MicroBooNE

Matt Toups

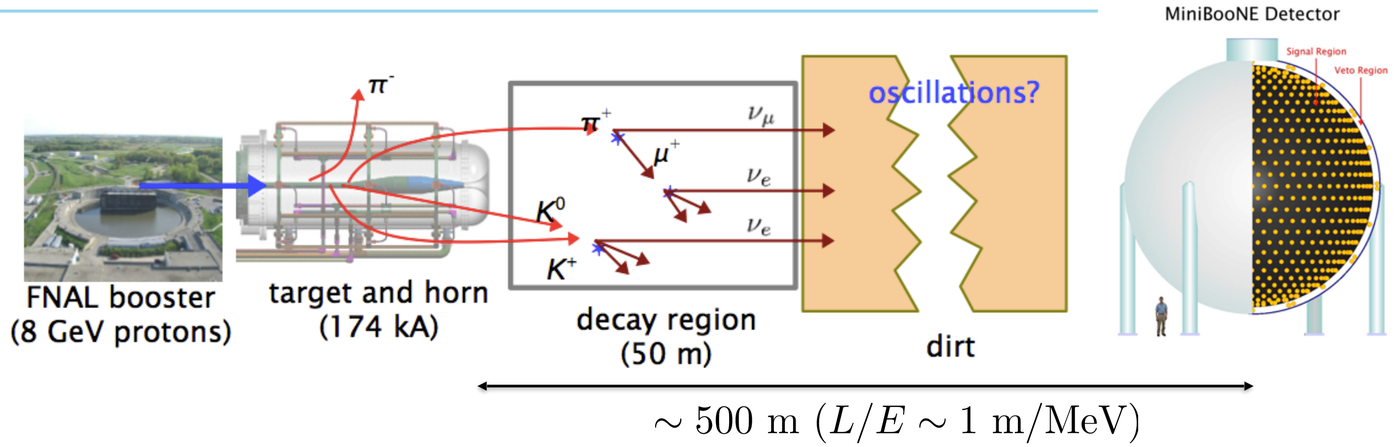
Neutrinos at Fermilab I Briefing to DOE OHEP

