BSM Searches in MicroBooNE

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On behalf of the MicroBooNE Collaboration

Path to Dark Sector Discoveries at Neutrino Experiments, CSU
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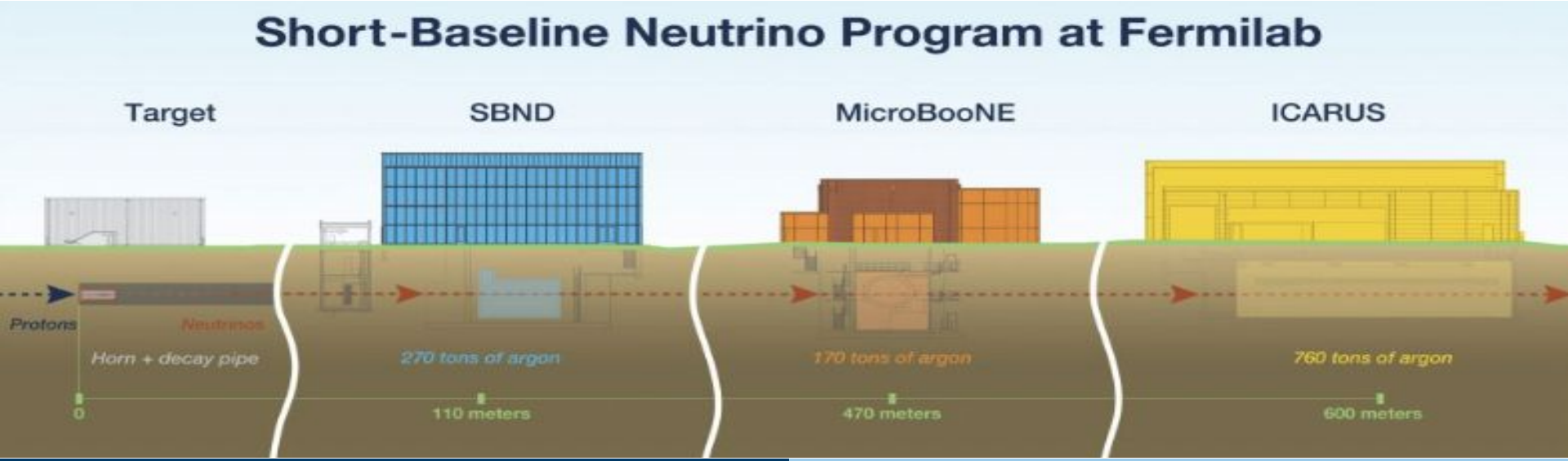
MicroBooNE & The Short Baseline Neutrino Program

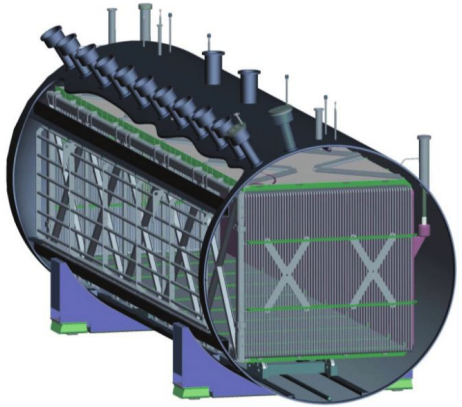
SBN Program

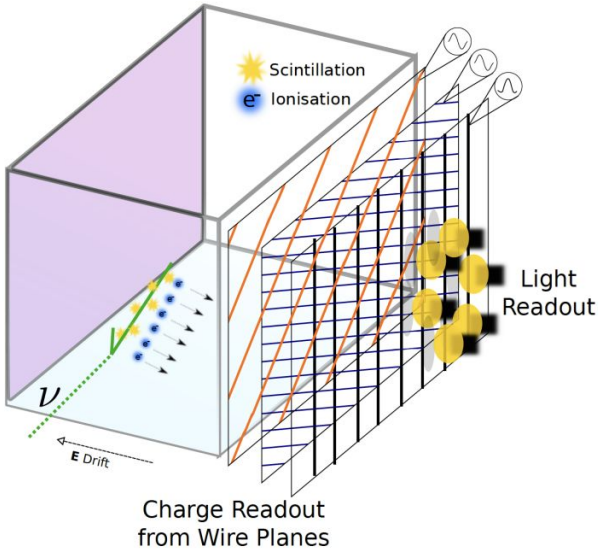
MicroBooNE is a part of the Short Baseline Neutrino (SBN) program. Three **L**iquid **Ar**gon **T**ime **P**rojection Chamber (LArTPC) detectors in **B**ooster **N**eutrino **B**eamline (BNB) at Fermilab.



MicroBooNE - A Liquid Argon Time Projection Chamber

- MicroBooNE is 85-tonne active mass LArTPC.
- Collected data from 2015-2021.
- Exposed to two beamlines-
  - On-axis to Booster Neutrino Beamline (BNB).
  - Off-axis to Neutrinos at Main Injector (NuMI) Beamline.



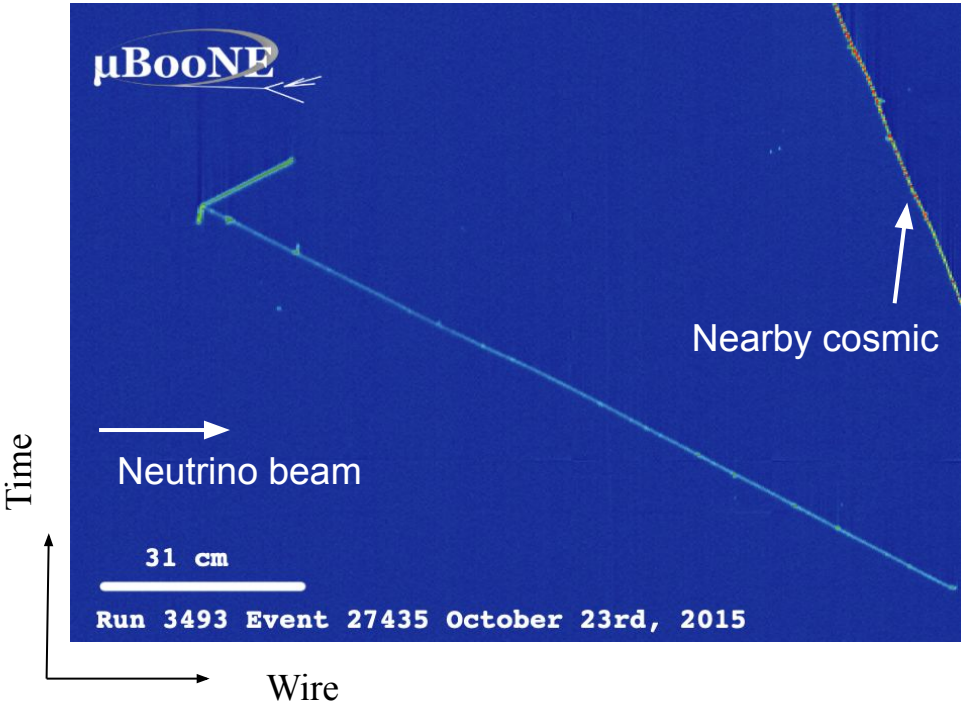


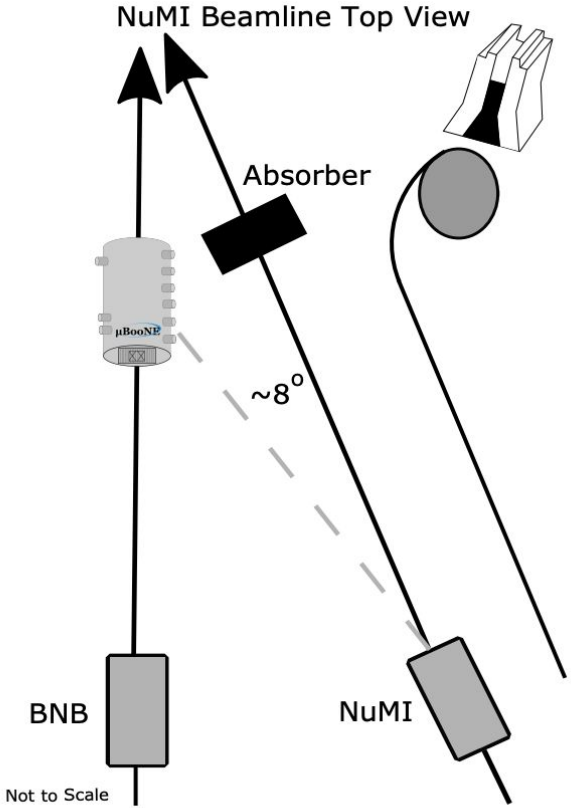
- 2-D images of interaction with information of deposited ionization as a function of wire and time.
- Excellent spatial resolution (3 mm for MicroBooNE) as well as excellent calorimetry.
- Powerful particle identification.

What MicroBooNE can search for?

Beam Events

MicroBooNE is on-axis to BNB beamline.

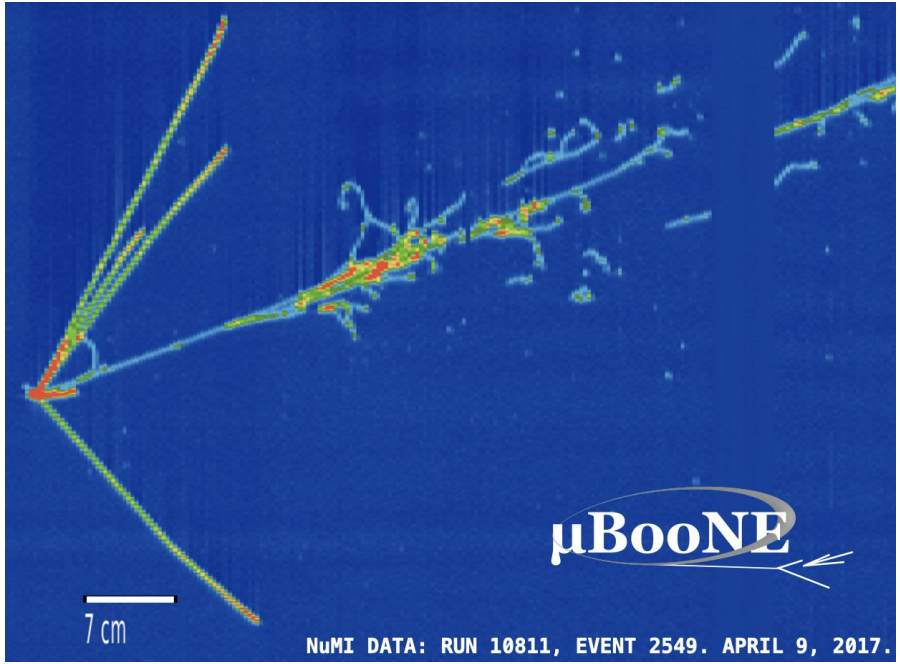


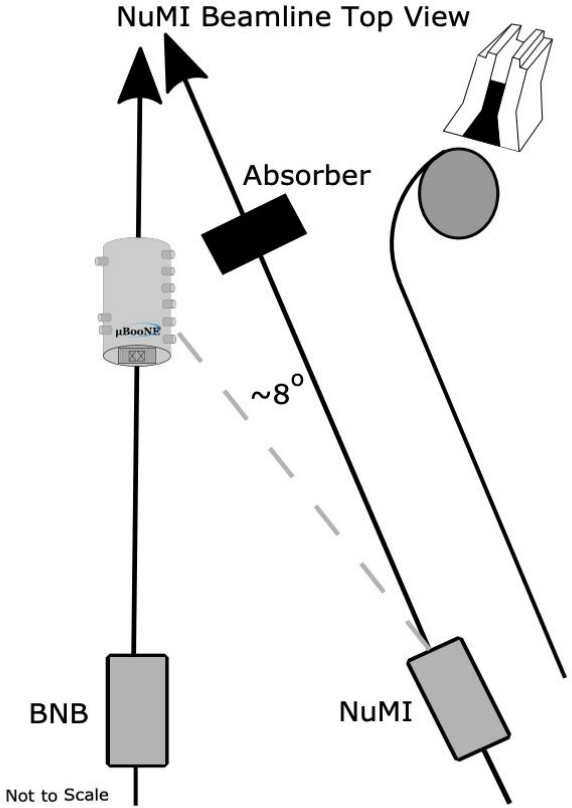


What MicroBooNE can search for?

Beam Events

MicroBooNE is off-axis to NuMI beamline.

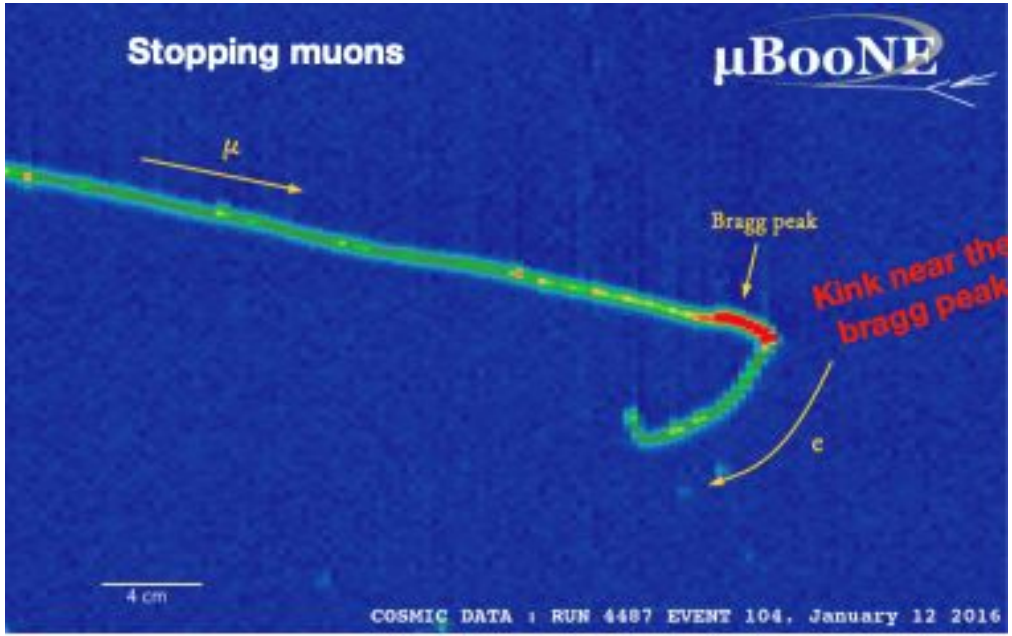




What MicroBooNE can search for?

