The STAR Forward GEM Tracker (FGT)

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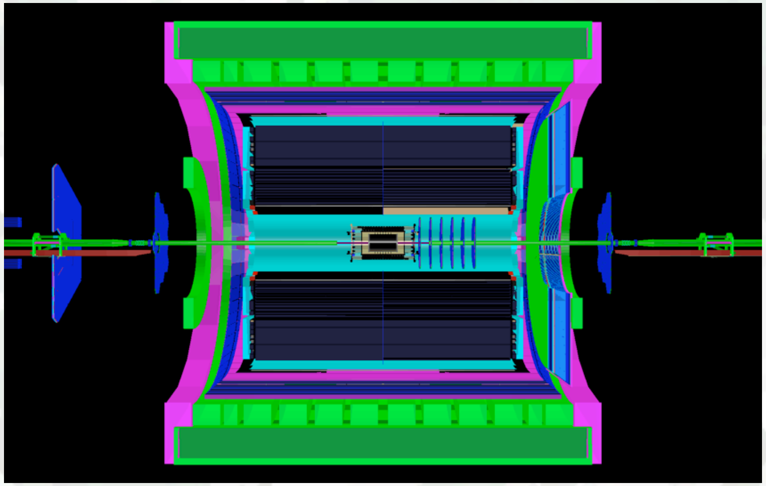
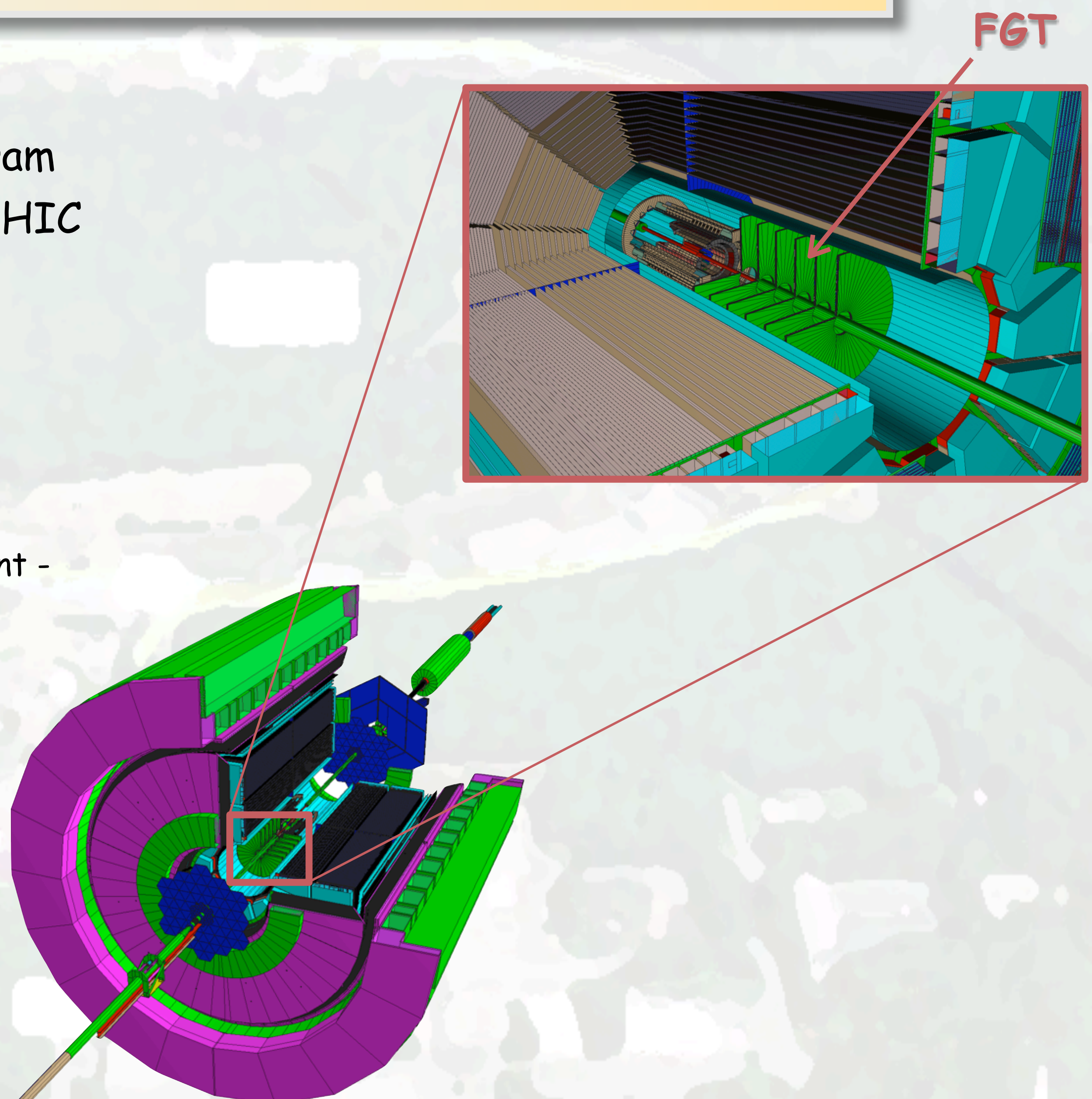


1st International Conference Micro-Pattern Gas Detectors - MPGD2009
Kolympari, Crete, Greece, June 13, 2009

Outline

- Physics motivation - W program in polarized pp collisions at RHIC
- FGT Layout
- FGT Technical Realization
  - Triple-GEM detector development - R&D
  - Mechanical design
  - Front-End Electronics
  - DAQ
- Summary

