Neutrino Frontier Probes of Dark Sectors

Kevin J. Kelly, Fermilab

Snowmass CPM Session 127, October 6 2020

Outline

- Identify and classify the types of dark sector searches that can be studied in neutrino experiments.
- I will focus on accelerator beam environments for some specificity, but there are many other ways that neutrino experiments can search for dark sectors.

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	SM Neutrino	Upscattering + Decay ($\nu \to \nu_D$, $\nu_D \to \nu\ell^+\ell^-$)
Dipole Portal	Dalitz Decay	Decay ($\nu_D \to \nu\gamma$)
νphilic Mediators	SM Neutrino	Scattering (Missing $\not{p}_T$, SM Tridents)

From SNOWMASS21-NF3_NF0-RF6_RF0-CF1_CF3-TF9_TF11-148

Sampling of Detectors

- Experiments that can search for many of these models (often simultaneously) – **not** an exhaustive list!

CHARM MINOS MINERvA

Nu-Cal MiniBooNE(-DM) T2K T2HK

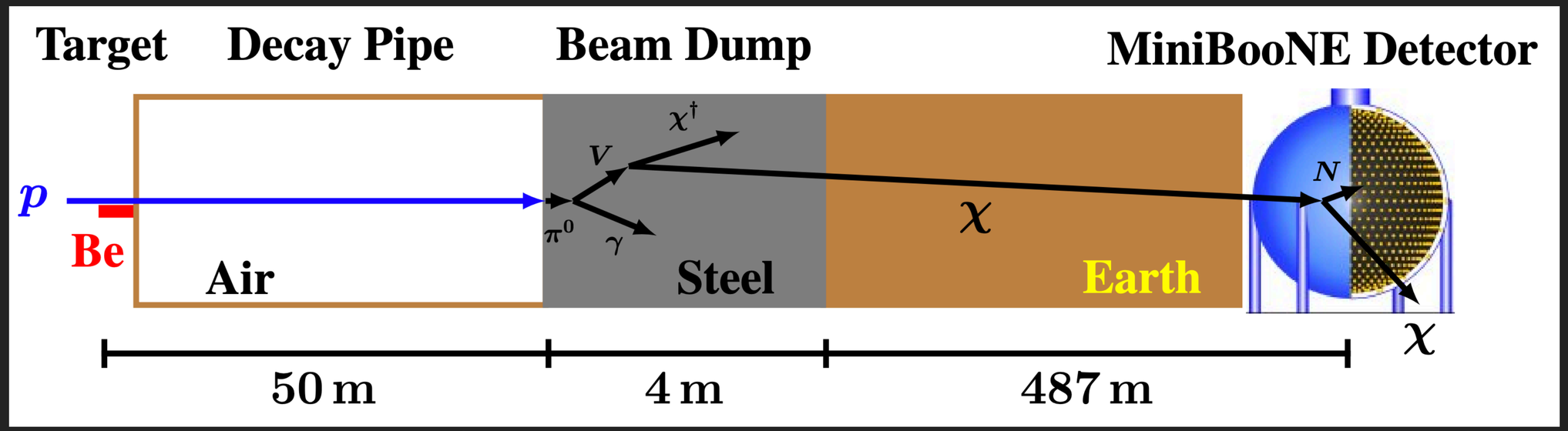
MicroBooNE ICARUS SBND DUNE

COHERENT Super-Kamiokande Borexino

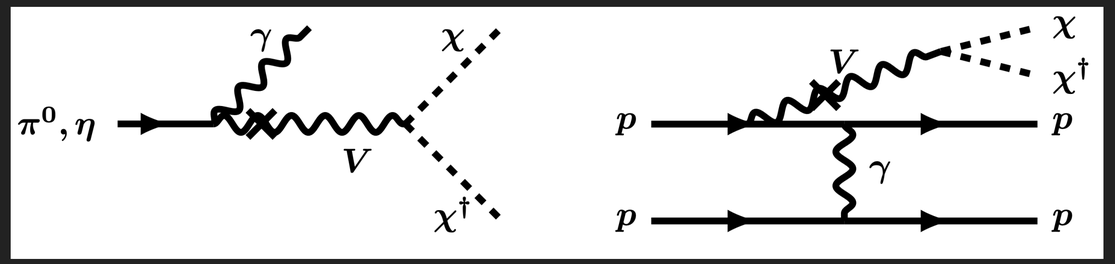
For more, see the NF03 Workshop Oct. 3rd

