APS Four Corners October 2022

Analysis of a Traditional Field-Shaping Structure for the ND-LAr Detector

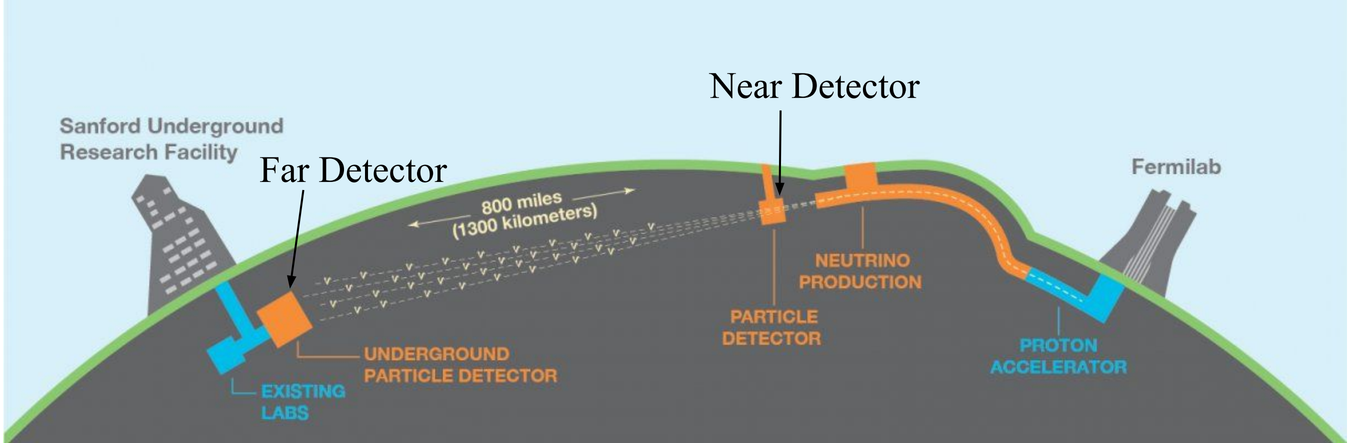
Eleanor Schnee for the DUNE Collaboration

University of Colorado **Boulder**

Introduction

Deep Underground Neutrino Experiment (DUNE)

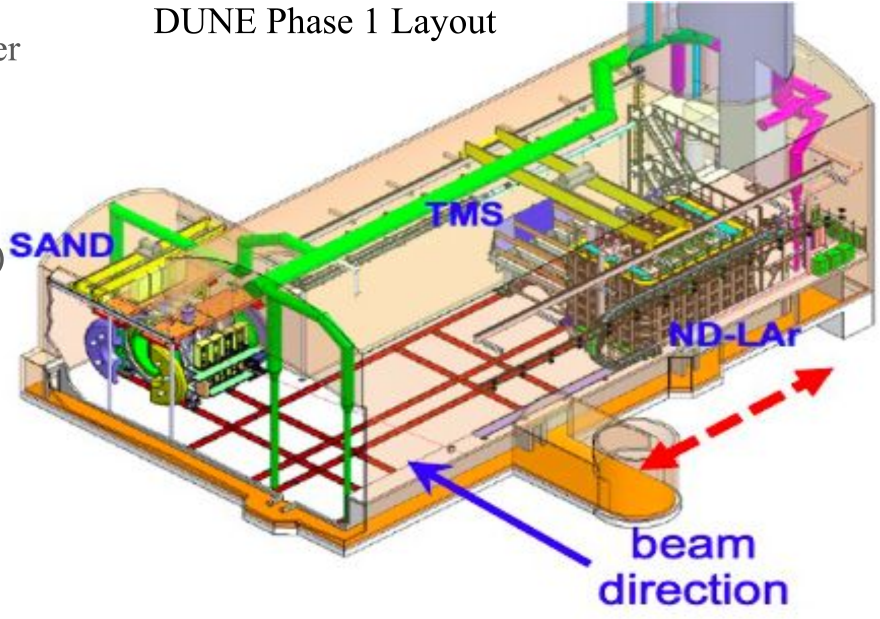
- Neutrinos pass through the Near Detector (ND) at Fermilab in Chicago before traveling 800 miles to the Sanford Underground Research Facility in South Dakota
- The goals of DUNE include measuring neutrino flavor oscillations, studying neutron star and black hole formation, as well as searching for evidence of physics beyond the standard model



