

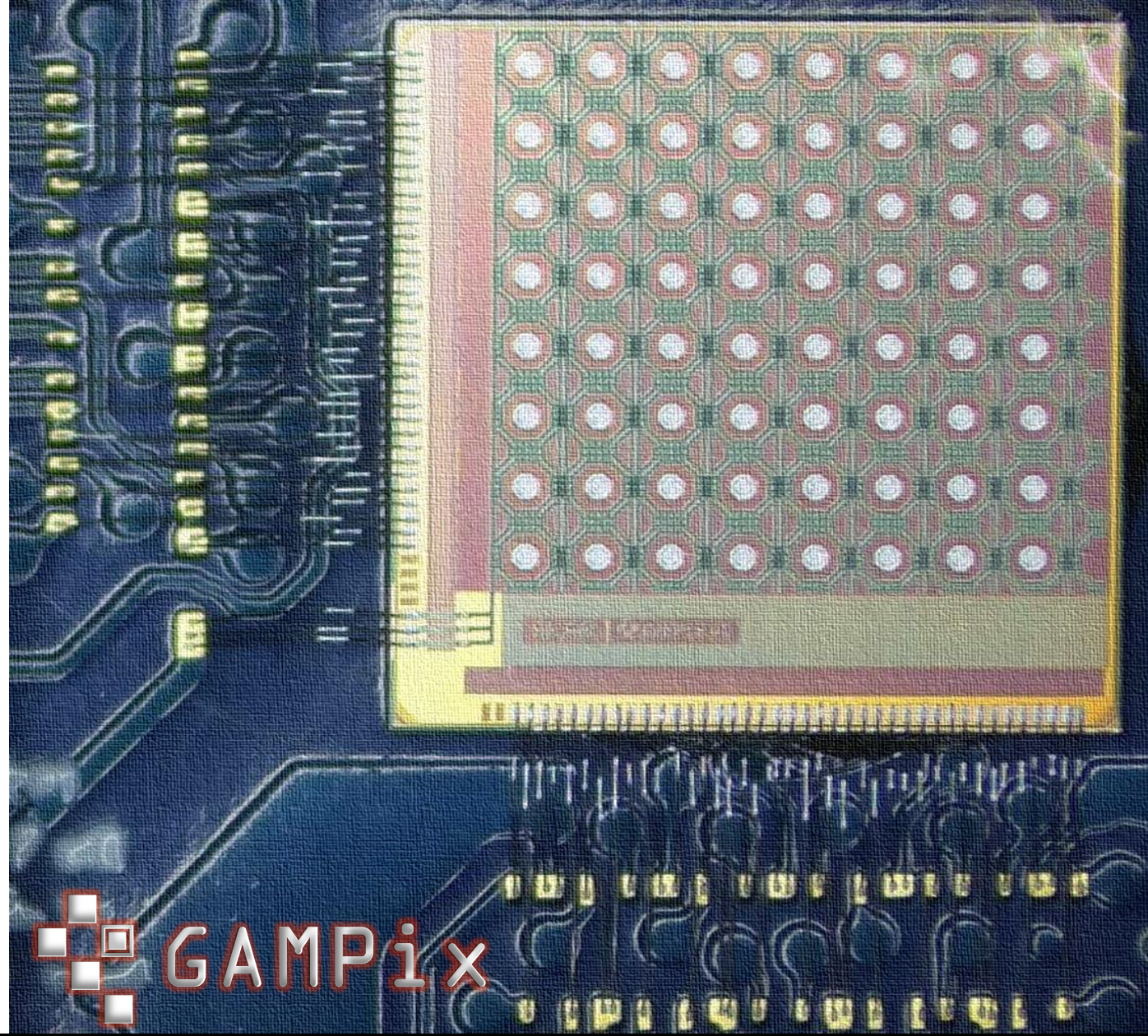
GAMPIX

Grid Activated Multi-scale Pixel Readout

First Prototype Results

Bahrudin Trbalic

SLAC | Stanford University



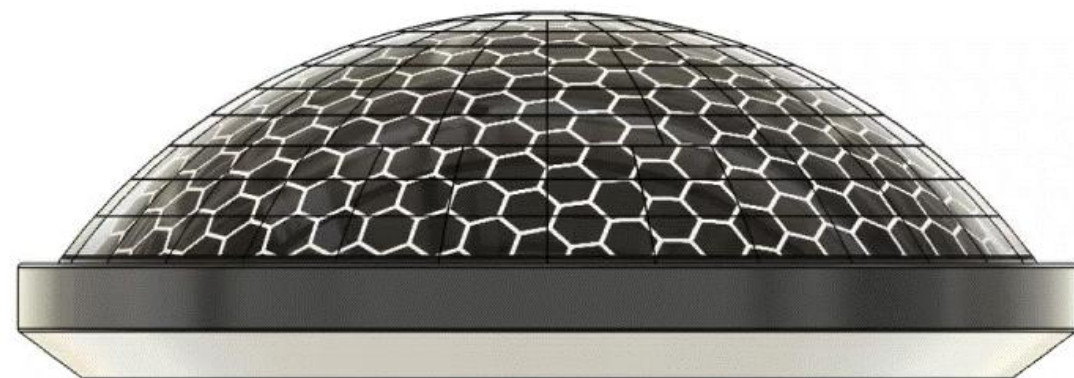
Agenda

1. Motivation for GAMPix
2. How it Works
3. First Prototype Results
& applications: GammaTPC, DUNE...

GammaTPC

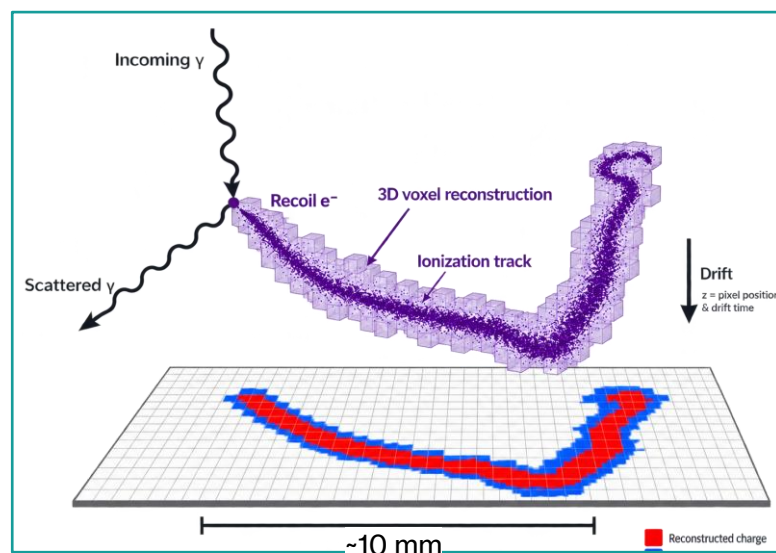
Instrument Concept

Large-area LAr TPC gamma-ray telescope

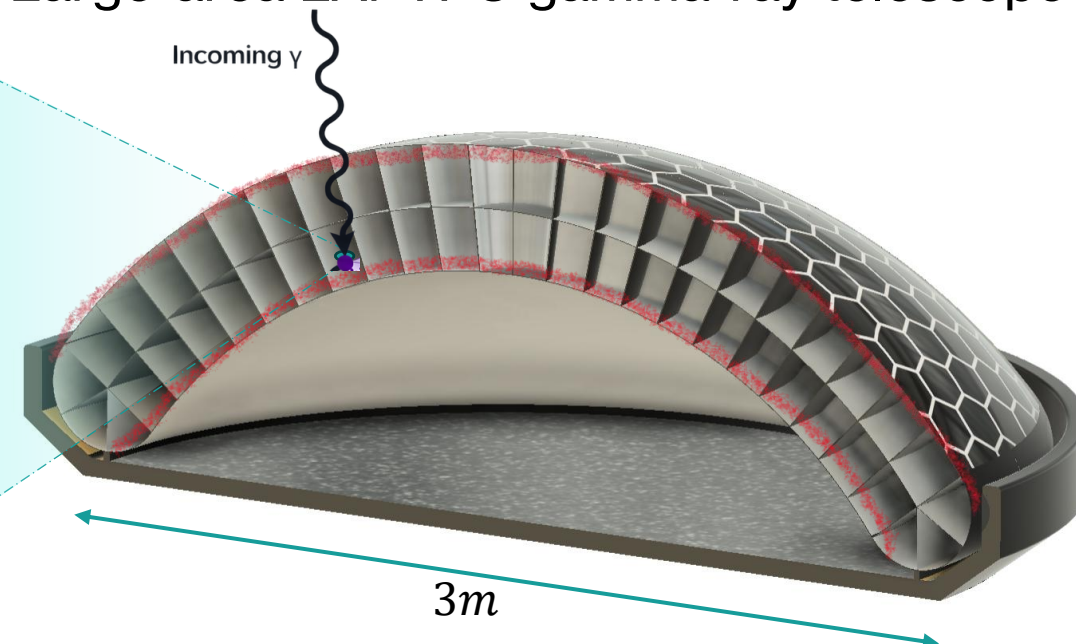


GammaTPC

Instrument Concept



Large-area LAr TPC gamma-ray telescope



SCIENCE-DRIVEN READOUT REQUIREMENTS

10 m²

Instrument area

3D readout

Uniform detector response

0.5 mm

Pixel pitch · 40M pixels

< 50 e⁻

Pixel noise

< 2 W/m²

Cooling budget at 100 K

~1%

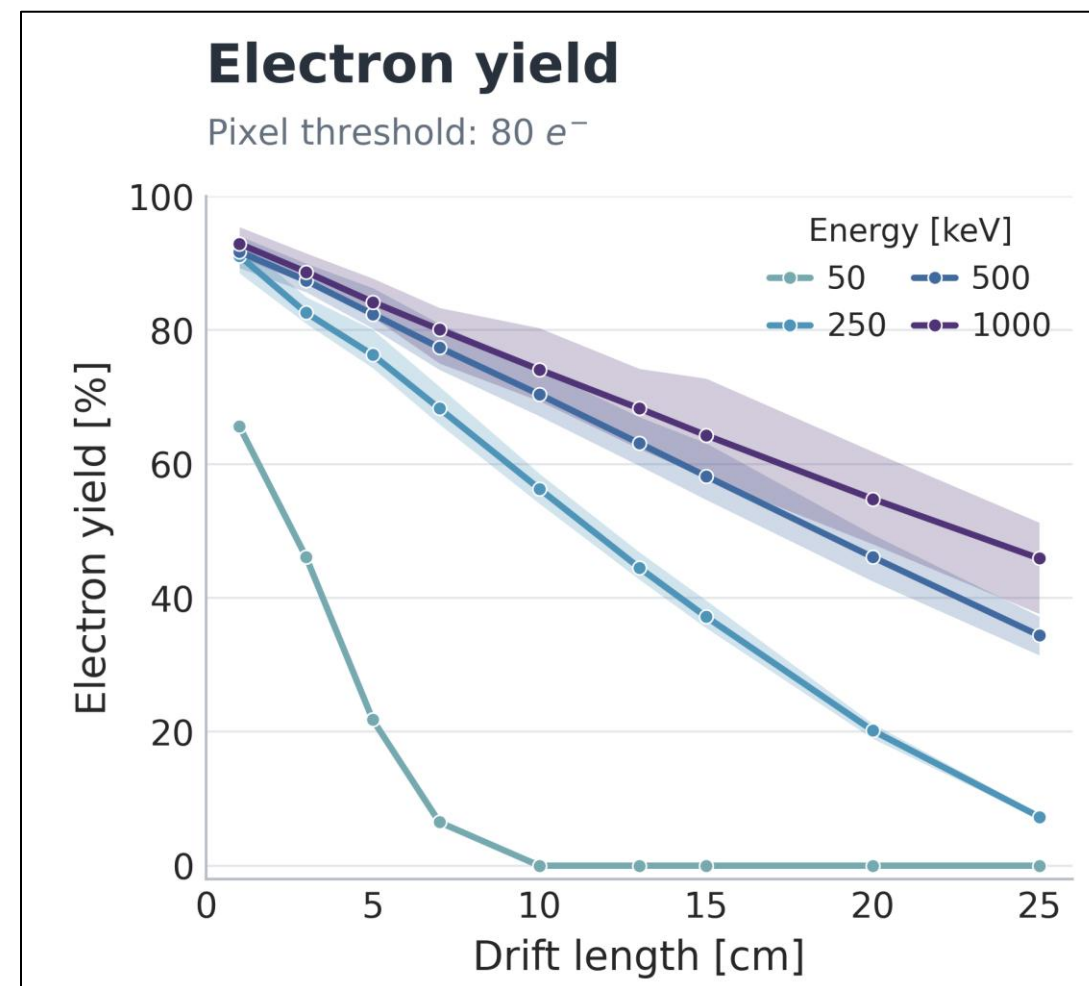
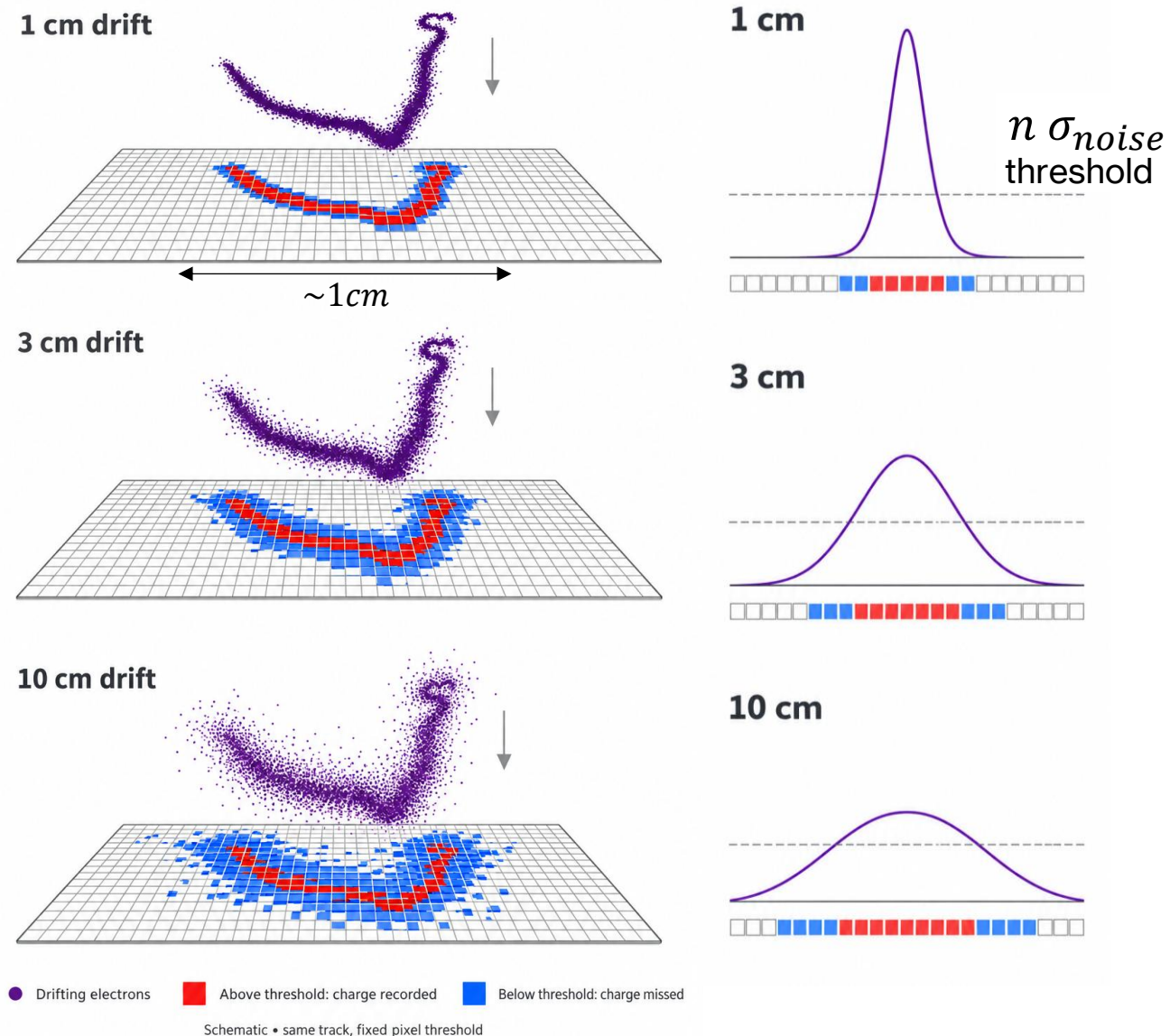
Track charge resolution

The challenge: Read out **millions of pixels** with **low noise, high charge precision**, and an exceptionally **small cryogenic power** budget.

