A Low-Gain, Integrated-Grid, Pixelated MPGD

Tanner Polischuk | University of Hawaii

CPAD 2026 | UW
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The Flexible, Ideal MPGD System (FIMS) Team

At The University of Hawai'i at Mānoa
Peter Lewis, **Tanner Polischuk,**
James Harrison IV, Haider Abbas,
Nai'a Nyza, Sven Vahsen

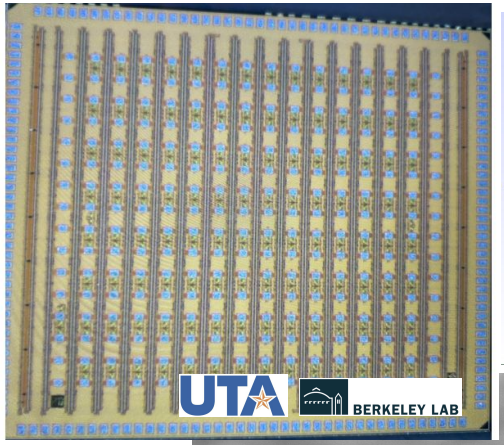
At Lawrence Berkeley National Laboratory
Peter Sorensen, Aikaterini Papadopoulou,
Tarun Prakash, Will Wright, Craig Tindall,
Yichen Liu, Carl Grace, Nowzesh Hasan

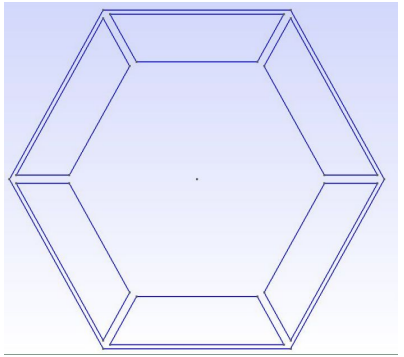
At The University of Texas at Arlington
Yuan Mei, Peng Miao

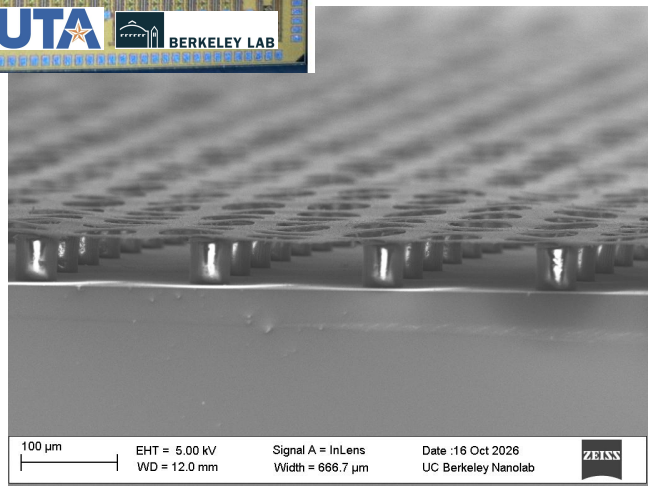
Roots in a CPAD 2023 coffee break!

RDC6 Priorities that FIMS Addresses

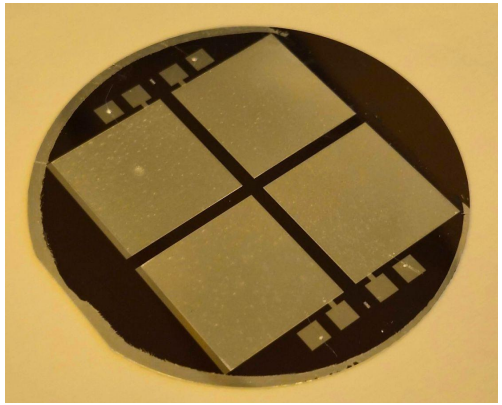
- Advancing gaseous detectors to the fundamental sensitivity limit.
- Developing new gas amplification structures for challenging environments.
- Establishing production facilities in the United States.
- Intelligence in the front-end electronics.

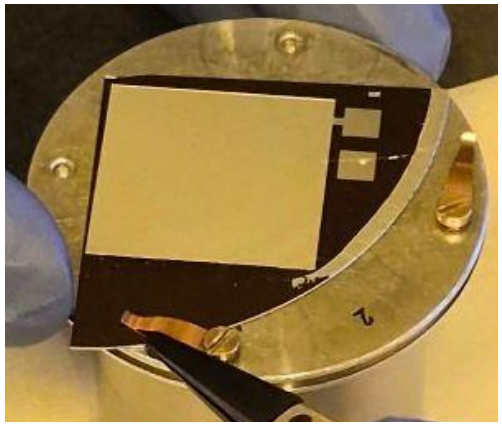


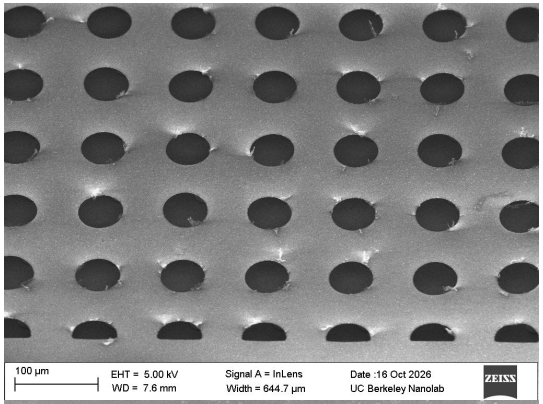


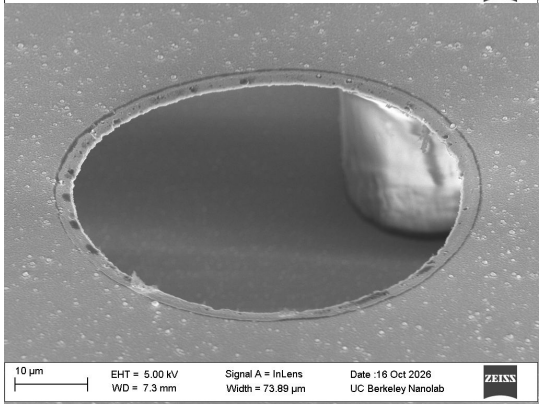


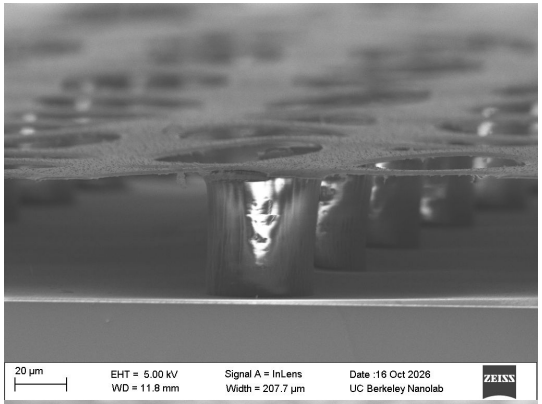
Microstructure Fabrication

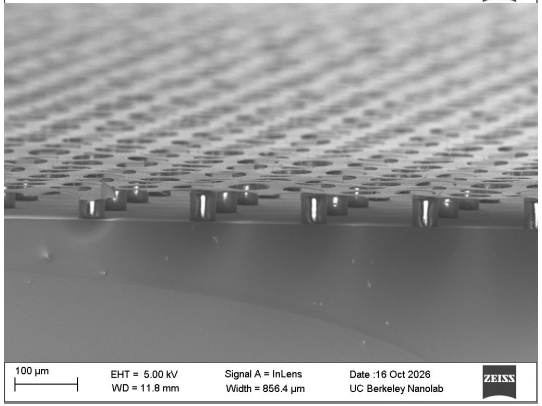




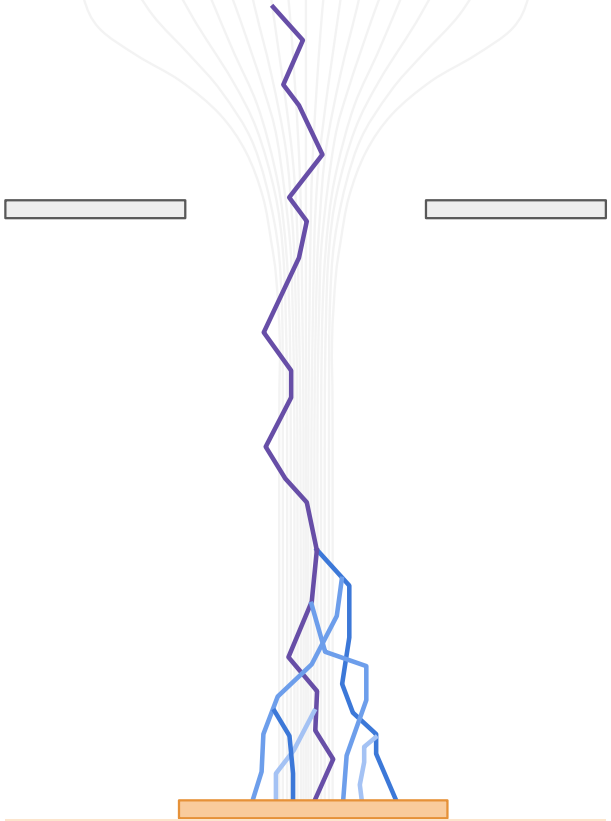








Single-Charge Detection

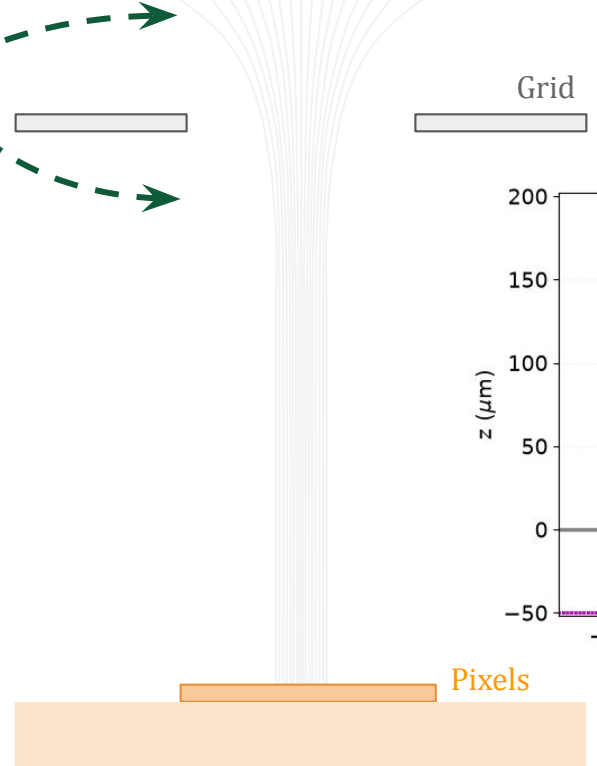


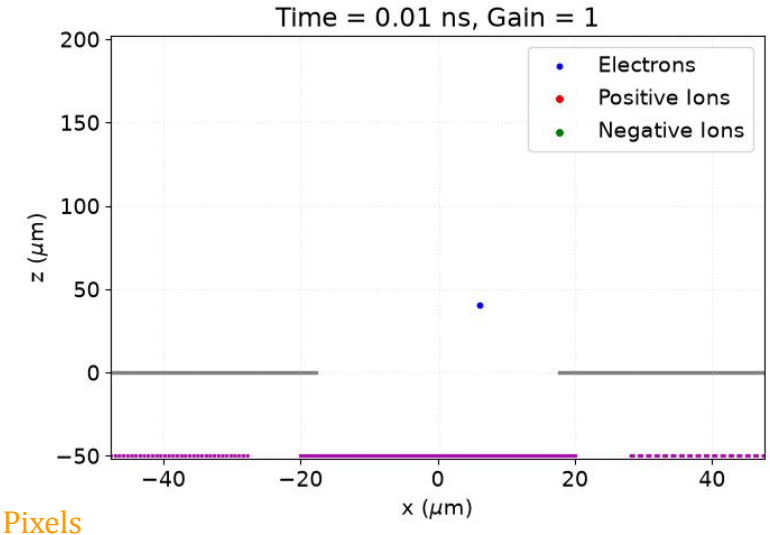
Making *every* primary charge *count*.

- **Targeting the high-precision limit of MPGDs.**
- **Utilizing *low noise* to push charge collection and detection to the *single-electron limit* with *low thresholds* and *low gas gains*.**
- In practical terms:
  - Optimal resolution.
  - Maximum efficiency.
  - Minimum IBF.
  - Optimal readout.

Low-Gain, Integrated-Grid, Pixelated MPGDs

Electric fields collect charge and cause **avalanches.**

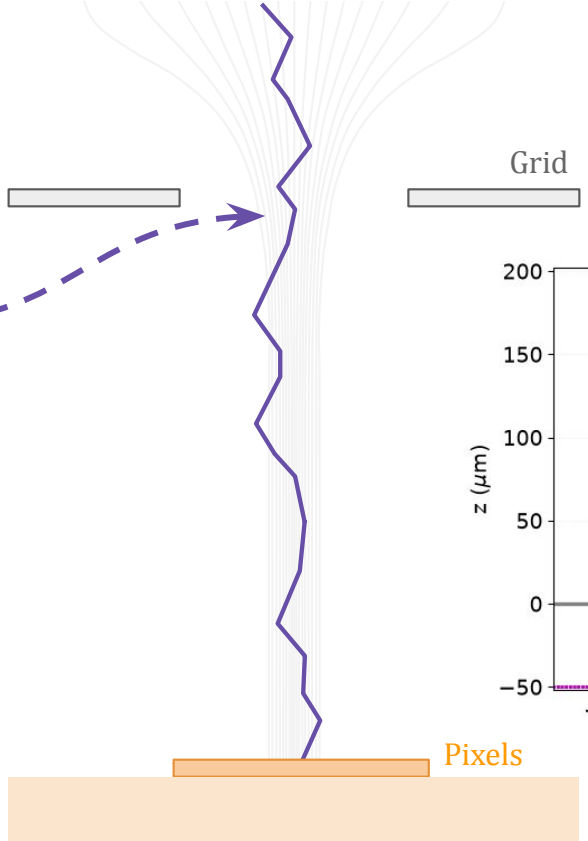


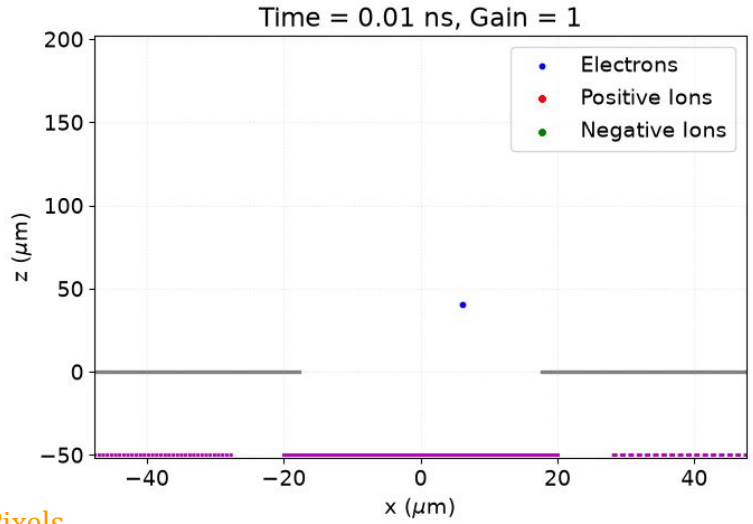


Low-Gain, Integrated-Grid, Pixelated MPGDs

Electric fields collect charge and cause **avalanches.**

Grid must be **transparent** to primary charges.



