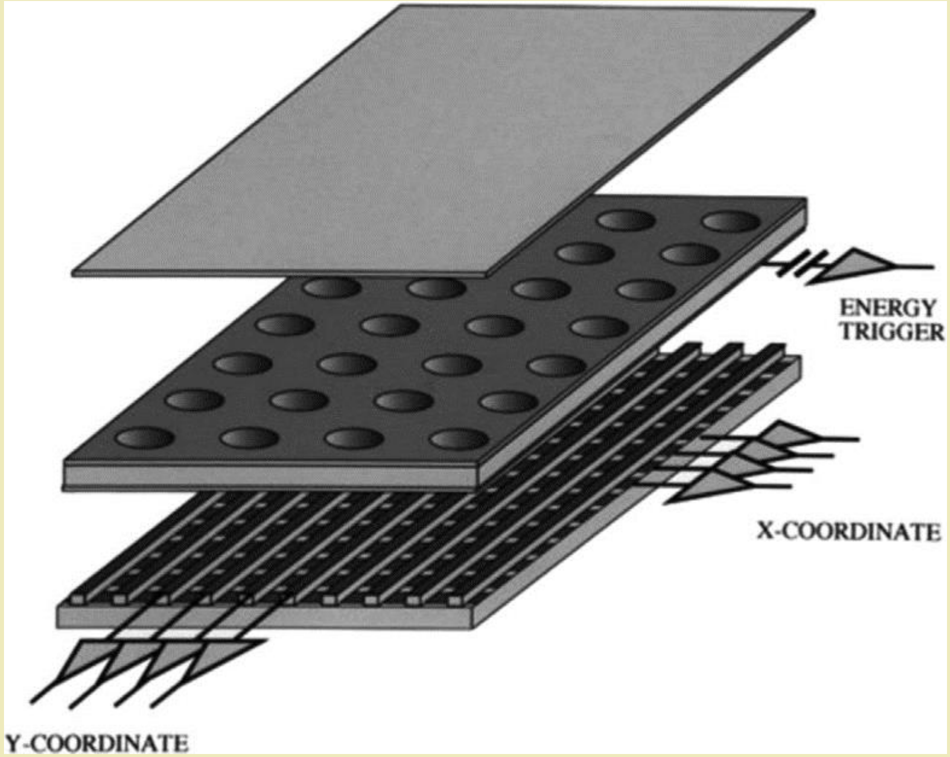
Design, Assembly, and Testing of a Small 3D-printed Thick-GEM

Jerry Lamar Collins II

FLORIDA TECH®

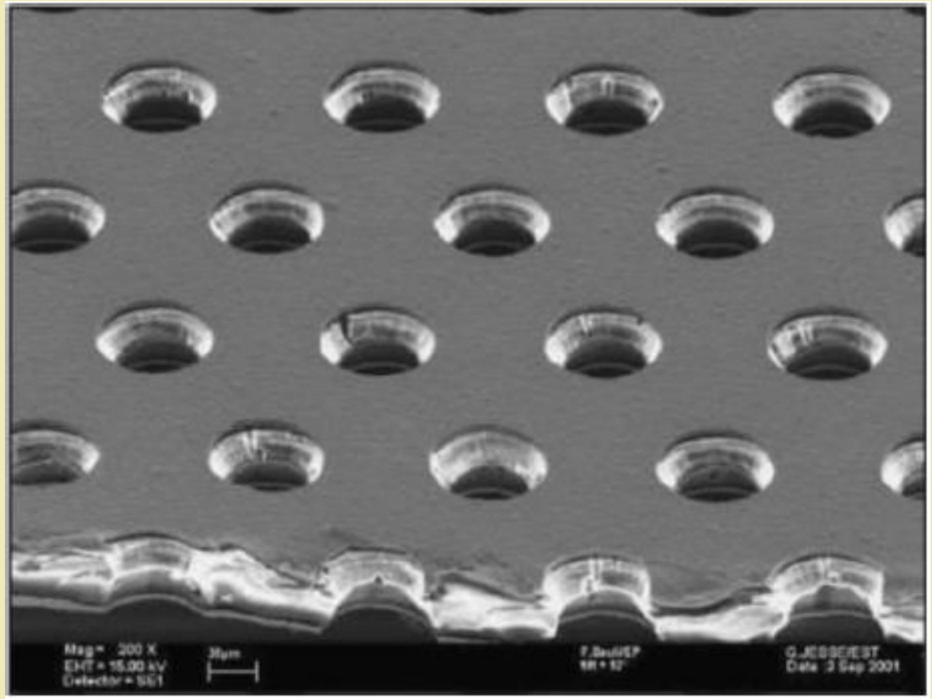
GEM Detectors

- Gas Electron Multiplier
- Gaseous detectors
- Drift cathode, GEM foils, Readout anode
- Exploits ionization throughout gas volume



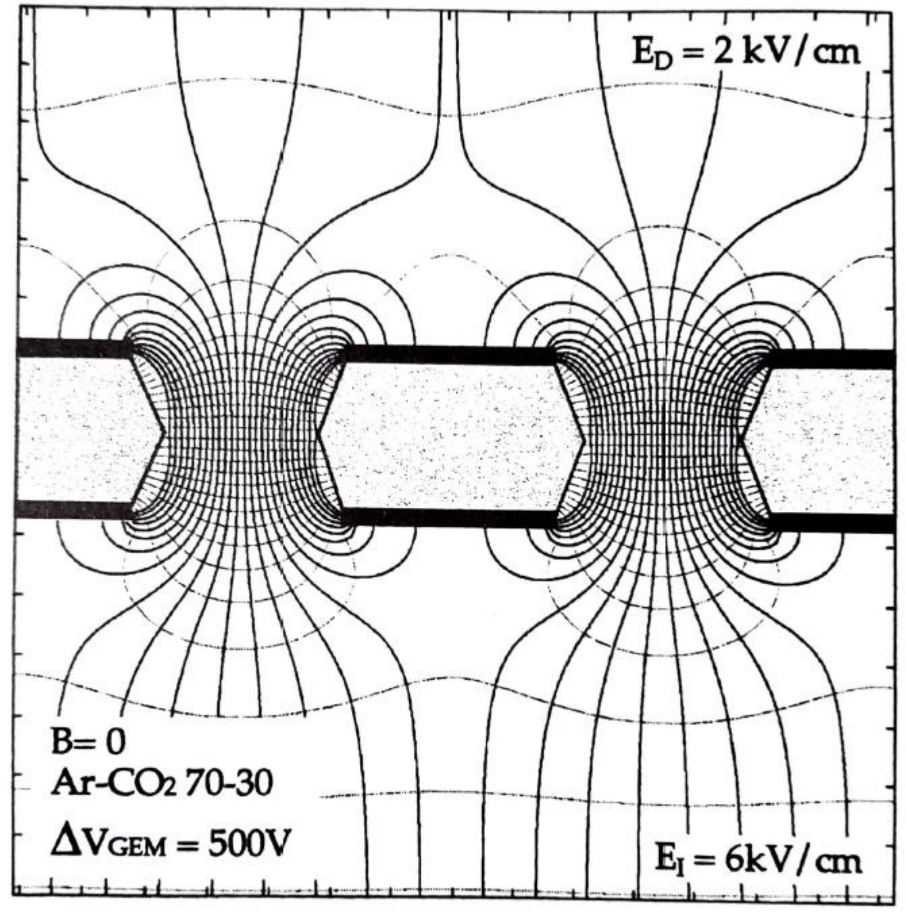
GEM Foils

- Metal-coated Polyimide foils
- Chemically etched
  - Typically 50-100 per sq. mm.
- Double-conical holes reduce charging up of the insulator, effecting gain



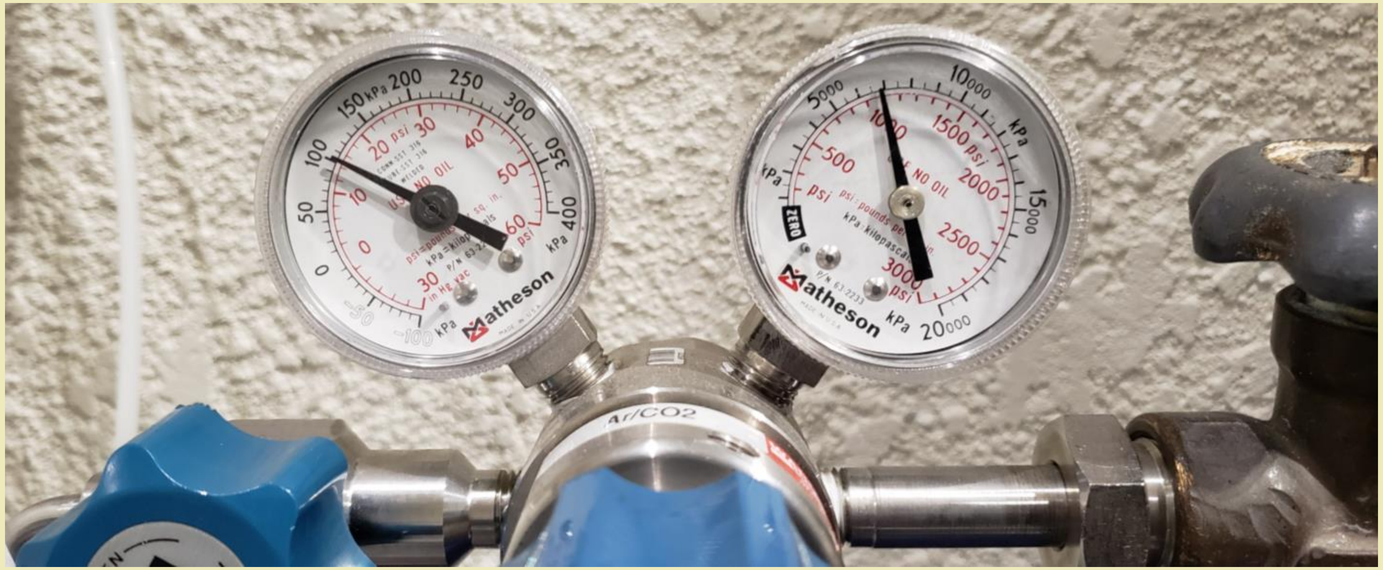
GEM Holes

- High potential difference across foil sides, high electric field
- Freed electrons accelerated through GEM holes
- High energy collisions cause further ionization
- Electron avalanche, signal amplification



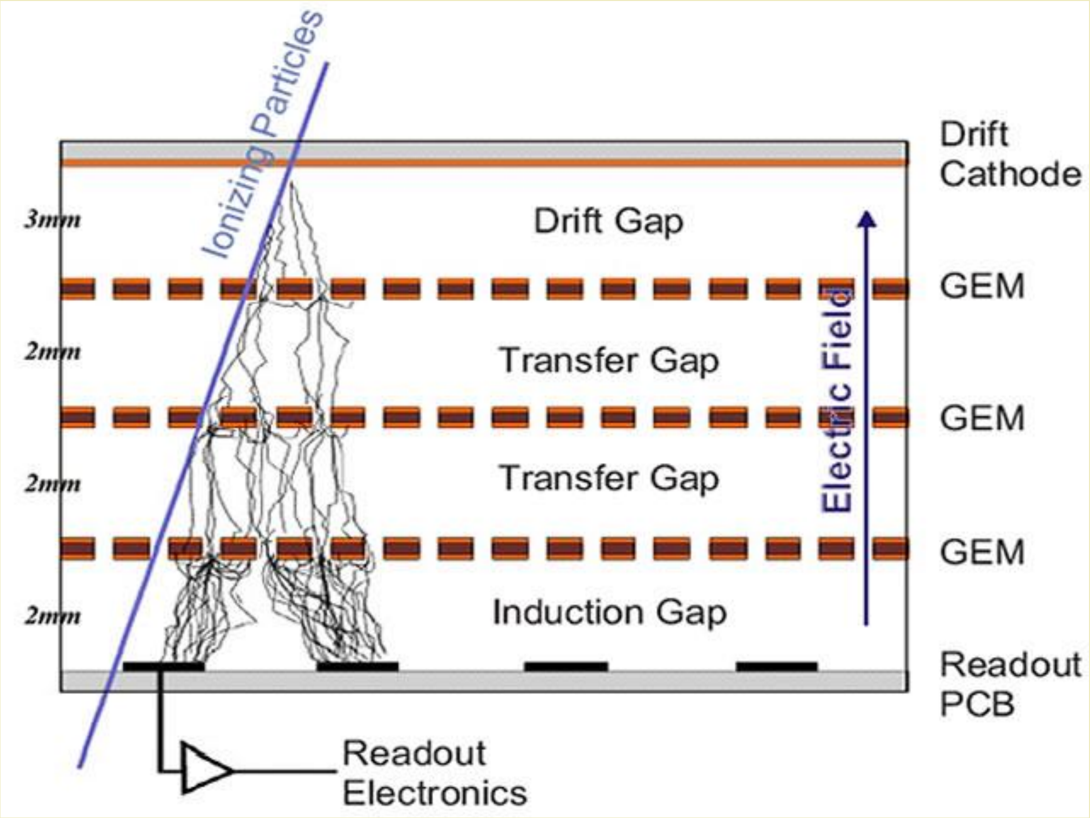
Gas

- Argon/CO_2 70:30
- Argon atoms ionized
  - De-excite via photon emission
- CO_2 dissipates energy without photon production
  - Important for stability at high gain



GEM Detectors

- Often have multiple GEM foils
- Works with the same method as single foil
- Divides the job of increasing gain, reducing change of discharges



Gas Gain

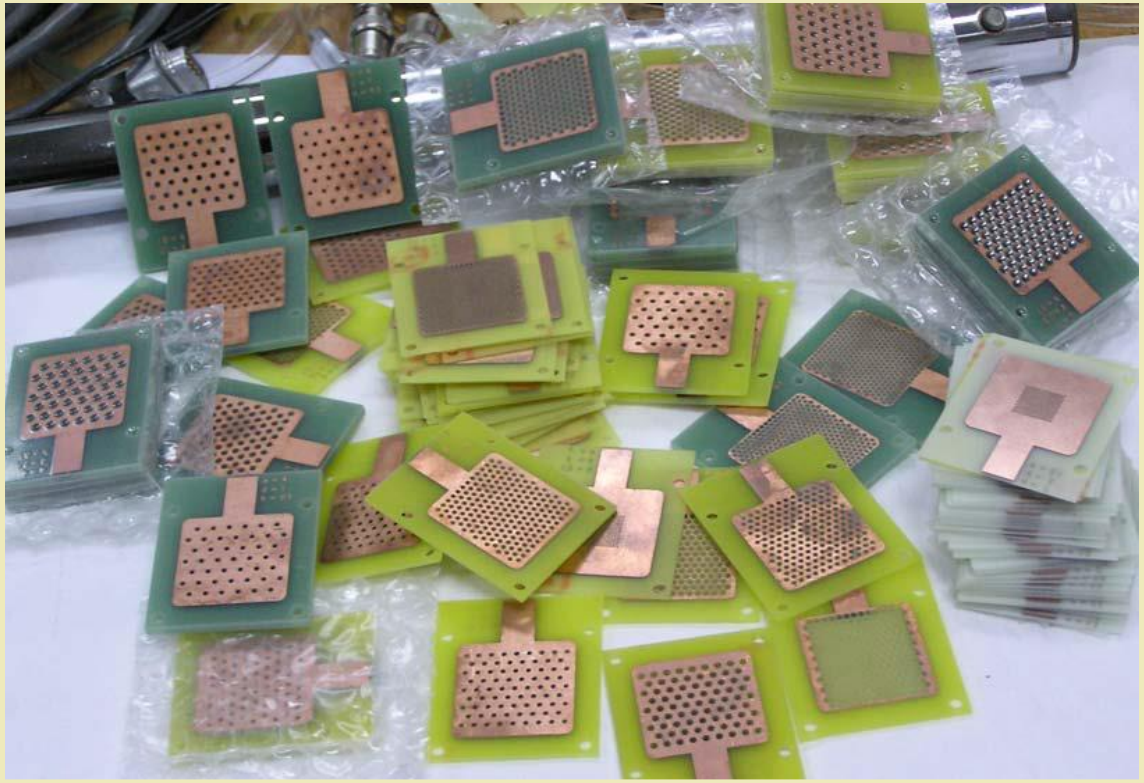
- Large number of electrons at anode greater than without avalanche
- Increase in signal known as Gas Gain
- 10^4-10^5 gains possible (not typical)

Gas Gain

- Measured by irradiating with X-rays, measure current and rate
- Multiplication factor
- $G = \frac{I}{eNR}$
  - e elementary charge, N number of primaries, R incident rate

Thick GEMs

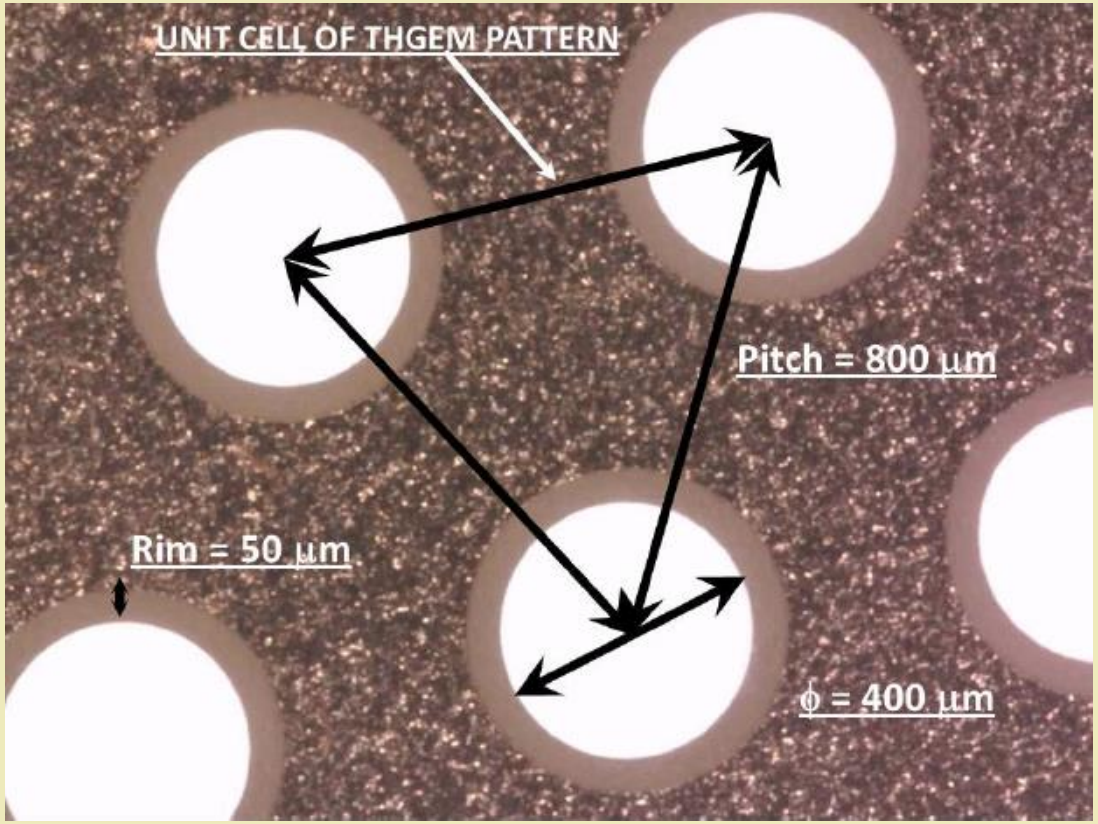
- Thicker version of GEMs
- Typically made of sturdier, more robust, PCB material
- Usually formed through PCB techniques, hole drilling
- Can be made cheaply
- Larger holes
- Comparable gain, moderate localization resolution
- High rate capabilities, fast signal production



R. Chechik, et al. Progress in Thick GEM-like (THGEM)-based Detectors. SNIC @ SLAC April 2006

THGEM Rims

- Clearance rims instead of double-conical holes
- Can have effects on the gain, as well as long-term effects

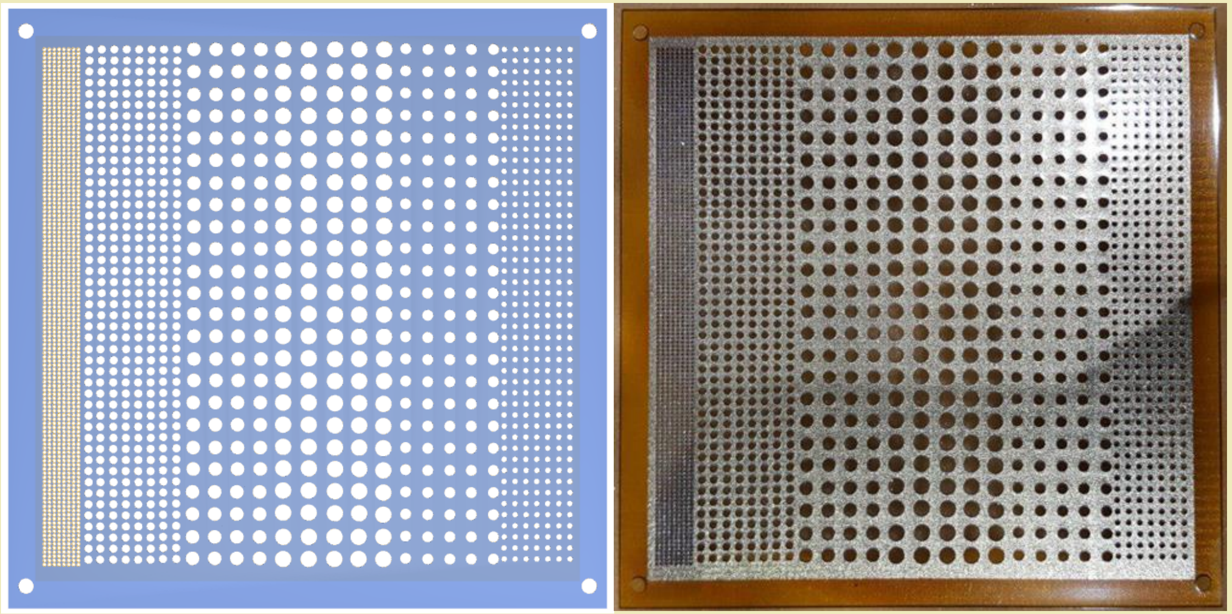


Question

- Can a 3D-printed Thick GEM serve as a functioning GEM in a detector?

THGEM Designs

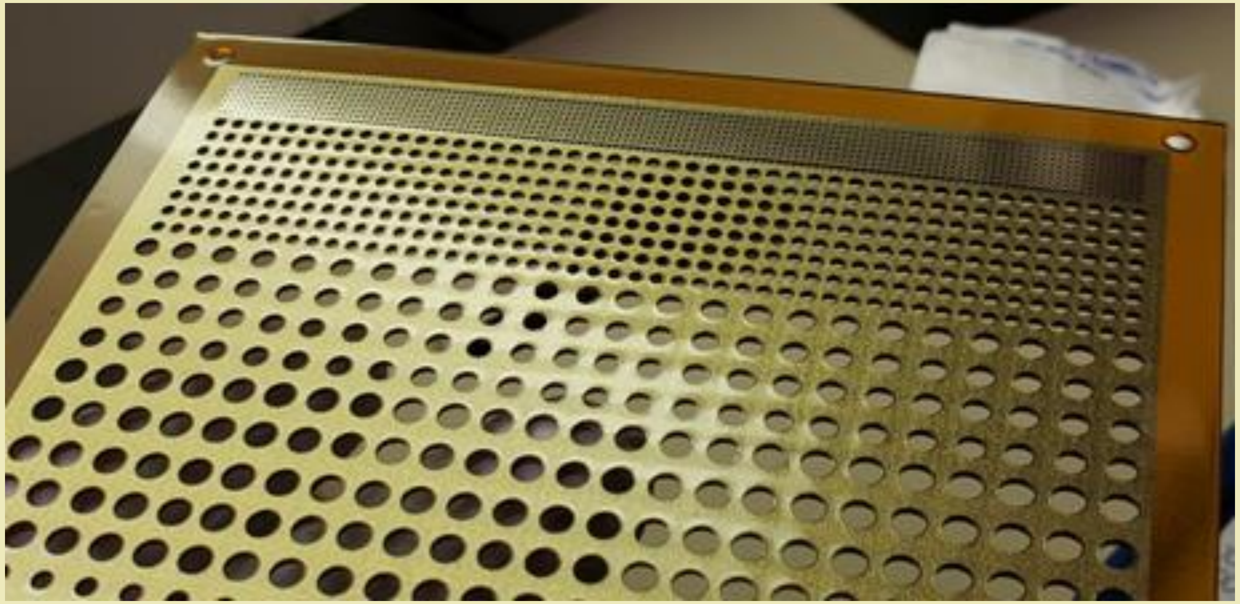
- Design depends on motivations for study
- 3D-printed THGEM
  - Altium Designer
- First design a 9 cm × 9 cm sampler
  - Hole sizes (mm): 0.5, 1.5, 2.5, 3, 2, 1 left to right
- Would examine which hole size produced the greatest gain



(Left) 3D Altium Designer view of board model; (right) printed version

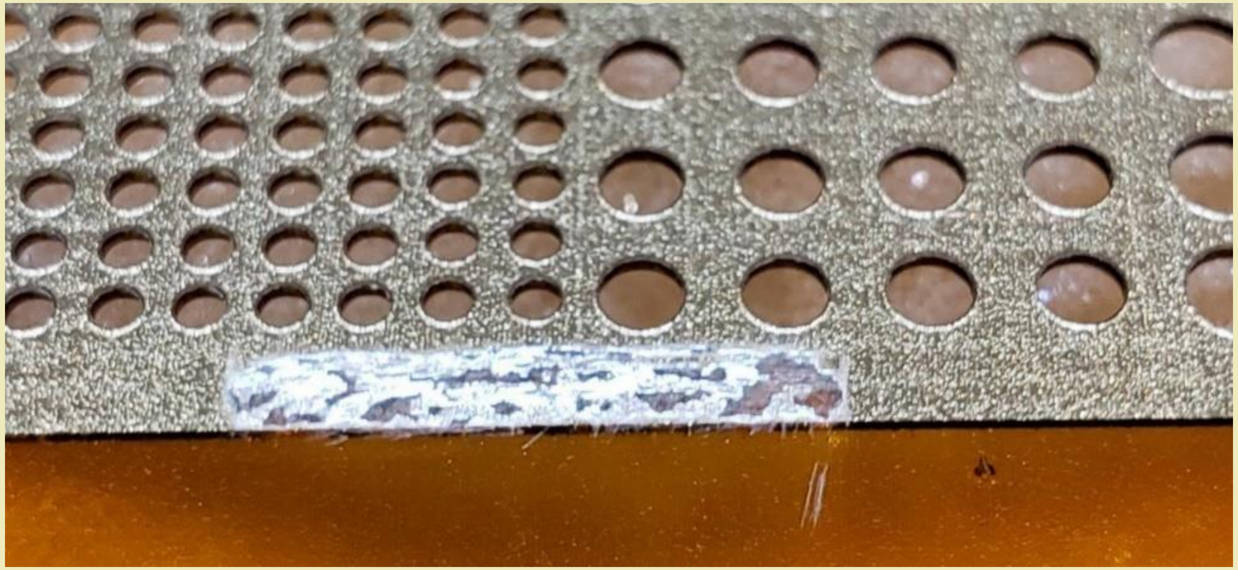
Solder Mask

- Solder mask placed over the silver layers of the board
- Glossy, can be seen in microscope images



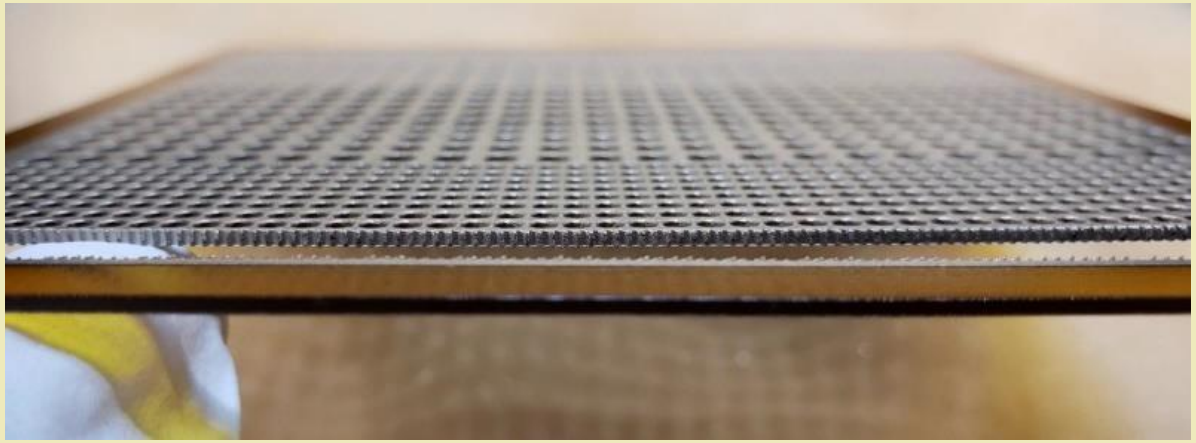
Solder Mask

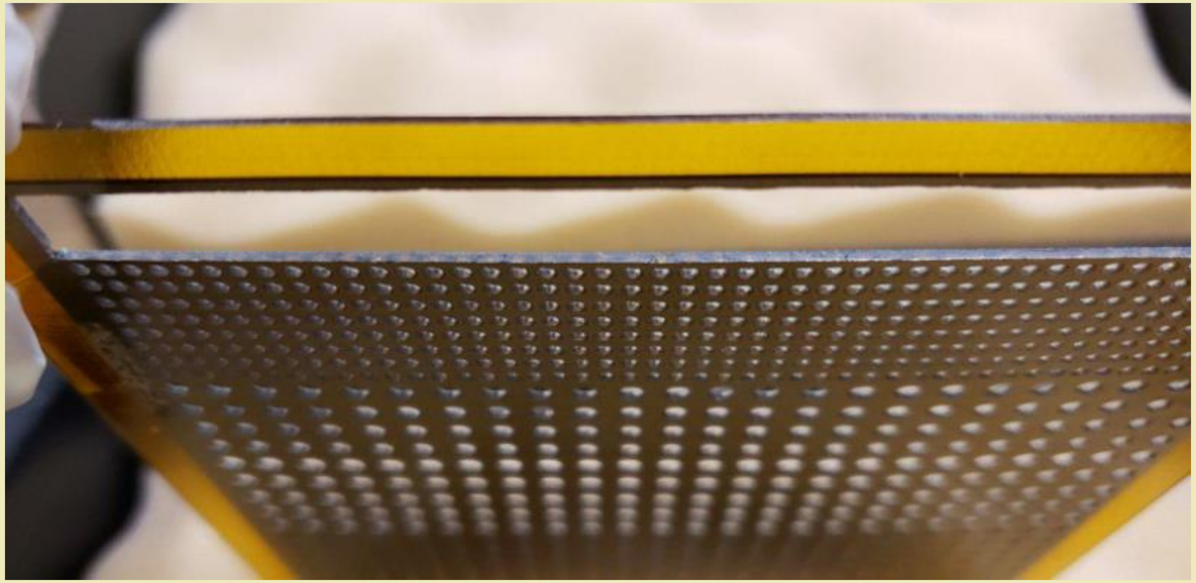
- Carbide Scribe used to remove mask material
- Revealed silver layer underneath
- Test with a digital ohmmeter confirmed underlying conductivity
- Could use exposed regions to power the board



Board Issues

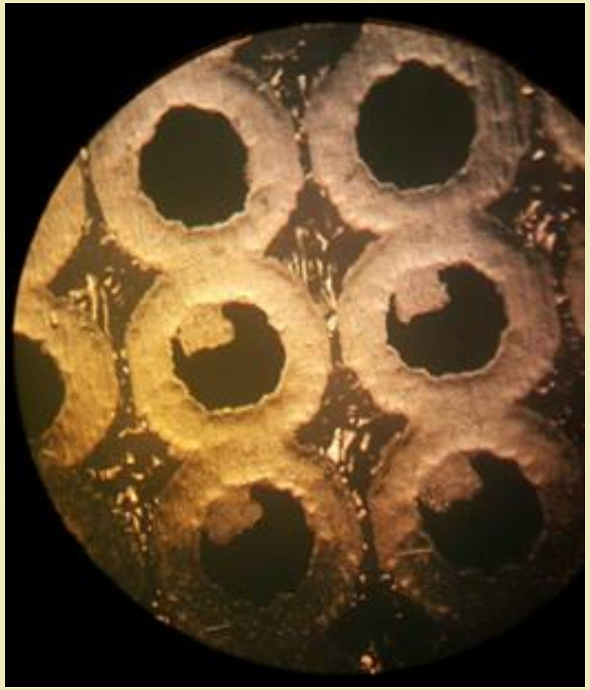
- 0.5mm holes did have exposed silver around them
- Holes erroneously made through-plated, which would short out the THGEM
- Became a weak region
- Had to be removed
- Shaved away metal with X-Acto knife
- Still some top-bottom connectivity

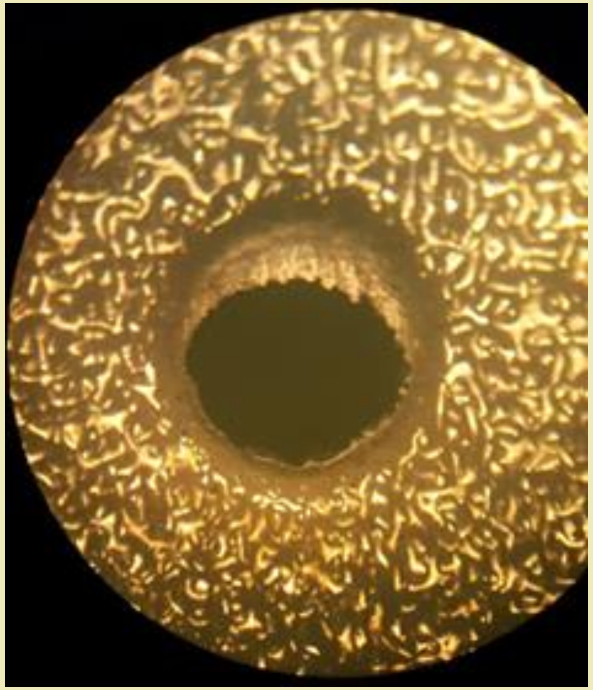




Hole Issues

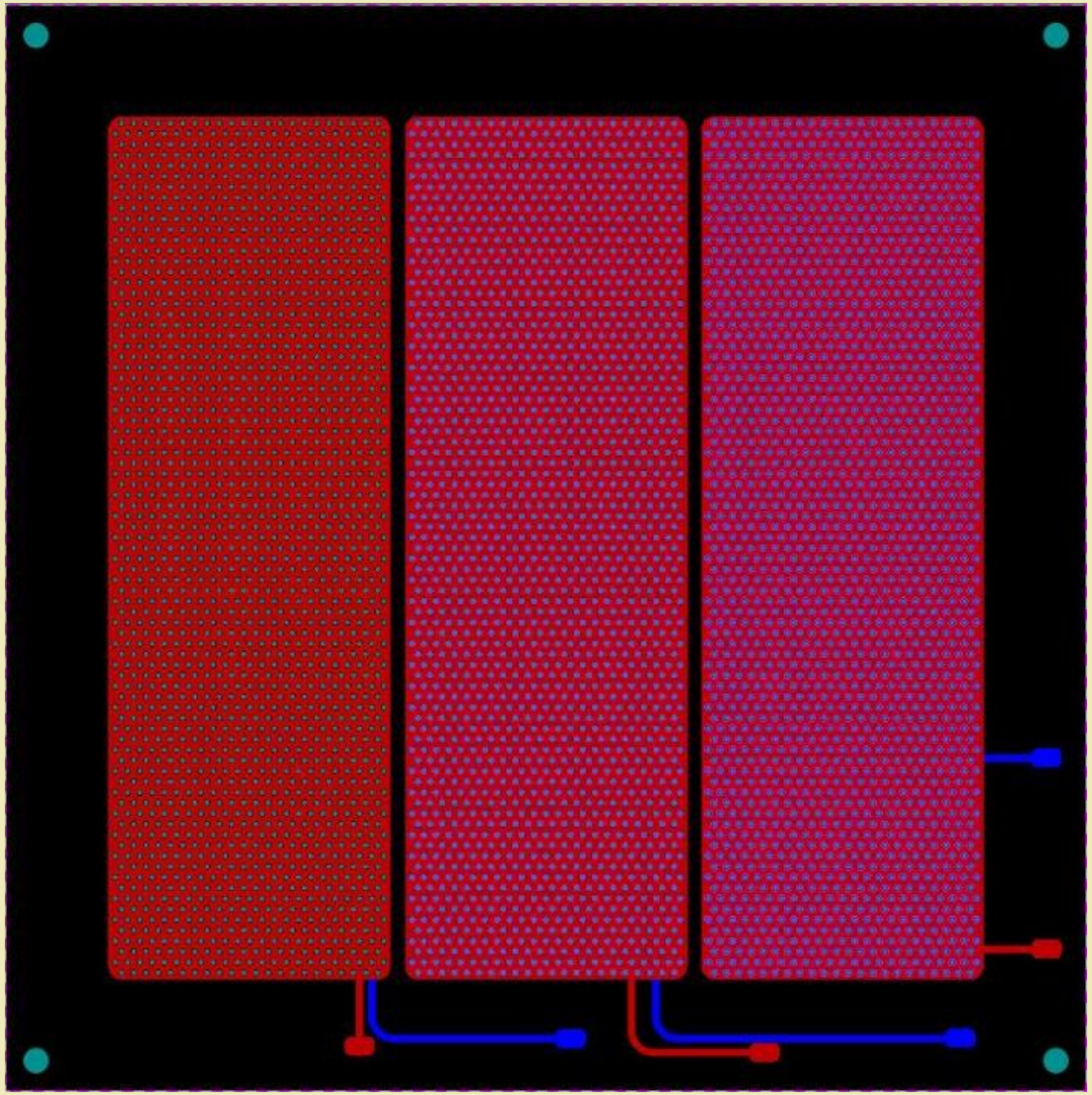
- Printing error artifacts very common on this board
- Could significantly affect the electric fields within the holes, thus the gain
- These errors as well as other damages which occurred led to this THGEM being abandoned





