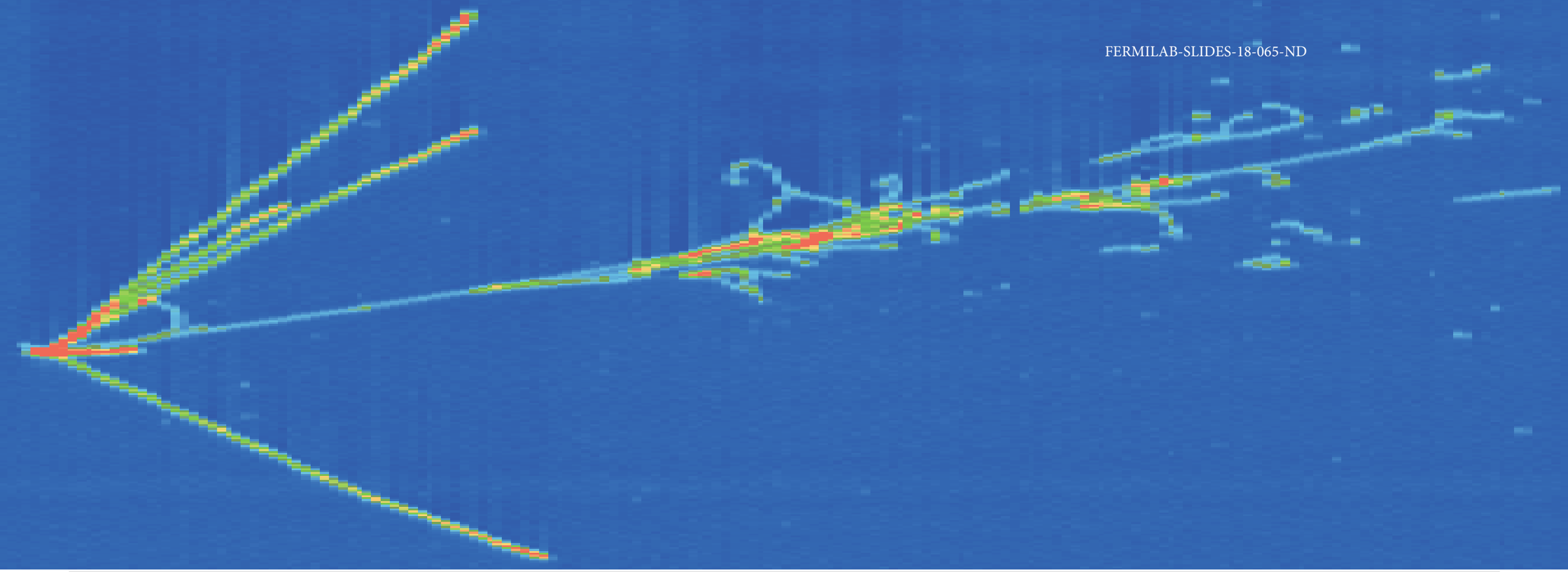

FERMILAB-SLIDES-18-065-ND

MicroBooNE and the future SBN program

Roxanne Guenette for the MicroBooNE and SBN collaborations

This document was prepared by [MicroBooNE and SBN Collaborations] using the resources of the Fermi National Accelerator Laboratory (Fermilab), a U.S. Department of Energy, Office of Science, HEP User Facility. Fermilab is managed by Fermi Research Alliance, LLC (FRA), acting under Contract No. DE-AC02-07CH11359

Short-baseline anomalies

- Puzzling collection of short-baseline anomalies
  - ➡ E. Huang's talk on new MiniBooNE results
  - ➡ M. Maltoni's talk on global picture of sterile neutrinos

- The search for new physics is the holy-grail of the particle physics community

- The DUNE long-baseline program will strongly rely on the resolution of these anomalies (extra oscillations can lead to mis-interpretation of the flagship δ_{CP} measurement)

References:
S. K. Agarwalla, S. S. Chatterjee, A. Dasgupta and A. Palazzo, JHEP 1602, 111 (2016)
D.Dutta, R. Gandhi, B. Kayser, M. Masud and S. Prakash, JHEP 11, 122 (2016)
B. Kayser, proceedings C16-03-12, 2016

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B. Kayser, proceedings C16-03-12, 2016

Need to resolve the anomalies ➡ Short-Baseline Neutrino program

MicroBooNE and the SBN program

- Staged approach: MicroBooNE (phase 1) and the SBN program (phase 2) is a powerful way to address the short-baseline anomalies

- Progress on ICARUS and SBND construction and installation

- MicroBooNE and the search for the low-energy excess:

1. Strong understanding of the detector and highly developed event reconstruction
   New results and reconstruction techniques (with data), paving the way to future LAr detectors

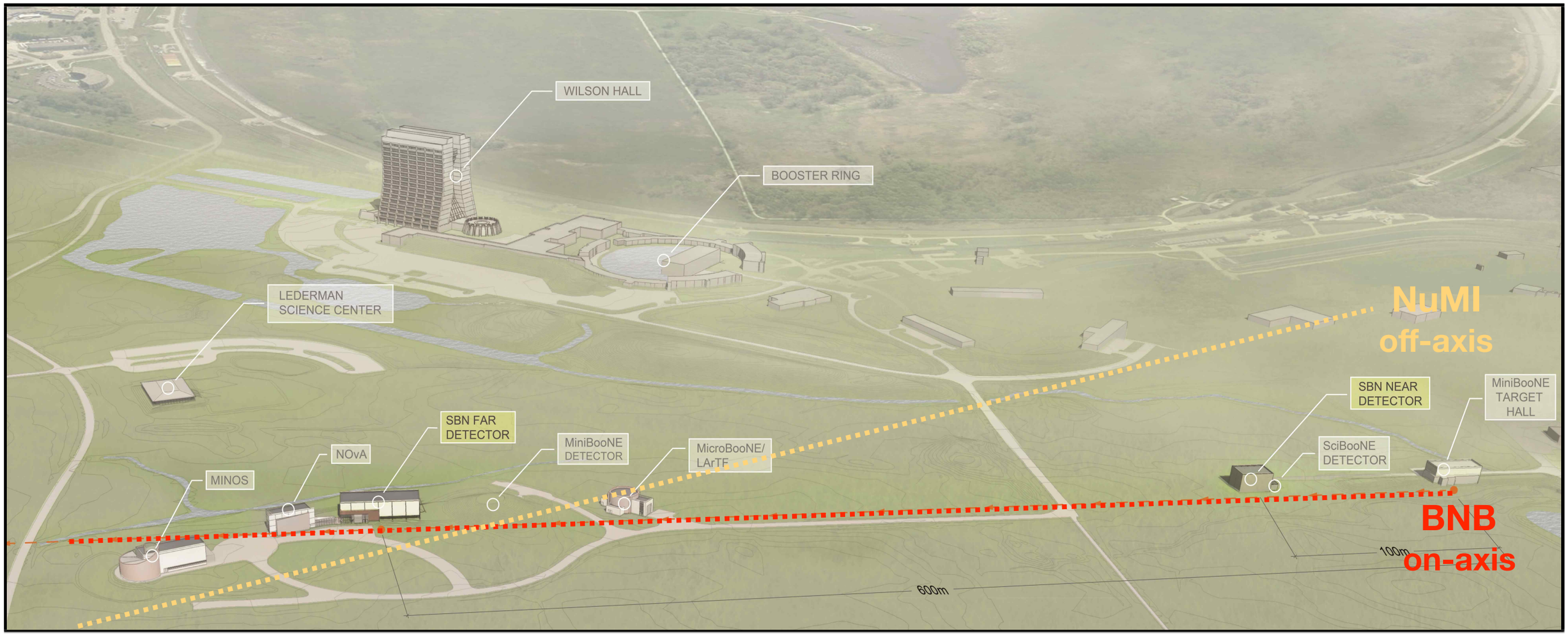
2. Neutrino interaction measurements
   New physics results presented here

3. Towards low-energy excess: solid validation of ν_e and photon analyses
   First results on ν_e and γ selections

Many new results from MicroBooNE
Only few highlights presented here
See all the new Public Notes (http://microboone.fnal.gov/public-notes/)

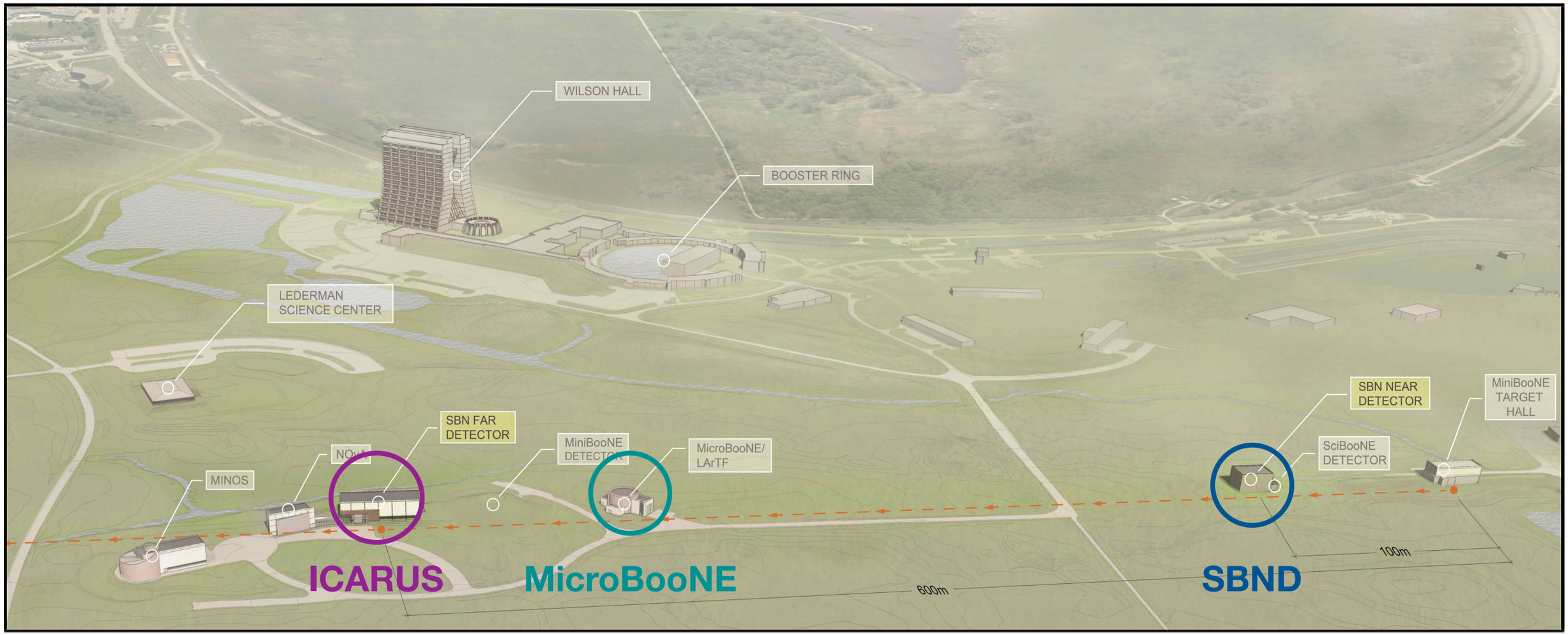
The Short-Baseline Neutrino Program

SBN Program



The Short-Baseline Neutrino Program

A three liquid argon detector experiment:



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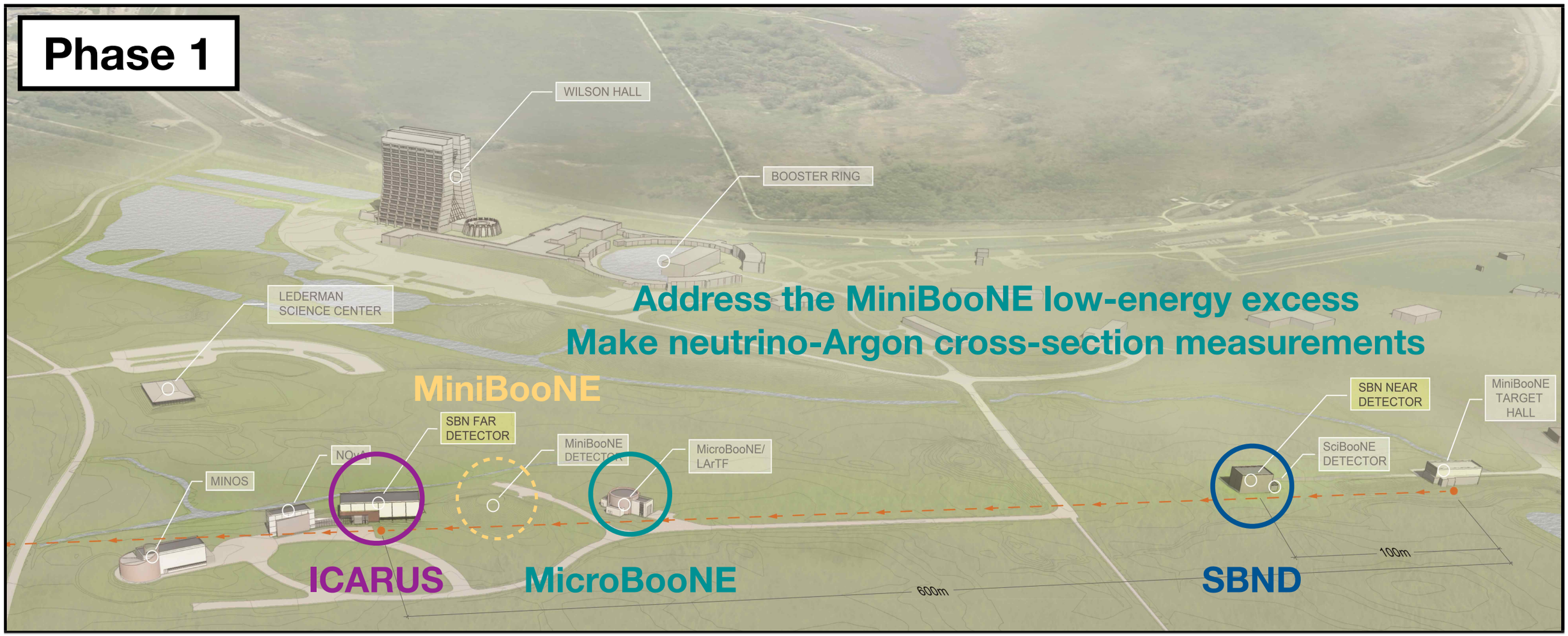
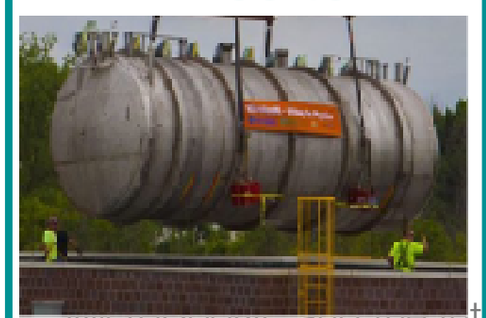


First detector
L = 470 m
M = 85 ton



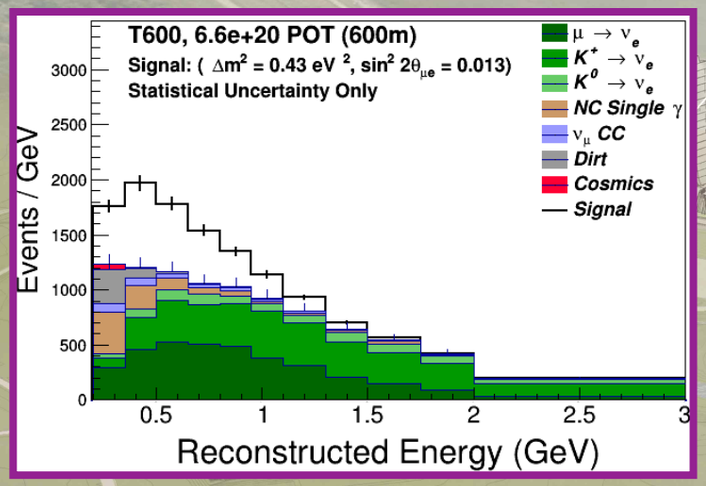
The Short-Baseline Neutrino Program

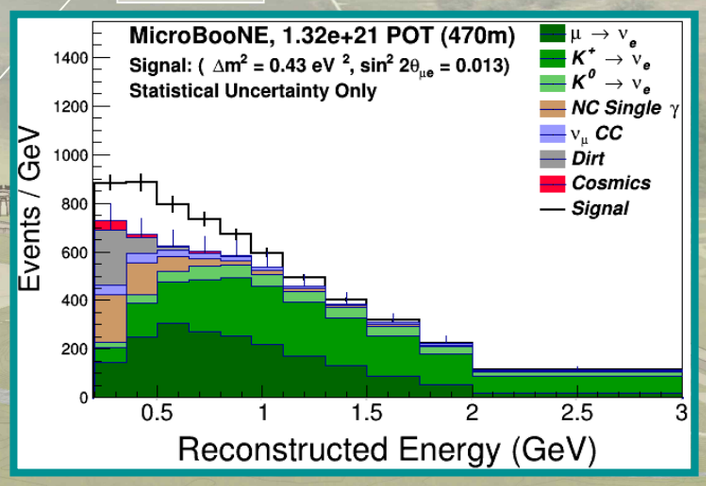
SBN Program

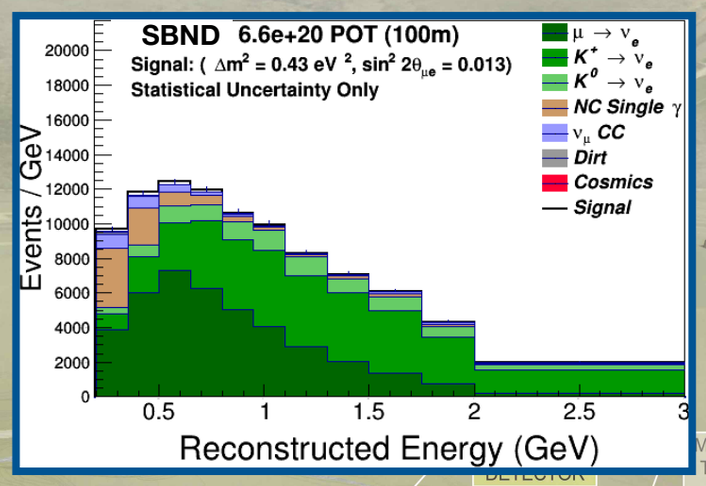
A three liquid argon detector experiment:

Phase 2

Example signal for a sterile neutrino (see SBN proposal for details)







Far detector
L = 600 m
M = 476 ton

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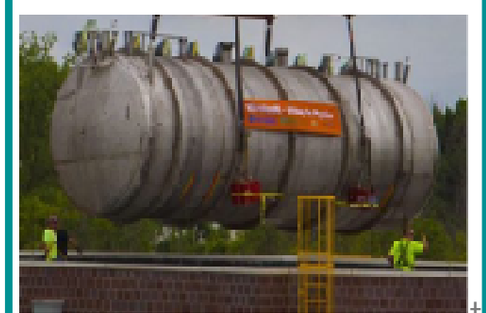
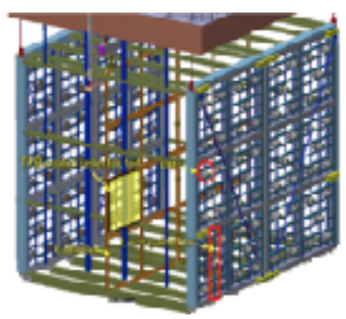
M = 85 ton



Near detector
L = 110 m
M = 112 ton

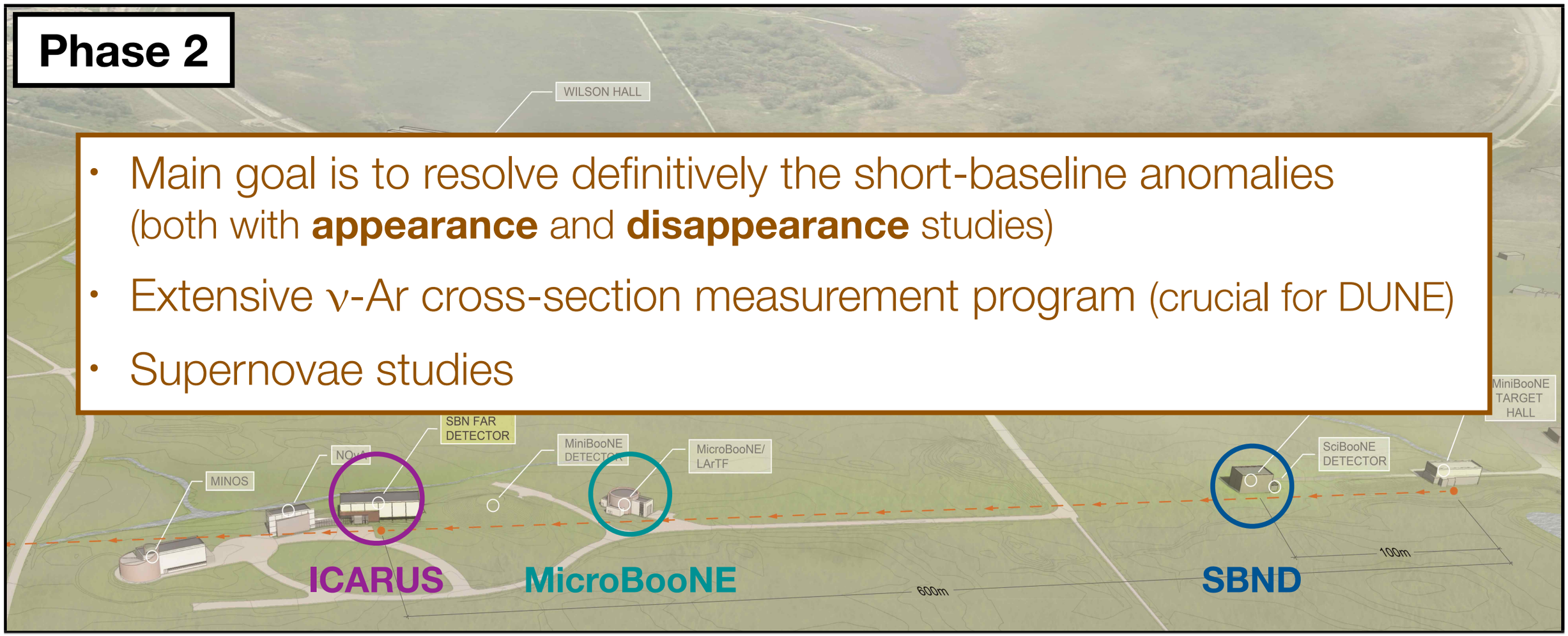


The Short-Baseline Neutrino Program

A three liquid argon detector experiment:

Phase 2

- Main goal is to resolve definitively the short-baseline anomalies (both with **appearance** and **disappearance** studies)
- Extensive ν-Ar cross-section measurement program (crucial for DUNE)
- Supernovae studies



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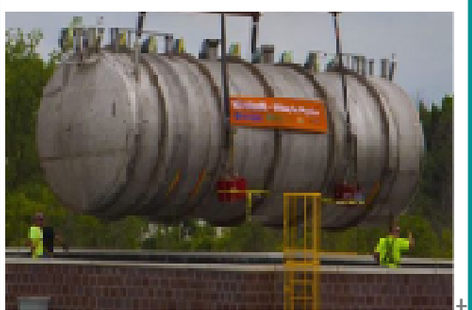

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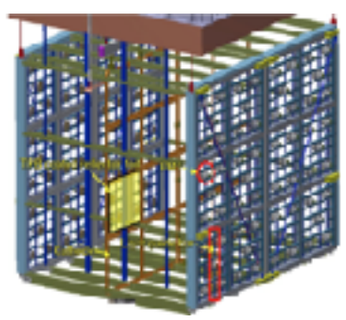
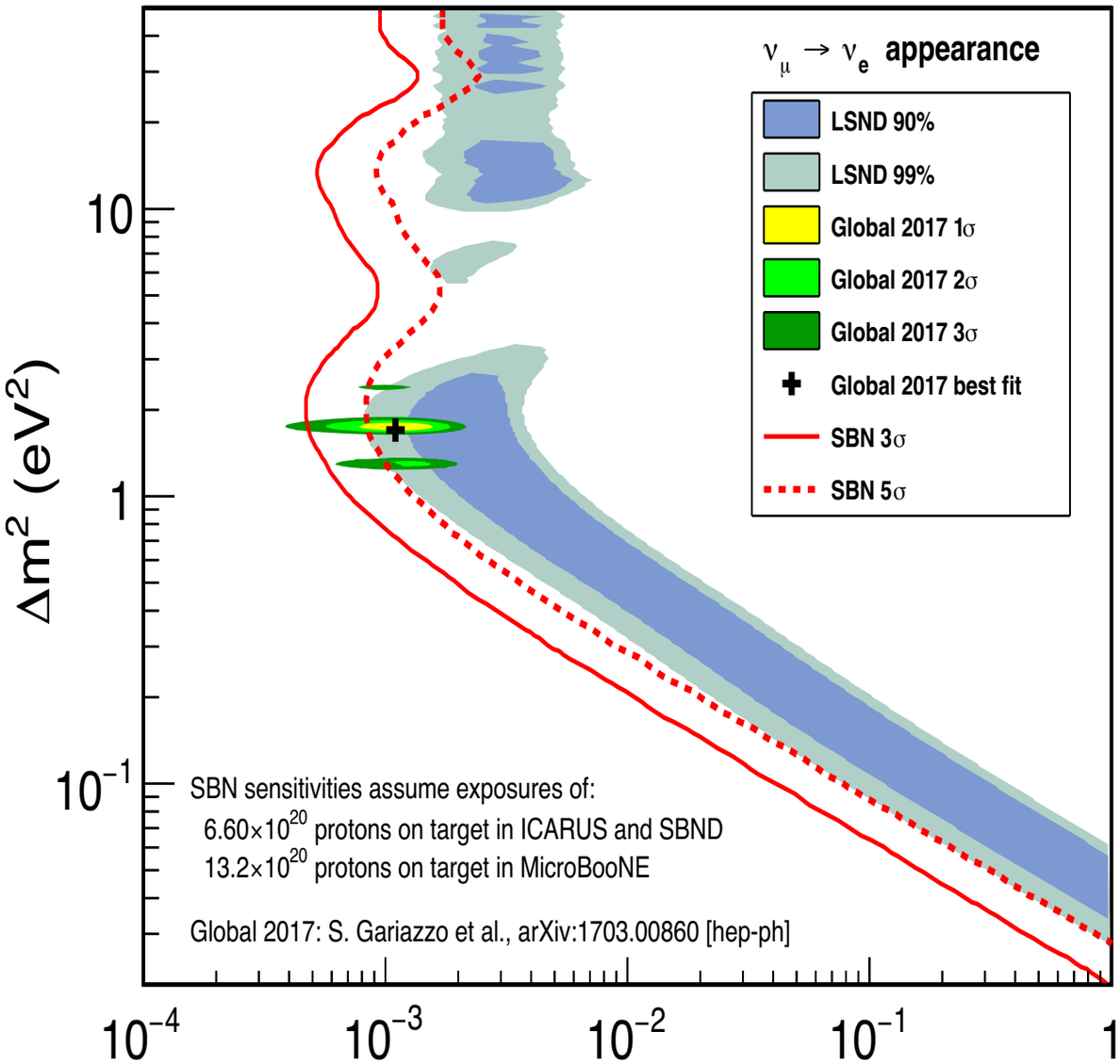
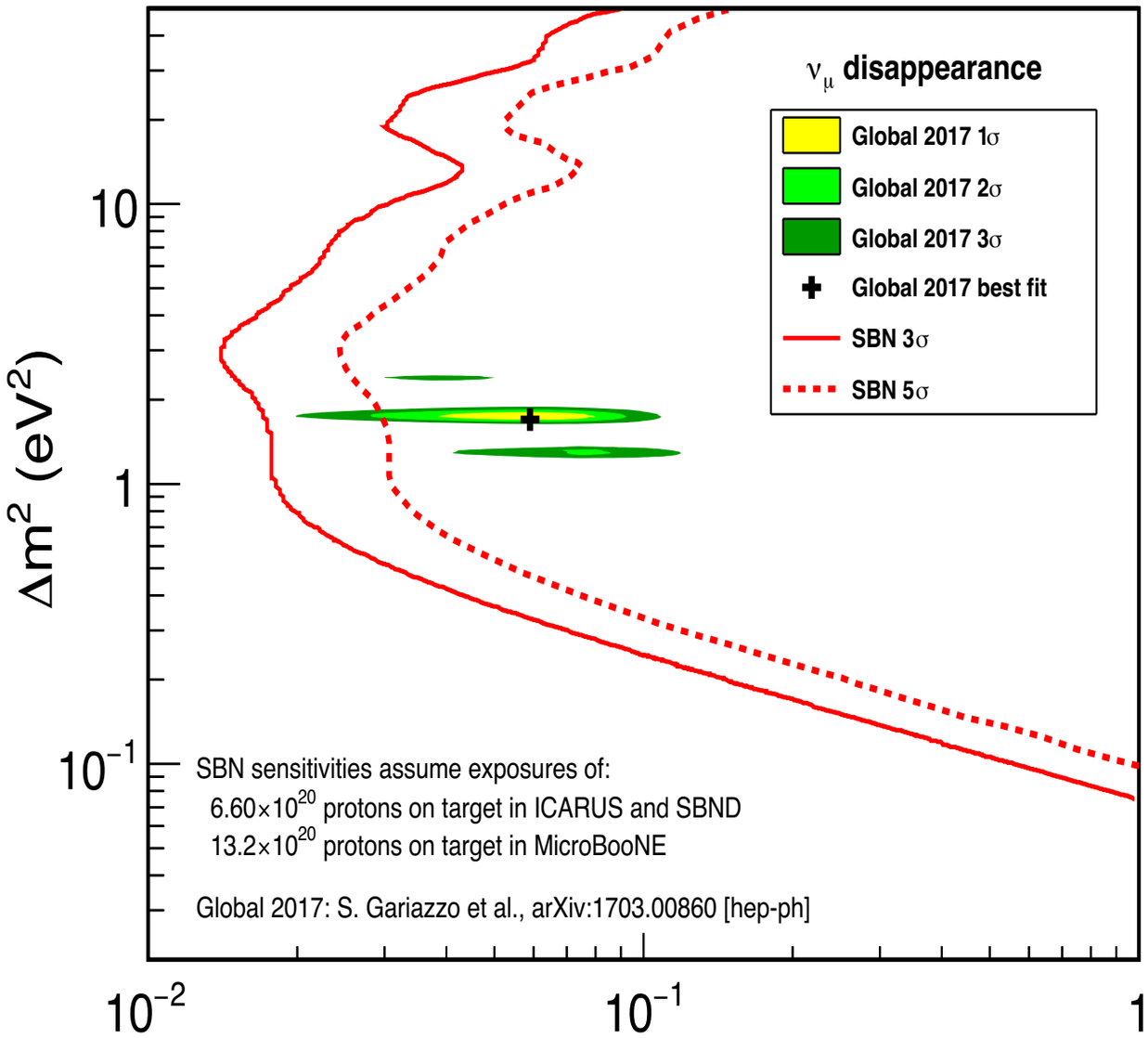


