Status and Results from MicroBooNE

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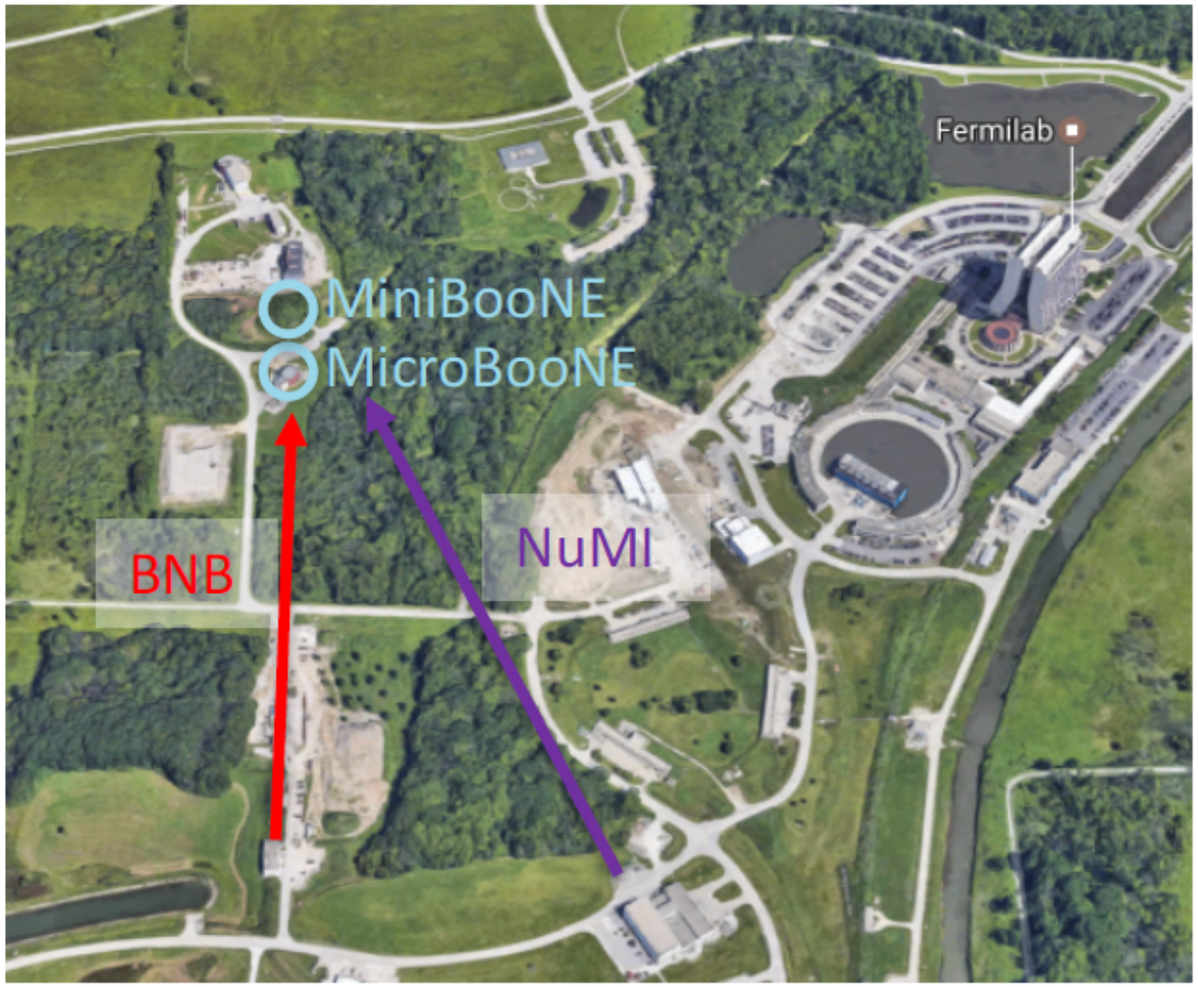
University of Cambridge
on behalf of the MicroBooNE collaboration

Rencontres du Vietnam
18th July 2017

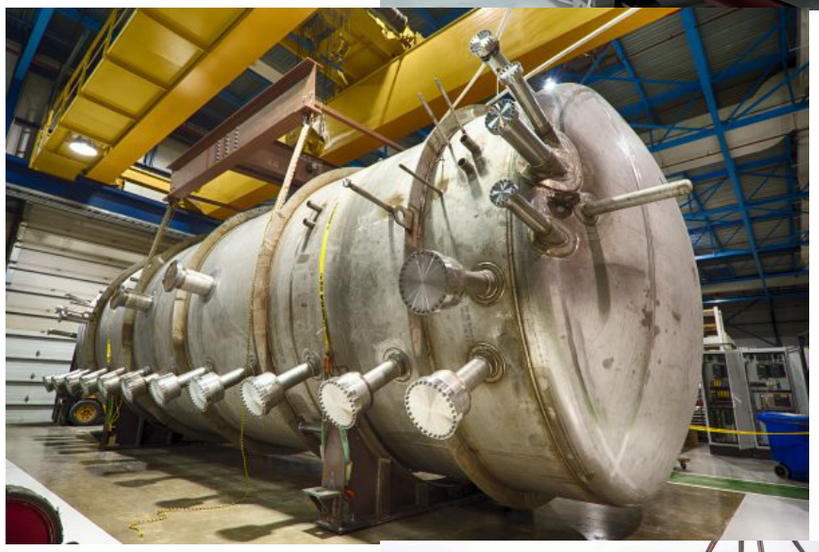
MicroBooNE

Micro Booster Neutrino Experiment



Part of the short baseline neutrino (SBN) program at Fermilab

A Liquid Argon TPC



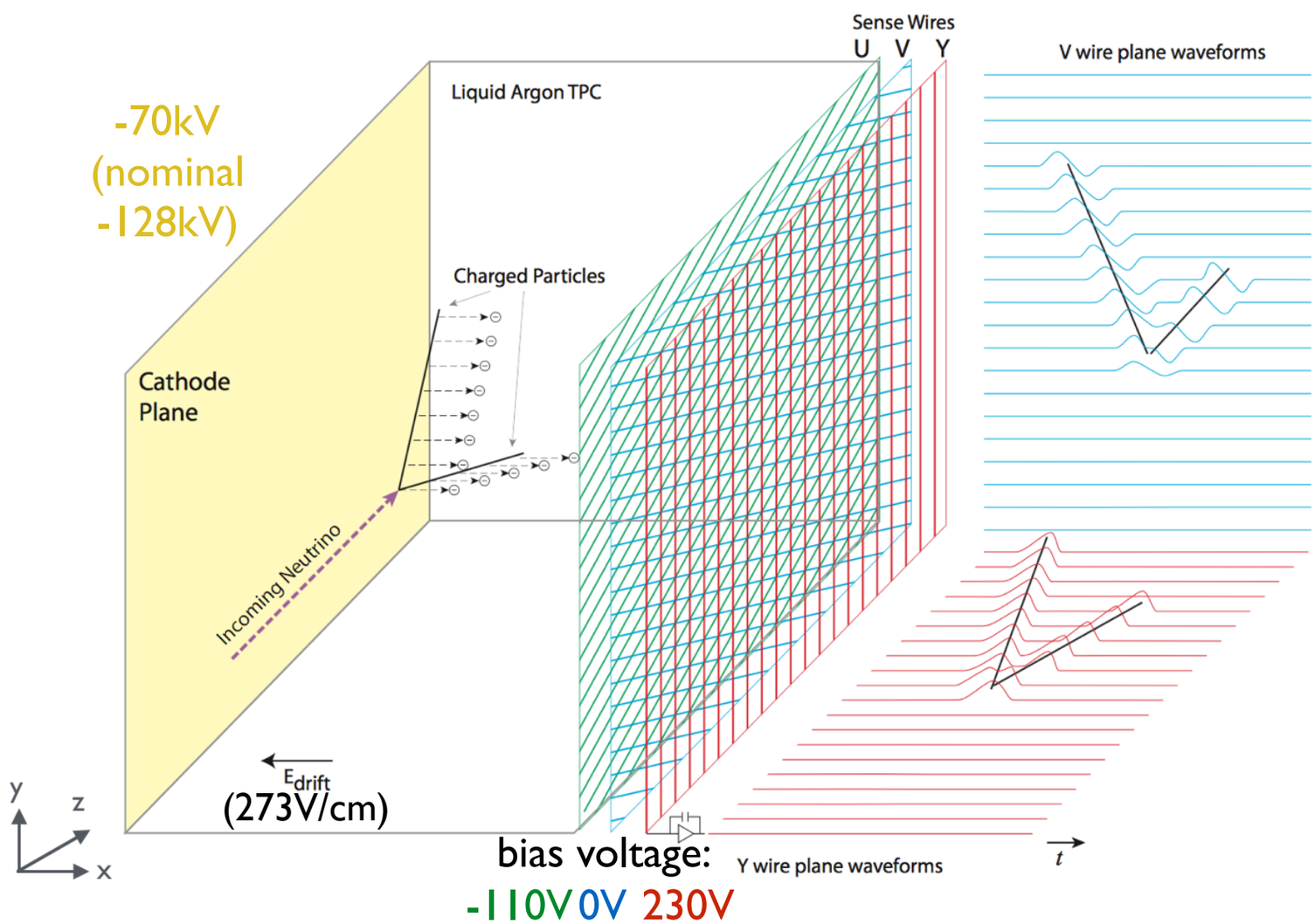
inside its cryostat

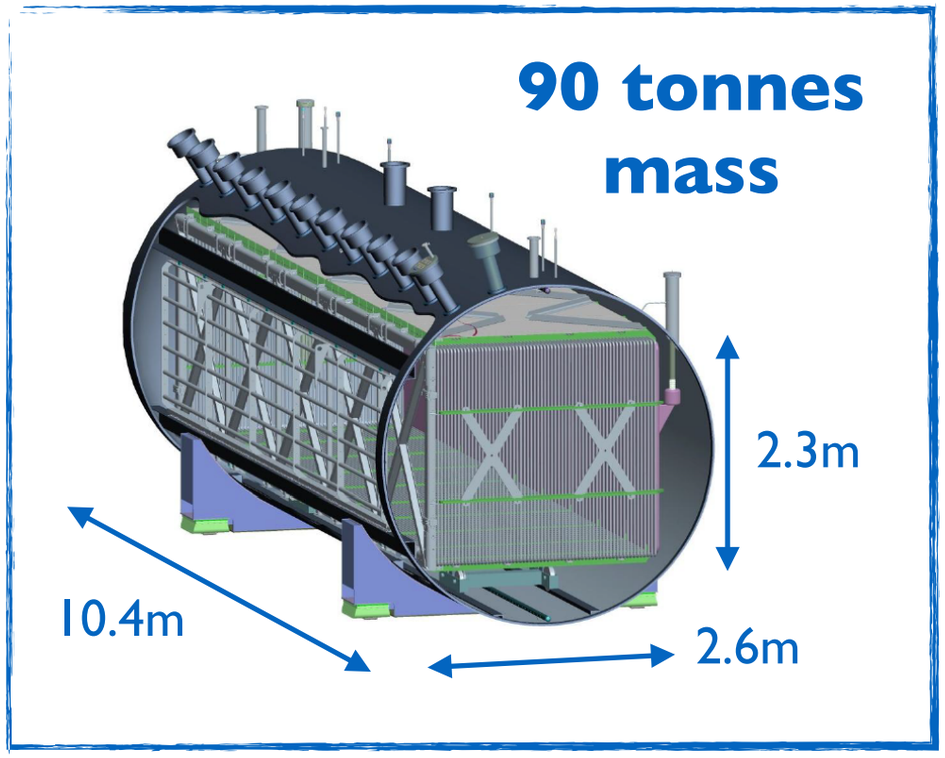
at LArTF (FNAL)

MicroBooNE: a LAr TPC

8256 (3 mm pitch) sense wires in 3 planes:

- The first two planes (U and V) are induction planes with wire orientation +/-60^0.
- The third plane (Y) is the collection plane with wires oriented vertically





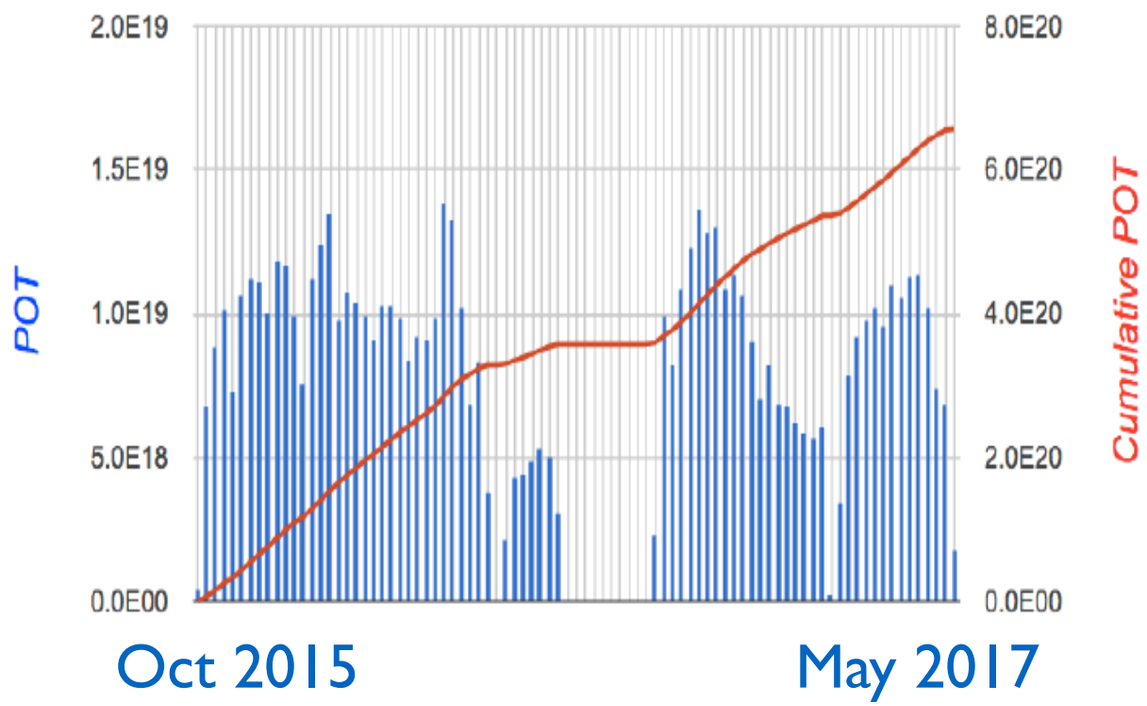
32(+4) PMTs behind the wire planes to record scintillation light and provide trigger information

arxiv:hep-ex/1612.05824 (JINST)

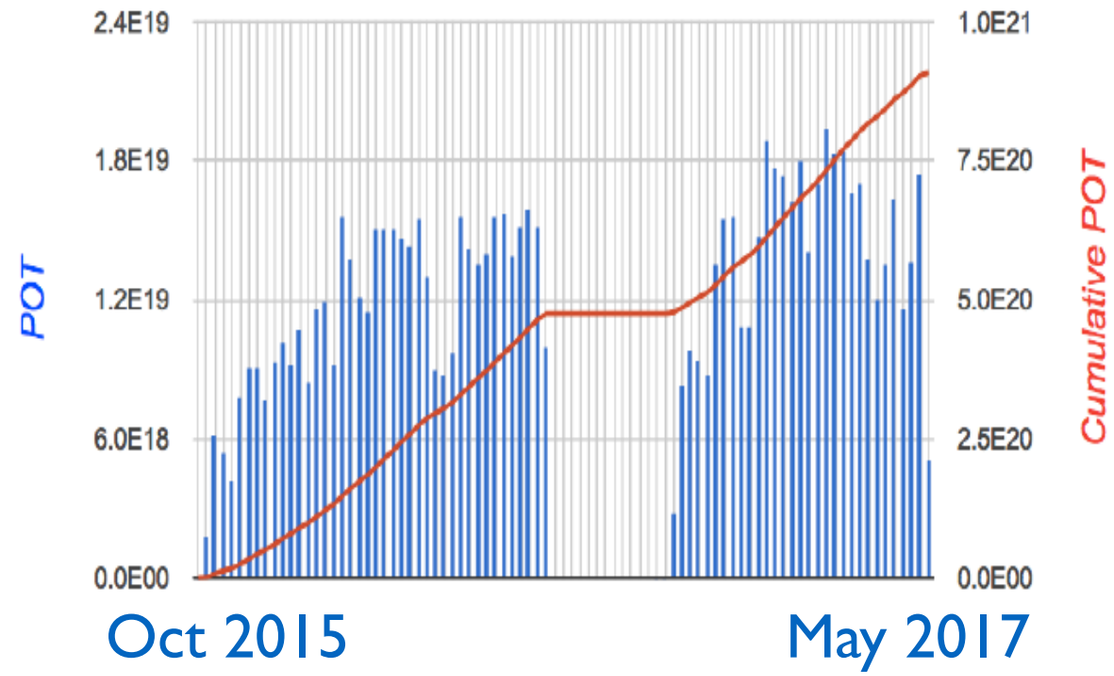
MicroBooNE data taking

Taking neutrino data since fall 2015

BNB POT ~ 5.5e20 POT BNB collected.

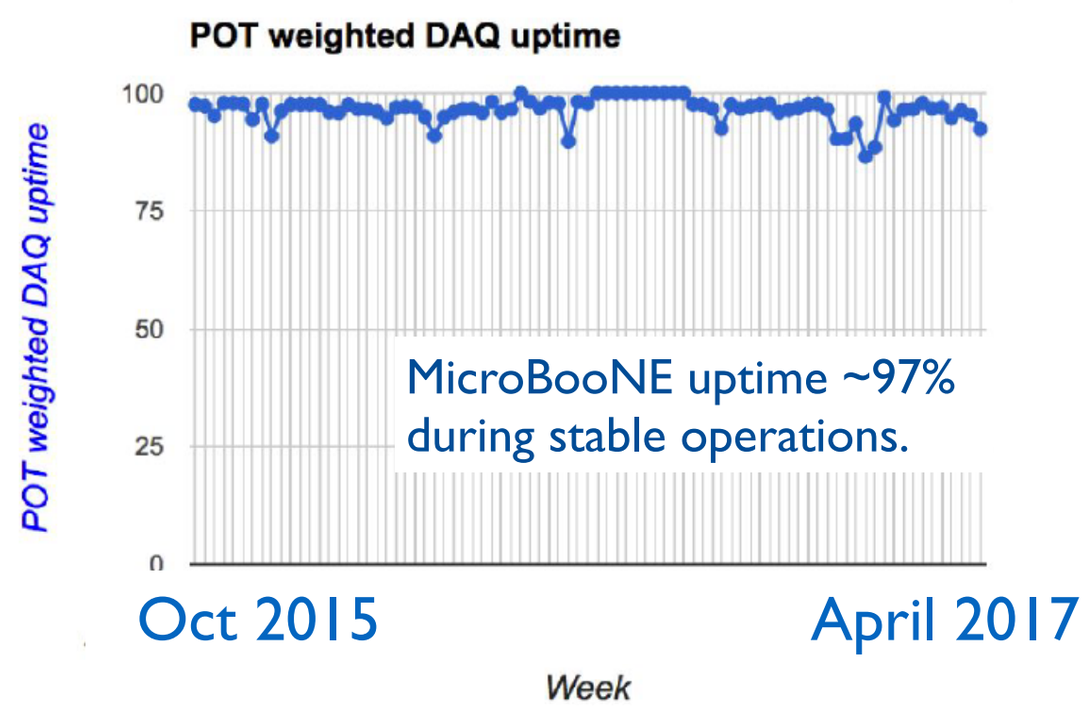


NuMI POT ~7.6e20 POT NuMI collected.