Final Design

- New design produced, having traces leading to pads for mounting HV
- 10 cm × 10 cm divided into 3 10 cm × 3.3 cm sectors
- Powered independently within this “10×10 Detector”
- Three THGEMs on one board

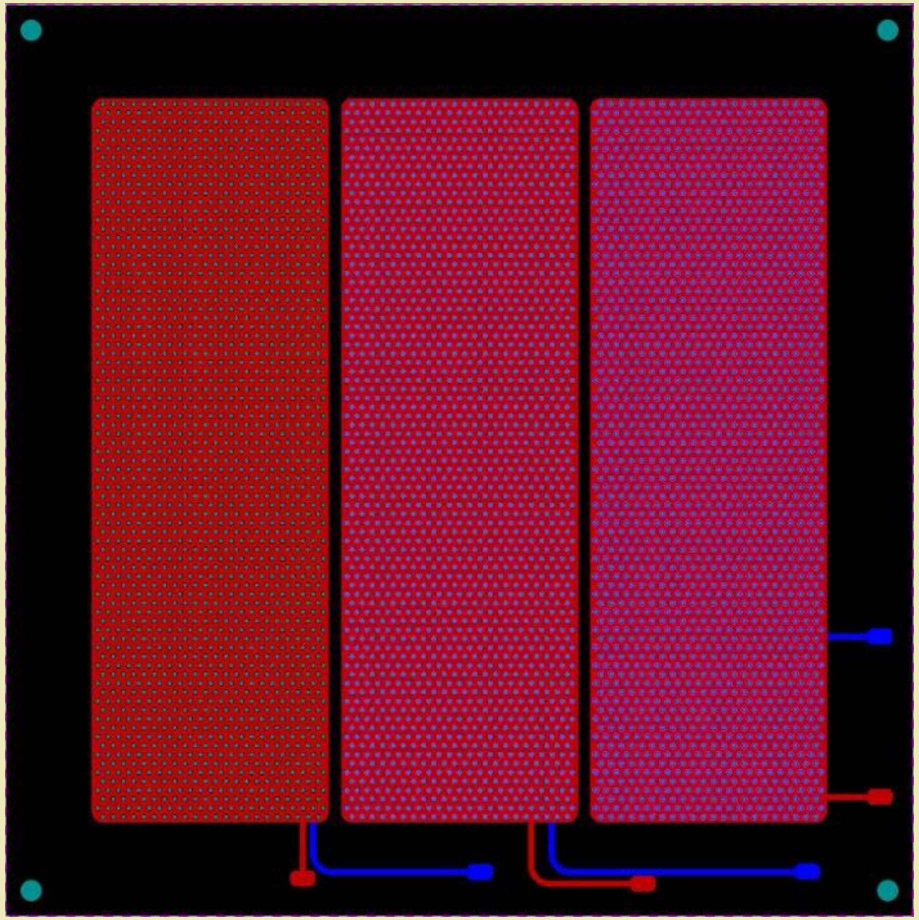


Design Motivations

- Effects of Rims on gain
- Long-term evolution of gain

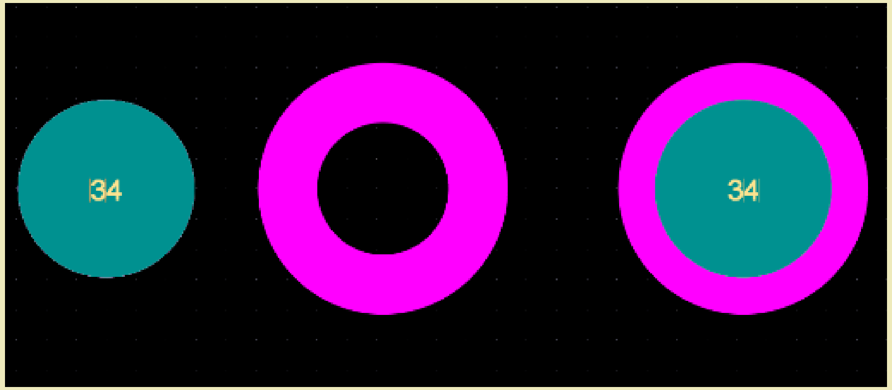
Board Design Details

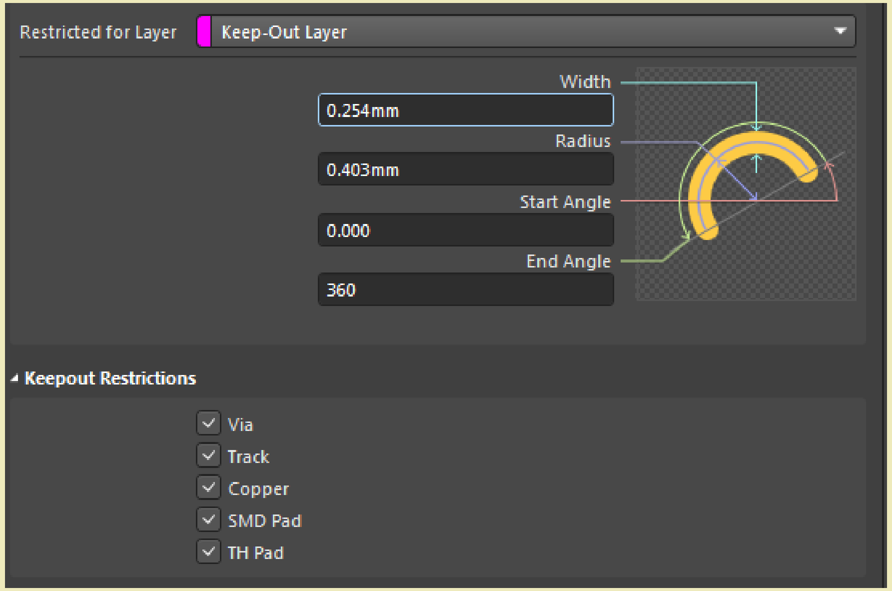
- All holes 0.7 mm
- Pitch 1.4 mm
- Thickness 0.7 mm
- Rims (left sector to right): 0 mm, 0.1 mm, 0.18 mm

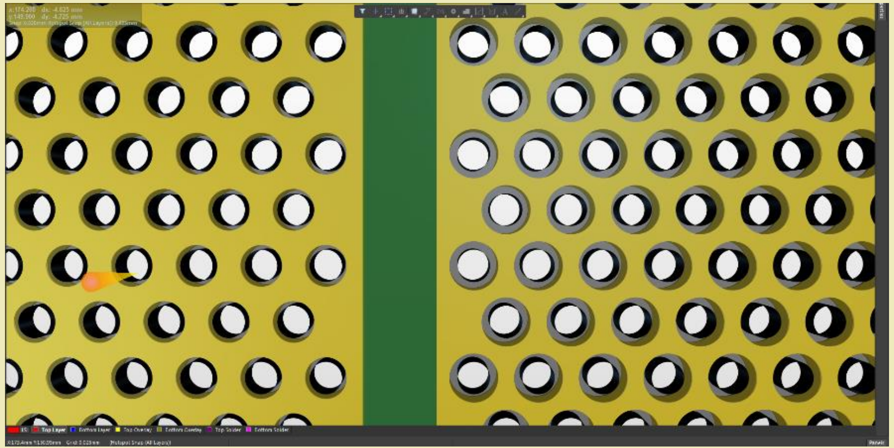


Board Design Details

- Non-plated through-holes
- Keep-out layer "rings" sized appropriately
- Produces an annulus in which no metal will be printed

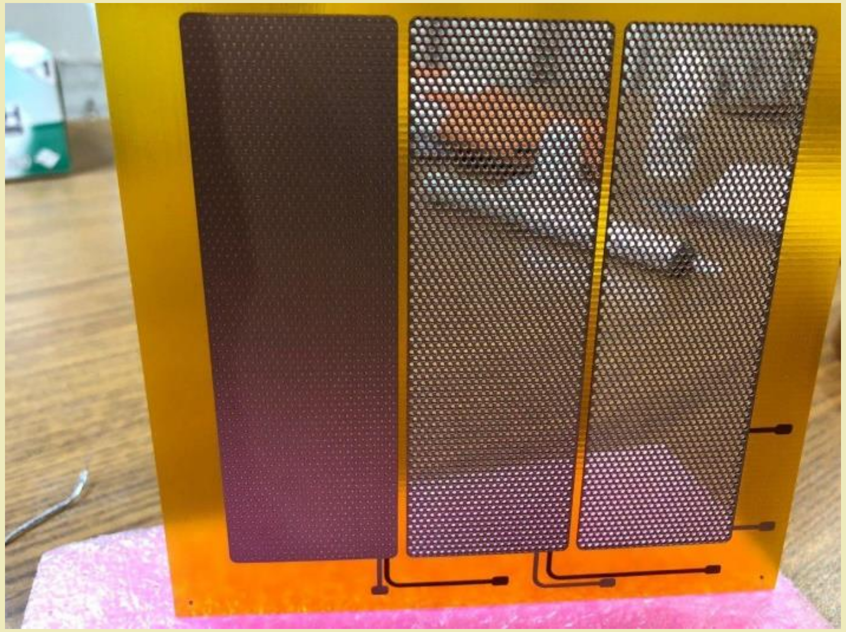


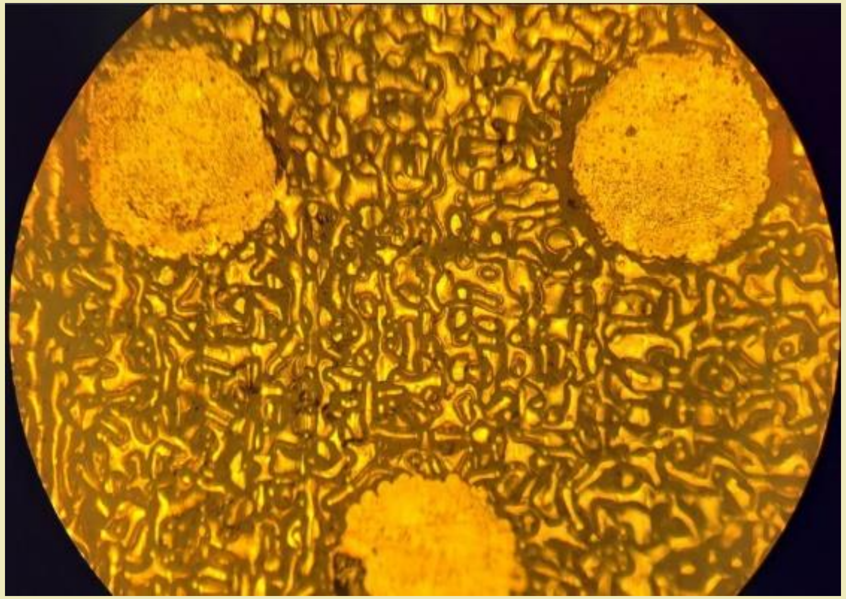




Solder Mask

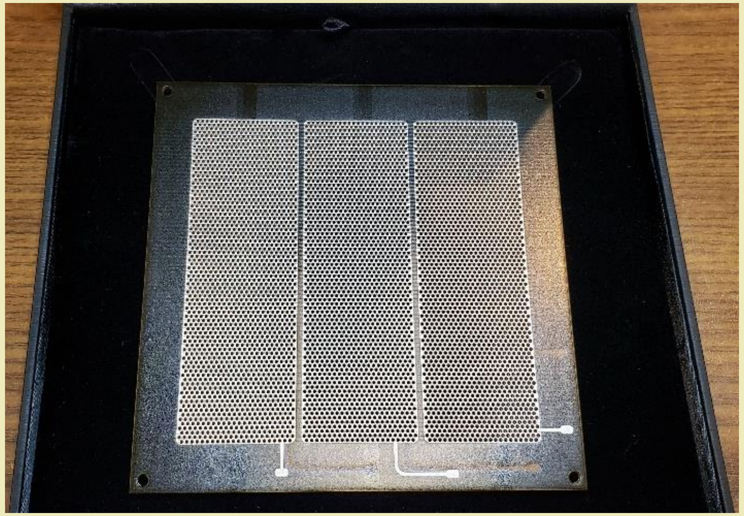
- Solder mask still present in print
- Covering whole metallic surface except a few patches
- Fully clogged the no-rim holes
- Eliminated any masking in the design file and worked with manufacturer to ensure none in the next print

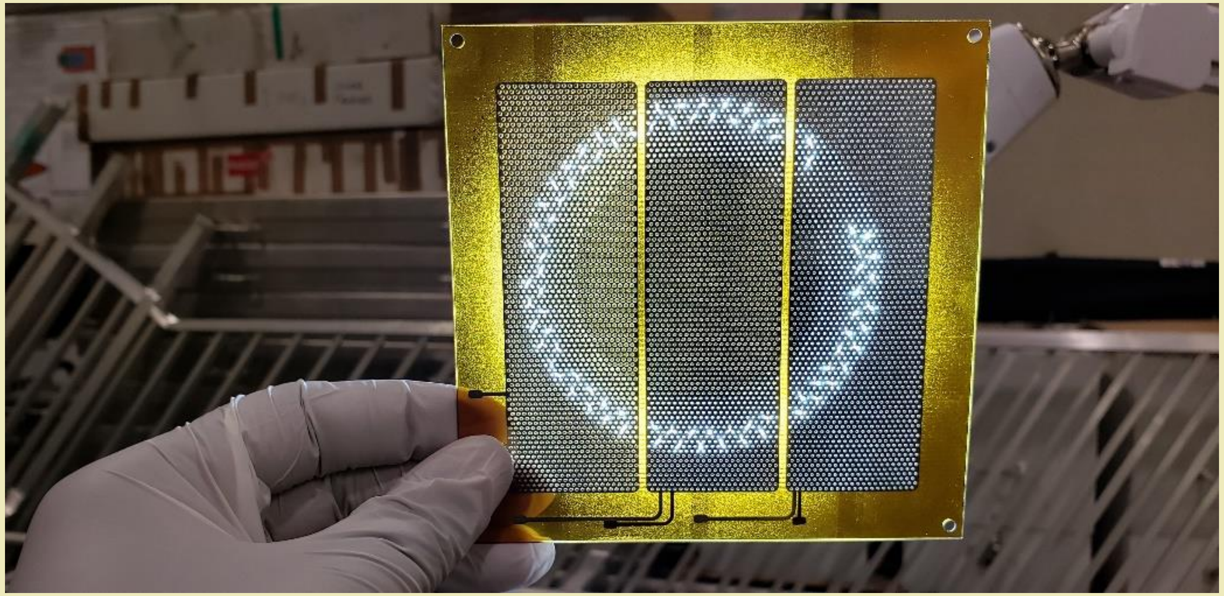




Successful THGEM Arrival

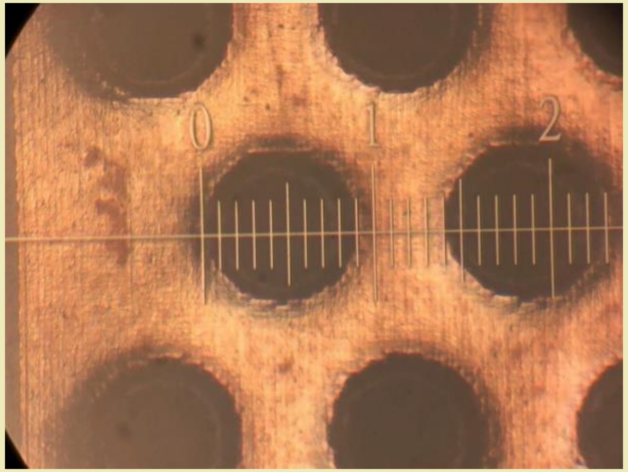
- New solder mask-free print arrived
- Conductive over the entire surface, front and back



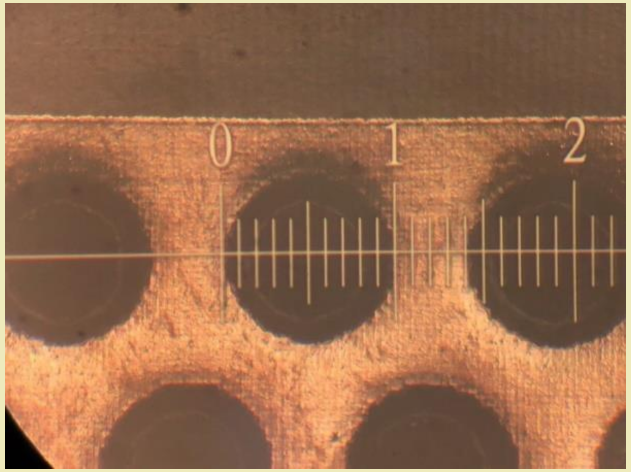


Hole Microscopy Investigation

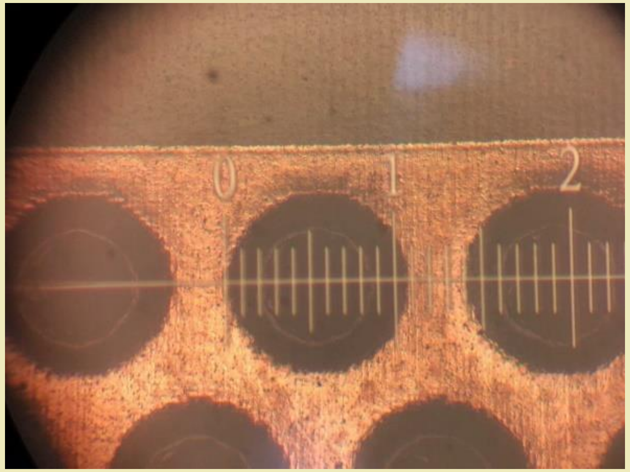
- No solder mask, holes look much more uniform
- Free of troublesome printing artifacts
- Holes for all sectors were 0.7 mm diameter
- Sector designed for no rim actually 0.1 mm rim
- Sector designed for 0.1 mm rim actually 0.15 mm rim
- Sector designed for 0.18 mm rim actually 0.2 mm rim



"No rim"



"0.1 mm rim"



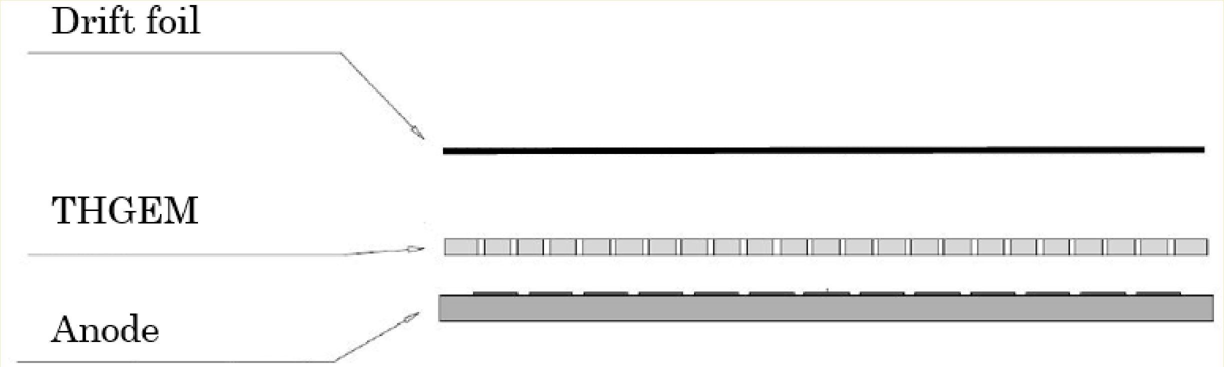
"0.18 mm rim"

THGEM Sectors Close-up

Close-up of the three sectors with rim sizes (from left to right) of 0.1mm, 0.15mm, and 0.2mm.

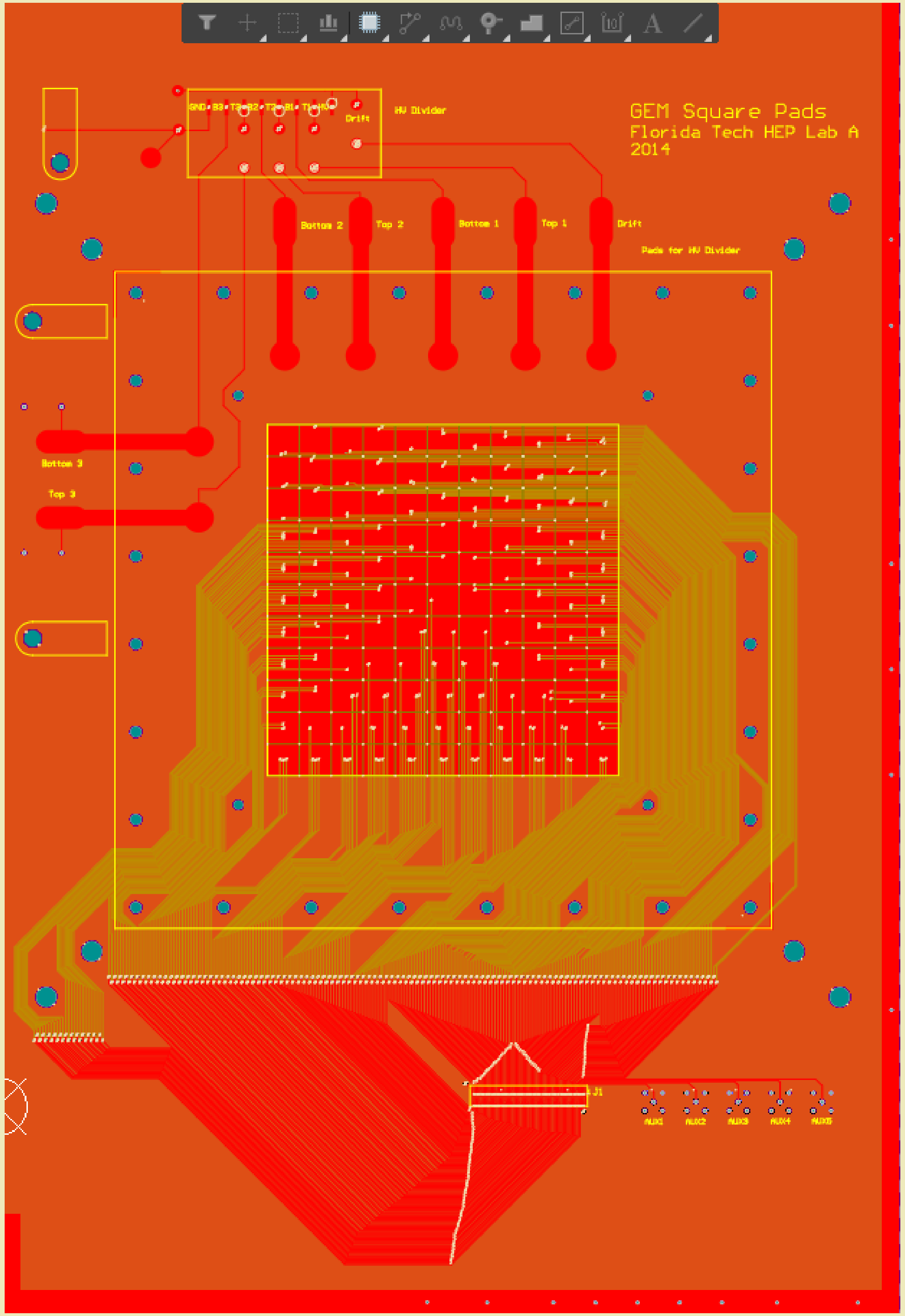
Assembly

- GEM stack formed from a drift cathode, the THGEM, and a readout anode
- Drift gap 3 mm
- Induction gap 1 mm



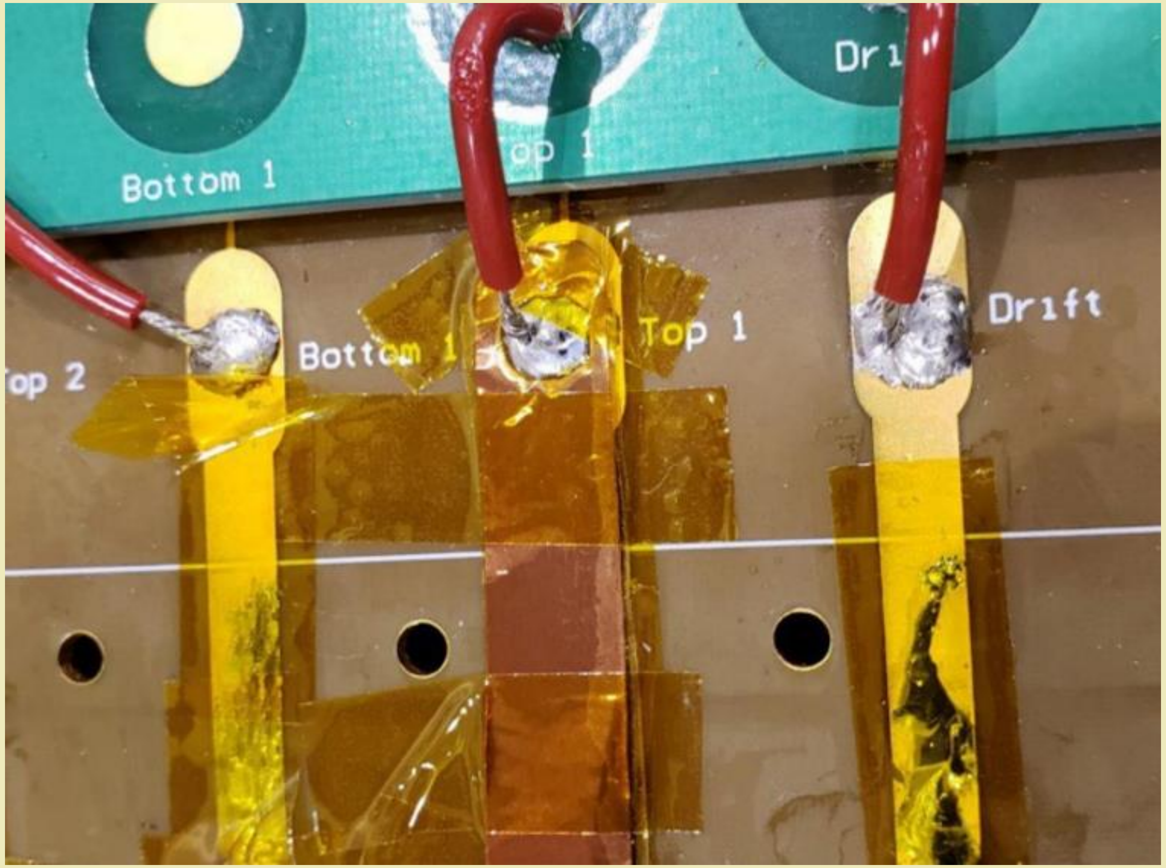
Readout

- Initial readout board was square pad pattern
- Issues found with components at the top
- L-shaped HV board used to power detector
- Continued to use this board



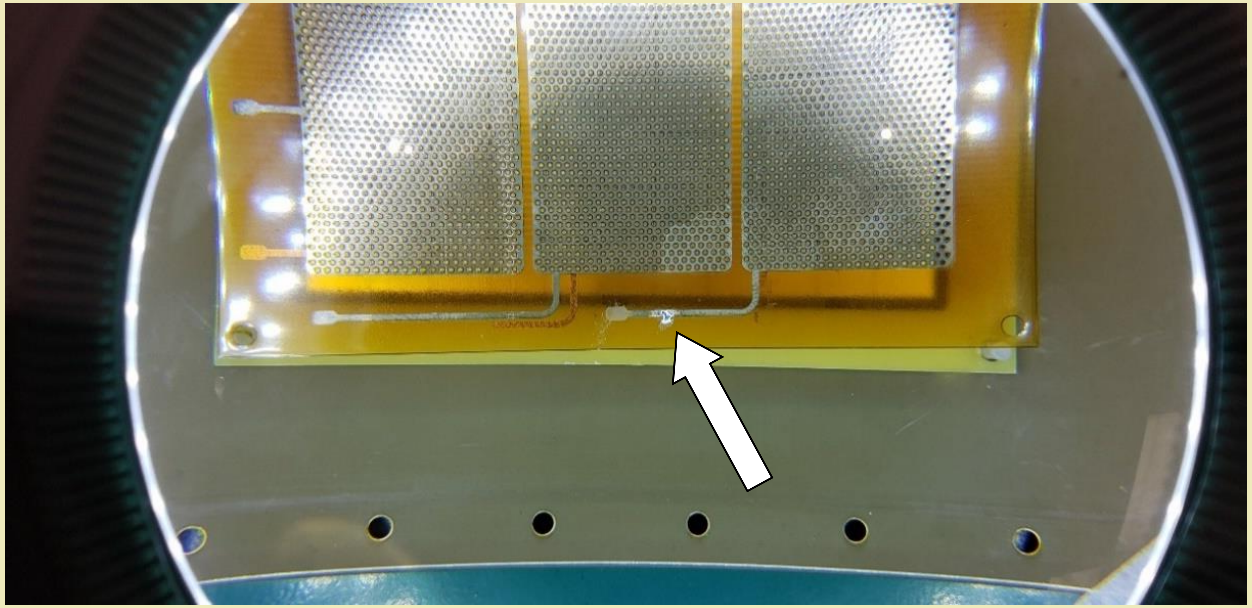
Trace issue

- The traces were also shown to have some issue
- Copper tape version made as a replacement



Powering THGEM

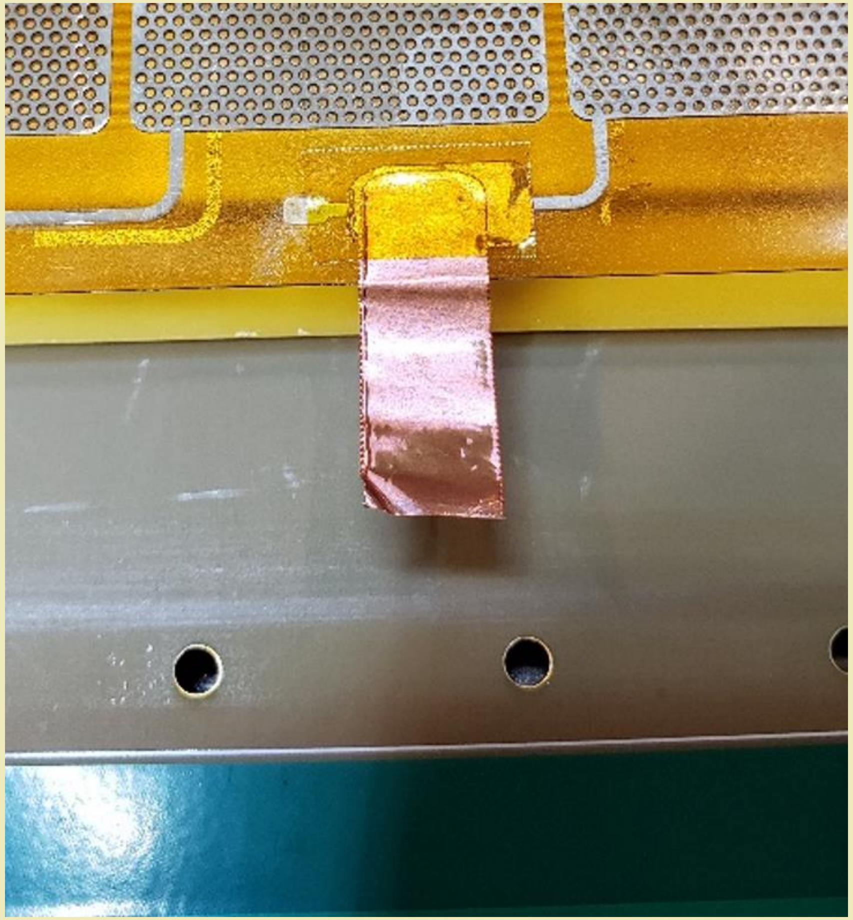
- In order to carry the HV to the THGEM electrodes, tried soldering copper tape strips to pads
- Often broke at the solder point when detector closed
- Silver layer peeled off



Exposed plastic material where there once was silver trace. Solder remaining after attempted removal can also be seen.

Powering THGEM

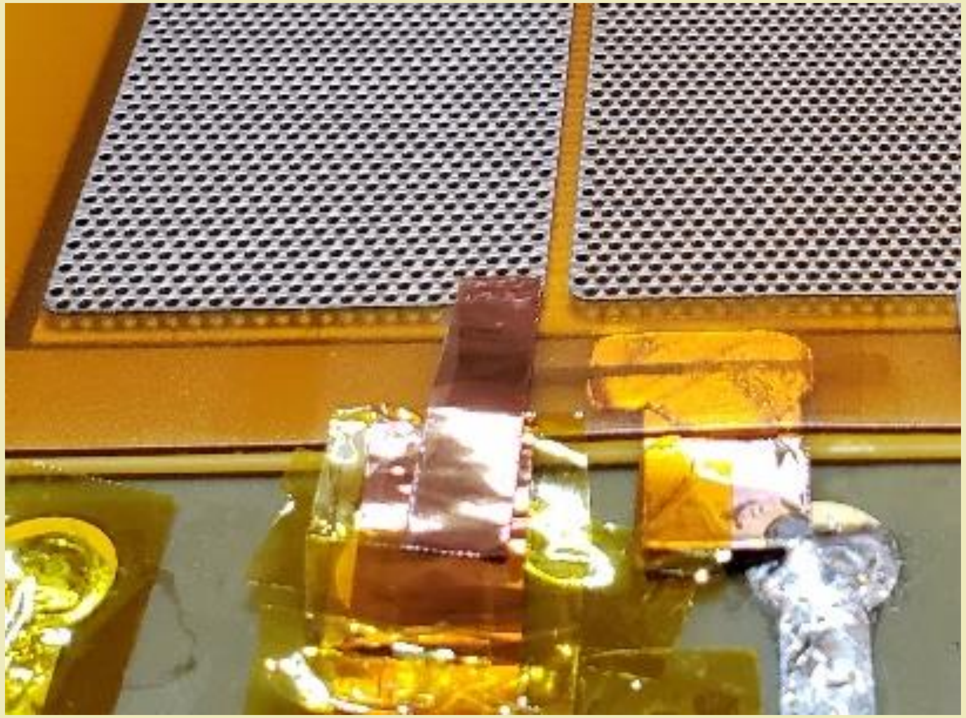
- Kapton-reinforced Copper Tape used to make connection without the use of solder
- Applied to remaining trace



Kapton-reinforced copper tape strip,
small rim sector bottom

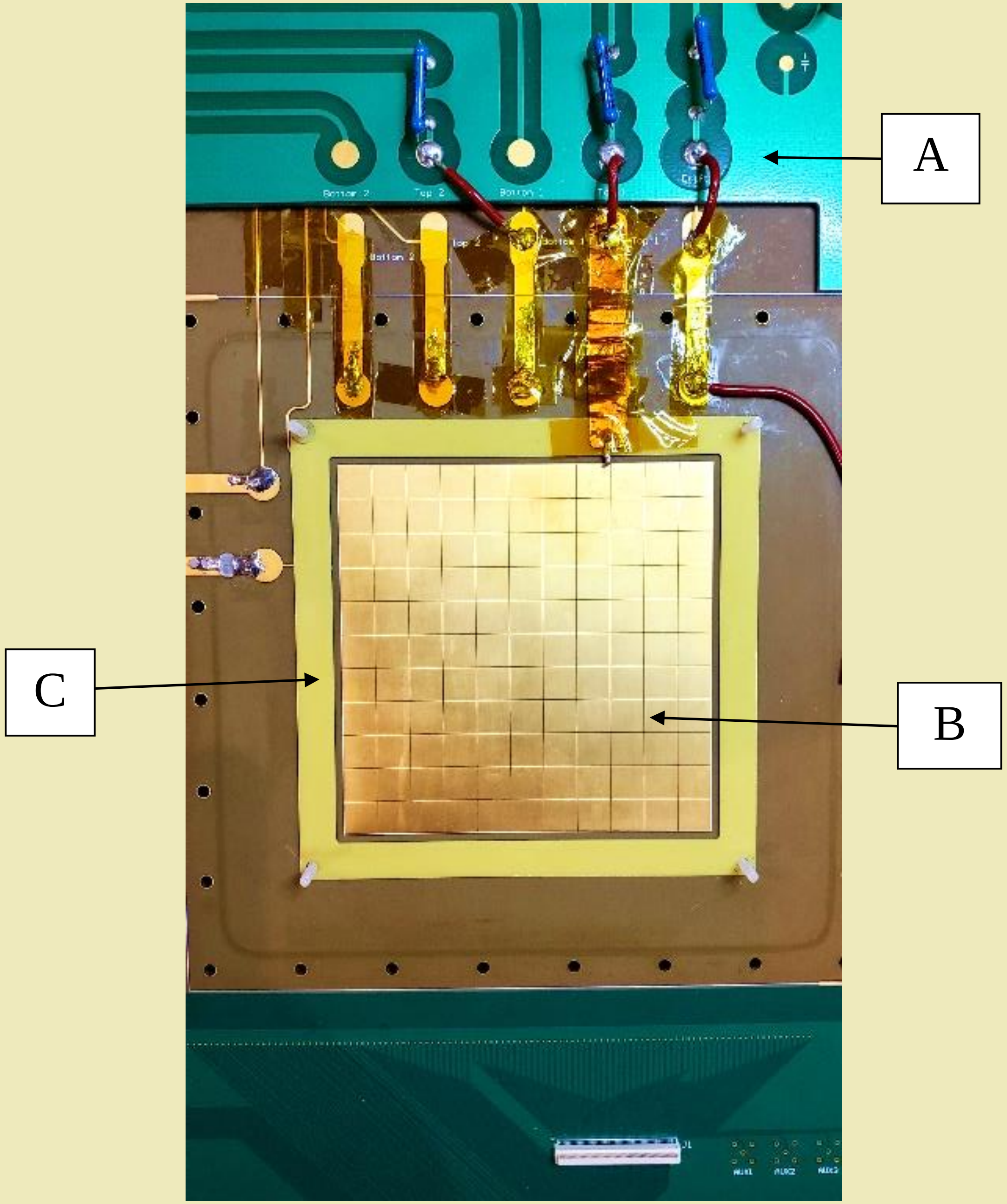
Powering THGEM

- Small rim sector Top lost a lot more trace
- Copper tape added directly to active region
- Top and Bottom both found to have good electrical conductivity



