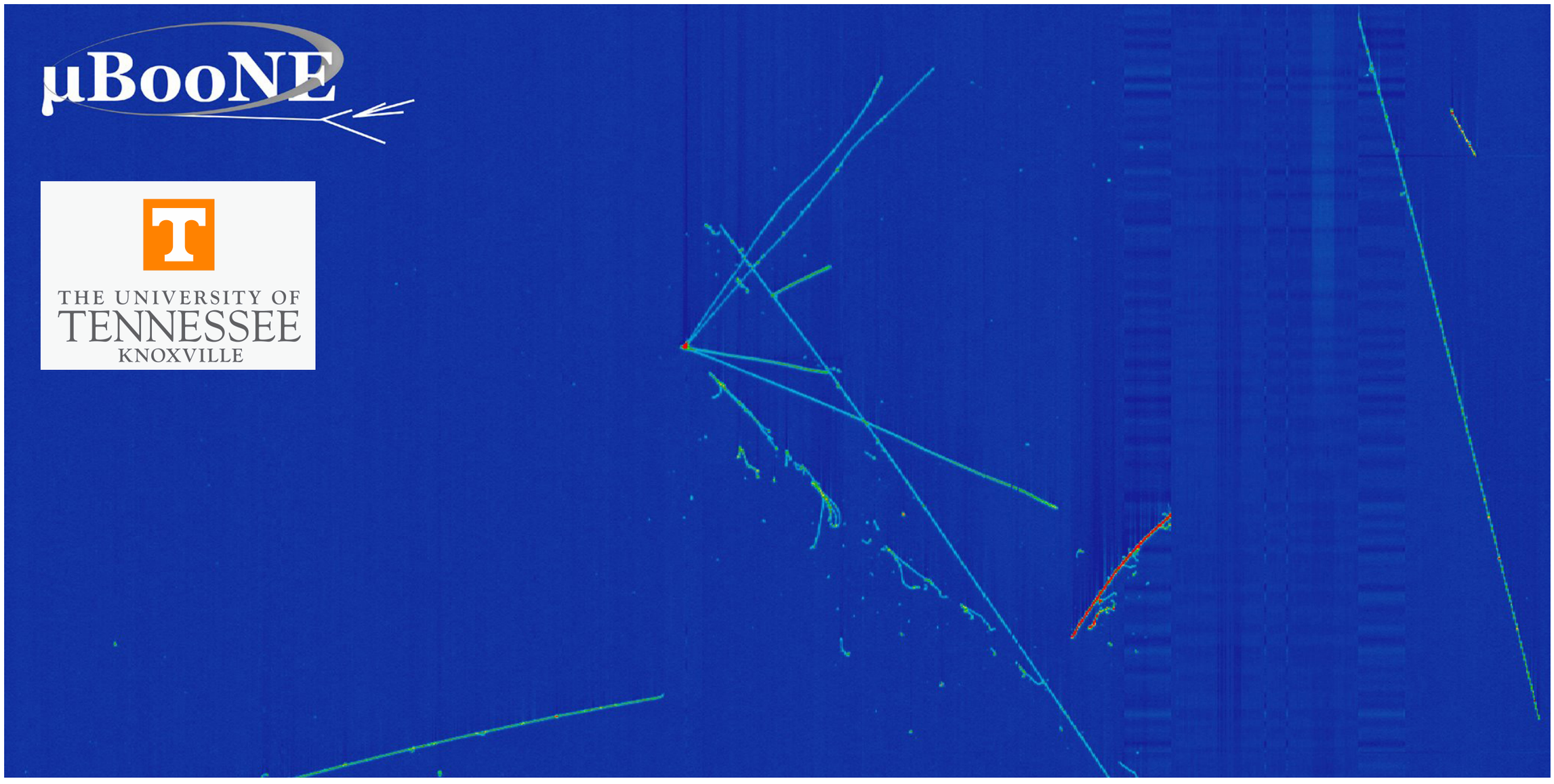


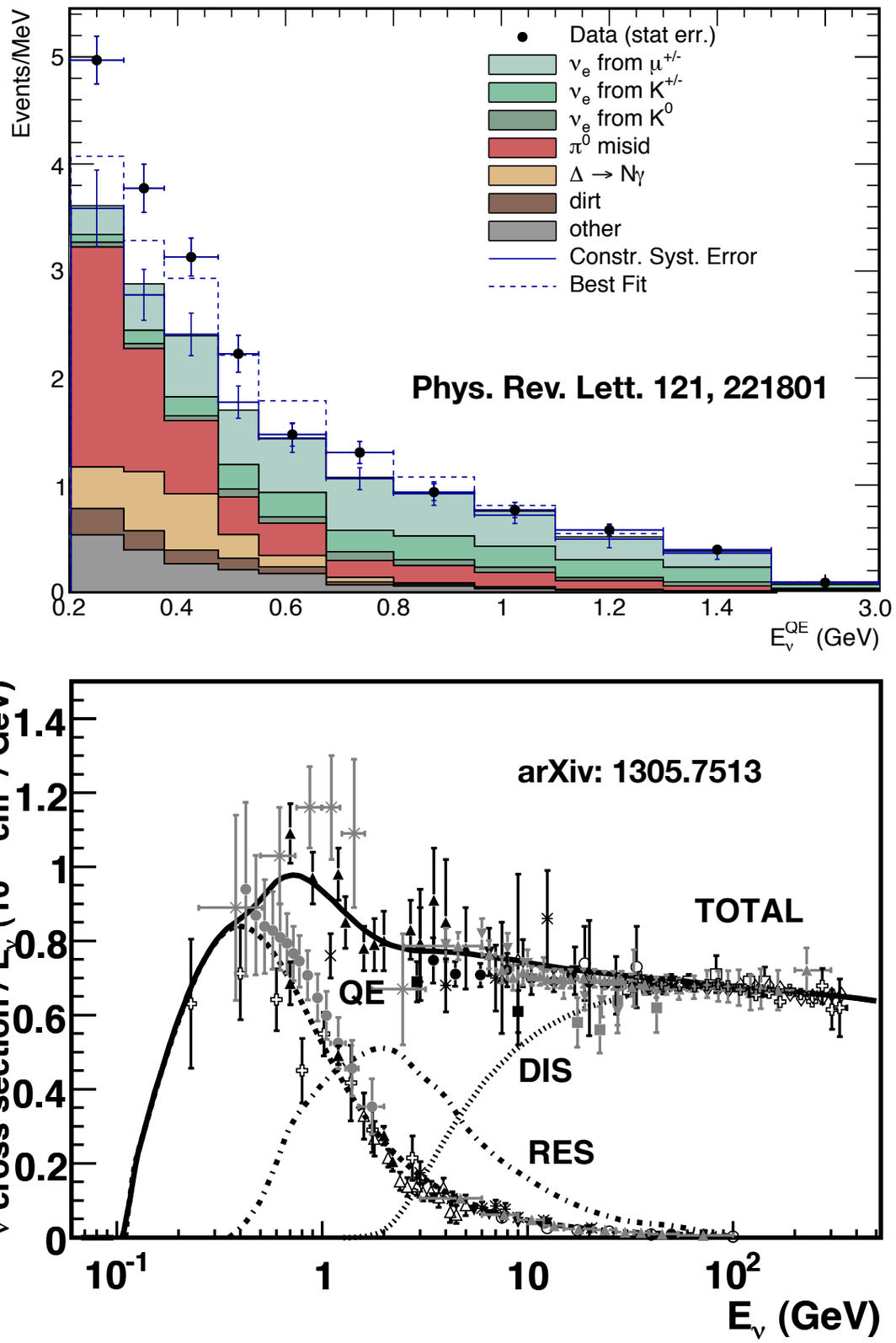
Recent Results from MicroBooNE

Wei Tang (UTK)

On Behalf of the MicroBooNE Collaboration

APS DPF Meeting, Northeastern University, Boston, 2019

The Main Goals of the MicroBooNE



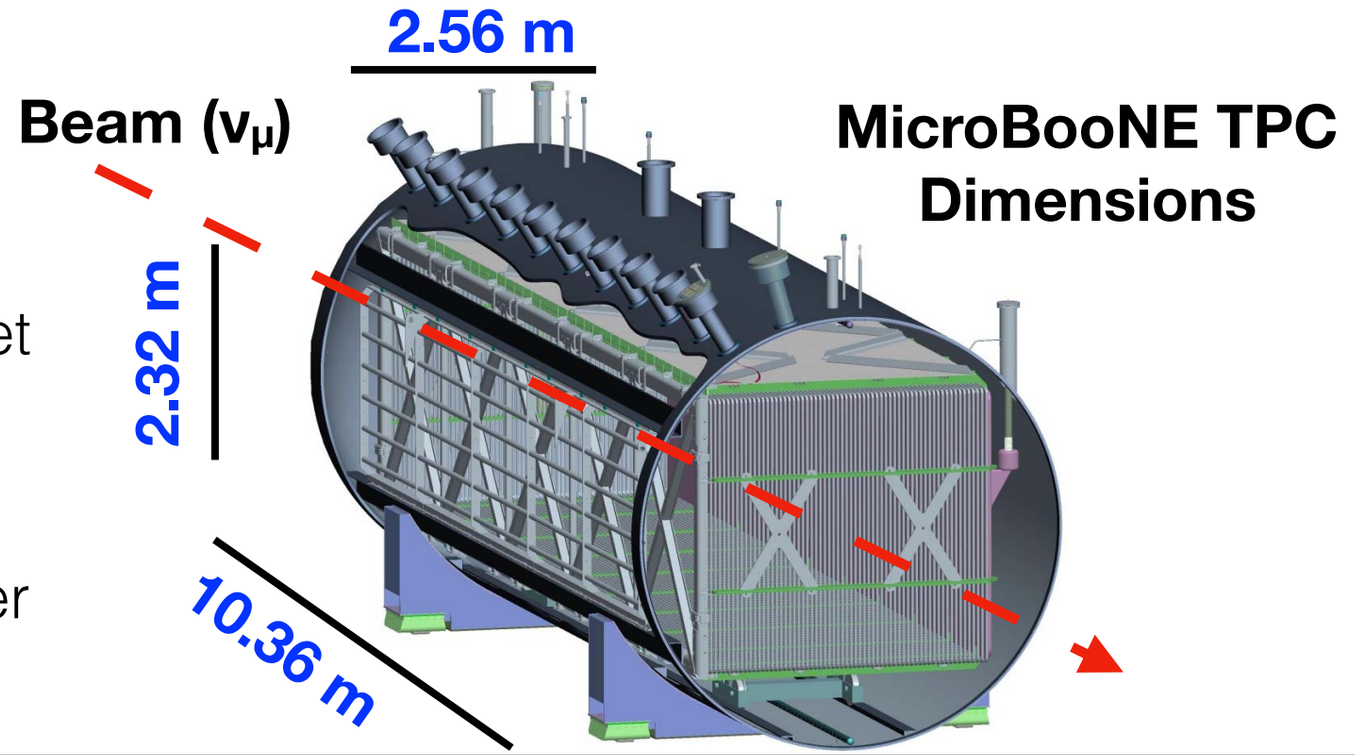
- To study short baseline neutrino oscillations, primarily the low energy excess (LEE) observed by MiniBooNE experiment
  - Is the LEE due to sterile neutrino(s) oscillations or backgrounds unpredicted by MiniBooNE

- High statistics precision measurement of ν - Ar cross sections ~ 1 GeV
  - Critical both for MicroBooNE and future LArTPC neutrino oscillation experiments

