Searching for beyond the Standard Model Physics with MicroBooNE

Daisy Kalra, Columbia University
On behalf of MicroBooNE Collaboration

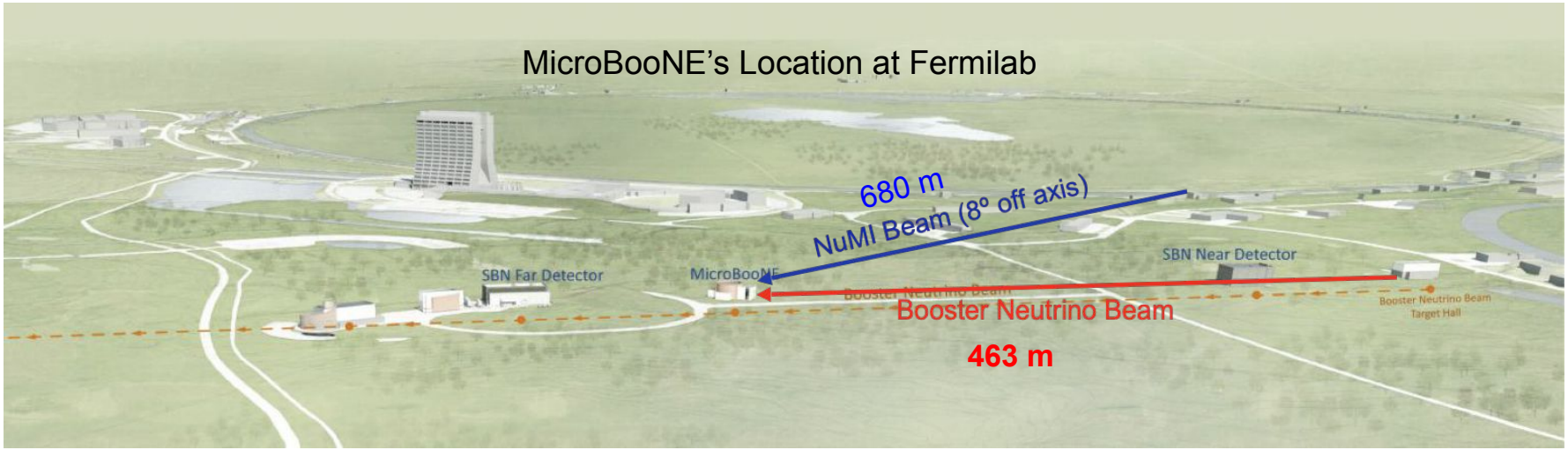
CoSSURF-2022 (May 12, 2022)

Outline

- Introduction to MicroBooNE
- Liquid Argon Time Projection Chamber and its capabilities
- Beyond the Standard Model physics searches in MicroBooNE
- Summary

MicroBooNE

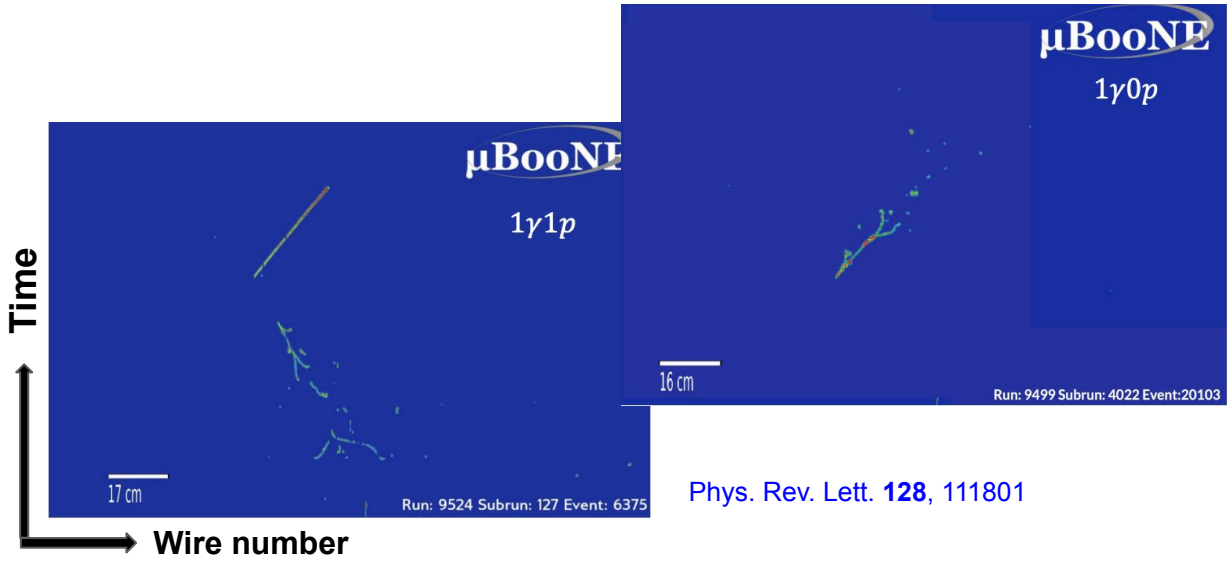
- MicroBooNE is 85 tonne active mass Liquid Argon Time Projection Chamber (LArTPC)
- On-axis to Booster Neutrino Beamline (BNB) with average Eν = 800 MeV
- Off-axis to Neutrinos at Main Injector (NuMI) with average Eν = 1.5 GeV



Goals of MicroBooNE

- **Primary goal** is to investigate MiniBooNE anomalous low energy excess (LEE).
  [(See talk by Ivan Caro Terrazas)]

Photon channel



Phys. Rev. Lett. **128**, 111801

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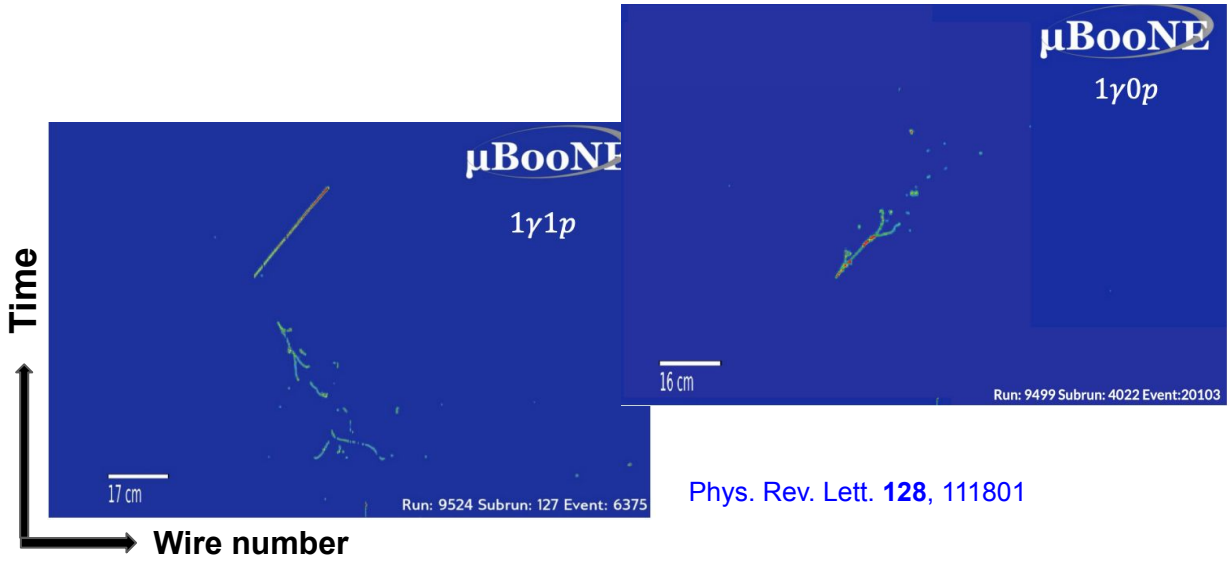