Assembly

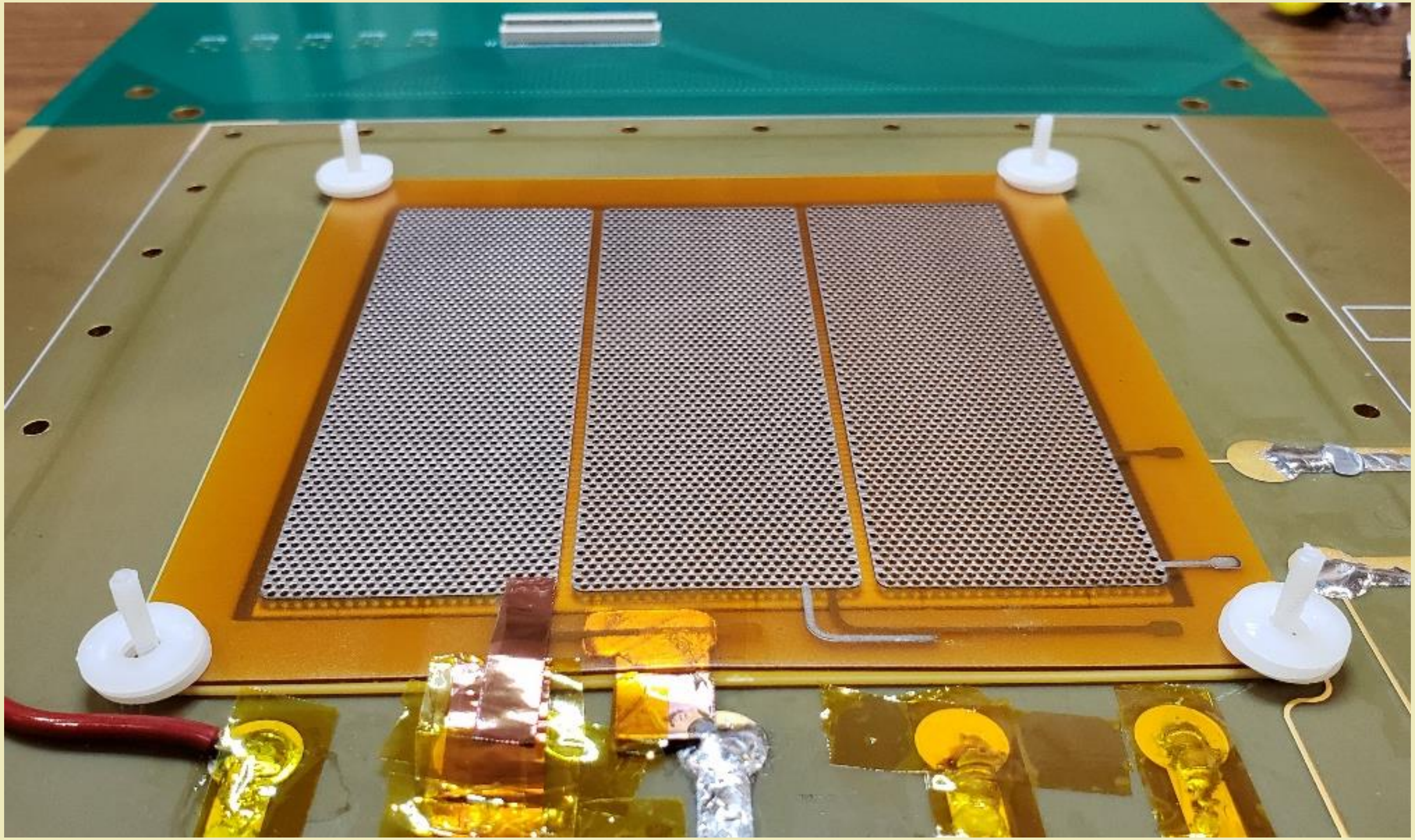
- Straightforward assembly
- Readout board contains anode and traces leading to Panasonic connector
- 1 mm spacer placed on top of 4 corner nylon rods
- HV moves through the protection resistors to the traces which connect to the THGEM electrodes
- Each electrode powered independently



HV board (A), anode (B), and induction gap spacer (C)

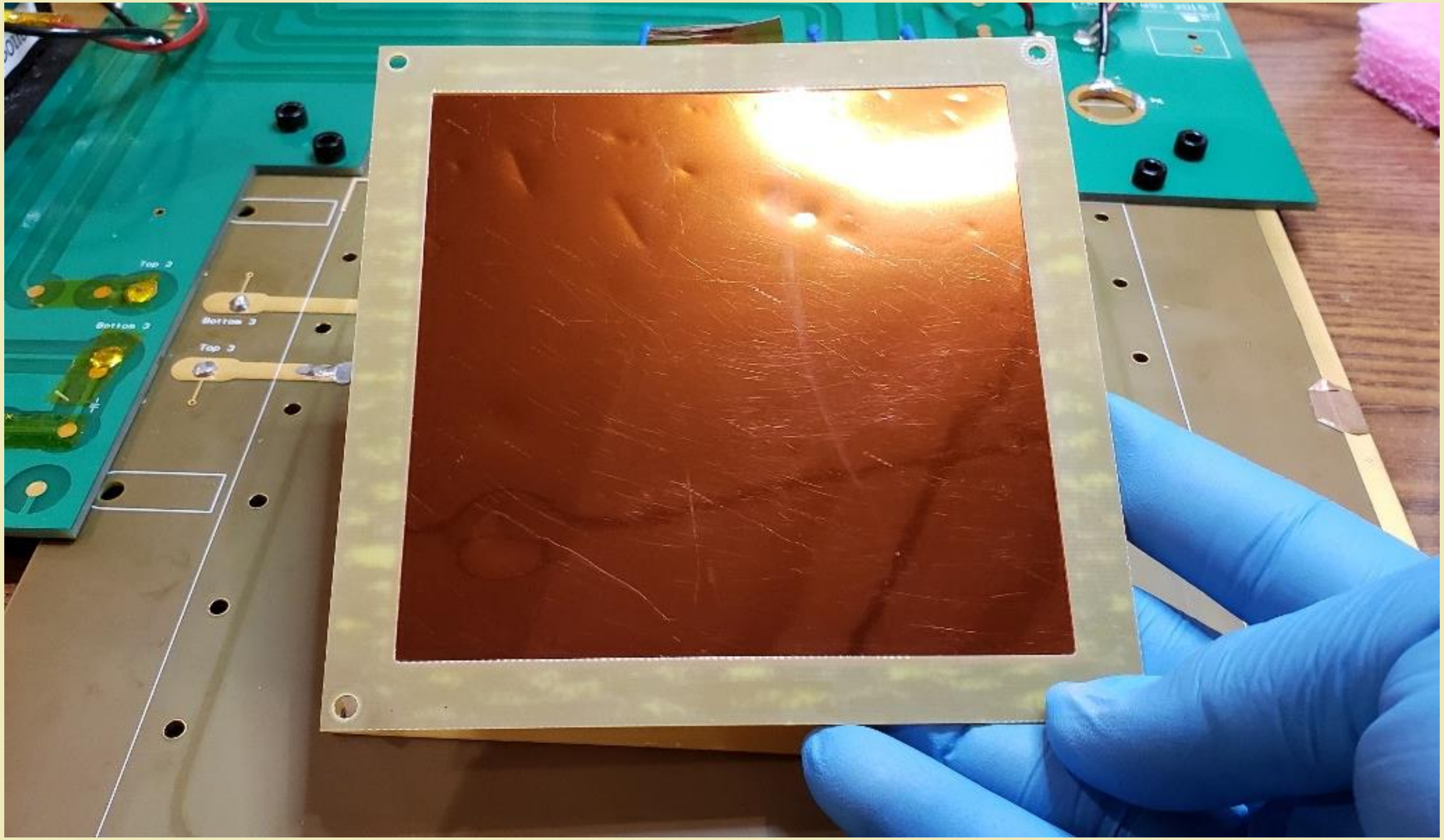
Assembly

- THGEM placed atop spacer
- Three 1-mm washers in each corner
- Forms drift gap



Assembly

- Drift cathode placed atop THGEM and washers

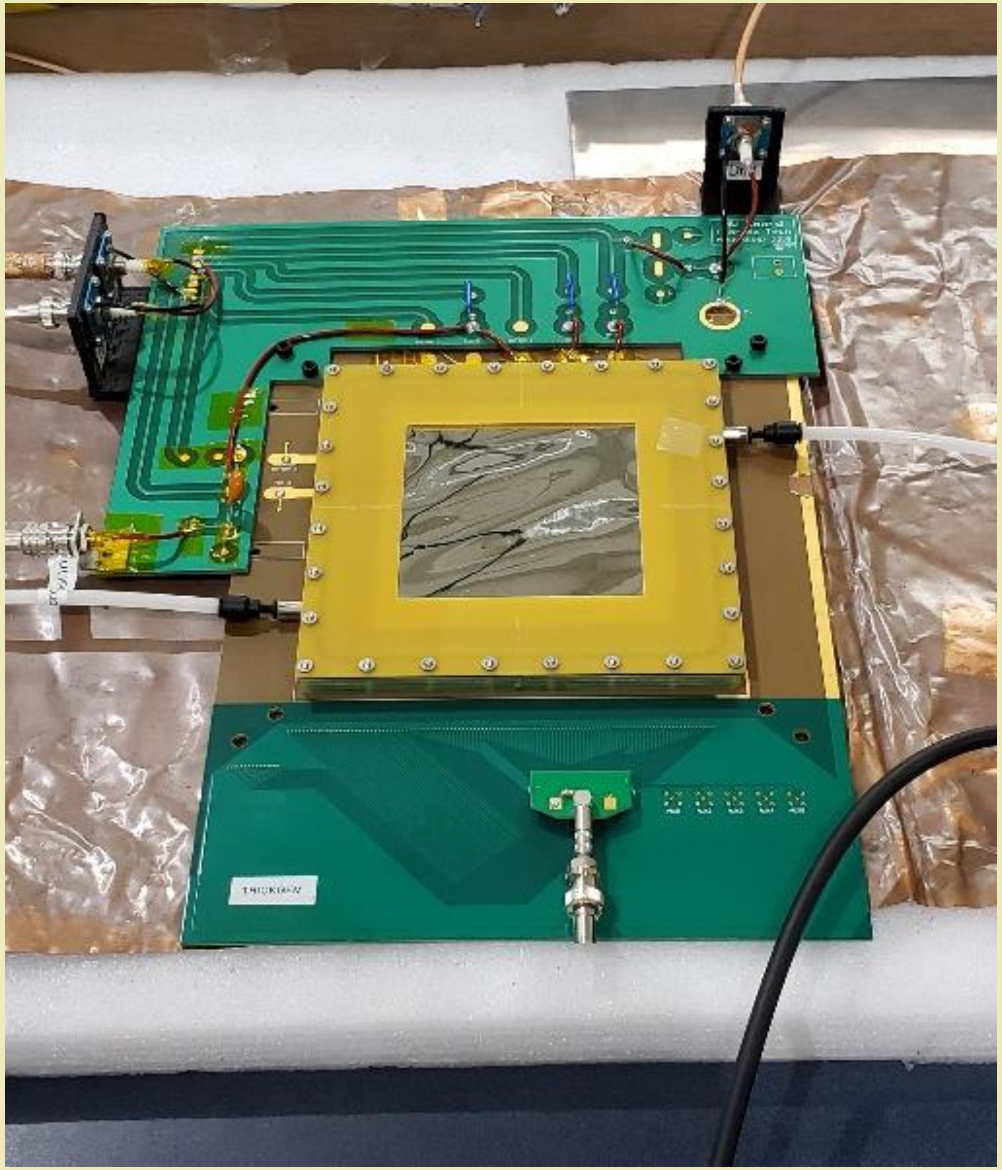


Assembly

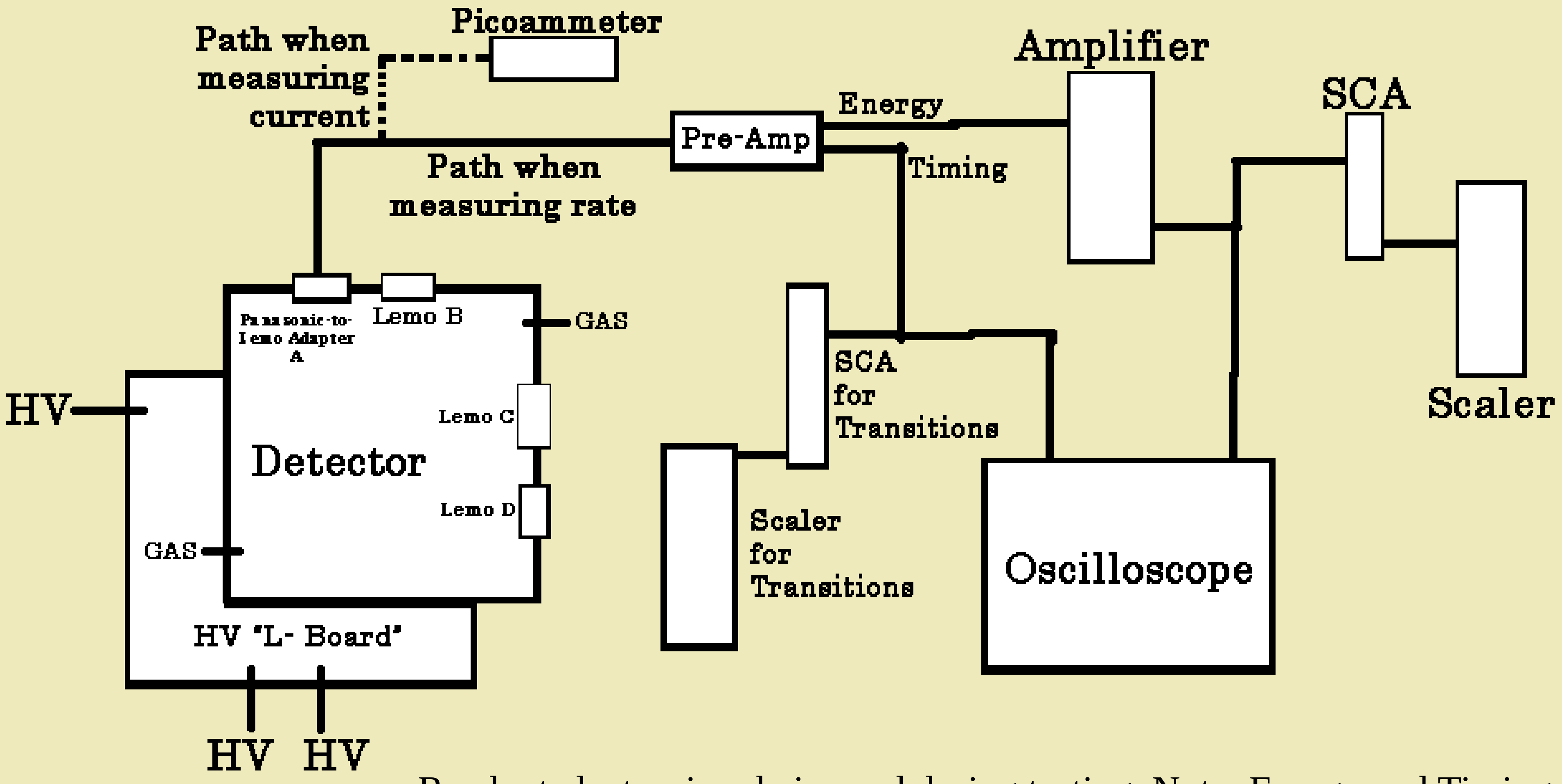
- Stack locked down with nylon nuts
- Outer frame placed around perimeter
- Contains Viton™ O-rings

Assembly

- Cover placed on, closed with nuts and screws
- Parts cleaned with silicon roller at each step
- Assembly completed



Readout Electronics Chain

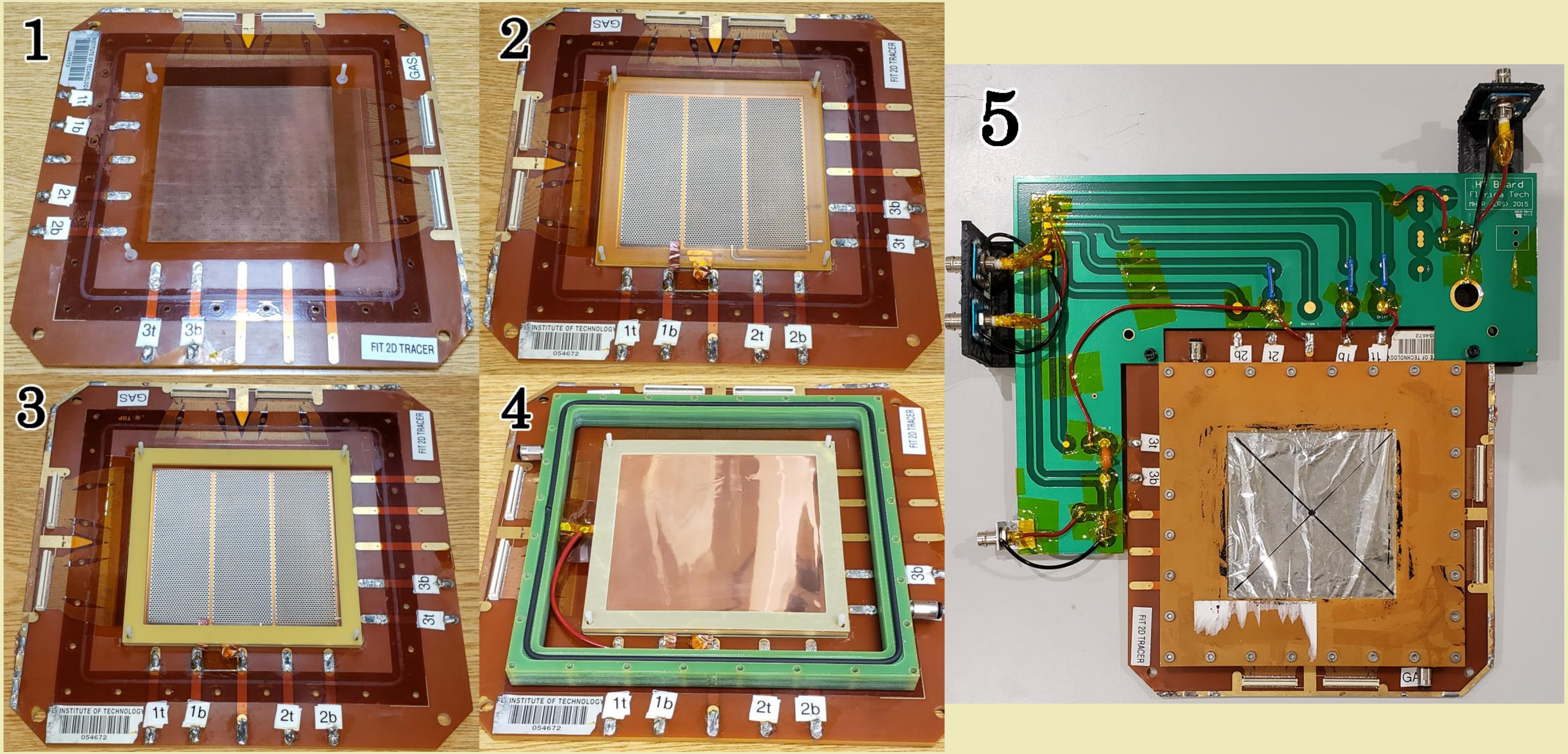


Readout electronics chain used during testing. Note: Energy and Timing outputs from the Pre-amp are just labels; the signal out of both is identical. SCA: Single Channel Analyzer.

Noise Issues

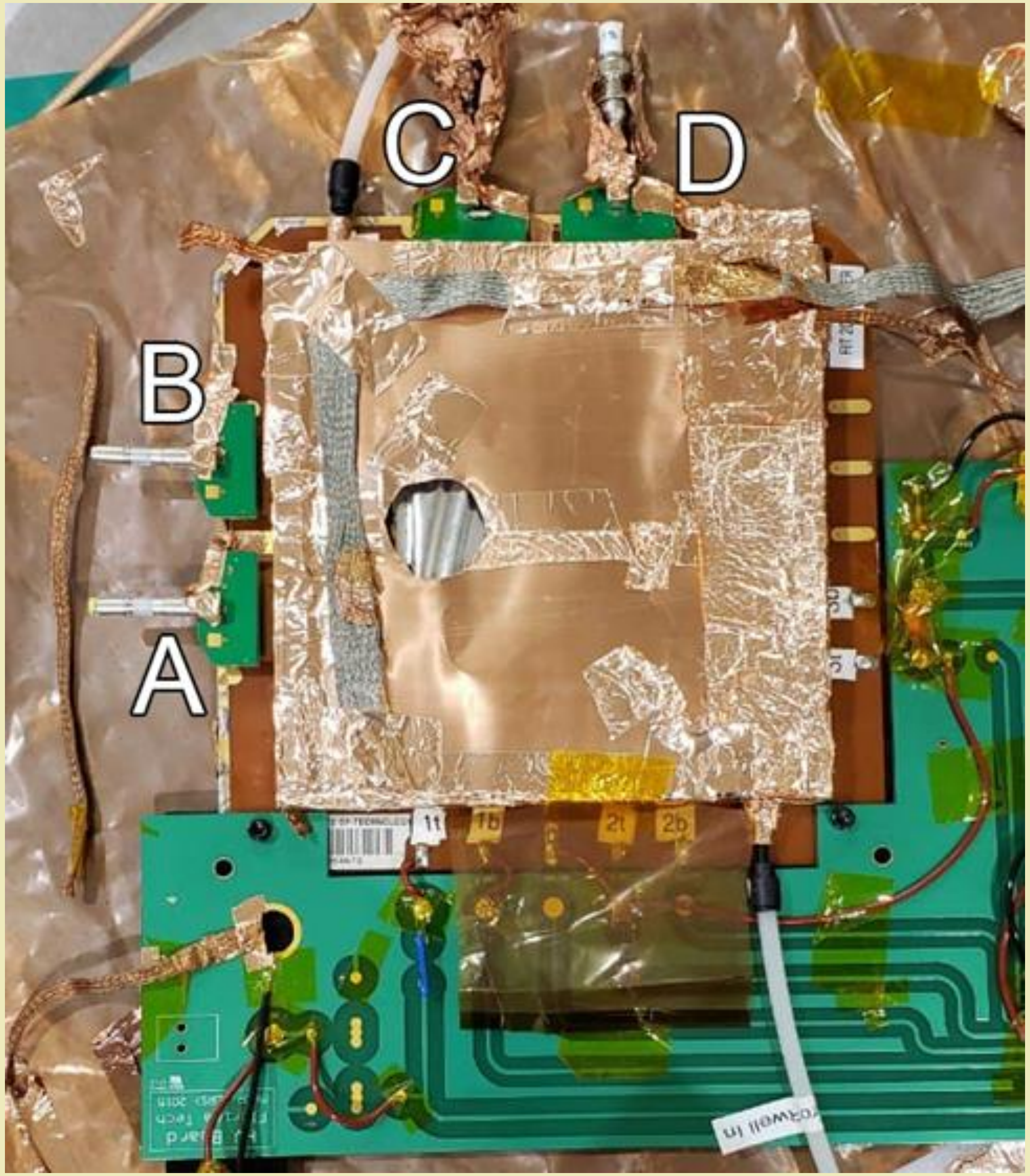
- Want threshold under 190 mV
- Ensure proper grounding, utilize copper shielding
- Sheet copper, copper tape, braided metal strips employed
- Considered input capacitance might be an issue, levels seemed reasonable
- Changed the readout board used for assembly
- XY straight strips, 128 per Panasonic

New Assembly



New Assembly

- Readout has two sets of 128 straight strips each in X and Y directions
- 4 total Panasonic connectors
- Signal charge induced by collected electrons → Panasonic connector → Panasonic-to-lemo adapter → pre-amp
    - Strips ganged together to form one signal per adapter
- Adapters labeled A, B, C, D
- C used for small rim sector, B used for medium rim, D used for large rim, unless otherwise indicated



Reading off THGEM Bottom

- It is also possible to read off of THGEM Bottom
- Special connection from end of testing shown here

Noise Solution

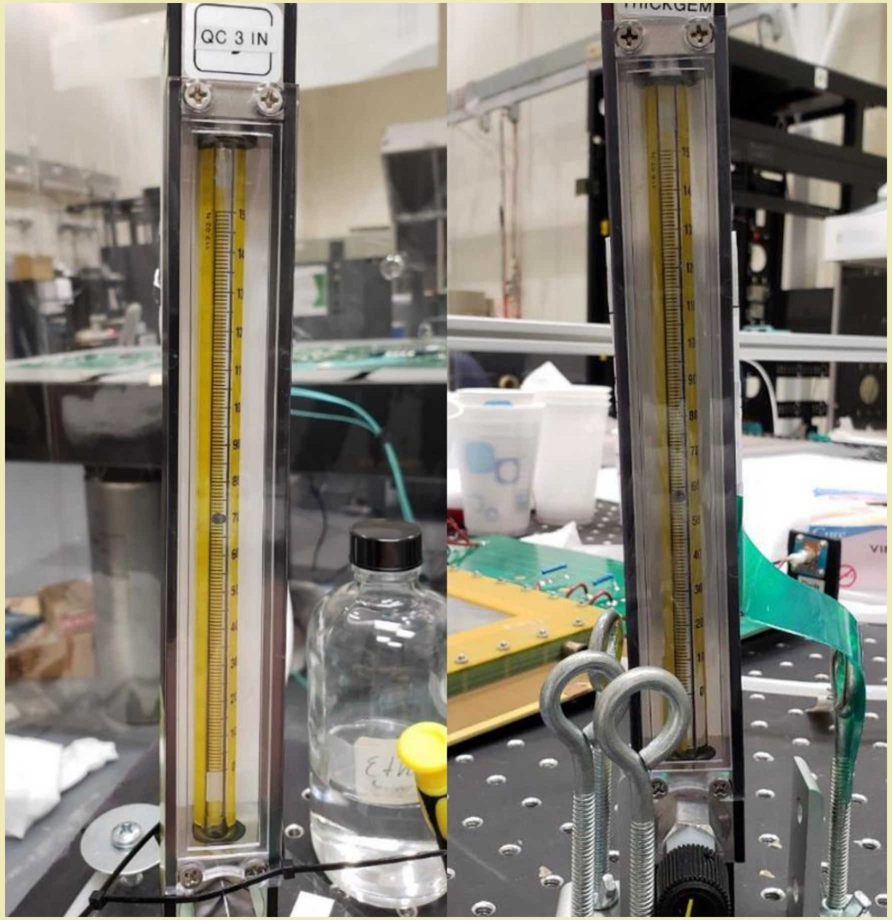
- The solution was found in swapping the ORTEC 142PC pre-amp for an ORTEC 142A
- ORTEC 142A accepts higher input capacitances with lower noise levels
- Also used better grounding techniques on the pre-amp, including large metal braid and wrapping in copper and aluminum shielding, all topped with weights
- Later found that lifting the detector off of the main table and onto a smaller stand reduced noise significantly
- In some cases the noise levels were considered too low, so Amp gain was increased to 27 or 36 from 18 in those cases

Testing

- Three main tests
- Test for shorts on the board
- Gas gain for each THGEM sector
  - Long-term behavior as well
- Test for any malfunctions

Gas Seal

- Detector needs to hold gas
- Checked if could hold gas pressure
- Leaked heavily, but outflow was reasonable compared to inflow
- Found to be sufficient under high flow



Test for Shorts

Foil Name	THGEM Small Sector				
Test date					
RH %	54.5				
Place	FIT				
Foil Version	3				
Batch number					
User name	Jerry				
Action taken					
Comment	Pressure: 1012.5 hPa, Temp: 24.9C				
QC2 fast					
Time	*Voltage(Volts)*	*Impedance(Gohms)*	*Current(nA)*	*Sparks*	*Sparks*
30s	504	100.00	5.04	0	0
1m	504	100.00	5.04	0	0
2m	504	100.00	5.04	0	0
3m	504	100.00	5.04	0	0
4m	504	100.00	5.04	0	0
5m	504	100.00	5.04	0	0
6m	504	100.00	5.04	0	0
7m	504	100.00	5.04	0	0
8m	504	100.00	5.04	0	0
9m	504	100.00	5.04	0	0
10m	504	100.00	5.04	0	0

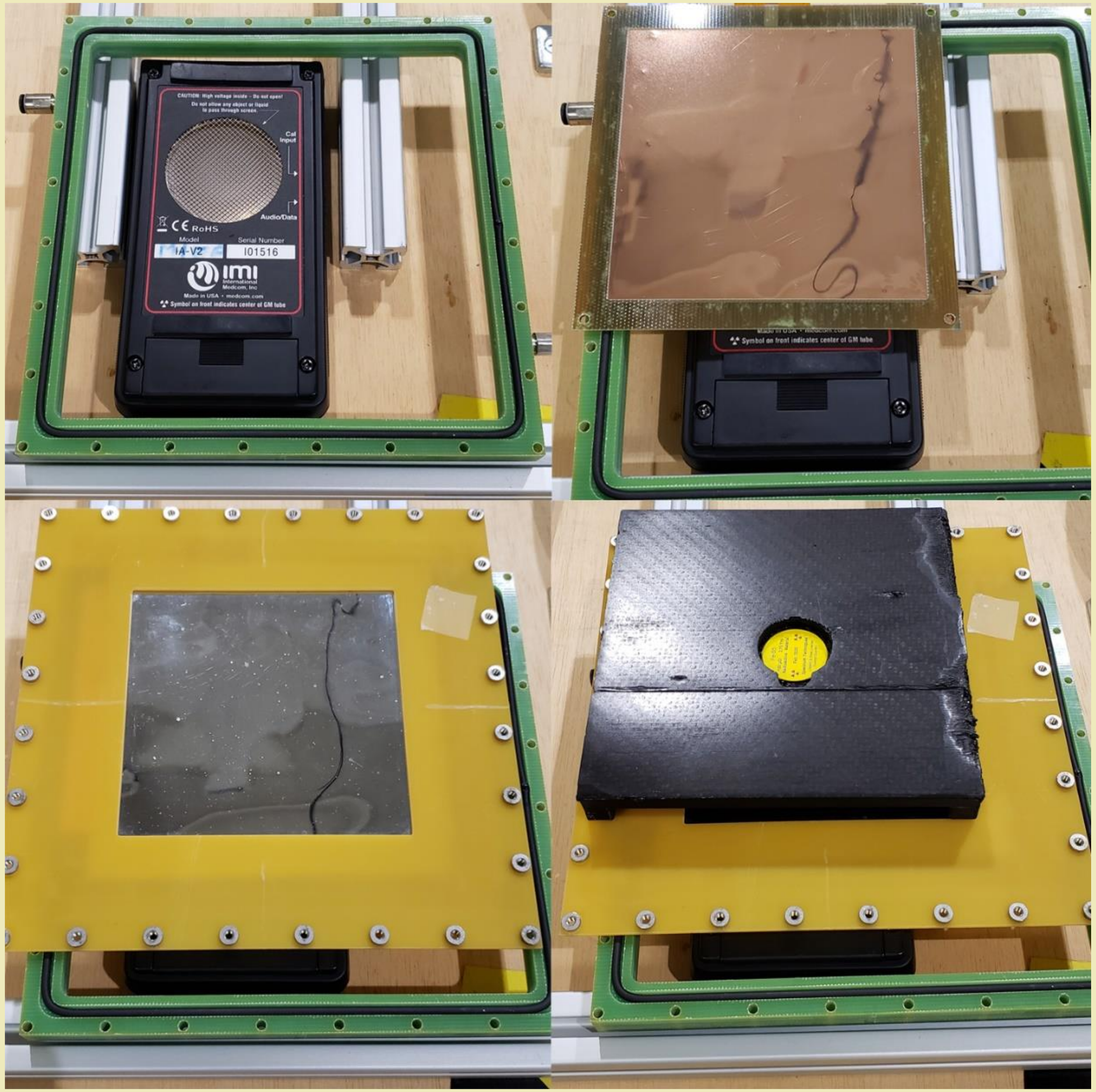
Results for all three board sectors indicate that there are no shorts across the THGEM board

Foil Name	THGEM Medium Sector				
Test date					
RH %	41.7				
Place	FIT				
Foil Version	3				
Batch number					
User name	Jerry				
Action taken					
Comment	Pressure: 1007.6 hPa, Temp: 25.8C				
QC2 fast					
Time	*Voltage(Volts)*	*Impedance(Gohms)*	*Current(nA)*	*Sparks*	*Sparks*
30s	504	100.00	5.04	0	0
1m	504	100.00	5.04	0	0
2m	504	100.00	5.04	0	0
3m	504	100.00	5.04	0	0
4m	504	100.00	5.04	0	0
5m	504	100.00	5.04	0	0

Foil Name	THGEM Large Sector				
Test date					
RH %	41.7				
Place	FIT				
Foil Version	3				
Batch number					
User name	Jerry				
Action taken					
Comment	Pressure: 1007.6 hPa, Temp: 25.8C				
QC2 fast					
Time	*Voltage(Volts)*	*Impedance(Gohms)*	*Current(nA)*	*Sparks*	*Sparks*
30s	504	100.00	5.04	0	0
1m	504	100.00	5.04	0	0
2m	504	100.00	5.04	0	0
3m	504	100.00	5.04	0	0
4m	504	100.00	5.04	0	0
5m	504	100.00	5.04	0	0

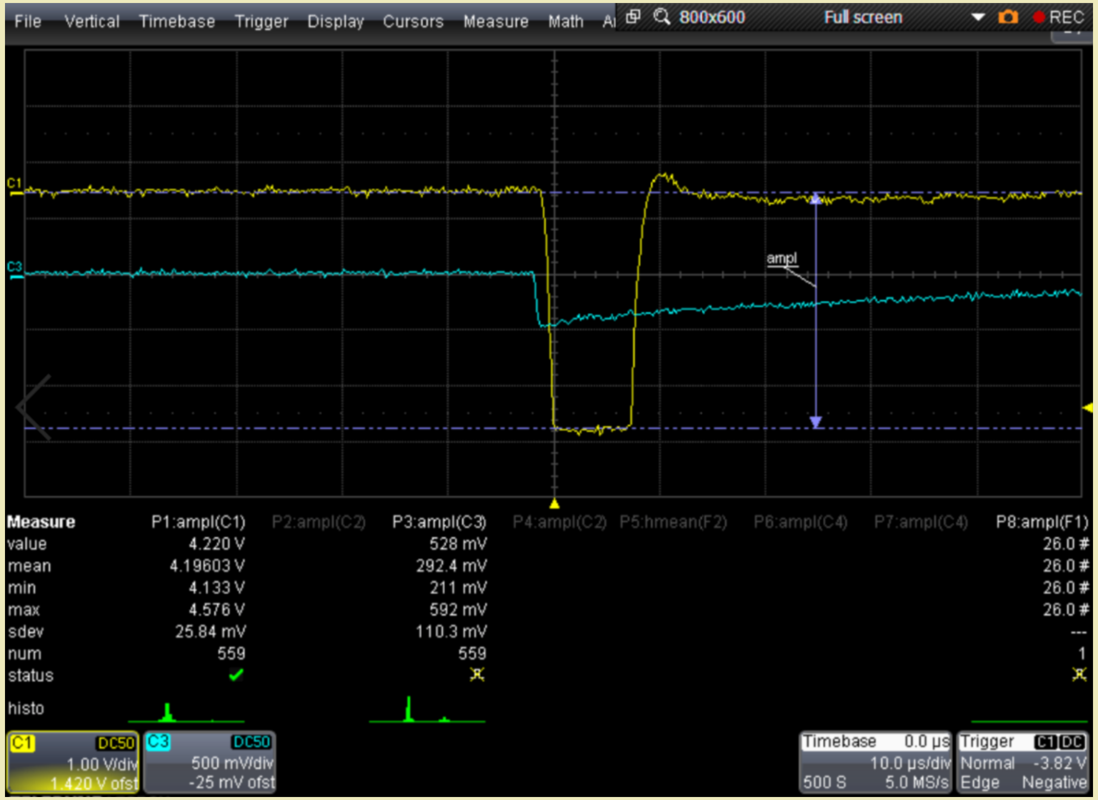
X-ray Penetration of Foils

- Test designed to be similar conditions to gain testing
- Fe-55
  - Without Foils
    - Without Source: 0.52 ± 0.10 Hz
    - With Source: 1673.33 ± 19.23 Hz
  - With Foils
    - Without Source: 0.78 ± 0.12 Hz
    - With Source: 592.00 ± 8.07 Hz
  - 35.4% X-ray penetration
- Cd-109
  - Without Foils
    - With Source: 152.30 ± 2.86 Hz
  - With Foils
    - With Source: 122.02 ± 2.44 Hz
  - 80.1% X-ray penetration



