

The DUNE Near Detector Complex as a Beam Dump Facility

Kevin Kelly, Fermilab



Outline

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- ❖ How can neutrino facilities serve as beam-dump facilities?

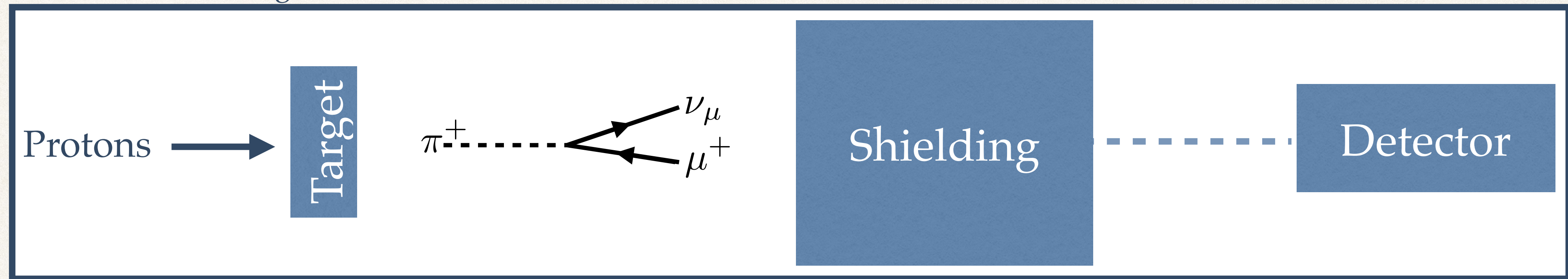
Outline

- ❖ How can neutrino facilities serve as beam-dump facilities?
- ❖ What kinds of new physics can the DUNE Near Detector search for in this context?

Oscillation Experiments & Near Detectors

Many present-day experiments operate similar to the original method used to discover the muon neutrino:

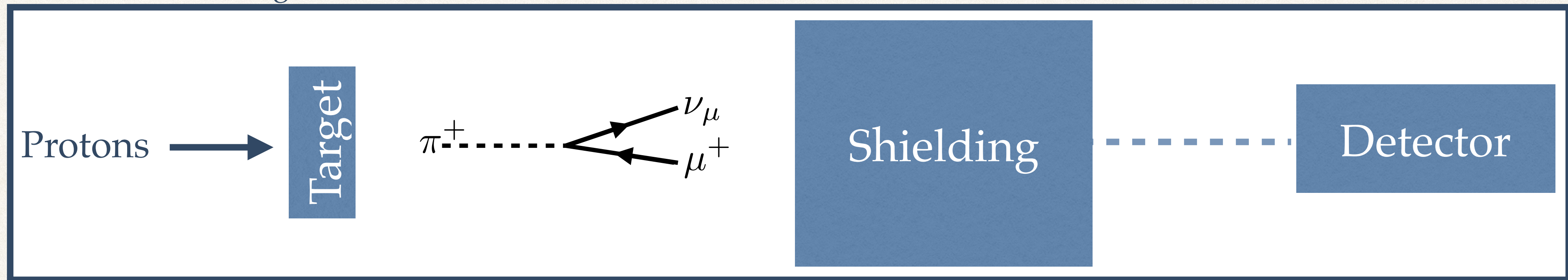
Lederman, Steinberger, Schwartz 1962



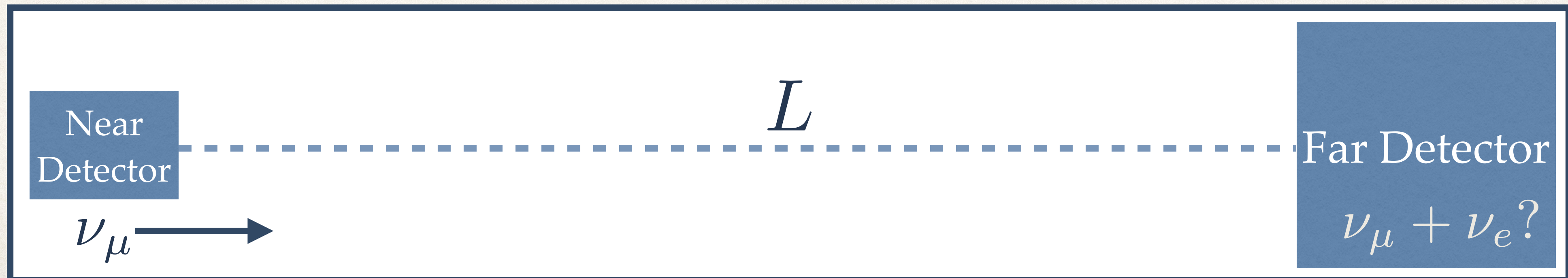
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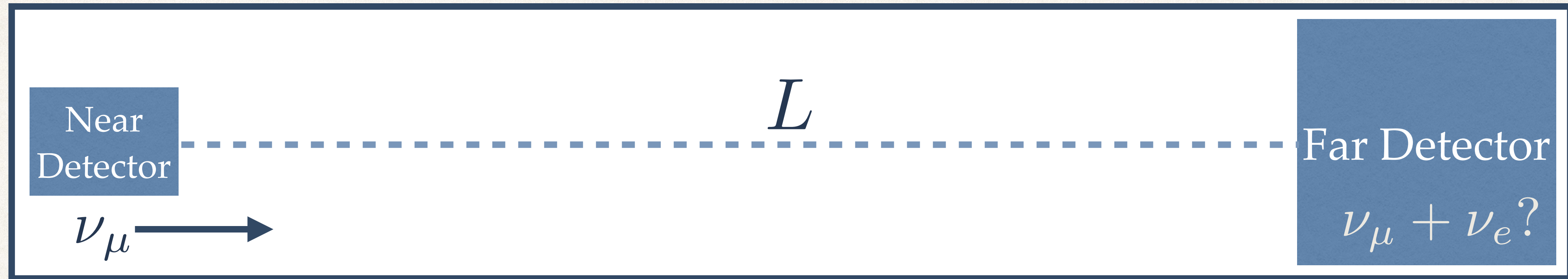
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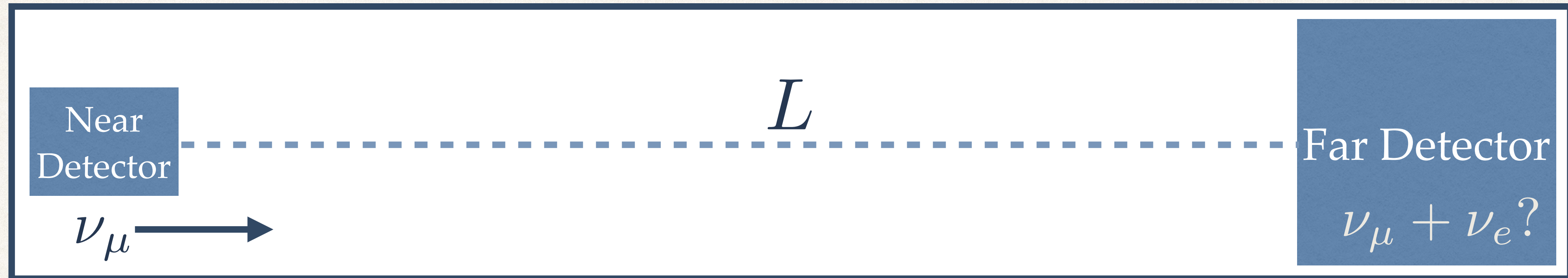
- ❖ Near detector and far detector measurements of flavor composition...



Oscillation Experiments & Near Detectors



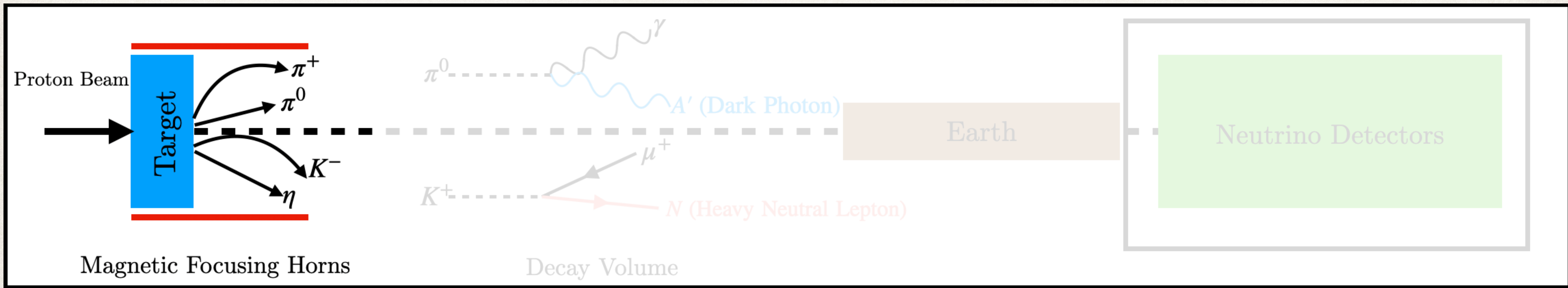
Oscillation Experiments & Near Detectors



$$\frac{\Phi_{\nu_\mu}(L)}{\Phi_{\nu_\mu}(0)} = P(\nu_\mu \rightarrow \nu_\mu) \quad \text{"Disappearance" or "Survival" Probability}$$
$$\frac{\Phi_{\nu_e}(L)}{\Phi_{\nu_\mu}(0)} = P(\nu_\mu \rightarrow \nu_e) \quad \text{"Appearance" Probability}$$

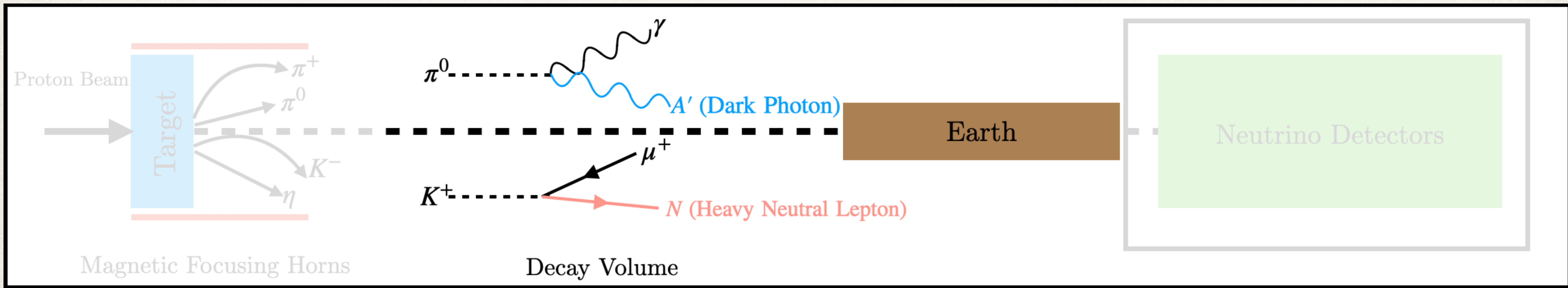
◆ Measure these probabilities, and extract information about oscillations.

How can these Near Detectors be Beam Dumps?



