Dark Matter from Neutrino Frontier

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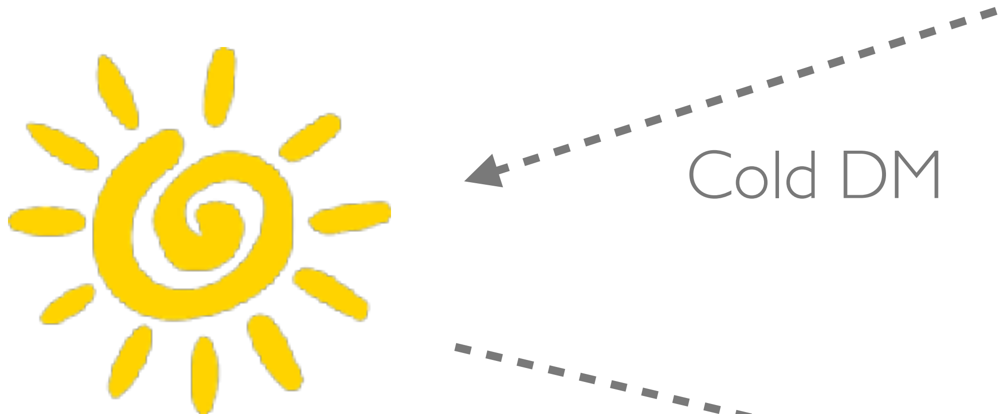
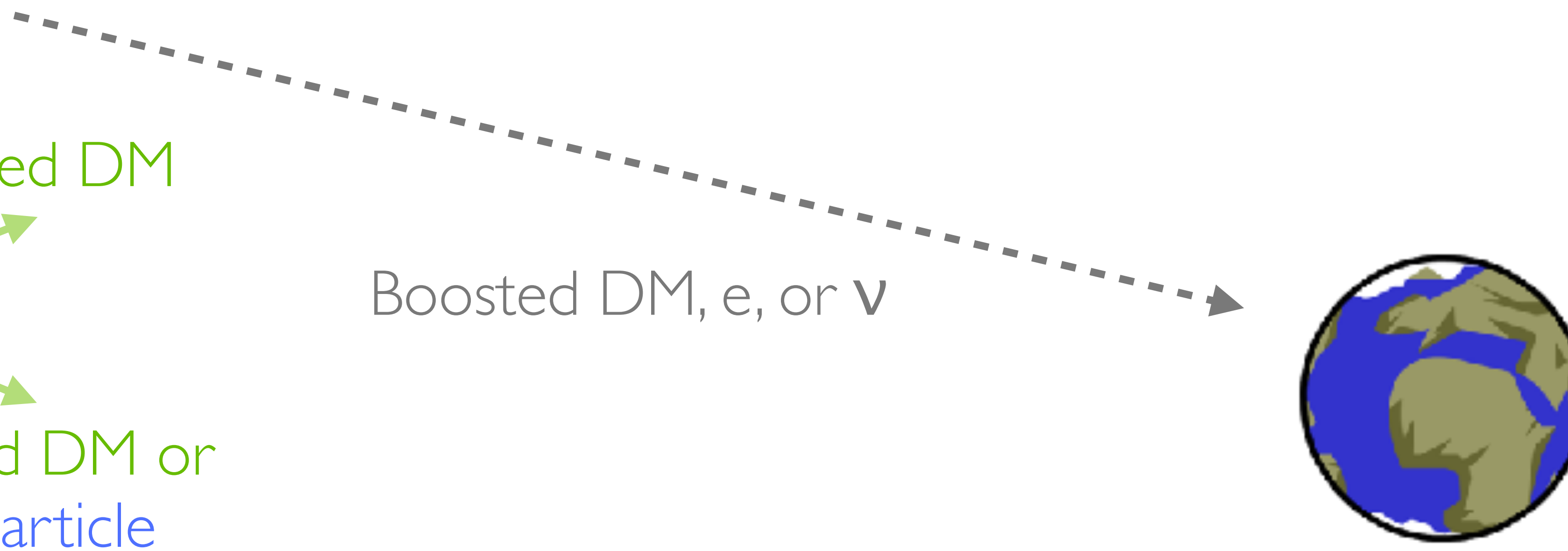
DM at Neutrino Frontier

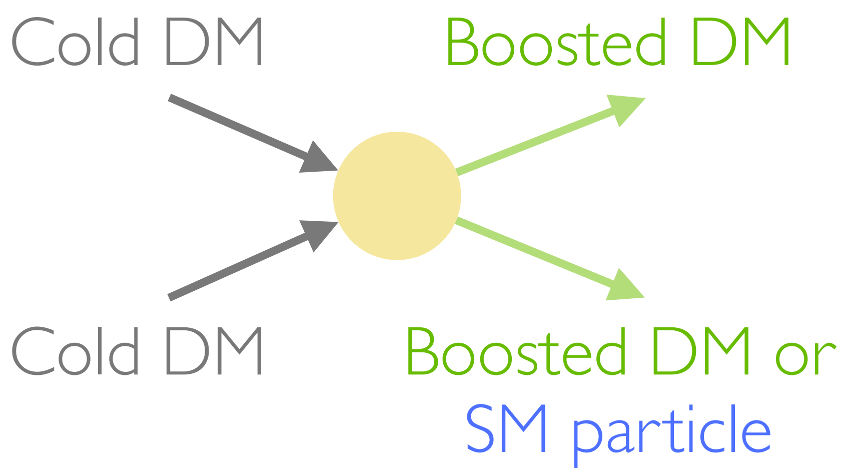
- Indirect search via spectra of neutrino fluxes, typically from natural sources
  - Constraints of DM via supernova neutrino measurements
  - DM-induced neutrinos
- Direct search for boosted dark matter (BDM) from natural sources (arXiv: 2207.02882)
- Direct search for sub-GeV dark matter (light dark matter or LDM) from artificial sources (arXiv: 2207.06898)

