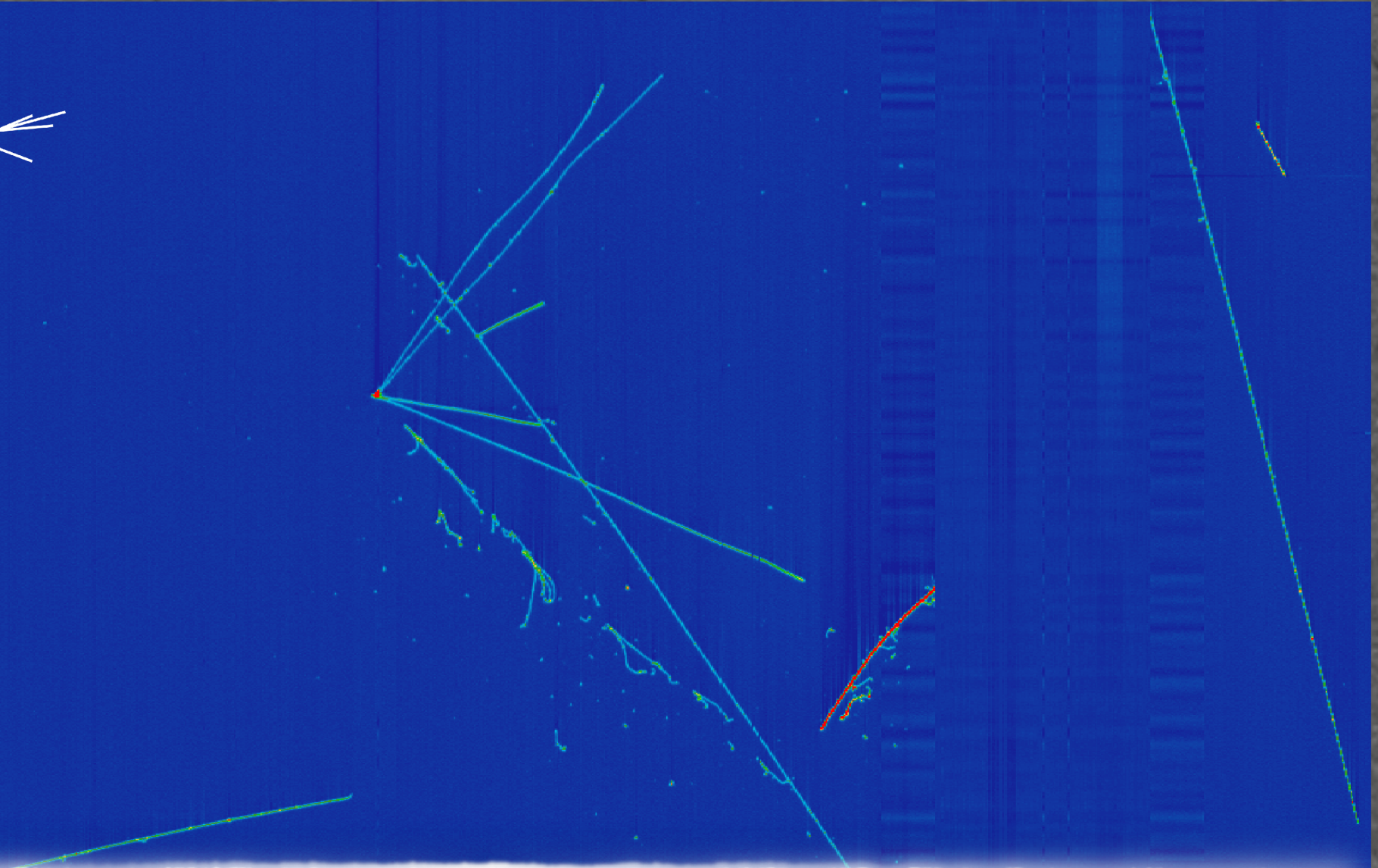# Characterizing LArTPC Detector Performance with MicroBooNE

μBooNE
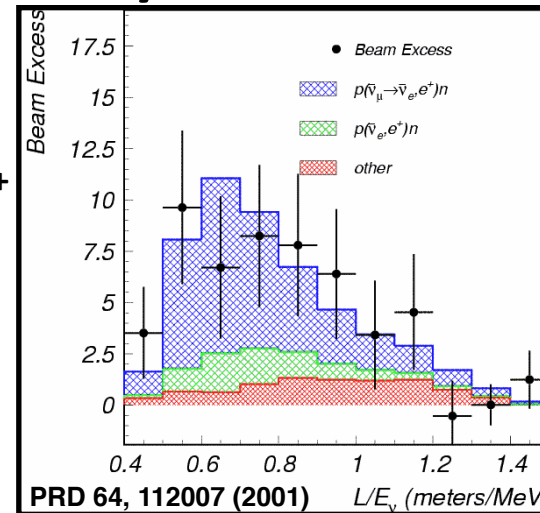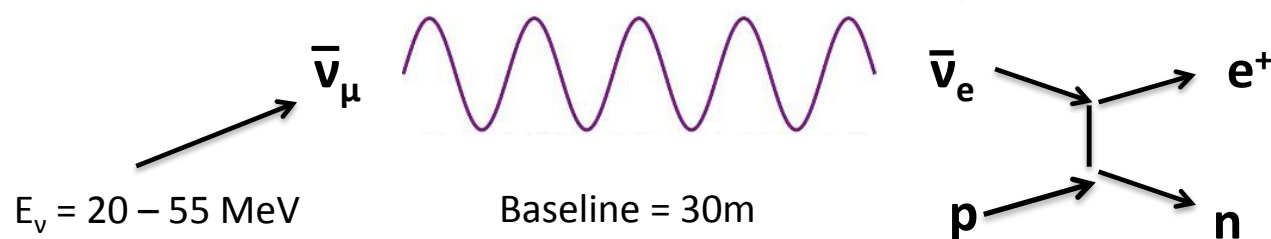
Jyoti Joshi
Brookhaven National Laboratory

DPF 2017, Fermilab, July 31st, 2017
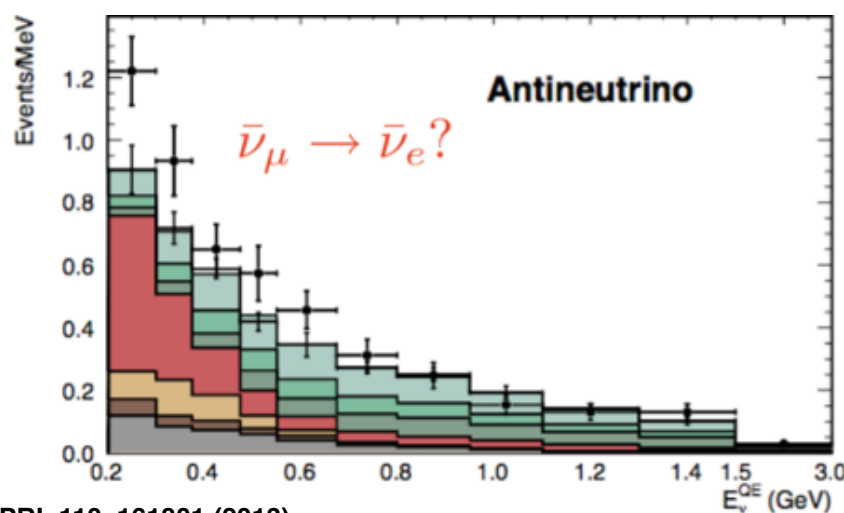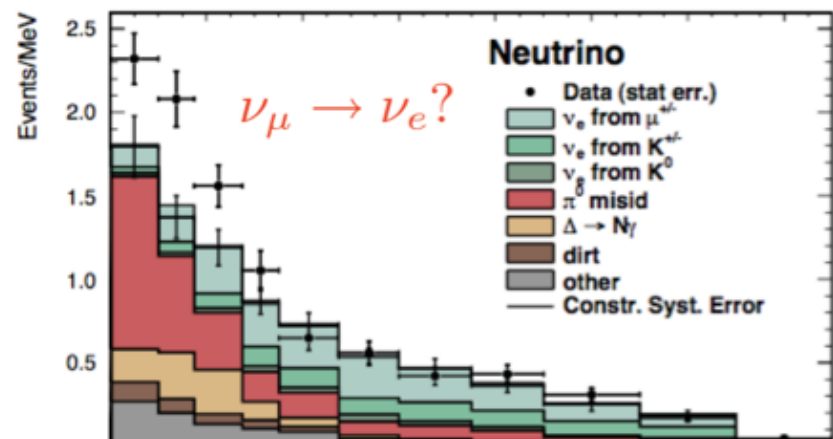
LSND (Liquid Scintillator Neutrino Detector):

Looking for $\bar{\nu}_e$ appearance signal in $\bar{\nu}_\mu$ beam

$\bar{\nu}_\mu$

$E_\nu = 20 - 55$ MeV

Baseline = 30m

$\bar{\nu}_e$ → e^+

p → n

PRD 64, 112007 (2001)

Observed $87.9 \pm 22.4 \pm 6.0$ events
above background
Oscillation Probability: 0.26%

Consistent with a Δm^2 on the order of 1 eV^2
(not consistent with 3 flavor picture)

MiniBooNE Result:

PRL 110, 161801 (2013)

Neutrino mode:
- Excess: 162.0 ± 47.8 (3.4σ)

Antineutrino mode:
- Excess: 78.4 ± 28.5 (2.8σ)

Combined:
- Excess: $240.3 \pm 34.5 \pm 53.6$
- **3.8σ significance**

Excess of low energy electromagnetic events in neutrino and antineutrino mode.

**But MiniBooNE can't differentiate between electrons and gammas!**

Physics Goals

* MiniBooNE low energy excess of electron-like events

* Cross-section measurement in ~1 GeV range

* Detector Physics

* Exotics and non-beam physics

Detector R&D

* Cold front end analog Electronics

* LAr fill without evacuation (gas argon purge)

* Challenges with near surface operation

* Data Handling

* UV laser calibration system
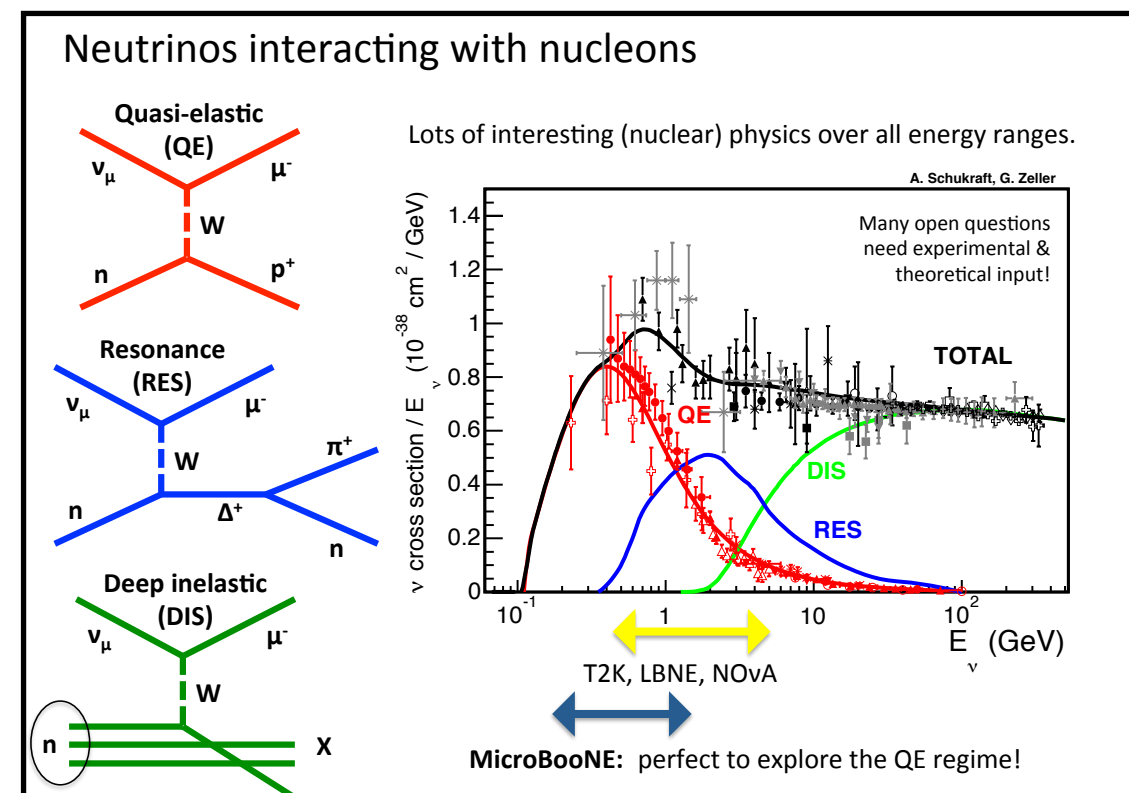
The Fermilab Neutrino Complex

