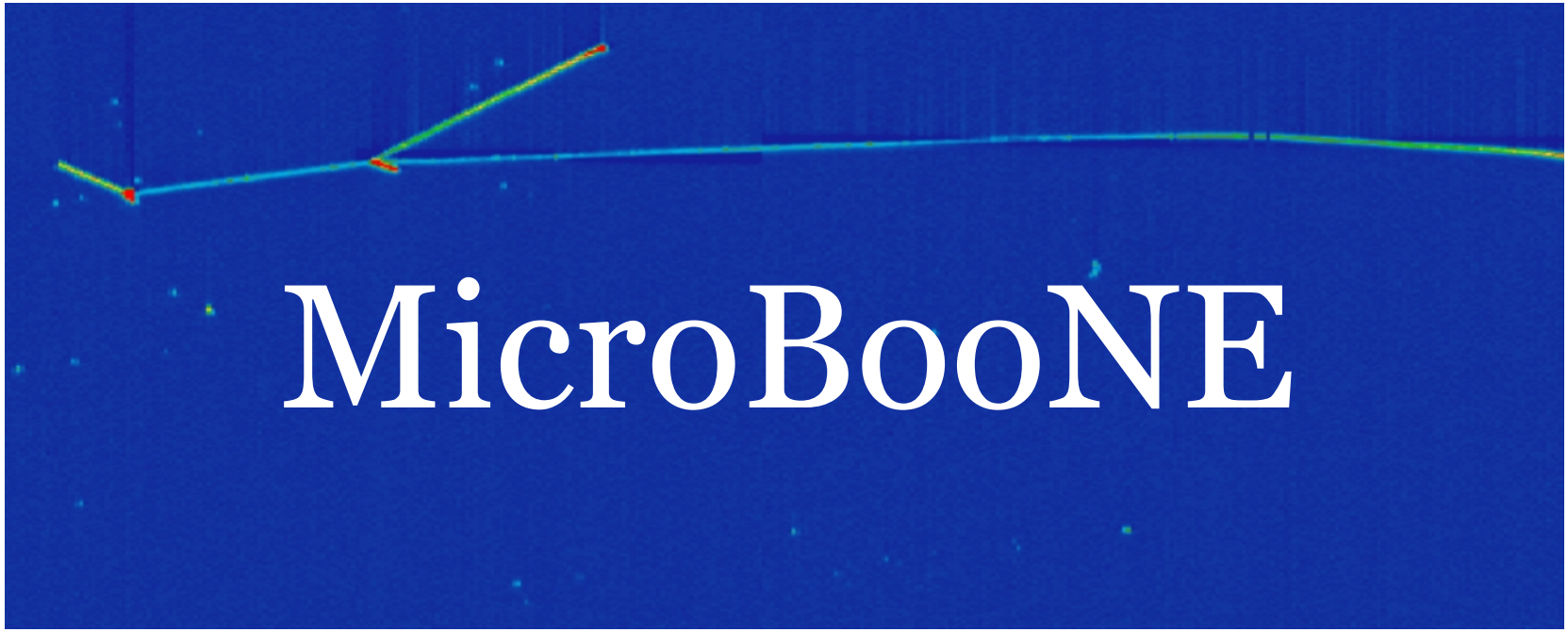


MicroBooNE

Michael Mooney

BNL

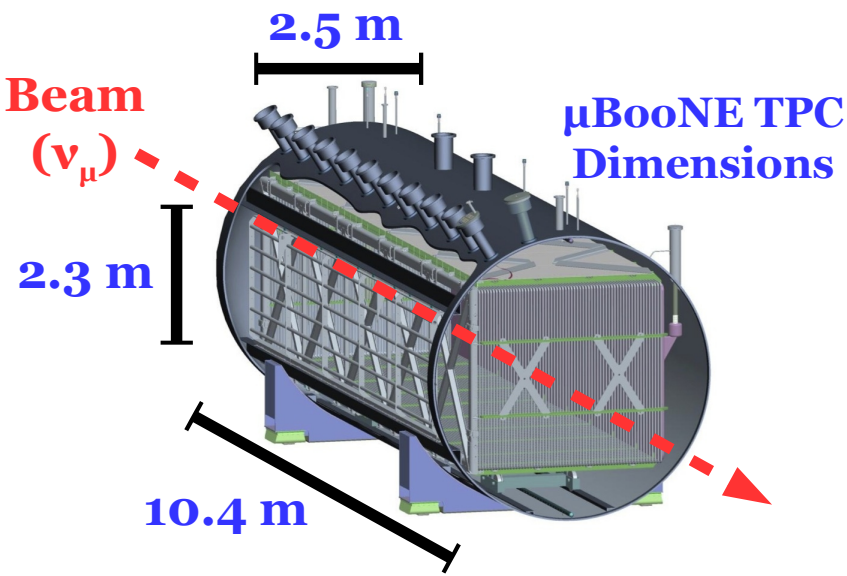
Fermilab User's Meeting

June 16th, 2016

MicroBooNE Overview

- "Micro Booster Neutrino Experiment"
  - 170-ton LArTPC
  - Non-evacuated liquid argon fill
  - Cold (in LAr) front-end electronics
  - Near-surface operation
  - UV laser calibration system

- Physics goals:
  - Investigate MiniBooNE low-energy $\nu_e/\bar{\nu}_e$ excess
  - Measure first low-energy ν-Ar cross sections
  - R&D for future detectors
  - Key first step for SBN program

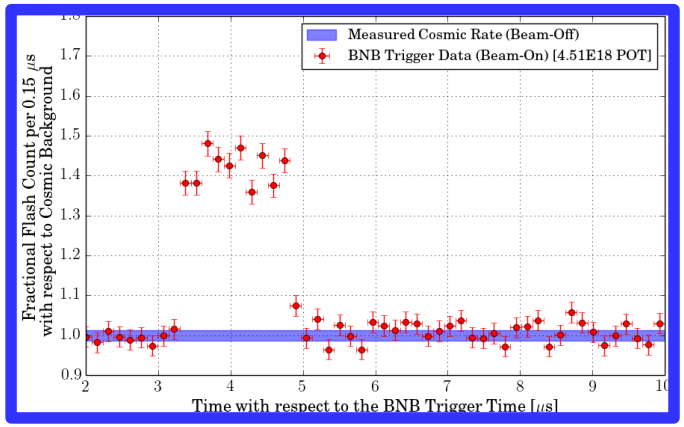


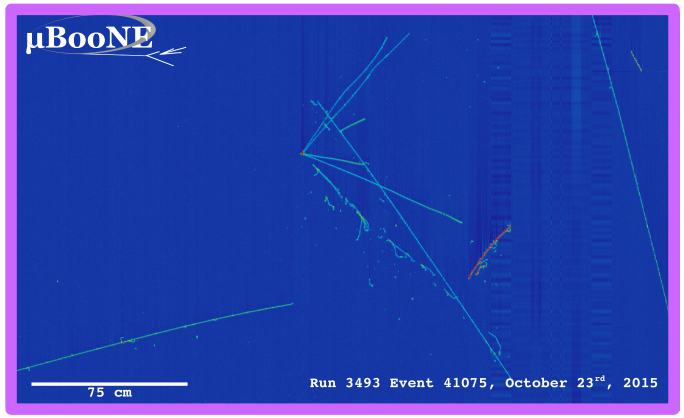
MicroBooNE Collaboration

- **143** collaborators from **28** institutions (6 non-U.S.)
  - **37** graduate students, **36** postdocs
- Roughly half of collaboration **students and postdocs!**

Two Years in a Nutshell

- What have we been up to the past two years?
  - '14-'15: LArTF Installation → Cryostat Installation → Start of Commissioning
  - '15-'16: Commissioning → Operations → First Beam → **First Neutrino Events!**





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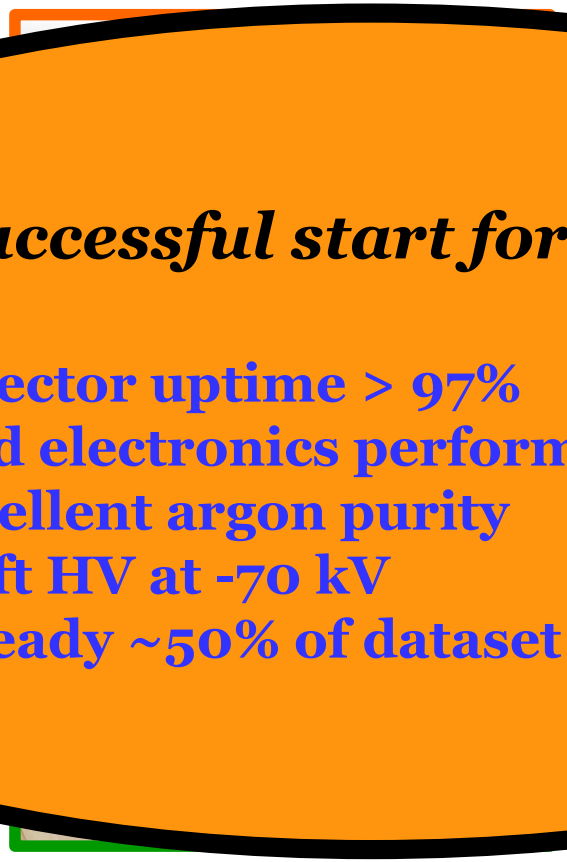
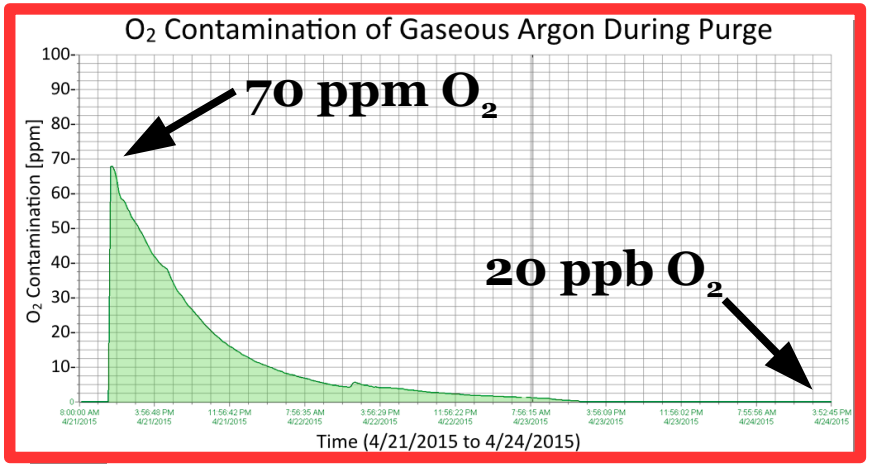


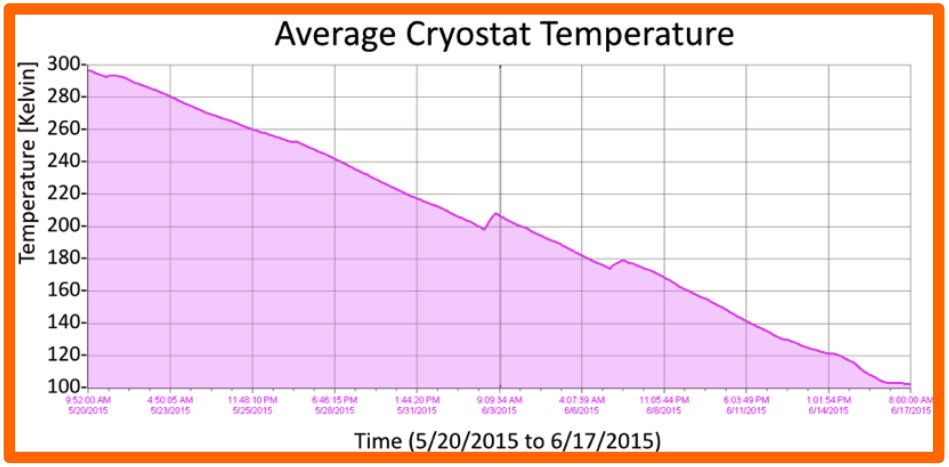
A very successful start for MicroBooNE!

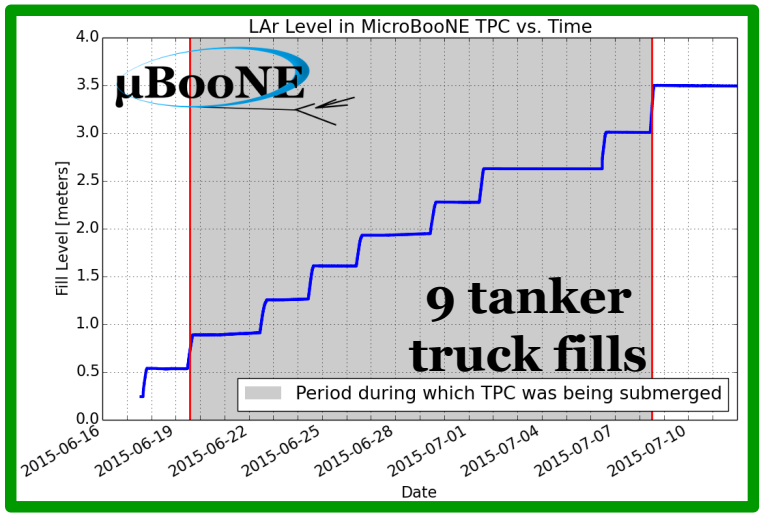
- Detector uptime > 97%
- Cold electronics performing well
- Excellent argon purity
- Drift HV at -70 kV
- Already ~50% of dataset collected

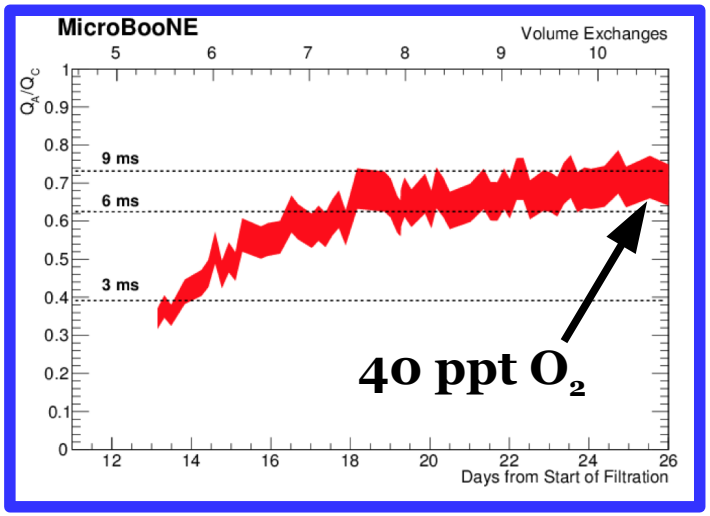
Cryogenics Commissioning

- Four stages: (1) purge (2) cool-down (3) LAr fill (4) recirculation and purification → **operating stably 2-3 times design purity!**









