The 2x2 Demonstrator: Overview and Physics Goals with DUNE's First Neutrino Beam Data
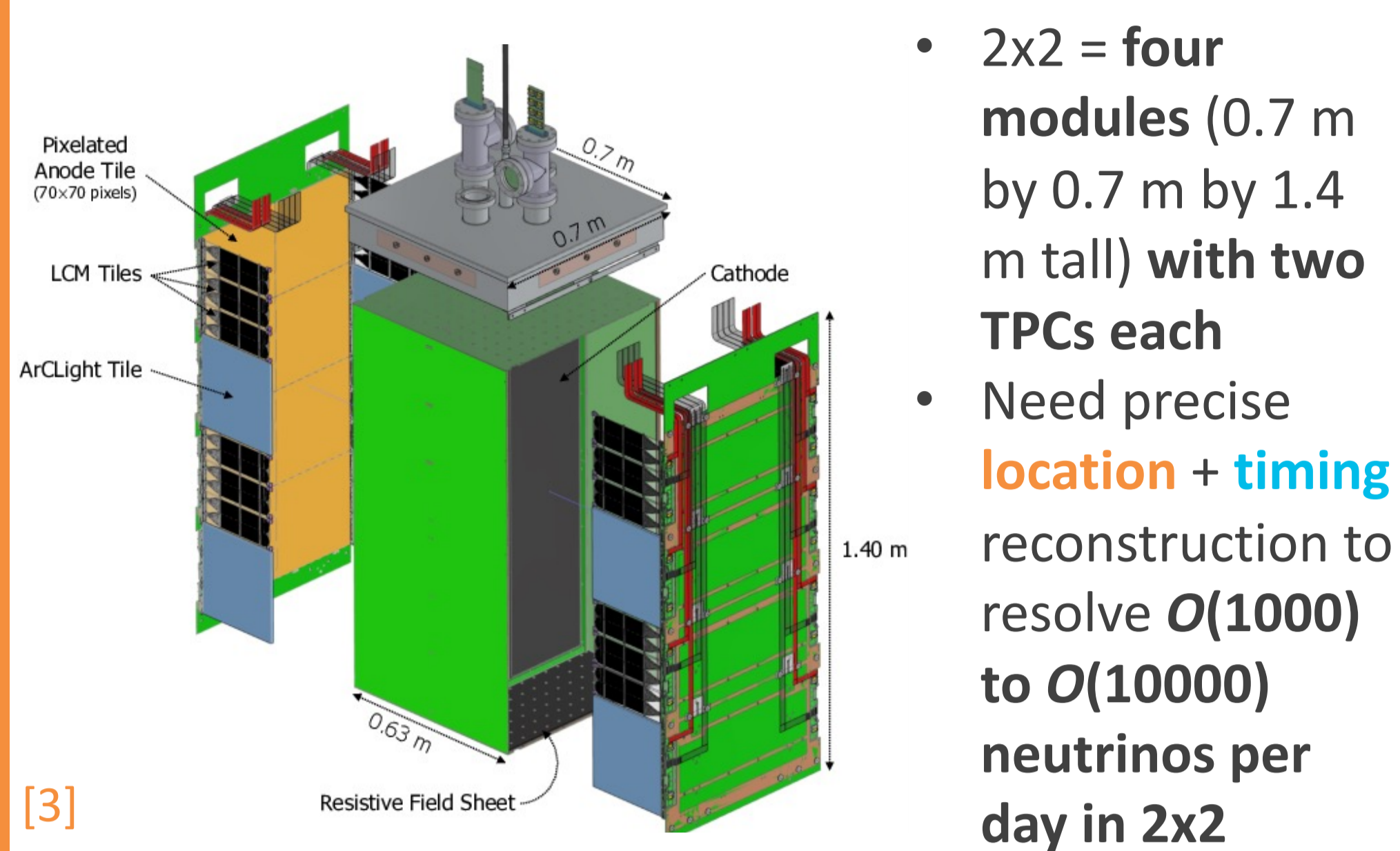
THE UNIVERSITY OF CHICAGO