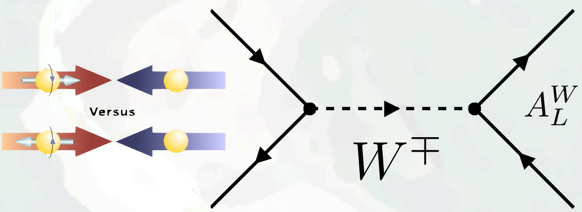


FGT Physics motivation - W program

Quark / Anti-Quark Polarization - W production

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

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

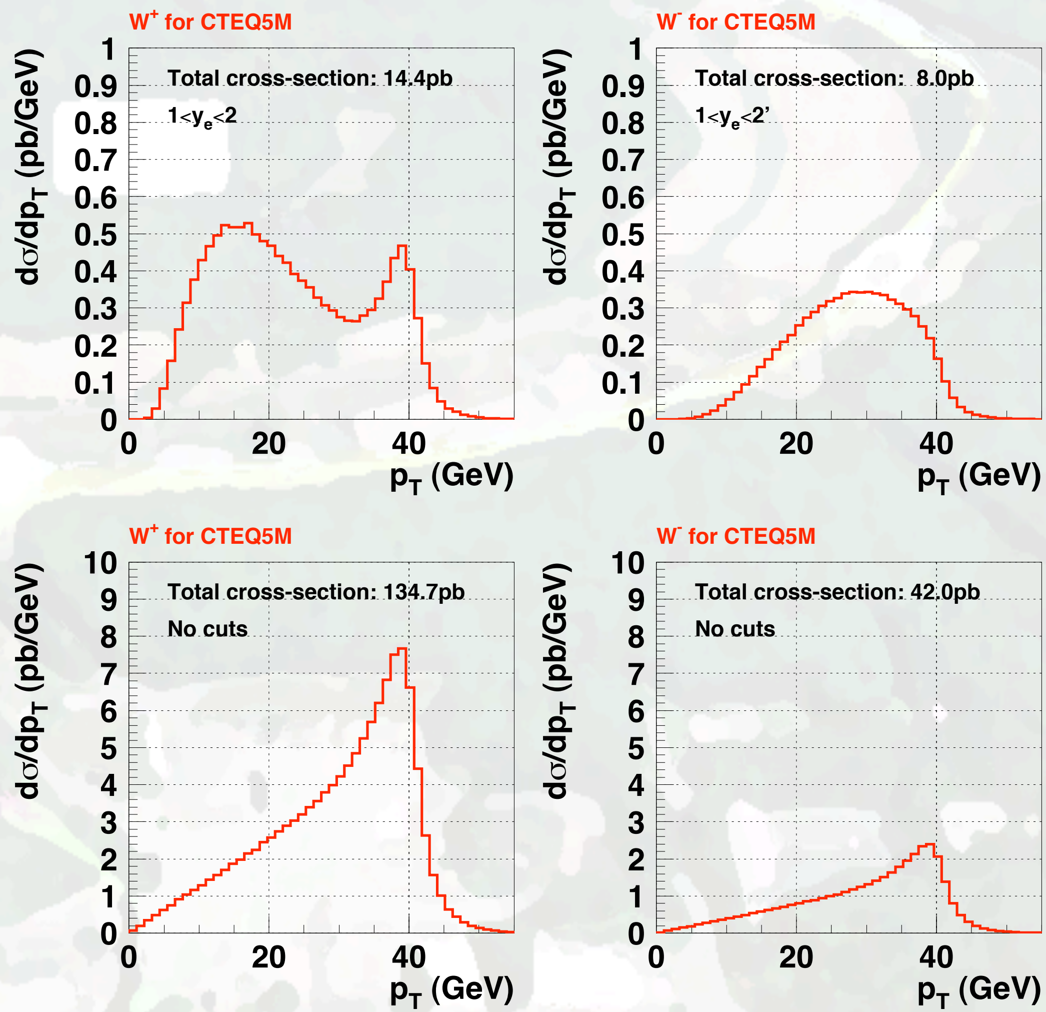


$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) - N^-(W)}$$

$$W^+ \rightarrow e^+ + \nu_e$$

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

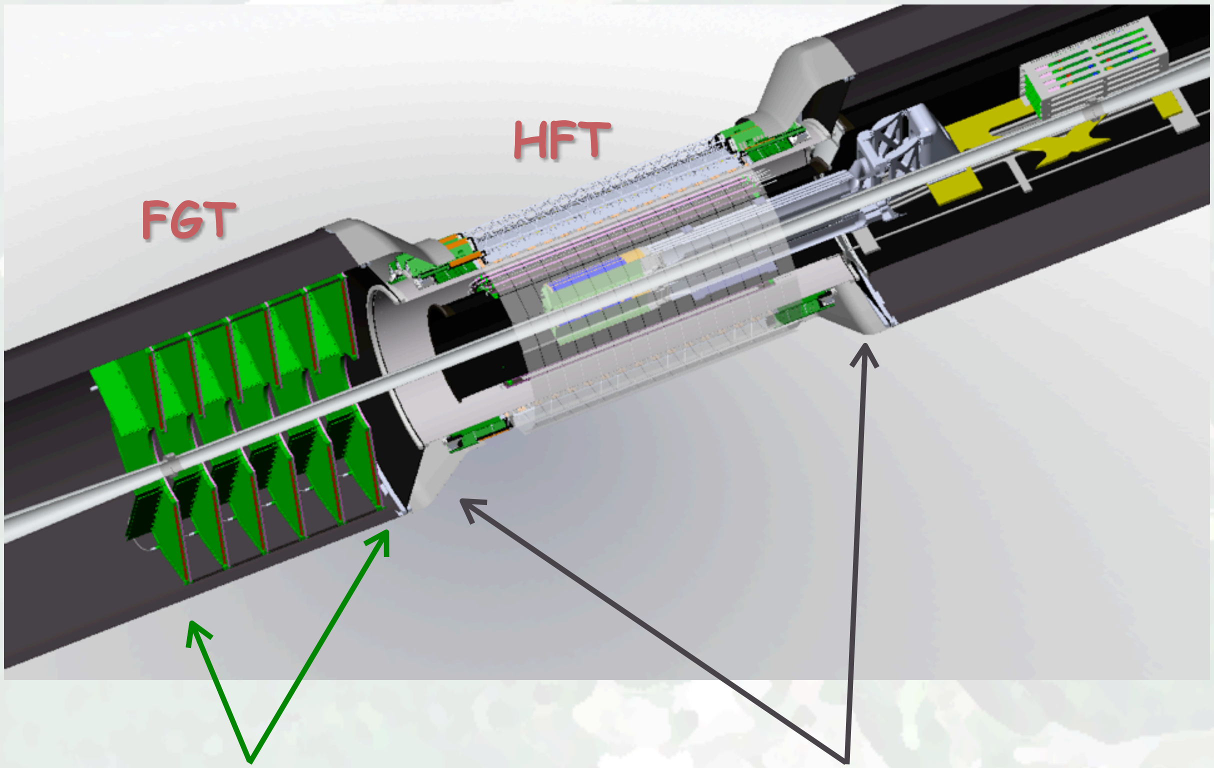
RHICBOS W simulation at 500GeV CME

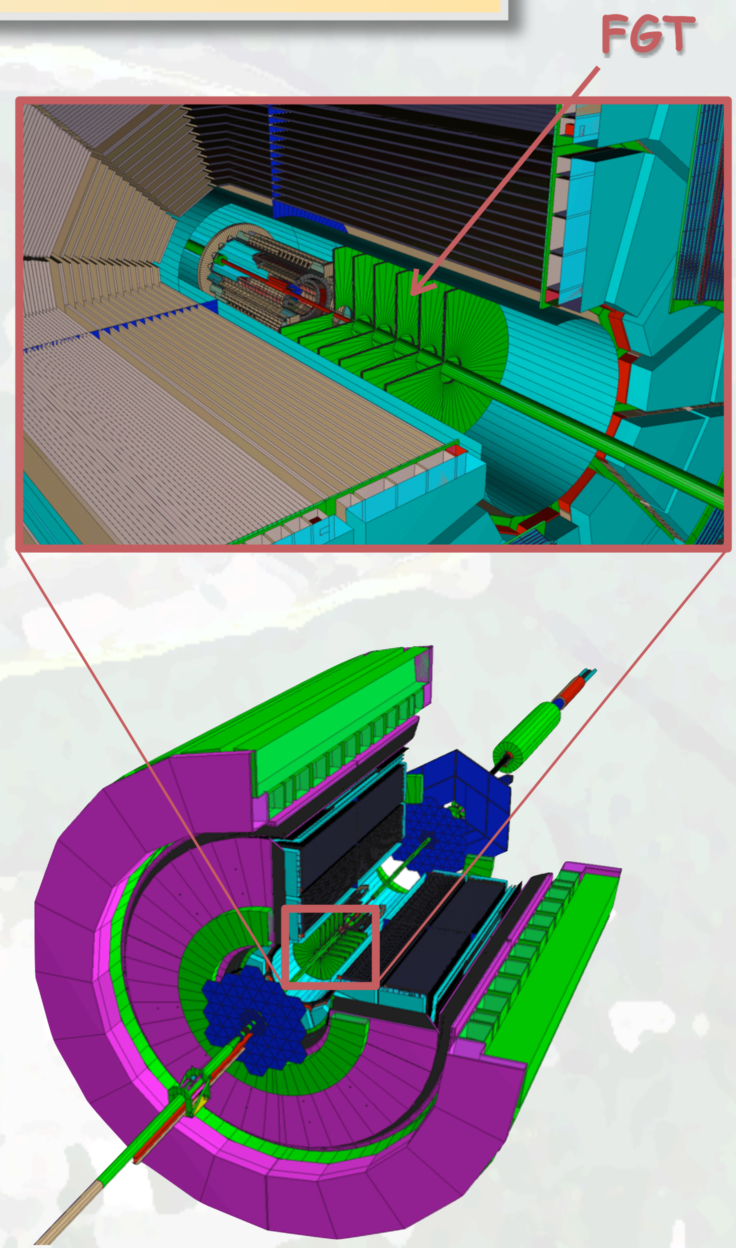


- **Key signature:** High p_T lepton (e^-/e^+ or μ^-/μ^+) (Max. $M_W/2$) - Selection of W^-/W^+ : Charge sign discrimination of high p_T lepton
- Required: Lepton/Hadron discrimination

FGT Layout

- Layout





- FGT: 6 light-weight triple-GEM disks - WEST side of STAR
- New mechanical support structure (STAR West / East)

FGT Technical realization

SBIR proposal (1)

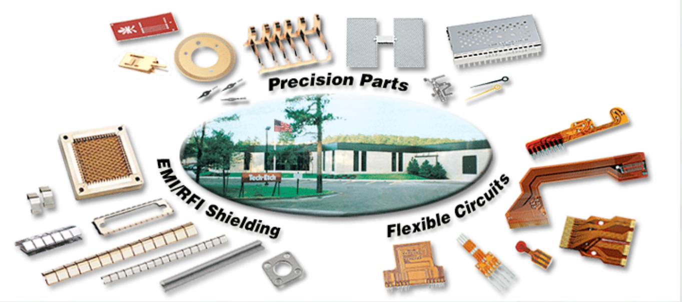
- SBIR: Small Business Innovation Research: US Government (DOE) funded program
  - ☑ Phase I: Explore feasibility of innovative concepts with award of up to $100k
  - ☑ Phase II: Principal R&D effort with award of up to $750k
  - ☐ Phase III: Commercial application
- SBIR: Collaborative effort of Tech-Etch Inc. with BNL, MIT and Yale University - Production of GEM foils
  - ☐ Develop optimized production process for small (10cm X 10cm) and larger GEM foils
  - ☐ Investigate a variety of materials
  - ☐ Study post production handling: Cleaning, surface treatment and storage
- New SBIR proposal: 2D readout board using chemical etching : Recently approved!

FGT Technical realization

- SBIR proposal (2)

  - Tech-Etch Inc.: Company profile
    - Manufacturer of precision flexible circuits
    - Extensive experience in etching of copper traces and polyamide
    - Strong ties to BNL, MIT and Yale University

Tech-Etch Inc.



http://www.tech-etch.com

  - Critical performance parameters
    - Achievable gain, gain uniformity and gain stability
    - Energy resolution

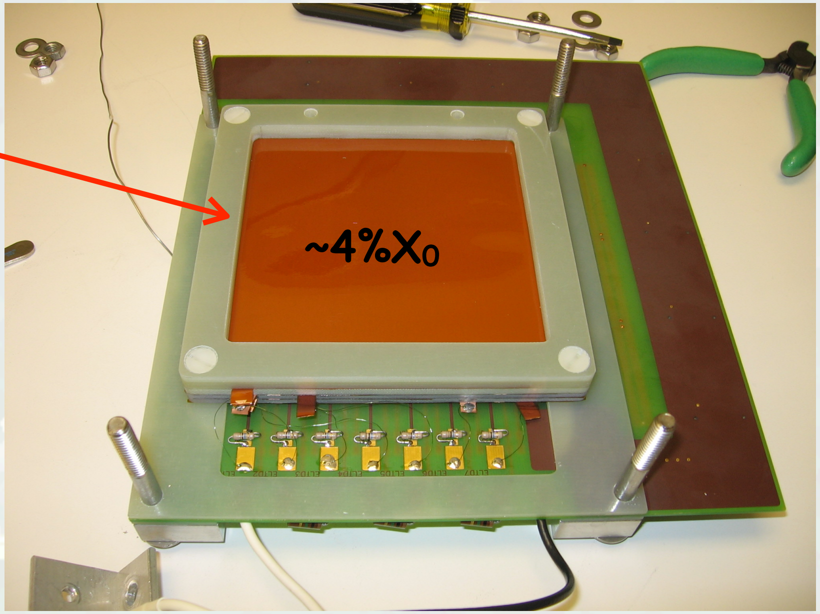
  - Status
    - Phase I / II approved - Dedicated production facility at Tech-Etch Inc.
    - Success with 10cm X 10cm samples / First large GEM foils received