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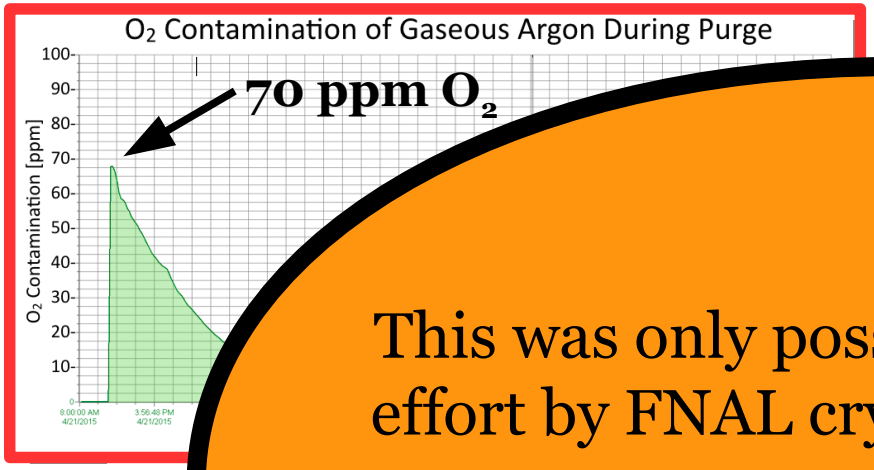
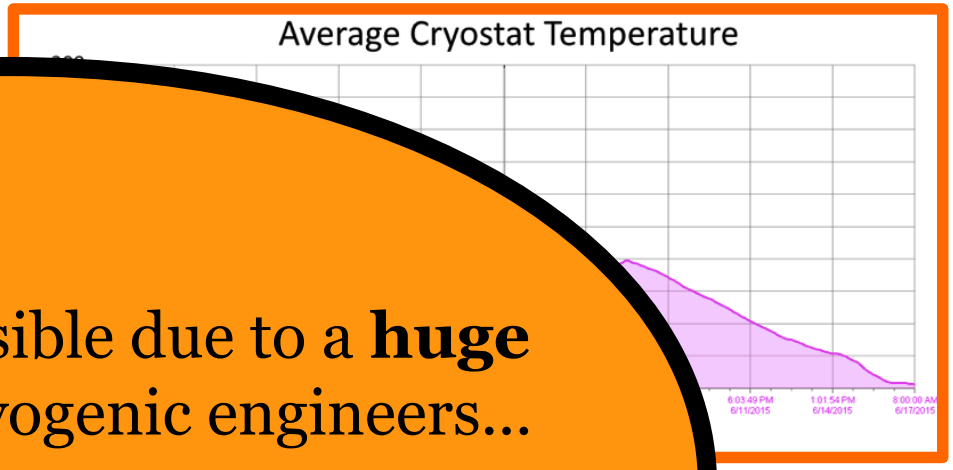
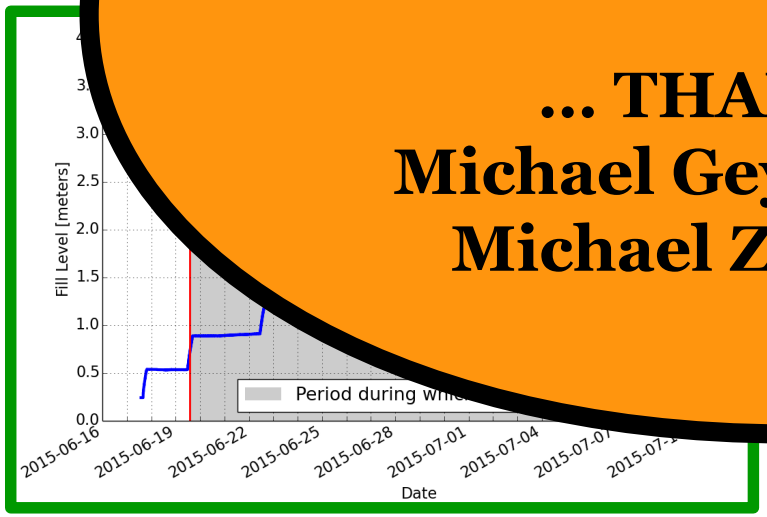
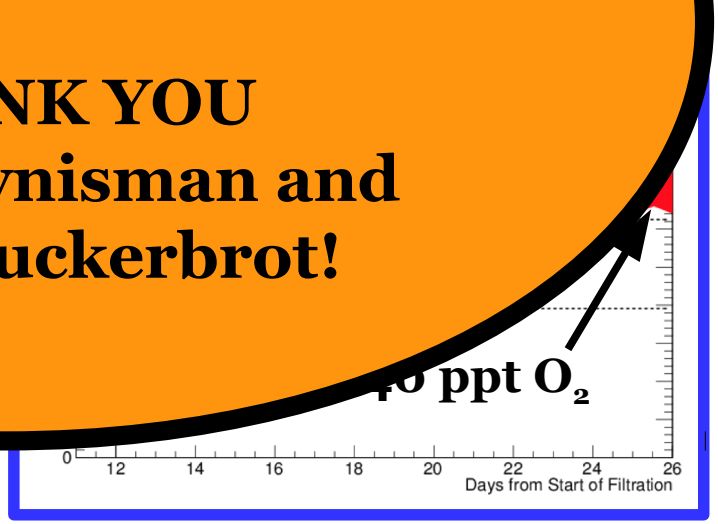






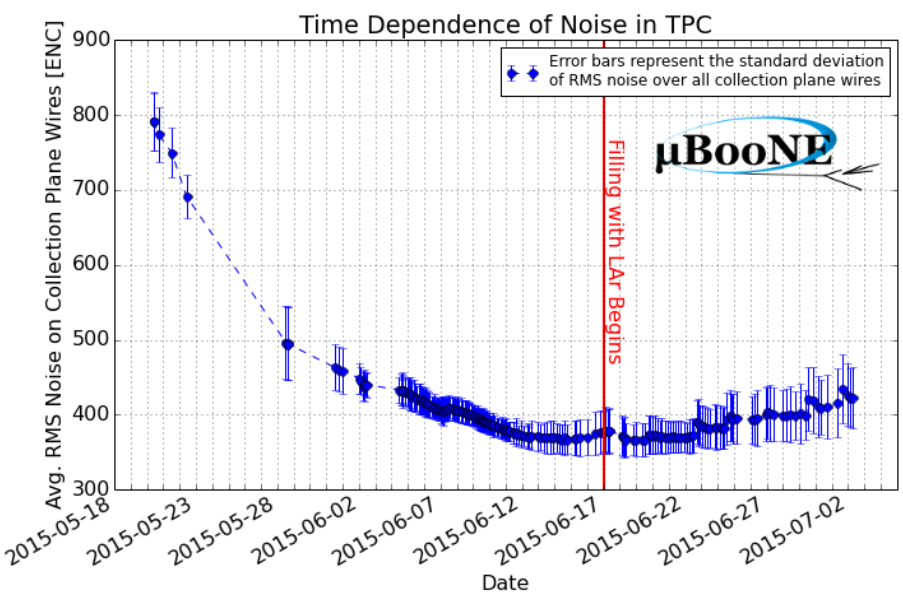


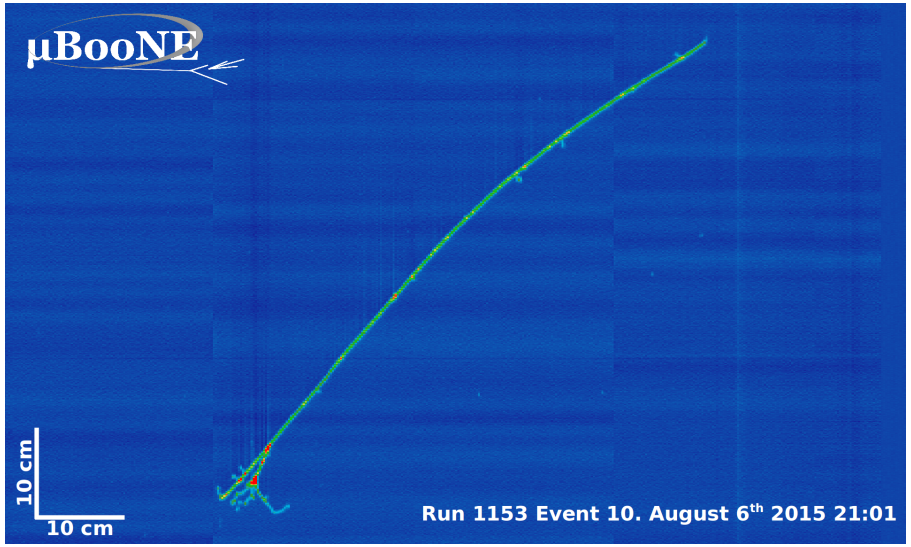
This was only possible due to a **huge** effort by FNAL cryogenic engineers…

… THANK YOU
Michael Geynisman and
Michael Zuckerbrot!

Noise Levels

- TPC noise level dropped during purge/cool-down, slowly rose with LAr fill (increased capacitance with LAr)
- Events look clean – even better after software noise filtering
- Public note discussing noise at MicroBooNE coming soon
  - Important read for the greater LArTPC community!





No Software Noise Filtering

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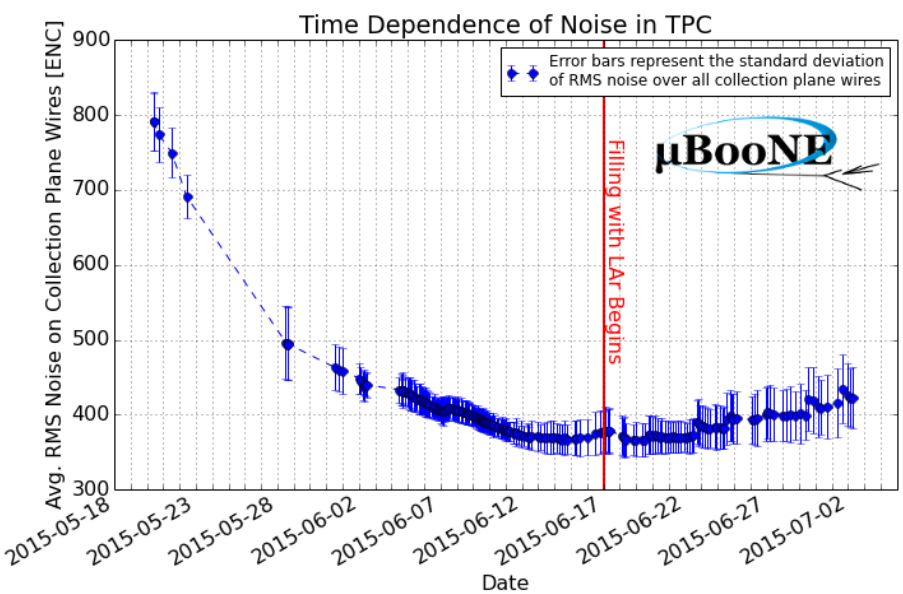
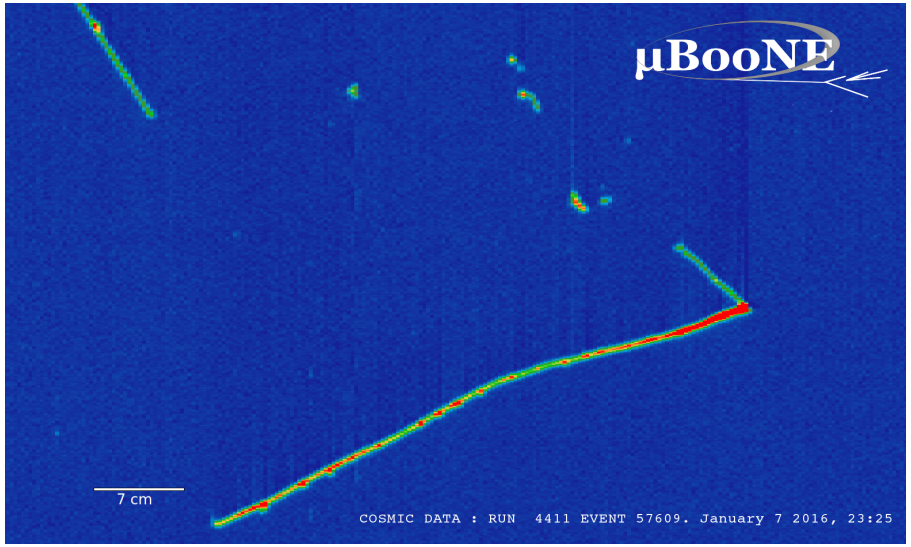




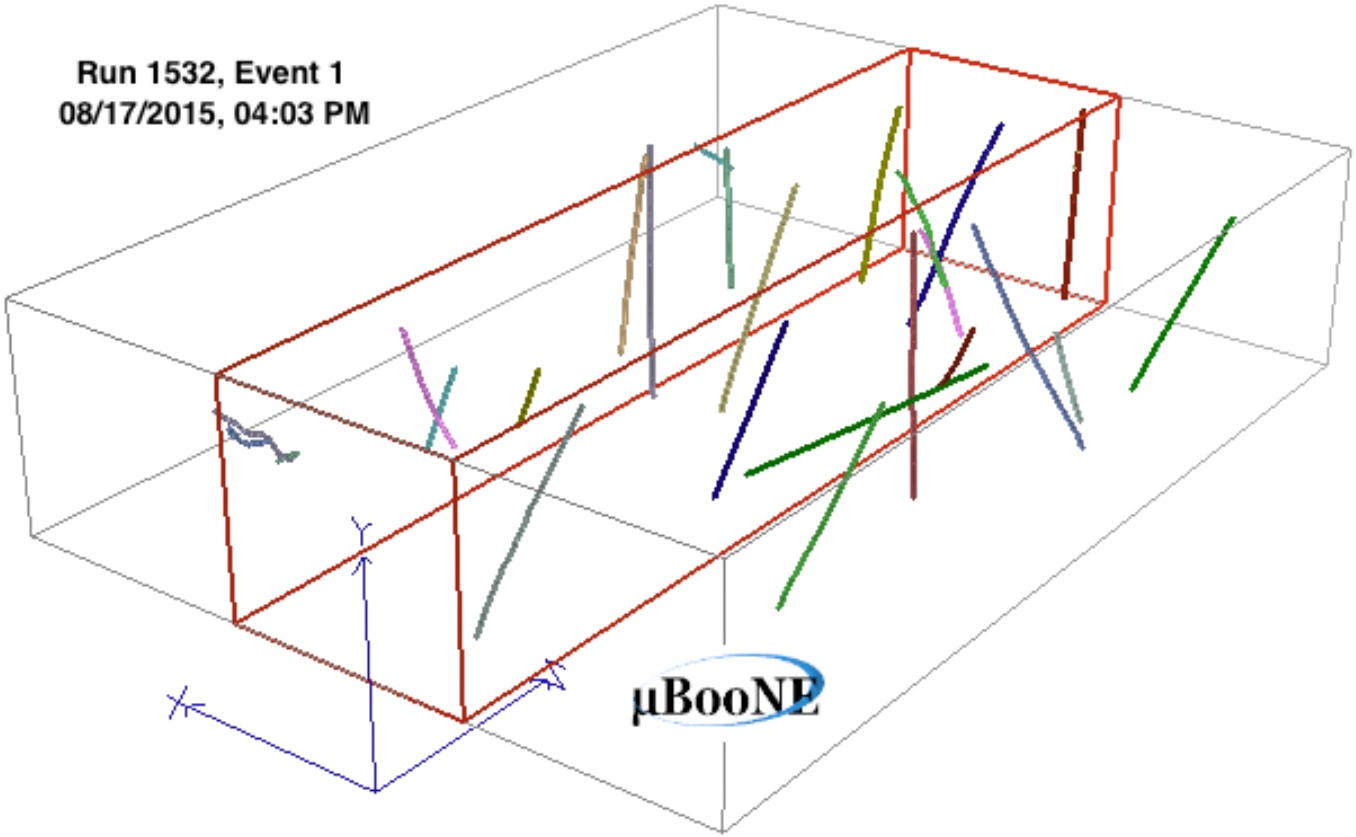
With Software Noise Filtering

End of Commissioning

Cathode HV Ramp from Control Room (August 2015)

- Commissioning finished in September 2015
  - First, all subsystems went through thorough internal review: TPC, PMT, Drift HV, DAQ, Readout, Slow Controls/Monitoring, Online Monitoring, Data Management

Cosmic Events

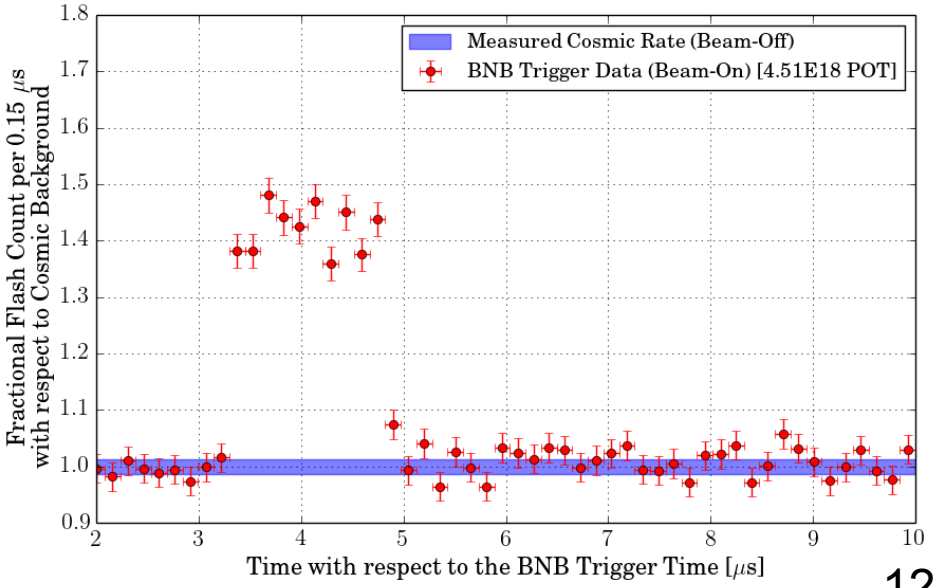


- With cathode HV up, began seeing first cosmic events in TPC
  - Allowed for testing of reconstruction machinery on actual data

