

1. Introduction & Motivation

- **2x2 and Full Scale Demonstrators:** prototypes of ND-LAr, the Liquid Argon Time Projection Chamber (LArTPC) used for the DUNE Near Detector
 - Innovative modular design with 3D pixelated charge readout and high-coverage light readout
 - Walls of each module provides electric field shaping
 - Efield non-uniformities still present → affects event reconstruction
 - **2x2:** 4 prototype modules built and operated at Univ. Bern, collected millions of cosmic rays
 - Modules then shipped to Fermilab, built in 2x2 array in the Neutrinos at the Main Injector (NuMI) Beam
 - **FSD:** Full-size ND-LAr module assembled & operated at Univ. Bern
- Samples of cosmic-ray muons used to study non-uniformities in efield for both Module 1 of 2x2 and FSD

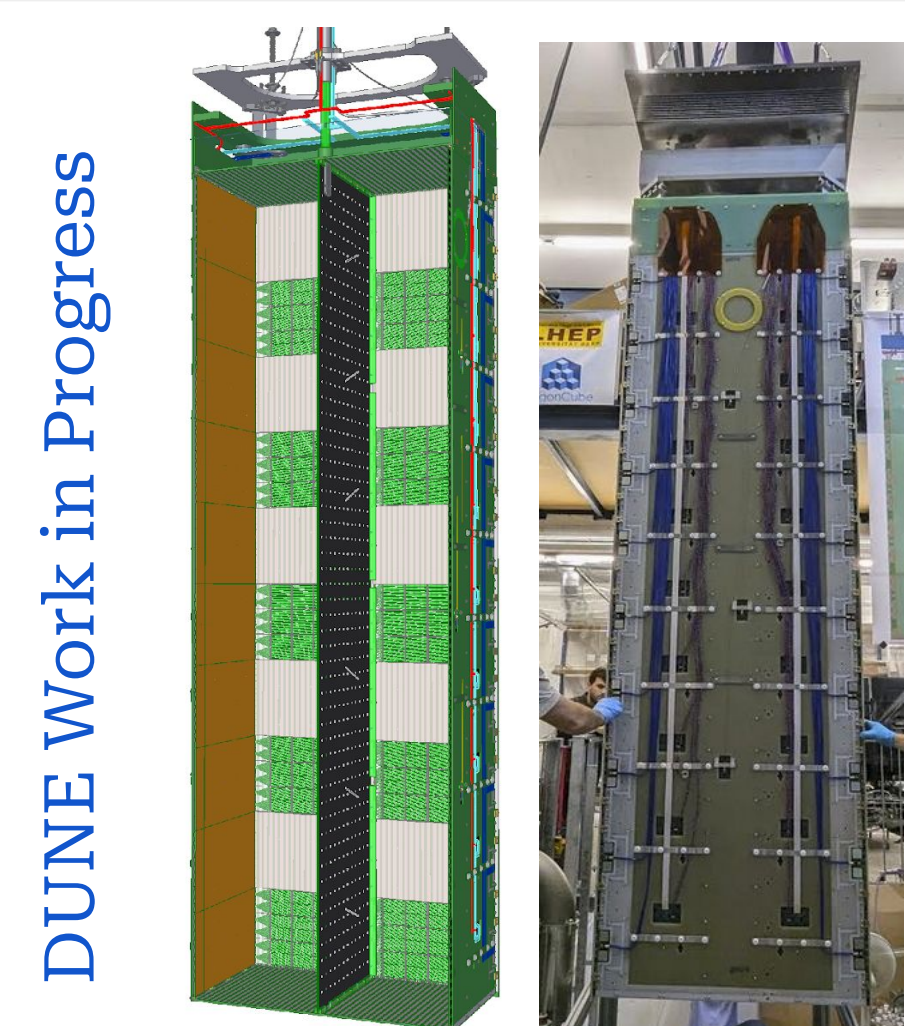
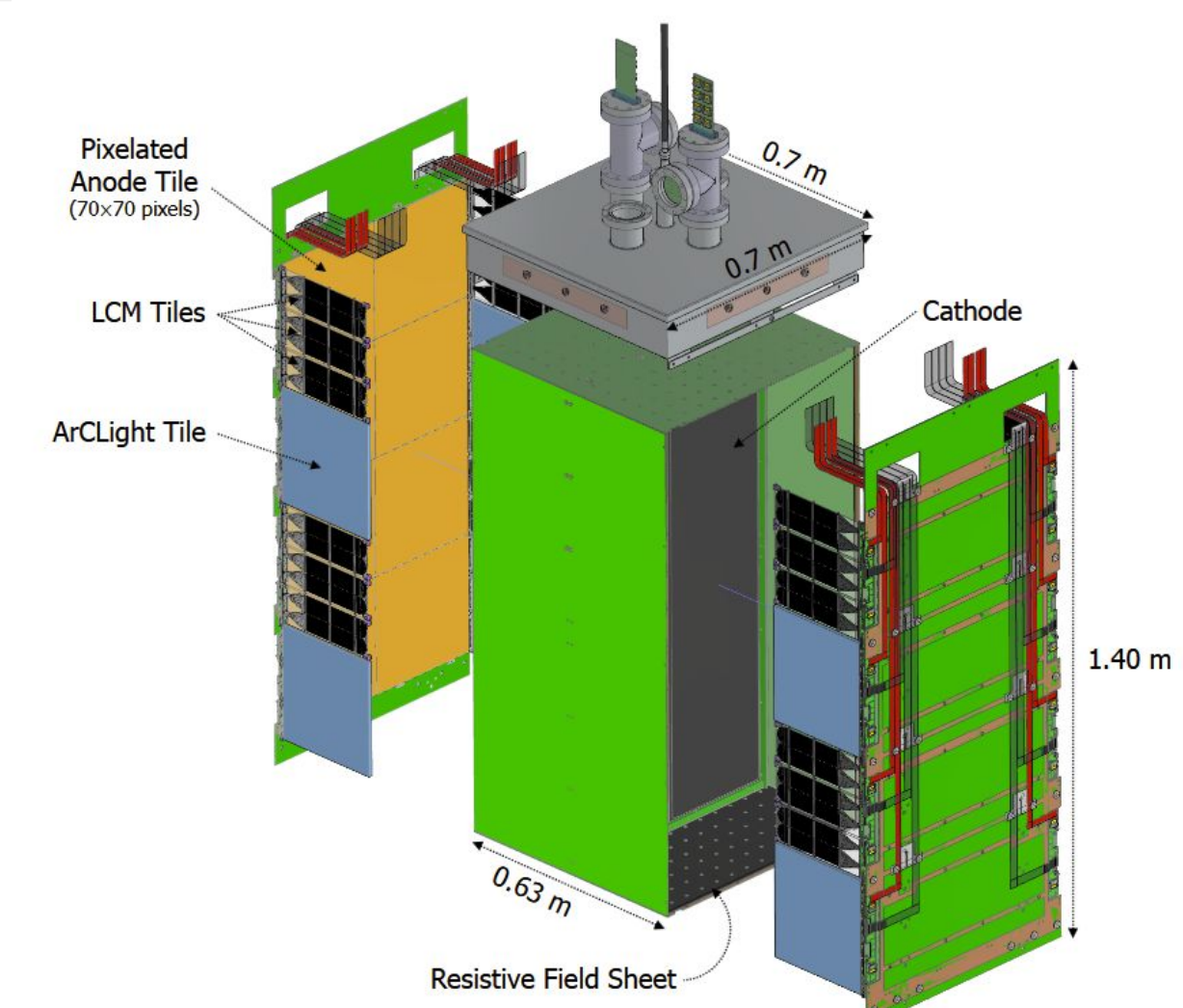


