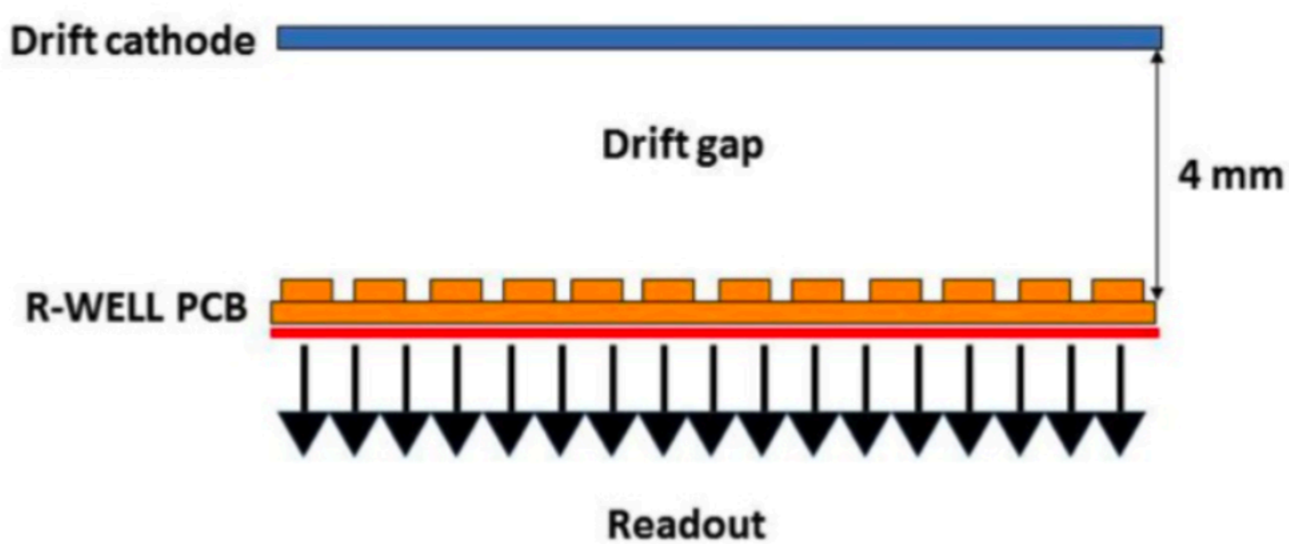
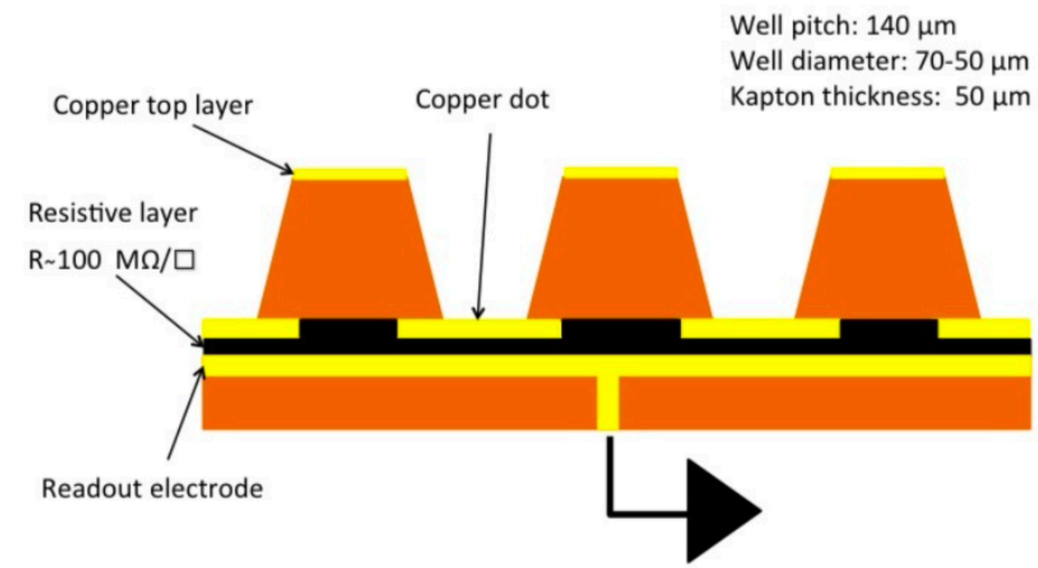
µRWELL detector developments at JLab

Florian Hauenstein
CLAS Collaboration Meeting
11/14/24

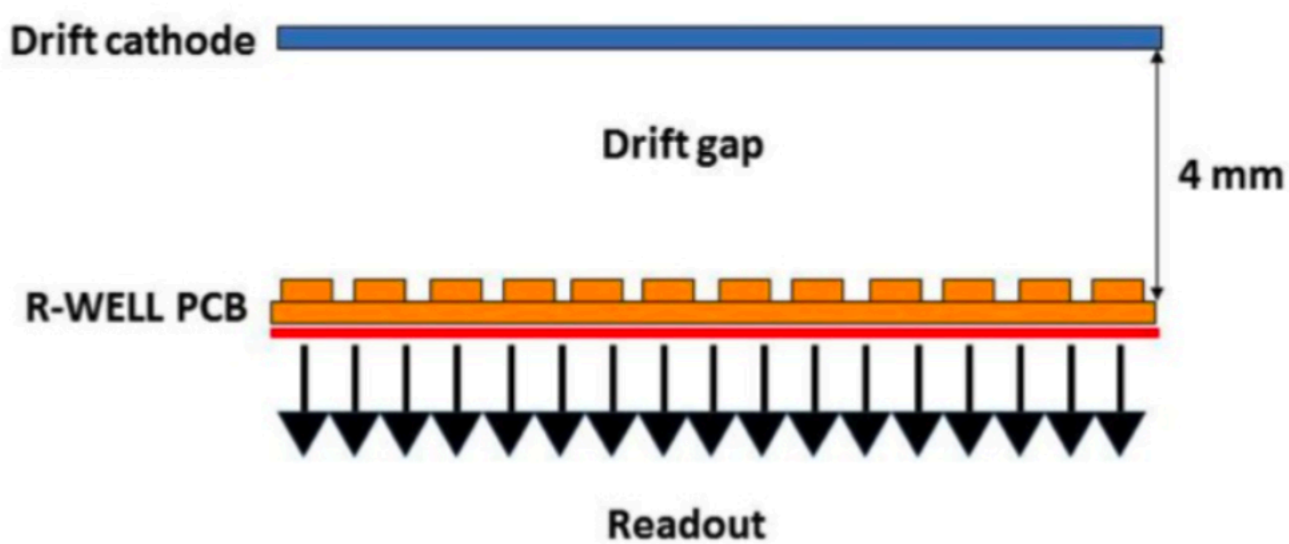
Micro-resistive Well (μRWELL) Detector

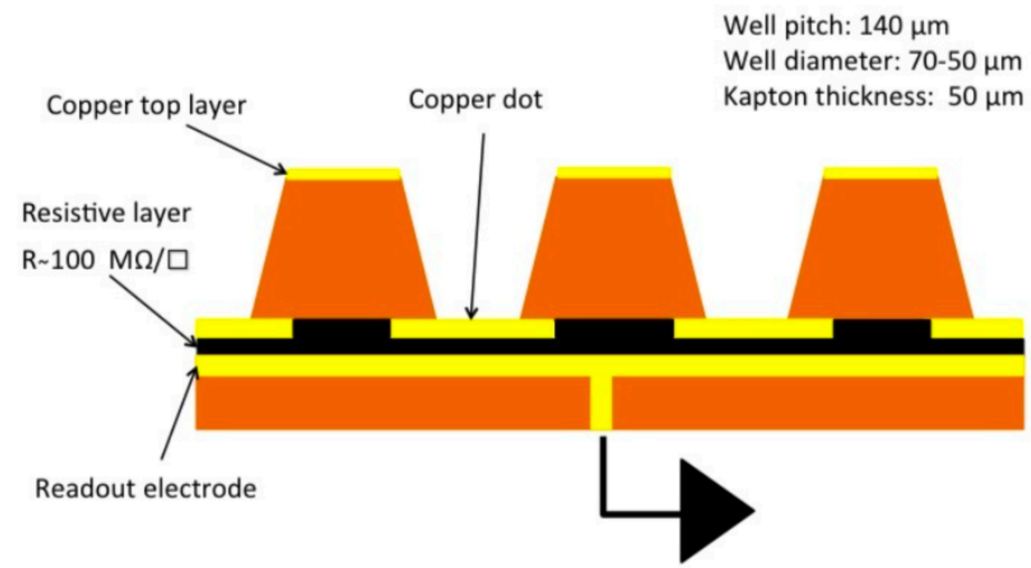




- μRWELL is a Micro-Pattern Gaseous Detector
  - Amplification in wells
  - Spark protection due to resistive layer
- Advantages
  - Intrinsic low-mass (low material budget)
  - Good spatial and timing resolution
  - Low production costs
  - No frames needed in active area
- Disadvantages
  - Operability under high particle fluxes > 1MHz/cm^2
  - Relative new detector technology

Micro-resistive Well (µRWELL) Detector



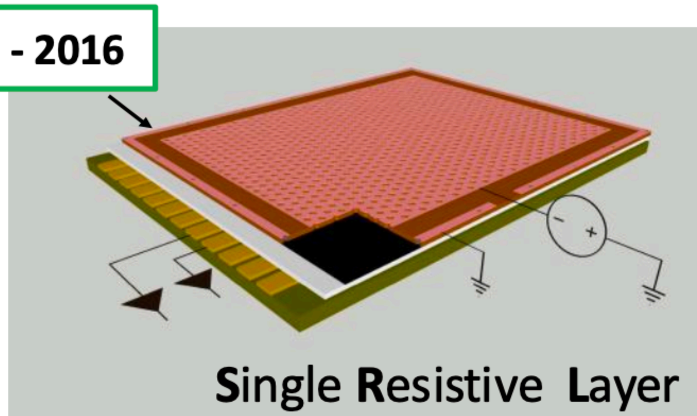


- µRWELL is a Micro-Pattern Gaseous Detector
  - Amplification in wells
  - Spark protection due to resistive layer (DLC)
- Advantages
  - Intrinsic low-mass (low material budget)
  - Good spatial and timing resolution
  - Low production costs
  - No frames needed in active area
- Disadvantages
  - Operability under high particle fluxes > 1MHz/cm^2
  - Relative new detector technology

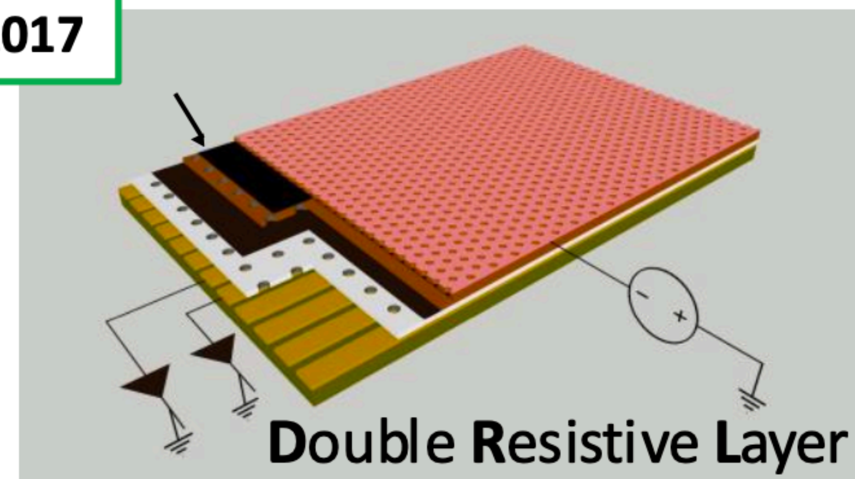
High-rate Layouts with DLC Segmentation

G. Bencivenni et al., *The μ-RWELL layouts for high particle rate*, 2019 *JINST* 14 P05014

2014 - 2016



2017



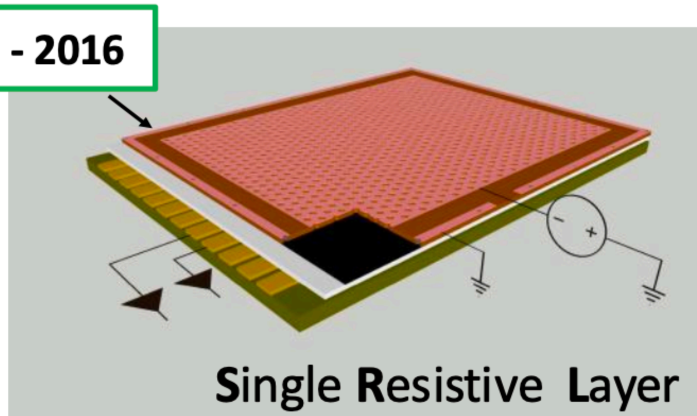
Double Resistive Layer

- 3D current evacuation
- Complex manufacturing
- Rates > 10 MHz/cm^2

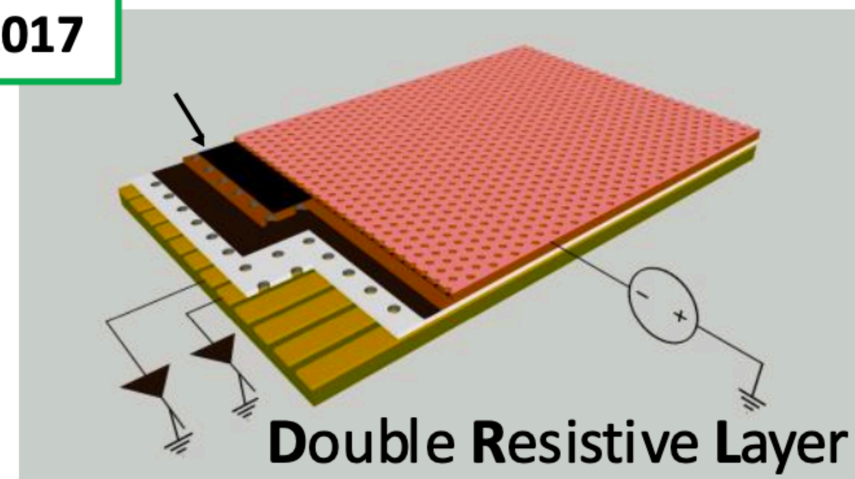
High-rate Layouts with DLC Segmentation

G. Bencivenni et al., *The μ-RWELL layouts for high particle rate*, 2019 *JINST* 14 P05014

2014 - 2016

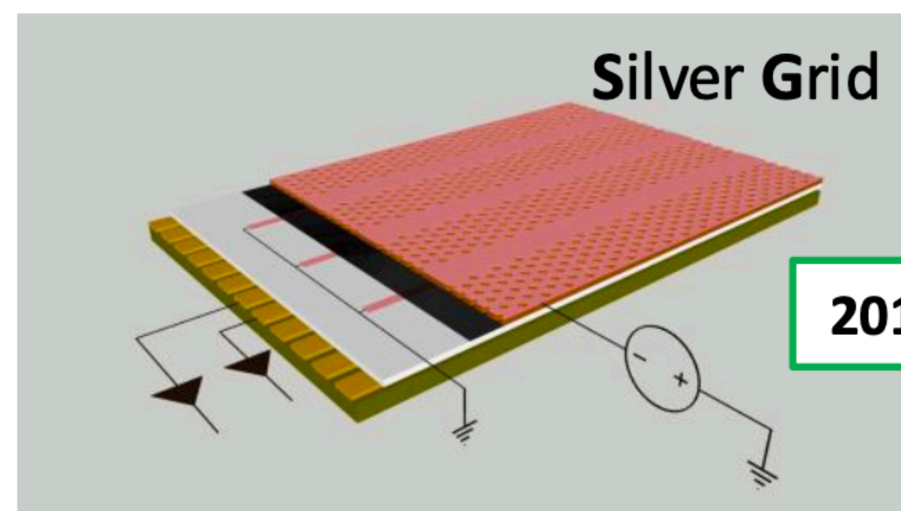


2017



Double Resistive Layer

- 3D current evacuation
- Complex manufacturing
- Rates > 10 MHz/cm^2



2018 - 2020

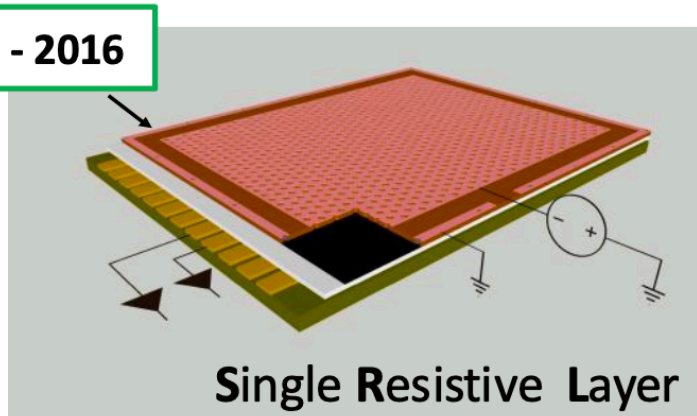
Silver Grid

- Single DLC layer
- 2D current evacuation through conductive grid on DLC
- Complex Cu+DLC sputtering and alignment
- Rates > 10 MHz/cm^2

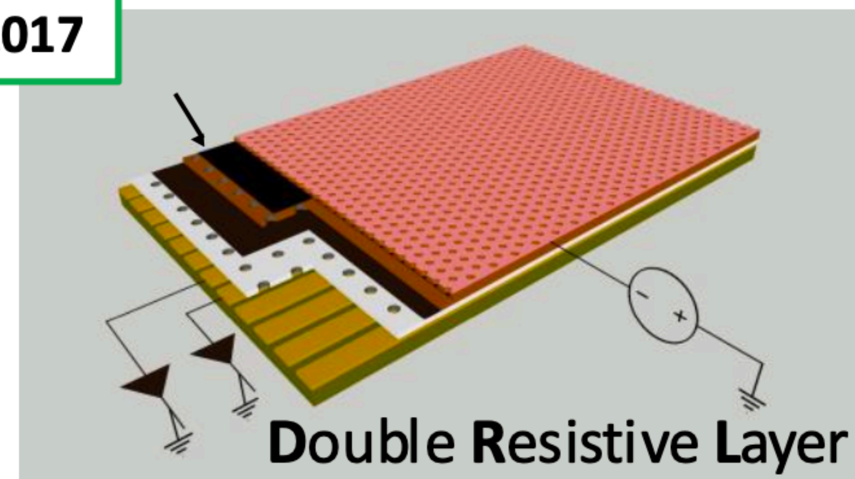
High-rate Layouts with DLC Segmentation

G. Bencivenni et al., *The μ-RWELL layouts for high particle rate*, 2019 *JINST* 14 P05014

2014 - 2016



2017



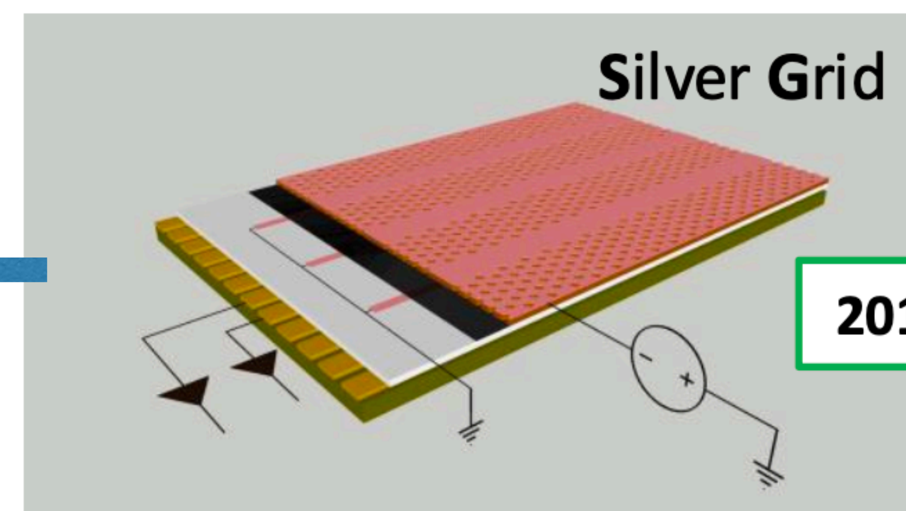
Double Resistive Layer

- 3D current evacuation
- Complex manufacturing
- Rates > 10 MHz/cm^2

2021/22

PEP (Patterning - Etching - Plating)

2018 - 2020



Silver Grid

- Single DLC layer
- 2D current evacuation through conductive grid etched from the top of the Kapton foil to the DLC
- No alignment issues and easily engineered
- Rates > 10 MHz/cm^2

- Single DLC layer
- 2D current evacuation through conductive grid on DLC
- Complex Cu+DLC sputtering and alignment
- Rates > 10 MHz/cm^2

PEP Designs

G. Bencivienni, Talk RD51 Meeting 2024

2022

PEP-Groove:

DLC grounding through conductive groove to ground line

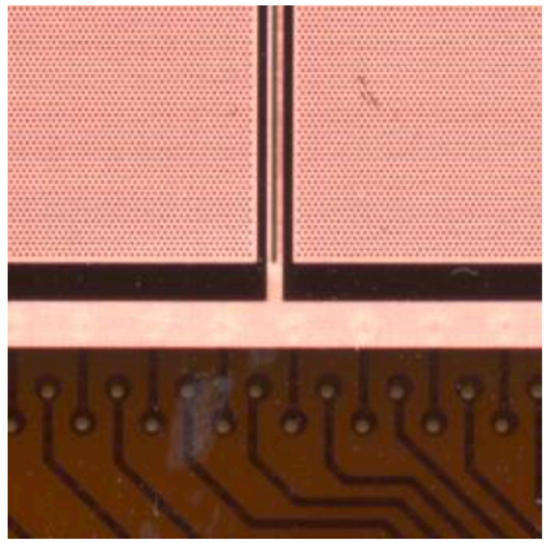
Pad R/O = 9×9mm²

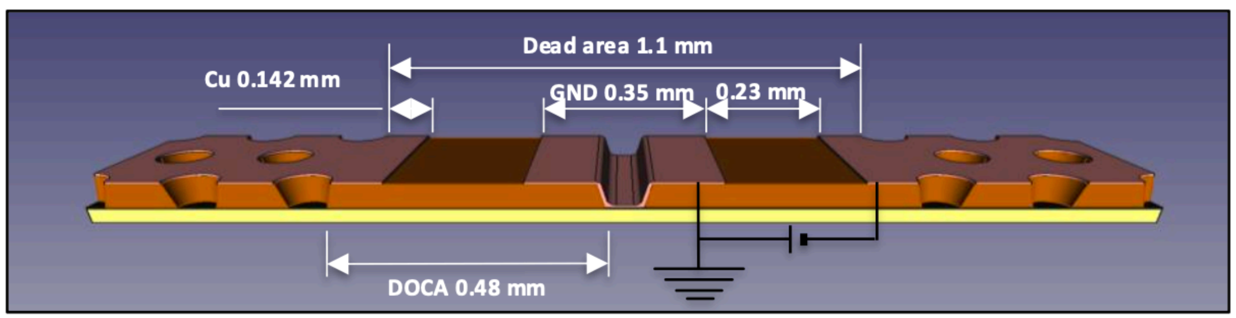
Grounding:

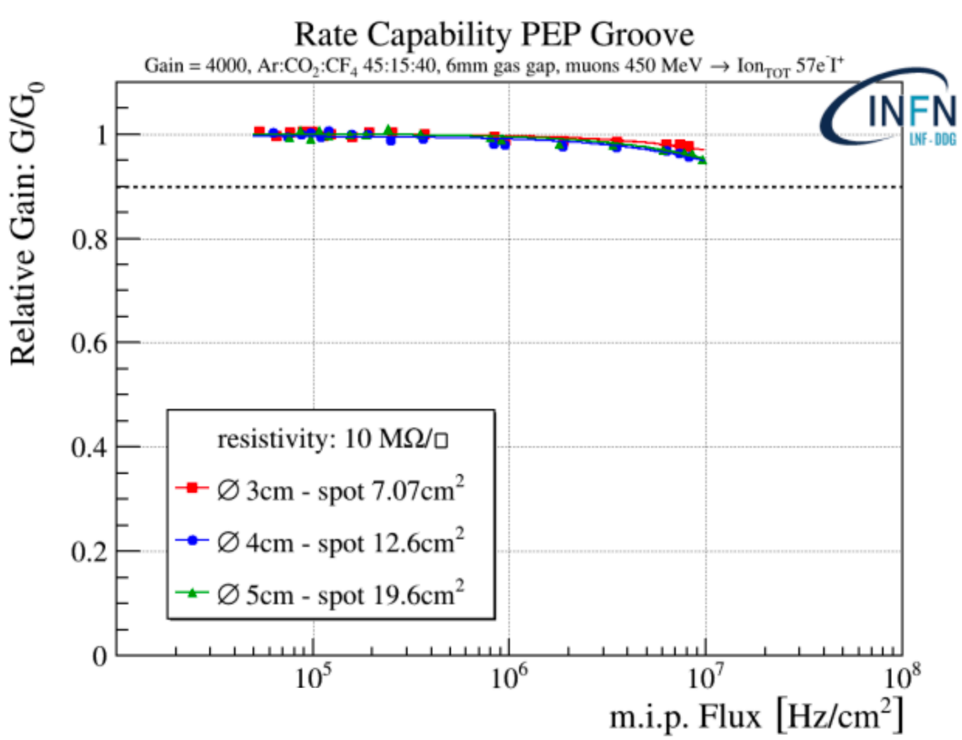
- Groove pitch = 9mm

- width = 1.1mm

→ 84% geometric acceptance







2023

PEP-DOT:

DLC grounding through conductive dots connecting the DLC with pad r/outs

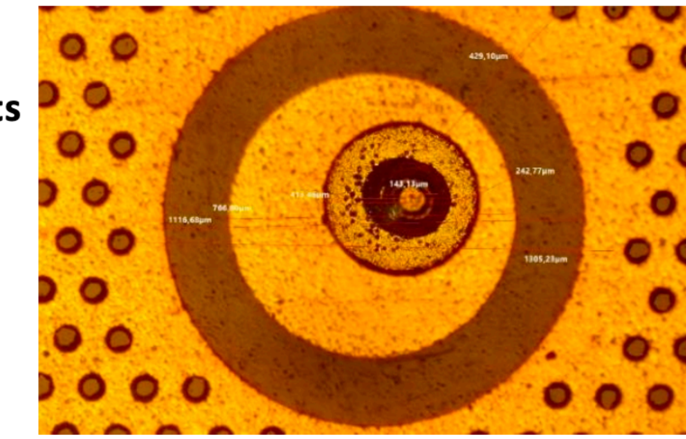
Pad R/O = 9×9mm²

Grounding:

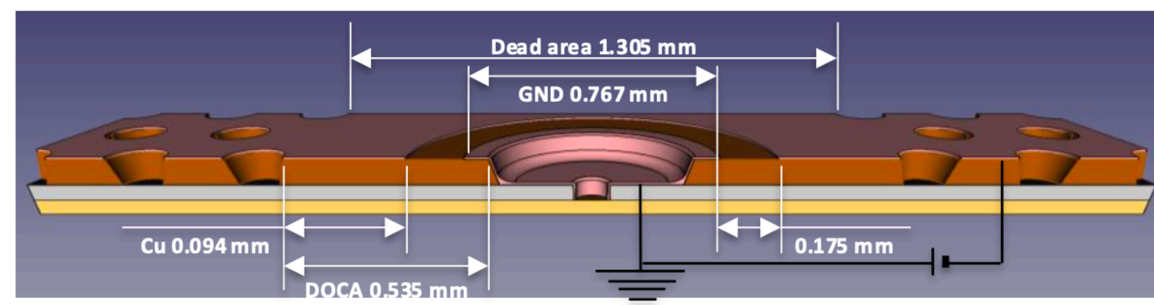
- Dot pitch = 9mm

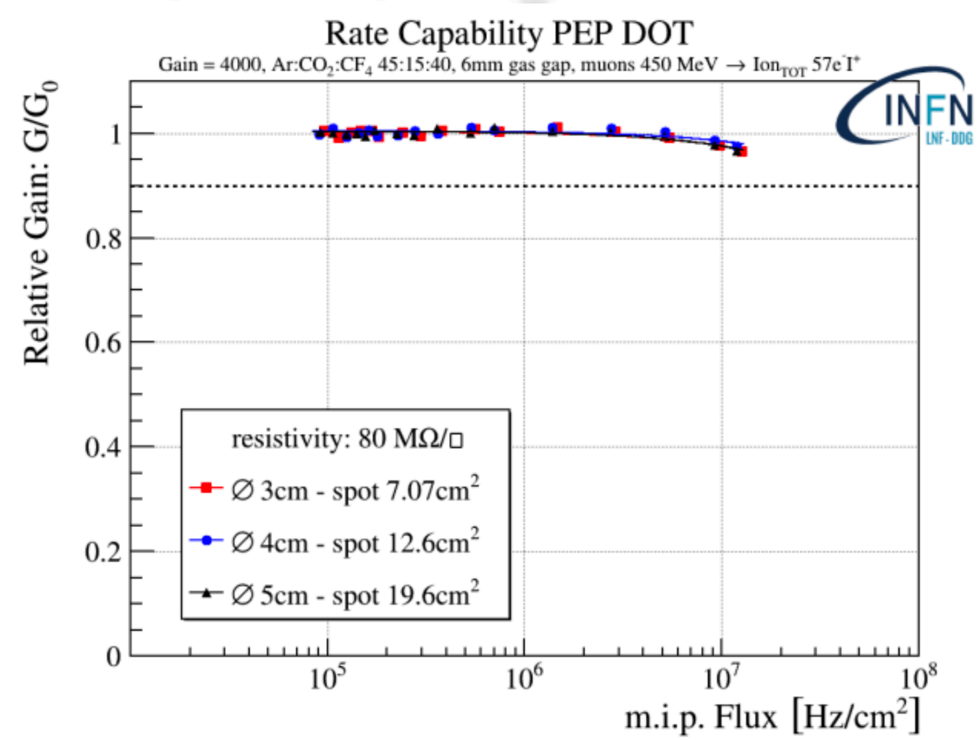
- dot rim = 1.3mm

→ 97% geometric acceptance



DOT → plated blind vias



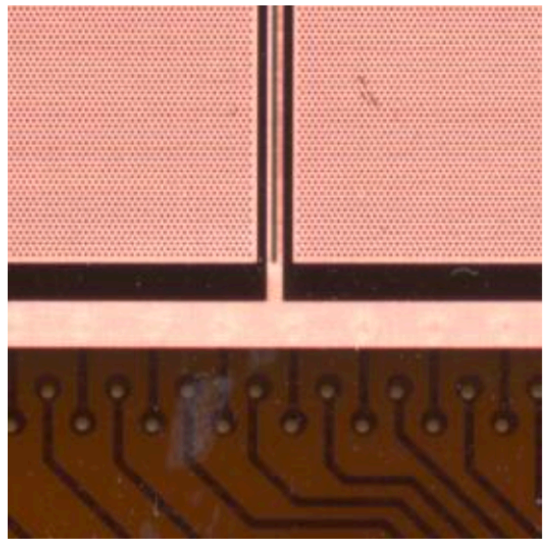


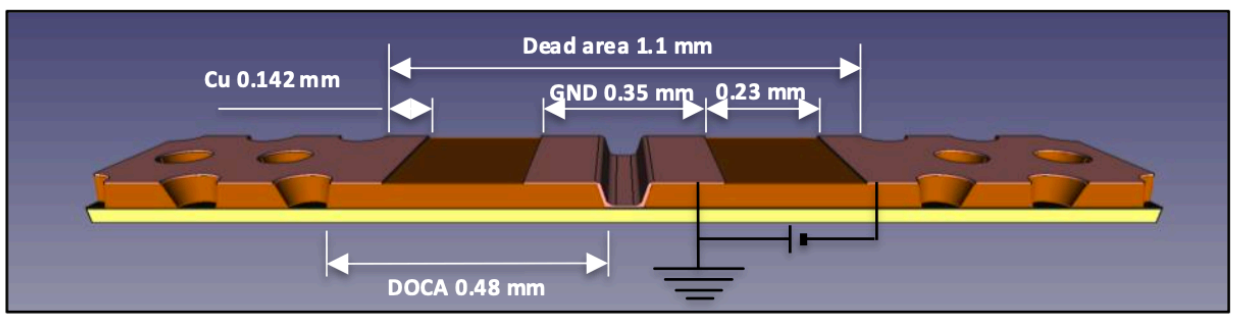
PEP Designs

2022

PEP-Groove:
DLC grounding through conductive groove to ground line
Pad R/O = 9×9mm^2
Grounding:
- Groove pitch = 9mm
- width = 1.1mm

→ 84% geometric acceptance



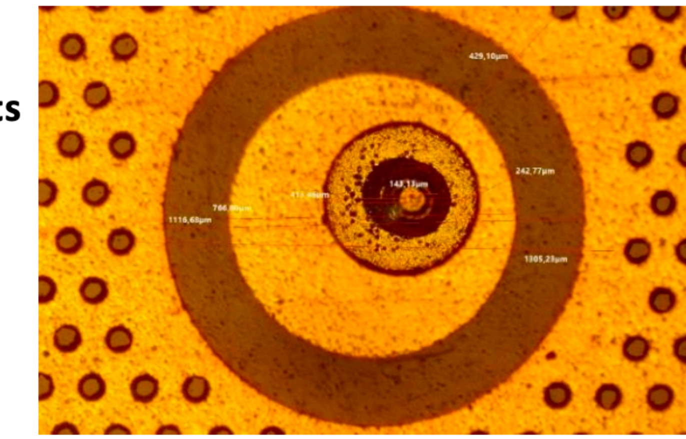


DLC Design for CLAS12 large prototype

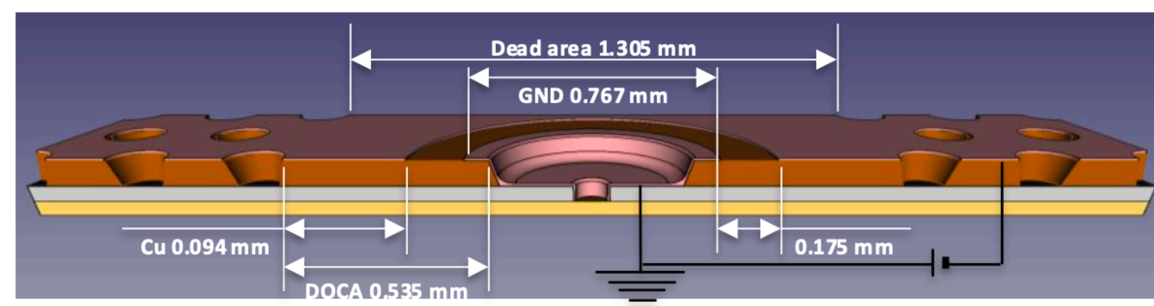
2023

PEP-DOT:
DLC grounding through conductive dots connecting the DLC with pad r/outs
Pad R/O = 9×9mm^2
Grounding:
- Dot pitch = 9mm
- dot rim = 1.3mm

→ 97% geometric acceptance



DOT → plated blind vias



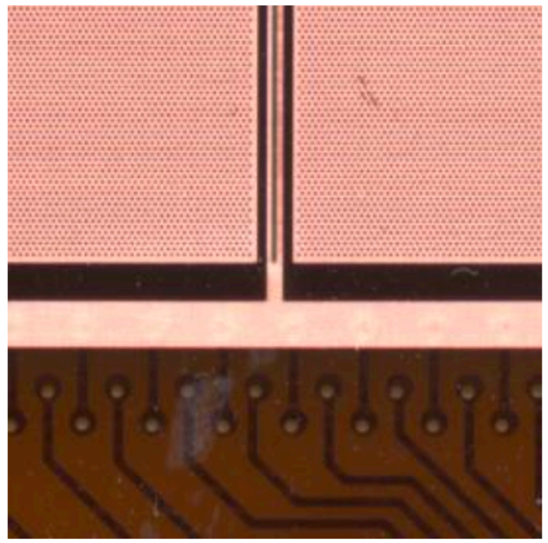
DLC Design for LDRD high-rate prototypes

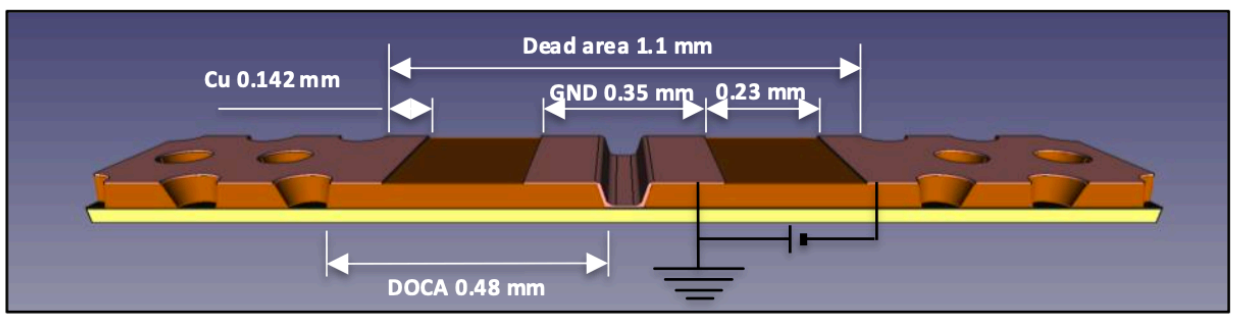
PEP Designs

2022

PEP-Groove:
DLC grounding through conductive groove to ground line
Pad R/O = 9×9mm^2
Grounding:
- Groove pitch = 9mm
- width = 1.1mm

→ 84% geometric acceptance



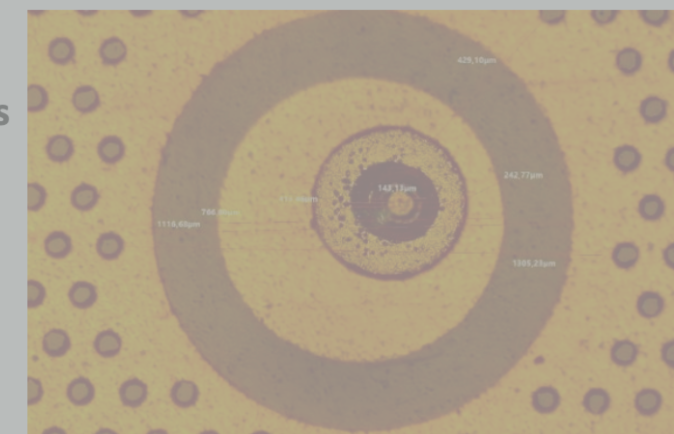


DLC Design for CLAS12 large prototype

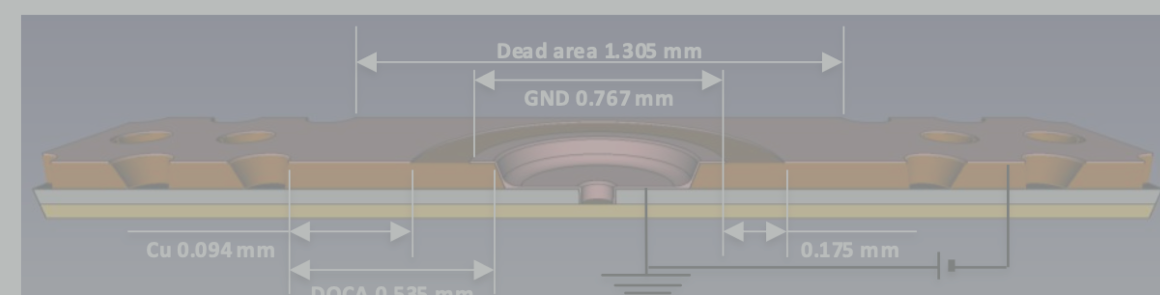
2023

PEP-DOT:
DLC grounding through conductive dots connecting the DLC with pad r/outs
Pad R/O = 9×9mm^2
Grounding:
- Dot pitch = 9mm
- dot rim = 1.3mm

→ 97% geometric acceptance



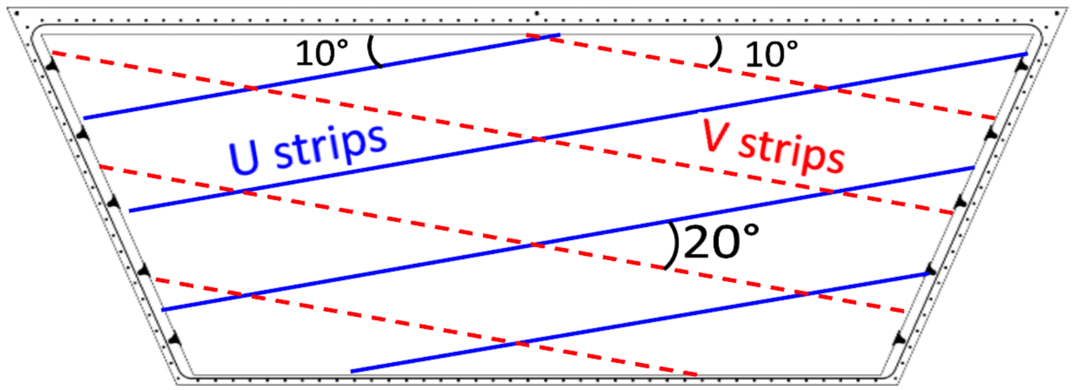
DOT → plated blind vias

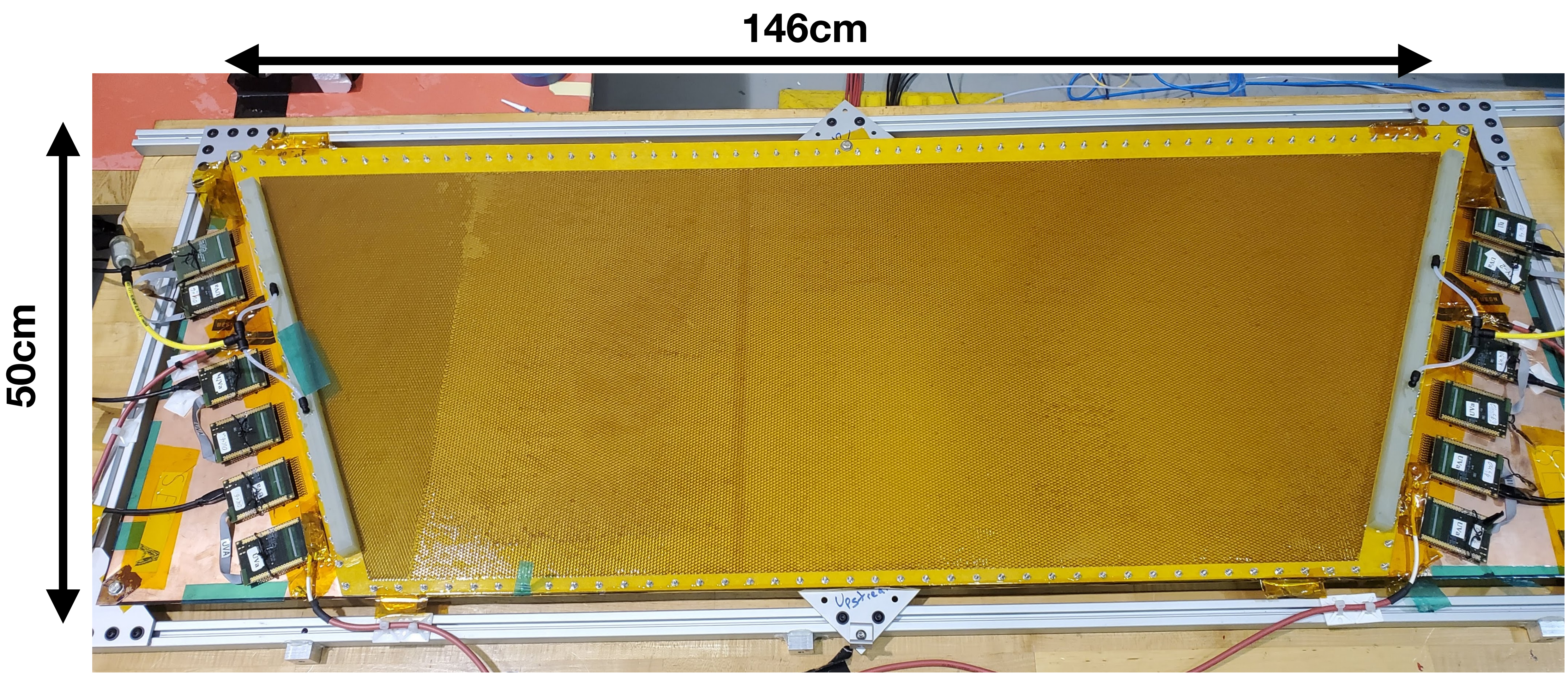


DLC Design for LDRD high-rate prototypes

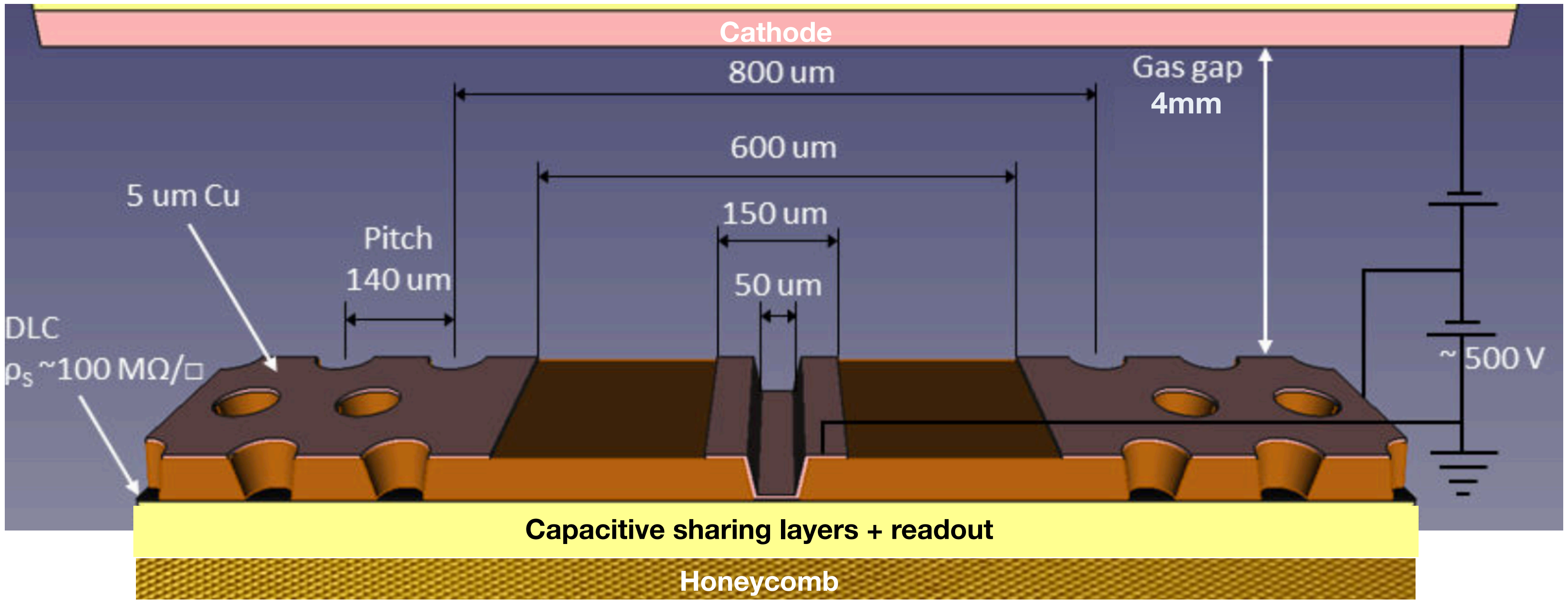
CLAS12 FD Upgrade µRWELL Prototype

- **Largest µRWELL build so far**
- **PEP-groove DLC**
- **2D-U/V strip readout with 10 deg stereo angle**
  - **pitch 1mm**
  - **various strip widths (to find optimum)**
- **Capacitive sharing**
- **Electronics APV25 and SRS**