First Beam from BNB

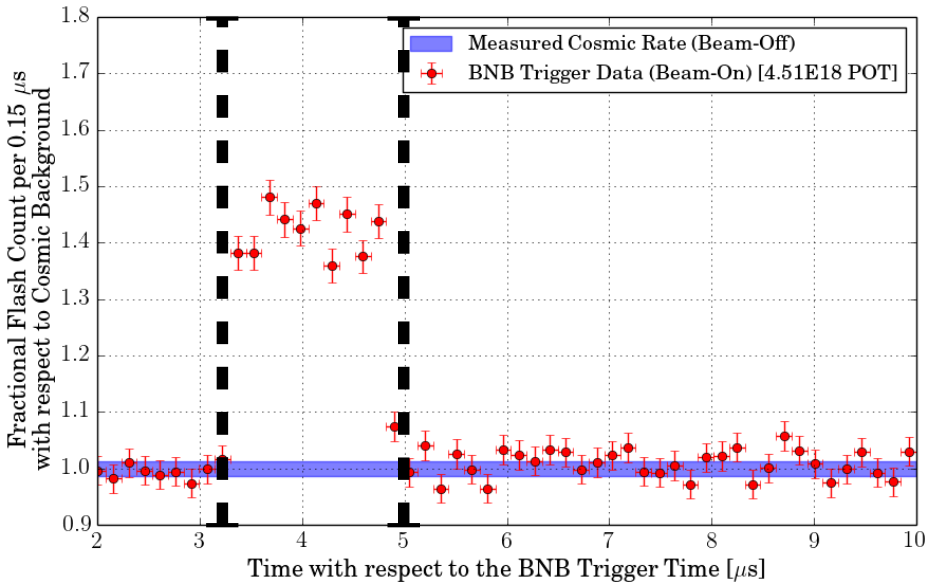
- First beam from BNB came on October 15th, 2015
  - MicroBooNE was ready with beam monitoring in control room
- Timed in beam spill within PMT beam-gate window by reconstructing time of large "flashes" in PMTs
  - Flash: optical hits in multiple PMTs coincident in time
  - Necessary for PMT trigger (used to reduce data-taking rate)

First Beam (ROC West Control Room)



First Neutrino ID

- Most recorded events only contain cosmic tracks
- Select out neutrino beam events using beam-spill window cut in PMT beam-gate readout
  - Also additional cuts targeting neutrino-like topology
  - Use **fully-automated** event reconstruction for selecting events
- First neutrino ID results: November 2015



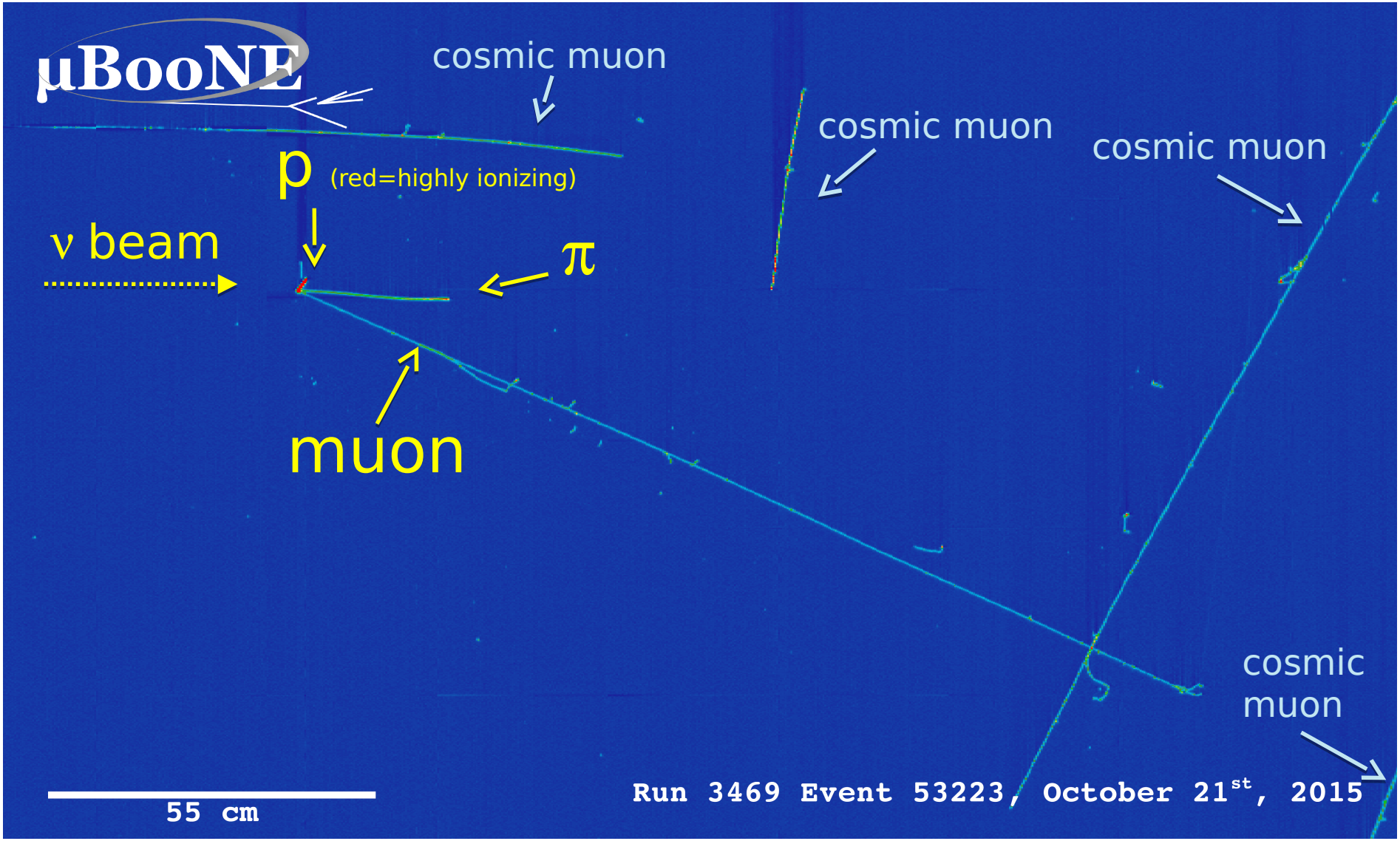
MicroBooNE preliminary
1.86e18 POT (BNB)

Fully automated selection

Number of events	Optical + 3D-based	Optical + 2D-based
Non-beam background (expected from off-beam measurements)	4.6 ± 2.6	385 ± 24
Total observed (during beam)	18	463

Clear excess of selected events over background

Neutrino ID Event



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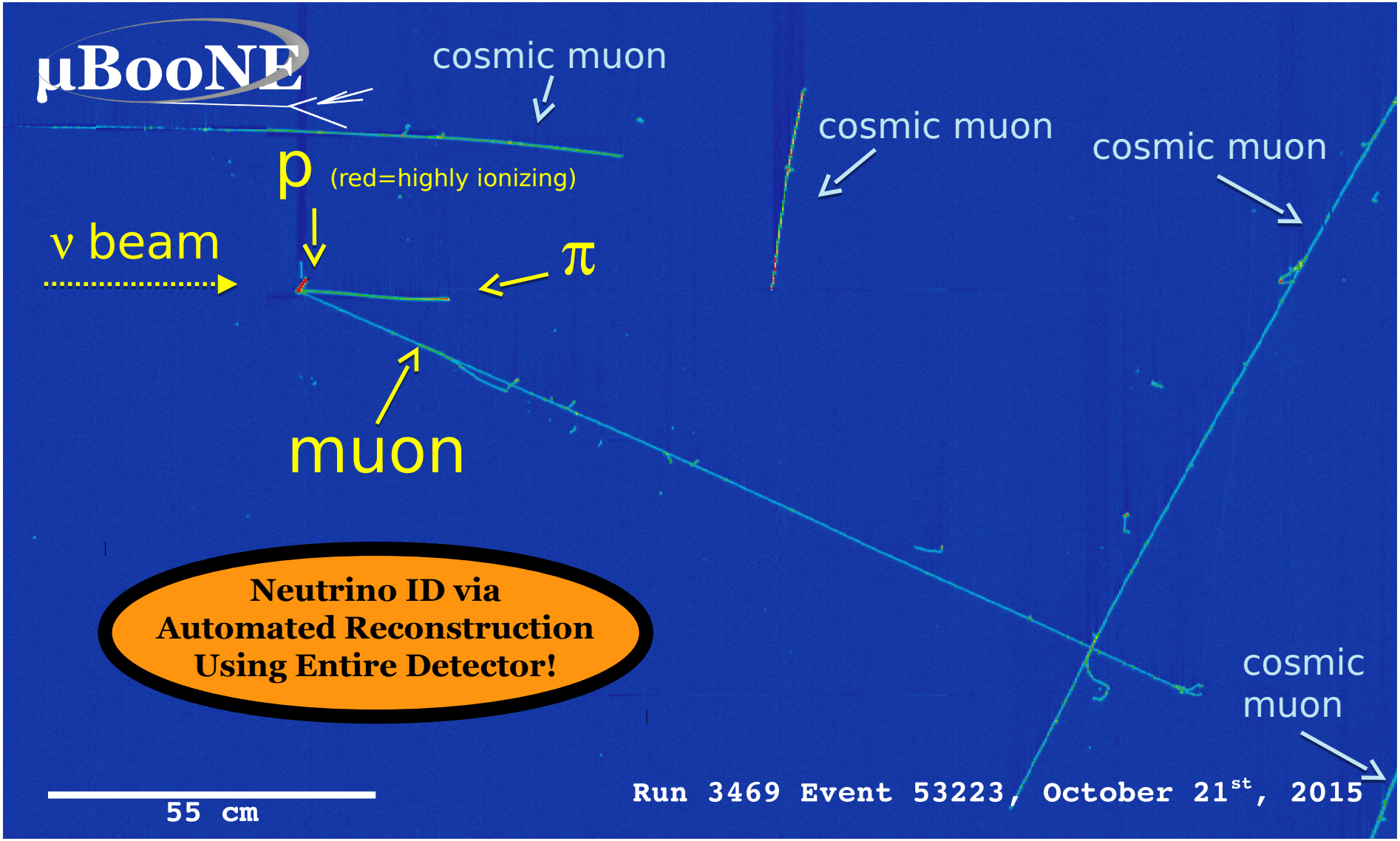
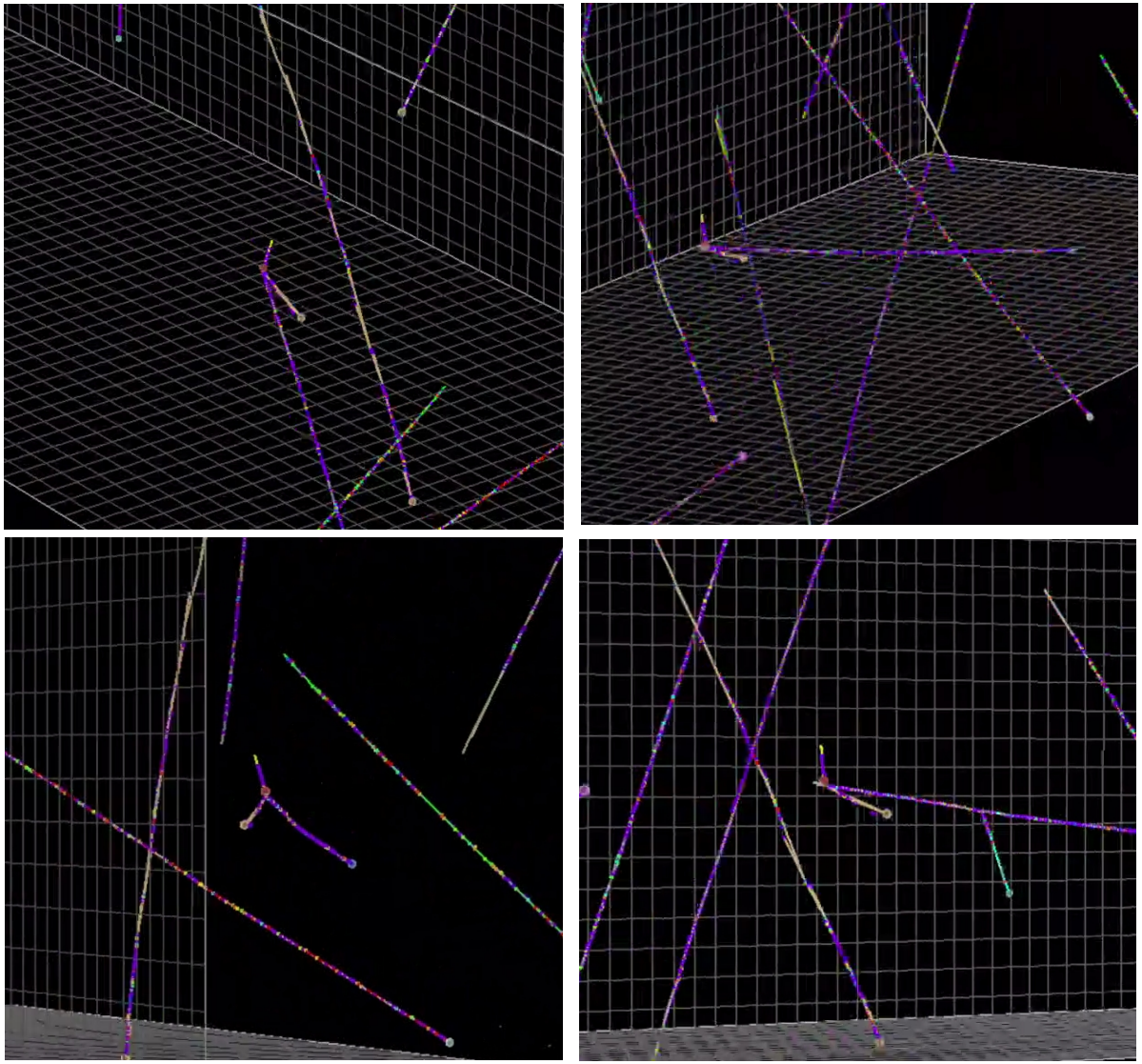


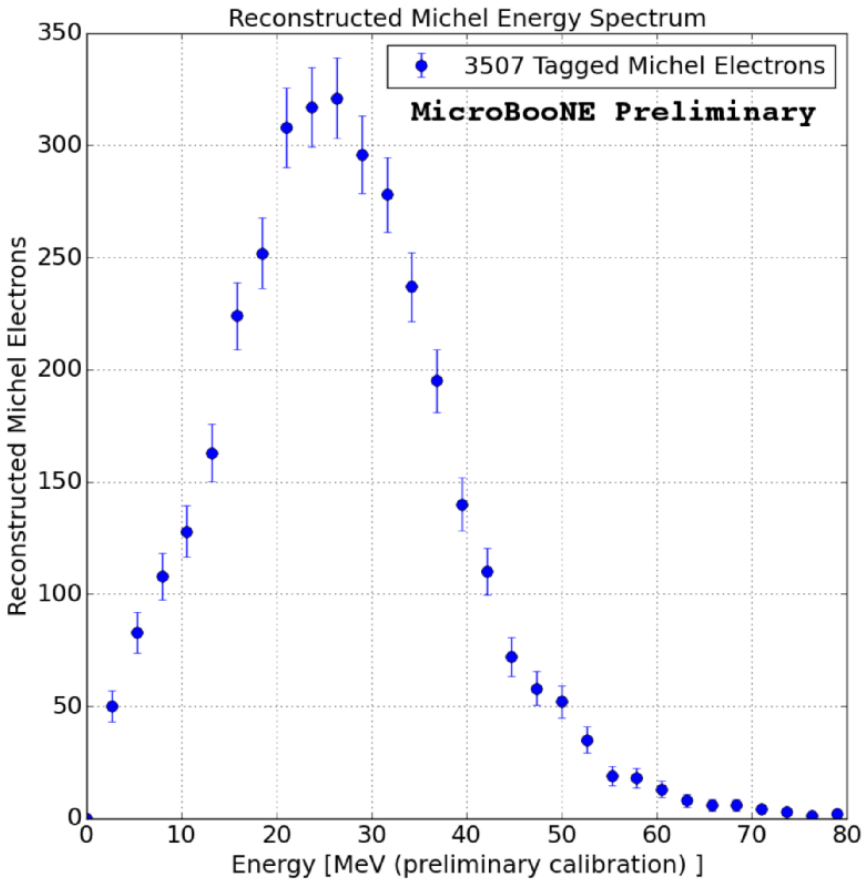
3D Neutrino Event

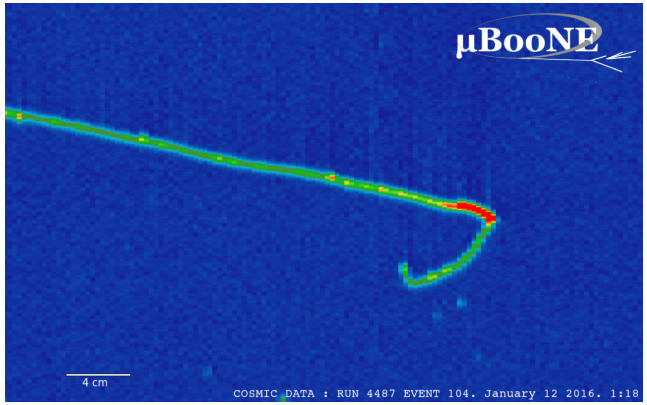


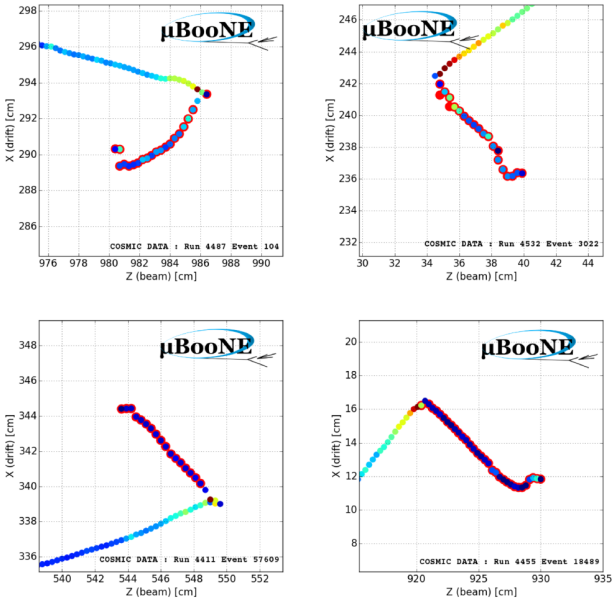
Four views of a single 3D-reconstructed neutrino interaction event, selected during the neutrino ID campaign