Elise Hinkle[1] for the DUNE Collaboration
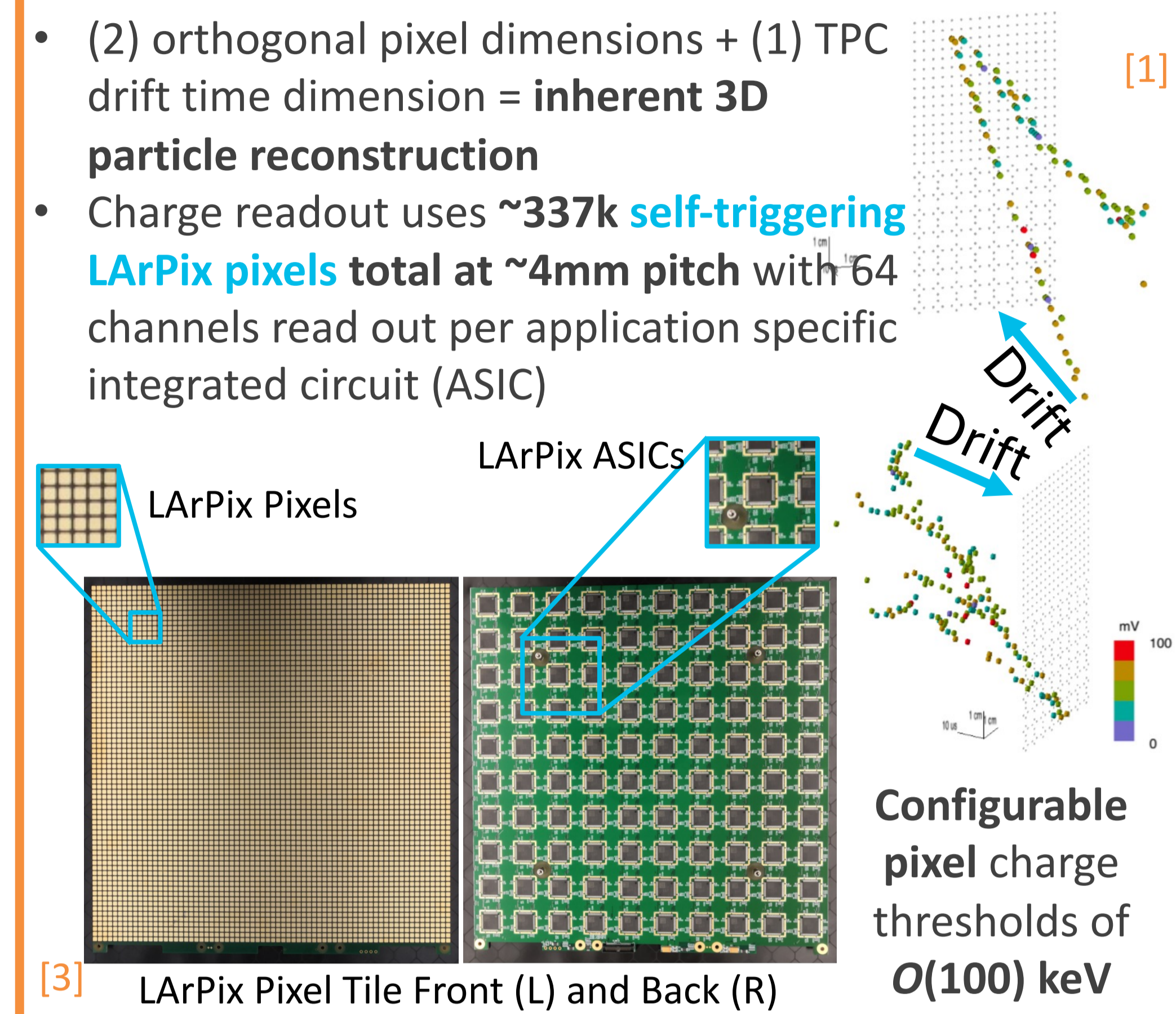[1]University of Chicago, Chicago, IL 60637, USA