- Supernova searches

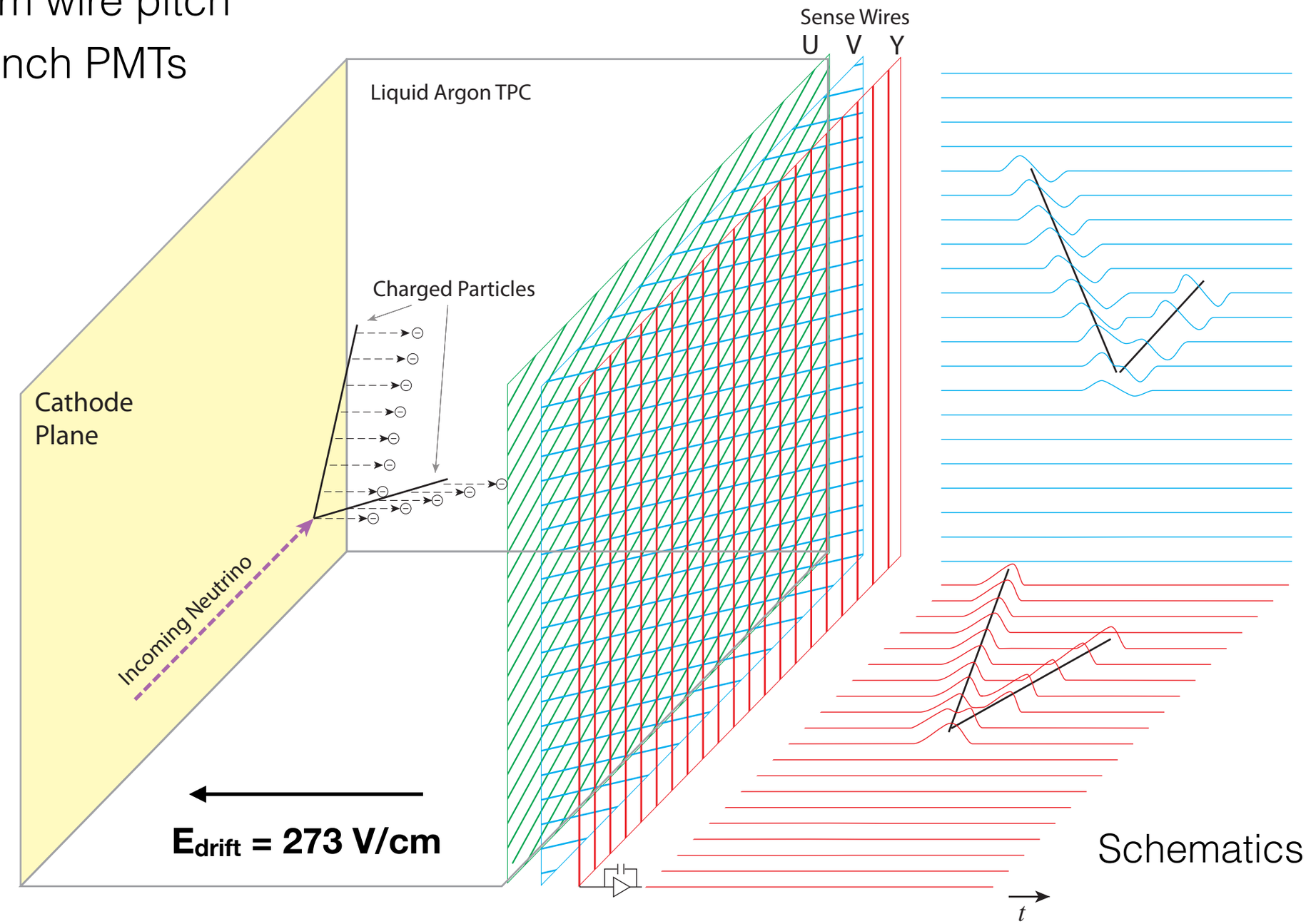
The MicroBooNE Experiment

- Accelerator ν experiment
- 8 GeV proton beam on beryllium target
- 800 MeV average ν energy
- 470 m baseline
- Liquid Argon Time Projection Chamber (LArTPC) with 85 ton active mass



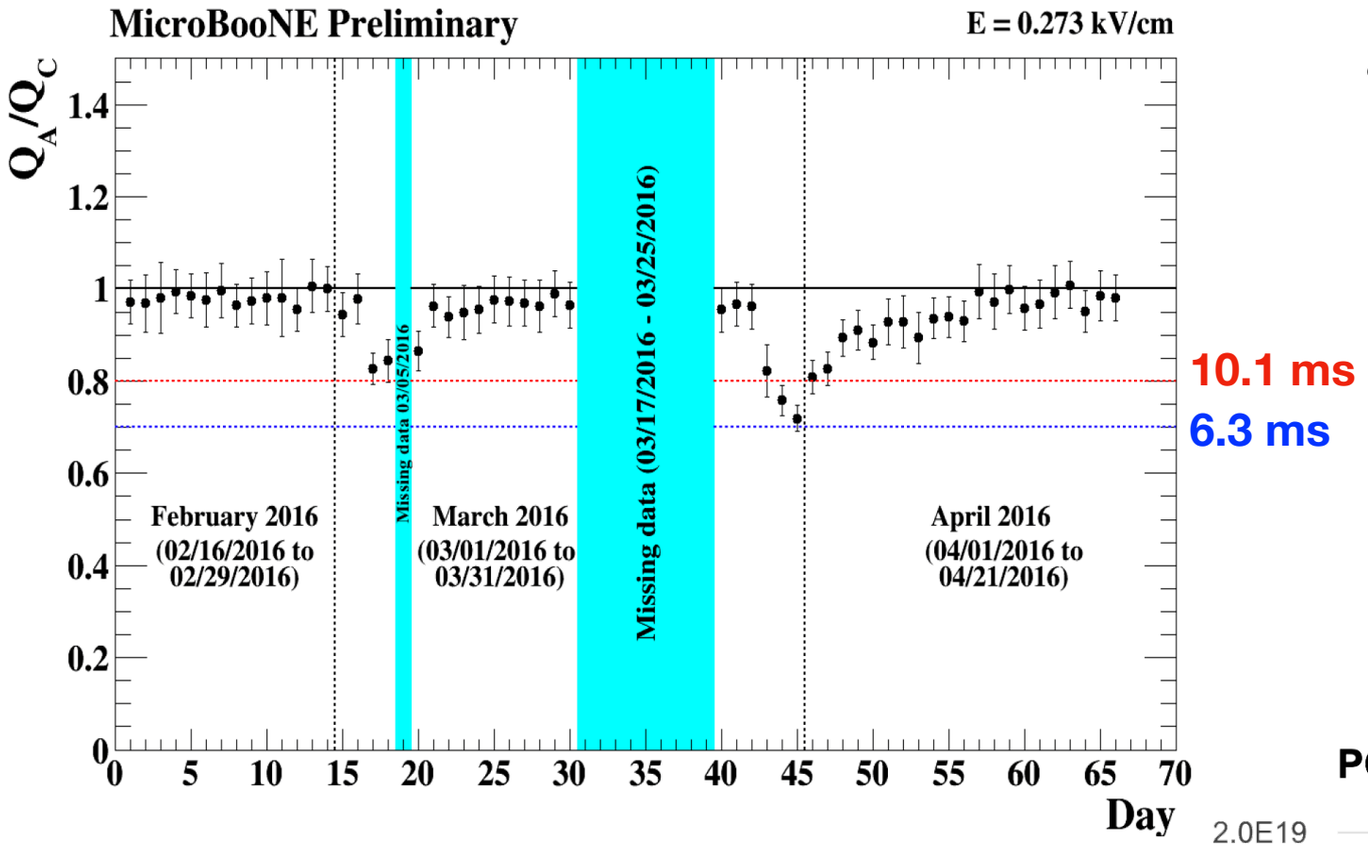
MicroBooNE Uses LArTPC Technology

- 3 wire planes with 8192 wires
  - 1 collection and 2 induction planes
  - 3 mm wire pitch
- 32 8-inch PMTs



