

New-Physics Searches at Beam Dump Experiments

Kevin Kelly, Fermilab



NF09 Workshop, 3rd Dec., 2020

Outline

- ✦ Types of BSM Searches with Neutrino Experiments
- ✦ Neutrino Experiments as Beam Dumps
 - ✦ Heavy Neutral Leptons
 - ✦ Dark Photon Searches

BSM with Neutrino Experiments

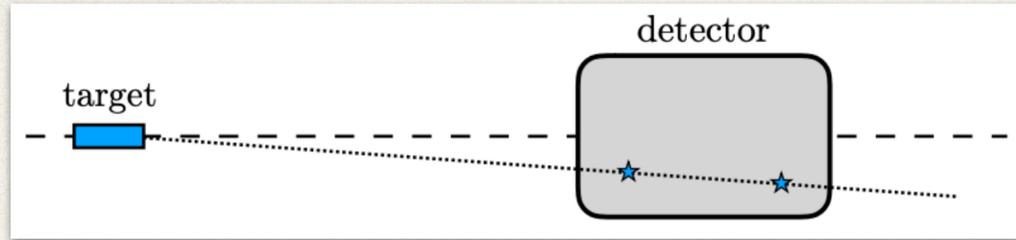
WHITE PAPER ON NEW OPPORTUNITIES AT THE NEXT-GENERATION NEUTRINO EXPERIMENTS (PART 1: BSM NEUTRINO PHYSICS AND DARK MATTER)

C.A. ARGÜELLES¹, A.J. AURISANO², B. BATELL³, J. BERGER³, M. BISHAI⁴, T. BOSCHI⁵, N. BYRNES⁶,
A. CHATTERJEE⁶, A. CHODOS⁶, T. COAN⁷, Y. CUI⁸, A. DE GOUVÊA^{* 9}, P.B. DENTON⁴,
A. DE ROECK^{* 10}, W. FLANAGAN¹¹, D.V. FORERO¹², R.P. GANDRAJULA¹³, A. HATZIKOUTELIS¹⁴,
M. HOSTERT¹⁵, B. JONES⁶, B.J. KAYSER¹⁶, K.J. KELLY¹⁶, D. KIM¹⁷, J. KOPP^{10,18}, A. KUBIK¹⁹,
K. LANG²⁰, I. LEPETIC²¹, P.A.N. MACHADO¹⁶, C.A. MOURA²², F. OLNESS⁶, J.C. PARK²³,
S. PASCOLI¹⁵, S. PRAKASH¹², L. ROGERS⁶, I. SAFA²⁴, A. SCHNEIDER²⁴, K. SCHOLBERG²⁵, S. SHIN^{26,27},
I.M. SHOEMAKER²⁸, G. SINEV²⁵, B. SMITHERS⁶, A. SOUSA^{* 2}, Y. SUI²⁹, V. TAKHISTOV³⁰,
J. THOMAS³¹, J. TODD², Y.-D. TSAI^{16,32}, Y.-T. TSAI³³, J. YU^{* 6}, AND C. ZHANG⁴

[1907.08311]