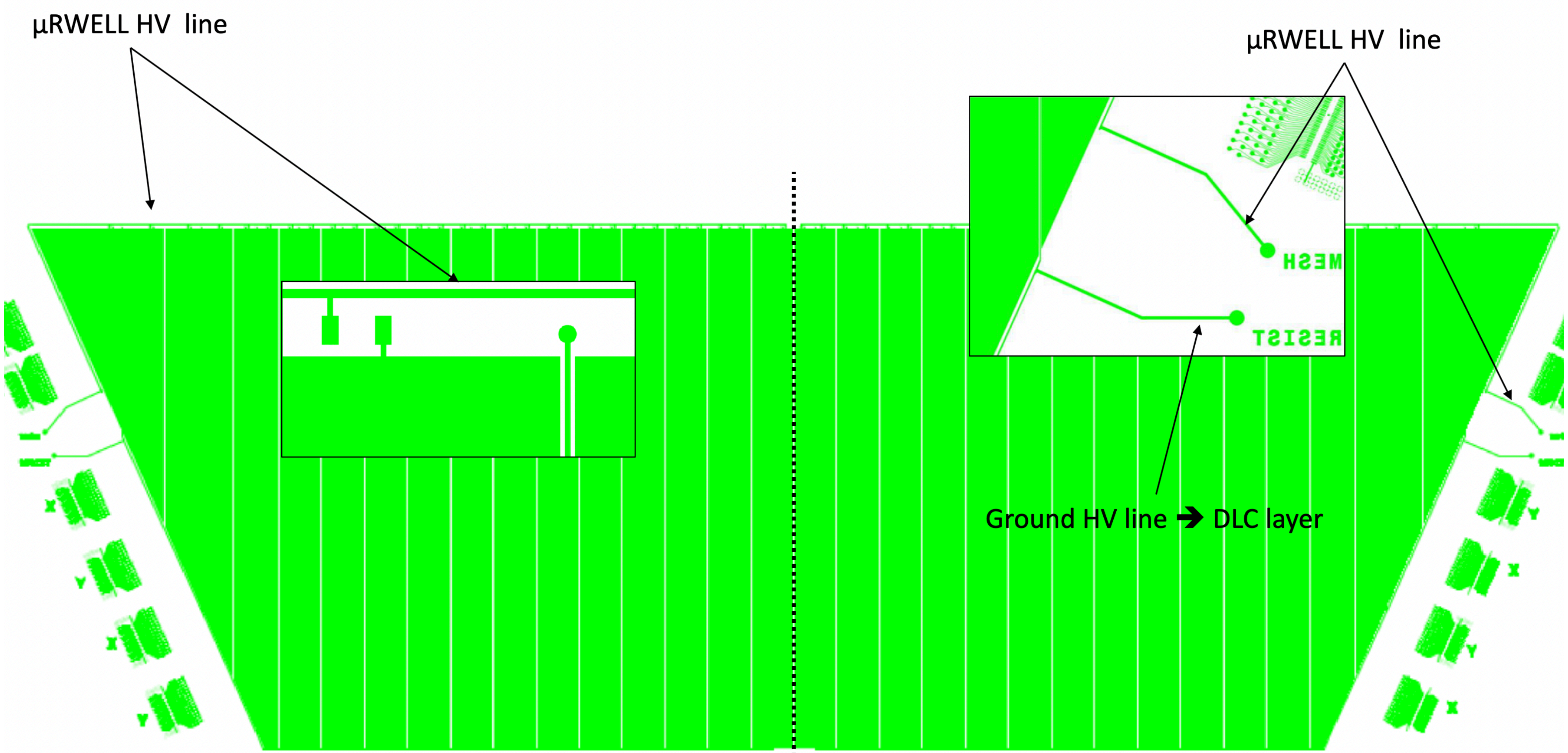




CLAS12 Prototype - Detector Structures



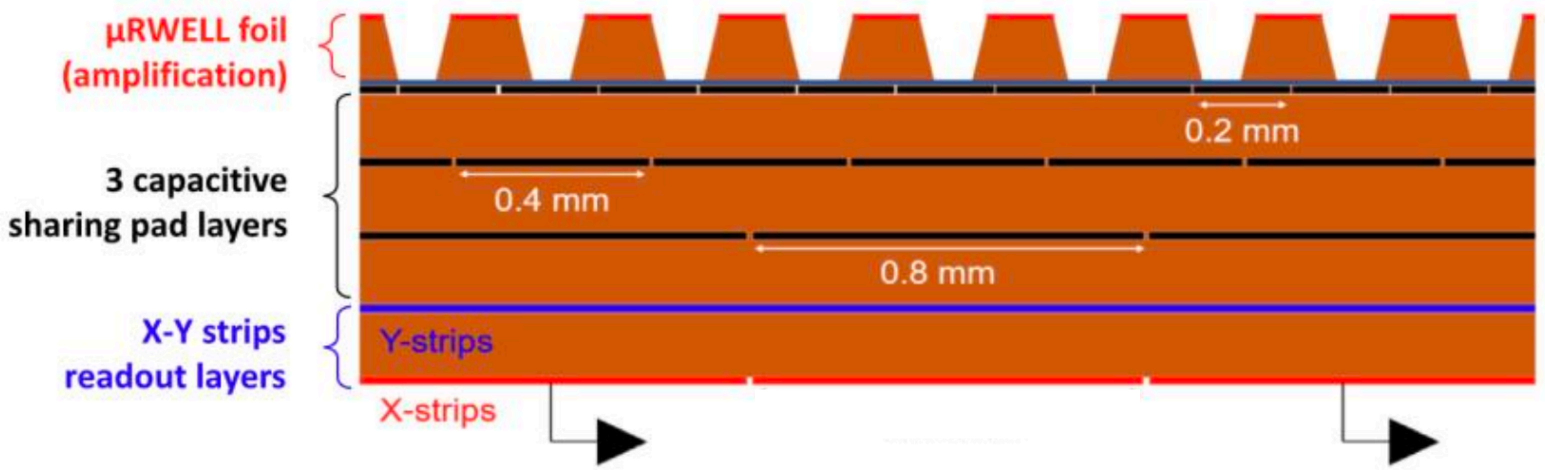
Cross section of prototype



μRWELL foil HV lines

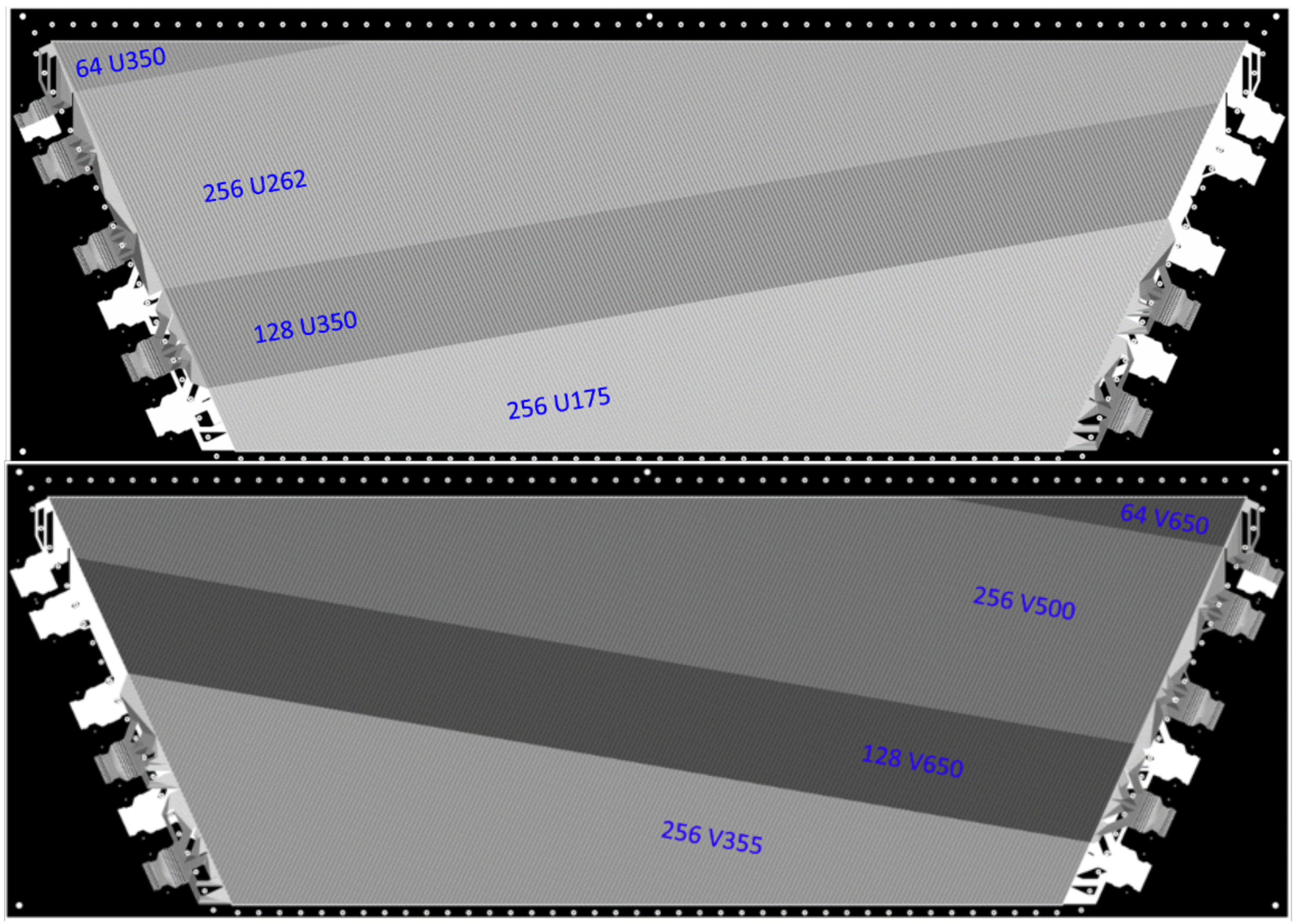
Split in two separate halfs

CLAS12 Prototype - Readout Structures



Capacitive sharing

K. Gnanvo, NIM A1047, 167782 (2023)

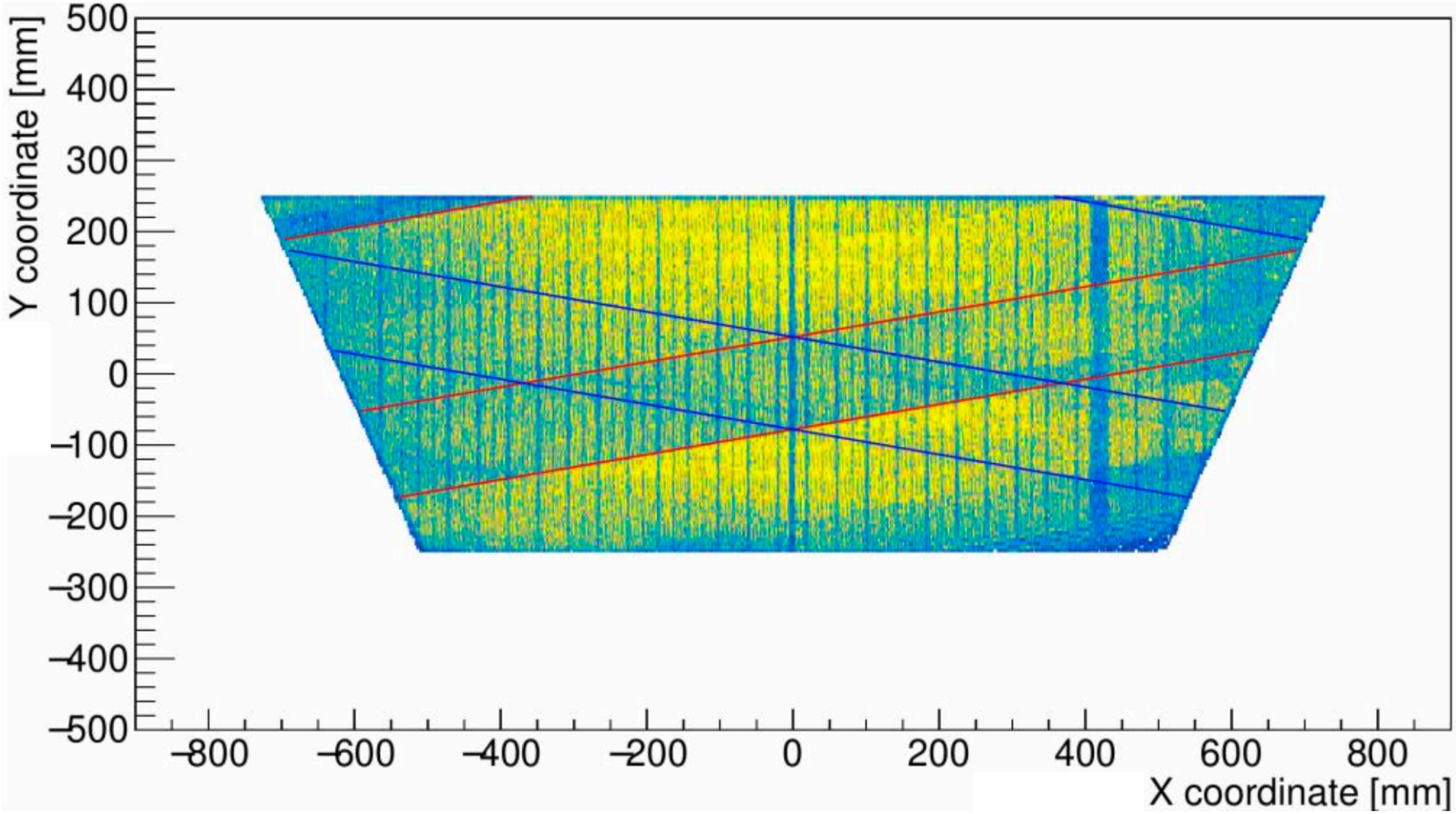


Readout Structures

U-strips widths:
- **350µm**
- **262µm**
- **175µm**

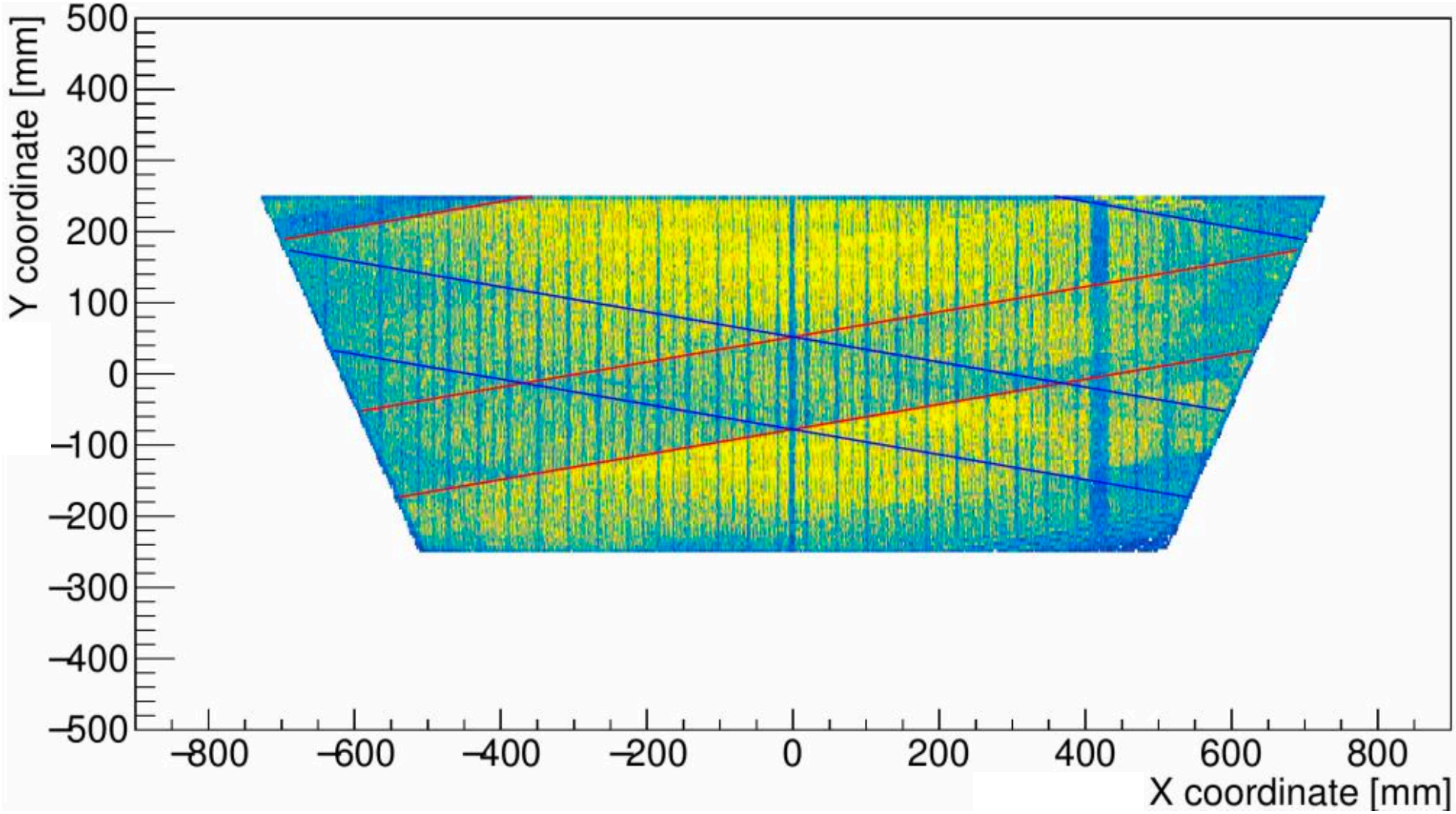
V-strips widths:
- **335µm**
- **500µm**
- **650µm**

2D Hit Distribution - Detector works!



- **µRWELL at 570V, cathode at 1020V, Ar:CO_2 (80:20)**
- **Substructure from strips, HV segmentation and APVs visible**

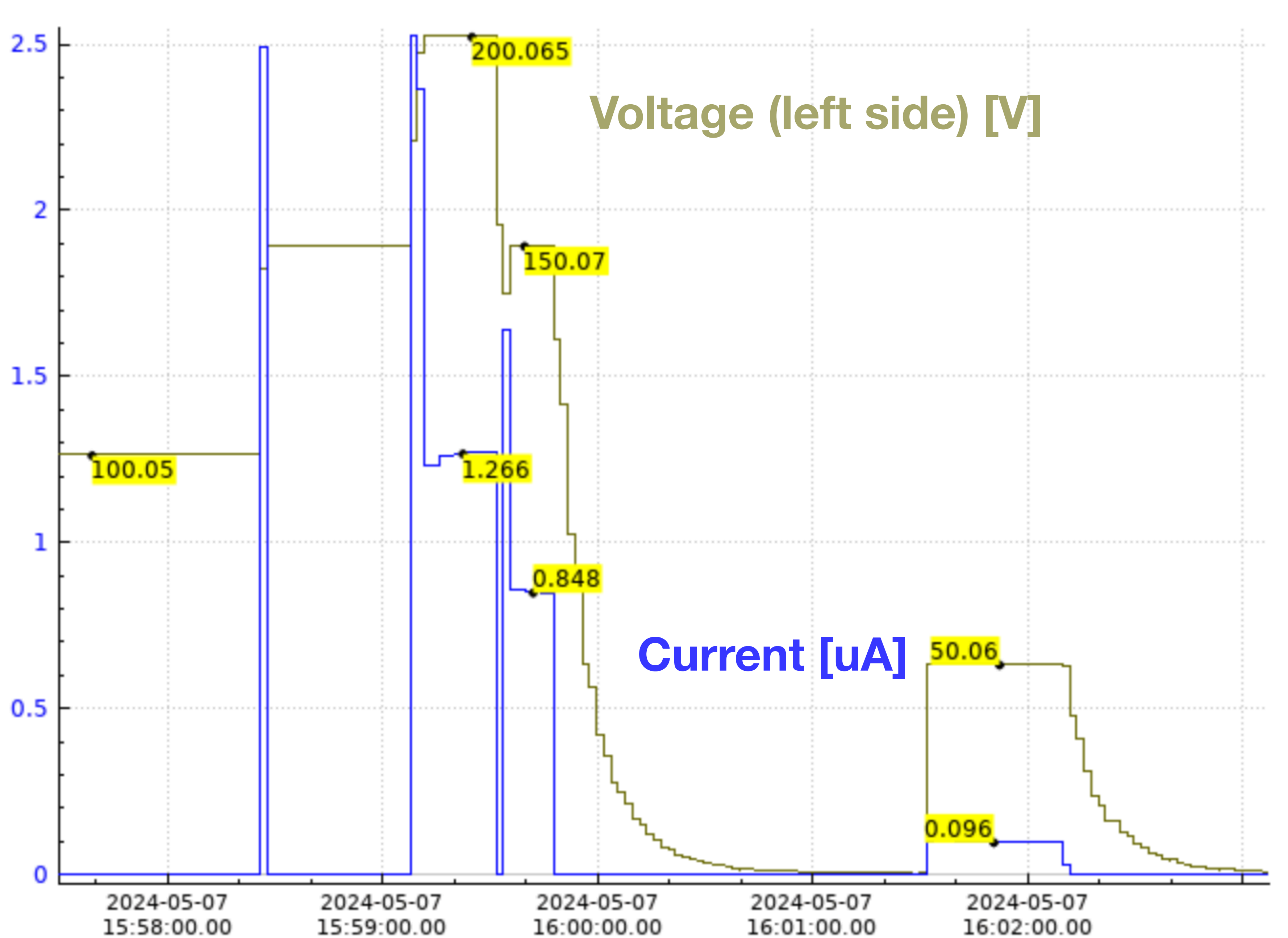
2D Hit Distribution - Detector works!



