Design of a Shielding Plane for LArPix

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LIDINE 2025

Oct. 22, 2025

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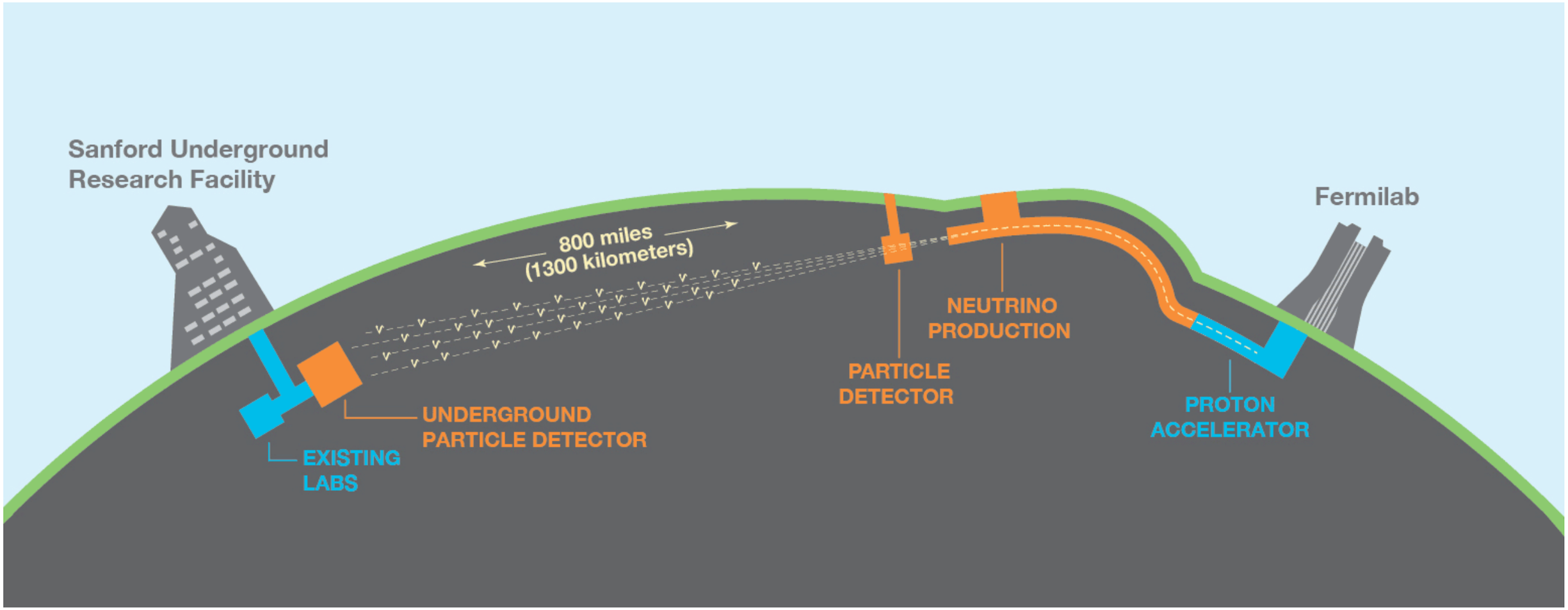
DUNE: Deep Underground Neutrino Experiment



Long-baseline neutrino oscillation experiment:

- 1.2 (upgradable to 2.4) MW neutrino beam will be produced at Fermilab
- Neutrino travels nearly 1300 km to the Far Detectors (FD) at the Sanford Underground Research Facility (SURF)
- Measured by a suite of Near Detectors (ND) about 0.5 km from the production target

A broad physics program centered on:

- Measuring CP violation in the neutrino sector
- Determining the neutrino mass ordering
- Precise measurements of the neutrino mixing angles

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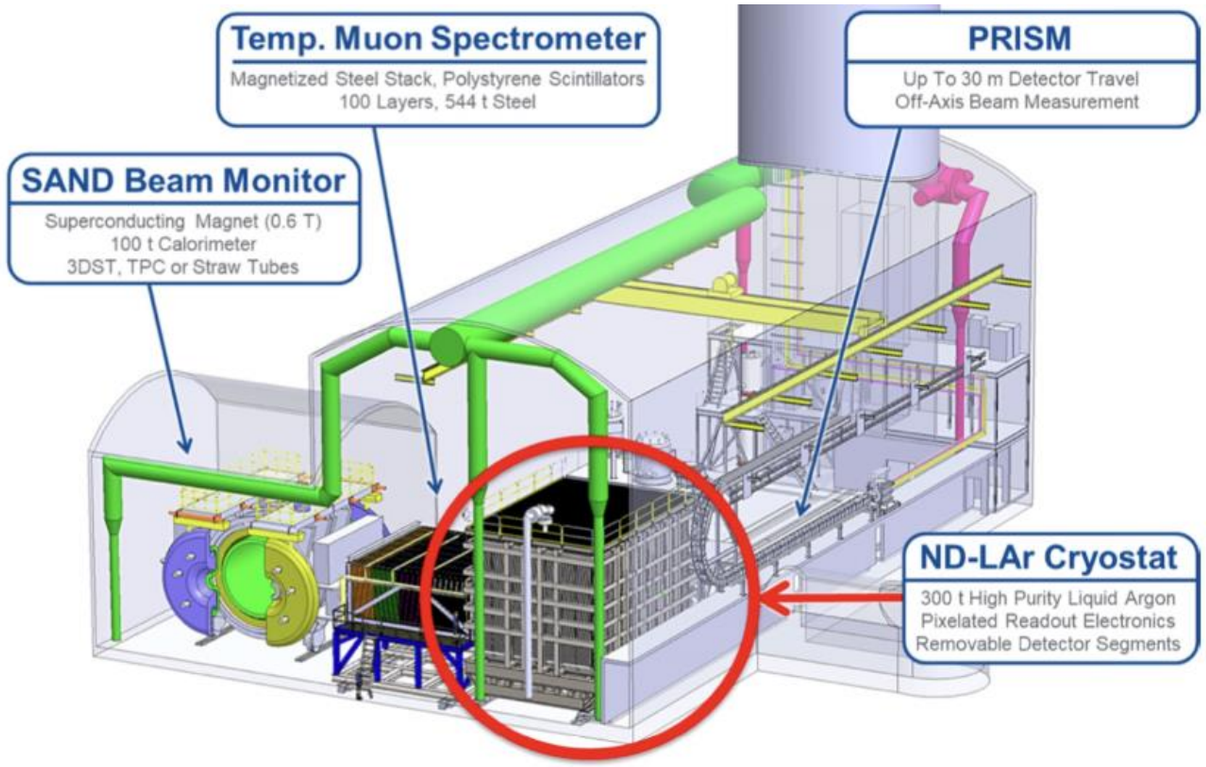
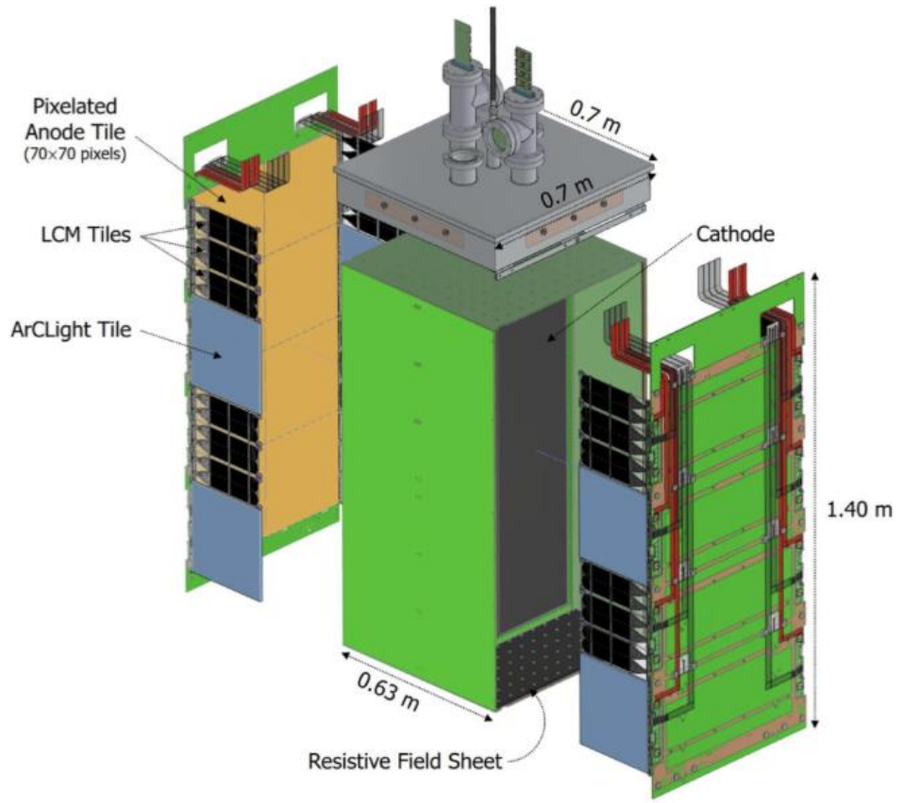
ND-LAr / 2x2 Demonstrator





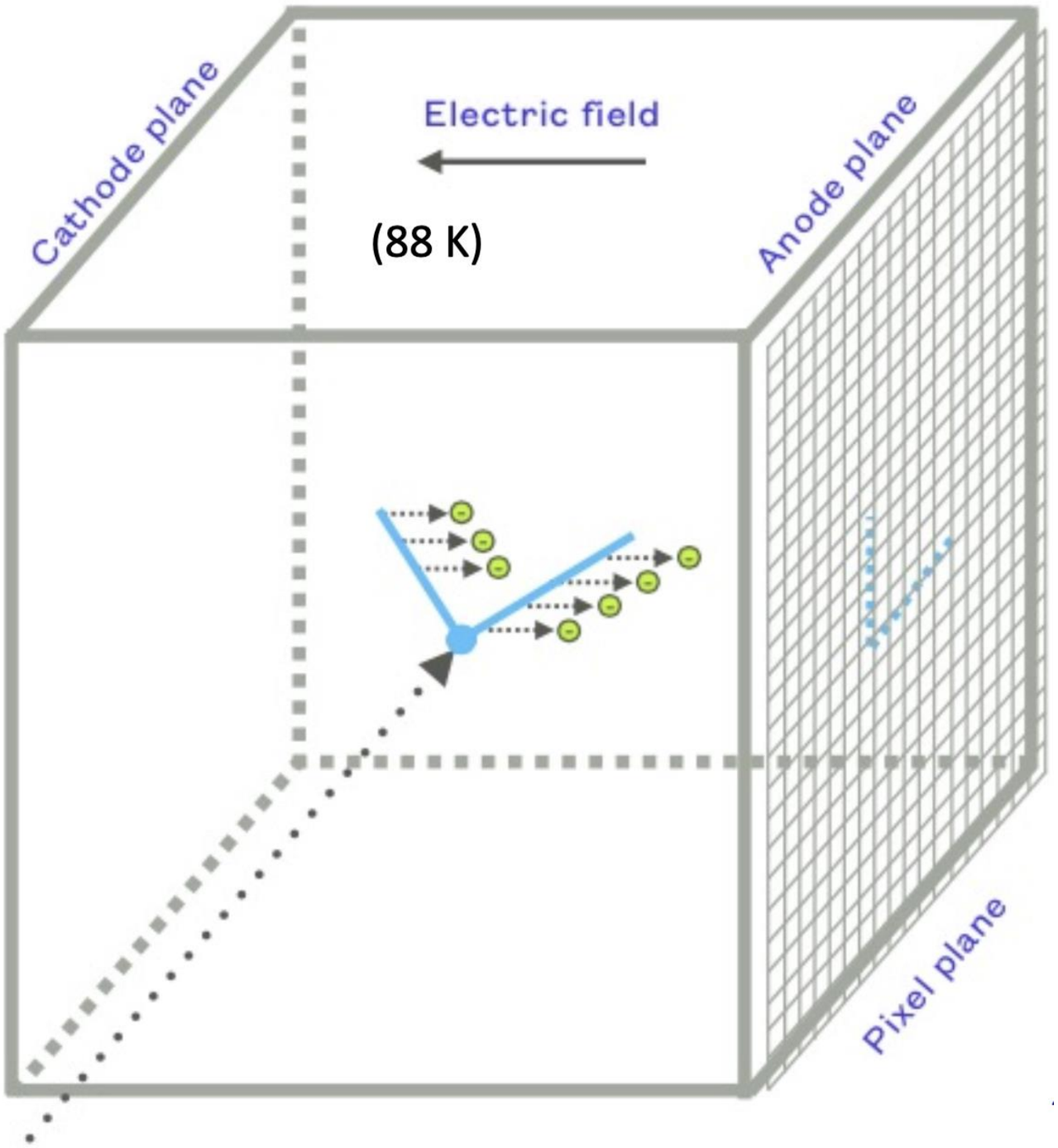
Features of ND-LAr:

- Pixel-based readout and optically separated modules to handle the high event rate and track multiplicity in the ND hall
- Light readout for measuring scintillation light
- Composed of 7 x 5 modules, 1m x 1m x 3m (L x W x H), all placed in a single movable cryostat
    - Two TPCs per module

2x2 Demonstrator:

- Scaled-down ND-LAr Modules
    - 0.6m x 0.6m x 1.2m active volume per module
- Total active mass ~2.4 tonnes
- First neutrino run in July 2024 [2509.07012]
- 1.5e19 POT (>30,000 antineutrino events)

LArTPC Signal Production



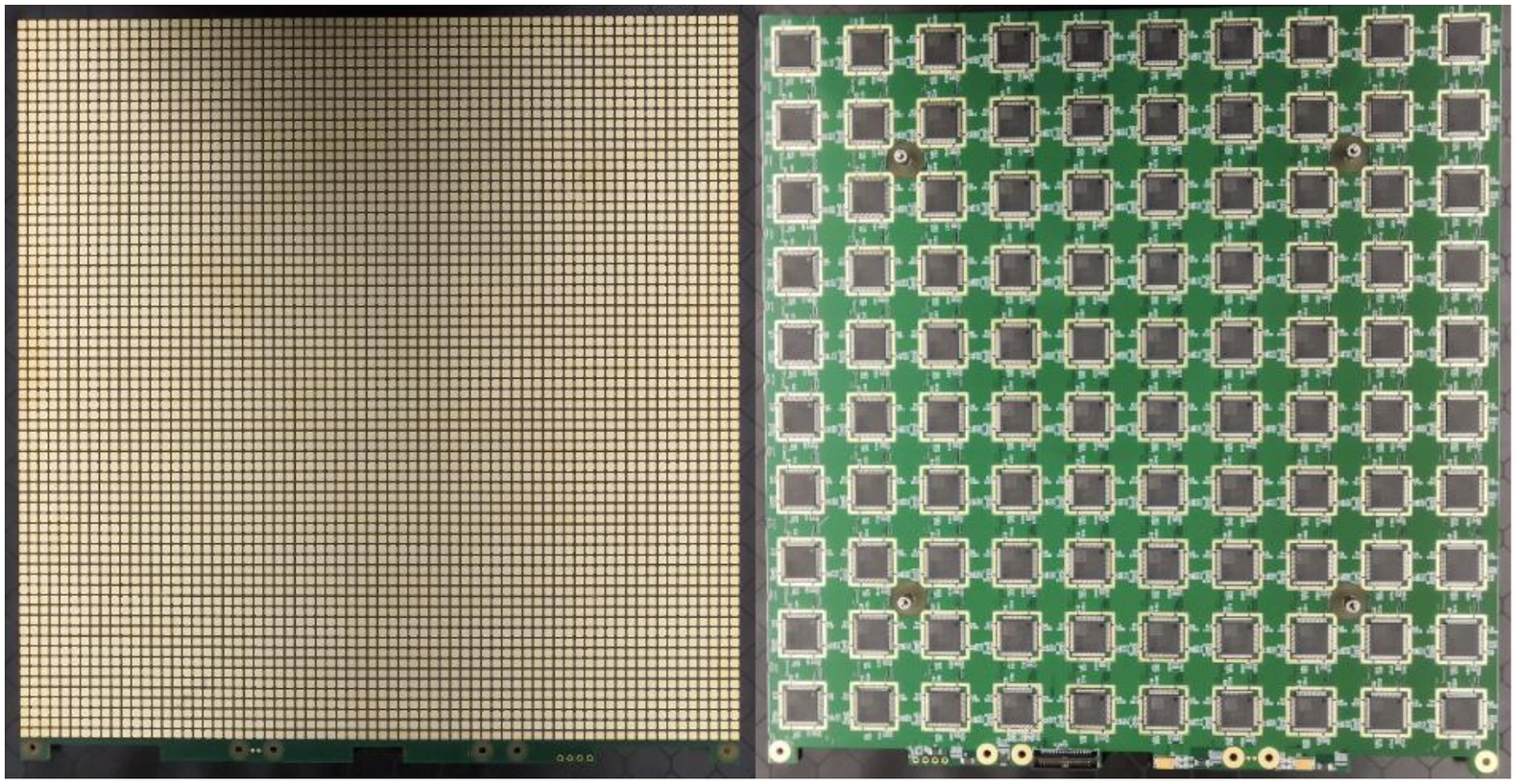
- Ionization electrons:
  - 23.6eV per e-
  - ~42k e-/MeV
- Recombination loss: @500V/cm
  - MIP: ~ 30%
  - Proton: ~70%
- Drift Velocity: @500V/cm
  - ~1.6mm/us
- Argon is also an effective scintillator, provides accurate timing

LArPix: Pixelated Charge Readout

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

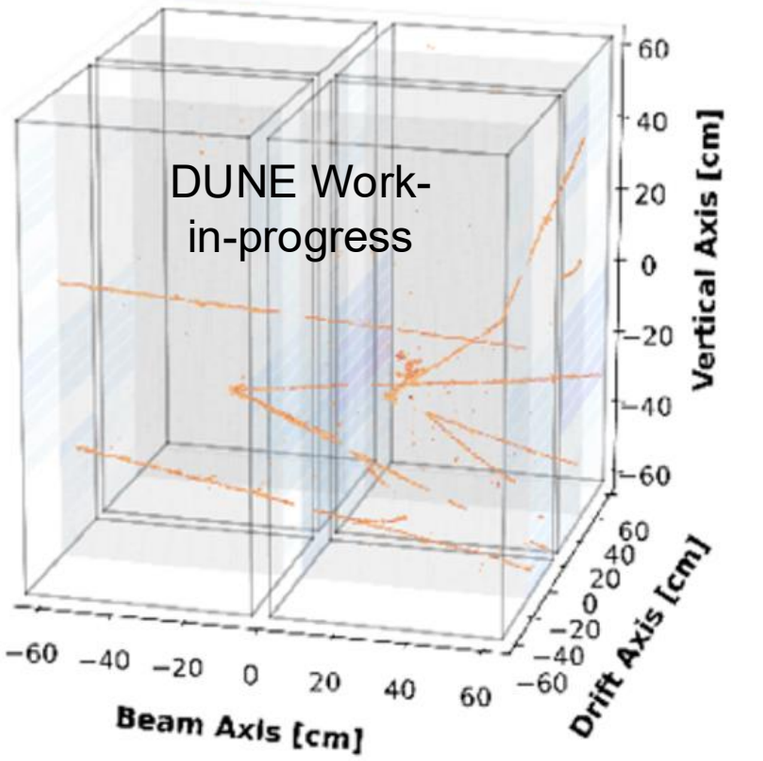
- **Example LArPix in 2x2:**
- **4900 pixels and 100 ASICs**
- **Pixel Pitch: ~ 4mm**

~ 30 cm



- **Self-triggering with configurable:**
- **charge thresholds of *O*(100) keV.**
- **hit cycles**

Example signals from antineutrino beam pulses, July 2024



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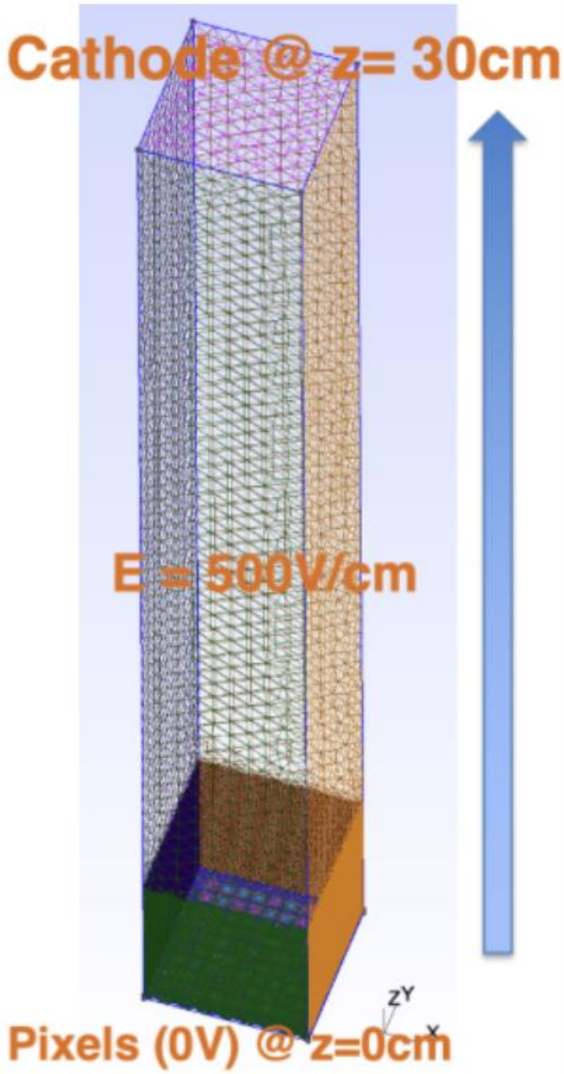
Field Response Simulation

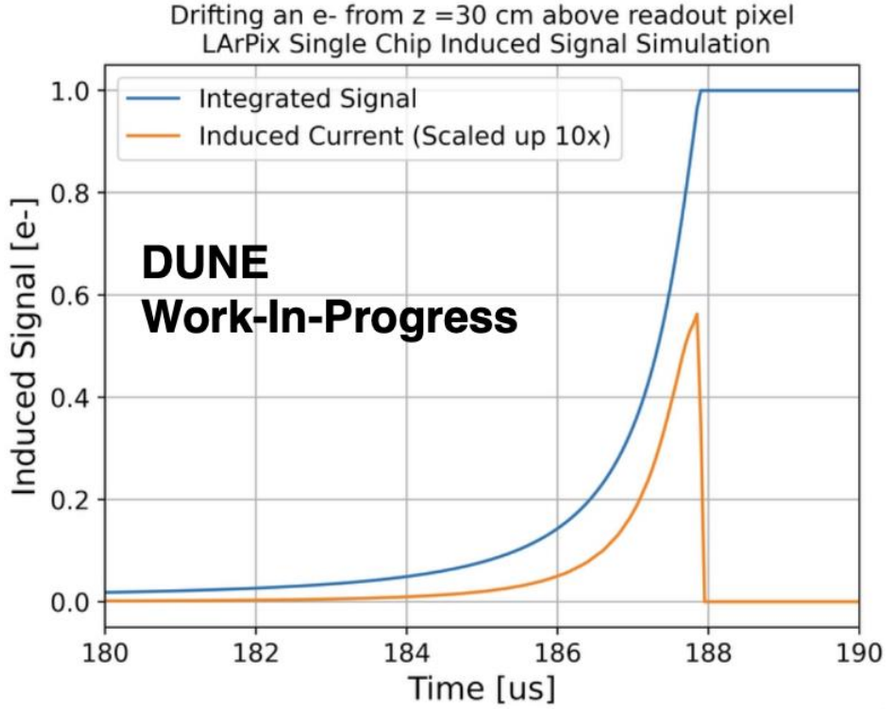
- Finite Element Method (FEM)



