

Toward an “ideal” gaseous TPC detector

“Maximally performant”

A collaboration born in a coffee
break at CPAD 2023!

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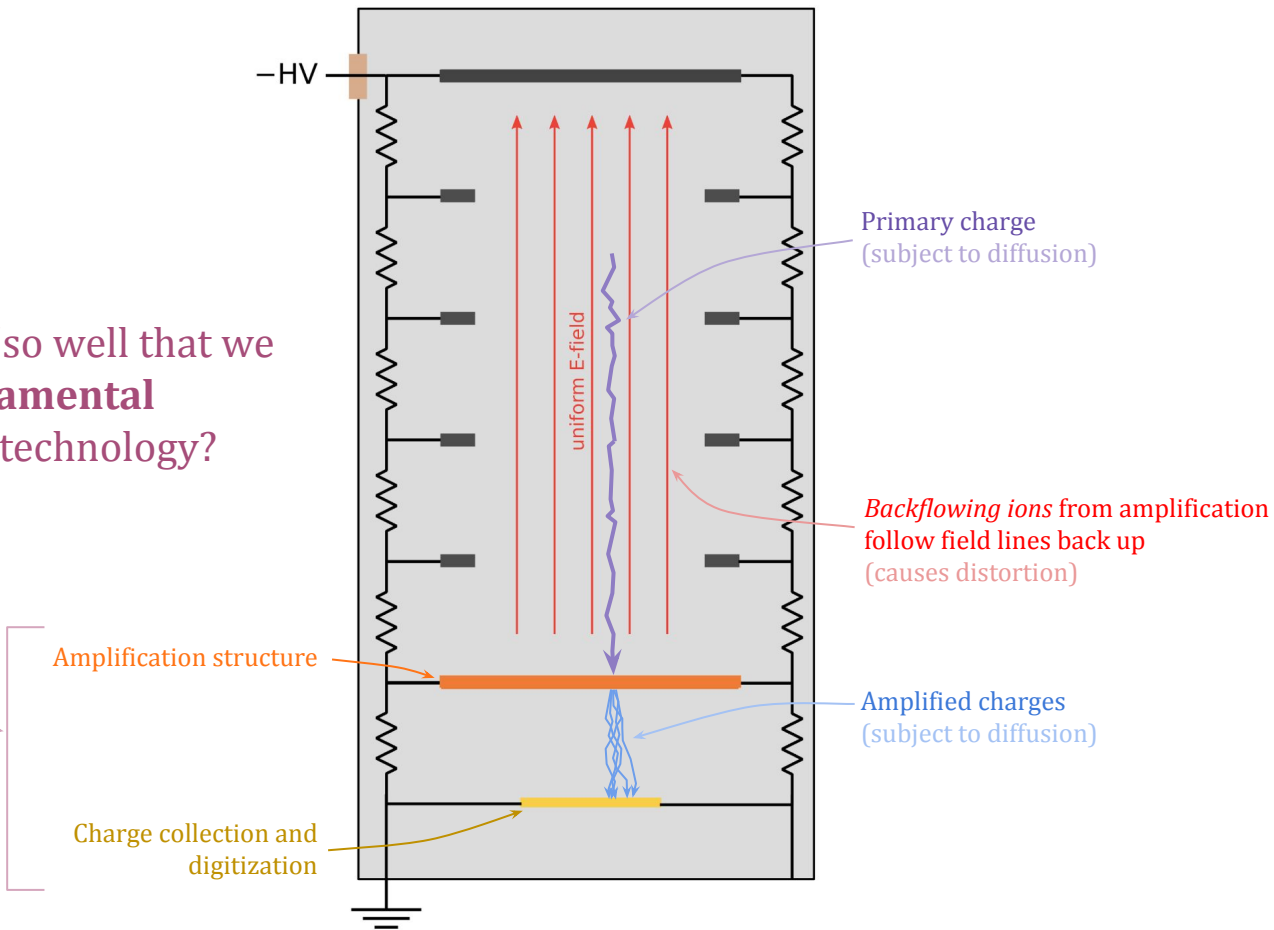


Knoxville



The question

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



What are the key metrics?

