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MĀNOA

Development of an Ideal Gaseous TPC Detector

Tanner Polischuk | University of Hawaii

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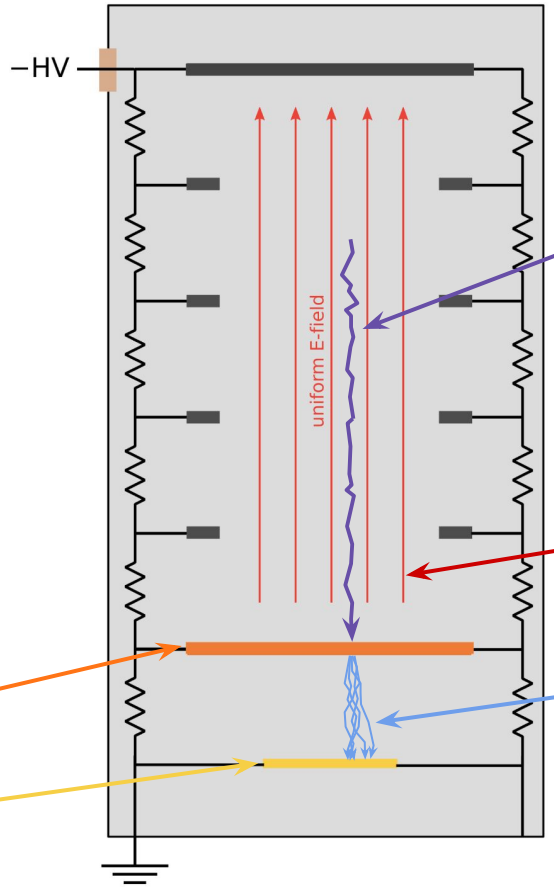
What is an ideal TPC?

The goal:

Can we do *this stuff* so well that we are limited by **fundamental physics** and not by technology? (for *any* application)



Primary charge (subject to diffusion)

Back-flowing ions from amplification follow field lines back up (causes distortion)

Amplified charges (subject to diffusion)

The stuff:

- Amplification grid
- Pixel ASIC

What are some TPC metrics?

3D spatial resolution

- ***x*** and ***y***: sensor **pitch**
- ***z***: drift velocity × time resolution

Single charge detection efficiency

- **Efficiency** = pixel ***hits*** / ***primary charges***

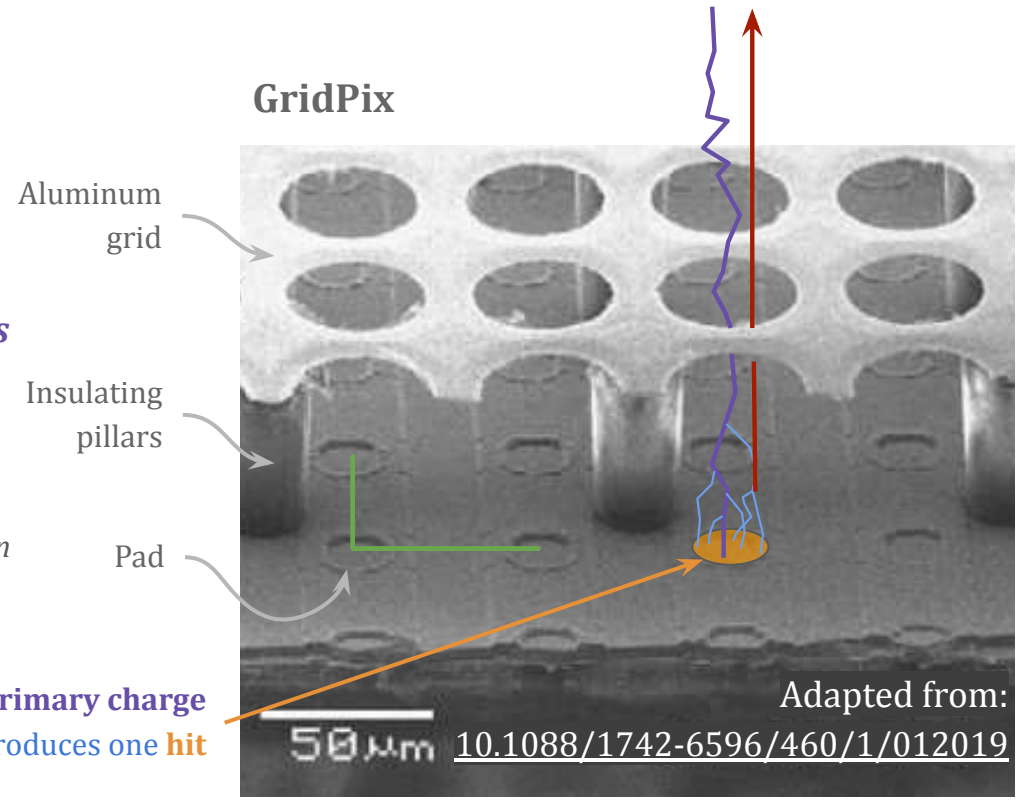
Ion backflow

- **IBN**: Number of ***back-flowing ions***.

IBN = Ion Backflow Fraction (IBF) × Gain

Potential applications:

High-luminosity colliders - ***IBN** is **critical***
Directional dark matter - ***Resolution** and **efficiency** are **critical***

