Tomographic Event Reconstruction with the MicroBooNE LArTPC

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MicroBooNE: A LArTPC Neutrino Detector

The Micro Booster Neutrino Experiment (MicroBooNE): A 170 ton liquid argon time projection chamber (LArTPC) neutrino detector. LArTPCs provide high resolution images of tracks and electromagnetic showers made by charged particles inside the detector.

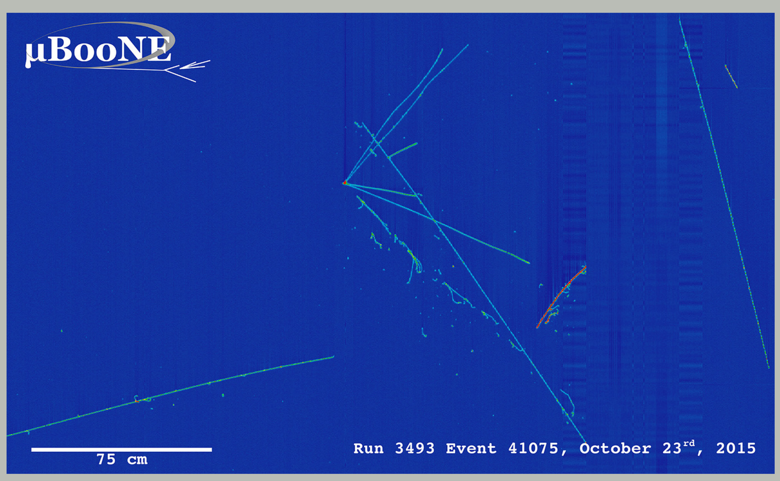

Figure 1: Neutrino candidate at MicroBooNE.

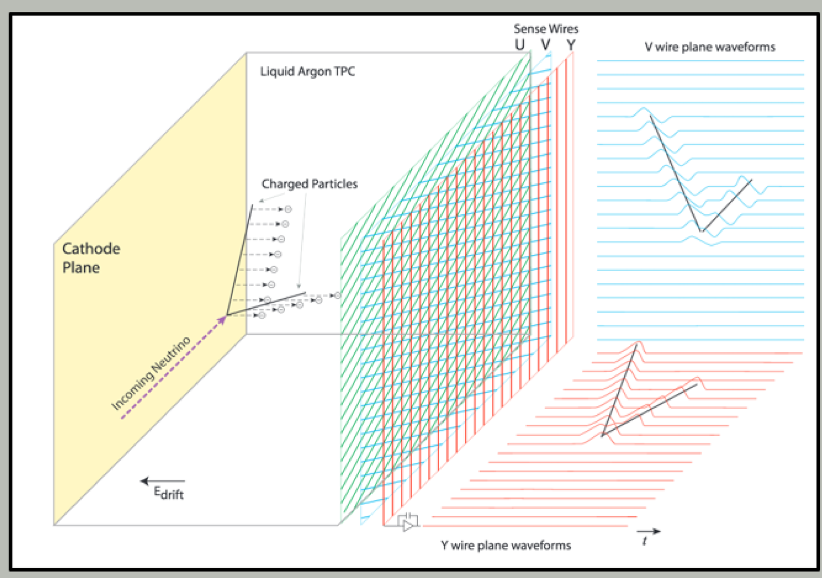

Figure 2: Time projection chamber.

How MicroBooNE LArTPC works:

- A charged particle moving inside the detector ionizes the argon atoms.
- Ionization electrons drift in 273 V/cm field towards three wire planes.
- Signal on wires: a current produced by charge induction/collection associated with drifting ionization electrons.
- Neutrino event reconstruction:
  - Three wire planes + photomultiplier tubes → 3D track and electromagnetic reconstruction.
  - Amount of charge deposited on wires → calorimetric reconstruction.

Signal Processing Chain

- Drifting electrons produce a signal on the wire planes represented by a wire field response.
- An electronics response represents the effect of the shaping and amplifying electronics.

