µBooNE

Recent results and prospects for Astroparticle and BSM Physics with MicroBooNE

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MANCHESTER 1824
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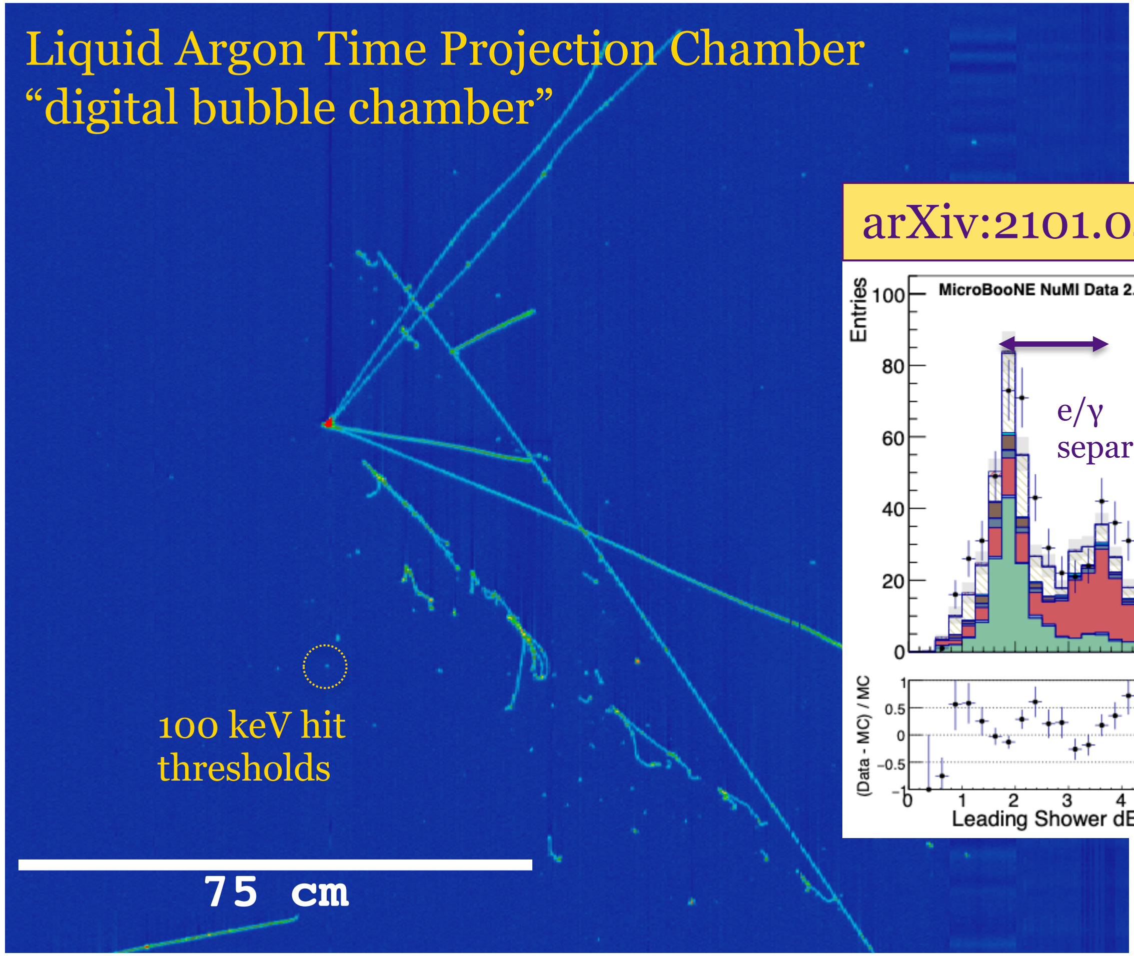
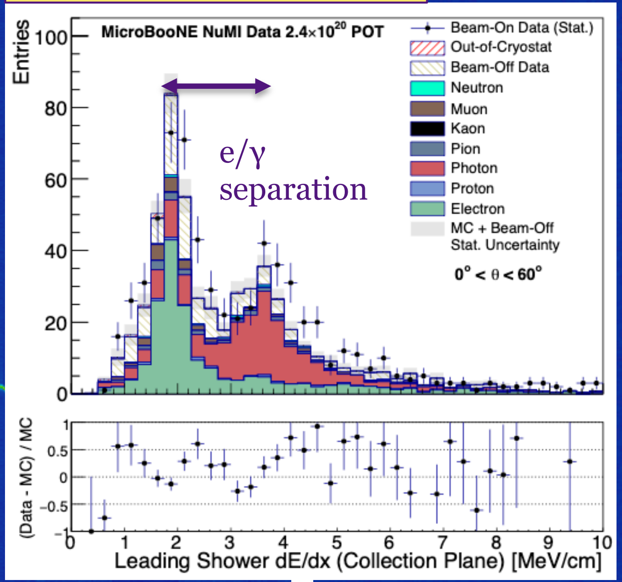
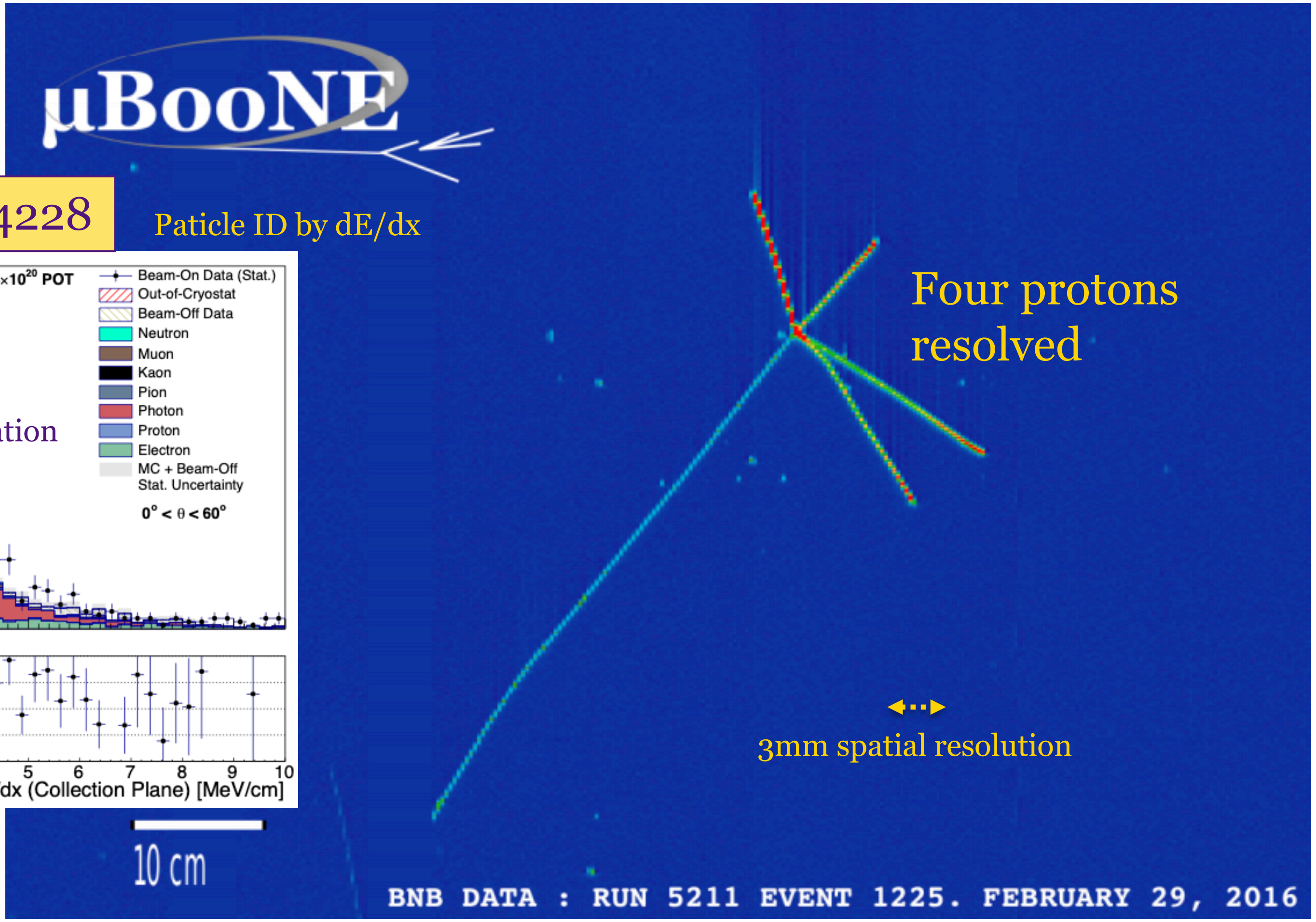
LArTPC capabilities



