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High NI Gain Micromesh Structures and the LARD Initiative:

Low-cost Amplification and Readout Device

Dr A. G. McLean

Postdoctoral researcher at Adelaide University

Visiting Researcher at The Australian National University

Email: alasdair.mclean@adelaide.edu.au

Co-Authors: R. R. M. Gregorio, D. Howgill, N. J. C. Spooner, M. White, G. Lane, L. Bignell, and V. Bashu

Identification of Dark Matter 2026

Zaragoza, Spain

04/JUN/2026

Background

Directional Dark Matter Searches with Gaseous TPCs

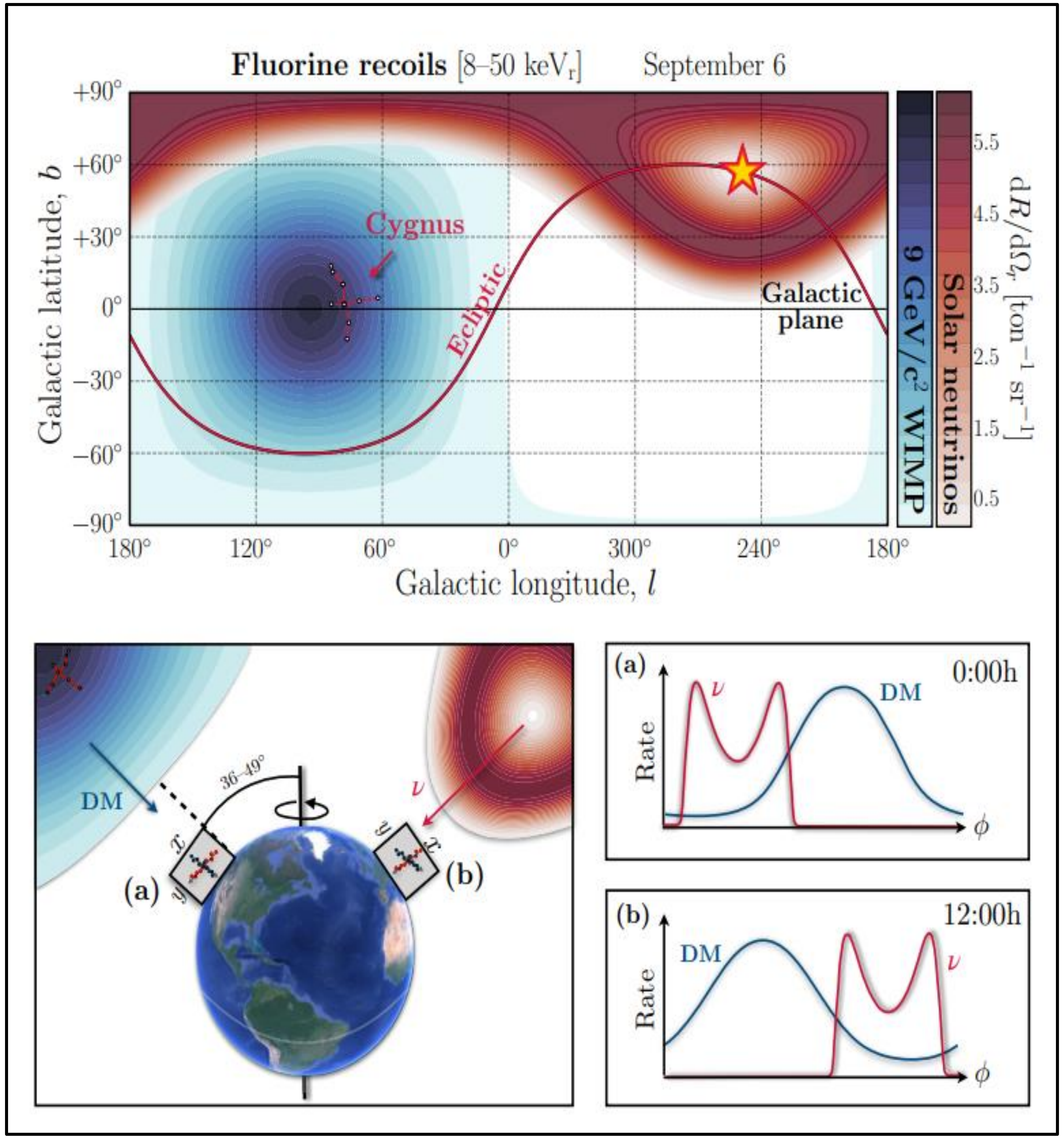
Directional Dark Matter Detection

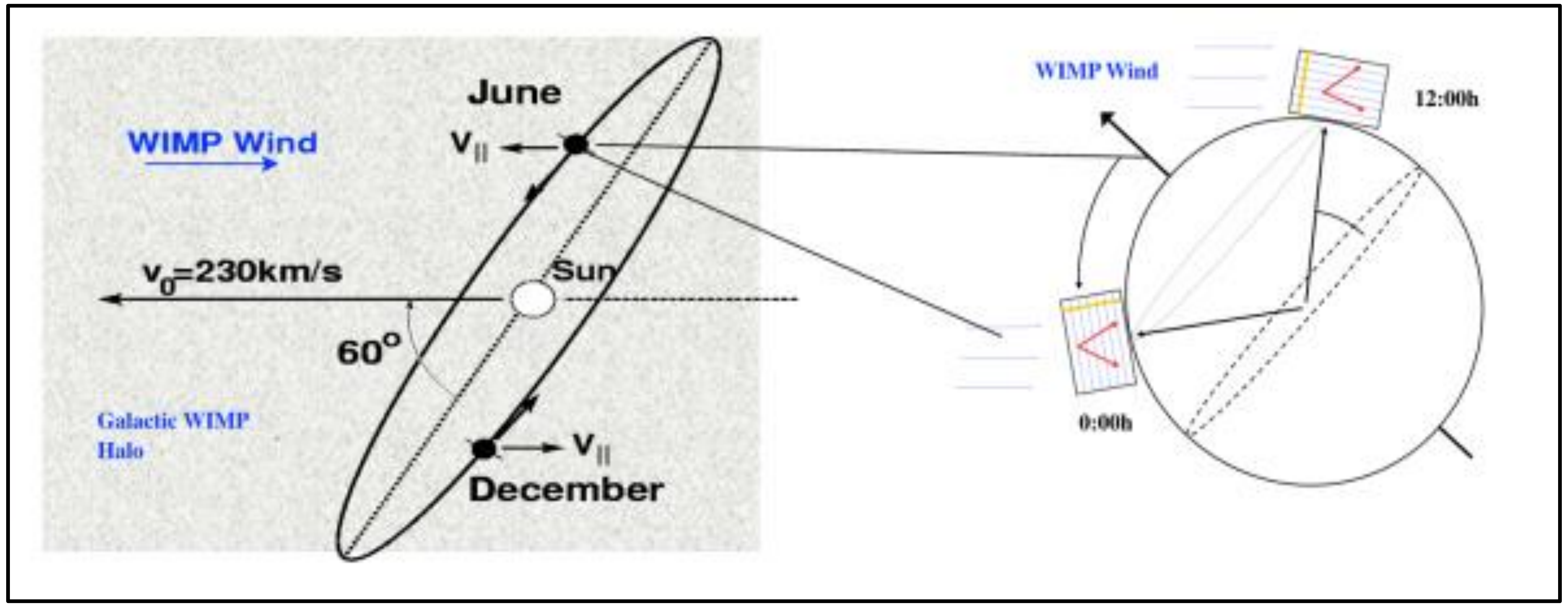
Directional identification of DM relies on the motion of the Earth:

- Solar System orbiting the centre of the Milky Way
- Earth orbiting the Sun
- Earth's axial rotation

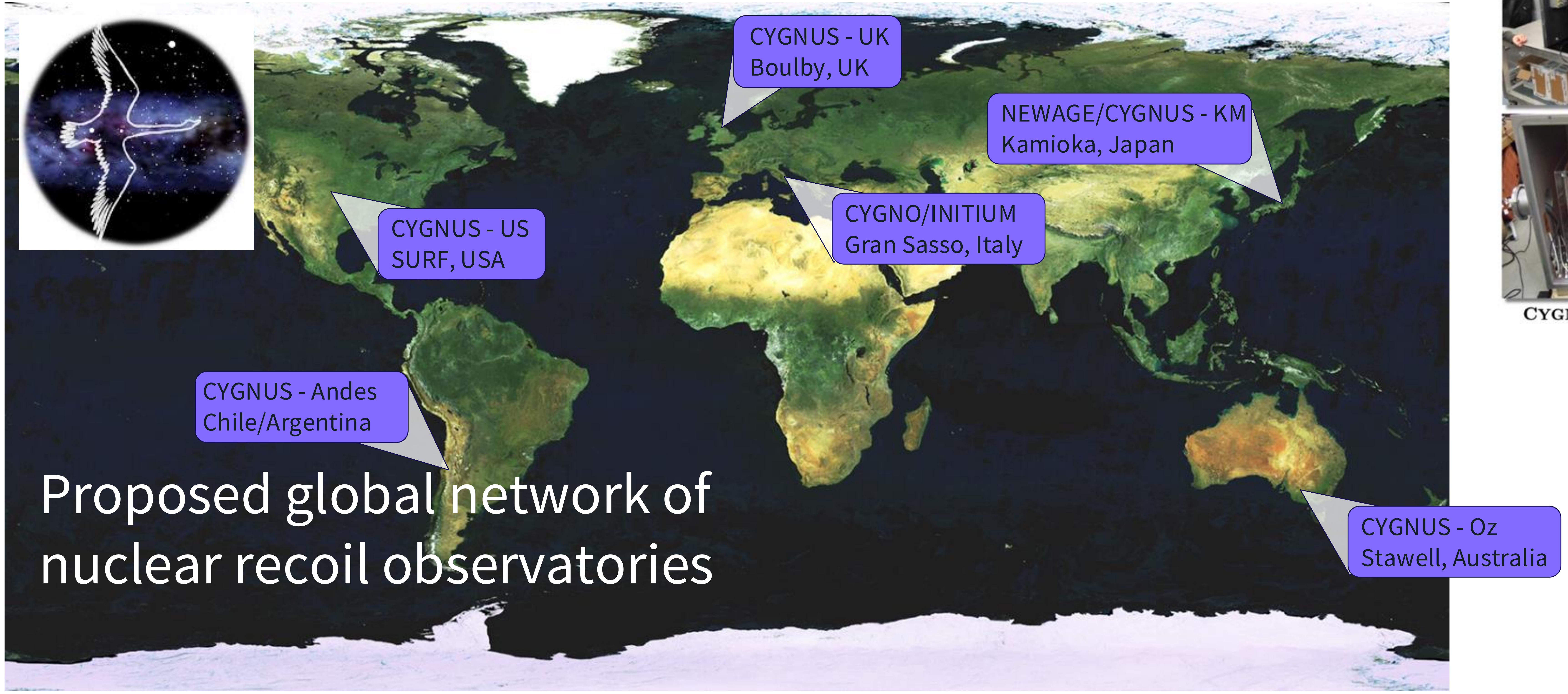
A directional signal will allow for discrimination between WIMP and solar neutrino signals

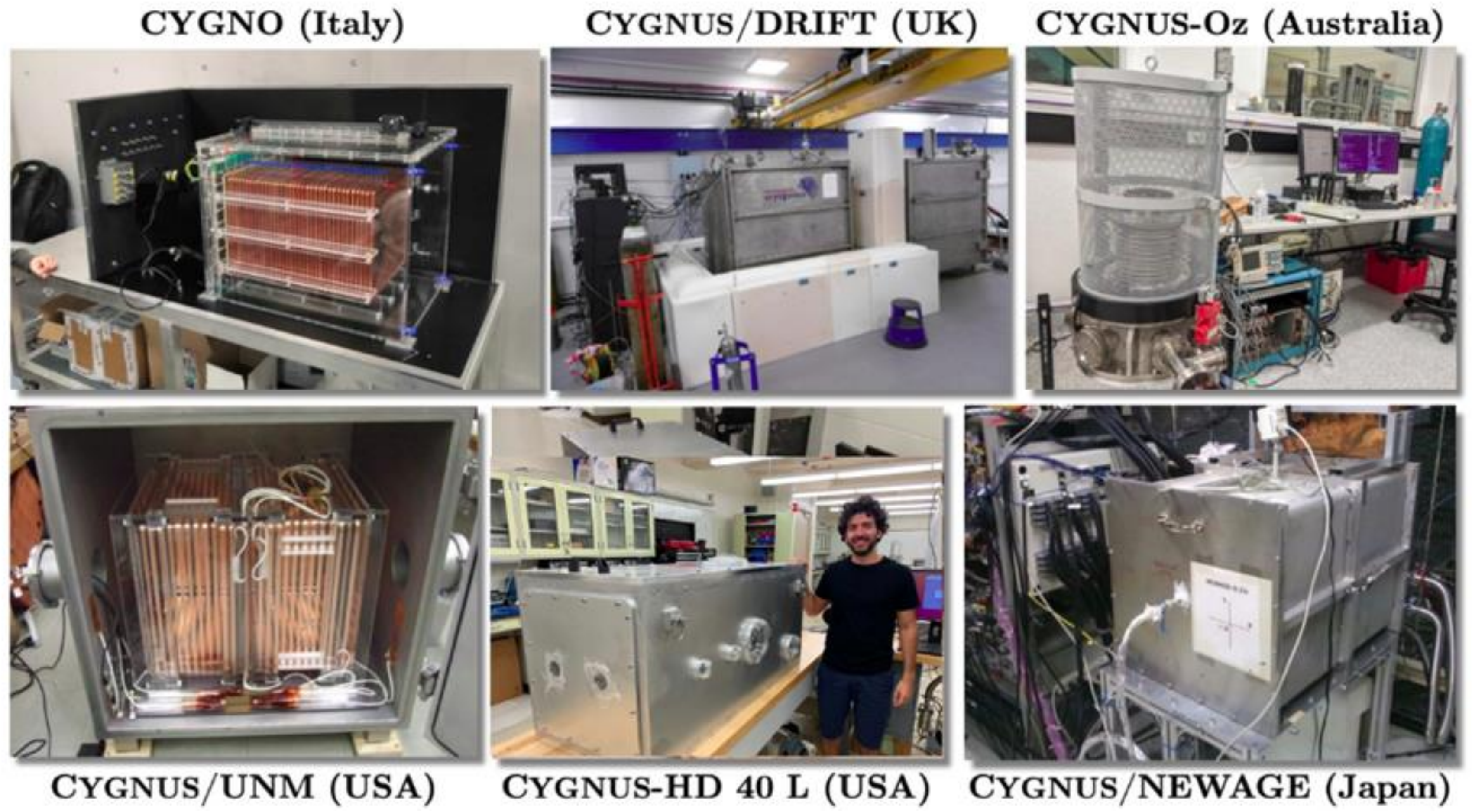
Most importantly: It can not be mimicked by a terrestrial background





The CYGNUS Consortium – Next Generation of Directional Dark Matter Detection



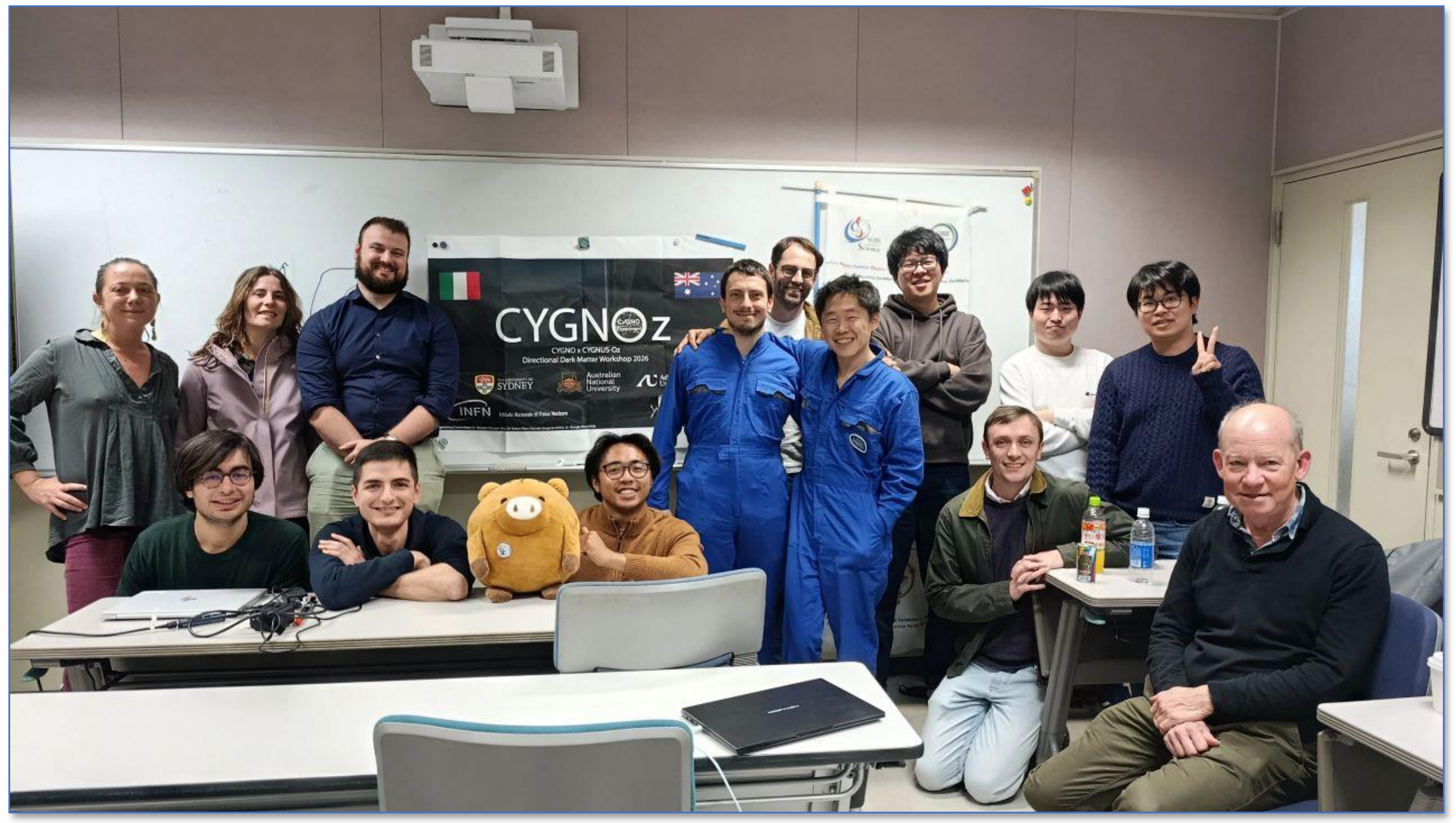


To name a few.

Recent CYGNUS Workshop in Kobe

Healthy collaboration meeting of 55 participants ->

Satellite conference first joint meeting between CYGNUS-Oz and CYGNO (CYGNOz)



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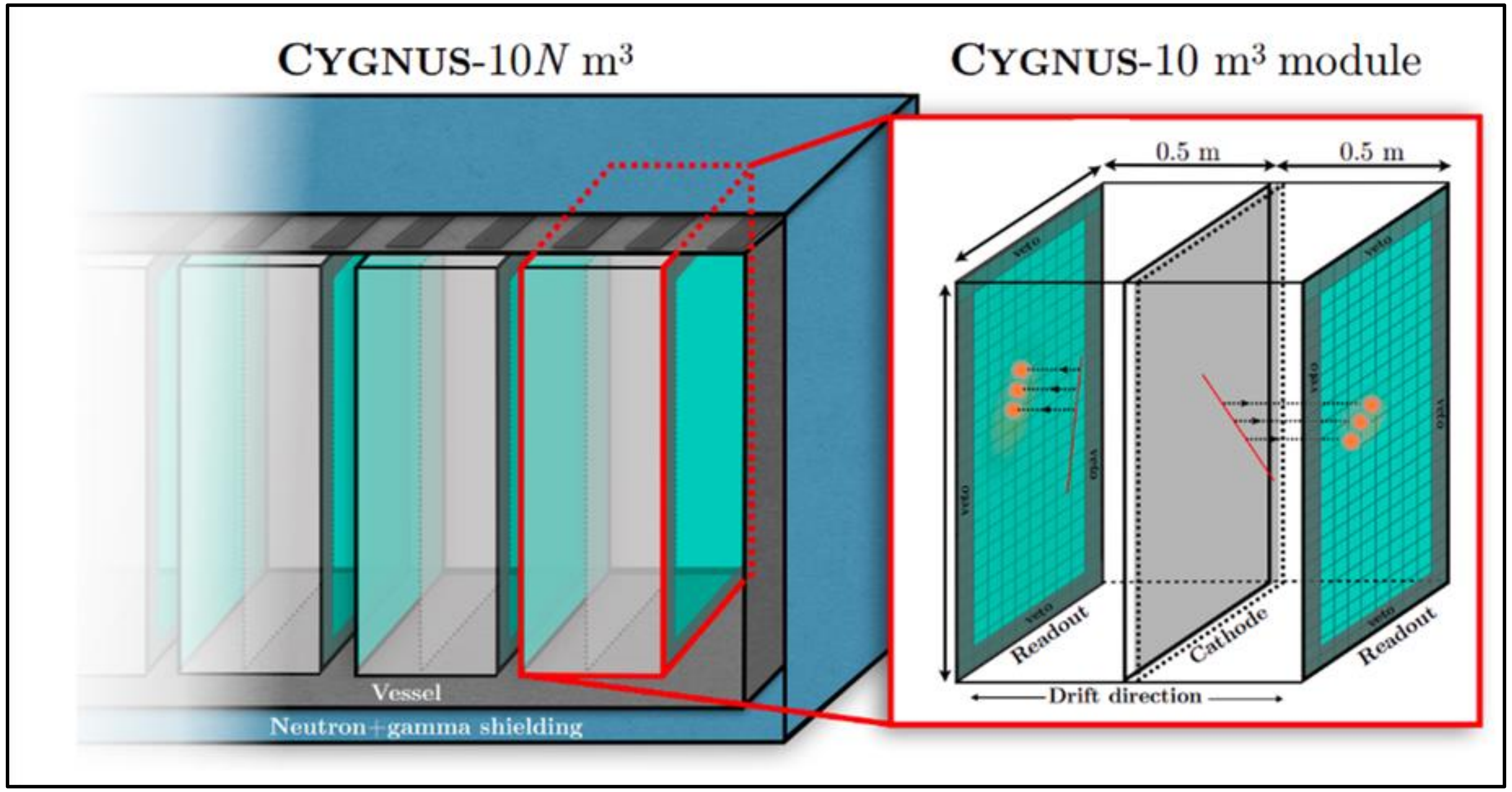
The CYGNUS Consortium – Next Generation of Directional Dark Matter Detection

CYGNUS: a modular and multi site nuclear recoil observatory

Time Projection Chamber (TPC) capable of reconstructing recoils

Directional sensitivity to dark matter and neutrino interactions



R&D with NID gases:

- CYGNUS modules will likely use a gas mixture with Negative Ion Drift (NID) gas component like SF_6
- NID gases require special techniques to achieve high charge amplification
- Recent work with a MMThGEM demonstrates strong avalanche capability in SF_6

Negative Ion Gases

Why do we want to use them?

