Stanford University

SLAC

GAMPix

Electron Track Detection with a Dual Scale LArTPC System

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Stanford

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GAMPix detector

Electron Track Detection with a Dual Scale System in TPCs

Low

- **Noise**
- **Threshold**
- **Power**

Diffusion Independent

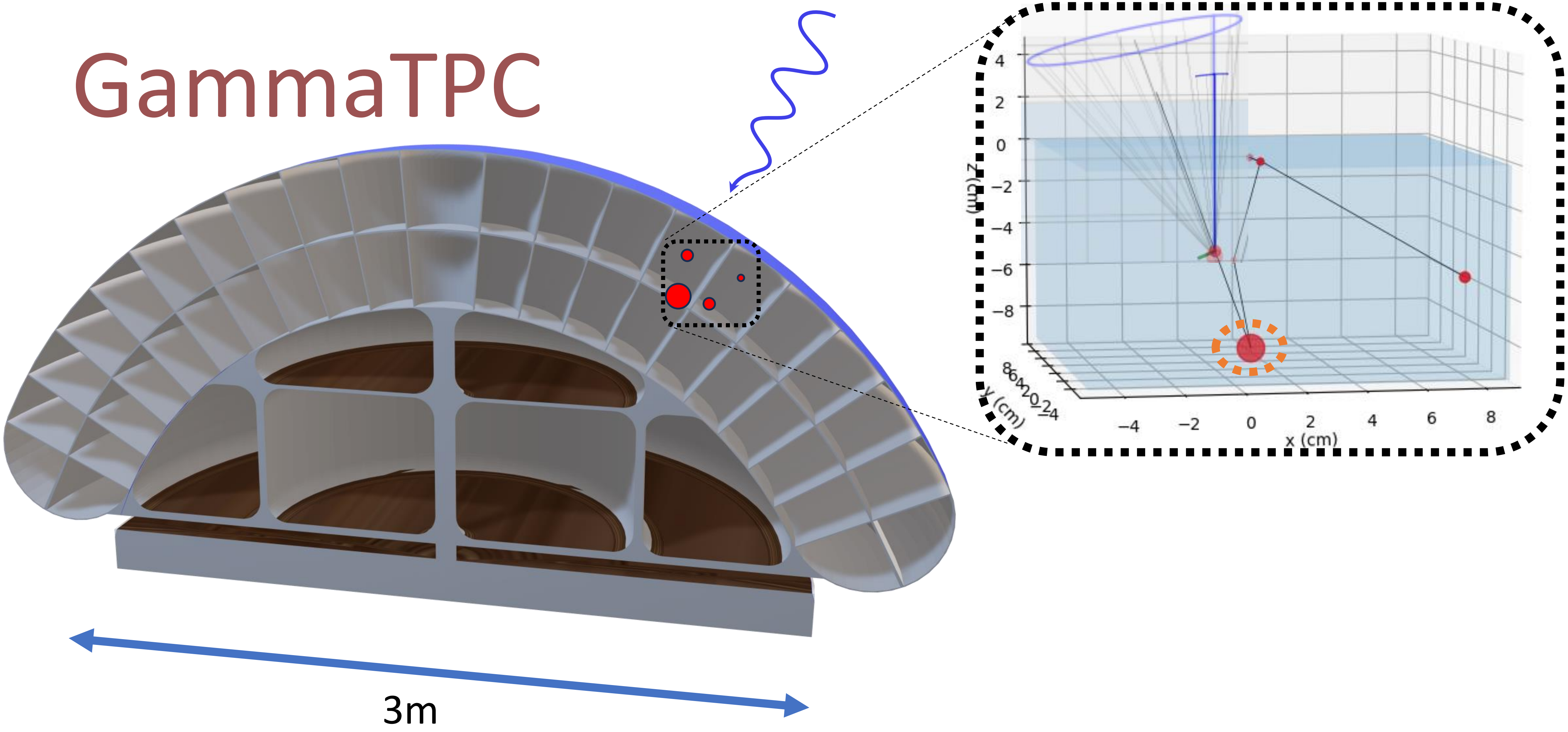
(Can use diffusion to estimate drift length)

GAMPix detector

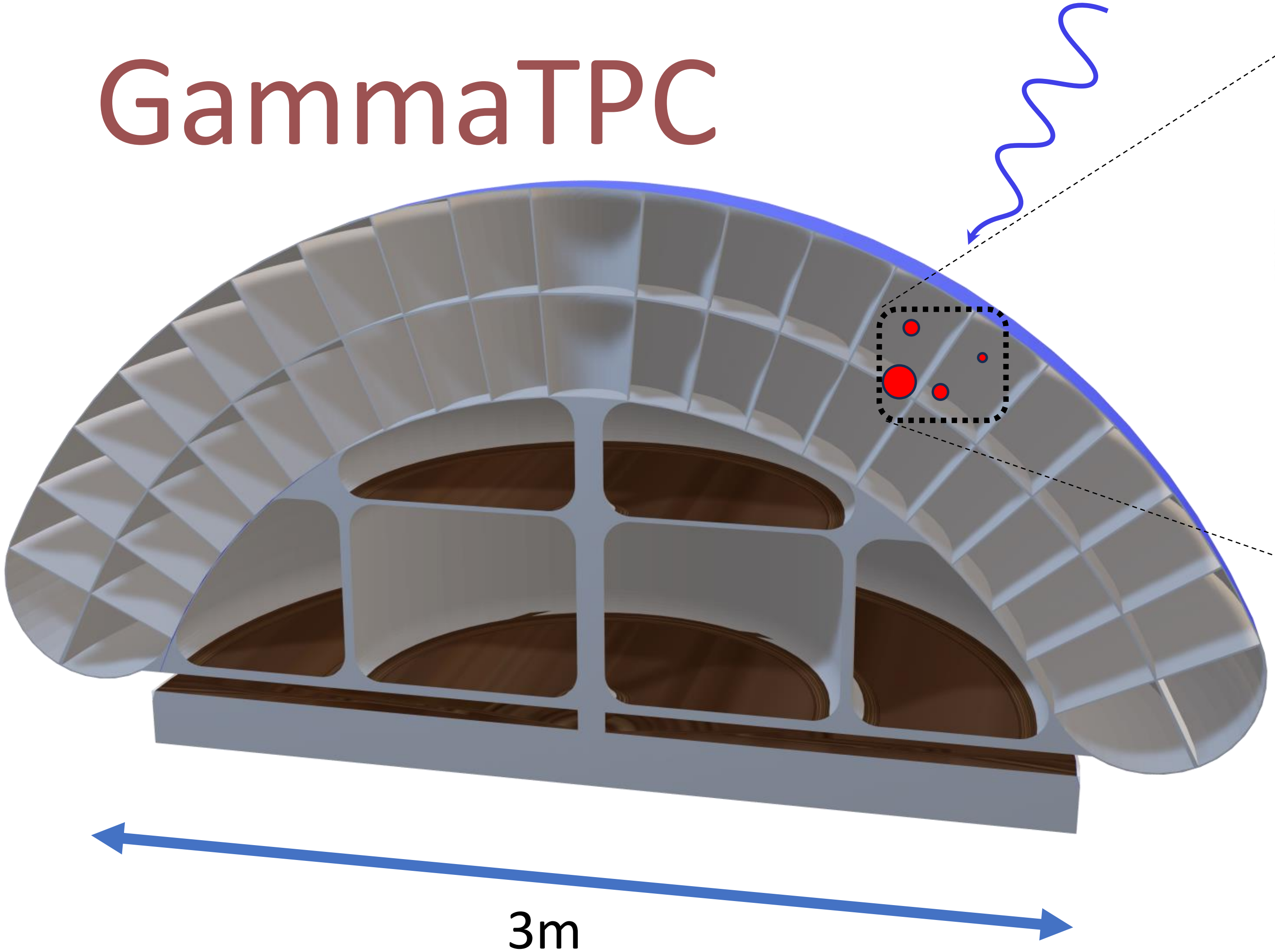
Electron Track Detection with a Dual Scale System in TPCs

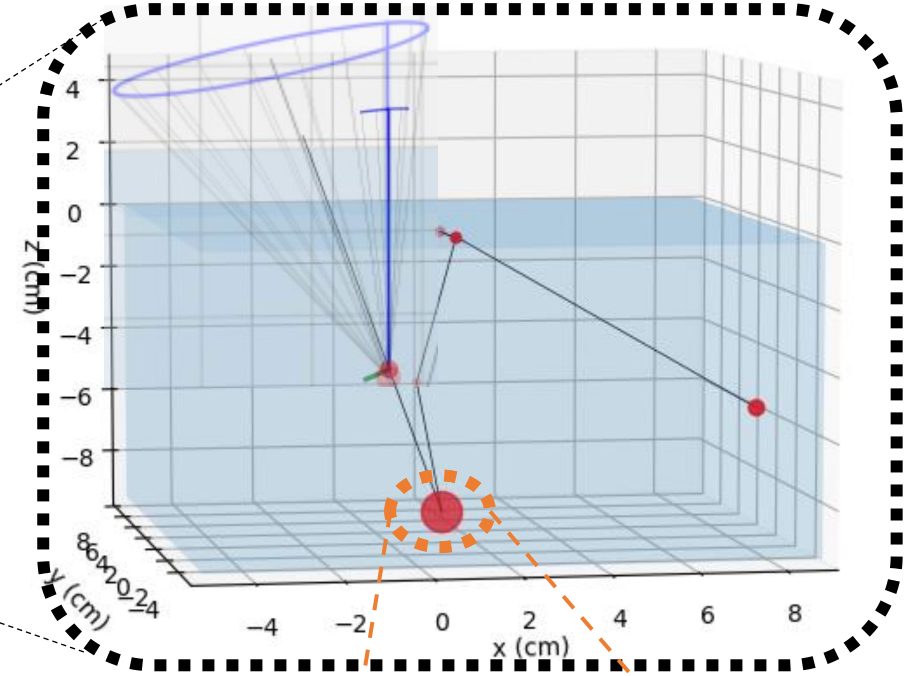
Low – **Noise**, **Threshold**, **Power**