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

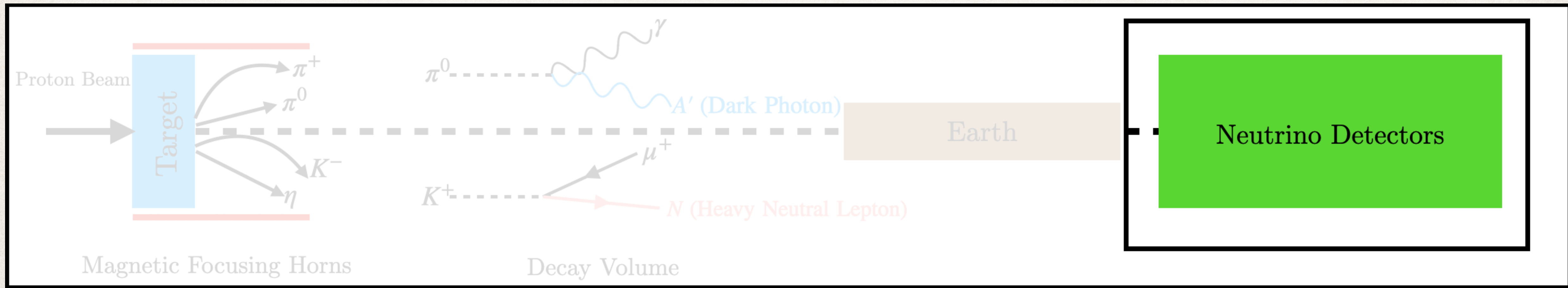
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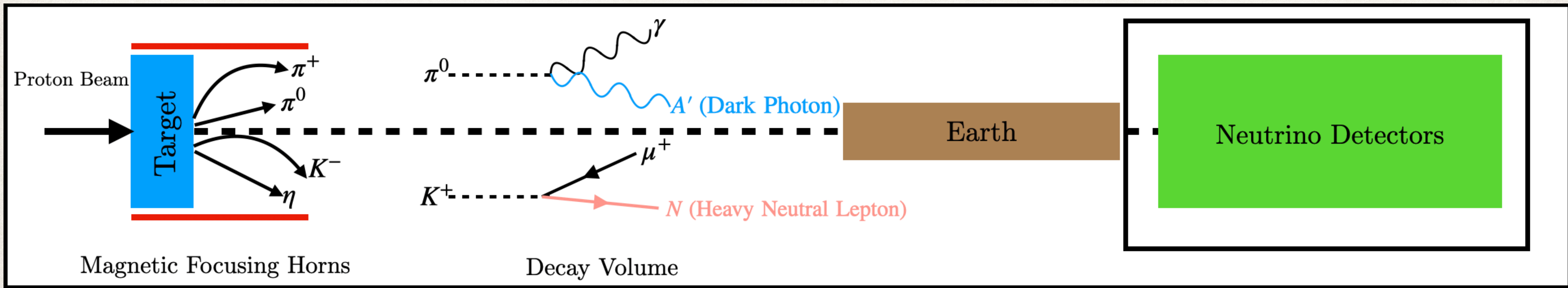


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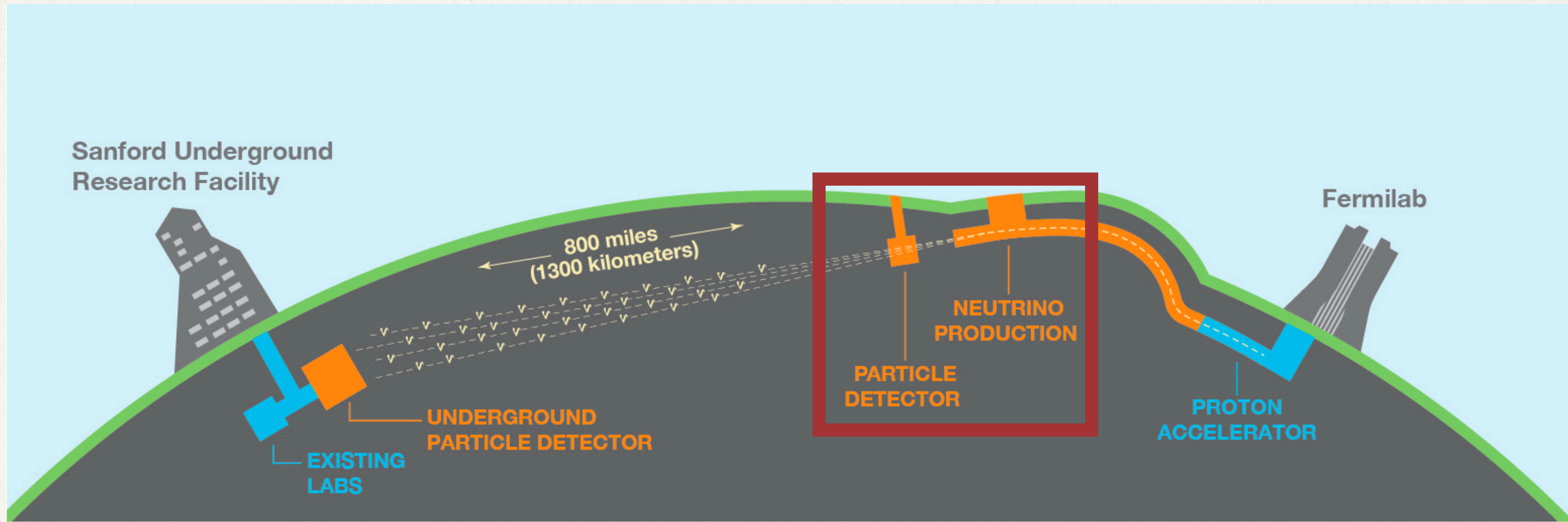


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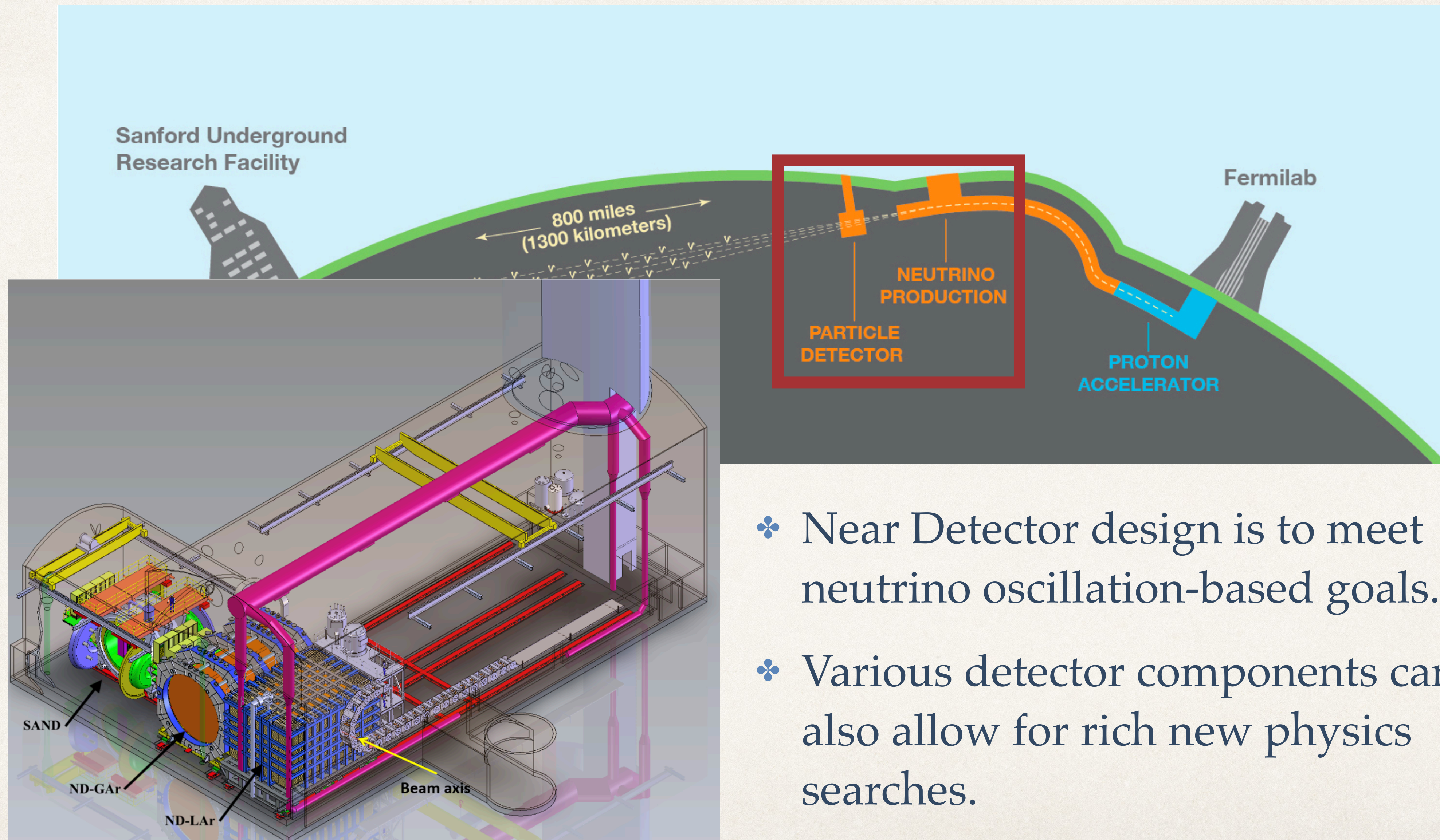
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The DUNE Near Detector Complex

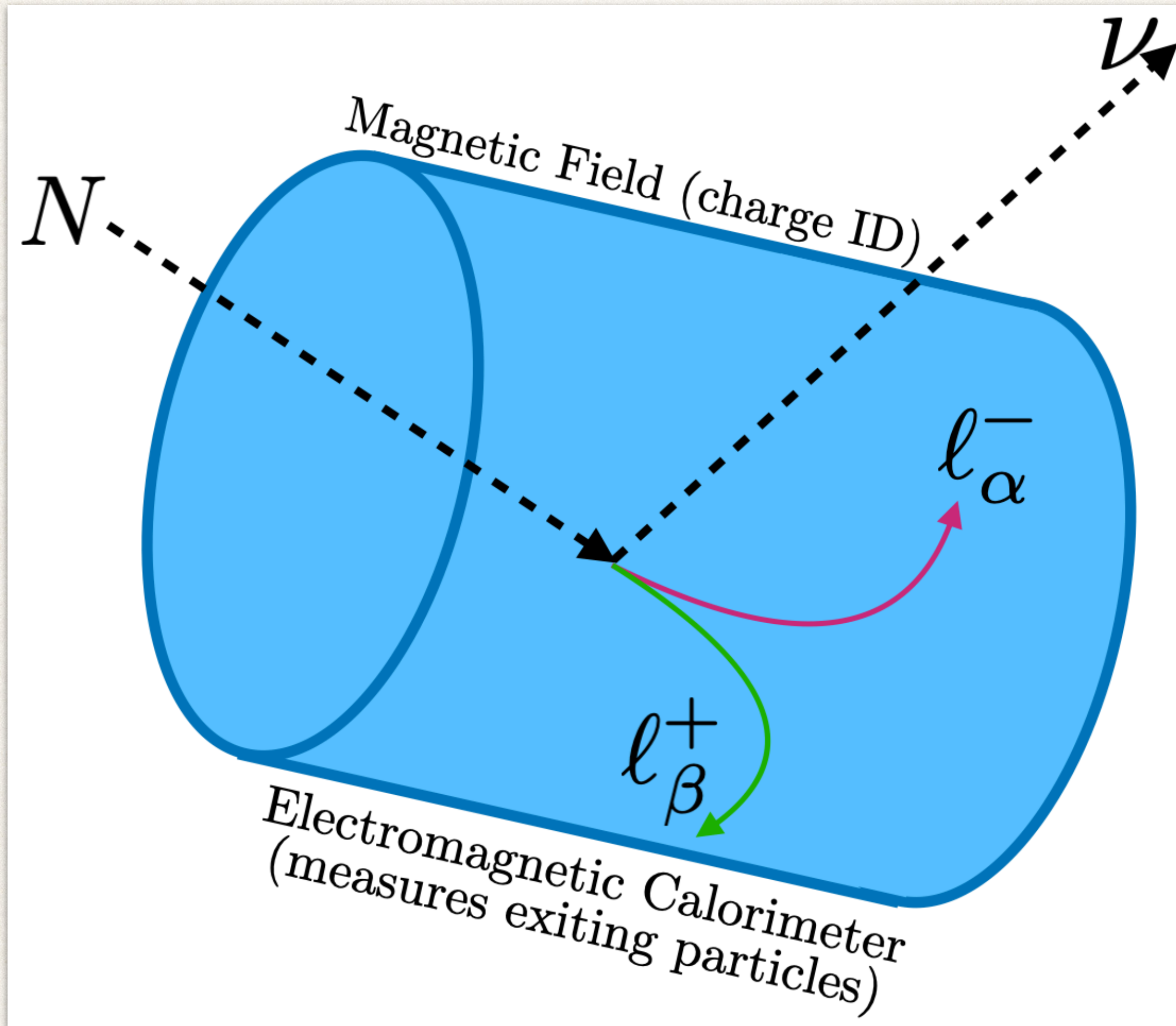


The DUNE Near Detector Complex



- ❖ Near Detector design is to meet neutrino oscillation-based goals.
- ❖ Various detector components can also allow for rich new physics searches.

