# Signal Simulation and Processing in the MicroBooNE LArTPC

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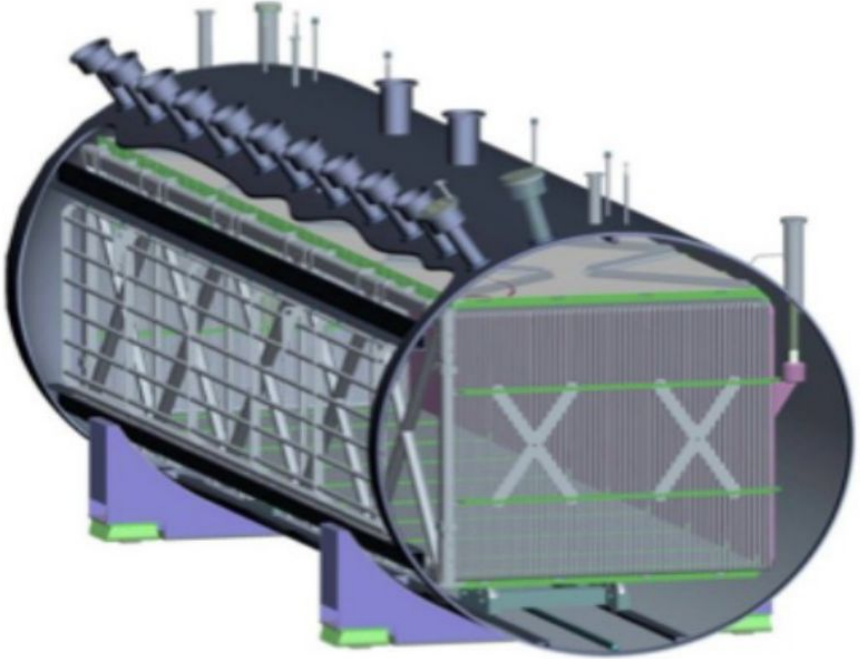
B.Kirby for the MicroBooNE Collaboration

# MicroBooNE Overview

**Micro Booster Neutrino Experiment**

- First large-scale US Liquid Argon Time Projection Chamber (LArTPC)
- LAr active target 89 tons (170 total)
- Cold front-end electronics
- Exposed to short baseline neutrino beam produced at Fermilab
- Taking neutrino data since Oct 2015!