Non Beam Events

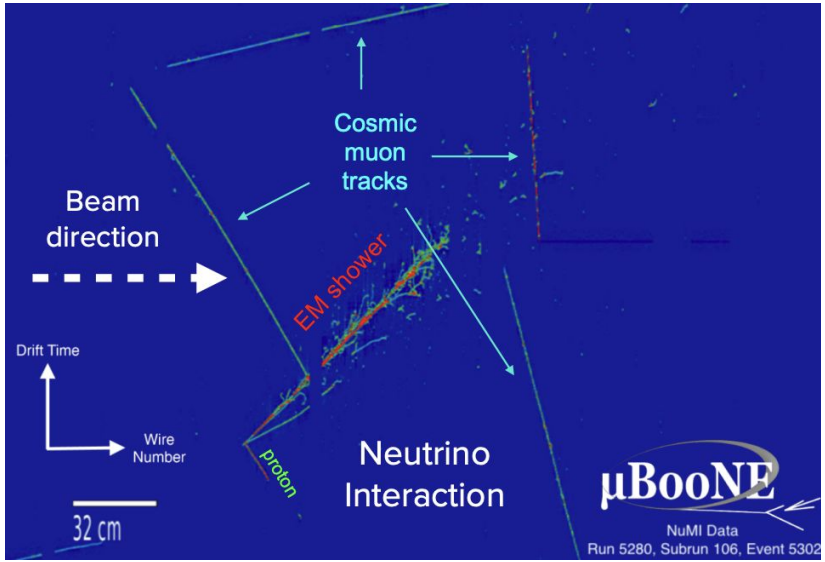
MicroBooNE has a dedicated continuous data stream to search for non-beam events.



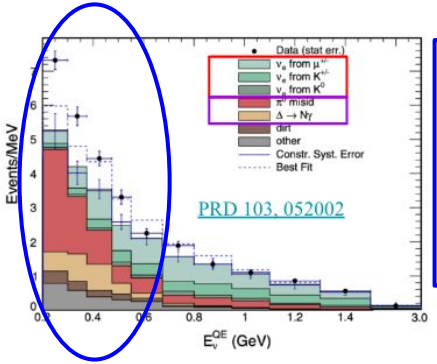
JINST 16 (2021) 02, P02008

What MicroBooNE is not Sensitive to?

- MicroBooNE is a small, on-surface detector.
  - Ambient cosmic ray background-
    - *Background is estimated using cosmic-only data collected during beam spill (when there is no neutrino beam running) → "beam-off" sample.*
    - *Cosmic Ray Tagger (CRT) is helpful in reducing cosmic background.*
  - **Not sensitive to atmospheric neutrino searches.**
- Great platform to do R&D studies for the next-generation large LArTPCs such as Deep Underground Neutrino Experiment (DUNE).

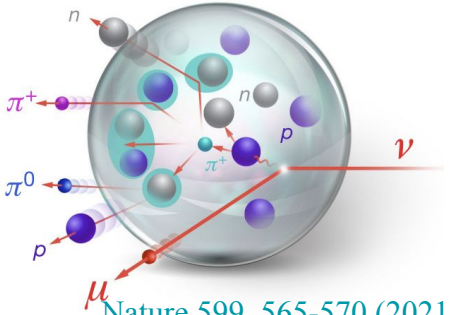


Scientific Goals of MicroBooNE

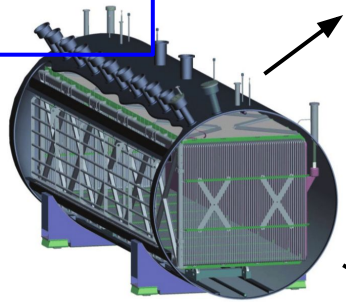


Resolve source of MiniBooNE Low Energy Excess (LEE)

Understand neutrino-Argon interactions



Nature 599, 565-570 (2021)



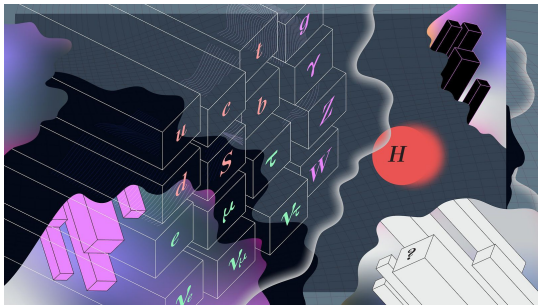


Image courtesy - Symmetry magazine

Searching for Physics beyond-the-Standard Model (BSM)

R&D for the next-generation LArTPC experiments as SBND and DUNE

MicroBooNE Publications

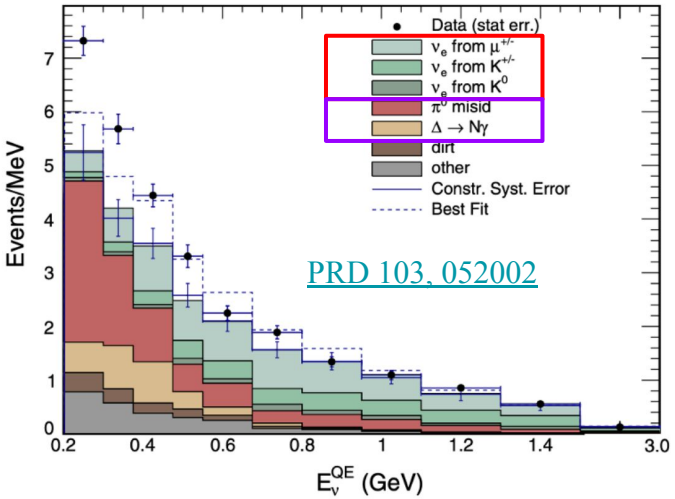
8 papers focused on exotic **BSM** physics and on flagship **Low-Energy Excess searches**

10 papers improving our understanding of neutrino cross-sections on Argon, with ~ 30 more analysis on the way!

Search for long-lived heavy neutral leptons and Higgs portal scalars decaying in the MicroBooNE detector
Measurement of neutral current single π^0 production on argon with the MicroBooNE detector
Observation of radon mitigation in MicroBooNE by a liquid argon filtration system
Cosmic ray muon clustering for the MicroBooNE liquid argon time projection chamber using sMask-RCNN
Novel approach for evaluating detector-related uncertainties in a LArTPC using MicroBooNE data
First measurement of energy-dependent inclusive muon neutrino charged-current cross sections on argon with the MicroBooNE detector
Search for an anomalous excess of inclusive charged-current ν_e interactions without pions in the final state with the MicroBooNE experiment
Search for an anomalous excess of charged-current quasi-elastic νe interactions with the MicroBooNE experiment using deep-learning-based reconstruction
New theory-driven GENIE tune for MicroBooNE
Search for an anomalous excess of inclusive charged-current ν_e interactions in the MicroBooNE experiment using Wire-Cell reconstruction
Search for an excess of electron neutrino interactions in MicroBooNE using multiple final state topologies
Wire-Cell 3D pattern recognition techniques for neutrino event reconstruction in large LArTPCs
Electromagnetic shower reconstruction and energy validation with Michel electrons and π^0 samples for the deep-learning-based analyses in MicroBooNE
Search for neutrino-induced NC Δ radiative decay in MicroBooNE and a first test of the MiniBooNE low-energy excess under a single-photon hypothesis
First measurement of inclusive electron-neutrino and antineutrino charged current differential cross sections in charged lepton energy on argon in MicroBooNE
Calorimetric classification of track-like signatures in liquid argon TPCs using MicroBooNE data
Search for a Higgs Portal Scalar Decaying to Electron-Positron Pairs in the MicroBooNE Detector
Measurement of the Longitudinal Diffusion of Ionization Electrons in the Detector
Cosmic Ray Background Rejection with Wire-Cell LAr TPC Event Reconstruction in the MicroBooNE Detector
Measurement of the Flux-Averaged Inclusive Charged Current Electron Neutrino and Antineutrino Cross Section on Argon using the NuMI Beam in MicroBooNE
Measurement of the Atmospheric Muon Rate with the MicroBooNE Liquid Argon TPC
Semantic Segmentation with a Sparse Convolutional Neural Network for Event Reconstruction in MicroBooNE
High-performance Generic Neutrino Detection in a LAr TPC near the Earth's Surface with the MicroBooNE Detector
Neutrino Event Selection in the MicroBooNE LAr TPC using Wire-Cell 3D Imaging, Clustering, and Charge-Light Matching
A Convolutional Neural Network for Multiple Particle Identification in the MicroBooNE Liquid Argon Time Projection Chamber
Vertex-Finding and Reconstruction of Contained Two-track Neutrino Events in the MicroBooNE Detector
The Continuous Readout Stream of the MicroBooNE Liquid Argon Time Projection Chamber for Detection of Supernova Burst Neutrinos
Measurement of Differential Cross Sections for Muon Neutrino CC Interactions on Argon with Protons and No Pions in the Final State
Measurement of Space Charge Effects in the MicroBooNE LAr TPC Using Cosmic Muons
First Measurement of Differential Charged Current Quasi-Elastic-Like Muon Neutrino Argon Scattering Cross Sections with the MicroBooNE Detector
Search for heavy neutral leptons decaying into muon-pion pairs in the MicroBooNE detector
Reconstruction and Measurement of O(100) MeV Electromagnetic Activity from Neutral Pion to Gamma Gamma Decays in the MicroBooNE LArTPC
A Method to Determine the Electric Field of Liquid Argon Time Projection Chambers Using a UV Laser System and its Application in MicroBooNE
Calibration of the Charge and Energy Response of the MicroBooNE Liquid Argon Time Projection Chamber Using Muons and Protons
First Measurement of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon at Enu ~0.8 GeV with the MicroBooNE Detector
Design and Construction of the MicroBooNE Cosmic Ray Tagger System
Rejecting Cosmic Background for Exclusive Neutrino Interaction Studies with Liquid Argon TPCs: A Case Study with the MicroBooNE Detector
First Measurement of Muon Neutrino Charged Current Neutral Pion Production on Argon with the MicroBooNE detector
A Deep Neural Network for Pixel-Level Electromagnetic Particle Identification in the MicroBooNE Liquid Argon Time Projection Chamber
Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions
Ionization Electron Signal Processing in Single Phase LArTPCs II: Data/Simulation Comparison and Performance in MicroBooNE
Ionization Electron Signal Processing in Single Phase LArTPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation
The Pandora Multi-Algorithm Approach to Automated Pattern Recognition of Cosmic Ray Muon and Neutrino Events in the MicroBooNE Detector
Measurement of Cosmic Ray Reconstruction Efficiencies in the MicroBooNE LAr TPC Using a Small External Cosmic Ray Counter
Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC
Michel Electron Reconstruction Using Cosmic Ray Data from the MicroBooNE LAr TPC
Determination of Muon Momentum in the MicroBooNE LAr TPC Using an Improved Model of Multiple Coulomb Scattering
Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber
Design and Construction of the MicroBooNE Detector

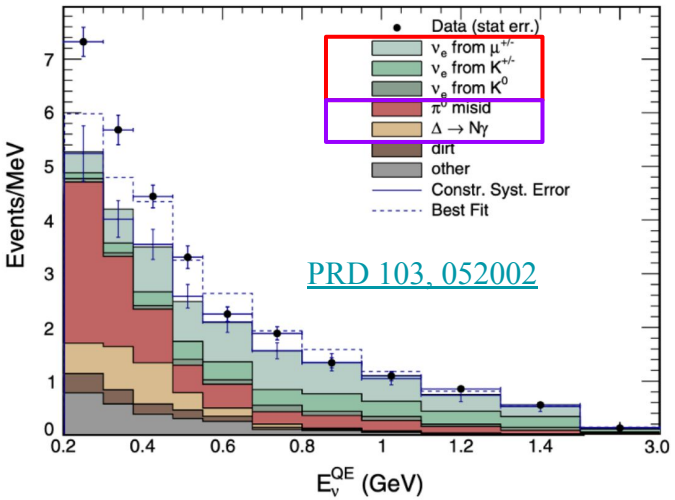
31 on **vital LArTPC hardware and software R&D,** dessiminiting pioneering info for DUNE and SBN program

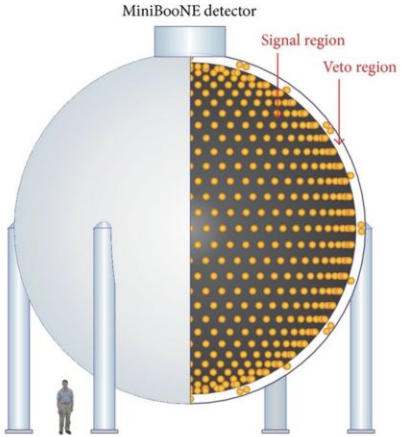
Resolving LEE and Exploring BSM Physics



- MicroBooNE attempted using two background-derived interpretations-
  - Excess is single electron-like.
  - Excess is photon-like.