The Near Detector

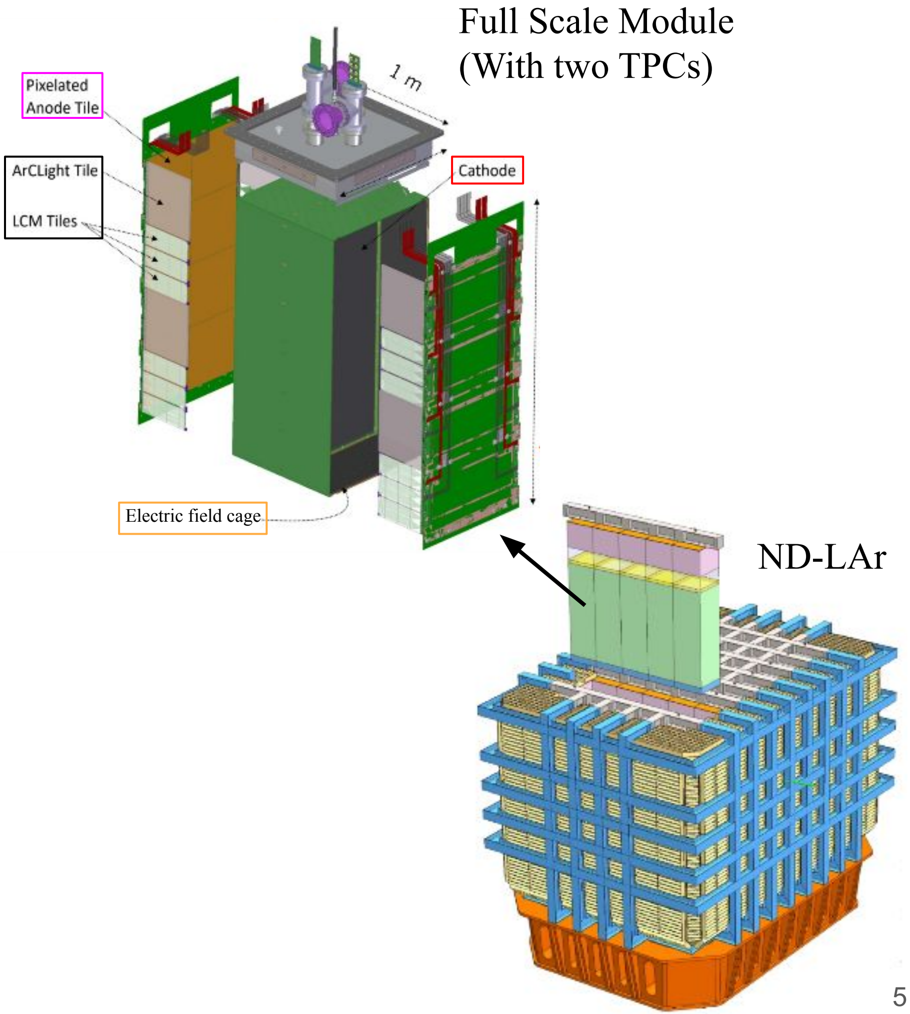
- The Near Detector utilizes three detectors:
  - 35 Liquid Argon (LAr) Time Projection Chamber (TPC) modules
  - Temporary Muon Spectrometer (TMS) → Magnetized Gaseous Argon TPC
  - System for on-Axis Neutrino Detection (SAND)
- ND-LAr and TMS will
- SAND monitors the on-axis neutrino flux

DUNE Phase 1 Layout



ND-LAr

- Neutrinos interact with the argon atoms to create high energy muons
- These muons ionize electrons in the surrounding atoms
- The field cage creates an electric field that drifts the ionization electrons to the Pixel Readout for detection

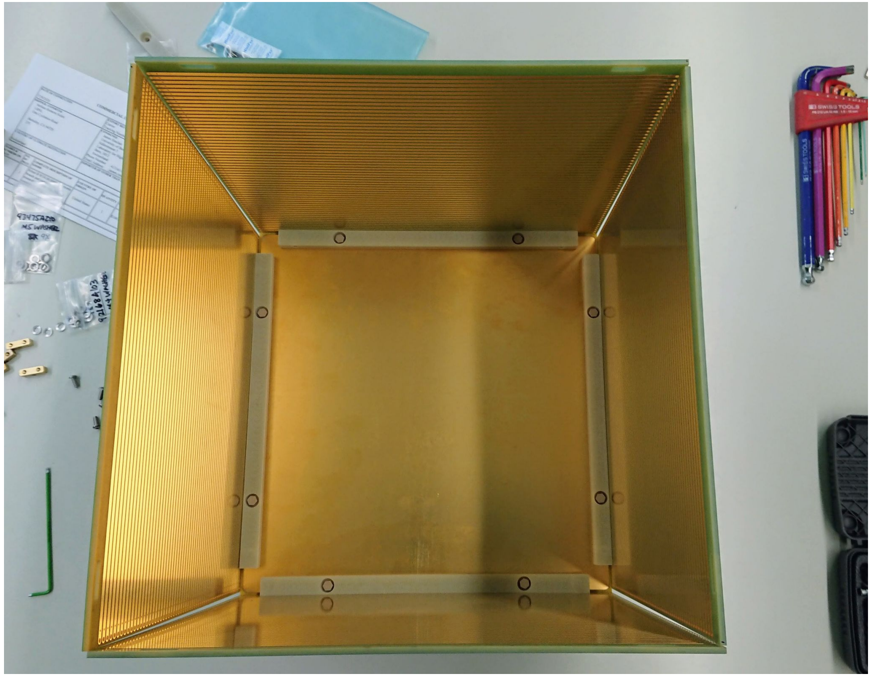


The Traditional Field Cage

- This design is under consideration to be the ND-LAr field-shaping structure
- Utilizes copper strips and resistors to step down the high voltage across the drift volume
- “Configuration” describes a particular strip width and strip spacing pair in mm
- For example: 10-3 would refer to 10 mm strip widths and 3 mm strip spacings

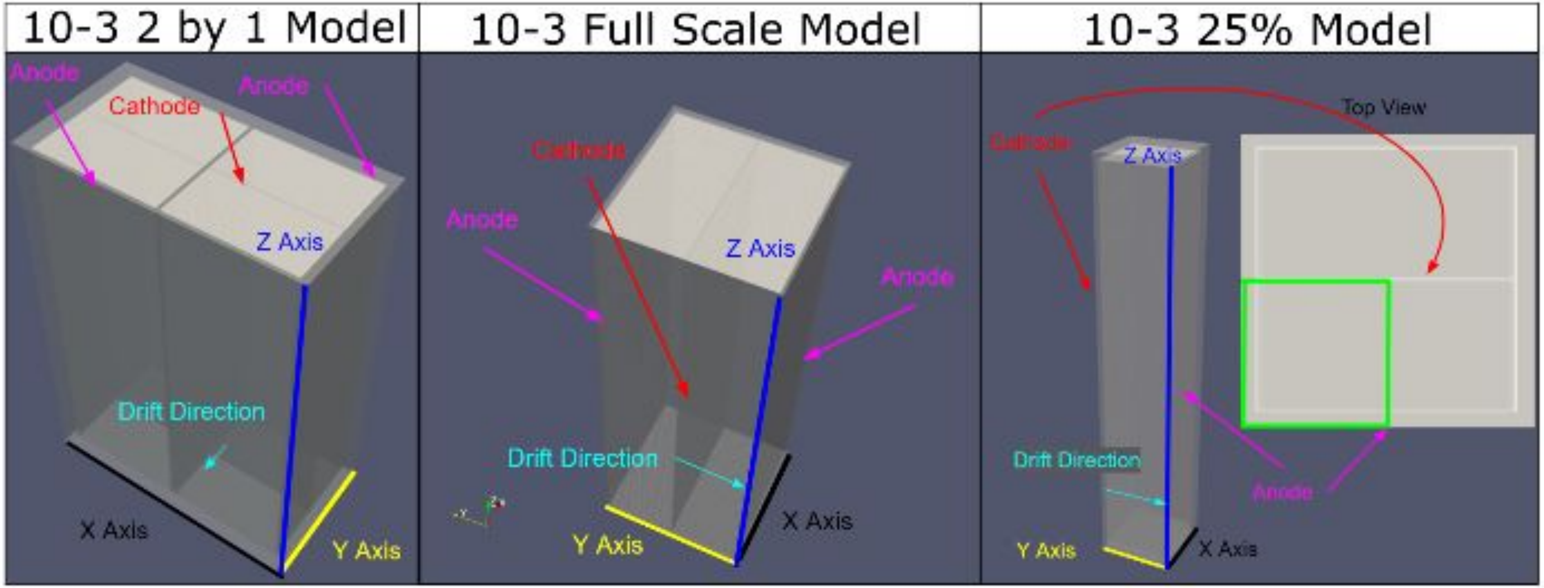
Why Simulate Before Building?

