Dark Matter
at DUNE

Kevin J. Kelly, CERN
Snowmass 2021 Community Summer Study, 20 July 2022
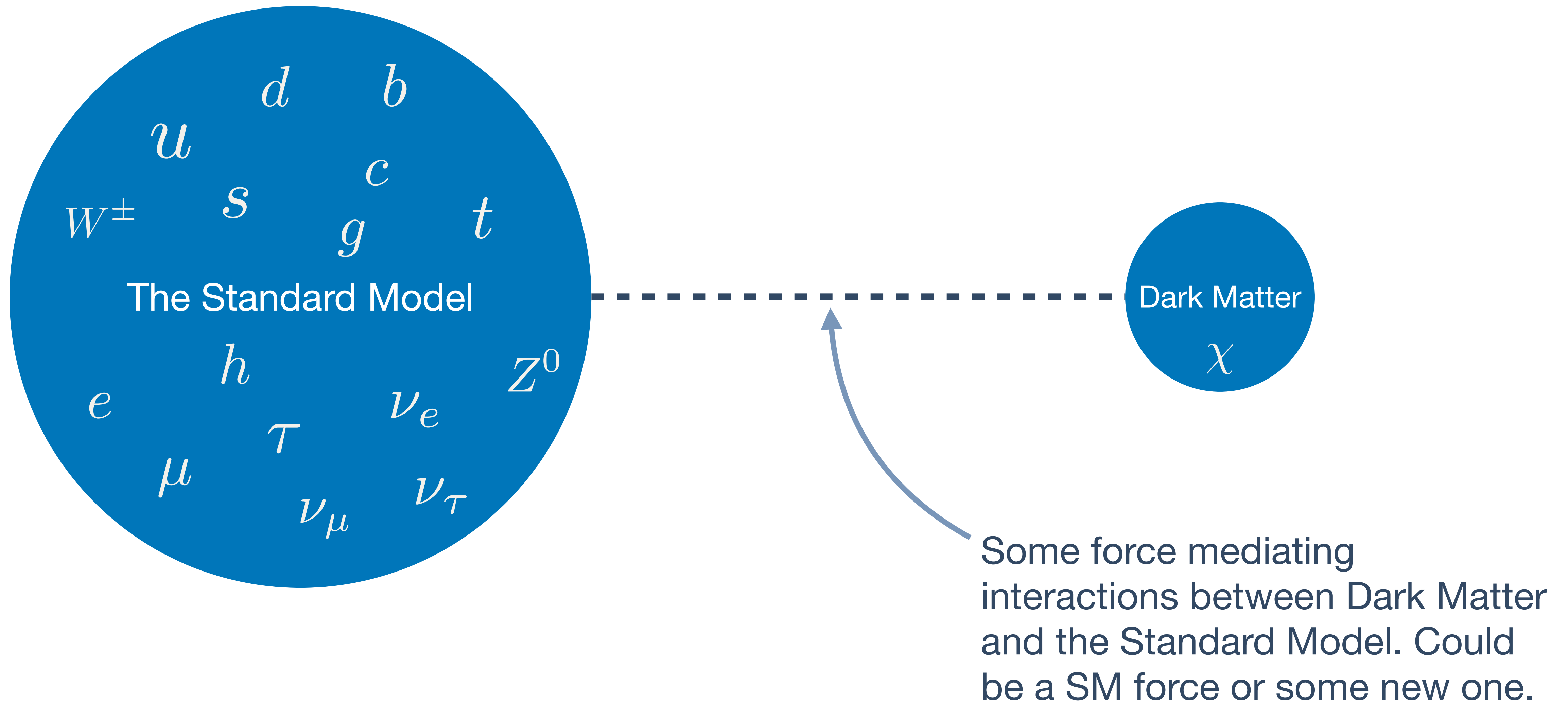
kjkelly_physics, kjkelly@cern.ch

Outline

- Dark Matter Searches
  - DUNE as a precision scattering detector

- Dark Mediator Searches
  - DUNE as a precision beam-dump facility

Dark Matter

Simplified Scenarios

The Standard Model

d b
u
c
$W^\pm$ s
g t

h Z^0
e ν_e
τ
μ ν_τ
ν_μ

Dark Matter
χ

Some force mediating interactions between Dark Matter and the Standard Model. Could be a SM force or some new one.
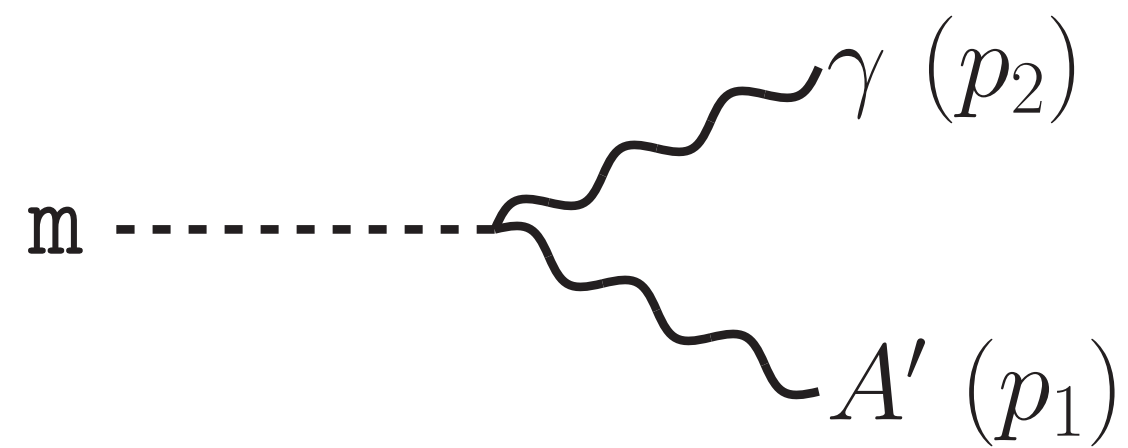
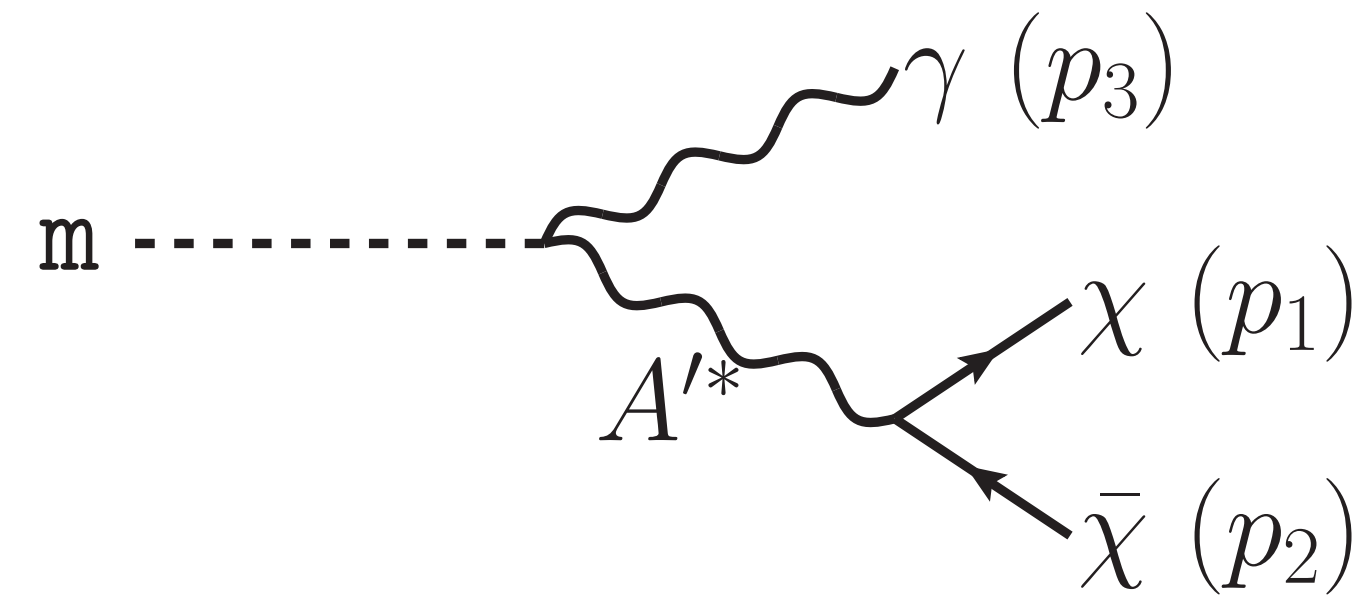# How to make Dark Matter in a Neutrino Facility?

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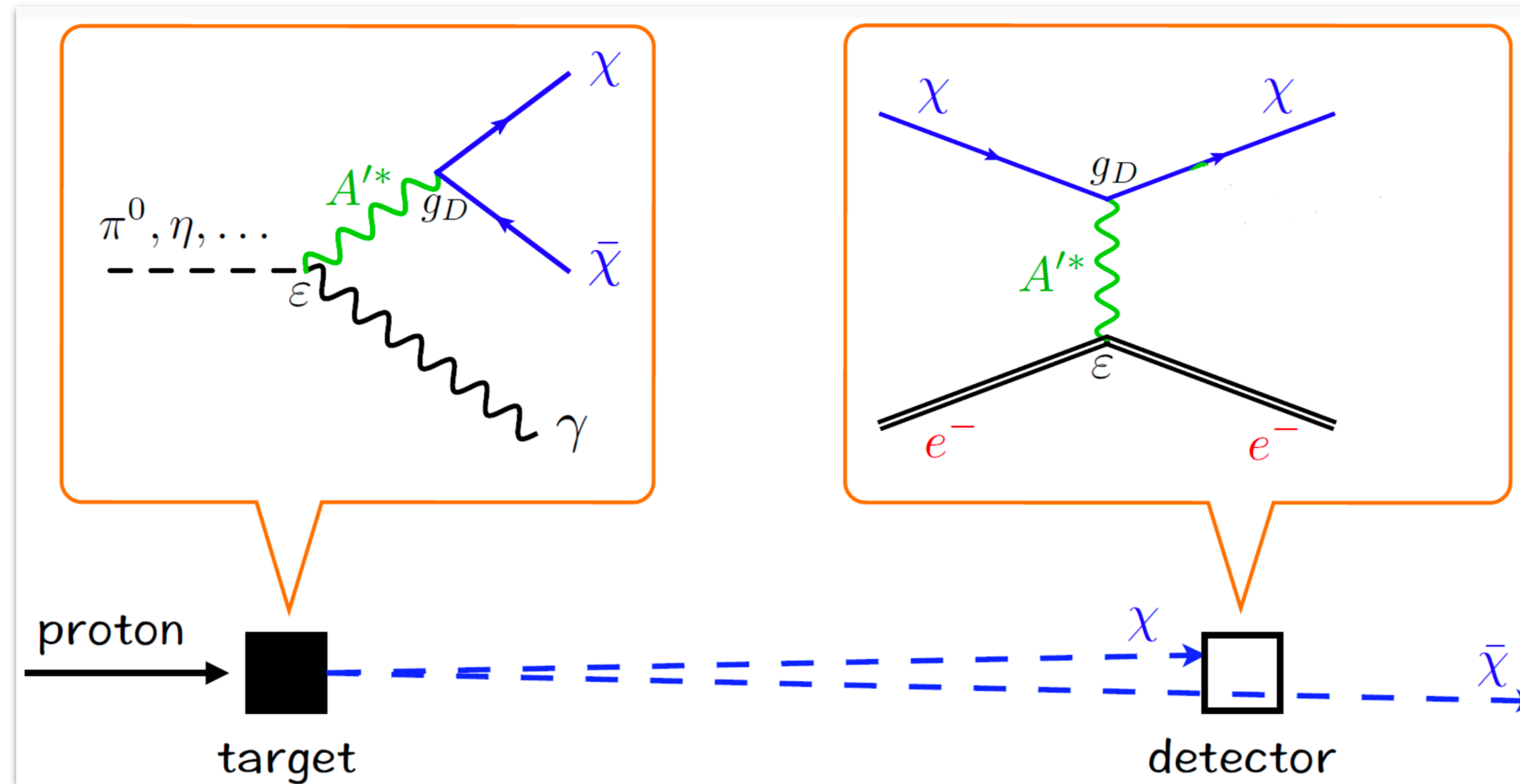
(or similar with scalar DM)

