µBooNE

Recent results and prospects for Astroparticle and BSM Physics with MicroBooNE

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On behalf of the MicroBooNE Collaboration

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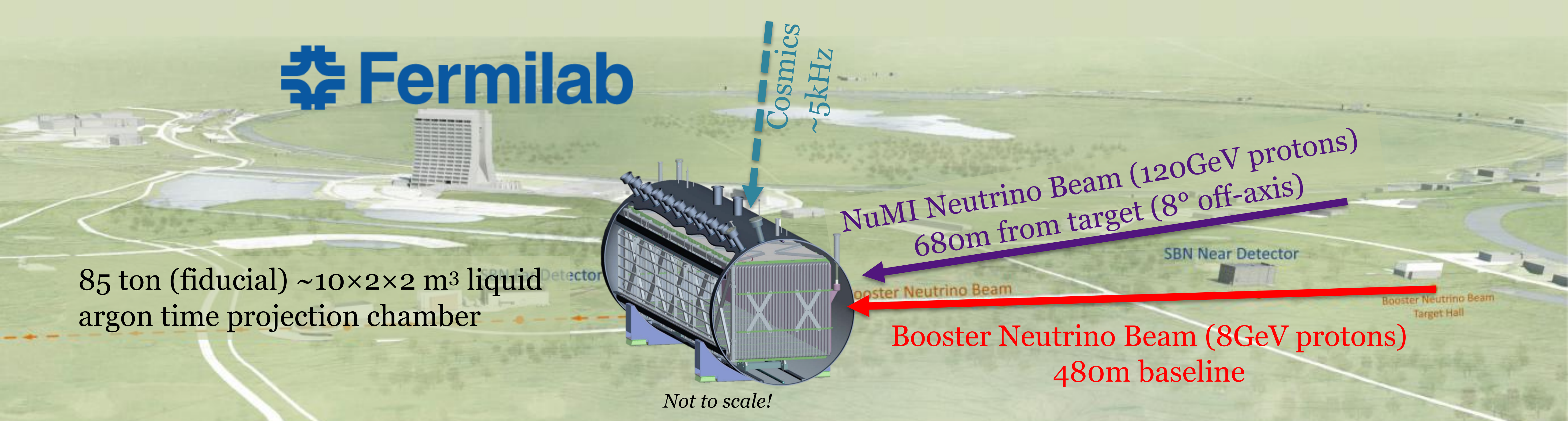
The University of Manchester

Introduction



Goals of the experiment:

Investigate the MiniBooNE anomalous excess
- Mark Ross-Lonergan – *Tue sterile parallel*
- Hanyu Wei – *Tue sterile parallel*
- Andrew Mogan – *Fri sterile flash*

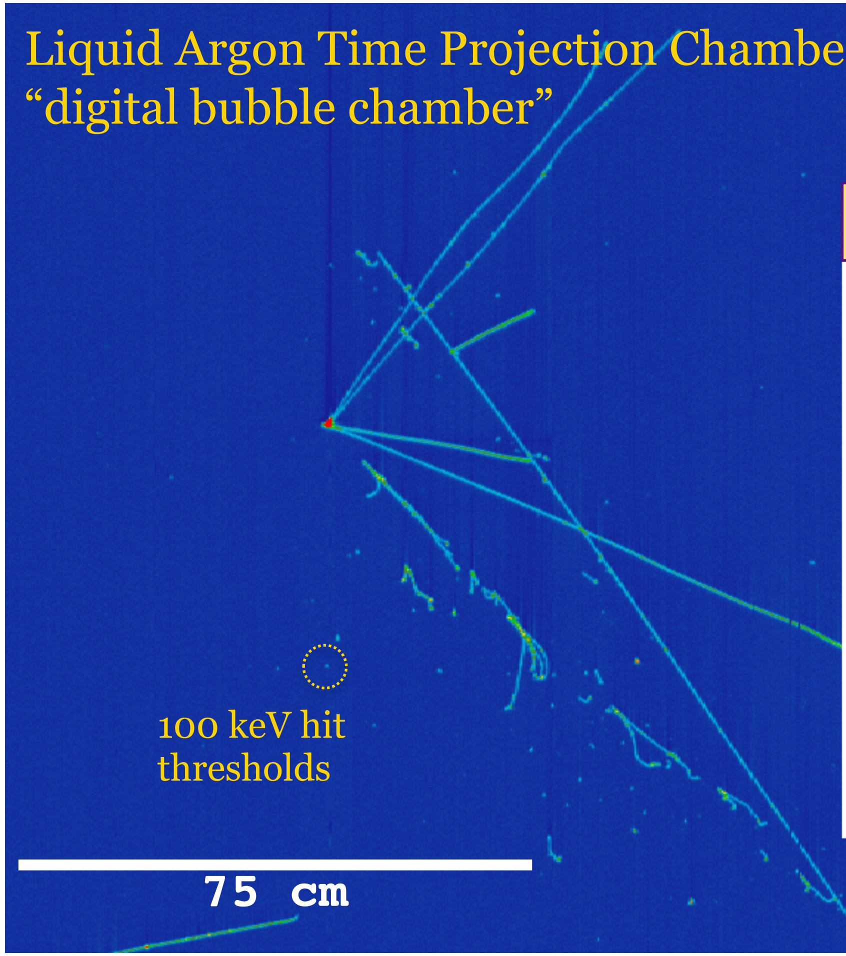
Cross-section measurements
- Marina Reggiani Guzzo – *Fri cross-section flash*
- Wenqiang Gu – *Fri cross-section flash*
- Krishan Mistry – *Fri cross-section parallel*

LArTPC detector physics, research and development
- Maya Wospakrik – *Wed detector parallel*

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

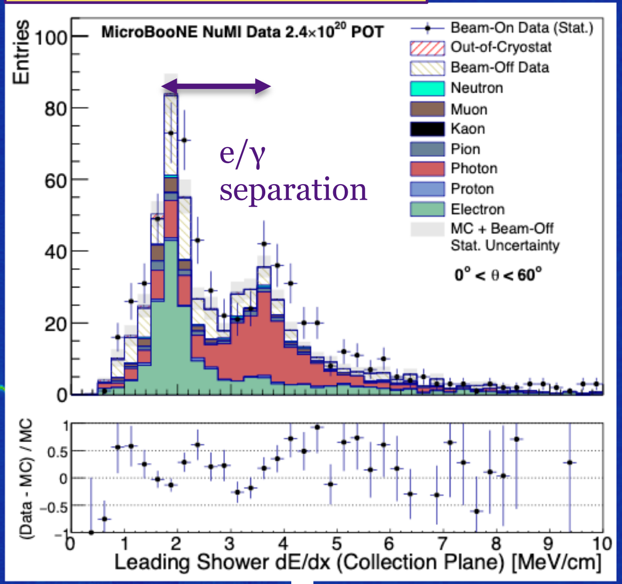
Liquid argon time projection chamber capabilities