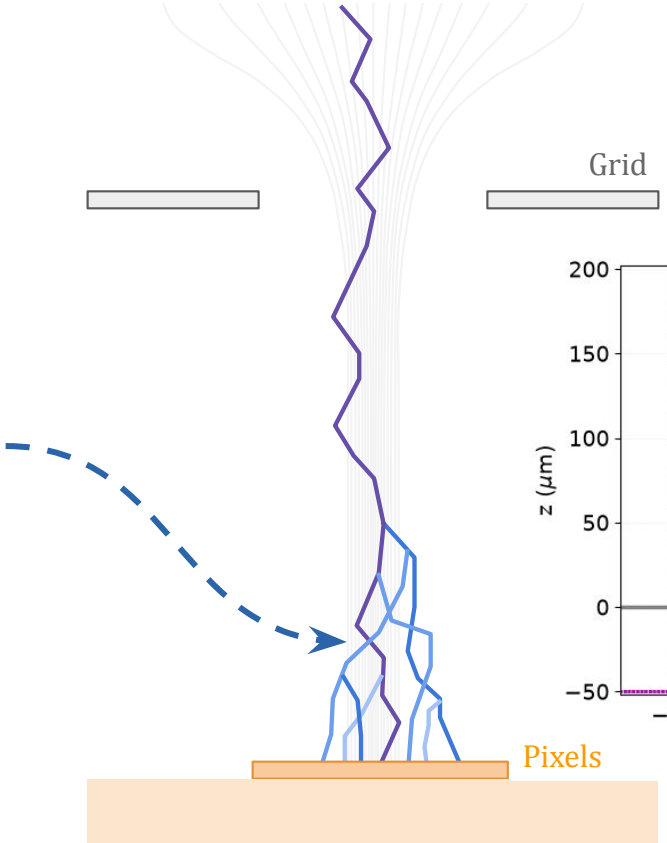


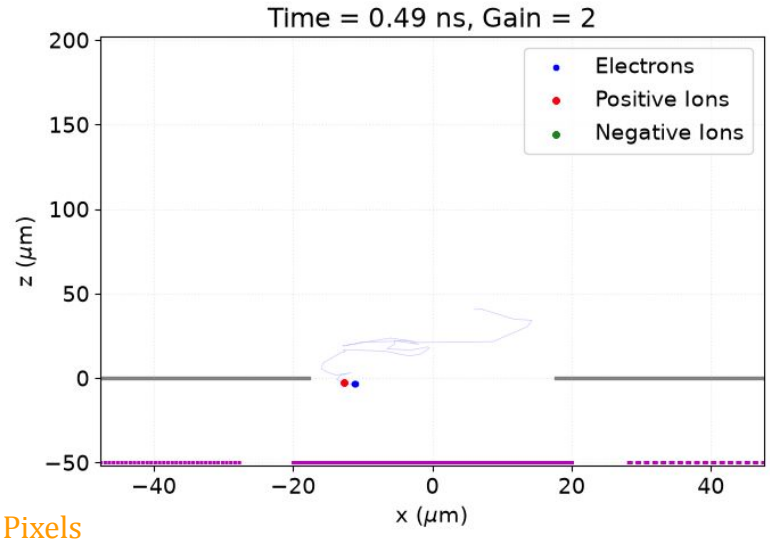
Low-Gain, Integrated-Grid, Pixelated MPGDs

Electric fields collect charge and cause **avalanches.**

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Gas gain needs to be higher than the pixel **threshold**.
*More **gain** means more **ions**.*





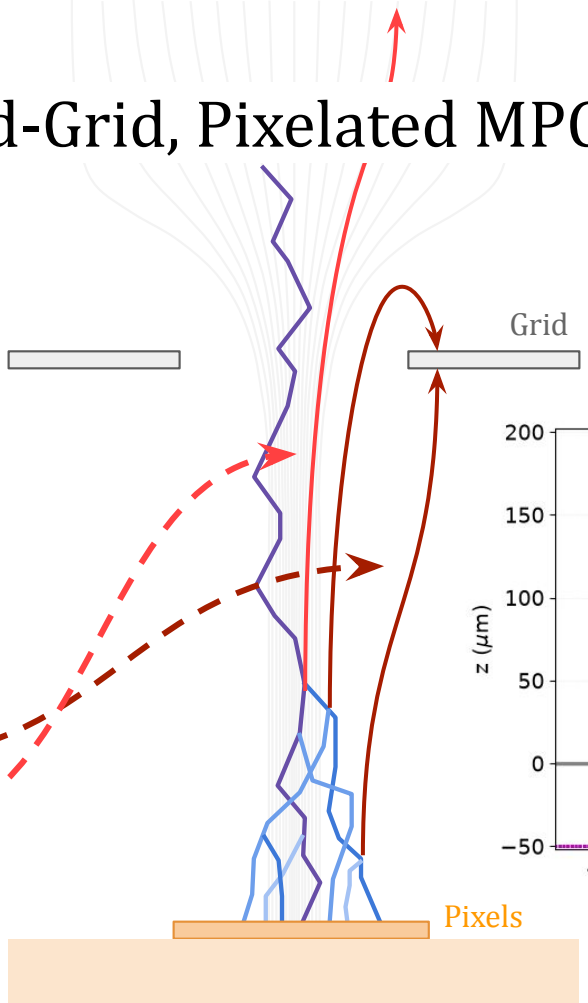
Low-Gain, Integrated-Grid, Pixelated MPGDs

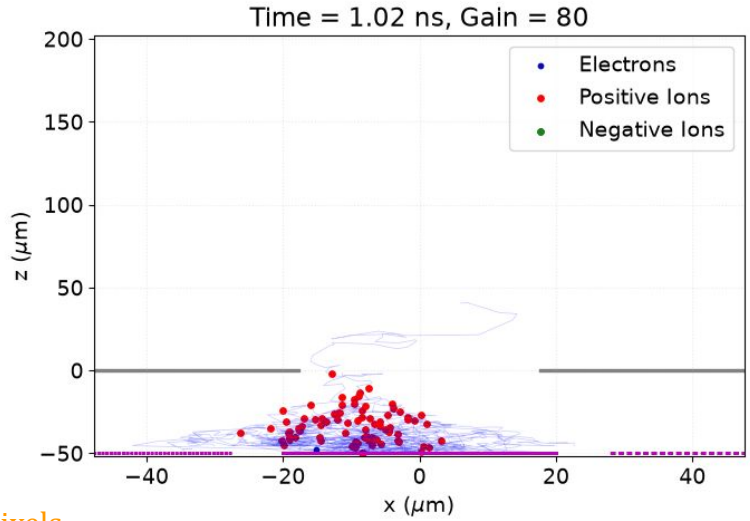
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Ion trajectories should terminate **on the grid.**
*Otherwise is **back-flowing.***





Low-Gain, Integrated-Grid, Pixelated MPGDs

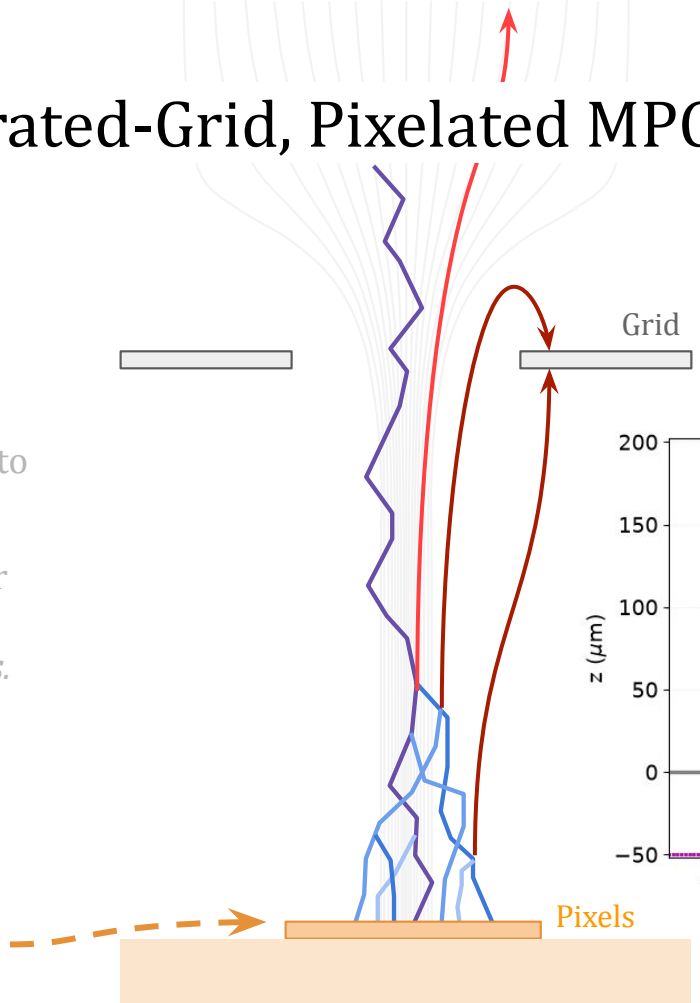
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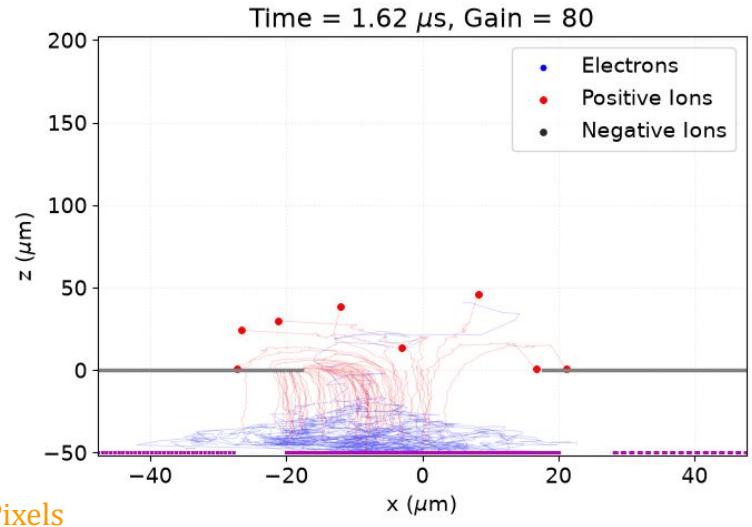
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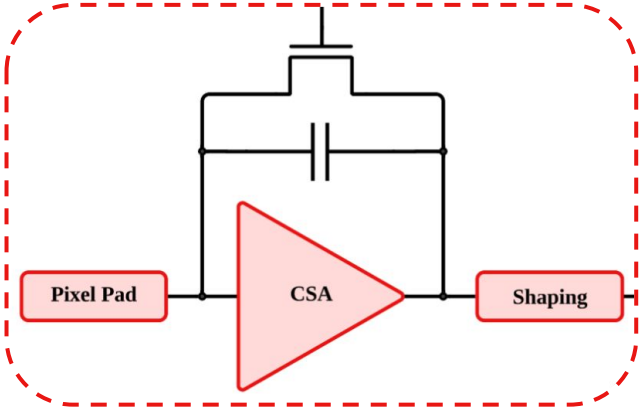
Ion trajectories should terminate **on the grid.** *Otherwise is **back-flowing.***

Pixel **noise** needs to be as **low as possible**.