Linac
Length: 150m
Proton Energy: 400 MeV

Booster
Circumference: 468m
Proton Energy: 8 GeV

Protons

Neutrinos

DUNE ν beam
(planned)

Main Injector
Proton Energy: 120 GeV
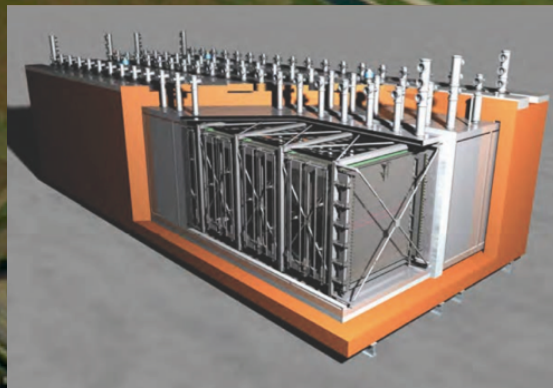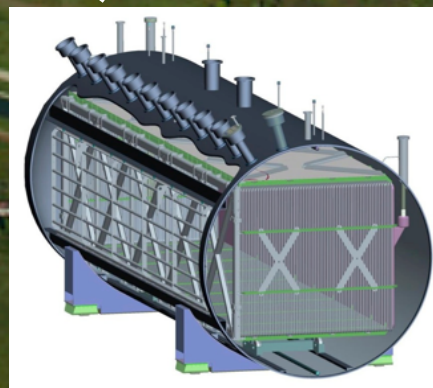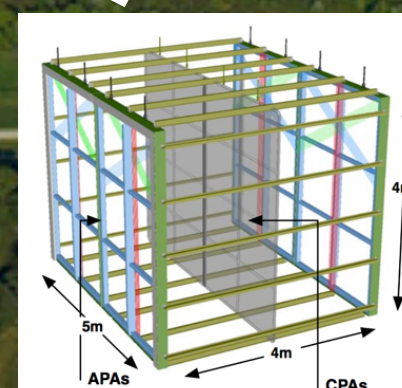
476 tons

85 tons

112 tons

ICARUS-T600

MicroBooNE

Short Baseline Near
Detector (SBND)

First detector to come online from the SBN Program!

* **Liquid Argon Time Projection Chamber:**

  • Three planes of wire at 3mm pitch
    - One Collection plane at 0° from vertical
    - Two induction planes at $\pm 60^o$
  • Total 8192 channels
  • 2.5 m drift length

* **Optical System:**

  • 32 cryogenic photomultiplier tubes (PMT)
  • LED based light injection system

* **UV Laser Calibration System**

* **External Muon Tagger System**

v beam

2.3 m

10.4m

2.5m

Drift

18" Sprayed Foam Insulation

Welded Removable End-Cap

HD Foam Saddles

PMTs

Anode Wires

HV Cathode

Drift
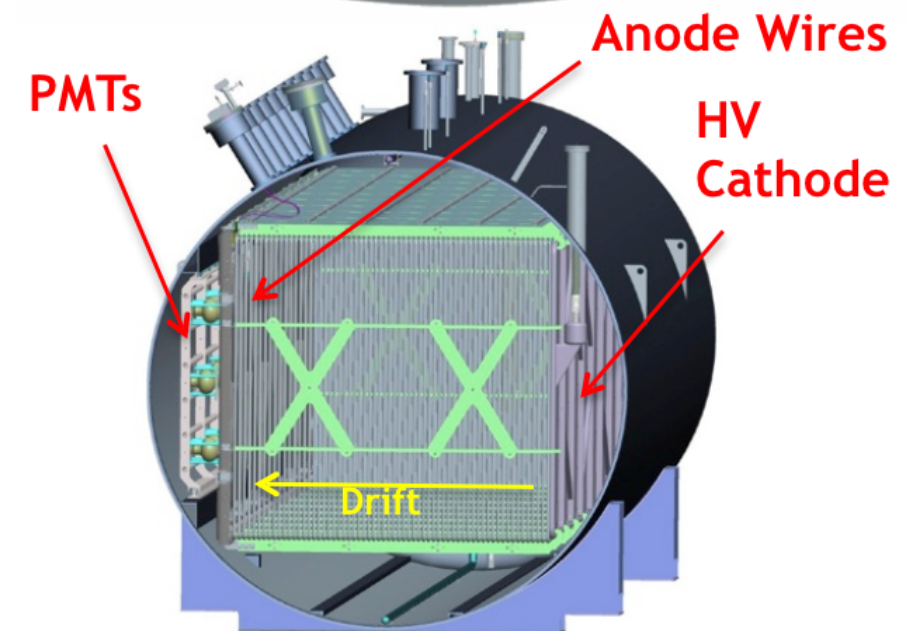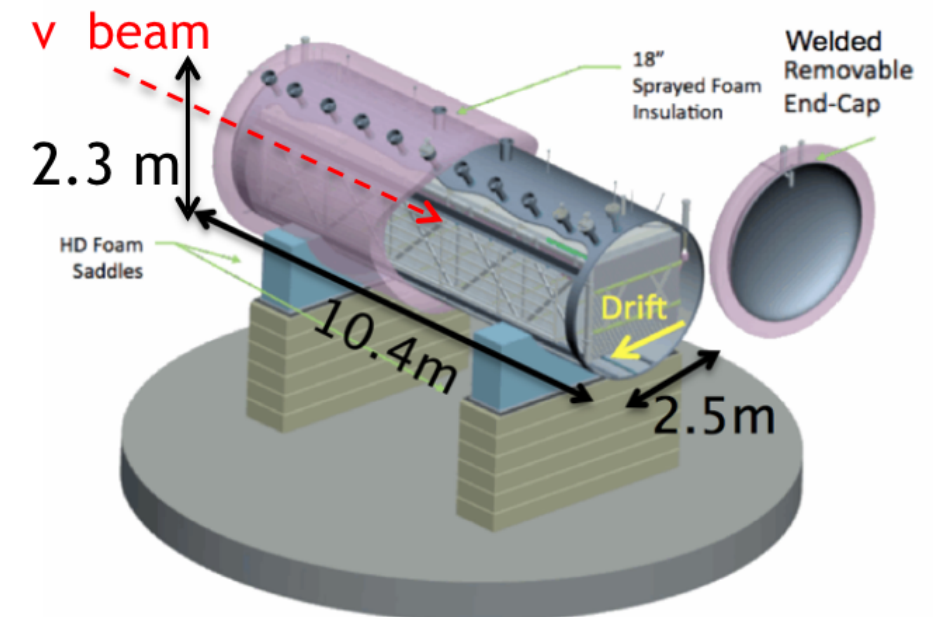
** 170 tons of purified LAr
(active mass ~85 tons)*

Excellent Resolution and Calorimetry!
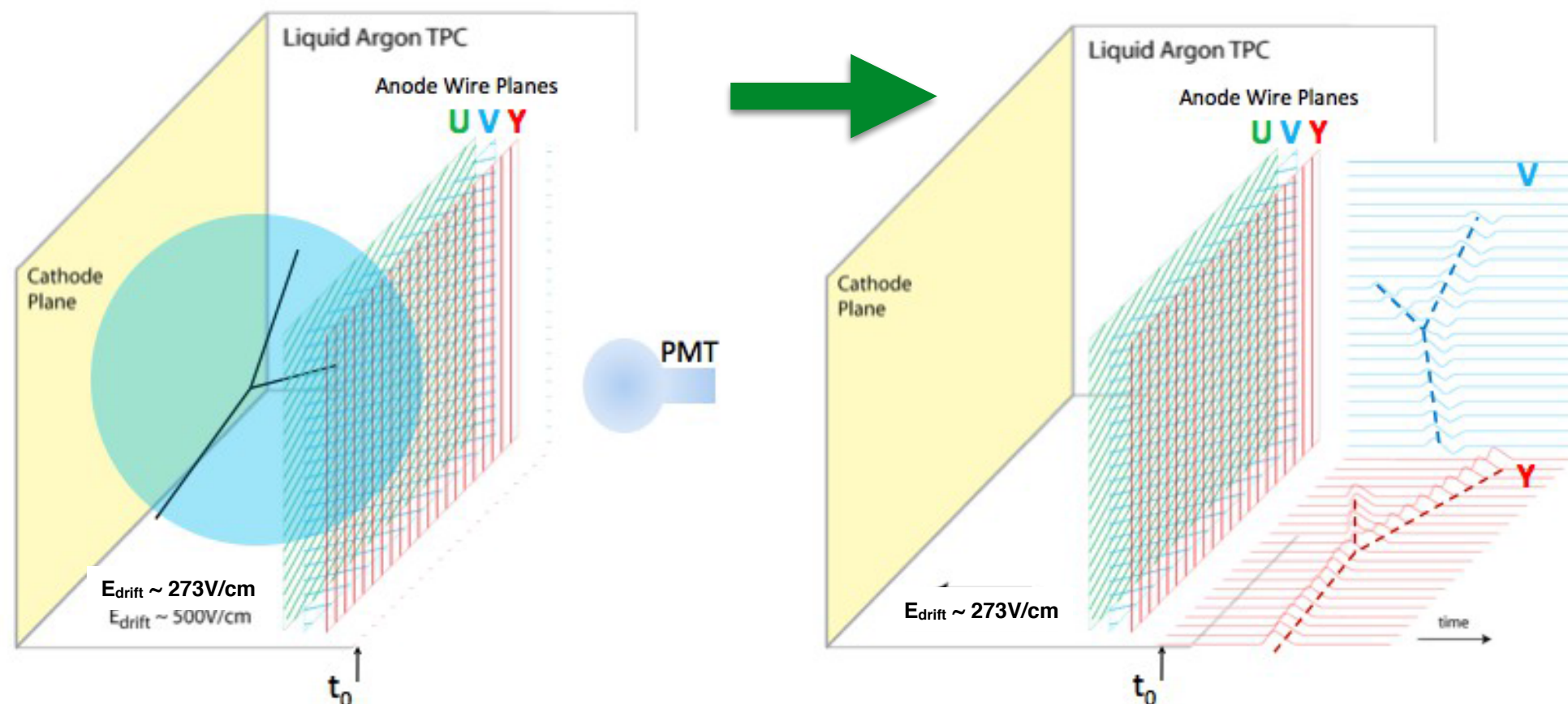
* Ionization electrons detected by a series of wire planes
  - Particle Identification, calorimetry and tracking