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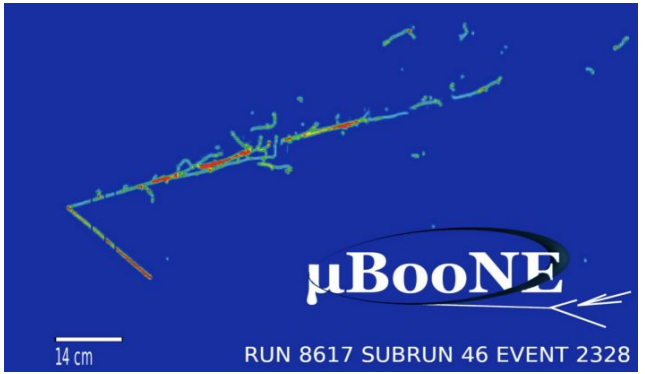


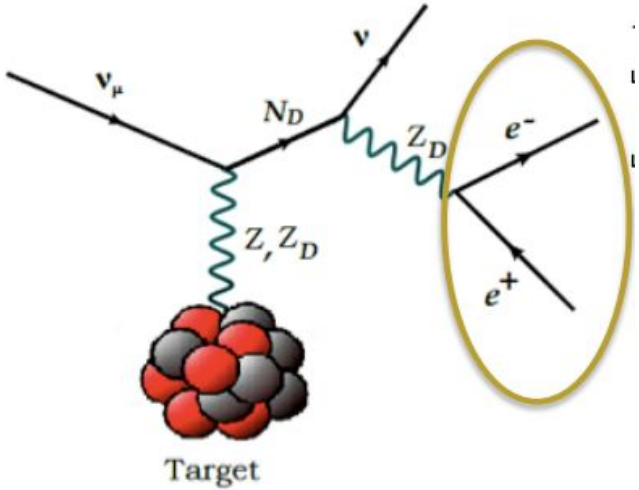
Electron channel

arXiv:2110.14080v2, arXiv:2110.14065 and arXiv:2110.13978 accepted to PRD

Goals of MicroBooNE

- Recent results on MicroBooNE LEE search stated that the excess is neither electron-like nor photon-like.

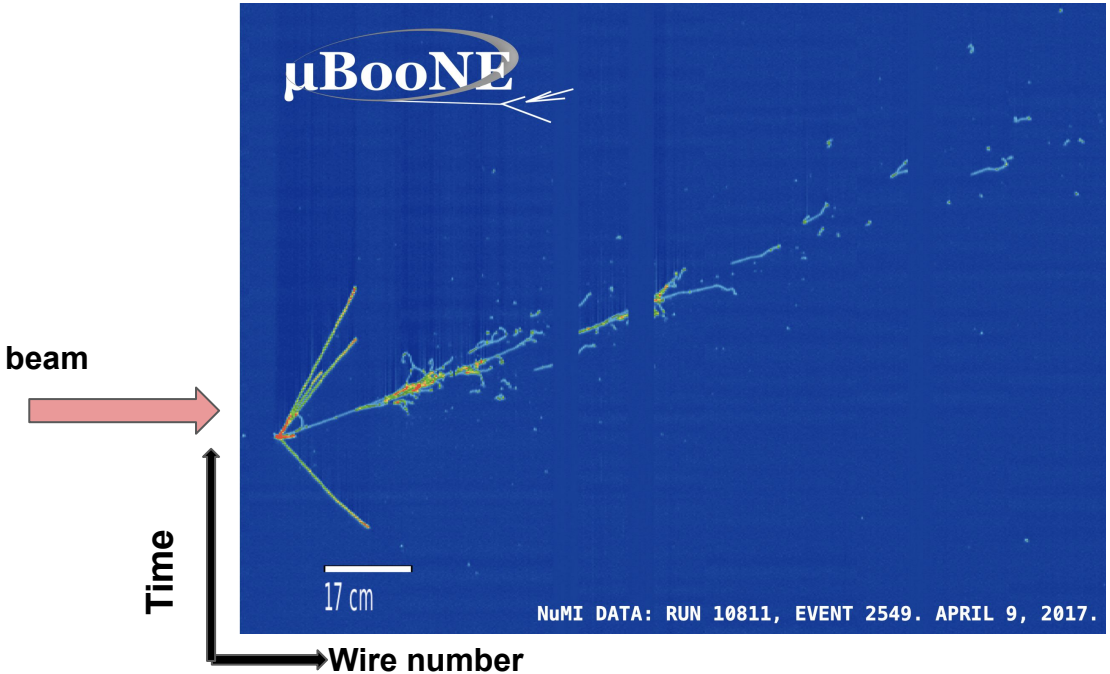
- Currently, exploring a variety of BSM models such as models with e^+e^- final states to target the nature of MiniBooNE's LEE.

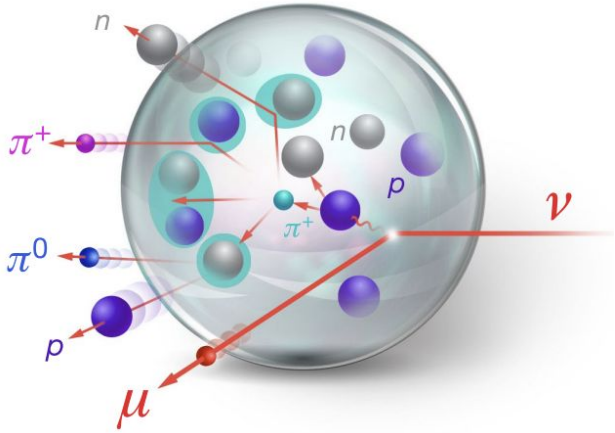


Phys.Rev.Lett 121.241801

Goals of MicroBooNE

- Rich Cross-section program using both the BNB and NuMI neutrinos.





Goals of MicroBooNE

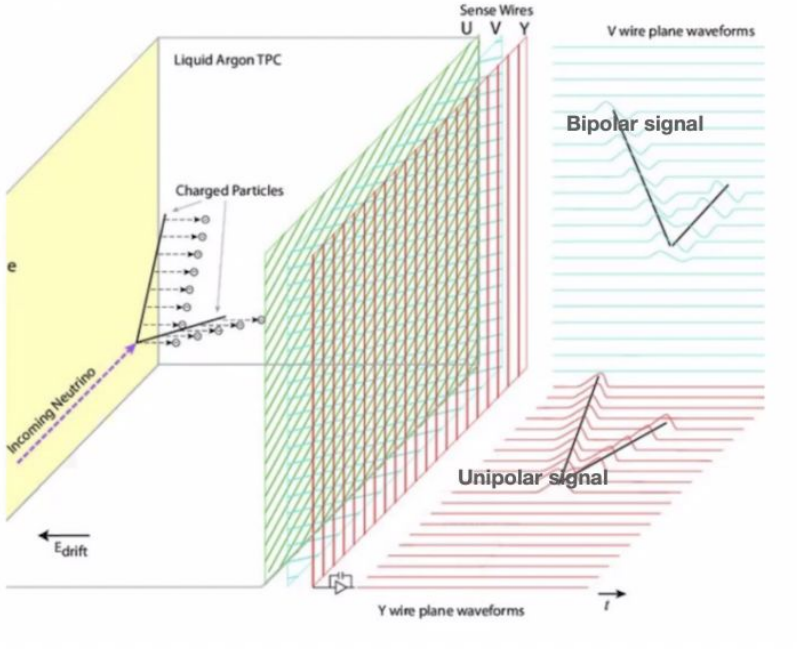
- MicroBooNE is exposed to both the NuMI and BNB providing an excellent opportunity to search for **beyond the Standard Model (BSM) physics processes.** ← **Focus of this talk**

- MicroBooNE's analysis as an important proof-of-principle for the future planned measurements in LArTPC detectors such as SBND, ICARUS, DUNE.

