



The University of Manchester



Recent results and prospects for BSM searches in MicroBooNE

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On behalf of the MicroBooNE Collaboration

SUSY 2022

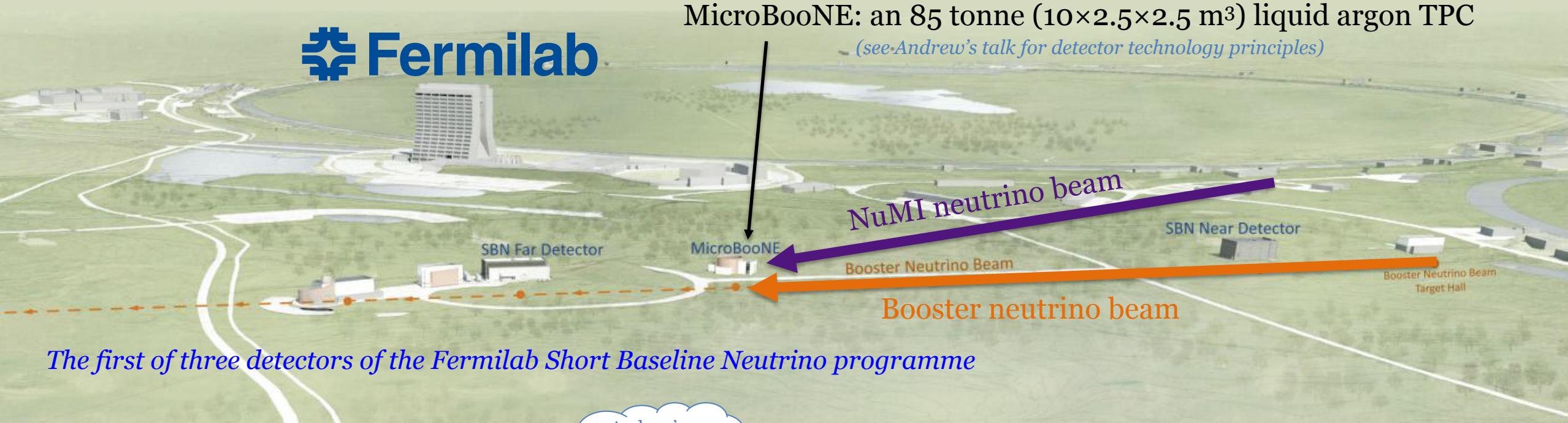
27 June 2022

Ιωάννινα, Ελλάδα

MicroBooNE



MicroBooNE: an 85 tonne ($10 \times 2.5 \times 2.5$ m 3) liquid argon TPC
(see Andrew's talk for detector technology principles)



The first of three detectors of the Fermilab Short Baseline Neutrino programme

Goals of the experiment

- Investigate the nature of the MiniBooNE low-energy electromagnetic anomaly
- Large-statistics ν -Ar cross-section measurements
- R&D and long-term operations of LArTPCs

Andrew's talk 20 minutes ago

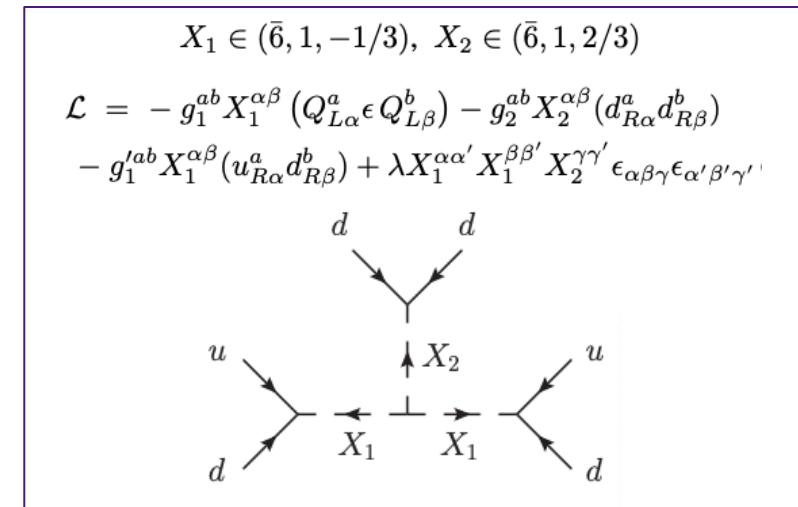
Xiao's plenary talk on Thursday

- **Searches for exotica: (This talk)**
 - R&D for future searches
 - Neutron-antineutron oscillation
 - Low-energy thresholds for millicharges
 - Nanosecond-scale timing for massive new physics
 - Searches for long-lived fermions and bosons produced in rare meson decays
 - Heavy neutral leptons
 - Higgs portal scalars
 - Prospects for beam-produced dark matter
 - Investigating beyond-the-sterile- ν -BSM explanations of MiniBooNE

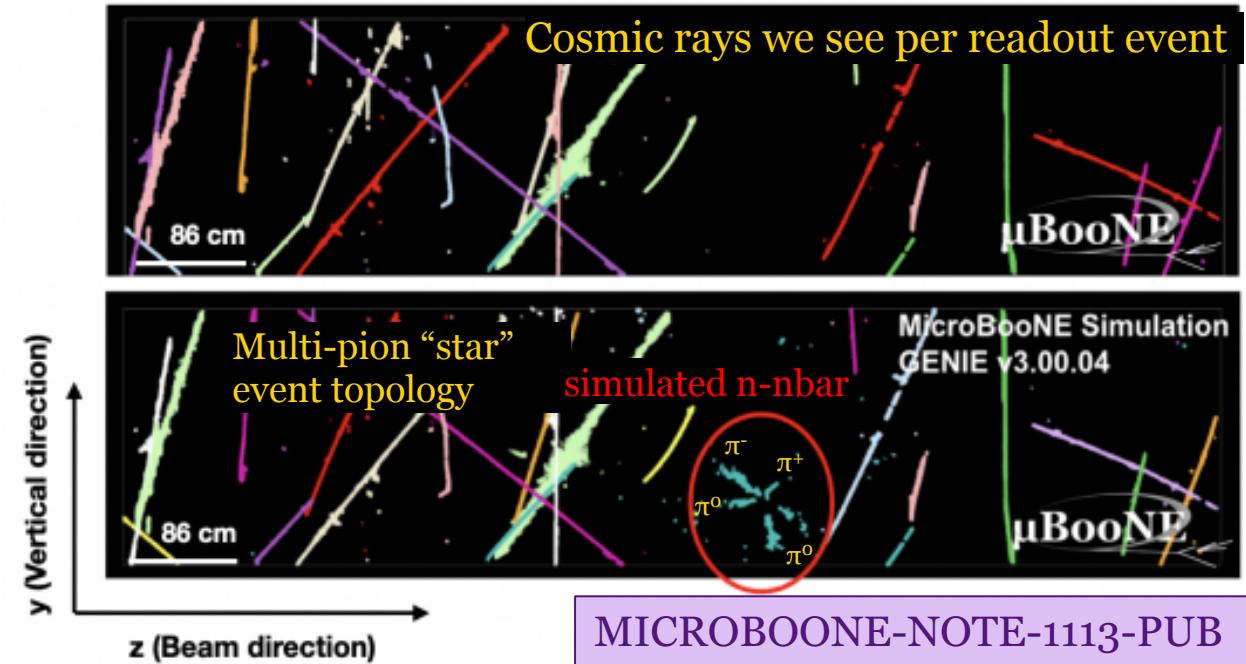
R&D EFFORT

Neutron-antineutron oscillation

- Baryon number violating process
 - Various BSM models predict this process, e.g.: (non-exhaustive list)
 - Babu et al, PRD 87, 115019 (2013)
 - Arnold et al, PRD 87, 075004 (2013)
- Neutron spontaneously oscillates into antineutron
 - prompt annihilation on nucleon
 - multi-hadron final state
- Development of techniques and demonstration of feasibility
 - to be used in DUNE, which will have competitive sensitivity
- Stats-only half-life sensitivity:
 3×10^{25} years