There is more...

Why TPC?

Charge Loss due to Diffusion



Even **50 e** noise is too high for the desired accuracy

“Decrease the pixel noise.”

– Someone, probably

$$\sigma_e \sim \frac{1}{\sqrt{P}}$$

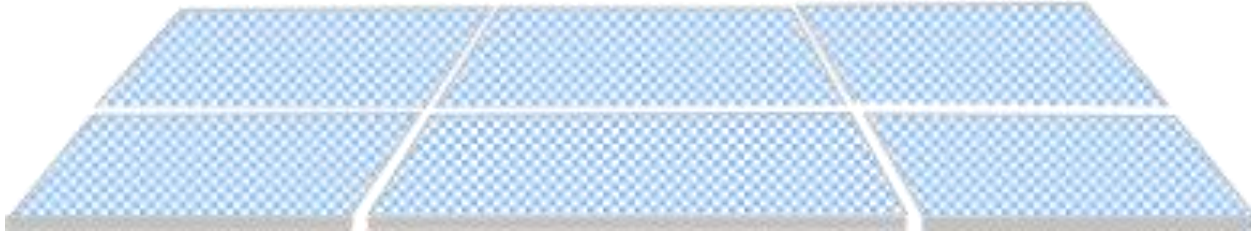
Even for 50e we would need $100 \mu W/\text{pixel} = 2 \text{ kW}/m^2$.

That is 1000x too high (**in space**, or anywhere)

Back to the drawing board...

We have the Pixels

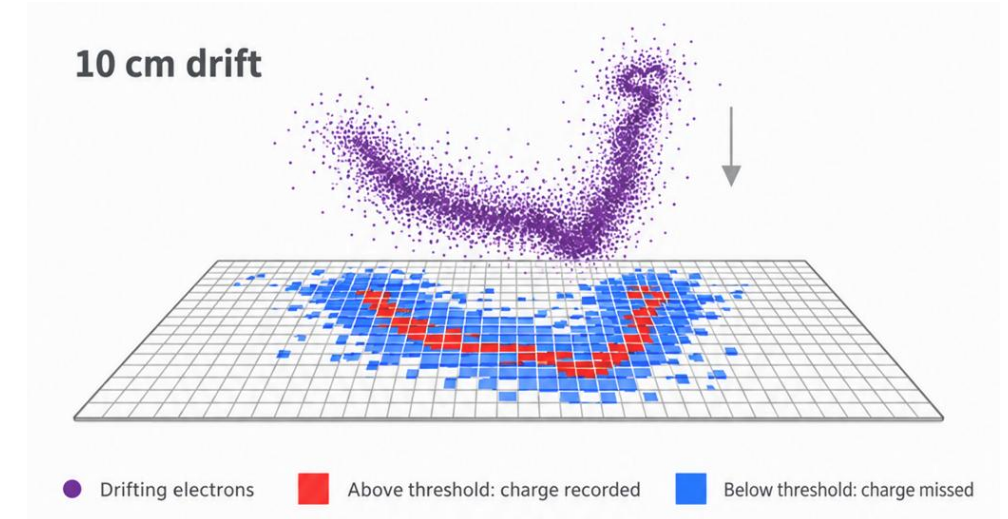
LArPIX for example



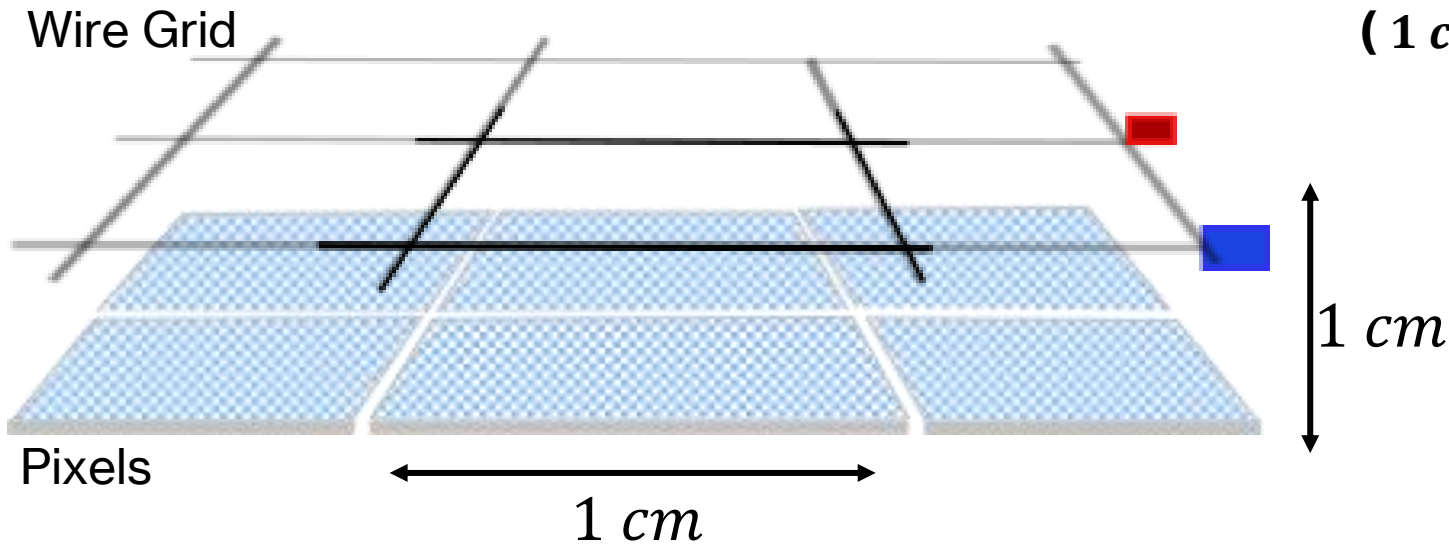
Pixels

Sensors too small

Too much charge sharing



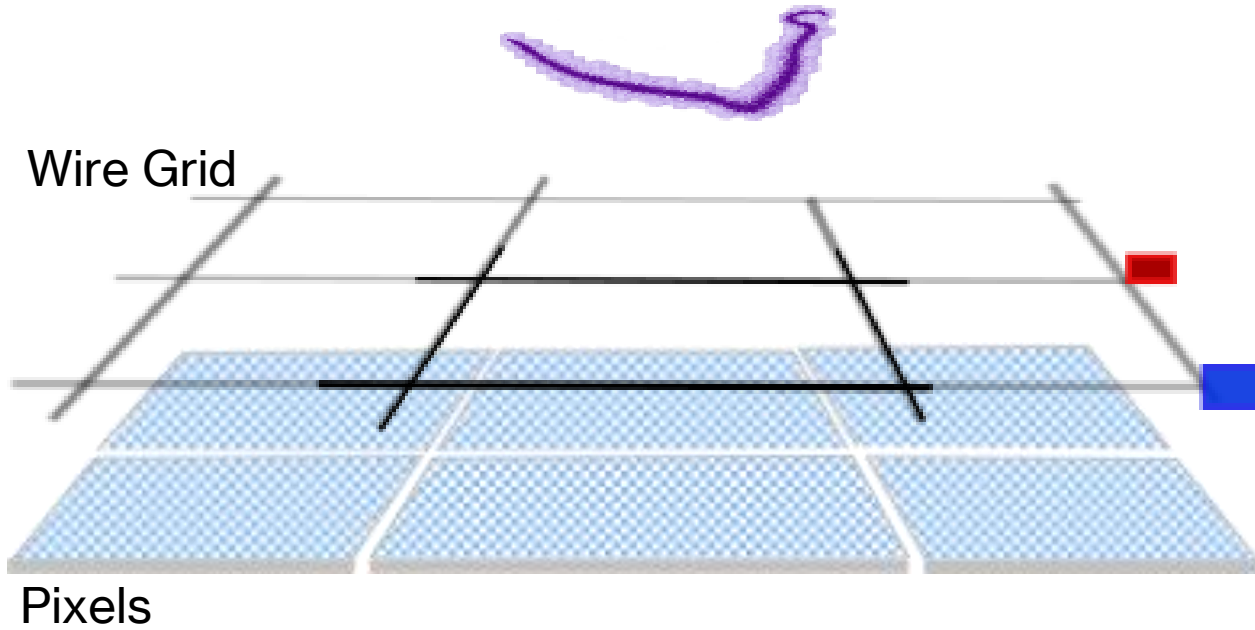
Wire Grid



Add a Wire Grid on top of the Pixels

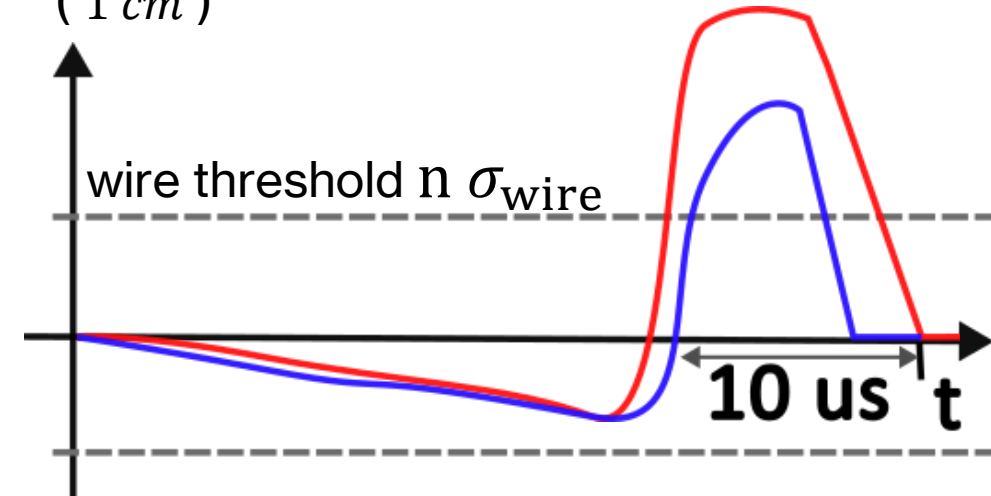
1. The pitch of the wires needs to be on the order of the diffusion (1 cm)
2. The vertical offset should be $\sim$ wire pitch (1 cm)

Wire Grid

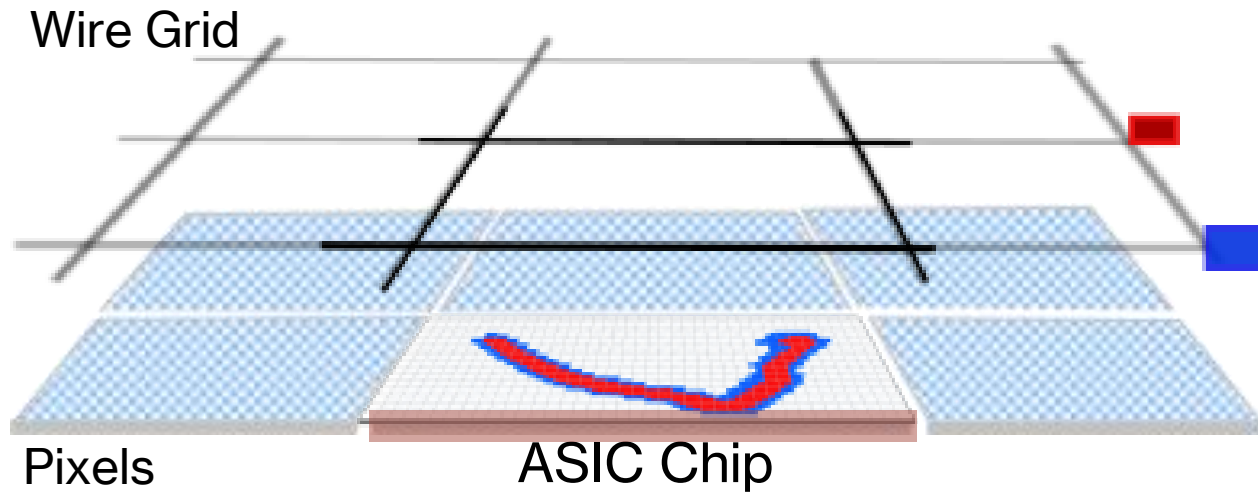


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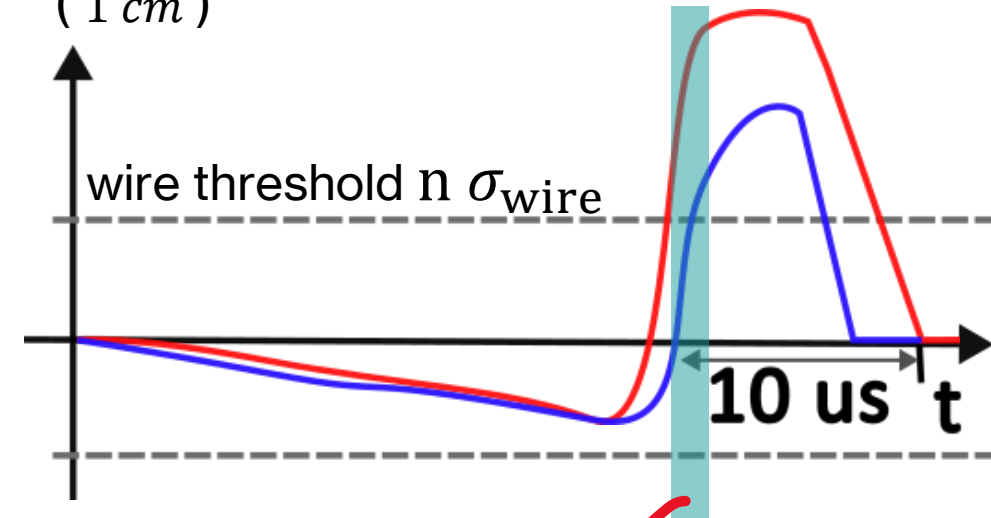