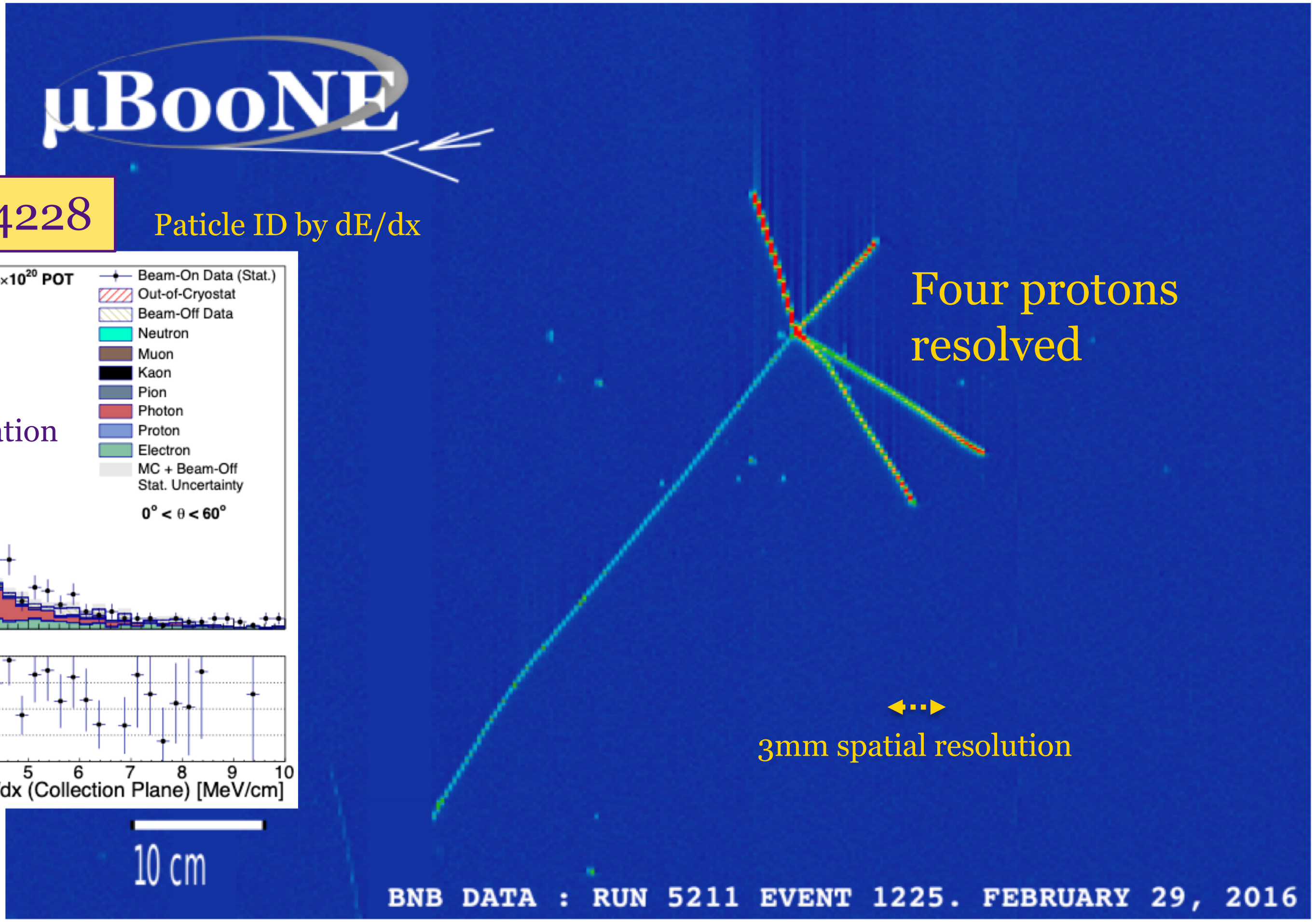
For more details on the detector principles: please see talks by Krishan Mistry and Maya Wospakrik



arXiv:2101.04228

Paticle ID by dE/dx





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

Astroparticle and exotic physics with MicroBooNE

- Results released in 2020

➢ Informing and developing for future experiments
  - Supernova neutrino R&D
  - Cosmic rate measurement
  - Baryon number violation

➢ Pushing reconstruction capabilities
  - MeV-scale physics

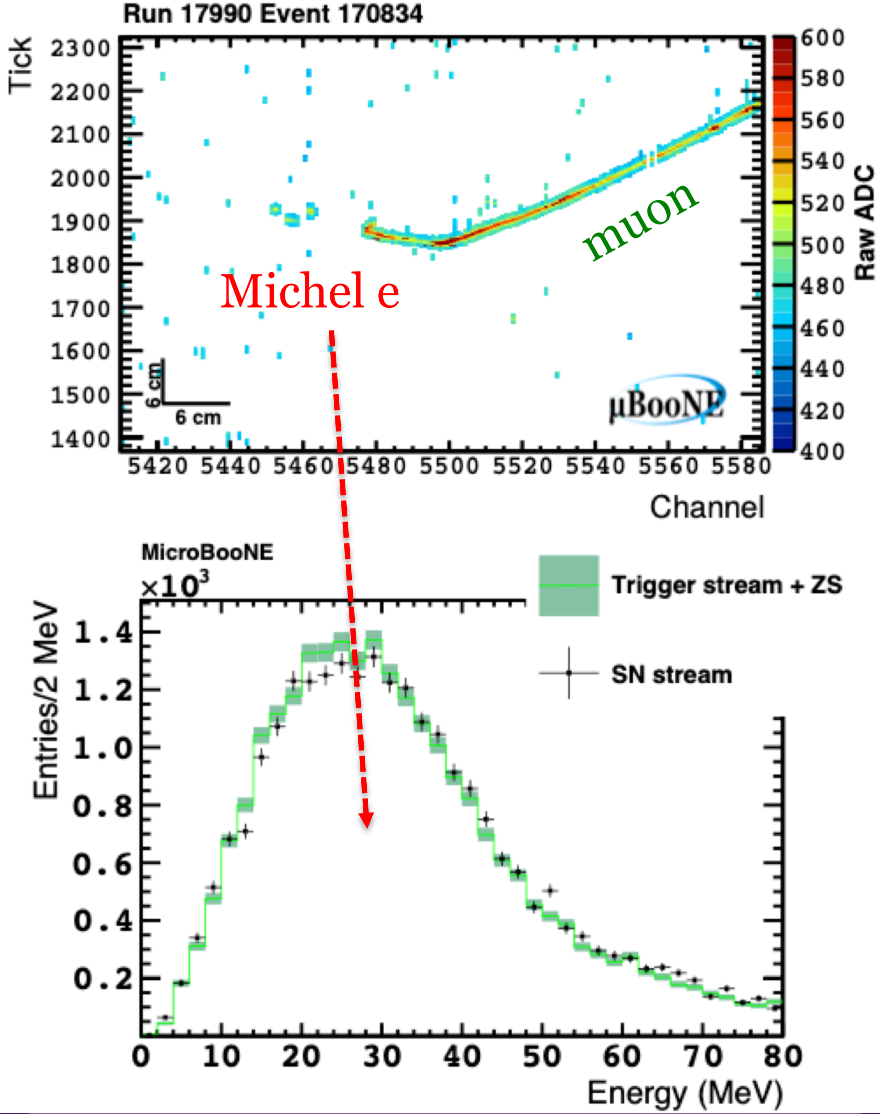
➢ Searches for new physics
  - Heavy neutral leptons
  - 'Higgs Portal' dark scalars

➢ Some prospects for future results

R&D for supernova neutrino detection

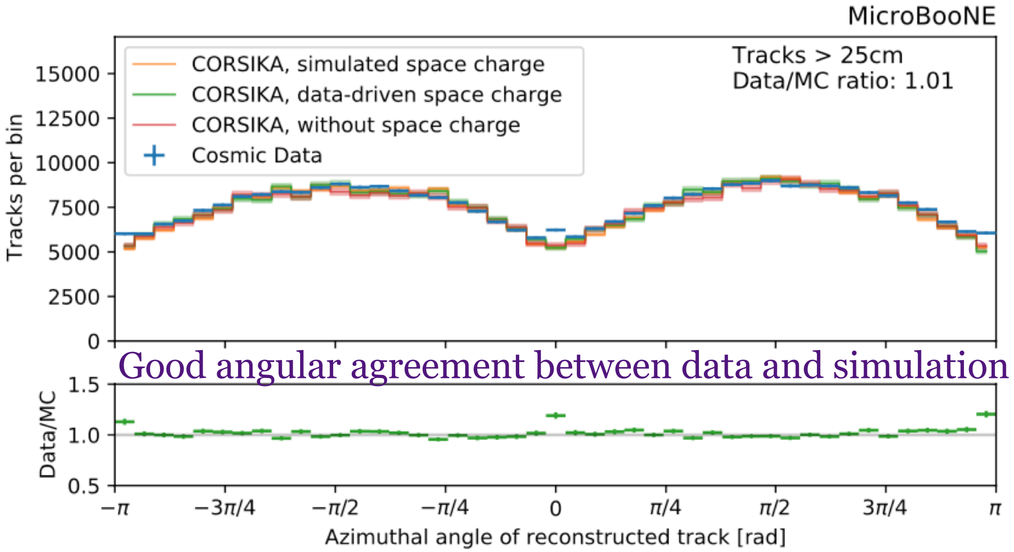
- A lot of data is produced by MicroBooNE – 33 GB/s
  - Orders of magnitude more expected in DUNE
- To observe supernova neutrino burst, would need continuous readout
- Pioneered a system to zero-suppress and compress the TPC data
  - Reduction of rates by over 80×
  - Prototype for DUNE
- Performance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

JINST 16, 02, P02008 (2021)

