STAR Forward GEM Tracking Upgrade

Physics Motivation

Design

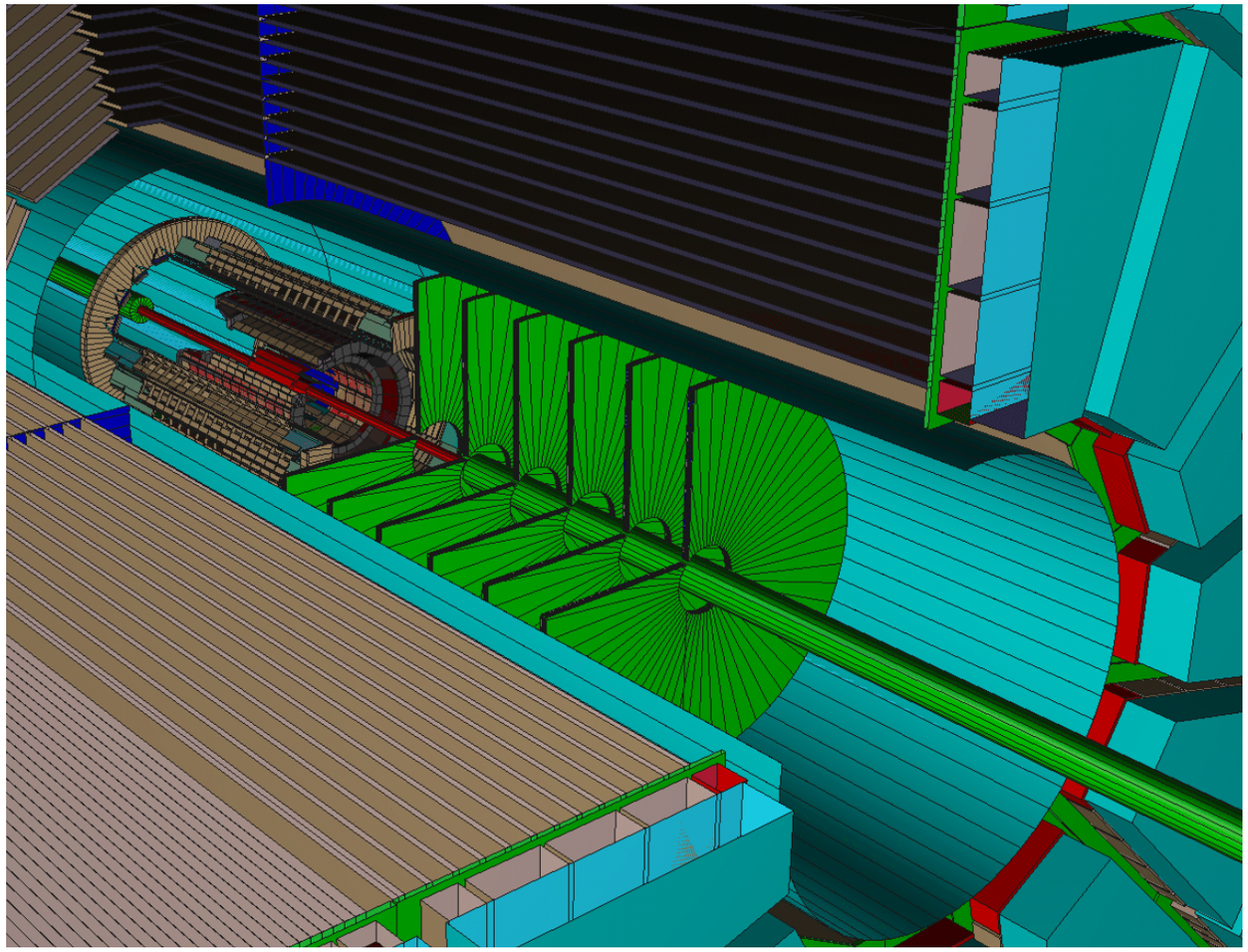
GEM Foils

2D Readout

APV Boards

Packaging APV Chips

RHIC Spin at STAR



500 GeV RHIC spin program

- flavour spin structure of proton
- tag $W^{\pm} \Rightarrow e^{\pm}$
- identify $e^{\pm}$ from curvature at forward angles
  - sagitta ~ 1 mm

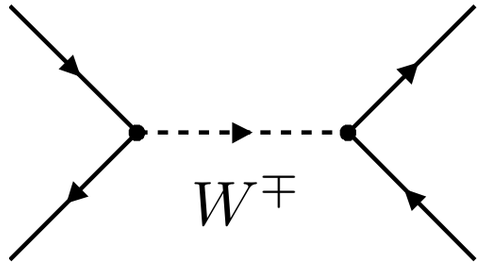
High rate environment

- beam crossing 107 ns
- minimise material

Choose GEM detectors

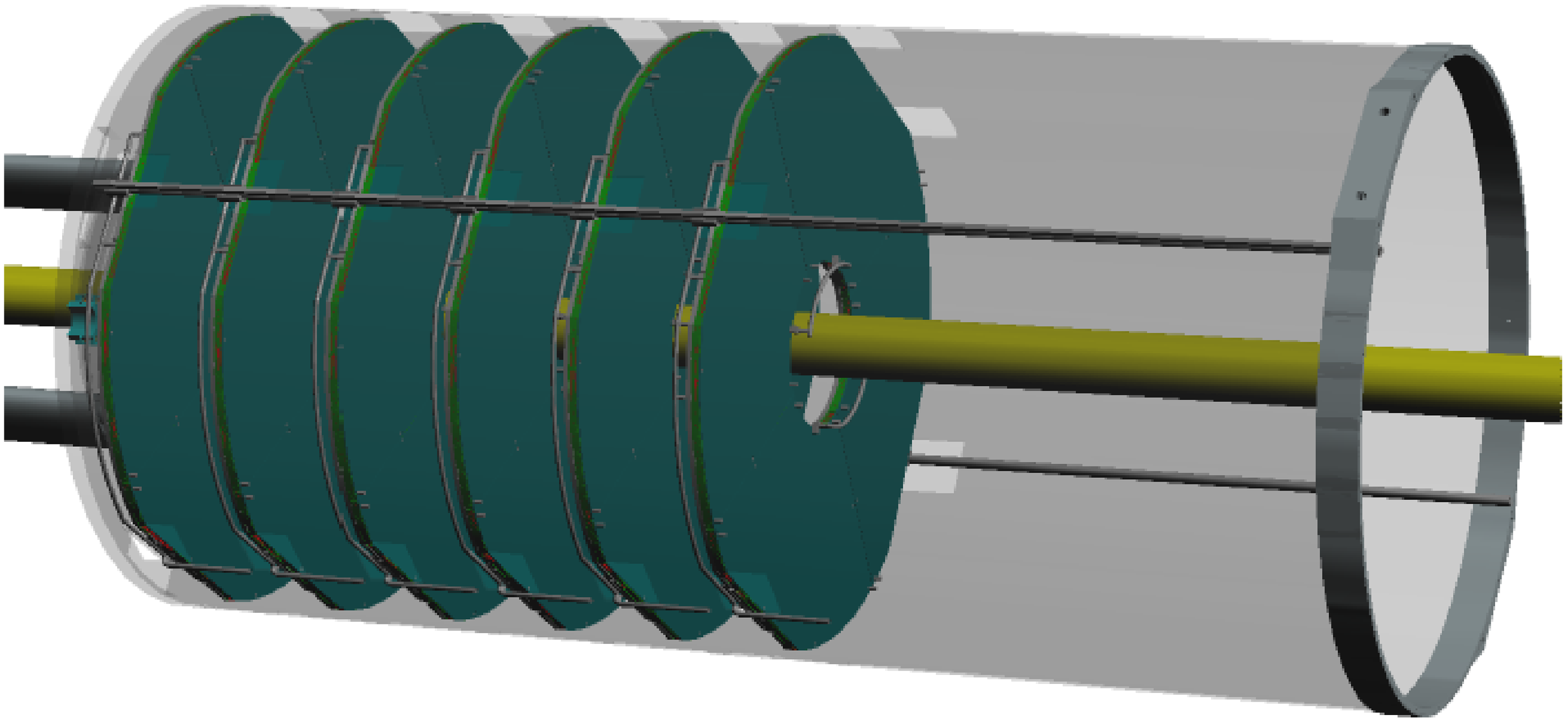
- 6 disks of triple GEM detectors
- active area R = 11.5 - 38.25 cm
- < 100 micron resolution
- ~0.67 % X_0

$$\Delta d + \bar{u} \rightarrow W^-$$
$$\Delta \bar{u} + d \rightarrow W^-$$
$$\Delta \bar{d} + \bar{u} \rightarrow W^+$$
$$\Delta u + \bar{d} \rightarrow W^+$$



$$W^- \rightarrow e^- + \bar{\nu}_e$$
$$W^+ \rightarrow e^+ + \nu_e$$

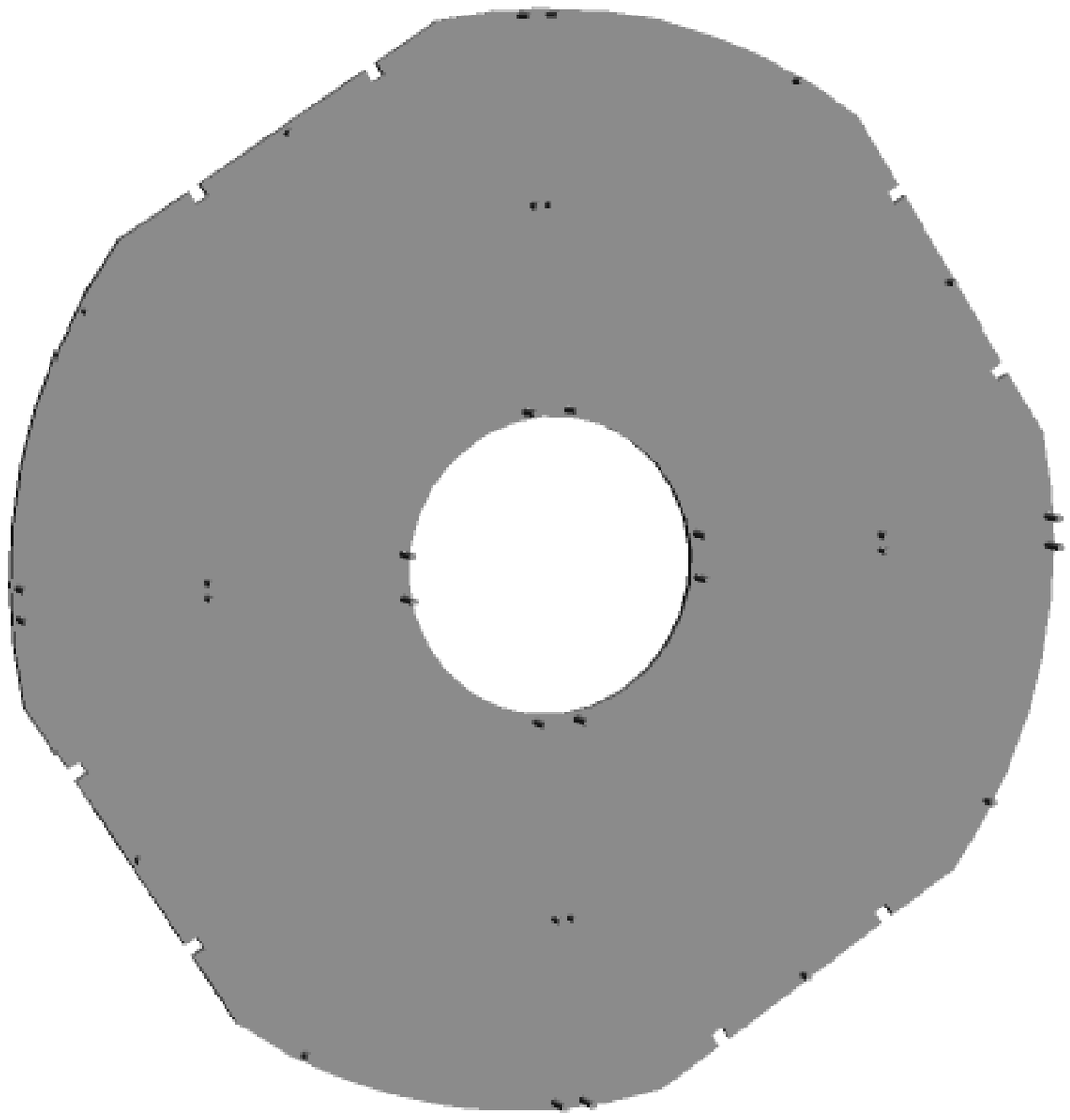
FGT Disks in West Support Cylinder



FGT Disk Concept

Nomex disk

- 5 mm thick honeycomb
- alignment pins



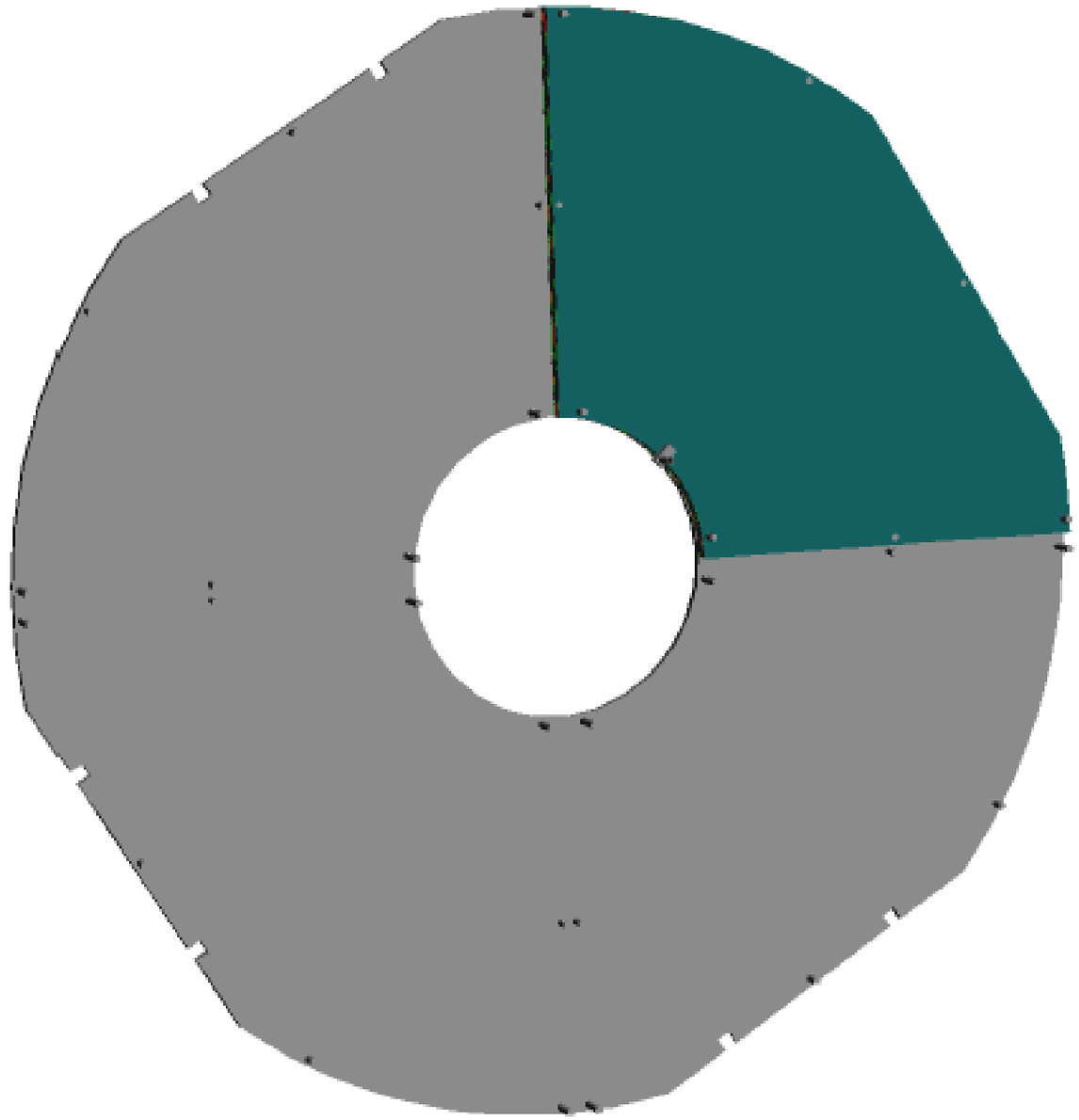
FGT Disk Concept

Nomex disk

- 5 mm thick honeycomb
- alignment pins

FGT quadrant

- single triple GEM detector
- pins preserve shape / tension



FGT Disk Concept

Nomex disk
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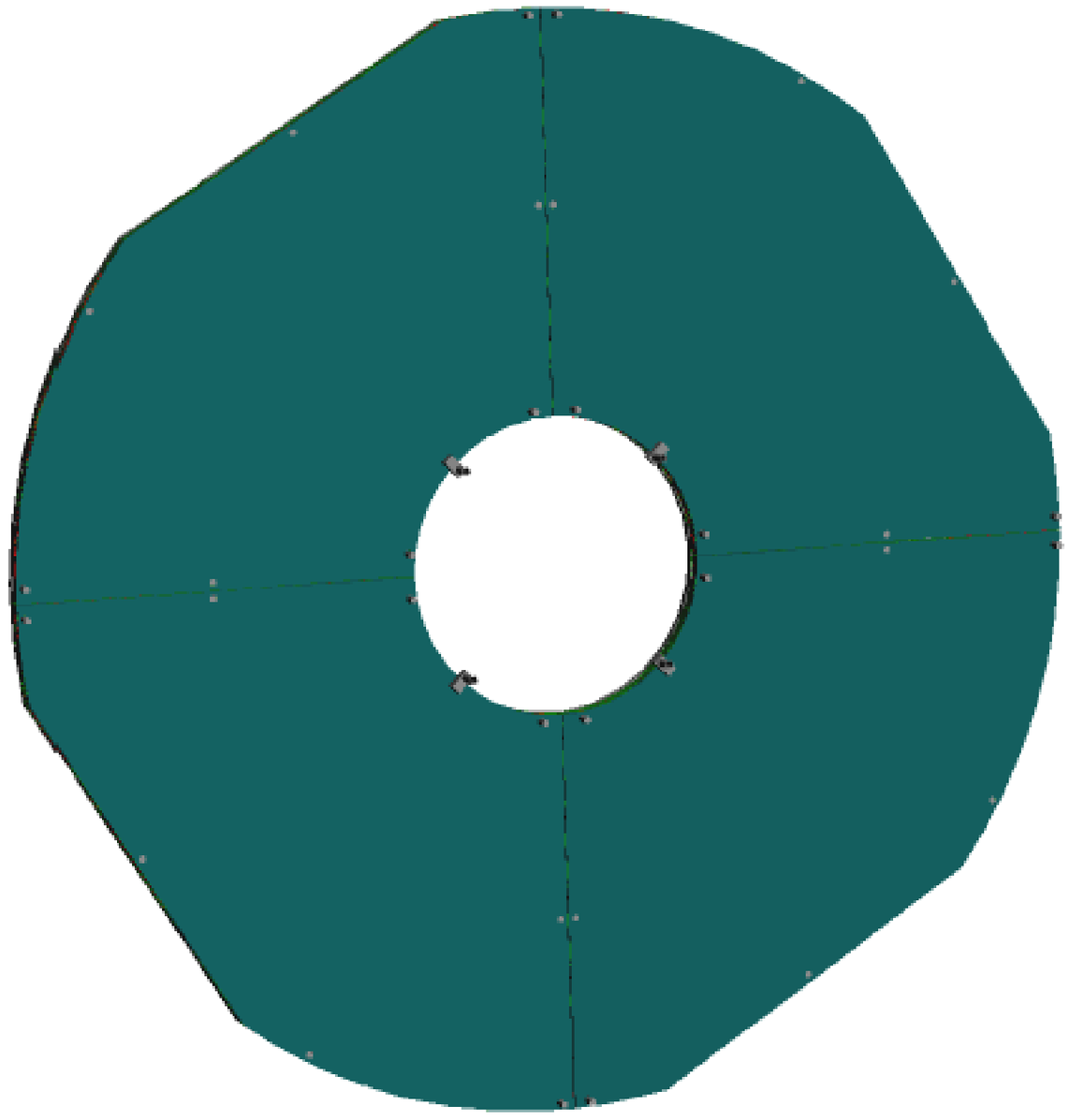
- alignment pins

