A 3D field response simulation for pixelated charge readout in LArTPC

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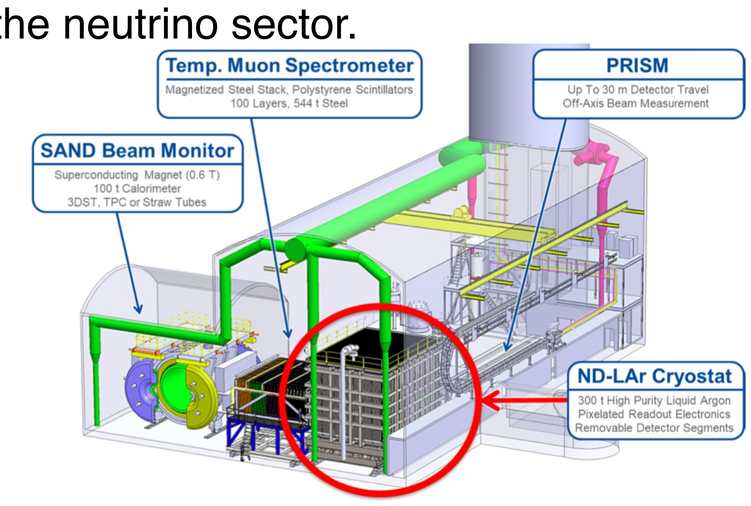
DUNE and ND-LAr

1

The Deep Underground Neutrino Experiment (DUNE) is a next-generation long-baseline neutrino oscillation experiment with a broad physics program centered on measuring Charge Parity Violation in the neutrino sector.

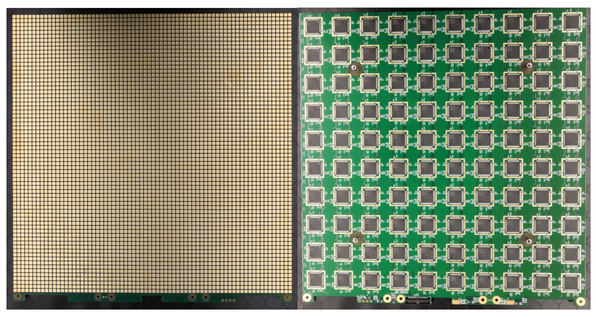


A critical component of the DUNE Near Detector (ND) is a Liquid Argon Time Projection Chamber (LArTPC), called ND-LAr. [1]

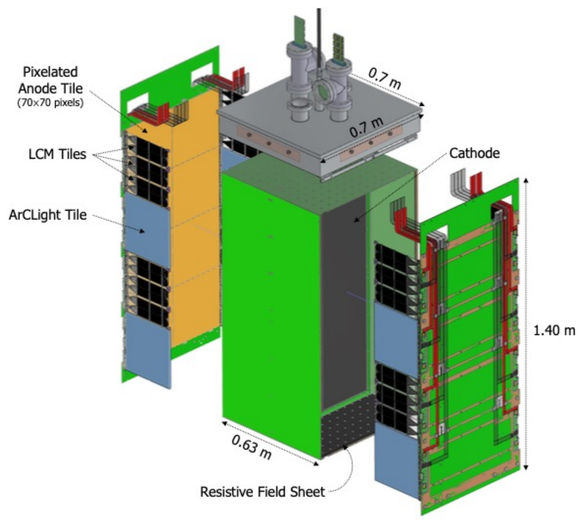
Pixelated Charge Readout for LArTPC

2

With the expected high rate of neutrino interactions at the ND, ND-LAr will consist of 7 x 5 LArTPC modules, each with a pixelated readout based on custom ASIC called LArPix, which provides native 3D readout to alleviate the pile-up issue.



- **Both sides of a 1000 cm² LArPix tile with 4900 pixels (left) and 100 ASICs (right).**
- **Pixels are self-triggering with configurable charge thresholds of *O*(100) keV. [2]**

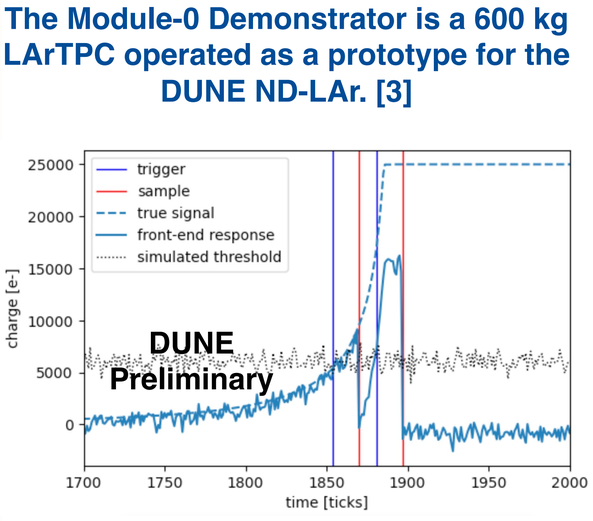


The Module-0 Demonstrator is a 600 kg LArTPC operated as a prototype for the DUNE ND-LAr. [3]

In the cosmic-ray run, evidence of LArPix retriggering has been noticed.