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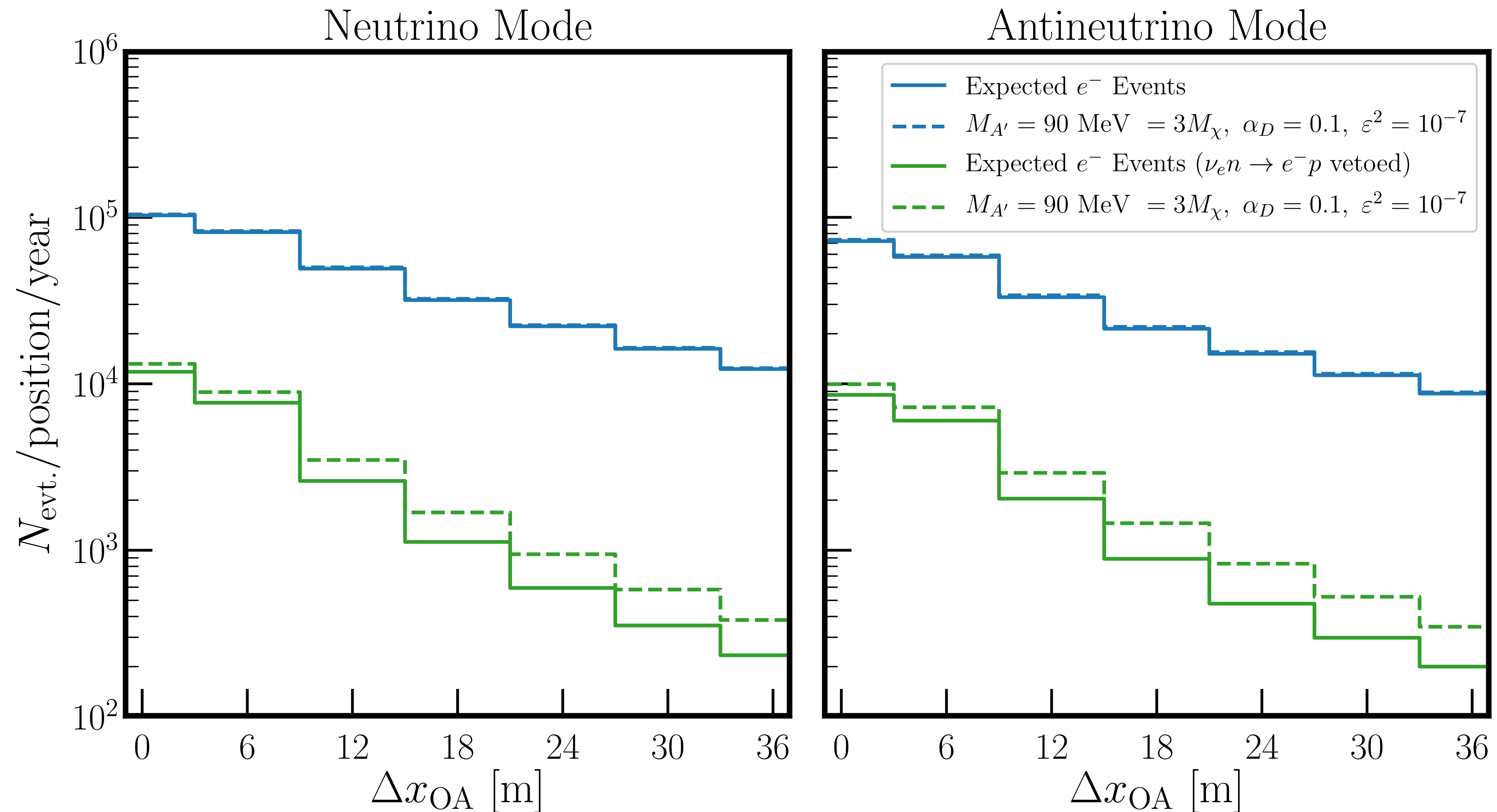are produced. With suitable masses, they can decay instead by
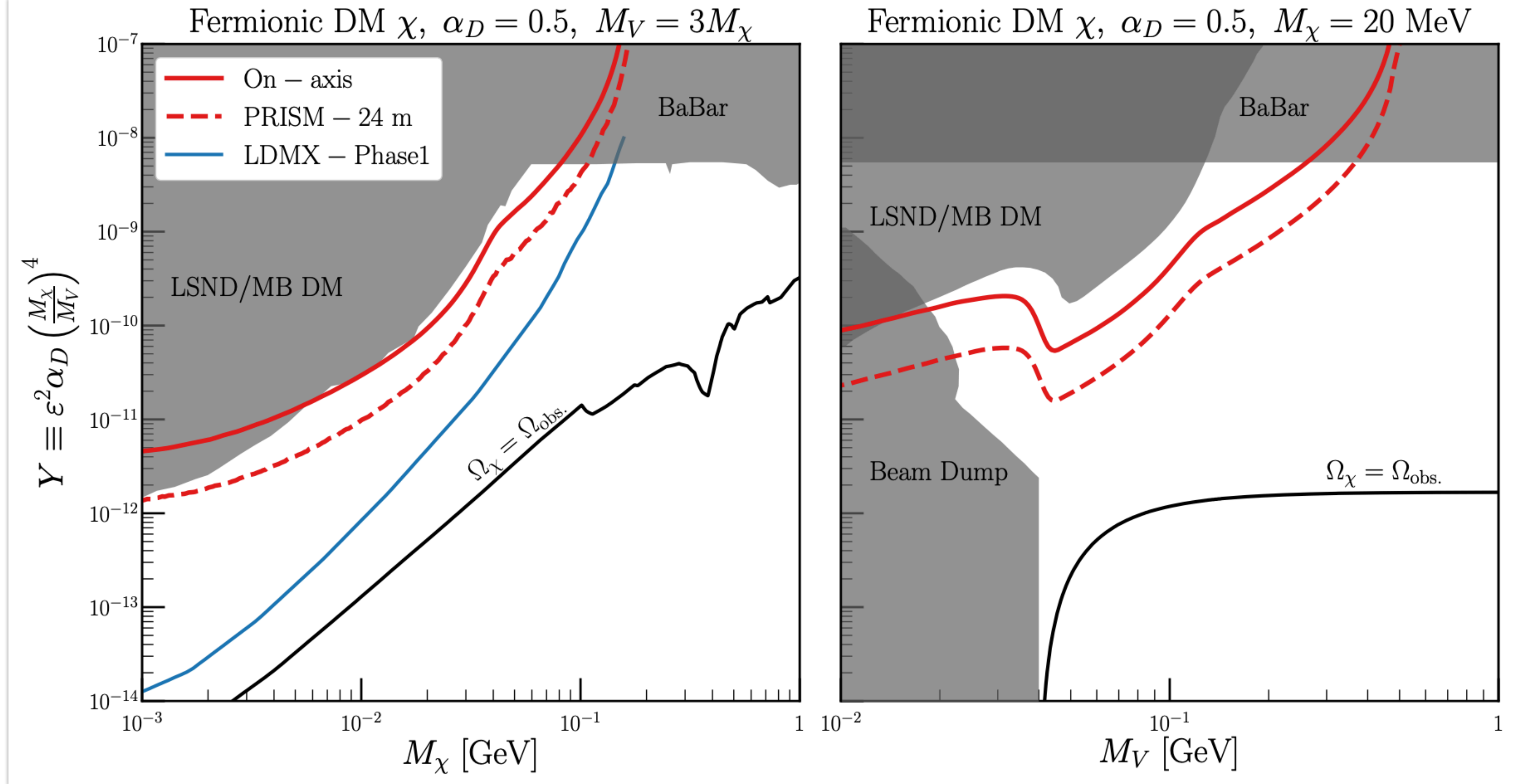

Or

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Boosted DM Scattering

- Signal looks identical to neutrino-nucleus neutral-current scattering or $\nu_\mu e^- \to \nu_\mu e^-$

- Going beyond a counting experiment is difficult — shape of the neutrino flux (in energy space) is constrained using $\nu_\mu e^- \to \nu_\mu e^-$ measurements!