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DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

Neutrino Pile-up Mitigation Using Optically Segmented LArTPC Modules

Pixelated Anode Tile (70x70 pixels) — 0.7 m — 0.7 m
LCM Tiles
ArCLight Tile
Cathode
1.40 m
0.63 m
Resistive Field Sheet
[3]

- 2x2 = **four modules** (0.7 m by 0.7 m by 1.4 m tall) with **two TPCs each**
- Need precise **location** + **timing** reconstruction to resolve $O(1000)$ to $O(10000)$ neutrinos per day in 2x2

Optically isolated modules = **improved event location**

- **25% optical coverage and $O(ns)$ timing resolution** with 2 SiPM-based light modules (ArCLight + LCM)

LArPix pixelated anode
Carbon-loaded Kapton field cage sheet
Cathode
LCM tile
ArCLight tile
[3]

Tracking Across Detectors Using MINERvA

DUNE:2x2 Work in Progress

MINERvA
2x2
MINERvA
SIMULATION

Tracks originating in the **2x2**
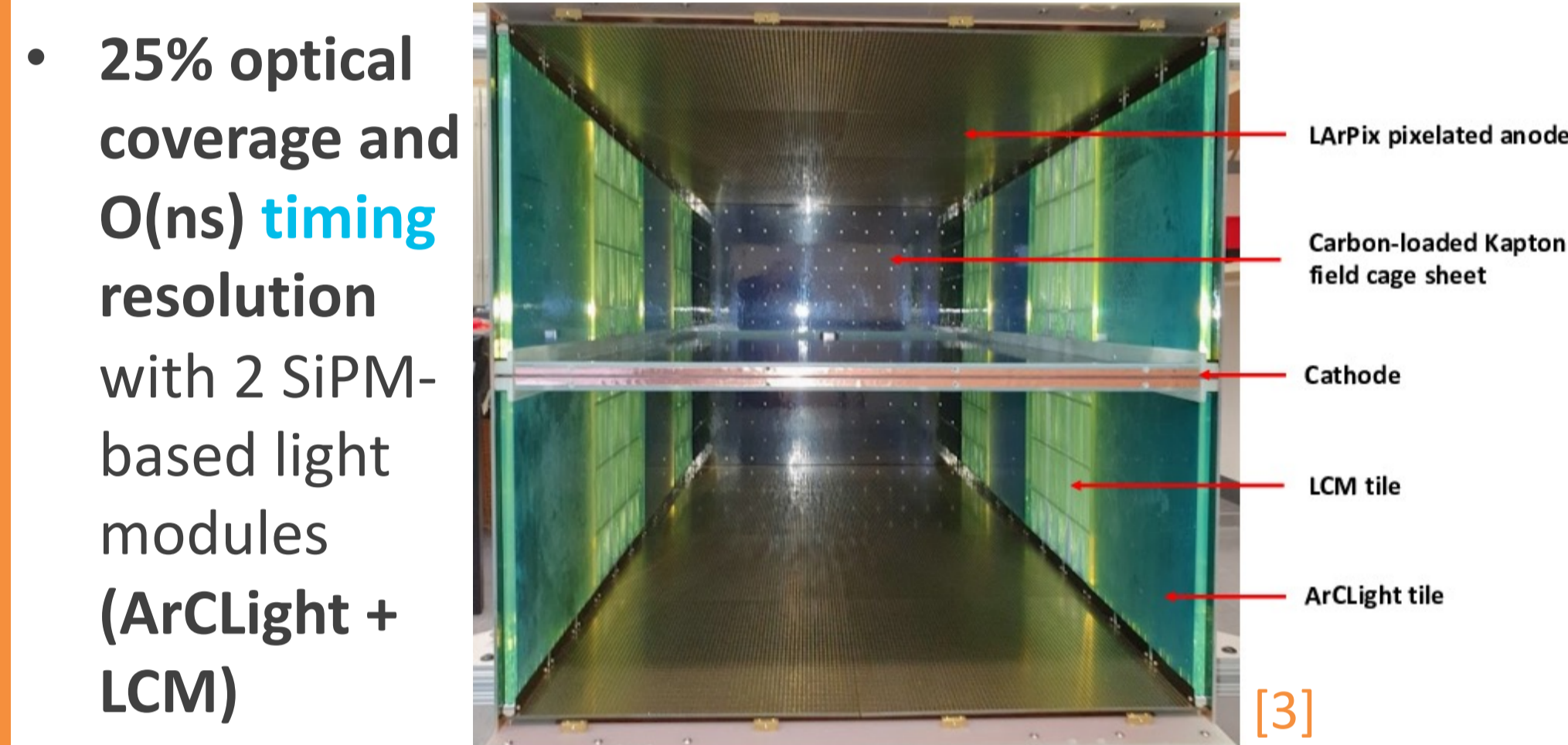
Follow tracks through **MINERvA**

