Measuring Electron Diffusion at MicroBooNE

Adam Lister, on behalf of the MicroBooNE Collaboration
IOP APP & HEPP Meeting 2018

An Introduction to MicroBooNE

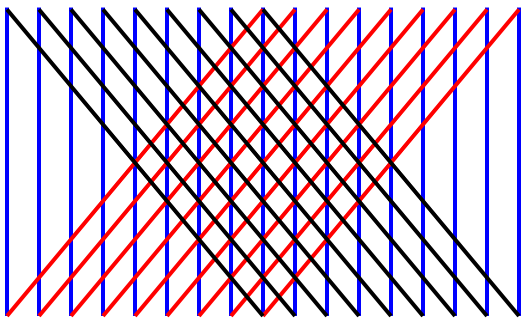
MicroBooNE:

- Liquid Argon Time Projection Chamber (LArTPC) in the Booster Neutrino Beam at Fermi National Accelerator Laboratory
- Taking physics data since August 2015
- Located on the surface, meaning there's a high rate of cosmic-ray muons

Primary Goals of MicroBooNE:

- Characterise **excess of events at low neutrino energy** observed by MiniBooNE
    - More on this in R. Murrells talk in this session
- Measurements of ***ν*-Ar cross-sections**
- **Detector R&D** for the next generation of LArTPCs

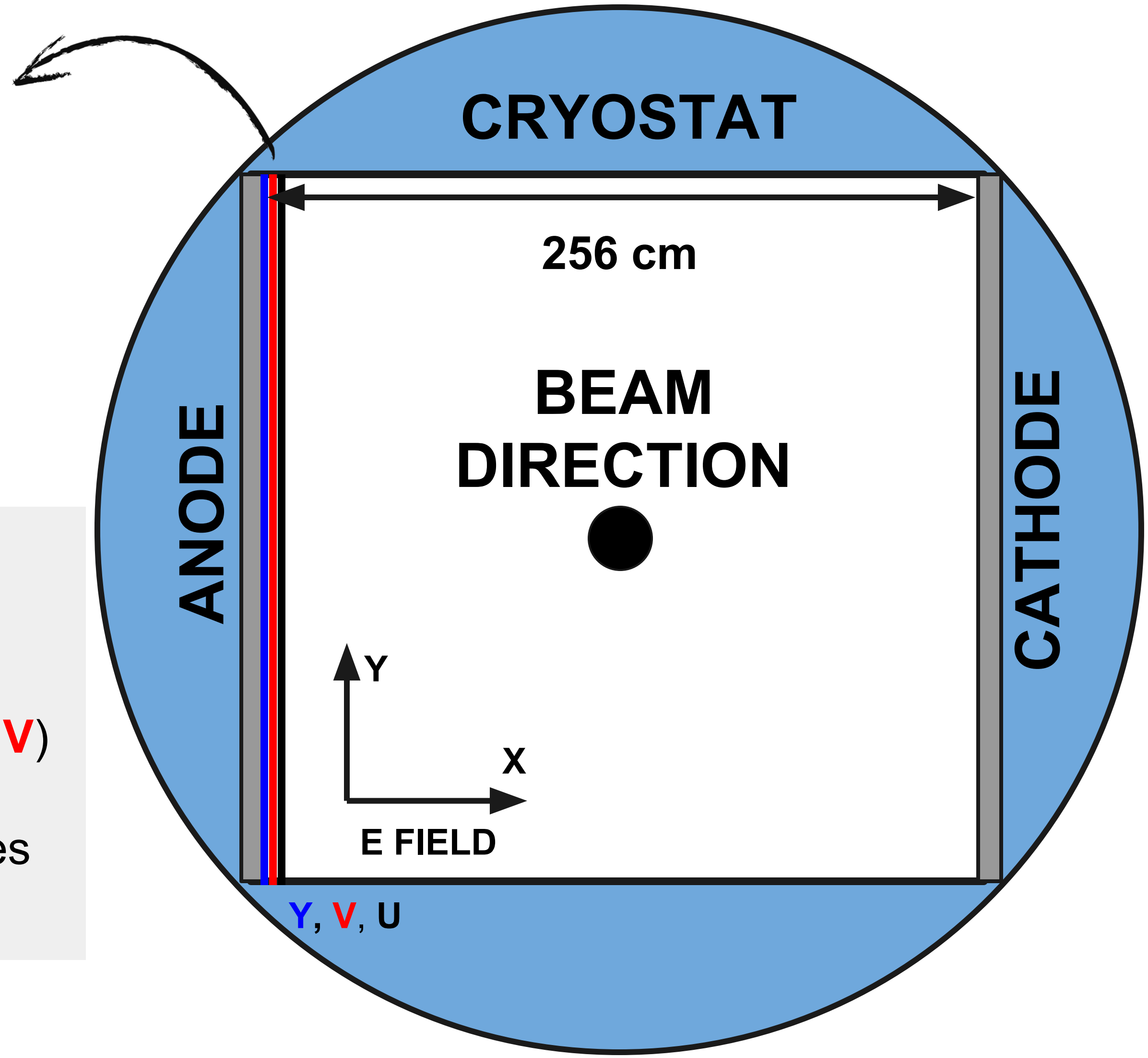
The MicroBooNE Time Projection Chamber



U & **V** plane wires ± 60° to the vertical **Y** plane wires

QUICK STATS

- 8256 Wires
- 3 Wire Planes
  - 2 Induction (**U** and **V**)
  - 1 Collection (**Y**)
- 32 PhotoMultiplier Tubes (PMTs)



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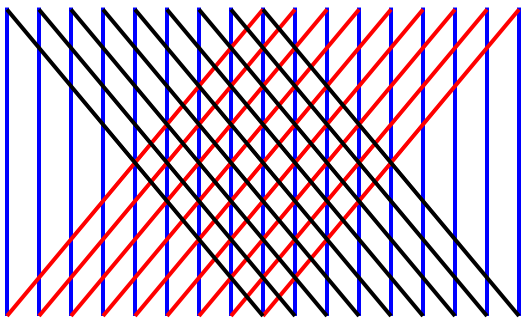

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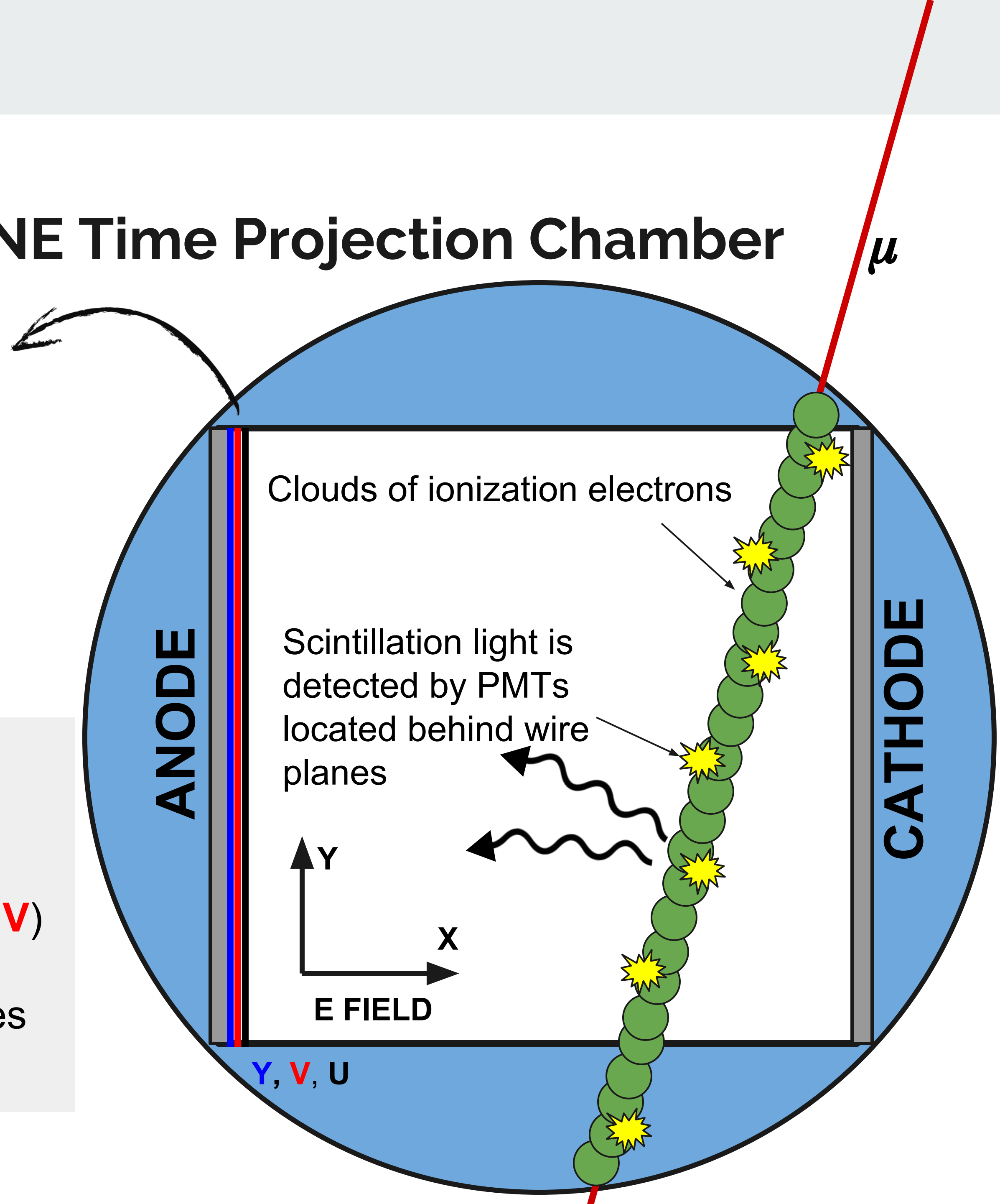

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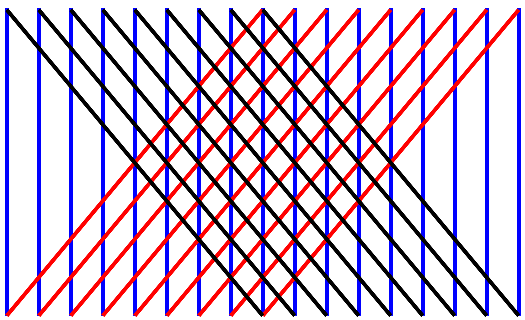

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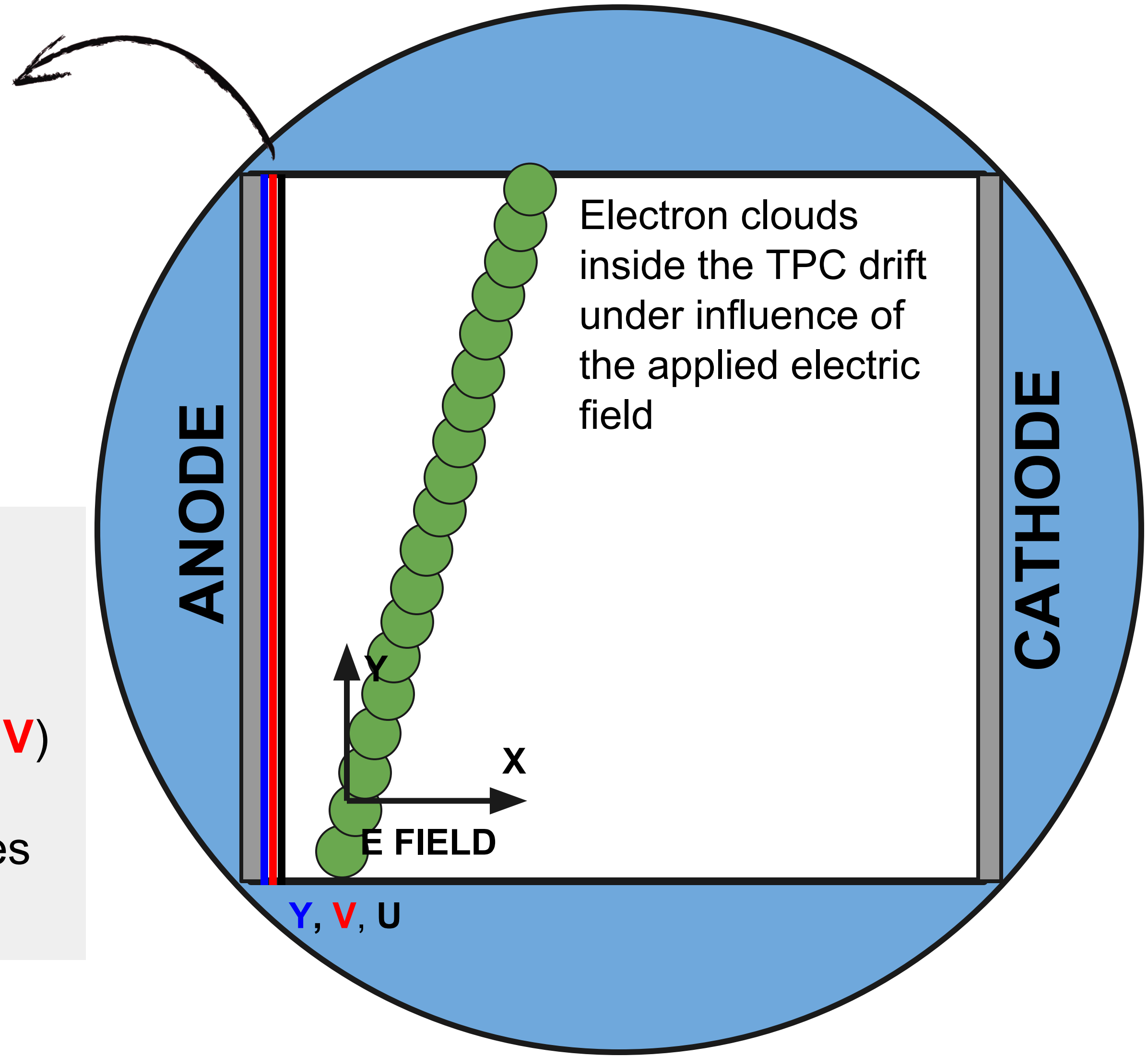