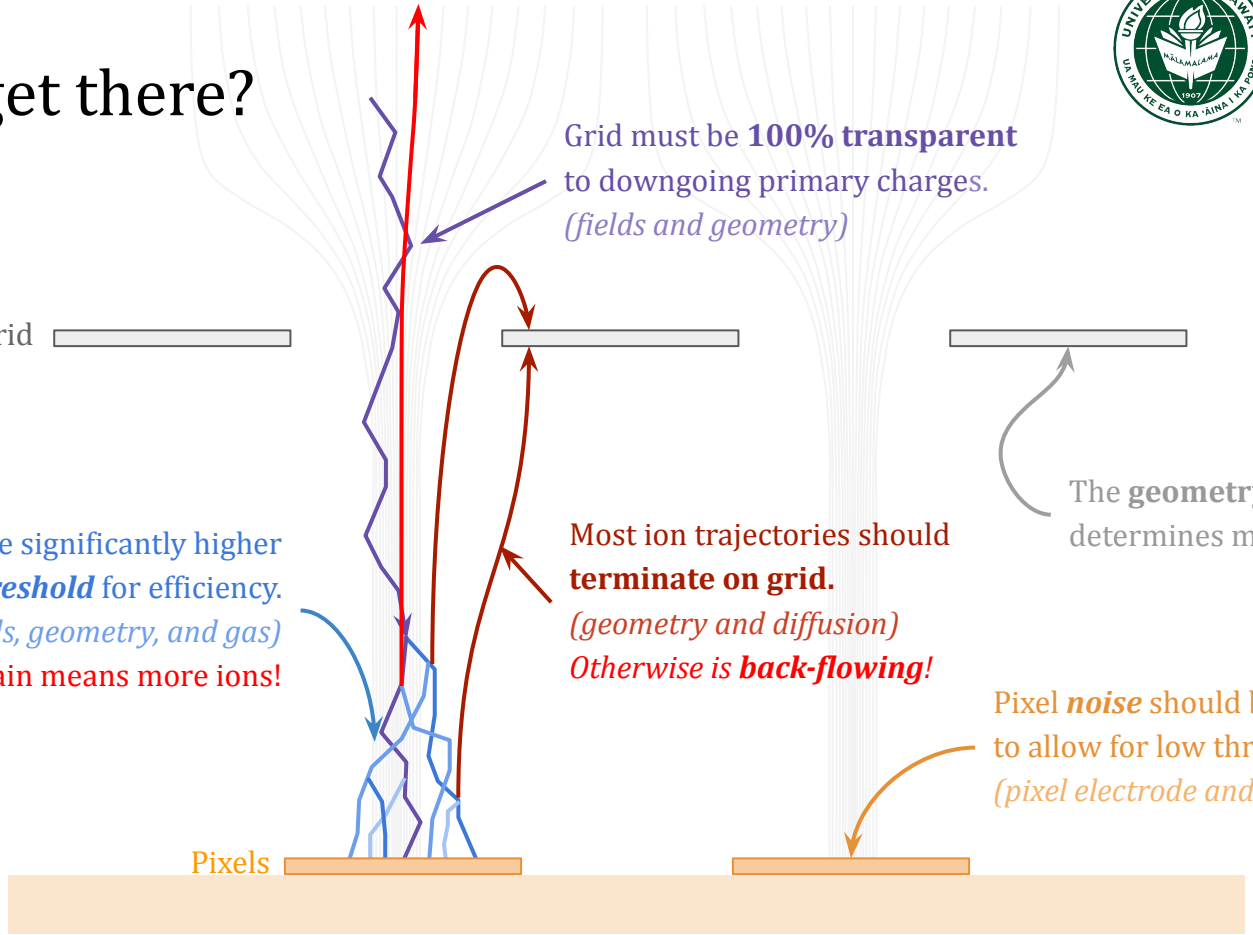


Ideal TPC Goals

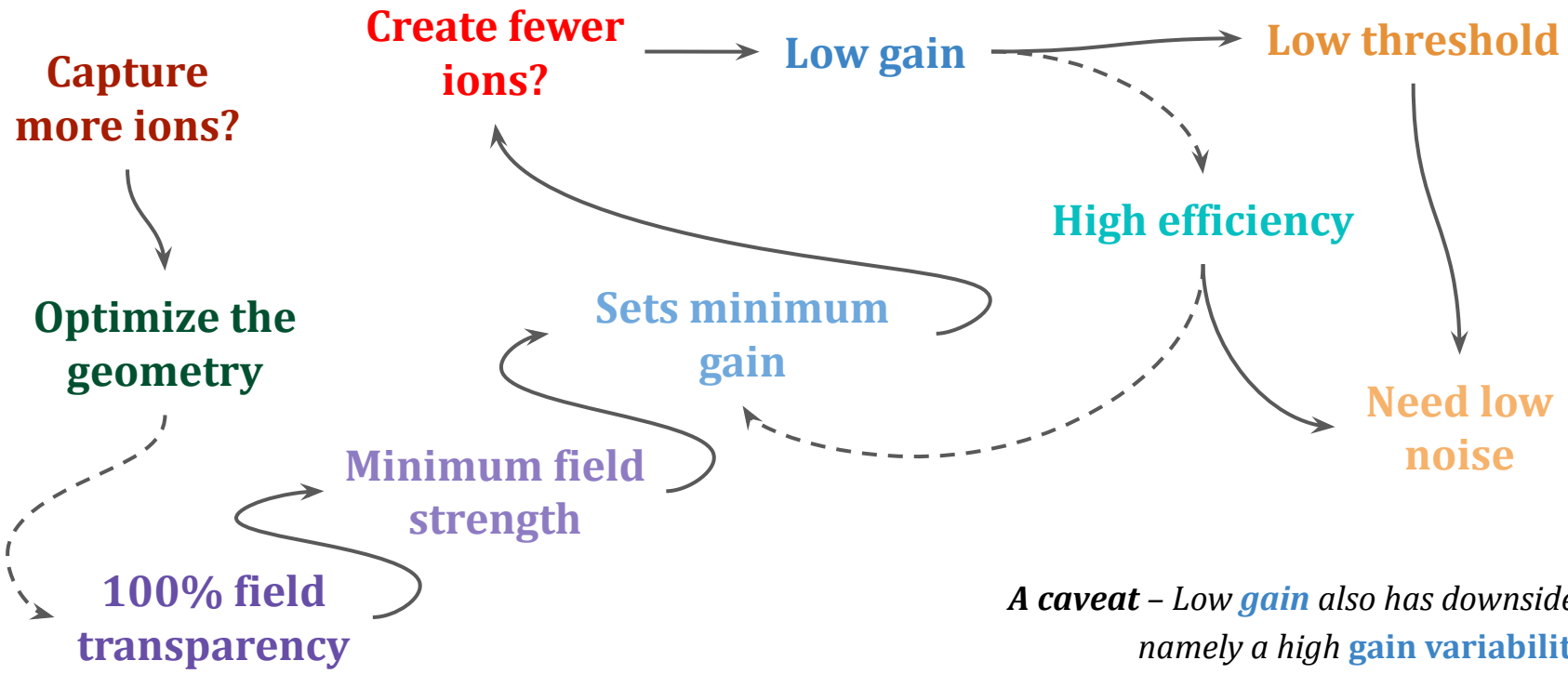
Metric	Ideal values	GridPix
3D spatial resolution	Much better than *diffusion* Electron drift: mm–cm Negative ion drift: 100μm–mm	x/y: 55μm/√12 = **16μm** z (t): comparable (depends on gas, fields)
Single charge efficiency: ε	>0.95	Electron drift: **>0.95** Negative-ion drift: **~0.60** [10.1016/j.nima.2021.165706]
Ion backflow: **IBN**	<1 (less than irreducible *primary* ions)	~0.01×2000 = **20**

GridPix is very good, but still not “ideal”.

How to get there?



How to minimize the **IBN** = ***IBF*** × ***Gain***?