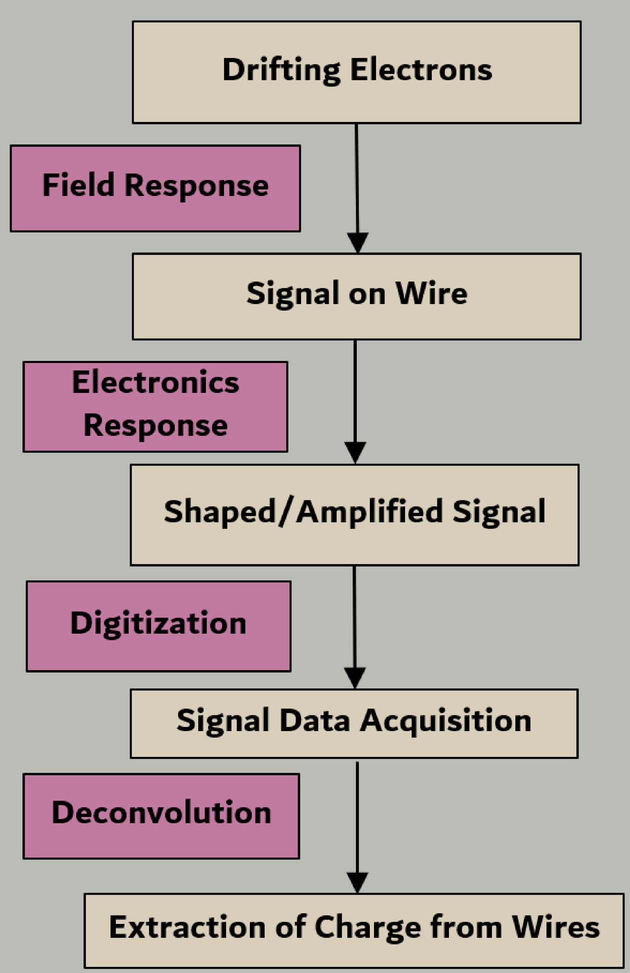

Figure 3: LArTPC charge signal formation.

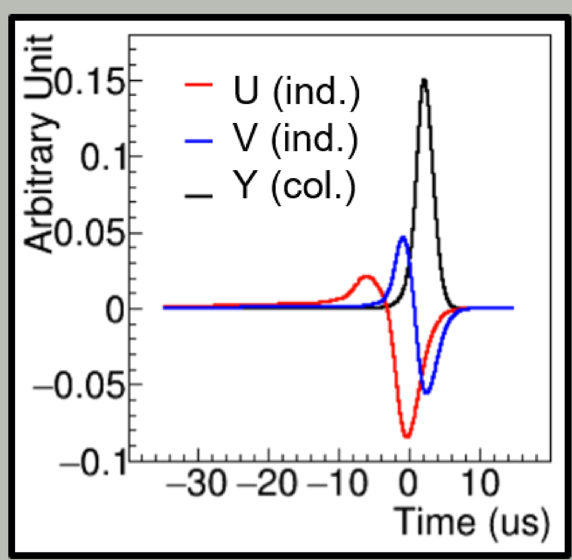

Figure 4: Wire field response functions for each plane.

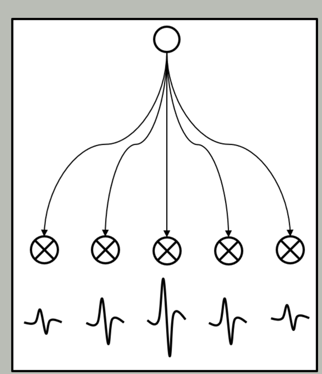

Figure 5: Signals induced on set of neighboring wires due to drifting charge.

- **Signal Deconvolution** (carried out in the frequency domain):

$$Estimated\ Signal = \frac{Measured\ Signal}{Response\ Function} \times Filter\ Function$$

- **2D vs 1D Deconvolution**: The electrons not only produce a field response on the closest wire, but also on neighboring wires. Therefore, instead of a 1D deconvolution involving only the time dimension, a 2D deconvolution involving both time and wire dimensions is performed to recover the original ionization electron distribution.

Event Reconstruction with LArTPCs

- **Standard Reconstruction Technique:** independent images of the event are formed for each wire plane (U, V, and Y). Event reconstruction consists of individual plane image 2D pattern recognition and merging using time information to form a 3D image.

