

Recent results and prospects for BSM searches in MicroBooNE

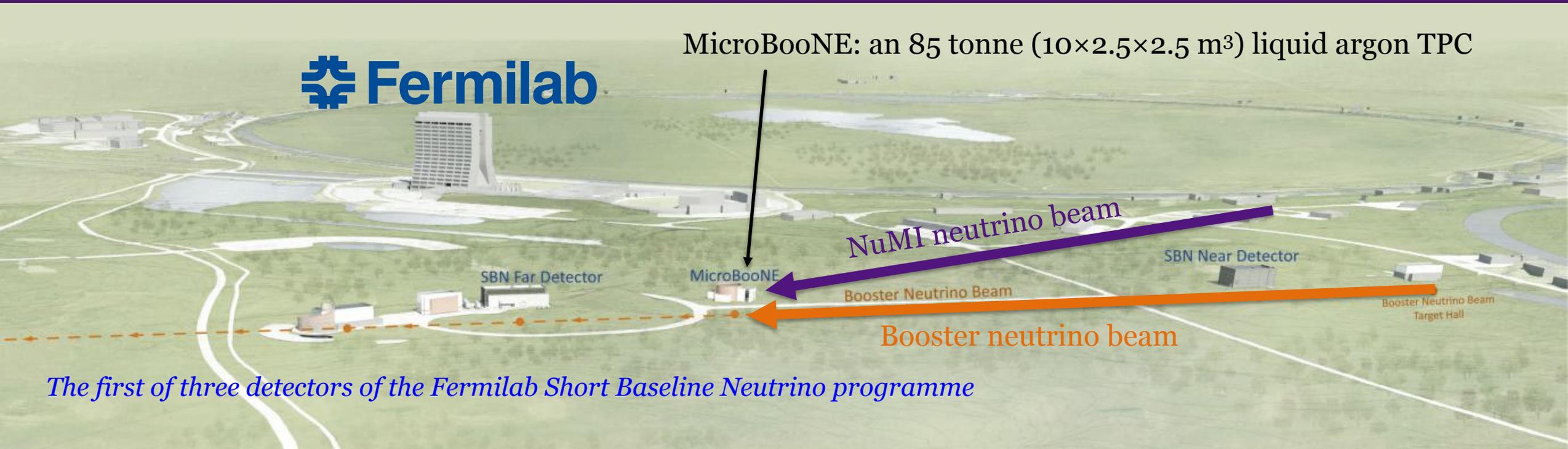
Pawel Guzowski

The University of Manchester

On behalf of the MicroBooNE Collaboration

SUSY 2023
21 July 2023
Southampton

MicroBooNE



Goals of the experiment

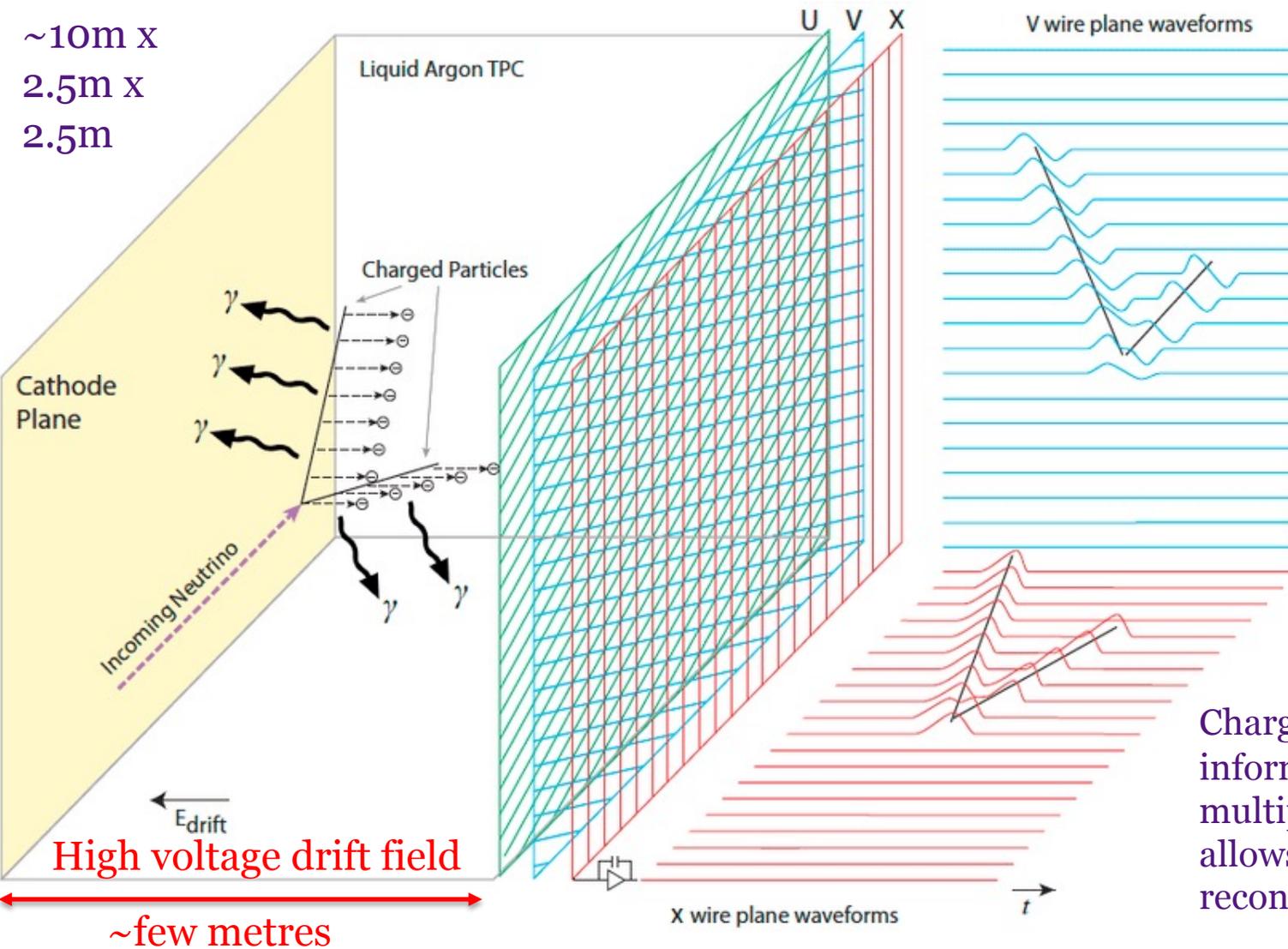
- Investigate the nature of the MiniBooNE low-energy electromagnetic anomaly
- Large-statistics ν -Ar cross-section measurements
- R&D and long-term operations of LArTPCs

• Searches for exotica: (This talk)

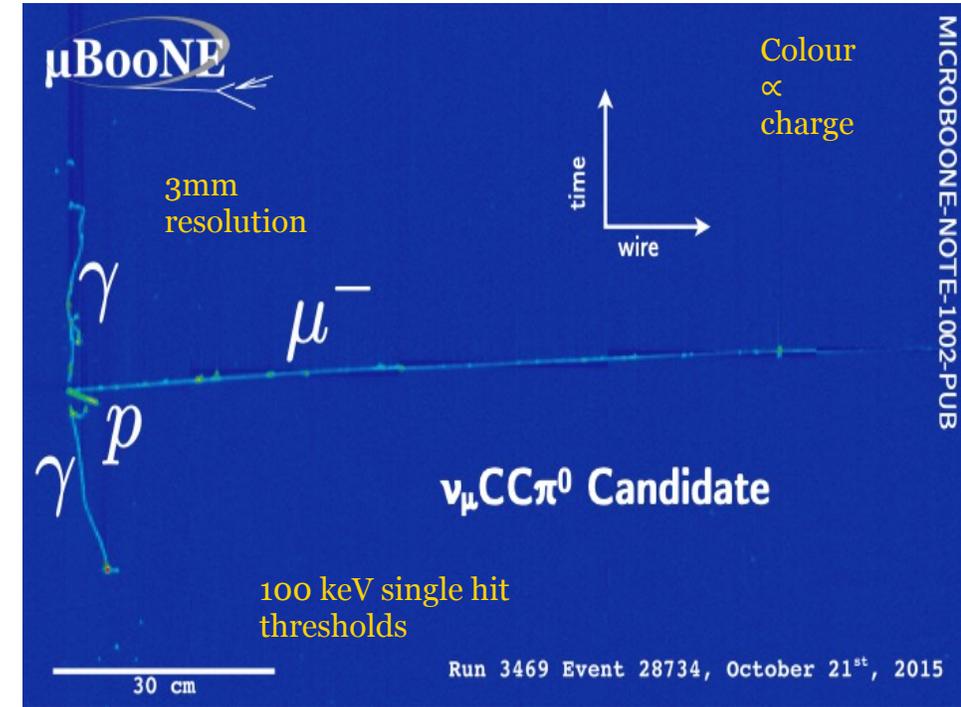
- R&D for future searches
 - Neutron-antineutron oscillation
 - Low-energy thresholds for millicharges
 - Nanosecond-scale timing for massive new physics
- Searches for long-lived fermions and bosons produced in rare meson decays
 - Heavy neutral leptons
 - Higgs portal scalars
- Prospects for beam-produced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

LArTPCs

Multiple planes of readout sense wires

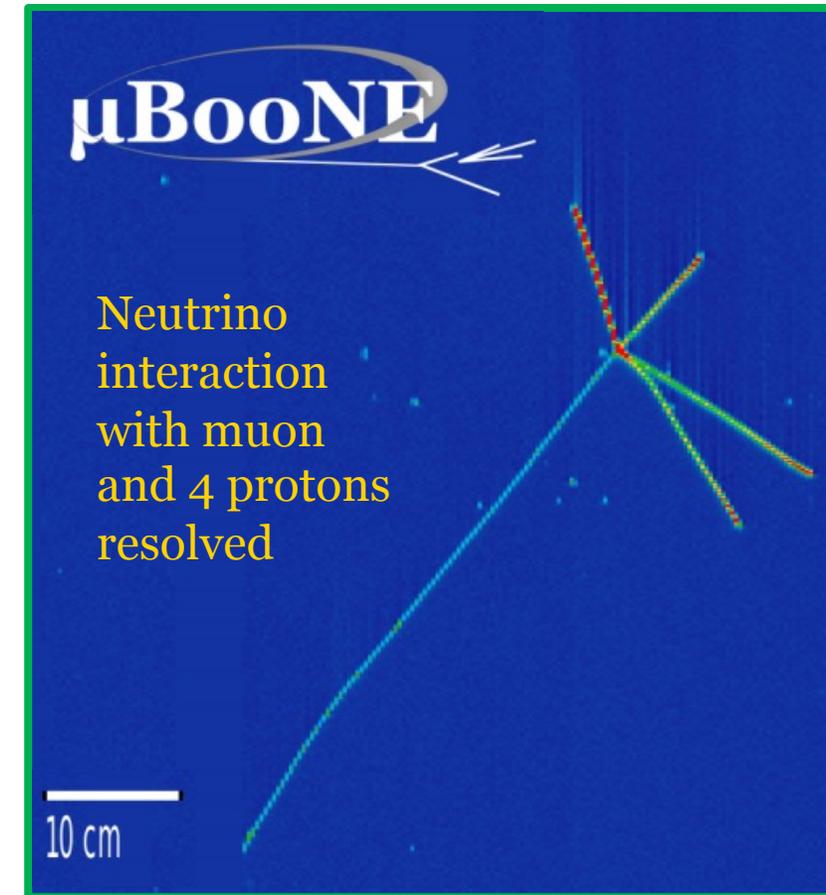


Charge vs time information on multiple planes allows for 3D reconstruction



Why BSM in MicroBooNE?