Resolving LEE and Exploring BSM Physics





Both photon and electron produce fuzzy cherenkov rings in MiniBooNE

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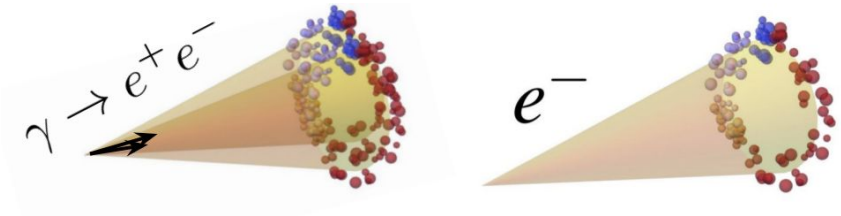
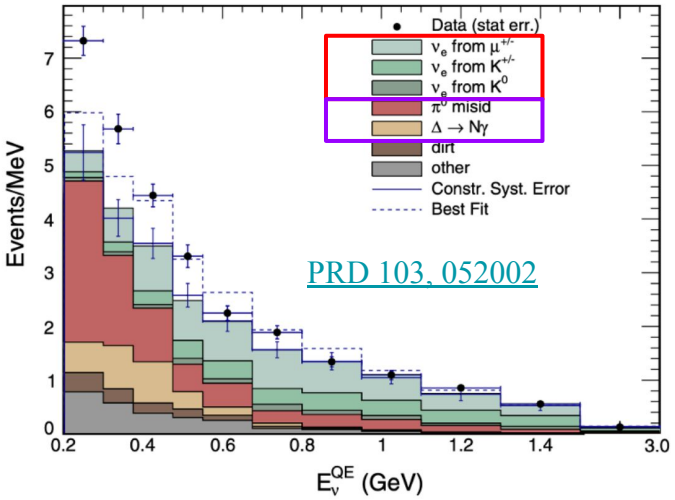
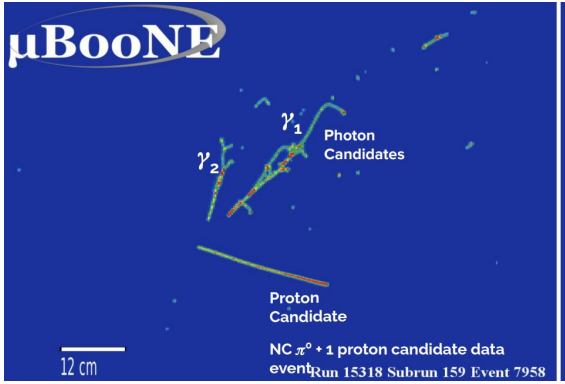
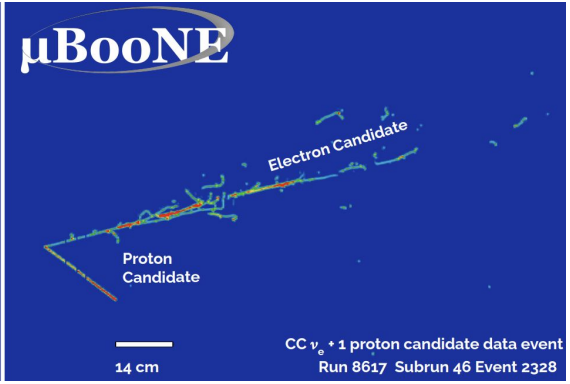


Resolving LEE and Exploring BSM Physics







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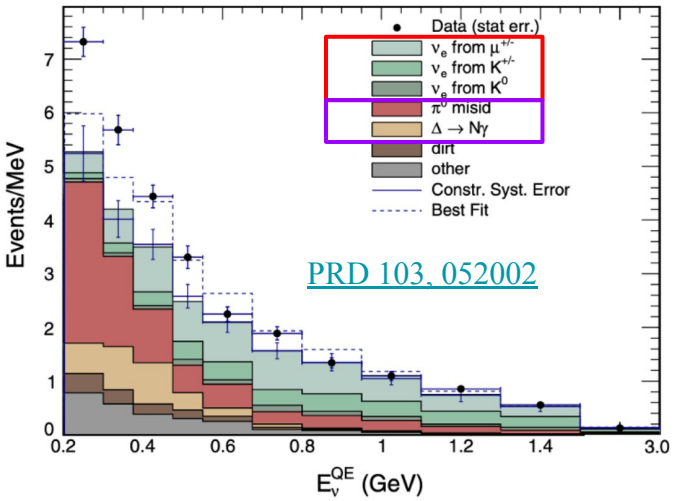
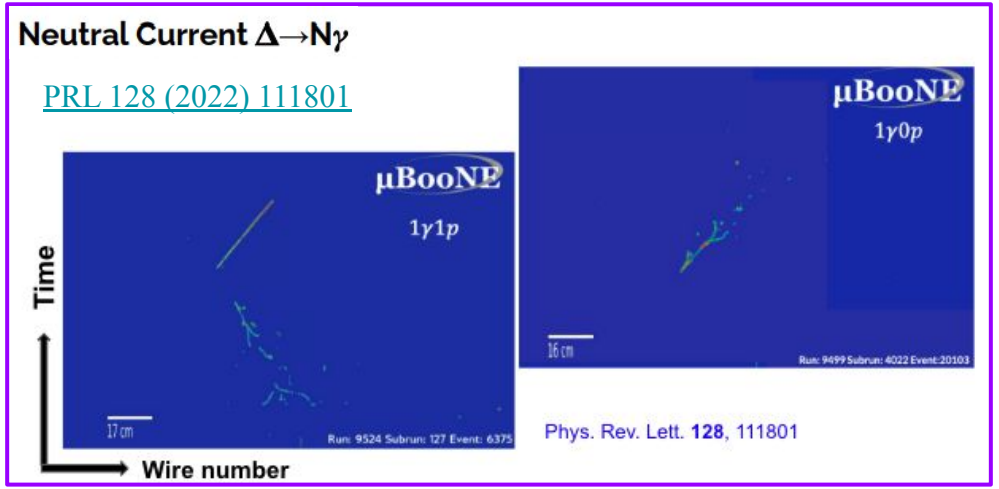
Clear distinction between electron and photon induced electromagnetic showers

Resolving LEE and Exploring BSM Physics





- MicroBooNE attempted using two background-derived interpretations-
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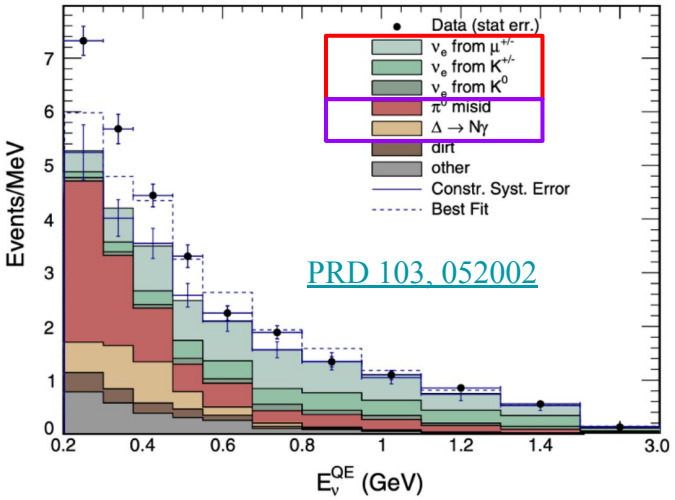
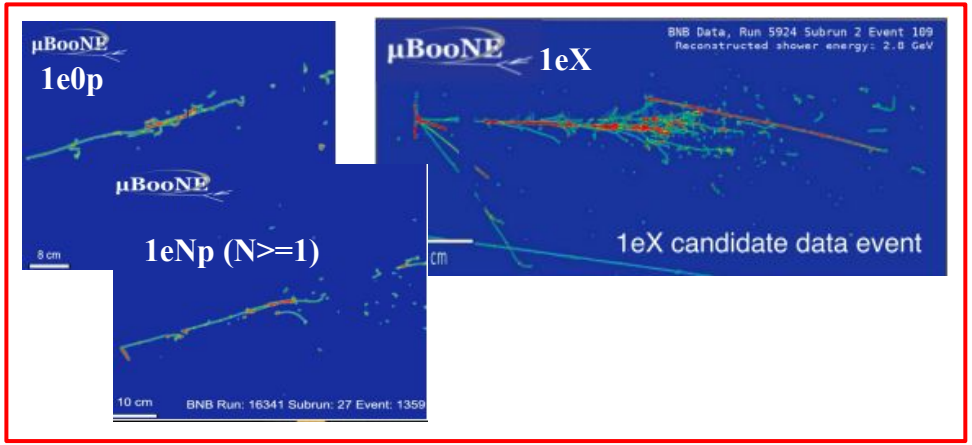
MicroBooNE data observed no evidence of underestimation of NC Δ radiative decay.

Resolving LEE and Exploring BSM Physics



PRD 105 (2022) 112005 PRD 105 (2022) 112003
PRD 105 (2022) 112004 PRL 128 (2022) 241801



- MicroBooNE attempted using two background-derived interpretations-
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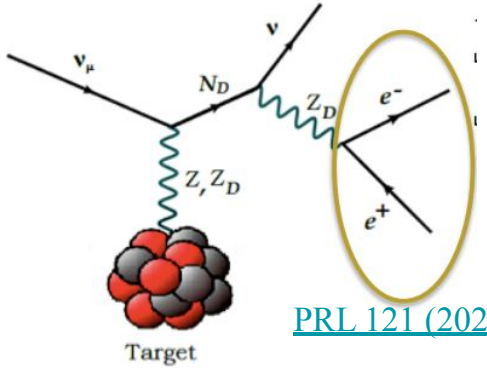
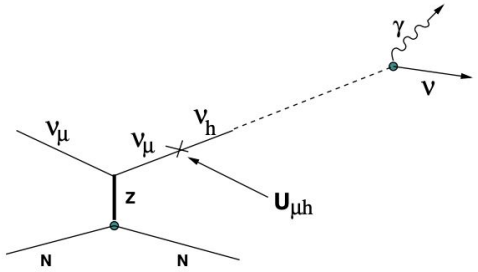
MicroBooNE data rejects the hypothesis that ν_e CC interactions are fully responsible for MiniBooNE LEE at >97% CL.

Resolving LEE and Exploring BSM Physics

- Exploring BSM models-
  - Exotic e+e- production through light dark photon mediated neutrino scattering.
  - Single photon production from heavy neutrino due to transition magnetic moment.



PRL 121 (2022) 241801



PRL 103 (2009) 241802

First series of results (1/2 the MicroBooNE data set)

Models \ Reco topology	1e0p	1e1p	1eNp	1eX	e^+e^- + nothing	e^+e^-X	1γ0p	1γ1p	1γX
eV Sterile ν Osc	✔	✔	✔	✔					
Mixed Osc + Sterile ν	✔[7]	✔[7]	✔[7]	✔[7]			✔[7]		
Sterile ν Decay	✔[13,14]	✔[13,14]	✔[13,14]	✔[13,14]			✔[4,11,12,15]	✔[4]	✔[4]
Dark Sector & Z' *	✔[2,3]				✔[2,3]	✔[2,3]	✔[1,2,3]	✔[1,2,3]	✔[1,2,3]
More complex higgs *					✔[10]	✔[10]	✔[6,10]	✔[6,10]	✔[6,10]
Axion-like particle *					✔[8]		✔[8]		
Res matter effects	✔[5]	✔[5]	✔[5]	✔[5]					
SM γ production							✔	✔	✔

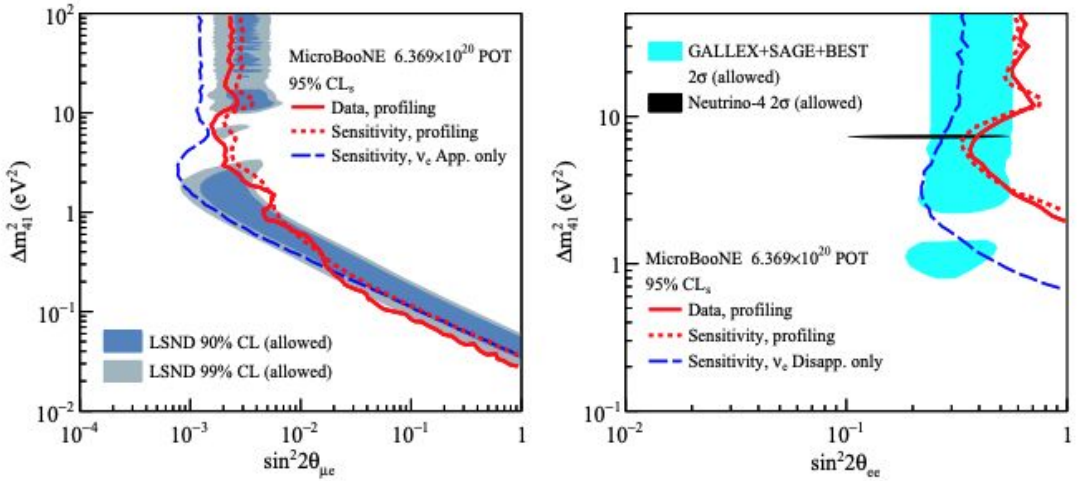
*Requires heavy sterile/other new particles also

Constraints on eV-scale Sterile Neutrinos

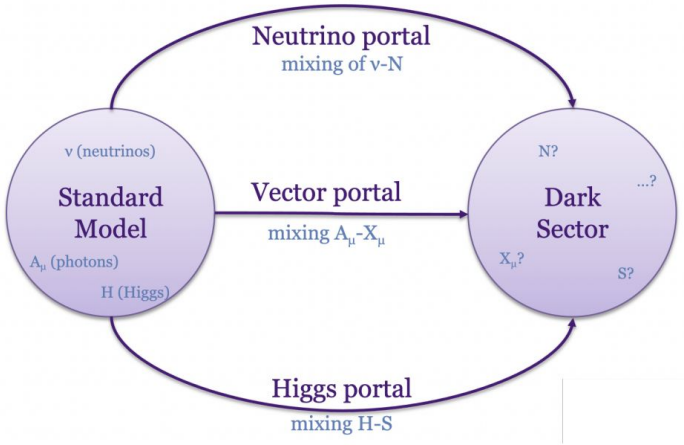
PRL 130, (2023) 011801

- First constraints on eV-scale sterile neutrino oscillations-
  - Under (3+1) hypothesis using ν_e and ν_μ charged current and neutral current channels **using neutrinos from BNB** with exposure 6.37 x 10^{20} protons on target (POT).
  - No evidence of sterile neutrino oscillations.