FGT quadrant
- single triple GEM detector
- pins preserve shape / tension

4 quadrants per disk
- 1 mm gap between quadrants



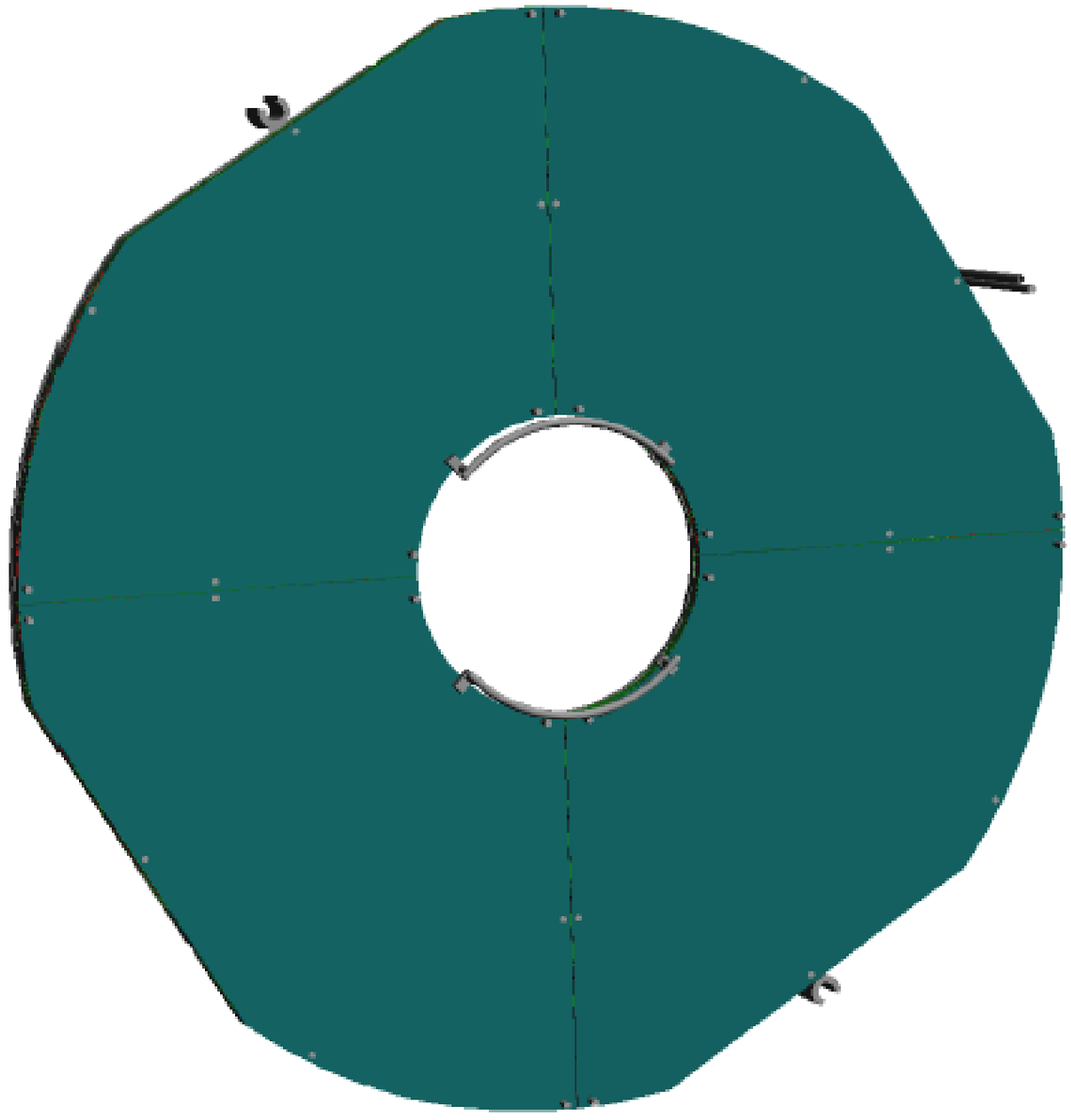
FGT Disk Concept

Nomex disk
- 5 mm thick honeycomb
- alignment pins

FGT quadrant
- single triple GEM detector
- pins preserve shape / tension

4 quadrants per disk
- 1 mm gap between quadrants

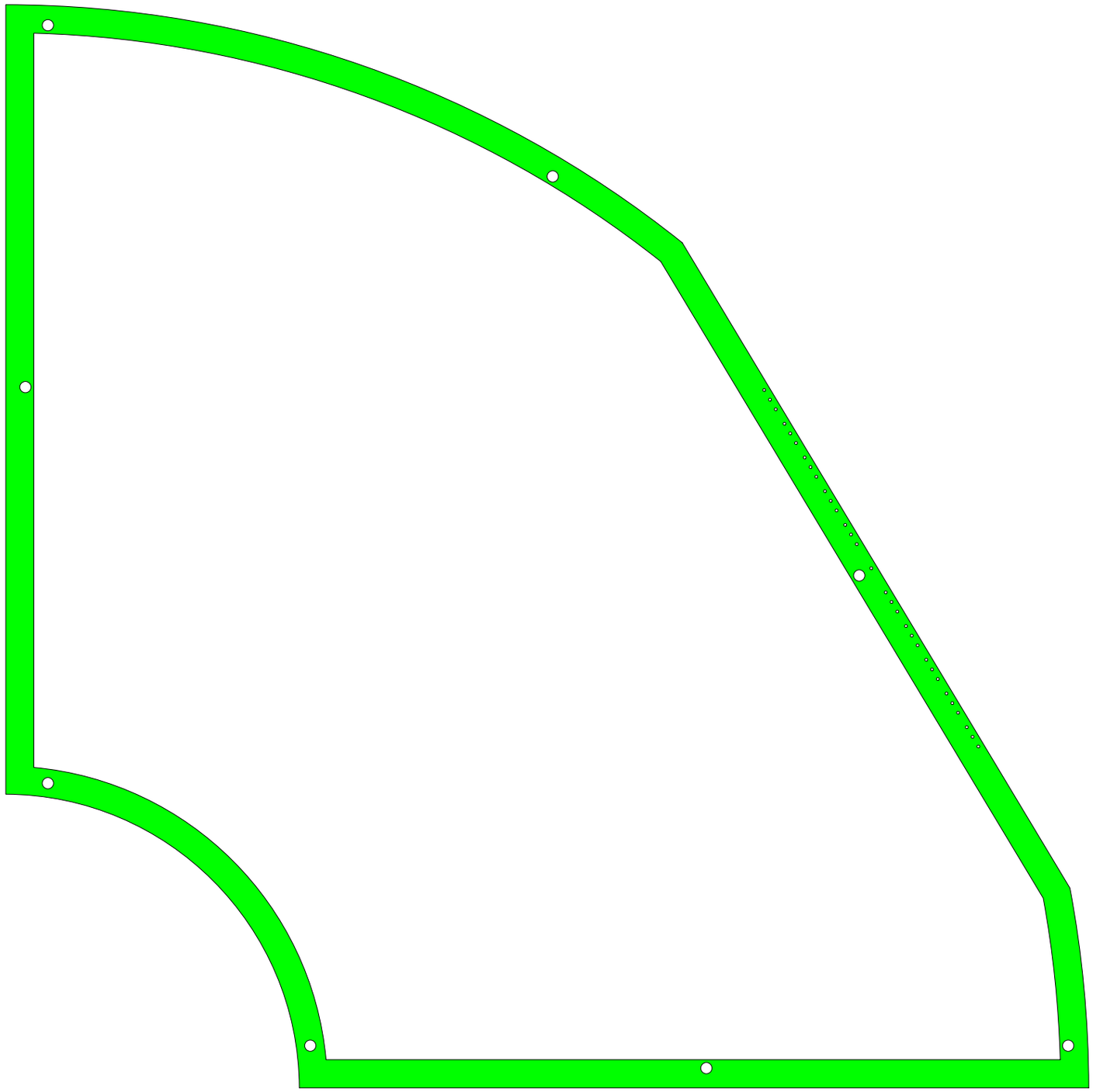
Infrastructure
- daisy chain gas supply / return
- rails in WSC position and alignment



FGT GEM Frame

Design

- 1.15 cm wide FR4
- glue trough
- 2 or 3 mm thick
- inner radius 10.35 / 11.5 cm
- outer radius 38.25 / 39.4 cm
- flat at 31°
  - required for TPC structure
  - used for routing services
- 8 holes for alignment pins
  - define position
  - preserve shape and tension
- 32 holes in flat for HV



FGT GEM Foil Design

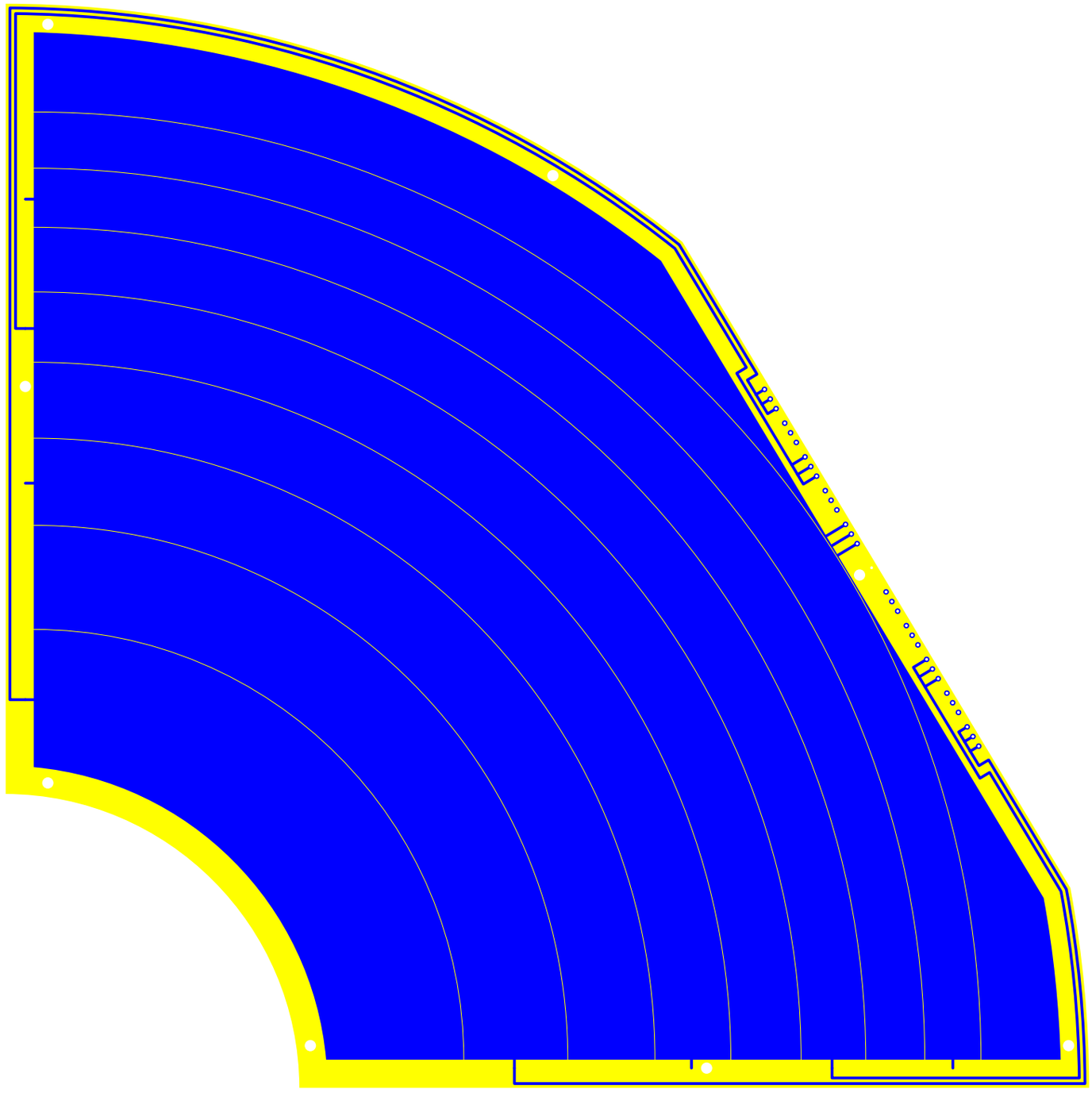
GEM holes
- 70 micron ID
- 140 micron pitch
- equilateral triangle pattern

Segmented top side
- 9 segments
- ~100 cm^2
- reduce breakdown damage
- 200 gap between segments

Bottom side not segmented

Routing for HV

Produced by Tech-Etch



Tech-Etch, Plymouth, MA

Photo-etching and flexible circuit board manufacturer

SBIR for GEM foils
- dedicated line for GEM foils
- measurement and QA

New SBIR for 2D readout
- using chemical etching

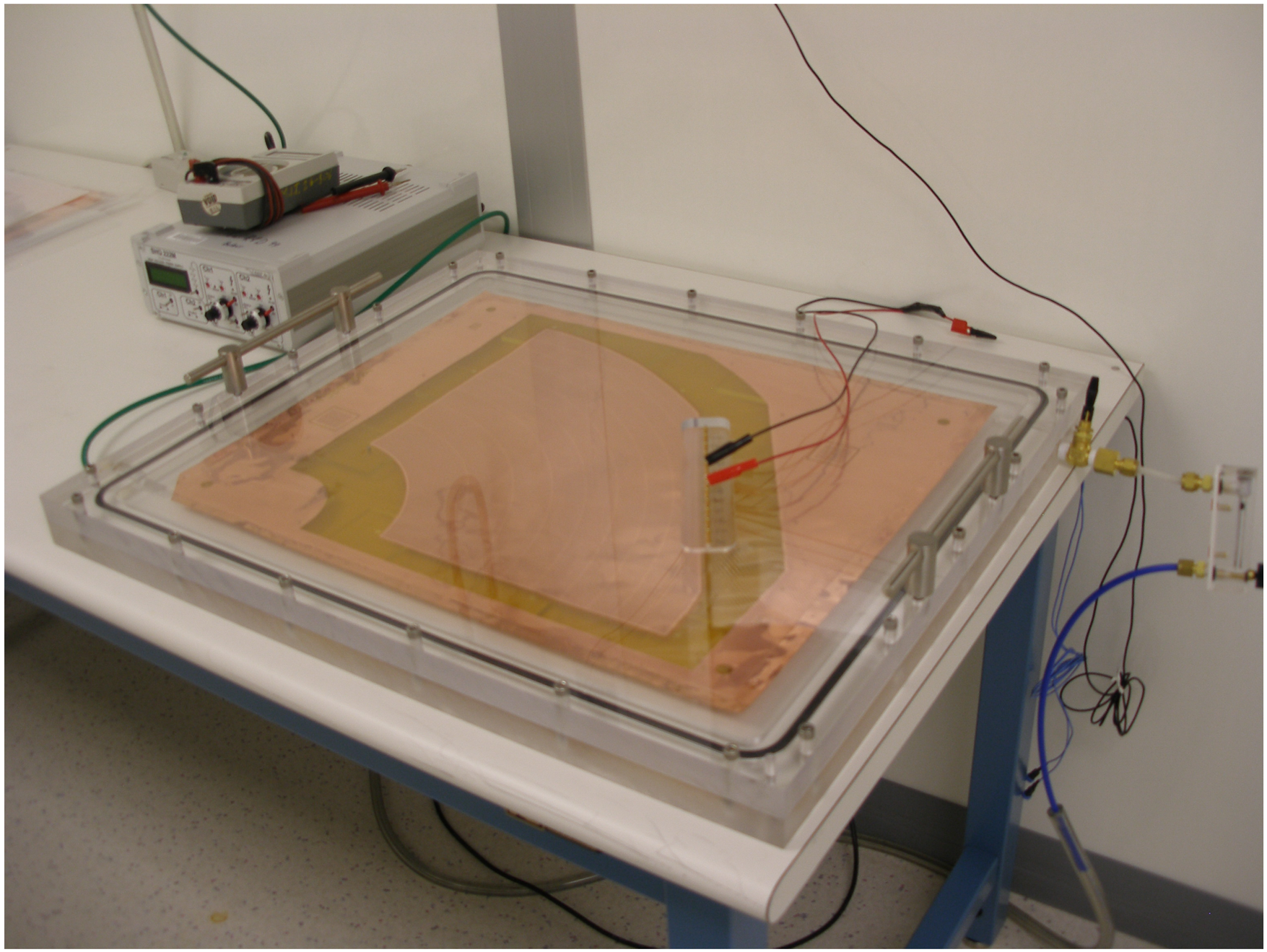
Tech-Etch FGT GEM Foil

HV Testing of GEM Foils - R. Corliss (MIT)

Minimal volume chamber

- rapid flush with dry N_2
- 5 l / min

- test to 700 V in 100 V steps
- measure current to 0.1 nA

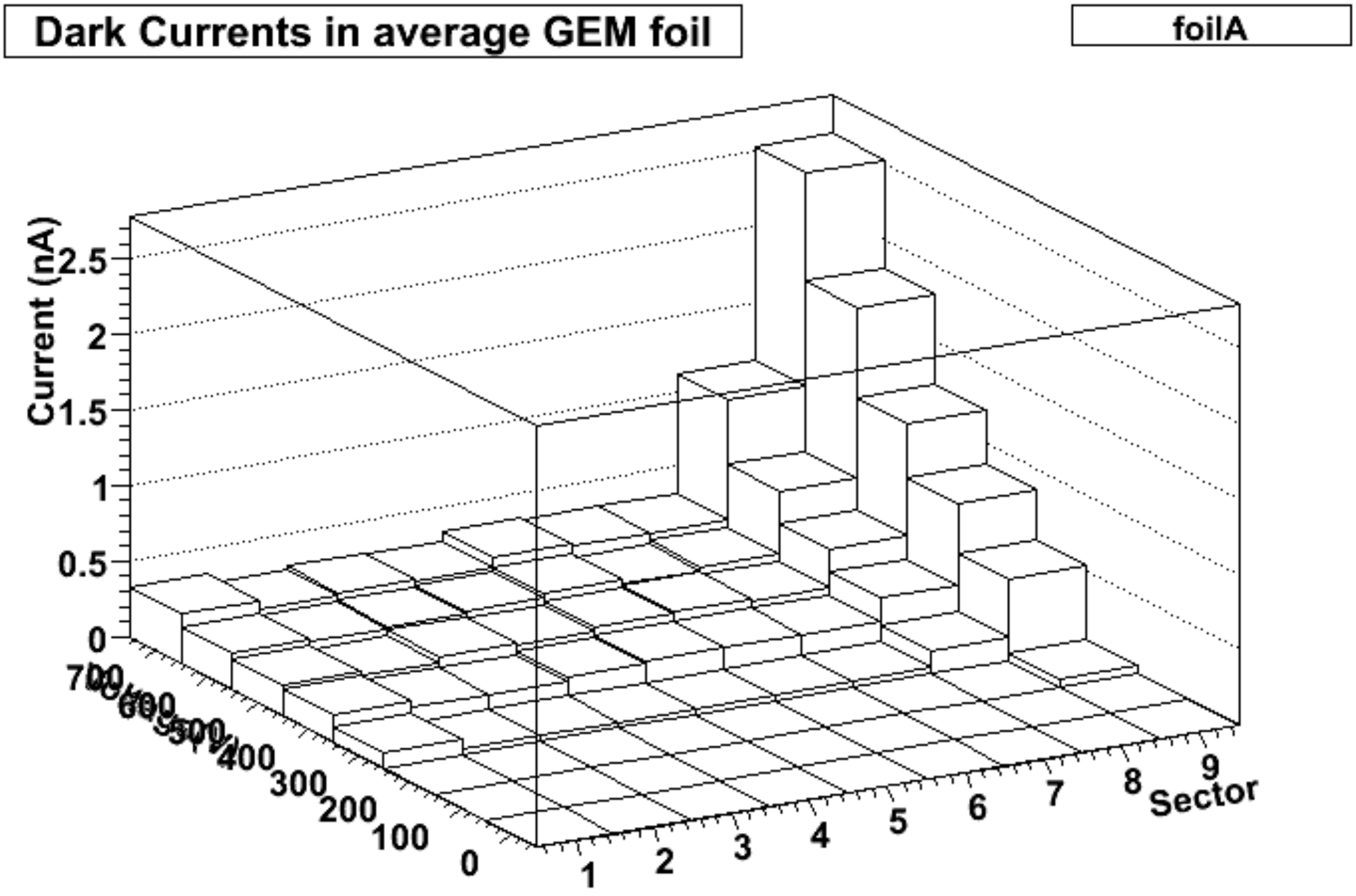


HV Tests

Tech-Etch - average 8 foils

- test to 700 V

- systematically higher currents in segments 8 and 9
- cleaning ? (R. de Oliveira)