What is the 2x2 Demonstrator?

- **Prototype** of the Liquid Argon Near Detector (ND-LAr) [2] for the Deep Underground Neutrino Experiment (**DUNE**)
- Based on **Liquid Argon Time Projection Chamber (LArTPC)** technology
- **Eliminates backgrounds by matching** between 2x2 and repurposed MINERvA tracking modules
- Currently filled with liquid argon and **expecting to see first (anti)neutrinos soon**

DUNE:2x2 Work in Progress

SIMULATION

Charge [10^3 e]

Light [ADC Counts]

Native 3D Reconstruction with Pixel-Based Charge Readout

- (2) orthogonal pixel dimensions + (1) TPC drift time dimension = **inherent 3D particle reconstruction**
- Charge readout uses **~337k self-triggering LArPix pixels** total at ~4mm pitch with 64 channels read out per application specific integrated circuit (ASIC)

LArPix Pixels
LArPix ASICs
Drift
Drift
[1]
[3] LArPix Pixel Tile Front (L) and Back (R)

Configurable pixel charge thresholds of $O(100)$ keV
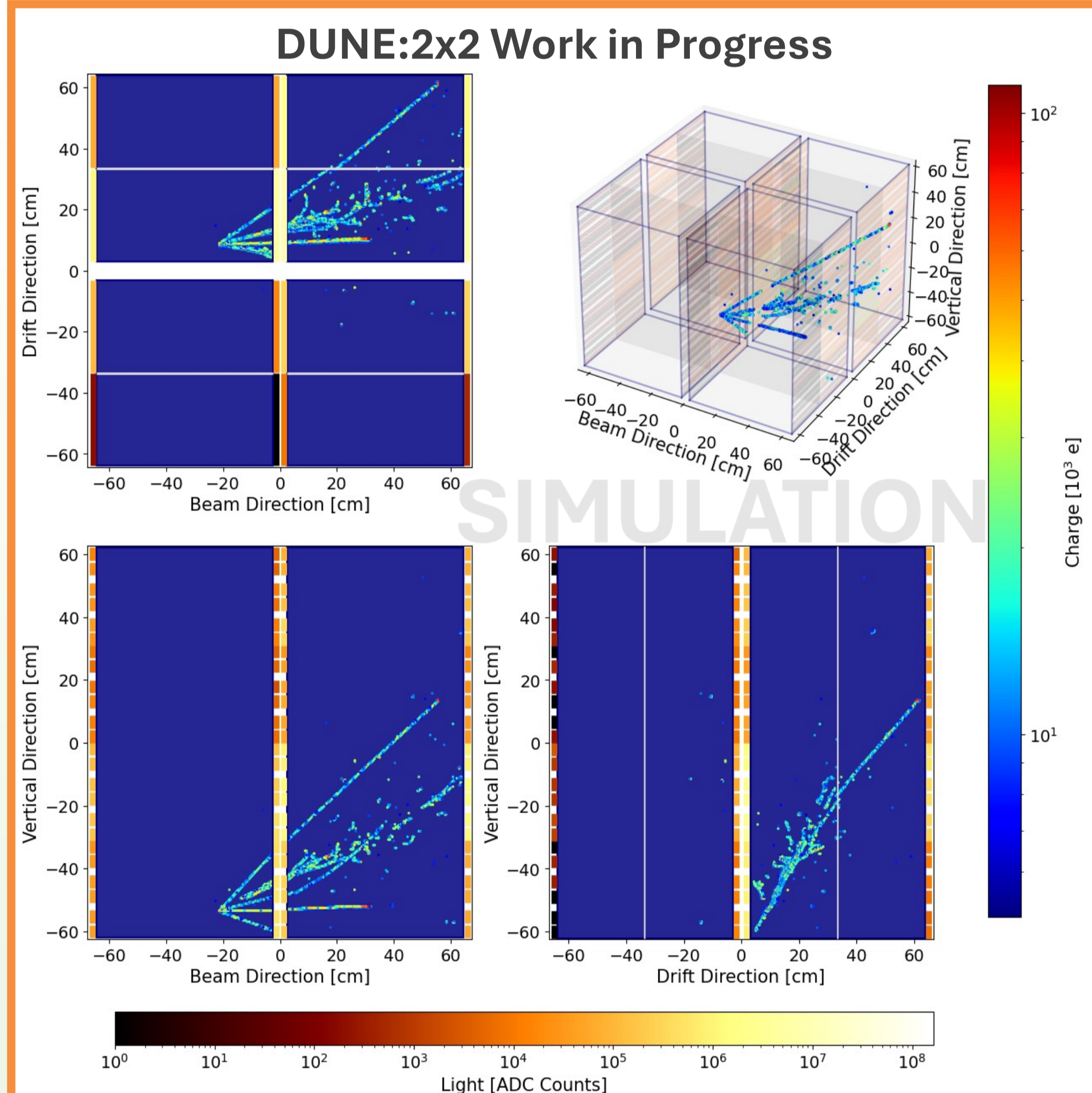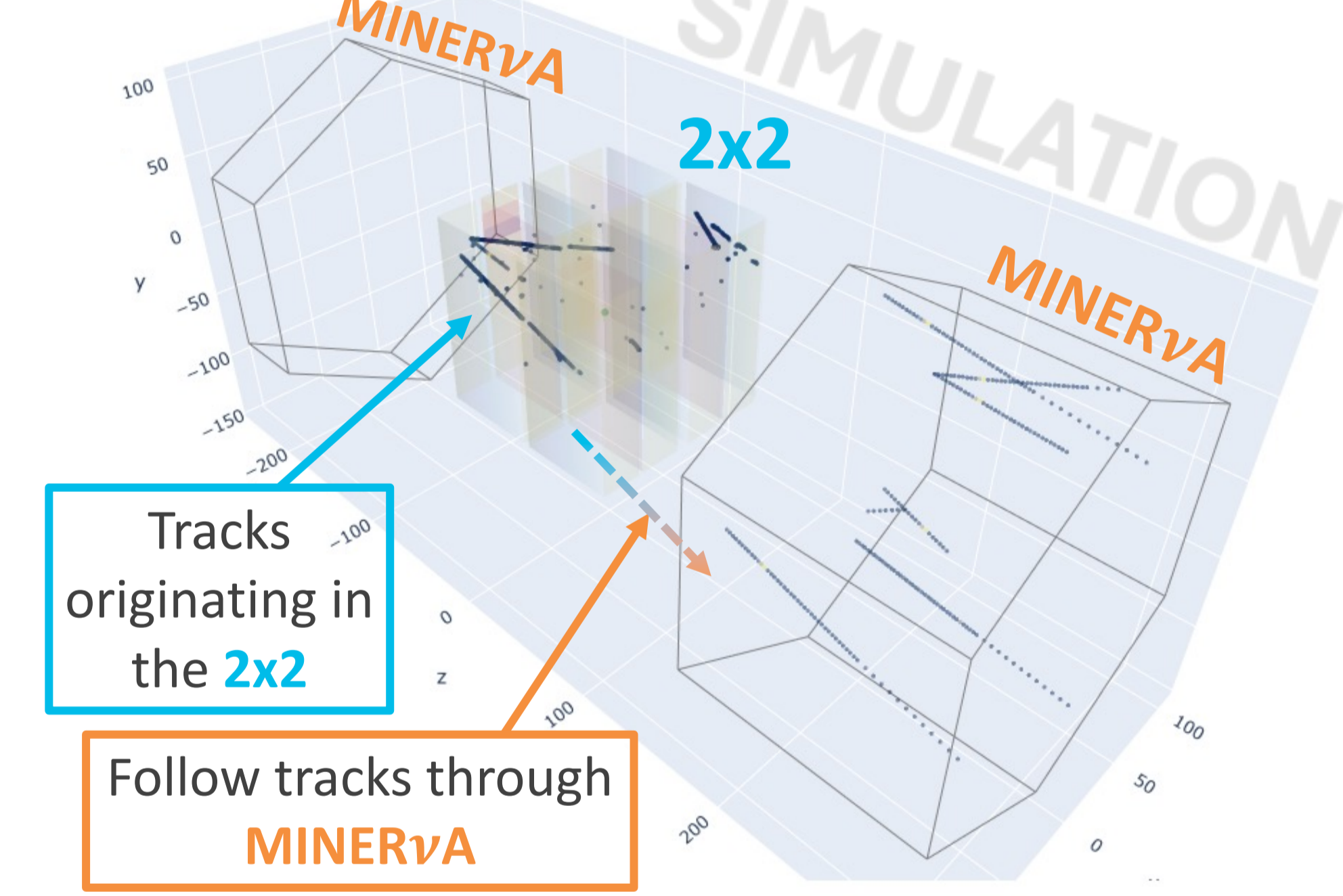
On-Axis Placement in the NuMI Beamline