On- and off-axis Measurements

DUNE PRISM can help constrain background positions as a function of off-axis position. As the angle increases, so does the signal-to-background ratio.
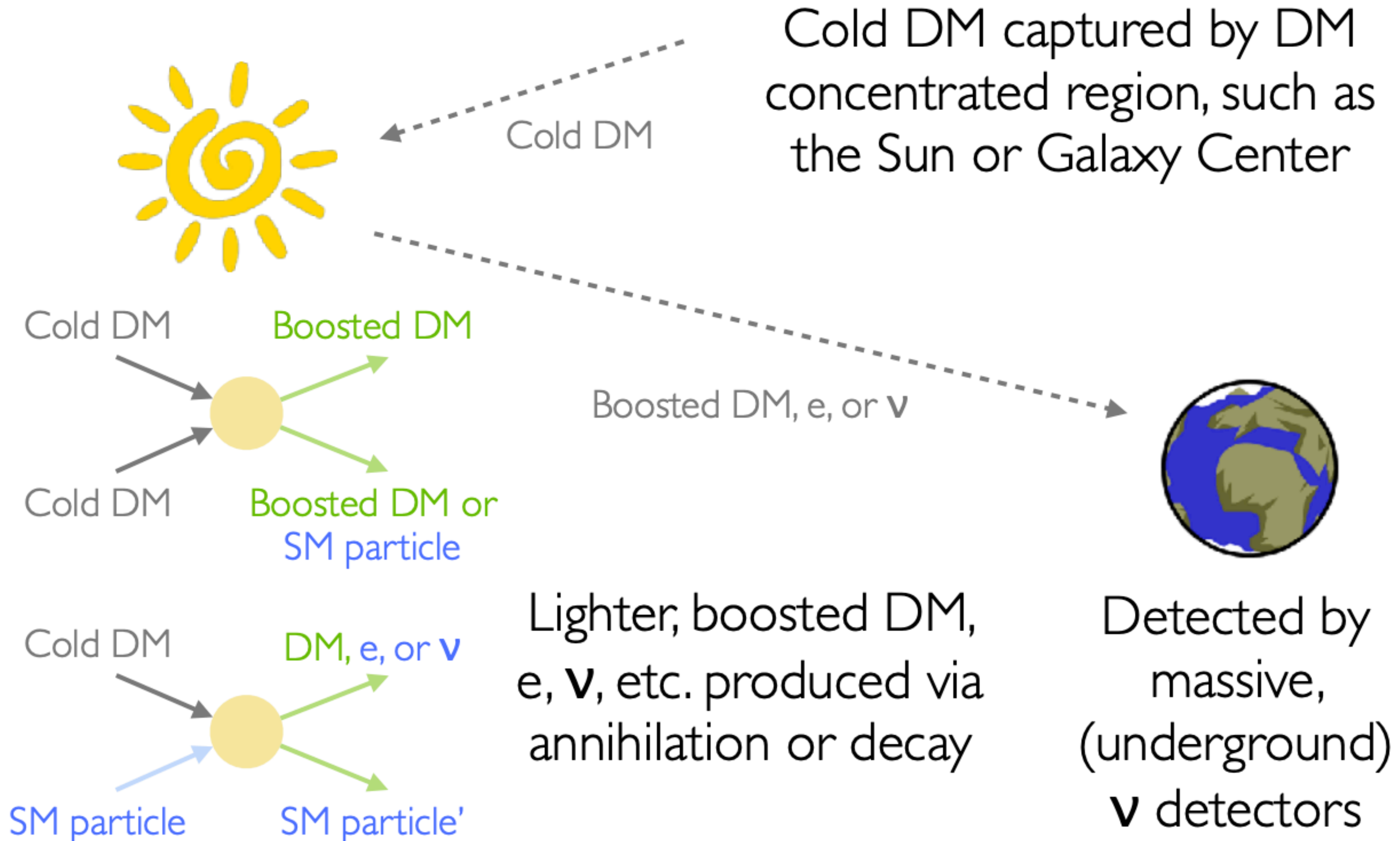
DM Sensitivity

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# DM Searches from Natural Sources

From Yun-Tse's Talk Yesterday

Cold DM

Cold DM captured by DM concentrated region, such as the Sun or Galaxy Center

Cold DM → Boosted DM
Cold DM → Boosted DM or SM particle

Boosted DM, e, or ν

Cold DM → DM, e, or ν
SM particle → SM particle'