Signals of rare decays

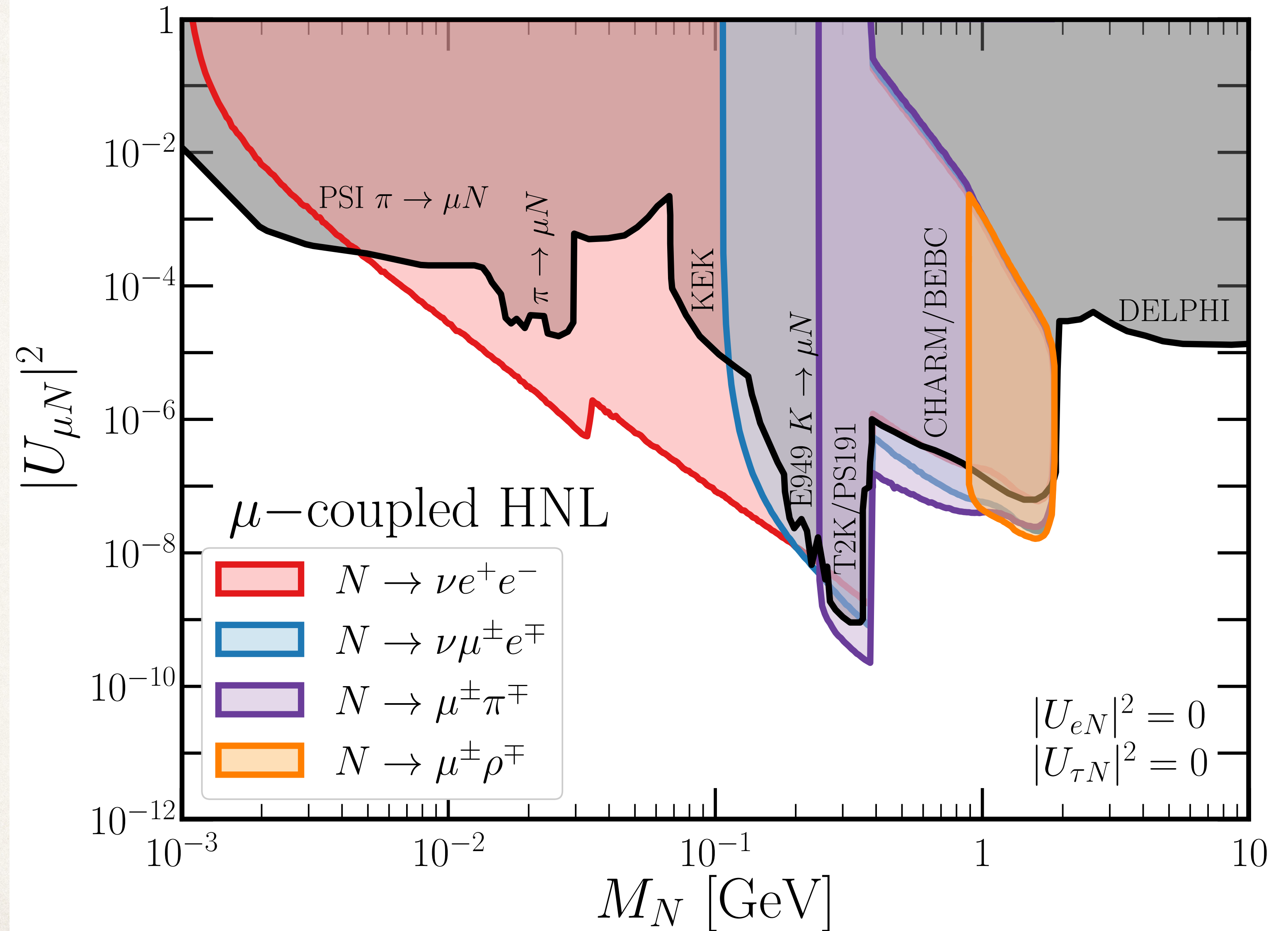


- ❖ Portal particles can decay inside of the gaseous argon detector and produce a signal that is difficult for the neutrino source to mimic.
- ❖ This includes sets of charged leptons, pions, etc.
- ❖ Low backgrounds in gaseous argon provide an ideal site to search for the rare decays.

Signal \propto Volume

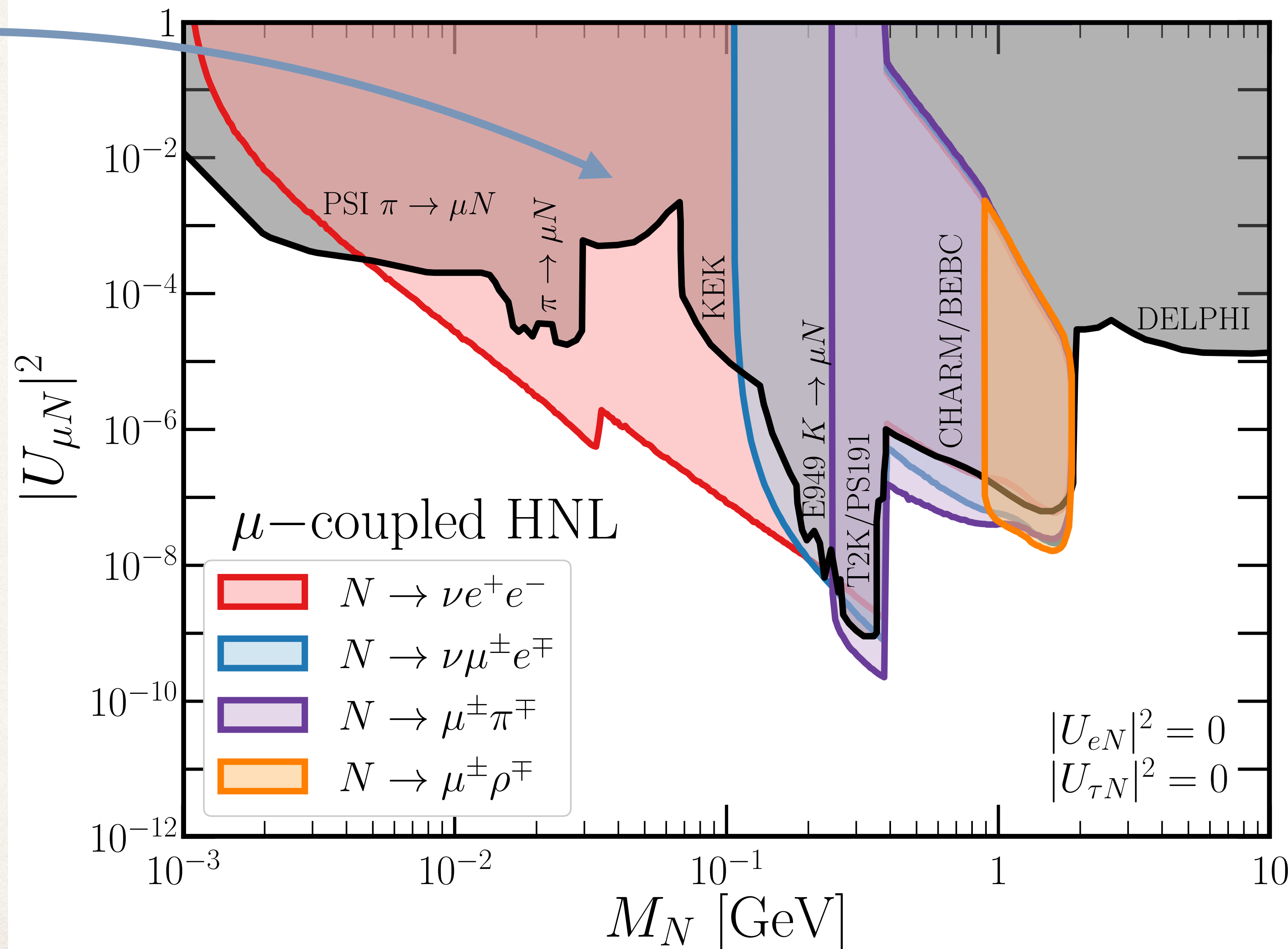
Background \propto Mass

Example: Sensitivity to Heavy Neutrinos



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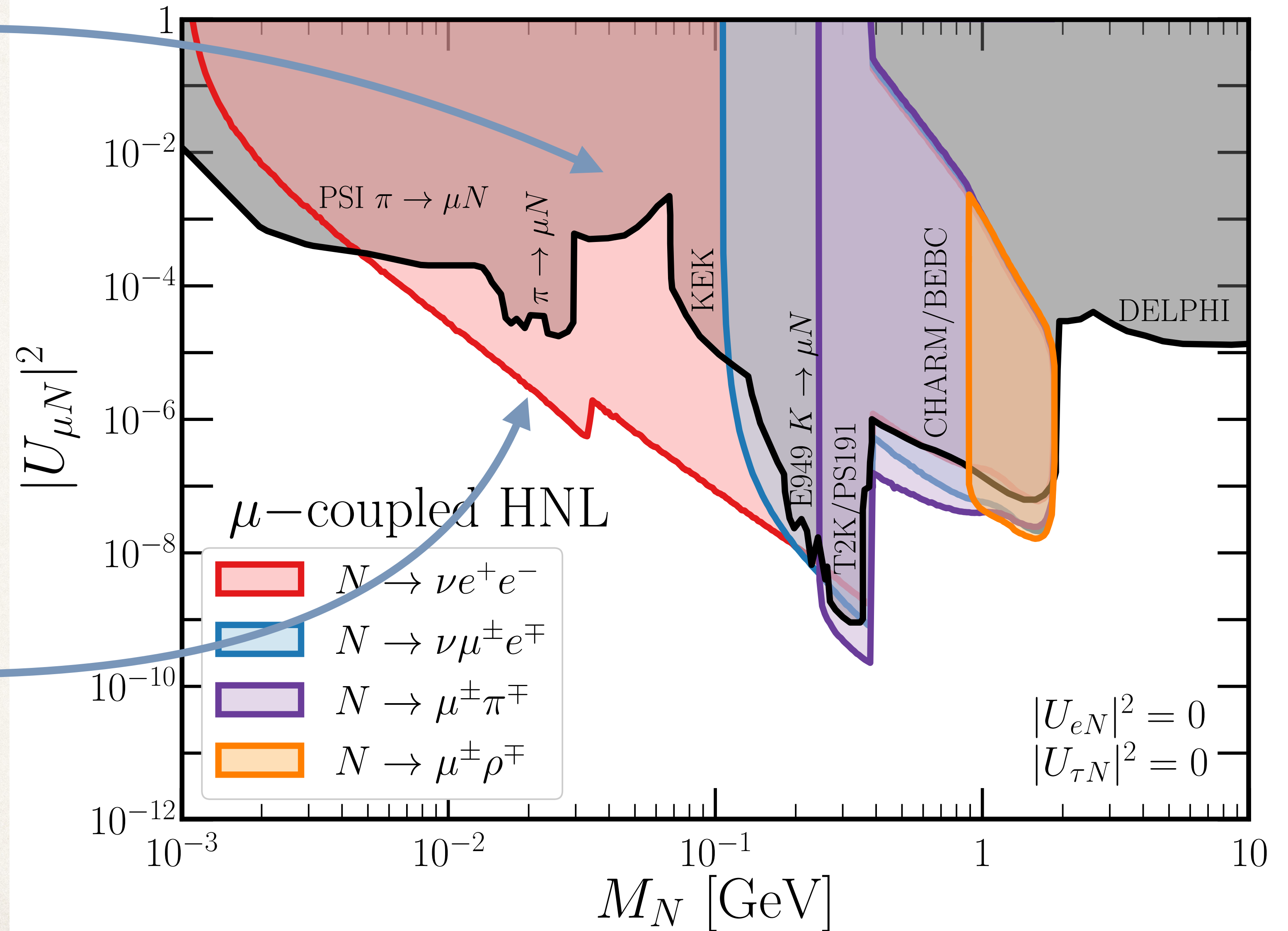
Shaded, gray regions: collection of existing constraints on this model scenario from a variety of laboratory-based measurements.