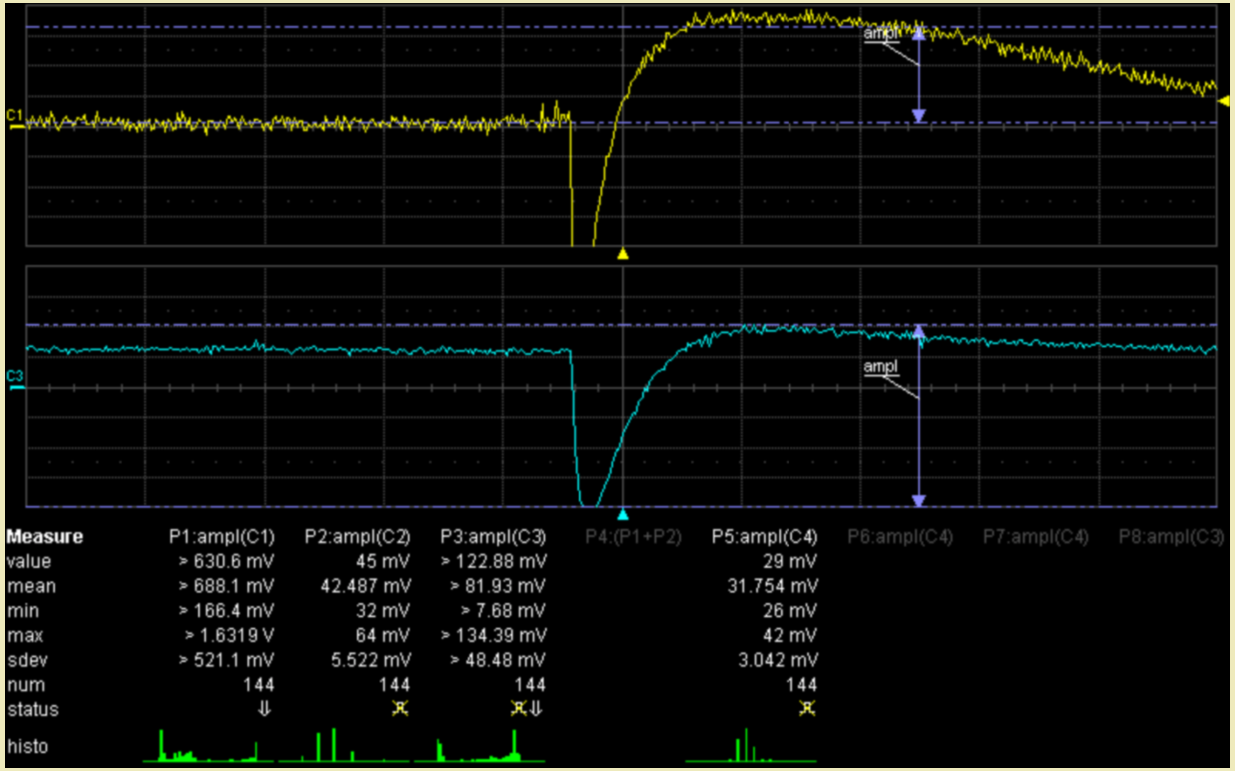
Negative Pulses

- Large saturating negative pulses observed during detector testing (Small rim)
- High rate with and without source, with no significant difference
- Stopped occurring, rarely ever observed again



Negative Pulses

- Later, predominant form of negative pulses were large timescale
- Overshoot into positive region
- Explains strange Scaler count behaviors
- Switched to an amp which could reverse polarity and allow negative pulses to be recognized by SCA

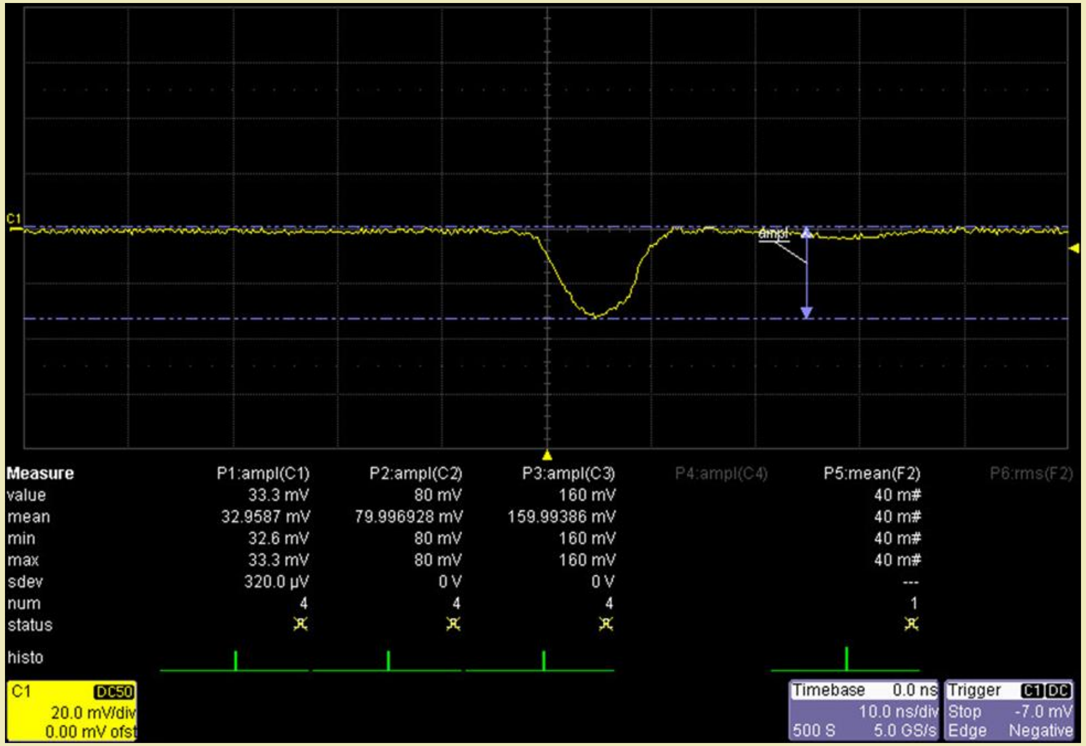


System Polarity Test

- Question arose regarding polarity of expected signal
- Had amp that can invert polarities
- Decided to verify which parts of the system invert the signal
- Find out if pulses should appear positive or negative on scope
- Confirmed Timing and Energy pre-amp channels had identical output

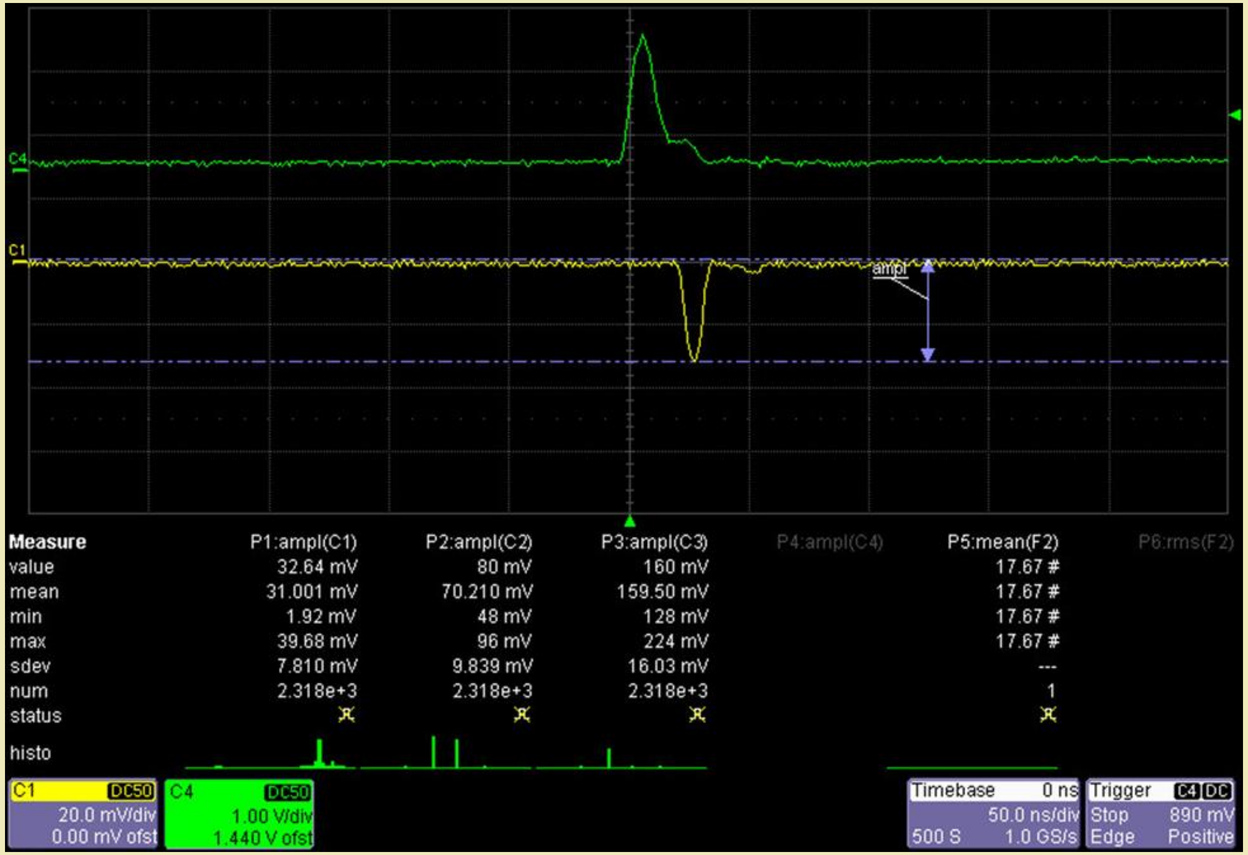
System Polarity Test

- Hewlett Packard 8012B Pulse generator
- Small negative single pulse representing detector pulse
- Most tests included 20 dB attenuator on generator output to reduce amplitude
- Amp set to positive polarity, gain of 3



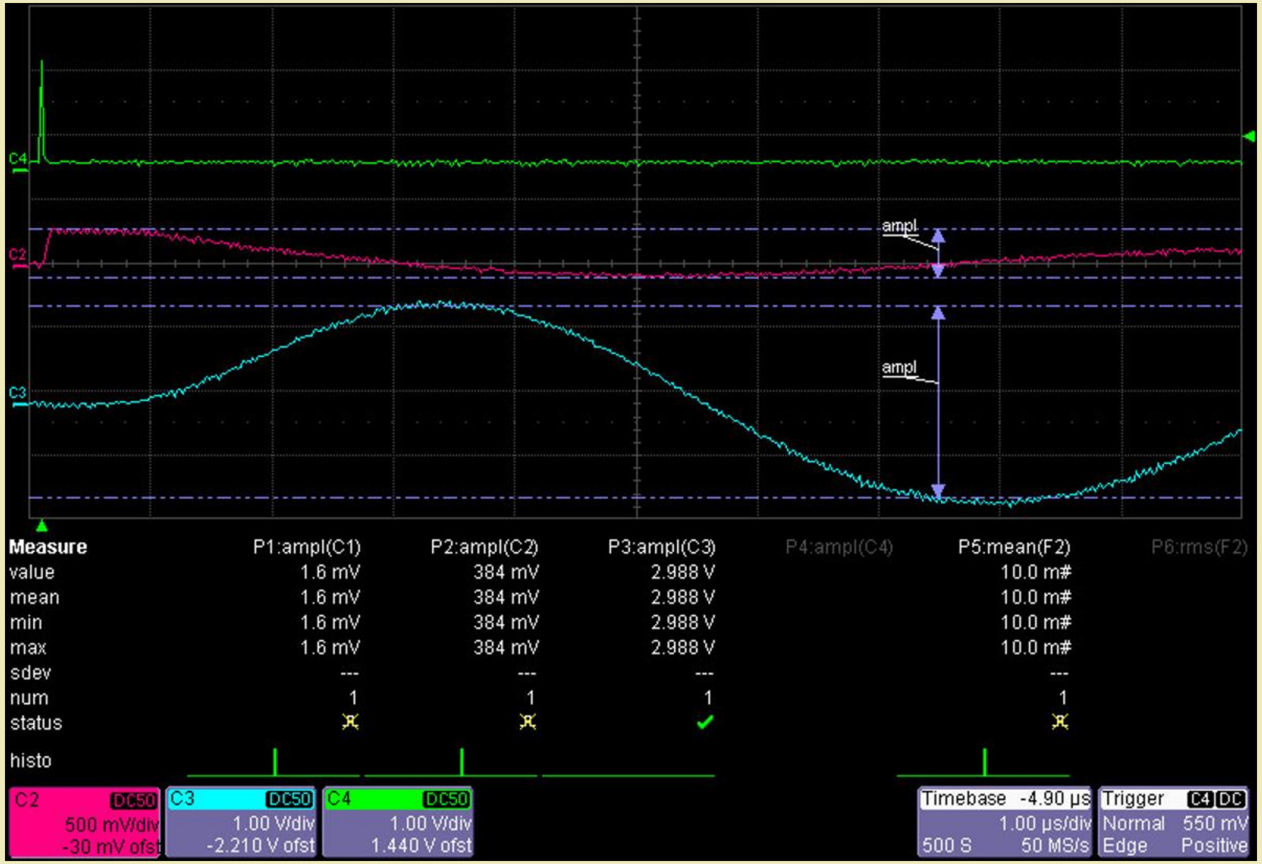
System Polarity Test

- Negative pulse on C1 paired with trigger output (+) on C4
- Trigger output (+): constant positive 1V across 50Ω pulse 16 ± 10 ns wide



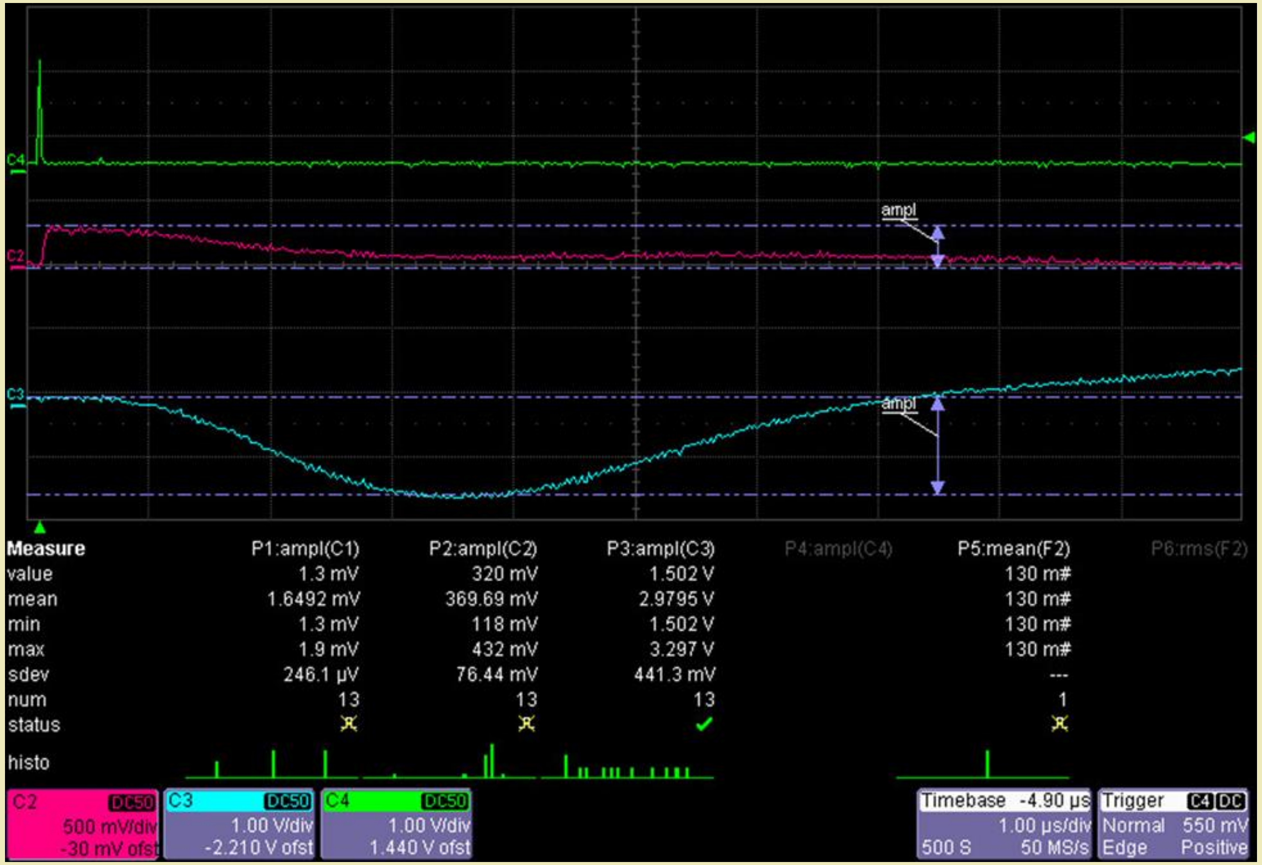
System Polarity Test

- Negative C1 pulse connected to pre-amplifier
- Pre-amp output displayed to C2
- Other pre-amp output connected to amp, amp connected to C3
- Pre-amp inverts negative C1 pulse to positive (C2)
- Amp (C3) leaves the now positive post pre-amp pulse positive, no inversion



System Polarity Test

- Amp signal (C3) is inverted however when amp switched to negative polarity setting
- Expected output pulse: negative from source → positive after pre-amp ⇒ should be positive, with amp in positive position

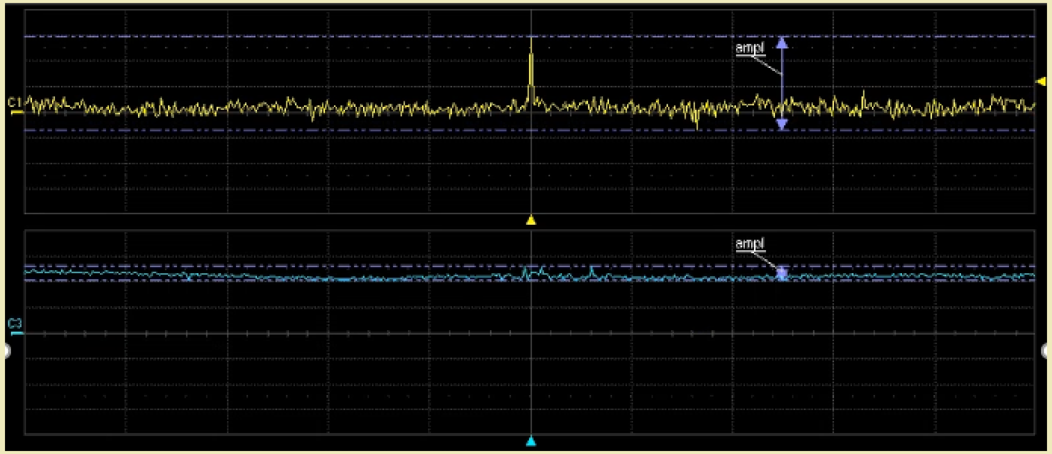


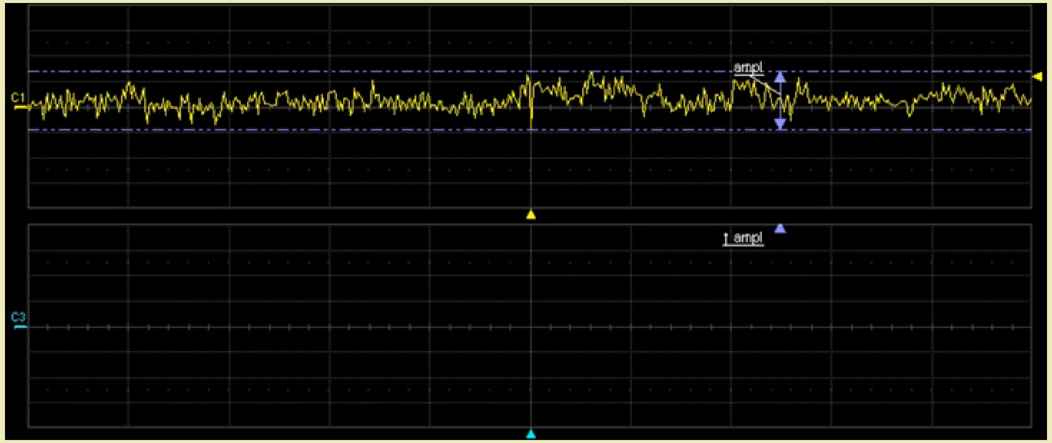
Test of Small (0.1mm) Rim Sector

- Initial observations made using scope to take counts
- Fe-55 used
- HV settings of electrodes
- C1 pre-amp + amp, C3 pre-amp
- Induction field 2 kV/cm
- Bias voltage 1800V ⇒ THGEM hole field 25.7 kV/cm
- Drift field 3.83 kV/cm
- Rate low
- Moments of sparking, overvoltage on bottom, wild scope behavior

Sparking Manifestations

- Sharp rising and falling scope trace
- Sudden drop in baseline of pre-amp signal that rises back up slowly
- Chaotic oscillations, often paired with chaotic behavior on HV monitor
    - Especially Bottom electrode
- Audible sparks



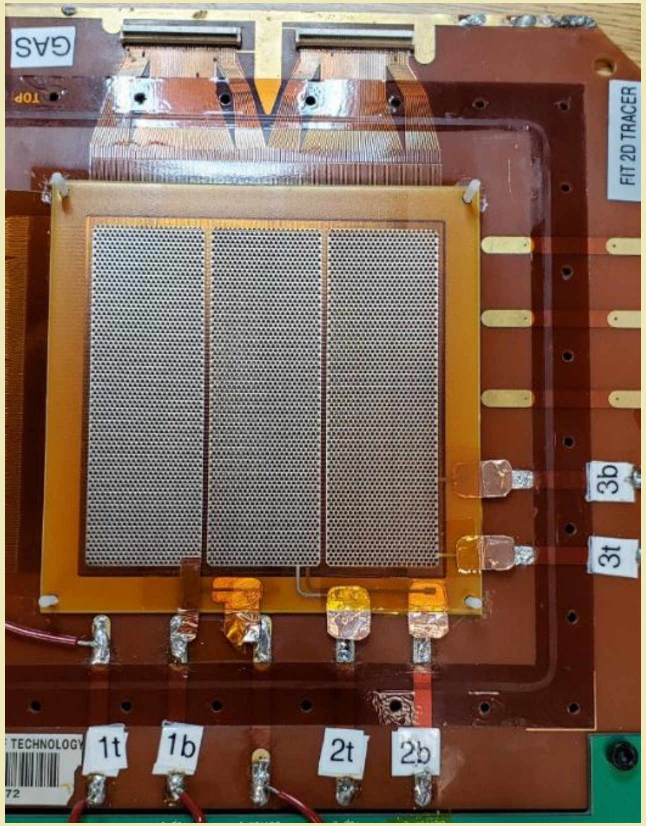


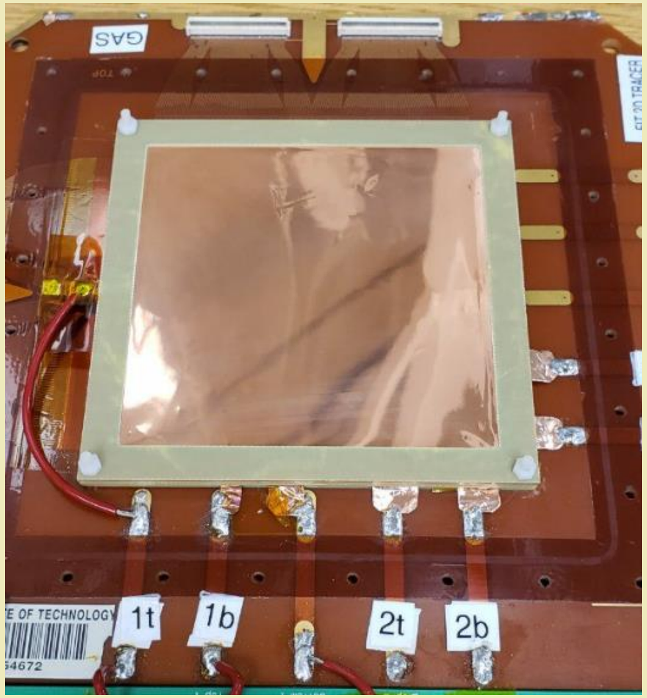
Custom	ISet	VSet	VMon	Pw	hStatı	RUp	RDwn	Trip	ıonRanç	IMonL	IMonH	MaxV	PDwn	'olarit
00.000	5.00 uA	200.0 V	455.0 V	On	Ovv	2 Vps	50 Vps	0.0 sec	Hi	0.00 uA	0.00 uA	1000 V	Kill	NEG
00.001	0.00 uA	0.0 V	10.8 V	Off	Dis...	5 Vps	50 Vps	0.0 sec	Hi	0.00 uA	3.80 uA	550 V	Kill	NEG
00.002	15.00 uA	2350.0 V	2349.6 V	On	On	2 Vps	50 Vps	0.0 sec	Hi	0.00 uA	3.40 uA	3000 V	Kill	NEG
00.003	10.00 uA	3100.0 V	3099.6 V	On	On	2 Vps	50 Vps	0.0 sec	Hi	0.00 uA	2.30 uA	4000 V	Kill	NEG

Custom	ISet	VSet	VMon	Pw	hStatı	RUp	RDwn	Trip	ıonRanç	IMonL	IMonH	MaxV	PDwn	'olarit
00.000	5.00 uA	200.0 V	454.8 V	On	Ovv	2 Vps	50 Vps	0.0 sec	Hi	0.00 uA	0.00 uA	1000 V	Kill	NEG
00.001	0.00 uA	0.0 V	10.8 V	Off	Dis...	5 Vps	50 Vps	0.0 sec	Hi	0.00 uA	3.75 uA	550 V	Kill	NEG
00.002	15.00 uA	2350.0 V	2350.0 V	On	On	2 Vps	50 Vps	0.0 sec	Hi	0.00 uA	2.40 uA	3000 V	Kill	NEG
00.003	10.00 uA	3100.0 V	3099.6 V	On	On	2 Vps	50 Vps	0.0 sec	Hi	0.00 uA	2.20 uA	4000 V	Kill	NEG

Discharge Concerns and Next Steps

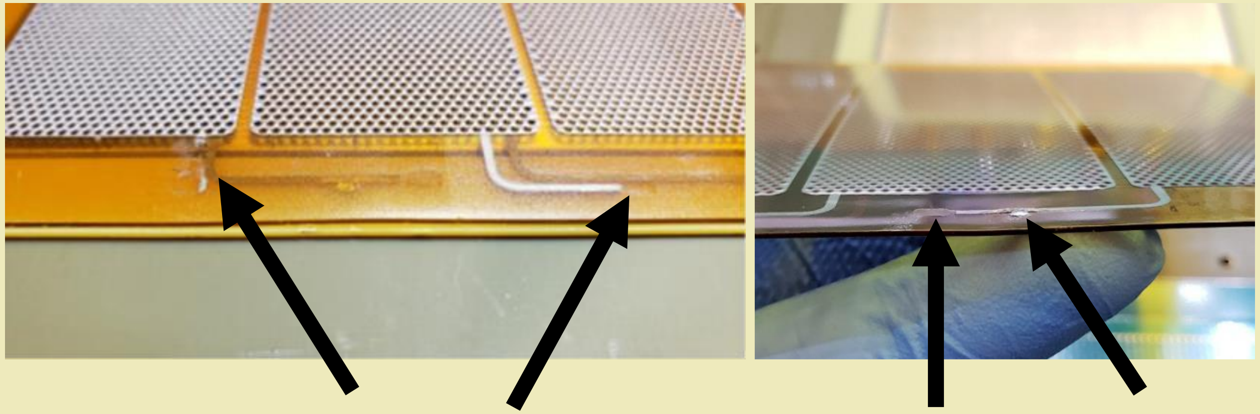
- Bias voltage limit “wall” of around 1900V
- Suspect hole fields not high enough
- Want to avoid increasing bias due to discharge
- Switched to next largest sector
- Copper tape tabs for each sector





Heat and Handling Damage

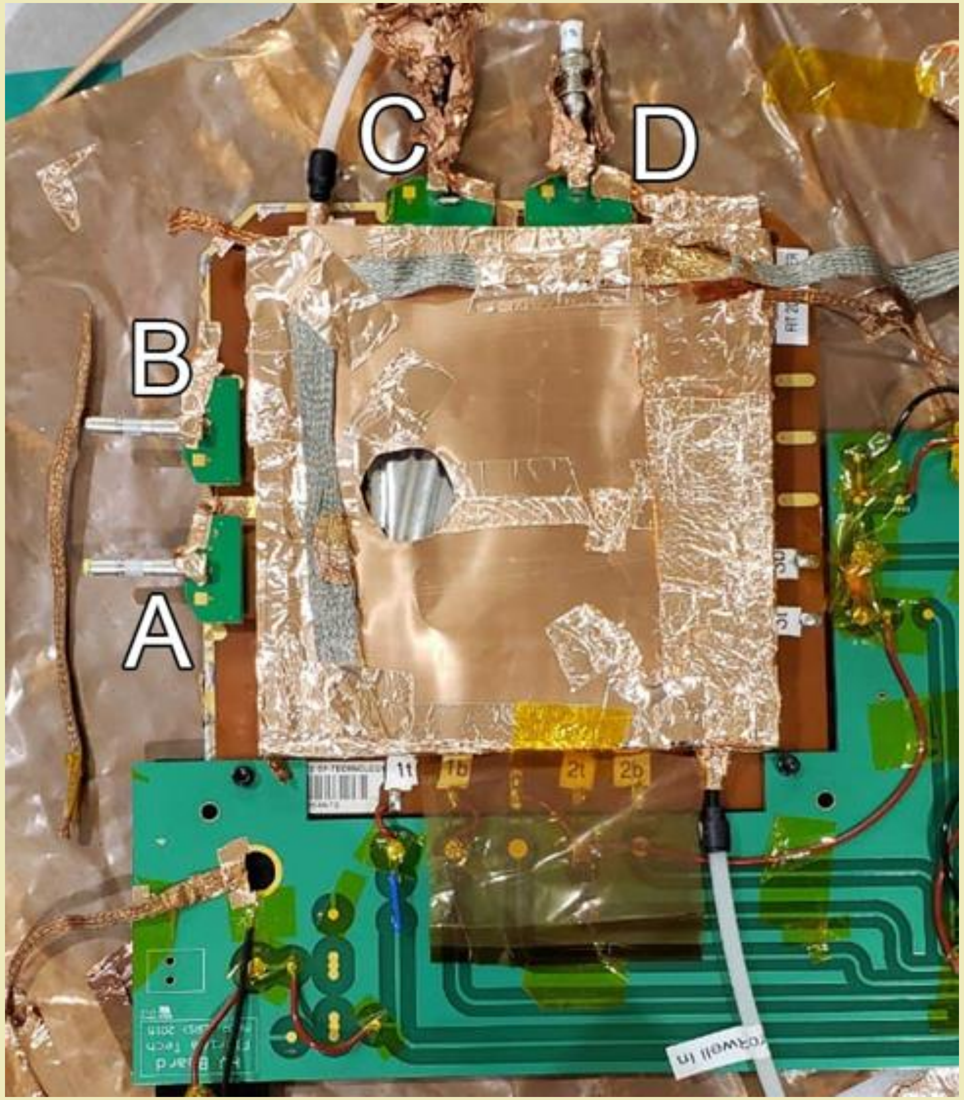
- Soldering directly to the board dangerous
- Heat removes the silver traces, allows breaks
- Warp the dielectric material
- Excess solder can remain
- Copper tape with conductive adhesive better
- With all sectors internally connected, just switch connection on outside



Various damages which can occur through soldering

Test of 0.15 mm Rim (Middle) Sector

- Drift and Induction fields 3 kV/cm
- At 1800V bias there was no significant difference on THGEM Bottom or Lemo C
- No significant difference at 1900V
- 2000V on Lemo C we see the first significant difference
  - Source off: 25.77 ± 1.78 Hz
  - Am-241 on: 60.40 ± 3.30 Hz
  - 134.38% increase
- 2100V
  - Source off: 34.27 ± 2.17 Hz
  - Am-241 on: 92.20 ± 4.50 Hz
  - 169.04% increase
- Few instances of discharge occurred

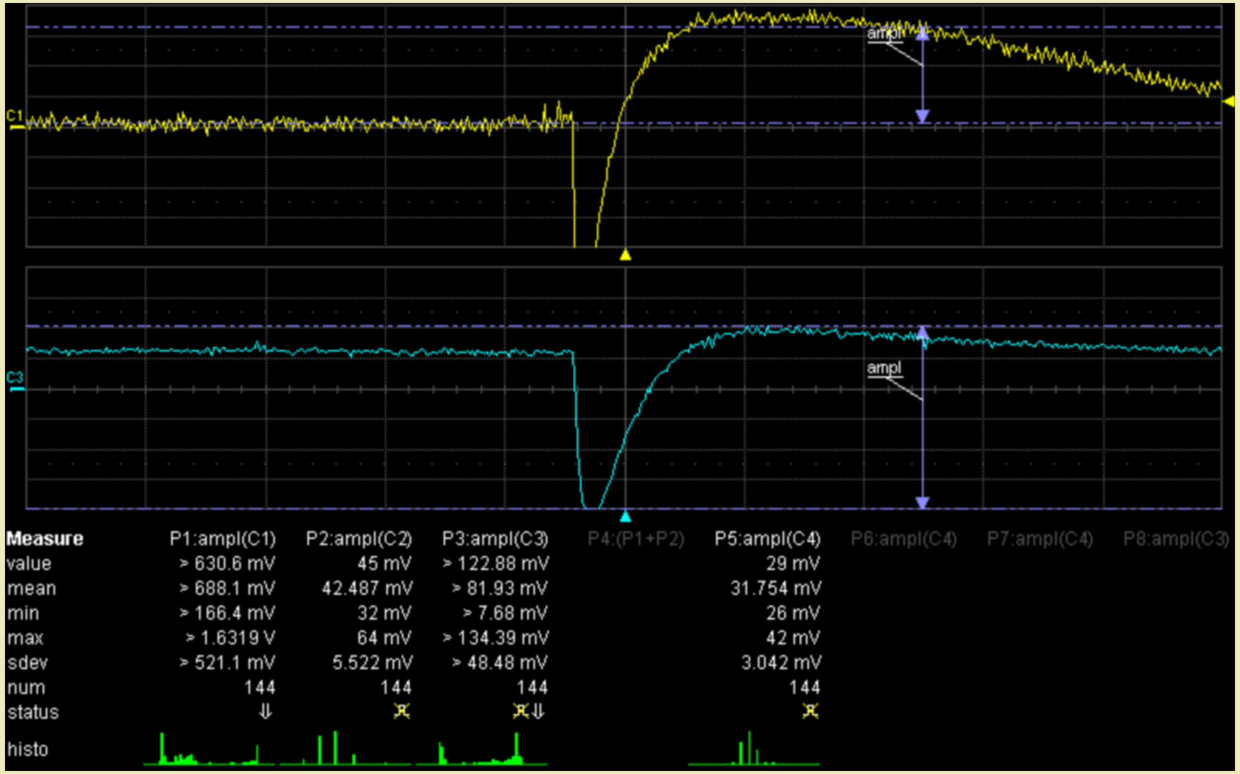


Test of 0.15 mm Rim (Middle) Sector

- For Lemo D, again at 1800V bias there was no significant difference
- No significant difference at 1900V (though more difference than for Lemo C)
- 2000V again marks significant difference
  - Source off: 4.00 ± 0.60 Hz
  - Am-241 on: 34.53 ± 2.18 Hz
  - 763.25% increase
- No bias wall preventing, continued
- 2100V
  - Source off: 6.43 ± 0.73 Hz
  - Am-241 on: 87.73 ± 4.29 Hz
  - 1264.39% increase
- 2200V
  - Source off: 6.10 ± 0.70 Hz
  - Am-241 on: 74.60 ± 3.80 Hz
  - 1122.95% increase
  - Occasional discharges
- Frequent discharge under Am-241 or Fe-55 at 2300V

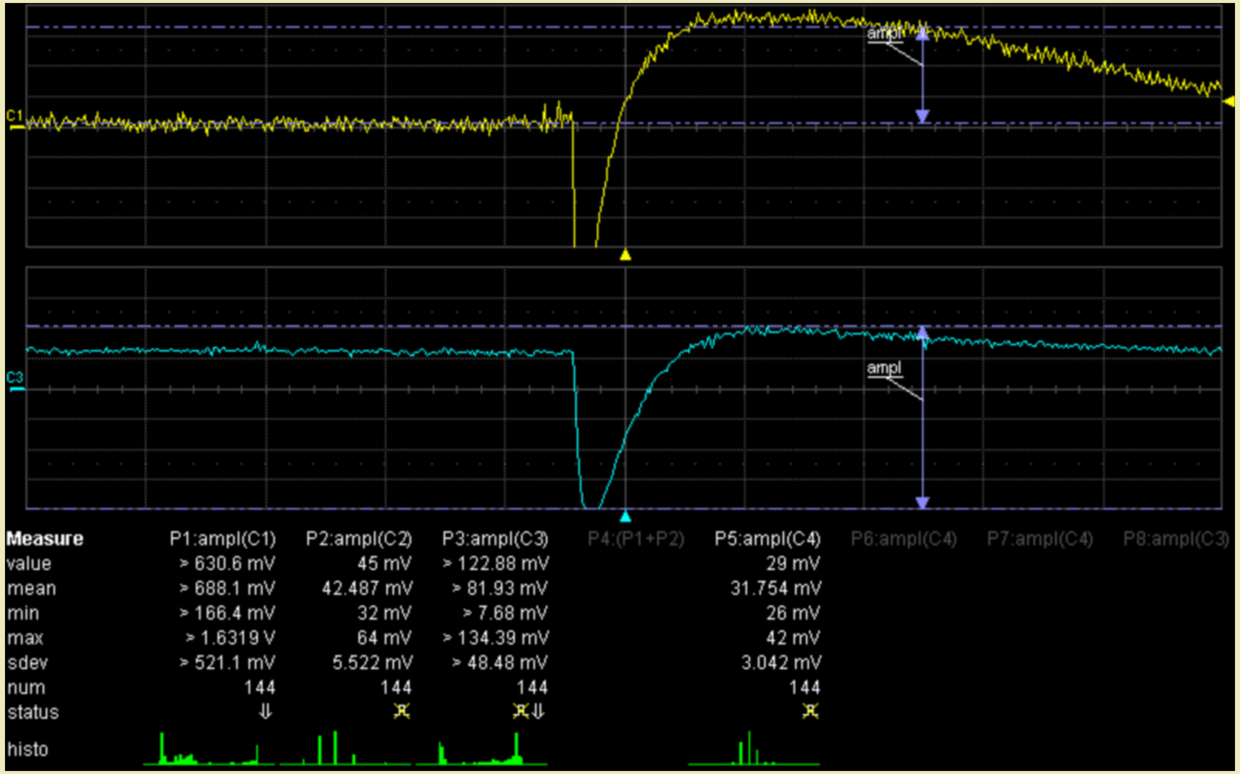
Middle Sector Observations

- Point of significant discharge now ~2300V for middle sector, unlike 1950-2000V for small sector
- Large overshoots discovered at 500 μs timescales