Lighter, boosted DM, e, ν, etc. produced via annihilation or decay

Detected by massive, (underground) ν detectors

Elastic BDM Sensitivity

- Hadronic scattering

- Point back to the BDM origin, the Sun
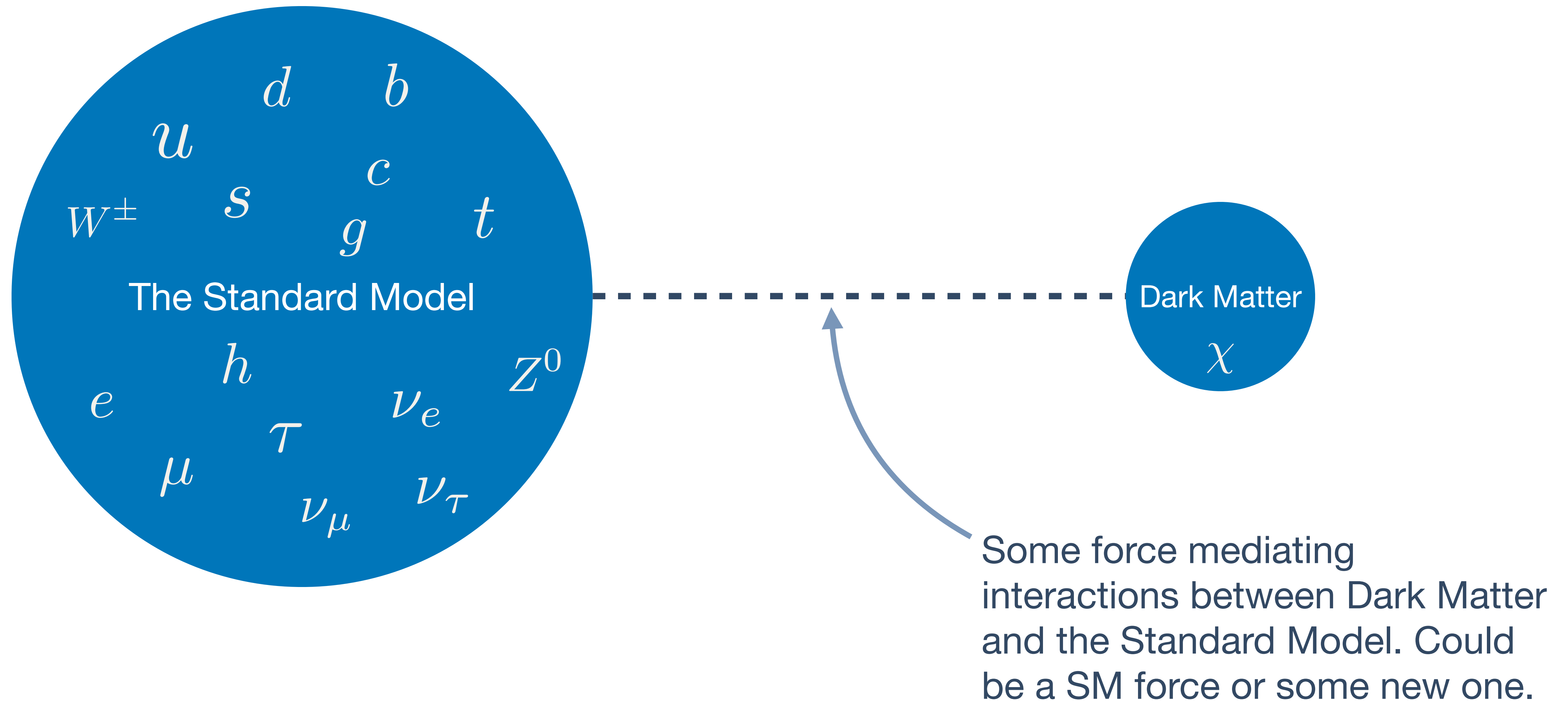
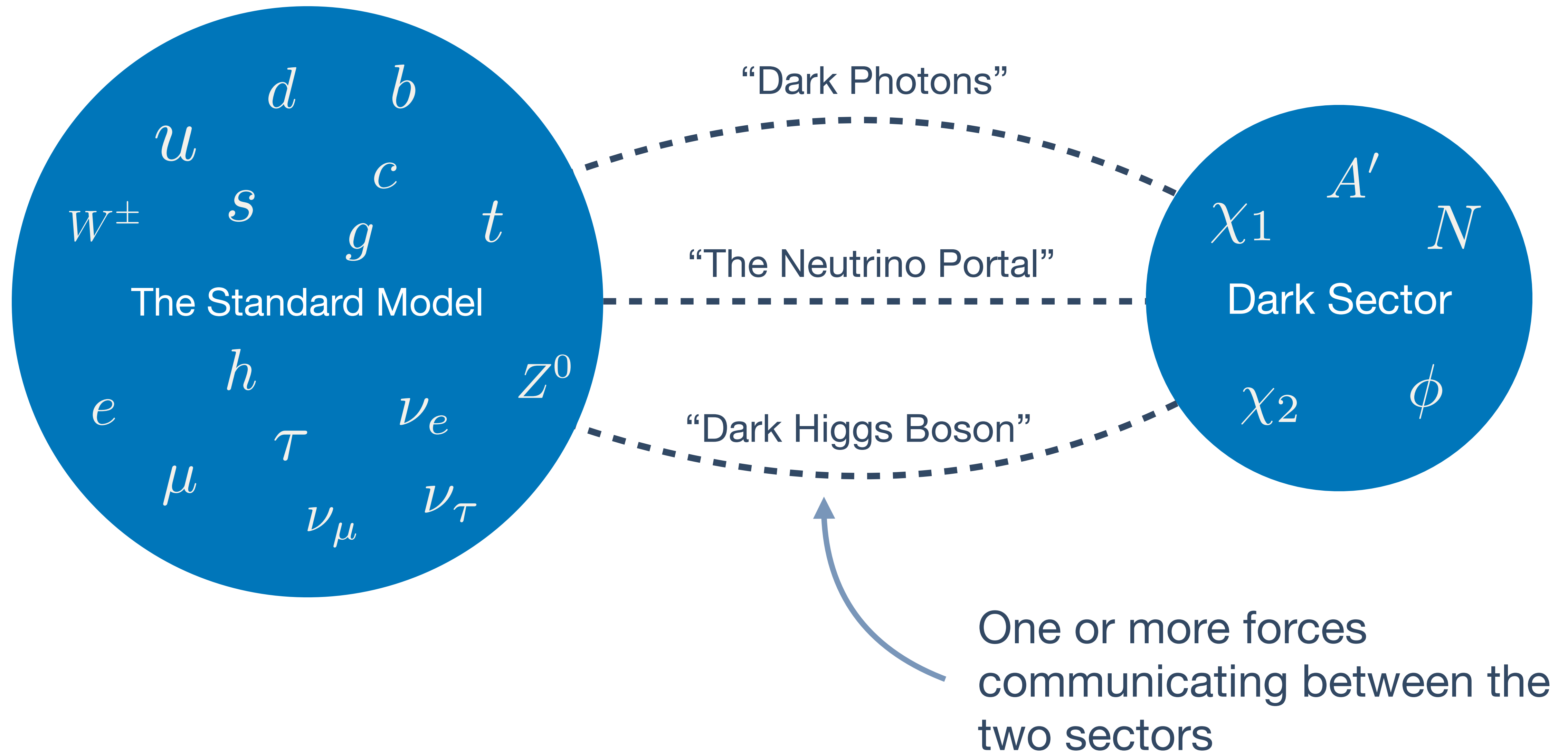- Take advantage of the low proton threshold in DUNE
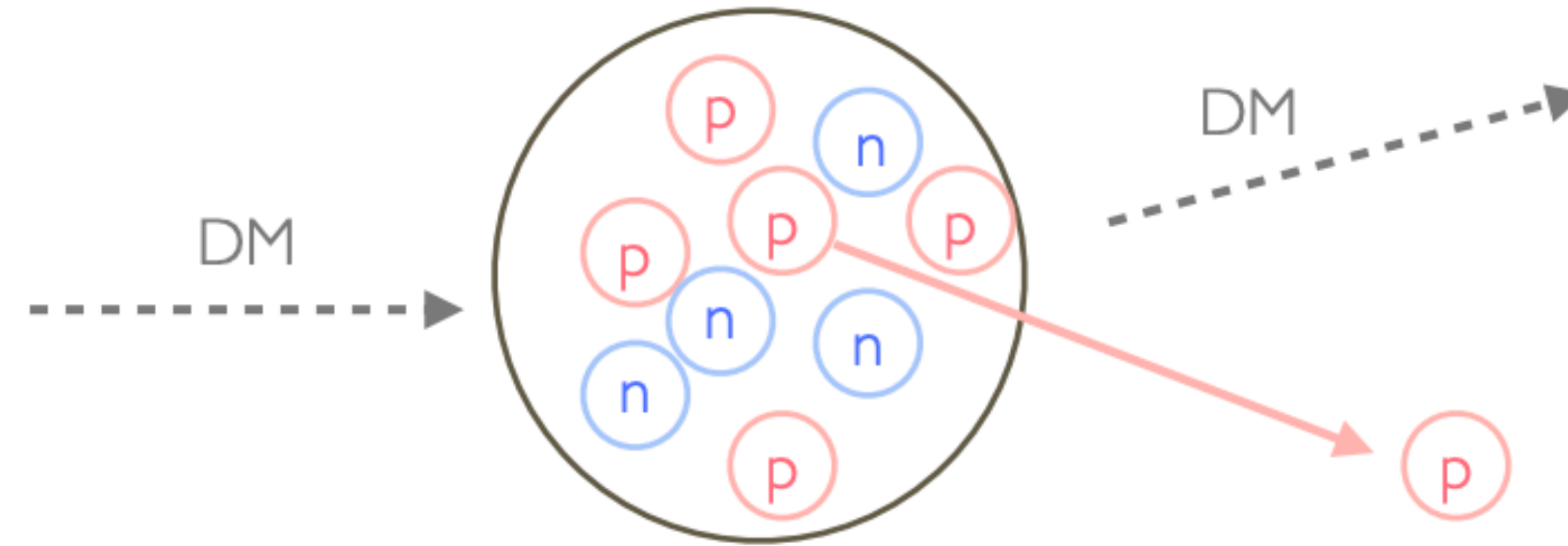
Phys. Rev. D 103, 095012
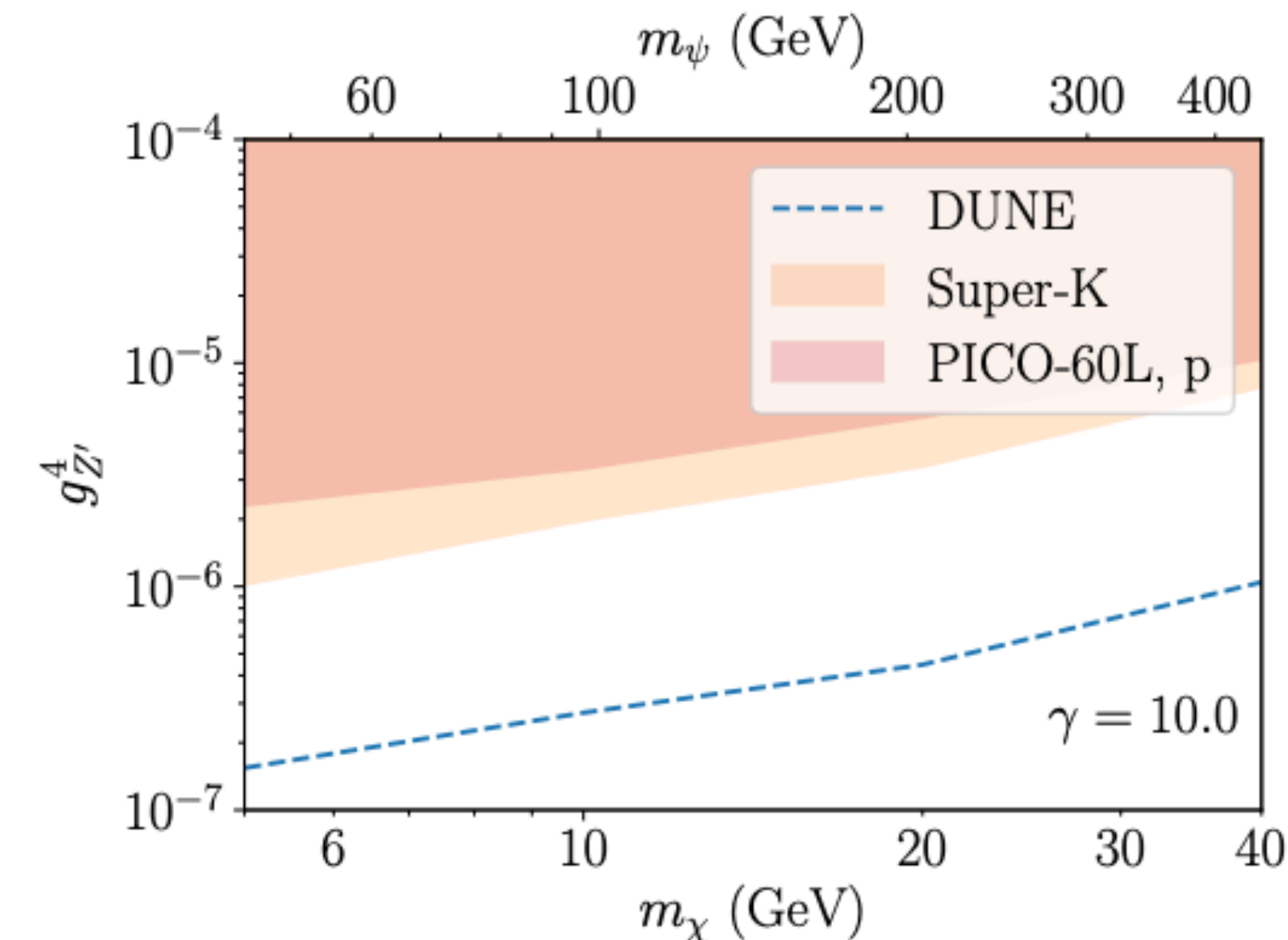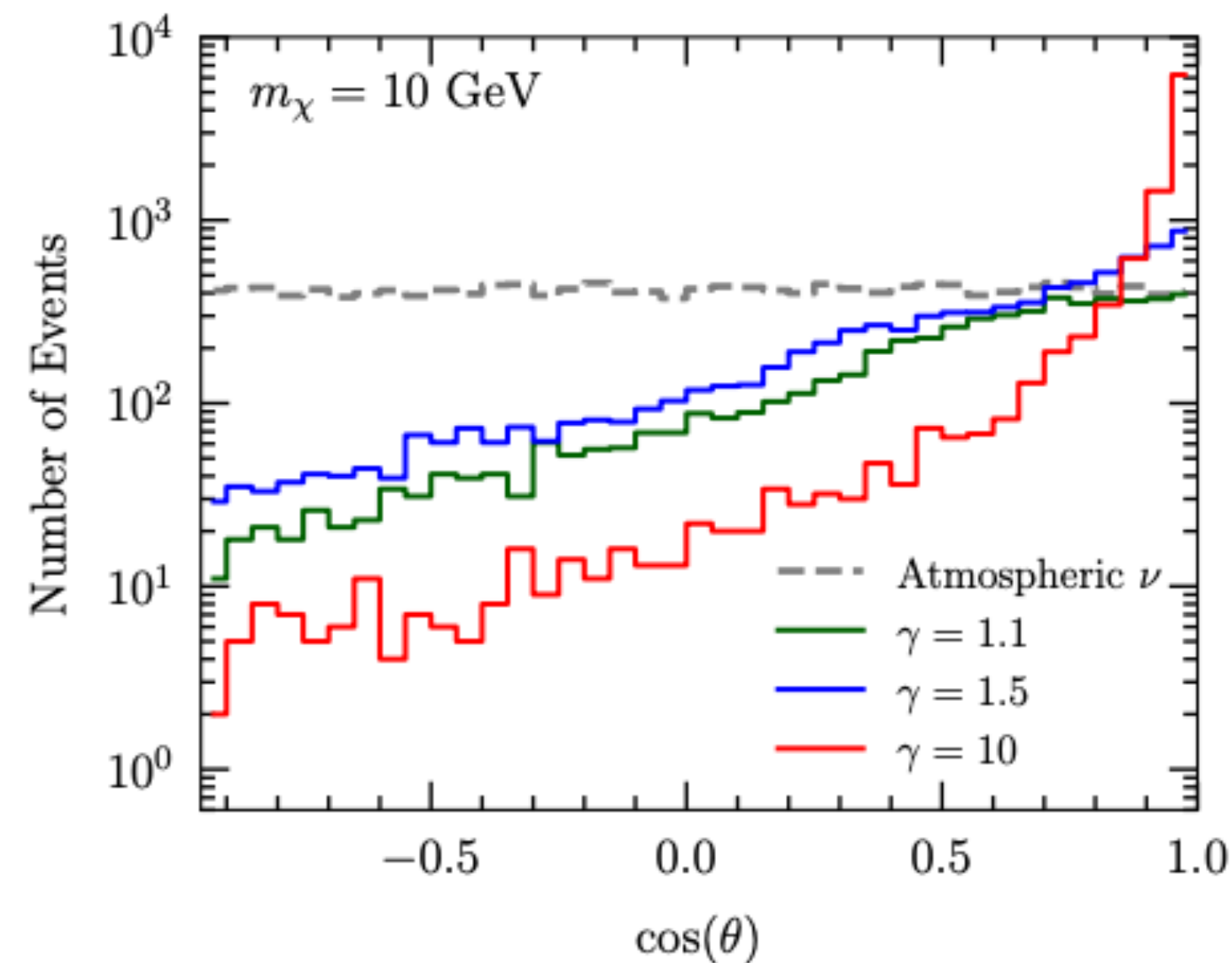
Dark Sectors & Dark Mediators
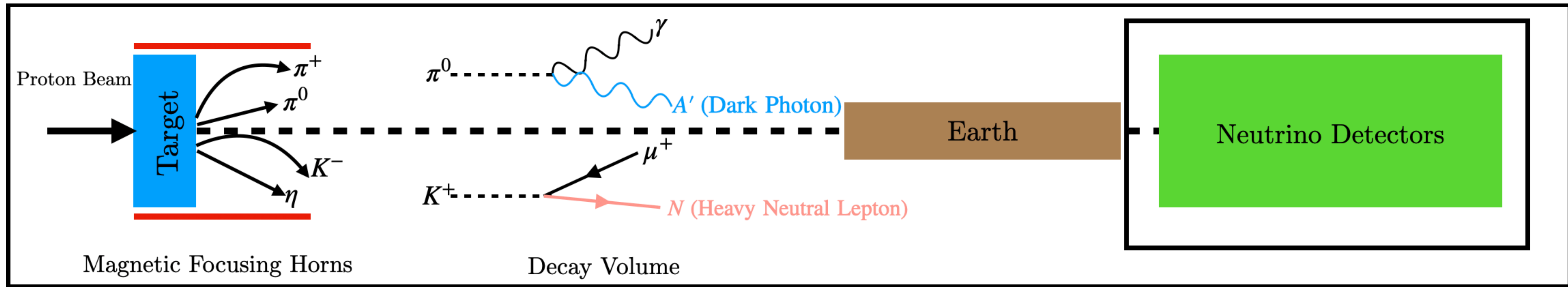
Dark Matter to Dark Sectors

Dark Matter to Dark Sectors

"Dark Photons"

"The Neutrino Portal"

"Dark Higgs Boson"