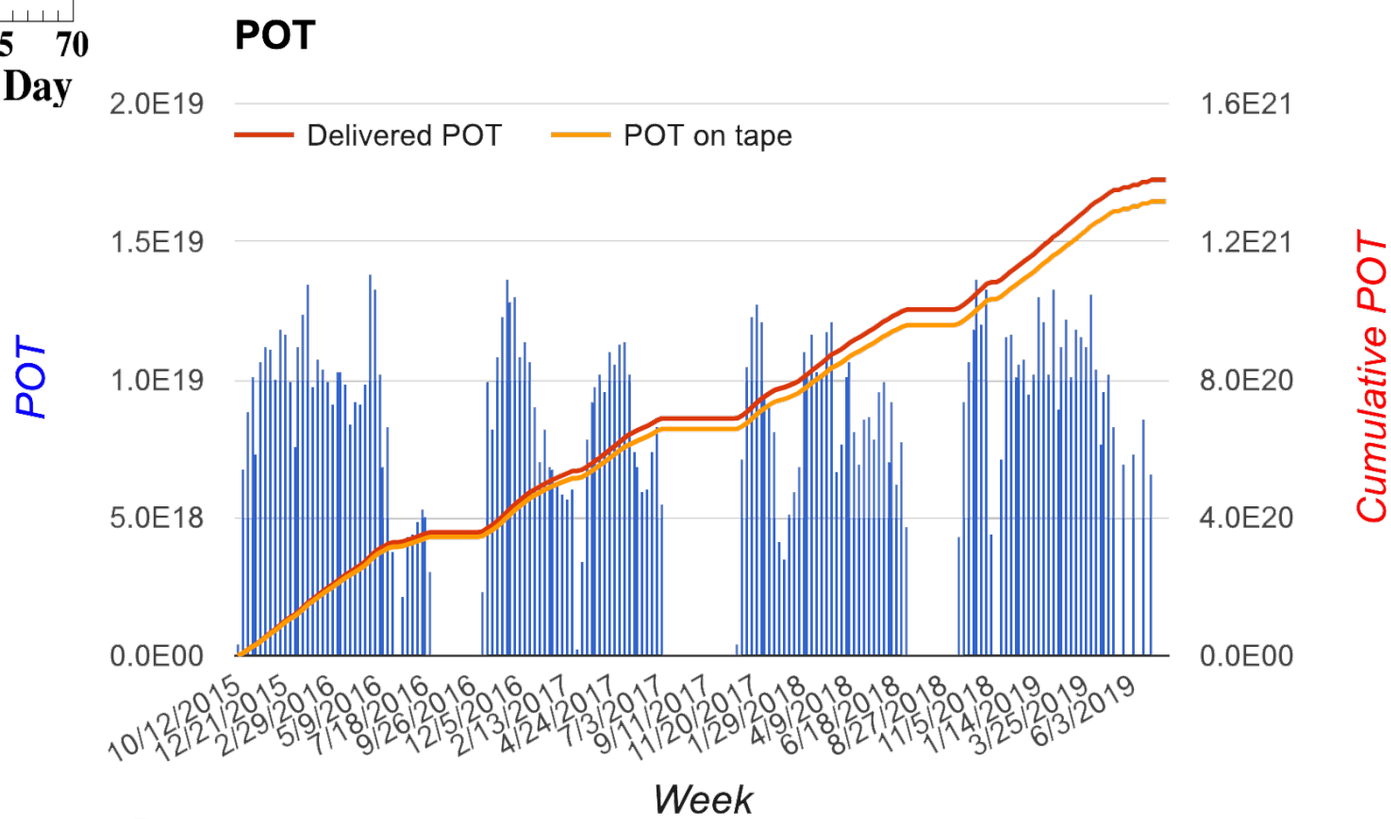
Schematics from Yu Bo

MicroBooNE Operations



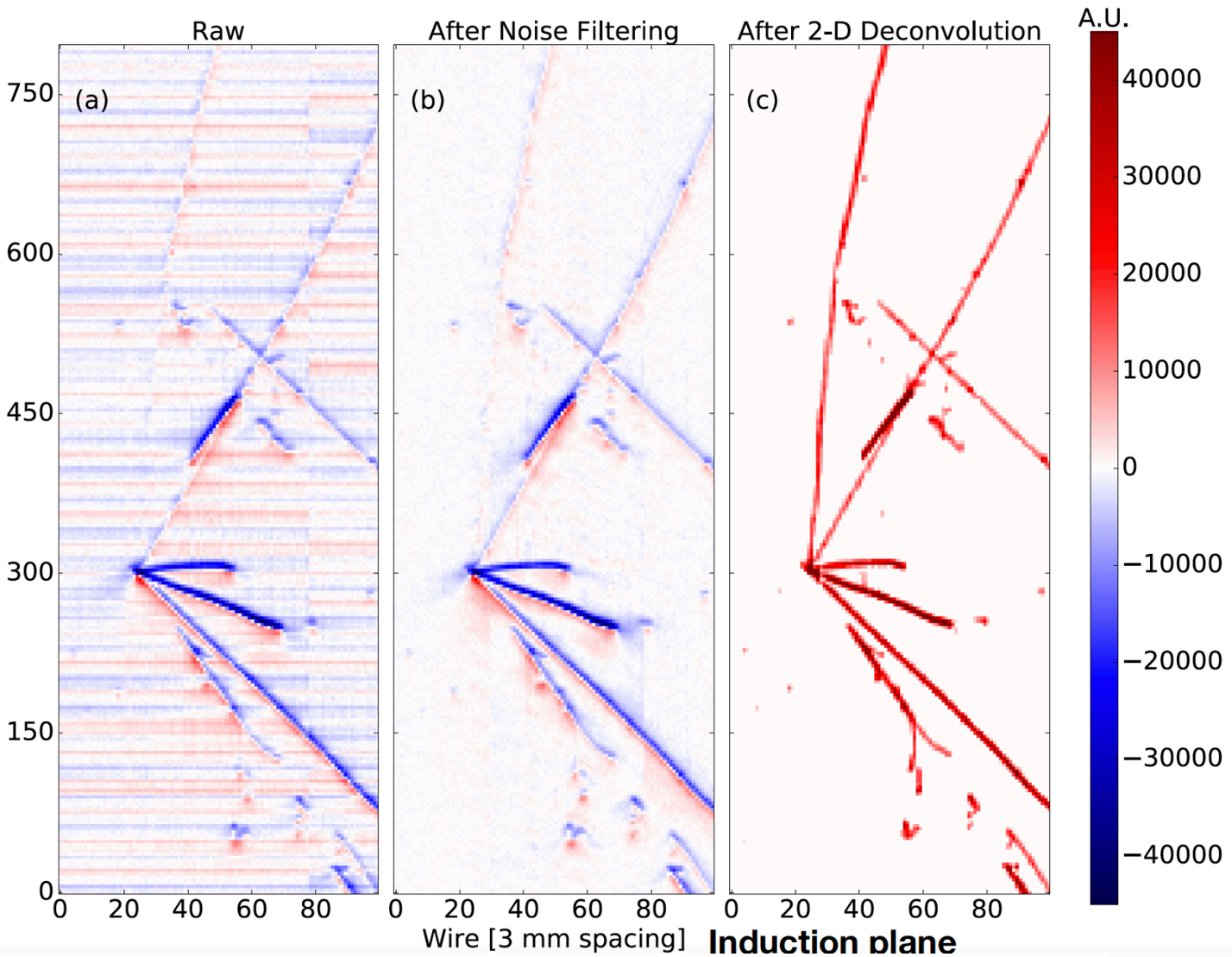
- Argon purity is critical for LArTPC operation,
  - Measured as the fraction of charge detected at its anode relative to its cathode
  - Electron lifetime is very high

- Data taking started in October 2015, now it is the longest running LArTPC to date
  - 1.34 x 10^{21} Protons On Target (POT) delivered now



Noise Filtering and Signal Processing

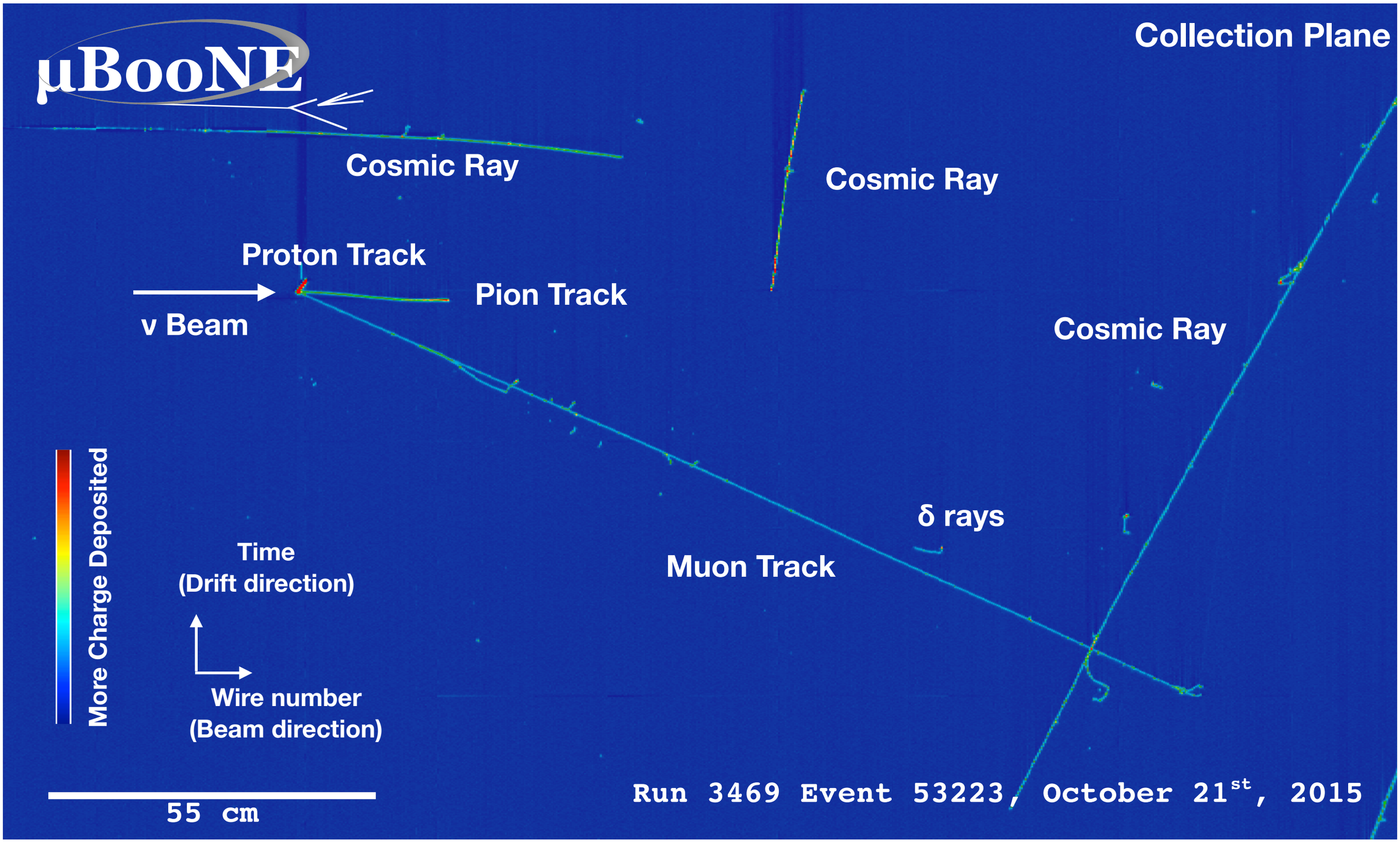
Detailed characterization of the detector is key to our Physics and to our R&D mission for future detectors



- 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)

- "Ionization Electron Signal Processing in Single Phase LAr TPCs I and II, **JINST 13, P07006 (2018) & JINST 13, P07007 (2018)**
- "Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC", **JINST 12, P08003 (2017)**

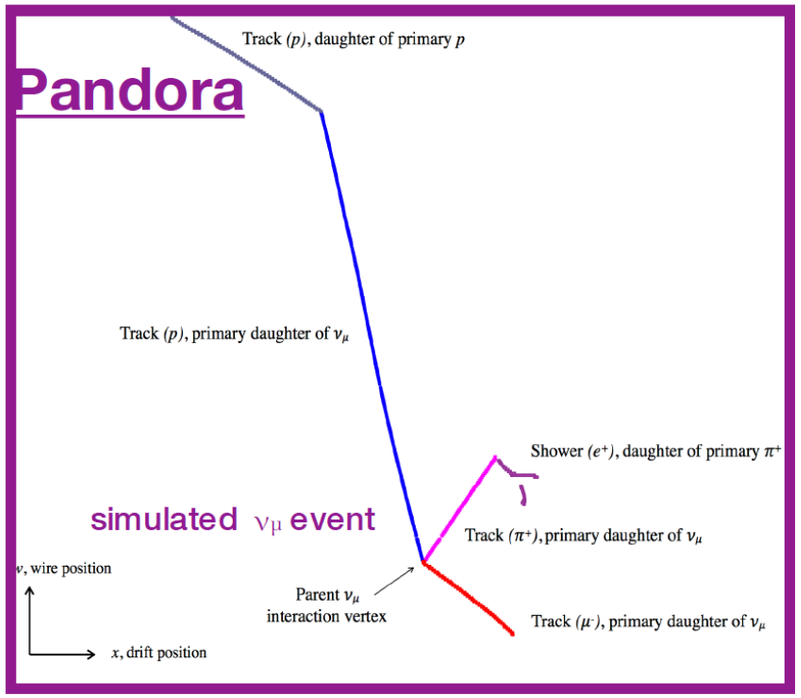
A Charged Current ν_μ Event in Data

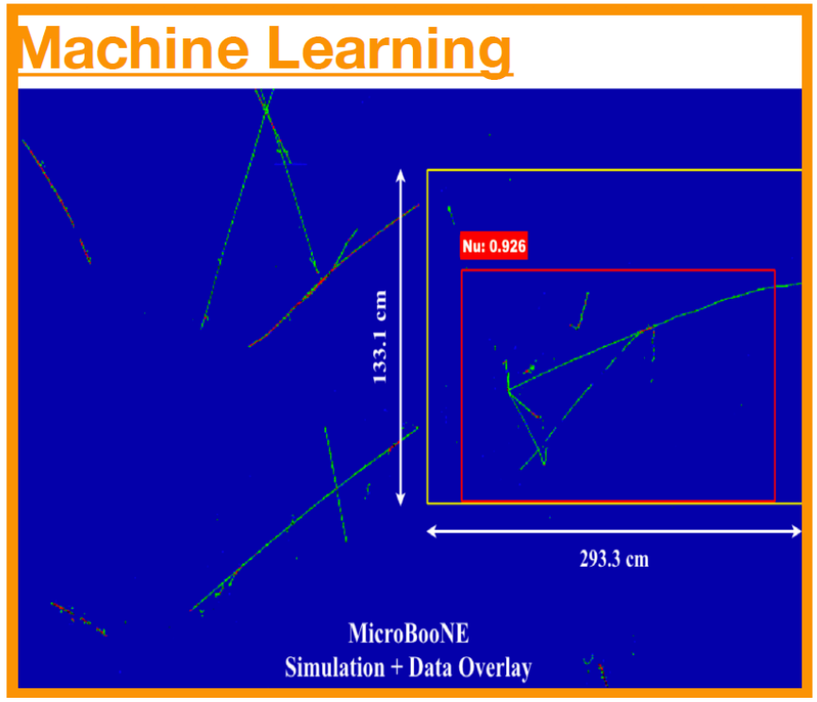


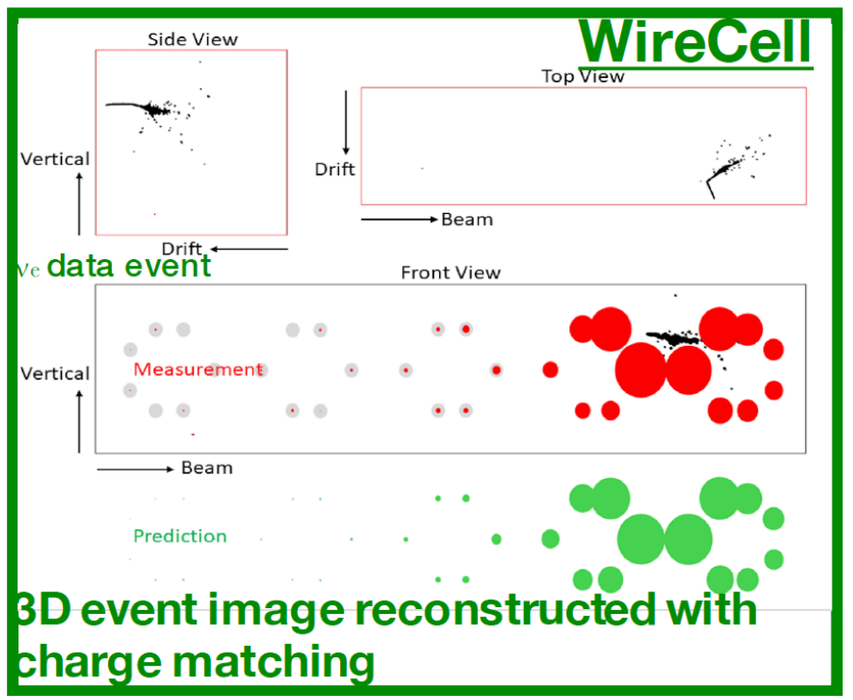
Event Reconstruction Techniques

- Different reconstruction techniques have been developed
- Reached high level of sophistication
- Essential for SBN and DUNE