Liquid Argon Time Projection Chamber

JINST 12(2017)09, P09014

- Interaction generates final state particles that leave a trail of ionization electrons and scintillation light.
- Anode plane wires record signature from ionization electrons.



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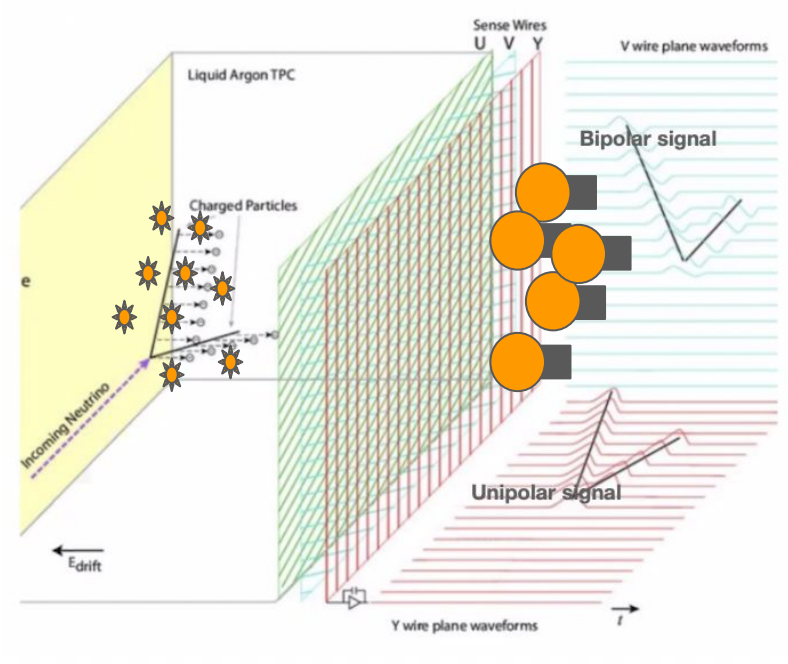
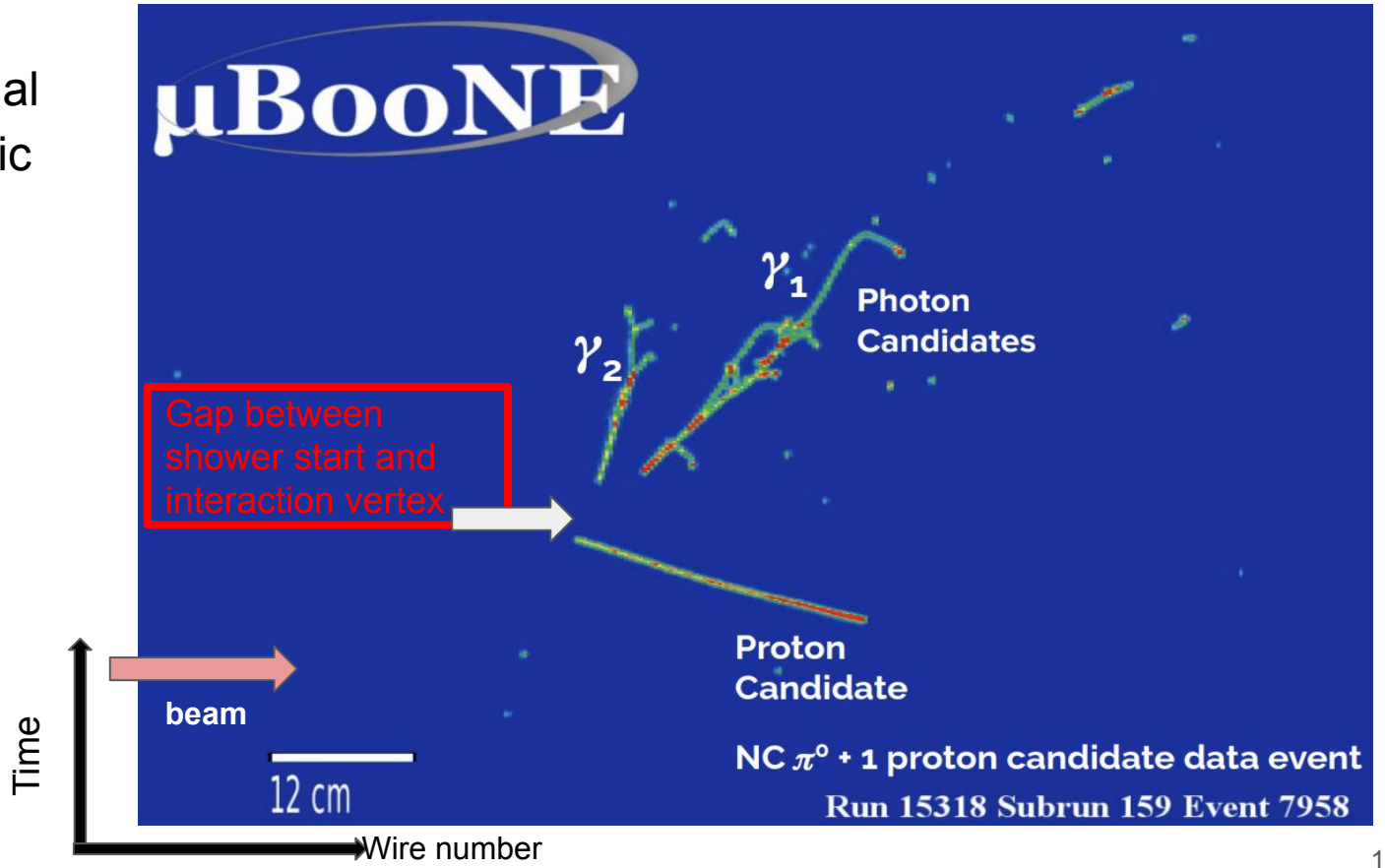
- Photomultiplier tubes (32 PMTs) capture scintillation light.