- Installed in the **NuMI beam** at Fermilab
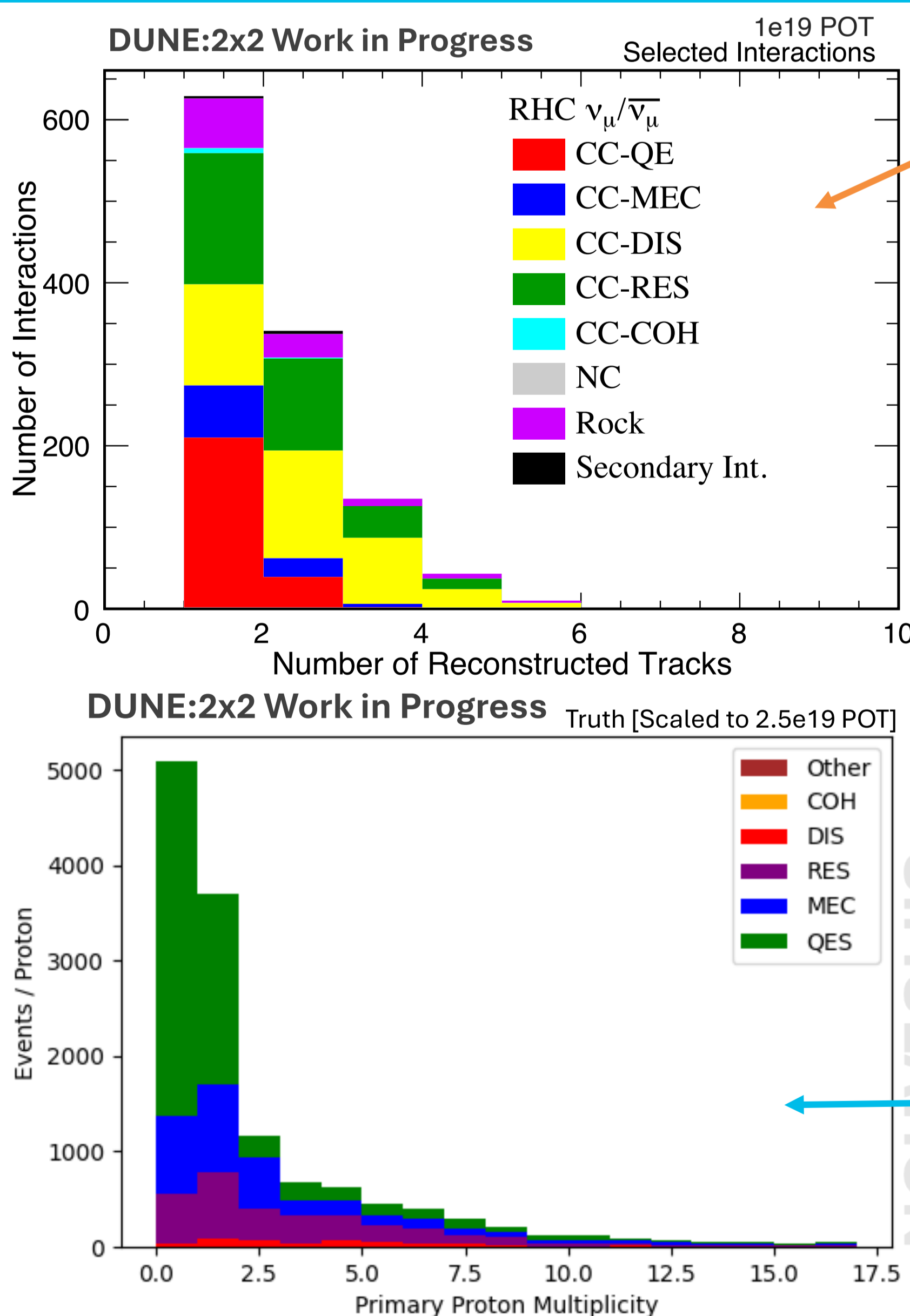- NuMI currently in **reverse horn current (RHC)** mode, so initial data mostly $\bar{\nu}$-Ar interactions

