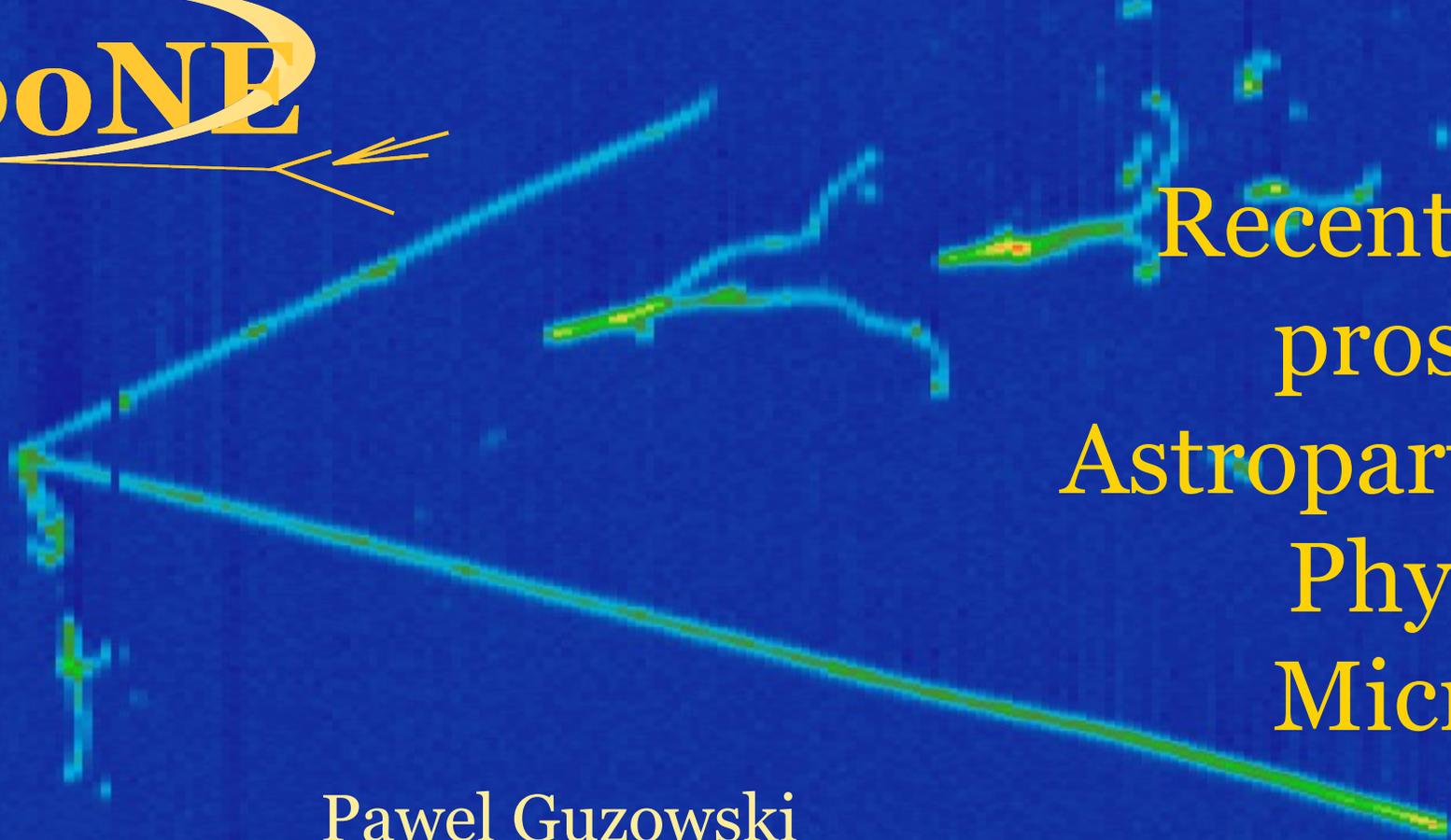


The logo for the MicroBooNE experiment, featuring the text "μBooNE" in a stylized yellow font with a white outline, set against a dark blue background. A white arrow points from the right towards the text.

μBooNE

A visualization of particle tracks within a detector, showing a central vertex from which several tracks emerge and spread out, resembling a cone. The tracks are rendered in shades of blue and green, with some segments highlighted in yellow. The background is a dark blue grid.

Recent results and prospects for Astroparticle and BSM Physics with MicroBooNE

Pawel Guzowski  
The University of Manchester  
*On behalf of the MicroBooNE Collaboration*  
EPS-HEP 2021 – 28 Jul 2021

The logo for The University of Manchester, consisting of the word "MANCHESTER" in a white serif font above the year "1824" in a smaller white serif font, all contained within a purple rectangular box.

MANCHESTER  
1824

The University of Manchester

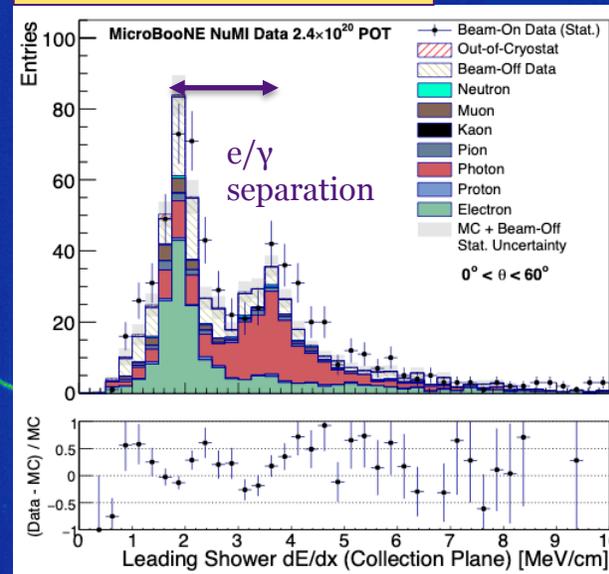
# LArTPC capabilities

Liquid Argon Time Projection Chamber  
“digital bubble chamber”



arXiv:2101.04228

Particle ID by dE/dx



100 keV hit thresholds

75 cm

10 cm

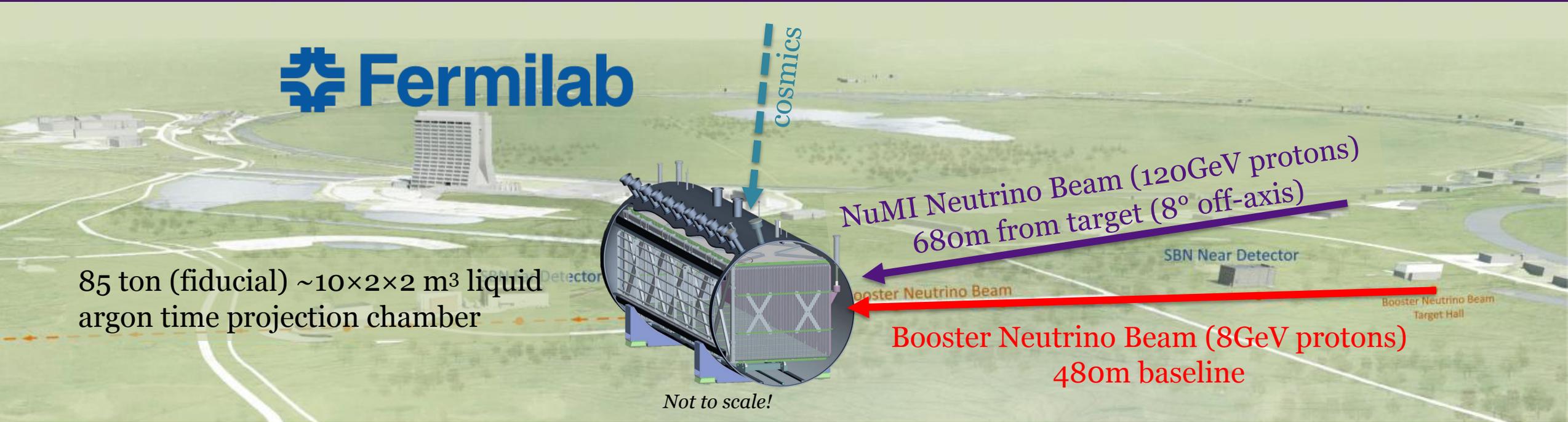
Four protons resolved

3mm spatial resolution

BNB DATA : RUN 5211 EVENT 1225. FEBRUARY 29, 2016

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

Journal of Instrumentation

The continuous readout of the MicroBooNE liquid argon time projection chamber for detection of supernova burst neutrinos

To cite this article: P. Abolins et al 2021, JINST 16 P03008

View the article

Progress Toward the First Search for Bound Neutron Oscillation into Antineutrino in a Liquid Argon TPC

MICROBOONE-NOTE-1093-PUB

The MicroBooNE Collaboration

August 3, 2020

PHYSICAL REVIEW D 101, 052001 (2020)

Search for heavy neutral leptons decaying into muon-pion pairs in the MicroBooNE detector

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Journal of Instrumentation

Measurement of the atmospheric muon rate with the MicroBooNE Liquid Argon TPC

MICROBOONE-NOTE-1076-PUB

The MicroBooNE Collaboration

August 3, 2020

MeV-scale Physics in MicroBooNE

MICROBOONE-NOTE 1076-PUB

The MicroBooNE Collaboration

Abstract: The scope of this public note is to present preliminary measurements of MeV energy signatures and relevant backgrounds for beam neutrino interactions using a dedicated reconstruction