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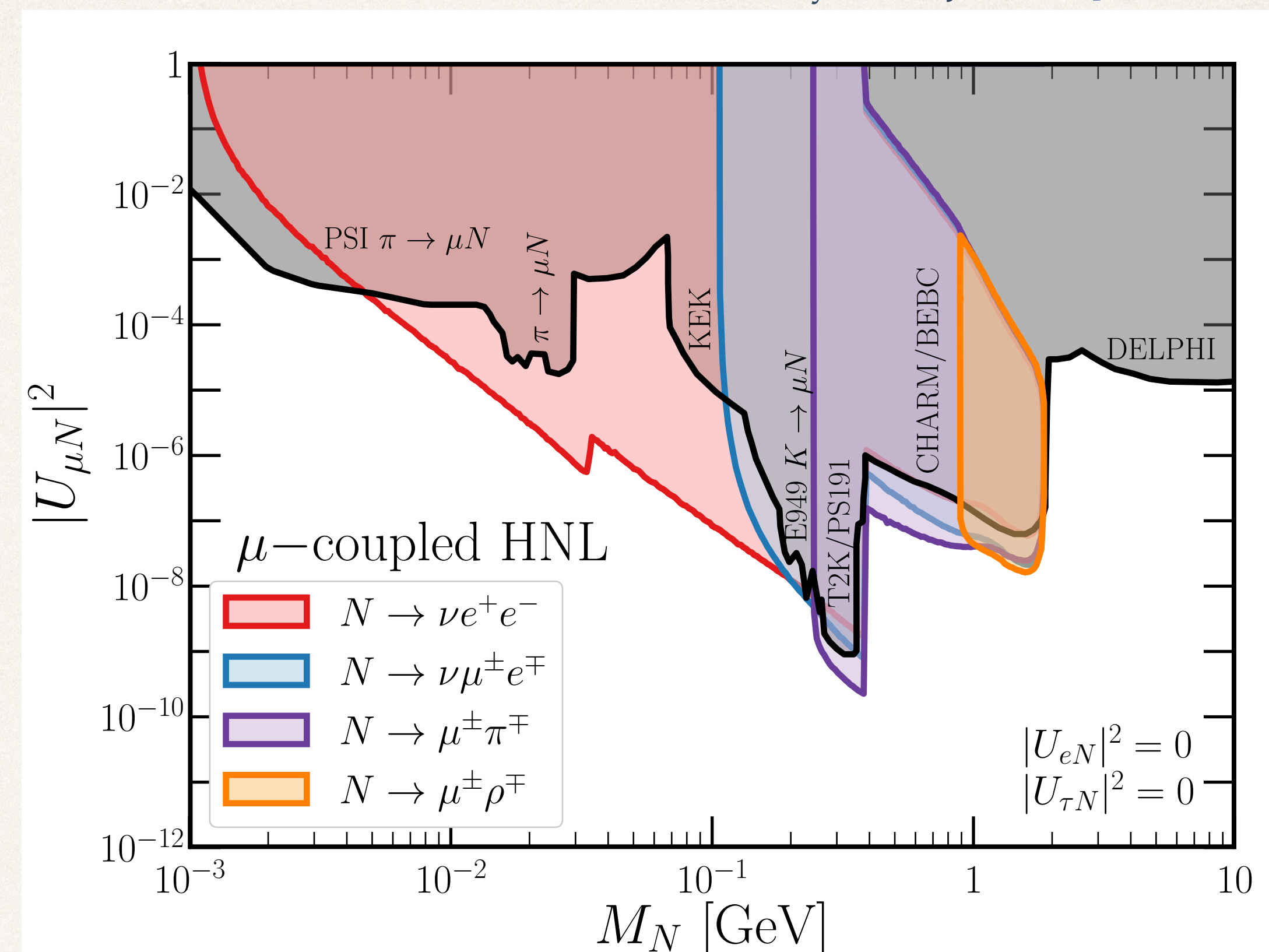
Colored regions: points in parameter space where DUNE could discover this type of particle with ten years of data. Different colors correspond to different signals in the detector.



Going Beyond Discovery?

Berryman, KJK, et al, [1912.07622]

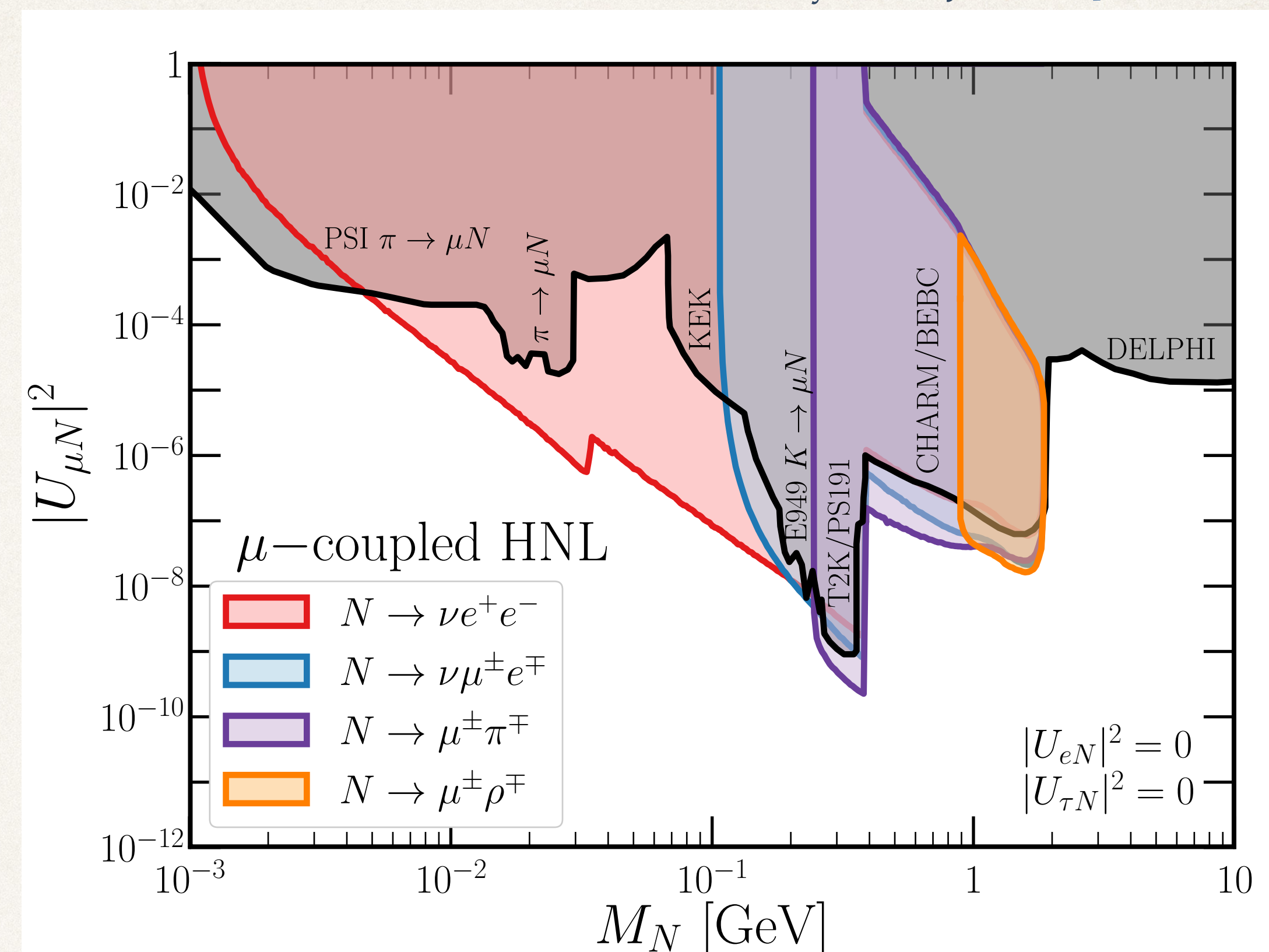
- ❖ Significant parameter space where next-generation experiments can discover these Heavy Neutral Leptons.
- ❖ If discovered, then what?
- ❖ Search for Lepton Number Violation!



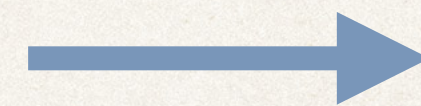
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Is Lepton Number Conserved?



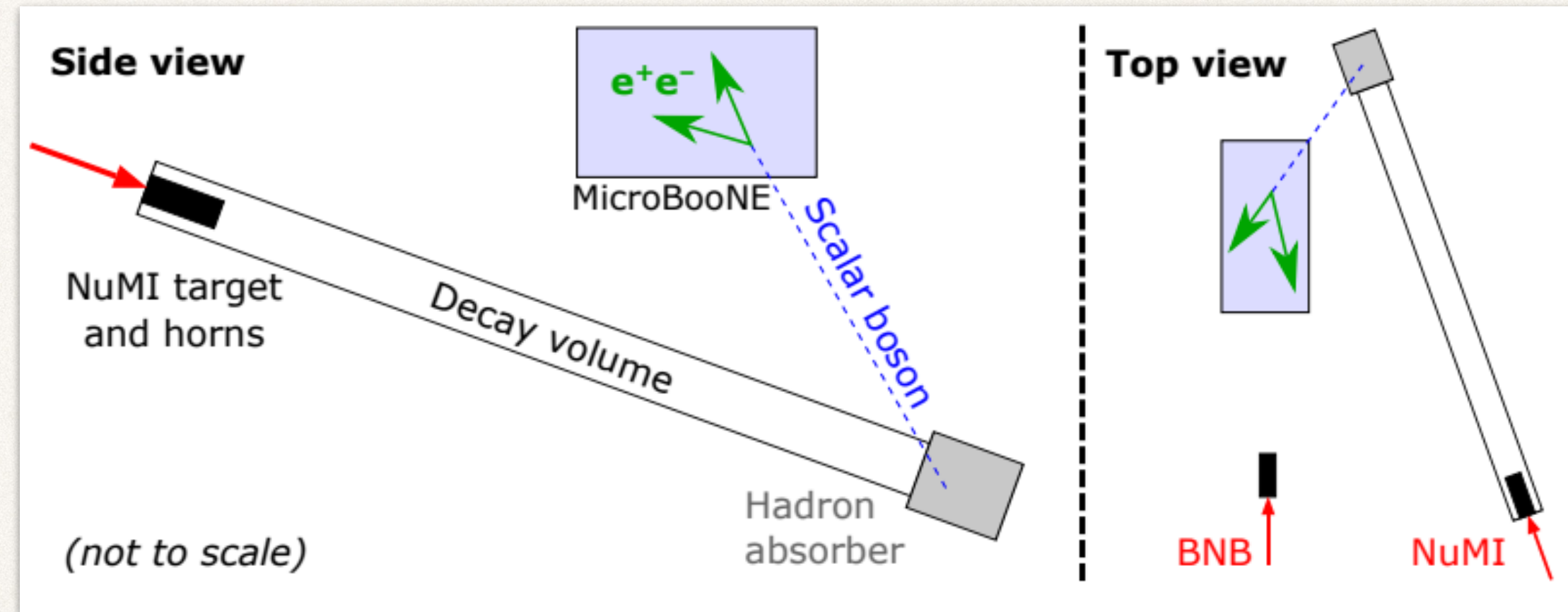
Are the HNLs their own antiparticles?