The Short-Baseline Neutrino Program

In the 3+1 sterile neutrino analysis context…





SBN Proposal: https://arxiv.org/abs/1503.01520

Definitive answer to the short-baseline anomalies in the next ~5 years

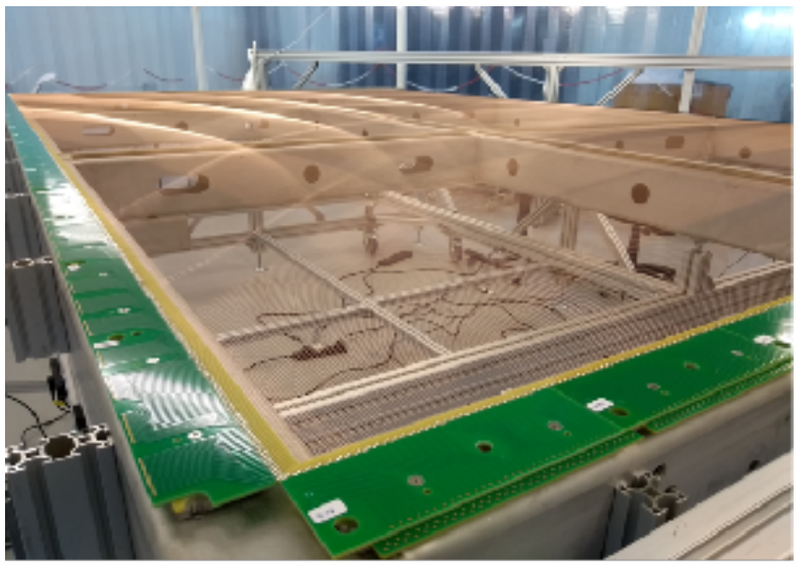
SBN (phase 2) current status: ICARUS and SBND

- Detector **installation** underway
- Planned data taking **2019**

- TPCs delivered at FNAL July 2017
- Warm vessel completed
- Cold shield under installation

- Detector **construction** underway
- Planned data taking **2020**

- CRT panels installed for preliminary beam data



- *Anode Plane Assemblies* and other components under construction (US & UK)

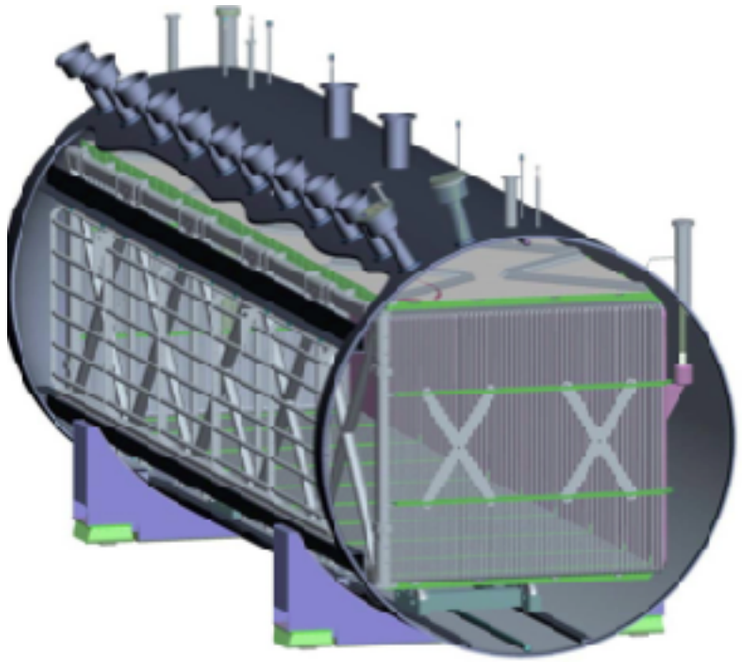
Posters:

C. Adams, Deep learning in LArTPC with SBND

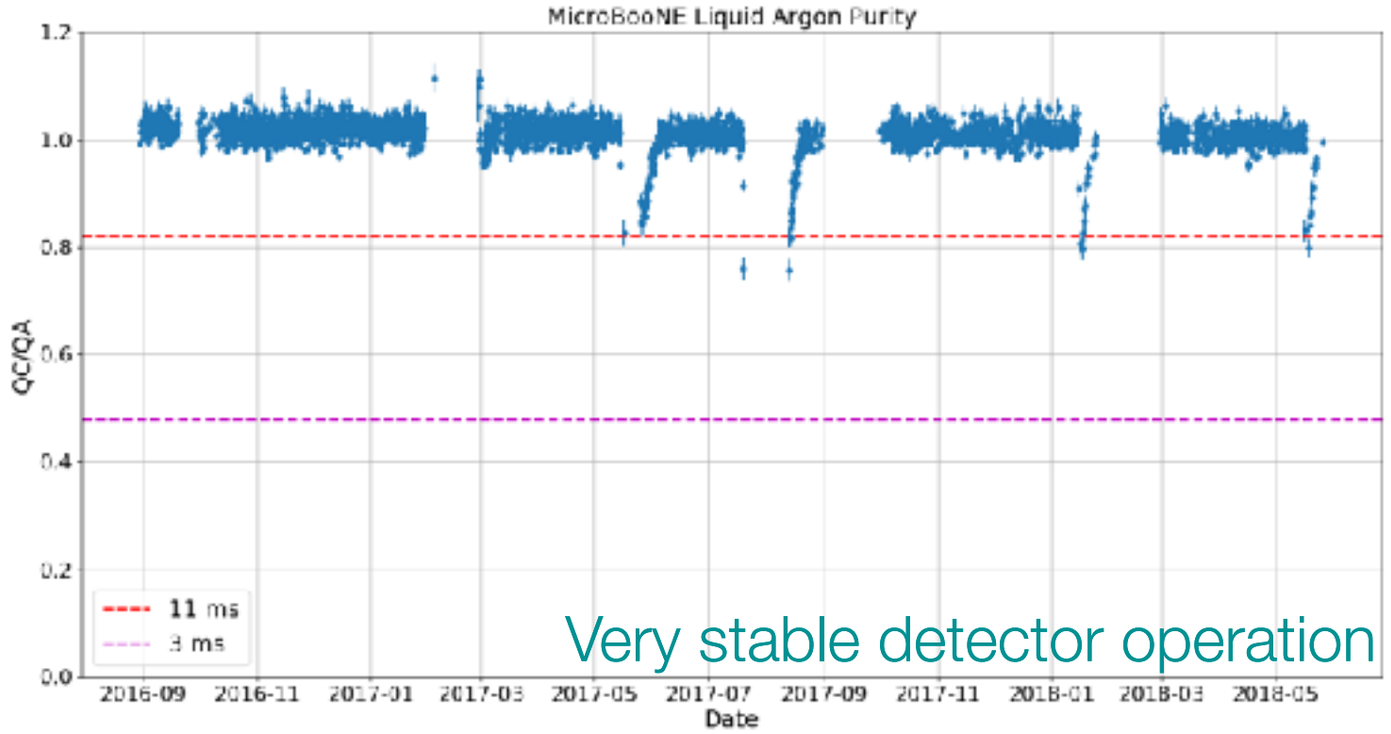
R. Jones, A preliminary ν_μCC-0π event selection in SBND

J. Tena Vidal, ν_μCC-1$\pi^\pm$ event selection in SBND

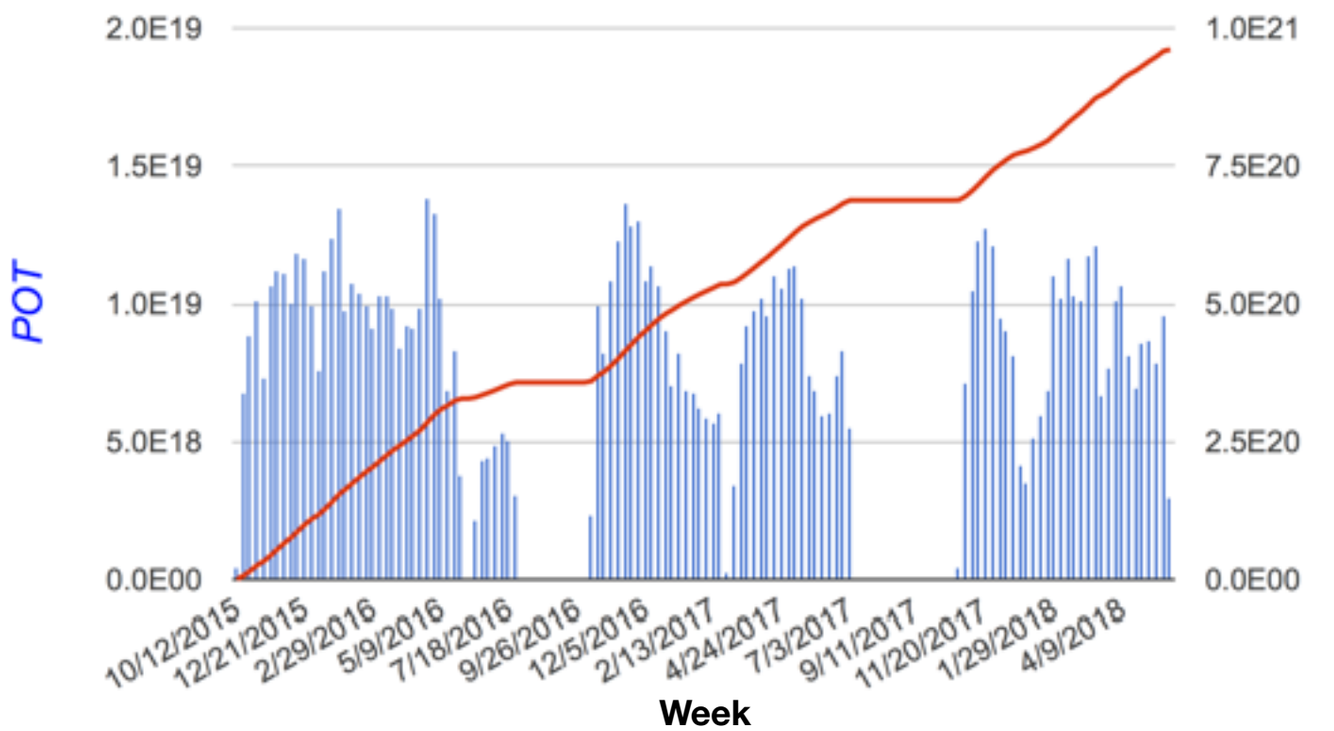
MicroBooNE



- 85 ton LArTPC
- 3 wires planes
- 32 PMTs
- Neutrino data taking since October 2015



Very stable detector operation



Smooth and steady data taking

Efficient data acquisition

Publication: *"Design and Construction of the MicroBooNE Detector"*, JINST 12, P02017 (2017)

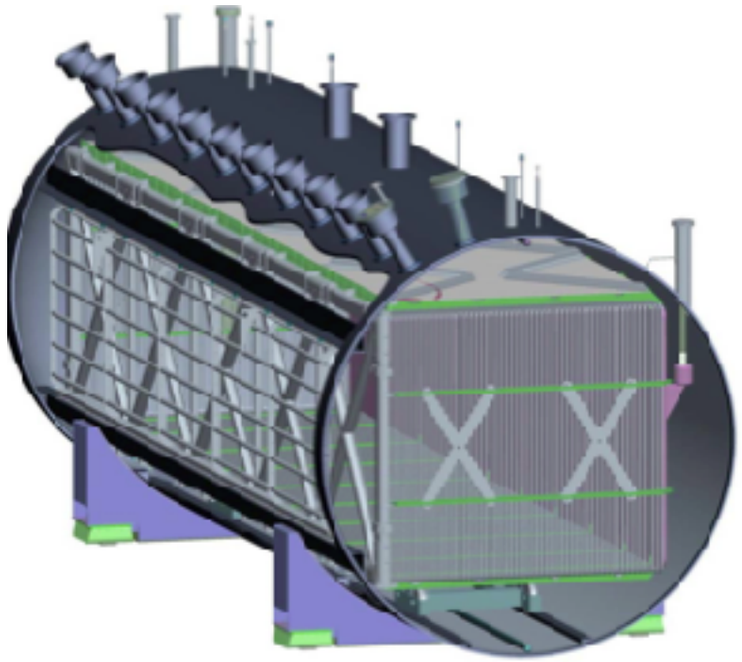
Public notes: *"A Measurement of the Attenuation of Drifting Electrons in the MicroBooNE LArTPC"*, MICROBOONE-NOTE-1026-PUB, (2017)

"Establishing a Pure Sample of Side-Piercing Through-Going Cosmic-Ray Muons for LArTPC Calibration in MicroBooNE", MICROBOONE-NOTE-1028-PUB, (2017)

"Study of Space Charge Effects in MicroBooNE", MICROBOONE-NOTE-1018-PUB, (2016)

And more…

MicroBooNE



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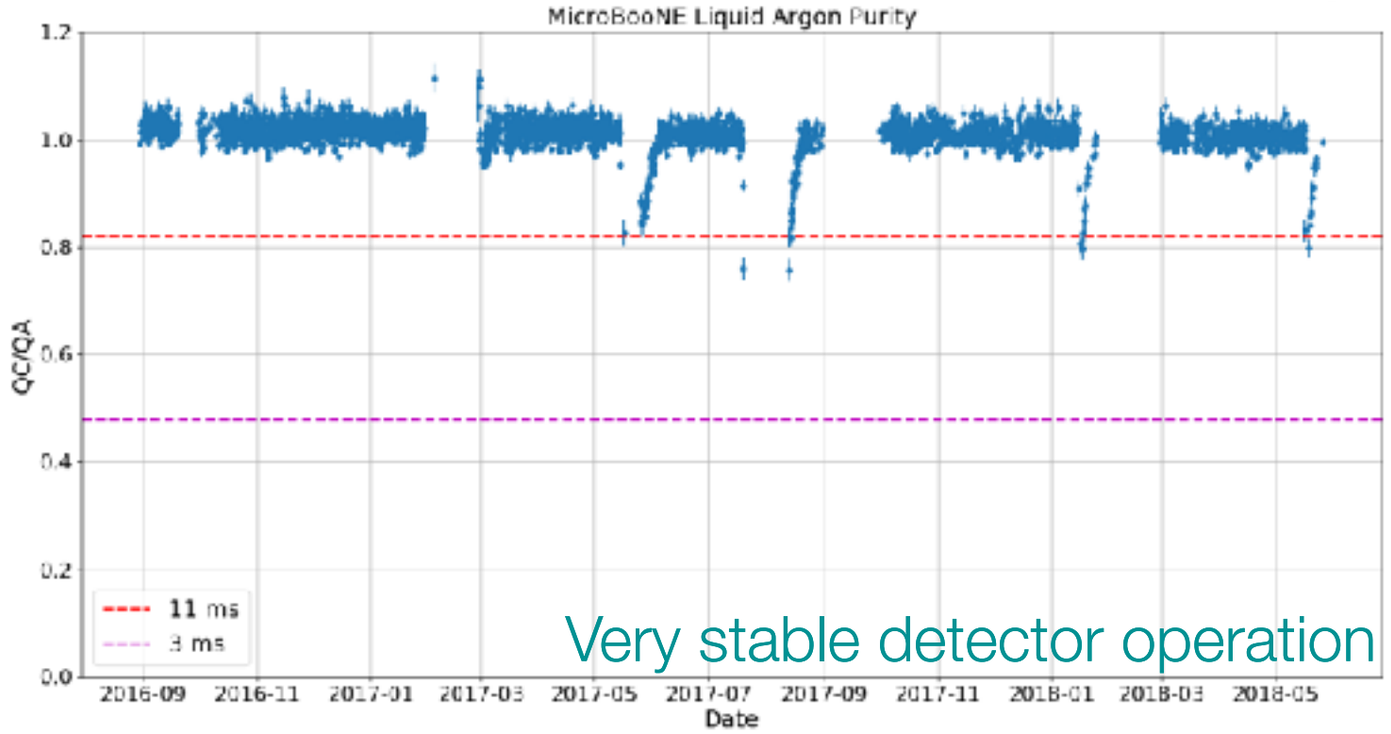

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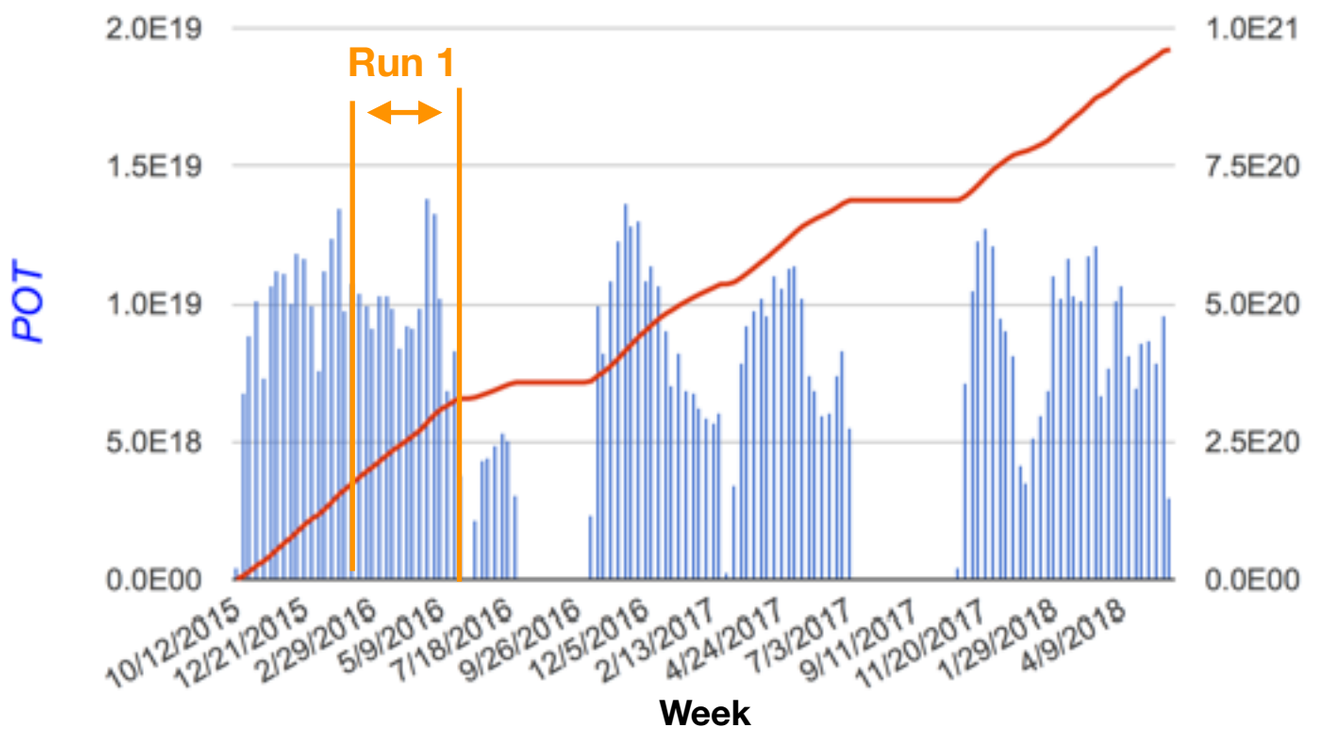

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Understanding a LArTPC

Detailed characterization of the detector is key to our Physics and to our R&D mission for future detectors

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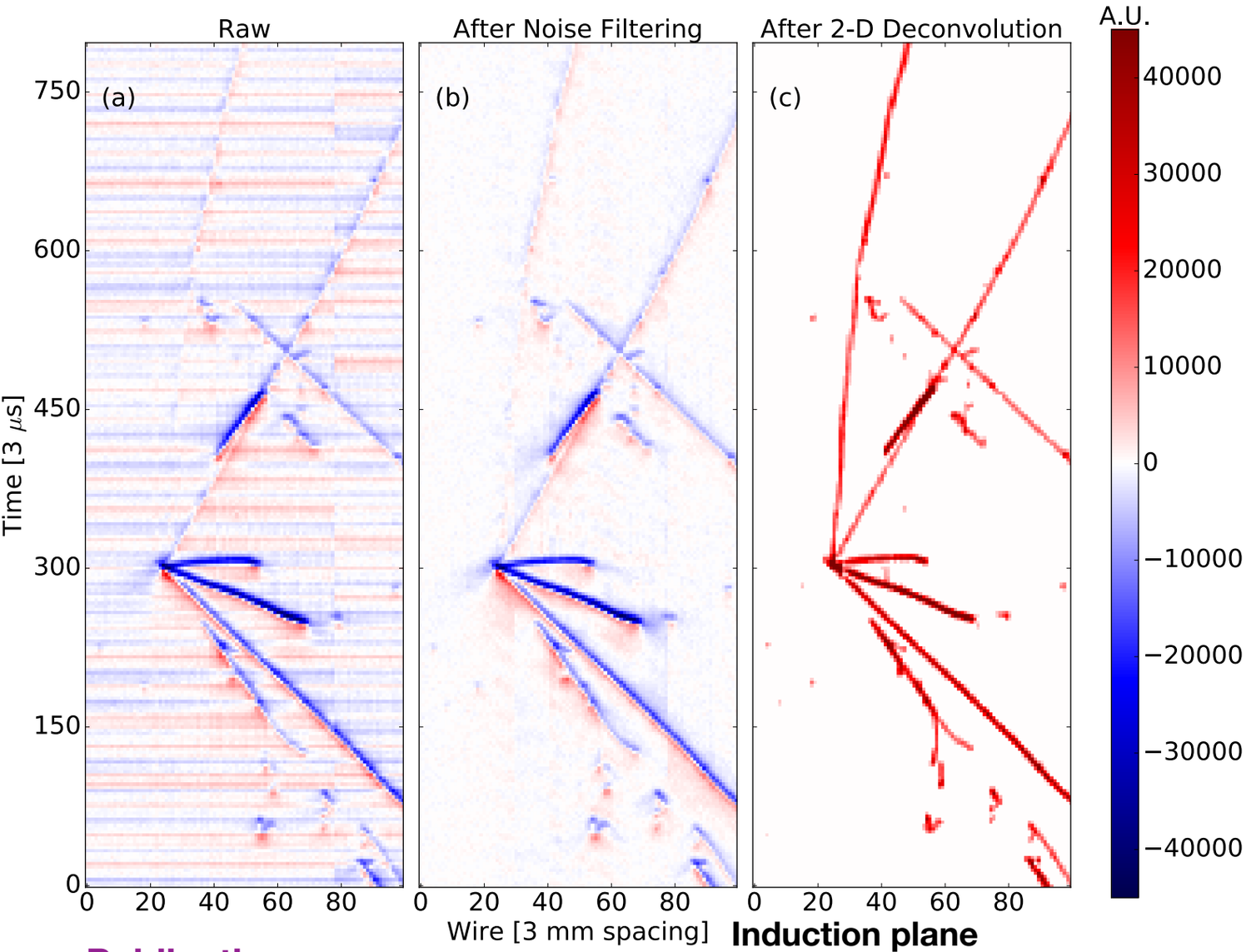


- Powerful filtering techniques can address many sources of noise
- Excellent characterization of multiple wire signal response (2d-deconvolution)
- Robust signal processing allows calorimetry in all three planes (**enabling induction planes**)

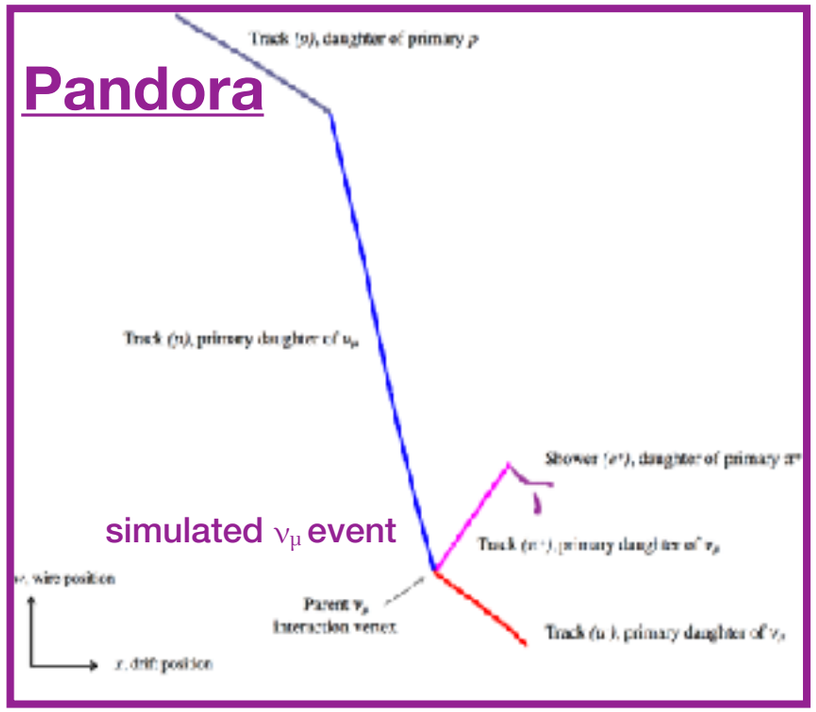
Publications

1. *"Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE"*, arXiv:1804.02583, submitted to JINST
2. *"Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation"*, arXiv:1802.08709, accepted by JINST
3. *"Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC"*, arXiv:1705.07341, JINST 12, P08003 (2017)
4. "Detector Calibration using through going and stopping muons in the MicroBooNE LArTPC", MICROBOONE-NOTE-1048-PUB, 2018

Event reconstruction techniques

- Different reconstruction techniques have been developed
- Reached high level of sophistication
- Essential for SBN and DUNE (shared software between all experiments!)