Wire Grid



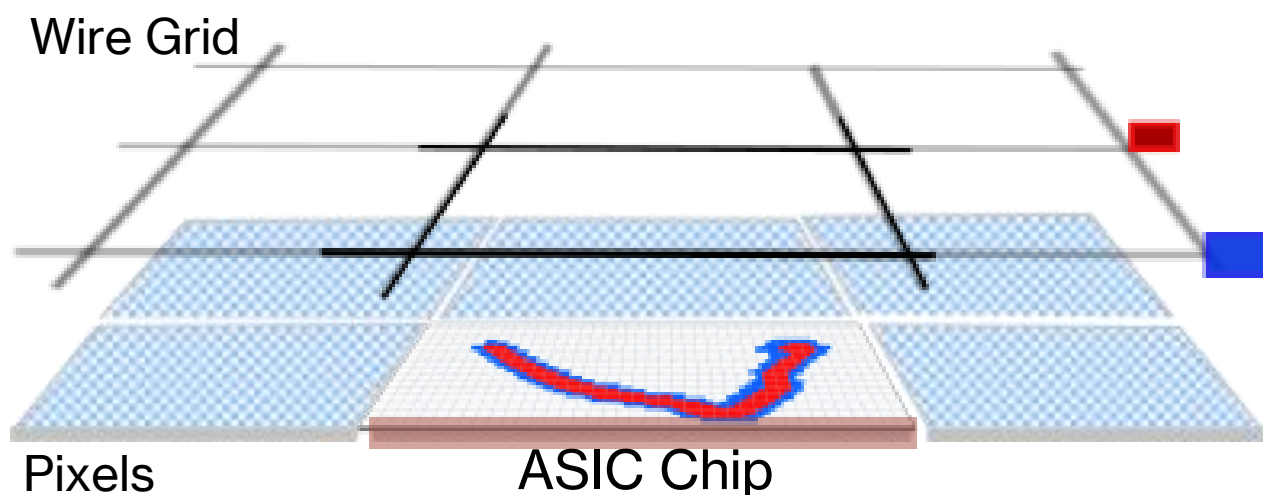
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- 1 Wire Grid Provides the **Trigger** for the Pixel ASIC Chip
 $\sim 10\text{ }\mu\text{s}$ ahead of charge arrival
+ location

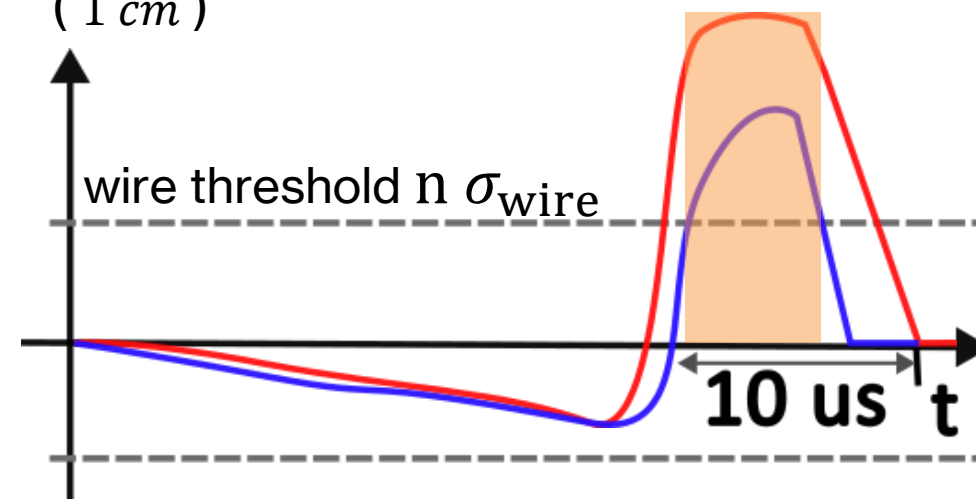
Wire Grid



1 | Wire Grid Provides the **Trigger** for the Pixel ASIC Chip
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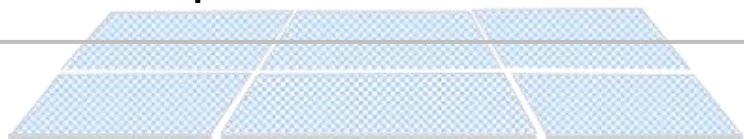


2 | Amplitudes of the Wire Signals* Provide the **Total Charge** of the Electron Track
 *Sum of 4 neighboring wires and a sophisticated reconstruction algorithm, see [1]

Pixels + Wires: More Than the Sum of Their Parts

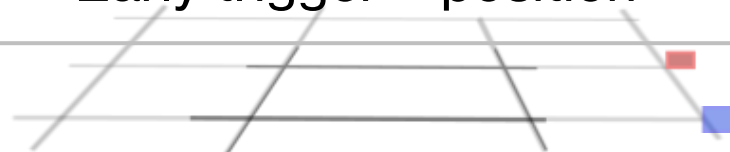
Pixels

Fine 3D tracking
Interaction position + recoil direction



Wires

Integrated Track Charge
Early trigger + position



Combine both measurements

Selective ASIC activation

$10^3\times$ Lower Pixel Power
(on average, for GammaTPC)

$\sim 10^3\times$ Less Data

Drift-length reconstruction

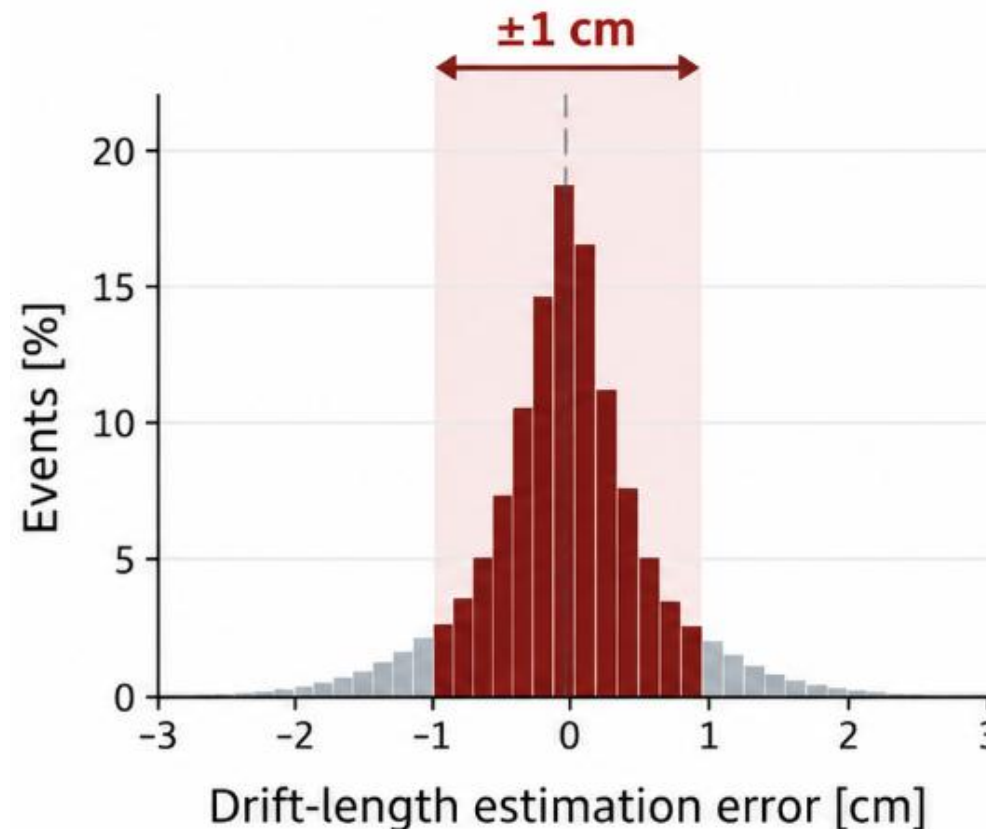
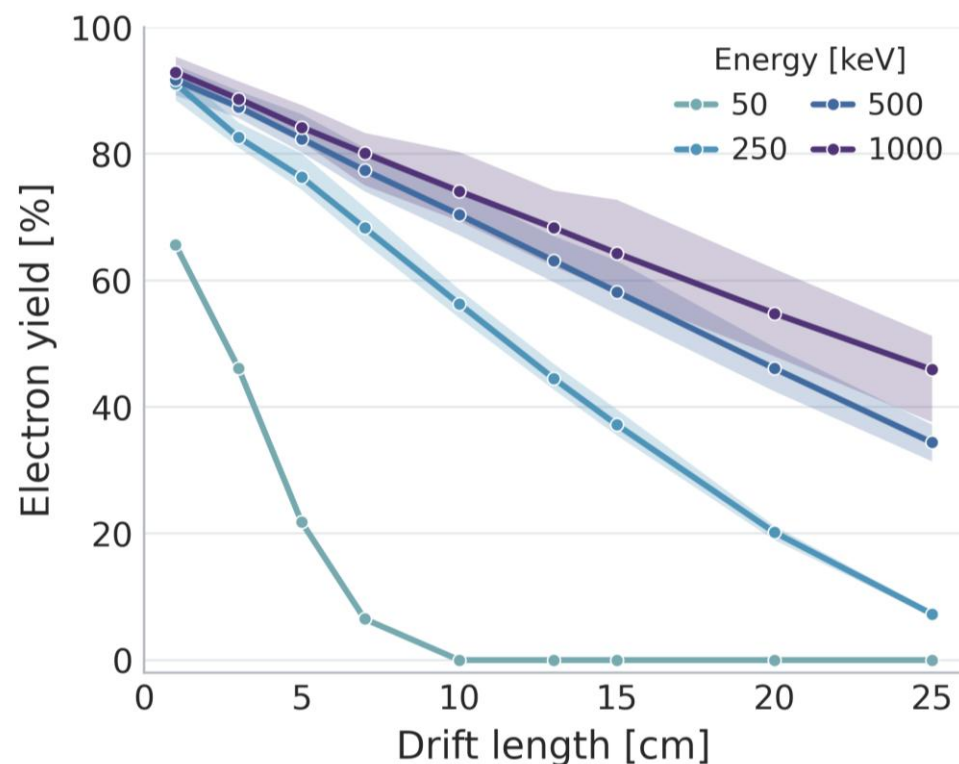
$$Q_{pixels} / Q_{wires}$$

Charge-yield information enables
drift-distance estimation

Complimentary Drift-length Reconstruction

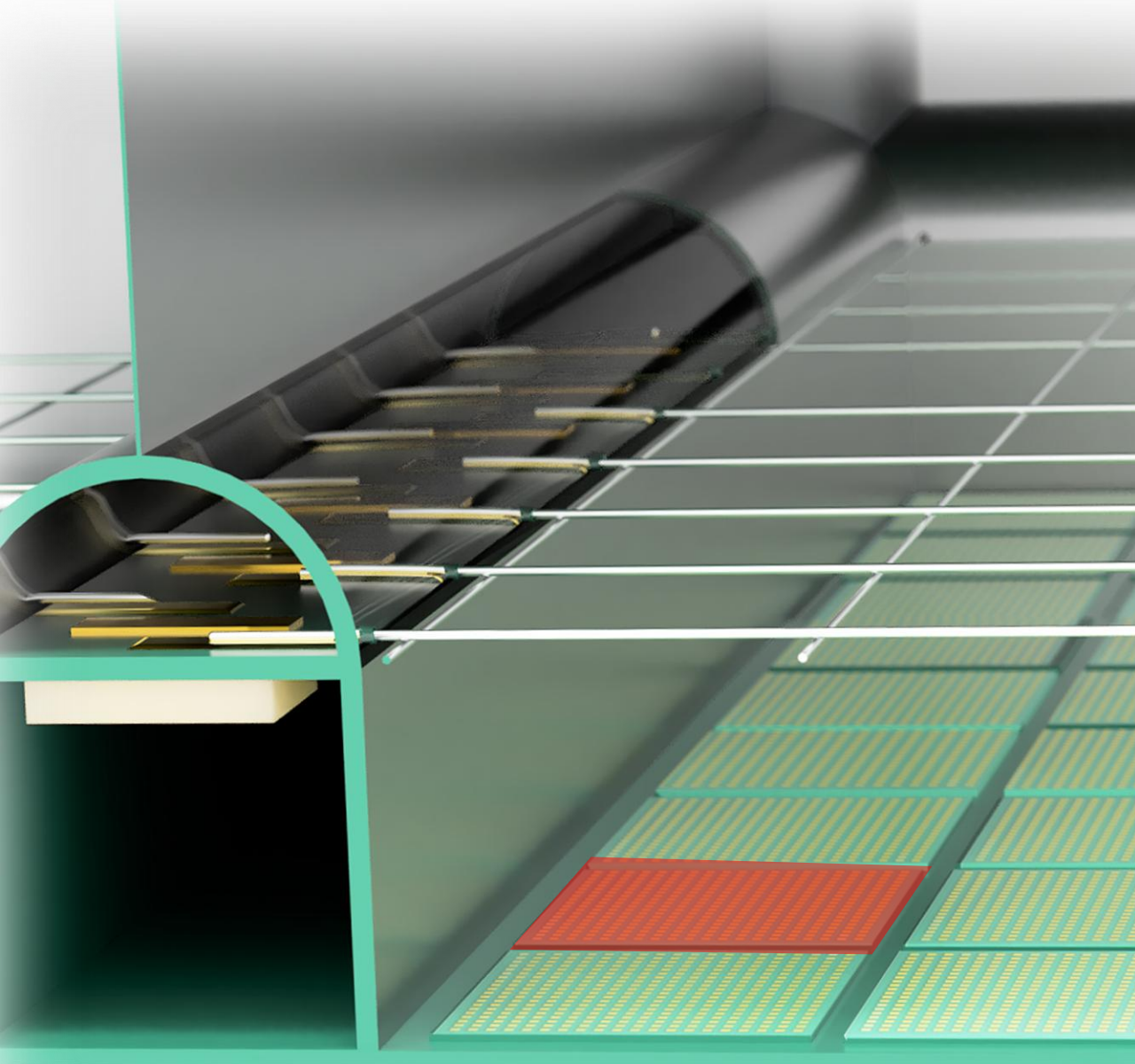
In addition to the light-based drift readout in TPCs

$$\text{Electron Yield} = Q_{\text{pixels}} / Q_{\text{wires}}$$



Method: Train a neural network using **electron yield** and **3D charge-distribution** to predict drift length, achieving ~90% of events reconstructed within $\pm 1 \text{ cm}$, which is ~5%

Good Idea! Does it Work?