Natural Source

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

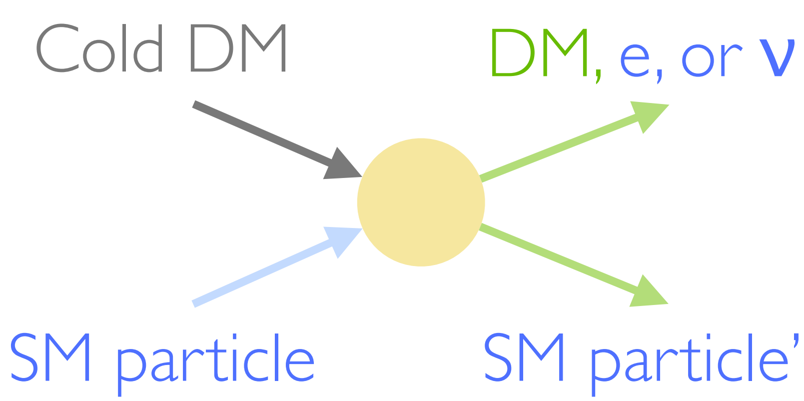




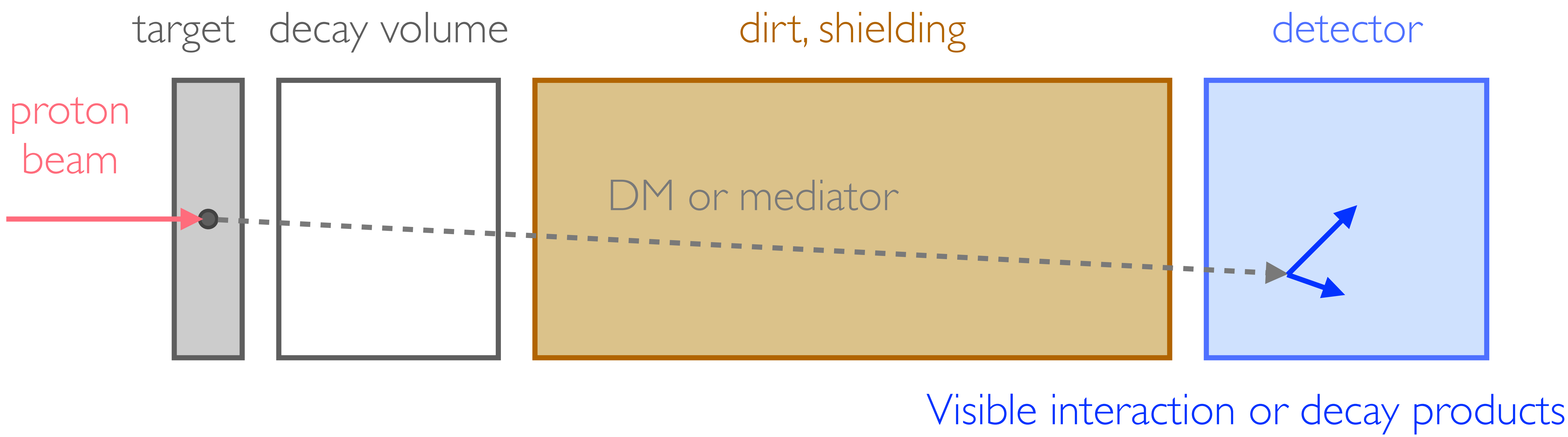


Lighter, boosted DM, e, ν, etc. produced via annihilation or decay

Detected by massive, (underground) ν detectors



Artificial Source



- Neutrino beam = high intensity proton beam + fixed target
- Short baseline (or near detector) **ν** detectors
  - design to detect a lot of weakly interacting particles
  - usu. capable of tracking, particle ID, calorimetry
- Reactor neutrino source

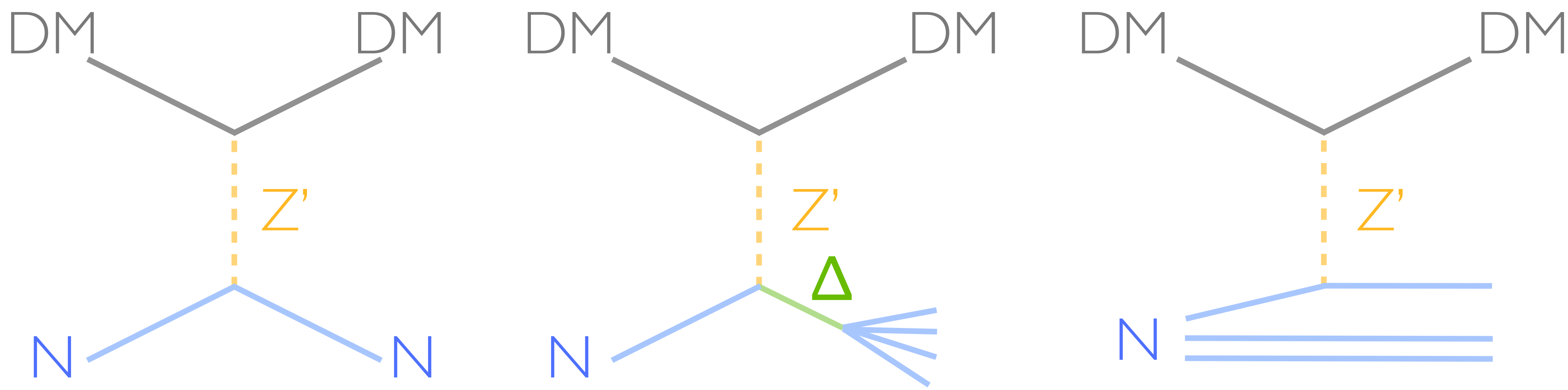
Dark Sector Landscape

Model	Production	Detection
Higgs Portal	K, B decay	Decay ($\ell^+\ell^-$)
Vector Portal	π^0, η Decay Proton Bremmstrahlung Drell-Yan	Scattering (χe^-, χX, Dark Tridents) Decay ($\ell^+\ell^-$, $\pi^+\pi^-$) Inelastic Decay ($\chi \to \chi' \ell^+\ell^-$)
Neutrino Portal	π, K, $D_{(s)}$, B decay	Decay (many final states)
ALP Portal (γ-coupling dominant)	Meson Decay Photon Fusion Primakoff Process	Decay ($\gamma\gamma$) Inverse Primakoff process
Dark Neutrinos Dipole Portal	SM Neutrino Dalitz Decay	Upscattering + Decay ($\nu \to \nu_D$, $\nu_D \to \nu\ell^+\ell^-$) Decay ($\nu_D \to \nu\gamma$)
νphilic Mediators	SM Neutrino	Scattering (Missing $\not{p}_T$, SM Tridents)

Table 1: A selection of models that can be probed by neutrino beam experiments.