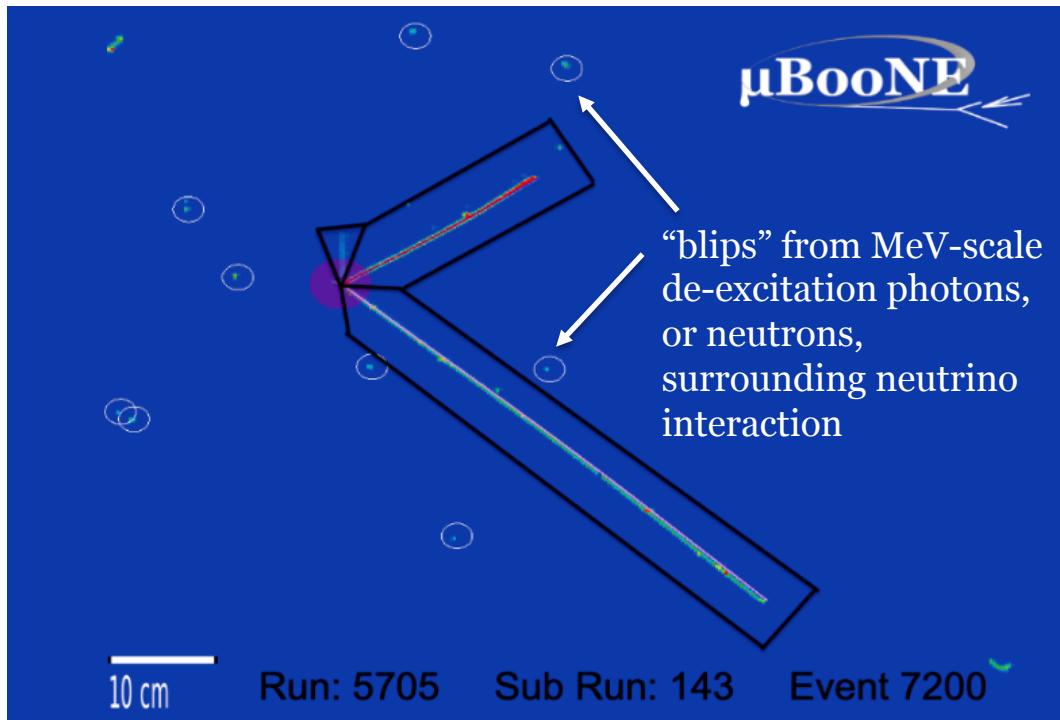


Arnold et al, PRD 87,
075004 (2013)



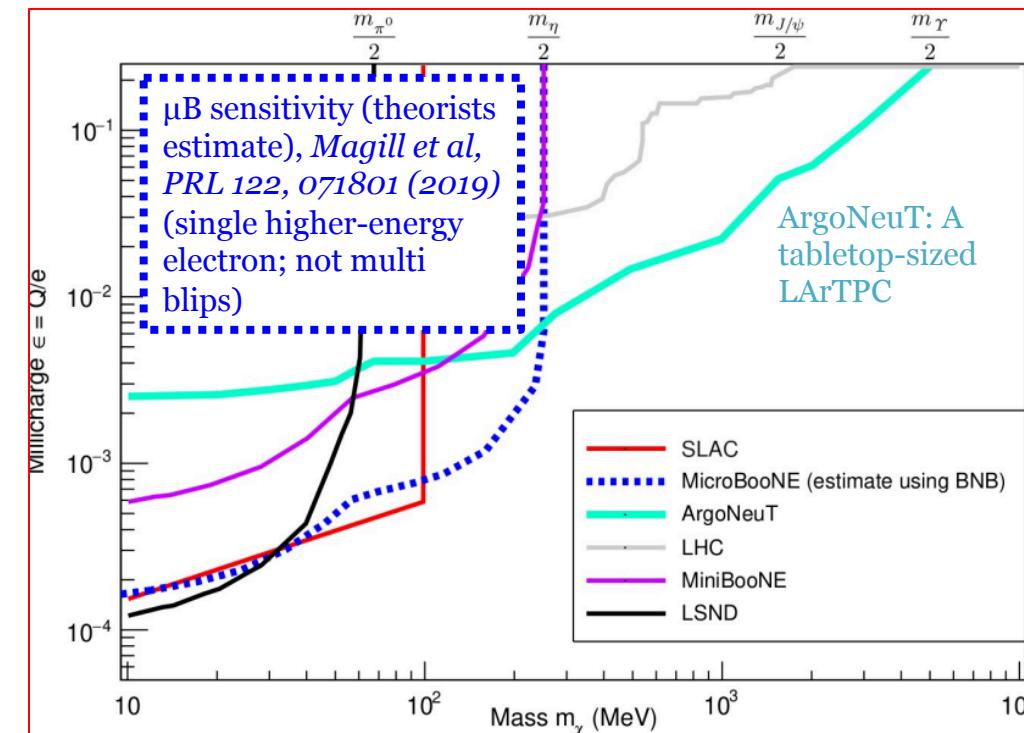
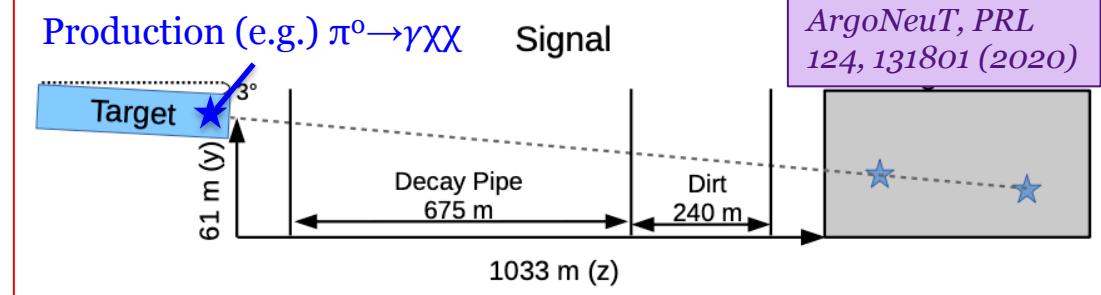
Low-energy hits and millicharged particles

- Lowered hit reconstruction thresholds to ~ 100 keV
 - 3x lower thresholds than previous LArTPCs
- Allows us to search for new physics signatures
 - For millicharged particles