- Subsequent searches to account for degeneracy resulting from ν_e appearance and ν_e disappearance effects-
  - Using neutrinos from the NuMI beamline
  - Performing multidetector oscillation analysis (SBN)



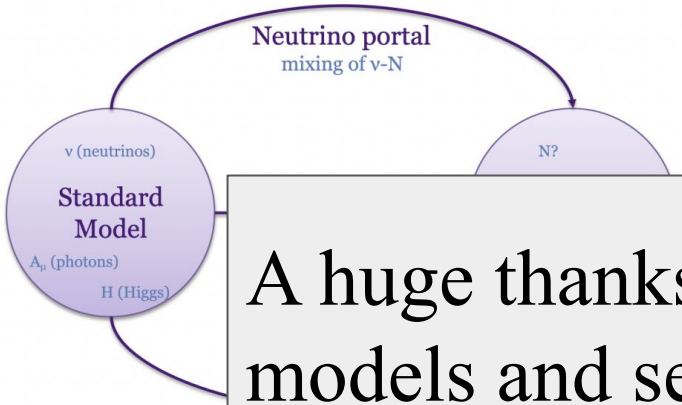
BSM Physics Searches in MicroBooNE



- ❖ Evidence of new interactions, symmetries that are not accounted for in the Standard Model.
- ❖ Connection between neutrinos and dark sector.
- ❖ Explanation of MiniBooNE LEE.

- ❖ Heavy Neutral Leptons
- ❖ Higgs Portal Scalars
- ❖ Dark Trident
- ❖ millicharged Particles
- ❖ Dark Neutrinos

BSM Physics Searches in MicroBooNE

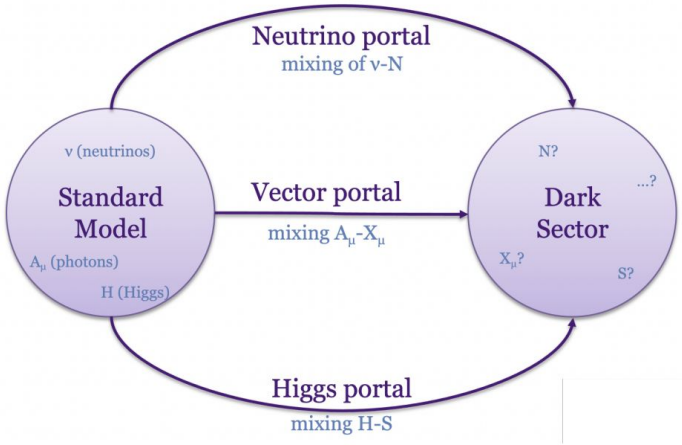


- Evidence of new interactions, symmetries that are not accounted for in the Standard Model.
- Connection between neutrinos and dark sector

A huge thanks to theorists for providing models and sensitivities!

- Heavy Neutral Leptons
- Higgs Portal Scalars
- Dark Trident
- millicharged Particles
- Dark Neutrinos

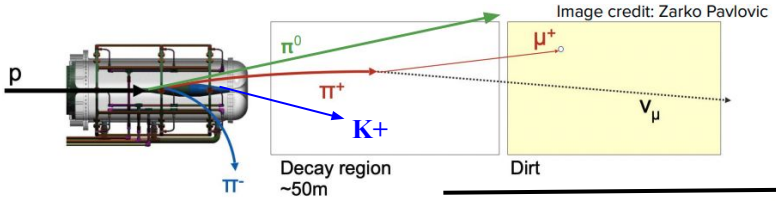
Search Strategy

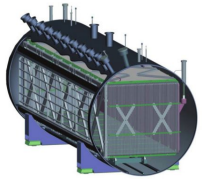


- Heavy Neutral Leptons
- Higgs Portal Scalars
- Dark Trident
- millicharged Particles
- Dark Neutrinos

Production mode

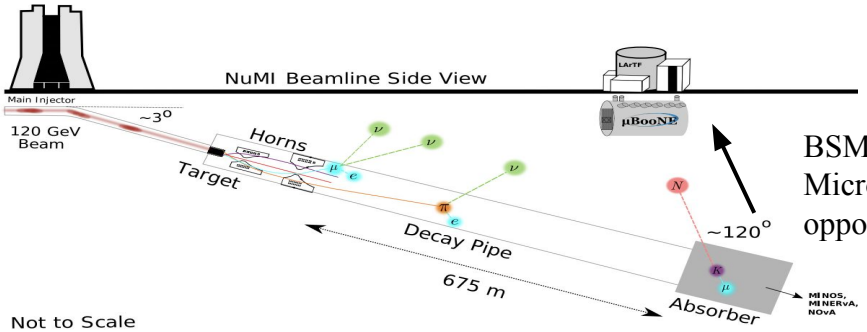
For BNB, charged mesons produced in decay region are considered.





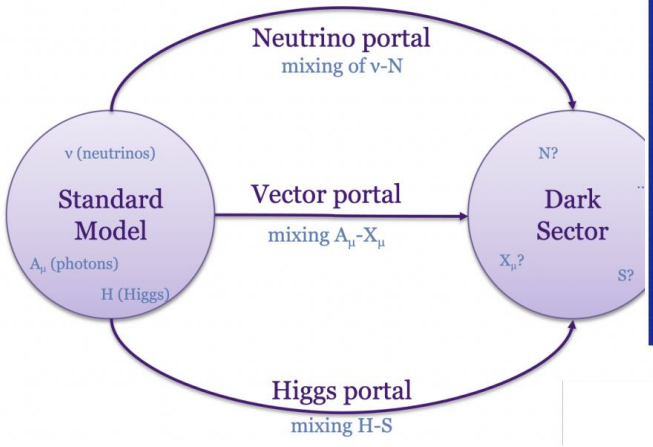
BSM particles reaching MicroBooNE along the standard beam direction

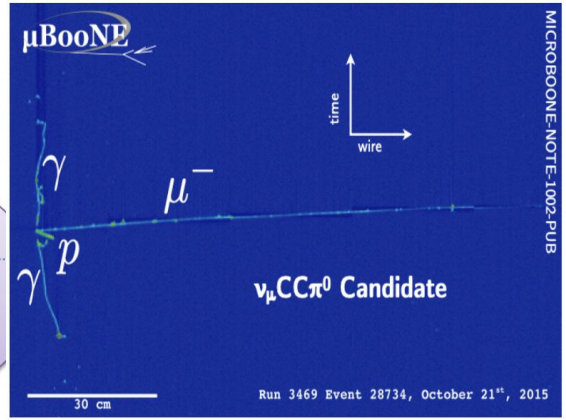
r NuMI, charged mesons produced in NuMI hadron absorber are considered.



BSM particles reaching MicroBooNE from opposite direction

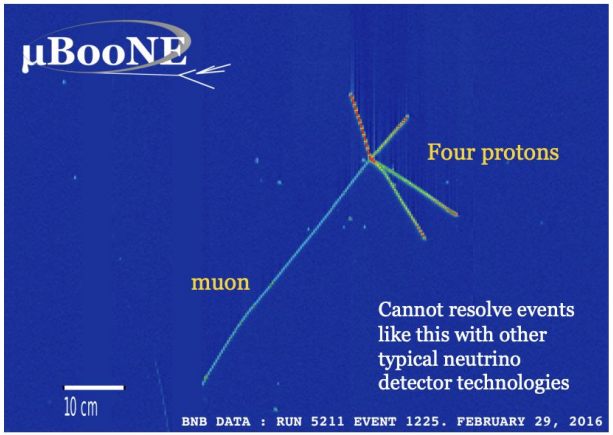
Search Strategy





- LArTPCs are an excellent choice for BSM physics searches-
  - Excellent spatial and charge resolution.
  - Powerful particle identification.

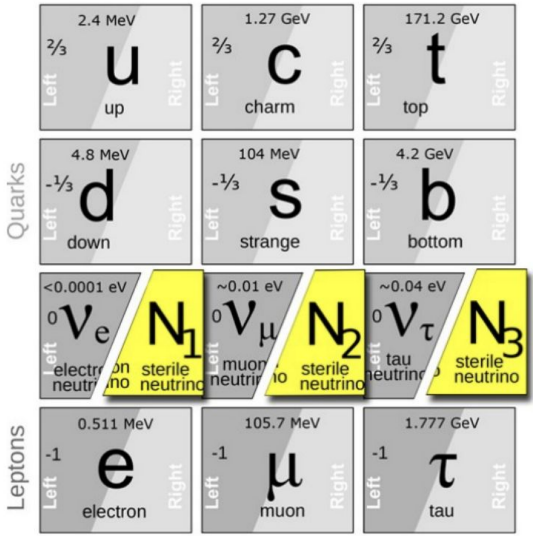
- Heavy Neutral Leptons
- Higgs Portal Scalars
- Dark Trident
- millicharged Particles
- Dark Neutrinos

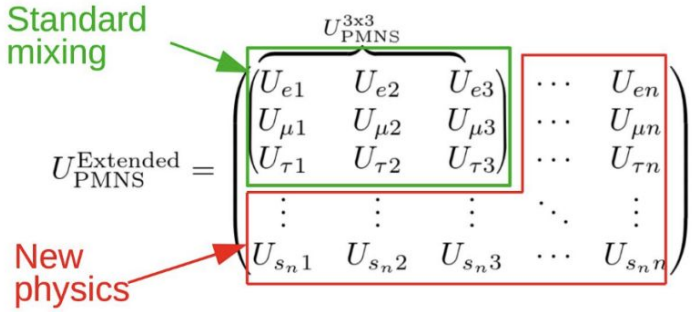


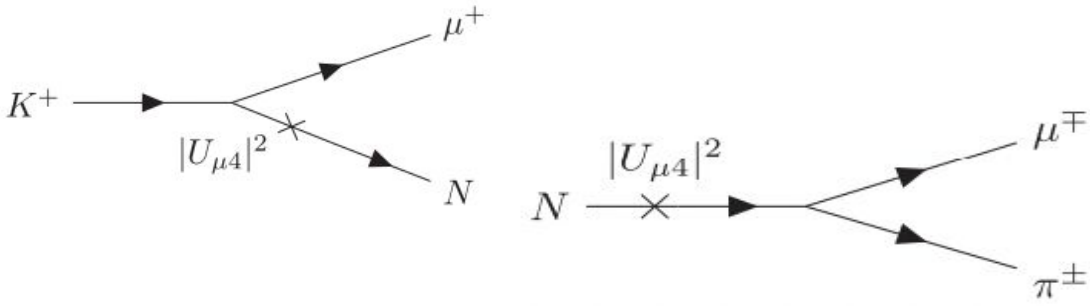
Heavy Neutral Leptons

Heavy Neutral Leptons

- Model - HNLs are produced from mixing with SM neutrinos via extended PMNS matrix element $|U_{\mu 4}|^2$.





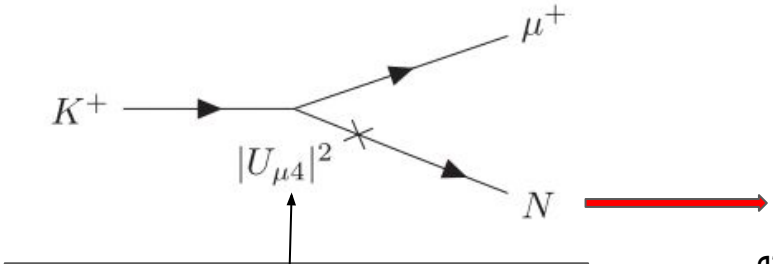


arXiv:1504.04855

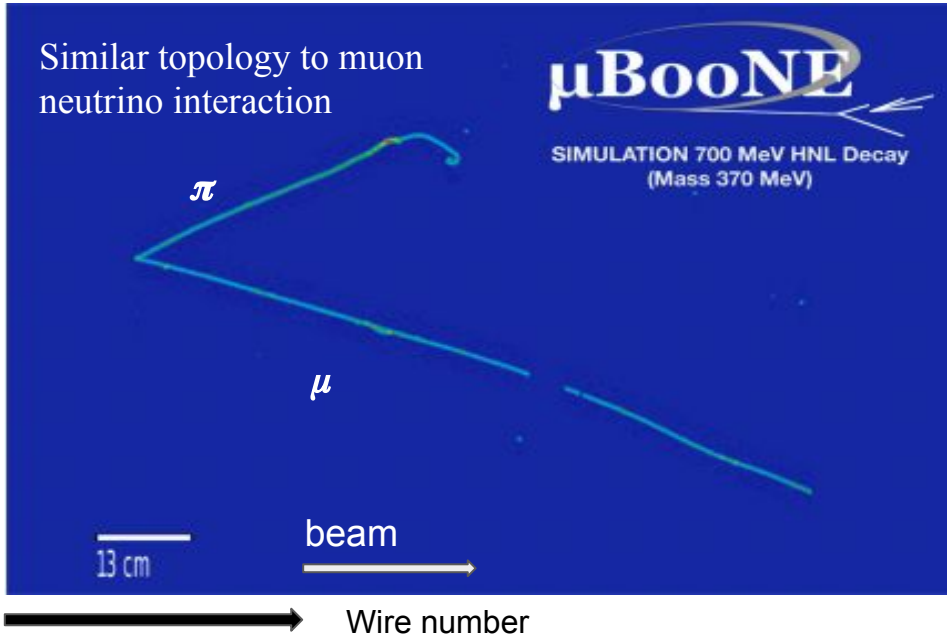
Heavy Neutral Leptons (in BNB)

PRD 101, (2020) 052001

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



Aim is to place limits on this mixing element

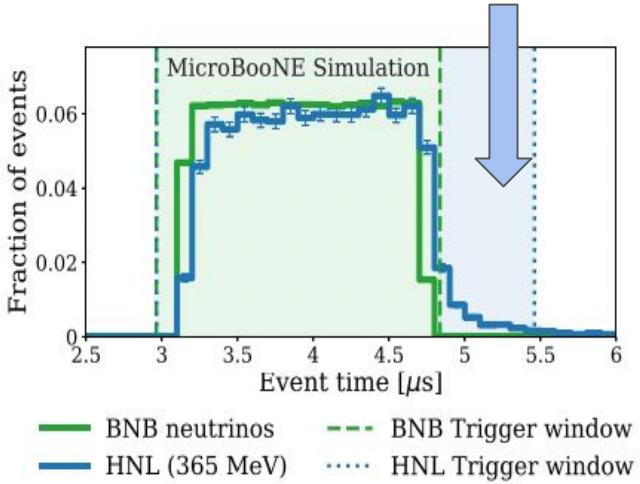


Heavy Neutral Leptons (in BNB)

PRD 101, (2020) 052001

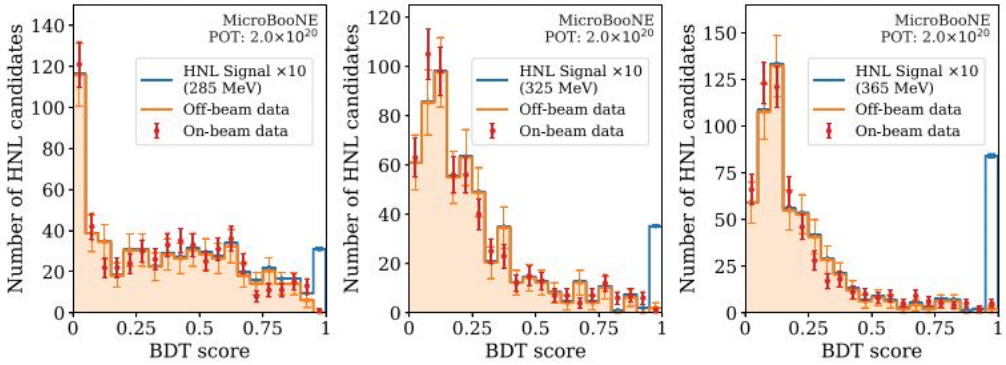
- A special trigger was designed to search for HNLs following the beam spill with an exposure of 2.0 x 10^{20} POT.