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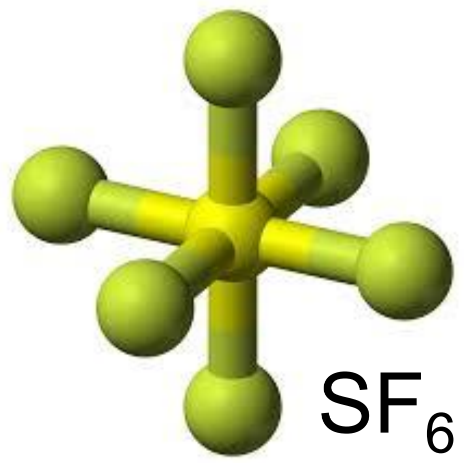
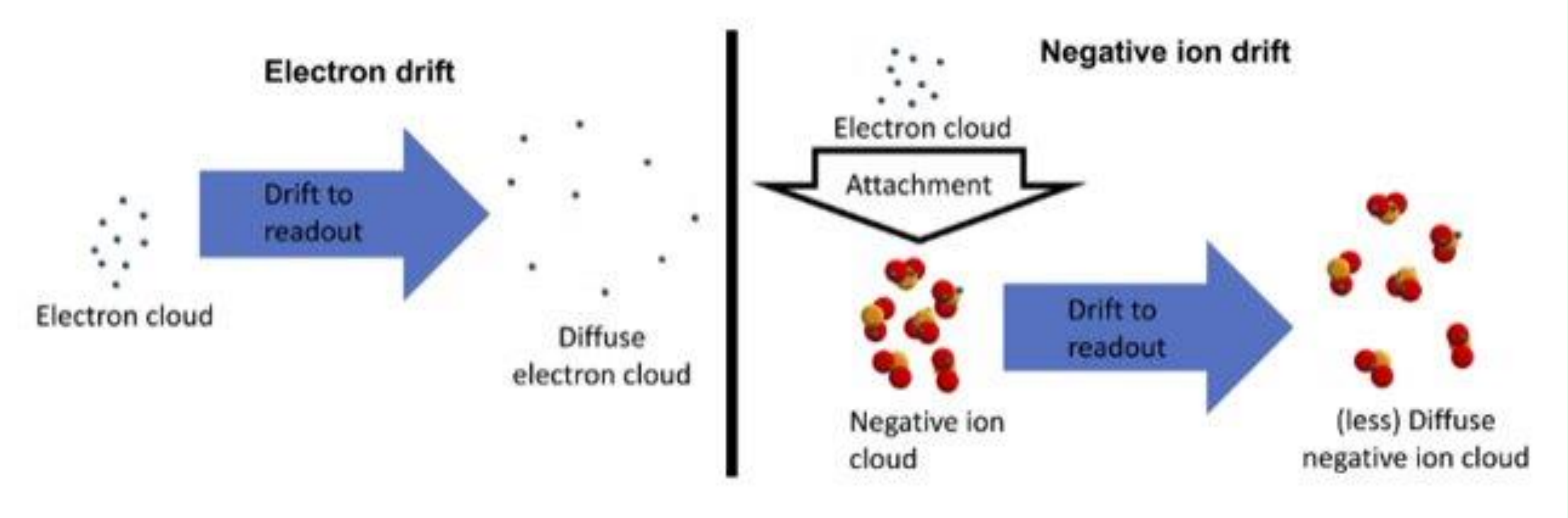
Why use SF_6 in a Directional Dark Matter Search?



SF_6

<u>Pros</u>

- Large fluorine content – improvement in SD WIMP-Nucleon cross section
- Electronegative/Negative Ion Drift (NID) gas – significantly reduced diffusion during drift phase
- Nontoxic – CS_2 used previously is toxic and potentially explosive



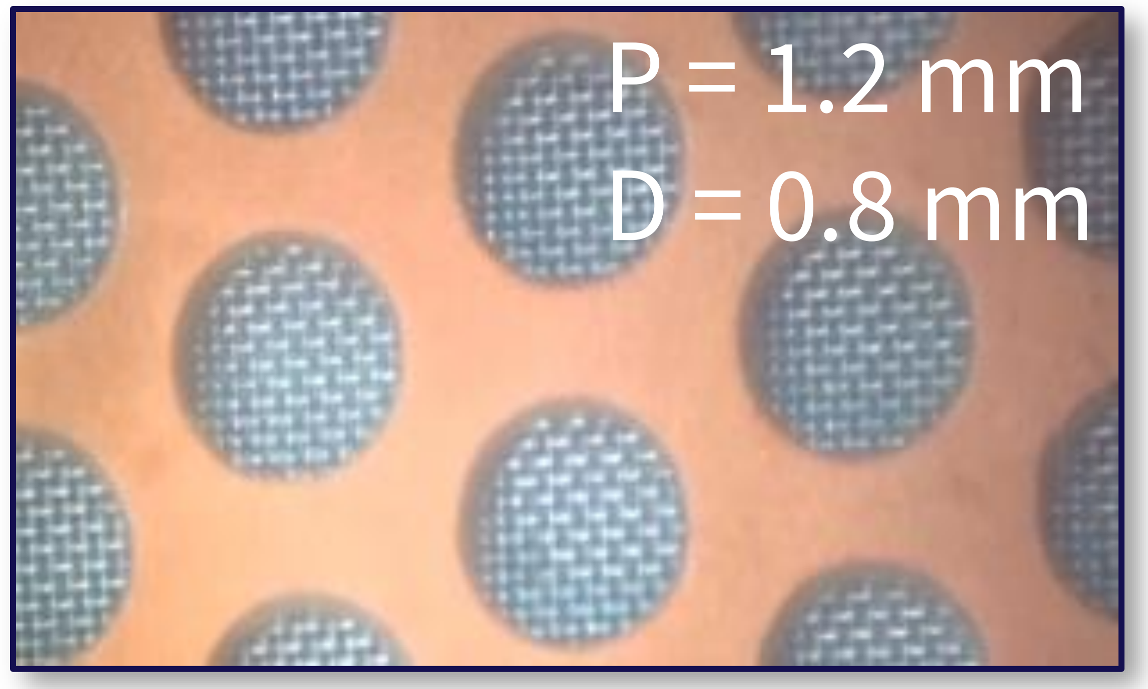
<u>Con</u>

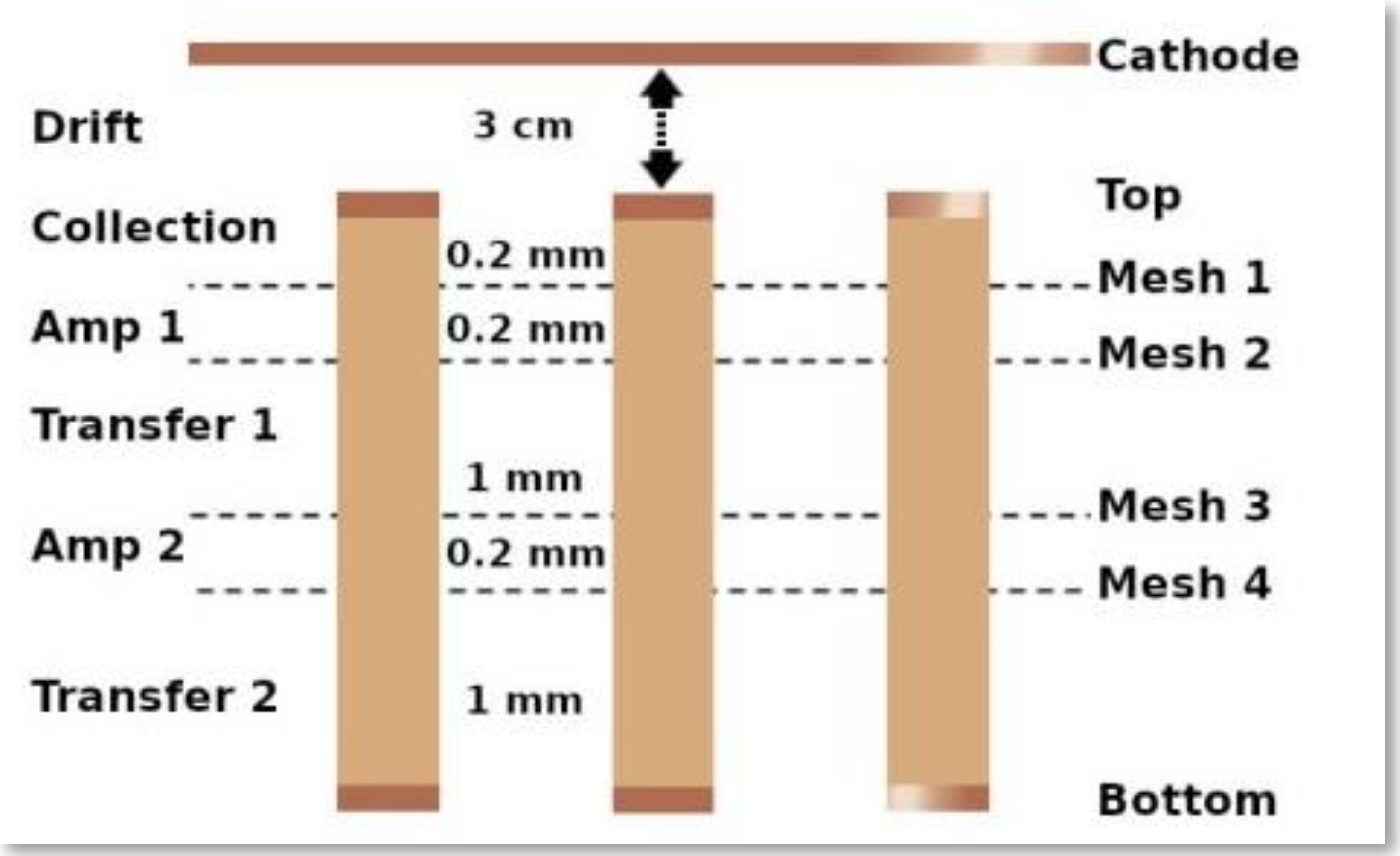
- Very difficult to produce significant gas gains – **typically limited to ~10^3**
- Electron must be stripped from NI before amplification
- Limits sensitivity to low energy recoils

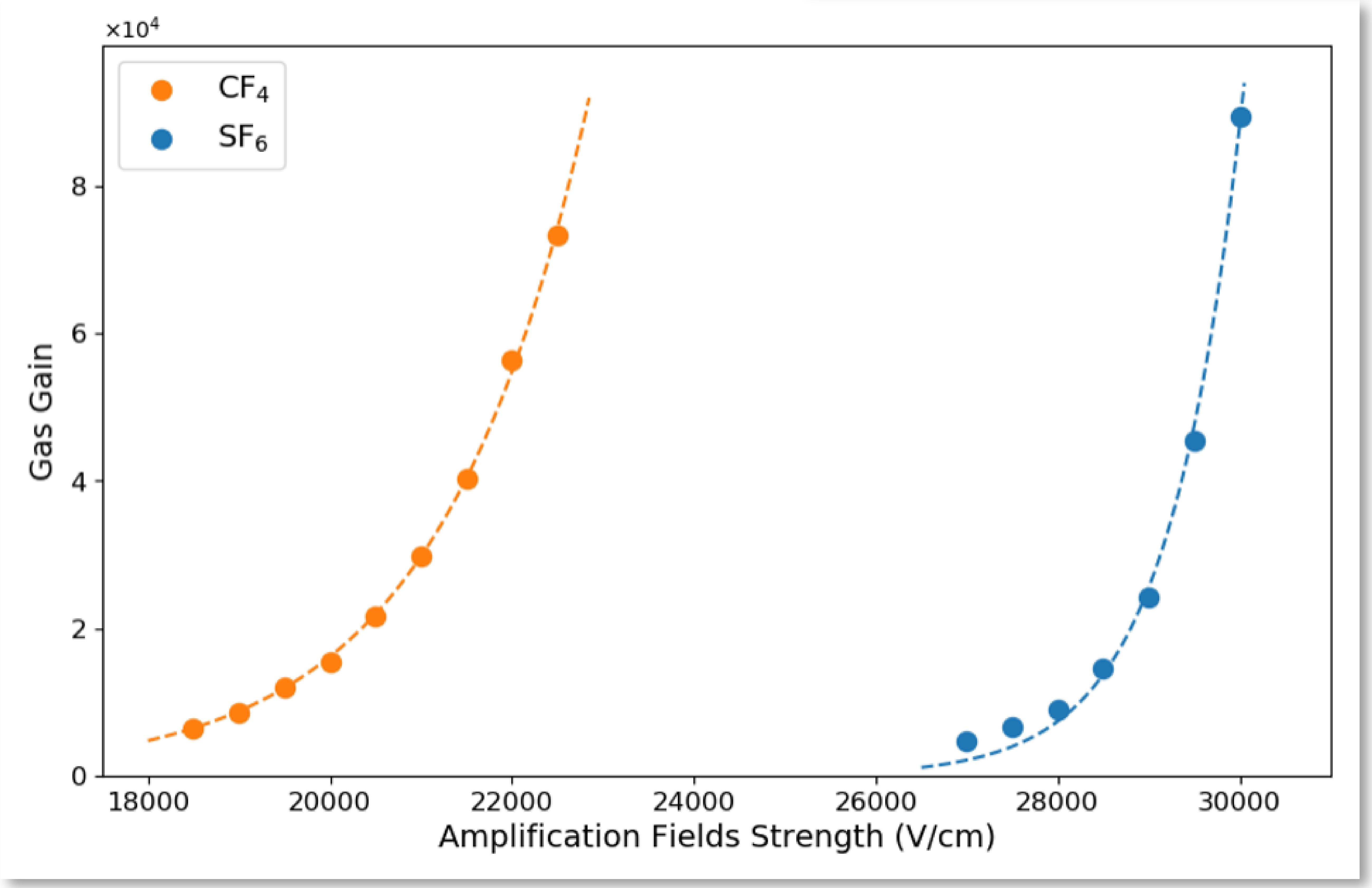
The Multi-Mesh ThGEM

An ideal NID gain stage?

Outstanding NID Gas Gain







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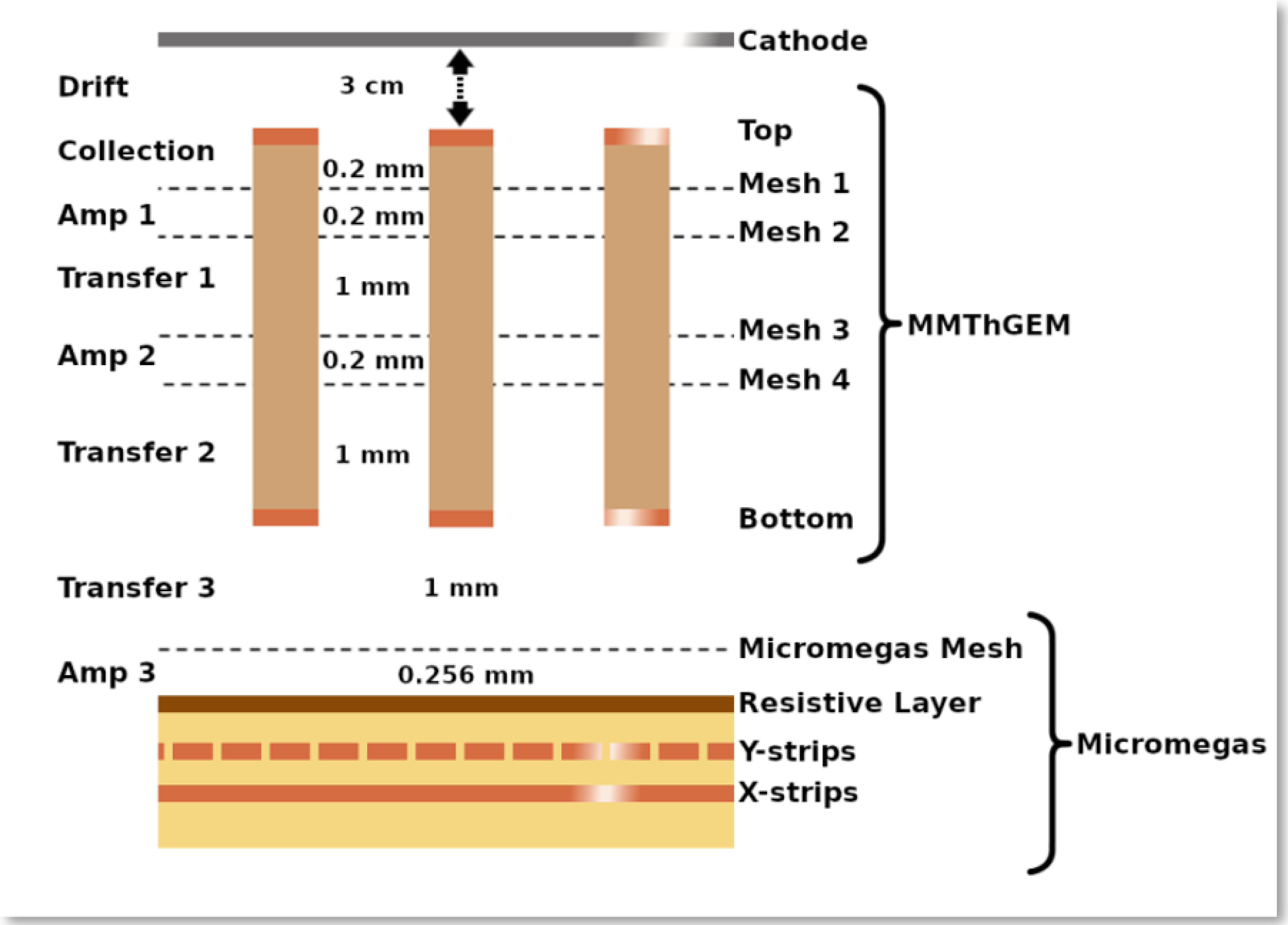
Coupled MMThGEM-Micromegas

A high NI gain detector with 2D/3D readout

Next step for the MMThGEM

- MMThGEM is a planar device (i.e. 1D readout)
- Needs to be coupled to a segmented anode readout plane for 2D/3D
- Strip readout = Micromegas