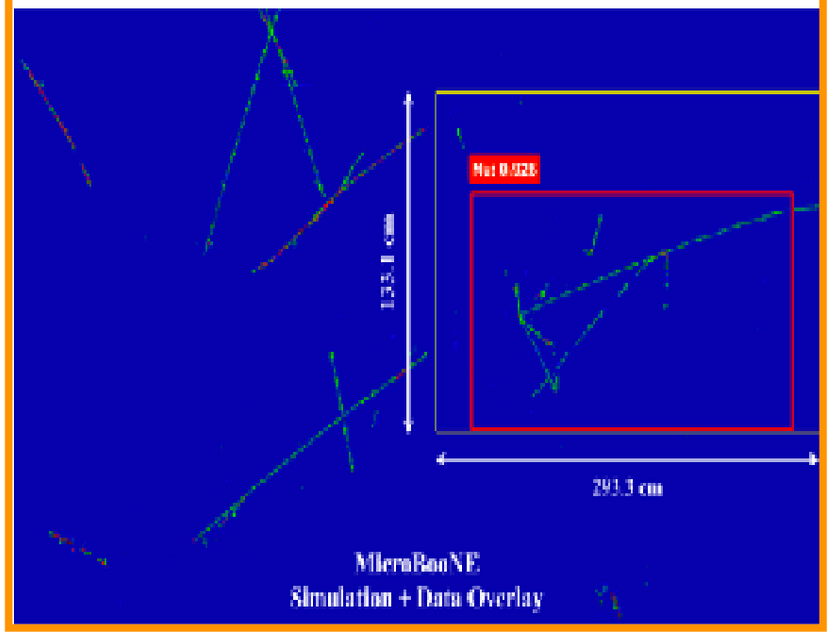
Pandora



simulated ν_μ event

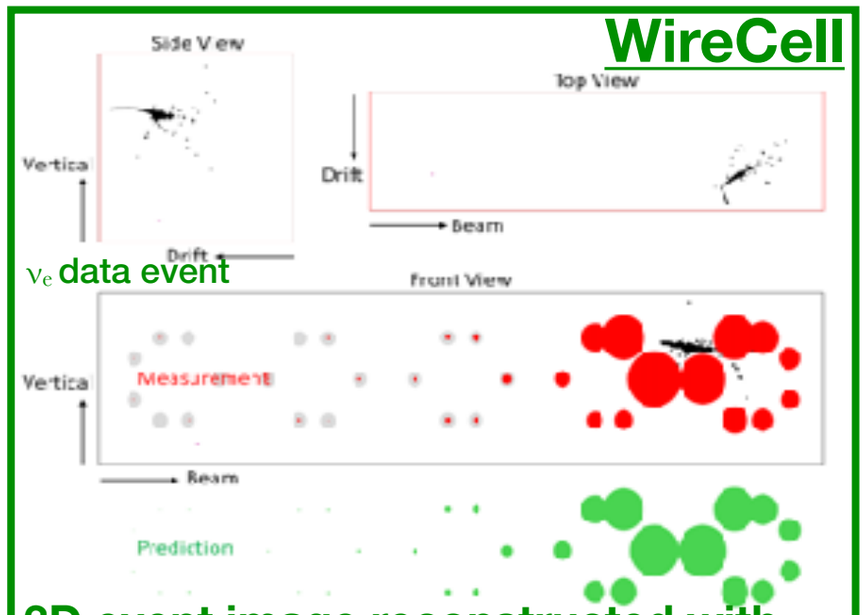
"The Pandora Multi-Algorithm Approach to Automated Pattern Recognition of Cosmic Ray Muon and Neutrino Events in the MicroBooNE Detector", Eur. Phys. J. C78, 1, 82 (2018)"

Machine Learning



"Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber", JINST 12, P03011 (2017)

WireCell



ν_e data event

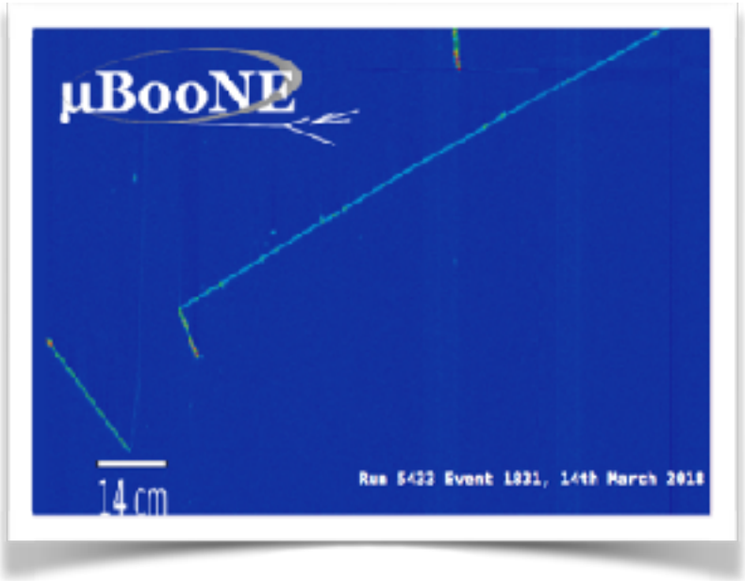
3D event image reconstructed with charge matching

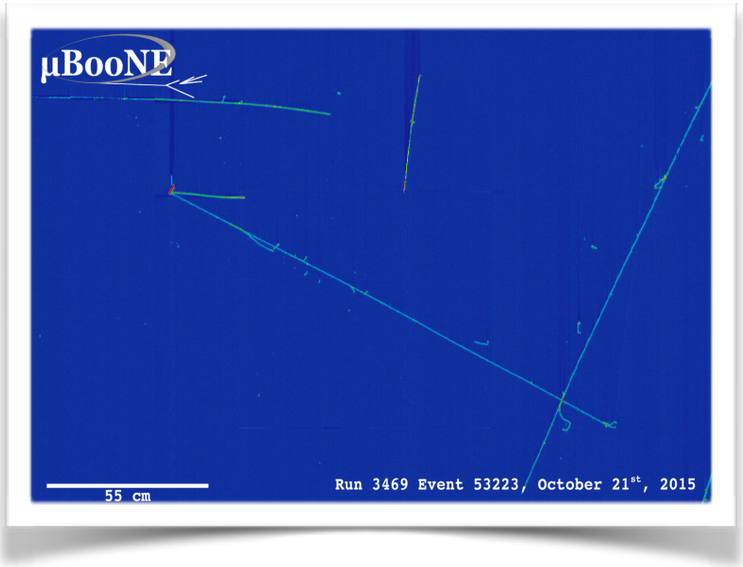
New Public Notes and Posters

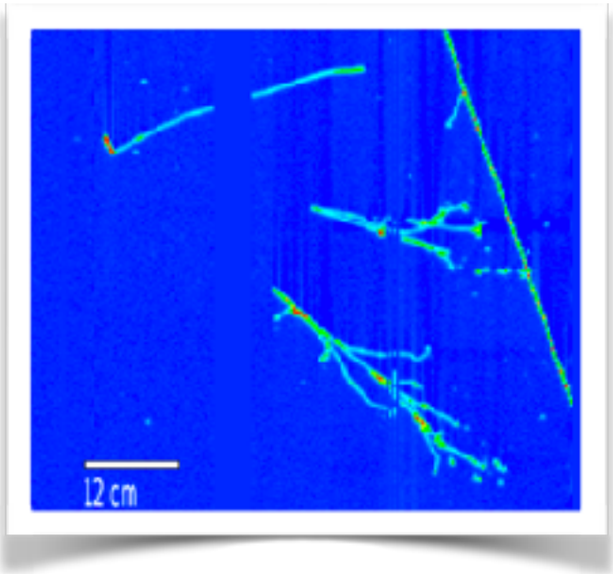
1. A. Hourlier, "Vertex finding and reconstruction for contained two-track events in the MicroBooNE detector", MICROBOONE-NOTE-1042-PUB, 2018
2. B. Russell, "Towards automated neutrino selection at MicroBooNE using tomorgraphic event reconstruction", MICROBOONE-NOTE-1040-PUB, 2018
3. H. Wei, "Recent progress on wire-cell tomographic event reconstruction for LArTPCs",
4. J. Moon, *Hunting muon neutrinos in microboone with deep learning techniques, MICROBOONE-NOTE-1051-PUB, 2018*
5. L. Domine & K. Terao, Applying deep neural network techniques for LArTPC data reconstruction(Kazu/Laura) **Finalist!**
6. **Reconstruction performance studies with MicroBooNE data,** *MICROBOONE-NOTE-1049-PUB, 2018*

Neutrino interaction measurements

- Cross-section measurements on Ar are **essential for our low-energy excess analysis** and for future LAr experiments (DUNE)
- LArTPCs are powerful to study final state topologies and inform theoretical models (e.g. Charged particle multiplicity studies)
- First step is to perform a ν_μ CC inclusive measurement
- Follow with suites of exclusive channel measurements (by final states)
  - ✓ ν_μ CC 1μNp (where N ≥ 0)
  - ✓ ν_μ CC-π^0
  - ✓ ν_μ CC-$\pi^\pm$
  - ✓ High-statistics analyses







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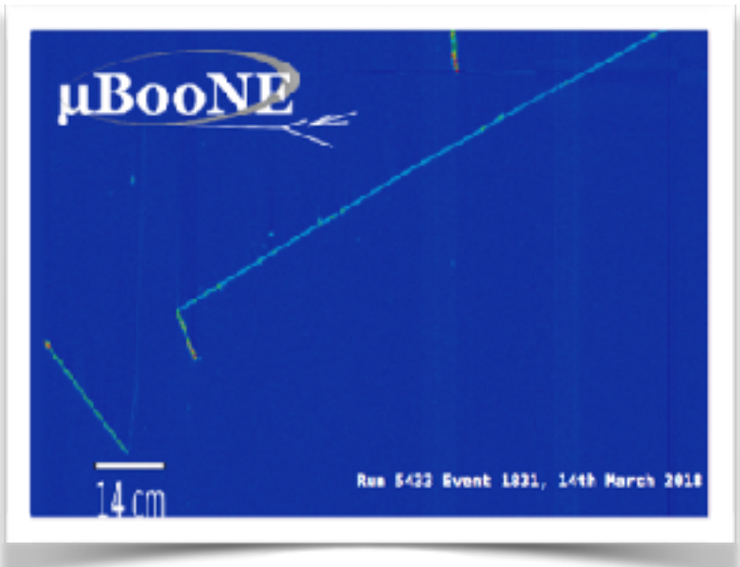
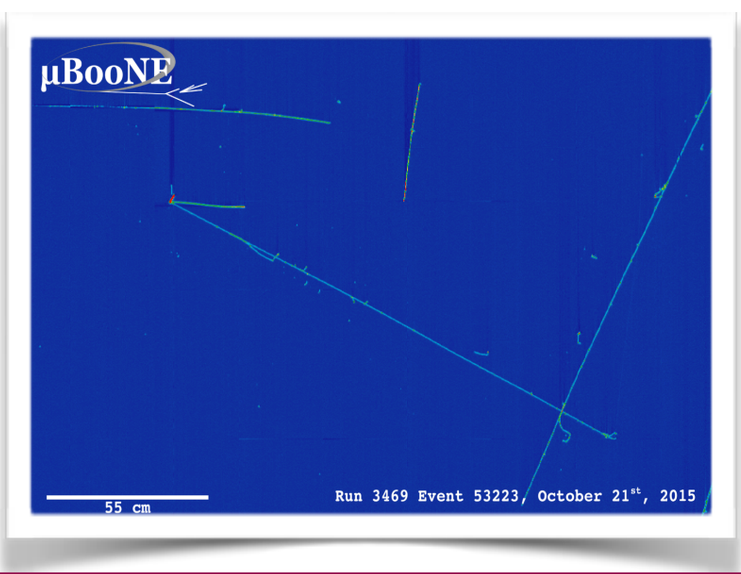
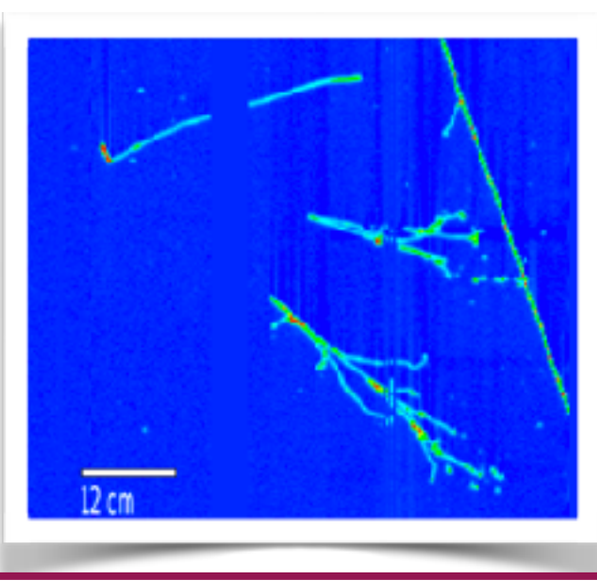
  - ✓ High-statistics analyses

New results presented in this talk!







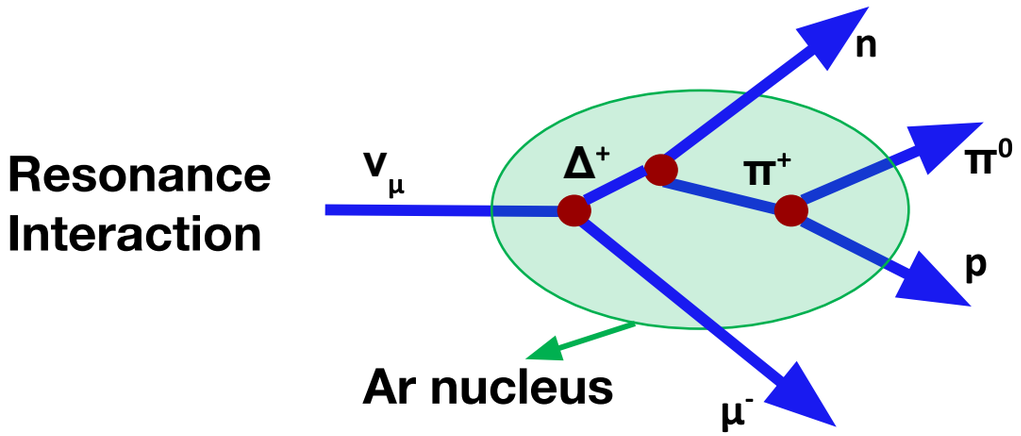
New Public notes and Posters

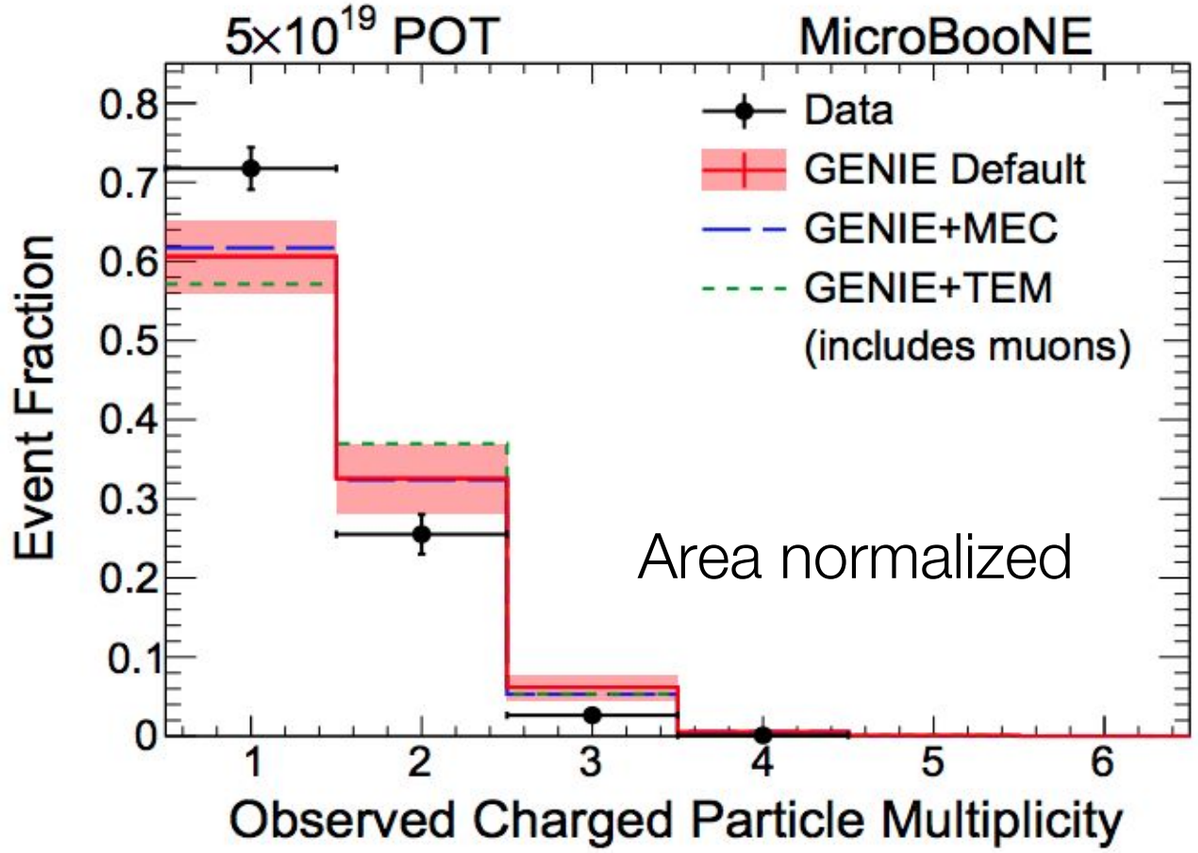
1. M. Del Tutto & A. Schukraft, First measurement of muon neutrino charged-current inclusive cross-section measurement in MicroBooNE, MICROBOONE-NOTE-1045-PUB, 2018
2. J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC, MICROBOONE-NOTE-1032-PUB, 2018
3. *A. Furmanski, Towards measurements of nuclear effects in MicroBooNE,* MICROBOONE-NOTE-1046-PUB, 2018

Neutrino interaction measurements

- Important step was to study the charged particle multiplicity (CPM) in ν_μ interactions
- Powerful way to validate nuclear models (and generators)
- First physics result!

Example of neutrino interaction with CPM = 2



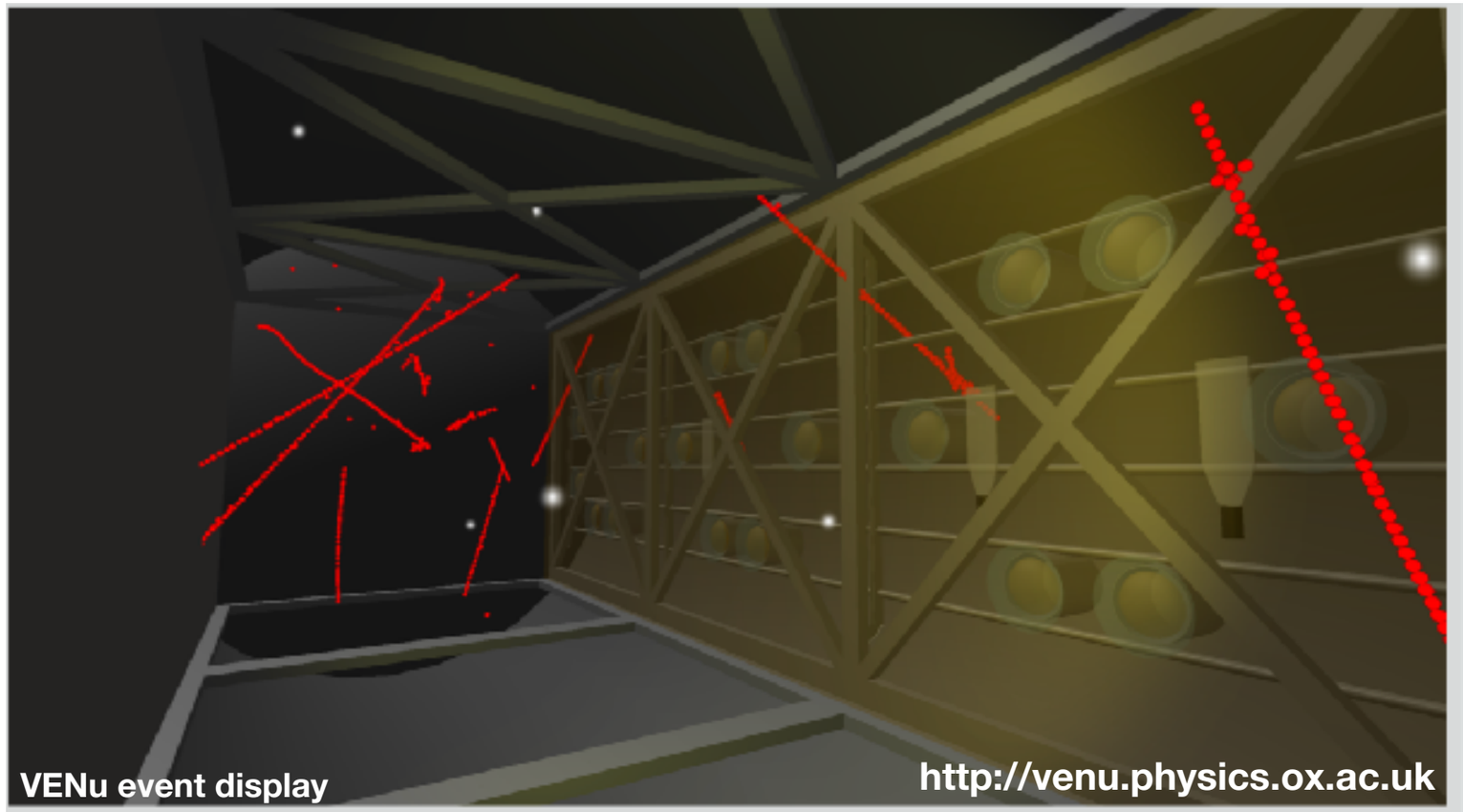


"Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions", arXiv:1805.06887, submitted to PRD (2018)

Poster: A. Rafique, Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions

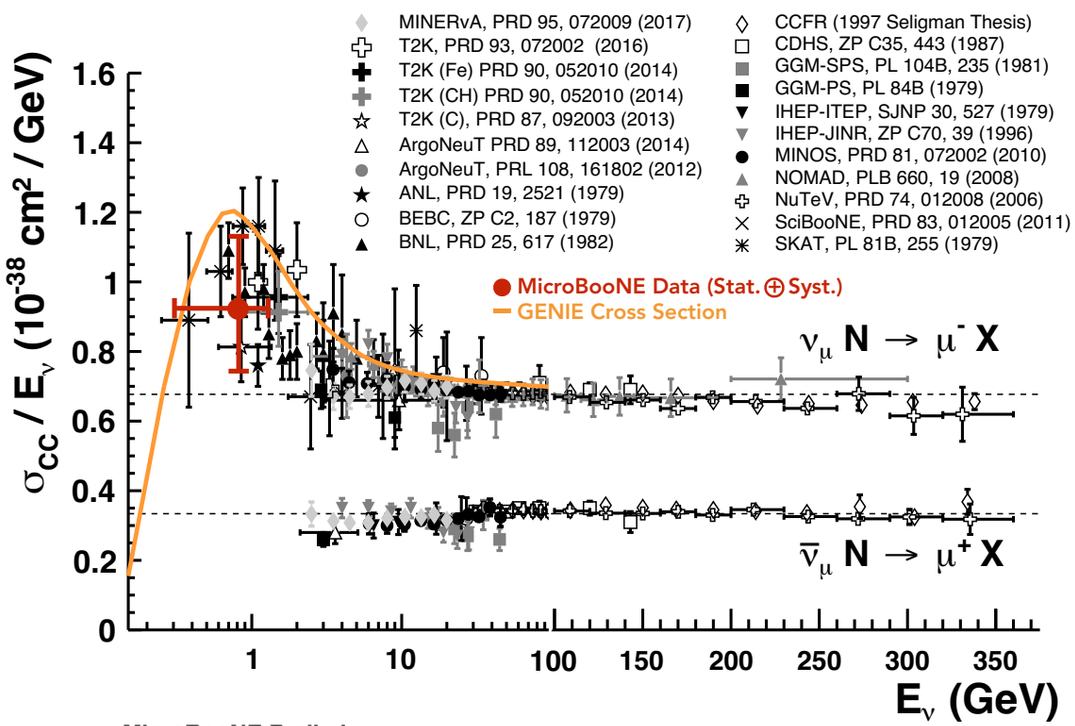
ν_μ CC Inclusive measurement

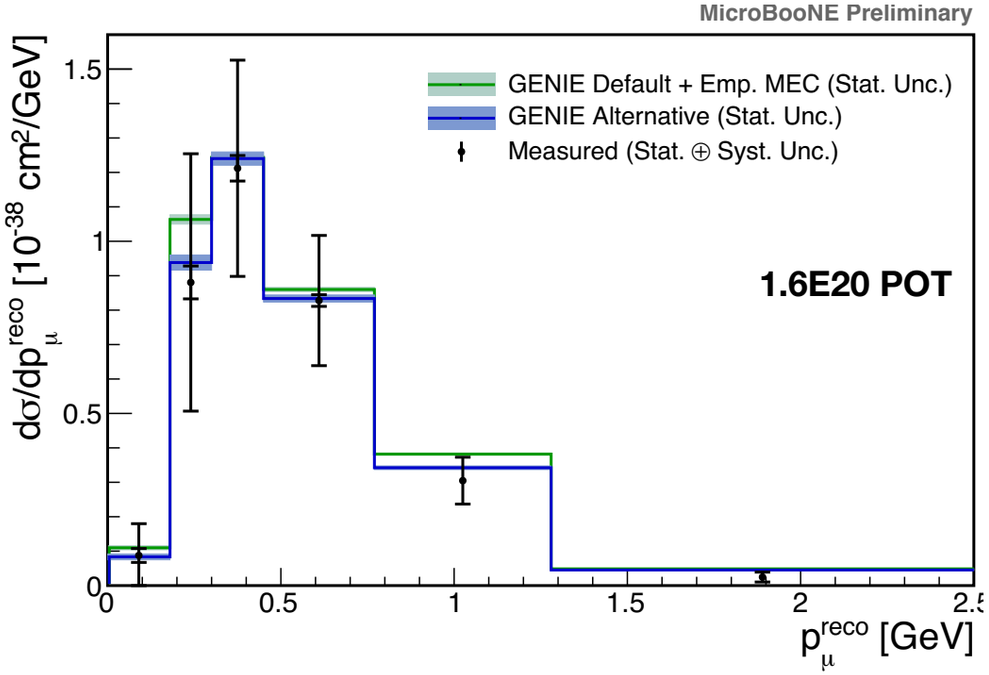
- Inclusive ν_μ CC interactions is the obvious first cross-section measurement
- It has been measured by many other experiments, making it a great benchmark
- Directly relevant to DUNE ν_μ CC signal

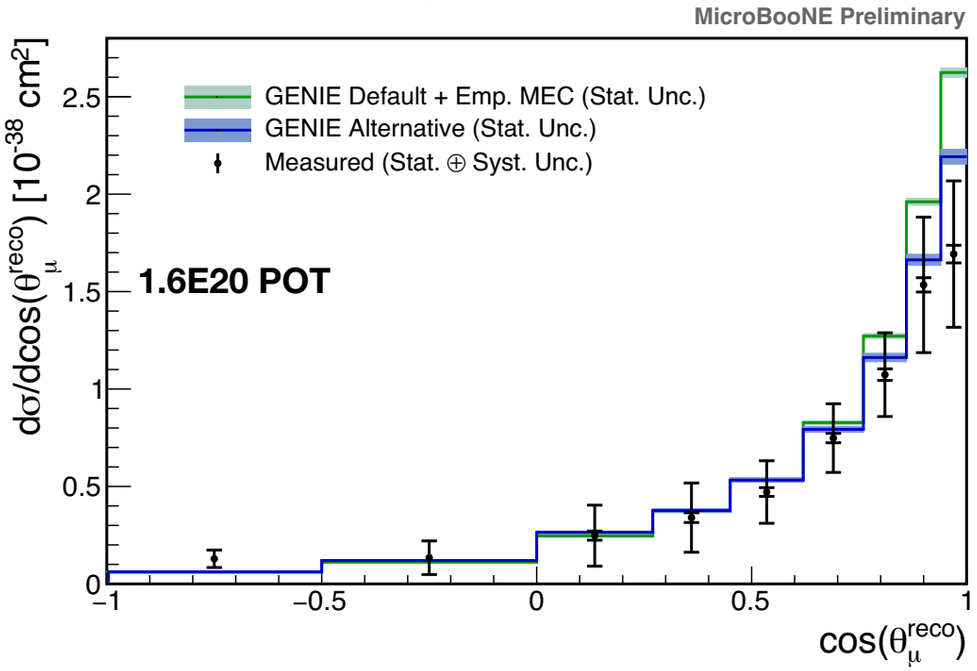


First public presentation of these results!

ν_μ CC Inclusive measurement







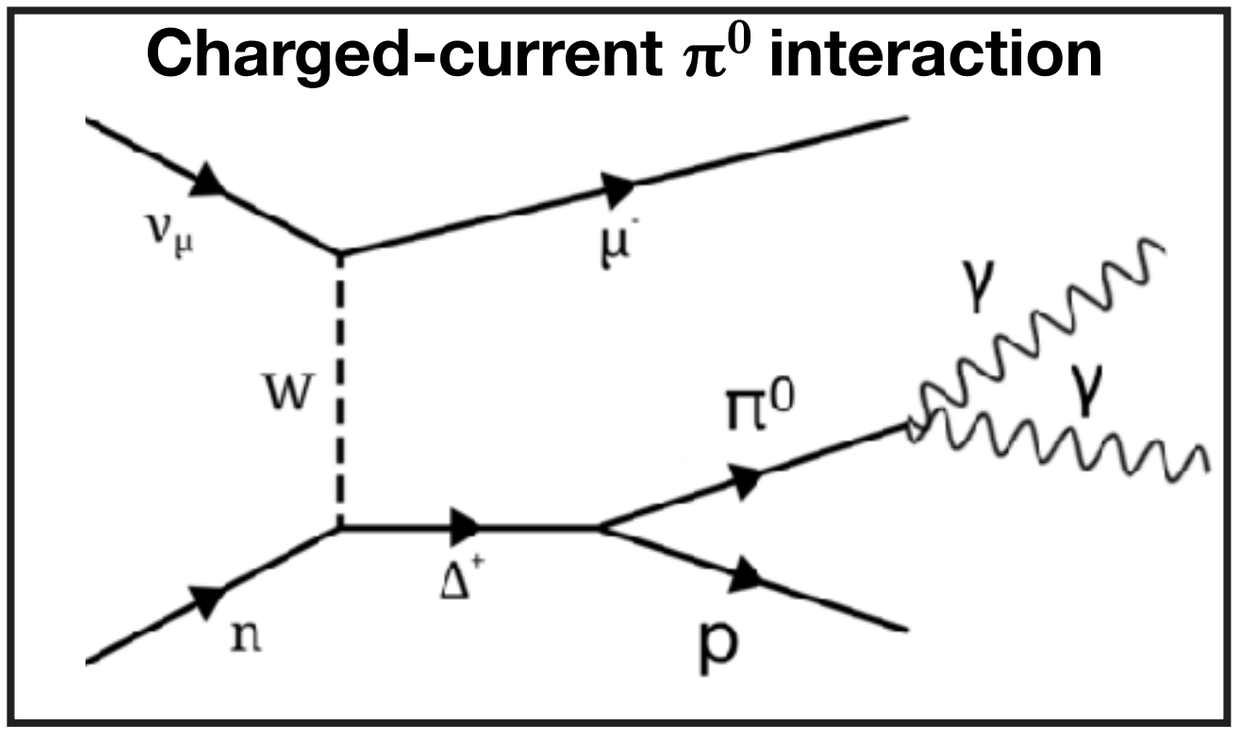
Double-differential cross section coming soon!