Search for a Higgs portal scalar decaying to electron-positron pairs in the MicroBooNE detector

P. Abolins<sup>10</sup>, R. An<sup>15</sup>, J. Anthony<sup>4</sup>, J. Asadi<sup>14</sup>, A. Ashkenazi<sup>19,23</sup>, S. Balasubramanian<sup>12</sup>, B. Baller<sup>12</sup>, C. Barnes<sup>21</sup>, G. Barr<sup>25</sup>, V. Basque<sup>10</sup>, J. Bhathe-Peters<sup>12</sup>, O. Benevides Rodrigues<sup>12</sup>, S. Berkman<sup>1</sup>, A. Bhandari<sup>18</sup>, A. Bhat<sup>16</sup>, M. Bishai<sup>1</sup>, A. Blake<sup>1</sup>, T. Bolton<sup>16</sup>, J. Y. Book<sup>14</sup>, L. Camilleri<sup>10</sup>, D. Caratelli<sup>1</sup>, I. Caro Terrazas<sup>8</sup>, R. Castillo Fernandez<sup>17</sup>, F. Cavanna<sup>12</sup>, G. Cerati<sup>12</sup>, Y. Chen<sup>12</sup>, D. Cline<sup>12</sup>, J. M. Conrad<sup>10</sup>, M. Convery<sup>23</sup>, L. Cooper-Troendle<sup>28</sup>, J. I. Crespo-Anadón<sup>9</sup>, M. Dal Toso<sup>12</sup>, S. R. Dennis<sup>12</sup>, D. Devitt<sup>12</sup>, R. Dirlikov<sup>27</sup>, R. Derrill<sup>15</sup>, K. Duffy<sup>12</sup>, S. Dyman<sup>28</sup>, B. Eberly<sup>12</sup>, A. Ereditato<sup>1</sup>, J. J. Evans<sup>19</sup>, R. Fine<sup>19</sup>, G. A. Fiorentini Aguirre<sup>29</sup>, R. S. Fitzpatrick<sup>27</sup>, B. T. Fleming<sup>29</sup>, N. Foppiani<sup>1</sup>, D. Franco<sup>24</sup>, A. P. Furnas<sup>10,23</sup>, D. Garcia-Gonzalez<sup>1</sup>, S. Gaudino<sup>12</sup>, G. Ge<sup>19</sup>, S. Gollapudi<sup>10</sup>, D. Goodwin<sup>10</sup>, E. Granelina<sup>11</sup>, P. Green<sup>19</sup>, H. Greenlee<sup>11</sup>, W. Gu<sup>28</sup>, R. Gussette<sup>14</sup>, P. Guzowski<sup>10</sup>, J. L. Hagmann<sup>28</sup>, H. Had<sup>20</sup>, O. Hen<sup>20</sup>, G. A. Horton-Smith<sup>1</sup>, A. Hourigan<sup>10</sup>, R. Iley<sup>20</sup>, C. James<sup>11</sup>, J. Jiang<sup>20</sup>, J. H. Jo<sup>19</sup>, R. A. Johnson<sup>1</sup>, J. Joo<sup>1</sup>, N. Kamp<sup>20</sup>, N. Kaushige<sup>10</sup>, G. Karagiorgis<sup>28</sup>, W. Ketchum<sup>12</sup>, M. Kirby<sup>12</sup>, T. Kobilarcik<sup>12</sup>, I. Kreslo<sup>1</sup>, R. LaZar<sup>12</sup>, I. Lepetic<sup>12</sup>, K. Li<sup>18</sup>, V. Li<sup>2</sup>, K. Lin<sup>16</sup>, B. R. Littlejohn<sup>1</sup>, W. C. Louis<sup>1</sup>, X. Luo<sup>10</sup>, K. Maity<sup>10</sup>, C. Mariani<sup>29</sup>, J. Marshall<sup>12</sup>, M. Marsden<sup>12</sup>, D. V. A. Martinez Caballero<sup>10</sup>, K. Mason<sup>13</sup>, A. Maslouski<sup>27</sup>, N. McCloskey<sup>12</sup>, V. Medjuga<sup>12</sup>, T. Mentler<sup>1</sup>, K. Miller<sup>1</sup>, J. Mills<sup>12</sup>, K. Mistry<sup>19</sup>, A. Mogan<sup>12</sup>, T. Mohr<sup>1</sup>, M. Mooney<sup>12</sup>, C. D. Moore<sup>12</sup>, L. Mora Lepin<sup>19</sup>, J. Monseau<sup>20</sup>, M. Murphy<sup>10</sup>, D. Naples<sup>20</sup>, A. Navrer-Agasson<sup>19</sup>, R. K. Neely<sup>12</sup>, J. Nowak<sup>12</sup>, M. Nunes<sup>24</sup>, D. Palamara<sup>12</sup>, V. Paolone<sup>12</sup>, A. Papadopoulos<sup>12</sup>, V. Papavasiliou<sup>12</sup>, S. F. Paul<sup>12</sup>, A. Paule<sup>12</sup>, Z. Pavlovic<sup>12</sup>, E. Pascazio<sup>12</sup>, L. D. Ponce-Pinto<sup>12</sup>, S. Ponce<sup>12</sup>, X. Qian<sup>12</sup>, J. L. Raaf<sup>12</sup>, V. Radzka<sup>12</sup>, A. Raff<sup>12</sup>, M. Reggiani-Guzzo<sup>19</sup>, L. Ren<sup>12</sup>, J. C. Rice<sup>20</sup>, L. Rochester<sup>12</sup>, R. Rodriguez-Rondon<sup>28</sup>, H. E. Rogers<sup>12</sup>, M. Rosenber<sup>28</sup>, M. Ross-Lonergan<sup>10</sup>, G. Scavini<sup>12</sup>, D. W. Schmitz<sup>12</sup>, A. Schukraft<sup>12</sup>, W. Seligman<sup>12</sup>, M. H. Shaevitz<sup>12</sup>, R. Sharankov<sup>12</sup>, J. Shi<sup>12</sup>, H. Siegel<sup>10</sup>, J. Sinclair<sup>12</sup>, A. Smith<sup>12</sup>, E. L. Snider<sup>12</sup>, M. Soltes-Rensbald<sup>19</sup>, S. R. Soletz<sup>12,19</sup>, P. Spentzos<sup>12</sup>, J. Spitz<sup>22</sup>, M. Stancari<sup>12</sup>, J. St. John<sup>12</sup>, T. Strass<sup>12</sup>, K. Sutton<sup>10</sup>, S. Sword-Fellberg<sup>22</sup>, A. M. Szek<sup>12</sup>, N. Tagg<sup>24</sup>, W. Tang<sup>24</sup>, K. Terao<sup>24</sup>, C. Thorpe<sup>12</sup>, D. Totani<sup>12</sup>, M. Toups<sup>10</sup>, Y. T. Tsai<sup>28</sup>, M. A. Uchida<sup>2</sup>, T. Usher<sup>2</sup>, W. Van De Pottsele<sup>25,14</sup>, B. Viren<sup>12</sup>, M. Weber<sup>12</sup>, H. Wei<sup>2</sup>, Z. Williams<sup>12</sup>, S. Wolbers<sup>12</sup>, T. Wengrad<sup>12</sup>, M. Wospakrik<sup>12</sup>, K. Wrenn<sup>10</sup>, N. Wright<sup>10</sup>, W. Wu<sup>12</sup>, E. Yandel<sup>12</sup>, T. Yang<sup>12</sup>, G. Yarbrough<sup>12</sup>, L. E. Yates<sup>12</sup>, G. P. Zeller<sup>12</sup>, J. Zennaro<sup>12</sup>, and C. Zhang<sup>12</sup>

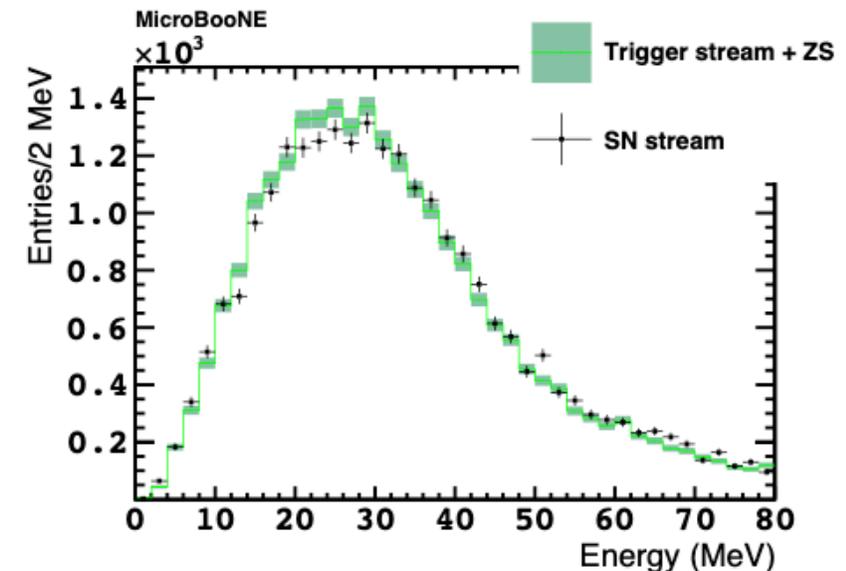
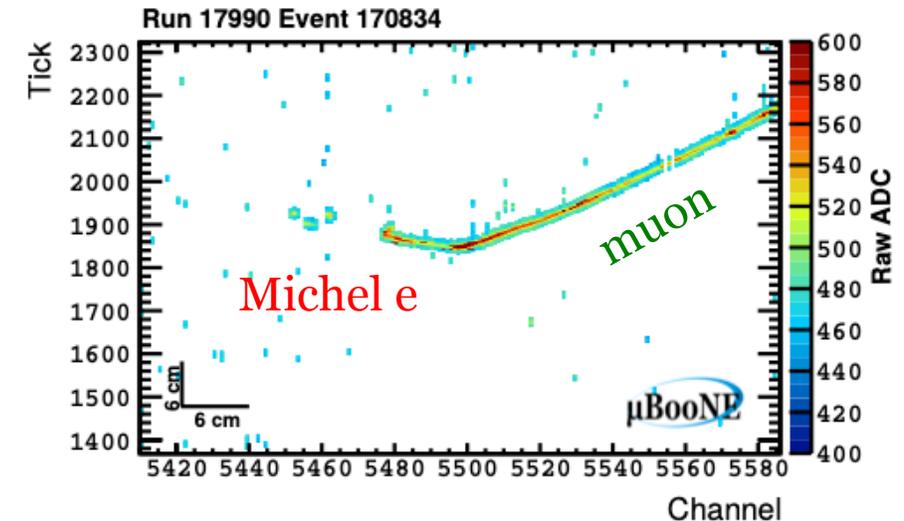
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# R&D for supernova neutrino detection