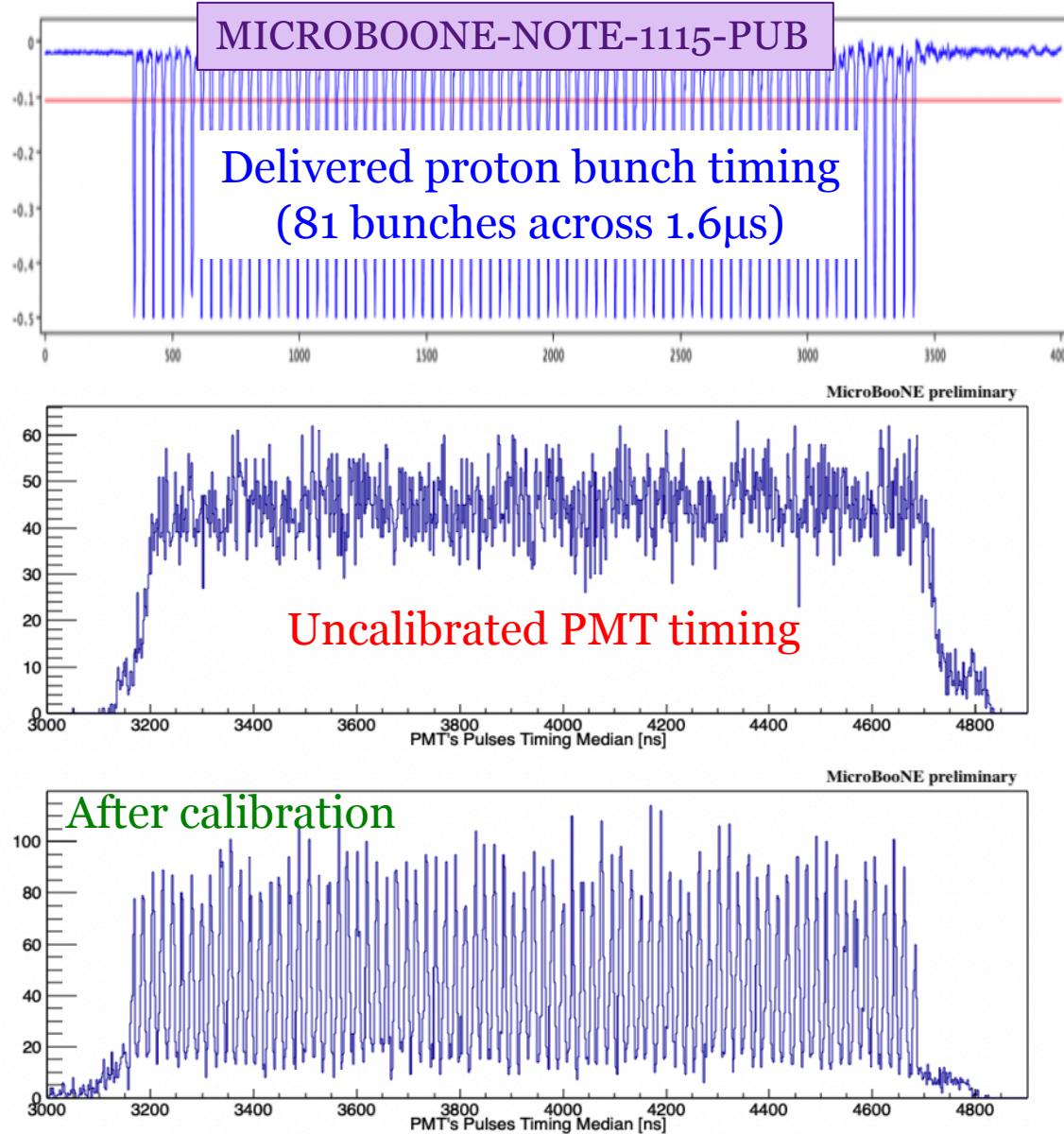


MICROBOONE-NOTE-1076-PUB

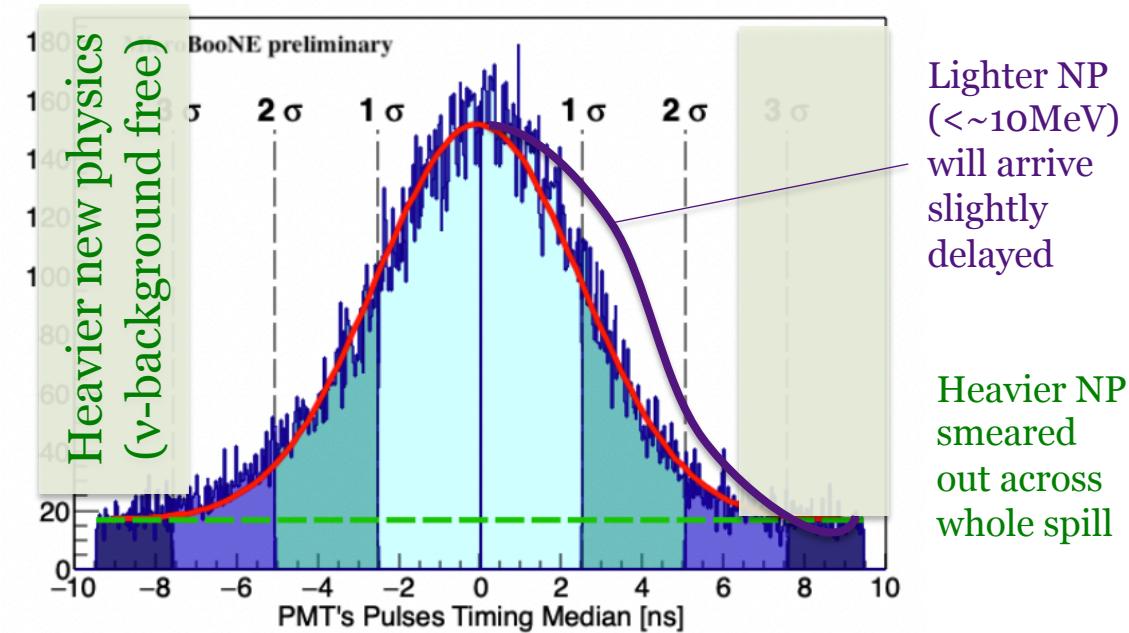
MCPs: two isolated low-energy hits pointing back to target



Event timing for new physics

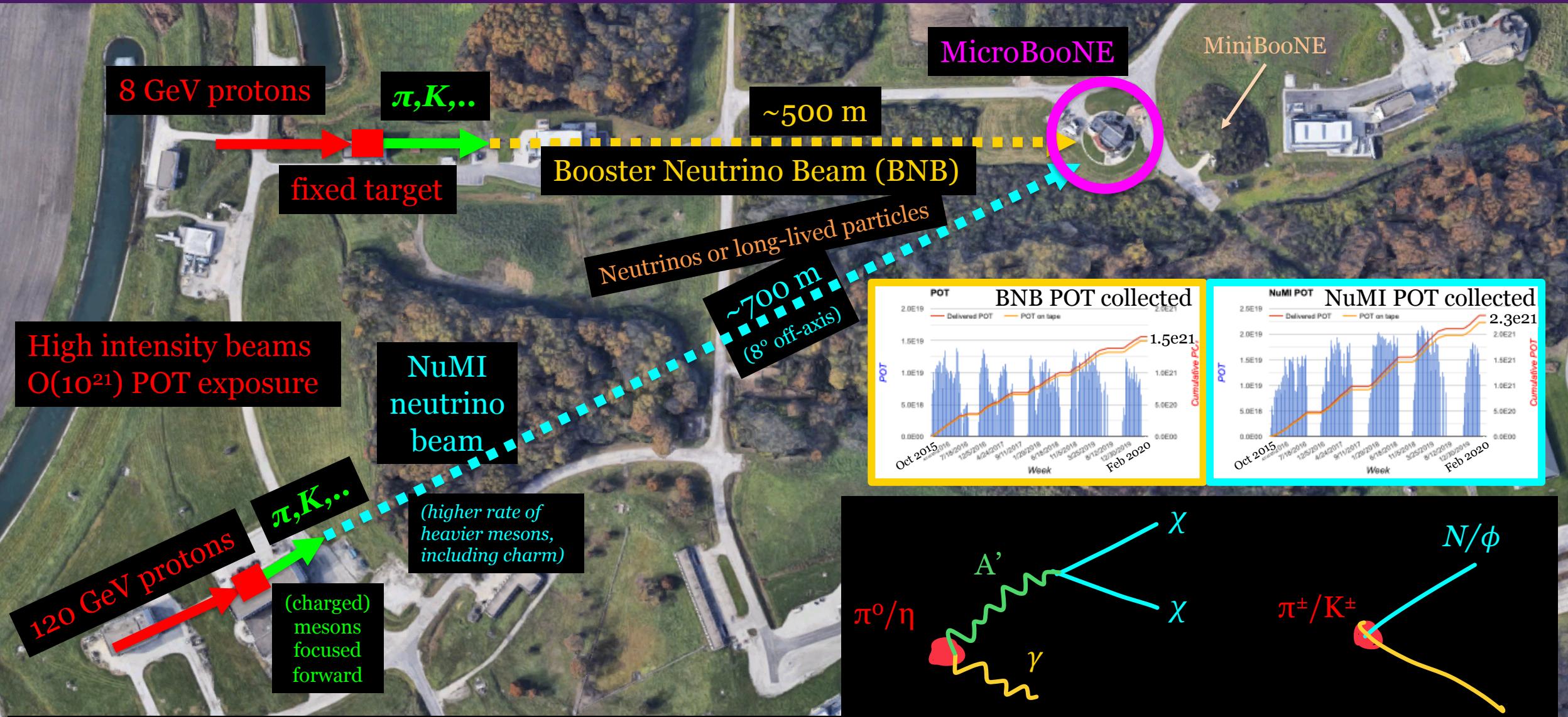


- MicroBooNE has been pioneering the calibration of LArTPC event timing down to the nanosecond scale
- Non-massless new physics produced in the beamline has delayed TOF with respect to neutrinos
 - Can use this high-resolution timing to enhance BSM searches



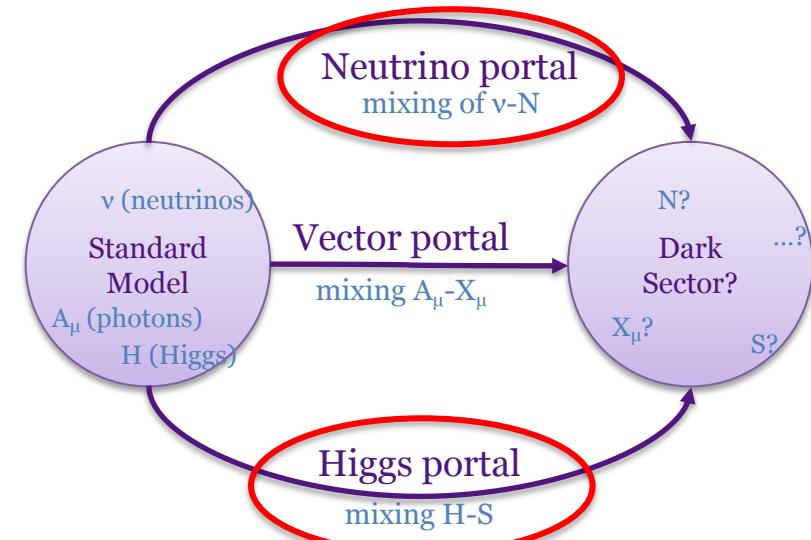
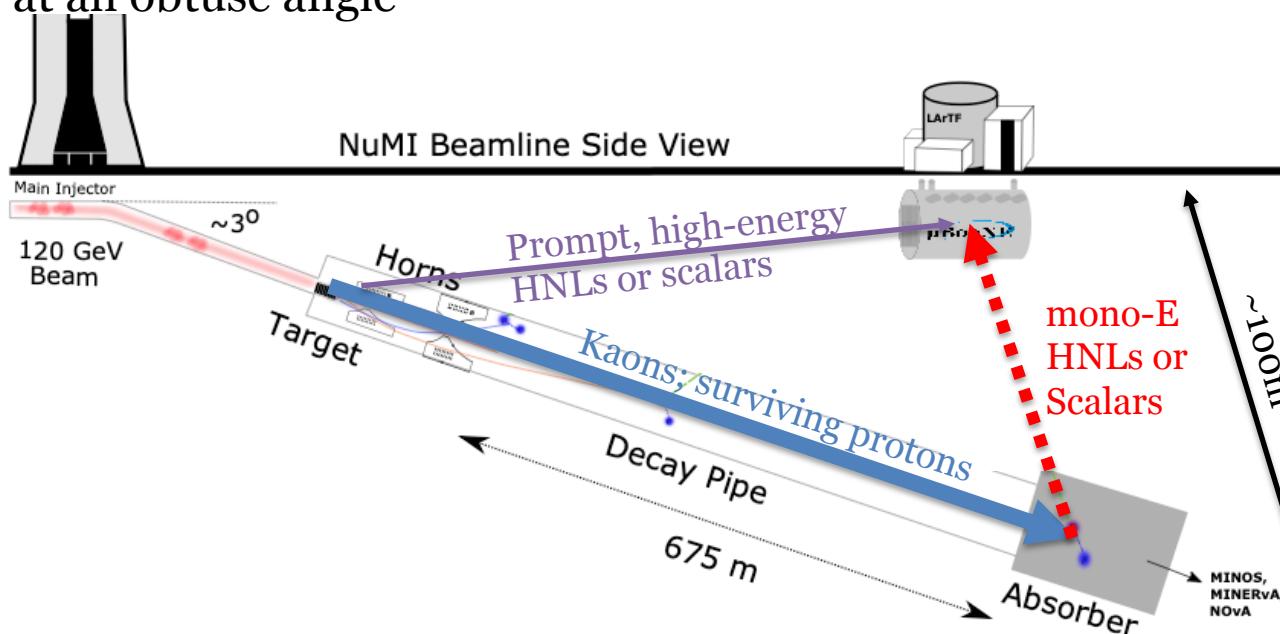
RECENT BSM SEARCHES