- **µRWELL at 570V, cathode at 1020V, Ar:CO_2 (80:20)**
- **Substructure from strips, HV segmentation and APVs visible**

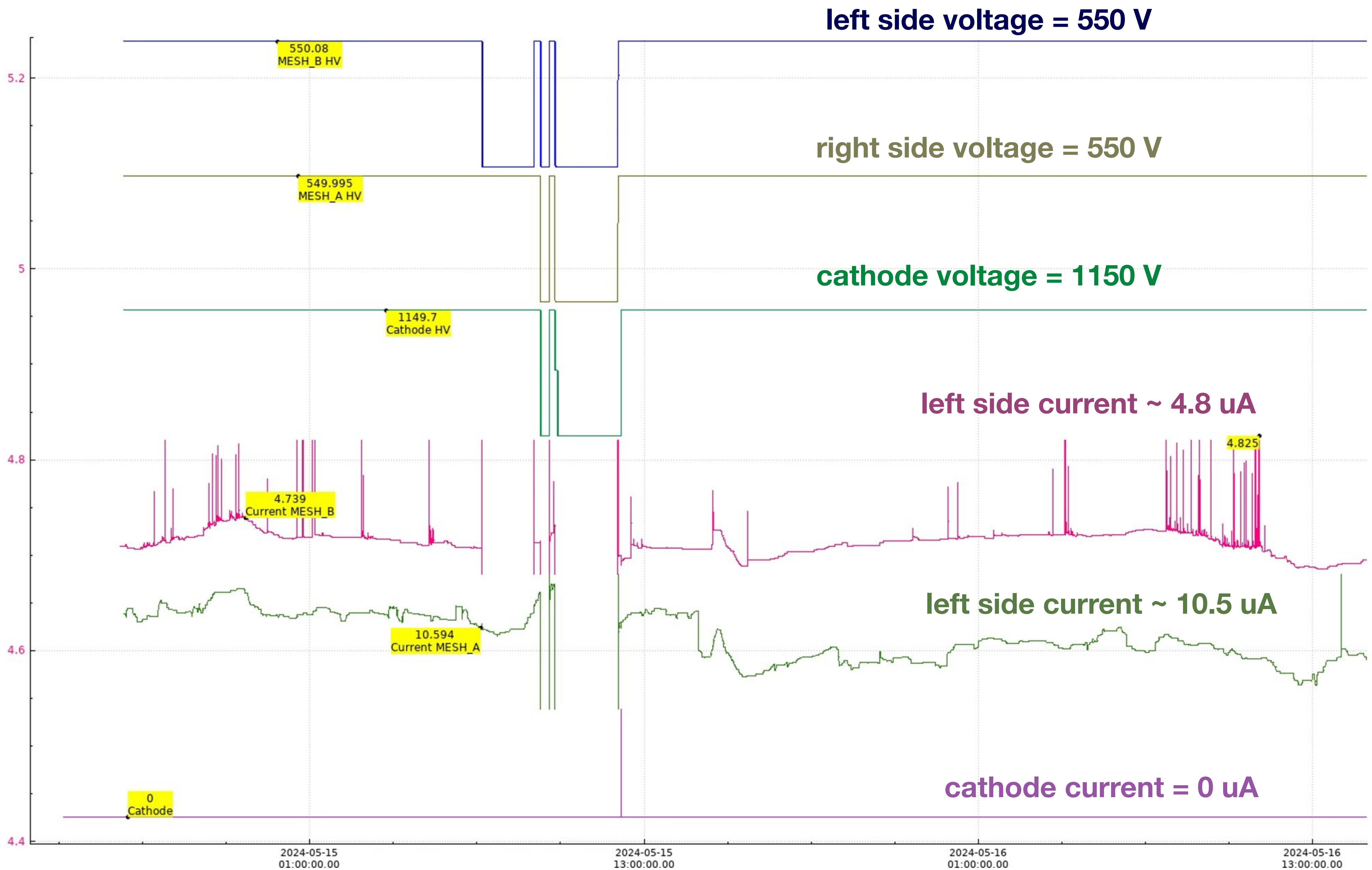
But: Issues with cathode and connections required us to replace cathode —> done in cleanroom at UVA together with Nilanga Liyanage's group

Leakage seen after Cathode Replacement

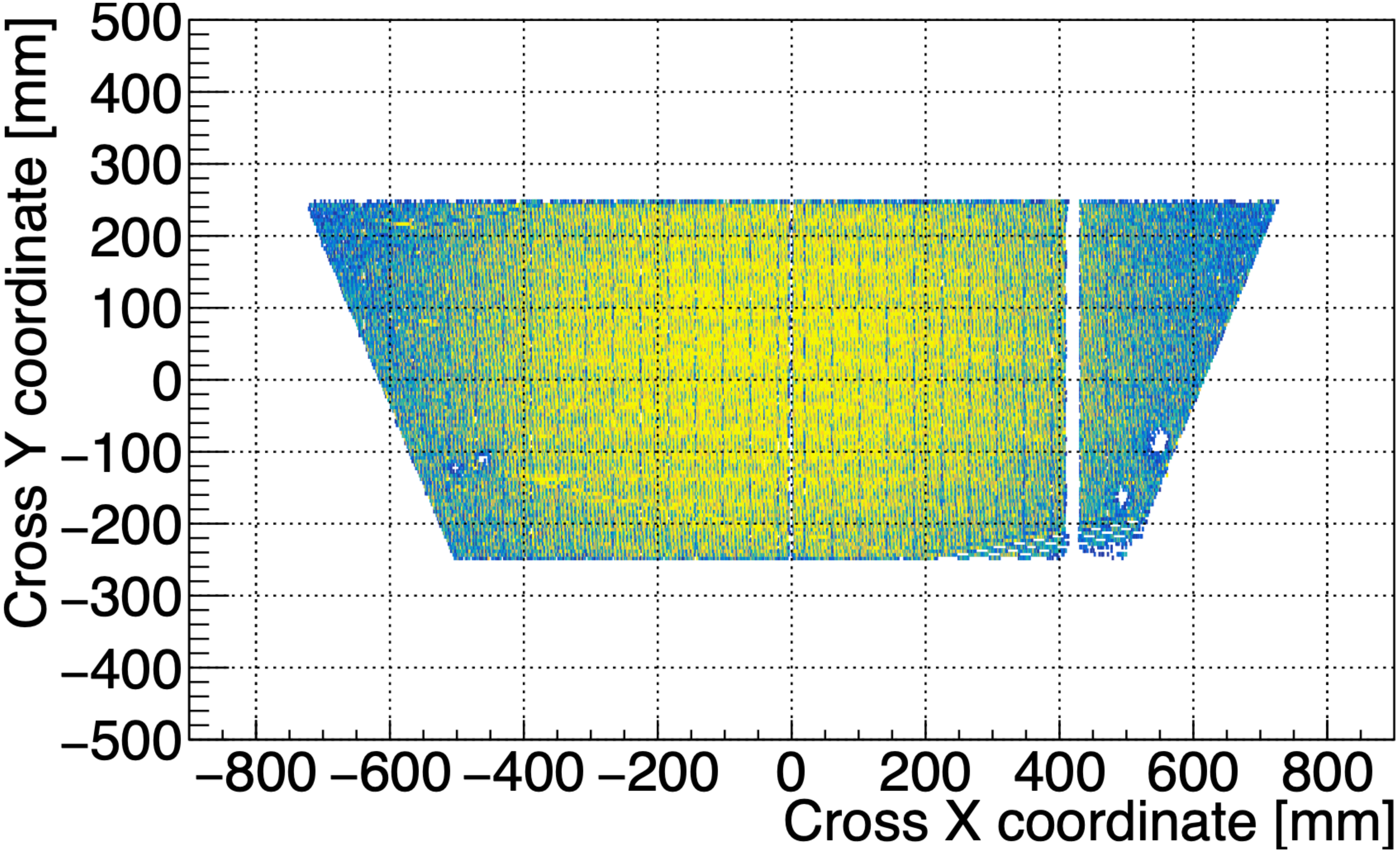


- **CO_2 gas**
- **Leakage current proportional to voltage up to 600V**
- **both sides have leakage**
- **decided to keep running with leakage and take data since current just increases linearly with voltage**

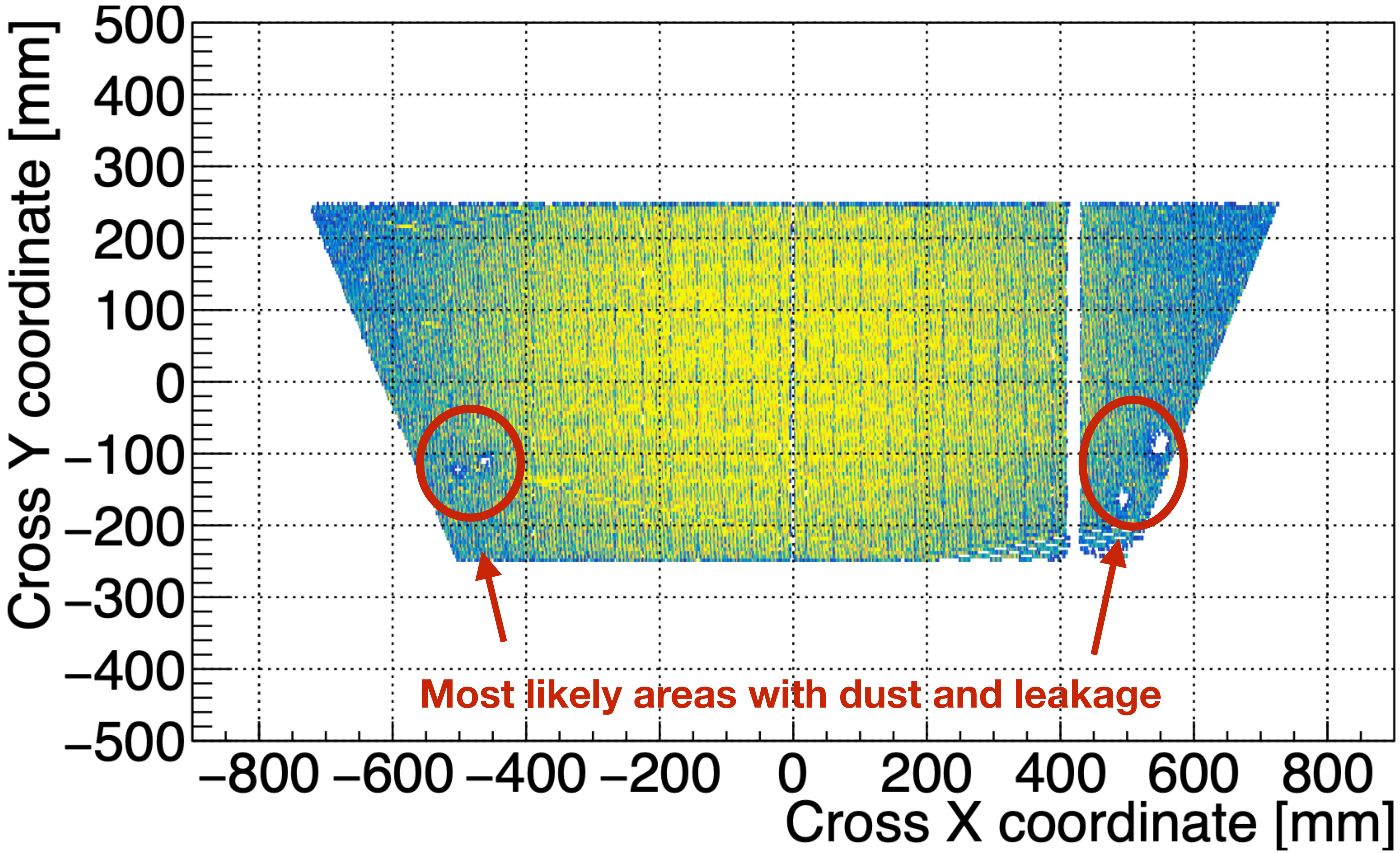
Currents and Voltages with Ar:CO_2 (80:20)



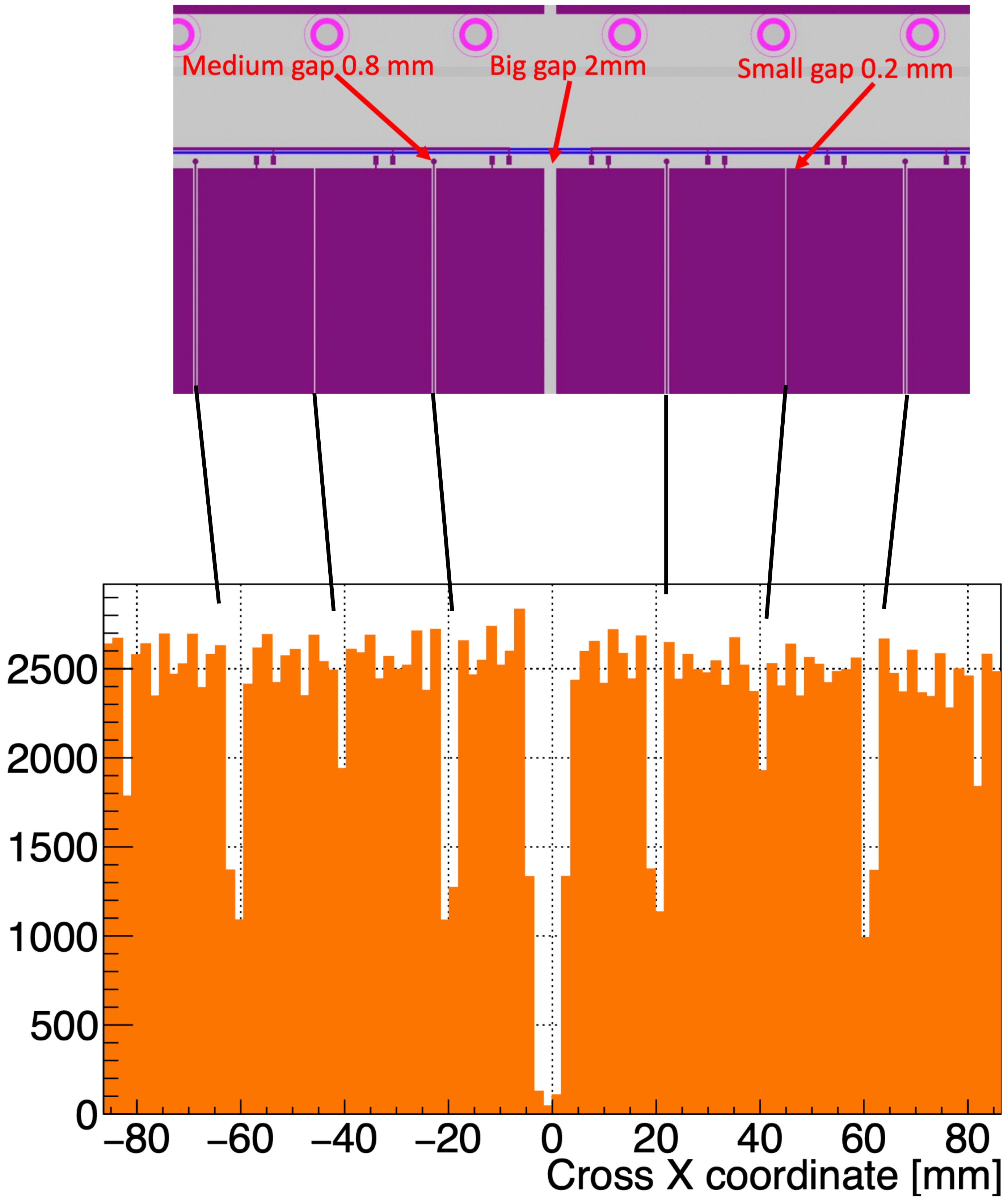
Still good data under these conditions



Still good data under these conditions



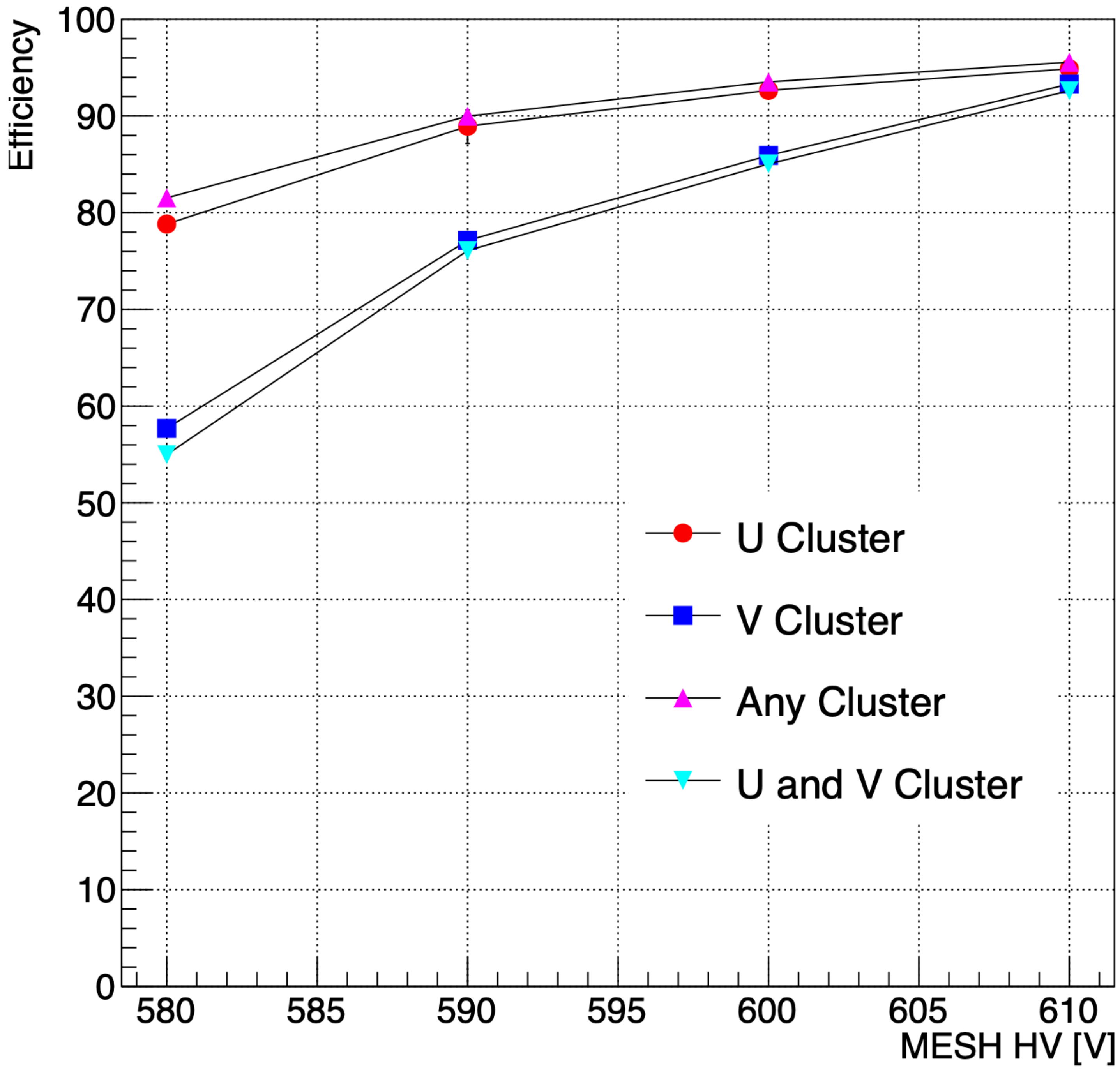
1D X-Distribution - HV sections visible!



- **Dip structure from gaps in foil between HV sections**
- **Width of gaps follow drawings**

Efficiency Results with Cosmics

Ar:CO_2 (80:20)

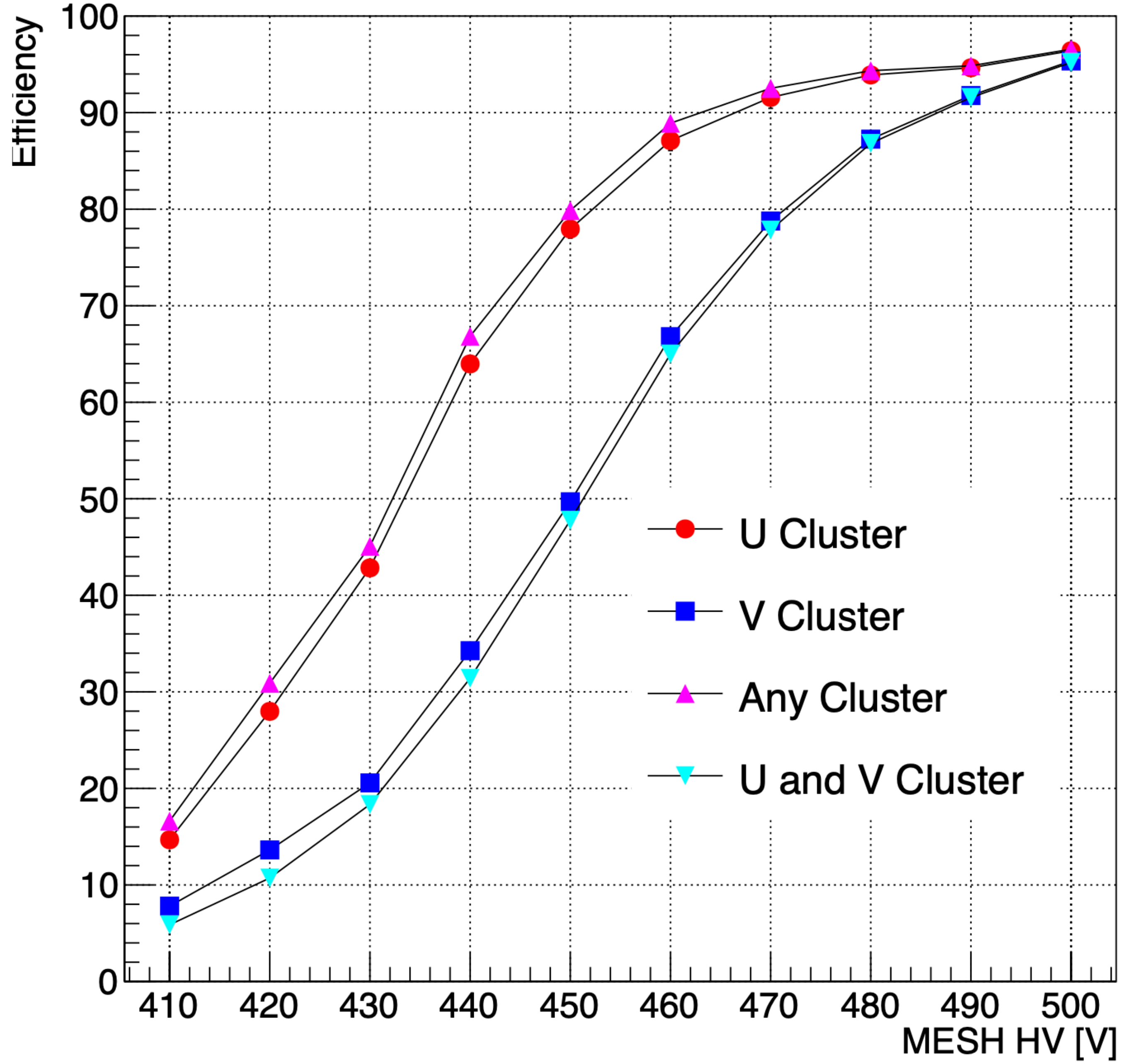


- **Reaching plateau**
- **Similar efficiency for U and V**

- **HV is very high and current unstable**

Efficiency Results with Cosmics

Ar:Isobutane (90:10)