The Standard Model

u d b s c g t $W^{\pm}$ h e τ ν_e Z^0 μ ν_μ ν_τ

Dark Sector

χ_1 A' N χ_2 ϕ

One or more forces communicating between the two sectors

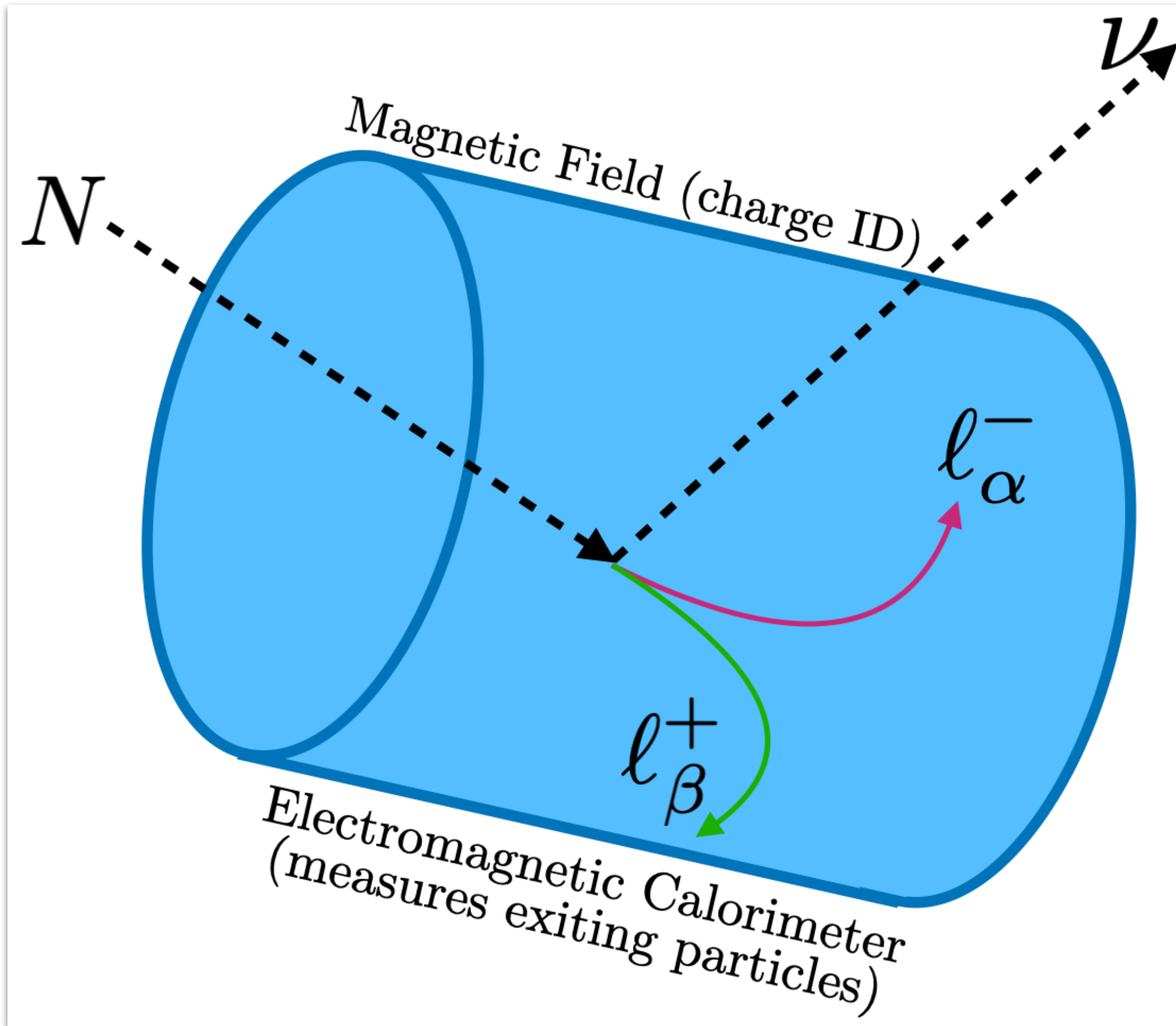# Neutrino Near Detectors as Beam-Dump Facilities

1) Charged and Neutral Mesons are produced in the high-energy/high-intensity proton collisions.

2) Mesons undergo rare decays into dark sector mediators that are long-lived. Some fraction of them travel in the forward direction.

3) Dark Sector particles decay inside the neutrino detector, leaving a striking signature.

Critical for Decay Searches: NDGAr

Labels in figure: N, Magnetic Field (charge ID), ν, ℓ_α^-, ℓ_β^+, Electromagnetic Calorimeter (measures exiting particles)

- ✤ The Gaseous Argon Near Detector, proposed as a future upgrade, is crucial for searching for these new-physics decays.
- ✤ Backgrounds are reduced significantly in lower-density environments.
- ✤ Low energy thresholds, better particle identification, and magnetic fields *all* help with signal characterization.
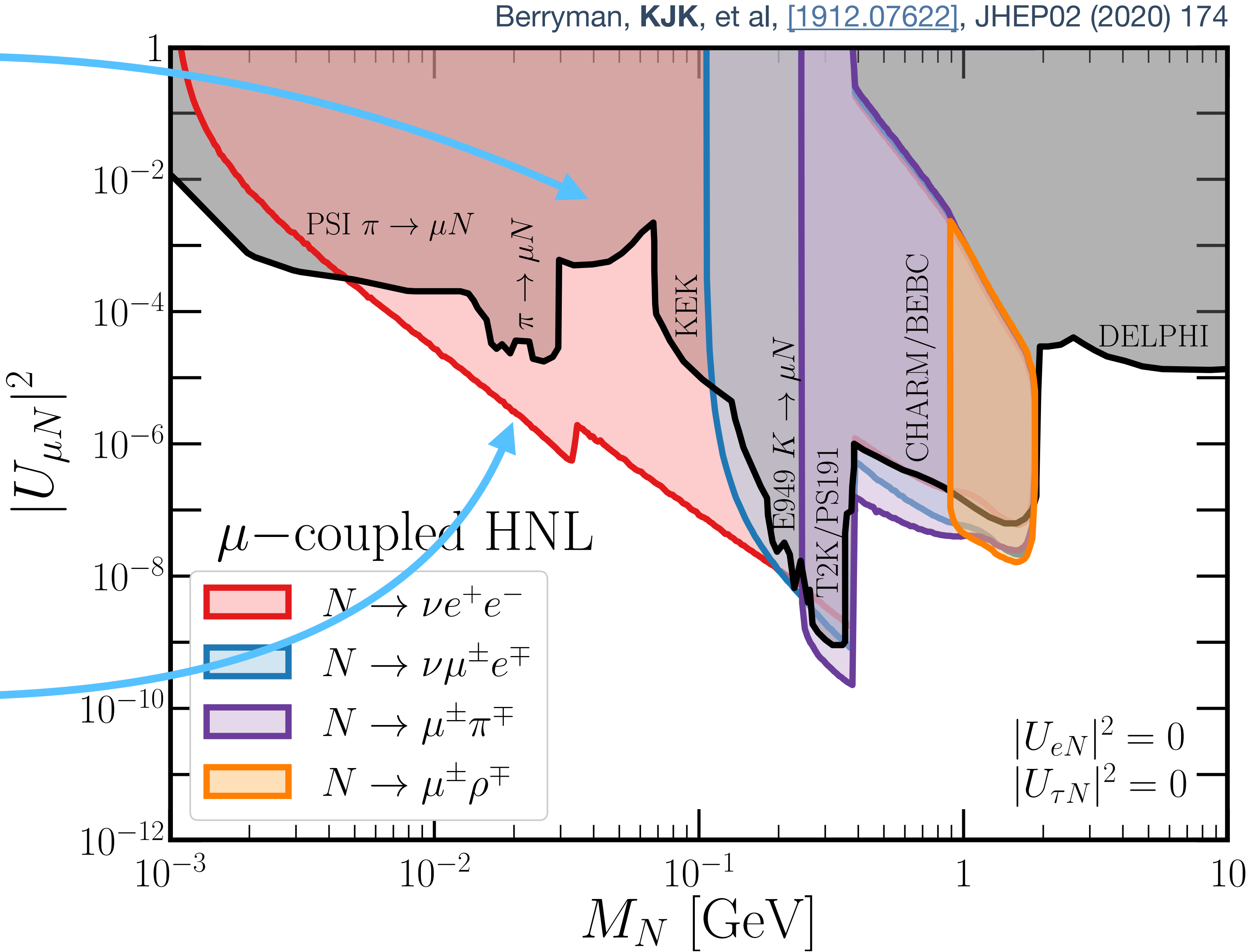
$$\text{Signal} \propto \text{Volume}$$

$$\text{Background} \propto \text{Mass}$$

Example 1: Heavy Neutral Leptons

Shaded, gray regions: collection of existing constraints on this model scenario from a variety of laboratory-based measurements.
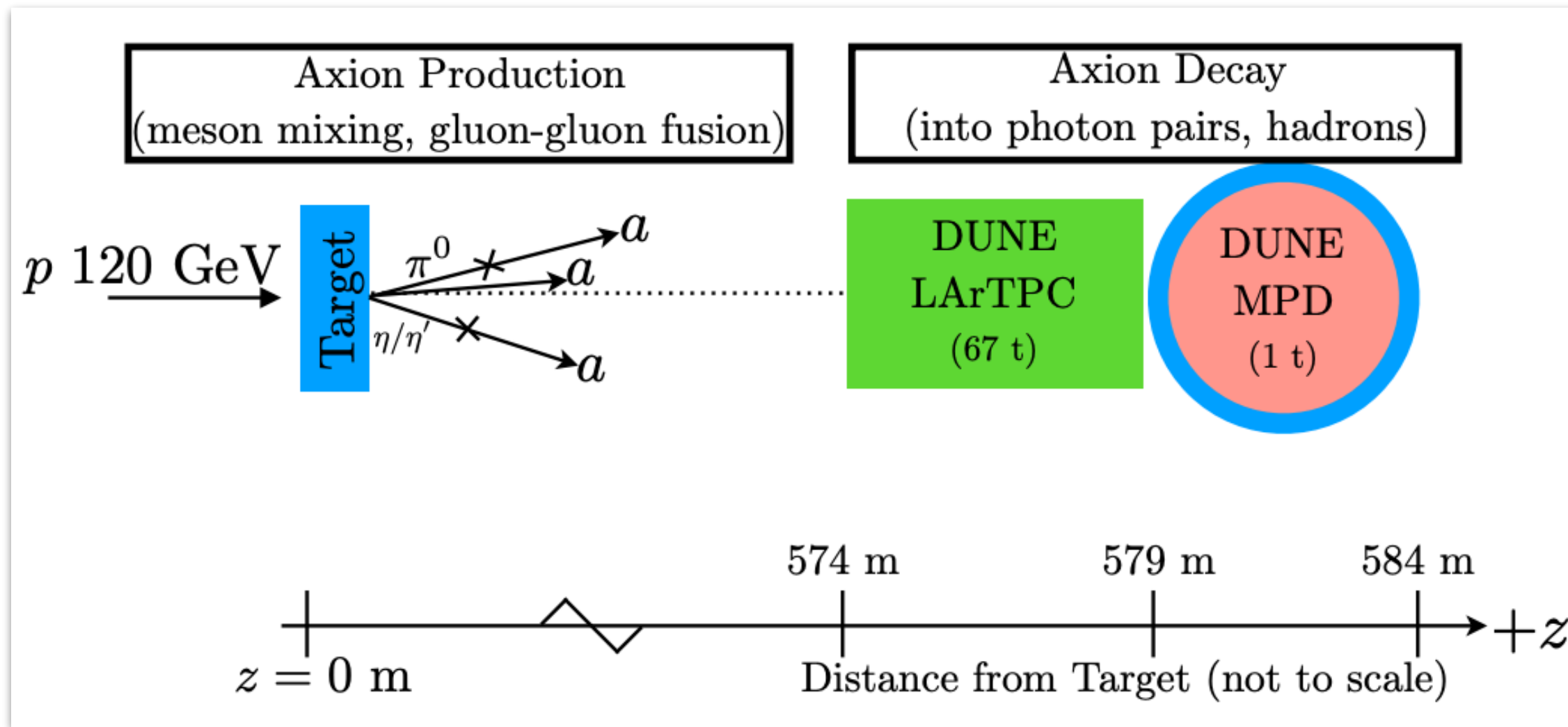
Colored regions: points in parameter space where DUNE could discover this type of particle with ten years of data. Different colors correspond to different signals in the detector.