First MicroBooNE Results

- Several results released from MicroBooNE for APS this April
  - Michel electron reconstruction







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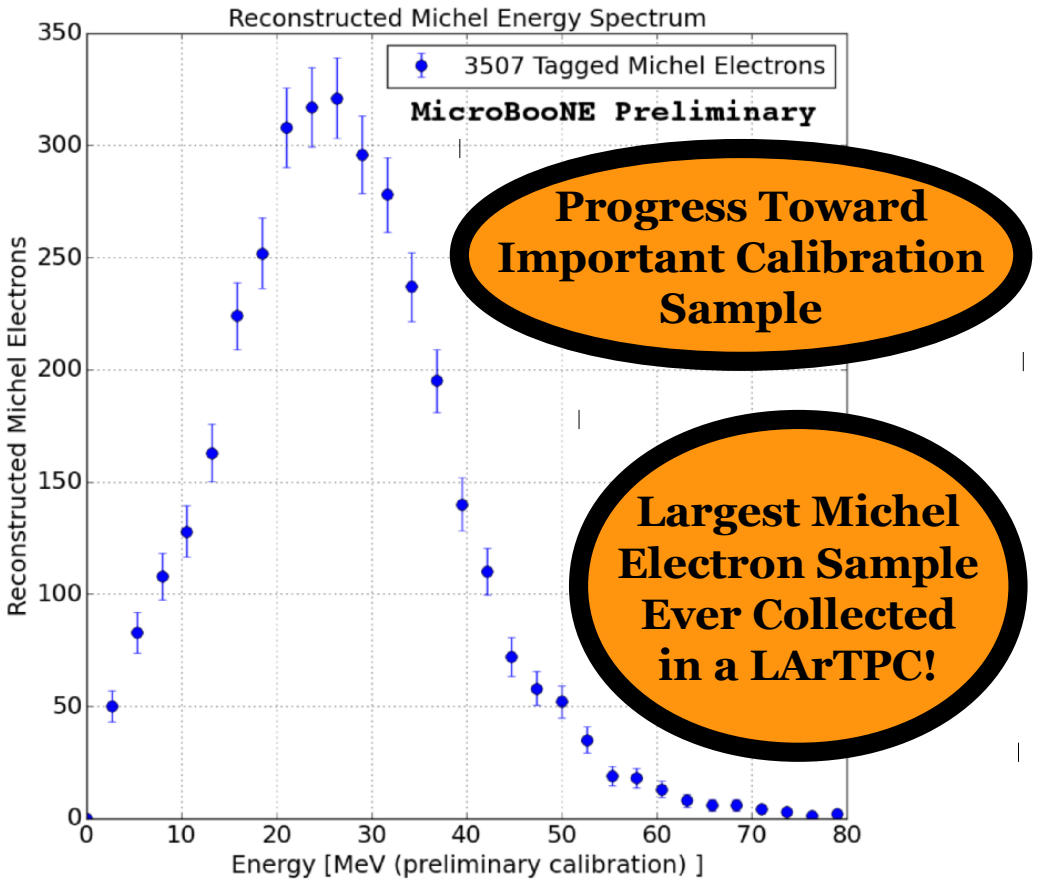
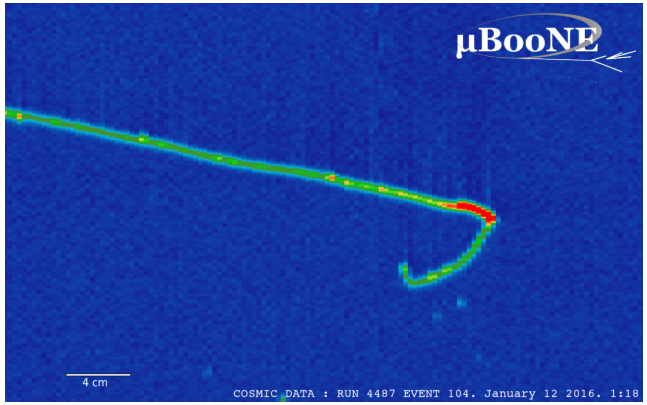
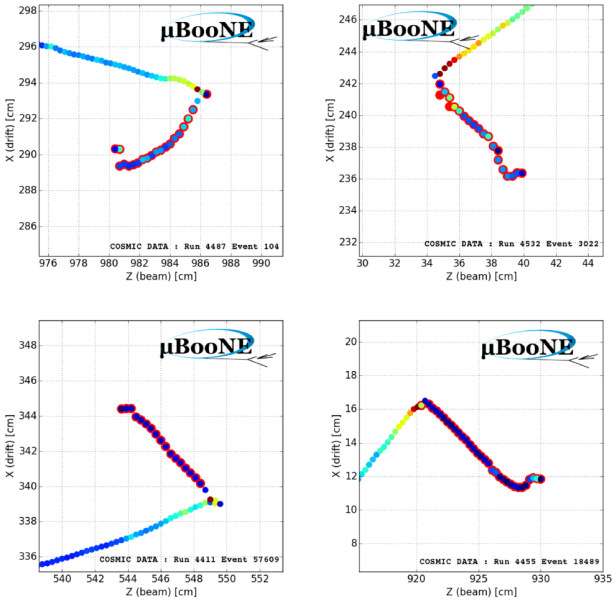


Progress Toward Important Calibration Sample

Largest Michel Electron Sample Ever Collected in a LArTPC!





First MicroBooNE Results

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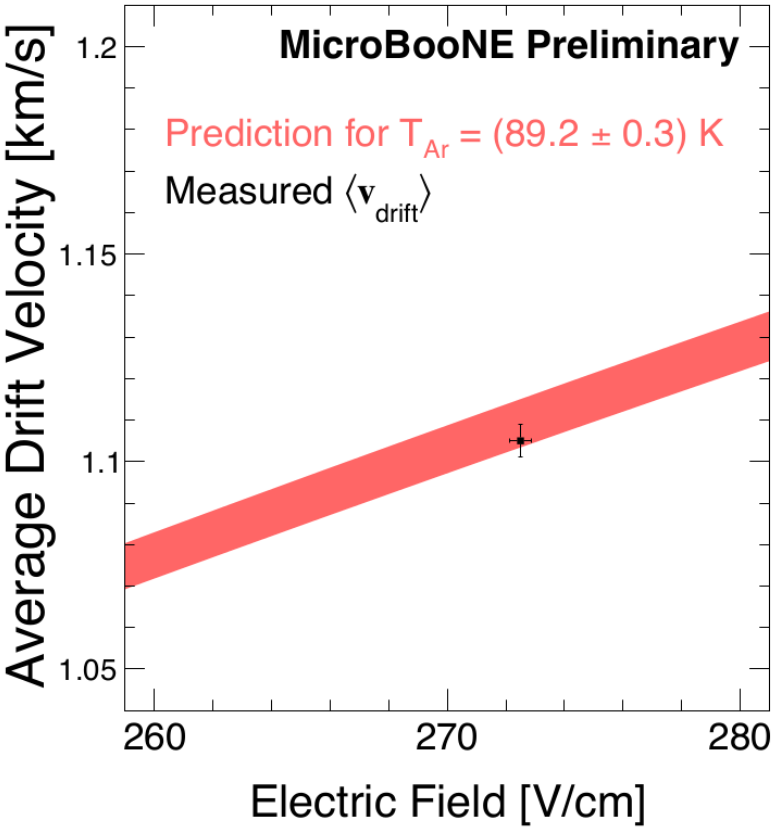
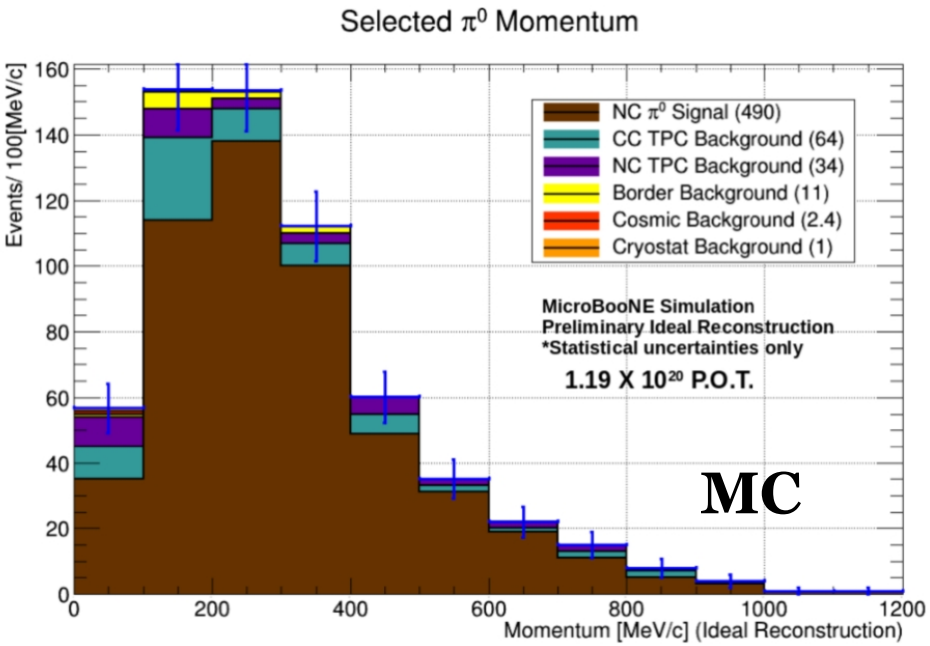
  - Drift velocity measurement using UV laser
  - NC inclusive single π^0 production study





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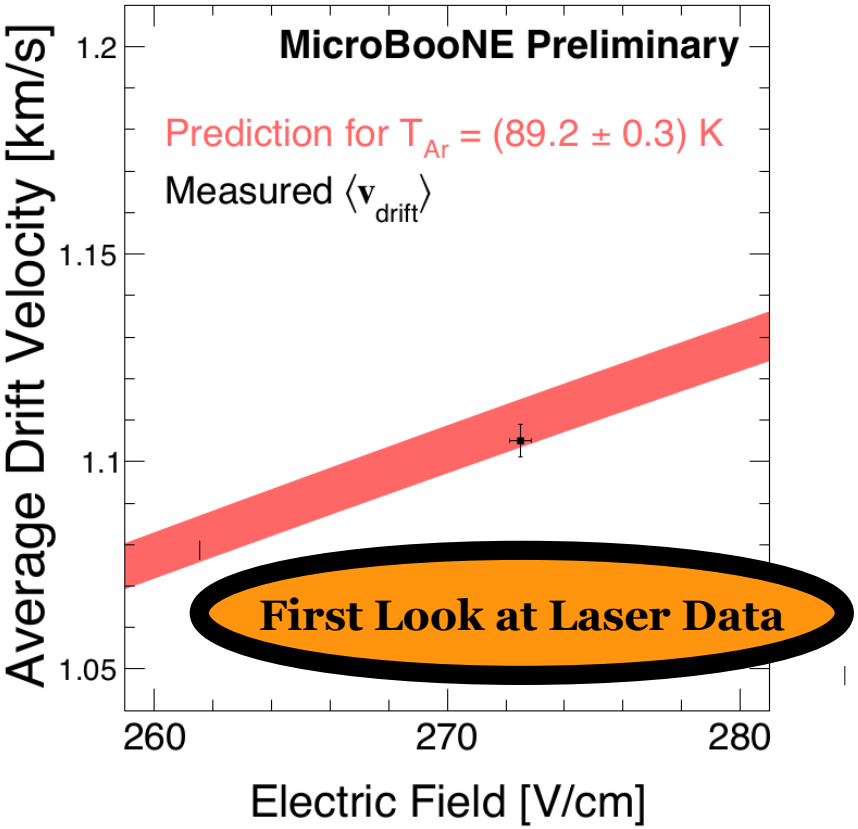
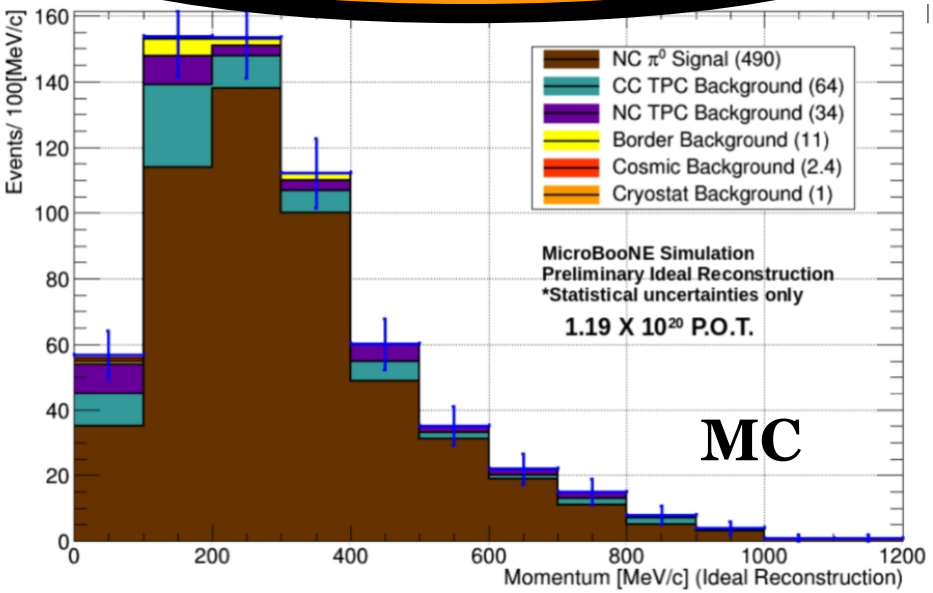
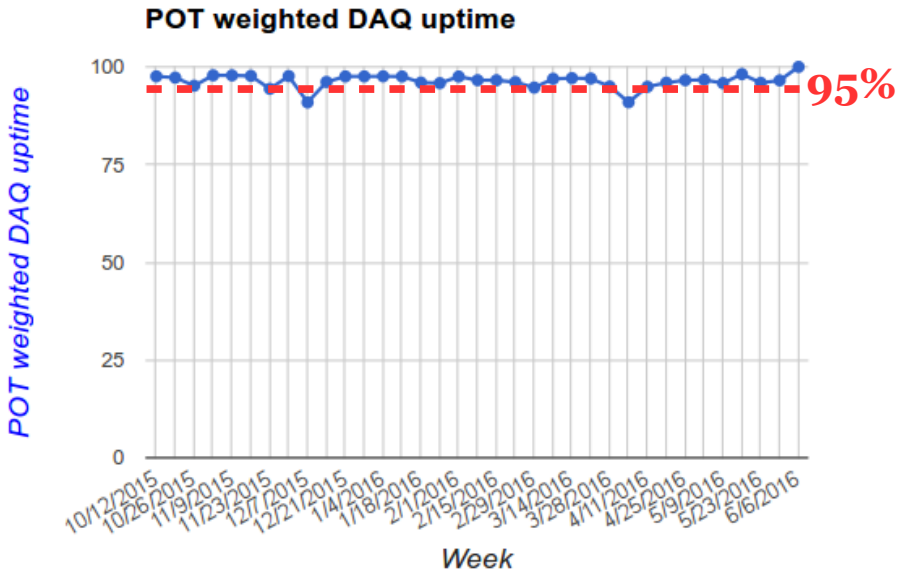
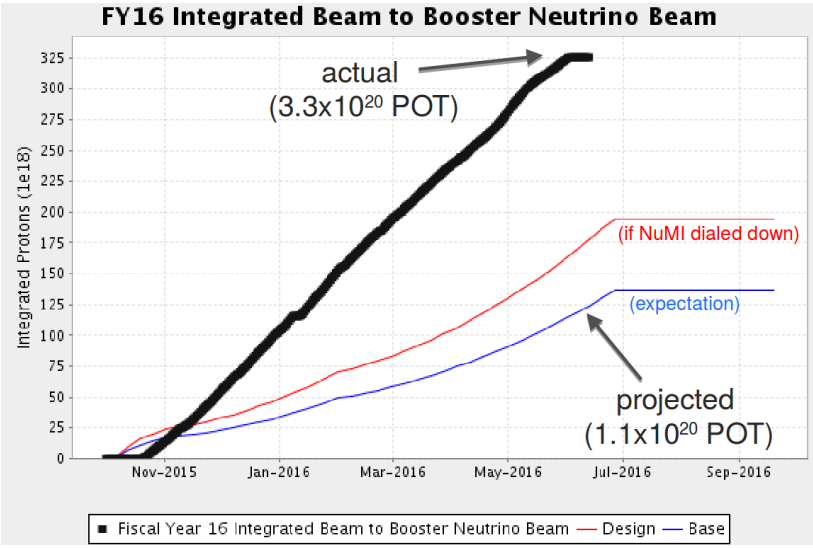