3D spatial resolution

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

Single charge detection efficiency

- ϵ = number pixel *hits* divided by number of *primary charges*
- (Assuming it *can* detect single charges)

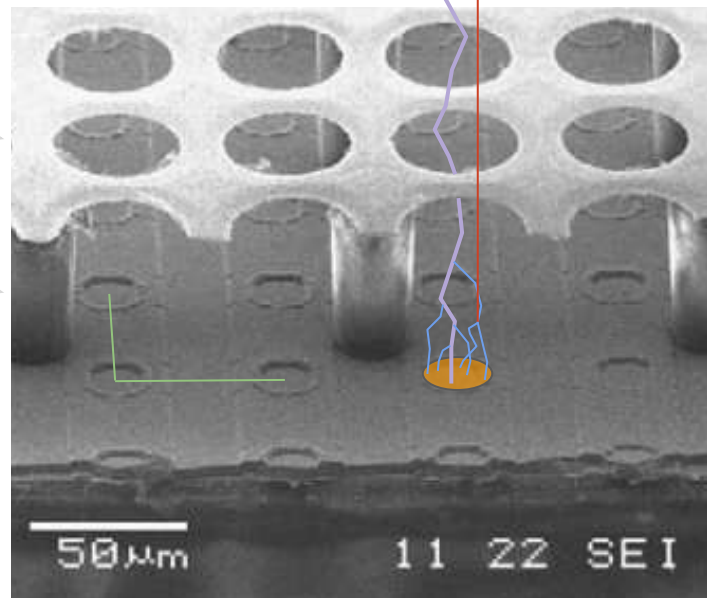
Ion backflow

- IBF: number *backflowing ions* divided by number of *primary charges*
- (relevant for *high-rate* detectors)

Aluminum grid

Insulating pillars

GridPix (adapted from [link](#))
Current state-of-the-art



One primary charge produces one **hit**

What would *ideal* mean?

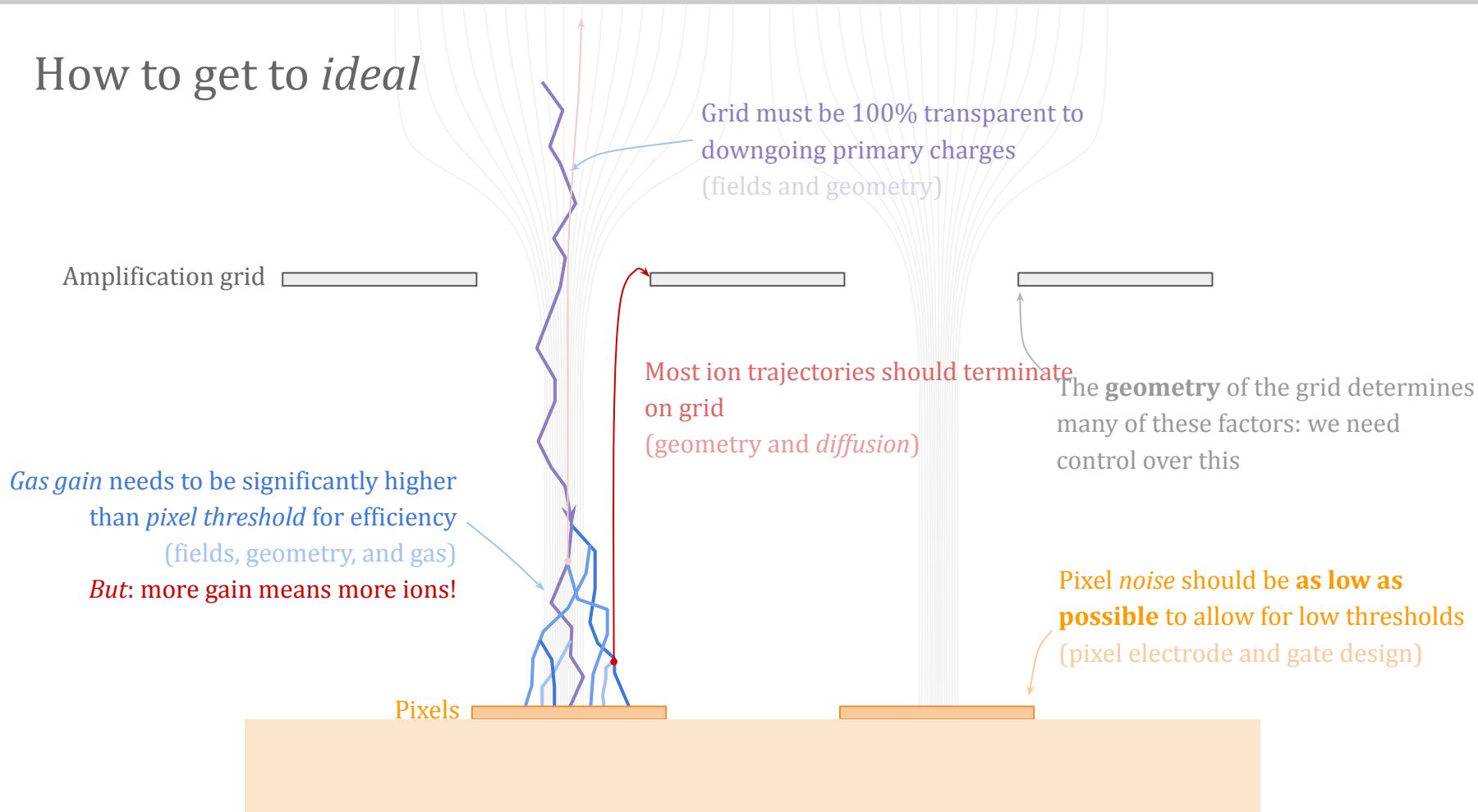
Metric	“Ideal” value	Current (GridPix)
3D spatial resolution	Much better than <i>diffusion</i> Electron drift: mm–cm Negative ion drift: 100μm–mm	$x/y: 55\mu\text{m}/\sqrt{12} = \mathbf{16\mu\text{m}}$ $z(t): \text{comparable (depends on gas, fields)}$
Single charge efficiency	>0.95	Electron drift: >0.95 Negative-ion drift: ~ 0.60 [source]
Ion backflow fraction \times gain	<1 (less than irreducible <i>primary</i> ions)	$\sim 0.01 \times 2000 = \mathbf{20}$

