Energy resolution in the DUNE Far Detector Vertical Drift module

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The Deep Underground Neutrino Experiment (DUNE) is a long-baseline neutrino experiment under construction in the USA, with a broad physics program including measurements of neutrino oscillation parameters, neutrino mass ordering, and CP violation in the lepton sector. Data taking is expected to begin in the early 2030s, with rapid sensitivity to the mass ordering and CP-violating phase.

DUNE employs a Near Detector complex at Fermilab to measure the unoscillated neutrino flux and a Far Detector complex located 1300 km away and 1.5 km underground to measure the oscillated flux. The first phase of the experiment will include two Far Detector modules, with plans to add two more in the second phase, reaching a total fiducial mass exceeding 40 kt. The initial modules use Liquid Argon Time Projection Chamber (LArTPC) technology, implemented in Vertical Drift (VD) and Horizontal Drift (HD) configurations that differ in geometry and electric field direction.

My thesis focuses on the Far Detector Vertical Drift module and its energy resolution. Although LArTPC technology offers excellent calorimetric and spatial resolution, early studies showed that the simulated energy resolution for electron neutrinos in the DUNE FD VD was insufficient for precision oscillation analyses. This motivated the development of a more realistic detector simulation during the first year of my PhD.

In the FD VD, charge is read out by Charge Readout Planes (CRPs) arranged in superstructures. Small gaps between CRPs and superstructures were initially modeled as fully inactive volumes, with unrealistic dimensions, leading to artificial charge loss. To address this, a new detector geometry and a charge recovery model were implemented, allowing a fraction of the ionization charge deposited in the gaps to be recovered in a way consistent with the expected physical behavior where the electrons can drift towards the nearest strips and get recovered. The method was validated using data from the ProtoDUNE VD detector at the CERN Neutrino Platform, which began data taking in August 2025. Good agreement between data and simulation was achieved, enabling calibration of the total recovered charge. The inclusion of realistic charge recovery results in a significant improvement in the electromagnetic shower energy resolution.