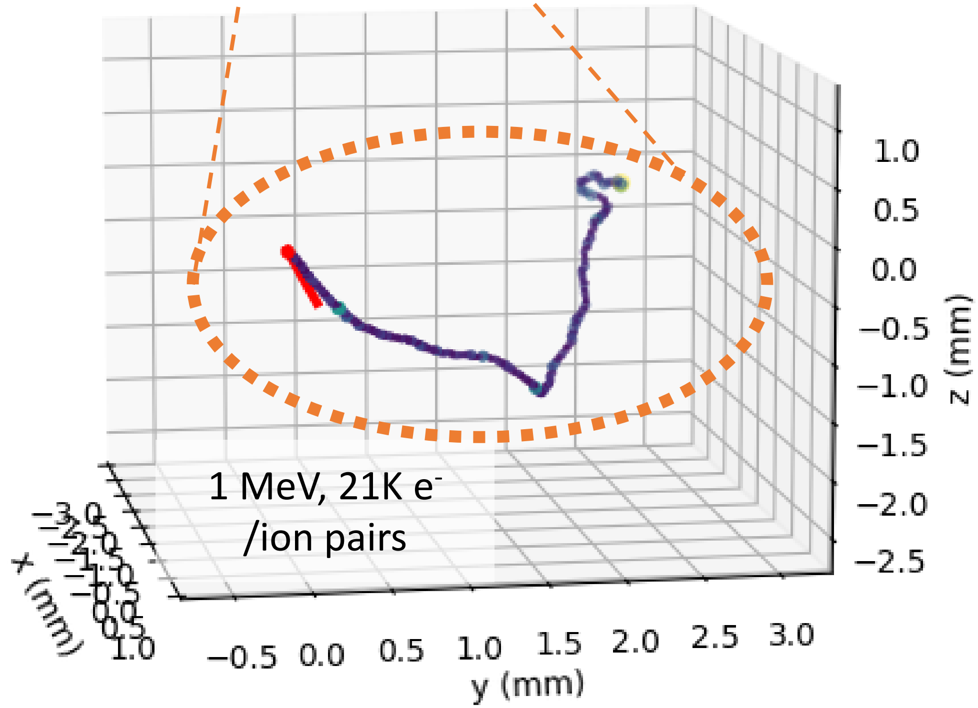
GammaTPC



GammaTPC



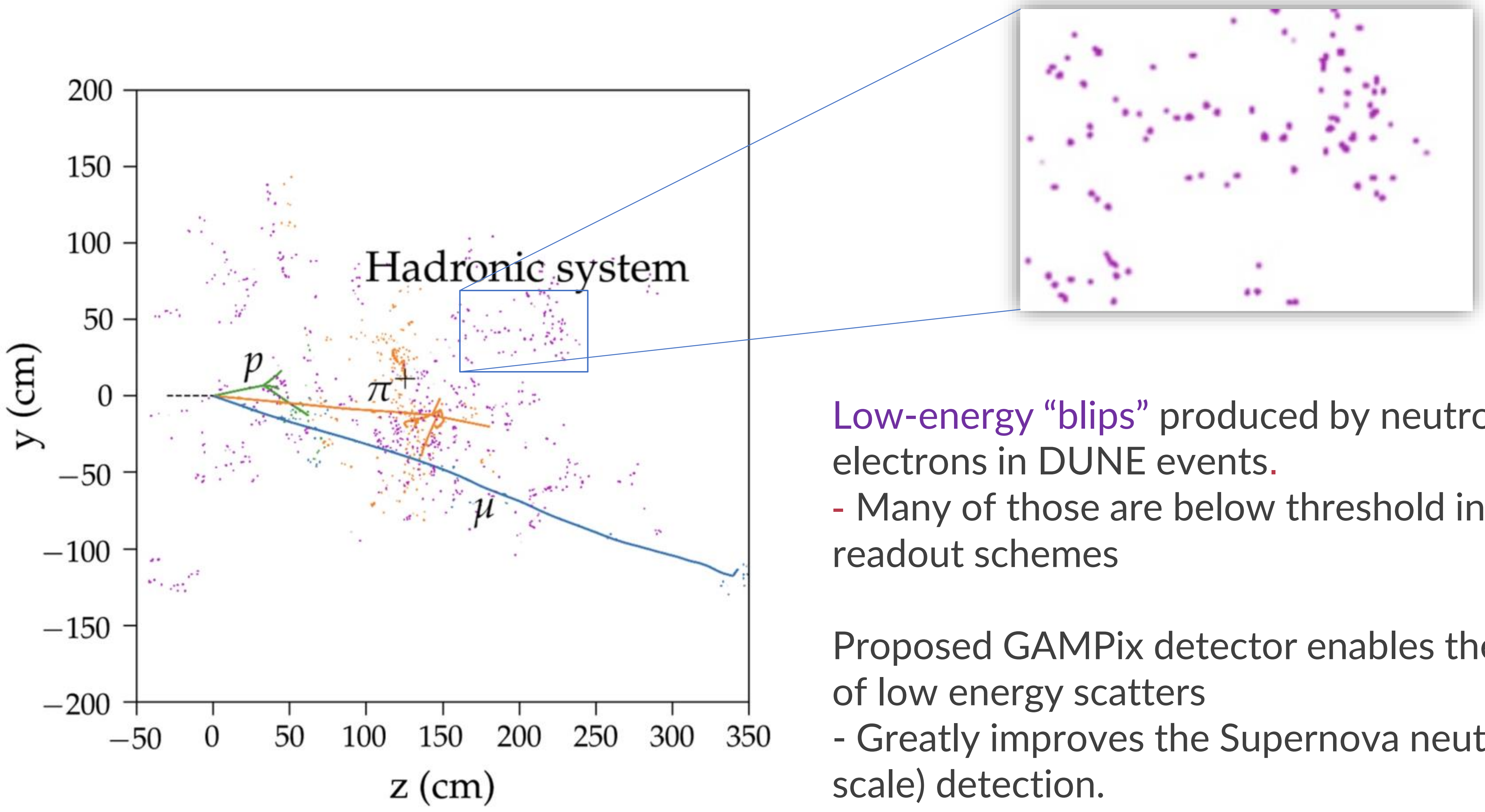




Technical Requirements

1. Submillimeter Track Imaging (3D)
2. Percent level Energy Resolution
3. Low Power Consumption $\sim 1\ W/m^2$

Possible Application in DUNE FD Phase 2



Low-energy "blips" produced by neutrons and electrons in DUNE events.
- Many of those are below threshold in current readout schemes

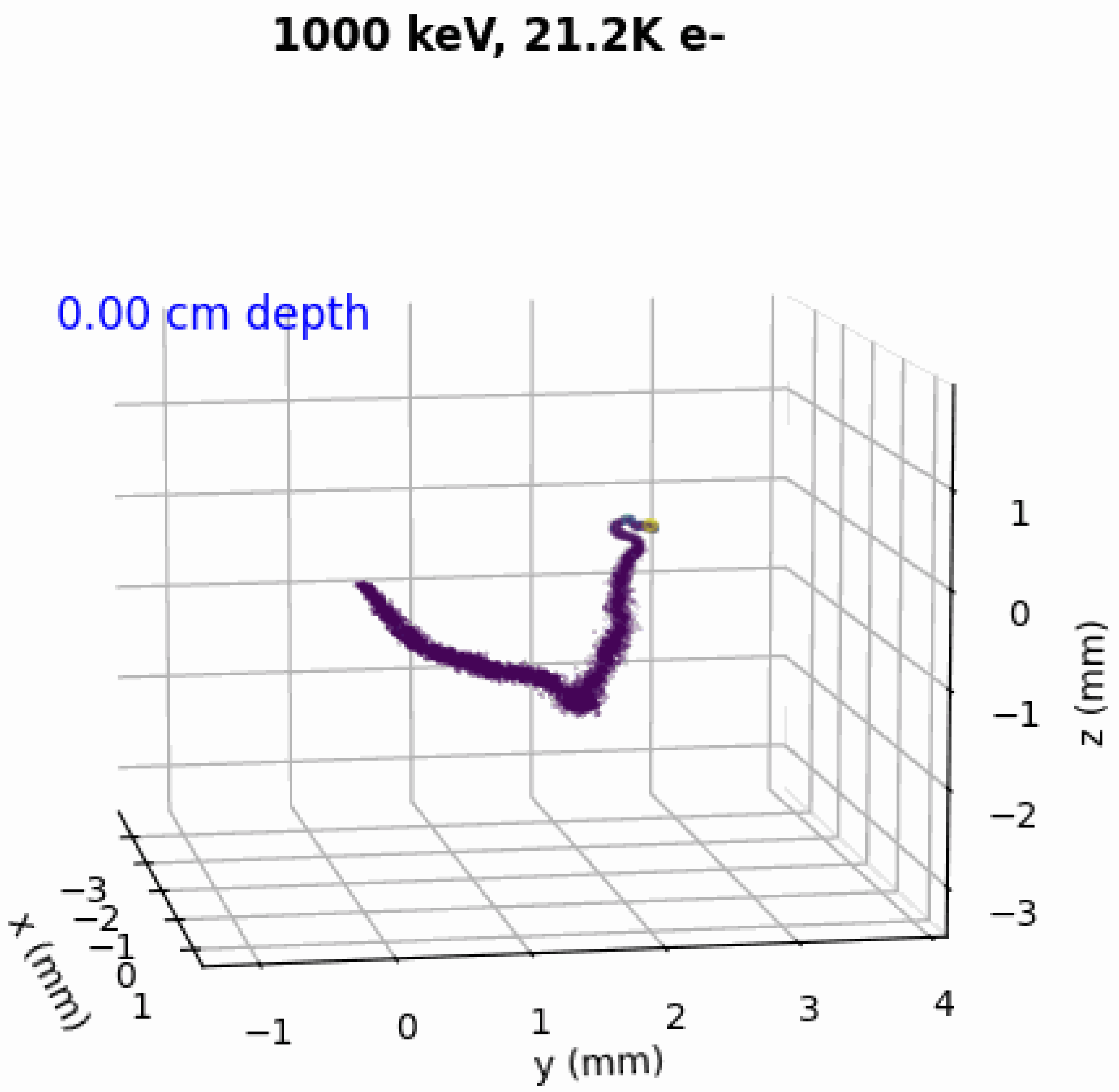
Proposed GAMPix detector enables the detection of low energy scatters
- Greatly improves the Supernova neutrino (MeV scale) detection.