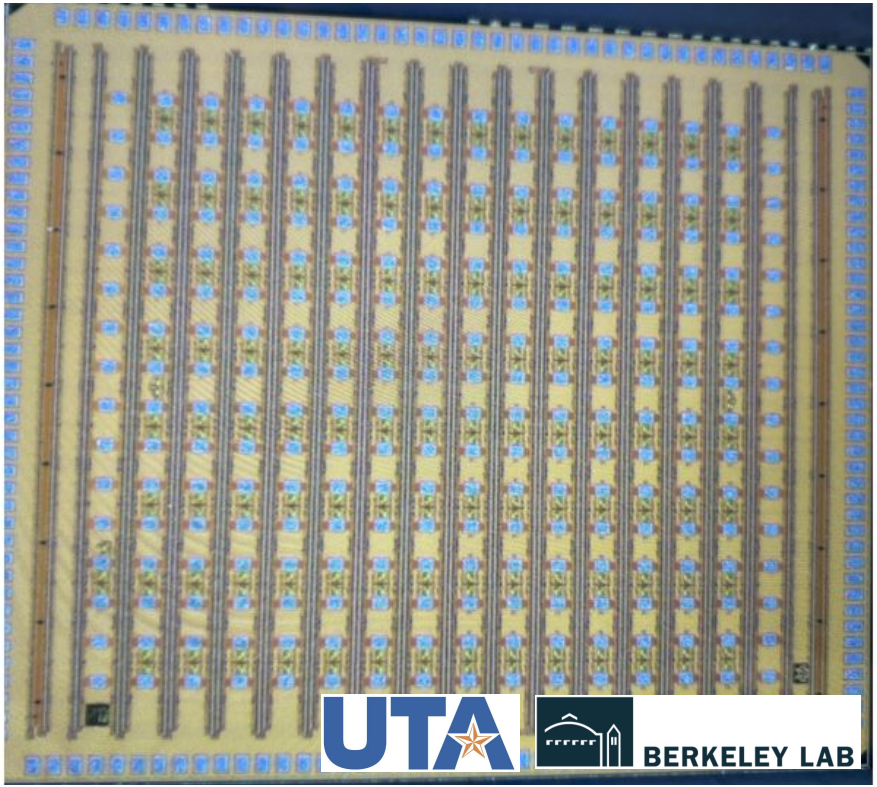
G3Pix – A Low-Noise ASIC



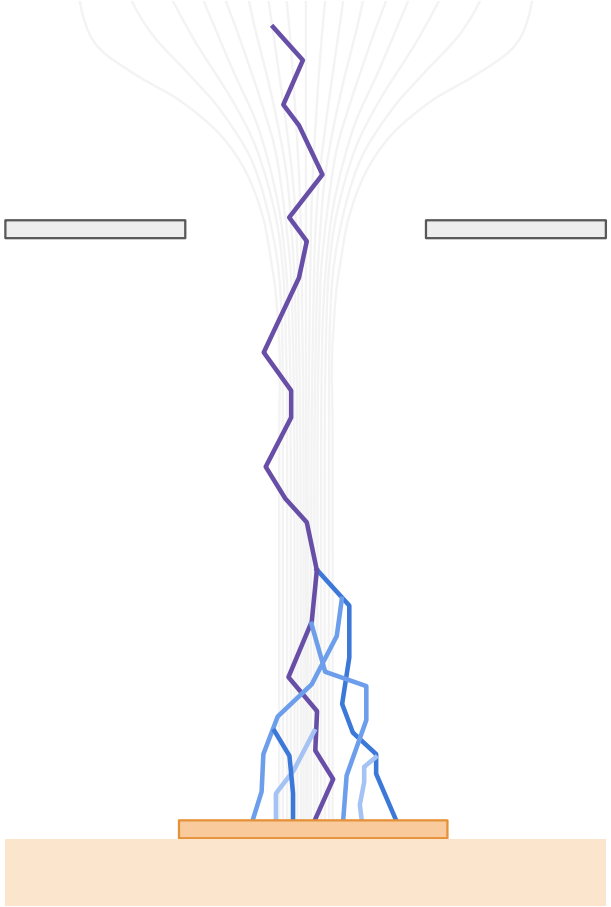
- *Minimal capacitance pixel*
- *Low-noise amplifier*
- *Ideal shaping times*

Design Specs:

- *2 μs shaping with **3 ENC***



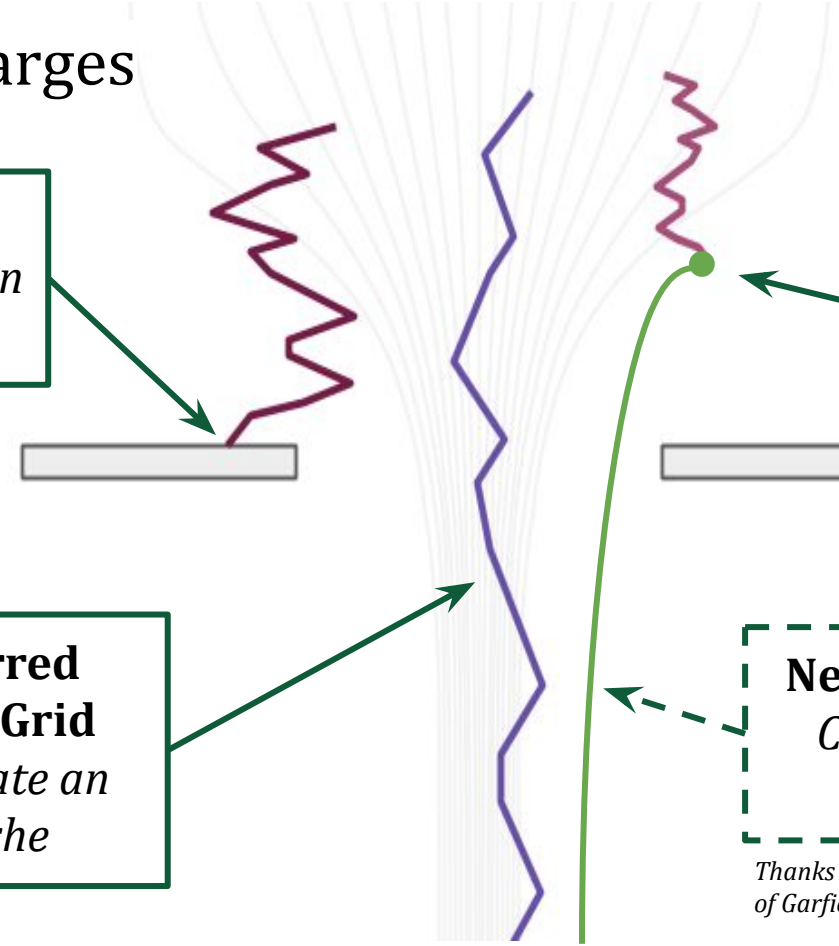
Maximizing Efficiency



Making *every* primary charge *count*.

- **To get ideal efficiency:**
  - Collection of all primary charges.
  - Detection of all avalanches.
  - No losses in readout.
- **Considerations:**
  - Field strengths and geometry.
  - Thresholds and noise.
  - Signal development and front-end electronics.

Collecting Charges



Hits Grid
Cannot generate an avalanche

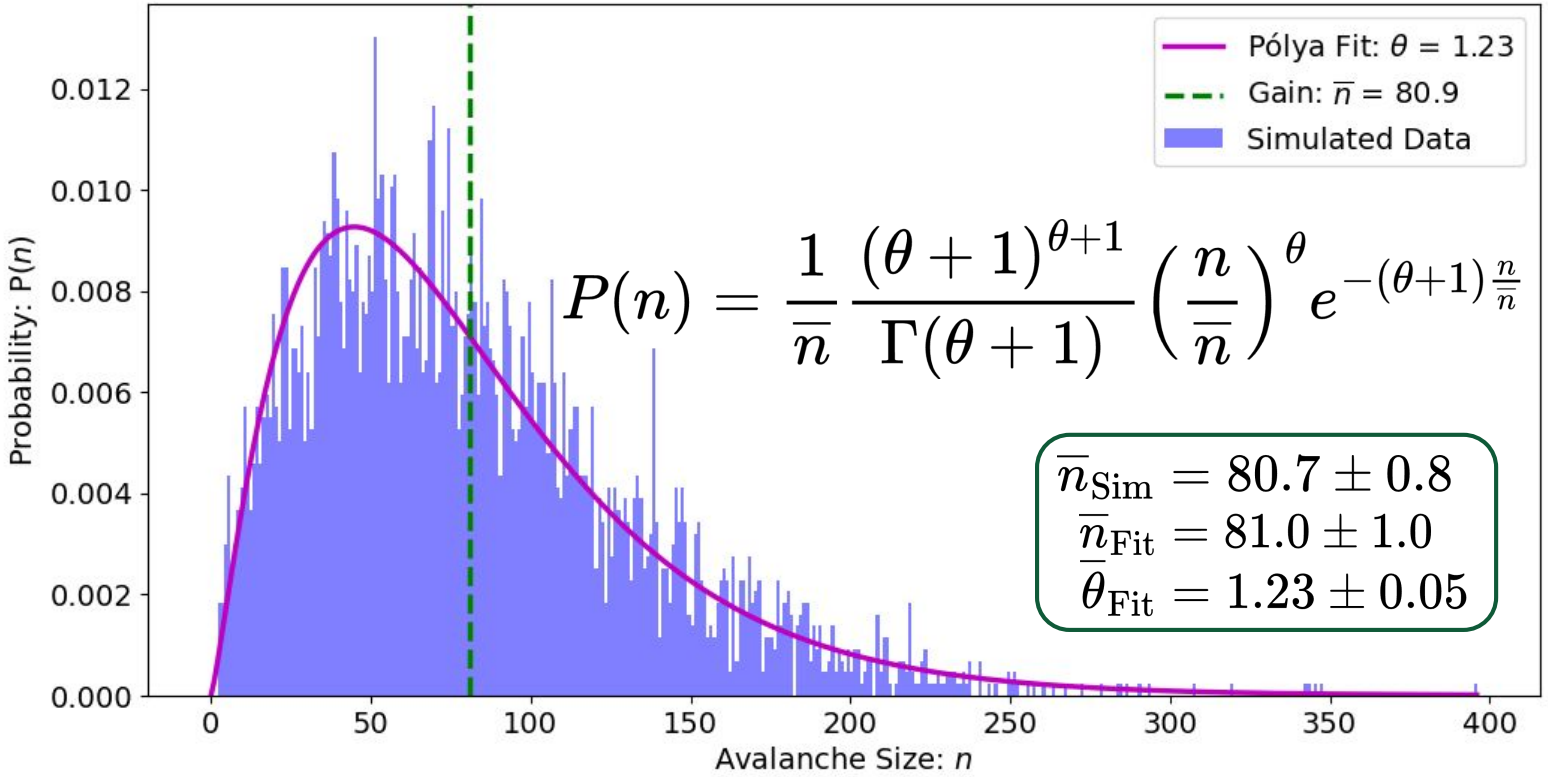
Attachment
Creates a negative ion

Transferred Through Grid
Can generate an avalanche

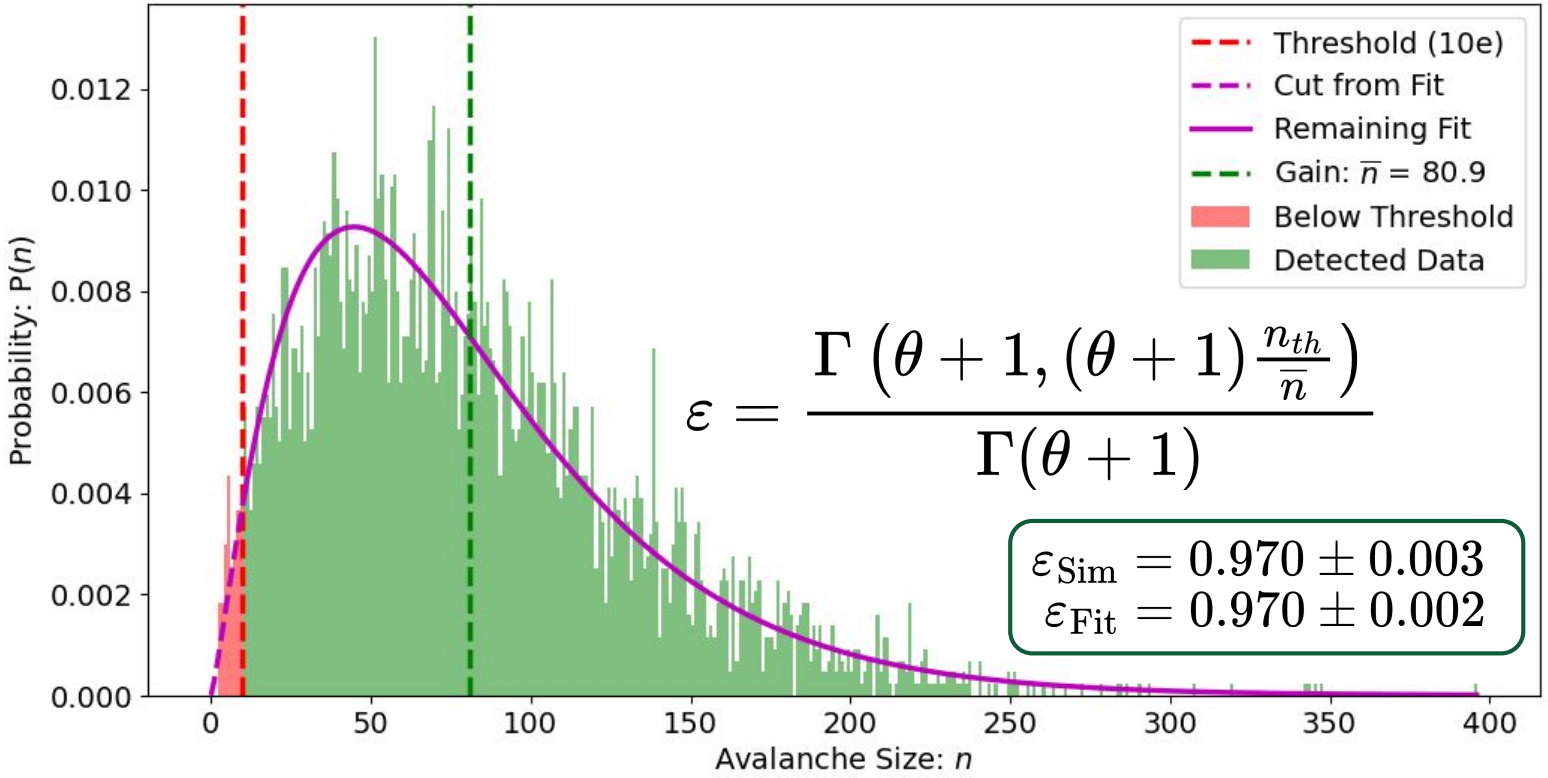
Negative Ion Drift
Can generate an avalanche

Thanks to Kentaro Muichi for a version of Garfield++ that allows this.

