MicroBooNE

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July 2019 PAC Presentation

Charge to MicroBooNE

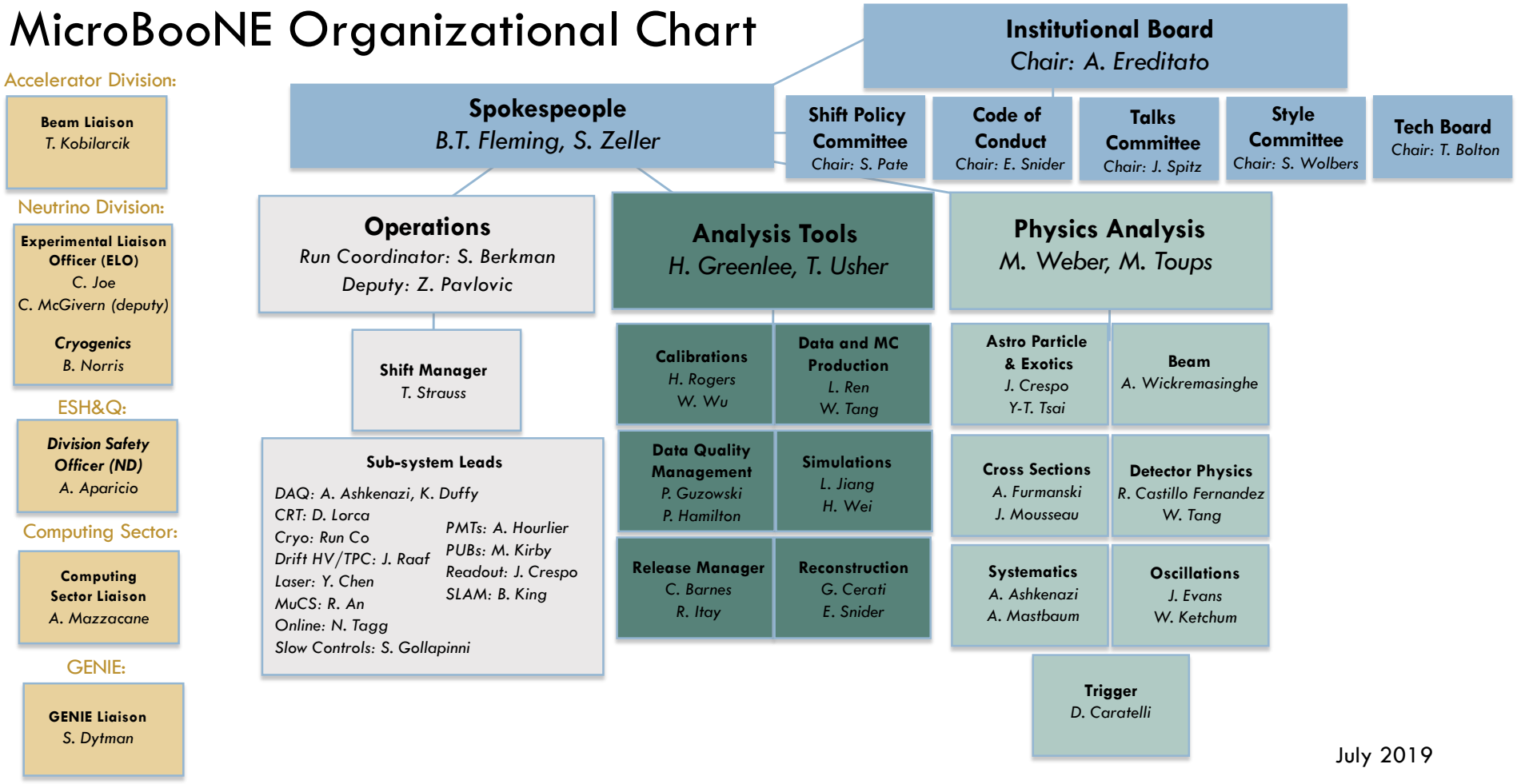
We would like to invite the MicroBooNE collaboration to present a “Report on the MicroBooNE experiment” at the next PAC Meeting in July 2019. The meeting will take place in downtown Chicago.

The speaker is expected to review the following topics:

- The current status of operations
- Physics program for 2019-2020
- Physics program for 2021 and beyond
- The improvement to the simulation, reconstruction, and estimate of systematic uncertainties, along with the expected impact on flagship analyses
- How the recent results from the collaboration are informing the flagship analyses
- The plan for reducing the systematic uncertainties (and how these are improved in MCC9)

[*] We ask the committee to review the short-term analysis plans for the collaboration over the next year, as well as its plans beyond this time scale, particularly in regard to the LEE analyses

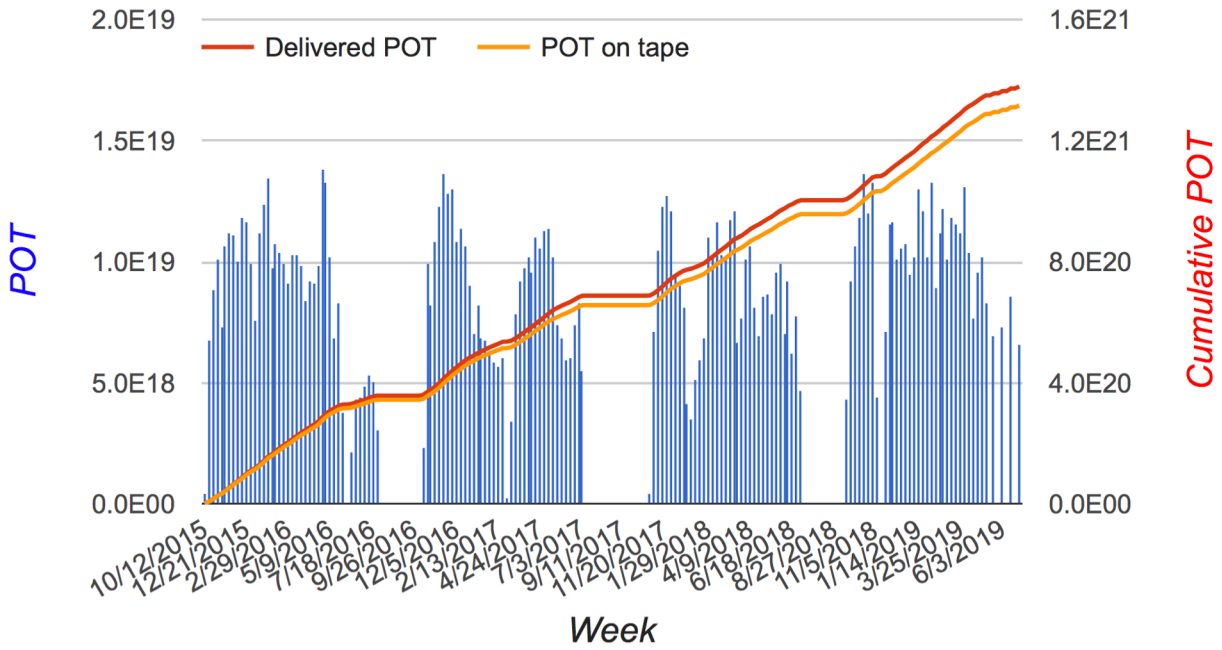
MicroBooNE Organizational Chart



July 2019

MicroBooNE Operations

- have collected a total of 13.4x10^{20} POT
  - 50% with full CRT installed and taking data
- detector continues to operate well: 96% detector + DAQ uptime
- BNB delivery has been excellent
- very dedicated MicroBooNE team committed to operating the experiment
- Sharing commissioning and operations tools, procedures, and experience with ICARUS and SBND



POT accumulation/year:

FY16: 3.6x10^{20} POT

FY17: 2.9x10^{20} POT

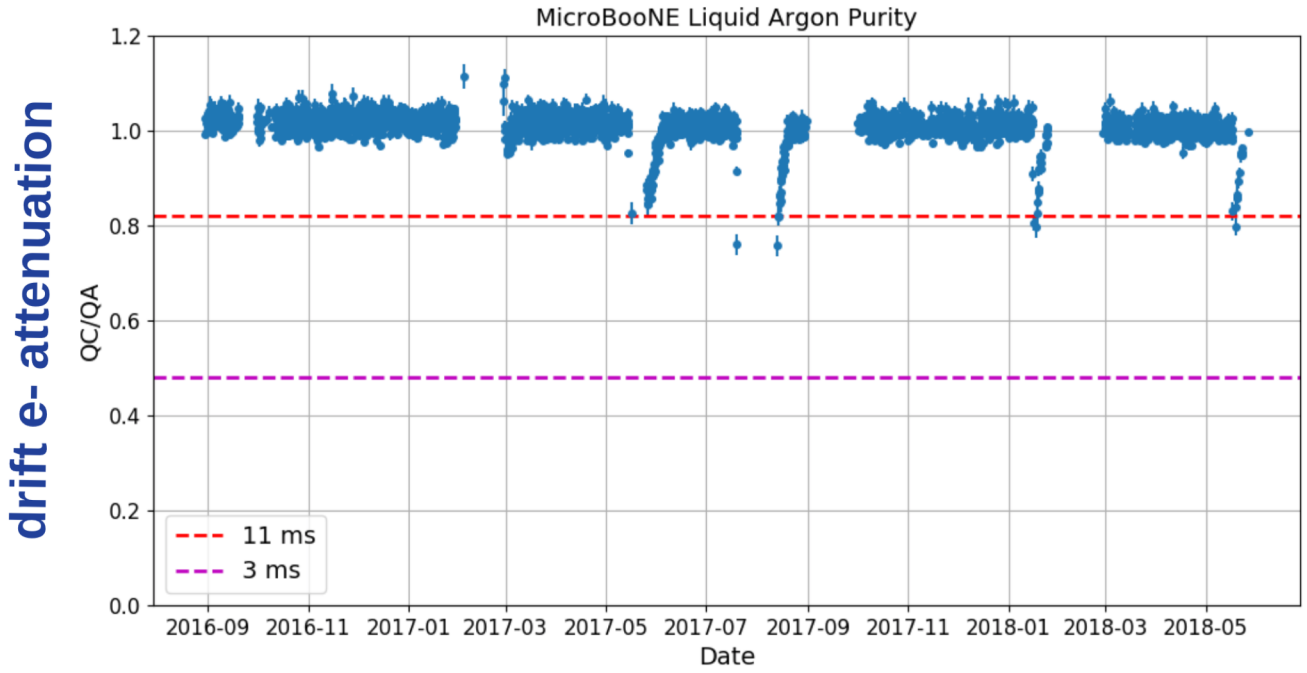
FY18: 3.1x10^{20} POT

FY19: 3.8x10^{20} POT

13.4x10^{20} POT

MicroBooNE Operations (cont'd)

- MicroBooNE is now the longest running LAr TPC to date
- we have learned a lot about long term liquid argon purity, drift high voltage, scintillation light, and cold electronics stability over time



- Over time, detector contaminant level decreases. Recovery time from low purity improves; recovery time: 6-9 days in early years, 2-3 days now

Motivation for FY2020 Running

- We need more data with the CRT
  - presently we have ~6×10^{20} POT with the CRT (50% of total data set)
  - would like to move closer to 13.2×10^{20} POT with CRT

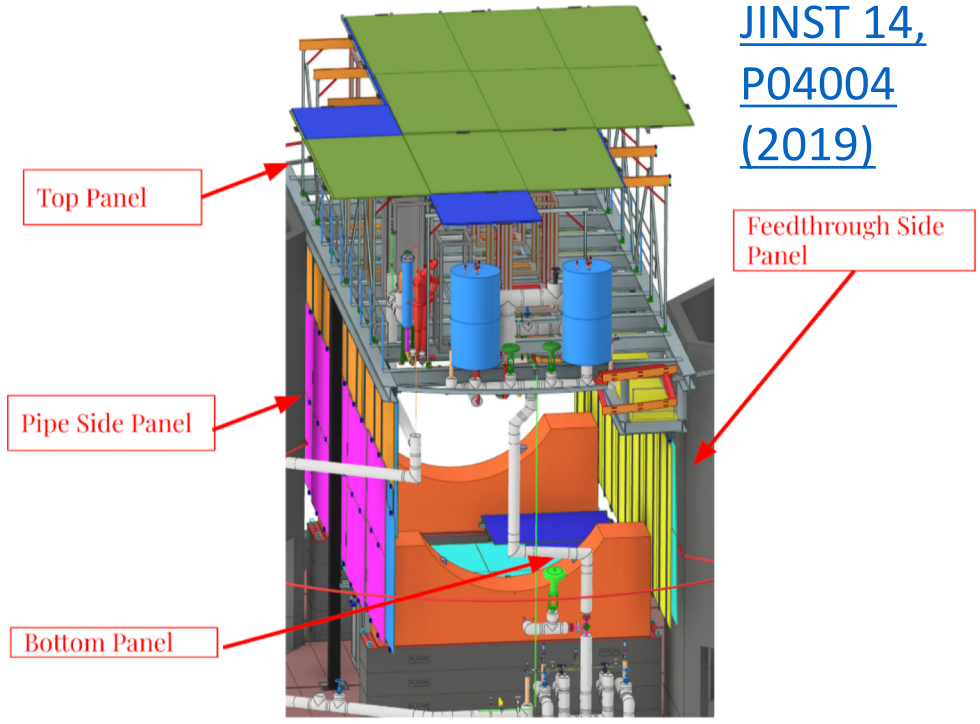
- Impact of running with CRT
  - can remove >40% of cosmics for ν_e analyses
  - allows relaxation of cuts downstream and hence increases selection efficiency for LEE analyses

- Overlap in data taking with first data from ICARUS
  - good for overall SBN program