Light Dark Matter at MiniBooNE

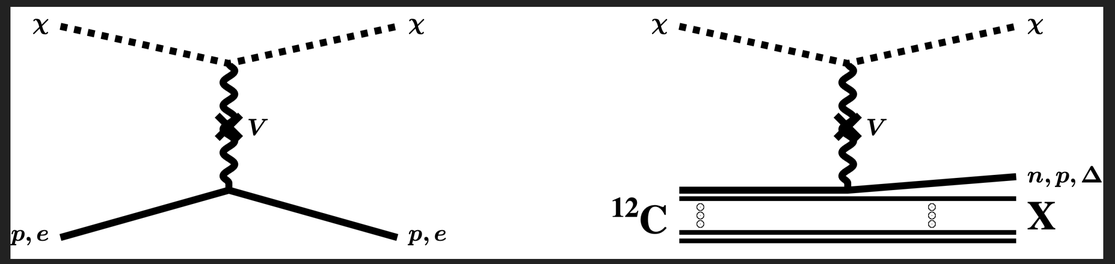
[1702.02688]



- Dedicated beam dump run of MiniBooNE: DM can be produced via the decays of neutral pions or in bremsstrahlung and travel to MiniBooNE, where they can scatter off nucleons/electrons.
- Beam dump suppresses neutrino "background" significantly, allowing for incredible sensitivity.



DM Production



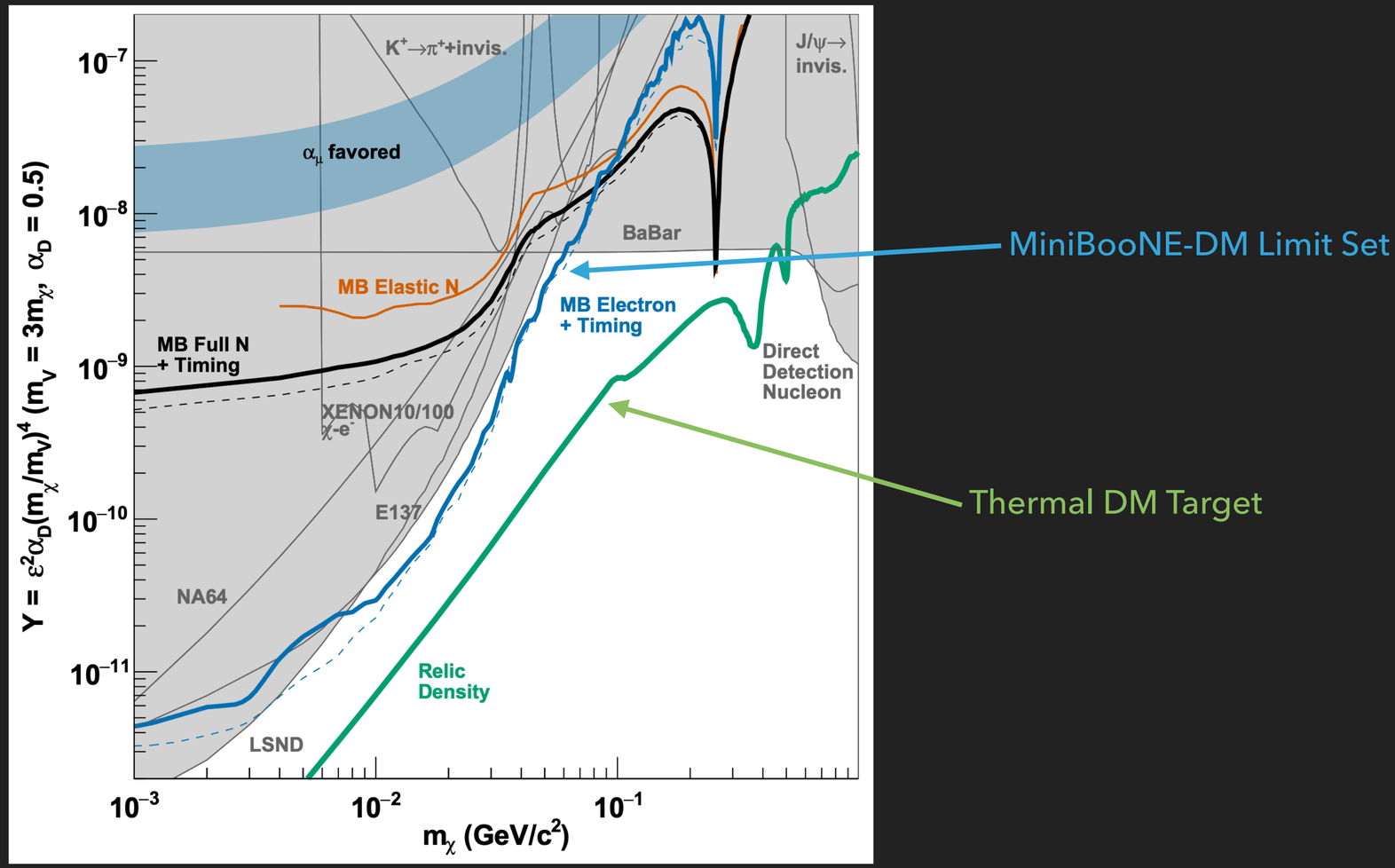
DM Scattering

Subset of theoretical work that inspired this: [0906.5614], [1107.4580], [1205.3499]