Many Single-Electron Avalanches

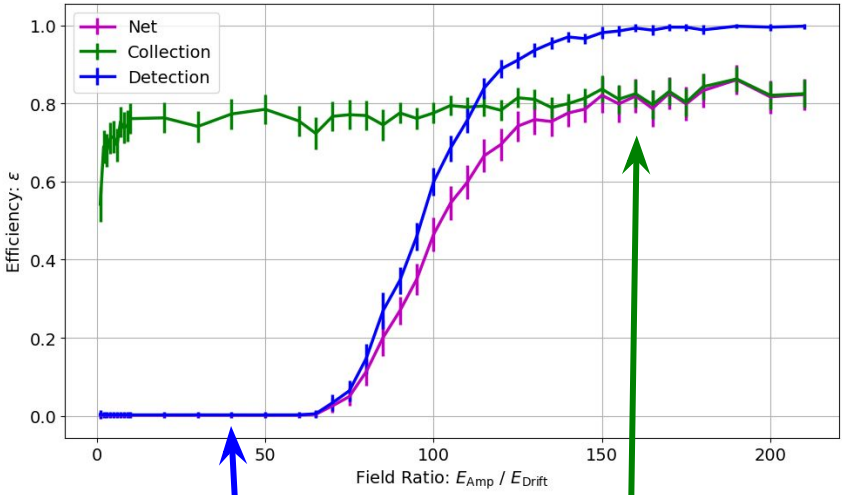


Applying a 10e Threshold



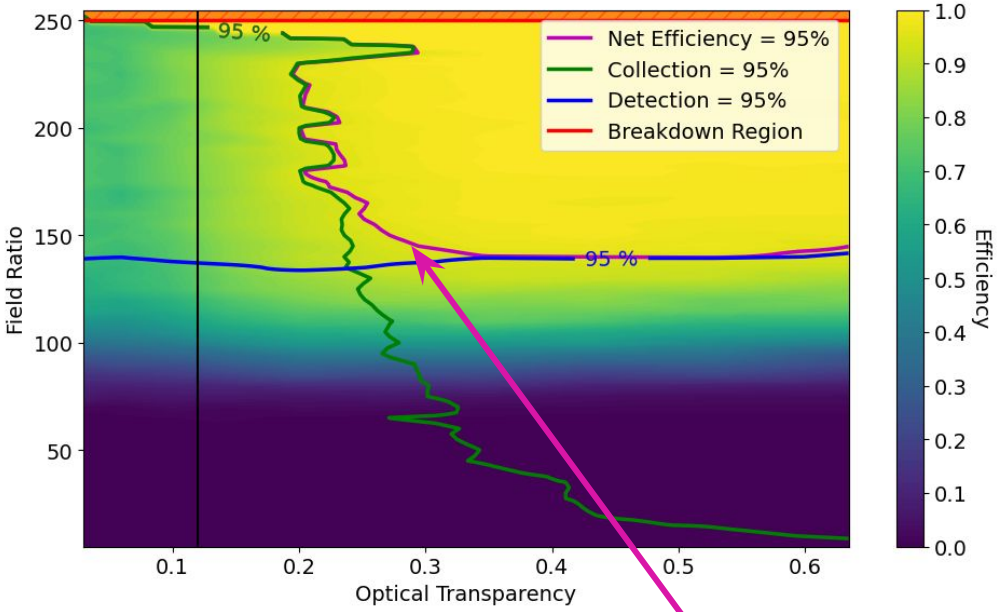
Mapping Efficiencies

$$\varepsilon_{\text{Net}} = \varepsilon_{\text{Col}} \cdot \varepsilon_{\text{Det}}$$