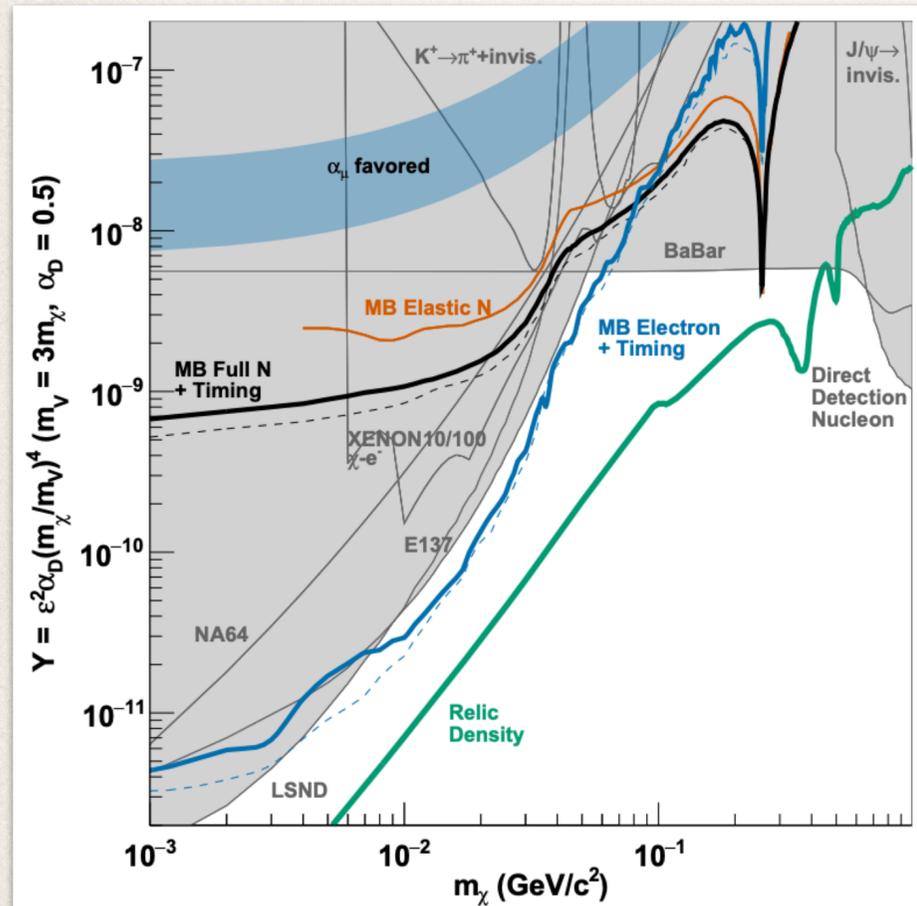
BSM Prospects with Neutrino Experiments

Millicharged Particles



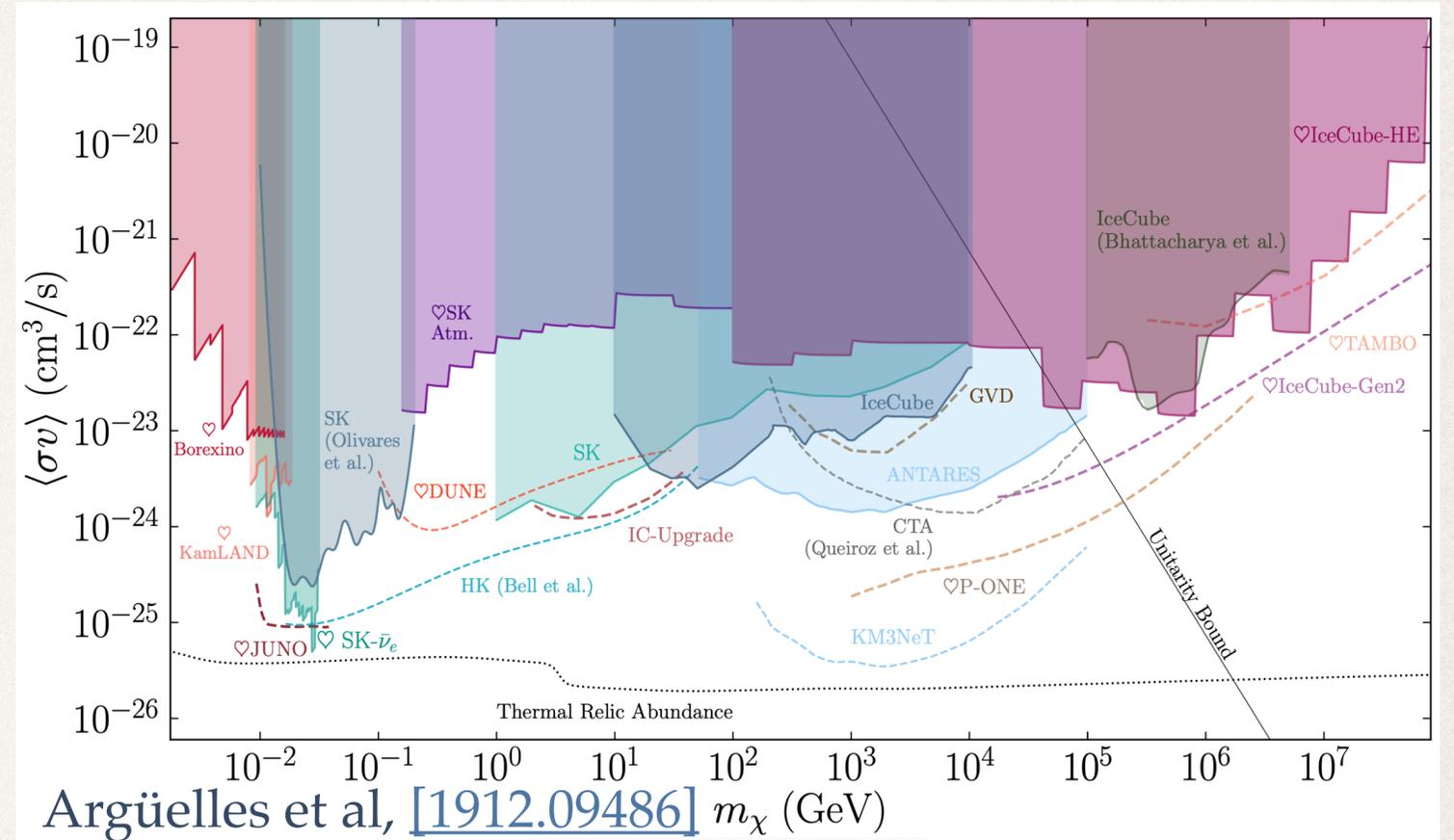
Harnik et al, [1902.03246]
See also Magill et al, [1806.03310]

Sub-GeV Dark Matter



MiniBooNE-DM Collaboration, [1807.06137]
See also M. Toups's talk (Wednesday)