* Scintillation light collection system
  - Trigger and t_0 reconstruction

* Understand detector effects to develop LArTPC Technology

  - Essential for SBN and DUNE
  - Noise studies, wire response, energy scale, cosmic ray rate, space charge effects, e⁻ lifetime, diffusion etc.
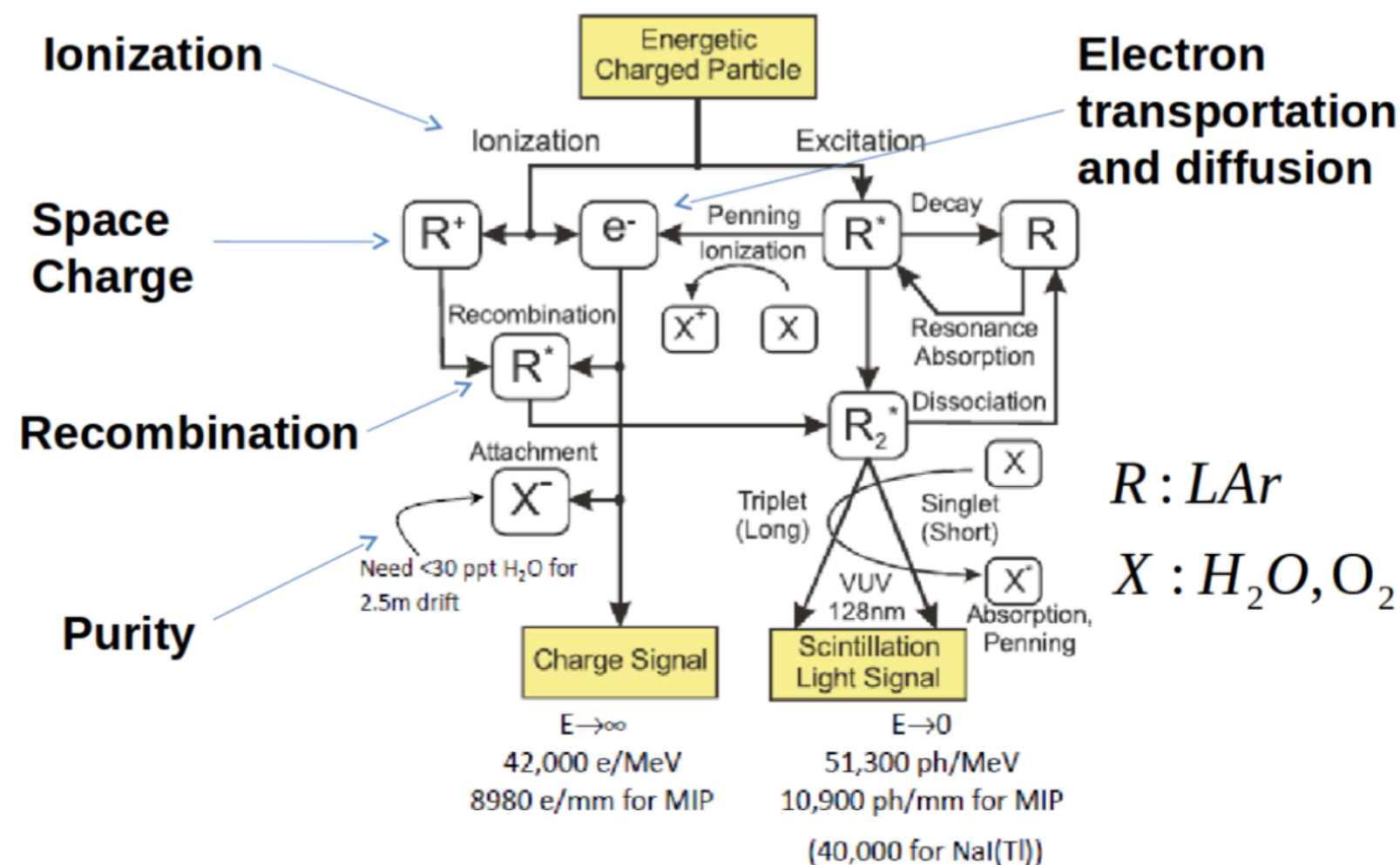
Ionization

Space Charge

Recombination

Purity

Electron transportation and diffusion

$R : LAr$

$X : H_2O, O_2$

Our primary focus of first results is to understand detector effects and develop robust calibration scheme for unbiased, precise determination of ionization charge

* Understand detector effects to develop LArTPC Technology

Next Talk by Roberto S. on Cosmic ray Reconstruction Efficiency in MicroBooNE
Talk by Brian K. on Signal Simulation and Processing in MicroBooNE TPC in Neutrino Parallel Session
Talk by Varuna M. on Electron Attenuation measurement in Neutrino Parallel Session

Poster by Brooke R. on Full TPC Signal and Noise Simulation in Poster session this evening
Poster by Jyoti J. on Drifted Charge Extraction in Single Phase LArTPCs in Poster session this evening
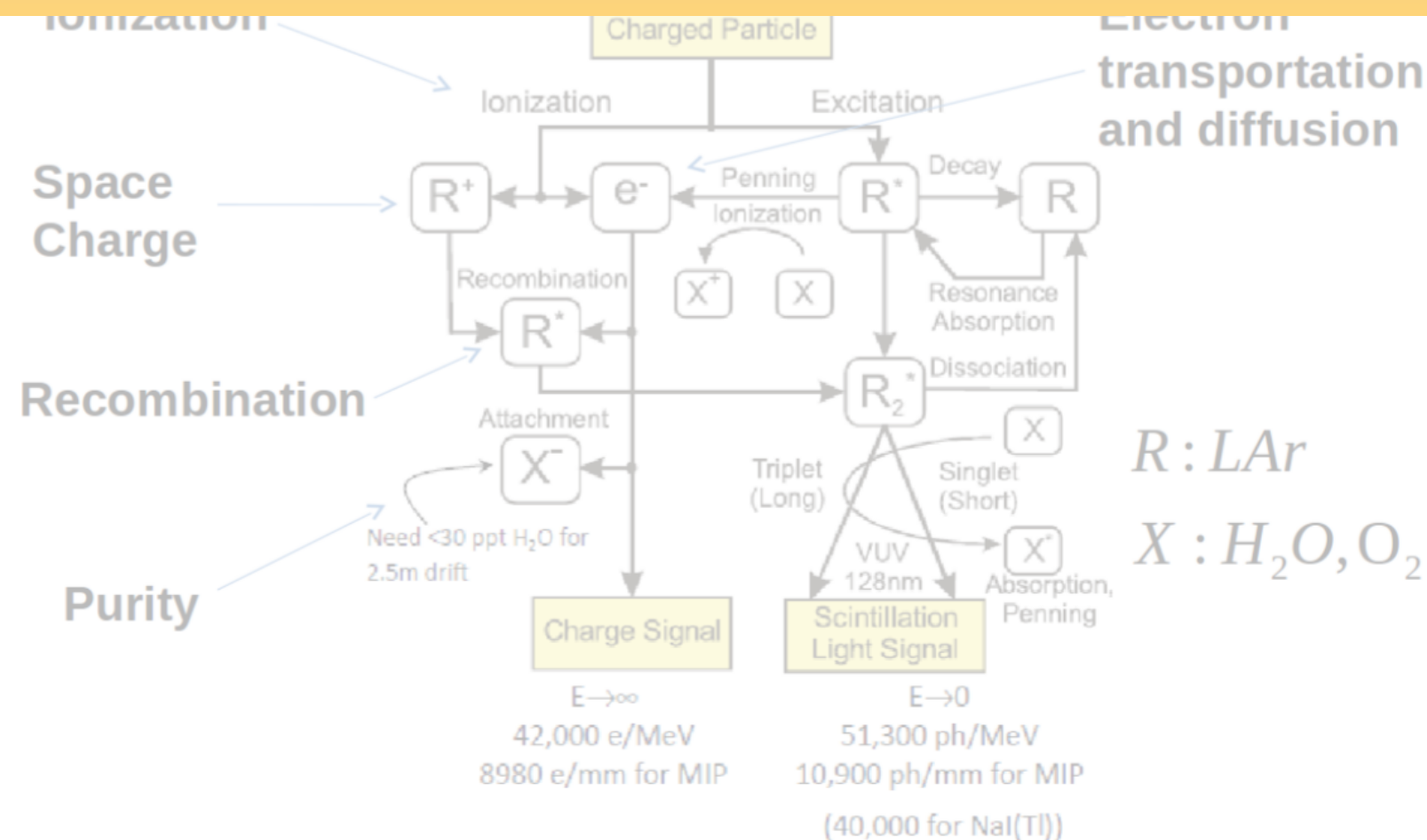
Our primary focus of first results is to understand detector effects and develop robust calibration scheme for unbiased, precise determination of ionization charge

$R : LAr$

$X : H_2O, O_2$
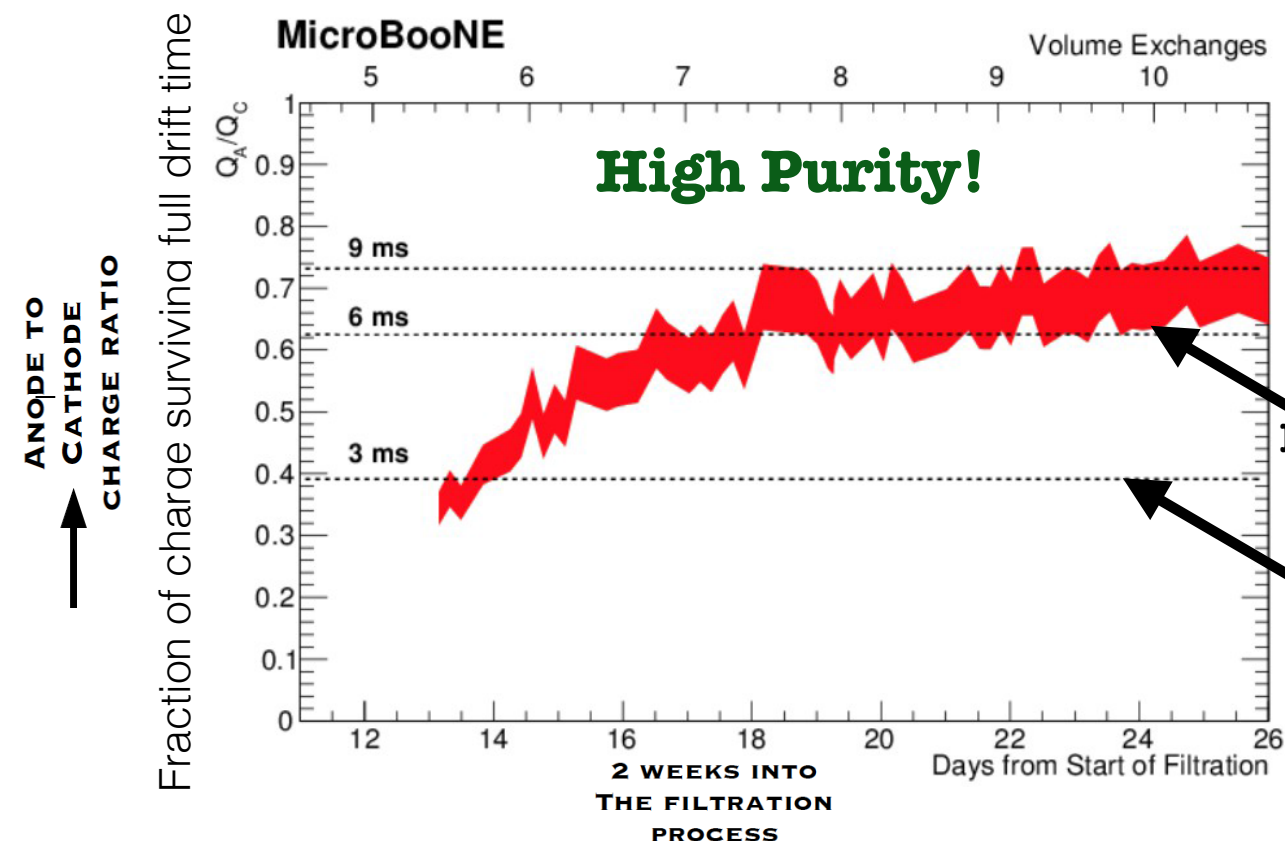
MicroBooNE-NOTE-1003-PUB.pdf