Fermilab neutrino beamlines



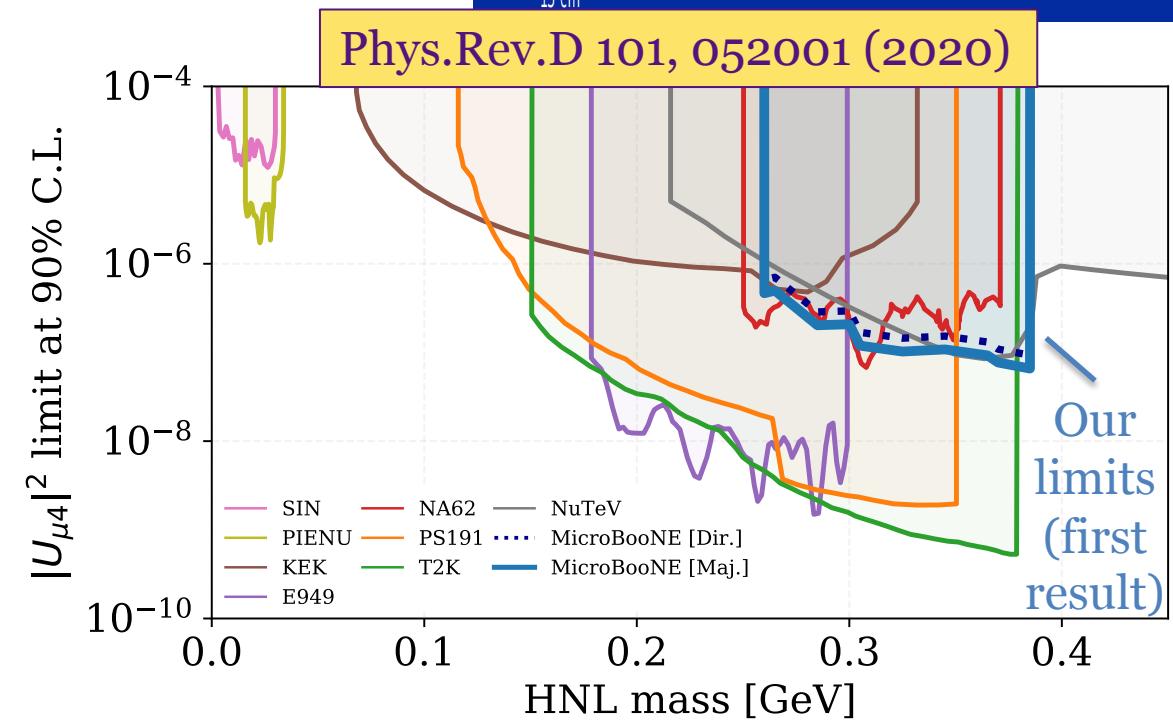
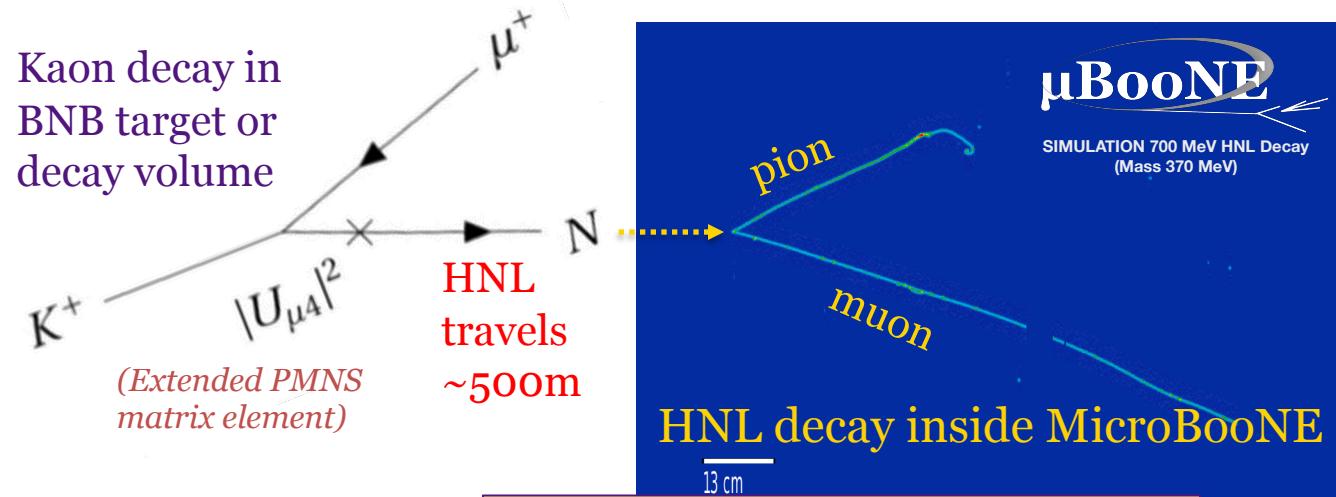
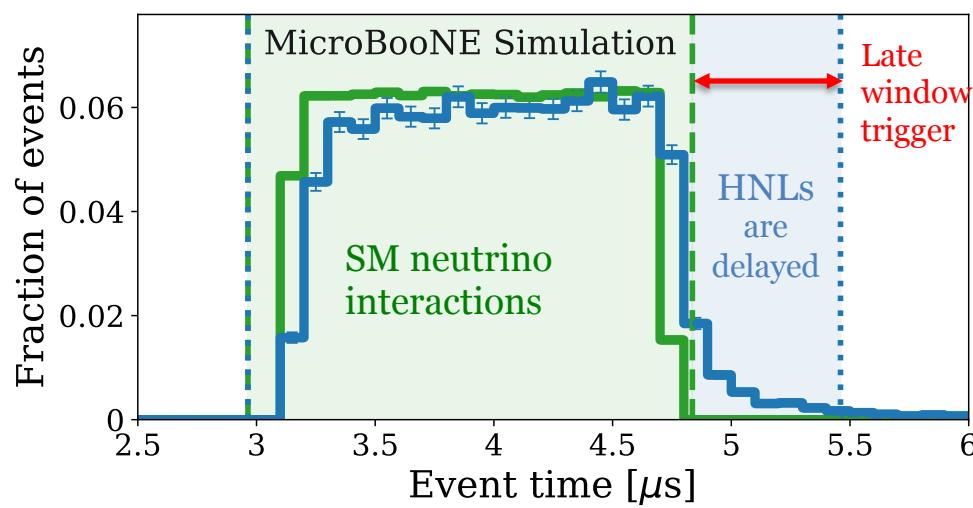
Heavy neutral leptons and Higgs portal scalars

- MicroBooNE has searched for certain “Portal” mediators:
 - Heavy neutral leptons
 - Dark sector “Higgs portal” scalars
- MicroBooNE sensitive to $O(100 \text{ MeV})$ mass long-lived particles mixing with the SM neutrinos or Higgs, produced in rare kaon or pion decays
- Can search in BNB or NuMI; NuMI also has kaons decaying at rest in the beam dump at the end of the decay pipe
 - Unique, striking signature of monoenergetic HNLs or scalars entering MicroBooNE at an obtuse angle



