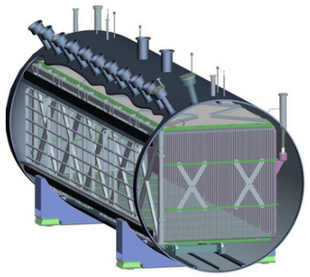
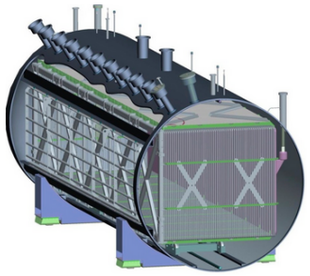


Studying Single-Phase LArTPC Detectors With MicroBooNE

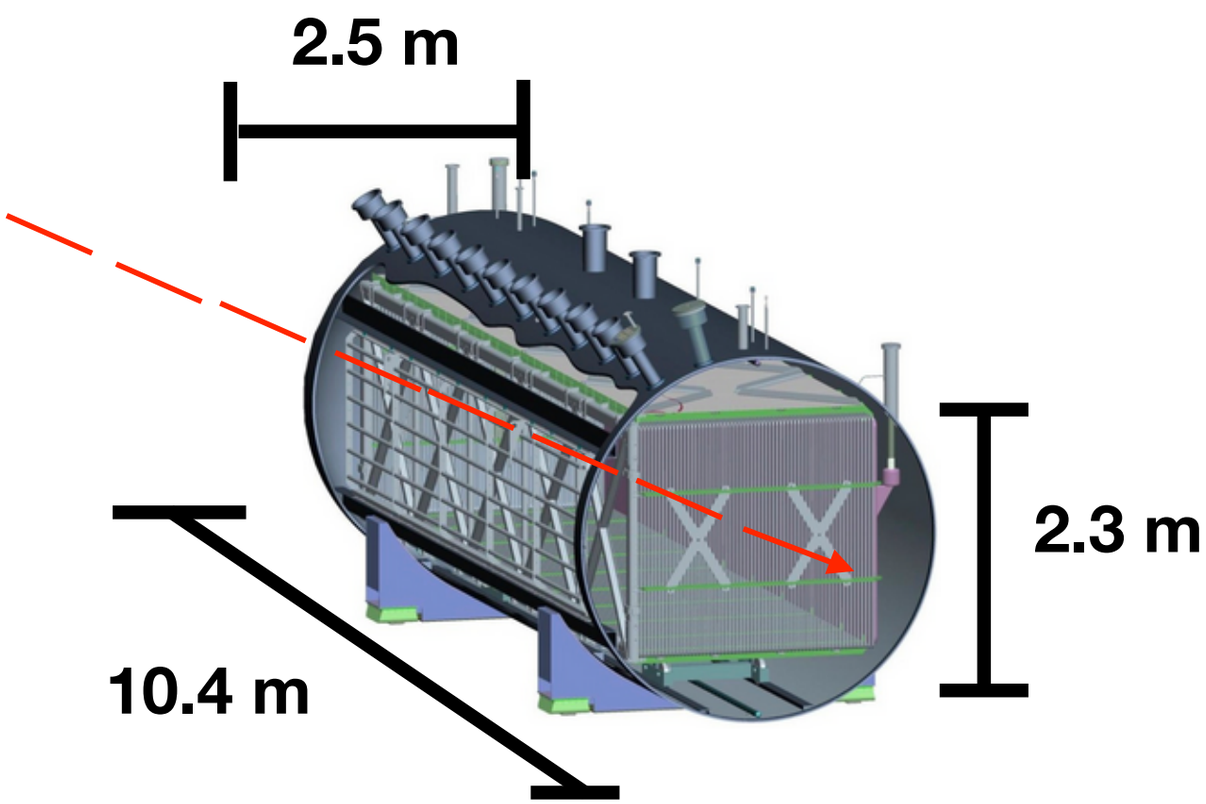
Christopher Barnes
Advisor: Prof. Joshua Spitz
University of Michigan

Lake Louise Winter Institute 2019
February 14th, 2019
Lake Louise, Alberta, Canada



MicroBooNE

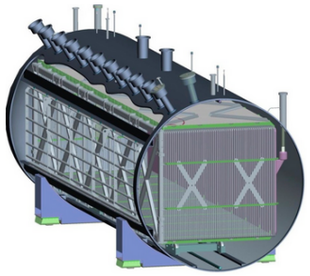
MicroBooNE is an important step in LArTPC development in preparation for DUNE.



Goals of MicroBooNE

- **Investigate the low-energy excess observed by the MiniBooNE experiment.**
- **Perform novel neutrino-LAr cross section measurements.**
- **Pioneer automatic reconstruction and calibration strategies for LArTPCs.**
- **Perform hardware R&D for LArTPCs.**

MicroBooNE is part of the Short Baseline Neutrino (SBN) program at Fermilab.

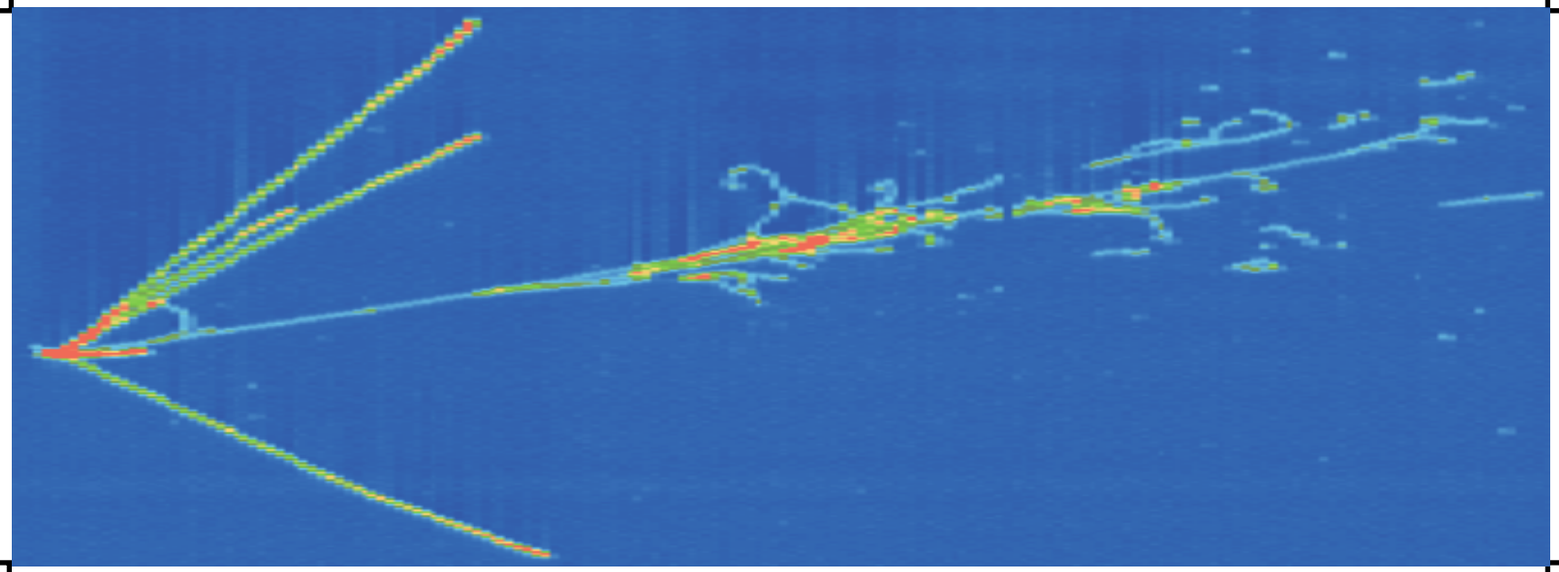


Detector Physics With MicroBooNE

MicroBooNE serves as a laboratory to study a number of LArTPC detector effects:

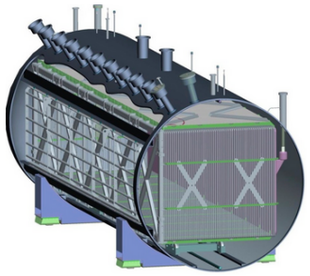
Charge Readout

Space Charge Effects



Electron Lifetime

Calorimetry



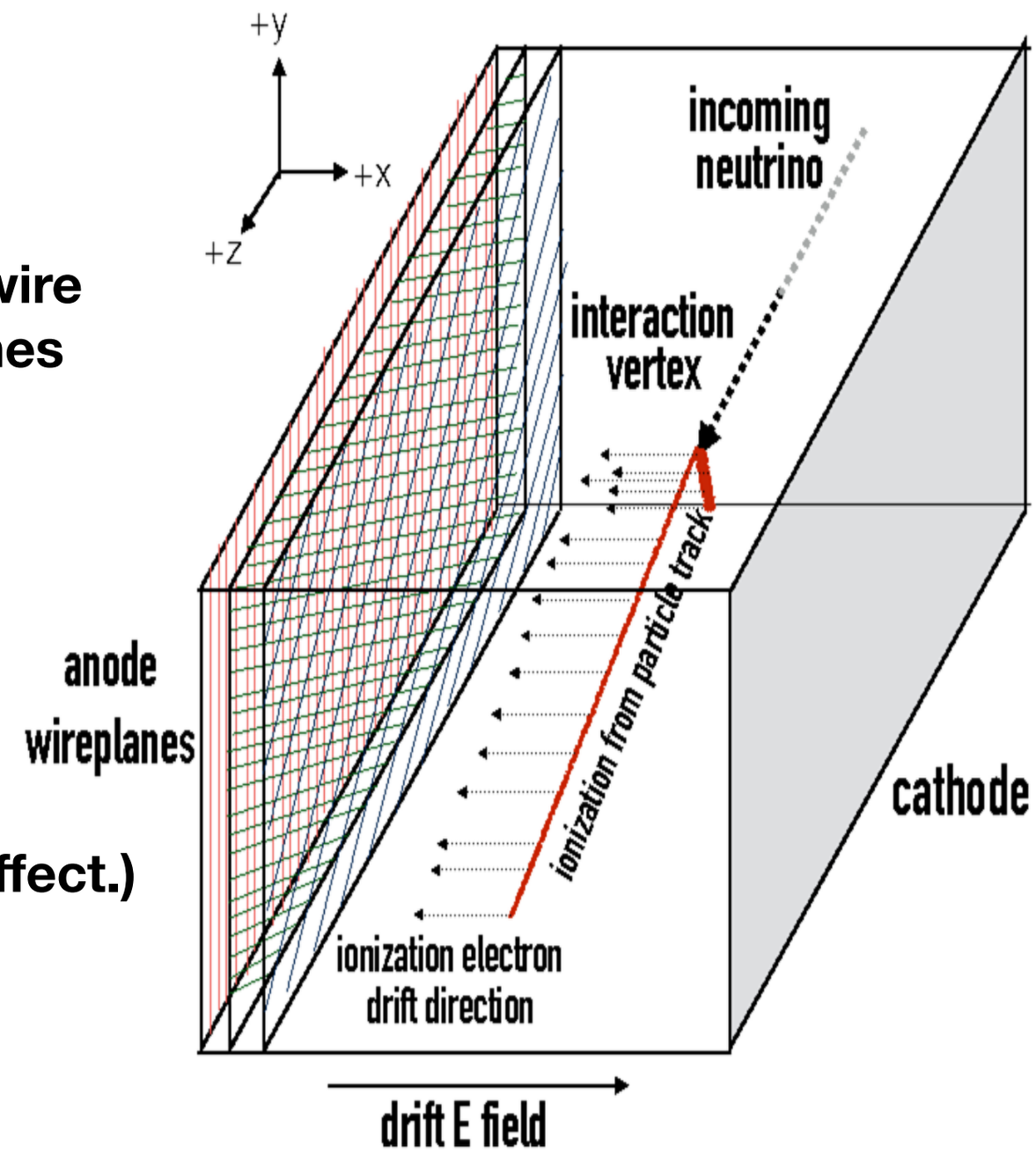
Charge Readout Calibration

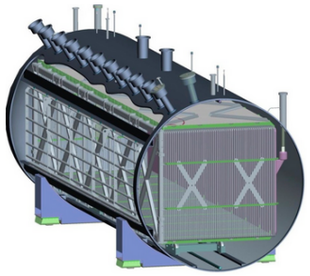
When ionization electrons drift to the anode wire planes, effects of charge readout on the planes must be calibrated first.