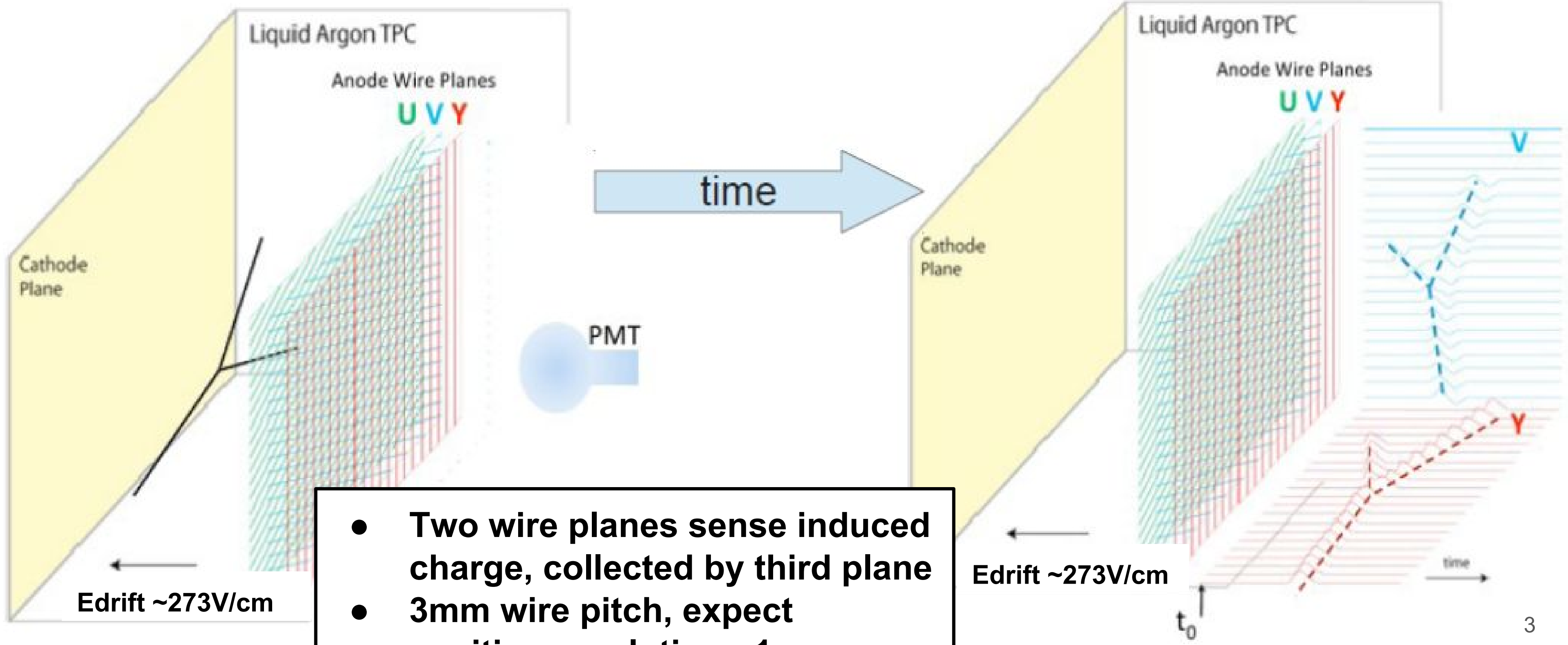
**MicroBooNE Cryostat**



**Physics Goals**

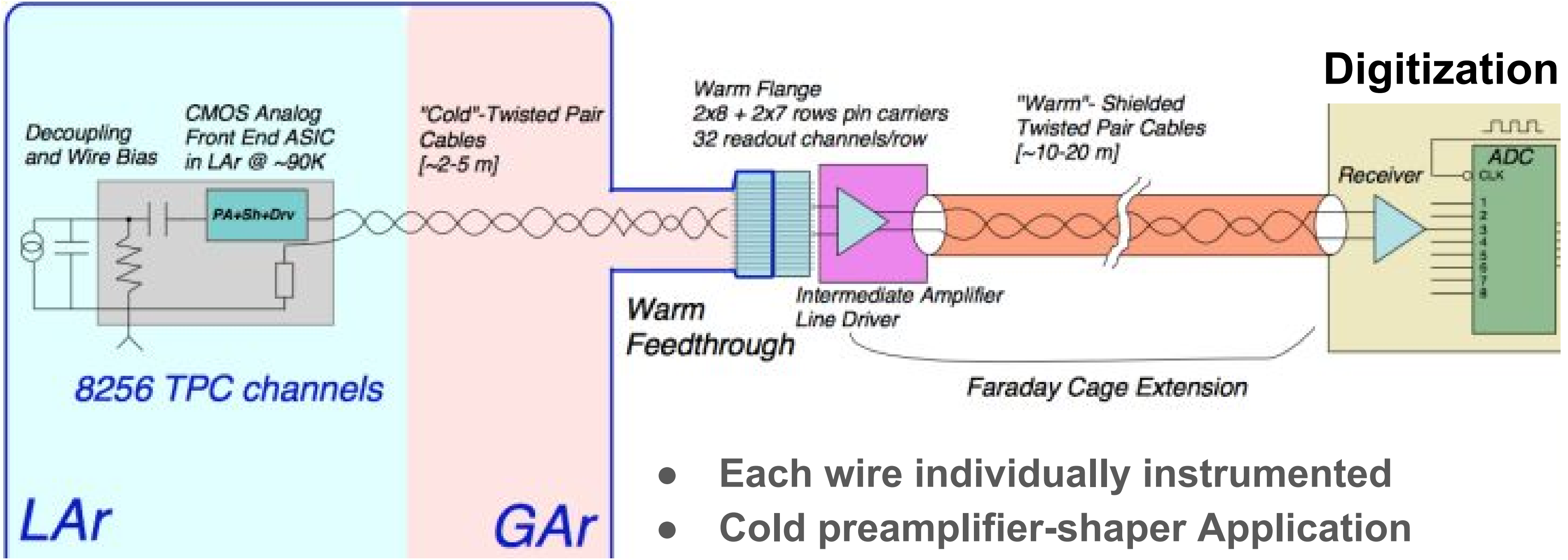
- Investigate MiniBooNE excess
- Neutrino-Ar cross-sections
- LArTPC Detector R&D

# MicroBooNE is a Single-Phase LArTPC




- **Two wire planes sense induced charge, collected by third plane**
- **3mm wire pitch, expect position resolution ~1mm**

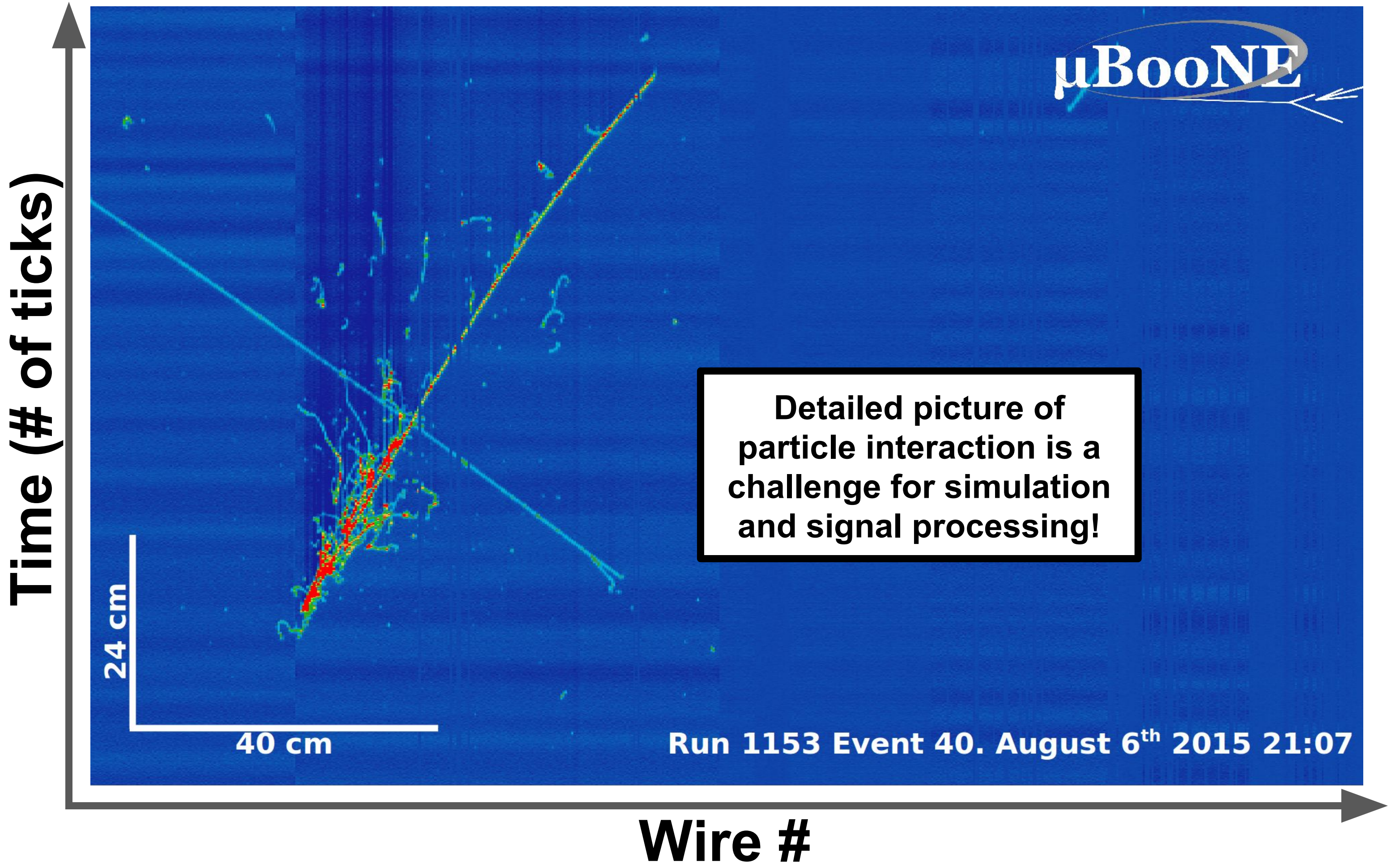
# MicroBooNE Uses Low Noise Cold Electronics