A caveat – *Low **gain** also has downsides, namely a high **gain variability**.*

The Flexible, Ideal MPGD System (FIMS) Collaboration

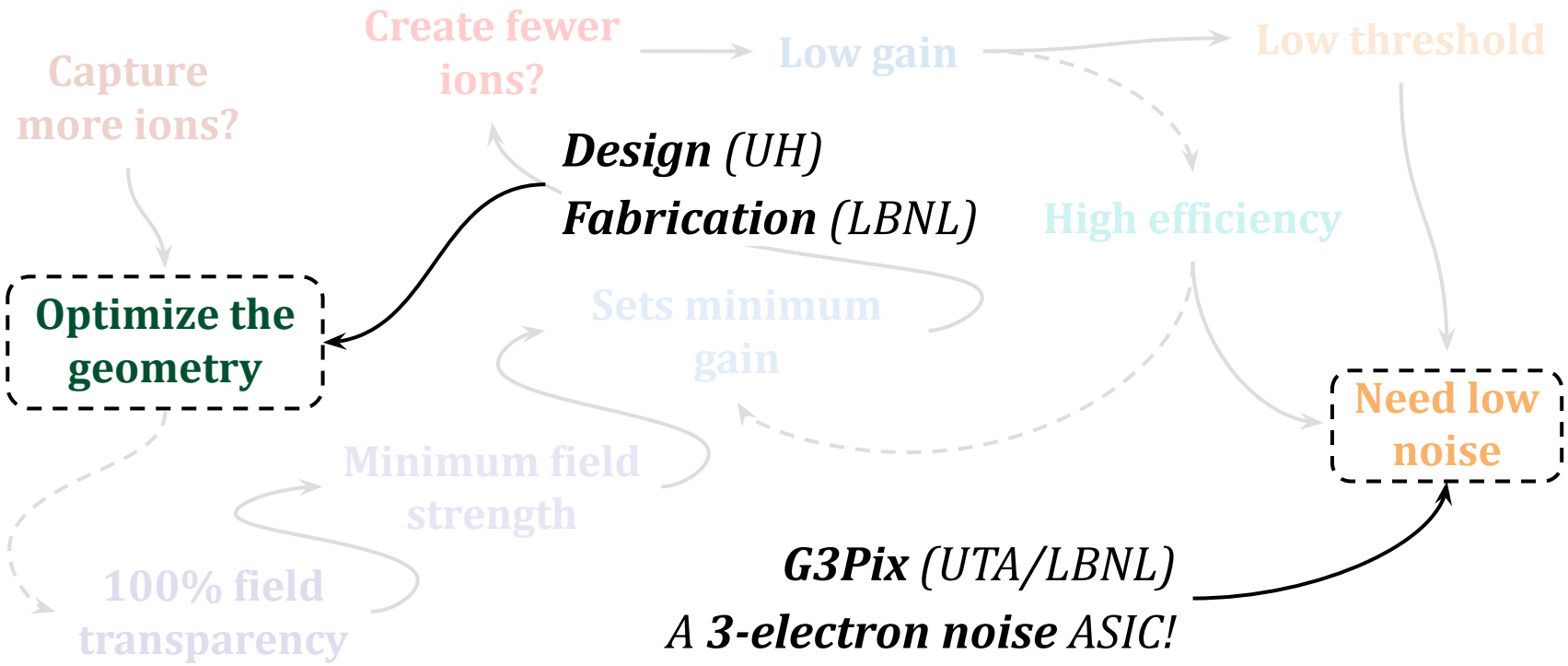
At The University of Hawaii at Manoa
Peter Mandeville Lewis,
Tanner Polischuk, Yubo Han,
James E Harrison IV, Sven Vahsen

At Lawrence Berkeley National Laboratory
Peter Sorensen, Carl Grace

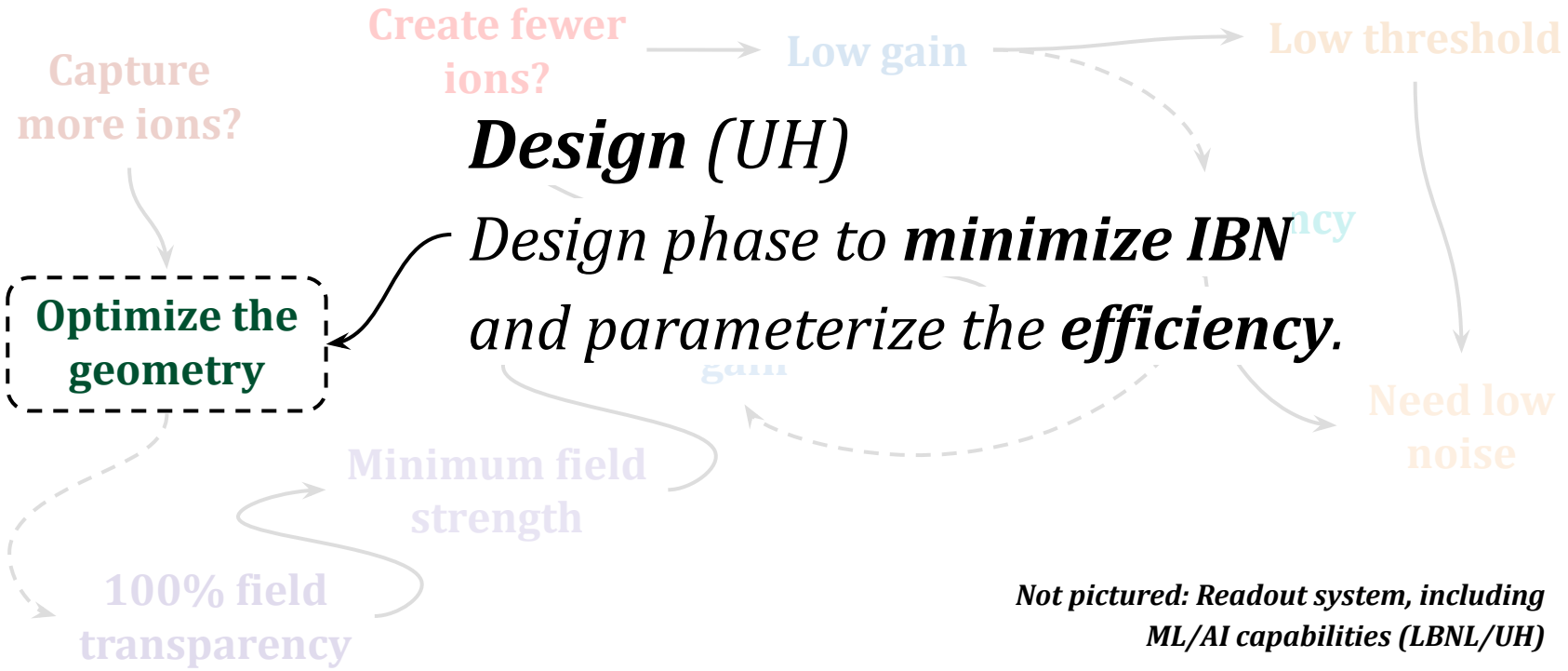
At The University of Texas at Arlington
Yuan Mei

Roots in a CPAD 2023 coffee break!