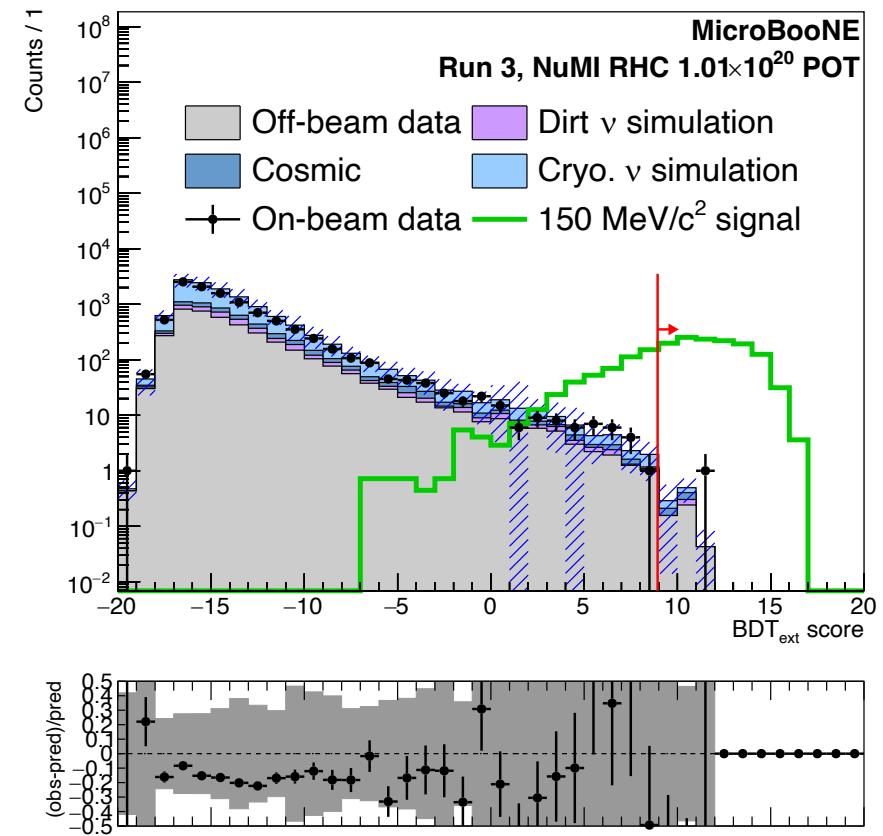
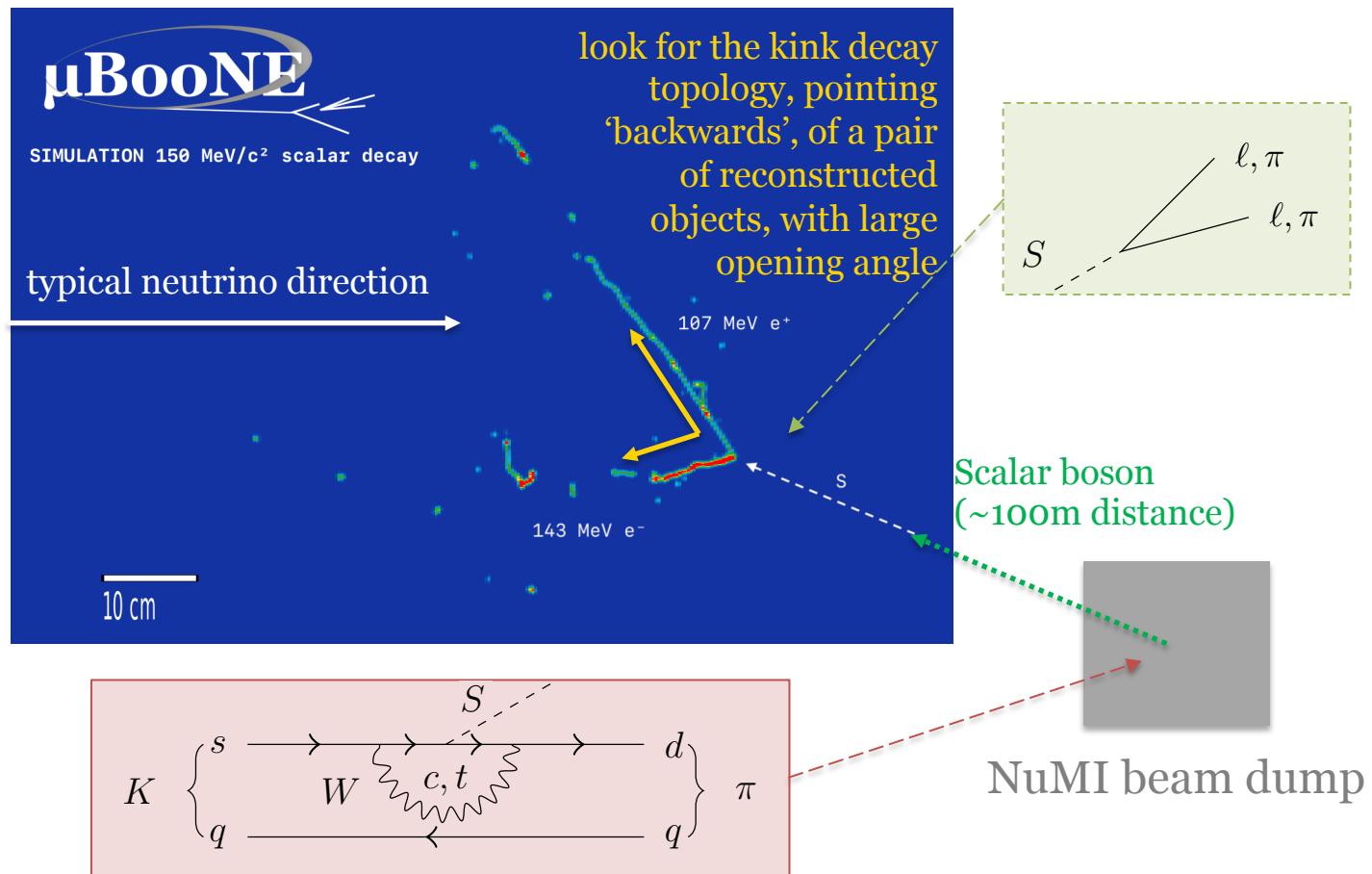
Heavy neutral leptons: first result

- “Late window” trigger developed for this analysis
 - Negligible neutrino backgrounds
- New publication out in the next few weeks



Higgs Portal scalars

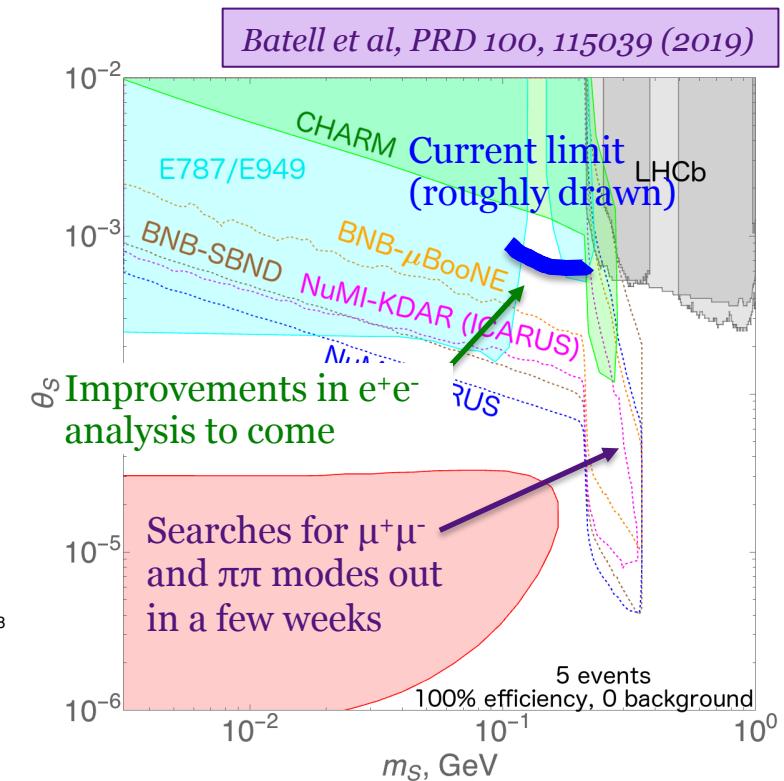
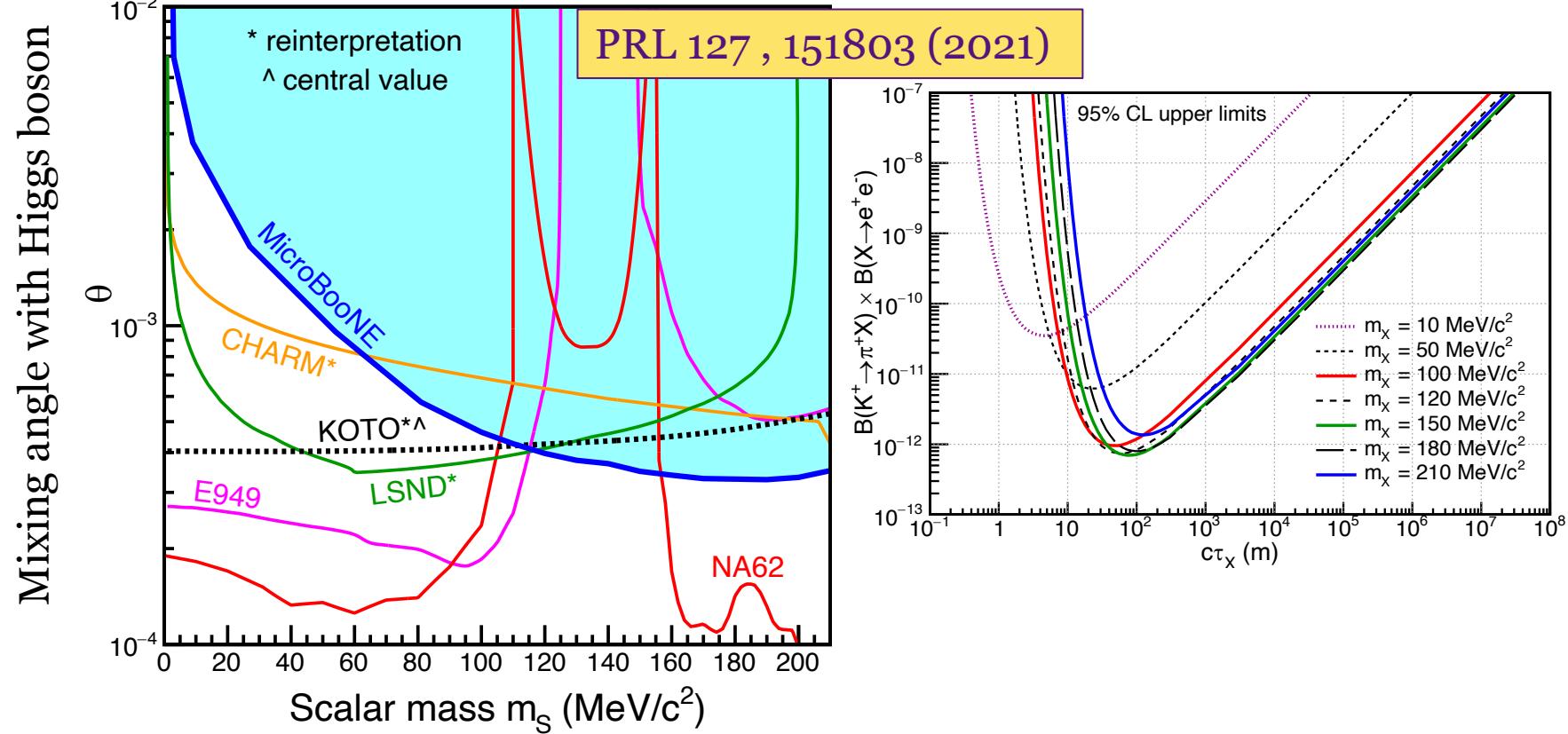
- For first results, searching for e^+e^- pairs from the decay of a <200 MeV scalar boson
 - Using a BDT-based analysis