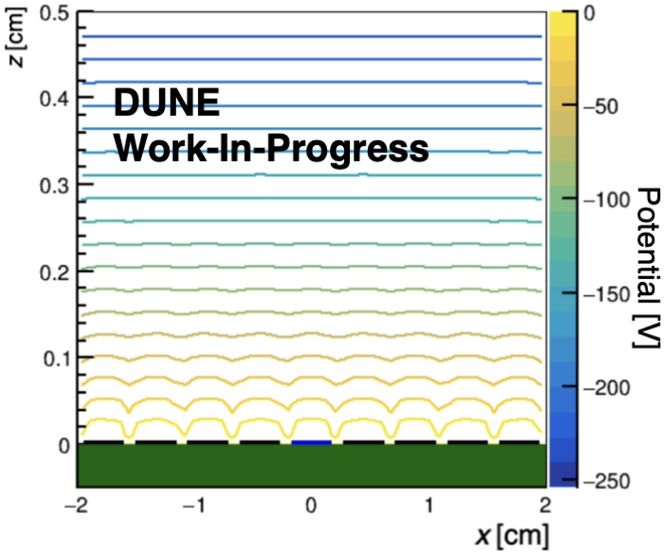
Induced current is calculated based on Shockley-Ramo formalism:

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

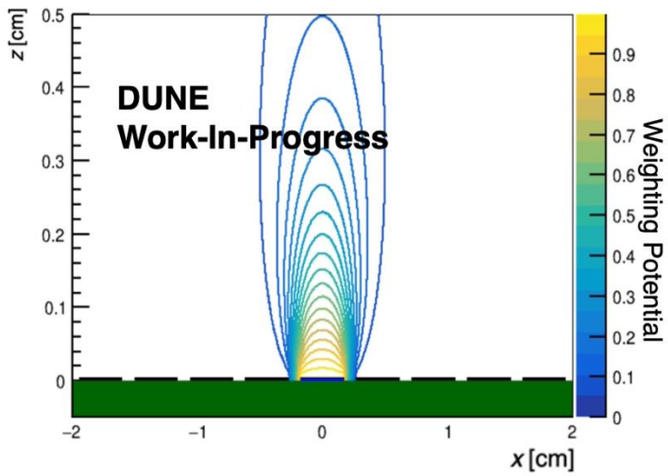
- $\bar{v}_d$ – Drift velocity that depends on electric potential
- W_i – Weighting Potential by fixing readout pixel to unit potential and other conductors to 0 V



Front-end will see the integrated signal



Electric potential near the pixel plane

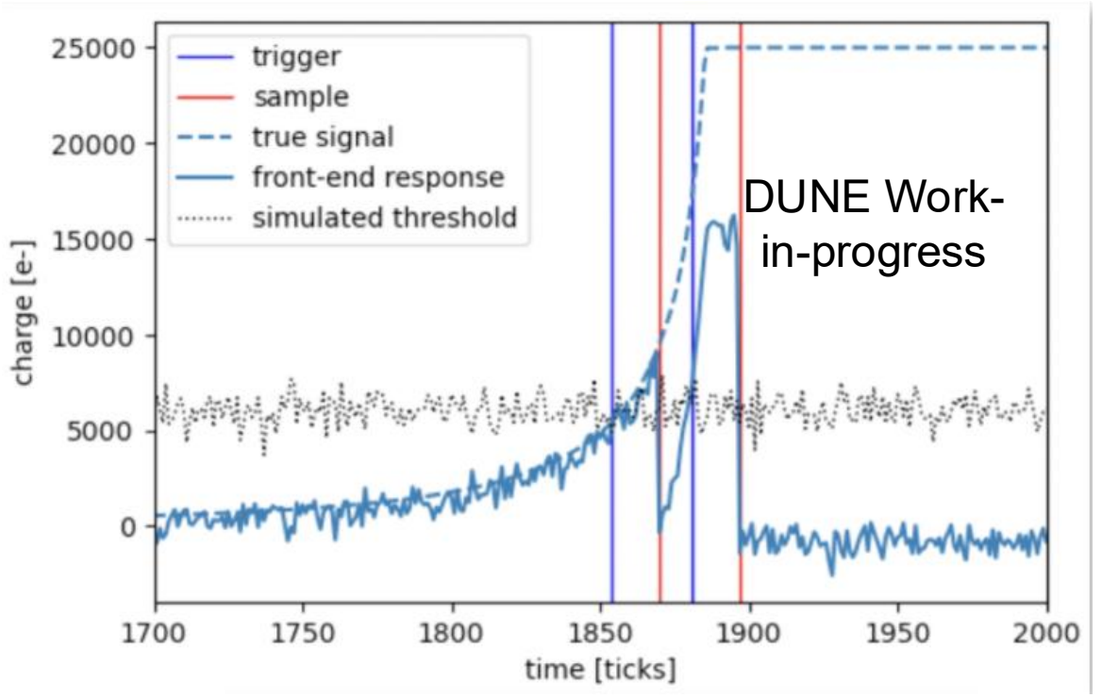


Weighting potential near a readout pixel

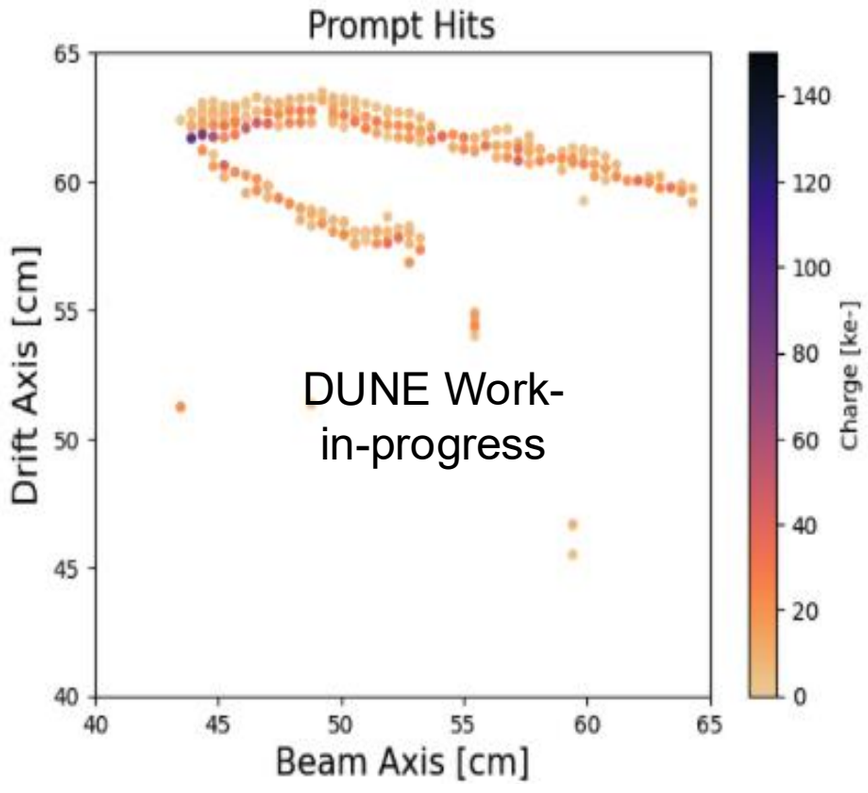
LArPix Pretriggering

LArPix may trigger, digitize, and reset multiple times on a single ionization trail, which could result in

- Partial charge collection
- Broadening reconstructed track

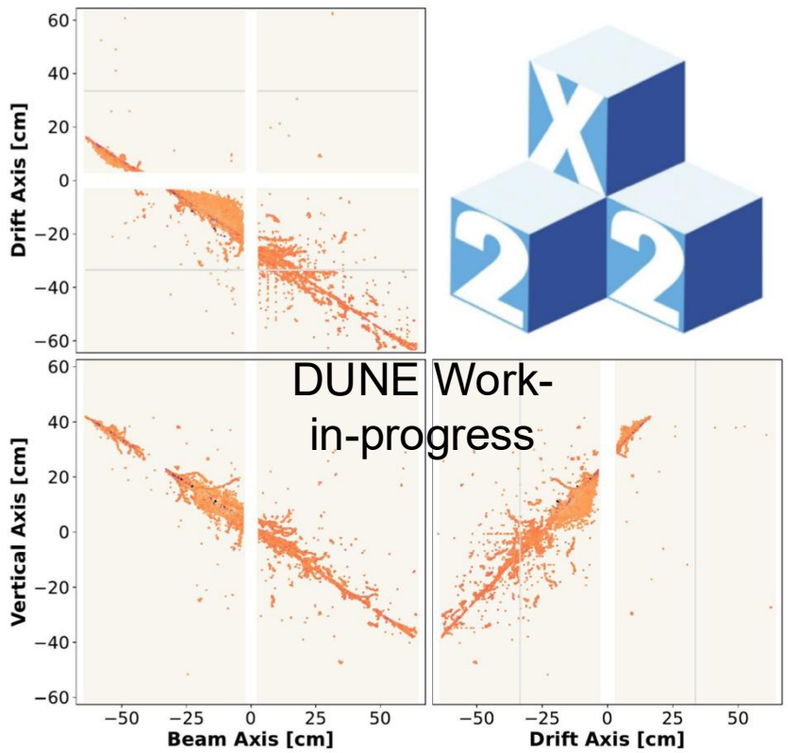


Example of a pixel readout retrigged by induced signal when an ionization cloud reaches the anode



Near-field
O(few) pixels

Along the drift direction, parallel hits can be seen preceding the track



Far-field
O(tens) pixels

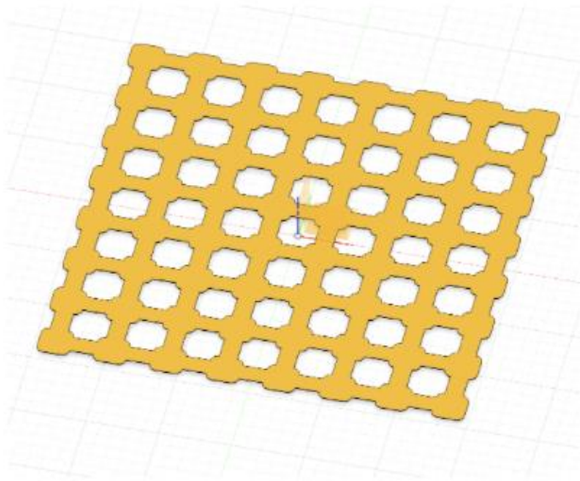
Neighbor induction

Shower Asymmetry

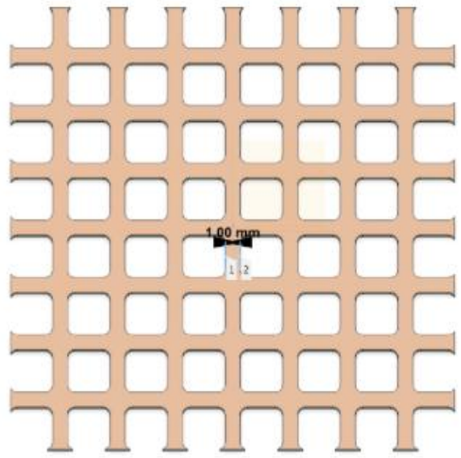
LArPix Shielding Plane

- To mitigate the pretriggering, one possible solution is to install a shielding plane upstream of LArPix
  - First, induce signals on the conductive shielding layer
  - LArPix will sense the signal when electrons are near the anode
  - Single trigger per ionization trail