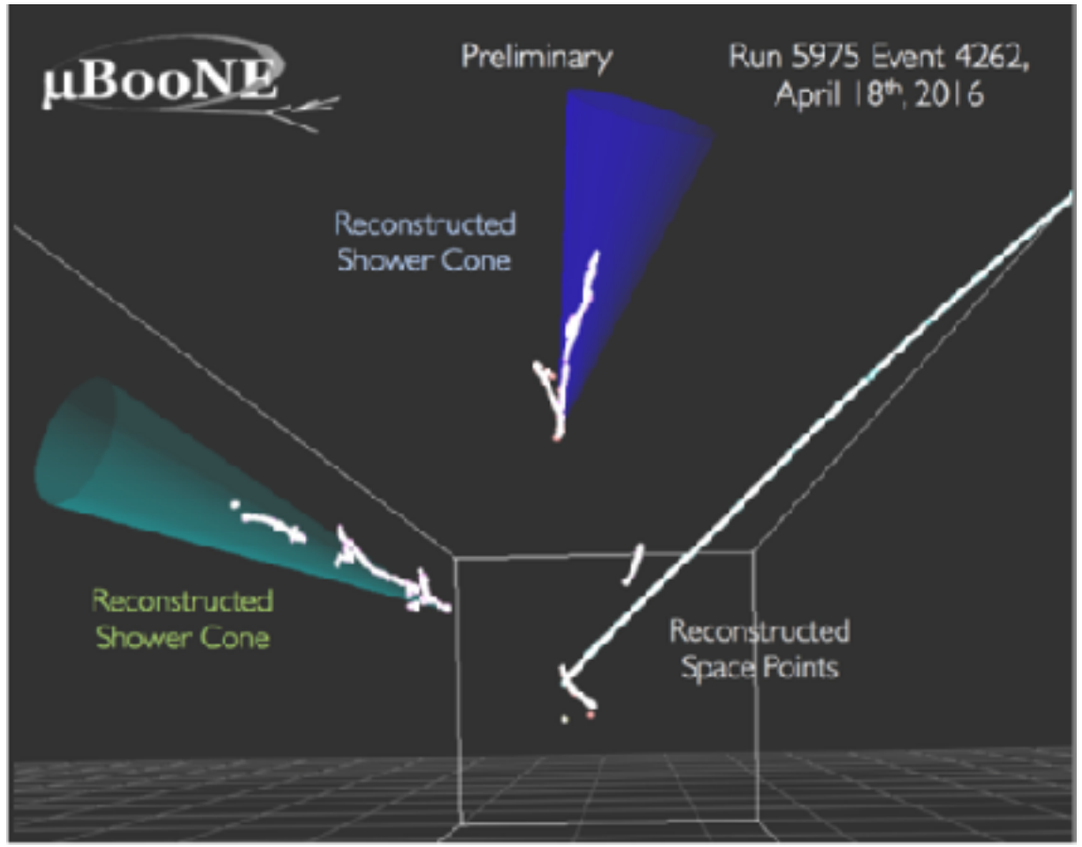
Poster: M. Del Tutto & A. Schukraft, First measurement of muon neutrino charged-current inclusive cross-section measurement in MicroBooNE

Public Note: MICROBOONE-NOTE-1045-PUB, 2018

CC-π^0cross-section measurement

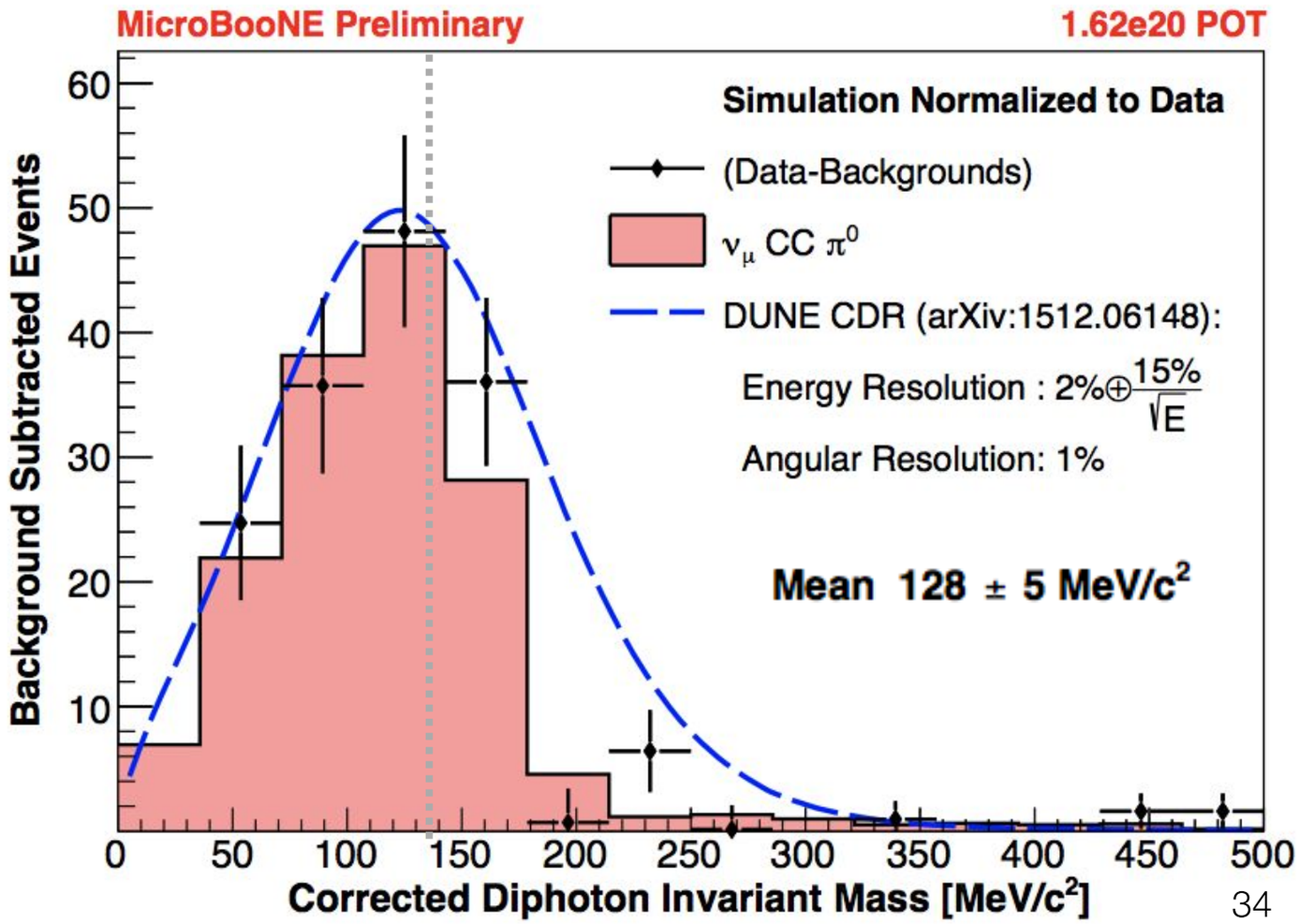
- Understanding π^0 is a crucial step towards searching for low-energy excess:
  - ✓Test shower reconstruction
  - ✓Validate electromagnetic shower energy resolution
- First measurement of CC-π^0 on Ar





CC-π^0 reconstruction and selection

Reconstruction of the π^0 mass peak:



34

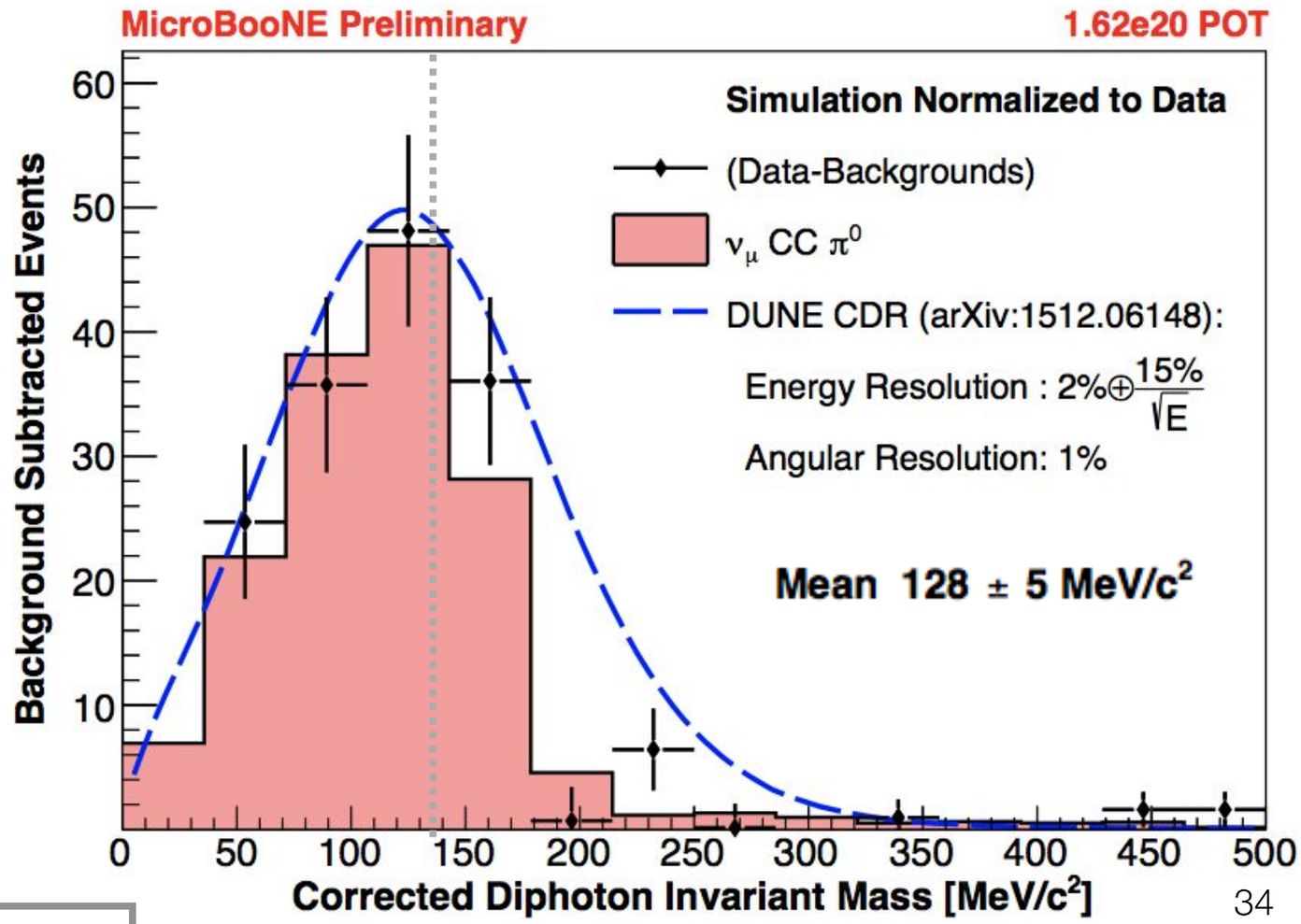
Mass of π^0: 135 MeV/c²

Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC

Public Note: MICROBOONE-NOTE-1032-PUB, 2018

CC-π^0 reconstruction and selection

Reconstruction of the π^0mass peak:



Total cross section:

Mass of π^0: 135 MeV

$$\left\langle \sigma^{\nu_\mu \mathrm{CC}\pi^0} \right\rangle_\Phi = (1.94 \pm 0.16\ [\mathrm{stat.}] \pm 0.60\ [\mathrm{syst.}]) \times 10^{-38}\ \frac{\mathrm{cm}^2}{\mathrm{Ar}}$$

Next steps: Higher statistics analysis → differential cross-section measurement

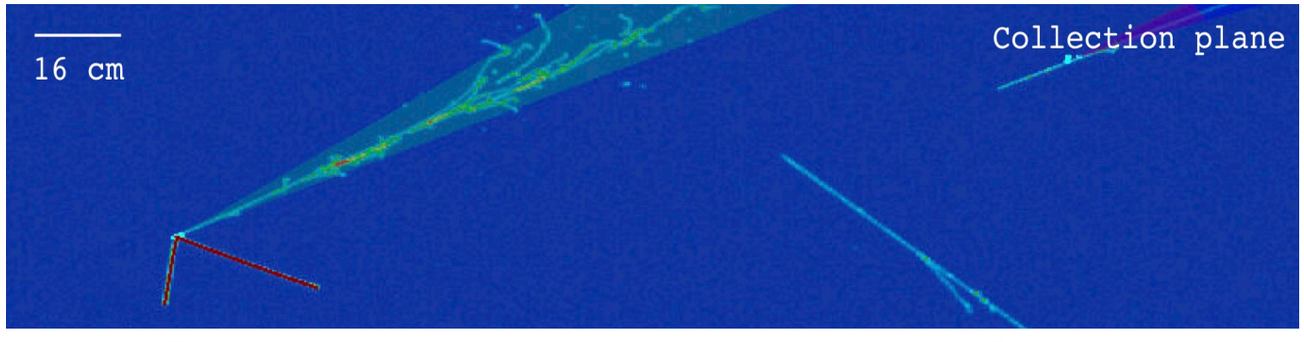
Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC

Public Note: MICROBOONE-NOTE-1032-PUB, 2018

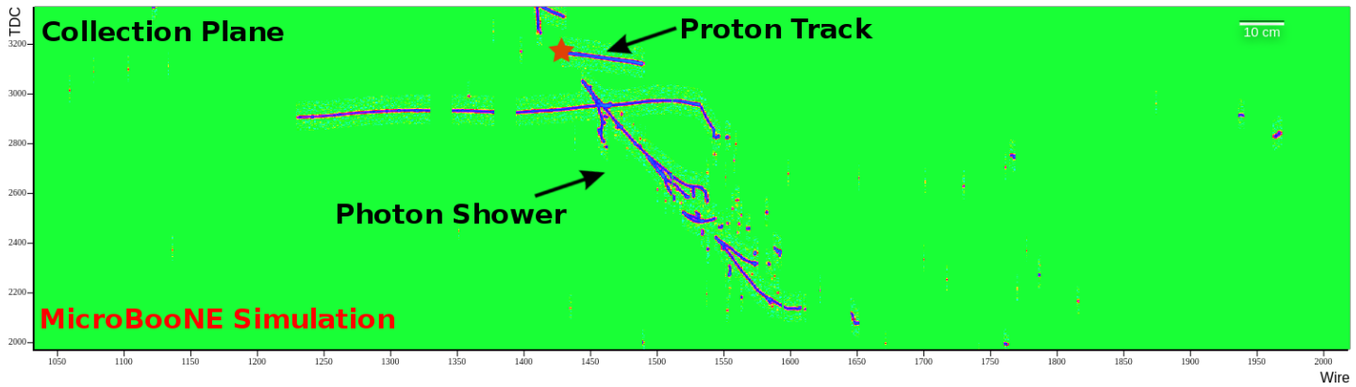
Towards the low-energy excess

Our current plan

- Several complementary LEE analyses:
  - ➡ ν_e analyses
    - ✓ 1e1p (Deep Learning)
    - ✓ 1eNp (Pandora)
    - ✓ Inclusive: 1e (Pandora, WireCell)
    - ✓ …
  - ➡ Single photon analyses
    - ✓ 1γ0p (Pandora)
    - ✓ 1γ1p (Pandora)
    - ✓ …



Example of reconstructed nue signal MC event



Example of reconstructed photon signal MC event

Crucial for testing different LEE models (e.g. 3+1 neutrinos, NC Δ radiative decays,…)

Towards the low-energy excess

Our current plan

- Several complementary LEE analyses:
  - ➡ ν_e analyses
    - ✓ 1e1p (Deep Learning)
    - ✓ 1eNp (Pandora)
    - ✓ Inclusive: 1e (Pandora, WireCell)
    - ✓ …
  - ➡ Single photon analyses
    - ✓ 1γ0p (Pandora)
    - ✓ 1γ1p (Pandora)
    - ✓ …

New Public Notes and Posters

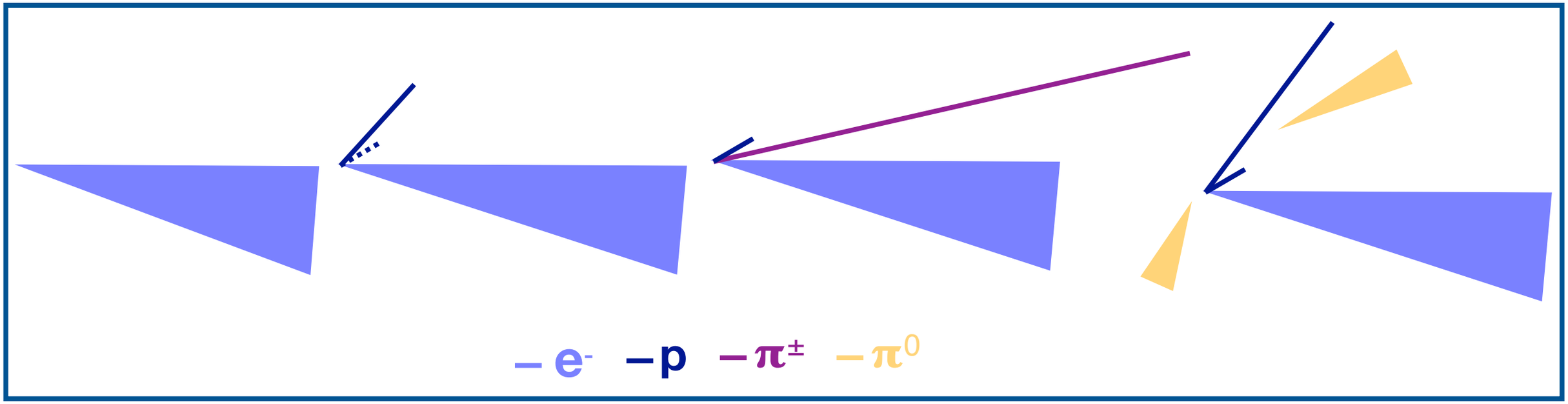
1. **R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction, MICROBOONE-NOTE-1038-PUB, 2018**
2. **R. Murrels, Search for NC single photon events in MicroBooNE, MICROBOONE-NOTE-1041-PUB, 2018**
3. **M. Ross-Lonergan, MicroBooNE tests of the MiniBooNE low-energy excess, MICROBOONE-NOTE-1043-PUB, 2018 Finalist!**

- Blind search strategy → Very small open data sample (~4%) to develop robust and careful analysis
- Large NuMI beam open data sample available for cross-checks
- We first want to perform our cross-section measurements to provide strong understanding of the interactions and backgrounds

ν_e analysis

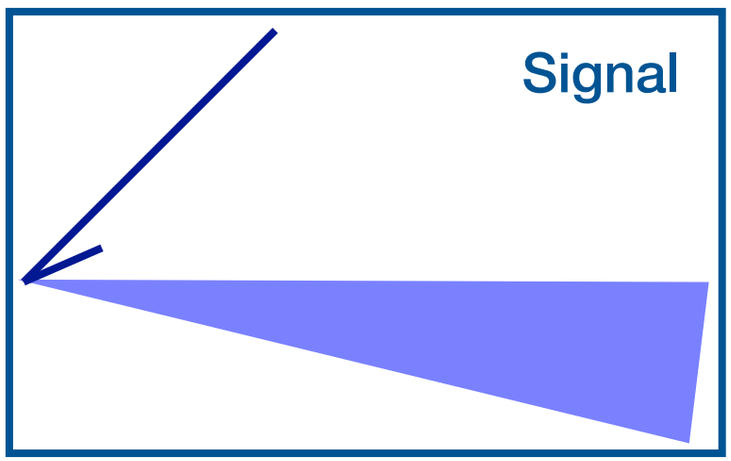
- Many different possible channels to study ν_e
- Each have different characteristics
- Power of LArTPC will allow for disentangling the potential effects of the analyzed channels

Example of signal topologies for ν_e

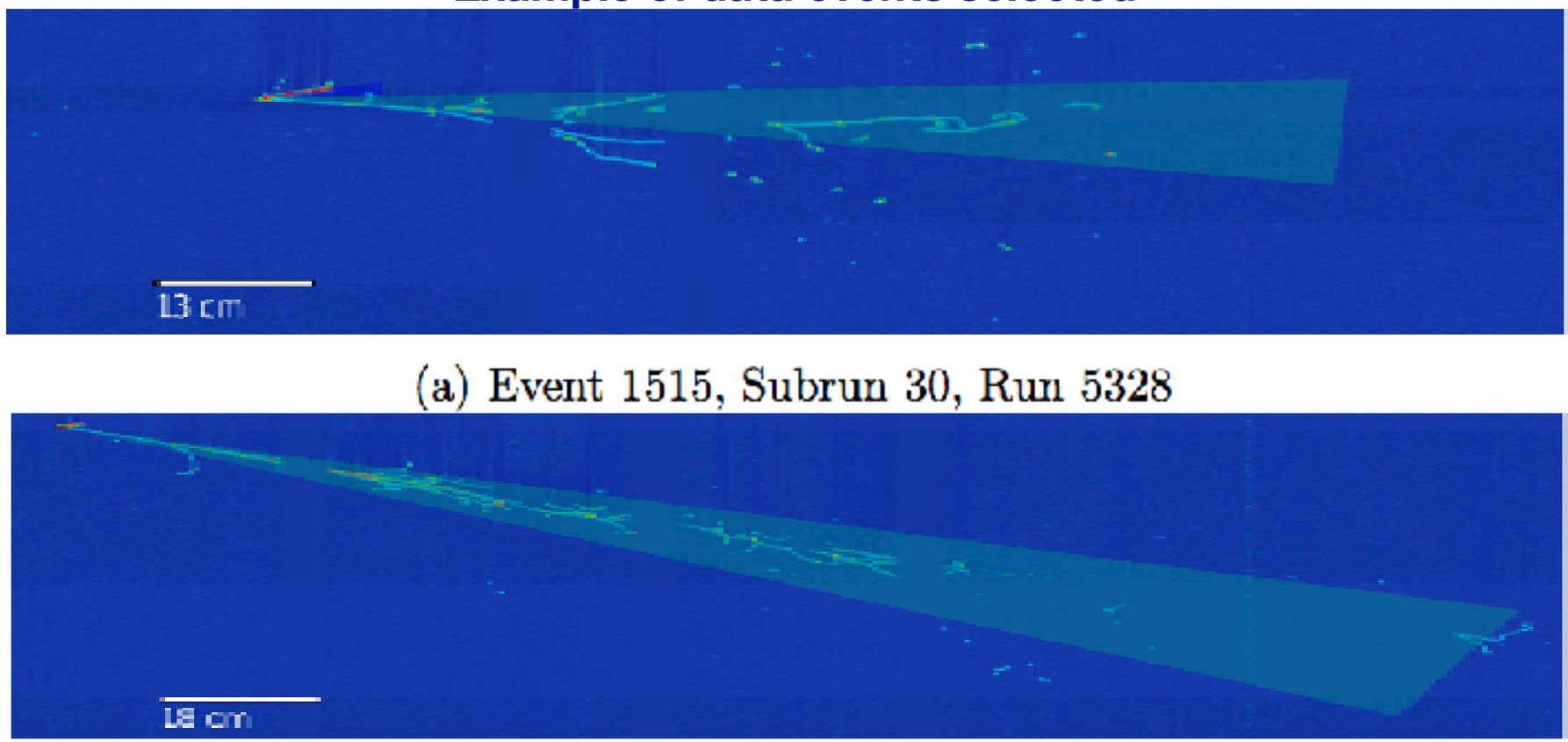


ν_e analysis

One of our first analyses focuses on the signal most similar to the MiniBooNE CC0π definition: 1 electron + N protons



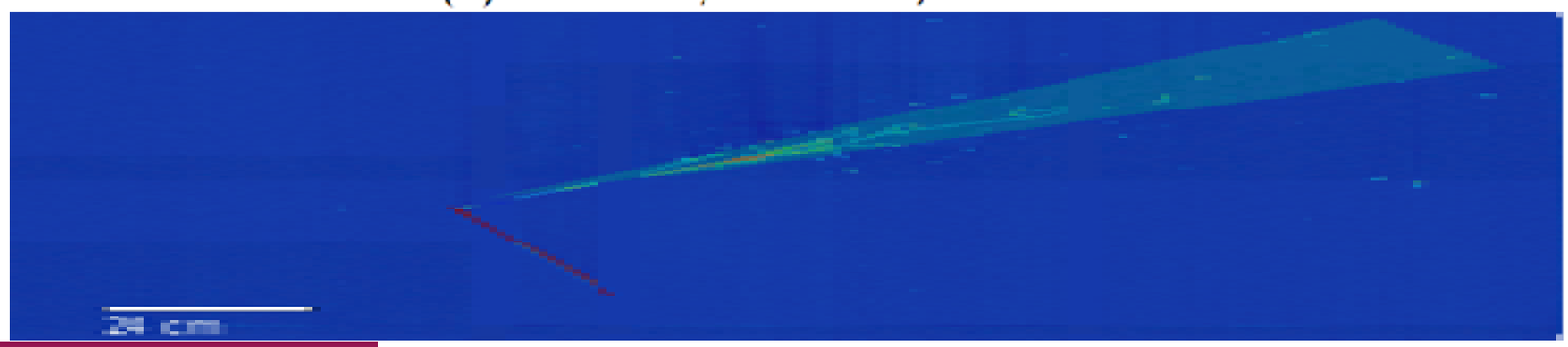
Example of data events selected



(a) Event 1515, Subrun 30, Run 5328

(b) Event 31, Subrun 0, Run 5513

Selected nue data events



(c) Event 3710, Subrun 74, Run 5906

Poster: R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction

Public Note: MICROBOONE-NOTE-1038-PUB, 2018

MicroBooNE summary

- MicroBooNE is an important milestone for LArTPC development and is providing invaluable LAr data - useful for future detectors
- We have been working at understanding the detector effects (noise, diffusion, recombination, space charge effect…), which are essential to understand our physics - **many new results!**
- We have made great progress on automated event reconstruction in LAr using **data** - significant progress in parallel to our physics results
- First physics results are presented (ν_μ CC inclusive differential cross section and CCπ^0 total cross section) and many more are underway
- We have performed our first fully automated ν_e and single photon selections and are addressing the improvements needed for the low-energy search

Towards the full SBN program

- MicroBooNE has been trailblazing the automated neutrino data reconstruction in LArTPC and in calibration techniques, which should provide a head-start for the other two experiments (note: all surface detectors → cosmic mitigation)

- The first stage (MicroBooNE) of the program will provide an answer of the origin of the MiniBooNE excess

- SBND will provide an unoscillated spectrum to identify the origin of a potential excess, in addition to an unprecedented amount of neutrino data on argon. Construction is underway with data taking planned for 2020

- ICARUS will provide the high-statistics coverage of a wide oscillation parameter space to give a definitive answer to the short-baseline anomalies. Construction is progressing well with data taking planned for 2019

- SBN is a definitive program to address LSND/MiniBooNE anomalies in the immediate future (~5 years)

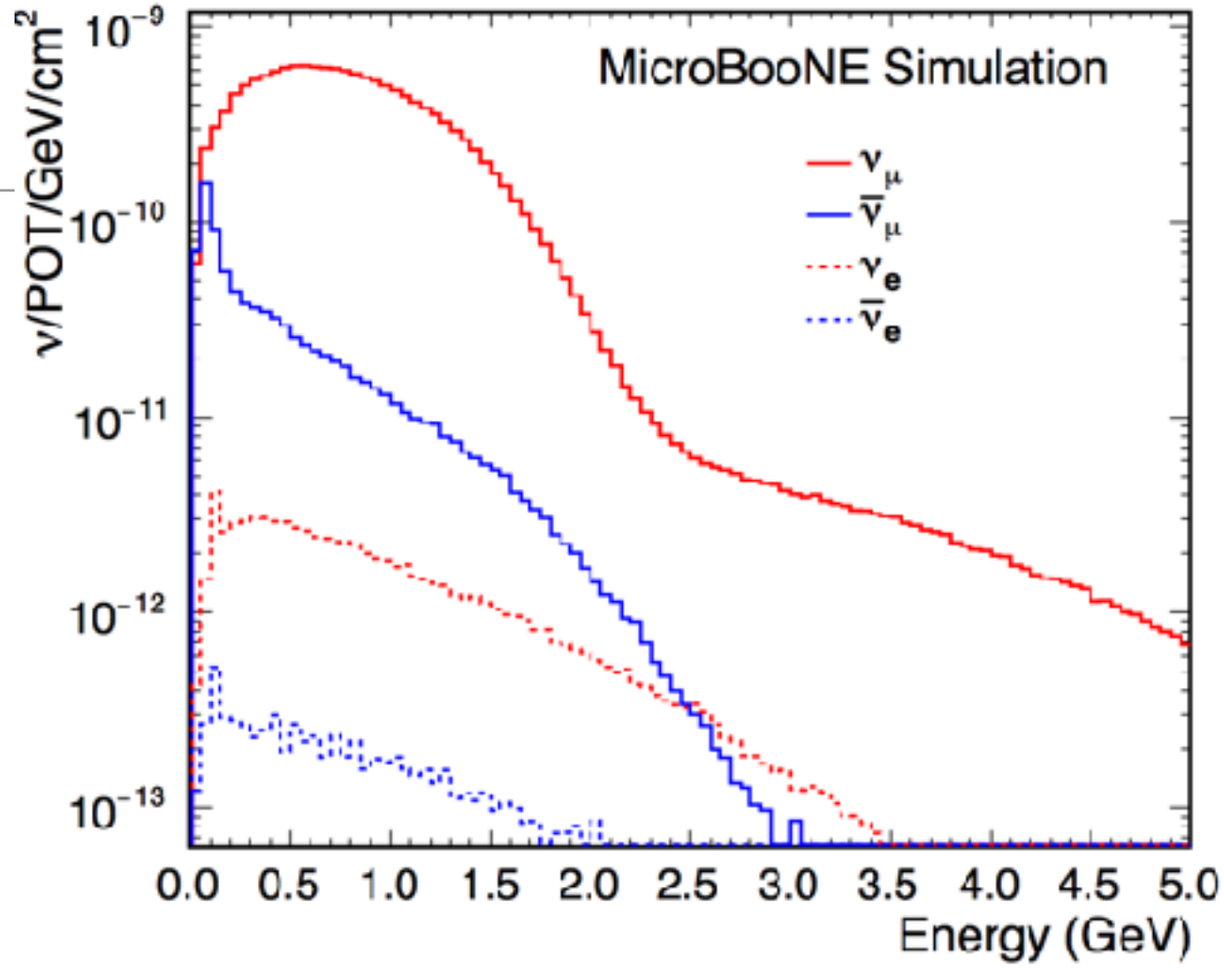
SBN Program

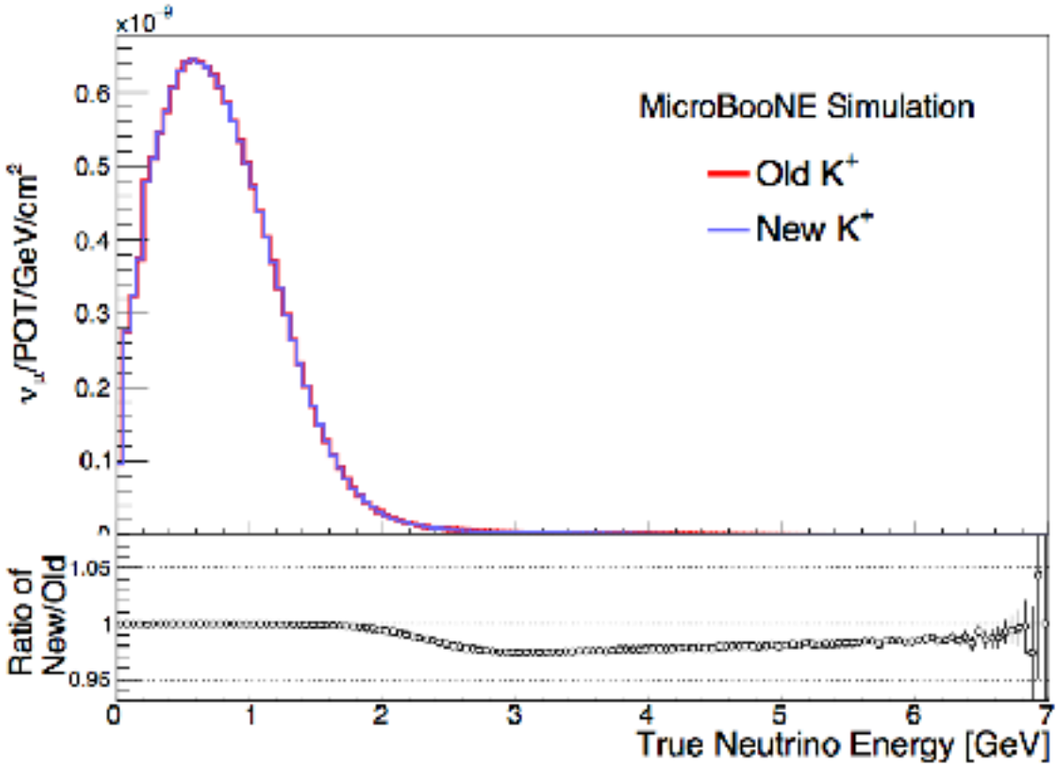
SBND

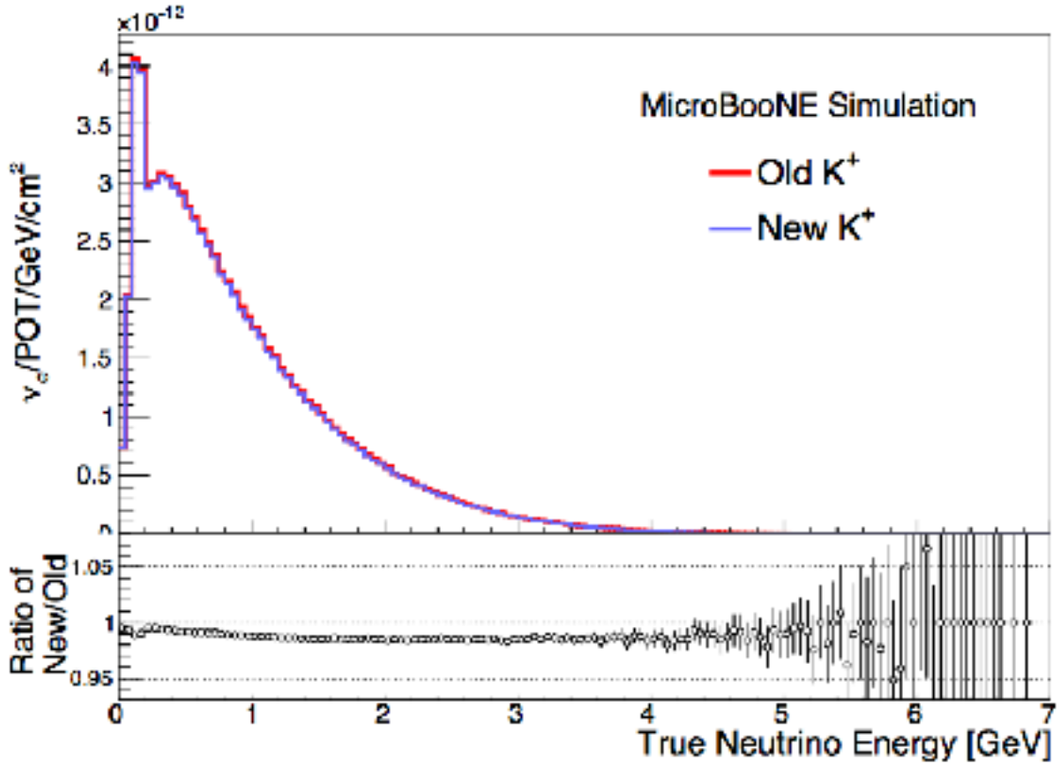
µBooNE

BNB flux

- MicroBooNE flux production based on MiniBooNE flux predictions
- New systematics study for MicroBooNE