Are the SM Neutrinos *their own* antiparticles?

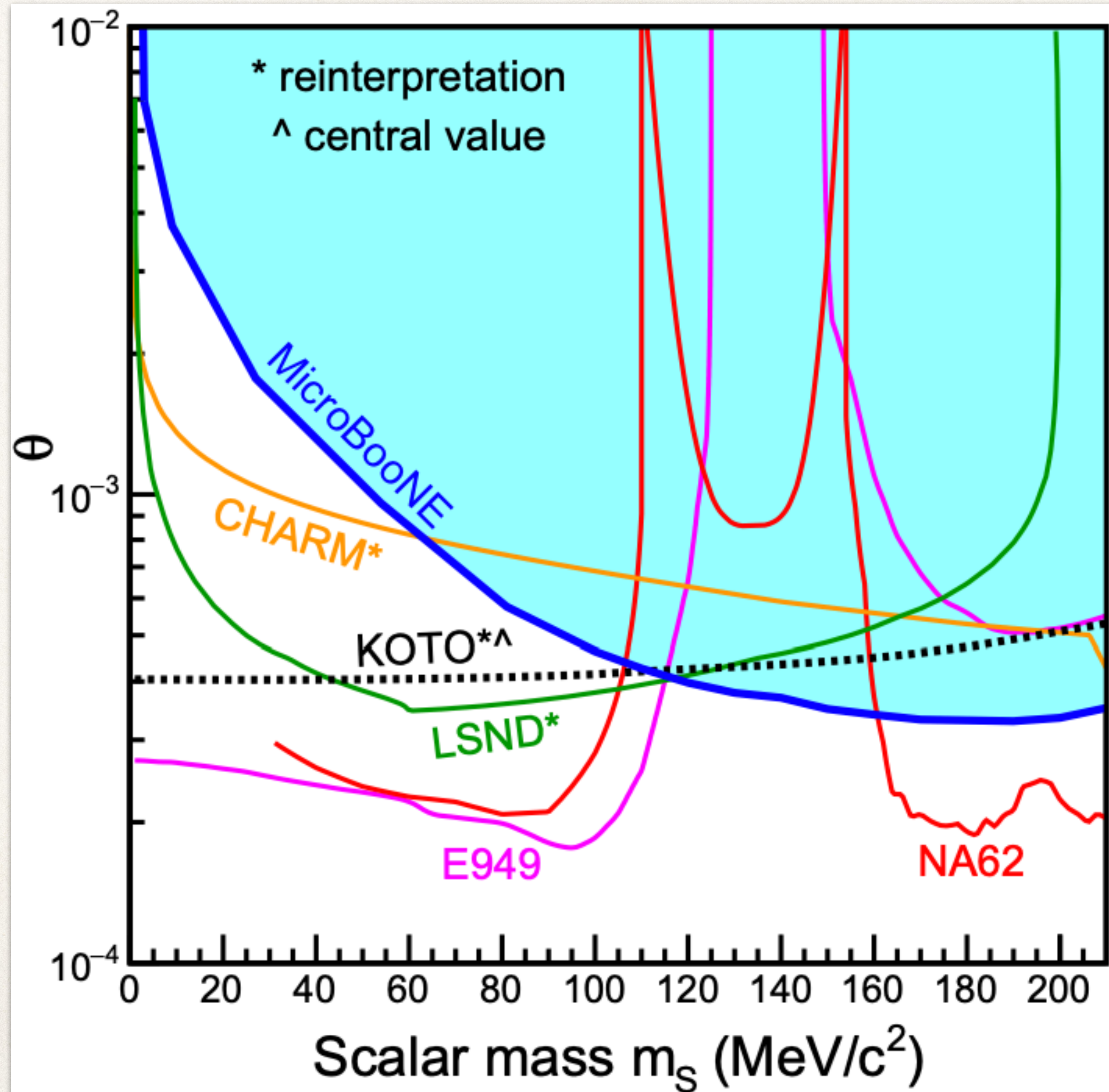
Dark Higgs Bosons

Recently, MicroBooNE [\[2106.00568\]](#) (based on Batell et al [\[1909.11670\]](#))