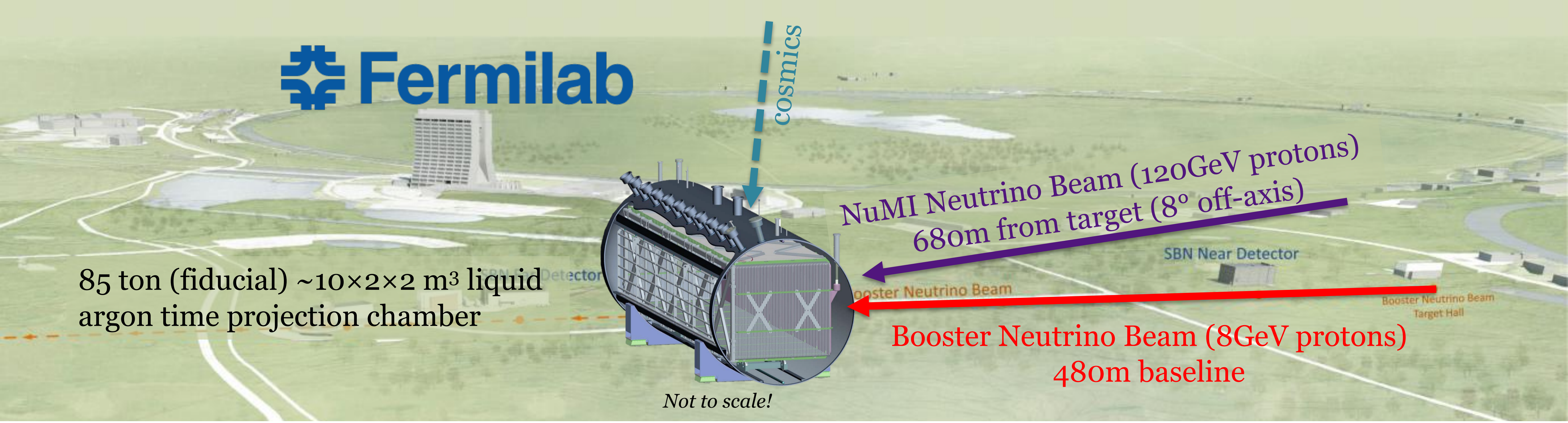
arXiv:2101.04228





Excellent spatial and charge resolution allows for unprecedented PID, and interesting *new physics searches via anomalous final state topologies*

MicroBooNE



Goals of the experiment:

Investigate the MiniBooNE anomalous excess

Cross-section measurements

LArTPC detector physics, research and development

Diverse variety of other topics in astroparticle and exotic physics, that MicroBooNE is capable of (this talk)

Astroparticle and exotic physics with MicroBooNE

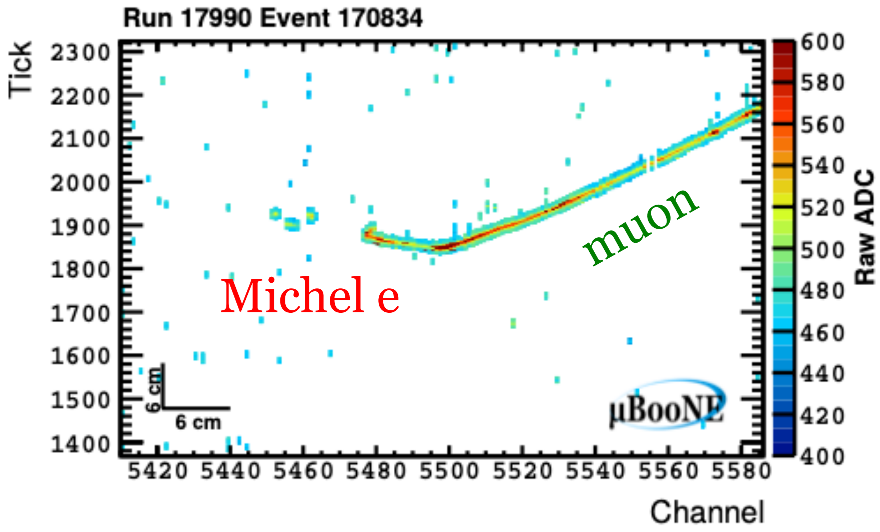
Outline of this talk:

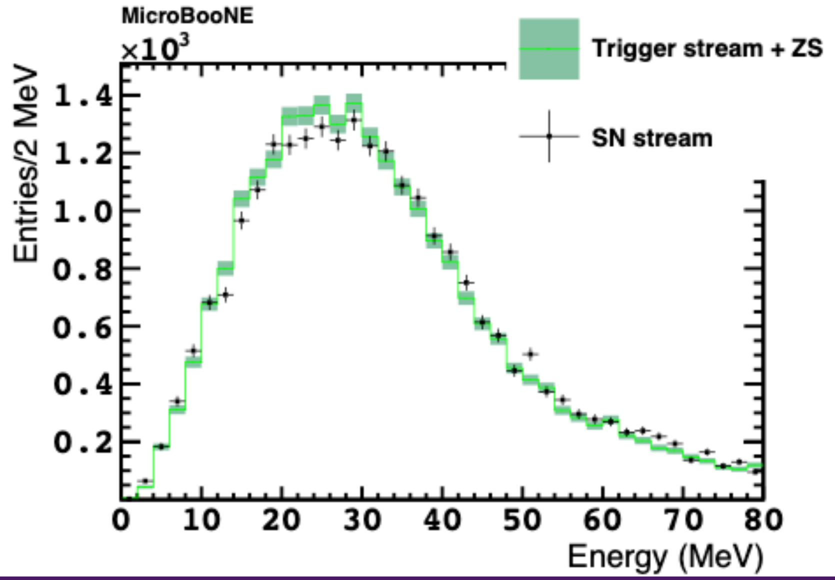
- Results released over past year
- Informing and developing for future experiments
  - Supernova neutrino R&D
  - Cosmic rate measurement
  - Baryon number violation
- Pushing reconstruction capabilities
  - MeV-scale physics
- Searches for new physics
  - Heavy neutral leptons
  - 'Higgs Portal' dark scalars
- Some prospects for future results

R&D for supernova neutrino detection

JINST 16, 02, P02008 (2021)

- A lot of data is produced by MicroBooNE – 33 GB/s
  - Orders of magnitude more expected in DUNE
- To observe supernova neutrino burst, would need continuous readout
- Pioneered a system to zero-suppress and compress the TPC data
  - Reduction of rates by over 80×
  - Prototype for DUNE
- Performance evaluated by reconstruction of Michel electrons
  - Comparable to full datastream

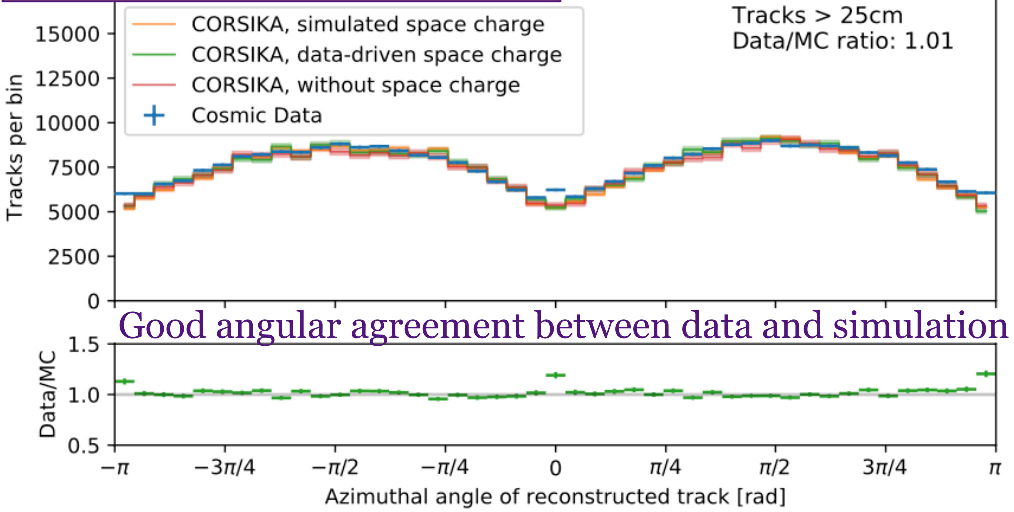




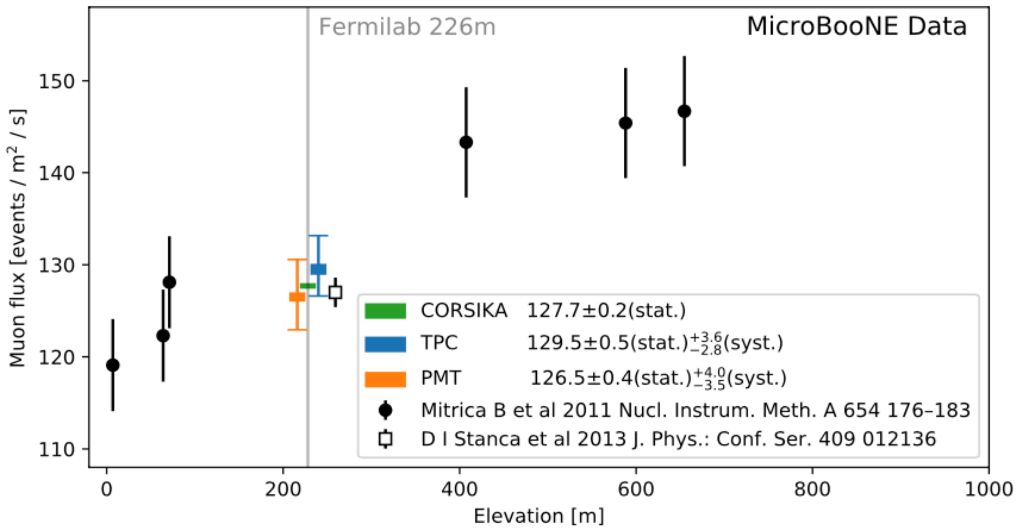
Cosmic ray rates

- Used our data to measure rate of cosmic rays on surface at Fermilab
  - First such measurement with a liquid argon TPC
- Allows tuning the cosmic simulation
  - Measurement agrees with 'out-of-the-box' CORSIKA simulation
  - Disagrees with 'constant mass composition' extension* of the simulation
- Useful input to future experiments at Fermilab, including SBN program and DUNE