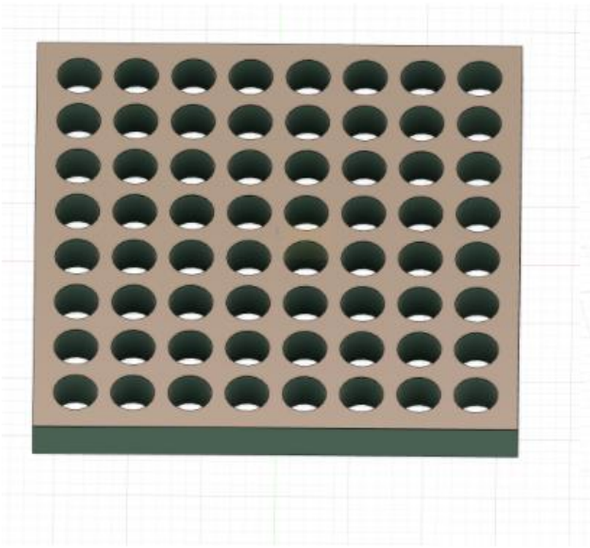
Examples of LArPix shielding plane design



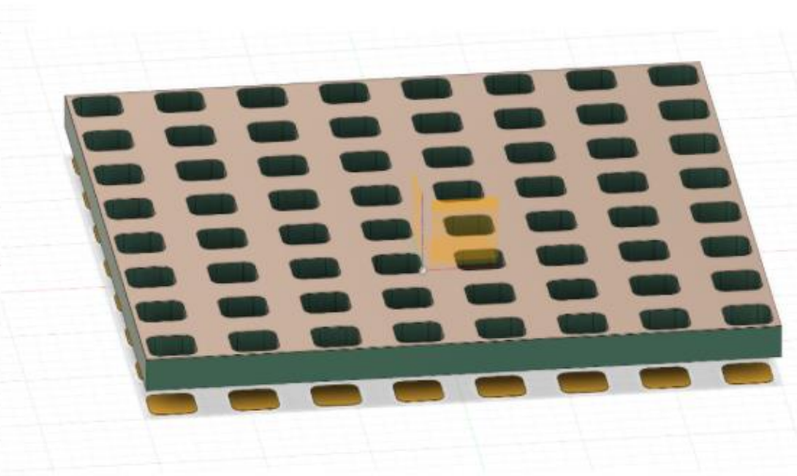
Conductive layer above pixels



Mesh type



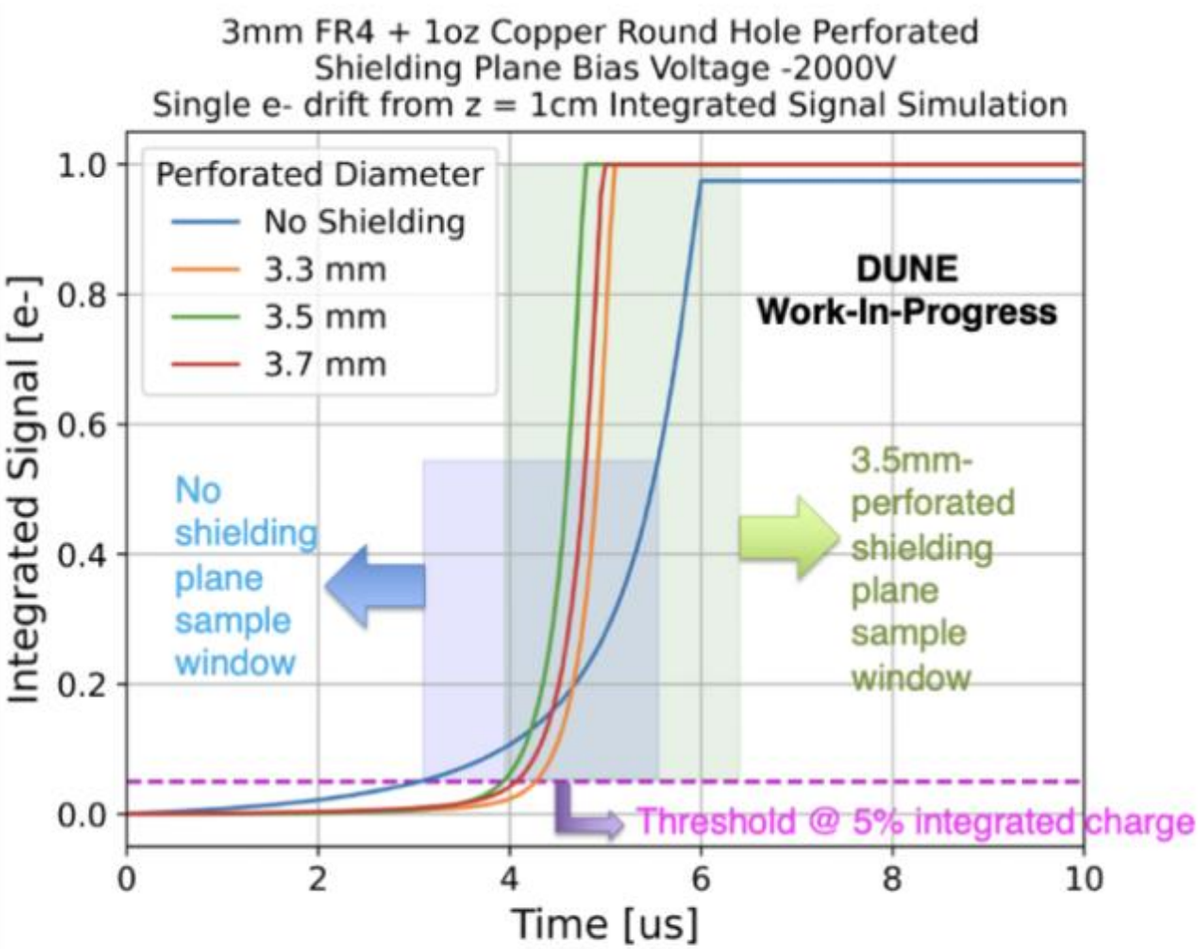
Circular Opening



Square Opening (conductive layer above the gap between pixels)

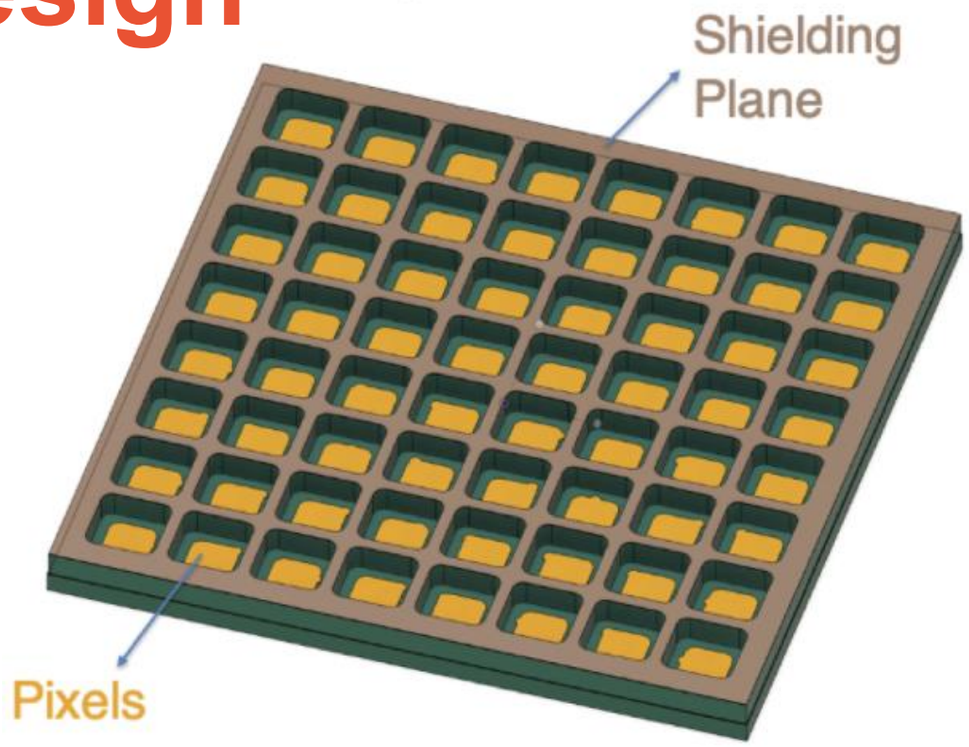
Current Design

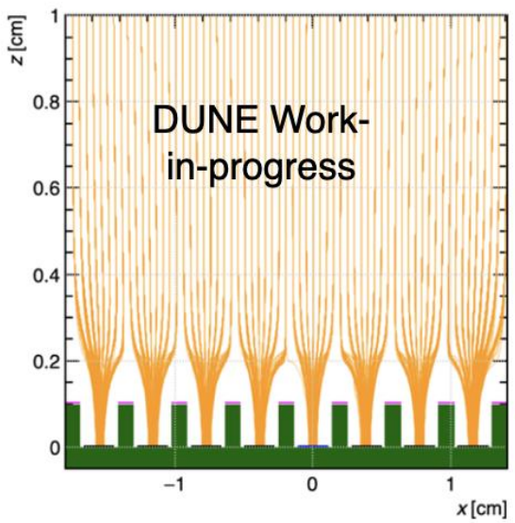
- FR4 (1.6mm) + Copper (1oz)
  - Directly sits on top of the anode plane
- Faster rising induced signal



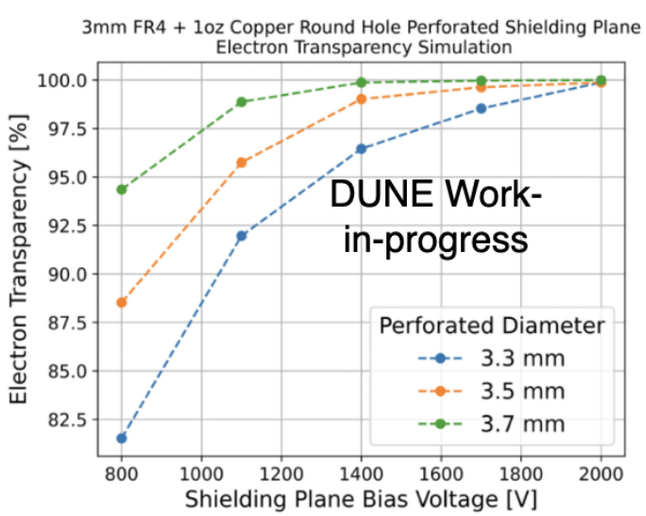
Charge can then be fully collected within single trigger sample window (~2.5 us).