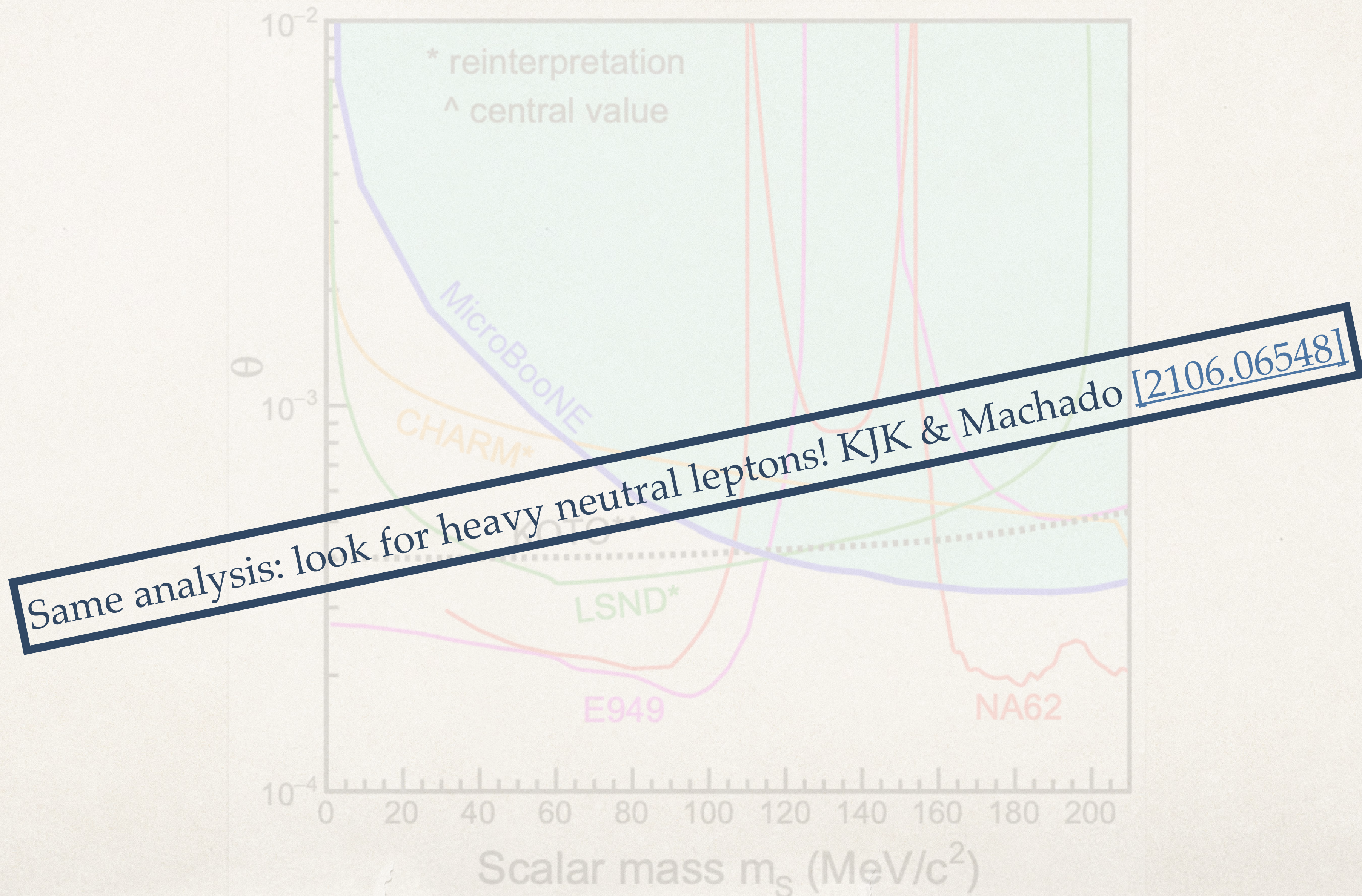
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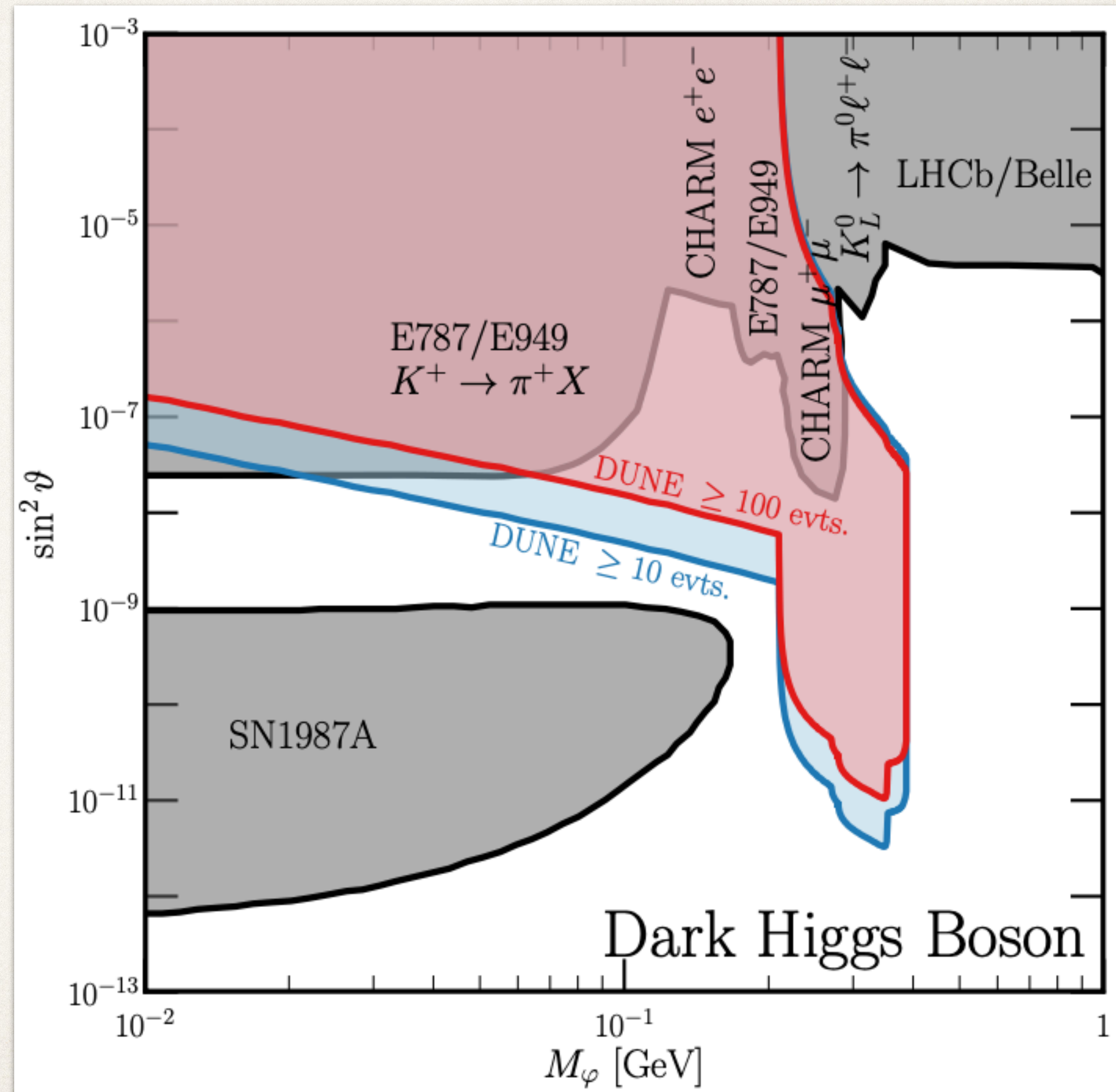
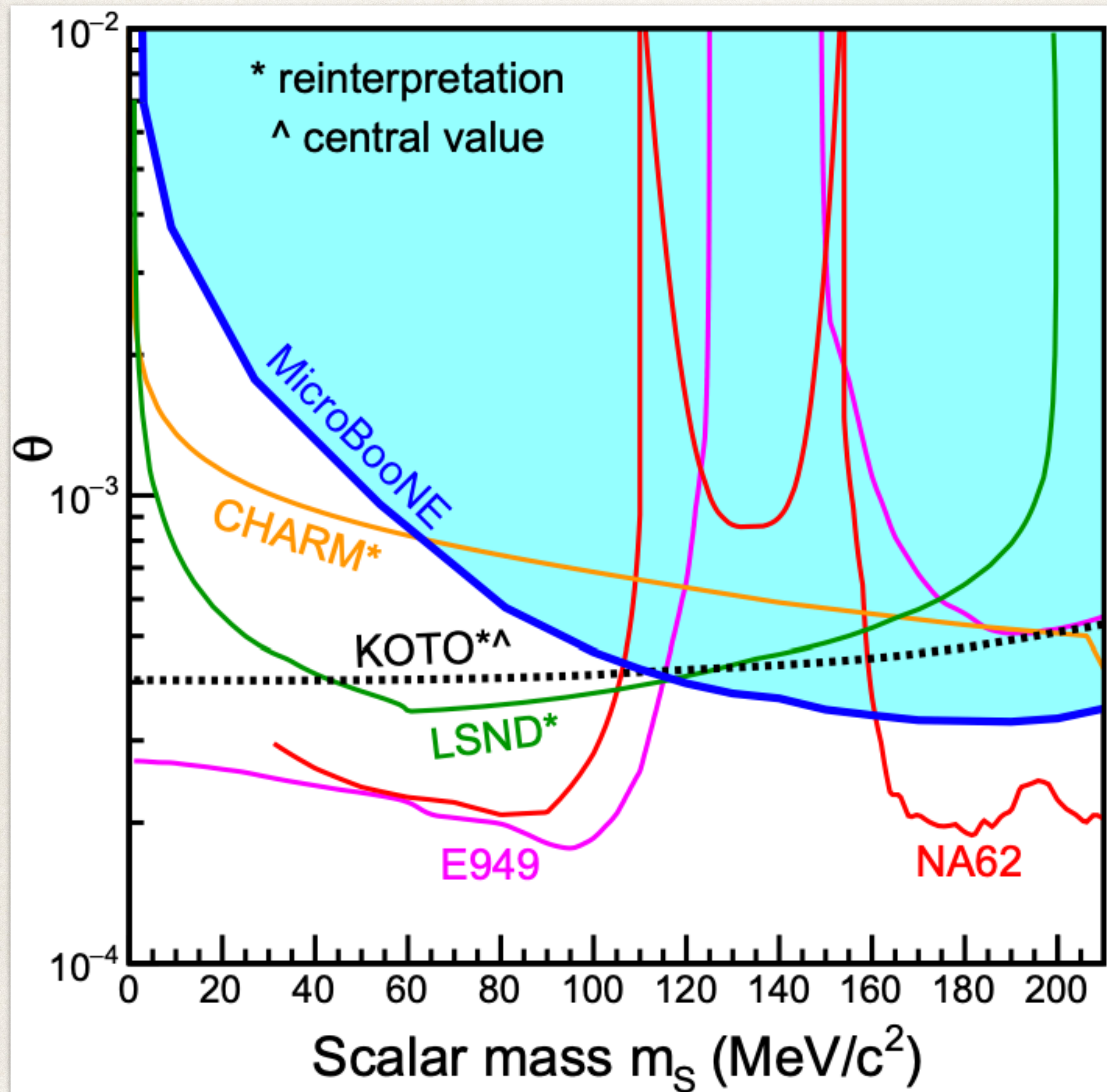
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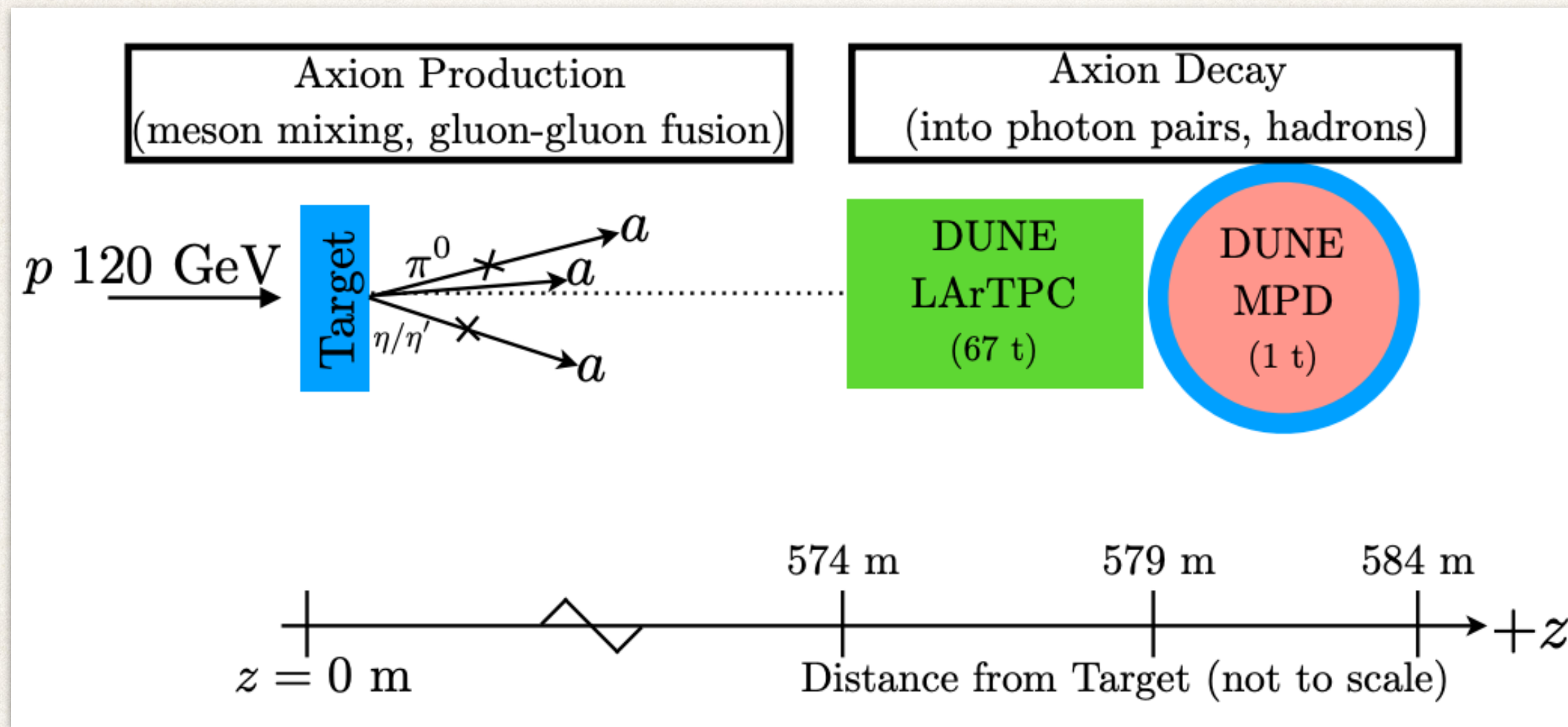
Dark Higgs Bosons @ DUNE

Berryman, KJK, et al, [1912.07622]



Axions & Axion-Like-Particles: Distinct Phenomenology

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

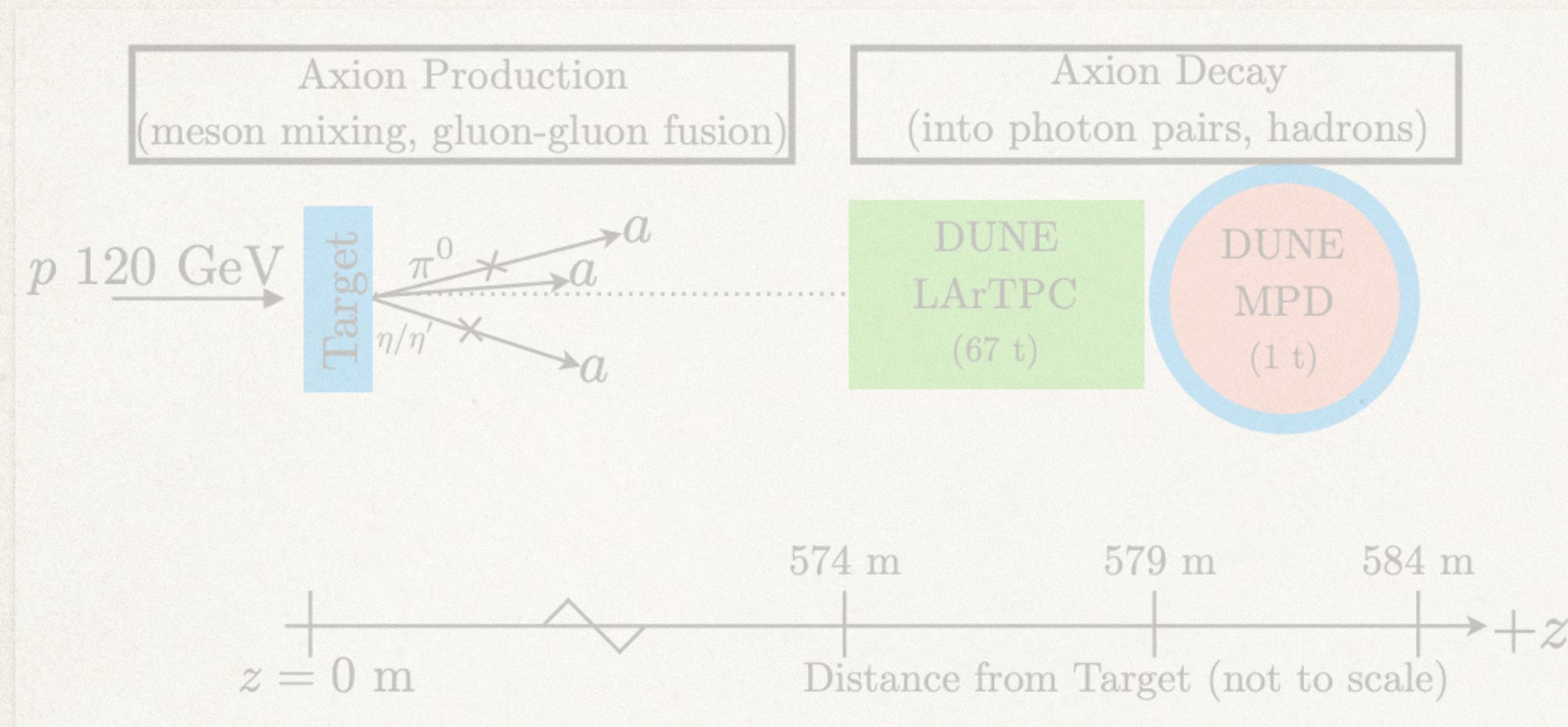


Production via *mixing* with SM mesons or gluon / gluon fusion.