JINST 16, 04004 (2021)

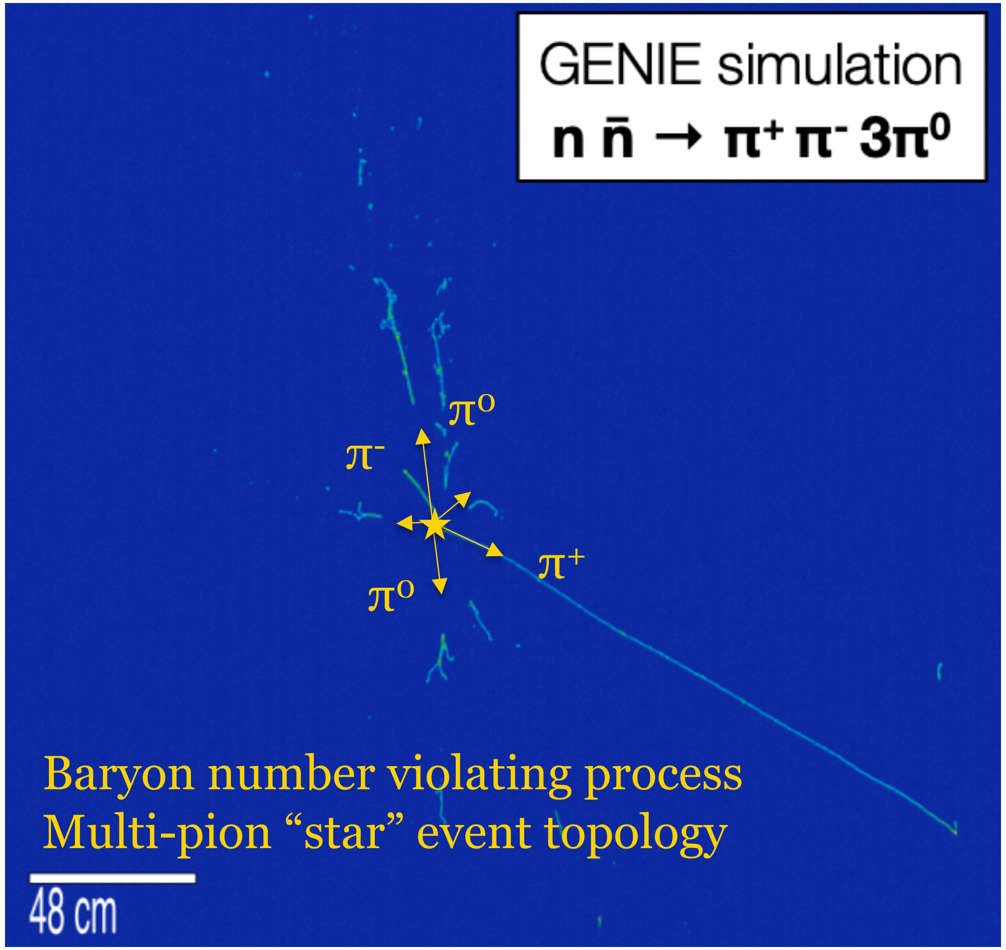


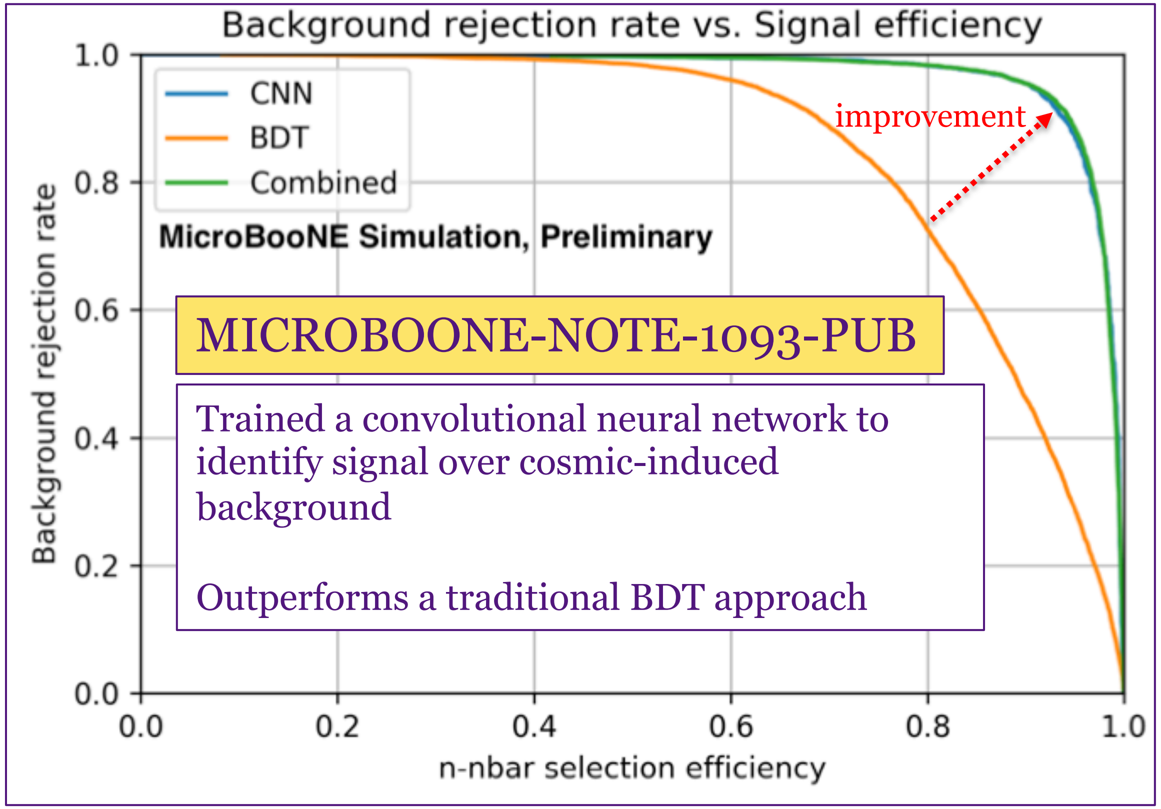
Good angular agreement between data and simulation



* Alternative spectral composition of light and heavy ion cosmic rays impacting atmosphere

Neutron-antineutron oscillation





MICROBOONE-NOTE-1093-PUB

Trained a convolutional neural network to identify signal over cosmic-induced background