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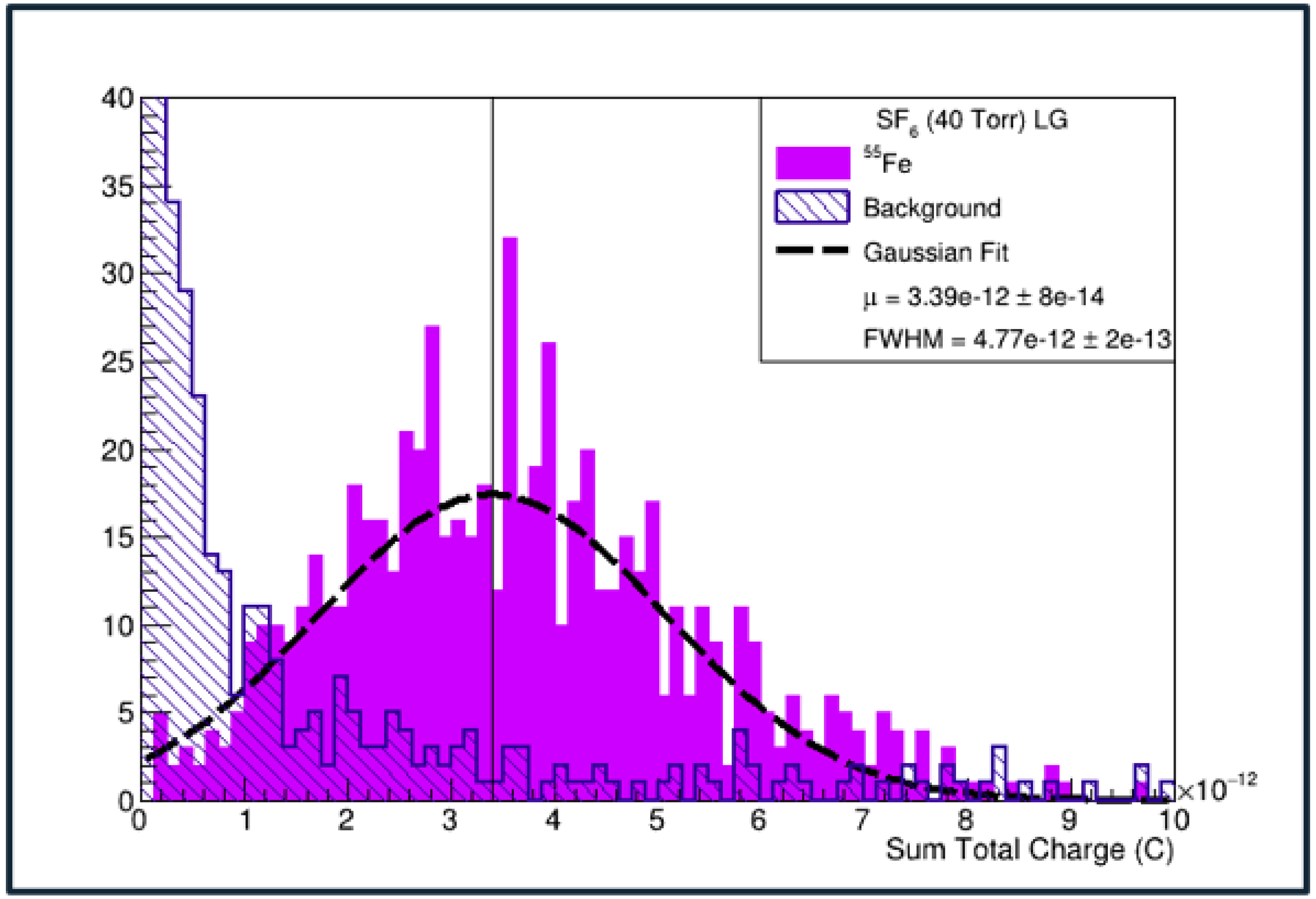
arXiv:2602.12658

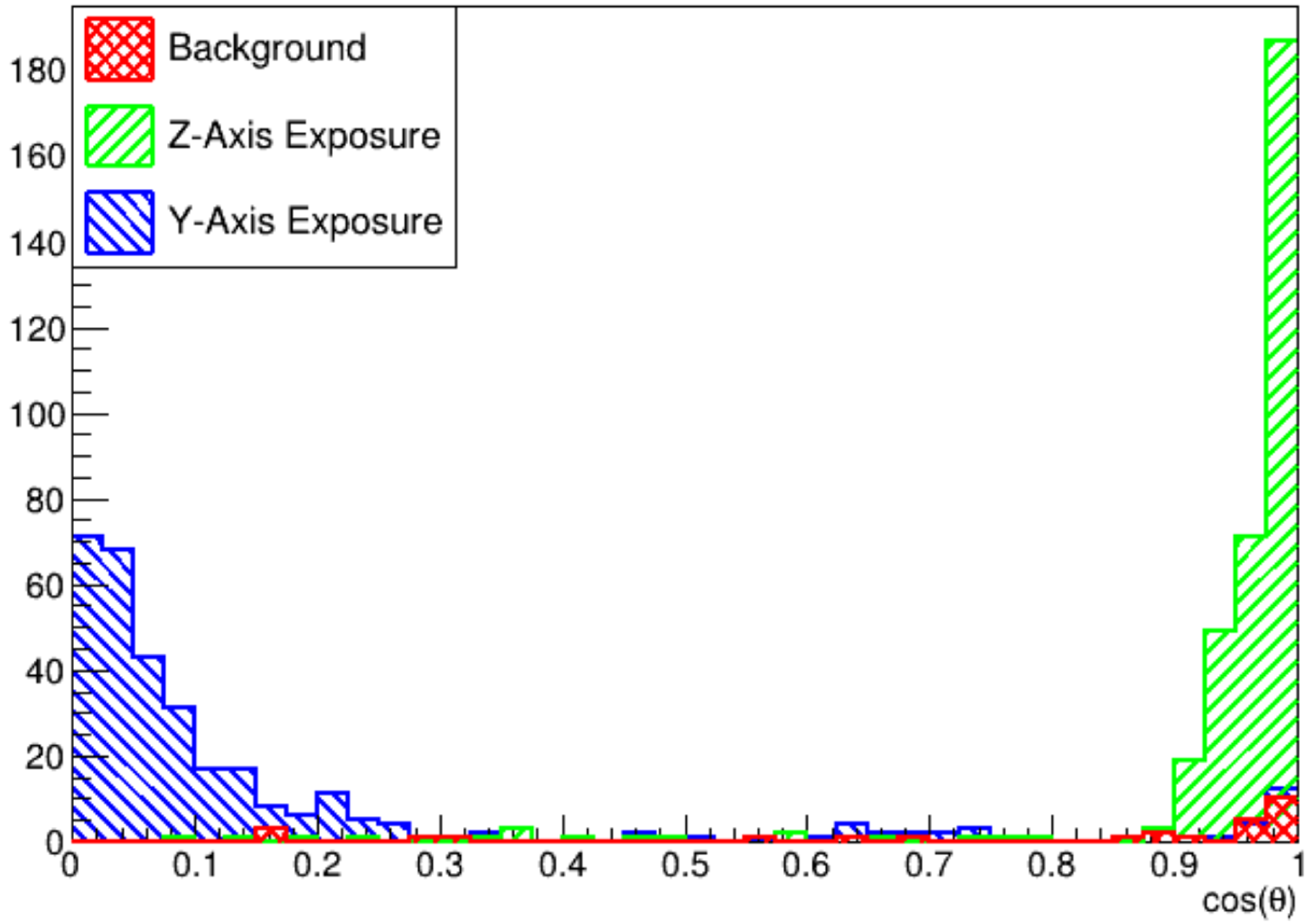
Unparalleled NID Charge Amplification

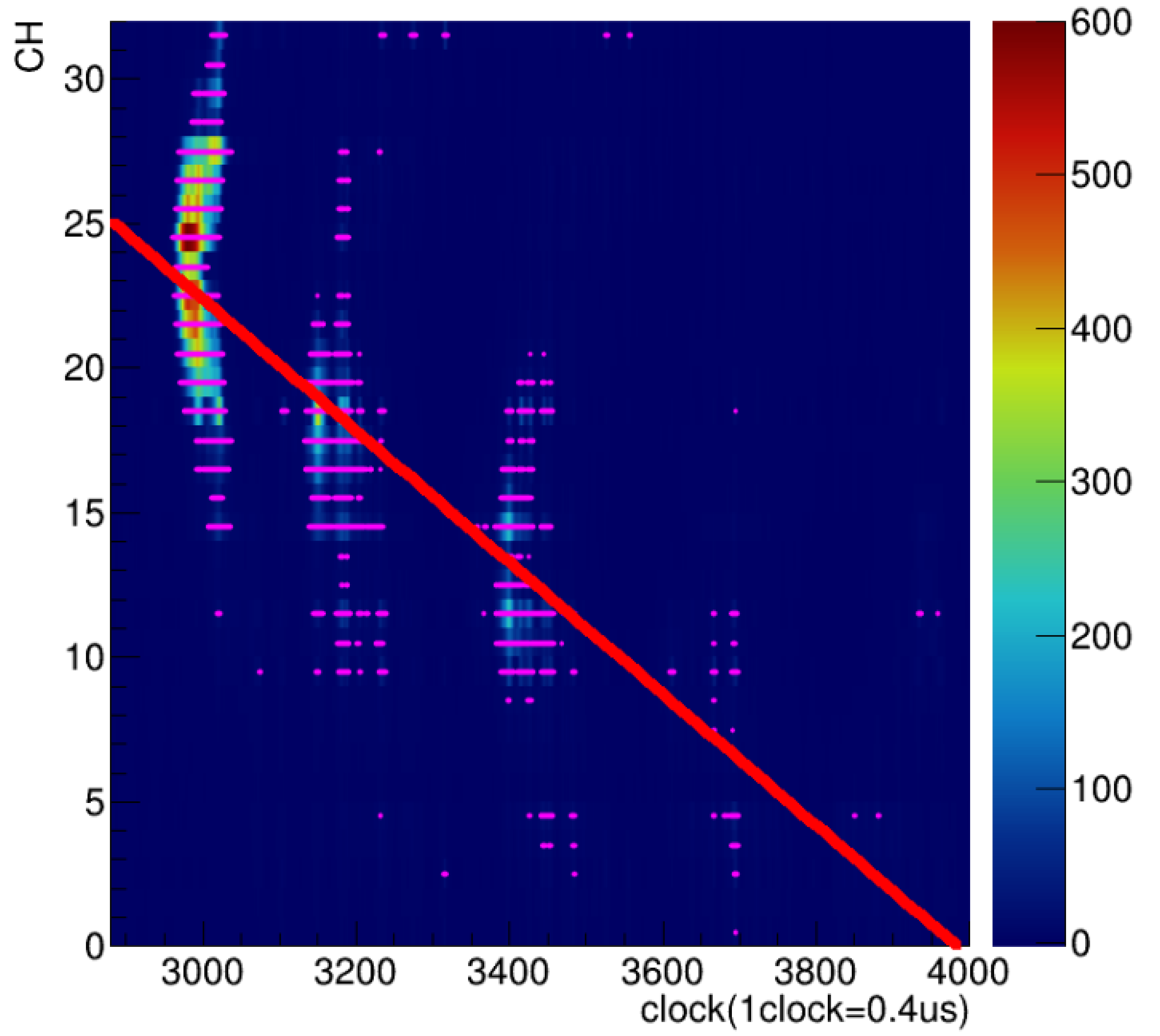
Additional amplification field provided by micromegas results in 10^5 gain for the first time