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



Background is mainly due to cosmic ray muons which is estimated using "beam-off" sample (as mentioned in slide-7)

Trained BDT to select HNLs
→ No excess in data.

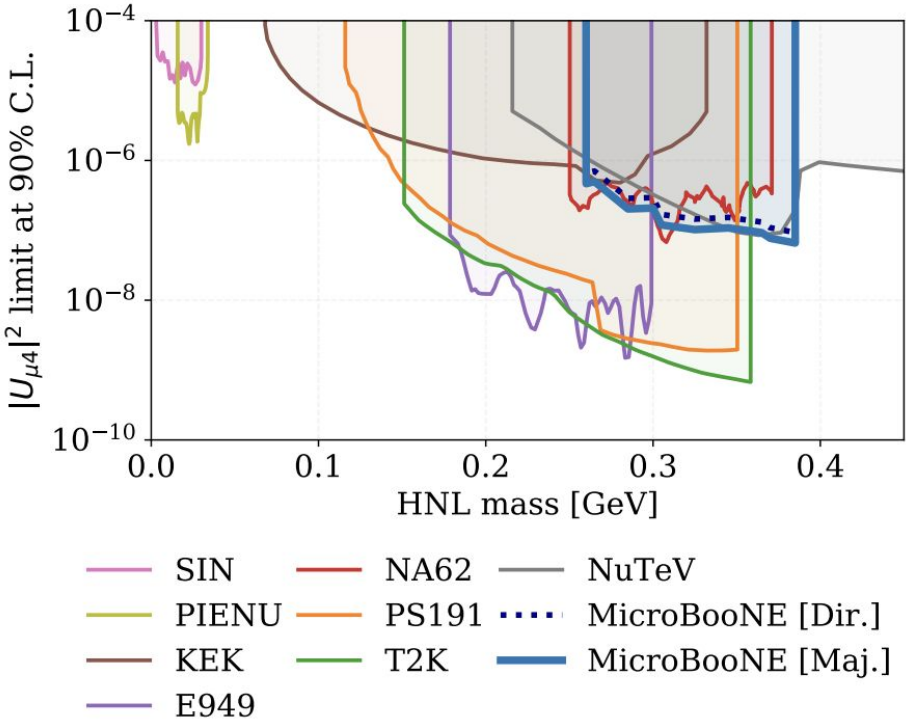


Heavy Neutral Leptons (in BNB)

PRD 101, (2020) 052001

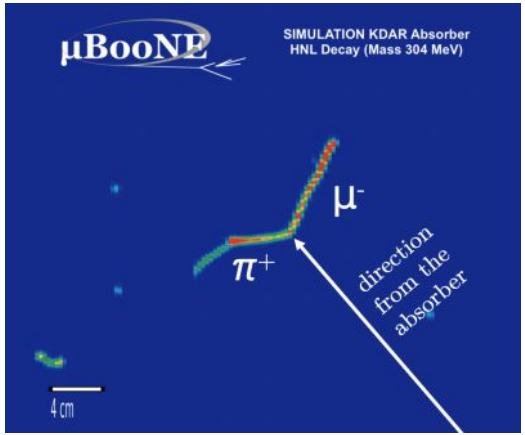
Set upper limits on $|U_{\mu 4}|^2$ with 90% CL by selecting HNLs in kinematically constrained region (260-385 MeV) assuming $|U_{e4}|^2$ and $|U_{\tau 4}|^2 = 0$

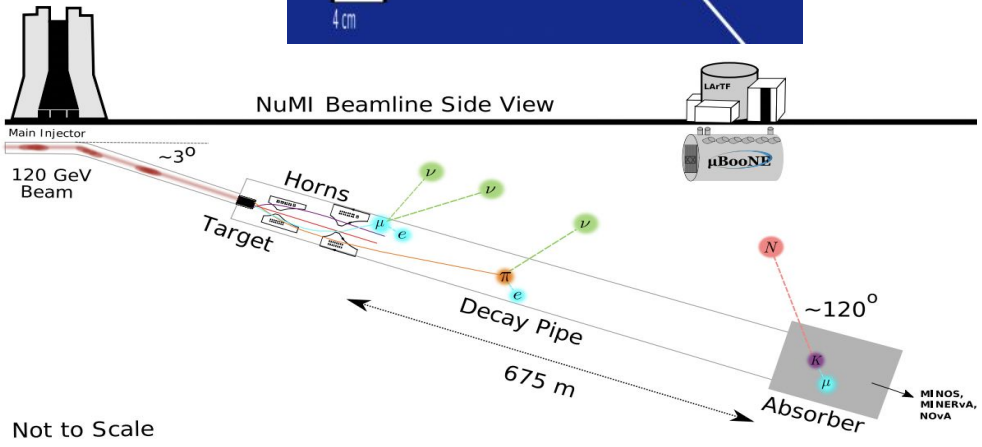
For Dirac HNLs - $|U_{\mu 4}|^2 < (6.6\text{-}0.9) \times 10^{-7}$
For Majorana HNLs - $|U_{\mu 4}|^2 < (4.7\text{-}0.7) \times 10^{-7}$



Heavy Neutral Leptons (in NuMI)

PRD 106, (2022) 092006





Signal- HNLs reaching the detector through opposite direction w.r.t standard beam direction.

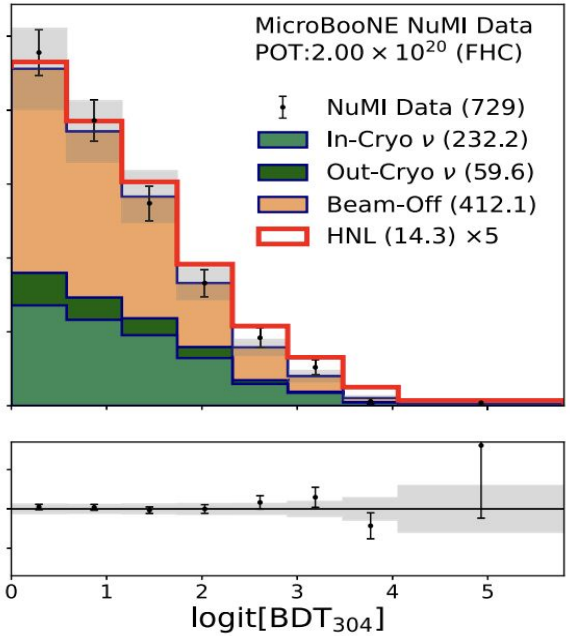
Background- Neutrino (mainly ν_μ CC interactions) and cosmic induced background.

Heavy Neutral Leptons (in NuMI)

PRD 106, (2022) 092006

- Look for signals in mass range of 246-385 MeV decaying to $\mu\pi$ with an exposure of 7.01 x 10^{20} POT.

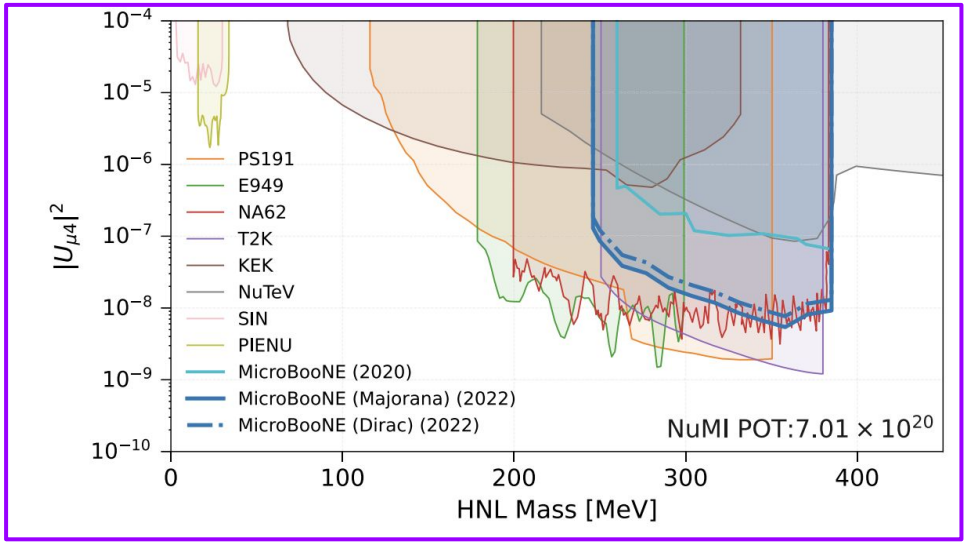
BDT is trained to target two decay particles topology using kinematic properties.

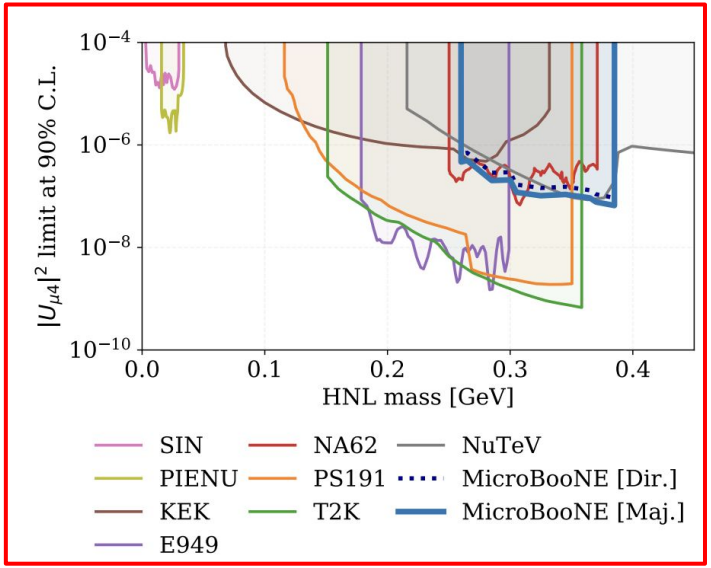


Heavy Neutral Leptons (in NuMI)

PRD 106, (2022) 092006

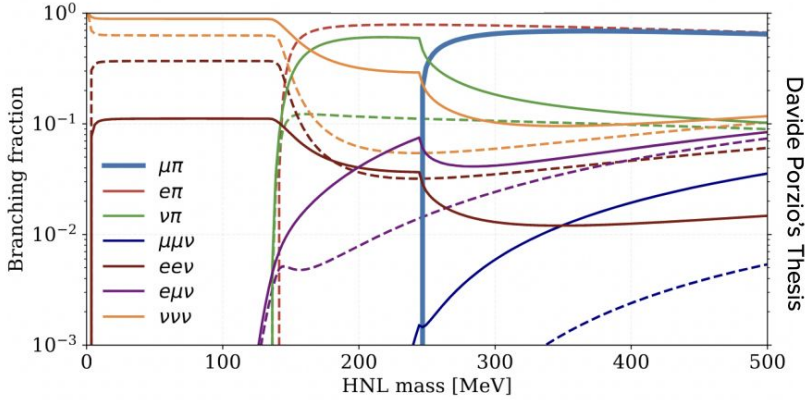
An order of magnitude increased sensitivity as compared to previous search with BNB in HNL mass range of 246-385 MeV.





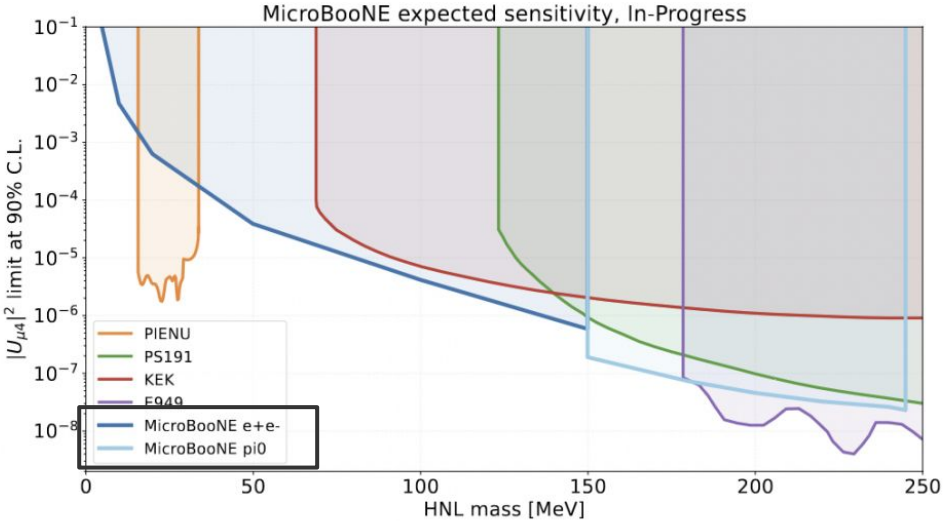
Heavy Neutral Leptons (in NuMI)

- Exploring different decay channels to search for HNLs with lower masses < 250 MeV.