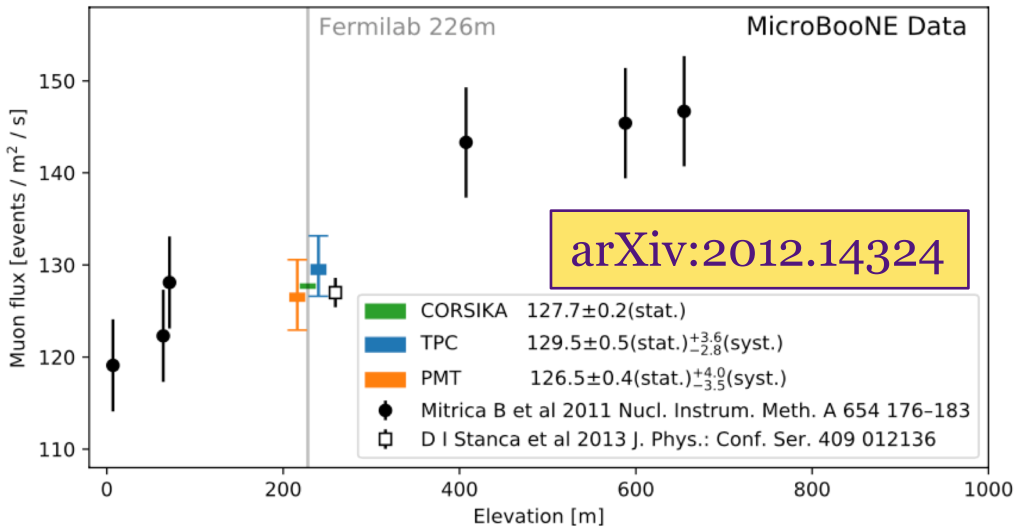


Cosmic ray rates

- 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
  - Incompatible with 'constant mass composition' extension* of the simulation
- Useful input to simulations of future experiments at Fermilab, including SBN program and DUNE

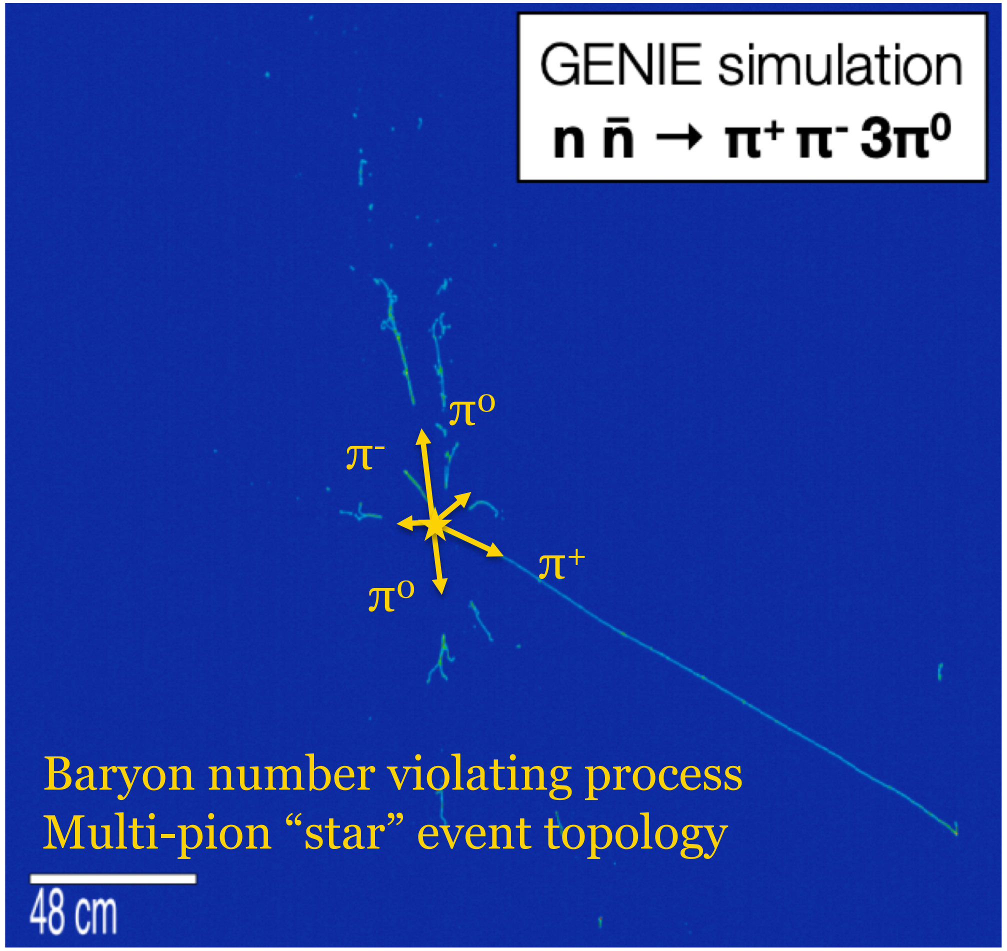


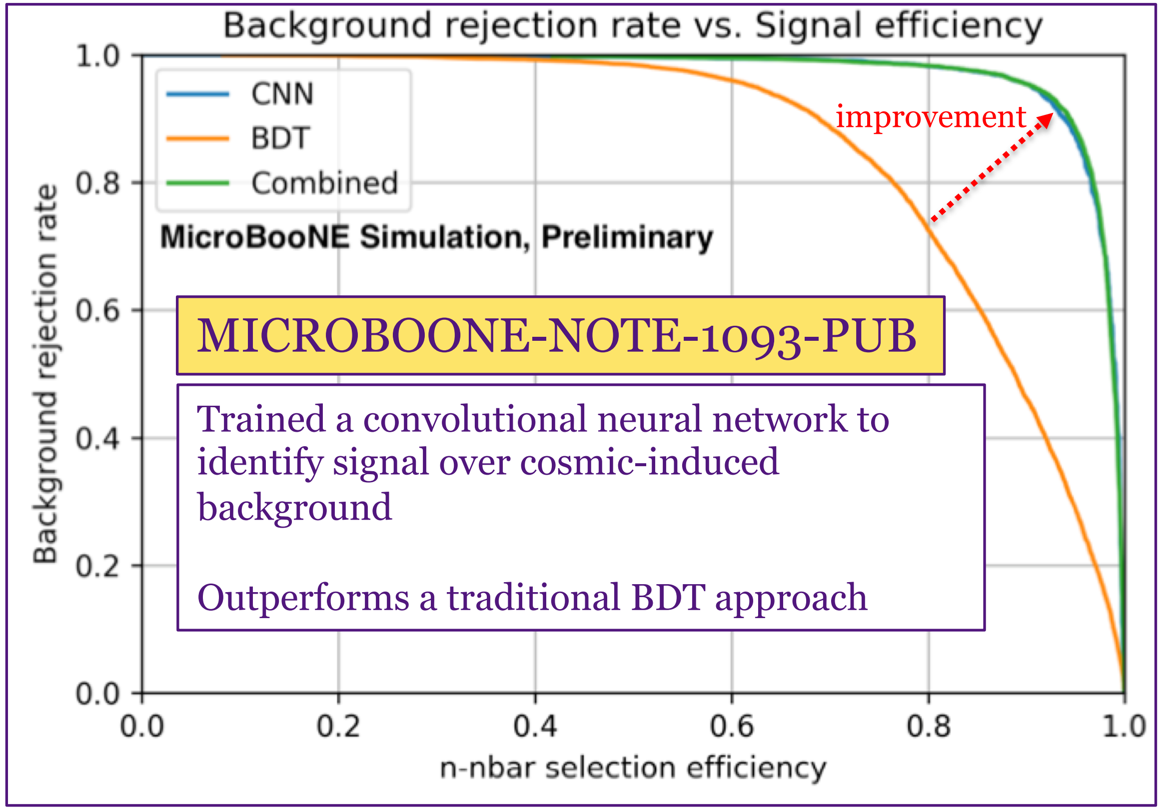
Good angular agreement between data and simulation