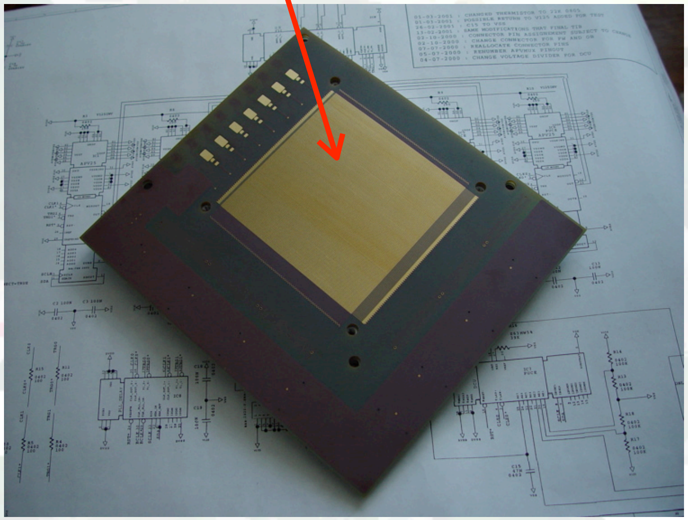
FGT Technical realization

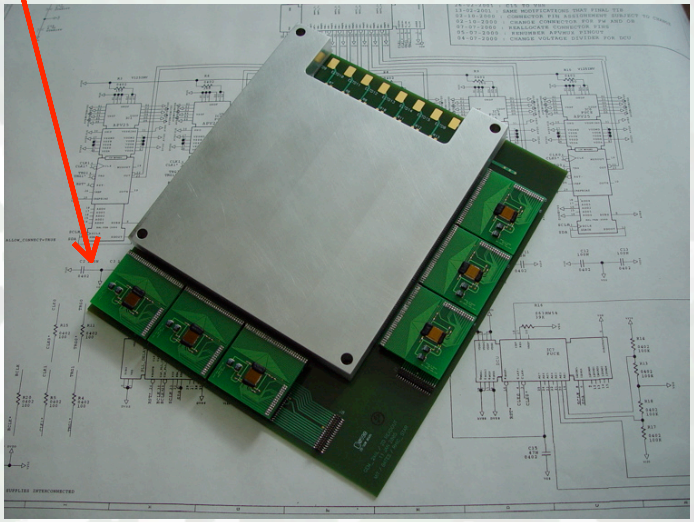
- R&D Development at MIT
  - Resources
    - 2 dedicated clean rooms (Class ~1000) (MIT Bates Laboratory / MIT Laboratory for Nuclear Science)
    - HV radioactive source setup / HV box / Light-microscope / Laminar flow hood / GEM foil CCD camera scanner
  - R&D Activities so far based on 10cm X 10cm samples
    - Dark current / resistivity tests
    - Optical scans
    - Sources tests and test beam experiment at FNAL
  - Publications: 1) U. Becker et al., NIM A556 527 (2006). 2) F. Simon et al., IEEE Trans. Nucl. Sci. 54, 2646 (2007). 3) F. Simon et al., NIM A598 432 (2009).

FGT Technical realization

- Prototype triple-GEM configuration (1)
  - Prototype triple-GEM detector (Ar/CO_2 70:30 gas-mixture) to allow flexible handling
  - Integrated APV25-S1 chip readout system
  - 2D projective readout board, using laser etching and micro-machining

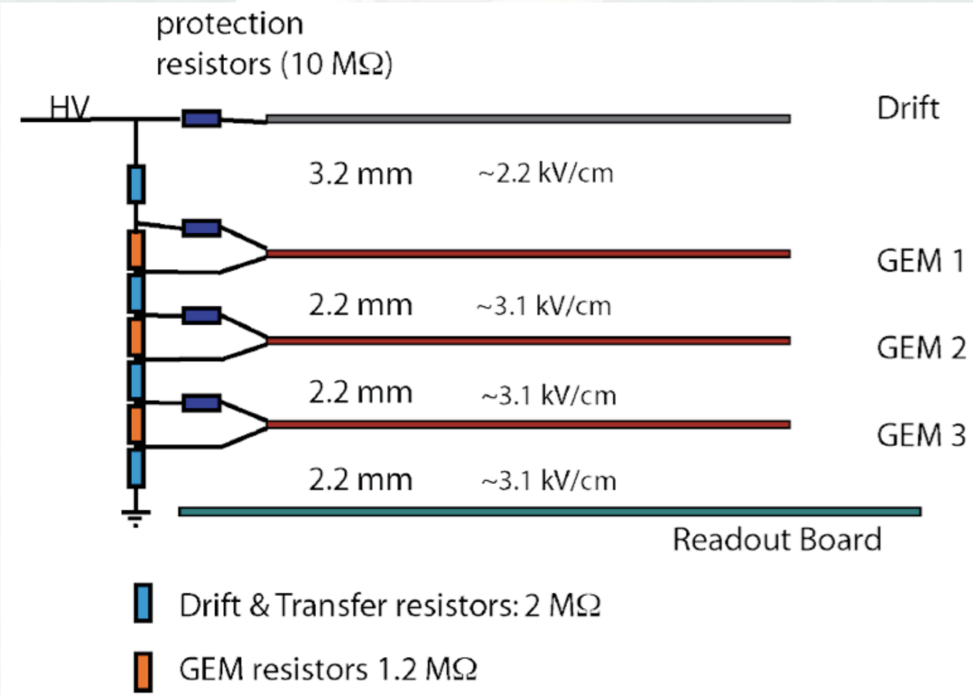


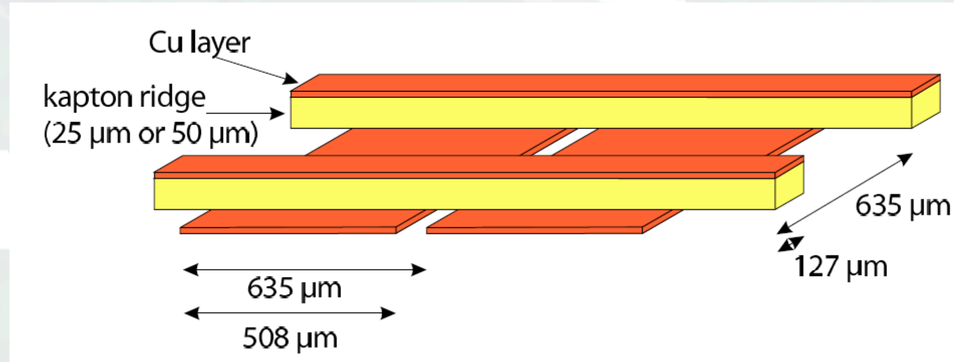




FGT Technical realization

- Prototype triple-GEM configuration (2)



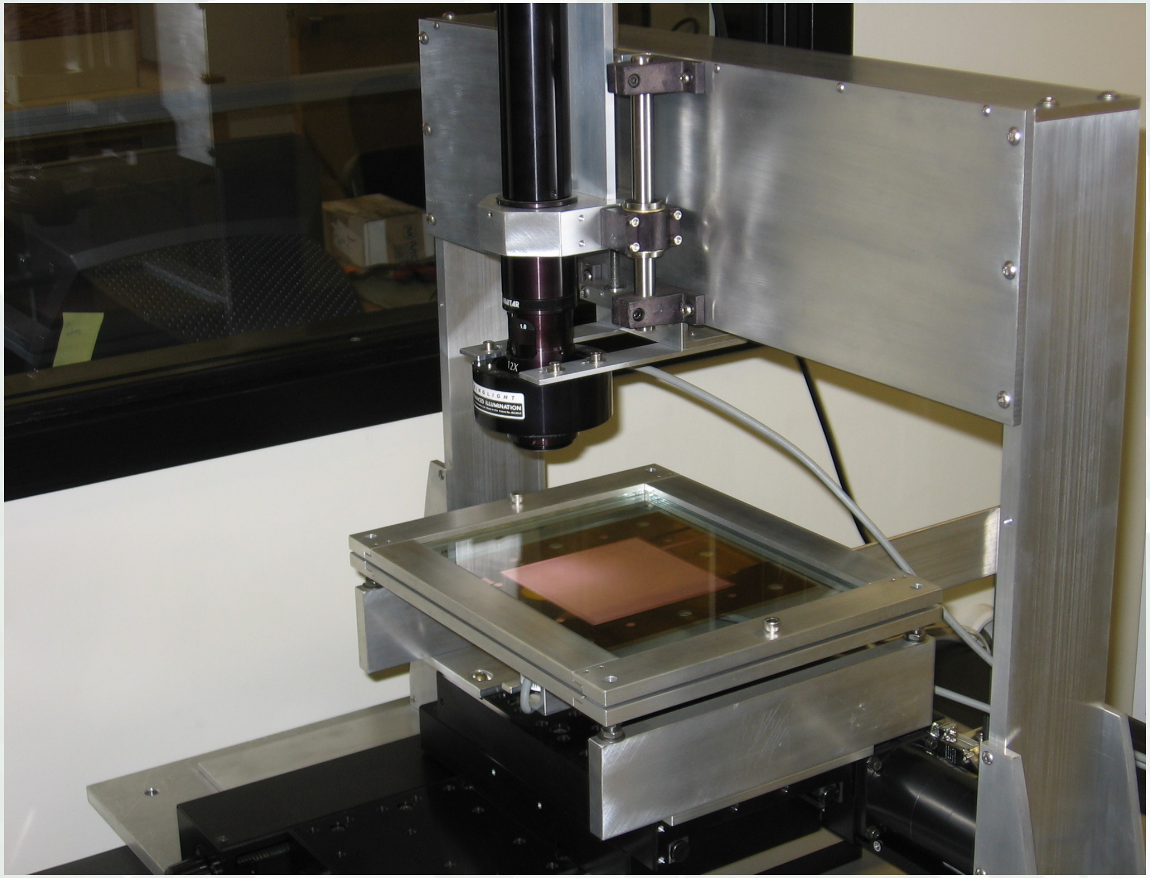


- Laser etched 2D readout board (Compunetics Inc.)
- Test beam configuration:
  Top strips (Y): ~127μm
  Bottom strips (X): 508μm
- Two separations: 25μm and 50μm

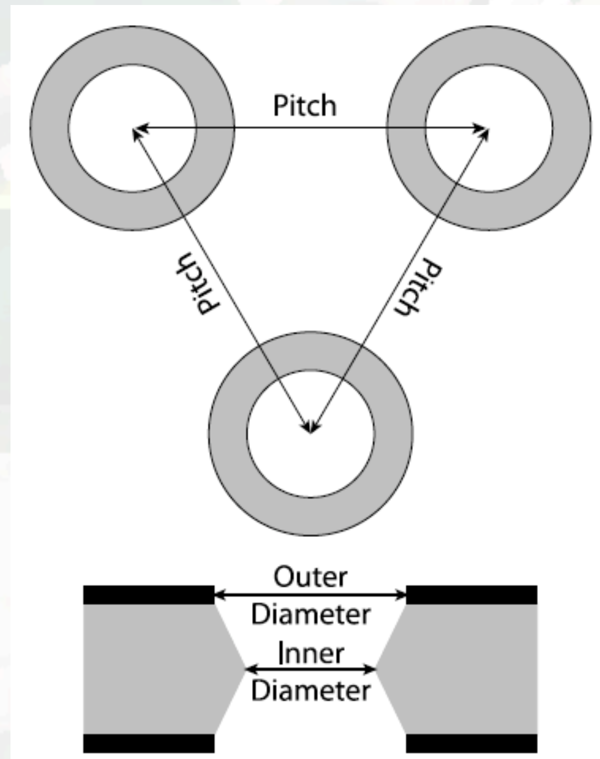
- Test beam operating voltage: ~3750V-3800V corresponding to ~385V-395V per GEM foil
- Testbeam effective gain: ~$3.5 \cdot 10^3$ (~$2.5 \cdot 10^4$ bench tests)