- 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  $80\times$
  - Prototype for DUNE
- Performance evaluated by reconstruction of Michel electrons
  - Comparable to full datastream

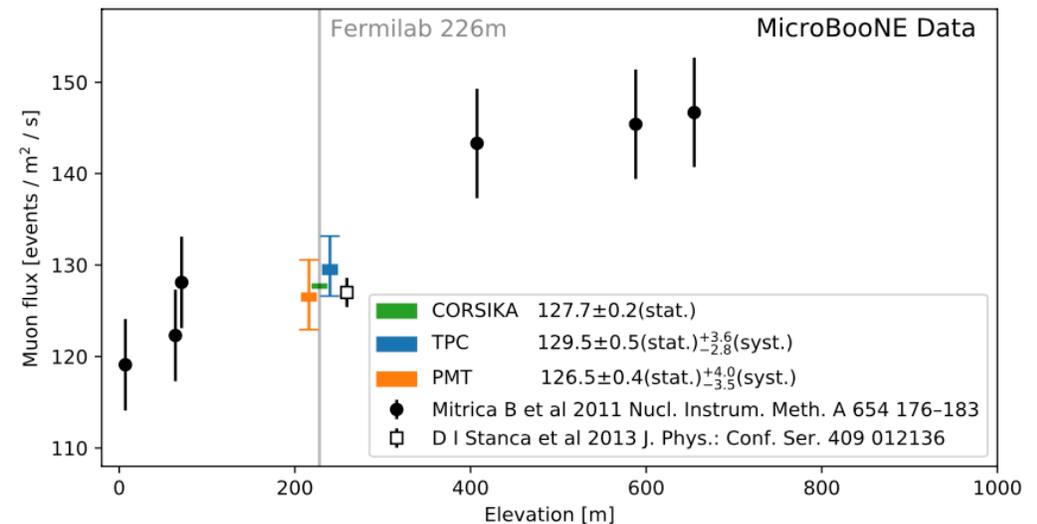
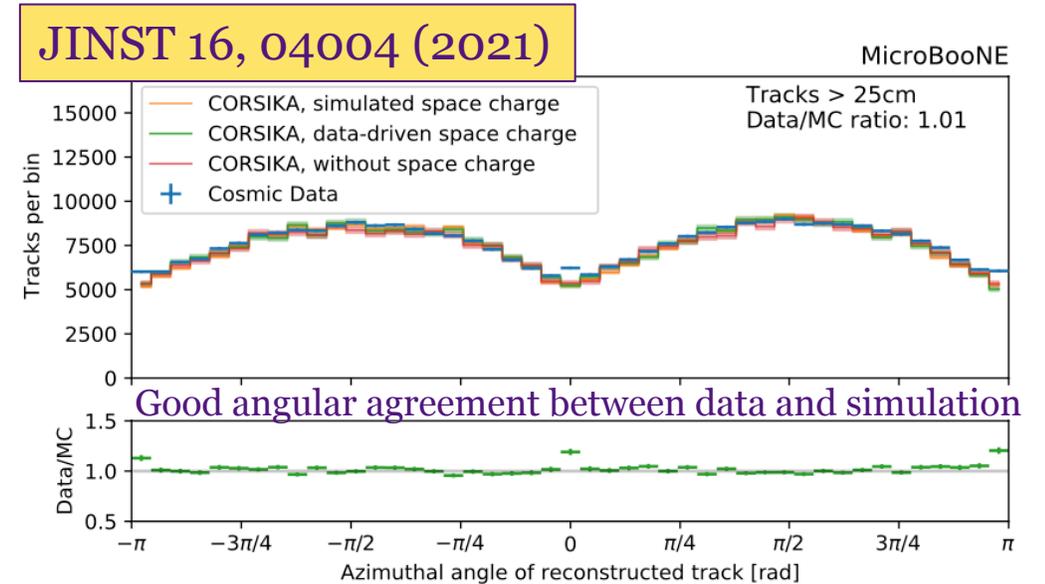
JINST 16, 02, P02008 (2021)



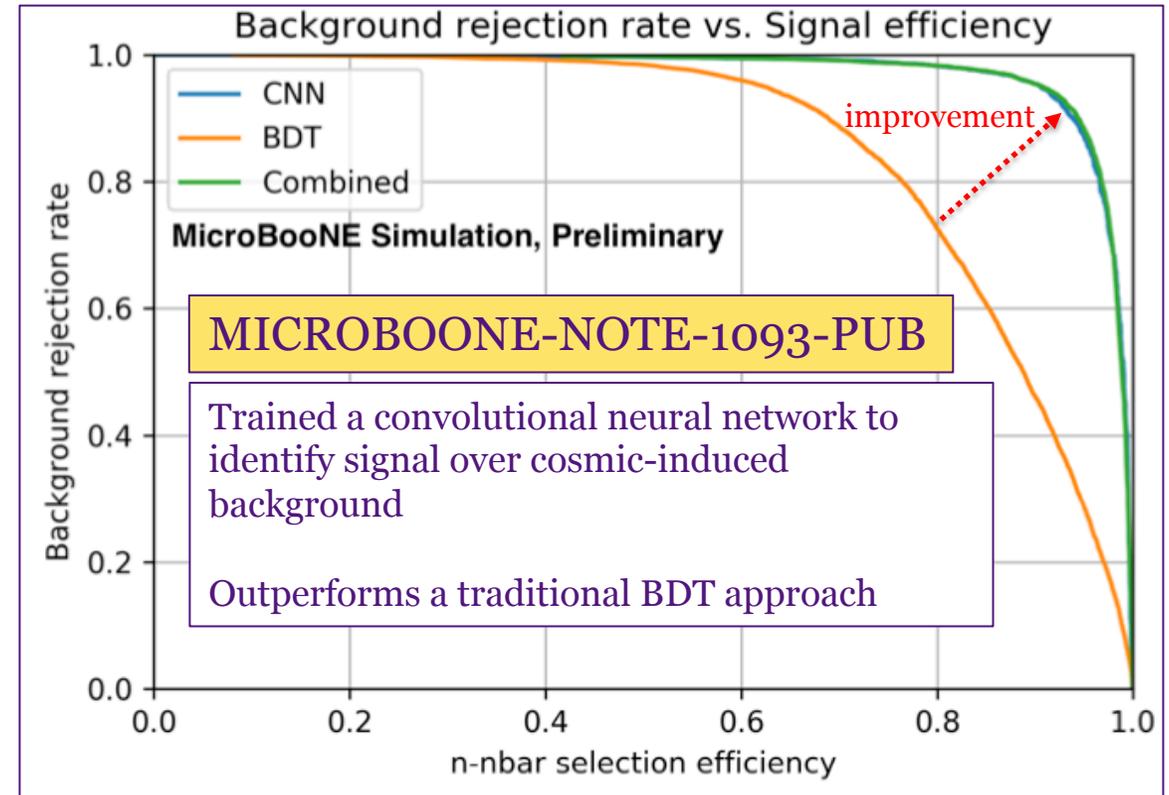
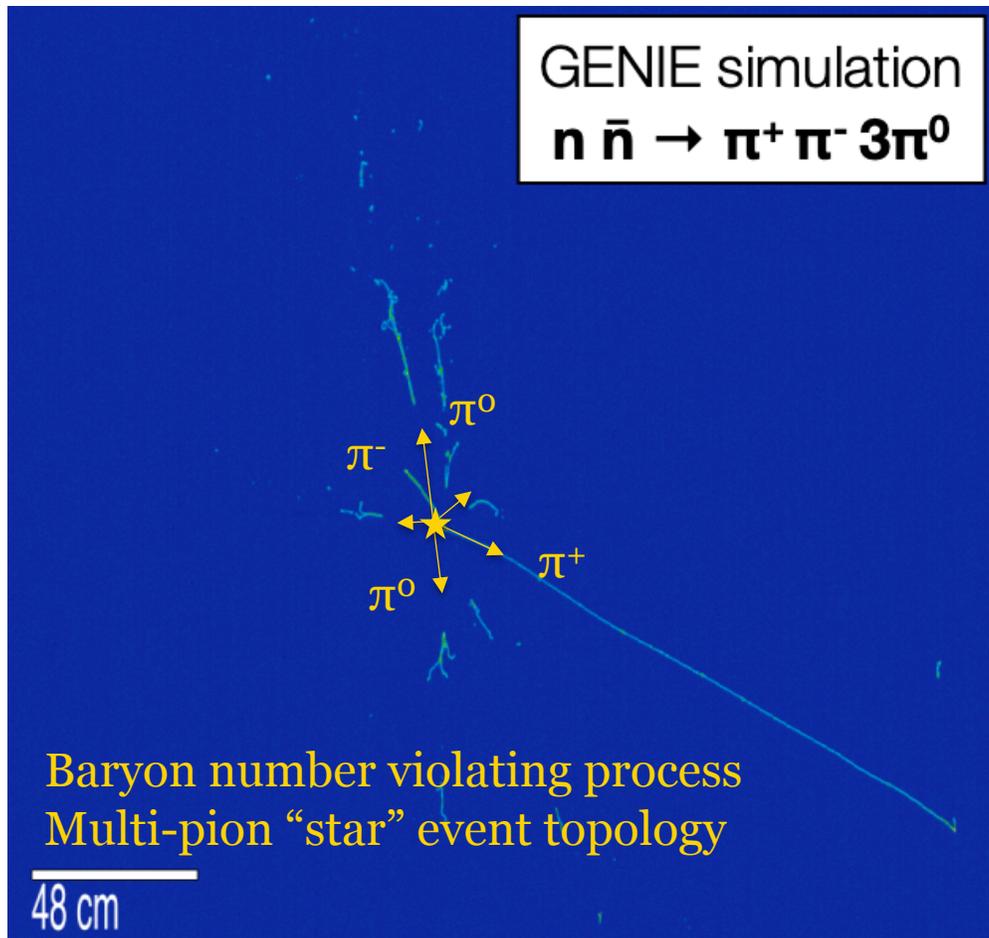
# Cosmic ray rates