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[1] The MicroBooNE Collaboration, **Ionization Electron Signal Processing in Single Phase LArTPCs I.**, arXiv 1802.08709

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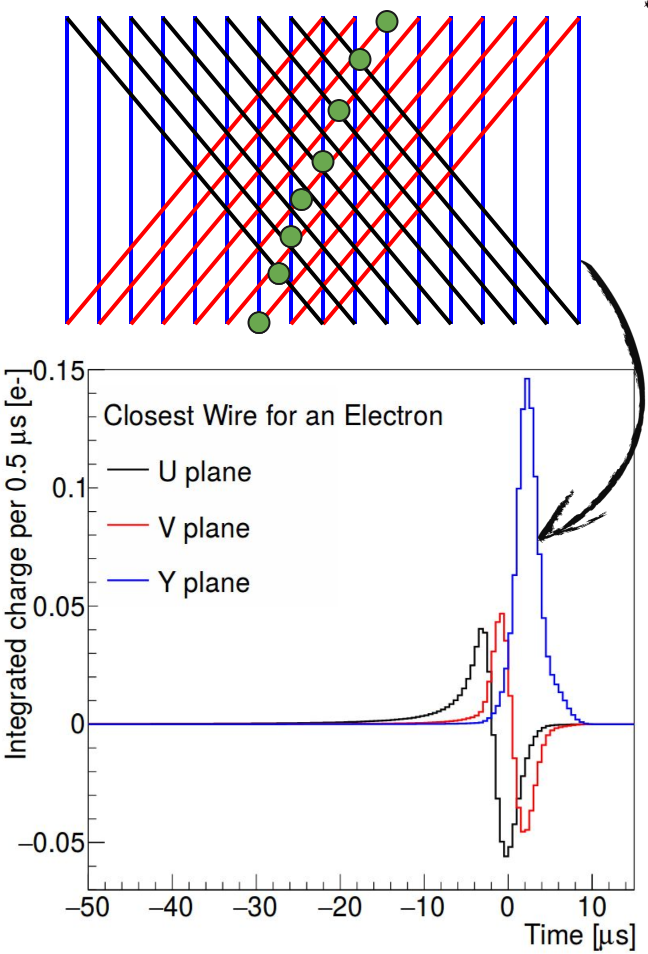

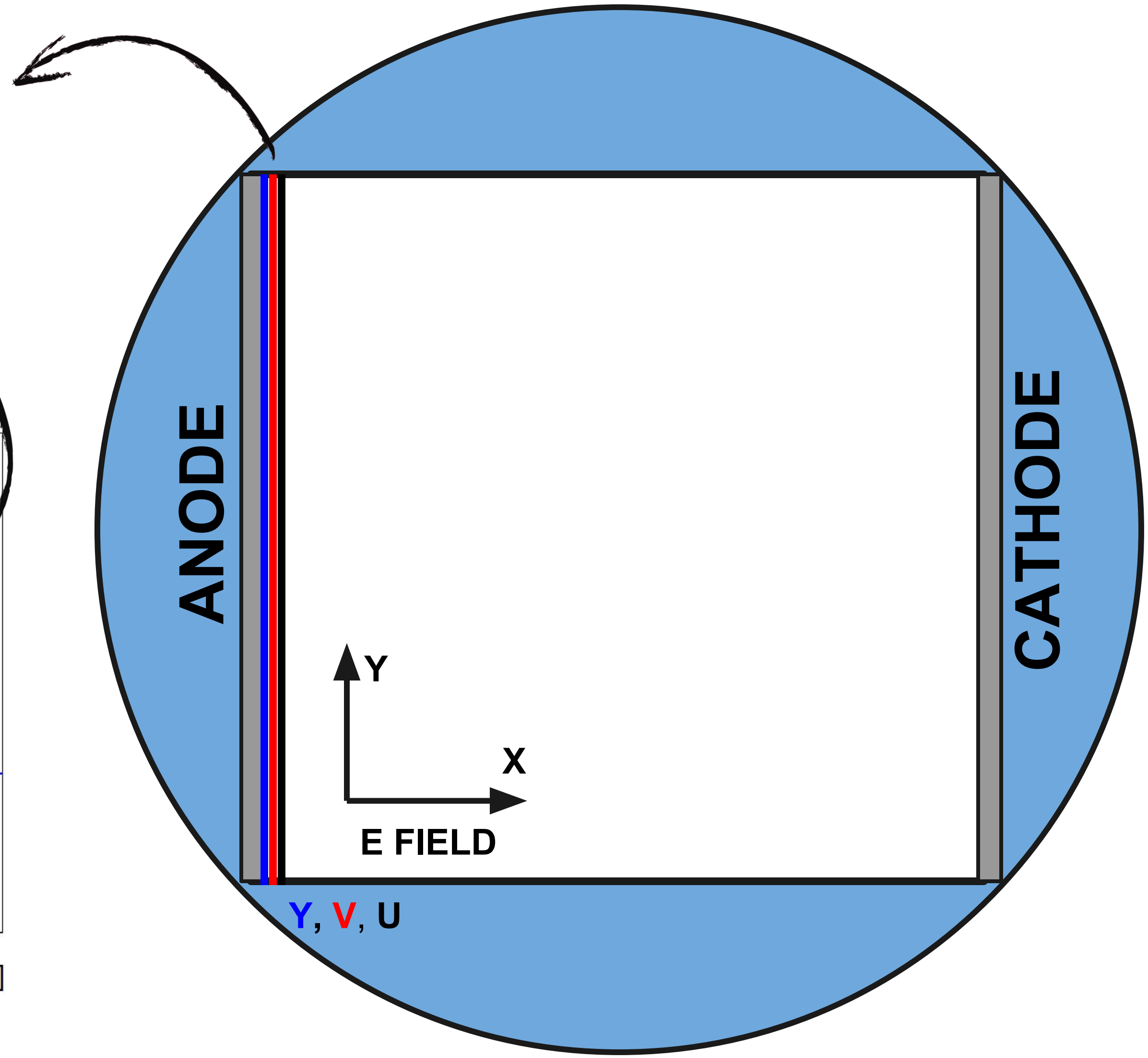

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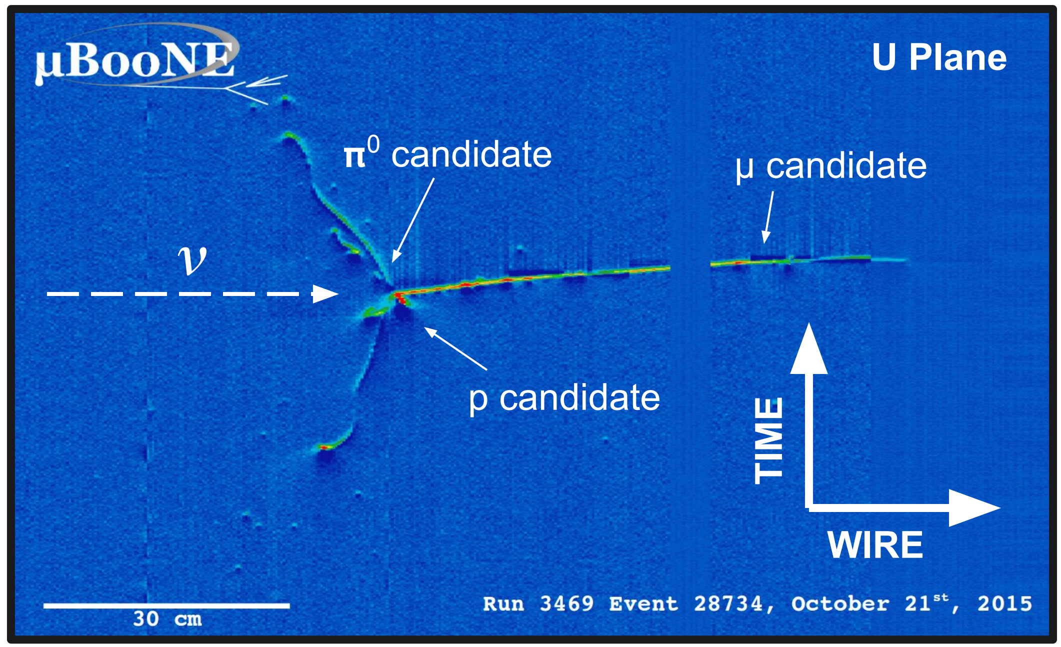

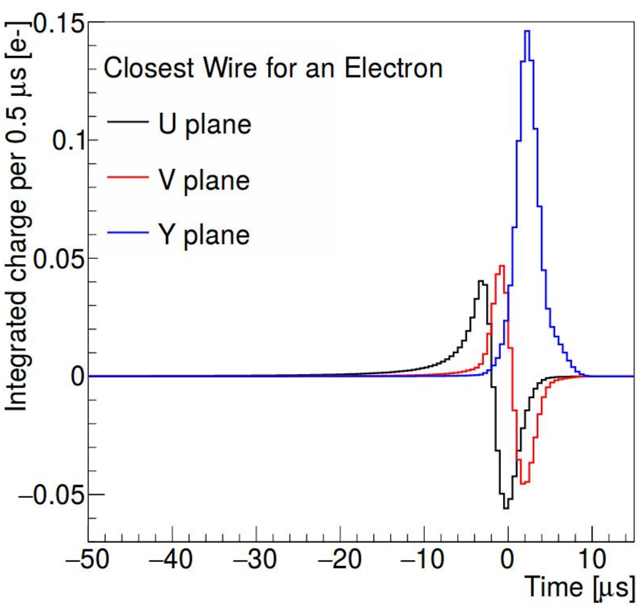

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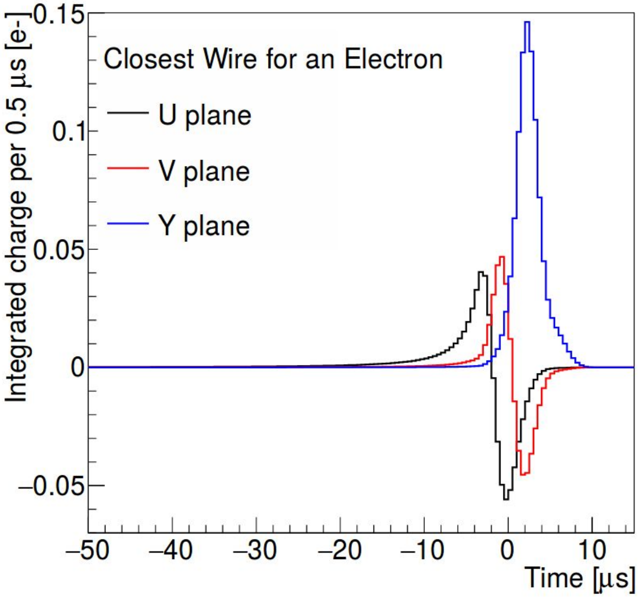