- Inform design choices, resistor-chain vs continuous field cage, may effect physics performance
- To have an accurate model of drift field for *a priori* calibrations
  - Correction for spatial distortions
  - Drift field recombination dependence



Models, Orientations, and Definitions

- Axes labeled with colored lines for each of the three models (y axis = drift axis)
- Fractional deviation, $\Delta E = (E_{pos} / E_{center}) - 1$, is defined relative to the E field at the center, since it is furthest away from the strips

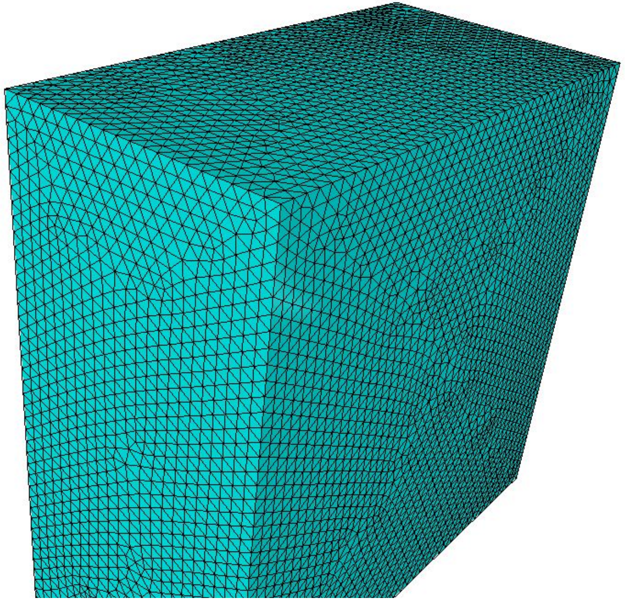


Simulation Workflow

Geometry Meshing

- Field cage geometries are constructed using the Open Cascade modules for Python
- A mesh of these geometries is created for use in the Elmer Finite Element Solver
- A smaller maximum mesh size will provide more accuracy in the solution, but leads to a larger file size

Each triangle is a mesh element with side length ≤ maxh



Electrostatic Solving

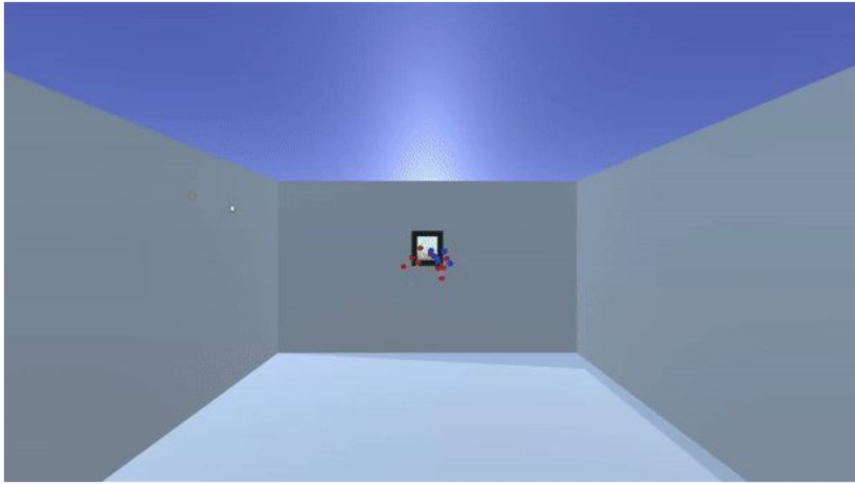
- Elmer solves the electrostatic Poisson's Equation iteratively over the mesh using given boundary conditions (BCs) and material properties
- Examples
  - BC: setting the cathode face to have an electric potential of 25 kV
  - Material Property: setting the relative dielectric strength of LAr to be 1.53
- The output contains the potential and electric field data at every vertex of the mesh
- These files can be interpreted using Python modules, or a program called ParaView

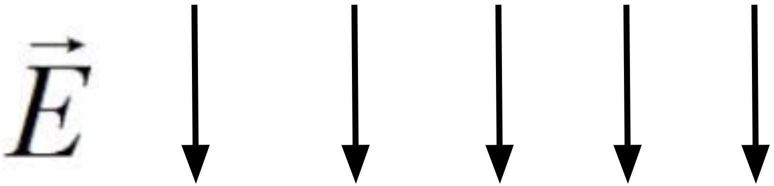
Poisson's Equation:

$$\nabla^2 V = -\frac{\rho_v}{\epsilon_0}$$

Drift Simulation

- Iterative process
  - Choose the initial position of electrons
  - Calculate the drift velocity at the electron's current position based on the magnitude of the electric field Ref. [1,2]
  - Multiply the drift velocity by the time step (and norm of the E field) and add it to the position
- Assumption that the electrons instantly achieve and maintain their drift velocities for that time step