Overshoots

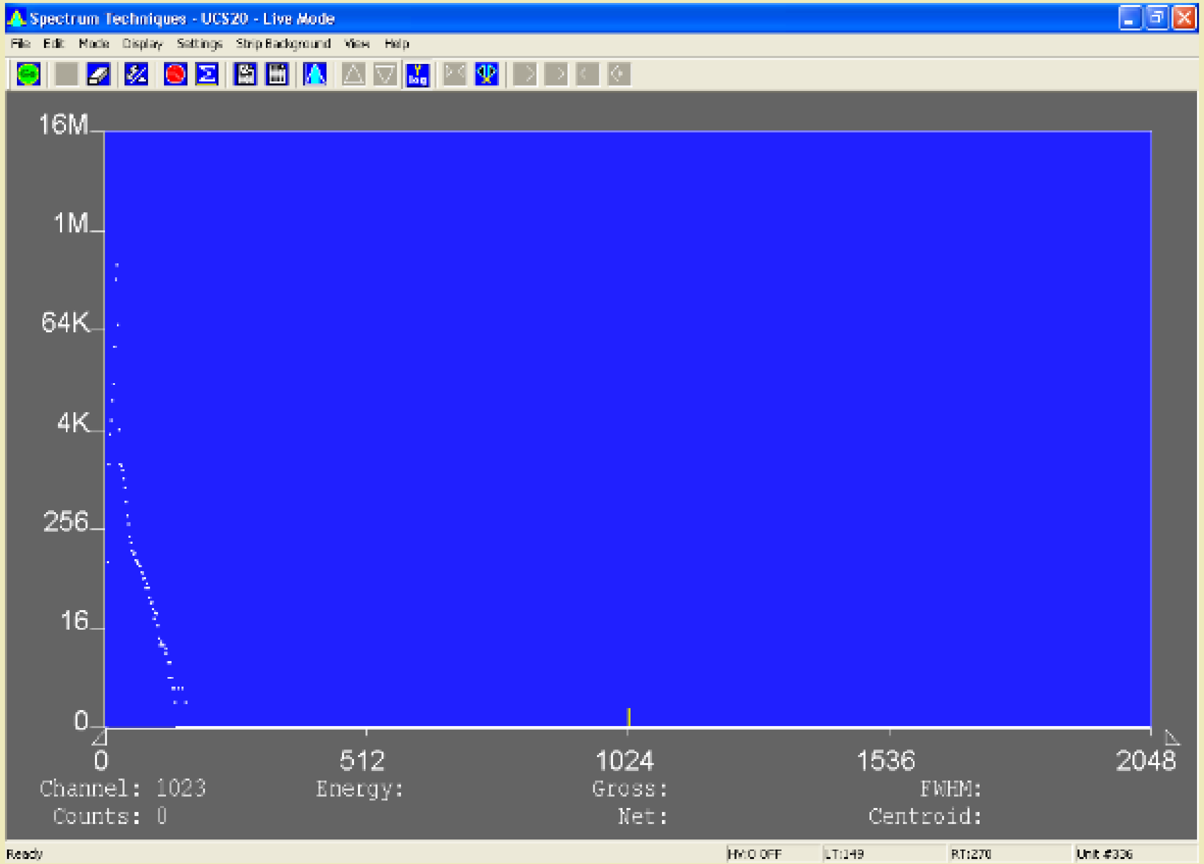
- Overshoots cause jumps in counts
- To account for this, switched to negative amp polarity, count negative pulses, and subtract from the positive counts
- “Corrected” values

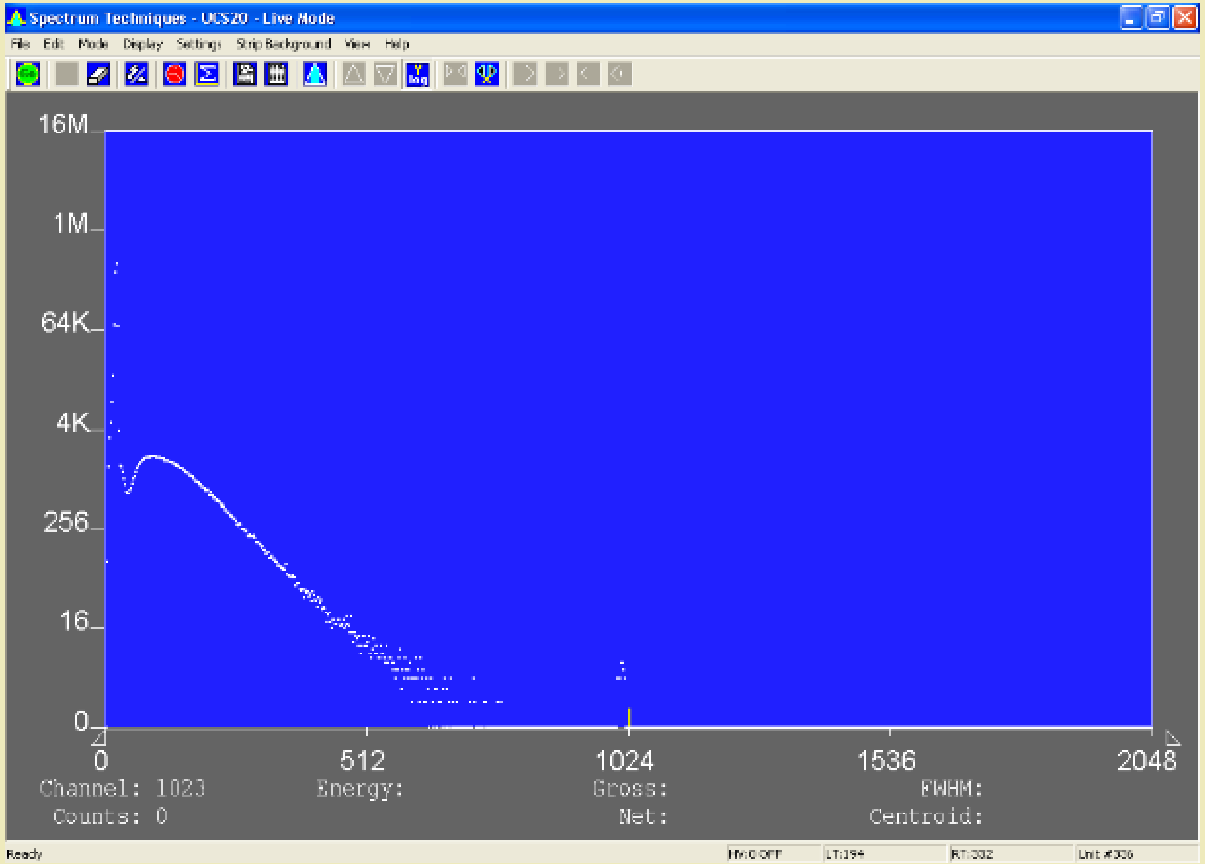


Corrected Values Tests

- Fe-55, Drift and Induction fields 3 kV/cm, bias 2100V
- Positive Polarity:
  - Source Off: 62.90 ± 3.40 Hz
  - Source On: 2340.00 ± 69.30 Hz
  - Corrected: -107.60 ± 10.50 Hz
- Negative Polarity:
  - Source Off: 170.50 ± 7.20 Hz
  - Source On: 230.80 ± 9.20 Hz
  - Corrected: 2109.20 ± 78.50 Hz
- Later at 2000V
  - Corrected Source Off: -0.65 ± 0.20 Hz
  - Corrected Source On: 880.40 ± 28.60 Hz

Pulse Height Measurements





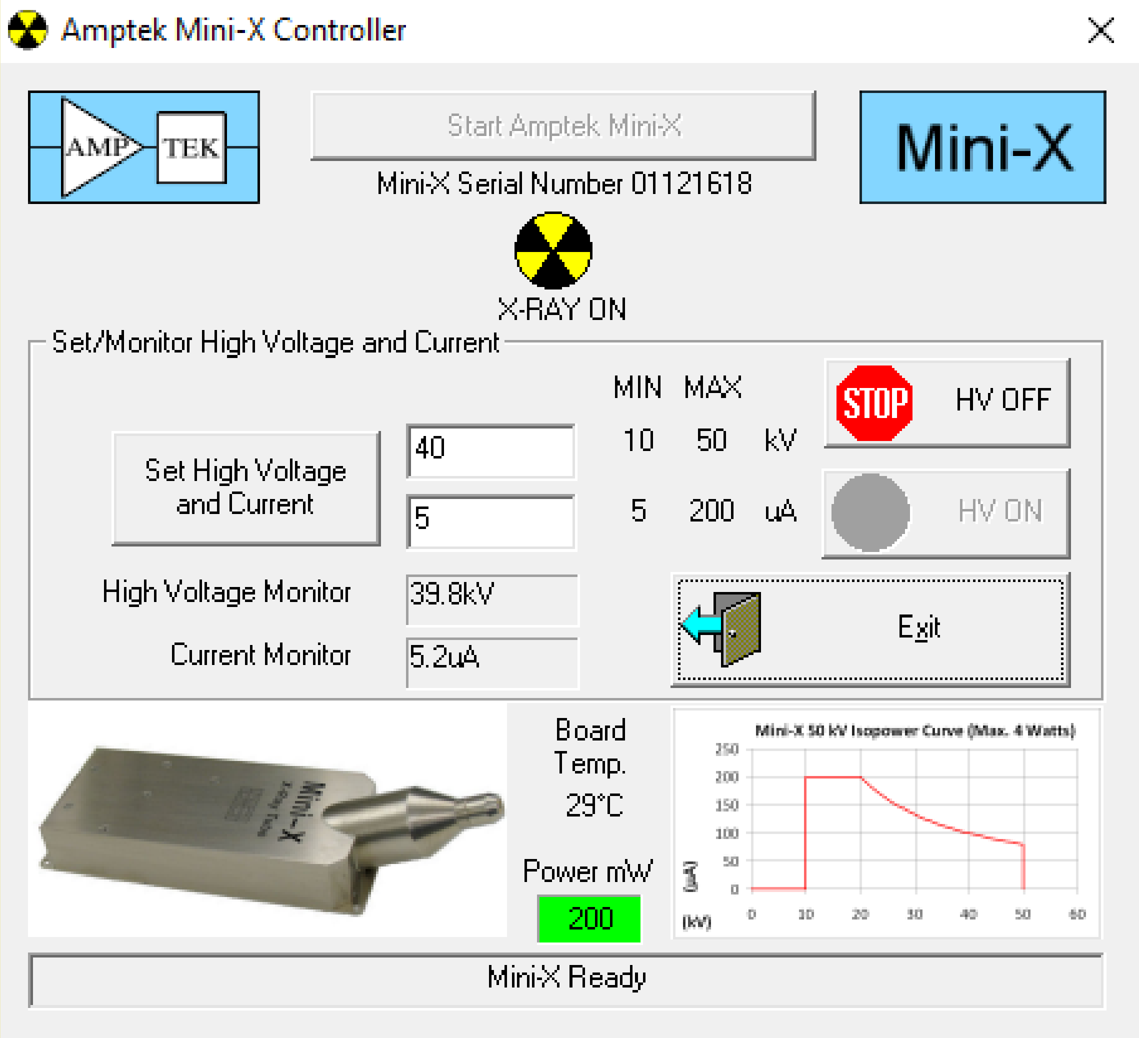
Initial pulse-height measurements taken using a Multi-Channel Analyzer source-off (left) and source-on (right)
Visual evidence of the detector functioning!

Gas Gain Tests

- Goal: Gather gain curves for each THGEM
- Fe-55 and Amptek Mini-X X-ray gun used as X-ray source
- Detector set up inside lead-lined box
- X-ray gun suspended ~1 cm over detector
- Operated via laptop outside of box
- Interlock systems shuts off X-ray gun if door opened while on

Arrow indicates the X-ray gun. The purpose of the fan is to keep the X-ray gun cool and maintain operating temperature

X-ray Gun


Amptek Mini-X Controller
AMP TEK
Start Amptek Mini-X
Mini-X Serial Number 01121618
Mini-X
X-RAY ON
Set/Monitor High Voltage and Current
MIN MAX
Set High Voltage and Current
40
5
10 50 kV
5 200 uA
STOP
HV OFF
HV ON
High Voltage Monitor
39.8kV
Current Monitor
5.2uA
Exit
Board Temp.
29°C
Power mW
200
Mini-X 50 kV Isopower Curve (Max. 4 Watts)
(uA)
(kV)
Mini-X Ready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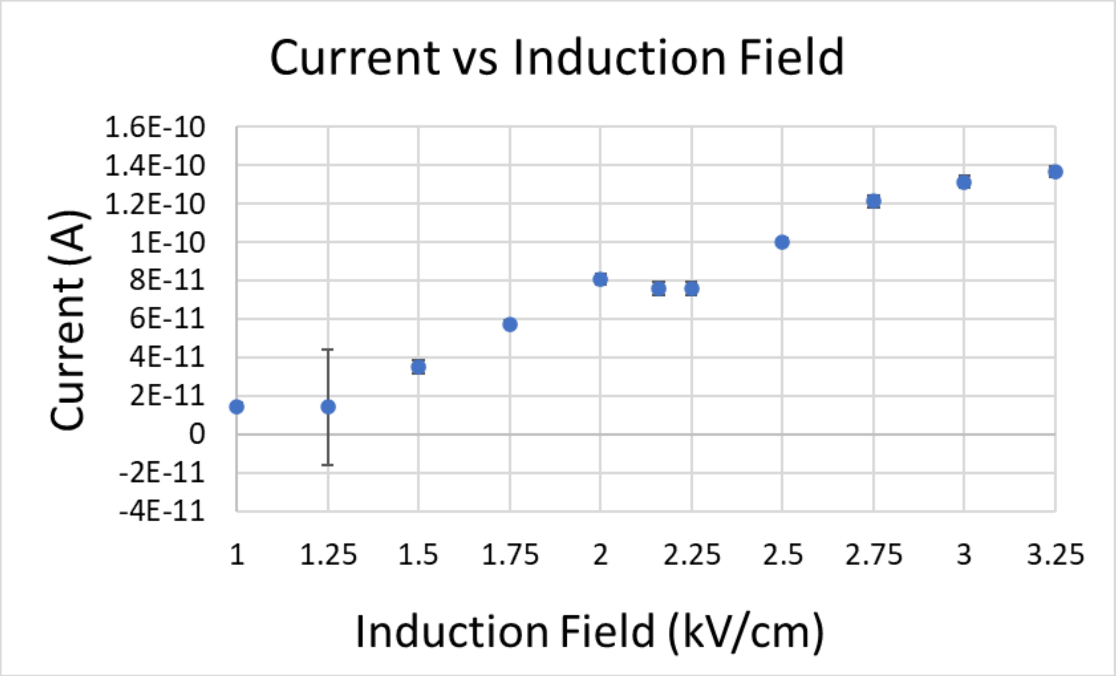
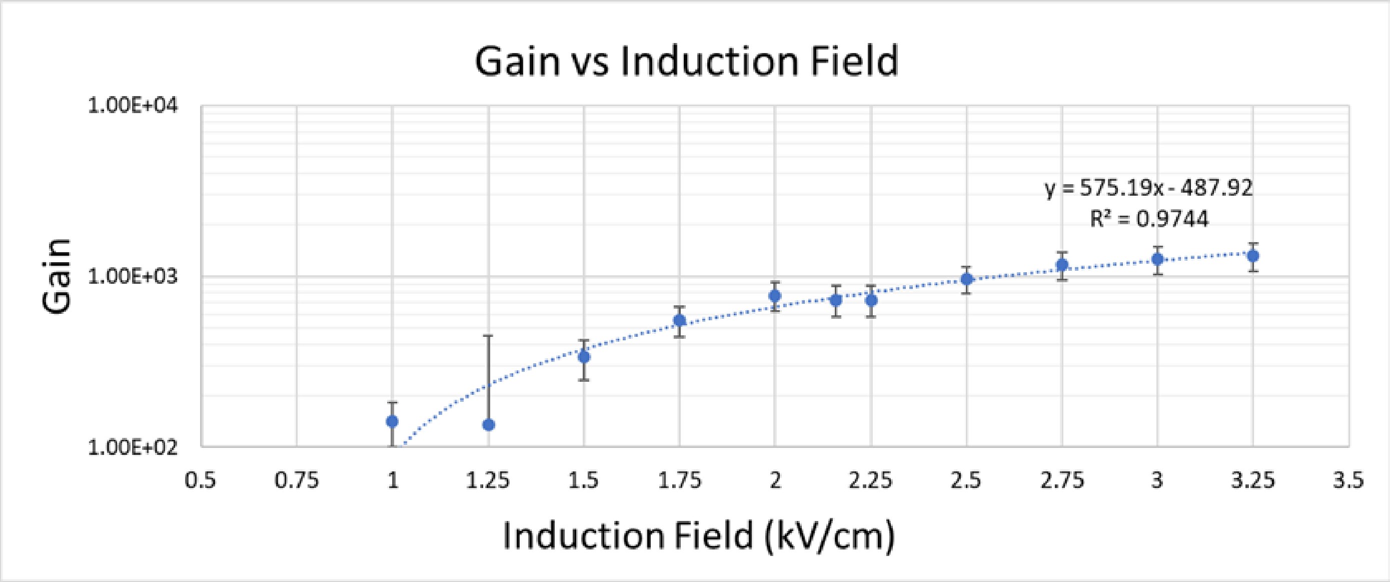
Fields

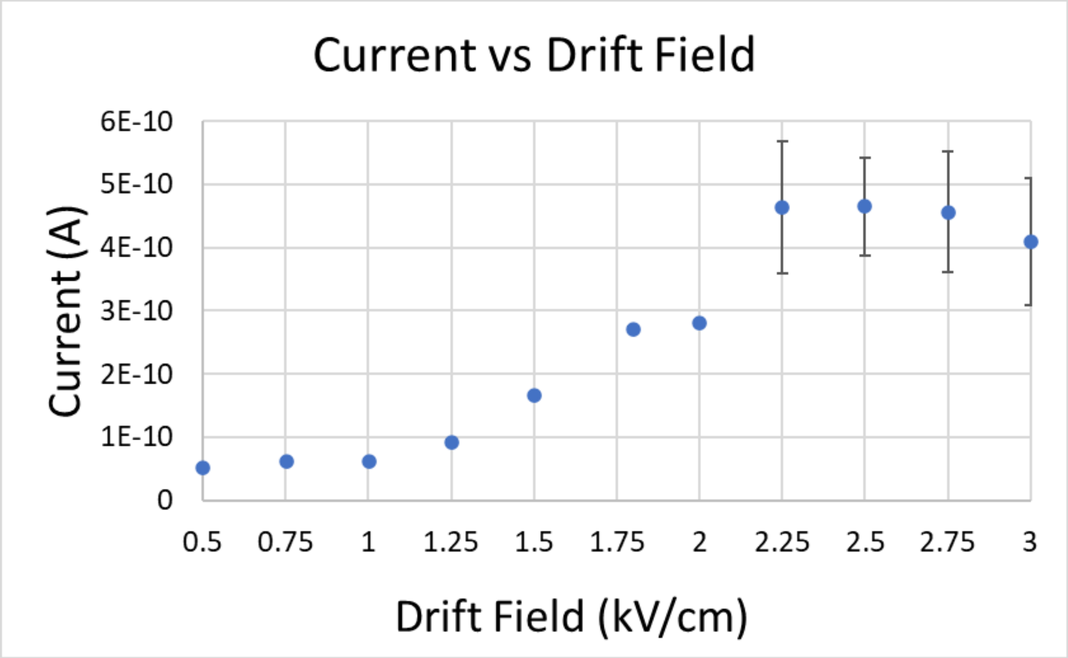
- Attempts at optimizing fields lead to selecting 1.8 kV/cm drift field and 2.16 kV/cm induction field
- They along with 1703V bias become test point for detector behavior while one of the two fields is constant
- For gain calculations, X-ray gun incident rate 1879.40 ± 289.20 Hz used
- Middle THGEM sector used

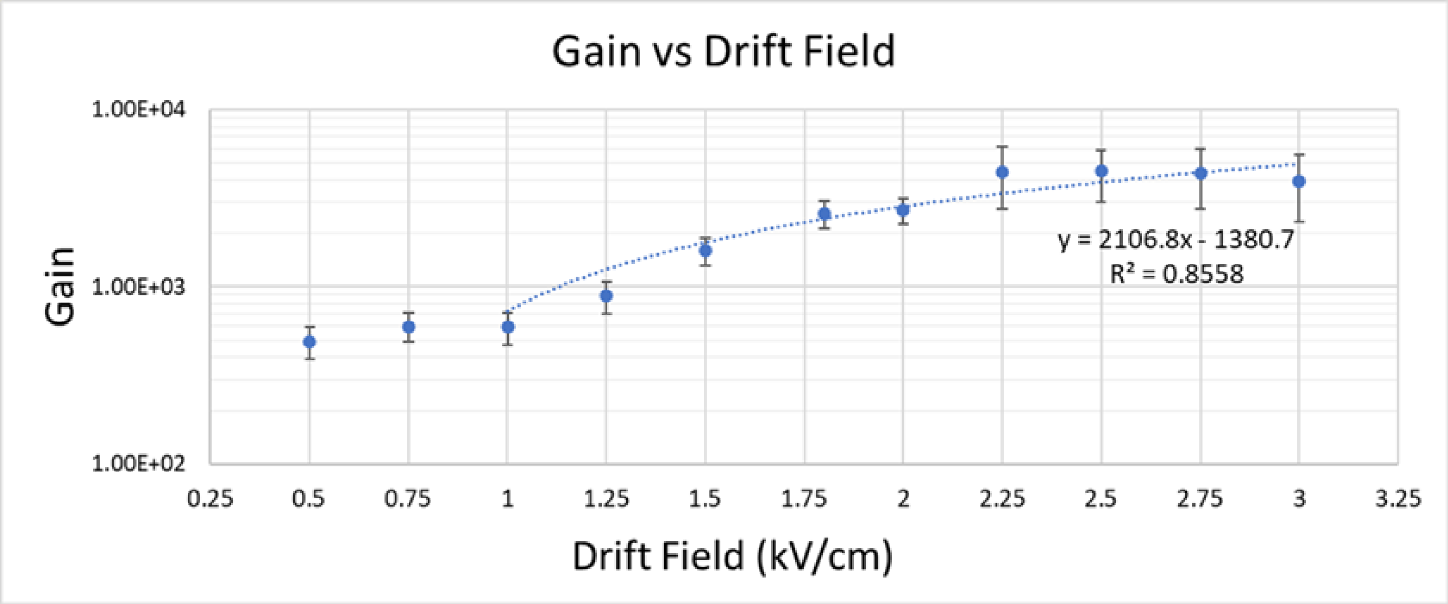
Constant 1.8 kV/cm Drift Field





Constant 2.16 kV/cm Induction Field



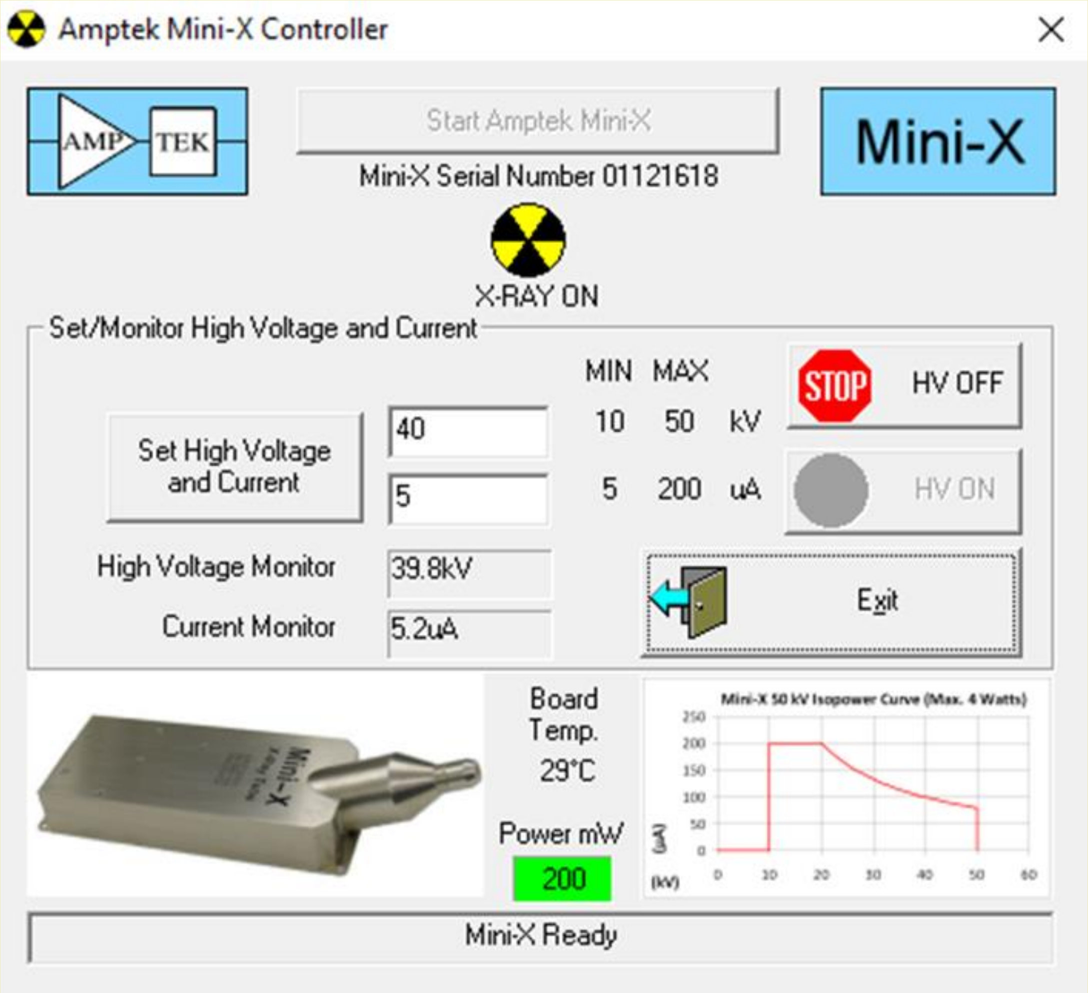


Fields

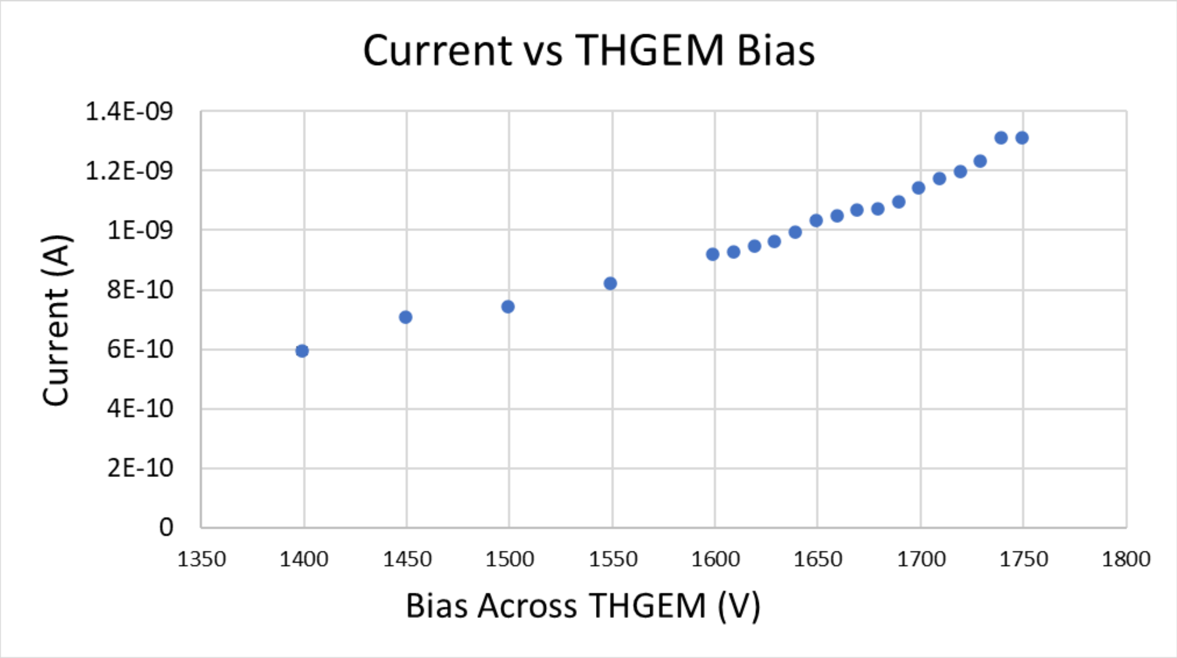
- So we see that purely changing the drift or induction fields affects gain
- These fields became the basis for the gas gain tests

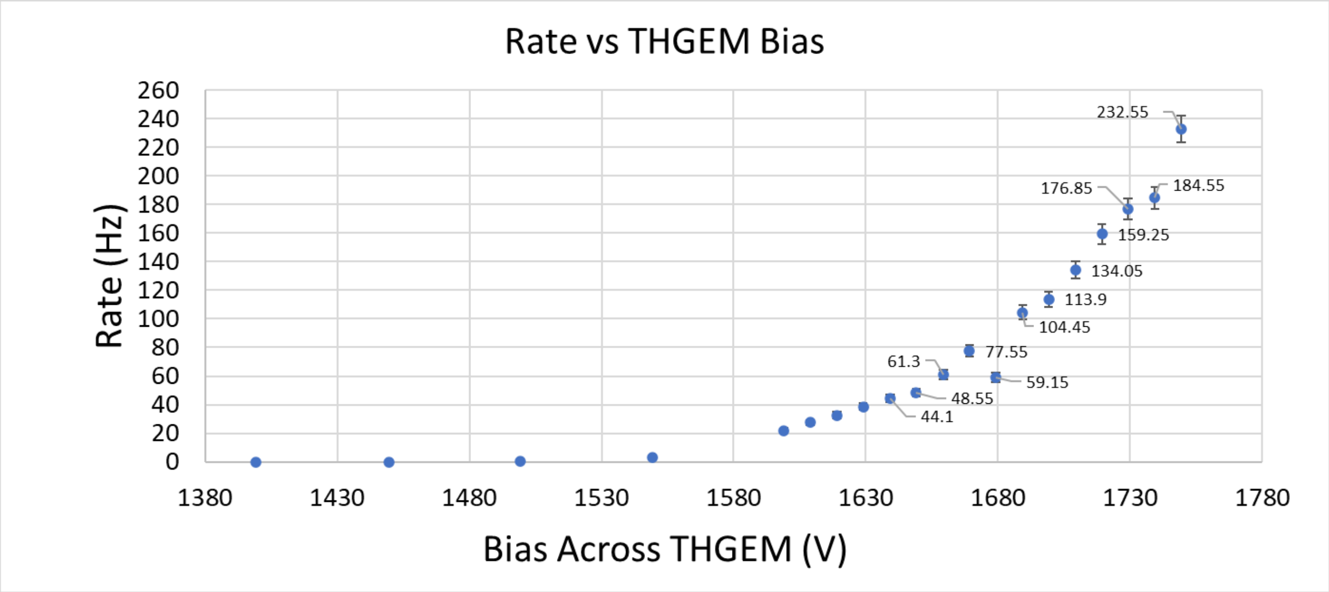
Middle Sector – 1st Gain Test

- Detector kept off for >24 hours
- X-ray off and on current and rate measurements
- Drift and induction fields constant, increasing THGEM Bias Voltage
- X-ray set to 40 kV 5 μA



Middle Sector – 1st Gain Test

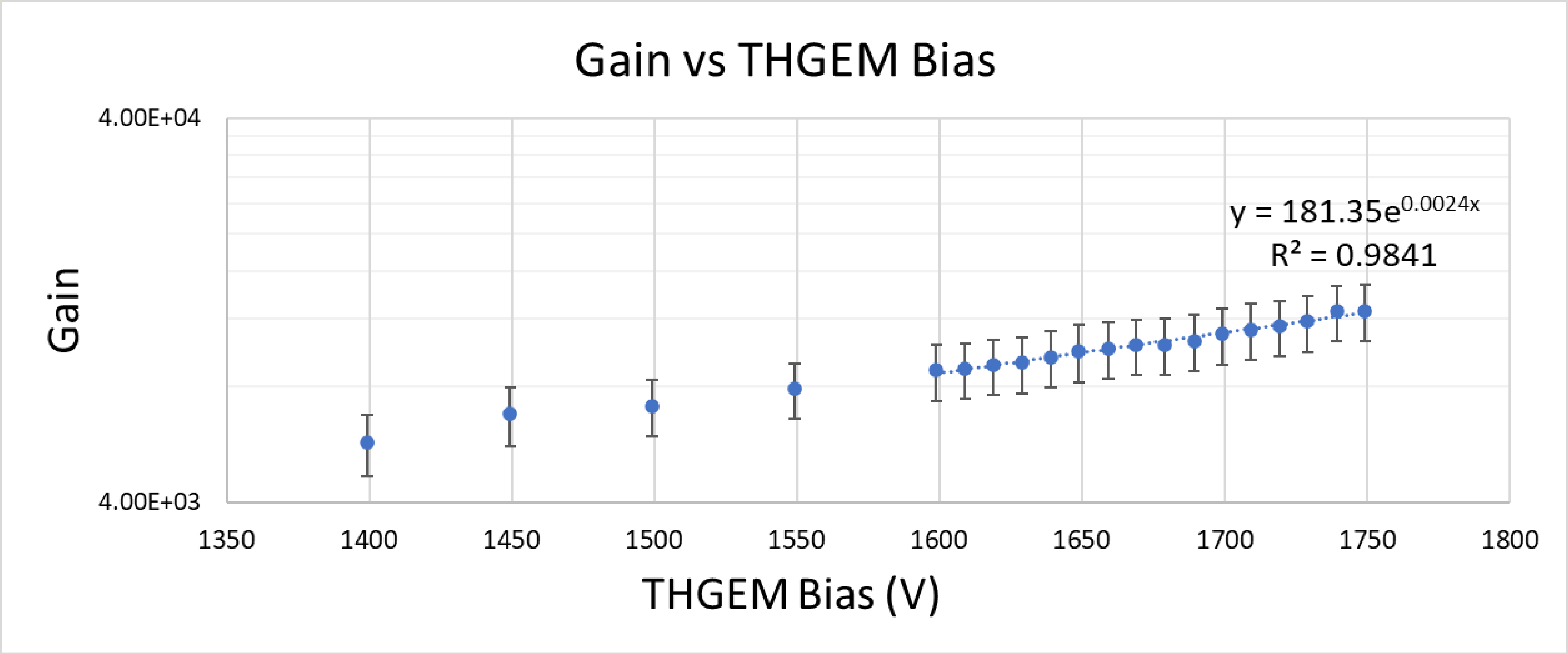




Rate increases due to increase in field in the holes

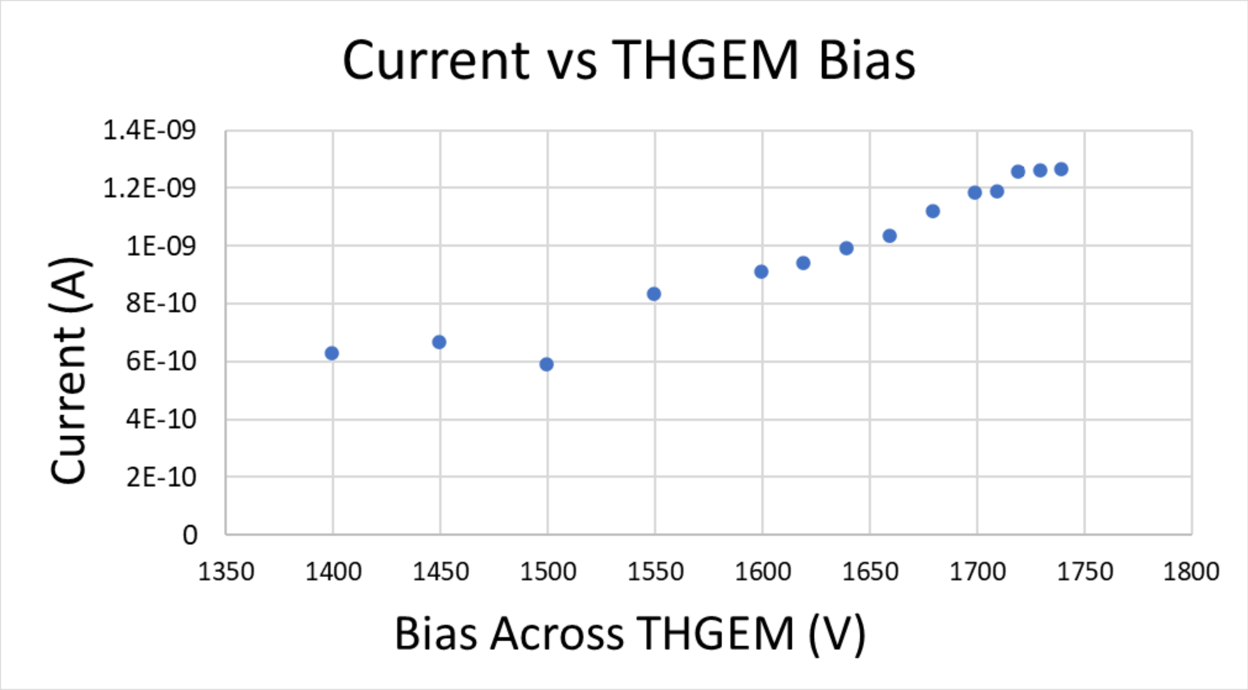
Note: For these and all subsequent plots, error bars are present but may be too small to see compared to axis size. Missing lower error bars are due to not being able to cross 0 in a log plot.