A. Friedland and S. W. Li, "Understanding the energy resolution of liquid argon neutrino detectors," Phys. Rev. D 99, no.3, 036009 (2019) [arXiv:1811.06159 [hep-ph]]

How to Image the Electron Tracks?

Challenges:

- **Charge loss** when diffusion is on the scale of sensors



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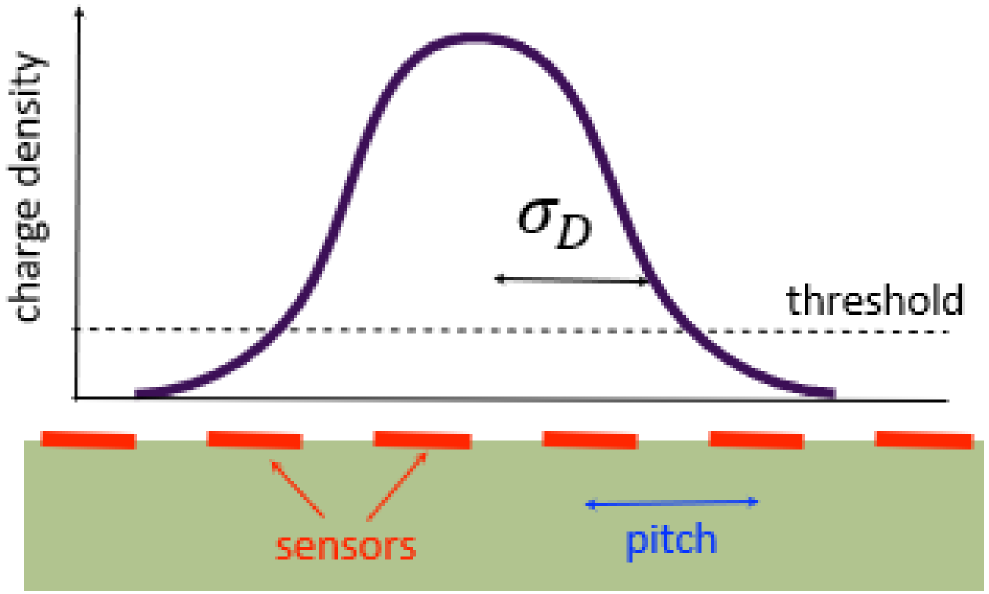
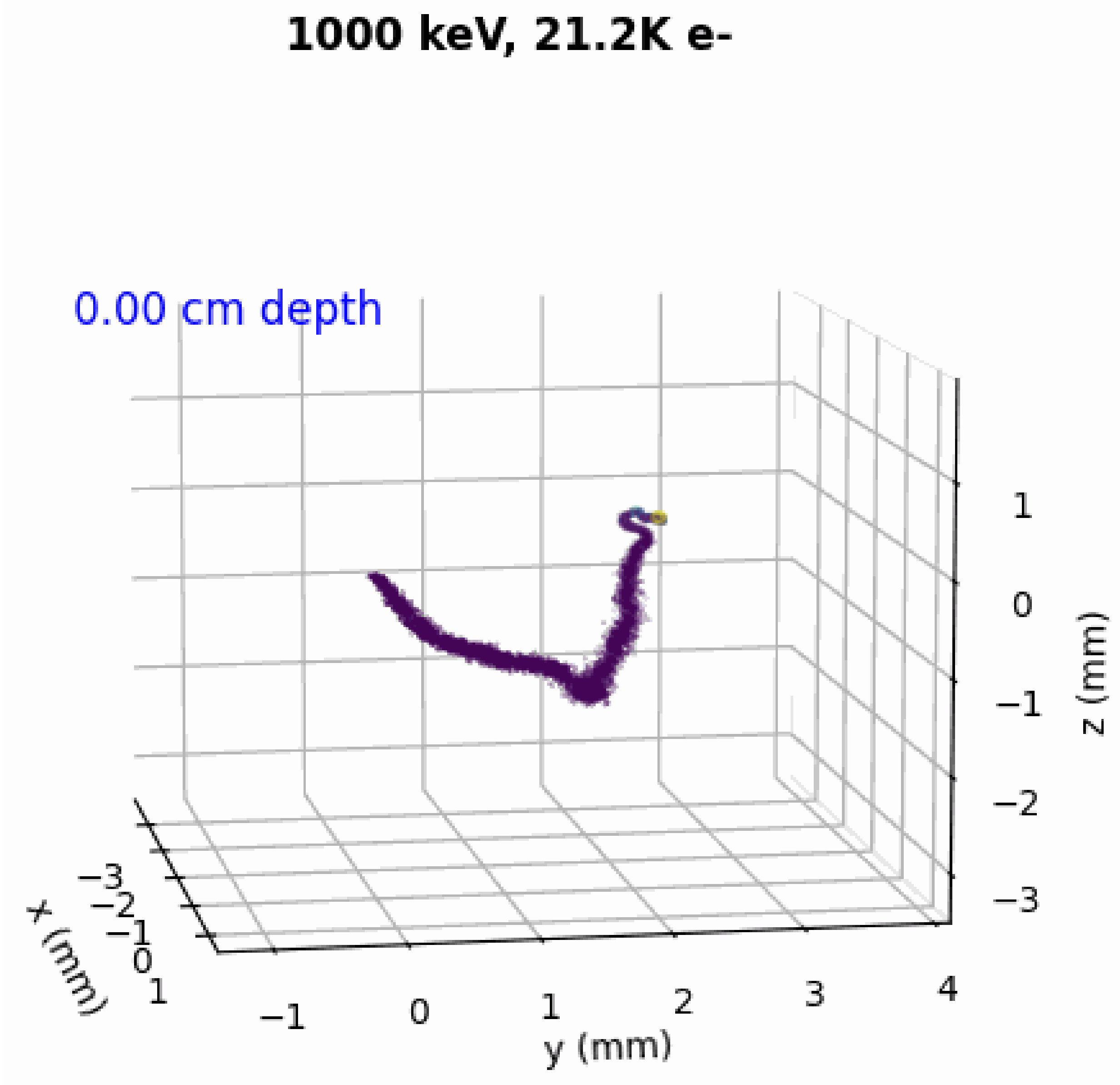
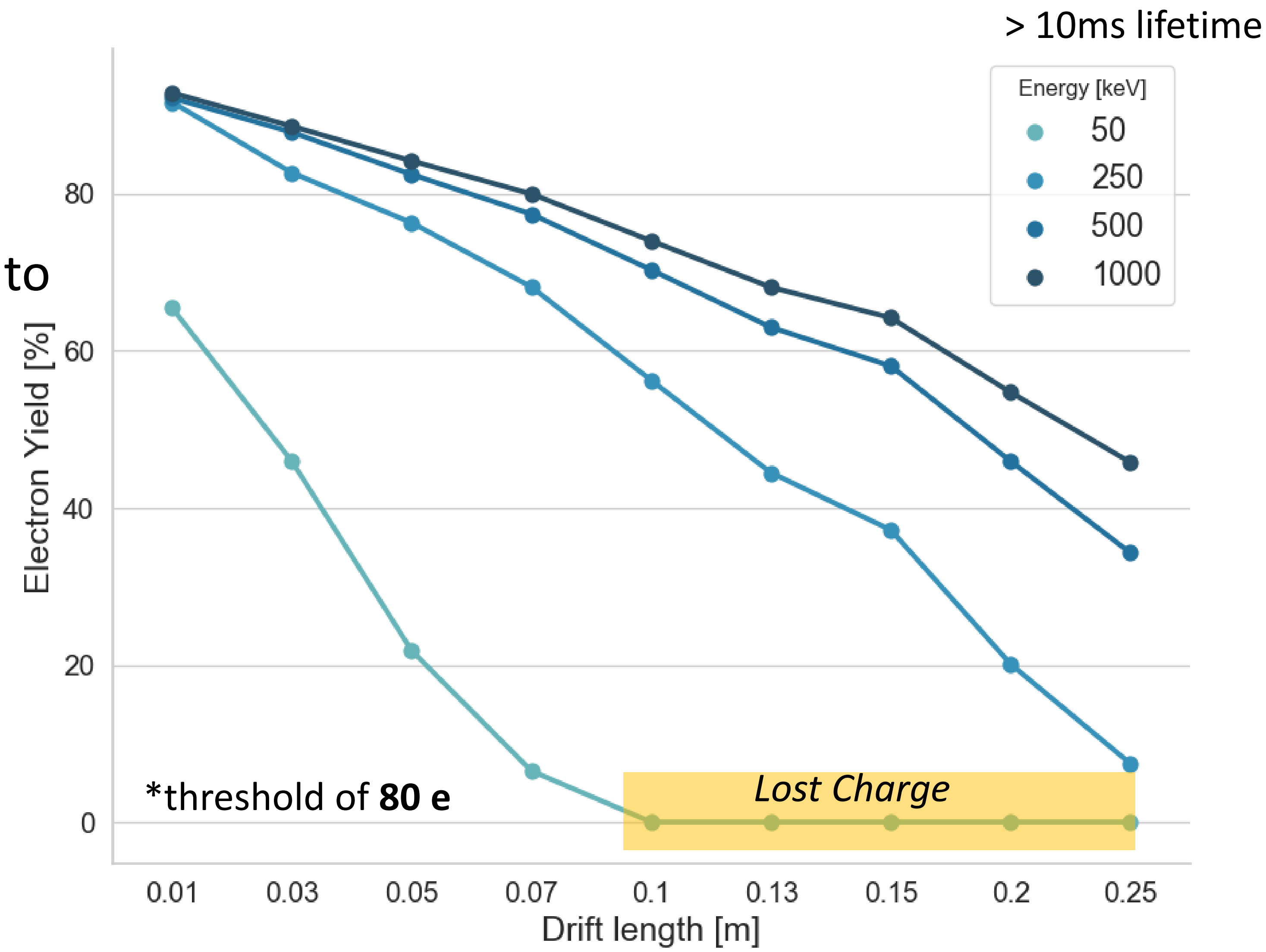




Example of **Pixels Only** Readout

Lost charge due to threshold



How to Image the Electron Tracks?