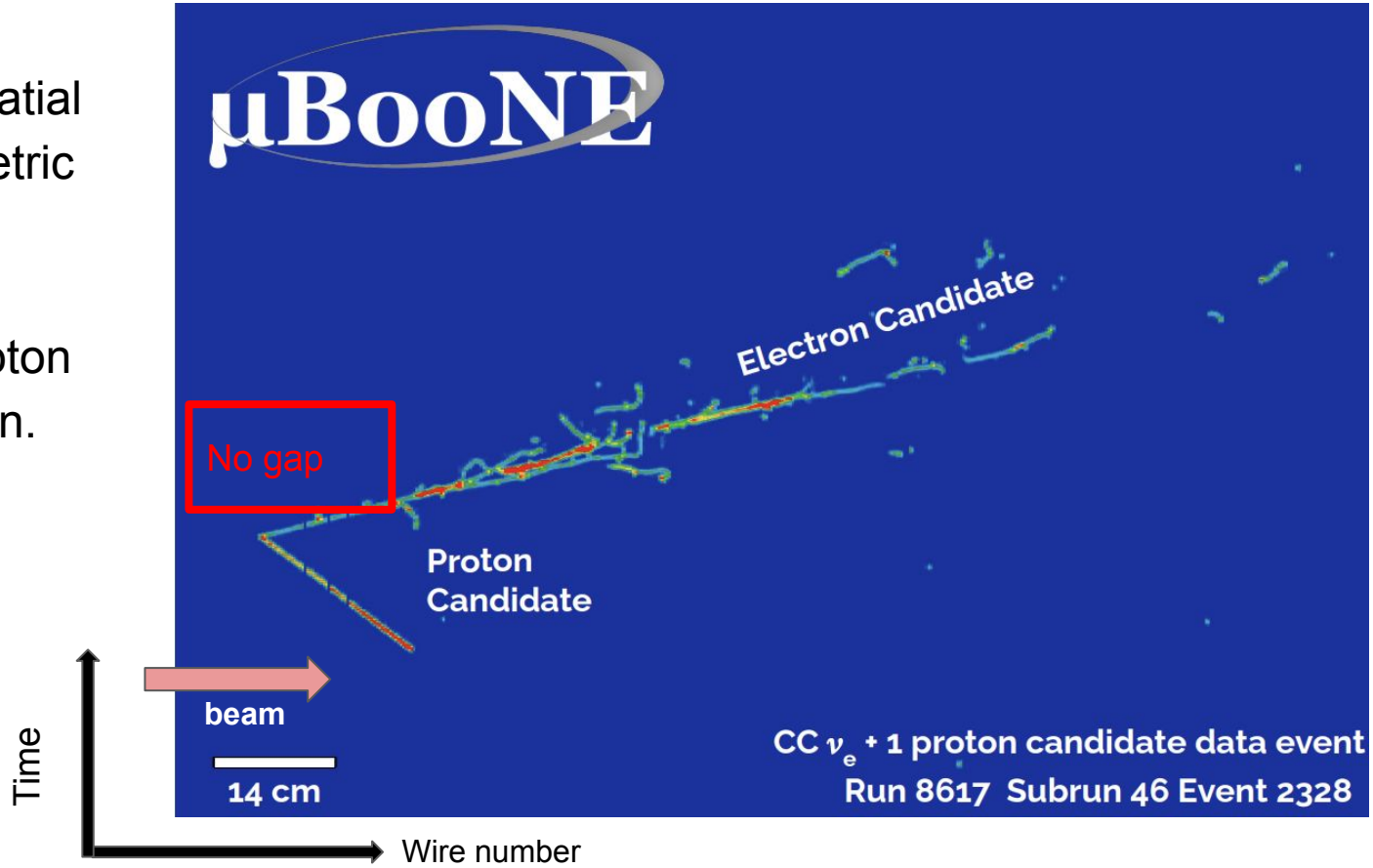
Liquid Argon Time Projection Chamber's Capabilities

- Excellent spatial and calorimetric resolution.



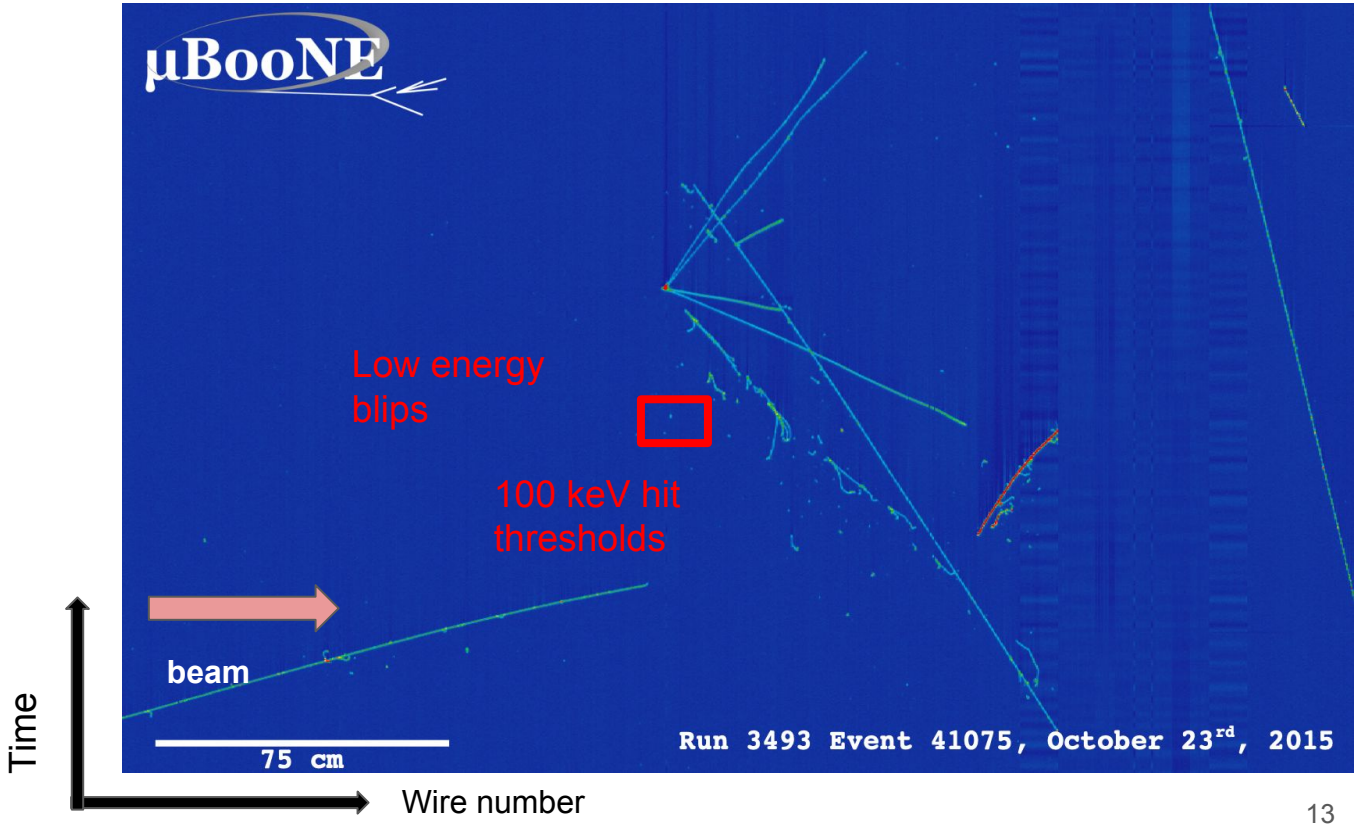
Liquid Argon Time Projection Chamber's Capabilities

- Excellent spatial and calorimetric resolution.
- Electron photon differentiation.



Liquid Argon Time Projection Chamber's Capabilities

- Low detection thresholds.
- An important ingredient in EM shower reconstruction.



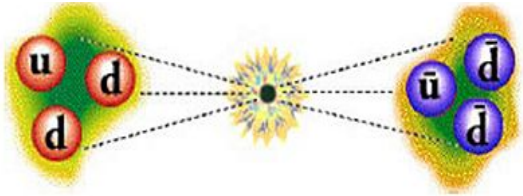
Beyond the Standard Model physics with MicroBooNE

- Due to their capability of tagging particles with excellent resolution, LArTPCs are an excellent choice for performing BSM physics searches.

- This talk will summarize MicroBooNE's BSM physics searches:
  - Baryon number violation (MICROBOONE-NOTE-1113-PUB)
  - Search for heavy neutral leptons (Phys.Rev.D 101, 052001 (2020))
  - Search for higgs portal dark scalars (Phys.Rev.Lett. 127, 151803 (2021))
  - MeV scale physics (MICROBOONE-NOTE-1076-PUB)
  - Other planned BSM searches

Neutron-Antineutron Oscillation

- Neutron-Antineutron (n-nbar) oscillation process violates baryon number by 2 units (See talk by Daisy K.)