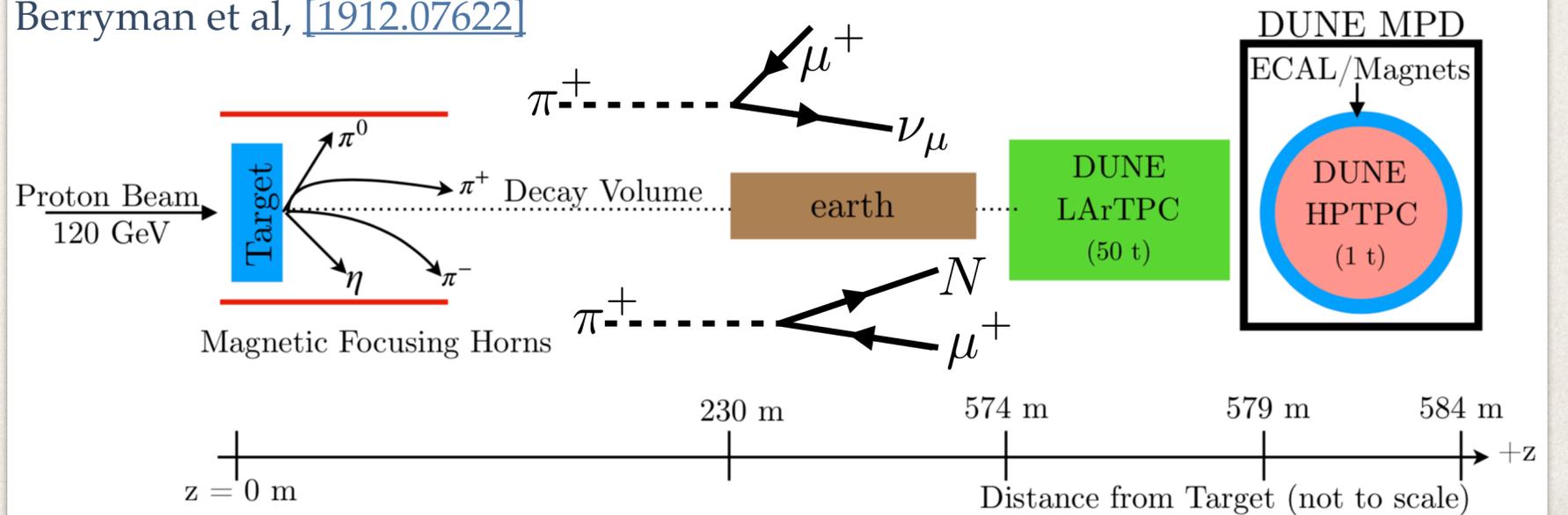
Dark Matter annihilation into Neutrinos



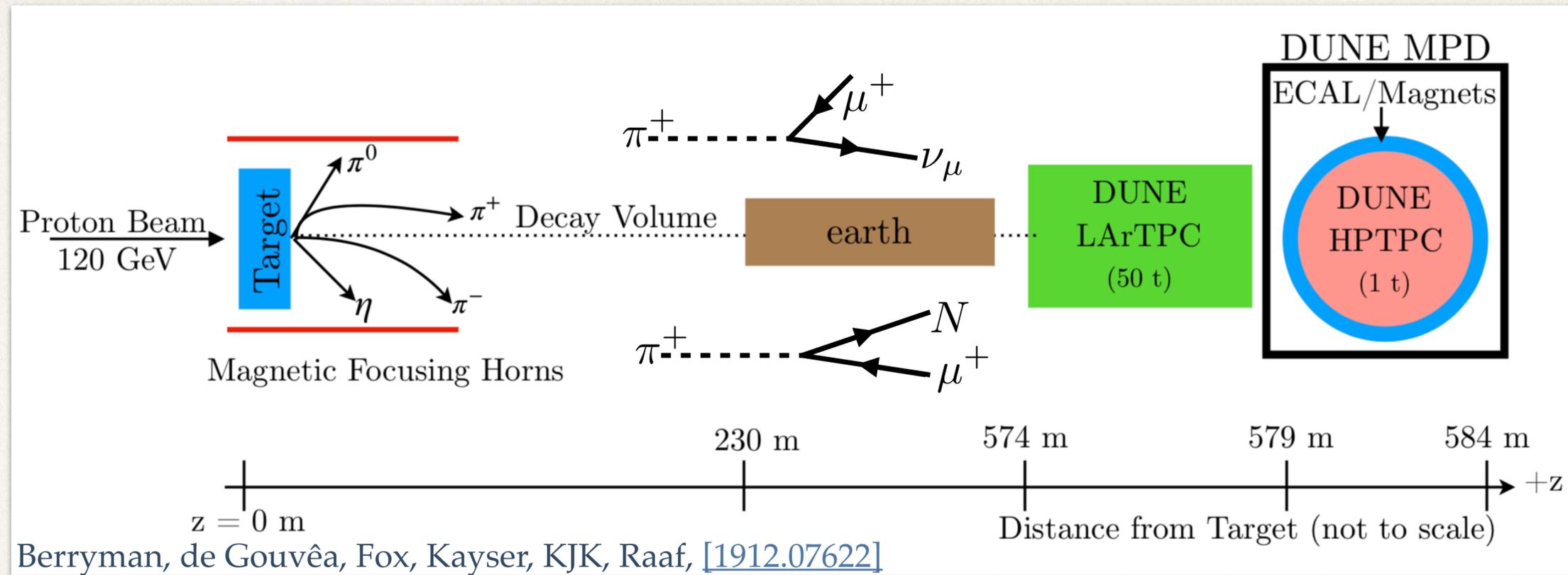
Argüelles et al, [1912.09486]

Neutrino Near Detectors as Beam Dump Facilities

Berryman et al, [1912.07622]



Neutrino Experiments as Beam Dump Facilities



- ❖ High-intensity proton beams (10^{21} or so protons on target per year), can produce copious amounts of SM mesons.
- ❖ Long-lived, charged particles can be focused / defocused by magnetic horns.
- ❖ Next-generation detectors can perform beam-dump style searches simultaneously with neutrino operation due to excellent particle identification, etc.

Example: Heavy Neutral Leptons

Flux at Near Detector, 5 years of Operation

Production Modes

Considered:

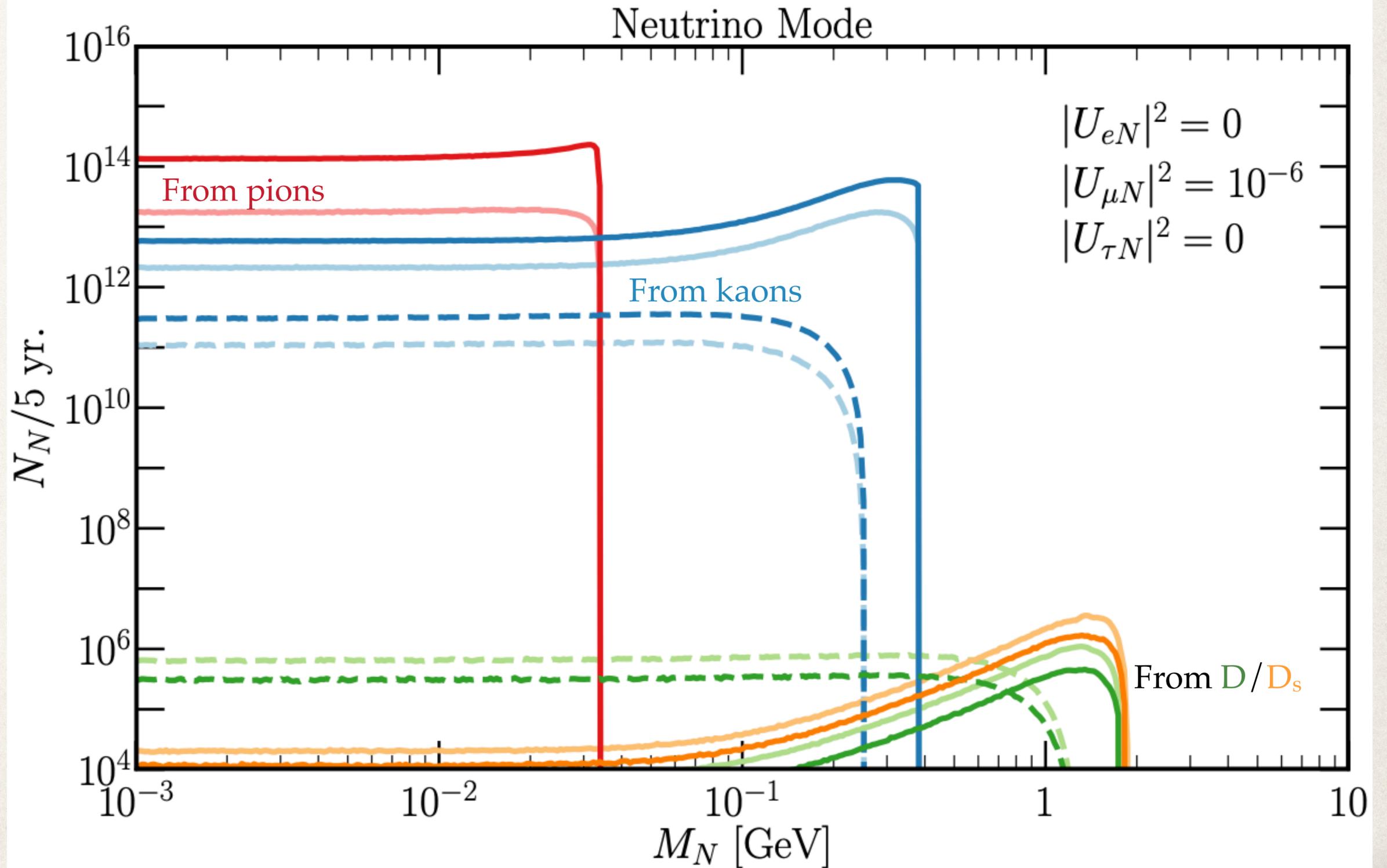
$$\pi^\pm \rightarrow \mu^\pm N$$

$$K^\pm \rightarrow \mu^\pm N$$

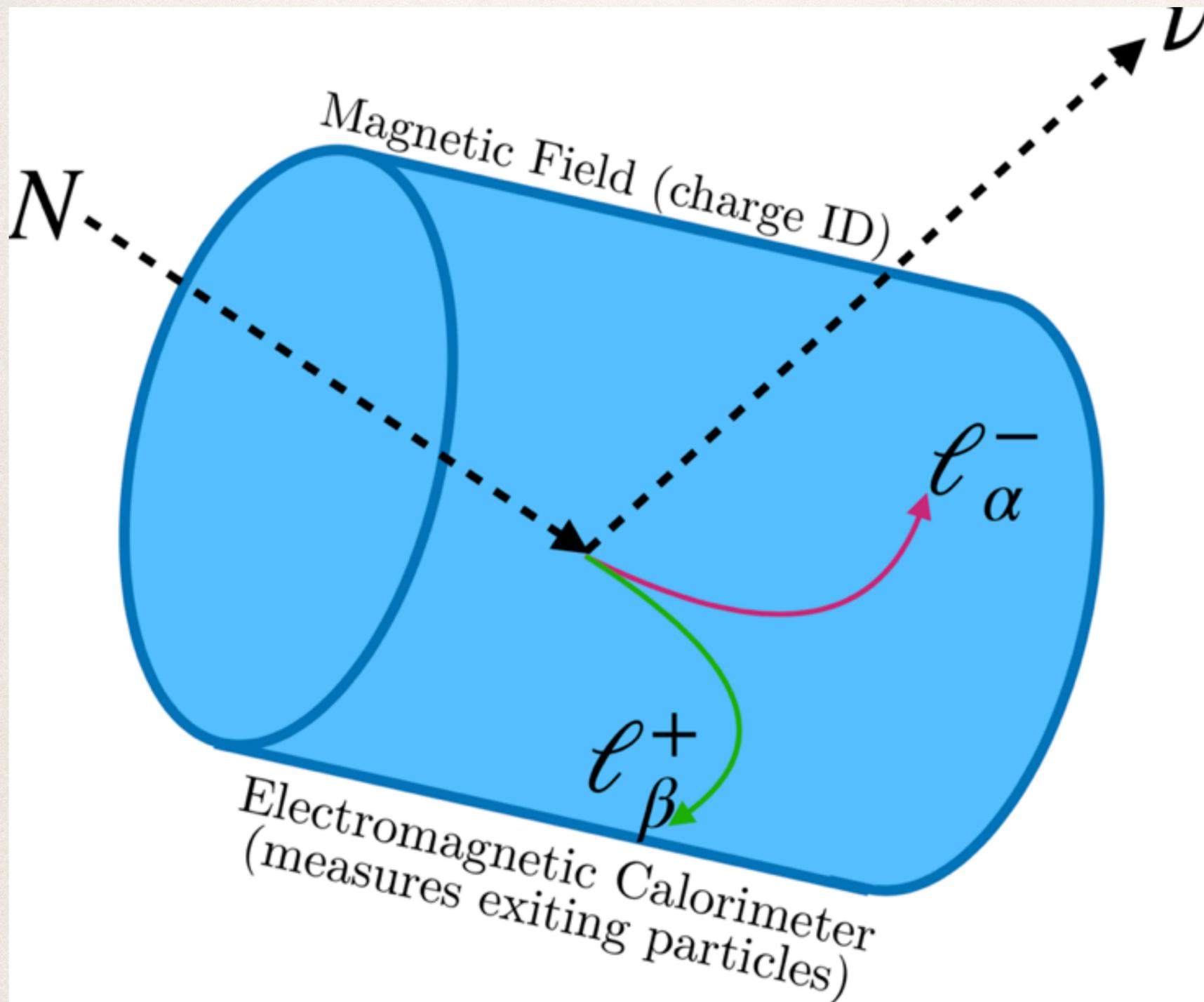
$$K^\pm \rightarrow \pi^0 \mu^\pm N$$

$$D^\pm \rightarrow \pi^0 \mu^\pm N$$

$$D_{(s)}^\pm \rightarrow \mu^\pm N$$



Decay Signature in Near Detector



- ❖ Heavy Neutrinos travel to the Gaseous Argon near detector and have some probability of decaying within.
- ❖ Several final states are “difficult” for neutrino interactions to mimic, for example,

$$N \rightarrow \nu \ell_{\beta}^{+} \ell_{\alpha}^{-}$$

$$N \rightarrow \ell_{\alpha}^{\pm} \pi^{\mp}$$

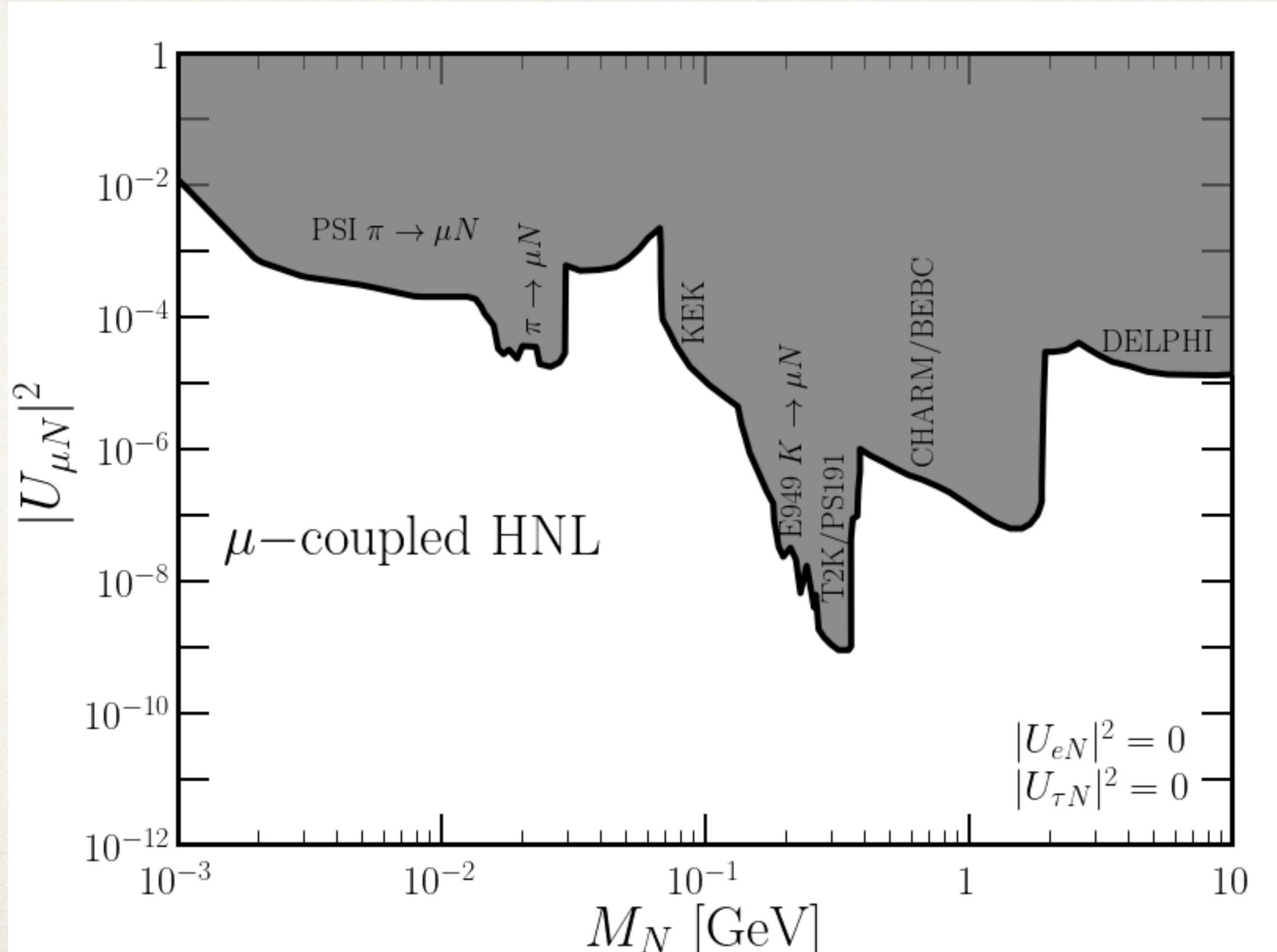
$$N \rightarrow \ell_{\alpha}^{\pm} K^{\mp}$$