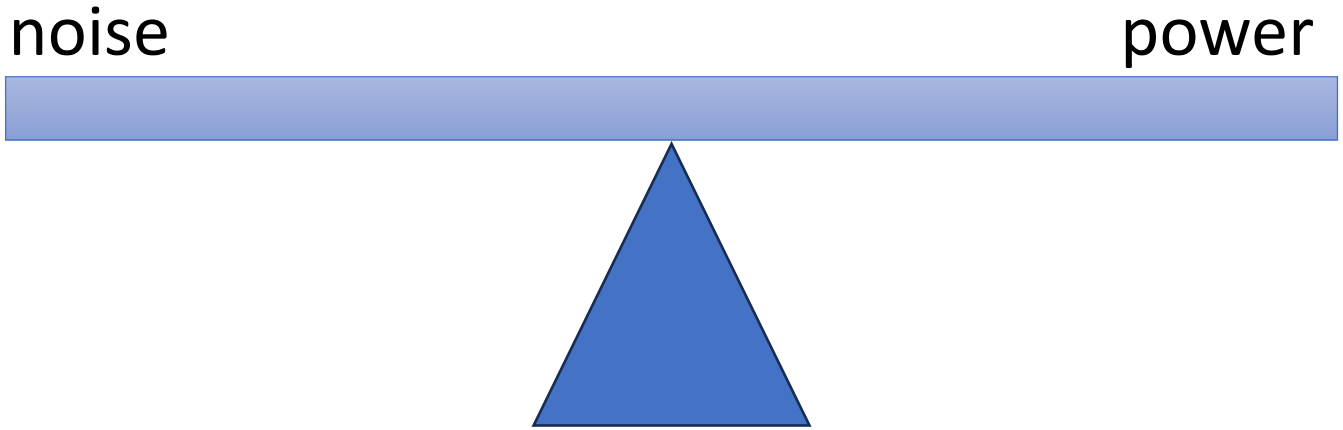
Challenges:

- **Charge loss** when diffusion is on the scale of sensors

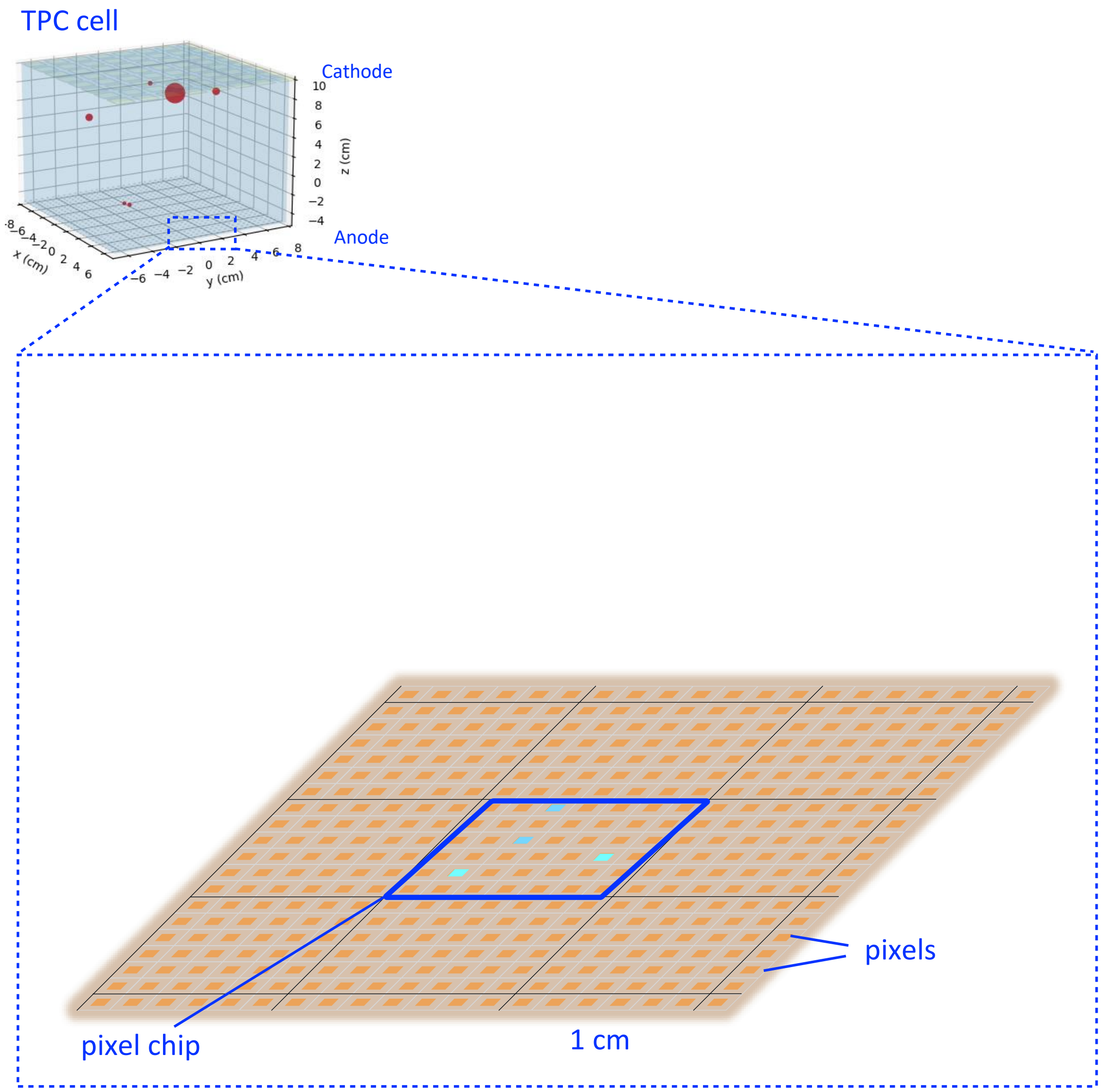
- Low noise needs **high power**

Noise sets the
- *energy resolution*
- *threshold*

$$\sigma_e \propto C^{1/2} I_D^{-1/2}$$

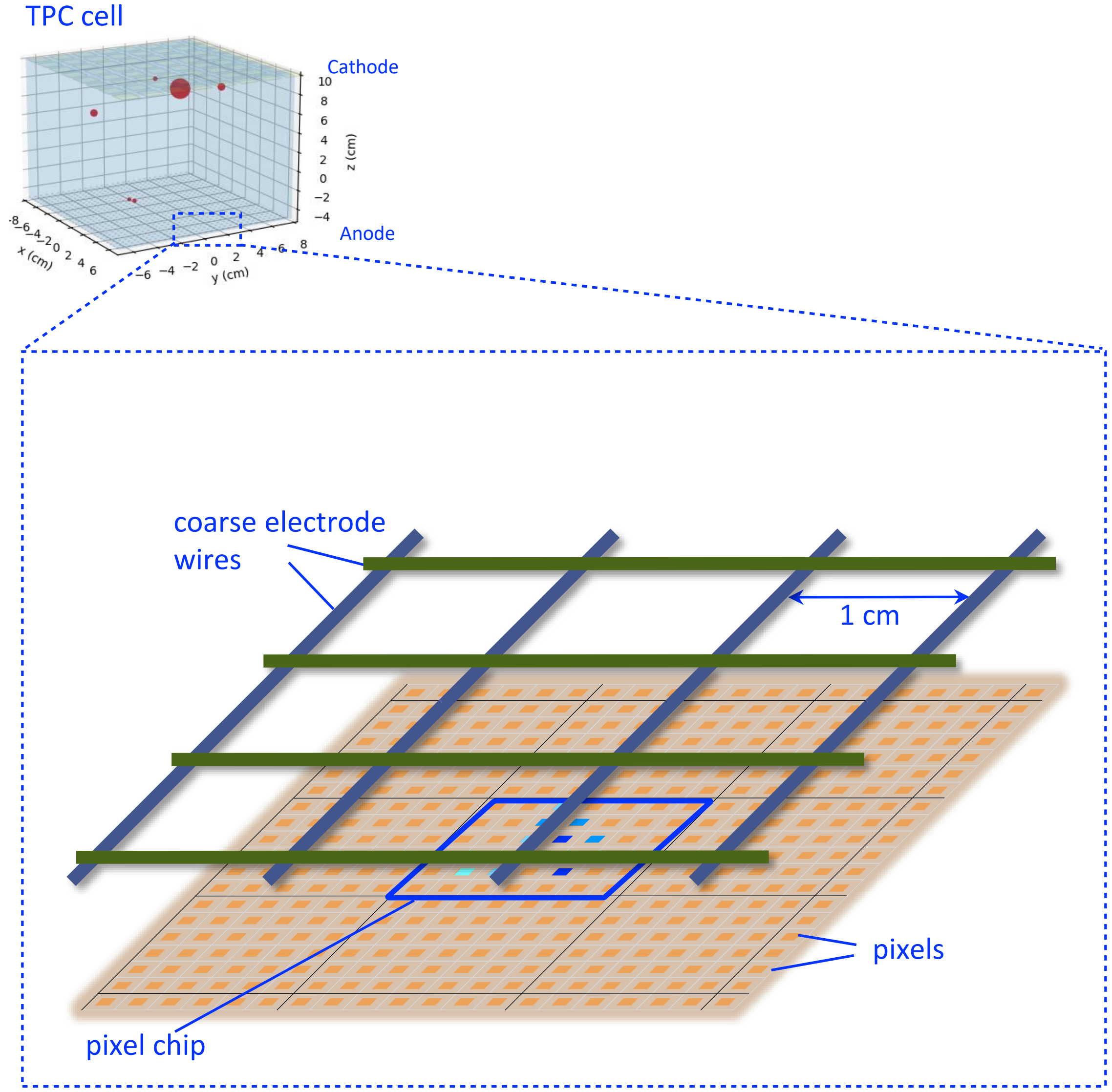


Grid Activated Multi-scale Pixel readout: GAMPix



- <u>Pixel chips:</u>
  - Image track

Grid Activated Multi-scale Pixel readout: GAMPix



Coarse (cm-pitch) induction grids followed by fine grained pixels

- <u>Coarse grids:</u>
  - Measure charge **integral**, with σ_e ~ 15 e$^-$
  - Provide **trigger signal (address)** to pixel chips
- <u>Pixel chips:</u>
  - Image track
  - Power-up in < 1 µsec following coarse trigger
  - Power, reduced by 10^{3}–10^{4}, to ~1 W/m^2