- DUNE-ND ν
- DUNE-ND $\bar{\nu}$
- 2x2 ν
- 2x2 $\bar{\nu}$
- BNB (SBND)

ν_μ/cm^2/GeV/year ($\times 10^{12}$) vs E_ν (GeV)

Complementary to SBND and ICARUS

Initial Physics Measurements: Track Multiplicity at the Neutrino Vertex and $\bar{\nu}_\mu$-Ar CC0π Cross Section

DUNE:2x2 Work in Progress — Selected Interactions — 1e19 POT

Number of Interactions vs Number of Reconstructed Tracks

RHC $\nu_\mu/\bar{\nu}_\mu$
- CC-QE
- CC-MEC
- CC-DIS
- CC-RES
- CC-COH
- NC
- Rock
- Secondary Int.

SIMULATION

DUNE:2x2 Work in Progress — Truth [Scaled to 2.5e19 POT]

Events / Proton vs Primary Proton Multiplicity
- Other
- COH
- DIS
- RES
- MEC
- QES

SIMULATION

1) Prepare a **generic neutrino selection**
2) Measure **track multiplicity** per interaction
3) Exercise tools like **particle identification** in other physics analyses such as **cross section measurements**

Measuring $\bar{\nu}$-Ar cross sections helps to **improve neutrino-nucleus interaction modeling** and **reduce systematic uncertainties** in oscillation measurements

- **First 2x2 cross section:** $\bar{\nu}_\mu$-Ar charged current (CC) interactions with zero final state pions (0π) over charge tracking threshold
- Look for one muon track originating in LAr and passing through downstream MINERvA planes = **simple topology**
- **Measure differential cross sections** of $\bar{\nu}_\mu$-Ar CC0π events with **protons** in the final state using:
  - **proton multiplicity**
  - leading proton momentum
  - opening angle between muon, leading proton

DUNE:2x2 Work in Progress

SIMULATION

Charge [10^3 e]