**Cryostat**
**Wires + Cold Electronics**

- **Each wire individually instrumented**
- **Cold preamplifier-shaper Application Specific Integrated Circuits (ASICs) significantly reduce electronics noise**

# MicroBooNE Provides Detailed Pictures of Particle Interactions




**Detailed picture of particle interaction is a challenge for simulation and signal processing!**

# Overview of Signal Simulation and Processing

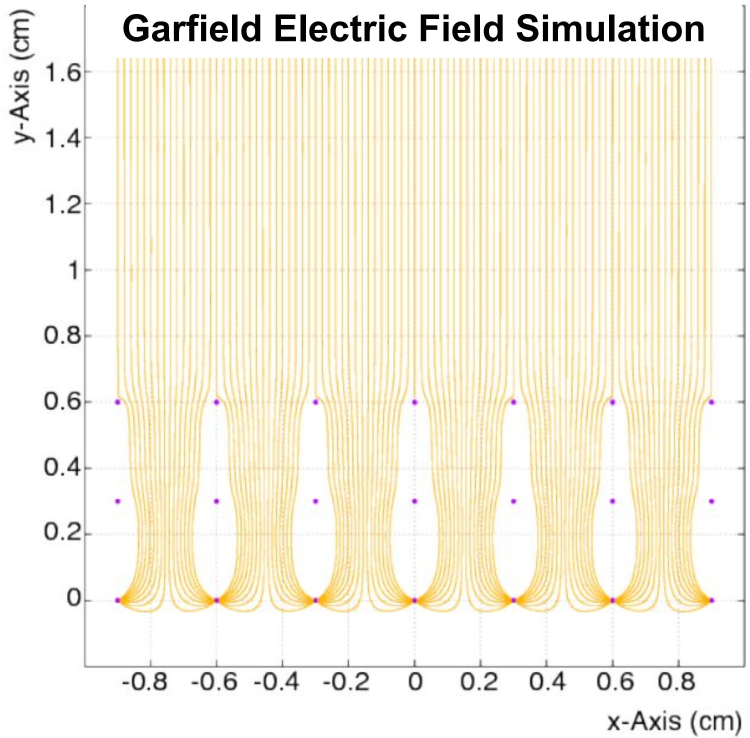
- **Signal simulation**
  - The 5 D’s of signal simulation
  - Electric field
  - Electronics response
  - Wire response to ionization charge, data/MC comparisons
- **Signal processing**
  - Noise filtering
  - Signal deconvolution
  - Impact

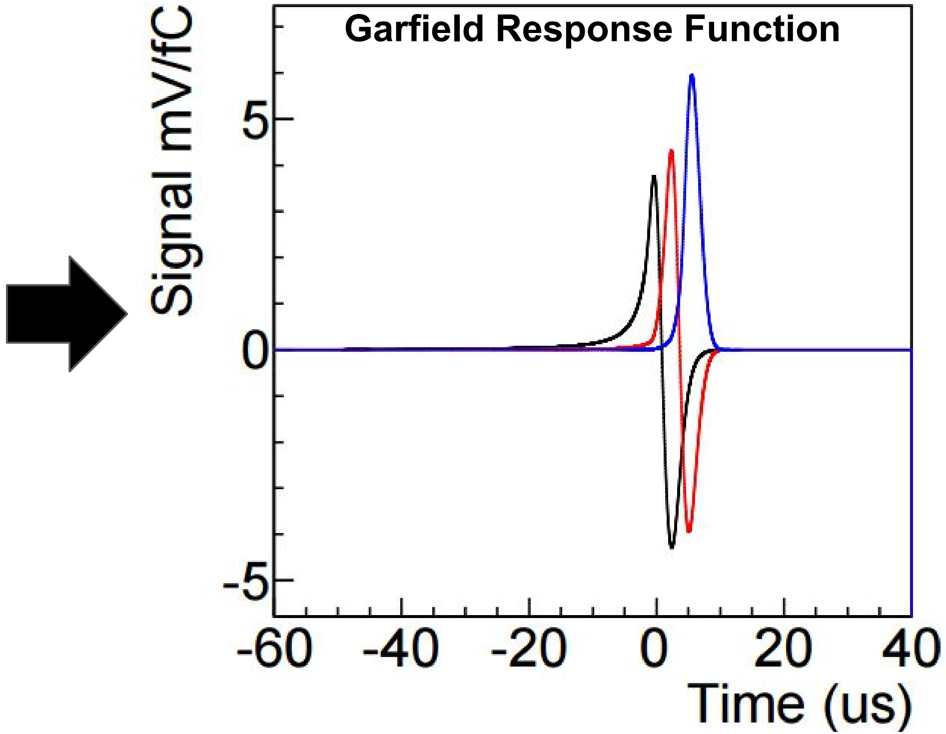
# The 5 D’s of Signal Simulation in LArTPCs

- **Deposition:** Geant4 simulates LAr ionization electrons from charged particles
- **Drifting:** includes statistical fluctuation of ionization electrons, diffusion, recombination and charge quenching
- **Ducting:** induced and collected charge on anode sense wires
- **Digitization:** conversion of analog to digital signals with sampling electronics
- **Dissonance:** inclusion of noise modelled from real data

**Detailed understanding of each “D” required to reproduce complex particle interaction pictures produced by MicroBooNE**