Solid: $[U_{e4} : U_{\mu 4} : U_{\tau 4}] = [0 : 1 : 0]$

Dashed: $[U_{e4} : U_{\mu 4} : U_{\tau 4}] = [1 : 0 : 0]$

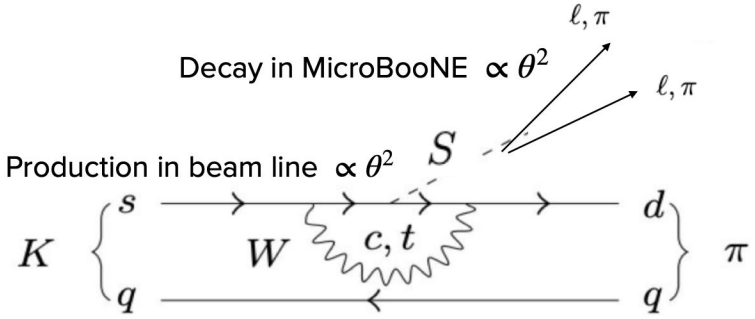


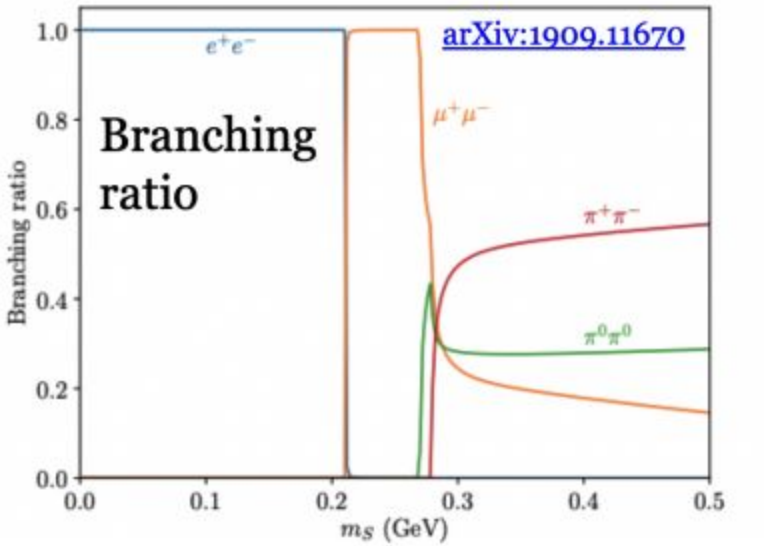
Higgs Portal Scalars

Higgs Portal Scalars

- Theoretically motivated dark scalars in context of Higgs portal model.
- Search motivated from KOTO's initial observation of 3 unexplained invisible decay candidates in $K^0 \rightarrow \pi^0$ + invisible decay candidates [PRL. **124**, 191801].
- Light HPS (< 240 MeV) can be produced in kaon decays.

Production and Decay Mode





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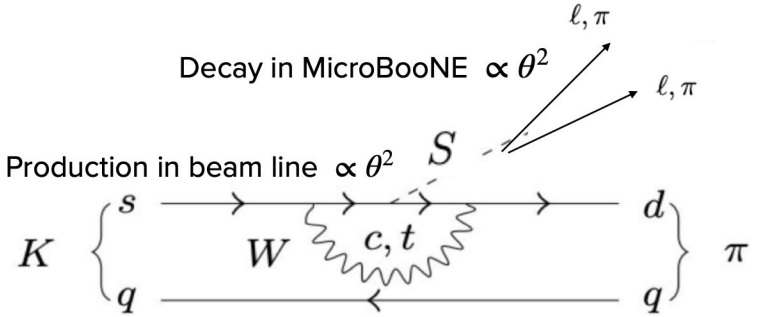
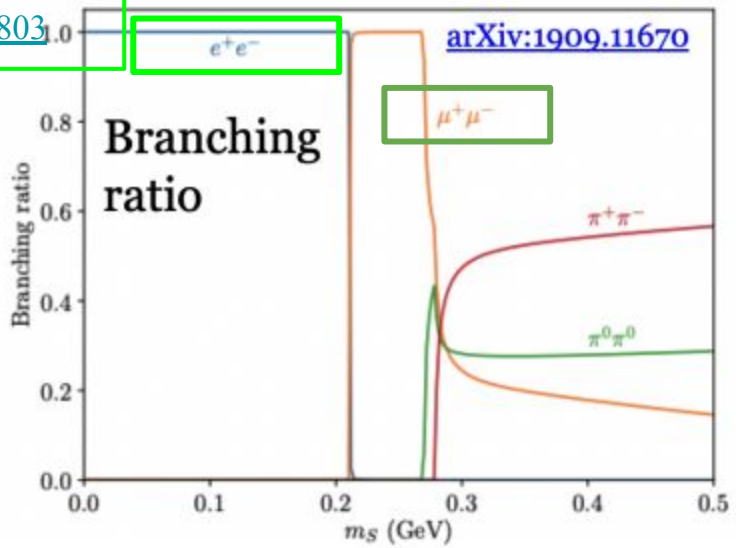
PRD 106, (2022) 092006

PRL. 127, (2021) 151803

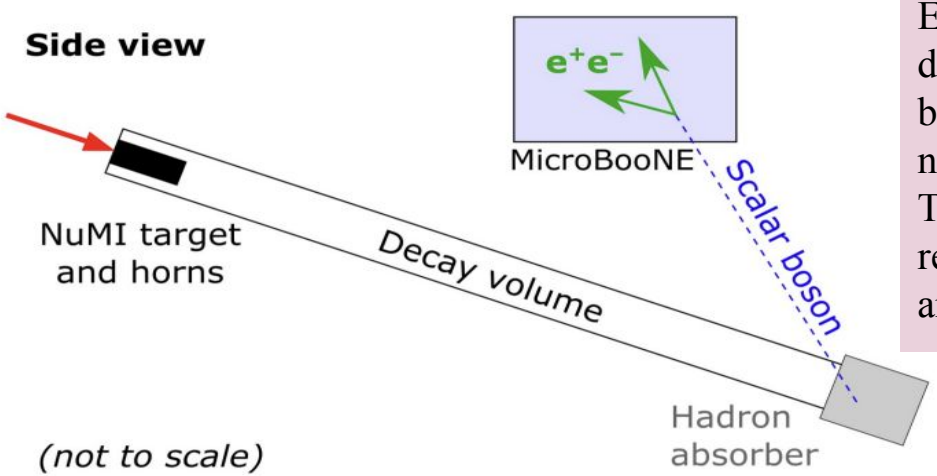
Production and Decay Mode





PRL. 127, (2021) 151803

Higgs Portal Scalars
Decay mode - e^+e^-

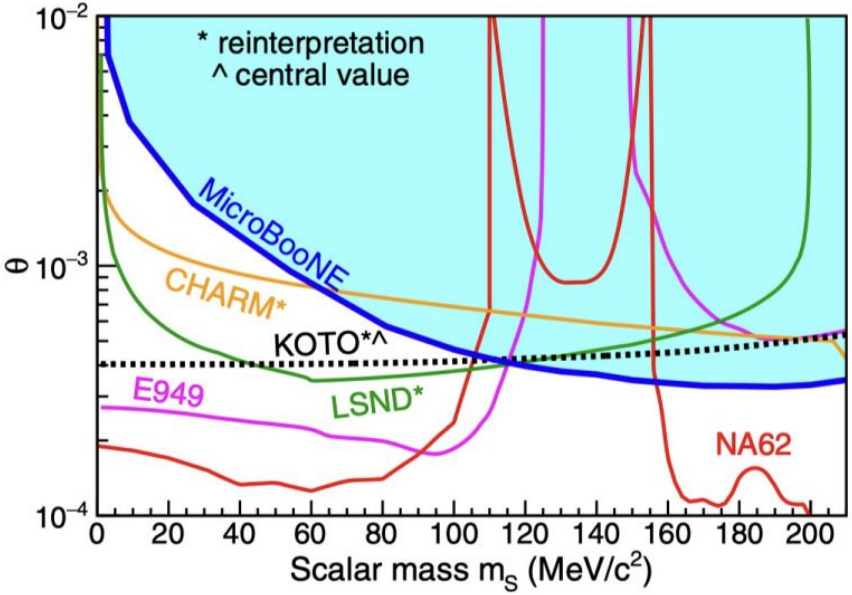


Energy and direction is used to distinguish this signal from background process (cosmic and neutrino induced interactions). Two separate BDTs are trained to reject background from cosmics and from neutrino interactions.

PRL. 127, (2021) 151803

Higgs Portal Scalars
Decay mode - e^+e^-

- Upper limits are placed on scalar mixing angle at 95% CL.
- This search used only 10% of the NuMI dataset corresponding to exposure 1.93 x 10^{20} POT.

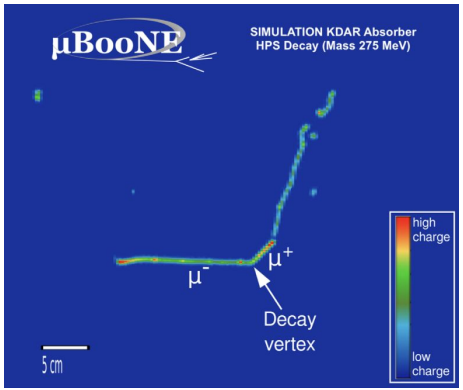


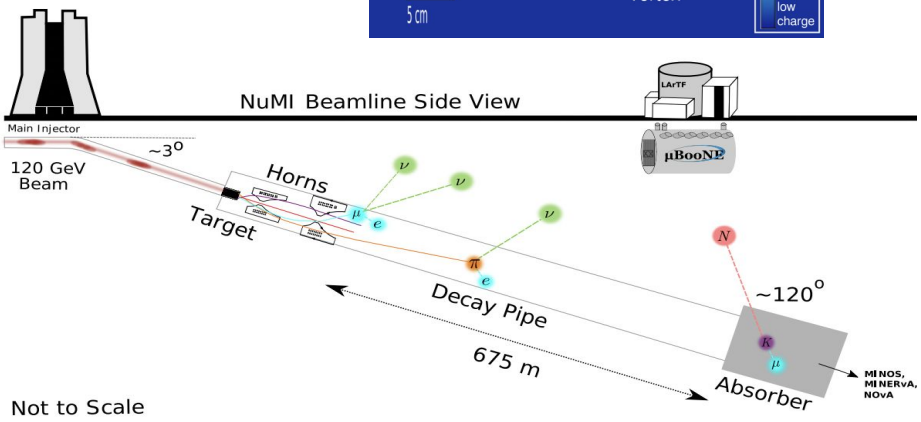
World-leading result for masses near π^0 mass
Upper limit on scalar-Higgs mixing angle
$\theta < (3.3 - 4.6)x10^{-4}$ at 95% CL.

PRD 106, (2022) 092006

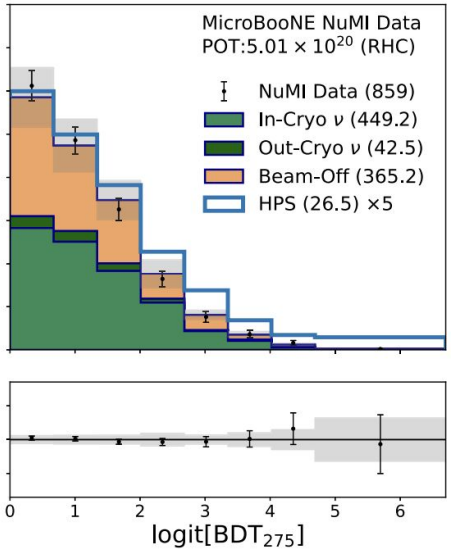
Higgs Portal Scalars

Decay mode - $\mu^+\mu^-$





- BDT is trained to target two decay particles topology using kinematic properties and using an exposure of 7.01 x 10^{20} POT.