This is *very good*... but not “ideal”

GridPix comes pretty close to ideal performance...

...how could we get *ideal*?

How to get to *ideal*



Our project

A synthesis of *new* and *ongoing* efforts

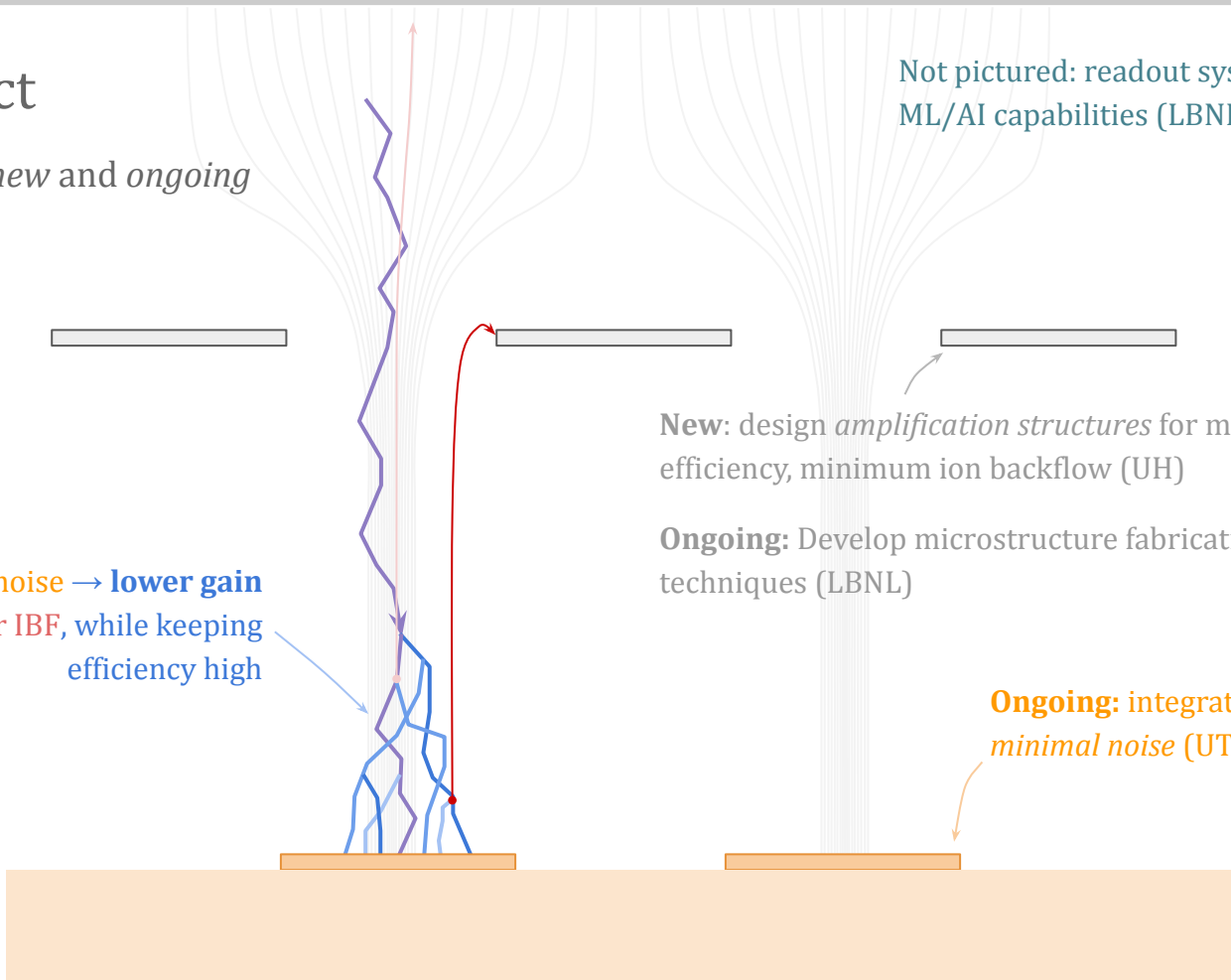
Not pictured: readout system, including ML/AI capabilities (LBNL and UH)

Lower pixel noise → lower gain
→ lower IBF, while keeping efficiency high

New: design *amplification structures* for maximum efficiency, minimum ion backflow (UH)

Ongoing: Develop microstructure fabrication techniques (LBNL)