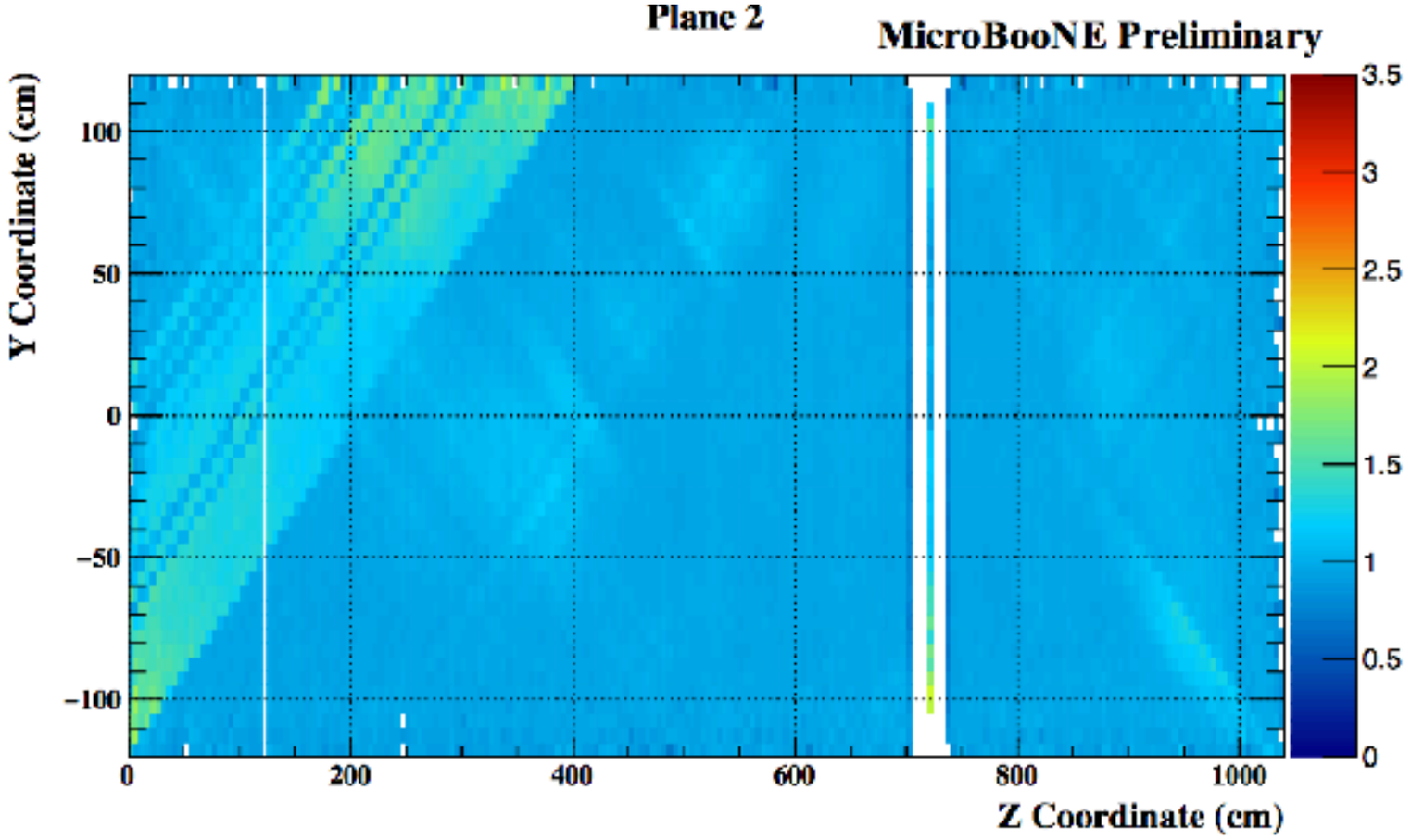


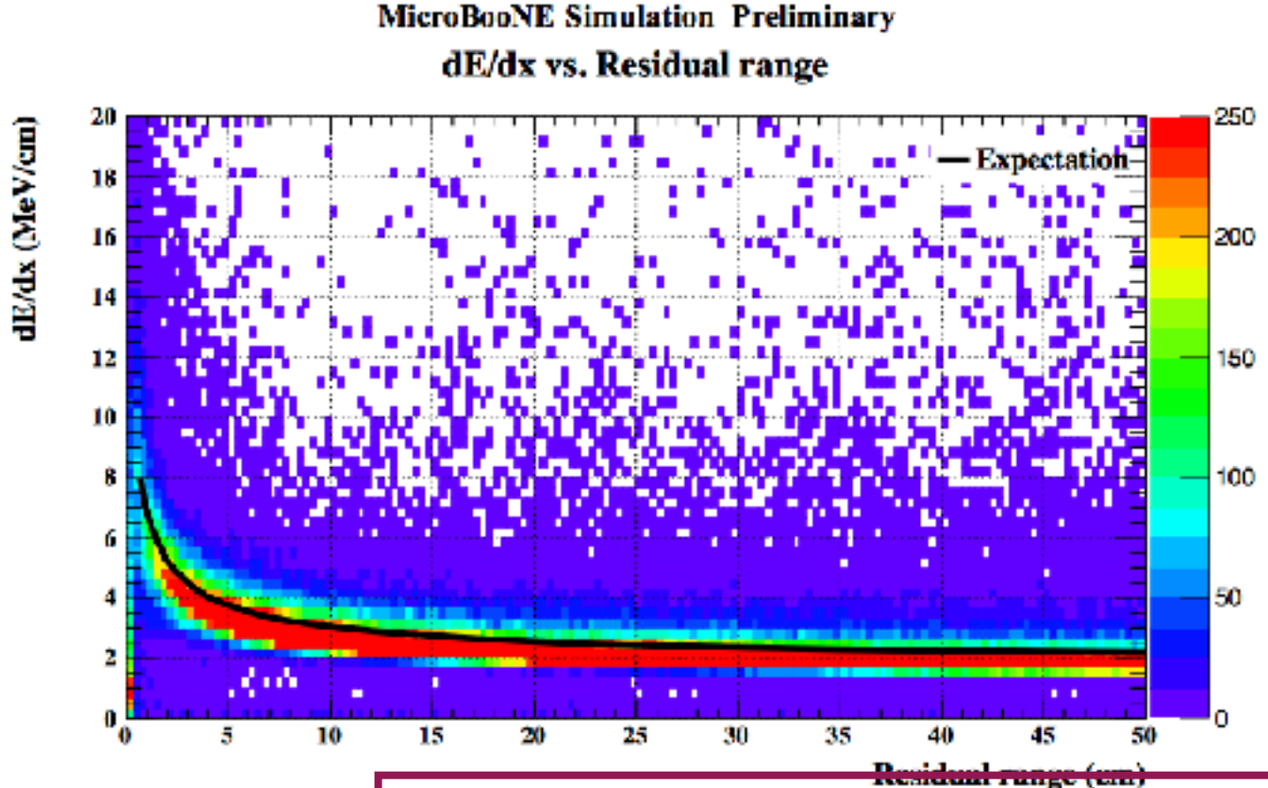


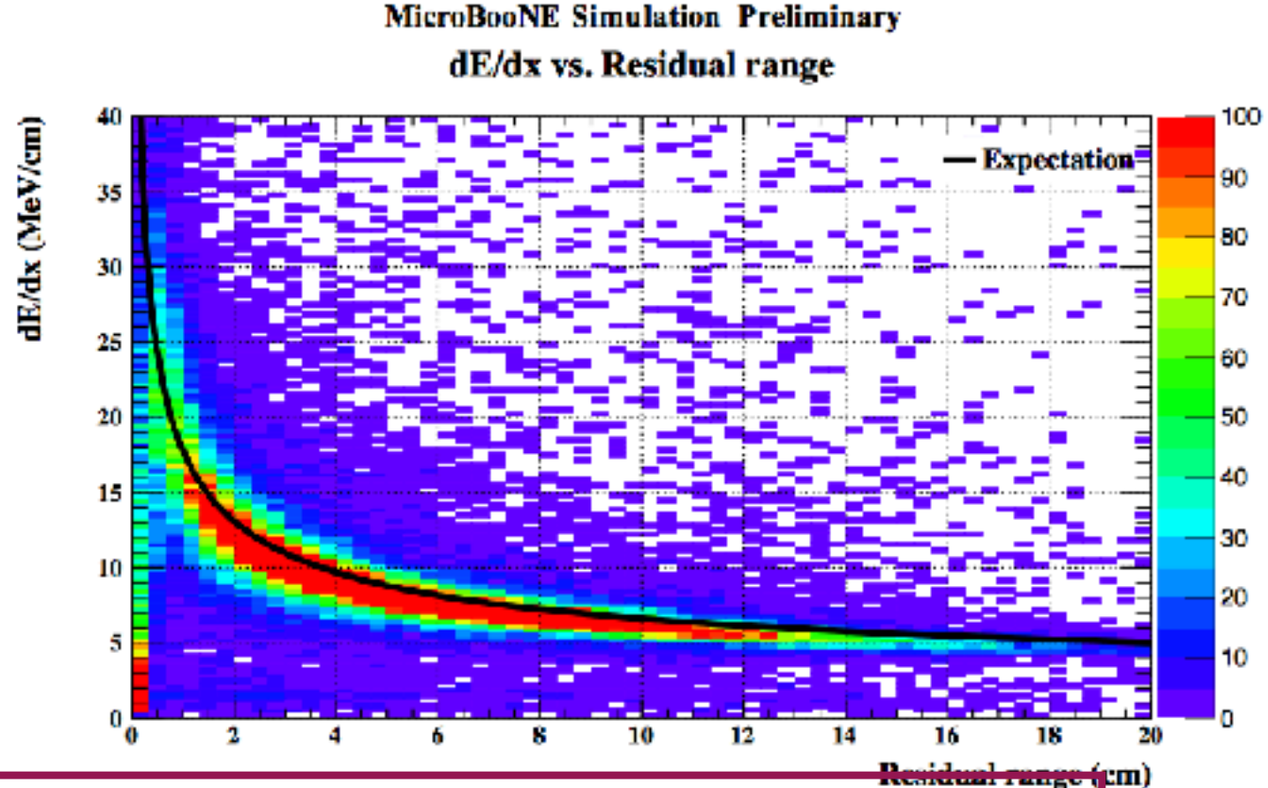
Public Note: MICROBOONE-NOTE-1031-PUB, 2018

Calibration

- YZ correction factors derived from data (Feb-May 2016). Time variation also studied.
- Calibrated dE/dx for stopping muons and stopping protons





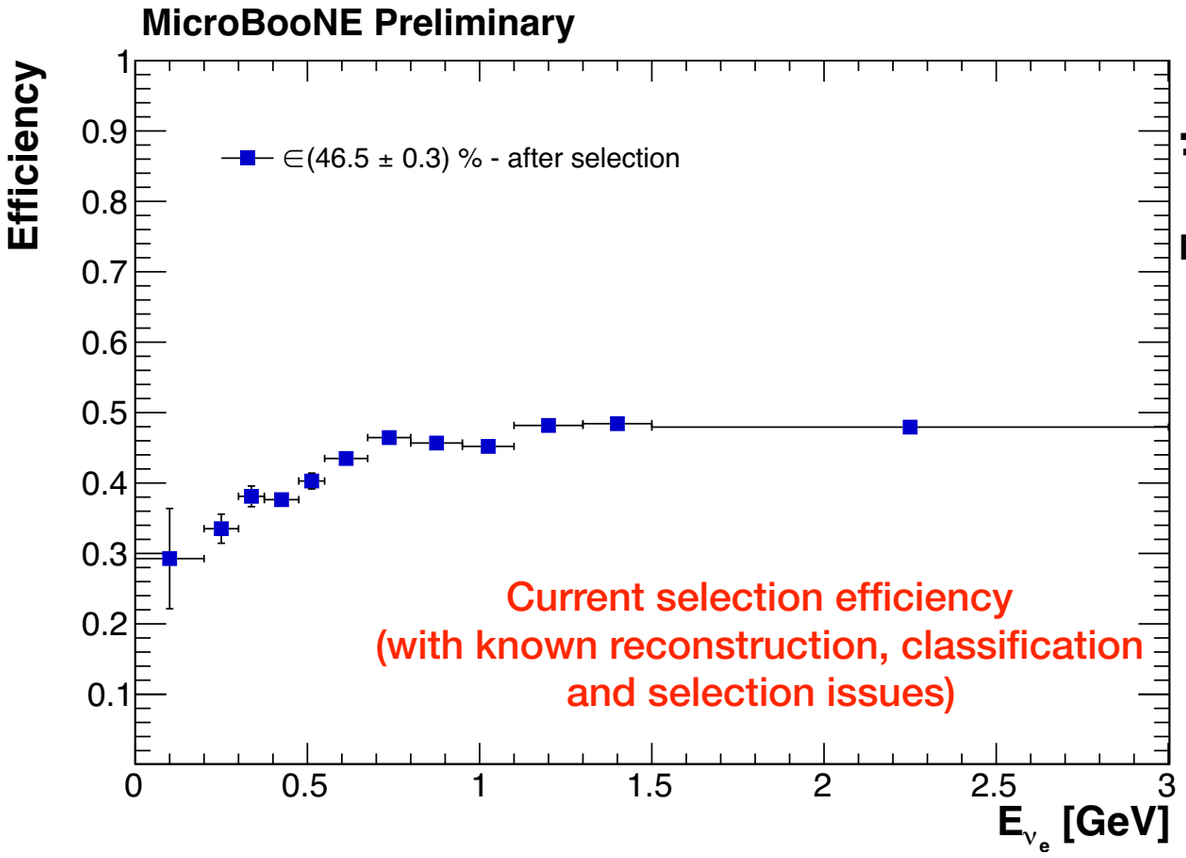


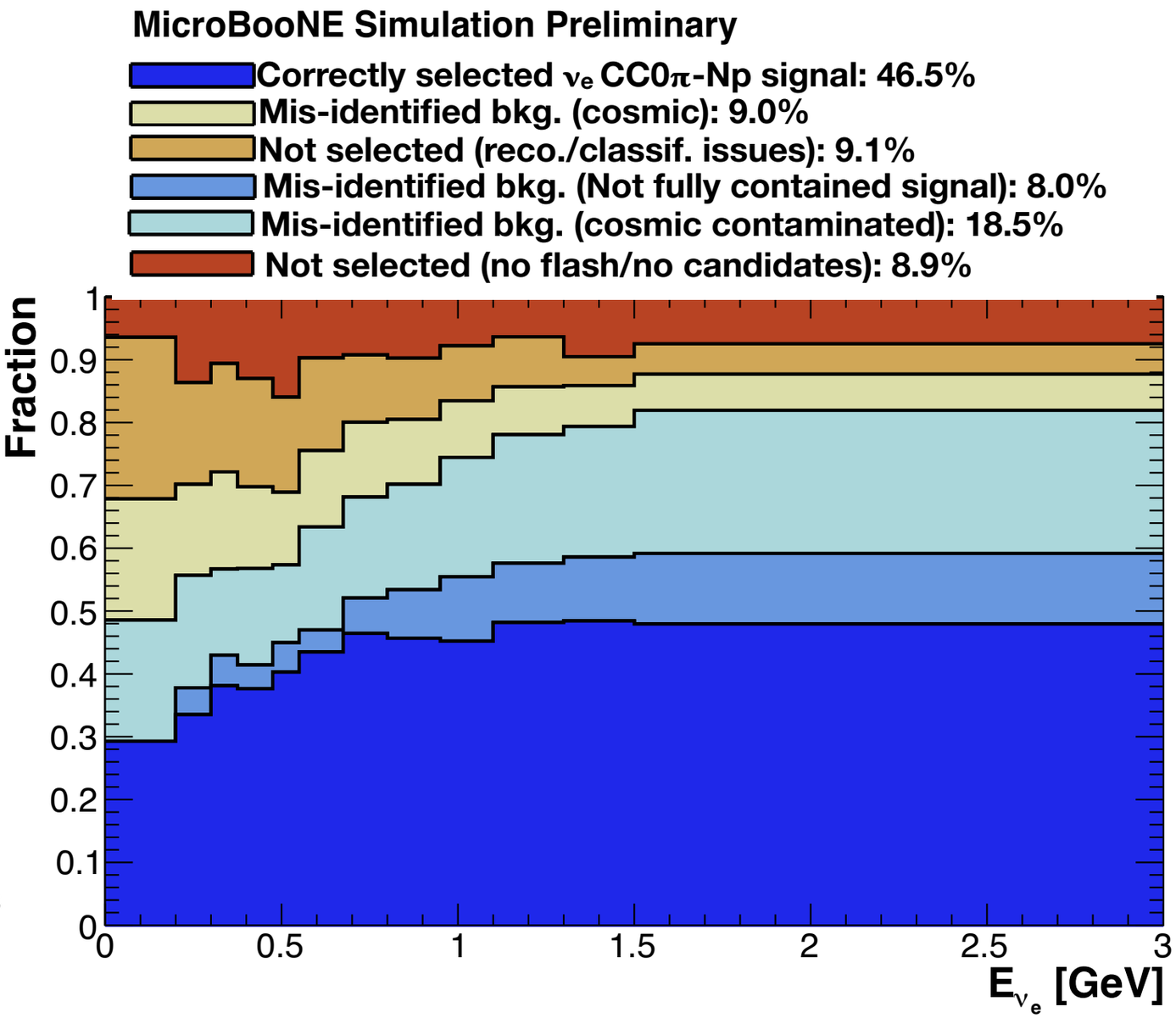
1. "Detector Calibration using through going and stopping muons in the MicroBooNE LArTPC", MICROBOONE-NOTE-1048-PUB, 2018

ν_e analysis

One of our first analyses focuses on the signal most similar to the MiniBooNE CC0π definition: 1 electron + N protons

Selection efficiency for 1e+Np





Poster: R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction

Public Note: MICROBOONE-NOTE-1038-PUB, 2018

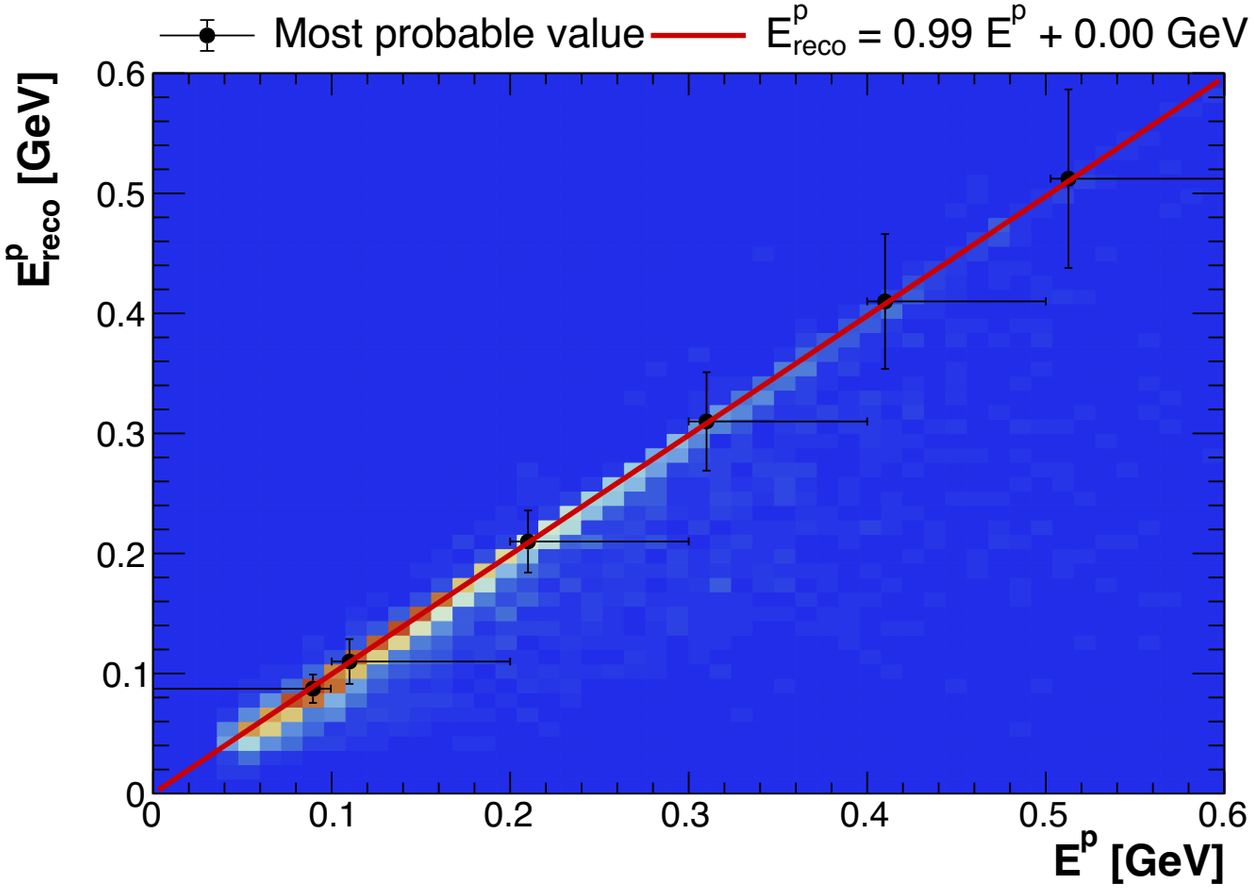
Low-energy excess analysis

- The currently ongoing ν_e (and other) analyses have informed us of where improvements are needed
  - ➡ Improved cosmic removal techniques + cosmic-ray tagger system
  - ➡ Robust PID will be implemented
  - ➡ Calorimetry on the 3 planes will improve the dE/dx measurements
  - ➡ Low energy reconstruction/classification improvements will increase the low energy efficiency
  - ➡ Continue to develop the Machine Learning analyses has they are very promising
- Perform end-to-end analysis with new improvements
- Validate analysis with side-bands
- Use NuMI ν_e events to validate the analysis with high statistics
- Perform the single photon analyses

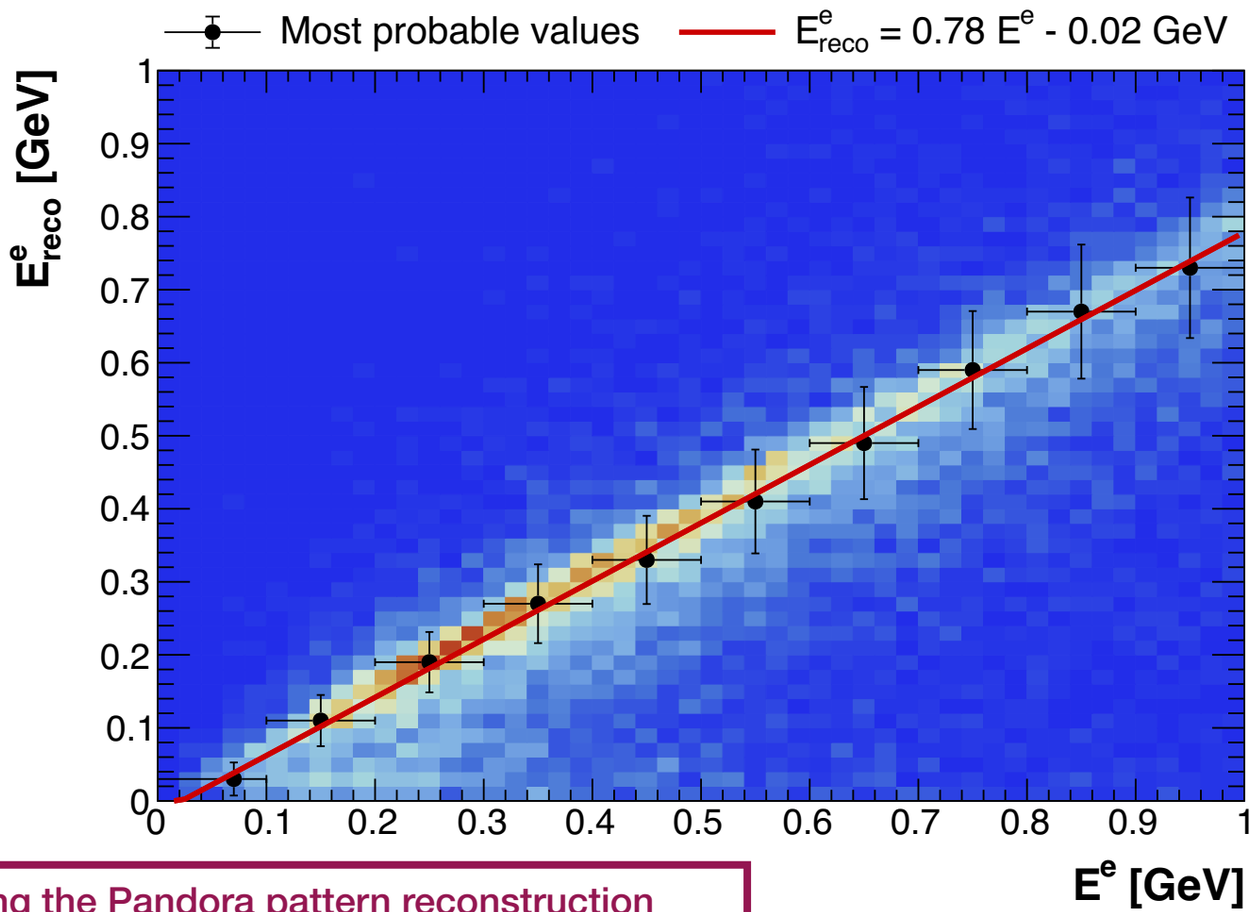
New Public Notes and Posters

1. R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction, MICROBOONE-NOTE-1038-PUB, 2018
2. R. Murrels, Search for NC single photon events in MicroBooNE, MICROBOONE-NOTE-1041-PUB, 2018
3. M. Ross-Lonergan, MicroBooNE tests of the MiniBooNE low-energy excess, MICROBOONE-NOTE-1043-PUB, 2018 **Finalist!**

Energy reconstruction of nue



- Energy reconstruction studies for protons and electrons



Poster: R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction

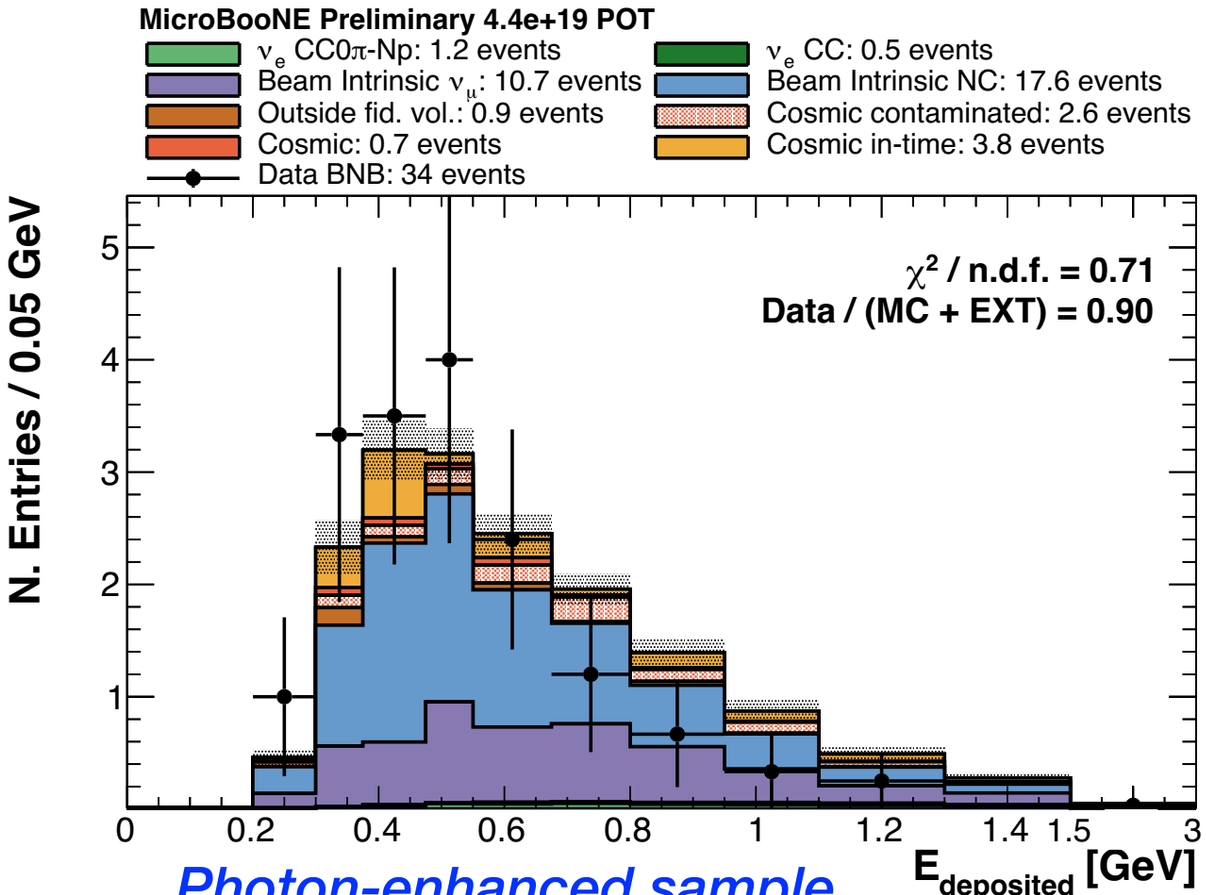
Public Note: MICROBOONE-NOTE-1038-PUB, 2018