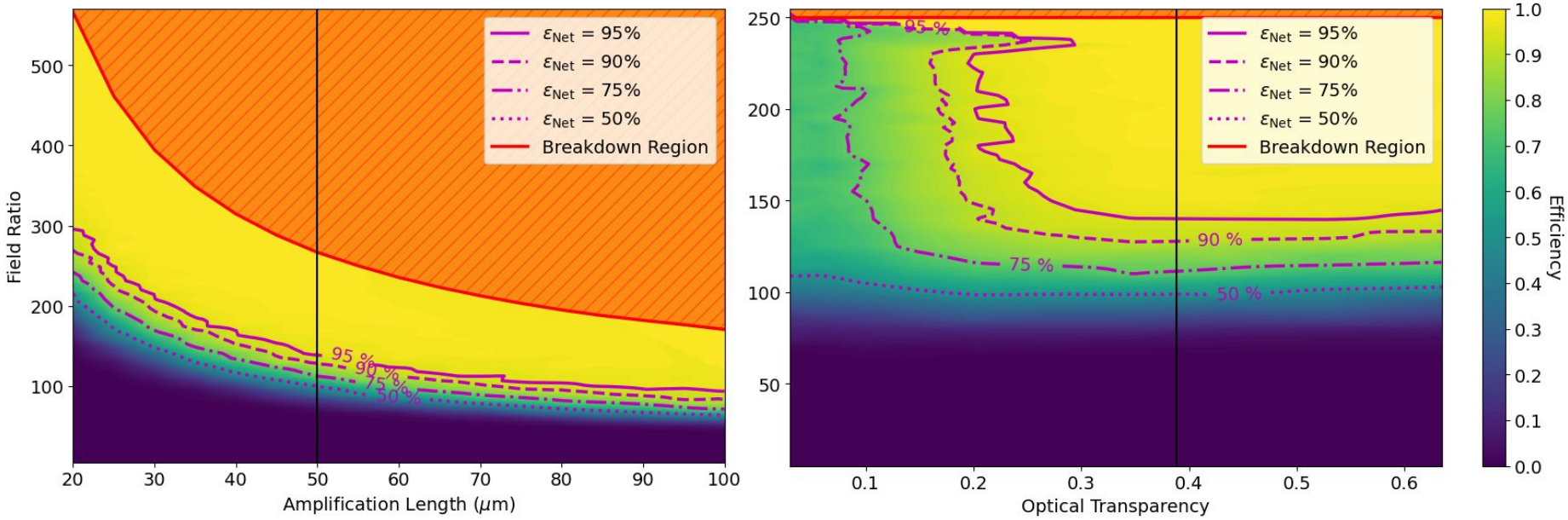
Detection-limited

Collection-limited

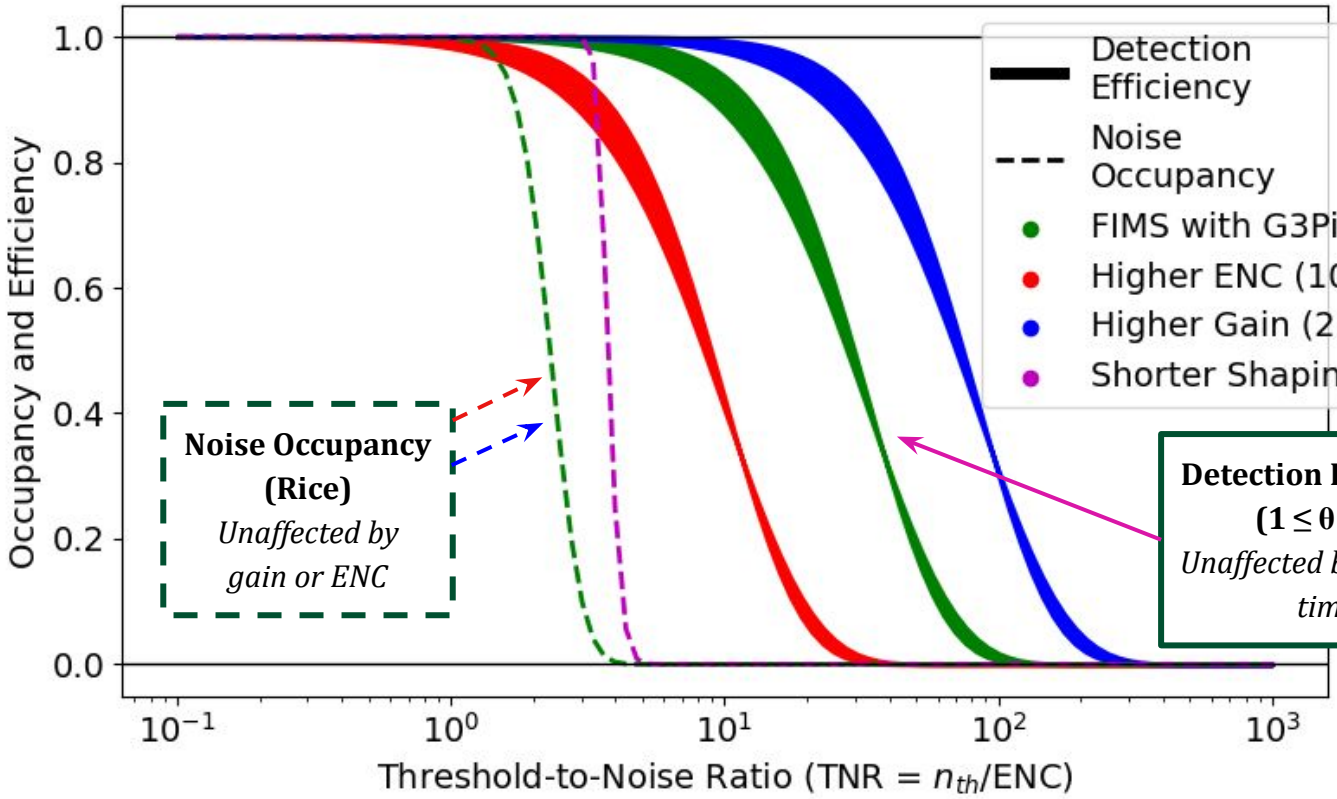


Net Efficiency of 95%

Net Efficiency Contours

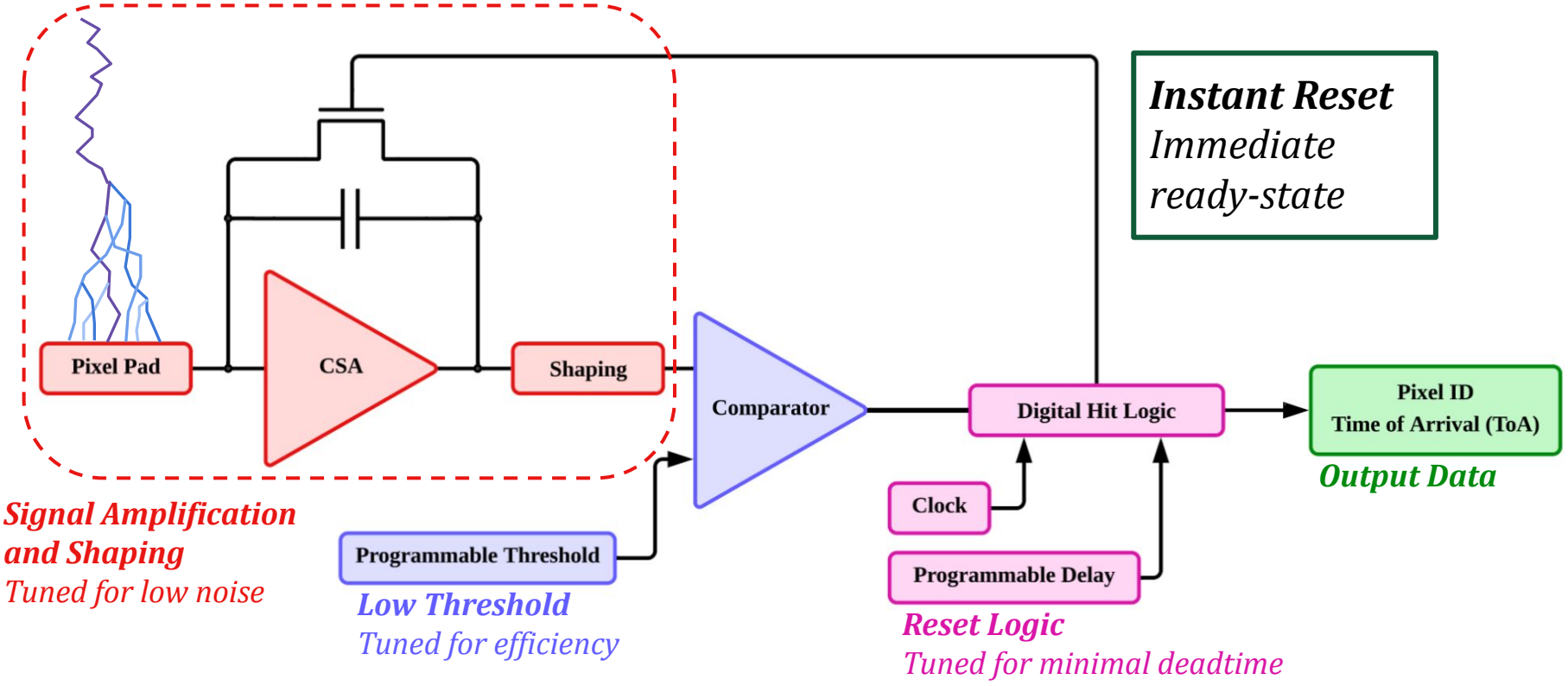


Noise and Occupancy

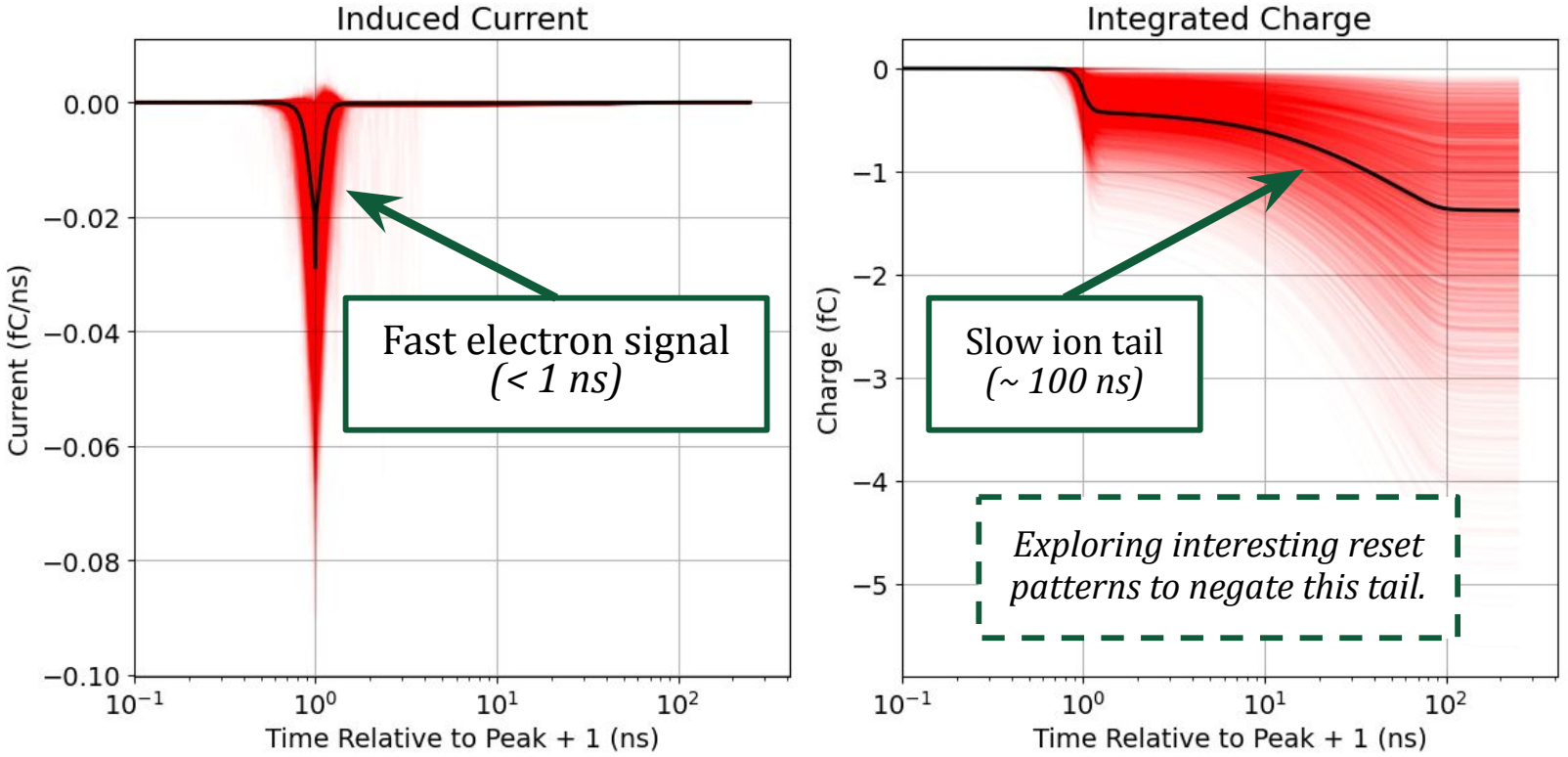


FIMS with G3Pix:
ENC = 3 e
Gain = 100 e
Shaping = 2 μs

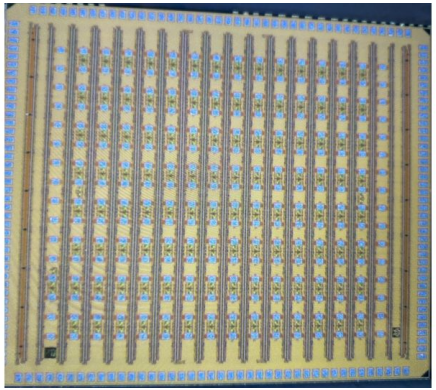
Front-End Electronics Concept

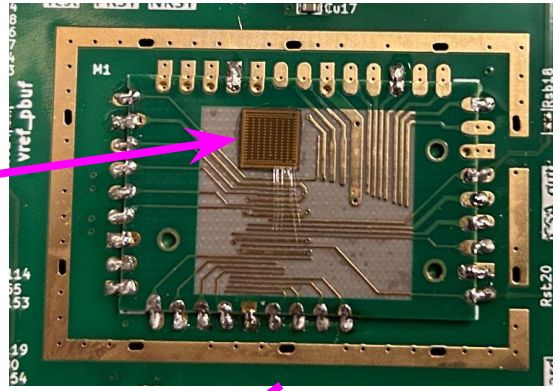


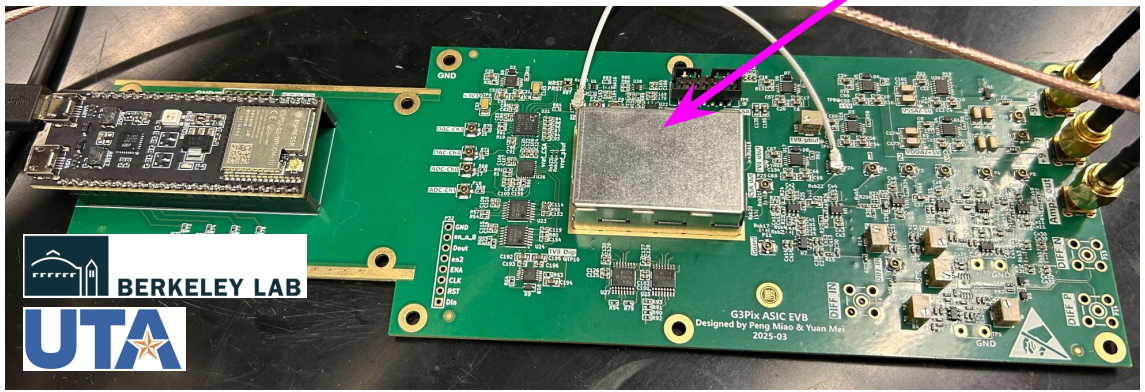
Signal Development



G3Pix – A Low-Noise ASIC



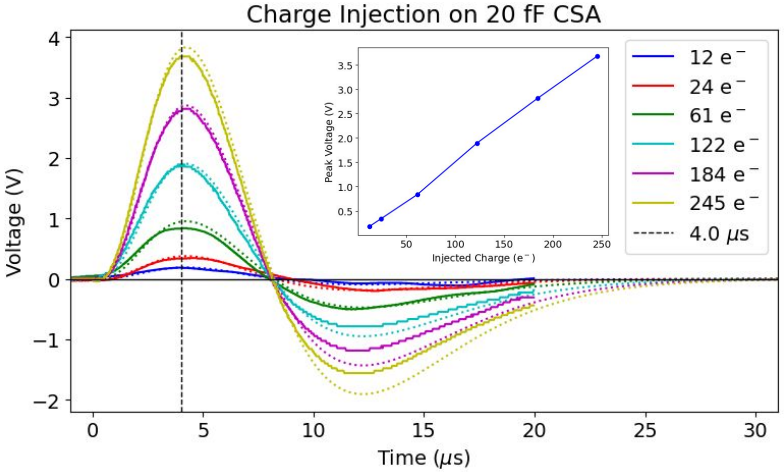


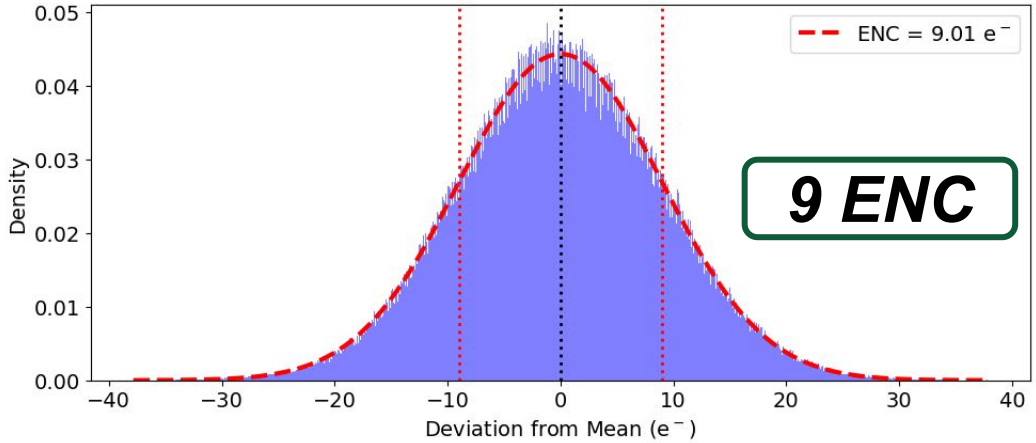


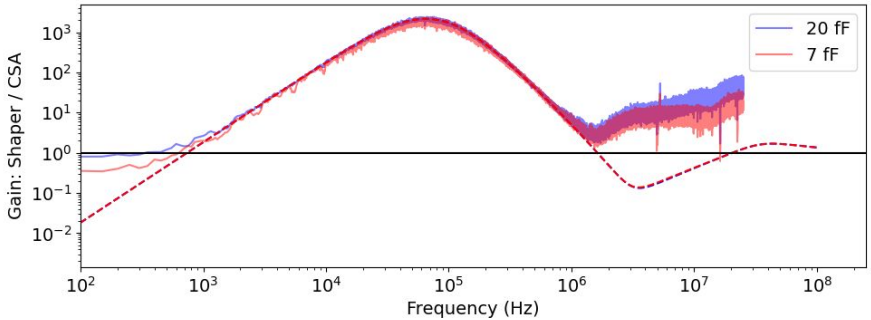
Design Specs:

- *2 μs shaping with **3 ENC***
- *TSMC 180*

Testing G3Pix







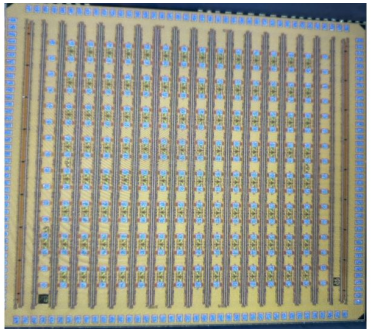
- *Peak at ~4 μs.*
- *Linear gain response.*
- *Consistent shaper gain.*
- *Measuring 9 ENC.*

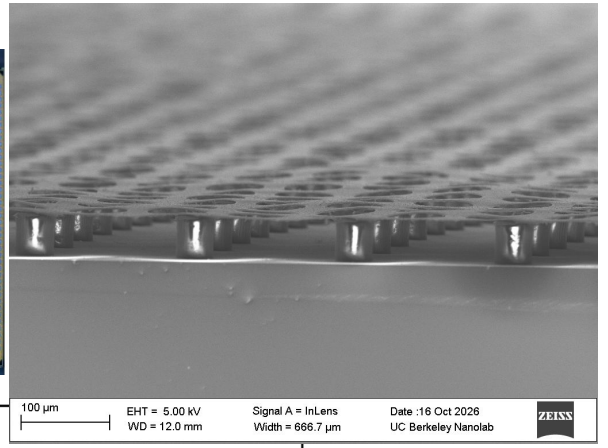
Why not 3 ENC?
We're working on this…

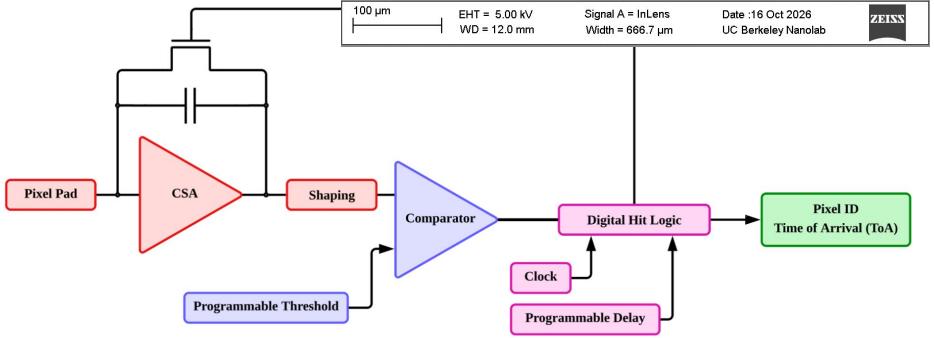
The Flexible, Ideal MPGD System

- **An ultra-low noise ASIC.**
  - Measuring 9 ENC.
- **With an integrated-grid amplification structure.**
  - Geometry chosen to maximize efficiency.
- **With instant-reset capability.**
  - Interesting pattern to negate ion tail.

Making *every* primary charge *count*.

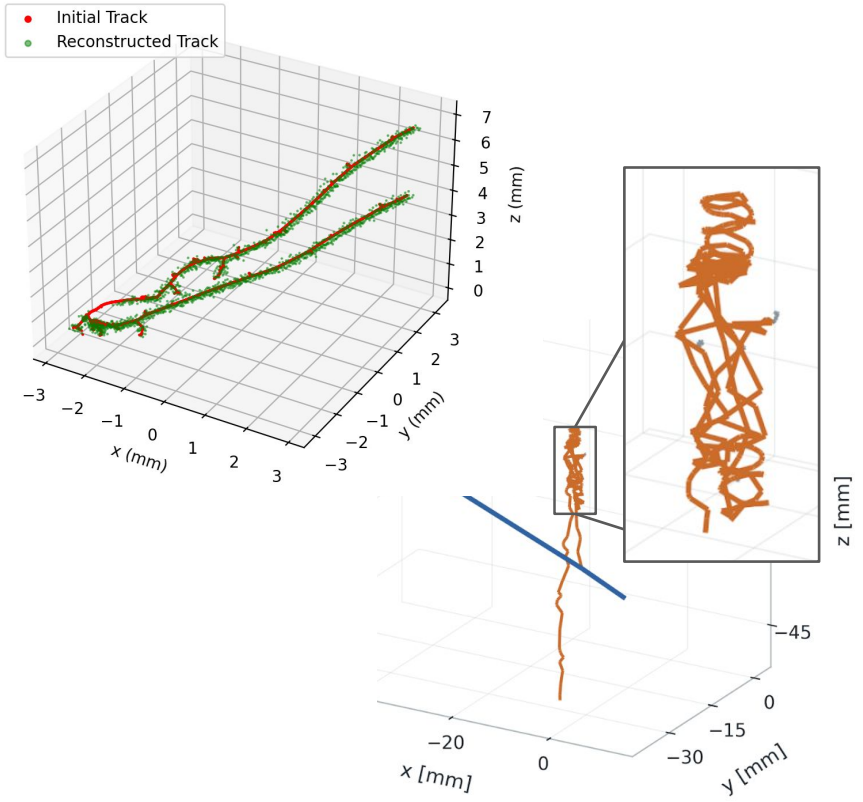






Summary

- Operational Limits:
  - Efficiency targets (detection and/or collection).
  - Gas breakdowns / discharges.
  - Noise occupancy.
- Signals and Front-End:
  - Fast electron and slow ion contributions.
  - Instant reset, with interesting pattern.
  - Event rejection at the hit level through machine-learning (*not covered here*).
- G3Pix:
  - An ultra-low-noise ASIC.
  - Measuring 9 ENC (*but might be less*).

