Recent Progress on Wire-Cell Tomographic Event Reconstruction for LArTPCs

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Abstract: Event reconstruction is one of the most challenging tasks in analyzing the data from current and future massive liquid argon time projection chambers (LArTPCs) and its performance is critical to achieve physics goals. A novel tomographic event reconstruction method, *Wire-Cell*, is under development and applied in MicroBooNE data. In this poster, we will describe the principle of *Wire-Cell* tomographic event reconstruction, which incorporates *the time, charge, geometry*, and *sparsity, connectivity* information to reduce the ambiguity from wire readout and *reconstructs the 3D image of ionization electrons independent of topology*.

Tomographic nature of the LArTPC

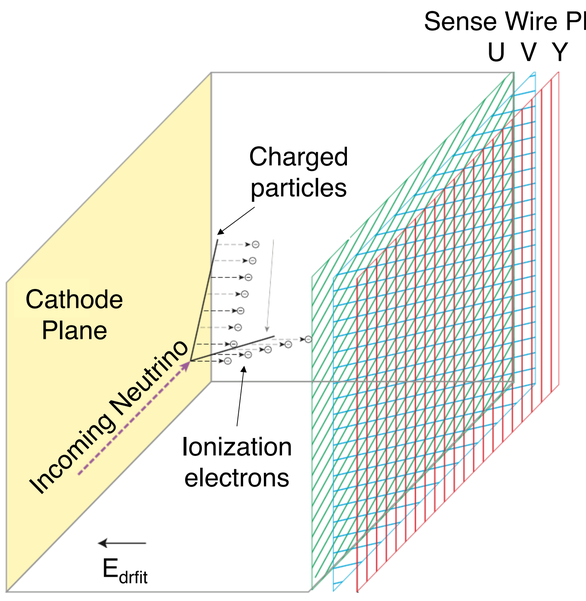


Figure 2 in JINST 12 P02017

- ❖ **Time**: when ionization electrons arrive at the anode wire planes **[≅Tomography cross section]**
- ❖ **Charge**: how many ionization electrons along each wire **[≅ Tomography radiograph]**
  - Noise filtering [1], robust signal processing [2, 3], particularly for induction planes
- ❖ **Geometry**: which wire is hit by ionization electrons **[≅ Tomography 1D projective view]**
  - Wire readout ambiguity: 1D projective position for each wire plane
  - Anode plane 2D geometry information is absent from $\mathcal{O}(n^2)$ to $\mathcal{O}(n)$

3D image of **ionization electrons** = 1D time + 2D anode plane position

* MicroBooNE has demonstrated good reconstructed charge matching among the three wire planes.. This is essential for tomographic event reconstruction and significantly reduce degeneracy inherent in a projective wire geometry.

- ✓ Three 1D projective views
- ✓ Robust time, geometry, and charge
- ✓ No topology (pattern recognition) involvement

Principle of Wire-Cell Tomographic Imaging

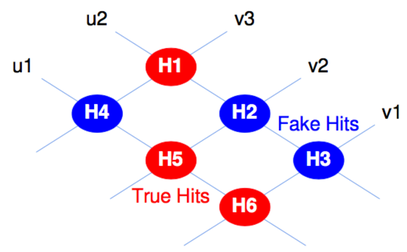


Illustration of the hit ambiguity caused by the wire readout in a simplified two-wire-plane example. Figure 2 in Ref. [4]