Light Dark Matter at MiniBooNE

[1807.06137]

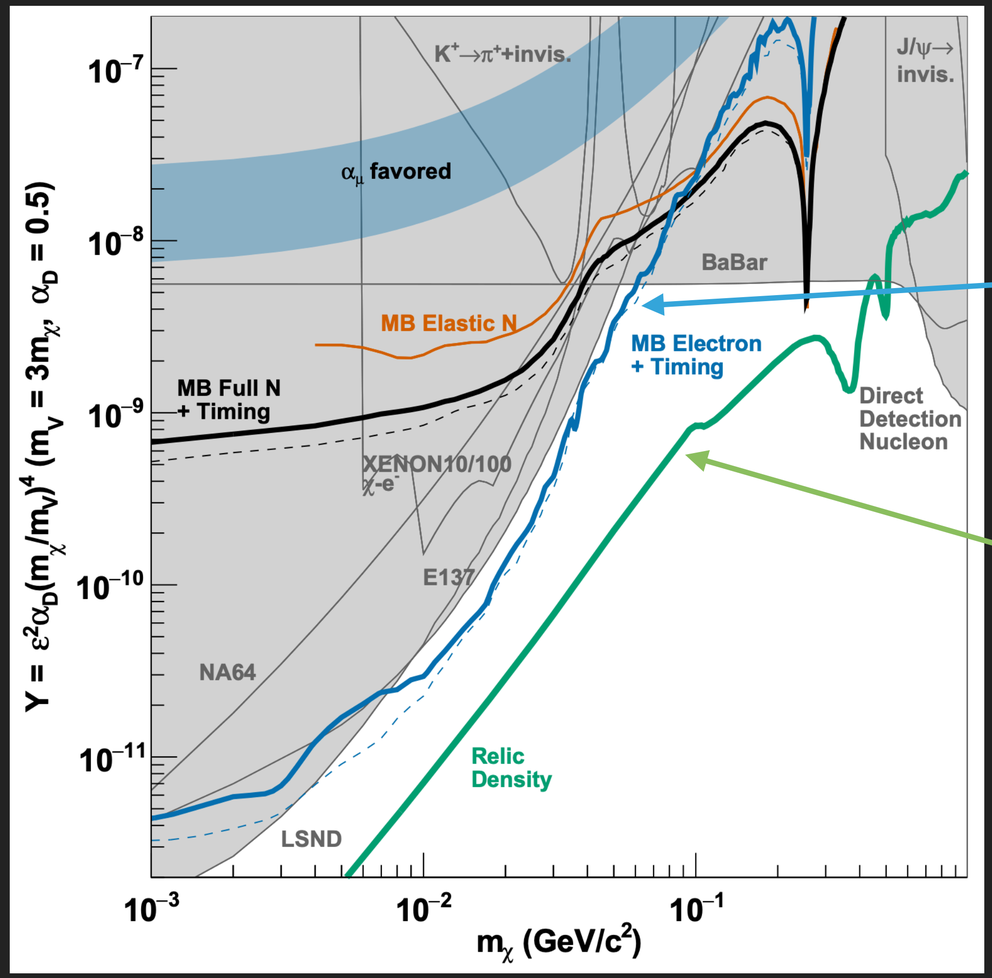
- Beam Dump operation occurred in 2013/2014, with a total of 1.86 x 10^{20} Protons on Target.
- Because of the dedicated Beam Dump operation, the limit set on light dark matter is among the most powerful, and is difficult for next-generation experiments to surpass without their own beam dump plans.



Light Dark Matter at MiniBooNE

[1807.06137]

- Beam Dump operation occurred in 2013/2014, with a total of 1.86 x 10^{20} Protons on Target.
- Because of the dedicated Beam Dump operation, the limit set on light dark matter is among the most powerful, and is difficult for next-generation experiments to surpass without their own beam dump plans.