Berryman, **KJK**, et al, [1912.07622], JHEP02 (2020) 174

More on HNLs at DUNE? Ballett et al [1905.00284], Coloma et al [2007.03701], Breitbach et al [2102.03383]

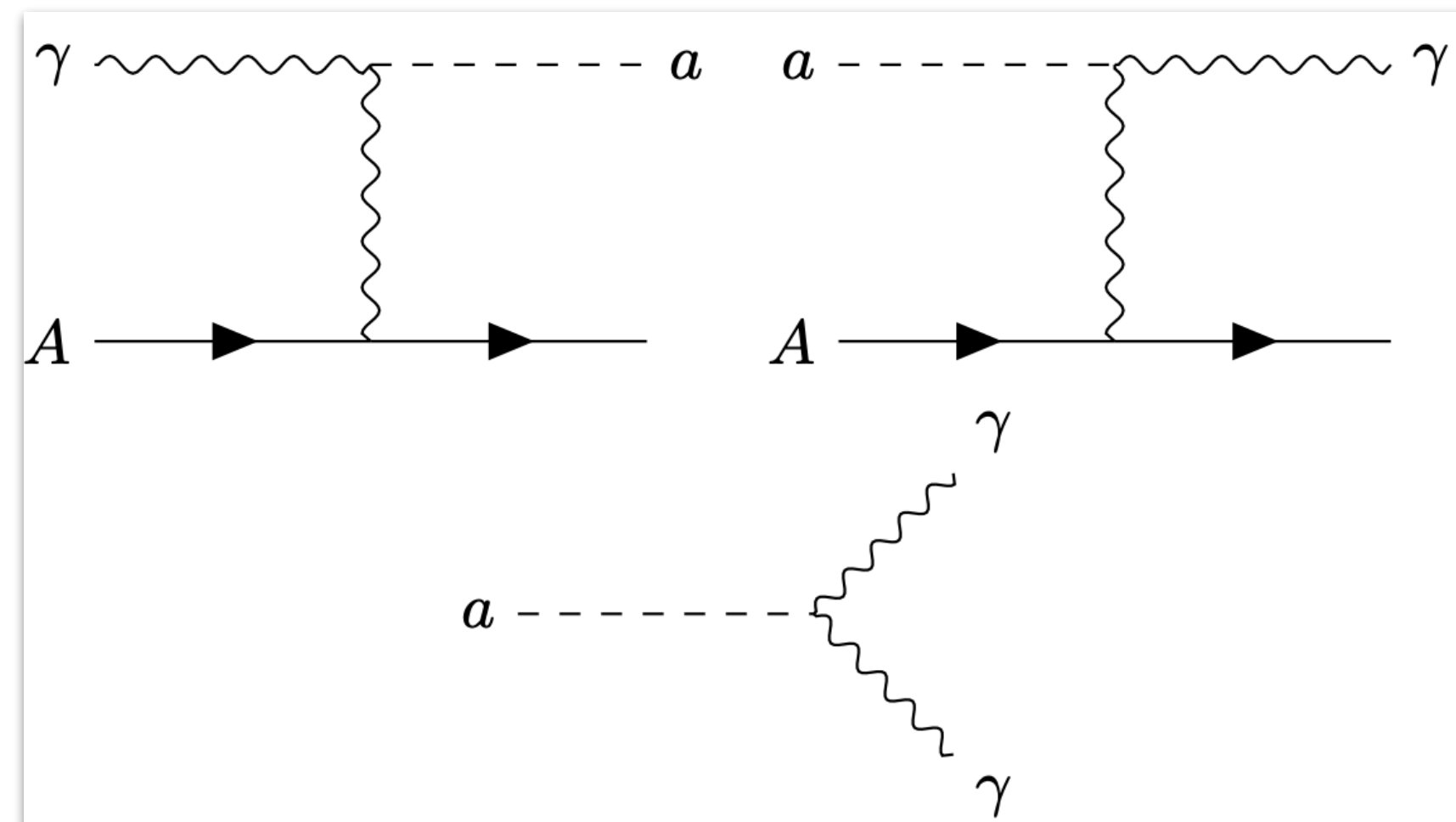# Example 2: Axions & Axion-Like-Particles

KJK, Kumar, and Liu [2011.05995]: "Heavy Axion"

Production via *mixing* with SM mesons or gluon/gluon fusion.

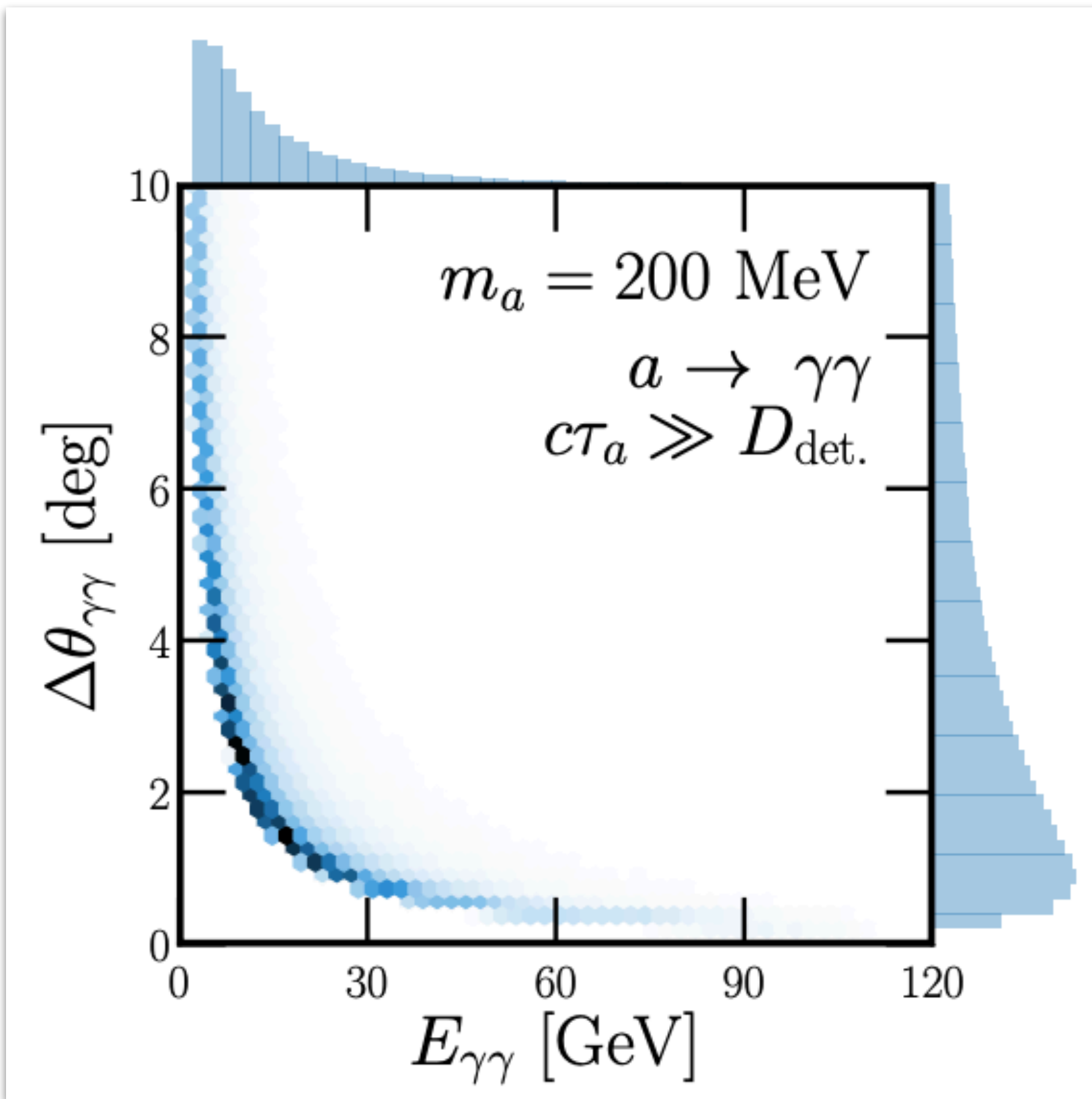Decay into pairs of (high energy) photons/hadrons.