See talk from Hanyu and posters from Katie and Joshua for more details on event reconstructions

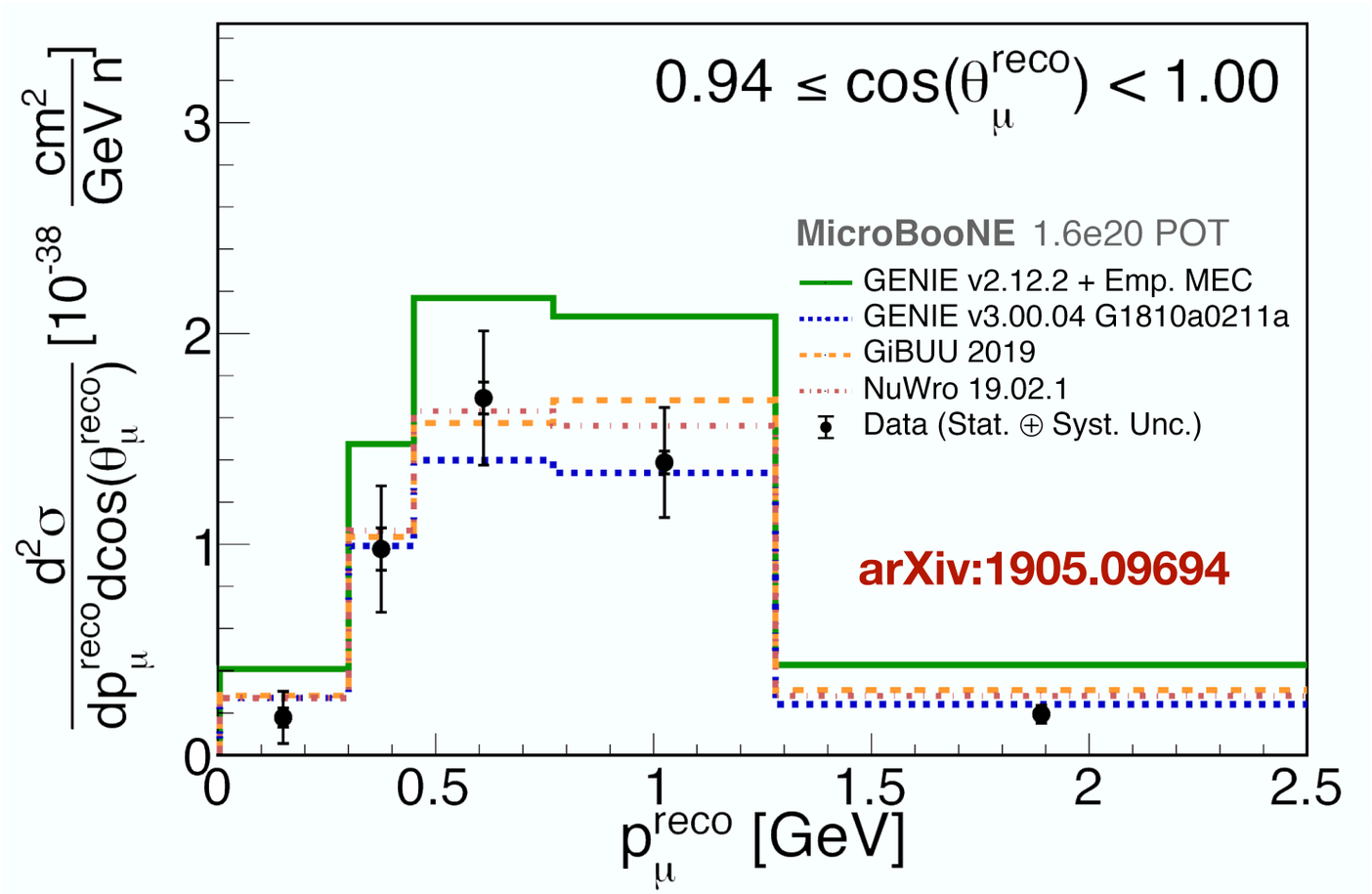






- "The Pandora Multi-Algorithm Approach to Automated Pattern Recognition of Cosmic Ray Muon and Neutrino Events in the MicroBooNE Detector", **Eur. Phys. J. C78, 1, 82 (2018)**"
- "Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber", **JINST 12, P03011 (2017)**
- "Towards automated neutrino selection at MicroBooNE using tomorgraphic event reconstruction", **MICROBOONE-NOTE-1040-PUB, 2018**

ν_μ Charge Current Inclusive Cross Section Measurement



- $\nu_\mu + Ar \rightarrow \mu^- + X$
- 26 k events (1.6x10^{20} POT data) used in the measurement
- Full muon momentum and muon angle coverage
  - Pioneering use of Multiple Coulomb Scattering (MCS) for muon momentum reconstruction
- First ν_μ-Ar double differential cross section measurement
- The data favors GENIE3 prediction with more sophisticated nuclear models

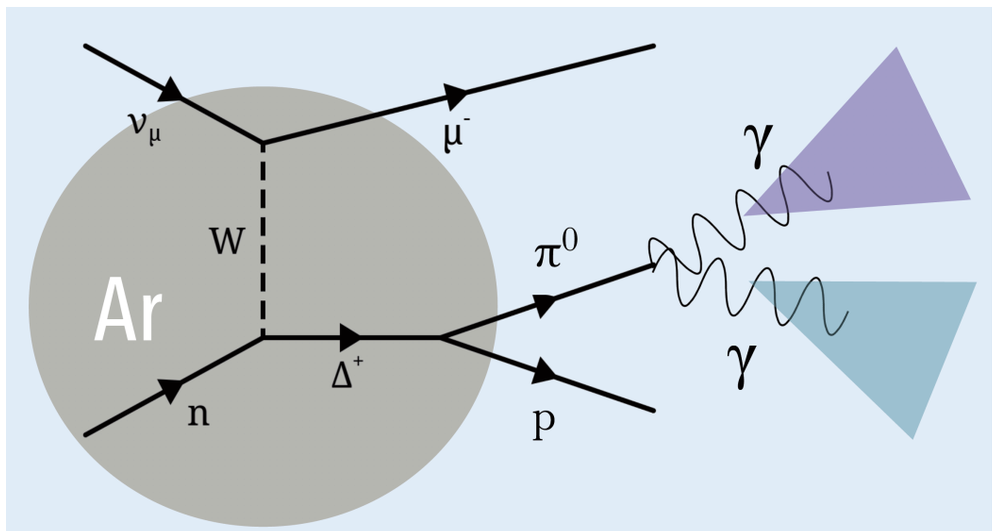
Flux integrated total cross section

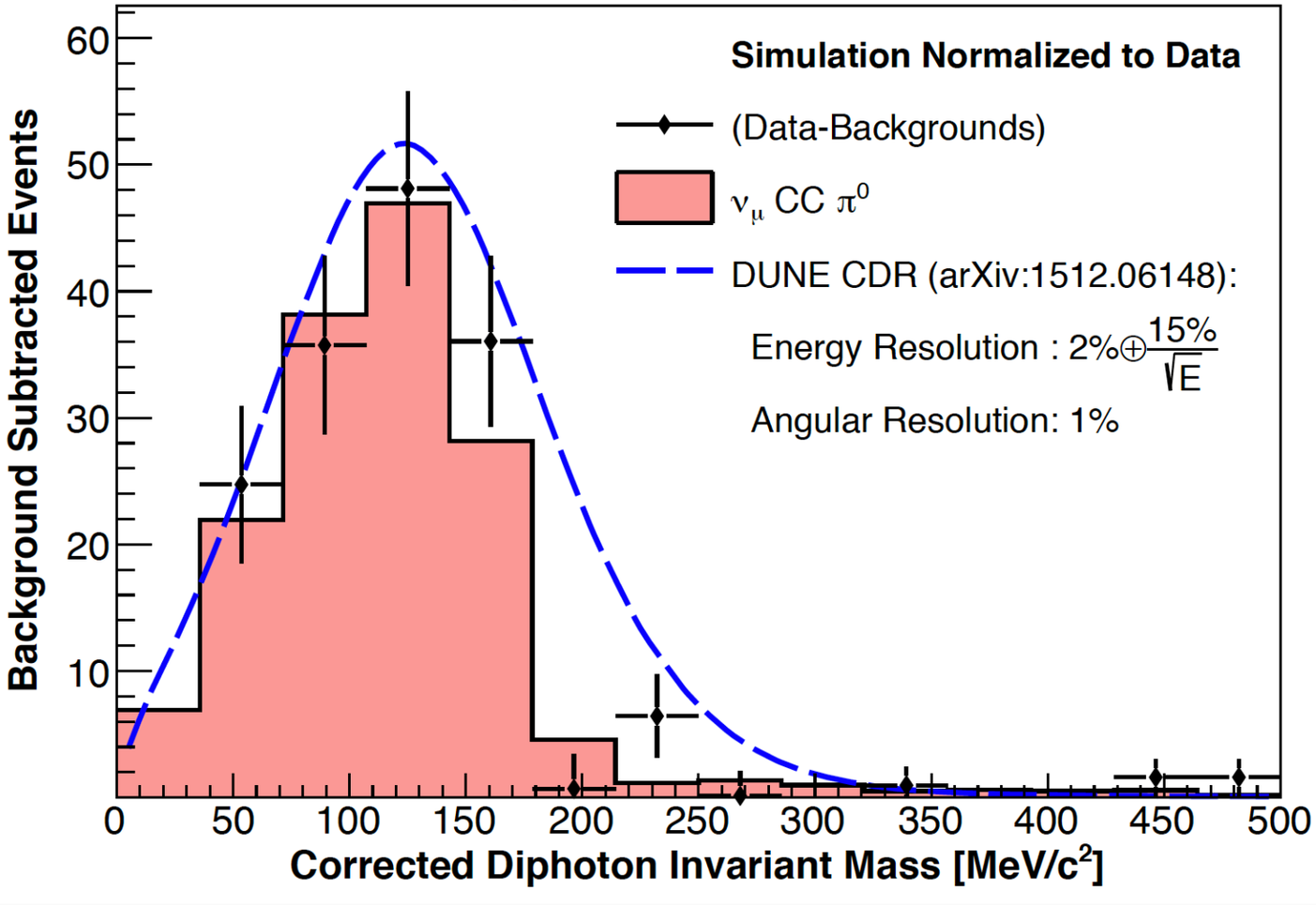
$$\sigma = (0.693 \pm 0.010 \pm 0.165) \times 10^{-38} cm^2$$

