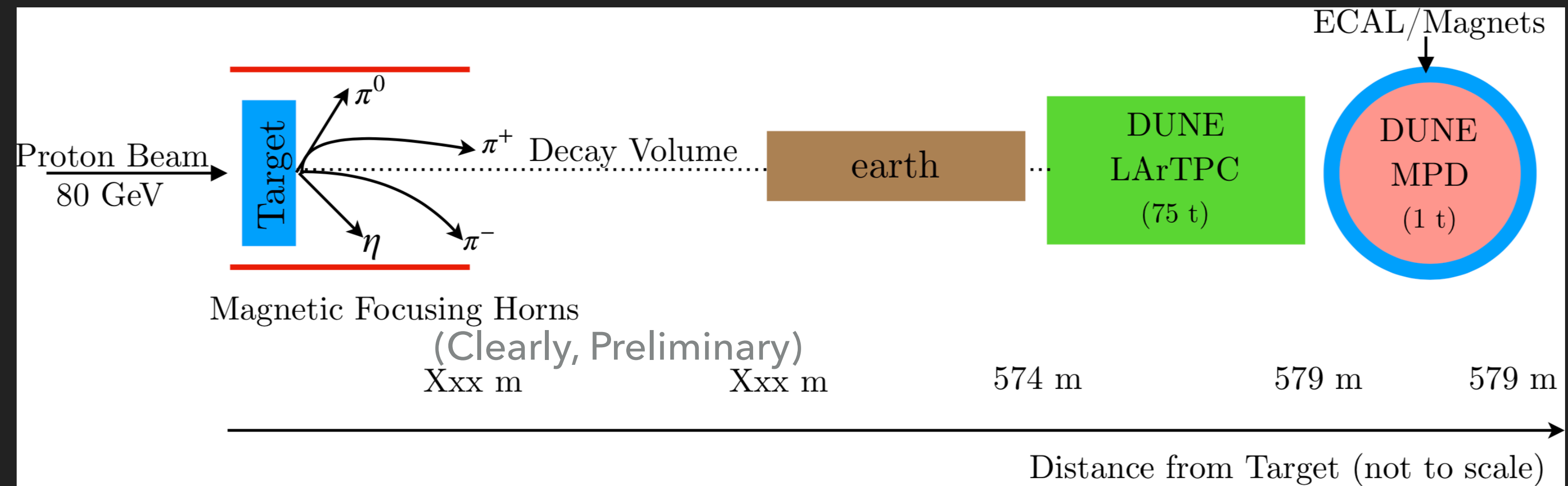
- Minimal dark photon assumptions:

- Mixes with the SM photon via kinetic mixing parameter,

- Decays preferentially into visible SM particles.
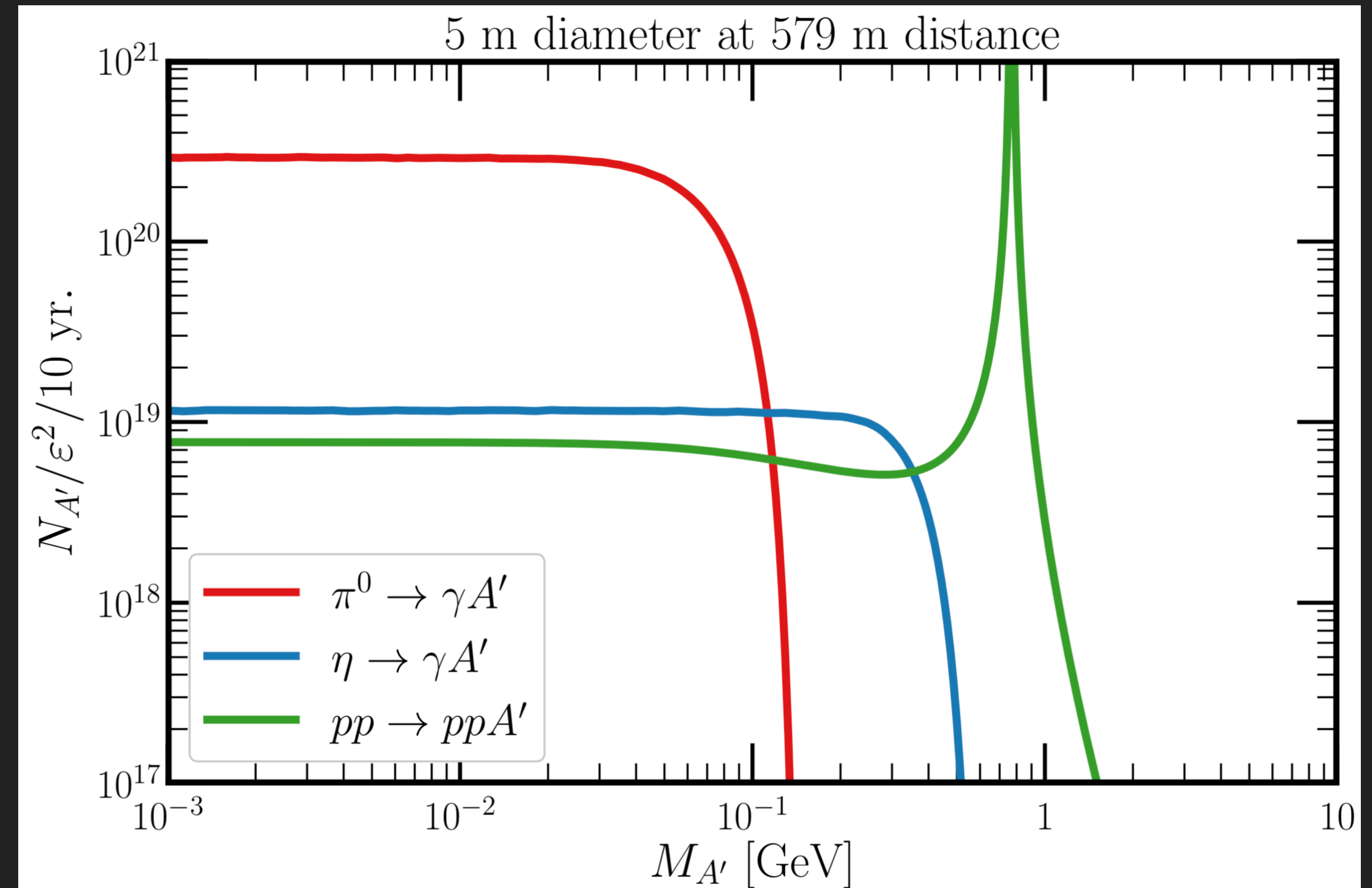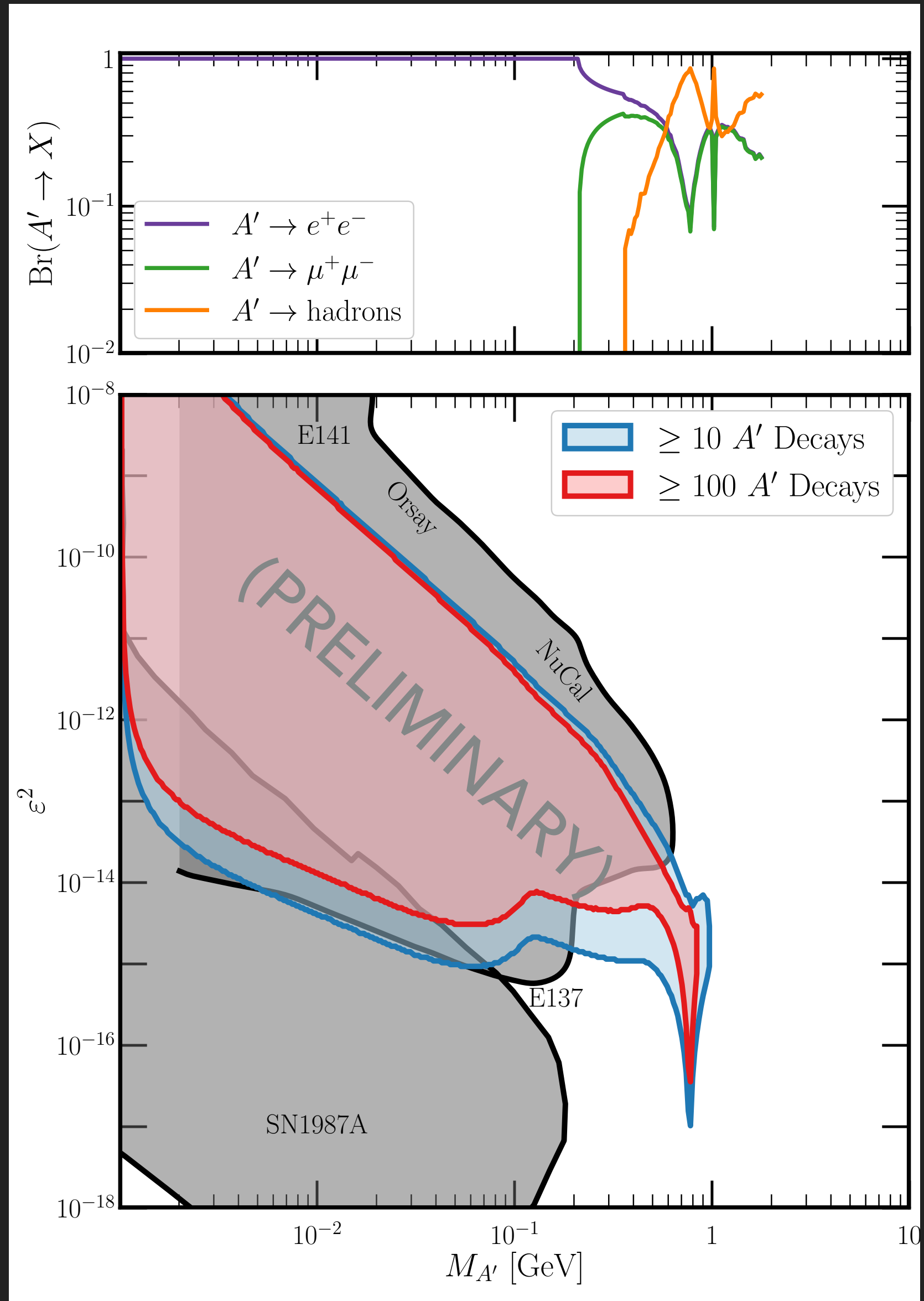
Number passing through MPD in 10 yr

Conclusions

▸ The DUNE Beamline can serve as a production mechanism for many hidden sector particles of interest.

▸ Beyond the benefits of a liquid argon TPC, the DUNE Near Detector complex has many features that may be exploited in searches for BSM physics.

▸ Two such features:

  ▸ DUNE-PRISM: moving off-axis to reduce neutrino-related backgrounds

  ▸ Multi-purpose Detector: Large volume with lower mass, beneficial for searches of decaying particles.