FERMILAB-SLIDES-20-067-V

Five Years of MicroBooNE and Beyond in Ten Minutes

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On Behalf of the MicroBooNE Collaboration

New Perspectives
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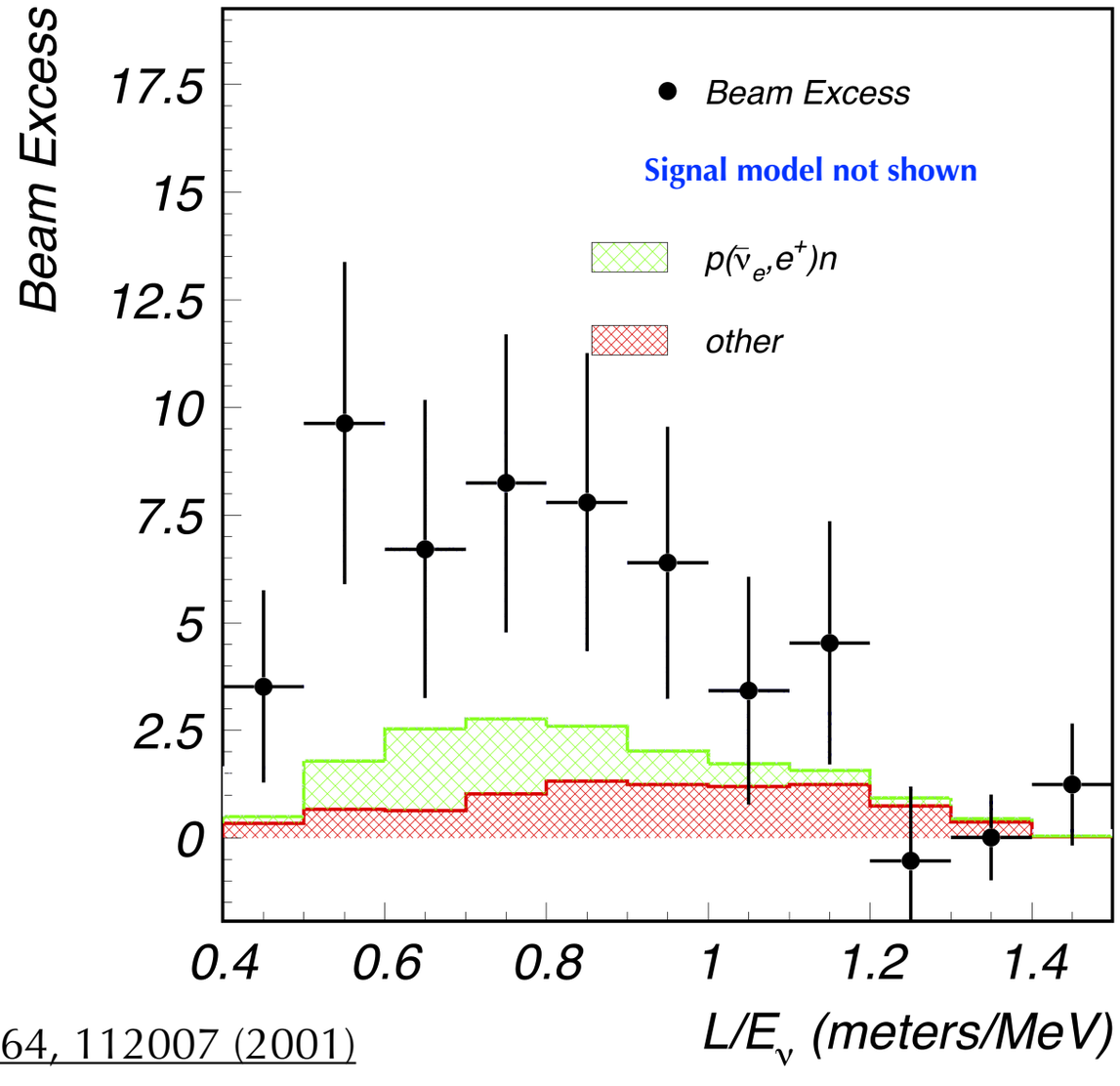
Overview

- MicroBooNE is a neutrino experiment based at Fermilab that utilizes a liquid argon time projection chamber (LArTPC) and has been collecting data since October 2015
- This talk will provide a brief overview of the rich and exciting physics program at MicroBooNE over the last five years and beyond
- MicroBooNE's body of work provides an important foundation for future LArTPC experiments, including SBN and DUNE

The LSND Anomaly

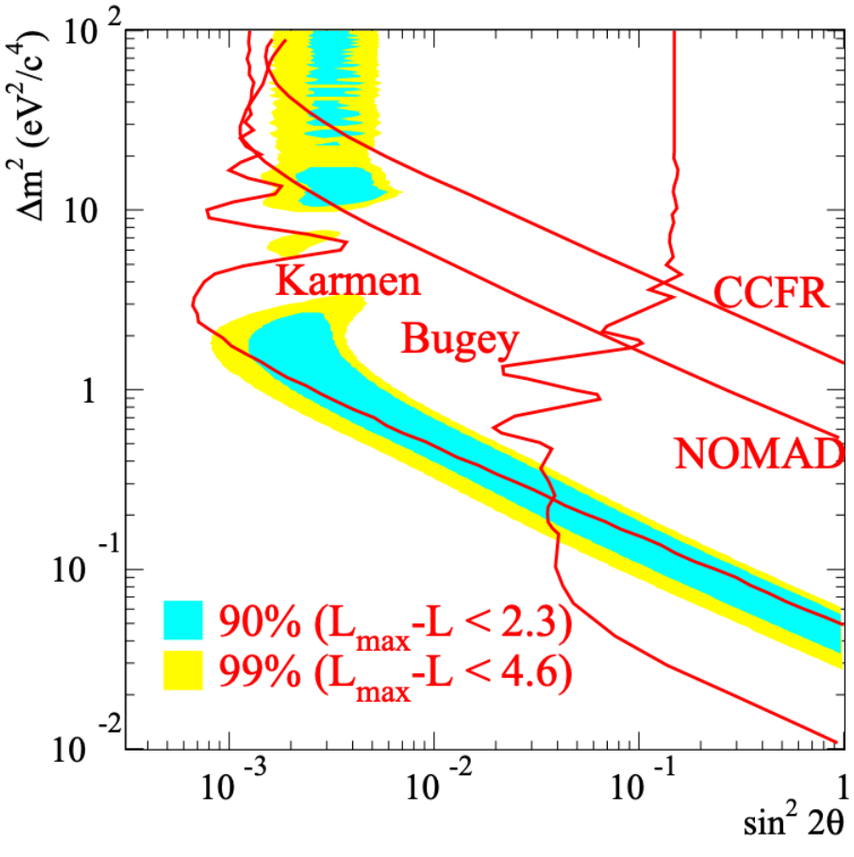
- LSND studied $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations, using $\bar{\nu}_\mu$ from μ^+ decay at rest
- Observed a 3.8σ excess of $\bar{\nu}_e$-like events, which can be interpreted as some probability of $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations due to a sterile neutrino



PRD 64, 112007 (2001)

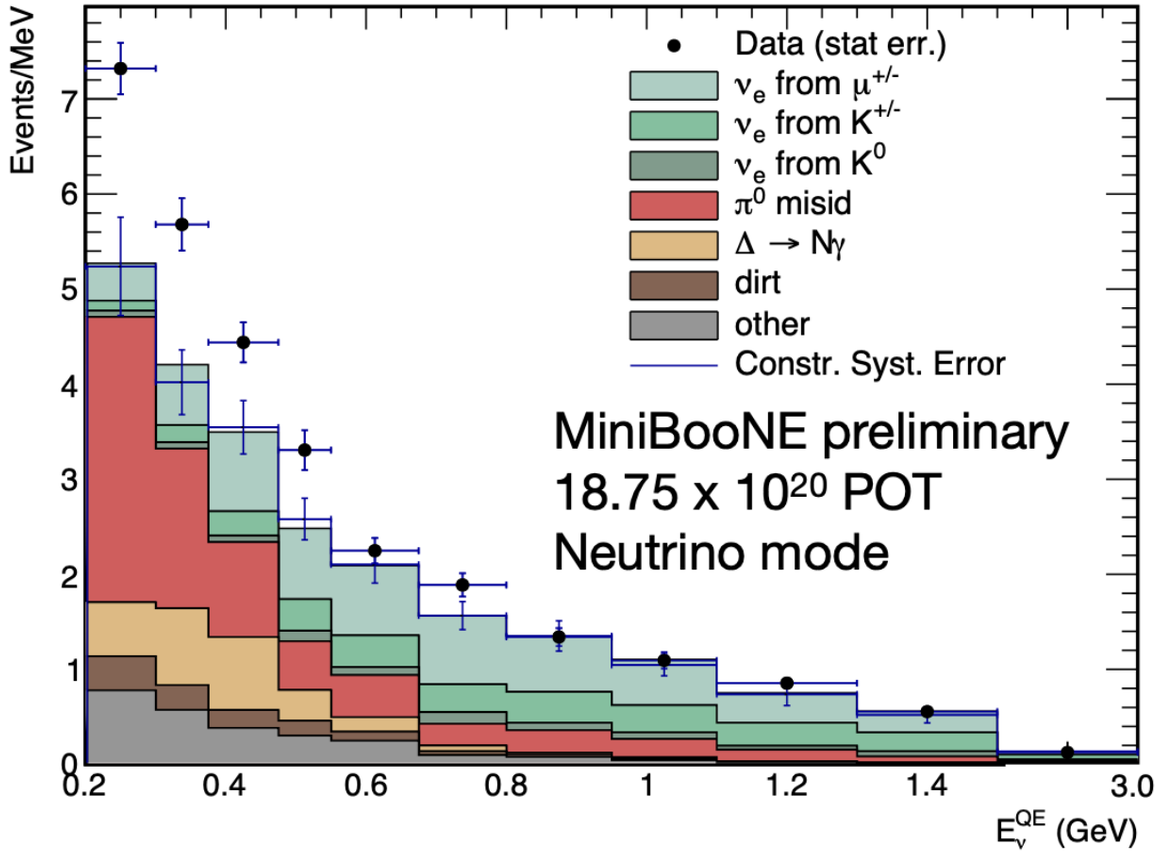
$$P_{\text{osc}} = \sin^2(2\theta)\sin^2\left(\frac{(m_1^2 - m_2^2)L}{4E_\nu}\right)$$