BDT distribution, well modelled with background-only expectation
We observe 1 event in signal region, with 2.0 ± 0.8 expected background

Higgs Portal scalars

- Set world's best limit for scalar masses $\sim \pi^0$ mass
 - Region where peak search experiments, like NA62, lose sensitivity
- This was with 10% of our NuMI dataset; further search results to come!

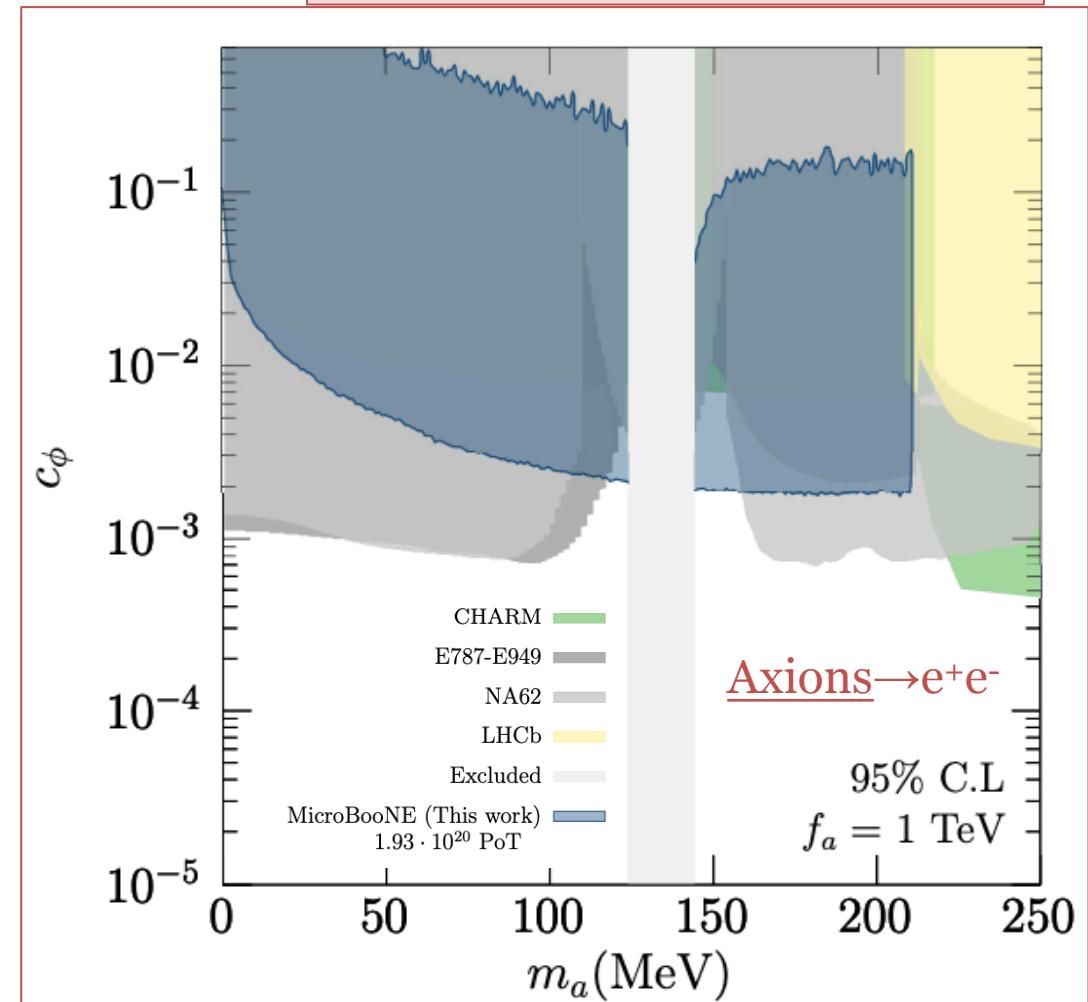
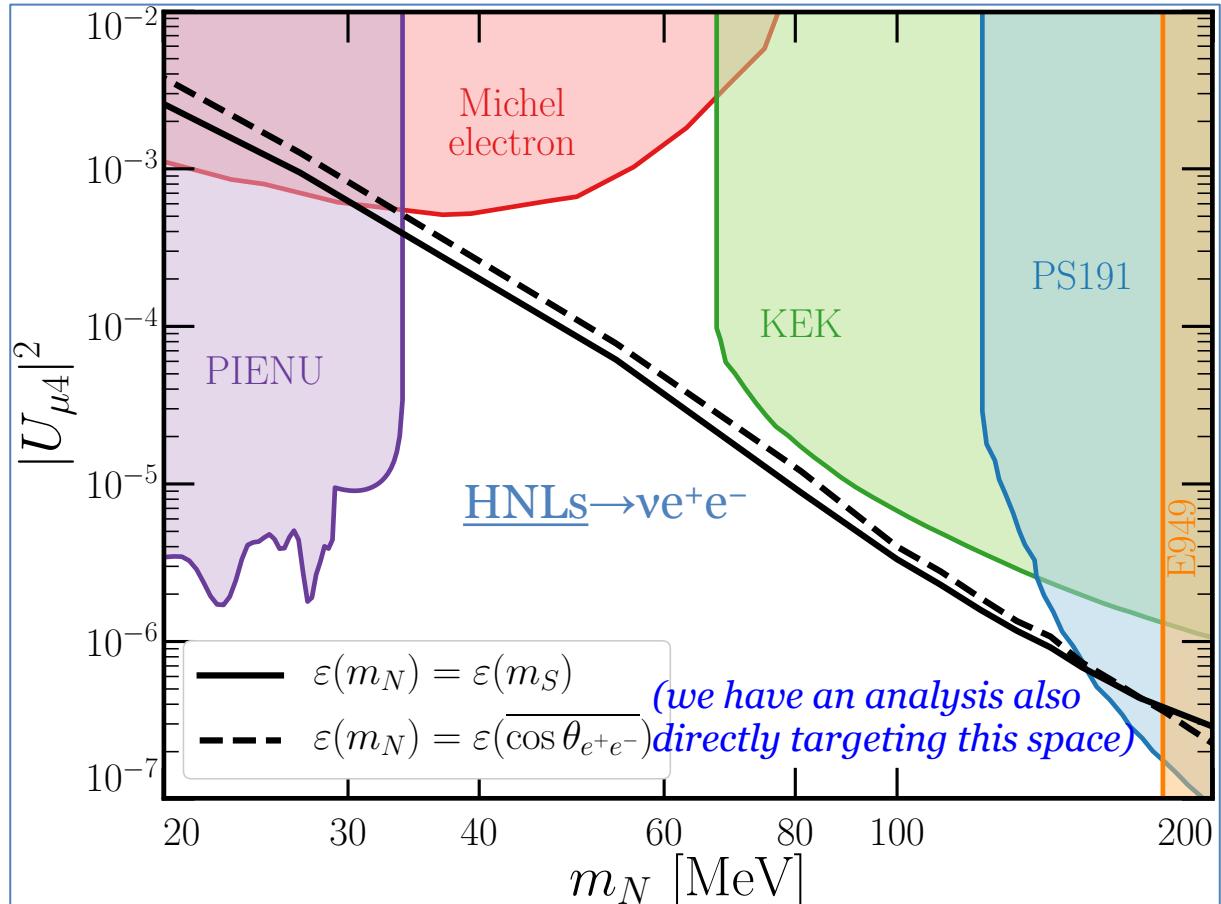