Progress Toward Understanding ν_e Appearance Backgrounds



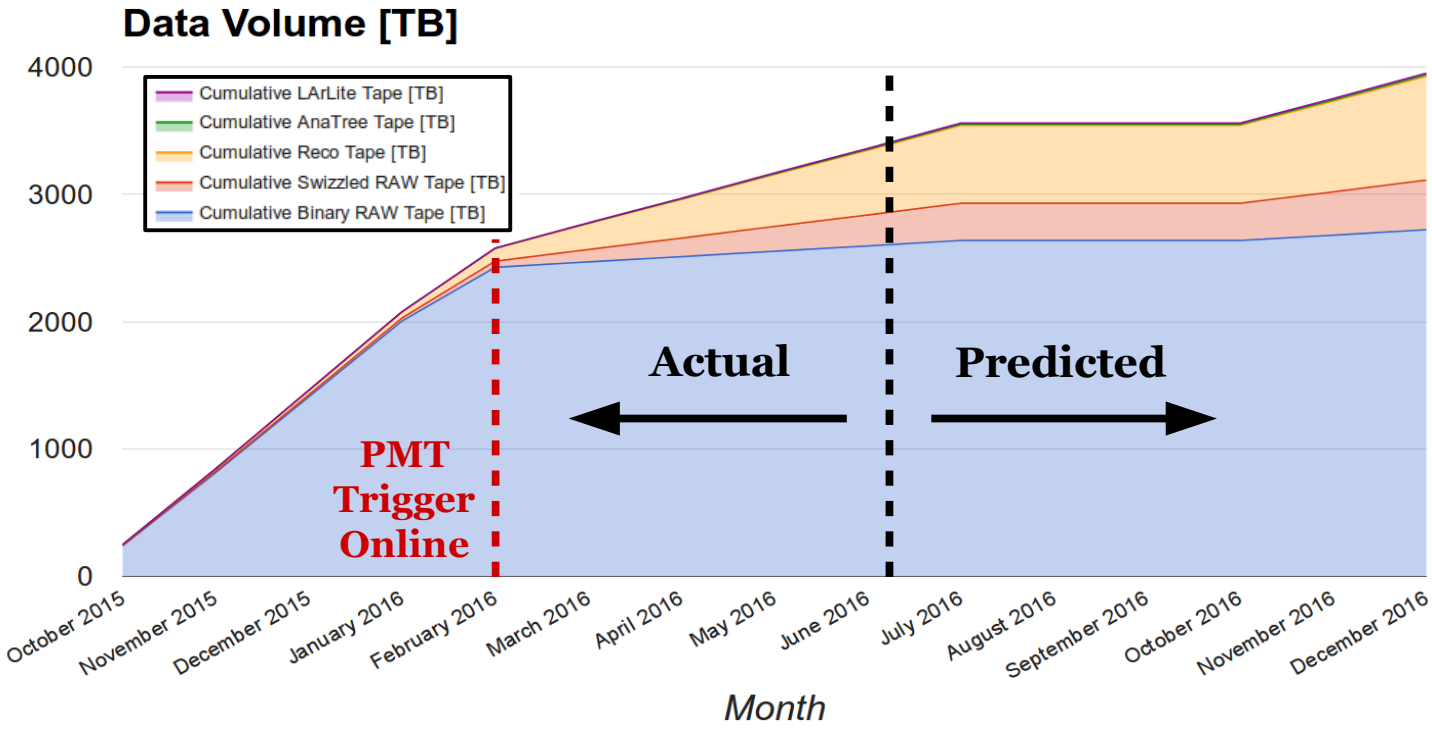
Uptime, Protons on Target





- Stable data-taking for the most part since beginning of operations – detector works out of the box!
- **Greater than 97%** POT-weighted DAQ uptime on average
- Roughly **3.3×10^{20}** POT delivered and **3.2×10^{20}** POT on tape
  - This is already **~50%** of our nominal three-year dataset
  - This is **three times** the first-year expectation… **THANK YOU!**

Data Volume



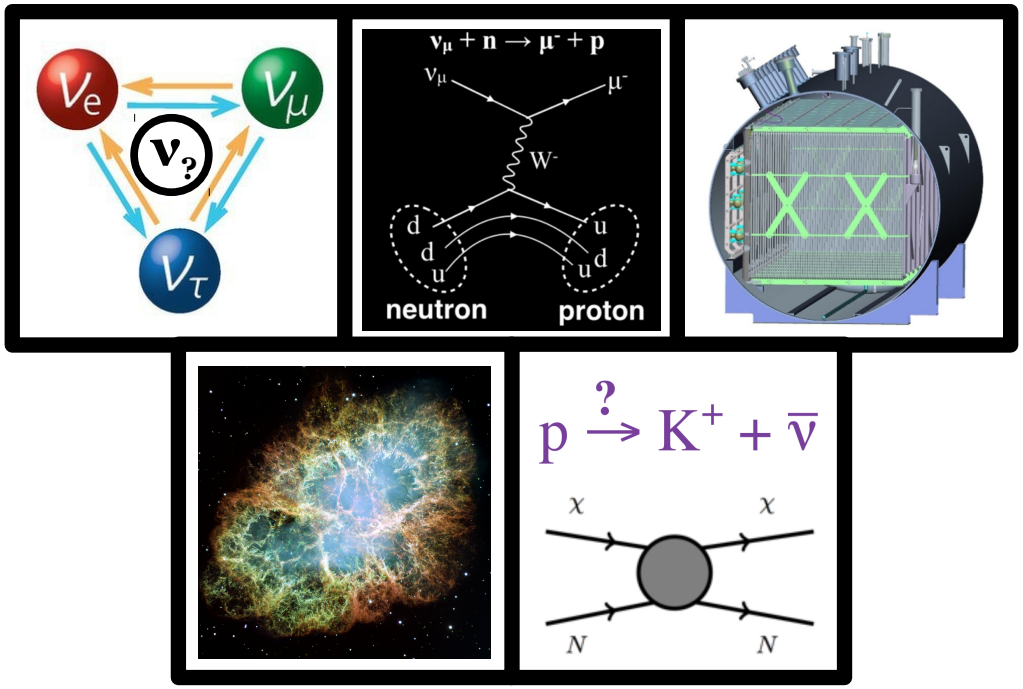
- Within the first year of data-taking, MicroBooNE has written a very sizable data volume to tape: **> 3 PB!**
  - Commissioning a PMT trigger substantially curbed data-taking rate
- Managing data volume has required significant help from SCD… **THANK YOU!**

What's Next?

Oscillation Physics (Investigate MiniBooNE Low-Energy Excess)

Cross-Section Measurements

Detector Physics for LArTPC R&D



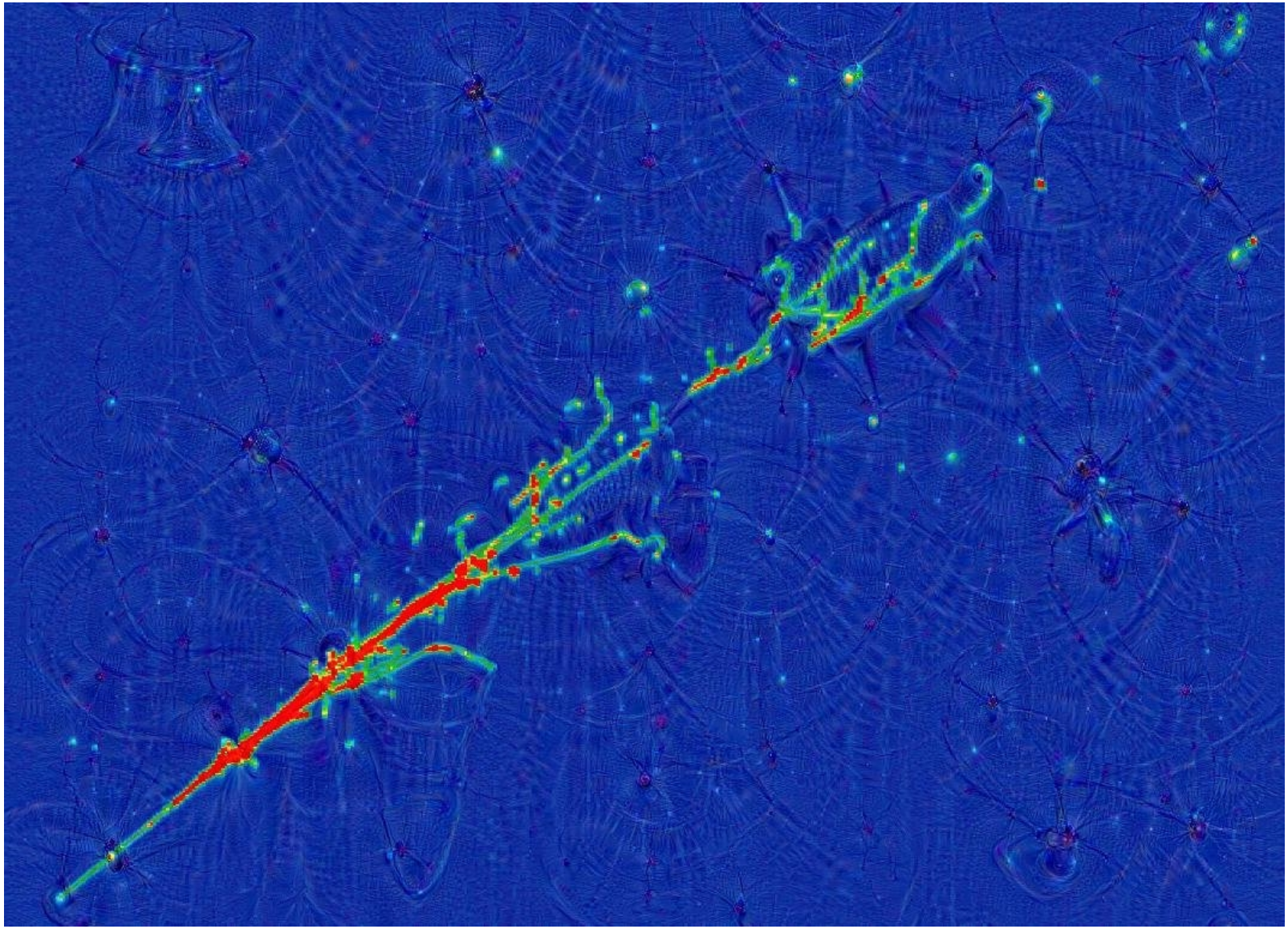
Supernova Neutrino Detection

Exotic Physics

Reflections, Moving Forward

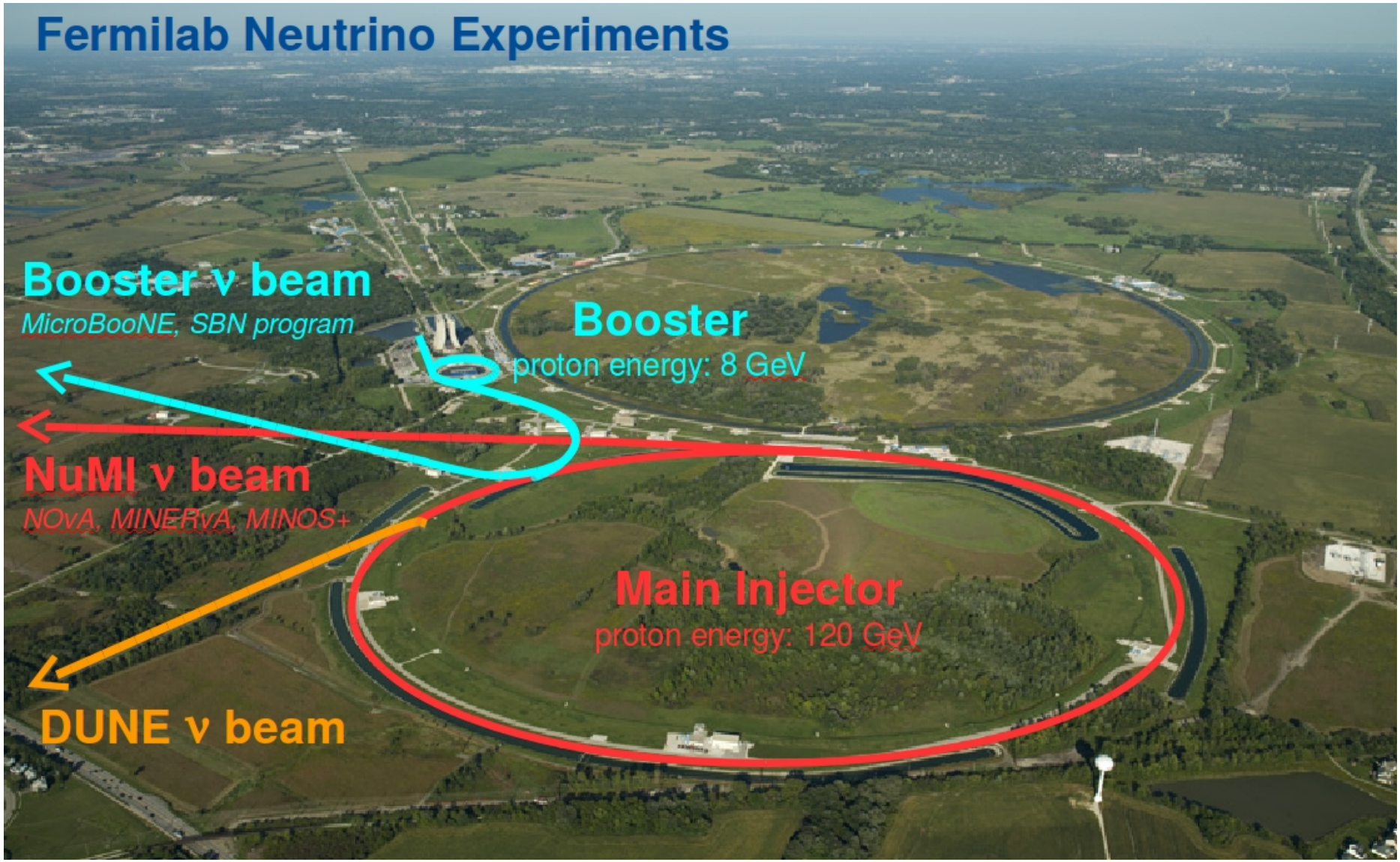
- MicroBooNE has had a **very** successful first year of data-taking
  - Greater than **97%** uptime on average
  - Already received **~50%** of our nominal three-year dataset
  - First public results out utilizing **automated reconstruction**
- Additional results upcoming for **Neutrino 2016** and **ICHEP**
  - Noise characterization
  - MC/data comparisons
  - Reconstruction performance
  - Detector physics
  - First look at neutrino events
- Our focus has been understanding our detector – we are marching carefully toward our primary physics goals

Thanks!