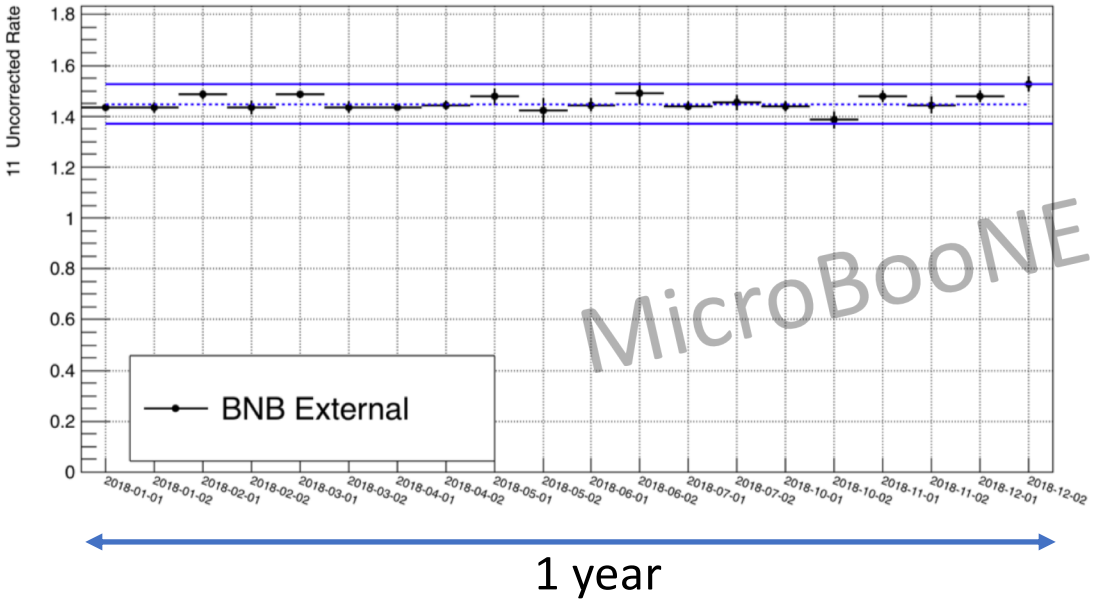
we request endorsement of continued running through FY2020 as is planned for in FNAL Operations Plan

CRT Performance

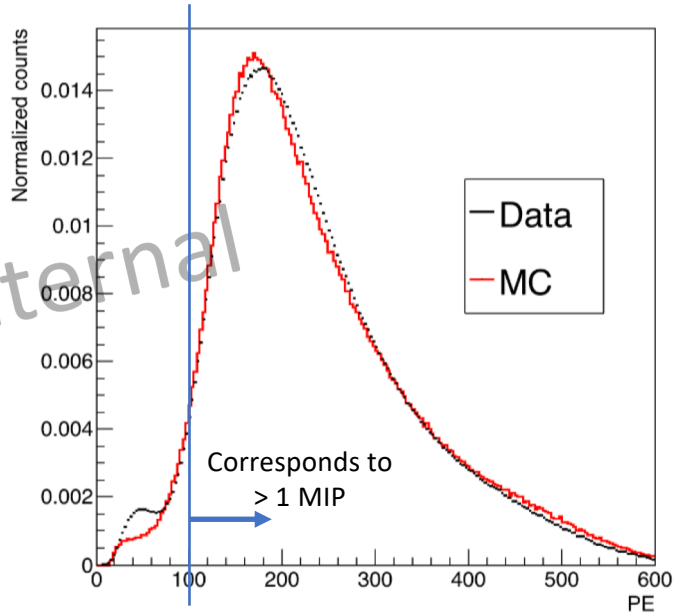
- CRT performance over time is stable in all 73 modules
- simulation and data for hits in each module are consistent above 100 PE threshold
- CRT has been successfully merged with in-tank events (important also for other SBN detectors)



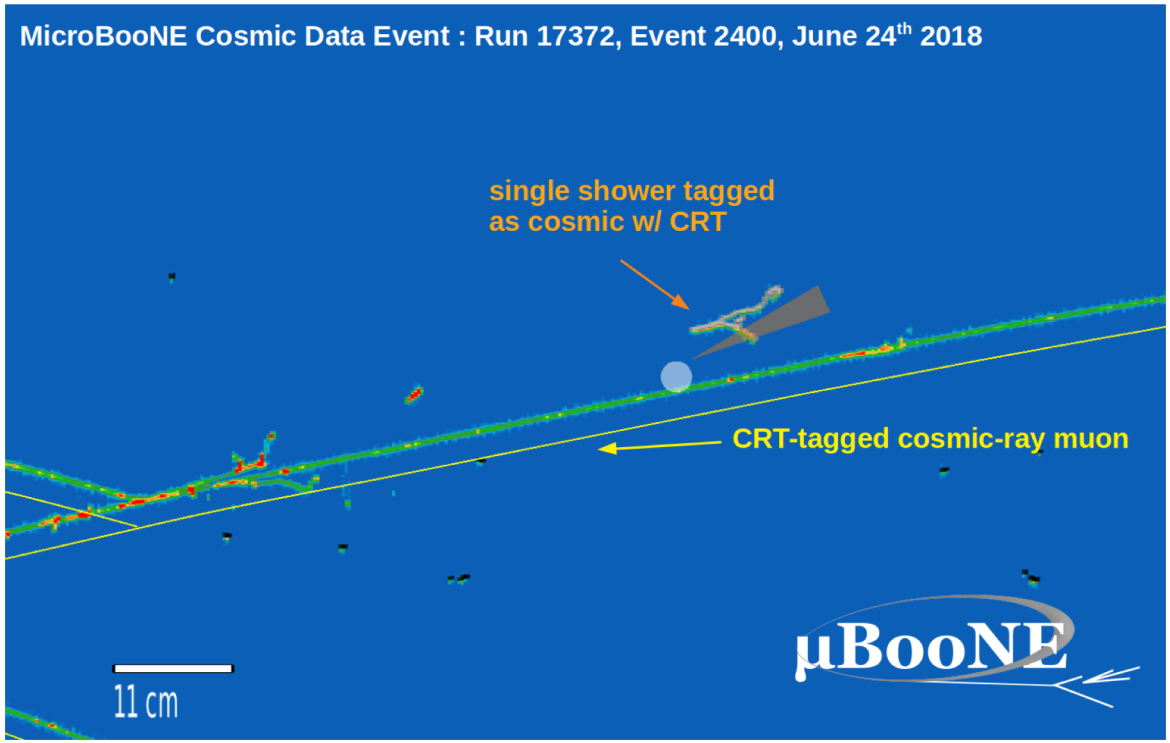
JINST 14, P04004 (2019)



All CRT Hits



Use of CRT as a Distance Tagger



example of passing cosmic where associated shower is instead reconstructed by Pandora as a candidate ν_e

(reconstructed quantities shown offset)

- use of external detector (CRT) to reject events like this enables relaxed use of pattern recognition with potential boost in efficiency. Quantitative analysis underway with MCC9.
- R&D: important input to rest of SBN program to inform optimal selection for removing isolated showers from cosmic ray activity, e.g. cylinder size 10cm → 14 cm?

Running beyond FY2020…

- Continued running with CRT will improve analysis with initial reduction in cosmic backgrounds in pre-selection phase (like all present surface LAr TPCs)
- Collect increased statistics for signature analysis, rare process analyses, differential and double differential cross section measurements

Signature results will guide decisions with respect to running beyond FY2020

Lessons Learned from MicroBooNE

- First use of cold front-end electronics in a LAr TPC (JINST 12, P08003, 2017)
  - ASIC saturation: new generation ASICs now have additional input bias current settings
  - Wire vibrations: spacers have been added to support the anode wires in the design of new LAr TPCs to reduce vibrations and wire motion from fluid flow
  - Misconfigured channels: additional electrostatic discharge protection has been added on the configuration pins in next generation ASICs
  - ASIC startup: design margin of the bandgap reference circuit has been increased in the new ASIC design to remove start-up problems
  - Electronics environment: additional attention is being paid to grounding during building construction (e.g., SBND, ICARUS) and during detector installation
  - Offline noise filtering: MicroBooNE noise filtering approach and code had an immediate impact on the analysis of DUNE 35 ton and protoDUNE data (JINST 12, P08003, 2017)
  -
- Demonstration of very high argon purity without evacuation in a fully instrumented vessel (public note #1026)
  - Breakdown in high purity argon is a serious issue in the design of LAr TPCs (JINST 9, T11004, 2014, JINST 9, P11001, 2014)
  - Very stable liquid argon purity can be achieved for years at a time with a properly designed cryogenics systems (public note #1026)
  - Argon delivery schedule should be well thought-out in advance; filling is the largest source of thermal gradients; can be controlled with heaters and gas flow
  - Learned that there is a trade-off between the requirements on argon purity and drift high voltage that has become an important part of planning for DUNE
- First use of a UV laser calibration system (public note #1055)
  - Electric field can be mapped using an in-situ steerable UV laser system; such a system is now under consideration for the DUNE far detector (JINST 9, T11007, 2014)
  - First high statistics measurement of space charge effects in a LAr TPC comparing measurements from cosmics and UV laser (public note #1018)
  - UV laser system requires special maintenance – lessons learned from MicroBooNE experience are being communicated to SBND
  - Lessons learned for future UV laser system designs in LAr communicated in a public note to DUNE for TDR preparation (public note #1055)
- LAr TPC calibrations and TPC signal processing
  - 2D-deconvolution improves reconstruction of particle tracks in liquid argon (JINST 13, P07006, 2018, JINST 13, P07007, 2018)
  - Multiple Coulomb scattering parameters tuned for argon (JINST 12, P10010, 2017)
  - Michel electron energy spectrum needs to be corrected for large radiative effects in argon (JINST 12, P09014, 2017)
  - Anode/cathode piercing muon tracks can be used to measure argon purity in real-time for detector monitoring and subsequent data analysis (public notes #2016, #1048)
  - ^{39}Ar beta decays as a possible calibration source for DUNE (public note #1050)
- Long Term LAr TPC Operations
  - Lessons learned from commissioning MicroBooNE were documented and communicated to protoDUNE (MicroBooNE docdb #15878)
  - Developed means to inspect the integrity of wire planes inside a sealed cryostat (JINST 10, T08006, 2015)
  - Raised awareness of the need to be able to assess HV feedthrough connectivity during operations; developed novel means to use anode plane signals to assess real-time connectivity
  - Documented stability a LAr TPC over years of operations (public note #1013)
  - MicroBooNE developed the first implementation of a continuous readout stream for supernova neutrino physics (JINST 12, P02017, 2017)
  - Serious thought should be given to the reduction of LAr TPC data rates both through triggering and further development of data compression techniques
  - An unknown source of large single photoelectron rates can be present in a surface LAr TPC which can impact triggering considerations and data rates; comparing rates with protoDUNE-SP
  - Experience from MicroBooNE operations led to plans for both overburden and cosmic ray taggers for the SBND and ICARUS detectors (JINST 14, P04004, 2019)
  - Developing CRT to TPC matching and sharing with SBN
- Neutrino Data Analysis
  - First detailed comparisons of neutrino kinematics in argon to GENIE (and other generator) predictions (arXiv:1905.09694, PRD99 091102(R) 2019, Eur.Phys. J. C79, 248, 2019)
  - First use of machine learning in the analysis of LAr TPC data (JINST 12, P03011, 2017, PRD99, 092001, 2019, public note #1051, #1042)
  - First tests of automated reconstruction on neutrino data and in the analysis of multiple different neutrino interaction types (public note #1049)
  - First development of tools to remove cosmic rays in neutrino interaction events (arXiv:1812.05679, public note #1005, JINST 12, P12030, 2017)
  - First demonstration of automated 3D shower reconstruction (public note #1012)
  - Reconstruction of protons down to low kinetmatic thresholds (public note #1056, #1053)
  - Validation and development of Pandora tool-kit also being used for DUNE and proto-DUNE using MicroBooNE neutrino data (Eur. Phys. J. C78, 1, 2018)

Where Are We Going and Where Are We Now?