These include:

- **detector noise (inherent & TPC-induced)**
- **charge exchange between neighboring wires**

(MicroBooNE is the first LArTPC studying this effect.)

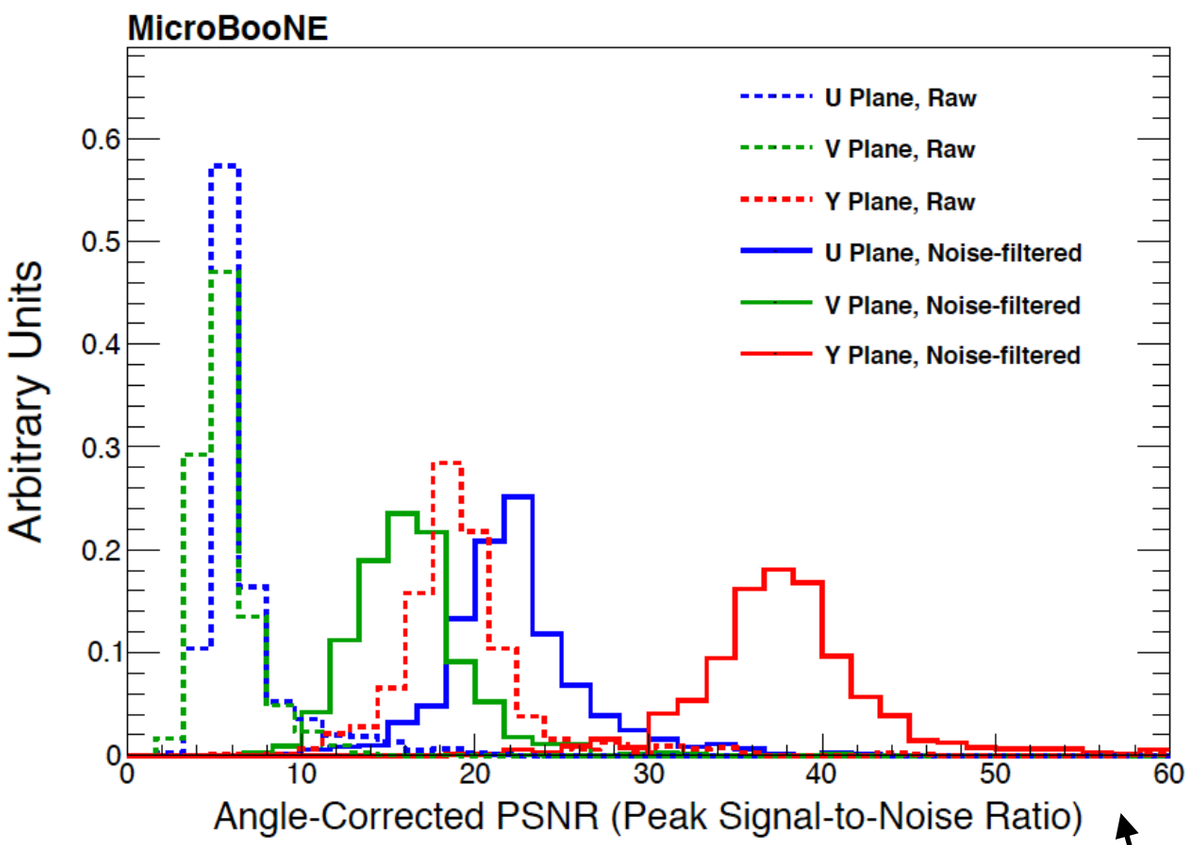




Noise Filtering

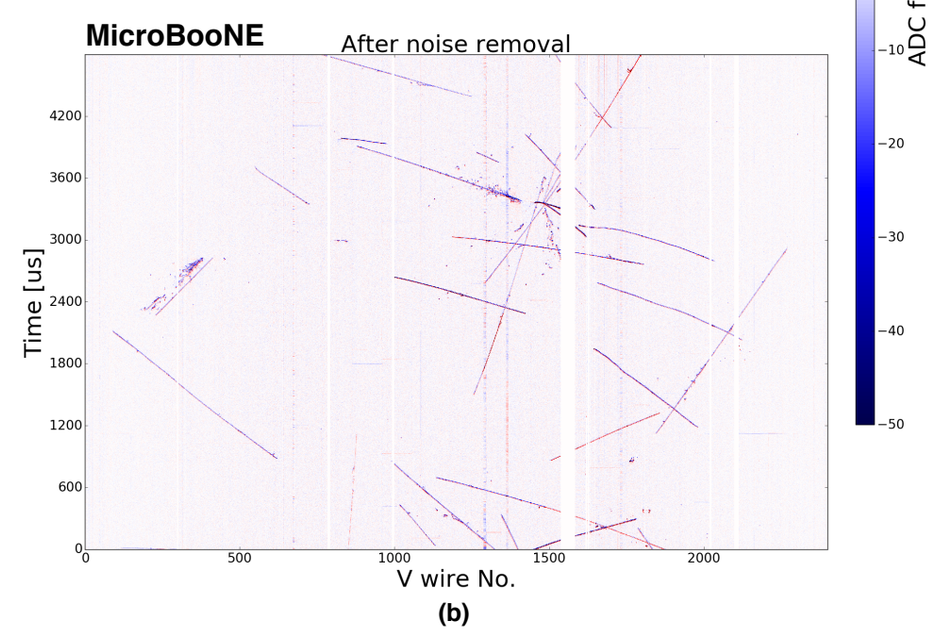
A paper on limiting detector noise has been published in JINST.

JINST 12, P08003 (2017).

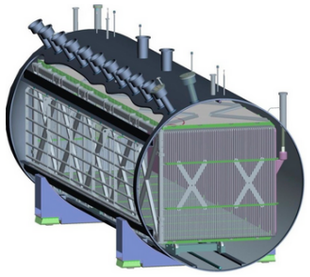


Before Noise Removal

After Noise Removal



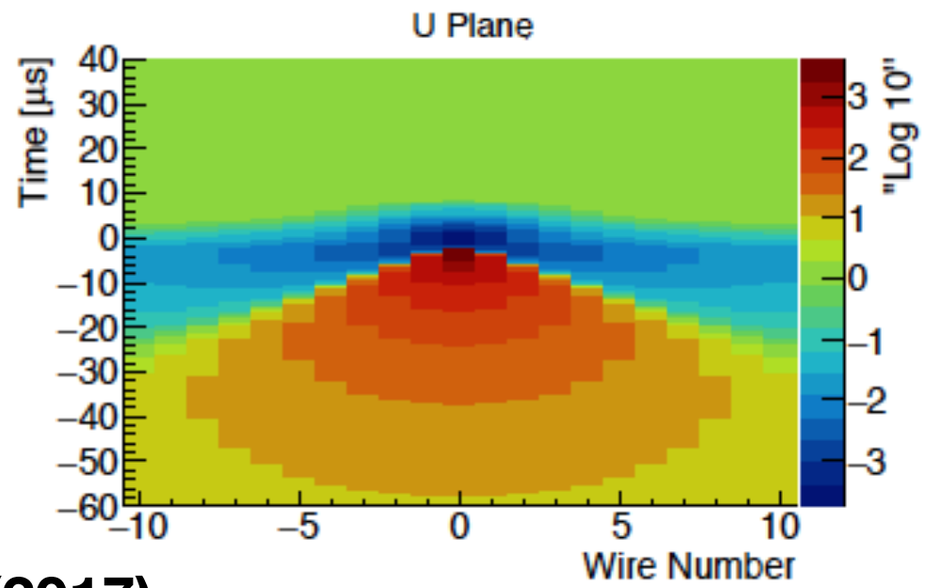
Peak Signal-To-Noise Ratio Before And After Use Of Offline Software Noise Removal Technique.

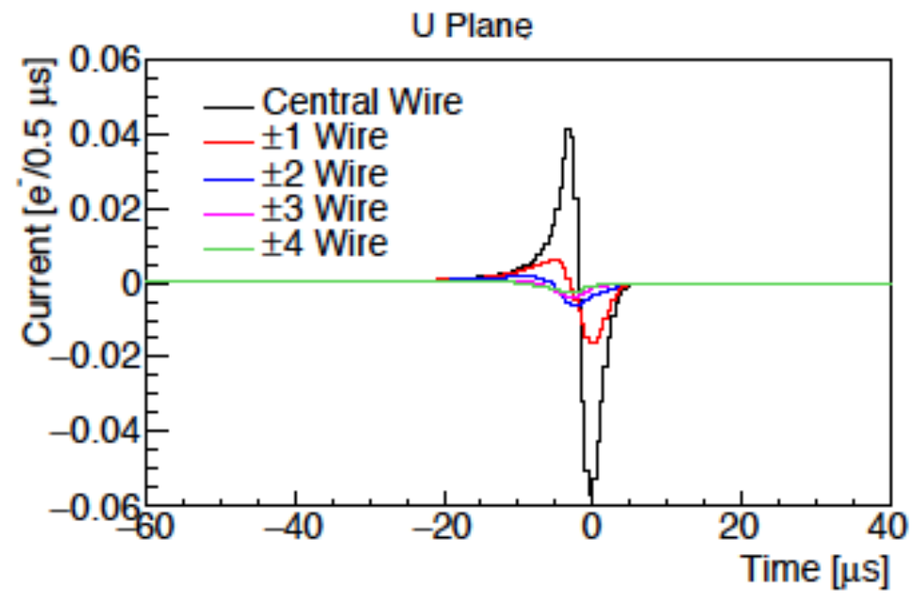


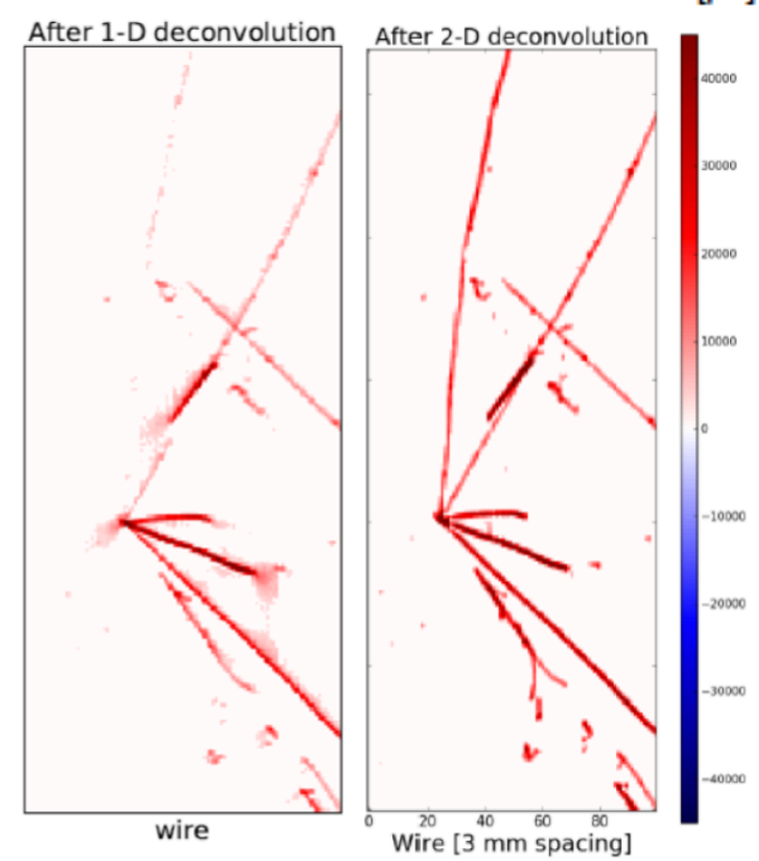
Signal Processing

MicroBooNE has published two signal processing papers in JINST.