FGT Technical realization

- Optical scans (1)



- 2D scanning table with CCD camera - fully automated
- Scan GEM foils to measure hole diameter (inner and outer) and pitch

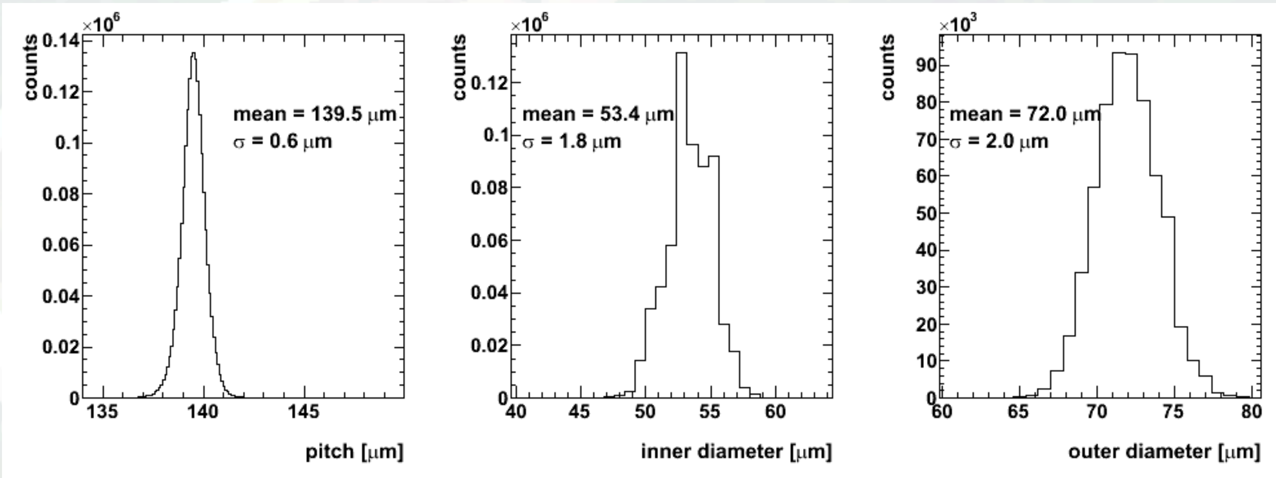


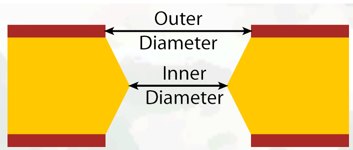
- Check for defects:
  - Missing holes, enlarged holes, dirt in holes and etching defects

FGT Technical realization

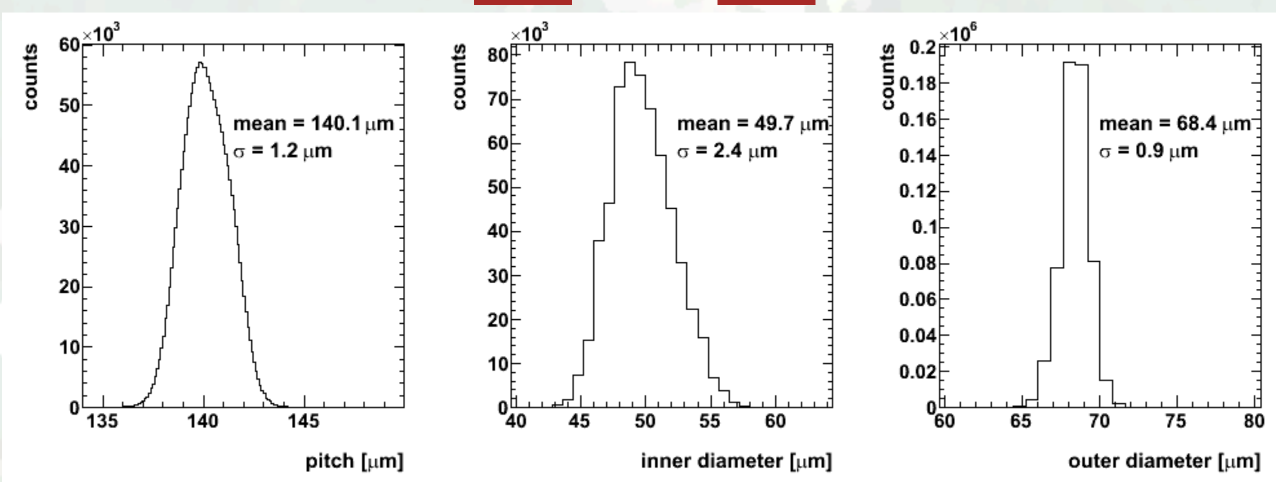
- Optical scans (2)

Tech-Etch





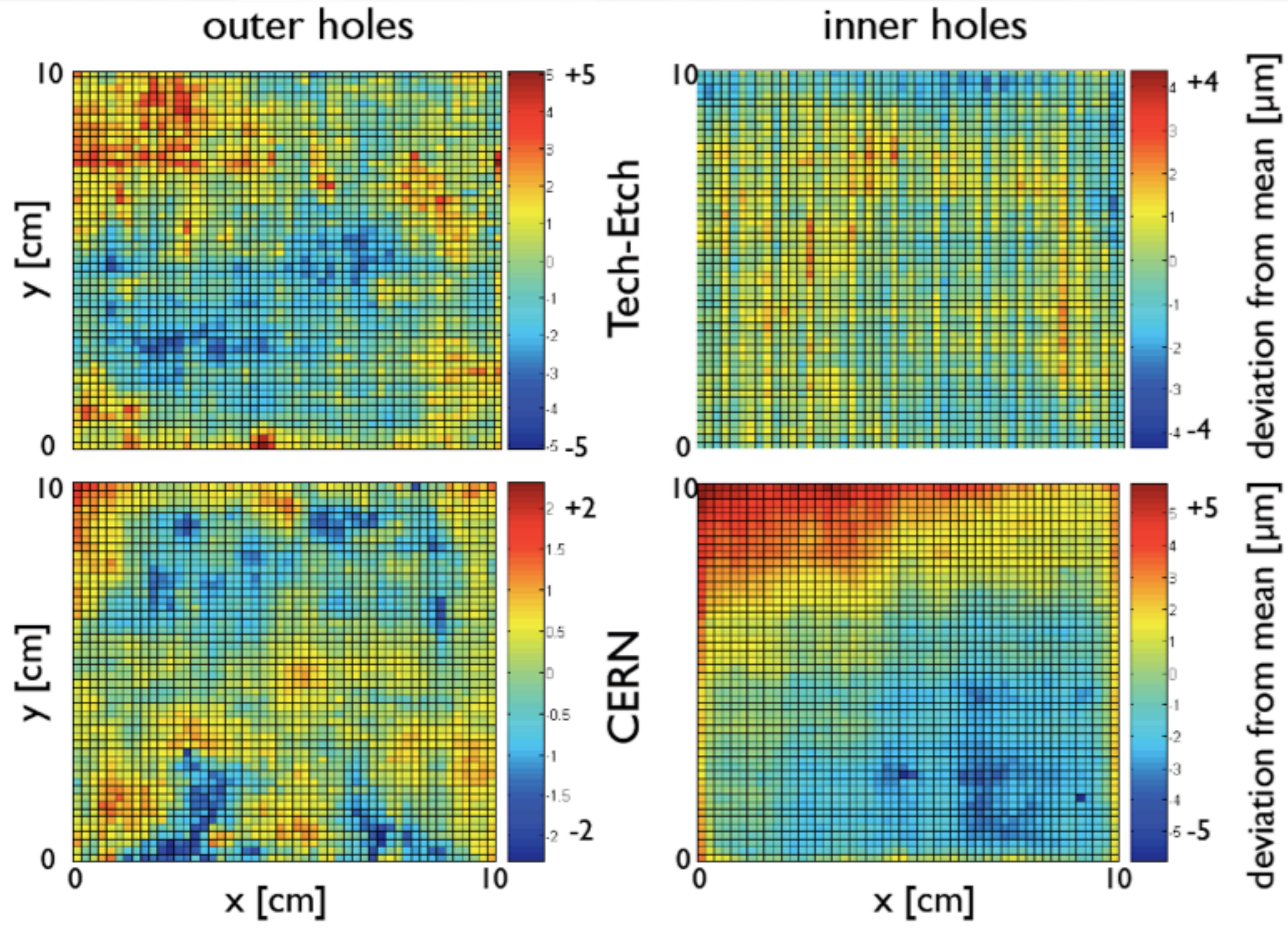
CERN

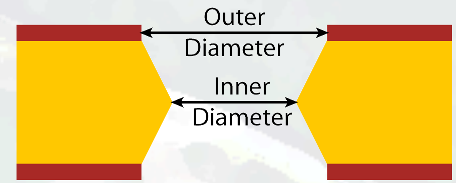


- Geometrical parameters are similar for Tech-Etch and CERN foils (10cm X 10cm samples)

FGT Technical realization

- Optical scans (3)