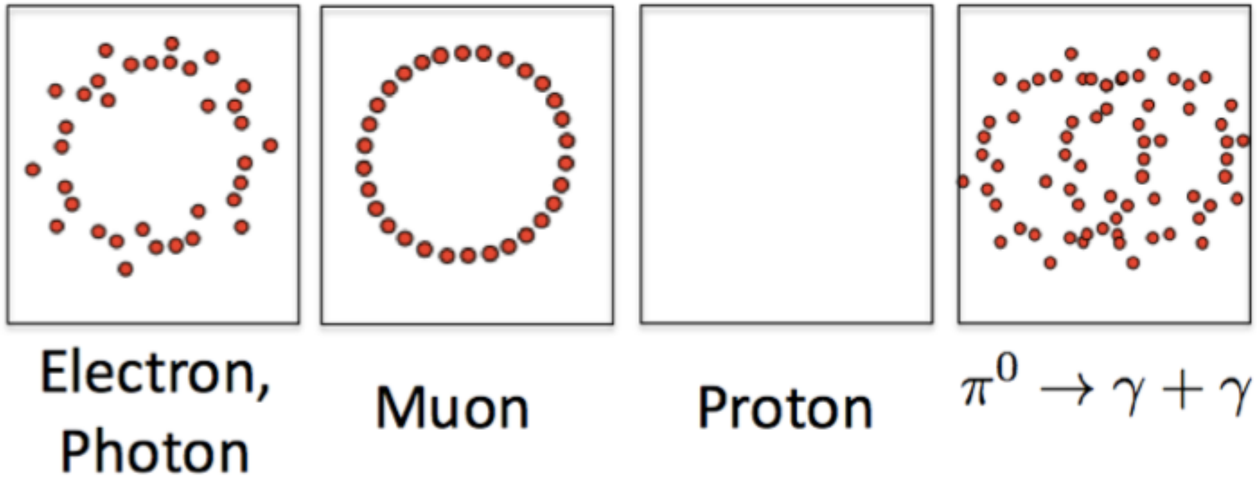
Tues 12 Jan 2021

Personal Introduction

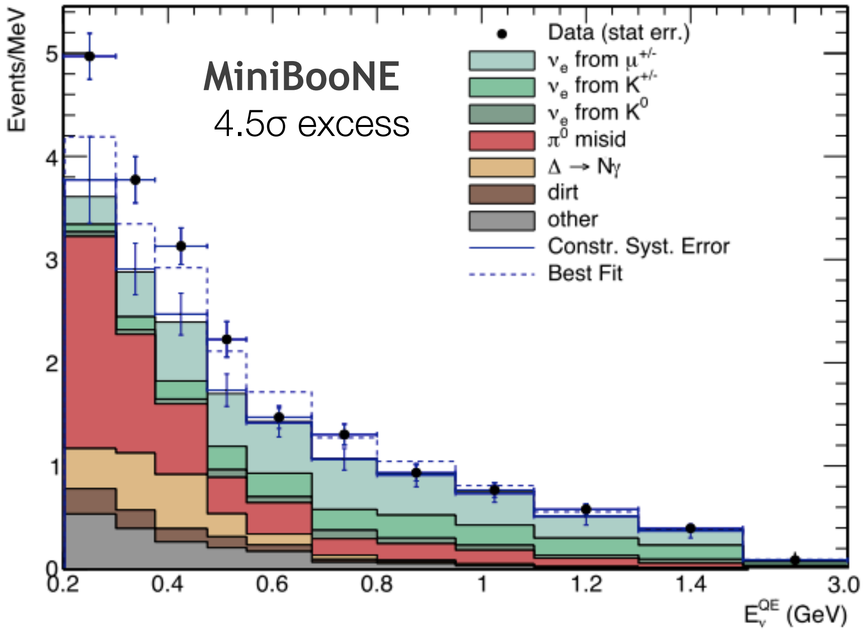
- Ph.D. from Columbia University in 2012
  - "A Search For Electron Antineutrino Disappearance with the Double Chooz Far Detector"
- Postdoc at M.I.T. from 2012-2015 focusing on photon detection in liquid argon in MicroBooNE, SBND, and DUNE (LBNE)
  - Received Alvin Tollestrup award in 2015 for "…contributions to the liquid-argon-based short-baseline neutrino program at Fermilab…"
- Joined FNAL as an Associate Scientist in 2015, now a Scientist with roles on
  - MicroBooNE: Physics Analysis Co-Coordinator
  - SBND: X-ARAPUCA-based Photon Detection System Co-Leader
  - DUNE: Photon Detection Consortium Electronics Working Group Co-Convener
    - Also led fabrication of 50% of protoDUNE's light-guide-based photon detectors at FNAL
  - Accelerator-based Fixed Target Dark Sector Searches at Fermilab
    - Snowmass working group leader, LDRD project, and ECA proposal