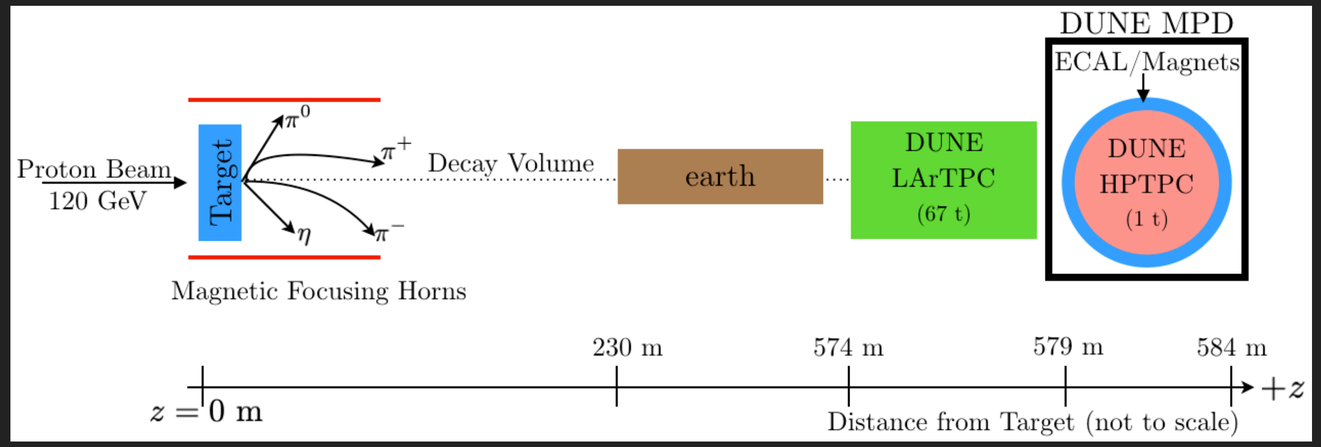


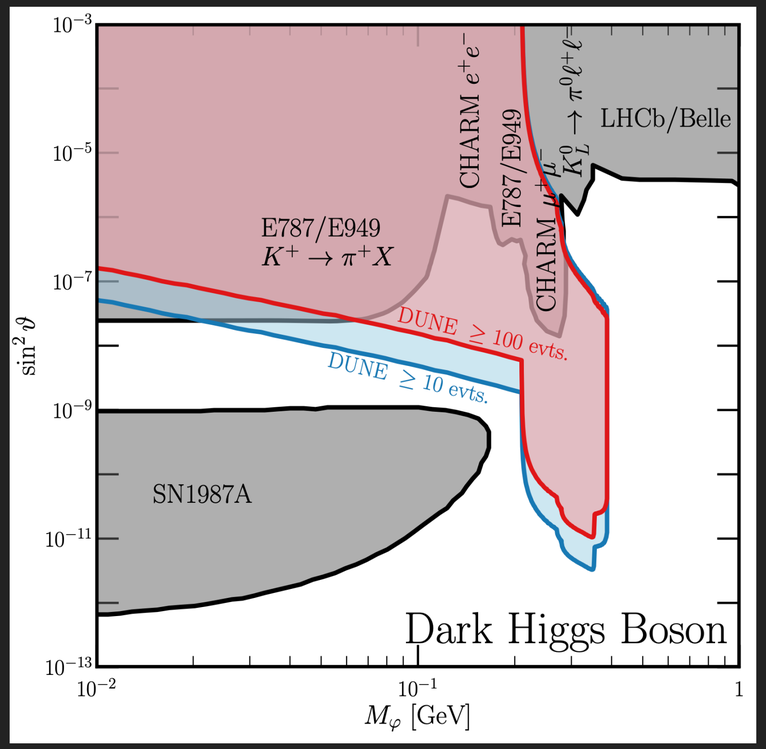
Are there ways of suppressing neutrino backgrounds without dedicated beam dump runs?