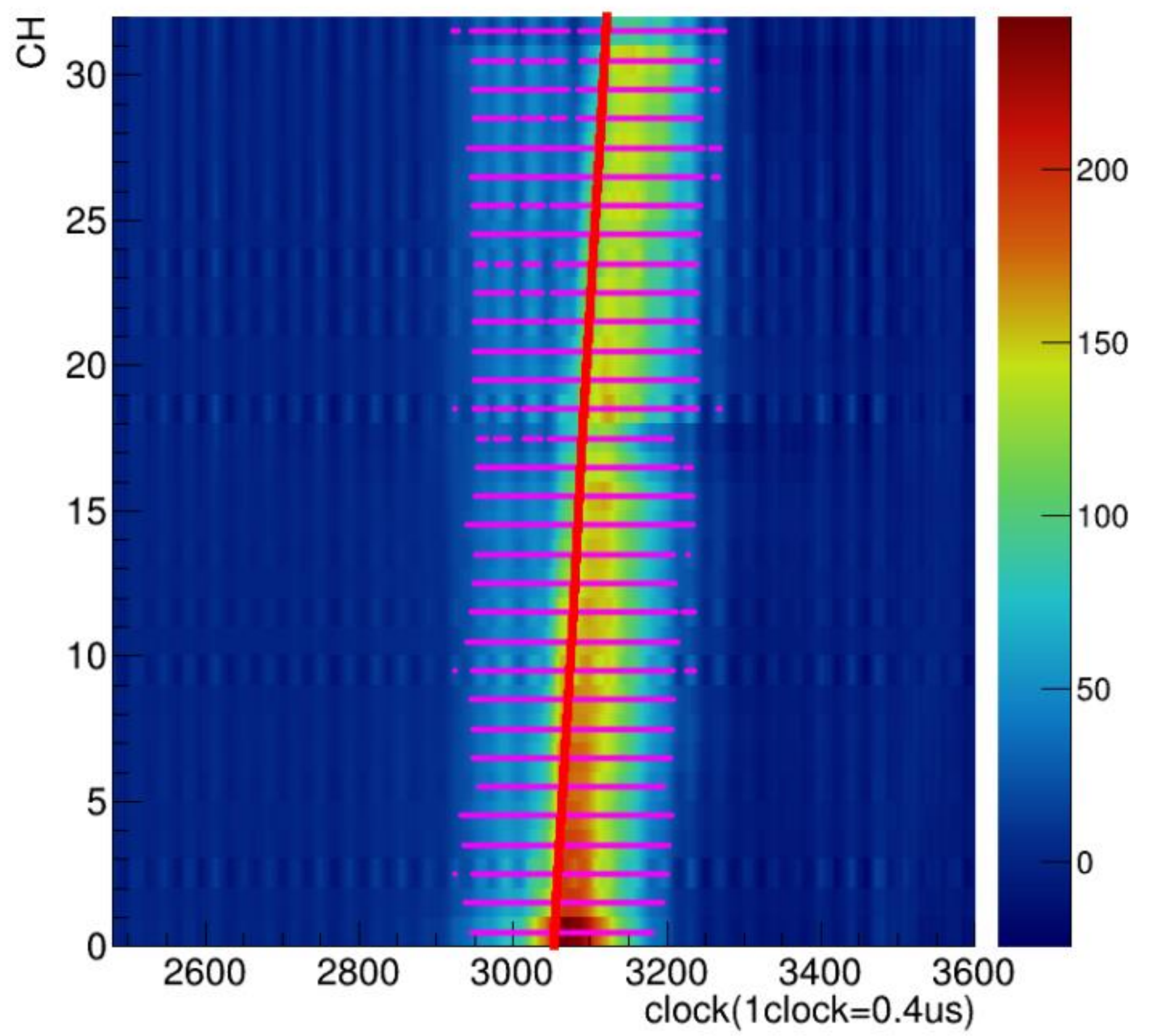
$(1.22 \pm 0.08) \times 10^5$



Clear angular separation of perpendicular exposures with alphas

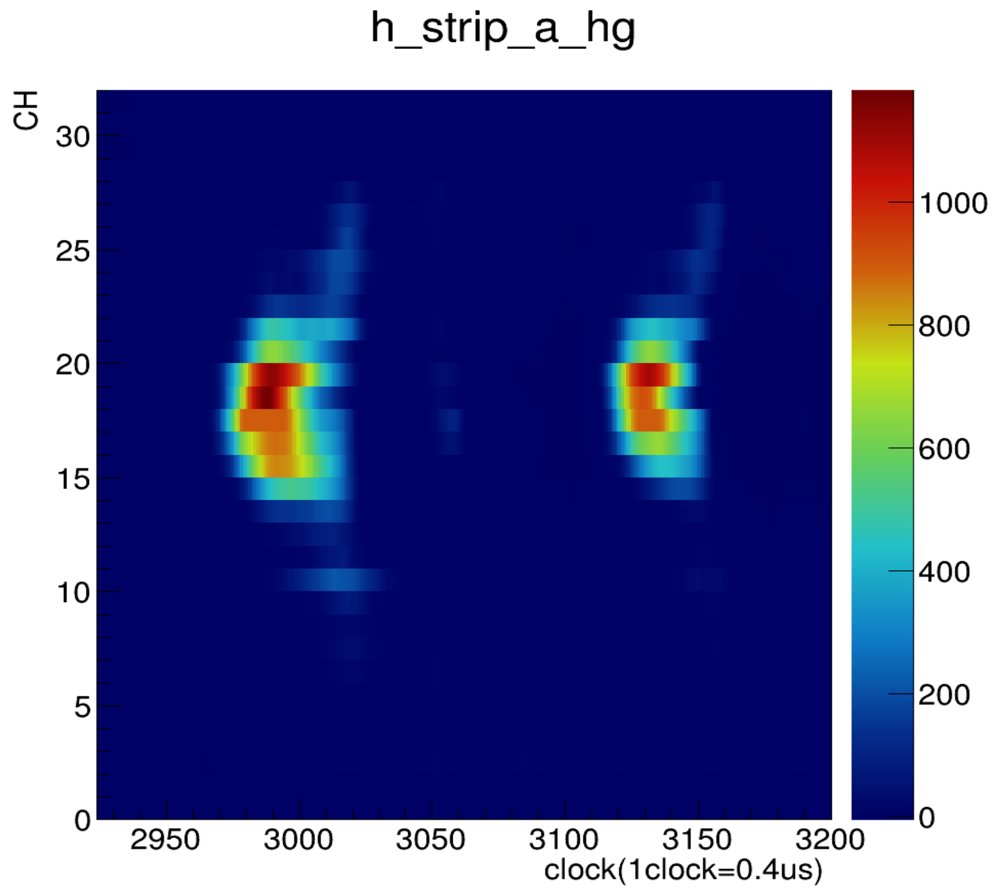


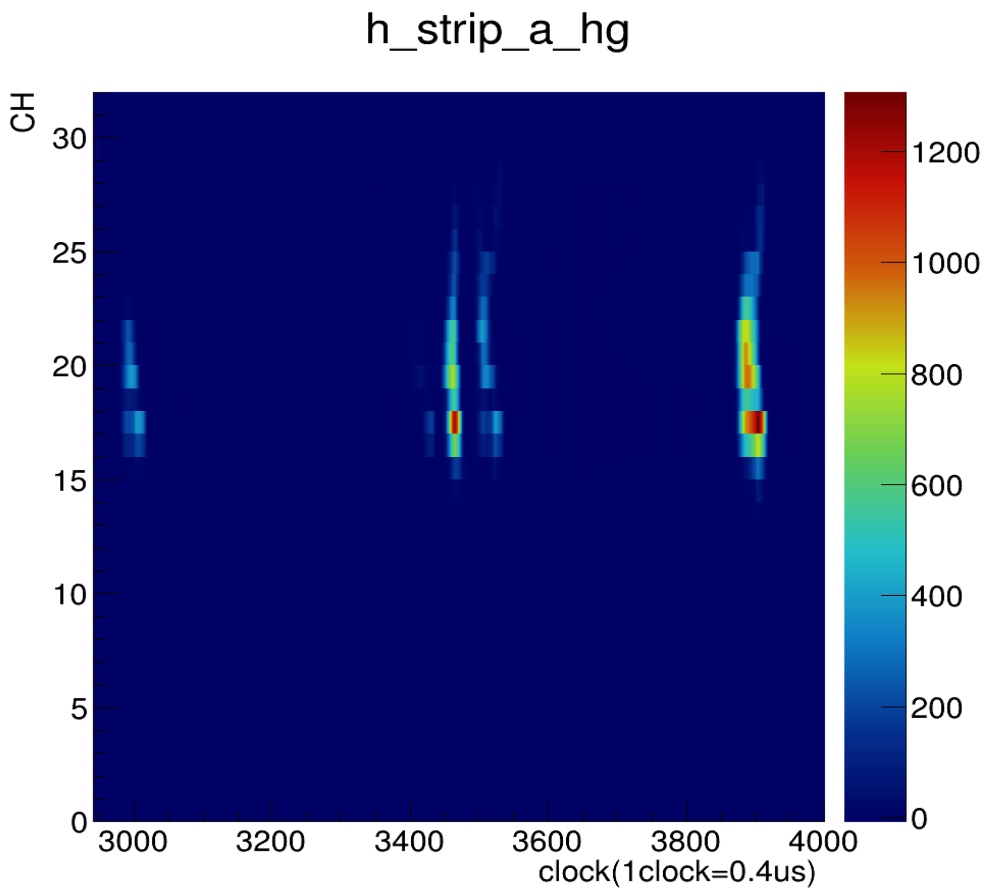




arXiv:2602.12658

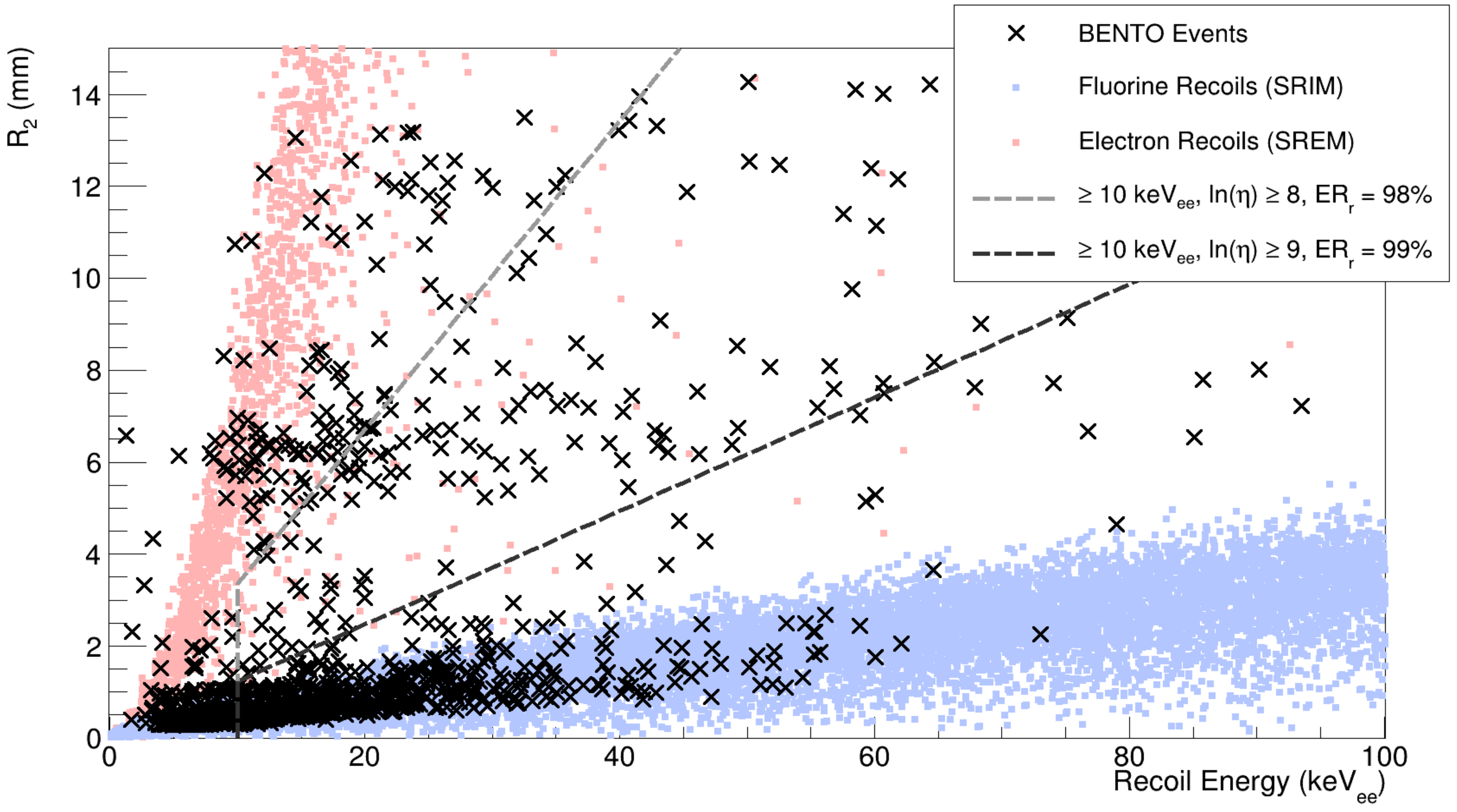
CYGNUS-m^3 Scale “BENTO” Vessel

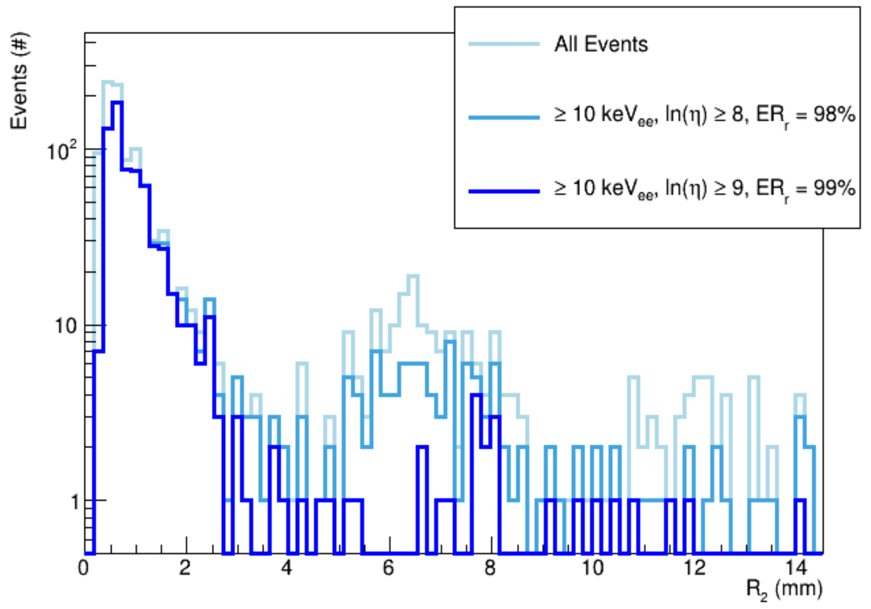


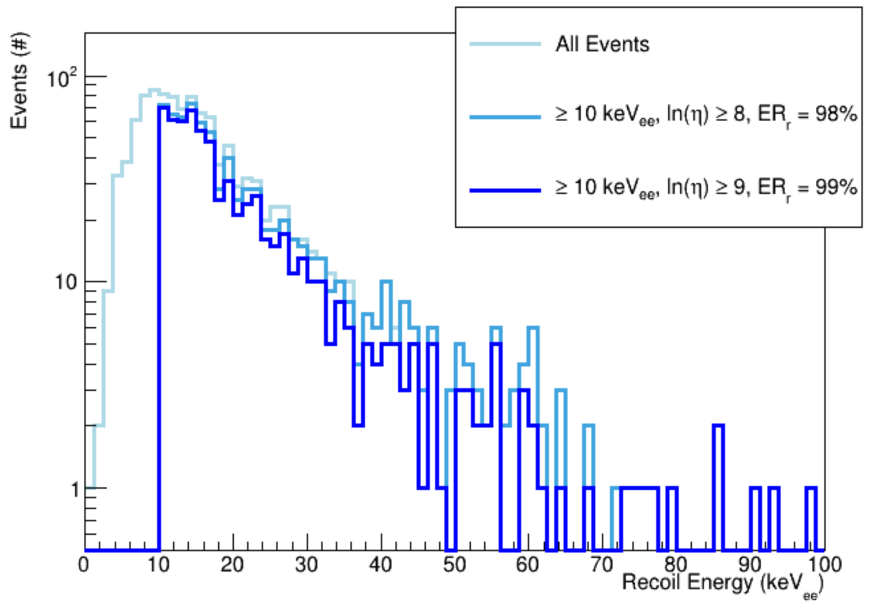


Possible evidence of head-tail asymmetries and SF_5^- minority peaks with ~30% amplitude of main peak!

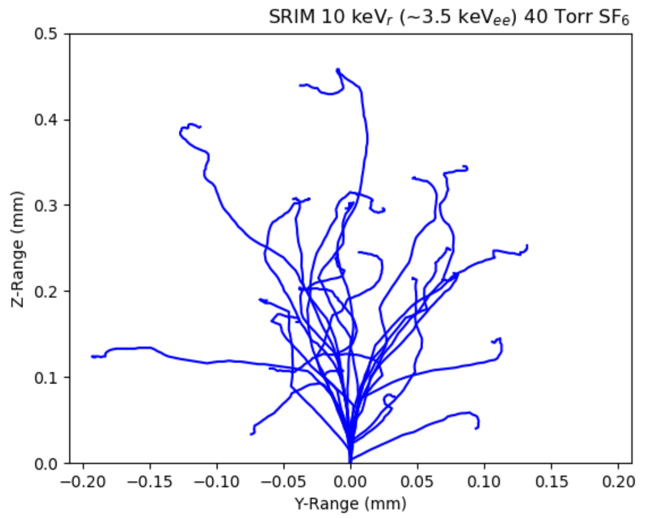
Further work required to confirm this is not due to MMThGEM hole pitch or other artifact

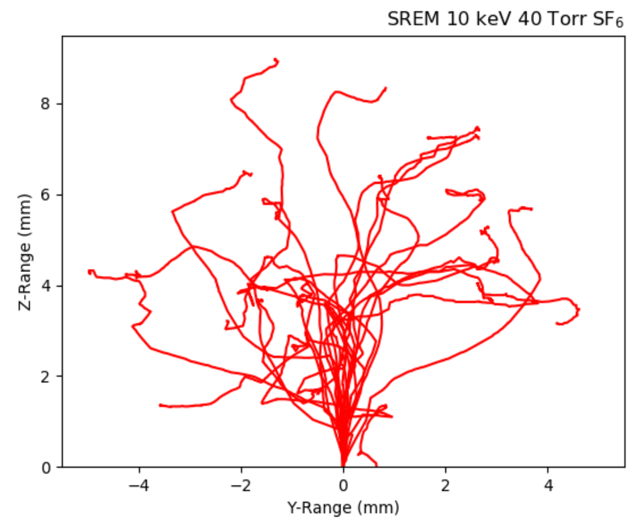


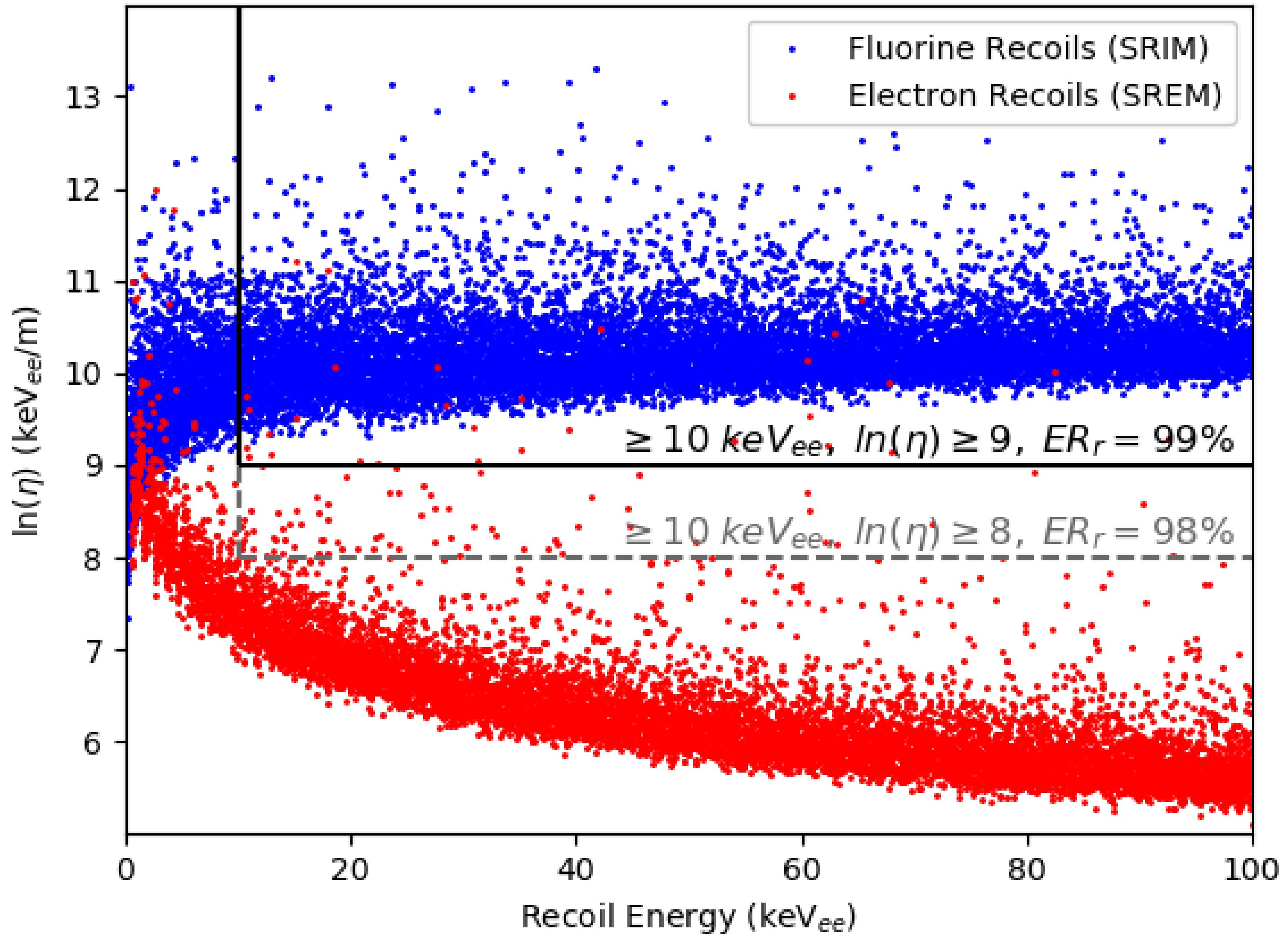




Supplementary simulations





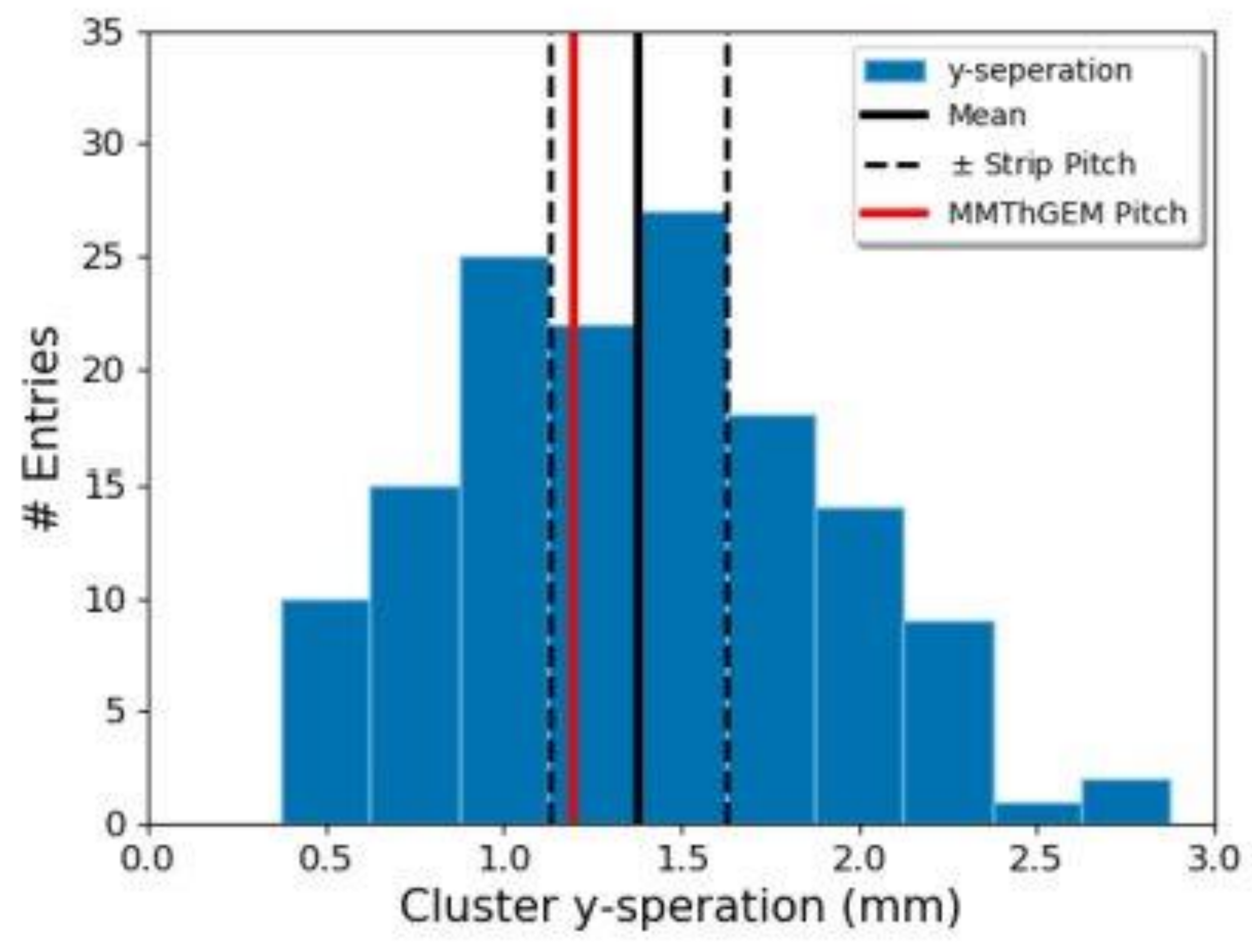


With simulated cuts applied, range and energy spectra are consistent with NR results previously obtained with Cf-252 NRs elsewhere.

Next step: scale up readout channels...

arXiv:2602.12658

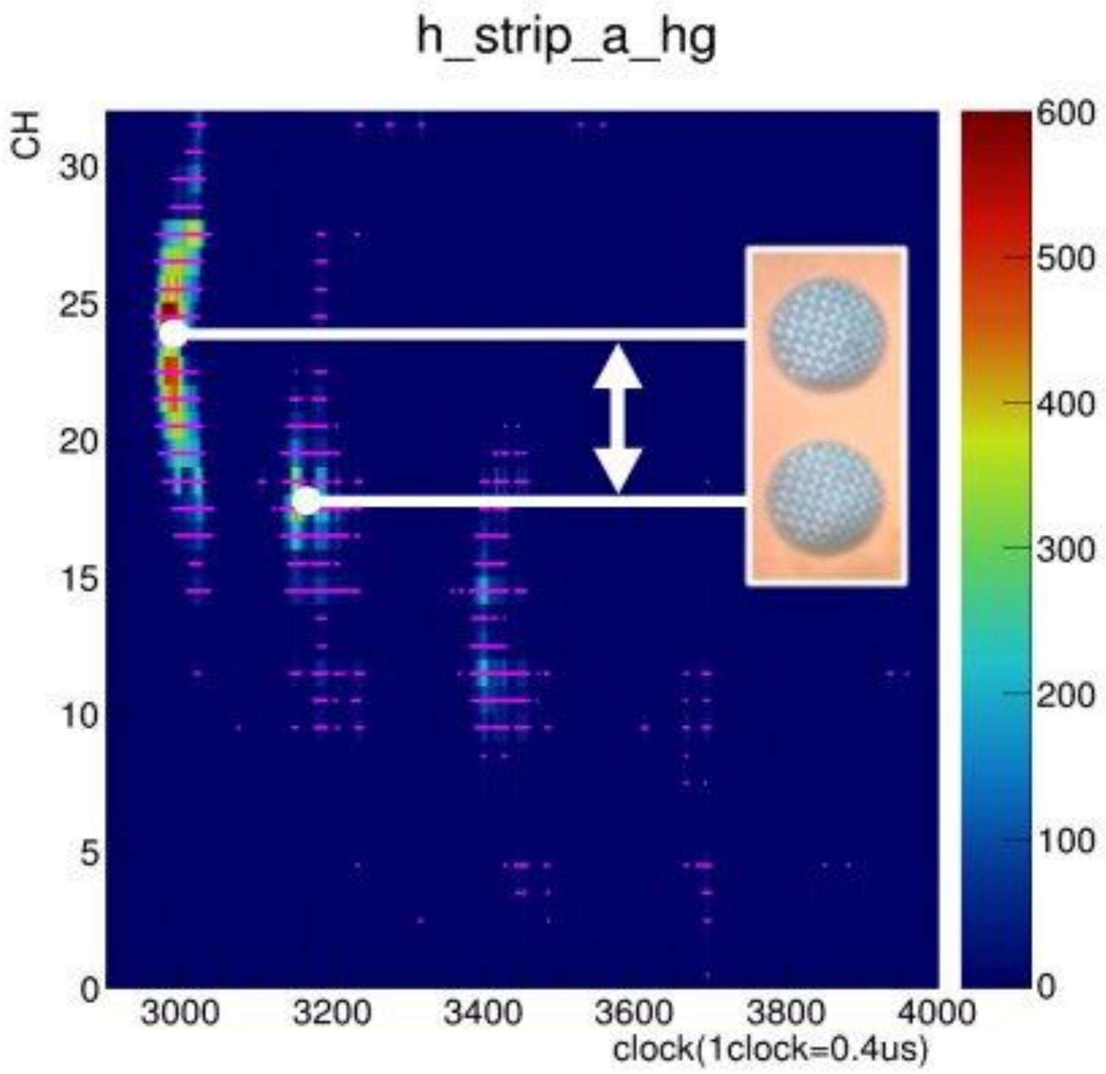
Coupled detector performs well, however…