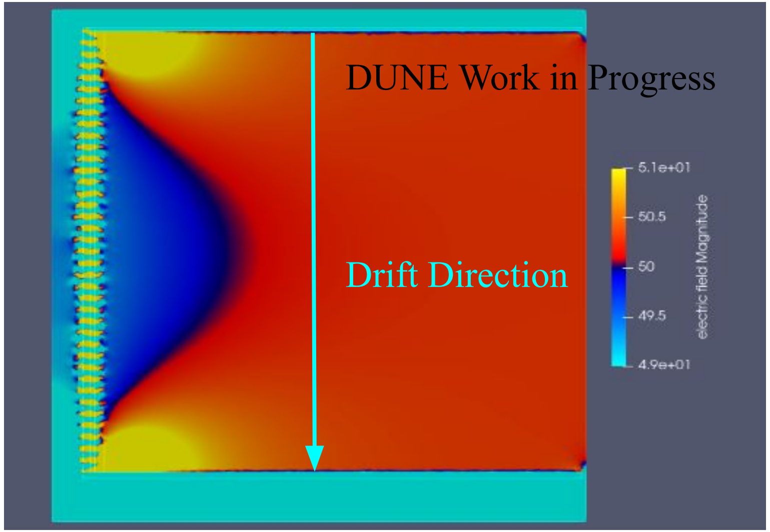


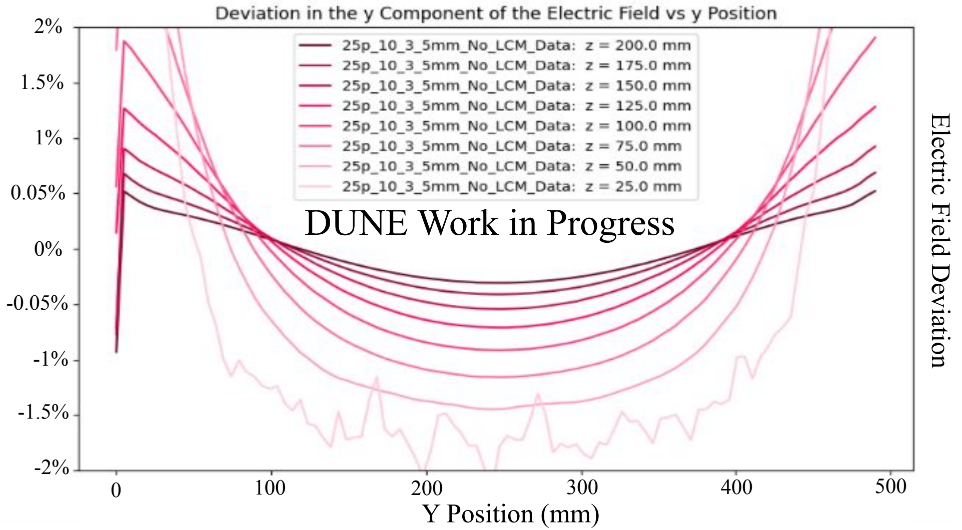


Recent Studies

Simulating the Traditional Field Cages

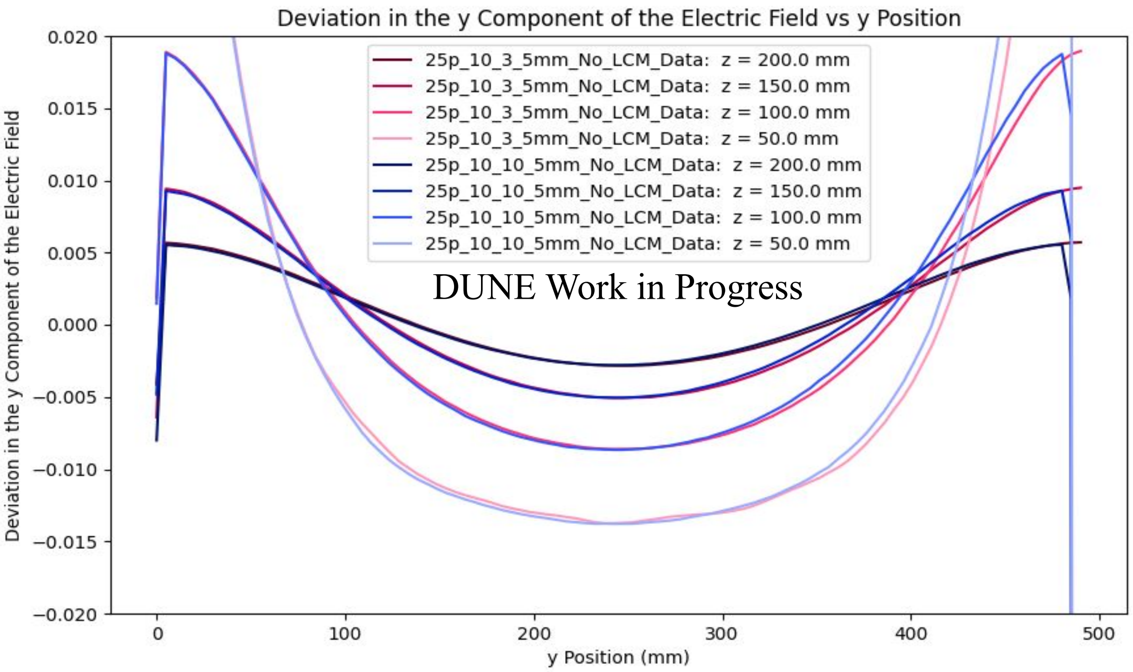
- Electric field magnitude calculations top down cross section (left), as well as line plots showing the deviation of the electric field vs position along the y-axis (right) were used in the analysis (both images for a 10-3 configuration)
- Deviations of more than 2% were seen when within 10 cm of the field cage wall





Changing the Strip Configuration (10-3 and 10-10)