arXiv: 2207.06898

Detection: Interaction

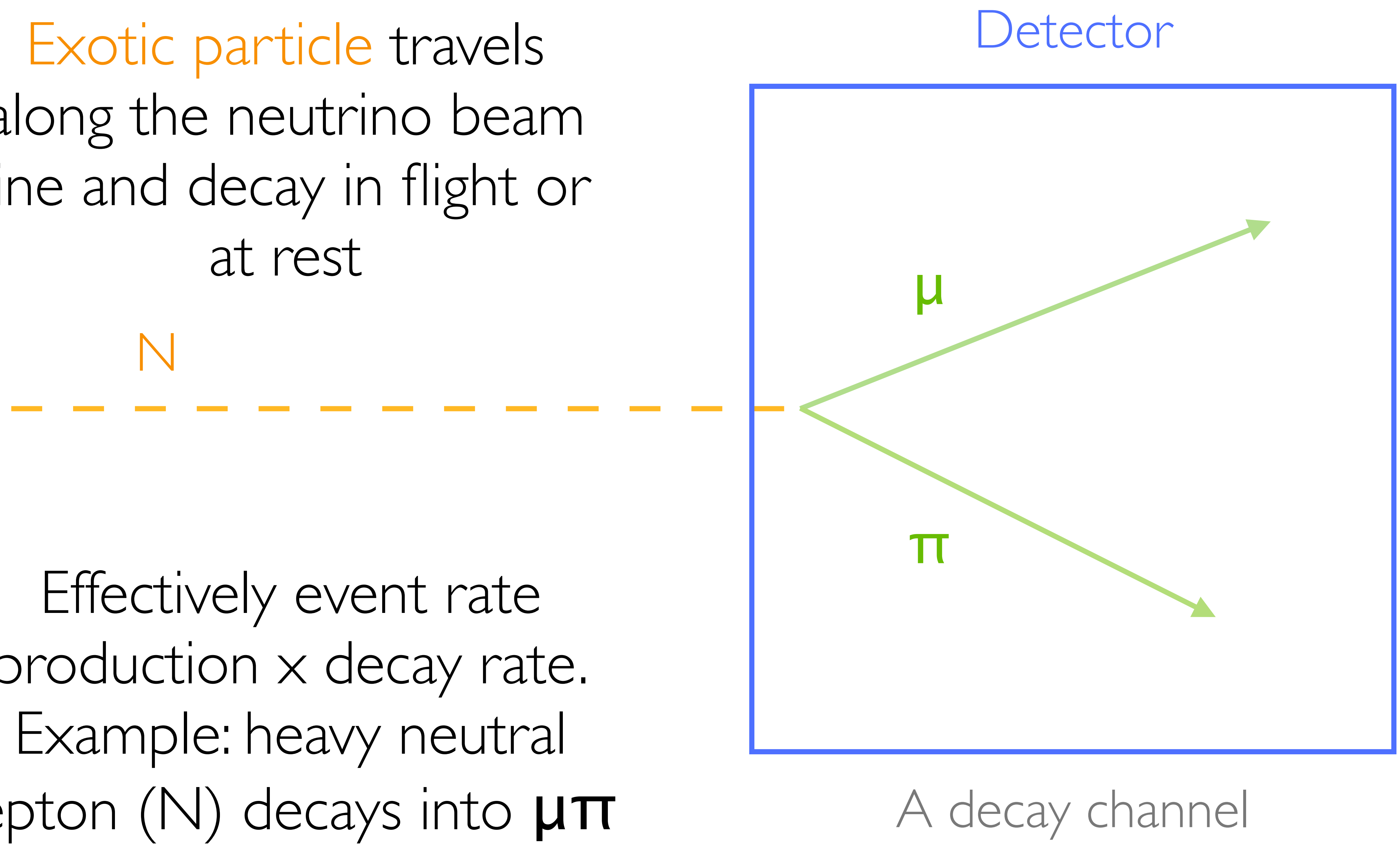


Elastic Scattering   Resonance Scattering   Deep Inelastic Scattering

- DM-electron scattering: e signature
- DM-nucleon scattering: typically neutral current-like
  - Nuclear effects smear the topology
- Challenging on reducing and precisely constraining neutrino background

Detection: Decay Products

Exotic particle travels along the neutrino beam line and decay in flight or at rest

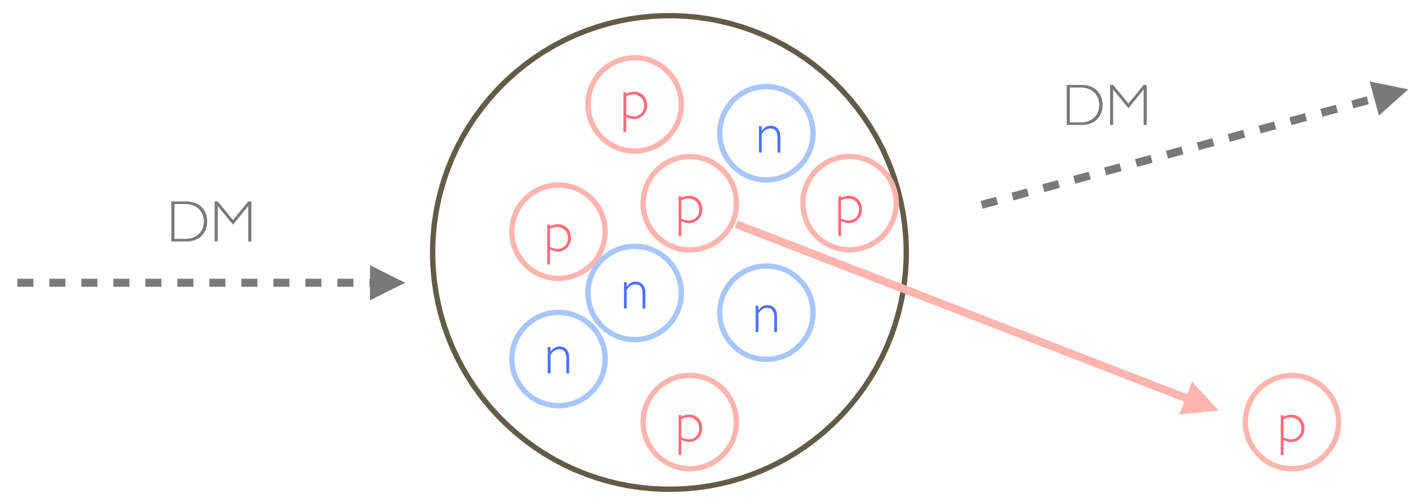


Effectively event rate production x decay rate. Example: heavy neutral lepton (N) decays into **μπ**