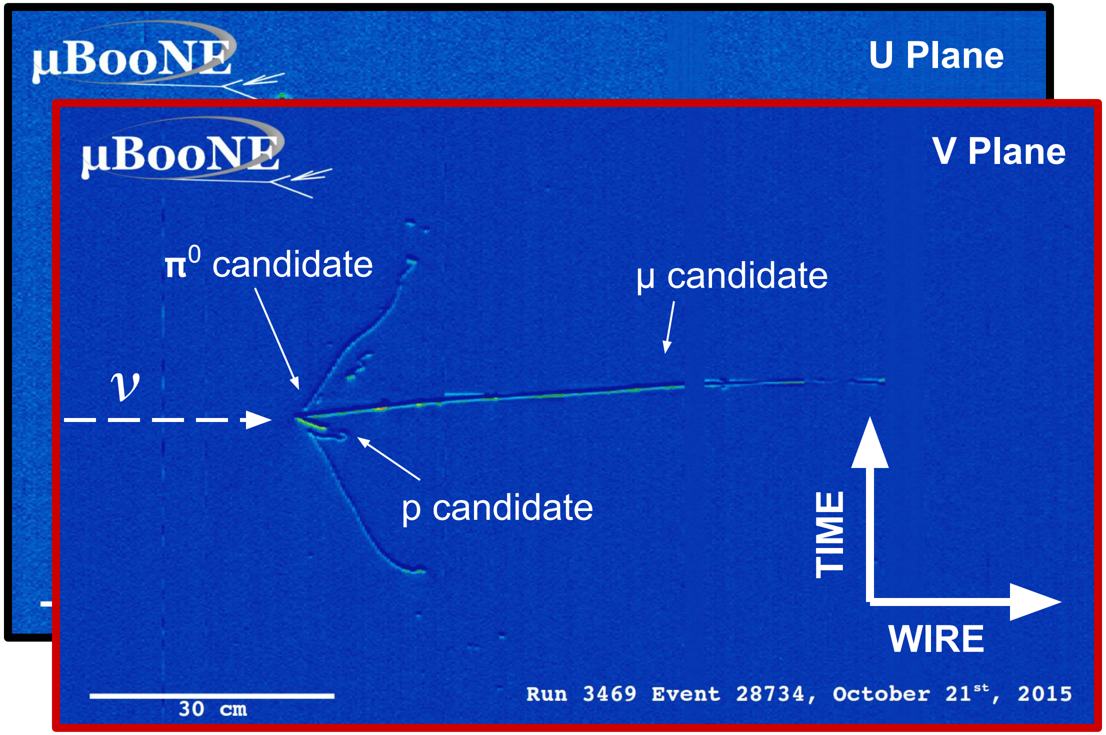

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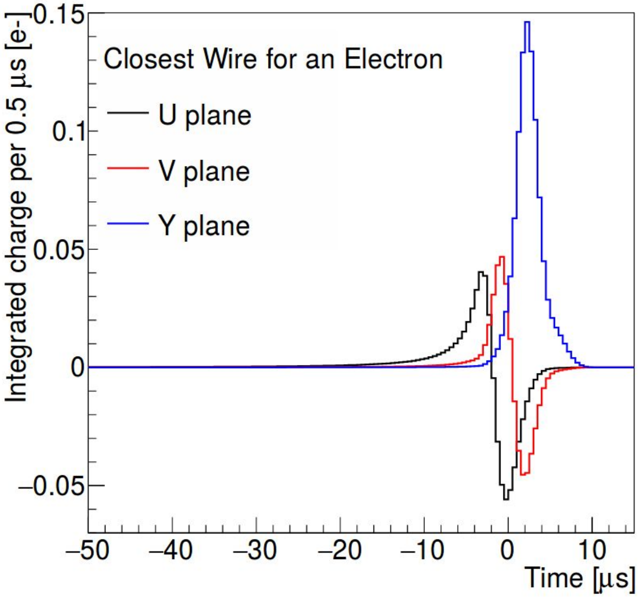

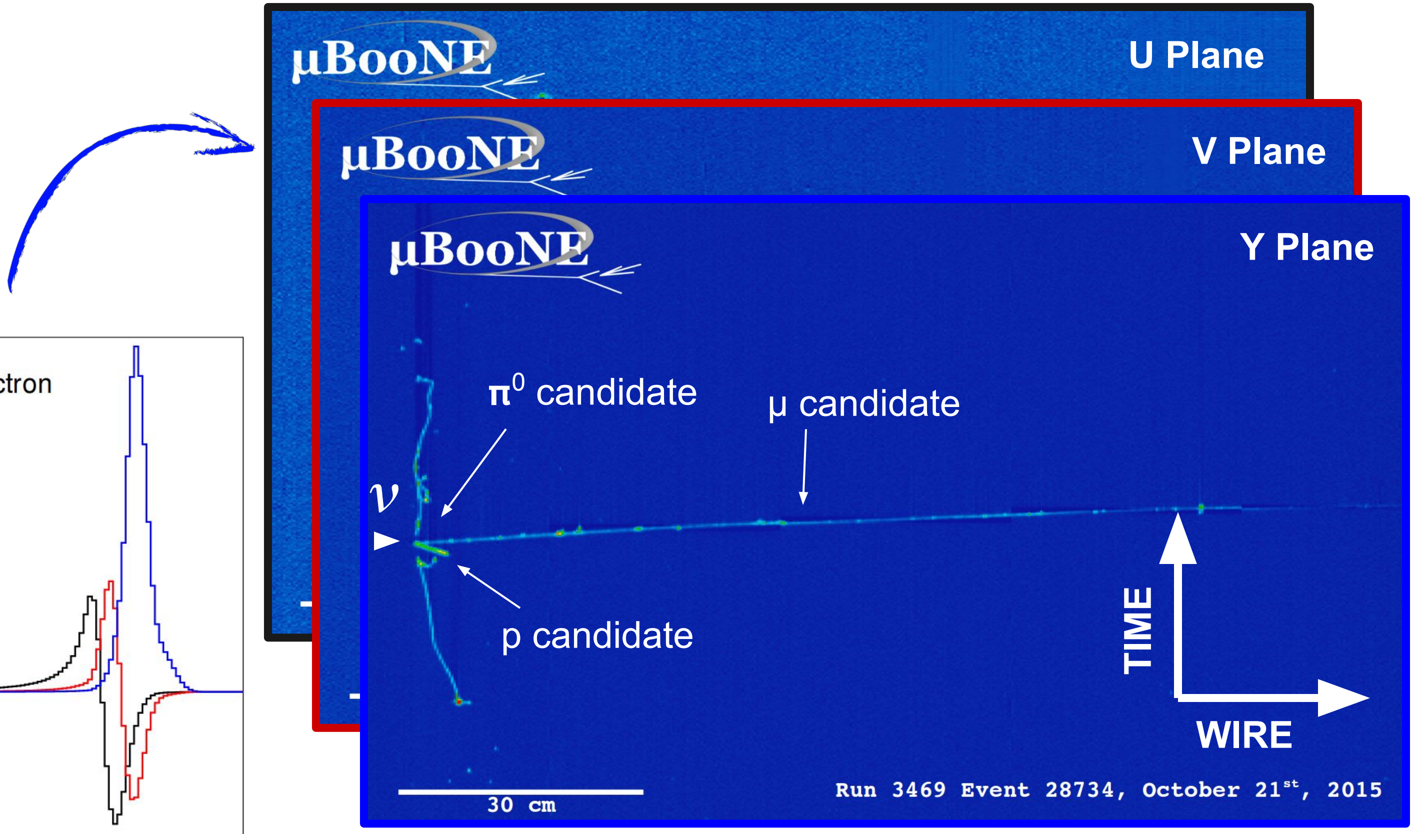

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Signal Processing at MicroBooNE

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S = true signal
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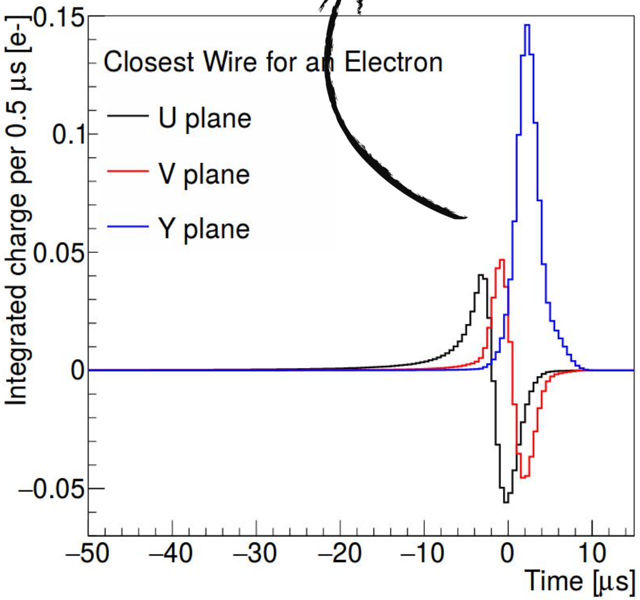

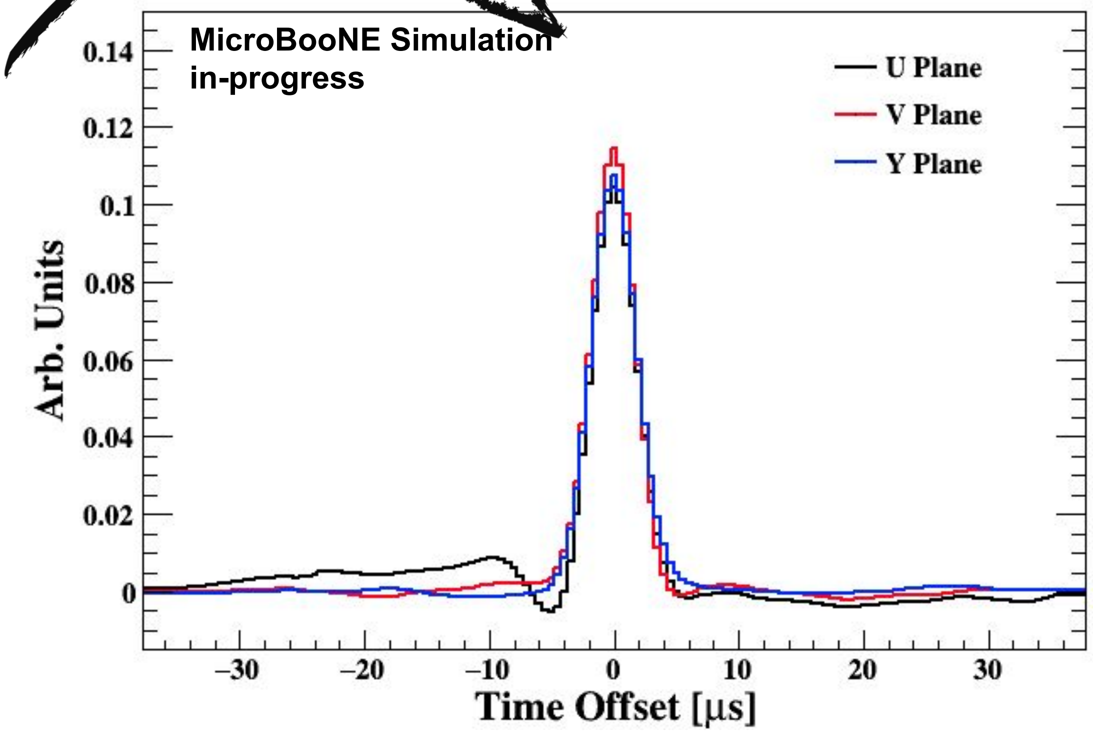

Post deconvolution, the pulses are significantly more Gaussian across the three planes.

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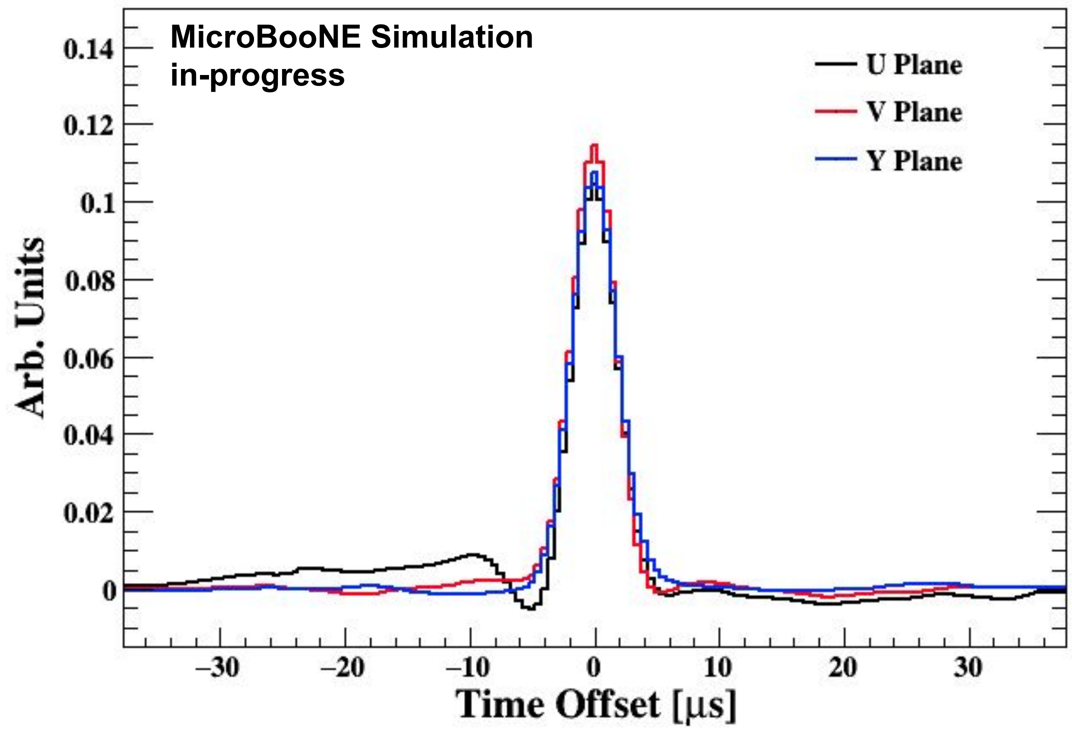
Signal Processing at MicroBooNE

Gaussian functional forms ("*hits*") are fit to the deconvolved waveforms on each wire, and these hits are used to construct tracks.

By design, the **collection plane** has the best signal-to-noise ratio, and so we proceed with the analysis only using this plane.