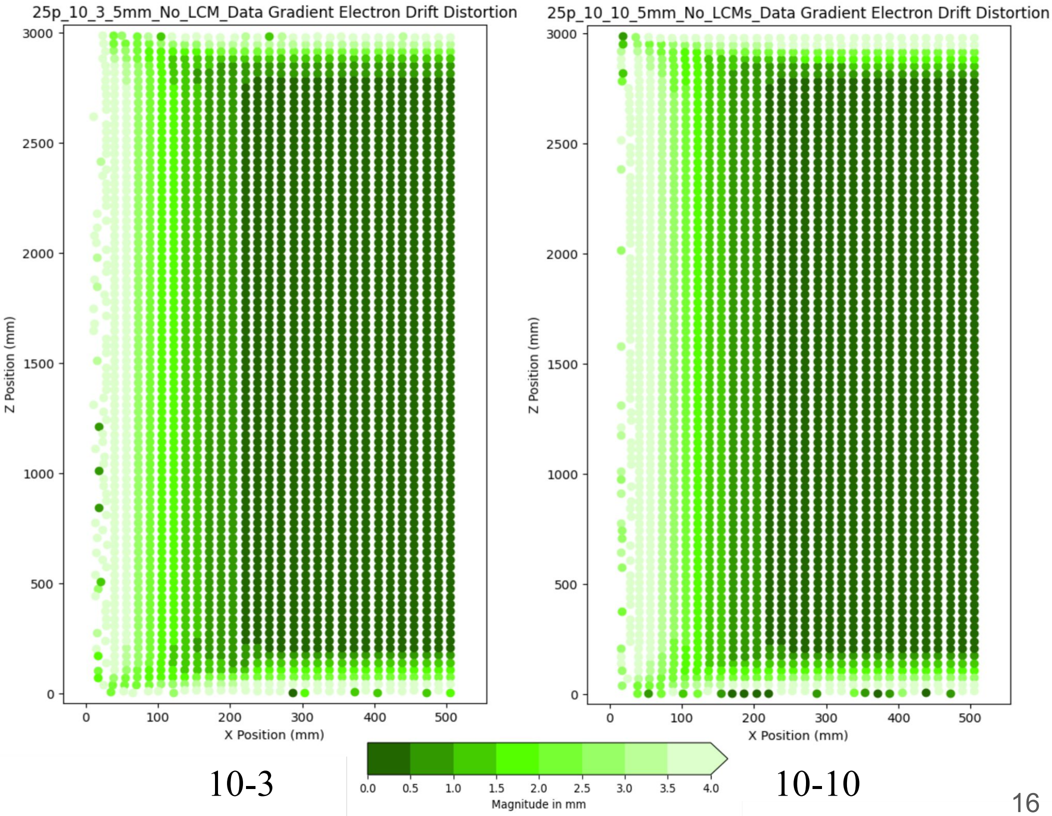
- 10-3 configuration plotted in red and the 10-10 configuration is plotted in blue
- The electric field uniformity is not affected by this increase in strip spacing



Changing the Strip Configuration (10-3 and 10-10)

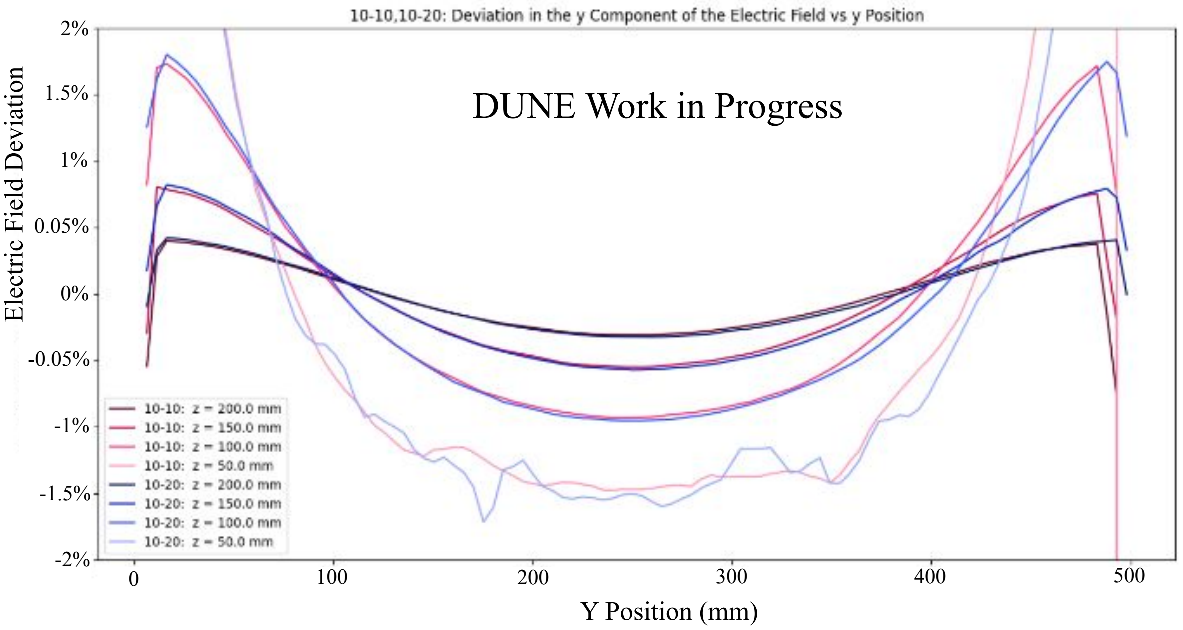
DUNE Work in Progress

- The drift path distortions also remain similar
- A uniform grid of electrons were placed at the cathode and drifted to the anode
- The color represents the magnitude of displacement in the x and z directions in mm