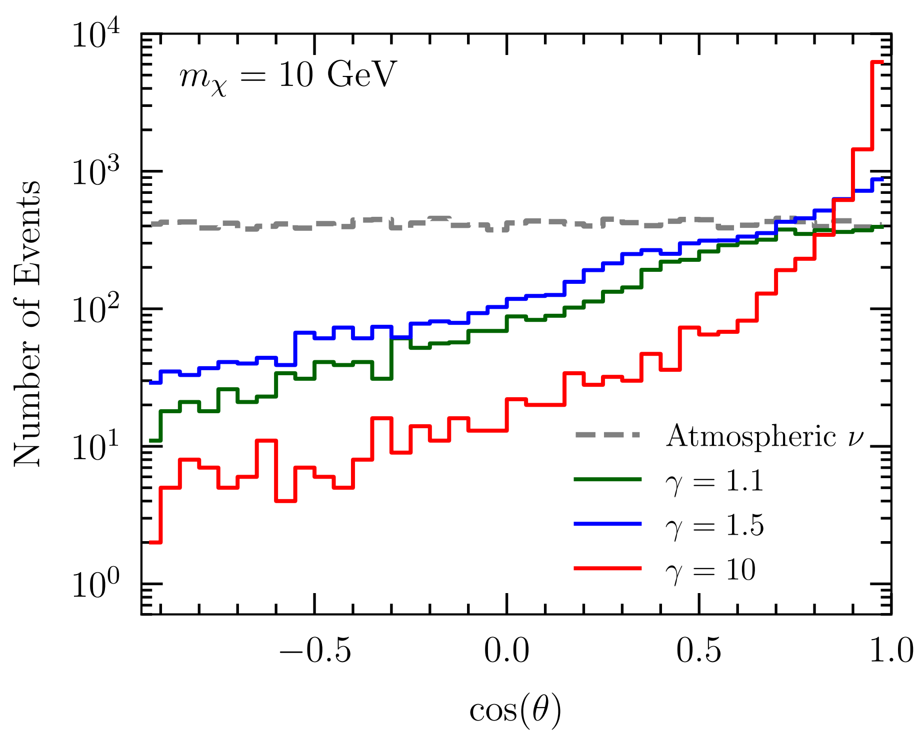
Examples

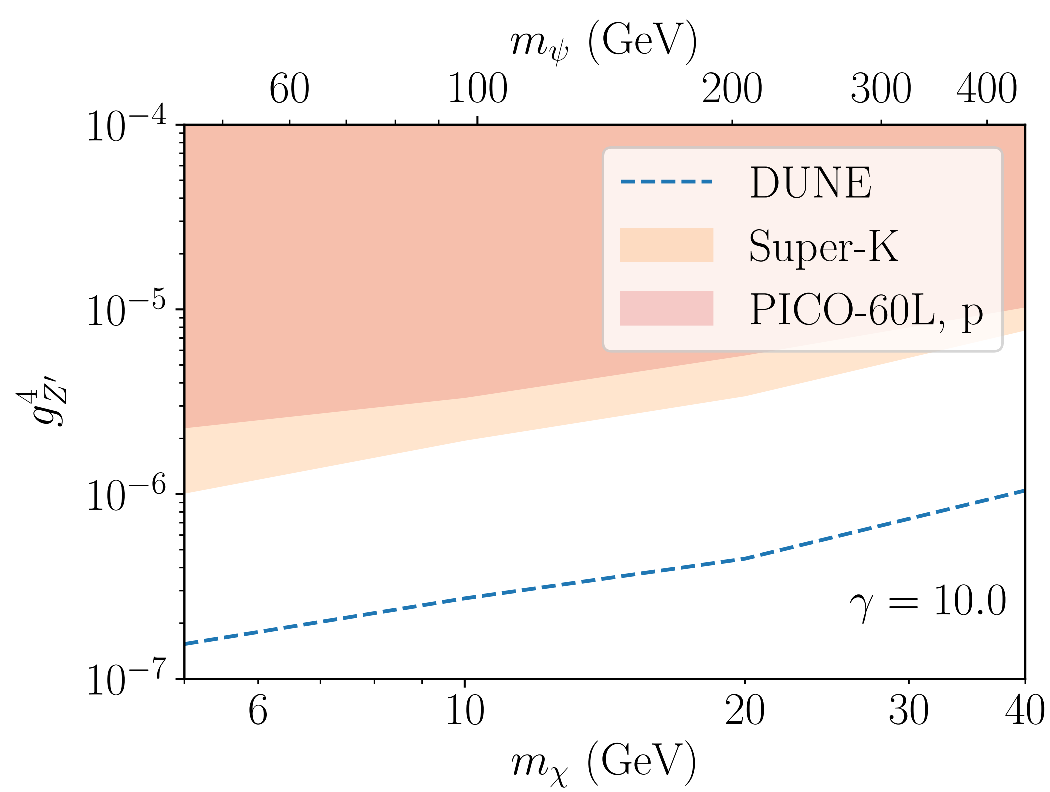
Elastic BDM

- Hadronic scattering
- Point back to the BDM origin, the Sun
- Take advantage of the low proton threshold in DUNE