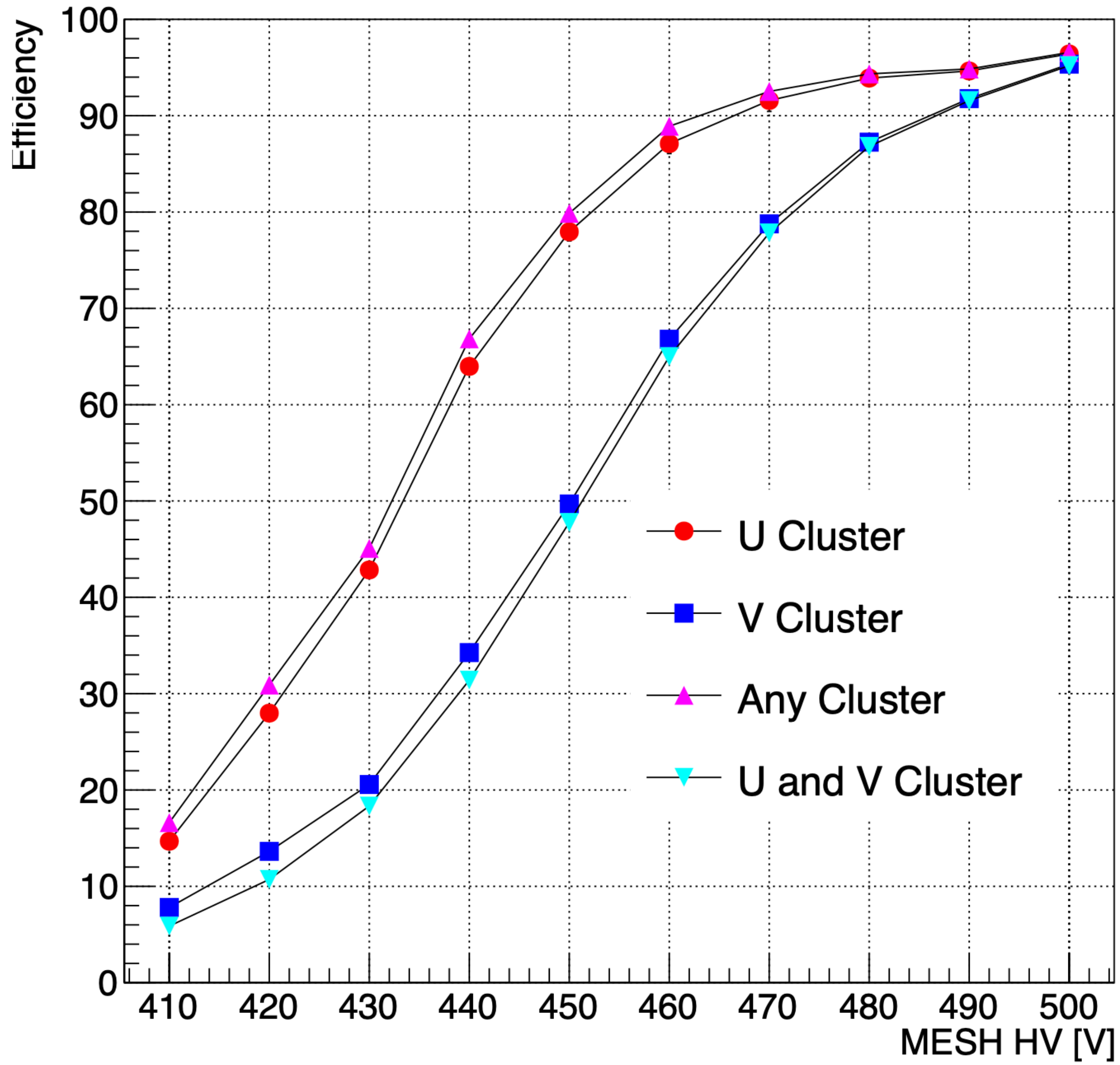


- **Reaching plateau at lower HV**
- **Similar efficiency for U and V at highest HV**
- **HV rather stable**

- **Prefer Ar:Isobutane gas over $Ar:CO_2$**

Efficiency Results with Cosmics

Ar:Isobutane (90:10)

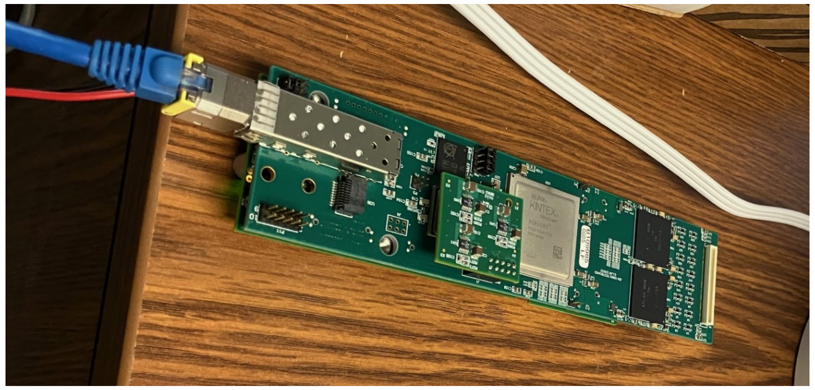


- **Reaching plateau at lower HV**
- **Similar efficiency for U and V at highest HV**
- **HV rather stable**

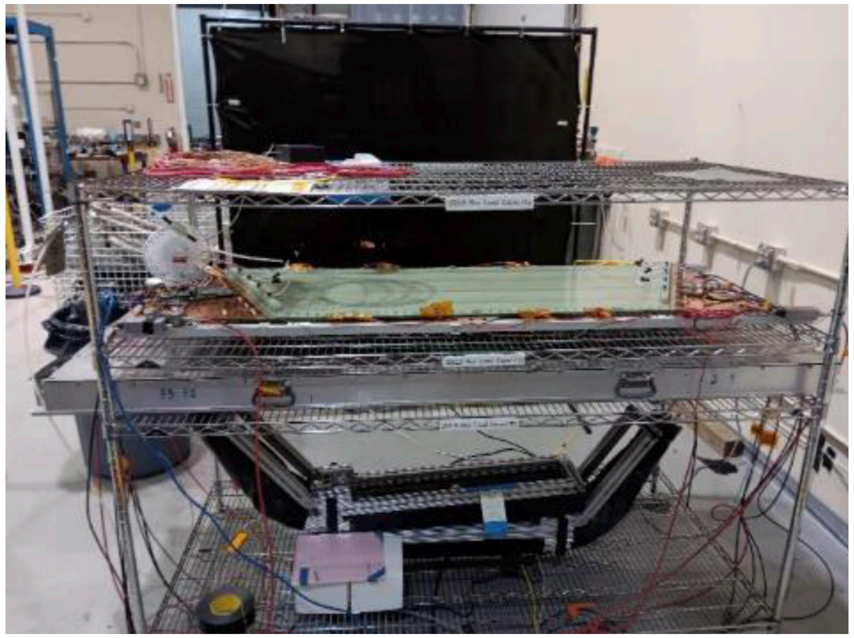
- **Prefer Ar:Isobutane gas over Ar:CO_2**

But: Signals in V smaller than U due to low amplification —> next prototypes with 1D readouts

Next Plans for CLAS12 FD µRWELL

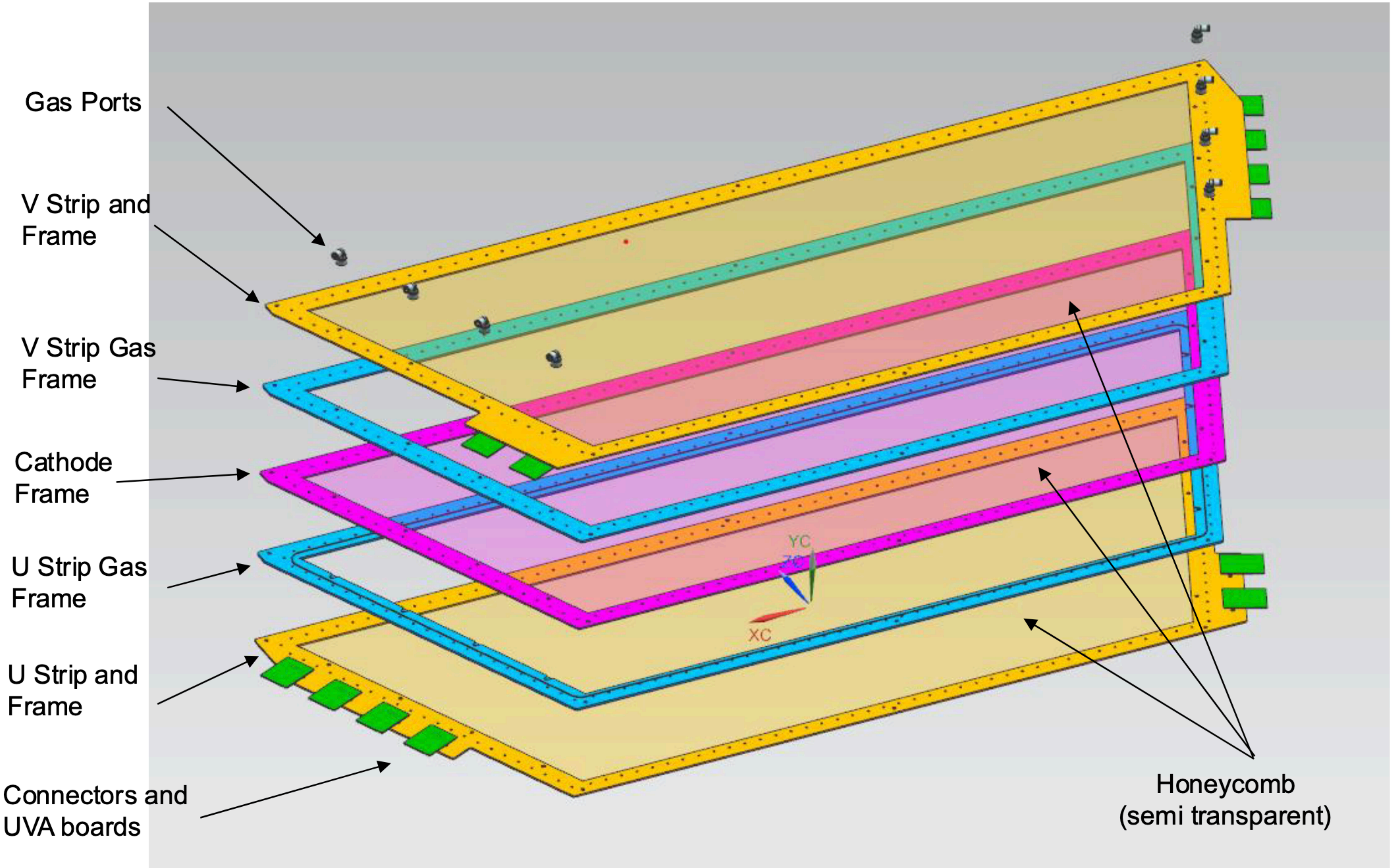


- **Measurement with VMM3 instead of APV**
  - **initial tests under way**



- **Measurements with new hodoscopes**
  - **first tests done**
  - **some debugging in progress**
- **Another test with beam (maybe)**
- **Design of new prototype with 1D readout structures**

Next Prototype Design



Drawings by Bob and Chris

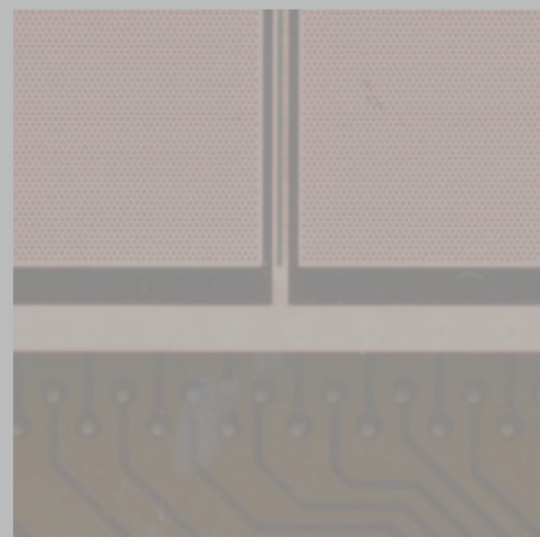
- **2 µRWELL in one combined frame**
- **Separate 1D readout strips (U and V) with same strip width**
- **Separate Cathode foils on shared honeycomb support**

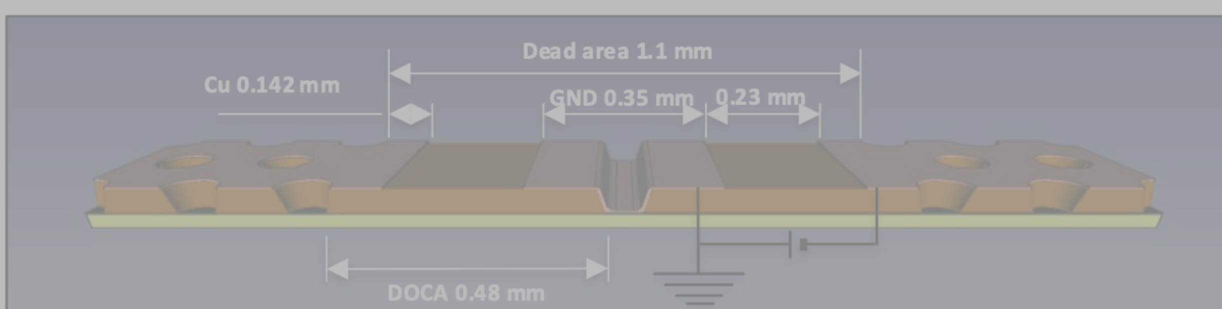
PEP Designs

2022

PEP-Groove:
DLC grounding through conductive groove to ground line
Pad R/O = 9×9mm^2
Grounding:
- Groove pitch = 9mm
- width = 1.1mm

→ 84% geometric acceptance



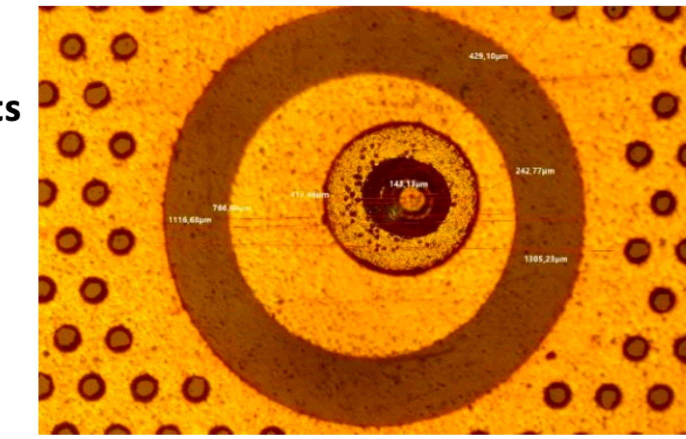


DLC Design for CLAS12 large prototype

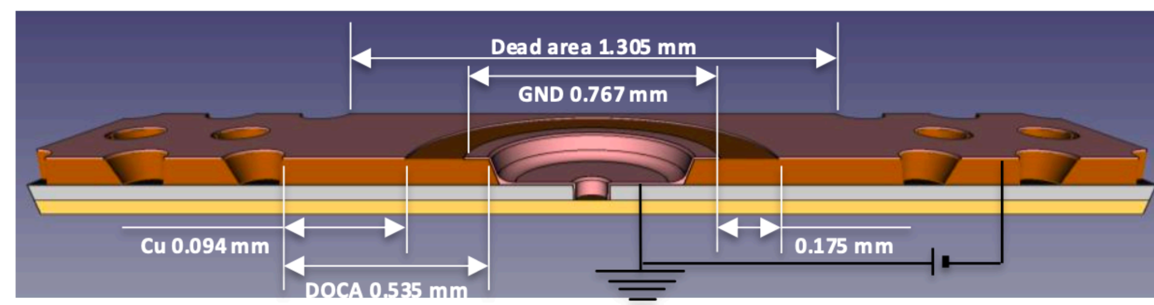
2023

PEP-DOT:
DLC grounding through conductive dots connecting the DLC with pad r/outs
Pad R/O = 9×9mm^2
Grounding:
- Dot pitch = 9mm
- dot rim = 1.3mm

→ 97% geometric acceptance



DOT → plated blind vias



DLC Design for LDRD high-rate prototypes

LDRD Project for µRWELLs at $10^{37} cm^{-2} s^{-1}$ Luminosities

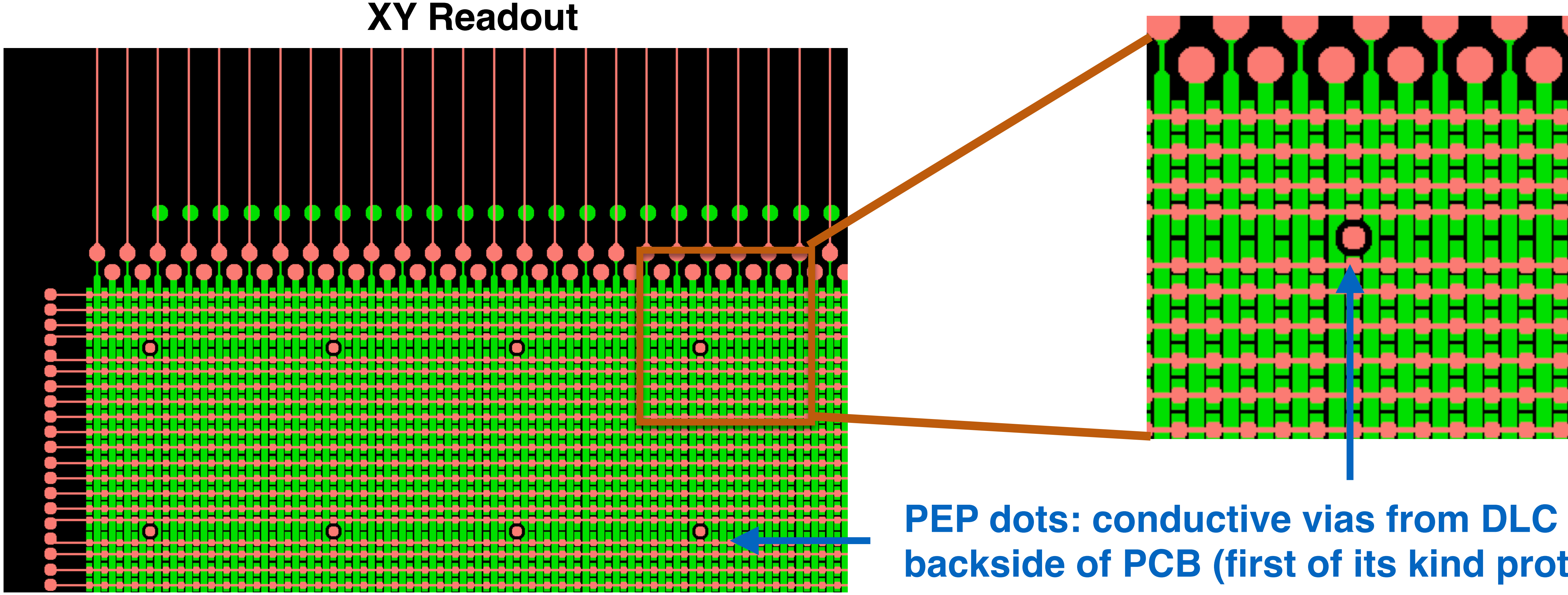
- **Goal: Development of µRWELL design suitable for high luminosity experiments at JLab for e.g DDVCS (see Rafos talk)**
- Methods:
  - Build and test small 10cm x 10cm prototypes with different designs and study “high-rate” capabilities
  - Use successful design and build larger prototype (30cm x 30cm) to test the scaling of design

- Design variations
  - Density of PEP-dots
    - more dots —> higher rate capability but larger dead area
  - Well pitch
    - less pitch —> more amplification per surface area —> more gain and improved spatial resolution and stability under high-rates
  - XY versus XYU readout
    - XYU better to resolve ambiguities under high-rates

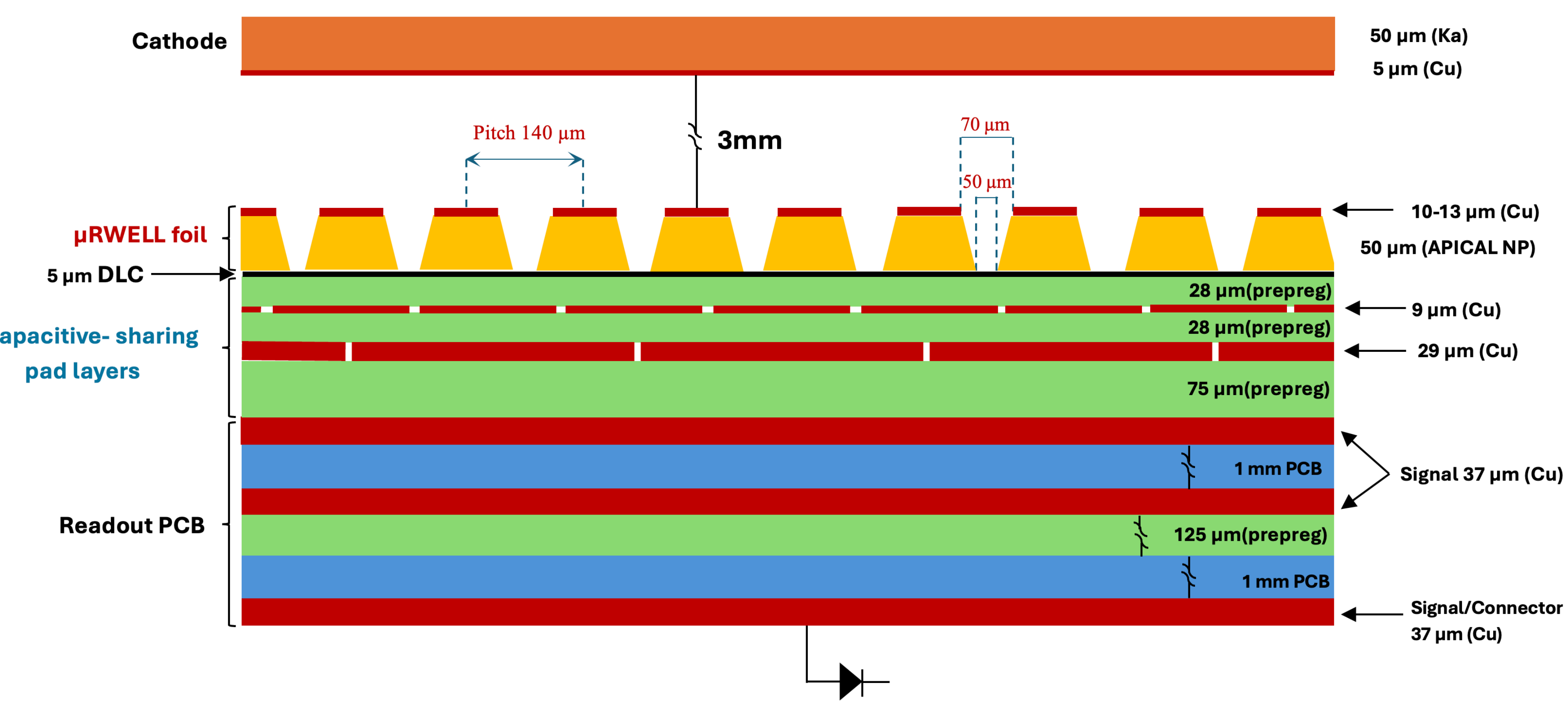
Prototype	Dots pitch	Readout	Readout strip pitch	Well pitch
A	2cm	XY	X=Y=800µm	140µm
B	1cm	XY	X=Y=800µm	140µm
C	2cm	XYU	X=Y=800µm, U=1.6mm	140µm
D	2cm	XY	X=Y=800µm	100µm

Readout Structures

XY Readout



PEP dots: conductive vias from DLC through backside of PCB (first of its kind prototype)



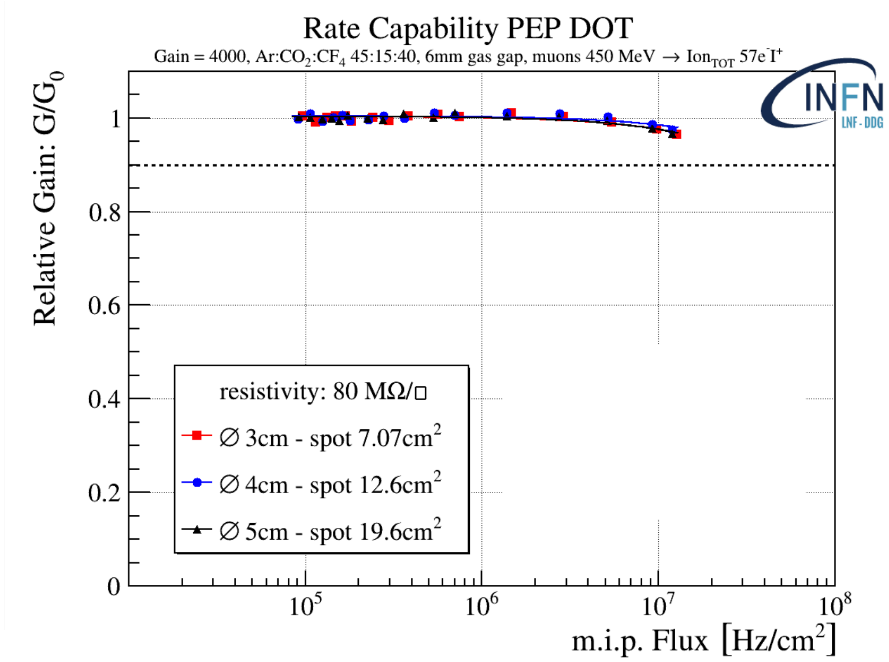
Cross section of prototypes

(for XYU the top of μRWELL foil is connected to readout)

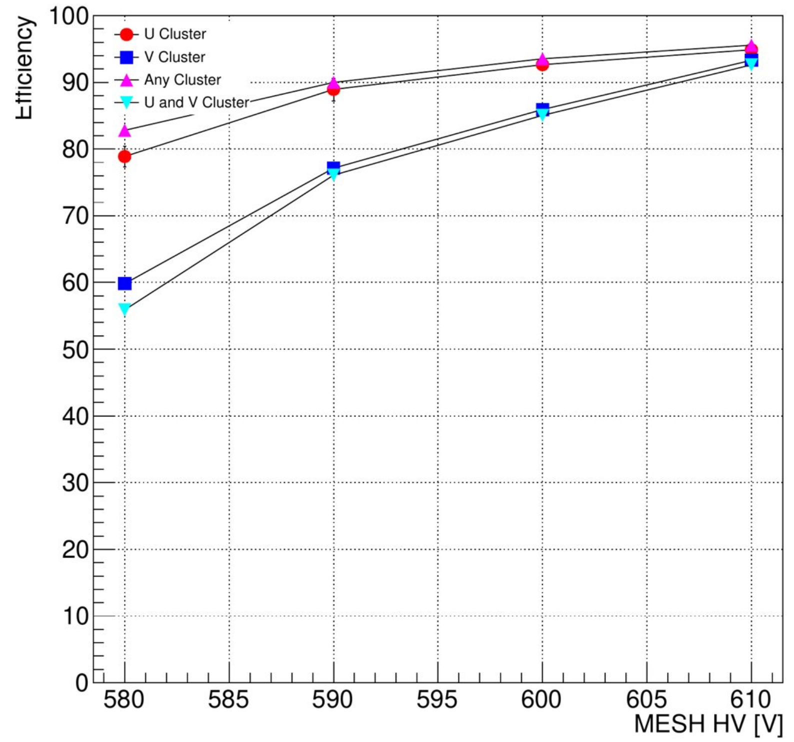
What do we want to study

- Rate capability
  - Stability of operation
  - When does gain drop?
- Efficiency dependence on HV and rate
  - When does efficiency reach plateau?
  - What is the behavior when rates increase?
- Spatial resolution
  - Dependence on HV and rate
  - XYU readout better than XY at high rates due to hit ambiguities?
  - Worse resolution at high rates?
- Dependence on gas mixtures
  - Ar:CO_2 (80:20)
  - Ar:Isobutane (90:10)
  - Ar:Isobutane:CO_2 (93:2:5)
  - What is the optimal gas?