Ongoing: integrate CMOS pixels with *minimal noise* (UTA)



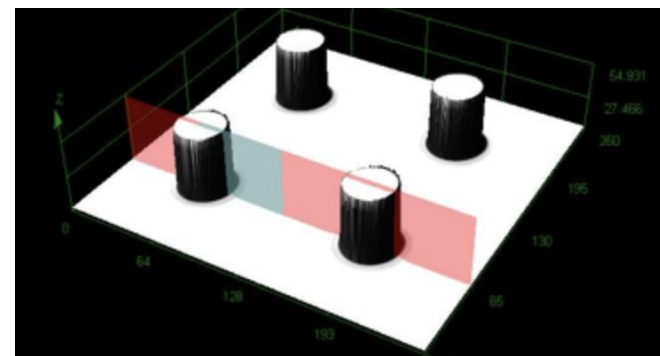
Amplification structures

Ongoing work at LBNL (Sorensen + UH)

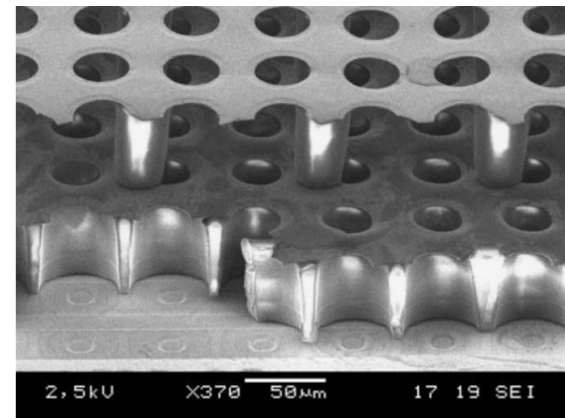
- First trying to replicate [GridPix process](#):
 - Thin patterned Al atop SU-8 photoresist
 - $\sim 50\mu\text{m}$ pillars remain after development of SU-8
- Proximate goal is for *focusing* structures; eventually amplification
- Current status: learning how to build SU-8 under Al... it is tricky!