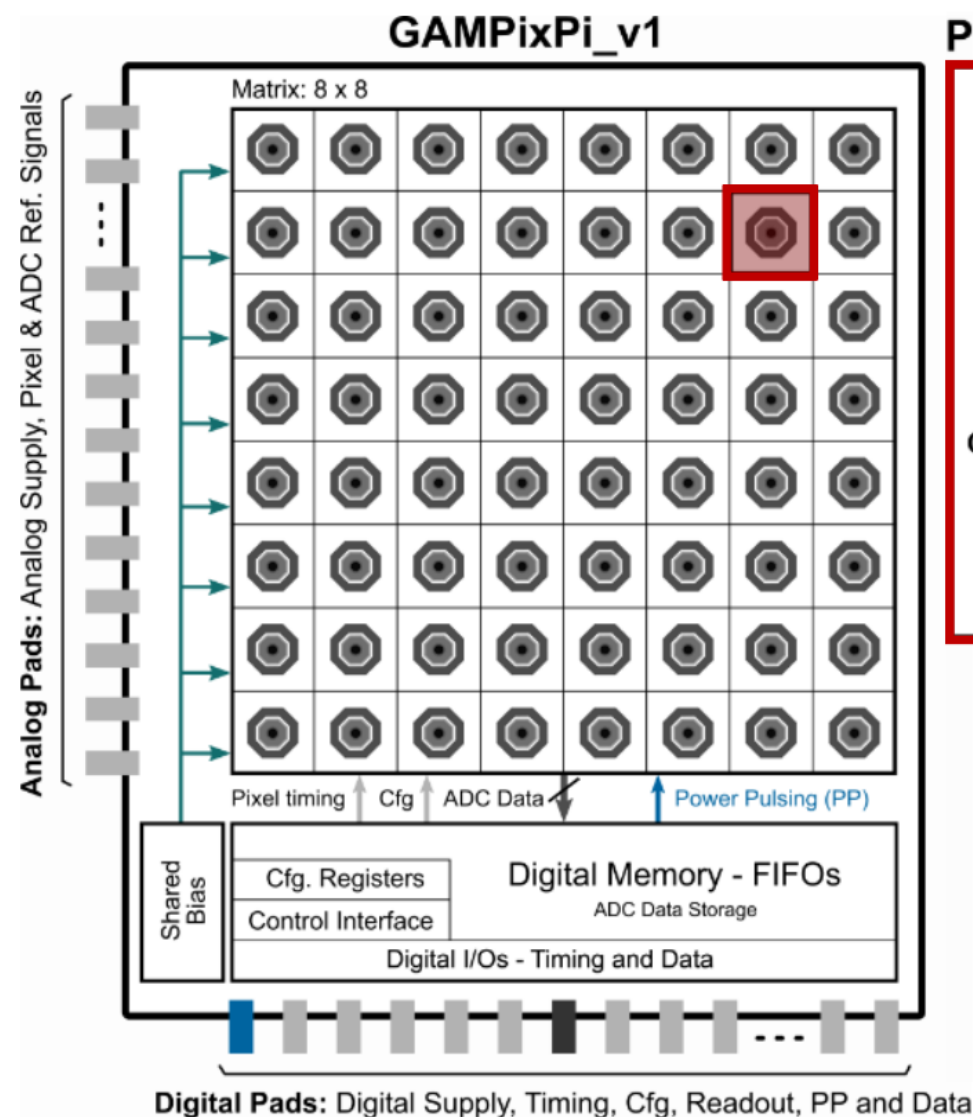
Requirements for **GAMPix_Pi**

Param	Spec
Temperature	LAr (87 K)
Pixel size	500 μm x 500 μm
Pad capacitance	≤ 500 fF
Noise - requirement	≤ 50 e ⁻
On power - expected	≤ 0.2 mW/pixel
Off power - expected	≤ 300 nW/pixel
Dynamic range	7000 e ⁻ (Q _{in} = ~ 1.1 fC)
Settling time after trigger	< 5 μs
Sampling rate	2.0 MS/s

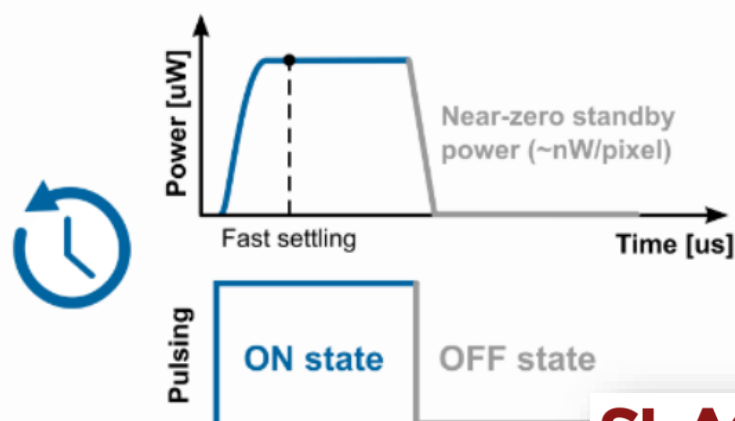
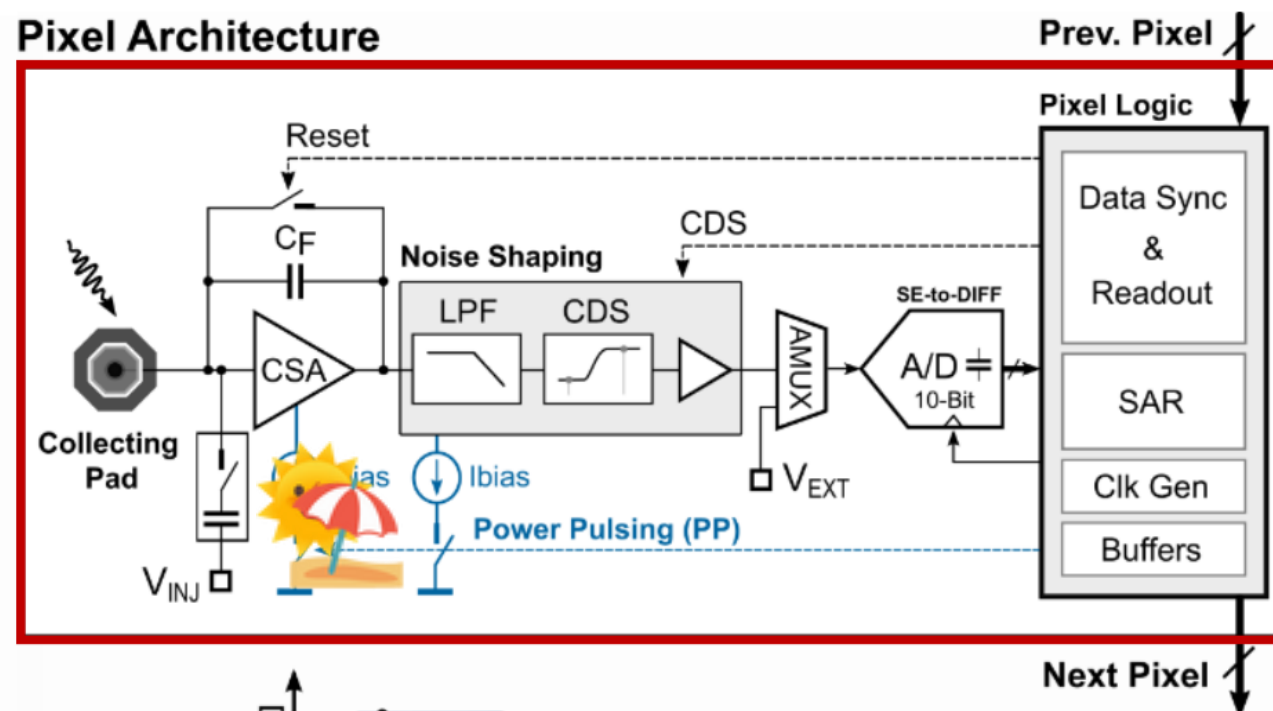
Let's design it...

ASIC architecture

GAMPiXPi-v1

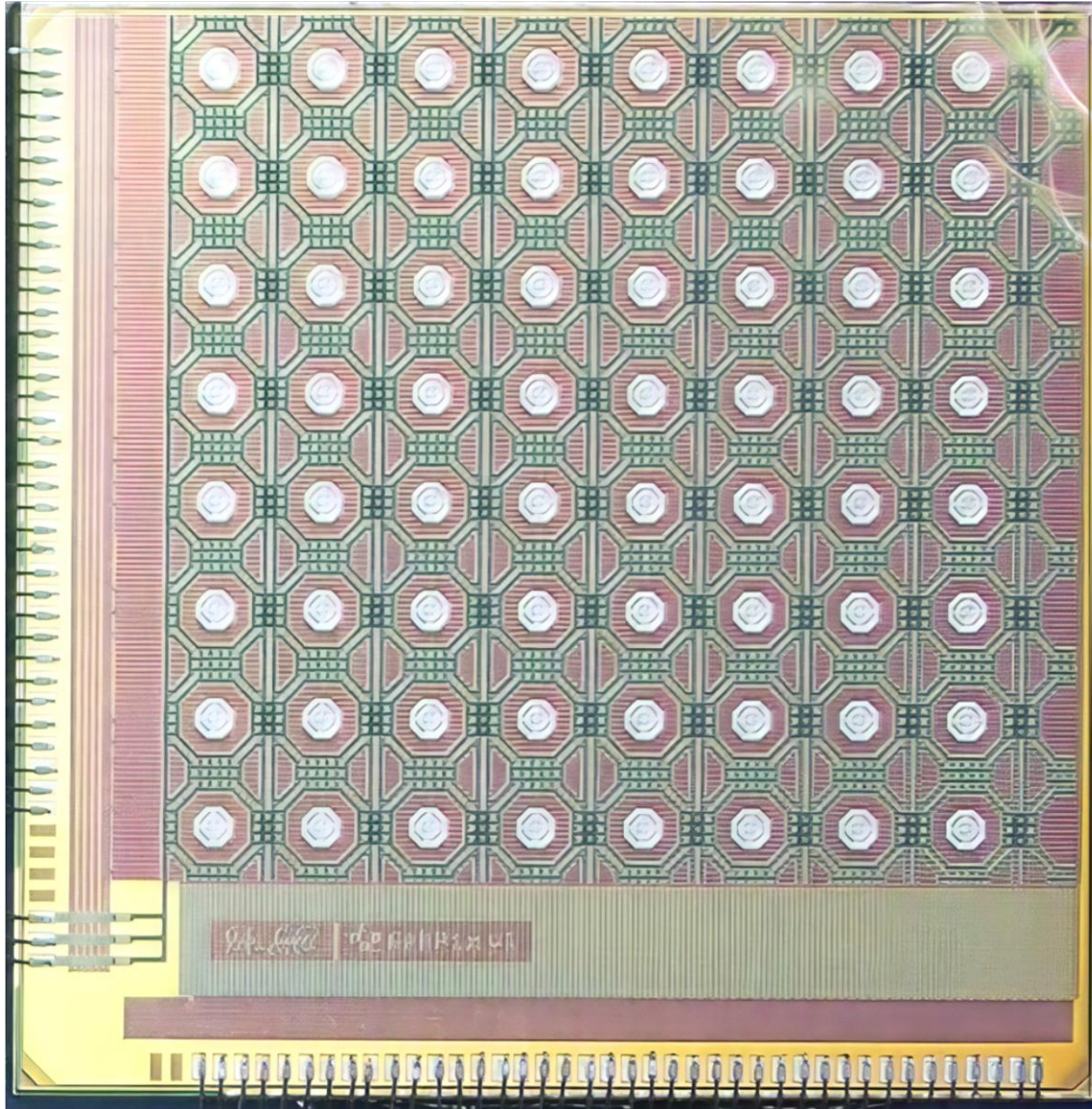


Pixel Architecture



New

*Mostly developed by student interns (PhD, MSc, and BSc) over the summer



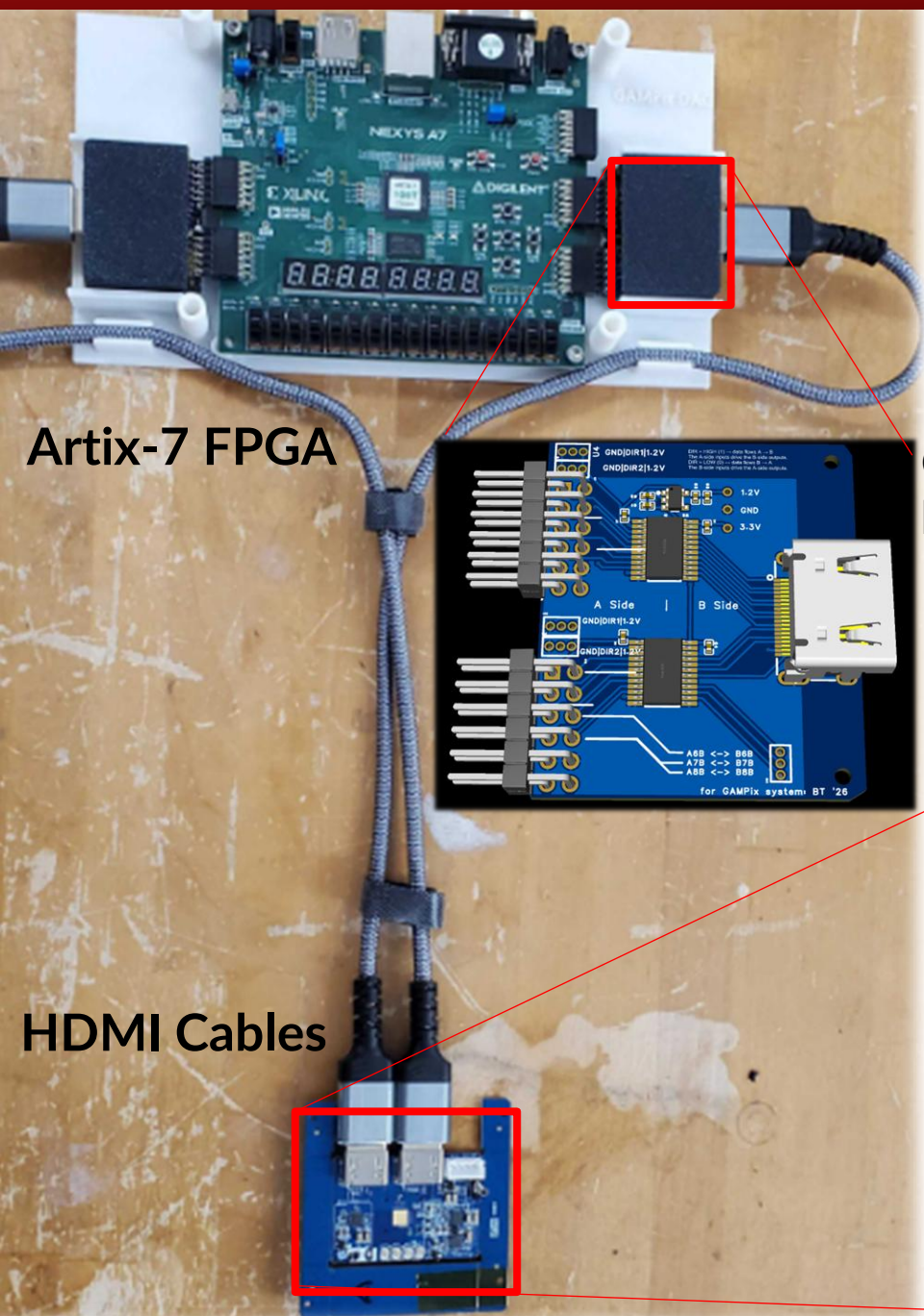
First Prototype

5x5 mm² proof-of-concept prototype

Fabricated in **130 nm** CMOS

~4 months of development

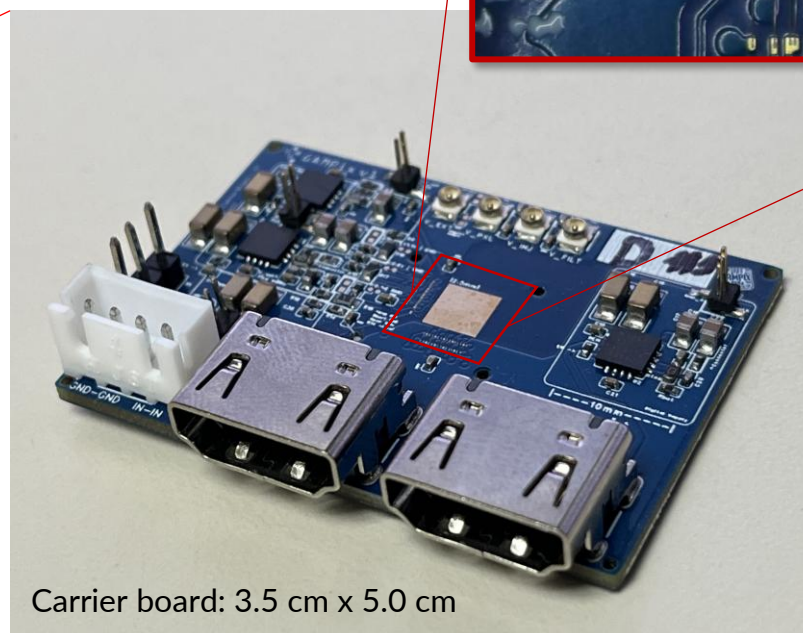
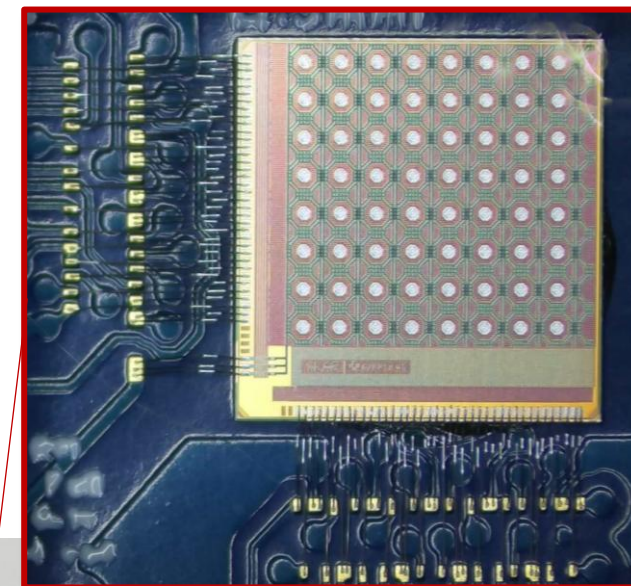
ASIC Support System