- 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
  - **Disagrees** with ‘constant mass composition’ extension\* of the simulation
- Useful **input to future experiments** at Fermilab, including SBN program and DUNE

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



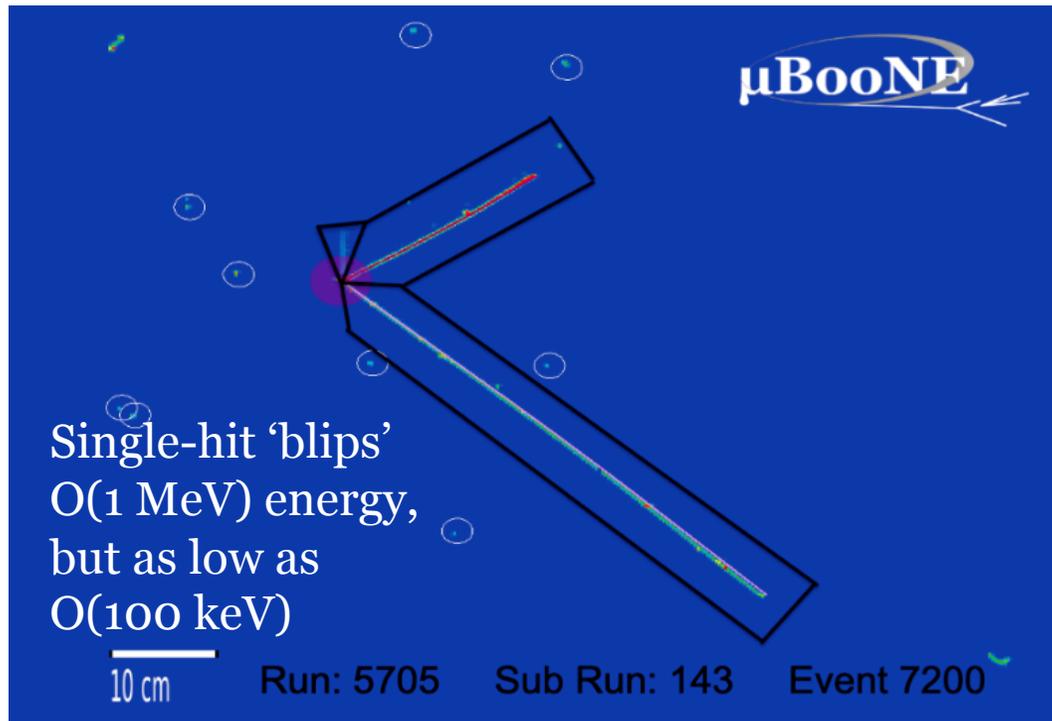
# Neutron-antineutron oscillation



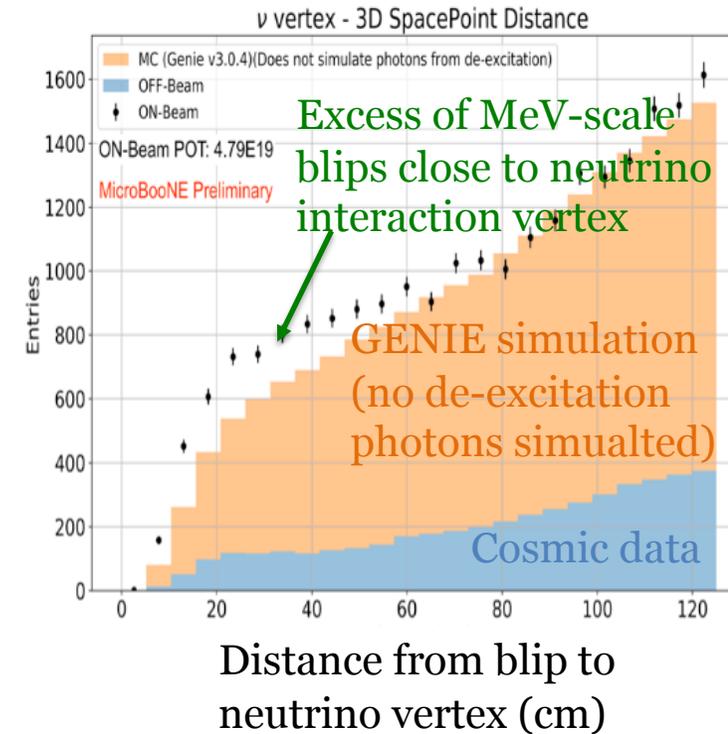
- MicroBooNE is pioneering techniques to be used in DUNE
- Convolutional neural network based search

# MeV-scale reconstruction

- Standard reconstruction algorithms designed for  $O(100 \text{ MeV})$  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

