Development of Shower Characterization Tools Within Pandora for the DUNE Near Detector

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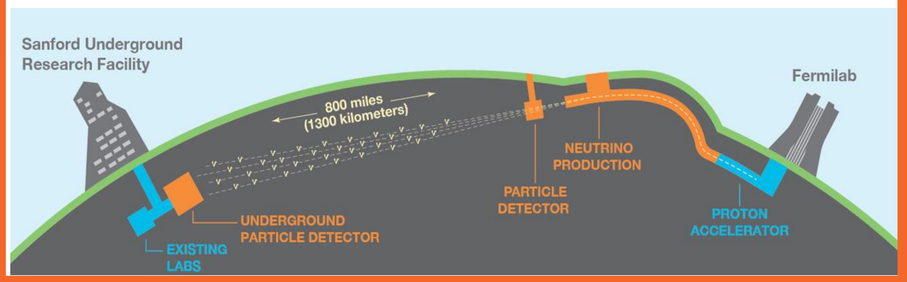
The Deep Underground Neutrino Experiment (DUNE)

- DUNE is a next generation neutrino oscillation experiment currently under construction.
- DUNE will use a powerful neutrino beam and a Near Detector at Fermilab, and up to four large-scale Far Detector modules at SURF.
- The experiment will utilize Liquid Argon Time Projection Chambers (LArTPC), which provide high-resolution charge-based representations of neutrino interactions and fast timing information from scintillation light.

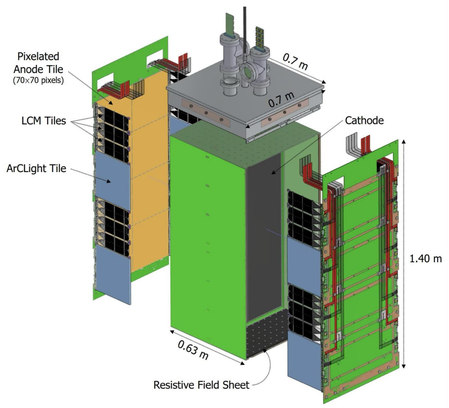


The DUNE Near Detector

- The Near Detector (ND) allows for characterization of the beam before the neutrinos oscillate, a basis for FD spectra predictions, and limiting systematic uncertainties.

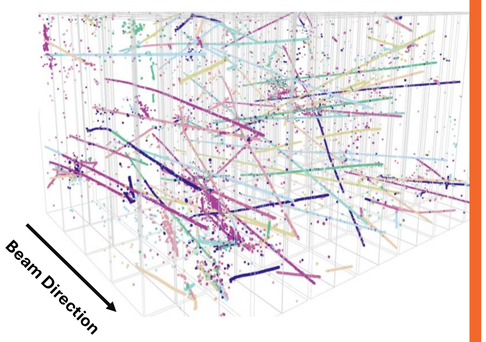
- ND-LAr (The Near Detector liquid argon time projection chamber) is made up of 5x7 LArTPC modules. These modules use charge pixel readout and two photon detector systems.

- Unlike the FD, the ND produces 3D charge readout positions, and will have a large amount of pile up events. These present unique challenges to ND reconstruction.



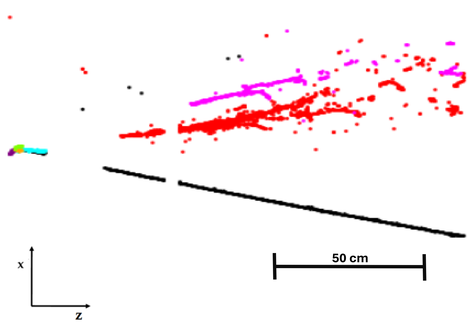
A graphic depicting one ND-LAr module.

DUNE WORK IN PROGRESS



A simulated event display of ND-LAr, illustrating the large amounts of pile up.