Electron lifetime, measured by purity monitors as the fraction of charge detected at its anode relative to its cathode, Q_A/Q_C
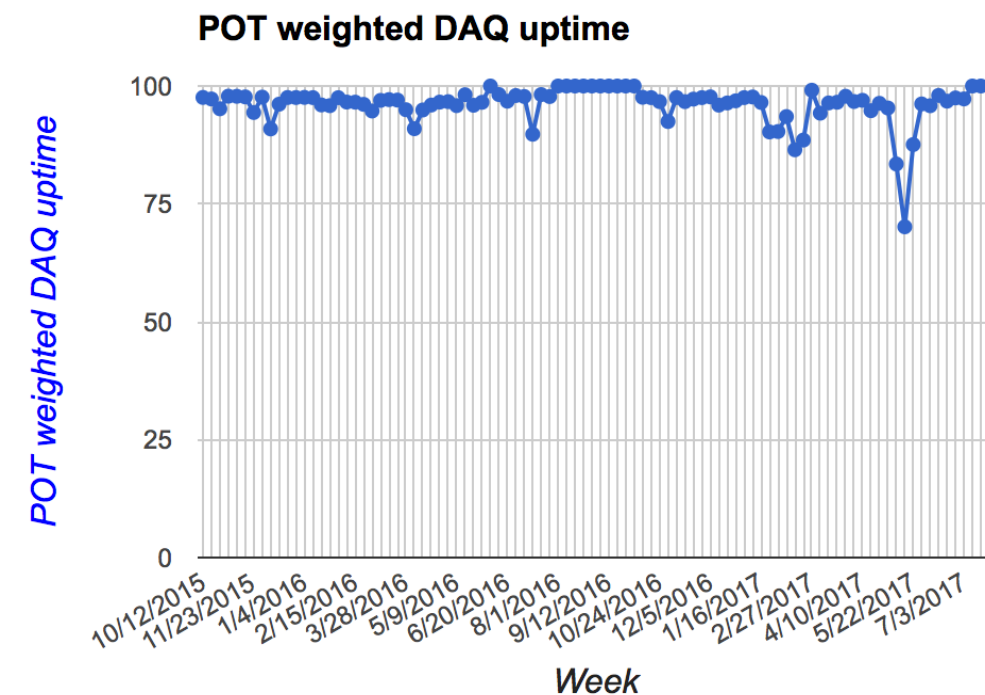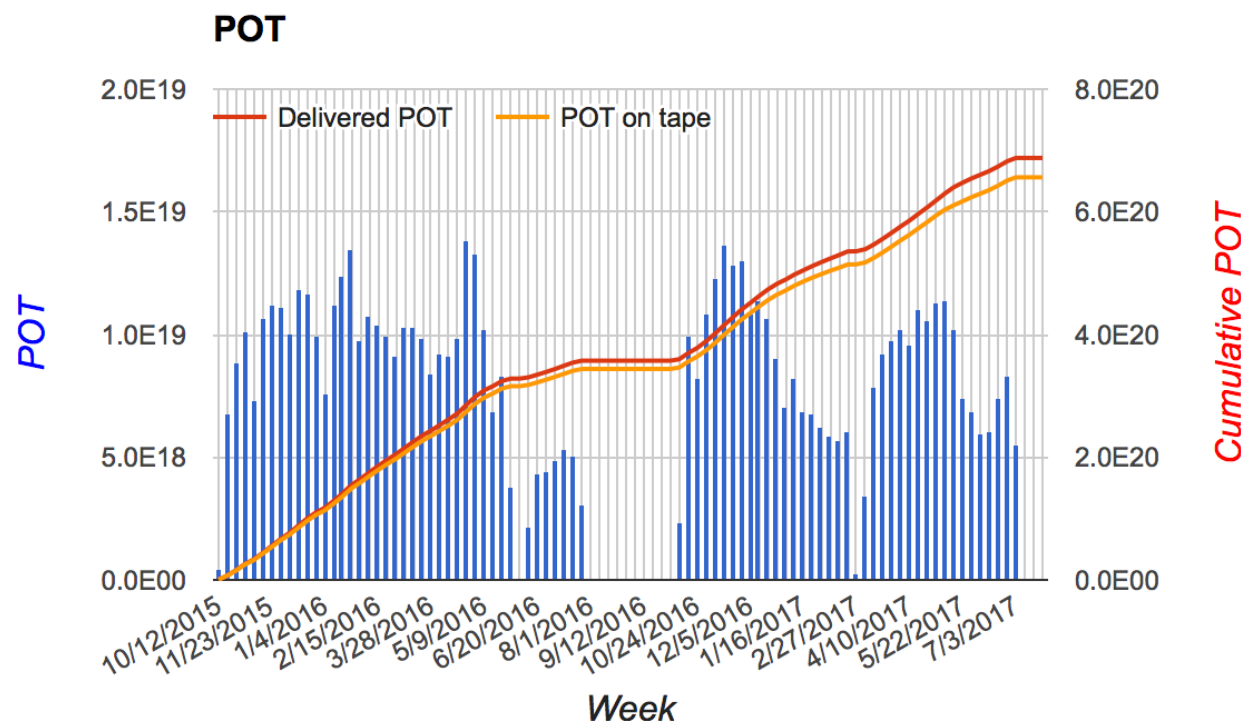
MicroBooNE DAQ and Fermilab Booster Neutrino beam are running extremely well!

During commissioning & first operations excess TPC noise sources were observed

- Low frequency noise from voltage regulator
- High Voltage power supply noise
- 900 kHz burst noise

Example of Excess Noise

Wire Noise Level in MicroBooNE
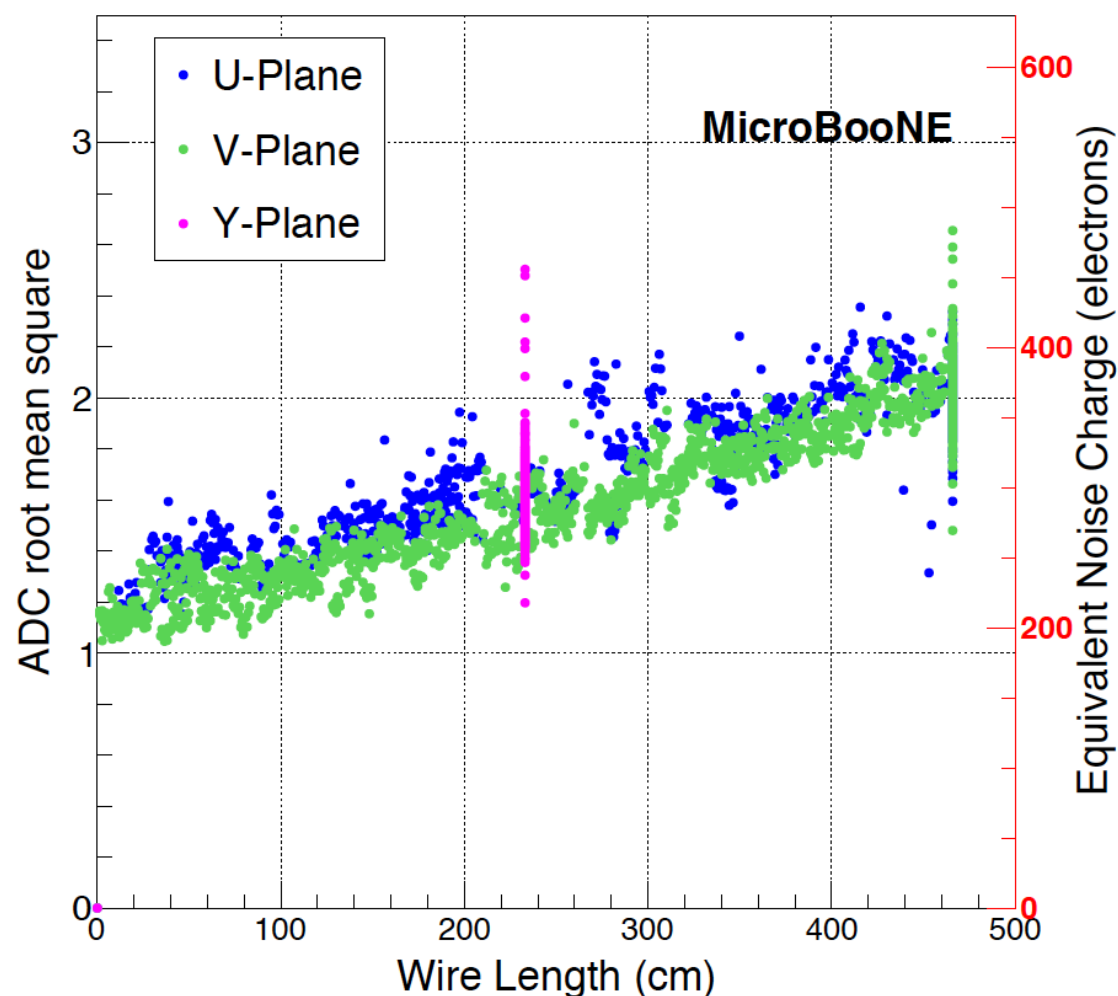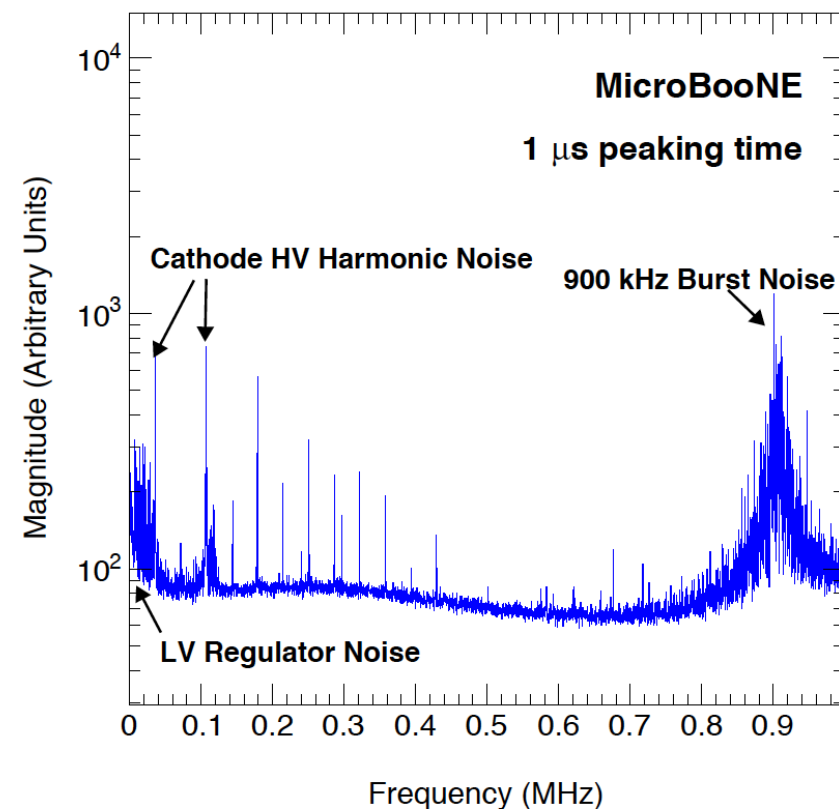
After offline noise filtering, noise levels agree with expectations and scale linearly with wire length (wire capacitance)

ENC < 400 e⁻

arXiv:1705.07341
Accepted by JINST!