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

Neutron-antineutron oscillation



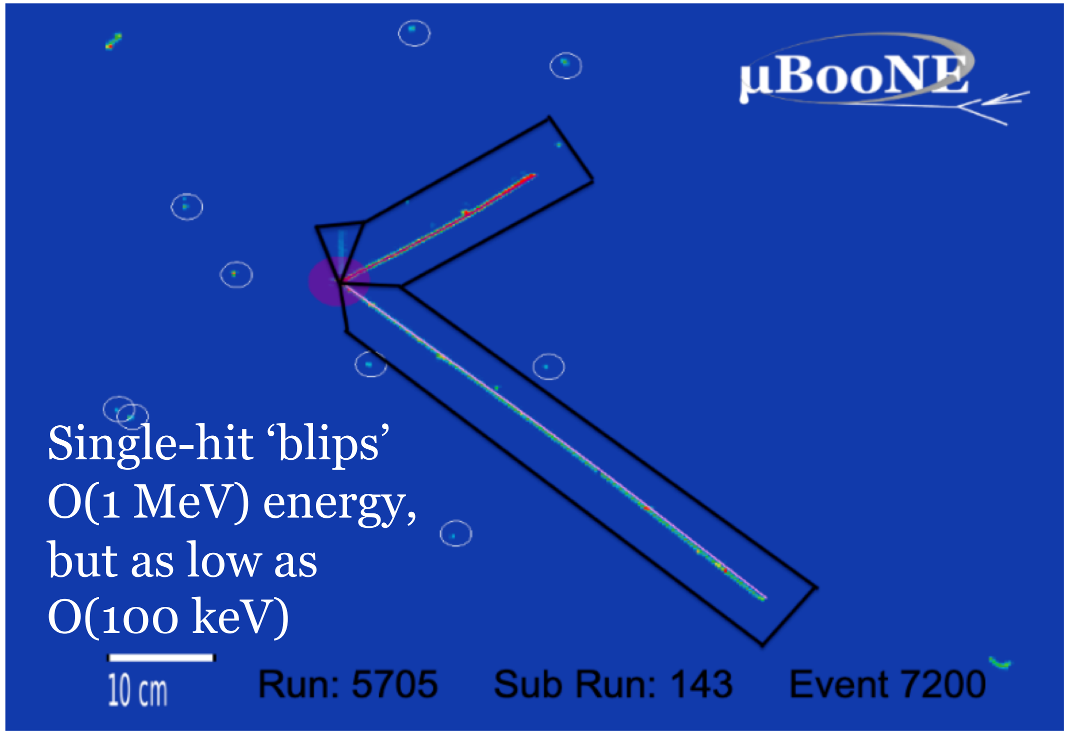


MicroBooNE is pioneering techniques to be used in DUNE

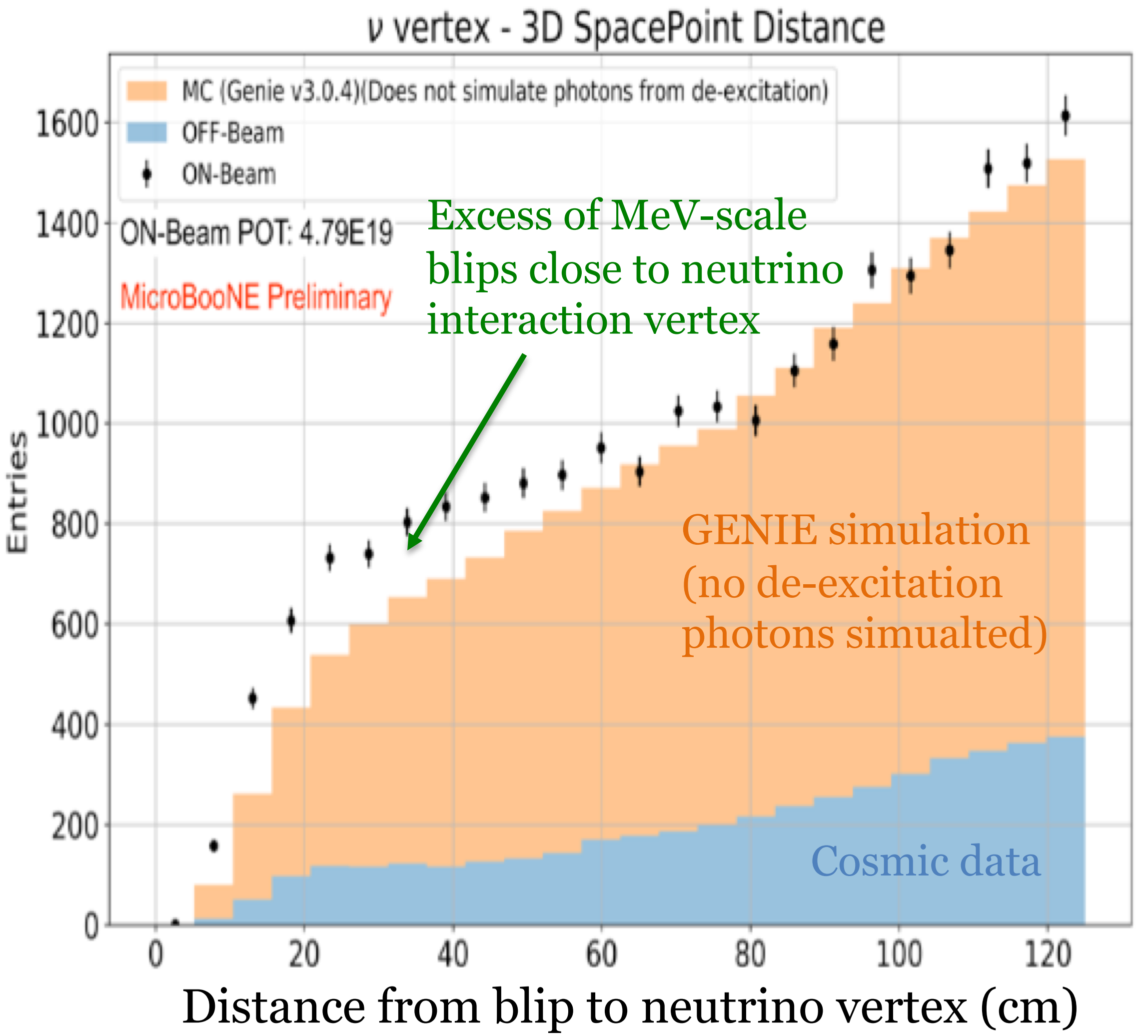
- Convolutional neural network based search

MeV-scale reconstruction

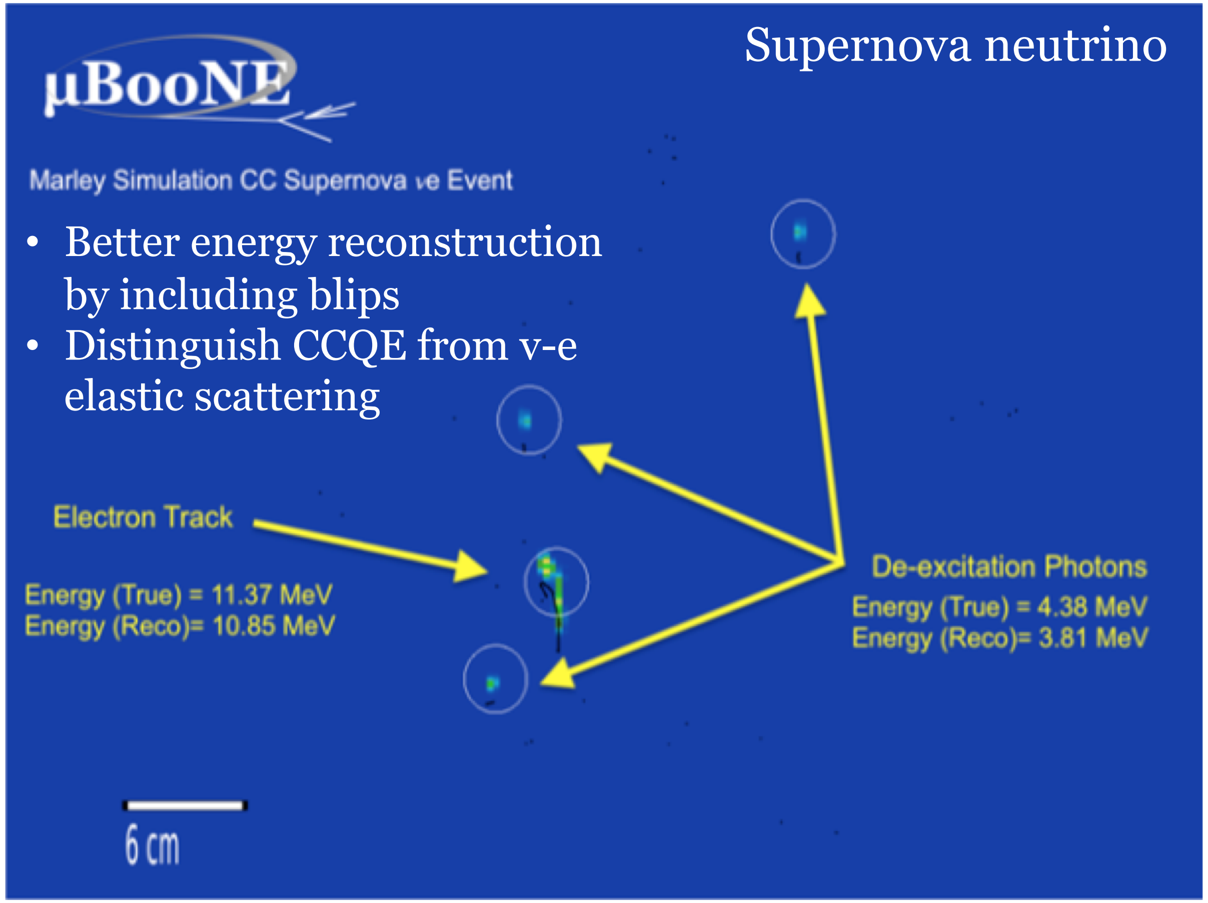
- Standard reconstruction algorithms designed for O(100 MeV) interaction
- 'Blips' of ionization produced by low-energy gammas or neutrons
- We are pushing down the thresholds for reconstructing this information