- Annihilation of antineutron with nearby nucleon generates multiple final state pions → a unique star-like topology

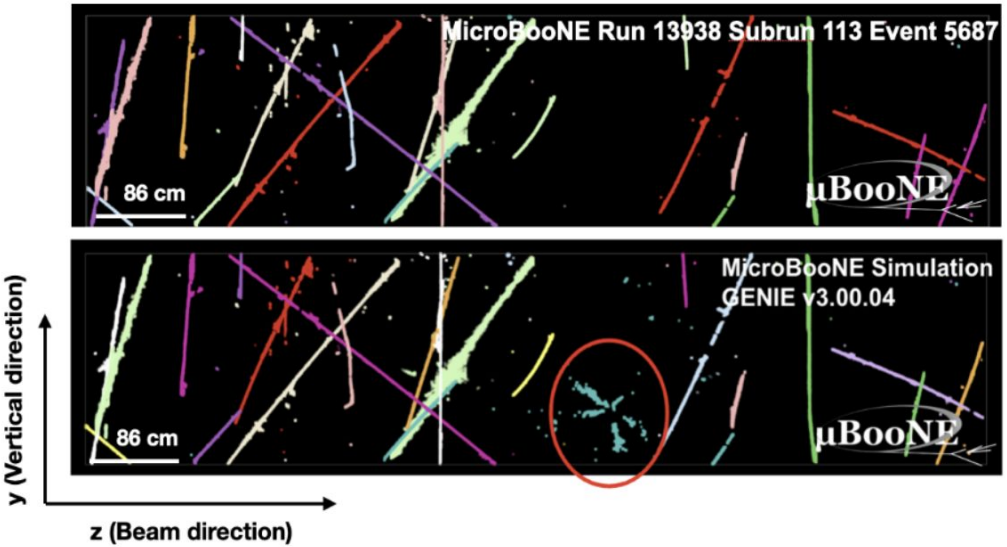
Neutron-Antineutron Oscillation

- No experimental evidence so far and current best limit on ^{16}O bound n-nbar transition rate is provided by Super-K experiment and is 3.6 x 10^{32} years. [Phys. Rev. D **103**, 012008]

- MicroBooNE's n-nbar oscillation search would be the **first-ever search within ^{39}Ar bound nucleus** ← Proof-of-principle for future LArTPC detectors such as SBN, DUNE.

Neutron-Antineutron Oscillation

- The analysis begins with reconstructed “clusters” and selection is applied in two stages



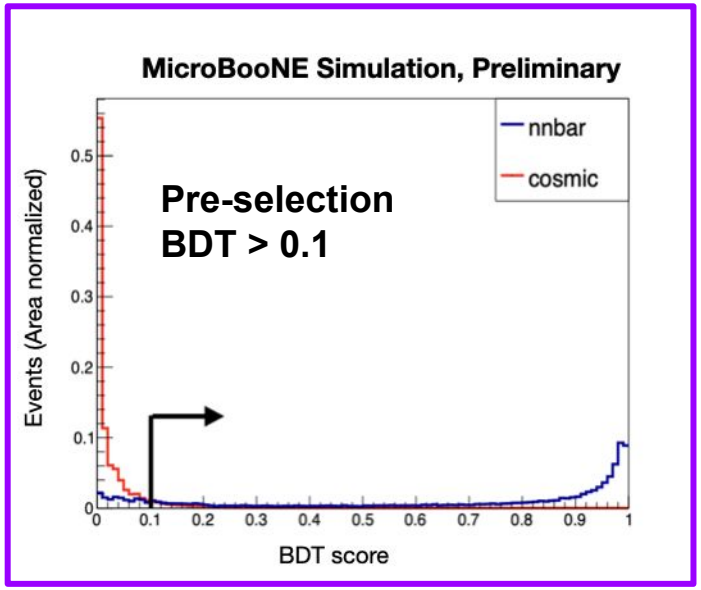
Background (off-beam data) clusters *(collection of spacepoints that carry information on wire position, time, energy deposition)*

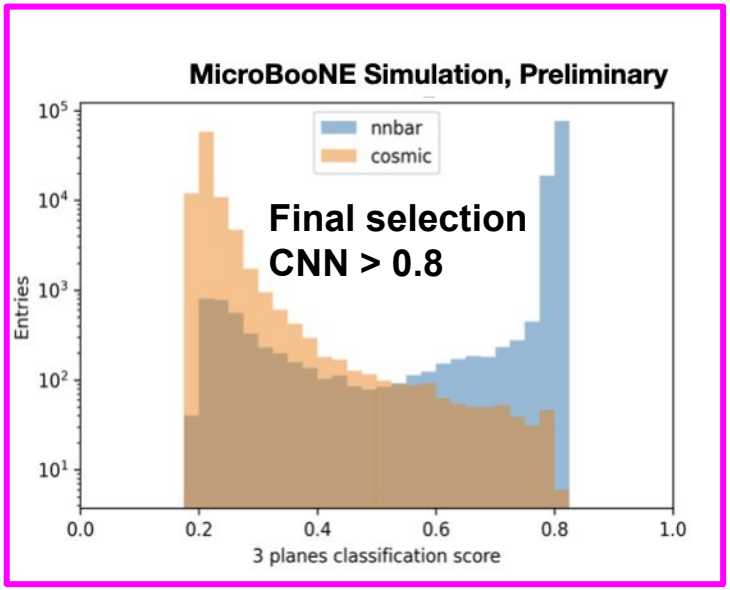
Signal overlaid on the background (off-beam data)

Neutron-Antineutron Oscillation

MICROBOONE-NOTE-1113-PUB

- Preselection → Boosted Decision Tree (BDT)-based to remove backgrounds.
- Final Selection → Image based analysis using Convolution Neural Network (CNN).





Neutron-Antineutron Oscillation

Signal efficiency	**73.6%**
Background efficiency	**0.0088%**
Sensitivity (stat-only errors with 372 seconds of exposure)	**3.059 x 10^{25} years**

MICROBOONE-NOTE-1113-PUB

Evaluation of systematic uncertainties and analysis validation are going on.

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MICROBOONE-NOTE-1113-PUB

Evaluation of systematic uncertainties and analysis validation are going on.

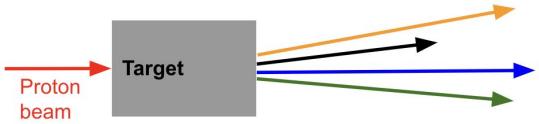
Aiming for publication based on this search, this summer!

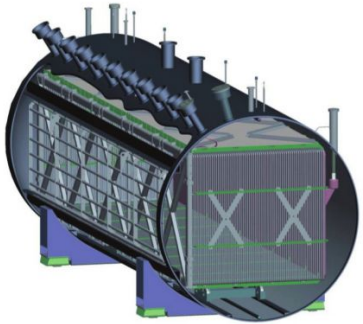
Heavy Neutral Leptons

(Phys.Rev.D 101, 052001 (2020))

- Theoretically motivated particles, much heavier than neutrinos.

charged and neutral
particles: pions, kaons





470 m

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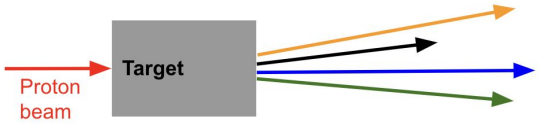
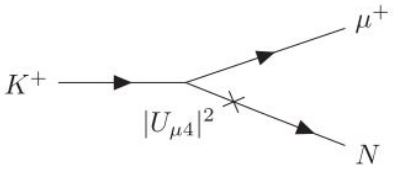
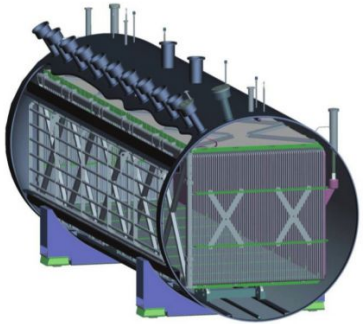