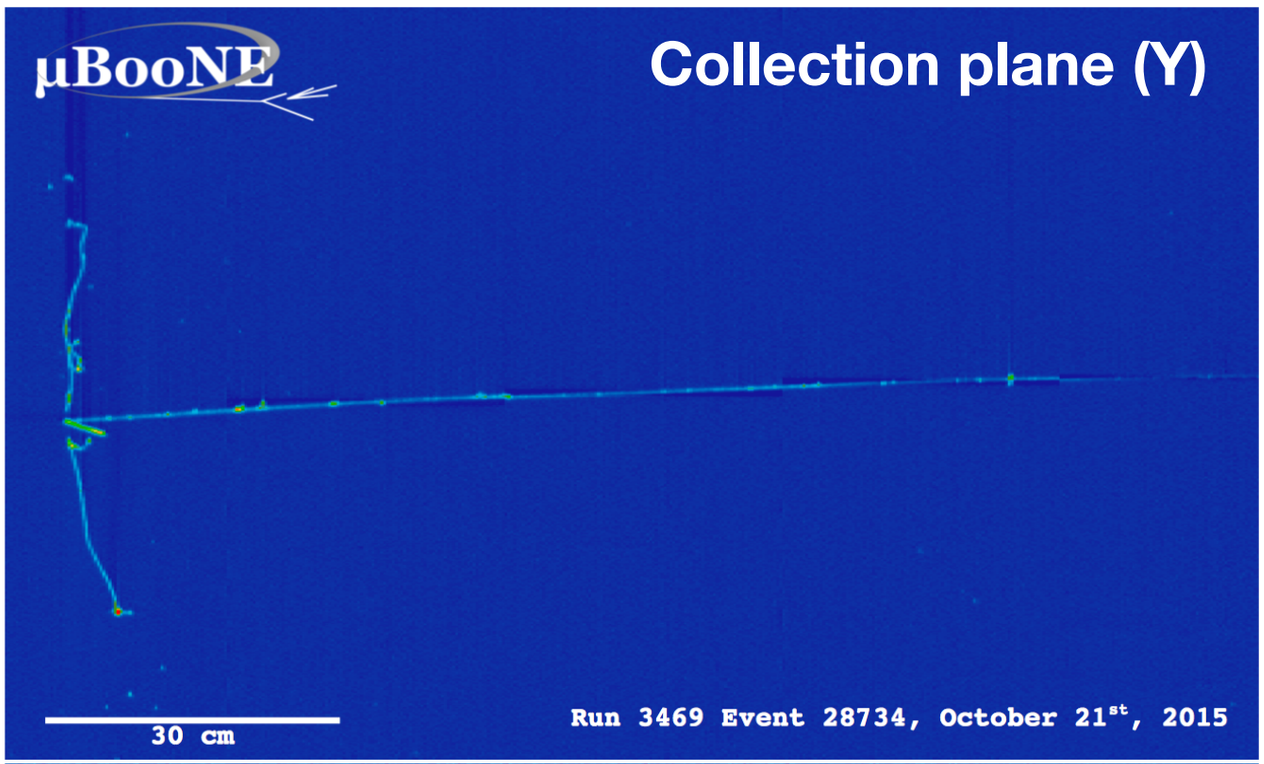


In terms of neutrino interactions for BNB:

~140k ν_μ CC interactions
~55k ν_μ NC interactions



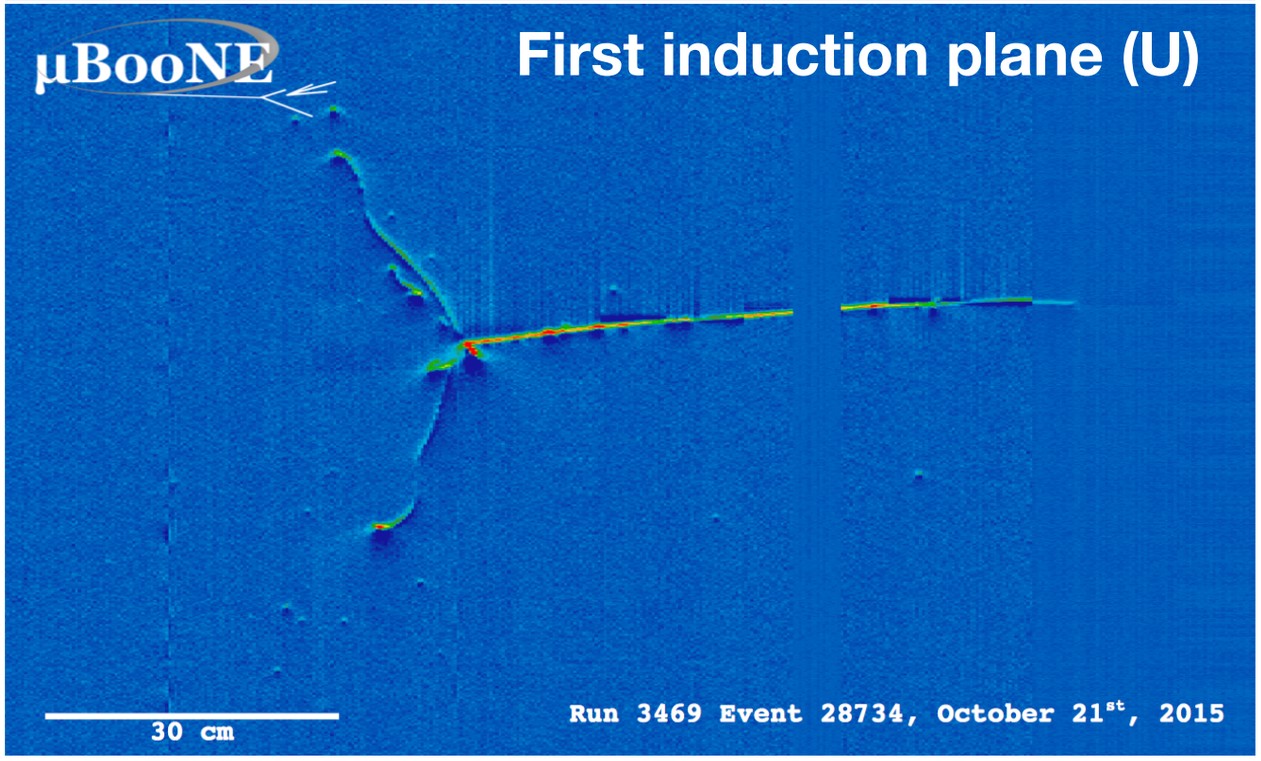
First MicroBooNE neutrino events

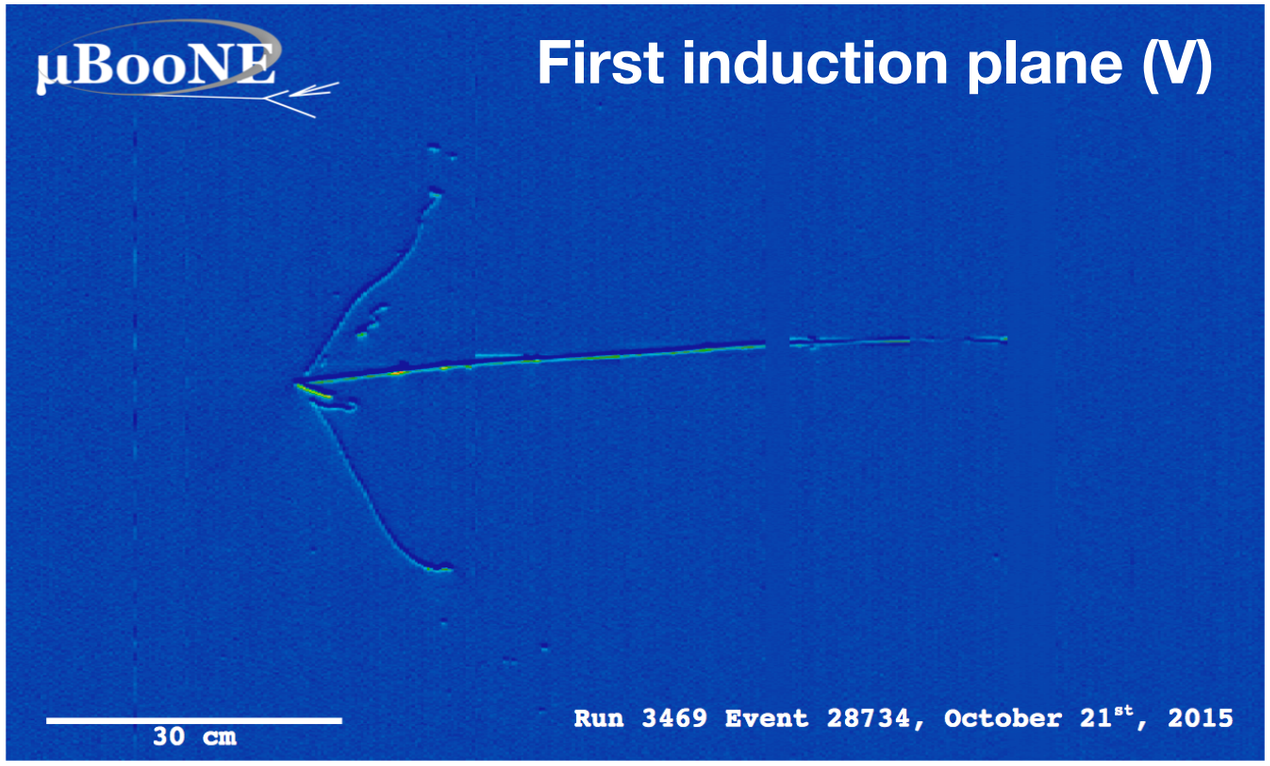


Automated neutrino event selection

- Beam timing coincidence and optical reconstruction
- Identification of neutrino event topologies and TPC reconstruction