# Signal Simulation of Drift Electric Field

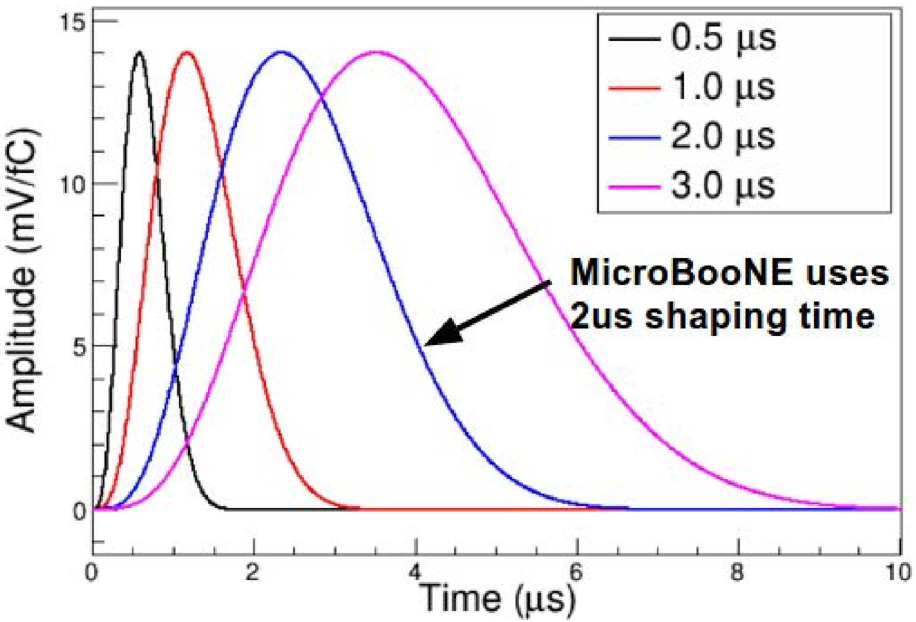


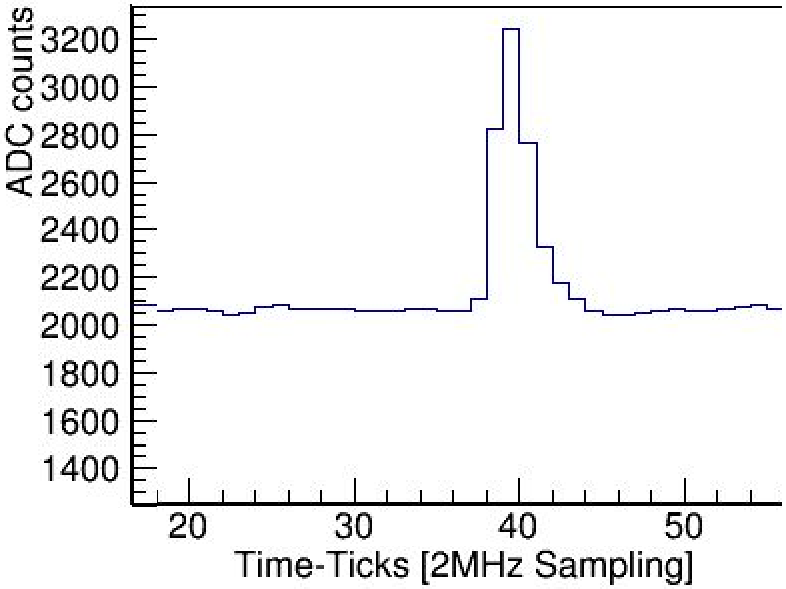

- Ionized electrons from tracks drift to anode sense wires (**D**eposition + **D**rifting)
- Detailed Garfield simulation models electric field (**D**ucting)
- **Significant effort to simulate electric field including realistic detector effects**