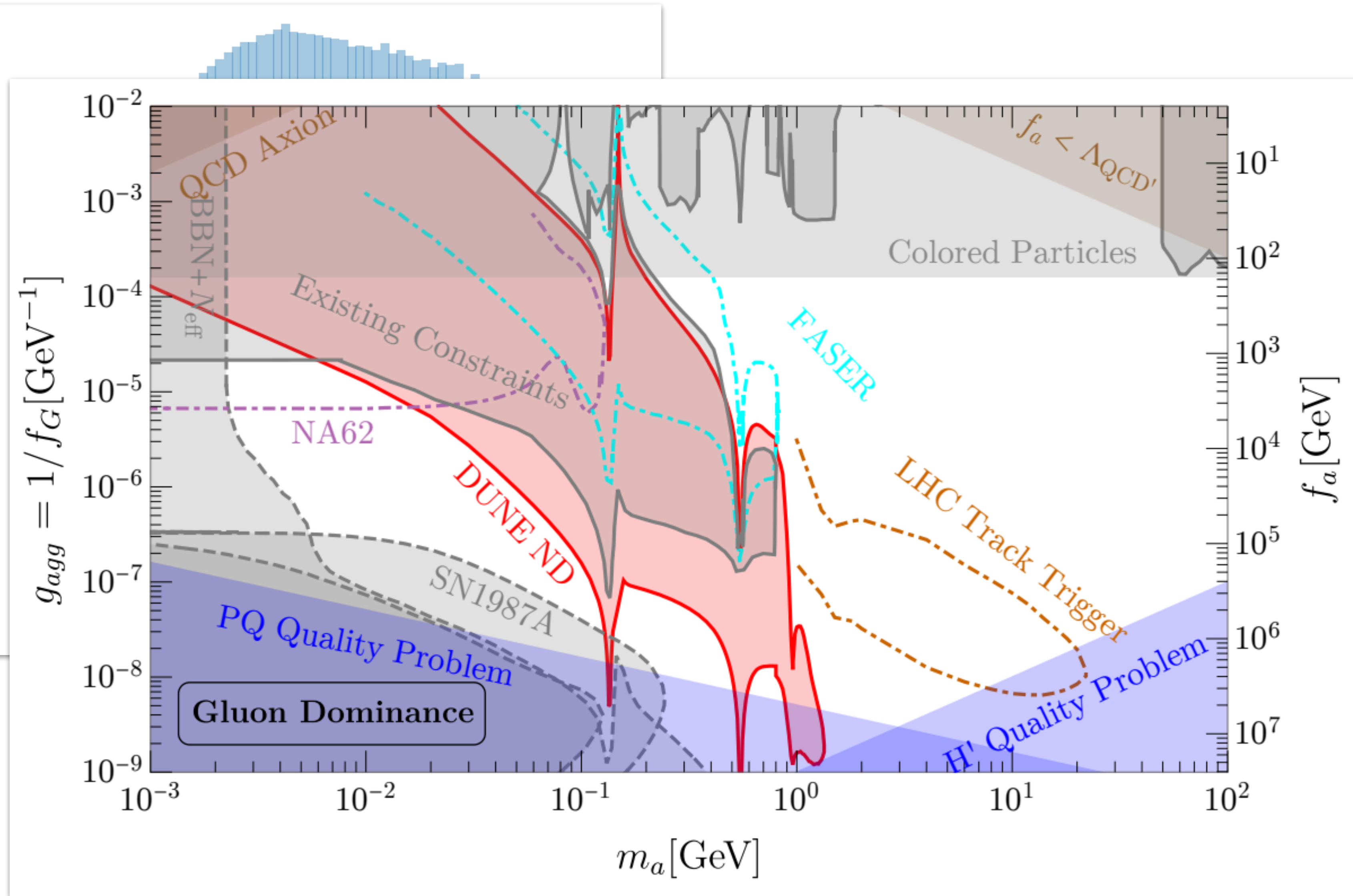Brdar et al [2011.07054]: "Axion-Like Particle"

Production via *decays* of SM mesons or Primakoff scattering.

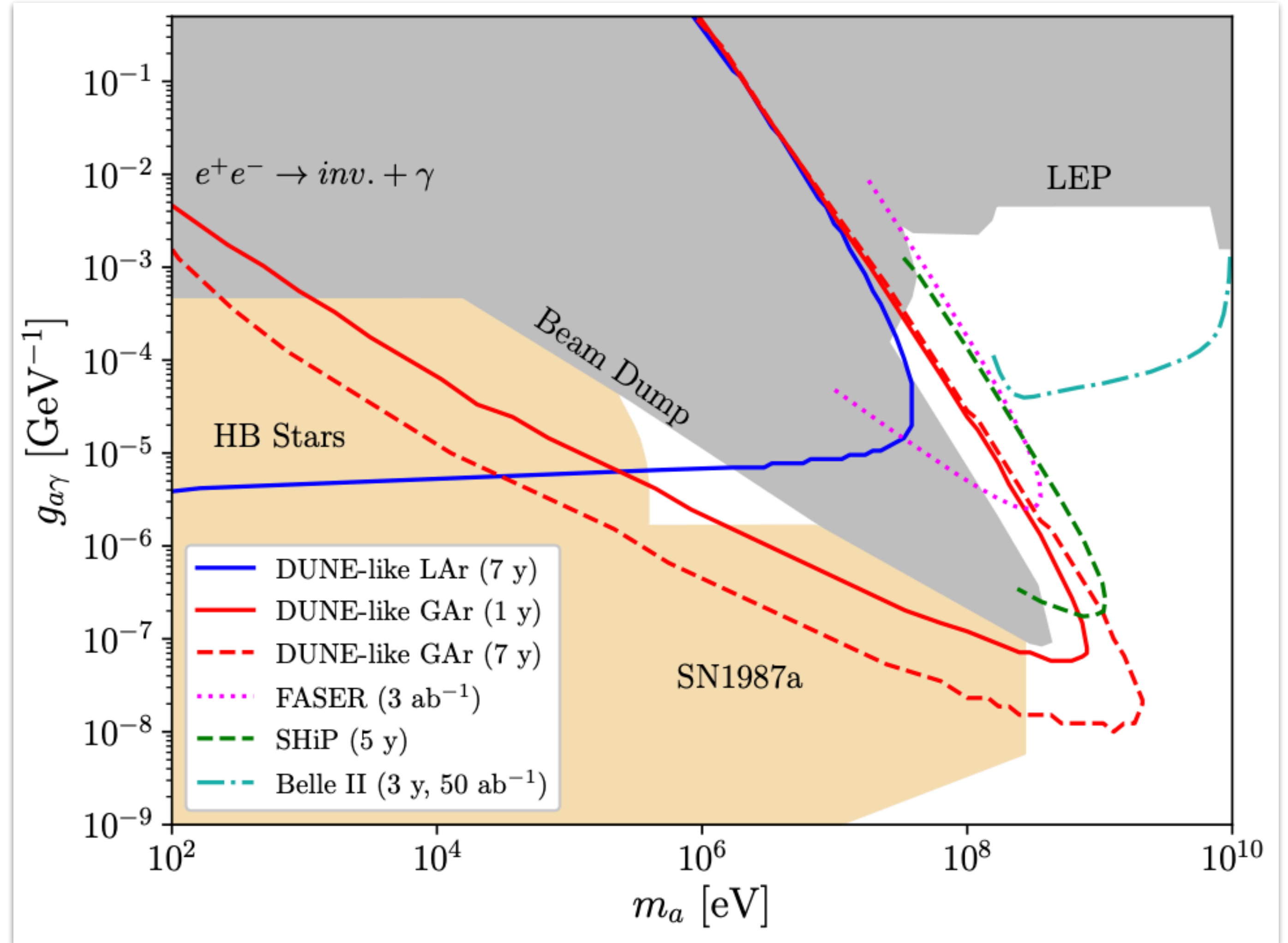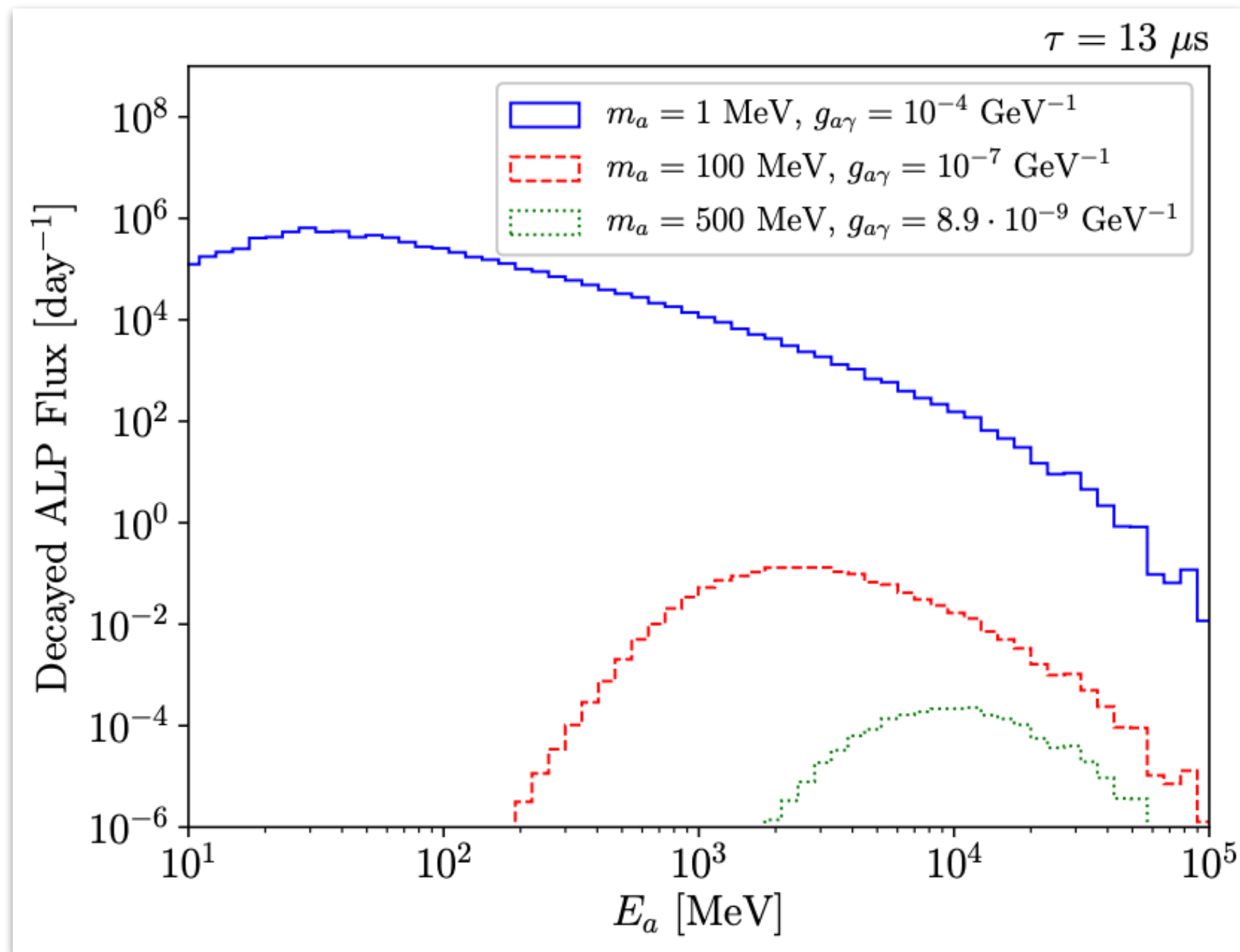Decay into pairs of photons or Primakoff scattering off targets in detector.