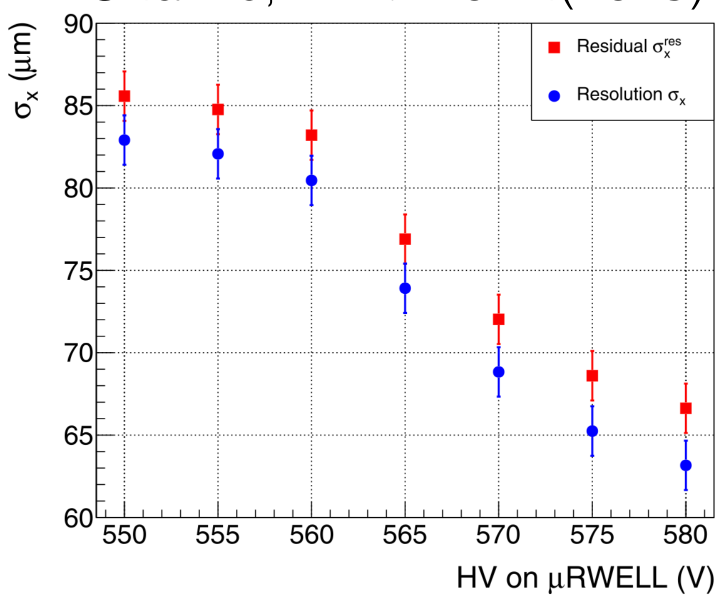
M. Giovanetti's Talk



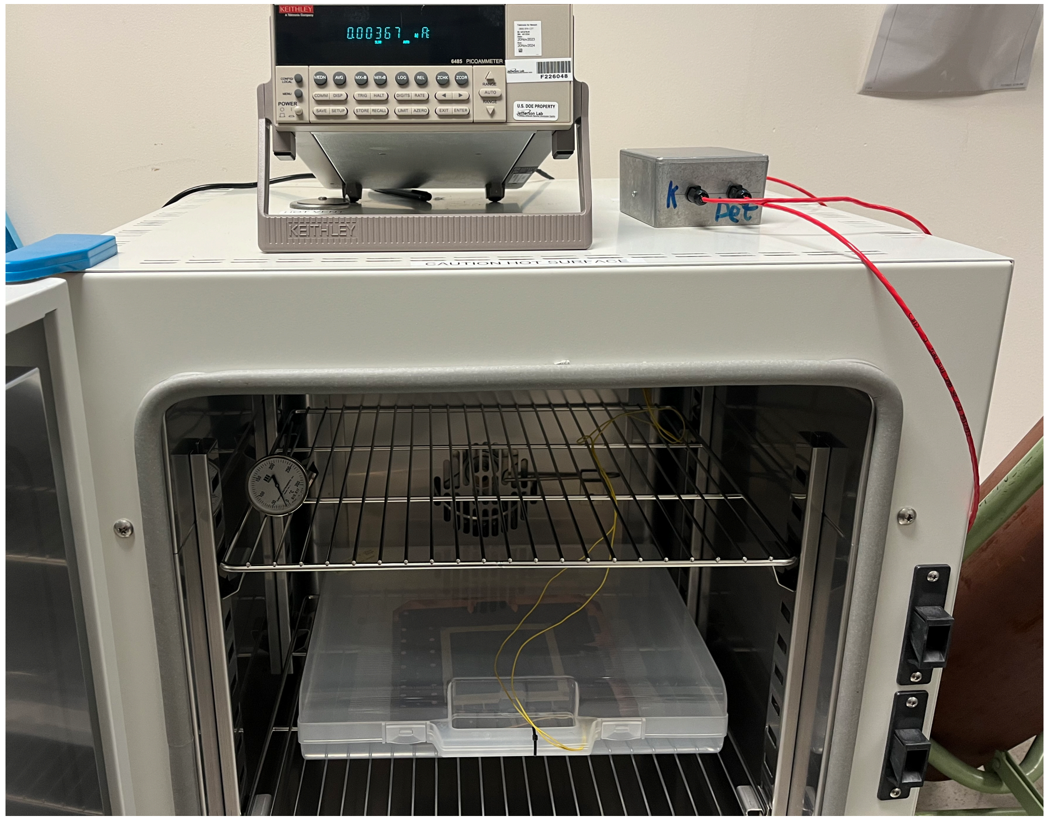
from CLAS12 μRWELL

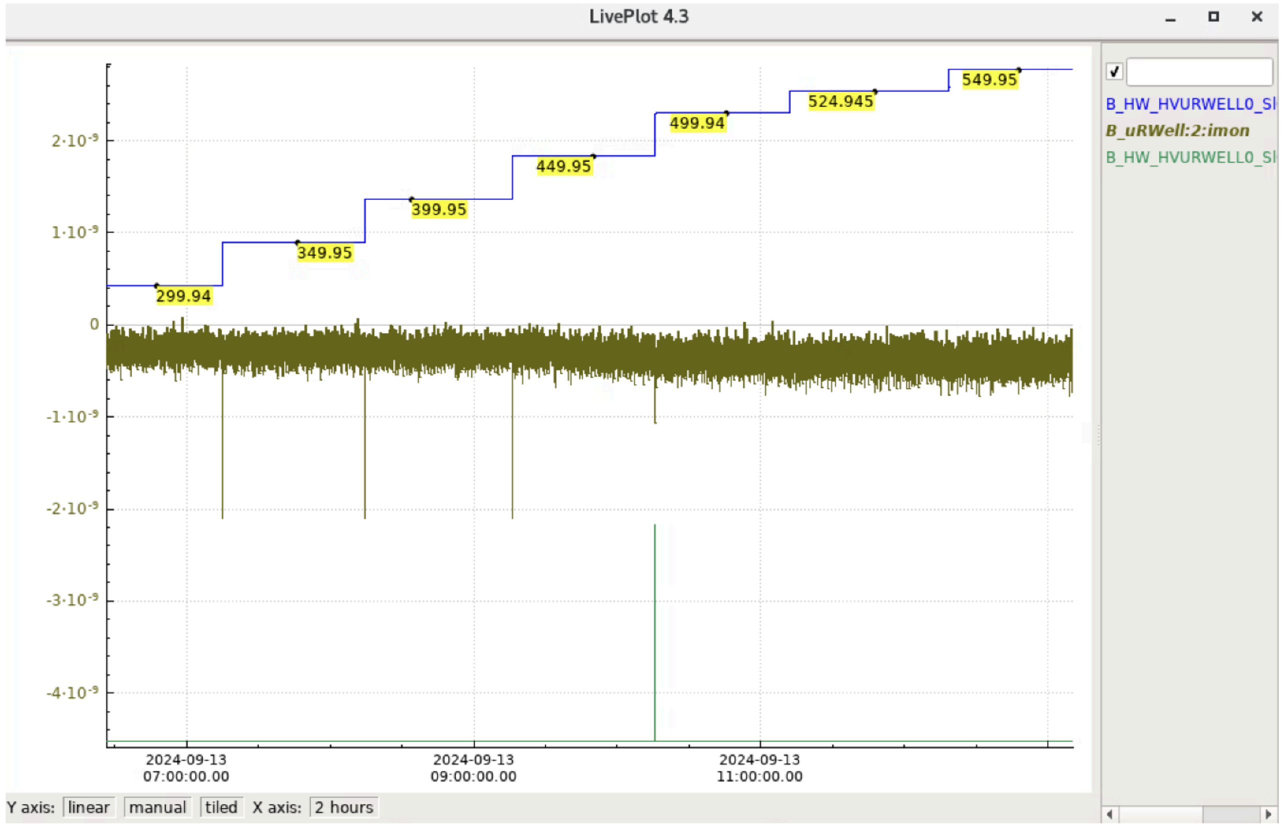


K. Gnanvo, NIM A1047 (2023)

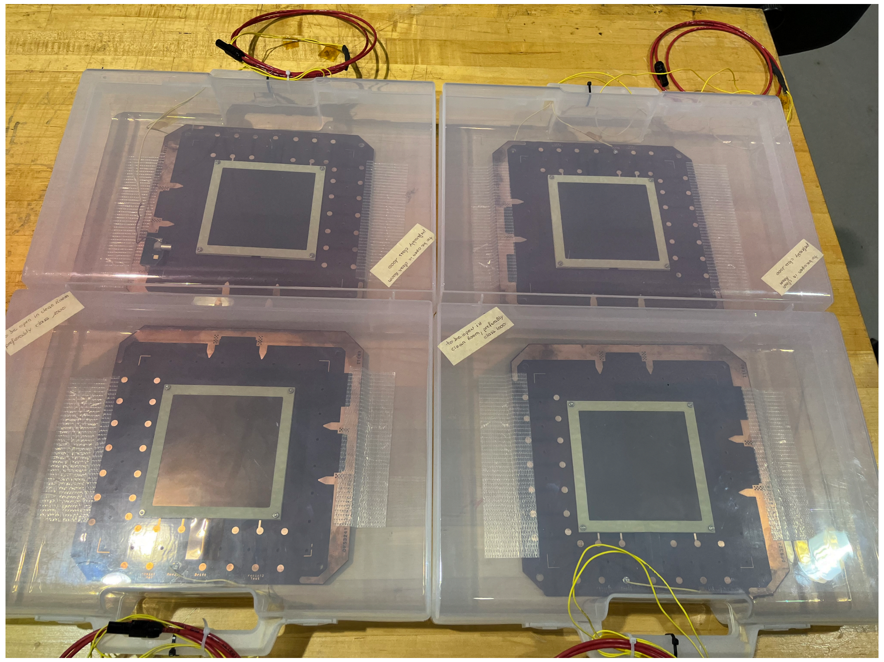


Initial Testing for Leakage Currents in Oven



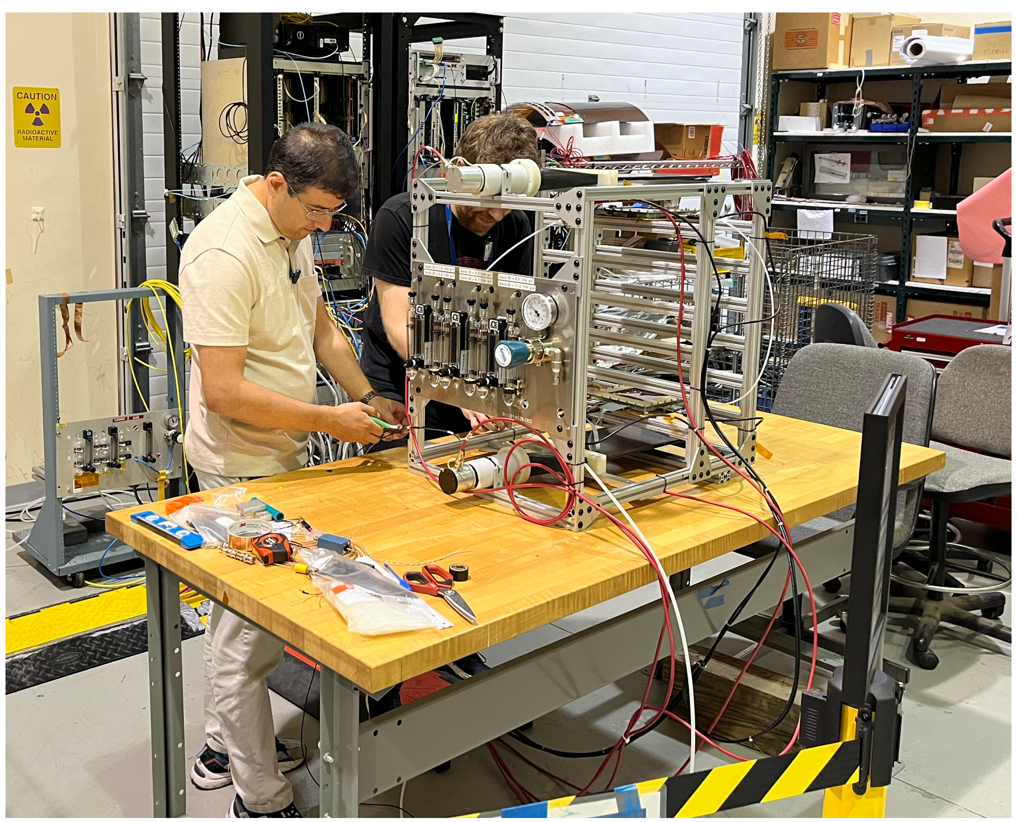


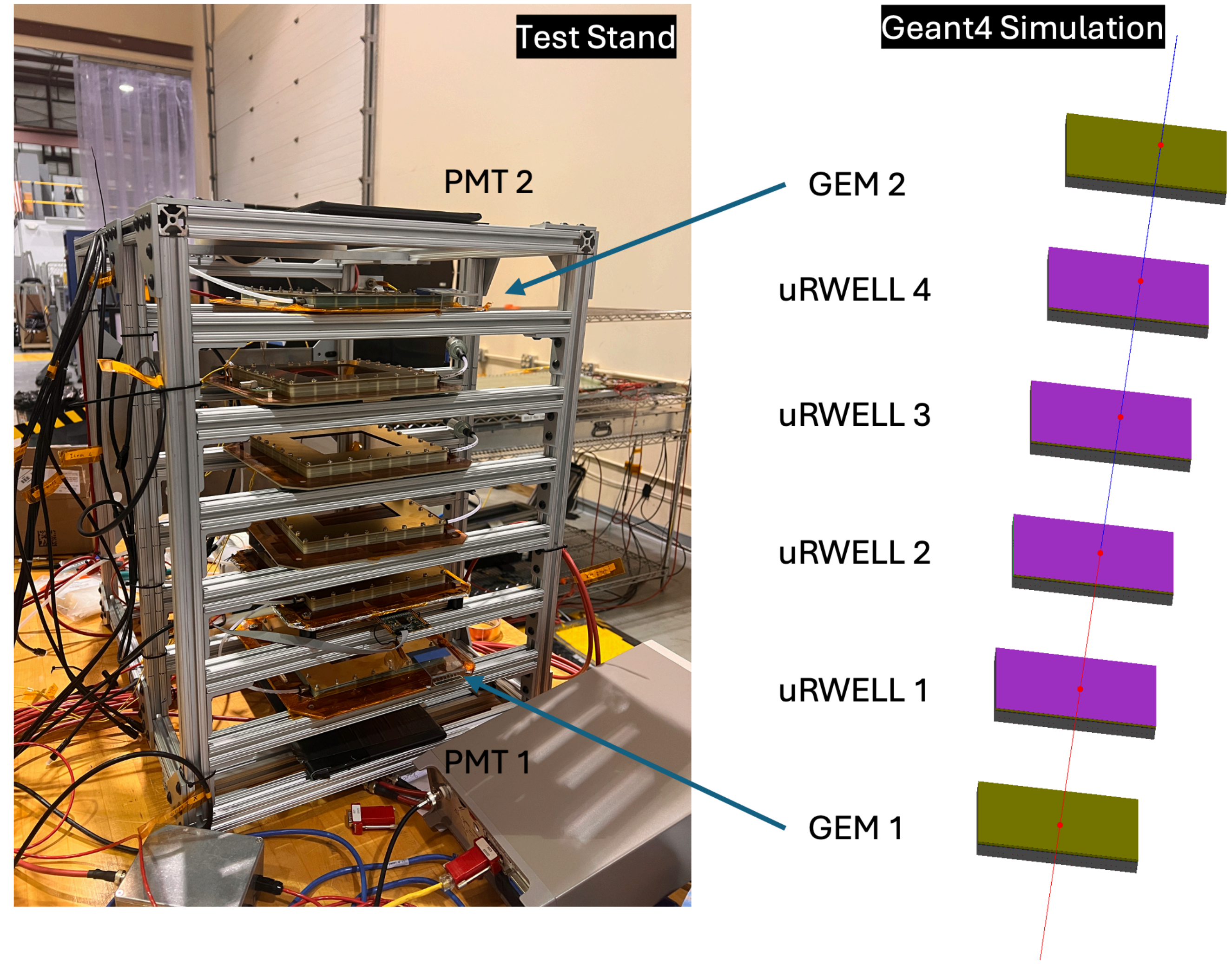
- Detector need to hold 600V with less than 1nA leakage at 50 deg in oven
- If leakage current is larger could be dust or humidity depending on HV behavior. Need to be addressed first before detectors can be used further
- Note: one prototype had to be put back in oven due to humidity

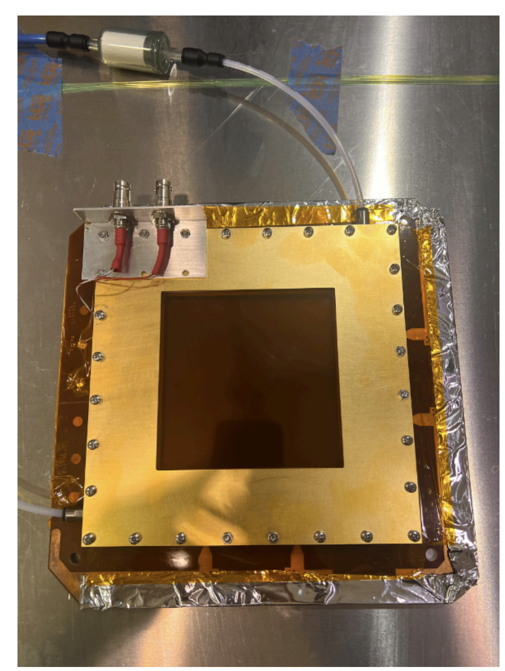


Prototypes Testing with Cosmic

- Test stand
  - GEM reference detectors
  - Scintillators for triggering
  - APV25/SRS readout
  - Gas panel