- BSM searches at the energy frontier are well known; what can a neutrino experiment add to our knowledge?
- Neutrino beamlines offer searches in **complementary parameter space**
 - Most significant in the $O(100\text{MeV})$ New Physics mass range
 - No ‘pT’ trigger (reduces collider sensitivities to low masses)
- **High intensities** – feebler coupling accessible
 - E.g. $O(1000)\times$ higher POT collected than NA62
- Actually taking images of interactions
 - **Excellent particle identification**
 - Anomalous high multiplicity final states are visible



R&D EFFORT

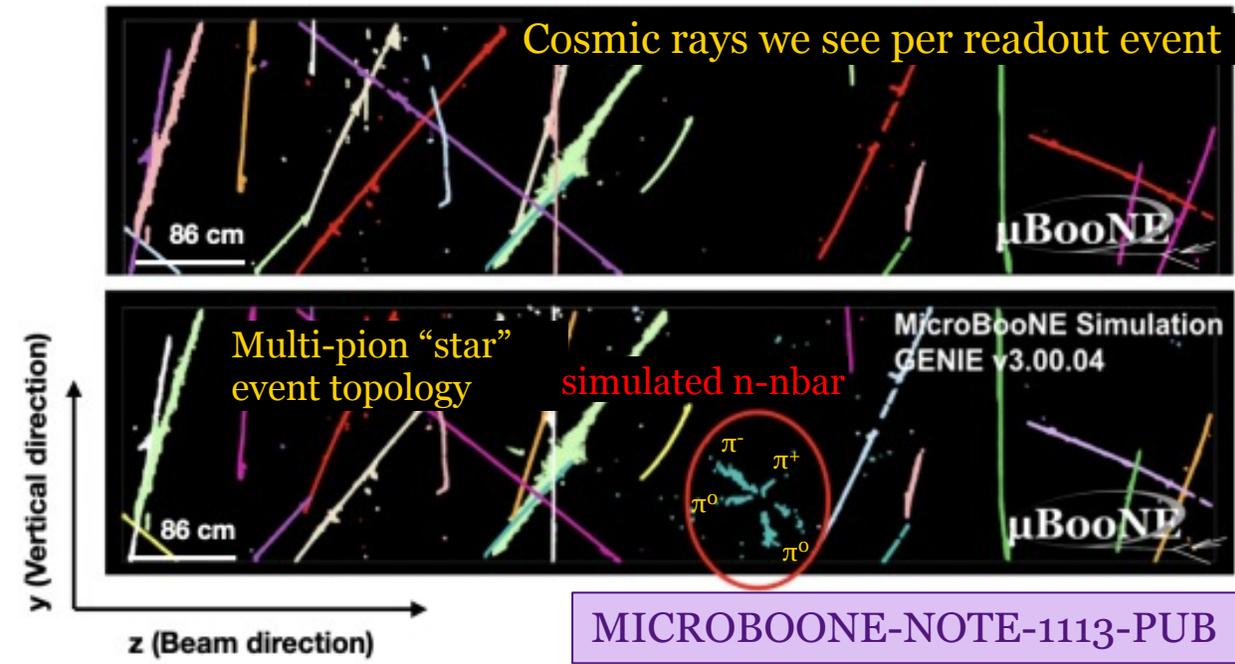
Neutron-antineutron oscillation

- 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 preliminary half-life sensitivity: 3×10^{25} years**
- **Paper out later this year**

$$X_1 \in (\bar{6}, 1, -1/3), X_2 \in (\bar{6}, 1, 2/3)$$

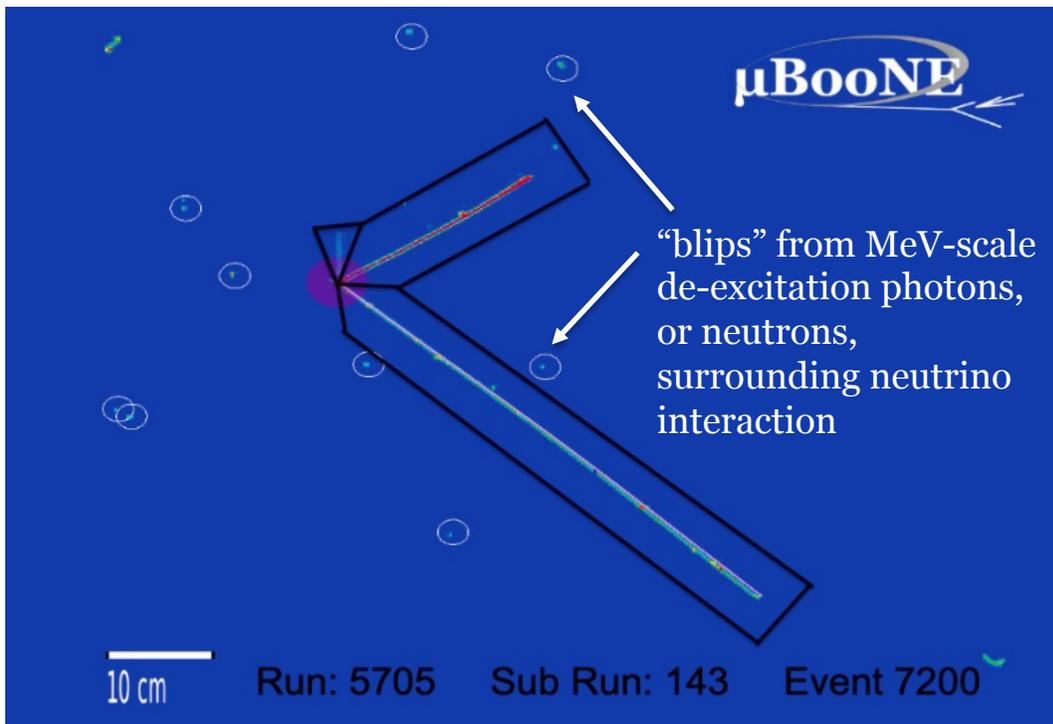
$$\mathcal{L} = -g_1^{ab} X_1^{\alpha\beta} (Q_{L\alpha}^a \epsilon Q_{L\beta}^b) - g_2^{ab} X_2^{\alpha\beta} (d_{R\alpha}^a d_{R\beta}^b) - g_1'^{ab} X_1^{\alpha\beta} (u_{R\alpha}^a d_{R\beta}^b) + \lambda X_1^{\alpha\alpha'} X_1^{\beta\beta'} X_2^{\gamma\gamma'} \epsilon_{\alpha\beta\gamma} \epsilon_{\alpha'\beta'\gamma'}$$

Arnold et al, PRD 87, 075004 (2013)



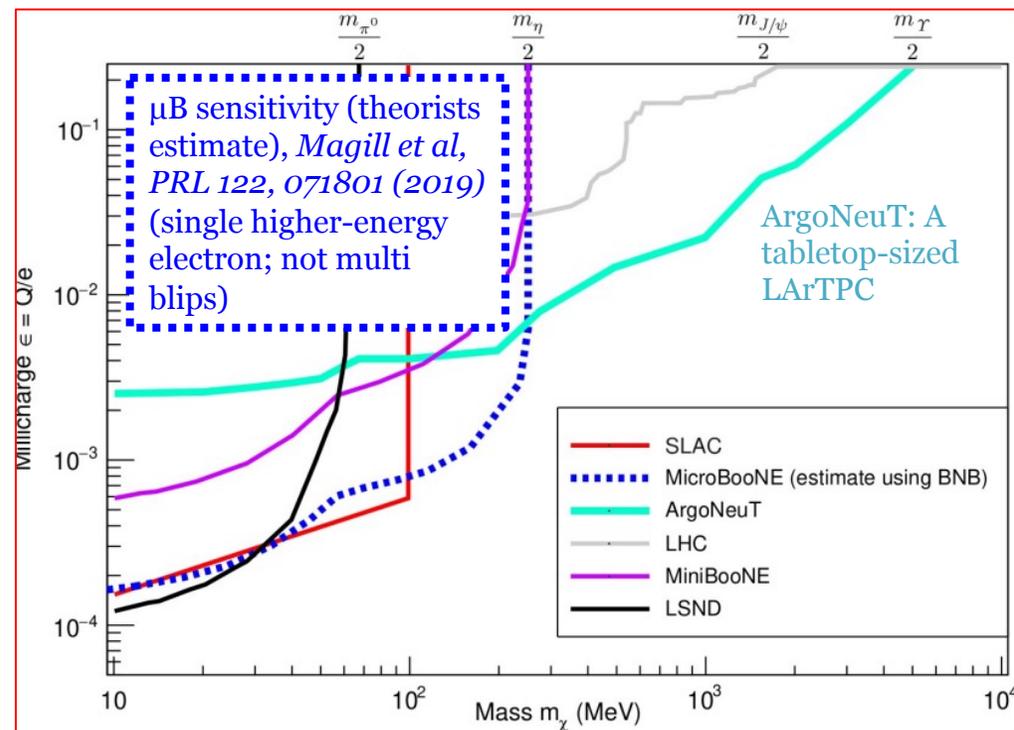
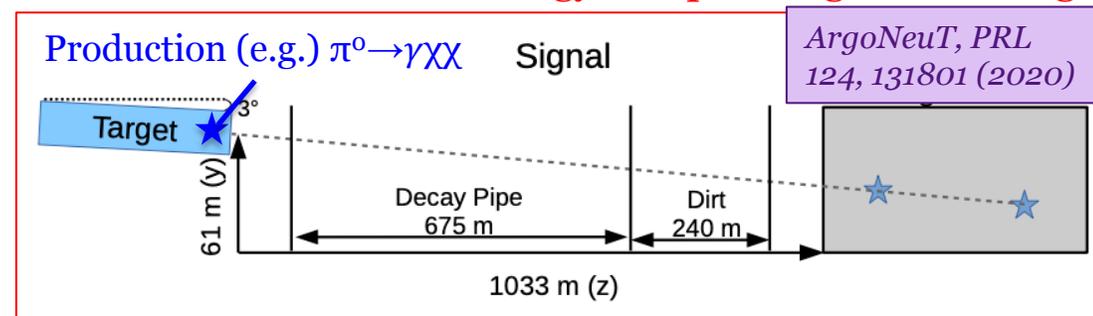
Low-energy hits and millicharged particles