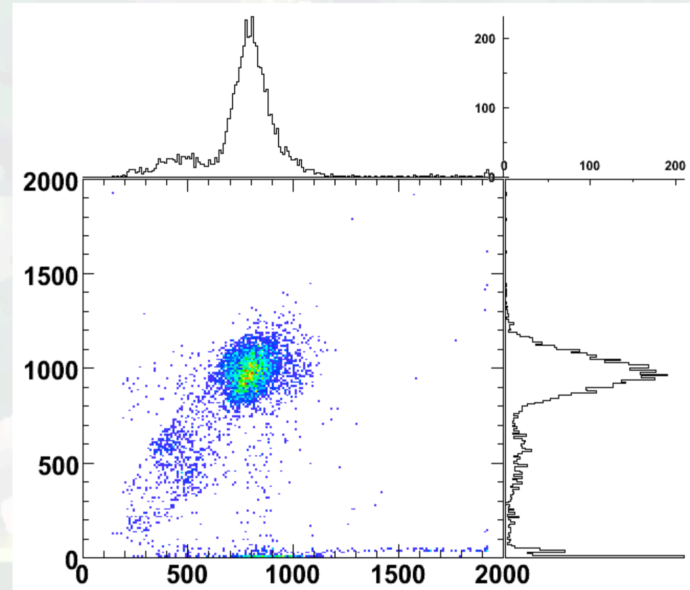


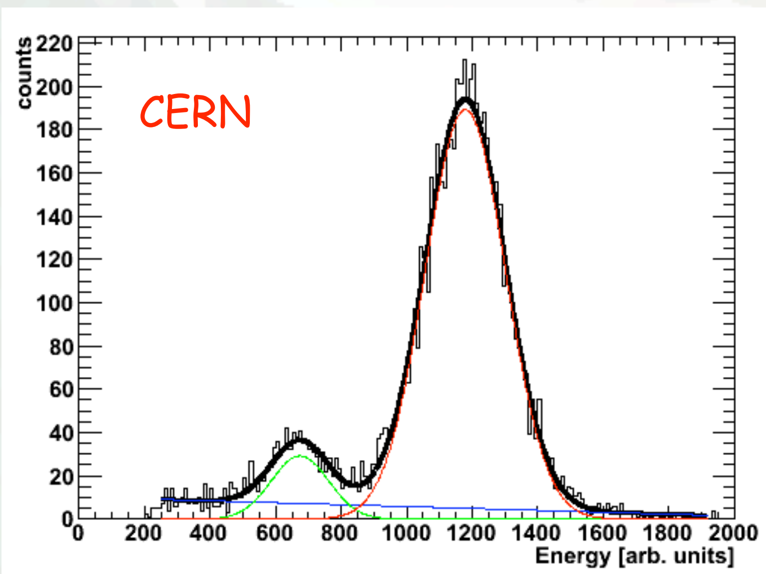
- Uniformity of outer/inner hole diameters for Tech-Etch and CERN foils (10cm X 10cm samples)

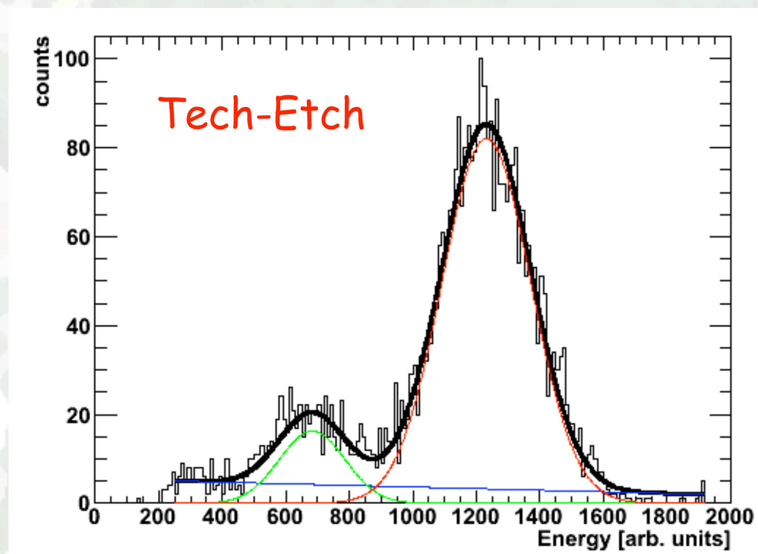
FGT Technical realization

- Source tests (1)
  - Two identical detectors, one with CERN foils, one using Tech-Etch foils
  - Both detectors give reasonable X-Ray spectrum using ^{55}Fe source with comparable energy resolution (~20%)

Correlation of X-Y readout plane

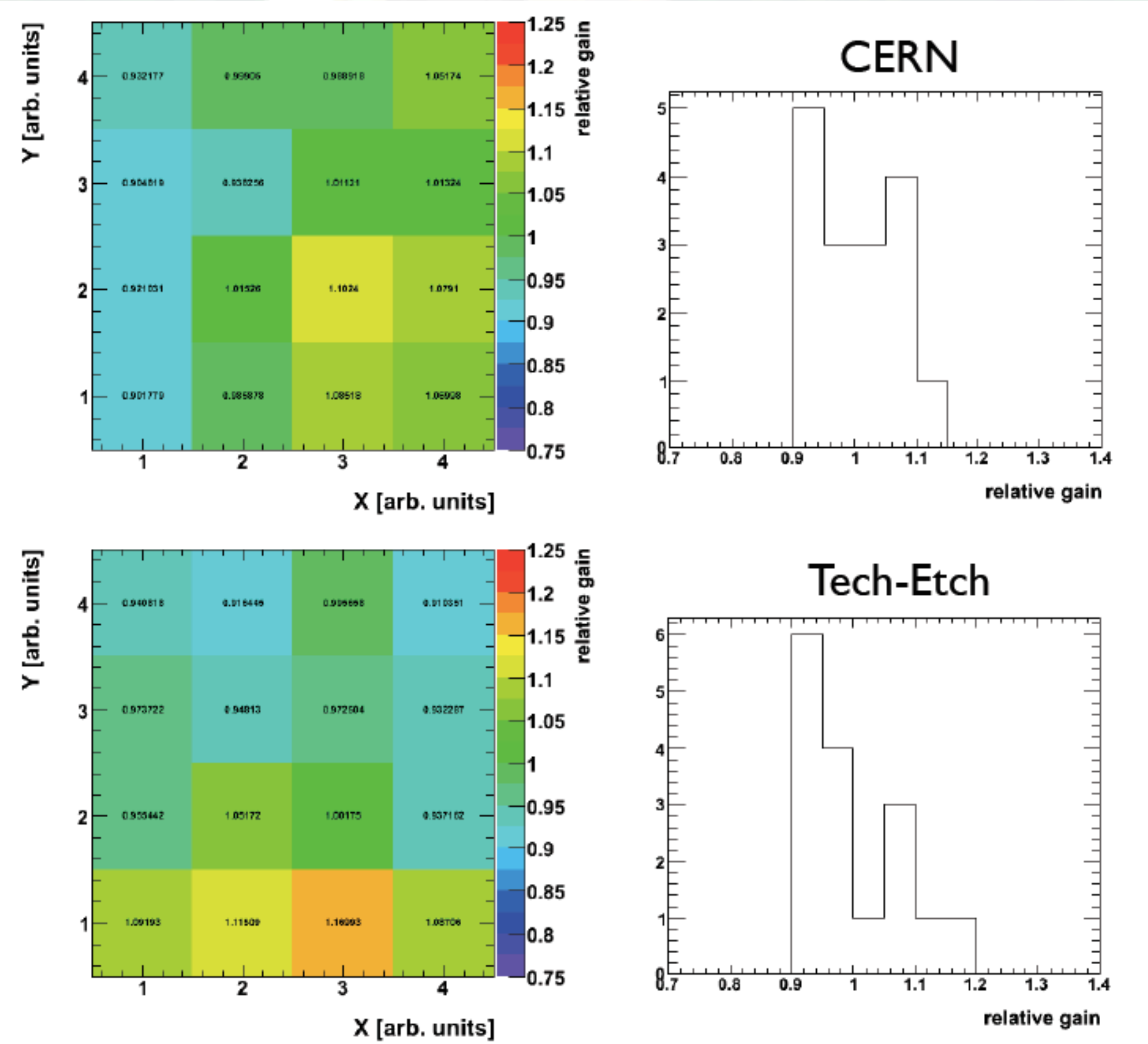






FGT Technical realization

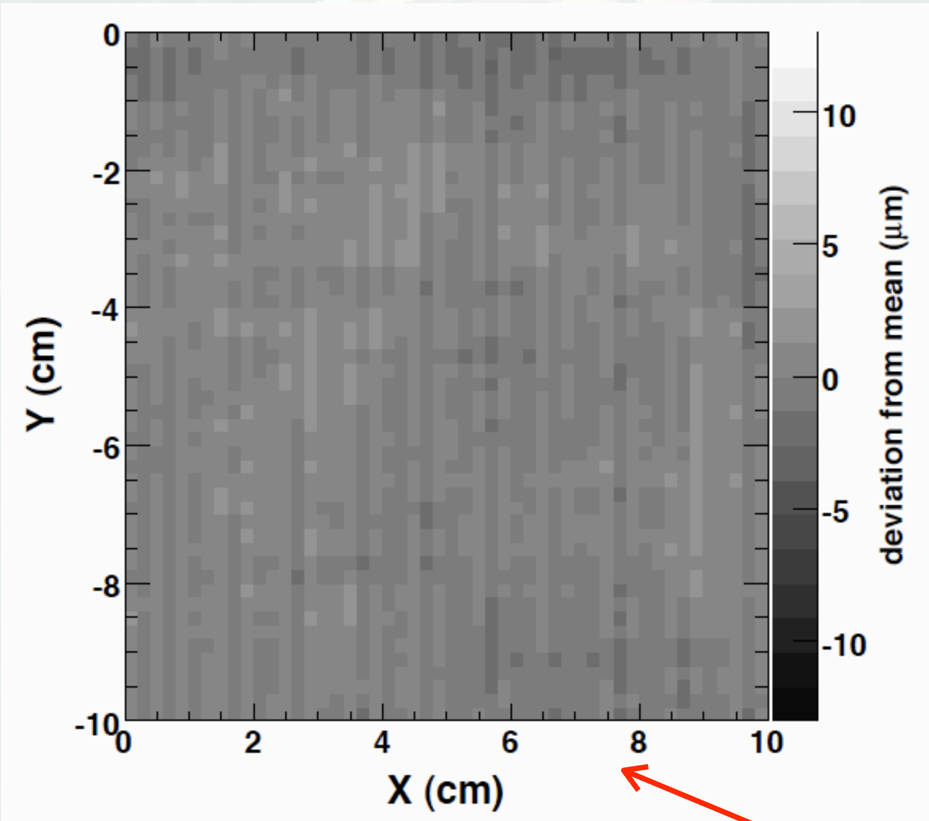
Source tests (2)