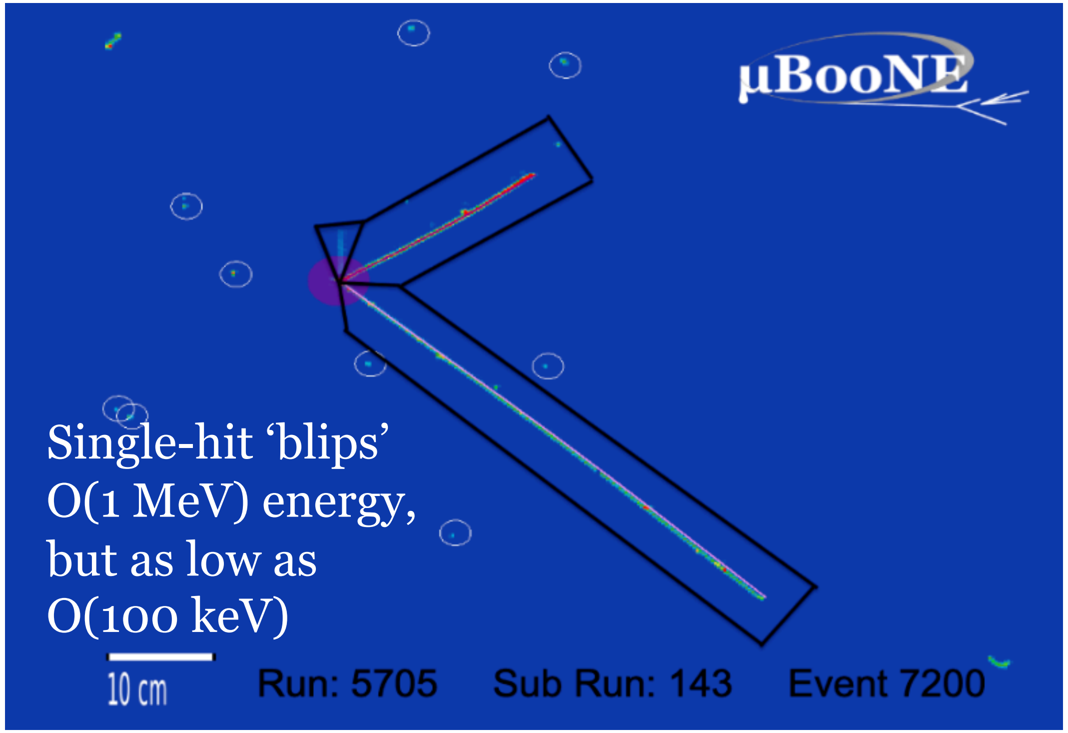
Outperforms a traditional BDT approach

MicroBooNE is pioneering techniques to be used in DUNE

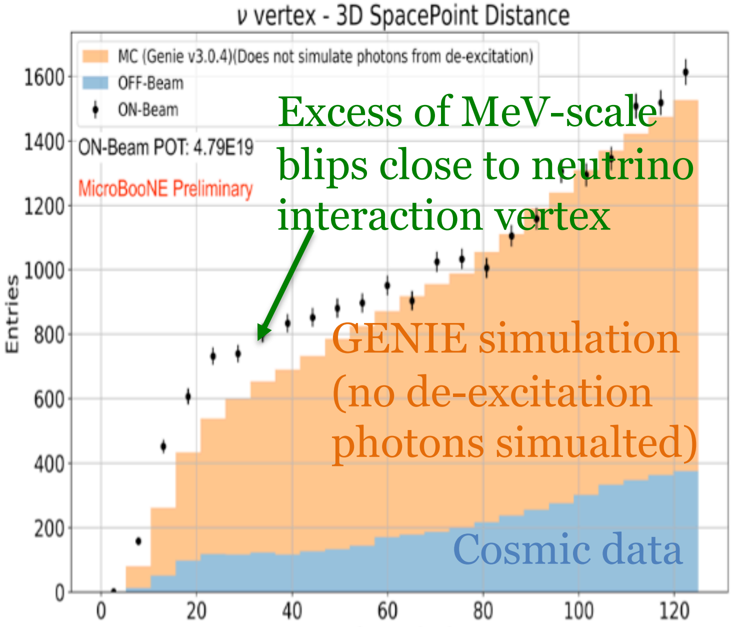
- Convolutional neural network based search

MeV-scale reconstruction

- Standard reconstruction algorithms designed for O(100 MeV) interaction
- ‘Blips’ of ionization produced by low-energy gammas or neutrons
- We are pushing down the thresholds for reconstructing this information



MICROBOONE-NOTE-1076-PUB



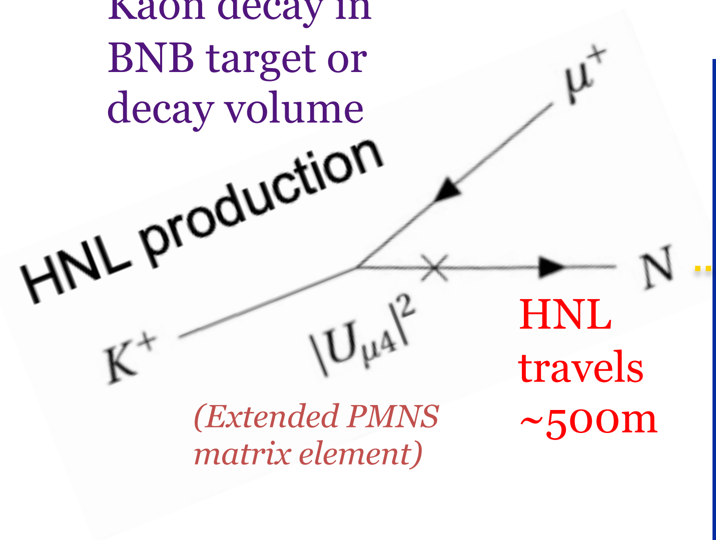
Distance from blip to neutrino vertex (cm)

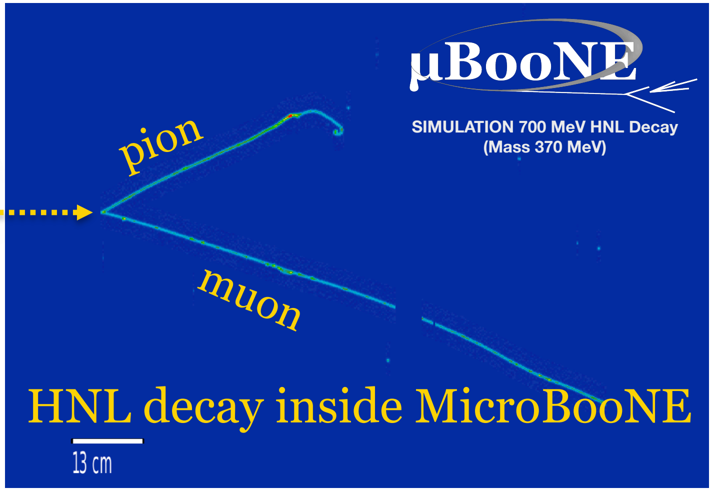
Applications:
- Supernova neutrino reconstruction
- Muon/pion separation
- Searches for millicharged particles

Heavy neutral leptons

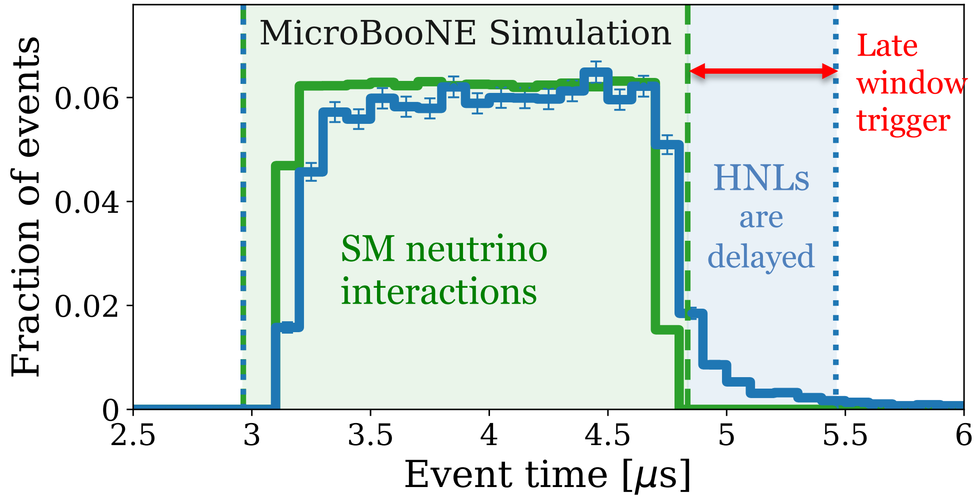
- O(100 MeV) mass neutral leptons; mixing with SM neutrinos
- Produced in the same way as standard neutrinos
  - We used kaon decays as the source, for this first search
- Decay via weak interaction
  - Muon+pion in our case
- "Late window" trigger developed for this analysis
  - Negligible neutrino backgrounds

Kaon decay in BNB target or decay volume



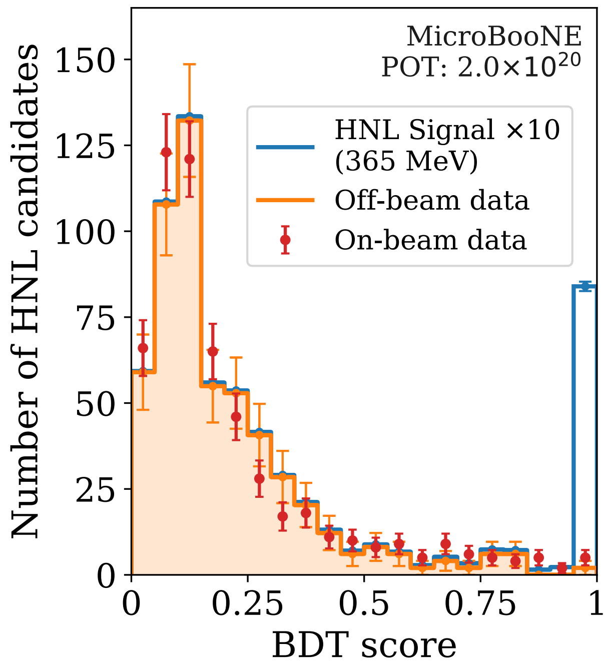


Phys.Rev.D 101, 052001 (2020)