Fig 1: Schematic of a single 2 x 2 module. Image originally from Ref [1].

Fig 2: FSD interior schematic (left, image provided by Knut Skarpaas) and external field cage (right, provided by Roberto Acciarri)

2. Methodology & Procedure

Data Used:

- Cosmic-ray data collected over 12+ hours for both Module 1 and FSD
- **Module 1:** ~51,000 tracks, **FSD:** ~1 million tracks

Data Selection:

- Hits sorted into tracks; tracks selected if they 1) have start & endpoints within 2 cm of detector faces, 2) have a variance of ≥ 0.974 , and 3) are ≥ 55 cm long
 - Subset of selected tracks: if track endpoints located at anodes, track saved as anode-to-anode (A2A) crossing track.
 - At anodes, hit positions highly accurate & evaluation of nonuniformity elsewhere is possible

Data Analysis:

1. **Track Ends**
 - Distance of track ends from closest face calculated & recorded.
 - Only relevant for **detector perimeter distortions**
2. **Residuals/1D Differences**
 - Average 1D difference in x = drift direction, y = vertical height, and z = transverse direction calculated for each cubic section (voxel) of detector
 - 2.217 cm voxel for Module 1, 2.232 cm voxel for FSD
 - Difference is calculated between hit position & closest track point
 - Used to determine **bulk/internal distortions**

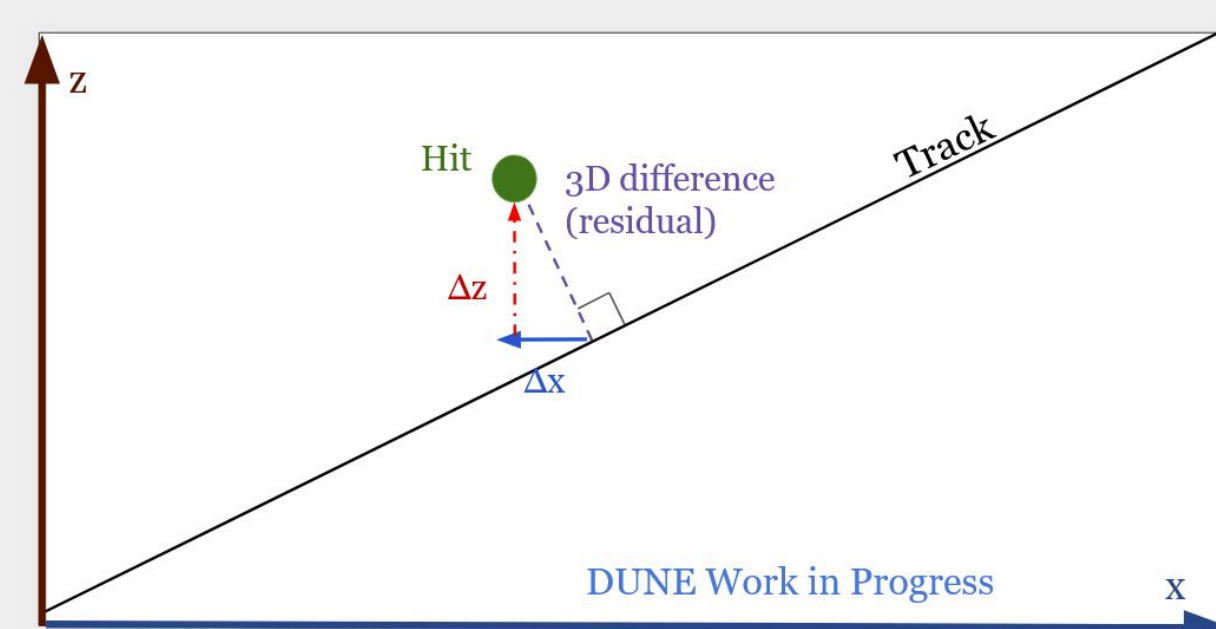
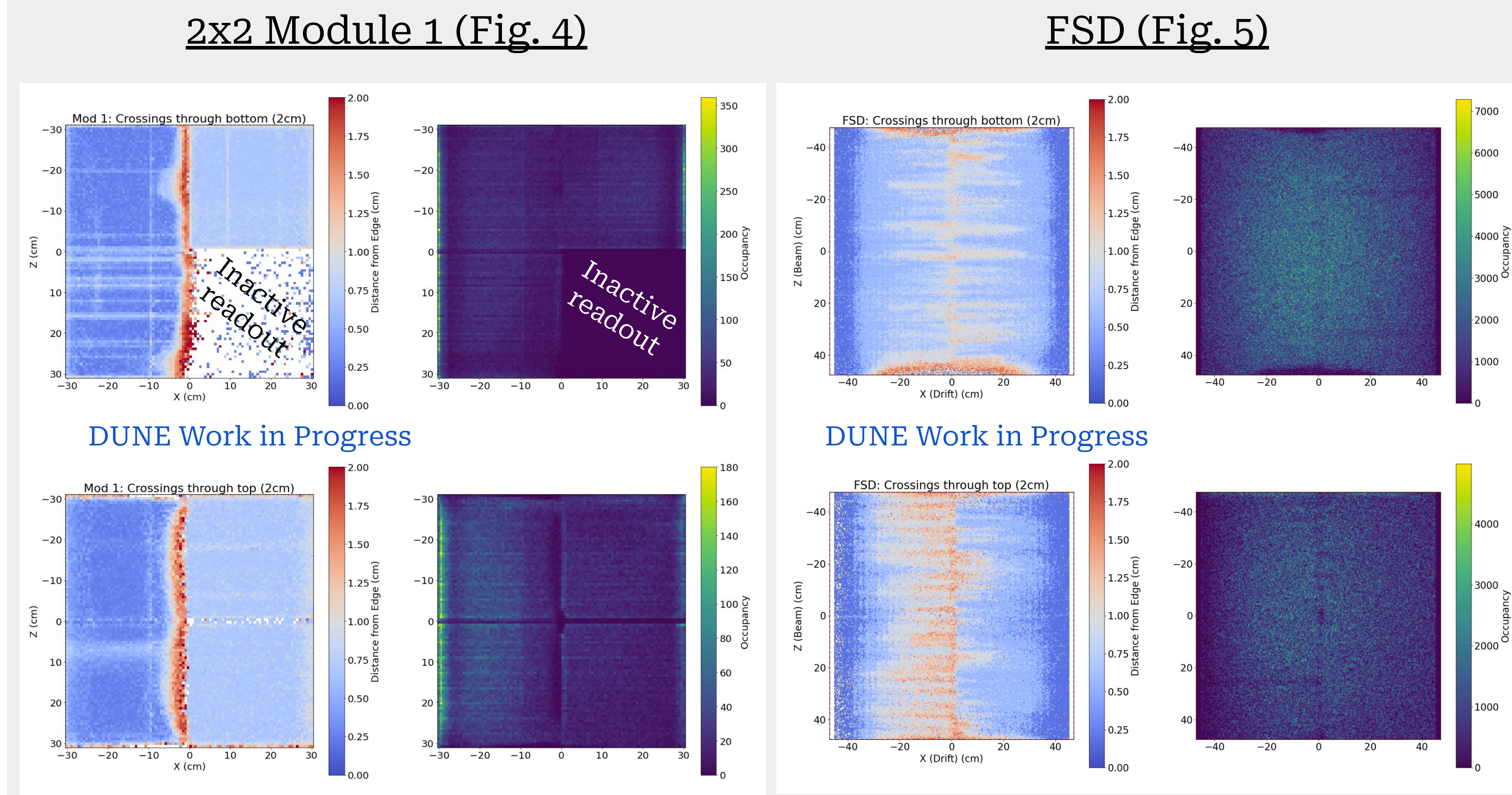