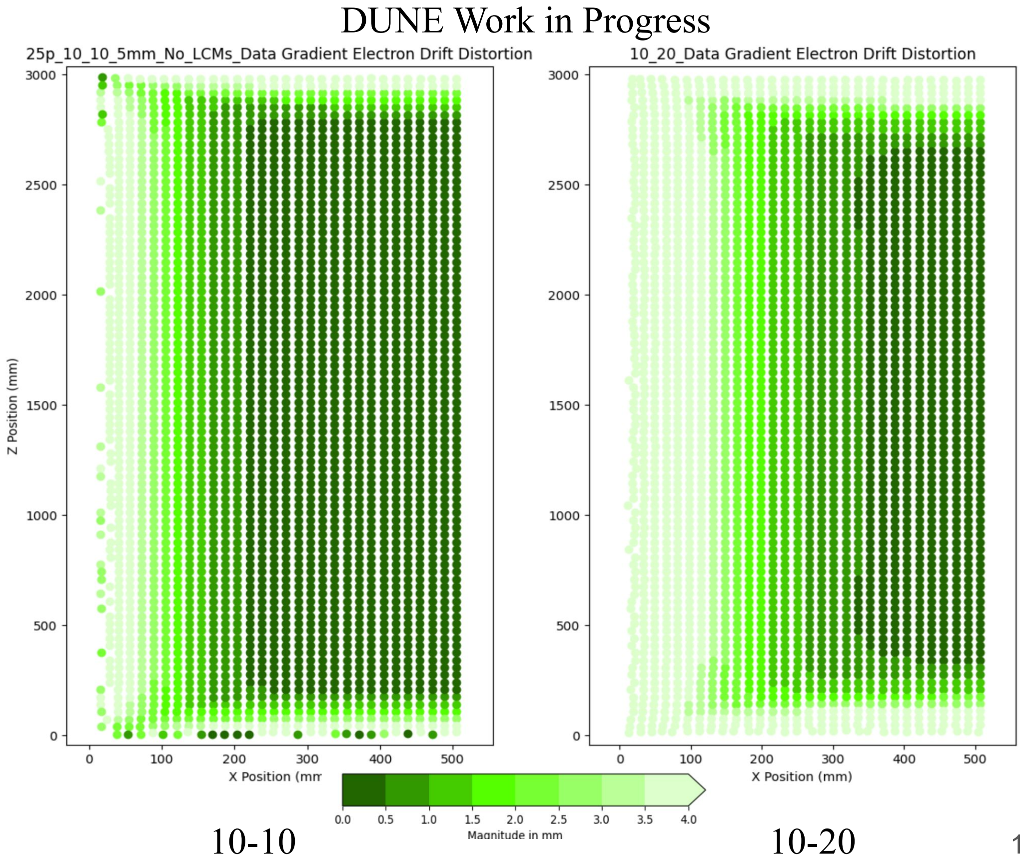
Changing the Strip Configuration (10-10 and 10-20)

- 10-10 configuration plotted in red and the 10-20 configuration is plotted in blue
- The electric field uniformity is also not affected by the increase in strip spacing



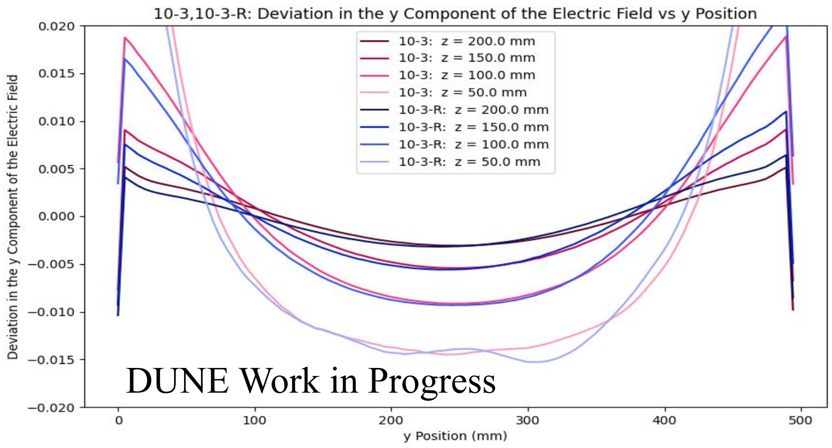
Changing the Strip Configuration (10-10 and 10-20)

- The drift path distortions significantly increase when changing the strip width from 10 mm to 20 mm

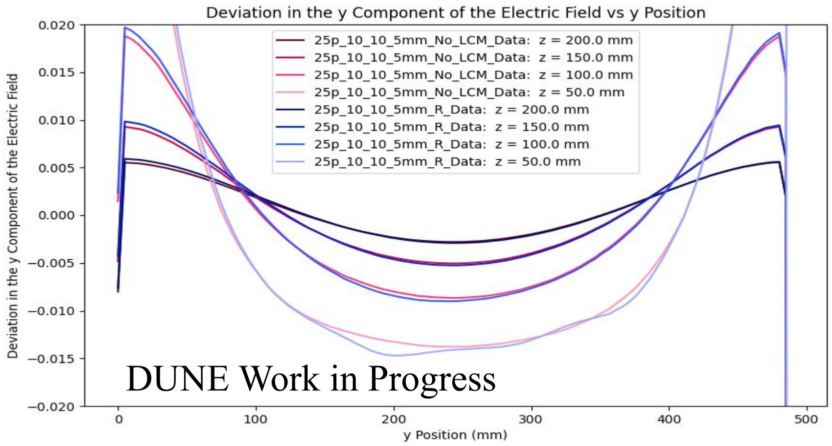


Non-Ideal Resistors

- Resistor values were randomly chosen from a Gaussian distribution
- The potential for each resistor was found using Kirchhoff Loops
- Still a static solution
- Little difference in electric field non-uniformities with a 1% tolerance on the resistor values