I. **JINST 13, P07006 (2017).**
II. **JINST 13, P07007 (2017).**

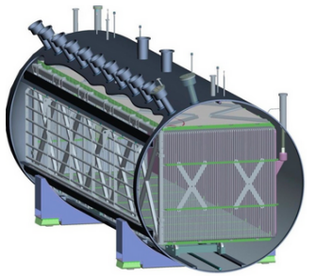






The first paper describes methods for simulating the response of a wire to charge deposition.

The second paper describes data-driven methods of correcting the response function.

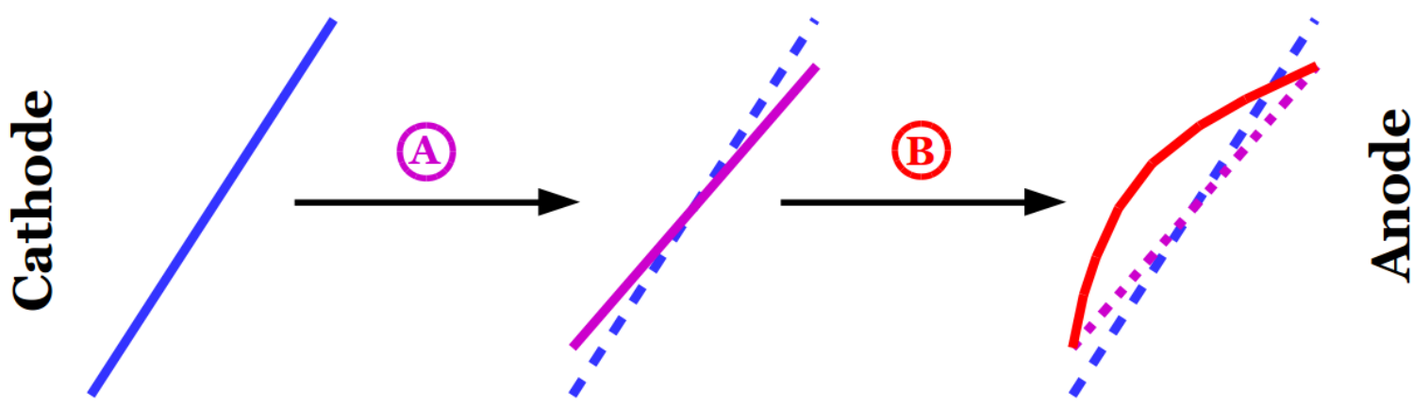


Space Charge Effects

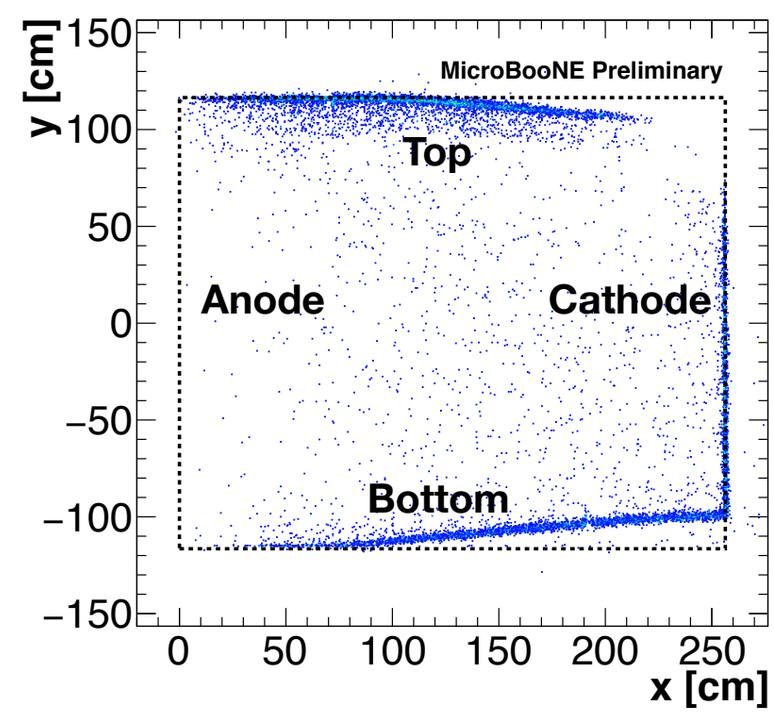
Space charge effects are the buildup of positive ions in the TPC active volume, distorting the electric field between the anode & the cathode.

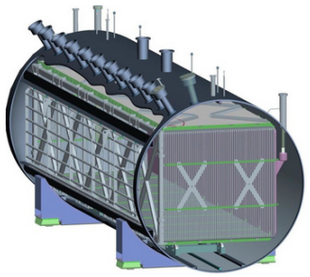
This dislocates ionization charge in the TPC, warps tracks, and worsens the calorimetry of the detector.

Twofold Result of Space Charge Effects



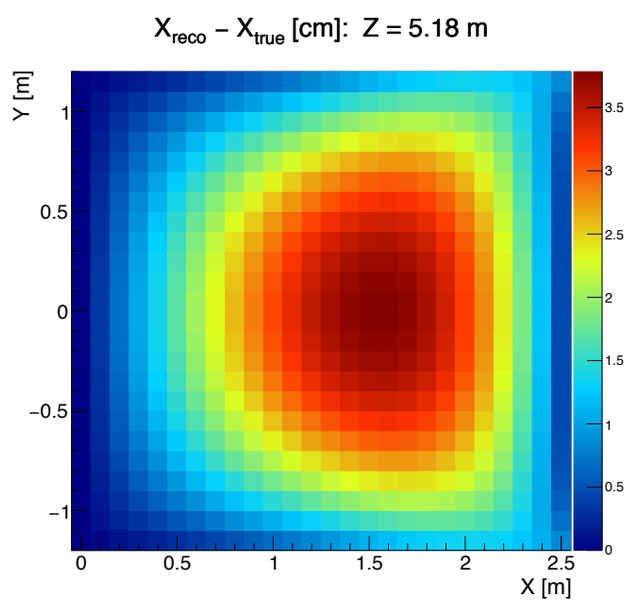
Tracks Tagged By An External Muon Counter System

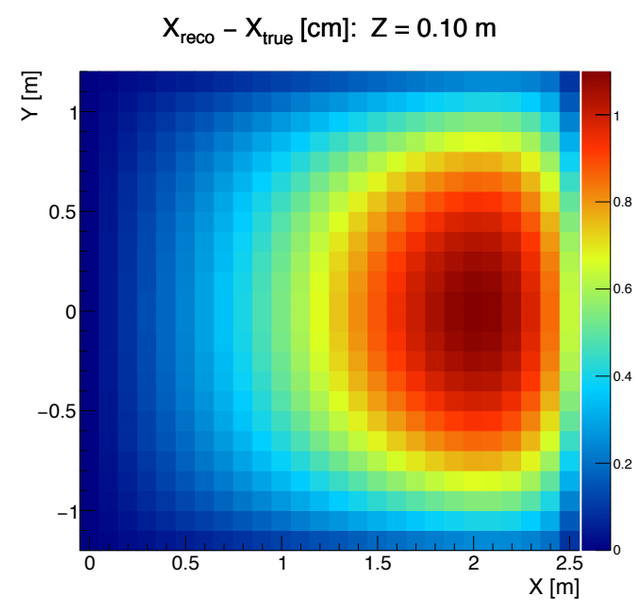




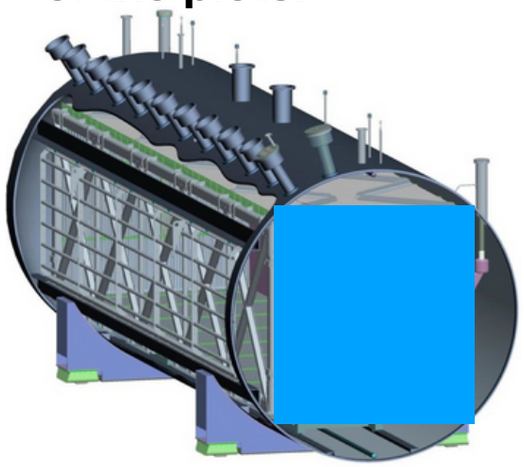
Accounting For Space Charge Effects

Consequences of space charge effects were integrated into our last simulation campaign (Spring 2017).



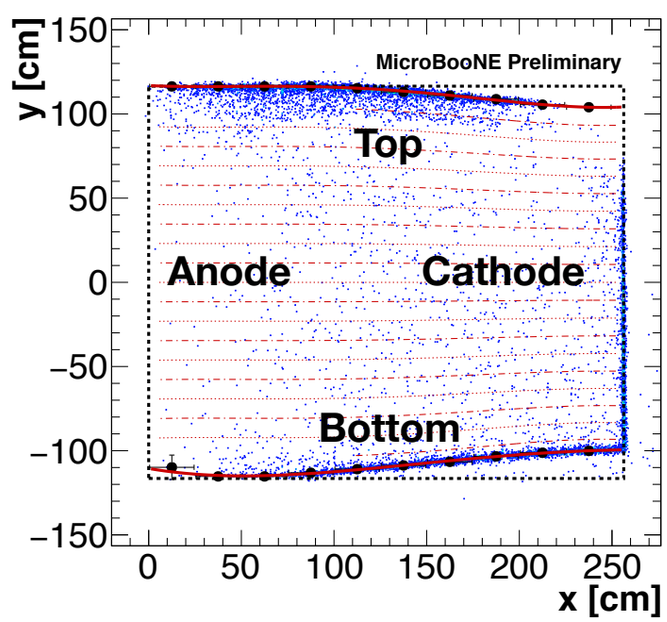


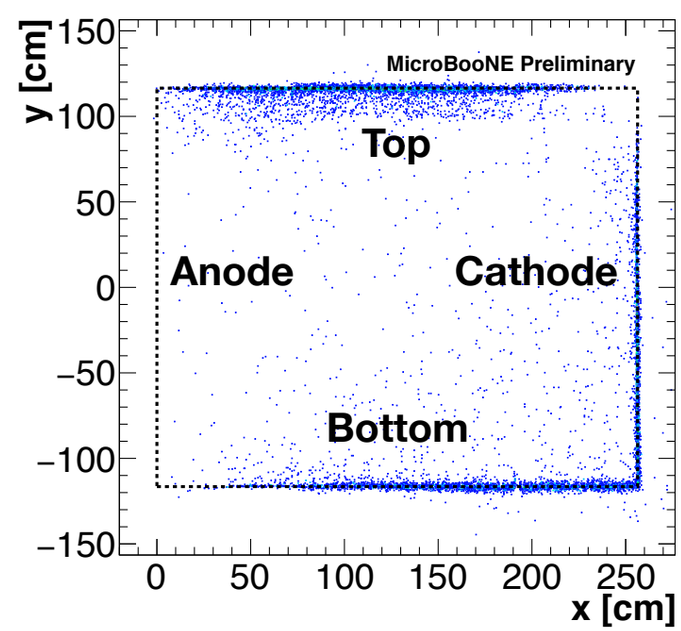
Note the different color scales of the plots!