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



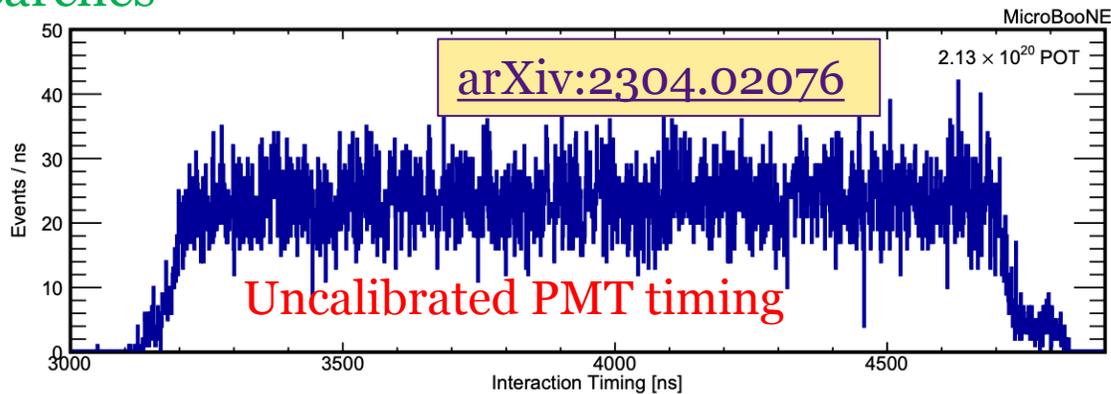
MICROBOONE-NOTE-1076-PUB

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

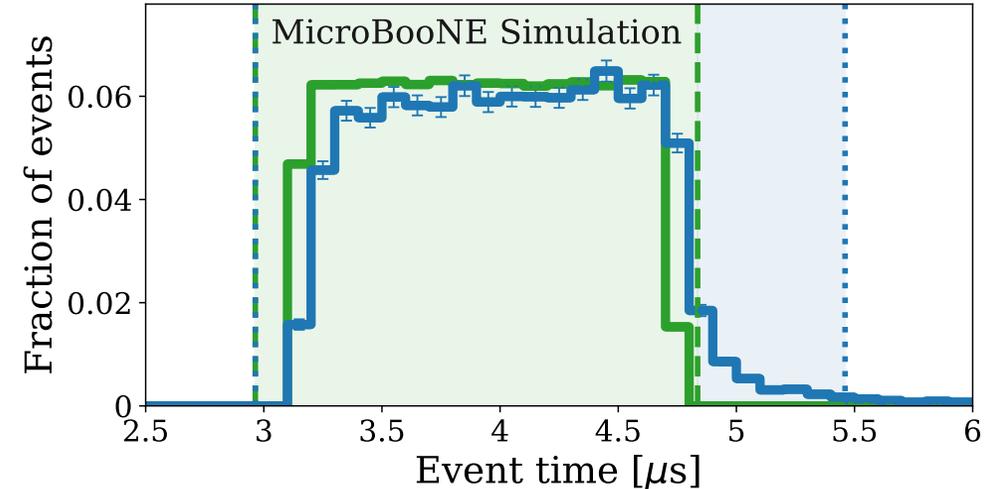
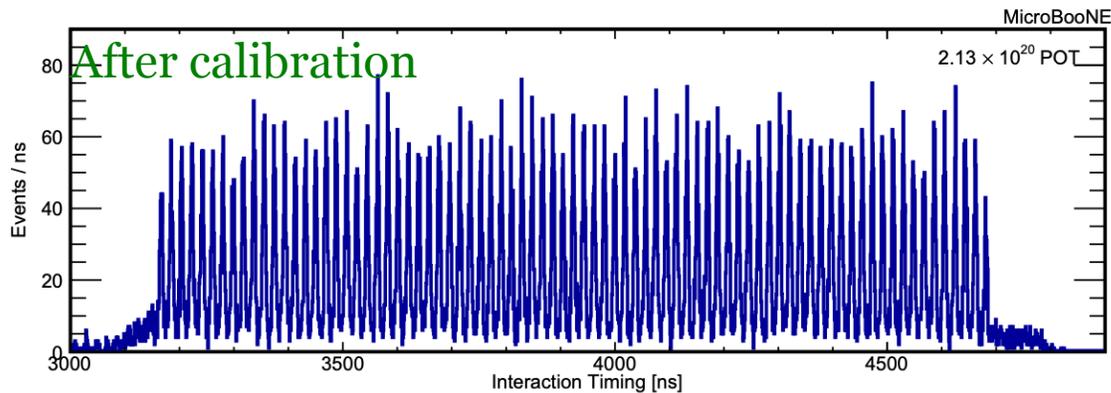


Event timing for new physics

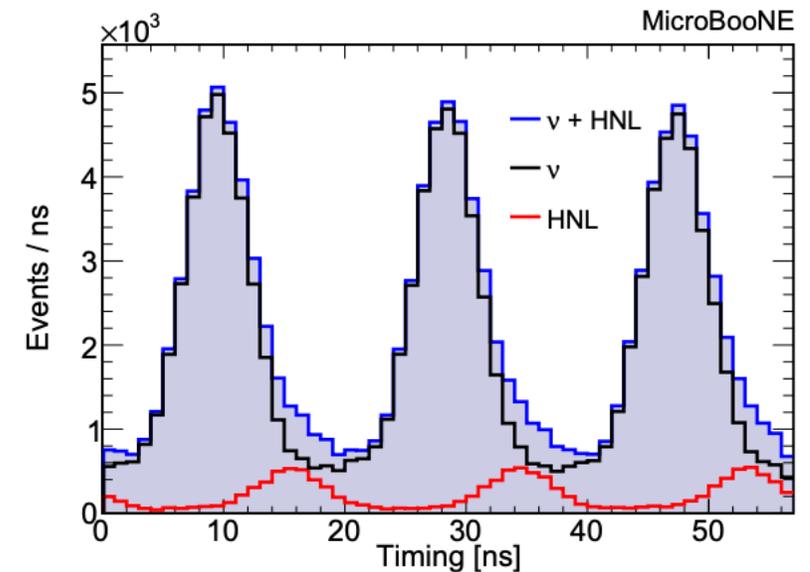
- MicroBooNE has been pioneering the calibration of LArTPC event timing down to the nanosecond scale
- Non-massless new physics produced in the beamline has delayed TOF with respect to neutrinos
 - Can use this high-resolution timing to enhance BSM searches



(a) Interaction timing distribution before the propagation reconstruction.



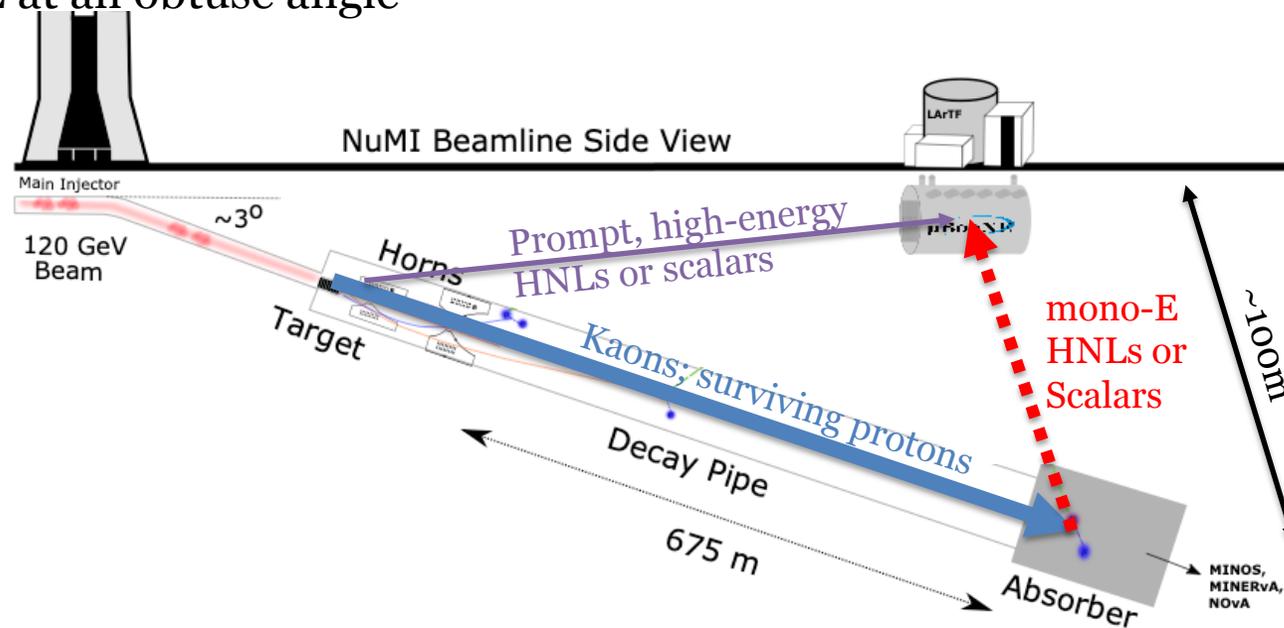
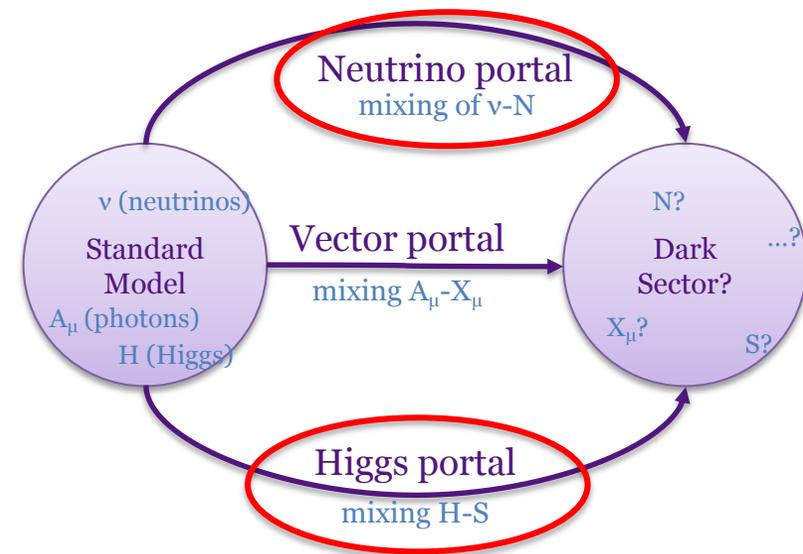
Phys.Rev.D 101, 052001 (2020)