# Signal Simulation of Cold Electronics Response

**Simulated Electronics Response**



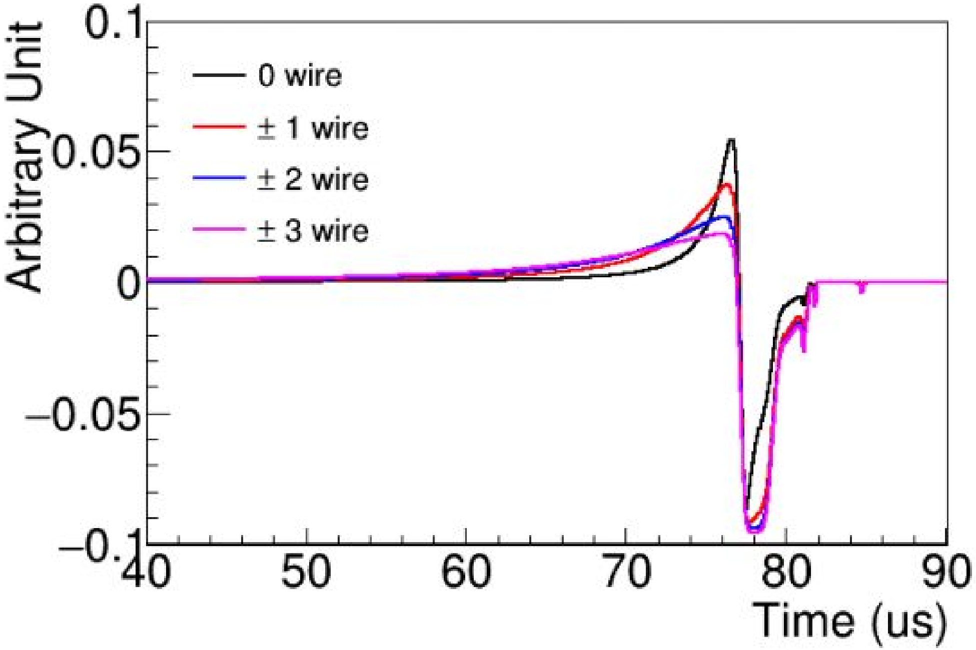

**Injected Calibration Signal**



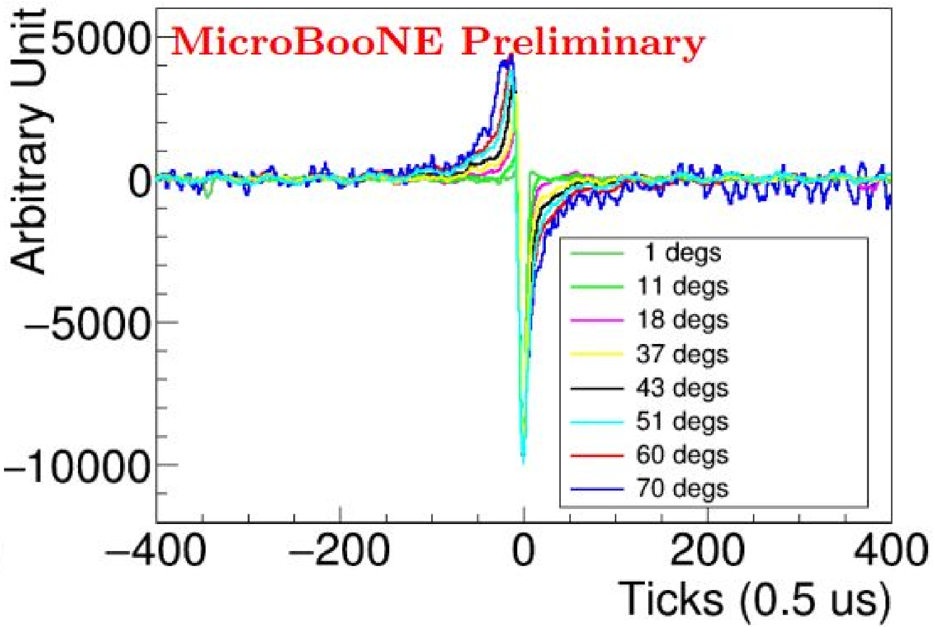

- Cold ASIC response well matched to LAr electron drift speed of ~1.1mm/us
- Simulation includes calibrated electronics response (**D**igitization)
- **Currently studying impact of non-ideal electronics response**

# Wire Response Data/MC Comparisons

**Garfield U-Plane Simulation**




**TPC Signal Measurements**



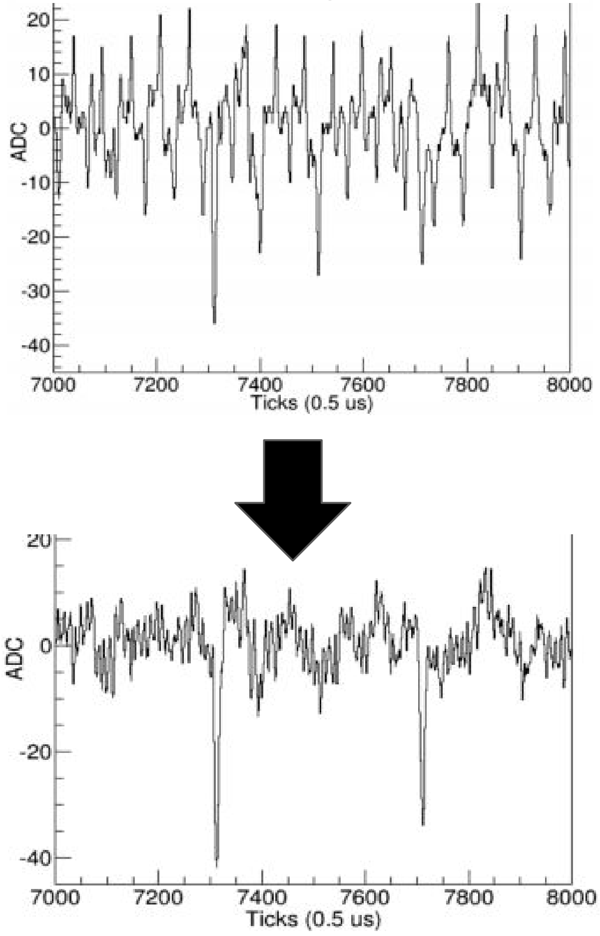

- Wire signals are convolution of electric field and electronics response
- **MicroBooNE is verifying simulated vs measured wire response**

# Simulation Informs Signal Processing

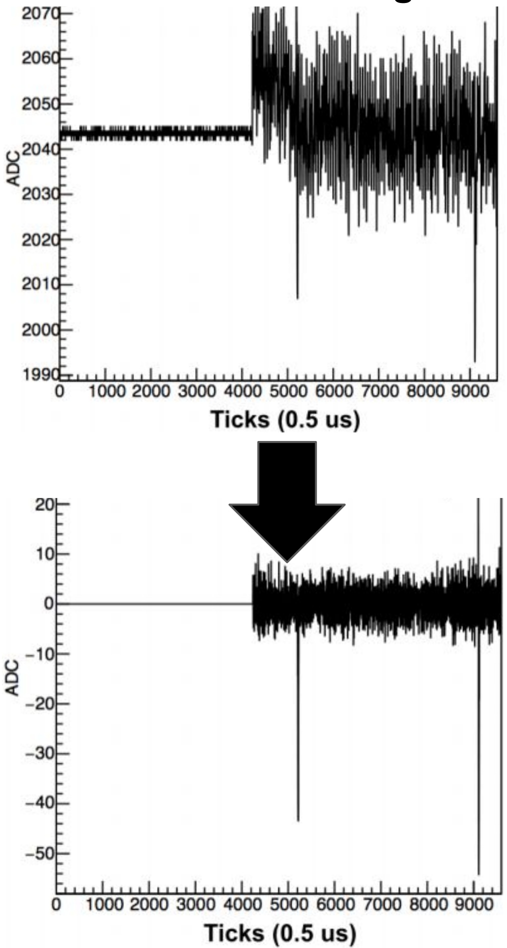
- **Signal simulation**
  - The 5 D’s of signal simulation
  - Electric field
  - Electronics response
  - Wire response to ionization charge, data/MC comparisons
- **Signal processing**
  - Noise filtering
  - Signal deconvolution
  - Impact