***Color scale indicates amount of deposited charge**



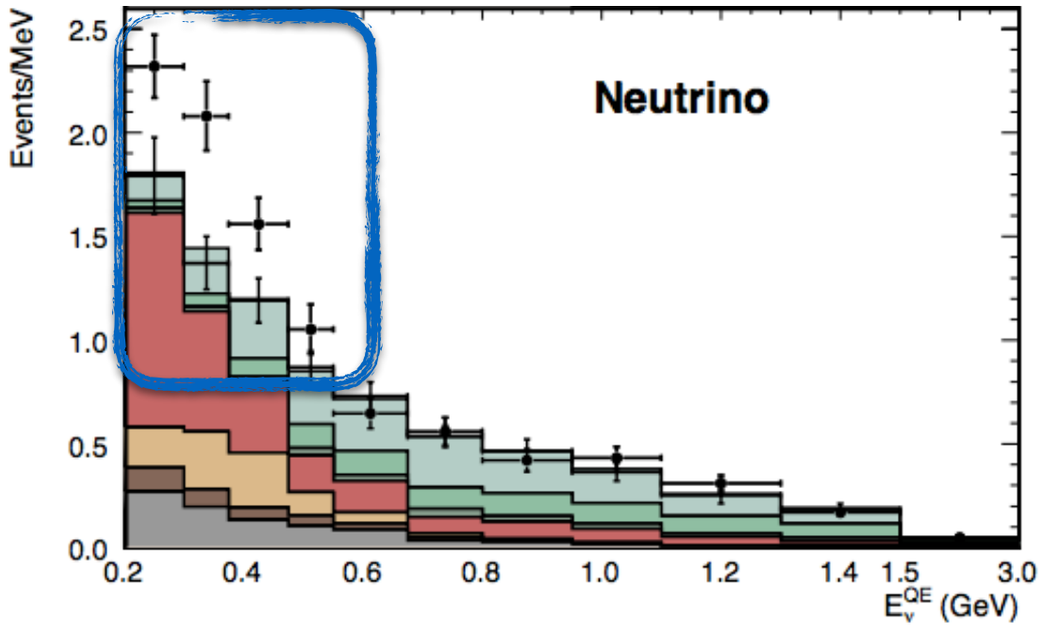


"Modern bubble chamber" images

MicroBooNE public note 1002

Physics goals

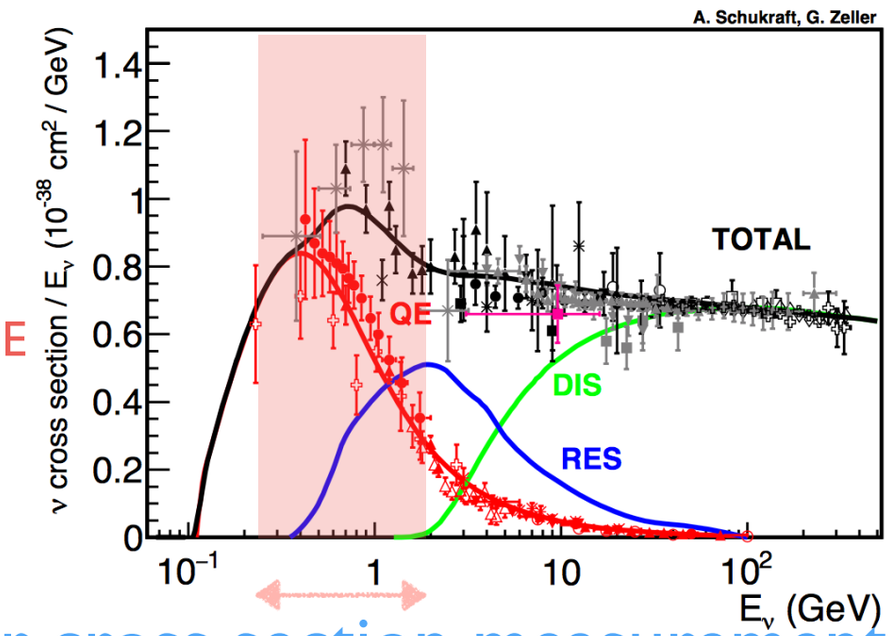
Neutrino Oscillations



Investigate MiniBooNE's low E excess

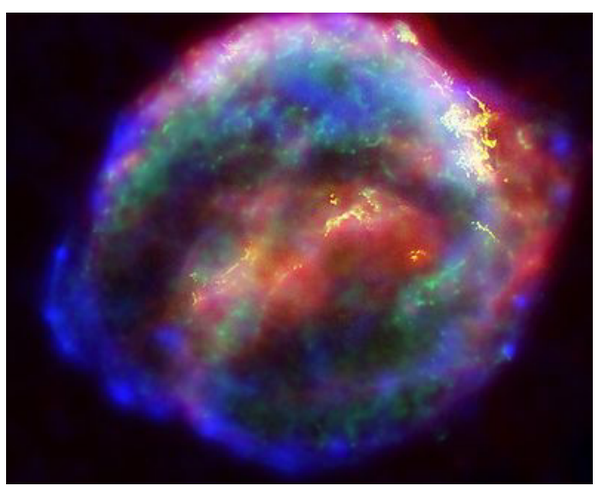
Neutrino Interactions

MicroBooNE E range

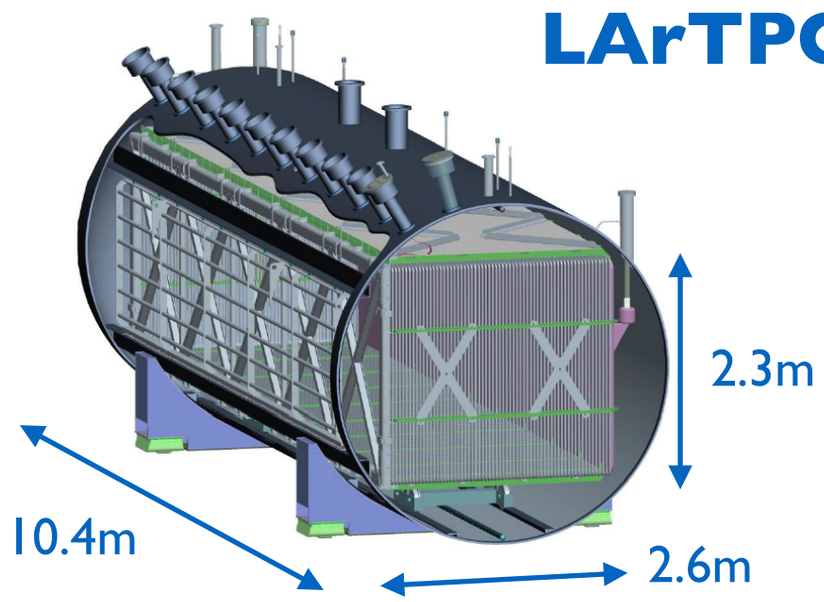


ν-Ar cross section measurements

Supernova neutrinos and Exotic Physics

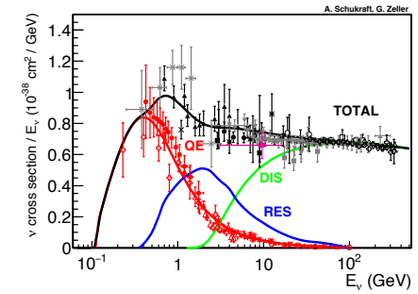


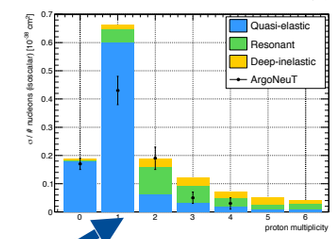
Detector Physics LArTPC R&D

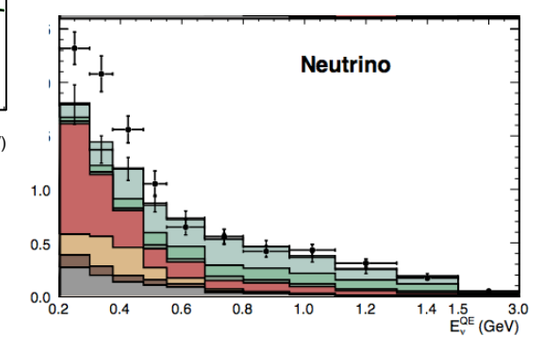


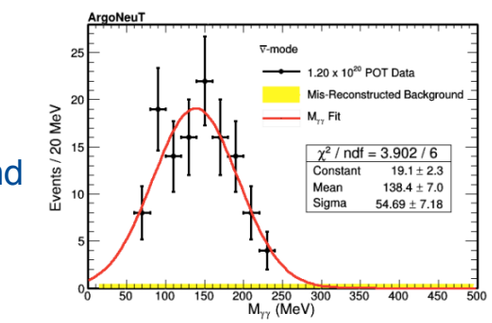
Roadmap

Results









Energy reconstruction and energy scale calibration

Momentum reconstruction

Particle & event ID

Cosmic removal

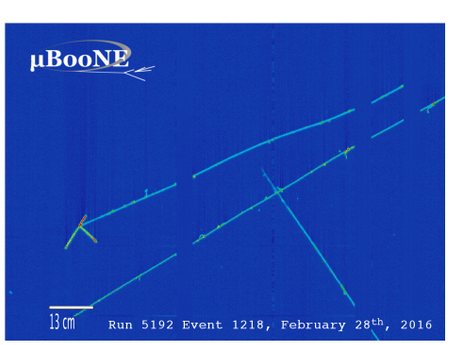
2D & 3D event reconstruction

Noise filtering & signal processing

Detector response calibration & simulation

LAr/e propagation properties

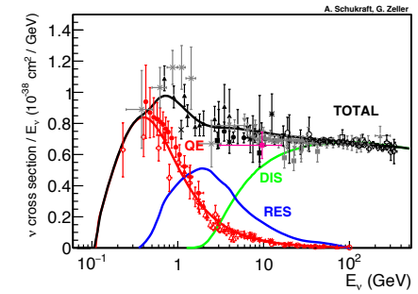
Data

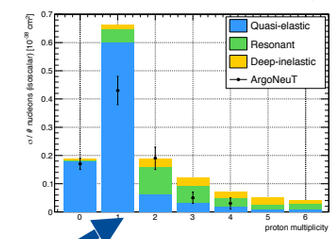


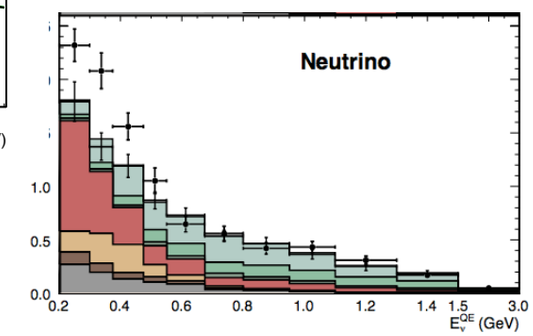
Slide from A. Schukraft

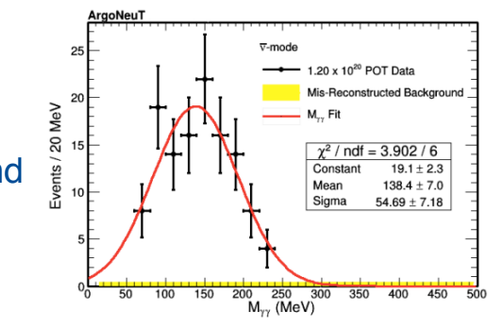
Publications

Results









Michel Electron Reconstruction Using Cosmic-Ray Data from the MicroBooNE LArTPC; arXiv:1704.02927

Determination of muon momentum in the MicroBooNE LArTPC using an improved model of multiple Coulomb scattering; arXiv:1703.06187

Measurement of cosmic-ray reconstruction efficiencies in MicroBooNE using a small external cosmic-ray counter; coming soon

Energy reconstruction and energy scale calibration

Momentum reconstruction

Particle & event ID

Convolutional Neural Networks Applied to Neutrino Events in a Liquid Argon Time Projection Chamber; arXiv: 1611.05531

Cosmic removal

2D & 3D event reconstruction

The Pandora multi-algorithm approach to automated pattern recognition of cosmic-ray muon and neutrino events in the MicroBooNE detector; coming soon

Noise filtering & signal processing

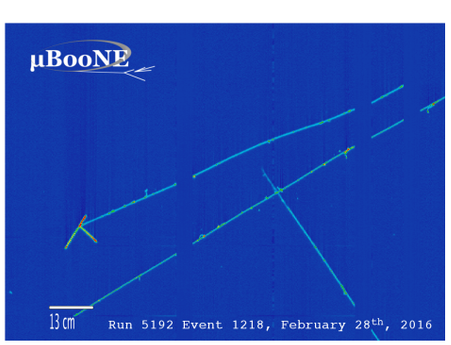
Detector response calibration & simulation

Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC; arXiv:1705.07341

LAr/e propagation properties

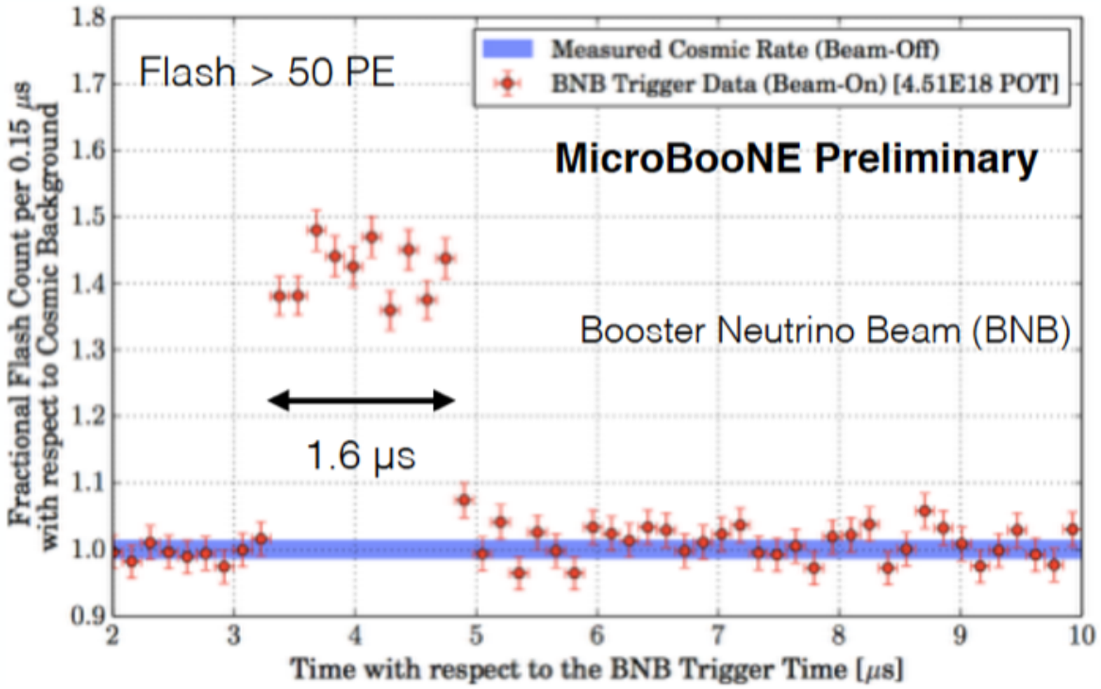
Design and Construction of the MicroBooNE Detector; arXiv:1612.05824

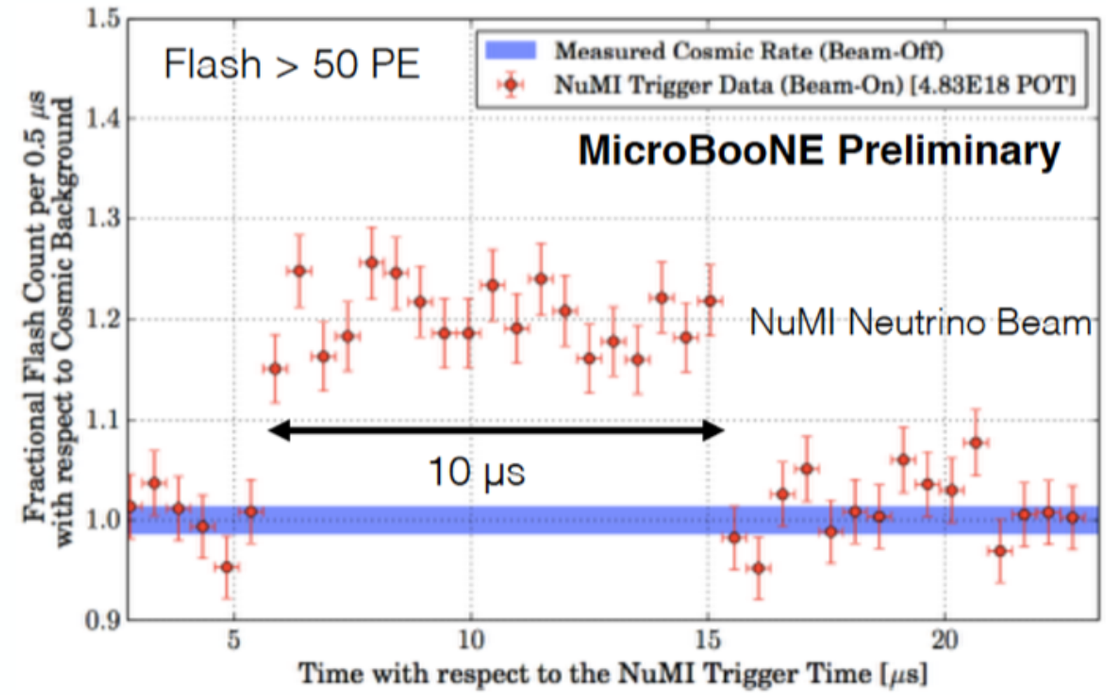
Data



Slide from A. Schukraft

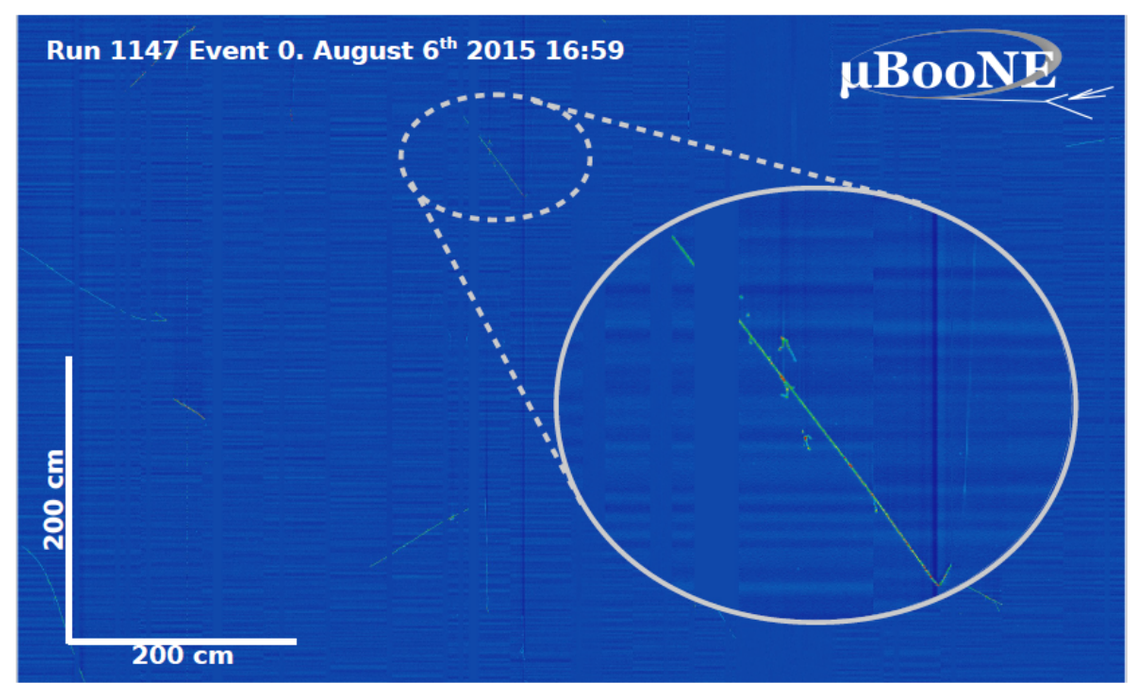
Recording neutrino interactions





multi-PMT coincidences ("flashes")

- Prompt scintillation light detected by the optical system and used as trigger to determine the beam spill period
- The duration of the beam spills is only a fraction of the e^- drift time (~2.3ms) and additional activity is recorded during drift time window due to cosmic rays



MicroBooNE public note 1002

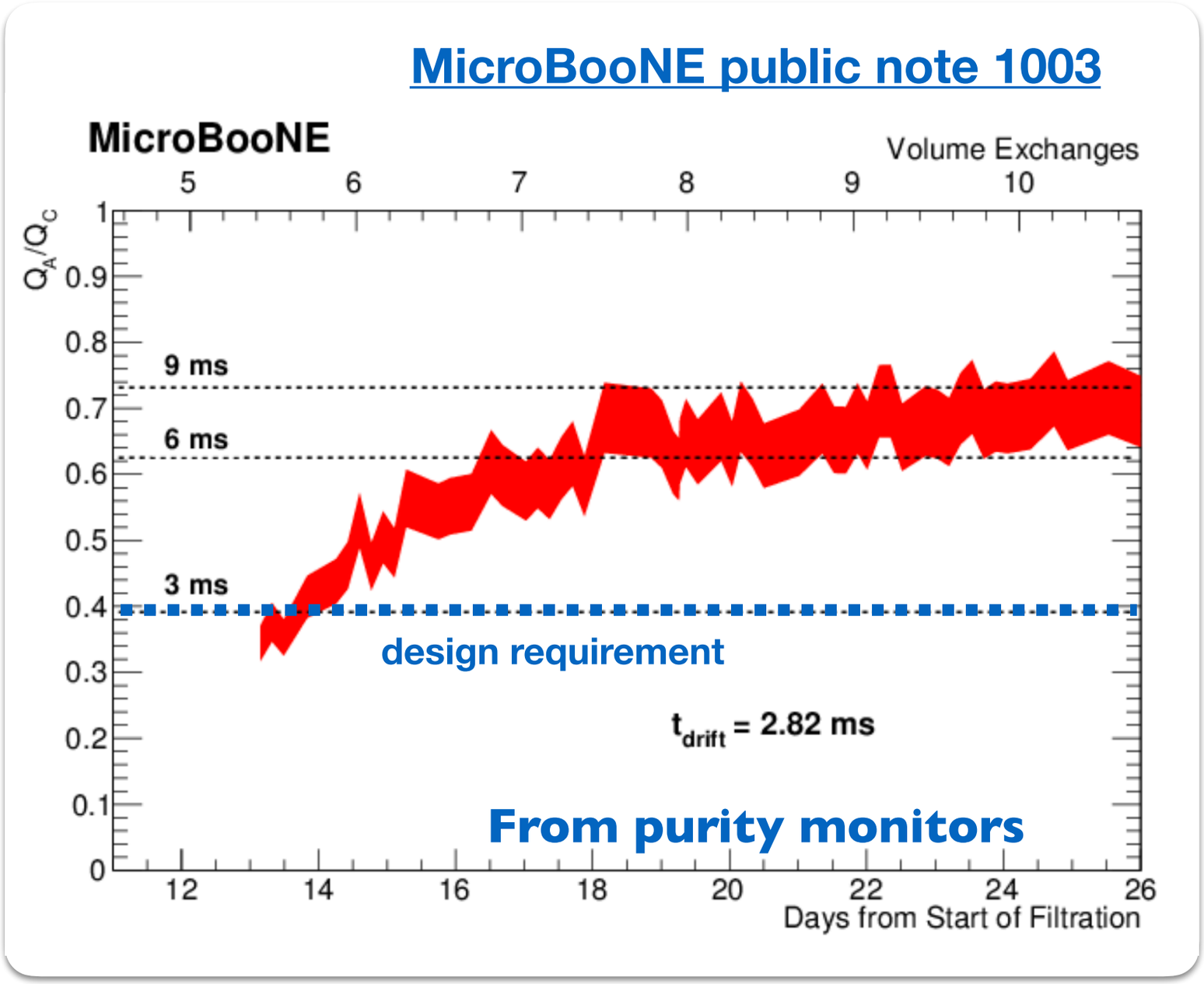
Electron drift and purity

- Long time for electrons to drift from cathode to anode (~2.3 ms)
- High-purity LAr is essential for a LArTPC operation

Main electronegative contaminants: O_2 & H_2O

- Removed:
  - Gasesous purge (April 2015)
  - LAr purification (July 2015)
- Monitored:
  - Gas analyzers
  - Purity monitors (measuring drift time of e^- between their cathodes and anodes)

Within 3 weeks from start of filtration, surpassed design expectation and achieved >= 6ms e^- drift lifetime, maintained since then