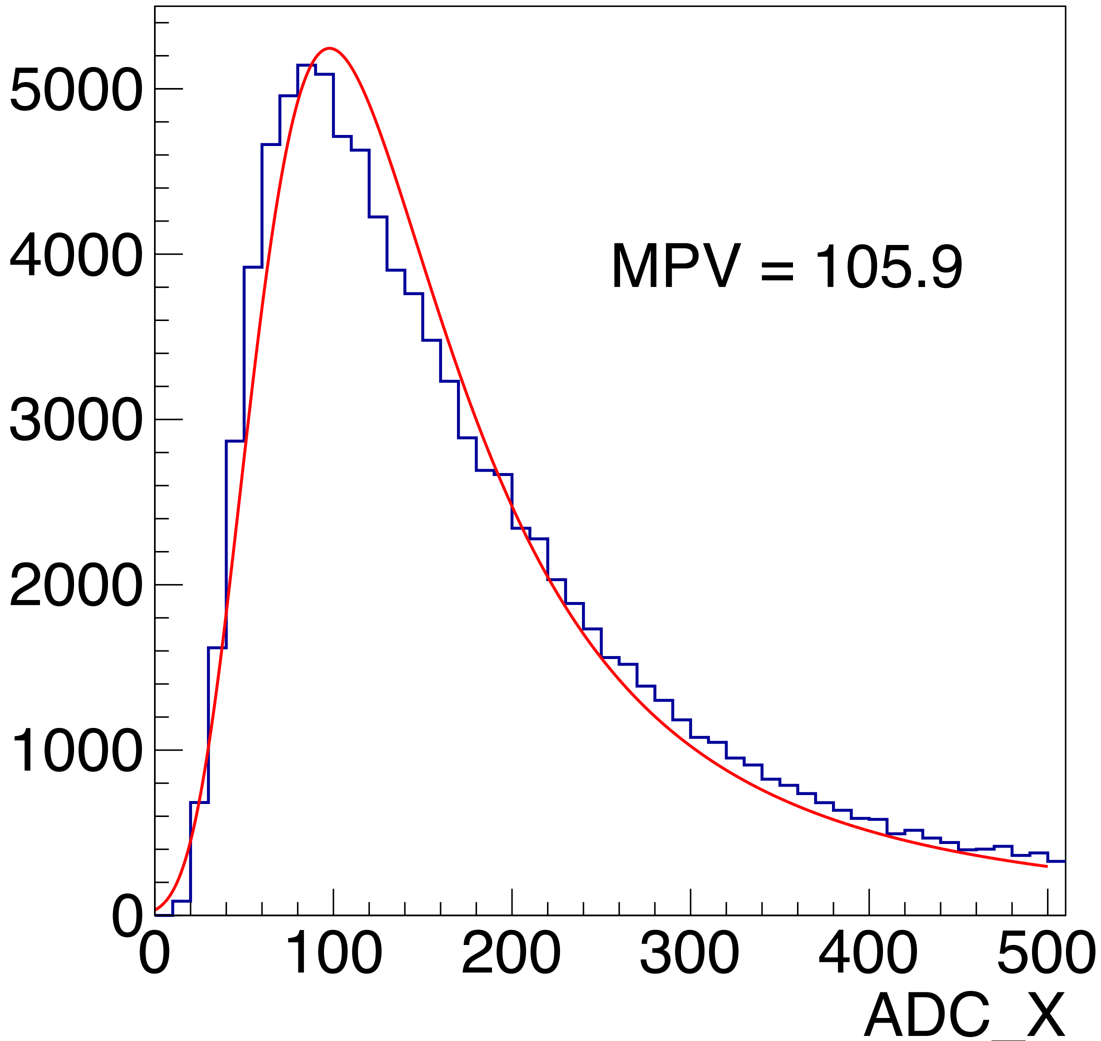


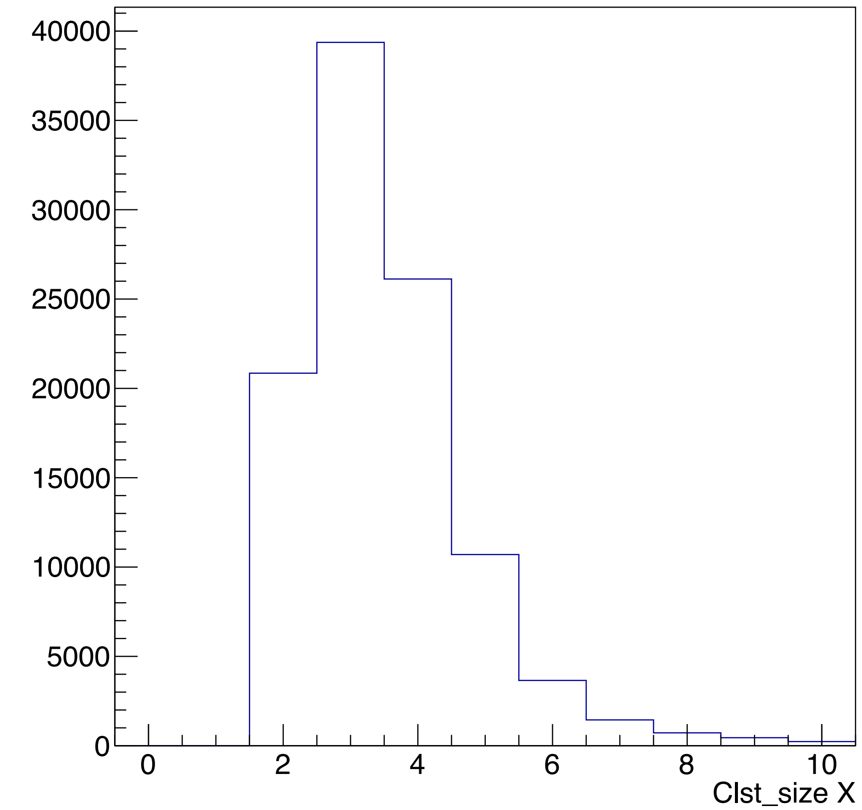


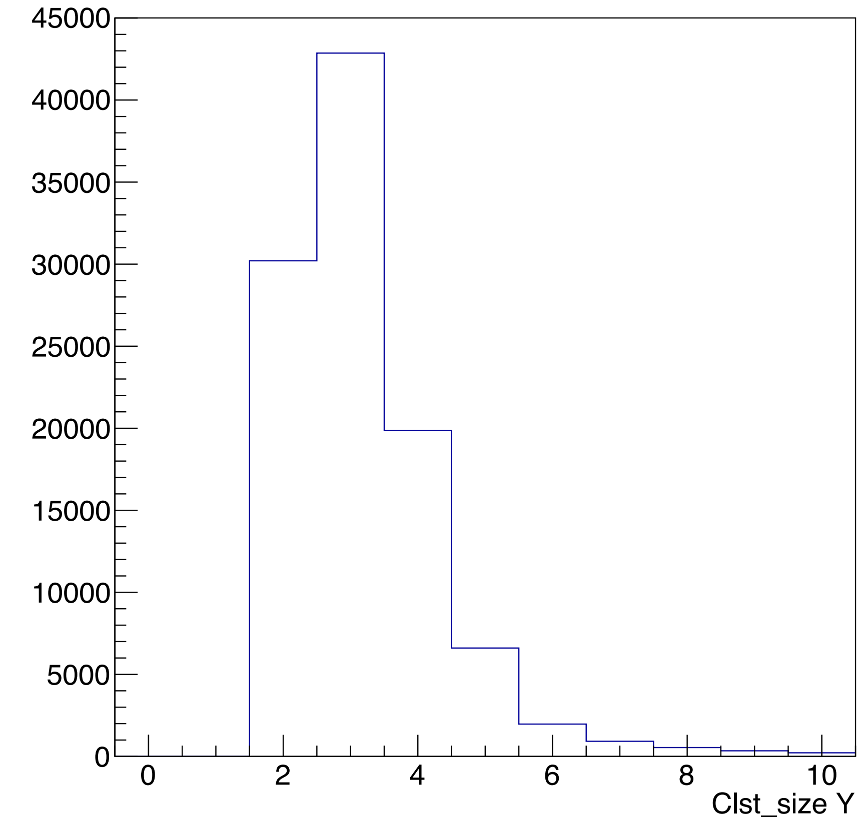


First Results from Cosmic Testing

- Prototype 1: Ar:CO2 80/20, 550V μRWELL





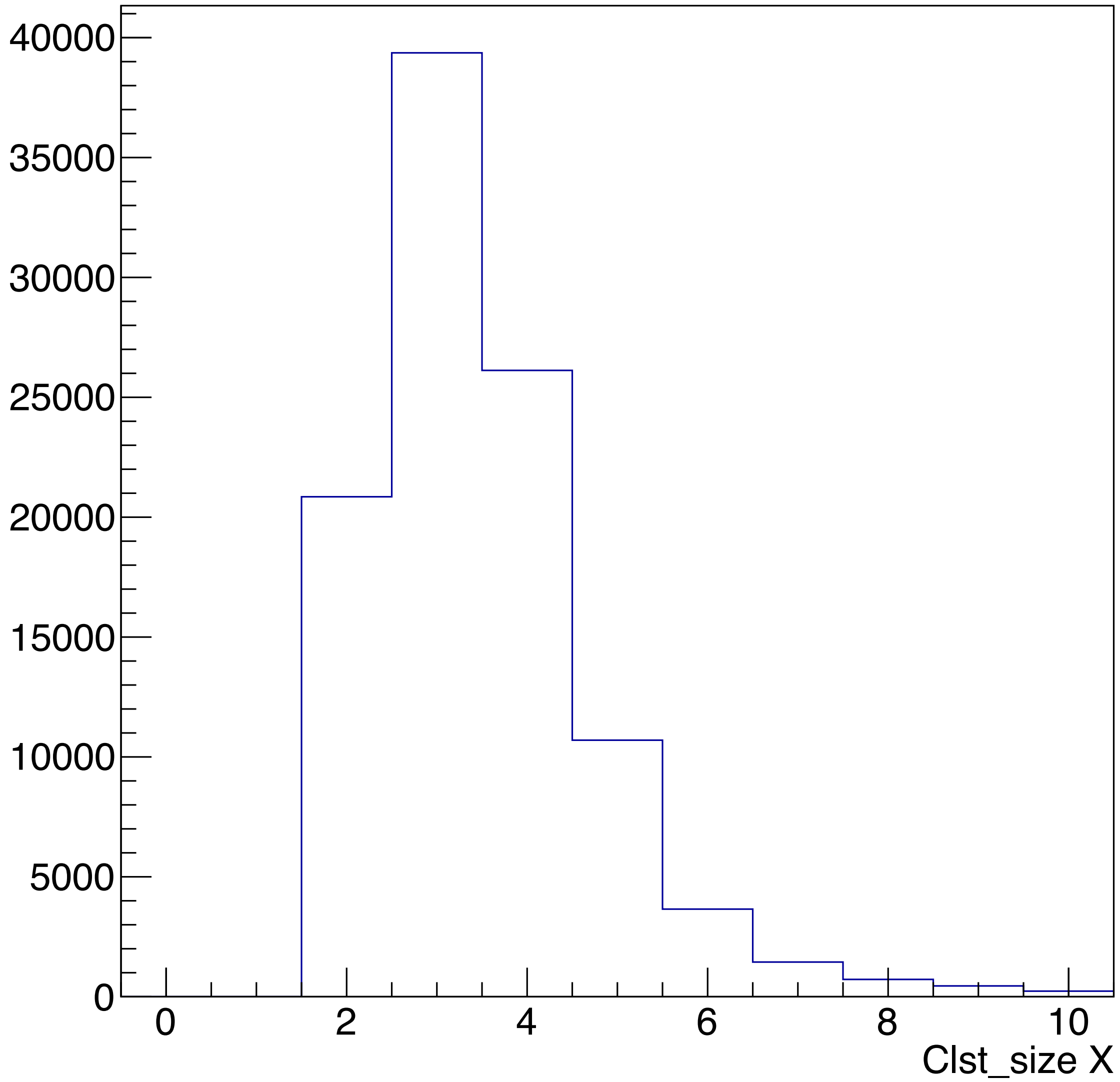


- similar cluster size in X and Y as expected

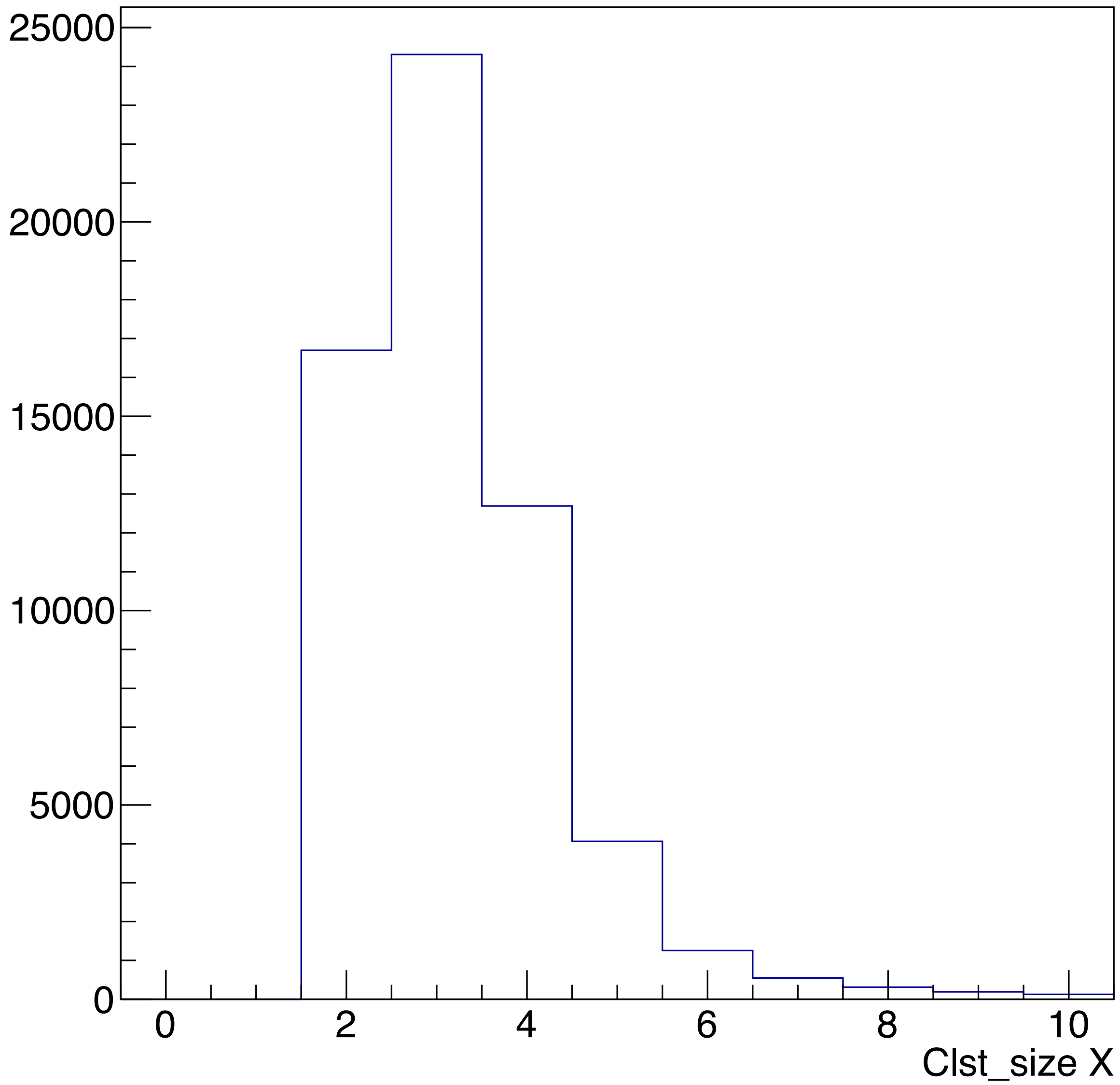
Comparison Prototype 1 and 2: Cluster size

- same WELL pitch and XY readout, different PEP-dot pitch

1



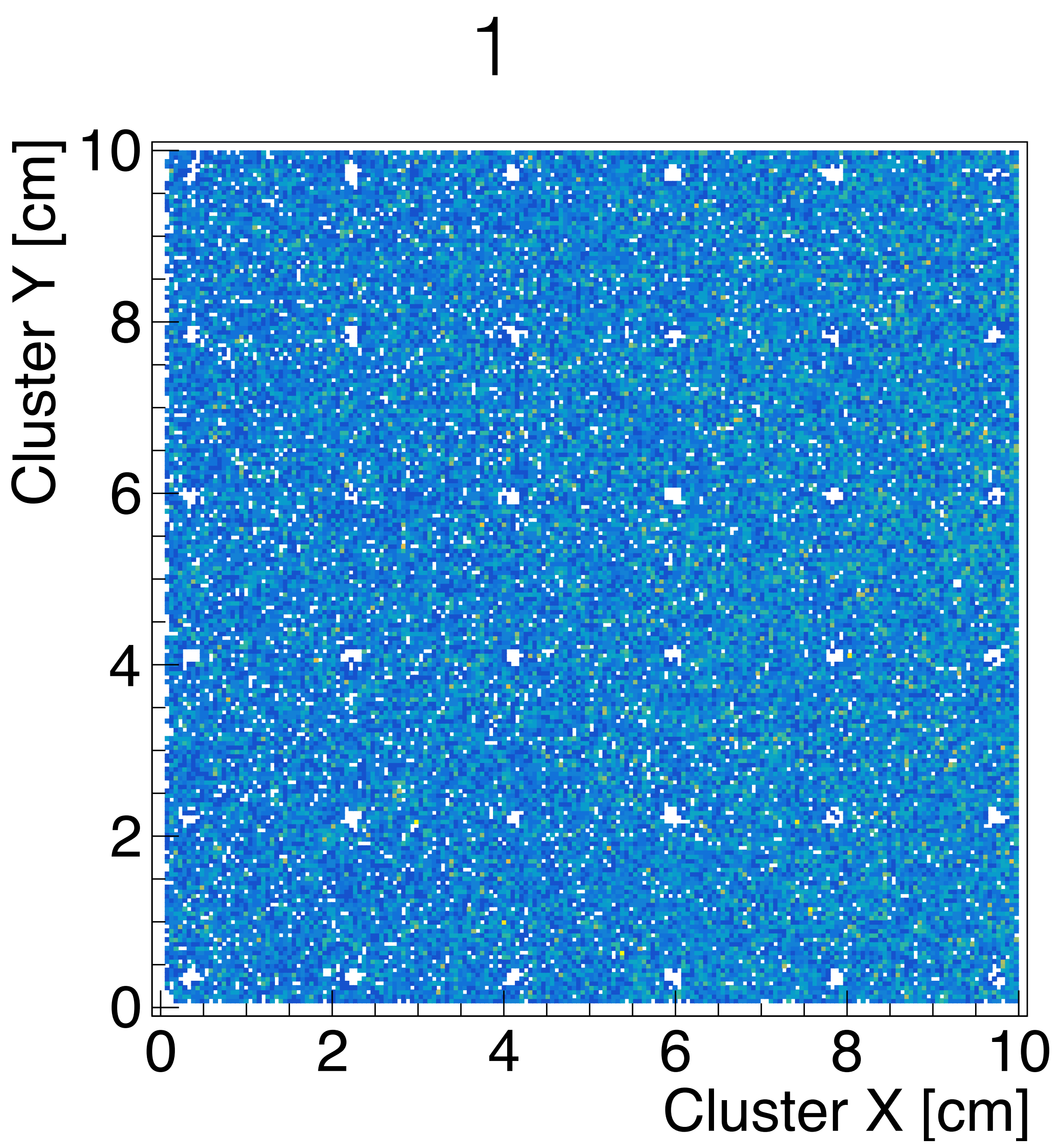
2

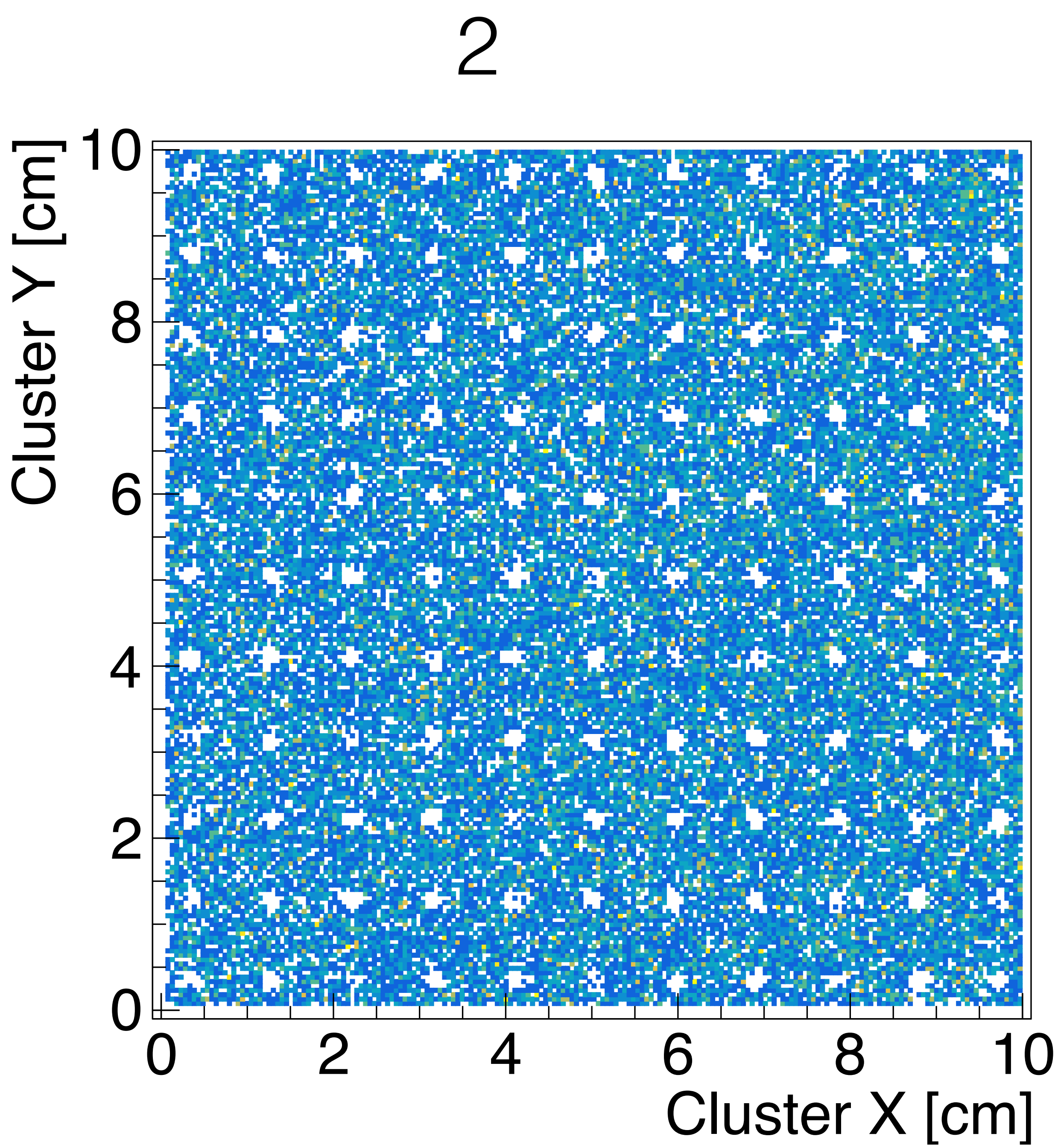


- similar cluster size as expected

Comparison Prototype 1 and 2: XY distribution

- same WELL pitch and XY readout, different PEP-dot pitch





- PEP-dots nicely visible as inefficiency area
- Density doubled for prototype 2 as expected

Next Plans for LDRD µRWELLs

- **Complete cosmic measurements for efficiency and resolution**
  - **HV dependence**
  - **Gas mixture dependence**

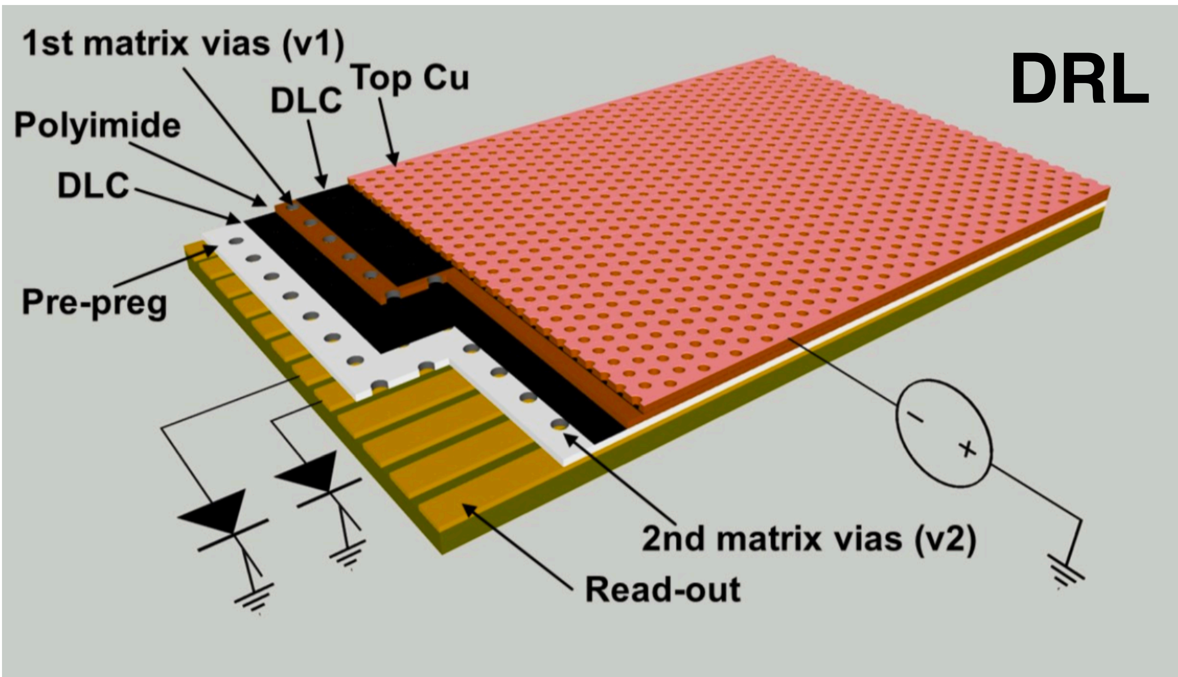
- **Measurements with beam in hall**
  - **large angle = kHz/cm particle rate**
    - **establish stable operation conditions**
    - **repeat HV scan and gas mixture study**
  - **move to smaller angles = MHz/cm particle rates**
    - **repeat measurement from larger angles**
    - **determine limitations for stability, gain drop etc.**