- a lot of new results since we last presented to the PAC
  - see next slides …
- MicroBooNE is developing the technology both from the hardware side and the analysis side
  - a lot of young people involved!
- we have neutrino data and that is our competitive advantage
- *we are on track on many fronts*

Low Energy Excess (LEE) Analyses

Deep Learning:

new capabilities in topology, kinematics, and particle content

Pandora gLEE: Photon analysis

Pandora eLEE : Electron analysis

consolidated Pandora output → new toolset, impact on development of downstream cuts

WC + Pandora hybrid eLEE:

upstream WC imaging + downstream hybrid Pandora toolset

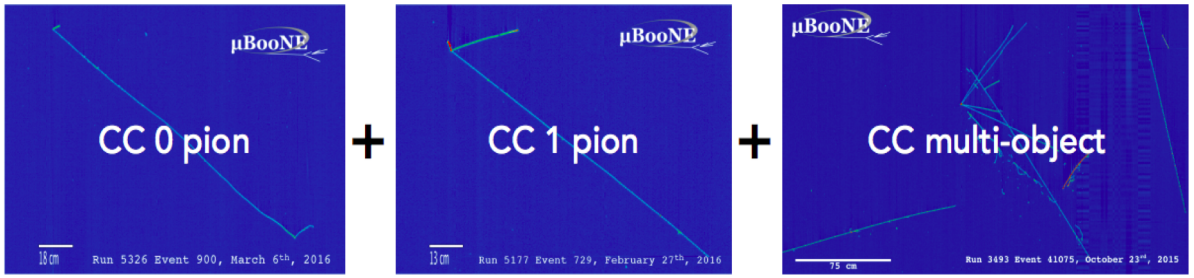
Foundation for all analyses

Foundation of all analyses now have access to:

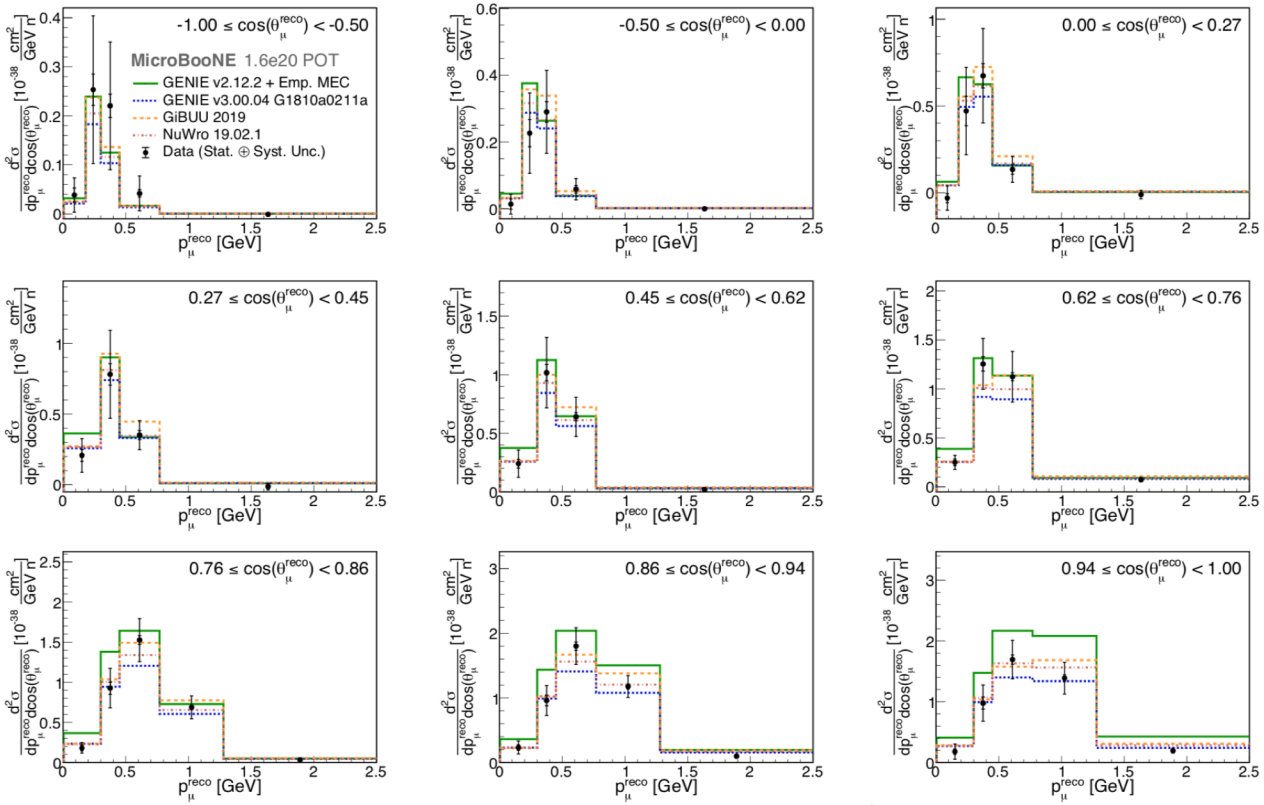
- 2D deconvolution and signal processing
- common optical filtering and improved track/flash matching
- CRT tagging for improved upstream cosmic rejection
- data-driven calibrations and systematic error determination
- centralized data and Monte Carlo production

CC Inclusive (ν_μ + Ar → μ + X)

arXiv:1905.09694
submitted to PRL



backwards going muons

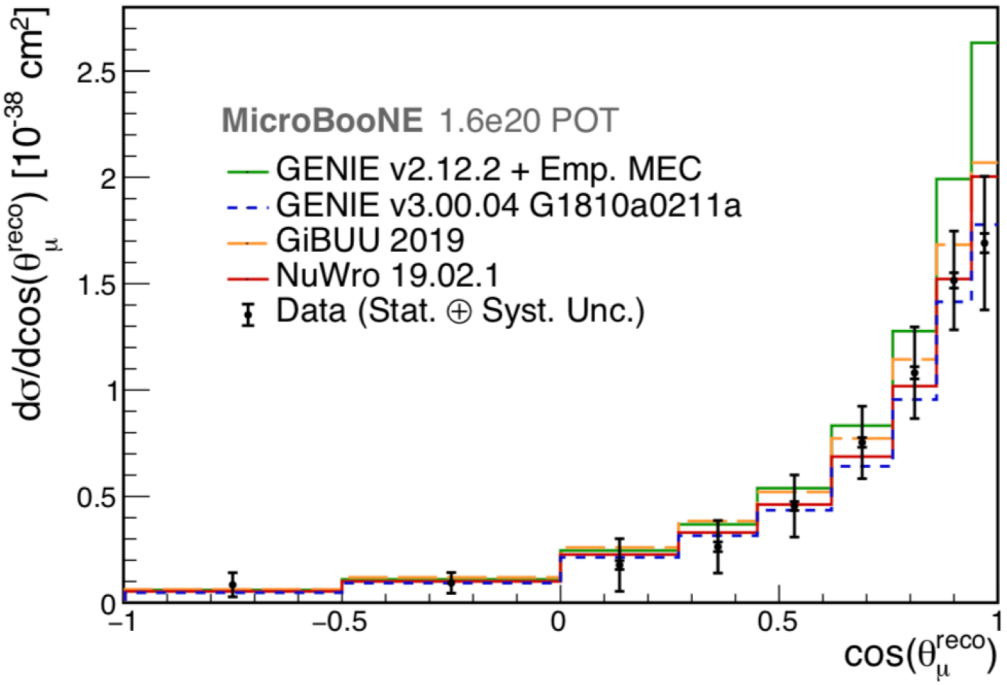


forward going muons

- 26k events (1.6x10^{20} POT)
- pioneering use of MCS to include exiting tracks → full kinematic coverage
- first neutrino double differential cross section measurement on argon
- Fermilab W&C seminar on May 29, 2019

CC Inclusive (ν_μ + Ar → μ + X)

arXiv:1905.09694
submitted to PRL



- PRL referee: *"Heard the MicroBooNE team lead the developments for the release of GENIE v3. I read the note describing the changes. Good work and thank you on behalf of the rest of the community."*

- first comparison of event generators to high statistics, 2D neutrino data on argon

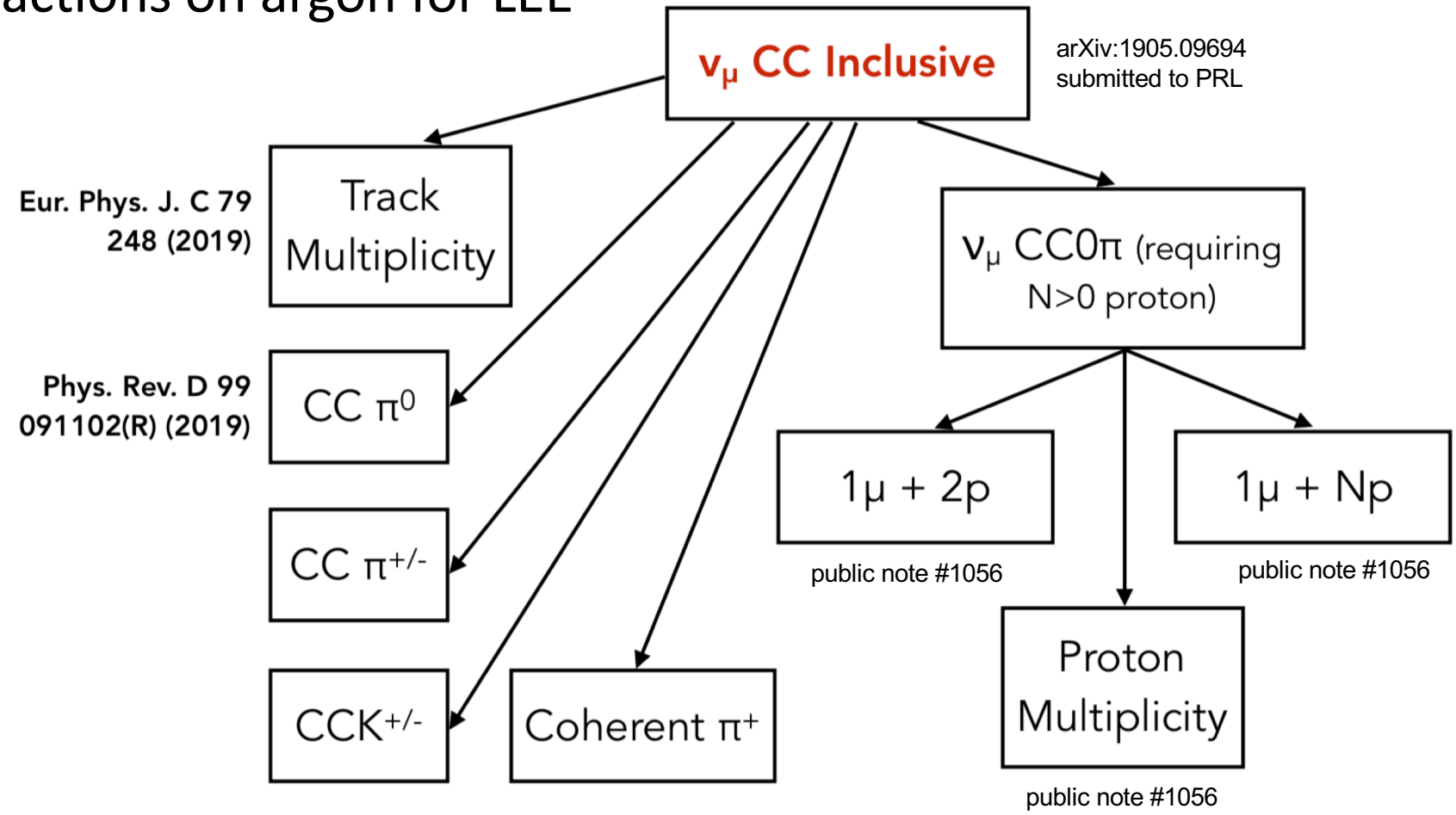
  → first test "with fire"

- MicroBooNE data prefers GENIE (v3) with more sophisticated nuclear models (local FG, RPA)

- GENIE is the most comprehensive simulation which plans to support the broader neutrino physics program in the coming decade. MicroBooNE's work with GENIE will ensure our data will be used in guiding improvements to modeling.

Many New Neutrino Results

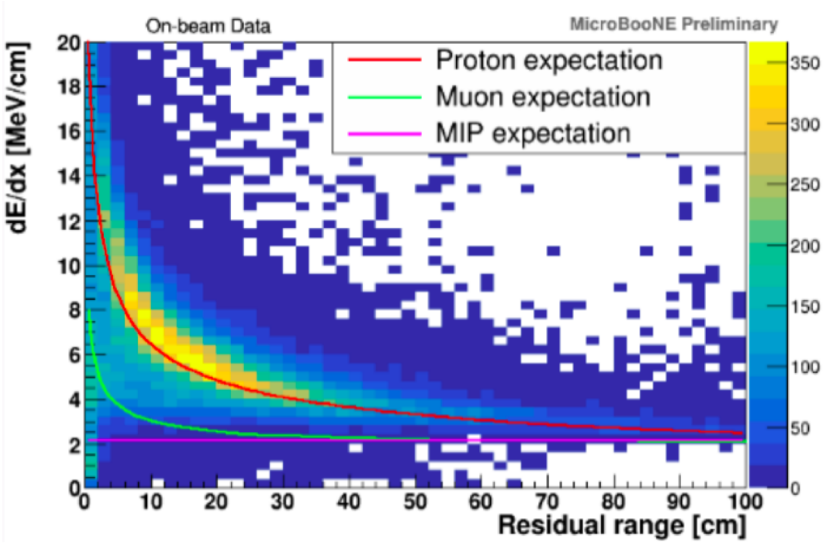
- have also studied multiple exclusive modes
- important basis for demonstrating that we understand neutrino interactions on argon for LEE