Artix-7 FPGA

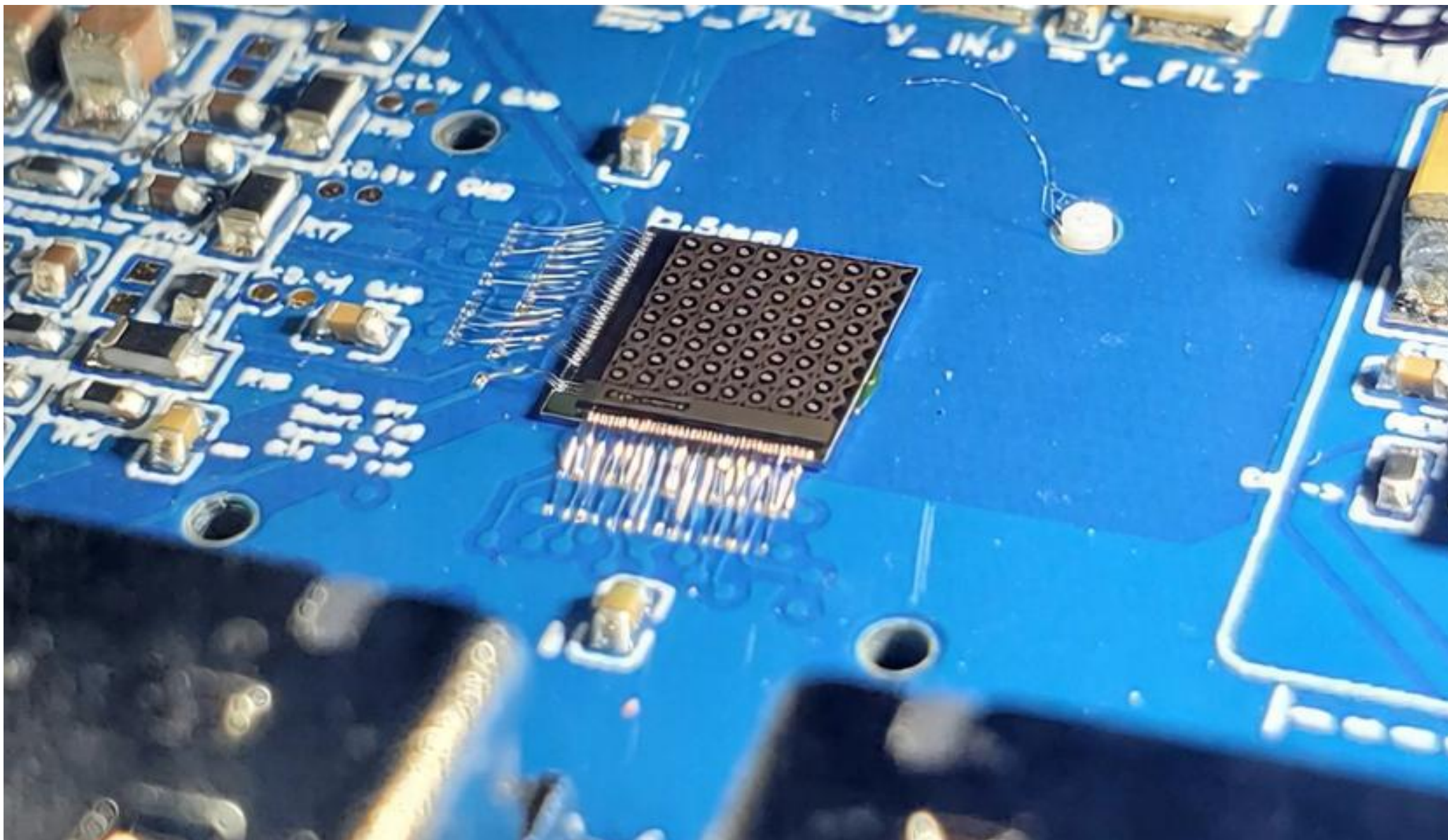
Custom board with level translators

HDMI Cables

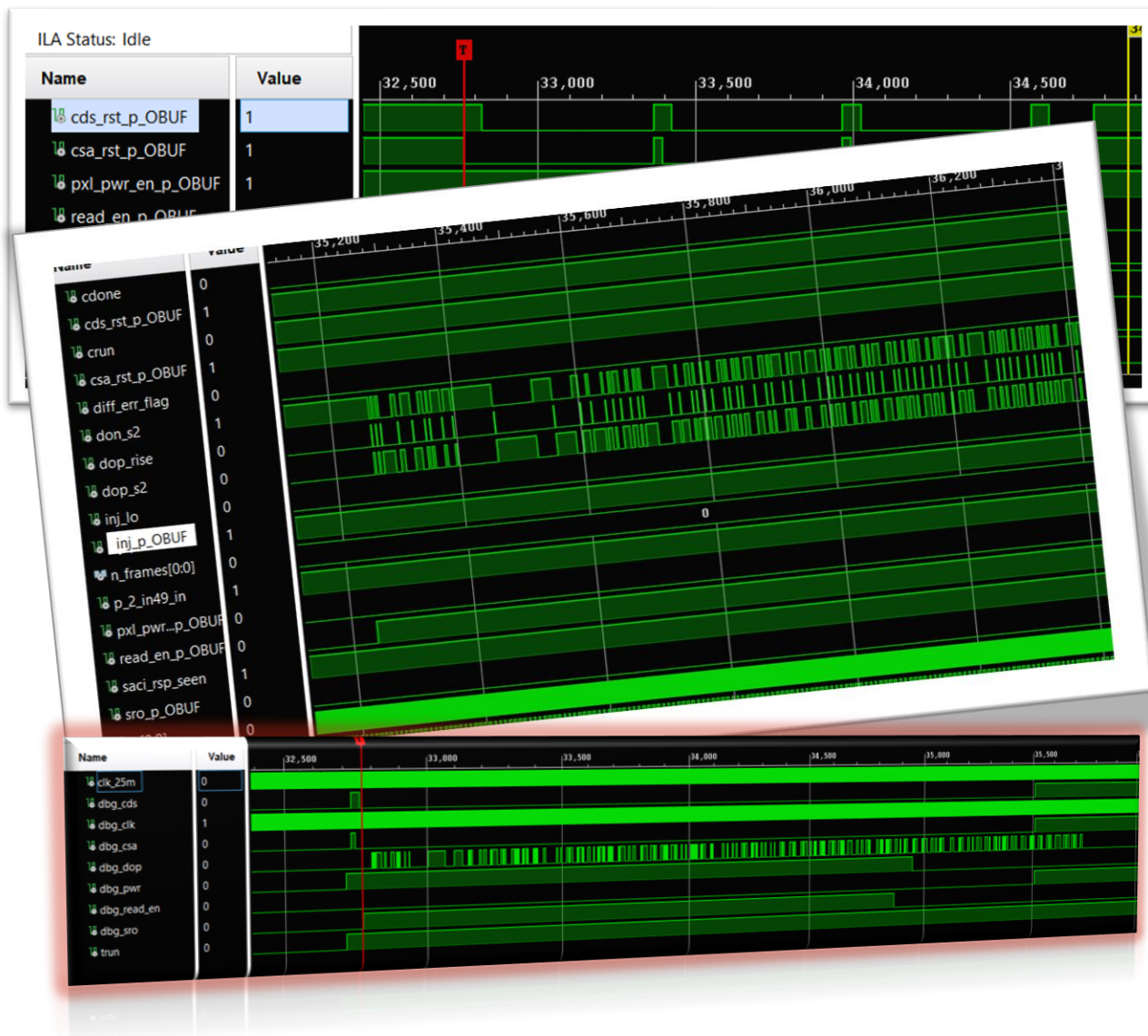


Carrier board: 3.5 cm x 5.0 cm

Wire-bonded GAMPix_Pi-v1



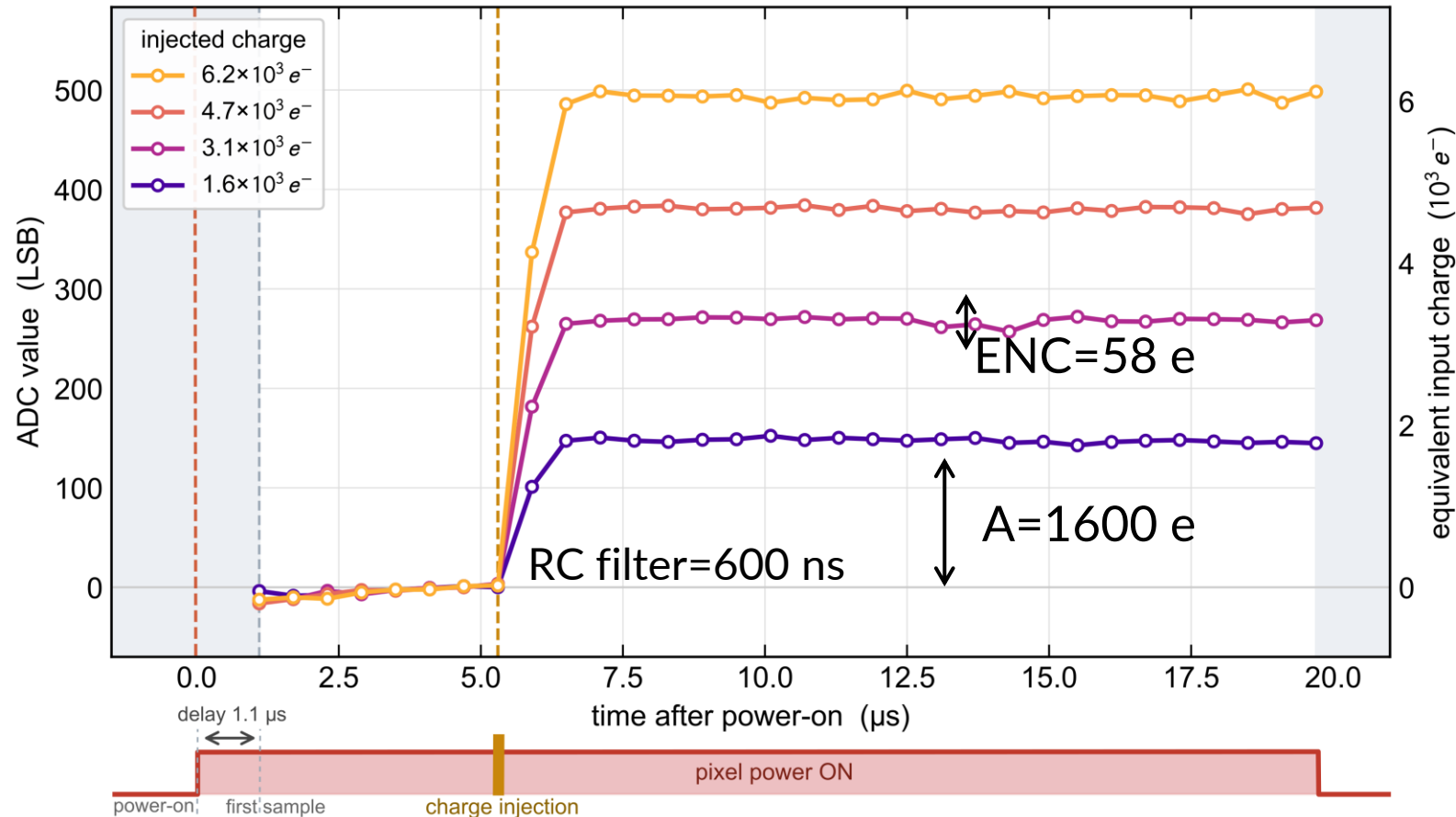
After Many of These...