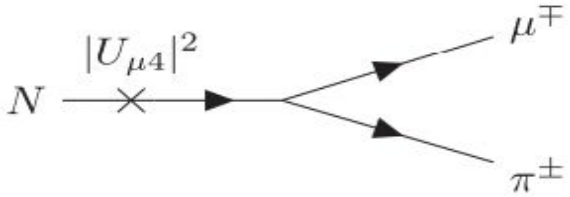




Production Channel of HNLs from BNB

470 m

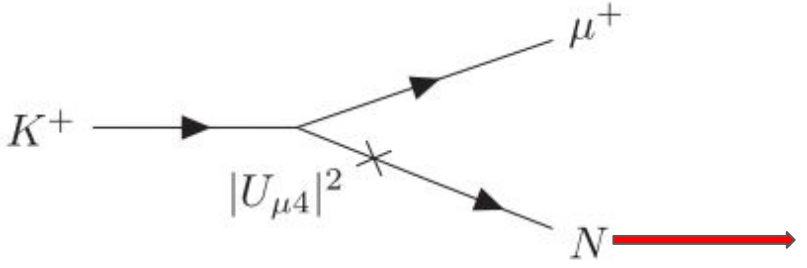
Decay Channel in MicroBooNE detector



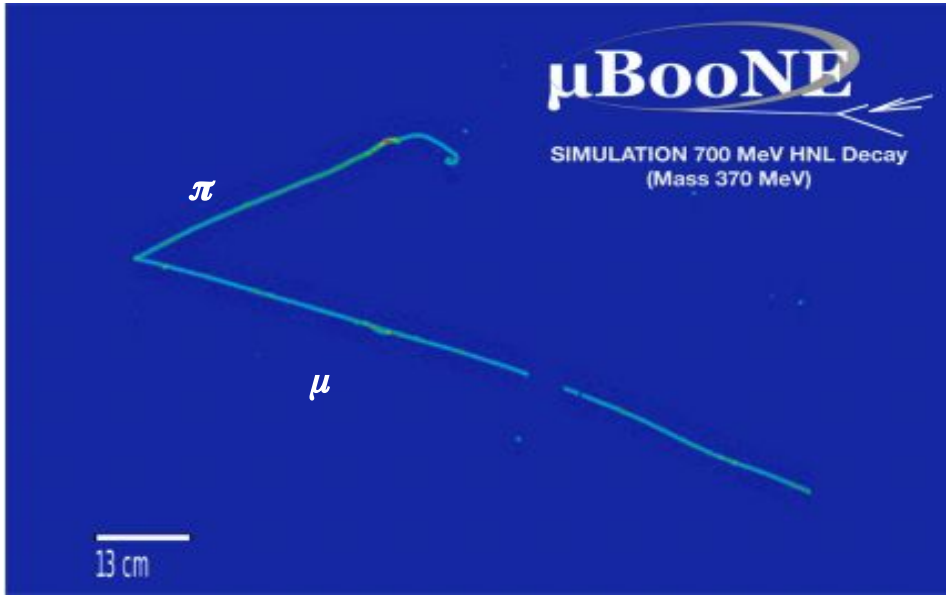
Heavy Neutral Leptons

(Phys.Rev.D 101, 052001 (2020))

- Challenge is to differentiate this process from neutrino (ν_μ)-induced processes.



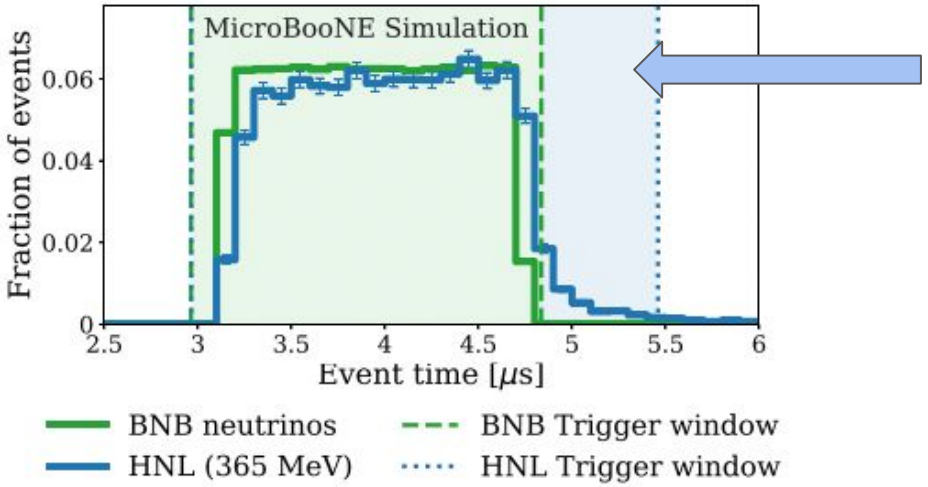
Production channel from BNB



Heavy Neutral Leptons

(Phys.Rev.D 101, 052001 (2020))

- HNLs being heavier than neutrinos, take longer time to get to the detector.
- A special trigger was designed to search for HNLs following the beam spill.

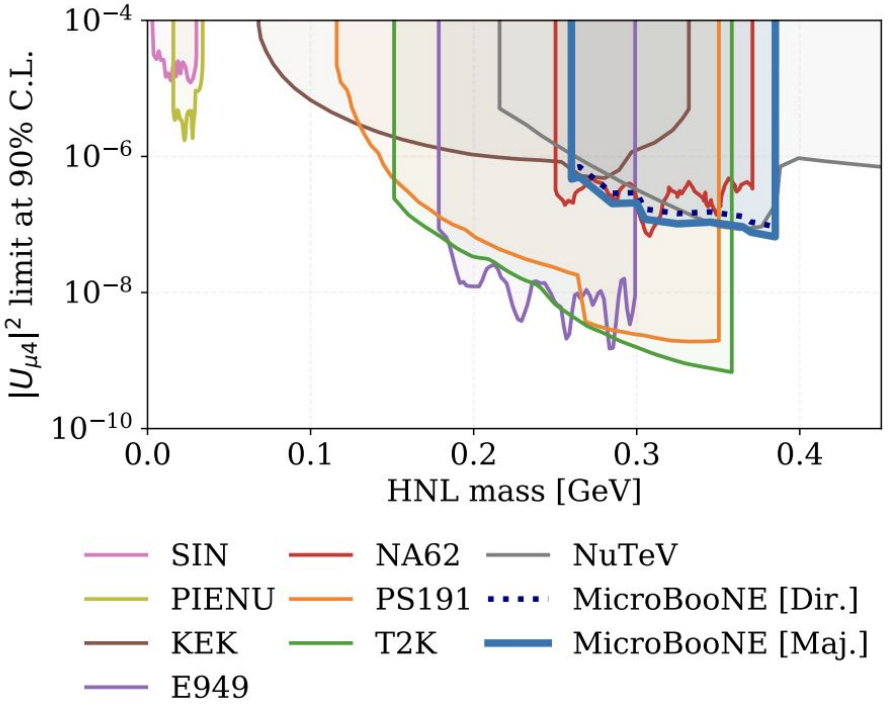


Signal (HNL) search region: No neutrino background in this region.

Heavy Neutral Leptons

(Phys.Rev.D 101, 052001 (2020))

- BDT is used to select signal (HNL) with masses of 260-385 MeV (kinematically constrained region)
- No data excess is observed.
- Limits are set on HNL production rate at 90% CL.