$$\Delta m^2_{12} \equiv m^2_1 - m^2_2$$



The MiniBooNE Anomaly

- MiniBooNE is a mineral oil Cherenkov detector located in Fermilab's Booster Neutrino Beam (BNB), which is primarily muon neutrinos
- MiniBooNE studied $\nu_\mu \rightarrow \nu_e$ appearance using ν_μ from Fermilab's Booster Neutrino Beam (BNB), and observed a 4.7σ excess of ν_e-like events
- Experiments have different baseline and energy but similar L/E at ~1 m/MeV, which suggests sterile neutrino oscillation could explain both anomalies



$$P_{\text{osc}} = \sin^2(2\theta)\sin^2\left(\frac{(m_1^2 - m_2^2)L}{4E_\nu}\right)$$

$$\Delta m^2_{12} \equiv m^2_1 - m^2_2$$

Similar L/E means similar P_{osc}
Given the same θ, Δm^2

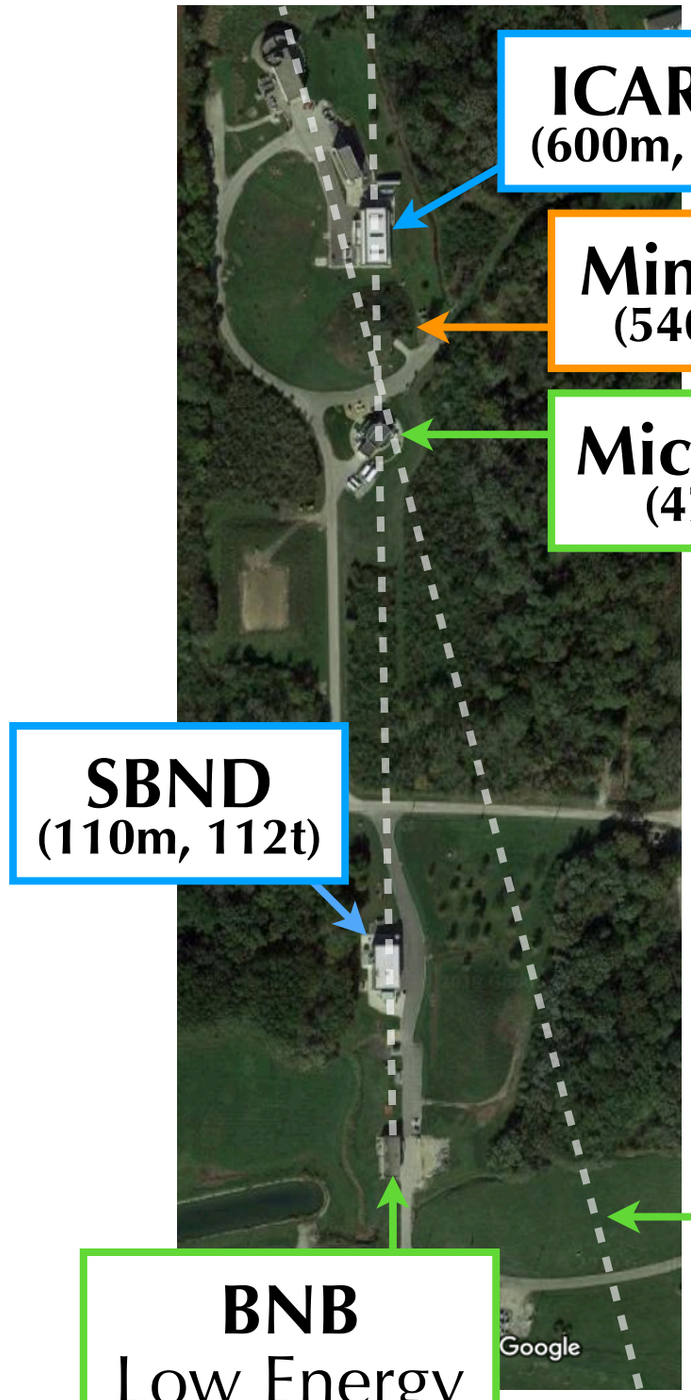
The SBN Program at Fermilab

- MicroBooNE was proposed as a follow-up to MiniBooNE
  - Same beam, similar baseline
  - Aims to check existence of excess, whether it's from e^- or γ

- Short Baseline Neutrino (SBN) Program consists of three LArTPCs: SBND, MicroBooNE, and ICARUS

- SBN will enable 5σ coverage of LSND allowed regions under the 3+1 sterile neutrino hypothesis

- SBN will also provide an important foundation for future LArTPC experiments, such as DUNE