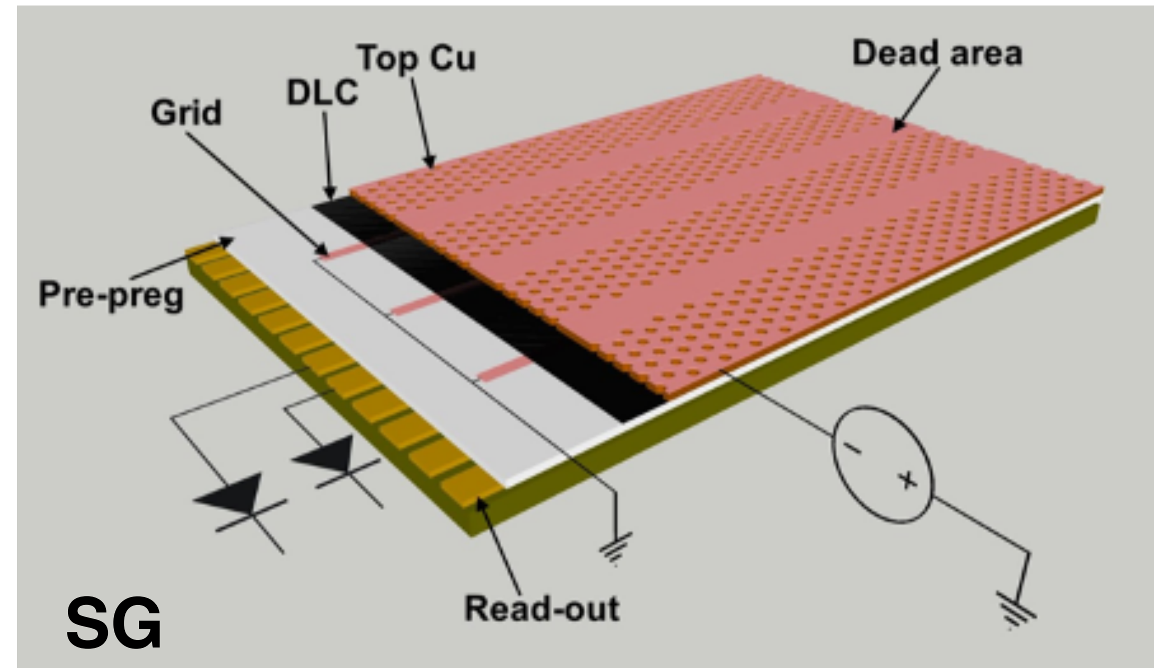
- **Design and build larger (30cm x 30cm) prototype**

Backup Slides

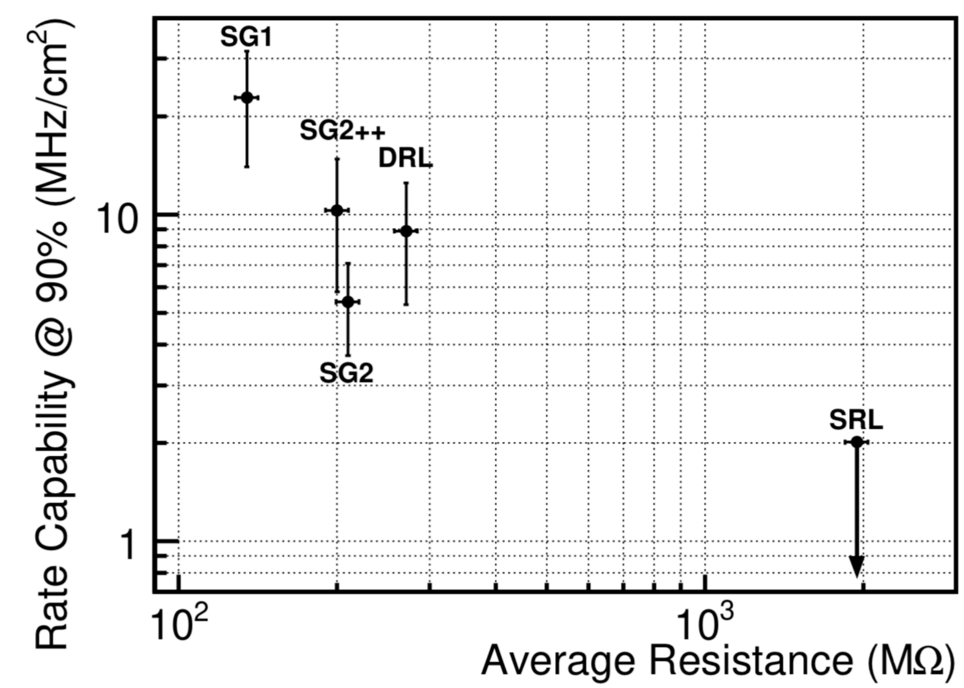
Previous Studies of High-Rate µRWELL Resistive Layers

G. Bencivenni et al., JINST 14, P05014 (2019)

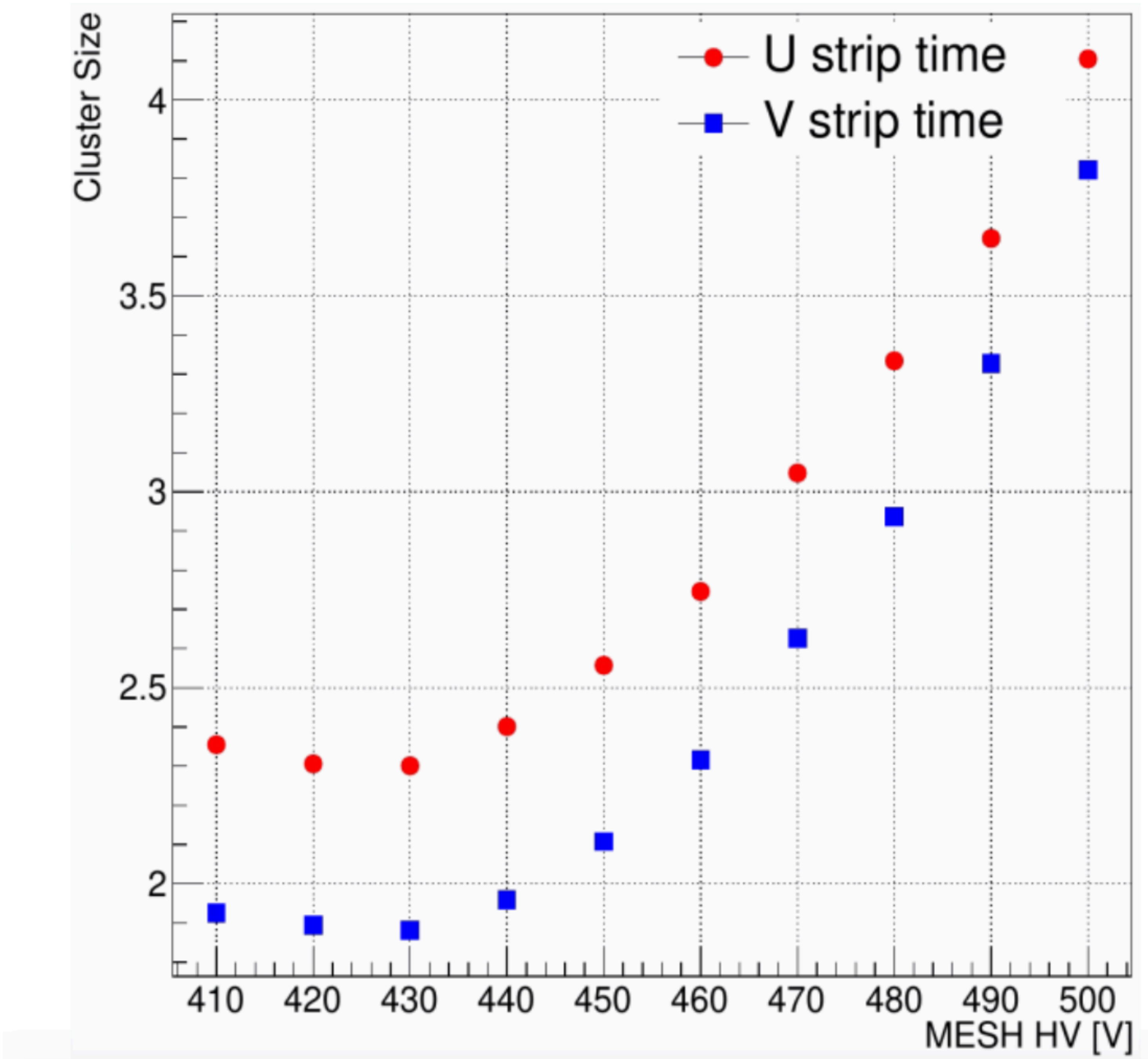




- High-rate layouts tested with pion beams at CERN
- >5 MHz/cm² rate capability with maximum 10% gain loss
- SG layout easier to fabricate than DRL



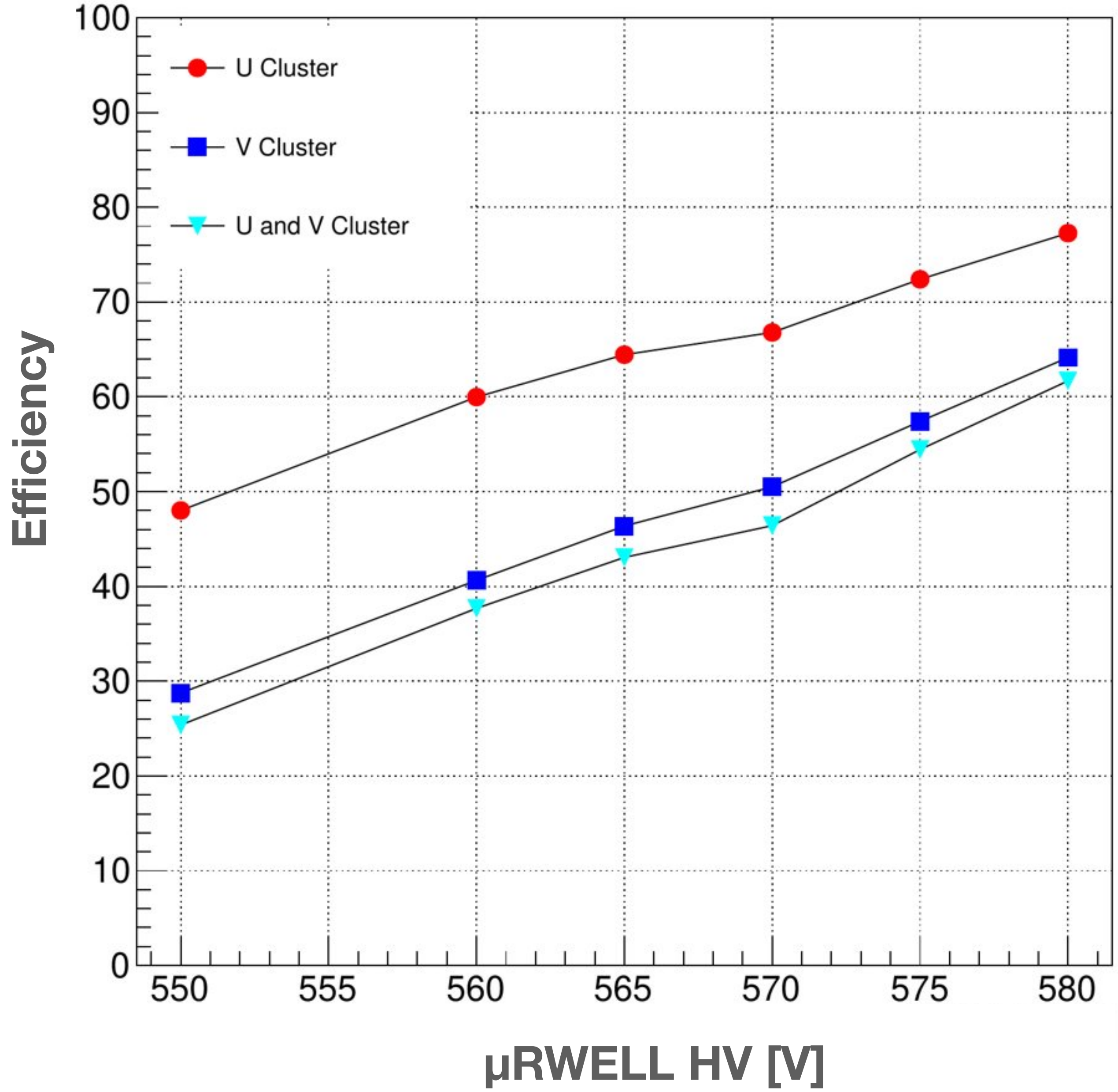
Cluster Size (Ar:CO2) - Large Prototype



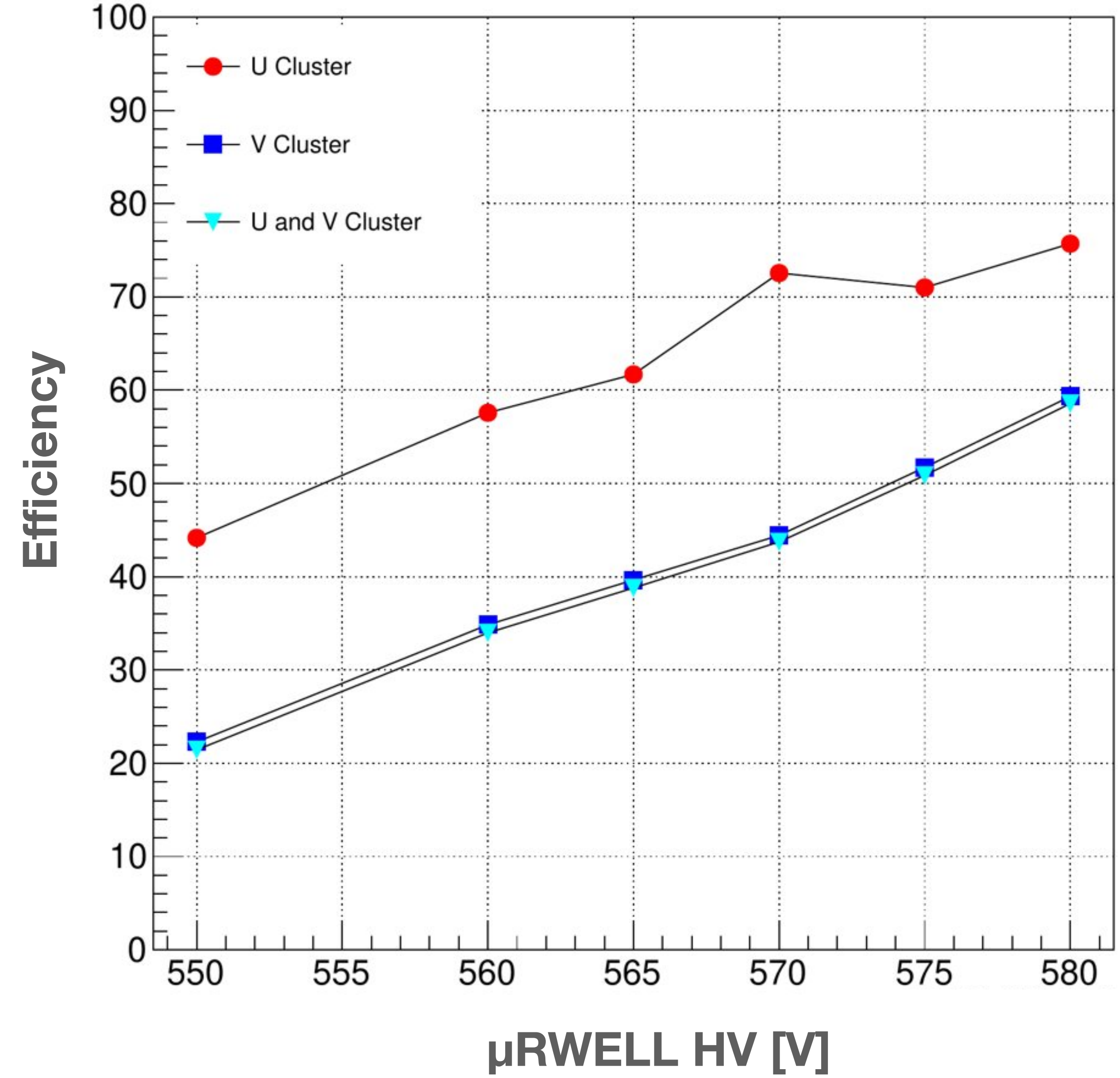
Efficiency Results (before Cathode change)

Ar:CO_2 80:20, Drift voltage 450V over µRWELL for each point

3σ, cluster with at least 2 hits



5σ, cluster with at least 1 hit

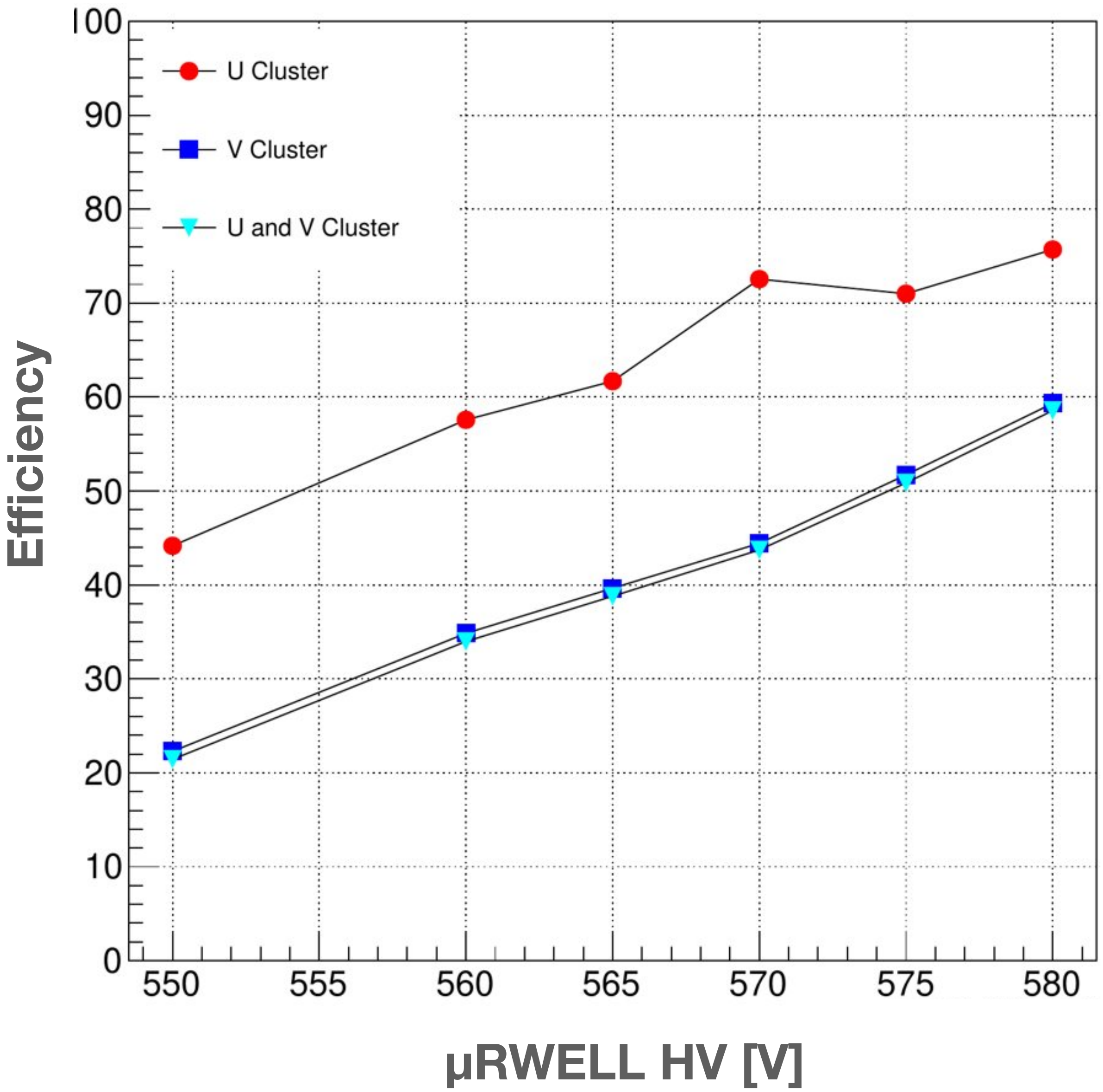


- **Increase of efficiency with voltage as expected**
- **More events have U and V cluster with 5σ cut**
- **Efficiency caps at around 80%, more events with U clusters only**

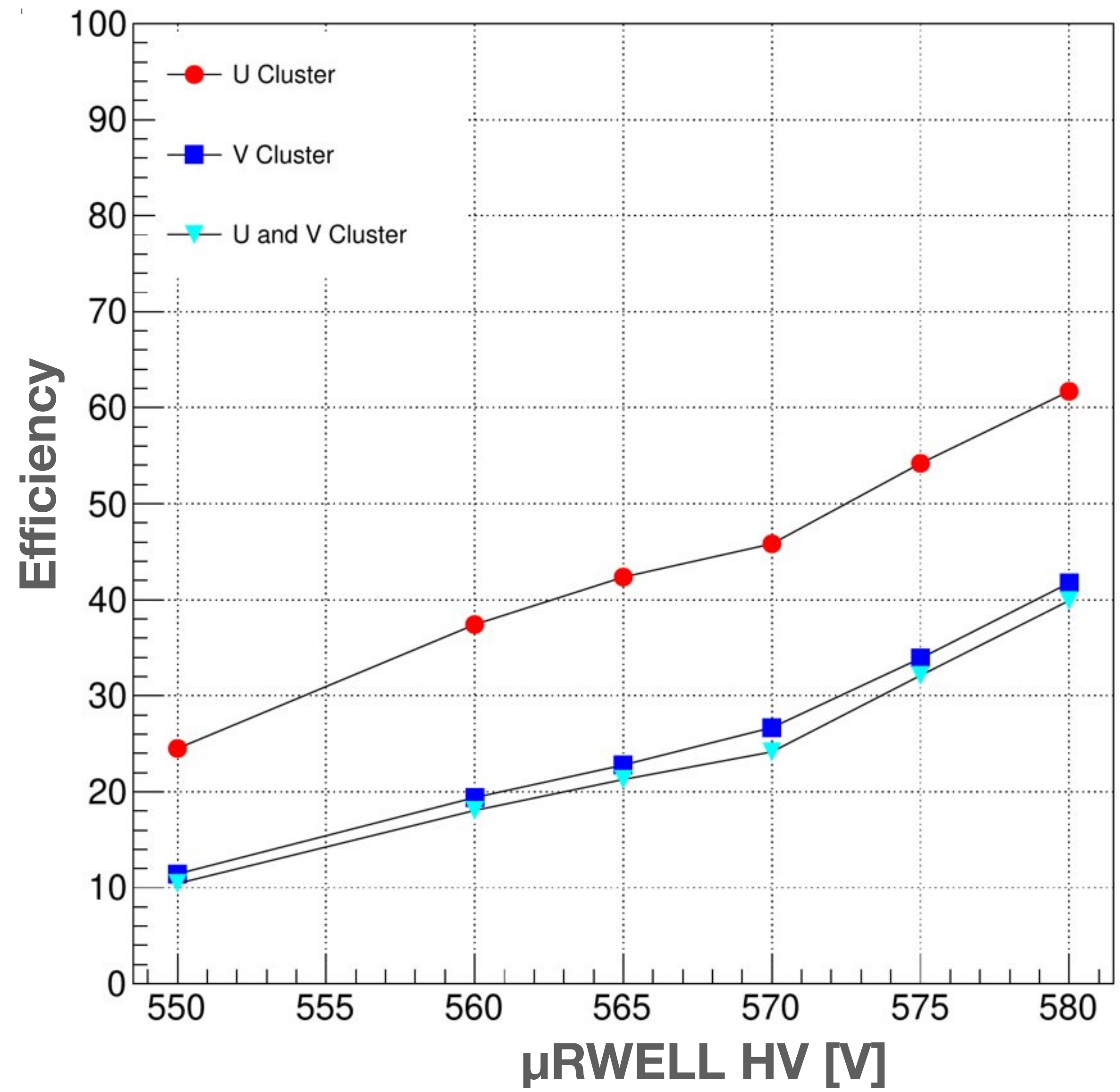
Efficiency Results (before Cathode change)

Ar:CO_2 80:20, Drift voltage 450V over μRWELL for each point

5σ, cluster with at least 1 hit



5σ, cluster with at least 2 hit



- **Cleaner events with 5σ and at least 2 hits**
- **But much lower efficiency (as expected)**