# Signal Processing and Electronic Noise Filtering

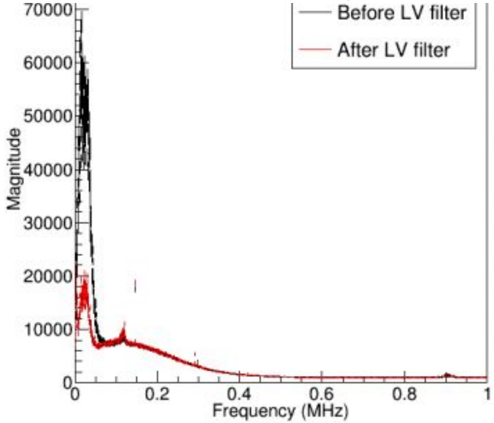
**Frequency Filter**




**ASIC Saturation Mitigation**




**Low Frequency Filter**

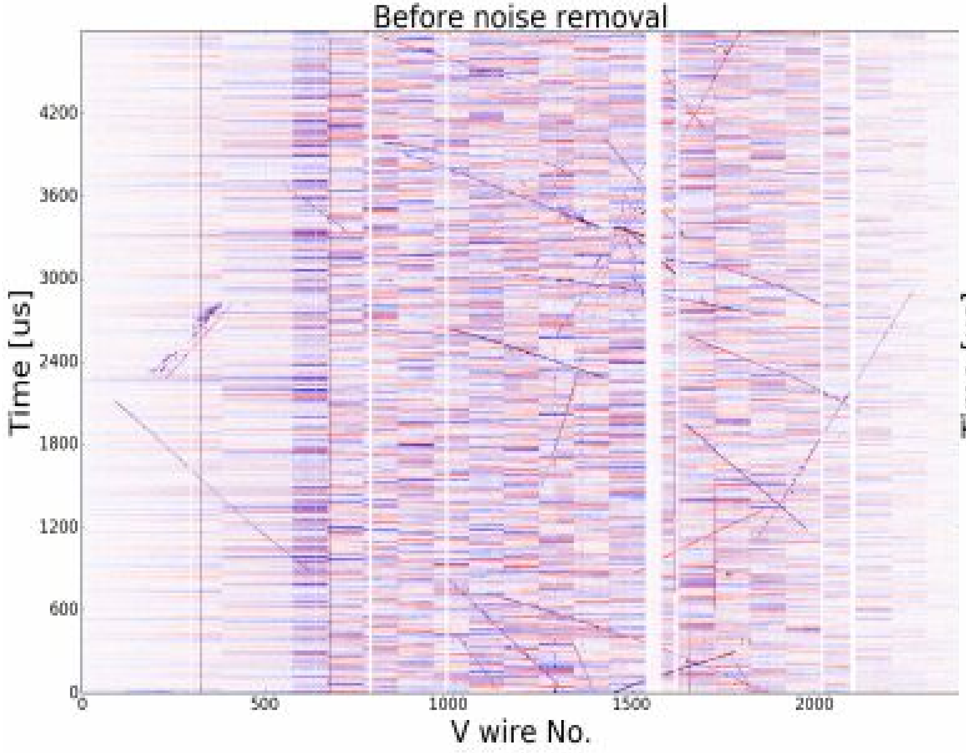


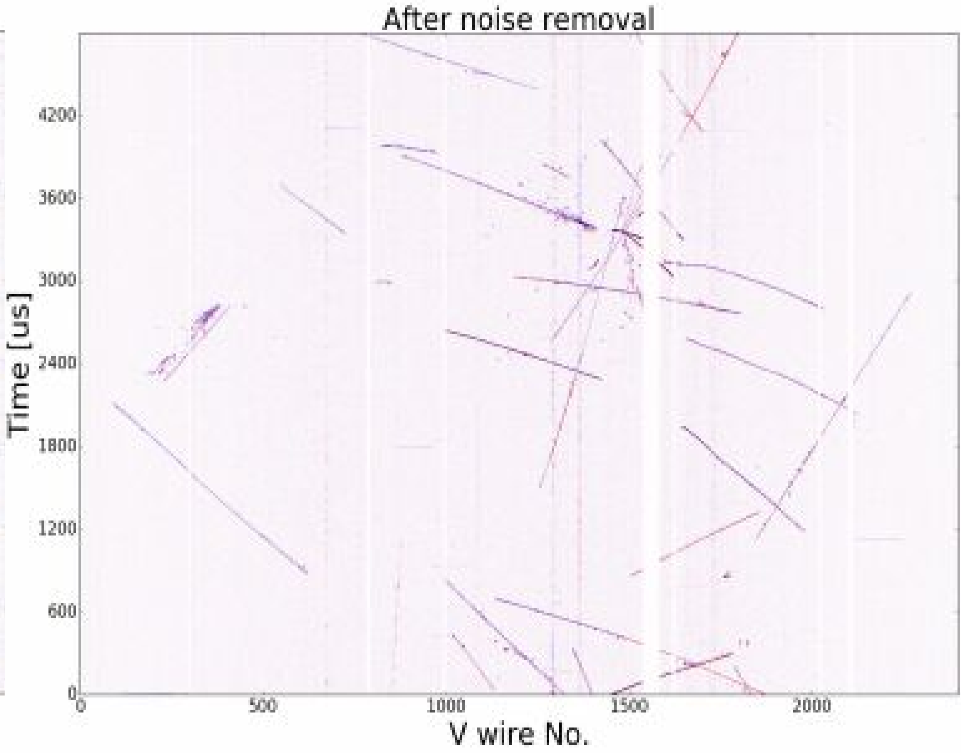

**Several electronic noise sources:**

- Cold ASIC first-transistor
- Warm electronics/readouts
- HV power supplies
- ASIC saturation via wire motion
- Regulator noise

**Software filtering and hardware upgrades can help!**

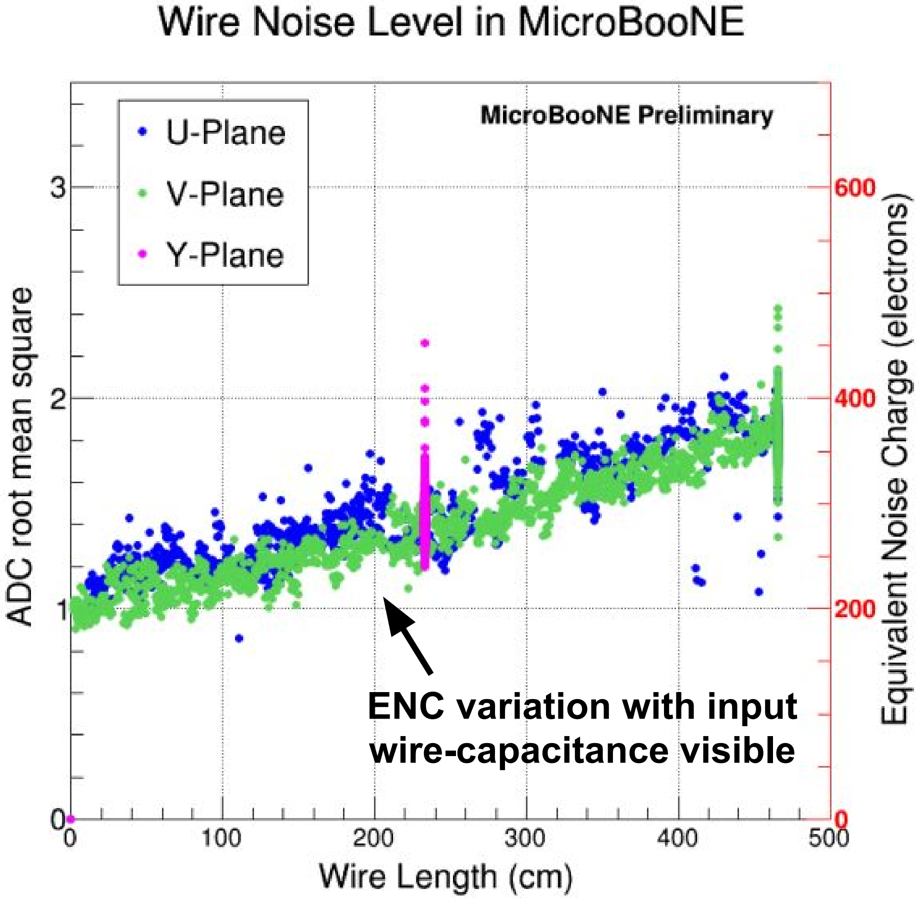
# Signal Processing and Event Display Pre/Post Filtering