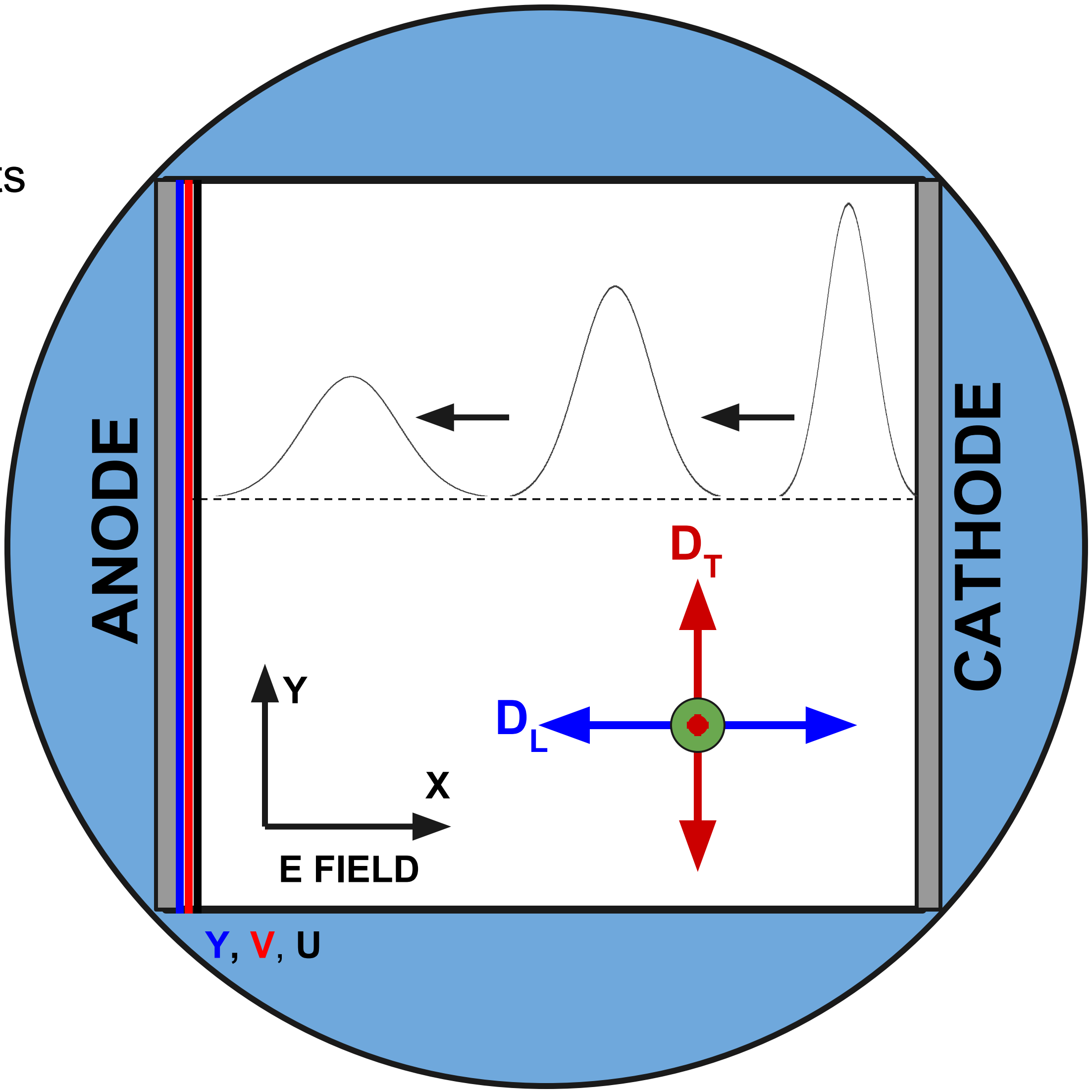


Diffusion in LArTPCs

Diffusion acts to spread out the ionisation electron cloud as it drifts through the TPC. In an electric field, this effect has separate **longitudinal** and **transverse** components.

Longitudinal diffusion:

- Acts in direction of E field, changing the pulse width, σ_t, as a function of drift distance
- Modifies temporal resolution
- Modifies charge resolution
- Understanding this effect is important for future long-drift detectors



Measuring Longitudinal Diffusion

Longitudinal diffusion can be related to the observed width of a pulse of signal as a function of drift distance in the form of a linear equation:

$$\sigma_t^2(x) \simeq \left(\frac{2D_L}{v_d^3}\right) x + \sigma_0^2$$

The strategy for this analysis is to measure the width of deconvolved signals as a function of drift distance, and extract D_L from the gradient.

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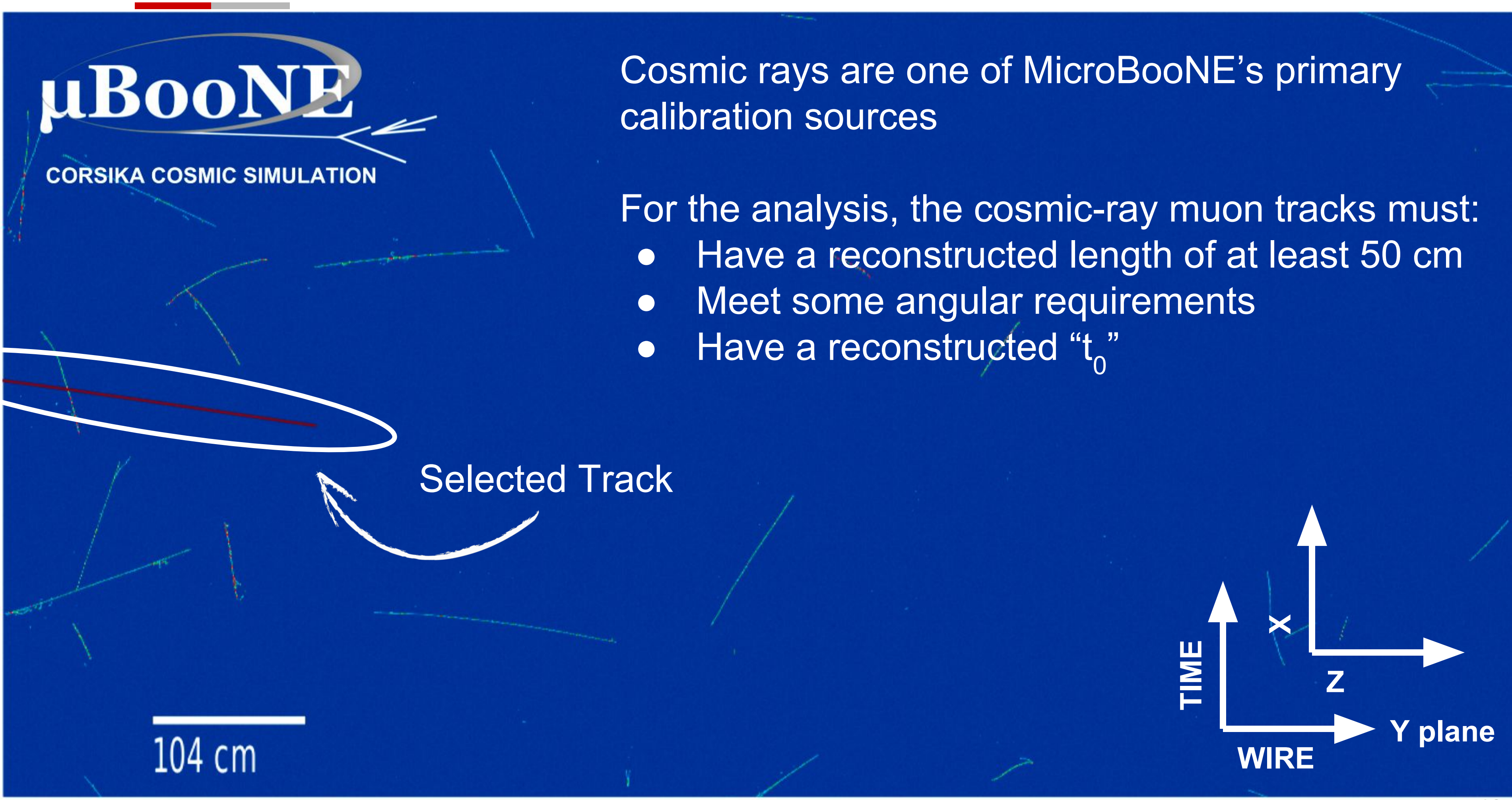
σ^2_t(x) = Time width of pulse squared (μs)^2

D_L = Longitudinal diffusion coefficient (cm^2/μs)

The strategy for this analysis is to measure the width of deconvolved signals as a function of drift distance, and extract D_L from the gradient.

Measuring Longitudinal Diffusion at MicroBooNE



Cosmic rays are one of MicroBooNE's primary calibration sources

For the analysis, the cosmic-ray muon tracks must:

- Have a reconstructed length of at least 50 cm
- Meet some angular requirements
- Have a reconstructed "t_0"

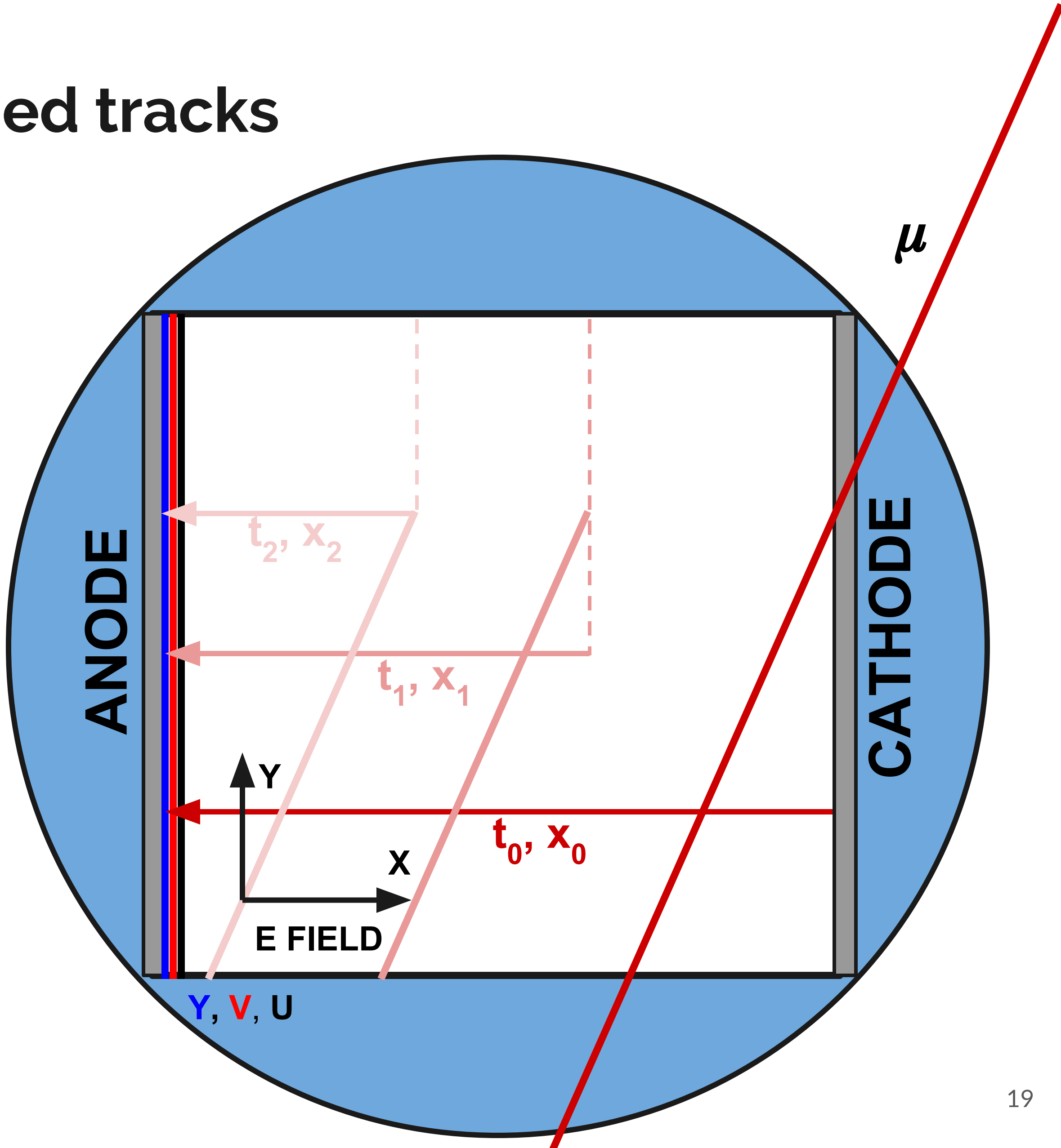
[2] The MicroBooNE Collaboration, **Establishing a Pure Sample of Side-Piercing Through-Going Cosmic-Ray Muons for LArTPC Calibration in MicroBooNE**, MICROBOONE-NOTE-1028-PUB

Selecting t_0-tagged tracks

It is vital for this measurement that tracks be reconstructed at the correct (t_0, x_0).