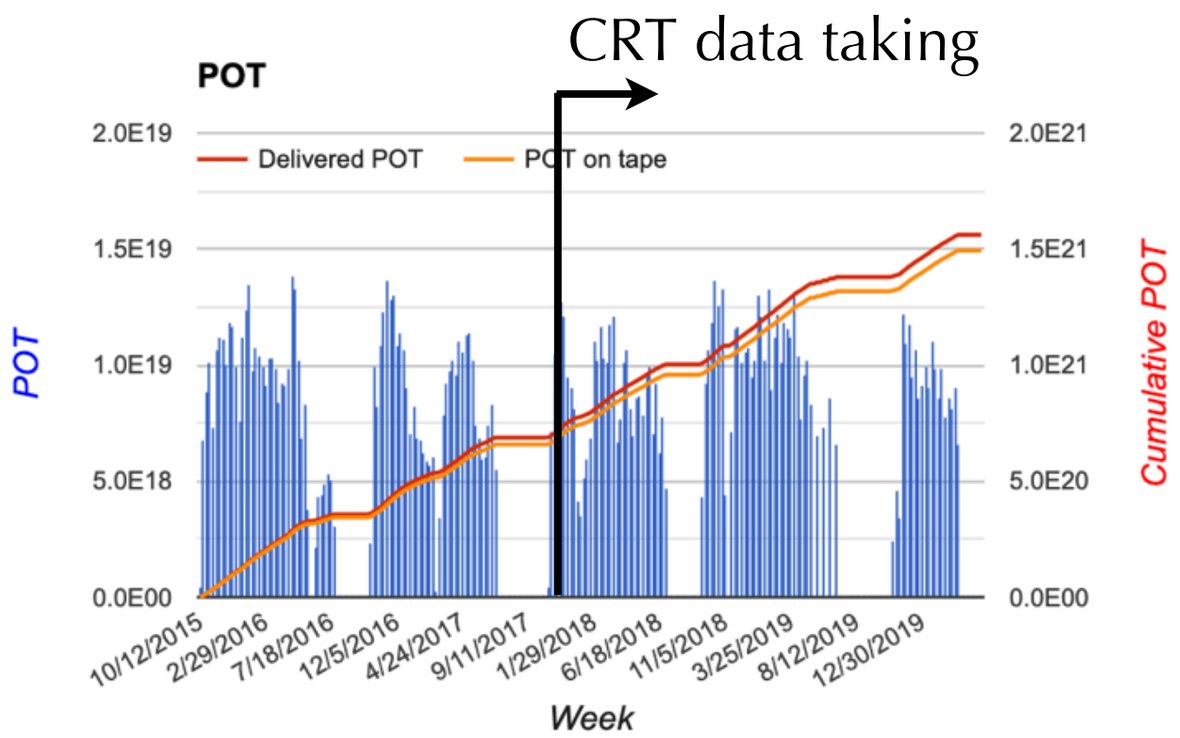
Fermilab Neutrino Campus

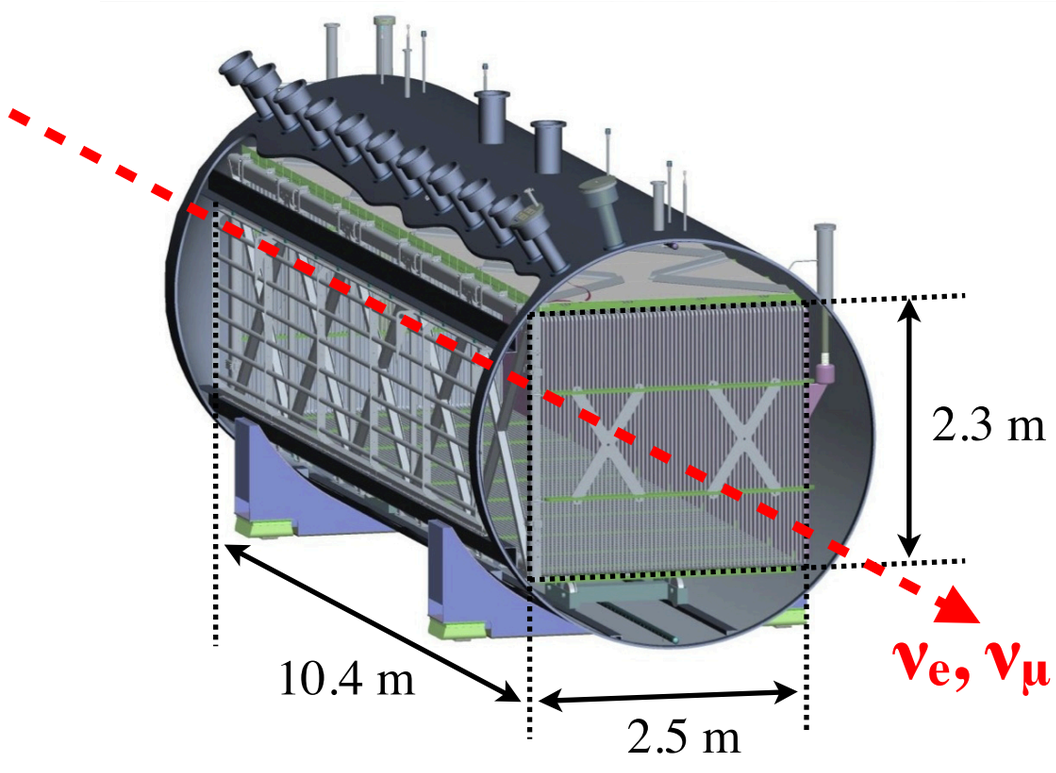
Past
Present
Future

BNB
Low Energy
ν_μ Beam

NuMI
High Energy
ν_μ Beam

Status of MicroBooNE

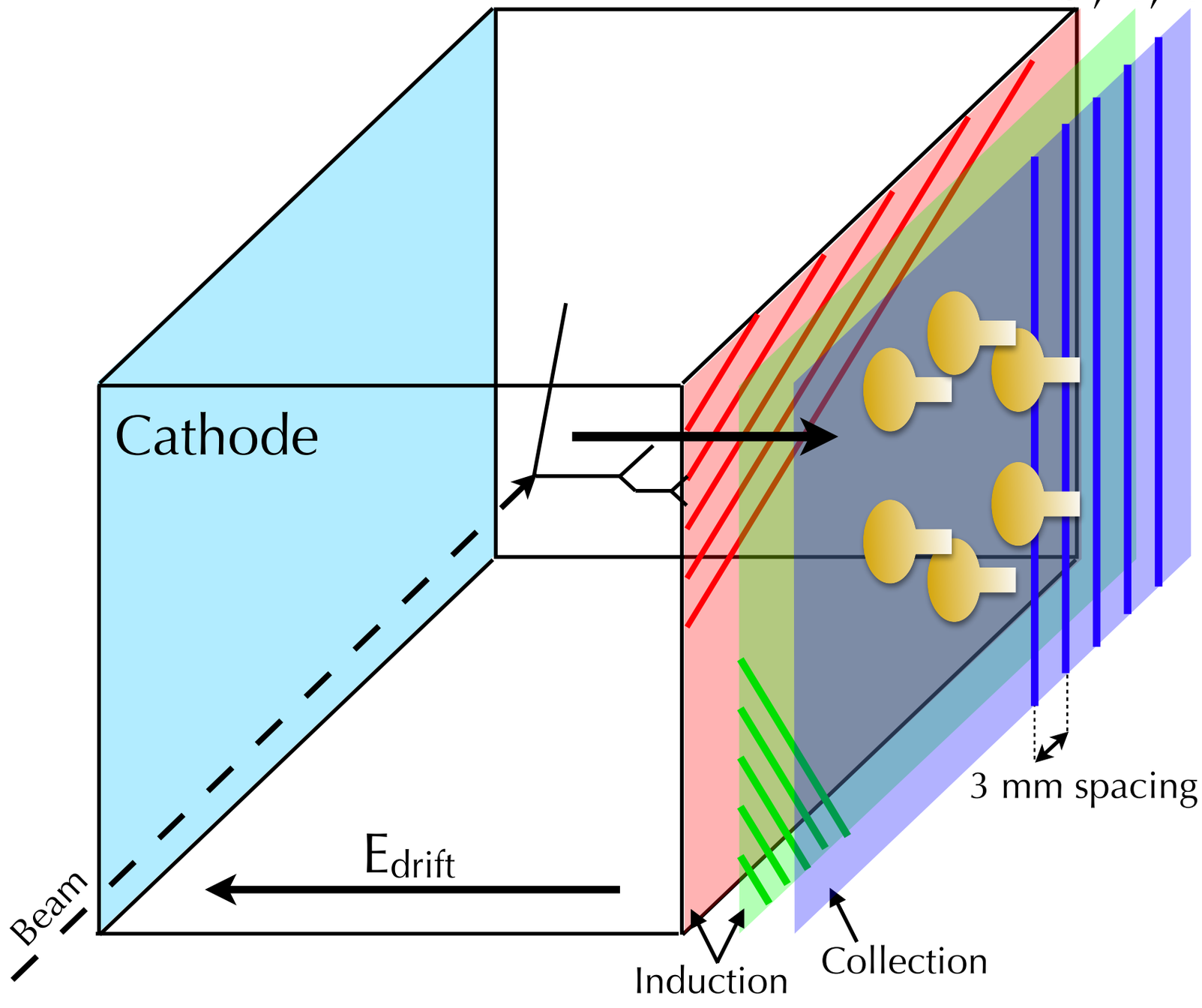


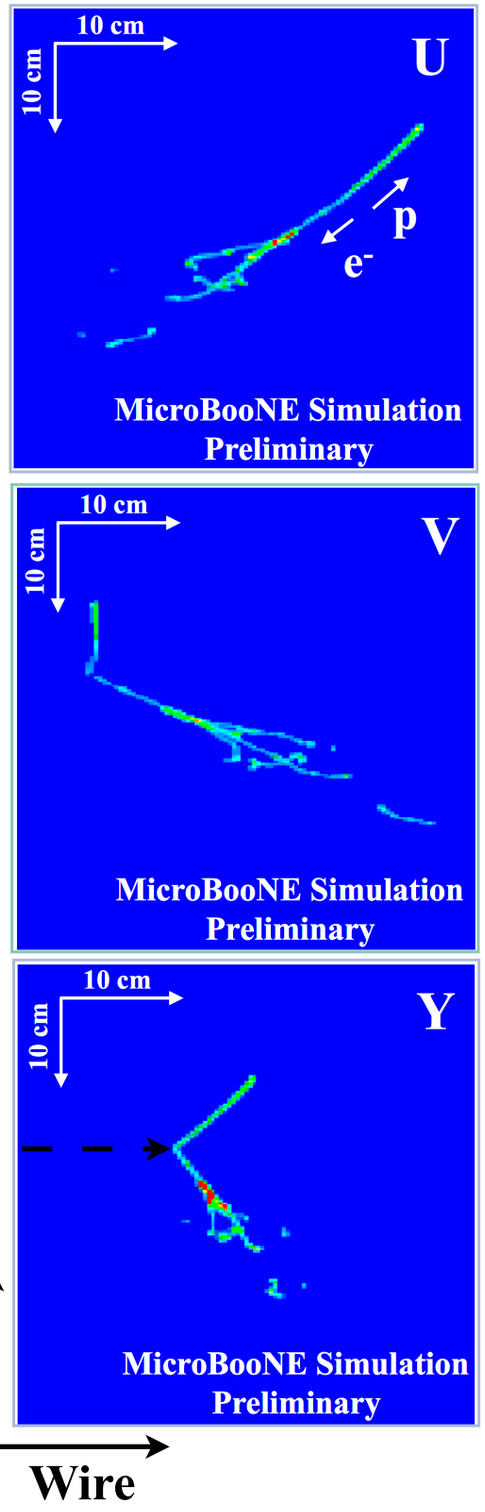


- Taking neutrino data since October 2015, now the longest-running LArTPC detector
- Detector continues to operate smoothly, with >95% detector + DAQ uptime
- Over 500k neutrino interactions recorded
  - More than half of this with our cosmic ray tagger (CRT) installed and taking data