FIMS Involvement



Current FIMS at UH



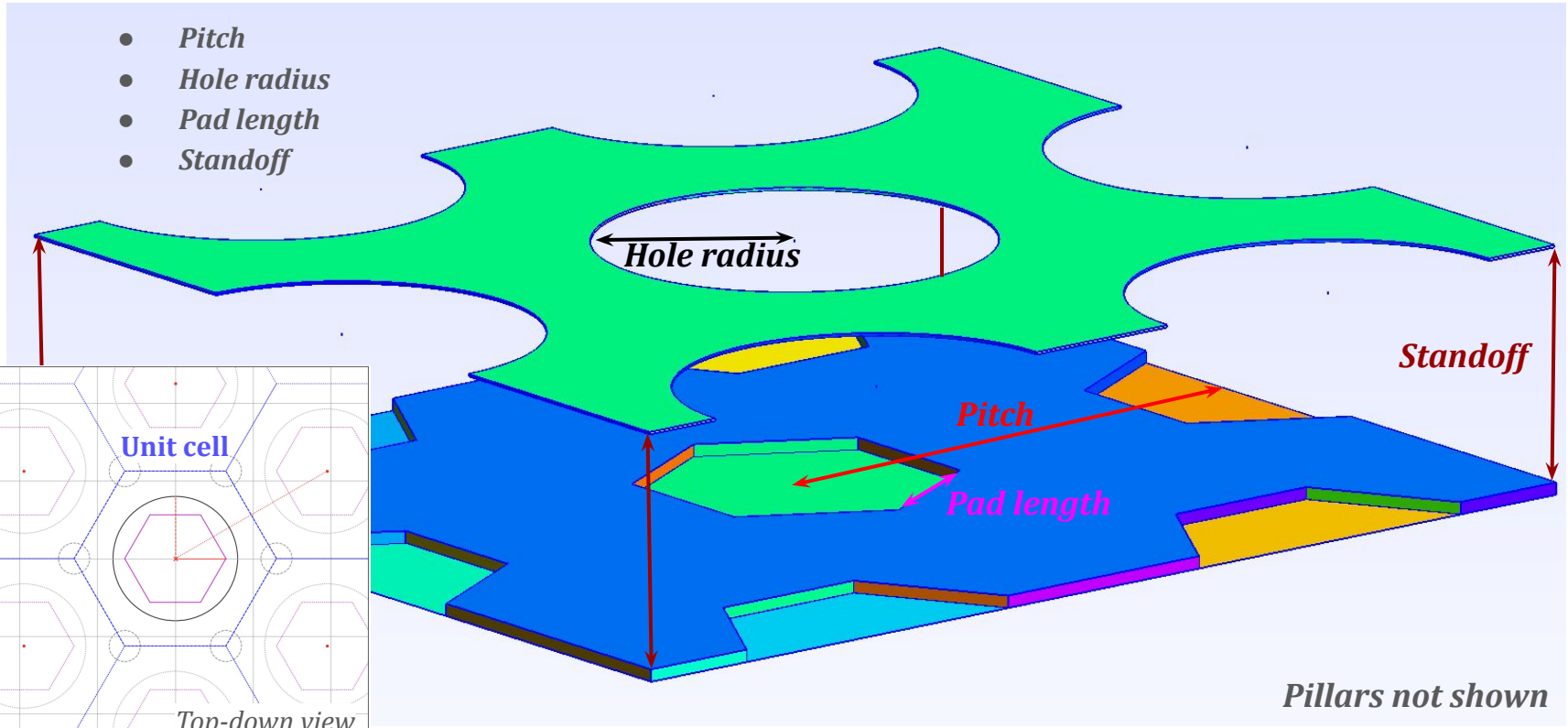
***Design** (UH)*

*Design phase to **minimize IBN** and parameterize the **efficiency**.*

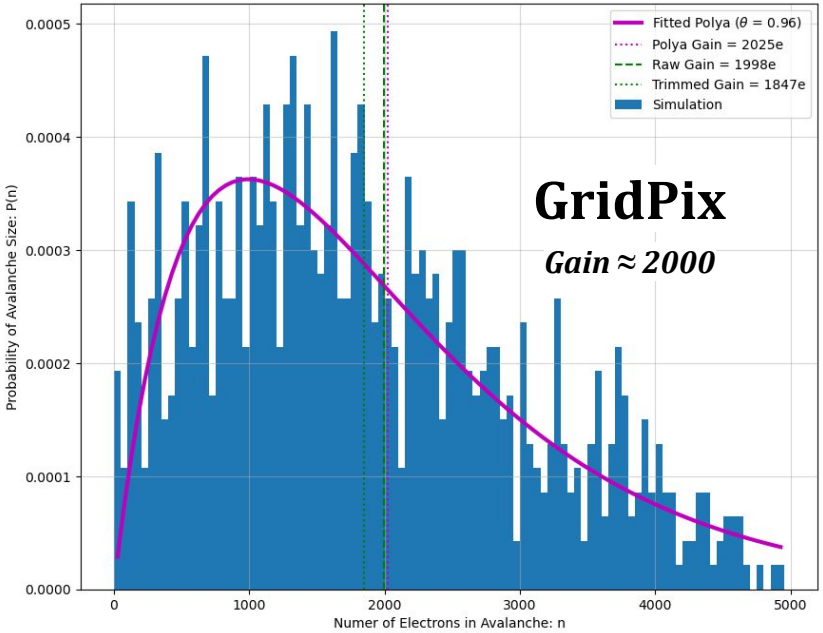
Not pictured: Readout system, including ML/AI capabilities (LBNL/UH)

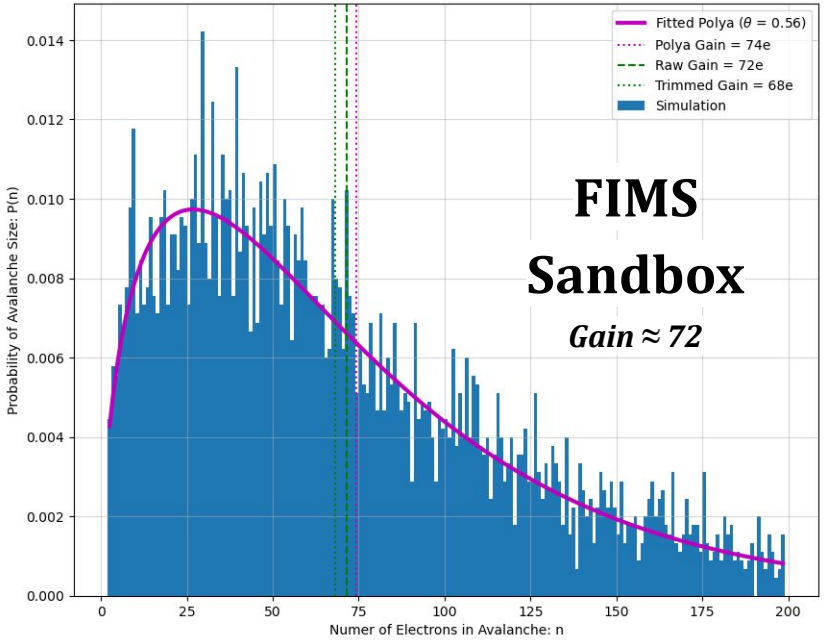
FIMS Geometry

- *Pitch*
- *Hole radius*
- *Pad length*
- *Standoff*



Simulated Single-e Gain Distributions





Reasonably fit with a **Pólya** distribution.