MICROBOONE-NOTE-1076-PUB



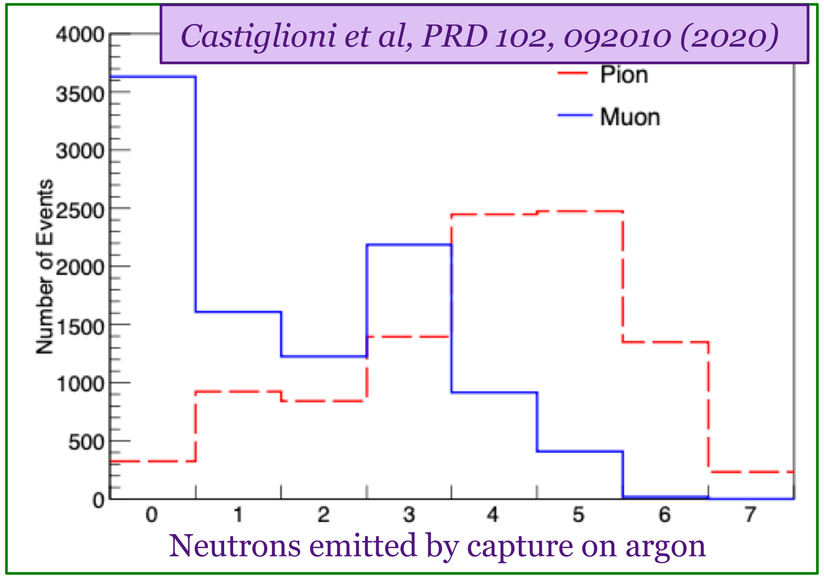
MeV-scale applications

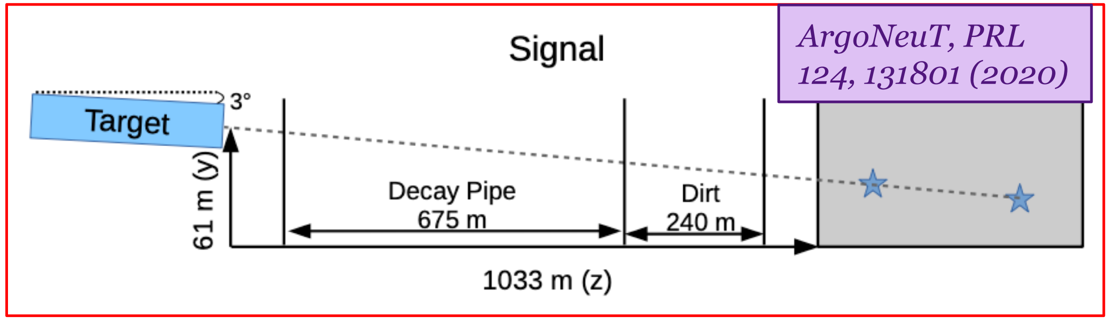


Supernova neutrino

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

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

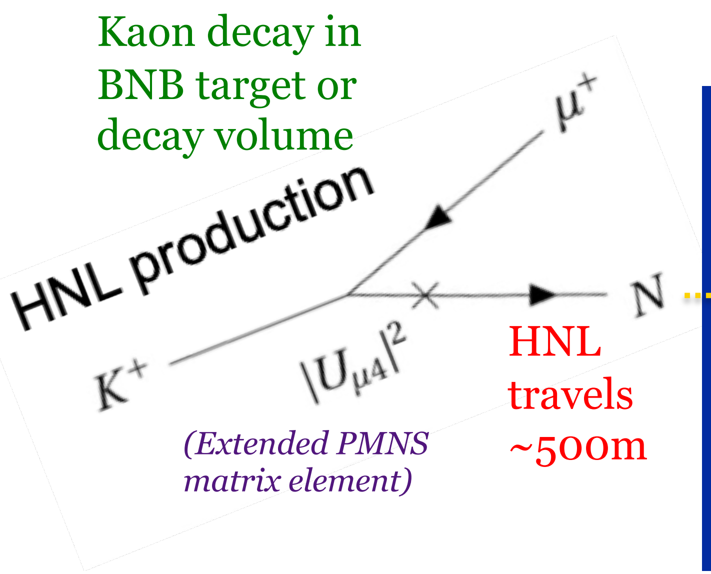


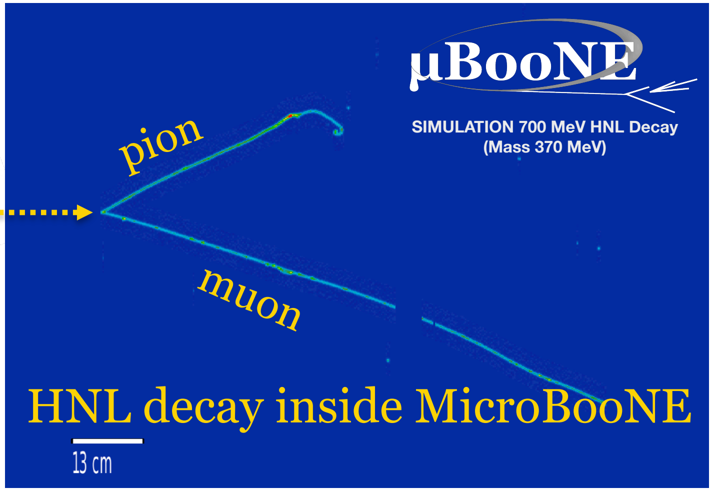


Searches for millicharged particles
(blips along a straight line, pointing back to target)

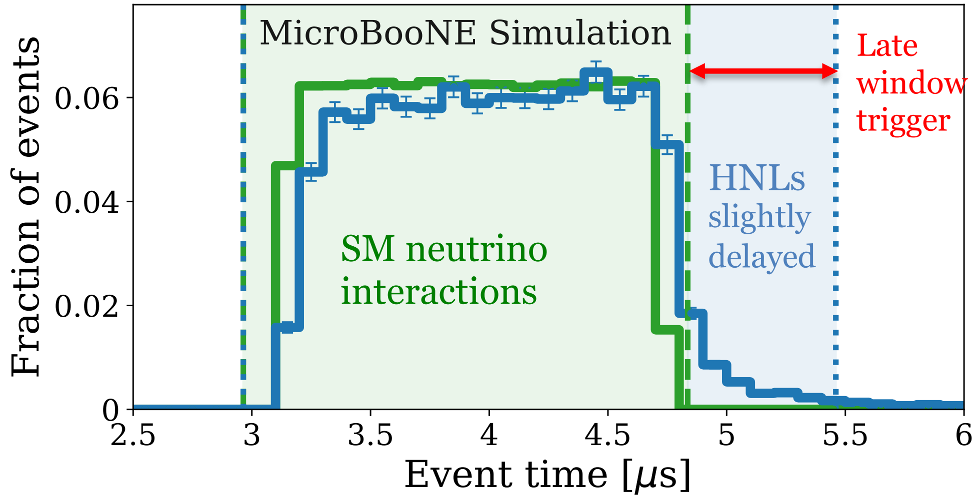
Heavy neutral leptons

- 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



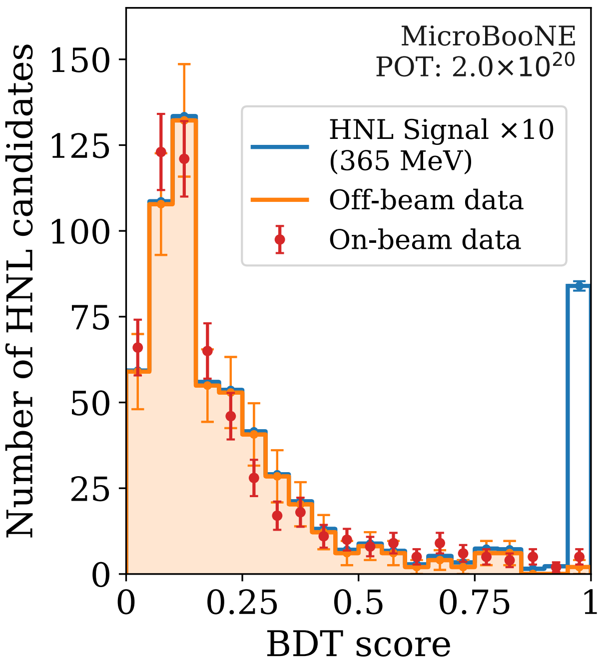


Phys.Rev.D 101, 052001 (2020)