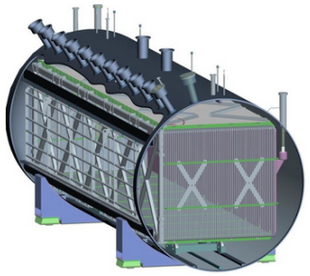


An effort to measure the distortions on reconstructed tracks and the TPC electric field is being finalized.

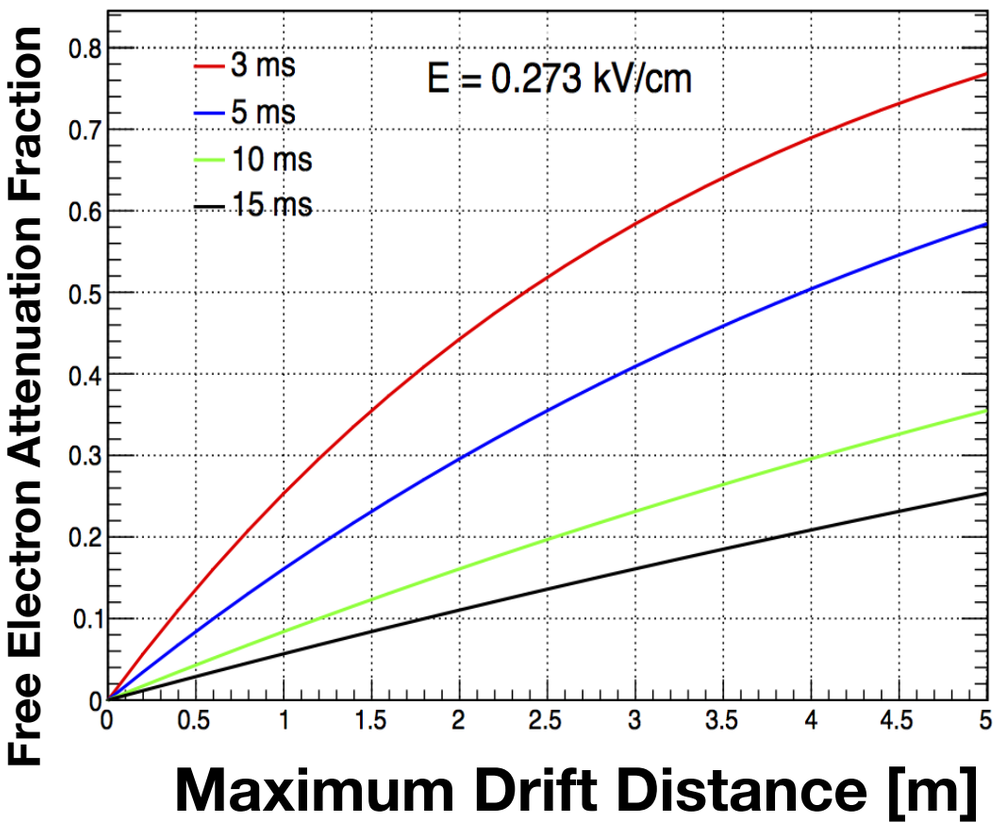
Crossing cosmic ray muons and laser tracks are used for this calibration.

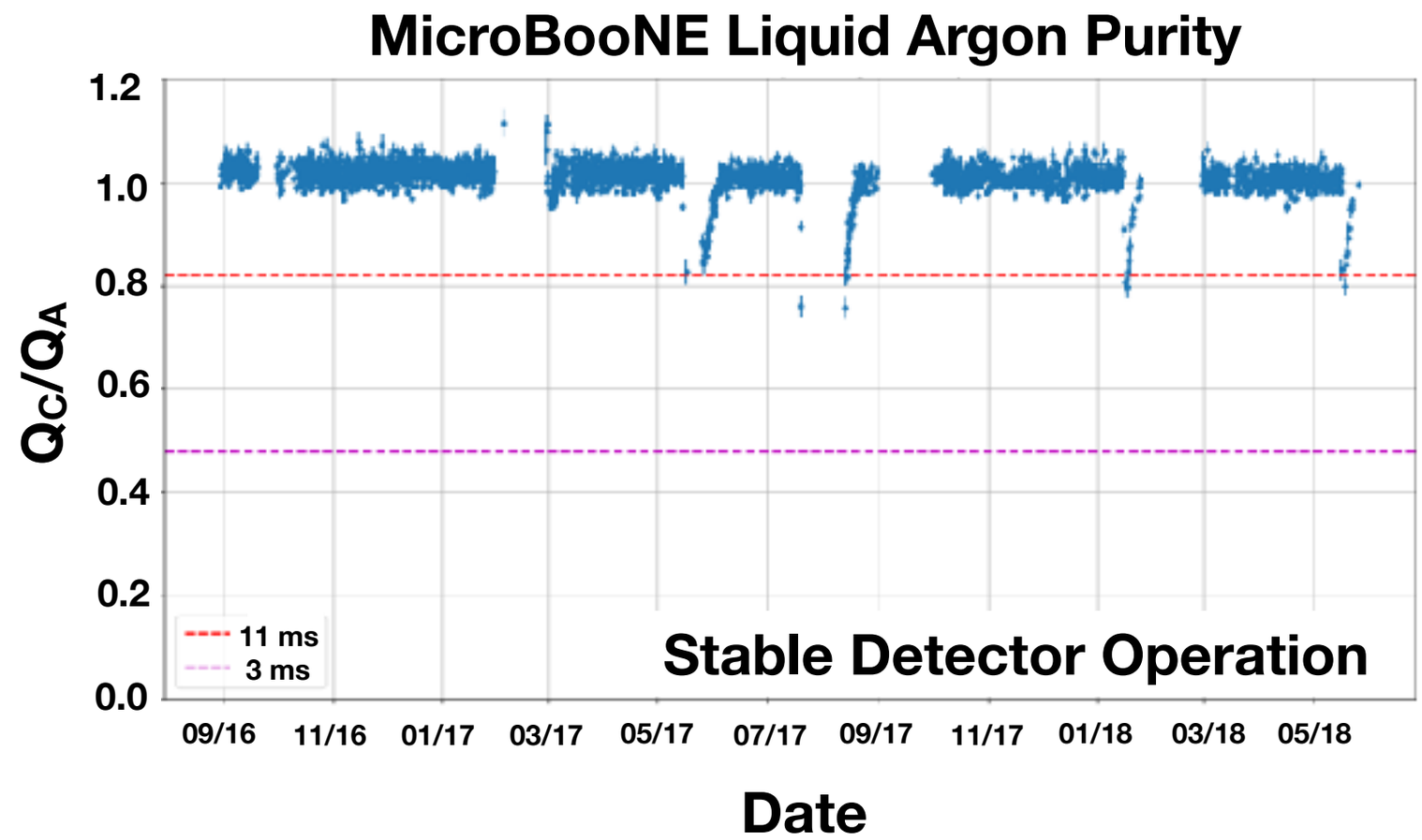






Electron Lifetime



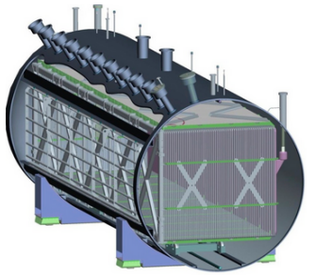


Stable Purity Period:

O_2 Equivalent Concentration: 17 ppt

Stable Purity Period:

Electron Lifetime: 18 ms
TPC Drift Time: 2.3 ms



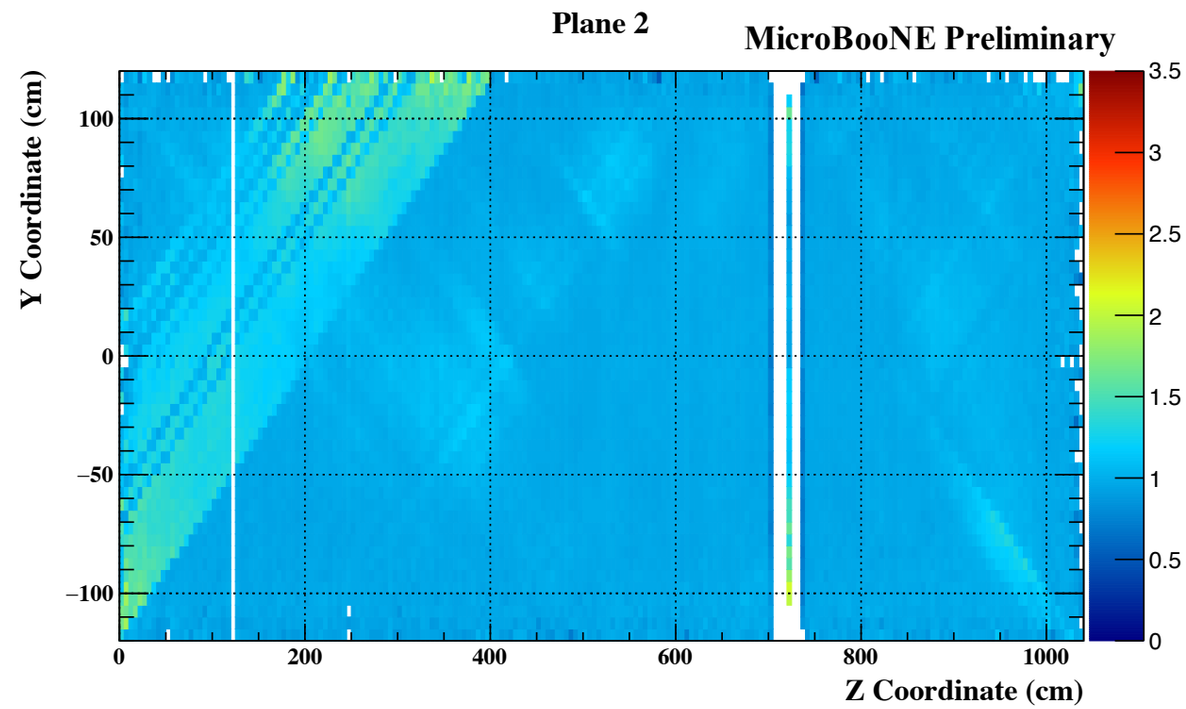
Calorimetry Calibration

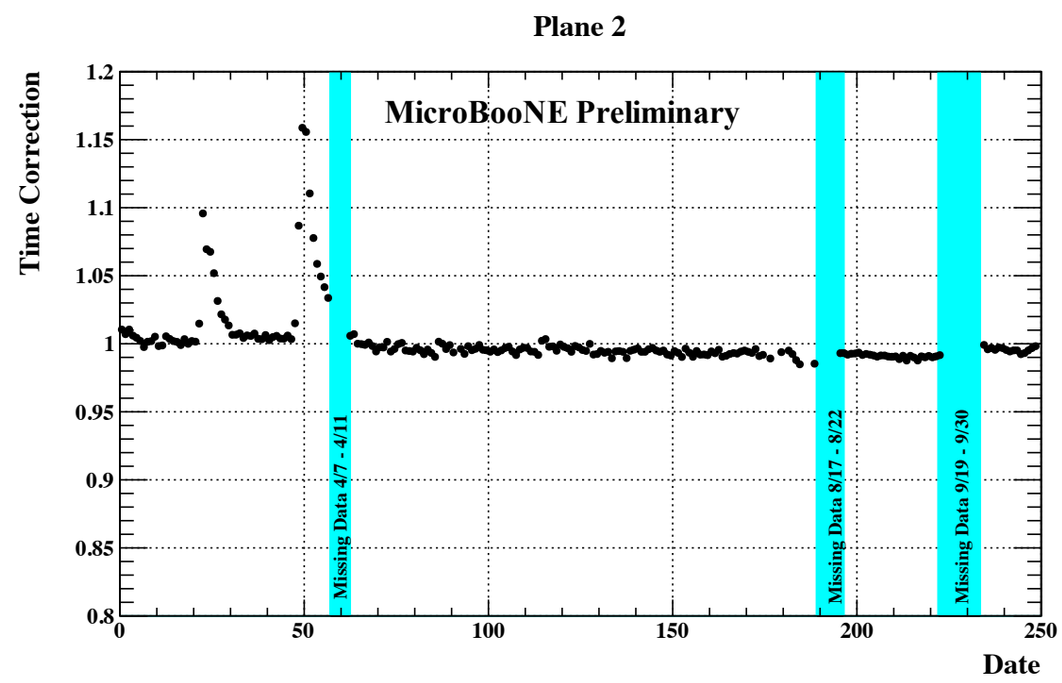
This calibration proceeds in two steps:

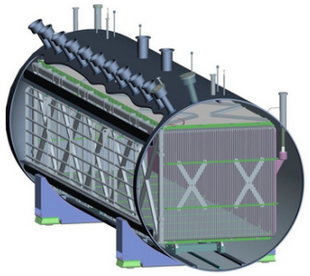
1. Charge Deposition Per Unit Length Calibration

- **Add a correction for variations in the wire coordinate direction.**
- **Add a correction for variations in the drift direction.**
- **Add a correction for daily variations.**

2. Energy Deposition Per Unit Length Calibration

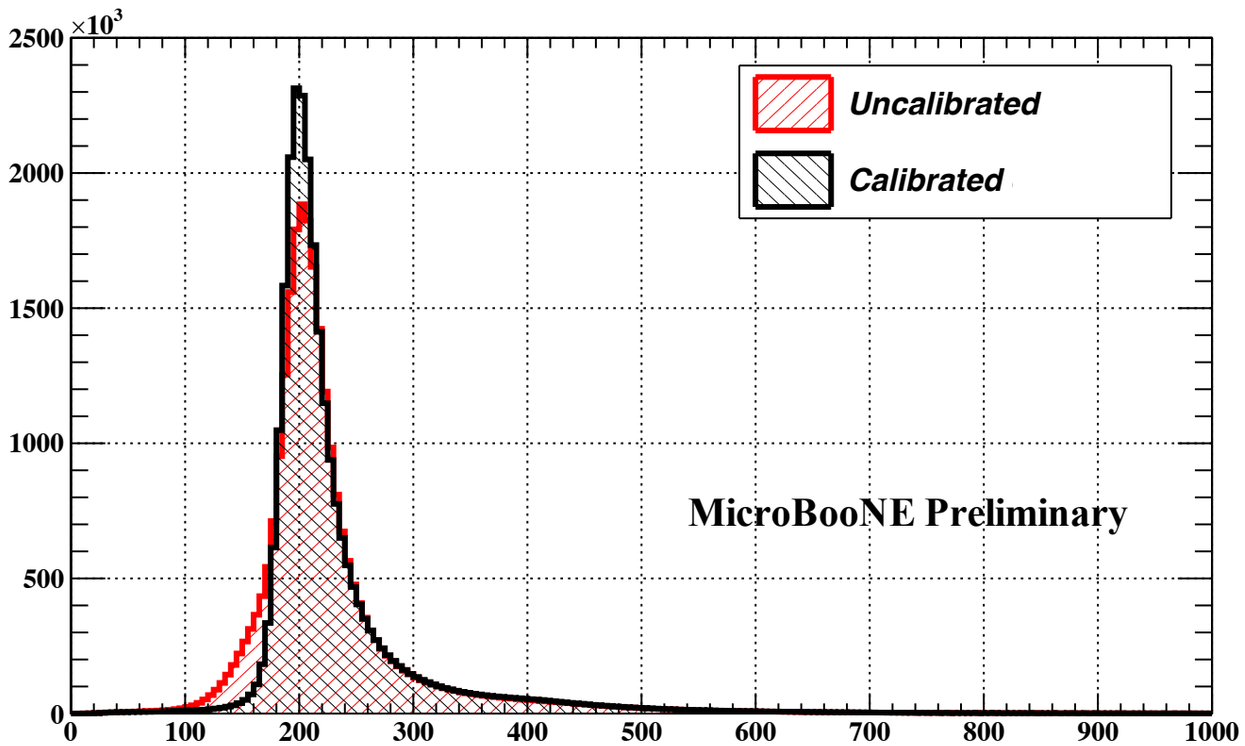




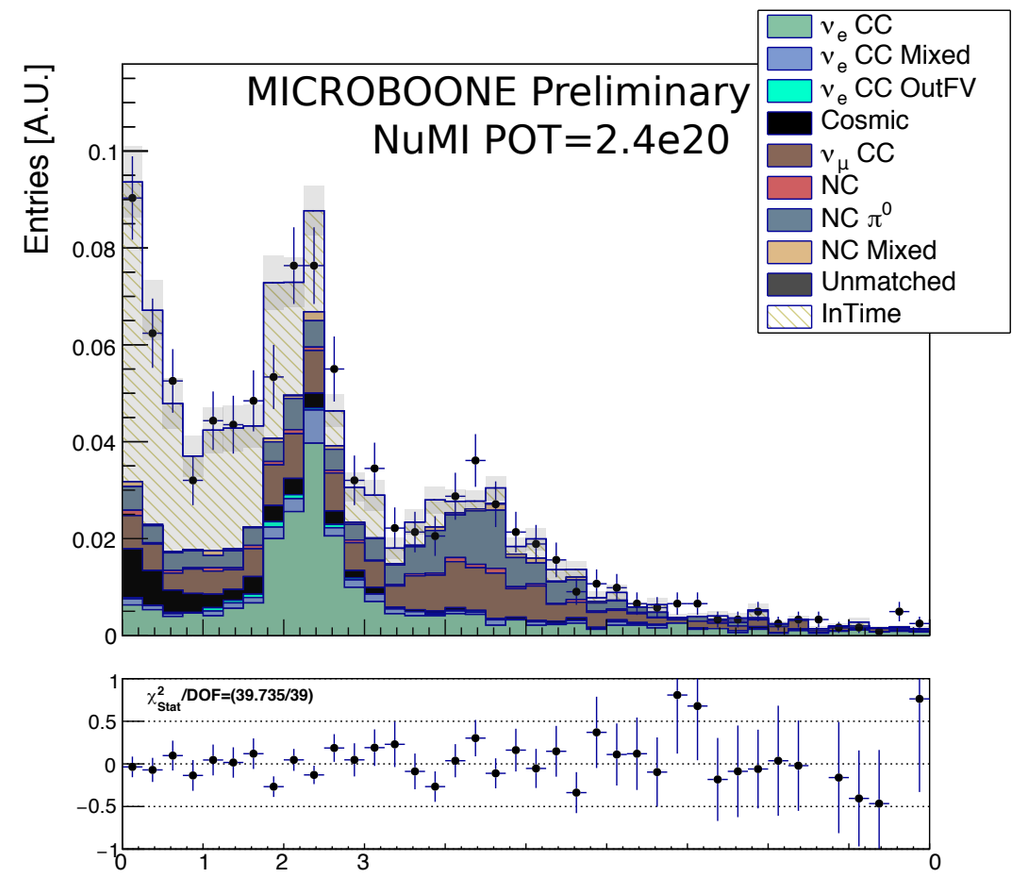


Calorimetry

Collection Plane Charge Deposited Per Unit Length



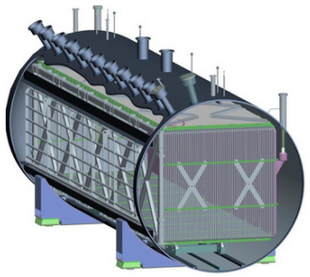
Charge Deposited Per Unit Length [ADC/cm]



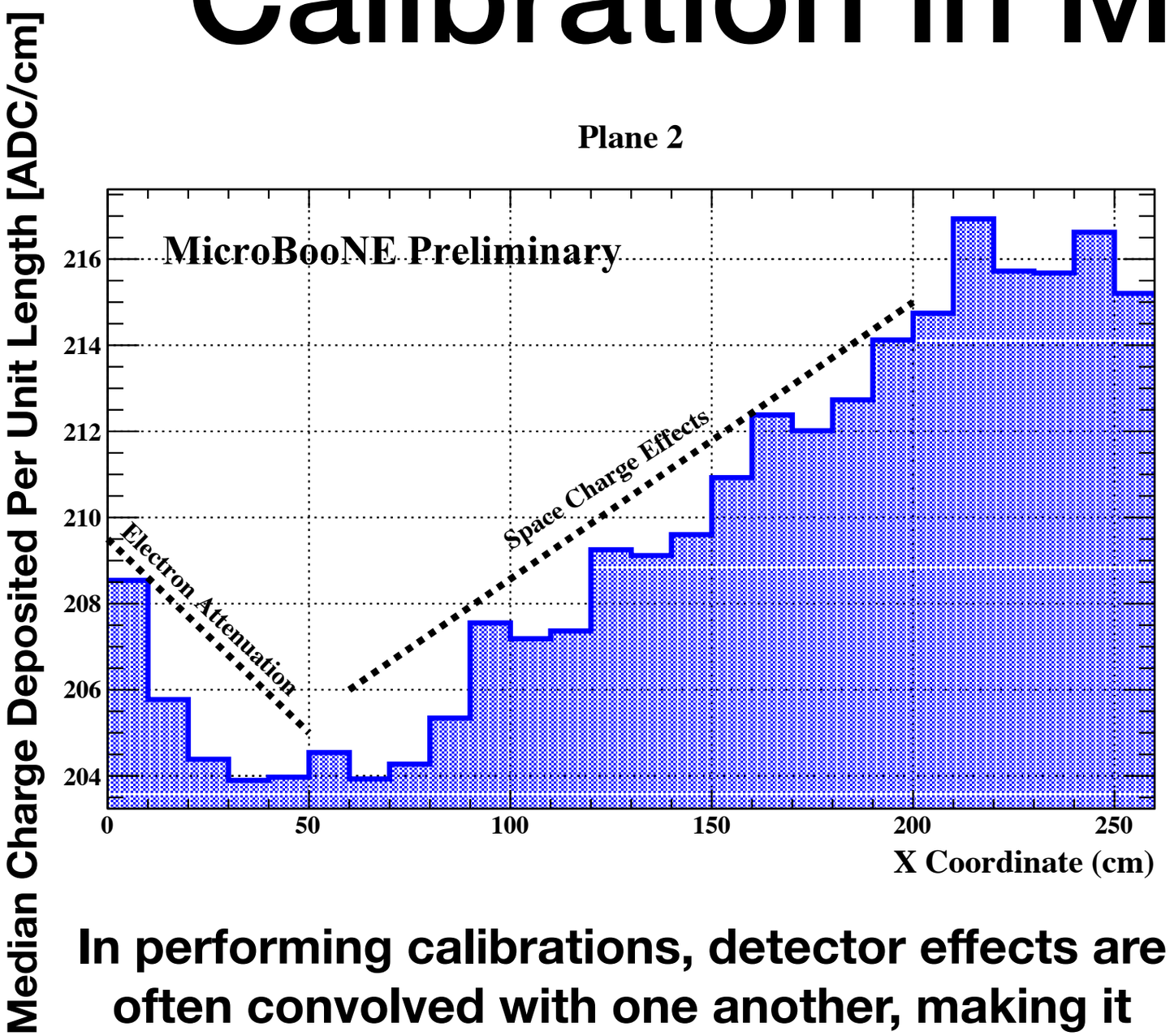
Collection Plane Energy Deposited Per Unit Length [MeV/cm]

MicroBooNE has released a public note highlighting calorimetry results, Public Note #48.