  2D imaging → 2D pattern recognition → 3D pattern recognition.
- **"Wire-Cell" Technique:** local charge matching across the three wire planes in a time slice, creating a tomographic image. Imaged time slices are then joined together to form a 3D image. This allows for direct 3D pattern recognition on a 3D image.

  3D imaging → 3D pattern recognition.
- **Charge Matching:** for the Wire-Cell technique to work, charge deposition must match across wire planes. To ensure that charge is successfully reconstructed on each of the three planes, a data-tuned simulation of the wire field response must be used in the deconvolution procedure.

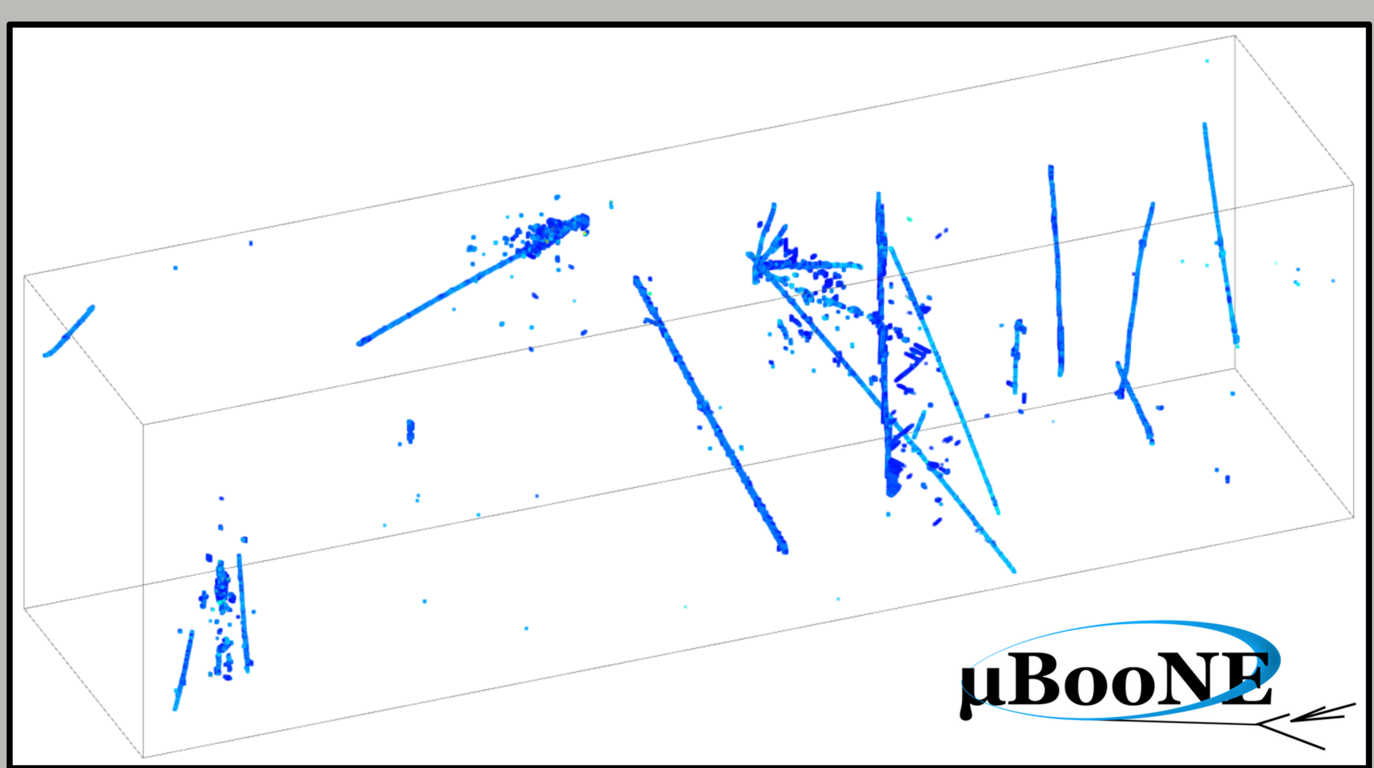

Figure 6: 3D image of neutrino interaction event in MicroBooNE LArTPC produced using the Wire-Cell technique.