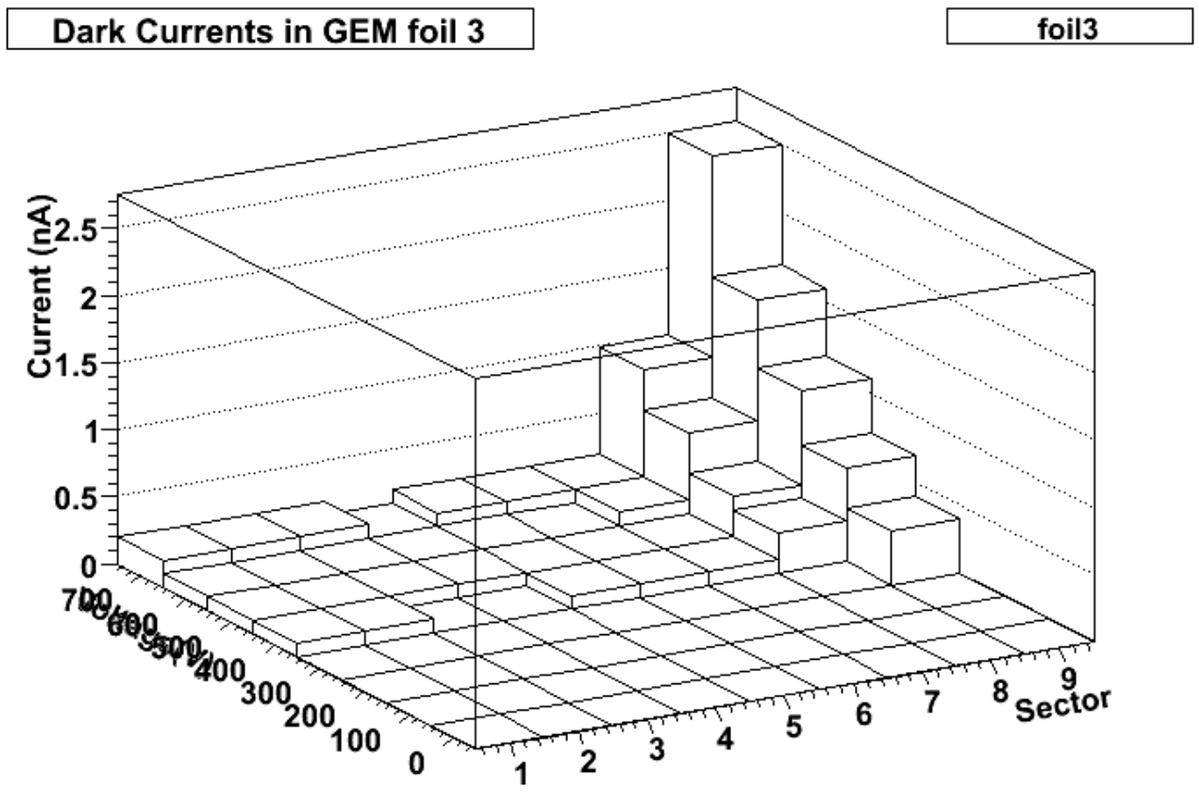


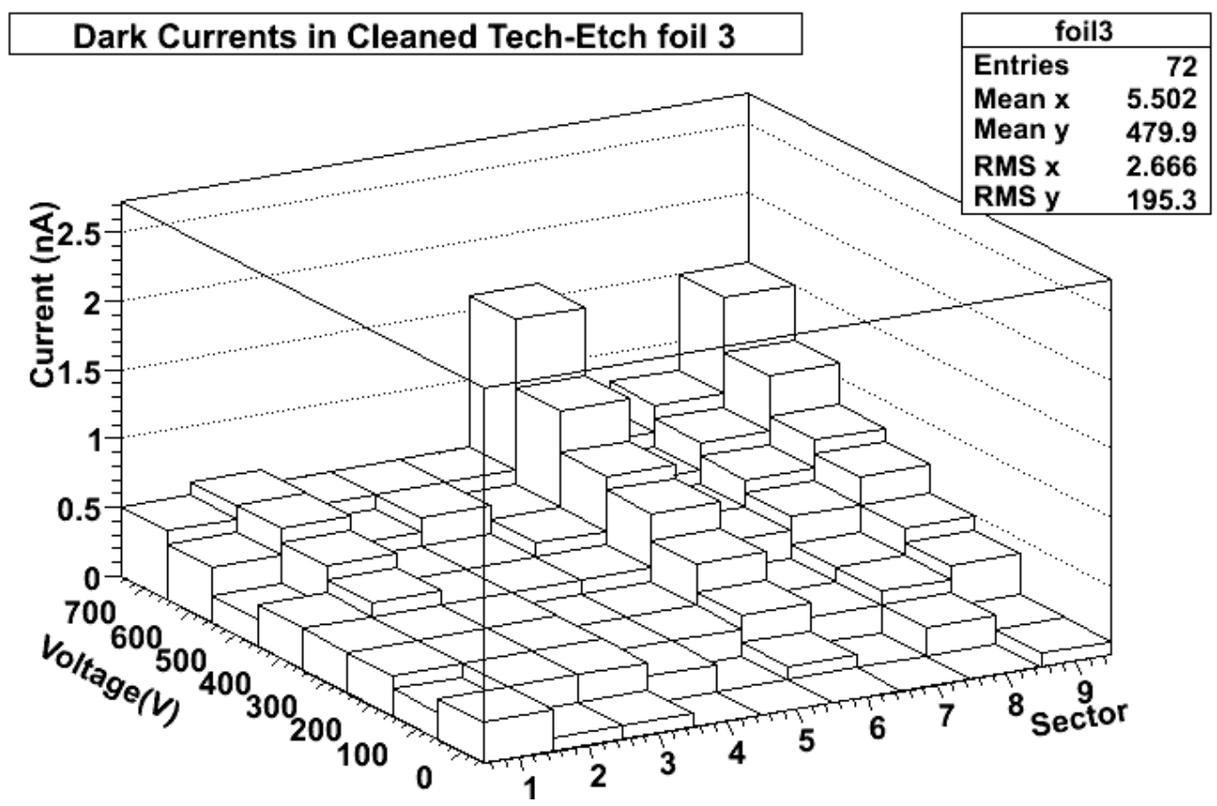
HV Tests

Before re-cleaning

After re-cleaning

- improved ?



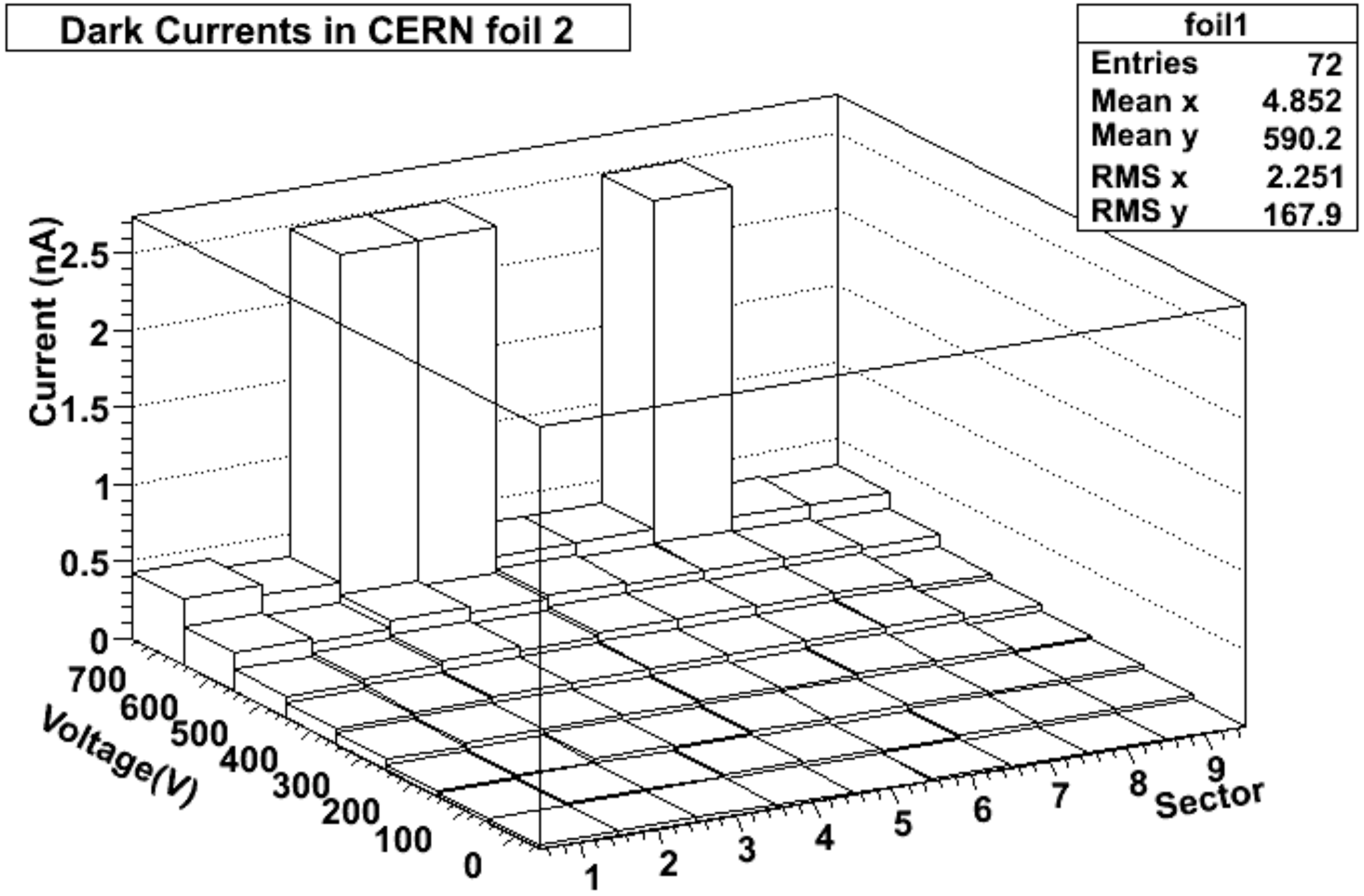


HV Tests

CERN - GEM foil 2

- we test to 700 V
- CERN tests to 600 V

- higher currents at 700 V
- often unstable above 600 V
- otherwise quieter



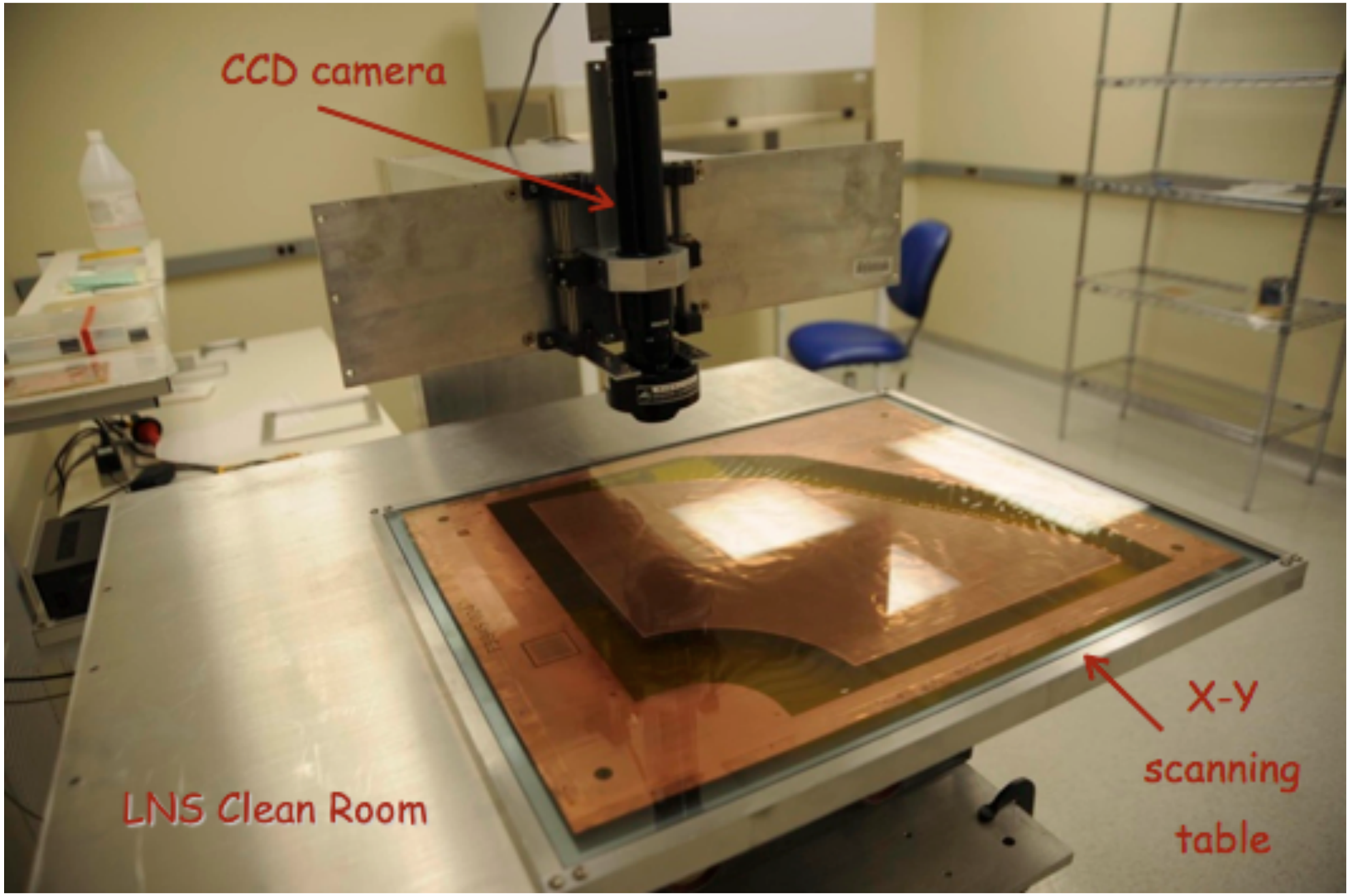
CCD GEM Foil Scans - J. Seele, W. Leight (MIT)