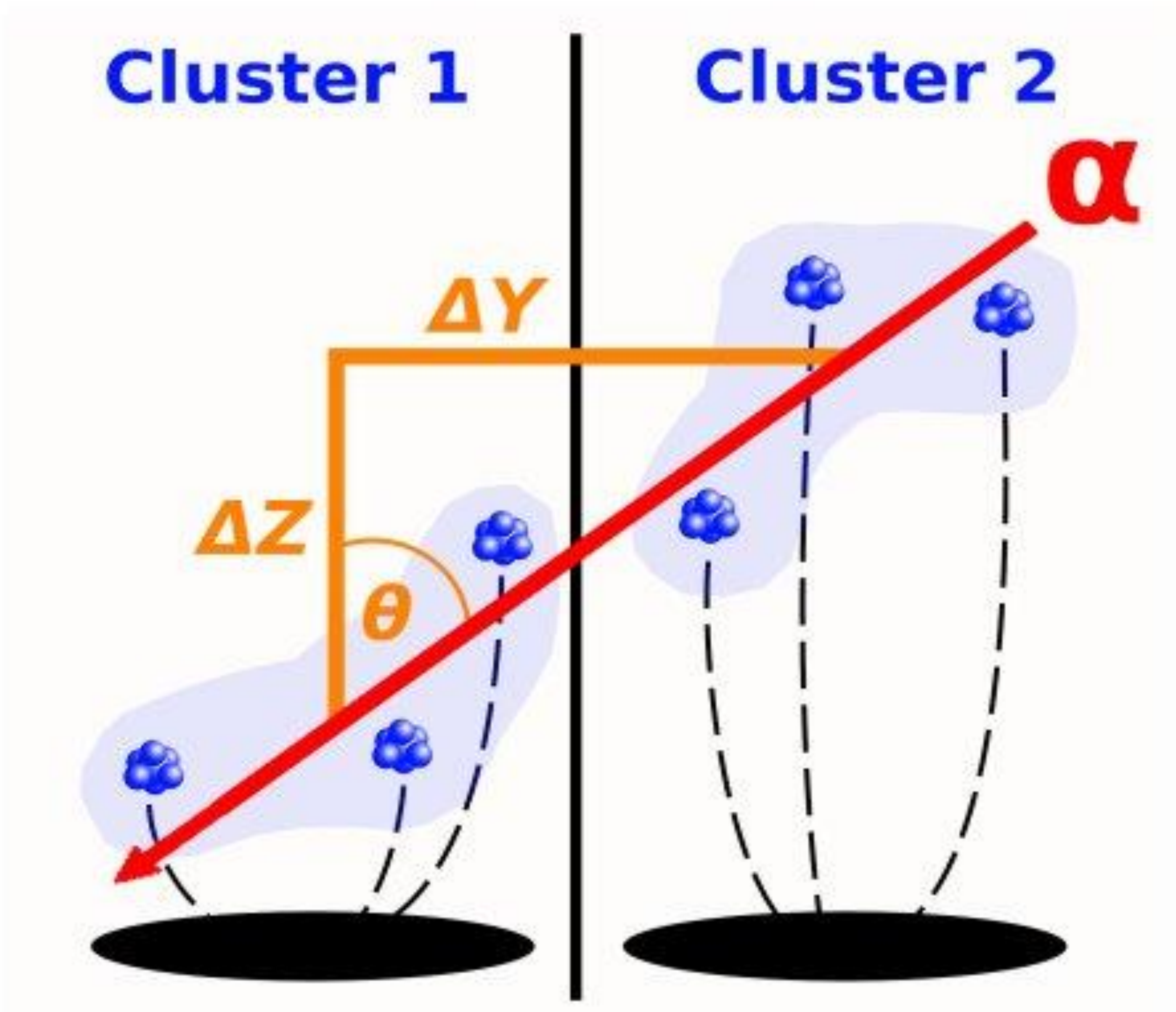


- Resolution is limited by the coarse MMThGEM hole diameter and pitch

- Large 0.8 mm diameter limits spatial reconstruction capability

- Large 1.2 mm pitch induces charge discontinuity effect – makes reliable track reconstruction challenging





What can we do about this?

- Remove effect of hole geometry via deconvolution algorithm?- not impossible but tried before with limited success
- Reduce diameter and pitch size? - limited by construction techniques
- Remove the issue altogether? - introducing a new initiative...

LARD: a Low-cost Amplification and Readout Device

A 'hot-swappable' platform for detector development

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LARD: 3D Printed Micromesh Structures

Main Challenges with MPGD development:

1. GEMs are expensive
2. Long lead times for prototyping
3. Scarce expertise in design and manufacture

Initiative between University of Adelaide, Australian National University and Queen Mary University London to create 3D printed mesh structures as a gain stage

Initial R&D group:

Alasdair McLean
Adelaide University

Robert Renz Marcelo Gregorio
Australian National University

Dominic Howgill
Queen Mary University London

Growing R&D group:

Victoria Bashu
Australian National University

Lindsey Bignell
Australian National University

Gregory Lane
Australian National University

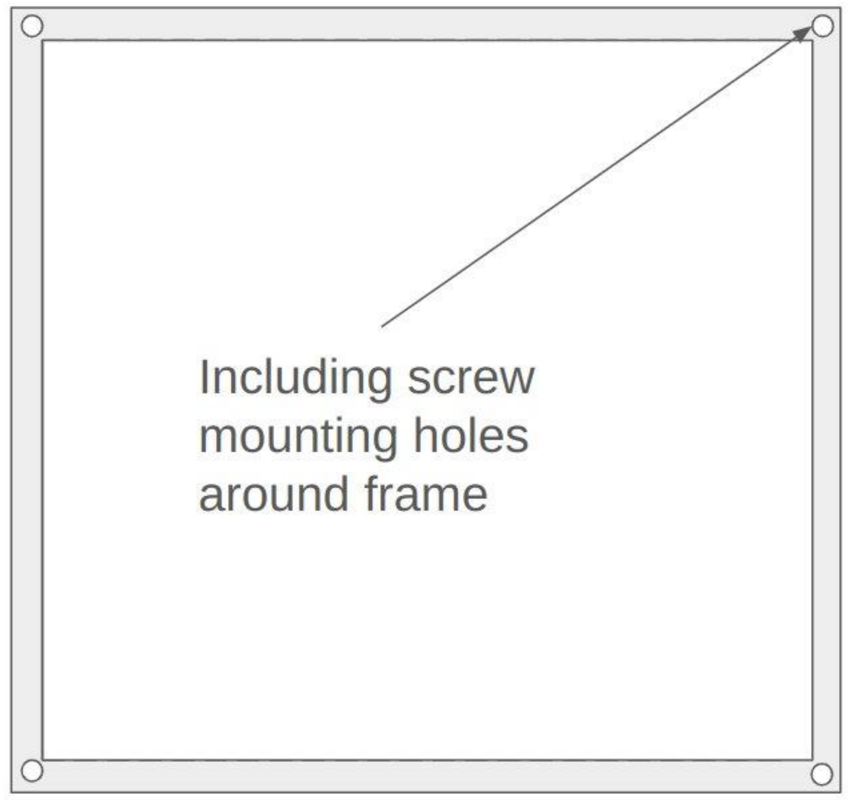
Open to growing collaboration…

LARD: Concept of a "Hot-Swappable" Detector

3D printed parts:

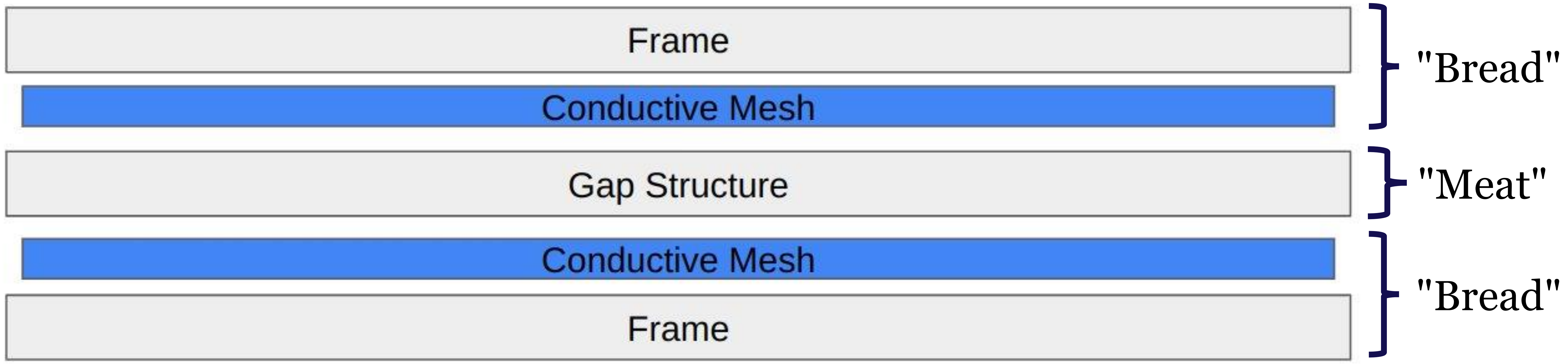
- Mounting frame (x2)
- Gap structure

Mounting Frame



Gap structure

Conductive mesh between layers for biasing



Burger analogy

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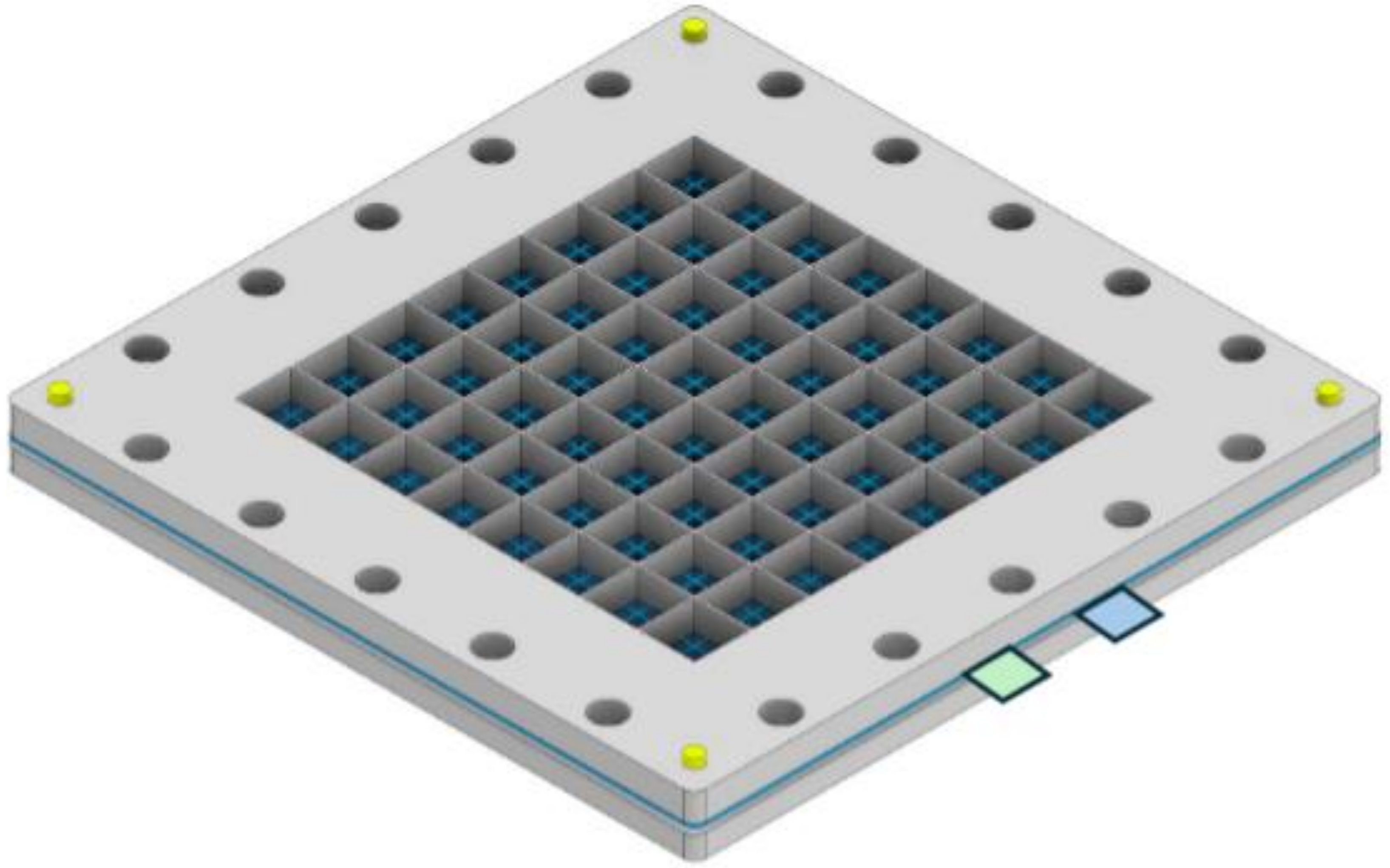
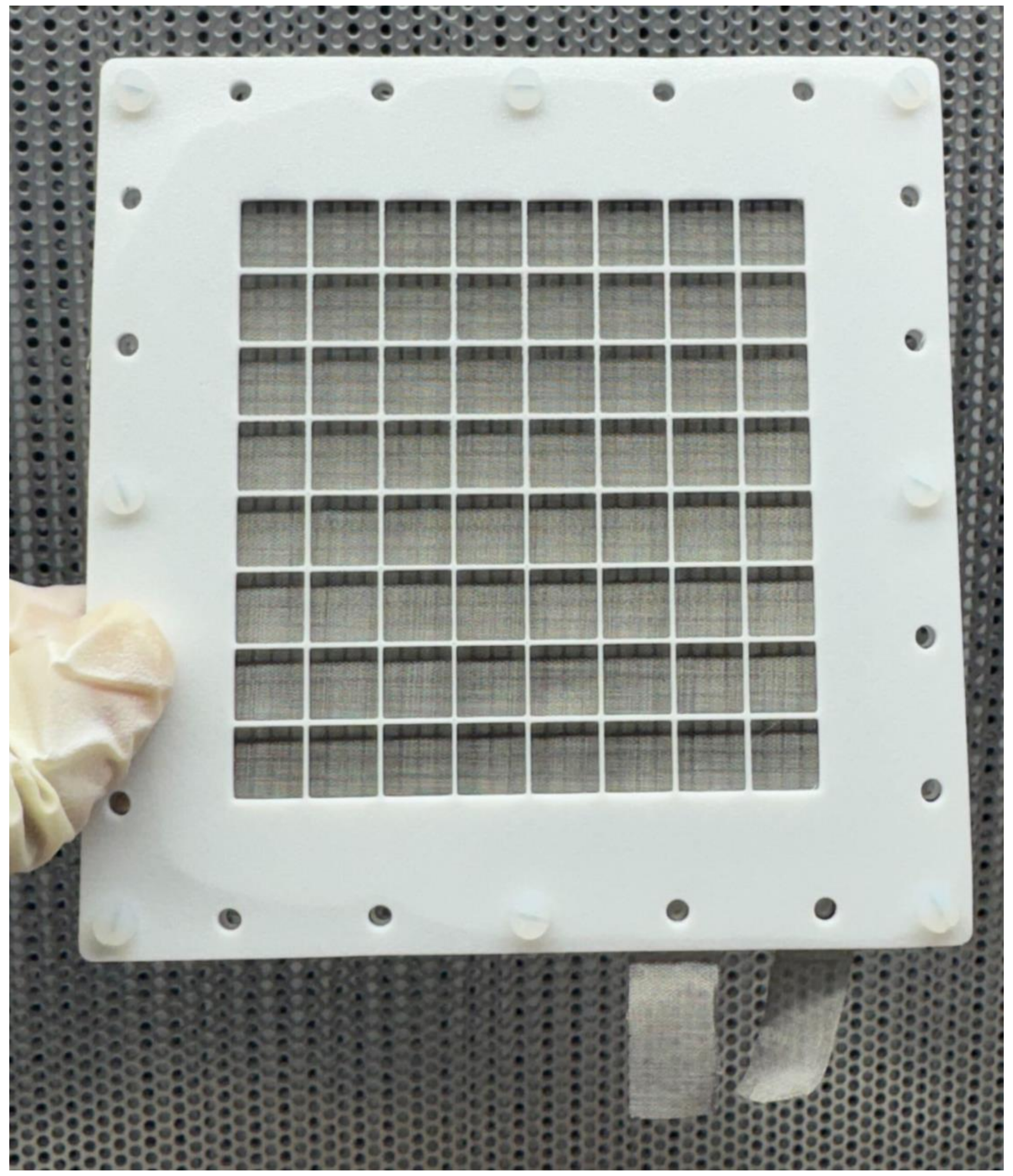
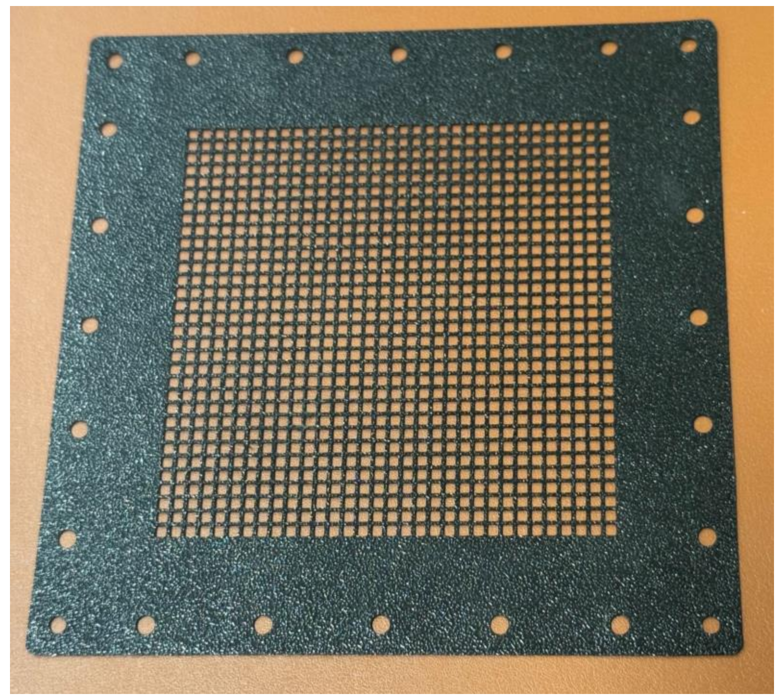
LARD V2 Prototype

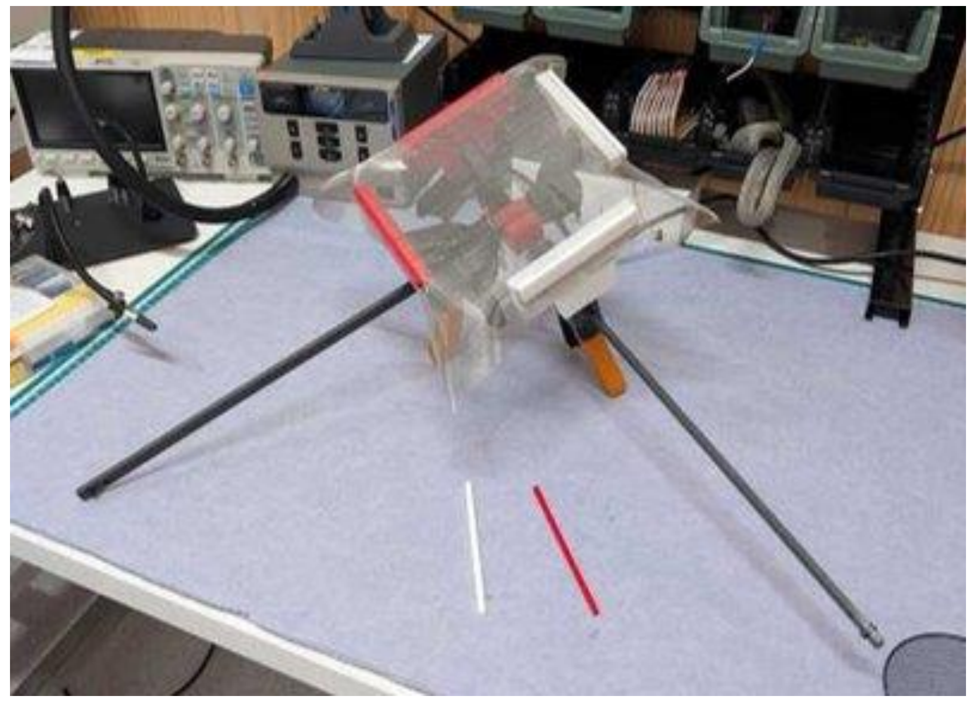




CAD model of LARDs V2 Prototype (left) and fully assembled prototype (right)

Manufacturing procedure





High-precision 3D printing capability:
- 500 μm thickness (scope to go thinner)
- Single pass printing to maximise support structure transparency

Mesh tensioning:
- Techniques developed by University of Melbourne (Prof. Martin Sevior's Group)
- x/y axis tensioning works better than the drum design