Theorist's expected sensitivity

Reinterpretations

Coloma et al, arXiv:2202.03447

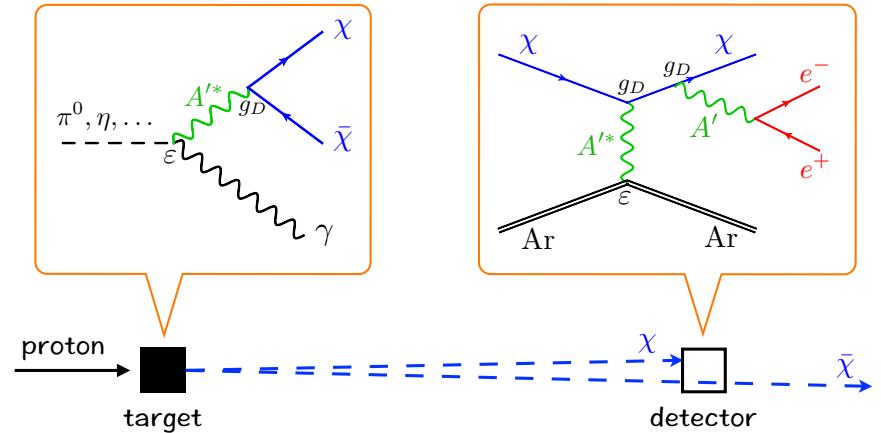
Kelly, Machado, Phys Rev D 104, 055015 (2021)



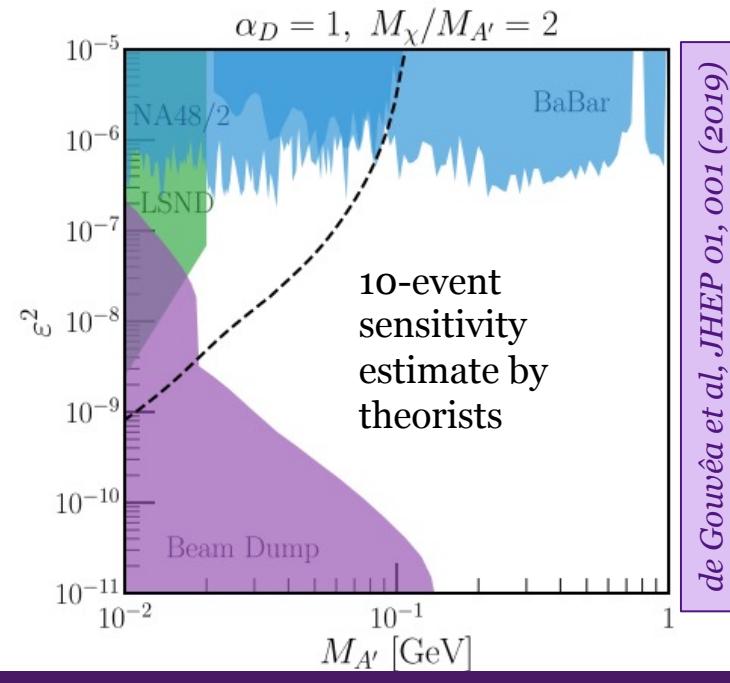
(NEAR) FUTURE BSM PROSPECTS

Dark matter (in the beam)

- Dark matter could be produced in neutral meson decays in our beams
- Other experiments have searched for elastic scattering signatures (electron or nuclear recoil)
- We will be searching for inelastic signatures
 - e^+e^- production in “darkstrahlung” scattering, aka “dark tridents”
- We are releasing our preliminary sensitivity in a few weeks for ICHEP
 - Incorporating full detector simulation, reconstruction efficiency, and backgrounds
 - Deep learning techniques
- Results of search in coming year



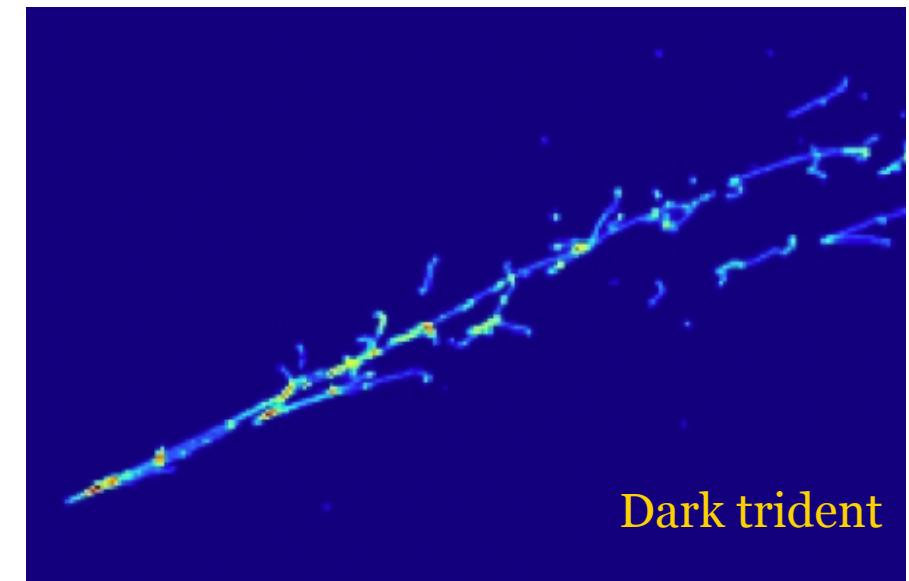
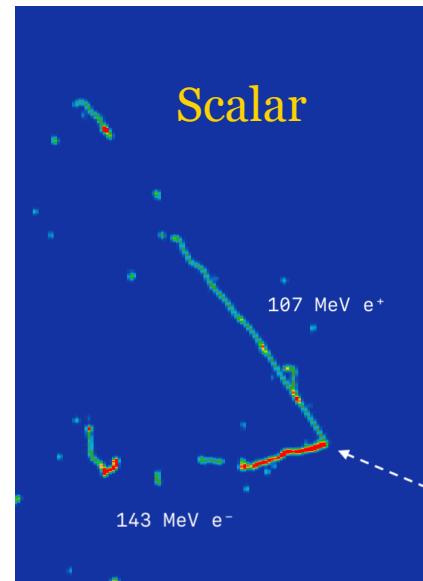
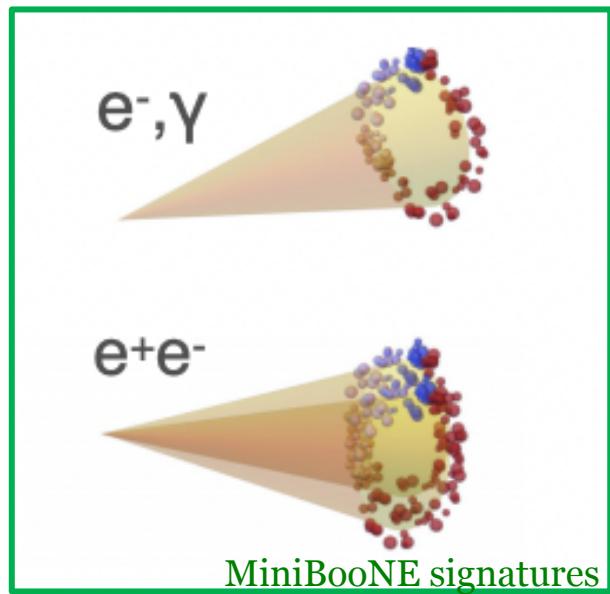
(Minimal model: one DM species; one $U(1)$ dark gauge)



de Gouvêa et al, JHEP 01, 001 (2019)

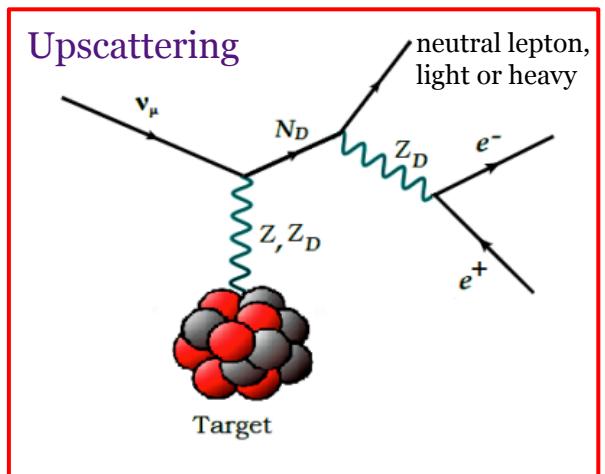
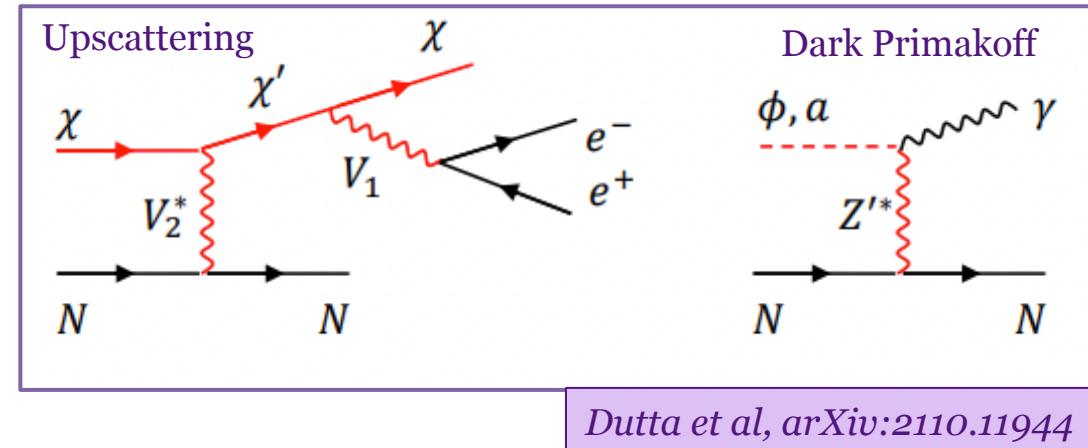
MiniBooNE: e^+e^- explanations