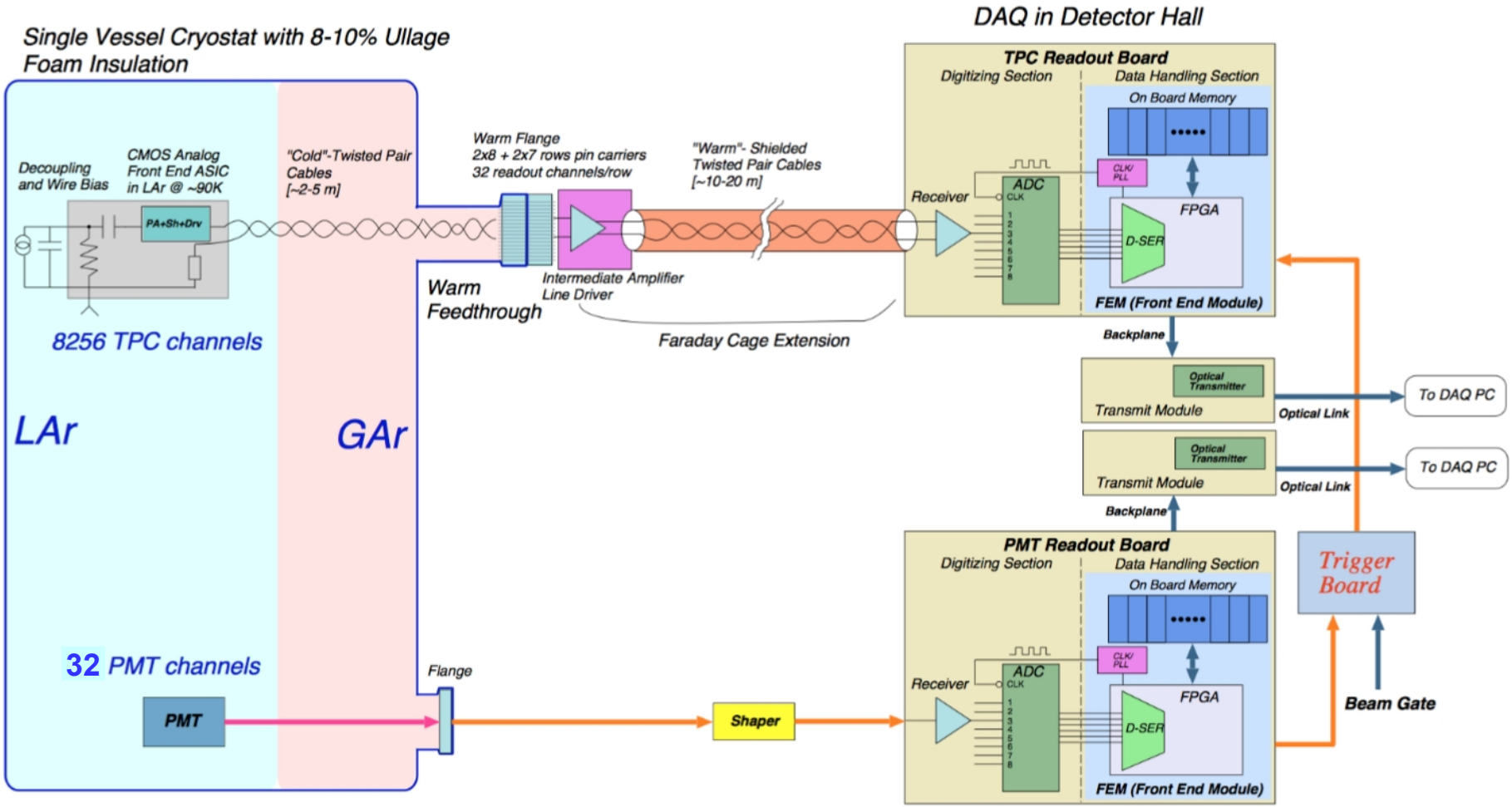


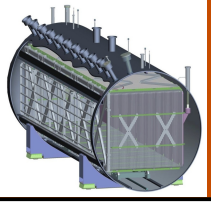
Backup

Aerial View of Fermilab



Electronics Chain





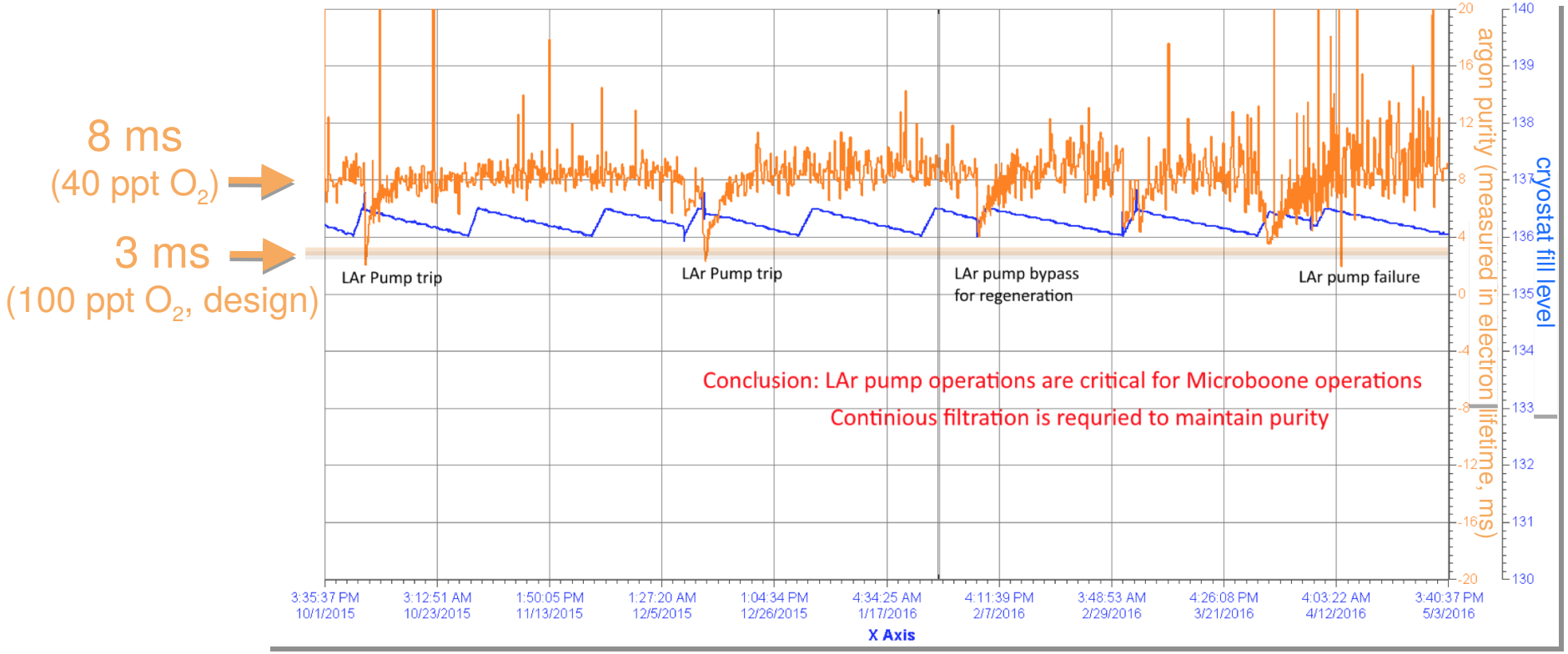
Why Liquid Argon?

Courtesy of M. Soderberg	He	Ne	Ar	Kr	Xe	Water
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120	165	373
Density [g/cm³]	0.125	1.2	1.4	2.4	3	1
Radiation Length [cm]	755.2	24	14	4.9	2.8	36.1
dE/dx [MeV/cm]	0.24	1.4	2.1	3	3.8	1.9
Scintillation [γ/MeV]	19,000	30,000	40,000	25,000	42,000	
Scintillation λ [nm]	80	78	128	150	175	
Approx. Cost [$/kg]	52	330	5	330	1200	

- Argon is cheap: **~1%** of atmosphere!
- Dense target (more ν-N interactions per unit time)
- High scintillation light yield, argon transparent to own light
- Relatively small radiation length for shower containment

Stable Electron Lifetime

- Performance of MicroBooNE cryogenics system excellent throughout data-taking – maintain average argon purity that is consistently above design

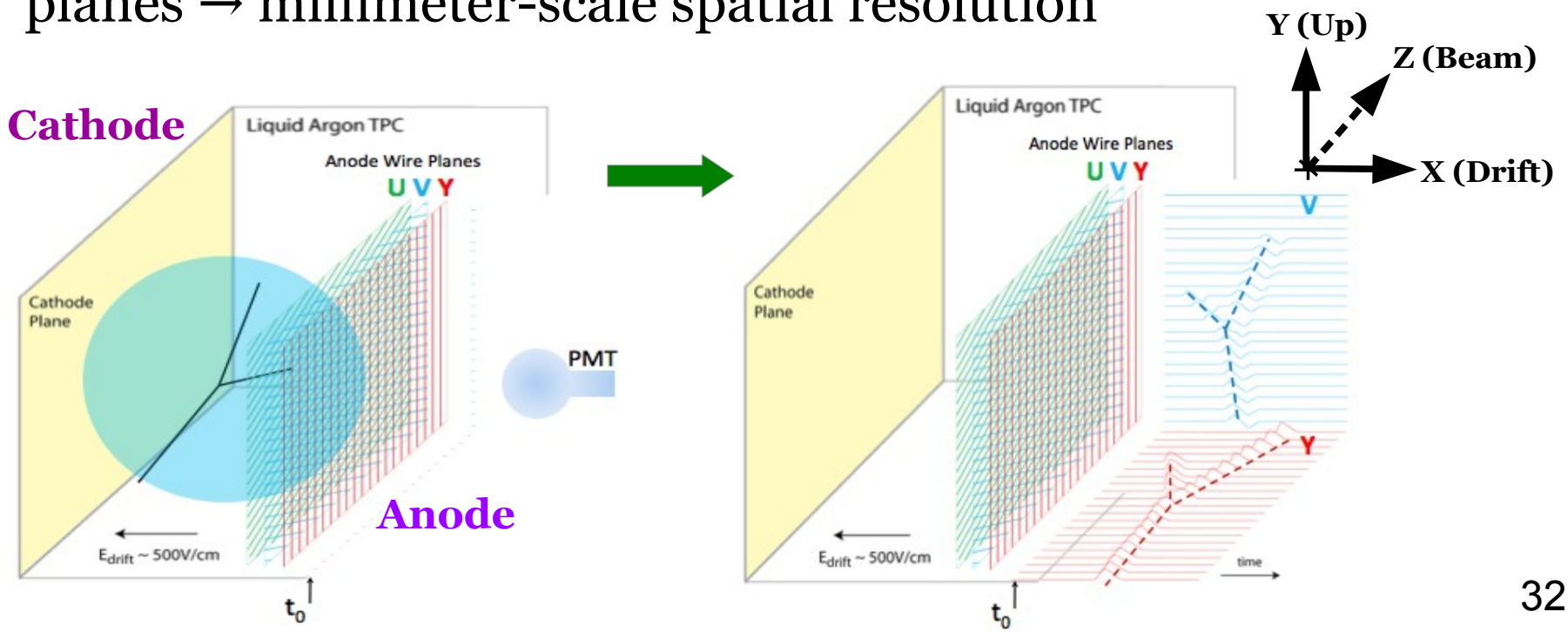


MicroBooNE Detector

- Cryostat allows for LAr purification without evacuation
- Reconstruction of neutrino-Ar interaction events with TPC
  - Signal: ionization electrons drifted to **three** wire planes at anode
  - Front-end electronics in LAr to reduce noise level
- Light collection system: **32** 8" PMTs (and four paddle PMTs)
  - Used for triggering and provides t_0 information (scintillation light)

Time Projection Chamber

- 8256 channels on two **induction** planes (U, V) and one **collection** plane (Y) – ionization puts signal on all three
  - Drift E field at 273 V/cm made ~uniform via surrounding field cage
  - TPC dimensions: **10.3 m** long, **2.3 m** tall, **2.5 m** wide
- 3D event reconstruction by combining signals from all three planes → millimeter-scale spatial resolution

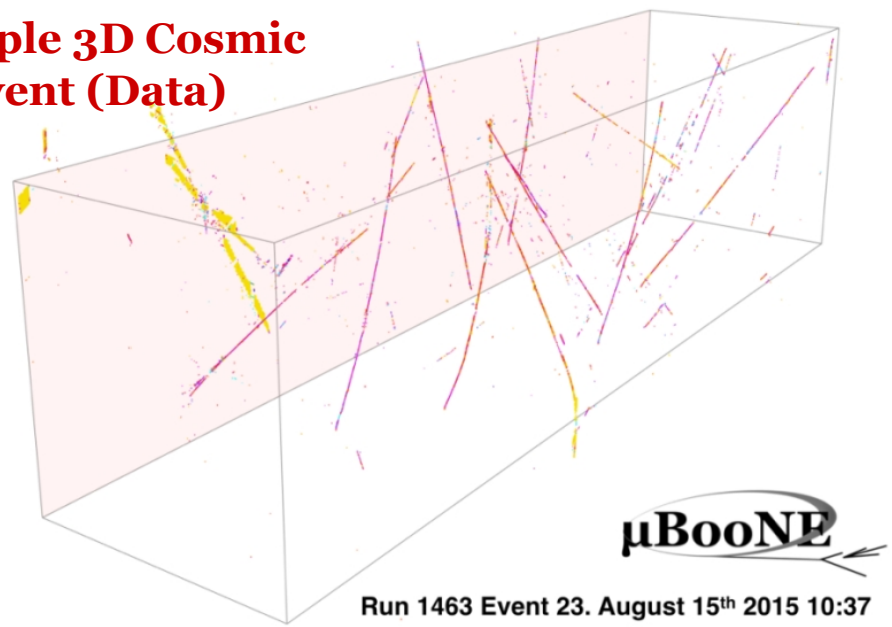


NIM 120 (1974), no. 2, 221-236

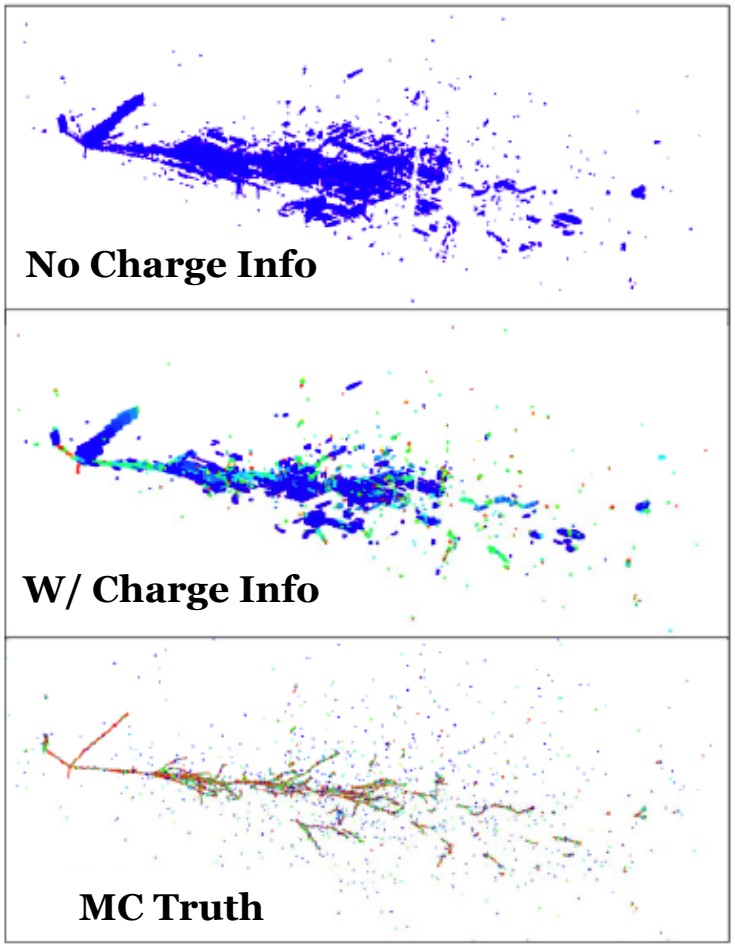
Event Reconstruction

- Multiple ways to get to 3D events:
  - Identify clustered tracks/showers in 2D, match across planes
  - Create 3D hits from wire triplets (matching charge) and directly cluster tracks/showers
    - "Wire-Cell" method (see images)

Example 3D Cosmic Event (Data)



Example MC Interaction Event (2D Projection of 3D)