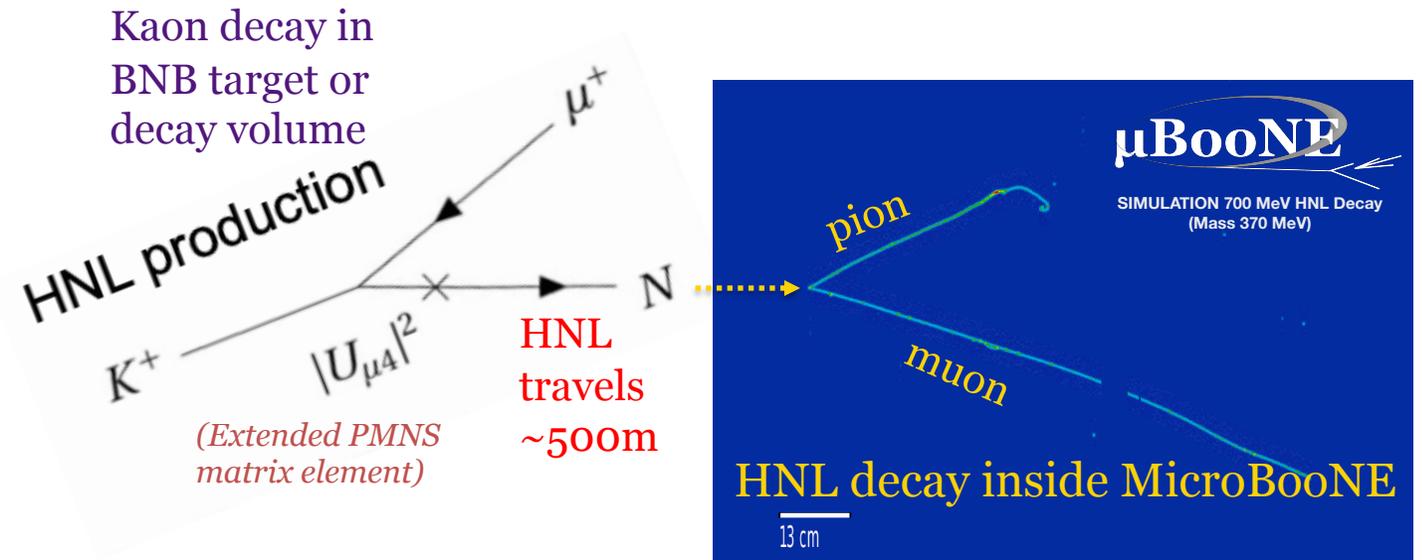


### Applications:

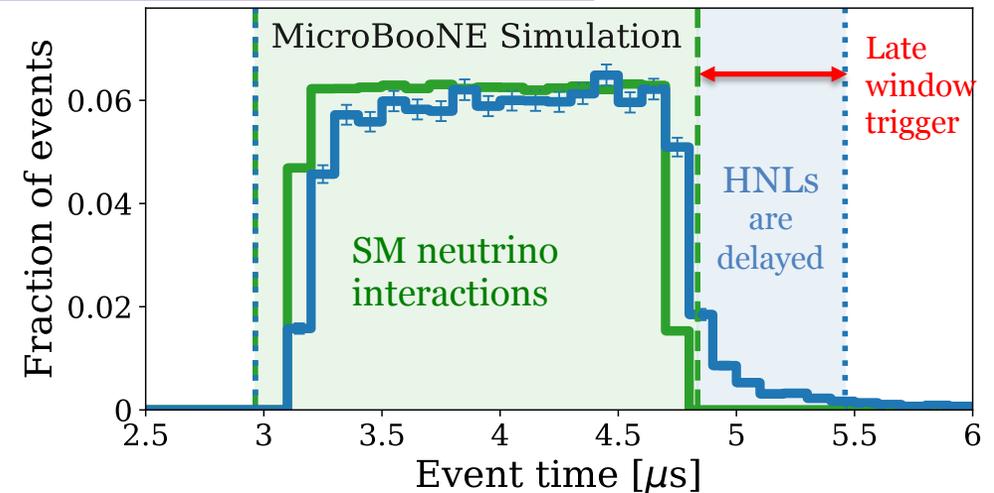
- Supernova neutrino reconstruction
- Muon/pion separation
- Searches for millicharged particles

# Heavy neutral leptons

- $O(100 \text{ MeV})$  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

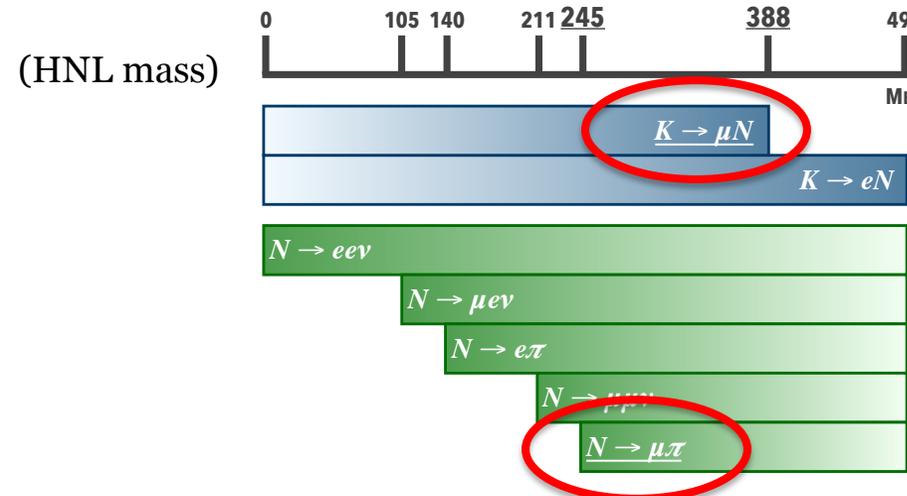
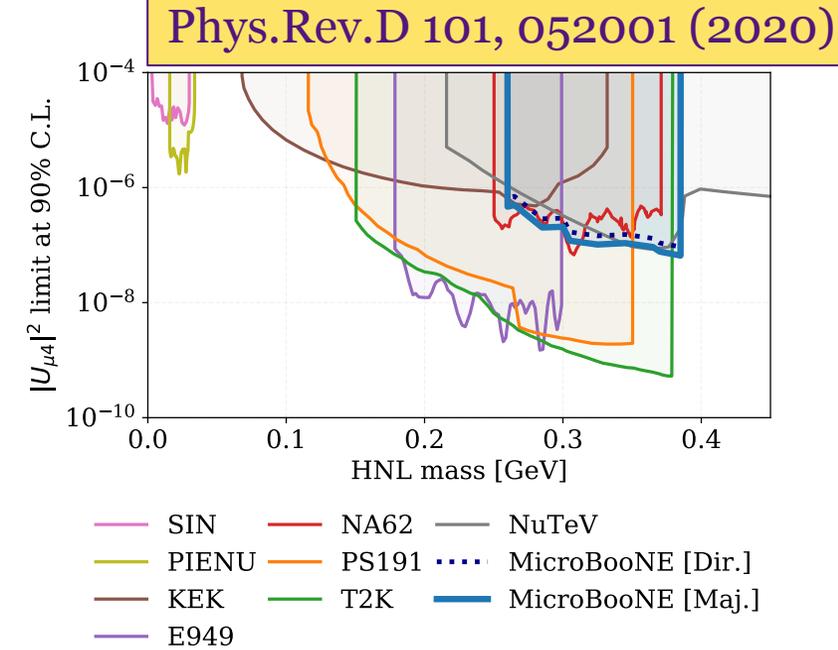
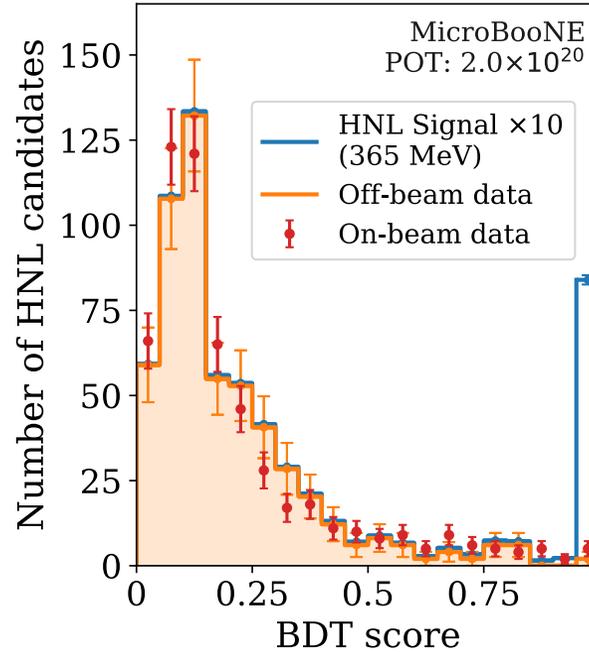


Phys.Rev.D 101, 052001 (2020)



# 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

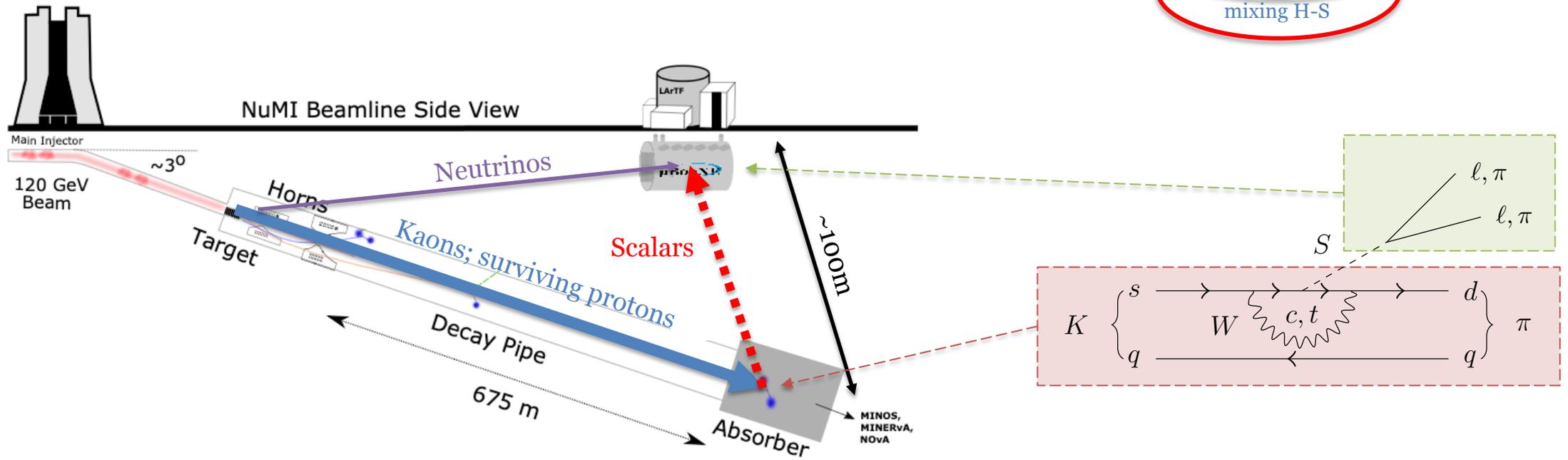
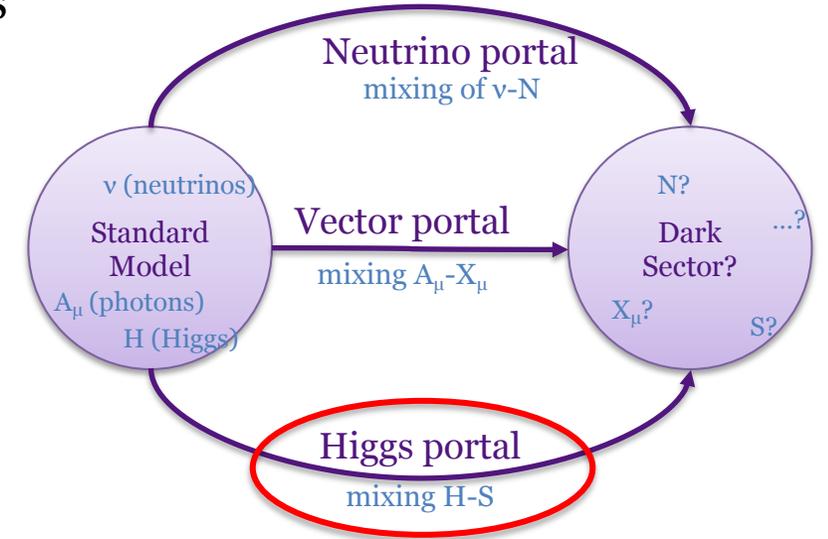