Functional verification at 300 K and LAr

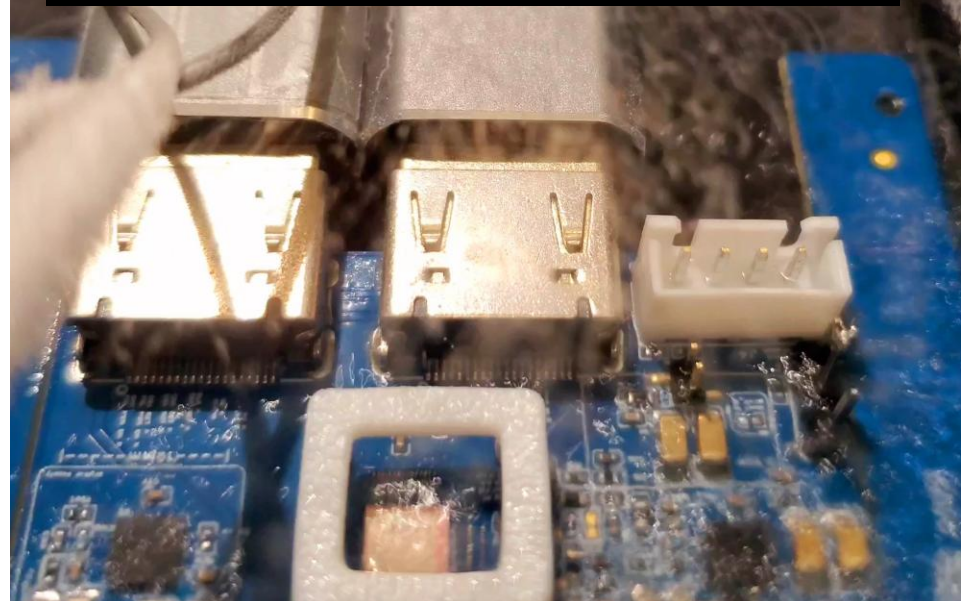
- Slow control ✓
- Digital memory ✓
- FPGA sync ✓
- Testing modes for calibration ✓
- ADC chain ✓
- Pixel readout and timing ✓
- Internal pixel pulsing injection ✓
- Full signal chain ✓
- Power-pulsing ✓
- Low-power operation ✓

Measured response on a single pixel with the chip operated in LAr



- Uniform response across all pixels
- Four resolved test-charge injection levels (see legend)
- 32 samples at 0.6 μs intervals.
- First valid sample ~1.1 μs after power-up, validating the power-pulsing capability

Carrier board and ASIC immersed in LAr

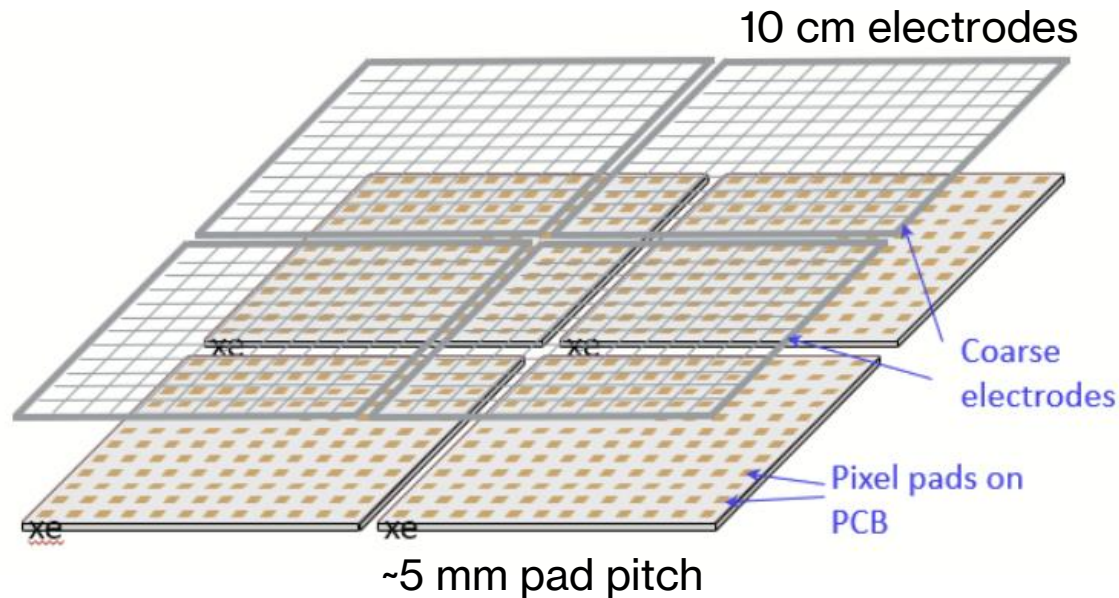


Measured Quantities

- Power ON: 260 nW/pixel
- Power OFF: 140 μW /pixel
- Noise*: ~58 e^-

*Noise measured in a noisy, non-shielded environment (preliminary result)

GAMPix for DUNE: *Tiles over Pixels*



Proposed Architecture

- Pixel pads on PCB, one ASIC per board
- Coarse electrode tile above each 20×20 block of pads
- Tile triggers and measures total charge
- Pixels power up and image only where a tile fires

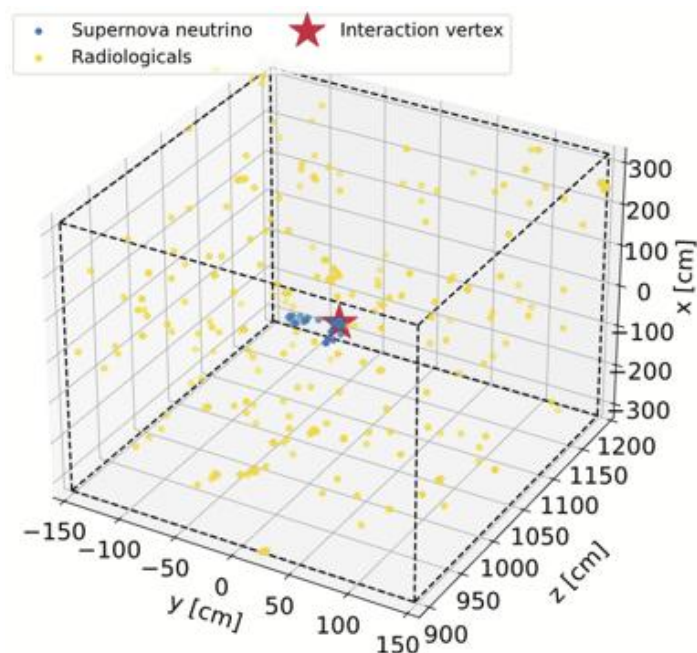
What it buys DUNE

- **Energy resolution:** tile sees full charge despite diffusion across sub-threshold pixels
- **More blips:** noise well below the $\sim 500 e^-$ strip baseline keeps MeV-scale deposits visible
- **Low power:** power-pulsed pixels free the budget for quieter front ends
- **Lower data volume:** Front end data reduction
- **Drift distance from charge alone ($\sim 15\%$):** pixel cloud width vs tile signal gives lifetime correction, edge-background cuts and charge–light matching in pile-up

Bottom line

Pixel-only readouts give 3D imaging but trade noise against power. GAMPix keeps the 3D and breaks that trade-off.

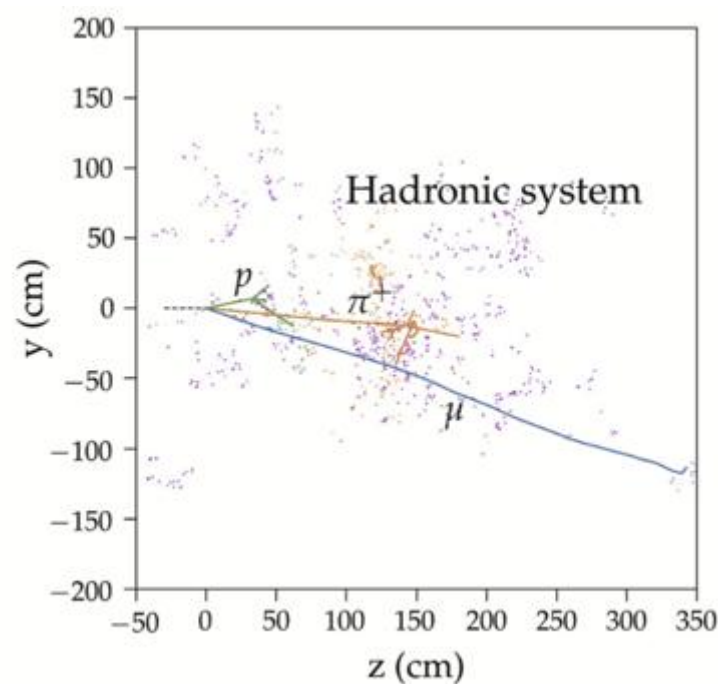
GAMPix for DUNE: Recovering Low-Energy Charge



arXiv: 2203.00740

Astrophysical neutrinos

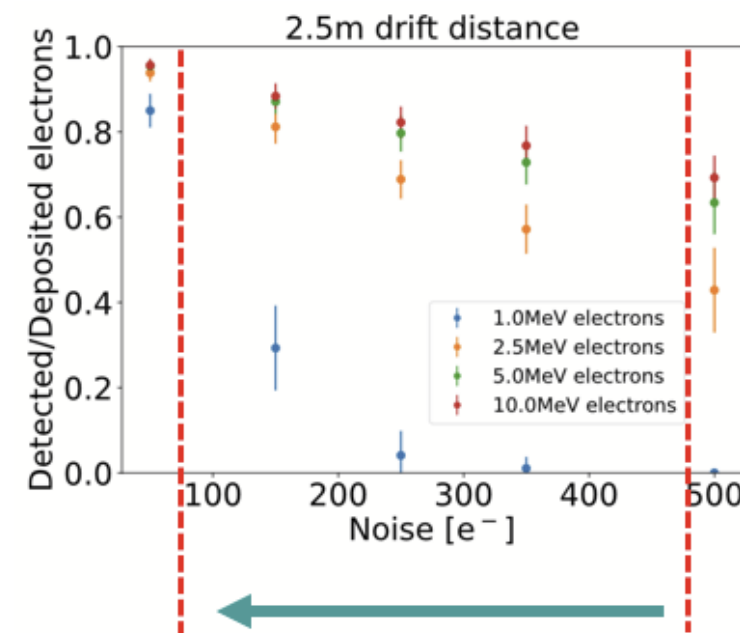
Supernova and solar ν deposit only MeV-scale energy, buried in radiological backgrounds



PRD 99, 036009 (2019)

GeV oscillation events

Neutron scattering and nuclear de-excitation leave a halo of MeV γ blips, lost if undetected

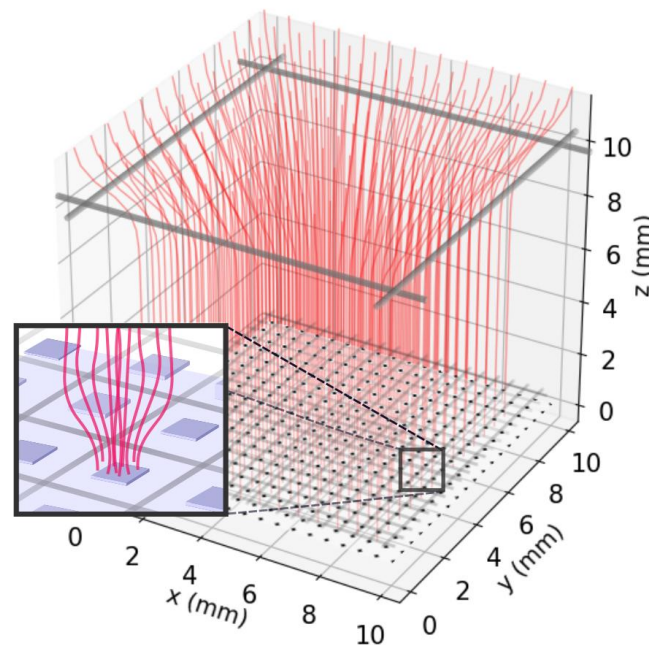


GAMPix simulation

Noise sets what survives drift

- ~500 e^- (strips): 1 MeV lost, 10 MeV loses ~30%
- 1 MeV: ~30% at 150 e^- , >85% at ~50 e^- (GammaTPC)

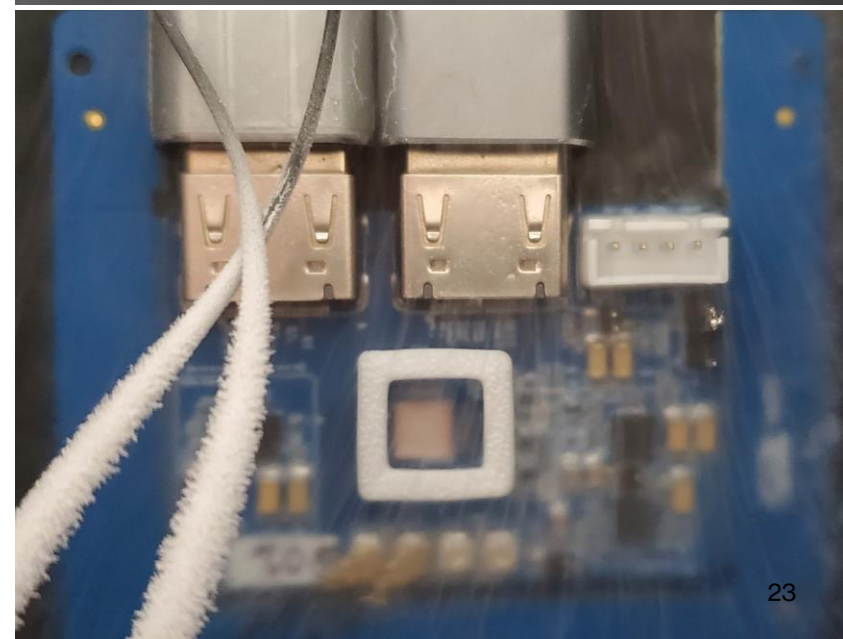
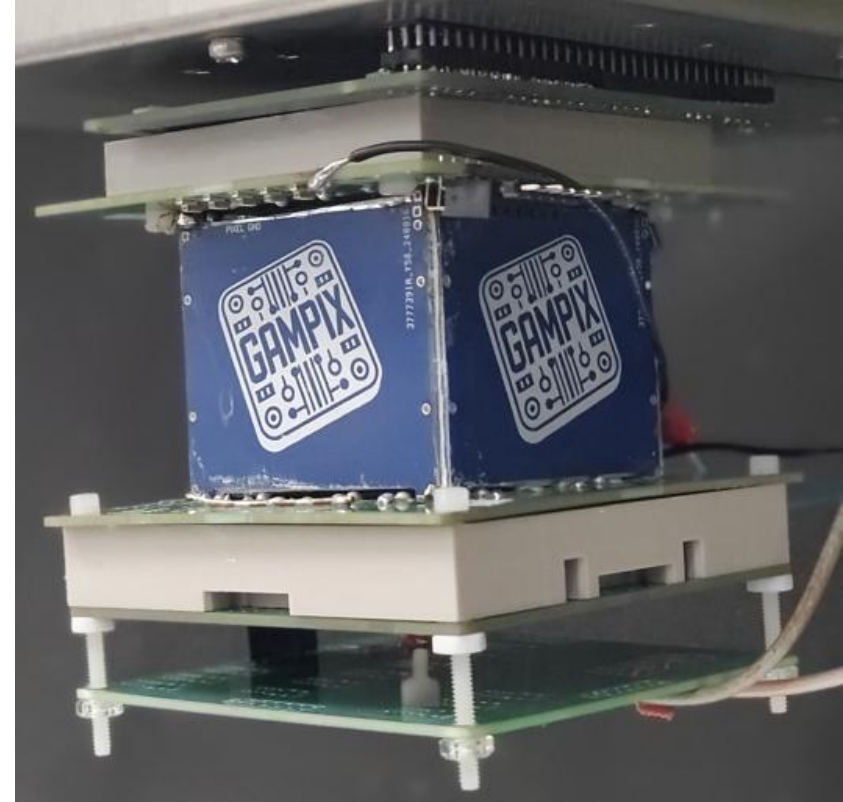
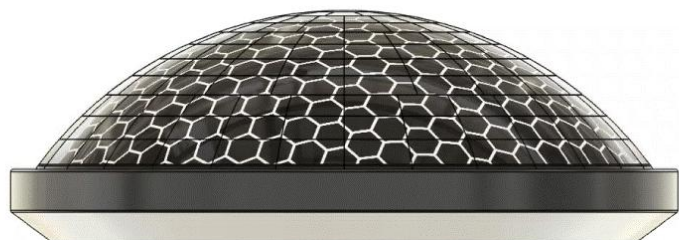
Thanks!