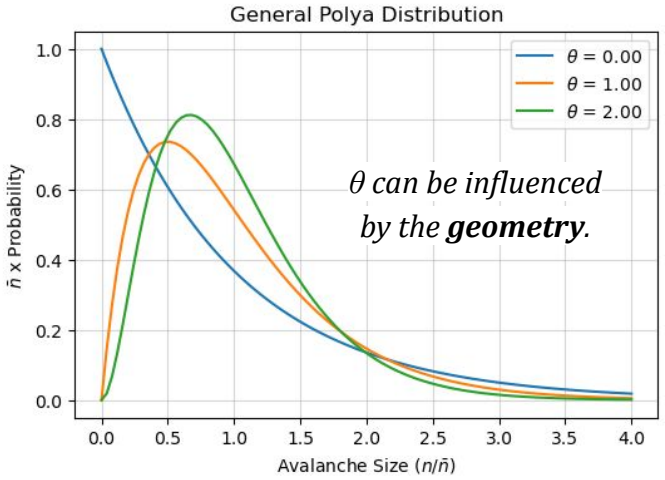
(This is expected)

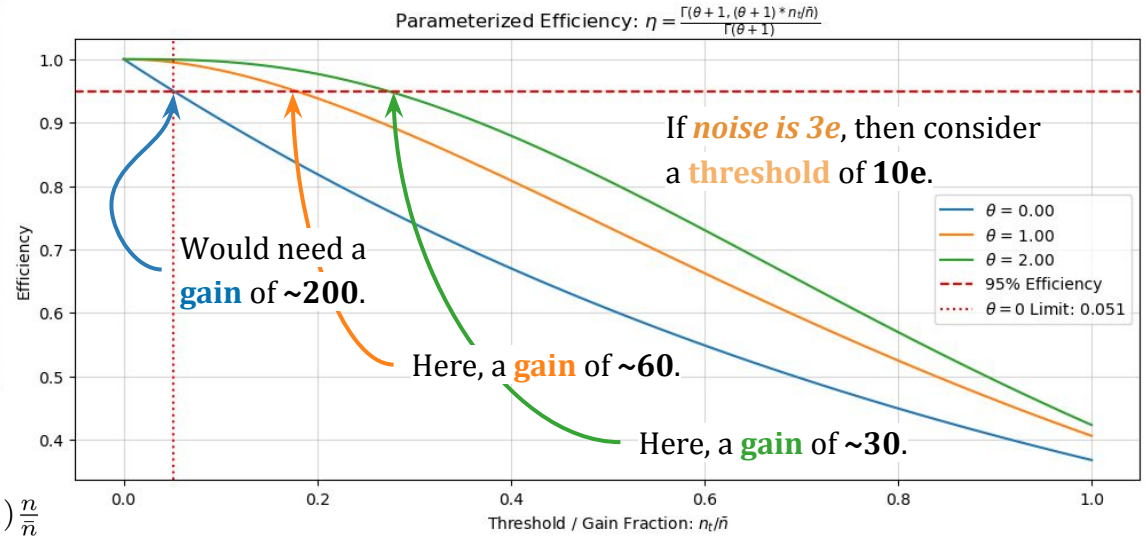
[10.1016/0029-554X(70)90818-9]

As an electron avalanche grows, the increasing number of electrons makes more ionizations even more likely.

Efficiency Parameterization

Ideal TPC goal: >0.95





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

$$\theta = \left(\frac{\bar{n}}{\sigma}\right)^2 - 1$$

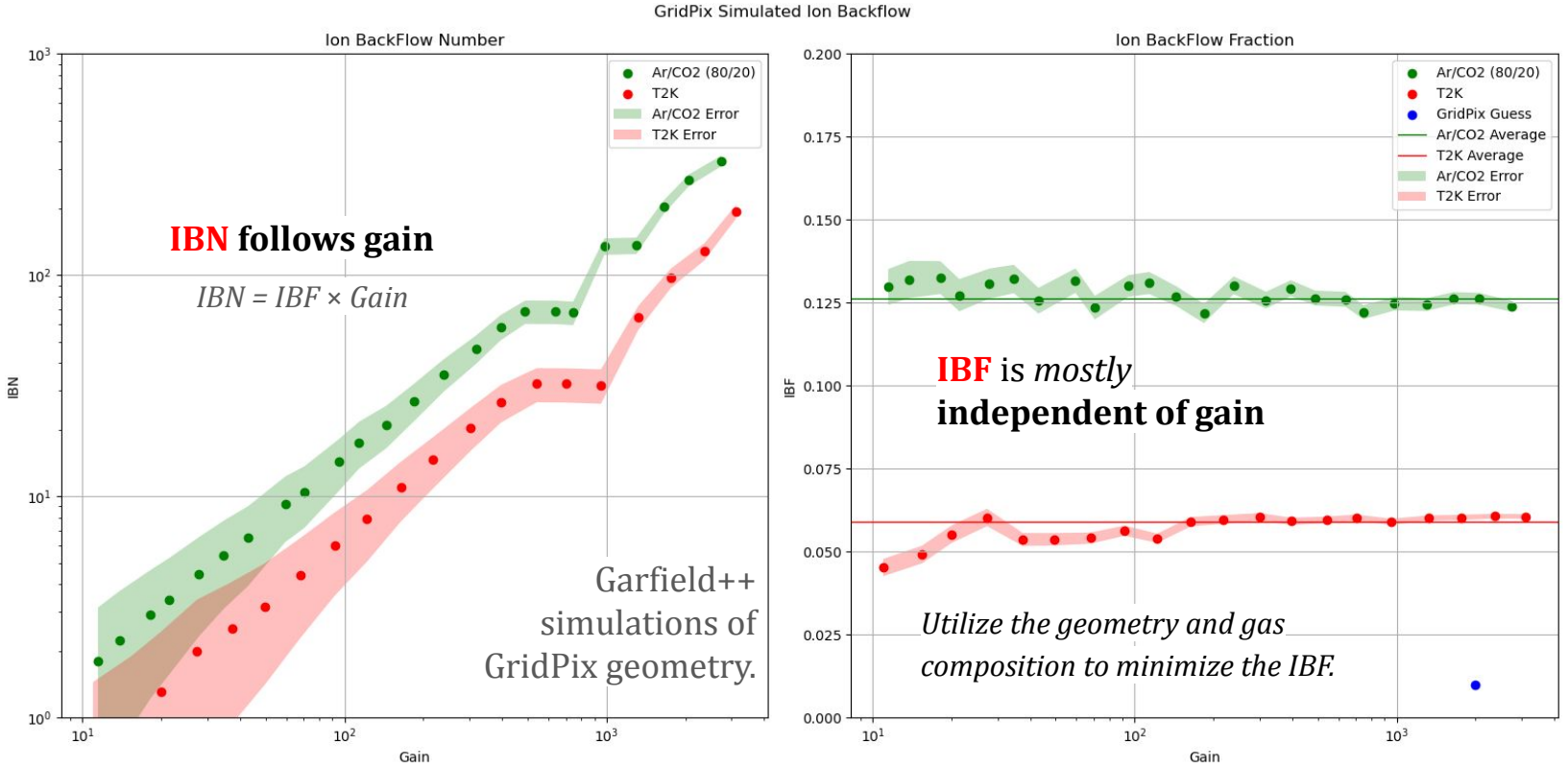
*θ relates to the **gain** and **gain variability**.*