MiniBooNE Low Energy Excess

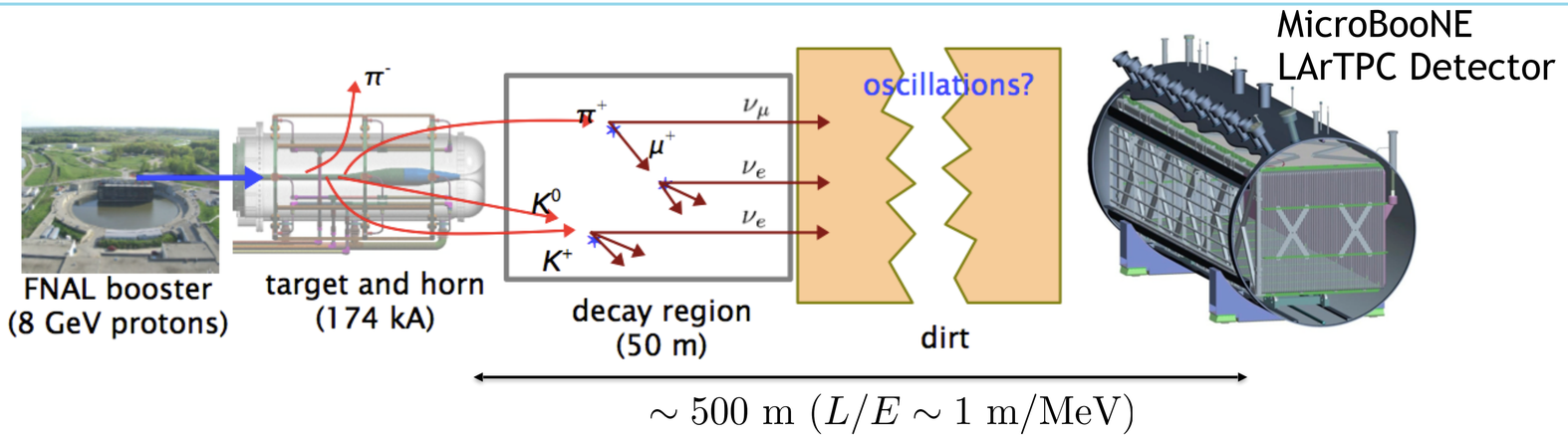


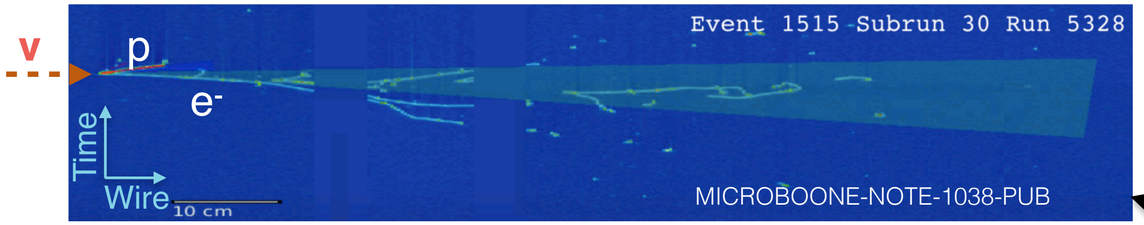


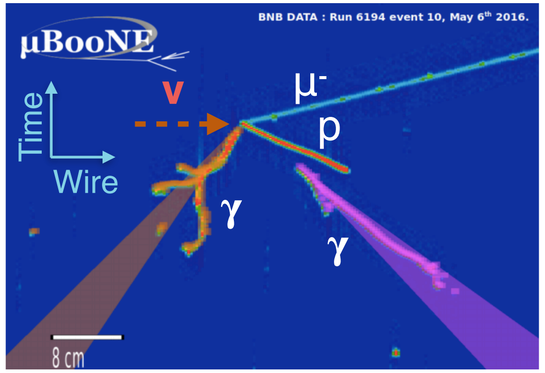
Phys. Rev. Lett. 121, 221801 (2018)

