DUNE Reconstruction Tool *Wire-Cell* : Introduction to Framework

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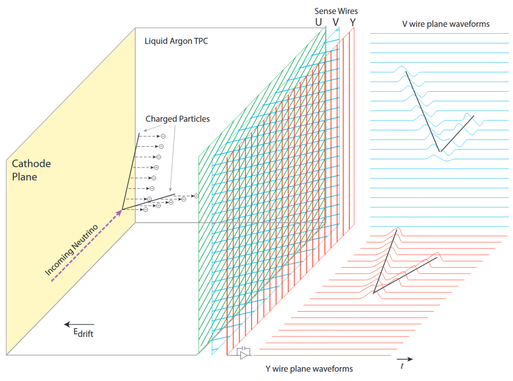
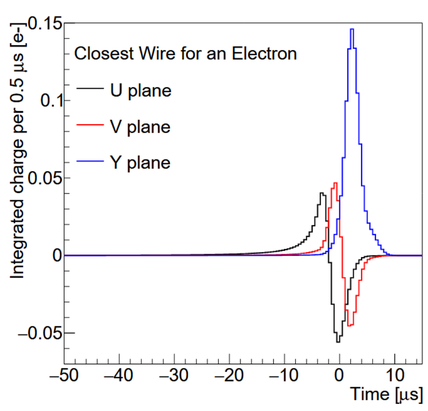
Abstract

Event reconstruction is a crucial technique in neutrino experiments utilizing Liquid Argon Time Projection Chamber (LArTPC). To enhance scientific performance, the Wire-Cell framework has been developed as a novel reconstruction method that utilizes the topology of 2D projections. It makes use of time, charge, and geometrical information encoded in 2D wire plane signals, and incorporates features such as sparsity and proximity across multiple wire planes. Owing to its versatility, Wire-Cell can be applied to a wide range of LArTPC-based experiments and is currently being optimized for use in the Deep Underground Neutrino Experiment (DUNE). In this work, we introduce the basic concepts and the core reconstruction procedure of the framework.

Introduction

- The **Deep Underground Neutrino Experiment (DUNE)**is a next-generation neutrino oscillation experiment with 1300km baseline.
- The **Liquid Argon Time Projection Chamber (LArTPC)**, deployed as the far detector in DUNE, features low diffusion, high charge mobility, low energy threshold, and high spatial resolution
- Its **readout system with 3 different oriented wire planes** captures signals from drifting ionized electrons

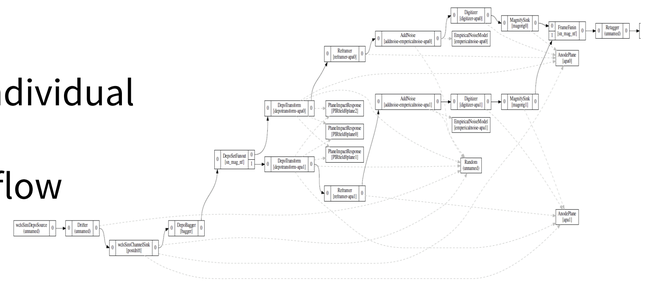




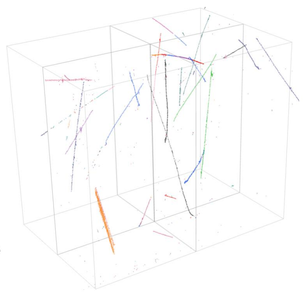
- Compared to pixel-based reconstruction, Wire-Cell offers cost advantages like electronics and power by utilizing the geometry of projective wire planes.
- **Wire-Cell-Toolkit (WCT)** is a software package which realize simulation and data processing based on Wire-Cell reconstruction framework.