Small X/Y table

- scan FGT foils in 6 sections
- measure from both sides

Measure hole diameters

- light above - outer diameter
- light below - inner diameter



CCD GEM Foil Scan - Inner Hole Diameter

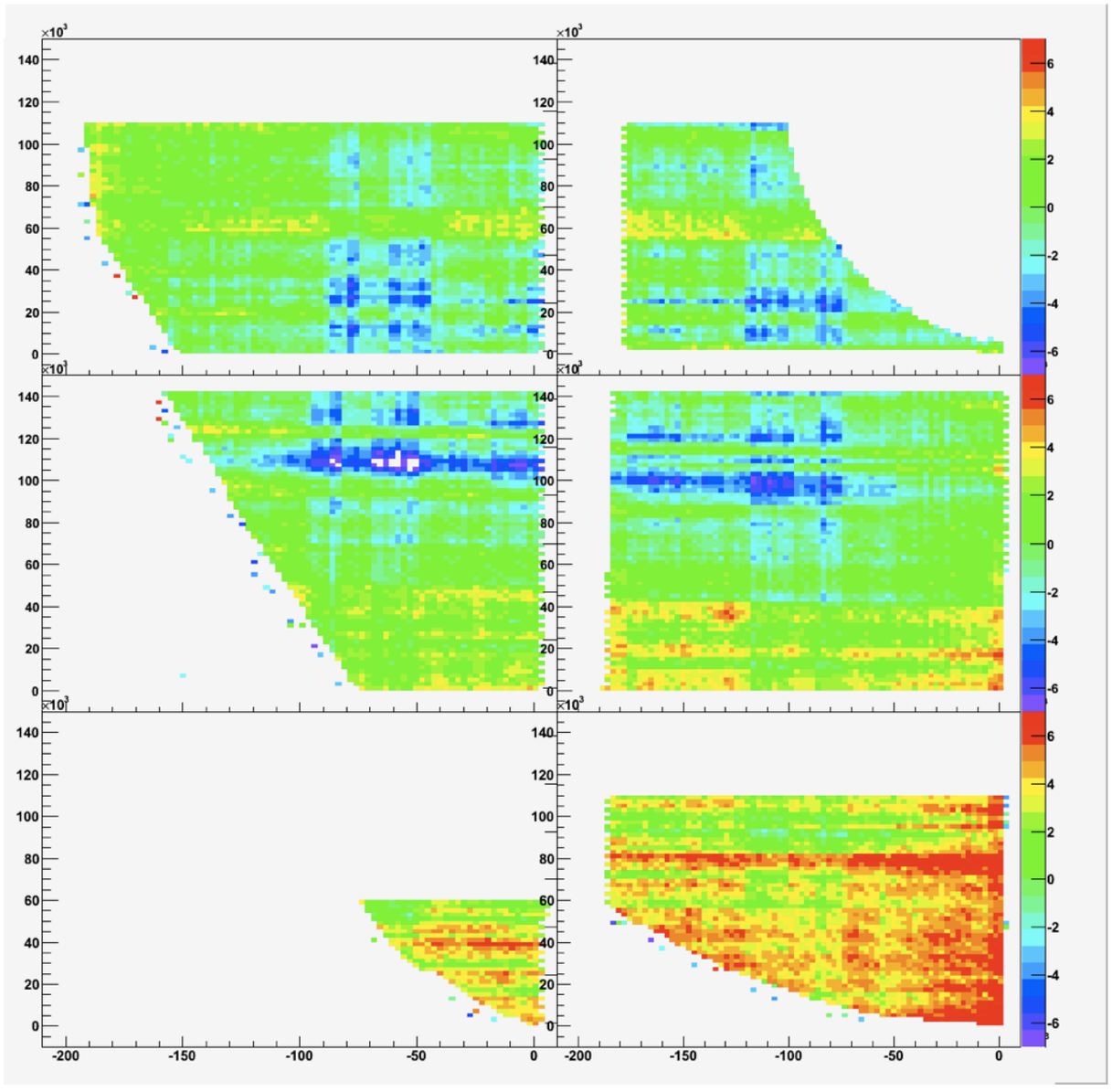
Tech-Etch - GEM foil 2

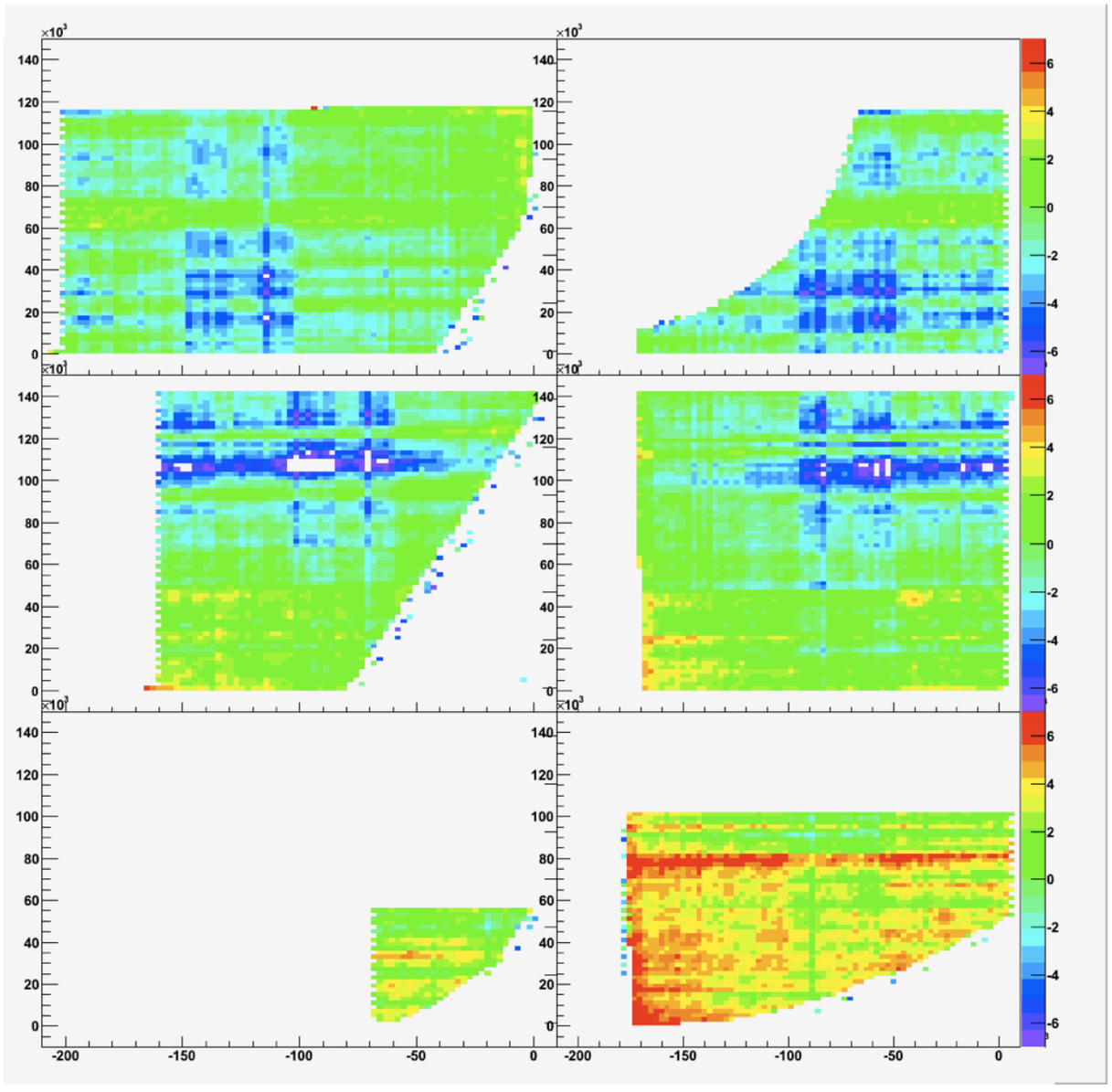
Inner hole diameter

- blue 6 micron below average
- red 6 micron above average

Striped pattern understood

- laser direct imaging
- fix (hopefully) with glass masks





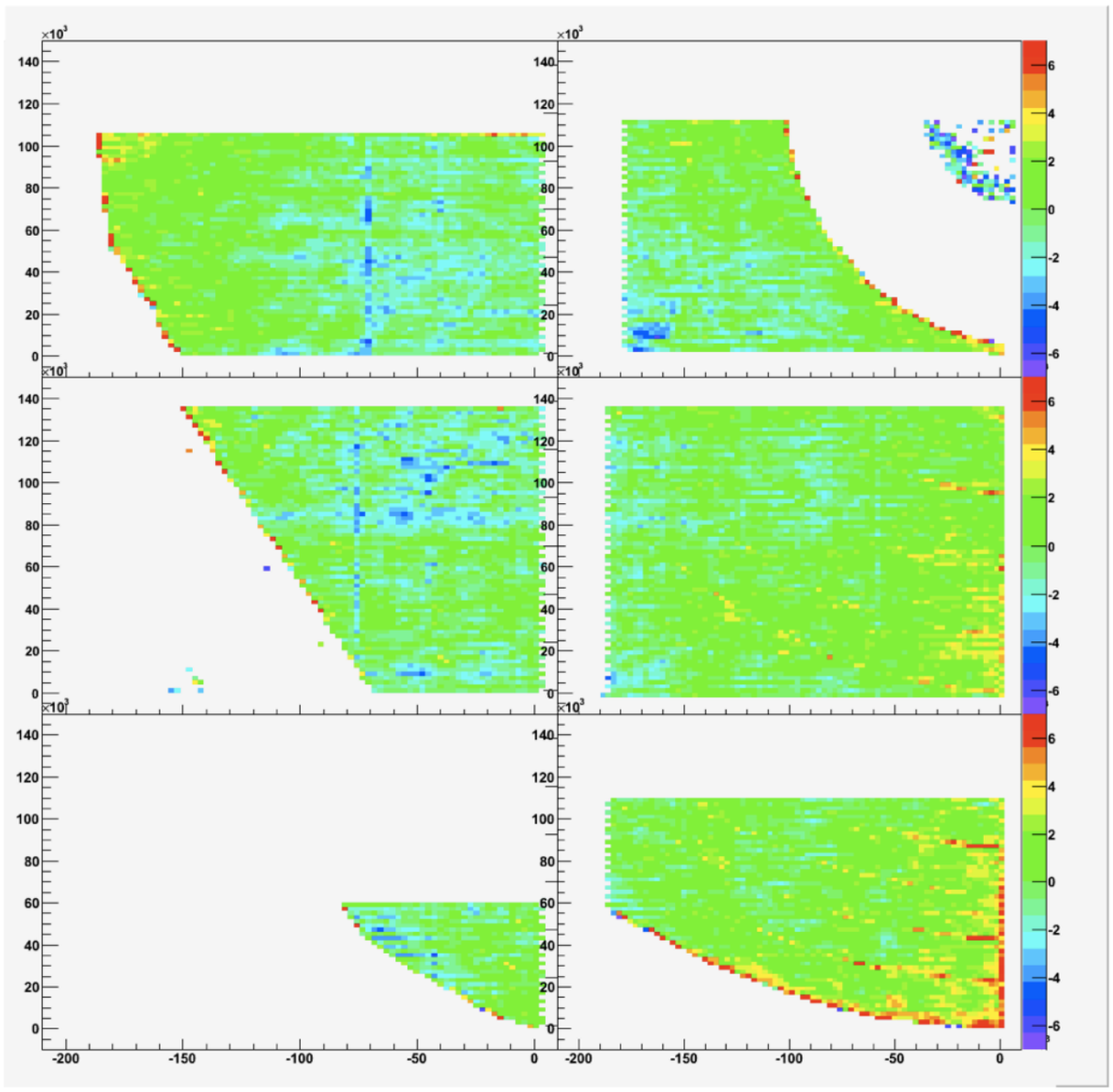
CCD GEM Foil Scan - Outer Hole Diameter

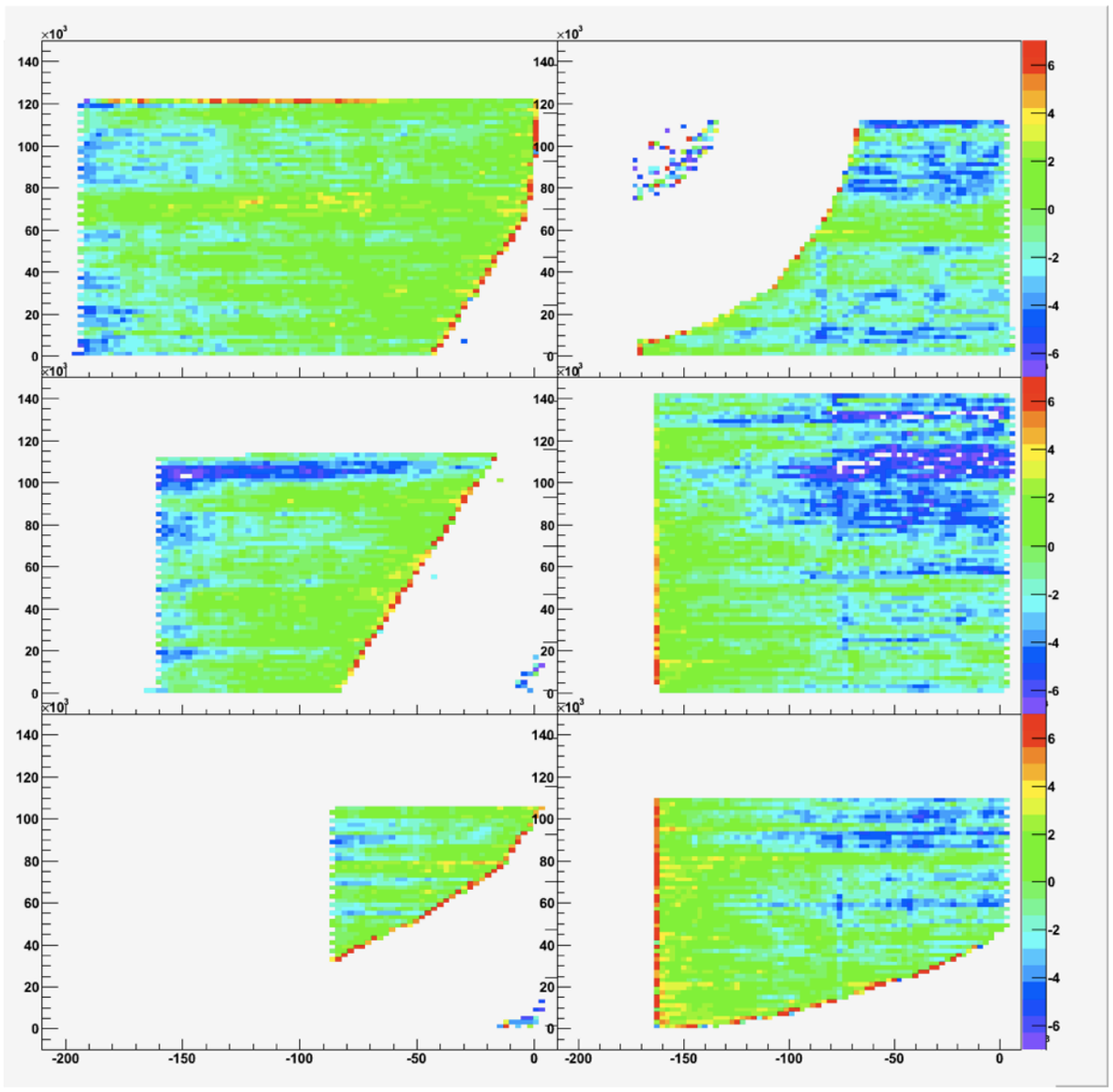
Tech-Etch - GEM foil 2

- similar striped pattern

Outer hole diameter

- blue 6 micron below average
- red 6 micron above average





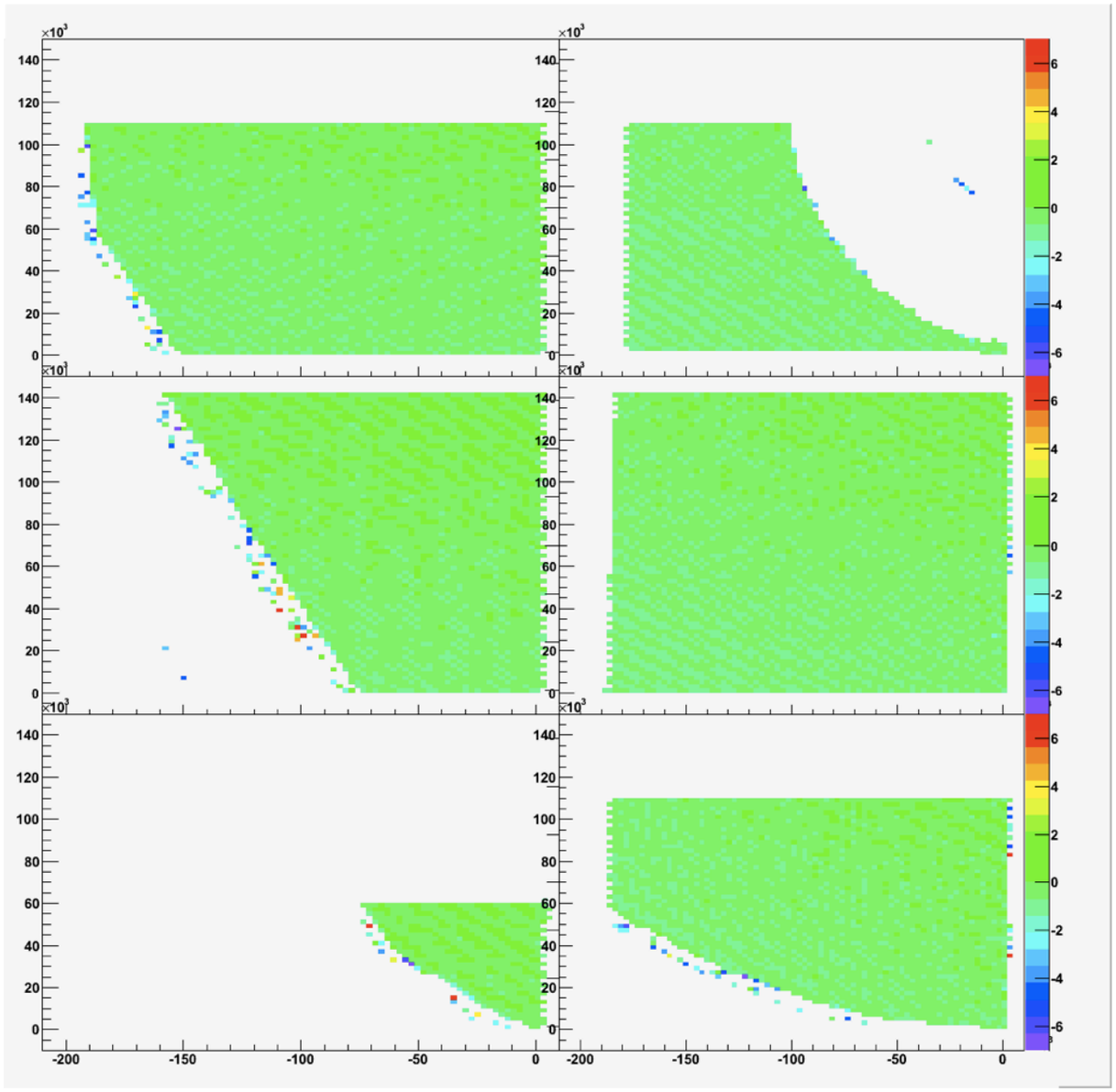
CCD GEM Foil Scan - Hole Pitch

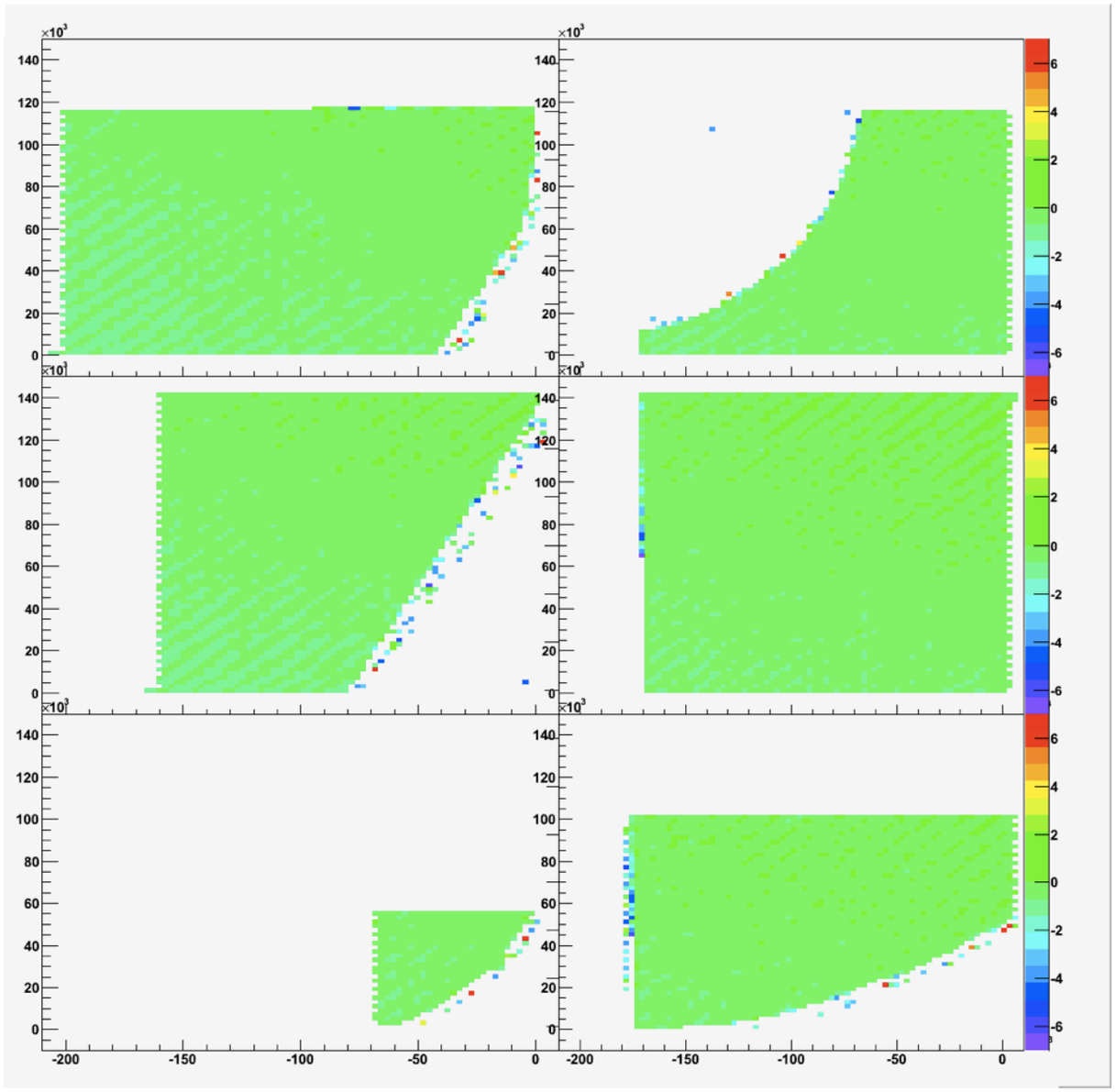