$$N \rightarrow \ell_{\alpha}^{\pm} \rho^{\mp}$$

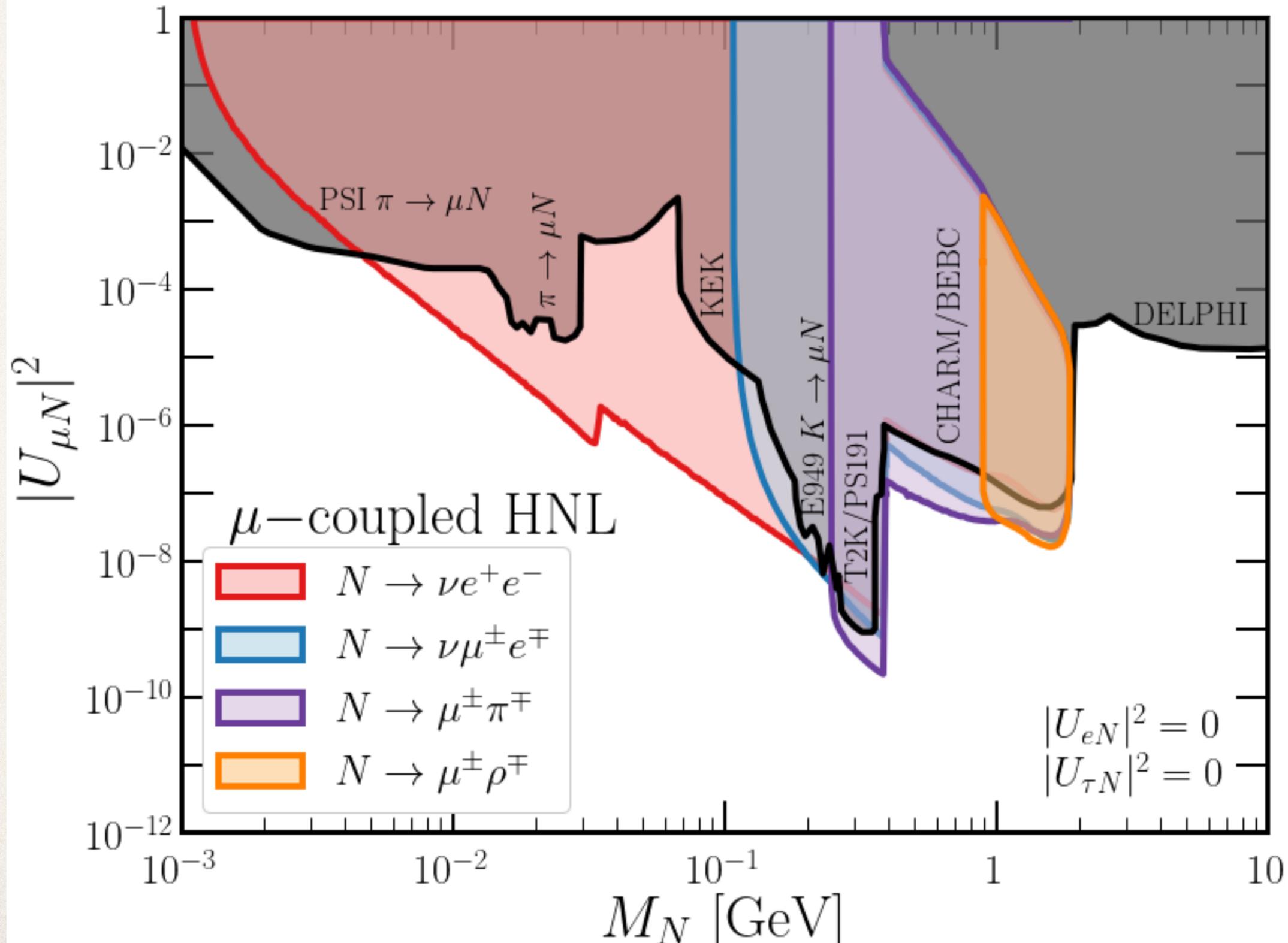
$$N \rightarrow \nu \pi^0$$

$$N \rightarrow \nu \nu \bar{\nu}$$