Event Reconstruction with Pandora



DUNE WORK IN PROGRESS

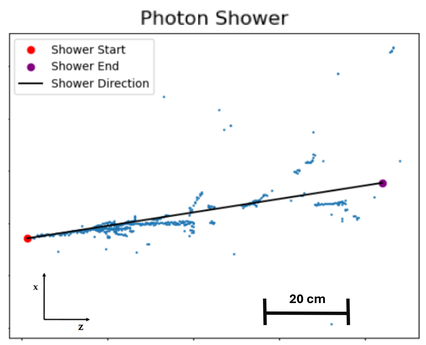
- Neutrinos are detected from the particles produced in their interactions; therefore, event reconstruction is a crucial step to interpret LArTPC data.
- Pandora is a reconstruction software for LArTPC experiments using 100+ pattern recognition algorithms to gradually build particle hierarchies. It is currently being tailored for native 3D inputs and pileup at the DUNE ND.
- Shower reconstruction strongly impacts neutrino flavor tagging and energy reconstruction. For example, photons from a neutral pion can be merged and mistaken as an electron.

Shower Characterization

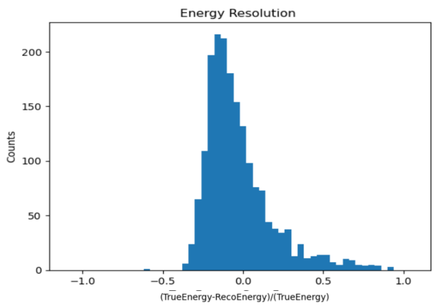
- This work introduces shower characterization tools for the ND Pandora reconstruction workflow, which run after pattern recognition.
- Identifying the particle that initiated a shower is important. This can be done using the conversion gap between the shower's start and the neutrino interaction vertex, and the energy deposition per unit length.

- Estimations of these variables require a precise reconstruction of the shower direction, start position, and calibrated energy.
- The tools were tested using cheated reconstruction, assigning hits to particles using truth information rather than Pandora's usual pattern recognition logic. This isolates the tools' performance from the previous pattern recognition stage.

- Energy estimation, which is essential for neutrino energy reconstruction and impacts oscillation analyses, includes calibration and lifetime corrections.
- Along with these shower tools, track characterization tools were also developed within the Pandora ND team.

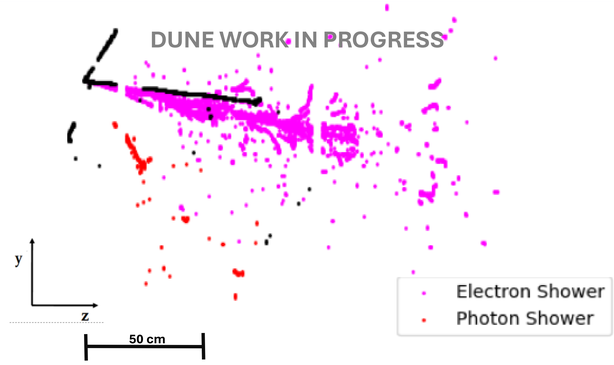


DUNE WORK IN PROGRESS

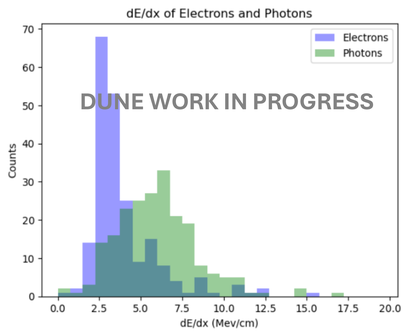


Results are from a collection of ~1800 single neutrino events from DUNE beam simulation. A majority of photons and electrons have energies < 1 GeV.

Electron/Photon Separation



- Electromagnetic showers are started by either photons or electrons.
- In the beginning of the shower, photons will deposit twice as much energy as electrons deposit.
- Photons can also present a conversion gap between the shower start and neutrino interaction vertex.
- Both variables can be exploited in analysis to separate electrons and photons.



From a sample of ~200 photons and electrons from DUNE beam simulation. Photon and electron energies are mainly < 1 GeV.

Summary

- Shower characterization tools are an important part of the efforts to reconstruct neutrino events at the DUNE ND.
- The higher level tools developed within this project will be used by the whole collaboration for analysis efforts. The initial version is complete, and will continue to be refined.
- Future goals will be to optimize these tools and Pandora's pattern recognition of shower-like particles. They will then be used in analysis of shower topologies such as charged-current (CC) electron neutrino interactions and CC muon neutrino interactions with final-state neutral pions, an important background channel in DUNE oscillation analysis.