Detecting Neutrinos with a LArTPC μBooNE

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

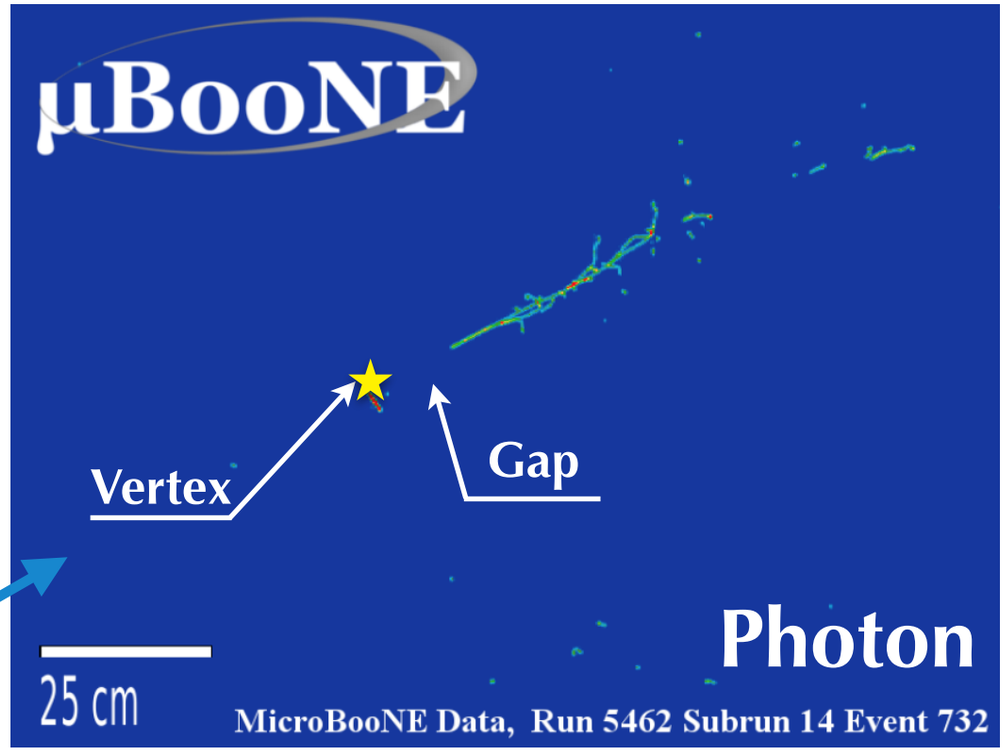


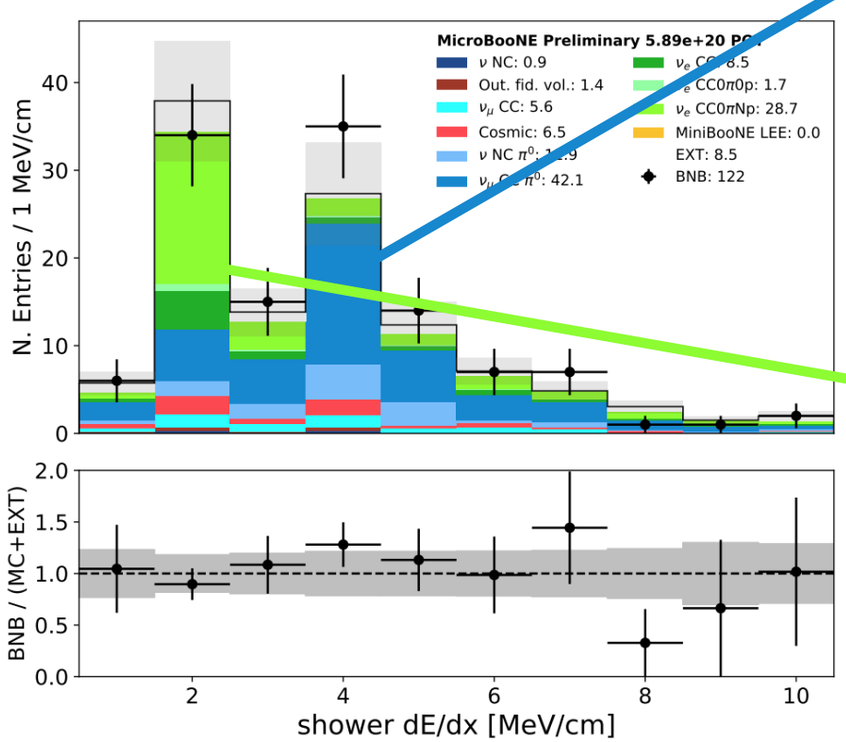


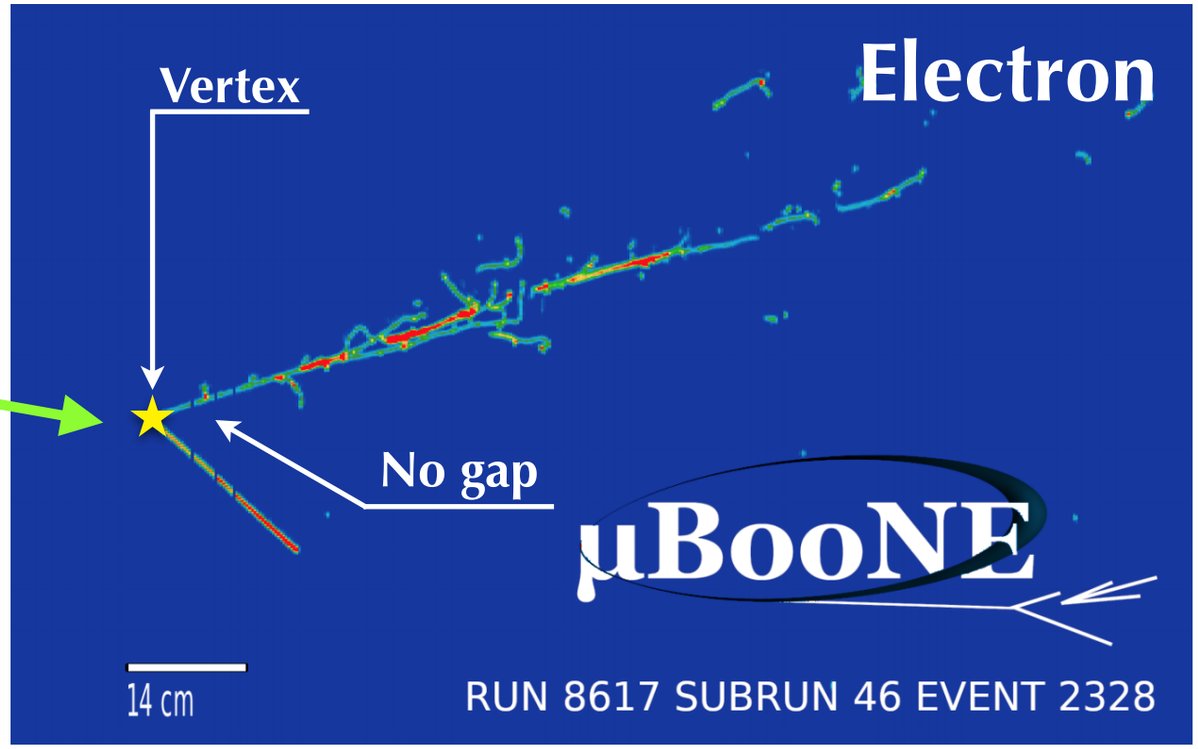
e^-/γ Separation in LArTPCs

LArTPCs offer two main ways to distinguish electrons and photons in neutrino interactions

- Amount of energy deposited per unit length in the trunk of the shower — e^- is ~2 MeV/cm, $\gamma \rightarrow e^+e^-$ is twice that
- Gap between the neutrino interaction vertex and the start of the shower