RECENT BSM SEARCHES

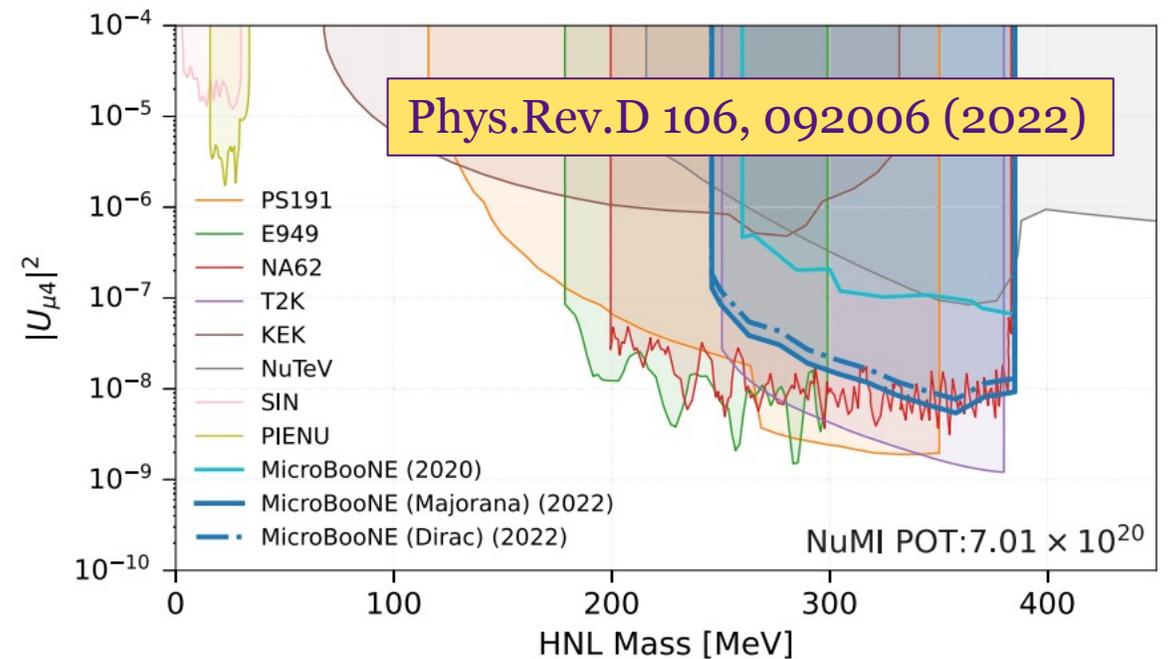
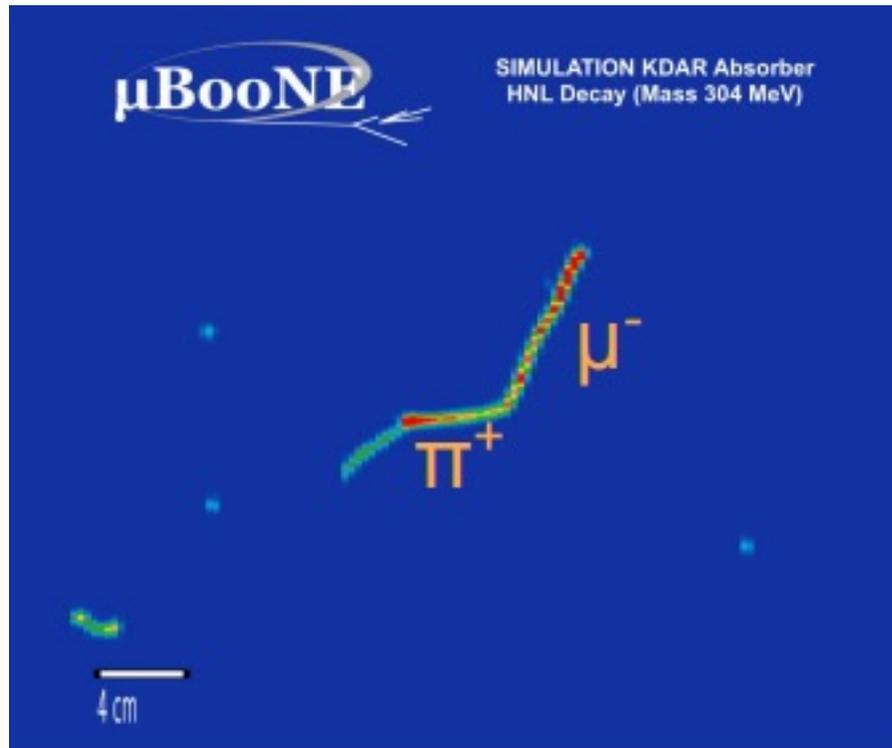
Heavy neutral leptons and Higgs portal scalars

- 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



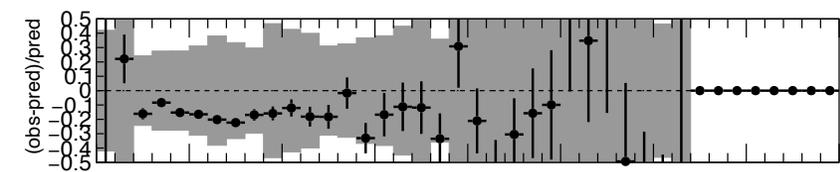
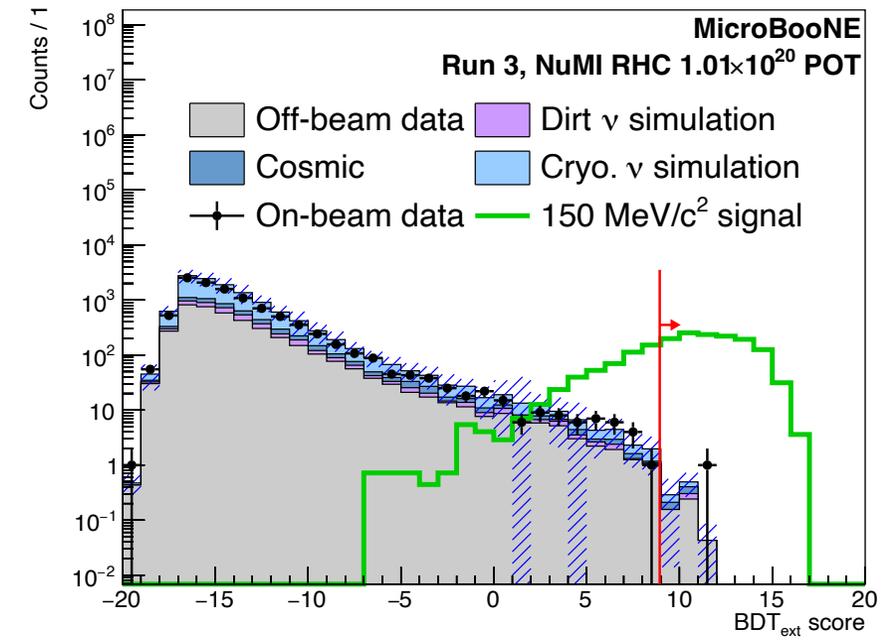
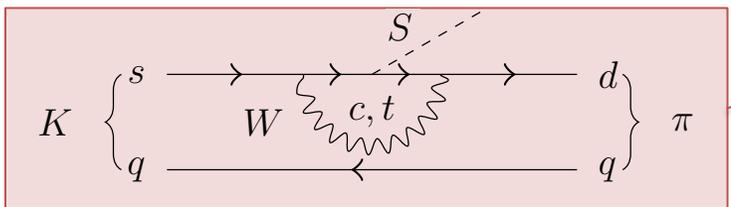
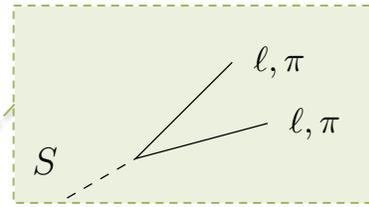
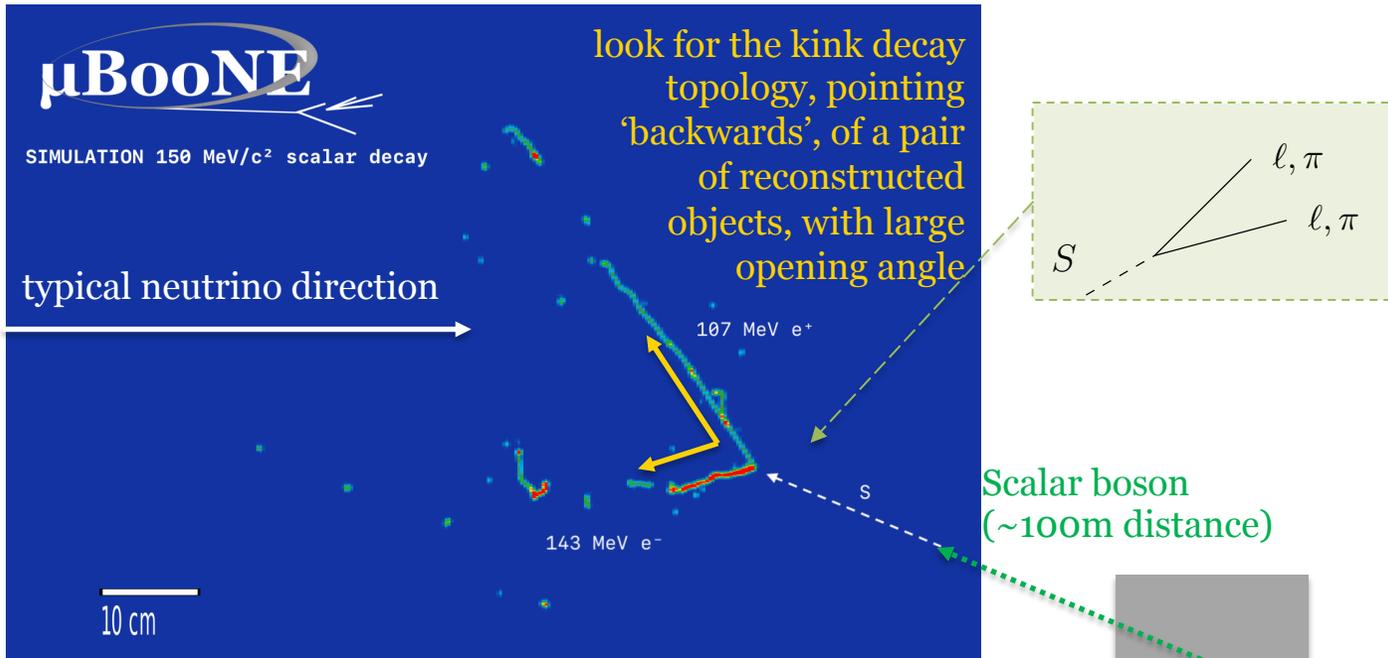
2022 HNL result