(Large θ → Less relative variability.)

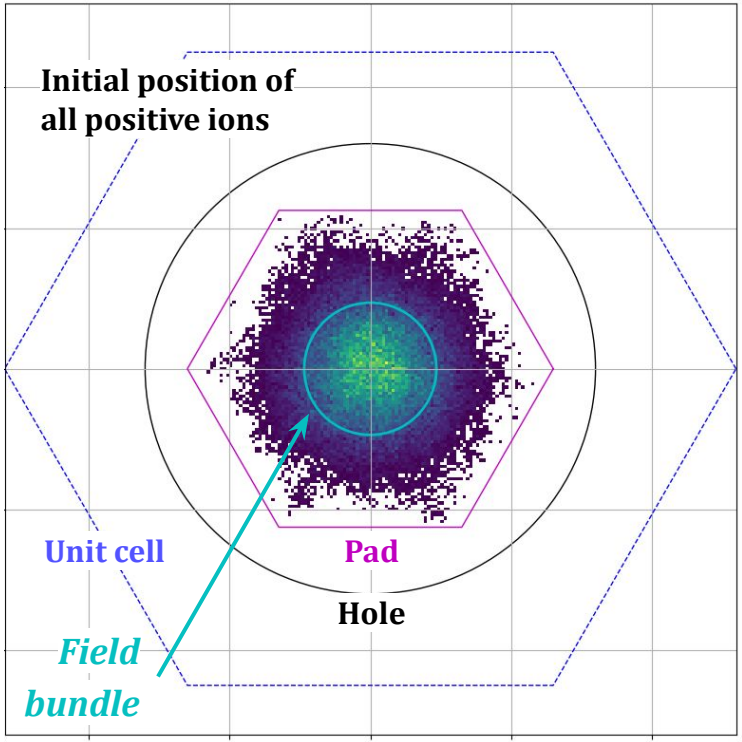
$$\eta = \frac{\Gamma(\theta+1, (\theta+1)\frac{n_t}{\bar{n}})}{\Gamma(\theta+1)}$$

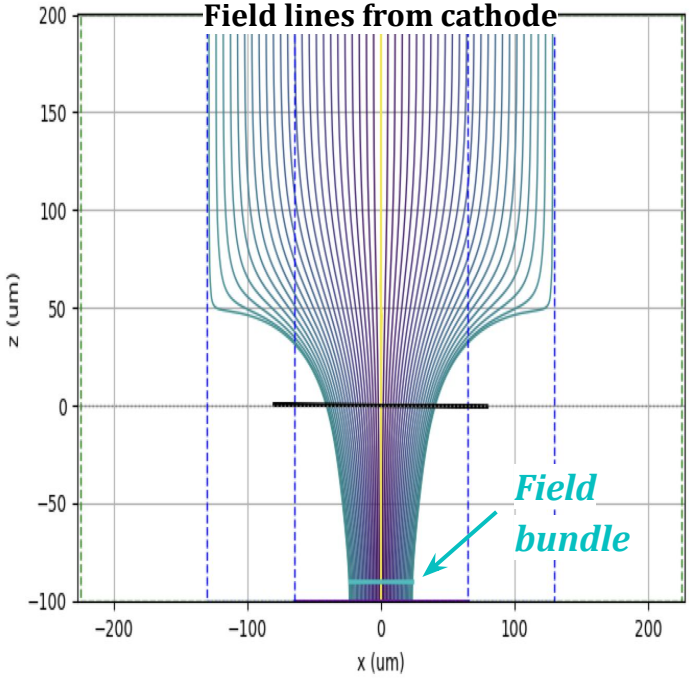
Low **threshold** allows for low **gain**, while maintaining a high **efficiency**.