Heavy Axion Signature & Sensitivity

Kelly, Kumar, Liu [2011.05995]

ALP Spectra & Sensitivity

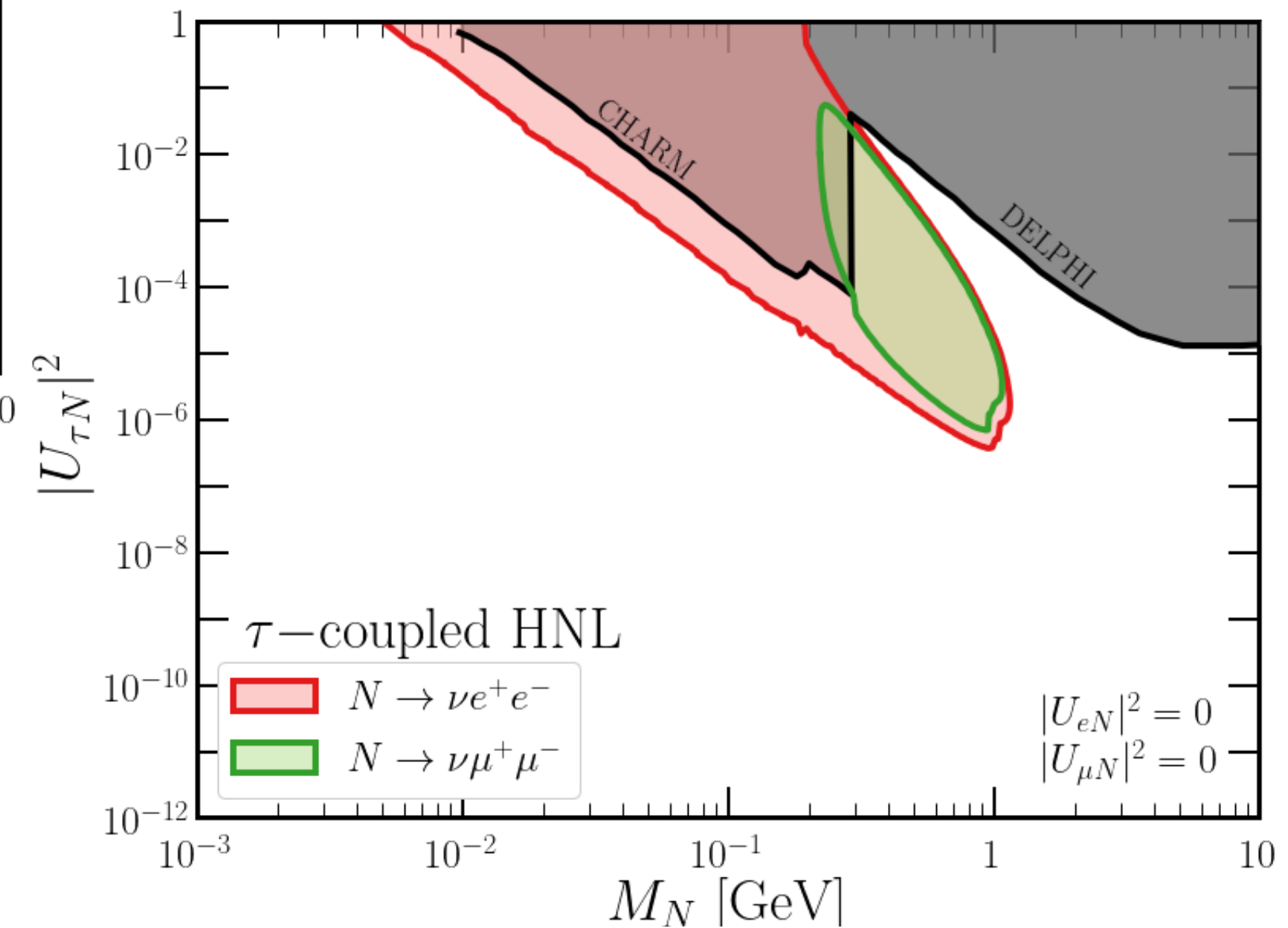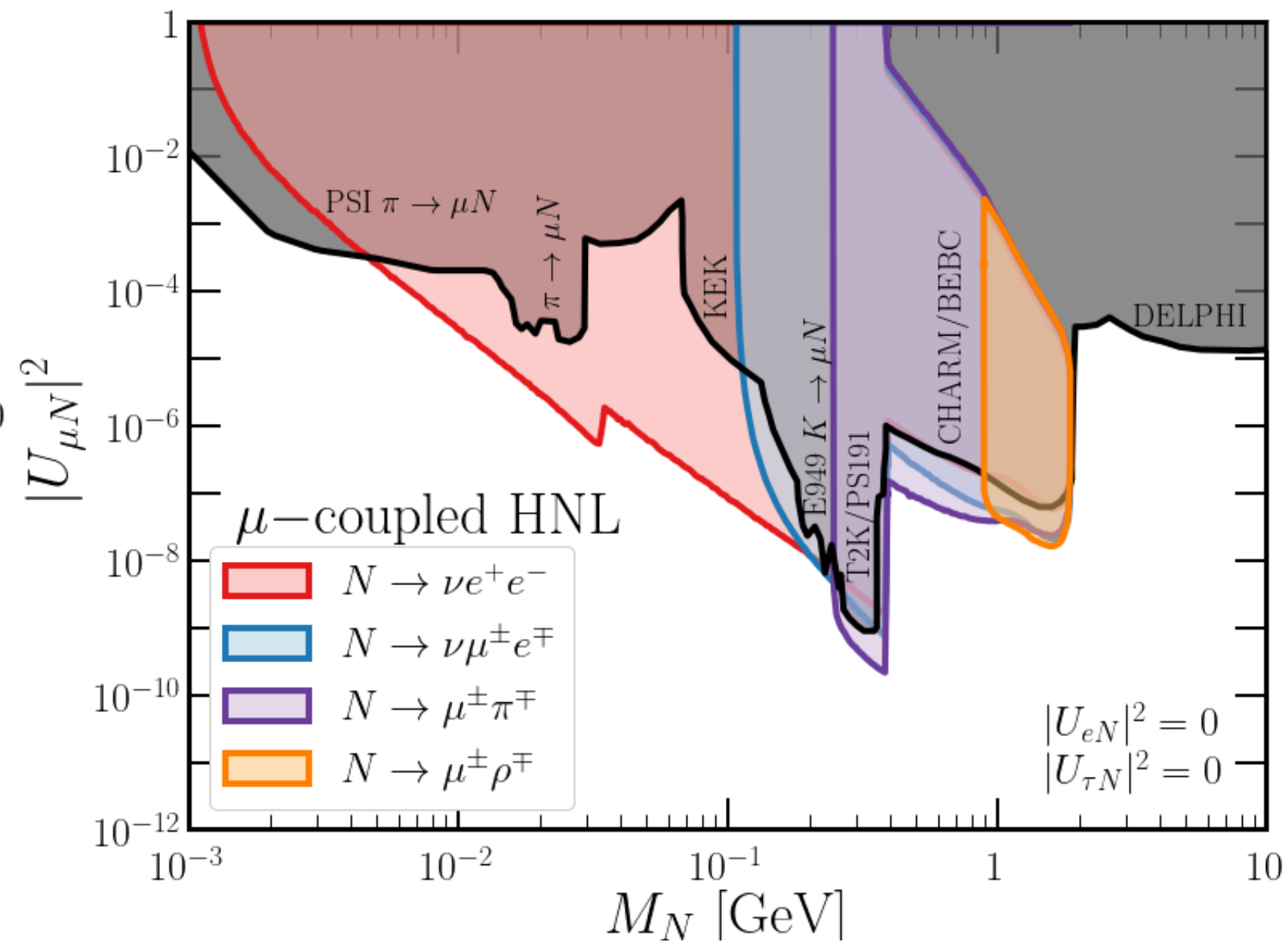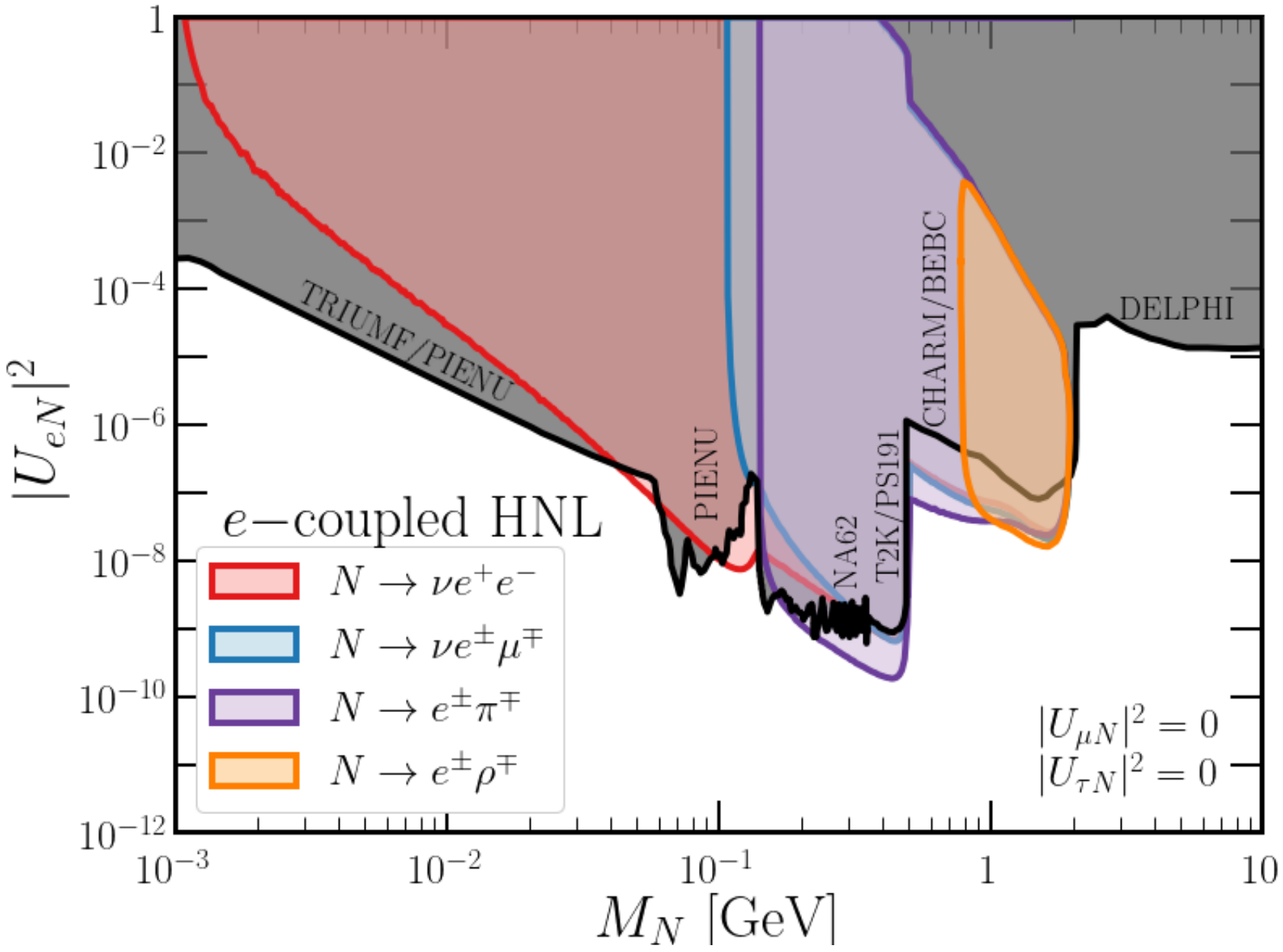Brdar, Dutta, Jang, Kim, Shoemaker, Tabrizi, Thompson, Yu [2011.07054]

Summary

○ Intense work ongoing by phenomenologists & experimentalists to identify all possibilities with DUNE and other upcoming neutrino experiments.

○ Over the last few years, dark matter and dark sector searches have become a particularly hot topic.

○ With precision measurements of things like electron recoils, DUNE NDLAr can search for dark matter produced via pion decays in the neutrino beam.

○ With the potential NDGAr detector, DUNE can search for many classes of dark sector mediators.

Thanks!

Backup

Other HNL Sensitivities @ DUNE

Berryman, de Gouvêa, Fox, Kayser, **KJK**, Raaf [1912.07622]

Dark Higgs Bosons at DUNE