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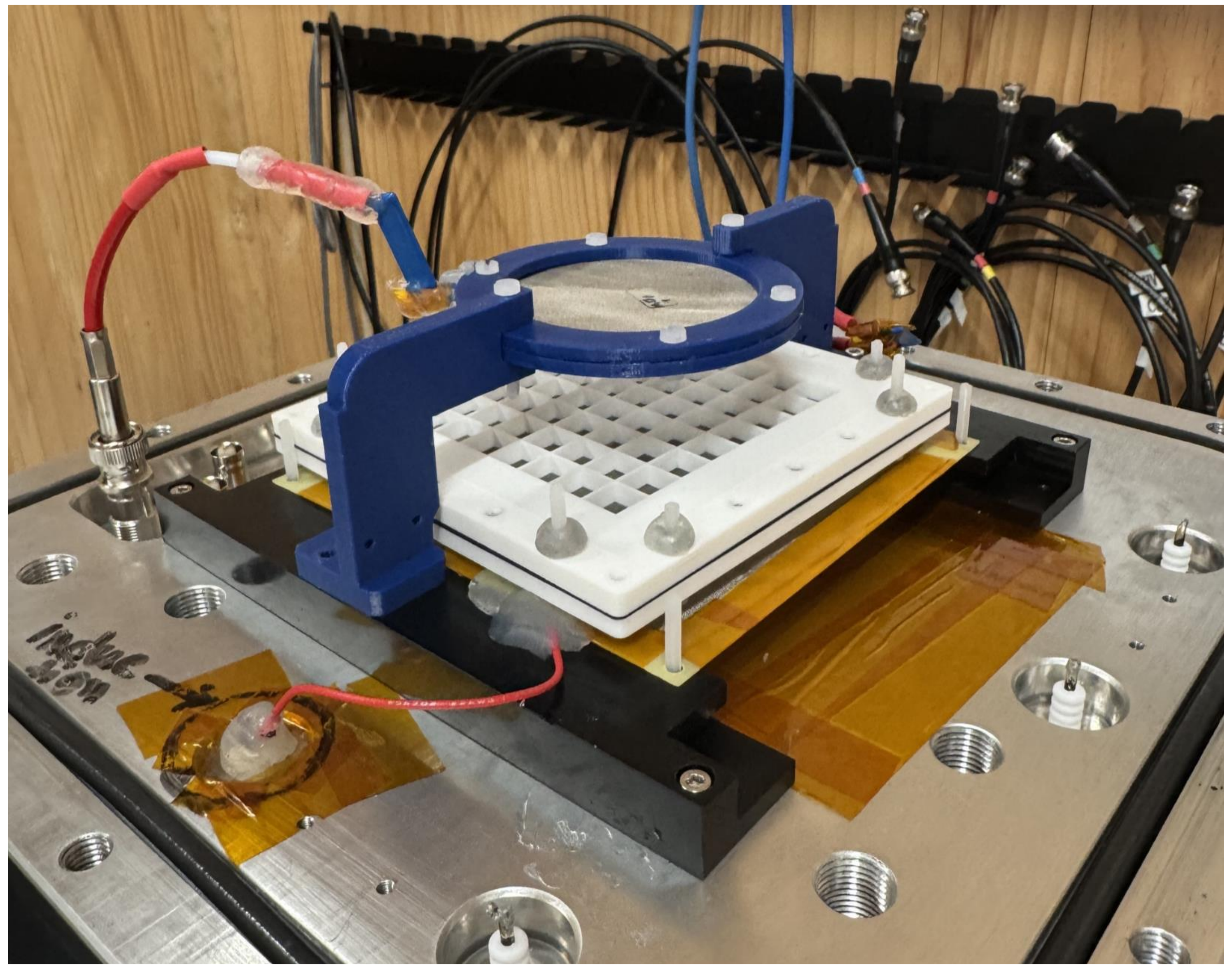
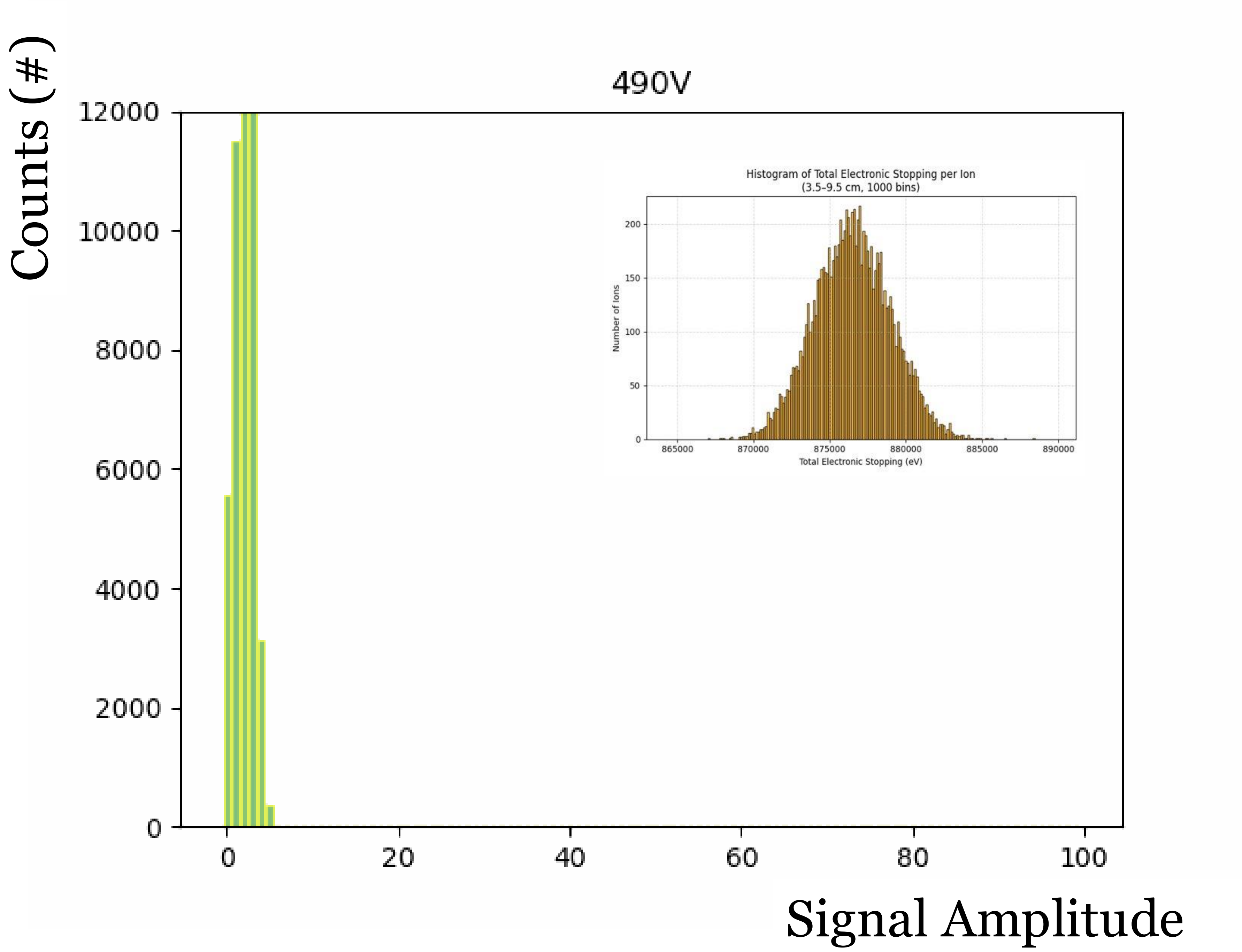
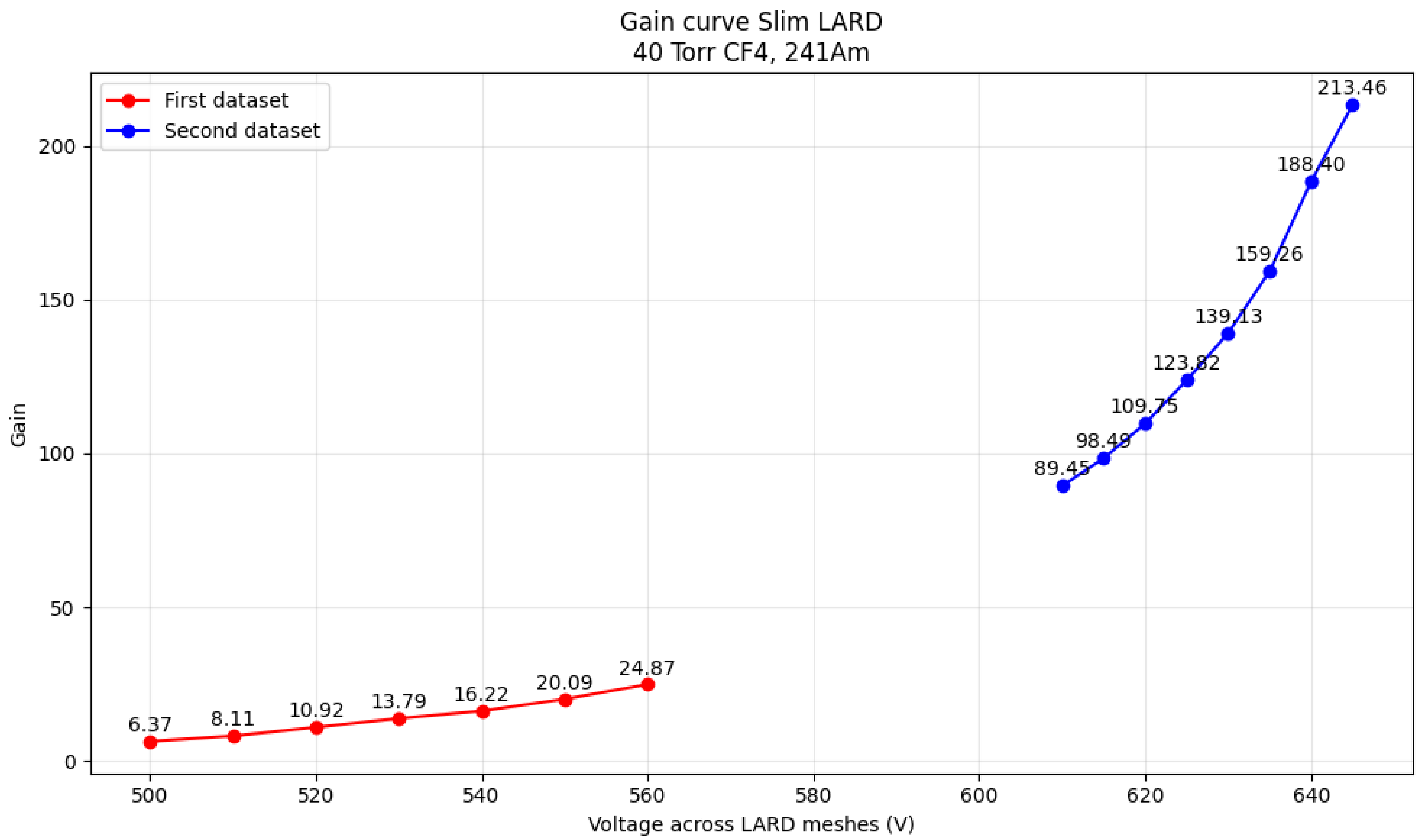
LARDs: Performance Testing

- First light testing with alpha source
- "easy" gas target (40 Torr CF4)
- Good agreement with SRIM simulations
- Effective alpha gas gain = 2.13×10^2



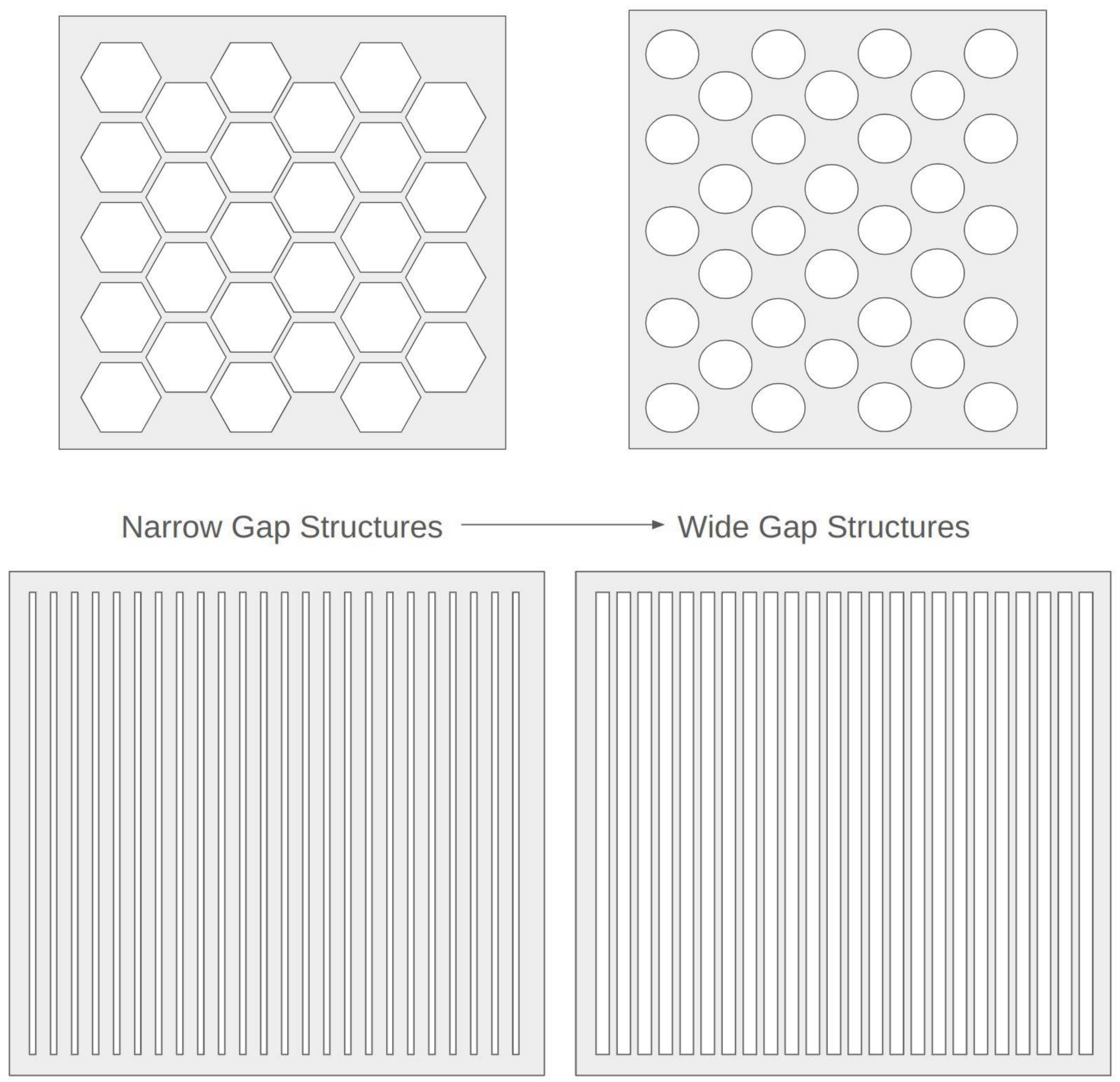


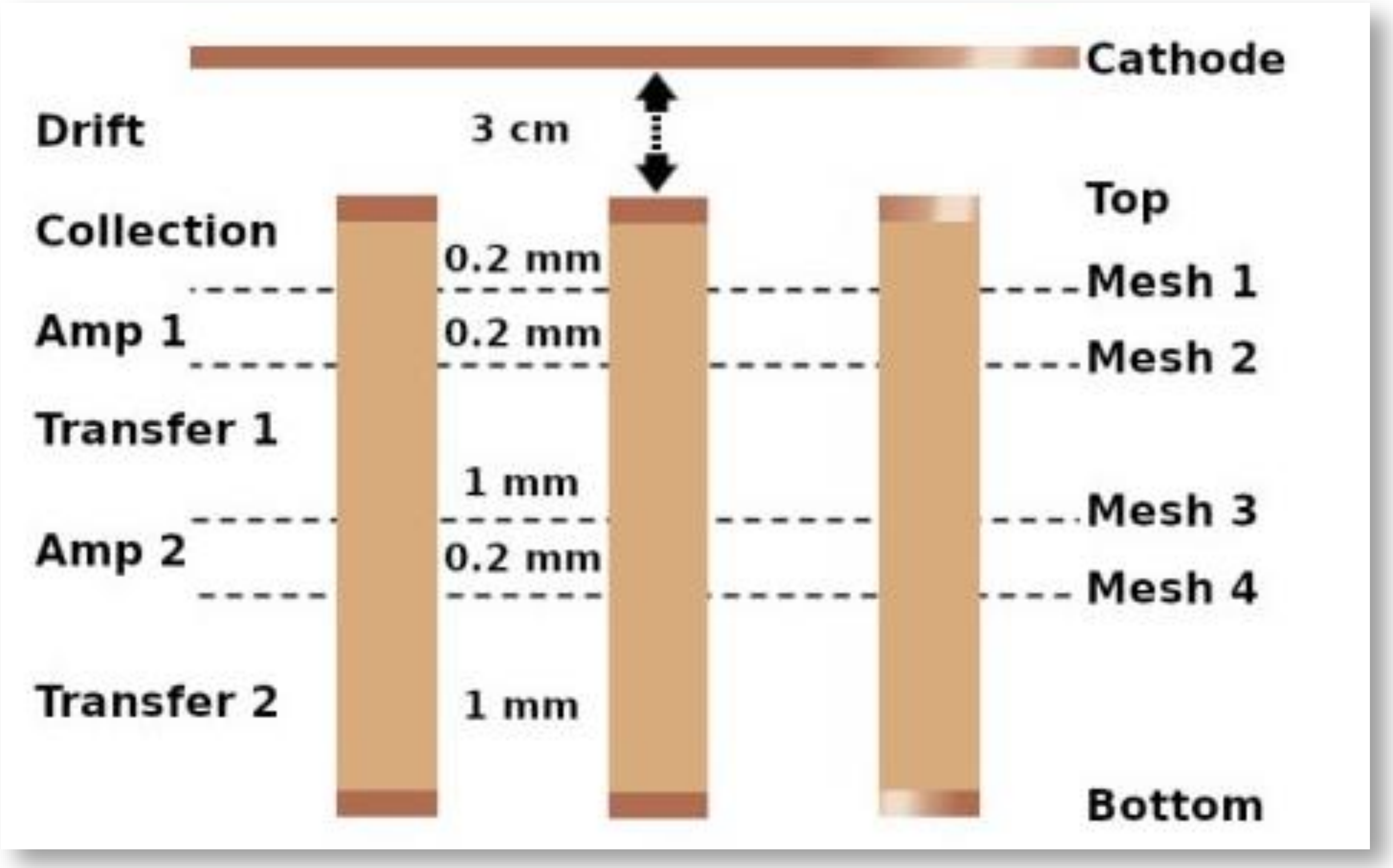


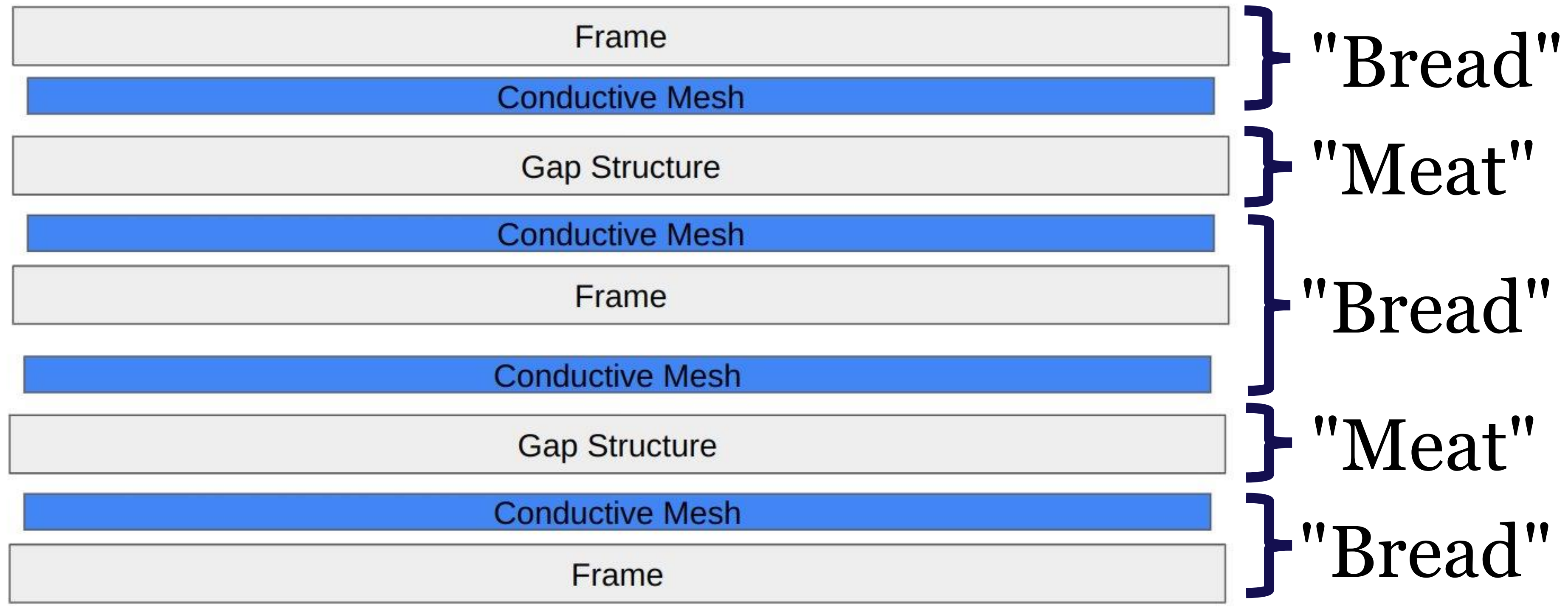
Performance testing and analysis by V. Bashu (PhD candidate, ANU)

LARDs: What's next?