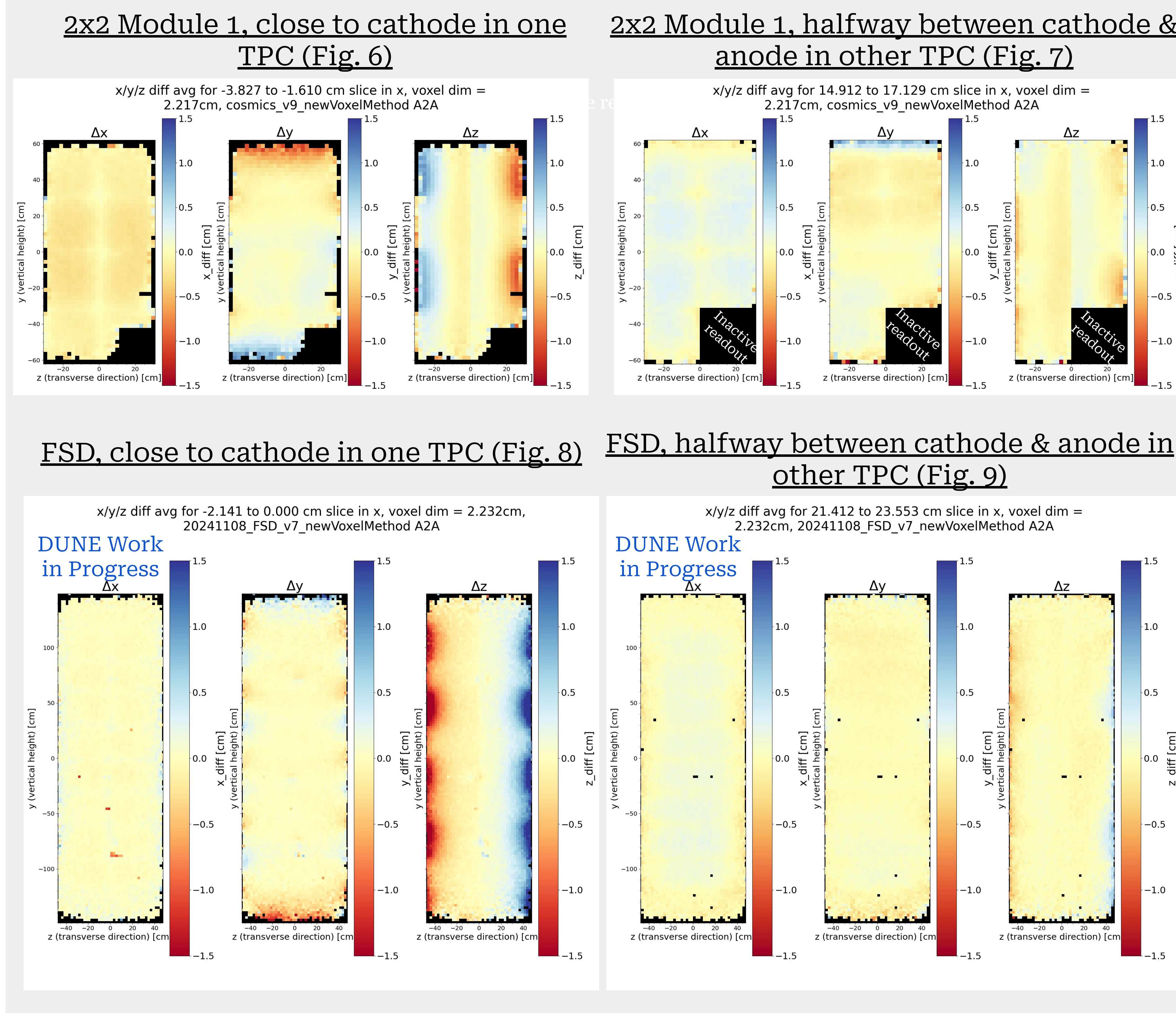
Fig 3: Example of a calculation of 3D distance, along with x and z diff values, for a hit belonging to a particular track. The purple dashed line = 3D distance between the hit & the straight line fit created by connecting the start and end point hits at the anodes, while the blue and red lines represent the x and z 1D distances.