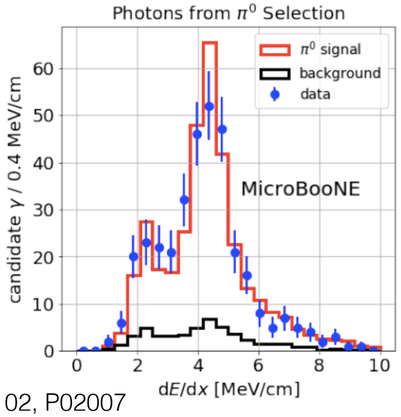


LArTPC: Fine-grain tracking, precise calorimetry for e/γ PID









JINST 15 (2020) 02, P02007

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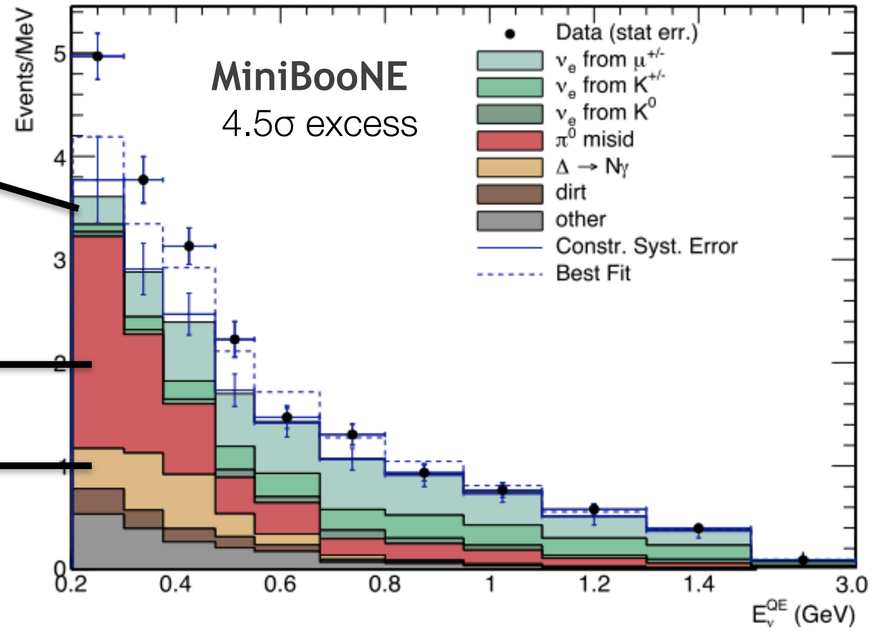
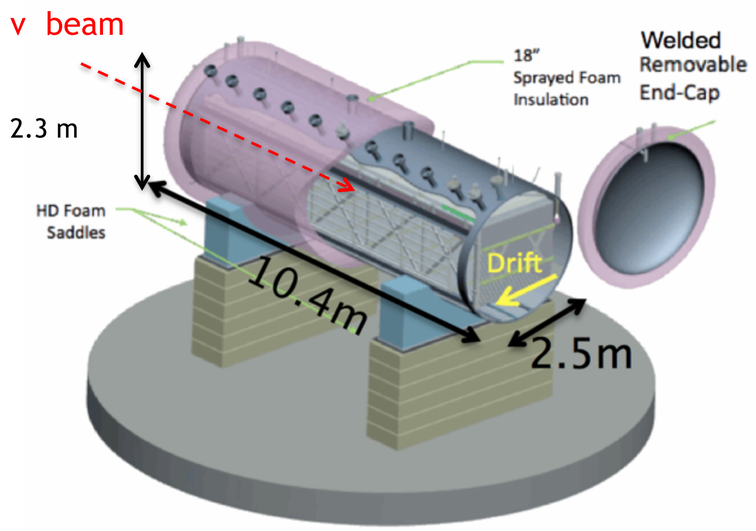
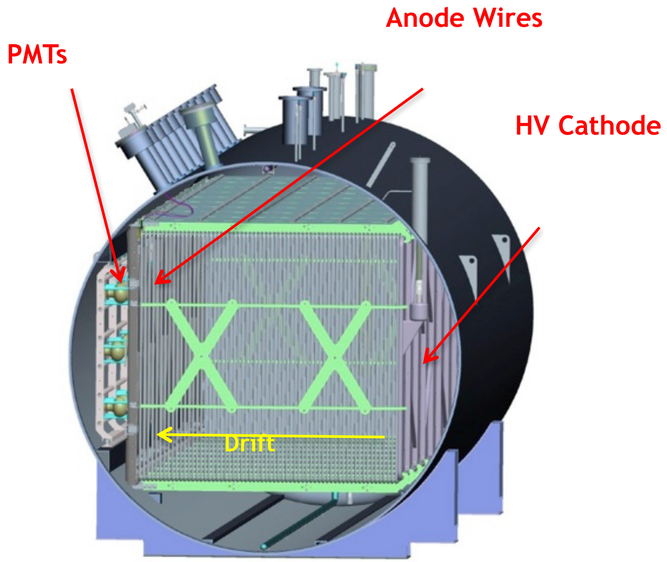


MicroBooNE

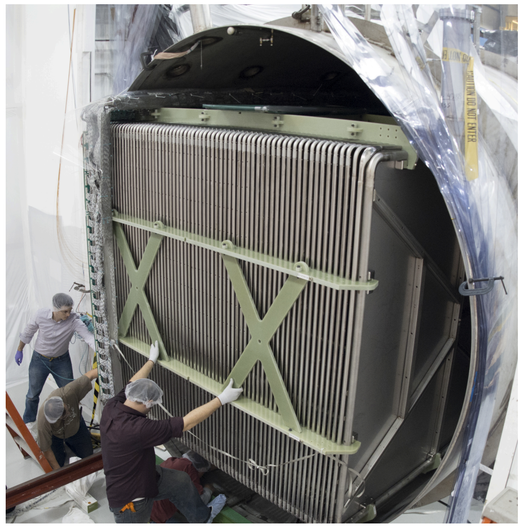
- First operating LArTPC of the FNAL short-baseline neutrino program
  - Started data-taking in 2015
- 85 tons (active mass)
  - 8192 wires (3 mm pitch) on 3 planes
  - 32 8” Cryogenic PMTs
  - UV laser calibration system
- Science goals:
  - Resolve low-energy event excess seen by MiniBooNE
  - Study GeV-scale ν-Ar interactions
- Also, LArTPC hardware, software R&D
  - E.g. First demonstration of E-field calibration with a UV laser system in a large LArTPC (JINST 15 (2020) 07, P07010)