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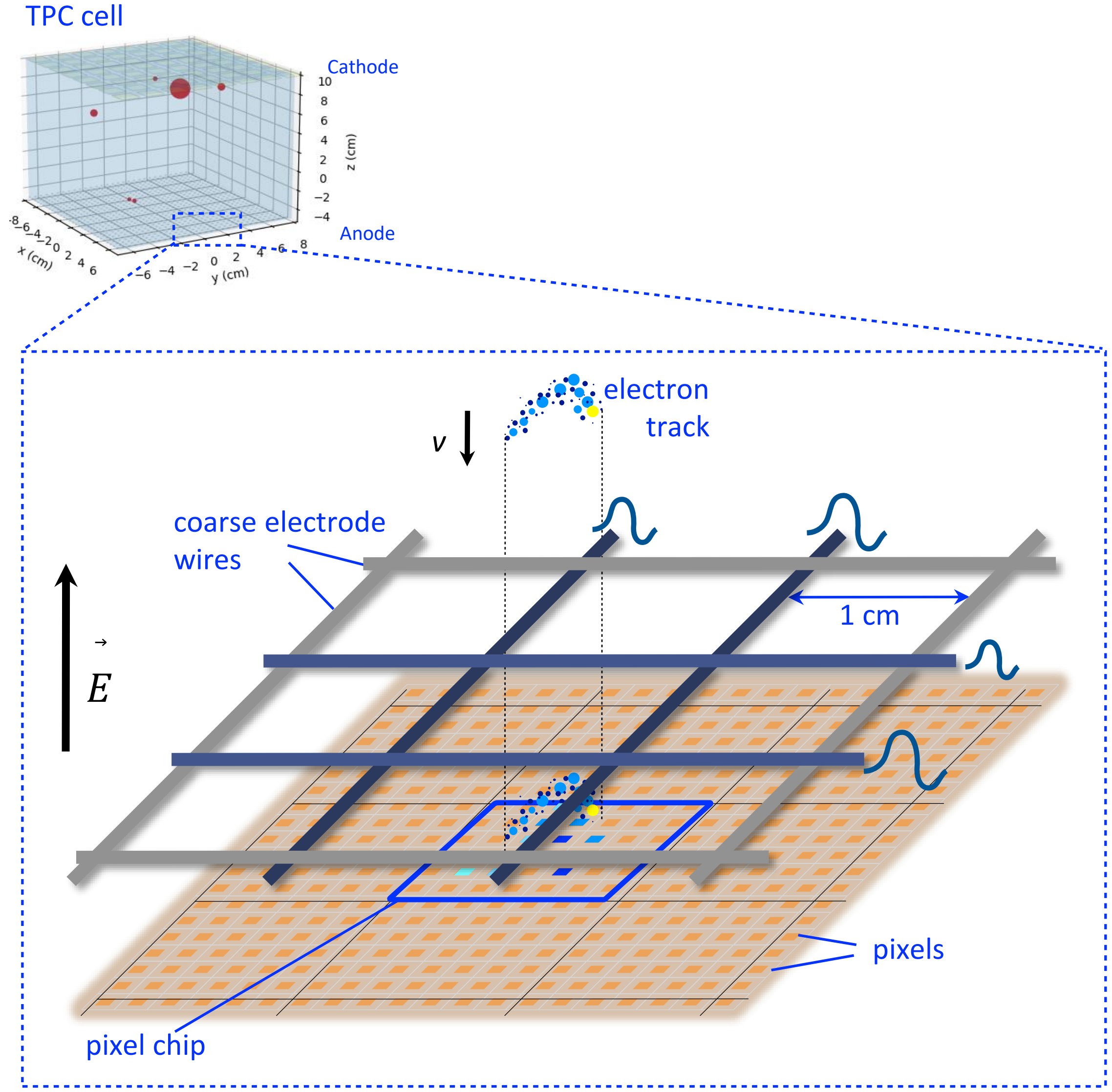