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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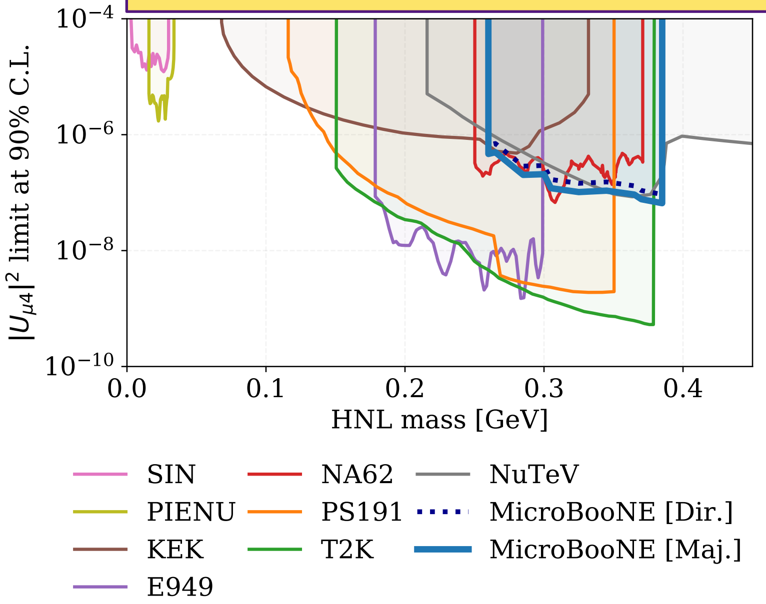
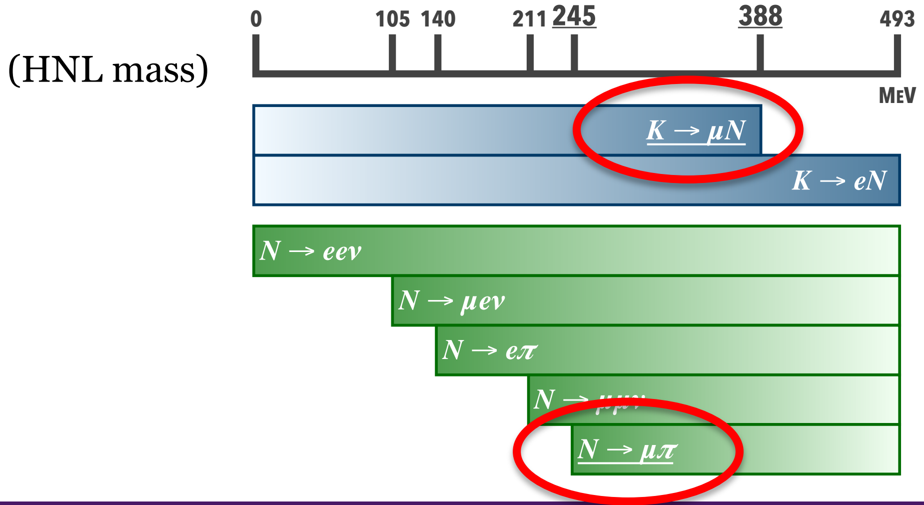


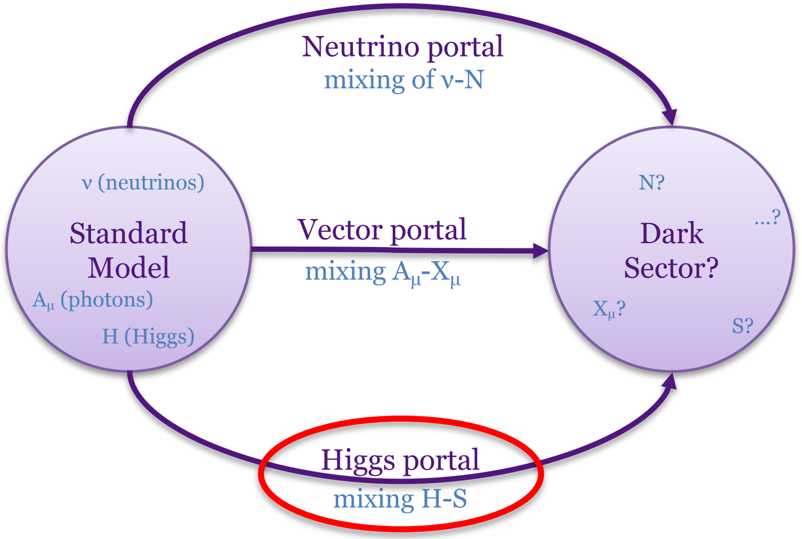


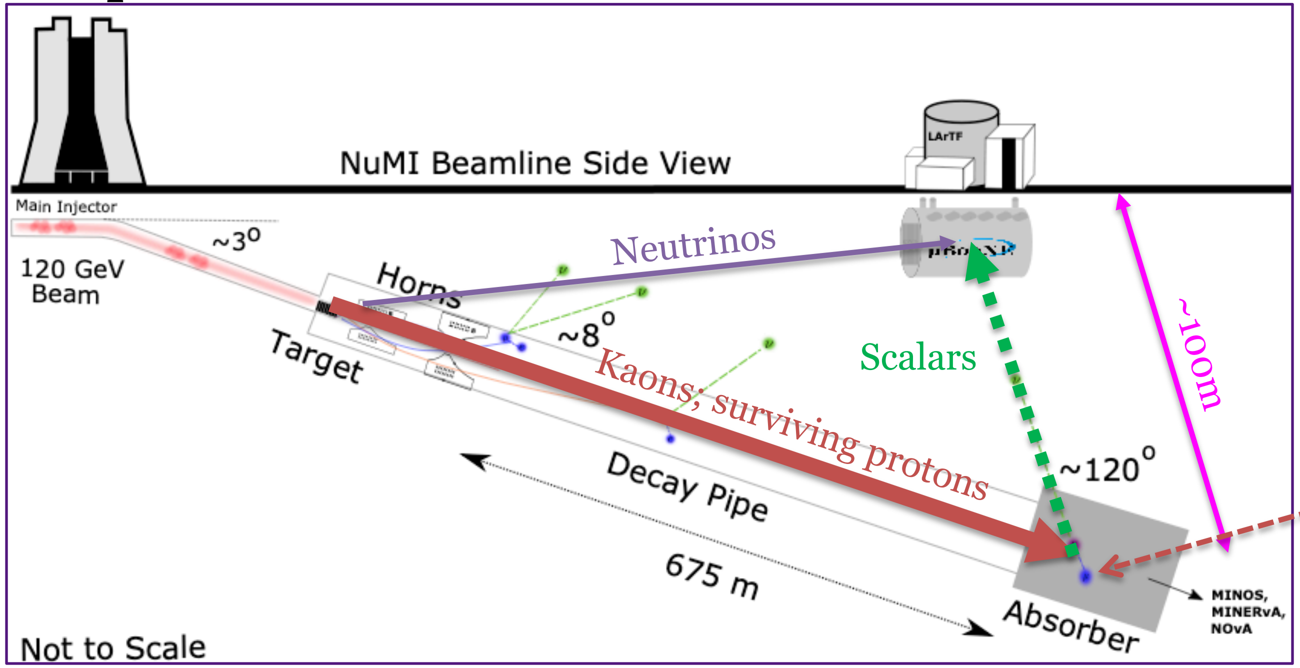
Only searched for this production mode

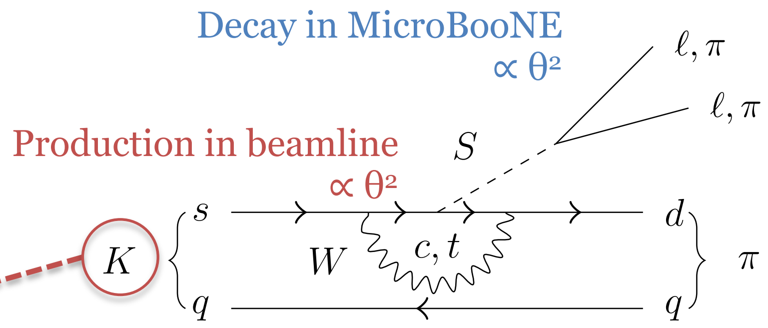
Only searched for this decay mode

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
  - Kaons decaying to scalars in beamline
  - Scalar decays to fermions in detector
- Our first search uses kaons decaying at rest in the NuMI beam dump