References

- [1] R. Veenhof. "GARFIELD, recent developments", Nucl. Instrum. Meth., A419:726730, 1998.
- [2] R. Acciarri et al. "Noise Characterization and Filtering in the MicroBooNE Liquid Argon TPC", JINST, 12:P08003, 2017.
- [3] MicroBooNE collaboration. "Ionization Signal Analysis and Processing in Single Phase LArTPCs. II. Data/Simulation Comparison and Performance in MicroBooNE", 2017. Paper in preparation.

Validation of the Simulated Wire Field Response

MicroBooNE is not a perfect detector; it has regions where the wires are shorted making around 5% of the total number of wires effectively dead. Cosmic muons are used to study the wire field response for both the non-shorted and shorted regions of the detector in data. Simulated response functions are made using Garfield-2D [1]. Furthermore, data is used to tune the response function simulation in the shorted regions. Altered response functions due to shorted wires are accounted for in the 2D deconvolution procedure.

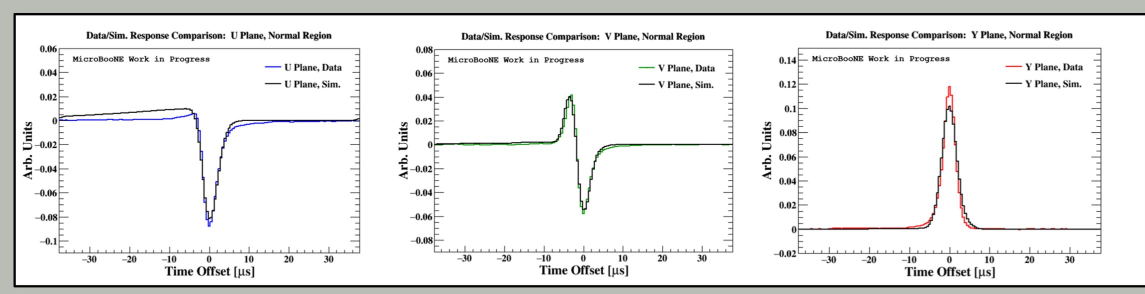

Figure 7: Normal region response functions for the three anode planes.

- Normal region of the detector where no shorted wires are present.

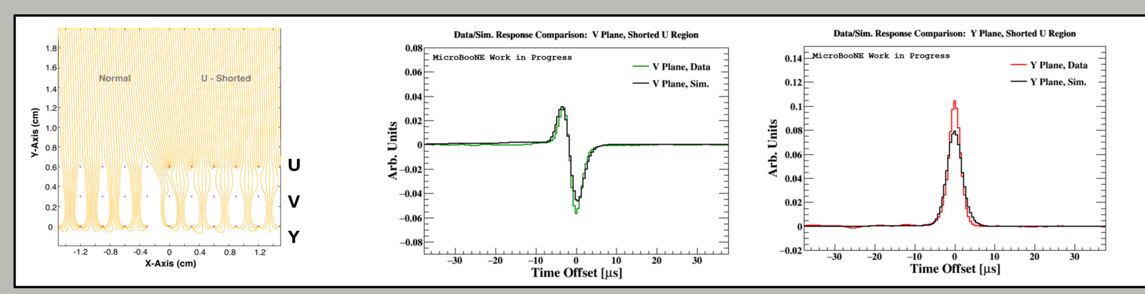

Figure 8: Shorted U region: (left) electron drift path and (right) response functions.

- In the shorted U region, the U plane collects a portion of the electrons coming to the anode planes reducing the ionization transparency for the V and Y planes.

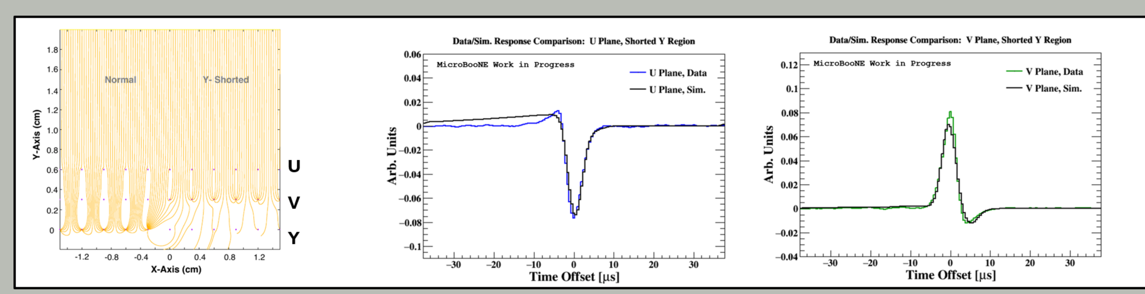

Figure 9: Shorted Y region: (left) electron drift path and (right) response functions.