M. Kirby already presented a nice summary yesterday, see Raquel's talk tomorrow for details on the MicroBooNE detector

Charge Current π^0 Exclusive Cross Section Measurement

- Understanding π^0 background is a crucial step towards searching for LEE
- First implementation of fully automated shower reconstruction to analyze LArTPC data
- First charge current single π^0 cross section measurement in ν_μ + Ar interactions





$$\nu_\mu + Ar \rightarrow \mu^- + \pi^0 + X$$

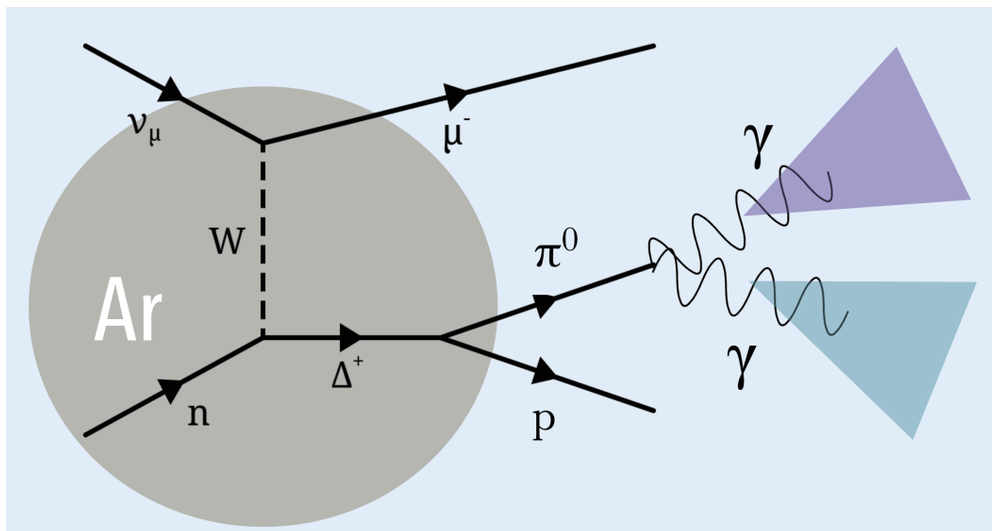
Total Cross Section

$$\sigma = (1.9 \pm 0.2 \pm 0.6) \times 10^{-38} cm^2$$

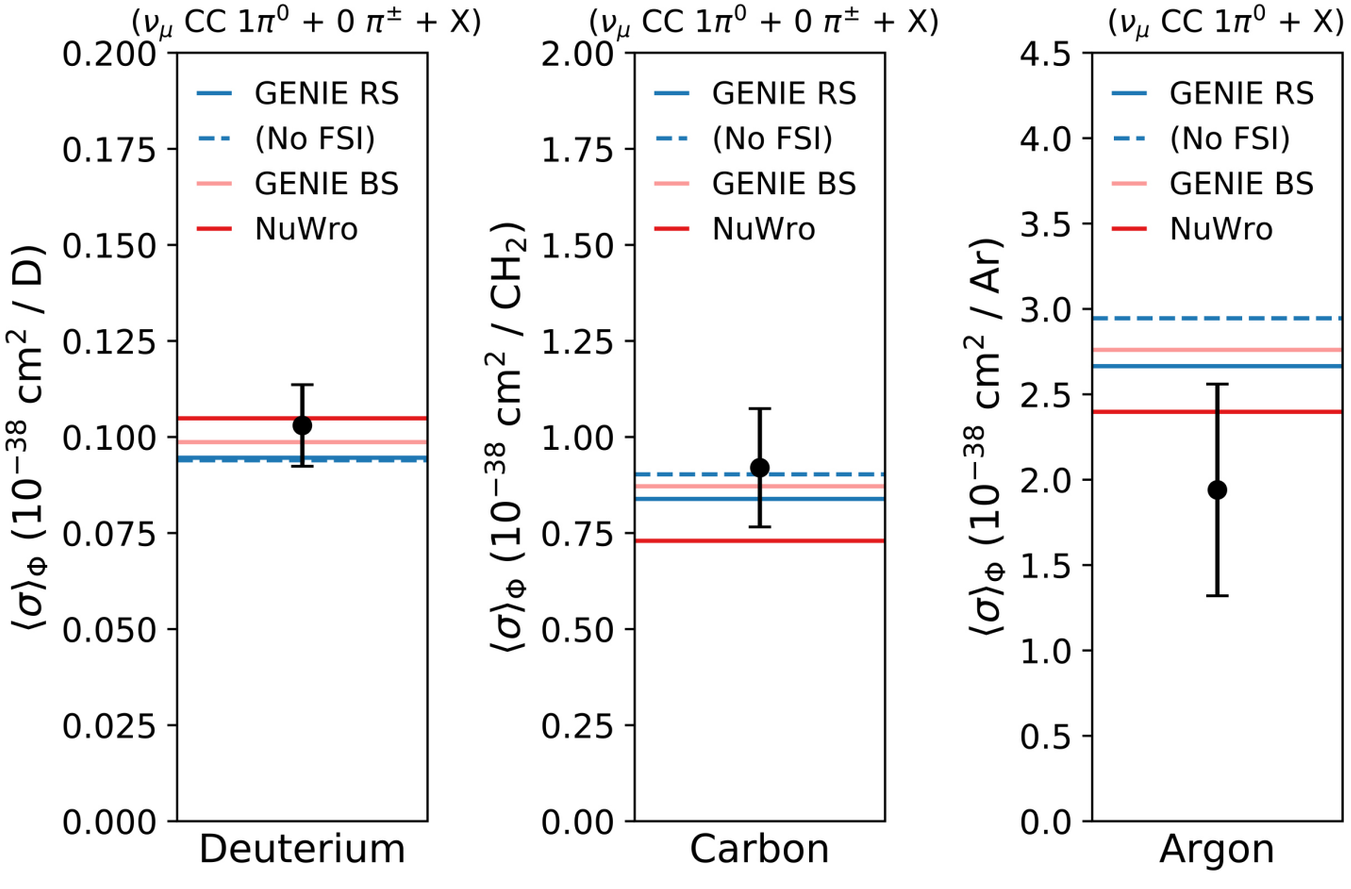
"First Measurement of ν_μ charged-current π^0 production on argon with the MicroBooNE detector" **Phys. Rev. D 99, 091102 (2019)**

Charge Current π^0 Exclusive Cross Section Measurement

- Verified the scaling used in models for larger nuclei is consistent with our data
- This measurement enables us to perform comparisons with past measurements on deuterium and carbon



$$\nu_\mu + Ar \rightarrow \mu^- + \pi^0 + X$$



Total Cross Section

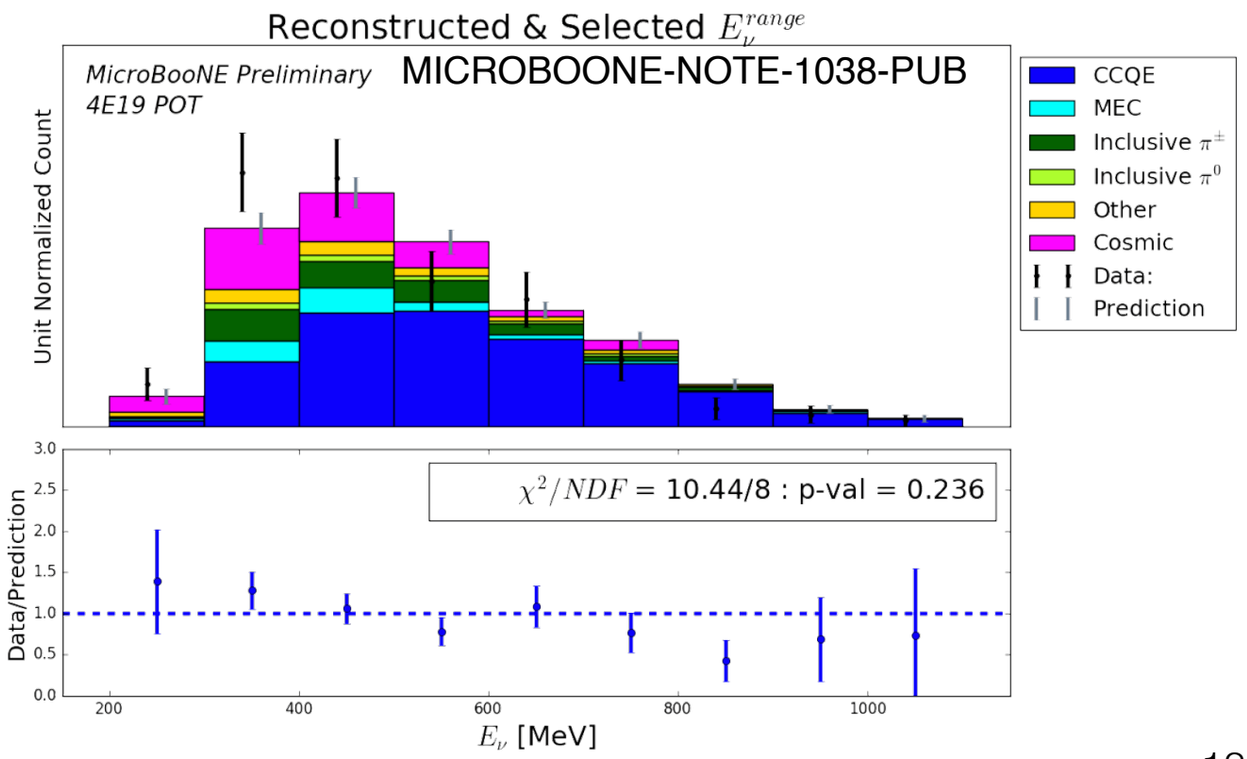
$$\sigma = (1.9 \pm 0.2 \pm 0.6) \times 10^{-38} cm^2$$

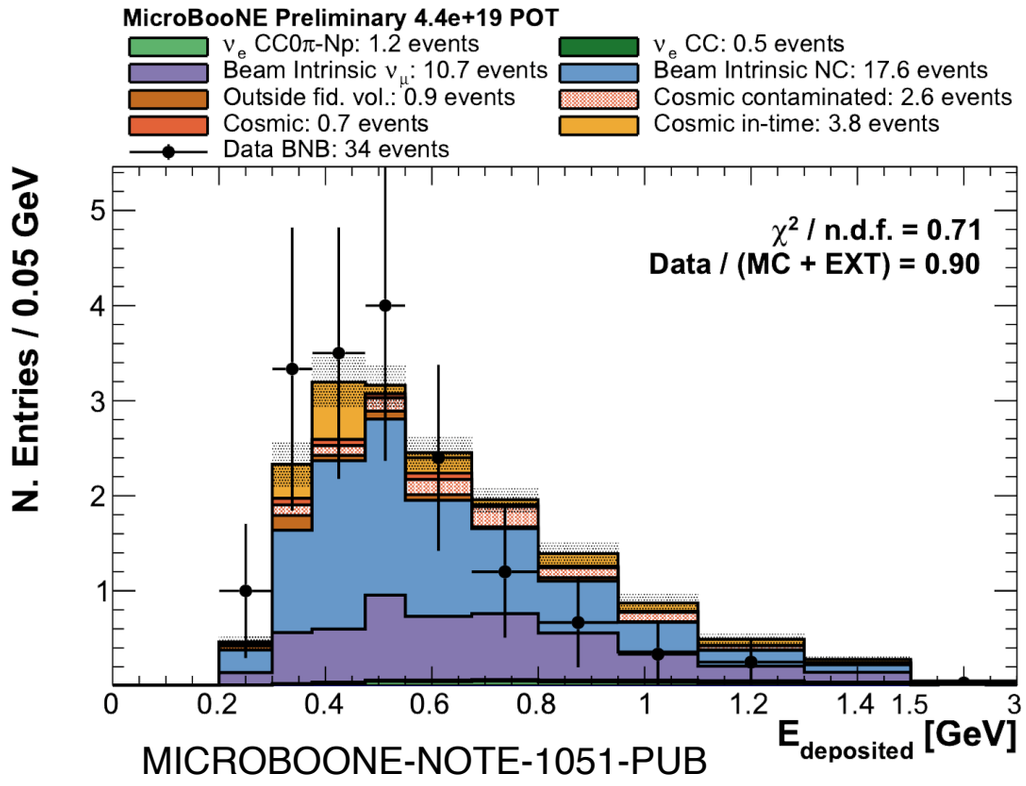
"First Measurement of ν_μ charged-current π^0 production on argon with the MicroBooNE detector" **Phys. Rev. D 99, 091102 (2019)**

Paths Toward Low Energy Excess (LEE) Results

- Electron-like LEE searches
  - ($1e^- + X, 1e^- + 1p, 1e^- + Np$ final states)
    - Requiring exclusive final states to maximize removal of backgrounds.
  - Simultaneous $\nu_e - \nu_\mu$ fit to constrain flux and cross section uncertainties
  - Backgrounds constraints from data using sidebands