http://www.phy.bnl.gov/wire-cell/bee/

Ionization Effects

$$dQ = dE \times \frac{W_{ion}}{e^-}$$

$$dE/dx = \frac{e^{\beta W_{ion}\, dQ/dx} - \alpha}{dE/dx\, \beta}$$

$$Q = Q_0 e^{-t/\tau}$$

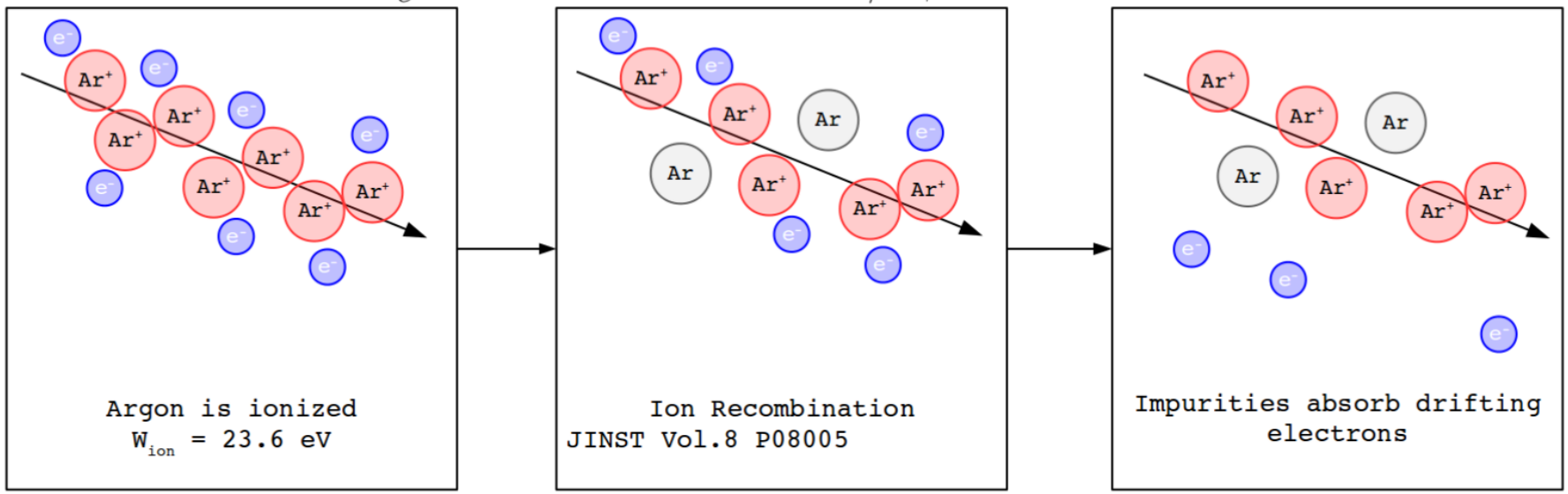
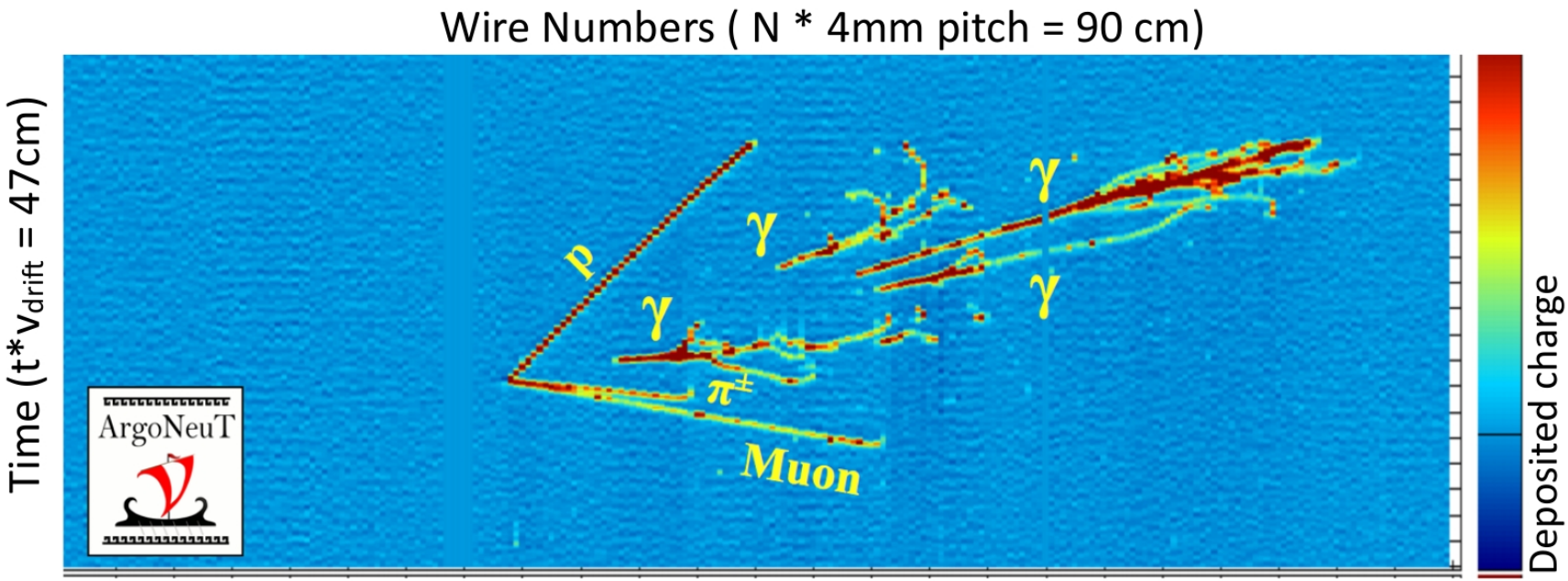


Image Credit: D. Caratelli

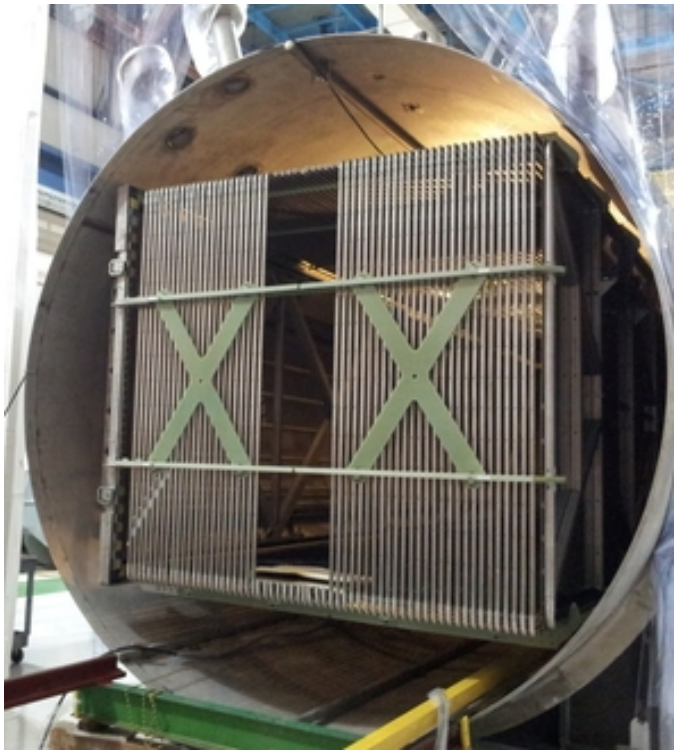
Neutrino Interaction Events



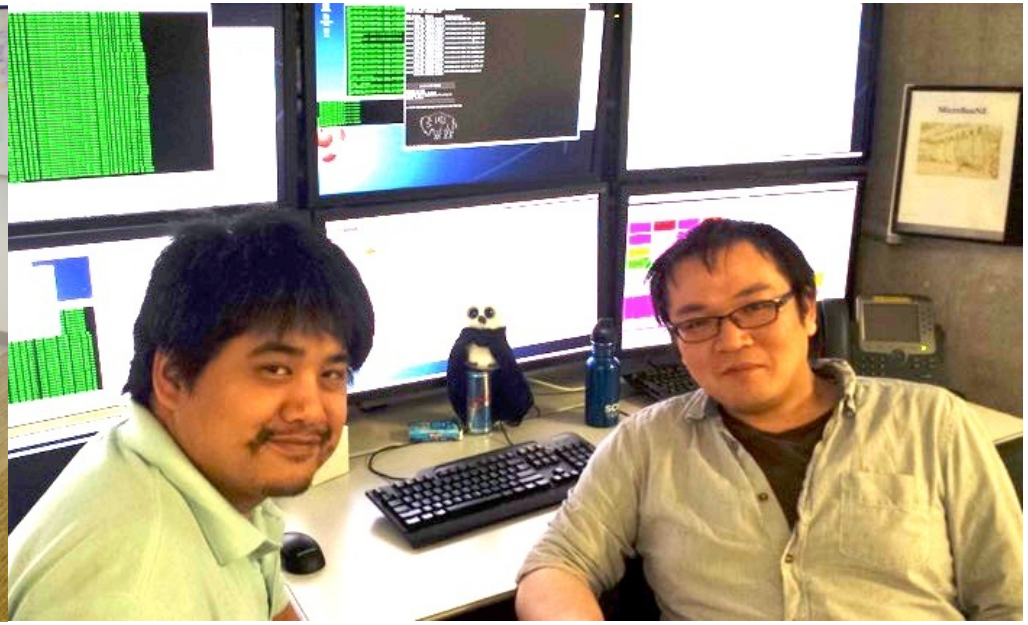
- Example event from ArgoNeuT LArTPC
  - First U.S. LArTPC in a neutrino beam (2009)
- Target event topology: tracks (p, $\pi^{\pm}$, μ) and showers (e, γ) with common vertex

Installation

- MicroBooNE installed in the Liquid Argon Test Facility (LArTF) at Fermilab in **June 2014**
  - TPC construction began in 2013
  - All electronics installed December 2014 → CD-4 on **December 22nd**

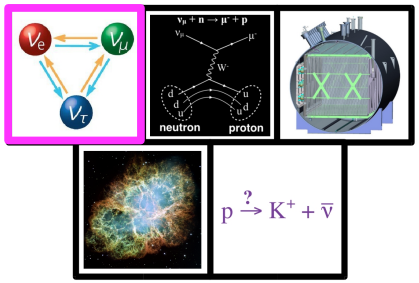


First Operations

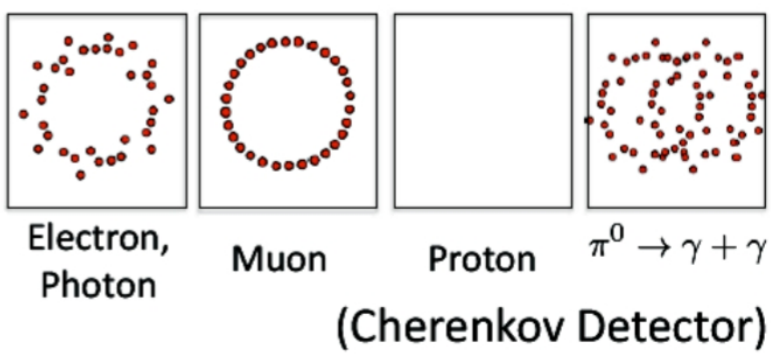


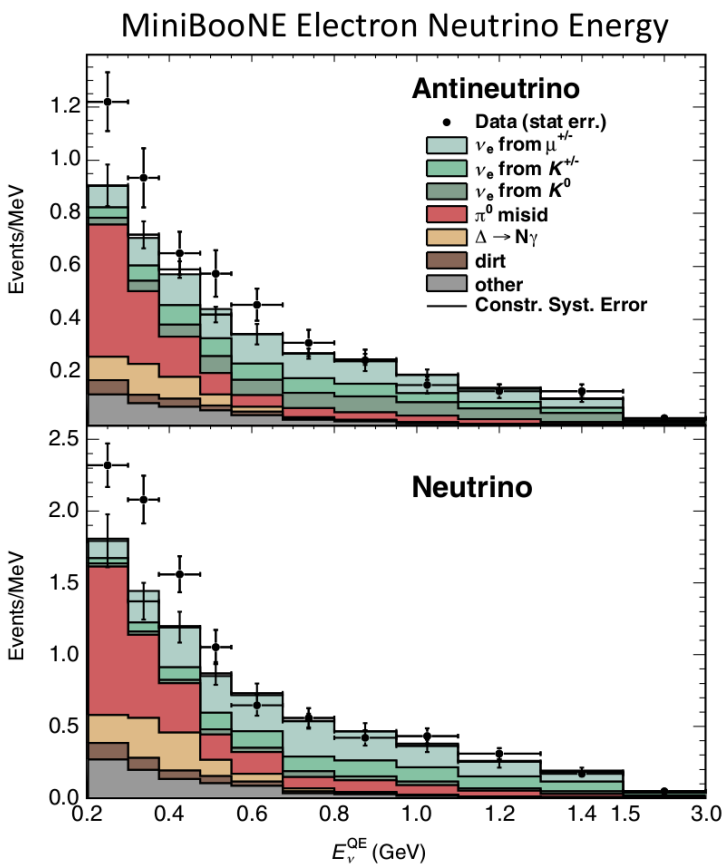
- Shifts began before commissioning finished (June 2015)
  - Two shifters, Mon-Thurs/Fri-Sun blocks, Owl/Day/Evening shifts
  - Since then have moved on to allow one remote shifter
- Operations and DAQ in stable state for first beam
  - Taking data (noise/cosmic runs) since June

Low-Energy Excess



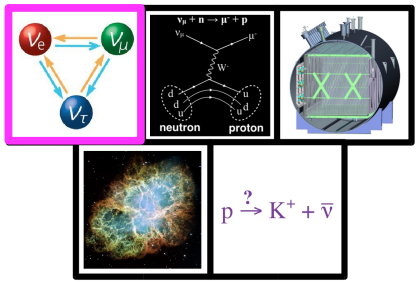
- Low-energy $\nu_e/\bar{\nu}_e$ excess seen at MiniBooNE
  - MiniBooNE: Cherenkov detector (also on BNB)
  - Baseline too short (541 m) for standard $\nu_\mu \rightarrow \nu_e$ oscillation
- No $e^{\pm}/\gamma$ separation… is excess misunderstood background, sterile neutrino, or… ?

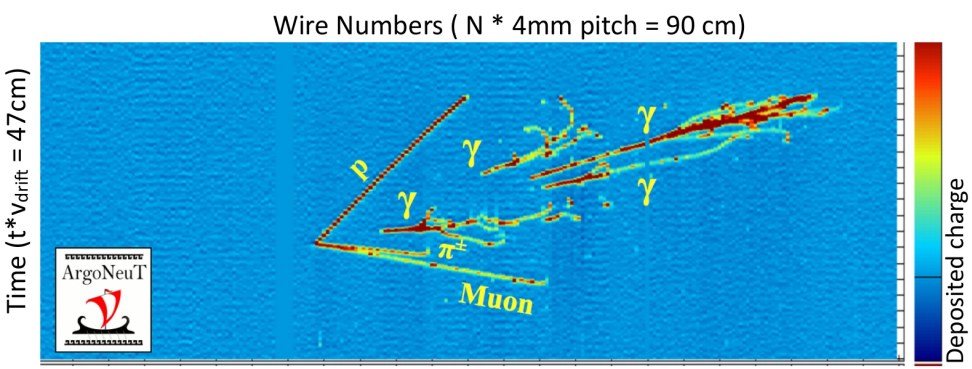


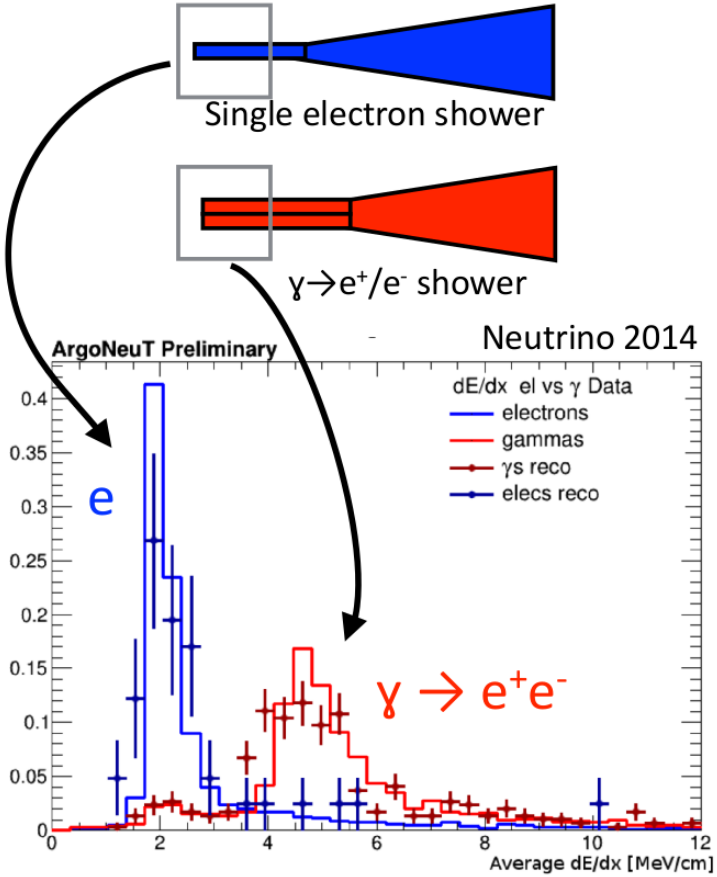


Low-Energy Excess (cont.)