**Significant improvement in event display after noise filtering**

# Signal Processing and Electronic Noise Performance

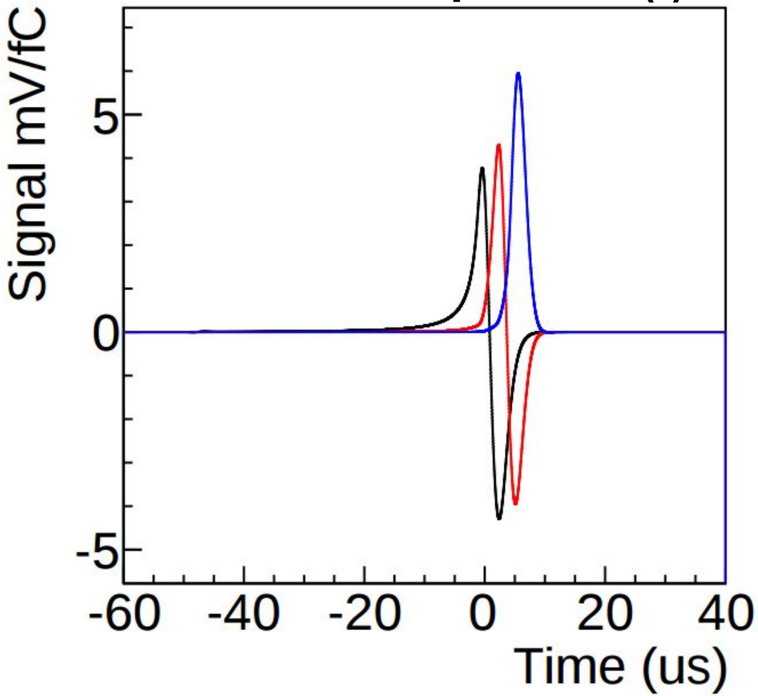



**Excellent performance (ENC <420e-) post-filtering!**

# Signal Processing and Deconvolution

- Recover ionization charge by deconvoluting waveforms with detector response

**Detector Response R(t)**




**Time Domain, Measured Signal as Convolution of Charge and Response**

$$M(t_0) = \int_{-\infty}^{\infty} R(t, t_0) \cdot S(t) \cdot dt$$

**Convert to Frequency Domain**

$$M(\omega) = R(\omega) \cdot S(\omega)$$

**Recover Charge Signal from Deconvolution**

**Noise filter term**

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

# Signal Processing and 2D Deconvolution

**1D Response in Frequency Domain**

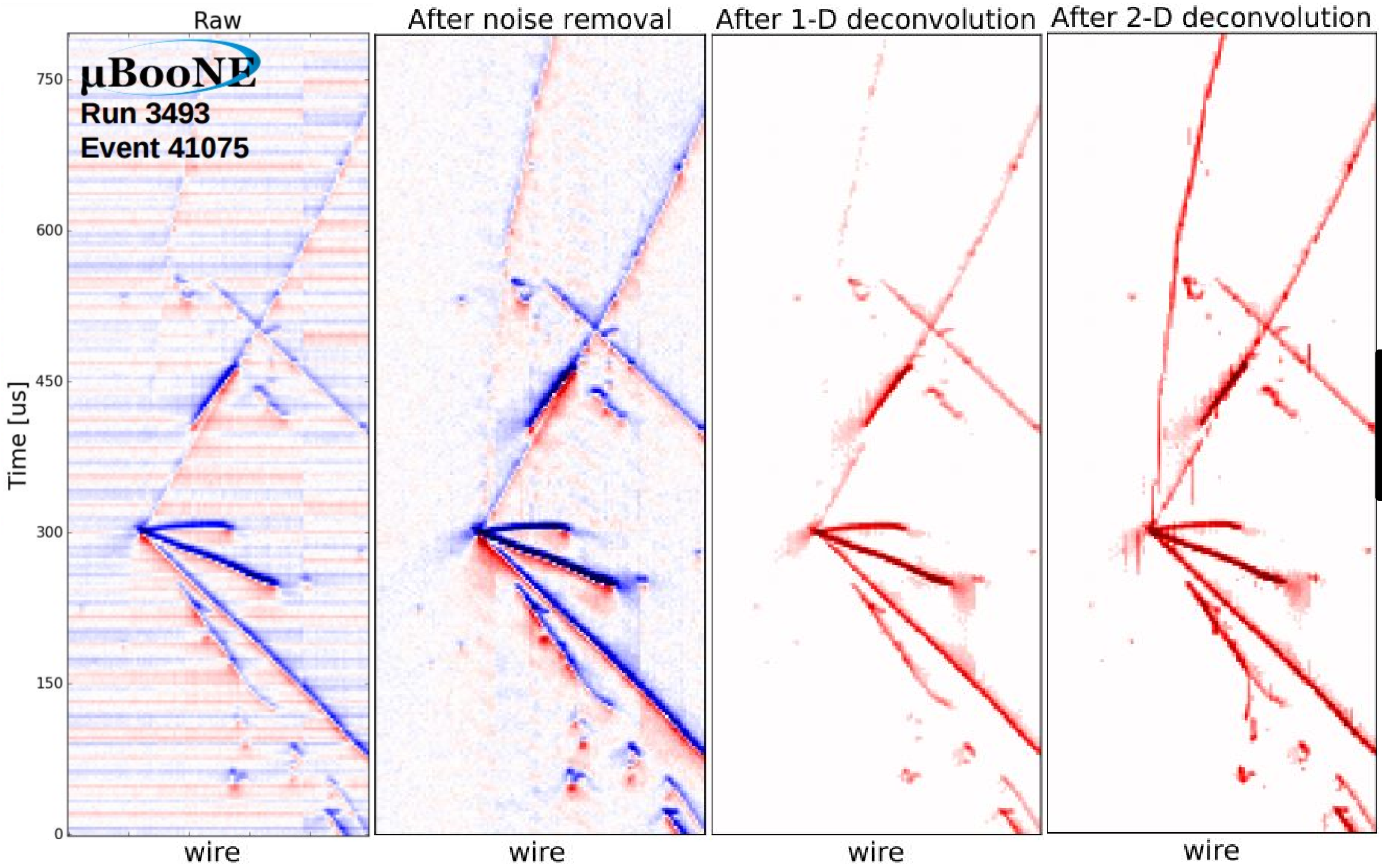
$$M(\omega) = R(\omega) \cdot S(\omega)$$