See Ralitsa's talk for more on electron-like LEE searches

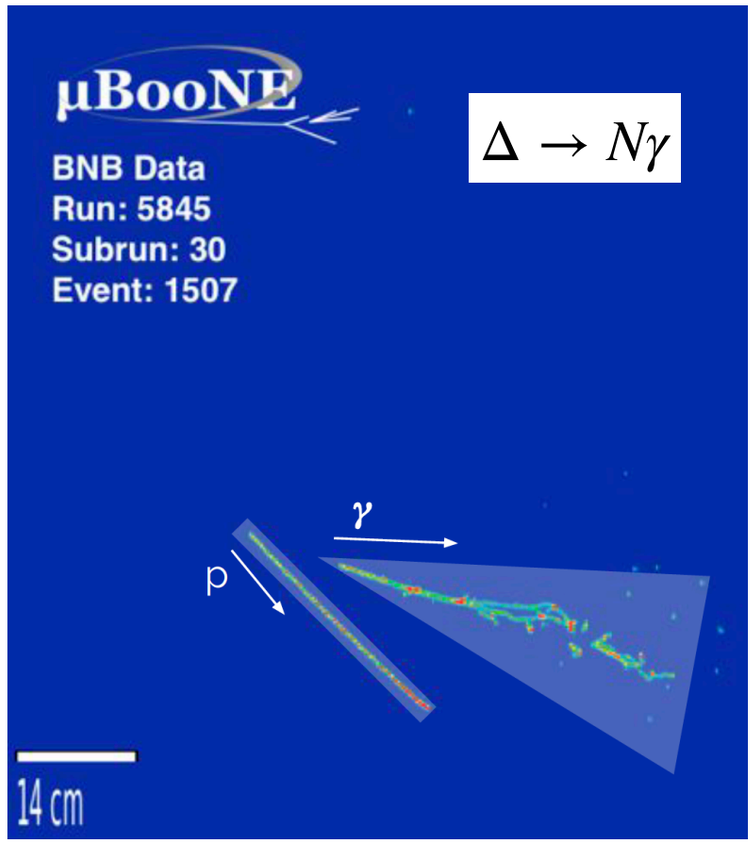


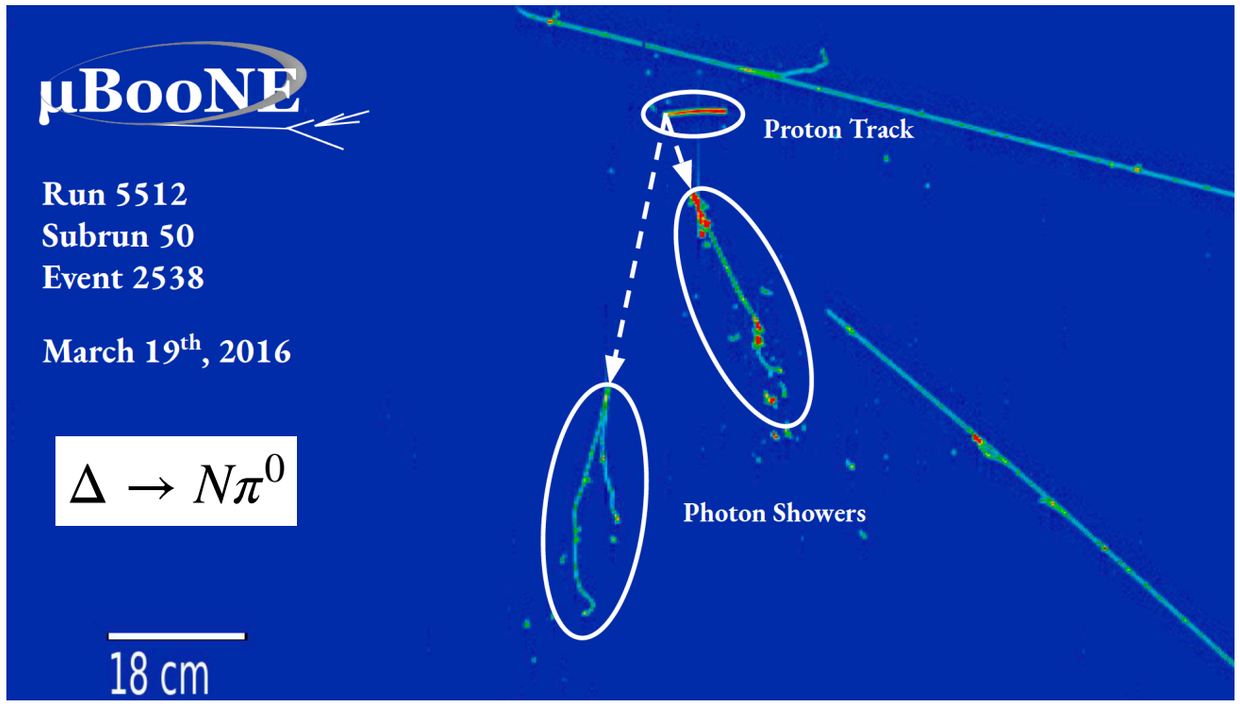


Paths Toward Low Energy Excess (LEE) Results

- Photon-like LEE searches
  - $\Delta \rightarrow N\gamma$ ($1\gamma 0p, 1\gamma 1p$ final states)
  - Never been measured before in a neutrino experiment
  - Use NC π^0 production to constrain the expected rate of radiative decays
  - Using a powerful Boosted Decision Tree (BDT) to distinguish signal from cosmic background

See Kathryn and Andrew's talk for more on photon-like LEE searches





MicroBooNE Publications and Public Notes

32 public notes

- MICROBOONE-NOTE-1055-PUB A Method to Determine the Electric Field of Liquid Argon Time Projection Chambers using a UV Laser System and its Application in MicroBooNE
- MICROBOONE-NOTE-1053-PUB Studying the Strange Axial Form Factor through Neutral-Current Elastic Scattering in MicroBooNE
- MICROBOONE-NOTE-1054-PUB Automated Selection of Electron Neutrinos from the NuMI beam in the MicroBooNE Detector and Prospects for a Measurement of the Charged
- MICROBOONE-NOTE-1051-PUB Selection of numu Events for the MicroBooNE Deep Learning Low Energy Excess Analysis
- MICROBOONE-NOTE-1056-PUB Selection of numu charged–current induced interactions with N>0 protons and performance of events with N=2 protons in the final state in the
- MICROBOONE-NOTE-1045-PUB First Muon-Neutrino Charged-Current Inclusive Differential Cross Section Measurement for MicroBooNE Run 1 Data
- MICROBOONE-NOTE-1048-PUB Detector calibration using through going and stopping muons in the MicroBooNE LArTPC
- MICROBOONE-NOTE-1038-PUB Electron-neutrino selection and reconstruction in the MicroBooNE LArTPC using the Pandora multi-algorithm pattern recognition

...

15 publications/documents

- “First Measurement of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon at Enu ~0.8 GeV with the MicroBooNE Detector”, **arXiv:1905.09694**
- “Design and Construction of the MicroBooNE Cosmic Ray Tagger System”, **JINST 14, P04004 (2019)**
- “Rejecting Cosmic Background for Exclusive Neutrino Interaction Studies with Liquid Argon TPCs: A Case Study with the MicroBooNE Detector”, **arXiv:1812.05679**
- “First Measurement of Muon Neutrino Charged Current Neutral Pion Production on Argon with the MicroBooNE LAr TPC”, **Phys. Rev. D, 99 091102**
- “A Deep Neural Network for Pixel-Level Electromagnetic Particle Identification in the MicroBooNE Liquid Argon Time Projection Chamber”, **Phys. Rev. D 99, 092001**
- “Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions”, **Eur. Phys. J. C79, 248 (2019)**
- “Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE”, **JINST 13, P07007 (2018)**
- “Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation”, **JINST 13, P07006 (2018)**

…

http://microboone.fnal.gov/documents-publications/

MicroBooNE Publications and Public Notes

32 public notes

- MICROBOONE-NOTE-1055-PUB A Method to Determine the Electric Field of Liquid Argon Time Projection Chambers using a UV Laser System and its Application in MicroBooNE
- MICROBOONE-NOTE-1053-PUB Studying the Strange Axial Form Factor through Neutral-Current Elastic Scattering in MicroBooNE
- MICROBOONE-NOTE-1054-PUB Automated Selection of Electron Neutrinos from the NuMI beam in the MicroBooNE Detector and Prospects for a Measurement of the Charged
- MICROBOONE-NOTE-1051-PUB Selection of numu Events for the MicroBooNE Deep Learning Low Energy Excess Analysis
- MICROBOONE-NOTE-1056-PUB Selection of numu charged–current induced interactions with N>0 protons and performance of events with N=2 protons in the final state in the
- MICROBOONE-NOTE-1045-PUB First Muon-Neutrino Charged-Current Inclusive Differential Cross Section Measurement for MicroBooNE Run 1 Data
- MICROBOONE-NOTE-1048-PUB Detector calibration using through going and stopping muons in the MicroBooNE LArTPC
- MICROBOONE-NOTE-1038-PUB Electron-neutrino selection and reconstruction in the MicroBooNE LArTPC using the Pandora multi-algorithm pattern recognition

...

15 publications/documents

- "First Measurement of Inclusive Muon Neutrino Charged Current Differential Cross Sections on Argon at Enu ~0.8 GeV with the MicroBooNE Detector", **arXiv:1905.09694**
- "Design and Construction of the MicroBooNE Cosmic Ray Tagger System", **JINST 14, P04004 (2019)**
- "Rejecting Cosmic Background for Exclusive Neutrino Interaction Studies with Liquid Argon TPCs: A Case Study with the MicroBooNE Detector", **arXiv:1812.05679**
- "First Measurement of Muon Neutrino Charged Current Neutral Pion Production on Argon with the MicroBooNE LAr TPC", **Phys. Rev. D, 99 091102**
- "A Deep Neural Network for Pixel-Level Electromagnetic Particle Identification in the MicroBooNE Liquid Argon Time Projection Chamber", **Phys. Rev. D 99, 092001**
- "Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions", **Eur. Phys. J. C79, 248 (2019)**
- "Ionization Electron Signal Processing in Single Phase LAr TPCs II: Data/Simulation Comparison and Performance in MicroBooNE", **JINST 13, P07007 (2018)**
- "Ionization Electron Signal Processing in Single Phase LAr TPCs I: Algorithm Description and Quantitative Evaluation with MicroBooNE Simulation", **JINST 13, P07006 (2018)**

...

Coming !!!

More results are coming !!!

http://microboone.fnal.gov/documents-publications/

Summary

- MicroBooNE has been taking data since the Fall of 2015
- We made enormous progress in understanding the detector and the LArTPC technology
- We have begun to utilize the full promise of the LArTPC to test our neutrino interaction models in GENIE
- We performed our first ν_μ CC inclusive cross section measurement in ν_μ + Ar interactions
- We first measured the ν_μ charged current single π^0 total cross sections in ν_μ + Ar interactions
- We making good progress towards LEE results

MicroBooNE Talks/Posters at DPF 2019

- Measurements of Charged-Current Muon-Neutrino interactions on Argon at MicroBooNE
  - **Michael Kirby** (17:15, July 29, Neutrino Physics Session)
- Status of the MicroBooNE eLEE search and application of deep learning to LArTPC data
  - **Ralitsa Sharankova** (16:00, July 30, Neutrino Physics Session)
- MicroBooNE's Search for a Photon-Like Low Energy Excess
  - **Kathryn Sutton** (16:15, July 30, Neutrino Physics Session)
- Constraining the Neutral Current pi0 Background for MicroBooNE's Single-Photon Search
  - **Andrew Mogan** (16:35, July 30, Neutrino Physics Session)
- Recent progress on Wire-Cell 3D imaging and tracking for LArTPC
  - **Hanyu Wei** (16:00, July 31, Computing, Analysis Tools, & Data Handling Session)
- Detector Physics with MicroBooNE
  - **Raquel Castillo** (16:36, July 31, Particle Detector Session)

- Using Convolutional Neural Networks to Reconstruct Dead Channels in MicroBooNE
  - **Katie Mason** (August 1st, Poster Session)
- Ancestor Particle Clustering in MicroBooNE using Deep Learning Neural Networks
  - **Joshua Mills** (August 1st, Poster Session)