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

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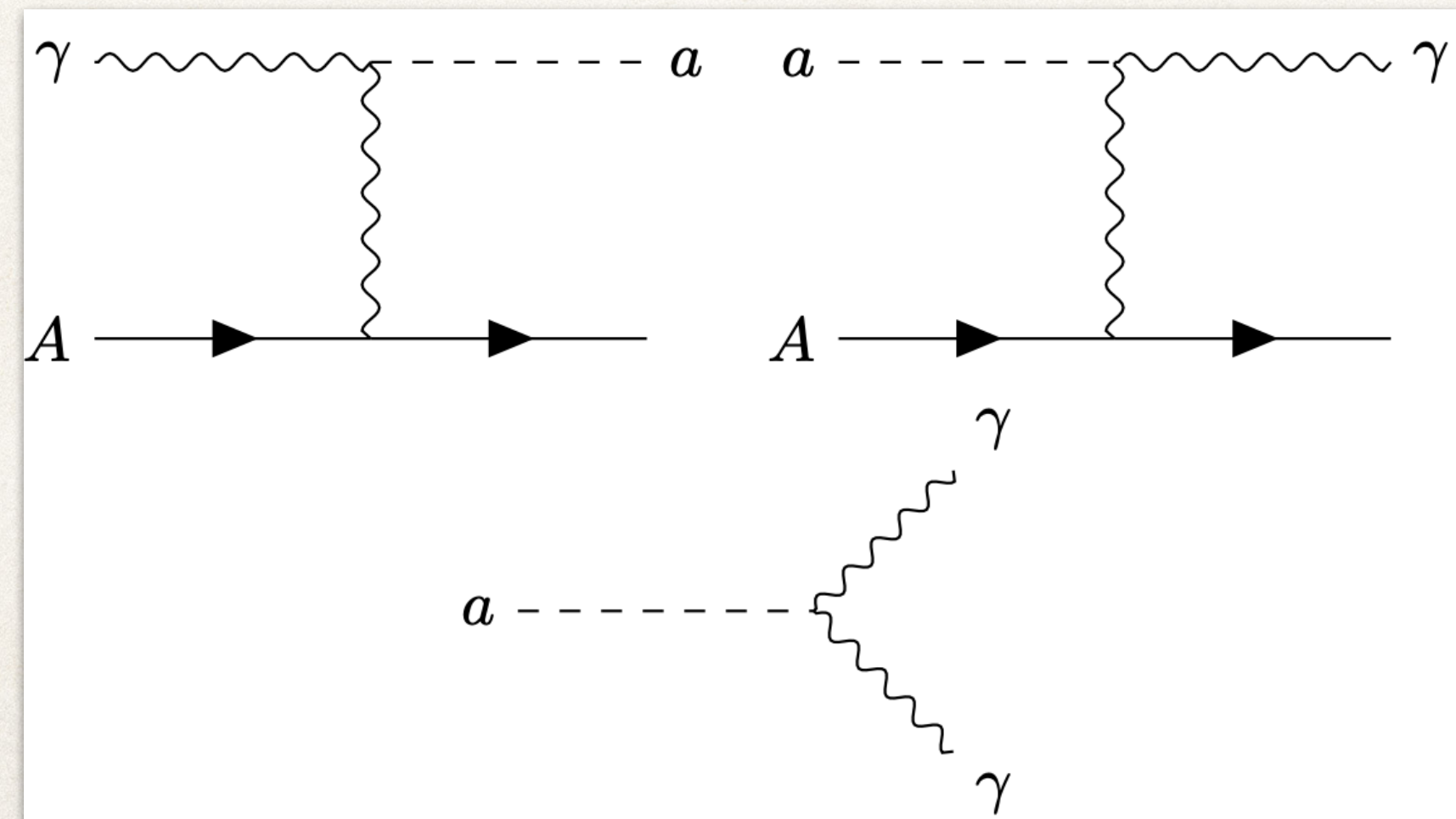
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Brdar et al [2011.07054]: “Axion-Like Particle”



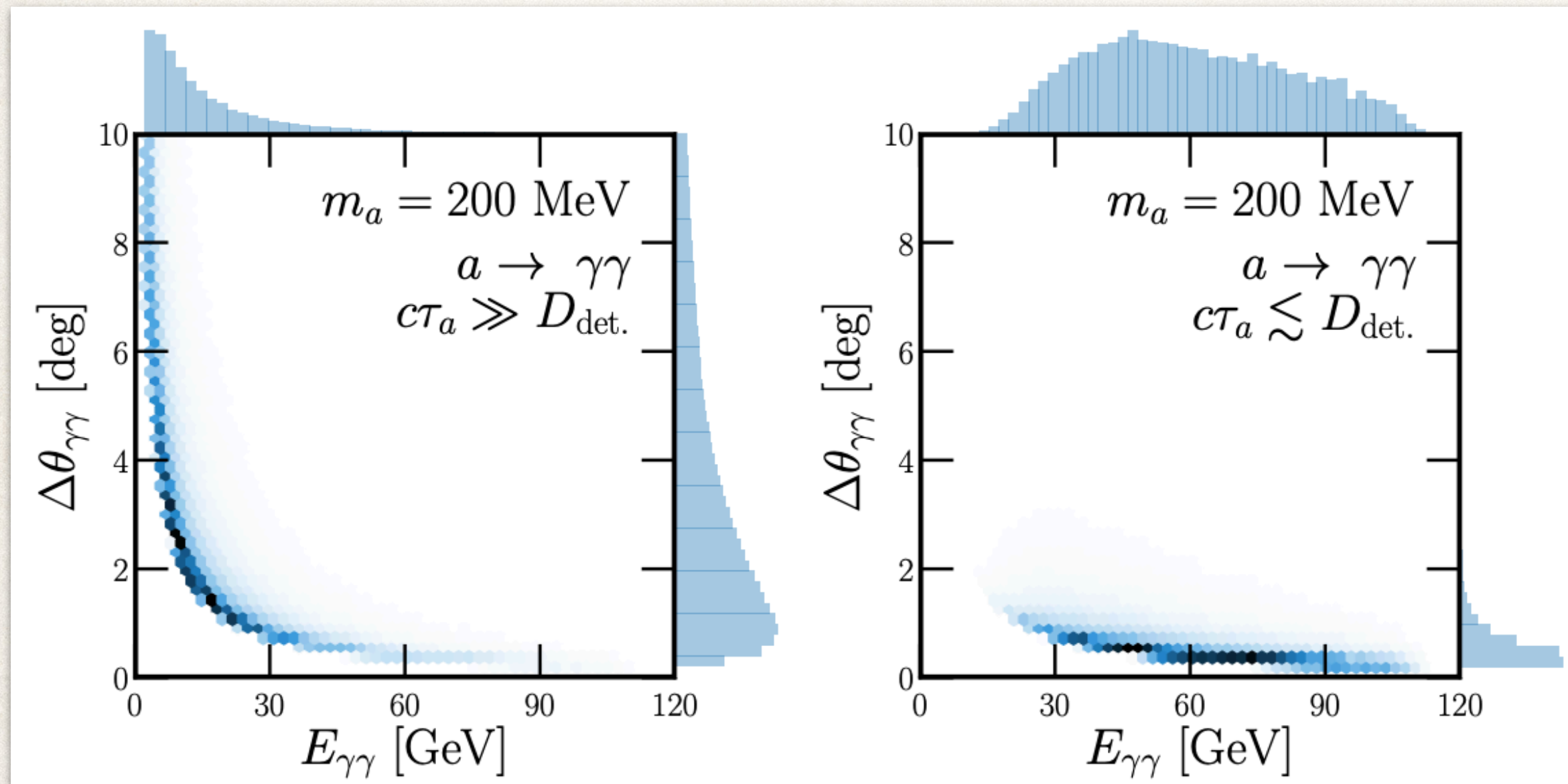
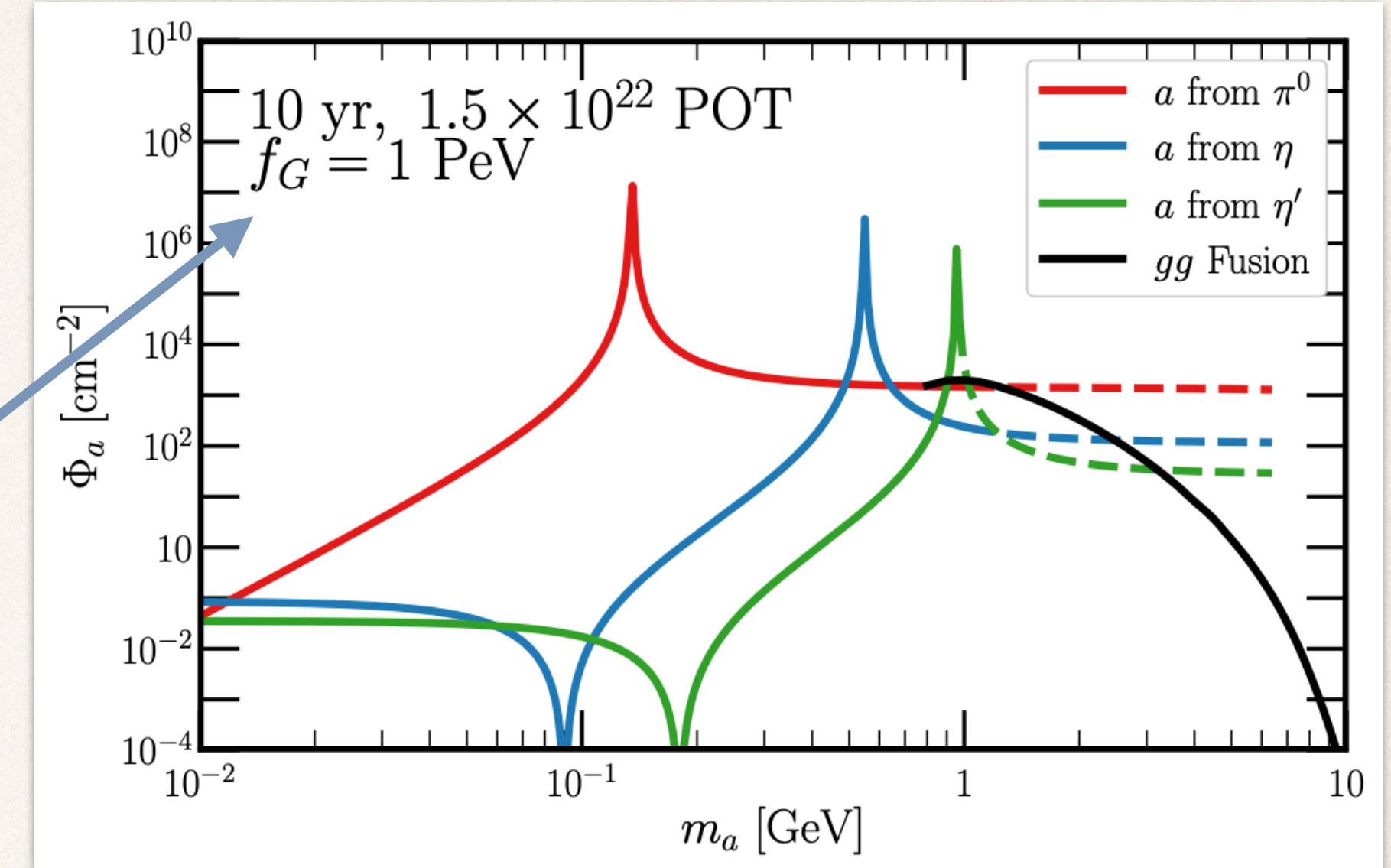
Production via *decays* of SM mesons or Primakoff scattering.

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

Heavy Axion Search

Production: either via mixing with SM mesons or gluon-gluon fusion. Peaks here are due to resonant mixing.