Currently, exploring more production modes (kaons from NuMI beam) and decay modes ($e^{\mp}+\pi^{\pm}$)

Higgs Portal Scalars

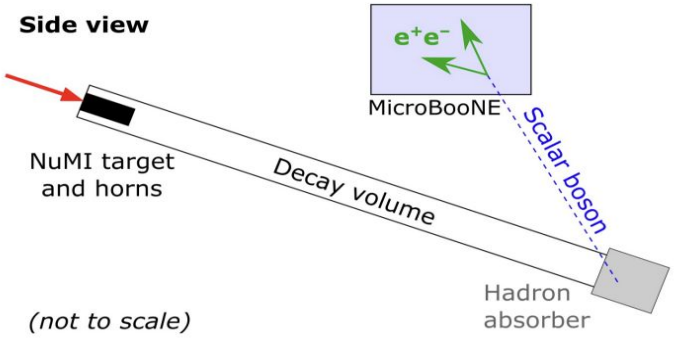
(Phys.Rev.Lett. 127, 151803 (2021))

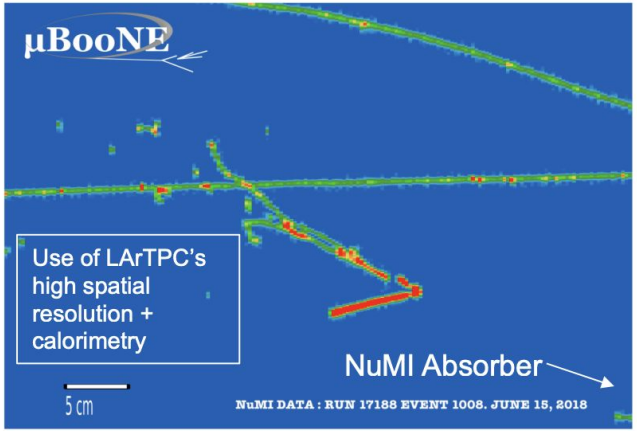
- Theoretically motivated dark scalars in context of the Higgs portal model.
- Production from kaons decaying at rest and decays into a pair of lepton.
- Search motivated from KOTO's initial observation of 3 unexplained invisible decay candidates in $K^0 \rightarrow \pi^0$ + invisible decay candidates [Phys. Rev. Lett. **124**, 191801]

Higgs Portal Scalars

(Phys.Rev.Lett. 127, 151803 (2021))

- This analysis focuses on searching these dark scalars using kaons in the NuMI beam dump.
- BDT is developed to search for S → e^+ + e^- decay.
- One event passes the selection, consistent with expected background 1.9 ± 0.8 using an exposure of 1.9 * 10^{20} POT.

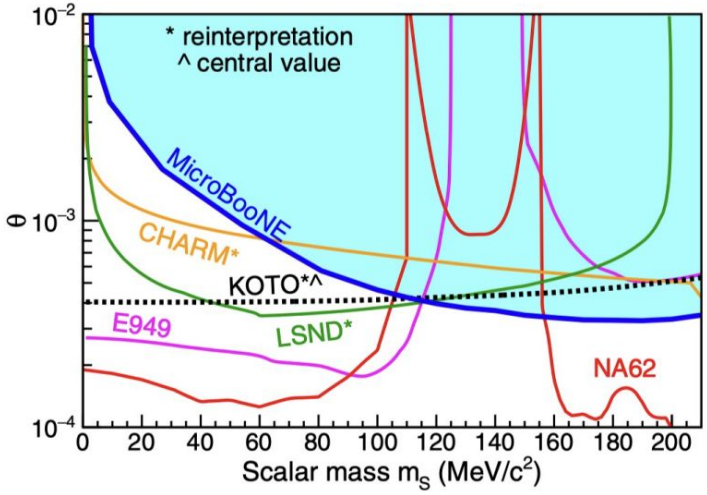




Higgs Portal Scalars

(Phys.Rev.Lett. 127, 151803 (2021))

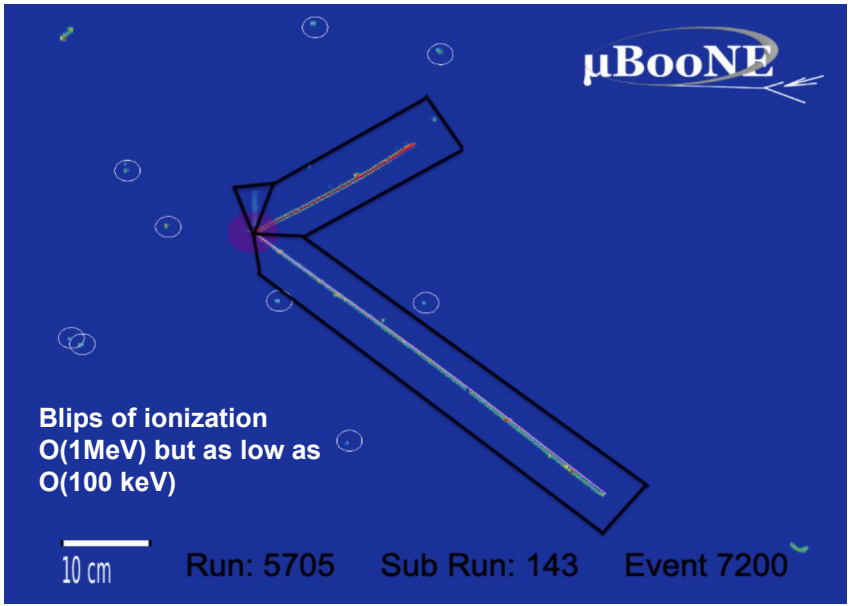
- Upper limit is set on scalar mixing angle at 95% CL.

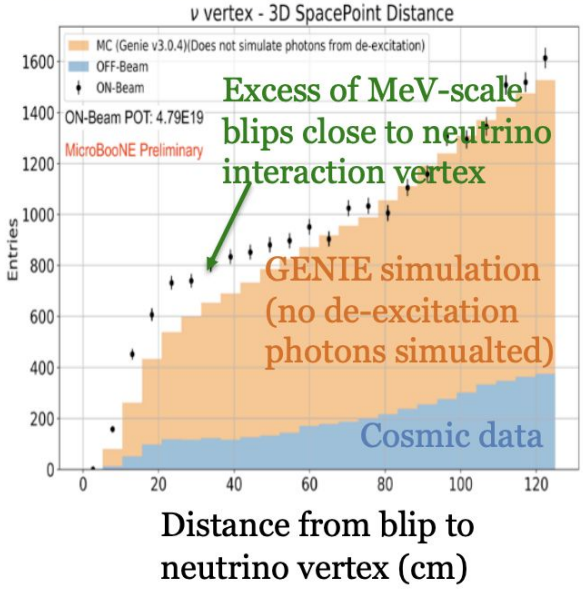


Current efforts include expanding the search to di-muon pairs and using more statistics

MeV-Scale Physics

- Low energy ionization, with energy ~< 100 MeV, produced by low energy gammas or neutrons.
- We are pushing down the thresholds for reconstructing this information.





MeV-Scale Physics

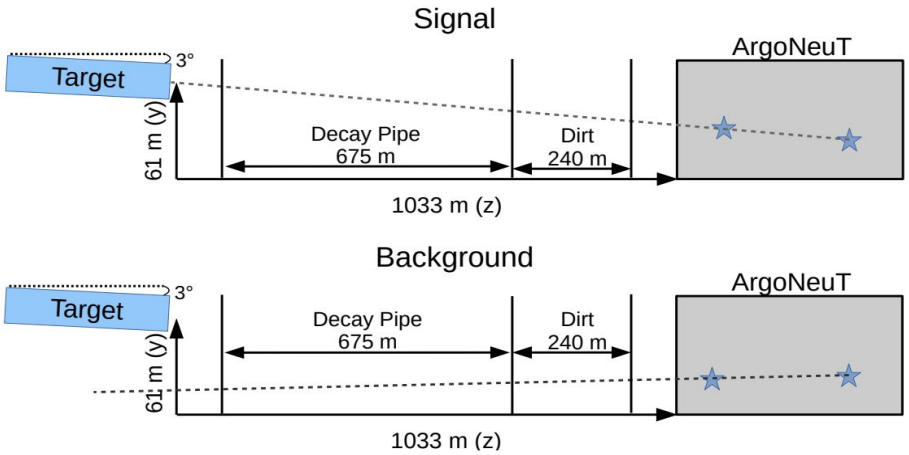
- Reconstruction of MeV scale energy depositions can benefit a wide selection of BSM searches such as millicharged particles, identification of pion-muon in final state.