Existing Constraints: Muon-Coupled HNL

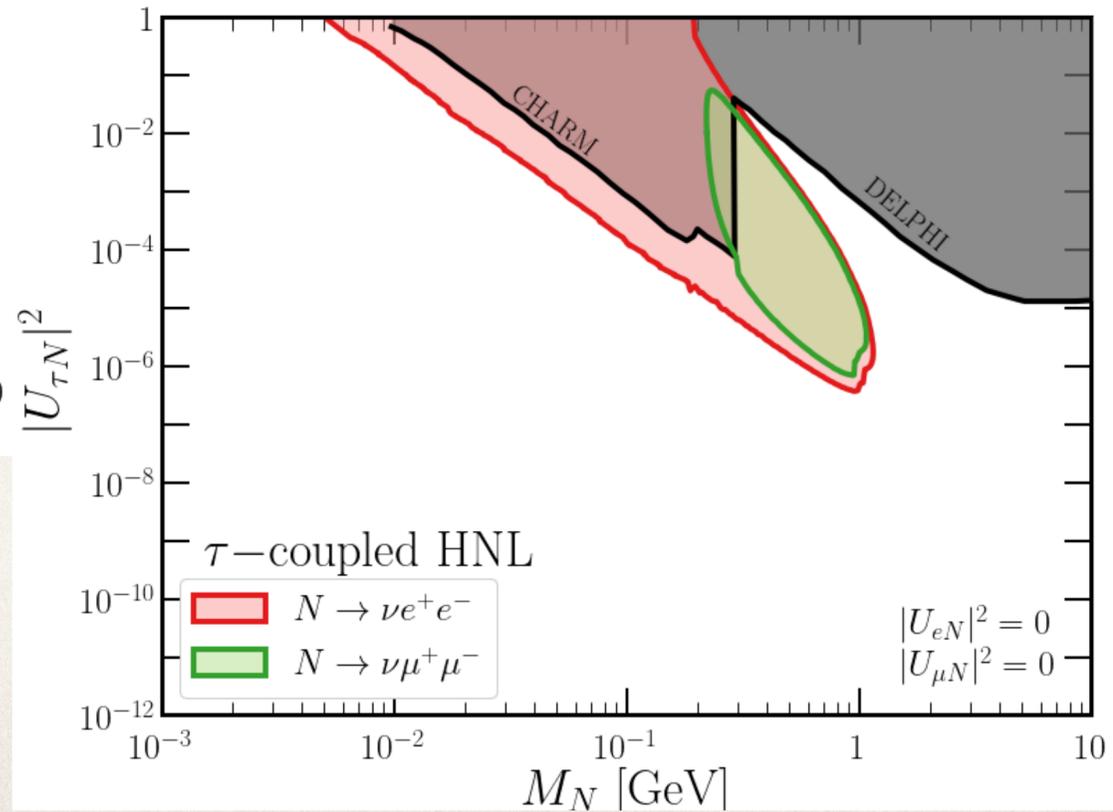
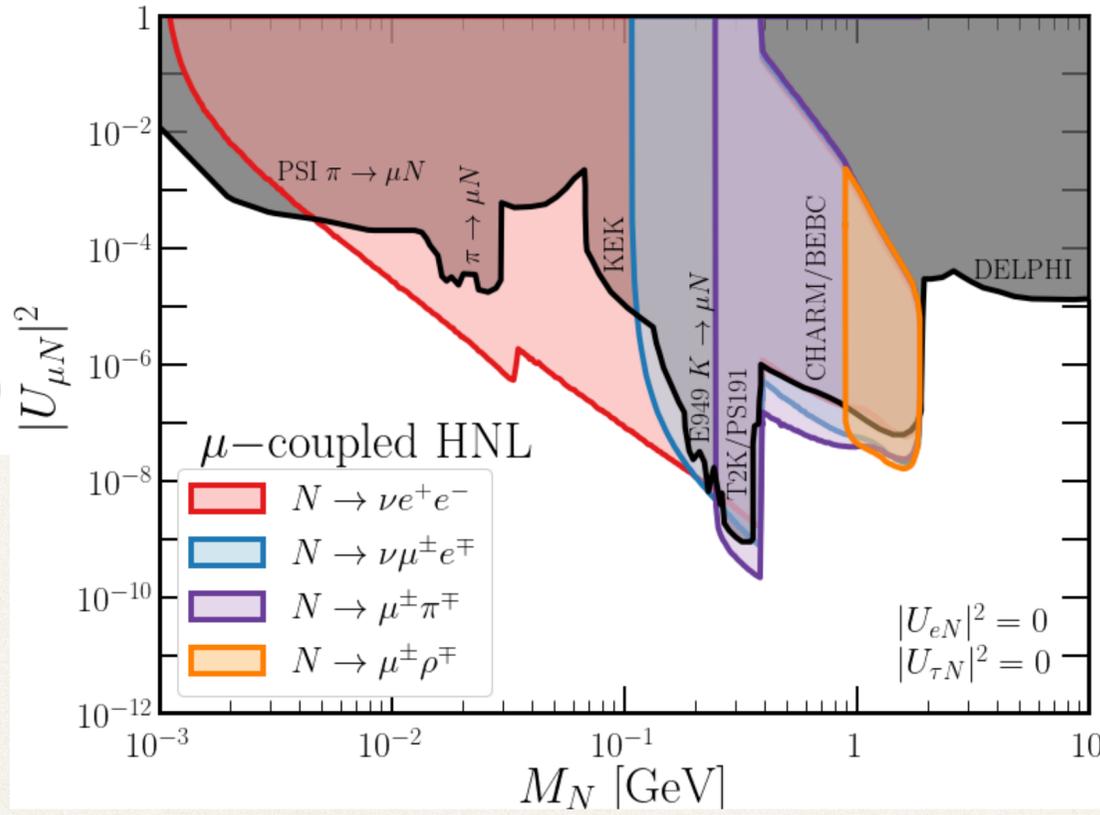
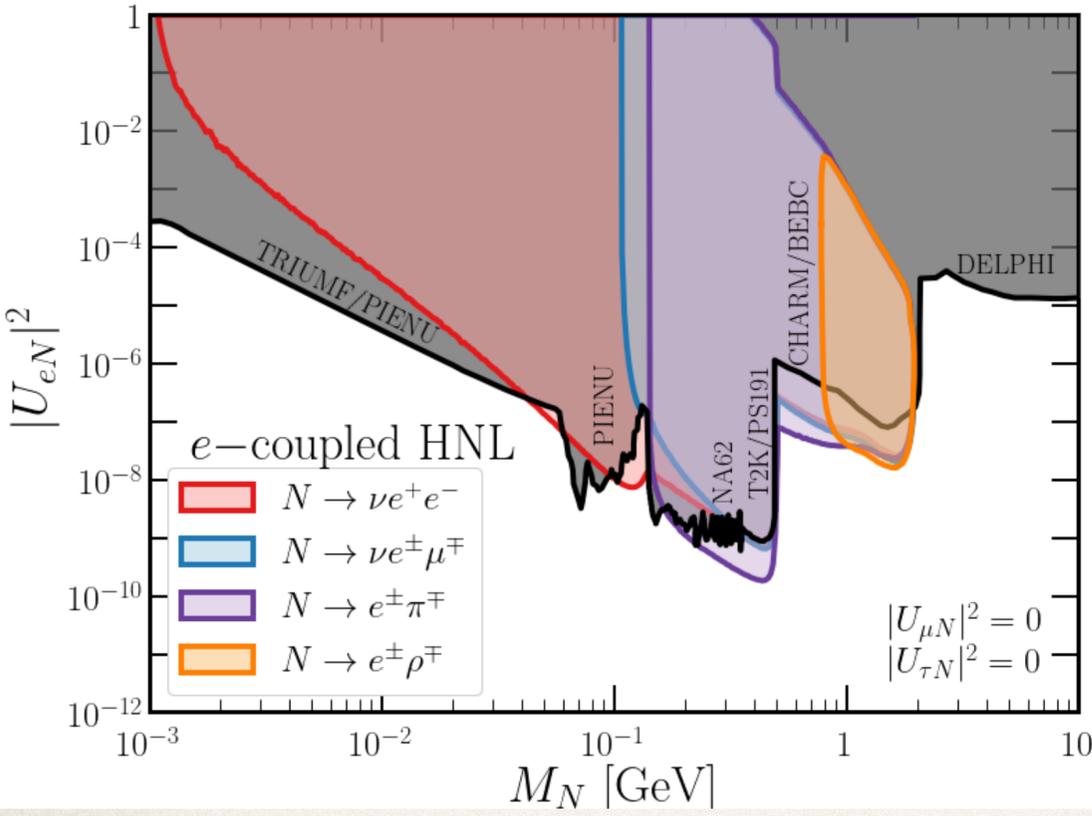