(Configurable thresholds and sample window)





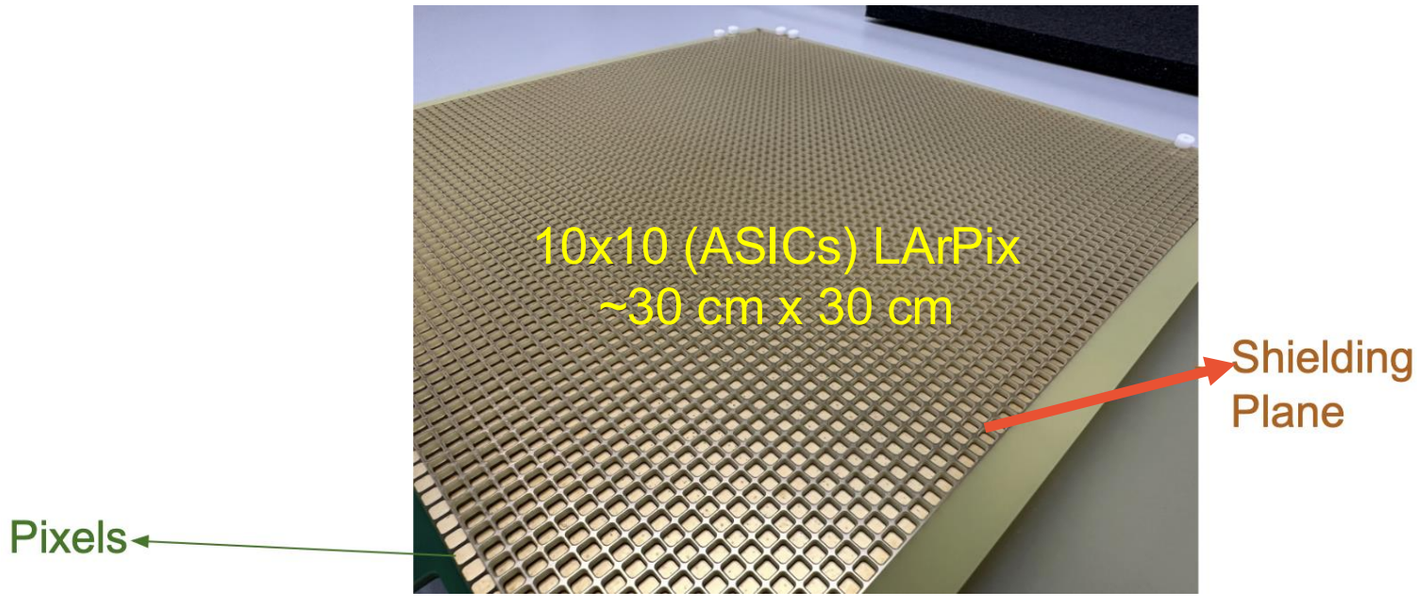
Electron Transparency: drifting ~5000 electrons above anode; counting how many arriving at pixels.



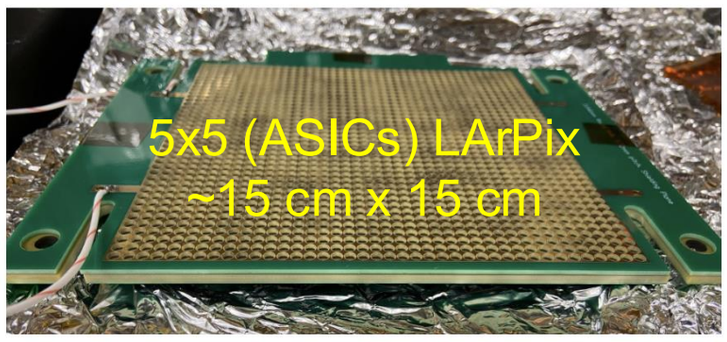
Optimize shielding plane geometry and bias voltage to enable full electron transparency.

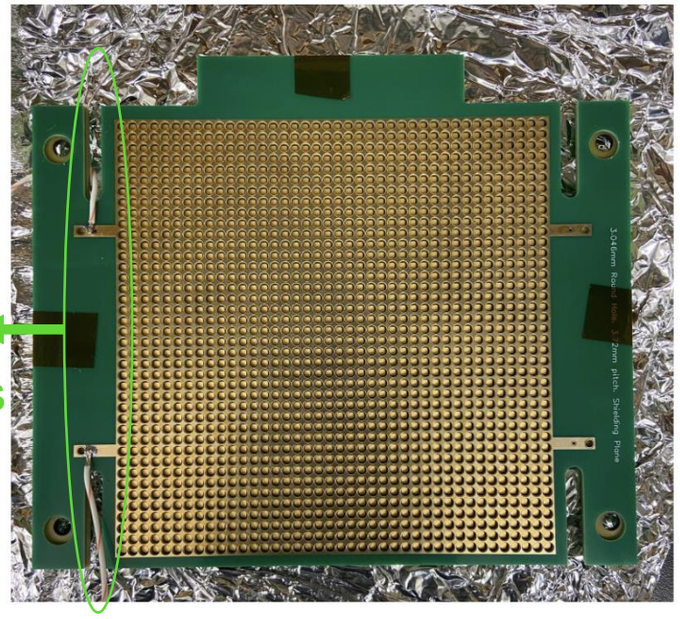
Prototyping

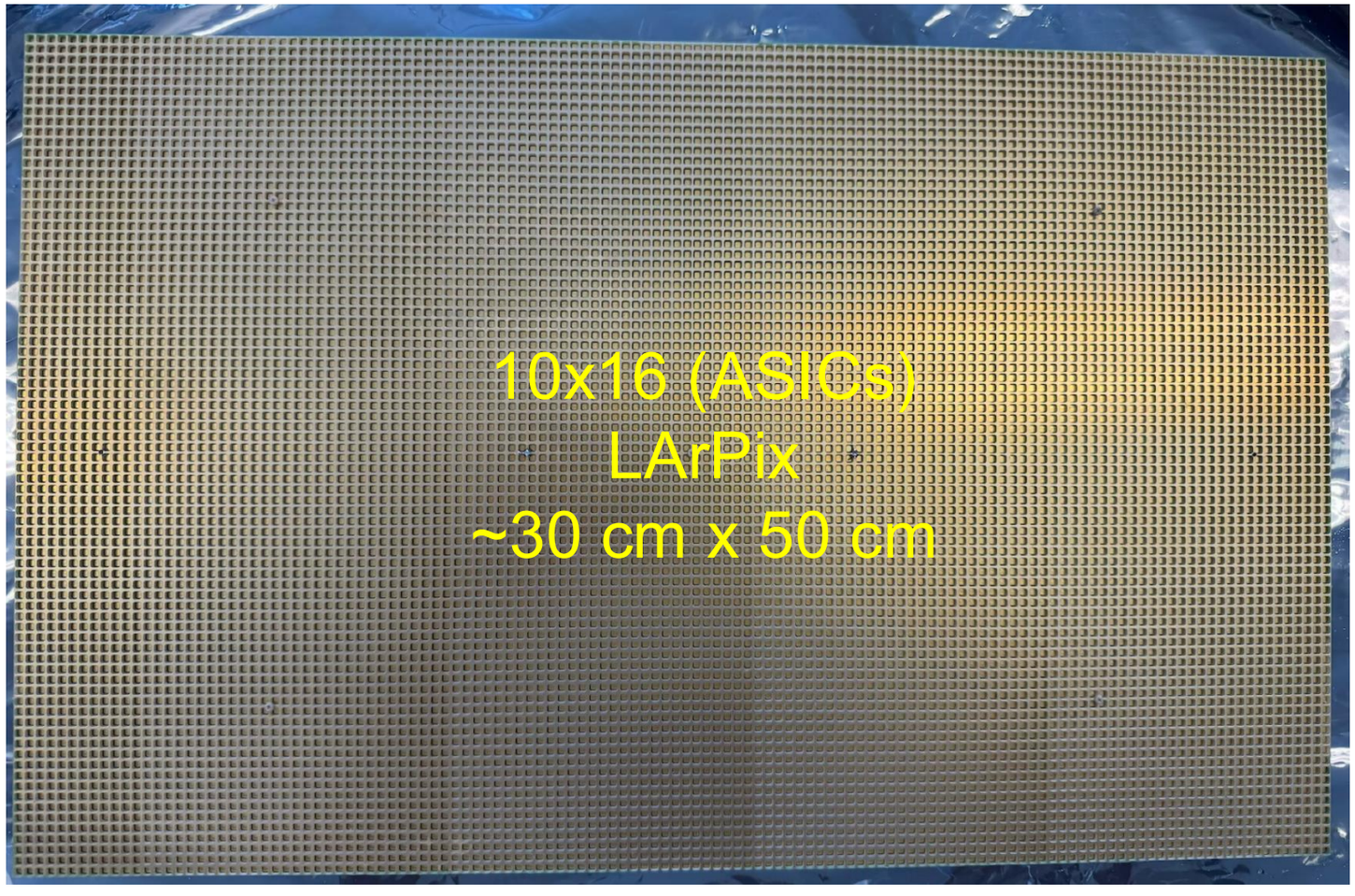
- Various shielding planes has been manufactured for different LArPix Tiles