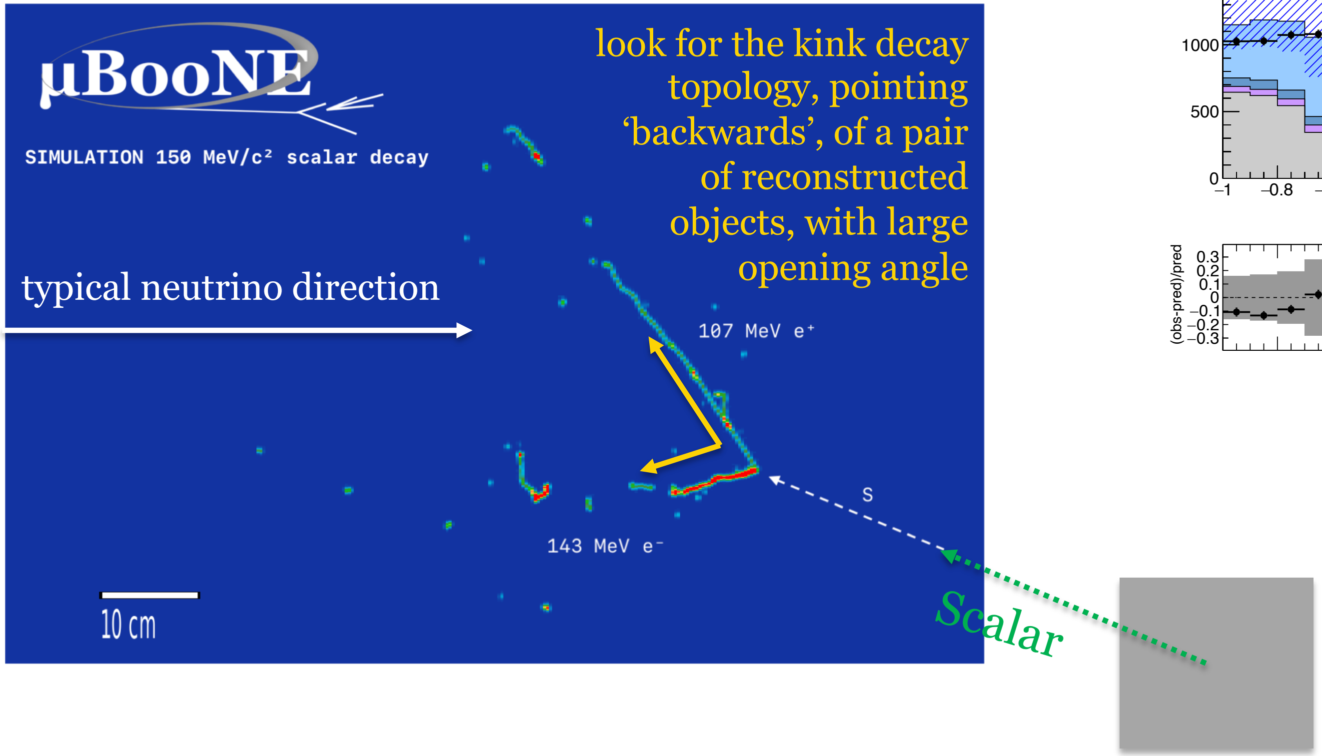


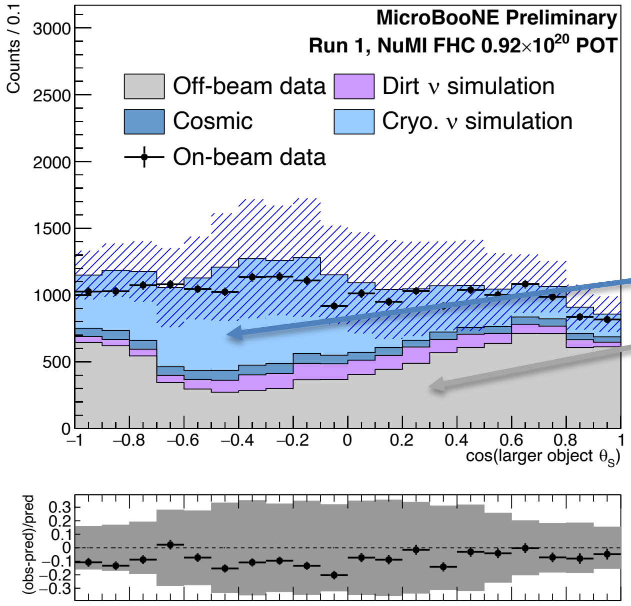




Higgs Portal scalars

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





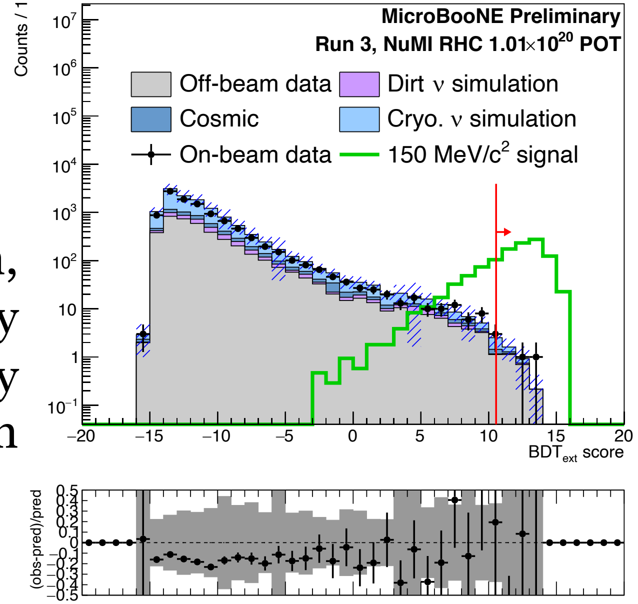
Angular variable (one of the most important for BDT); Simulation is well modelled with respect to the data

Neutrino simulation (GENIE)