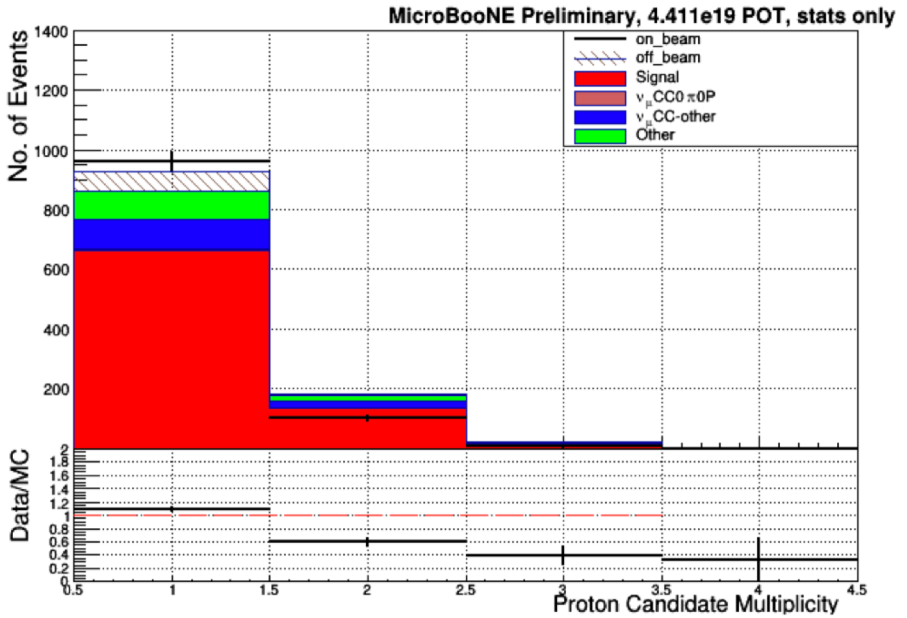


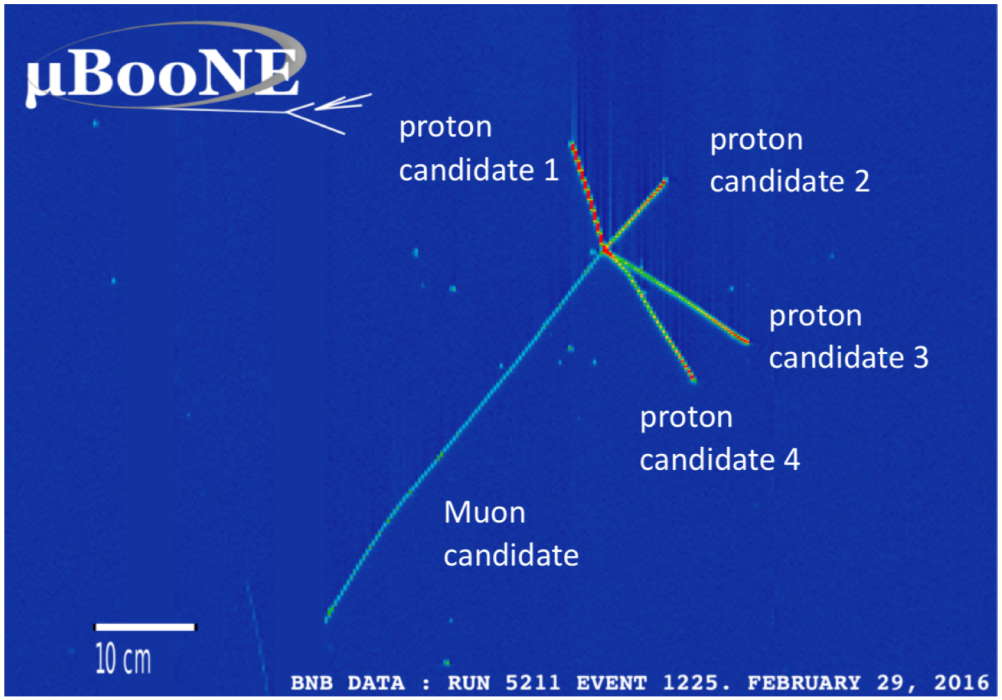
MicroBooNE public note #1056

Proton Multiplicity

- we can successfully identify protons
- multiplicity distribution provides important check of nuclear effects, FSI modeling
- direct relevance to LEE analyses that preferentially select nucleon final states (1p, Np)

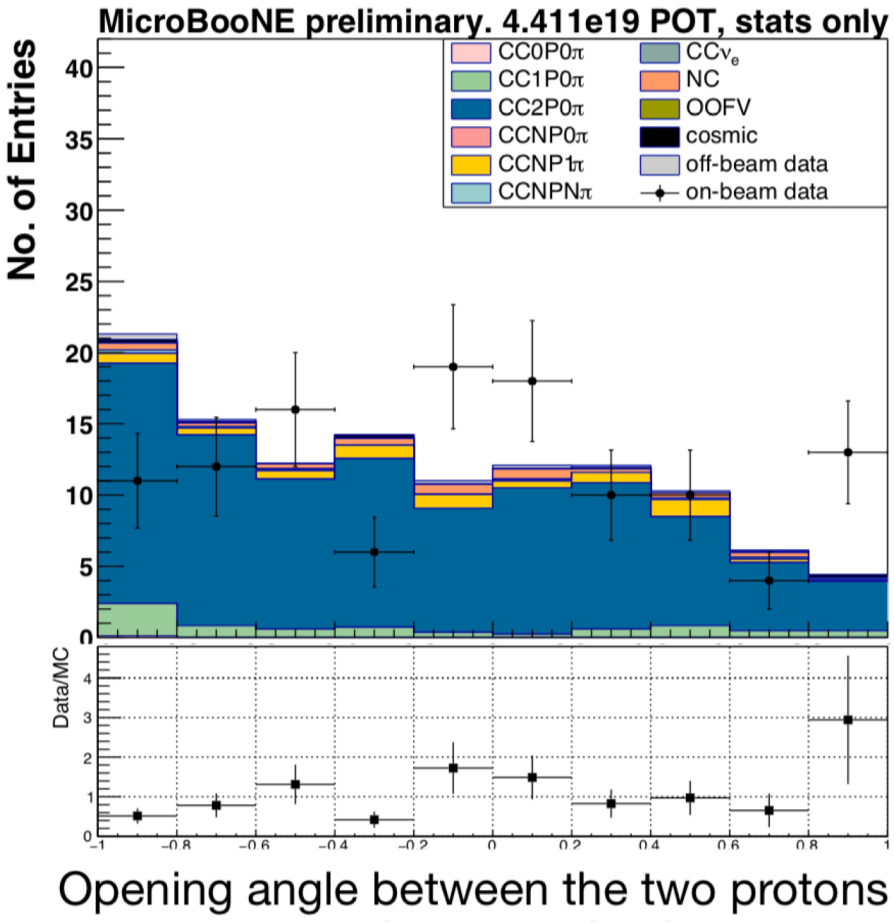


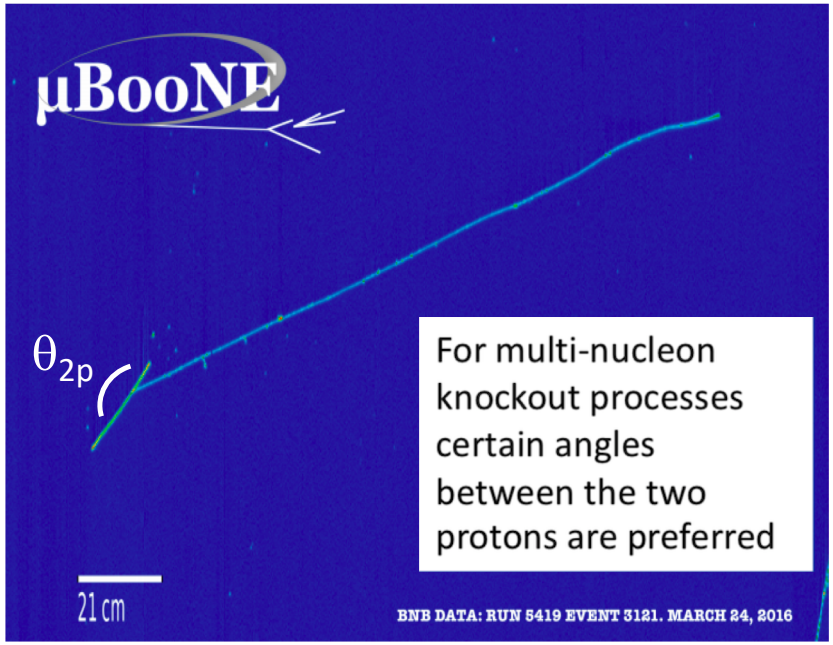




MicroBooNE public note #1056

1μ2p (ν_μ + Ar → μ + 2p)



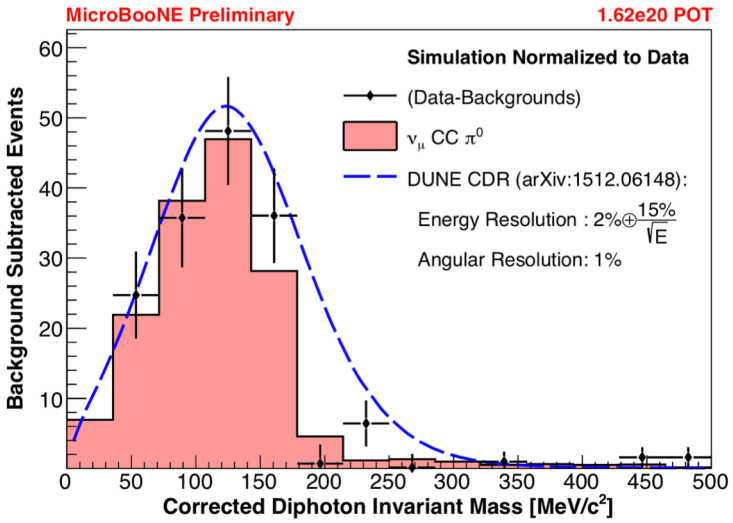


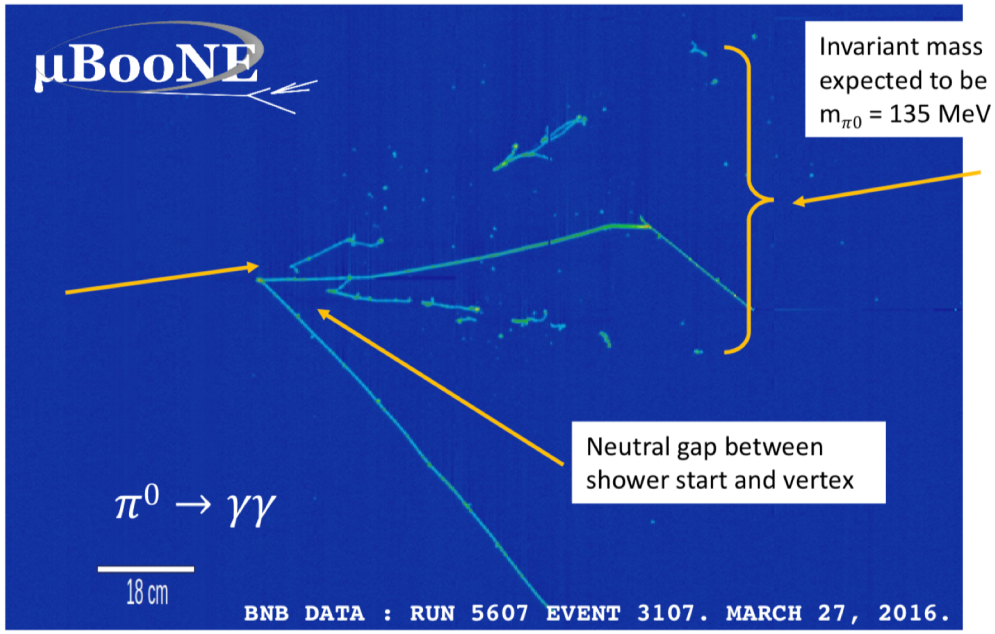
- kinematics impacted by short range correlations and FSI
- distribution can look very different for different generators
- data-driven check of potential feed-down into LEE 1p channels

Moving Now from Tracks to Showers …

CC π^0 (ν_μ + Ar → μ + π^0)

PRD 99, 091102(R), 2019





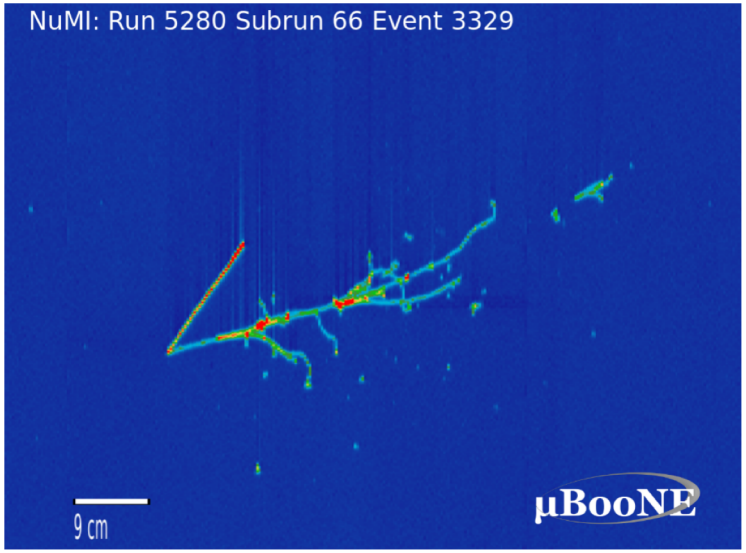
- electron and photon reconstruction is key to neutrino oscillation measurements
- MicroBooNE has developed the first fully automated reconstruction tools for EM reconstruction in LAr TPCs
- observe 20% energy resolution with good data/MC agreement
- first measurement of ν_μ CC π^0 cross section on argon
- validates π^0 production in argon (x2 higher predicted absorption rate than in hydrocarbon)

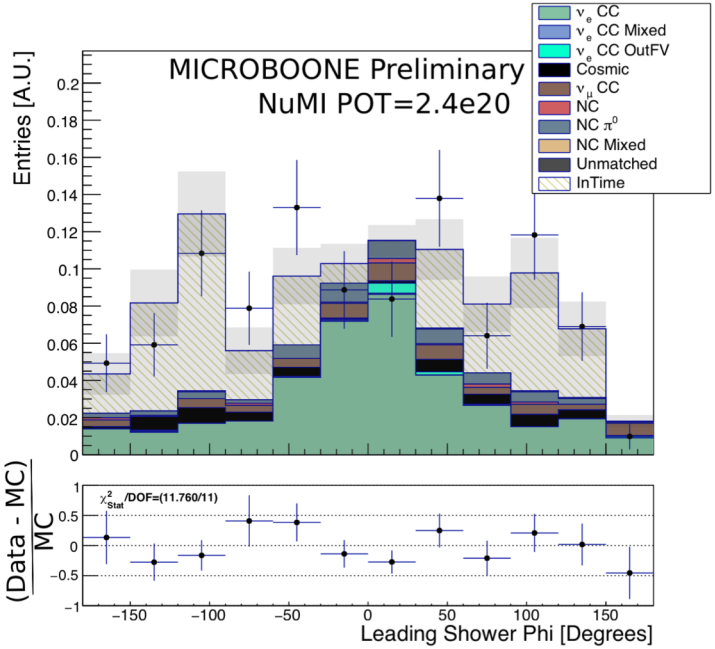
new paper on π^0 reconstruction coming soon