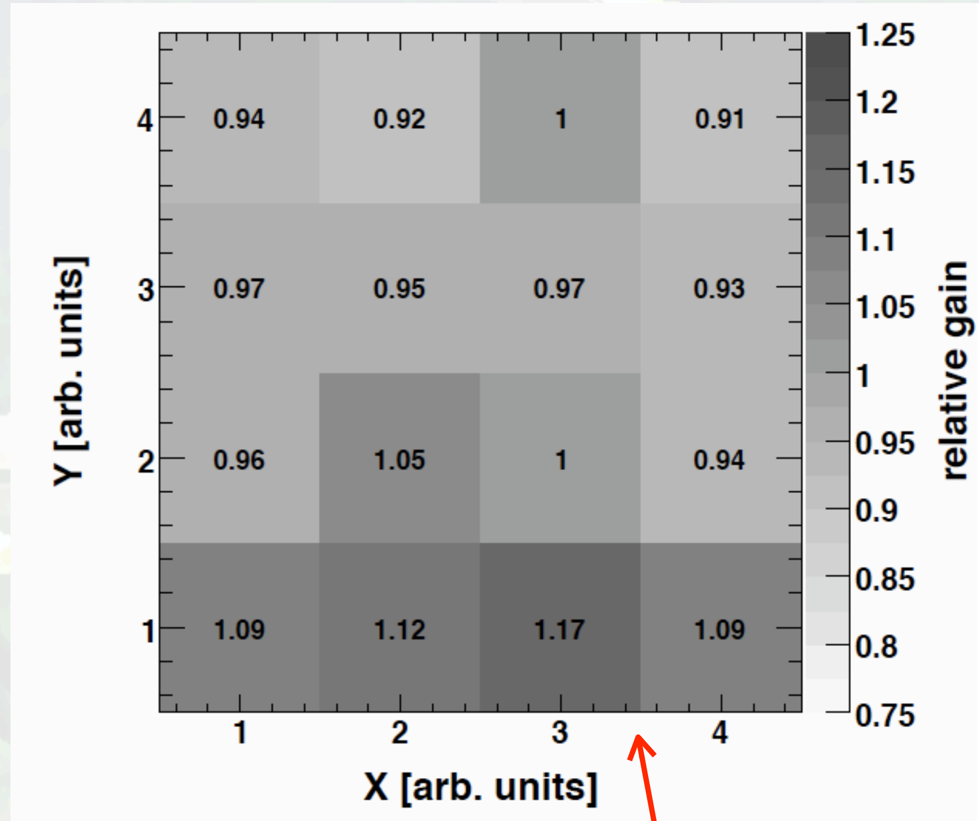


- Gain measured with low intensity ^{55}Fe source (~0.5Hz/mm^2)
- Good gain uniformity over full active area (Measured after charge built-up)

FGT Technical realization

- Source tests (3)



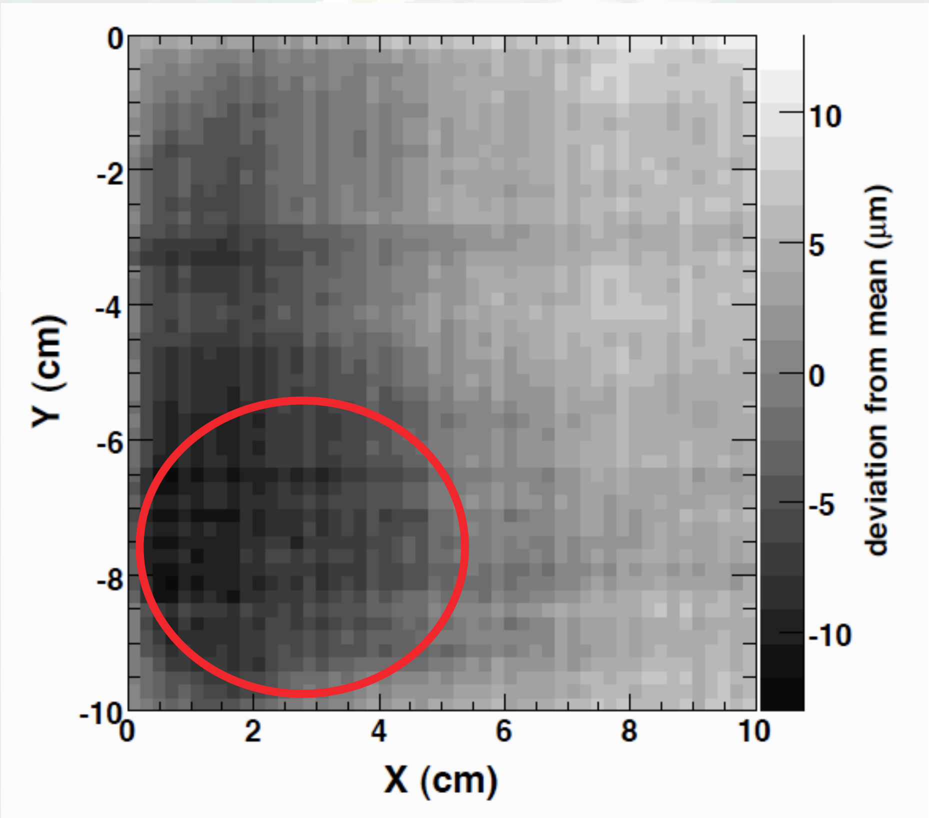


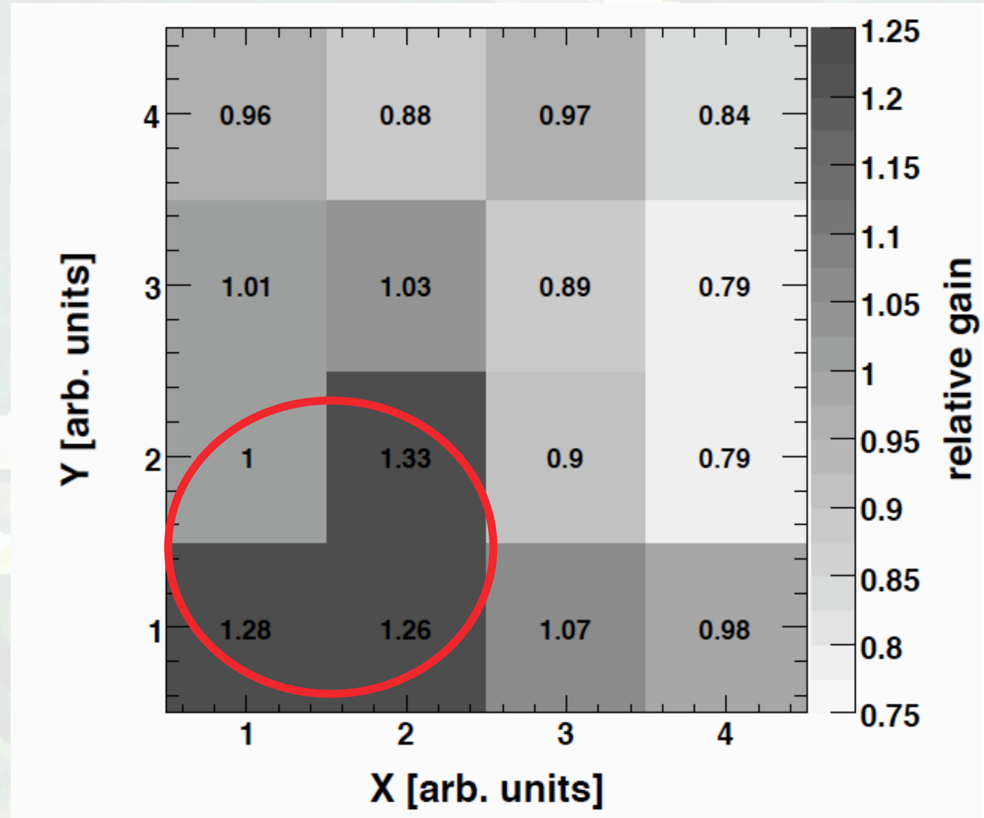
- Comparison of optical scans of inner hole diameter uniformity and gain uniformity

  from low-intensity ^{55}Fe source (~0.5Hz/mm^2) measurements

FGT Technical realization

Source tests (4)



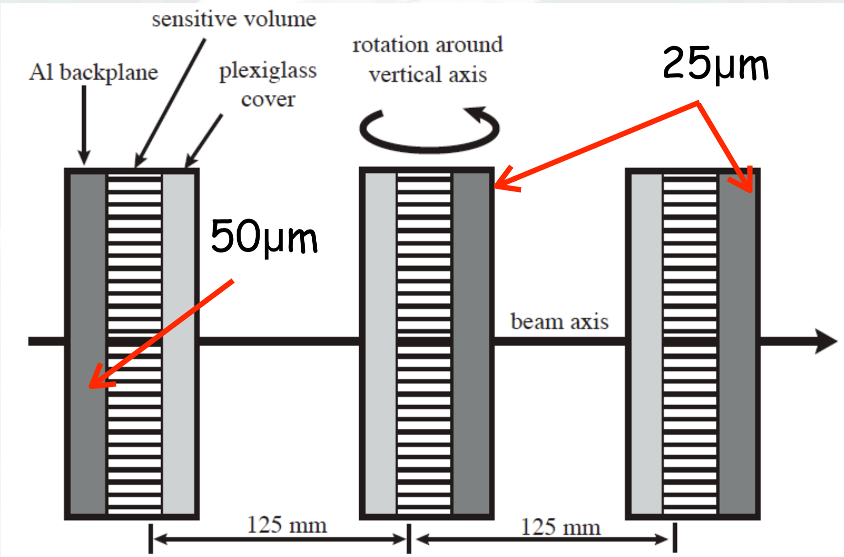


- Non-uniformity of inner hole diameter (~20µm smaller on left side compared to right side)

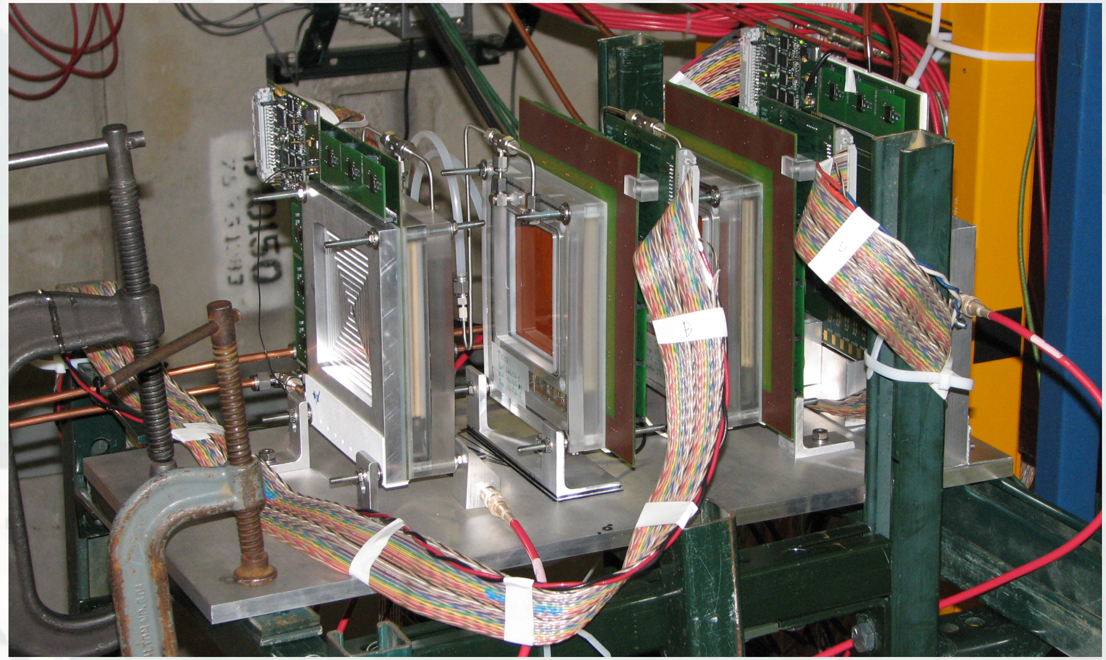
  reflected in large non-uniformity of source scan gain measurements