Shielding Plane installed on LArPix Tile

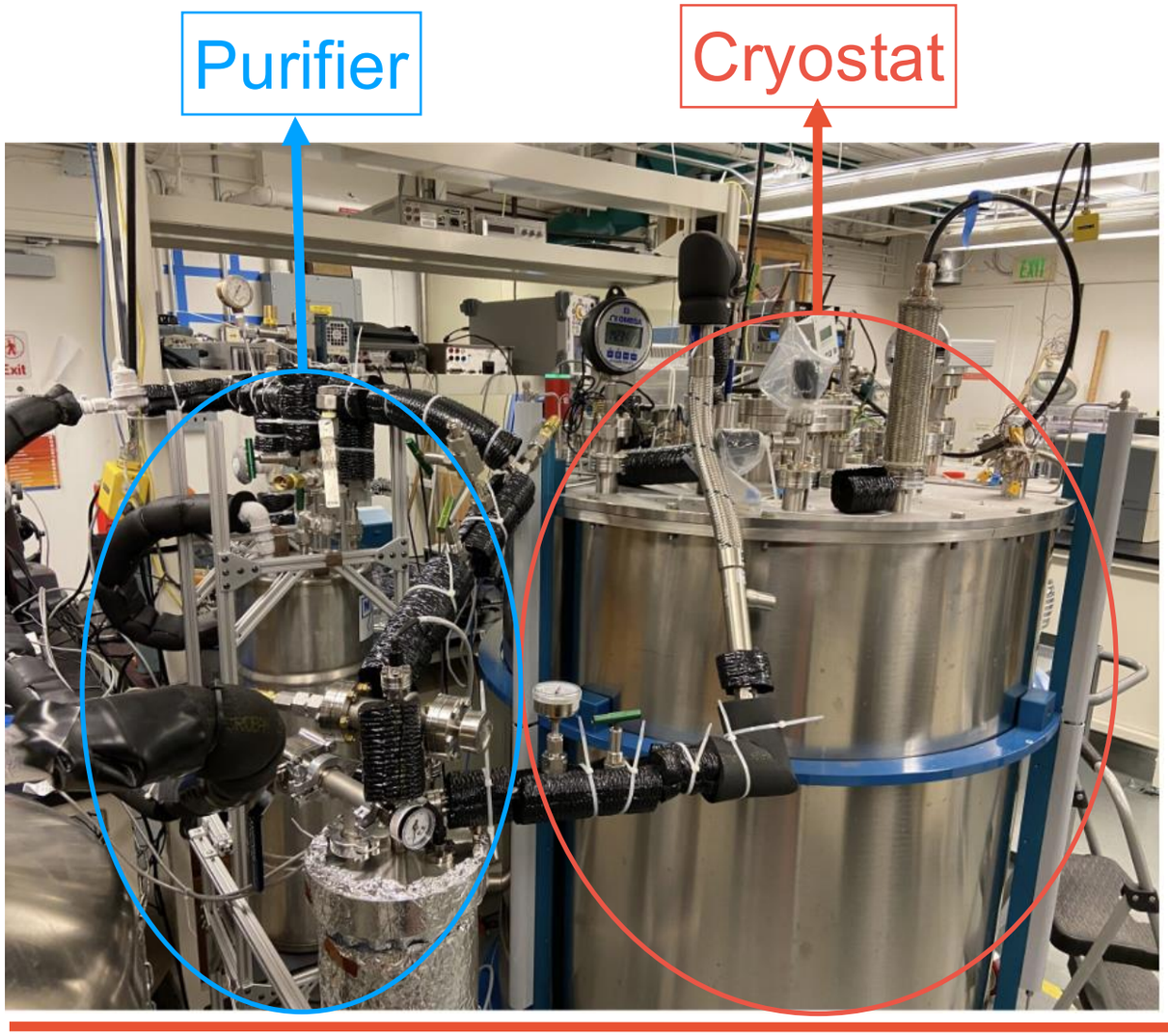


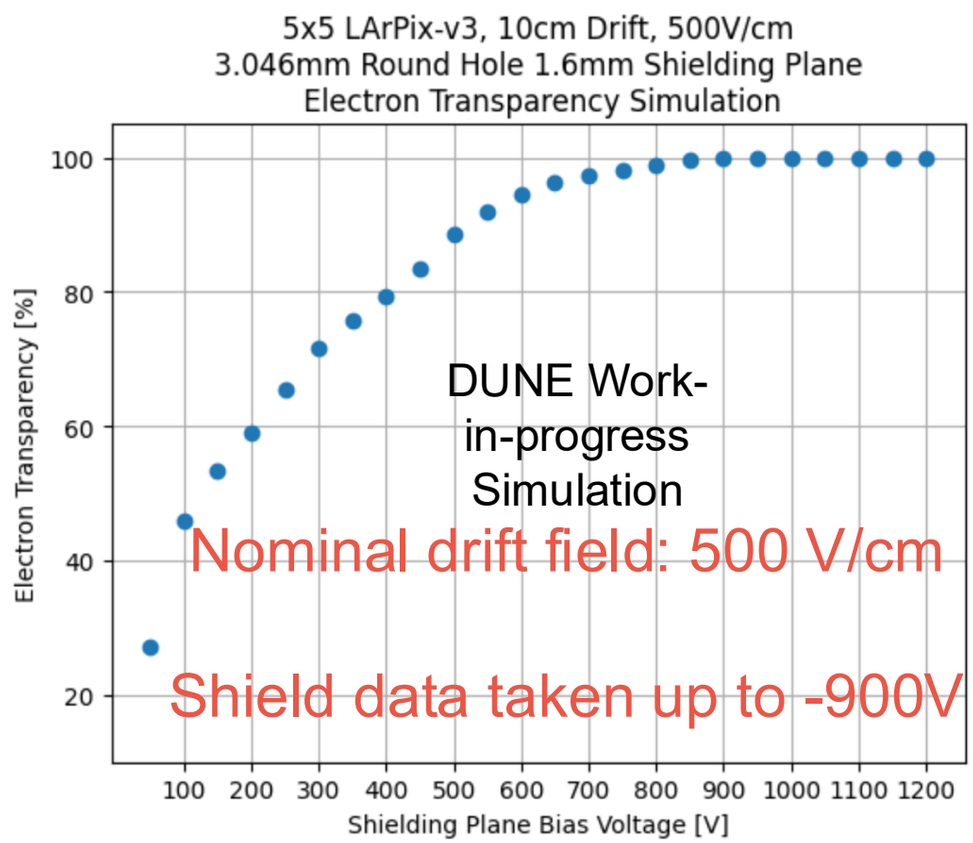




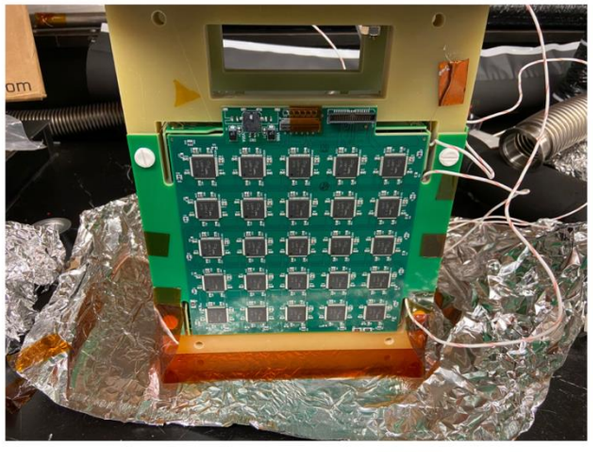
Cosmic-ray Tests

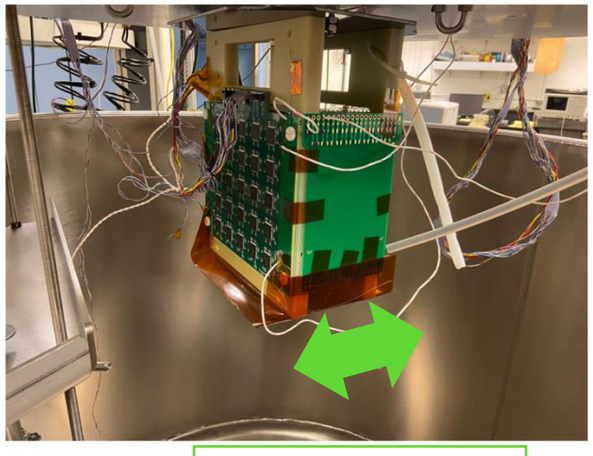
- Cosmic-ray data have been collected at LBNL
  - 5x5 (ASICs) LArPix-v3
  - TPC drift length: 10 cm





TPC Pictures





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10cm drift

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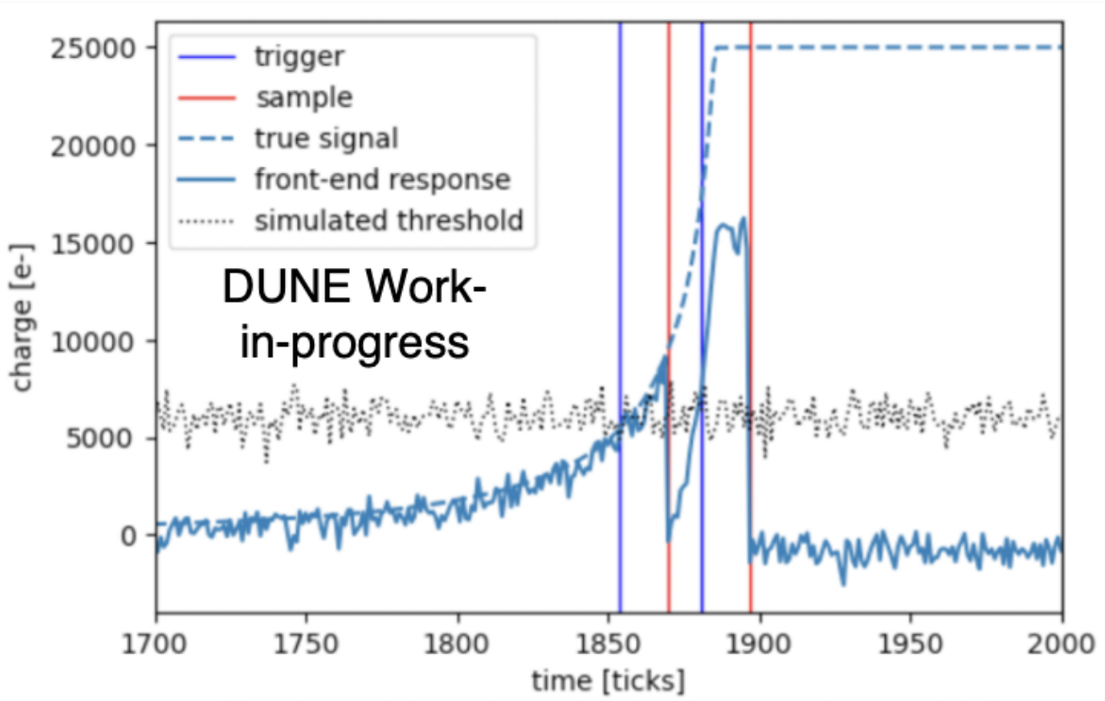
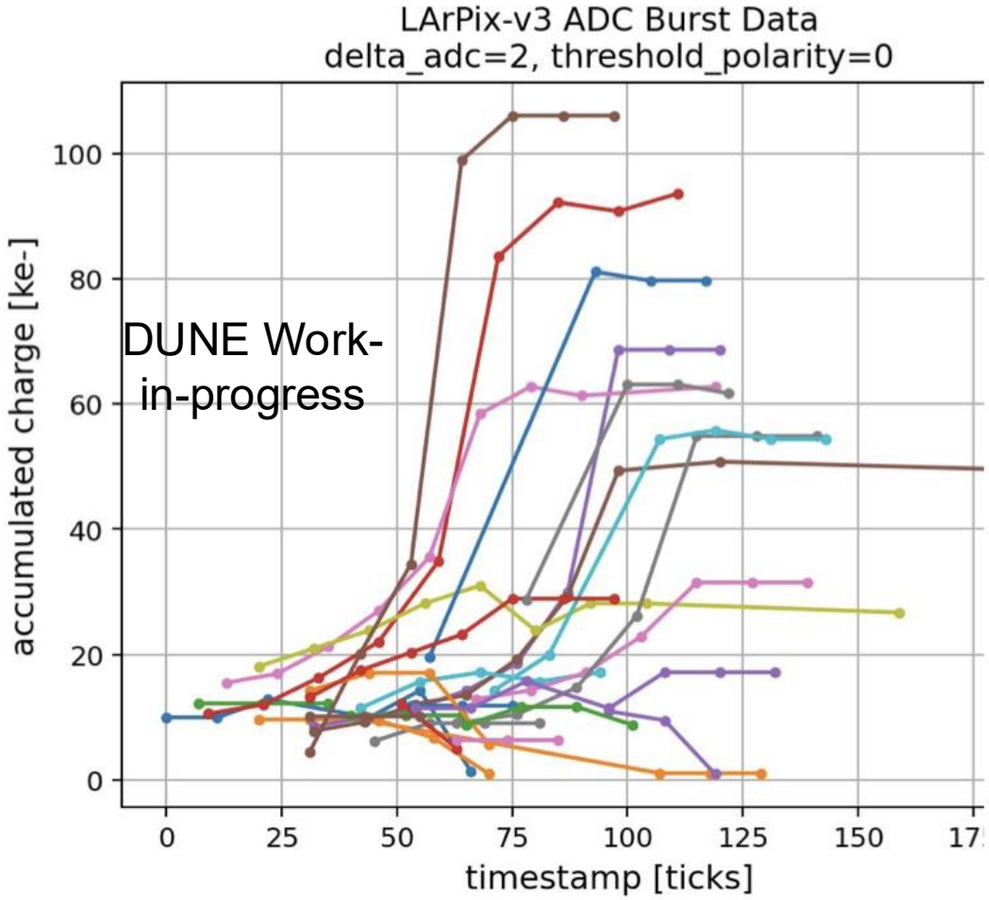
Data Trigger Modes