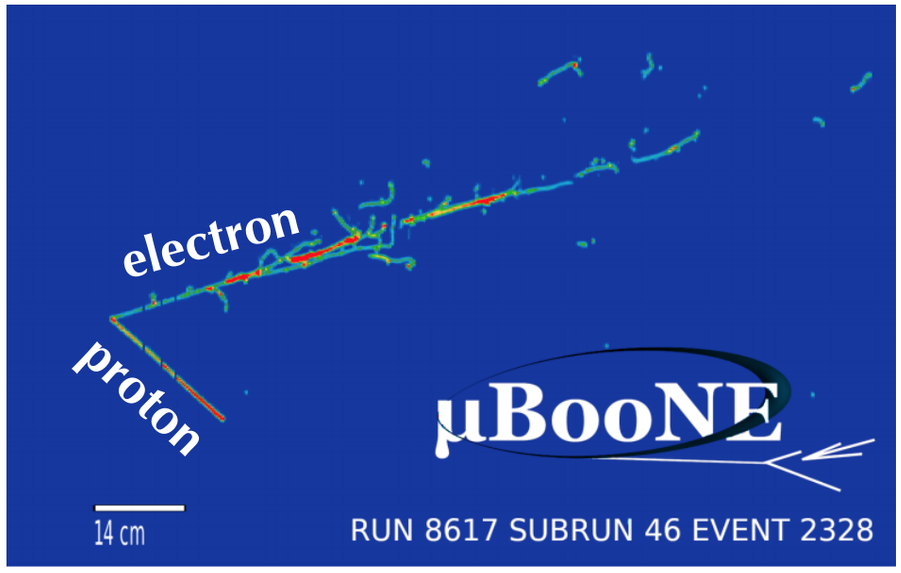


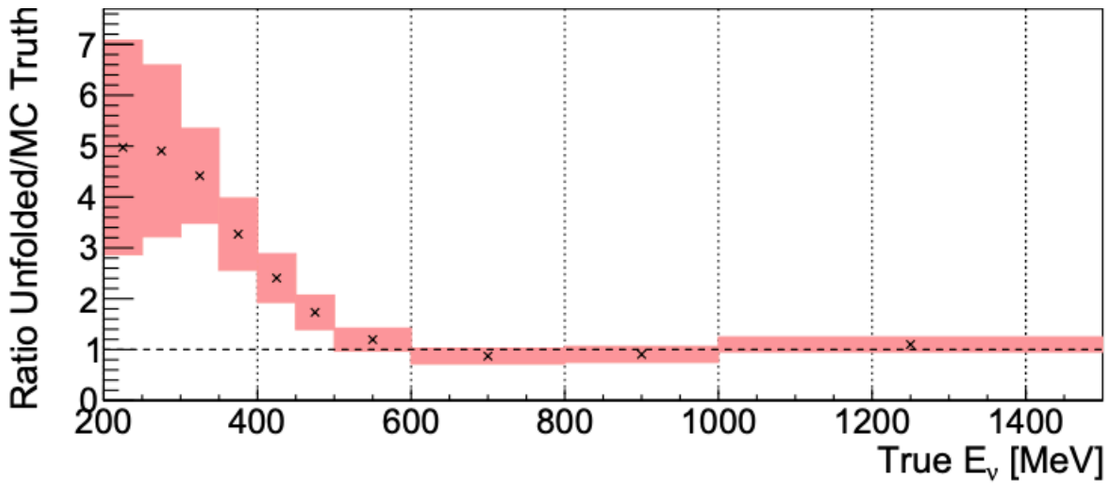


Addressing the MiniBooNE Anomaly

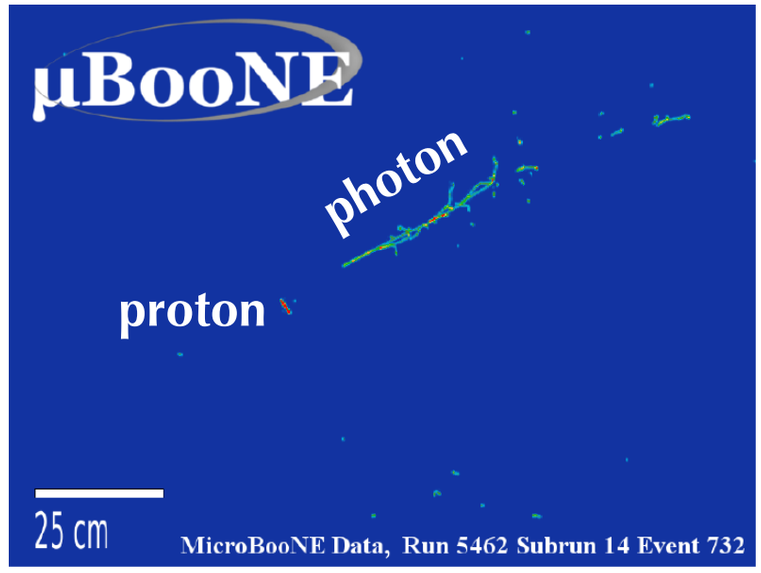
MicroBooNE is pursuing two main signal hypotheses:

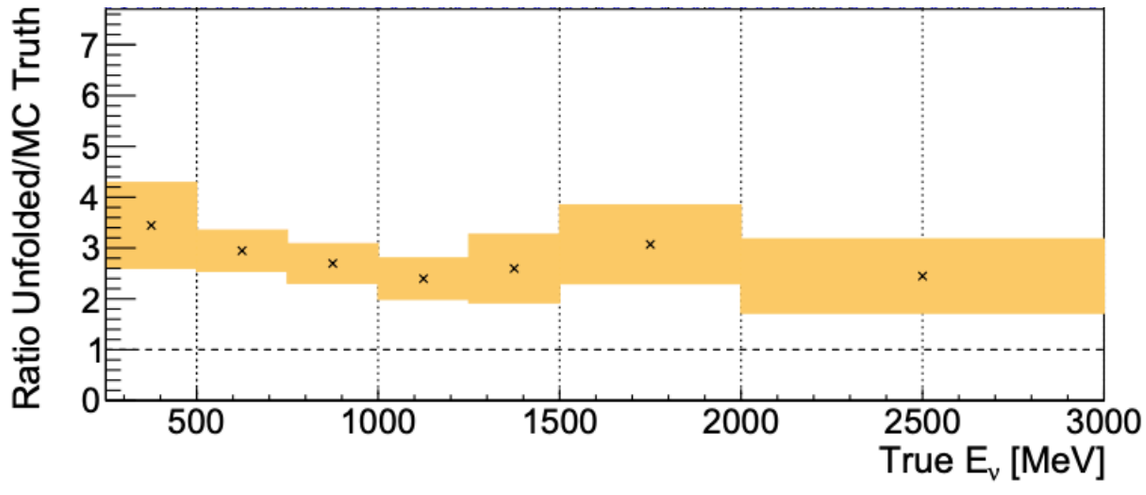
Electron-Like Model
Electron Neutrino Events





Photon-Like Model
NC $\Delta \rightarrow N\gamma$ Events



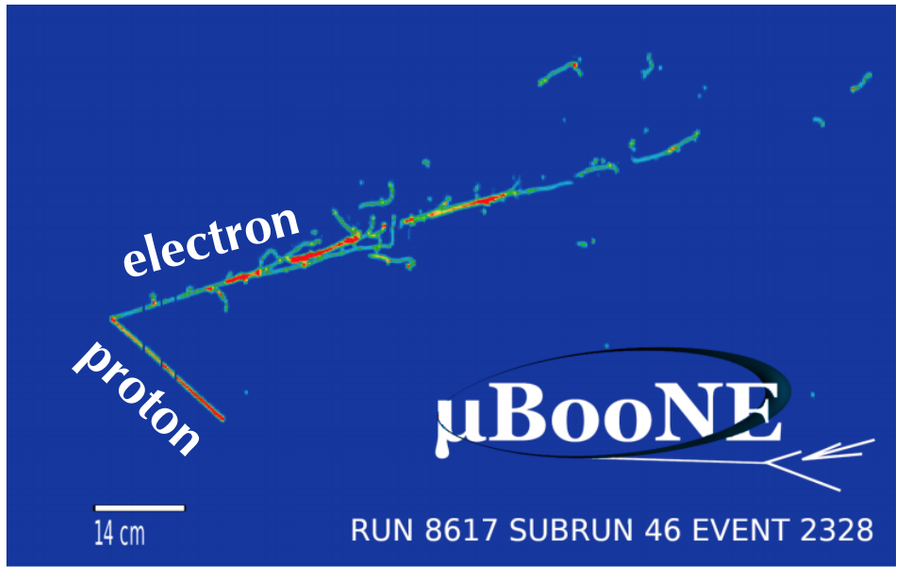


Unfolding method described in MICROBOONE-NOTE-1043-PUB

Addressing the MiniBooNE Anomaly

For each signal hypothesis, a few possible channels:

Electron-Like Model
Electron Neutrino Events



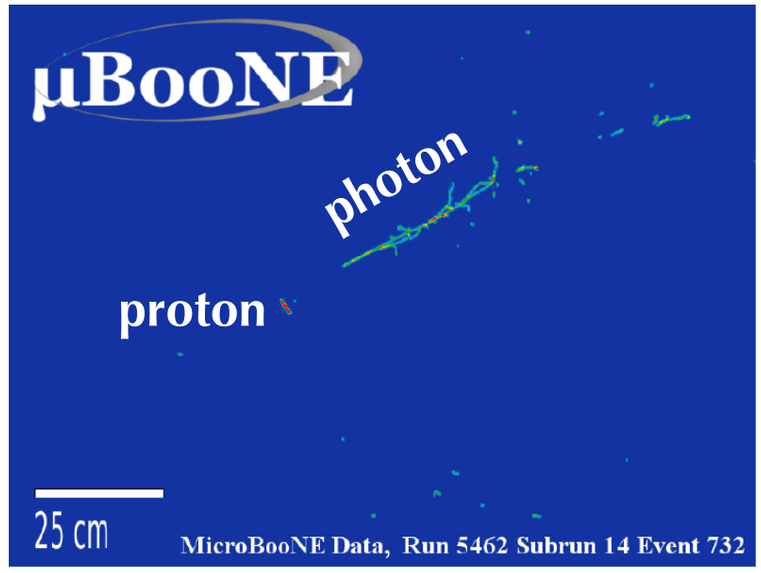
$\nu_e + Ar \rightarrow e^- + 1\,p$ (1e1p)

$\nu_e + Ar \rightarrow e^- + N\,p$ (1eNp)

$\nu_e + Ar \rightarrow e^- + 0\,p$ (1e0p)

$\nu_e + Ar \rightarrow e^- + X$ (incl.)