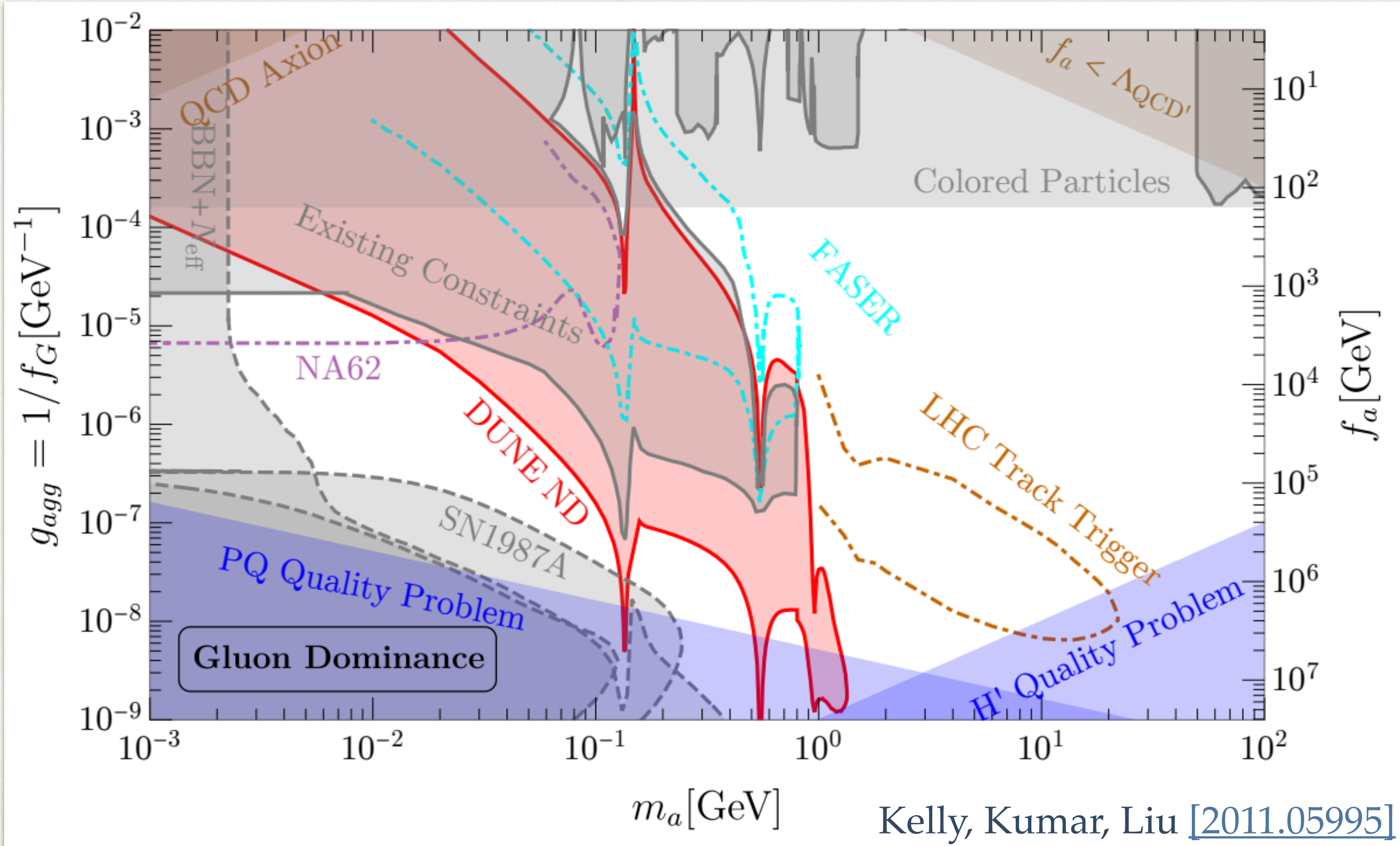
Axion decay constant



Detector Signature: A pair of high-energy photons or hadrons with a relatively small opening angle.

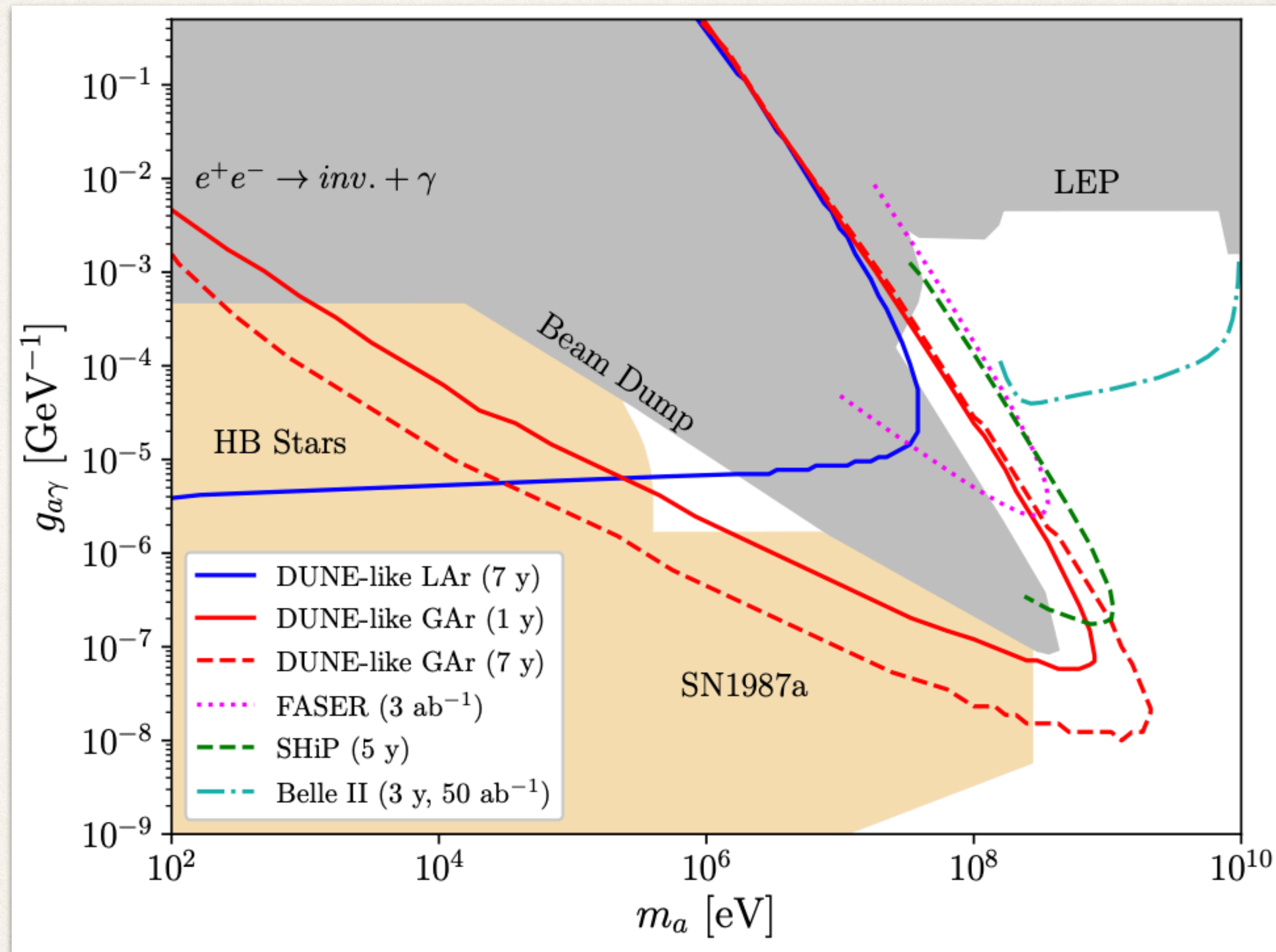
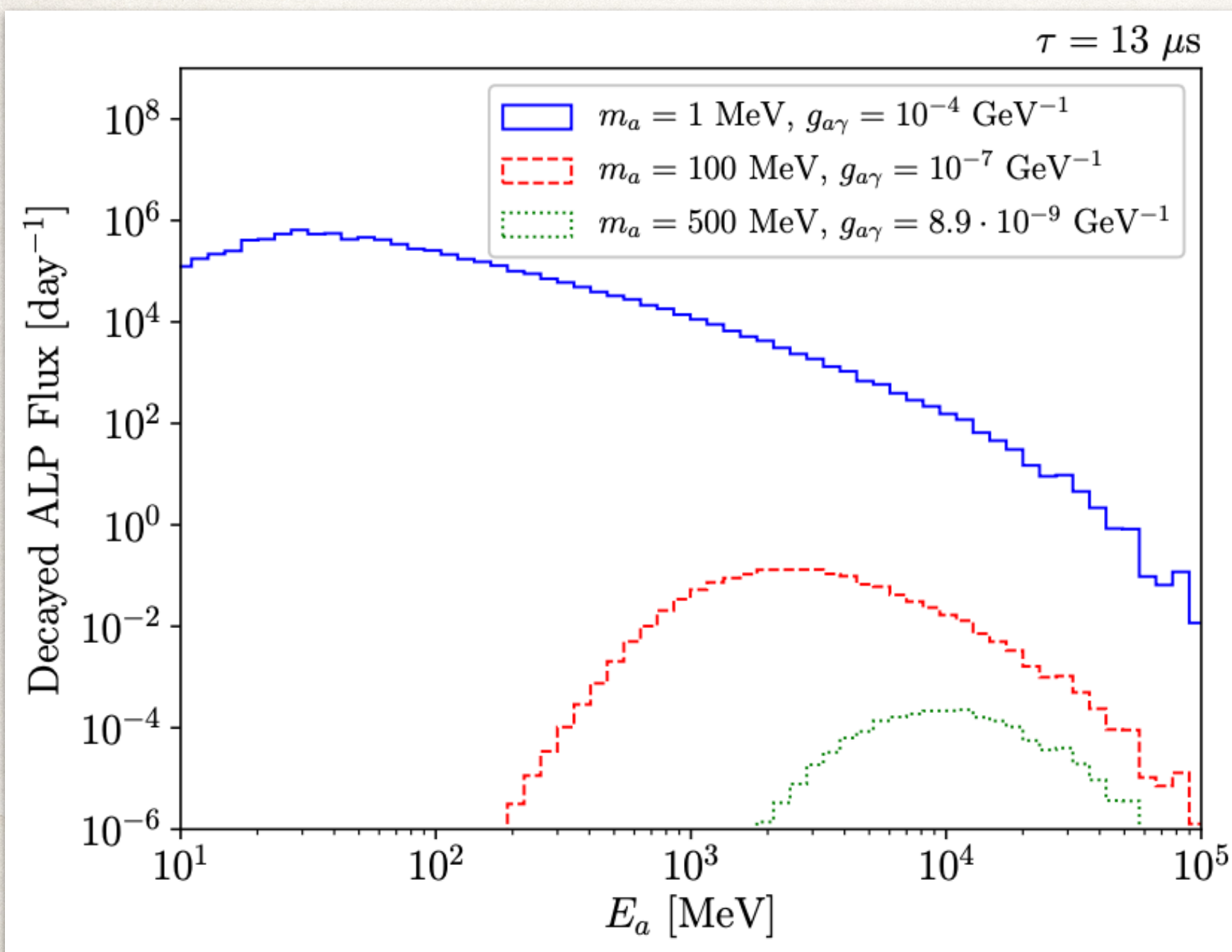
Energy spectrum depends strongly on the lifetime of the Axion.

Heavy Axion Sensitivity



Kelly, Kumar, Liu [2011.05995]

ALP Spectra & Sensitivity



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

Conclusions

- ❖ With rich detectors and intense proton beam sources, neutrino facilities can be imagined as next-generation beam dump experiments.
- ❖ DUNE's near detector complex, especially the gaseous argon component, will serve as an excellent spectrometer for particles coming from new-particle decays
- ❖ Searches that can be performed include: Heavy neutral leptons, dark Higgs bosons, Axions / Axion-like-particles, and more!

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Thank you!