1. **Platform for fundamental micromesh MPGD research – thickness, hole width, pitch, geometry, mesh parameters etc...**
2. **Comparison to industry standard GEM**
3. **"Stack-ability" - can we replicate or improve the NI MMThGEM amplification results without the issue of the coarse hole structure?**
4. **Scope for CYGNET implementation – highly scalable**







Summary

Summary and Outlook

- **MMThGEM micromesh structures have shown huge potential with 10^5 gas gain in SF_6**
- **MMThGEM design currently limiting positional/track reconstruction capability**
- **Practical solution: continue developing LARD as an in-house MPGD R&D capability**
- **Lots of scope for novel MPGD research output**

Thank you for listening

Any questions?

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Acknowledgements

Thank you to:

- **The Conference Organisers** for putting on such a fantastic conference and for the financial aid which made this talk possible
- **Kentaro Miuchi, Satoshi Higashino and wider Kobe group** for hosting the field research with the coupled MMThGEM-Micromegas testing
- **Dominic Howgil, Robert Renz Marcelo Gregorio, Lindsey Bignell, Gregory Lane, Victoria Bashu** without whom the LARDs development would not be possible
- **Neil Spooner** for your continued support and guidance

What can we do to Improve Charge Amplification in SF_6?

The Problem with Gaseous Electron Multipliers (GEMs):

1. Multi-stage amplification often required for significant amplification -> charge lost during transfer
2. Positive ion backflow –> charge buildup alters field strength and shape
3. Dipole like electric field shape –> path dependent amplification

The Solution -> micromesh structures:

1. Multi-stage amplification in a single "stand alone" unit
2. Suppression of positive ion backflow
3. Uniform amplification fields

MMThGEM?

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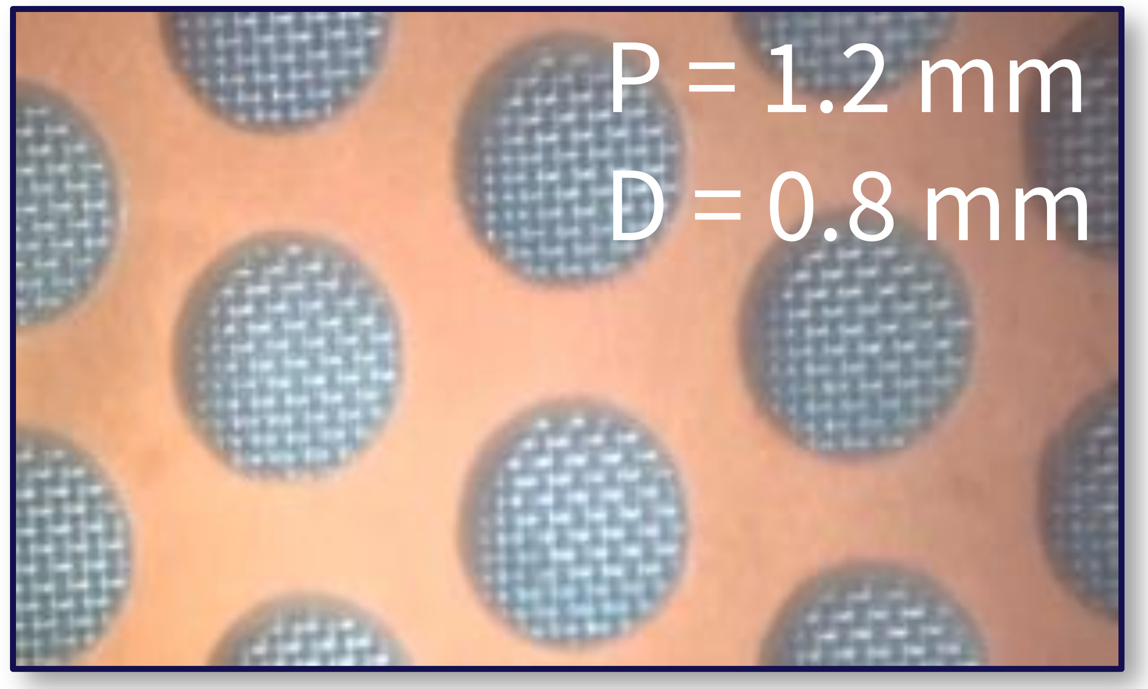
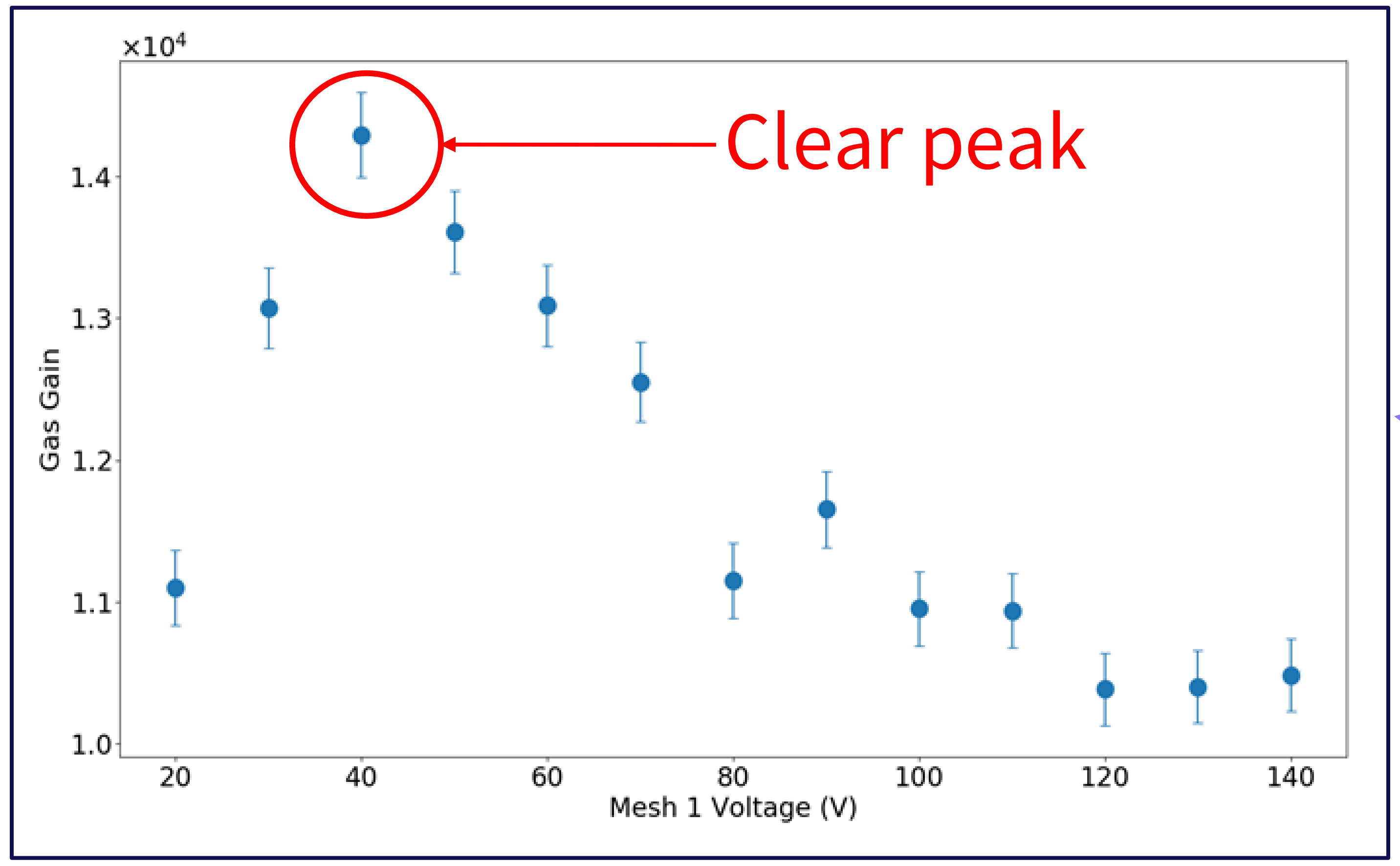
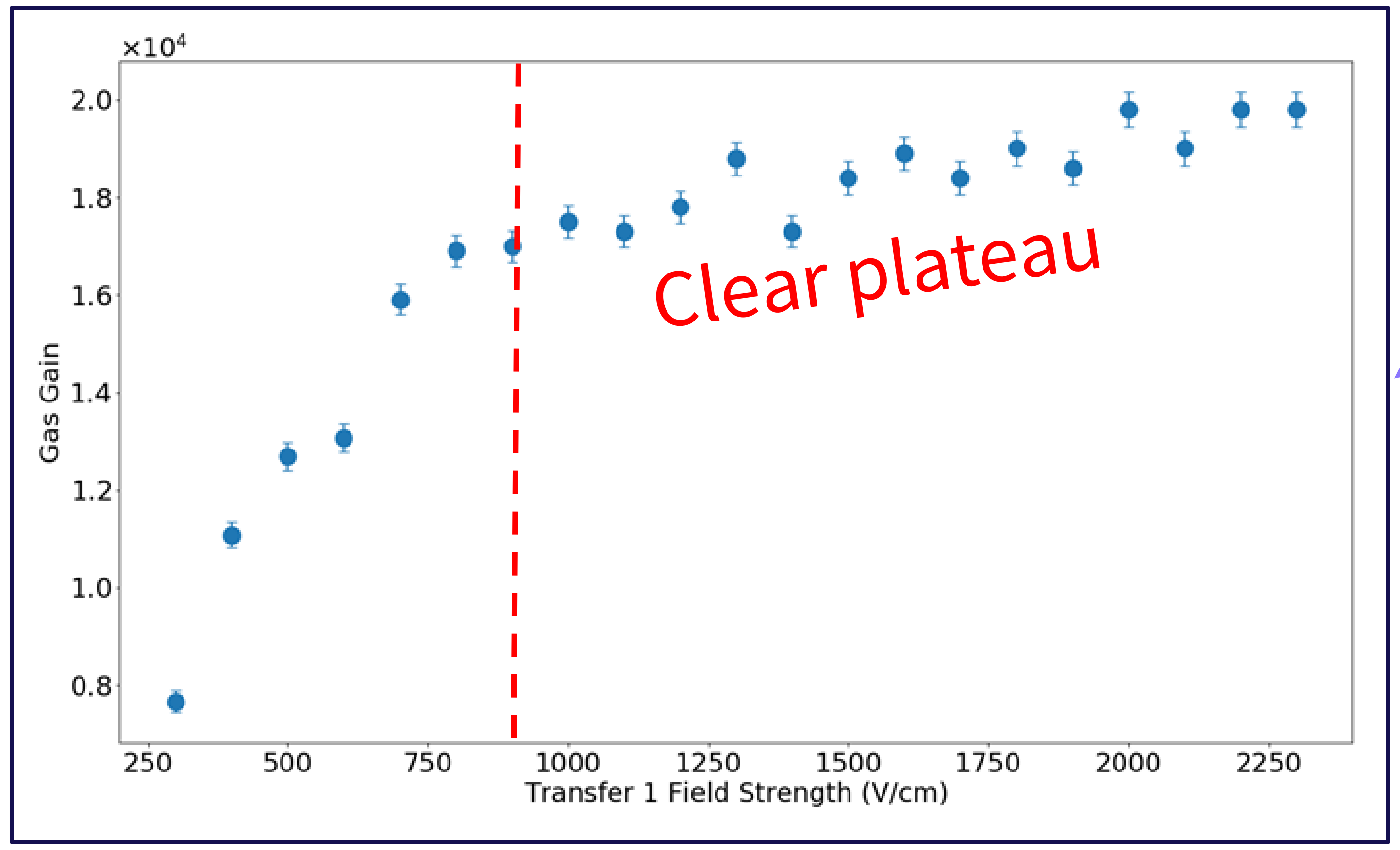
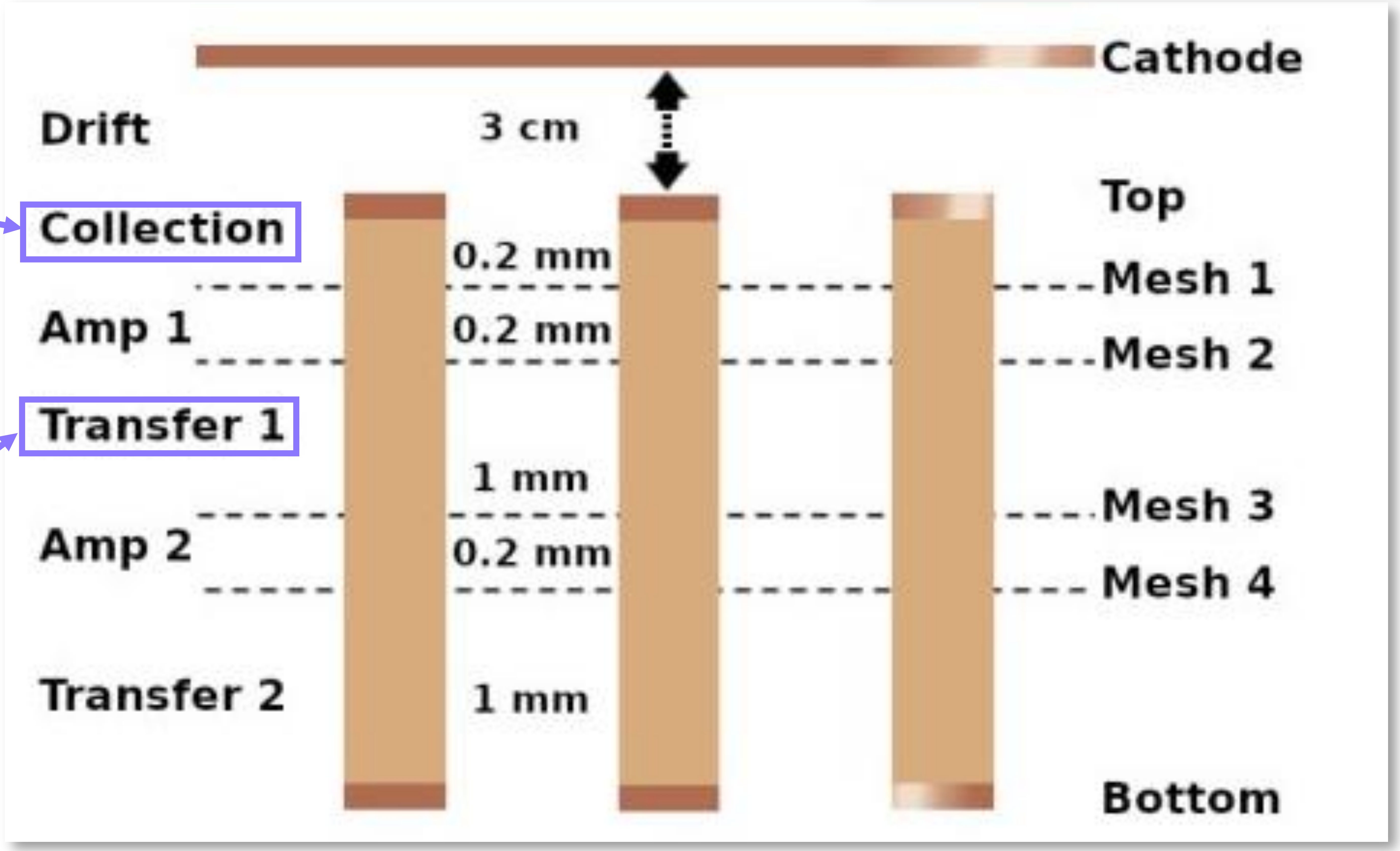
Optimisation of MMThGEM









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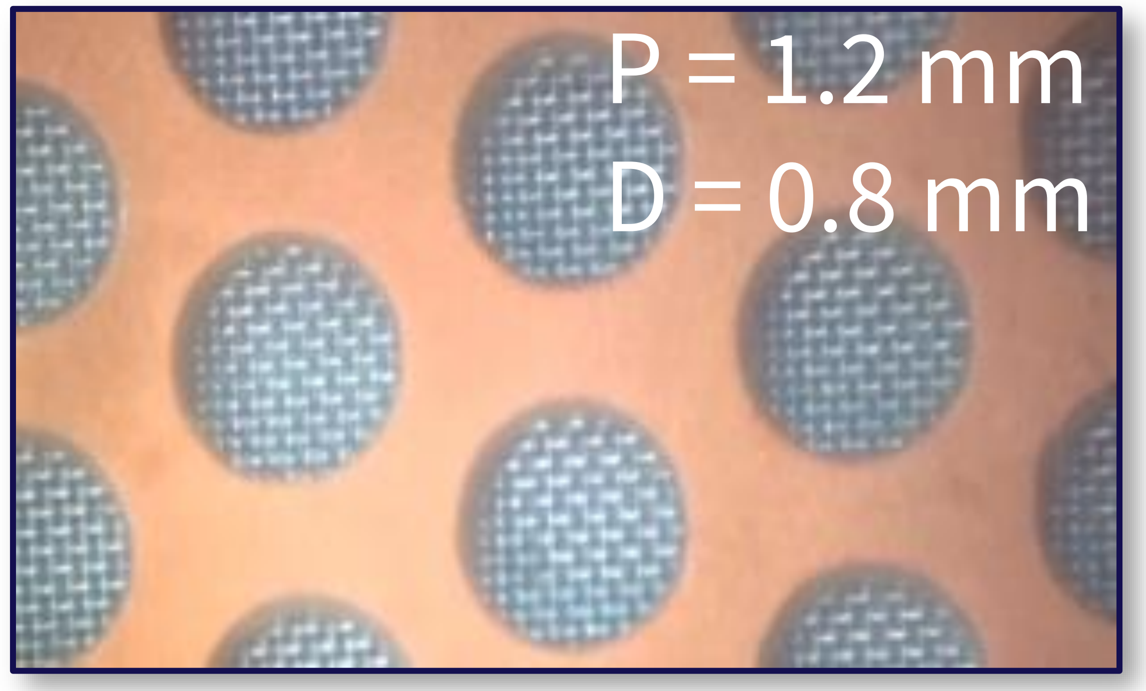
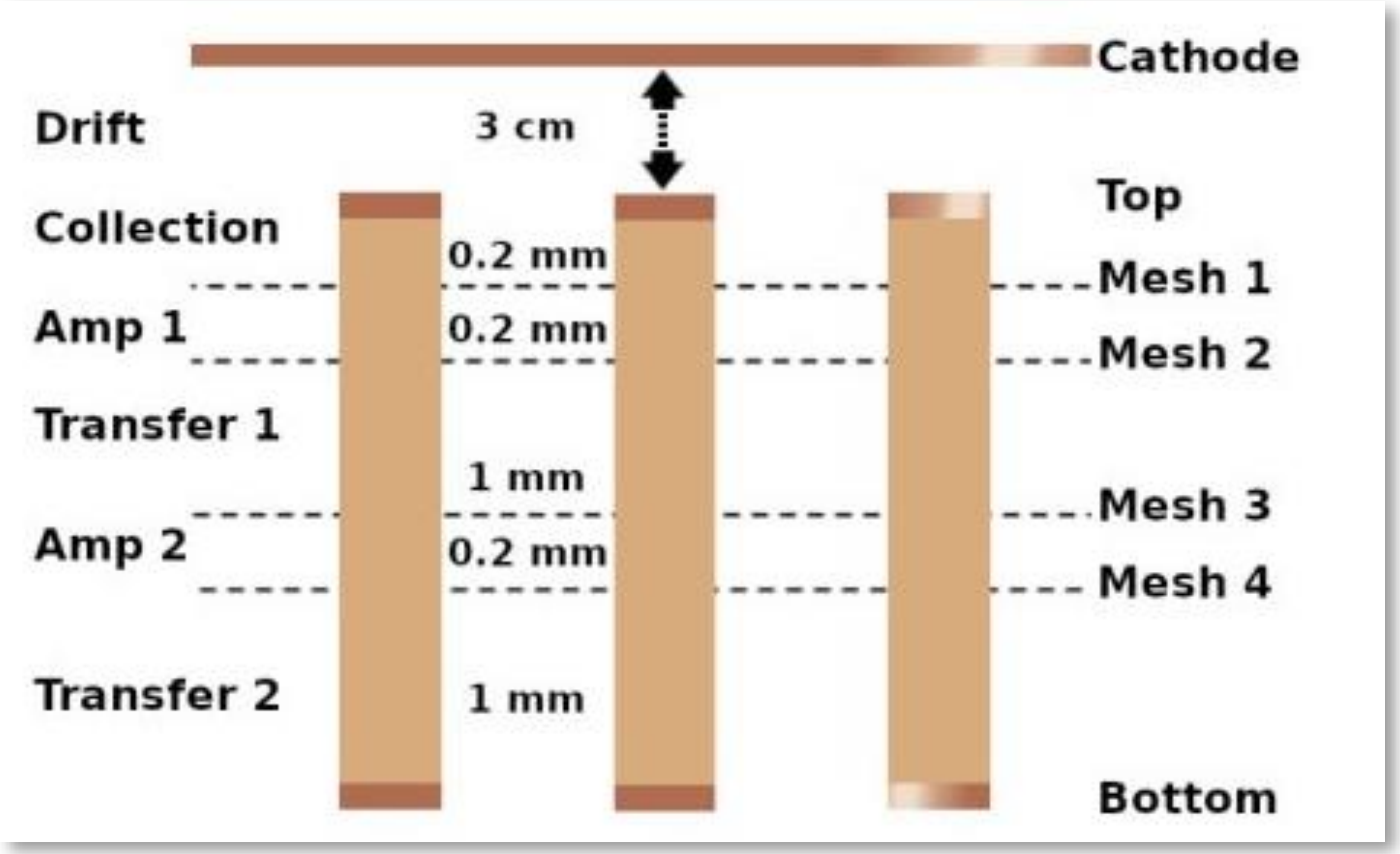
Is the MMThGEM an Ideal NID Gain Stage?