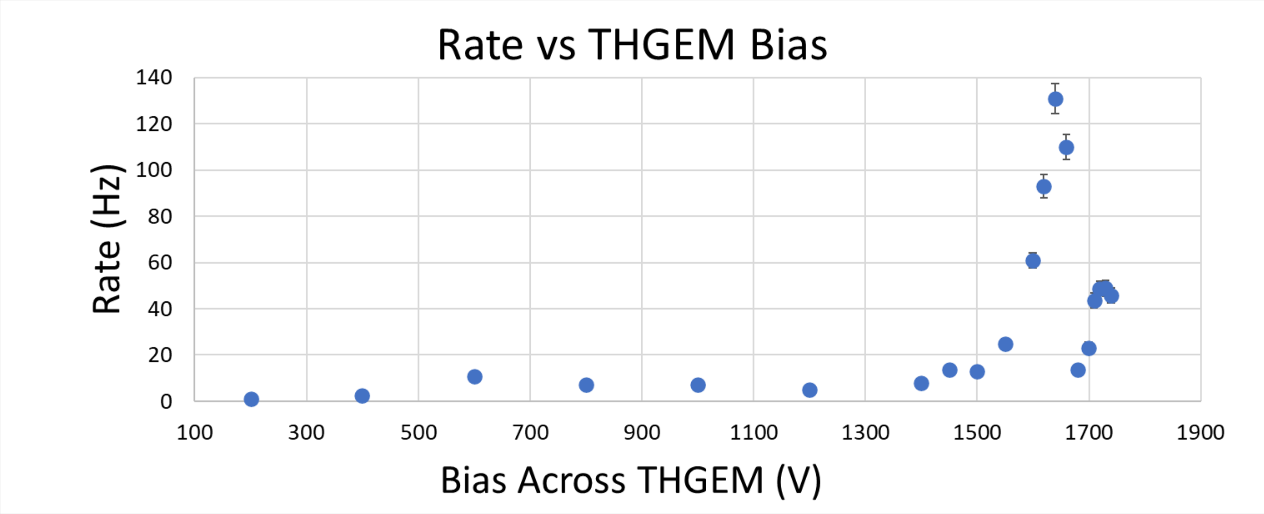
Middle Sector – 1st Gain Test



Incident Rate of 1879.41 ± 289.23 based on Geiger counter values used. Max of 1750V to avoid discharges typical beyond 1800V.

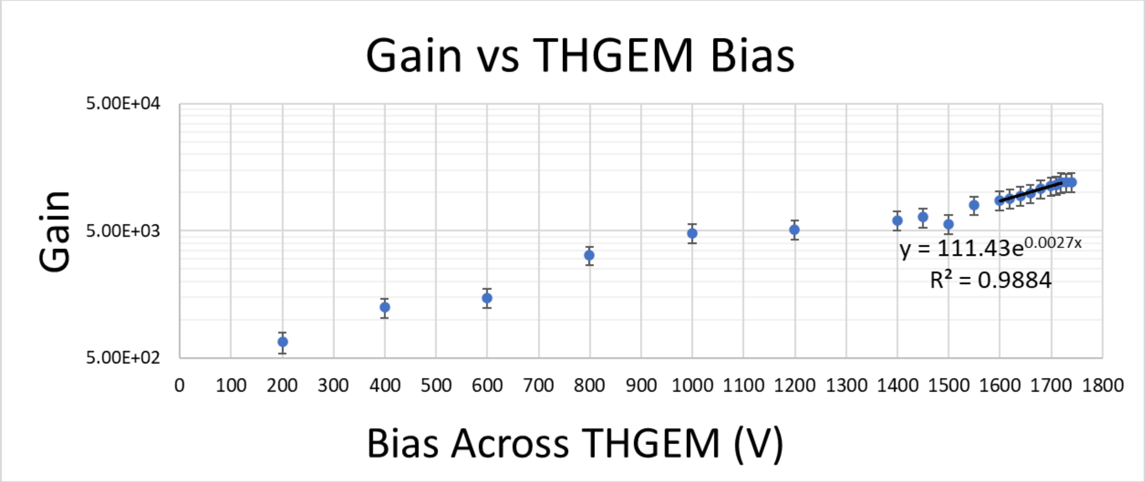
Middle Sector – 2nd Gain Test

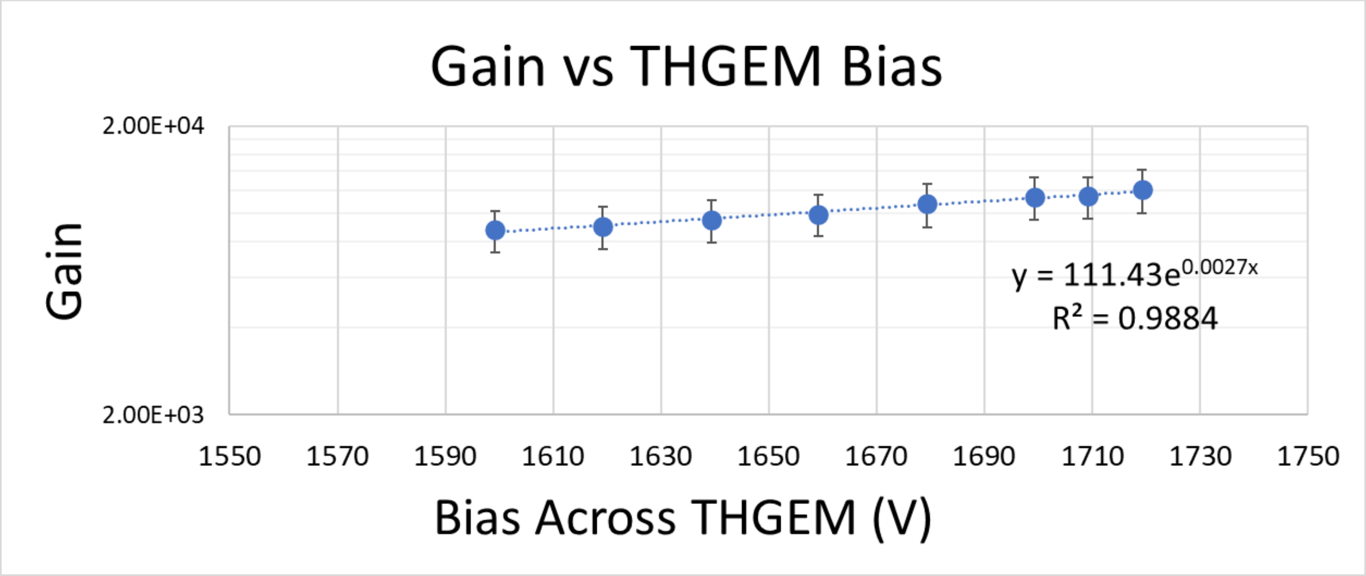




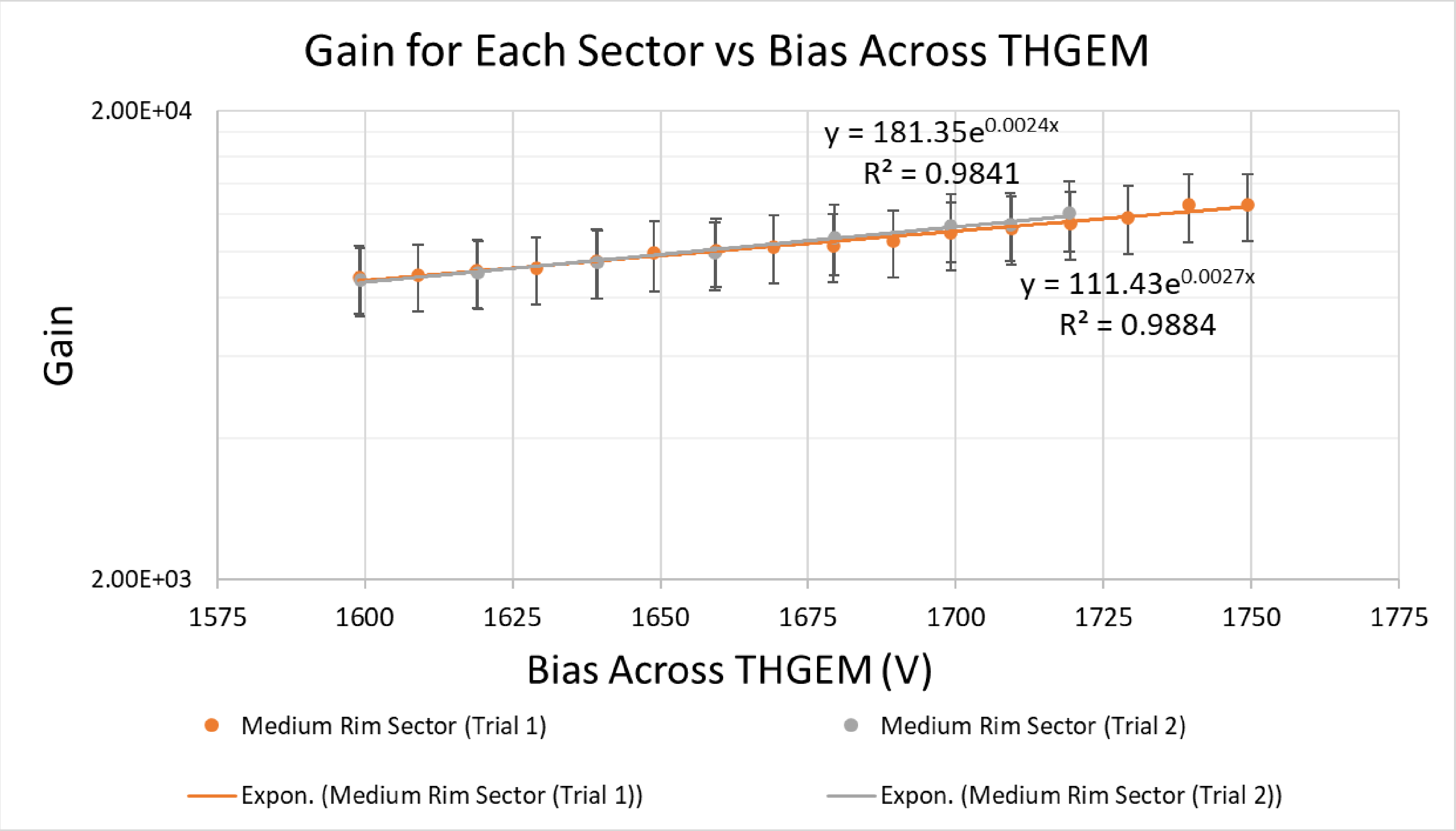
Curious drop in rate around 1670V

Middle Sector – 2nd Gain Test





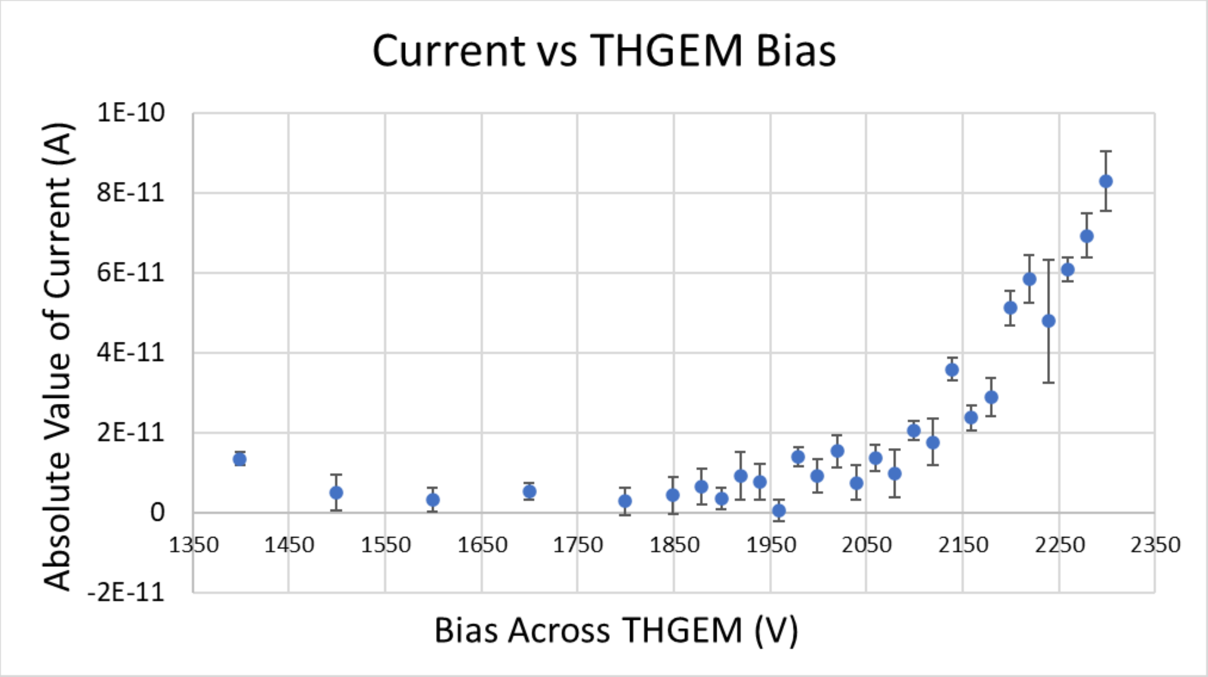
Middle Sector – 2nd Gain Test

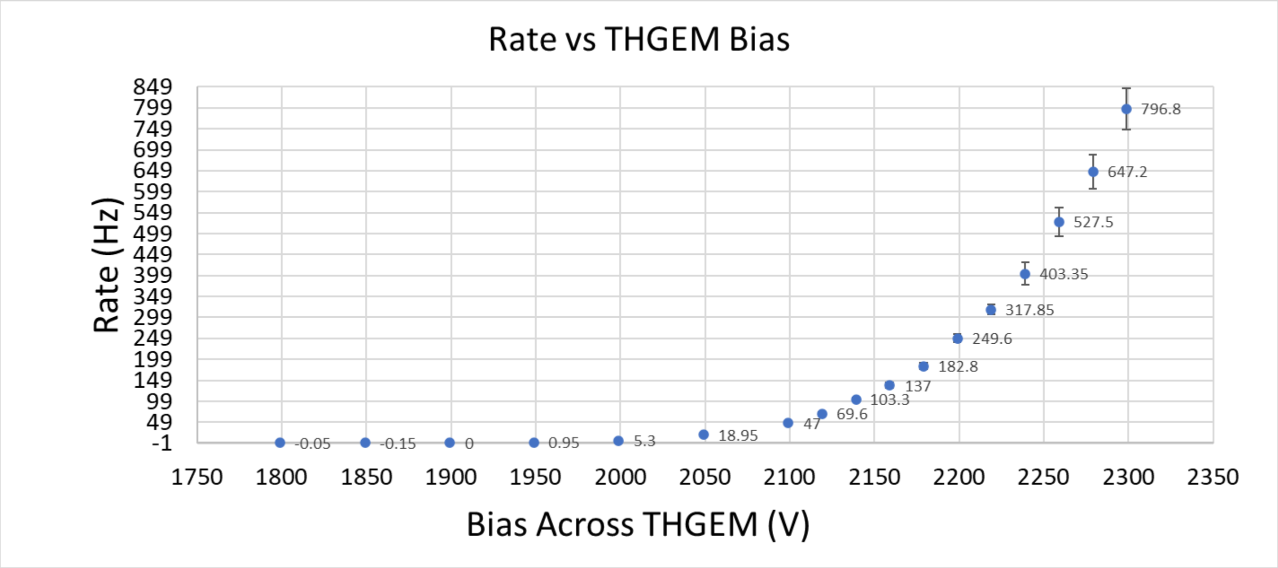


Next Gain Tests

- Switching to Fe-55 out of abundance of caution
- Large Rim Sector up next

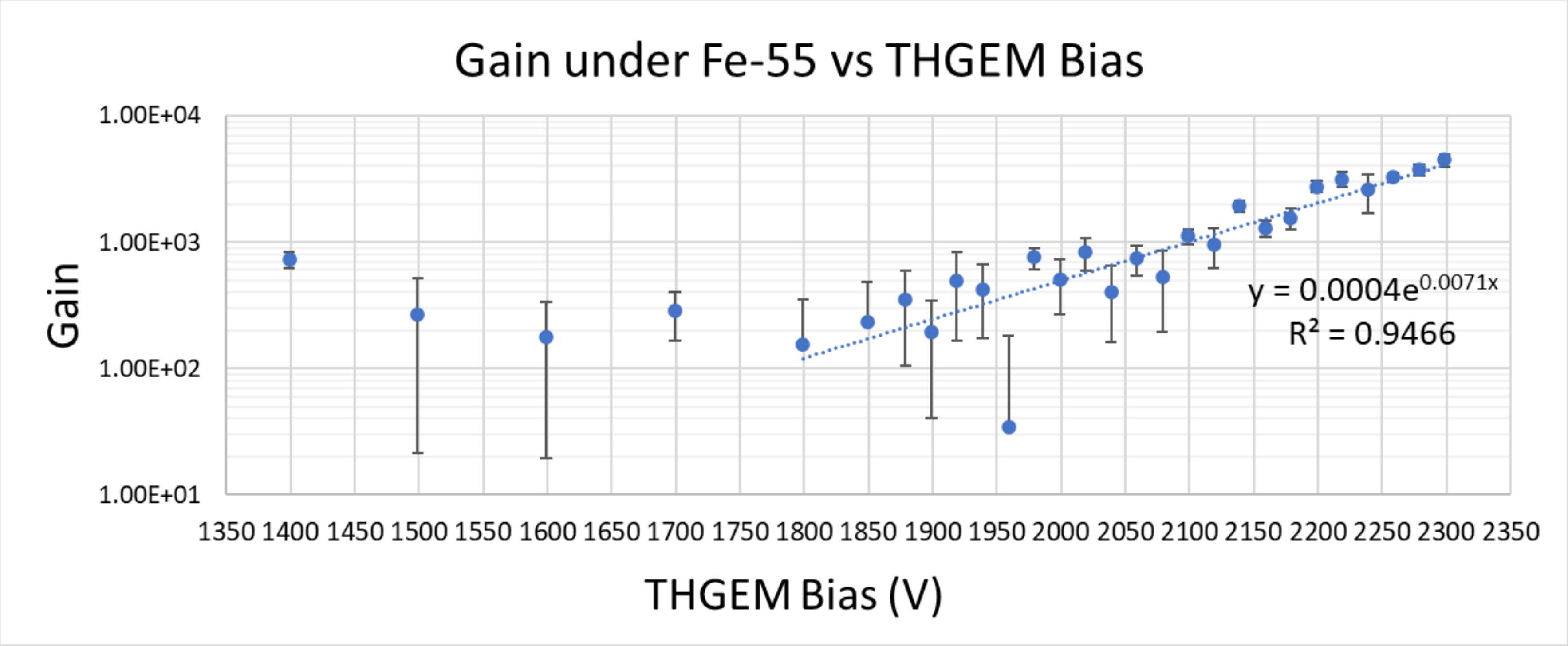
Large Rim Sector – Gain Test





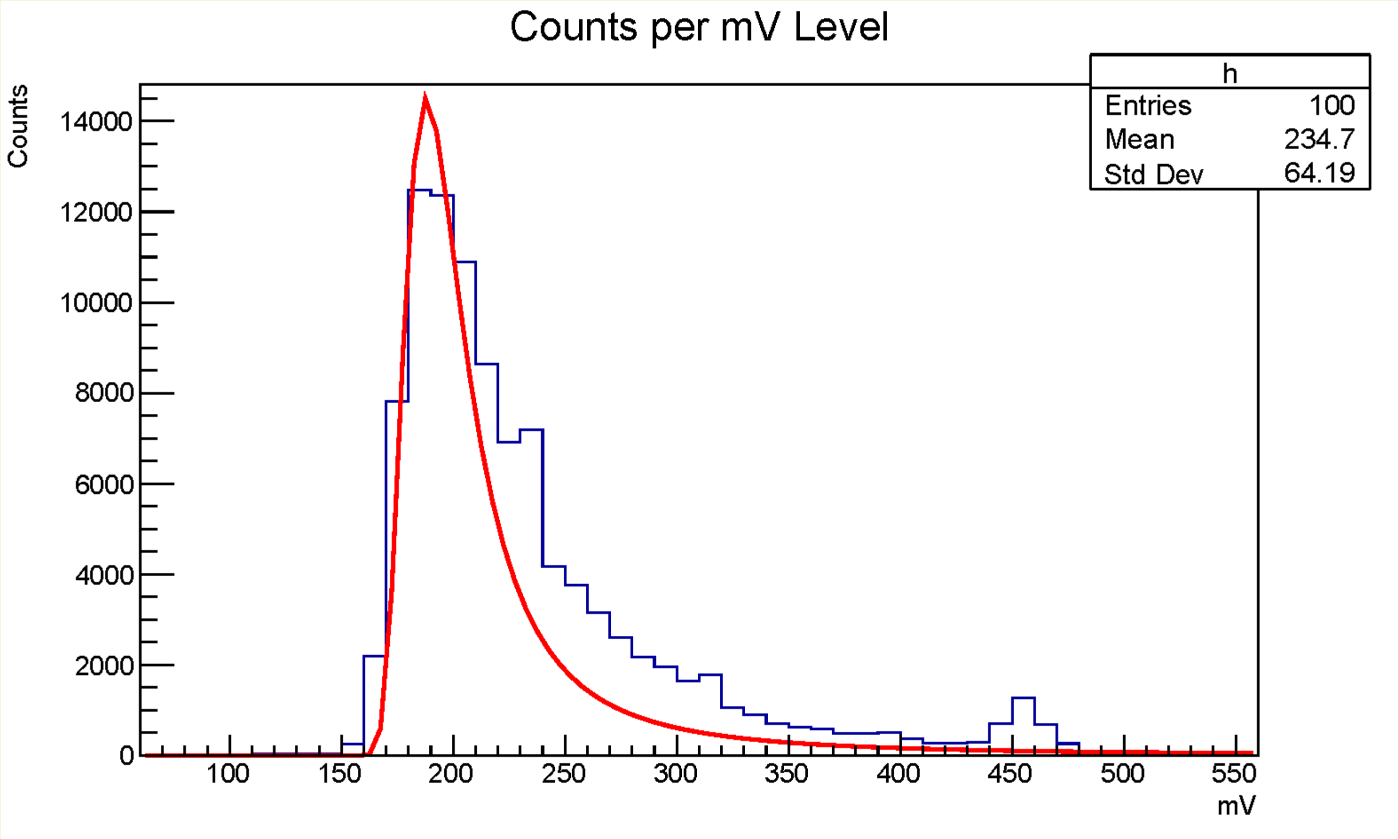
Large Rim Sector – Gain Test

- Fe-55
- Incident Rate: 591.22 ± 8.20 Hz



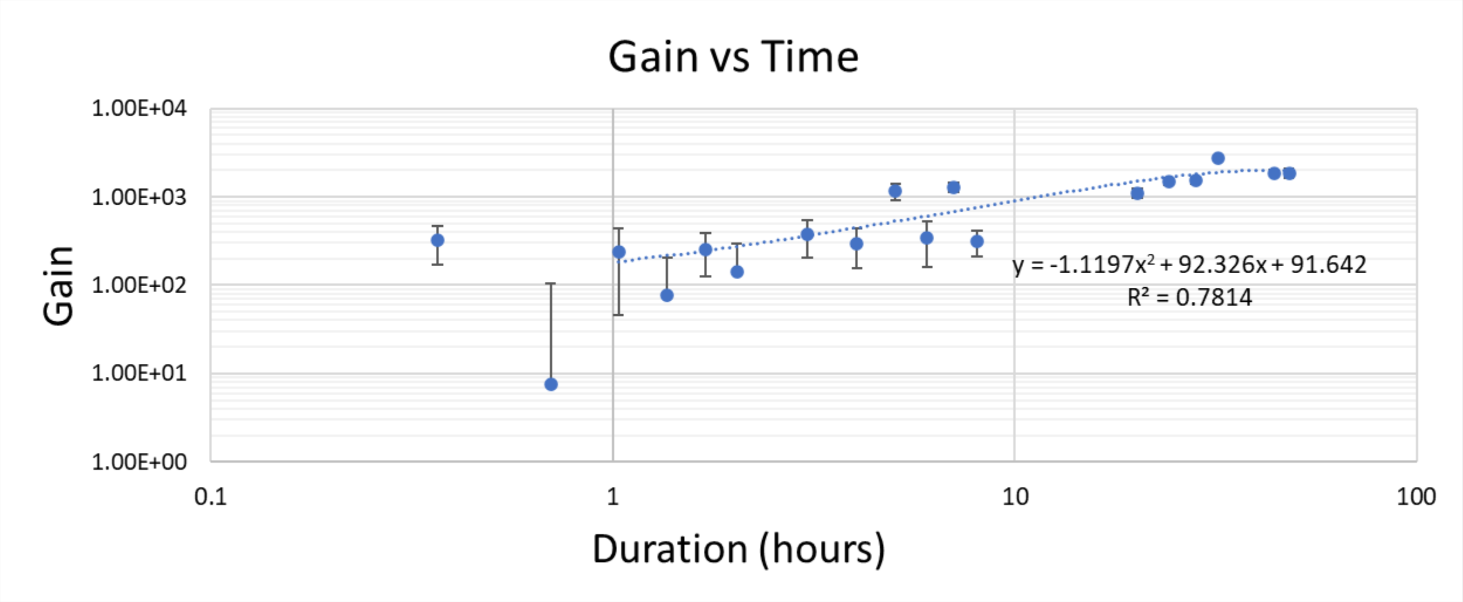
Large Rim Sector – Gain Test

- Pulse height distribution under Fe-55
- THGEM Bias 2200V
- Landau fit MPV 189.83 ± 0.10 mV



Large Rim Sector – Gain Test 48-hour

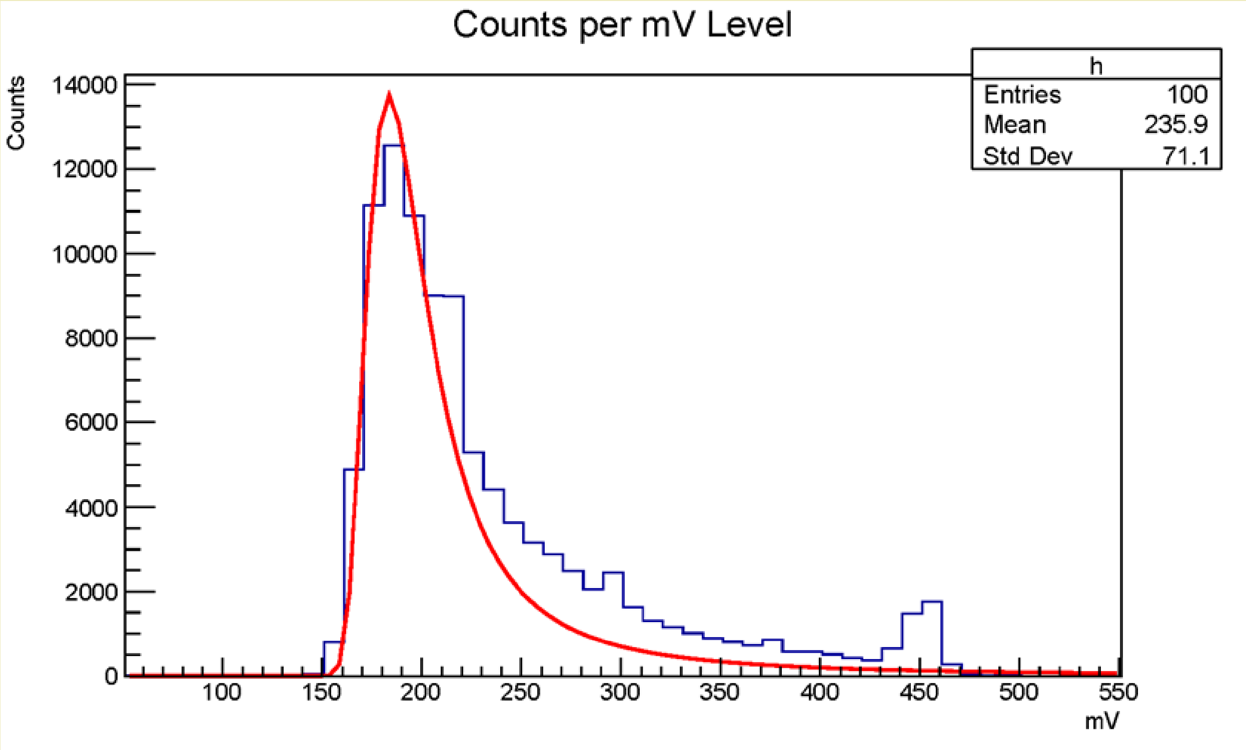
- Every 20 mins for first 2 hours, then once per hour for the remainder of 8 hours
- Came back and measured next day and then every 4 hours for 12 hours
- Came back next day and took a measurement, then one more after 4 hours to complete 48 hours



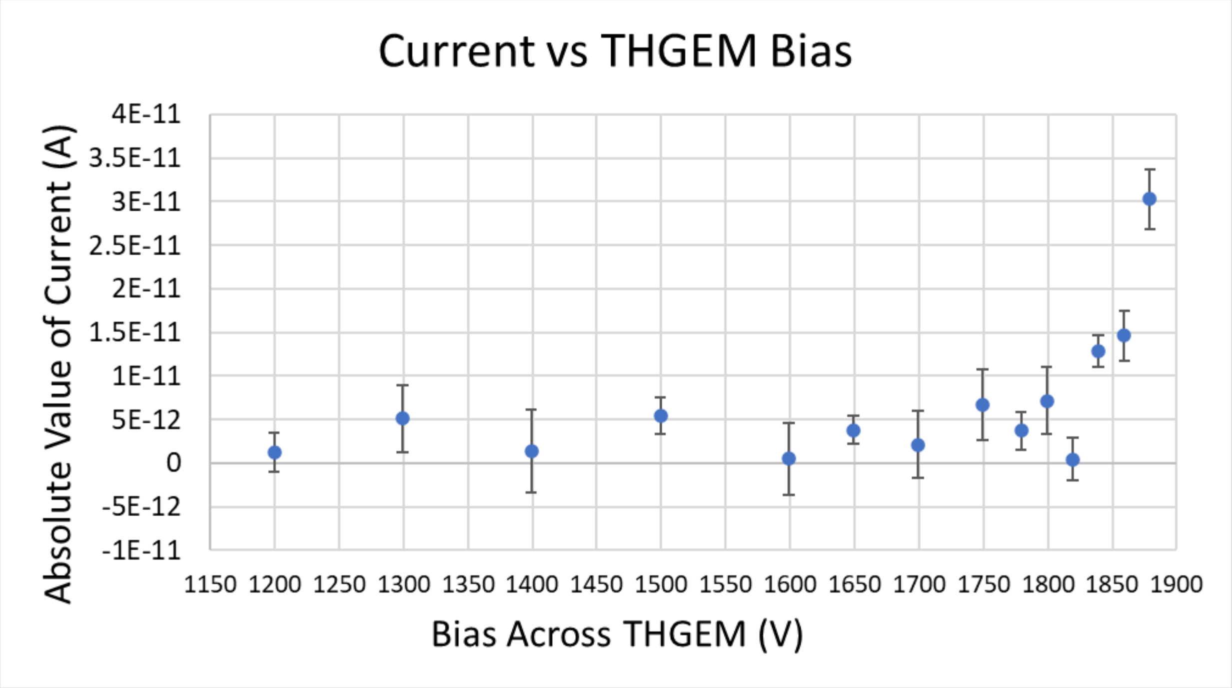
Held at 2120V under Fe-55 constantly

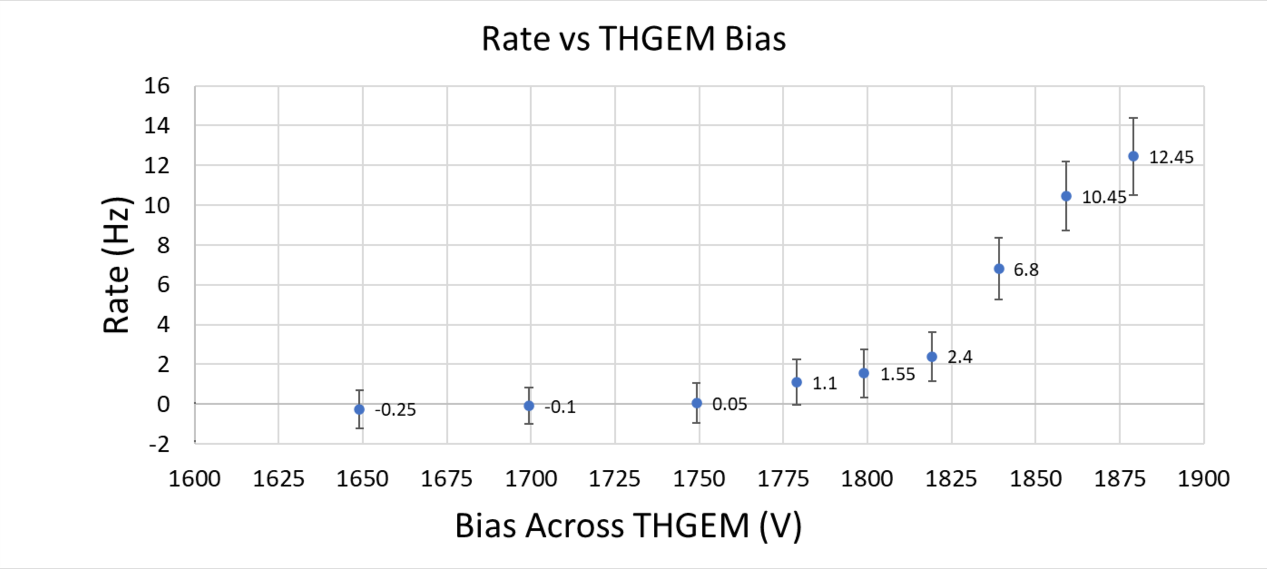
Large Rim Sector – Gain Test 48-hour

- Pulse height distribution under Fe-55 toward end of 48-hour study
- THGEM Bias 2120V
- Landau fit MPV 185.54 ± 0.09 mV
- Both have primary peak ~190 mV