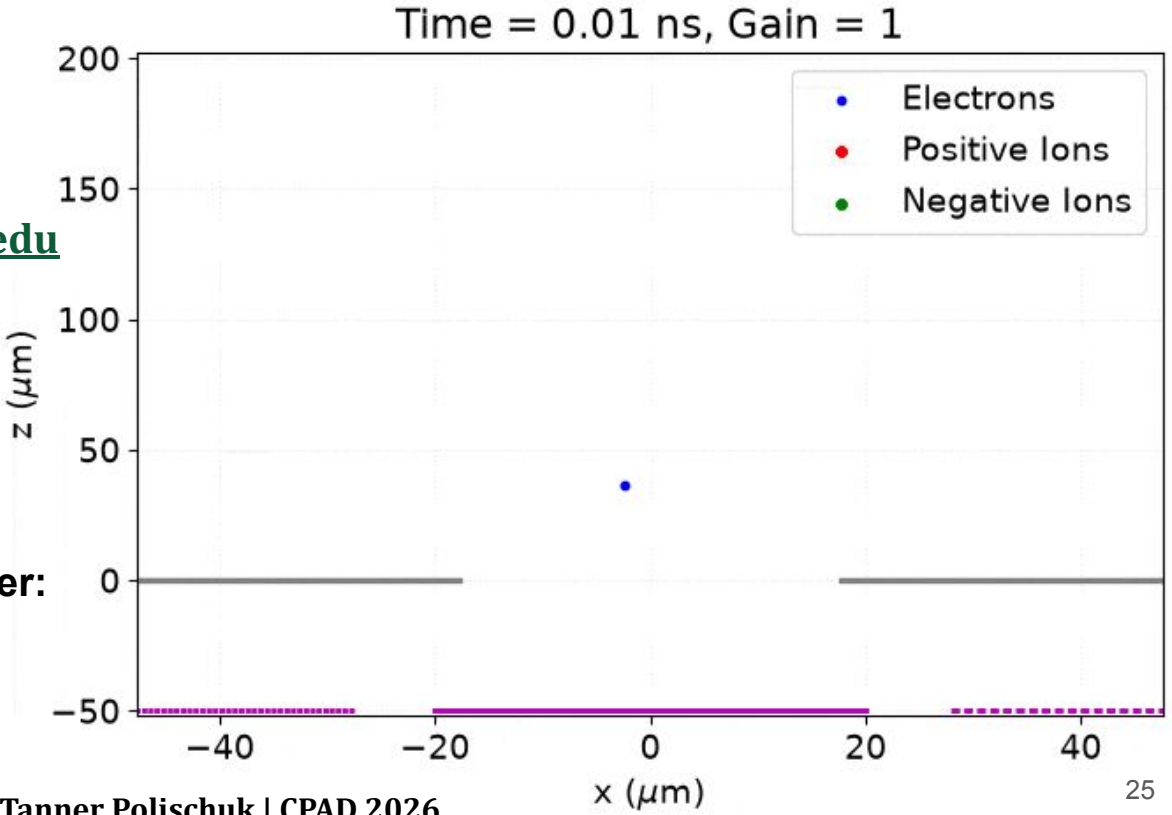


Thank you!

Peter Lewis:
peter.mandeville.lewis@hawaii.edu

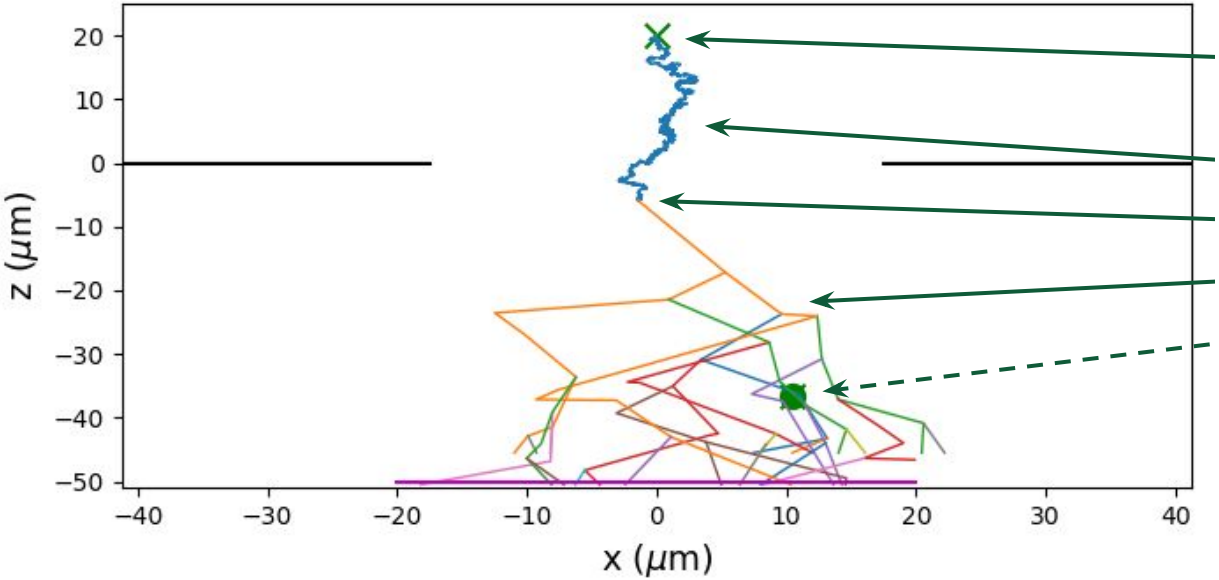
Tanner Polischuk:
tanner.polischuk@hawaii.edu

Check out James Harrison's poster:
A Complete Ion Screening Amplification Structure



Backups

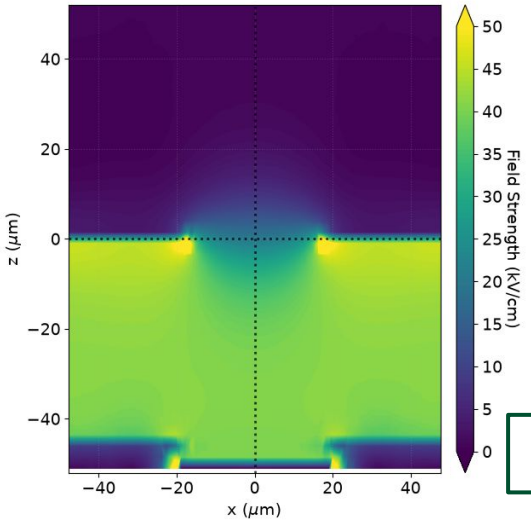
Simulating Negative Ion Drift

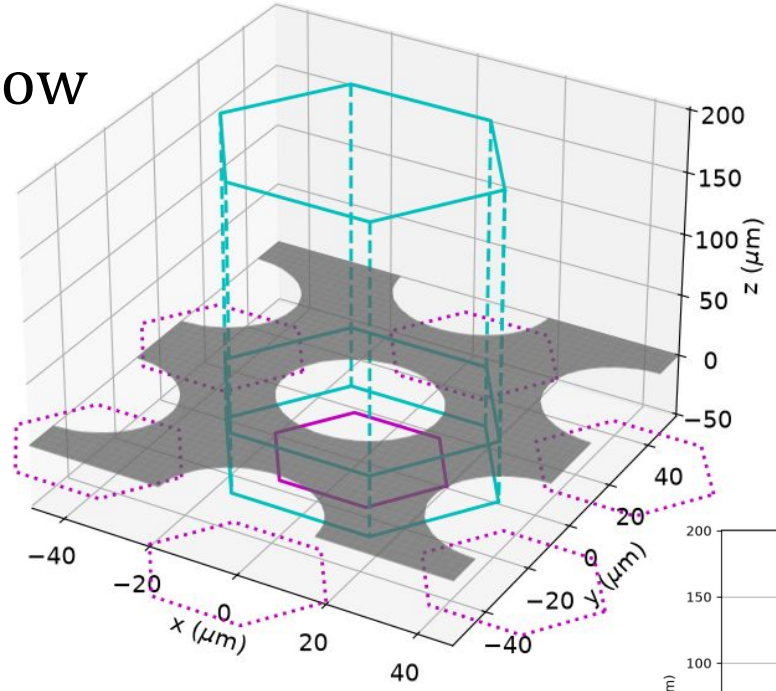


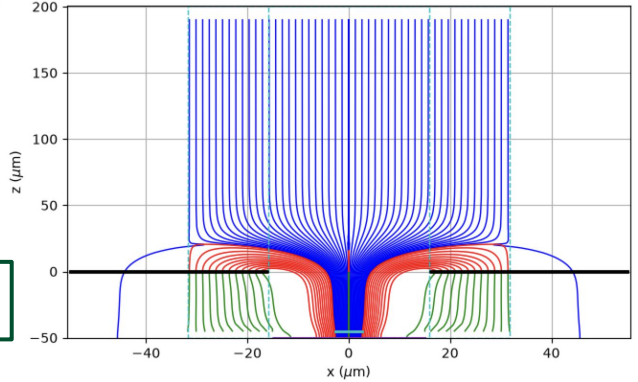
- Populate with electron
  - Immediate attachment
- Negative ion drift
- Electron detachment
- Electron avalanche
  - Re-attachment/detachments

This uses a threshold-based model for detachment. Verification of a scattering-based model is ongoing.

Simulation Workflow





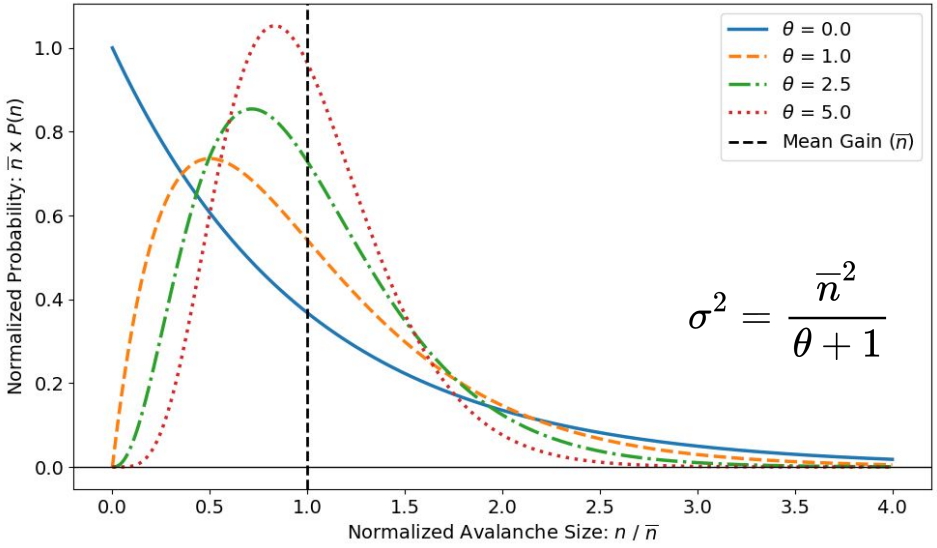


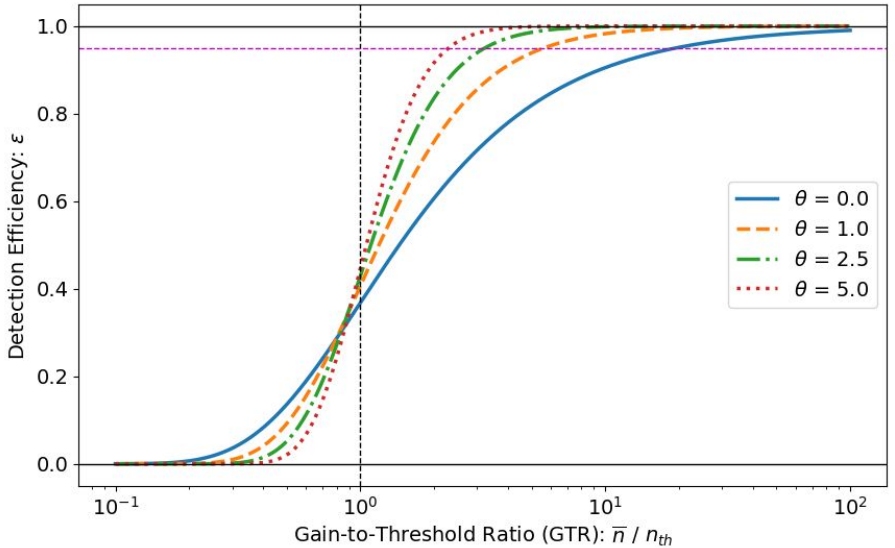
Gmsh → Elmer → Garfield++

Pólya Parameterizations

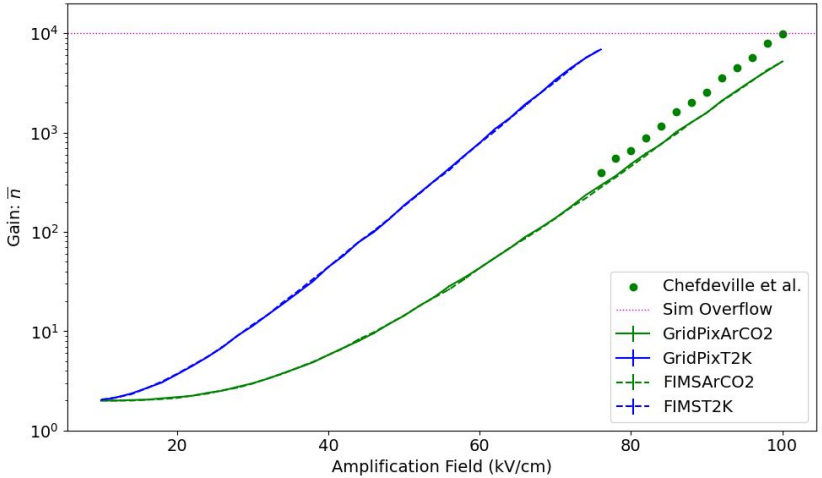
$$P(n) = \frac{1}{\overline{n}} \frac{(\theta+1)^{\theta+1}}{\Gamma(\theta+1)} \left(\frac{n}{\overline{n}}\right)^{\theta} e^{-(\theta+1)\frac{n}{\overline{n}}}$$

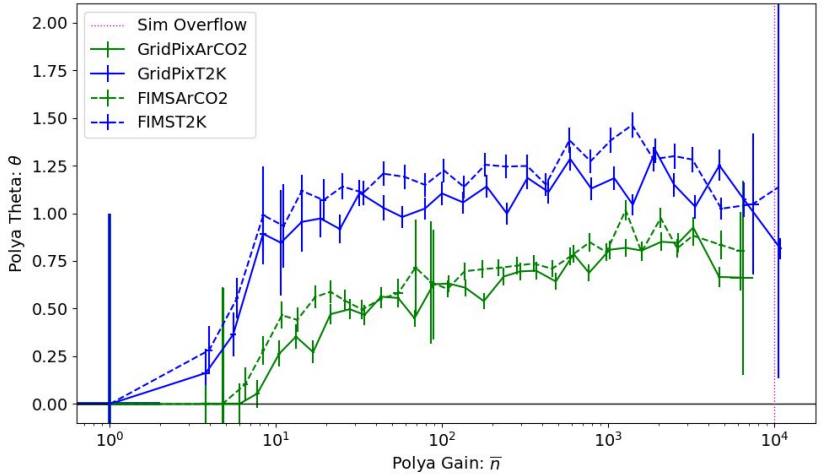
$$\varepsilon = \frac{\Gamma\left(\theta+1, (\theta+1)\frac{n_{th}}{\overline{n}}\right)}{\Gamma(\theta+1)}$$