Noise

Front-end ASIC inherent noise reduced with operation in cold

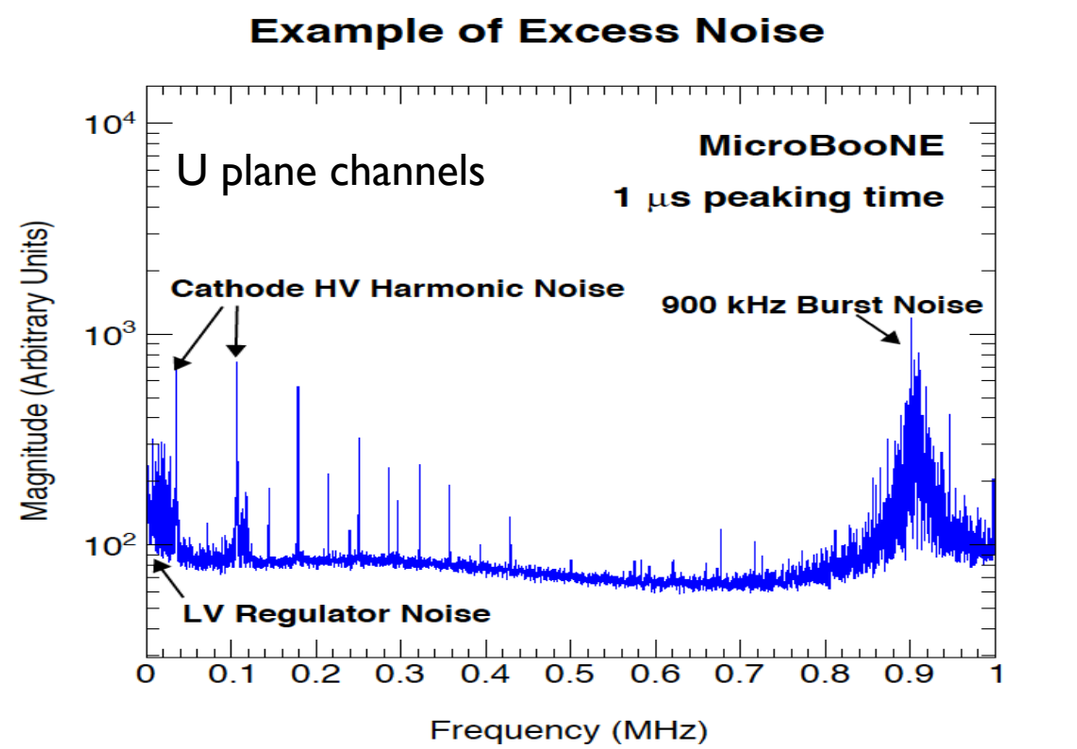
TPC excess noise

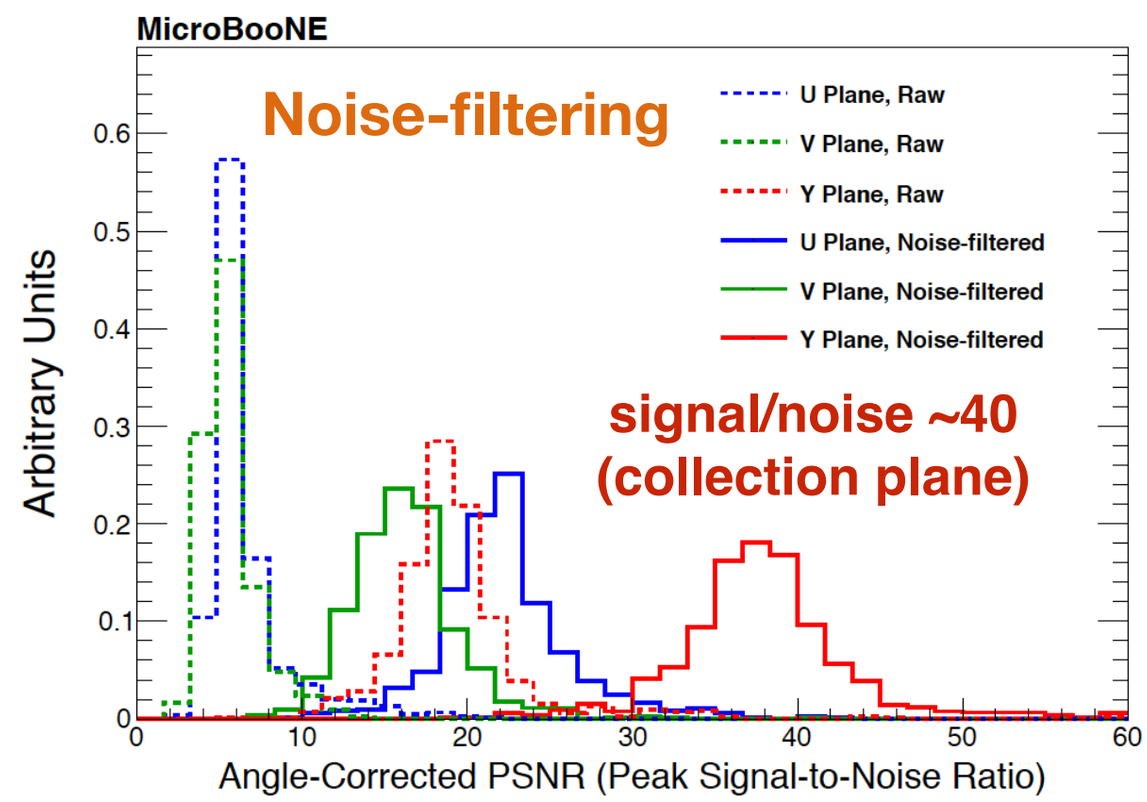
- Coherent noise: induced by the low-voltage regulators
- Harmonic noise: induced by the cathode high-voltage power supply (appearing at odd harmonics of its ripple frequency 36kHz)
- Burst noise at 900kHz, source not confirmed yet (suspected PMT HV supply or interlock system power supply)

With hardware upgrades in summer 2016 (for coherent and harmonic noise) and noise-filtering, greatly improved ratio signal/noise

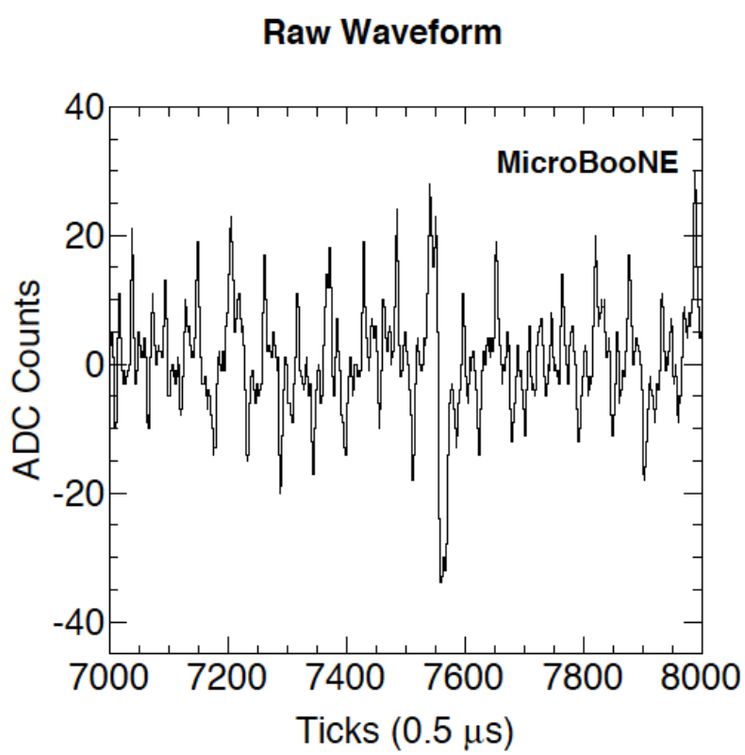
Important LAr R&D results!

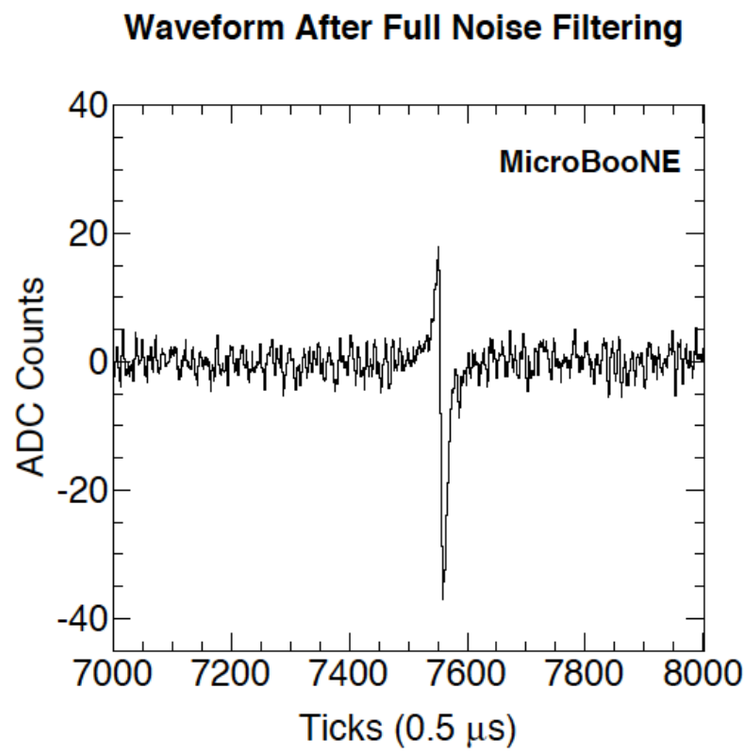
arxiv:hep-ex/1705.07341 (submitted to JINST)





Noise filtering

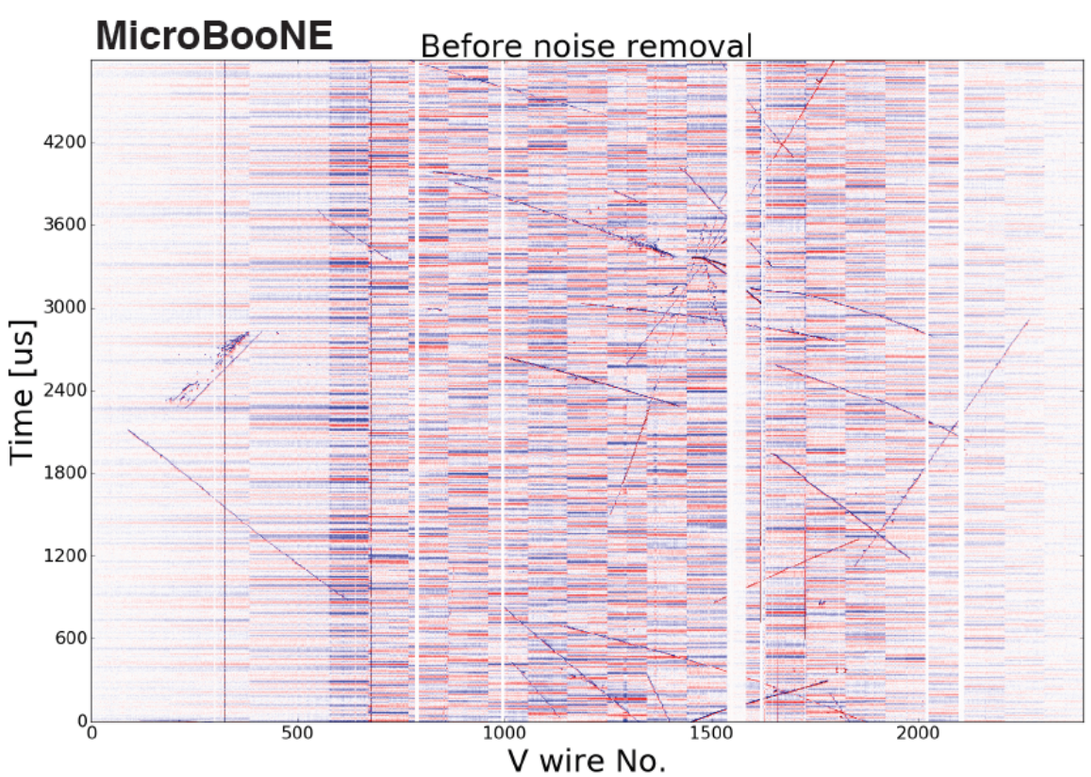


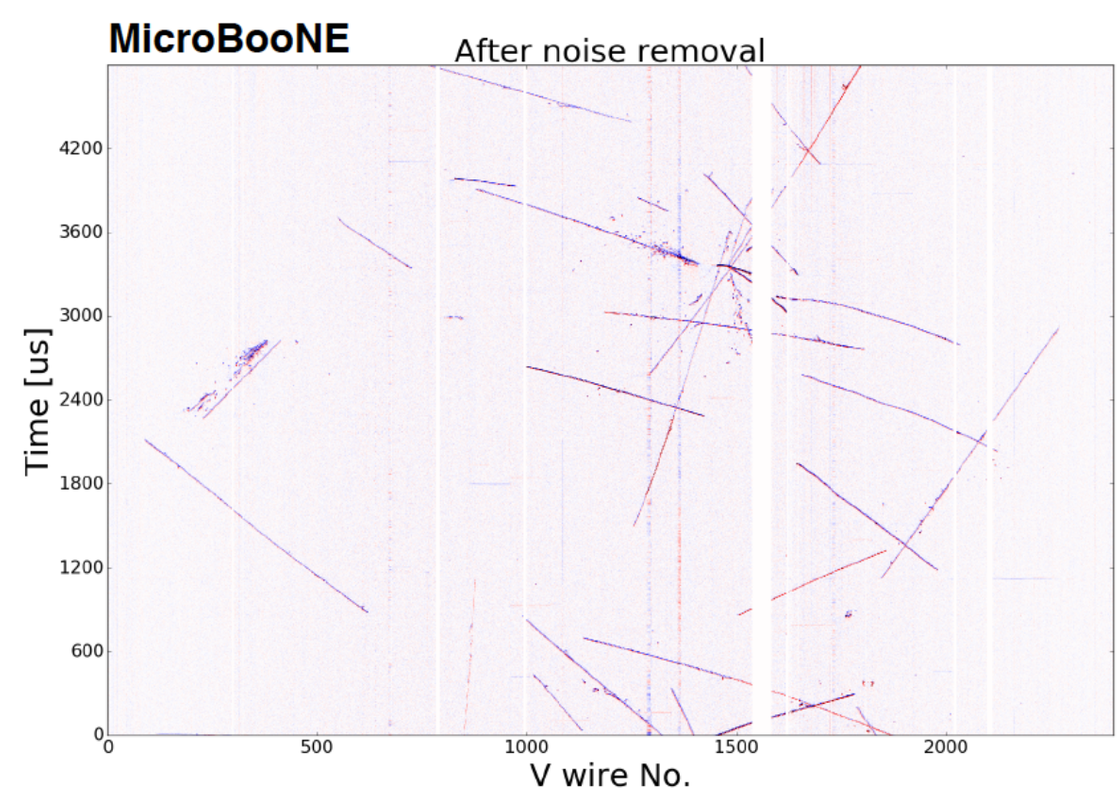


arxiv:hep-ex/1705.07341
(submitted to JINST)

Extensive work done to identify and filter out excess noise, with impressive results!

Important LAr R&D results!

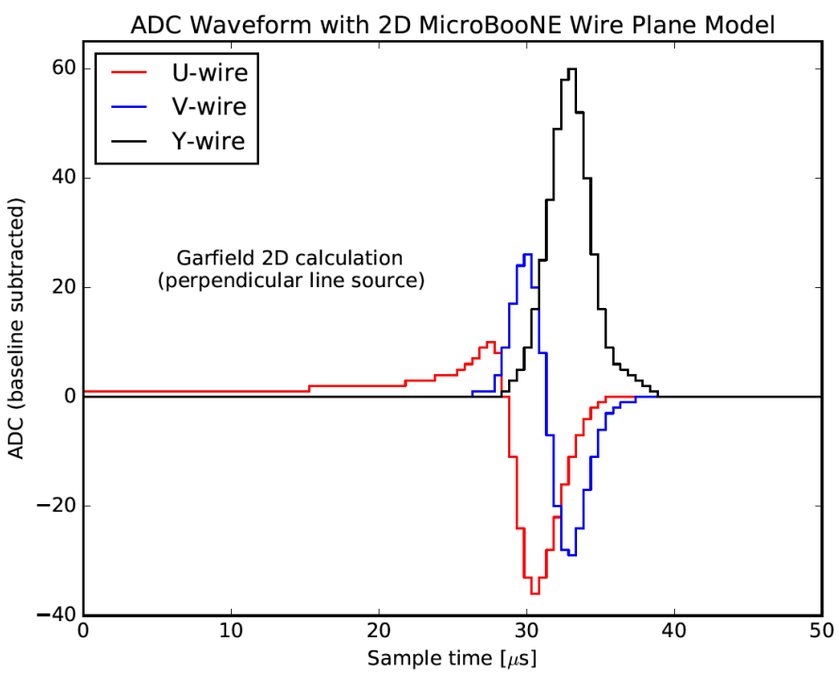


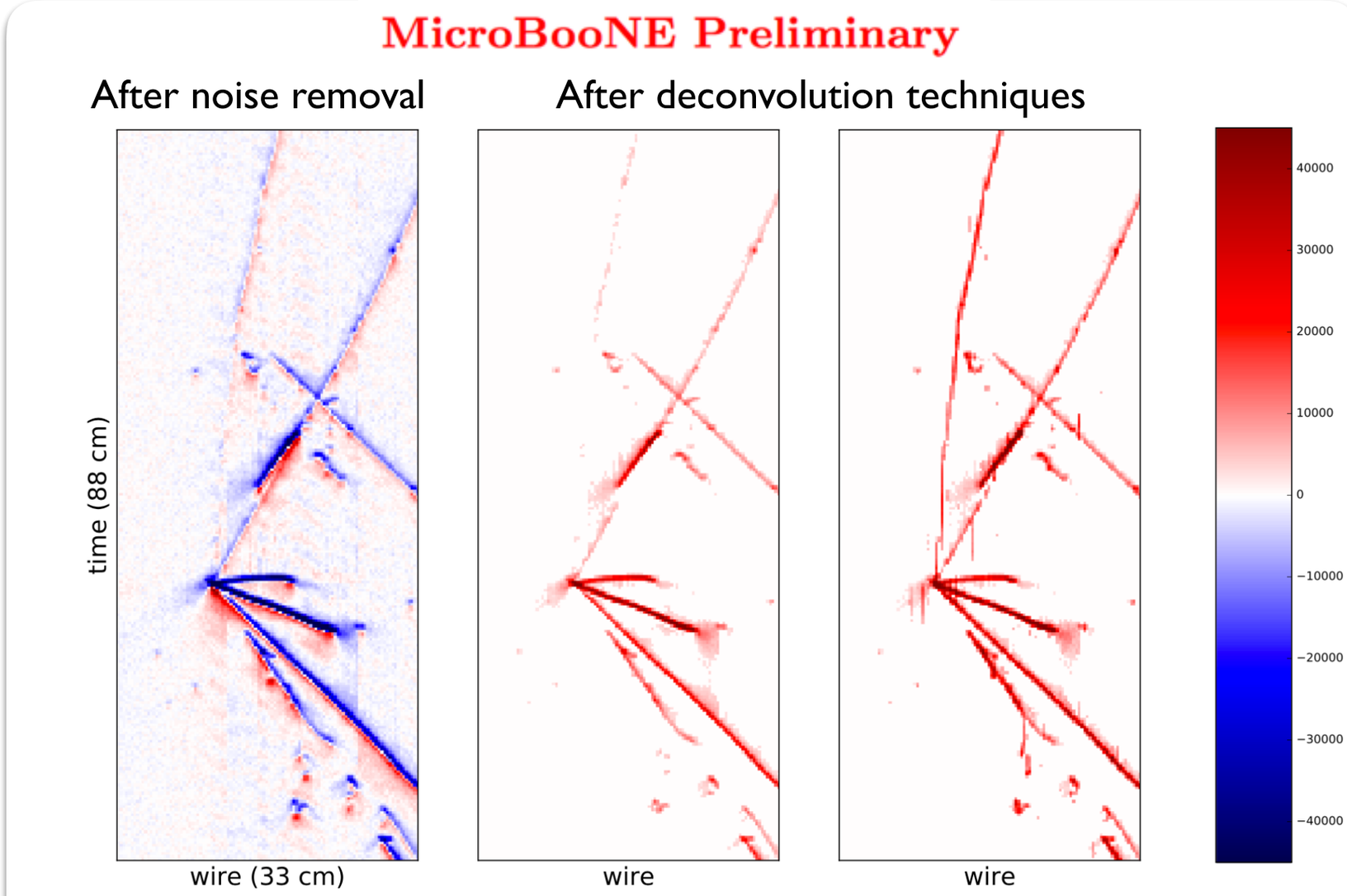


Signal processing and hit reconstruction

MicroBooNE public note 1017

After noise filtering, we want to convert the raw digitized TPC waveform to the number of ionized electrons