FGT Technical realization

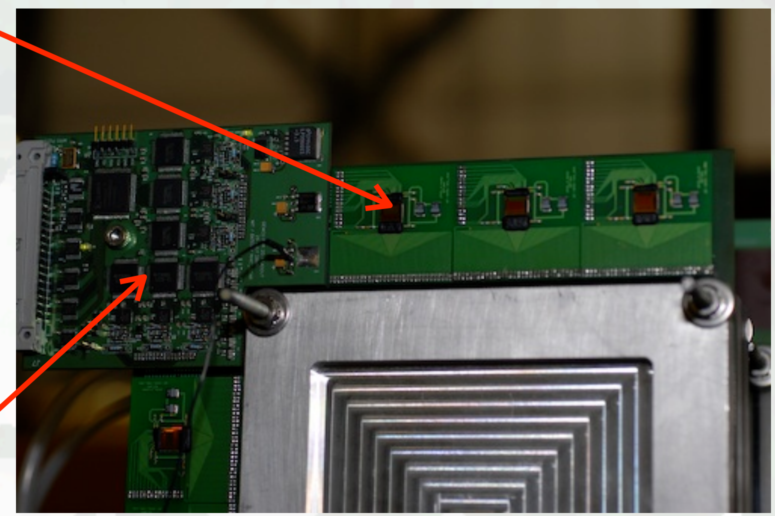
- Testbeam results (1)



Det0 Det1 Det2



APV25-S1

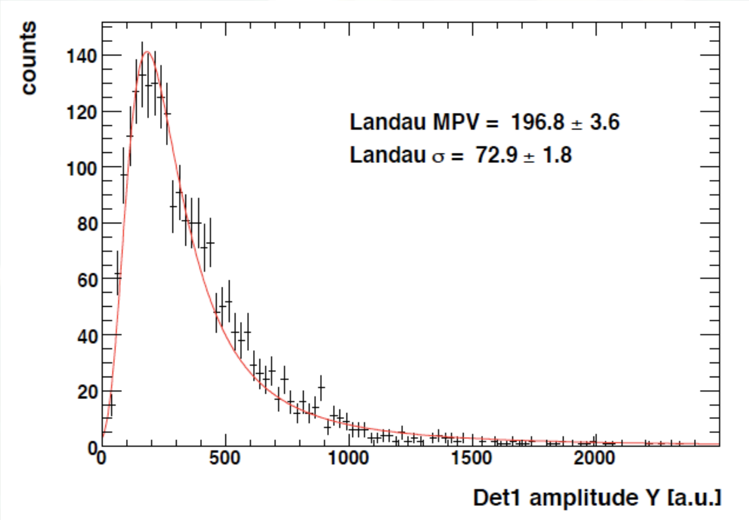


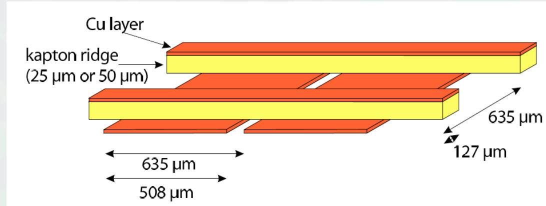
FPGA Readout System

- FNAL Meson Test Beam Facility: Data taking with 4GeV-32GeV unseparated secondary beam and 120GeV primary proton beam

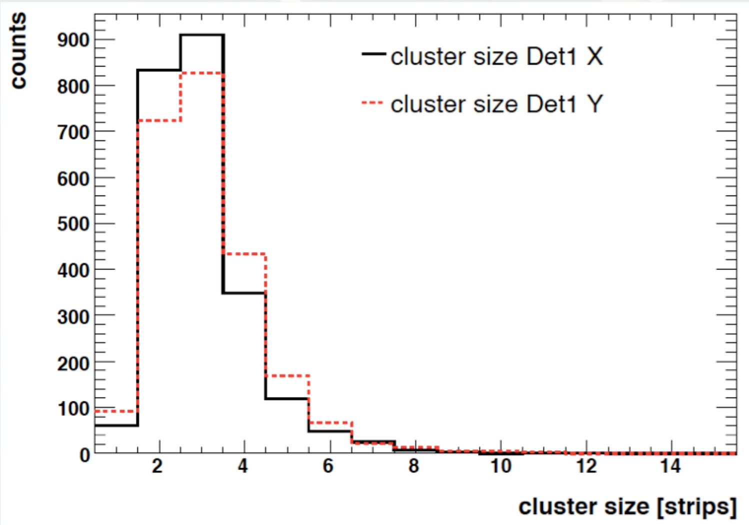
FGT Technical realization

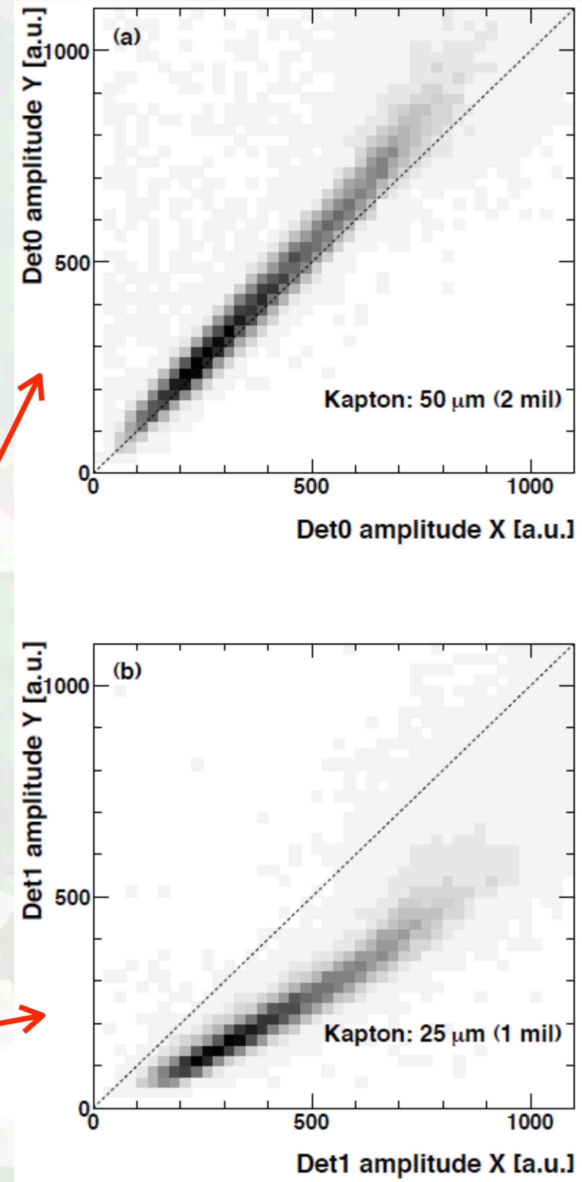
Testbeam results (2)





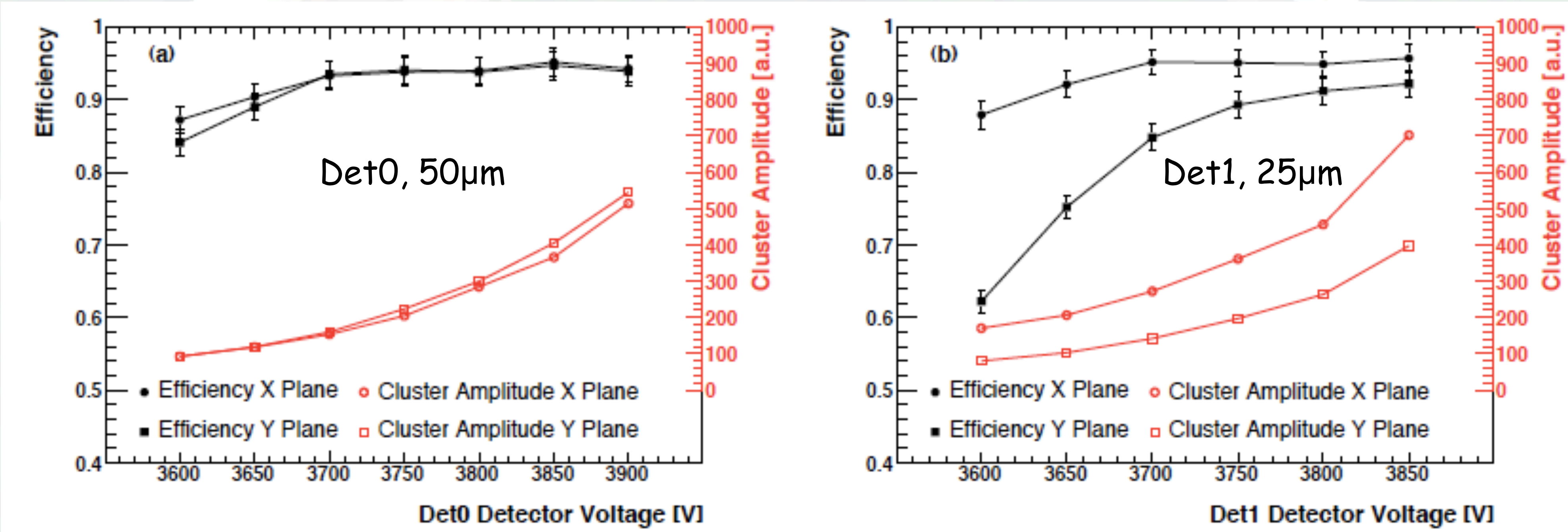
- Cluster charge follows expected distribution
- Two version of readout board (50µm and 25µm)