Tech-Etch - GEM foil 2

- hole pitch very uniform

Hole pitch

- blue 6 micron below average
- red 6 micron above average



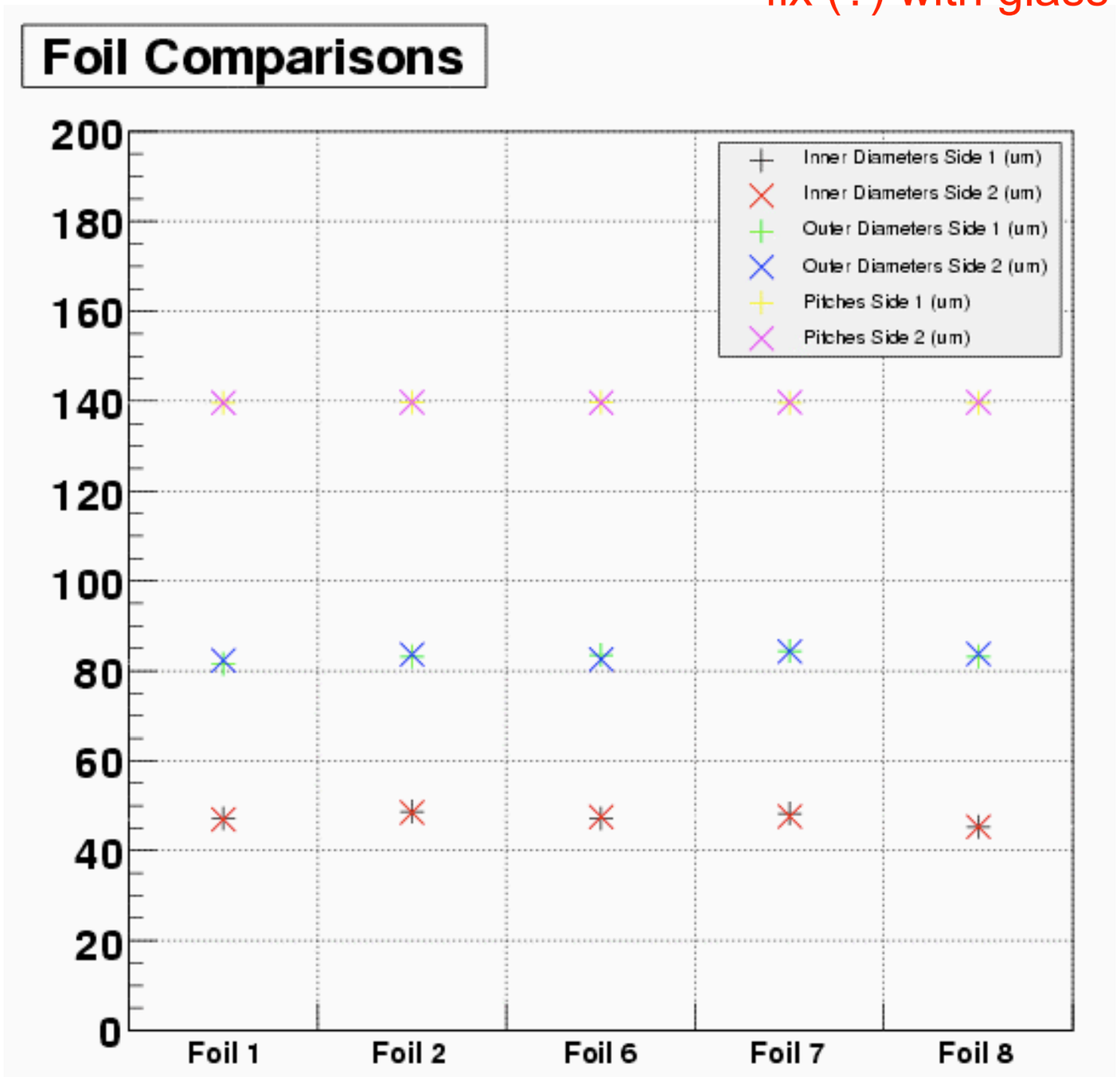


CCD GEM Foil Scans

Tech-Etch foils

- consistency in production good
- diameters slightly off 70 / 50

- holes also offset from one side to the other
  - LDI
  - fix (?) with glass masks



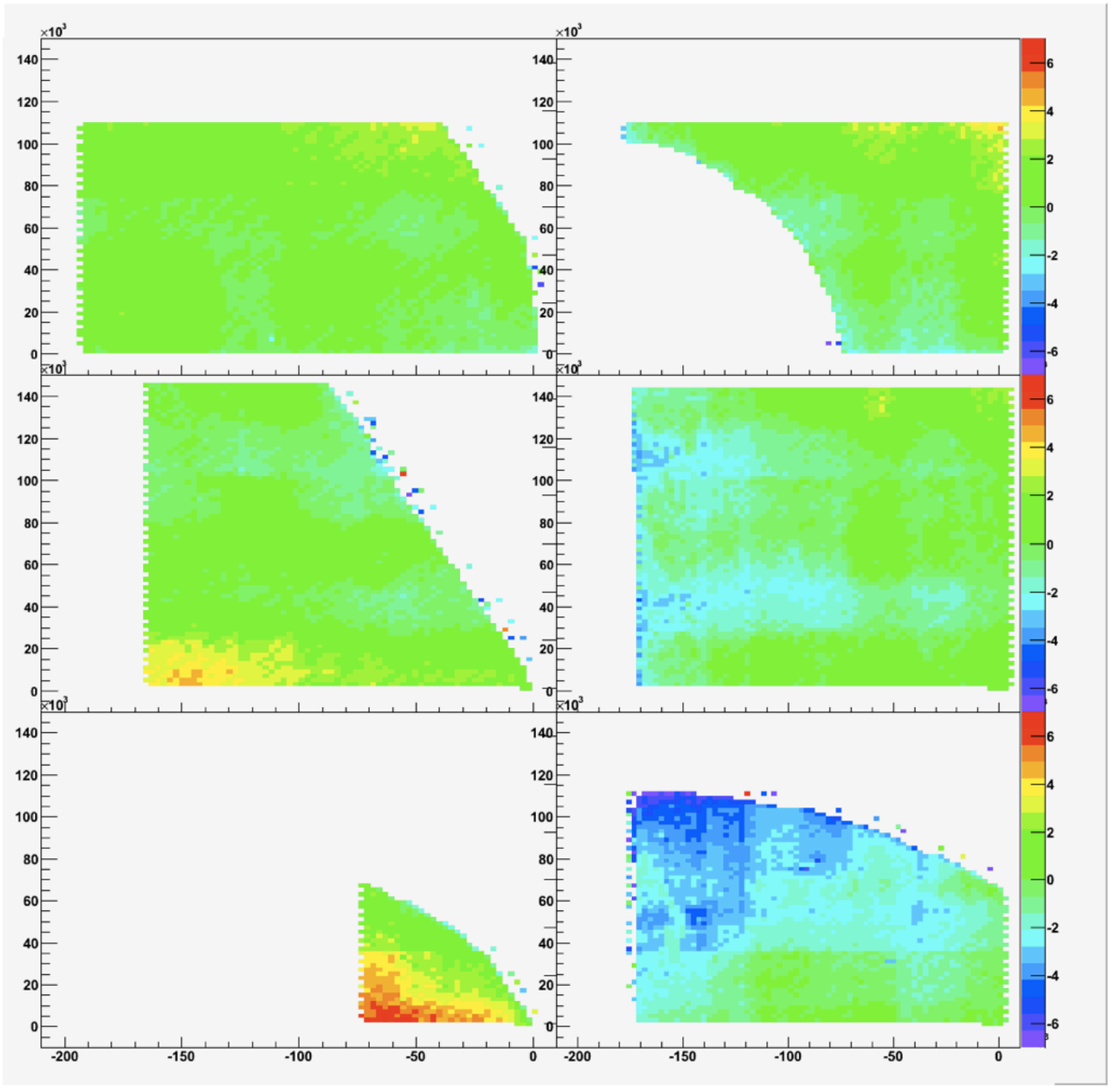
CCD GEM Foil Scan - Inner Hole Diameter

CERN - GEM foil 2

- stripe pattern not so obvious
- inner hole diameter more uniform (?)

Inner hole diameter

- blue 6 micron below average
- red 6 micron above average



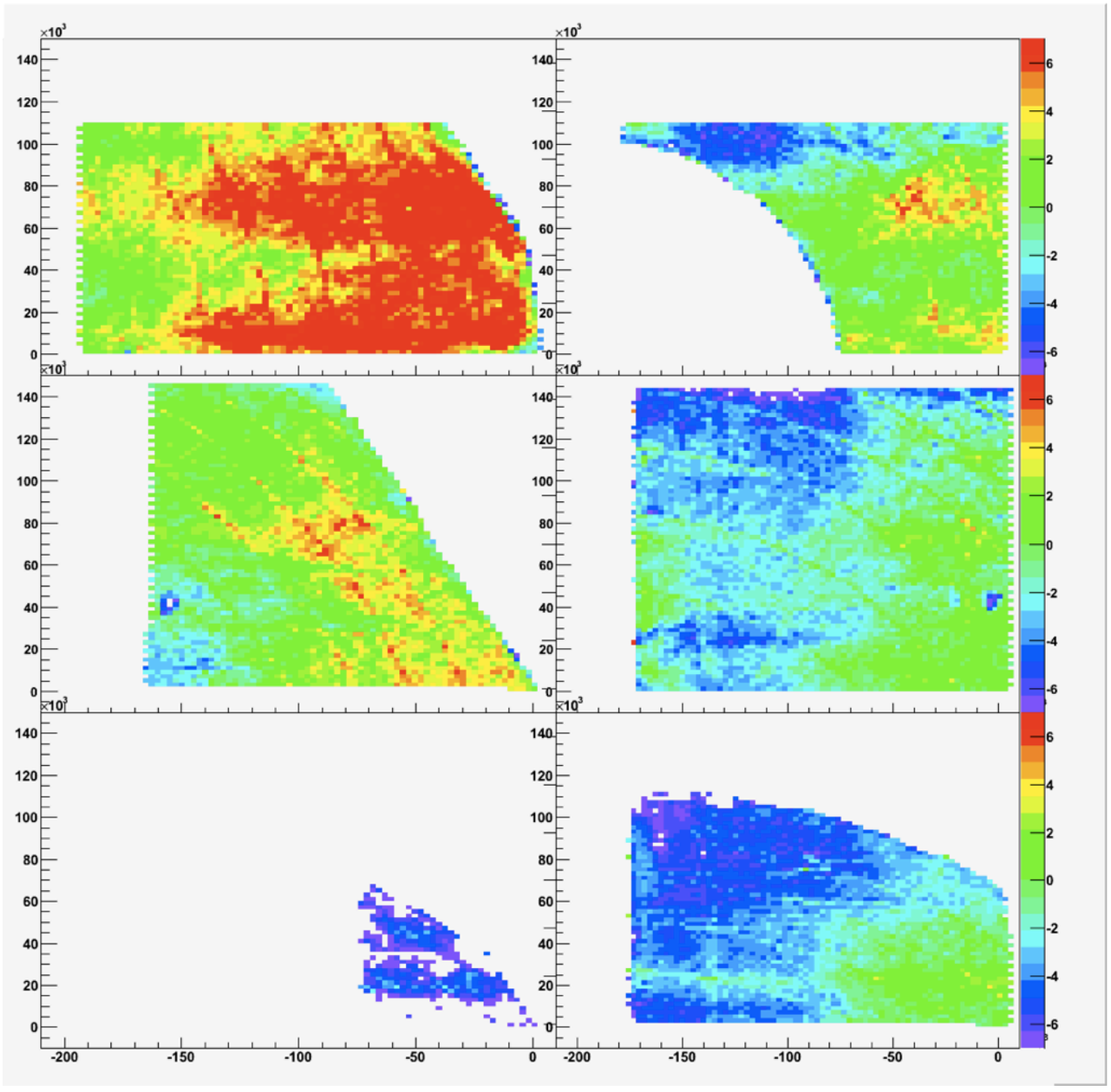
CCD GEM Foil Scan - Outer Hole Diameter

CERN - GEM foil 2

- stripe pattern not so obvious
- outer diameter not so uniform
  - distinct regions with different diameters