Effective dE/dx is critical for a LArTPC experiment to obtain correct energy deposition profiles.



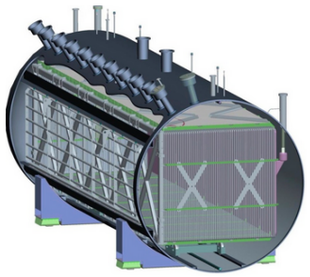
Importance of Calibration in MicroBooNE



In performing calibrations, detector effects are often convolved with one another, making it difficult to separate them.

Calibrating MicroBooNE occurs in a chain that ultimately benefits the experiment's physics goals:

- **Signal Processing**
- **Calorimetry/SCE Corrections**
- **Analysis Selection**

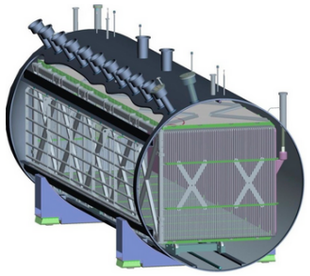


Conclusions

- The noise filtering/signal processing calibrations are complete. We have demonstrated the purity of the liquid argon in MicroBooNE.
- A full SCE calibration is coming soon.
- We are simultaneously working to calibrate other fundamental detector effects.
- Publications of MicroBooNE calibrations inform other LArTPC experiments (protoDUNE, ICARUS, SBND, DUNE).
- Thank you!

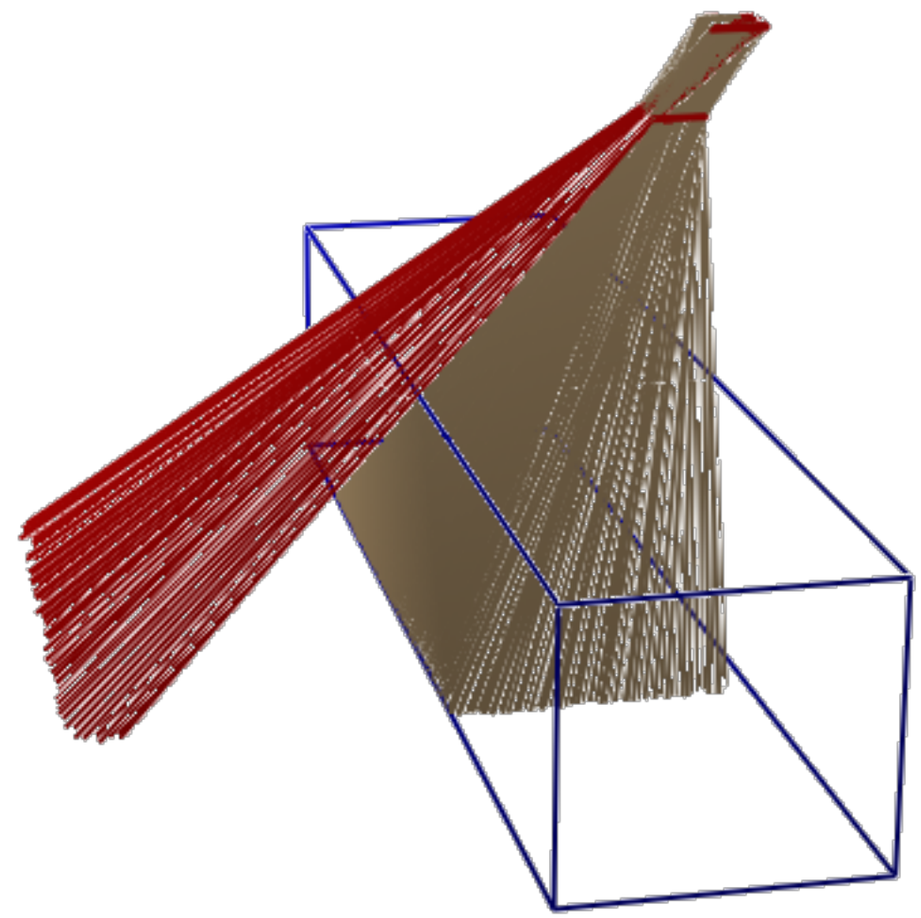
Fermilab
U.S. DEPARTMENT OF ENERGY | Office of Science
NSF
FNSNF SWISS NATIONAL SCIENCE FOUNDATION
Science & Technology Facilities Council
THE ROYAL SOCIETY

Backup



Through-Going Muons

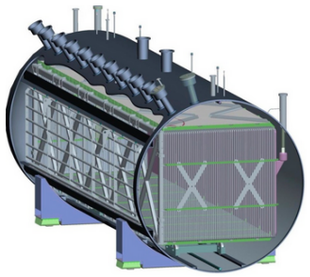
Tracks Missing TPC
Tracks Intersecting TPC



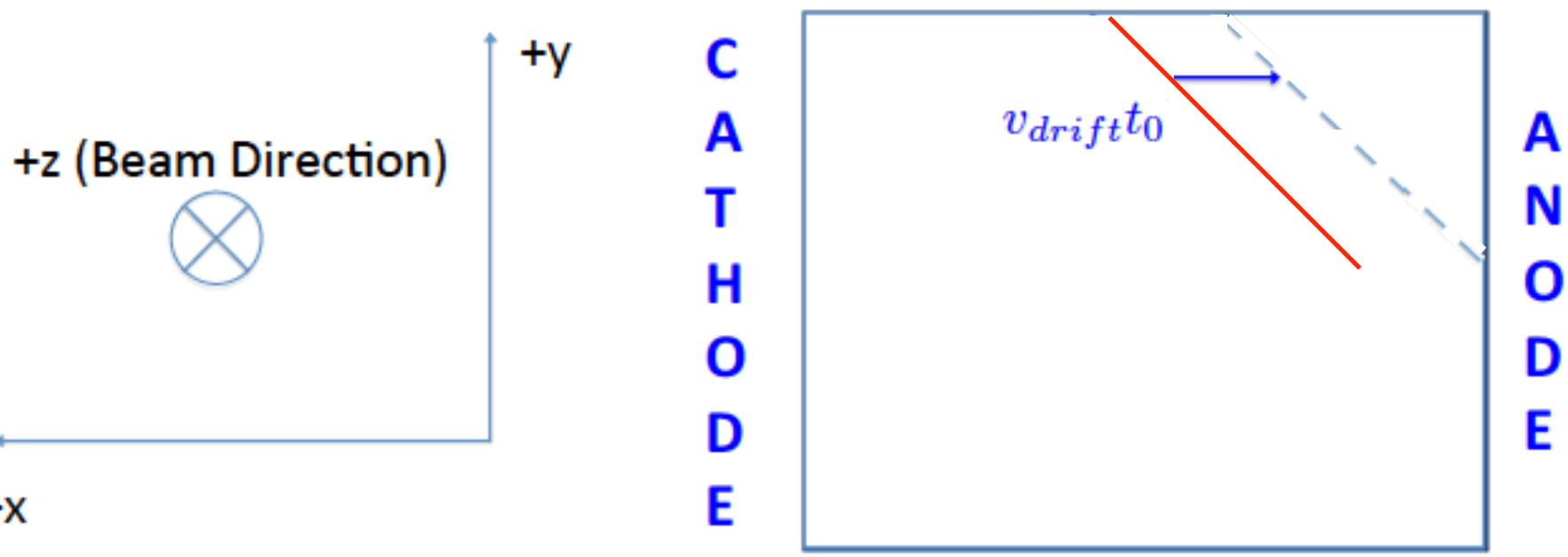
MicroBooNE currently employs two methods for tagging through-going muons:

1. MuCS (Muon Counter System)
JINST 12, P12030 (2017).

2. Anode-Piercing/Cathode-Piercing Tracks
MicroBooNE Public Note #28 (2017).



t_0-tagging Procedure

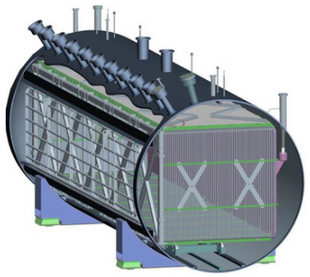


: Reconstructed Track

: t_0 - Corrected Track

Through-going cosmic ray tracks must have full 3D information available to be used in calibrations.

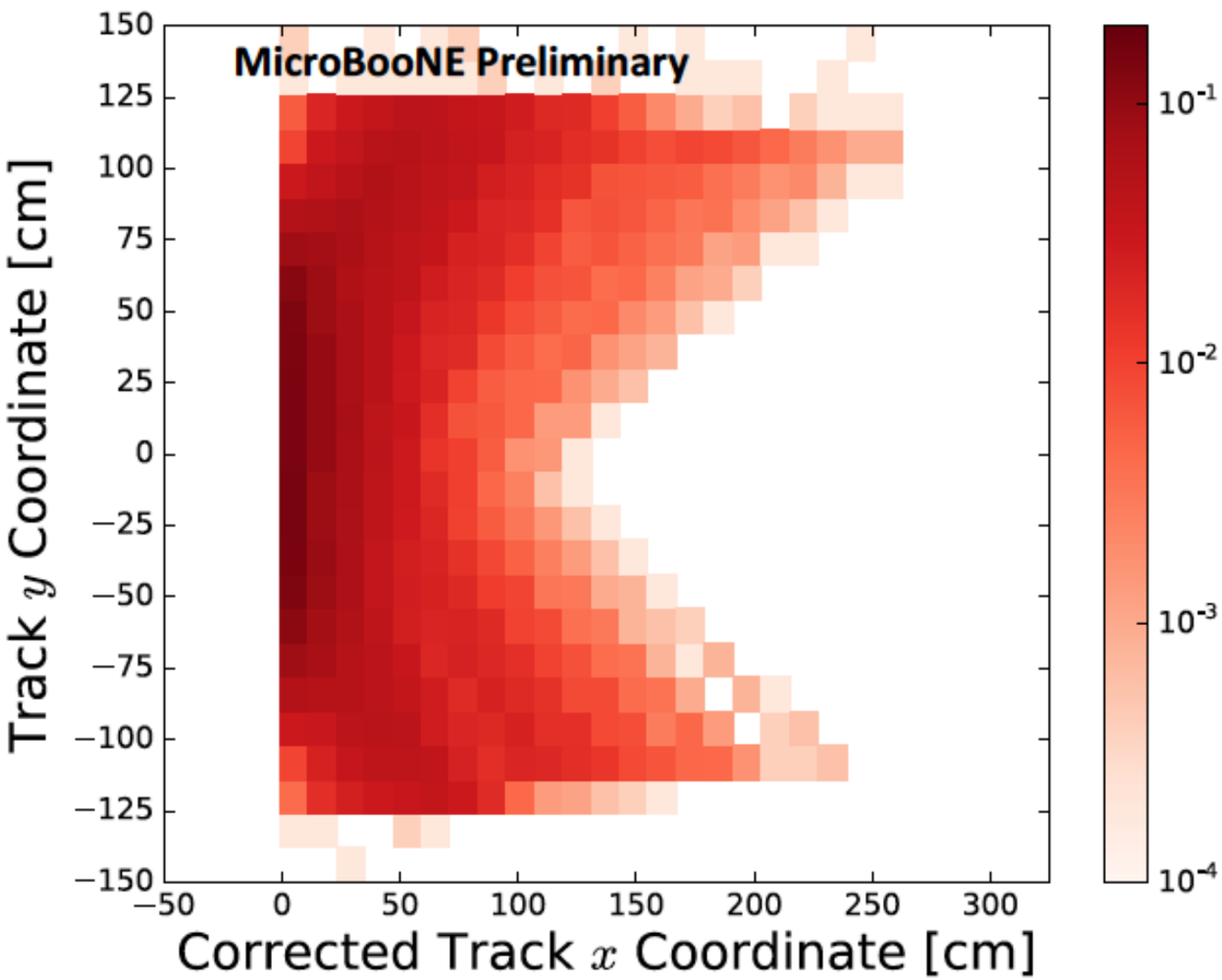
Cosmic ray tracks that pierce both the anode and the cathode can also be used for detector calibrations.