Detector Construction

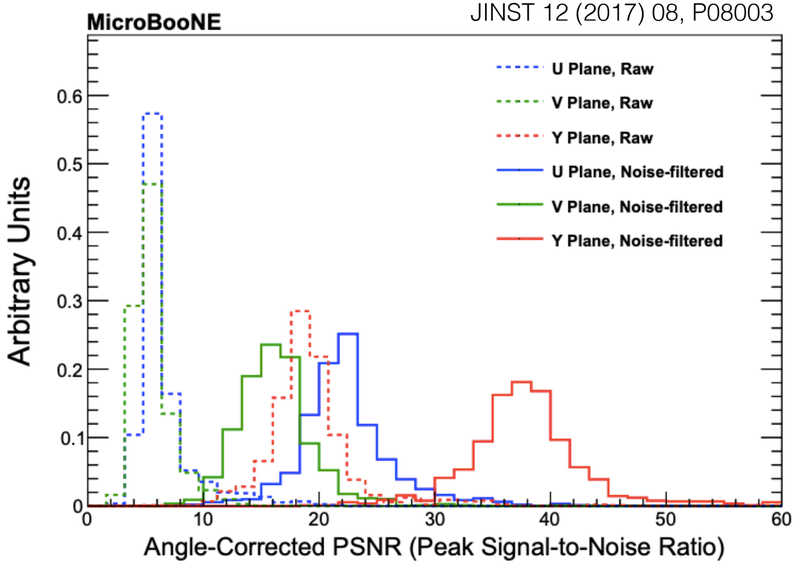
- Led by FNAL Project Management Team (Rameika, James)
  - Obtained early CD-4 approval in 2014 and received a DOE Secretary's Award of Achievement in 2016
- FNAL scientists (Raaf, Baller, Rebel) served as L2 managers for major detector subsystems, e.g. DAQ, cryogenics, TPC
- First large-scale (100 ton) LArTPC constructed in the U.S.
  - Major contributions to LArTPC detector development, including new insights into HV breakdown in LAr → follow-up LDRD (Lockwitz)
  - Detector paper (JINST 12 (2017) 02, P02017) has 199 citations since 2017

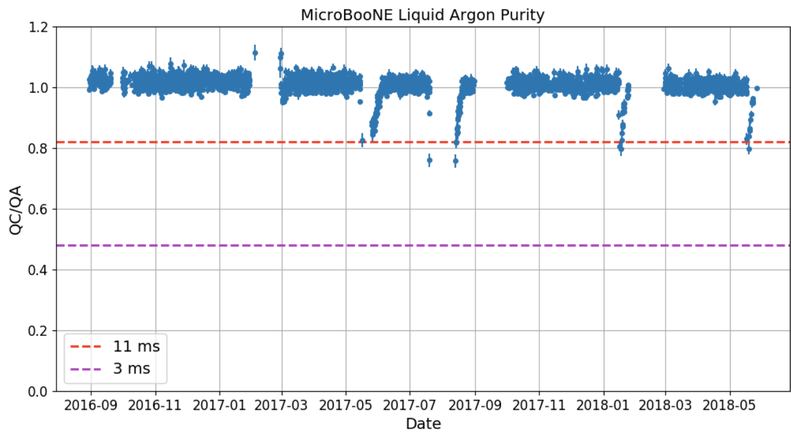


Commissioning and Operations

- Detector commissioning completed in October 2015, led by FNAL scientists (Baller, Toups)
  - First neutrino events a few weeks later
- First demonstration operationally in a ν LArTPC of technology crucial for scaling mass up to DUNE
  - Cold electronics: 40:1 signal-to-noise ratio achieved
  - Gas piston purge: >18 ms electron lifetime achieved
- Now holds the record for being the longest continuously-operated LArTPC in the world
  - Five-year physics run collected 500k ν's with high uptime
  - Now, R&D phase will bring further insights to the community