- Normal Mode
  - May trigger, digitize, and reset multiple times on a single ionization trail



Example of a pixel readout retrigged by induced signal when an ionization cloud reaches the anode

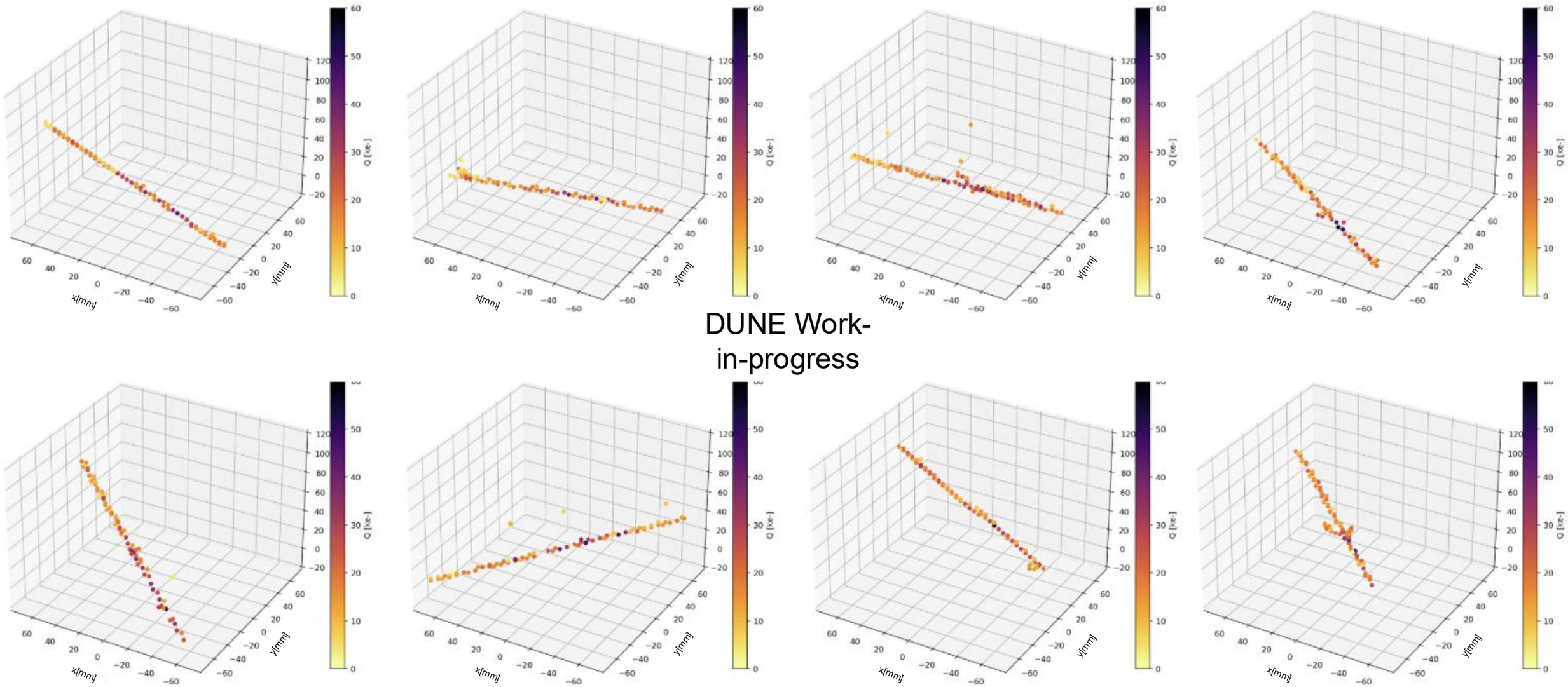
- ADC Burst Mode
  - Continuous sample until charge plateau



Event Display (w/ Shield)

Normal Trigger

Tracks



DUNE Work-in-progress

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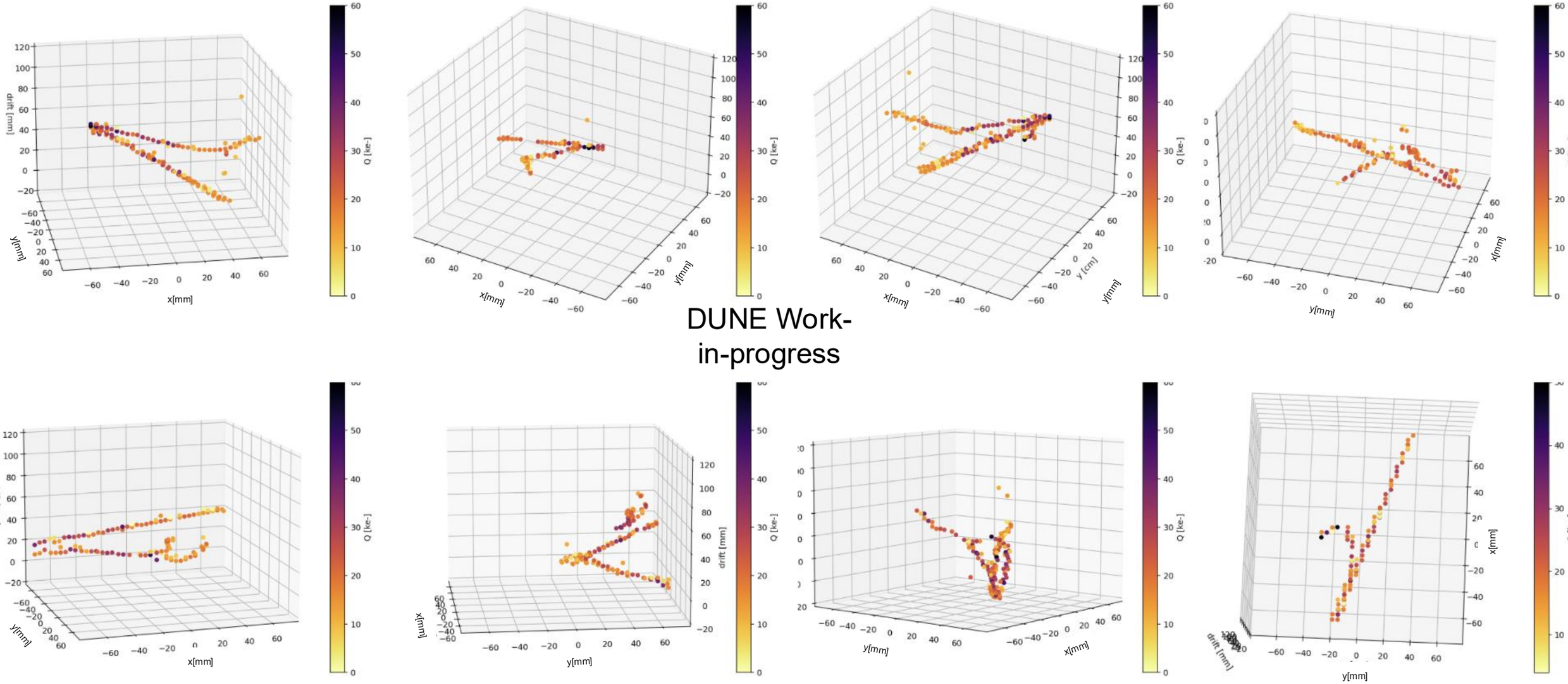
Event Display (w/ Shield)

Normal Trigger

Other Topologies



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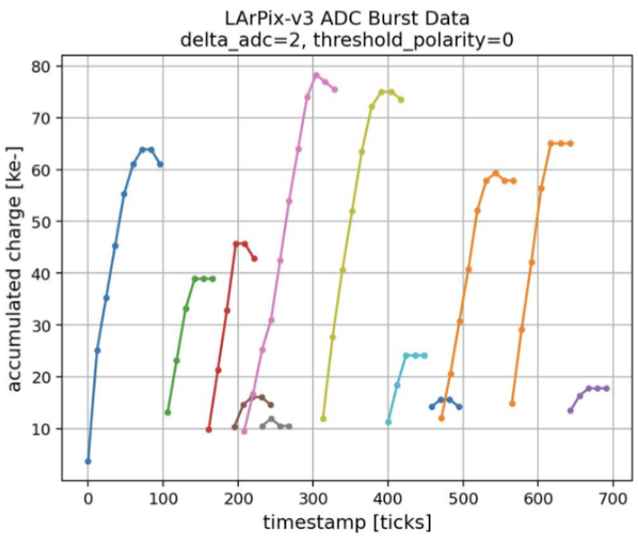
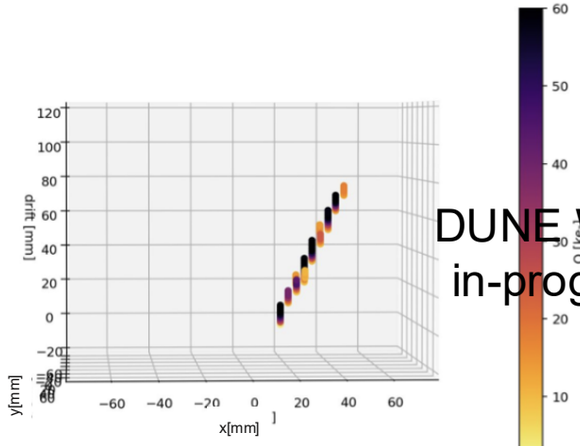
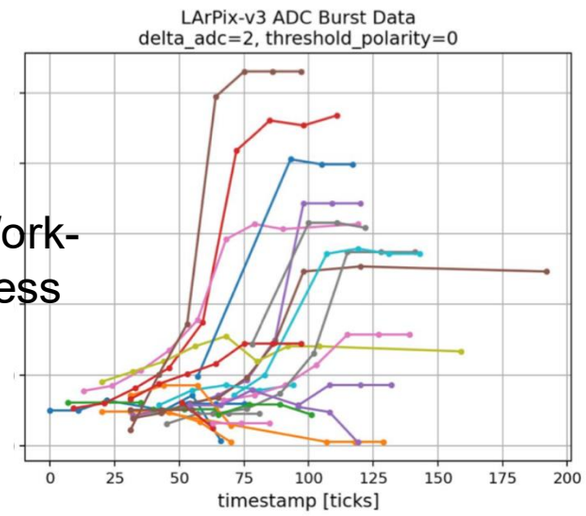
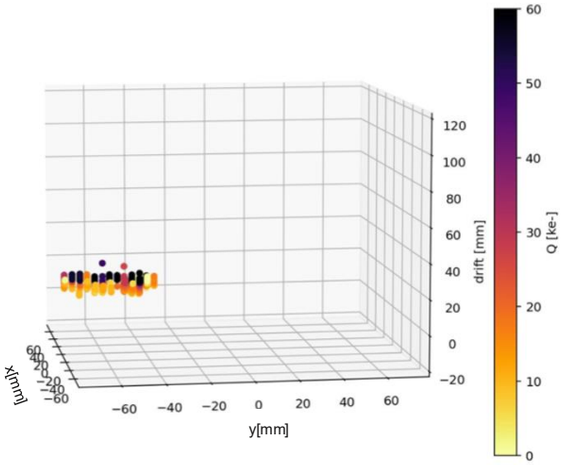
ADC Burst Data