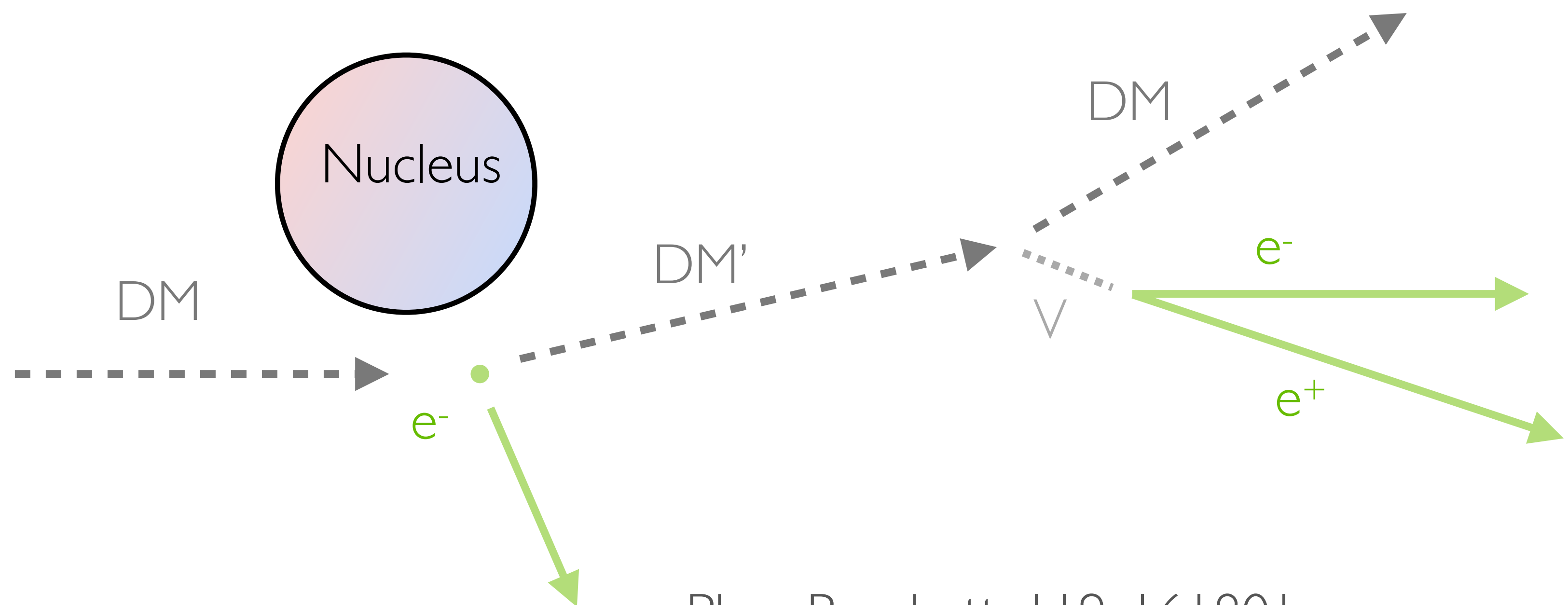
Phys. Rev. D 103, 095012



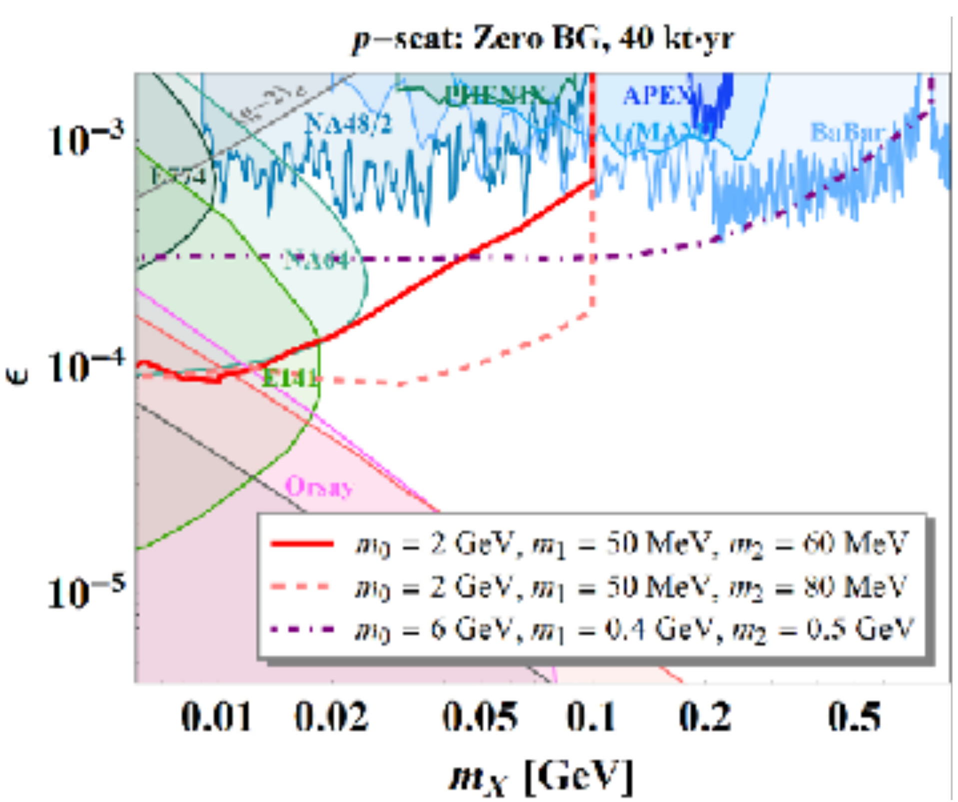


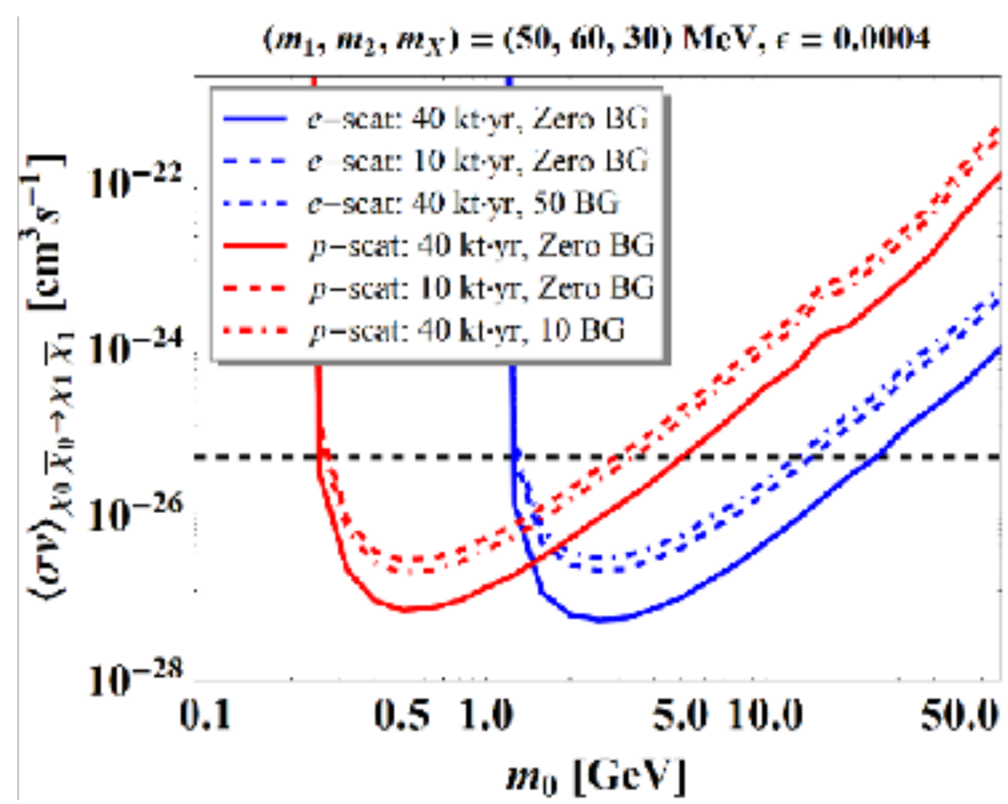
Inelastic BDM

- Distinctive signature of 3 leptons and displaced vertex
- Utilize the tracking capability of DUNE