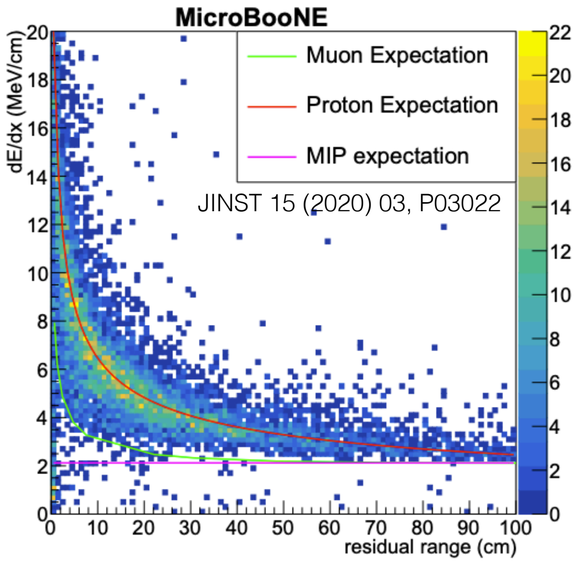
JINST 12 (2017) 08, P08003

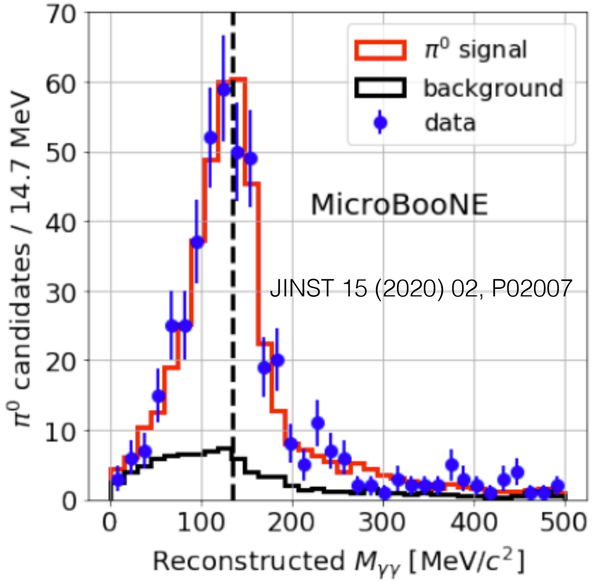




Calibration & Detector Response Systematics

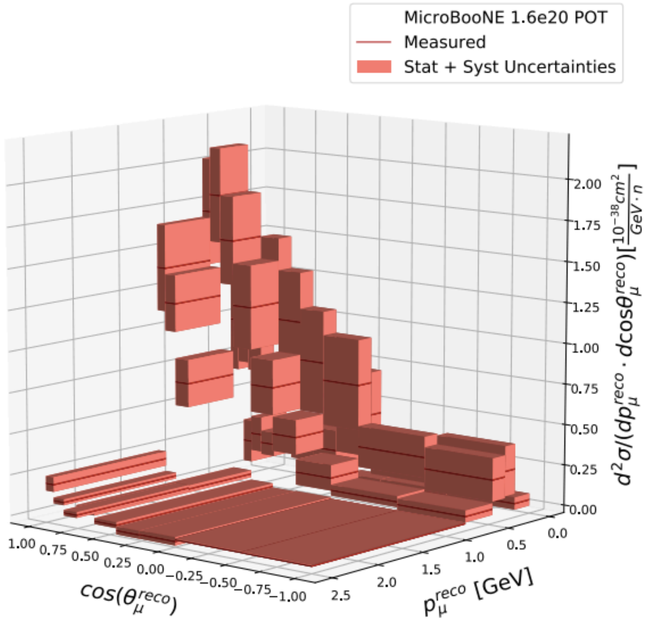
- Accurate reconstruction of ν events in a LArTPC requires a thorough understanding of the detector response
- Methods for calibrating the charge and energy response of tracks and showers in a LArTPC largely driven by FNAL contributions (Yang, Caratelli)
  - Methods that have now also been applied to protoDUNE
- MicroBooNE developed the first comprehensive treatment of systematic uncertainties in a ν LArTPC informed by data
  - FNAL scientists (Caratelli, Ketchum, Zennamo) played a central role in working out a novel method for evaluating systematic uncertainties related to the detector response that will influence data analysis in future LArTPCs