**2D Response in Frequency Domain**

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

- Extending deconvolution procedure to 2D
- Combine signals from multiple induction and collection plane wires
  - Account for correlations, dynamic induced charge effect
- **2D deconvolution extracts ionization charge from the induction wire planes**

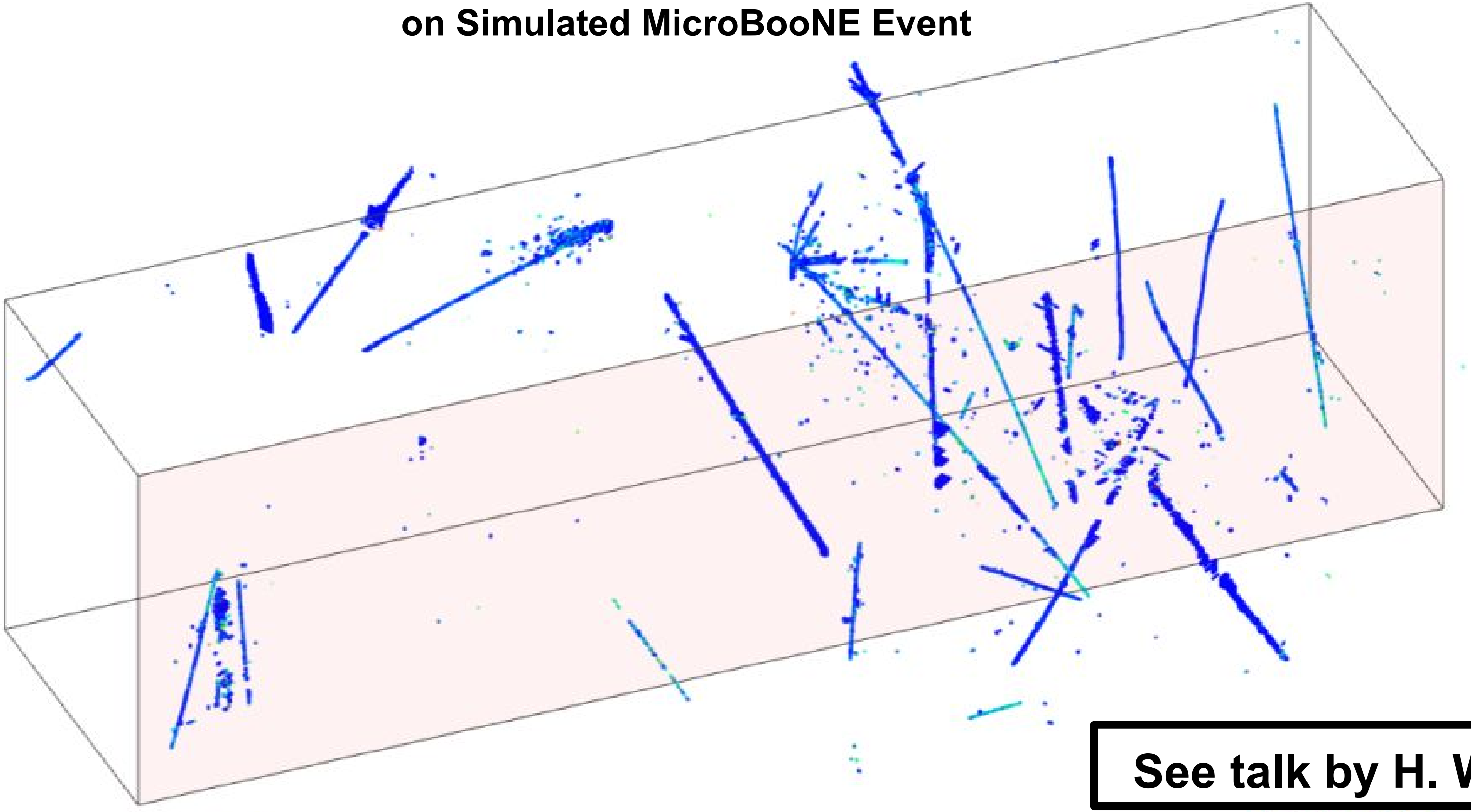
# Signal Processing and 2D Deconvolution




**See posters by J. Joshi and B. Russell**

# Signal Processing and 3D Ionization Charge Measurement

**Wire-Cell 3D Tomographic Reconstruction on Simulated MicroBooNE Event**



**See talk by H. Wei**

- Improved signal processing and multi-wire plane charge measurements enable new approaches to LArTPC event reconstruction

# Conclusions

- MicroBooNE is an ongoing short-baseline neutrino experiment
- First large scale LArTPC using cold-electronics
- Demonstrated excellent noise performance
- "5-Ds" simulation applies detailed knowledge of detector response
- 2D deconvolution measures ionization using collection AND induction planes
- Improved signal processing enables new approaches to event reconstruction
- Helps collaboration achieve physics goals!