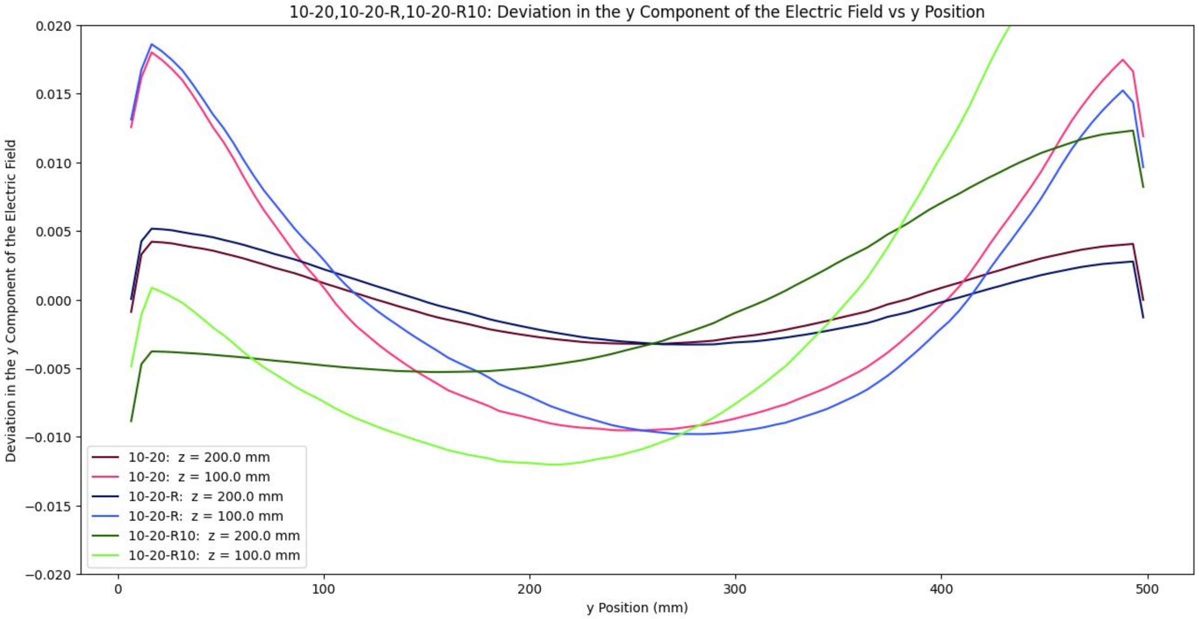
10-3



10-10

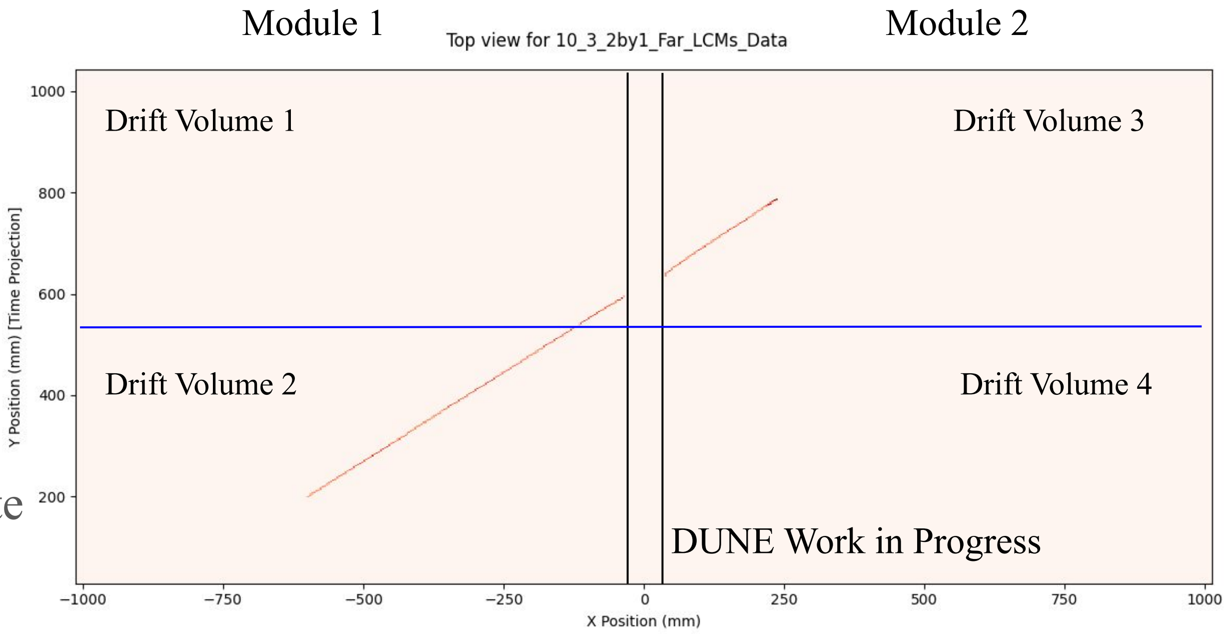
Non-Ideal Resistors Cont.

- Same setup as before but one resistor value was set to 110% the nominal value (green)
- As a result, there is large asymmetry in the uniformity across the drift length



Multiple Modules and Muon Track Simulations

- Two TPC modules side by side (using the 10-3 configuration)
- Simulated track for a 266 MeV muon Ref. [3] (left)
- The vertical axis is a time projection
- Black vertical lines indicate the innermost edge of the light collection system
- Blue line represents the cathode



Summary

- The electric field cage is used to drift ionization electrons to the pixel readout
- A small strip width/spacing produced the most uniform electric field and the least drift distortions
- Resistors should have resistance values that fall below a 1% tolerance to maintain electric field uniformity
- Muon tracks that cross between TPCs will have gaps in the track data, but should not experience significant curvature

References

[1] P. Przewlocki, “ICARUS — THE LIQUID ARGON DETECTOR FOR NEUTRINO PHYSICS.”, Acta Physica Polonica B 37, 1245 (2006).

[2] W. Walkowiak, “Drift velocity of free electrons in liquid argon.”, Nucl. Instrum. Meth. A 449, 288 (2000).

[3] P. A. Zyla et al., [Particle Data Group Collaboration], “Review of Particle Physics.”, Progress of Theoretical and Experimental Physics 2020 (2020), https://academic.oup.com/ptep/article-pdf/2020/8/083C01/34673722/ptaa104.pdf, 083C01.

[4] Y. Li et al., “Measurement of longitudinal electron diffusion in liquid argon.”, Nuclear Instruments and Methods in Physics Research Section A: Accelerators, Spectrometers, Detectors and Associated Equipment 816, 160 (2016).

[5] [DUNE Collaboration Collaboration], “Physics analysis of data from a novel pixelreadout liquid argon 4 Time Projection Chamber.”, Instruments.