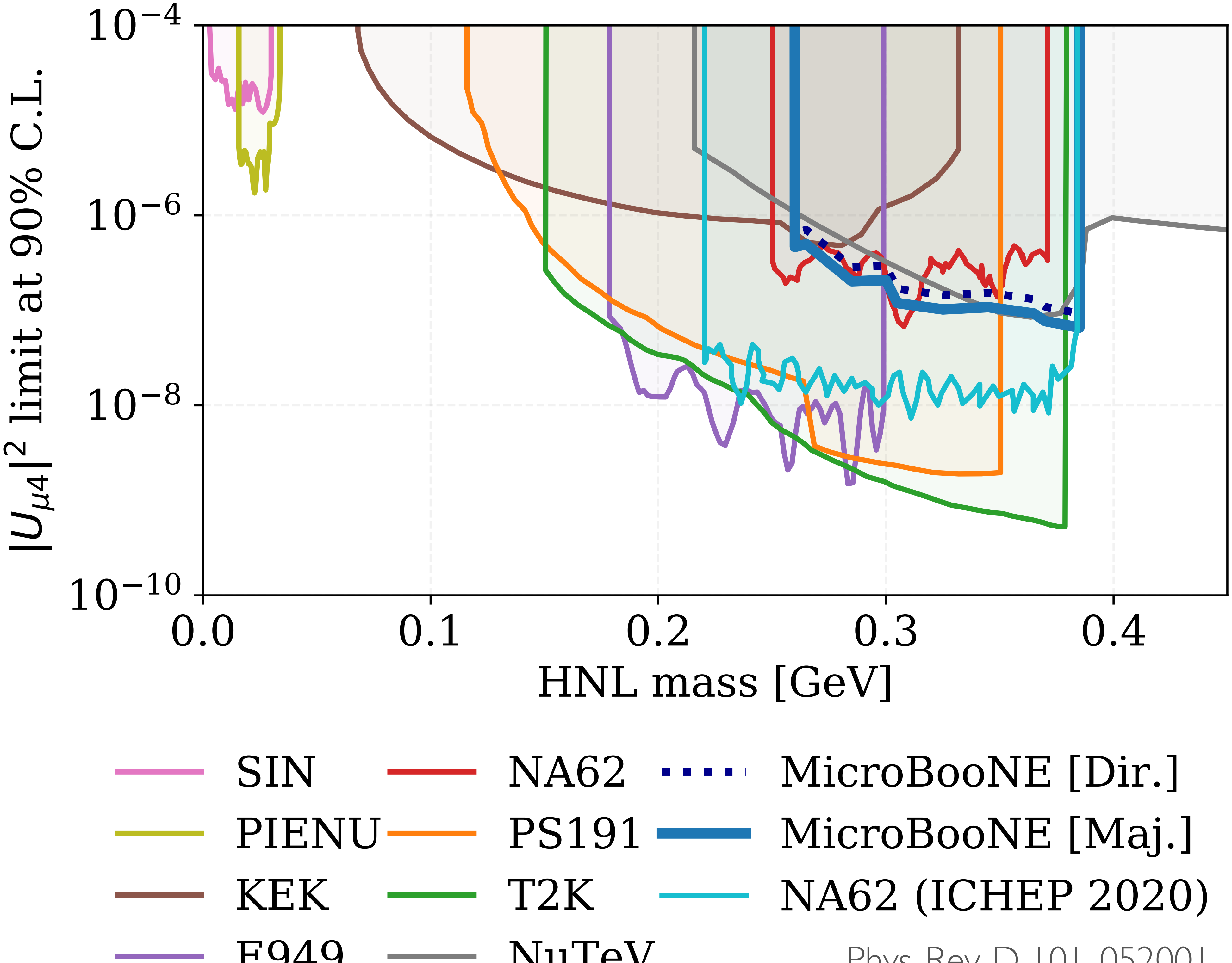


Phys. Rev. Lett. 119, 161801





Heavy Neutral Lepton



Phys. Rev. D 101, 052001

Complementarity and Desired Capabilities

Neutrino Measurement

- Look for deviation
  - Require precise measurements
- Indirect DM search
  - Require complementary experiments to pin down the interpretations
- Broad energy range of natural neutrino sources
  - Desire to cover as wide as possible
  - Experiments based on different technologies complement each other
    - Neutrino energy and flavors

DM Particle Detection

- Massive, underground neutrino detectors:
    - MeV detection threshold
    - Kiloton scale
    - Sensitive to boosted DM (with small fluxes)
    - Complementary to direct DM particle detectors
- Similar to measurements of neutrinos, desire broad energy ranges for particle detection and massive detector
- Challenging to distinguish the DM signature from neutrinos
- For distinctive signatures, require specific detector specs

Sub-GeV DM Search

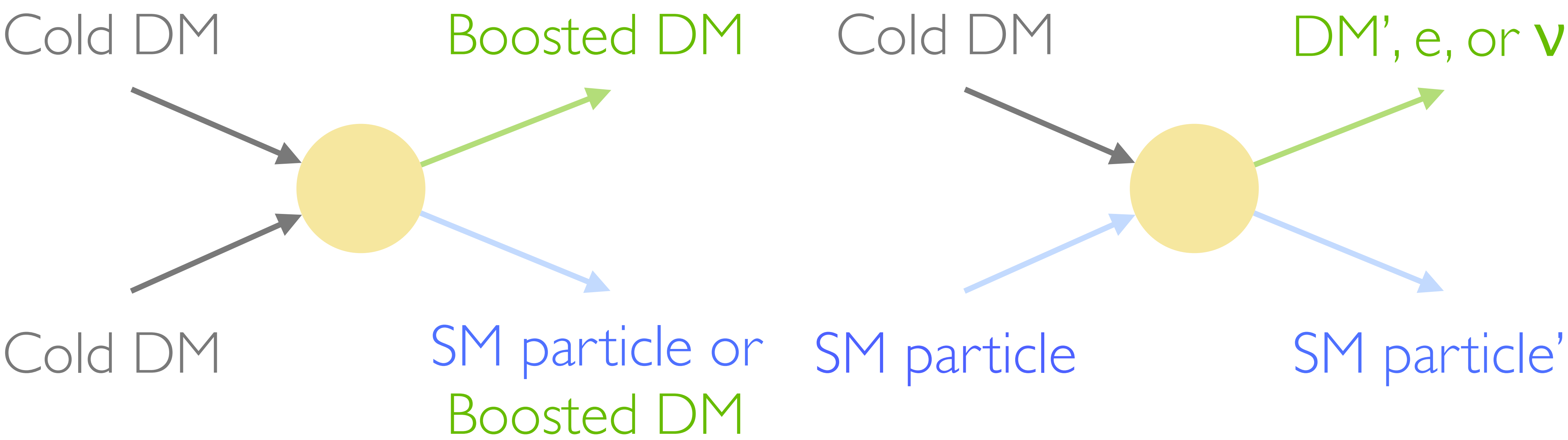
- Hadron production and interaction from fixed target-proton beams less precise than electron beams
  - More sensitive to leptophobic models
  - Complementary to experiments based on electron beams
- Energy range (sub-GeV - a few GeV) complementary to collider experiments
- Different detector components desired; e.g. dense target for interactions, sparse target for decays
- Neutrino background elimination is challenging

Summary & Outlook

- Neutrino experiments offer facilities for a wide range of DM search
- Complementarity among neutrino detectors based on different technologies, and other experiments
- Studies on landscape of exiting results, complementarity and guidelines on theoretical/experimental priorities desired
- Important to eliminate or constrain neutrino background