10

PSNR

MicroBooNE — Before noise removal (a)

MicroBooNE — After noise removal (b)
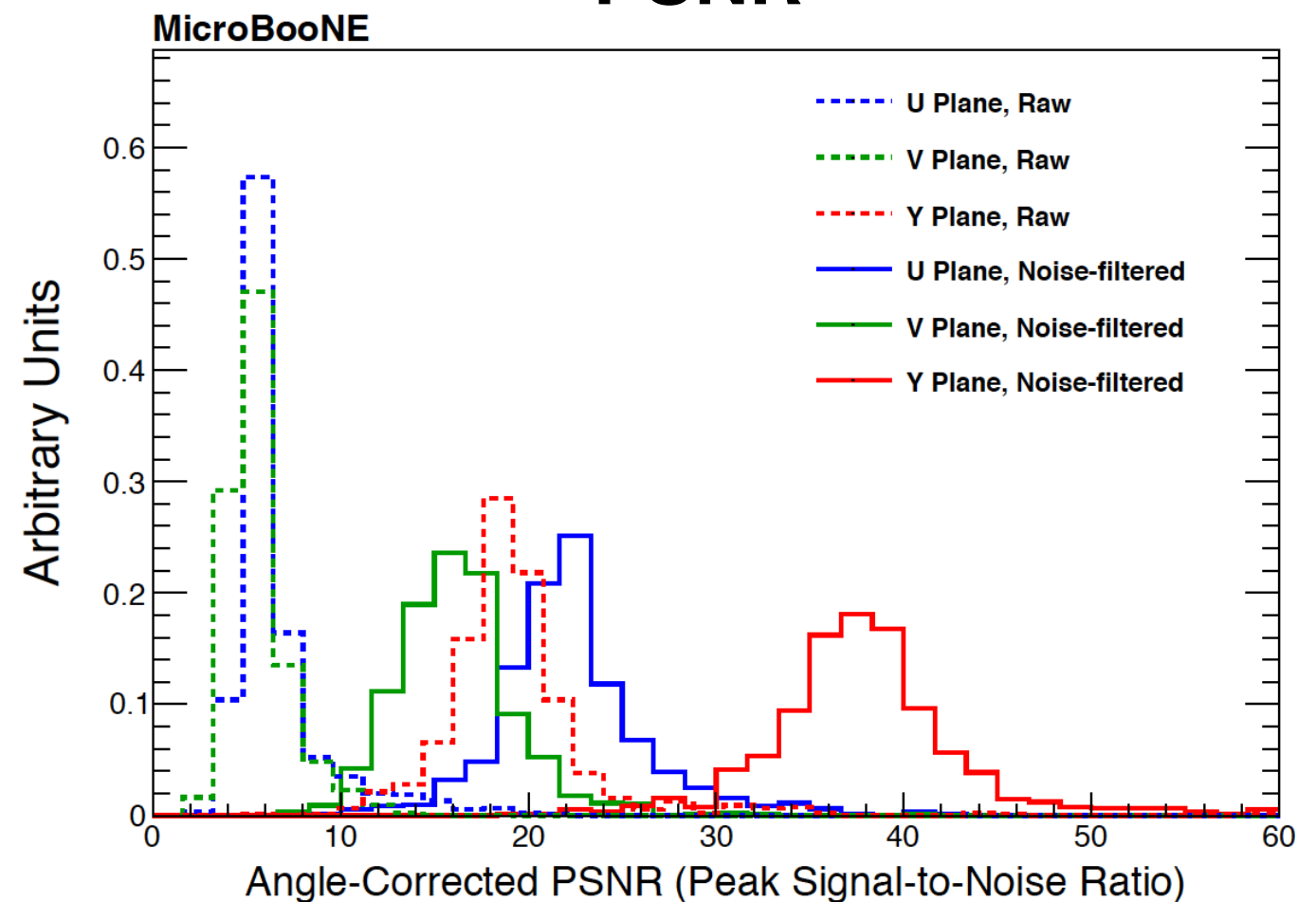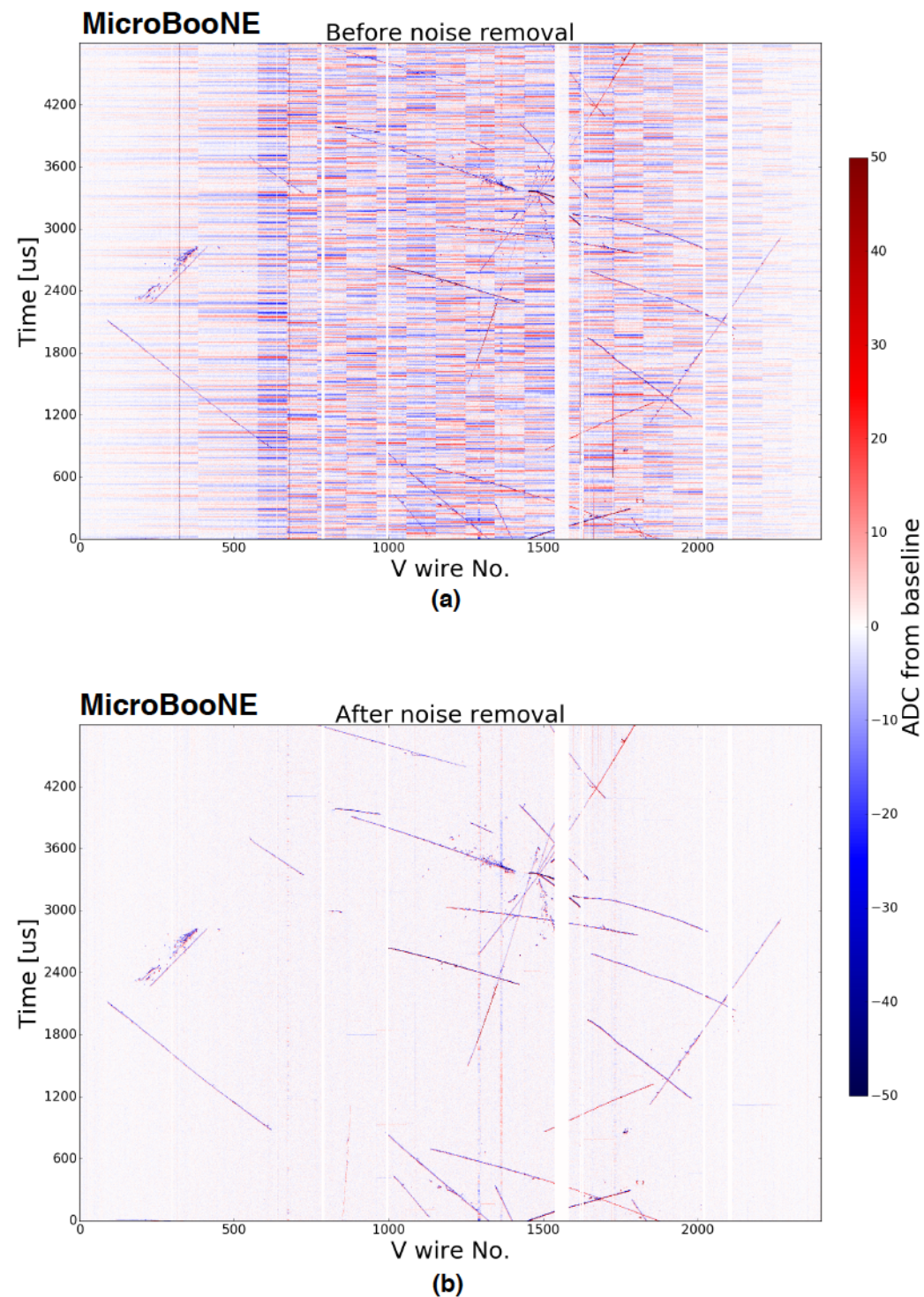
Waveform Type	U Plane PSNR	V Plane PSNR	Y Plane PSNR
Raw Data	6.6	5.7	19.5
After Noise Filtering	22.3	16.2	37.9

Software noise filter is applied which improves peak-signal-to-noise ratio by a factor of 2-3

LArTPC drifted charge extraction!

MicroBooNE-NOTE-1017-PUB.pdf
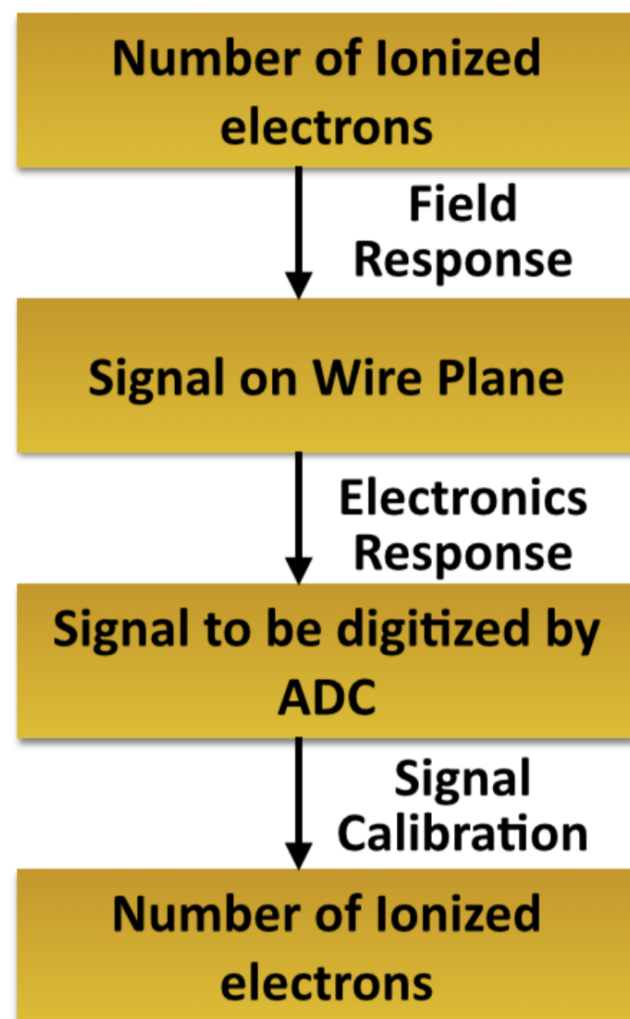
Challenges in TPC Signal Calibration:

* Noise Filtering
* Dynamic Induced Charge
* Field Response Calibration

Number of Ionized electrons

↓ Field Response

Signal on Wire Plane

↓ Electronics Response

Signal to be digitized by ADC

↓ Signal Calibration

Number of Ionized electrons
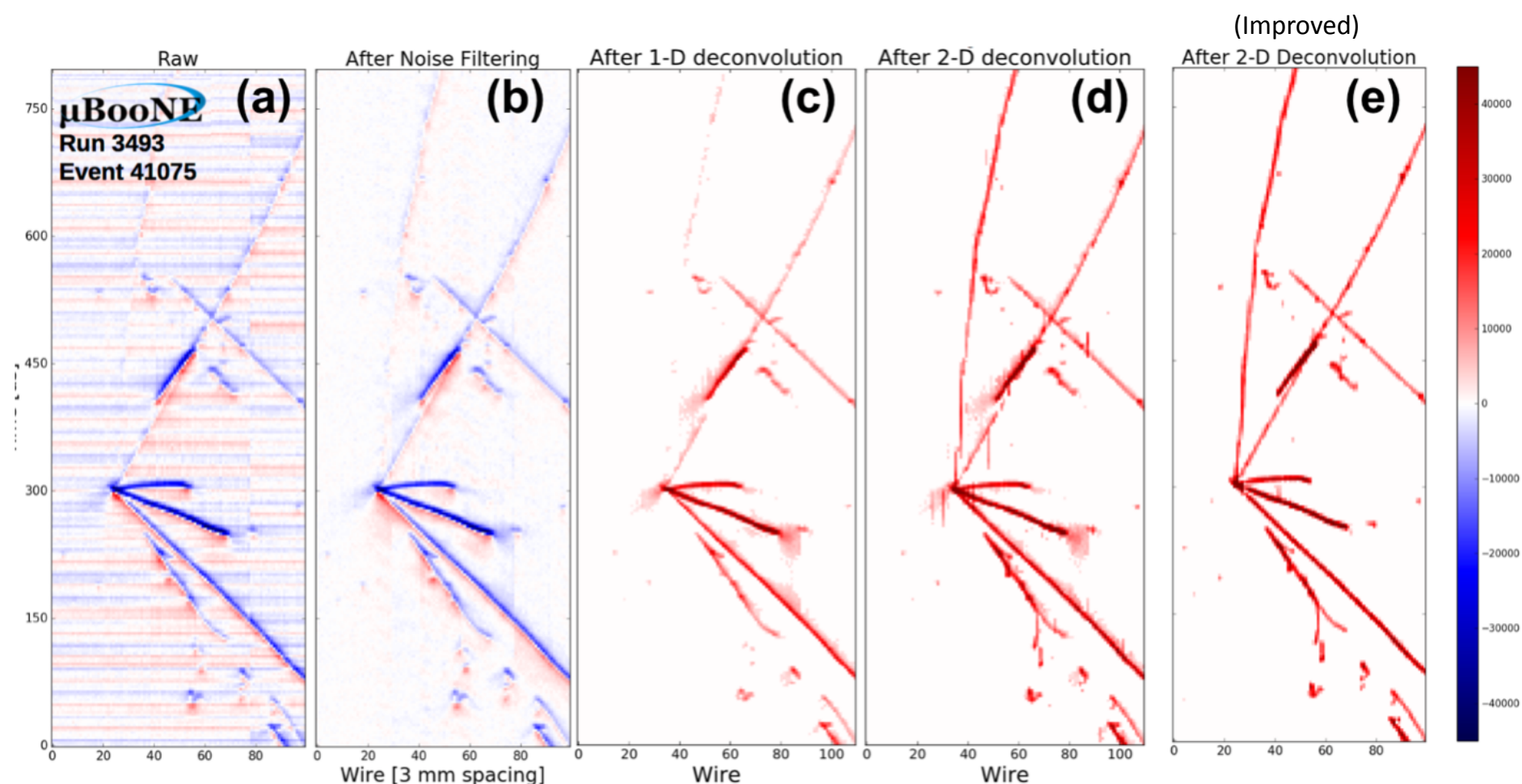
Demonstrated 2-Dim deconvolution technique to extract number of ionized electrons from wire planes