Validating ν_e analysis

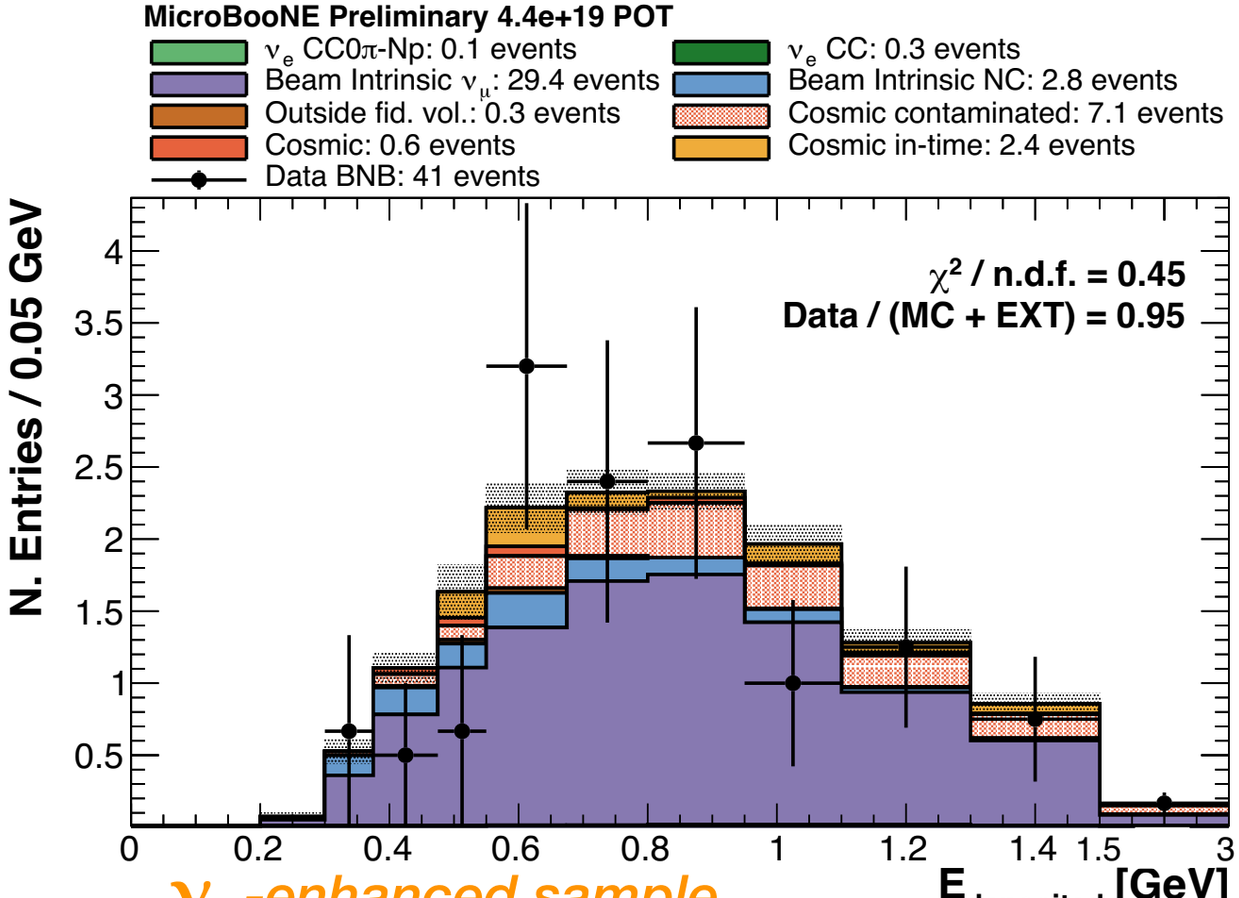
Poster: R. Soleti, Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction

Public Note: MICROBOONE-NOTE-1038-PUB, 2018

- Small unblinded data sample available for testing (4.4x10^{19} POT)
- Validation using side-bands (ν_μ charged current or neutral current events)
- Use cuts to select non-ν_e events:
  - ✓dE/dx of showers
  - ✓Distance between shower start and track start
  - ✓Proton identification score (from boosted decision tree)

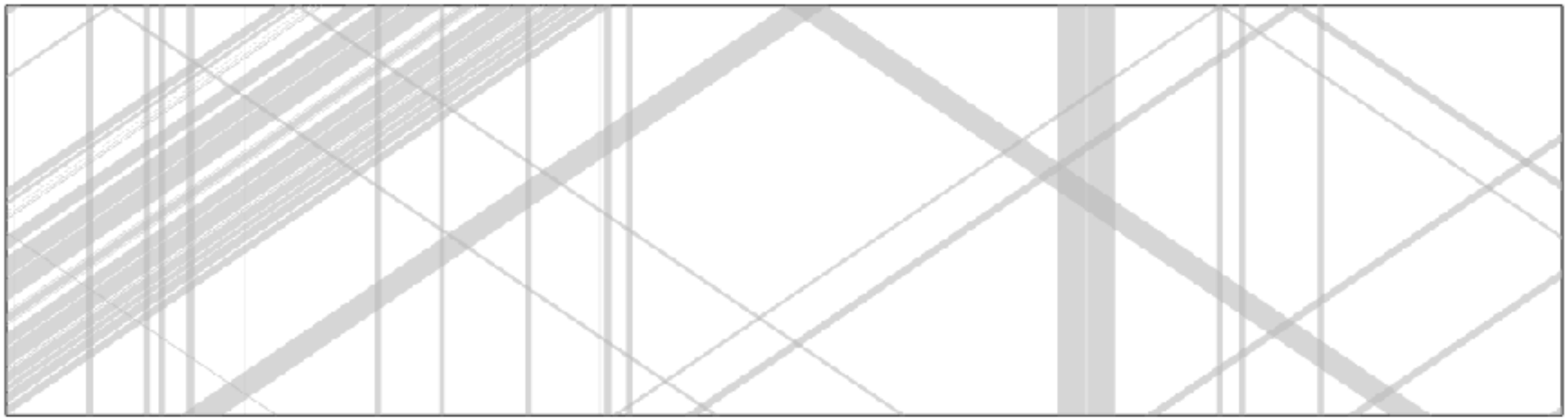


Photon-enhanced sample



ν_μ-enhanced sample

Unresponsive wires

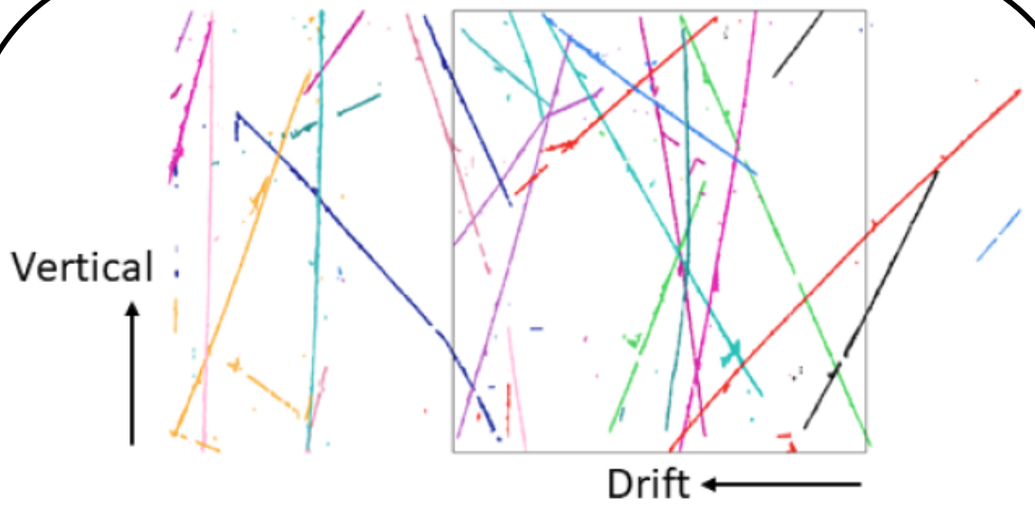


All unresponsive wires on all three planes (~10%)

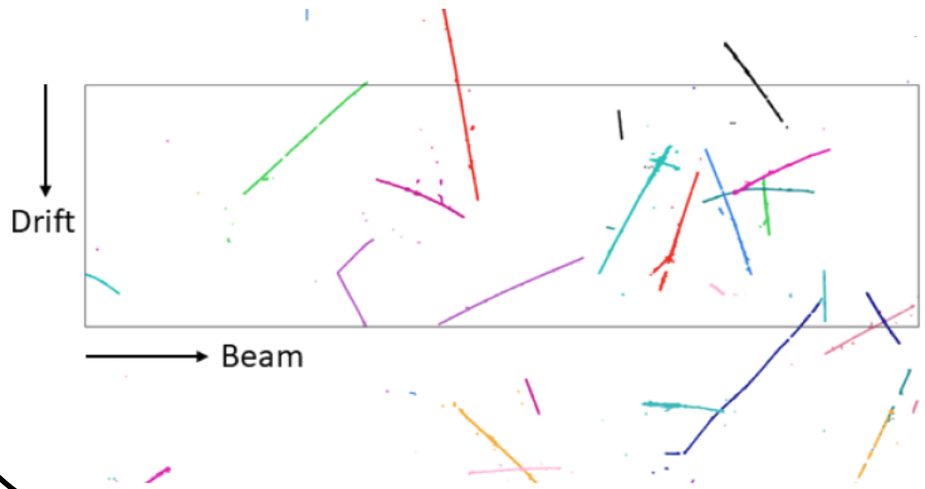
All unresponsive wires with no redundancy (~3%)

1. “Towards automated neutrino selection at MicroBooNE using tomorgraphic event reconstruction”, MICROBOONE-NOTE-1040-PUB, 2018

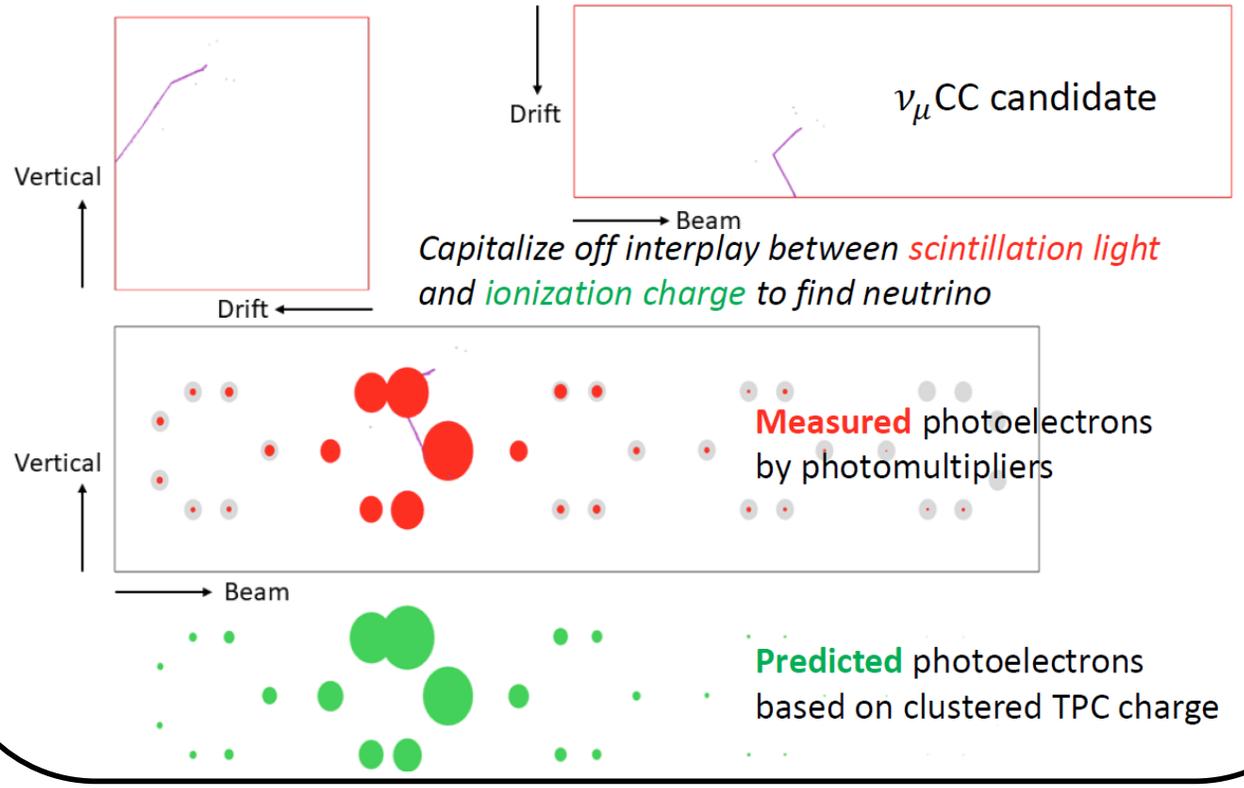
Wirecell



Recognized clusters based on 3D event image reconstructed with charge matching



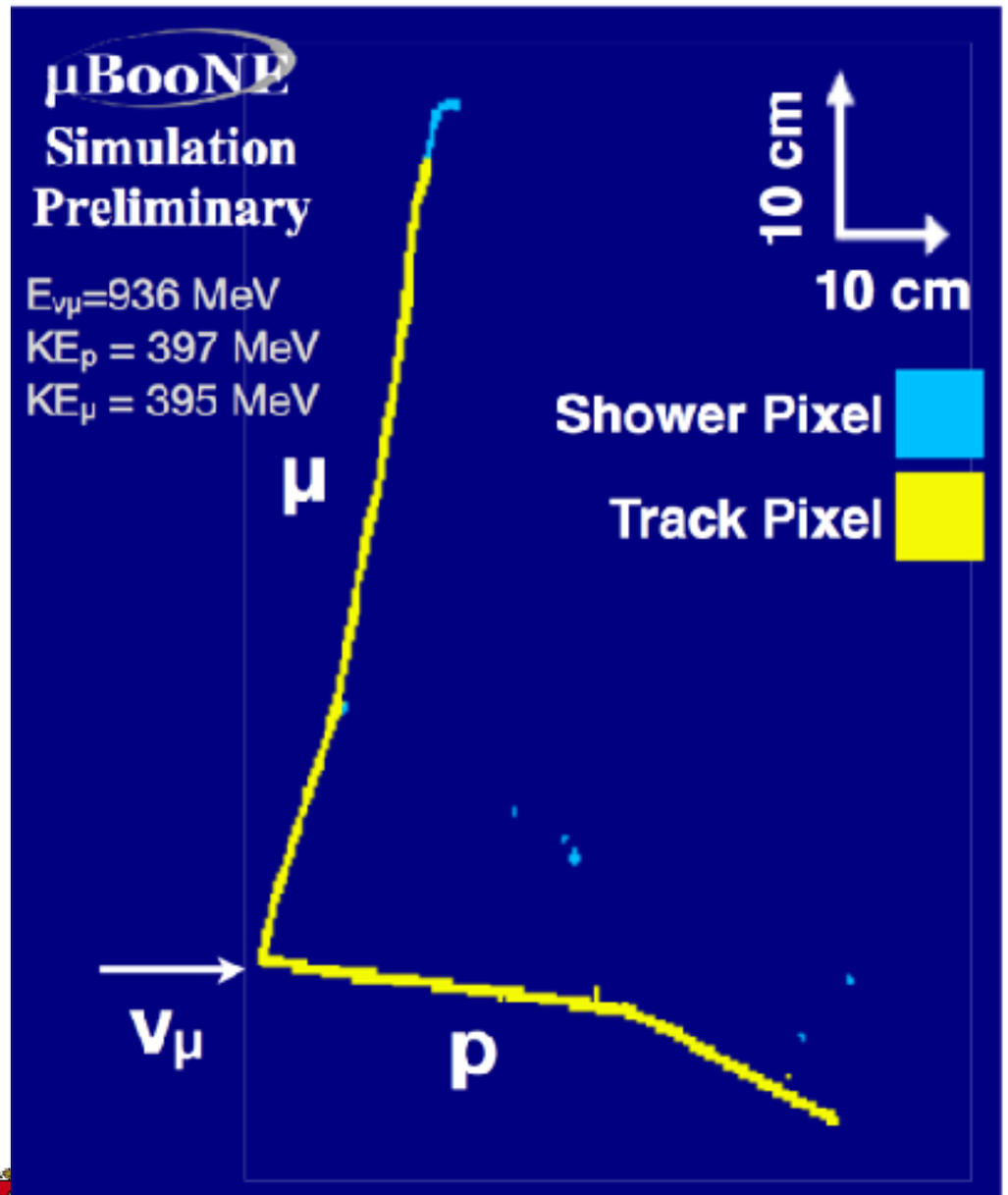
Cosmic removal after TPC cluster/ PMT flash matching

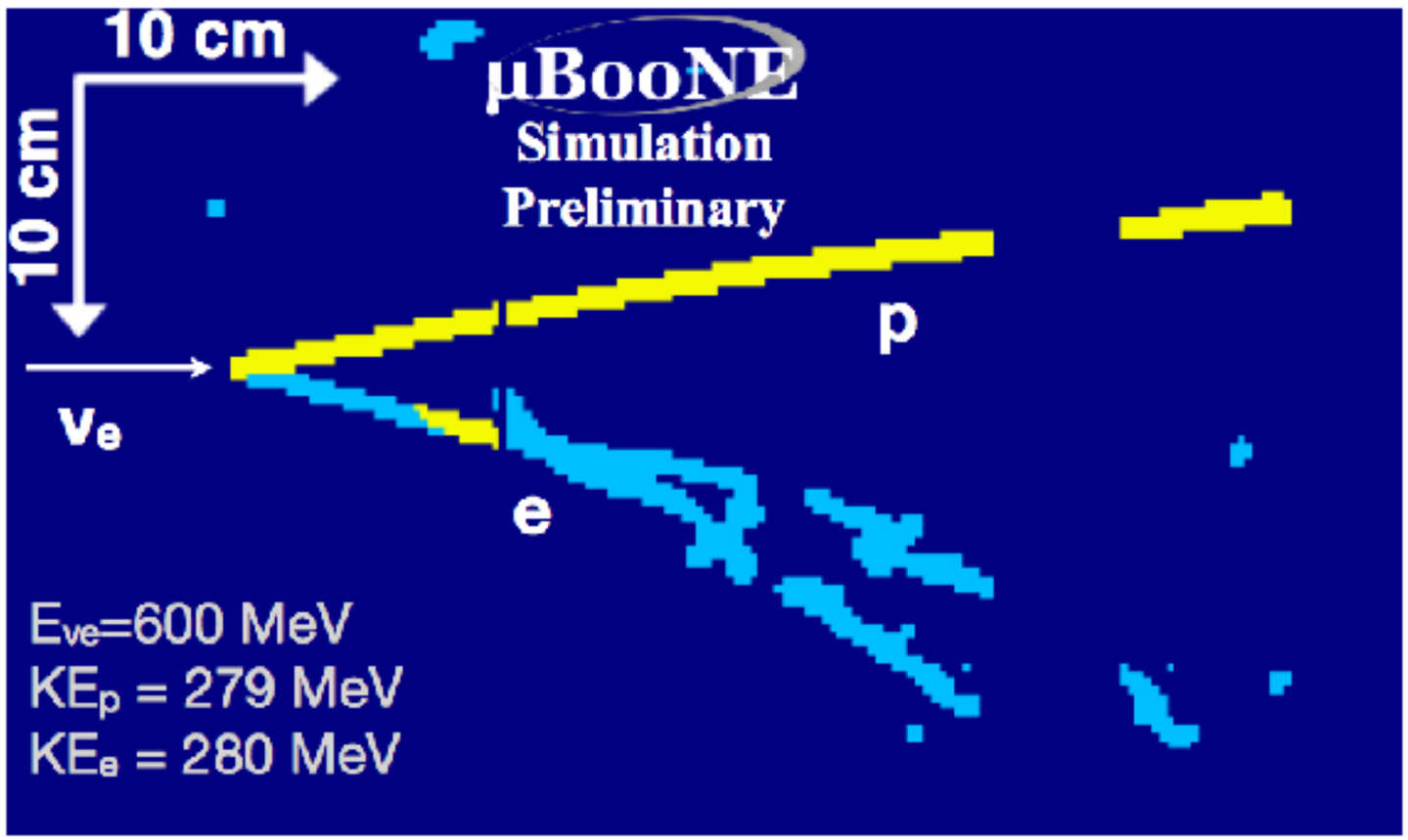


- "Three-dimensional imaging for large LArTPCs", JINST 13, P05032
- Poster: "Recent Progress on Wire-Cell Tomographic Event Reconstruction for LArTPCs", H. Wei
- Poster: "Towards Automated Neutrino Selection at MicroBooNE using Tomographic Event Reconstruction", B. Russell
- MICROBOONE-NOTE-1040-PUB

Deep Learning

Example of SSNET pixel labeling





Noise Filtering in MicroBooNE

- Initial data taking indicated significant “noise” on TPC waveforms above what was expected by the reconstruction team
- Significant effort undertaken on the part of many people to identify the various sources of noise and other issues
  - Identification of the sources of noise seen on the waveforms:
    - Low frequency “coherent” noise due to voltage regulators on the service boards
    - Harmonic noise due to HV power supplies
    - High frequency “Burst” noise probably associated to PMT HV supply
  - Understanding other issues impacting waveforms
    - Misconfigured channels - wrong gain and/or shaping time
    - Shorted channels
    - Periodic saturation of ASIC’s
- Sophisticated software noise filtering mitigation package put in place

Publication

1. ***“Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC”*, arXiv:1705.07341, JINST 12, P08003 (2017)**

Signal Processing

- Digitized signal we measure differs from the actual ionization deposited by the original particle due to several effects:
  - Physics of the drift: recombination, electron lifetime, diffusion, etc.
  - Electric field signal response on the wires (field response)
  - Electronics response

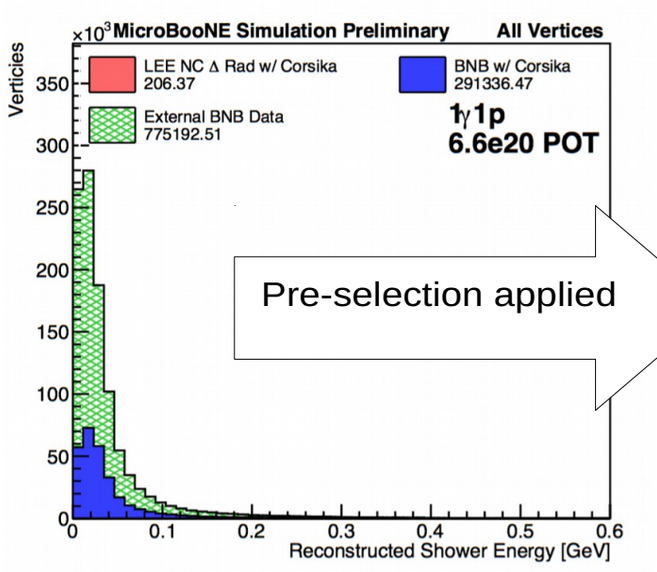
- The Signal Processing stage has as its primary goal to unfold the field and electronics responses to recover the number of ionization electrons passing by each wire at each sampled time.
  - Recombination, lifetime, diffusion, etc., are addressed in the reconstruction and analysis stages

1. ***"Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE"*, arXiv:1804.02583, submitted to JINST**
2. ***"Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation"*, arXiv:1802.08709, accepted by JINST**

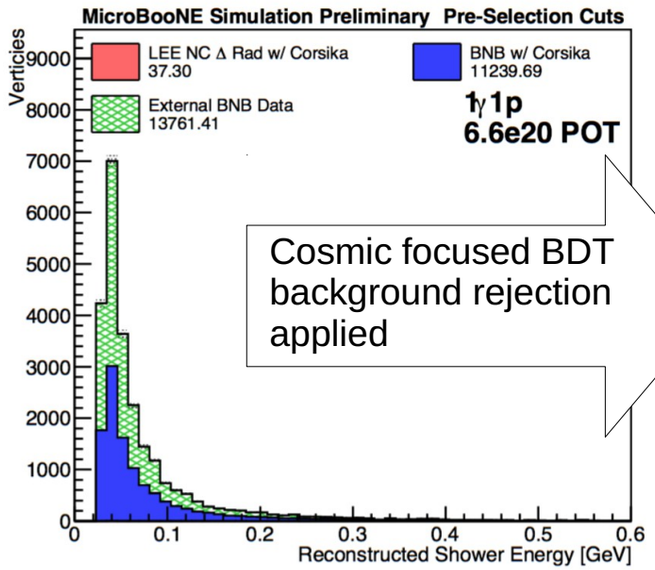
Slide from T. Usher

Single photon

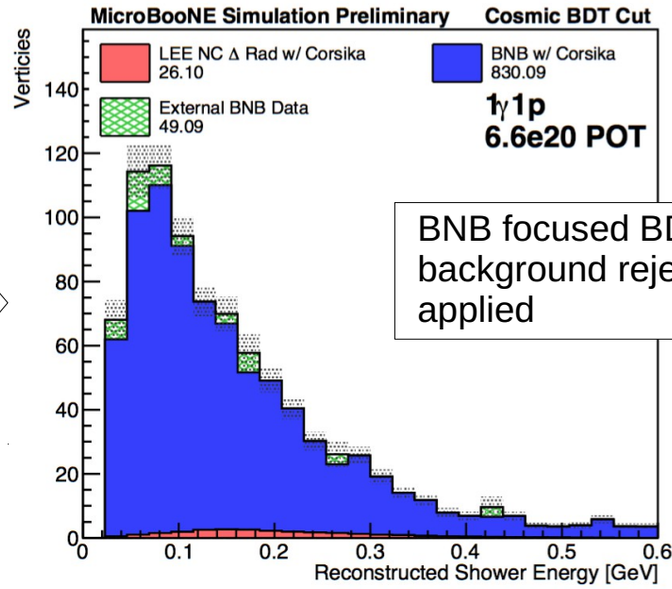
Starting with Pandora-reconstructed and vertex-optimized 1g1p events...



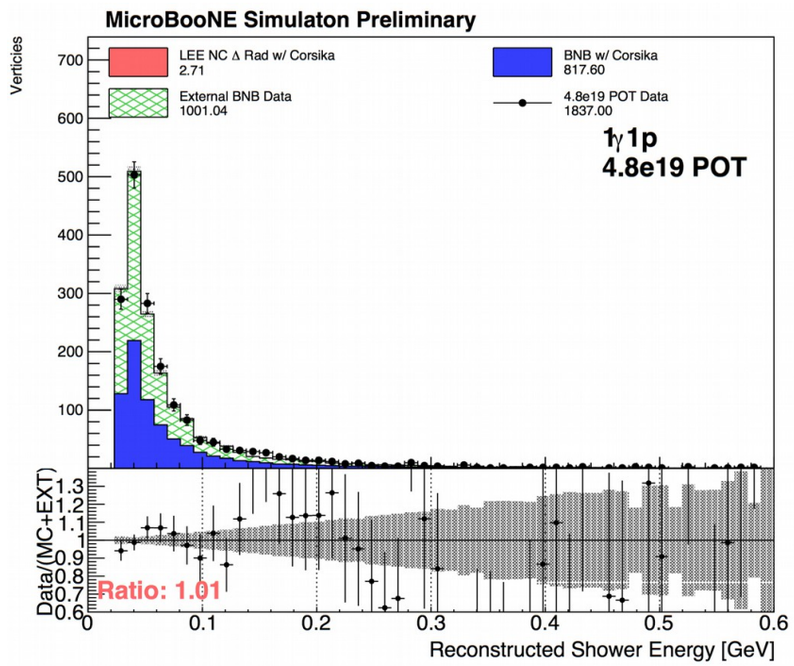
Pre-selection applied



Cosmic focused BDT background rejection applied



BNB focused BDT background rejection applied

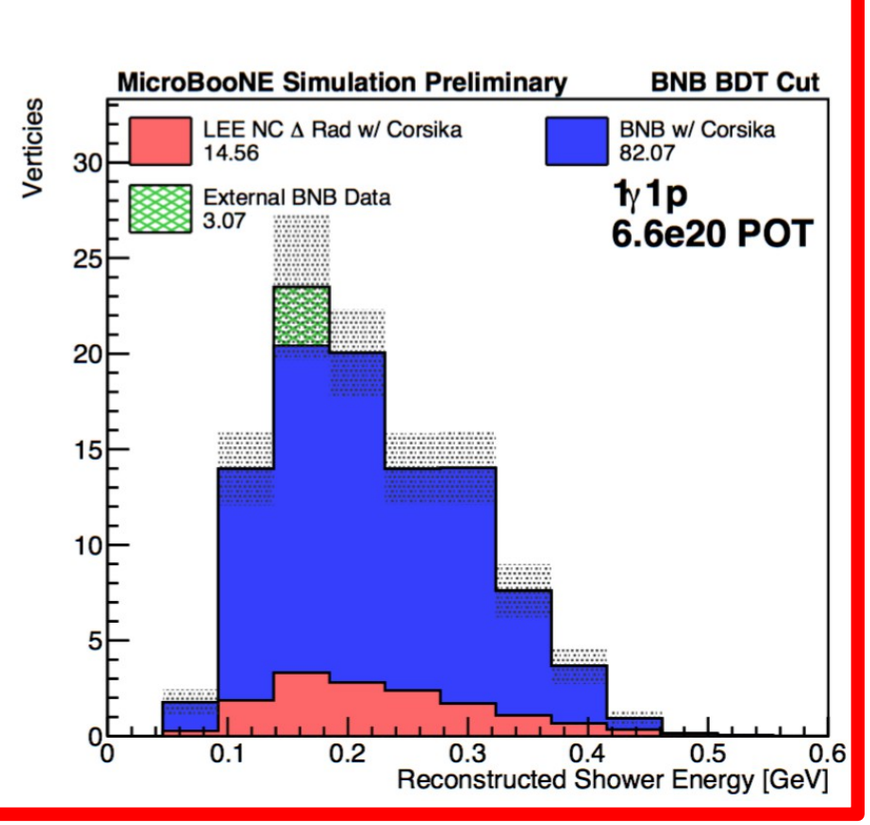


Current state of analysis: validation on 4.8e19 POT unblinded data.