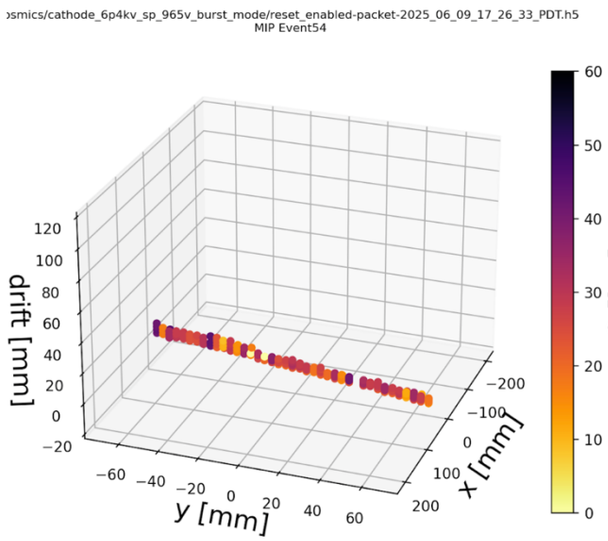
DUNE Work-in-progress

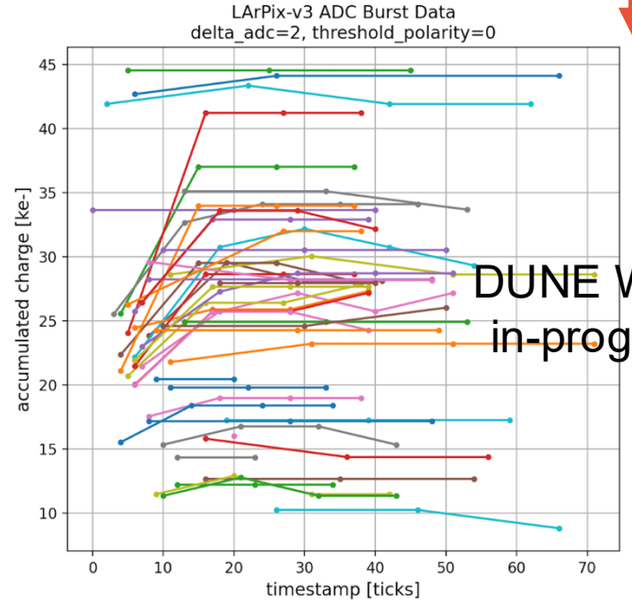




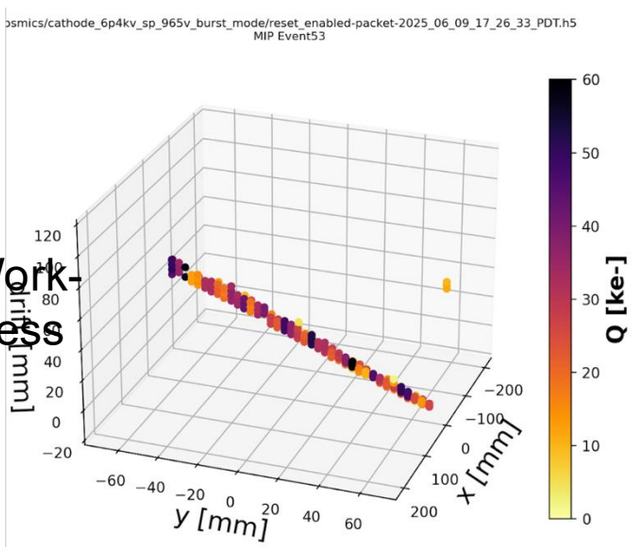
w/o Shield

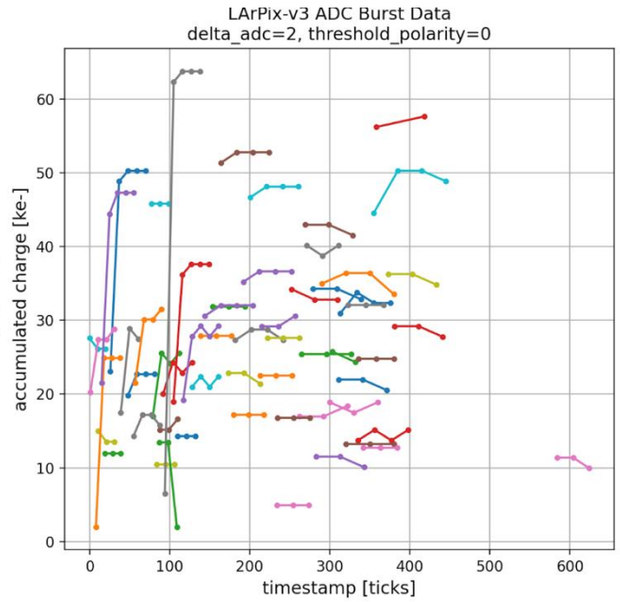
w/ Shield





DUNE Work-in-progress





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Technical Challenges

- Dielectric breakdown
- Leakage current
- Field cage integration

No issue found in current tests
Still need to address if scaling up

  - Match shield bias with field ring potential

- Shield Plane to LArPix integration

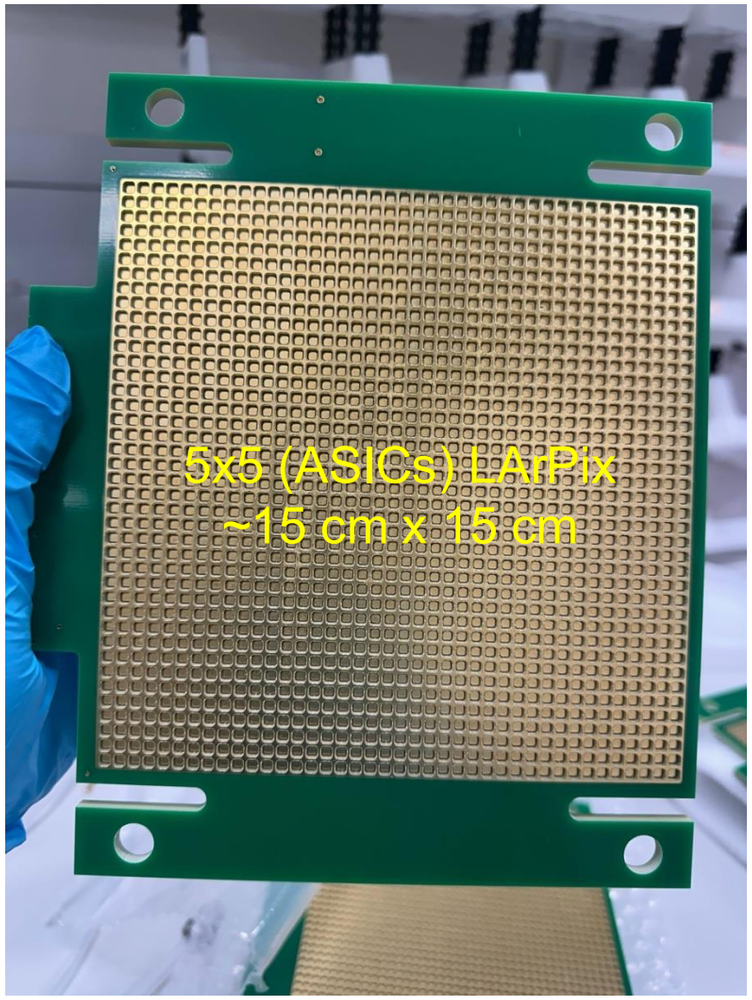
  - Screw and/or Epoxy

Vibrations due to the purifier venting into the cryostat

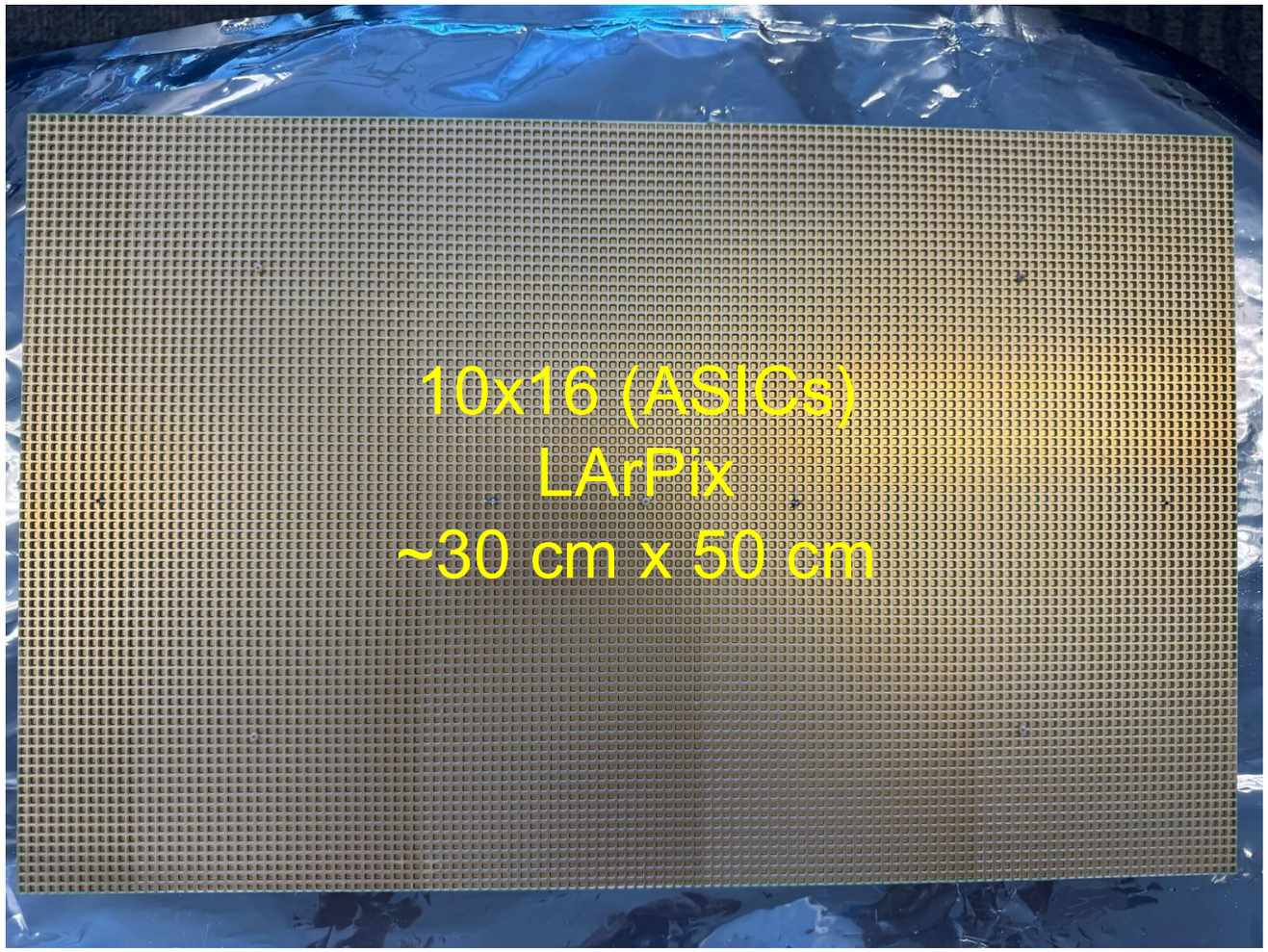
Microphonic Noises

Ongoing R&D

- Integrated Board
  - Fabricate LArPix and shield plane into one unit
  - To mitigate microphonic noises



- ND-LAr size tile
  - TPC drift length: 50 cm
  - To evaluate the far-field effects



Summary

- Designed and tested a shielding plane for LArPix
- Cosmic-ray tests with a small LArPix tile demonstrate the shield's:
  - Good imaging capability
  - Induced signal rising edge suppression
- R&D is ongoing
  - Full-scale ND-LAr tiles to study far-field effects
  - Developing integrated boards to combine LArPix and the shielding plane