Simulating Ion Backflow

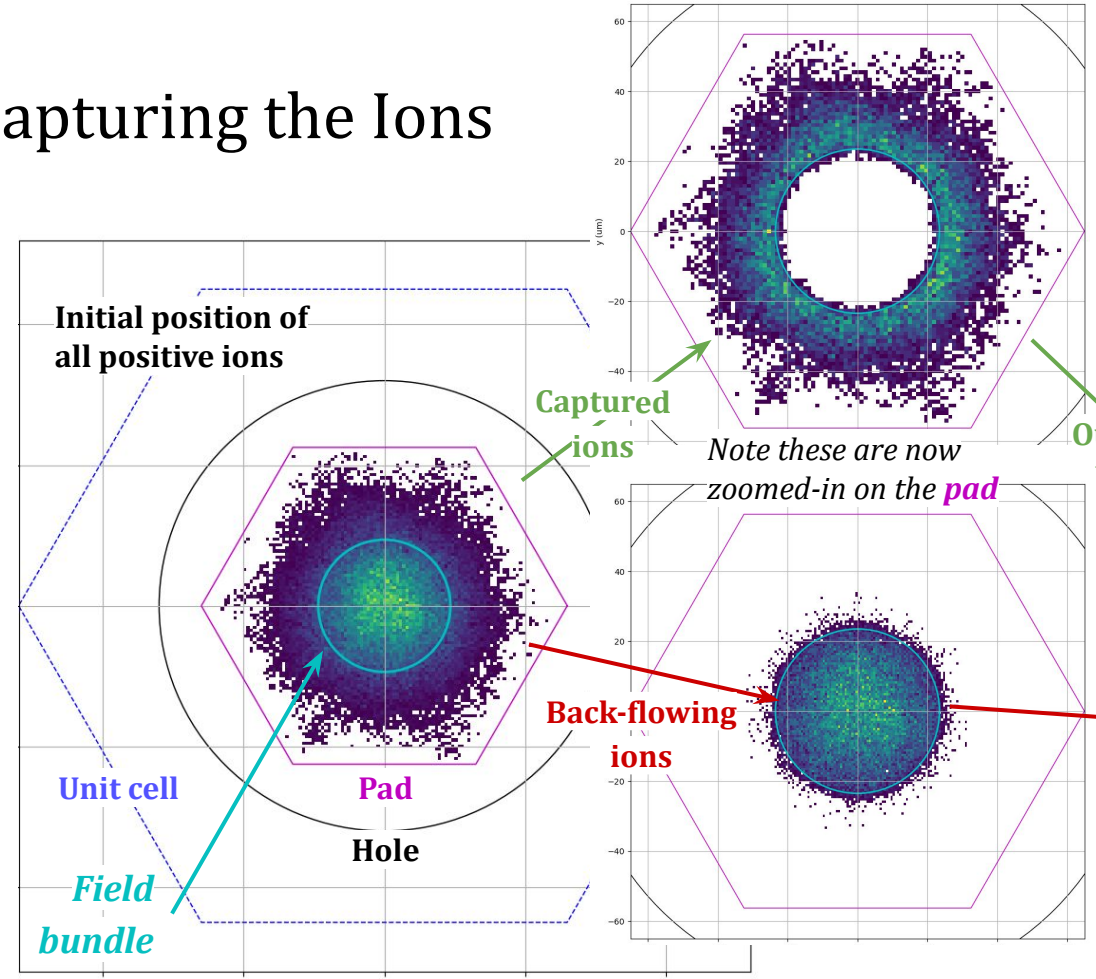


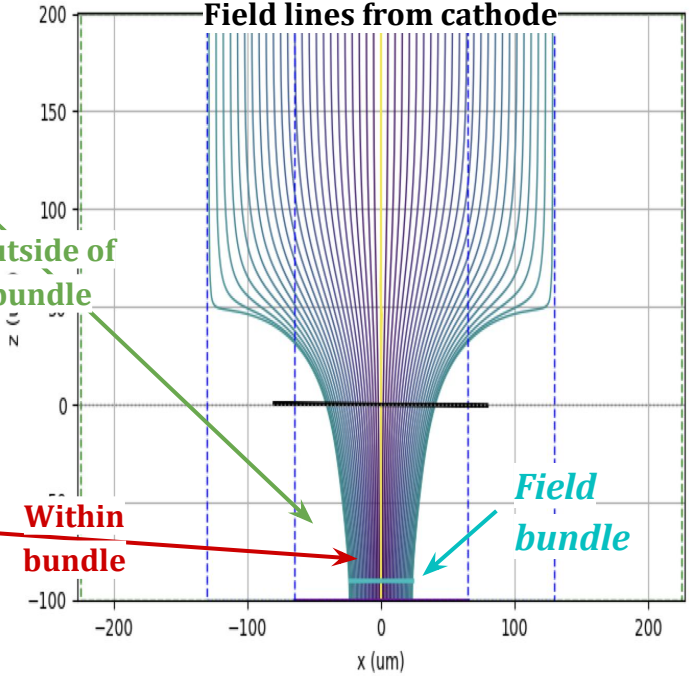
Capturing the Ions





Capturing the Ions

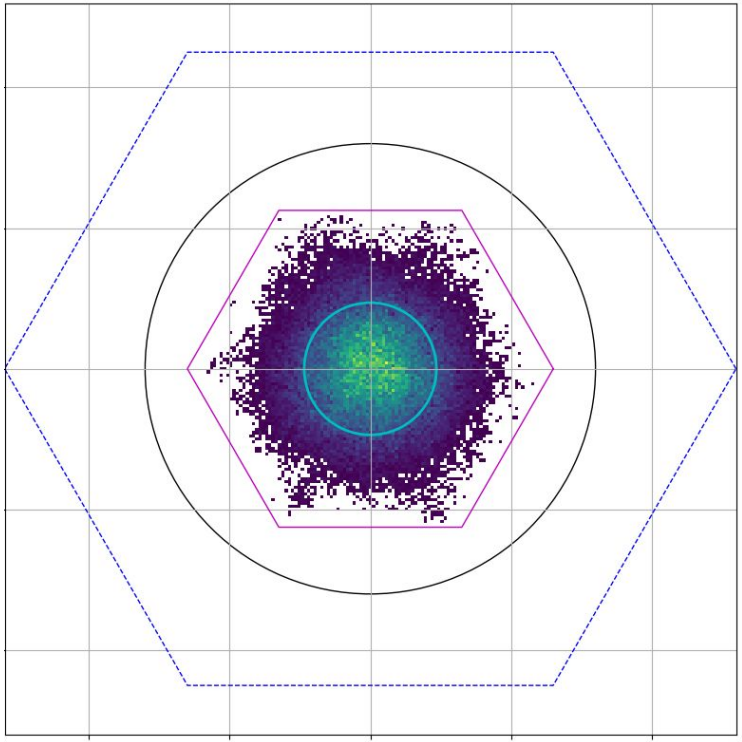




Hypothesis:

*A small **field bundle** relative to the **avalanche diffusion** means more **captured ions**.*

A Complicated Multidimensional Problem…



Large **pitch**:

➔ High **field strength** → high **gain**. ✘

Large **hole radius** or **pad size**:

➔ Low **field strength** → low **gain**. ✔

➔ Large ***field bundle*** → high **IBN**. ✘

Large **standoff height**:

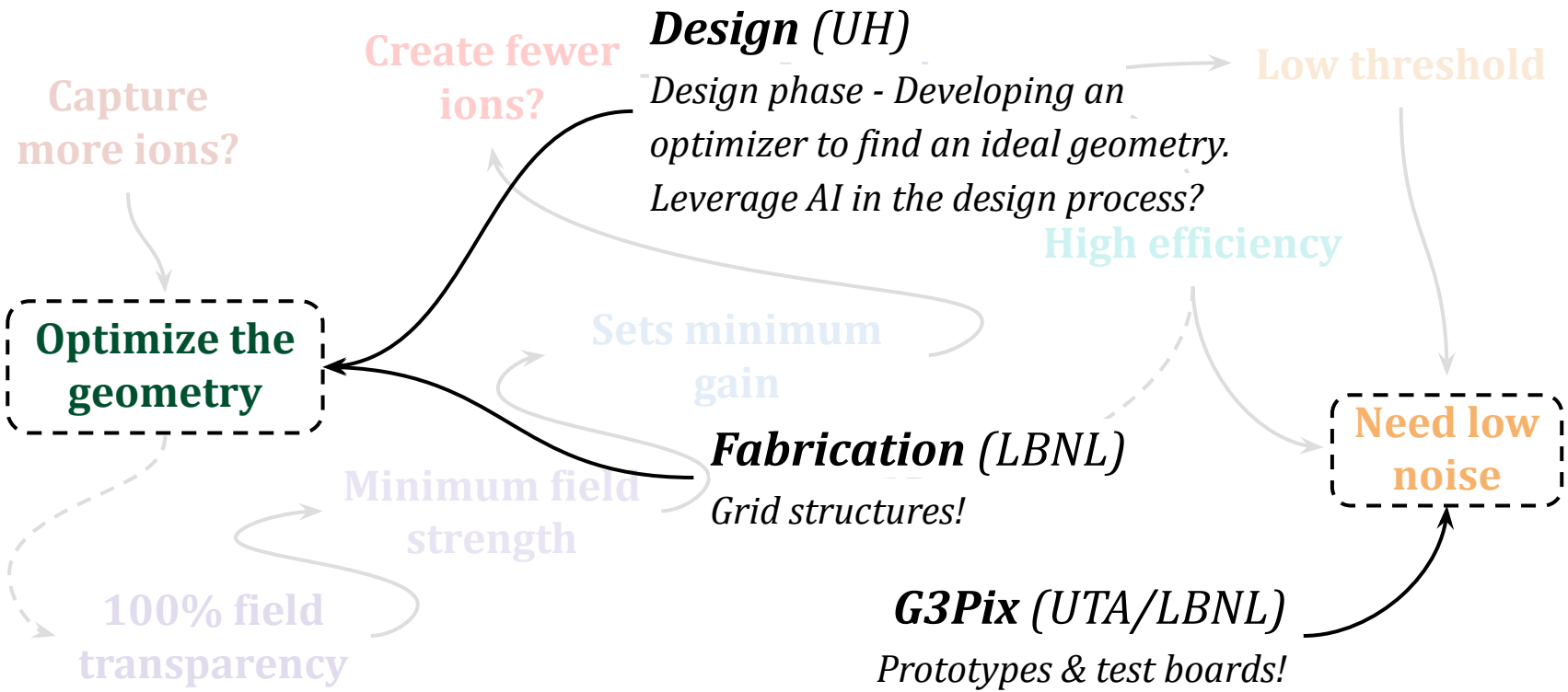
➔ Low **field strength** → low **gain**. ✔

➔ Small ***field bundle*** → low **IBN**. ✔

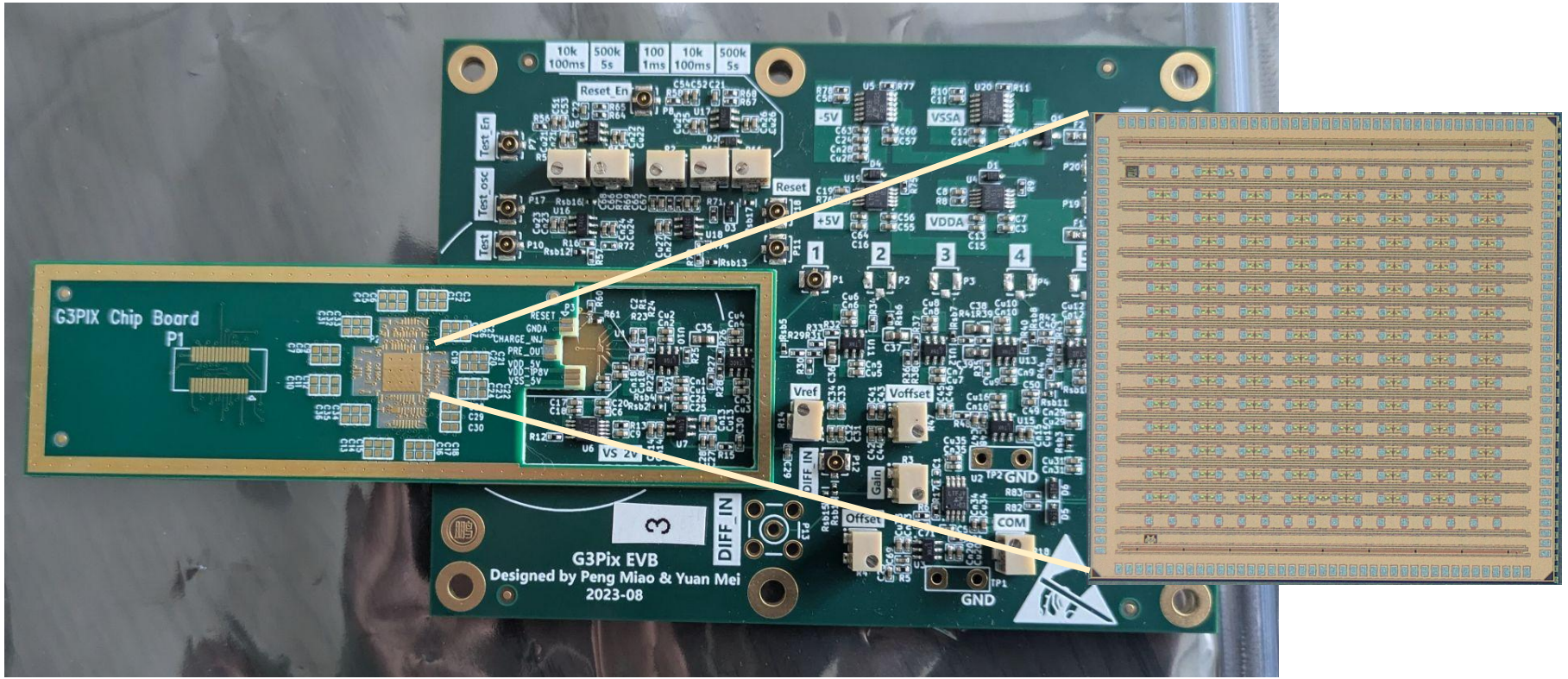
➔ Large ***drift distance*** → large **gain variability**. ✘

What is the sweet-spot?

FIMS Current Status



G3Pix Test Boards (LBNL/UTA)



Thank you!

Let us know if you're interested!

Peter Lewis:
peter.mandeville.lewis@hawaii.edu
Tanner Polischuk:
tanner.polischuk@hawaii.edu

If you have any wild geometry suggestions, we have a grad student who would love to test it!