Example event in first induction plane

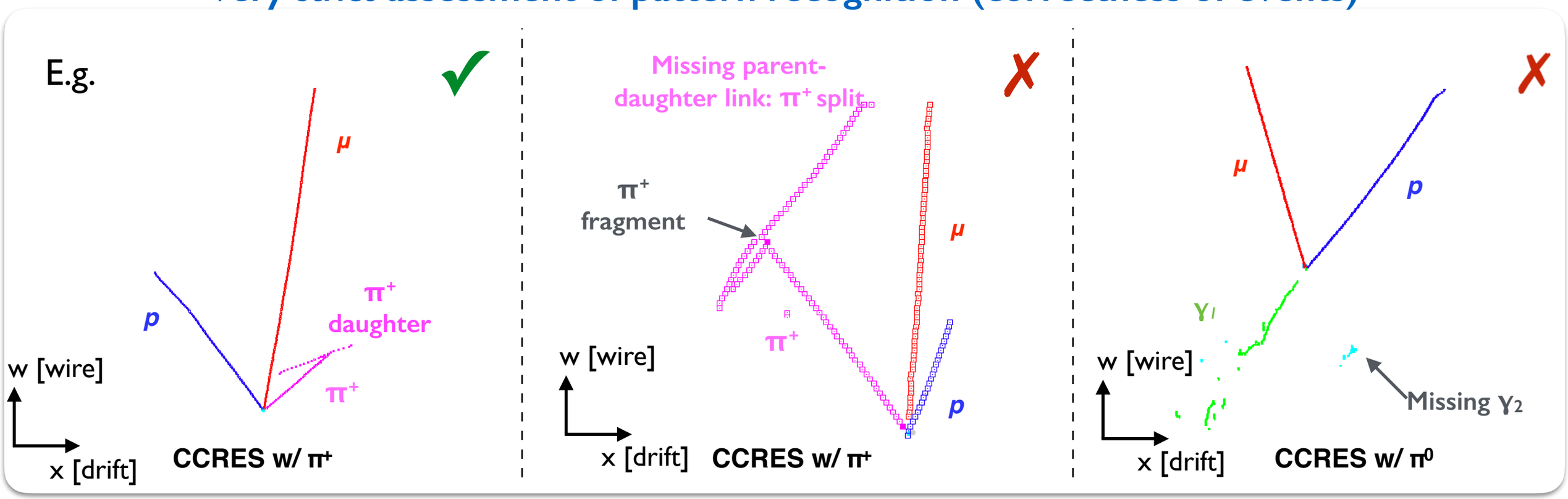
***Deconvolution* techniques to remove the impact of field and electronics response**

***Hit finding*:** find regions with a wire waveform above a threshold at a definite drift time, calculate deposited charge corresponding to the hits found, and input them to the pattern recognition

Pandora pattern recognition

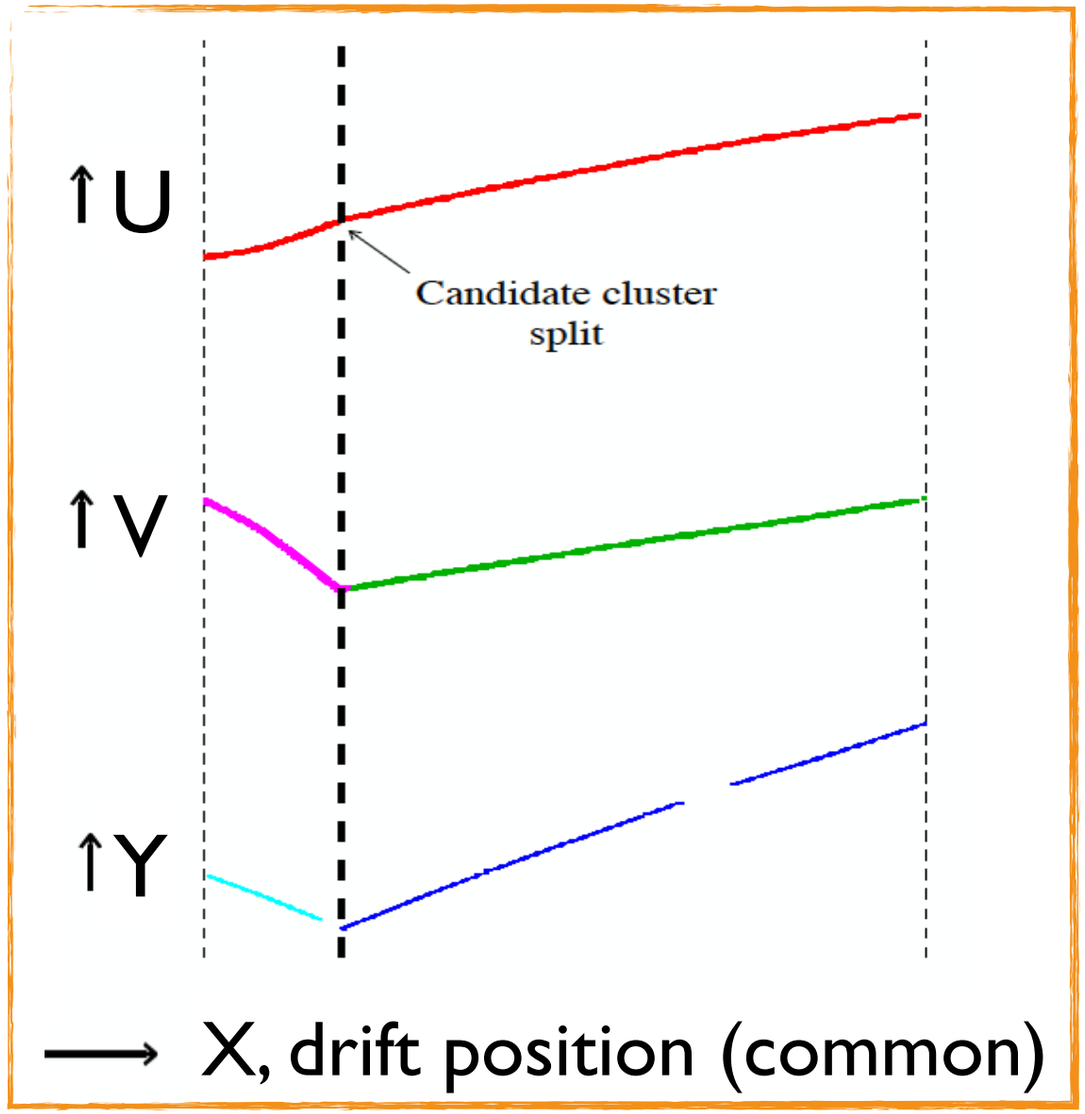
- **Pandora provides a multi-algorithm approach to automated pattern recognition for LAr TPC detectors (MicroBooNE, DUNE, protoDUNE…)**
- Address problem with many "small" algorithms (~120 available) and build up event gradually:
  - Each step is incremental - aim not to make mistakes (undoing mistakes is hard…)
  - Can build in some basic physics knowledge in algorithms
- Pandora provides the software infrastructure to manage algorithm chain, visualisation, etc. (PandoraSDK Eur. Phys. J. C 75, no. 9, 439)

Very *strict* assessment of pattern recognition (correctness of events)



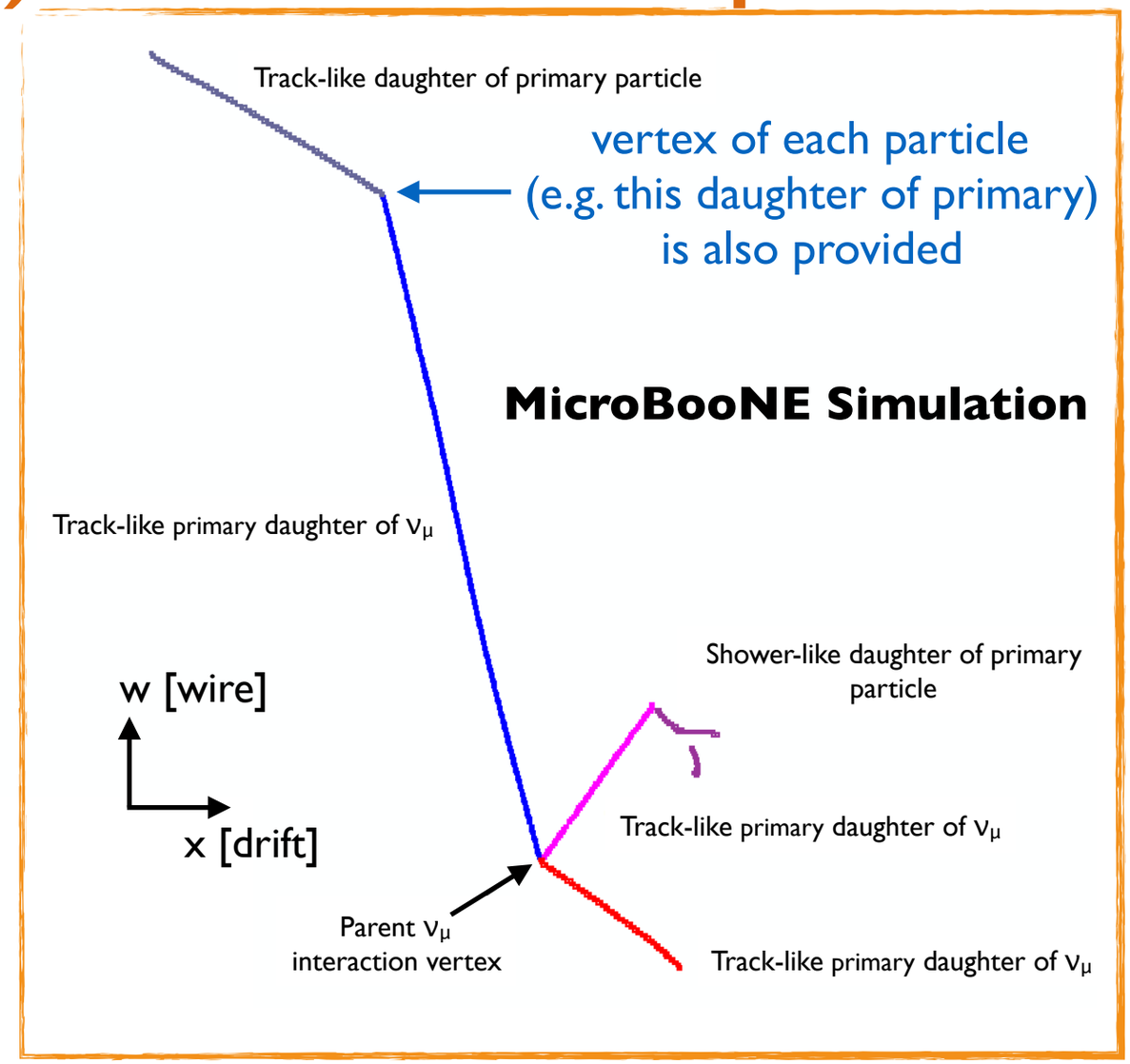
Pandora 2D and 3D reconstruction

Pandora uses many algorithms and tools to exploit the information in the **3 (views) x 2D reconstruction (x-wire)**



Example of a Pandora algorithm tool using the information in the V and W views to split a cluster in U which has accidentally merged two particles

After features are examined and correlated in 2D, a **3D reconstruction is performed**



The final output provided consists of particles and their vertices, 2D clusters, 3D spacepoints, and their hierarchy (parent/daughter)

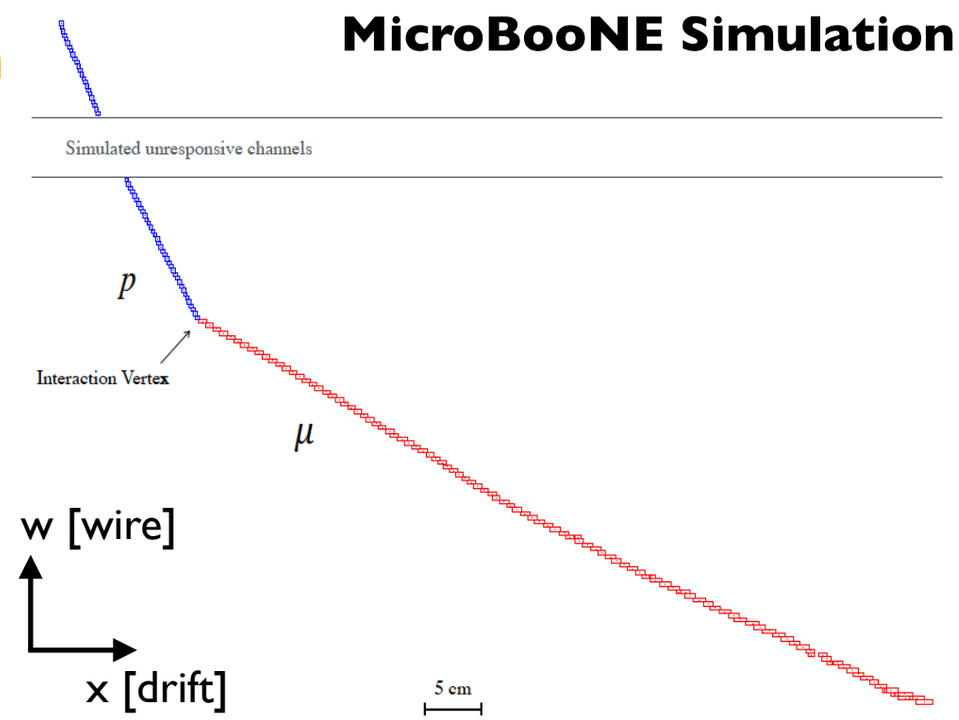
Pandora perfomance on MicroBooNE

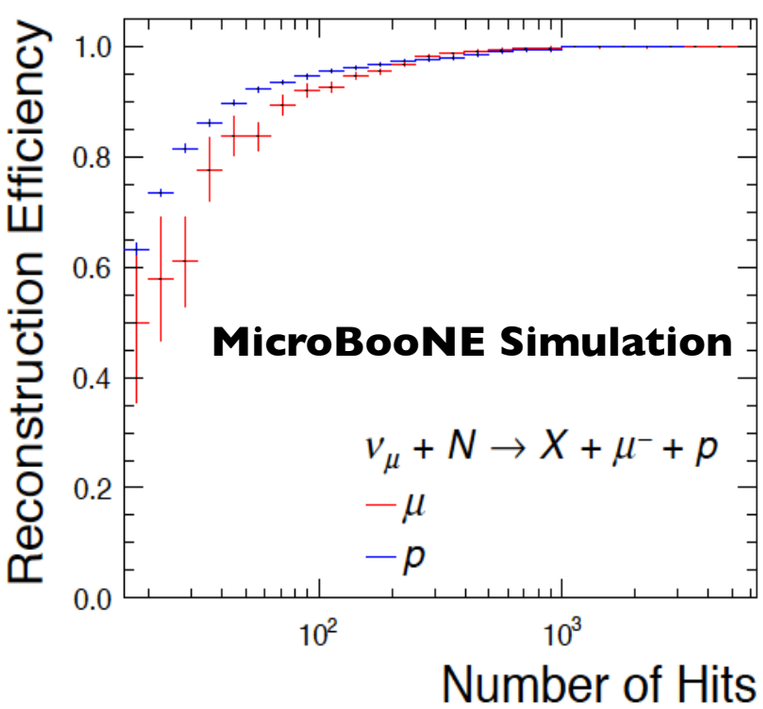
Performance studied looking at matching true-reconstructed particles for different interaction types and final state particles