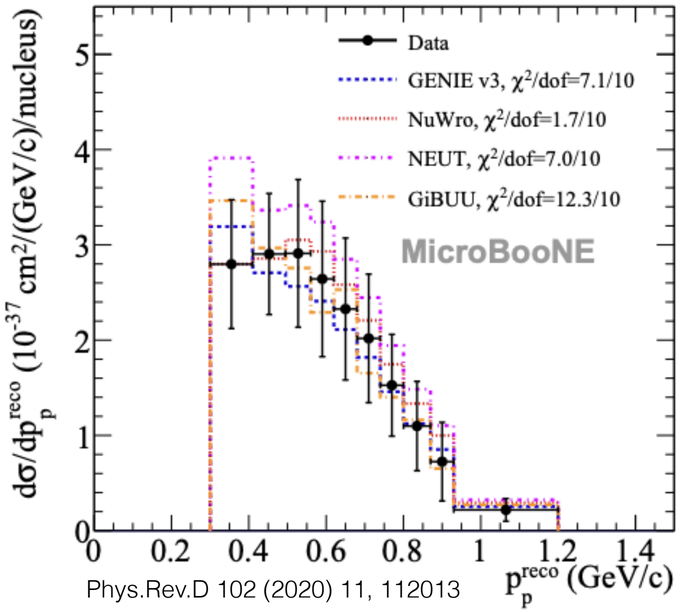


Understanding ν-Ar Interactions

- Better understanding of ν-nucleus interactions required to maximize physics reach of future neutrino oscillation experiments such as DUNE
- MicroBooNE is now producing the world's first high statistics measurements of ν-Ar interactions with key contributions from FNAL scientists (Kirby, Schukraft, Zennamo)
  - Published measurements in PRL(2), PRD(2), and EPJC
- FNAL Research Associates (Duffy, Gardiner) co-convene MicroBooNE's Cross Sections Working Group
  - Led the tuning, validation, and uncertainty estimation for the world's first ν-Ar interaction model tailored to low energies



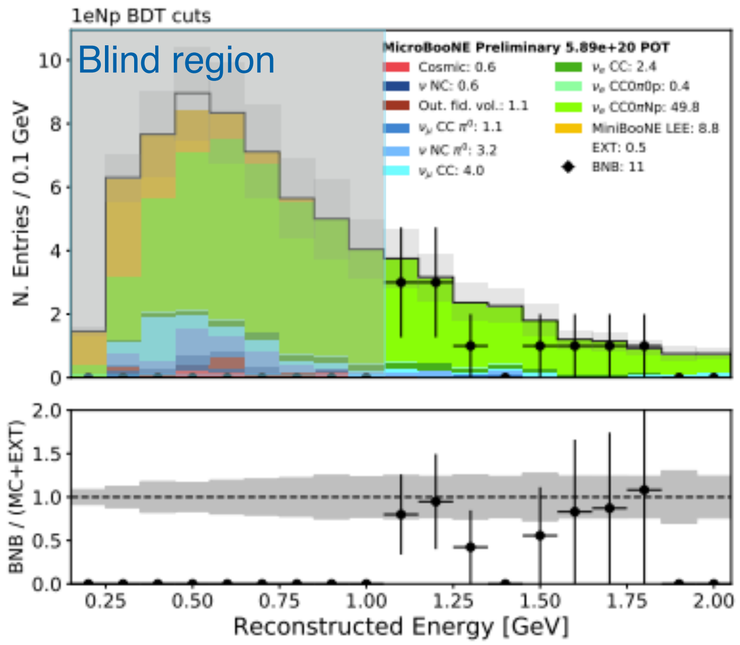
Phys.Rev.Lett. 123 (2019) 13, 131801



Phys.Rev.D 102 (2020) 11, 112013

Low Energy Excess Search

- Flagship physics analysis searches for an anomalous excess of ν_e's or single γ's in a predominantly ν_μ beam
  - FNAL scientists (Ketchum, Yang) have served as Co-conveners of the corresponding physics working group since 2017
- Same type of search to look for leptonic CP violation in DUNE, which can leverage tools and methods established for ν_e identification in MicroBooNE LArTPC
  - MicroBooNE has developed several automated reconstruction tools that are being used to pursue multiple search strategies
    - Will bring out the results in phases likely within the next 2-6 months as we complete them
- FNAL (Berkman, Caratelli, Cerati, Gramellini, Wospakrik) leads one such ν_e search team in collaboration with Harvard, Oxford, CSU