Only searched for this production mode

Only searched for this decay mode

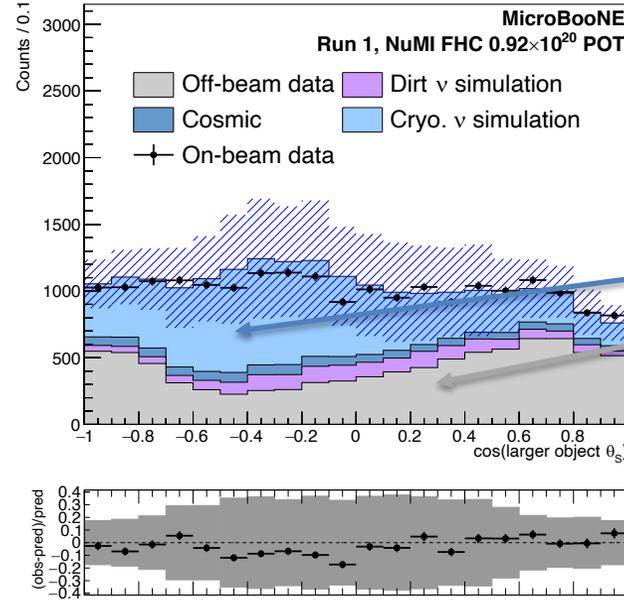
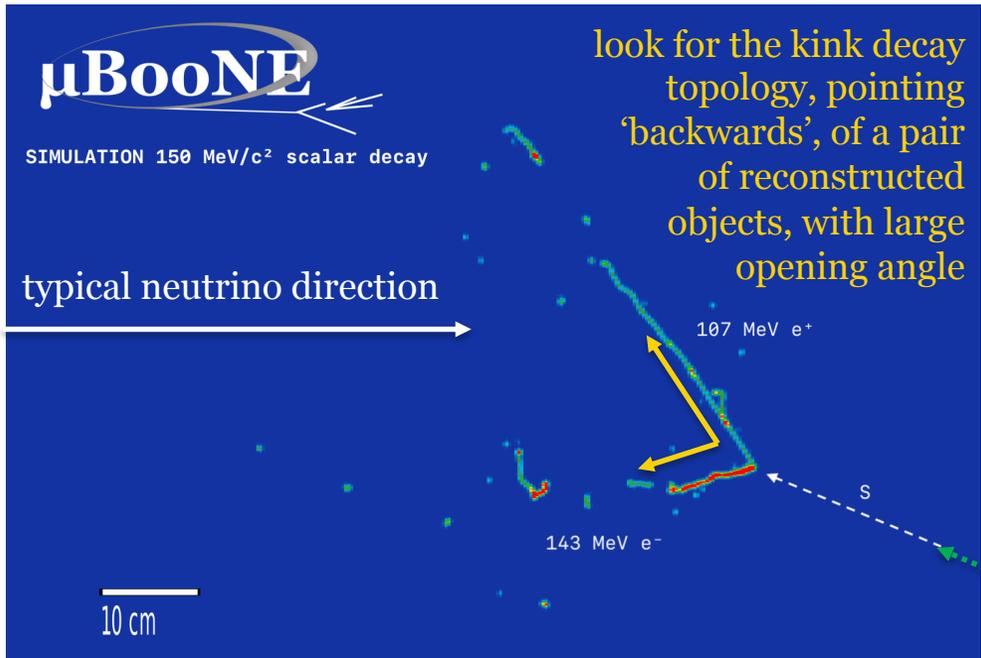
# Higgs Portal scalars

- “Portal” to the dark sector, via a dark scalar mixing with the Higgs (mixing angle  $\theta$ )
  - Couples to SM fermions via Yukawa couplings  $\propto \theta^2 m^2$
- 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



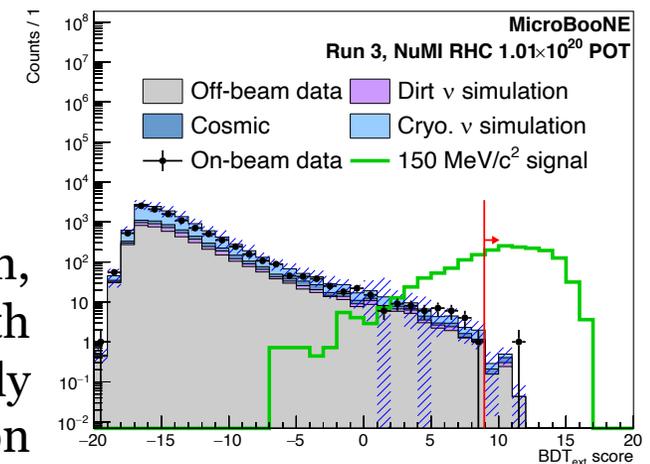
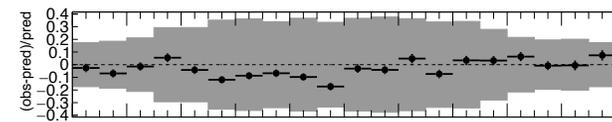
# Higgs Portal scalars

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

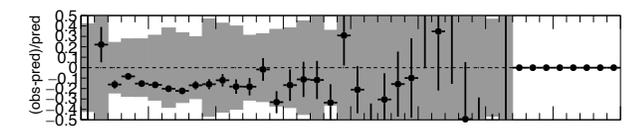


Angular variable (one of the most important for BDT); Simulation is well modelled with respect to the data

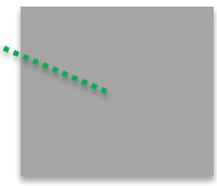
Neutrino simulation (GENIE)  
Data-driven cosmic background



BDT distribution, well modelled with background-only expectation



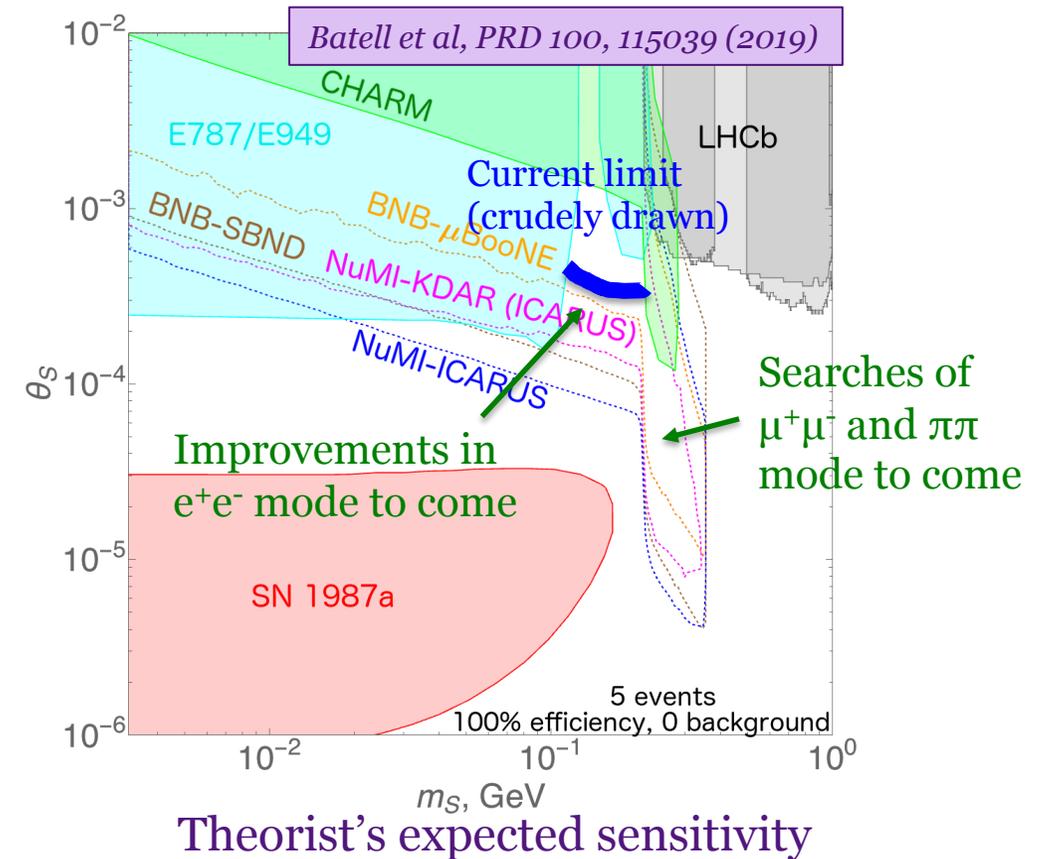
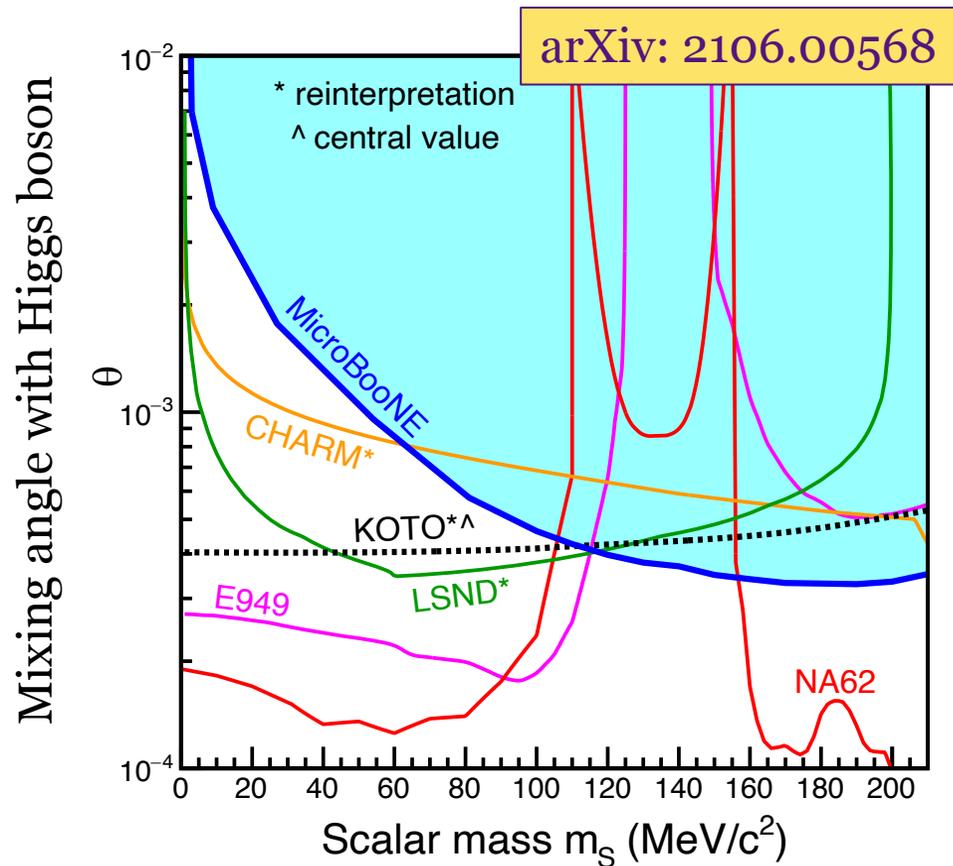
Scalar boson