3. Results

Track Endpoints



ΔX, ΔY, and ΔZ Average Value Distributions



4. Conclusions & Future Work

Track End Analysis:

- **Module 1:** Distortion of ~1.75 cm in distance from top/bottom faces of detector observed around cathode
- **FSD:** Distortion of ~1.25-1.75 cm in distance from top/bottom faces of detector observed around cathode, up to 1.0 cm distortion at other locations on the face

Detector Volume Analysis:

- **Module 1:**
 - Roughly constant distortion of ± 0.5 cm in ΔX throughout detector.
 - Maximum distortion of ± 1.0 cm in ΔY and ΔZ at cathode. Distortion lessens as distance from cathode increases.
- **FSD:**
 - Minimal distortion in ΔX throughout detector - negative distortion in one TPC, positive distortion in another - due to drift velocity mismatch.
 - Maximum distortion of ± 1.5 cm in ΔY and ΔZ at cathode. Distortion lessens as distance from cathode increases.
- Overall, clear improvement from Module 1 to FSD due to redesign of cathode connections
 - Distortion in Mod1 & FSD minimal (~1 cm) compared to other LArTPCs (~10-20 cm)

Further Work:

- Further detailed examination of regions of high non-uniformity
- Once magnitude of non-uniformity regions confirmed, begin tool development for non-uniformity corrections, e.g. voxel-by-voxel distance correction mapping & simulation cross-comparison

5. References & Acknowledgements

[1] DUNE Collaboration, "Performance of a modular ton-scale pixel-readout liquid argon time projection chamber." *Instruments*, 2024, 1, 0; arXiv:2403.03212.

[2] Douglas, D. "Design and Calibration of the DUNE Liquid Argon Near Detector." Ph.D. Thesis, *Michigan State University*, 2022.

[3] DUNE Collaboration, "Deep Underground Neutrino Experiment (DUNE), Far Detector Technical Design Report, Volume II: DUNE Physics." arXiv:2002.03005

[4] Adamson et. al, "The NuMI Neutrino Beam." *Nuclear Instruments and Methods in Physics Research A: Accelerators, Spectrometers, Detectors and Associated Equipment*, Volume 806, 2016; arXiv:1507.06690

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