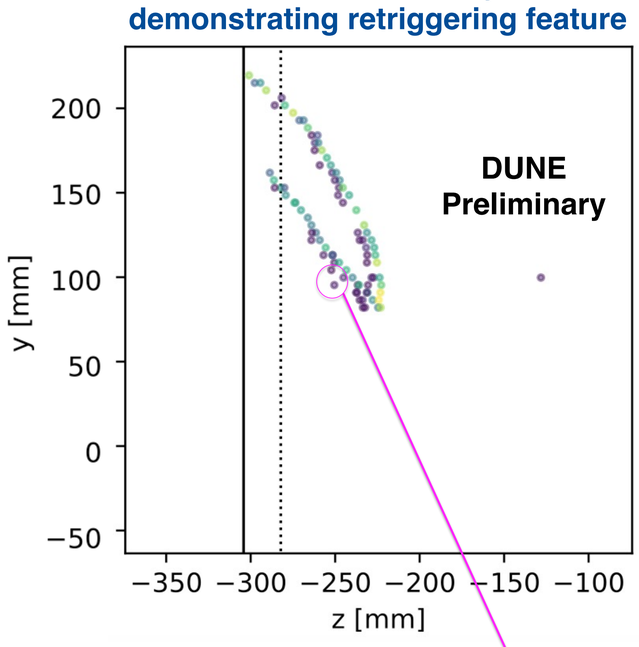
This retriggering feature could result in:

- Partial charge collection
- Broadening reconstructed track



Example of a pixel readout retriggered by induced signal when an ionization cloud reaches the anode. [4]

Candidate Muon-decay event demonstrating retriggering feature



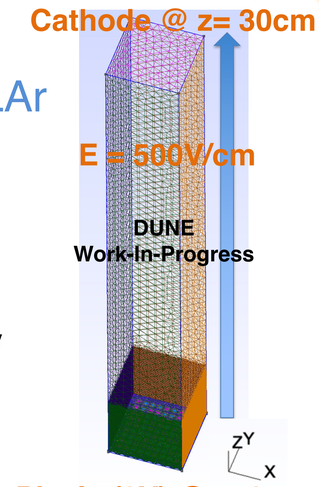
Along the drift direction (z), hits of a smaller amplitude (purple) can be seen preceding the track. [4]

3D Field Response Simulation

3

A new 3D field response simulation for ND-LAr has been developed using Finite Element Method (FEM):

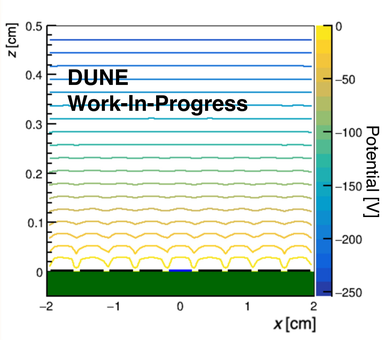
- Gmsh [5]: Mesh geometry into small elements
- Elmer [6]: Calculate Potential in a detector geometry
- Garfield++ [7]: Detailed simulation of signals in detectors



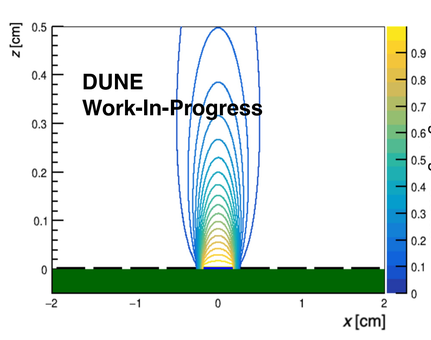
Induced current is calculated based on Shockley-Ramo formalism:

$$I_i = q * \bar{v}_d * \bar{\nabla} W_i$$

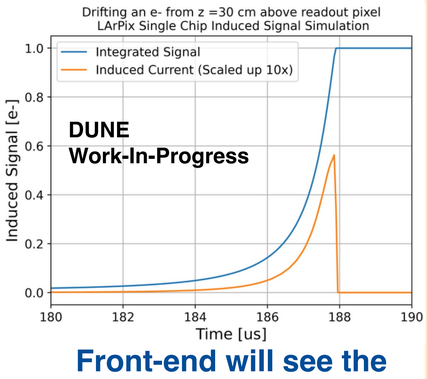
- $\bar{v}_d$ – Drift velocity that depends on electric potential
- W_i – Weighting Potential by fixing readout pixel to unit potential and other conductors to 0 V