NuMI beam dump

# Higgs Portal scalars

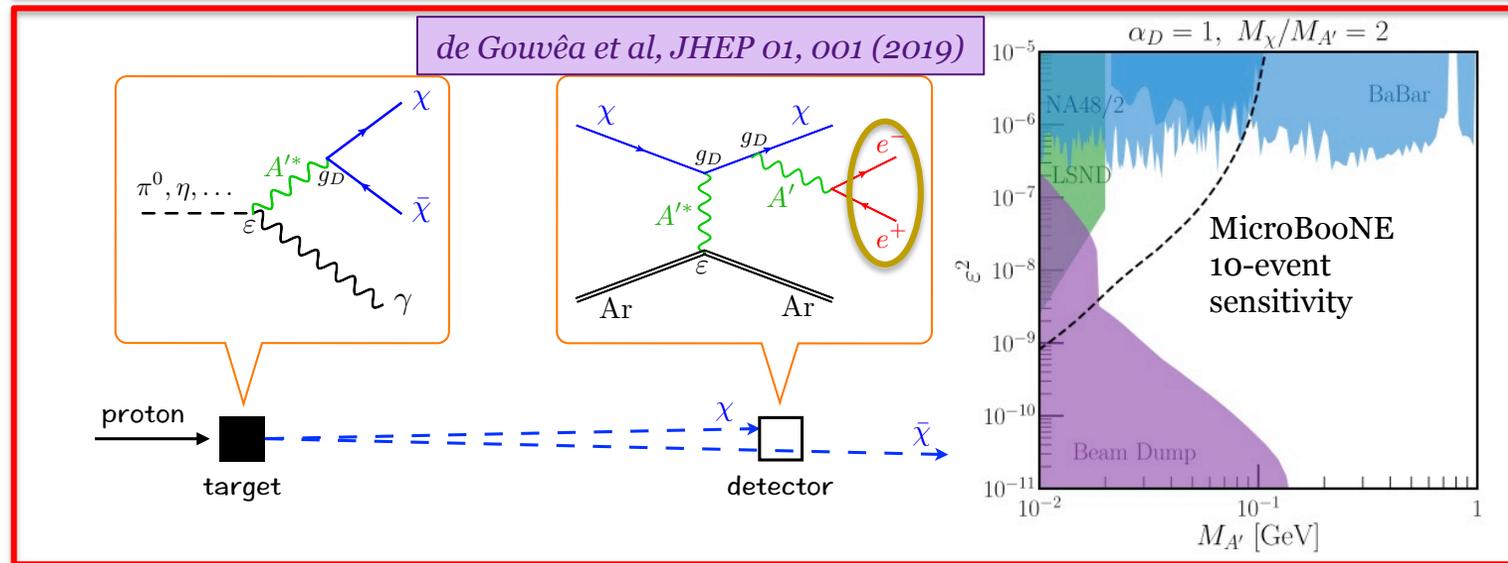
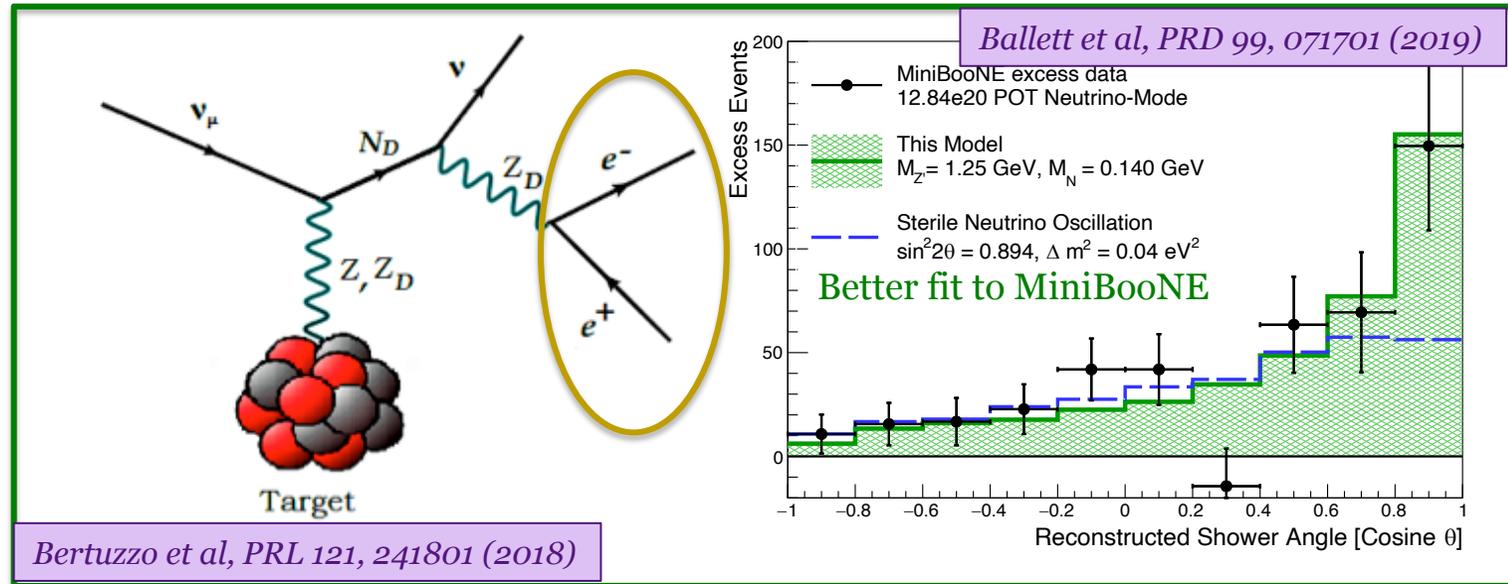
- We observe 5 events in signal region, with  $2.0 \pm 0.8$  expected
- Can exclude model central value parameters required to explain KOTO anomaly\*
- This was with 10% of our NuMI dataset; further search results to come!