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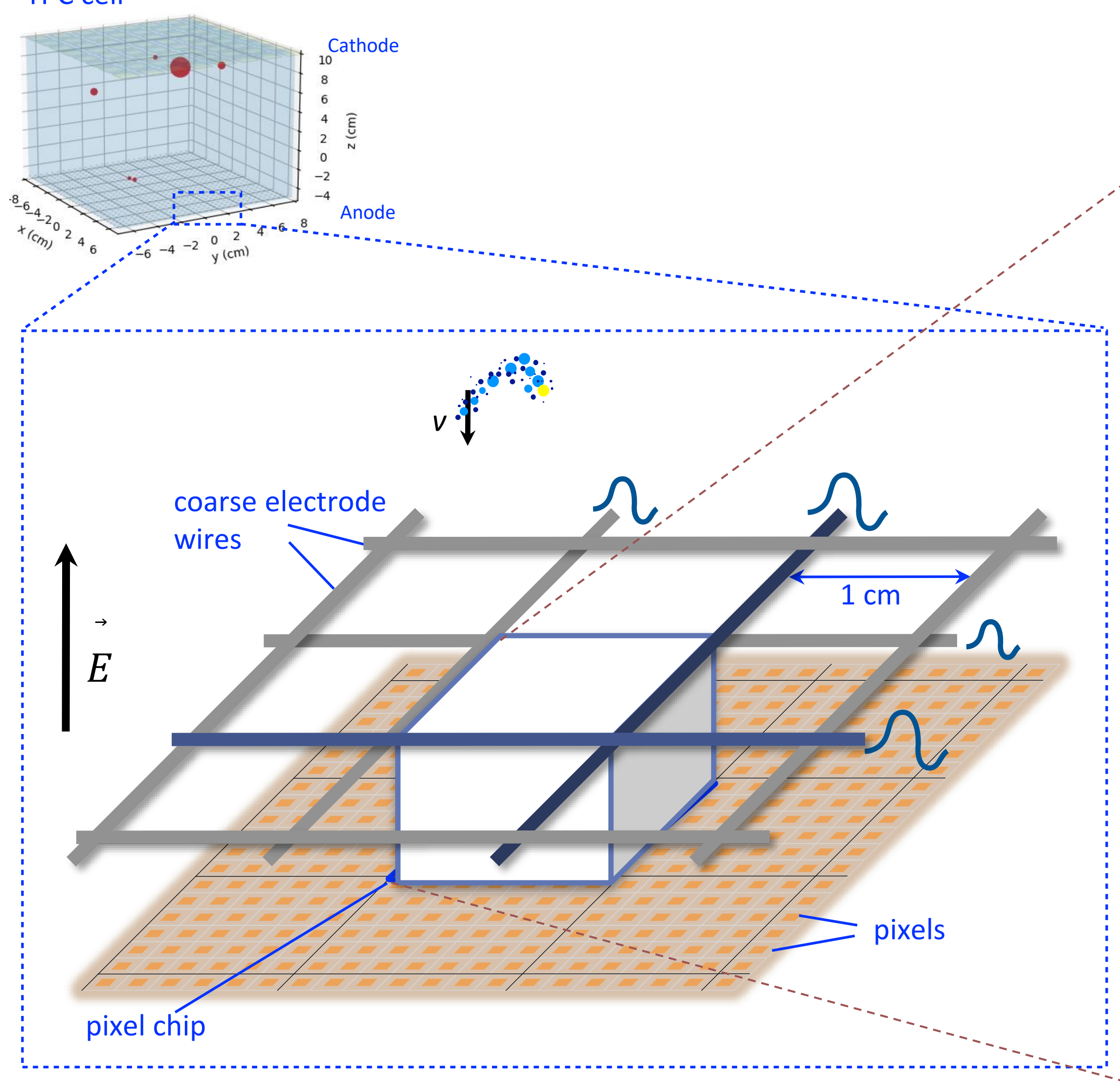
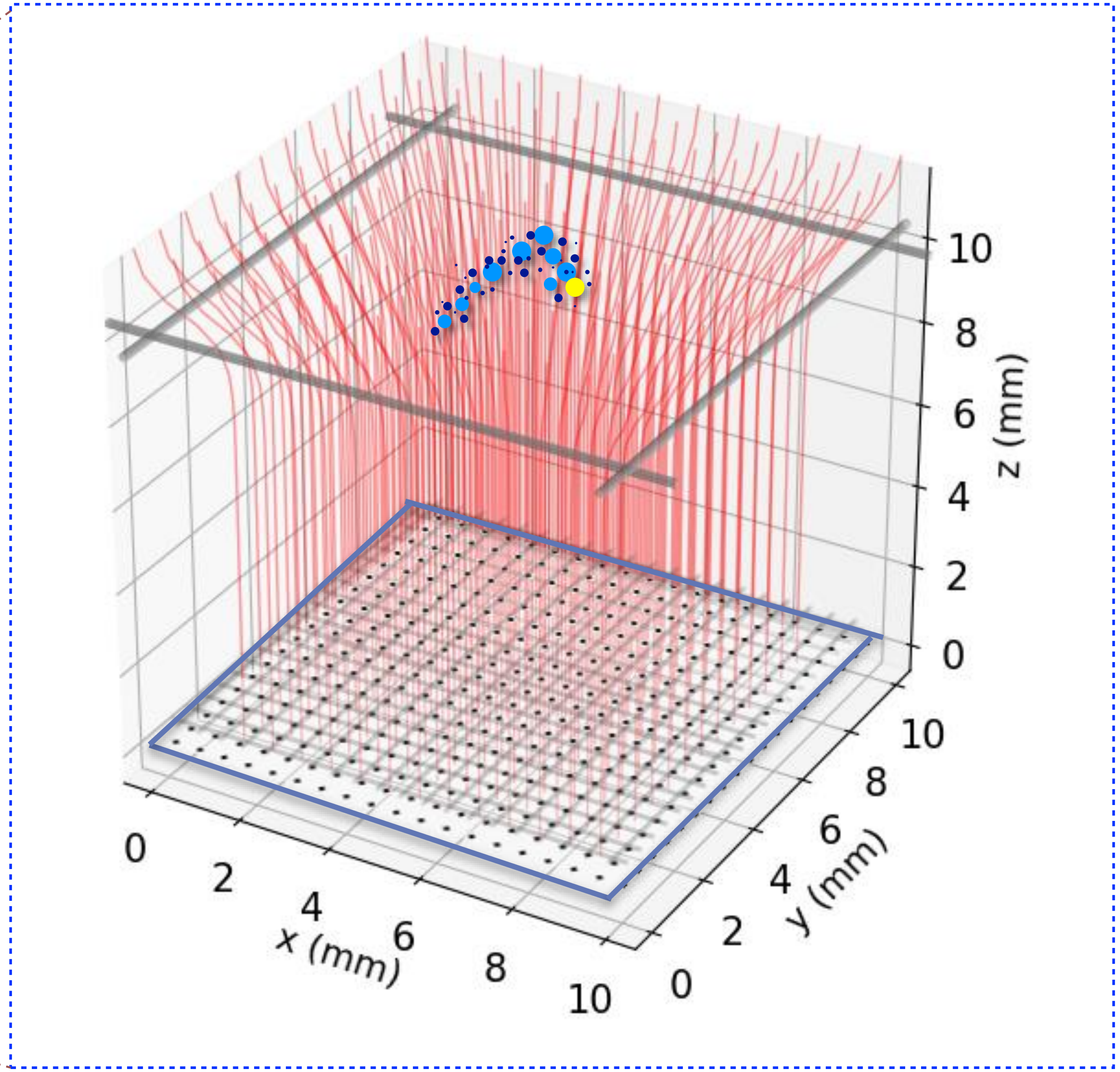
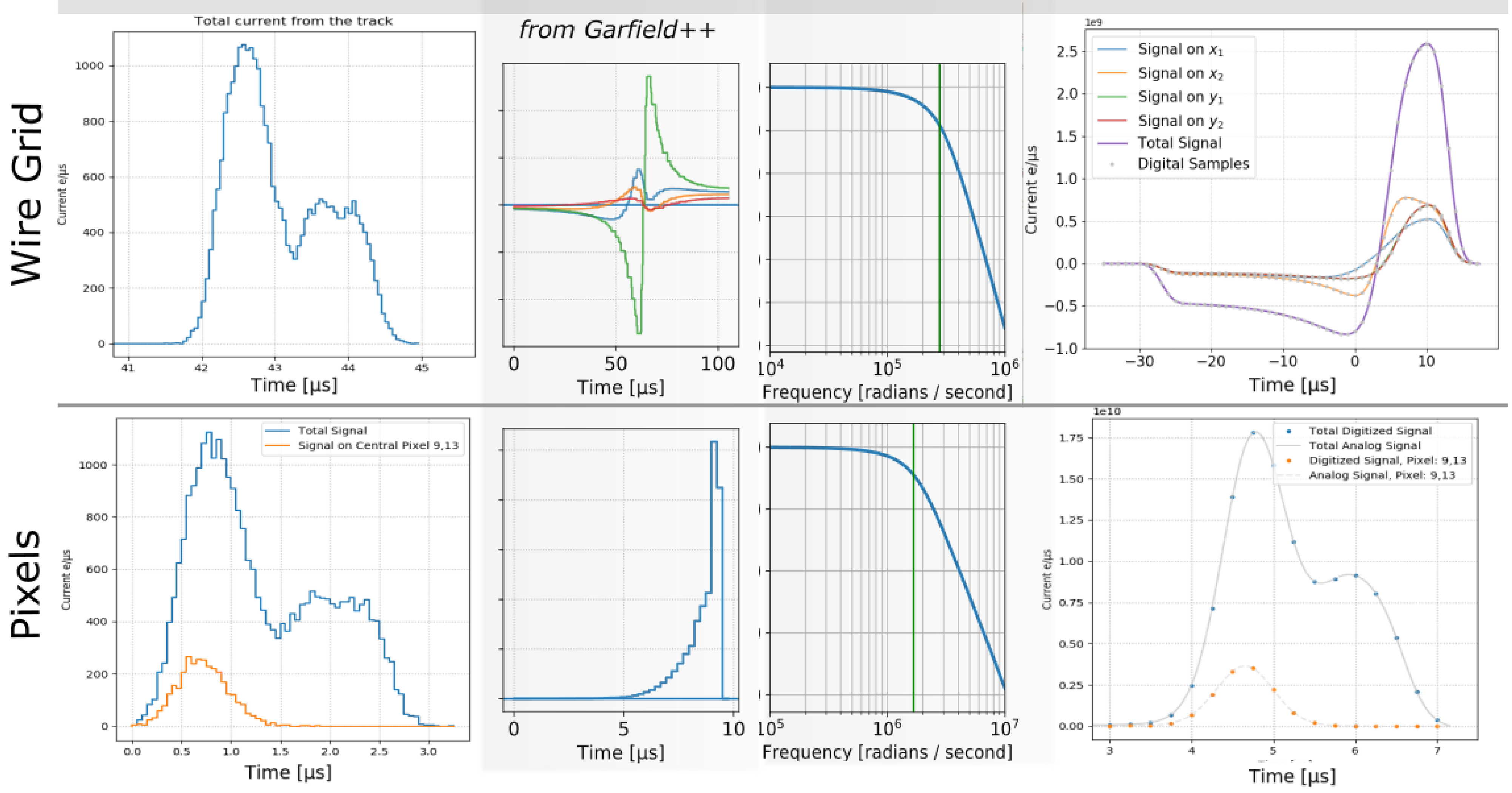


Electric Fields in GAMPix Unit



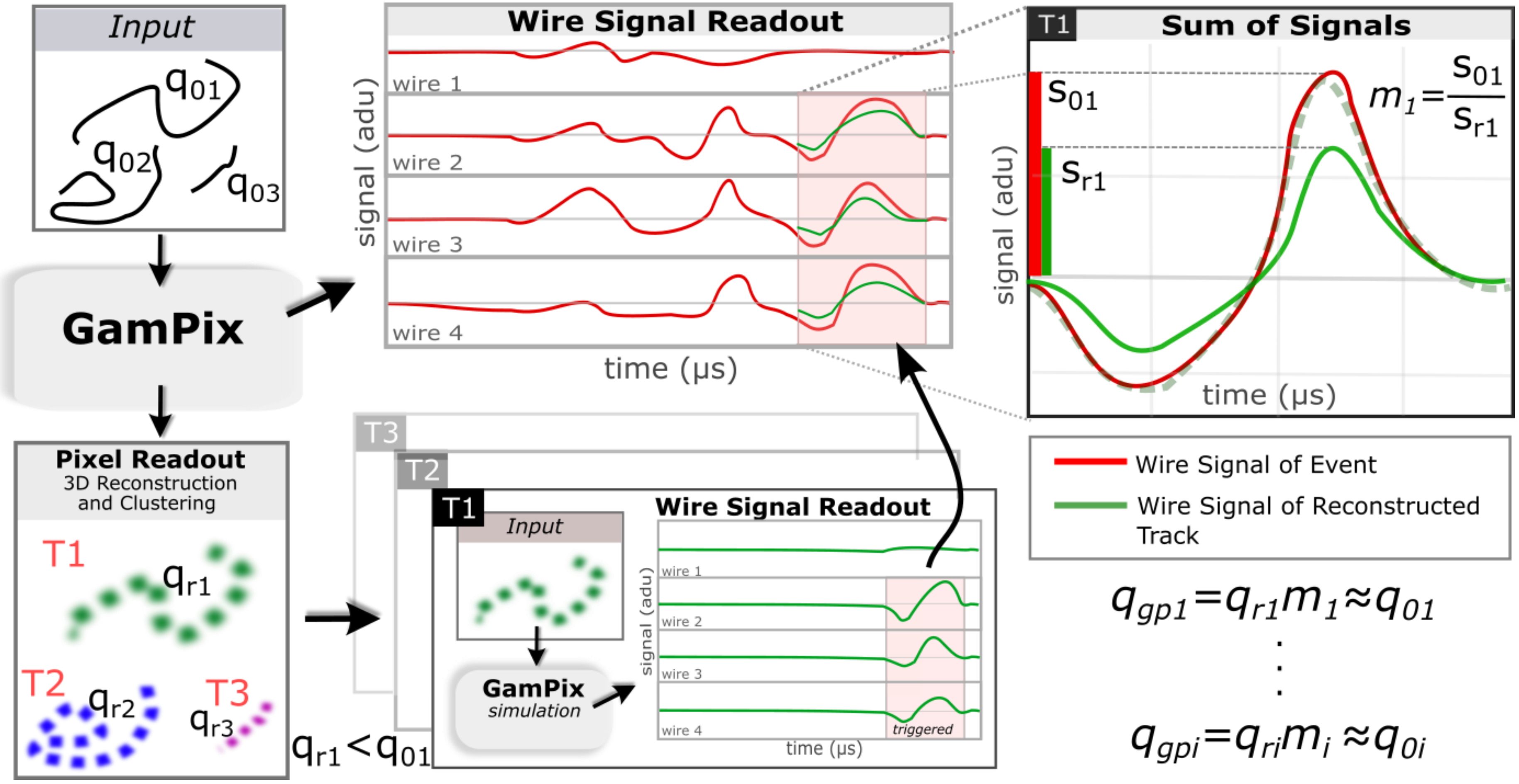
GAMPix | Simulated Signal Chain

Current from Drifting Electrons	Electric Field Response	Analog Bessel Filter	Analog and Digital Output



GAMPix | Simulated Signal Chain

Issue: Non-uniform response from the wire grid



$$q_{gp1}=q_{r1}m_1\approx q_{01}$$

$$\vdots$$

$$q_{gpi}=q_{ri}m_i\approx q_{0i}$$

GAMPix | Simulation Results

GammaTPC

Submillimeter (0.25mm) **Resolution**
Pixelated Track Imaging

Energy Resolution of < 1%
for electron tracks >100 keV (2k e^-) with an ENC of $20e^-$ on pixels and $30e^-$ on wires.