- New strategy: search for HNLs produced in the NuMI beam dump



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

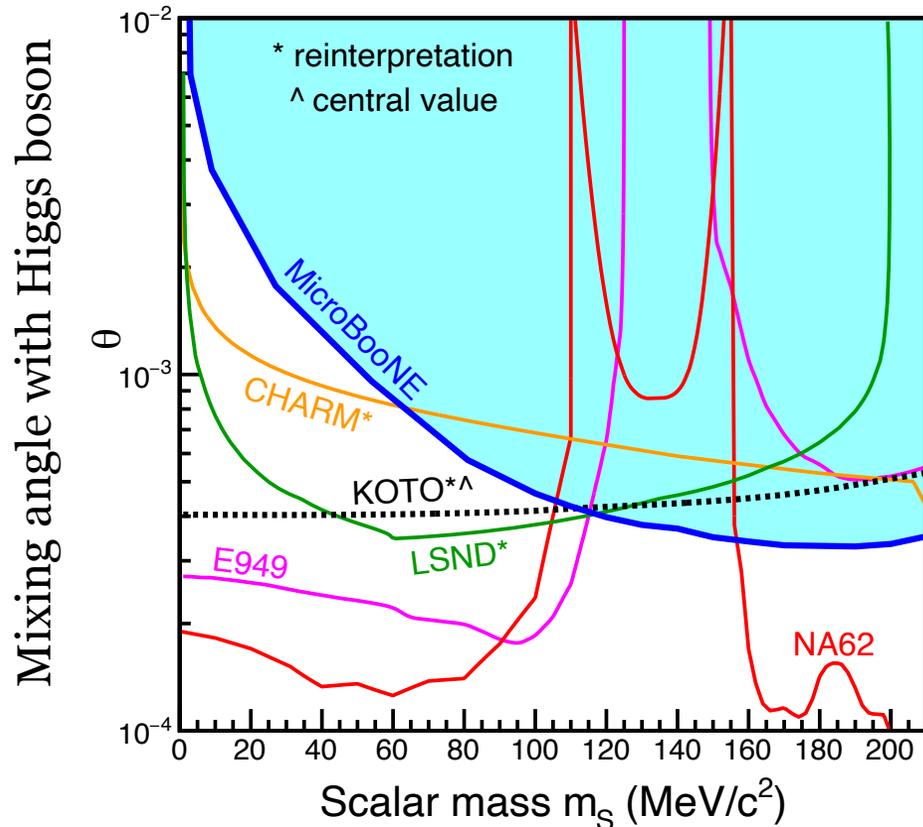


BDT distribution, well modelled with background-only expectation

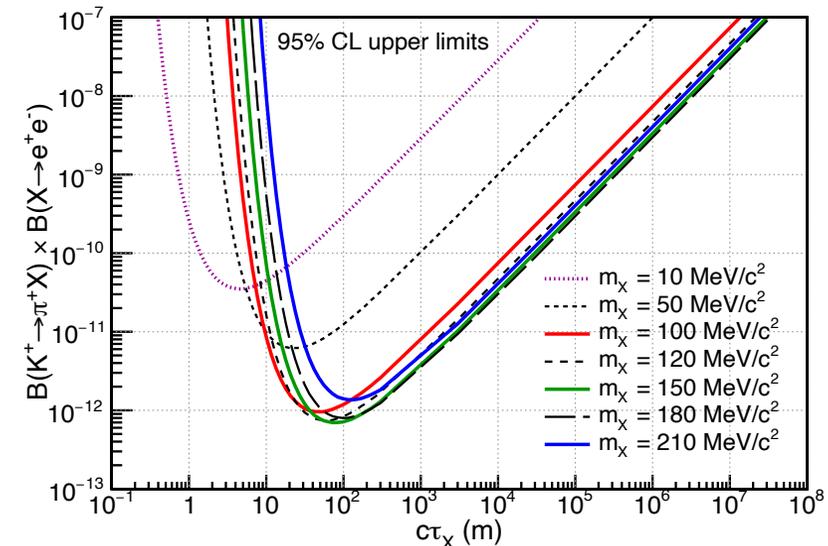
We observe 1 event in signal region, with 2.0 ± 0.8 expected background

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!



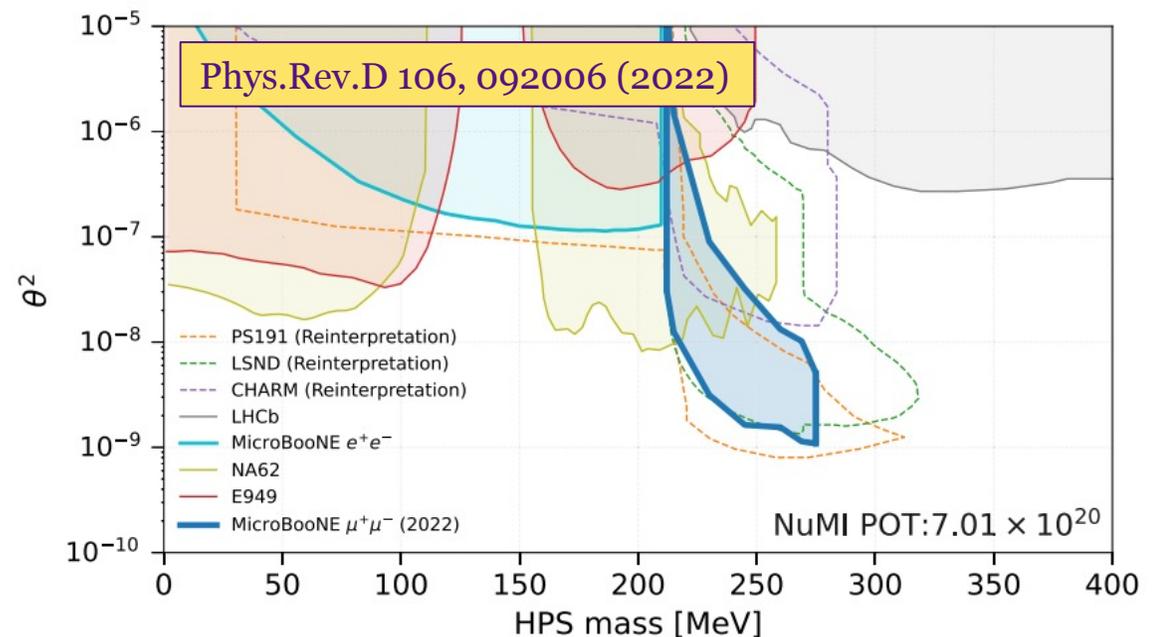
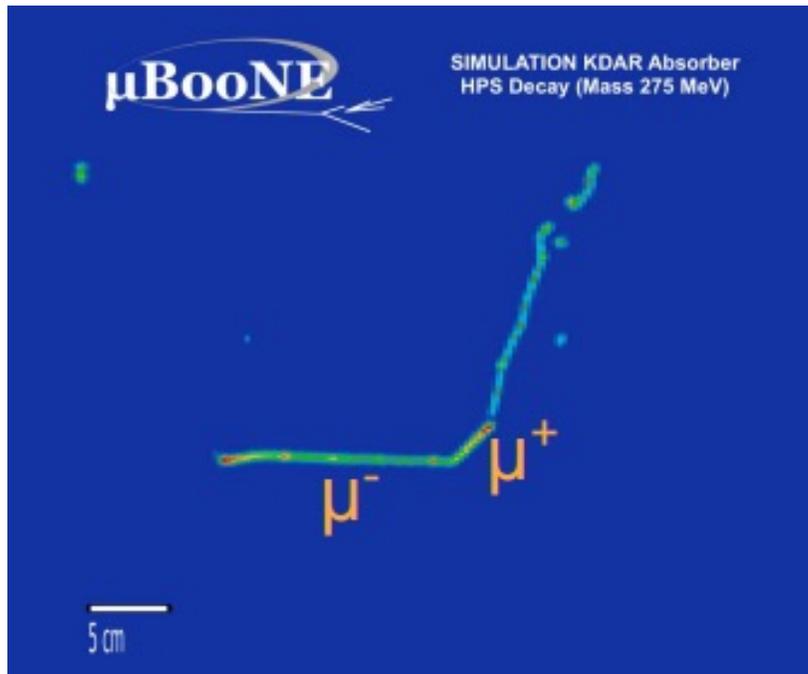
PRL 127, 151803 (2021)



Model-independent LLP limit also available

Dimuon decay mode

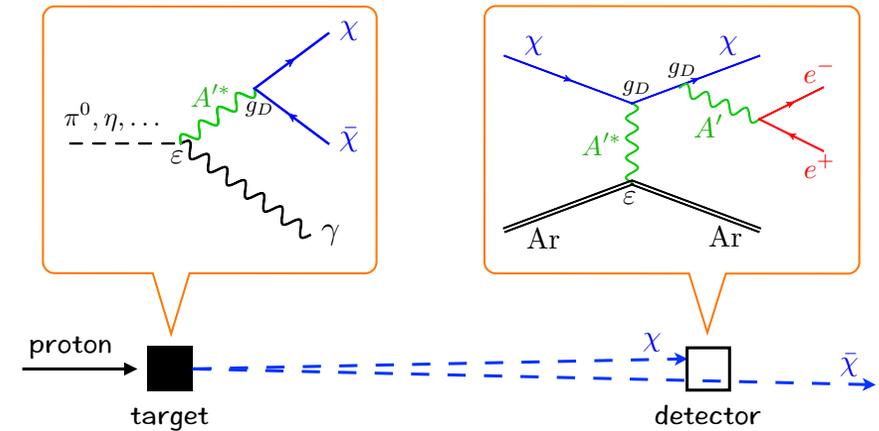
- We also adapted the HNL search (mu-pi decays) to search for scalars
 - Muons & pions look almost identical in our detector
- Set world-leading direct limits for masses $\sim 210\text{-}270$ MeV



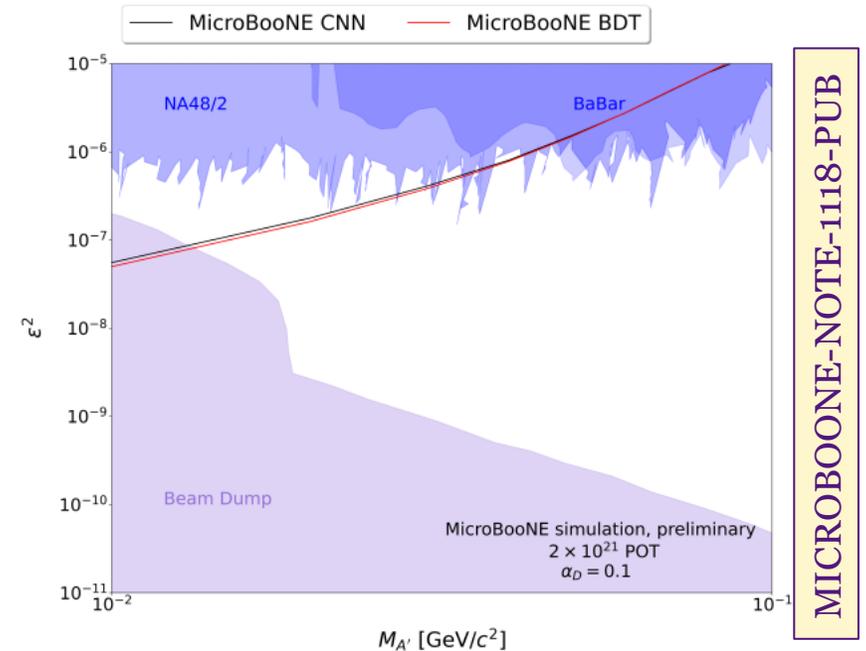
(NEAR) FUTURE BSM PROSPECTS

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”
- Sensitive to new regions of the parameter space
- Search results coming this year