μBooNE Run 3493 Event 41075

| Raw (a) | After Noise Filtering (b) | After 1-D deconvolution (c) | After 2-D deconvolution (d) | (Improved) After 2-D Deconvolution (e) |

Wire [3 mm spacing]   Wire   Wire

* Space Charge Effect (SCE) is a build up of slow-moving Ar^+ ions possibly due to cosmic muons impinging active volume of TPC

  - MicroBooNE being a near-surface experiment has ~ 20 -30 comics per 4.8ms readout window
  - Leads to E field distortions, spatial distortion in ionization position
  - Can impact track/shower reconstruction and calorimetry

MICROBOONE-NOTE-1018-PUB.pdf

Simulated E_y / E_0 [%]:   Z = 5.00 m $\Delta E_y / E_o$ [%]
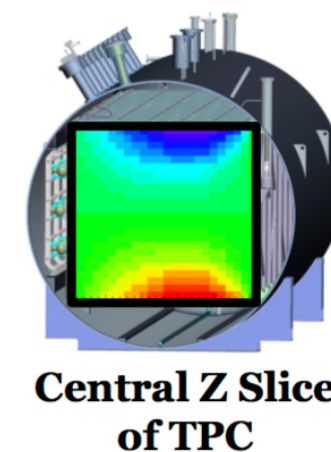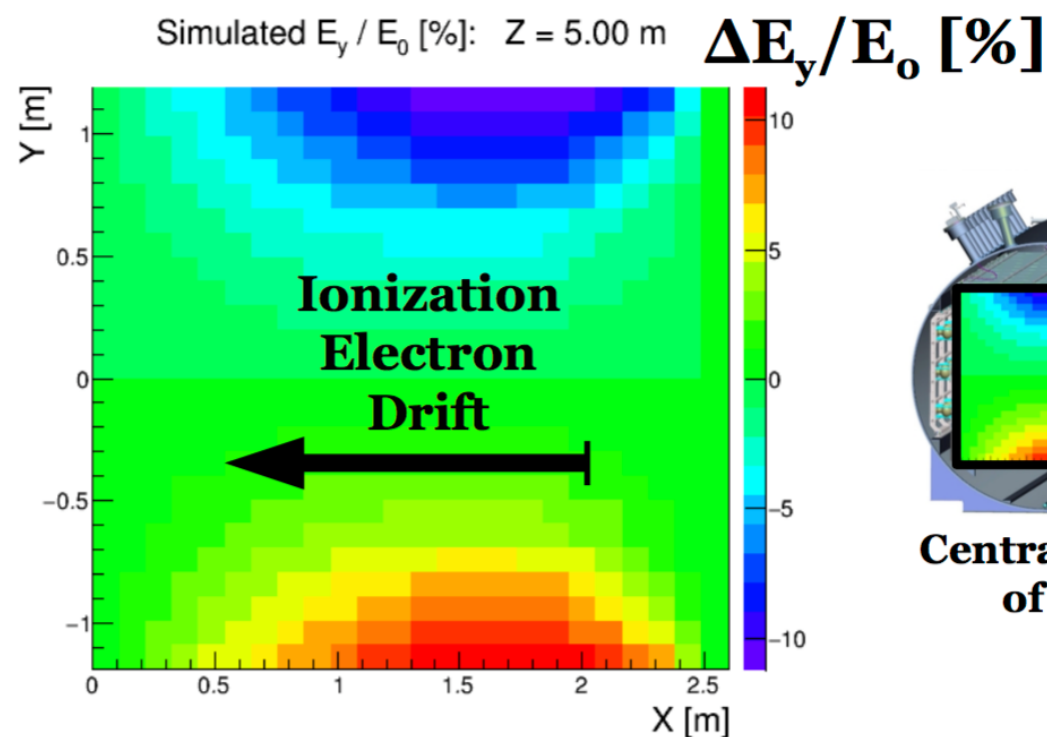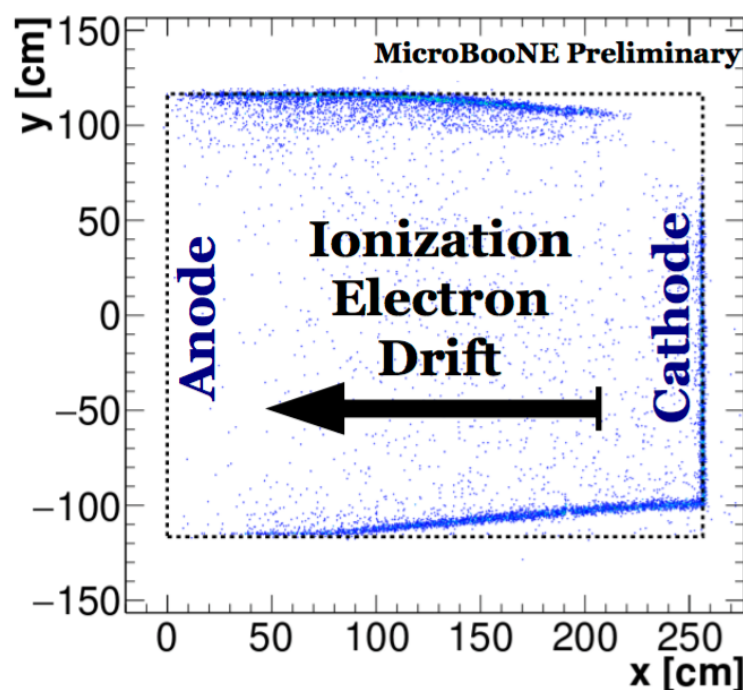
See next Roberto's talk

Central Z Slice of TPC

Working towards calibrating out in 3D using UV laser system and cosmic muon tracks

What a Michel electron looks like in MicroBooNE:

COSMIC DATA : RUN 4468 EVENT 1293. JANUARY 10 2016.

Tons of cosmic data available due to the detector being at the surface!
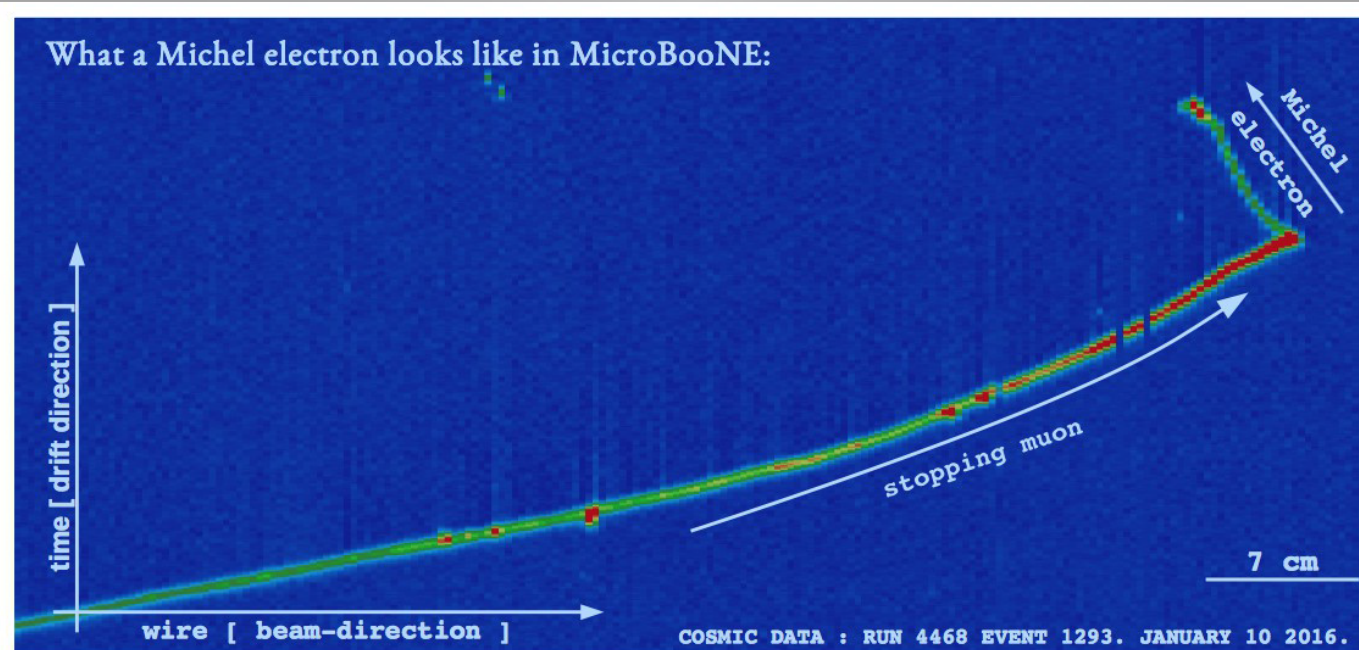
Submitted to JINST, arxiv:1704.02927

* Ideal to study detector's response to electrons in the tens of MeV energy scale and further develop reconstruction
* Michel electron identified by Bragg peak and kink in the track
* Preliminary calibration using stopping muons depositing known dE/dx
* Missing energy from radiated photons accounts for spectral distortions

Michel Electron Reconstructed Energy Spectrum

MicroBooNE

statistical errors only
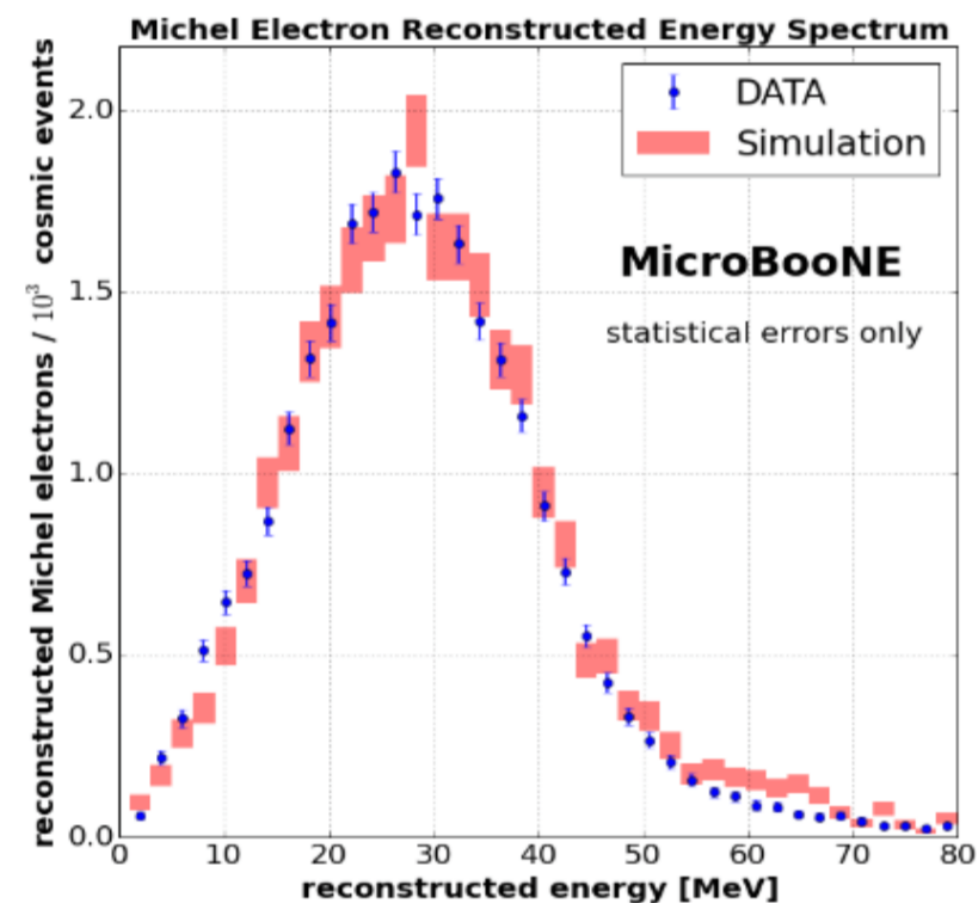
* First results on detector R&D and physics are shown with details available here:
http://www-microboone.fnal.gov/publications/index.html

* Achieved Ultra-low noise levels being first large LArTPC operating with cold front-end electronics

* Advancing in our understanding of the detector to achieve our physics goals!