Ultimately, we hope this develops into a *US-based microstructure fabrication facility* that limits reliance on European facilities

Scan of produced SU-8 pillars



[TwinGrid](#): an extremely ambitious possibility

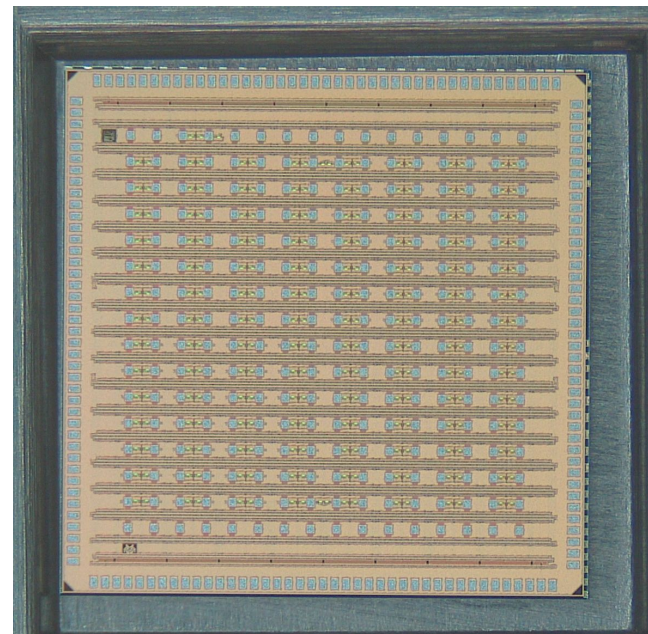


Pixel chip

G3pix: Lab-Directed R&D project at LBNL (Mei and Sorensen)

- Targeting a **3e** noise pixel chip (!!!)
 - $\mathcal{O}(100)$ reduction in noise \rightarrow needs $\mathcal{O}(100)$ less gain for same efficiency $\rightarrow \mathcal{O}(100)$ reduction in *ion backflow*
 - Or: efficiency $\rightarrow 1$ in *low-gain* applications like negative ion drift
- *Status:* testing of first chips commencing now, both at Berkeley at at Arlington

Originally an unrelated project, but it could be a game-changer. Backup plan is to use TimePix3, like GridPix.



Efficiency	<i>e</i> drift: >0.95 NID: ~0.60
IBF \times gain	~20

Readout system

ML/AI capable frontend (Grace + UH)

An ideal *readout system* will need realtime hit logic capabilities:

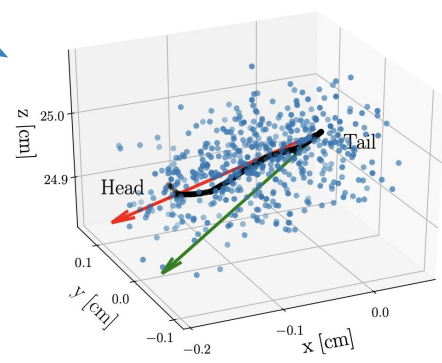
- High-rate tracking detectors: *microcurlers* can be overwhelming (>99% of hits) but are distinctive
- Low-*E* nuclear recoil detectors: realtime **recoil discrimination** to reject overwhelming rates of *electron recoils*

This is *essential*: even an “ideal” detector could be inoperable at high rates

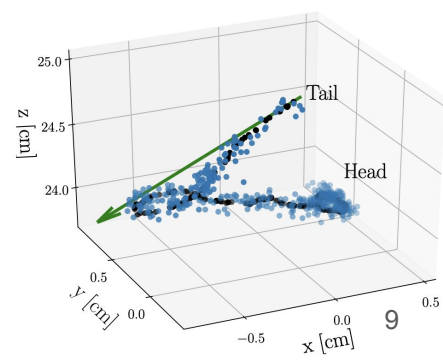
Simulation of a *microcurler*, seen end-on, from preliminary studies on a Belle II tracking TPC.