Light [ADC Counts]
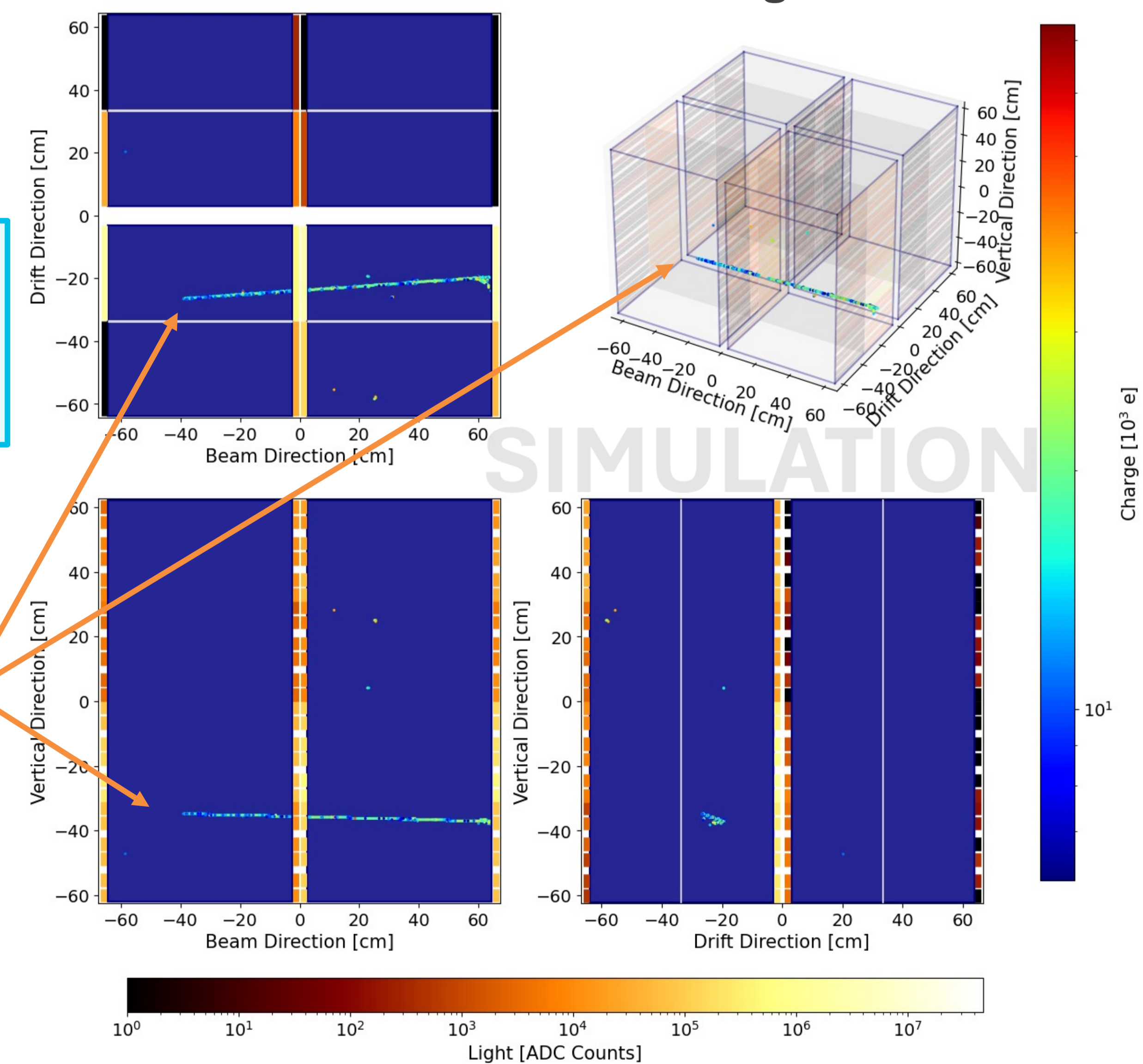
REFERENCES

[1] 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.
[2] DUNE Collaboration. "Deep underground neutrino experiment (DUNE) near detector conceptual design report." Instruments 5, no. 4 (2021): 31.
[3] DUNE Collaboration. "Performance of a modular ton-scale pixel-readout liquid argon Time Projection Chamber." arXiv preprint arXiv:2403.03212 (2024).