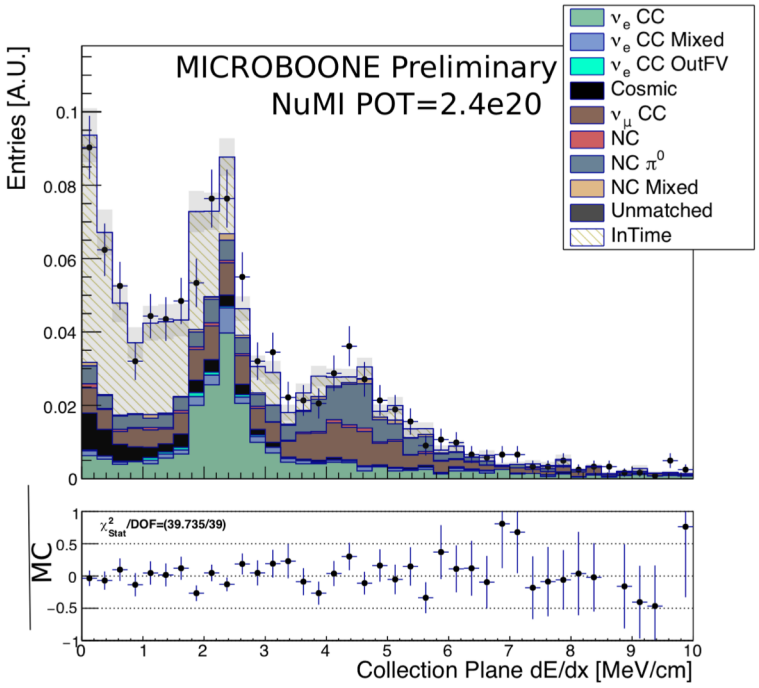
MicroBooNE public note #1054

ν_e from NuMI Beam

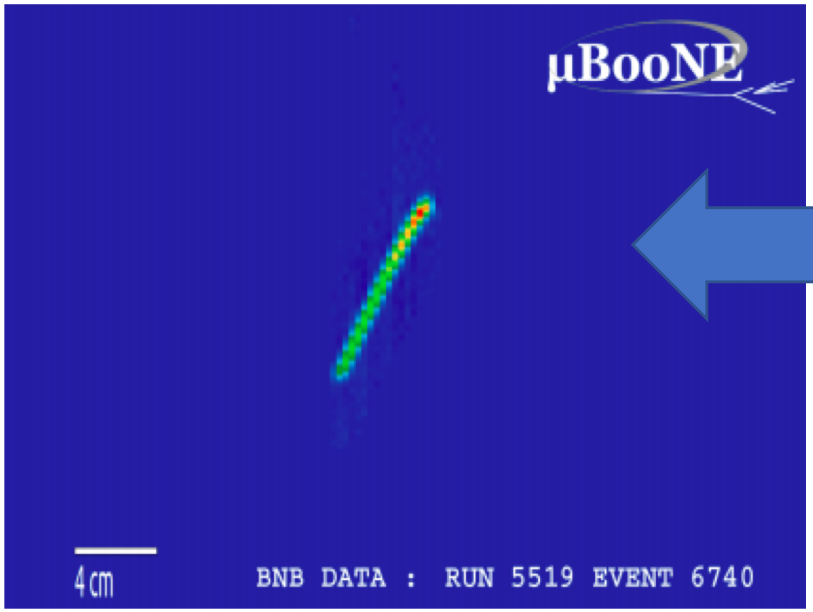
- MicroBooNE sits 8^0 off axis from the NuMI beam
  - NuMI beam is a source of ν_e's in MicroBooNE
  - similar energy as BNB ν_e's
- fully automated ν_e selection and reconstruction
- first e/γ separation in MicroBooNE





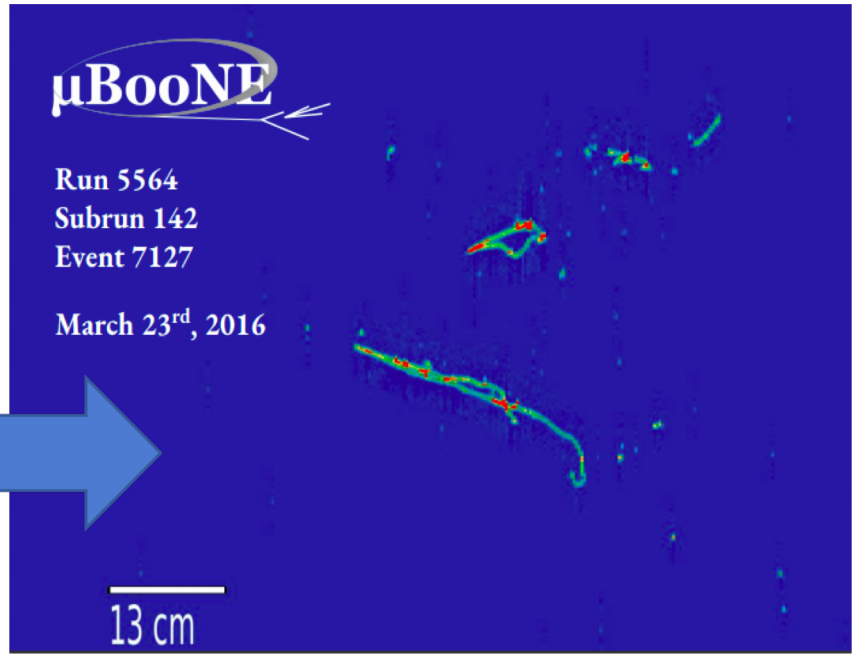


Additional On-Going Neutrino Analyses

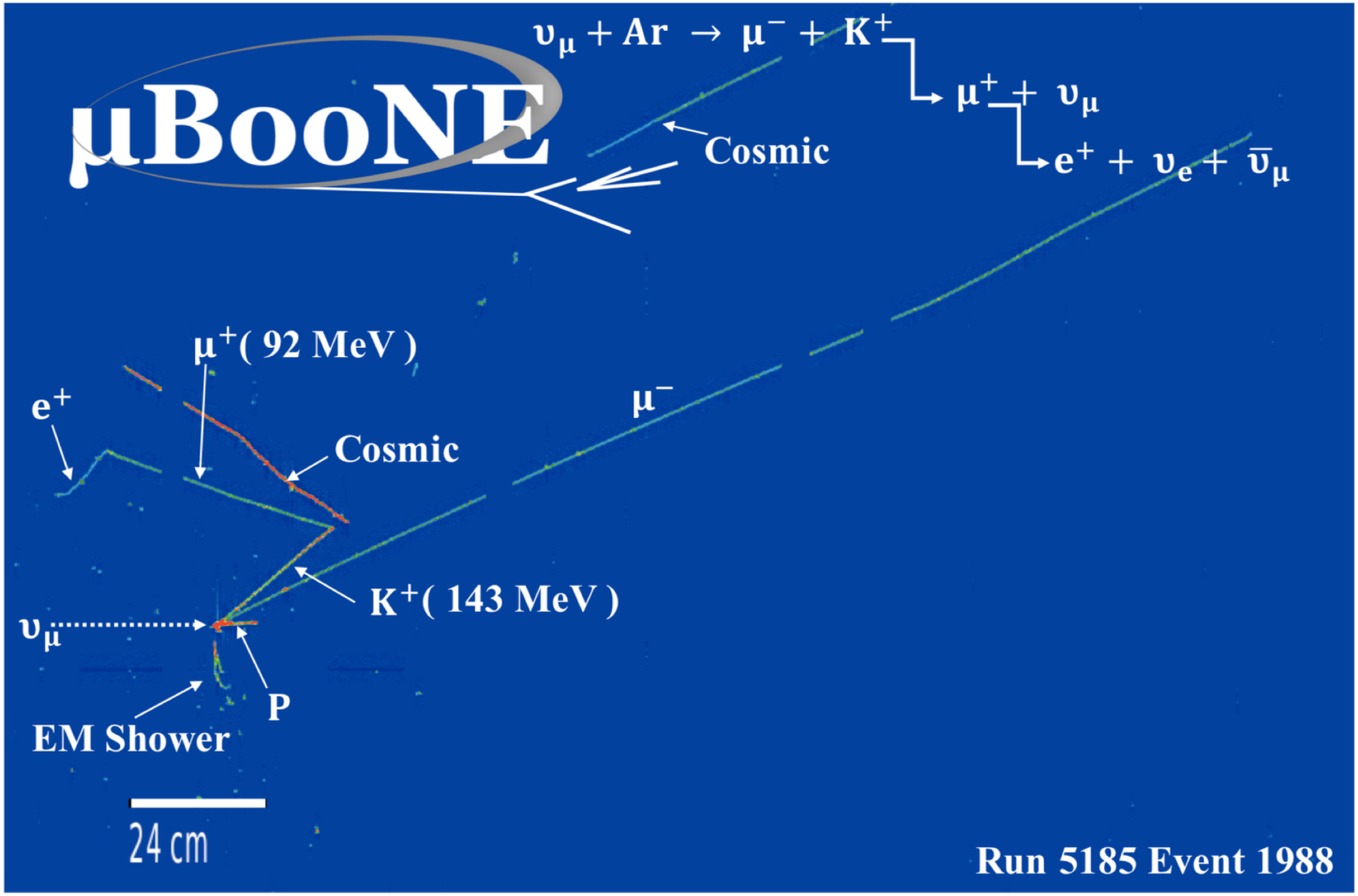


- ν_μ NC elastic scattering
- proton identification and reconstruction
- with low proton detection thresholds, we are at the forefront
- MicroBooNE public note #1053

- ν_μ NC π^0 production
- crucial background constraint for γ LEE
- MicroBooNE public note #1041



We Are Even Reconstructing Kaons



- relevant for DUNE nucleon decay sensitivity validations
- plan to measure neutrino-induced rate of kaon production in argon

What We Are Learning for LEE

neutrino results	role in developing LEE analysis
charged track multiplicity Eur. Phys. J. C79, 248 (2019)	initial combined tests of GENIE modeling of argon, detector simulation, vertex and track reconstruction
CC inclusive arXiv:1905.09694	muon identification and reconstruction, cosmic rejection, initial evaluation of detector systematics for tracks, central value GENIE selection using 2D kinematics
CC π^0, NC π^0 PRD99, 091102(R) (2019)	shower reconstruction, initial evaluation of detector systematics for showers, background constraint
CC Np, CC 1p, CC 2p public note #1056 arXiv:1812.05679	calorimetry, recombination, proton ID, understanding systematics for 1p final states, migration in/out of 1p channel, cosmic rejection for 1mu1p final states
NuMI ν_e public note #1054	electron identification and reconstruction using data, dE/dx for electrons

What We Are Learning for LEE

detector physics & reconstruction	role in developing LEE analysis
electric field MicroBooNE public note #1055	data-driven electric field maps
dQ/dx → dE/dx calibration paper currently in collaboration review	detector uniformity, calorimetry validation
Wire Cell arXiv:1803.04850	optical reconstruction, flash-track matching, cosmic rejection Wire Cell imaging performance
2-track reconstruction MicroBooNE public note #1042 paper currently in collaboration review	Deep Learning-based LEE 1μ1p analysis reconstruction validation and performance
electromagnetic PID PRD99, 092001 (2019)	Deep Learning network demonstration, validation, and and performance
data-driven reconstruction studies MicroBooNE public note #1049	tracking, MCS performance, vertex finding
π^0 reconstruction paper currently in collaboration review	improved shower reconstruction with SSNet, dE/dx for photons

Recent Progress

- MicroBooNE has a well-operating detector and large neutrino data samples that are being analyzed

- We have a mature software framework (Major collaboration wide effort!) (through 3 major releases: MCC7 → MCC8 → MCC9)
  - simulation tuned to MicroBooNE data
  - fully calibrated data and Monte Carlo
  - robust reconstruction tools
  - use of data-driven methods in as many places as possible

- MCC8 is producing physics publications now, but we need the improvements in MCC9 for our signature LEE results

MCC9

- MicroBooNE has incorporated significant improvements in MCC9
- This has been a major collaboration-wide effort
  - Improved Signal processing, better dynamic induced charge model (JINST 13, P07006 (2018), JINST 13, P07007 (2018))
  - CRT is bringing new information from an entirely new system
  - Making use of data-driven methods to replace simulation *(electric field maps, cosmic data overlays, data-driven calibrations, etc.)*
  - Upgraded GENIE with improved physics models
  - Better use of induction planes for reconstruction and calorimetry
  - Creation of lighter files for faster processing of higher level reconstruction *(MCC8: > 50 MB/evt → MCC9: < 7 MB/evt; months → weeks of processing time)*
- These are not tweaks

Plan for Reducing Systematic Uncertainties

- uncertainty table from ν_μ CC inclusive cross section measurement (arXiv:1905.09694)

Source of Uncertainty	Relative Uncertainty
Beam Flux	12.2
Cross Section Modelling(*)	3.9
Detector Response	16.2
POT Counting	2.0
Dirt Background	10.9
Cosmics (Corsika)	4.1
Cosmic (data)	0.7
MC Statistics	0.2
Stat	1.4
Total	23.8