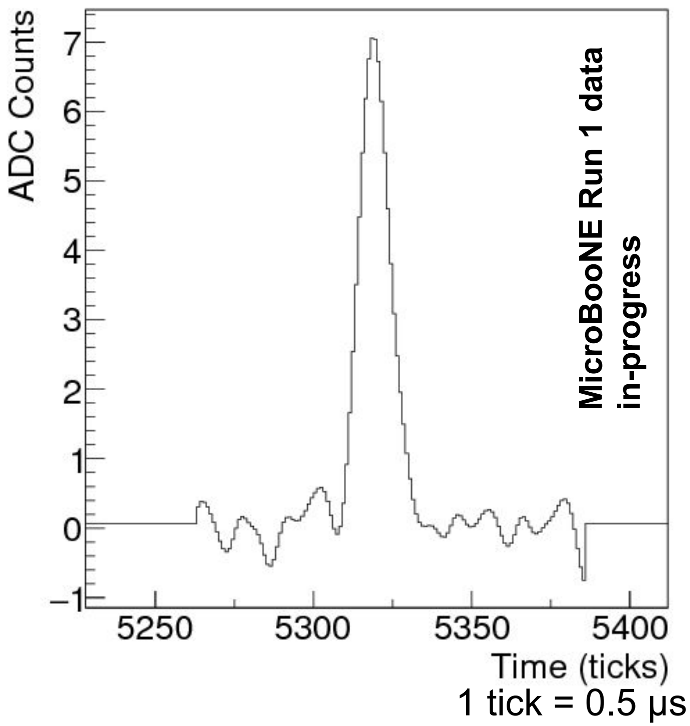
The reconstructed t_0 is checked for consistency with optical activity in the TPC.

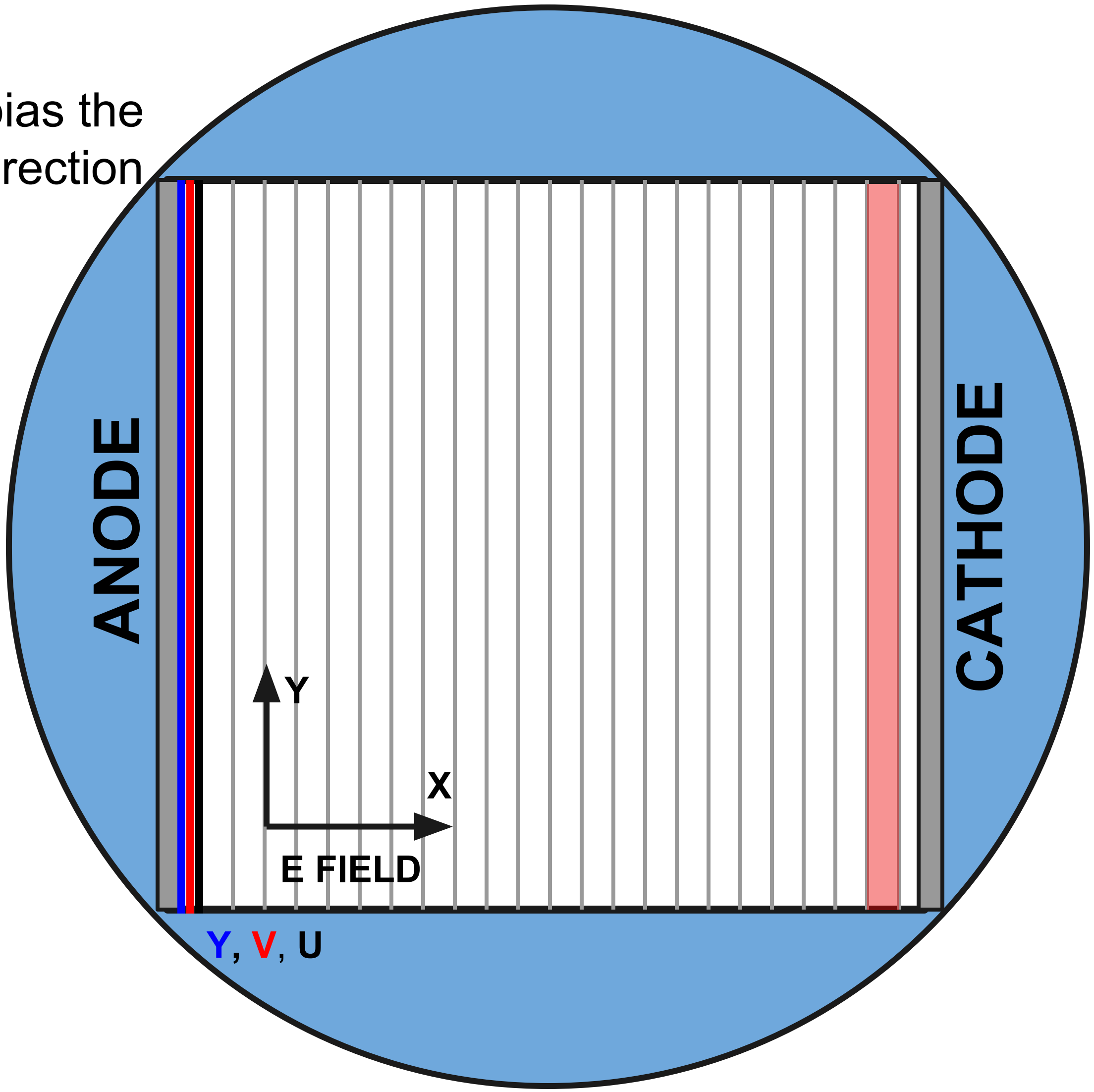
If no optical activity is consistent with the reconstructed t_0, the reconstructed t_0 is assumed to be incorrect.



Noise Mitigation Technique

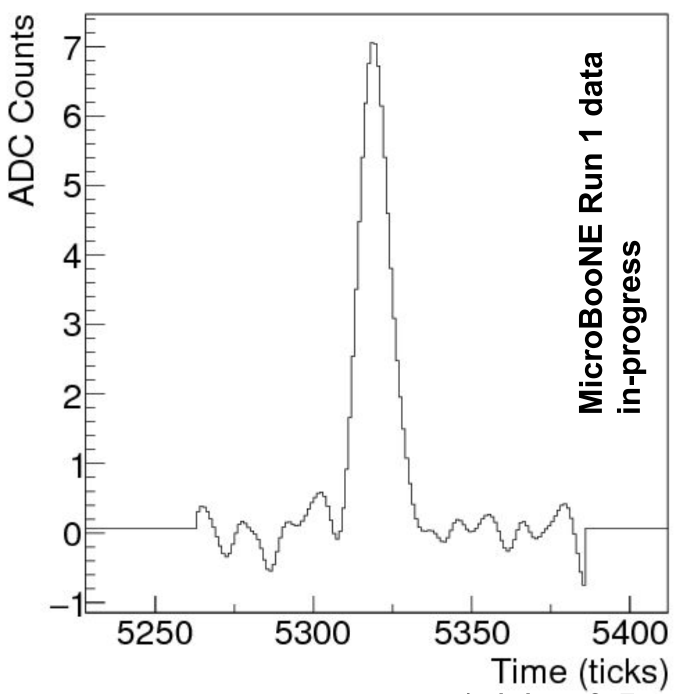
Noise on single waveforms may bias the measurement. We split the drift direction into bins and sum waveforms.



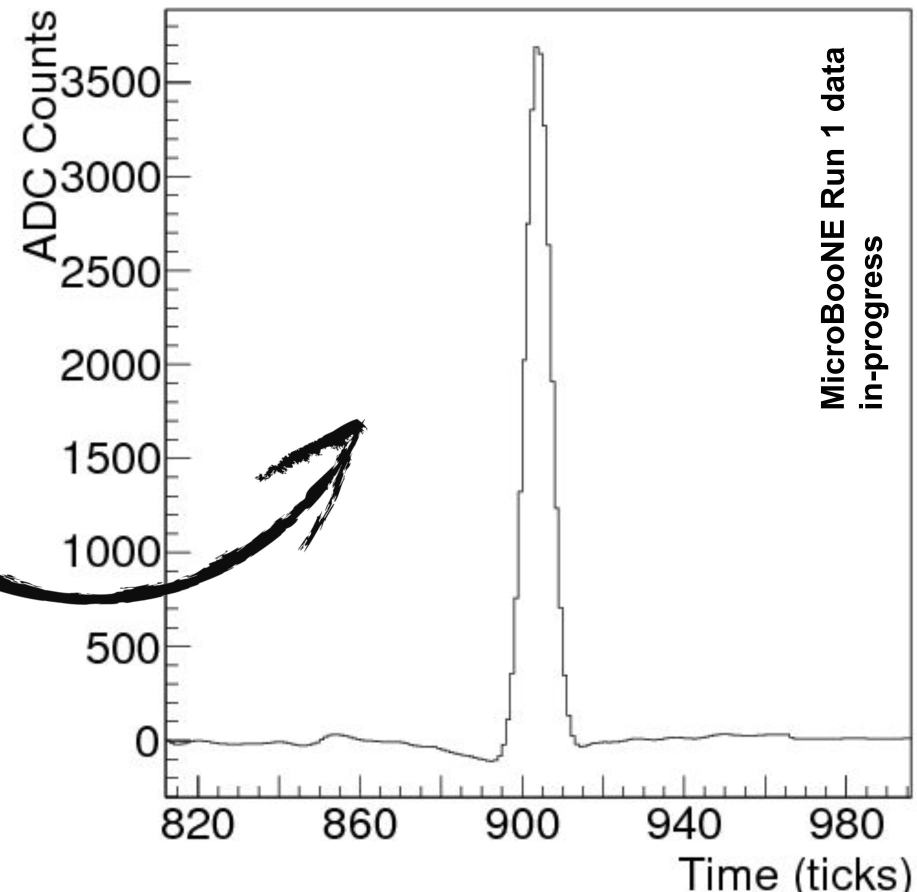


Noise Mitigation Technique

The **summed waveform** has a significant reduction in the noise contribution



1 tick = 0.5 μs



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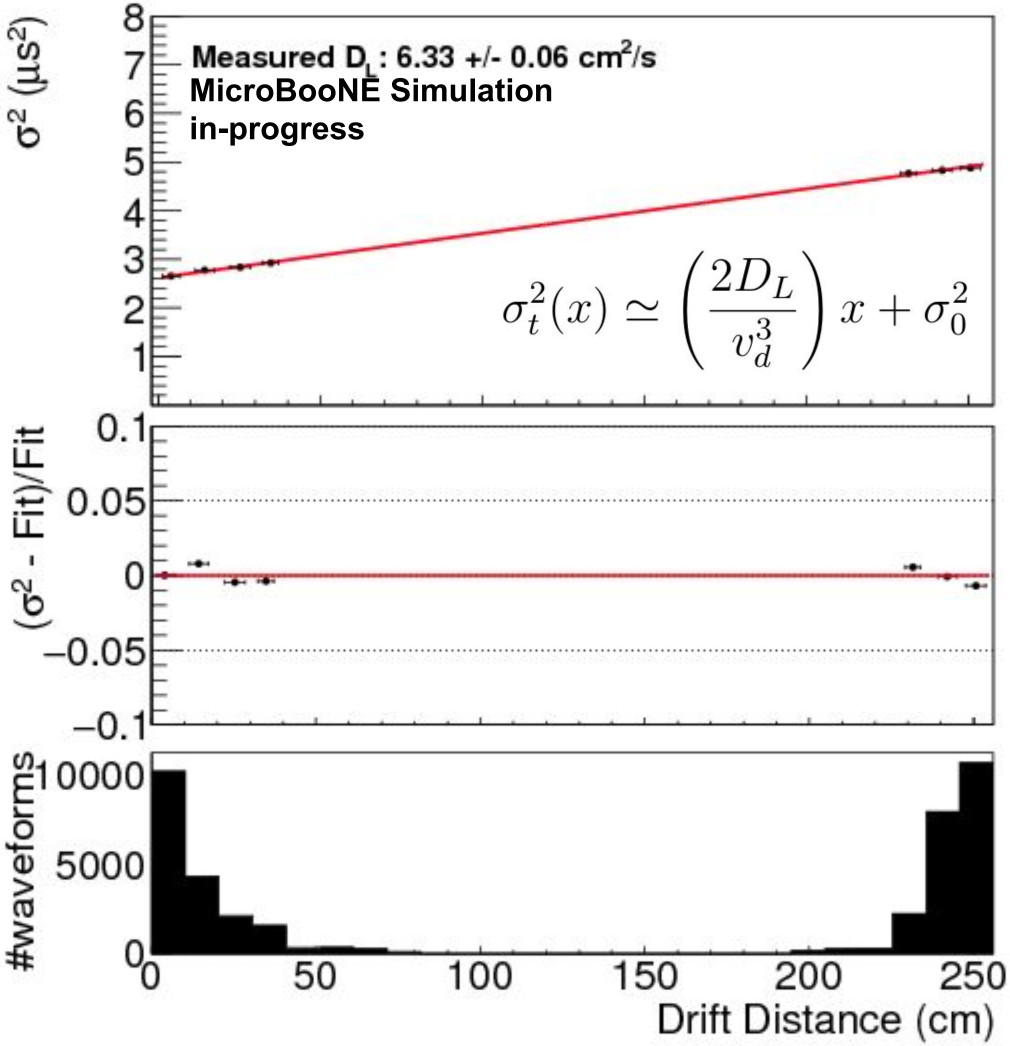
Results on Simulation

To each of these **summed** waveforms, we fit a Gaussian functional form, and take the standard deviation to be time width of the pulse, $\boldsymbol{\sigma_t}$.