- In the shorted Y region, the V plane will exhibit collection plane properties. V plane wires that overlap with this region will see both unipolar and bipolar signals.

Results: Evaluation of Signal Processing Performance

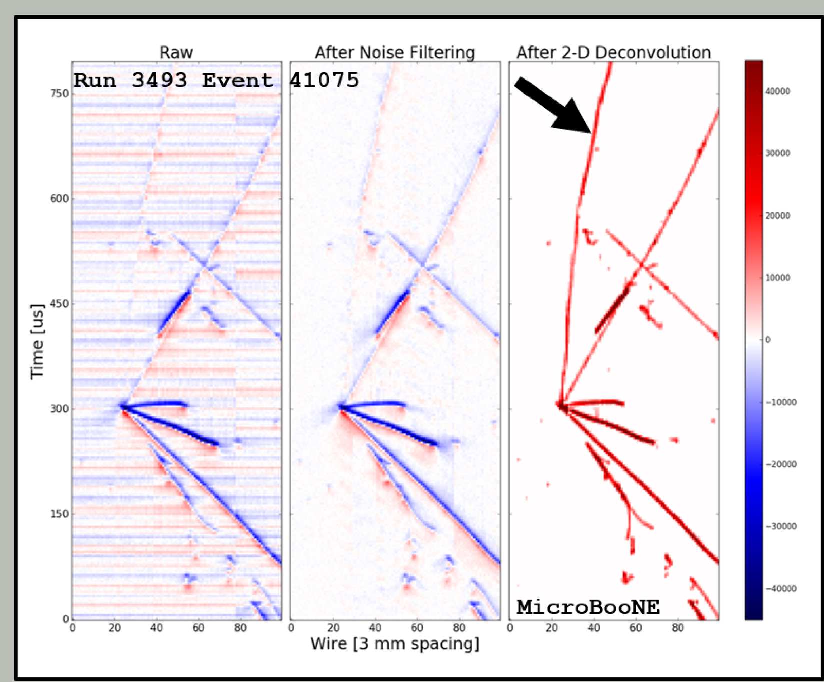

Figure 10: Imaging of neutrino interaction, before/after noise-filtering [2] and after 2D deconvolution.

- Crisper images of events in data observed after 2D deconvolution.
- Recovery of track nearly orthogonal to the wire planes.
- Improved image quality allows for more accurate pattern recognition.

Results: Cross-Plane Charge Matching - Different Charge Sources

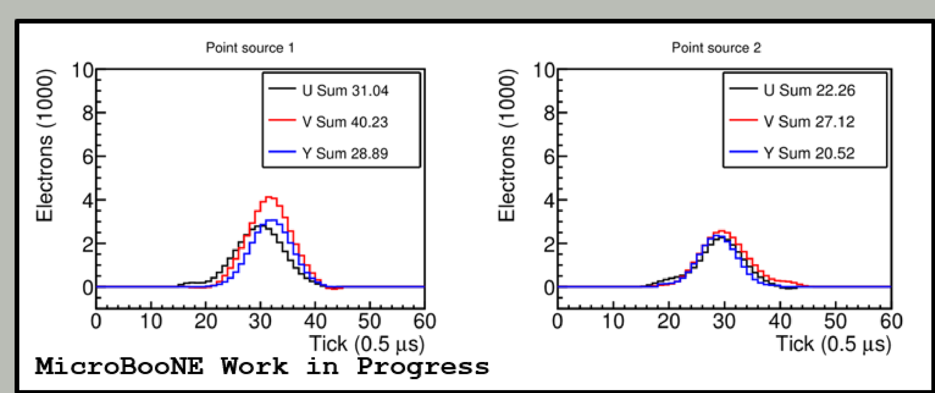

Figure 11: Point-like charge sources.