Measured charges on wires

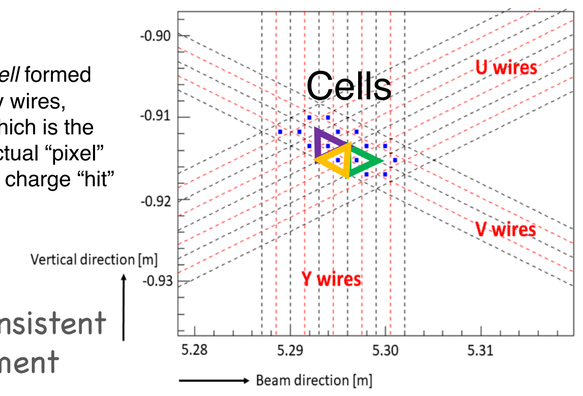
True charge hits to be resolved

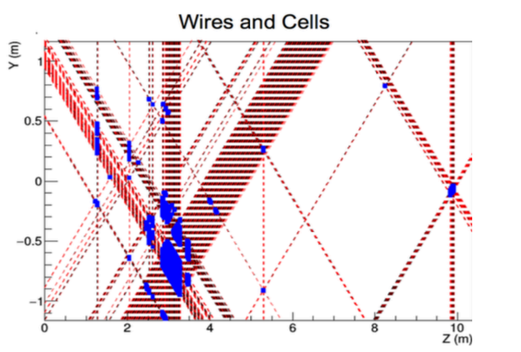
$$\begin{pmatrix} u1 \\ u2 \\ v1 \\ v2 \\ v3 \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 0 \end{pmatrix} \cdot \begin{pmatrix} H1 \\ H2 \\ H3 \\ H4 \\ H5 \\ H6 \end{pmatrix}$$

Matrix determined by wire geometry

*Solution is strictly consistent with original measurement

Cell formed by wires, which is the actual "pixel" of charge "hit"





Blue: single cell Blob: merged cells if connected

- Unknowns >> knowns
  - Combinatorial removal of unknowns, $C_6^2 = 15$ v.s. (real case) $C_{35}^{10} = 1.8\times10^8$, for unique/best solution
- NP (non-deterministic polynomial time) hard problem

⇨ Compressed sensing (a signal processing technique) to efficiently & rapidly recover ***sparse*** signal (remove fake hits) for incomplete and inaccurate measurements.

⇨ In practice, minimizing $\chi^2 = \left(C\cdot\vec{W} - G\cdot\vec{B}\right)^T V^{-1}\left(C\cdot\vec{W} - G\cdot\vec{B}\right) + \left\|\lambda\vec{B}\right\|_1$

$C\cdot\vec{W}(ire)$: charge measurement in grouped wire

$\vec{B}$: charge to be solved in blob (merged cells)

(Compressed sensing) L_1 regularized: $\|x\|_1 = \Sigma|x_i|$

Realistic Issues & Solutions

Issues (gaps in the detector):

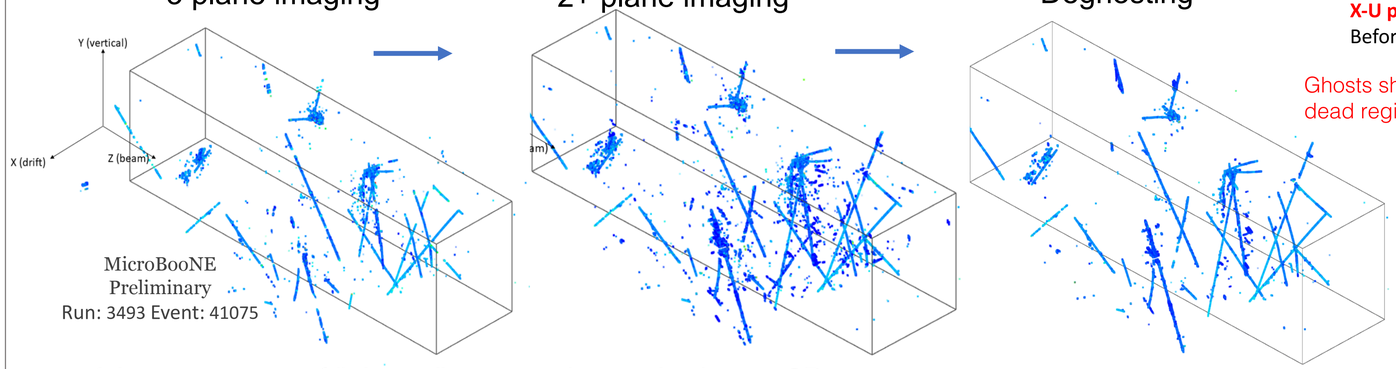
- 10% dead wires in MicrooBooNE
- Induction plane inefficient charge extraction for prolonged (large inclination angle to anode plane) tracks

Solutions:

- [**Increase volume efficiency**] Imaging in the regions where **two** (27% volume) or **three** (70% volume) plane active
- [**Bridge gaps**] Initial clustering solely based on connectivity + further clustering based on directionality

Two/Three plane imaging & Deghosting

3 plane imaging → 2+ plane imaging → Deghosting



A large amount of "ghosts" appear due to the larger 2D position ambiguity from 2 planes than 3 planes