Helium recoil



Electron recoil

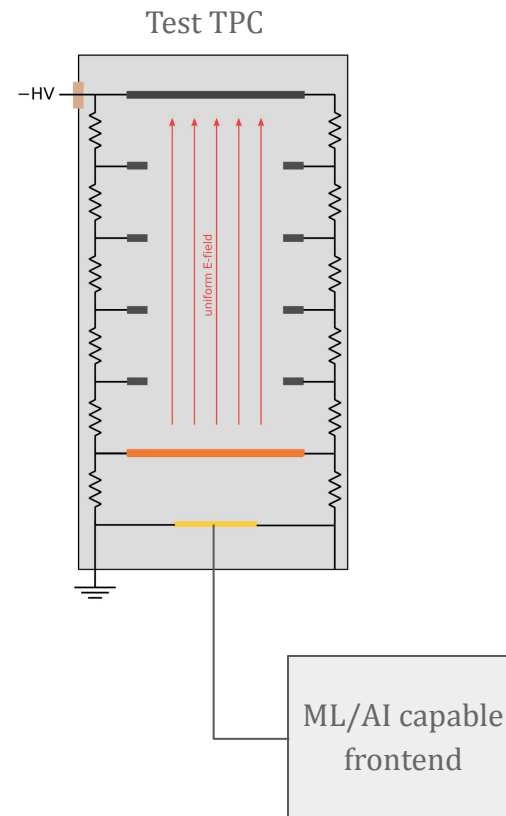


Integration

Flexible, Ideal MPGD system (FIMS): Putting this all together (Lewis)

- Four-year EPSCoR funding starting ~now
- UH team includes (starting January):
 - Yubo Han, postdoc: working with Grace to design and deploy ML/AI hit logic at frontend
 - Tanner Polischuk, postdoc: working with Sorensen to develop ideal amplification structures
 - James Harrison, PhD student: simulation, integration, and source tests

Development with an eye towards Belle II tracking upgrade (~2032) and CE ν NS @ SNS applications

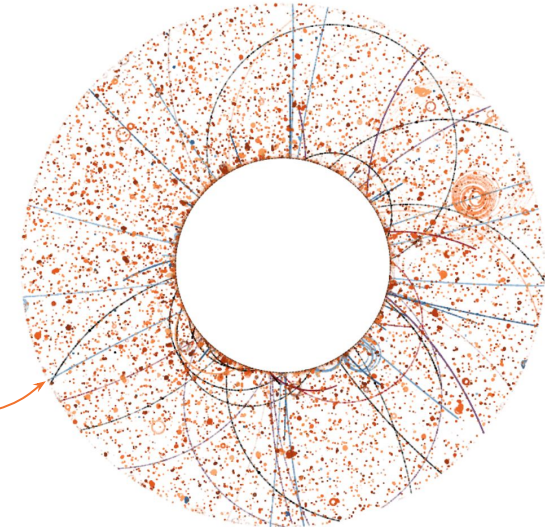


Applications

Can one technology be *ideal* for extreme **opposite** use cases?

Tracking TPCs at high-luminosity colliders [Lewis]

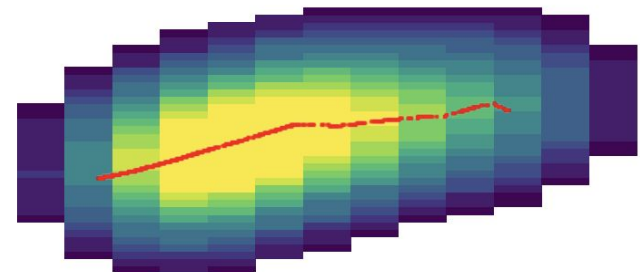
- Minimum ionizing tracks in very high-background environment
- Electron drift (high gain, high diffusion)
- **Ion backflow is critical**
- Frontend hit processing to reject ubiquitous *microcurlers*



Directional Dark Matter detection [Vahsen]

- Tiny nuclear recoils in low-background environment
- Negative ion drift (low gain, low diffusion)
- **Ion backflow is irrelevant**
- **Resolution and efficiency (via gain) is critical**
- Frontend hit processing for recoil discrimination

Low-E nuclear recoil [\[link\]](#)



Test campaigns for both applications planned

Status

We have just started collaborating! Let me know if you are interested!