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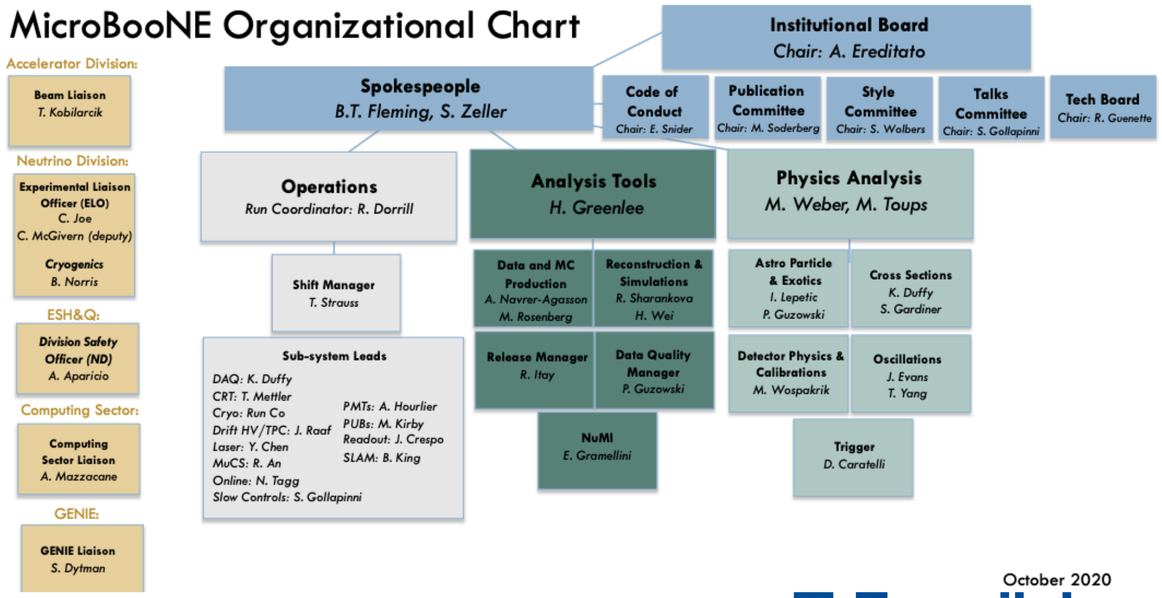
Scientific Output

- 29 papers since 2017
  - 14 last year
    - Surpasses output of CMS & ATLAS if measured in terms of papers/collaborator
- 55 public notes since 2015 to rapidly disseminate preliminary results
  - 19 last year
- Major collaboration leadership roles held by FNAL scientists
  - Co-spokesperson (Zeller), Physics Analysis Co-Coordinator (Toups), Analysis Tools Co-Coordinator (Greenlee, Ketchum)

MicroBooNE: Incredible track record of papers since 2017

2017 ↓ 2018 ↓ 2019 ↓ 2020

- High-performance Generic Neutrino Detection in a LArTPC near the Earth's Surface with the MicroBooNE Detector
- Neutrino Event Selection in the MicroBooNE Liquid Argon Time Projection Chamber 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
- Semantic Segmentation with a Sparse Convolutional Neural Network for Event Reconstruction in MicroBooNE
- Measurement of Differential Cross Sections for Muon Neutrino Charged Current Interactions on Argon with Protons and No Pions in the Final State with the MicroBooNE Detector
- The Continuous Readout Stream of the MicroBooNE Liquid Argon Time Projection Chamber for Detection of Supernova Burst Neutrinos
- Measurement of Space Charge Effects in the MicroBooNE LArTPC Using Cosmic Muons
- First Measurement of Differential Charged Current Quasi-Elastic-Like Muon Neutrino Argon Scattering Cross Sections with the MicroBooNE Detector
- Vertex-Finding and Reconstruction of Contained Two-track Neutrino Events in 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 LArTPC
- 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



October 2020

Summary

- MicroBooNE: a revolutionary experiment
  - Pioneered many hardware and software advances in LArTPC detector technology now being deployed on the SBN and DUNE
  - Producing high statistics cross section measurements at a fast clip that are rapidly improving our understand of v-Ar interactions
  - Developed the first trailblazing v_e and single γ search analyses in liquid argon with results expected in the next 2-6 months
- FNAL scientists have played a key role throughout program that carry over to DUNE