Heavy neutral leptons

- BDT based analysis with 10 HNL mass points (245-388 MeV)
- No excess observed
- Competitive limits, with only small fraction of our dataset
- We will be using more production and decay modes, full trigger window, and NuMI data, in the near future
  - Stay tuned



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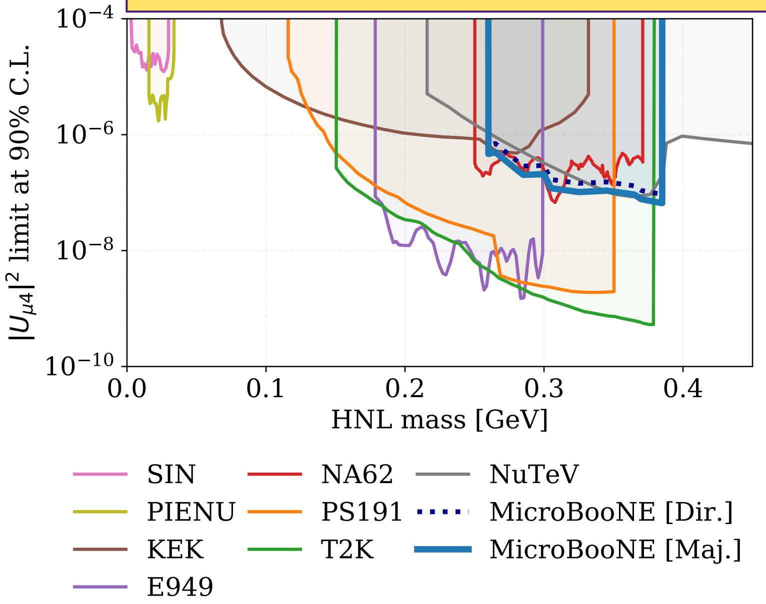
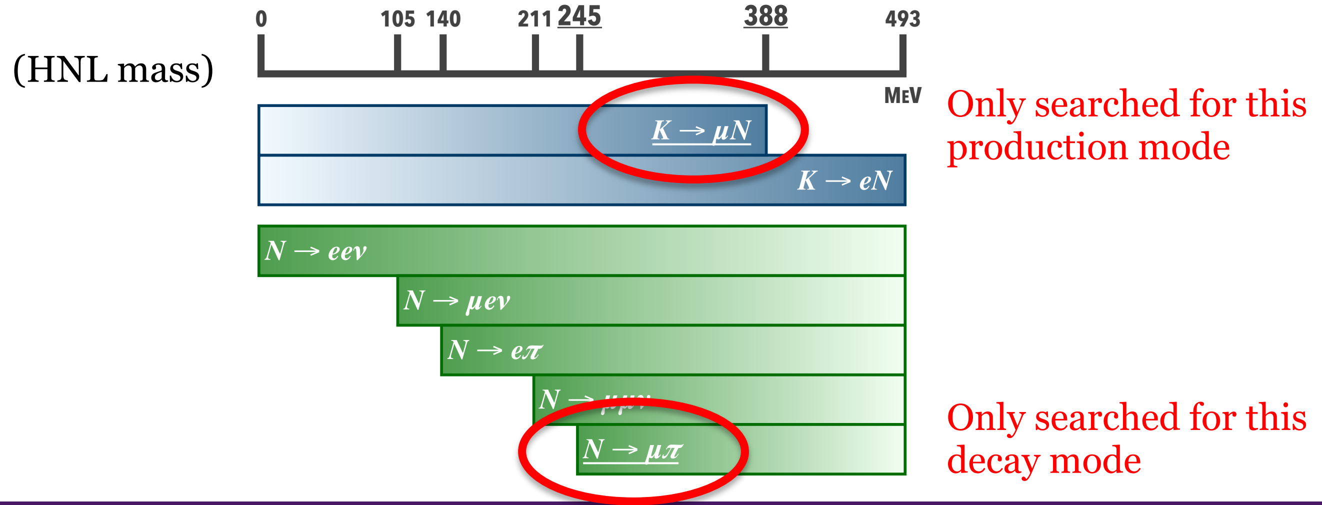
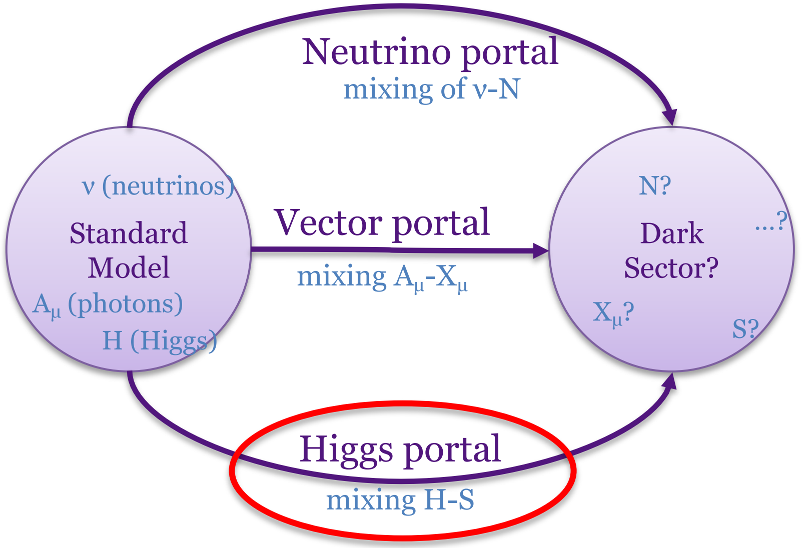
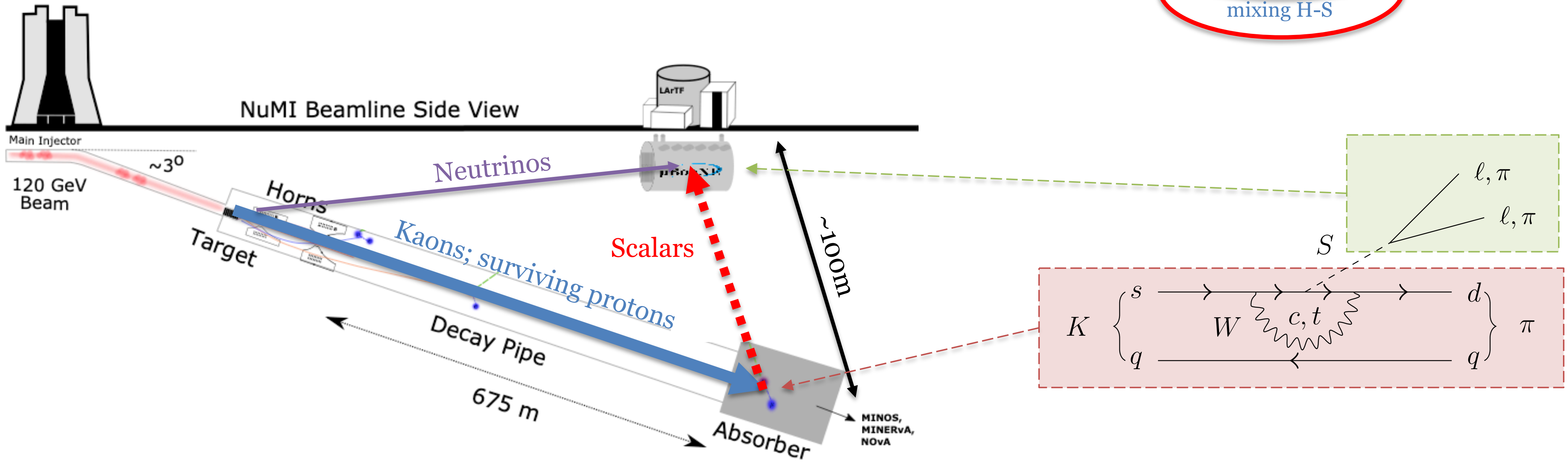