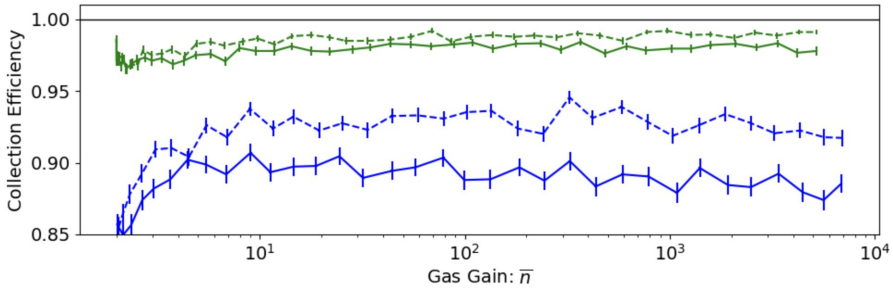
Different Geometries and Gases



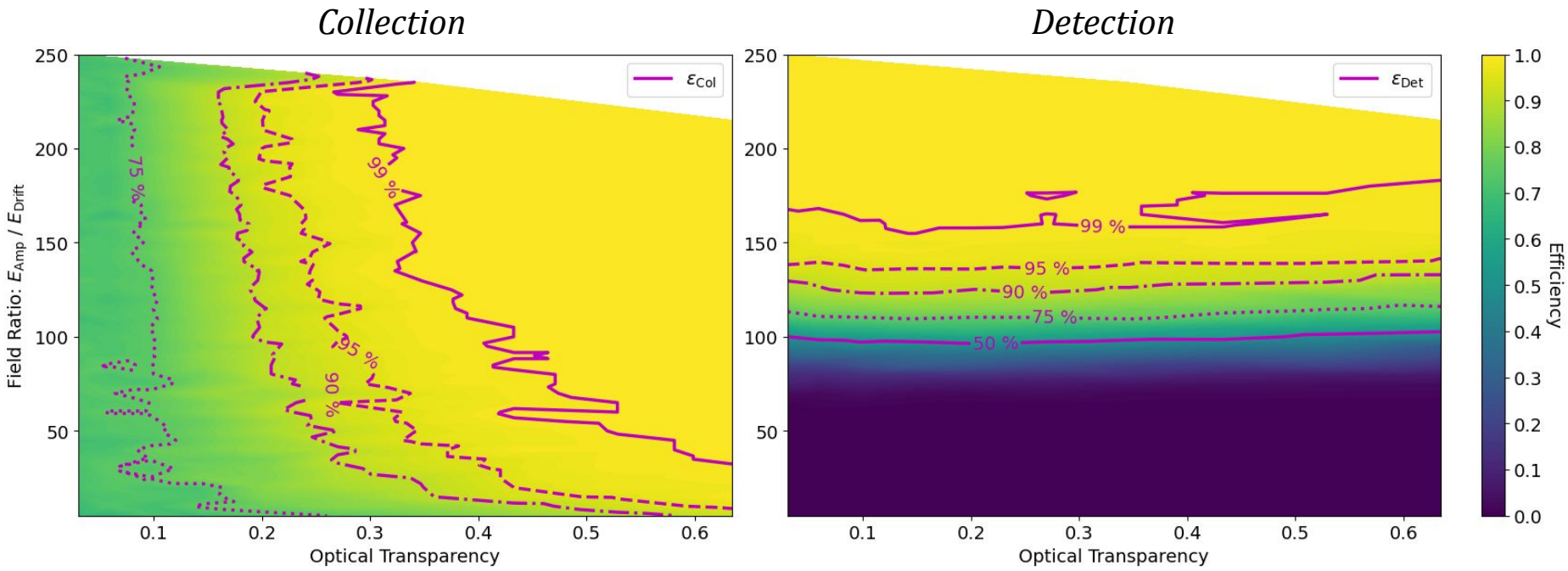


GridPix: Square unit cell, circular holes, octagonal pads.
FIMS: Hexagonal unit cell, circular holes, hexagonal pads.
Data: *10.1016/j.nima.2005.11.065*

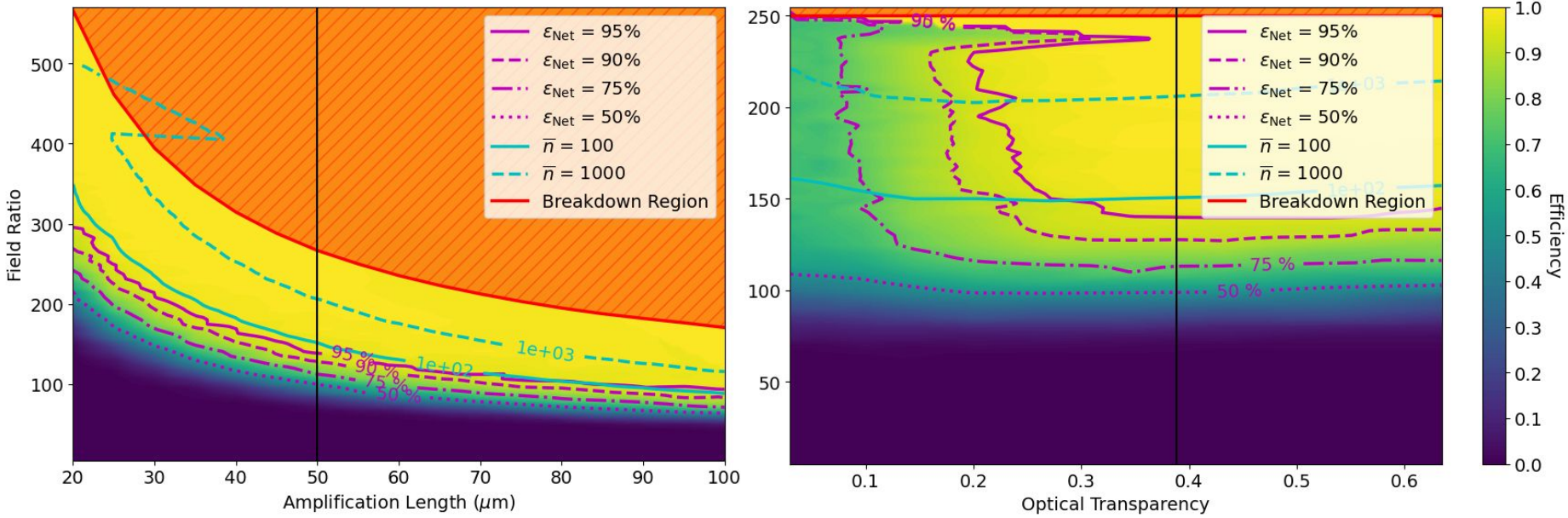
ArCO2: Ar/CO_2 – 80/20 *(Penning = 0.51)*
T2K: Ar/CF_4/isobutane – 95/3/2 *(Penning = 0.385)*



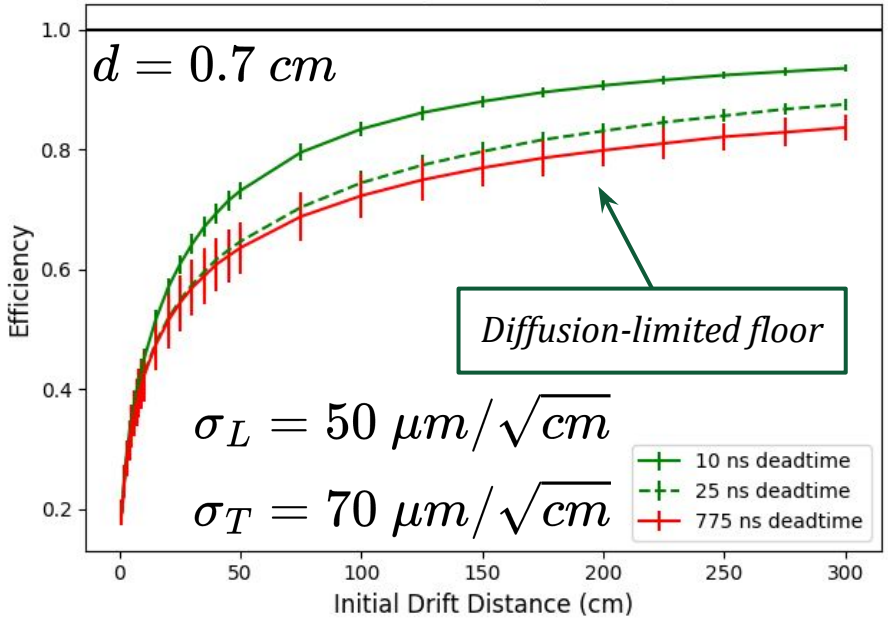
Efficiency Contours

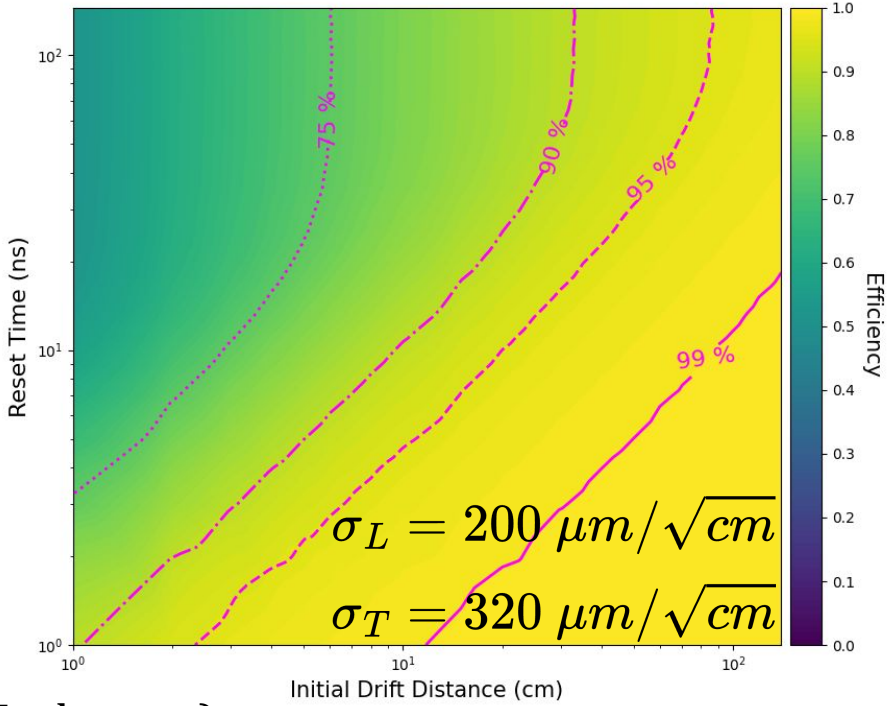


Net Efficiency and Gain Contours



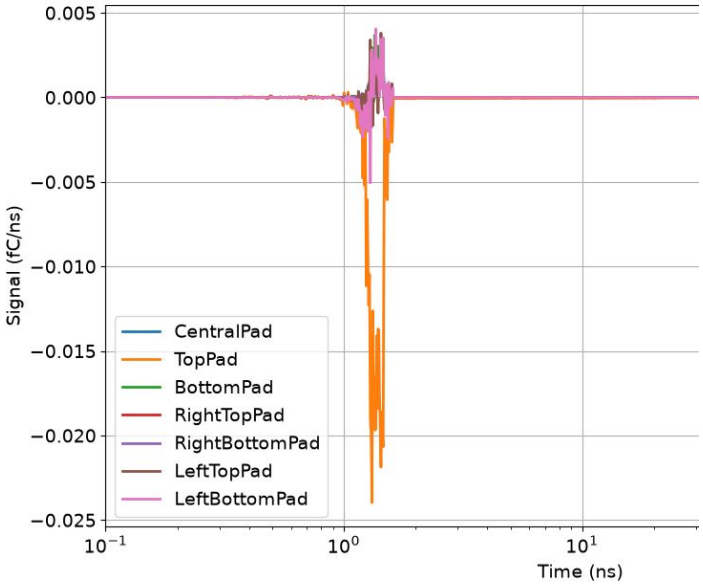
Reset Time and Pileup

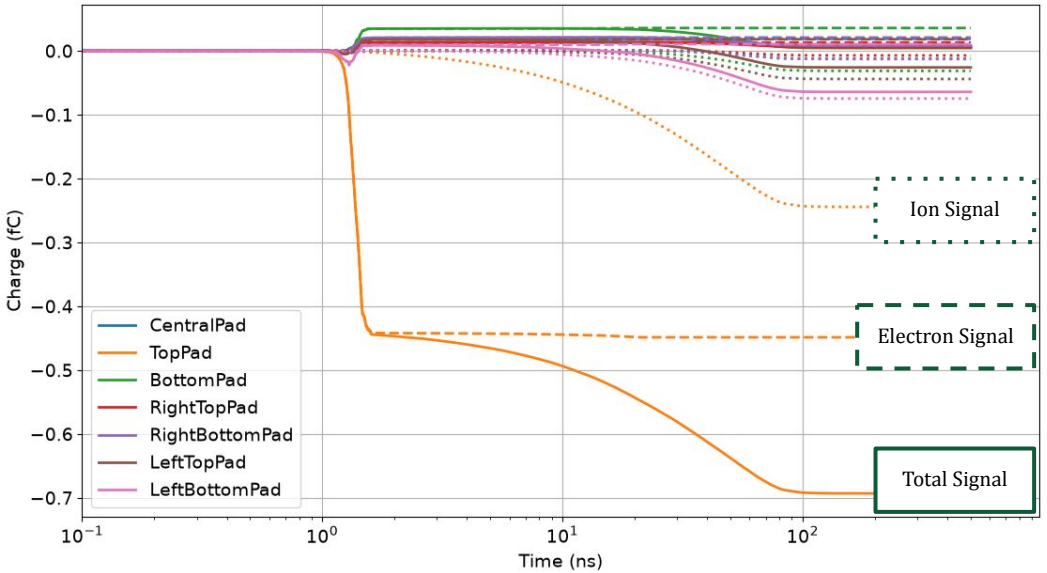




Nuclear recoils in T2K gas (95/3/2 Ar/CF4/Isobutane).