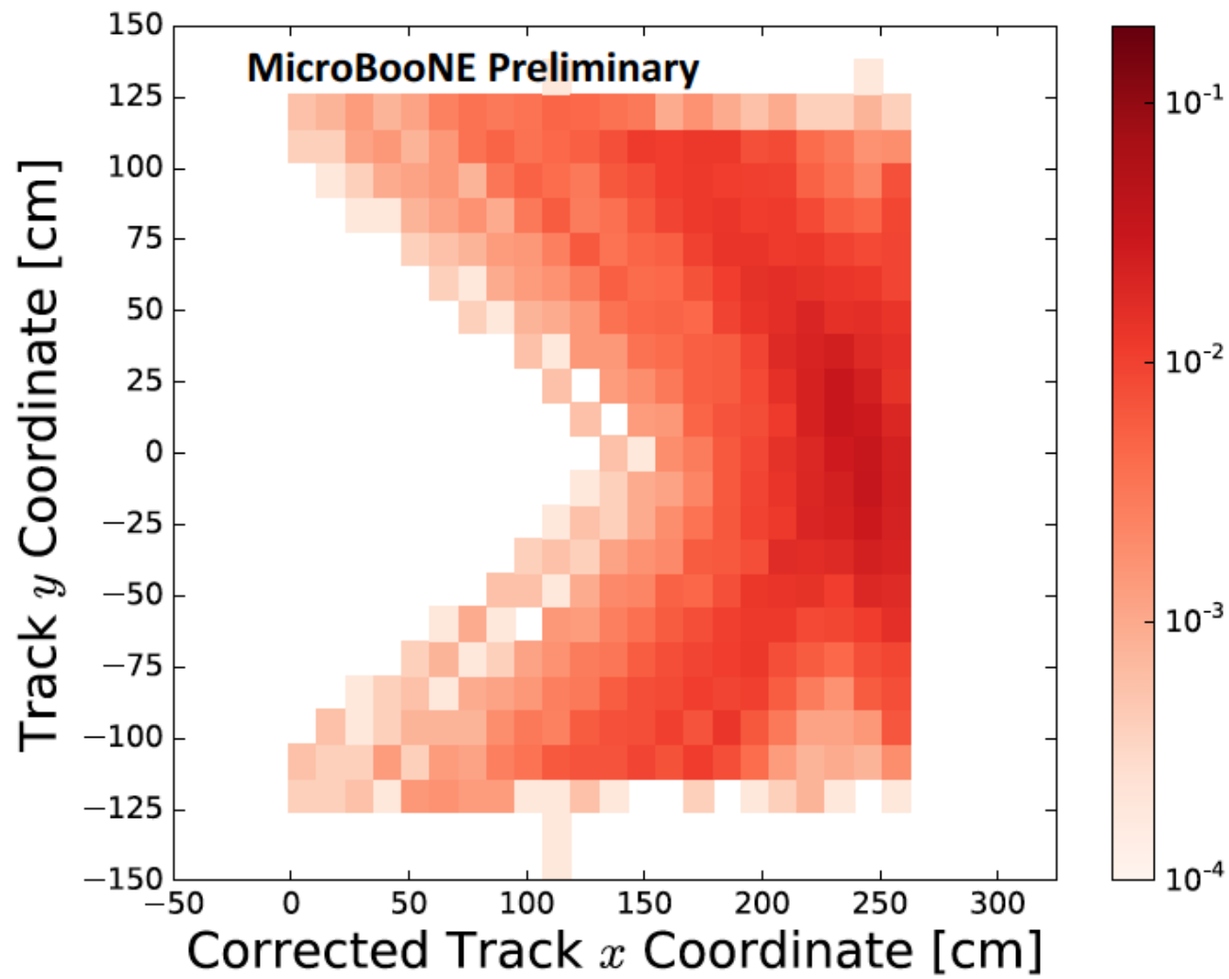
Anode-Piercing/Cathode-Piercing Tracks Coverage

Off-Beam Cosmic Sample:

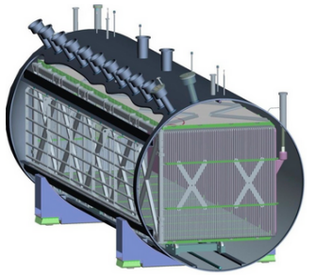
Anode-Piercing Track Coverage



Cathode-Piercing Track Coverage

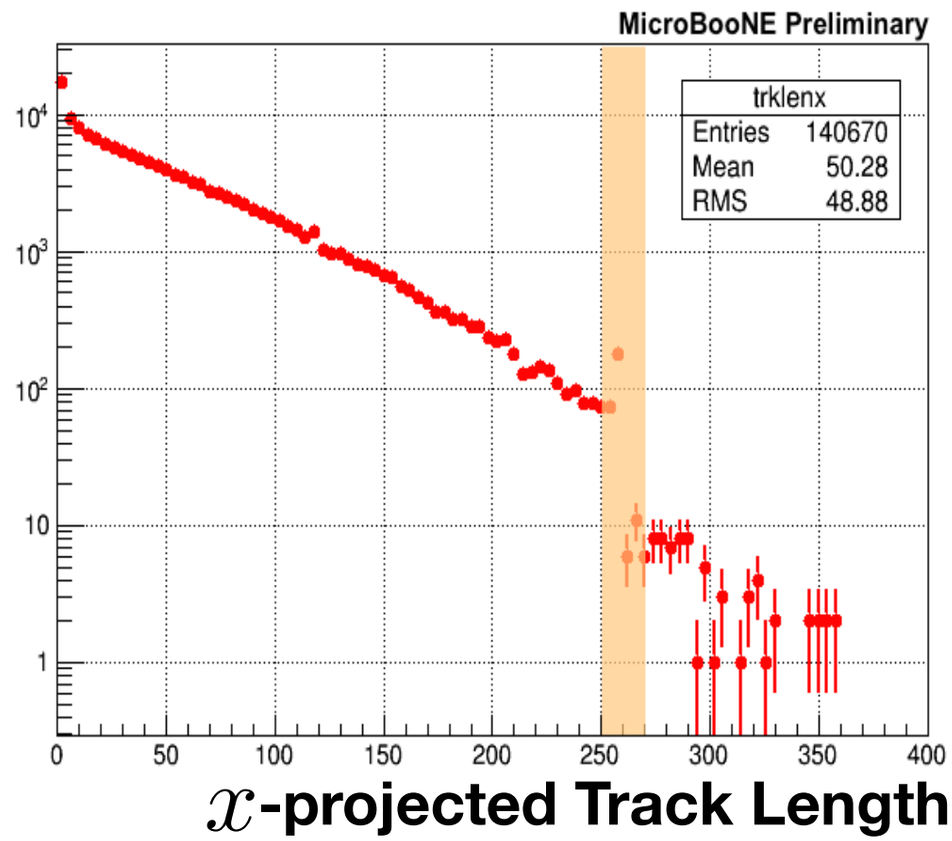


The coverages of anode-piercing and cathode-piercing tracks are biased because they must pierce that respective side of the TPC.



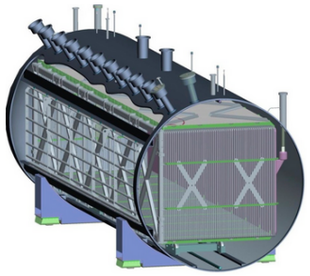
Anode-Cathode Crossing Muons

x-projected length of cosmic ray muon tracks.



Anode-cathode crossing tracks are selected according to their x-projected length.

This distribution has contingency ([250 cm, 270 cm]) to account for reconstruction effects.

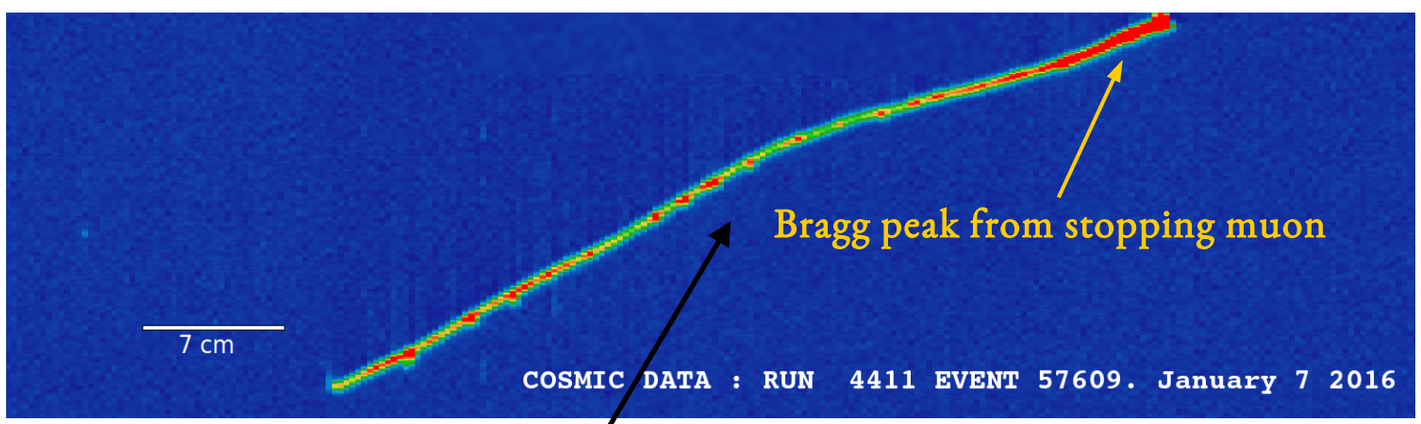


Stopping Muons

Stopping muons have a distinct energy loss profile in liquid argon.

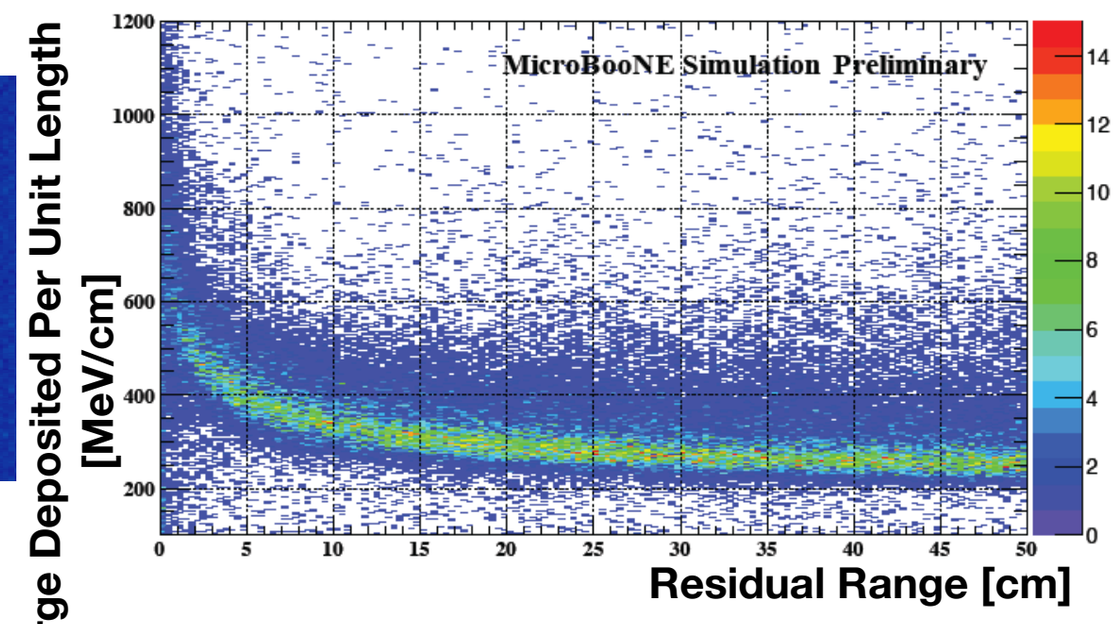
Therefore, with a pure sample of these tracks, we can compare to lookup tables to calibrate the dE/dx extrapolation of our detector.