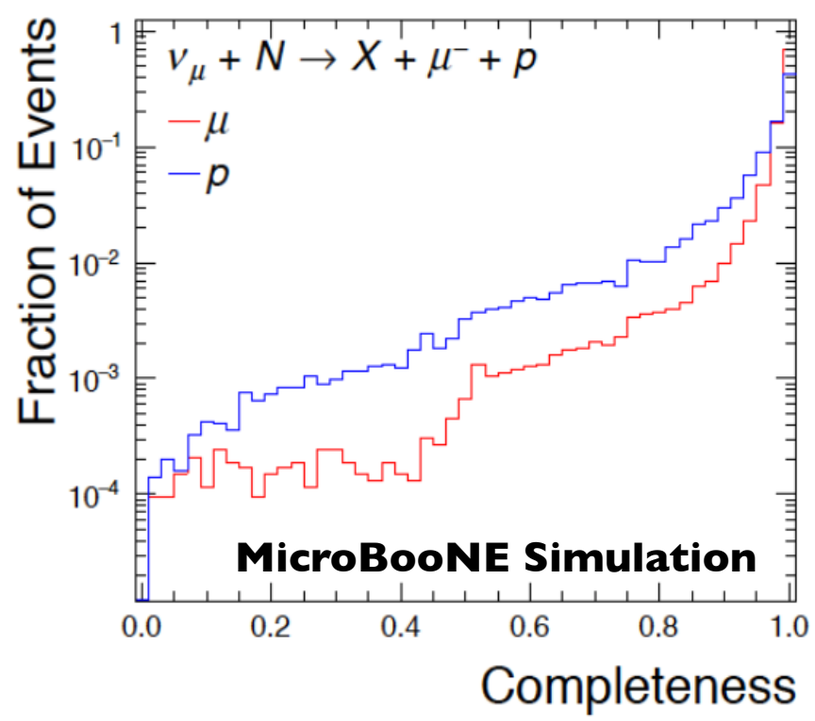
Example: CCQEL ν_μ -> μ + p

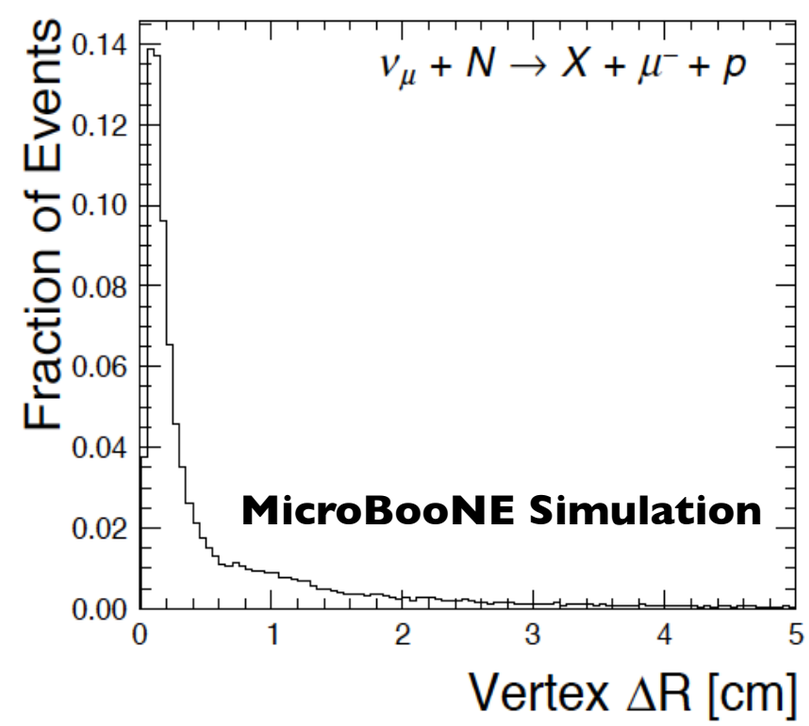
#Matched Particles	0	1	2	3+
μ	1.3 %	95.8 %	2.9 %	0.1 %
p	8.9 %	87.3 %	3.6 %	0.2 %

arxiv: coming soon



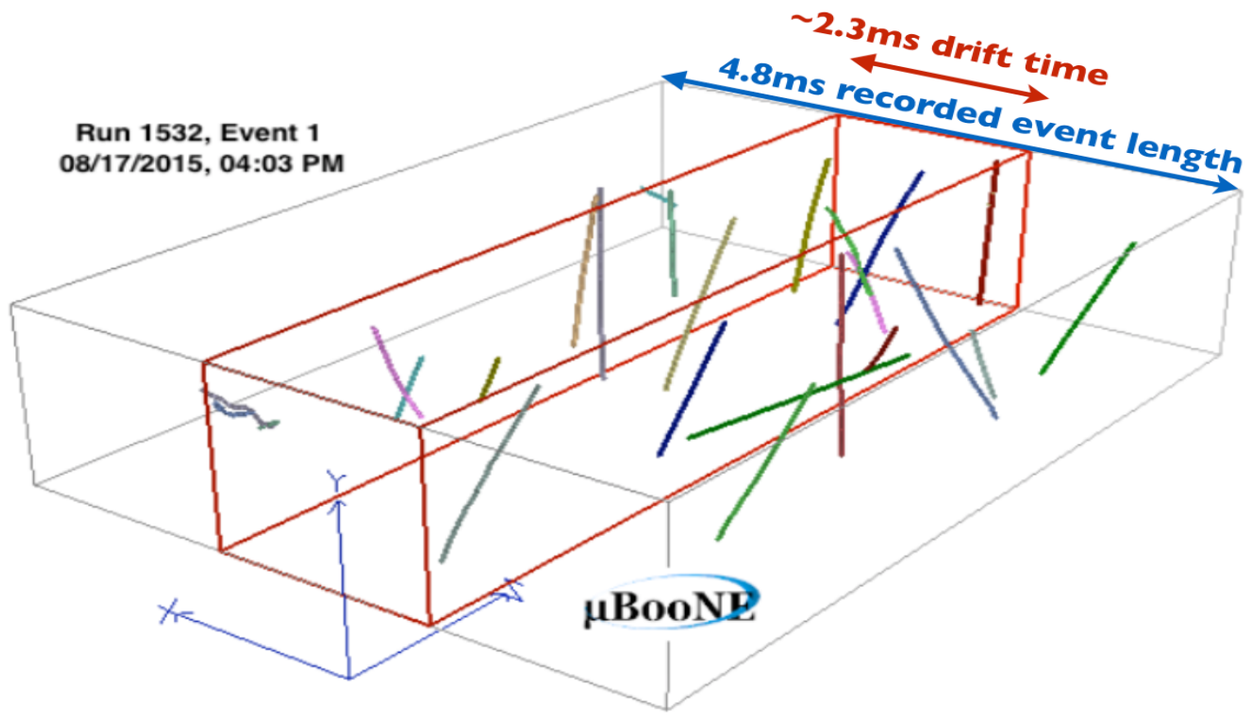




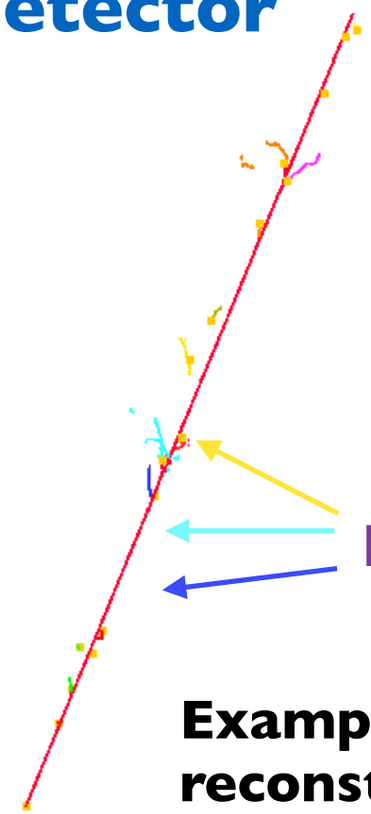


Cosmic rays

Cosmic rays: the challenge of a surface detector



~10 cosmics/drift period



Cosmic ray (track) particles

Delta ray (shower) particles, daughters of the cosmic ray

Example of cosmic ray reconstructed by Pandora

Removing them

Main background for analyses

- Readout before and after trigger: identify cosmics crossing anode/cathode
- Identify trough-going tracks
- Check consistency between scintillation light at PMTs and position at TPC

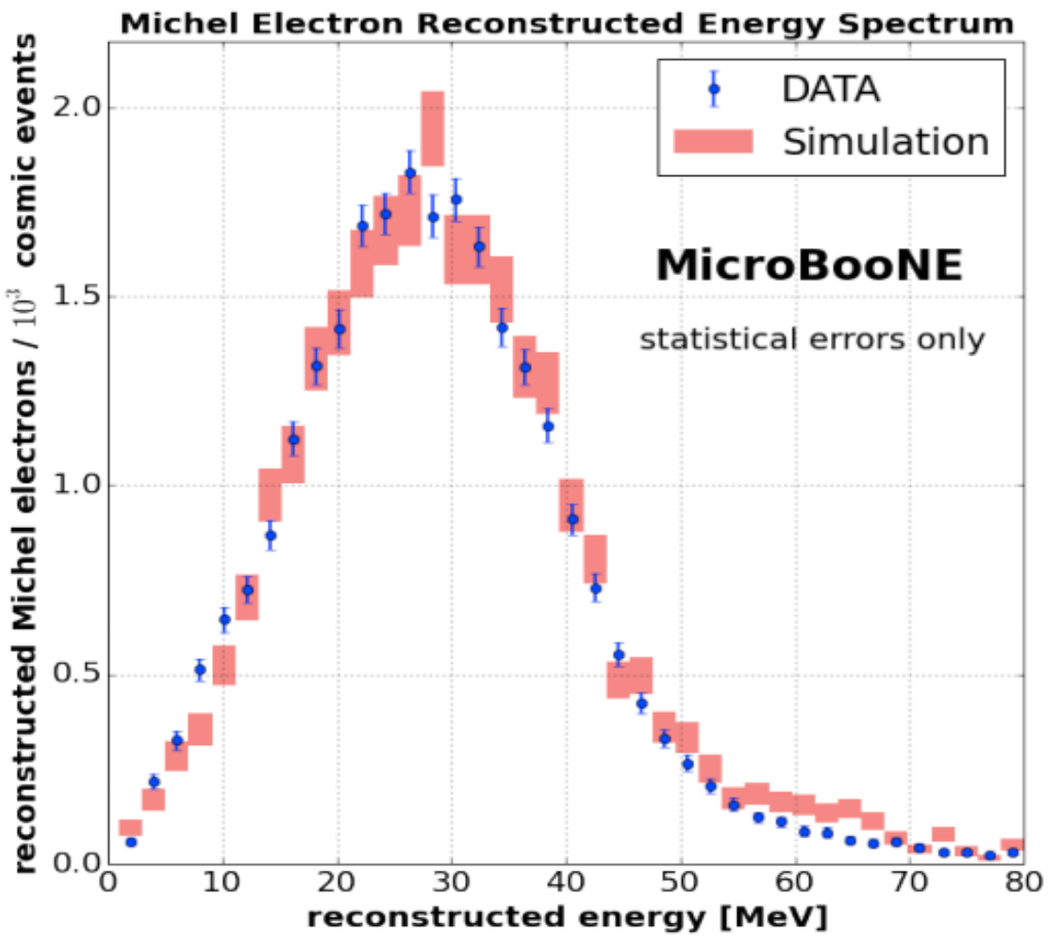
Using them

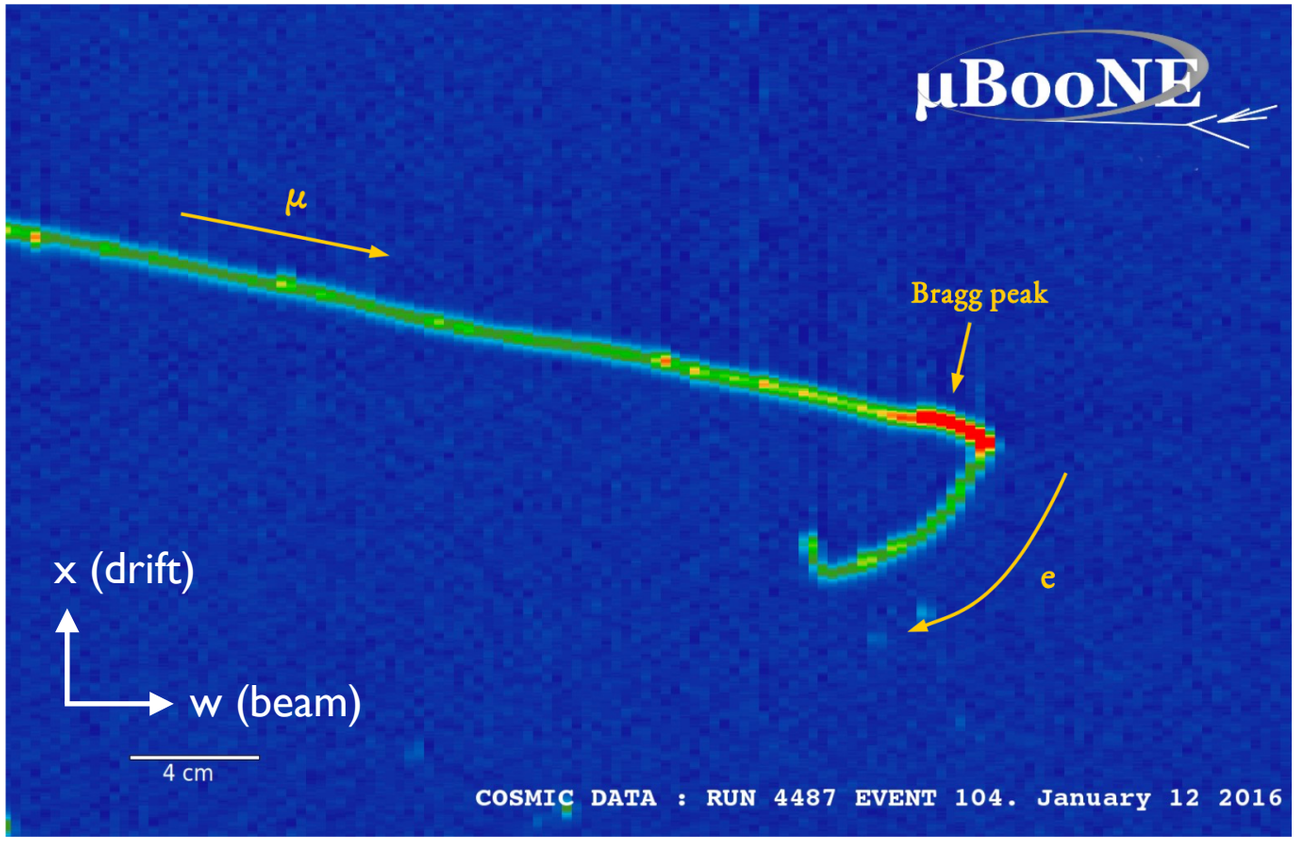
Used as source of calibrations:

- Space charge effects
- Lifetime, diffusion, calorimetric calibration
- Michel electrons identification and energy reconstruction

Michel electrons

arxiv:hep-ex/1704.02927 (submitted to JINST)





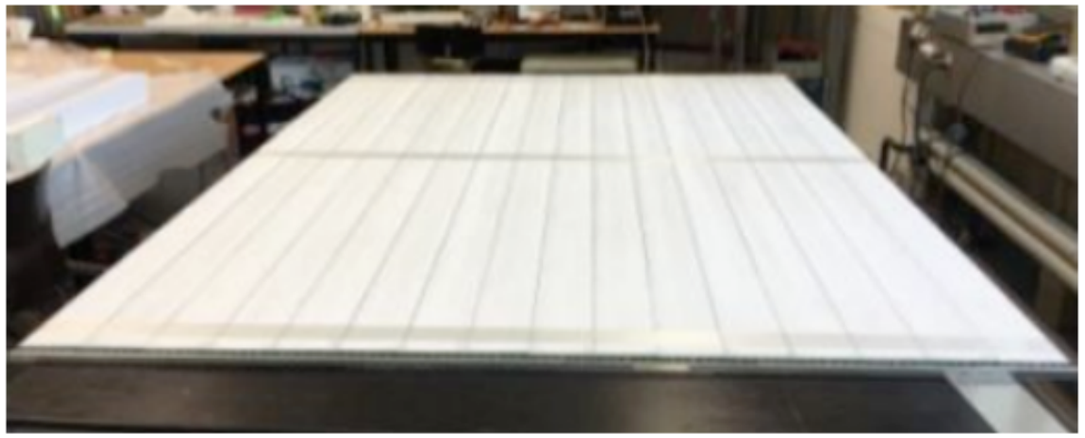
- Automated reconstruction of ~14k Michel electrons produced by decay at rest of cosmic-ray muons
- Low energy electrons (up to ~50MeV)
- Bragg peak and kink information used to identify Michel electrons
- Studied the impact of energy lost to radiative photons produced by ionisation and bremsstrahlung

Cosmic Ray Tagger

New Cosmic Ray Tagger providing external cosmic ray tagging system to MicrobooNE installed and fully operational since March 2017

Composed of 73 individual modules, proving 85% coverage

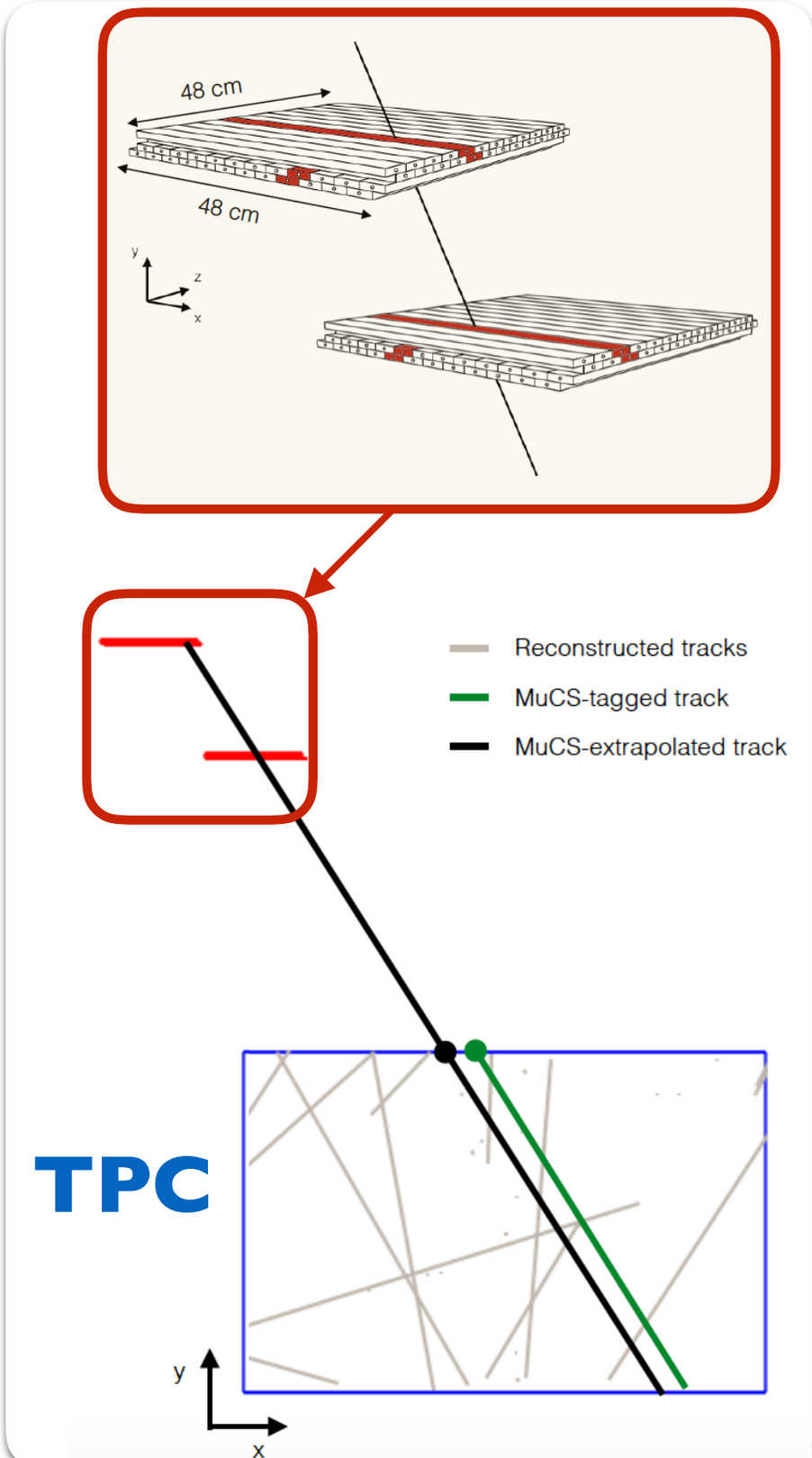
- Plastic scintillator strips readout by 2 WLS fibres and SiPMs (2 xy layers)
- Custom designed electronics for digitization and triggering (now licensed to CAEN) with ~ns timing precision



Made in-house at Bern University

MDPI paper (Instruments 2017, 1, 2.)