Low Power Consumption ~ 1 W/m^2

Due to the **triggering** capability and **fast pixel power cycling**, the pixel plane has a low duty-cycle.
Energy saving by a factor of 10^3 to 10^4

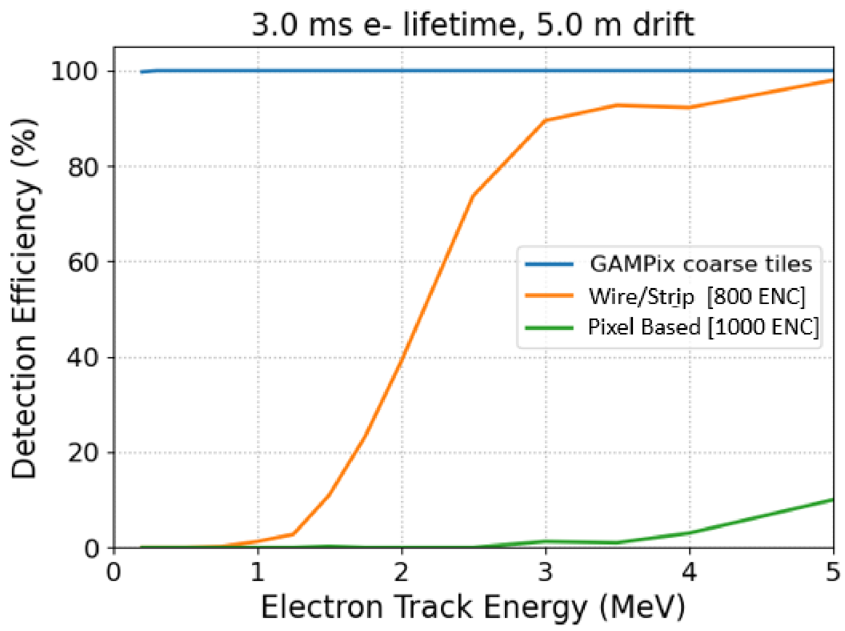
Drift Length Estimation via Diffusion with ~5% accuracy

DUNE

Geometry:

~ 5mm pitch pixels

~ 5 cm pitch grid

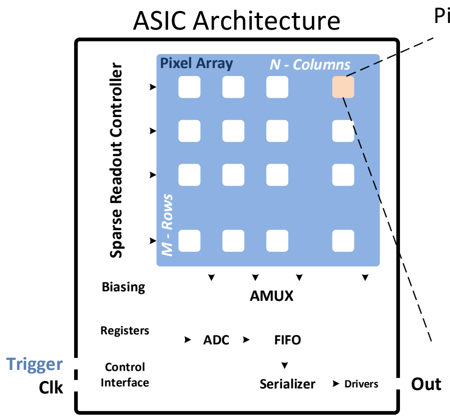


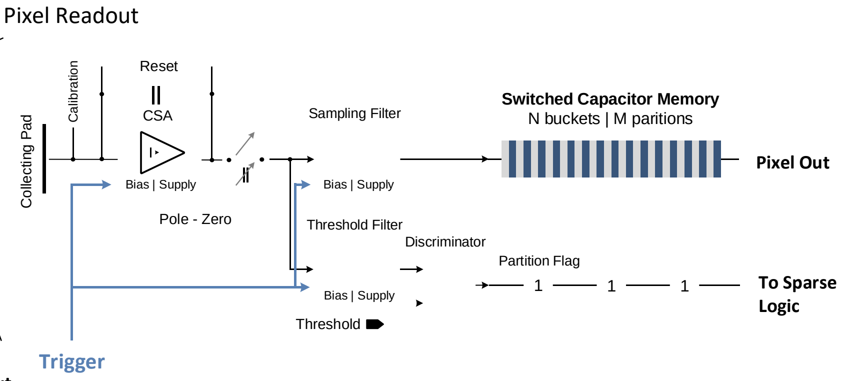
Outcomes
Electronic noise reduction from ~500e- to ~50e- lowers threshold for “blip” detection from >1MeV to **much less**

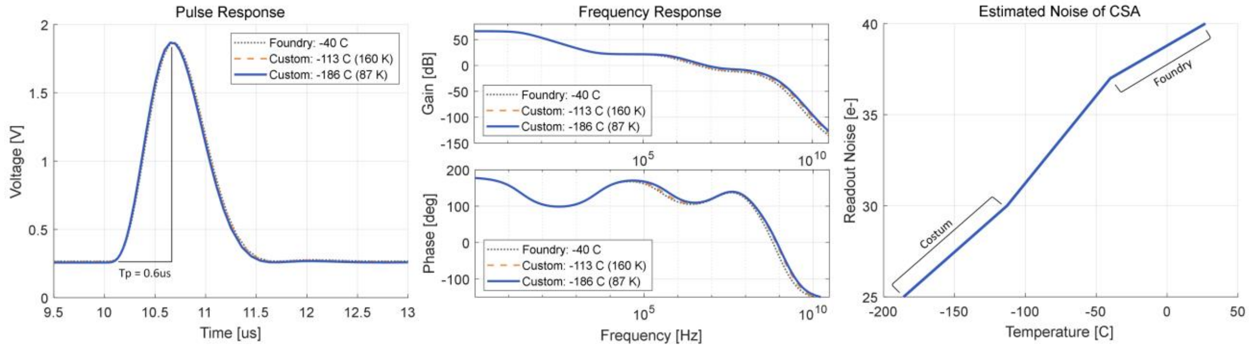
Power cycling the pixels’ front-end reduces the average power to acceptable levels

Drift Length Estimation via Diffusion with **~5%** accuracy (Helps with background rejection for SN)

GAMPix fast power cycle ASIC







- Builds on pixelated ASICs from SLAC TID-ID, cryogenic SoC ASIC development for nEXO/DUNE and quantum instrumentation
- 130nm CMOS process (foundry + SLAC custom cryo models)
- Preliminary transistor-level modeling of power switching CSA: **ΔT_{on}~500 ns, $\sigma_e \sim 25e-$**