Photon-Like Model
NC $\Delta \rightarrow N\gamma$ Events



$\nu + Ar \rightarrow \gamma + 1\,p$ (1γ1p)

$\nu + Ar \rightarrow \gamma + 0\,p$ (1γ0p)

Unfolding method described in MICROBOONE-NOTE-1043-PUB

Status of Low-Energy Excess Searches

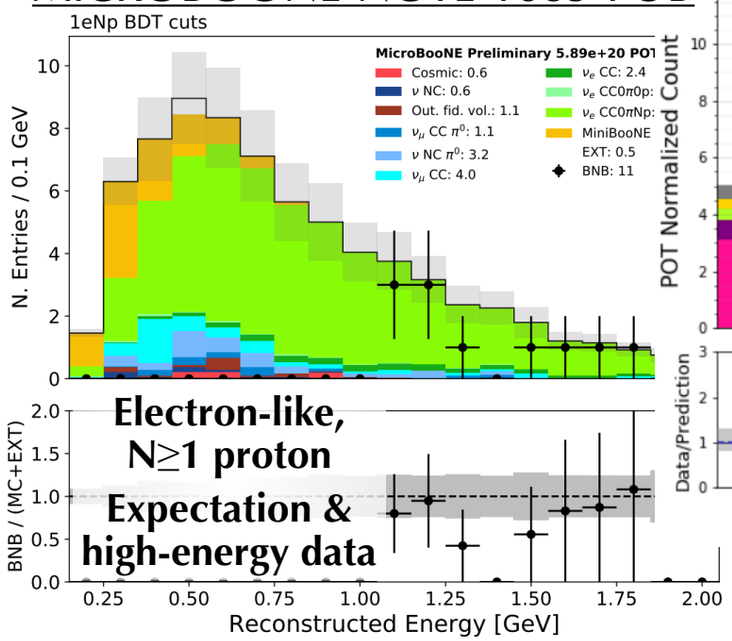
We are here!

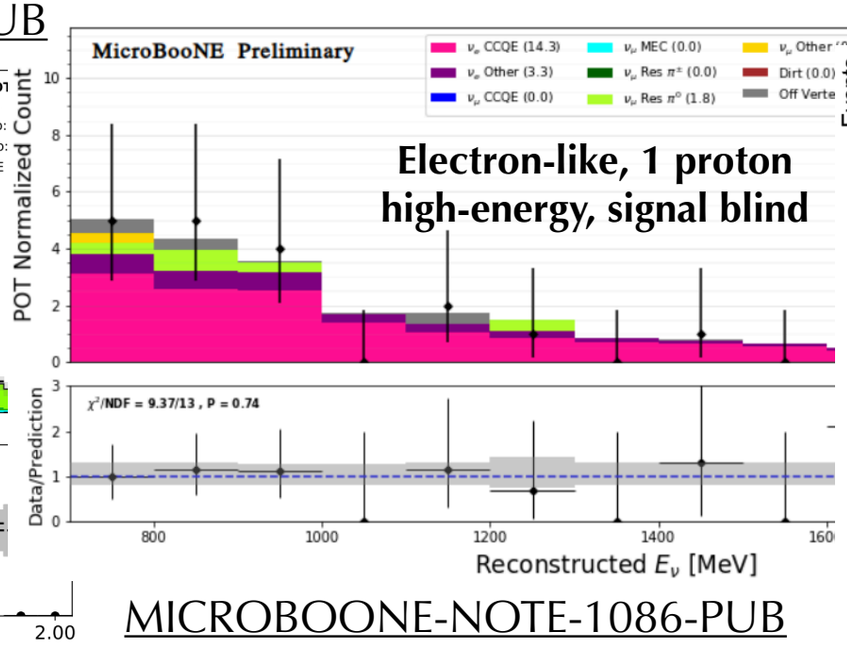
reconstruction, calibration, cross-section tuning → **event selection, systematics, sensitivity evaluation** → **validation with signal-blind datasets** → **far sideband unblinding** → **near sideband unblinding** → **signal box opening**

- Have developed end-to-end analyses searching for both signal hypotheses
- Multiple complementary selections using different analysis techniques
- On the cusp of unblinding for our first results — stay tuned!

- All of this builds on important work in a number of other areas

MICROBOONE-NOTE-1085-PUB





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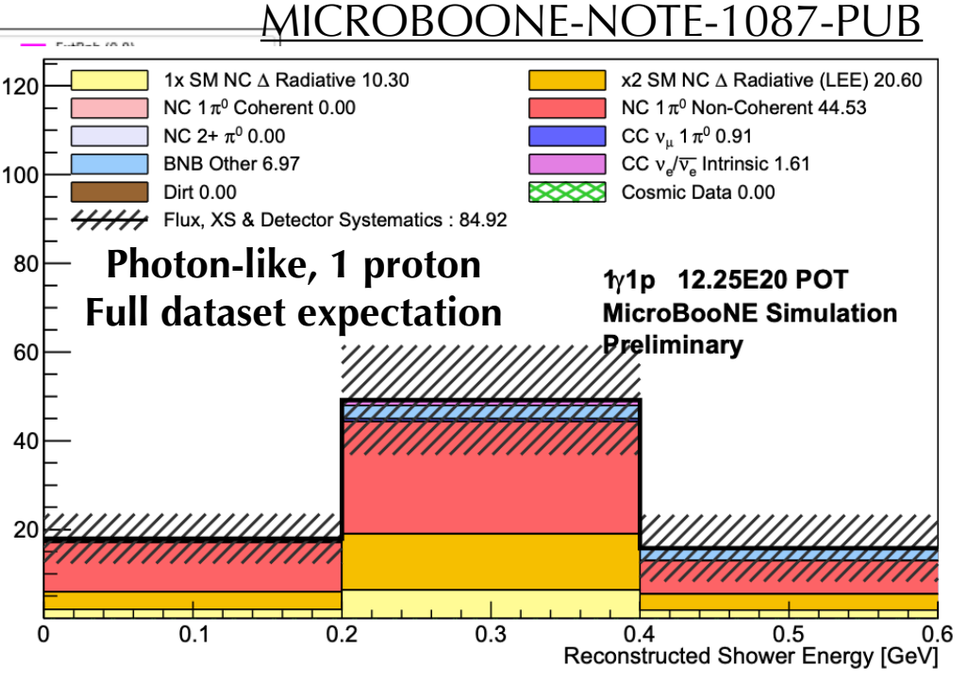
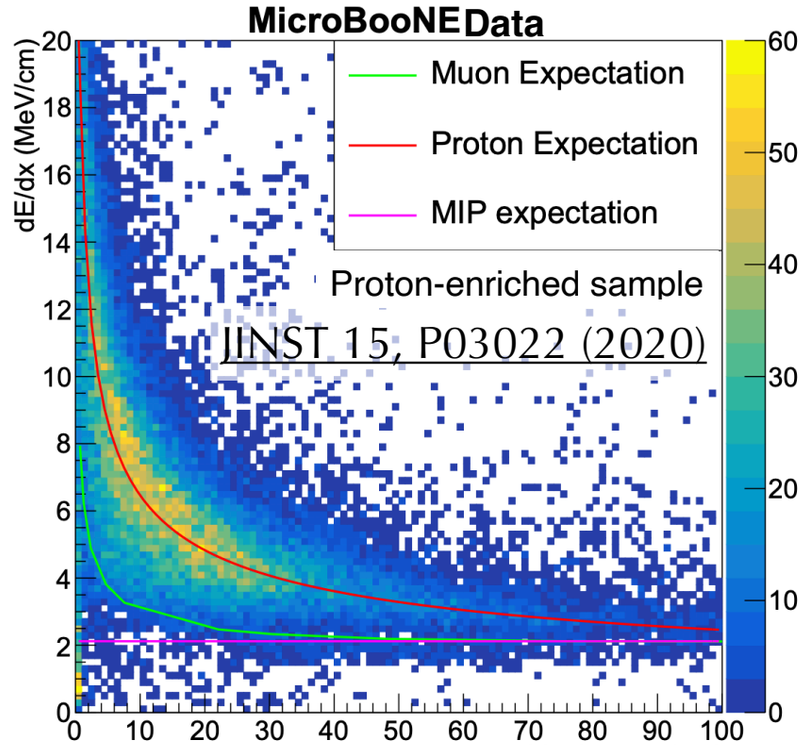
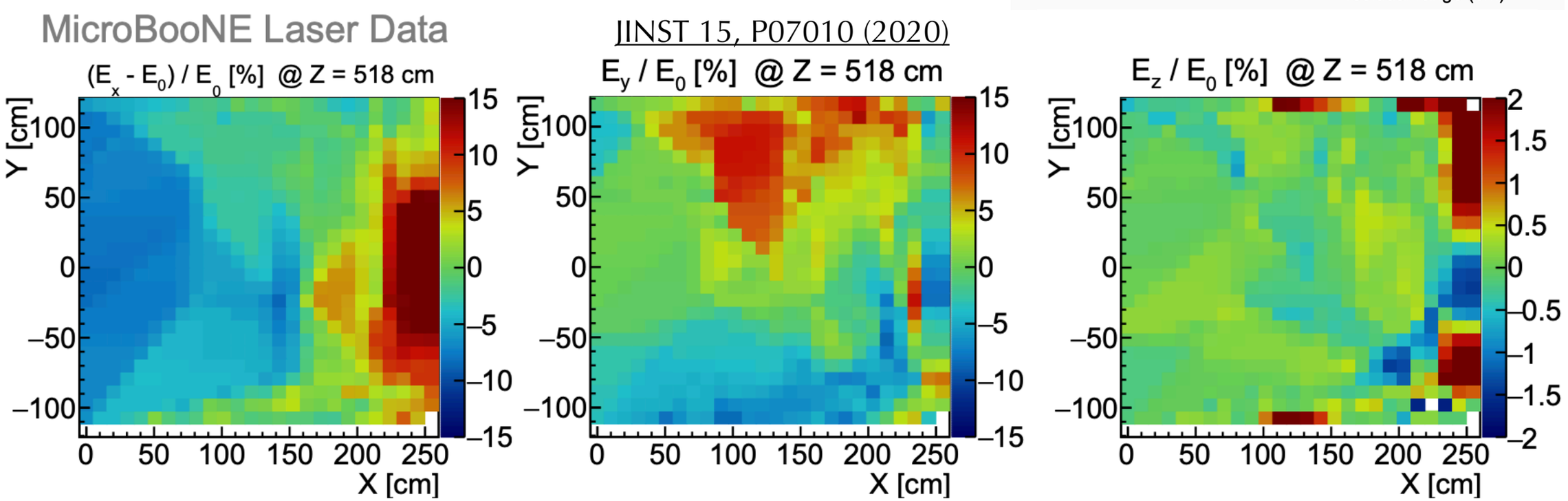