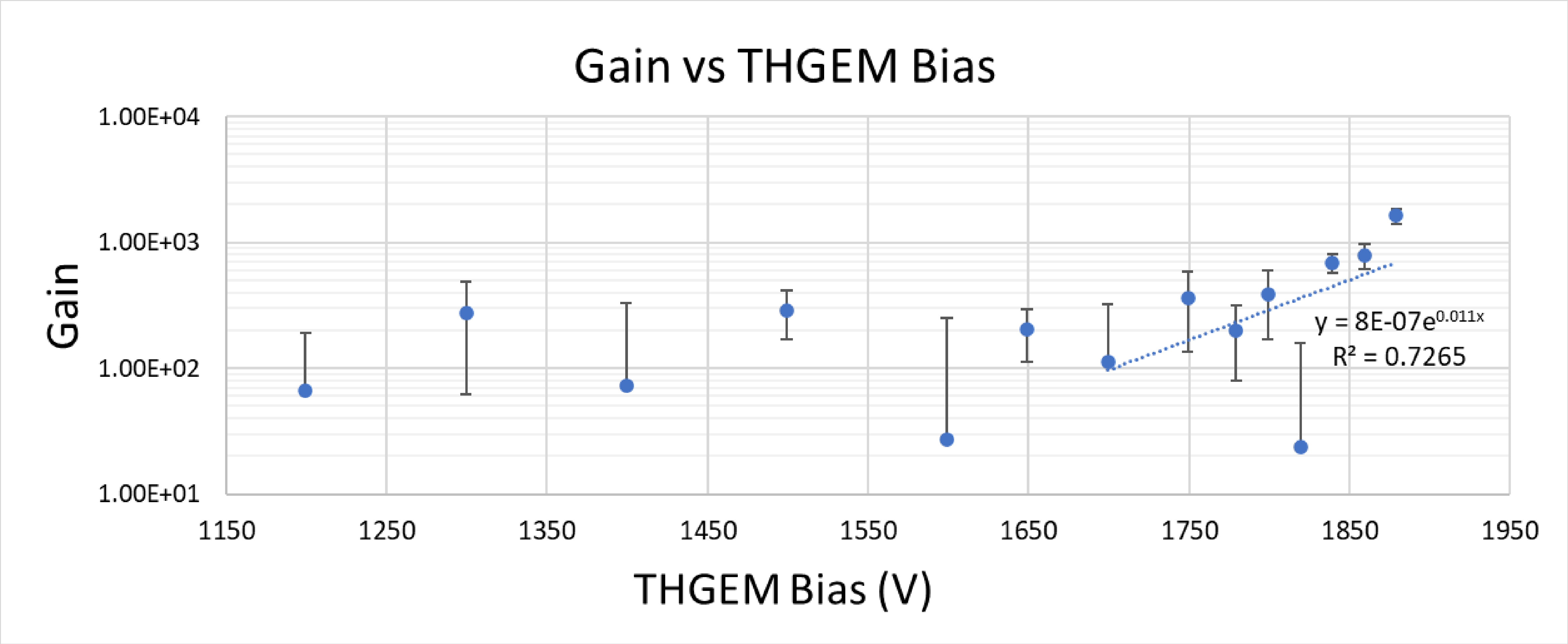


Small Rim Sector – Gain Test



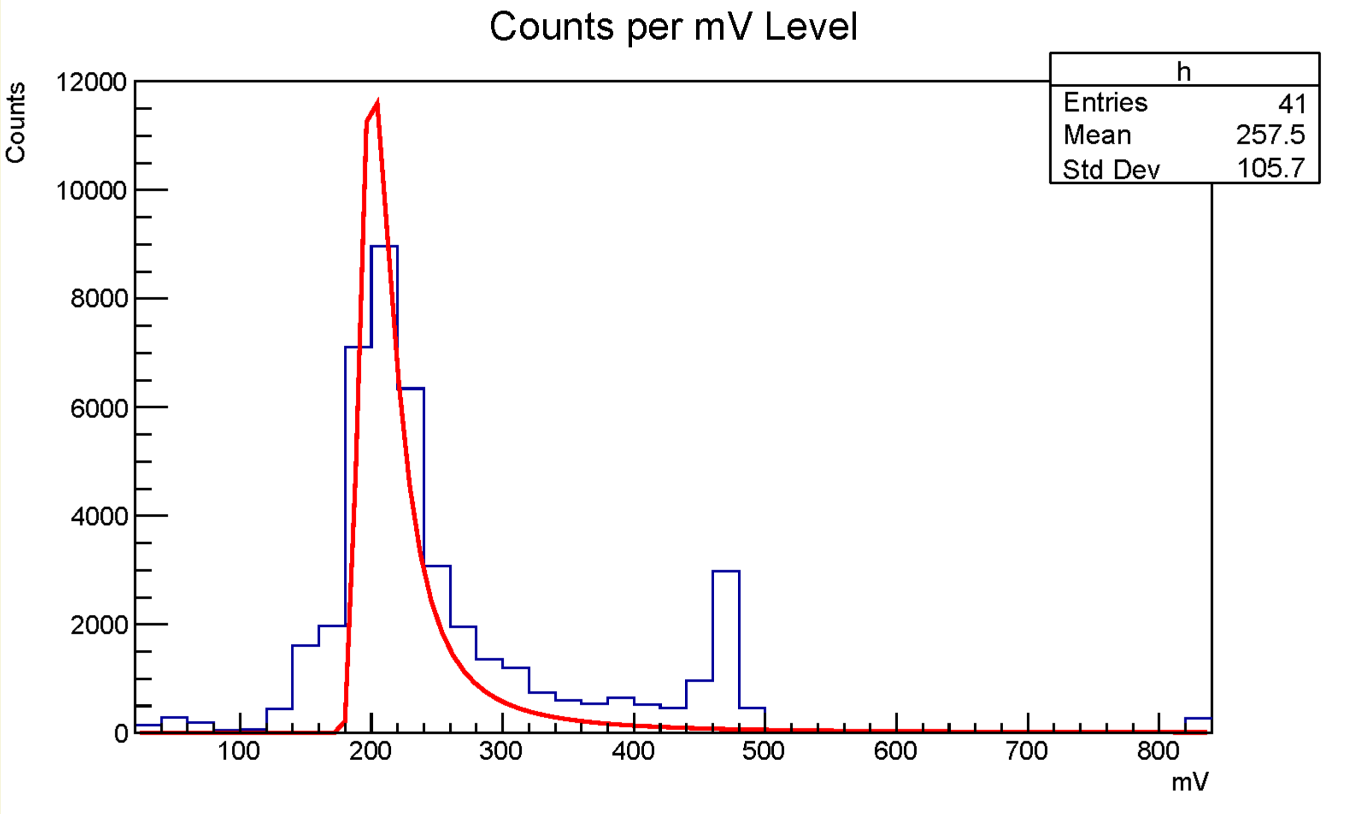


Small Rim Sector – Gain Test

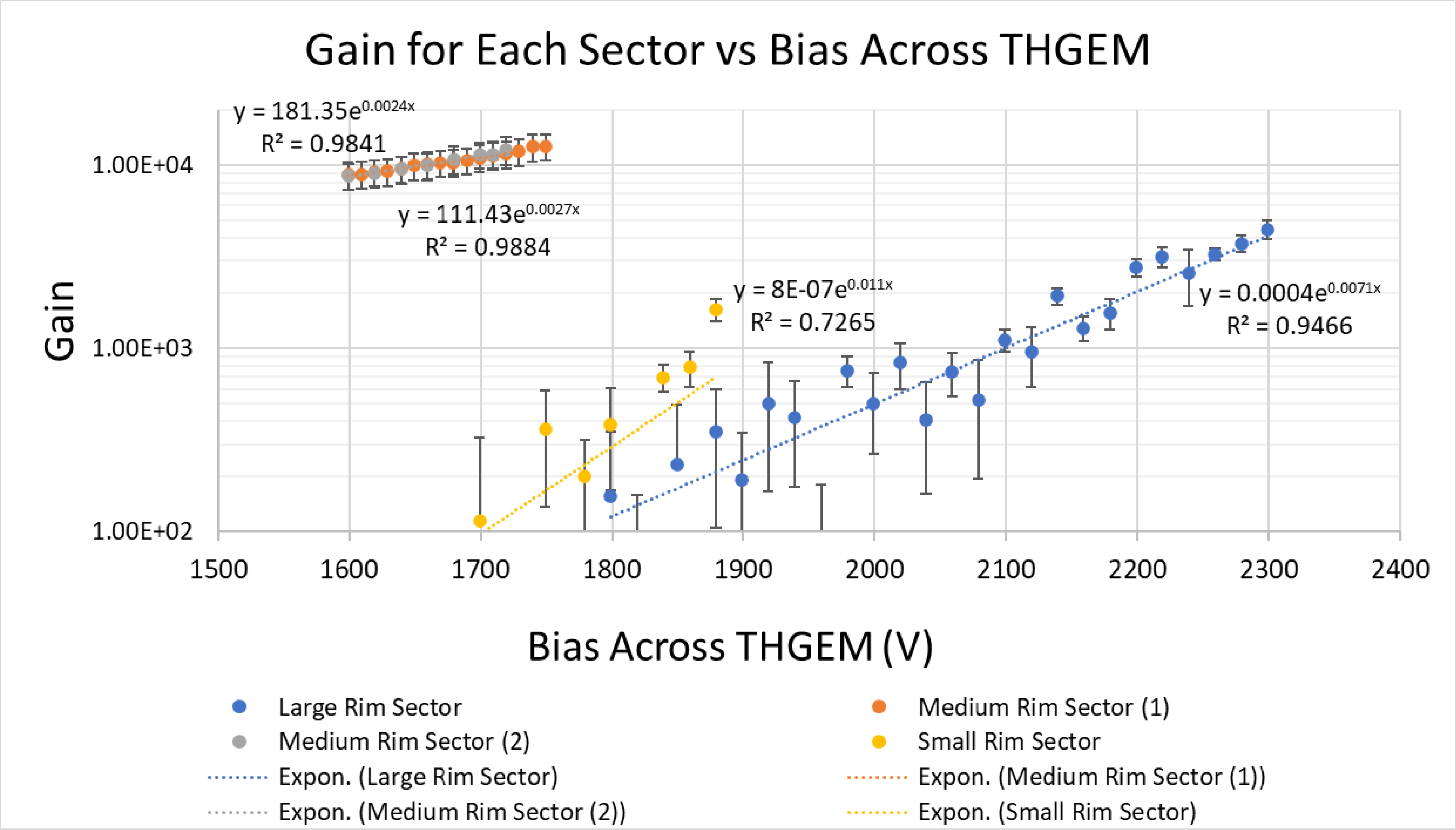


Small Rim Sector – Gain Test

- Pulse height distribution under Fe-55
- THGEM Bias 1840V
- Landau fit MPV 202.41 ± 0.11 mV



Gain vs THGEM Bias Voltage – All Sectors

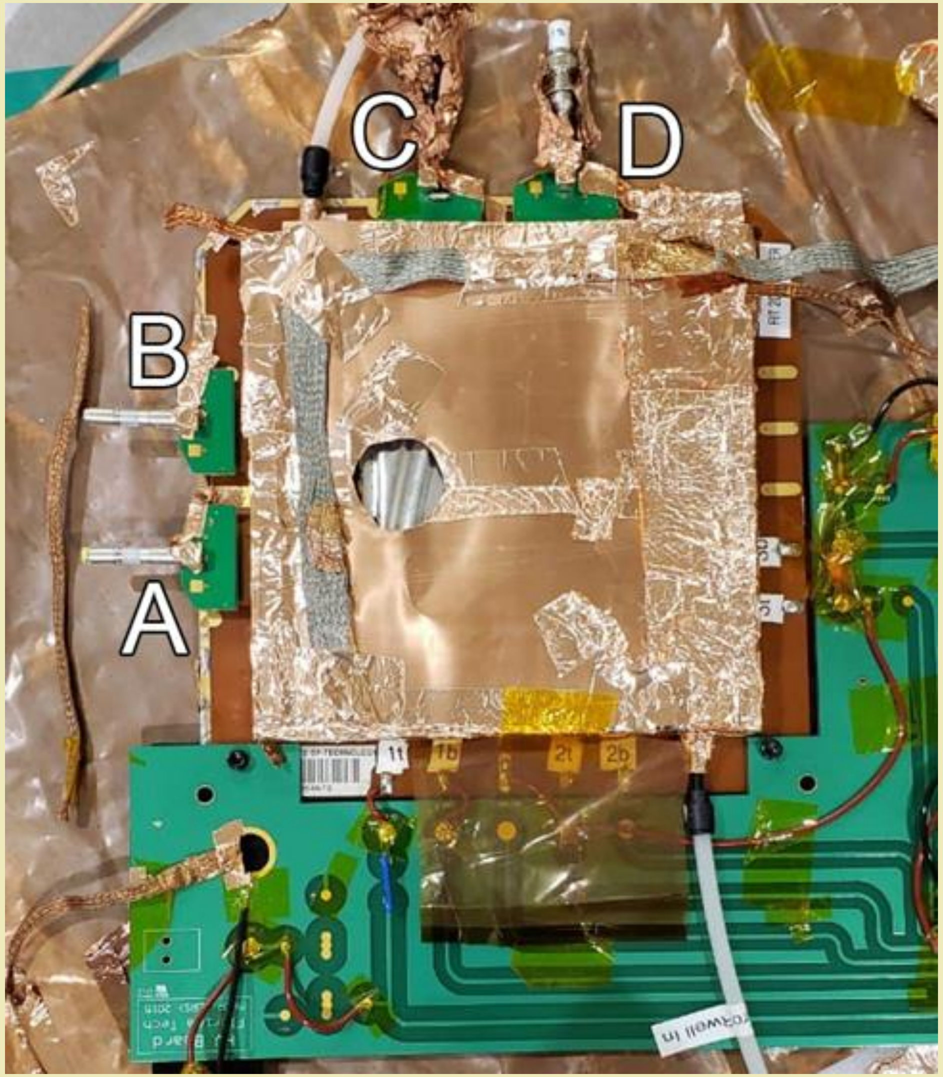


Long-term Tests

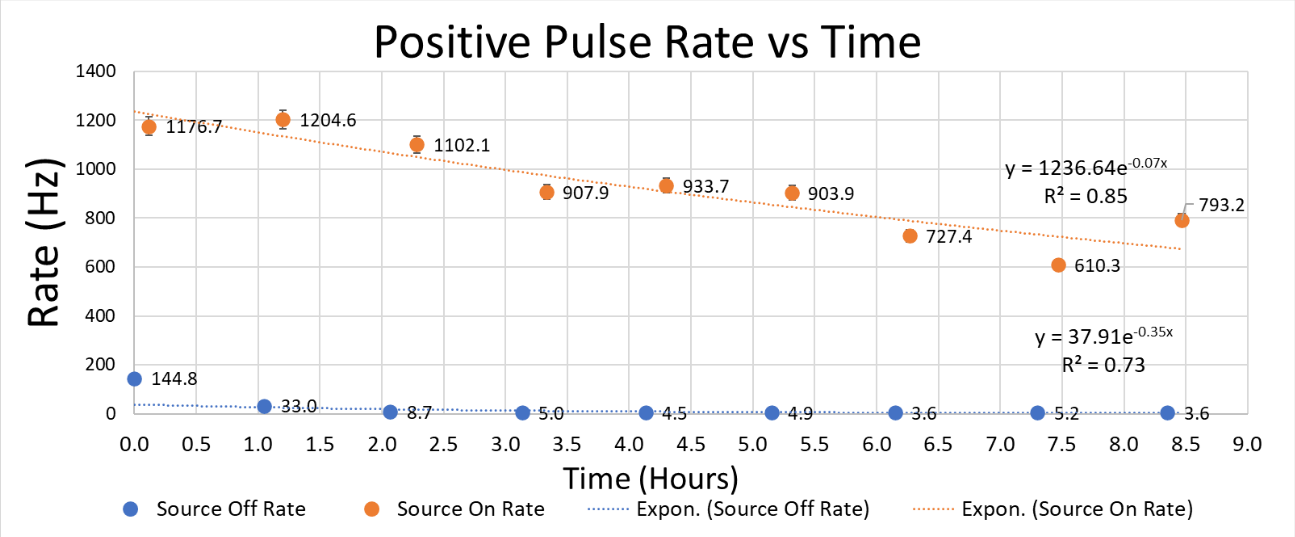
- THGEM under Fe-55 irradiation for 5-48 hours
- Observe HV stability, long-term evolution of count rate and gain
- Behavior of positive-to-negative “transitions” (large pulses with negative components)
- Second Timing SCA added to count transitions

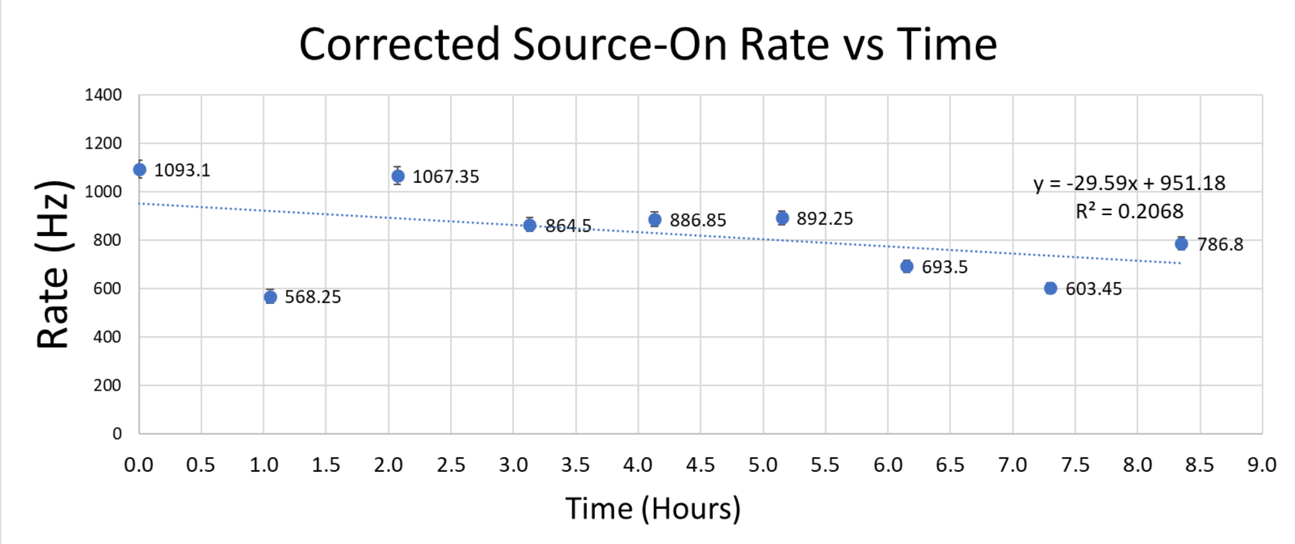
First Long-term Test

- Middle Sector, Lemo D
- Drift and induction fields 3 kV/cm
- THGEM Bias 2000V
- Fe-55 X-ray source



First Long-term Test



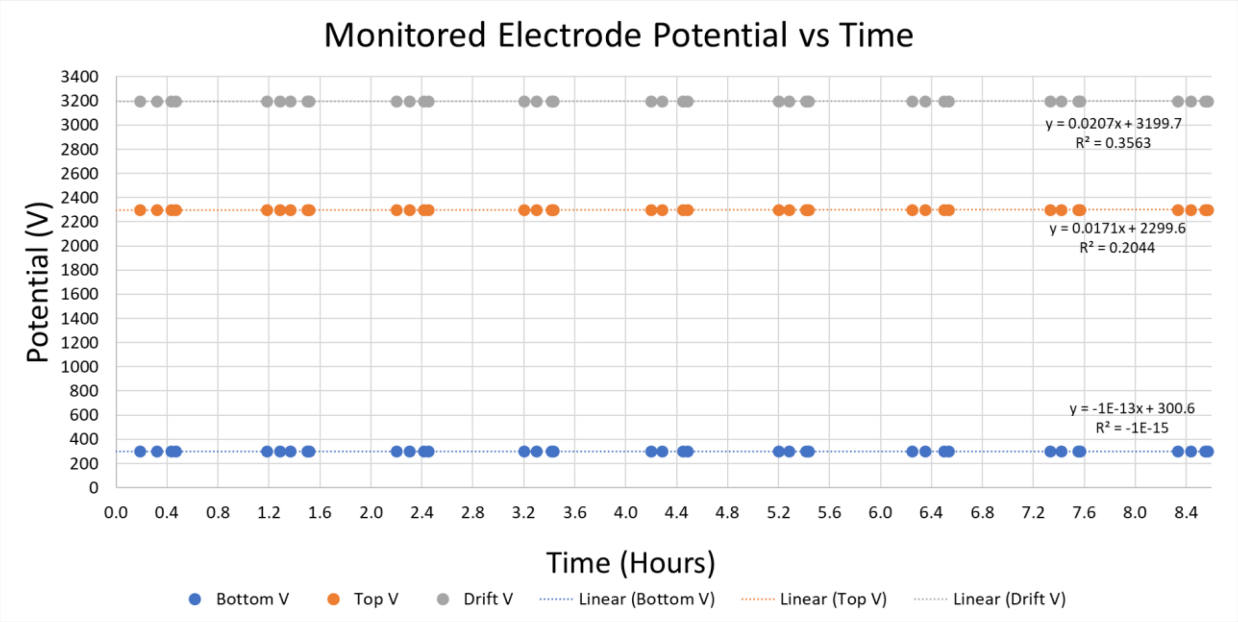


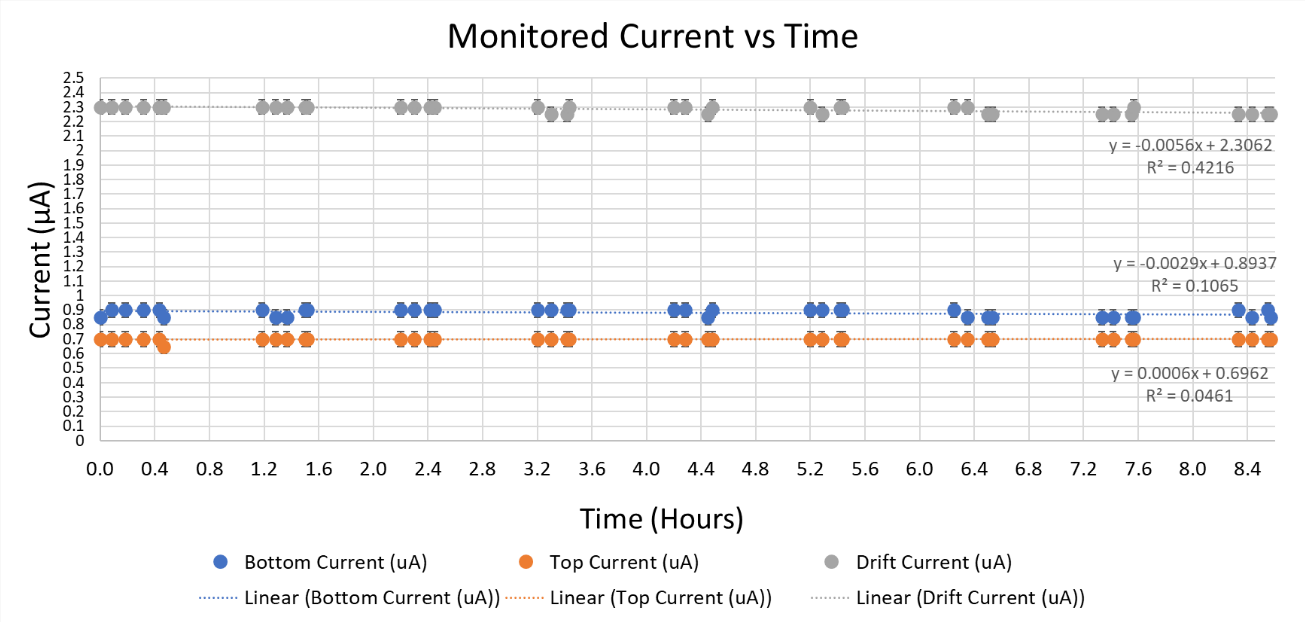
Note: Fe-55 removed in between data-taking

Second Long-term Test

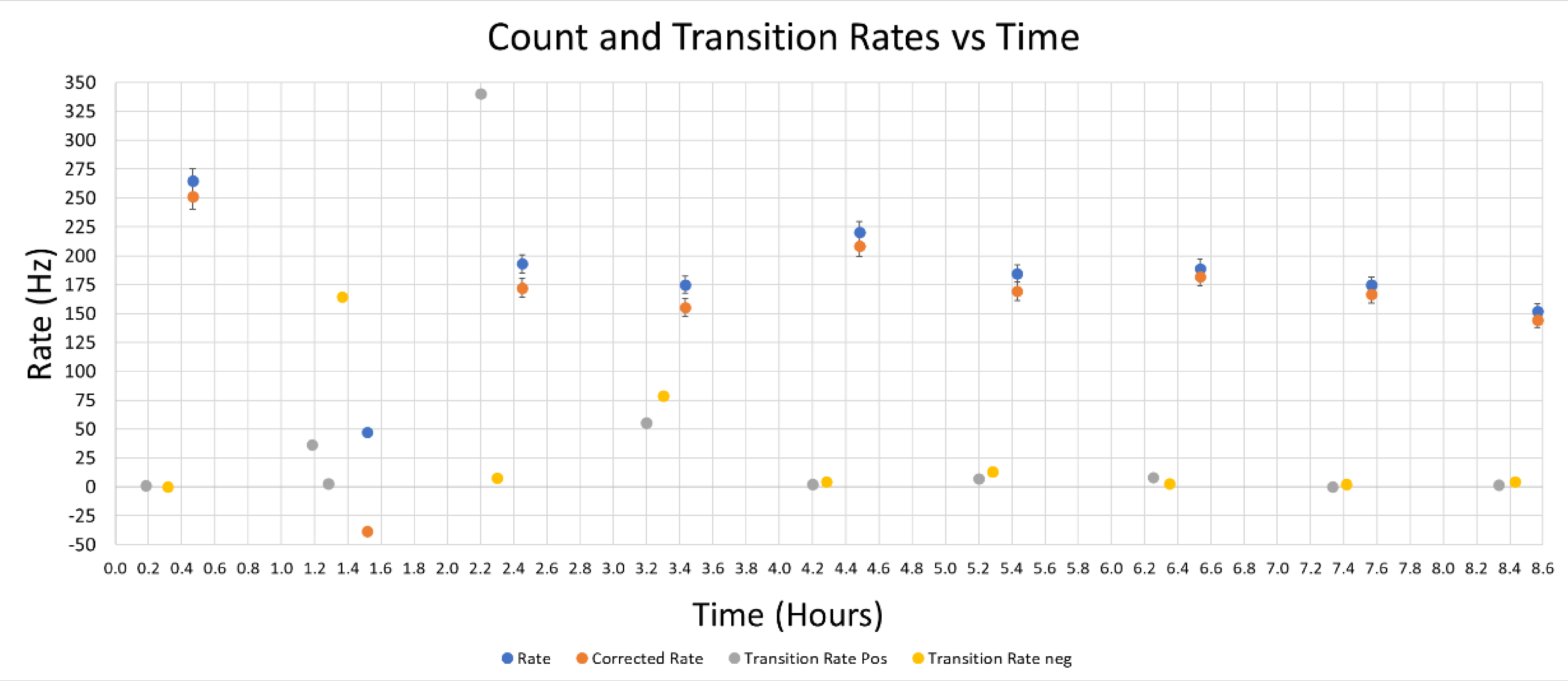
- Kept Fe-55 on constantly to observe behavior with charging up of insulating material
- HV monitor information maintained
- Leakage current from HV module
  - Constant unless discharge or similar phenomenon

Second Long-term Test





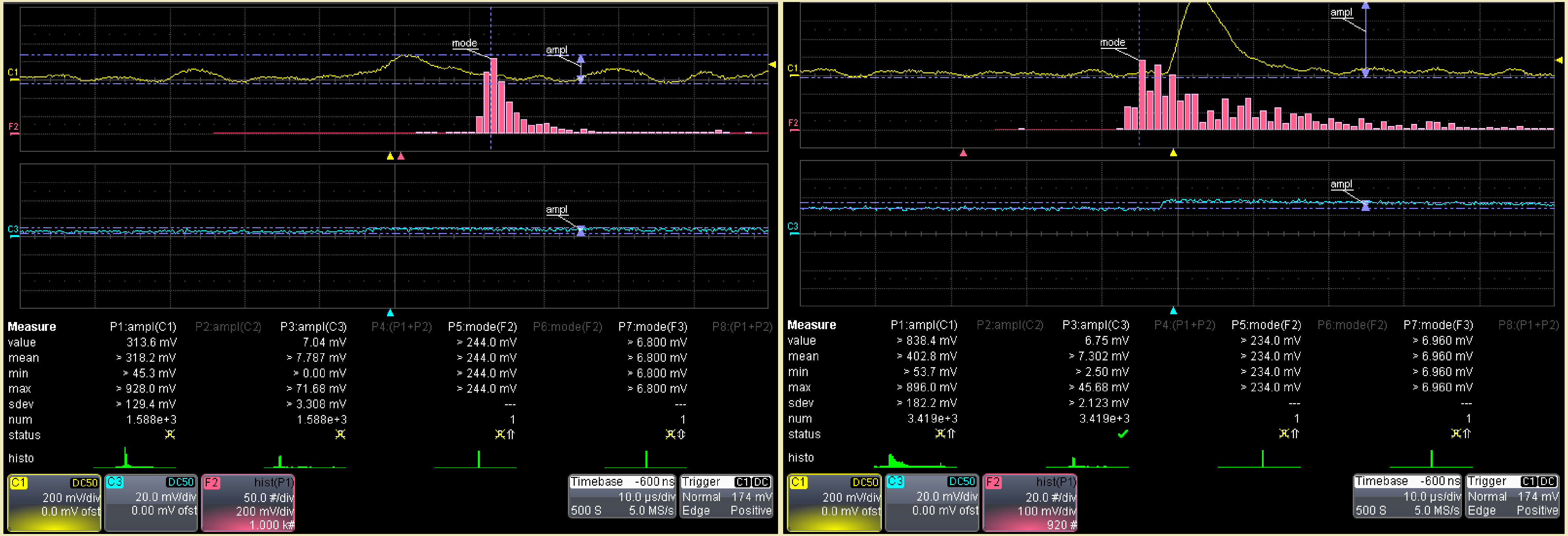
Second Long-term Test



Third Long-term Test

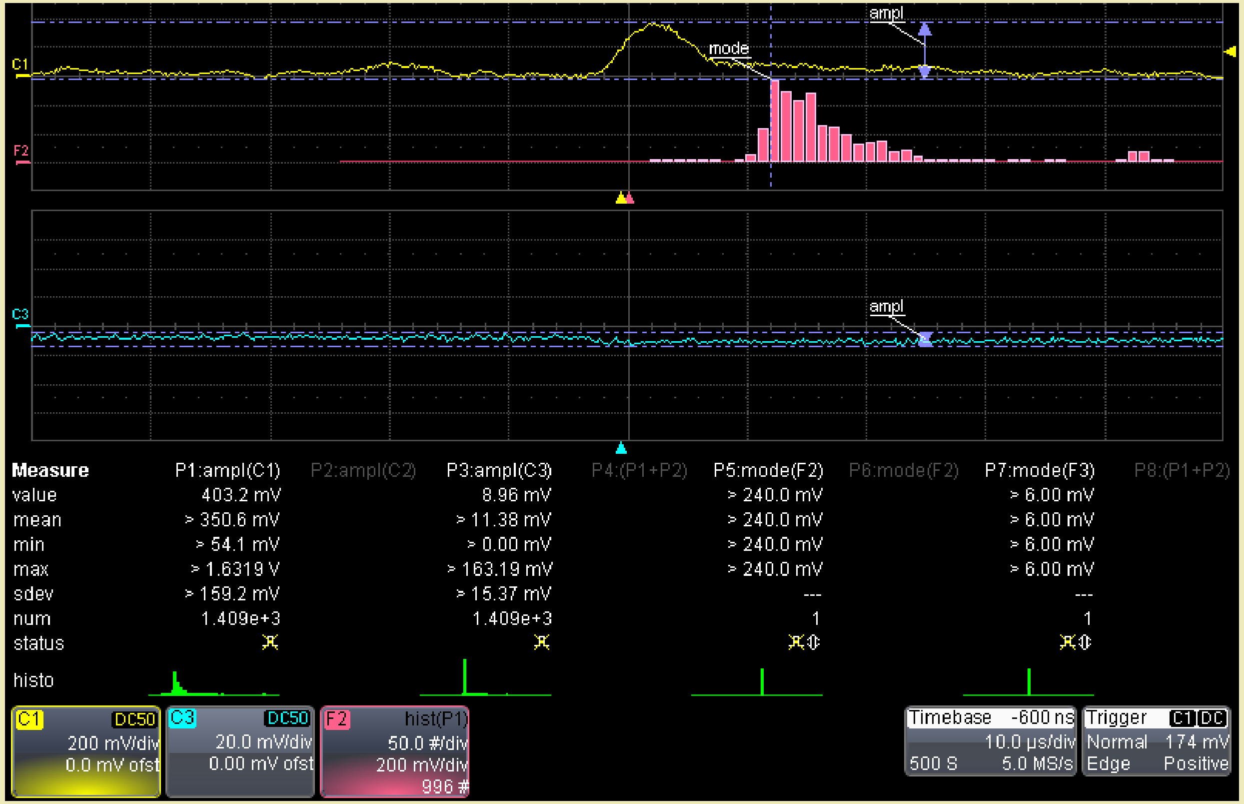
- Over ~48 hours
- Detector constantly 3 kV/cm drift and induction fields, 2000V THGEM bias, Fe-55
- Every 20 mins for 2 hours, every hour for remainder of 8 hours, next day every 4 hours, then final 2 points the day after

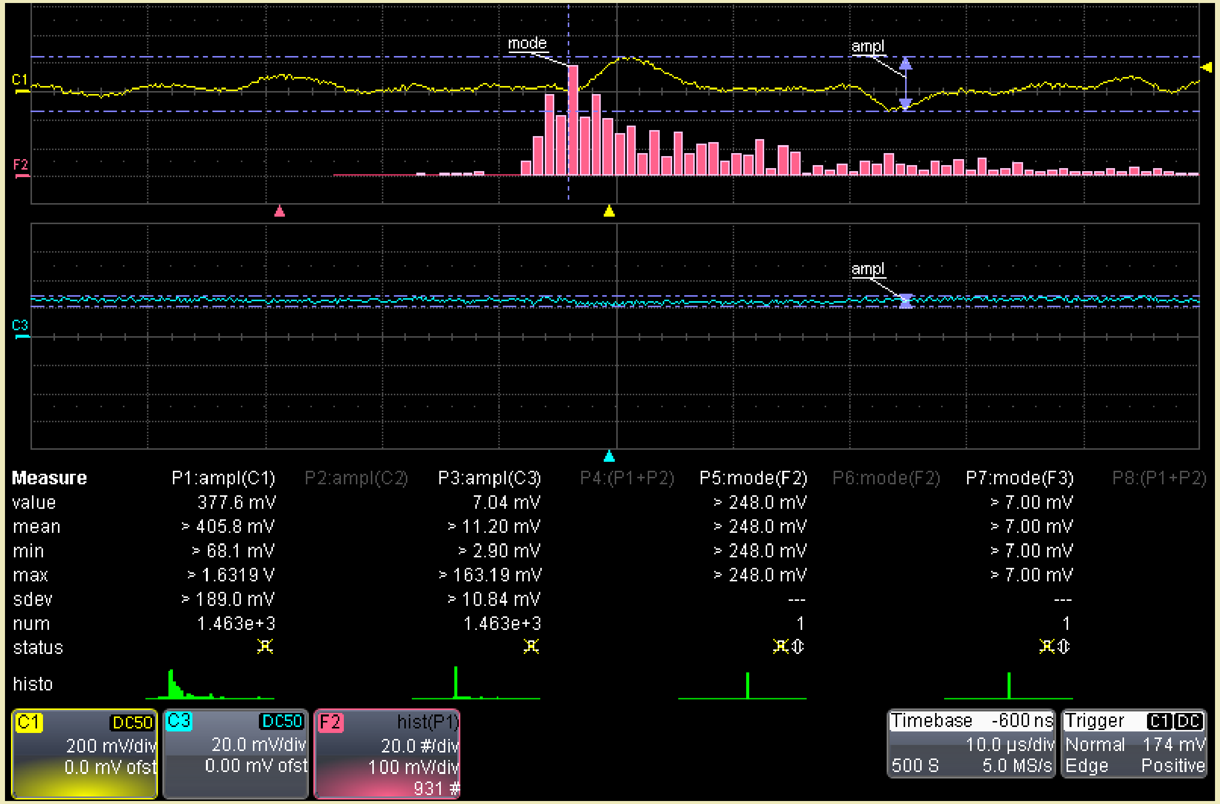
Third Long-term Test



Histogram with amp signal at beginning (left) and end (right) of 48-hour study, positive polarity

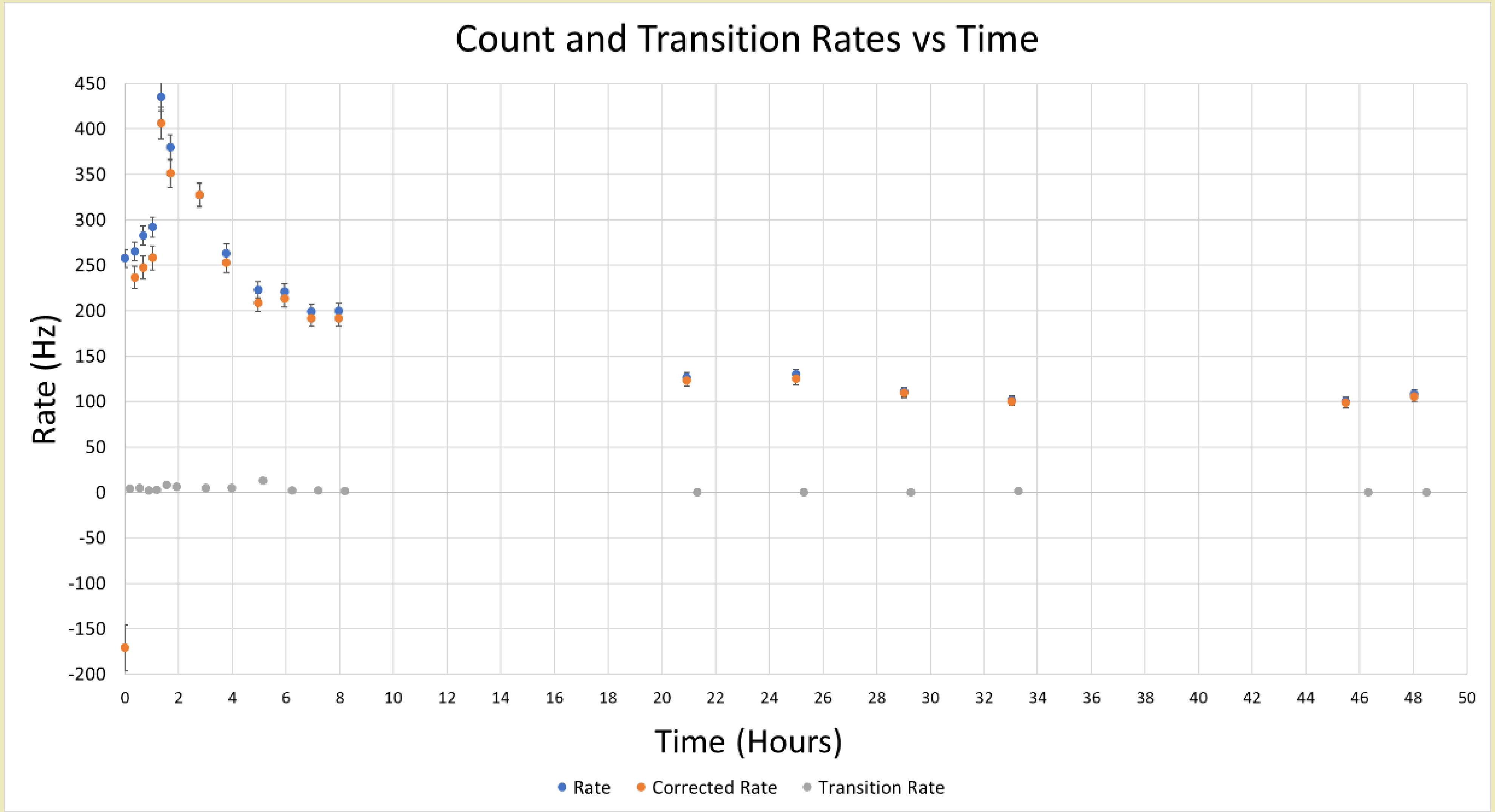
Third Long-term Test





Histogram with amp signal at beginning (left) and end (right) of 48-hour study, negative polarity

Third Long-term Test



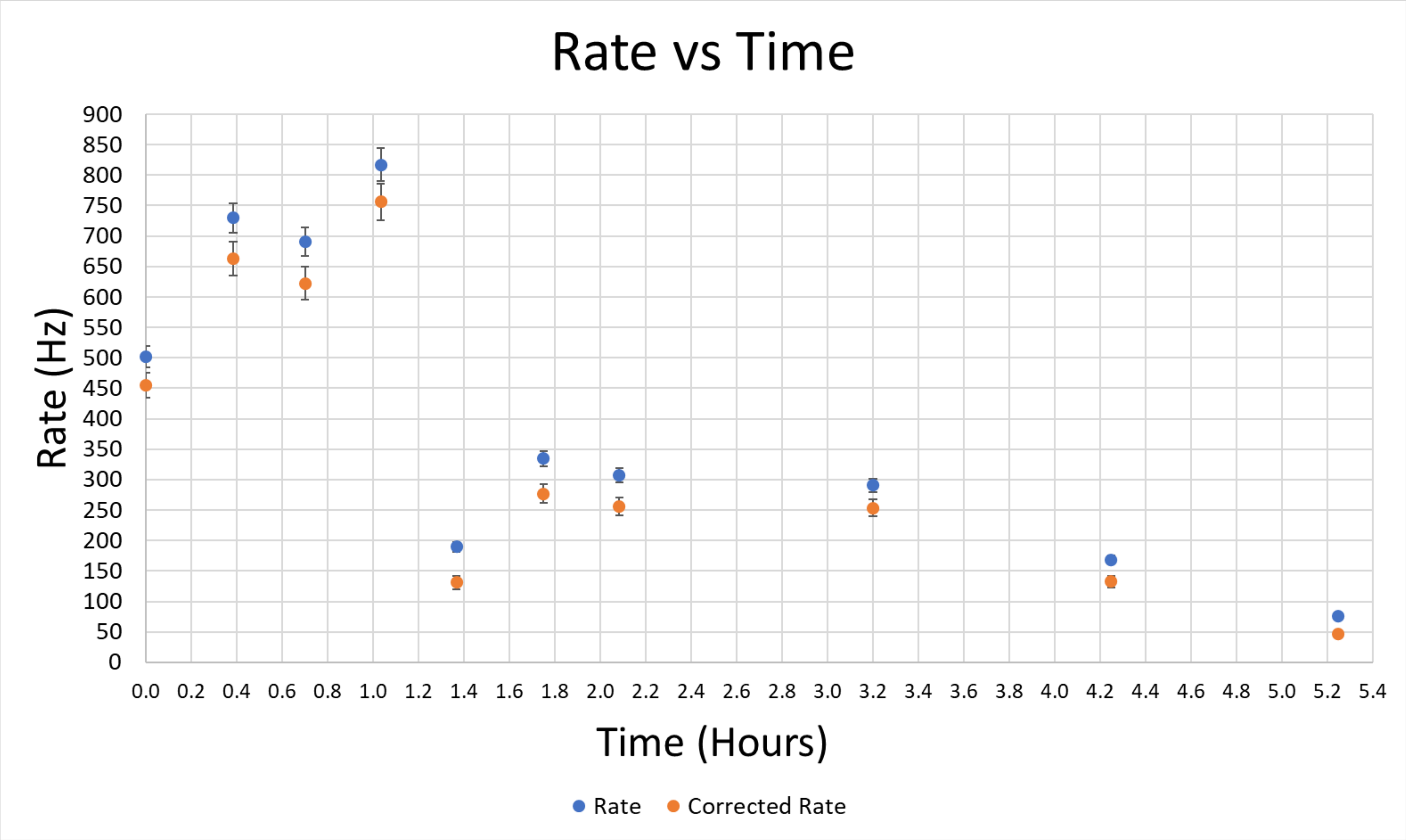
Notice the difference between Rate and Corrected shrinks over time, meaning negative pulse (and overshoot) rate drops over time