DUNE

Thank you!

Undergraduate Research Opportunities Program

UNIVERSITY OF COLORADO **BOULDER**

UNDERGRADUATE ENRICHMENT PROGRAMS

U.S. DEPARTMENT OF

ENERGY

Office of Science

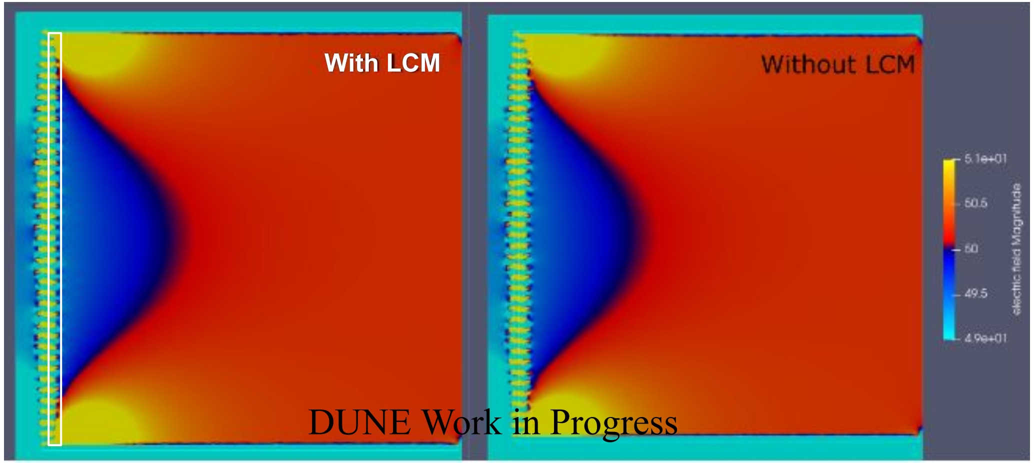
Supplemental

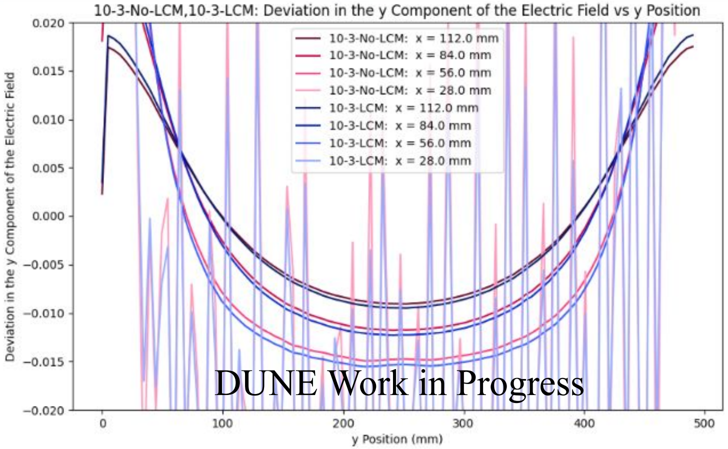
Light Modules Setup

- Light collection modules were also added to the simulation
- These were simplified down to 10 mm sheets of plastic placed 5 mm from the sides of the field cage perpendicular to the anode and cathode Ref. [5]
  - The ArCLight system uses EJ280 which has polyvinyl toluene (PVT) as its base polymer
  - The LCM system uses polyvinyl chloride (PVC)
- The dielectric constants for these plastics are PVT = 2.55 and PVC = 3.4
- Since PVC has a higher dielectric constant, the effects would be greater, and thus it was primarily used in comparisons with and without the light collection systems

Light Modules Results

- Side by side ParaView plots of the electric field for the 10-3 configuration with and without the LCM panels, outlined in white, using the 25% geometries (left)
- Electric field deviation vs y axis with (blue) and without (red) the panels, the color gradient corresponds to staring at the black line (x = 112 mm) and moving in the direction of the arrow (right)

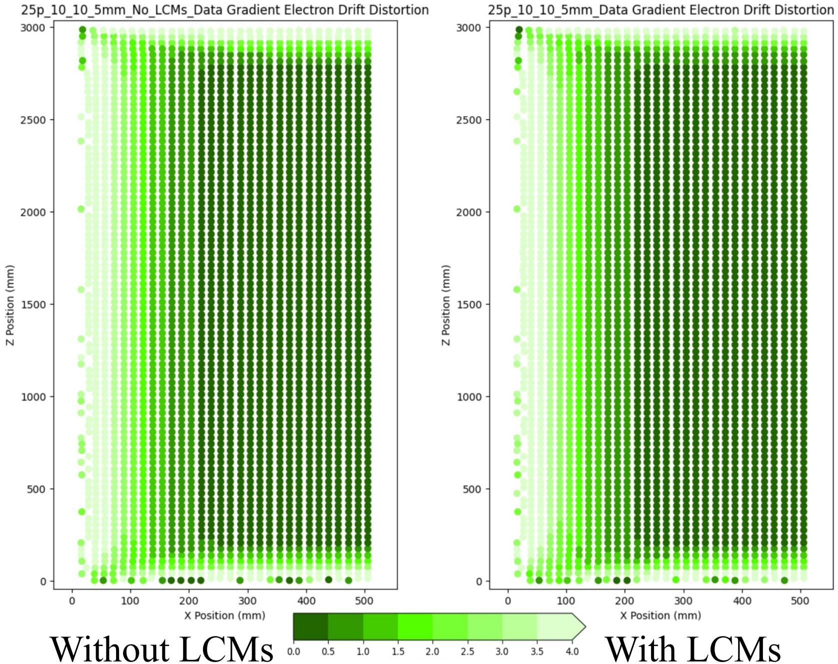




Light Modules Results

- There was no difference in the uniformity of the electric field or drift distortions with and without the light collection panels
- Caveats:
    - This is a statics solution (i.e. no charge build up, or active currents)
    - The light collection panels were “removed” from the model by setting the dielectric constant equal to the liquid argon

DUNE Work in Progress



Without LCMs With LCMs