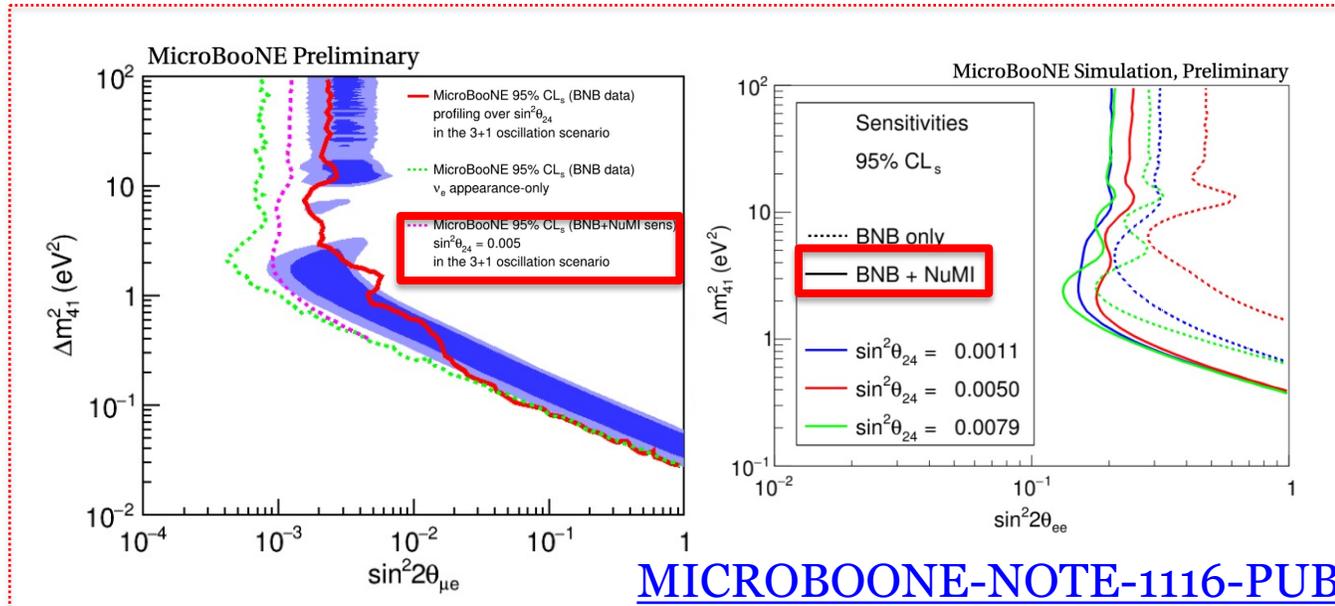
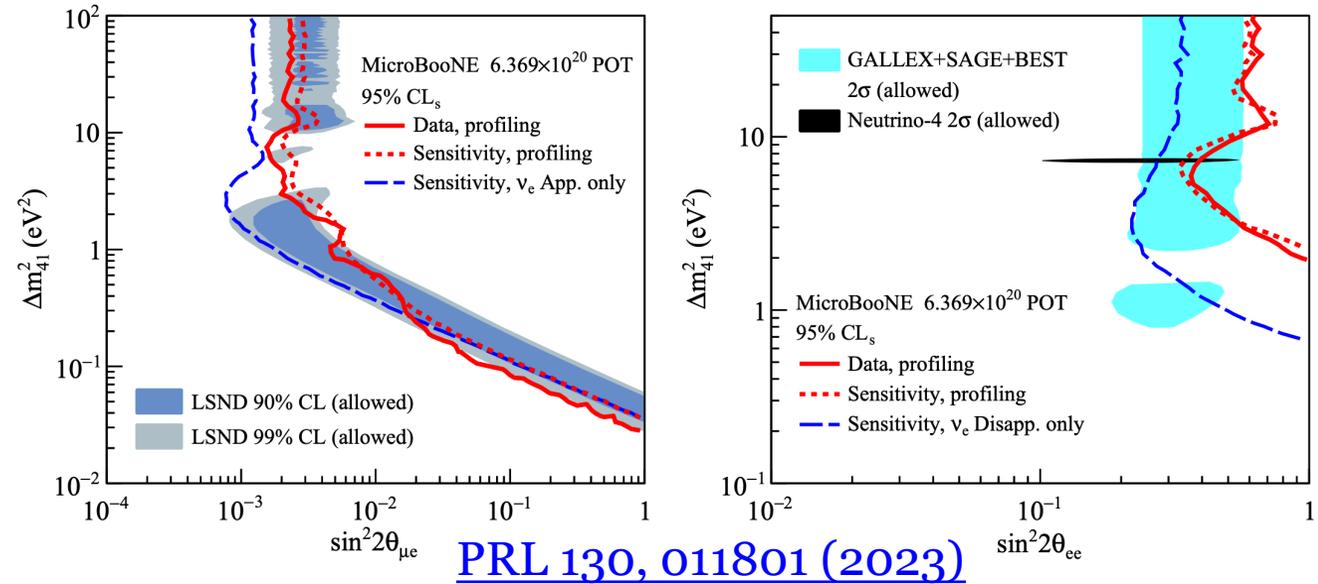


(Minimal model: one DM species; one $U(1)$ dark gauge)



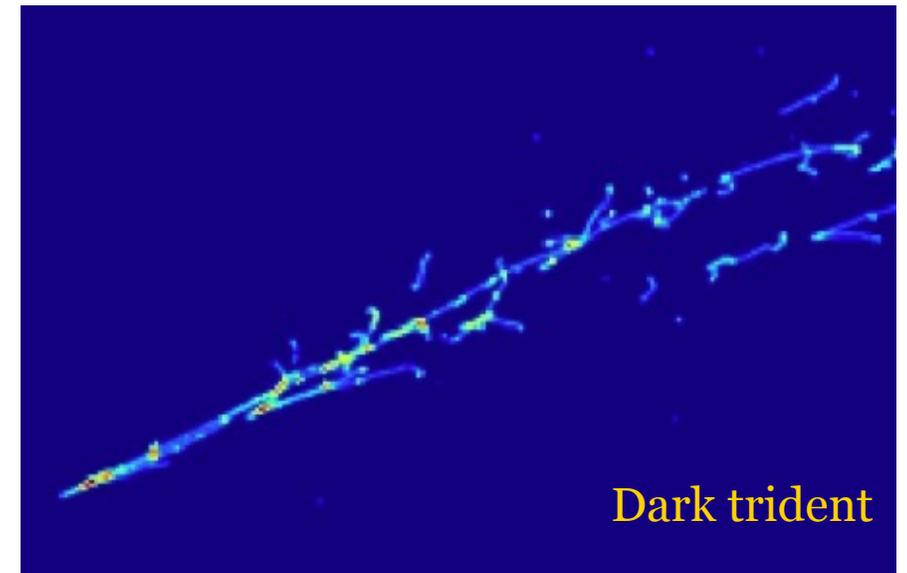
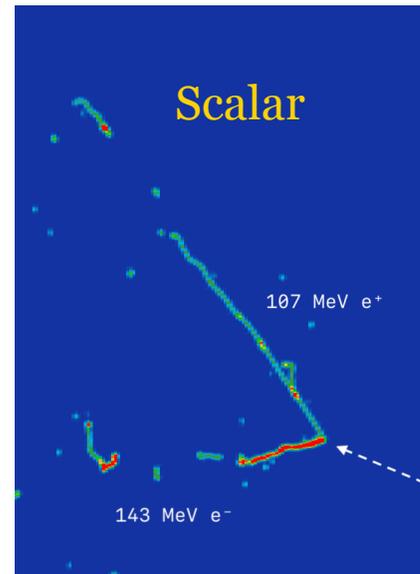
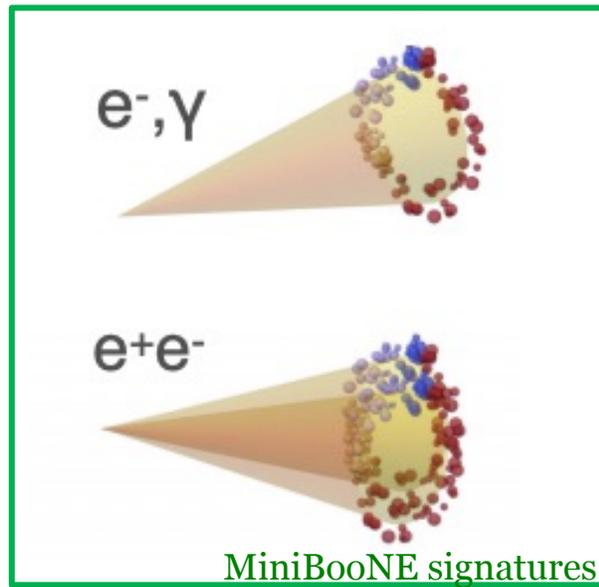
MiniBooNE 3+1 light neutrinos

- For a (1+1) nue appearance only analysis, we are sensitive to the whole LSND/MB allowed region
- Extending to a 3+1 model, there is cancellation between nue appearance and intrinsic nue disappearance
- Degeneracy can be broken by using **NuMI data**
 - Different L/E
 - Larger intrinsic nue contribution