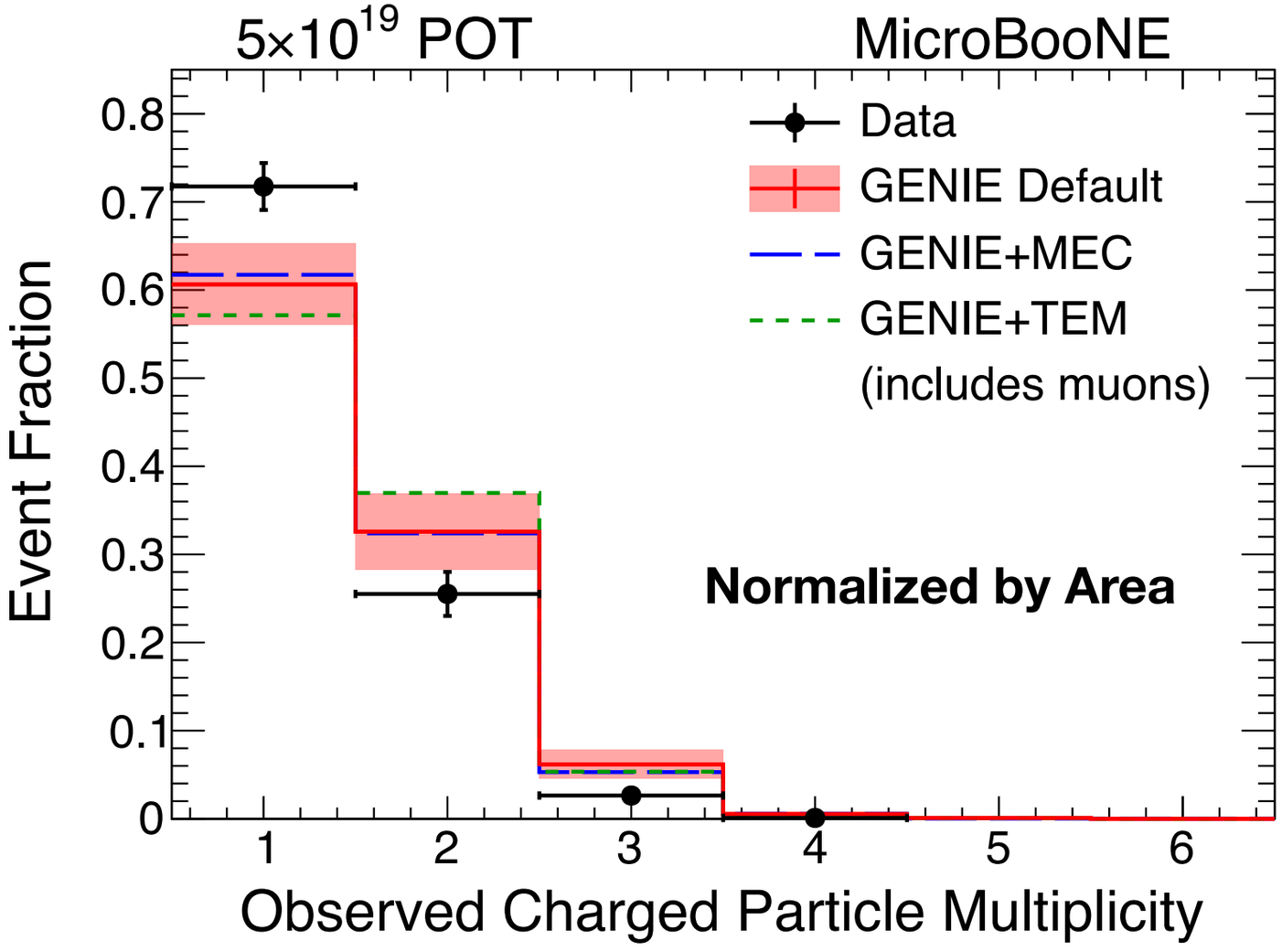
Thank You!

MicroBooNE Collaboration, July 2018

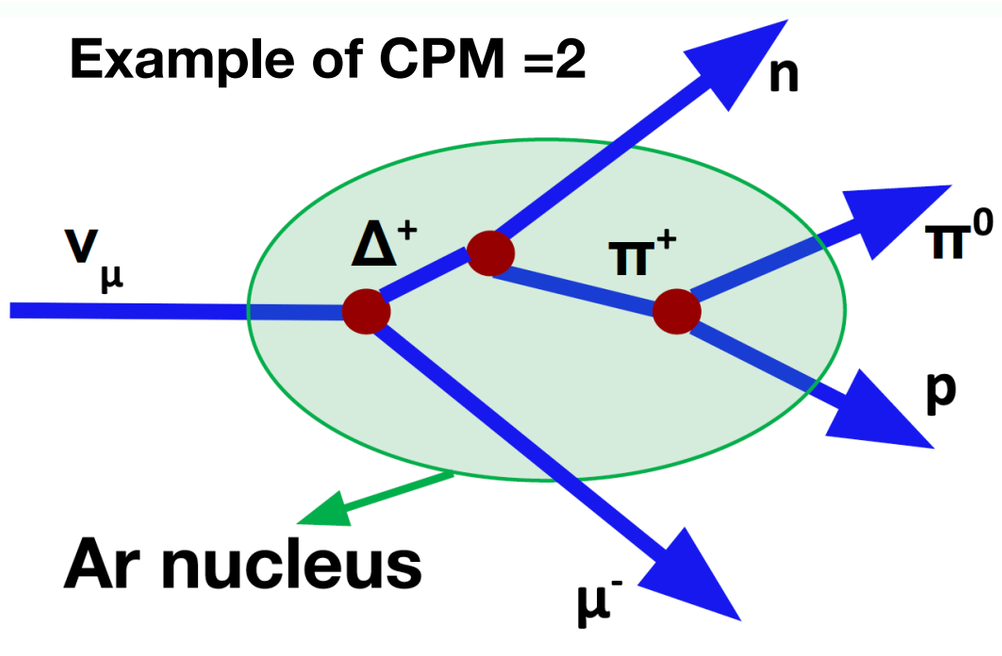
Backup Slides

Charge Particle Multiplicity (CPM)

- How many charged particle emerge from the nucleus in ν_μ – Ar interactions?
  - Powerful way to validate nuclear models and generators



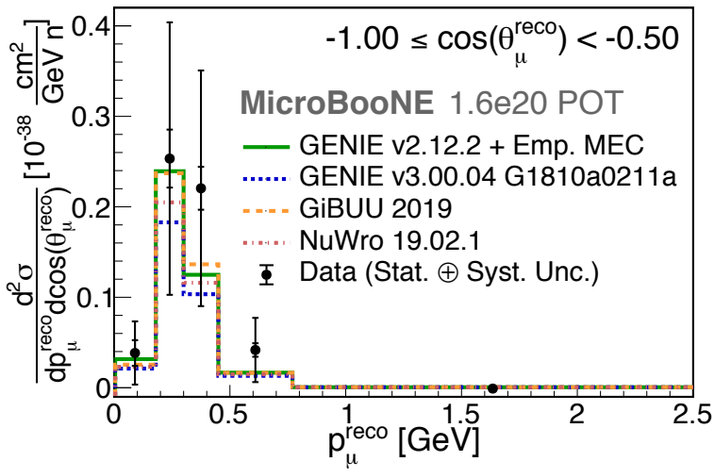
MEC = meson exchange current (populates multi-nucleon final states)
TEM = transverse enhancement model (larger transverse QE form factor)

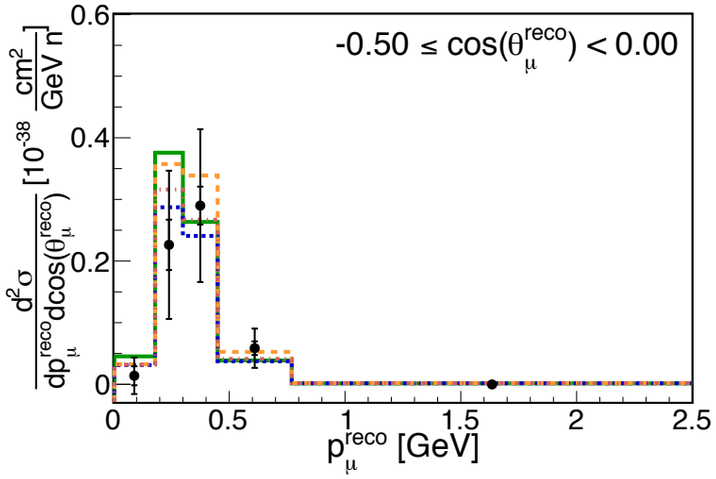


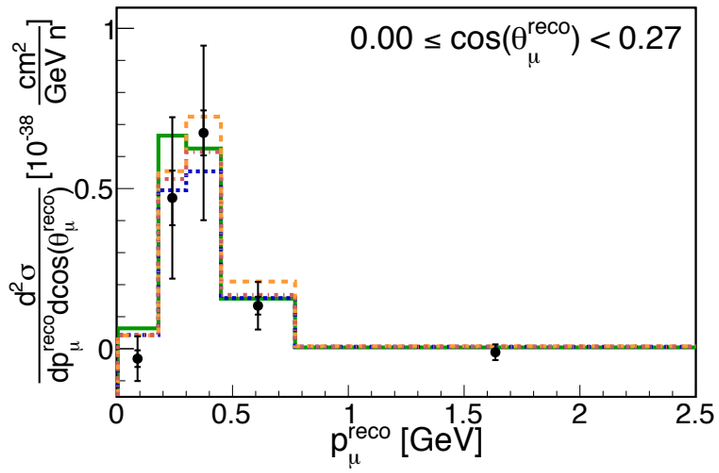
The Charge Particle Multiplicity of MicrobooNE data and GENIE simulation agree within 2σ

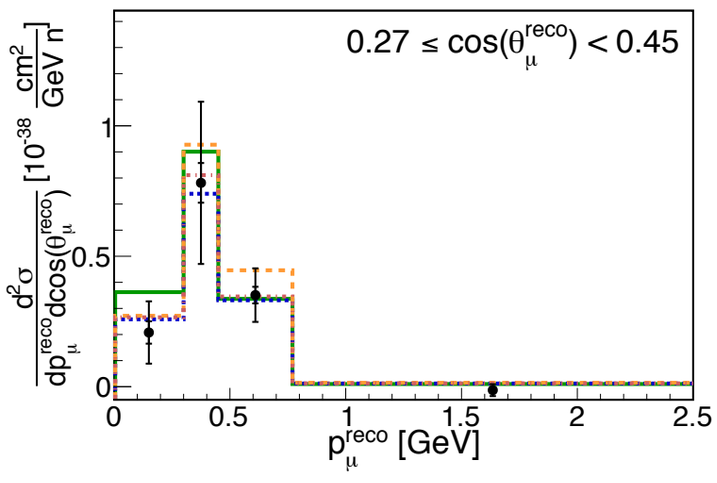
"Comparison of Muon-Neutrino-Argon Multiplicity Distributions Observed by MicroBooNE to GENIE Model Predictions"
Eur. Phys. J. C 79:248 (2019)

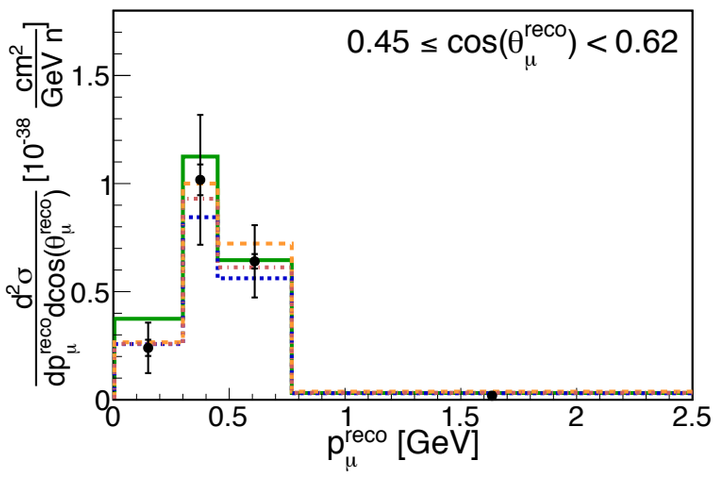
ν_μ Charge Current Inclusive Cross Section Measurement (Cont')