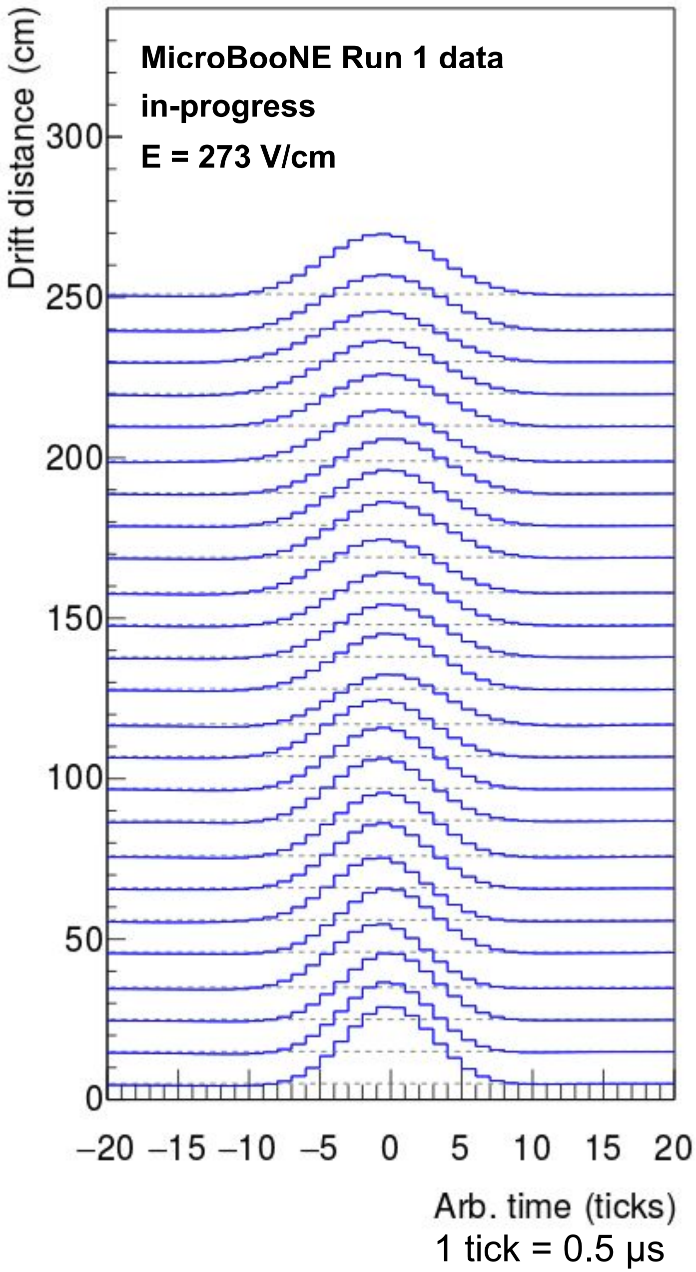
This is the result of the using the method I've outlined here on MicroBooNE Cosmic Simulation.

We achieve a **value of 6.33 cm^2/s on an input value of 6.2 cm^2/s**, which is within the expected bias caused by D_T.



Conclusions

- MicroBooNE is a LArTPC at Fermilab with one of its primary goals being detector R&D
- We have developed a method for measuring the longitudinal diffusion coefficient in the detector using cosmic rays
- Currently in the process of estimating systematic biases and uncertainties
- We have taken a first look at data and things look good
- We expect a measurement on data soon



Thank You!

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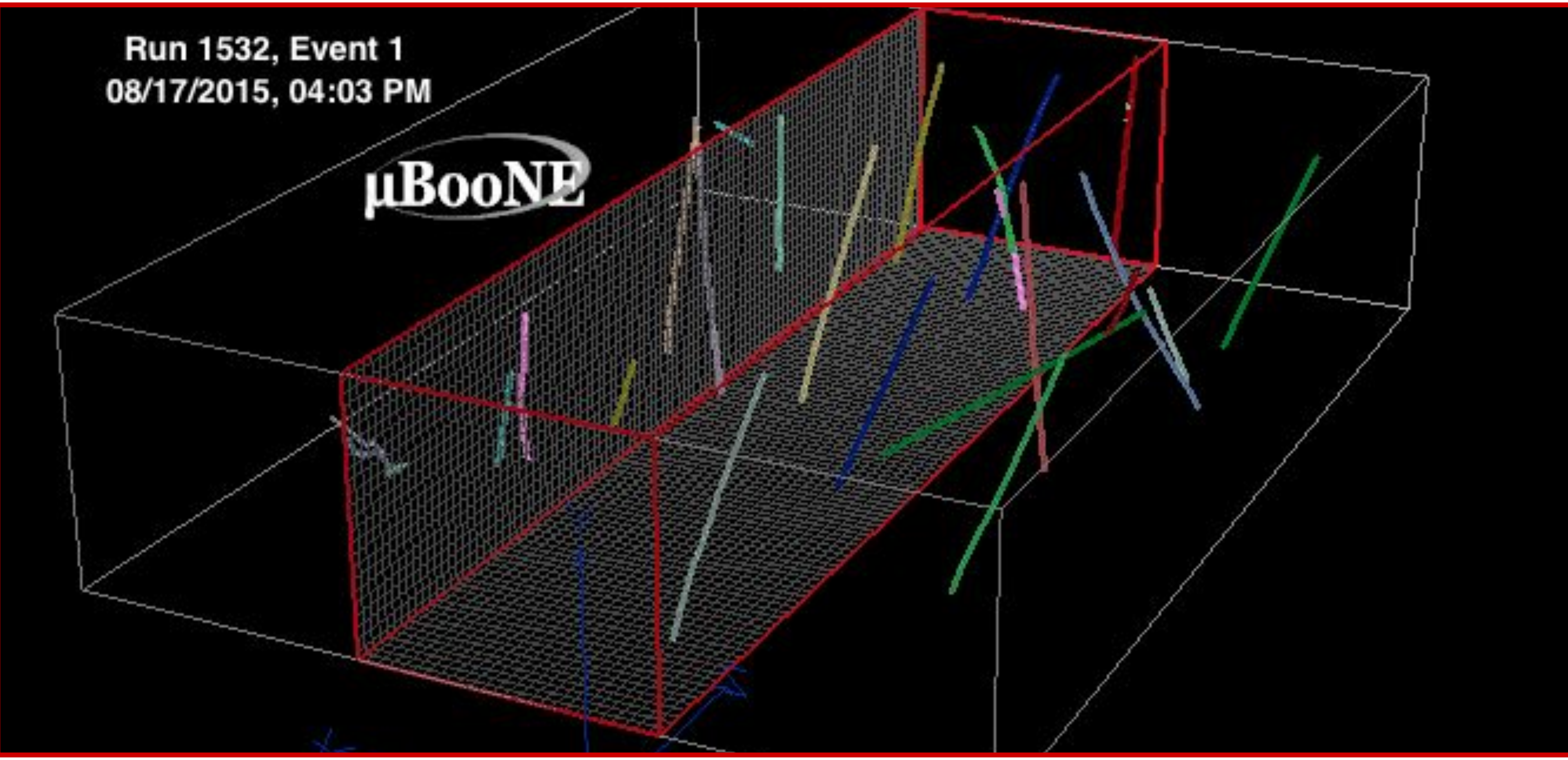
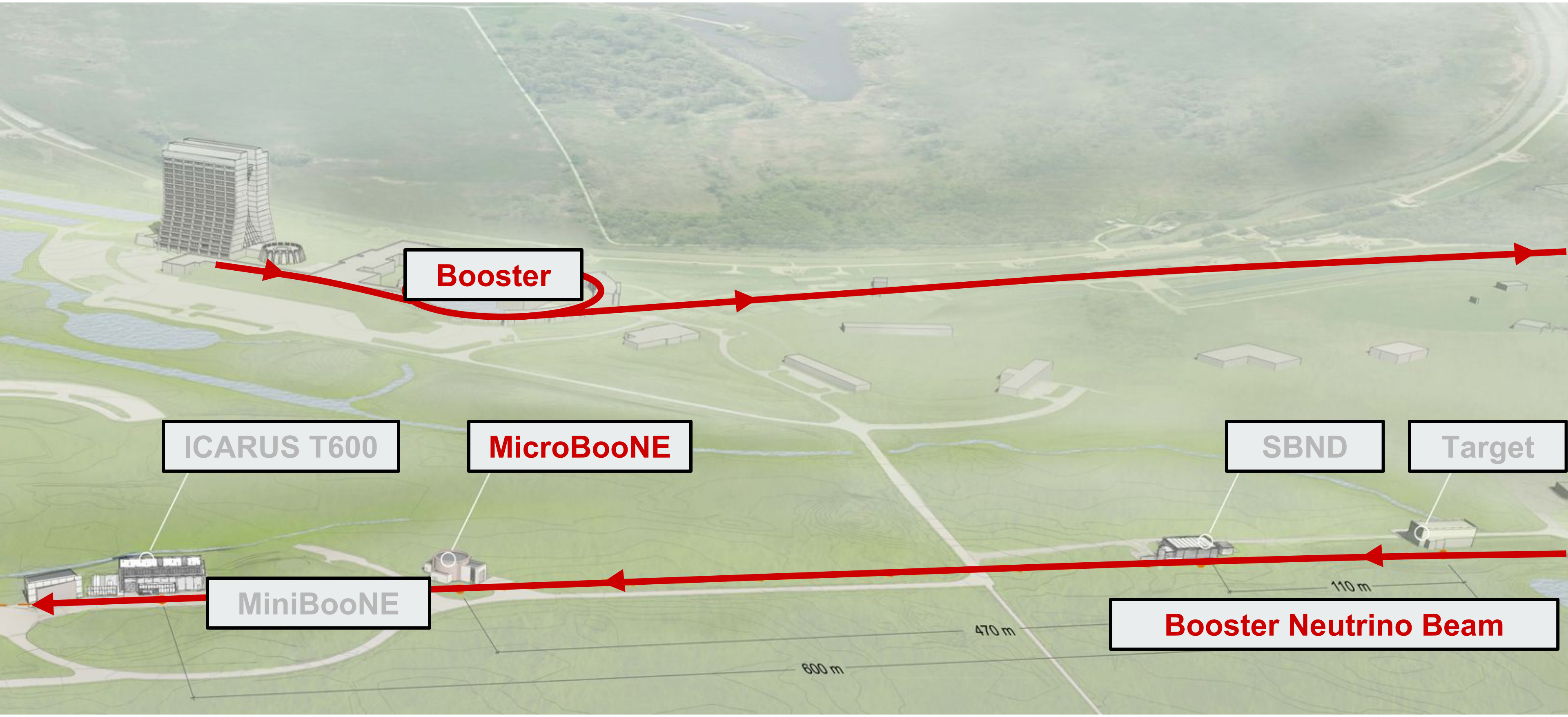
[3] Li, et al., **Measurement of Longitudinal Electron Diffusion in Liquid Argon**., 10.1016/j.nima.2016.01.094
[4] Atrazhev and Tomishkin, **Transport of electrons in atomic liquids in high electric fields**, IEEE Transactions on Dielectrics and Electrical Insulation, 5. 450 - 457. 10.1109/94.689434.