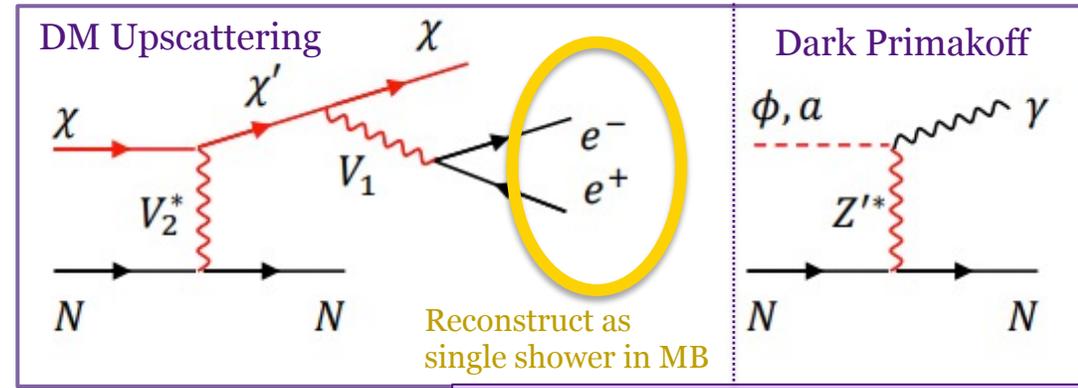
MiniBooNE: e^+e^- explanations

- 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

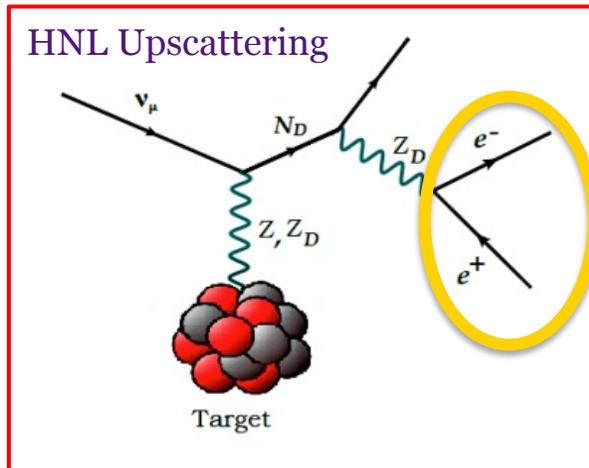


Newer BSM models

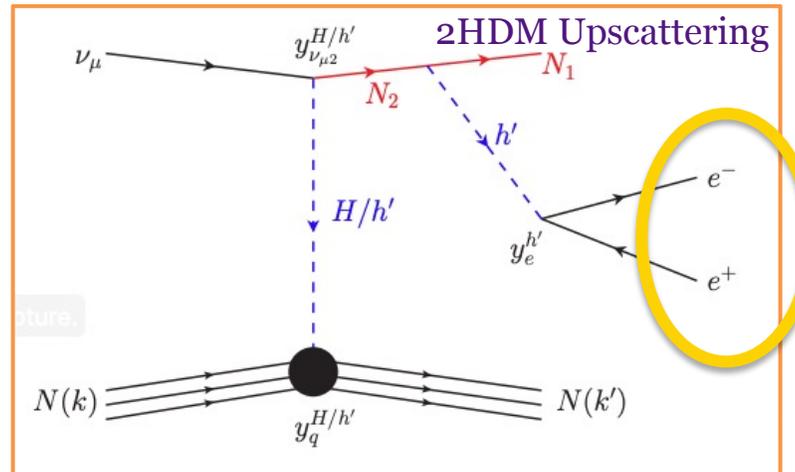
- Over past few years, theorists have been having new BSM ideas for explaining MiniBooNE beyond light sterile neutrinos
- Models involving **dark lepton sector & dark U(1) gauges**; **adding new scalars (2HDM etc)**; or even **dark-matter based solutions** unrelated to neutrinos (plus many others...)
- Contact us if you have a favourite model to test...**



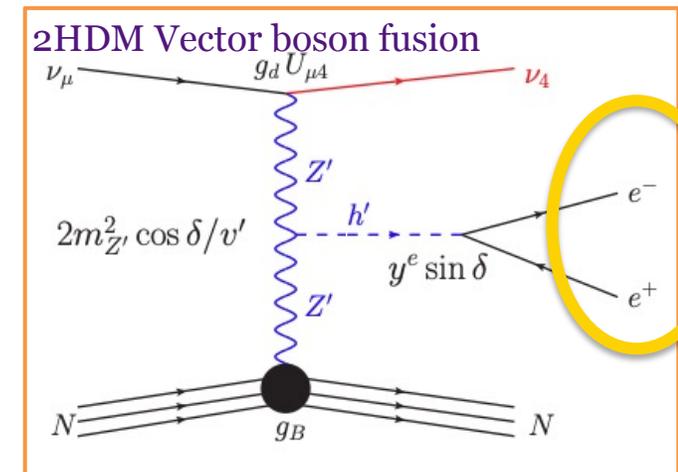
[Dutta et al, PRL 129, 111803 \(2022\)](#)



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



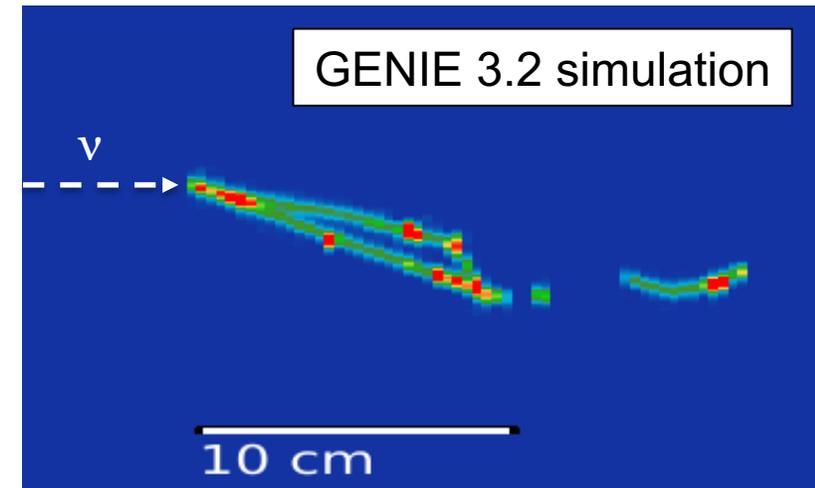
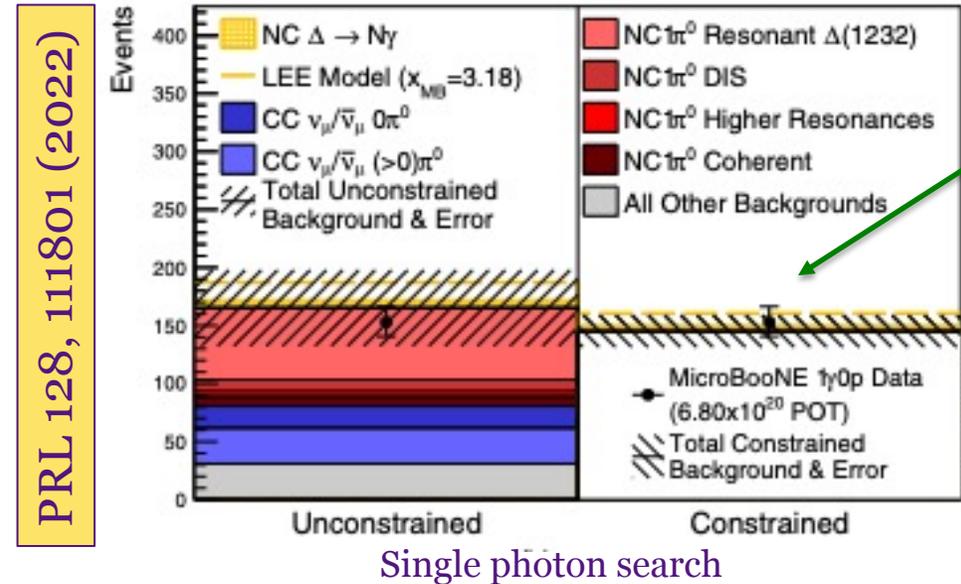
[Dutta et al, PRD 102, 055017 \(2020\)](#)
[Abdallah et al, PRD 104, 055028 \(2021\)](#)



[Abdallah et al, JHEP 12, 188 \(2020\)](#)

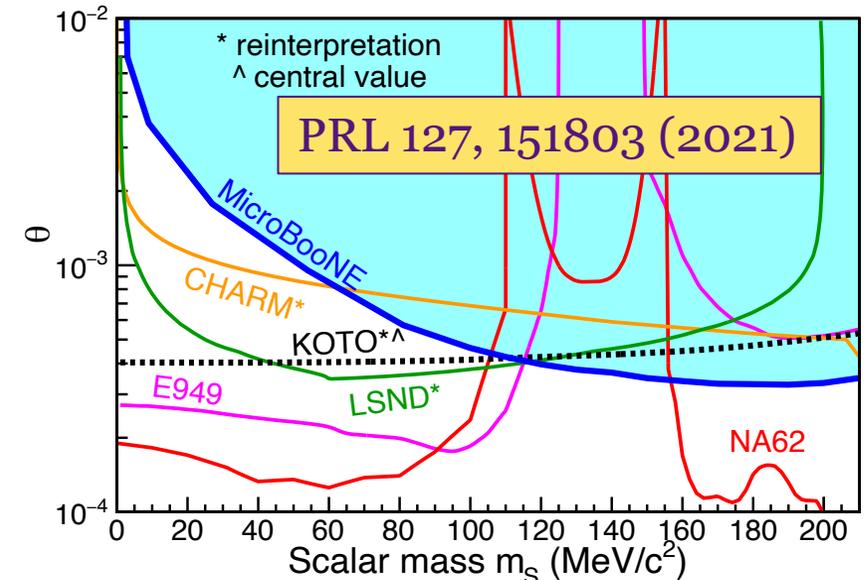
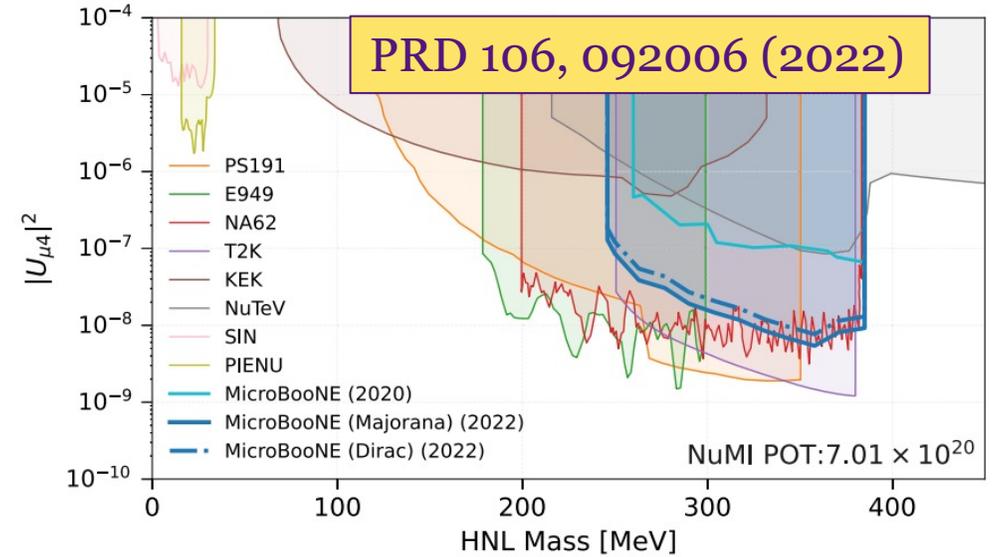
MicroBooNE e^+e^- searches

- These e^+e^- signatures may look like single photons in certain phase space
 - We may have some sensitivity to these models in our photon measurements
- We are also developing dedicated searches for these models
 - Stay tuned for first results coming later this year