Fourth Long-term Test

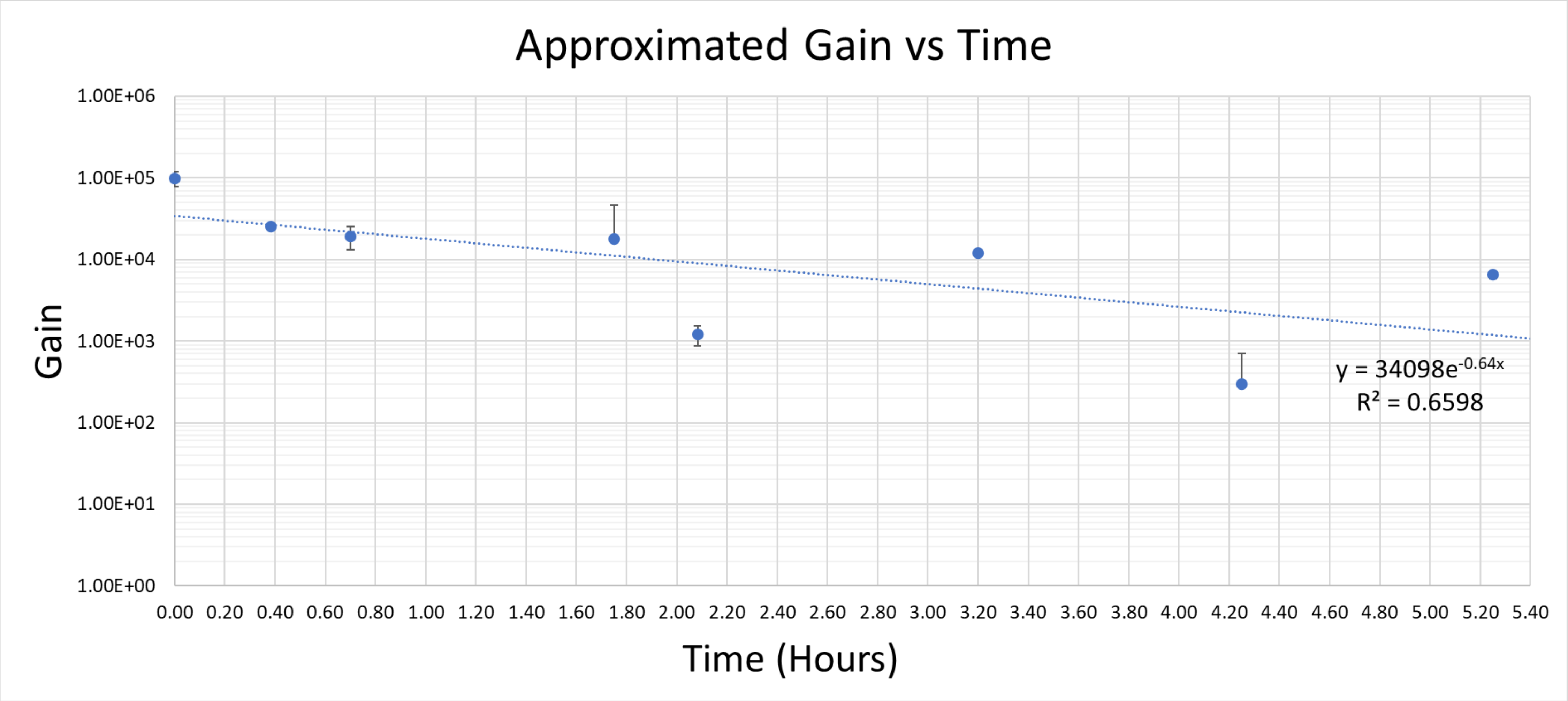
- Want to investigate and confirm the initial behavior as seen in previous plot
- Repeated shorter version of trial
- Signal current monitored throughout, source-off reference at end
- Allow for an approximation of gain over time
- Incident Rate 591.22 ± 8.20 Hz used

Keithley Picoammeter used for signal current measurements

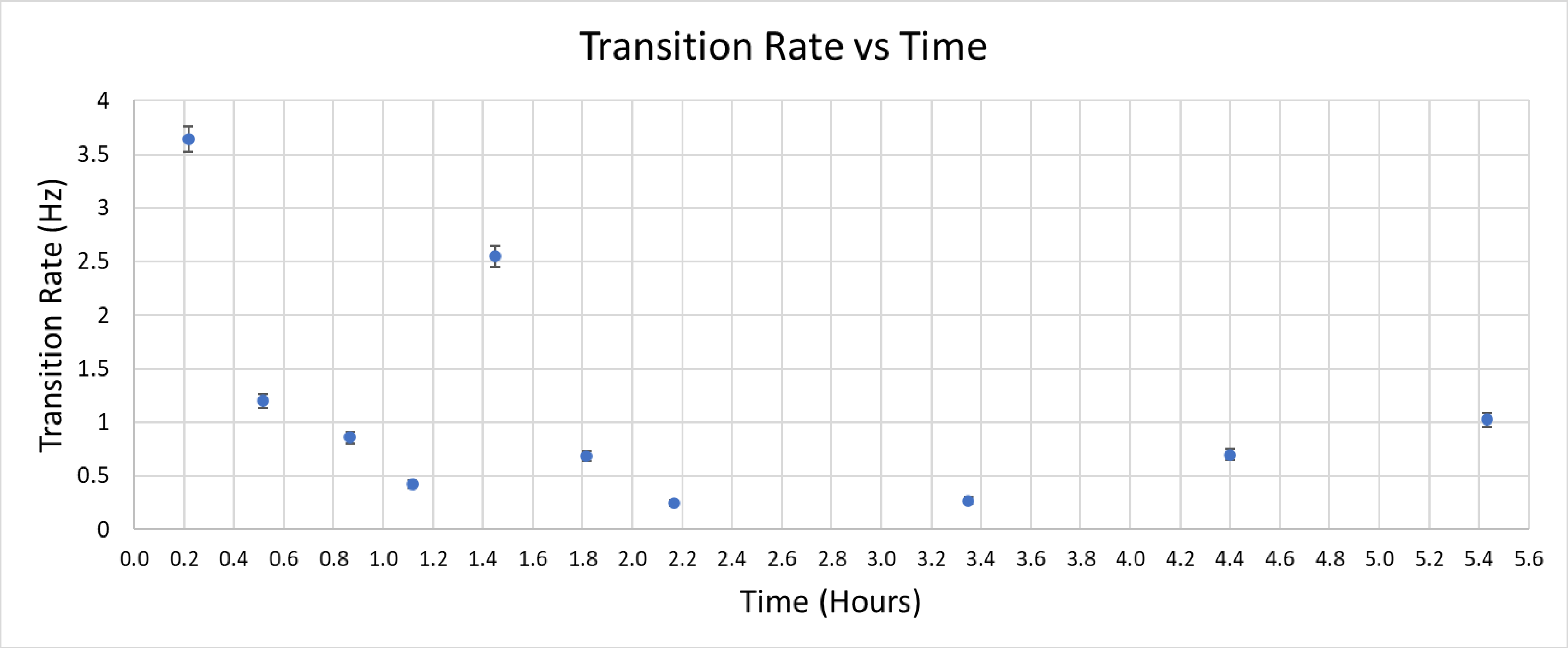
Fourth Long-term Test



Fourth Long-term Test

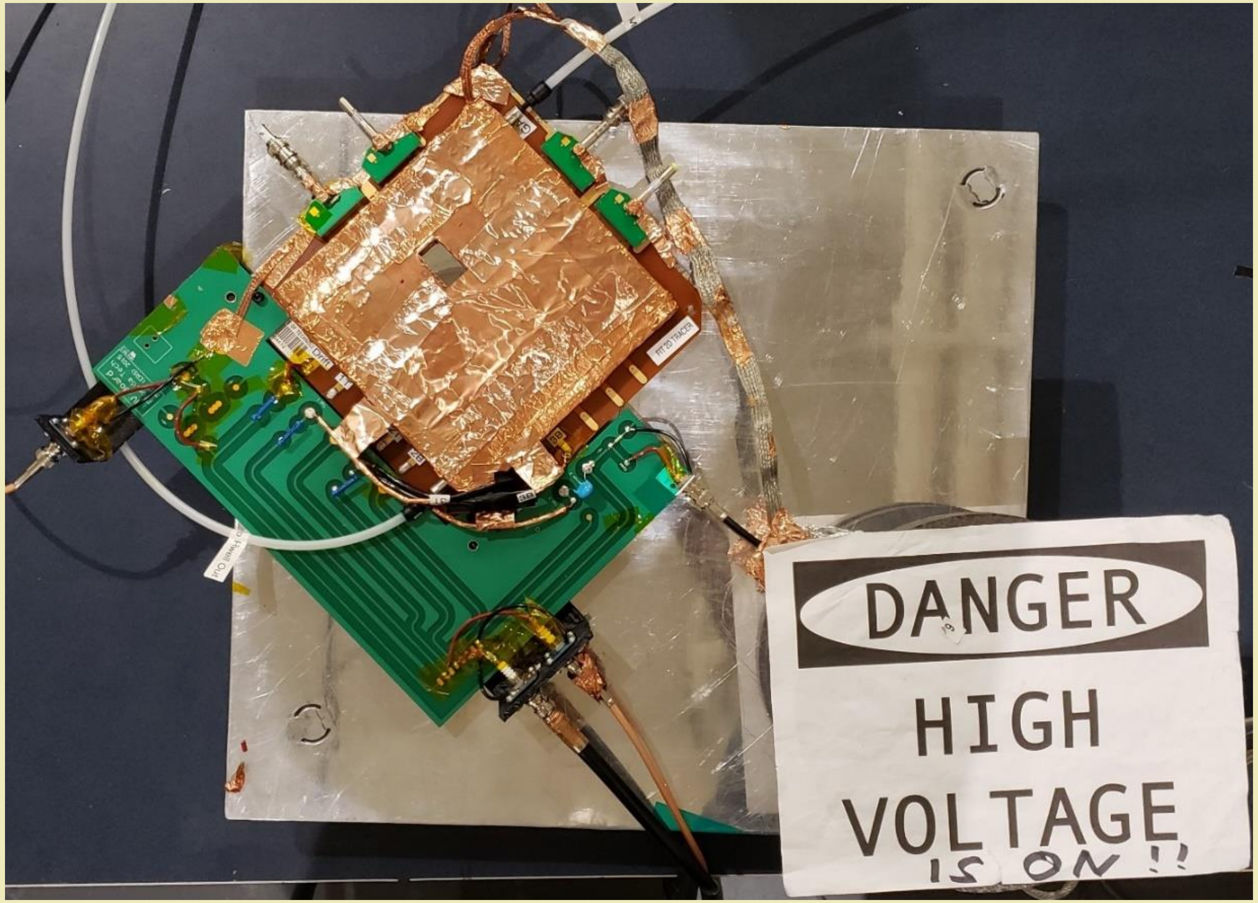


Fourth Long-term Test



HV Functionality

- Each sector tested under pure CO_2
- Observe functionality without amplification
- Read off THGEM Bottom
  - Allows to gather data from full sensitive area



HV Functionality – Small Rim Sector

- Constant 2.6 kV/cm induction field, 1.8 kV/cm drift field
- Taken through several bias voltage levels
- Count rate of 0 Hz was found regardless of voltage
  - Reasonable as no electron avalanche

HV – Functionality Medium and Large Rim Sectors

- Medium and Large rim sectors did not function as smoothly
- Medium sector at 1000V and lower than standard drift field showed instability on Bottom and scope, overvoltage
- Large sector better than medium, at 1000V had large and long-lasting pulses, preventing reasonable rate measurements
- Suggests some physical issue with these sectors at the end of experimentation, possibly exacerbated by amplification under Ar/CO_2

Summary and Conclusions

- In optimal conditions, max functional bias voltage achievable increases with rim annulus
- Small rim sector able to achieve higher voltage levels than medium in final gain tests
  - 48-hour test attempted however and unable to go beyond 1730V
  - Toward the beginning able to go up to 1900-2000V
- Medium Rim sector when first switched to allowed 2200-2300V
  - Held stably at 2100V with higher 3 kV/cm drift and induction fields during early long-term tests
  - No longer possible by the time the gain curves were found

Summary and Conclusions

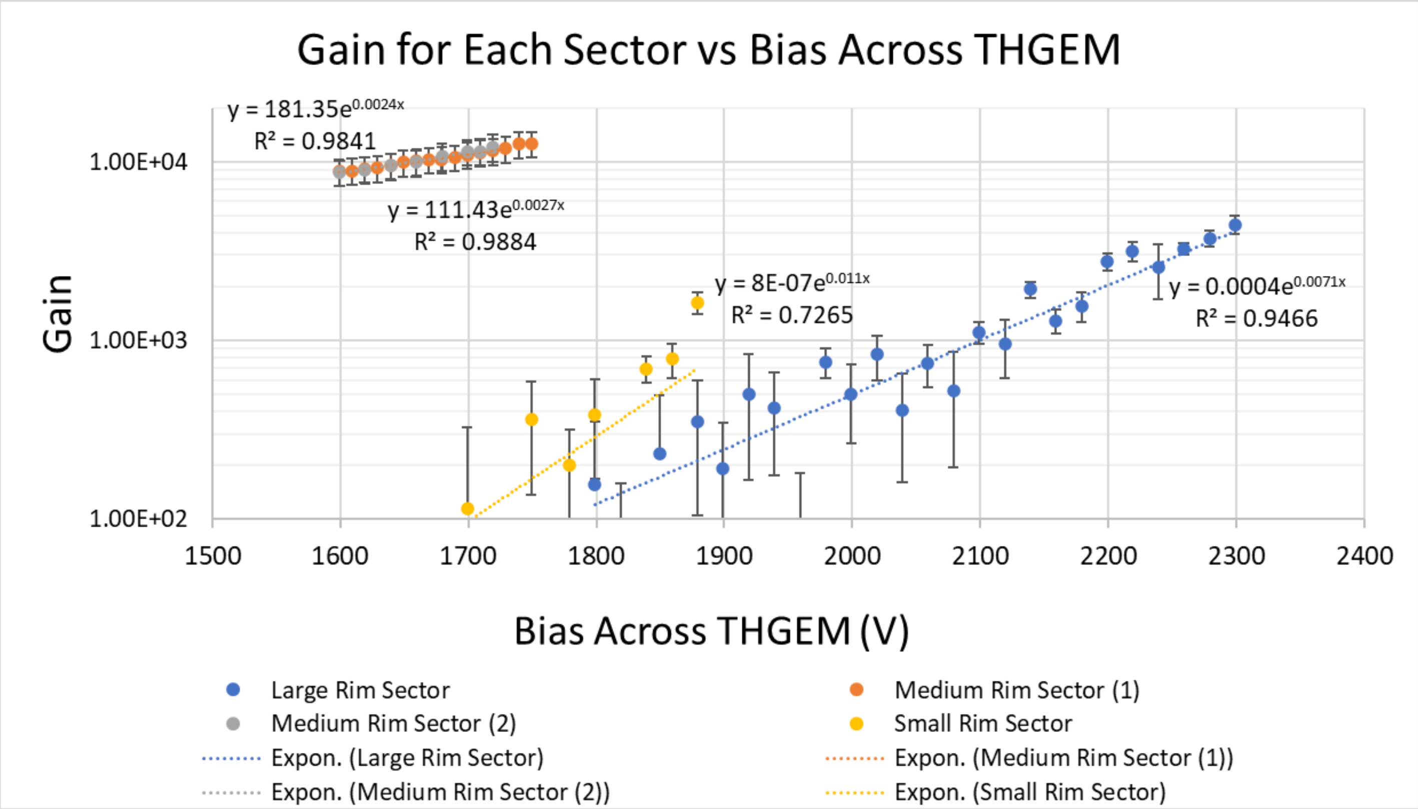
- Fe-55 study shows that large rim sector can be operated at even 2300V
- Greater stability at that level than other sectors
- Higher bias voltages with larger rim sizes

Summary and Conclusions

- Detector seems to reduce in functionality over time
- By the end, heavily used middle sector no longer able to achieve voltages for gain
- Small rim sector only one to perform well under pure CO_2
- Possibly some physical issue exacerbated by amplification

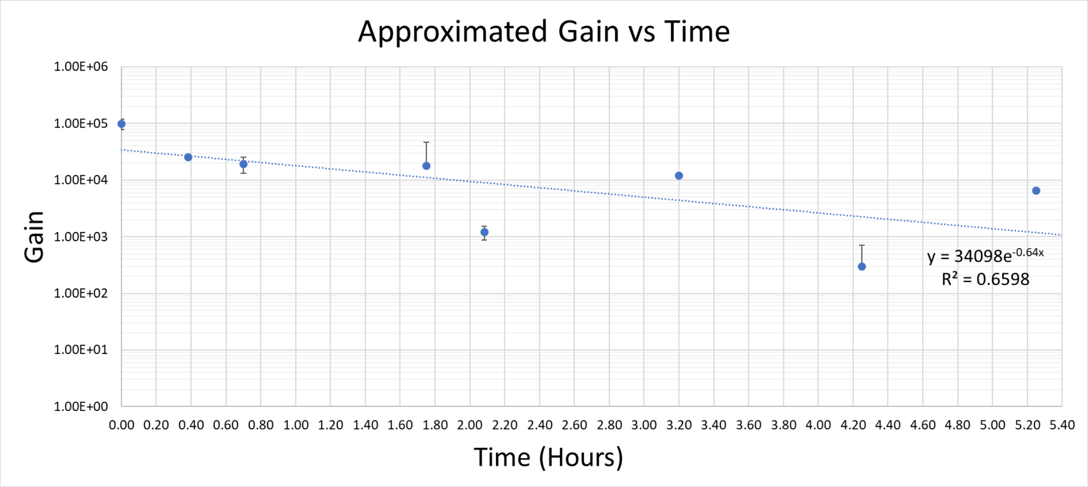
Summary and Conclusions

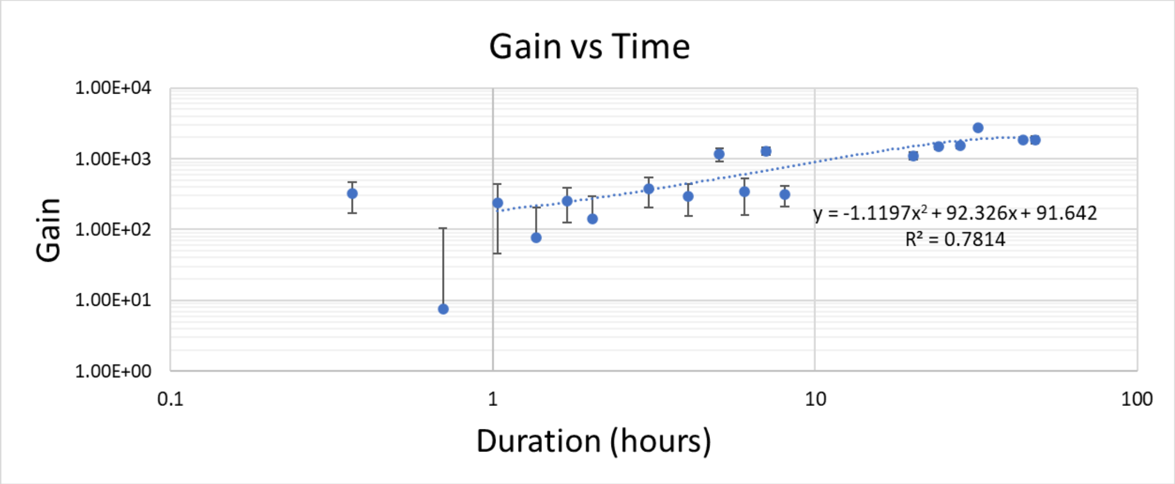
- 10^2 and 10^3 gains most common, middle sector achieved 10^4
  - Middle only sector to use X-ray gun
  - Middle had higher gains at lower voltages
- Small sector also higher gains at lower voltages than large sector
- Large sector able to achieve highest voltages, thus ultimately higher gains than small sector



Summary and Conclusions

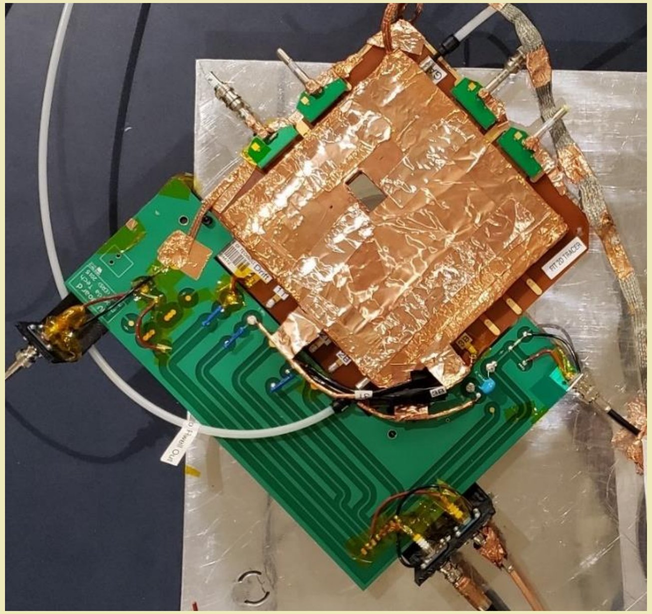
- Approximation of gain for middle sector decreased over time
- Gain vs time for large rim sector increased over time, flattening out after approximately the 10-hour mark
- Suggests for max gain stability, best to allow detector to remain powered (and irradiated) for at least 10 hours
- Could be an effect of charging up of dielectric material in rims

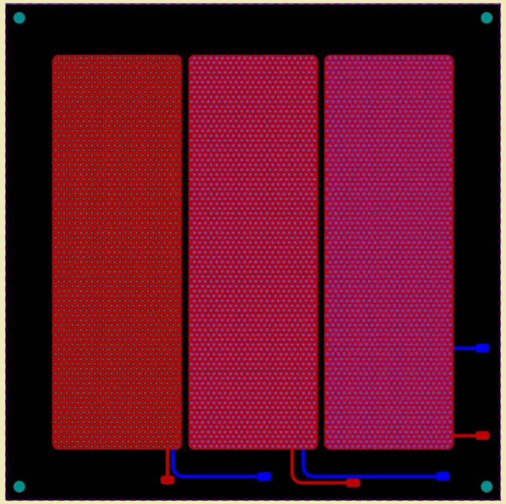


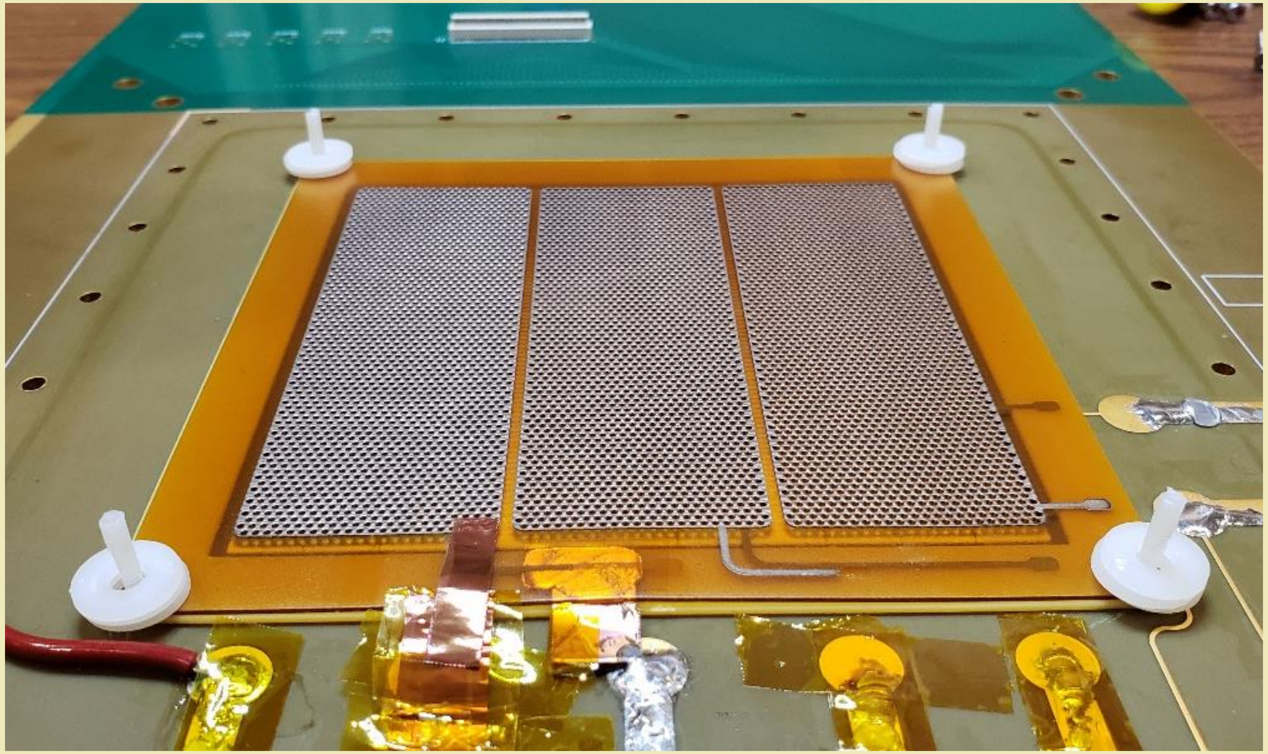


Final Thoughts

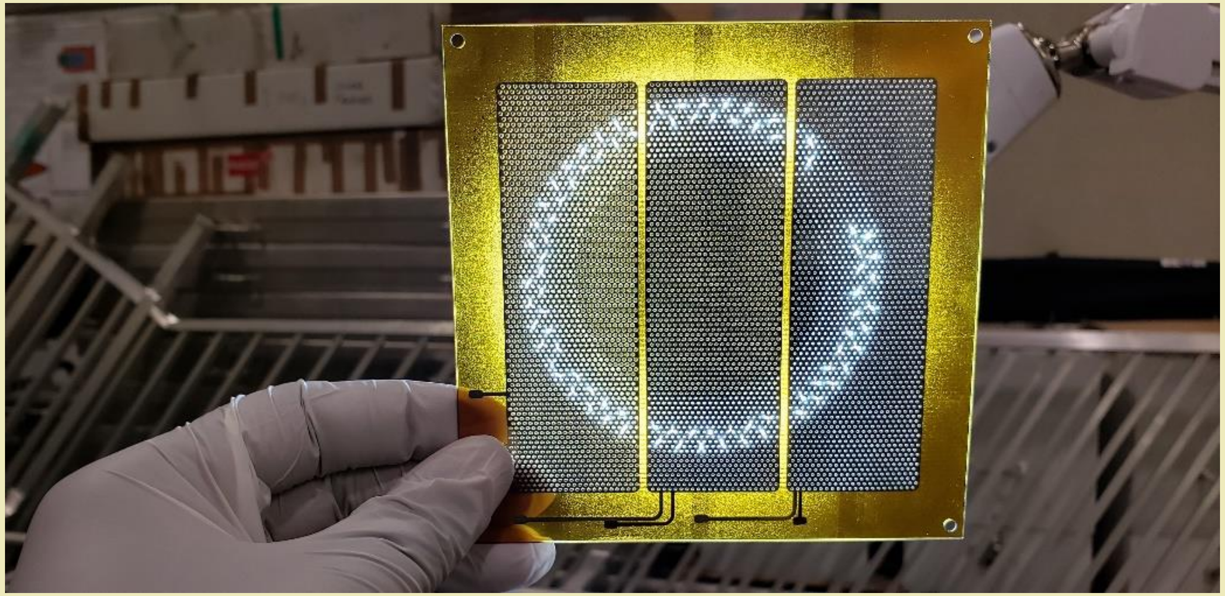
- While there are some concerns with long-term functionality, 3D-printed THGEM can serve as a functioning GEM in a detector







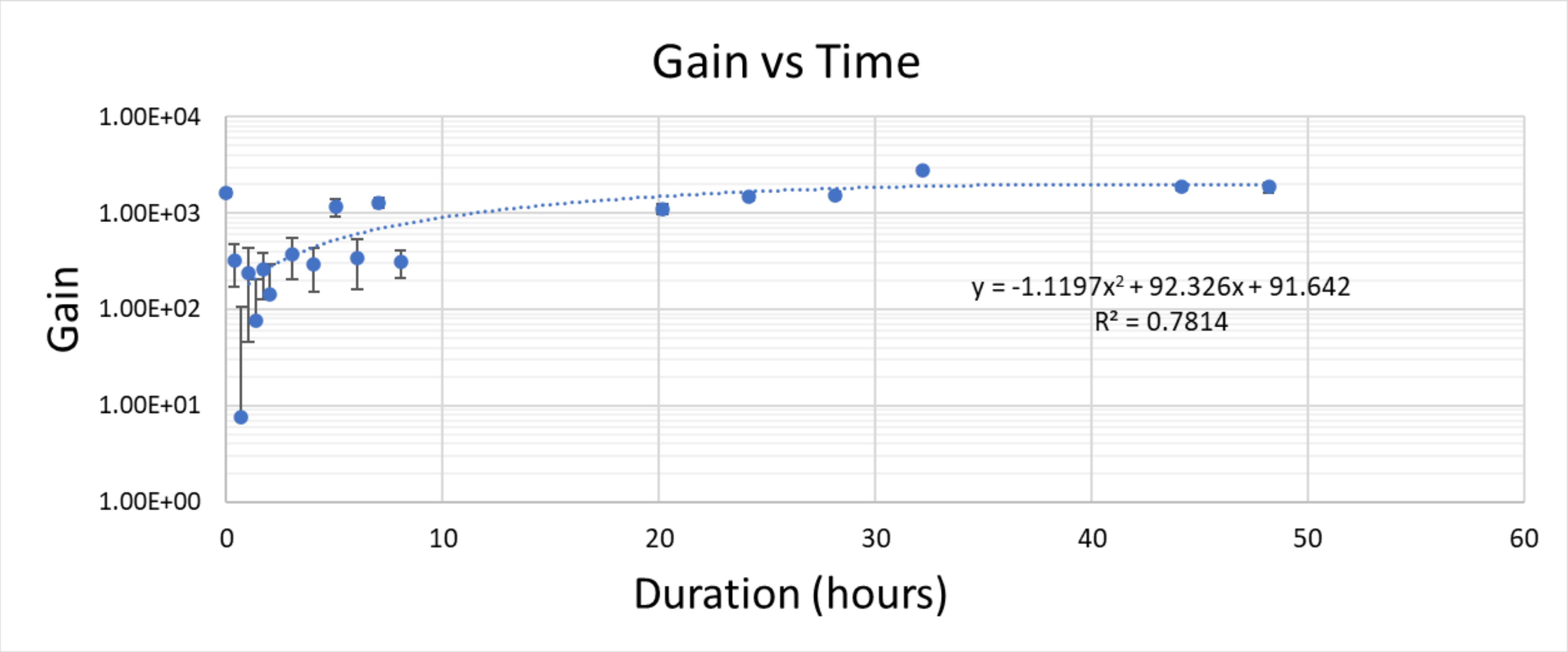
Any Questions?



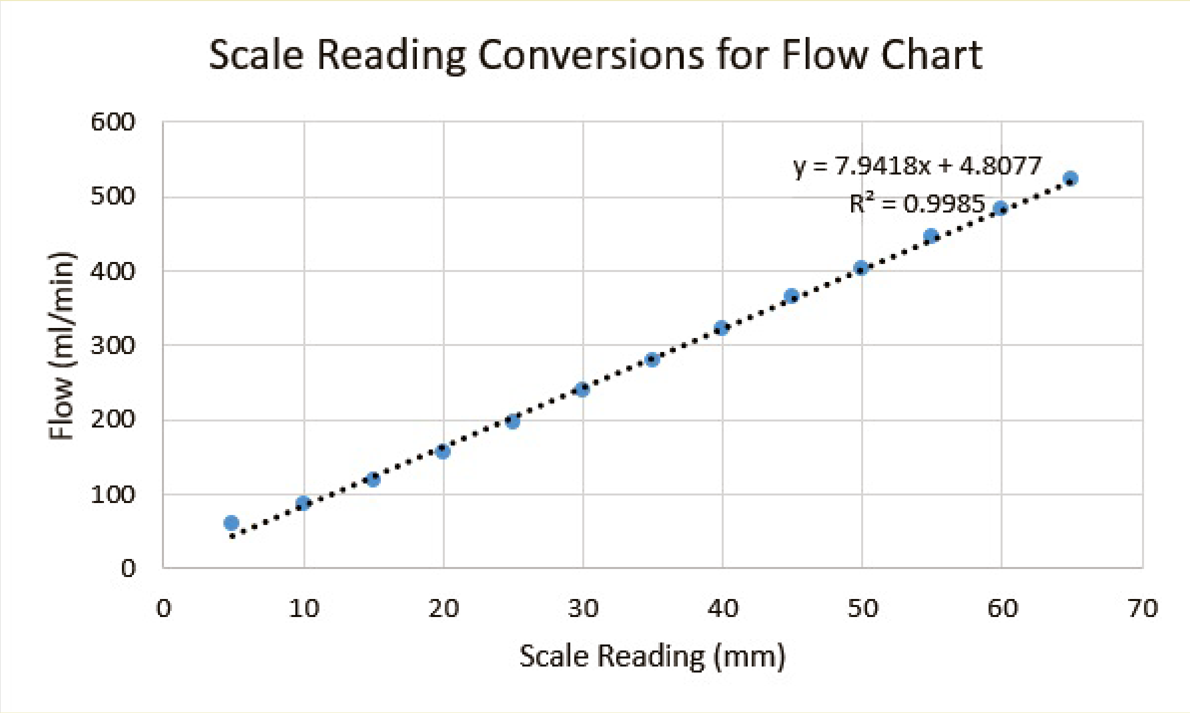
FLORIDA TECH

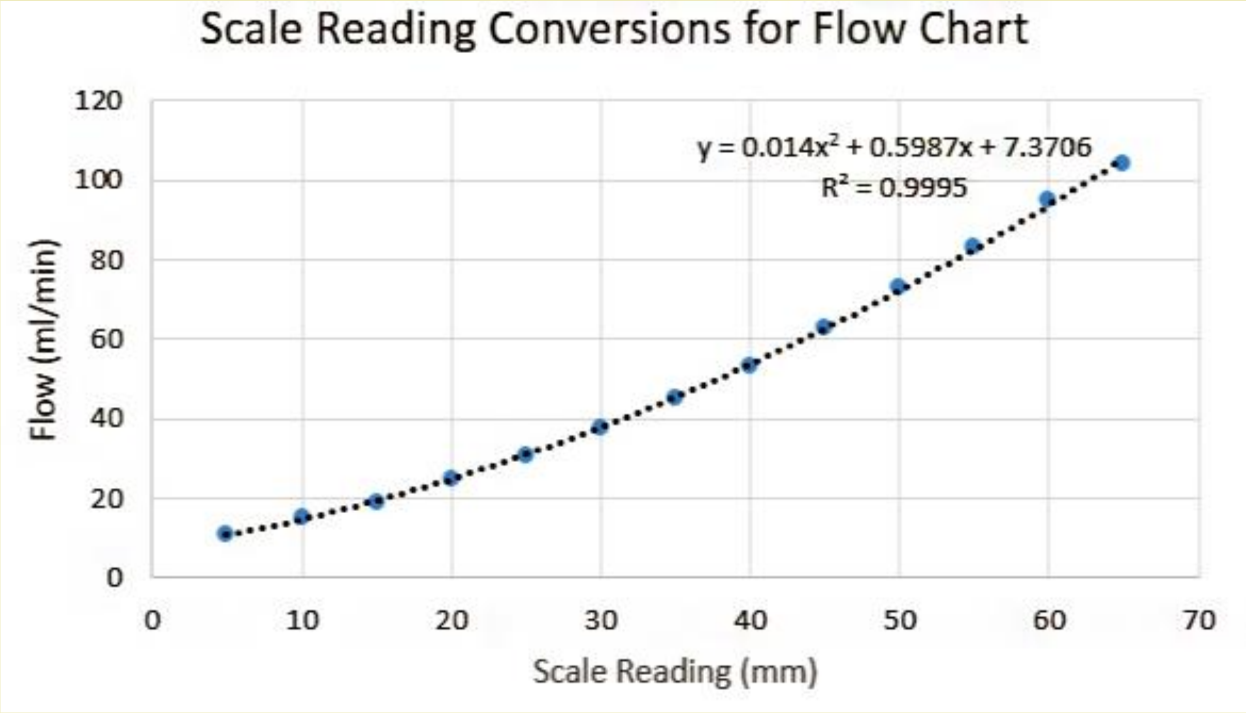
Backup

- Large rim gain 48-hour test without log on time axis



Backup





Large Flowmeter: Inflow ~ 43.17 L/hr, Outflow ~14.11 L/hr

Small Flowmeter: Outflow ~3.76 L/hr