Problem:

1. Single "stand alone" unit with multistage amplification – **solved** ✅
2. Mesh electrode to suppress positive ion backflow –**solved** ✅
3. Mesh electrode create uniform electric field – **solved** ✅

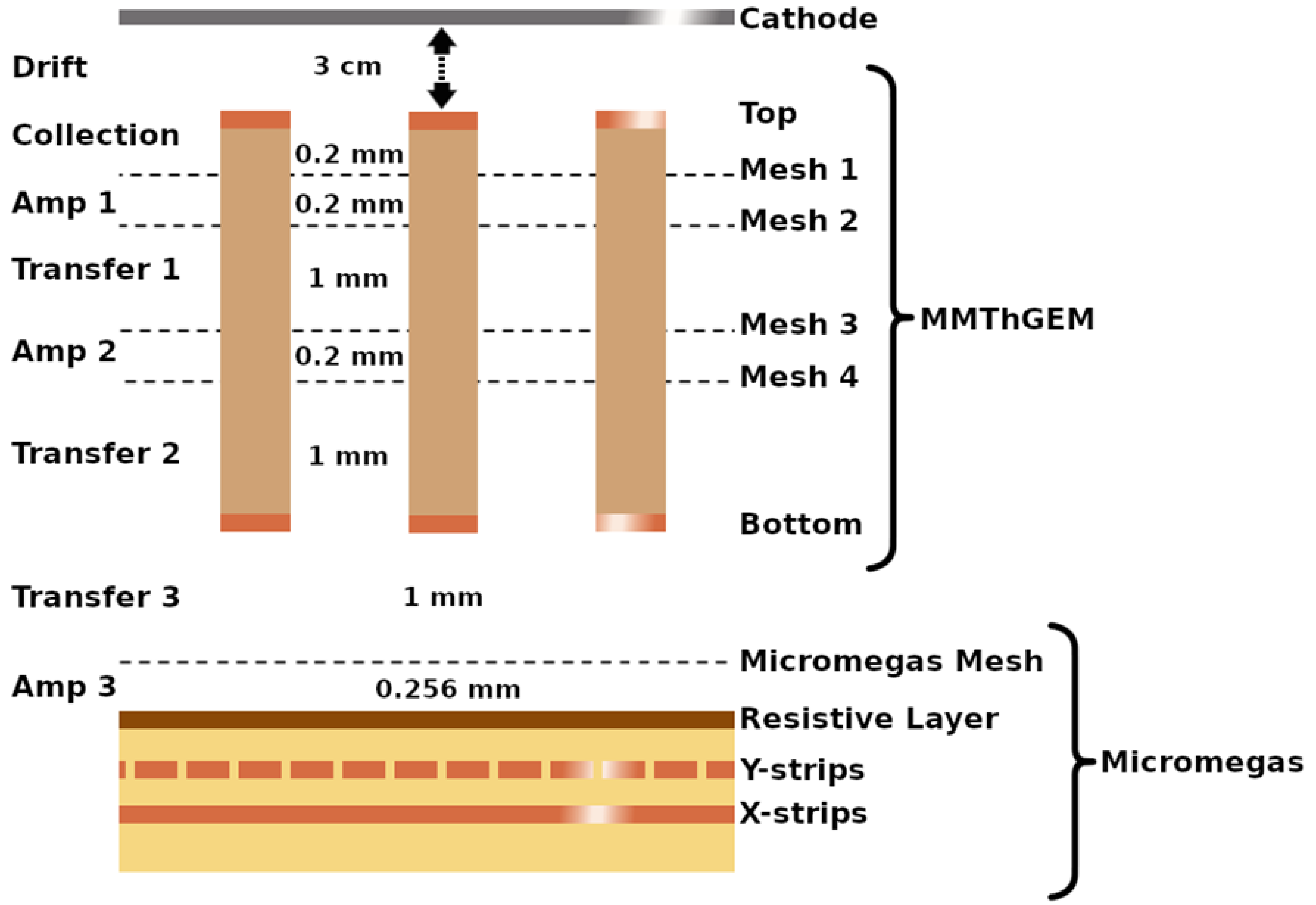


Let's see...

Coupled MMThGEM-Micromegas

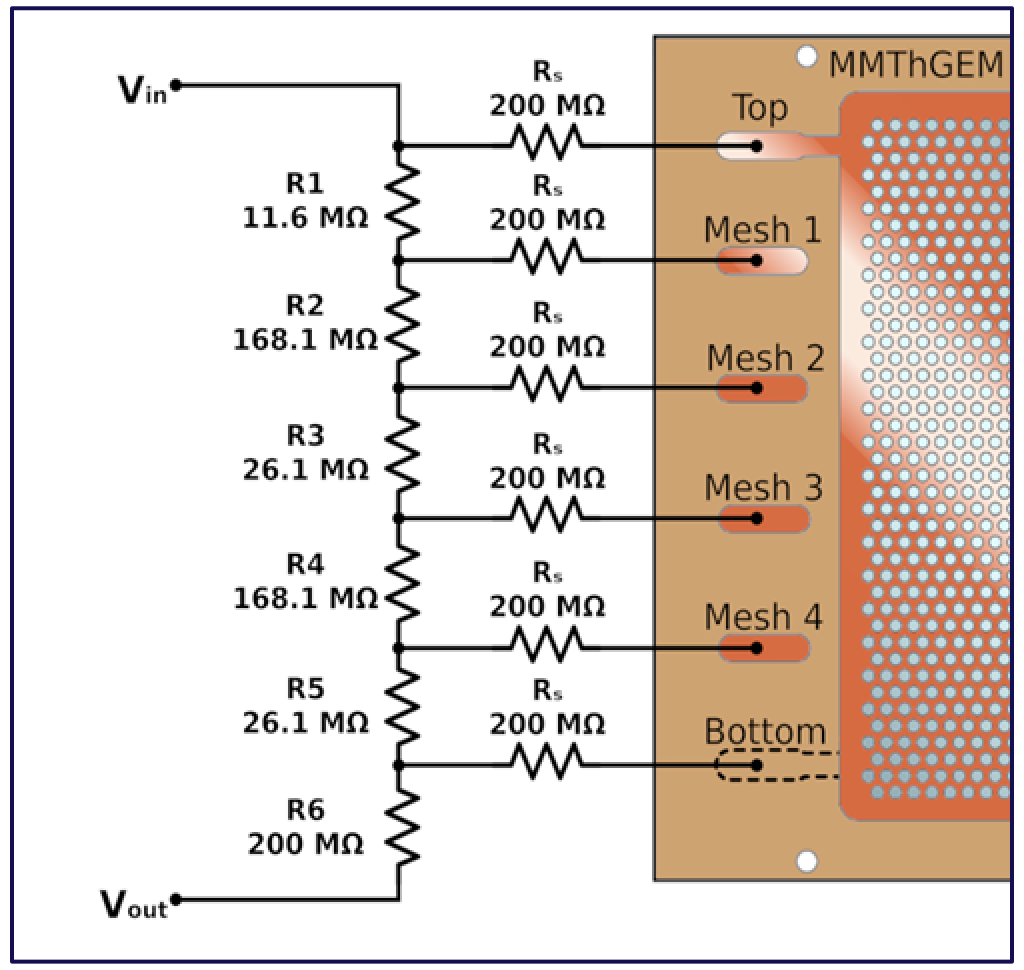
Micromegas Device - (MMThGEM is used as a gain stage device)

- Perpendicular x-y strip readout plane
- Resolution/strip pitch: 250 μm
- Strip width: 100 μm (y) and 220 μm (x)
- Active area: 10 x 10 cm
- Amplification gap: 256 μm
- Diamond Like Carbon (DLC) layer: 50 MΩ/□

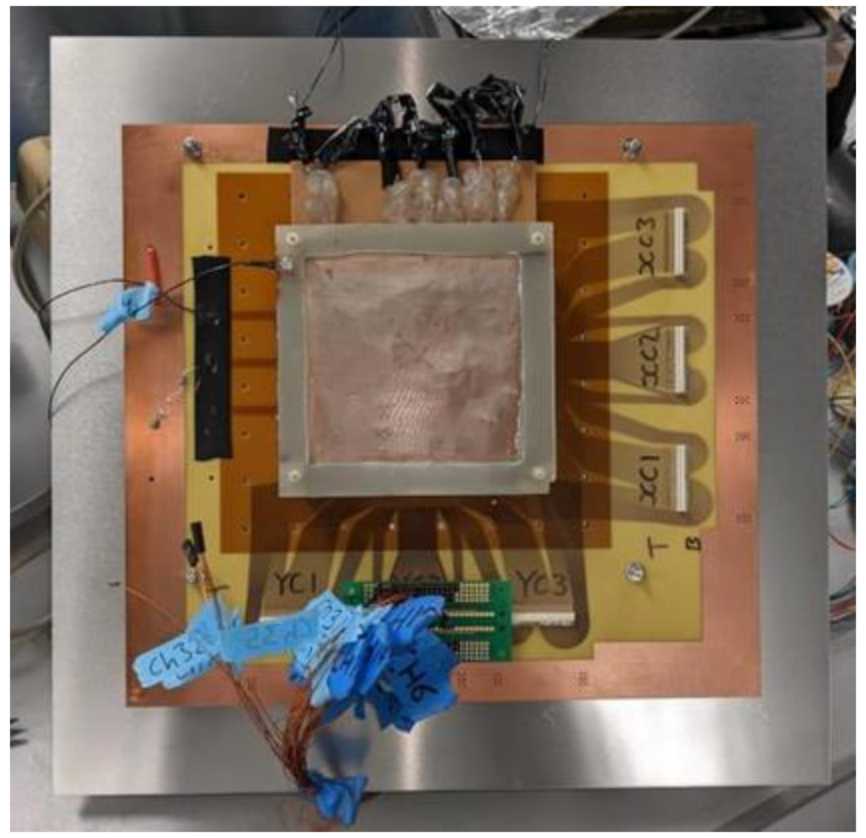


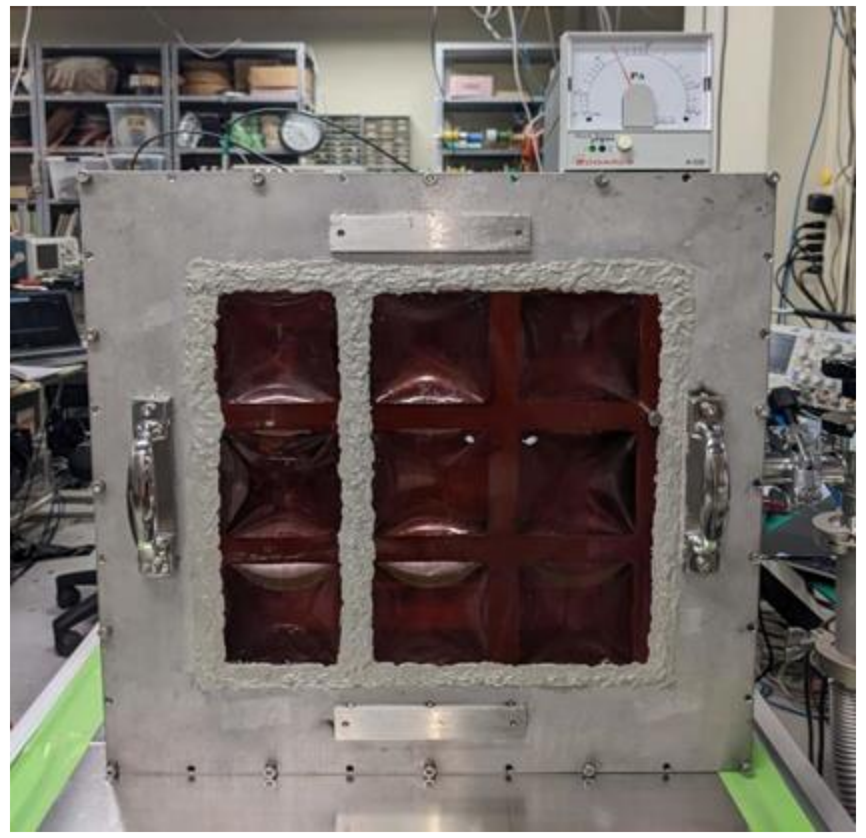
Biasing Scheme for MMThGEM

- Resistor chain soldered to electrode contacts
- Resistor values dictated by previous optimisation
- Reduces the number of HV feedthroughs required for operation



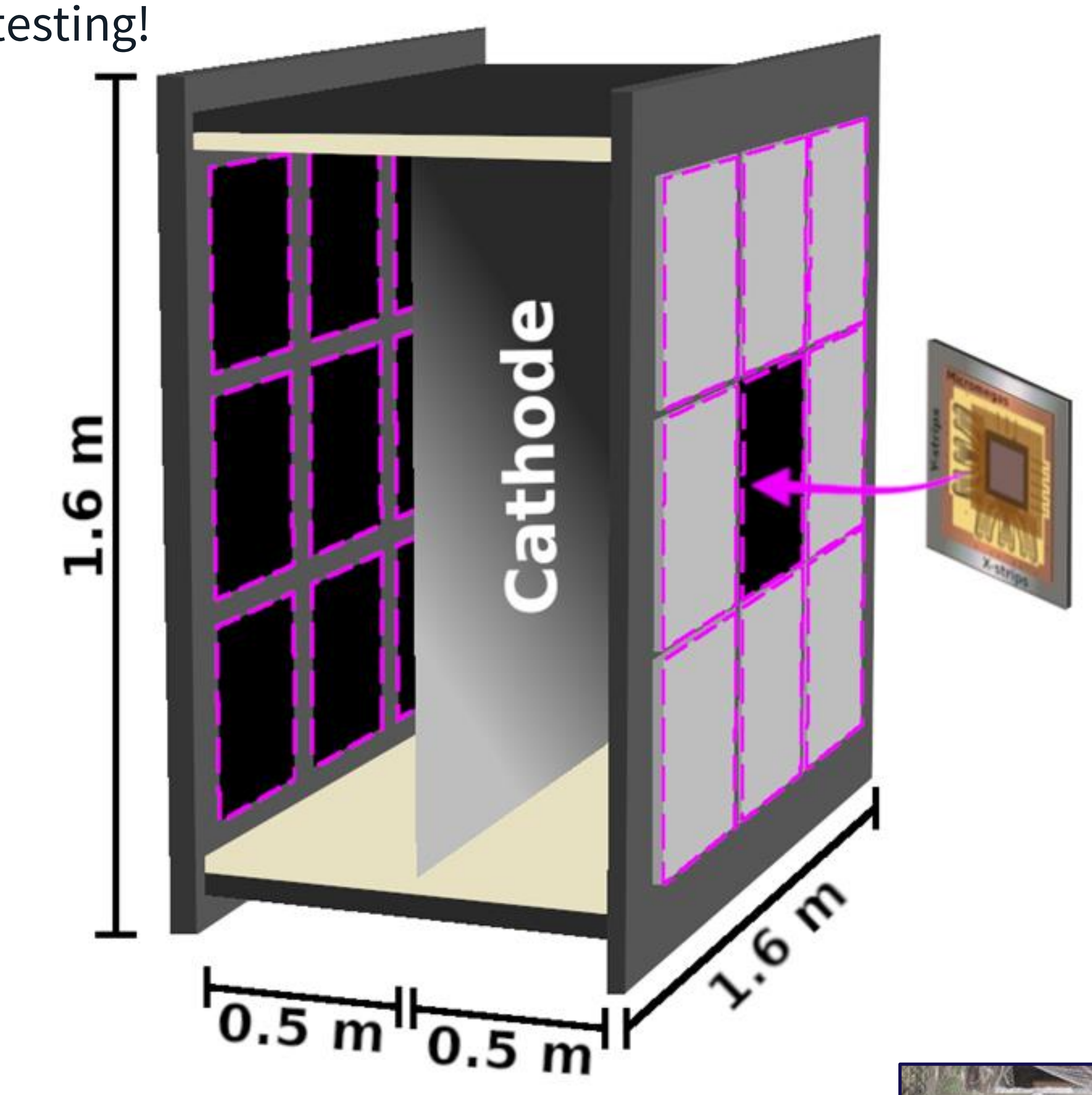
Kobe test vessel



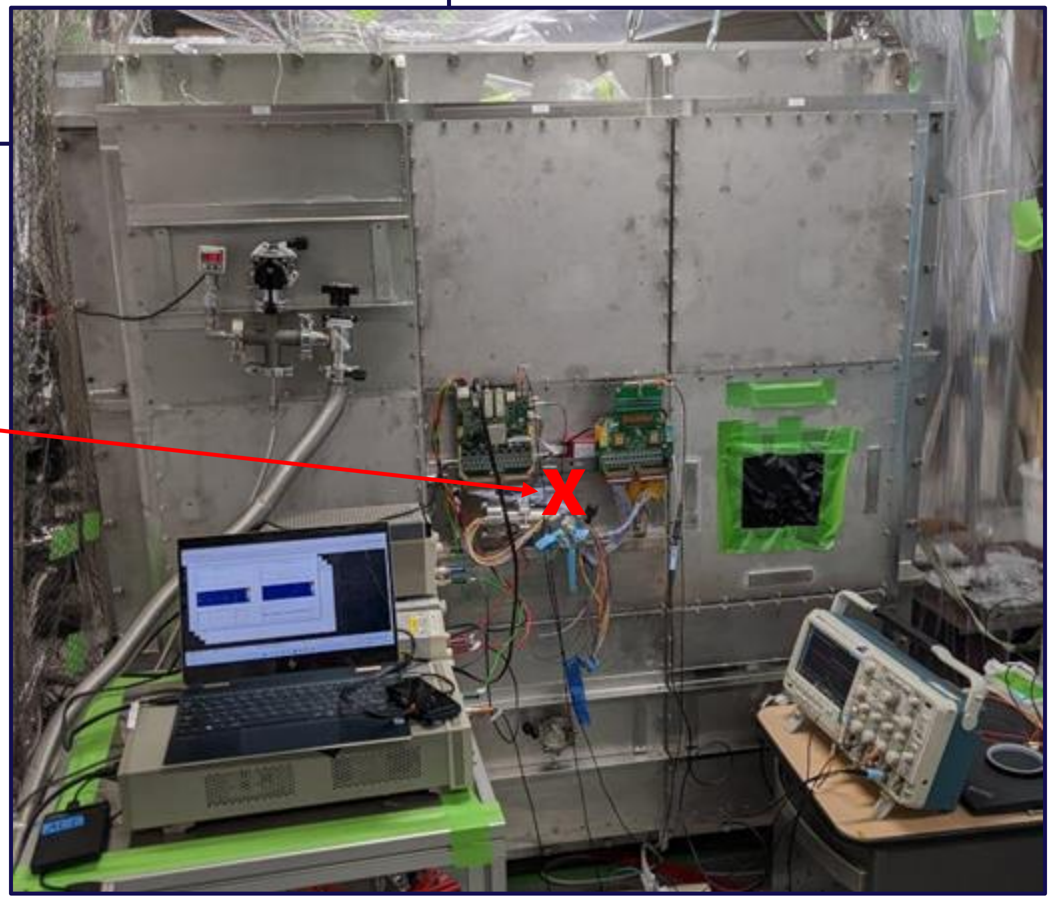


CYGNUS-m^3 Scale C/N-1.0 “BENTO” Vessel

Kentaro and Satoshi welcome your detector modules for testing!



^{252}Cf source positioned externally



The C/N-1.0 vessel at Kobe University

Large CYGNUS-10 scale vessel - 50 cm drift length

Modular design which can support up to 18 readout detector planes

MMThGEM-Micromegas was transferred to the central panel on the BENTO vessel

Detector mounting conveniently fits test vessel dimensions

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