Summary

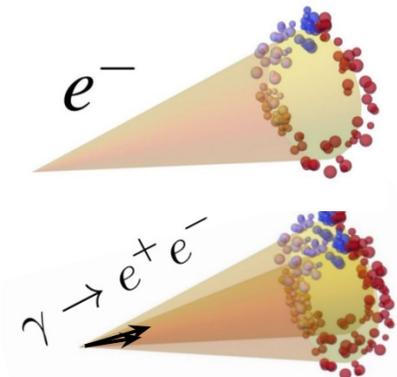
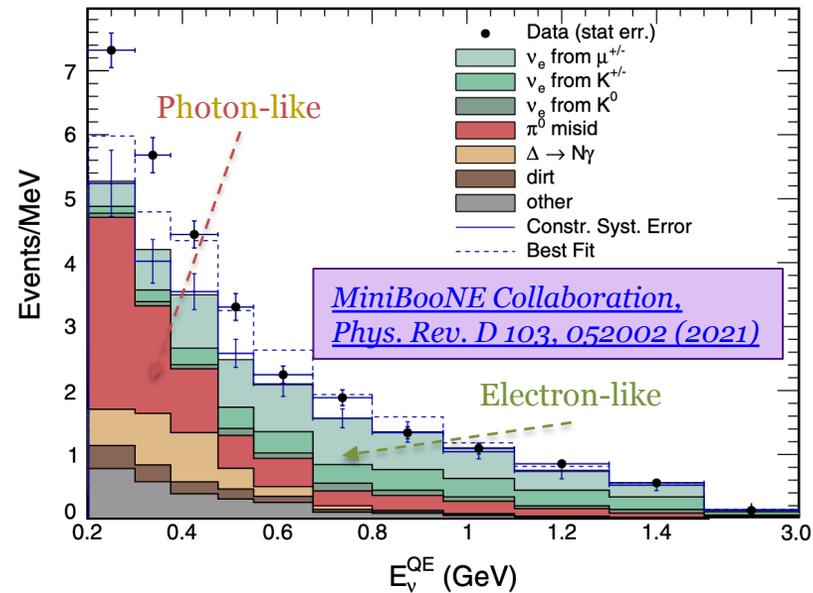
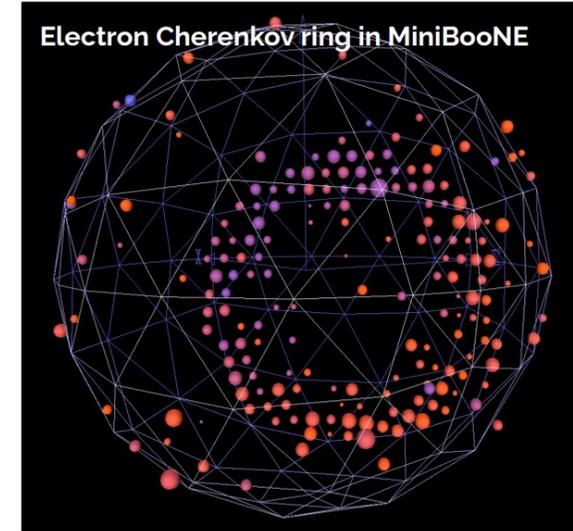
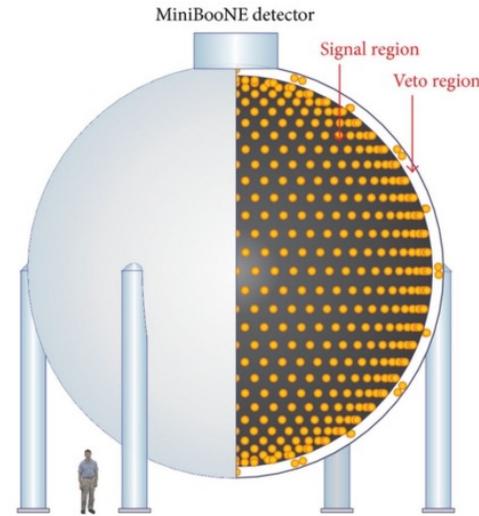
- MicroBooNE is not only a neutrino oscillation or cross-section experiment, but has a **strong BSM programme** too
 - Wide variety of New Physics models are accessible
- **R&D effort to enable world-leading BSM searches:**
 - Development of reconstruction techniques for n-nbar oscillation searches
 - Pushing low-energy hit reconstruction thresholds to unprecedented levels
 - Timing resolution at the ns-scale, best for any LArTPC
- **Demonstrated competitive 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**



ADDITIONAL SLIDES

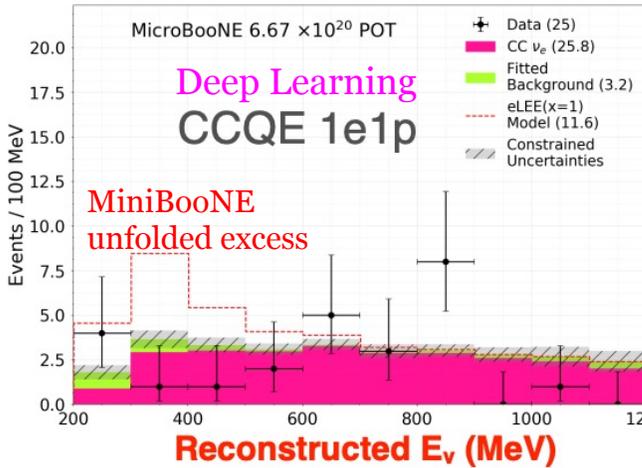
MiniBooNE anomaly

- Long-standing 4.7-sigma excess of electron-neutrino-like interactions in MiniBooNE
- Mineral oil Cherenkov detector
 - Cannot distinguish electrons from photons
- Is excess due to electron neutrinos appearing in the muon neutrino beam? Or photons? Or some other electromagnetic activity?

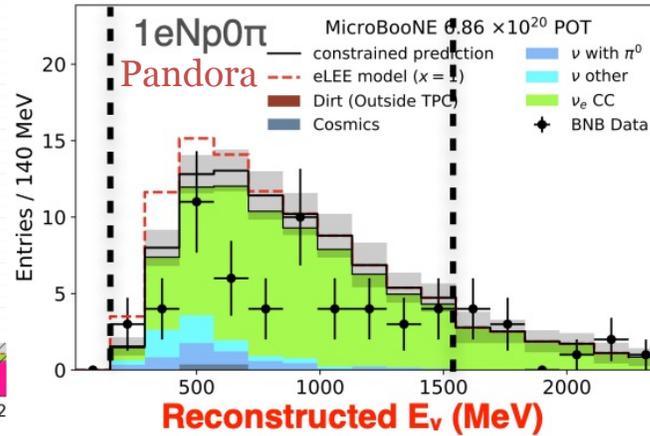


Single electron results

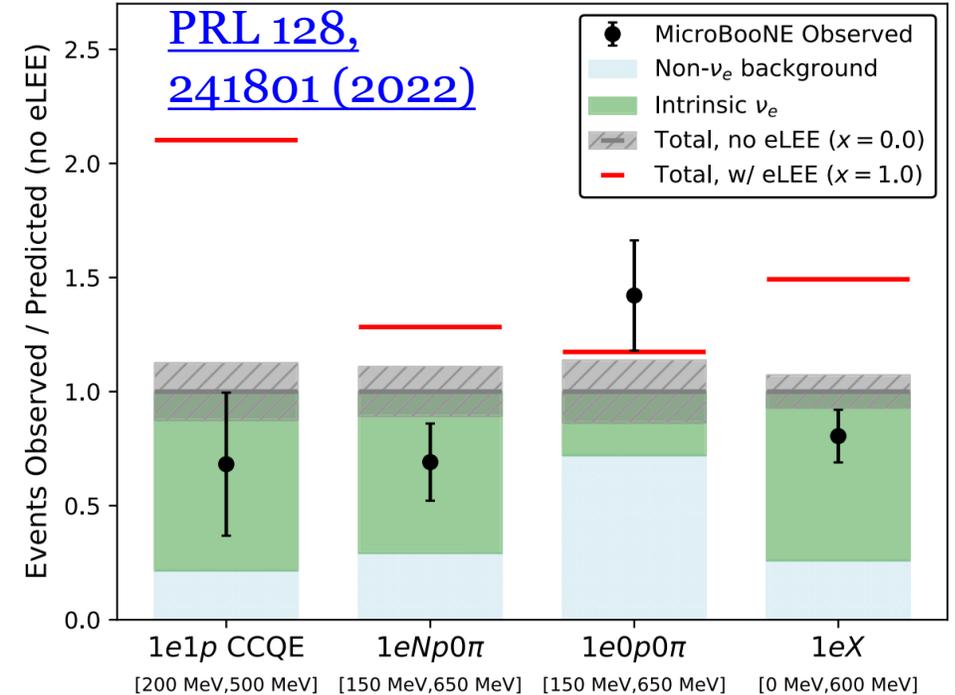
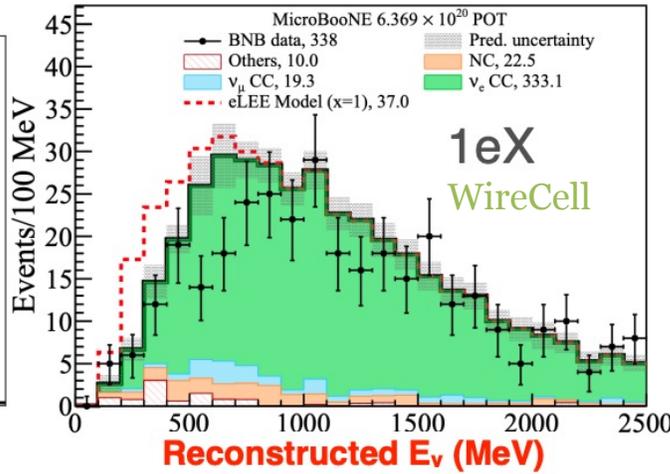
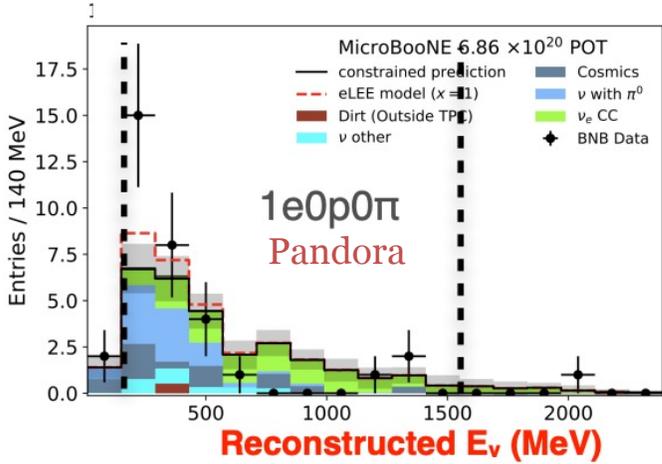
[PRD 105, 112003 \(2022\)](#)



[PRD 105, 112004 \(2022\)](#)



- No significant excess is observed
 - Some deficits, except for least sensitive, most background dominated channel
- Single-electron-alone explanation for MiniBooNE is ruled out at >97% CL



[PRD 105, 112004 \(2022\)](#)

[PRD 105, 112005 \(2022\)](#)