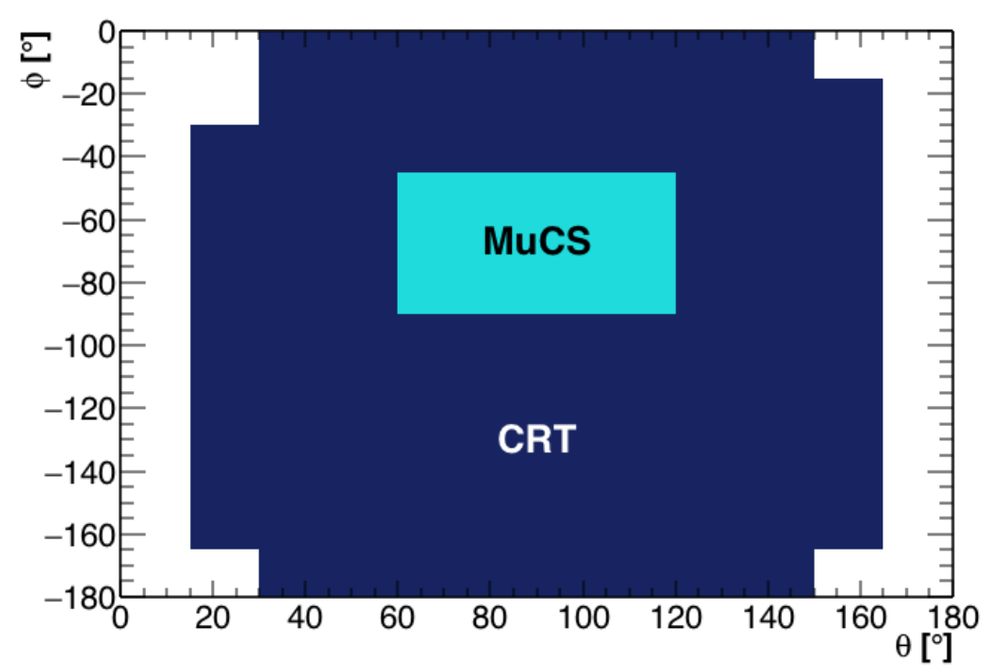
Muon Counter Stack



A small cosmic tagger:

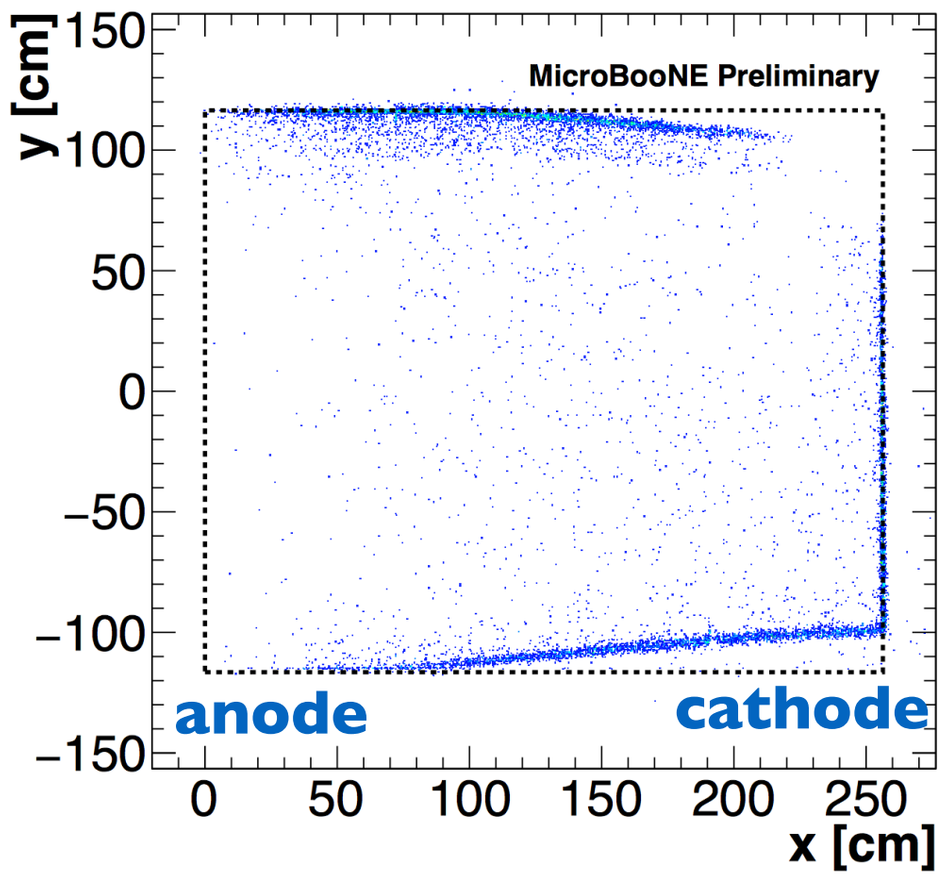
- installed above the TPC
- consists of 2 sets of XY scintillator strip modules
- muons tagged used to study **space charge effects** by using their reconstructed entry and exit points

Larger coverage provided by the new CRT

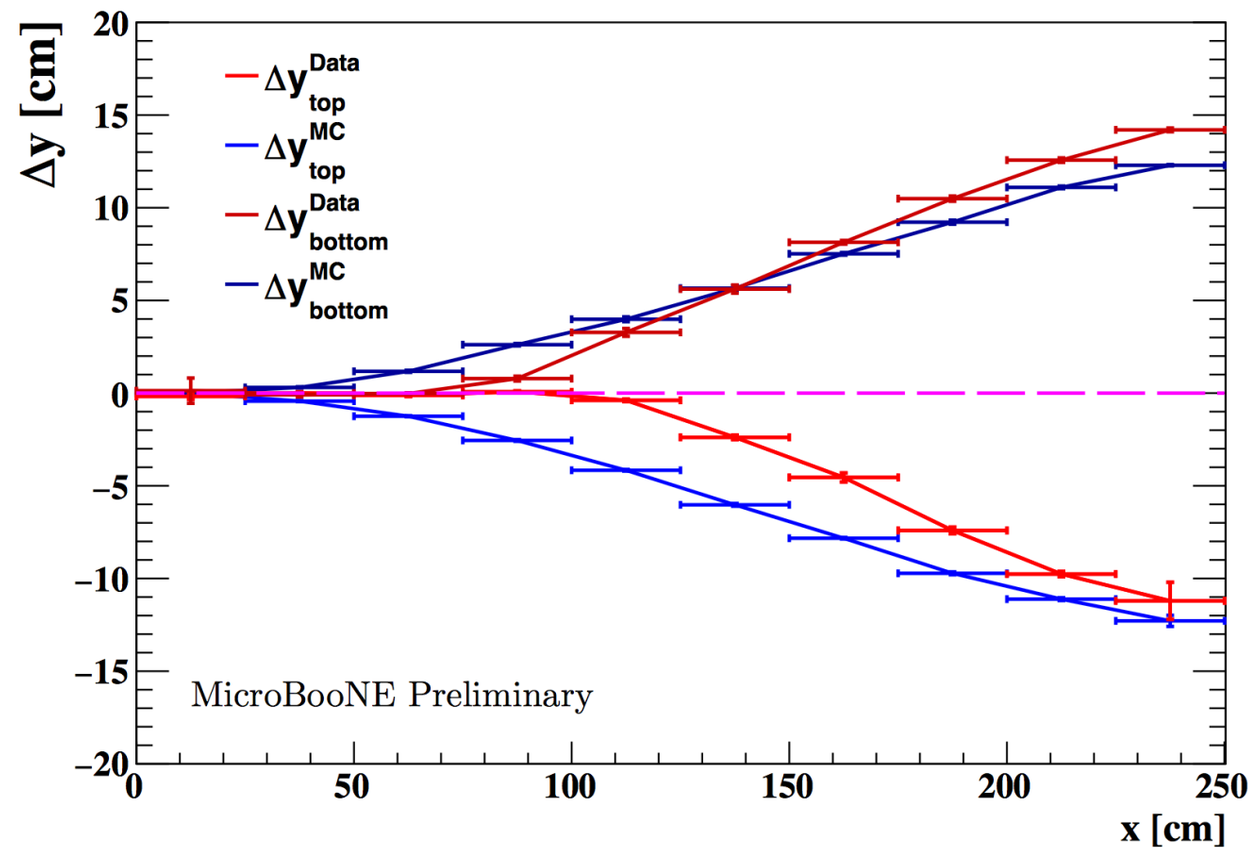


Space charge effects

MicroBooNE public note 1018



Predicted/measured SCE spatial distortions



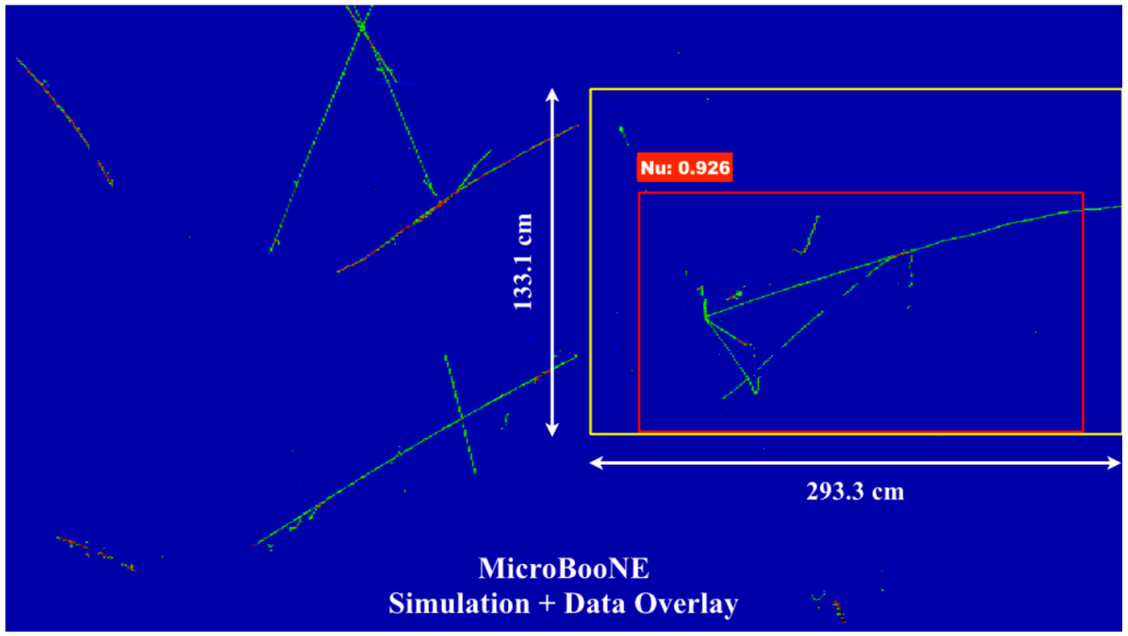
Space charge effect

- due to build-up of positive Ar ions (slow-moving)
- can impact the drift electric field
- and lead to spatial variations of the amount of recombination
- thus distorting tracks

Measuring it with

- Start/end point of reconstructed tracks in the TPC for MIPs (cosmics) tagged by the Muon Cosmic Stack in off-beam data
- Laser calibration system (UV laser) can produce a useful sample as well
- Detailed calibration is on its way!

Convolutional Neural Networks



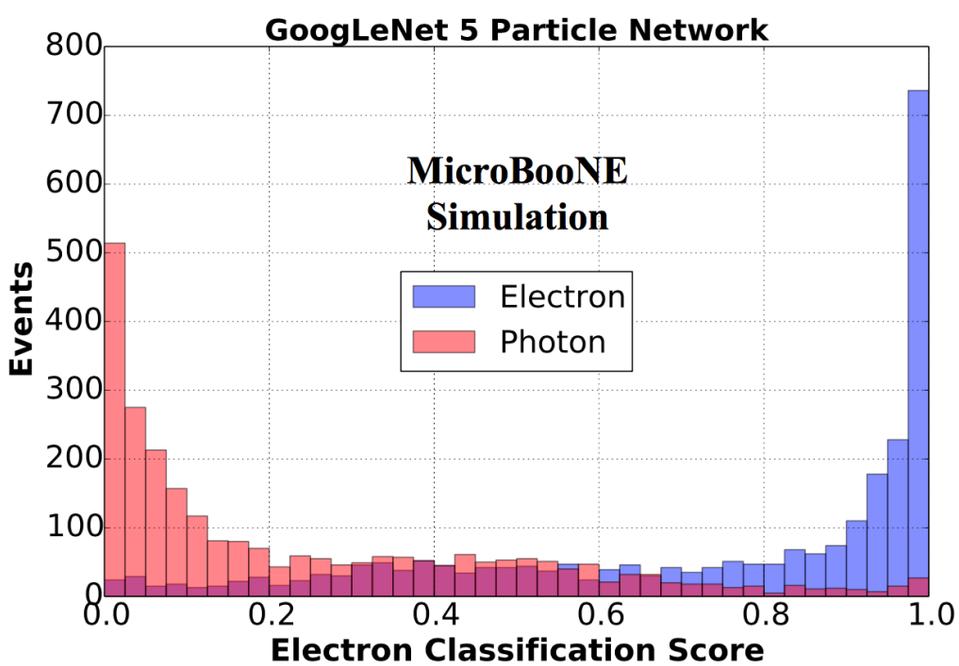
Convolutional Neural Networks

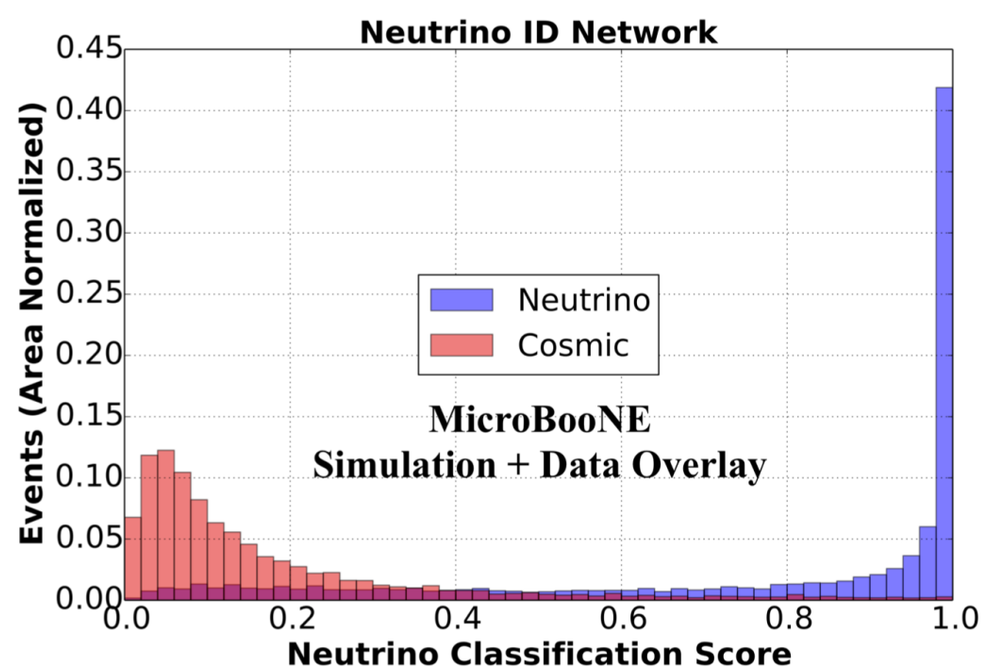
CNNs are tools developed for image analysis, help exploiting the **high quality LArTPC images**

Work on-going to apply these techniques to neutrino analyses.

JINST 12, P03011 (2017)

Studies demonstrate the potential of convolutional neural networks for particle ID and identification of neutrino interactions.