Wire-Cell-Toolkit

- WCT supports both **standalone and LArSoft-based simulations and data processing**, enabling flexible integration with the conventional LArTPC software framework.
- WCT offers **abstract interfaces** for each module and component, , allowing **users to easily use the framework by setting up a configuration**, despite its many dependencies and complex internal structure.
  - **Dataflow Programming**
    - Data I/O to each module
    - Data processing within individual module
    - Visualization of the data flow graphs



  - **Bee**
    - Web-based interactive 3D event displayer
    - Visualizing 3D space points reconstructed by WCT
    - Providing various physical information

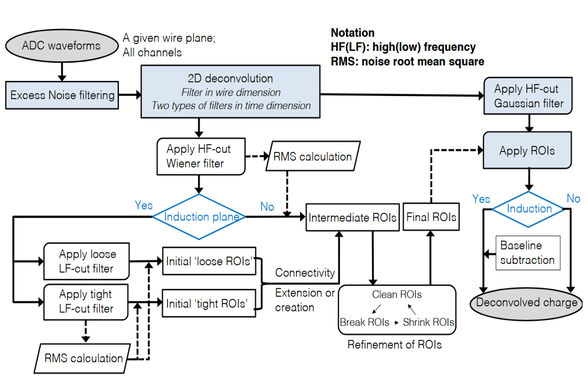


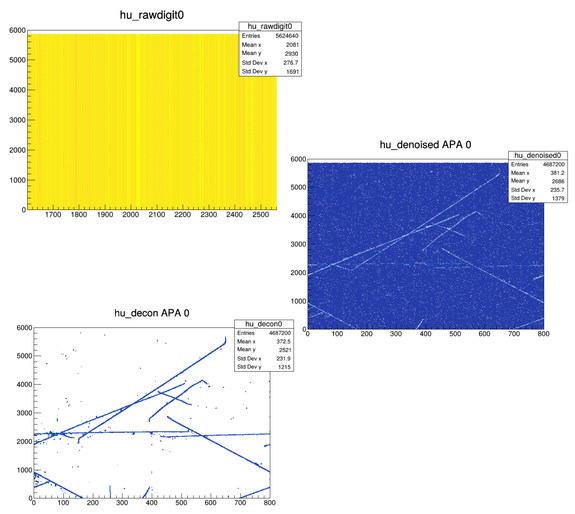
Wire-Cell

Ref) WCT repository : https://github.com/wirecell/wire-cell-toolkit
Bee : https://www.phy.bnl.gov/twister/bee/

Wire-Cell Signal Processing

- **Signal processing for induction planes** is important due to their bipolar nature.
- To consider long range induce effect, The **2D deconvolution** is introduced. It removes signals from distant drifting electrons.
- **Wiener filters** remove high-frequency regions with low signal-to-noise ratio.
- **Region of Interest(ROI)** finding is applied to reduce noise at low frequency.

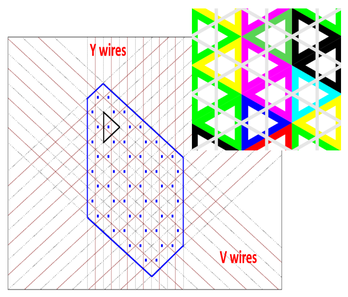


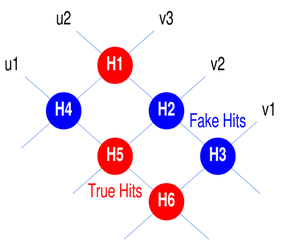


Ref) JINST 13 P07006 (2018)

Wire-Cell 3D imaging

- Compensation for the information loss inherent in the wire readout system is essential.
- Multiple types of information are incorporated :
  - **Time, Charge, and Geometry**
  - **Sparsity, Proximity**
- Iterative procedure : **Tilting → Charge solving → De ghosting**





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

$$\chi^2 = ||y' - A'x||_2^2 + \lambda||x||_1$$

Ref) JINST 13 P05032 (2018) / JINST 16 P06043 (2021)

- **3D clustering**
  - Clustering based on their physical origins
  - Merging separated clusters from the same neutrino interaction
- **Charge-light matching**
  - Event start time estimation for special resolution improvement

Further steps

- dQ/dx fitting for energy reconstruction
- Cosmic muon tagger for background removal
- Particle Identification
- Data Analysis

Conclusion

- Wire-Cell is an efficient and robust framework for neutrino event reconstruction.
- Signal processing techniques are applied to enhance performance on the induction planes.
- For 3D imaging, the framework maximizes the use of various information to mitigate information loss inherent in the wire readout scheme.
- Each step in Wire-Cell is currently being optimized for the DUNE.

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