[1] GAMPix Paper <https://arxiv.org/abs/2402.00902v1>

[2] GammaTPC Paper <https://arxiv.org/abs/2502.14841>

also: gammatpc.com

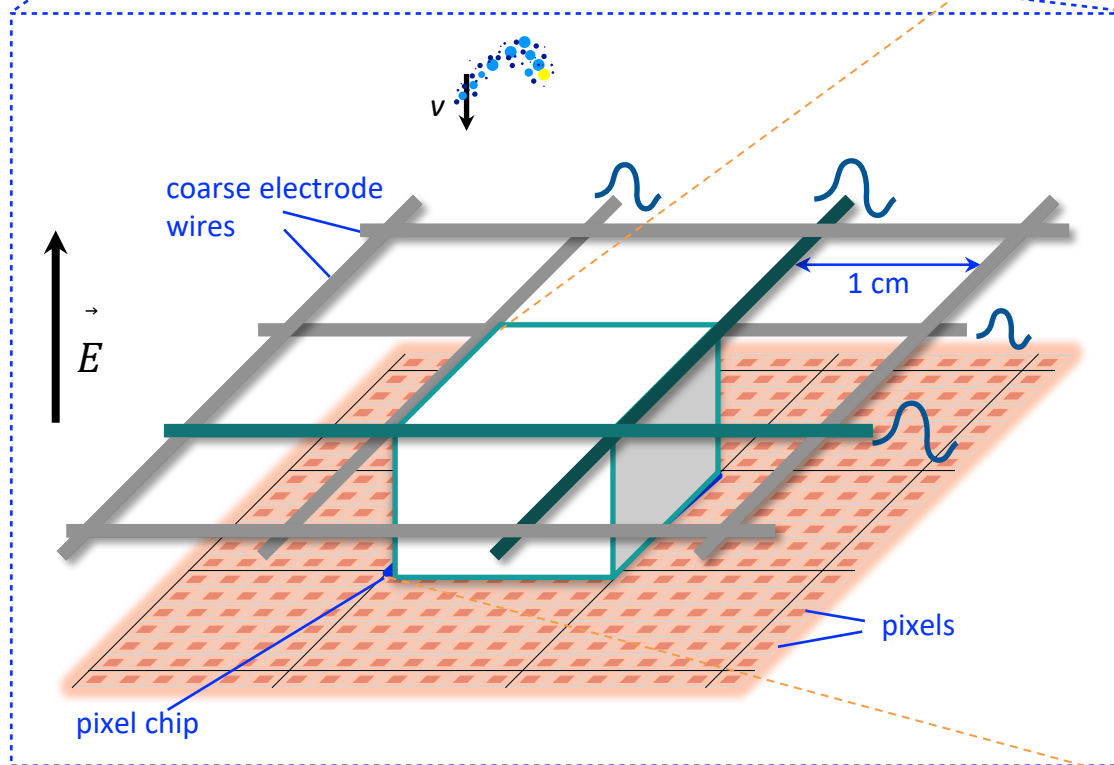
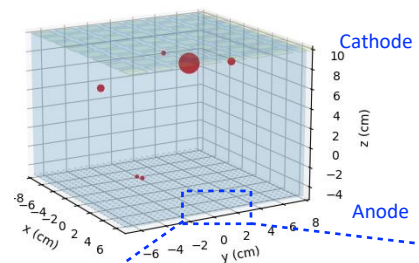




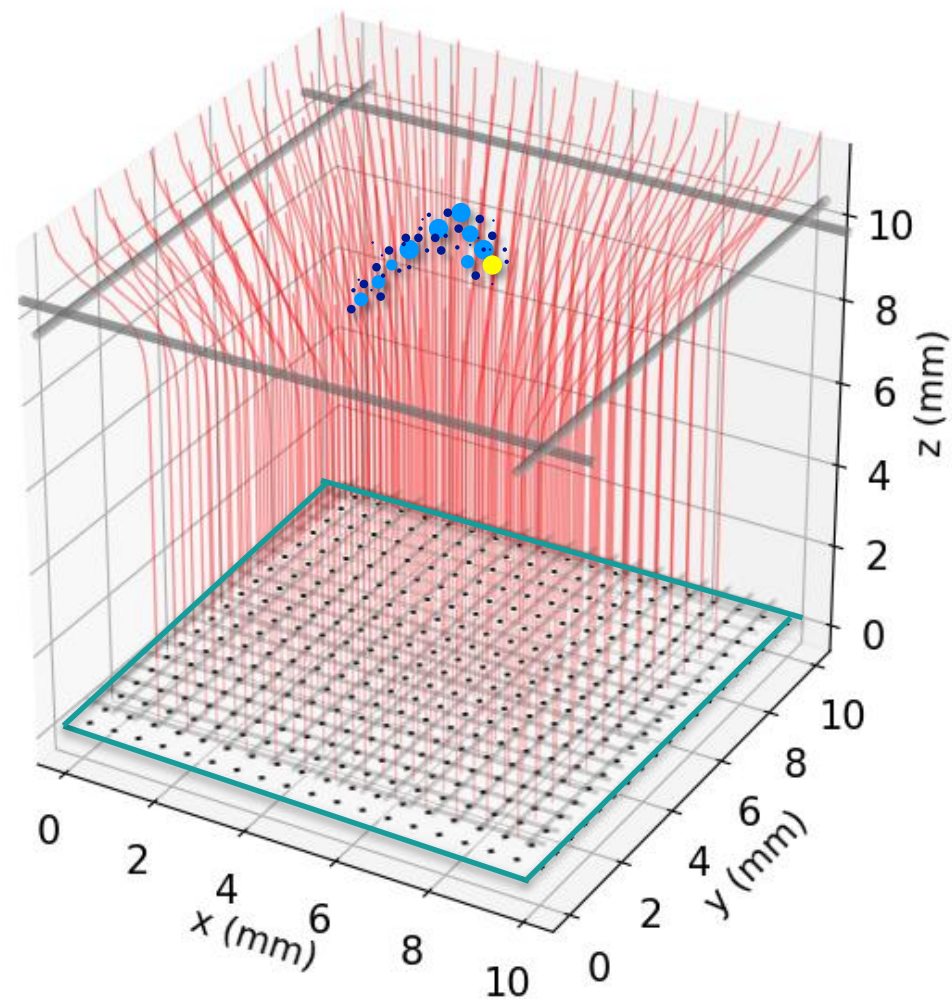
BACKUP SLIDES

Just in case

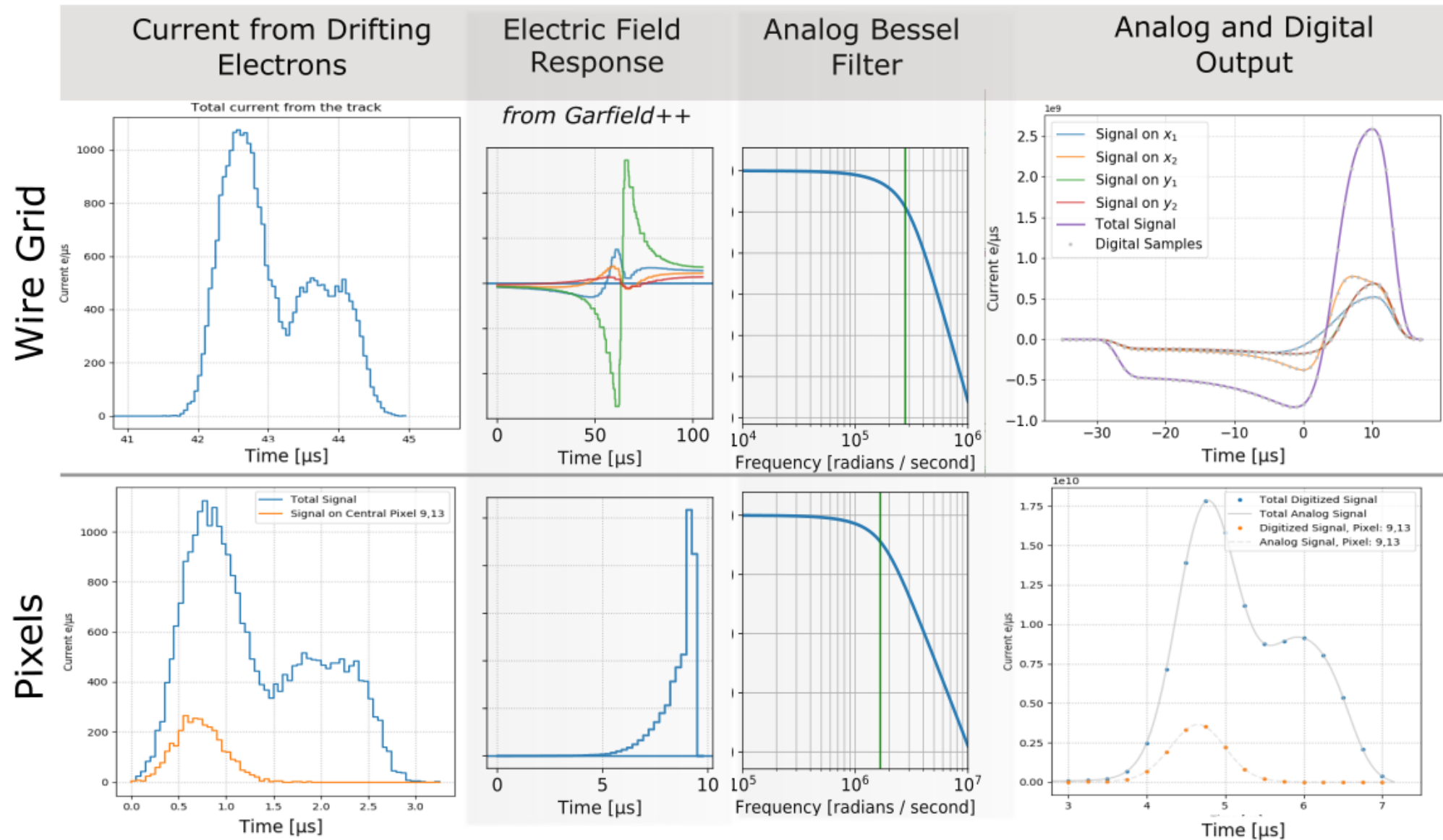
TPC cell



Electric Fields in GAMPix Unit

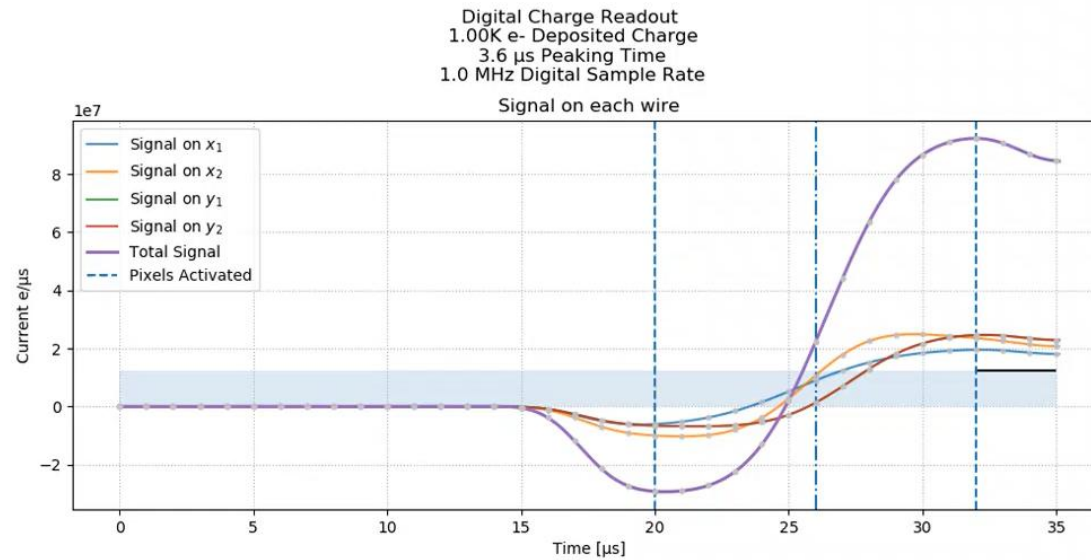
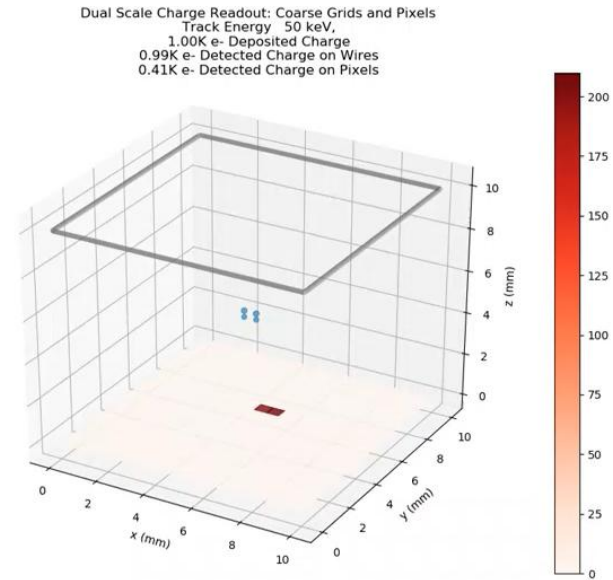