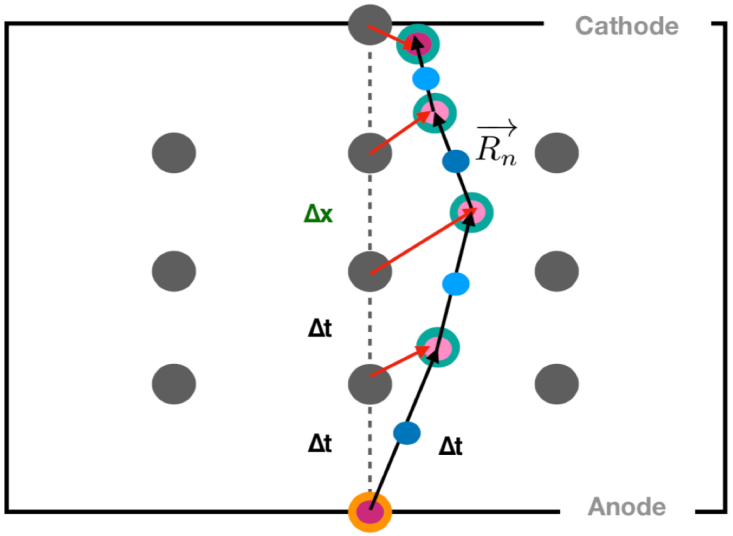
dominated by uncertainty in induced charge effects (13%); and E-field effects (see next slide)

CRT & improved reconstruction will help reduce out of detector backgrounds

will be reduced with use of cosmic data overlays

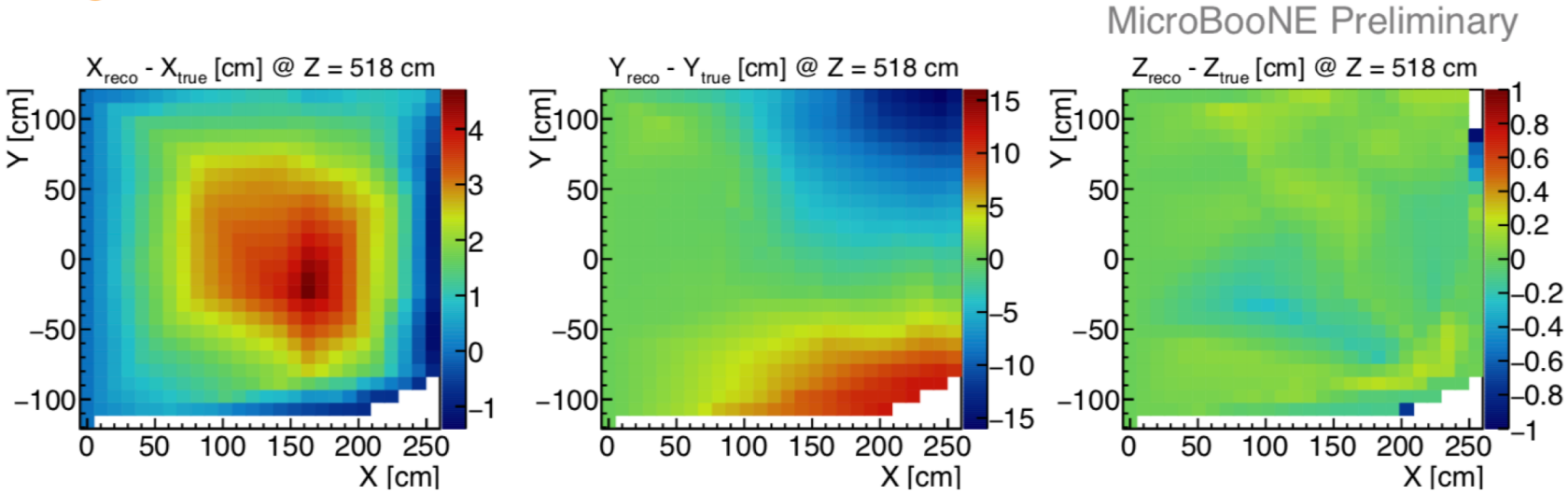
MicroBooNE public note #1055

Data-Driven Electric Field Maps



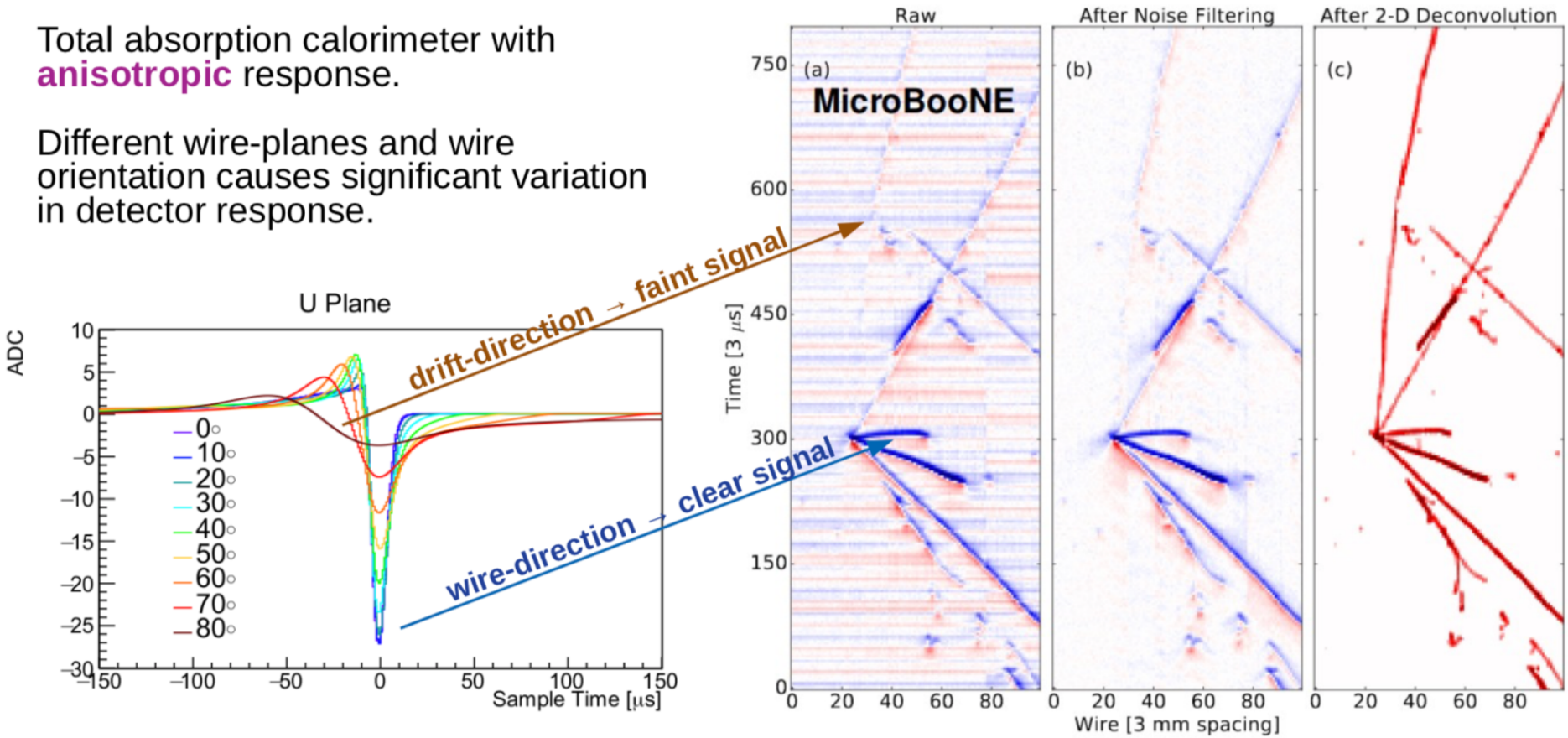
- we are no longer using simulation for mapping the electric field in MicroBooNE
- this is new in MCC9 and will reduce space charge uncertainties in MicroBooNE
- public note on UV laser produced as input to DUNE Technical Design Report (TDR)

distortion map using laser data



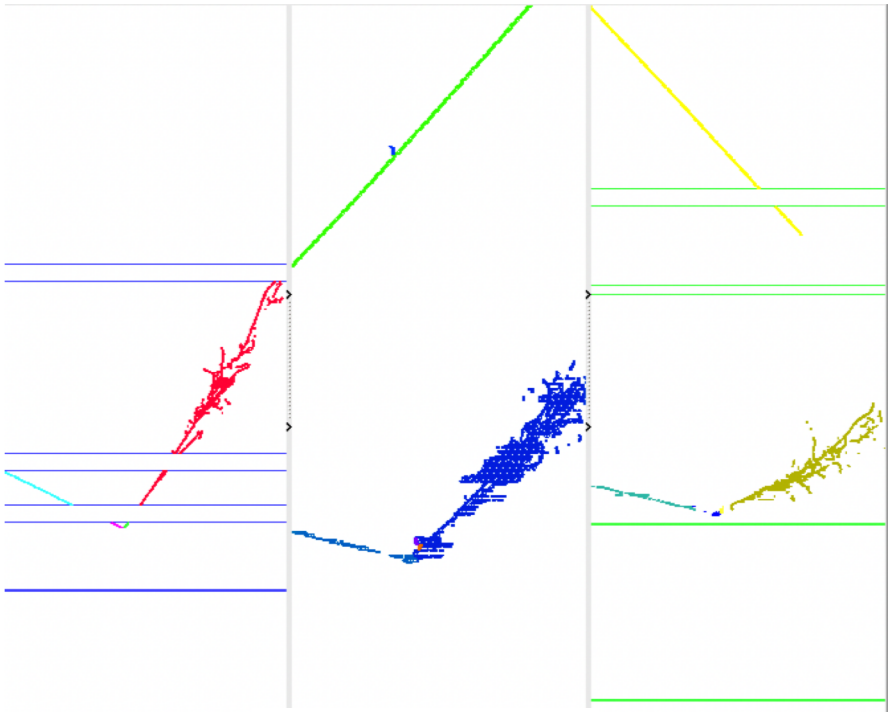
MCC9

- extensive development of advanced techniques for noise filtering and signal processing (JINST 12, P08003 (2017), JINST 13, P07006 (2018), JINST 13, P07007 (2018))



- with proper de-convolution, are able to pick out more detail especially in induction planes; clarity is better with improved signal processing

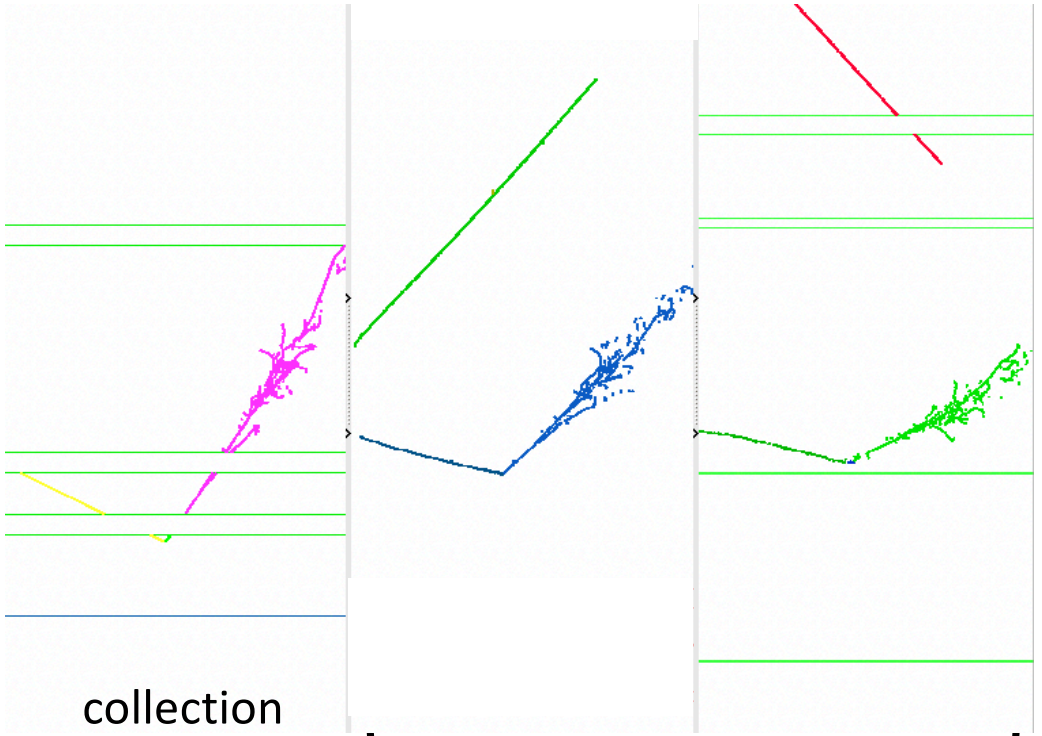
MCC8



collection plane

induction planes

MCC9



collection plane

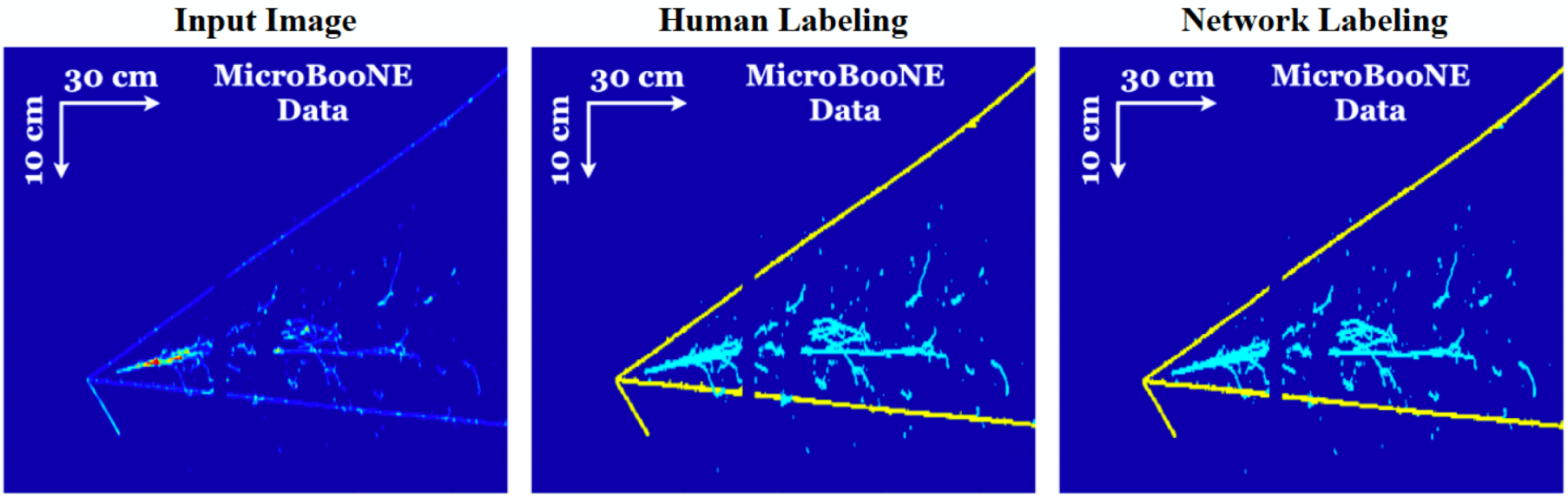
induction planes

SSNet Hit Tagging

PRD 99, 092001 (2019)