Induced Signals





For primary pad:

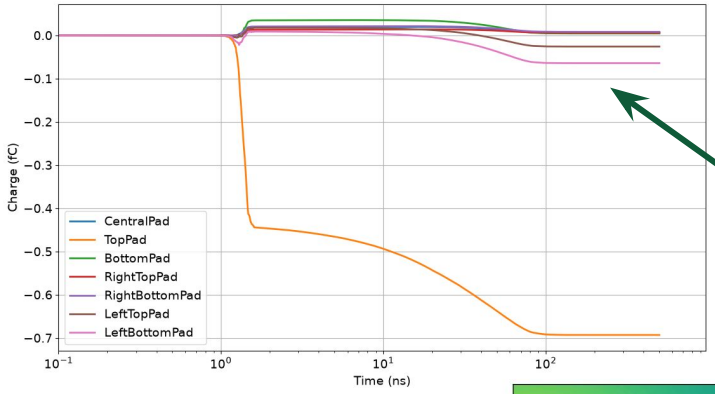
- *Rapid, negative electron signal.*
- *Long, negative ion signal.*

For neighbor pads:

- *Rapid, positive electron signal.*
- *Long, negative ion signal.*

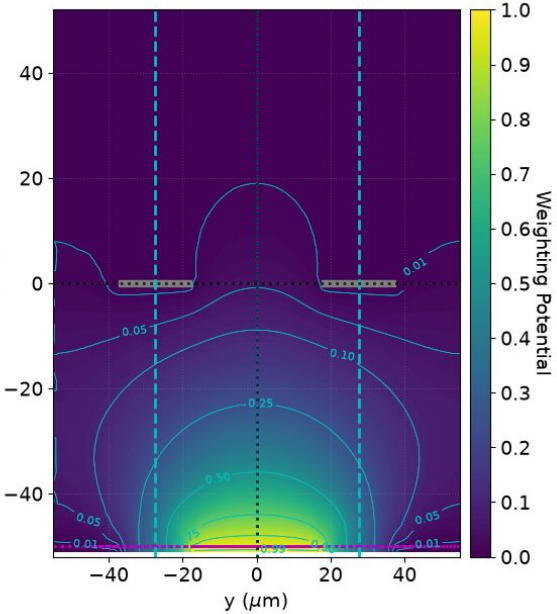
Transient Signals

All Induced Signals



These change baselines. *Can be solved by also resetting neighbours*

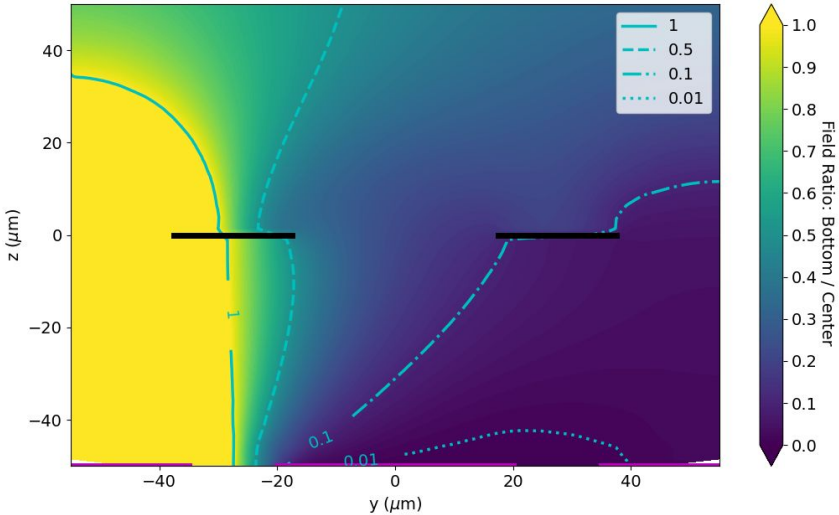
Weighting Field for Individual Pad



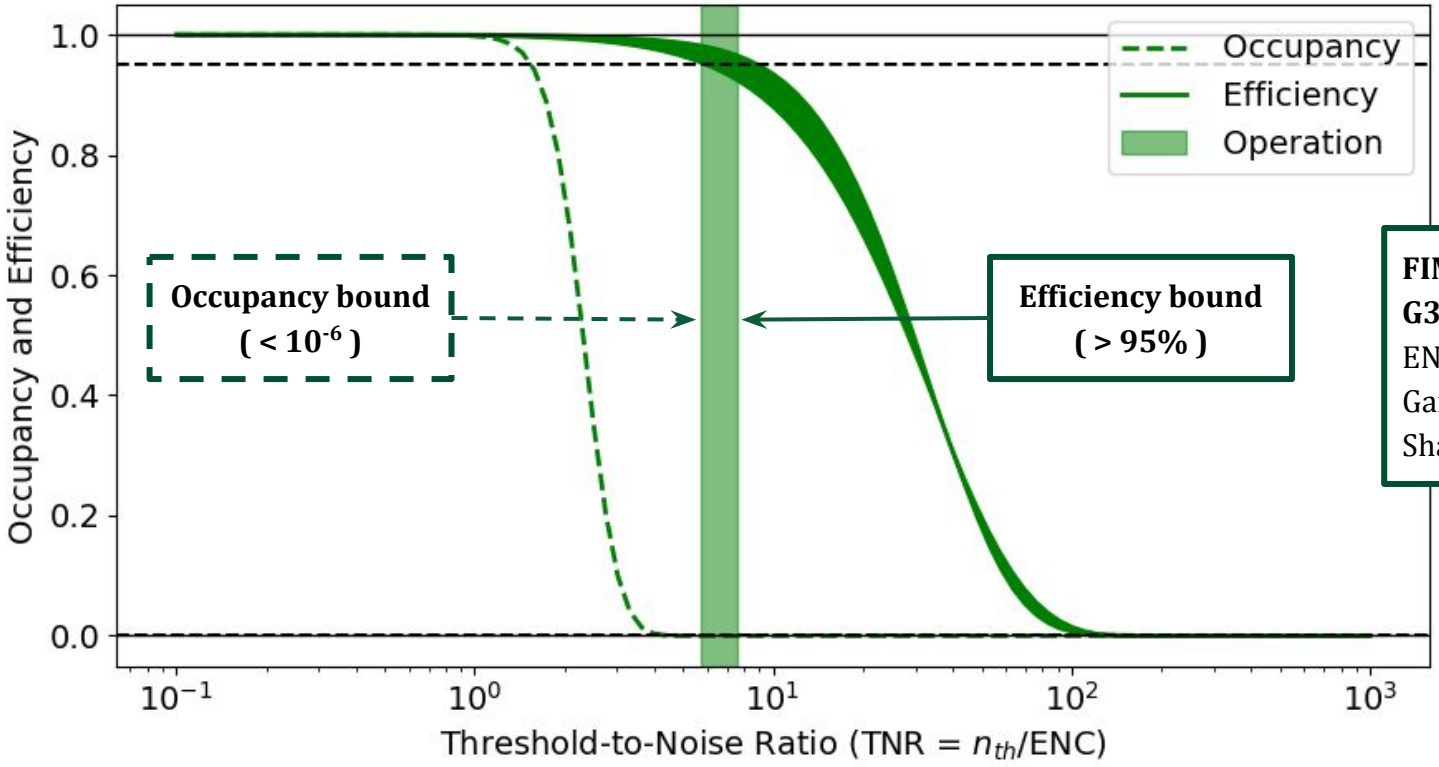
For neighbor pads:

- *Rapid, positive electron signal.*
- *Long, negative ion signal.*

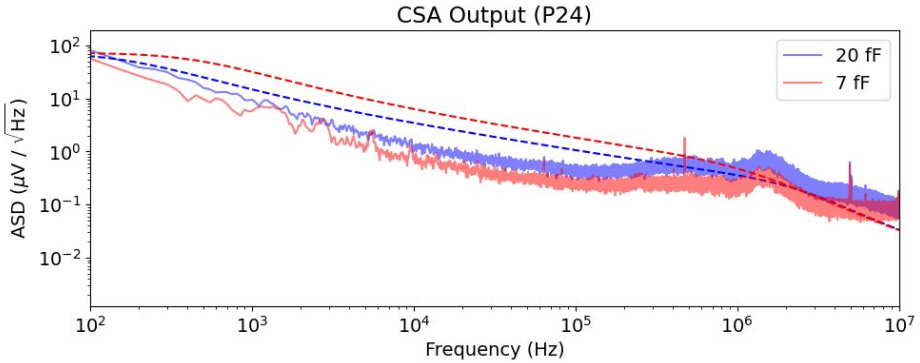
Relative Strength of Neighbor Pad

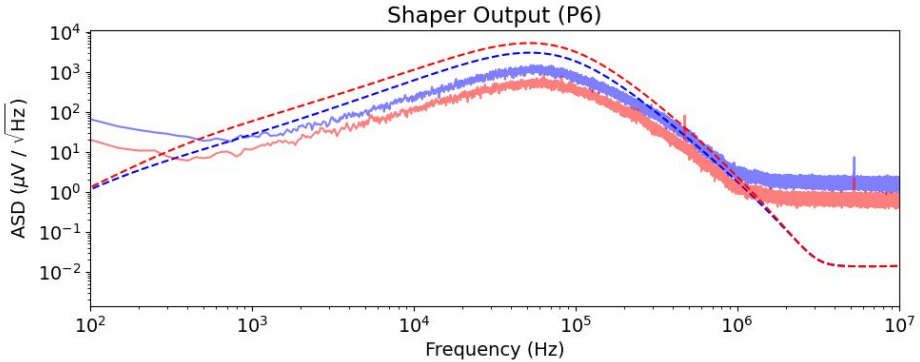


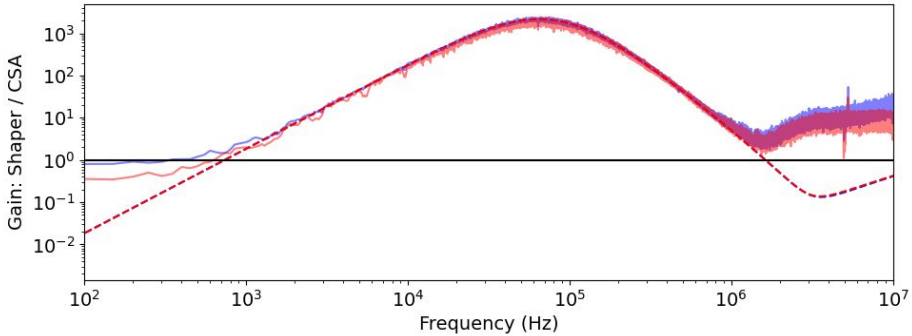
FIMS with G3Pix Operational Regime



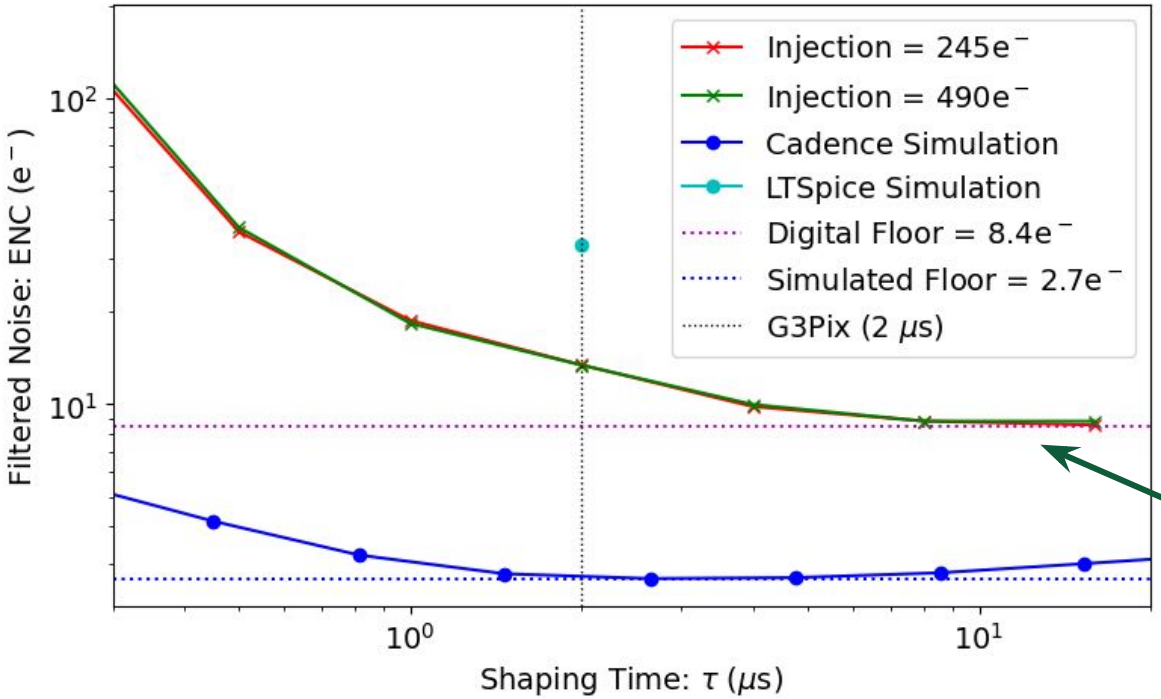
G3Pix – More Testing Results

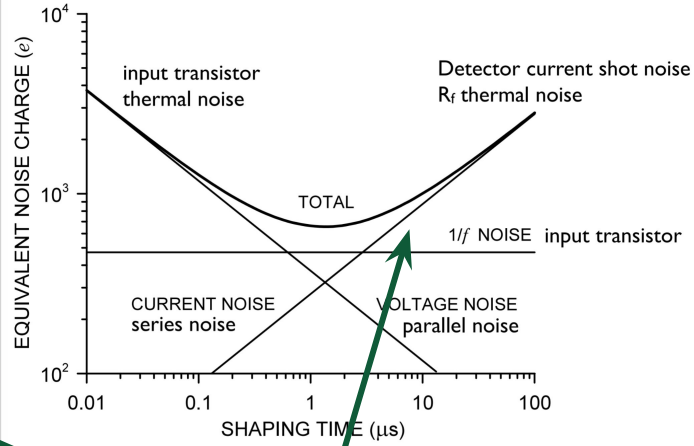






CMOS ENC and Shaping





No Series Noise