Higgs Portal scalars

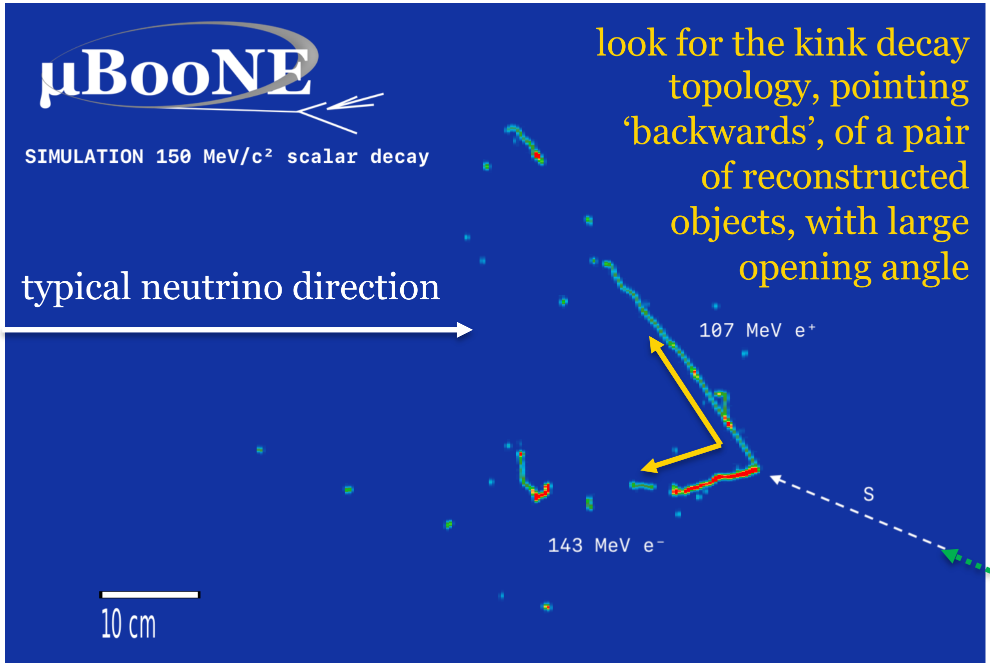
- "Portal" to the dark sector, via a dark scalar mixing with the Higgs (mixing angle θ)
  - Couples to SM fermions via Yukawa couplings ∝ $\theta^2 m^2$
- Very similar phenomenology as HNLs
  - Search for kaons decaying to scalar in beam
  - Scalar decays to fermions in detector
- Our first search uses kaons decaying at rest in the NuMI beam dump





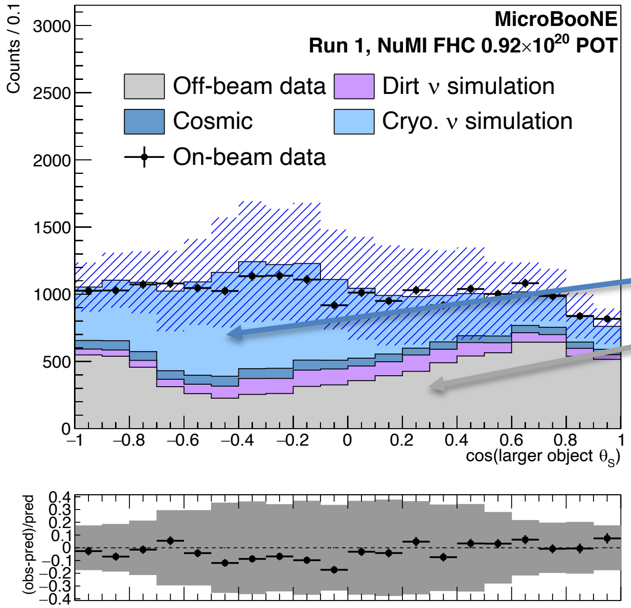
Higgs Portal scalars

- Searching for e^+e^- pairs from the decay of a <200 MeV scalar boson
- Using a BDT-based analysis



Scalar boson

NuMI beam dump

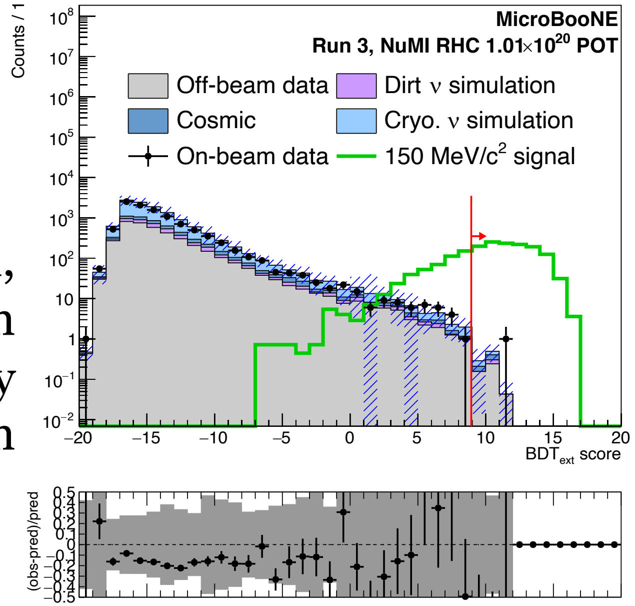


Angular variable (one of themost important for BDT); Simulation is well modelled with respect to the data

Neutrino simulation (GENIE)

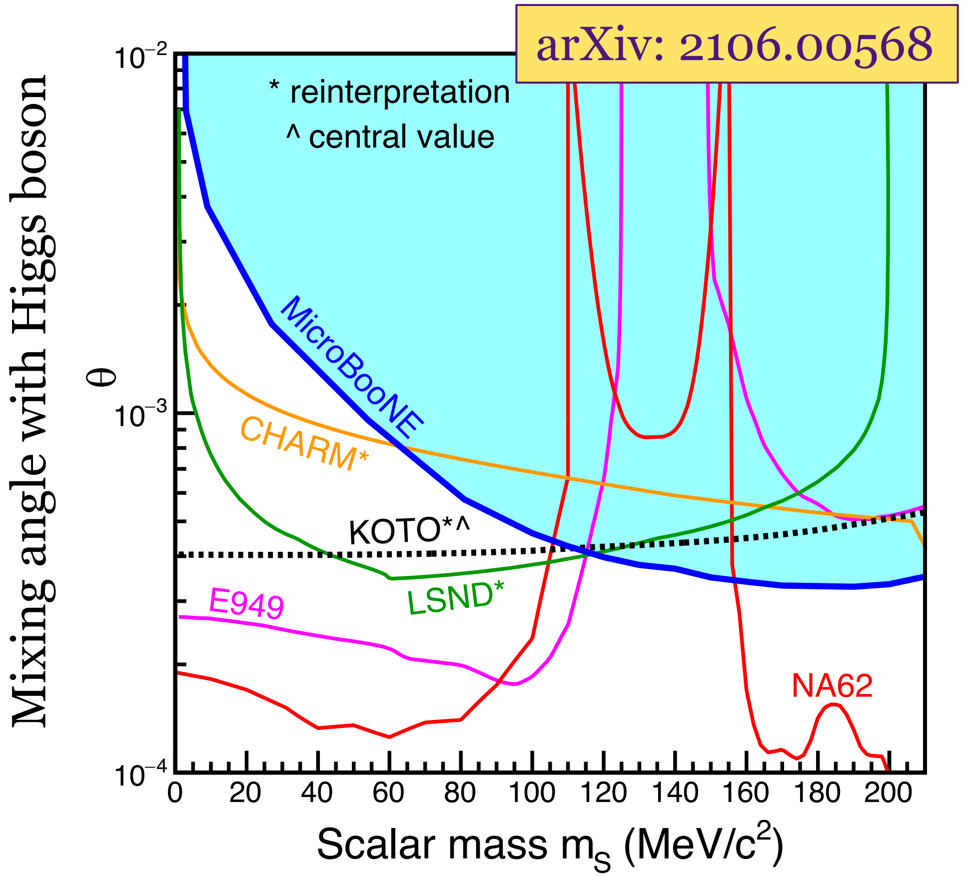
Data-driven cosmic background

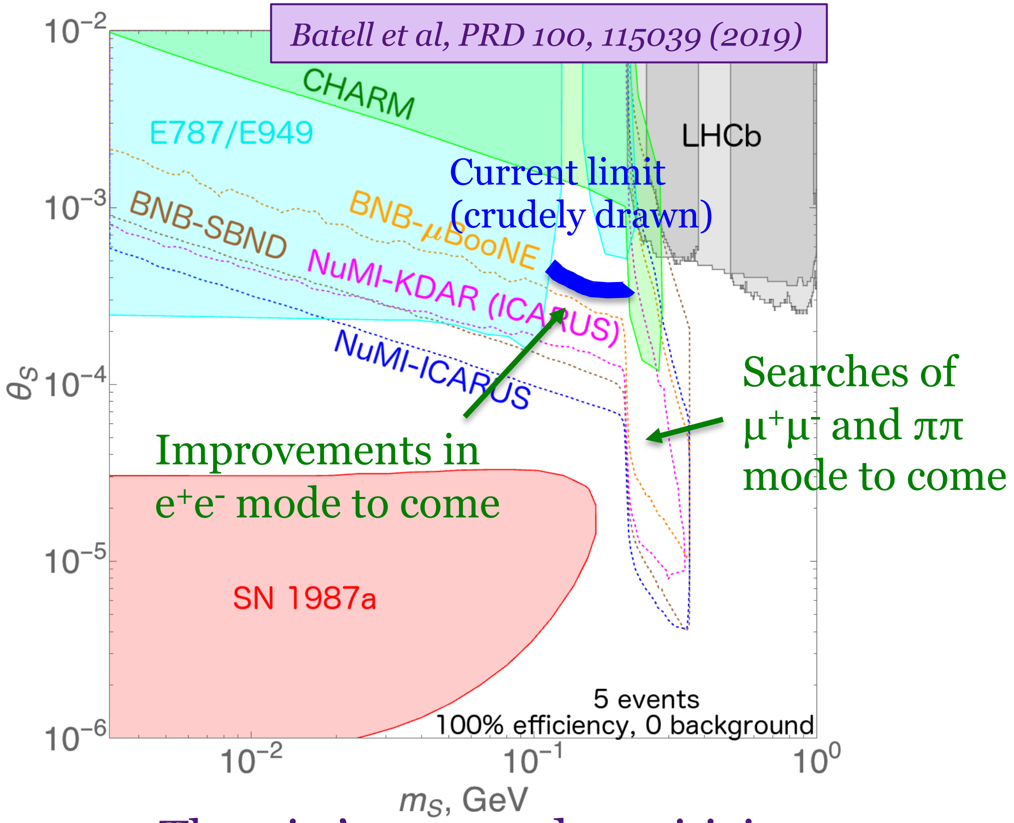
BDT distribution, well modelled with background-only expectation



Higgs Portal scalars

- We observe 5 events in signal region, with 2.0±0.8 expected
- Can exclude model central value parameters required to explain KOTO anomaly*
- This was with 10% of our NuMI dataset; further search results to come!