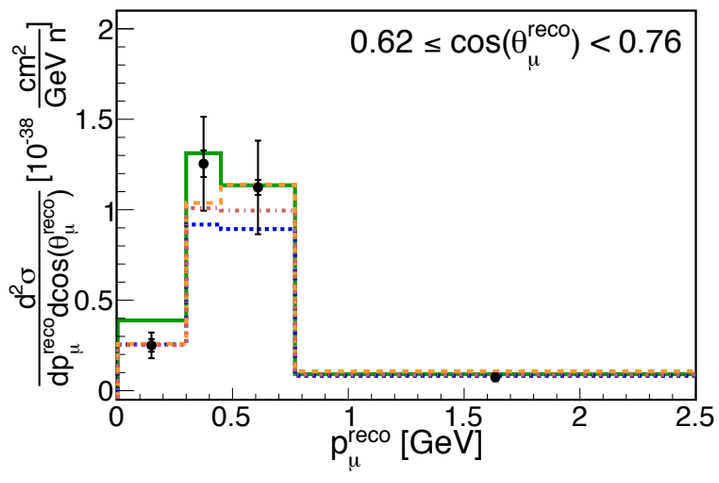


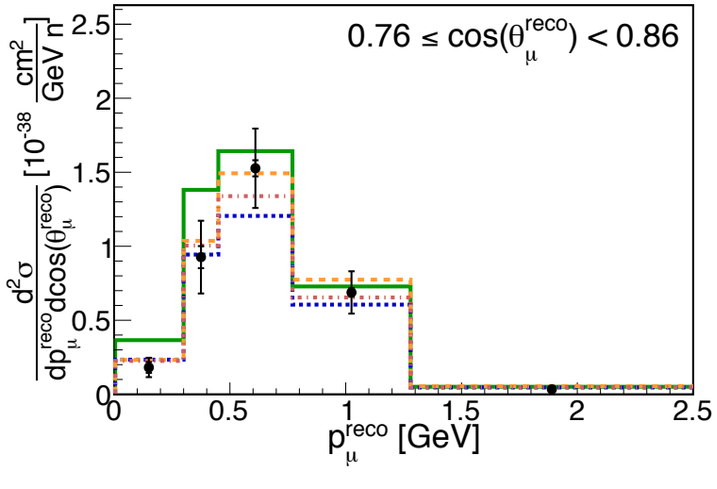


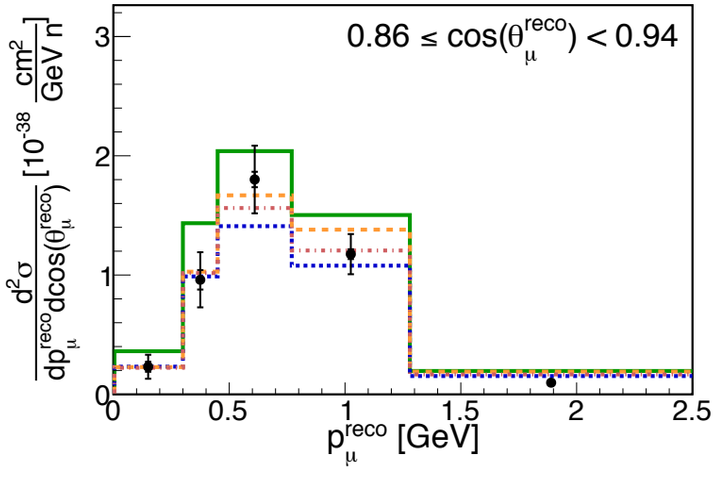


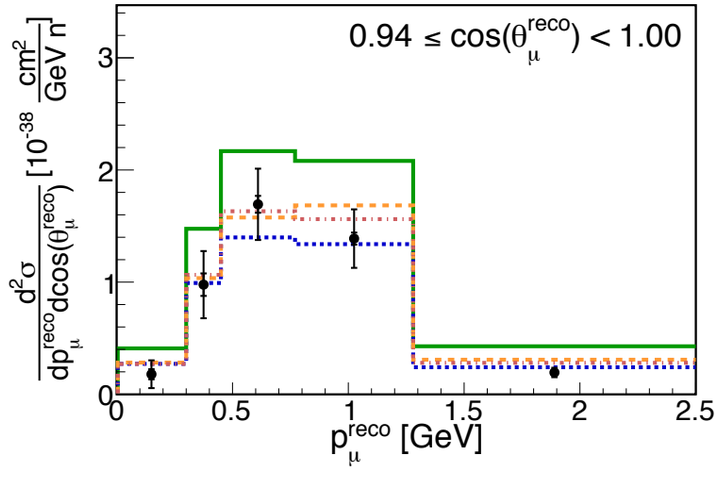










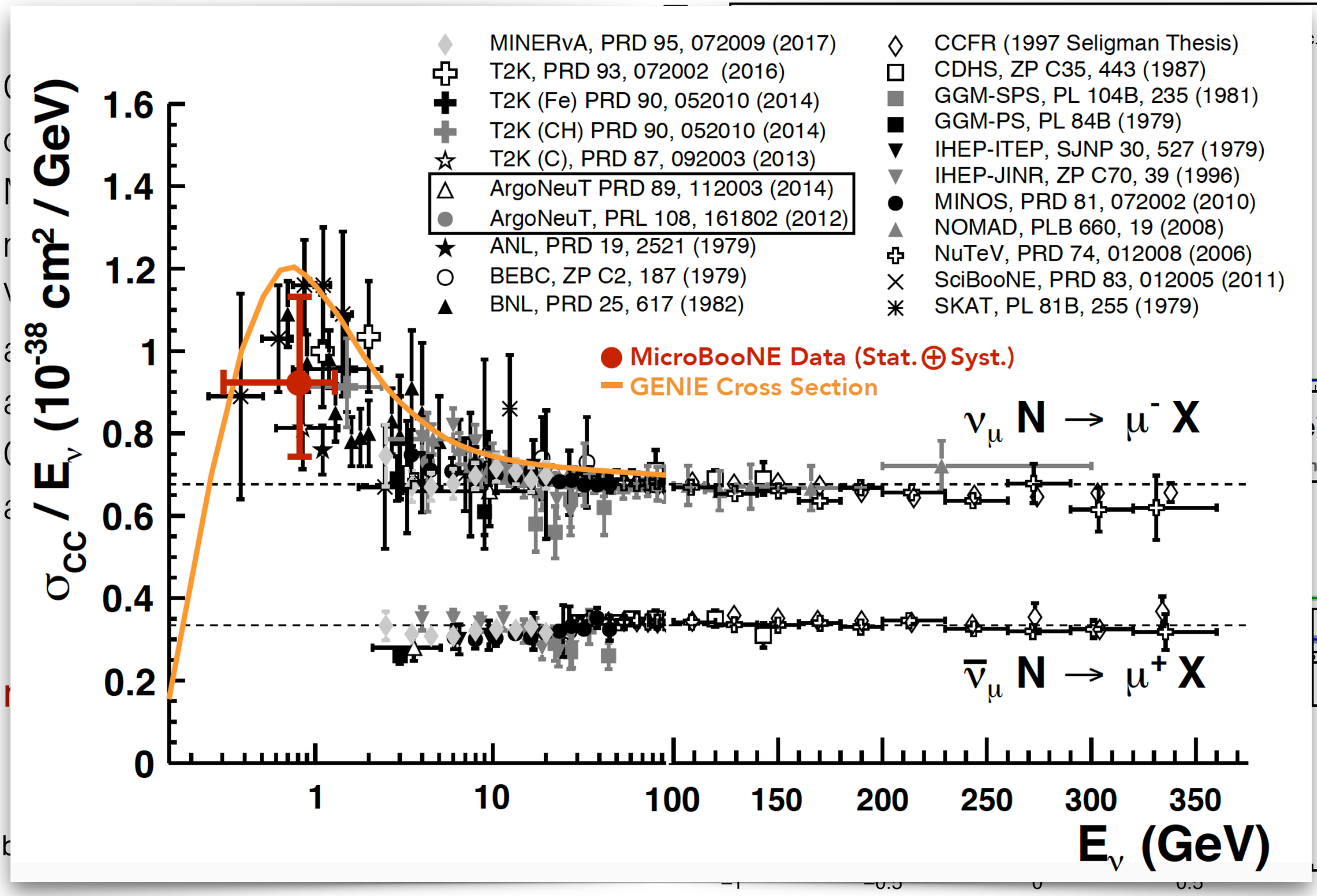


arXiv:1905.09694

ν_μ Charge Current Inclusive Cross Section Measurement

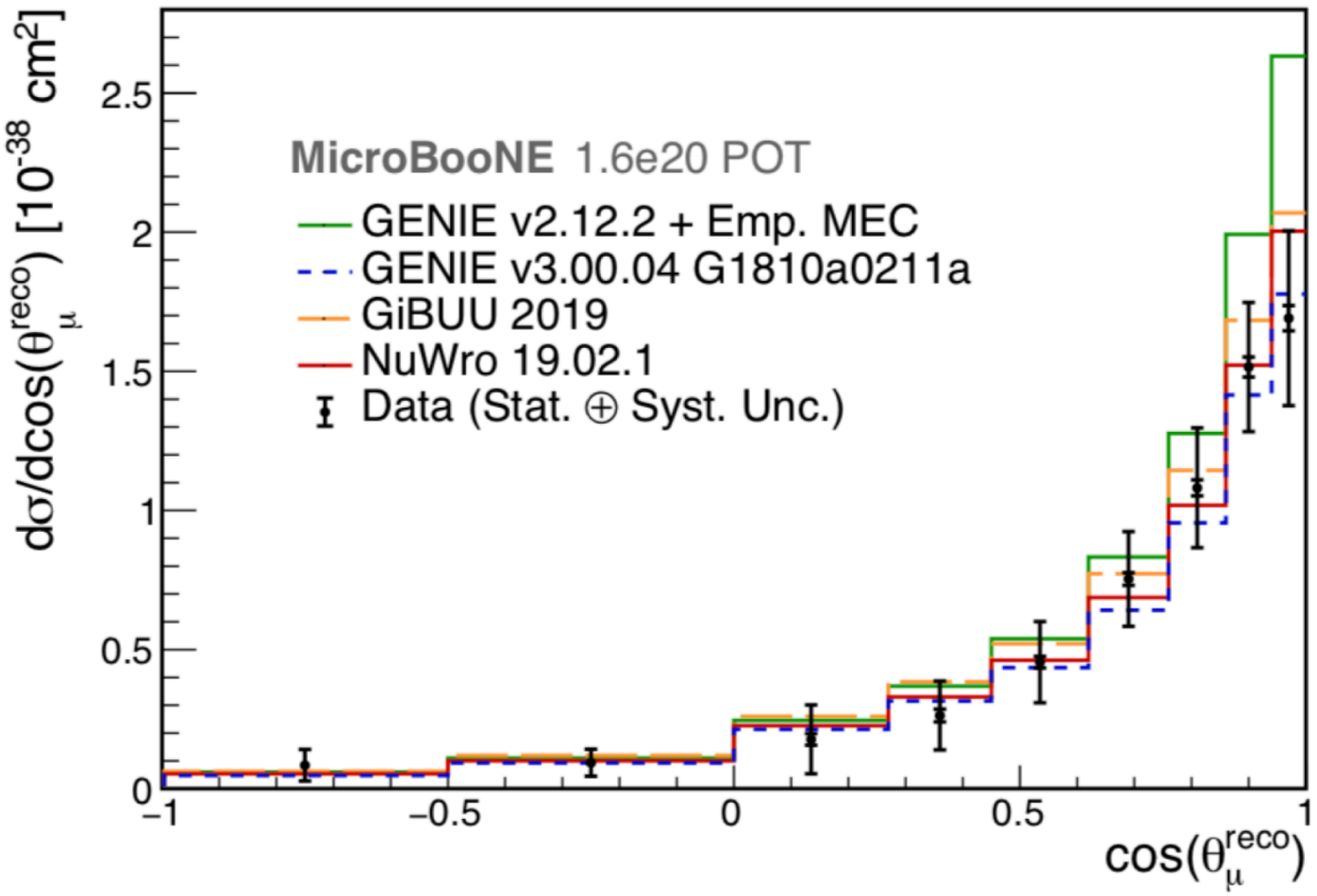
MicroBooNE Preliminary

- C
- M
- V
- C



Pub

ν_μ Charge Current Inclusive Cross Section Measurement



Flux integrated total cross section

$$\sigma = (0.693 \pm 0.010 \pm 0.165) \times 10^{-38} cm^2$$

- $\nu_\mu + Ar \rightarrow \mu^- + X$
- 26 k events (1.6x10^{20} POT data) used in the measurement
- Full muon momentum and muon angle coverage
  - Pioneering use of Multiple Coulomb Scattering (MCS) for muon momentum reconstruction
- First ν_μ-Ar double differential cross section measurement
- The data favors GENIE3 prediction with more sophisticated nuclear models

M. Kirby already presented a nice summary yesterday, see Raquel's talk tomorrow for details on the MicroBooNE detector