Outer hole diameter

- blue 6 micron below average
- red 6 micron above average



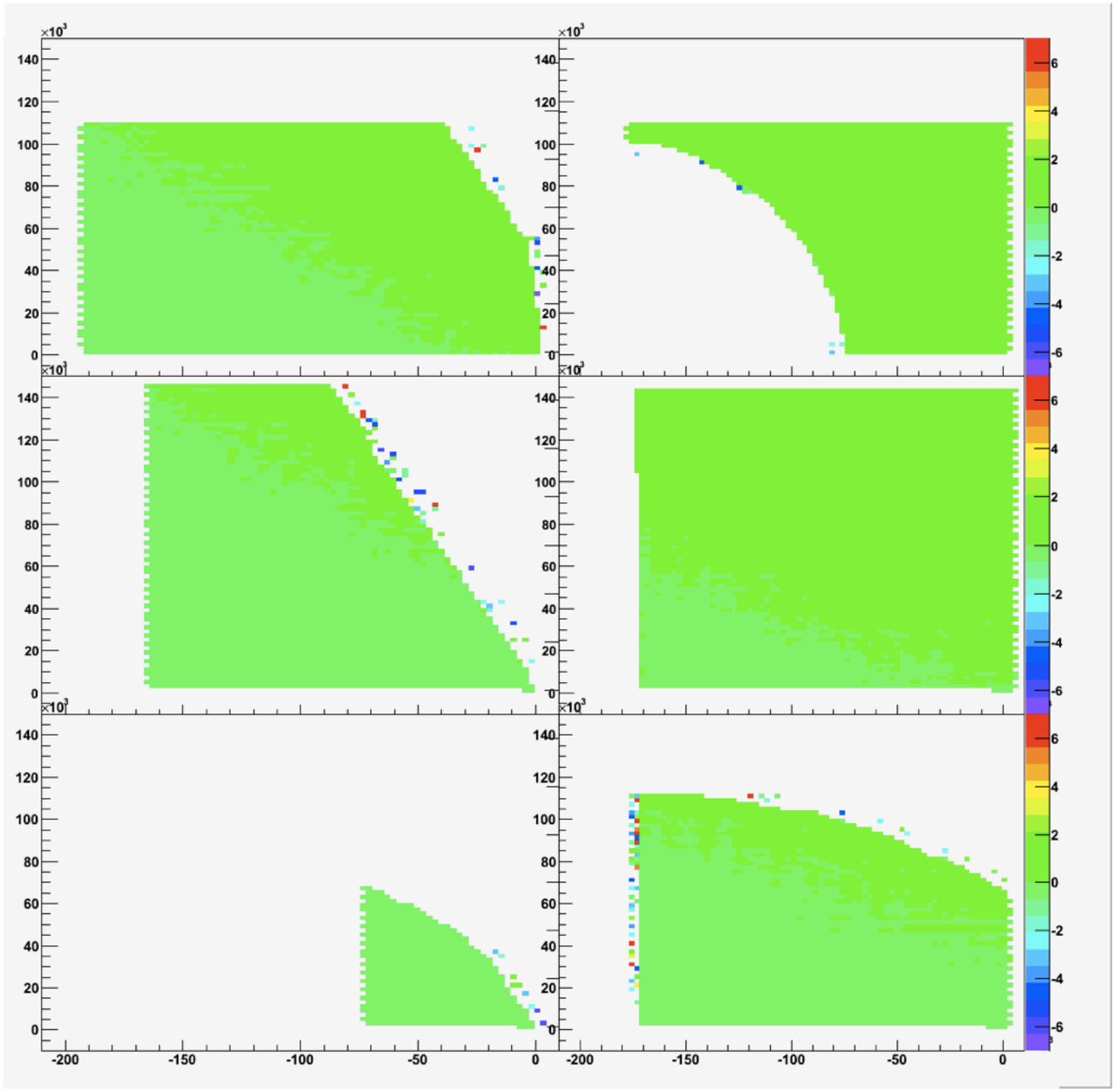
CCD GEM Foil Scan - Hole Pitch

CERN - GEM foil 2

- hole pitch very uniform

Hole pitch

- blue 6 micron below average
- red 6 micron above average



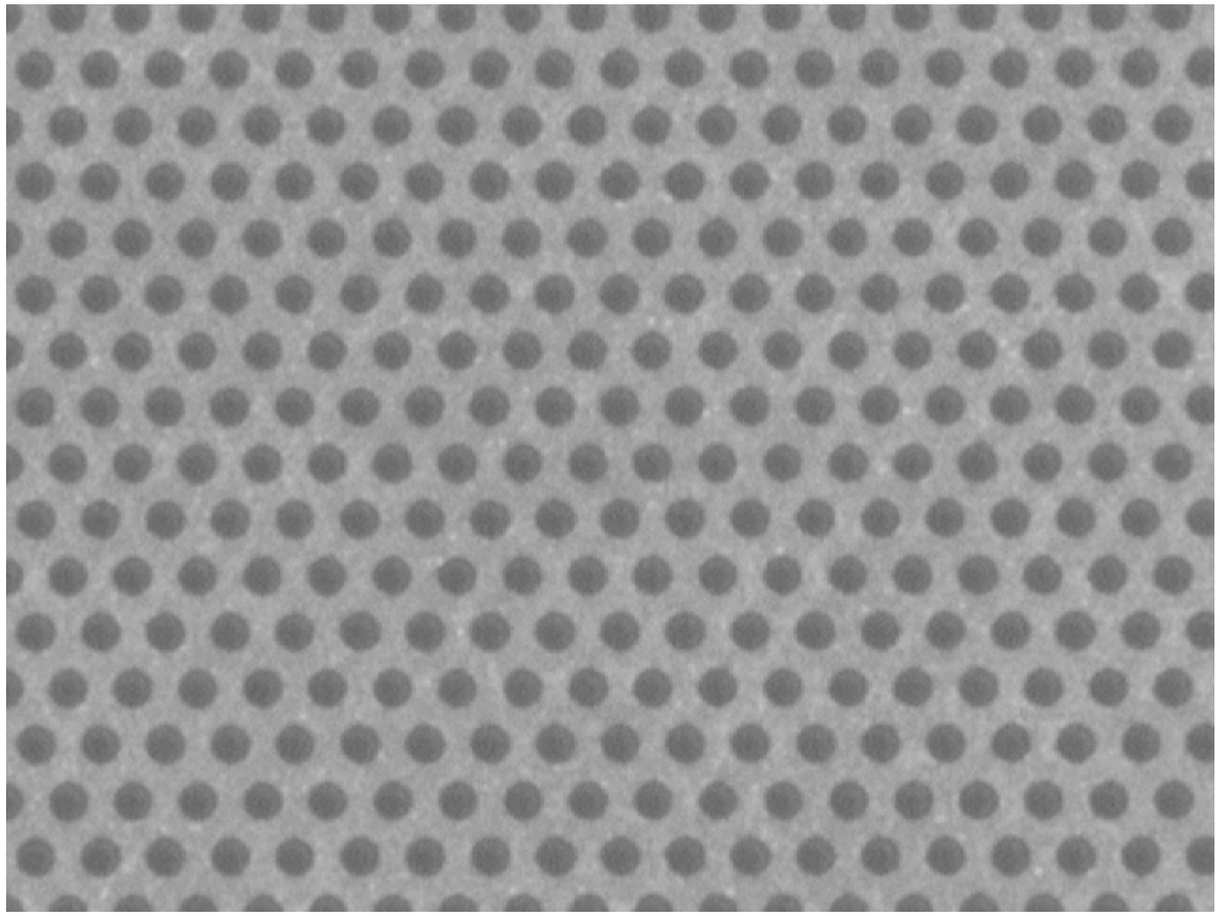
CCD GEM Foil Scan

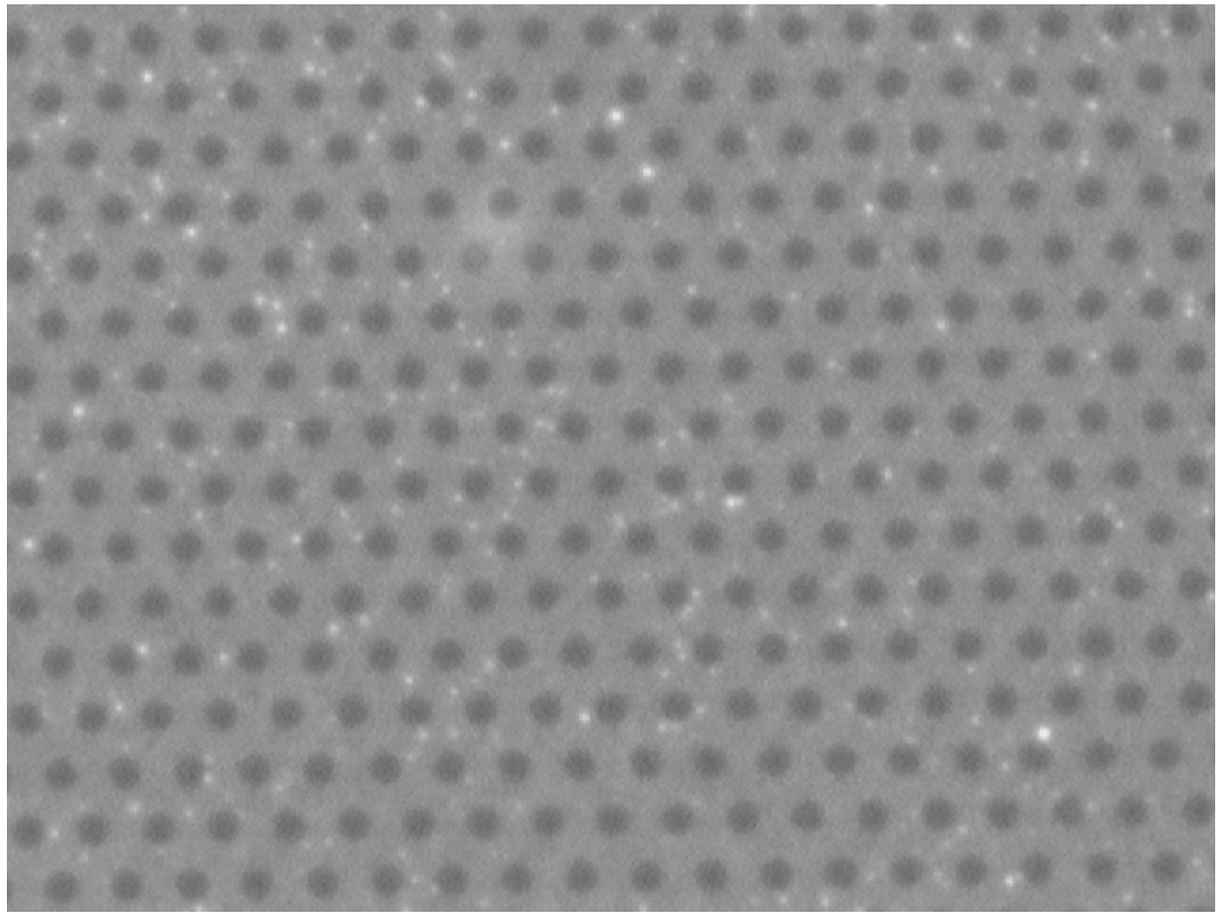
Tech-Etch - GEM foil 2

- mean pitch = 140 micron
- mean ID = 47 micron
- mean OD = 83 micron
- large difference ID - OD
  - explains HV to 700 V ?

CERN - GEM foil 2

- mean pitch = 140 microns
- mean ID = 53 micron
- mean OD = 66 microns
- speckling made measurement difficult

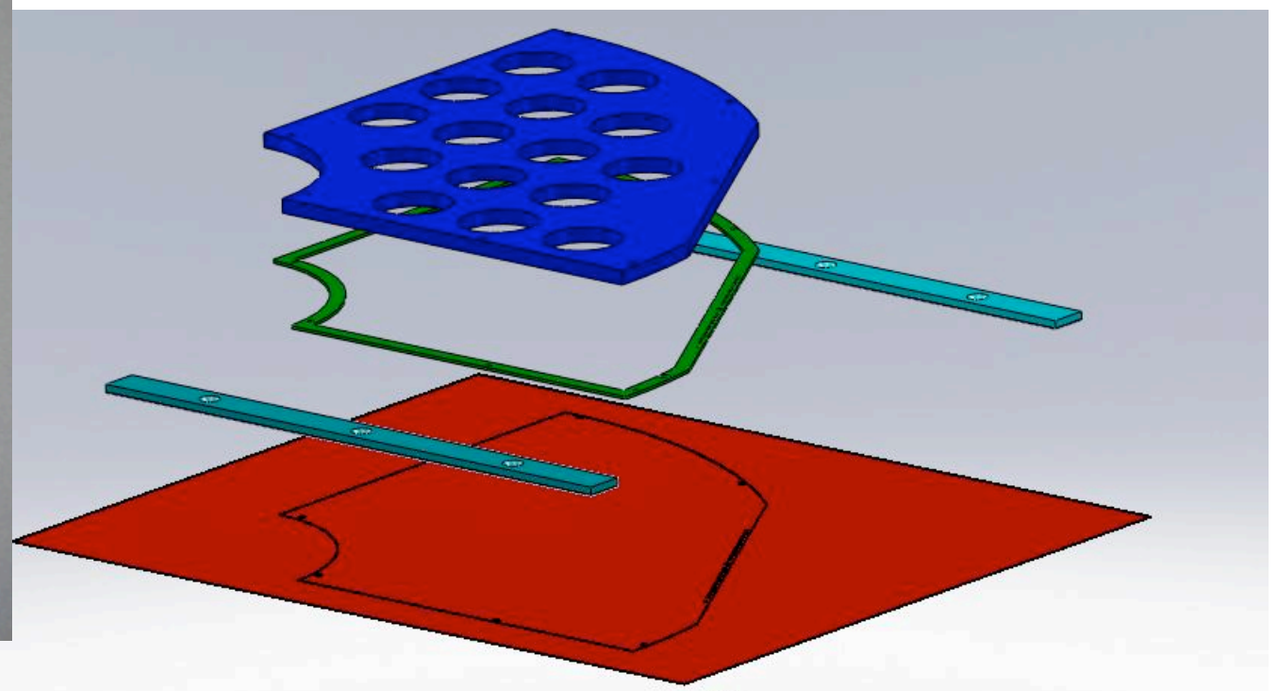




GEM Foil Stretching/Gluing - J. Bessuille (MIT)

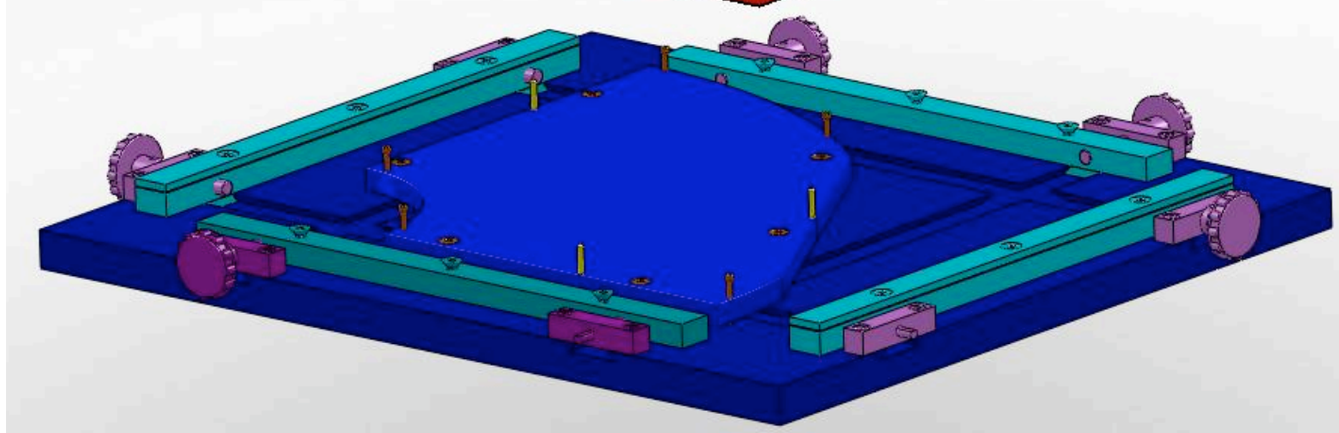
Pneumatic cylinders

- 50-60 psi →
- foil and frames aligned by 8 reference pins

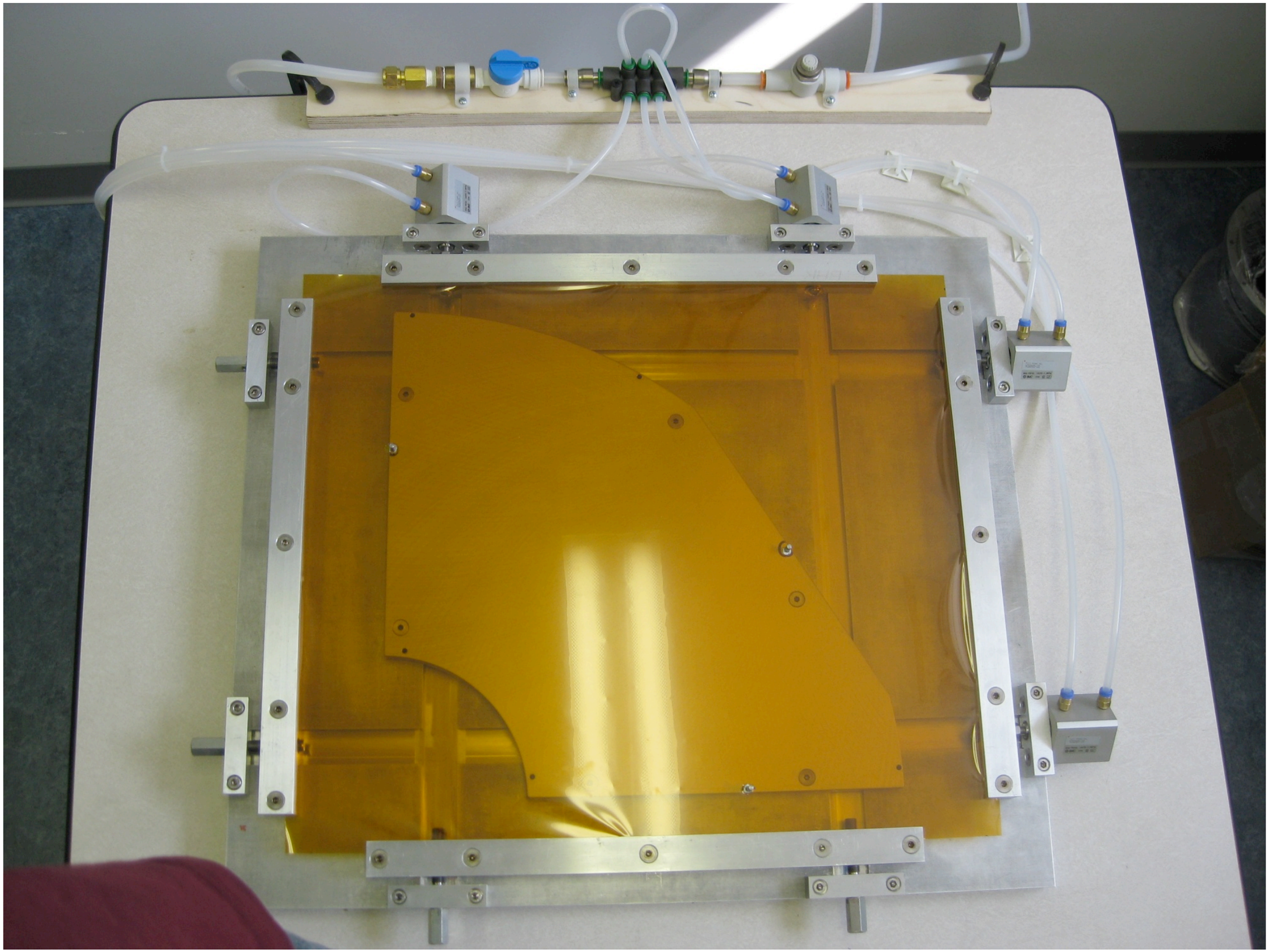


Deflection tests in progress

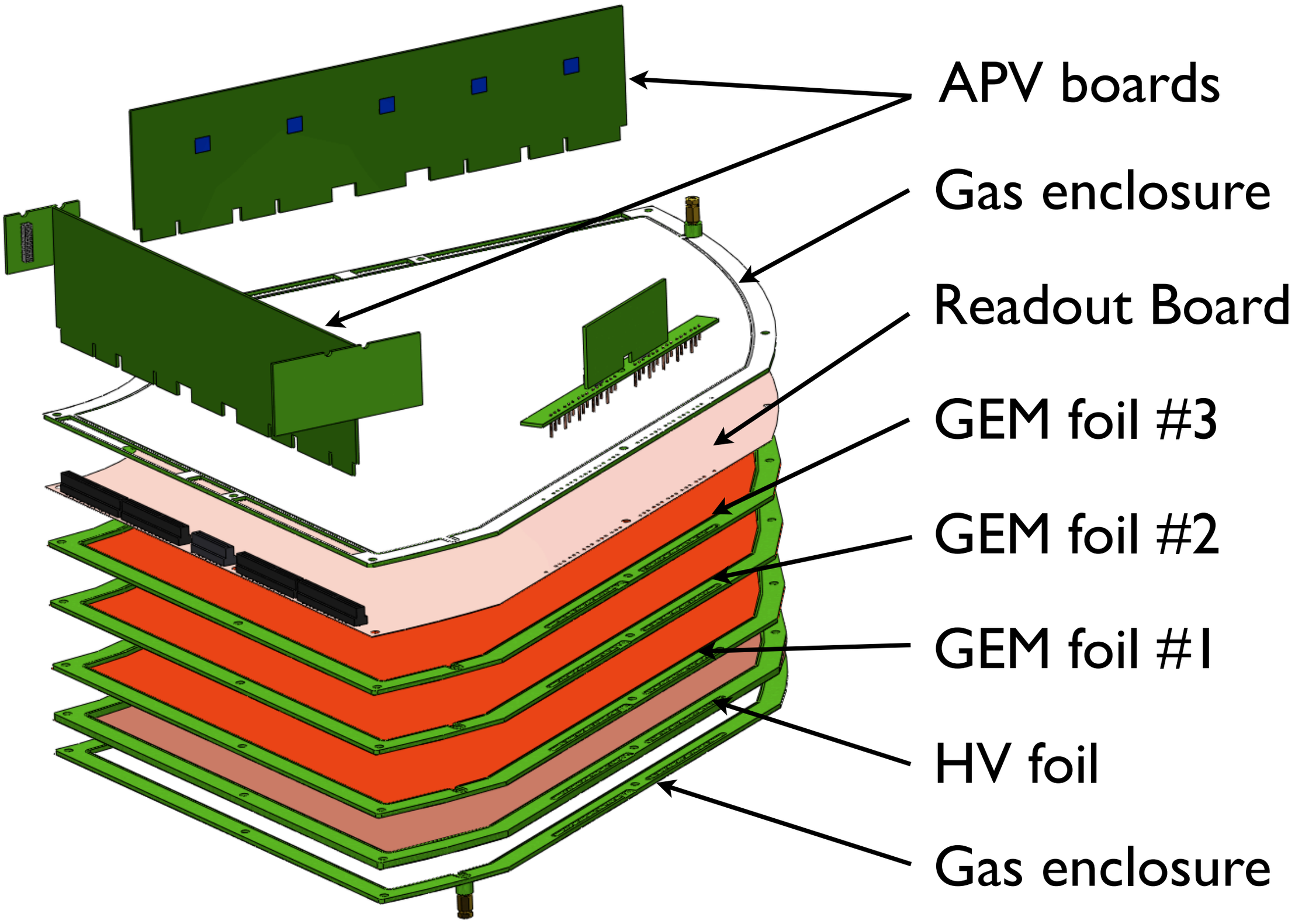
- slight delay due to accident !



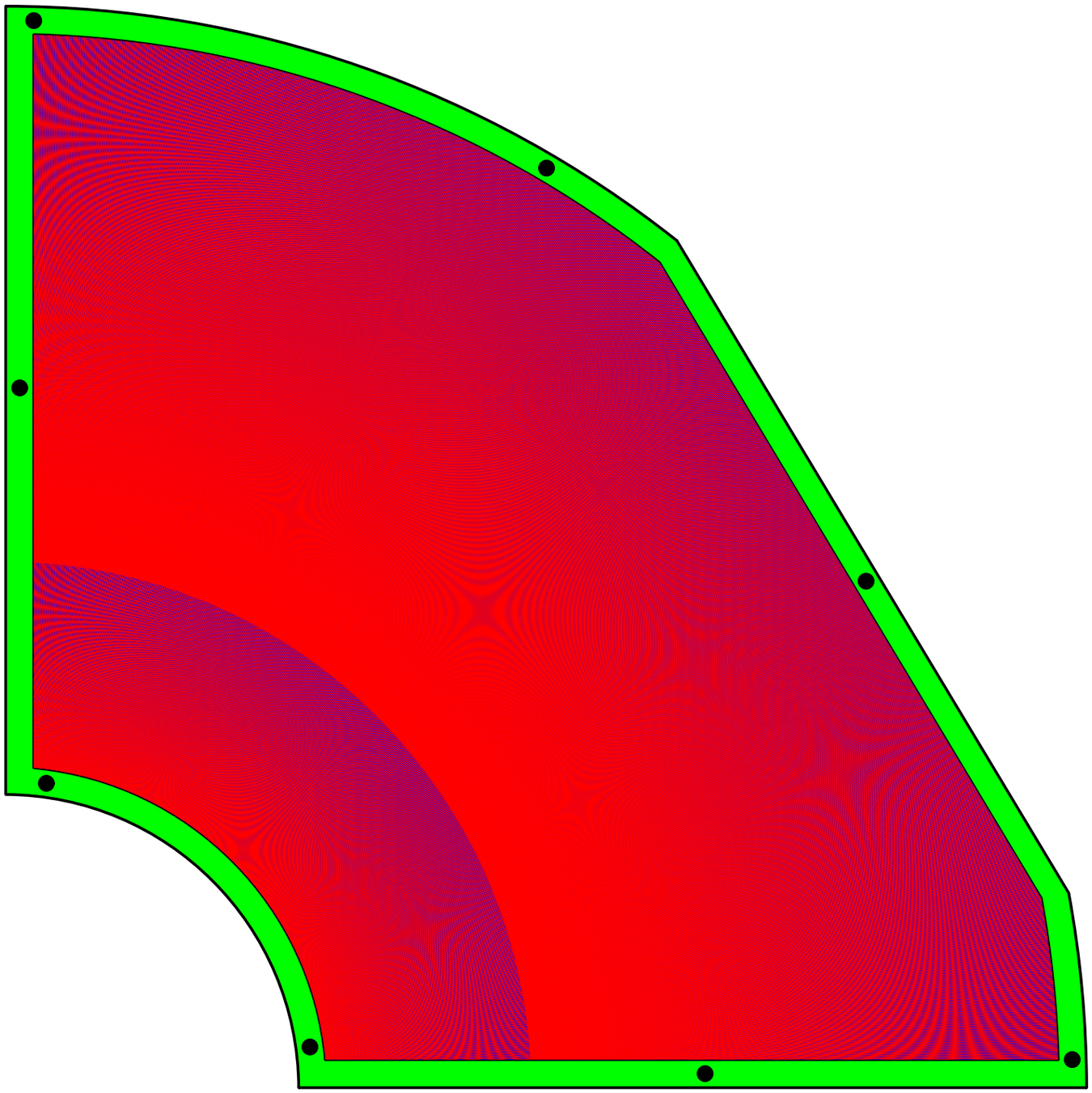
FGT GEM Foil Stretching/Gluing Fixture



FGT Triple GEM Quadrant



Preliminary 2D Readout Design



50 micron Kapton

- copper both sides
- laser etching exposes bottom layer
  - Compunetics, Pittsburgh, PA