Detector Physics & Calibrations

- Have completed major calibration campaign
- Have measured our E-field *in situ* with cosmic ray muons and with UV laser
- Have incorporated the results of both into our current default simulation
- More exciting and important detector physics measurements to come

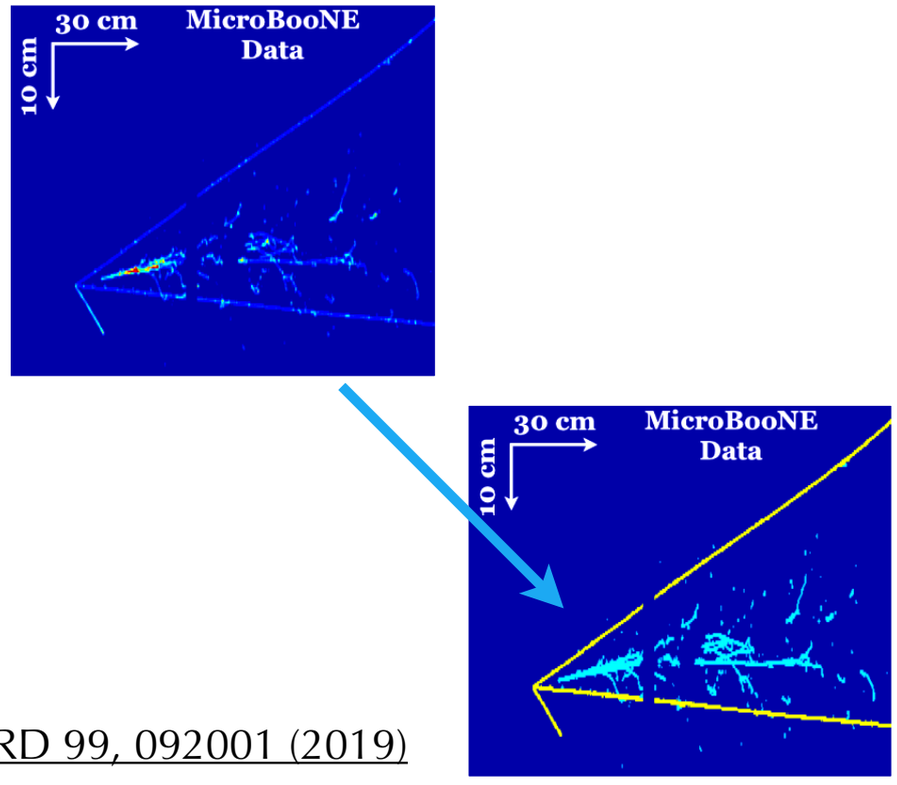




Novel Reconstruction Methods

- MicroBooNE is developing a number of novel reconstruction techniques applicable to LArTPC data and putting them to the test in physics analyses
- Have demonstrated the use of deep learning techniques using CNNs on LArTPC images, including for track/shower labeling and for particle identification
- Have demonstrated the WireCell 3D clustering and reconstruction, which provides powerful cosmic rejection and increased neutrino efficiency over other methods

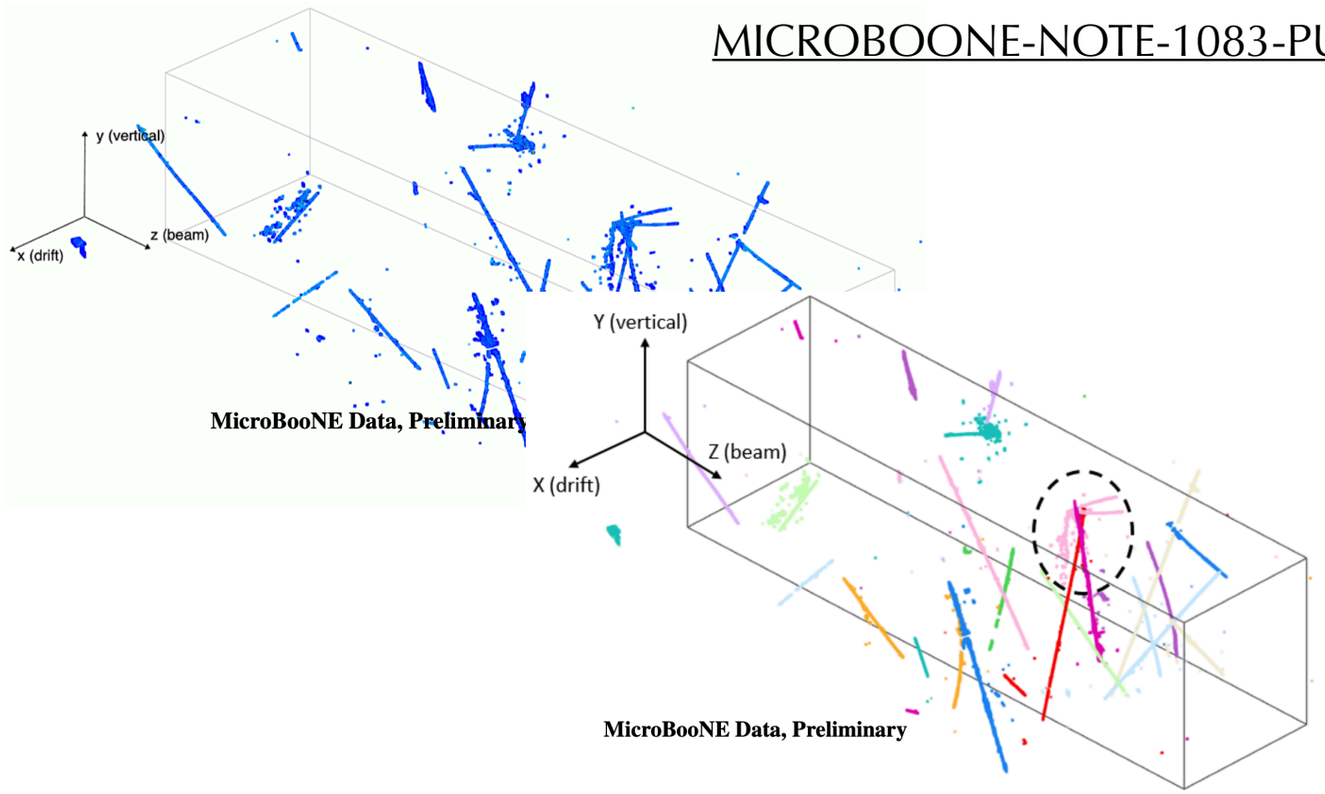
Deep Learning Pixel Labeling Example on a ν_μ CC π^0 Event



PRD 99, 092001 (2019)