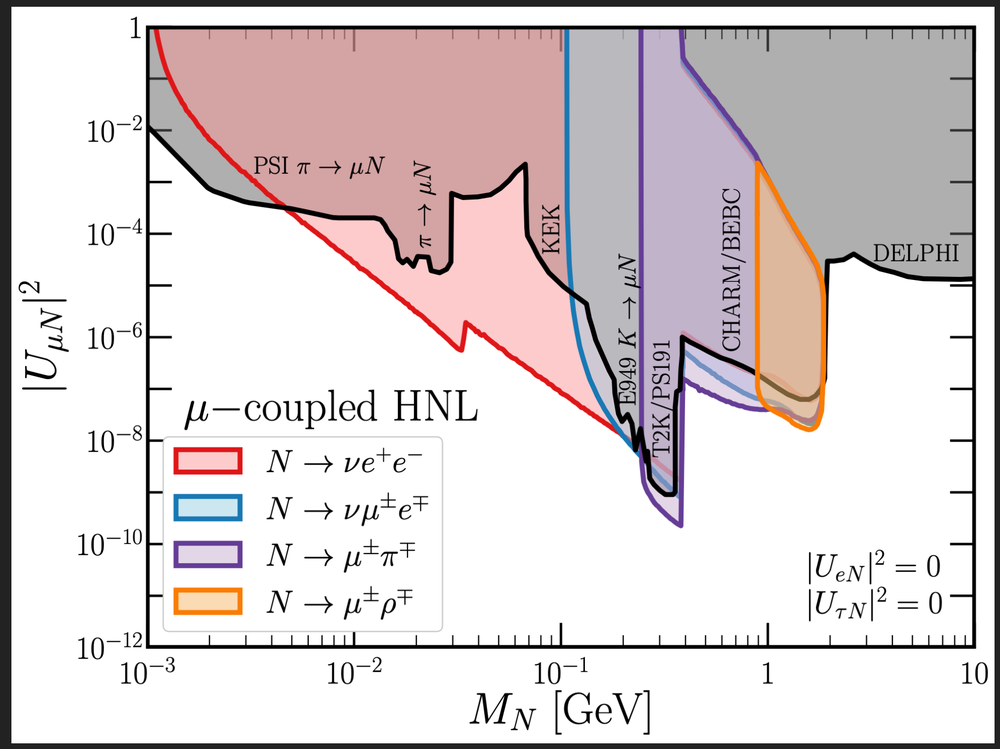
Dark Mediator Decays in DUNE

[1912.07622]

Symbiotic – can perform highly sensitive searches *during* neutrino beam operation. In fact, focusing of charged mesons can enhance sensitivity to some dark sector scenarios.







Tools for Accelerator-Produced Dark Sectors

[1812.05616]

A Module For Boosted Dark Matter Event Generation in GENIE

Joshua Berger

Models that produce a flux of semi-relativistic or relativistic boosted dark matter at large neutrino detectors are well-motivated extensions beyond the minimal weakly interacting massive particle (WIMP) paradigm. Current and upcoming liquid argon time projection chamber (LArTPC) based detectors will have improved sensitivity to such models, but also require improved theoretical modeling to better understand their signals and optimize their analyses. I present the first full Monte Carlo tool for boosted dark matter interacting with nuclei in the energy regime accessible to LArTPC detectors, including the Deep Underground Neutrino Experiment (DUNE). The code uses the nuclear and strong physics modeling of the GENIE neutrino Monte Carlo event generator with particle physics modeling for dark matter. The code will be available in GENIE v3. In addition, I present a code for generating a GENIE-compatible flux of boosted dark matter coming from the Sun that is released independently.

GENIE-based code for DM production and DM/SM interactions

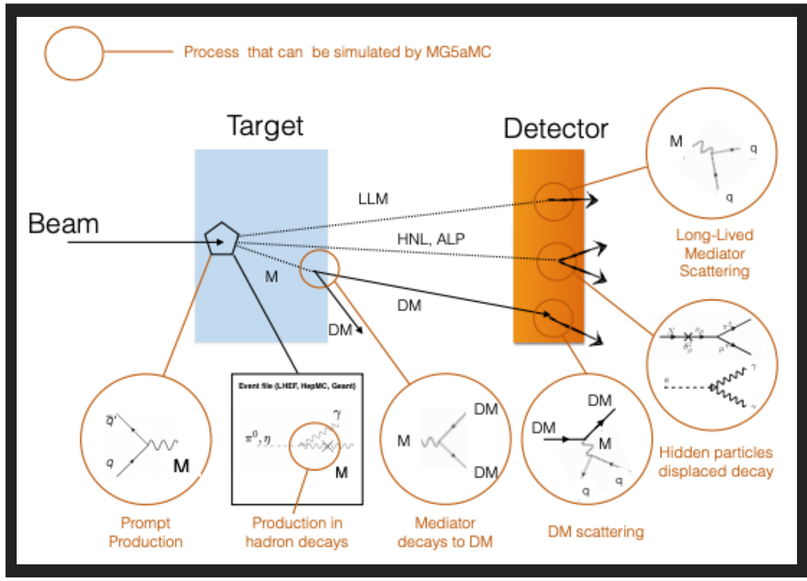
BdNMC: [1609.01770]

Light dark matter in neutrino beams: production modelling and scattering signatures at MiniBooNE, T2K and SHiP

Patrick deNiverville,[1] Chien-Yi Chen,[1,2] Maxim Pospelov,[1,2] and Adam Ritz[1]
[1] *Department of Physics and Astronomy, University of Victoria, Victoria, BC V8P 5C2, Canada*
[2] *Perimeter Institute for Theoretical Physics, Waterloo, ON N2J 2W9, Canada*
(Dated: September 2016)