Final 1y+1p selection

New Public Notes and Posters

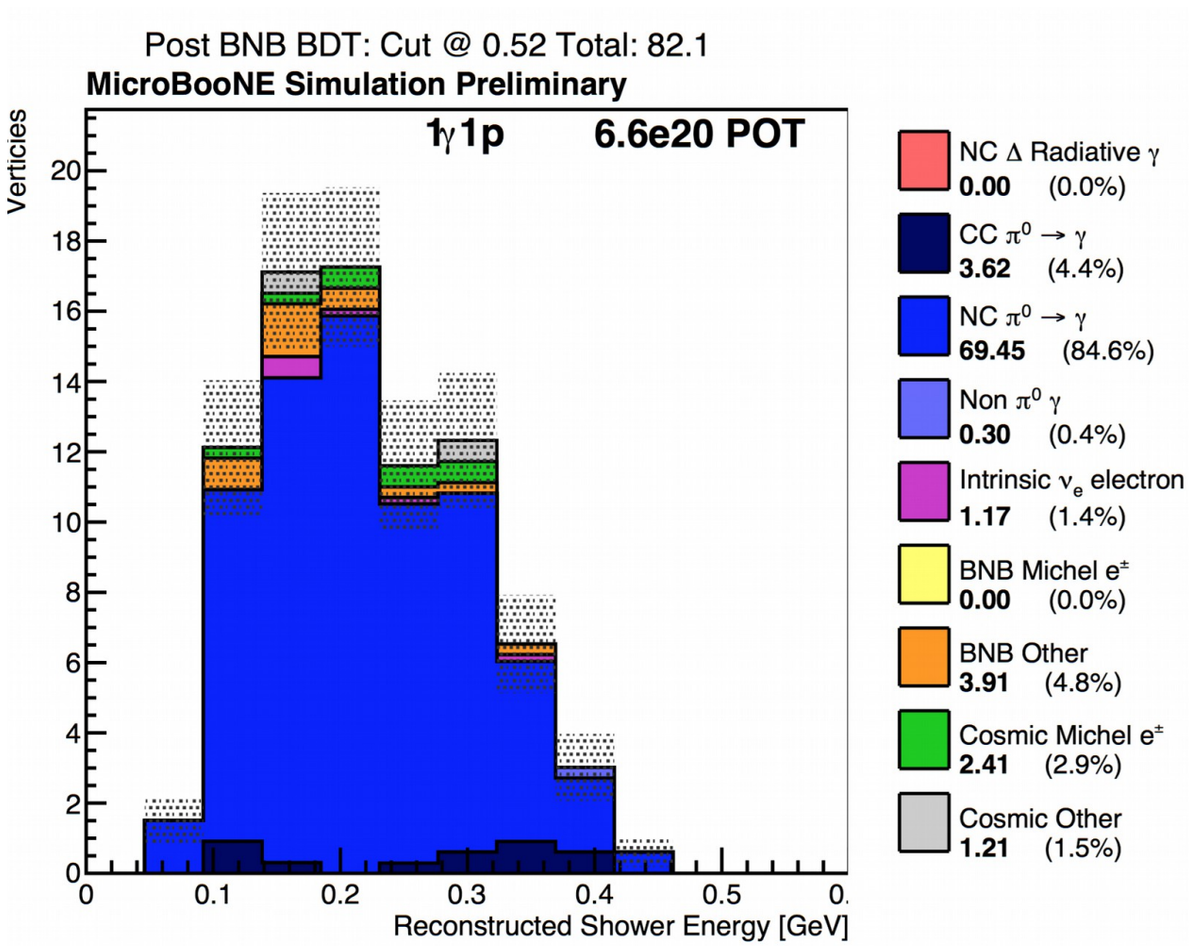
1. R. Murrels, Search for NC single photon events in MicroBooNE, MICROBOONE-NOTE-1041-PUB, 2018



Single photon

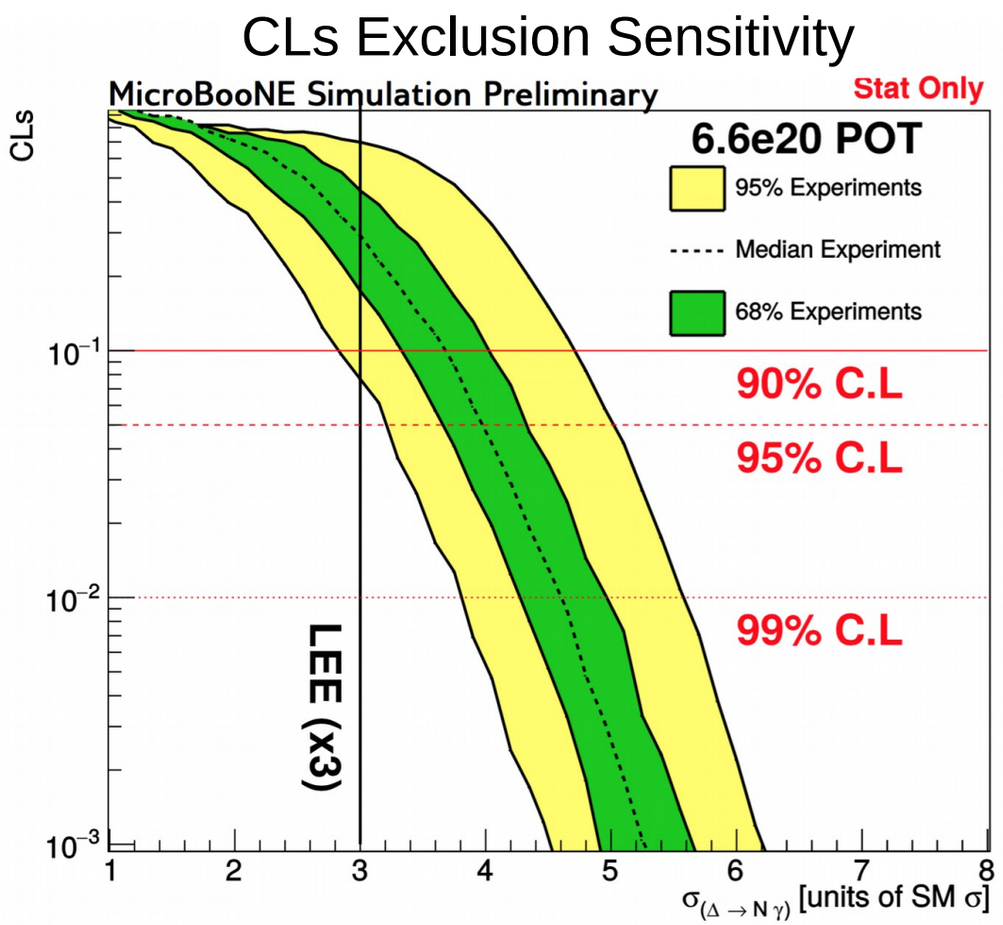
New Public Notes and Posters

1. R. Murrels, Search for NC single photon events in MicroBooNE, MICROBOONE-NOTE-1041-PUB, 2018



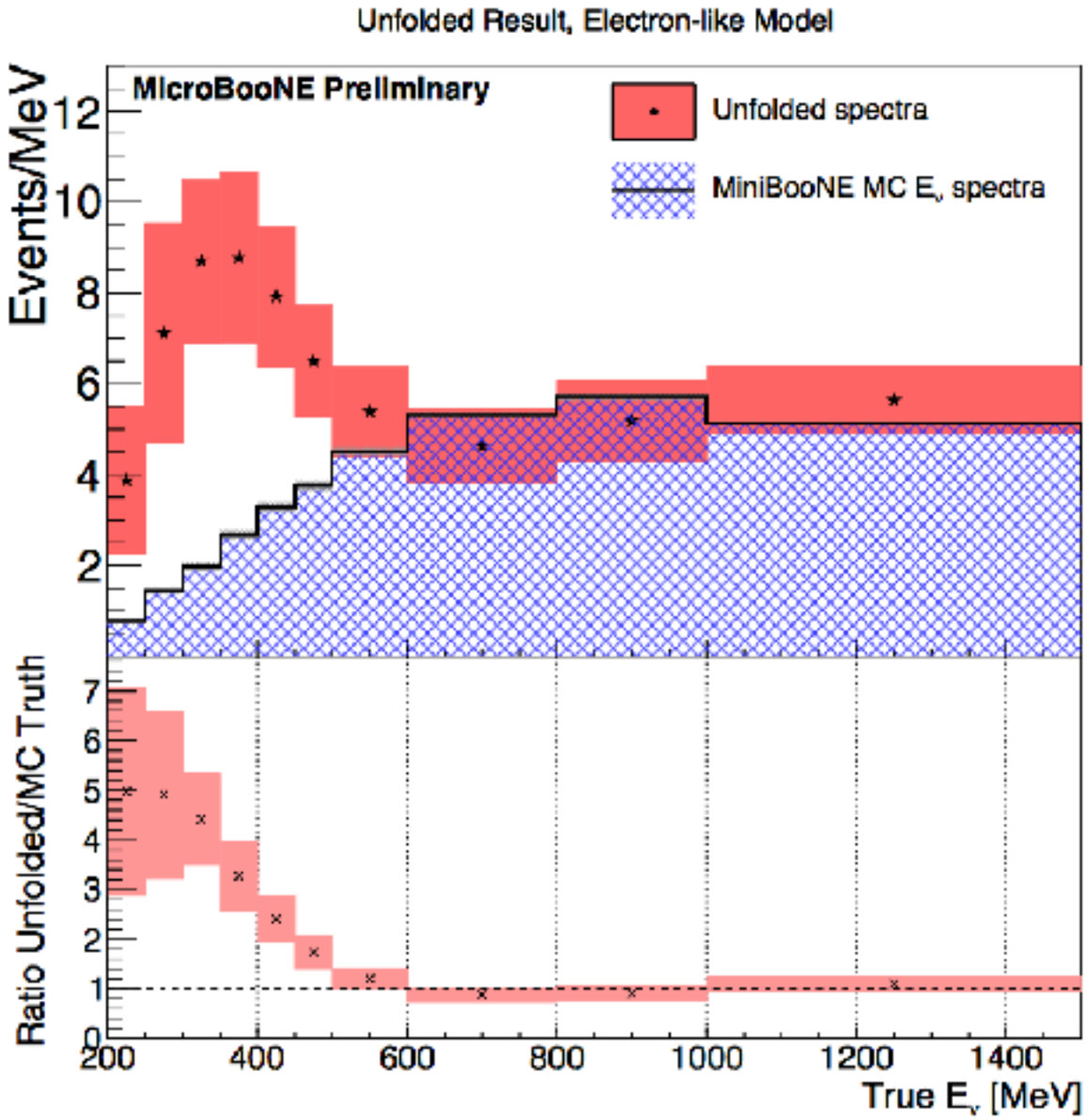
Vast majority of remaining background comprised of NC $\pi^0 \rightarrow 2\gamma$ decay. Working on further background reduction strategies for NC $\pi^0 \rightarrow 2\gamma$ decay

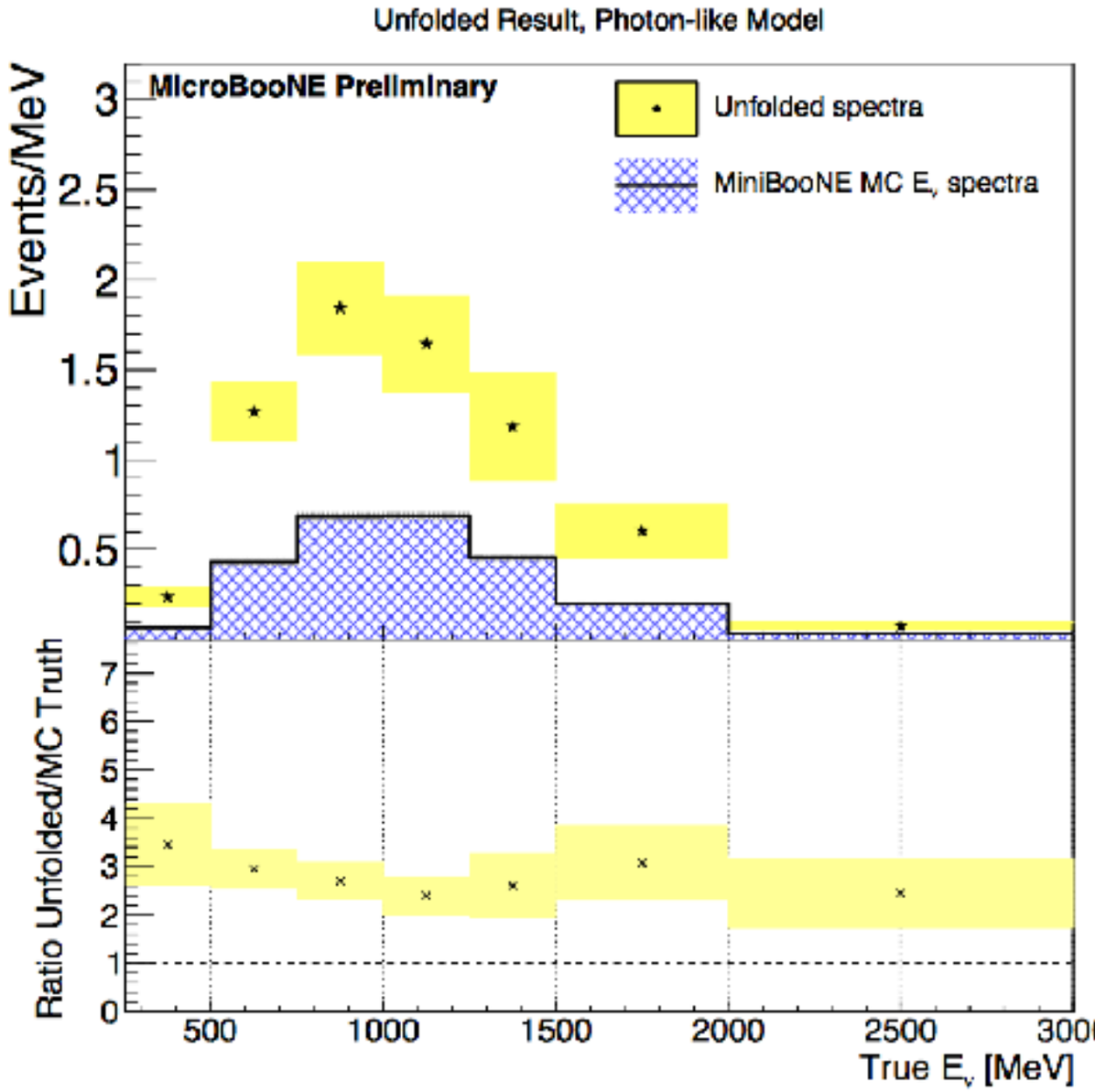
Projected stats-only sensitivity on the 6.6e20 POT dataset would exclude a 4.6xSM cross-section at 99 % C.L. (photon LEE at 3xSM).



Potential signal modeling

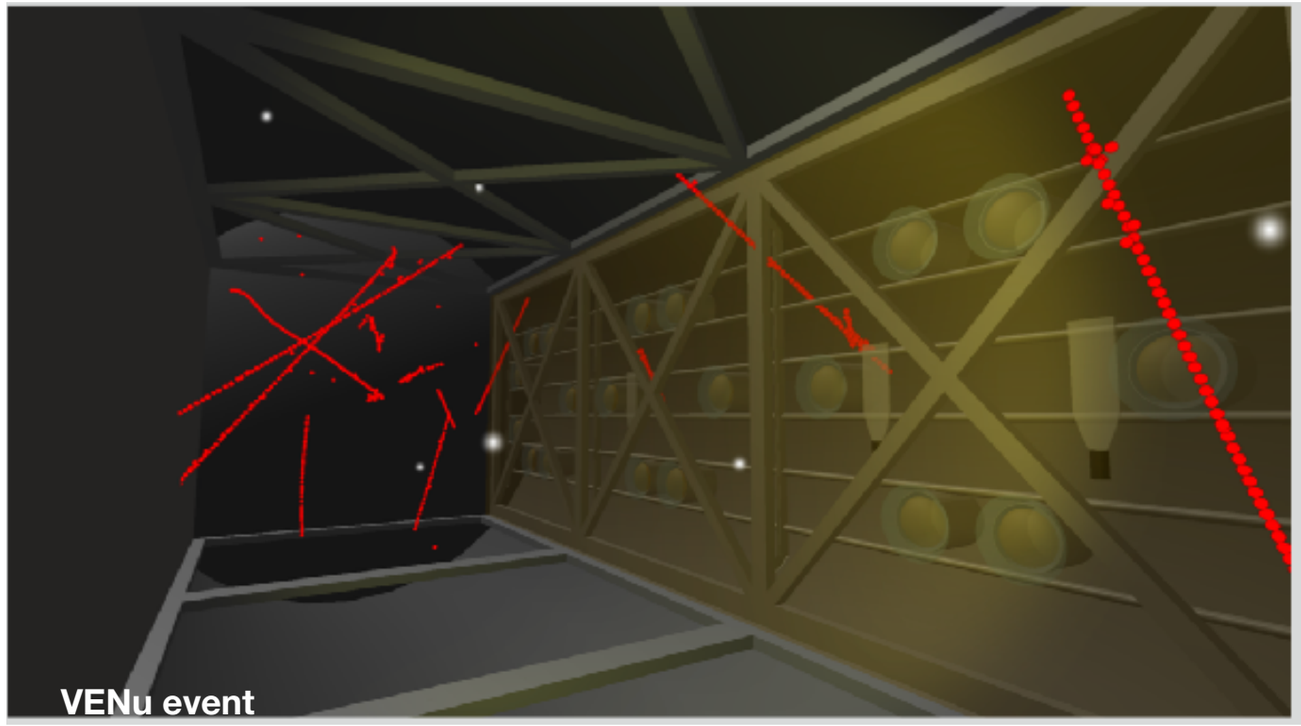
- Example of nueCC and single photon (NC resonant delta production) signal modeling in MicroBooNE





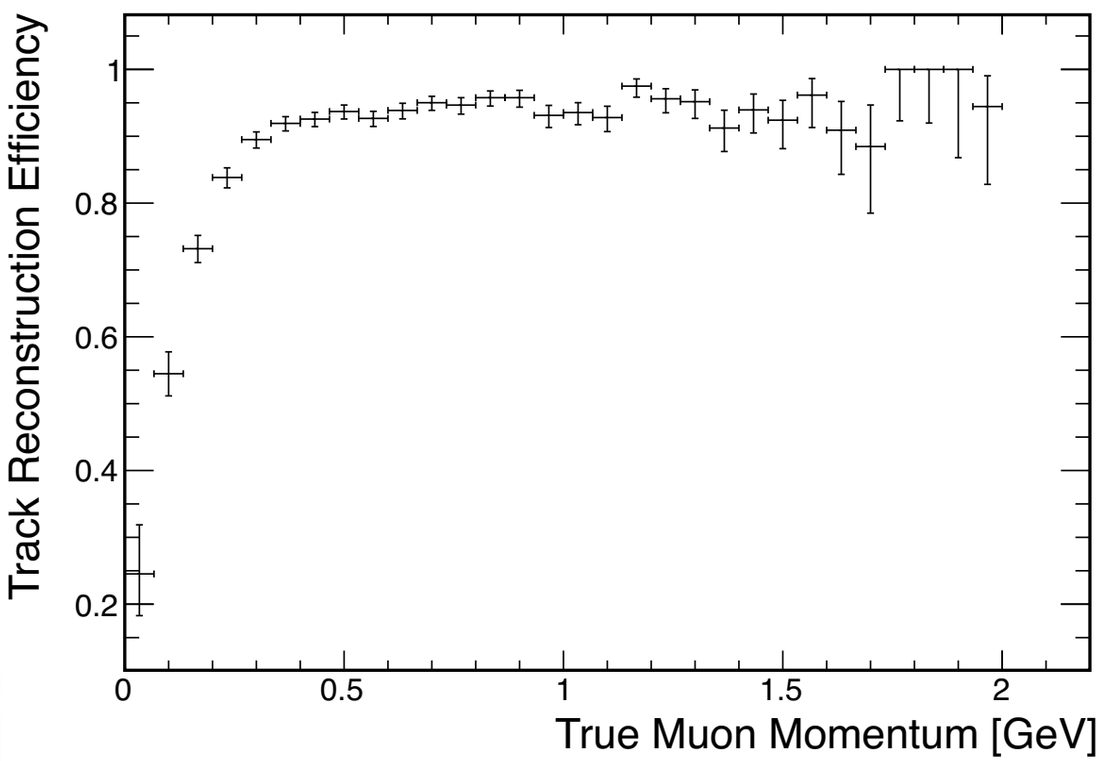
1. MicroBooNE tests of the MiniBooNE low-energy excess, MICROBOONE-NOTE-1043-PUB, 2018

ν_μ CC Inclusive measurement

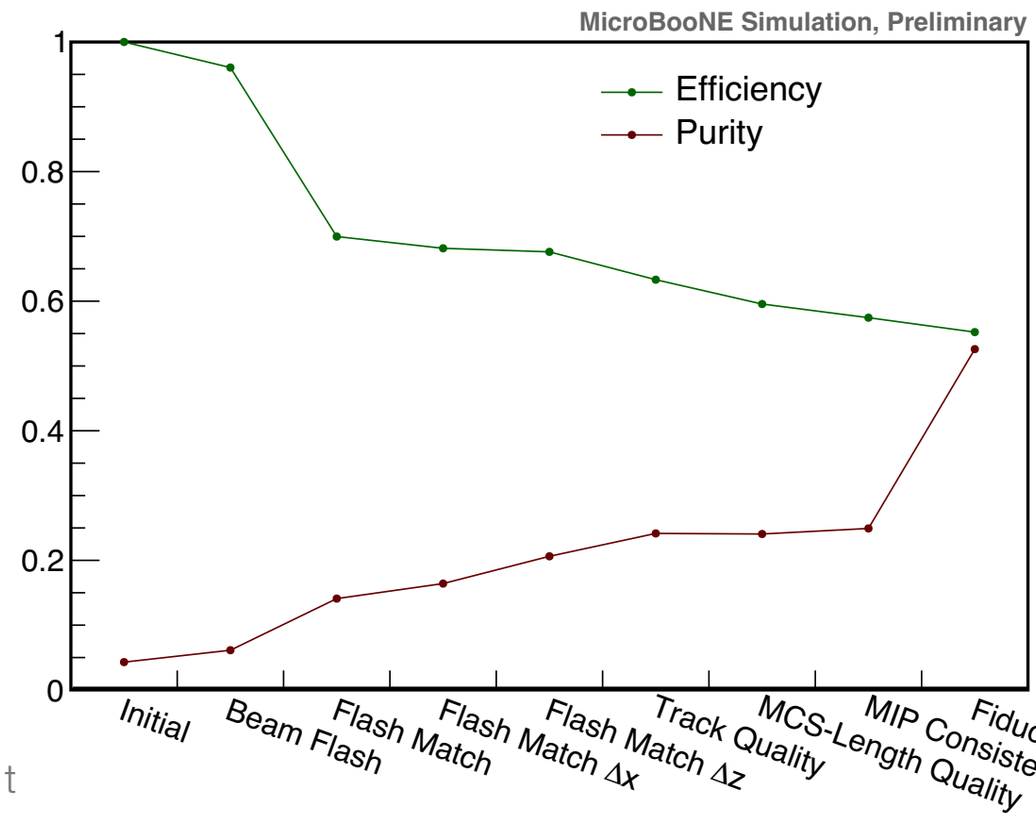


Poster: M. Del Tutto & A. Schukraft, First measurement of muon neutrino charged-current inclusive cross-section measurement in MicroBooNE

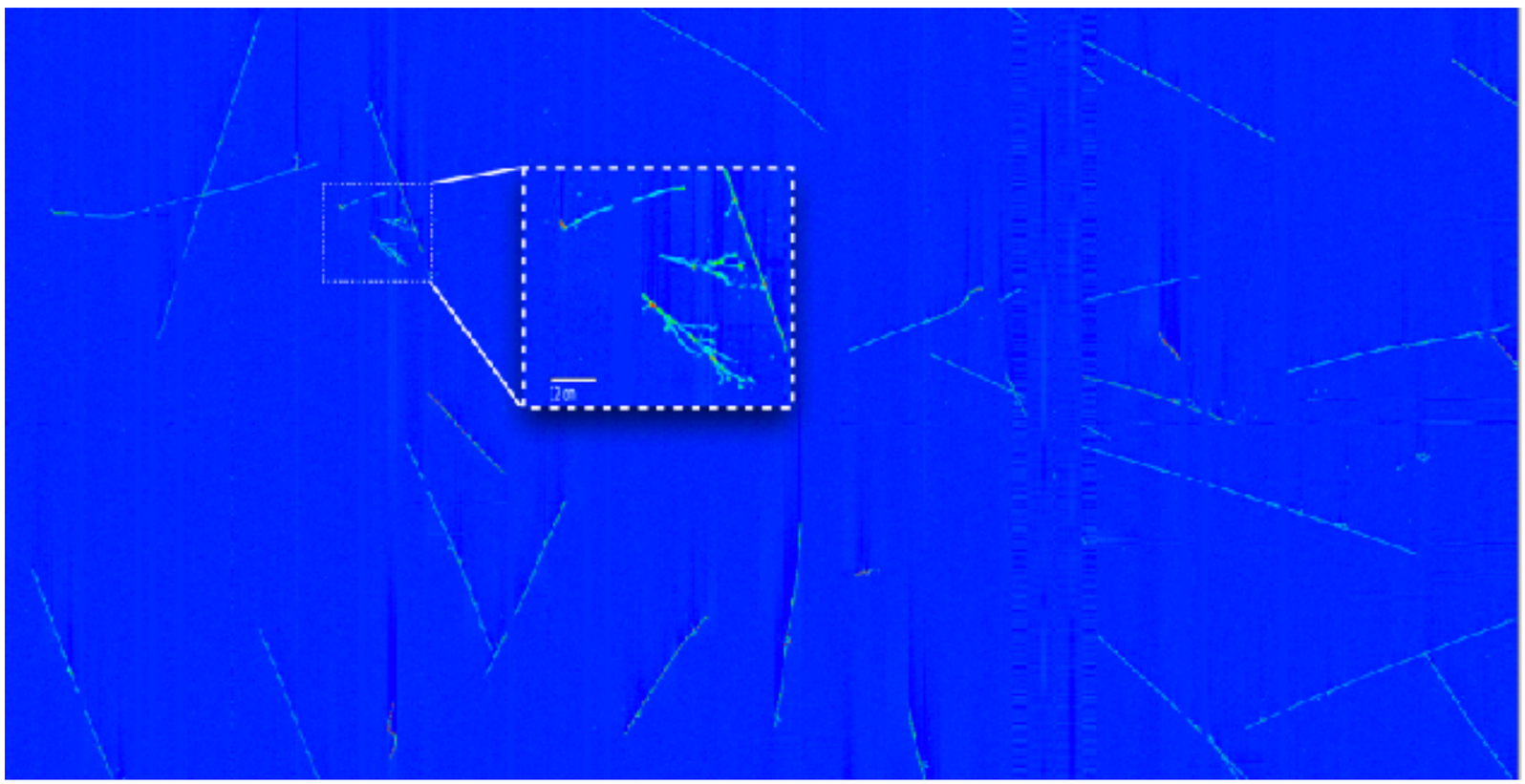
Public Note: MICROBOONE-NOTE-1045-PUB, 2018