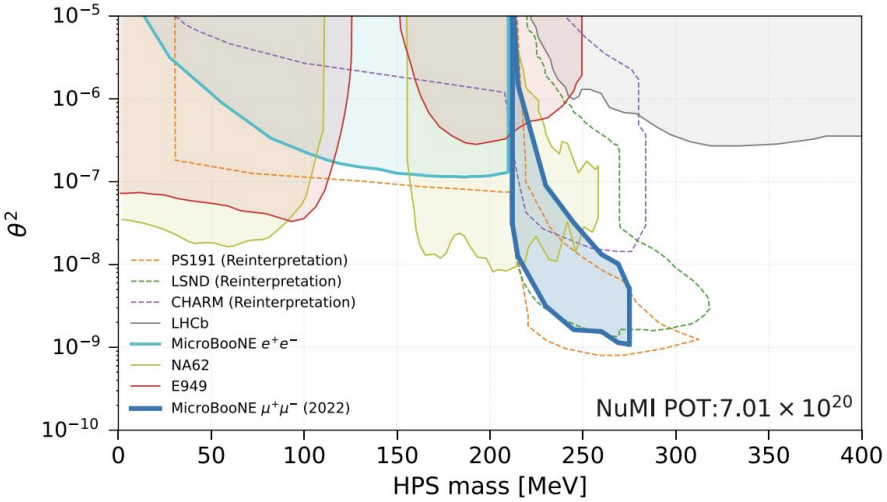


PRD 106, (2022) 092006

Higgs Portal Scalars
Decay mode - $\mu^+\mu^-$

First constraints on mixing angle in HPS mass range 212-275 GeV (the region not previously excluded by any dedicated experimental searches)

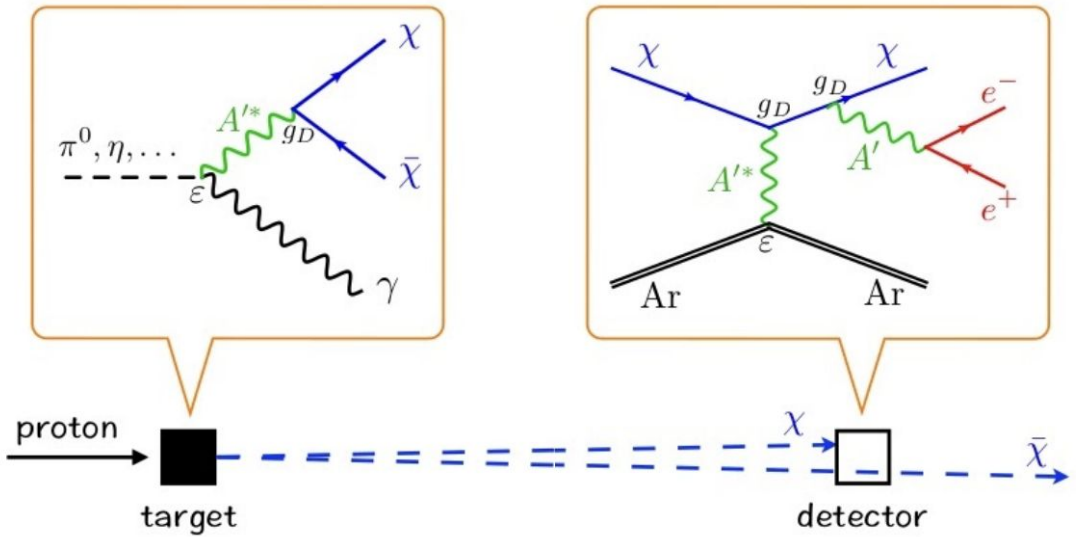
$\theta^2 < (31.3)\times10^{-9}$ at 90% CL for HPS mass 212 MeV
$\theta^2 < (1.09)\times10^{-9}$ at 90% CL for HPS mass 275 MeV



Dark Trident

Dark Trident

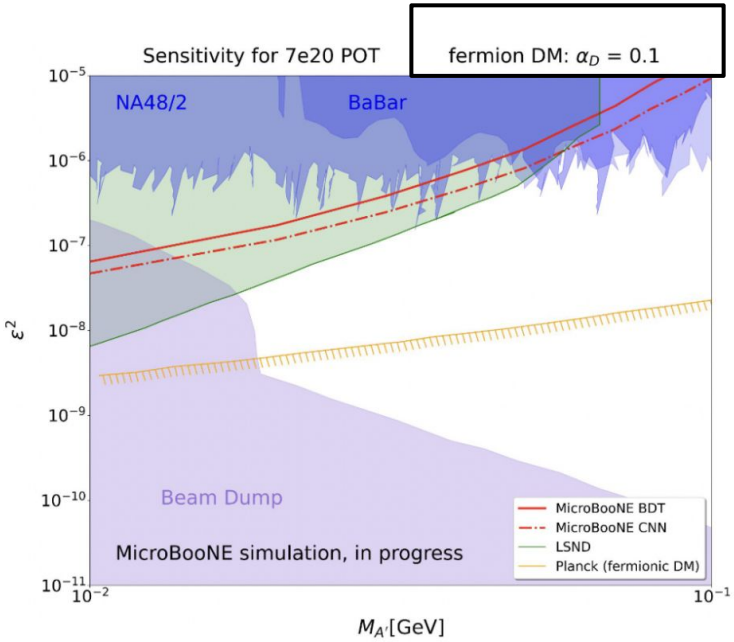
- Dark matter produced from neutral mesons in the beam (BNB) can scatter off argon and accompanied by dark radiation which can decay to produce e^+e^-, $\mu^+\mu^-$

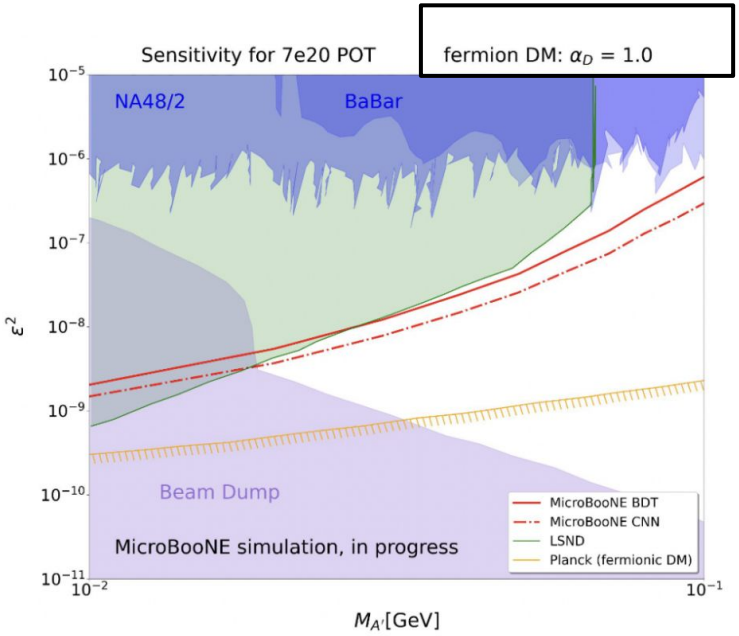


We look for e^+e^- final states

Dark Trident

α_D Dark fine structure constant





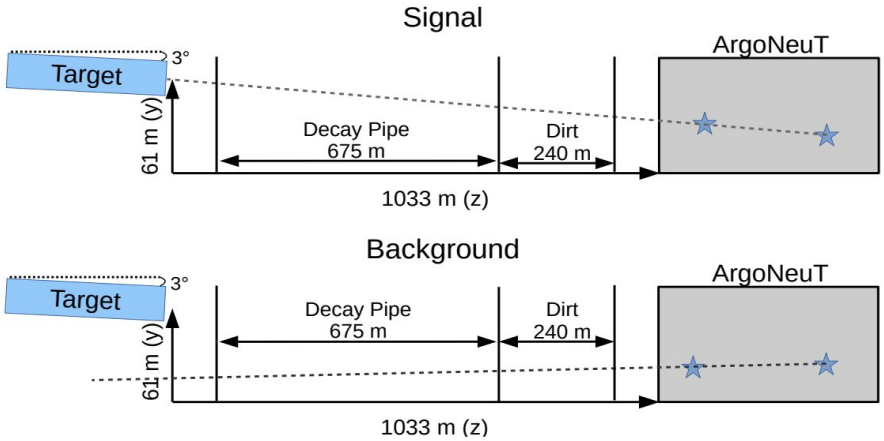
- Expect to have a publication soon!

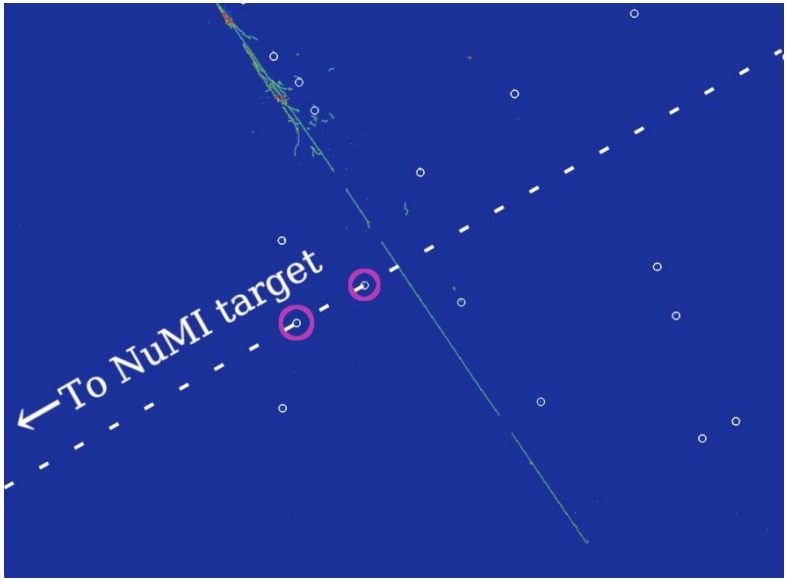
millicharged Particles

millicharged Particles

ONGOING

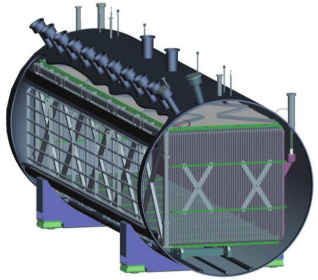
- Particles with fractional charge → Potential dark matter candidates.
- Elastic scattering with atomic electrons (mostly below threshold) → MeV reconstruction tool is useful here.

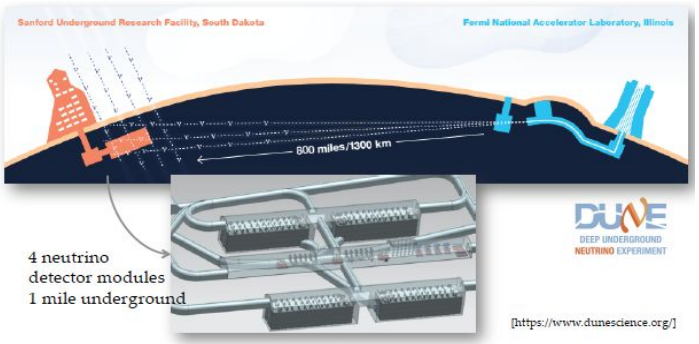




PRL 124 (2020) 131801

MicroBooNE - R&D for the next-generation experiments

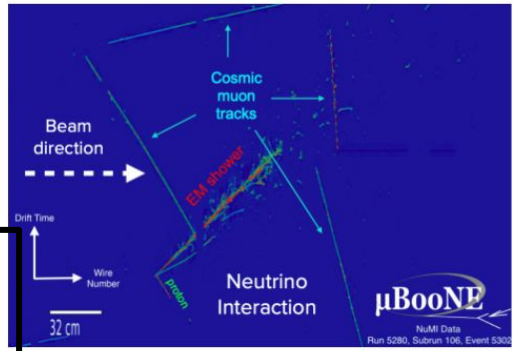




Recalling

What MicroBooNE is not sensitive to?

- MicroBooNE is a small, on-surface detector
  - Ambient cosmic ray background.
    - *Background is estimated using cosmic-only data collected during beam spill (when there is no neutrino beam running) → "beam-off" sample*
  - Not sensitive to atmospheric neutrino searches.
- Great platform to do R&D studies for the next-generation large LArTPCs such as Deep Underground Neutrino Experiment (DUNE).

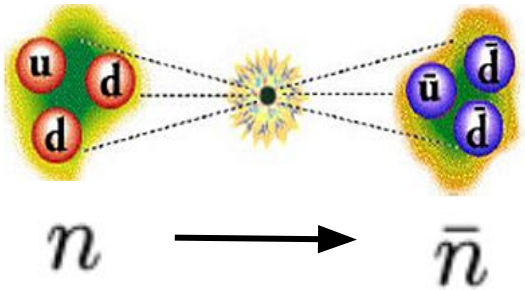


Neutron Antineutron Transitions

MICROBOONE-NOTE-1113-PUB

Neutron Antineutron Transitions

- A baryon number violation process, where a neutron transforms itself into an antineutron with a subsequent annihilation of antineutron with a nearby nucleon.
- **First demonstration of searching for this process within an argon nucleus using LArTPC-based MicroBooNE detector.**



$\bar{n}+p$		$\bar{n}+n$	
Channel	Branching ratio	Channel	Branching ratio
$\pi^+\pi^0$	1.2%	$\pi^+\pi^-$	2.0%
$\pi^+2\pi^0$	9.5%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	11.9%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	26.2%	$\pi^+\pi^-2\pi^0$	11.0%
$2\pi^+\pi^-2\pi^0$	42.8%	$\pi^+\pi^-3\pi^0$	28.0%
$2\pi^+\pi^-2\omega$	0.003%	$2\pi^+2\pi^-$	7.1%
$3\pi^+2\pi^-\pi^0$	8.4%	$2\pi^+2\pi^-\pi^0$	24.0%
		$\pi^+\pi^-\omega$	10.0%
		$2\pi^+2\pi^-2\pi^0$	10.0%

Phys. Rev. D 103 012008

Phys. Rep. 413, 197
Nucl. Phys. A720, 357

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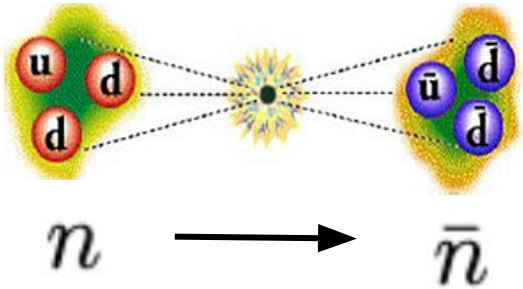
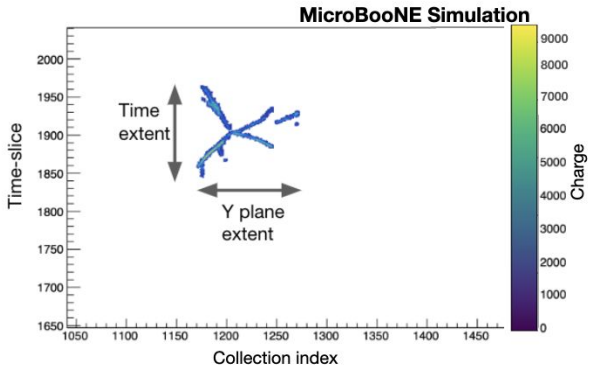
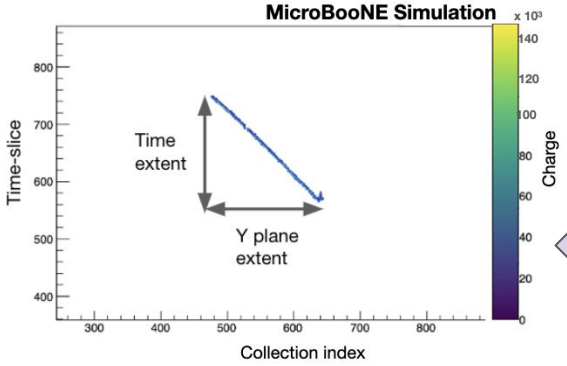


A characteristic star-like topology in LArTPC

Neutron Antineutron Transitions

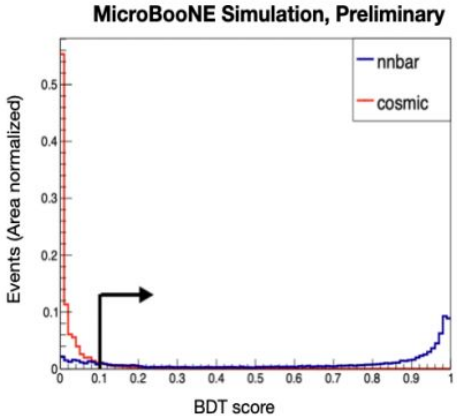
MICROBOONE-NOTE-1113-PUB

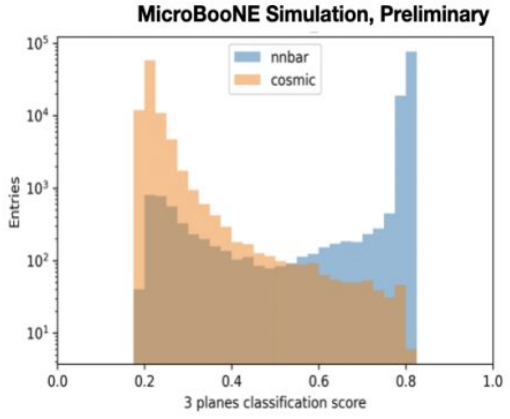




Topological features (spherical topology and more localized for signal and straight-track like topology for background) are used to develop selection.