- Can discriminate $e^{\pm}/\gamma$ with MicroBooNE's LArTPC
  - Separation with dE/dx
  - Shower displacement from vertex for γ also provides separation
- Either discover new particle or improve MC for future experiments

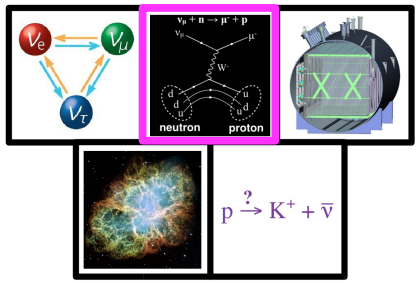


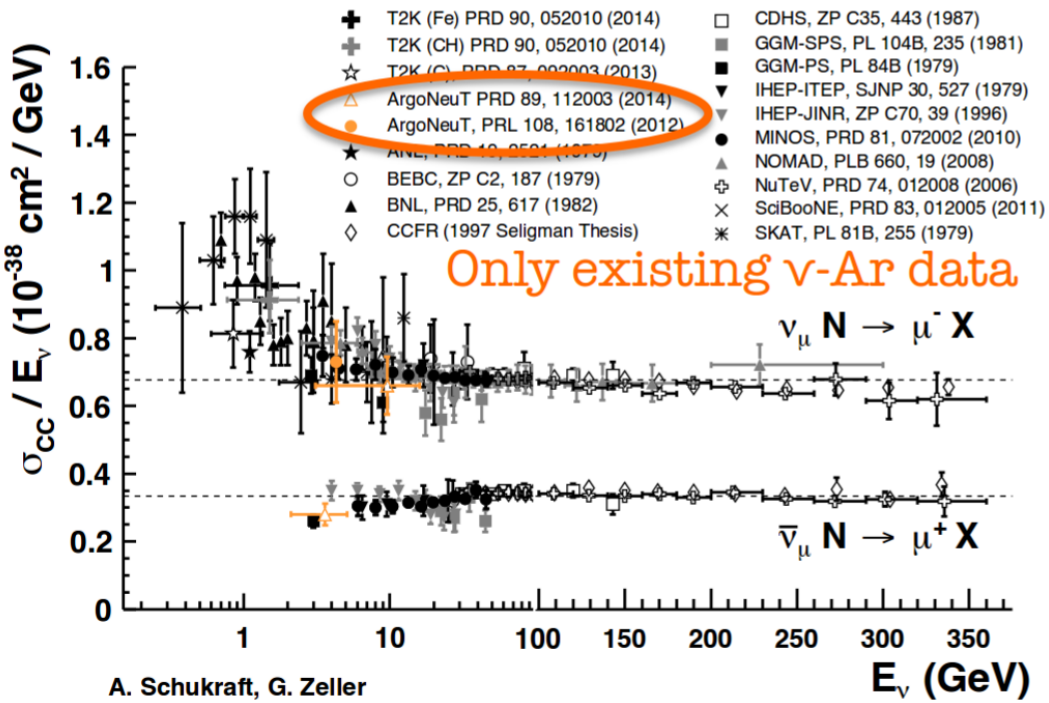


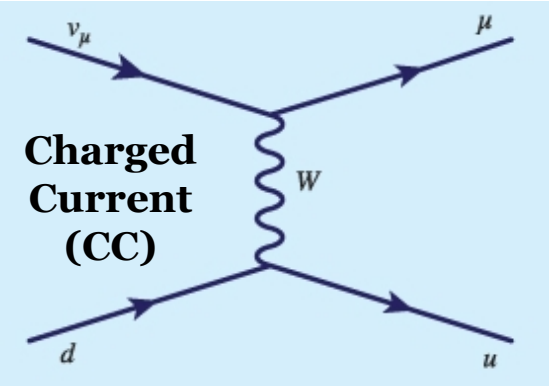


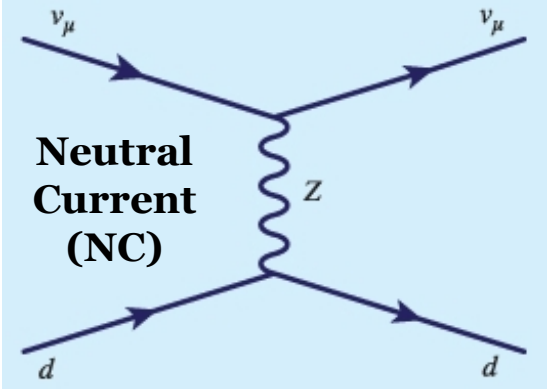
Cross Section Measurements

- Cross-section measurements at MicroBooNE will teach us more about nuclear effects, neutrino energy reconstruction, etc.
  - e.g. nucleon-nucleon correlations
  - Energy range: QE/RES

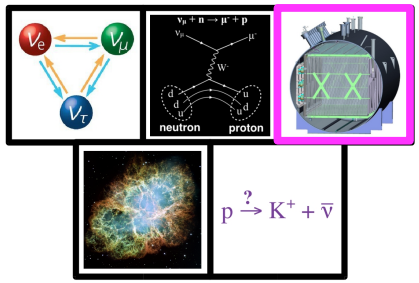






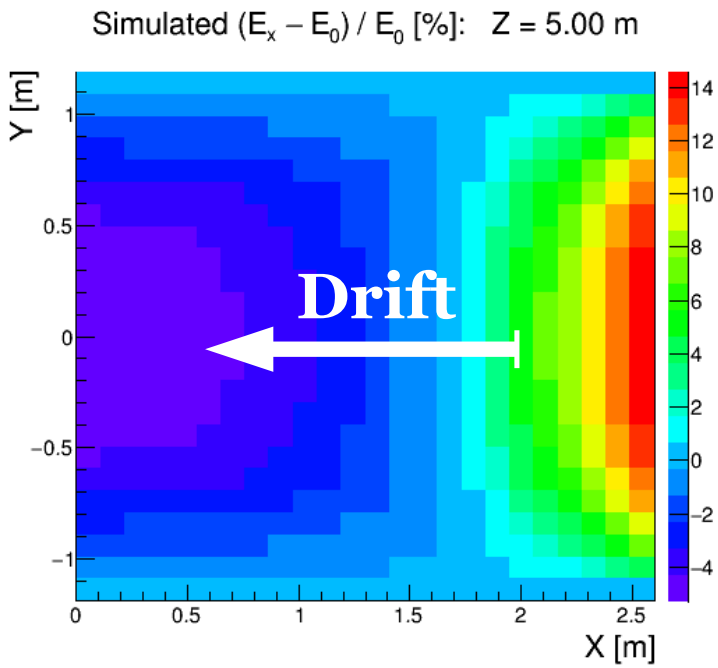


Detector Physics

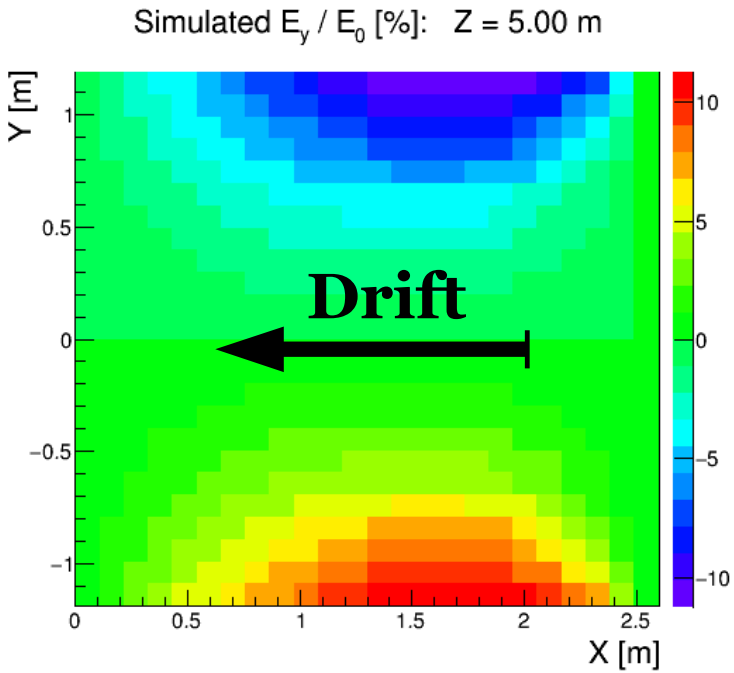


- Must understand detector effects to develop LArTPC technology (essential for SBN/DUNE)
  - Space charge effects (SCE), wire response, energy scale, noise characterization, diffusion, e^- lifetime, etc.

Sim. SCE E-Field Distortions: Drift Direction

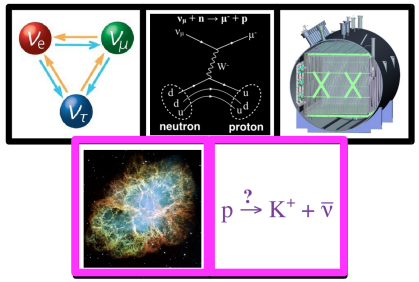


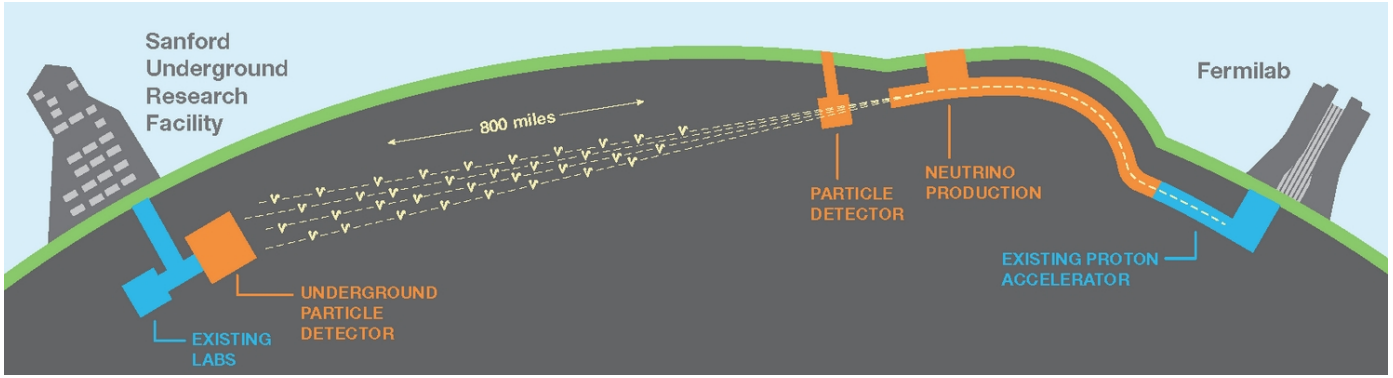
Sim. SCE E-Field Distortions: Lateral Directions



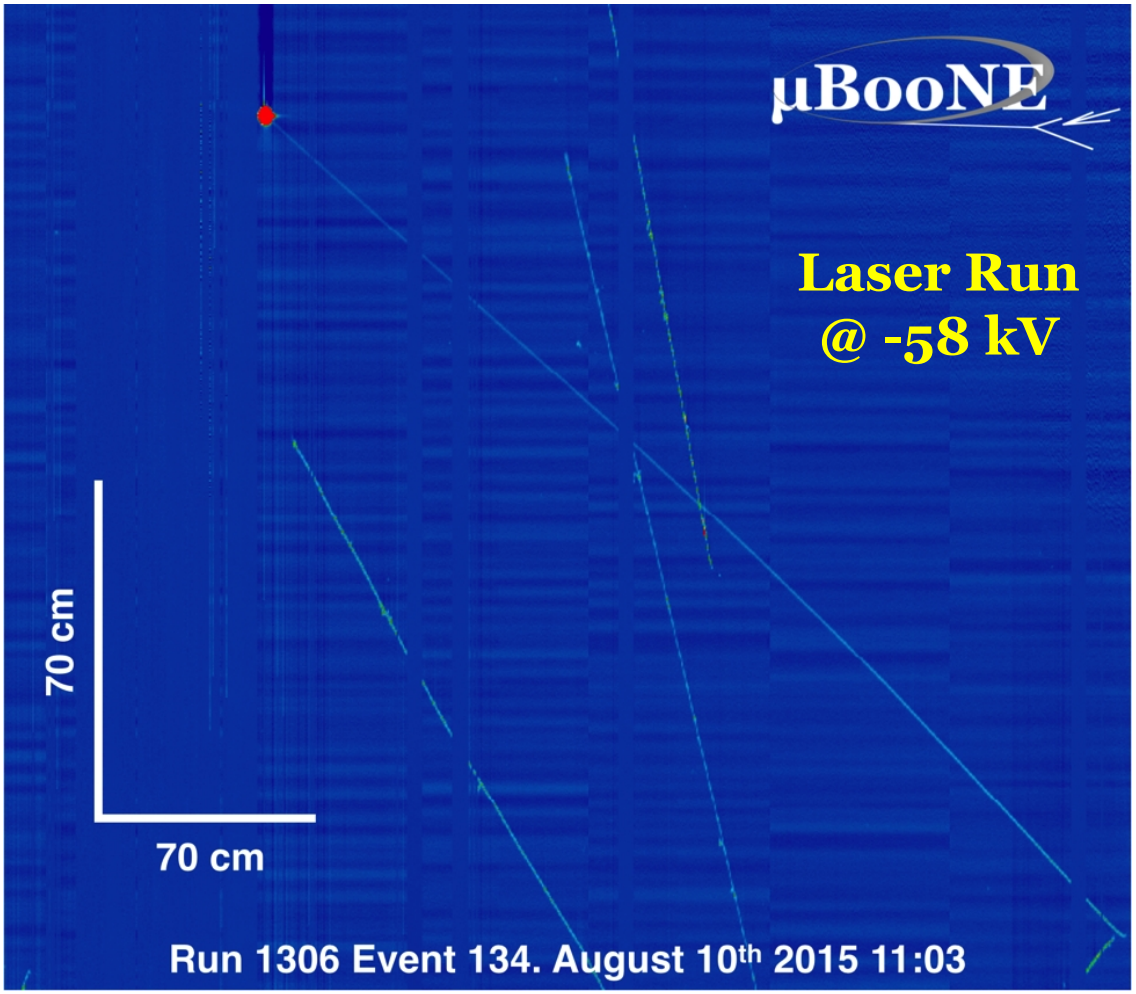
Supernova ν, Proton Decay

- Additional physics topics include supernova neutrino and proton decay searches
  - If we're lucky, supernova neutrinos (~10 MeV) captured using continuous readout stream (two-hour buffer) and SNEWS alert system
  - Can study proton decay backgrounds in MicroBooNE's LArTPC
    - Signal: $\mathbf{p \rightarrow K^+ + \nu}$
    - Background (cosmogenic): $\mathbf{K^0_L + p \rightarrow K^+ + n}$
- Both helpful to physics program at DUNE



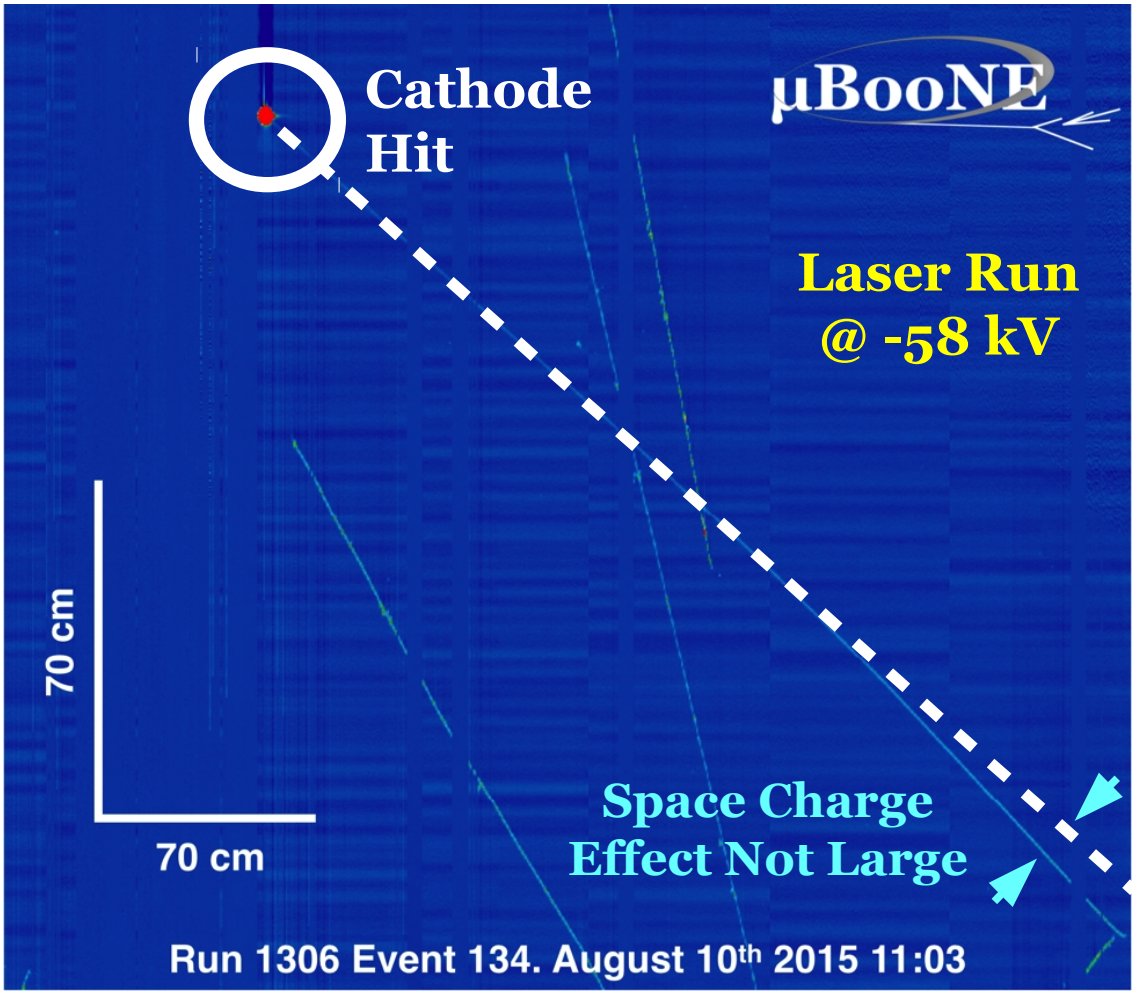


Special Runs



- Also have taken special runs for calibrations and detector physics – laser, cosmic, special ASIC settings, etc.

Special Runs



- Also have taken special runs for calibrations and detector physics – laser, cosmic, special ASIC settings, etc.

Expected BNB Events

1e20 POT (~6 months)

	numu	numubar	nue	nuebar
CC Total	26226	214	223	5.4
CC - QE	14456	117	111	2.5
CC – RES	11413	92	106	2.7
CC – DIS	244	0.2	4.4	0.08
CC - COH	112	4.4	1.3	0.1
NC Total	9809	152	76	2.6
NC - QE	5454	96	39	1.1
NC - RES	4196	54	36	1.4
NC - DIS	79	0.2	1.3	0.03
NC - COH	80	1.5	0.5	0.1