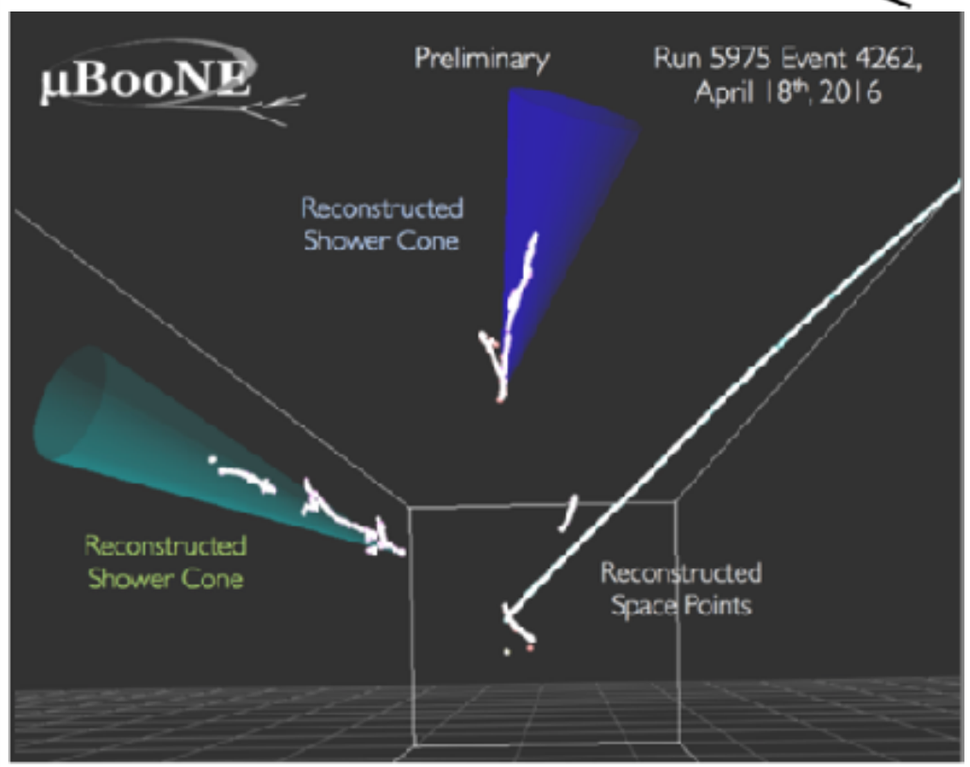


and t



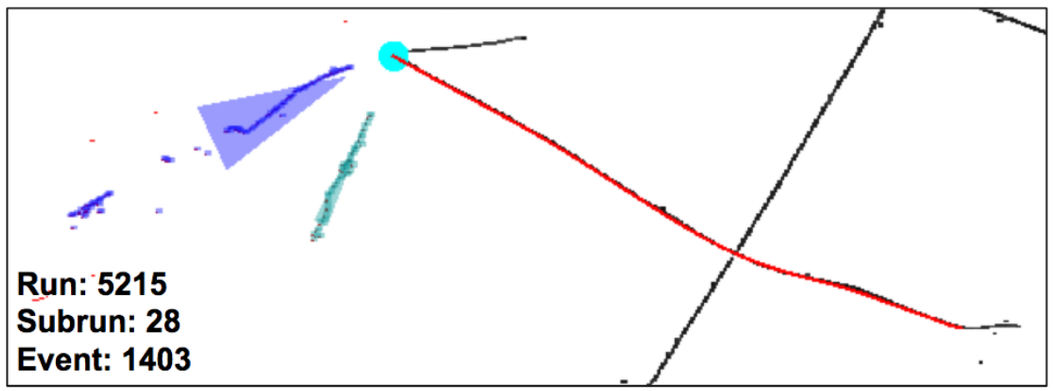
CC-π^0cross-section measurement

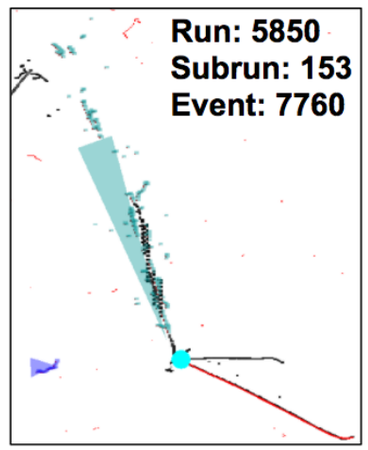


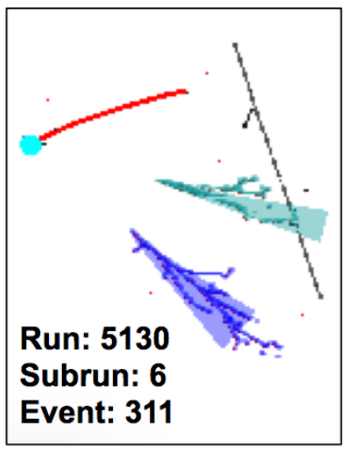


Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC

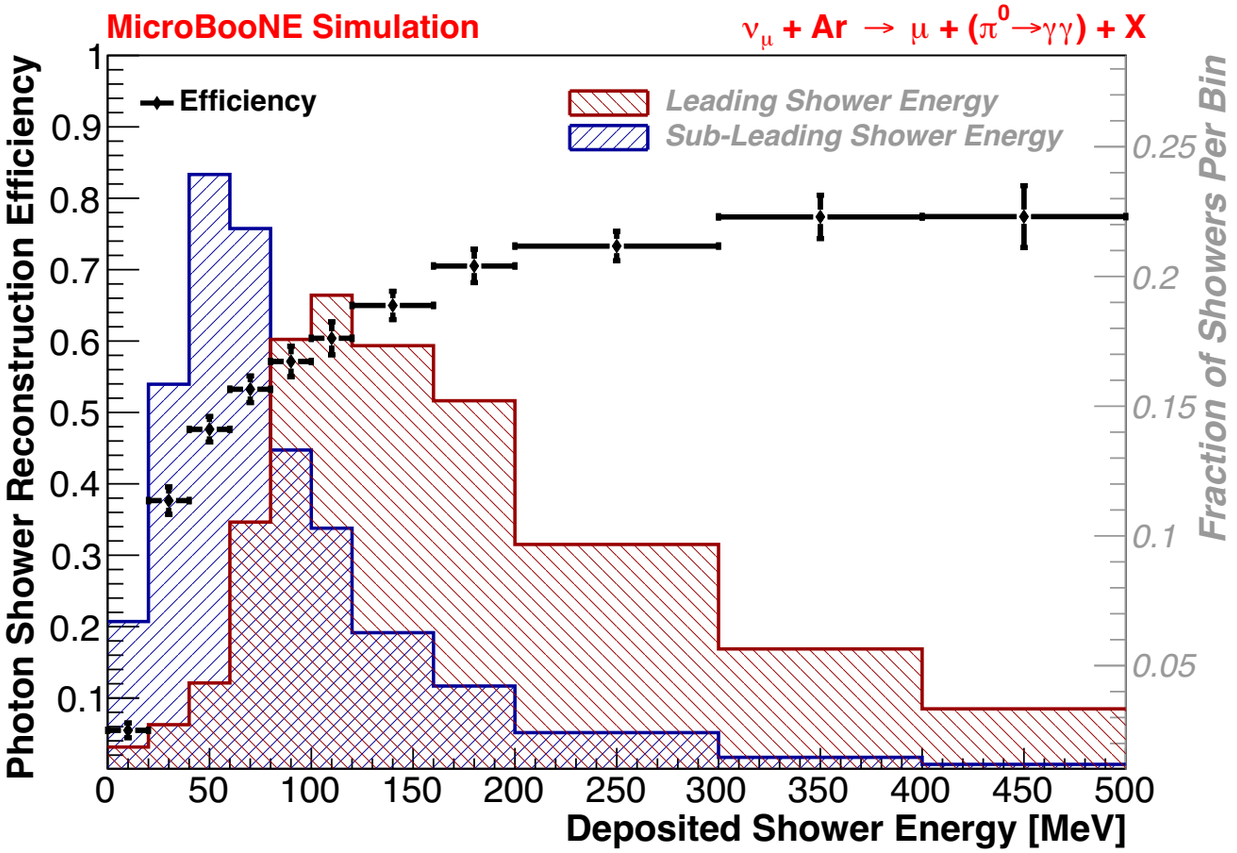
Public Note: MICROBOONE-NOTE-1032-PUB, 2018







CC-π^0 reconstruction and selection



Average reconstruction efficiencies:

62% for leading CC-π^0 shower

50% for subleading CC-π^0 shower

80% above 300 MeV

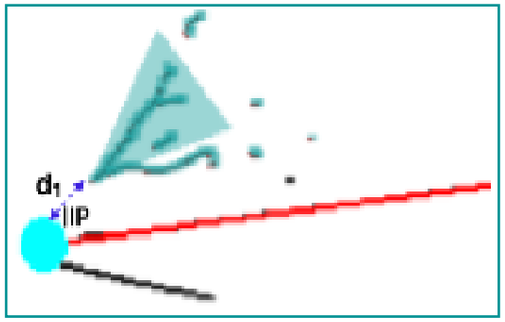
Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC

Public Note: MICROBOONE-NOTE-1032-PUB, 2018

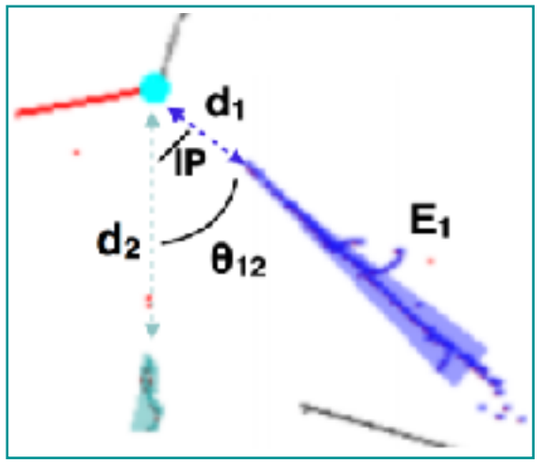
CC-π^0 results

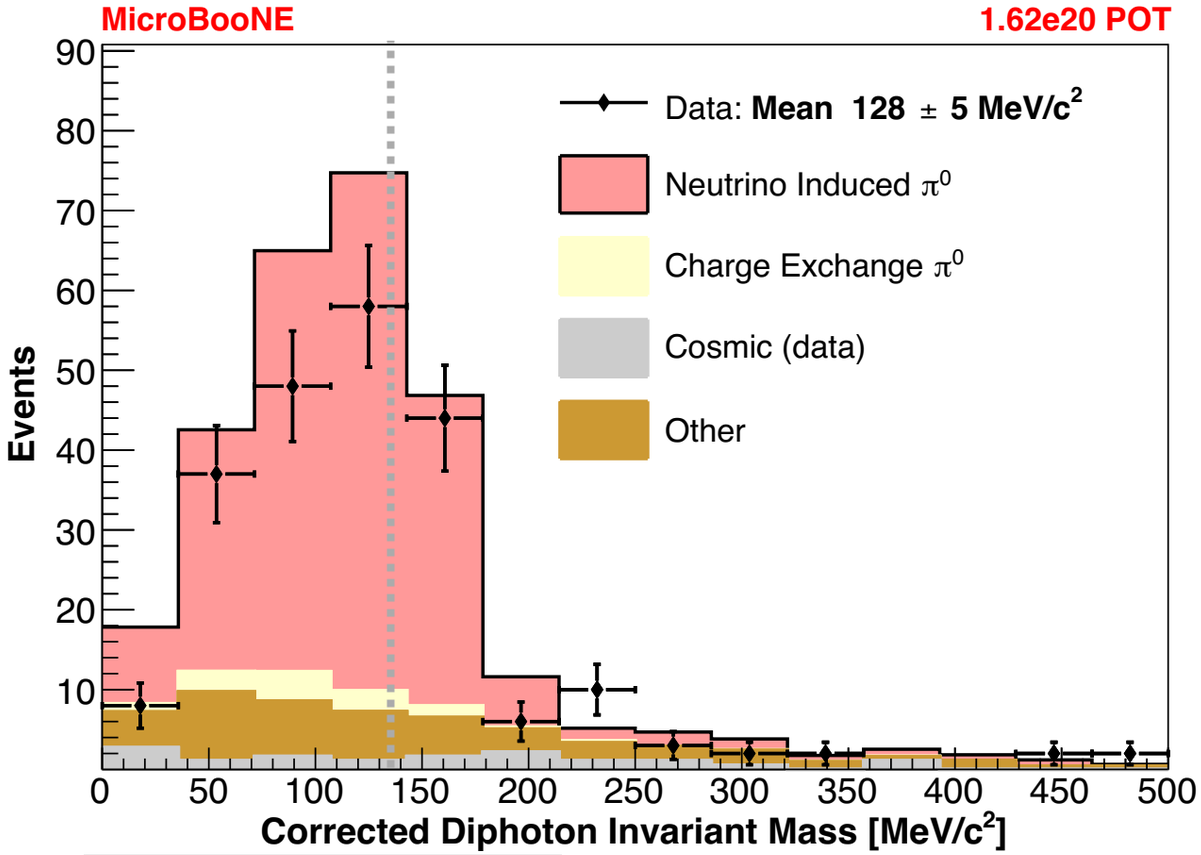
CC-π^0 selections:

- One shower: 771 events:
  Efficiency 17% and Purity 53%



- Two showers: 224 events
  Efficiency 6% and Purity 64%





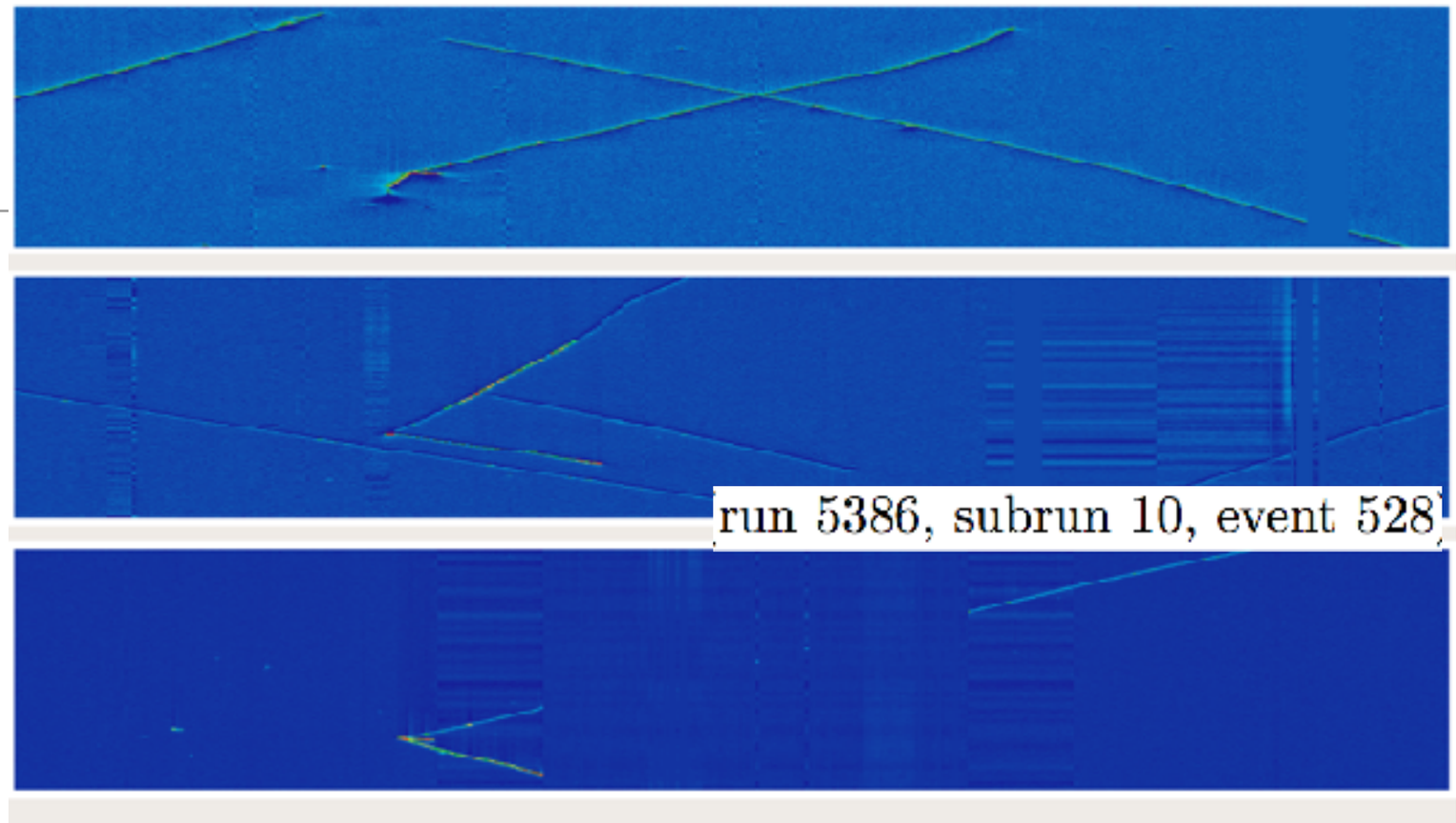
Mass of π^0: 135 MeV

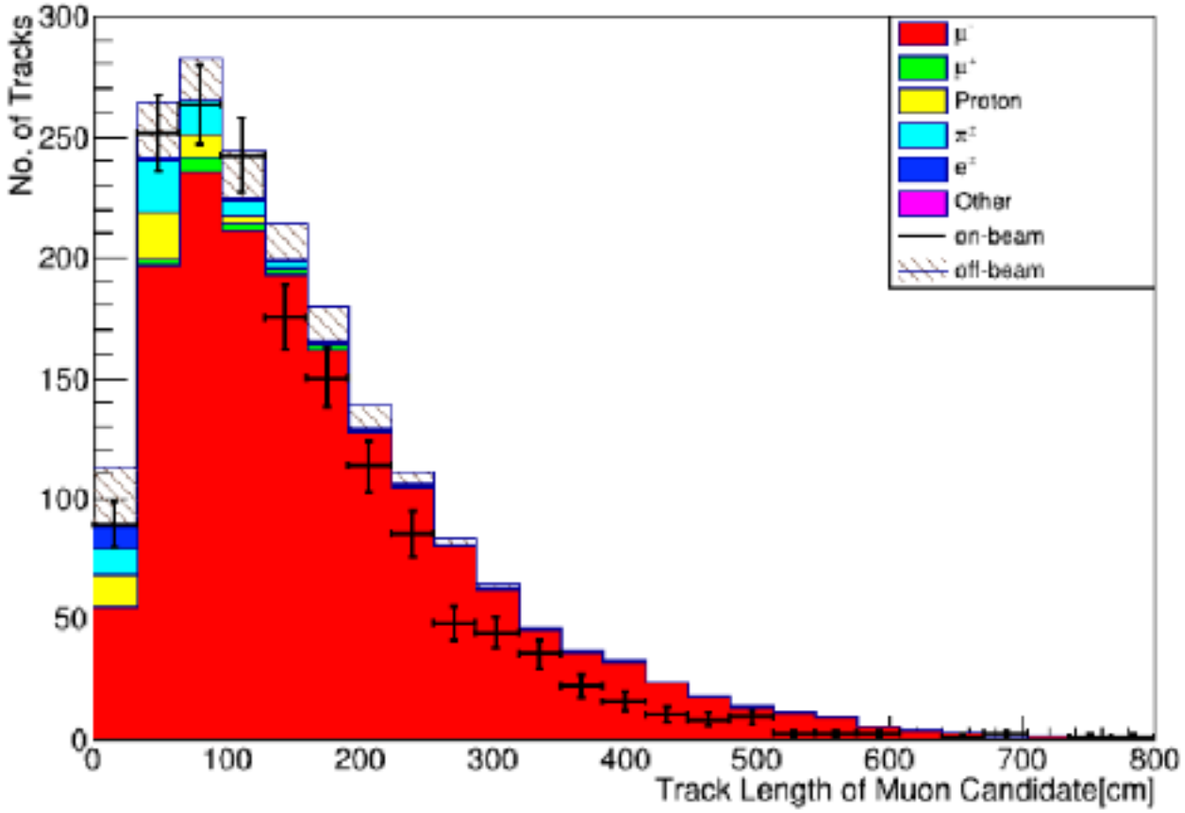
REFERENCE here

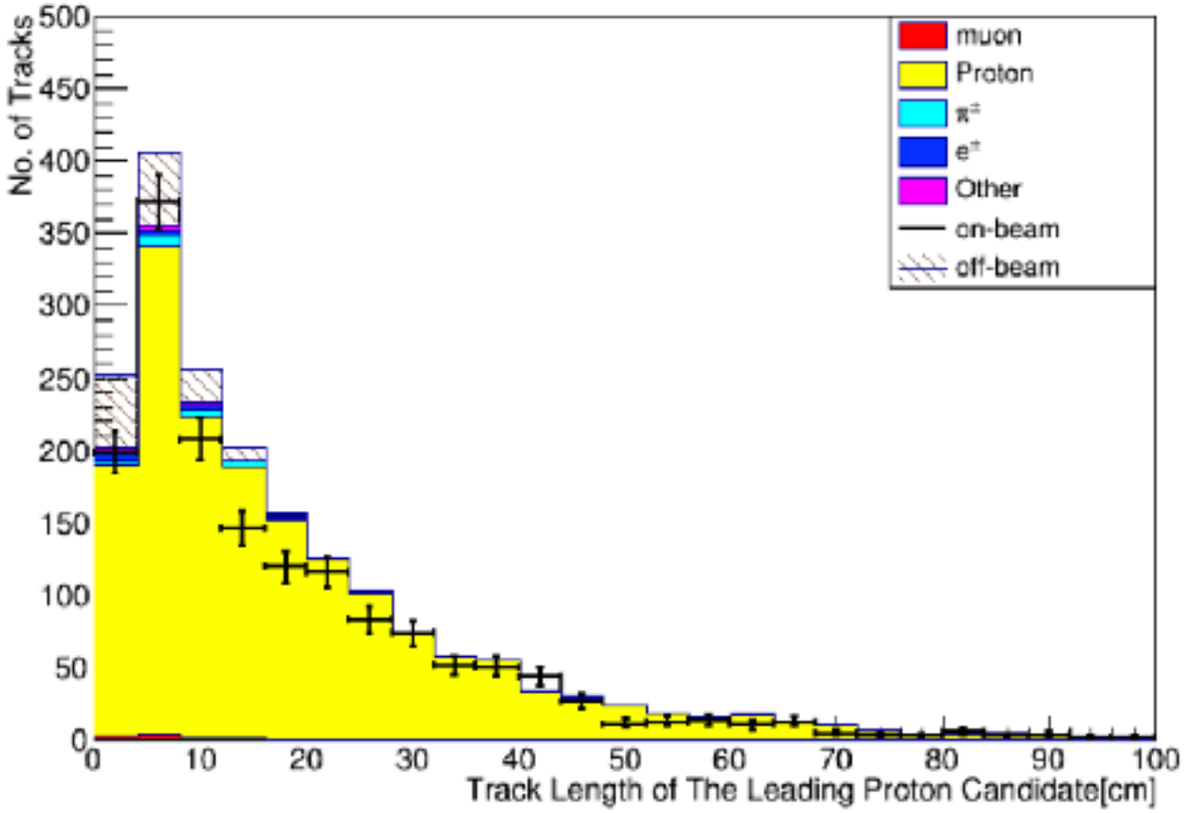
Poster: J. Zennamo, First measurement of muon neutrino charged-current neutral pion production in LArTPC

Public Note: MICROBOONE-NOTE-1032-PUB, 2018

numuCC (1μNp)





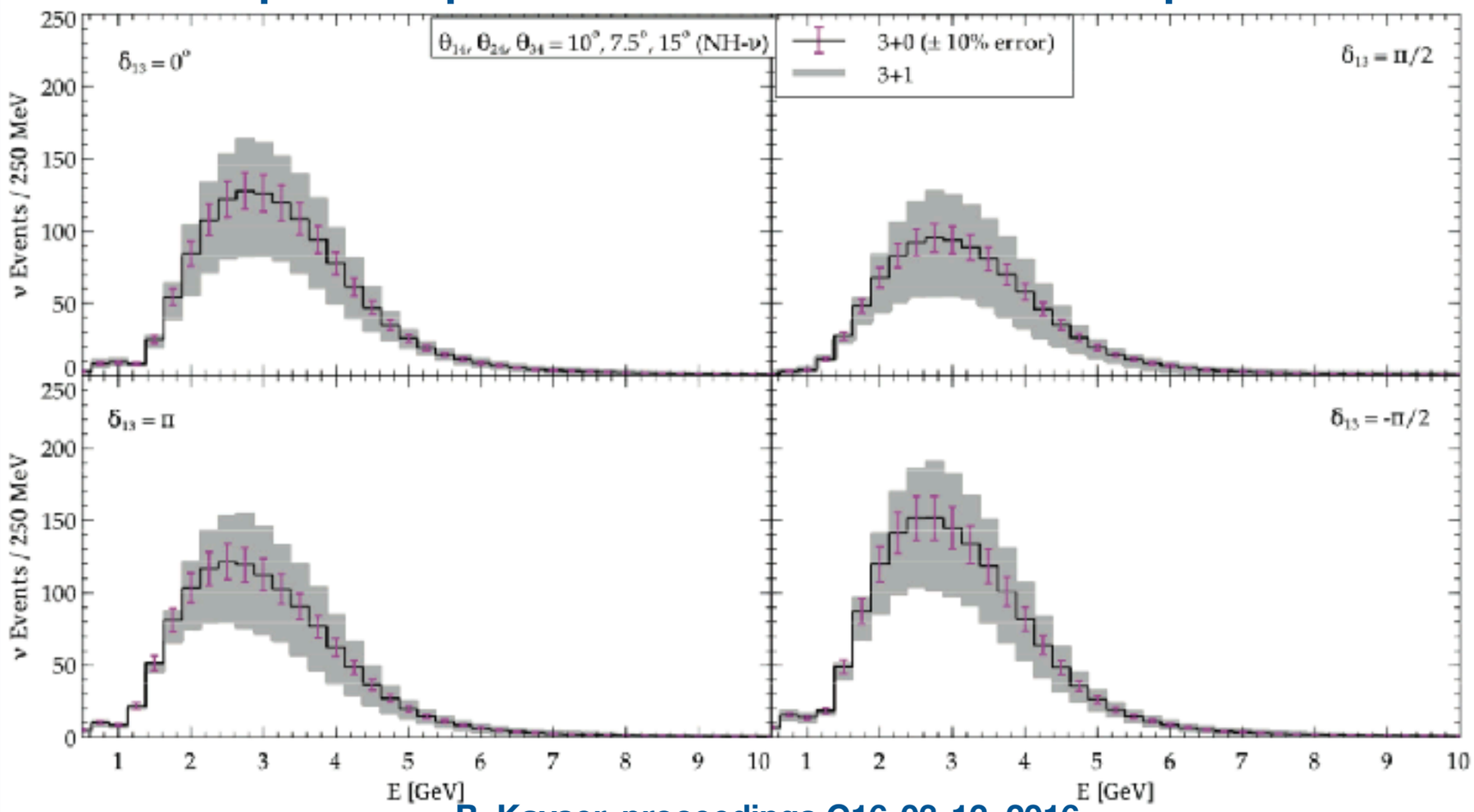


1. ***"Towards measurements of nuclear effects in MicroBooNE"*, MICROBOONE-NOTE-1046-PUB, 2018**

Short-baseline anomalies:

- The search for new physics is the holy-grail of the particle physics community
- The DUNE long-baseline program will strongly rely on the resolution of these anomalies (extra oscillation can lead to mis-interpretation of the flagship δ_{CP} measurement

Example of impact of sterile neutrino on LBL experiment



B. Kayser, proceedings C16-03-12, 2016

Presence of sterile neutrinos directly affect the oscillation spectrum at DUNE, leading to the wrong interpretation

Other references: S. K. Agarwalla, S. S. Chatterjee, A. Dasgupta and A. Palazzo, JHEP 1602, 111 (2016)
D.Dutta, R. Gandhi, B. Kayser, M. Masud and S. Prakash, JHEP 11, 122 (2016)

Physics results

Publications

1. “Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions”, arXiv:1805.06887, submitted to PRD (2018)

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1. “First measurement of muon neutrino charged-current neutral pion production in LArTPC”, MICROBOONE-NOTE-1032-PUB, 2018
2. “First measurement of muon neutrino charged-current inclusive cross-section measurement in MicroBooNE”, MICROBOONE-NOTE-1045-PUB, 2018
3. “*Towards measurements of nuclear effects in MicroBooNE”,* MICROBOONE-NOTE-1046-PUB, 2018
4. “Electron-neutrino reconstruction in MicrobooNE using the Pandora pattern reconstruction”, MICROBOONE-NOTE-1038-PUB, 2018
5. “Search for NC single photon events in MicroBooNE”, MICROBOONE-NOTE-1041-PUB, 2018
6. “MicroBooNE tests of the MiniBooNE low-energy excess”, MICROBOONE-NOTE-1043-PUB, 2018
7. “Booster Neutrino Flux Prediction at MicroBooNE”, MICROBOONE-NOTE-1031-PUB, 2018

Detector Physics results

Publications

1. *"Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE"*, arXiv:1804.02583, submitted to JINST
2. *"Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation"*, arXiv:1802.08709, accepted by JINST
3. *"Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC"*, arXiv:1705.07341, JINST 12, P08003 (2017)
4. *"Design and Construction of the MicroBooNE Detector"*, arxiv:1612.05824, JINST 12, P02017 (2017)

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1. *"A Measurement of the Attenuation of Drifting Electrons in the MicroBooNE LArTPC"*, MICROBOONE-NOTE-1026-PUB, (2017)
2. *"Establishing a Pure Sample of Side-Piercing Through-Going Cosmic-Ray Muons for LArTPC Calibration in MicroBooNE"*, MICROBOONE-NOTE-1028-PUB, (2017)
3. *"Study of Space Charge Effects in MicroBooNE"*, MICROBOONE-NOTE-1018-PUB, (2016)
4. *"A Method to Extract the Charge Distribution Arriving at the TPC Wire Planes in MicroBooNE"*, MICROBOONE-NOTE-1017-PUB, (2016)
5. *"MicroBooNE Detector Stability"*, MICROBOONE-NOTE-1013-PUB, (2016)
6. *"Measurement of the Electronegative Contaminants and Drift Electron Lifetime in the MicroBooNE Experiment"*, MICROBOONE-NOTE-1003-PUB, (2016)
7. *"Noise Dependence on Temperature and LAr Fill Level in the MicroBooNE Time Projection Chamber"*, MICROBOONE-NOTE-1001-TECH , (2016)

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1. “Measurement of Cosmic Ray Reconstruction Efficiencies in the MicroBooNE LAr TPC Using a Small External Cosmic Ray Counter”, arXiv:1707.09903, JINST 12, P12030 (2017)
2. “Michel Electron Reconstruction Using Cosmic Ray Data from the MicroBooNE LAr TPC”, arXiv:1704.02927, JINST 12, P09014 (2017)
3. “Determination of Muon Momentum in the MicroBooNE LAr TPC Using an Improved Model of Multiple Coulomb Scattering”, arXiv:1703.06187, JINST 12 P10010 (2017)

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1. “Vertex finding and reconstruction for contained two-track events in the MicroBooNE detector”, MICROBOONE-NOTE-1042-PUB, 2018
2. “Towards automated neutrino selection at MicroBooNE using tomorgraphic event reconstruction”, MICROBOONE-NOTE-1040-PUB, 2018
3. Hunting muon neutrinos in microboone with deep learning techniques, MICROBOONE-NOTE-1051-PUB, 2018
4. “Reconstruction Performance Studies with MicroBooNE Data in Support of Summer 2018 Analyses”, MICROBOONE-NOTE-1049-PUB, 2018
5. ““Detector Calibration using through going and stopping muons in the MicroBooNE LArTPC”, MICROBOONE-NOTE-1048-PUB, 2018
6. Proton Track Identication in MicroBooNE Simulation for Neutral Current Elastic Events, MICROBOONE-NOTE-1025-PUB, 2017
7. ”A Comparison of Monte-Carlo Simulations and Data from MicroBooNE”, MICROBOONE-NOTE-1014-PUB, 2017
8. “Demonstration of 3D Shower Reconstruction on MicroBooNE Data”, MICROBOONE-NOTE-1012-PUB, 2016