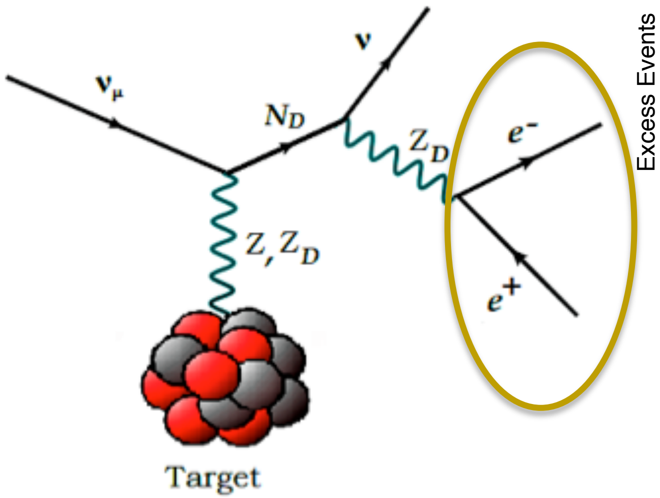


Theorist's expected sensitivity

*In 2019, KOTO reported anomalous excess of $K^0 \to \pi^0$+invisible decays, although significance of the excess has decreased in 2021 paper

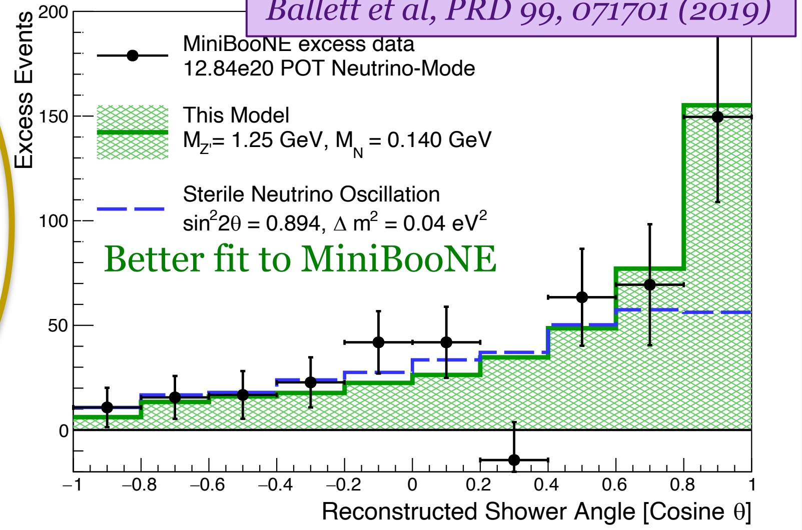
Dark prospects

- Further BSM models being explored with e^+e^- final states
- Dark neutrino portal, with dark Z' decay
  - could explain MiniBooNE: if e^+e^- resolved as single shower
- Dark matter produced in beamline; inelastic scattering off argon
  - MicroBooNE has excellent sensitivity

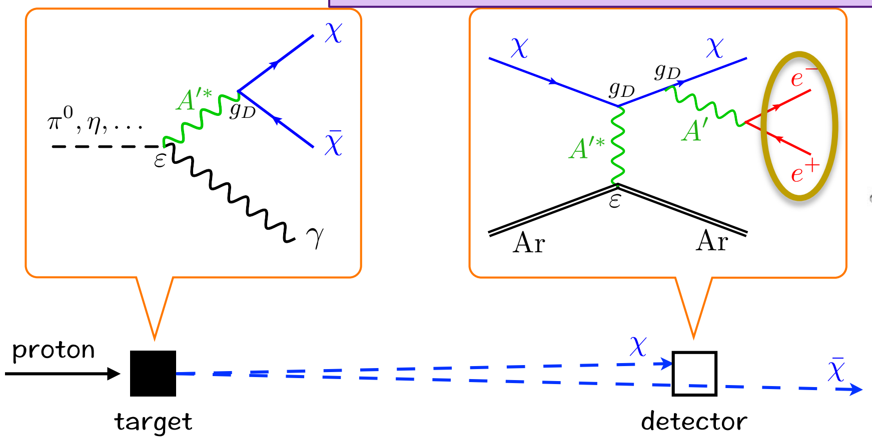


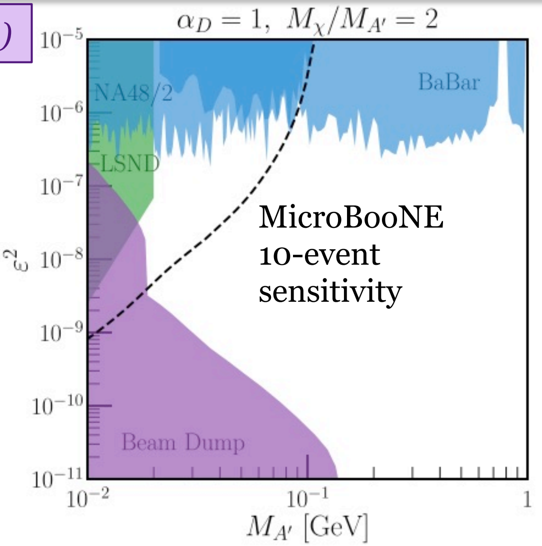
Bertuzzo et al, PRL 121, 241801 (2018)

Ballett et al, PRD 99, 071701 (2019)



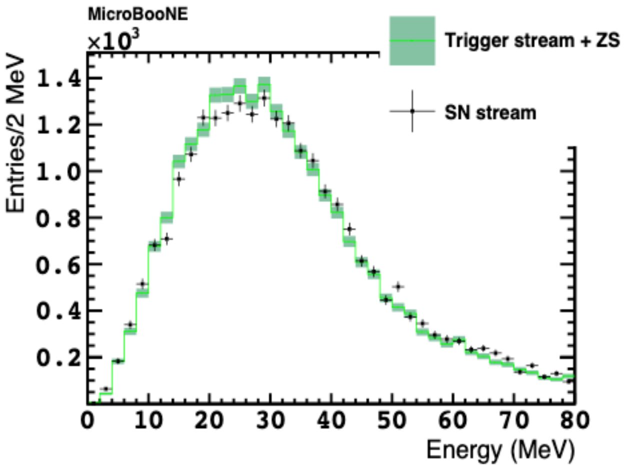
de Gouvêa et al, JHEP 01, 001 (2019)