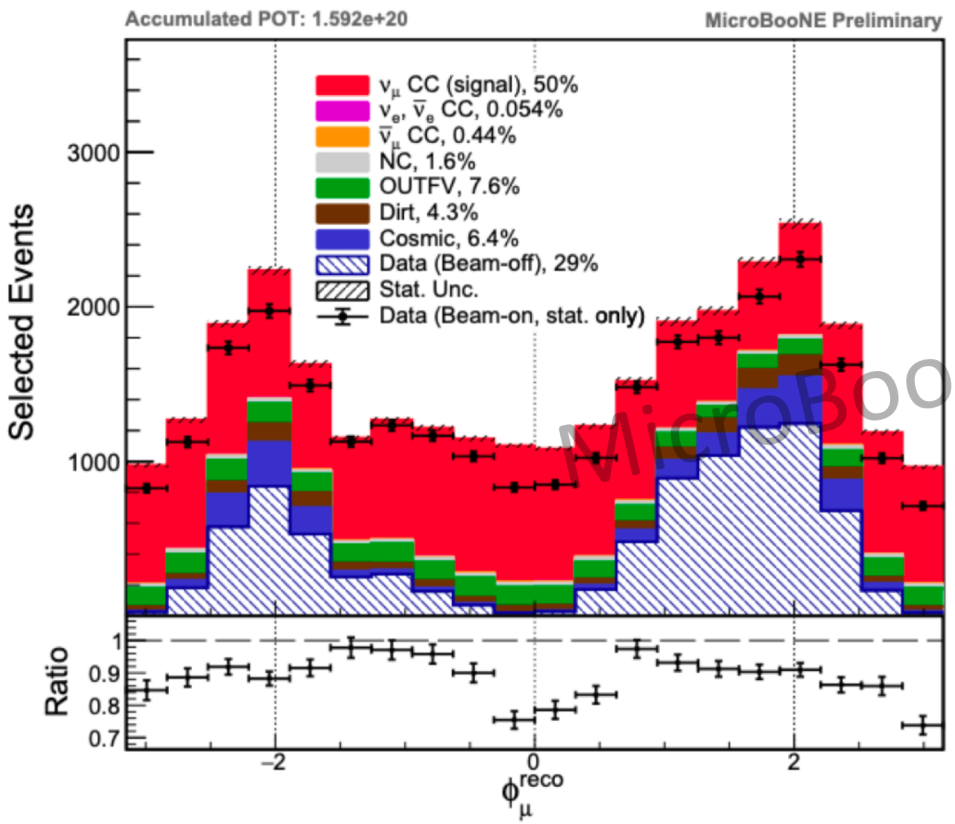
DOE Science highlight
Jan 2019

- separate tracks (yellow) and showers (cyan) to aid in downstream reconstruction
- validated in data with stopping muons and CC π^0 events
- disagreement between network and human labeling at the 2.5% level; data/MC is consistent

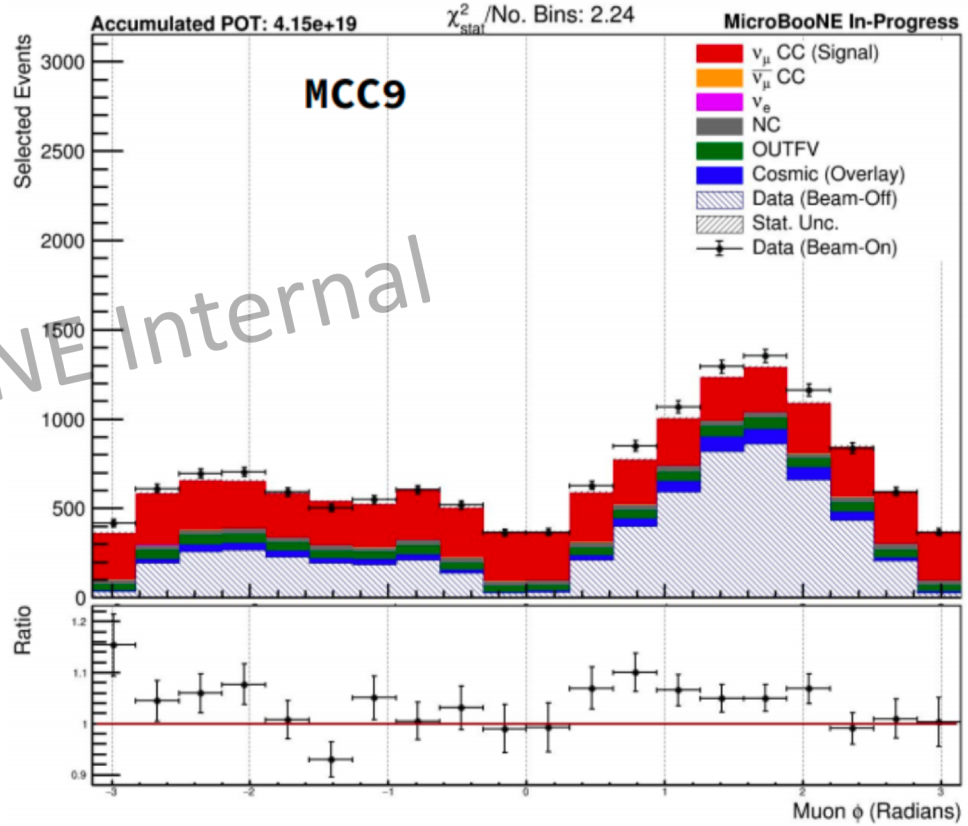


ν_μ CC Inclusive Analysis

MCC8



MCC9

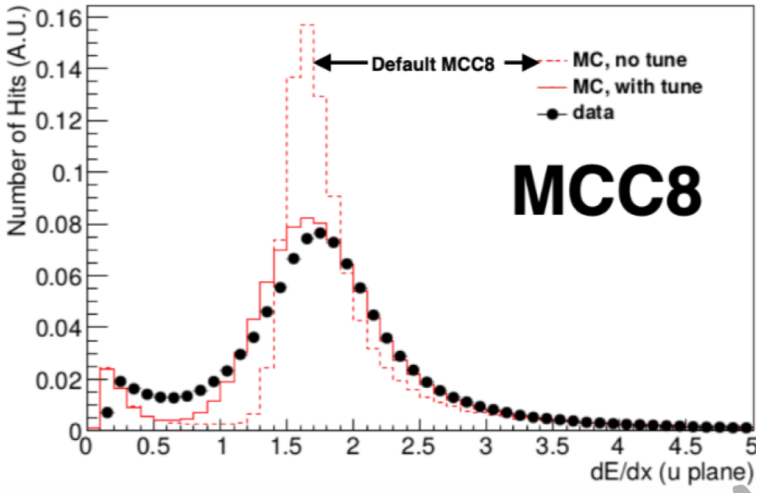


- improved data/MC agreement in drift direction due to improved signal processing

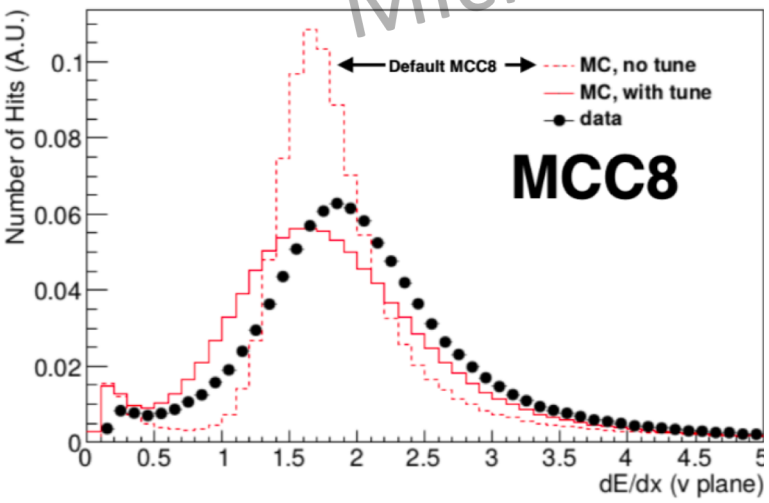
dE/dx

- large data/MC disagreement in MCC8 → adhoc modeling done to try and reproduce observed shape
- with 2D de-convolution, agreement is much better in MCC9 in modeling low level signals
- allows us to make more use of induction planes

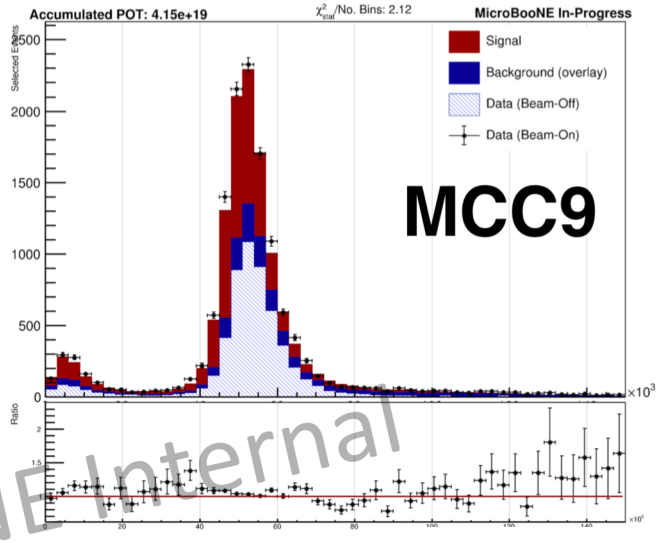
MCC8



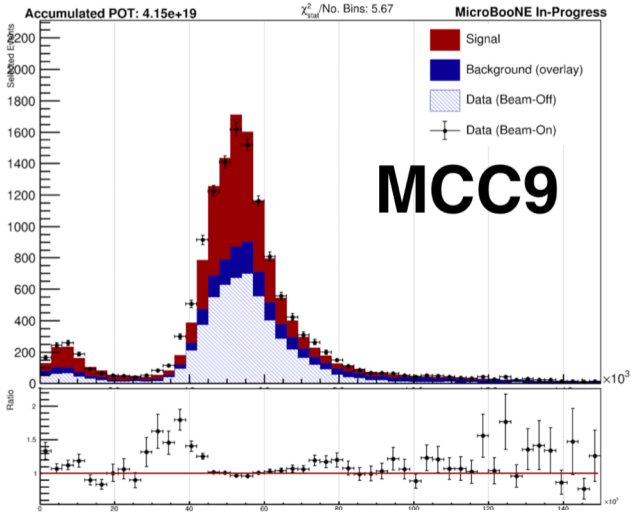
(a)



MCC9

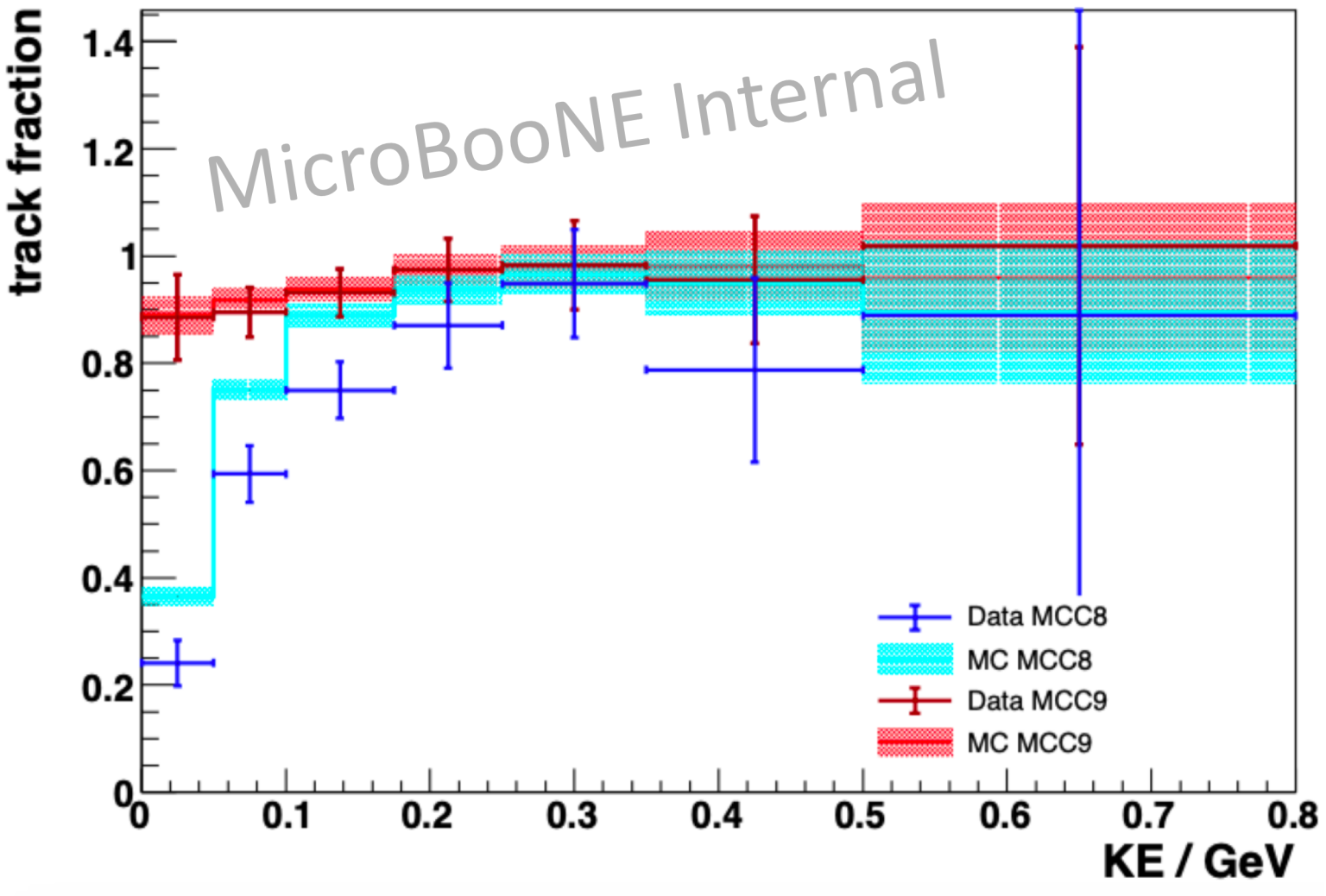


dQ/dx (U plane)



dQ/dx (V plane)

Proton Reconstruction: much better at proton ID at low energies → better hit finding efficiency, better pattern recognition, better data/MC agreement → puts it all together!