* MicroBooNE is the first and key component of Short Baseline Program and is an important test bed for future multi-kton LArTPC detectors.

* Running and collecting data since more than 1 year with stability.

Thanks!

MicroBooNE Collaboration — July 2017

University of Bern, Switzerland: M. Auger, Y. Chen, A. Ereditato, D. Goeldi, I. Kreslo, D. Lorca, M. Lüethi, T. Mettler, C. Rudolf von Rohr, J. Sinclair, M. Weber

Brookhaven: M. Bishai, H. Chen, J. Joshi, B. Kirby, Y. Li, M. Mooney, X. Qian, V. Radeka, B. Viren, H. Wei, B. Yu, C. Zhang

University of Cambridge: J. Anthony, L. Escudero Sanchez, J. Jan de Vries, J. Marshall, A. Smith, M. Thomson

University of Chicago: A. Mastbaum, D.W. Schmitz, J. Zennamo

University of Cincinnati: R. Grosso, R.A. Johnson, J. St. John

Columbia University: L. Camilleri, D. Caratelli, D. Cianci, J. Crespo, A. Fadeeva V. Genty, Y.-J. Jwa, D. Kaleko, G. Karagiorgi, M. Ross-Lonergan, W. Seligman, M. Shaevitz, K. Sutton

Fermilab: F. Cavanna, R. Castillo Fernandez, G. Cerati, H. Greenlee, C. James, H. Jostlein, W. Ketchum, M. Kirby, T. Kobilarcik, S. Lockwitz, B. Lundberg, A. Marchionni, S. Marcocci, C. Moore, O. Palamara, Z. Pavlovic, S. Pordes, J.L. Raaf, A. Schukraft, A. E. Snider, P. Spentzouris, T. Strauss, M. Toups, S. Wolbers, T. Yang, G.P. Zeller*

Harvard University: C. Adams, R. Guenette

Illinois Institute of Technology: R. An, B. Littlejohn, D. Martinez

Kansas State University: M. Alrashed, T. Bolton, G. Horton-Smith, V. Meddage, A. Rafique

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

Los Alamos: G. Garvey, E-C. Huang, W.C. Louis, R. Van de Water

University of Manchester: J. Evans, A. Furmanski, D. Gamez, P. Guzowski, J. Hewes, C. Hill, R. Murrells, D. Porzio, S. Söldner-Rembold, A.M. Szelc

MIT: R. Carr, J.M. Conrad, G. Collin, A. Diaz, O. Hen, A. Hourlier, J. Moon, A. Papadopoulou, L. Yates

University of Michigan, Ann Arbor: C. Barnes, R. Fitzpatrick, J. Mousseau, J. Spitz

New Mexico State University: V. Papavassiliou, S.F. Pate, S. Sword-Fehlberg, K. Woodruff

Otterbein University: N. Tagg

University of Oxford: G. Barr, M. Bass, M. Del Tutto, A. Laube, R. Soleti, W. Van De Pontseele

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

Pacific Northwest National Laboratory: E. Church, K. Bhattacharya, K. Wierman

Saint Mary's University of Minnesota: P. Nienaber

SLAC: M. Convery, B. Eberly, L. Rochester, K. Terao, Y-T. Tsai, T. Usher

Syracuse University: A. Bhat, J. Esquivel, 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, E. Davenport, Z. Williams

Tubitak Space Technologies Research Institute, Turkey: F. Bay, B. Kocaman, M. Kopru

Tufts University: T. Wongjirad

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

Yale University: S. Balasubramanian, B.T. Fleming*, E. Gramellini, A. Hackenburg, X. Luo, B. Russell, L. Cooper-Troendle, S. Tufanli

170 collaborators
30 institutions (7 non-U.S.)
39 postdocs
54 graduate students

*spokespeople

16

Backup

MicroBooNE Timeline

December, 2013
TPC inserted into Cryostat

June, 2014
Moved to LArTF
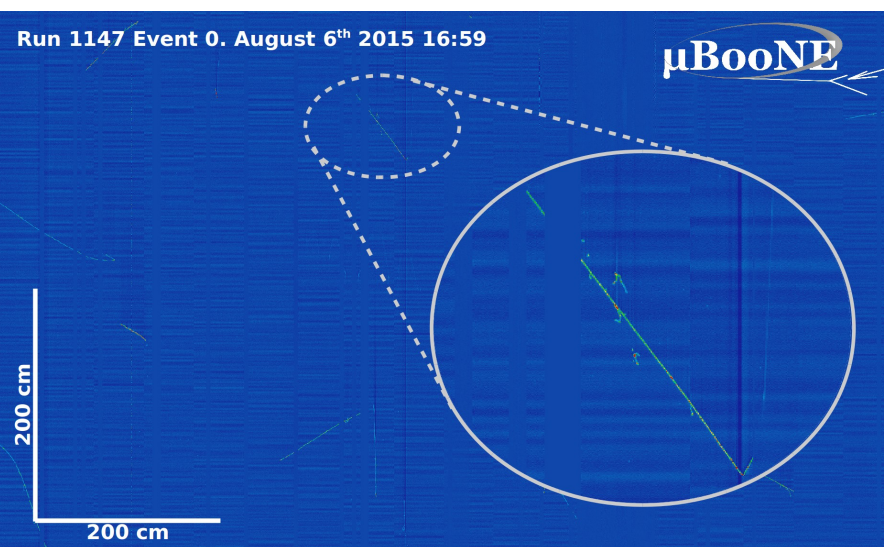

July, 2015
Fill with 170 ton LAr
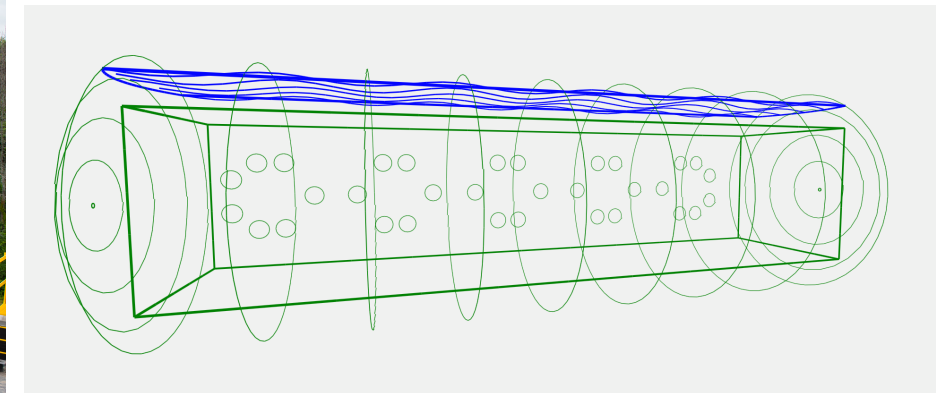
August, 2015
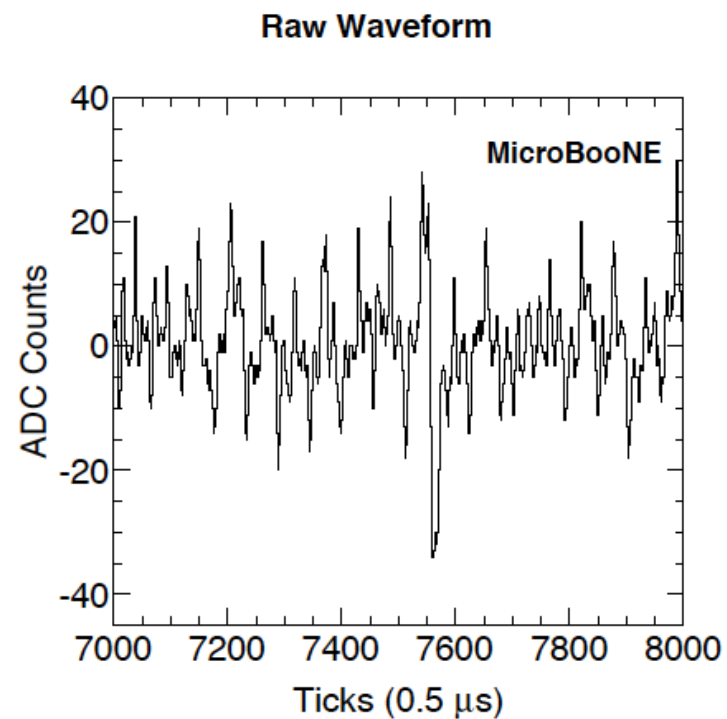**First Cosmic tracks with HV**

October, 2015
First Neutrino Beam

November, 2015
First Public Result

Raw Waveform

(a)

Waveform after 36 kHz filter

(b)

Waveform after 36 kHz and 108 kHz filter

(c)