Backup

Example MicroBooNE Event Display



MicroBooNE in The SBN Program



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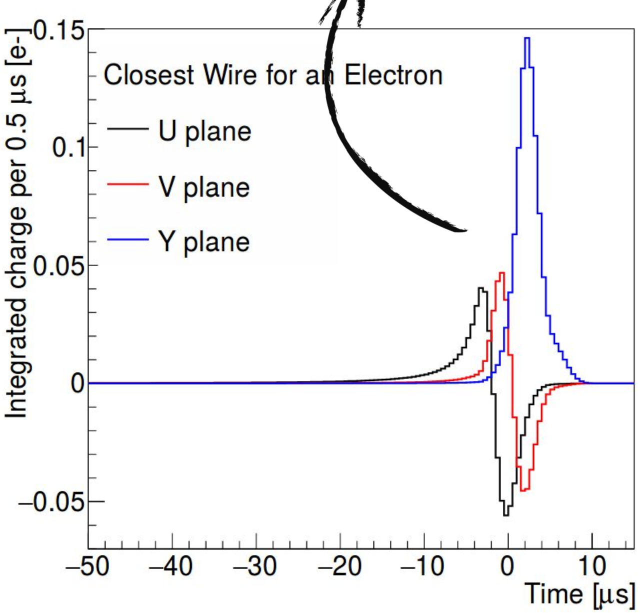
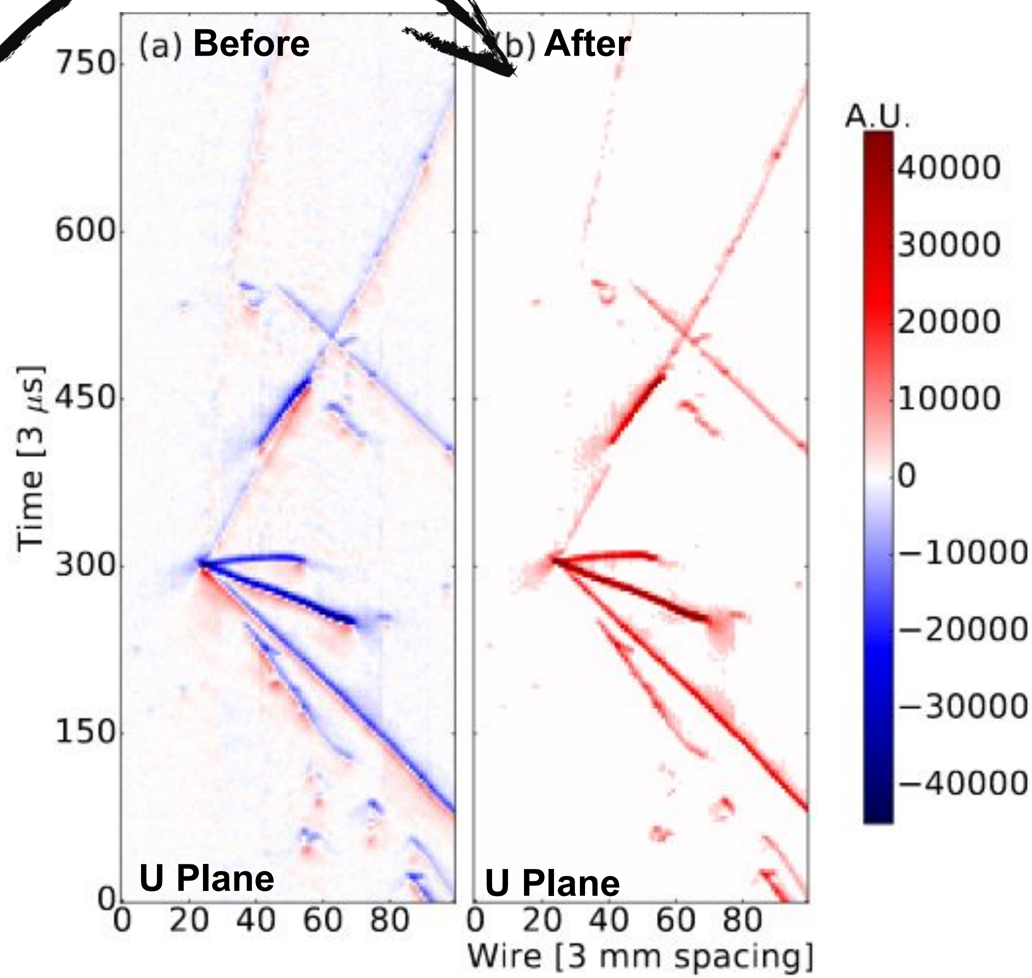
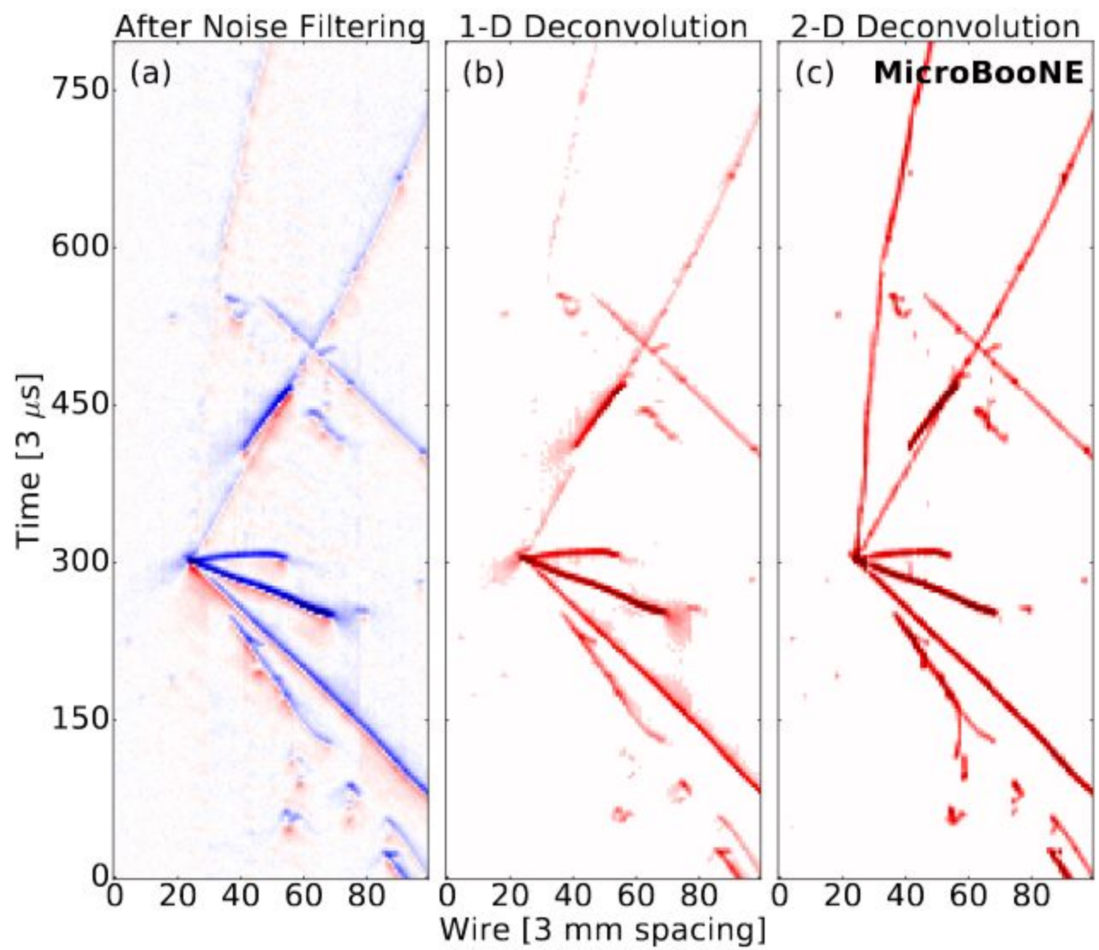




2D Deconvolution

$$S(\omega) = \frac{M(\omega)}{R(\omega)} \cdot F(\omega)$$

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



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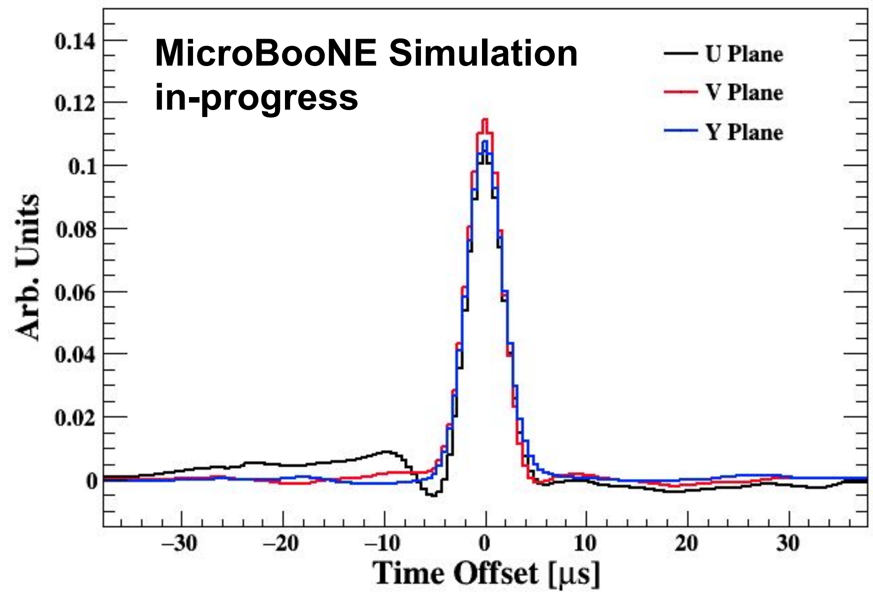
1D deconvolution



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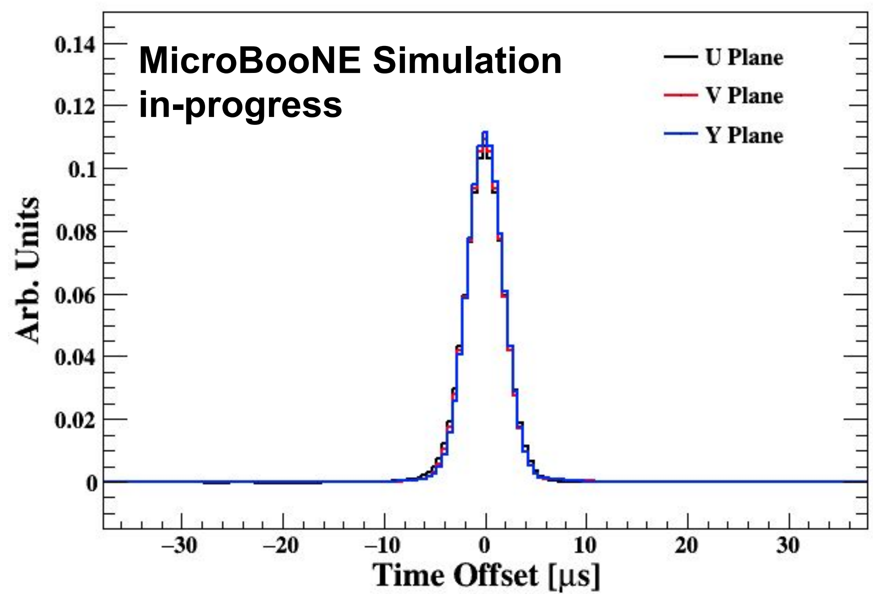
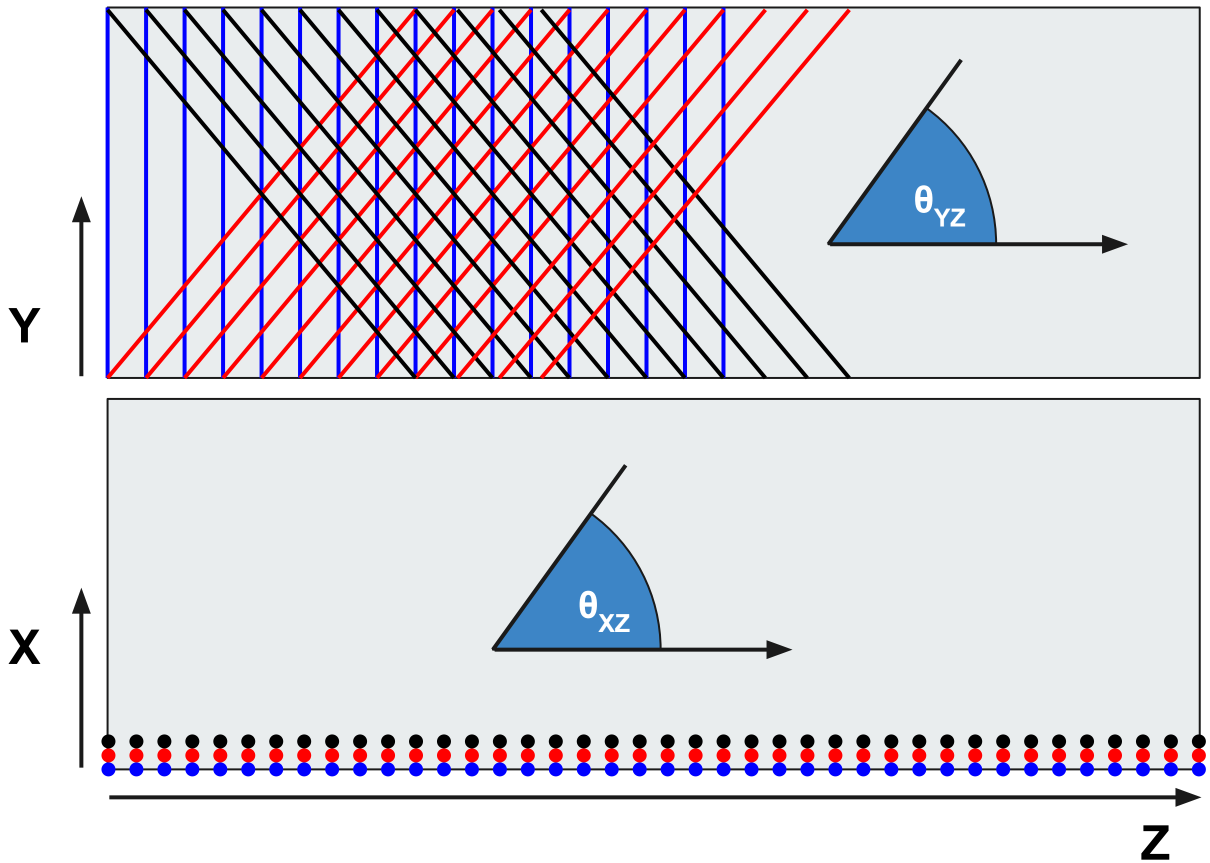