Data-driven cosmic background

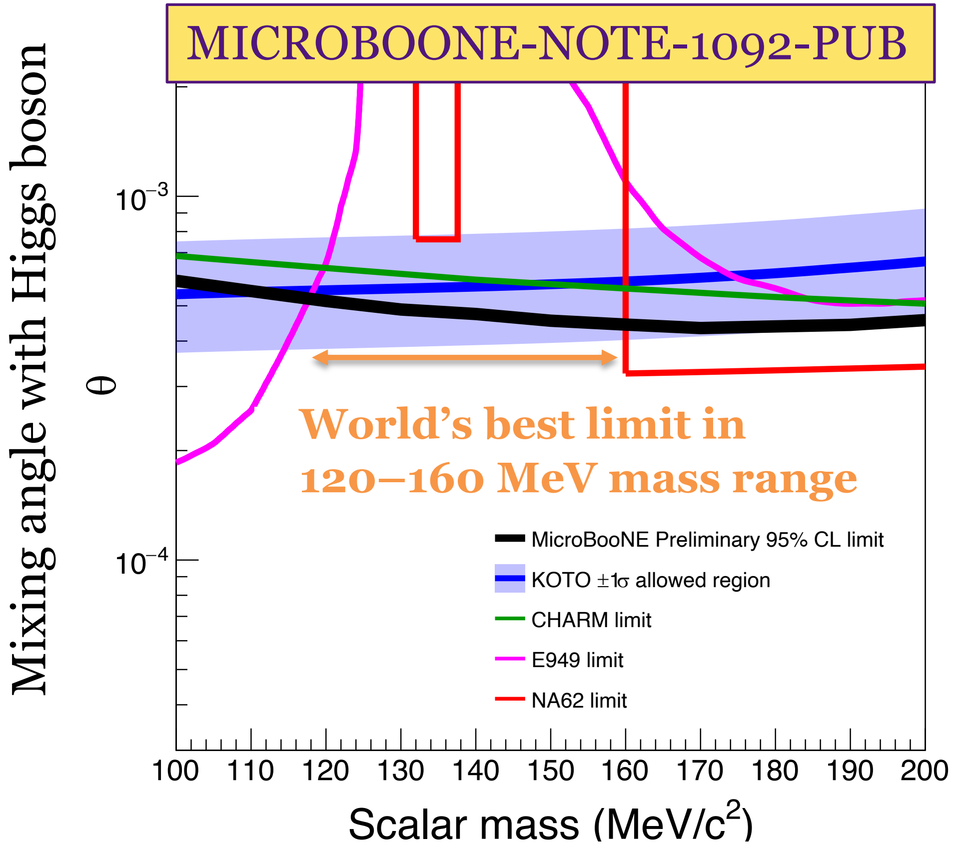
MICROBOONE-NOTE-1092-PUB

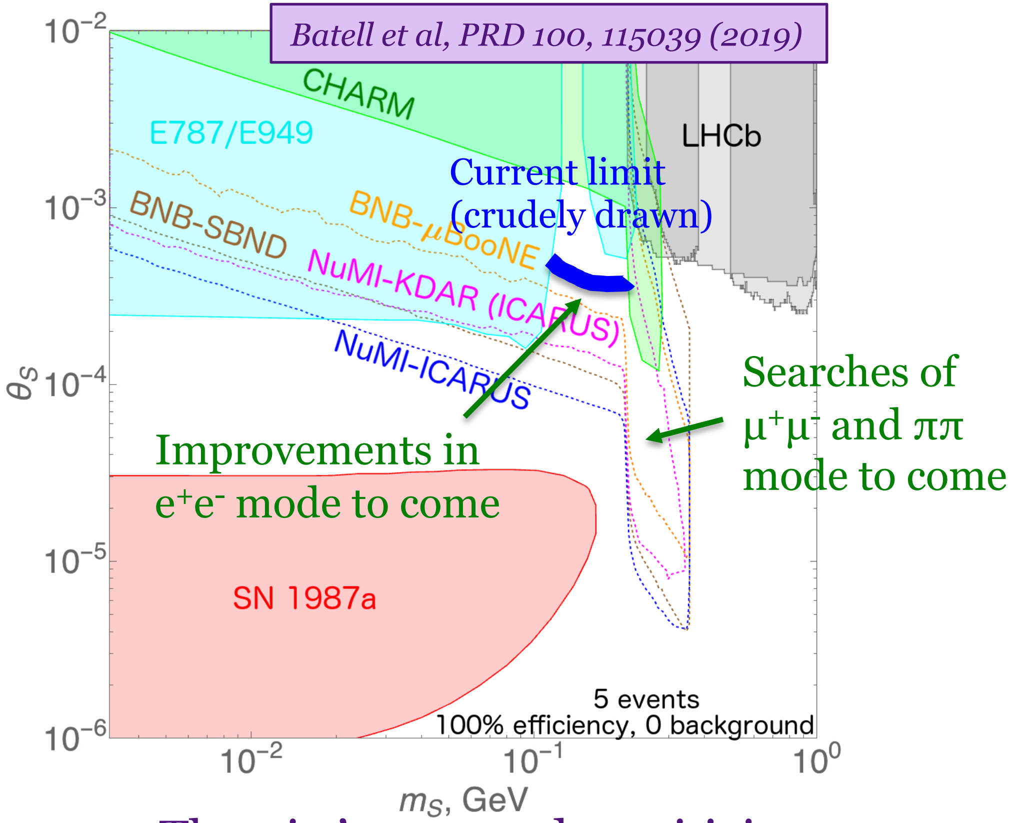
BDT distribution, well modelled by background-only expectation



Higgs Portal scalars

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



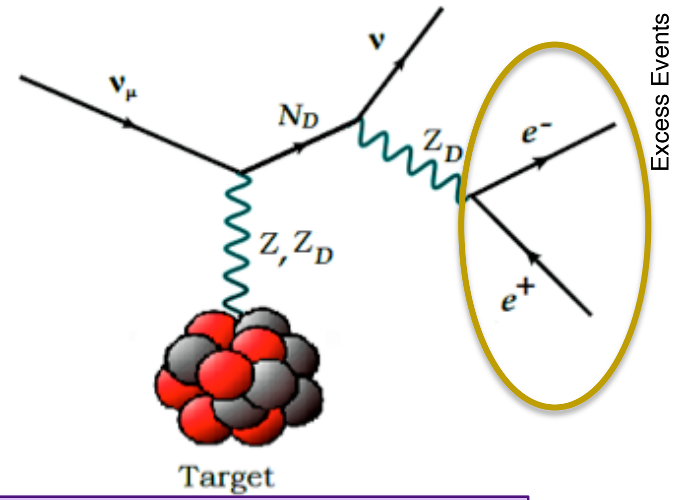


Theorist's expected sensitivity

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

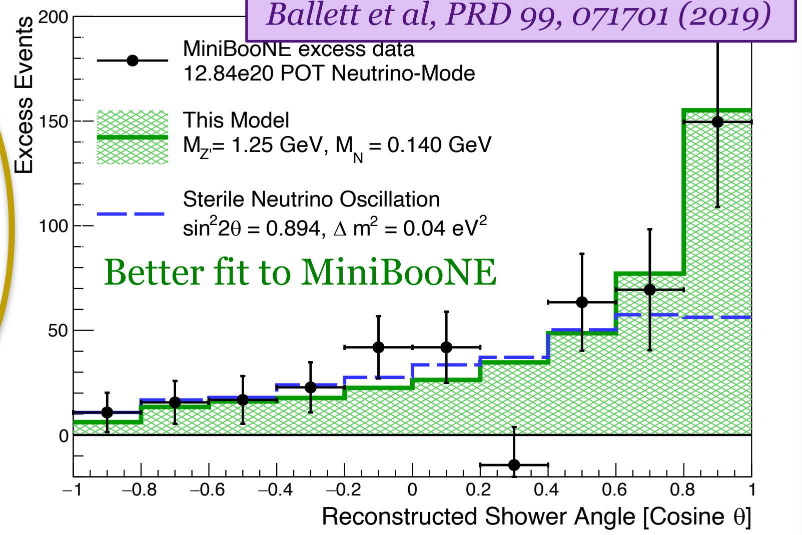
Dark prospects

- 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

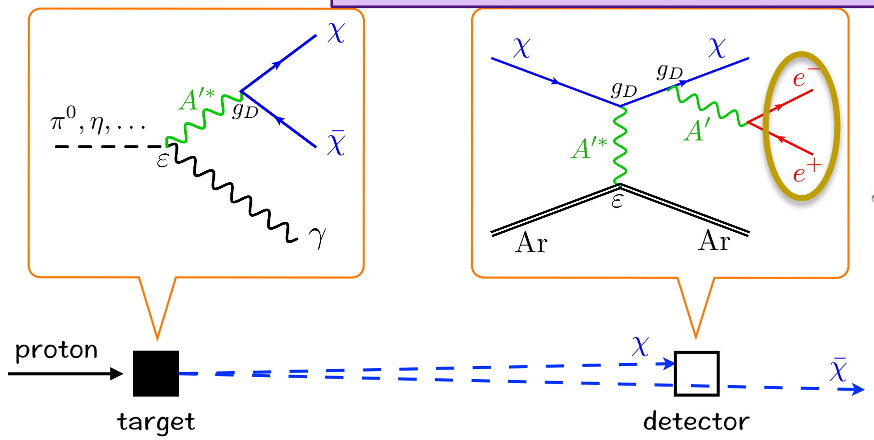


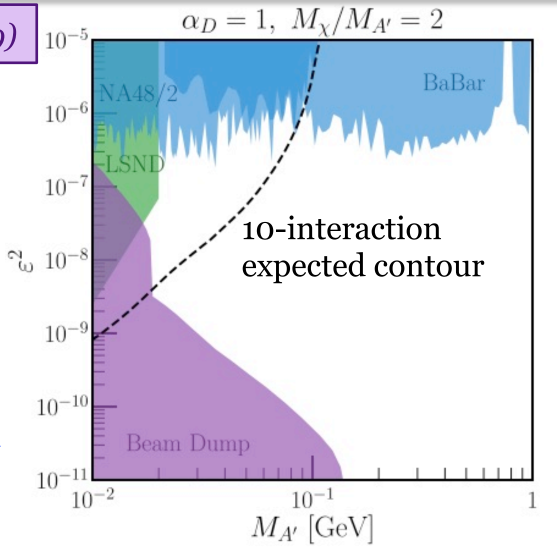
Bertuzzo et al, PRL 121, 241801 (2018)

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 (arXiv:2012.14324)
  - Neutron-antineutron oscillation analysis development (MICROBOONE-NOTE-1093-PUB)
  - Searches for heavy neutral leptons (Phys.Rev.D 101, 052001 (2020)), and dark sector scalars (MICROBOONE-NOTE-1092-PUB)
- We do have a lot more results to come in the near future
  - watch this space!