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

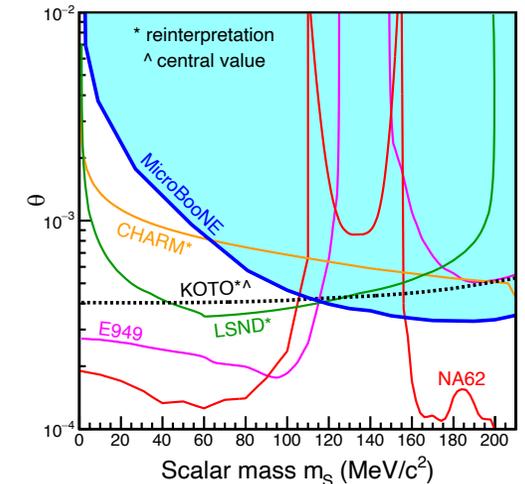
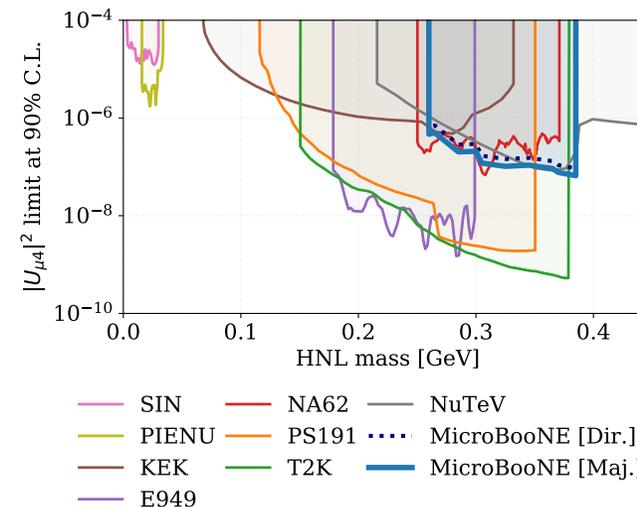
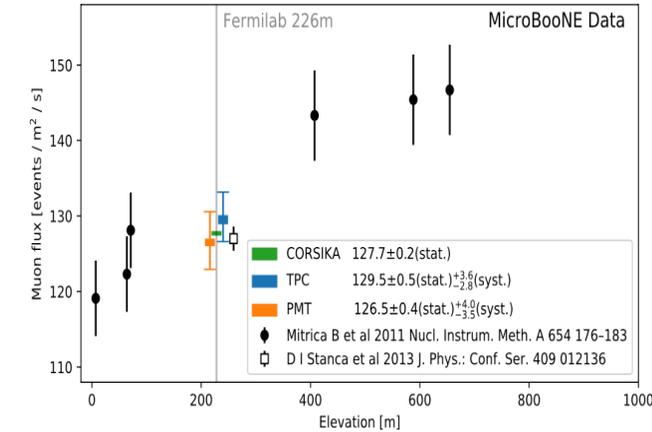
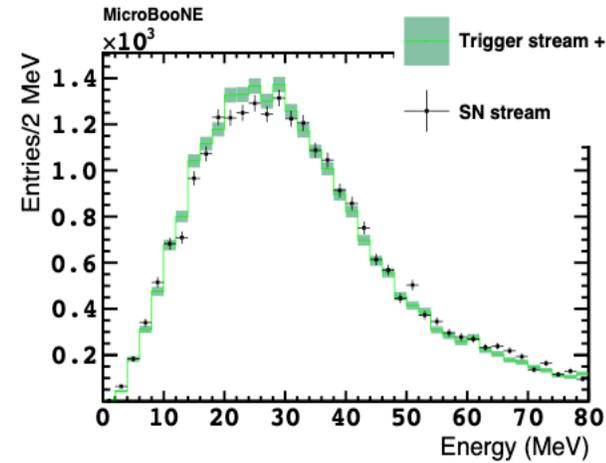
# Dark prospects

- 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



# Summary

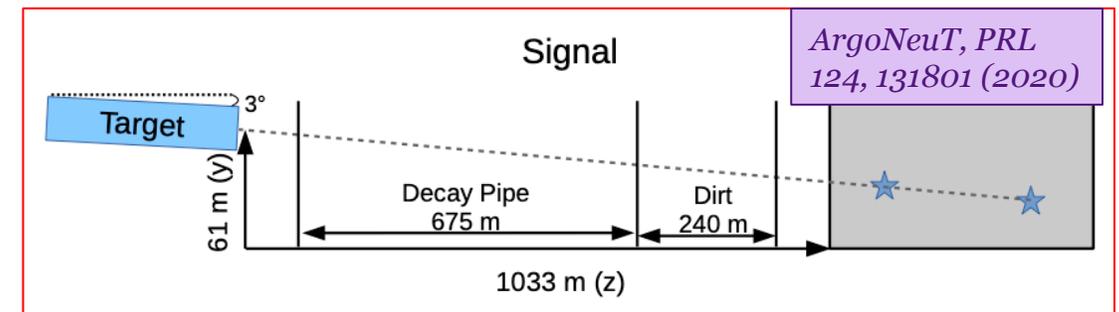
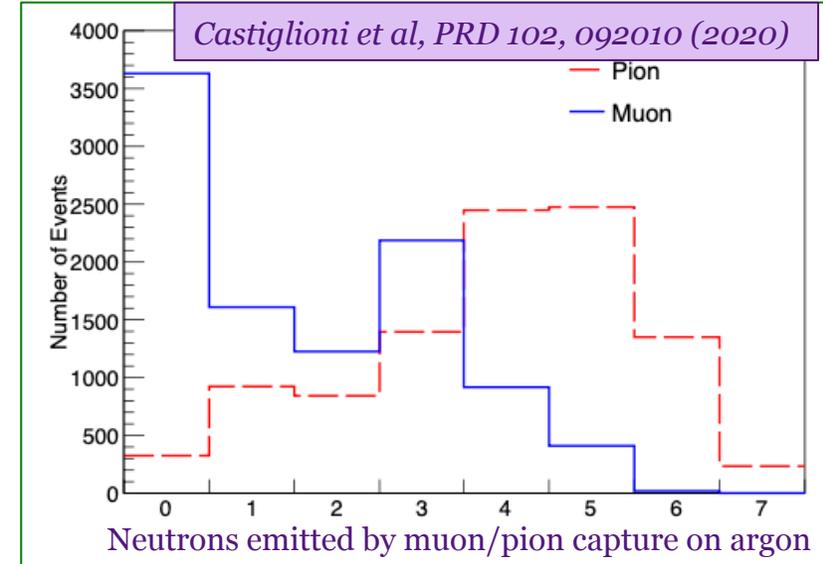
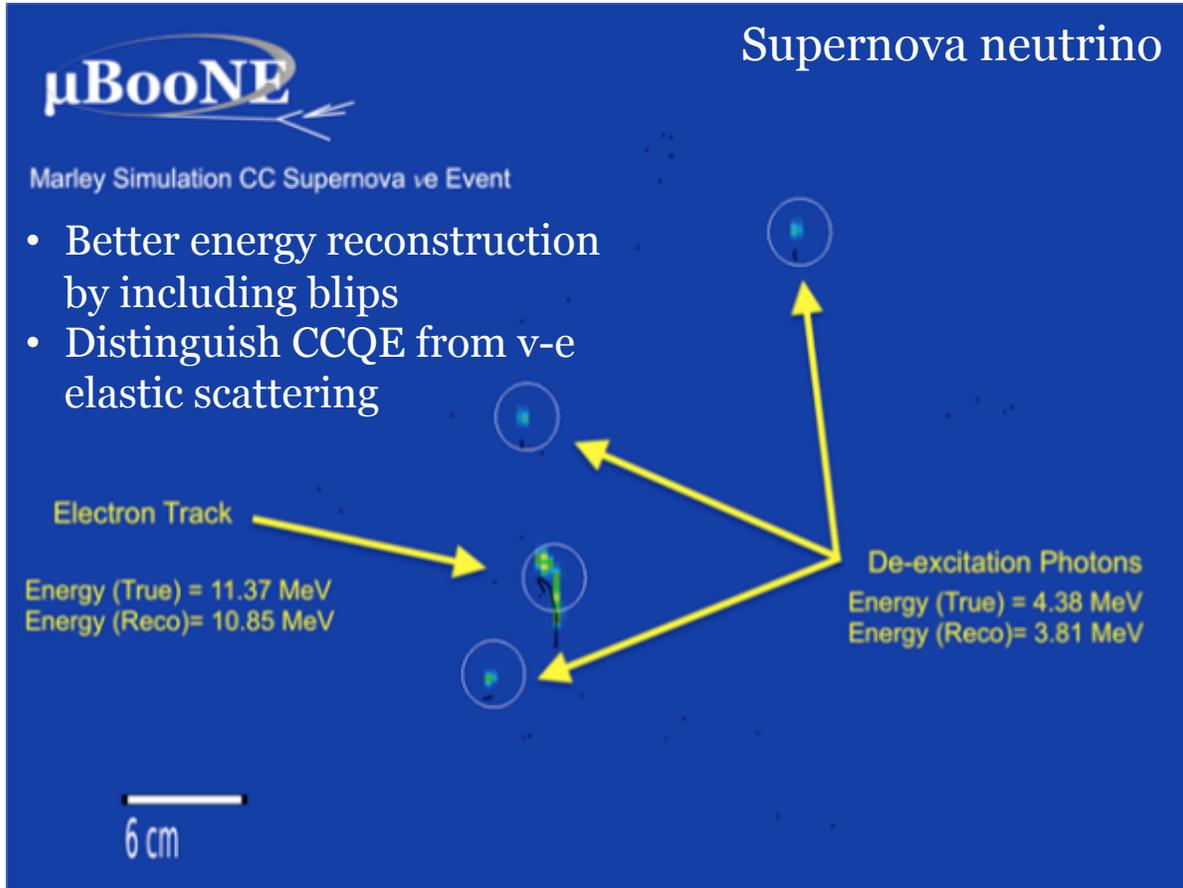
- MicroBooNE is not only excellent for investigating MiniBooNE or measuring cross sections, but can also perform a **diverse variety** of astrophysical or exotic measurements
- We have produced some **exciting results** in the past year
  - Supernova continuous readout ([JINST 16, 02, P02008 \(2021\)](#))
  - 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

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)