TID-ID INTEGRATED CIRCUITS DEPARTMENT

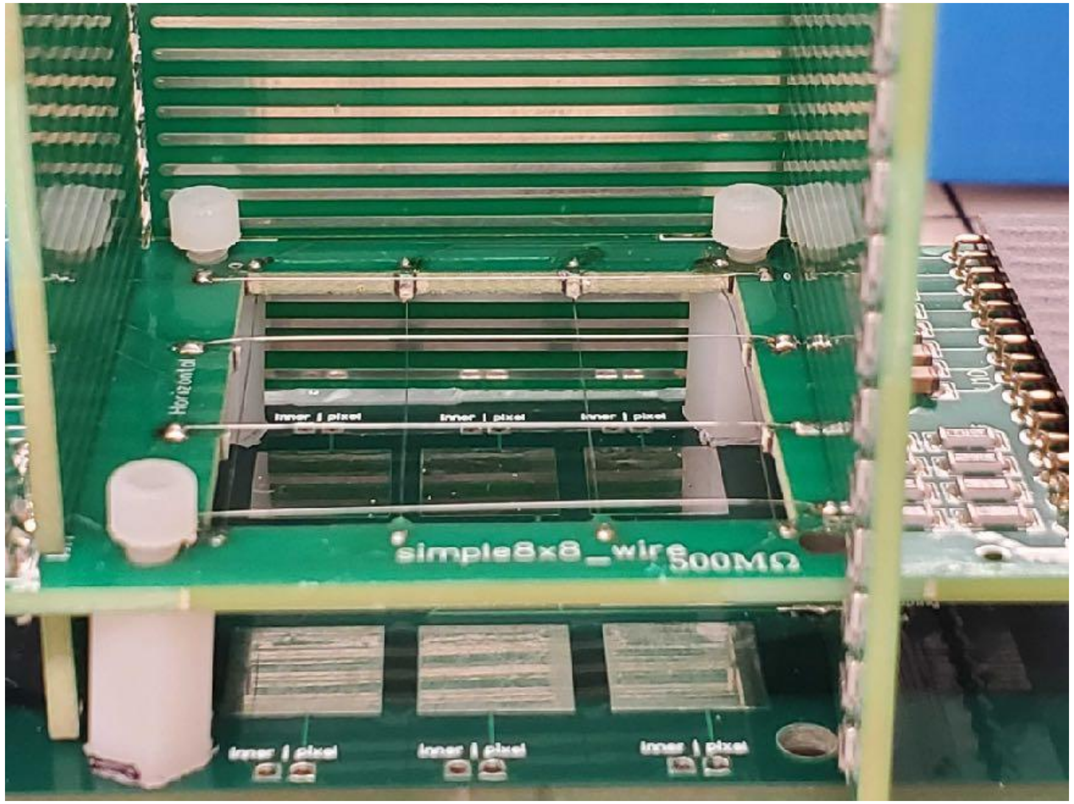
I would like to continue talking about…

- Other possible applications of GAMPix
- GAMPix hardware test
- GammaTPC

\- Machine learning for GAMPix

  \+ Depth estimation via diffusion

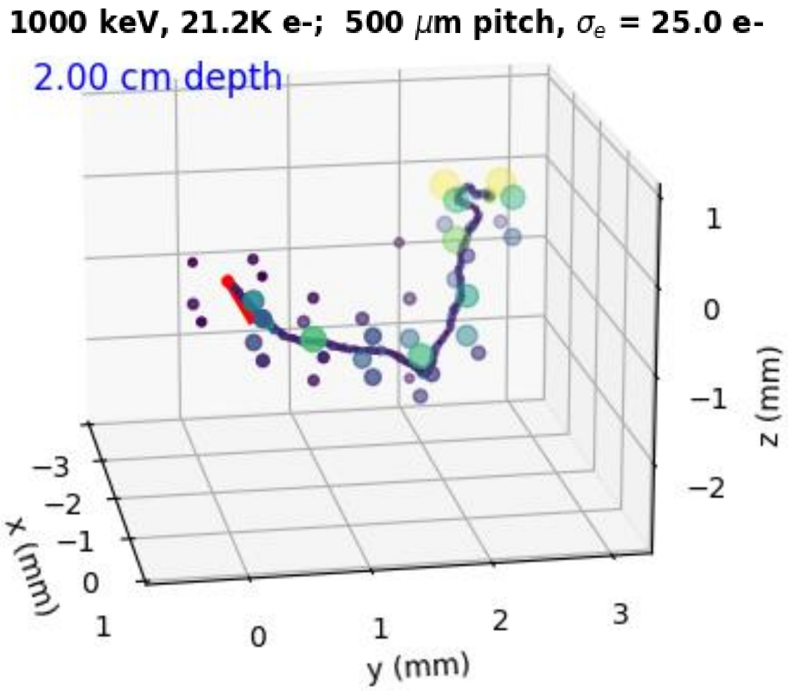
  \+ Initial electron direction estimation



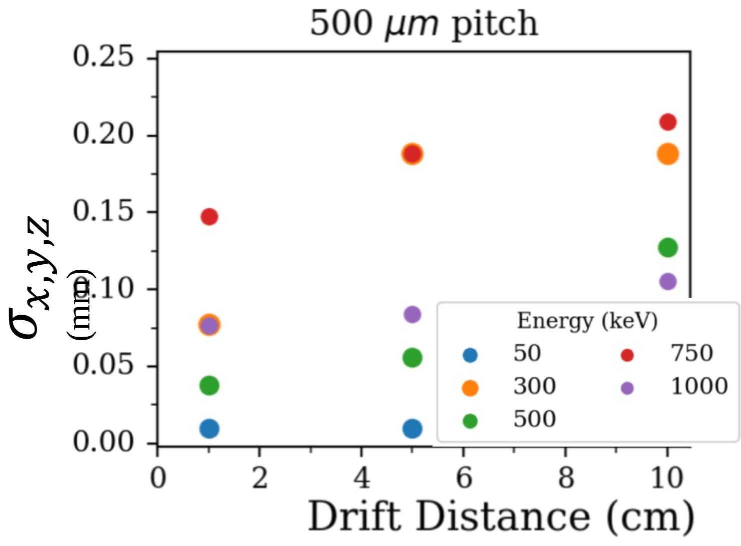
Upcoming test with CRYO (σ_e~100e-) readout

BACKUP Slides

Track reconstruction promising



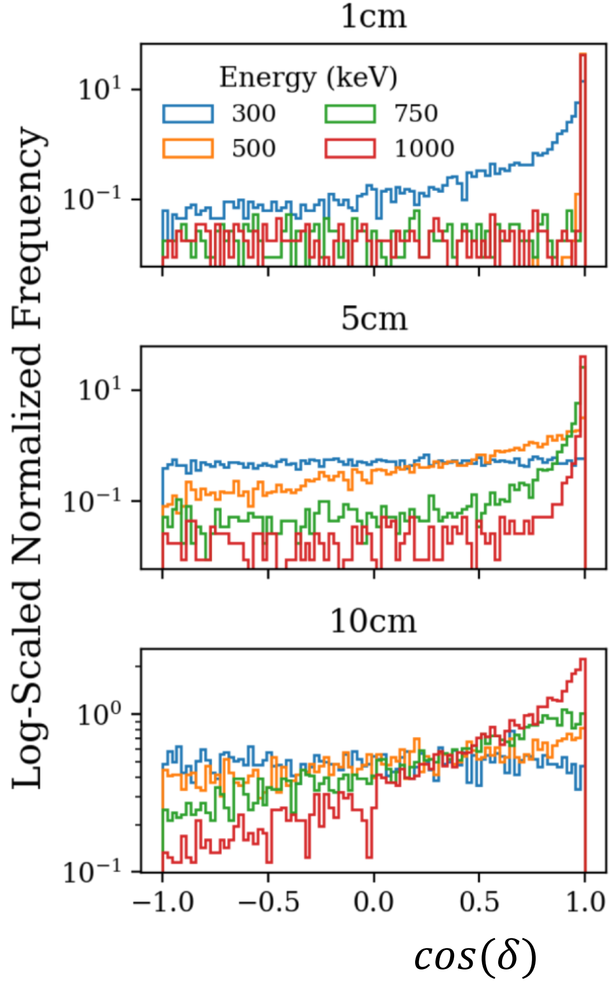
Track head location



CNN study: M. Buuck, B. Khek, A. Mishra, ArXiv/2207.07805

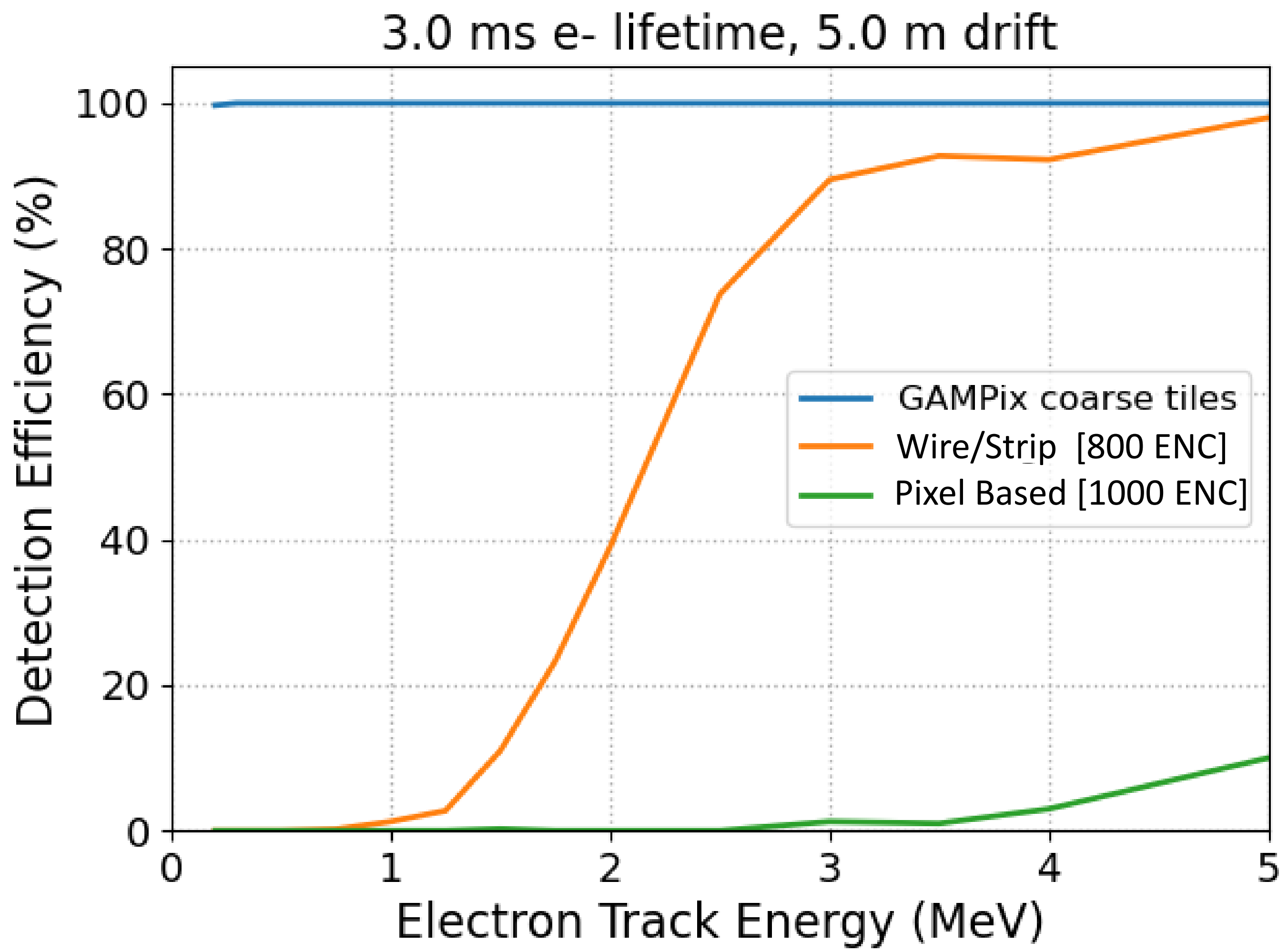
0.25 mm !!!

Initial direction



- Powerful measurement of initial direction
- Also: ~5% estimate of drift distance

GAMPix for DUNE



Energy Threshold Improvement

Geometry:

~ 5mm pitch pixels

~ 5 cm pitch of unified grid

Outcomes

- A pixel-based readout system that reduces that electronic noise from ~500e- to ~50e- lowers threshold for "blip" detection from >1MeV to **much less**

- An "activation" signal from a coarse electrode "grid" to power the pixels' front-end and reduce the **average power to acceptable levels**

- Drift length estimation via diffusion measure (with ~ 5% accuracy)