- Crucial for reconstructing low energy electrons from Supernova and solar neutrino interactions. (Snowmass white paper Low Energy Physics in Neutrino LArTPCs arxiv:2203:00740)

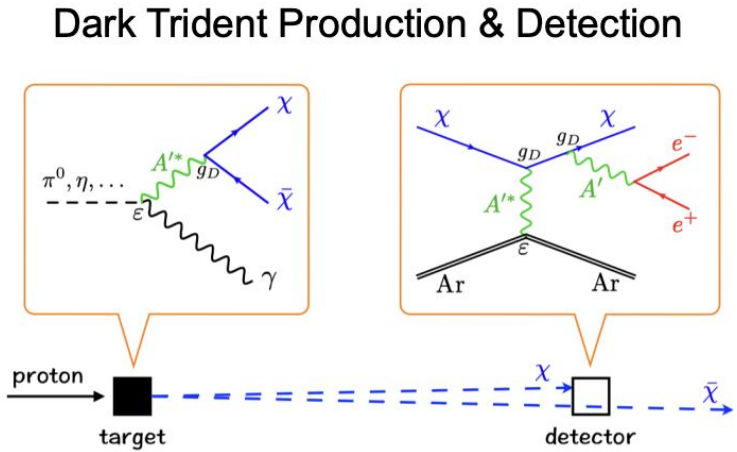
- Reconstruction of low energy ionization or blips was previously demonstrated in ArgoNeuT experiment (Phys.Rev.D 99, 012002 (2019)).

Other BSM searches

- Millicharged particles (previous search using ArgoNEUT experiment)
- Dark Tridents : exploring BSM models with e^+e^- final states.

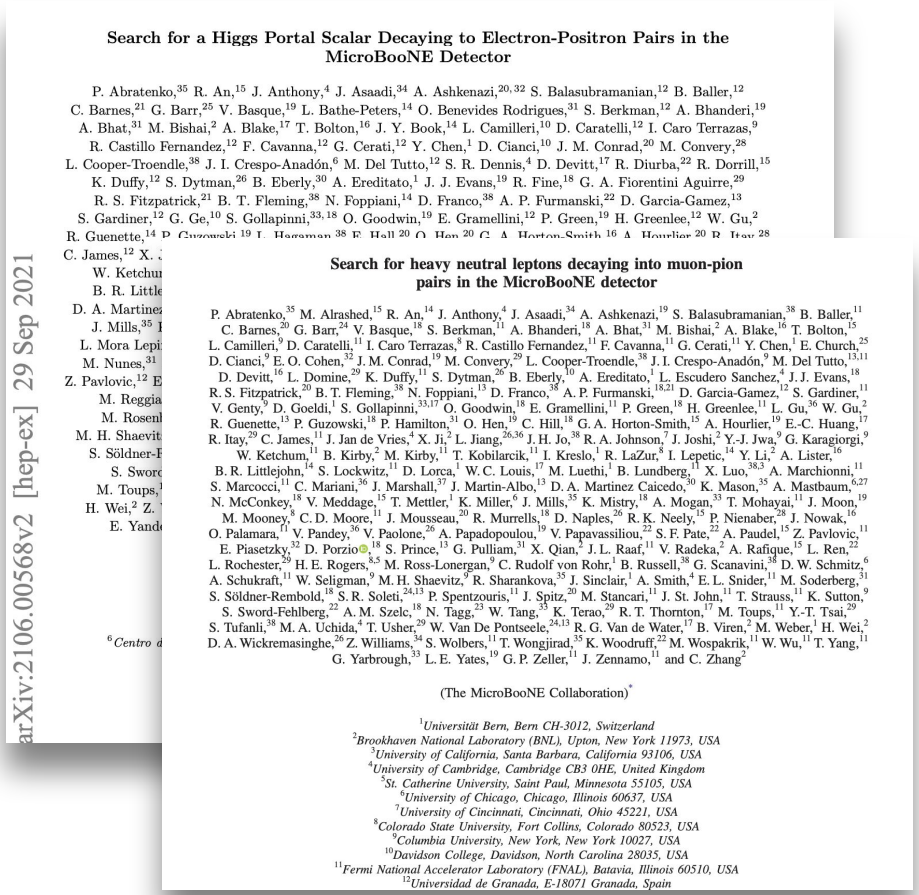


JHEP 01(2019) 001



Summary

- MicroBooNE has demonstrated LArTPC capability to perform world leading BSM physics searches.
- Many exciting results:
  Heavy Neutral Leptons
  Higgs Portal Scalars
- Aiming for publication based on Neutron-Antineutron Oscillation, this summer.
- Stay tuned!



Search for a Higgs Portal Scalar Decaying to Electron-Positron Pairs in the MicroBooNE Detector

P. Abratenko,[35] R. An,[15] J. Anthony,[4] J. Asaadi,[34] A. Ashkenazi,[20,32] S. Balasubramanian,[12] B. Baller,[12] C. Barnes,[21] G. Barr,[25] V. Basque,[19] L. Bathe-Peters,[14] O. Benevides Rodrigues,[31] S. Berkman,[12] A. Bhanderi,[19] A. Bhat,[31] M. Bishai,[2] A. Blake,[17] T. Bolton,[16] J. Y. Book,[14] L. Camilleri,[10] D. Caratelli,[12] I. Caro Terrazas,[9] R. Castillo Fernandez,[12] F. Cavanna,[12] G. Cerati,[12] Y. Chen,[1] D. Cianci,[10] J. M. Conrad,[20] M. Convery,[28] L. Cooper-Troendle,[38] J. I. Crespo-Anadón,[6] M. Del Tutto,[12] S. R. Dennis,[4] D. Devitt,[17] R. Diurba,[22] R. Dorrill,[15] K. Duffy,[12] S. Dytman,[26] B. Eberly,[30] A. Ereditato,[1] J. J. Evans,[19] R. Fine,[18] G. A. Fiorentini Aguirre,[29] R. S. Fitzpatrick,[21] B. T. Fleming,[38] N. Foppiani,[14] D. Franco,[38] A. P. Furmanski,[22] D. Garcia-Gamez,[13] S. Gardiner,[12] G. Ge,[10] S. Gollapinni,[33,18] O. Goodwin,[19] E. Gramellini,[12] P. Green,[19] H. Greenlee,[12] W. Gu,[2] R. Guenette,[14] P. Guzowski,[19] L. Hagaman,[38] E. Hall,[20] O. Hen,[20] G. A. Horton-Smith,[16] A. Hourlier,[20] R. Itay,[28] C. James,[12] X. [illegible] W. Ketchu[illegible] B. R. Littl[illegible] D. A. Martine[illegible] J. Mills,[35] [illegible] L. Mora Lepi[illegible] M. Nunes,[31] Z. Pavlovic,[12] E[illegible] M. Reggia[illegible] M. Rosen[illegible] M. H. Shaevit[illegible] S. Söldner-[illegible] S. Sword[illegible] M. Toups,[illegible] H. Wei,[2] Z. [illegible] E. Yand[illegible]

[6] Centro d[illegible]

arXiv:2106.00568v2 [hep-ex] 29 Sep 2021

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

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Thank you!
"Yesterday was the watershed moment where neutrino analyses reached the same sophistication as LHC analyses; this, made possible by the LArTPC technology …"
Joseph Lykken, Fermilab Deputy Director
Oct. 2, 2021
17 cm
Run: 9524 Subrun: 127 Event: 6375