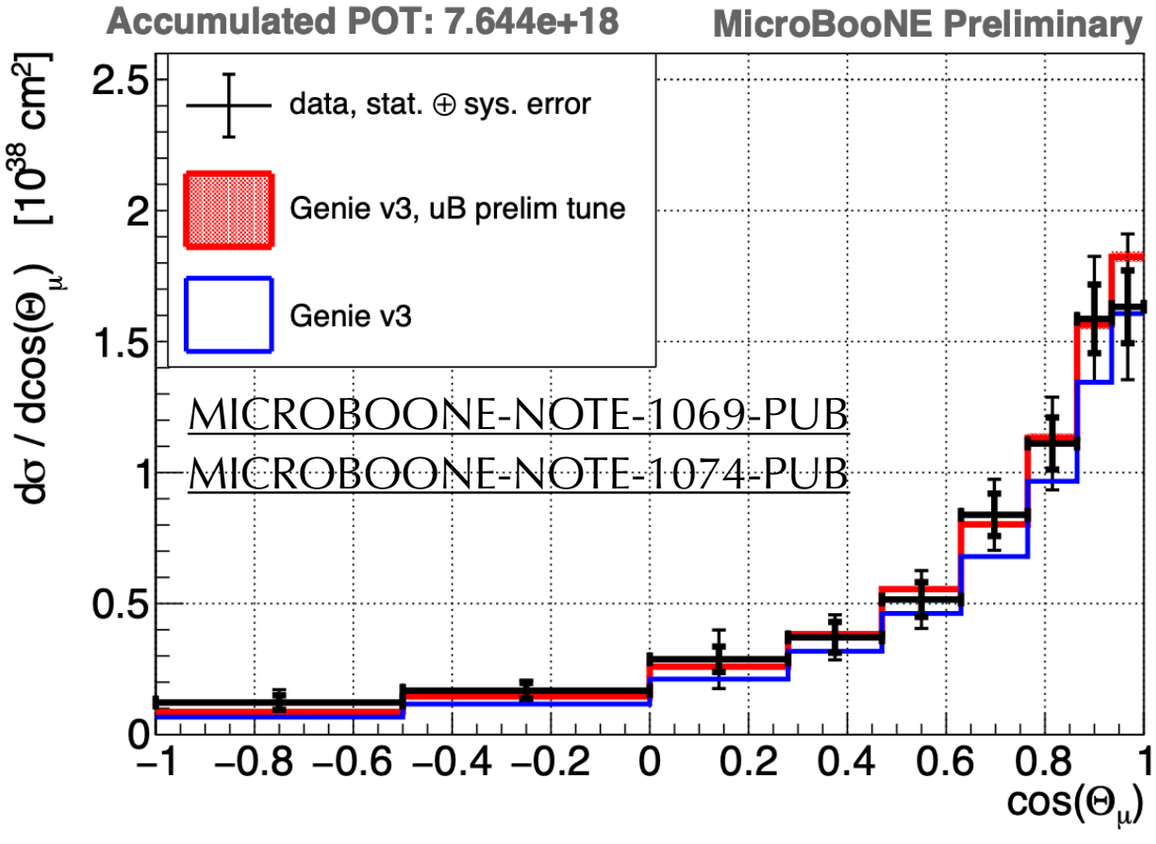
WireCell 3D Reconstruction and Clustering

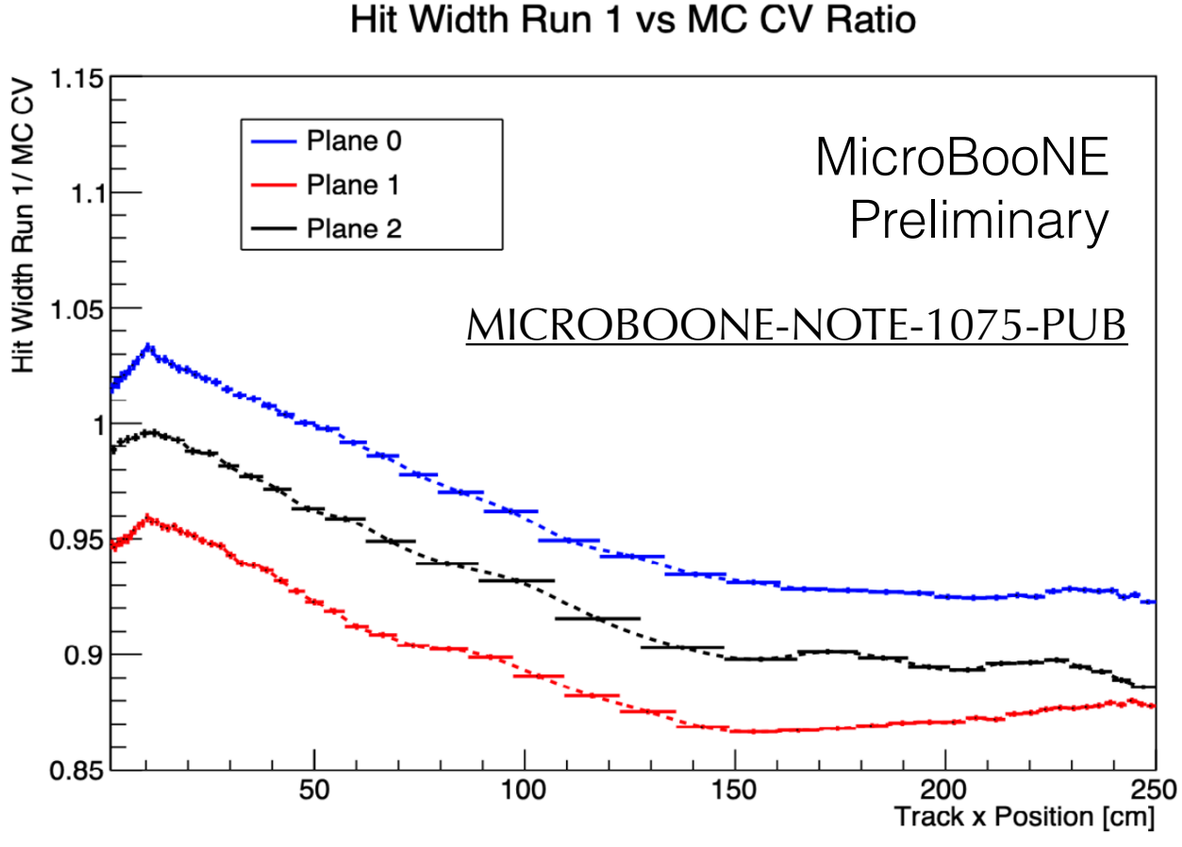
MICROBOONE-NOTE-1083-PUB



Model Tuning & Systematics

- Recent and future results use an updated cross section model based on GENIE v3 with CCQE and CC MEC channels tuned to T2K ν_μ CC 0π data
  - New model shows better agreement with MicroBooNE data than previous results
- Have developed a novel, data-driven method for assessing detector systematics uncertainties in MicroBooNE
  - Similar approach could be applied to future LArTPC experiments





Neutrino–Argon Interactions

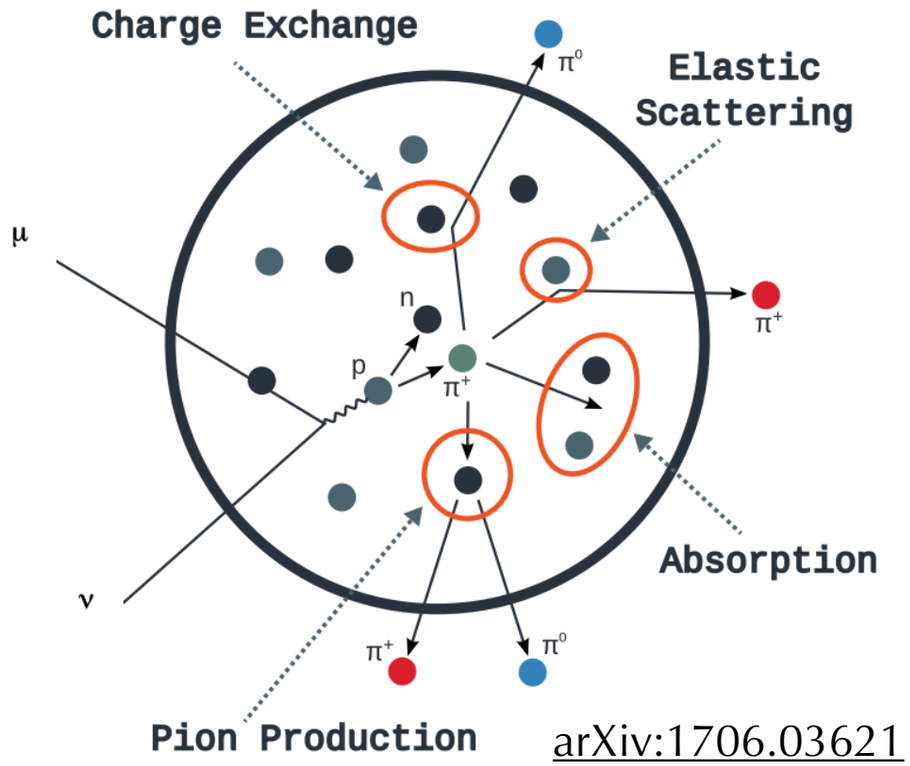
MicroBooNE is measuring neutrino–argon interaction cross sections in a range of channels, which are critical to reduce systematic uncertainties for the SBN program and DUNE

BNB:

- ν_μ CC inclusive
  PRL 123, 131801 (2019)
- ν_μ CC π^0
  PRD 99, 091102(R) (2019)
- ν_μ CCQE-like
  EPJ C 79, 673 (2019), arXiv:2006.00108 [hep-ex]
- ν_μ CC Np, 2p
  MICROBOONE-NOTE-1056-PUB
- NC elastic
  MICROBOONE-NOTE-1067-PUB
- CC $K^{\pm}$
  MICROBOONE-NOTE-1071-PUB
- CC $1\pi^+$
- CC coherent π
- NC π^0
- … and more!

NuMI:

- ν_e CC inclusive
  MICROBOONE-NOTE-1054-PUB
- ν_e CCQE-like
- Kaon decay-at-rest (KDAR)



arXiv:1706.03621 [hep-ph]

Summary

- MicroBooNE has made significant progress towards analyses that will test electron- or photon-like nature of the MiniBooNE excess, stay tuned for first results!
- The SBN program aims to conclusively address the possibility of sterile neutrino oscillations suggested by LSND and MiniBooNE
- Beyond that, MicroBooNE has a rich research program including pioneering work in detector physics, calibrations, reconstruction, systematics evaluation, and neutrino–argon interactions
- This work is foundational for the Short Baseline Neutrino Program and for future LArTPC experiments, including DUNE

Thank you!