GAMPix | Simulated Signal Chain



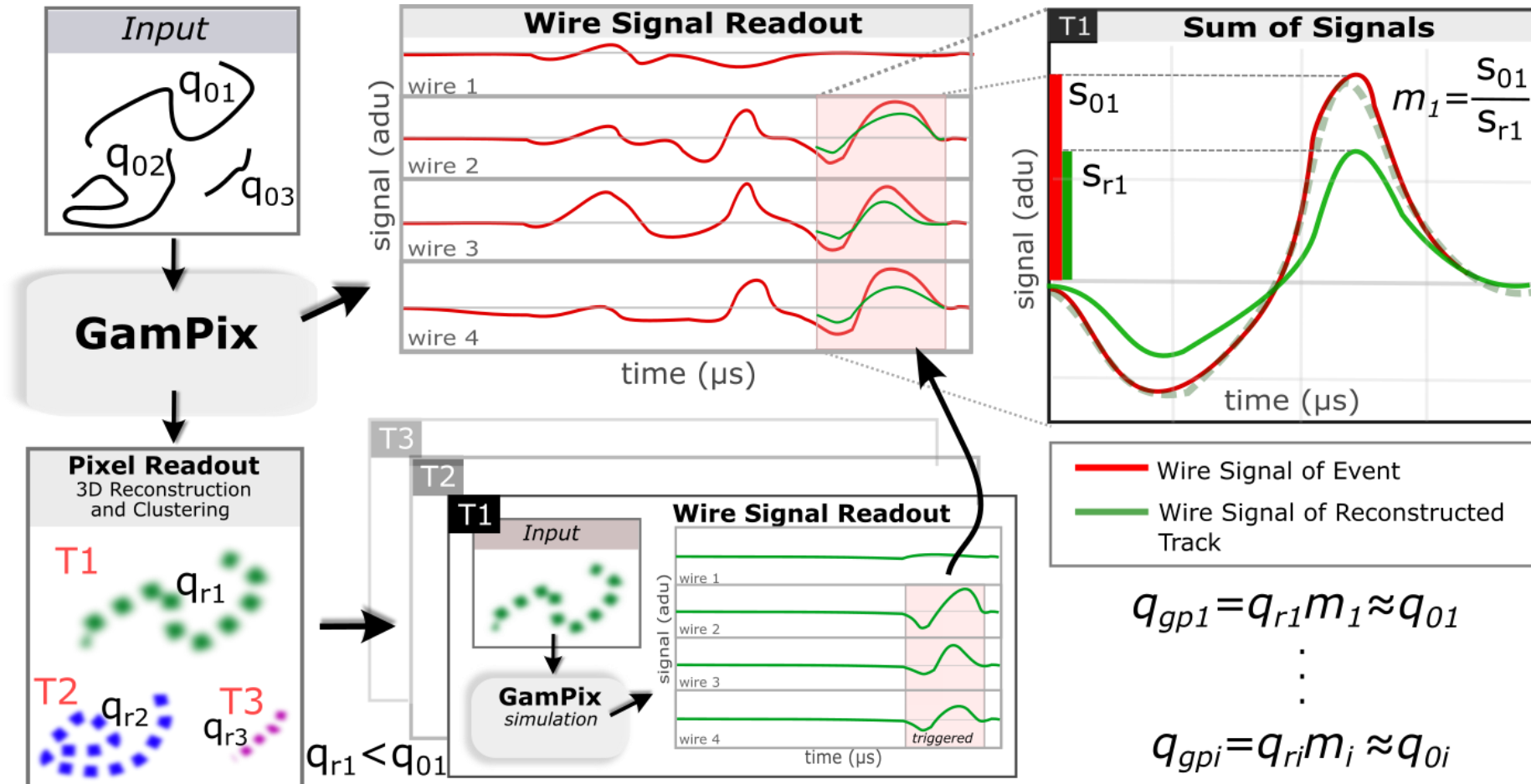
GAMPix | Simulated Signal Chain

Impuls Response: 1.0K electrons



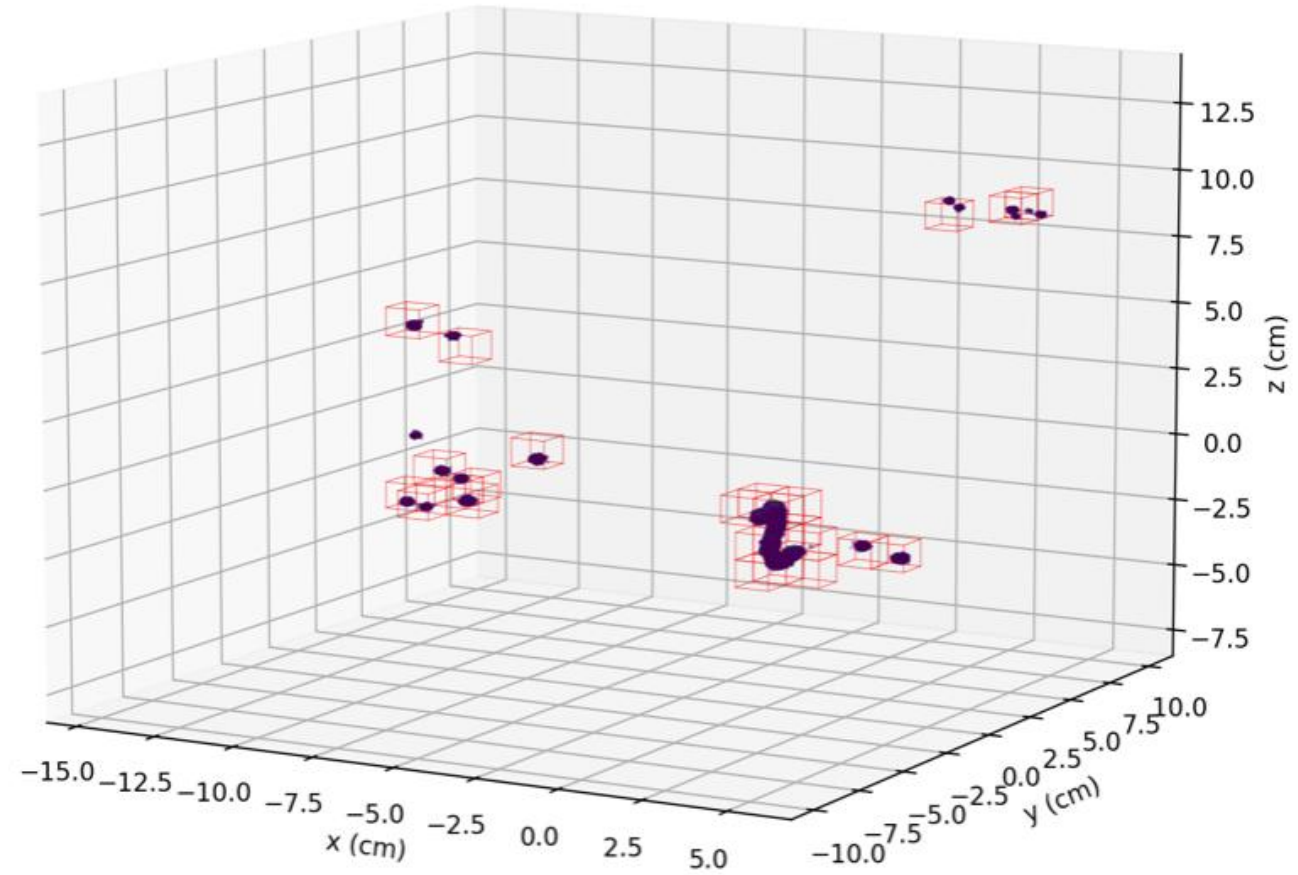
GAMPix | Simulated Signal Chain

Issue: Non-uniform response from the wire grid

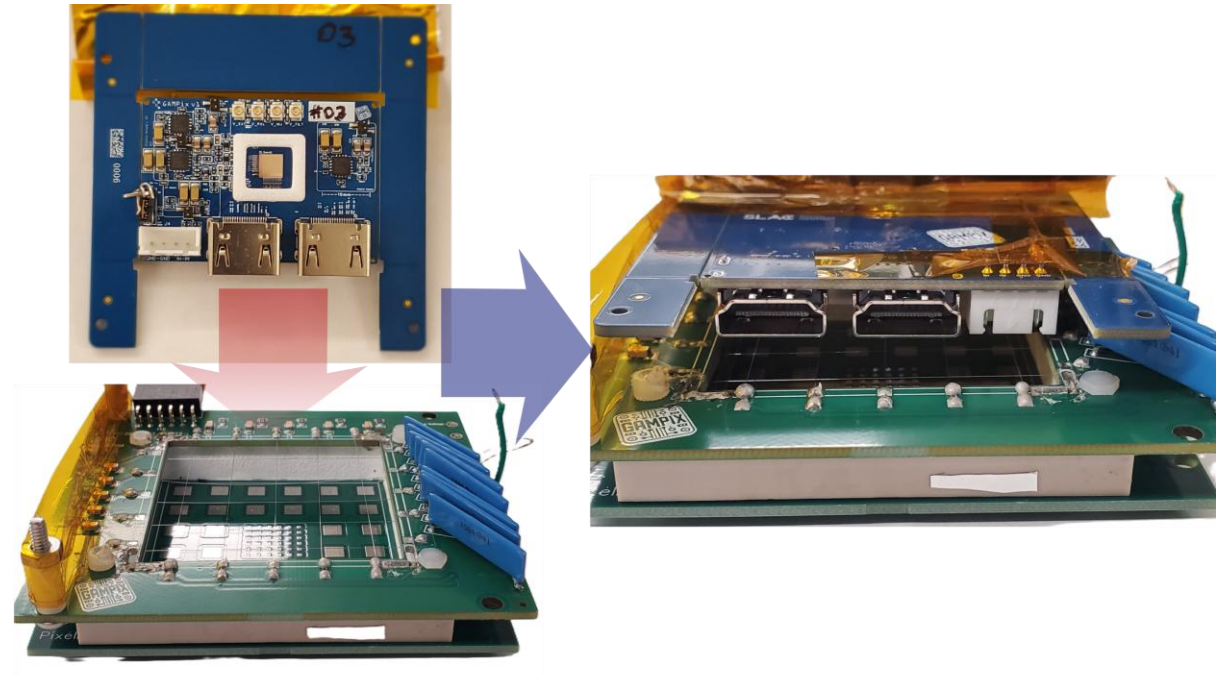


Power Saving

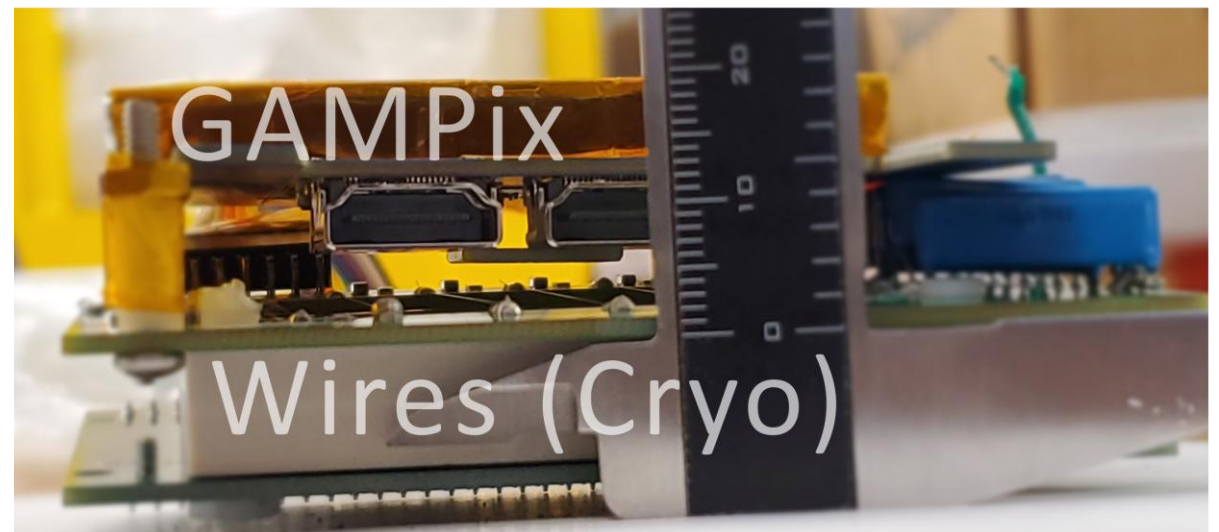
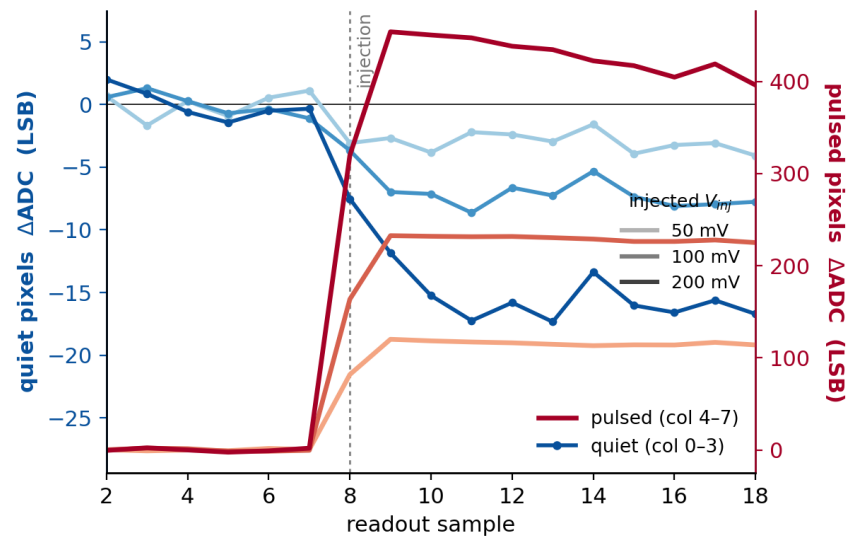
10 MeV photon

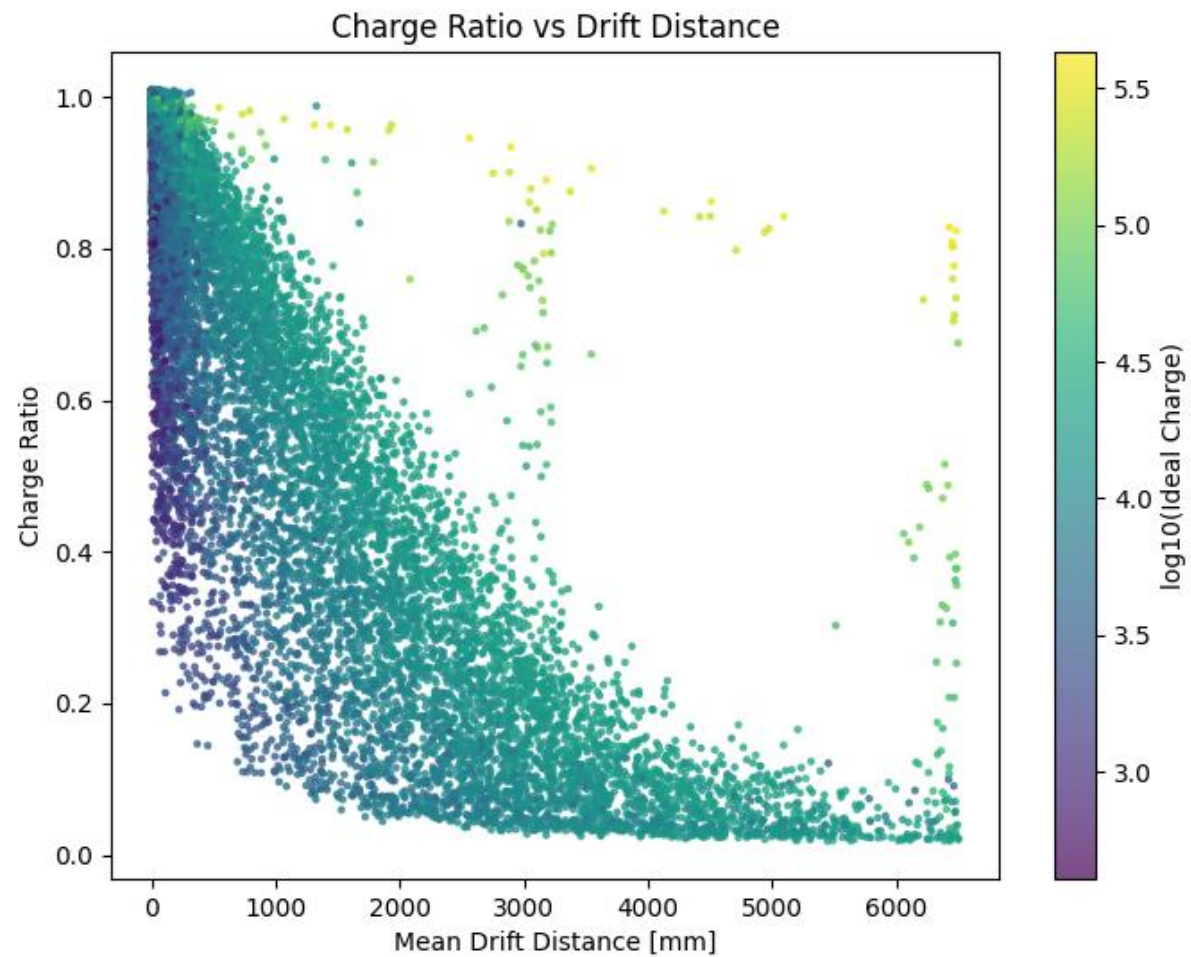


- 40 coarse voxels are $\sim 10^{-3}$ of $(30 \text{ cm})^3$ volume.
 - This is reduction in pixel on power
- 10^4 pixel samples read out, $\sim 2e4$ reduction over all pixels



Injection-locked crosstalk: quiet pixels respond in anti-phase





Length Estimation Error