Independent code for DM production and scattering off nucleons/electrons

Code available on github



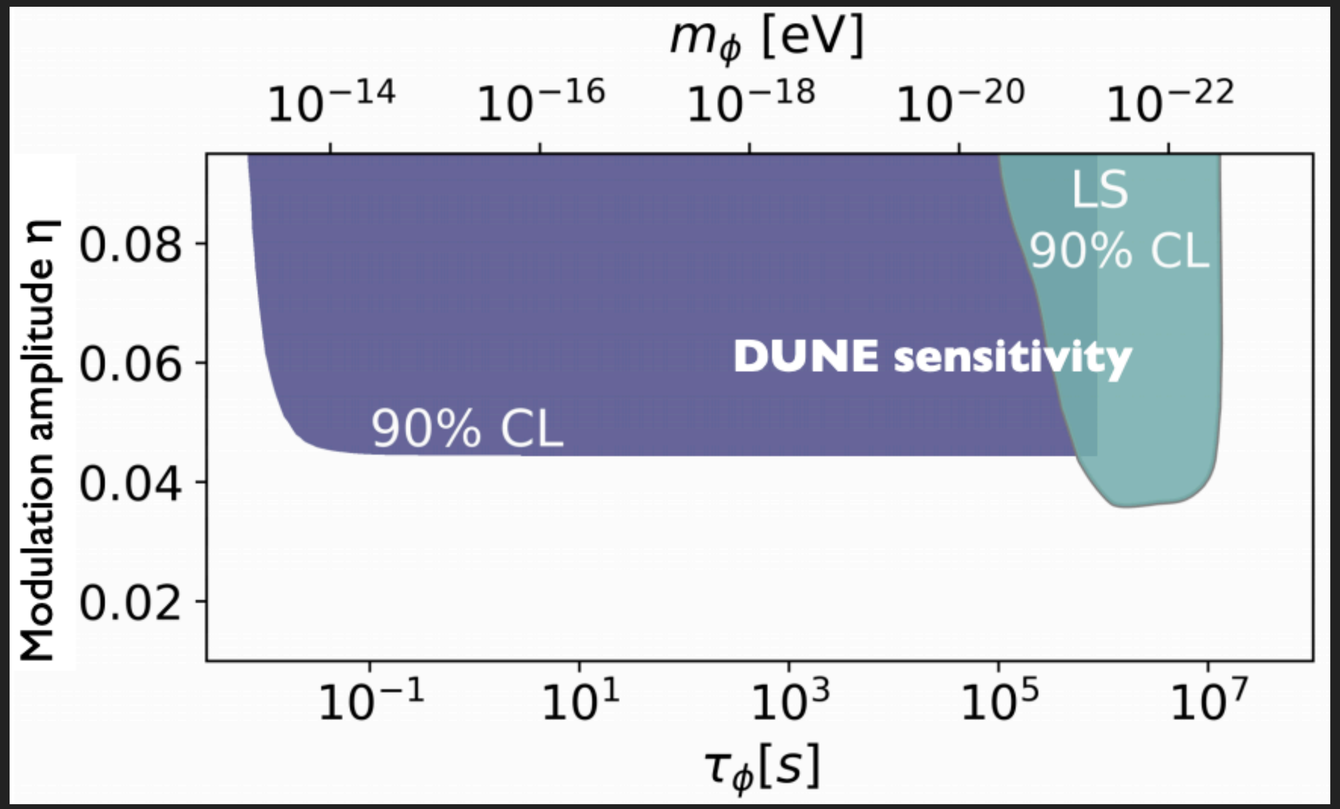
[1812.06771]

MG5aMC: MadGraph-based code for DM production and a variety of detector signatures.

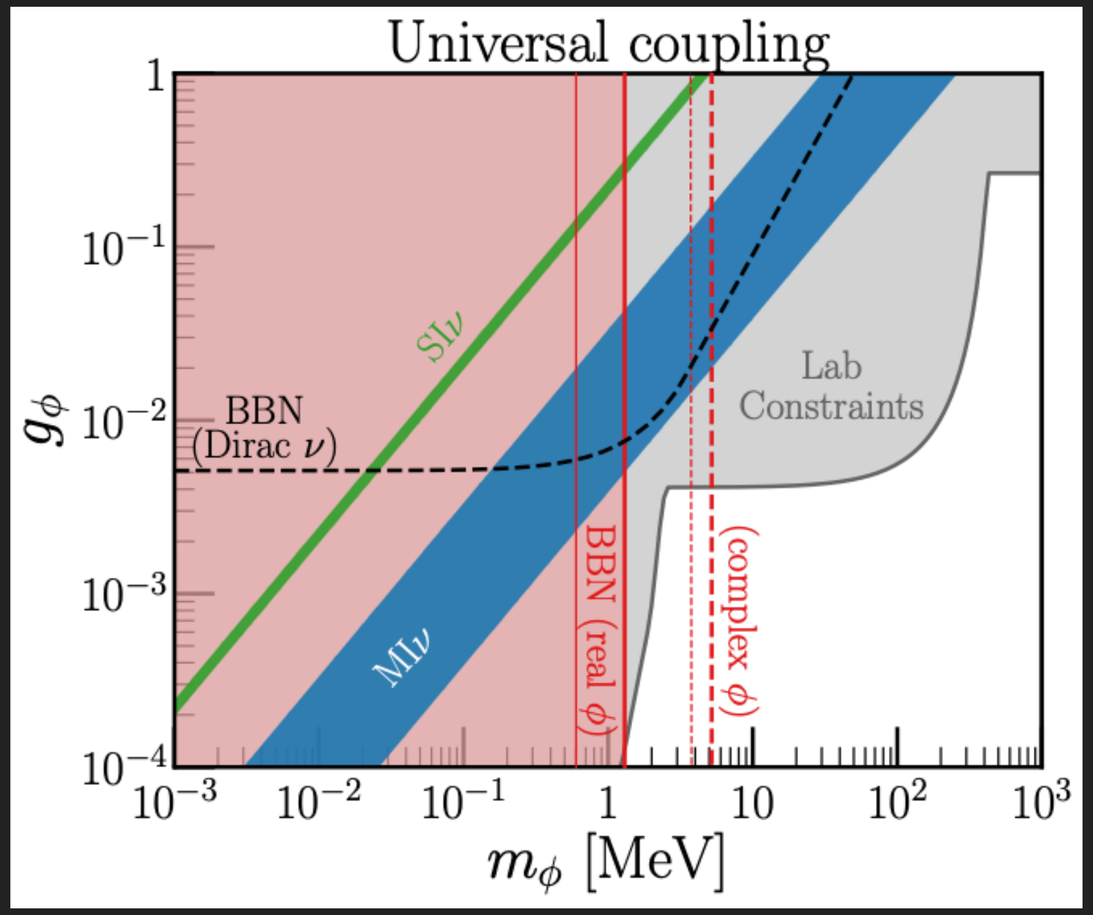
By Luca Buonocore, Claudia Frugiuele, Fabio Maltoni, Olivier Mattelaer, Francesco Tramontano