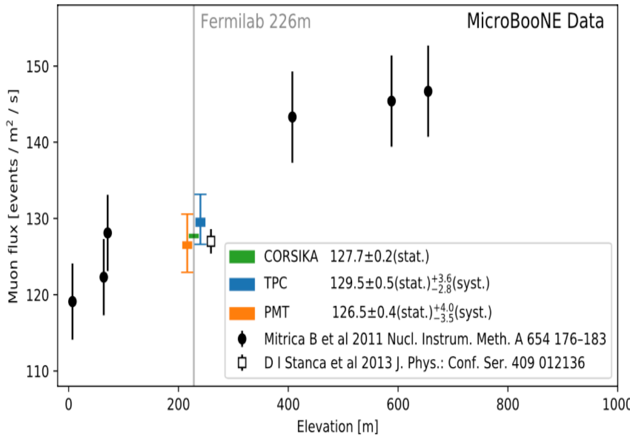


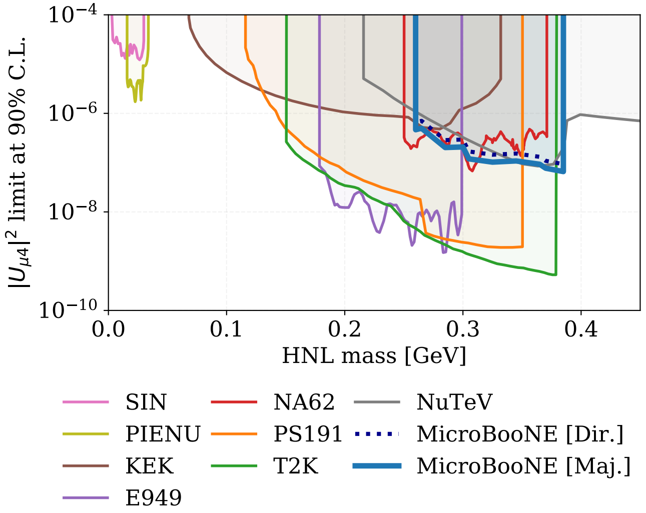


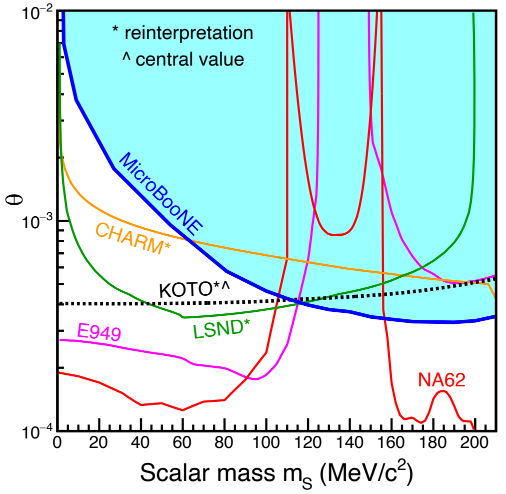
Summary

- MicroBooNE is not only excellent for investigating MiniBooNE or measuring cross sections, but can also perform a diverse variety of astrophysical or exotic measurements
- We have produced some exciting results in the past year
  - Supernova continuous readout (JINST 16, 02, P02008 (2021))
  - MeV-scale physics (MICROBOONE-NOTE-1076-PUB)
  - Cosmic ray rate measurement (JINST 16, 04, P04004)
  - Neutron-antineutron oscillation analysis development (MICROBOONE-NOTE-1093-PUB)
  - Searches for heavy neutral leptons (Phys.Rev.D 101, 052001 (2020)), and dark sector scalars (arXiv:2106.00568)
- We do have a lot more results to come in the near future
  - watch this space!



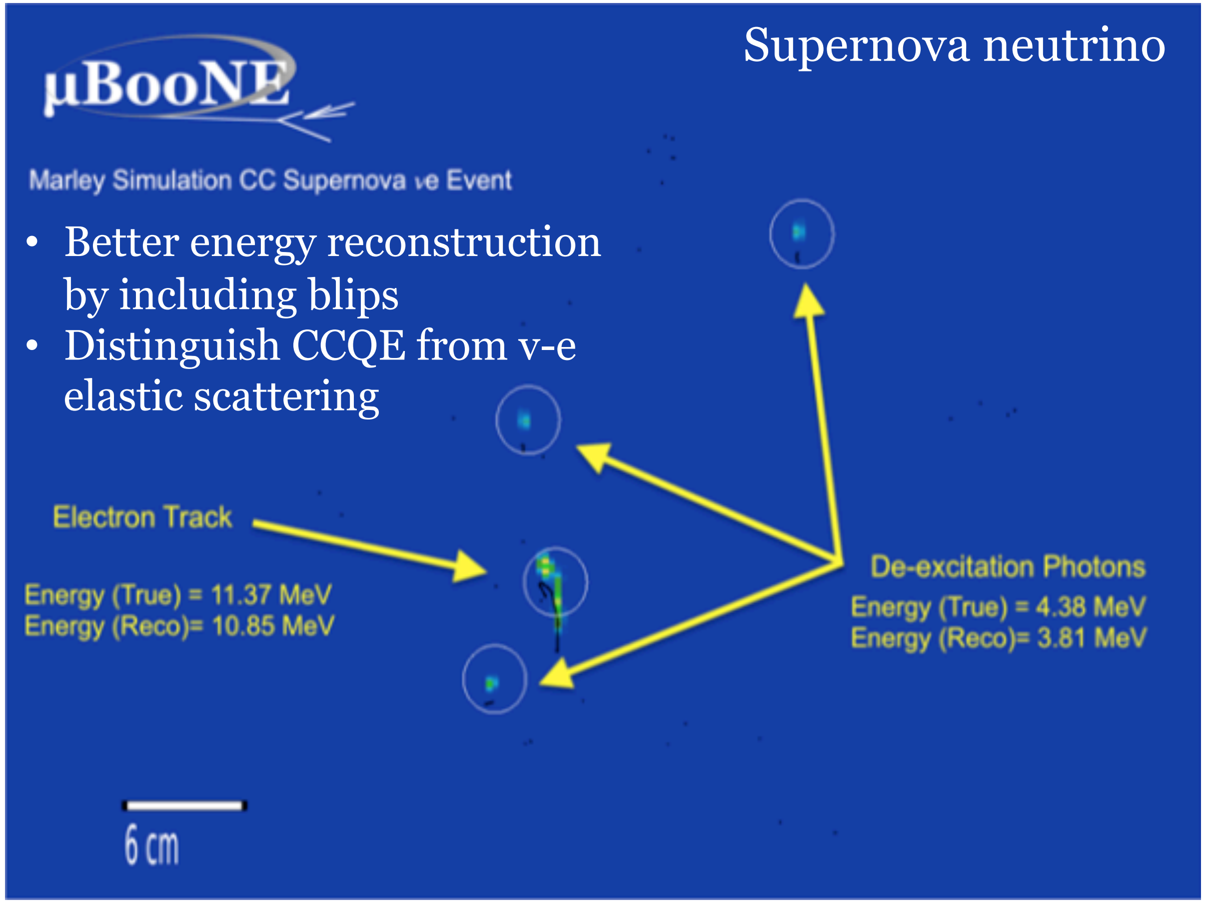






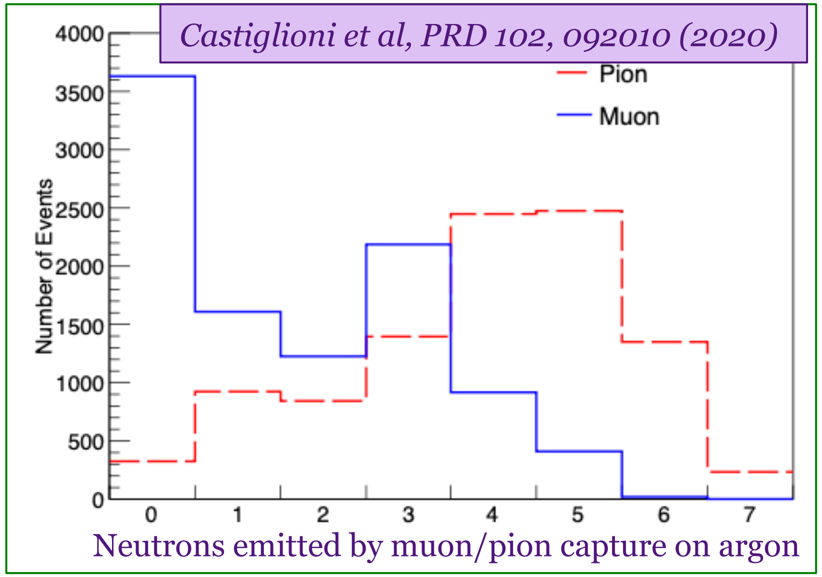
EXTRA SLIDES

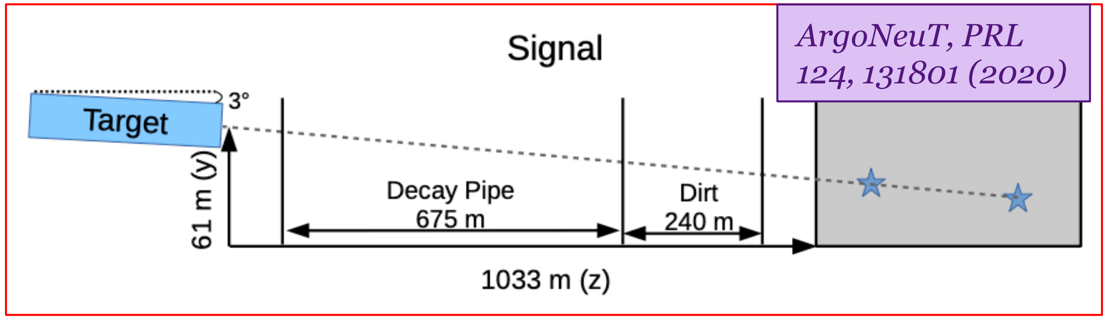
MeV-scale applications



- Better energy reconstruction by including blips
- Distinguish CCQE from v-e elastic scattering

Muon-pion separation, allowing e.g. distinguishing BSM di-muon signals from SM muon-pion backgrounds





Searches for millicharged particles (blips along a straight line, pointing back to target)