- ✓ Absent tracks in dead region were recovered
- ✓ Ghosts in dead region were created as well

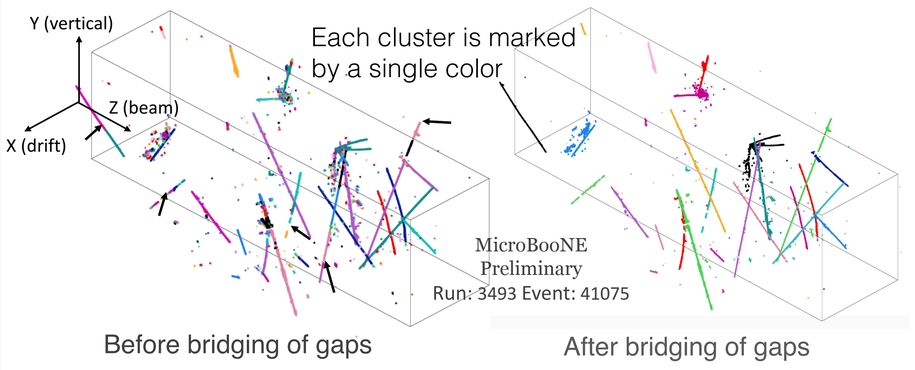
Multiple rounds of [charge solving, deghosting, clustering]

- ✓ Deghosting procedure is on each cluster
- ✓ More proper clustering will remove more ghosts

Bridging of gaps

Key: directionality + distance

Challenge: Huge amounts of 3D space points.



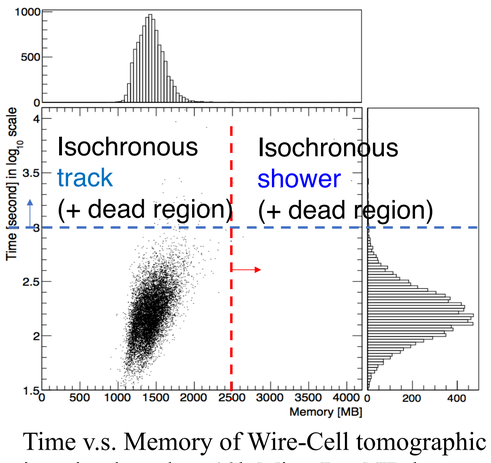
Before bridging of gaps

Broken tracks as indicated by arrows. Multiple colors for a single track.

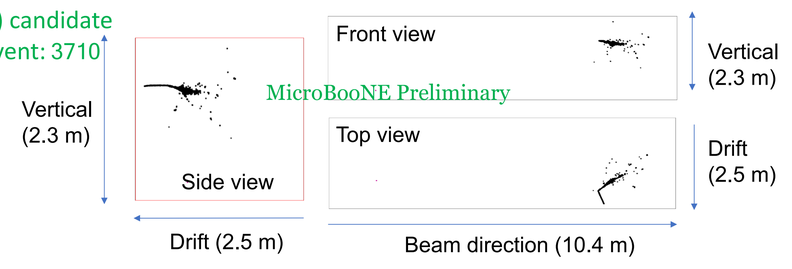
After bridging of gaps

Broken tracks are fixed (enable further deghosting). One track one color.

Application with MicroBooNE data & Summary



Time v.s. Memory of Wire-Cell tomographic imaging based on 10k MicroBooNE data events.



- ✓ A novel tomographic method independent of topology
- ✓ The projections of the 3D image are strictly consistent with the original measurements (i.e. solution to the first principle equation)
- ✓ Realistic issues, e.g. 10% dead wires, are properly addressed
- ✓ Good performance was qualitatively demonstrated by hand scan of thousand events & quantitative evaluation/optimization is ongoing

Explore more in B. Russell's poster "Towards automated neutrino selection at MicroBooNE using tomographic event reconstruction"

References:

[1] 2017 *JINST* **12** P08003 [arXiv:1705.07341].
[2] arXiv:1802.08709. (accepted by JINST)
[3] arXiv:1804.02583. (under JINST review)
[4] arXiv:1803.04850. (accepted by JINST)

Supporting note:

MICROBOONE-NOTE-1040-PUB
http://microboone.fnal.gov/public-notes/

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