Complementary Directions

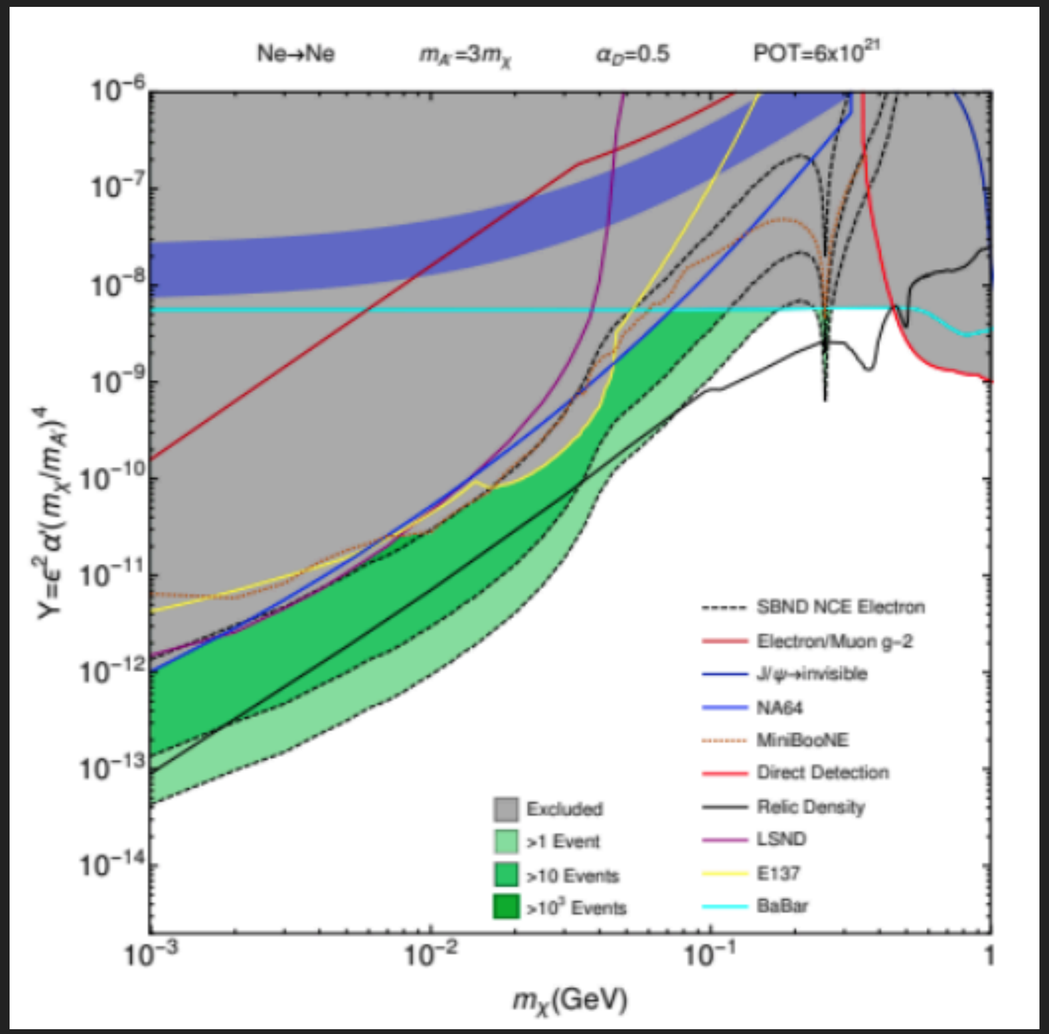
Ultralight DM (LOI Link):
Modulation of neutrino oscillation parameters