Electric potential near the pixel plane



Weighting potential near a readout pixel



Front-end will see the integrated signal

Mitigation of Induced Signal Retriggering

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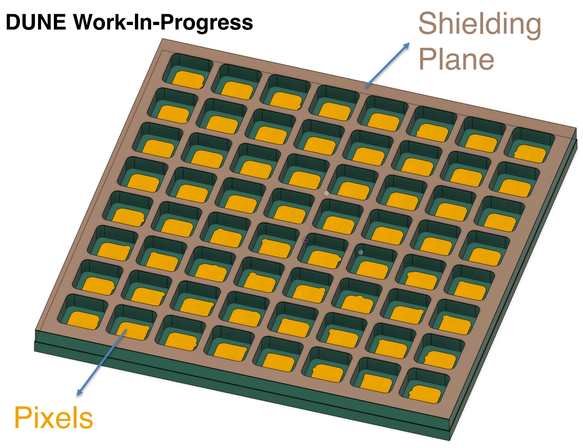
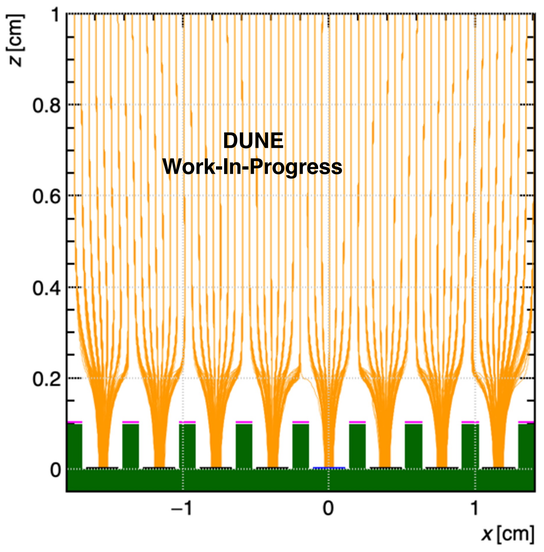
One possible solution is to install a shielding plane upstream of LArPix.

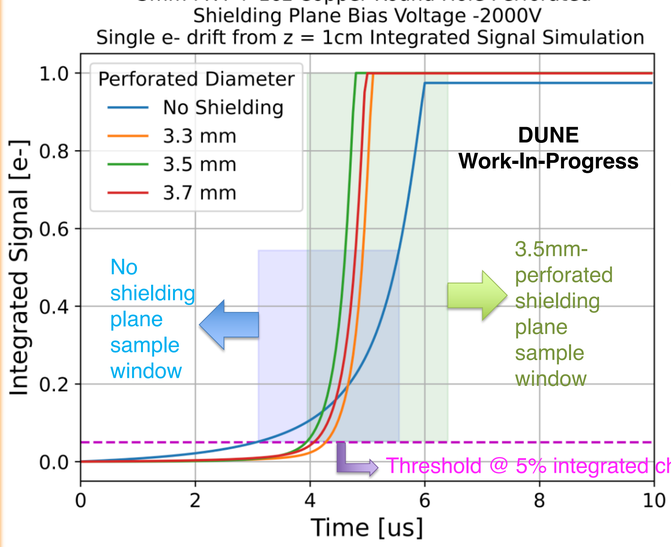
Example design of a LArPix shielding plane



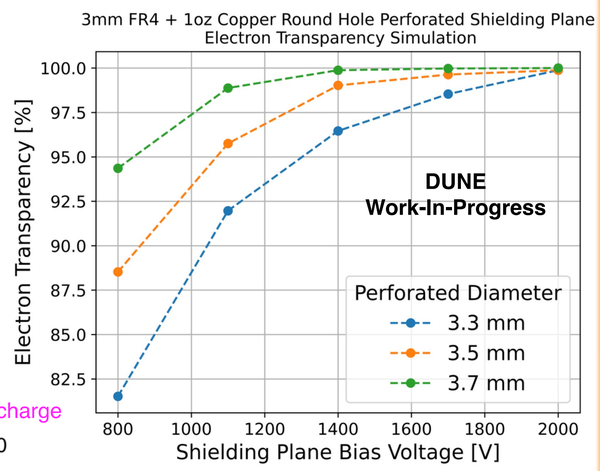
With a shielding plane, induced signal has faster rising edge.



Electron Transparency: drifting ~5000 electrons above anode; counting how many arriving at pixels.



Charge can then be fully collected within single trigger sample window (~2.5 us).



Optimize shielding plane geometry and bias voltage to enable full electron transparency.

[1] DUNE Collaboration. "Deep underground neutrino experiment (DUNE) near detector conceptual design report." Instruments 5, no. 4 (2021): 31.
[2] D.A. Dwyer et al. “LArPix: demonstration of low-power 3D pixelated charge readout for liquid argon time projection chambers.” *JINST* 13, no. 10 (2018): P10007.
[3] DUNE Collaboration. "Performance of a modular ton-scale pixel-readout liquid argon Time Projection Chamber." arXiv preprint arXiv:2403.03212 (2024).
[4] Peter Madigan. “Measurement of Muon Capture on Argon with a pixelated Liquid Argon Time Projection Chamber.” PhD thesis. UC Berkeley., (2023).
[5] C. Geuzaine and J.-F. Remacle, “Gmsh: a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities,” *International Journal for Numerical Methods in Engineering*, vol. 79, pp. 1309–1331, 2009.
[6] C. I. C. for Science, *Elmer: Open Source Finite Element Software for Multiphysical Problems, http://www.csc.fi/english/pages/elmer*.
[7] H. Schindler, R. Veenhof, *et al.*, *Garfield++*. http://garfieldpp.web.cern.ch/garfieldpp.