A Preliminary on Track Angles

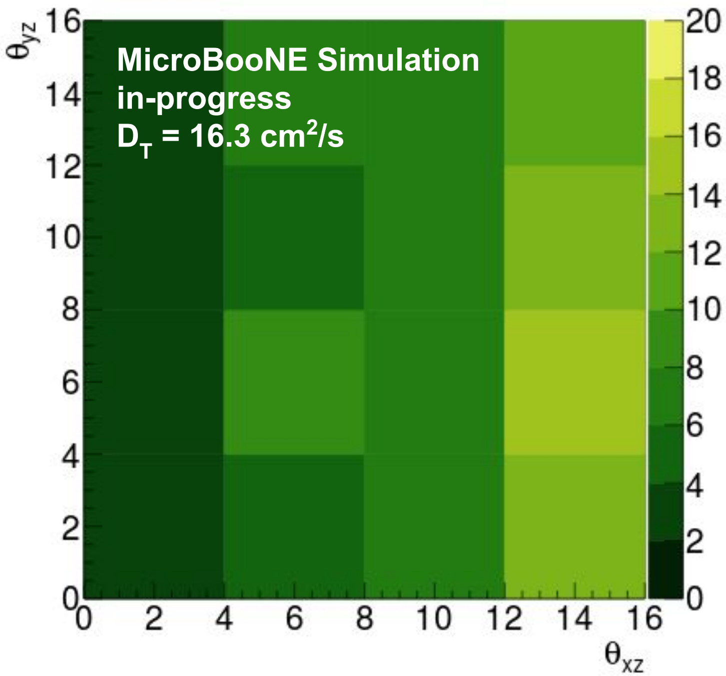


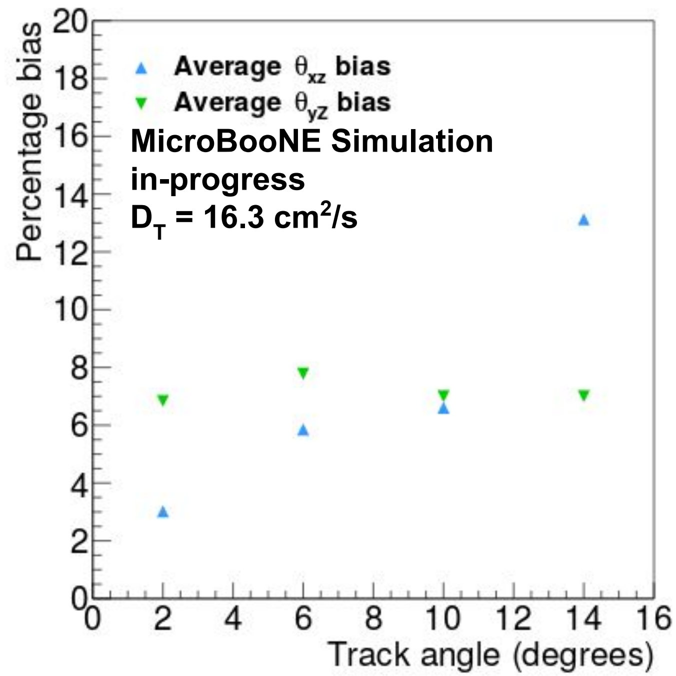
$\theta_{XZ} = \theta_{YZ} = 0$ ° is the direction of the beam.

Any deviation in θ_{XZ} means the track is at an angle with respect to the anode plane.

Any deviation in θ_{YZ} means the track is at an angle with respect to the TPC bottom.

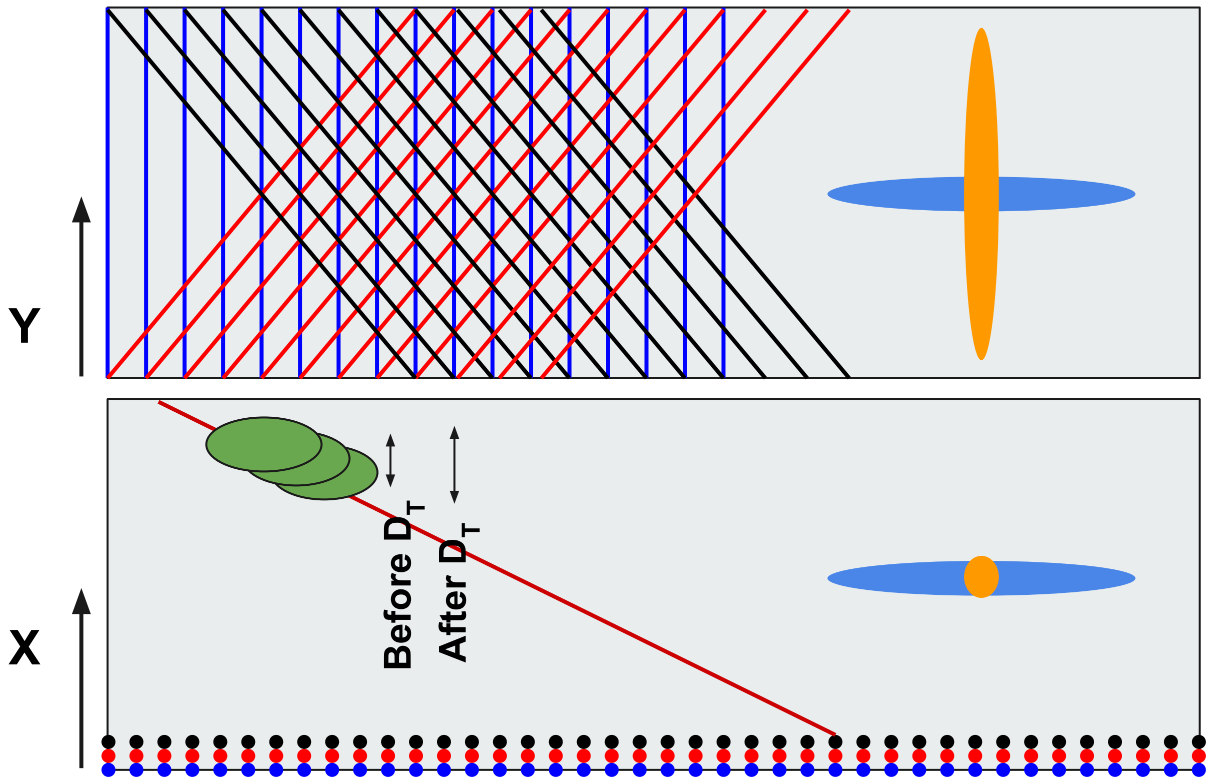
Effects of Transverse Diffusion





We expect a bias in this measurement due to the effects of D_T. To minimise this we choose to have a tight angular selection in θ_{XZ} of between 0 and 4 degrees, and a slightly looser cut in θ_{YZ} of between 0 and 16 degrees.

Effects of Transverse Diffusion

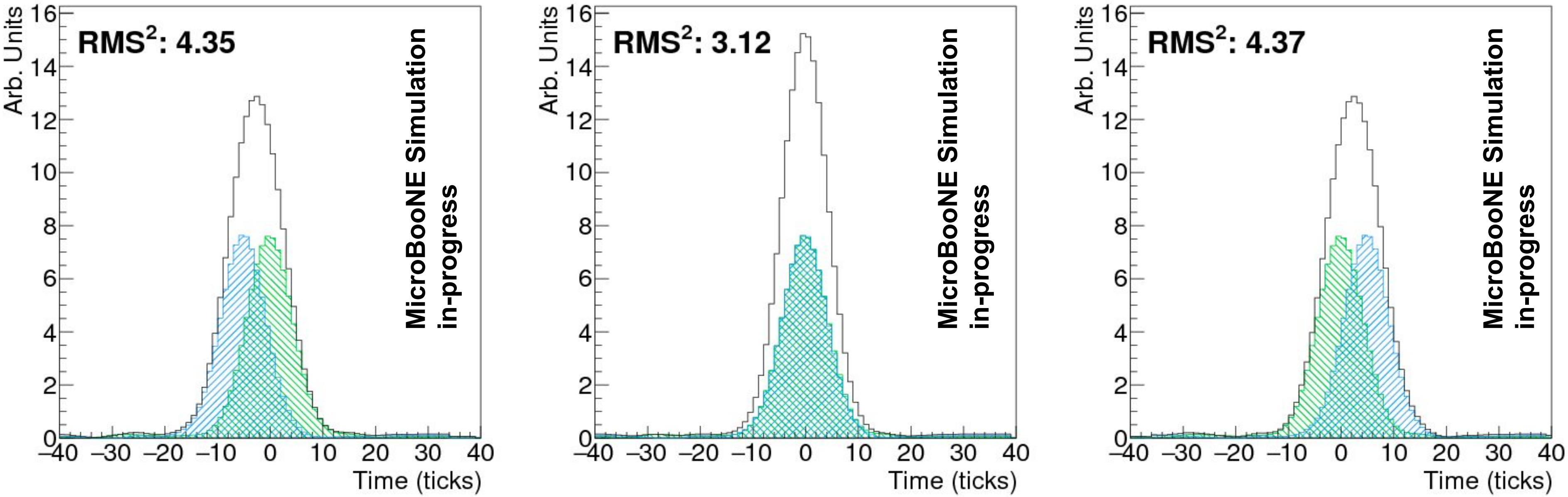


Transverse diffusion can be thought of as a smearing in either the **Z direction** or the **Y direction**.

Because we use only collection plane (vertical) wires, the spreading in Y has little effect --- the pulses still arrive at the same time, on the same wires.

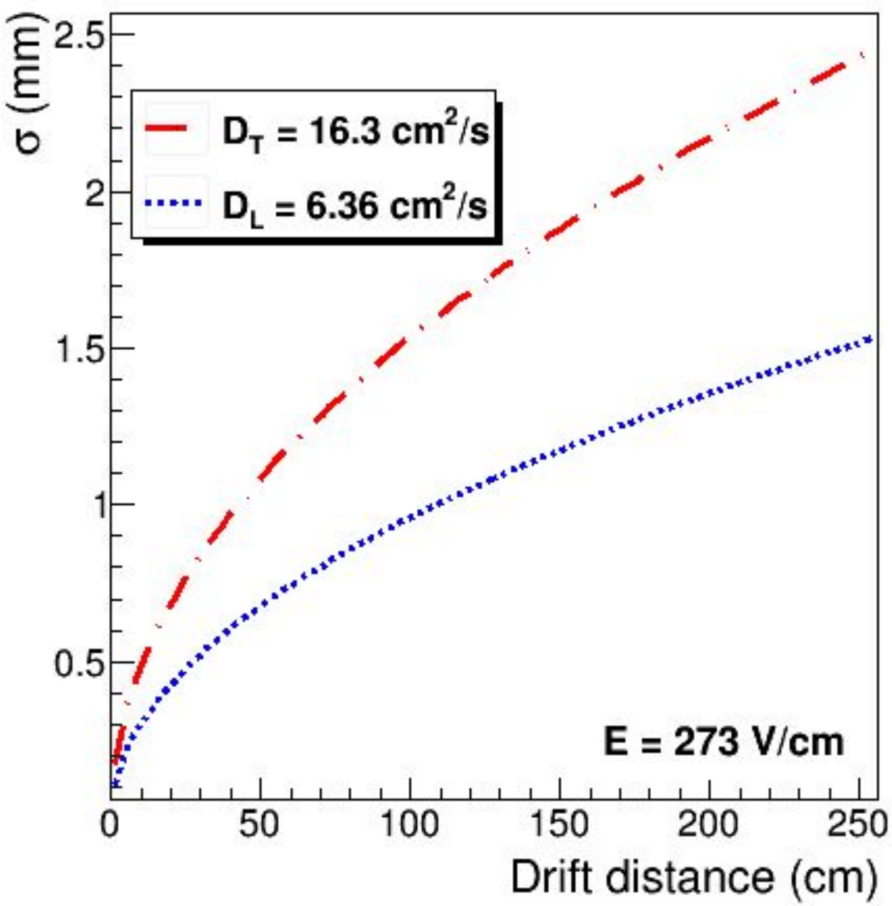
However, the Z component acts to spread the cloud onto neighbouring wires, meaning the x-width of the cloud appears to gain additional width.

Summing Waveforms Technique



This is done in a way which minimises the width of the summed waveform by sliding the waveforms through each other and calculating the RMS^2 at each step, and then selecting the combination of waveforms which gives the minimum RMS^2.

Scale of diffusion in Length Units



An electron cloud which travels the full drift distance of MicroBooNE in the MicroBooNE Electric field will spread approximately 1.4 mm longitudinal and 2.5 mm transversely.

[3] Li, et al., **Measurement of Longitudinal Electron Diffusion in Liquid Argon**., 10.1016/j.nima.2016.01.094
[4] Atrazhev and Tomishkin, **Transport of electrons in atomic liquids in high electric fields**, IEEE Transactions on Dielectrics and Electrical Insulation, 5. 450 - 457. 10.1109/94.689434.

World Measurements

This shows a selectionof world data for diffusion on liquid argon, taken from reference [3]. Electron energy is proportional to the diffusion constant, i.e.:

$$D_L = \frac{\mu \times \epsilon_L}{e}$$

With μ = electron mobility and e = electron charge.

The Longitudinal and Transverse theory calculations are taken from [4].

There is a systematic shift of the BNL measurements with respect to the Longitudinal calculation.