Physics Program in 2019-2020

- Get out our first low energy excess results
  - Crucial add'l supporting work that is needed and in progress
    - comprehensive calibration paper
    - trigger efficiency paper
    - scintillation light yield paper
    - electric field paper (using cosmics and laser)
  - Putting the result in context
    - if we confirm MiniBooNE, what is the nature of the excess?
    - is it electrons or photons?

Physics Program Beyond 2020

MicroBooNE's publication plans …

Low Energy Excess
- Low Energy Excess (LEE) update(s)
  → depends on what we see
- MicroBooNE ν_μ/ν_e fitting method
- joint analyses with SBN

Astroparticle Physics and Exotics
- heavy sterile neutrino search in BNB
- heavy sterile neutrino search in NuMI
- supernova neutrino readout stream
- dark tridents (e^+e^- final states)

Detector Physics
- calibrations (long term time dependence)
- scintillation light yields & triggering
- electric field maps (laser + cosmics)
- diffusion
- Recombination
- Ar^{39}

Neutrino Cross Sections
- updated CC π^0
- updated CC inclusive
- CC Np
- CC 1p
- CC Np
- CC 0π (MiniBooNE-like)
- NuMI ν_e
- NC elastic
- NC π^0
- CC π^+
- CC coherent π^+
- kaon production
- NuMI KDAR
- transverse kinematics

Reconstruction
- updated π^0 reconstruction
- updated Michel e^-
- flash-track matching
- many-to-many flash matching
- CRT-TPC matching
- Wire Cell imaging
- PMT reconstruction
- MeV activity in a LAr TPC
- cosmic-correlated activity
- data-driven reconstruction performance validation
- Deep Learning advances

MicroBooNE Collaboration

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Davidson College: B. Eberly

Fermilab: S. Berkman, D. Caratelli, R. Castillo Fernandez, F. Cavanna, G. Cerati, K. Duffy, S. Gardiner, E. Gramellini, H. Greenlee, C. James, W. Ketchum, M. Kirby, T. Kobilarcik, S. Lockwitz, A. Marchionni, S. Marcocci, T. Mohayai, O. Palamara, Z. Pavlovic, J.L. Raaf, A. Schukraft, E. Snider, P. Spentzouris, M. Stancari, J. St. John, T. Strauss, M. Toups, S. Wolbers, M. Wospakrik, W. Wu, T. Yang, G.P. Zeller*, J, Zennamo

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Lancaster University: A. Blake, D. Devitt, J. Nowak

Los Alamos: E-C. Huang, W.C. Louis, T. Thornton, R. Van de Water

Manchester: V. Basque, A. Bhanderi, J. Evans, O. Goodwin, P. Green, P. Guzowski, N. McConkey, K. Mistry, D. Porzio, S. Söldner-Rembold, A.M. Szelc

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University of Minnesota: A. Furmanski

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New Mexico State University: V. Papavassiliou, S.F. Pate, L. Ren, S. Sword-Fehlberg

Otterbein University: N. Tagg

University of Oxford: G. Barr, W. Van De Pontseele

University of Pittsburgh: S. Dytman, L. Jiang, D. Naples, V. Paolone

Pacific Northwest National Laboratory: E. Church

Rutgers: A. Mastbaum

St. Catherine University: H. Rogers

Saint Mary's University of Minnesota: P. Nienaber

SLAC: M. Convery, L. Domine, R. Itay, L. Rochester, K. Terao, Y-T. Tsai, T. Usher

South Dakota School of Mines & Technology : A. Fiorentini, D. Martinez, J. Rodriguez Rondon

Syracuse University: A. Bhat, P. Hamilton, G. Pulliam, M. Soderberg

Tel Aviv University: E. Cohen, E. Piasetzky

University of Tennessee, Knoxville: S. Gollapinni, A. Mogan, W. Tang, G. Yarbrough

University of Texas at Arlington: J. Asaadi, Z. Williams

Tufts University: K. Mason, J. Mills, R. Sharankova, T. Wongjirad

Virginia Tech: L. Gu, C. Mariani, M. Murphy, V. Pandey

University of Warwick: J. Marshall

Yale University: S. Balasubramanian, L. Cooper-Troendle, B.T. Fleming*, D. Franco, J.H. Jo, B. Russell, G. Scanavini

since last PAC,
we have added
7 new institutions:

- UCSB
- Granada
- Minnesota
- Rutgers
- St. Catherine
- SDSMT
- Warwick

170 collaborators
38 institutions
41 postdocs
47 grad students (30% international)

*spokespeople

MicroBooNE Postdoc Placement

Name	Position taken after MicroBooNE postdoc
Corey Adams	Assistant Computer Scientist, Argonne Leadership Computing Facility
Roberto Acciarri	Applications Physicist, Fermilab
Jonathan Asaadi	Assistant Professor, Univ of Texas, Arlington
Martin Auger	DAQ Software Engineer, Medical Equipment Company, Bern
Matt Bass	Principle Data Scientist, White Ops
Andy Blake	Lecturer, Lancaster University
Ben Carls	Data Scientist, ComEd
Eric Church	Scientist, PNNL
Michael Cooke	AAAS Science & Technology Fellow, DOE
Brandon Eberly	Assistant Professor, Davidson College
Andy Furmanski	Assistant Professor, University of Minnesota
Sowjanya Gollapinni	Assistant Professor, Univ of Tennessee, Knoxville
Nick Graf	Data Scientist, Allstate
Roxanne Guenette	Assistant Professor, Harvard
Leonidas Kalousis	Research Associate, Vrije Universiteit Brussel
Teppei Katori	Lecturer, Queen Mary University London
Georgia Karagiorgi	Assistant Professor, Columbia University
Wes Ketchum	Associate Scientist, Fermilab
Bryce Littlejohn	Assistant Professor, IIT
Xiao Luo	Assistant Professor, UC Santa Barbara
John Marshall	Lecturer, University of Warwick
David Martinez	Assistant Professor, South Dakota School of Mines & Technology
Andy Mastbaum	Assistant Profressor, Rutgers
David McKee	Assistant Professor, Missouri Southern State
Tia Miceli	Data Scientist, Allstate
Mike Mooney	Assistant Professor, Colorado State University
Zarko Pavlovic	Applications Physicist, Fermilab
Hannah Rogers	Assistant Professor, St. Catherine's University
Anne Schukraft	Associate Scientist, Fermilab
Josh Spitz	Assistant Professor, University of Michigan, Ann Arbor
Jason St. John	Applications Physicist, Fermilab
Thomas Strauss	Associate Scientist, Fermilab
Andrzej Szelc	Lecturer, University of Manchester & Royal Society Univ Research Fellow
Kazu Terao	Associate Staff Scientist, SLAC
Matt Toups	Associate Scientist, Fermilab
Yun-Tse Tsai	Associate Staff Scientist, SLAC
Serhan Tufanli	CERN Fellowship
Athula Wickremasinghe	Research Associate, Fermilab Accelerator Division
Kevin Wierman	Machine Learning Scientist, Blue Origin
Taritree Wongjirad	Assistant Professor, Tufts University
Tingjun Yang	Associate Scientist, Fermilab
Joseph Zennamo	Wilson Fellow, Fermilab

- ~80% of former postdocs remain in particle physics (35/42)
- ~70% have remained on MicroBooNE
- faculty placements in 2018-2019
  - Brandon Eberly, Davidson
  - Andy Furmanski, Minnesota
  - Xiao Luo, UCSB
  - John Marshall, Warwick
  - David Martinez, SDSM&T
  - Andy Mastbaum, Rutgers
  - Hannah Rogers, St Catherines
  - Serhan Tufanli, CERN Fellowship
  - Joseph Zennamo, Wilson Fellow

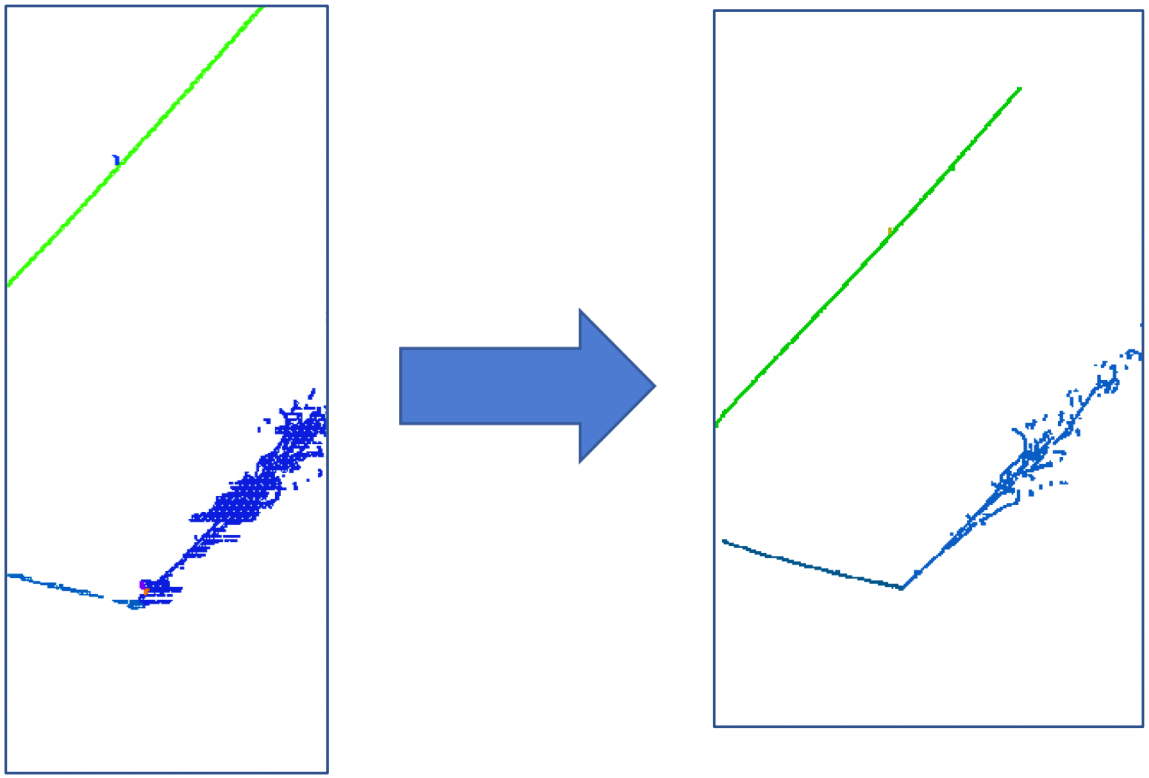
MicroBooNE Grad Student Placement

Name	Year of PhD	Position taken after PhD
Christina Ignarra	2014	SLAC postdoc
Ben Jones	2015	UT Arlington faculty
David Kaleko	2017	Senior Data Scientist, Motorola
Jeremy Hewes	2017	U Cincinnati postdoc
David Caratelli	2018	Fermilab postdoc
Ariana Hackenburg	2018	Data Scientist, Wayfair
Ryan Grosso	2018	Senior Data Scientist, Spark Beyond
Jessica Esquivel	2018	Fermilab postdoc
Aleena Rafique	2018	Argonne postdoc
Katherine Woodruff	2018	UT Arlington postdoc
Marco Del Tutto	2019	Lederman Fellow, Fermilab
Roberto Soleti	2019	Chamberlain Fellow, LBNL
Matthias Luethi	2019	Medical Physics postdoc, Switzerland
Damian Goeldi	2019	Carleton University postdoc
Adam Lister	2019	UW Madison postdoc
Varuna Meddage	2019	University of Florida postdoc
Vic Genty	2019	Data Scientist, Spark Beyond
Colton Hill	2019	Chiba University postdoc
Brooke Russell	exp 2019	Chamberlain Fellow, LBNL

- out of 19 former MicroBooNE graduate students, 14 remain in particle physics and 5 have private sector jobs

We have a very good team. We are on track on many fronts…

MCC8



MCC9

MCC9 campaign incredibly impactful for us and incredibly impactful for SBN and DUNE
We are seeing all the ripple effects downstream

We ask for your endorsement of FY2020 running