Top layer - Φ readout

- lines radiate from centre
- alternate lines end at 38.25/2
- line width and pitch varies with radius
  - line width 70 - 120 micron
  - line pitch 300 - 600 micron

Bottom layer - R readout

- lines at constant radius
  - line width 800 micron
  - line pitch 900 micron

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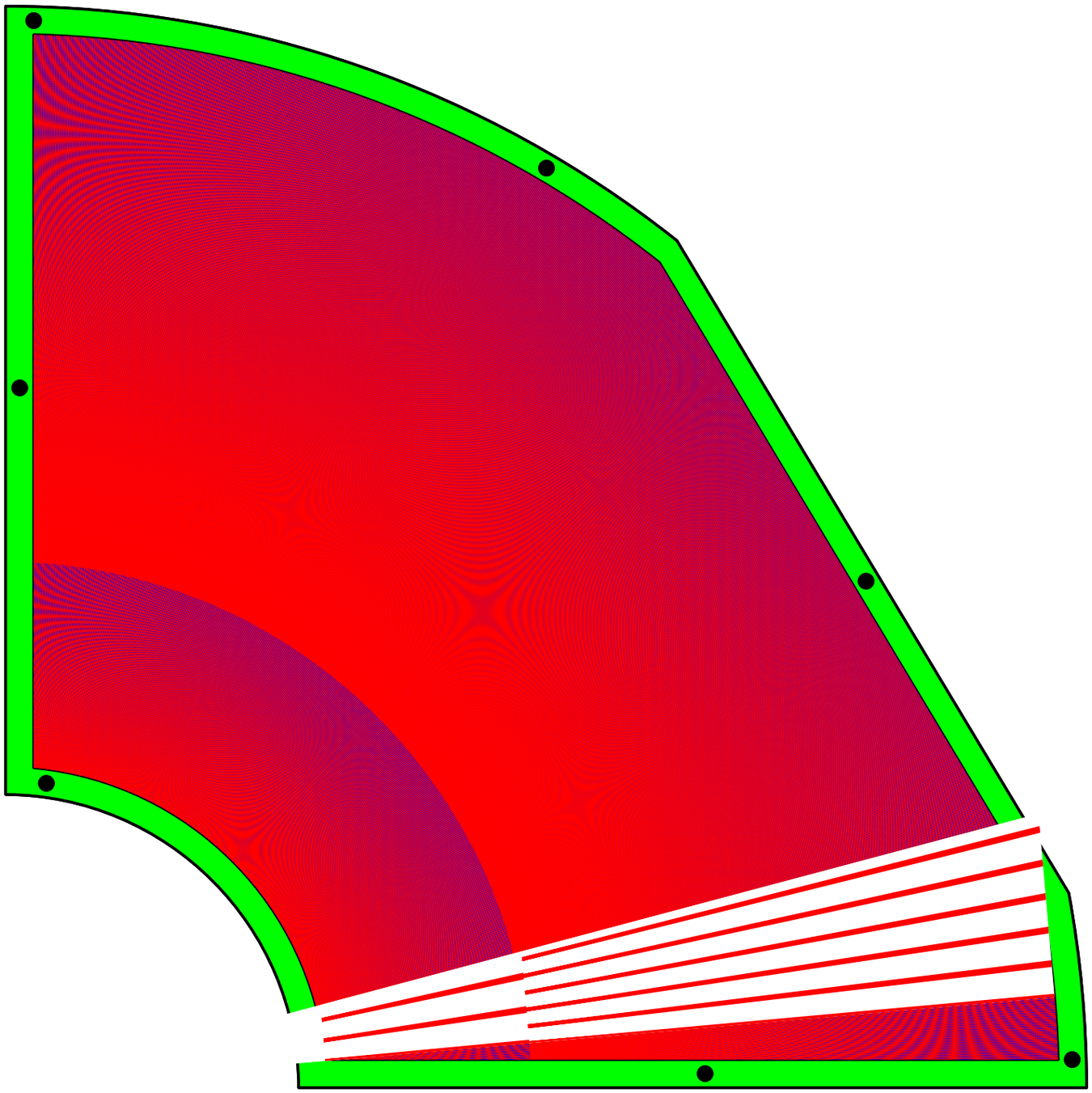

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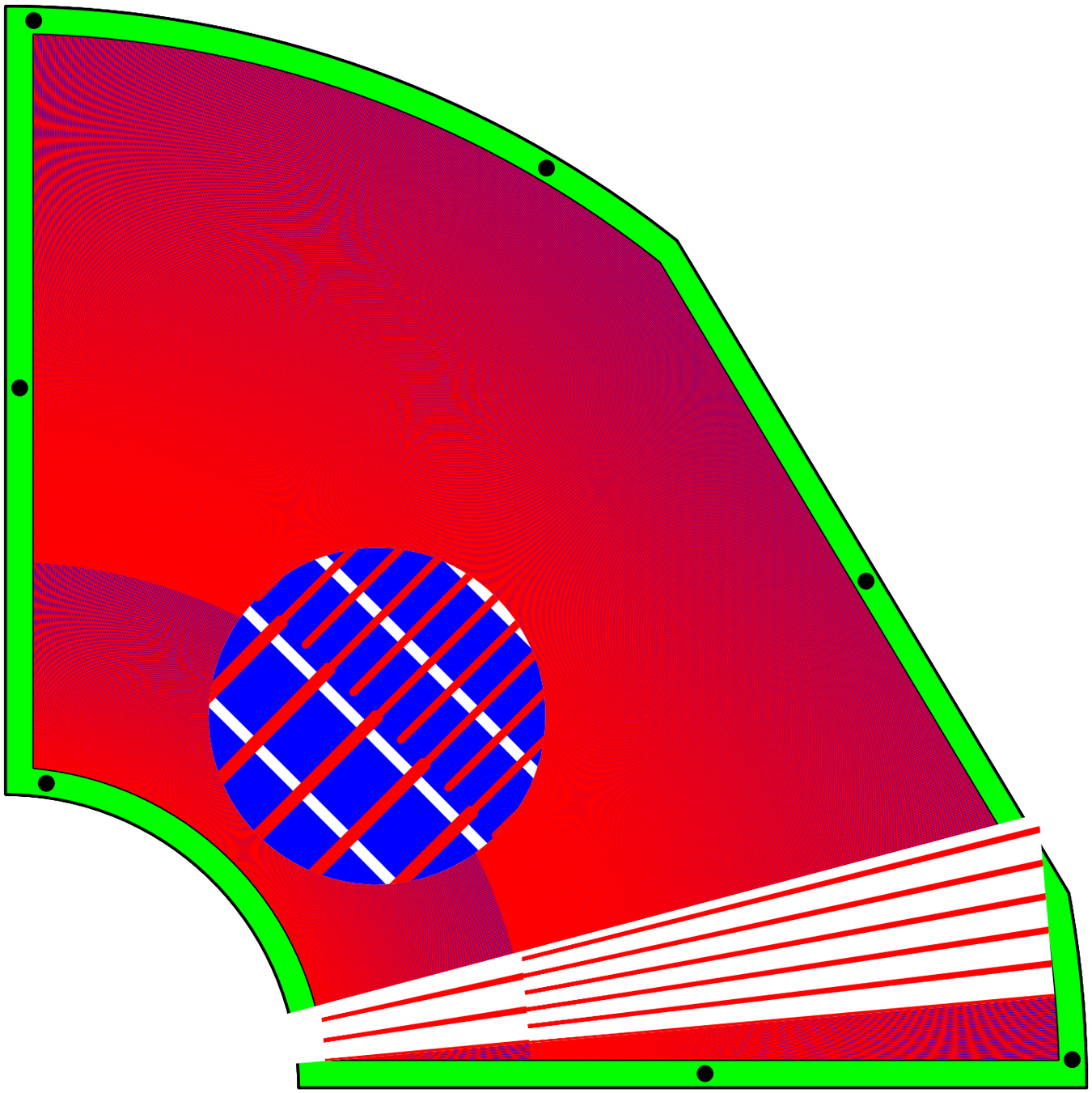

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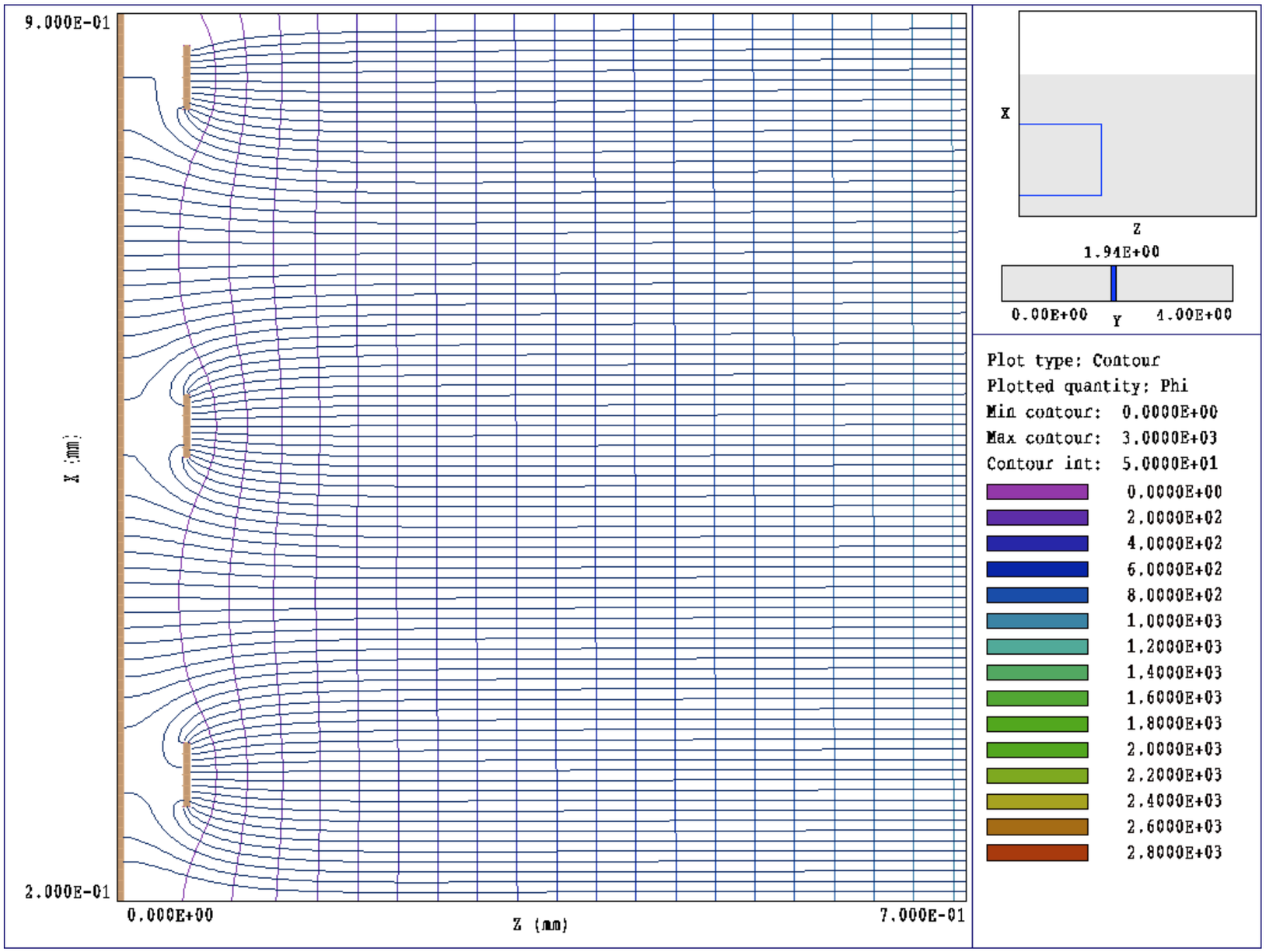
Charge Sharing Calculations - R. Majka (Yale)



To resolve multiple hits need to know charge sharing ratio

- combination of line width and pitch for ~1:1 charge sharing

3D electrostatics calculations

- did not match results from previous detectors

Build charge sharing test

2D Charge Sharing Test Board

10x10 cm^2 test board

- test with ^{55}Fe source

Bottom layer

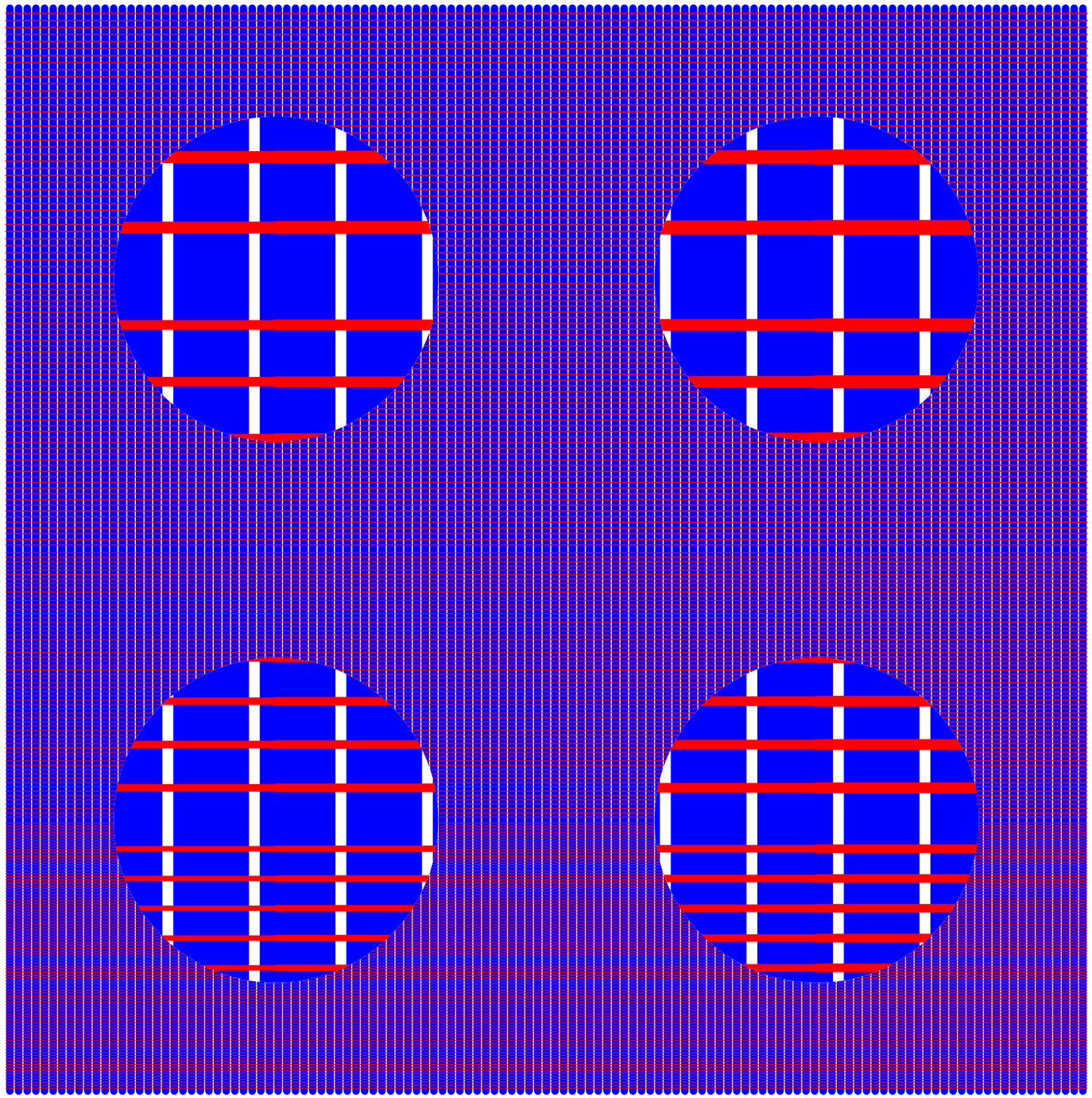
- uniform line width and pitch
  - 700 micron line width
  - 800 micron line pitch

Top layer

- 16 regions of different width and pitch

Pitch [μm]	Line width [μm]			
650	110	120	130	140
525	90	100	110	120
400	70	80	90	100
275	50	60	70	80

2D Charge Sharing Test Board



10x10 cm^2 test board

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Top layer

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Pitch [μm]	Line width [μm]			
650	110	120	130	140
525	90	100	110	120
400	70	80	90	100
275	50	60	70	80

Preliminary Charge Sharing - R. Majka (Yale)

Integrated charge on lines

- no individual line readout
- repeat test with line readout

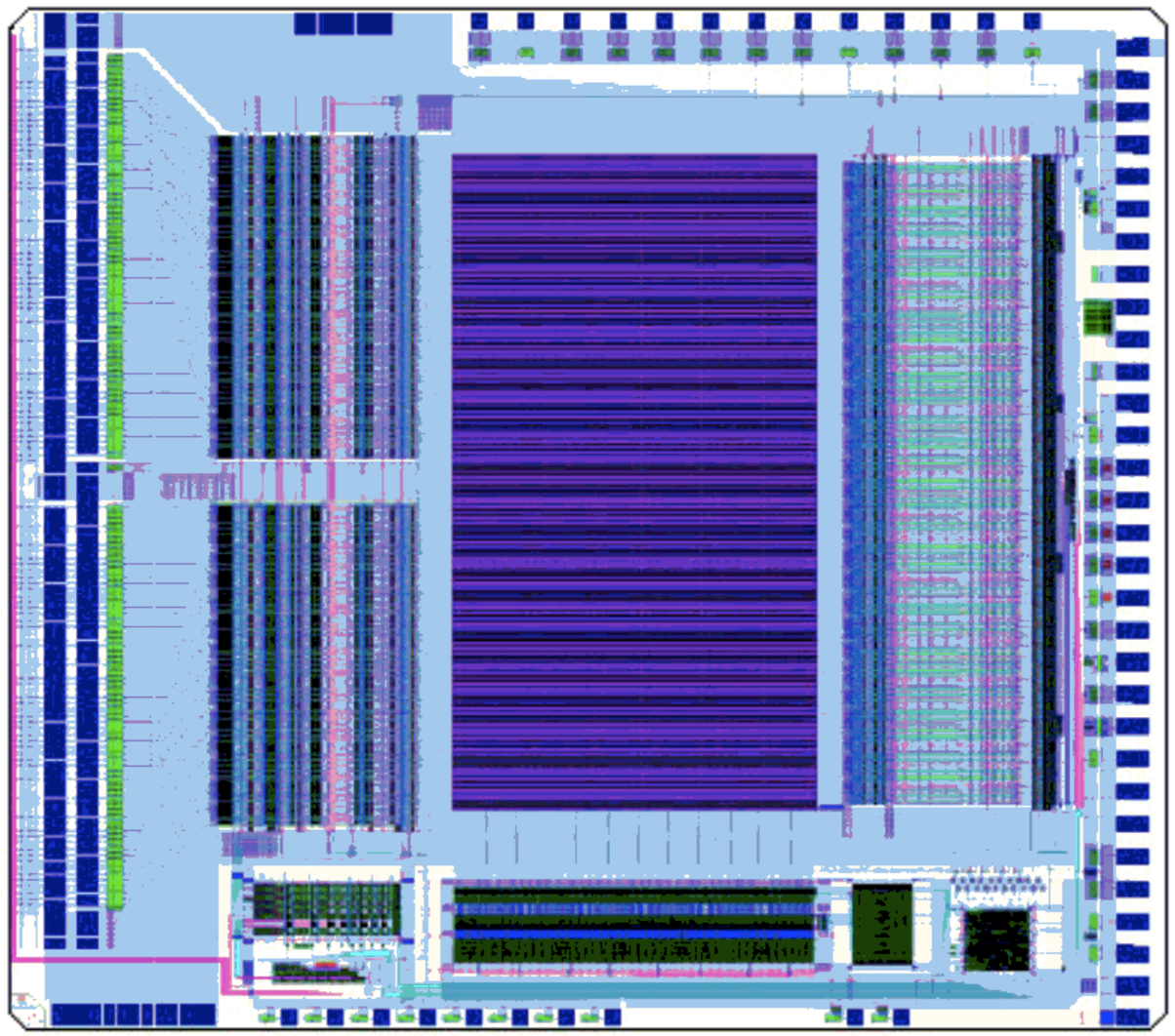
line pitch / line width

measured calculated

ratio

275 / 50	275 / 60	275 / 70	275 / 80
2.16 1.22	2.46 1.38	2.69 1.67	2.75 1.85
1.77	1.79	1.61	1.48
400 / 70	**400 / 80**	**400 / 90**	**400 / 100**
1.60 0.81	1.55 0.92	1.68 1.03	1.80 1.20
1.97	1.69	1.63	1.49
525 / 90	**525 / 100**	**525 / 110**	**525 / 120**
1.26 0.65	1.21 0.74	1.30 0.83	1.36 0.83
1.94	1.65	1.56	1.63
650 / 110	**650 / 120**	**650 / 130**	**650 / 140**
0.95 0.57	0.91 0.65	0.96 0.67	1.01 0.68
1.67	1.41	1.44	1.48