Neutrinophilic Mediators (Paper Link):
Possible solution to the Hubble Tension

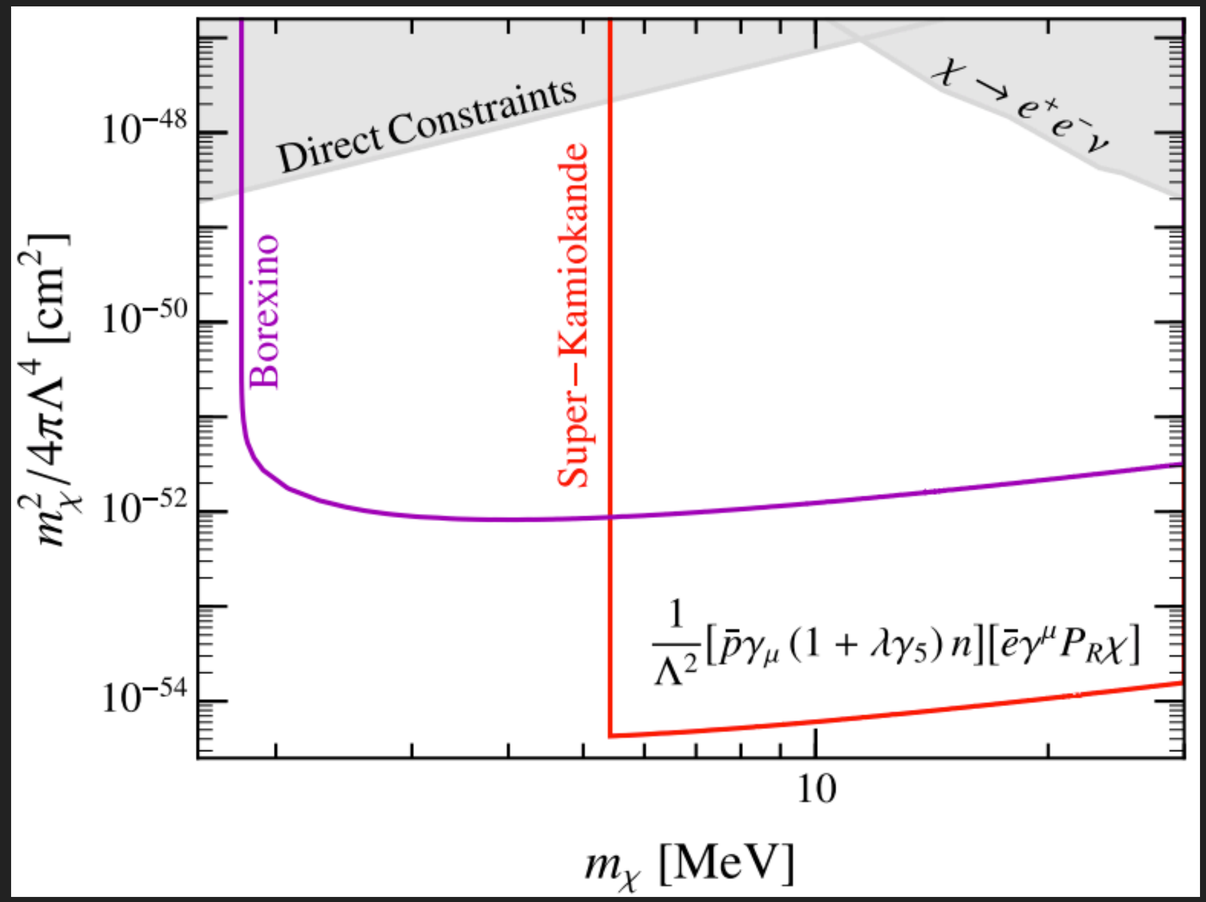


Complementary Directions



O(10) GeV Beam Dump from PIP-II (LOI Link):
Impressive coverage of thermal relic target

Fermionic Dark Matter (Paper Link):
Sensitive searches in large neutrino detectors



Conclusions

- Neutrino experiments combined with intense beams provide a mechanism to search for many interesting, well-motivated dark sector scenarios.
- Rich phenomenology between different production mechanisms (including using the neutrino beam itself), different scattering signatures, and different decay signatures.
- Searches can be performed in dedicated “beam dump” modes or simultaneously with neutrino beam operation – different benefits and disadvantages for each.

Stay tuned for more. Thanks!