Waveform After Full Noise Filtering
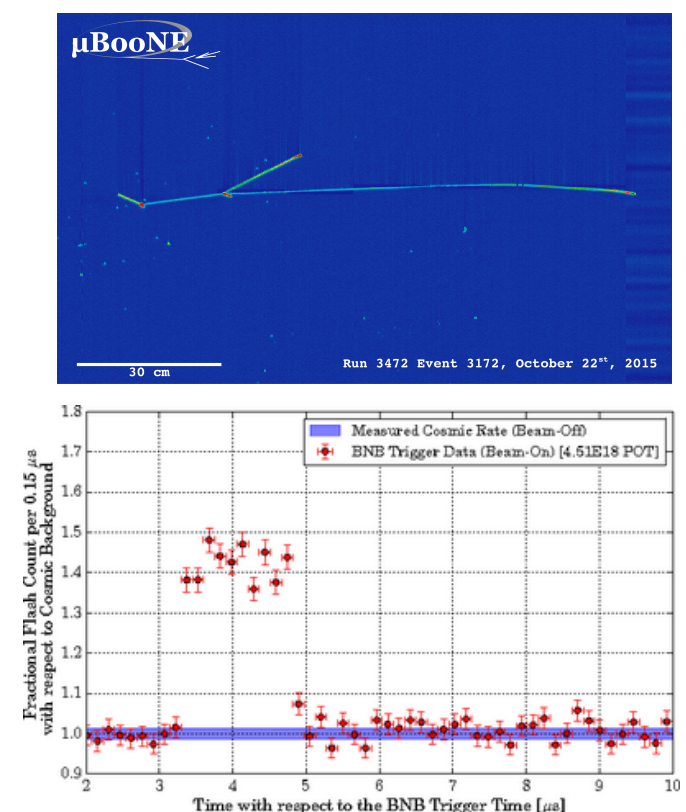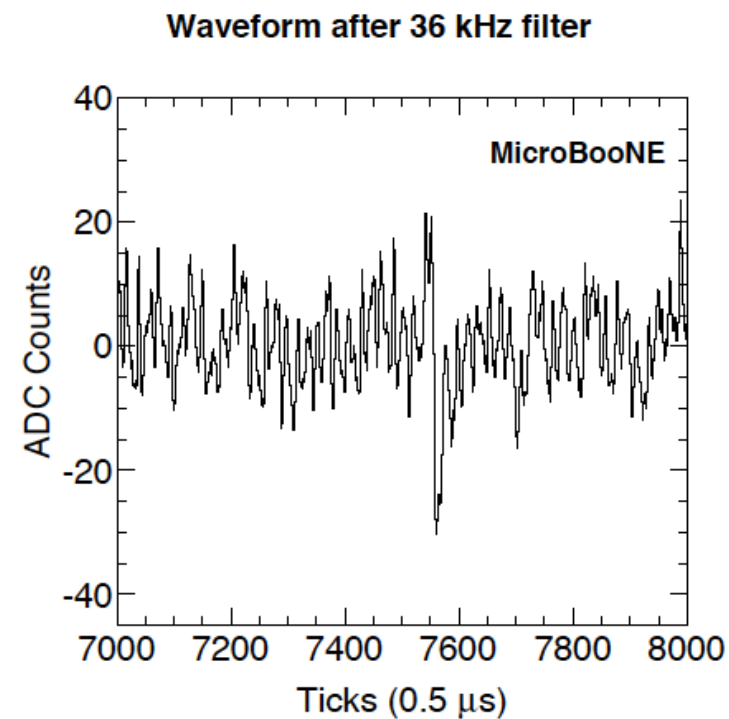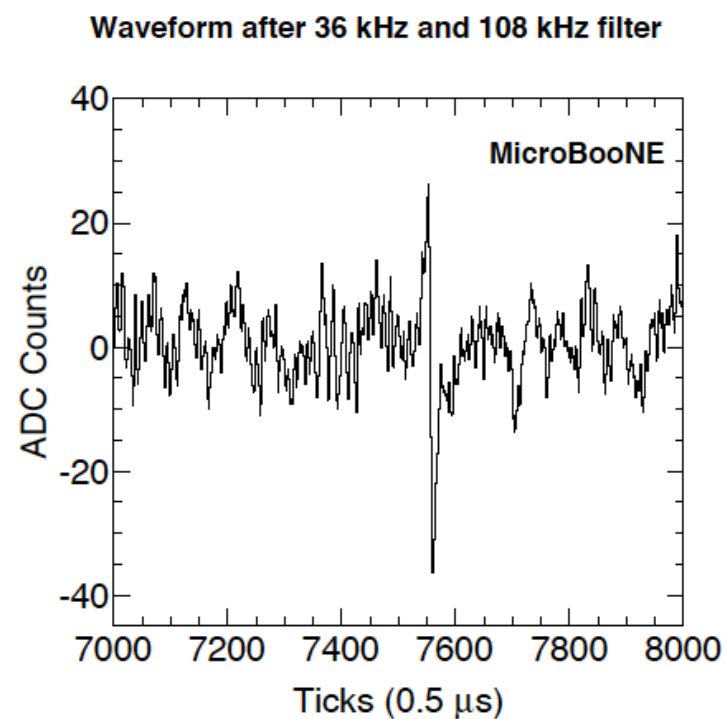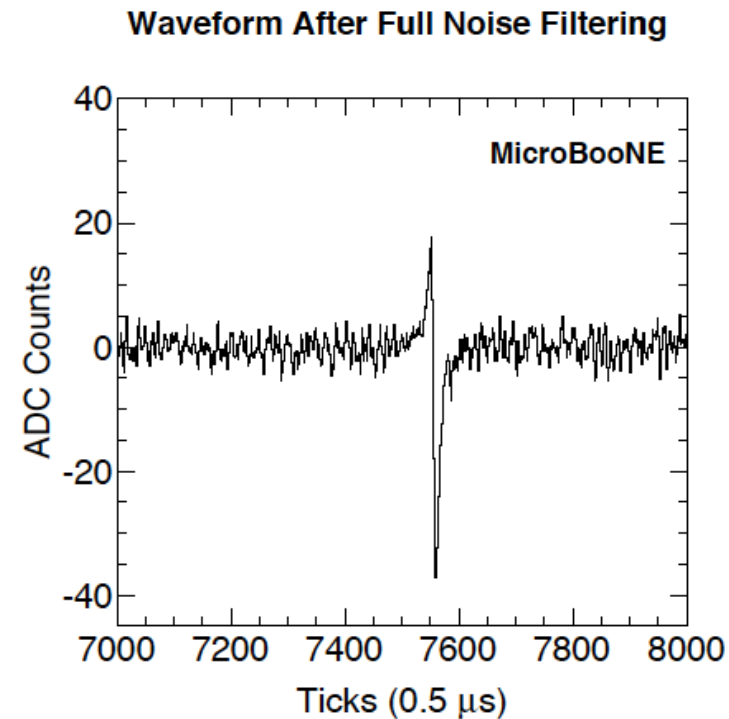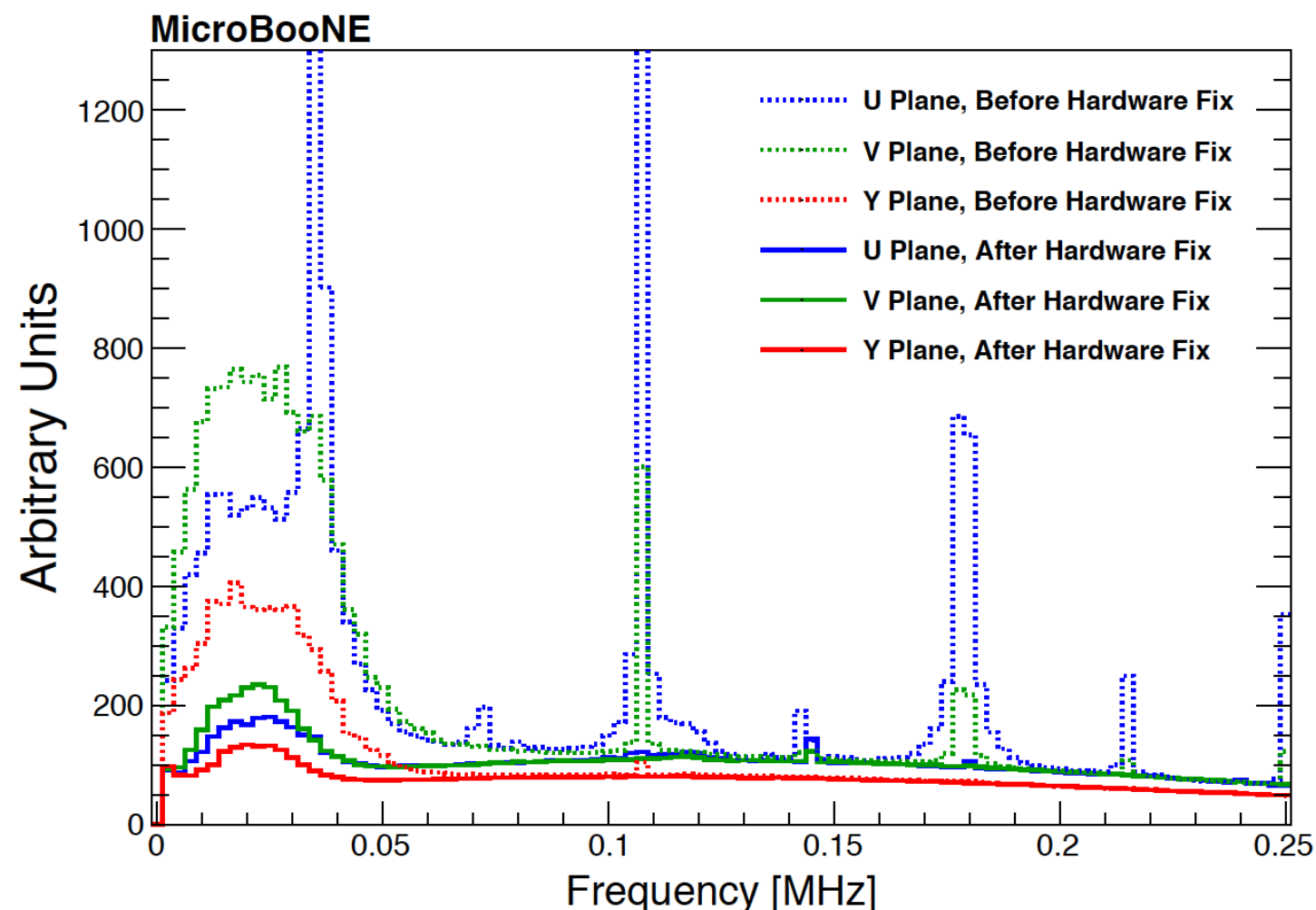
(d)

During Summer Shutdown, Successful hardware upgrades were performed to suppress two main excess noise sources

Waveform Type	U Plane ENC	V Plane ENC	Y Plane ENC
Before Hardware Fix	1570	1340	640
After Hardware Fix	480	490	350
Subsequent Offline Filter	400	380	300

Publications by the MicroBooNE Collaboration:

◇ Public Notes page

◇ MicroBooNE collaboration, "Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC", arXiv:1705.07341, accepted by JINST

◇ MicroBooNE collaboration, "Michel Electron Reconstruction Using Cosmic Ray Data from the MicroBooNE LAr TPC", arXiv:1704.02927, submitted to JINST

◇ MicroBooNE collaboration, "Determination of Muon Momentum in the MicroBooNE LAr TPC Using an Improved Model of Multiple Coulomb Scattering", arXiv:1703.06187, submitted to JINST

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

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

15 Public Notes!

Already 5 Publications this year!

http://www-microboone.fnal.gov/publications/index.html

Public Notes:

◇ 6/4/17 MICROBOONE–NOTE–1024–PUB
Measurement of Reconstructed Charged Particle Multiplicities of Neutrino Interactions in MicroBooNE

◇ 1/26/17 MICROBOONE–NOTE–1025–PUB
Proton Track Identication in MicroBooNE Simulation for Neutral Current Elastic Events

◇ 11/29/16 MICROBOONE–NOTE–1018–PUB
Study of Space Charge Effects in MicroBooNE

◇ 7/4/16 MICROBOONE–NOTE–1017–PUB
A Method to Extract the Charge Distribution Arriving at the TPC Wire Planes in MicroBooNE

◇ 7/4/16 MICROBOONE–NOTE–1015–PUB
The Pandora multi-algorithm approach to automated pattern recognition in LAr TPC detectors

◇ 7/4/16 MICROBOONE–NOTE–1014–PUB
A Comparison of Monte-Carlo Simulations and Data from MicroBooNE

◇ 7/4/16 MICROBOONE–NOTE–1013–PUB
MicroBooNE Detector Stability

◇ 7/4/16 MICROBOONE–NOTE–1012–PUB
Demonstration of 3D Shower Reconstruction on MicroBooNE Data

◇ 7/4/16 MICROBOONE–NOTE–1010–PUB
Selection and kinematic properties of numu charged–current inclusive events in 5E19 POT of MicroBooNE data

◇ 5/3/16 MICROBOONE–NOTE–1006–PUB
Study Towards an Event Selection for Neutral Current Inclusive Single Pi0 Production in MicroBooNE

◇ 5/30/16 MICROBOONE–NOTE–1005–PUB
Cosmic Shielding Studies at MicroBooNE

◇ 11/6/15 MICROBOONE–NOTE–1004–PUB
MC performance study for an early numu charged–current inclusive analysis with MicroBooNE

◇ 5/29/16 MICROBOONE–NOTE–1003–PUB
Measurement of the Electronegative Contaminants and Drift Electron Lifetime in the MicroBooNE Experiment

◇ 11/2/15 MICROBOONE–NOTE–1002–PUB
First neutrino interactions observed with the MicroBooNE Liquid–Argon TPC detector

◇ 8/28/15 MICROBOONE–NOTE–1001–TECH
Noise Dependence on Temperature and LAr Fill Level in the MicroBooNE Time Projection Chamber