Backup

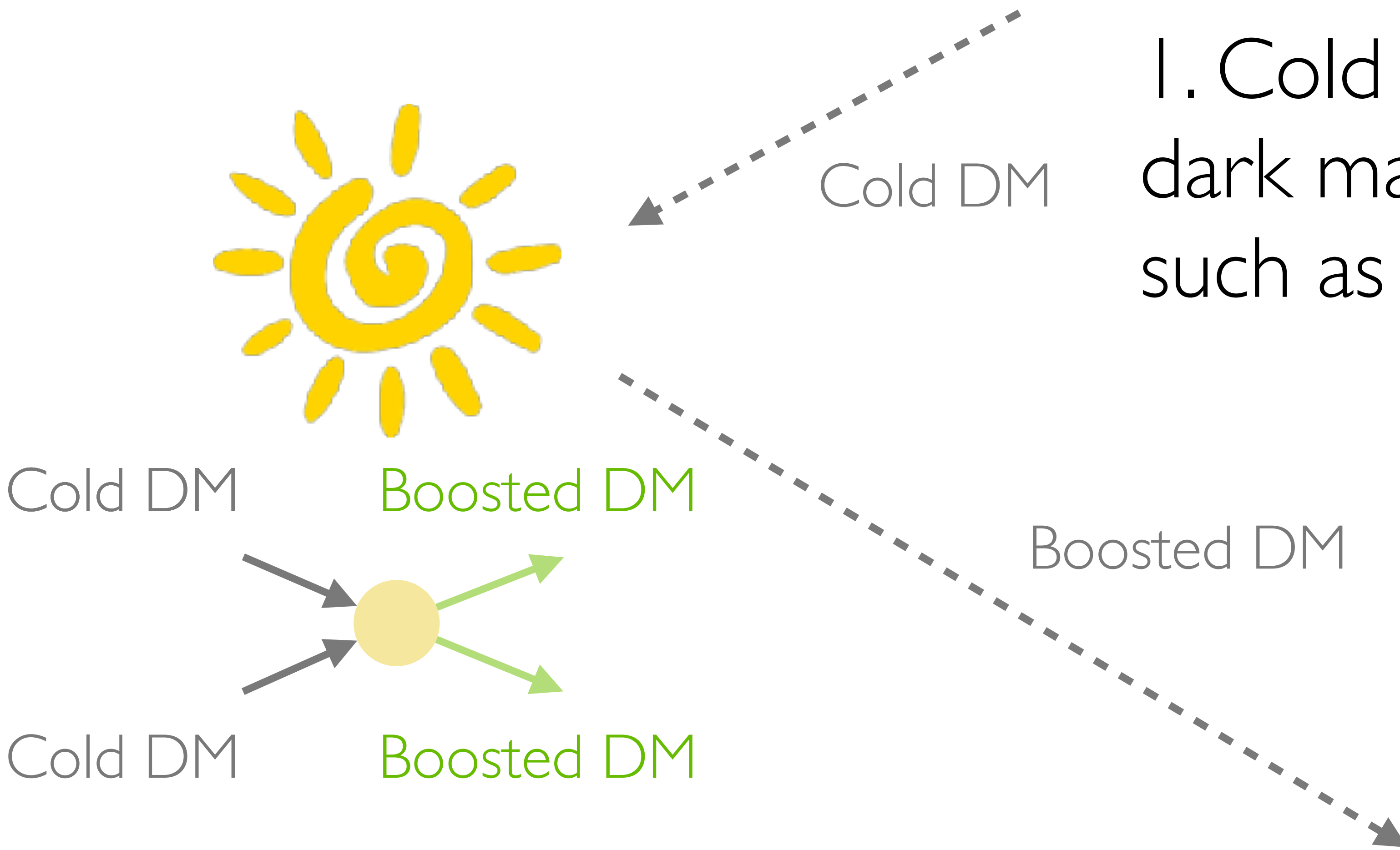
Natural Source



- Dark-matter-induced neutrinos
- Boosted dark matter
- Explosive slow-moving dark matter
- etc.

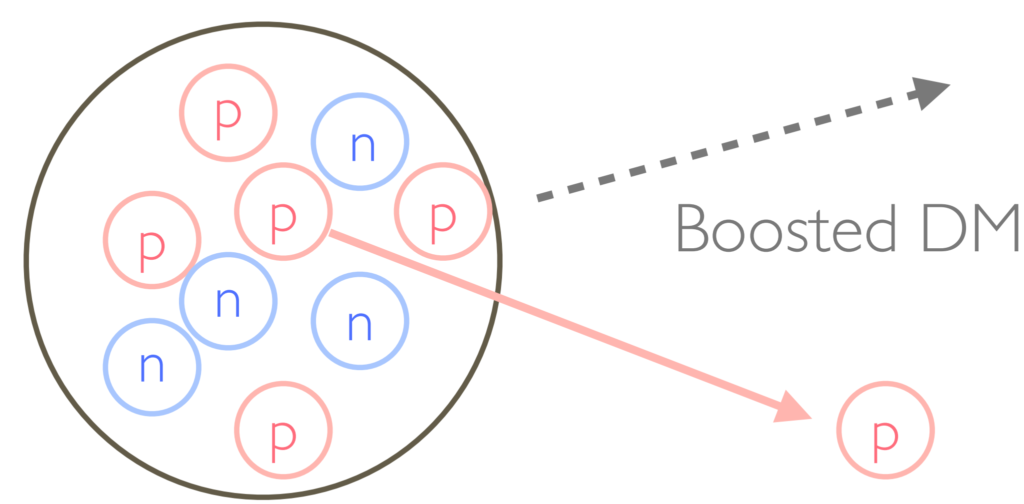
Boosted Dark Matter

1. Cold dark matter captured by dark matter concentrated region, such as the Sun or Galaxy Center



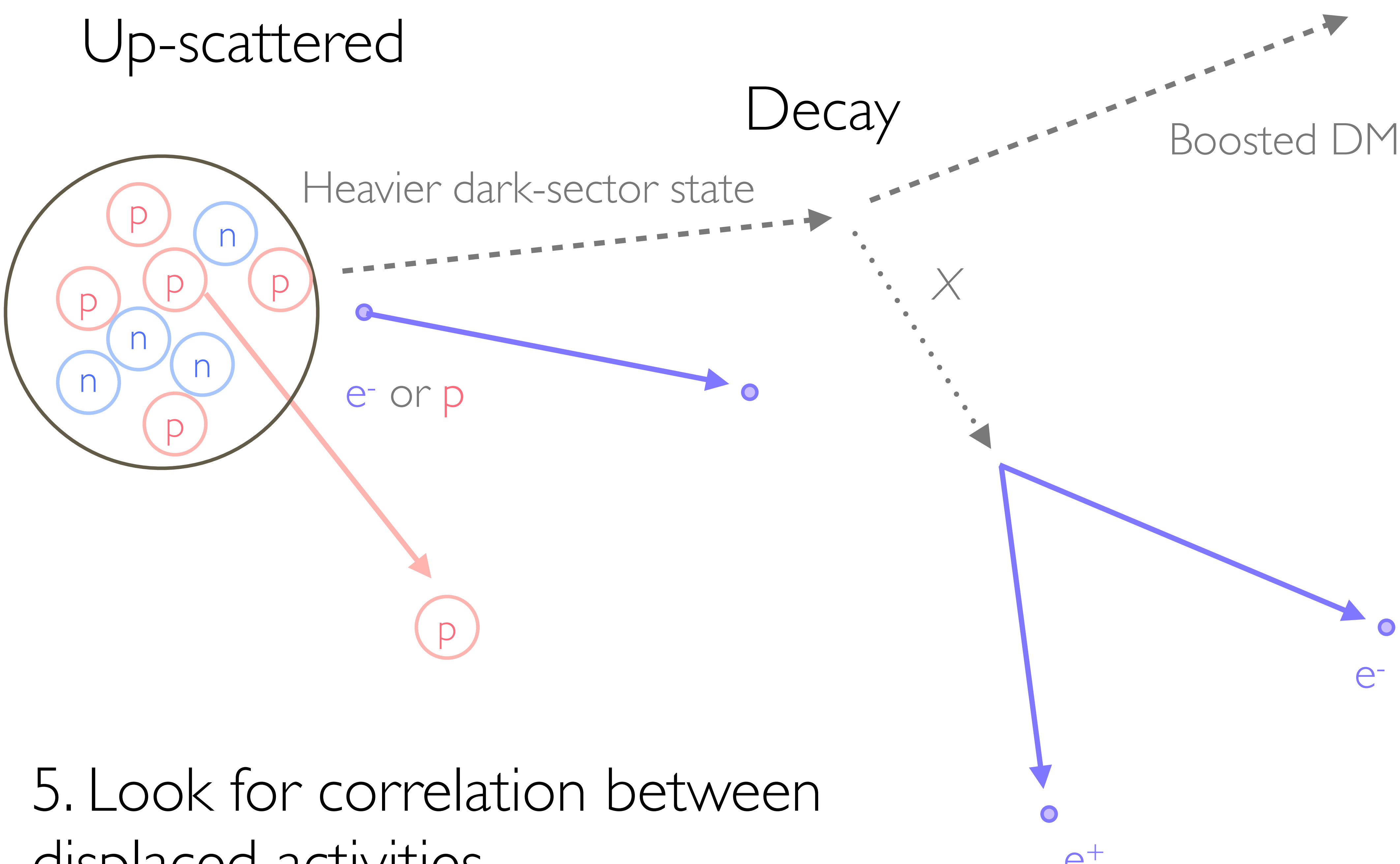
3. Boosted dark matter interact with electrons or nucleons in detectors