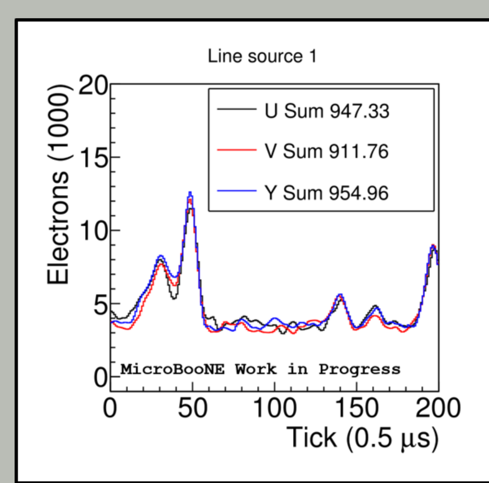

Figure 12: Track-like charge source.

Charge matching is observed across all three planes using the deconvolved ionization charge distributions for point-like and track-like sources. Distortions in charge distributions between planes are due to extrinsic noise.

Point-like charge sources:

- Possible Ar-39 decays present inside of the detector.

Track-like charge sources:

- Cosmic muon tracks were used.
- The spikes observed along the track are due to signal fluctuations and delta rays.

Results: Cross-Plane Charge Matching - dQ/dx

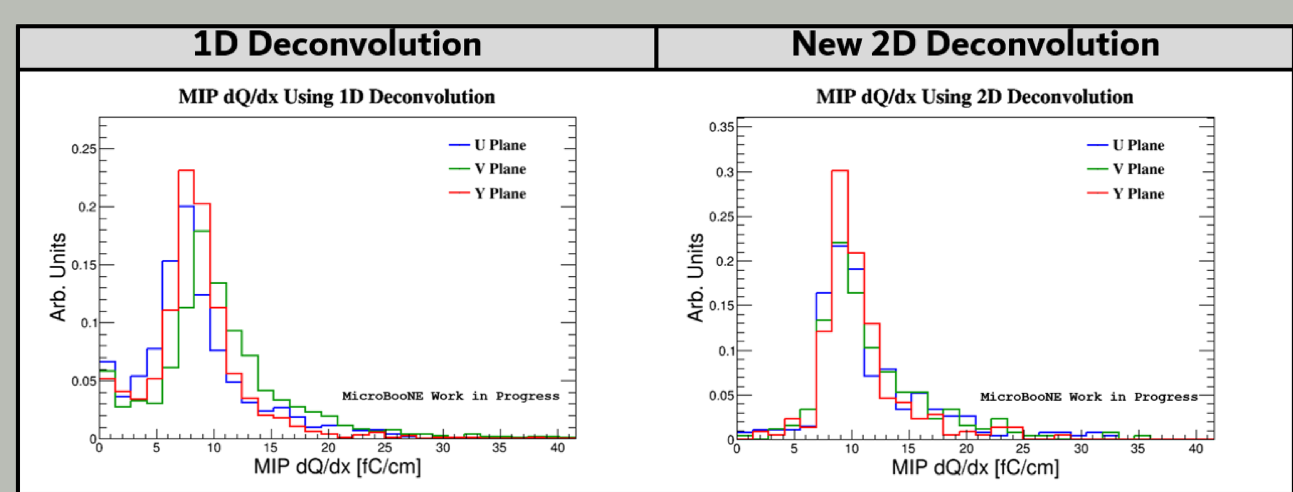

Figure 13: Distribution of dQ/dx for 1D deconvolution and 2D deconvolution.

The MIP (minimum ionizing particle) dQ/dx distribution for both the 1D and 2D deconvolution procedures are shown. This is the distribution of the charge deposited over a unit length of a cosmic muon track measured in data. It is observed that the peaks of each distribution have a better alignment in the 2D deconvolution case indicating better cross-plane charge matching.

Conclusion

- Introduced a novel imaging technique that uses cross-plane charge matching to create 3D images of events occurring inside LArTPCs.
- Looked at problematic regions of the detector affecting cross-plane charge matching and discussed how they are handled.
- Demonstrated successful cross-plane charge matching in LArTPC using MicroBooNE data.
- Next step: unleash powerful new reconstruction technique on physics measurements at MicroBooNE.