APV25-S1 Readout Chip



Developed for CMS

- silicon strip detector
- used on GEMs by COMPASS

0.25 micron CMOS process

- 128 channels pre-amp/shaper
- 4 μs pipeline
- 40 MHz sampling rate

Power

- 194 mW / chip

Input double row of staggered pads

- pads 136 × 58 μm
- pitch 44 (88) μm

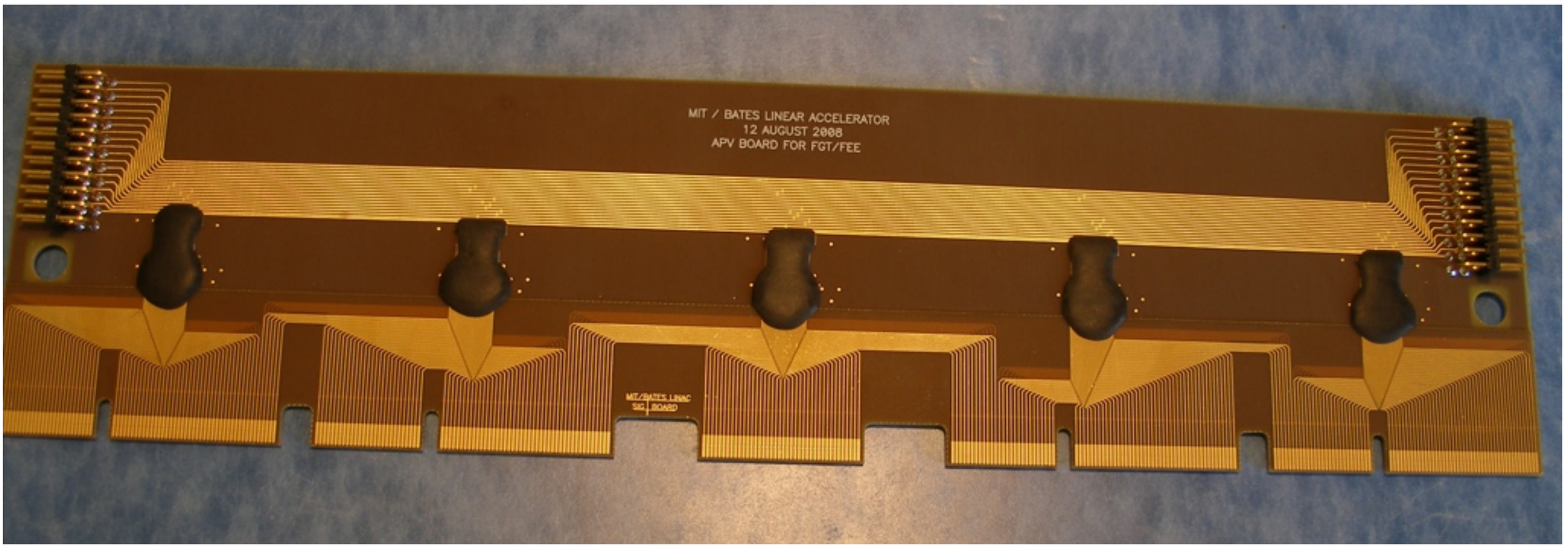
FGT APV Board - M. Plesko (MIT)

Fine pitch on APV inputs

- understandable for silicon strip detectors
- not well matched to typical GEM pitches

Several APV chips on board

- difficult to bond to normal PCB
- requires multiple layers with cut-outs
- expensive
- difficult to repair



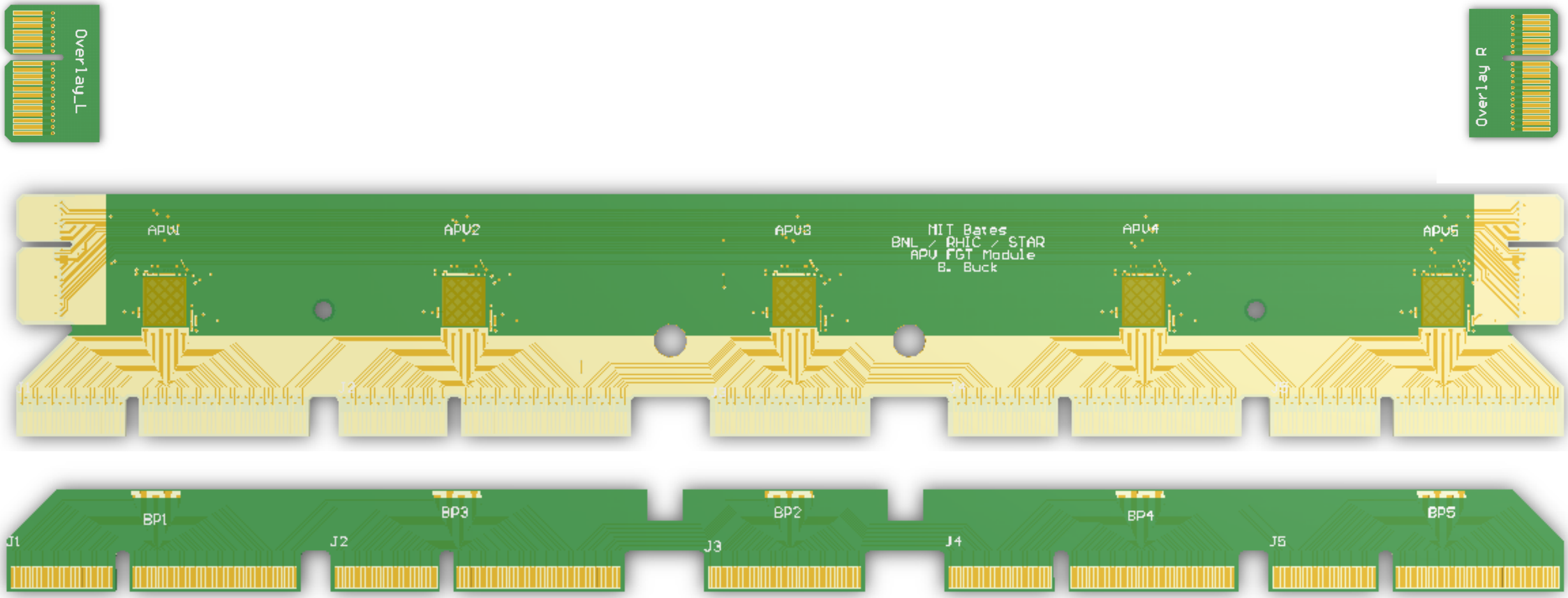
FGT APV Board - B. Buck (MIT), G. Visser (IUCF)

FGT design

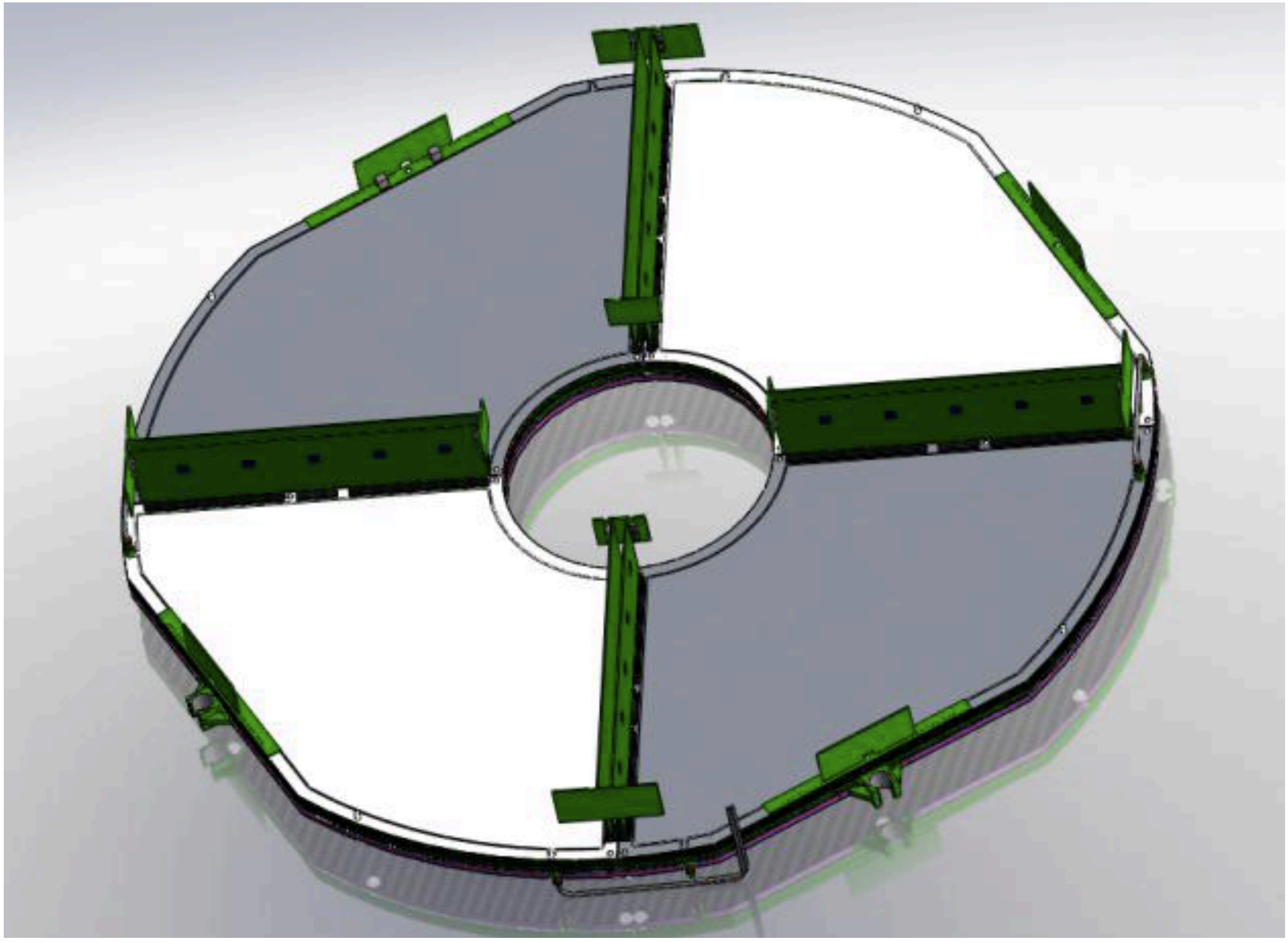
- 2 APV boards / quadrant
- 1 on each quadrant boundary
- pairs of APV boards connected and terminated together

New APV board

- assembly of 4 PCB
- slightly simpler design
- slightly cheaper
- still difficult to bond and repair



FGT Quadrant



Packaging APV Chips

Investigating packaging of APV chips

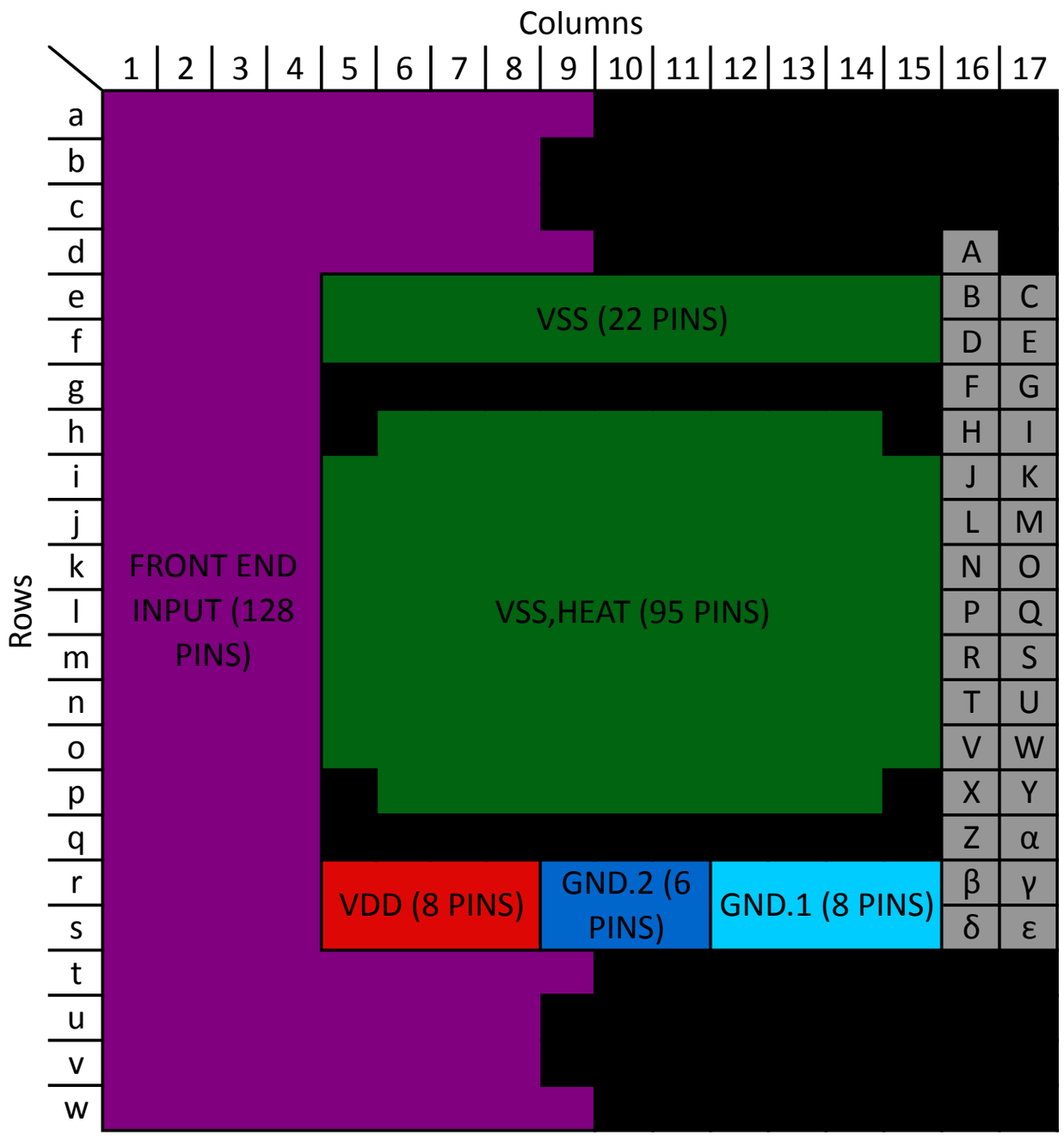
- Compunetics, Pittsburgh, PA
- First Level, York, PA

Simplify APV board

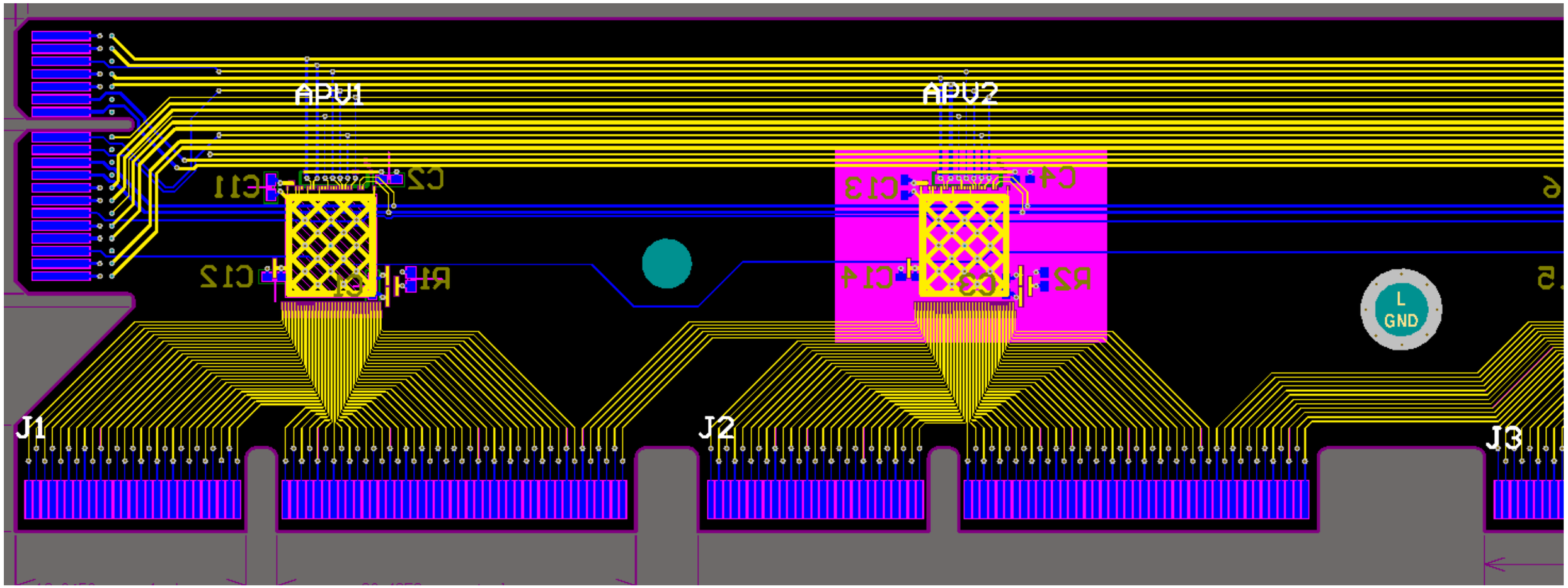
- normal PCB
- standard SM technology
- possible to replace packages

Ball Grid Array

- 23x17 rectangular package
- 0.8 mm pitch between pins
- package 20 x 15.2 mm^2
- multiple pins for power
- heat sink
- still iterating on design / pin-out



APV Board with 23x17 BGA



Forward GEM Tracking Upgrade for STAR

Future

- production of GEM foils with Tech-Etch seems to be well in-hand
  - improved dark currents with cleaning (R. de Oliveira)
  - glass masks to address hole offset and stripped pattern
- still have a number of tests to conduct and details to finalise
  - charge sharing with individual line readout → finalise 2D readout design
  - deflection of GEM foils → tension or need for spacers
- APV boards
  - have existing solution using complicated board and bonding directly to board
  - but packaging of APV chips could simplify design and reduce cost

Schedule

- production to start early 2010
- expect to complete in ~6 months after start
- test quadrants with source, cosmics, and real STAR readout system
- install in STAR summer 2011

Thank you