2. Produce lighter, boosted dark matter via annihilation or decay



4. Look for scattered electrons or recoil protons

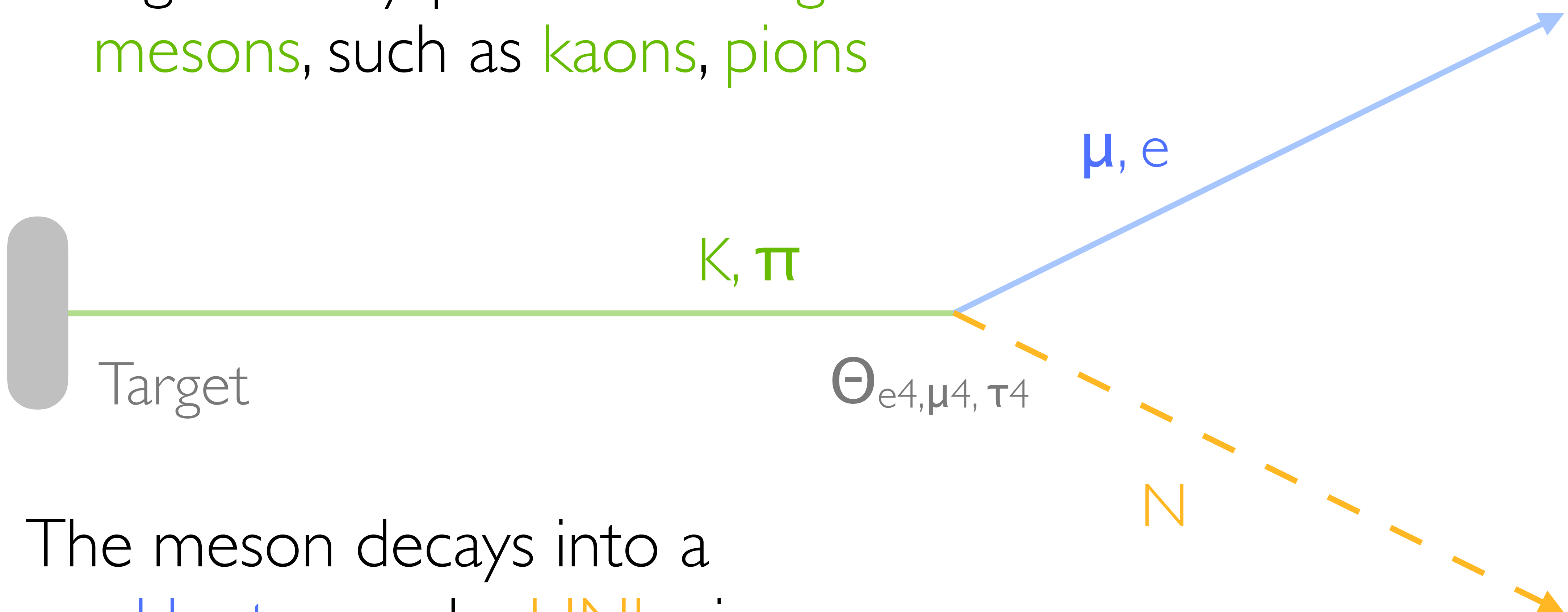
Inelastic Boosted DM



5. Look for correlation between displaced activities

Production

Accelerator neutrino beam or fixed target facility produce charged mesons, such as kaons, pions



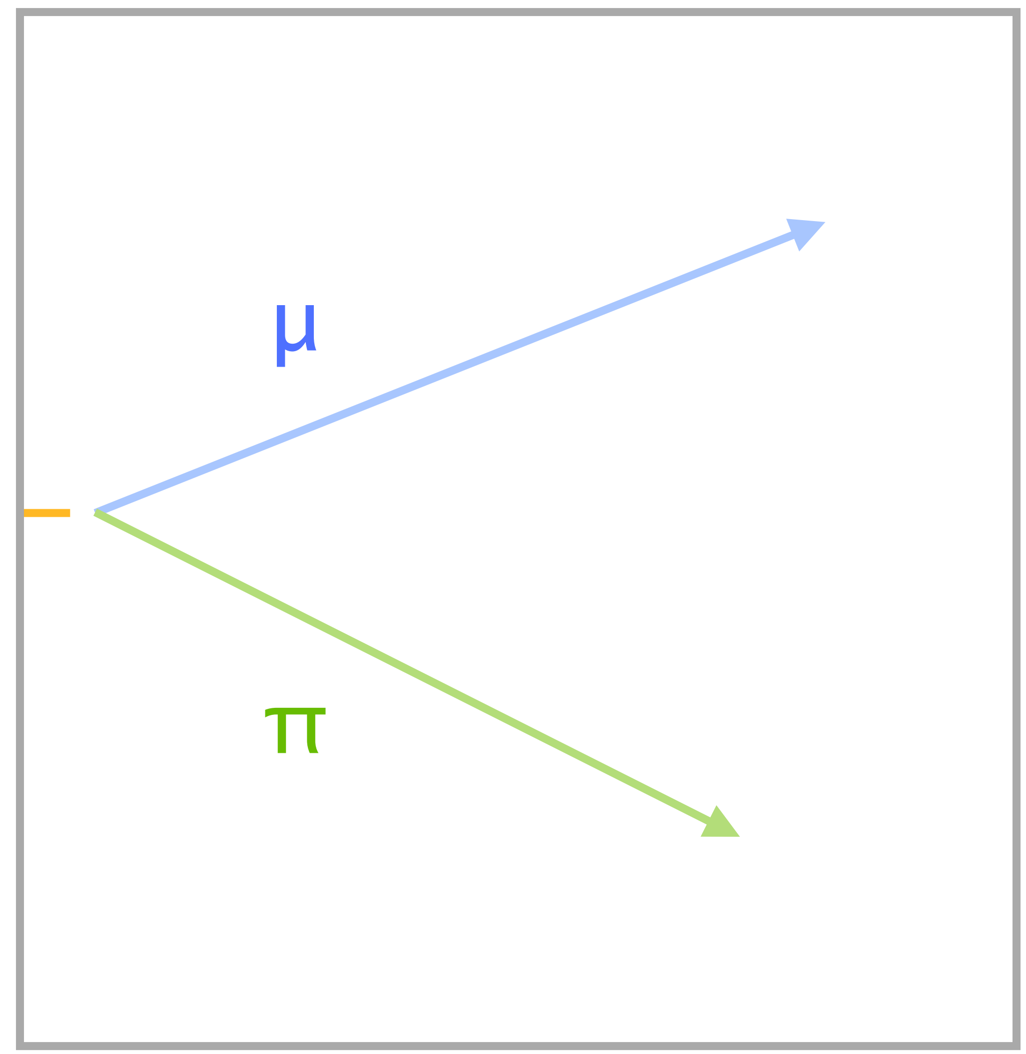
The meson decays into a charged lepton and a HNL via a mixing angle, $\Theta_{e4, \mu4, \tau4}$, between the SM neutrino and the HNL

No helicity suppression

HNL Detection

HNL travels along the neutrino beam line and decay in flight

Detector



A decay channel

Detect the decay products in the detector. Effectively event rate production x decay rate. Measure the mixing angle $\Theta_{\mu 4,\, e4,\, \tau 4}$ with each M_N