- MiniBooNE saw an excess of low-energy electromagnetic activity
 - Cherenkov detector cannot tell apart electrons from photons or from collimated or asymmetric e^+e^- pairs
- Since ~2018, theorists have been building many models involving e^+e^- production in MiniBoonE
- MicroBooNE has already been pioneering e^+e^- searches in LArTPCs as part of our BSM programme; can begin to explore MiniBooNE space

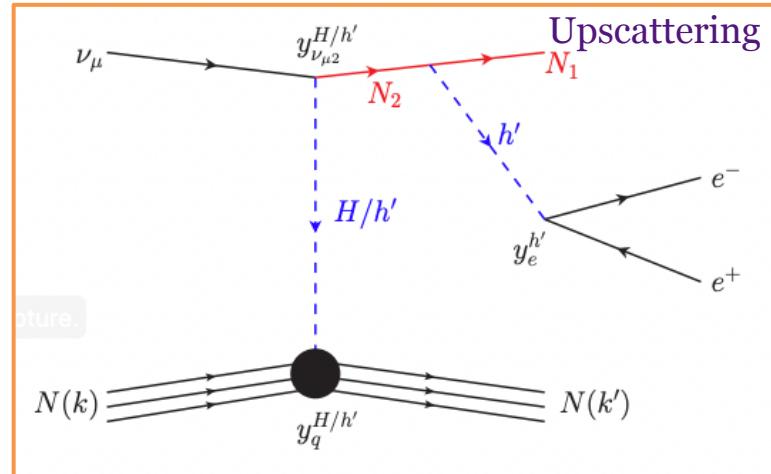


Example MiniBooNE-BSM models we can probe

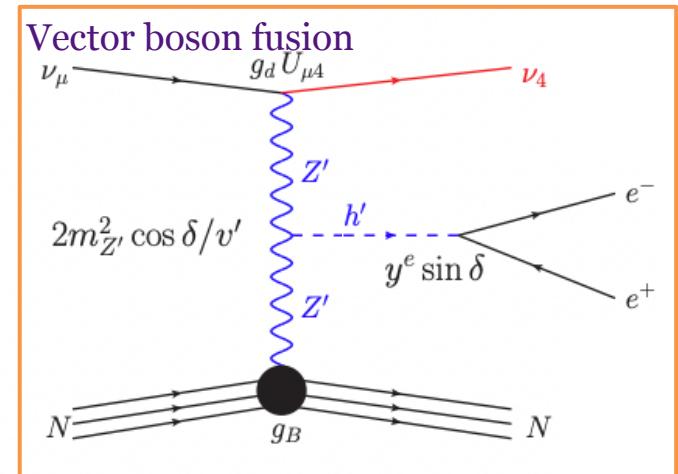
- Non-exhaustive list of a few of these models...
 - Apologies if your favourite model is not mentioned.
[Contact us to add it to our searches](#) ([bonus points if you have written a generator we can use to test it](#))
- Models involving **dark lepton sector & dark U(1) gauges**; **adding new scalars (2HDM etc)**; or even **dark-matter based solutions unrelated to neutrinos** (plus many more I haven't mentioned...)



Bertuzzo et al, PRL 121, 241801 (2018)
Ballett et al, PRD 99, 071701 (2019)
Abdullahi et al, PLB 820, 136531 (2021)



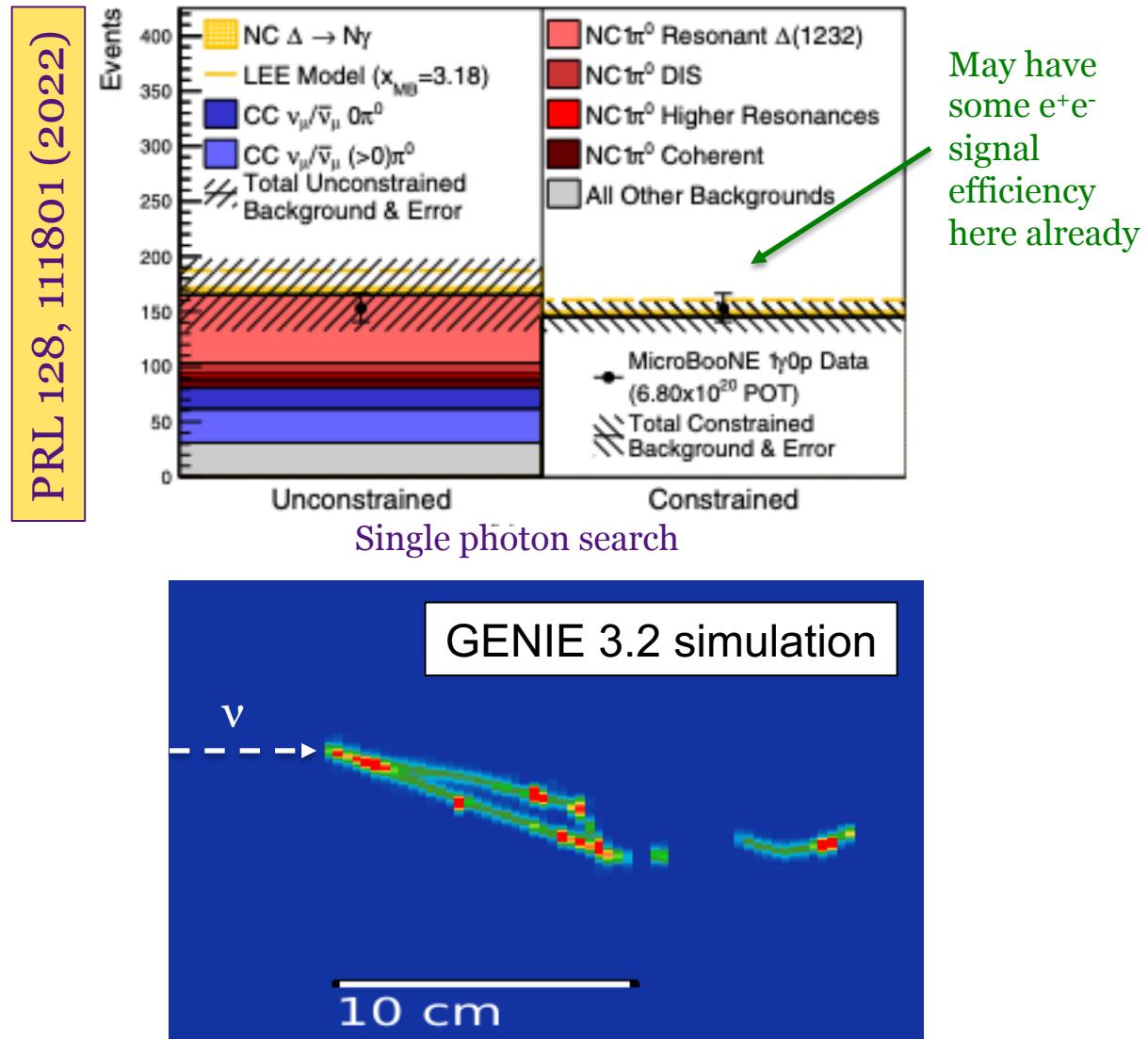
Dutta et al, PRD 102, 055017 (2020)
Abdallah et al, PRD 104, 055028 (2021)



Abdallah et al, JHEP 12, 188 (2020)

MicroBooNE e^+e^- searches

- These e^+e^- signatures may look a lot like single photons
 - We may have some sensitivity to these models in our photon measurements (Andrew's talk)
- We are also developing dedicated searches for these models
 - Only really kicking off this year, due to lack of event generators
 - GENIE 3.2 released in March
 - DarkNews released in June
 - Achilles coming soon



GENIE: <http://www.genie-mc.org/>; DarkNews: <https://github.com/mhostert/DarkNews-generator>; Achilles: *Phys.Rev.D* 105, 096006 (2022)

Summary

- MicroBooNE is not only a neutrino oscillation or cross-section experiment, but has a strong BSM programme too
- R&D effort to enable world-leading BSM searches:
 - Development of reconstruction techniques for n-
nbar oscillation searches
 - Pushing low-energy hit reconstruction thresholds to unprecedented levels
 - Timing resolution at the ns-scale, best for any LArTPC
- Capabilities of searching for dark matter, long-lived particles or portal mediators, from high-intensity meson decays
 - Published competitive searches for heavy neutral leptons and scalars, with more on the way very soon
 - Have competitive sensitivity to sub-GeV dark matter produced in the beam
- Aiming to release first results on MiniBooNE-targeted BSM e^+e^- searches in the coming year