Selection is developed based on machine learning (BDT) and deep learning (CNN) algorithms

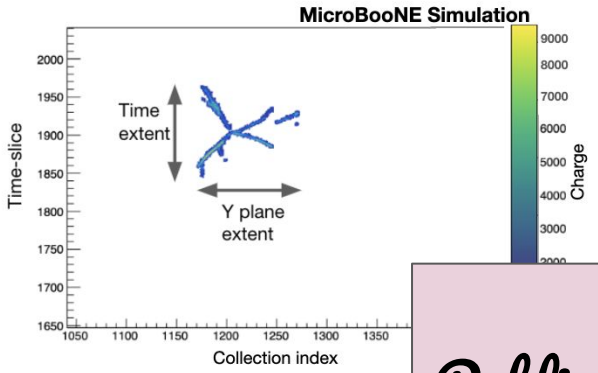


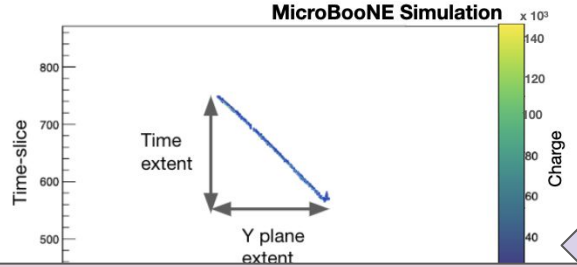


Stat-only sensitivity - 3.0 x 10^{25} years at 90% CL. **Signal and background efficiencies ~73% and 0.008% resp.**

Neutron Antineutron Transitions

MICROBOONE-NOTE-1113-PUB





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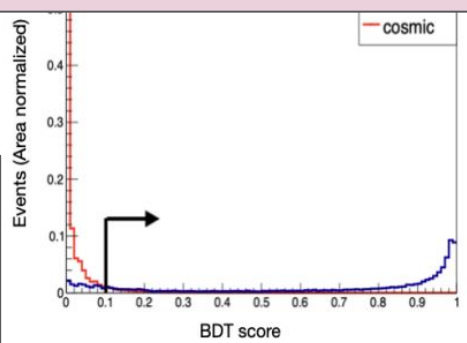
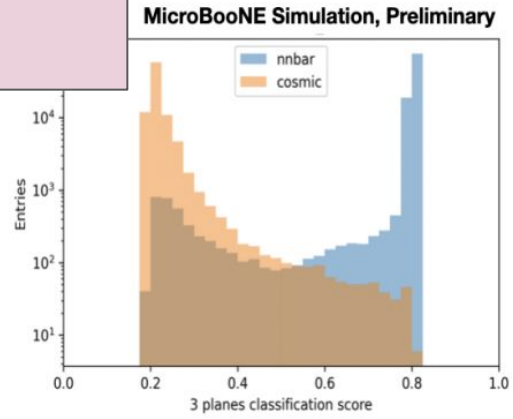
Publication forthcoming!

Selection is dev
machine learnin
learning (CNN) algorithms





Stat-only sensitivity - 3.0 x 10^{25} years at 90% CL.
Signal and background efficiencies ~73% and 0.008% resp.

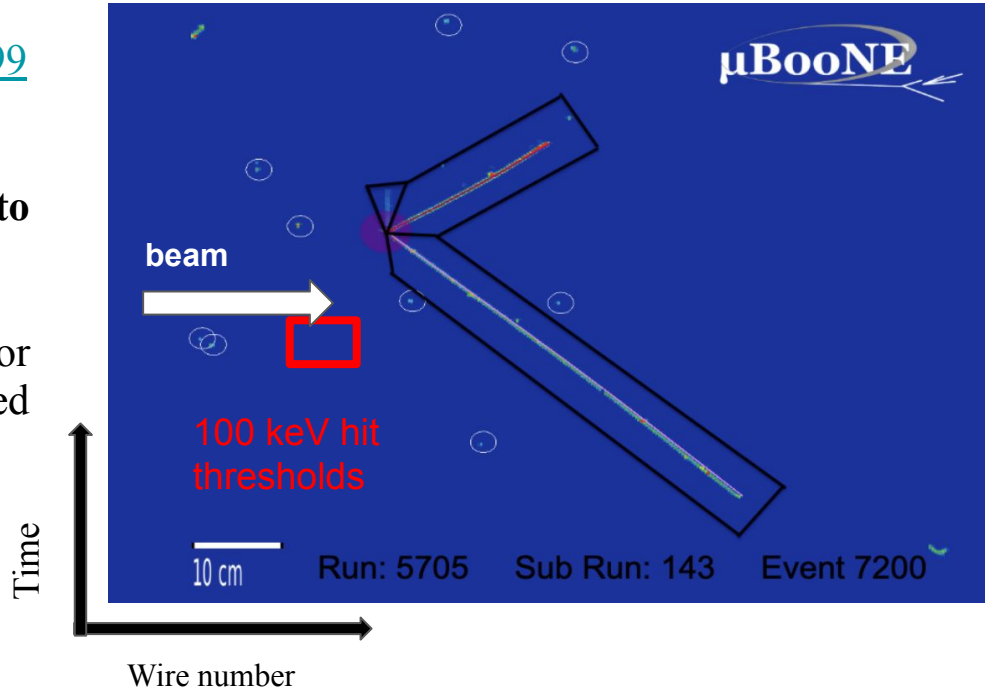
MeV Scale Reconstruction

MICROBOONE-NOTE-1076-PUB

MeV Scale Reconstruction

- Demonstrated by ArgoNEUT PRD 99 (2019) 012002
- Low detection thresholds to ~100 keV
  - ➢ **Best thresholds of LArTPCs to date**

- This has opened a possibility to search for new physics signatures e.g. millicharged particle search.



PRD 99 (2019) 012002

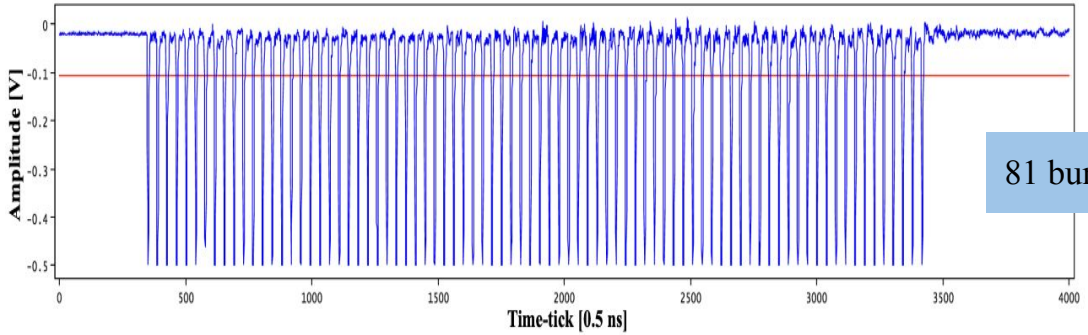
ns-Timing Resolution

LinkToArXiv

ns-Timing Resolution

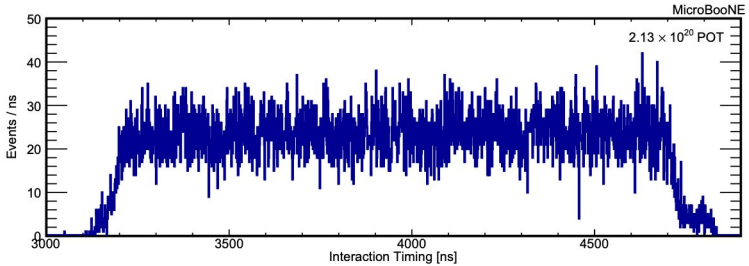
LinkToArXiv

Probing BNB beam substructure for the first time in LArTPC detector

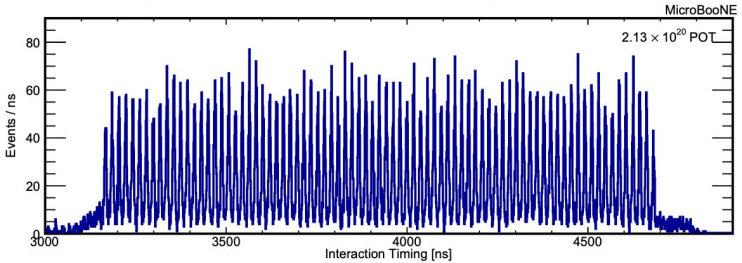


81 bunches across 1.6 μs

Neutrino interaction timing



calibration

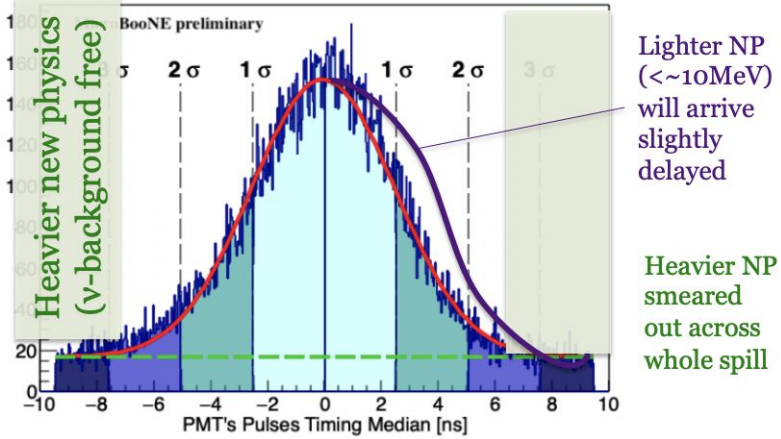


81 bunches are visible after calibration

ns-Timing Resolution

LinkToArXiv

This high resolution helps -
In reduction of cosmic backgrounds (dominant due to MicroBooNE's on-surface location) → one of the dominant backgrounds in BSM searches.
To Enhance BSM searches with higher sensitivities.



Lighter NP (<~10MeV) will arrive slightly delayed

Heavier NP smeared out across whole spill

Cut	BG_{Tot} (%)	ν_{eff} (%)	BG_{rej} (%)
No cut	27.1	100	0
$\pm 3\sigma$	21.7	99.7	19.8
$\pm 2\sigma$	15.2	95.5	46.6
$\pm\sigma$	10.6	68.3	73.3

Continuous readout stream

JINST 16 (2021) 02, P02008

Continuous readout stream

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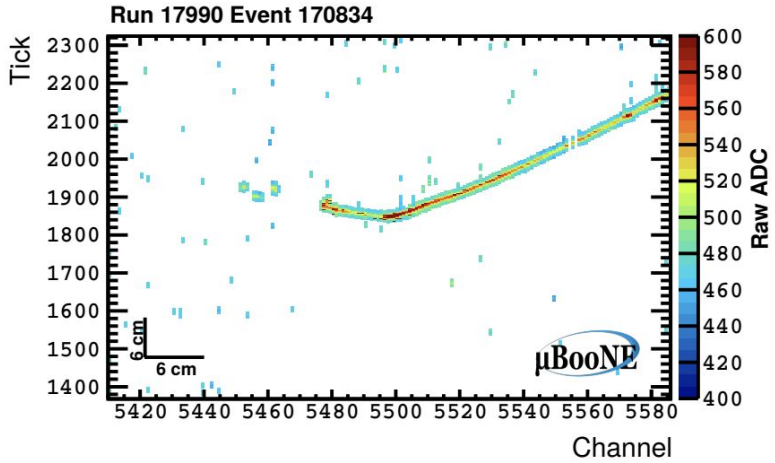
- Two independent data streams in MicroBooNE-
  - Neutrino - Triggered/Lossless data stream.
  - **Continuous - Lossy, zero-suppressed data stream → to study non-beam physics processes** such as neutrinos from Supernova burst.

Demonstrated by reconstructing low energy electrons (similar spectrum to neutrinos from supernova burst)



Zero-suppressed raw waveform

Contribution of MicroBooNE to Future Experiments

- MicroBooNE provides a strong contribution to the next-generation LArTPC-based detectors-
  - Essential operational experience for upcoming SBND and DUNE experiments.
  - R&D platform-
    - Understand detector effects to reduce the uncertainties on future BSM searches.
    - Develop tools and techniques to search for rare processes such as neutron antineutron transitions in larger, well shielded detectors like DUNE.
  - Data and techniques are available to test new BSM models-
    - To resolve the source of MiniBooNE's Low Energy Excess → the primary goal for MicroBooNE .
- If you have new models, new ideas that we should test, please reach out to us.
- This is very exciting time in MicroBooNE. Stay tuned for the new results and upcoming publications!


Thanks