MicroBooNE Event Display: False Color



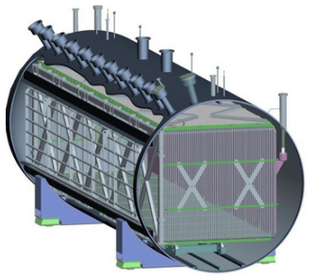
Stopping Muon

Charge Deposited Per Unit Length vs. Residual Range



Muon dE/dx

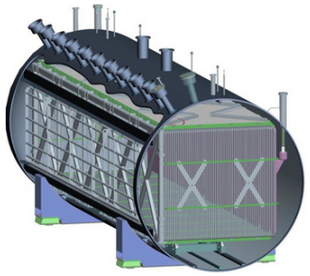
Muon Kinetic Energy



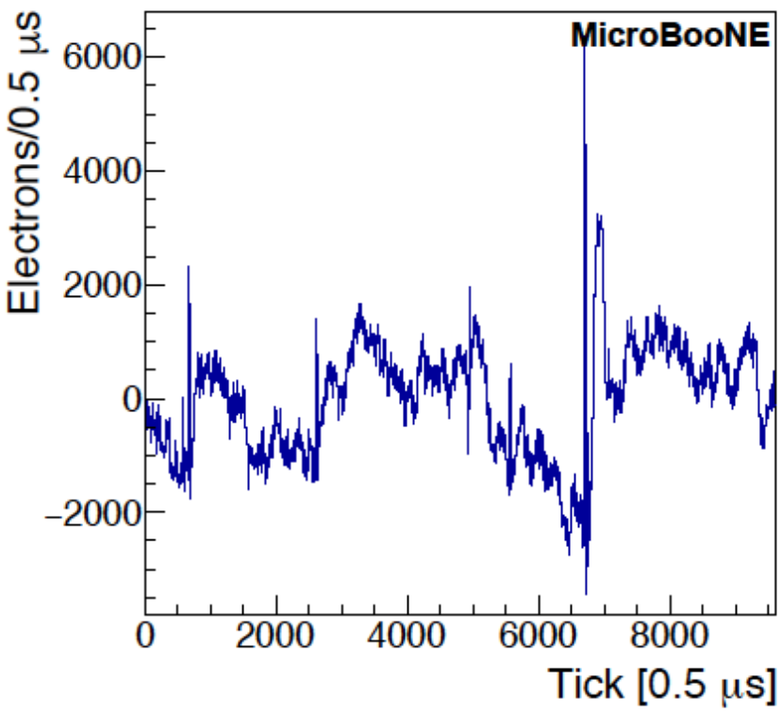
“Log 10” Scale

$$i = \text{electrons per } 0.5\,\mu\text{s}$$

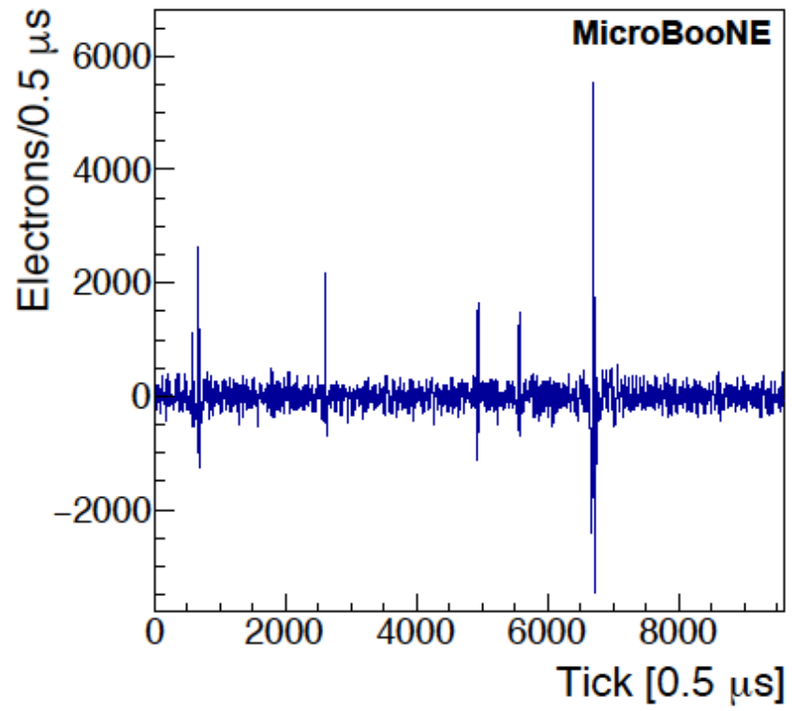
$$i \text{ in “Log 10”} = \begin{cases} \log_{10}(i \cdot 10^5), & \text{if } i > 1 \times 10^{-5}, \\ 0, & \text{if } -1 \times 10^{-5} \leq i \leq 1 \times 10^{-5}, \\ -\log_{10}(-1 \cdot i \cdot 10^5) & \text{if } i < -1 \times 10^{-5}. \end{cases}$$



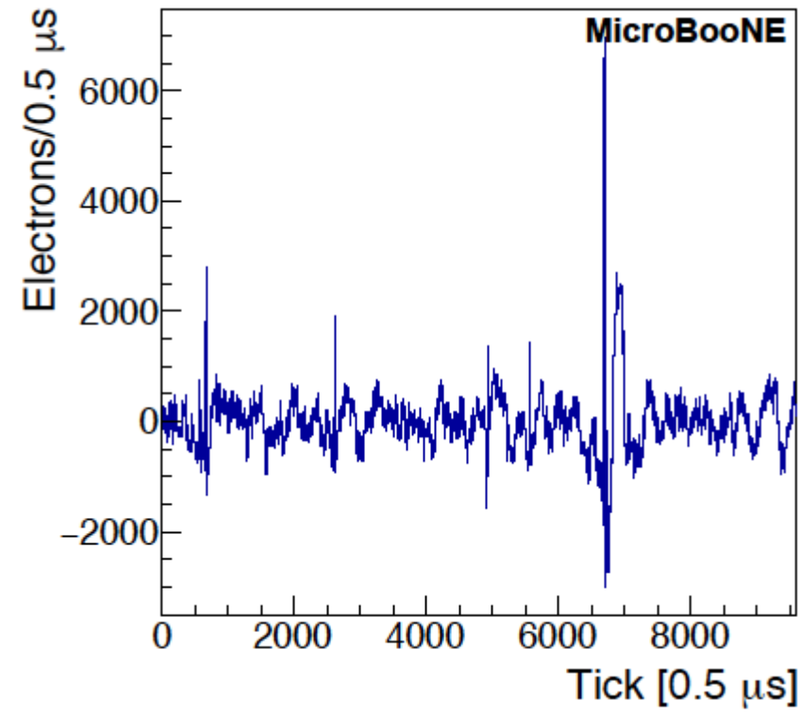
ROI Finding



No low-frequency filter

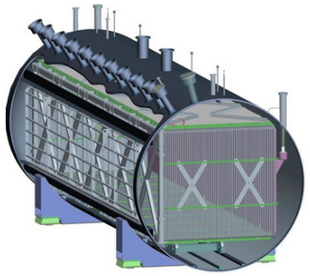


Tight low-frequency filter



Loose low-frequency filter

Two filters intended to remove low-frequency components of the input signal are used to find the signal Regions of Interest (ROIs). They are used on the induction planes only.

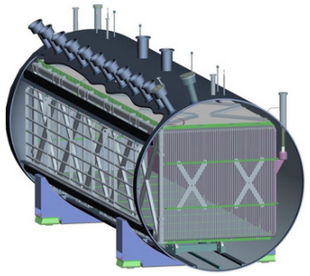


2D Deconvolution

$$\begin{pmatrix} M_1(\omega) \\ M_2(\omega) \\ \vdots \\ M_{n-1}(\omega) \\ M_n(\omega) \end{pmatrix} = \begin{pmatrix} R_0(\omega) & R_1(\omega) & \dots & R_{n-2}(\omega) & R_{n-1}(\omega) \\ R_1(\omega) & R_0(\omega) & \dots & R_{n-3}(\omega) & R_{n-2}(\omega) \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R_{n-2}(\omega) & R_{n-3}(\omega) & \dots & R_0(\omega) & R_1(\omega) \\ R_{n-1}(\omega) & R_{n-2}(\omega) & \dots & R_1(\omega) & R_0(\omega) \end{pmatrix} \cdot \begin{pmatrix} S_1(\omega) \\ S_2(\omega) \\ \vdots \\ S_{n-1}(\omega) \\ S_n(\omega) \end{pmatrix}$$

In our signal processing, we now use a 2D filter, in time and in the wire coordinate.

Previously, only 1D convolution in time was used.



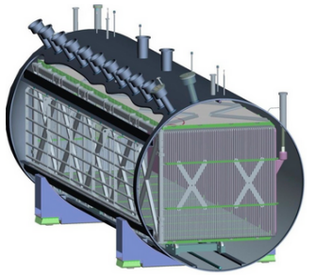
Data-Driven MuCS Correction

$$y_{\text{corr}} = y_{\text{reco}} - \Delta y(x_{\text{reco}}, y_{\text{reco}})$$

$$\Delta y(x_{\text{reco}}, y_{\text{true}}) = \begin{cases} (f_{\text{top}}(x_{\text{reco}}) - y_{\text{top}})\, g(y_{\text{true}}), & \text{if } y_{\text{reco}} > 0 \\ (f_{\text{bottom}}(x_{\text{reco}}) - y_{\text{bottom}})\, g(y_{\text{true}}), & \text{if } y_{\text{reco}} < 0 \end{cases}$$

$f_{\text{top}}(x_{\text{reco}})$ $(f_{\text{bottom}}(x_{\text{reco}}))$ **: a quartic polynomial that gives the correction that must be applied as a function of x.**

$g(y_{\text{true}})$**: is a scaling function that describes the change in the correction with y.**



dE/dx Calculation

We calculated dE/dx from dQ/dx by using the following formula:

$$\left(\frac{dE}{dx}\right)_{calibrated} = \frac{exp\left(\frac{\left(\frac{dQ}{dx}\right)_{calibrated}}{C} \cdot \frac{\beta_p W_{ion}}{\rho\varepsilon}\right) - \alpha}{\frac{\beta_p}{\rho\varepsilon}}$$

C – Calibration constant to convert ADC values to number of electrons

W_{ion} – 23.6 x 10^{-6} MeV/electron (work function of argon)

ε – 0.273 kV/cm (MicroBooNE drift electric field)

ρ – 1.38 g/cm^3 (liquid argon density at a pressure 18.0 psia)

β_p and α were determined by ArgoNeuT, which operated at a drift electric field of 0.481 kV/cm.