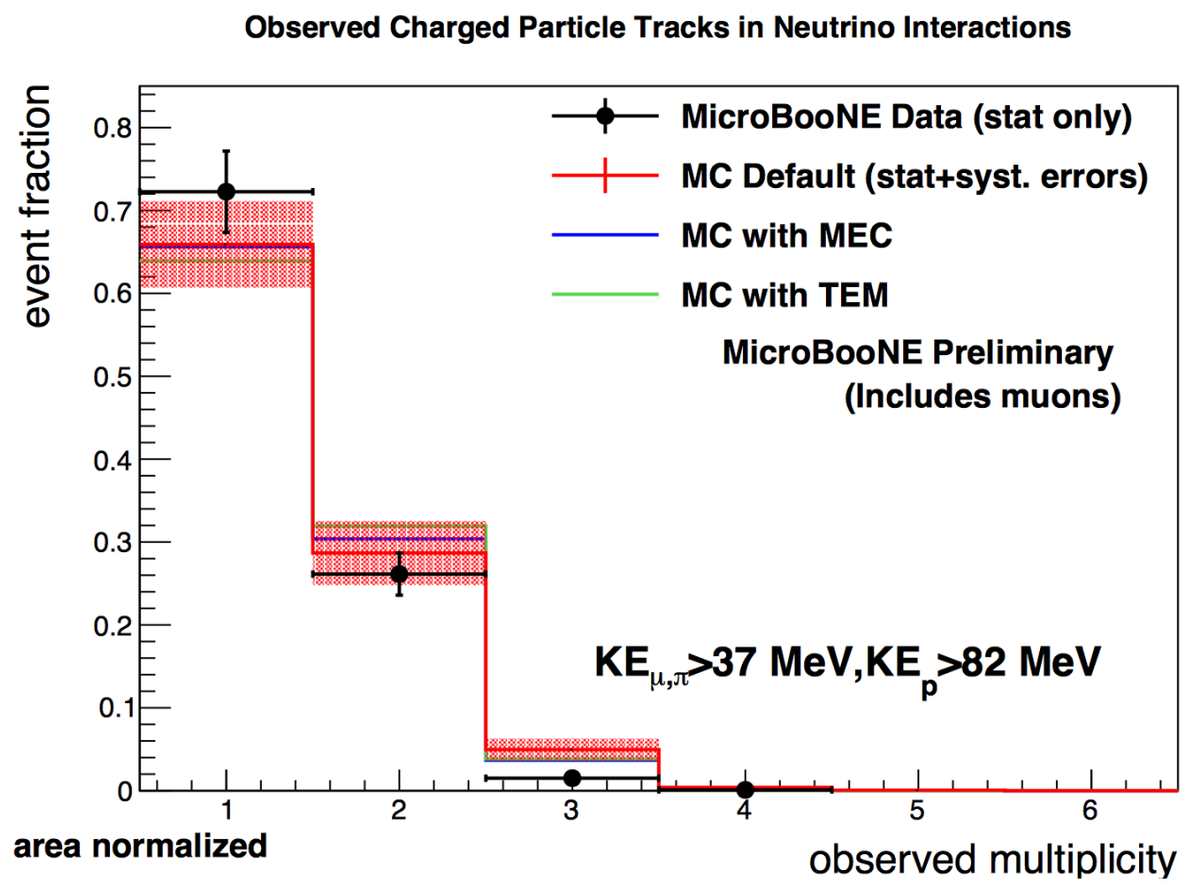


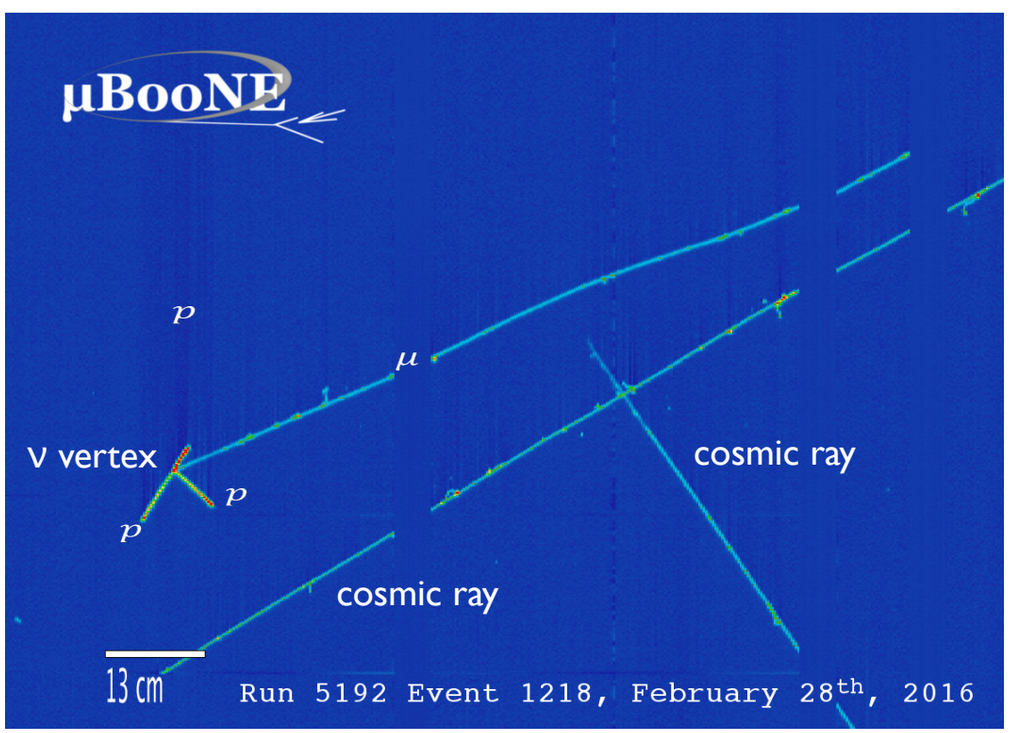


Charged-particle multiplicity in ν_μ CC

Study the observed charged particle multiplicity distribution (number of reconstructed tracks from interaction vertex) compared to predictions from several GENIE models.

- Select events with a fully contained muon
- Check light associated with the muon track coincident with beam spill
- Directionality checks to reject cosmics





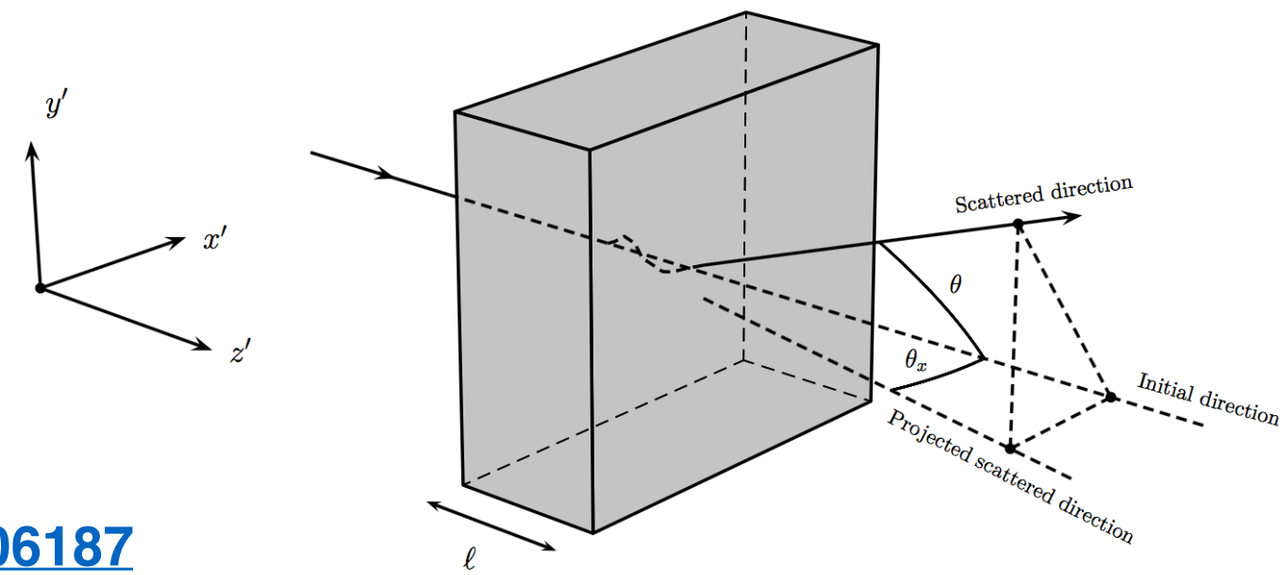
Proves the ability to **resolve and fully reconstruct events with multiple tracks** from a common neutrino vertex

MicroBooNE public note 1024

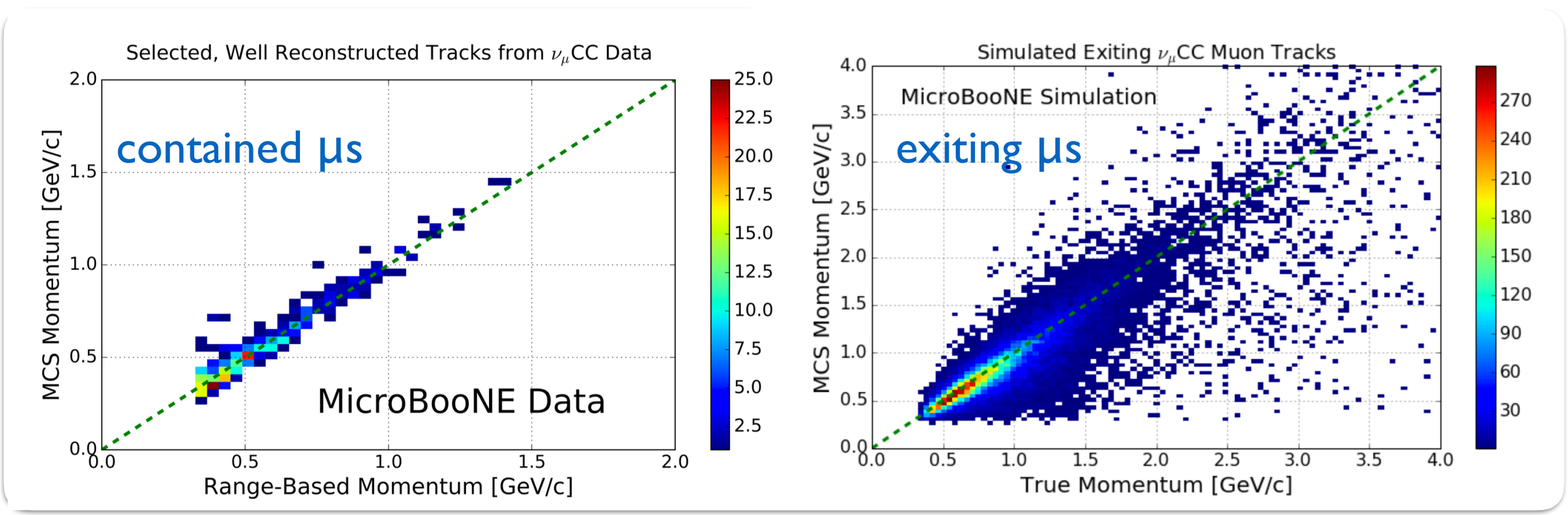
Muon momentum with MCS

Multiple Coulomb Scattering used for momentum estimation

- Contained and exiting muons
- Analyze deflection angular scattering
- Likelihood-based method
- Tuning of the Highland formula for LArTPCs

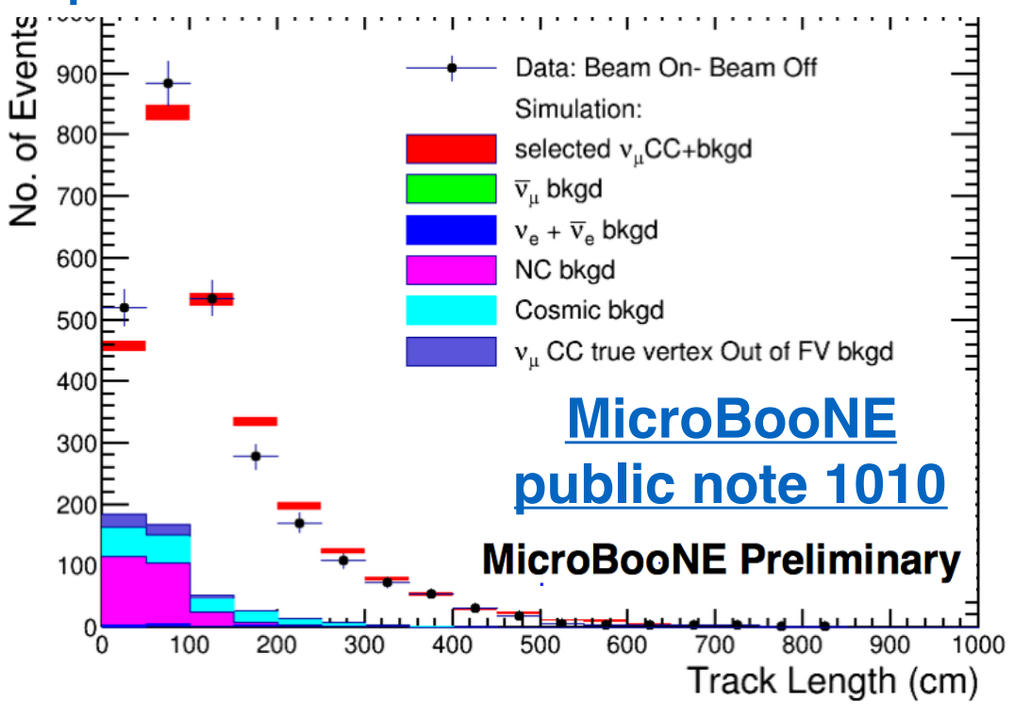


arxiv:hep-ex/1703.06187



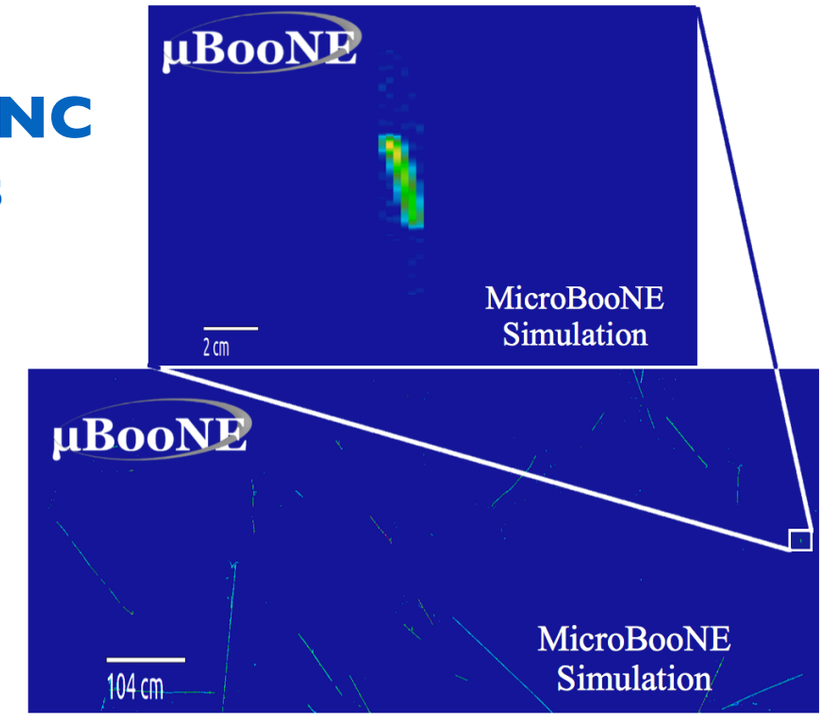
Other MicroBooNE analyses

ν_μ CC inclusive cross section

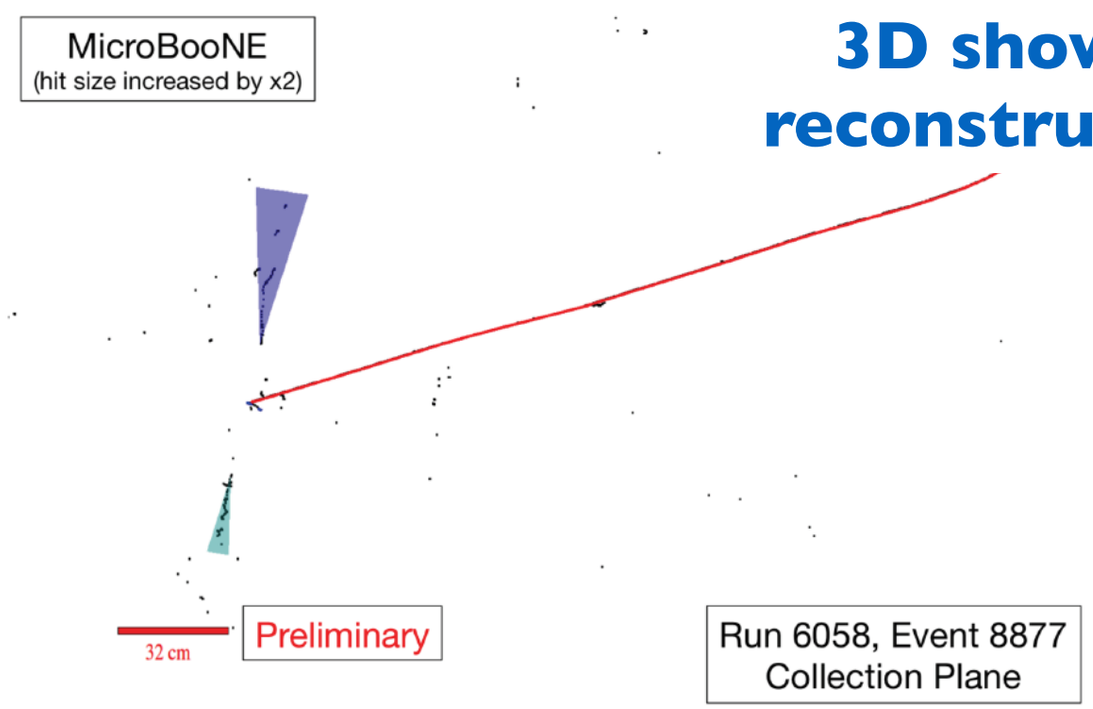


MicroBooNE public note 1010

Proton identification in NC elastic events



MicroBooNE public note 1025



3D shower reconstruction

And others...

Exotic physics
SuperNova
NuMI Physics

Find more in:

MicroBooNE public notes

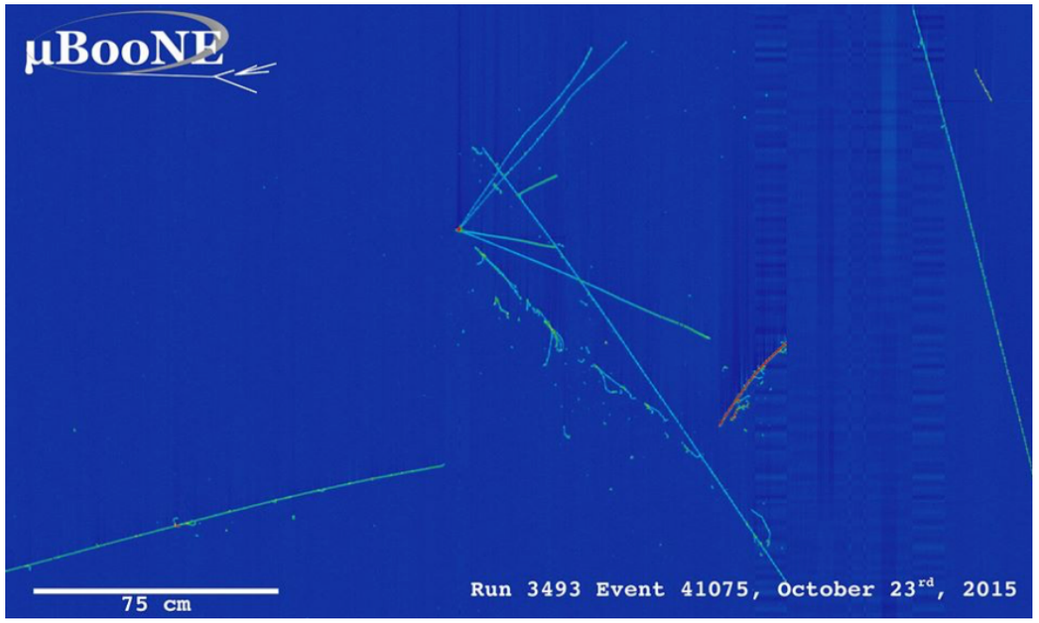
Summary

MicroBooNE LArTPC is up and running, collecting and analyzing neutrino interactions

Since it started collecting data in fall 2015:

- 5.5E20 BNB POT has been collected
- Extensive work on validating the performance of our detector has been carried out
- First υ-Ar interaction cross section measurements are ongoing

More exciting results towards determining the origin of MiniBooNE's low energy excess and more are on their way, so stay tuned to MicroBooNE



Thanks!

µBooNE

MicroBooNE