DUNE Sensitivity: Muon-Coupled HNL



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

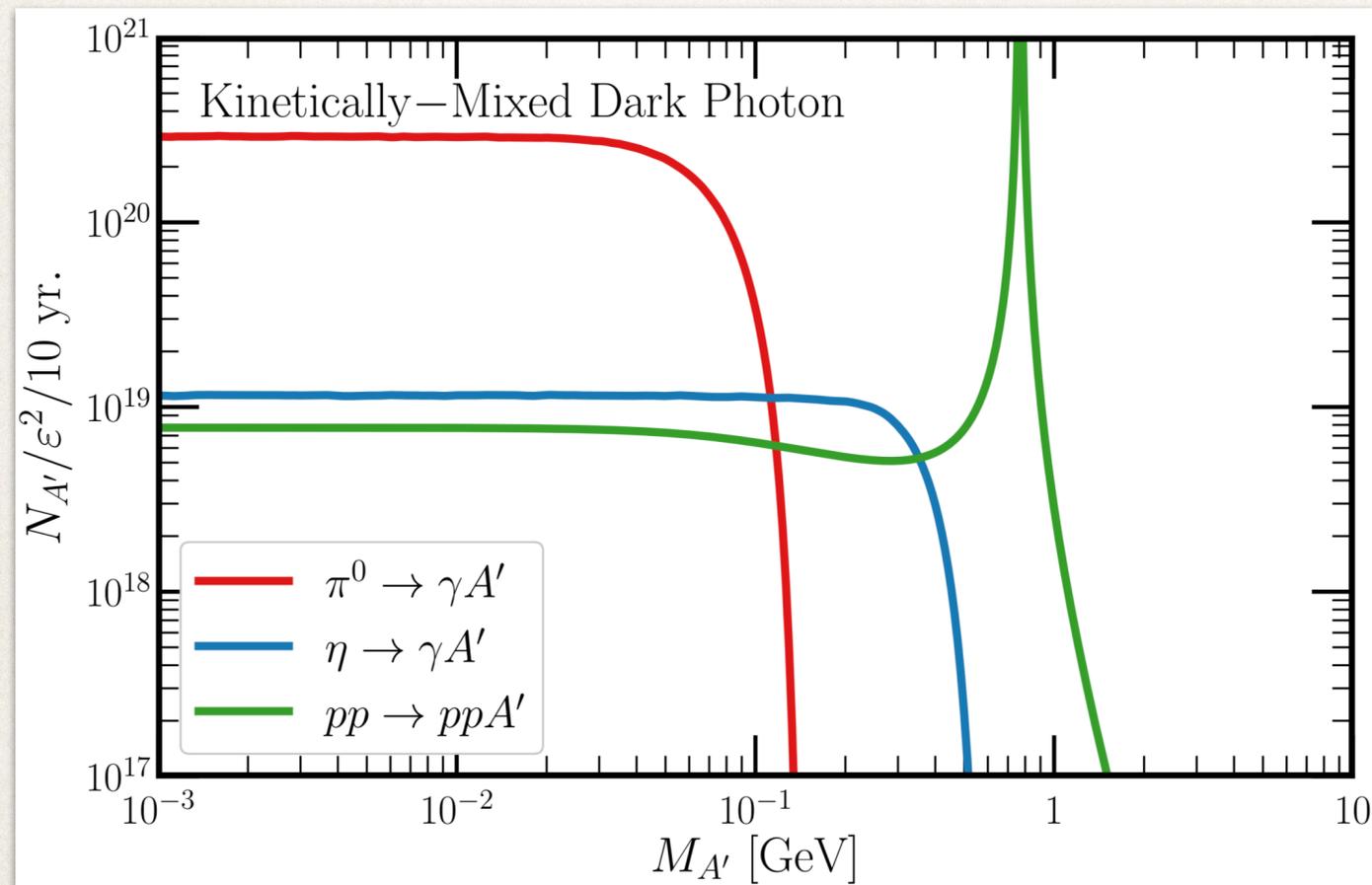
DUNE Sensitivity, All Couplings



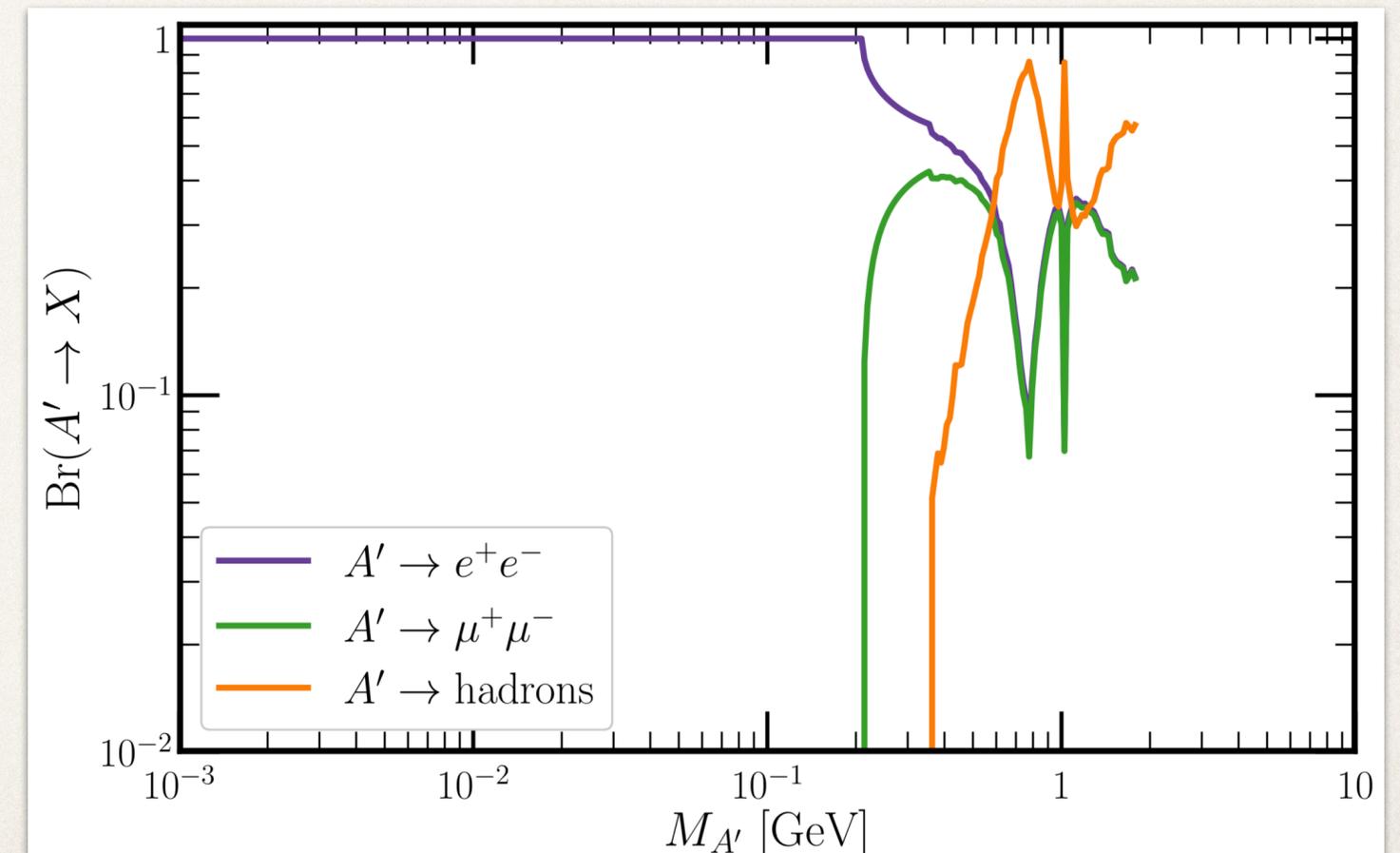
Non-Focused Scenario: Dark Photons

Dark Photons at Beam Dumps

- ❖ Assume a new, massive vector boson that mixes with the Standard Model photon. It can be relatively long-lived, potentially long enough to travel from the DUNE target to the near detector hall.



Production



Detection

Signal vs. Background

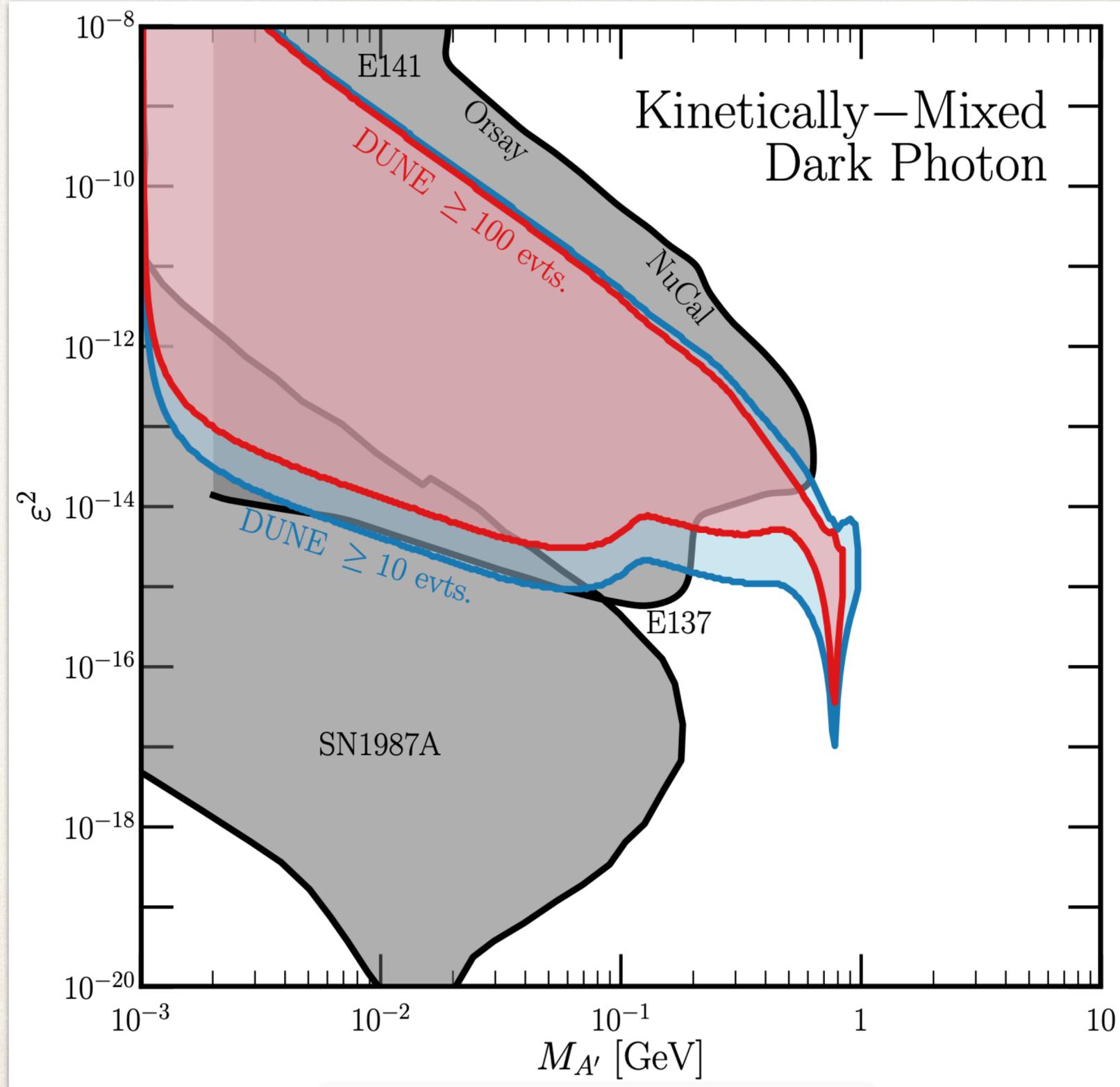
$$A' \rightarrow e^+ e^-$$

- ❖ Dominant background will come from neutral current pion production, where the pion decays into two photons, one is missed, and the other is misidentified as an electron.
 - ❖ Identification of low-energy recoils, and understanding of photon/electron discrimination is critical for reducing this background
-

$$A' \rightarrow \mu^+ \mu^- / \text{hadrons}$$

- ❖ Backgrounds here will be mostly from charged-current single pion production, where the muon-pion system can be misidentified a pair of either muons or pions.
- ❖ Again, rejecting hadronic activity (none present in signal) will help greatly here.

Decaying Dark Photon Sensitivity



Summary

- ❖ Neutrino facilities have incredible capabilities for searches for non-neutrino BSM physics. Lately, near detector facilities are gaining more and more interest thanks to the high-intensity beams.
- ❖ With precision detectors, we can perform highly-sensitive searches without compromising the neutrino-related missions of these experiments.
- ❖ DUNE, in particular, will be able to improve on existing limits for — or, potentially discover — several well-motivated models, like those of Heavy Neutral Leptons and Dark Photons.

Thank you!