FGT Technical realization

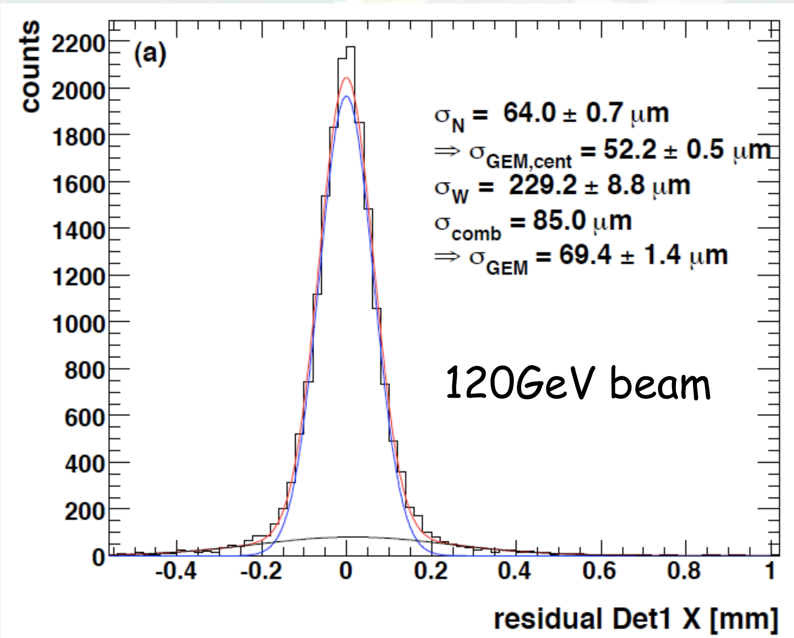
Testbeam results (3)

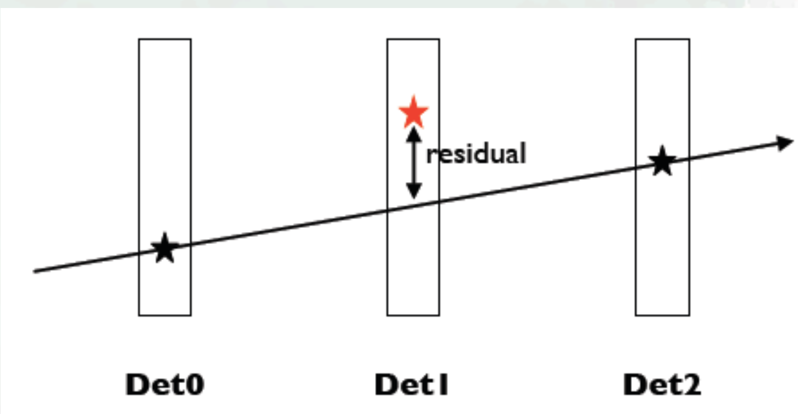


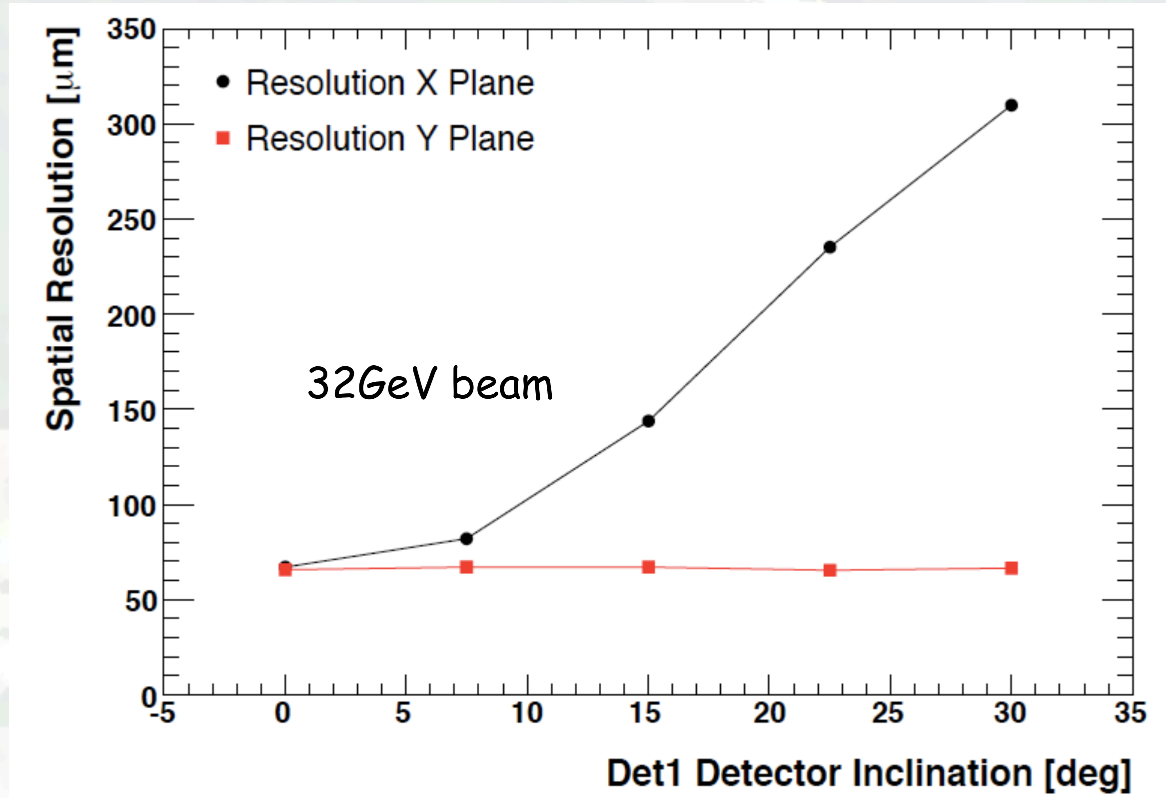
- Efficiencies at the level of ~95%-98% were reached in regions which limit the impact of noisy and dead regions with Tech-Etch GEM foils (Not affected by high intensity studies)
- Clear difference between Det0 (50μm) and Det 1 (25μm) for efficiency and cluster amplitude (Most probable value of Landau distribution)

FGT Technical realization

Testbeam results (4)



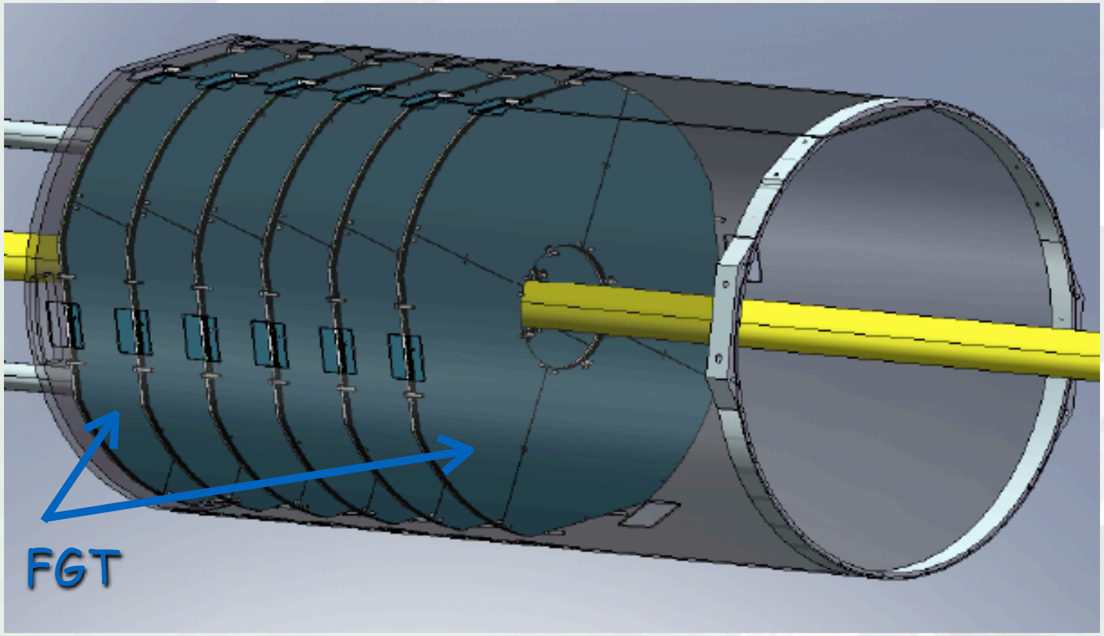


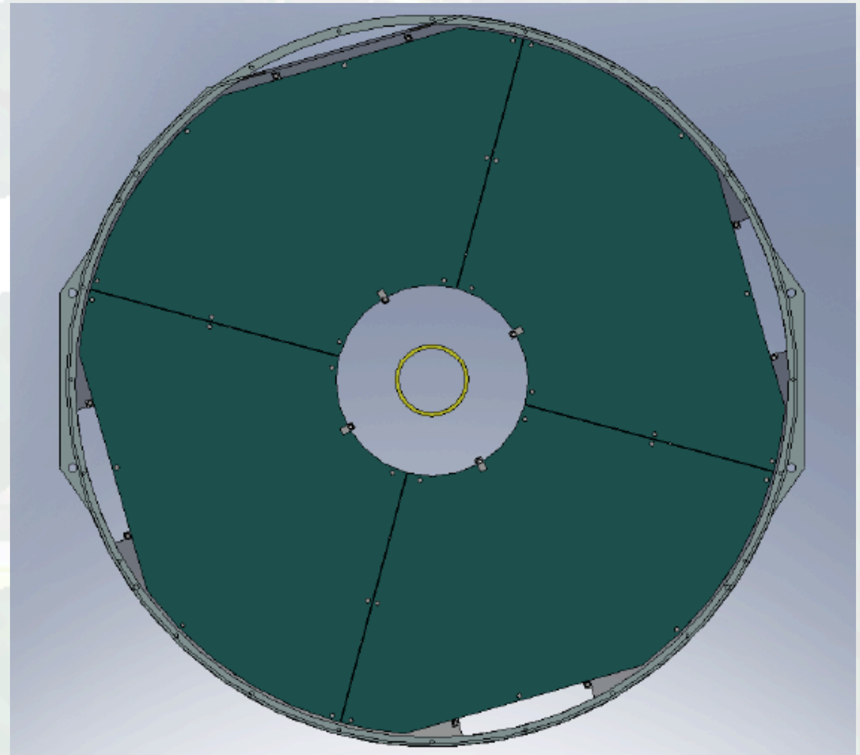


- Study of inclination by up to 30°: Only X (horizontal) resolution is affected, not so for Y (vertical) coordinate as expected!

FGT Technical realization

- Layout

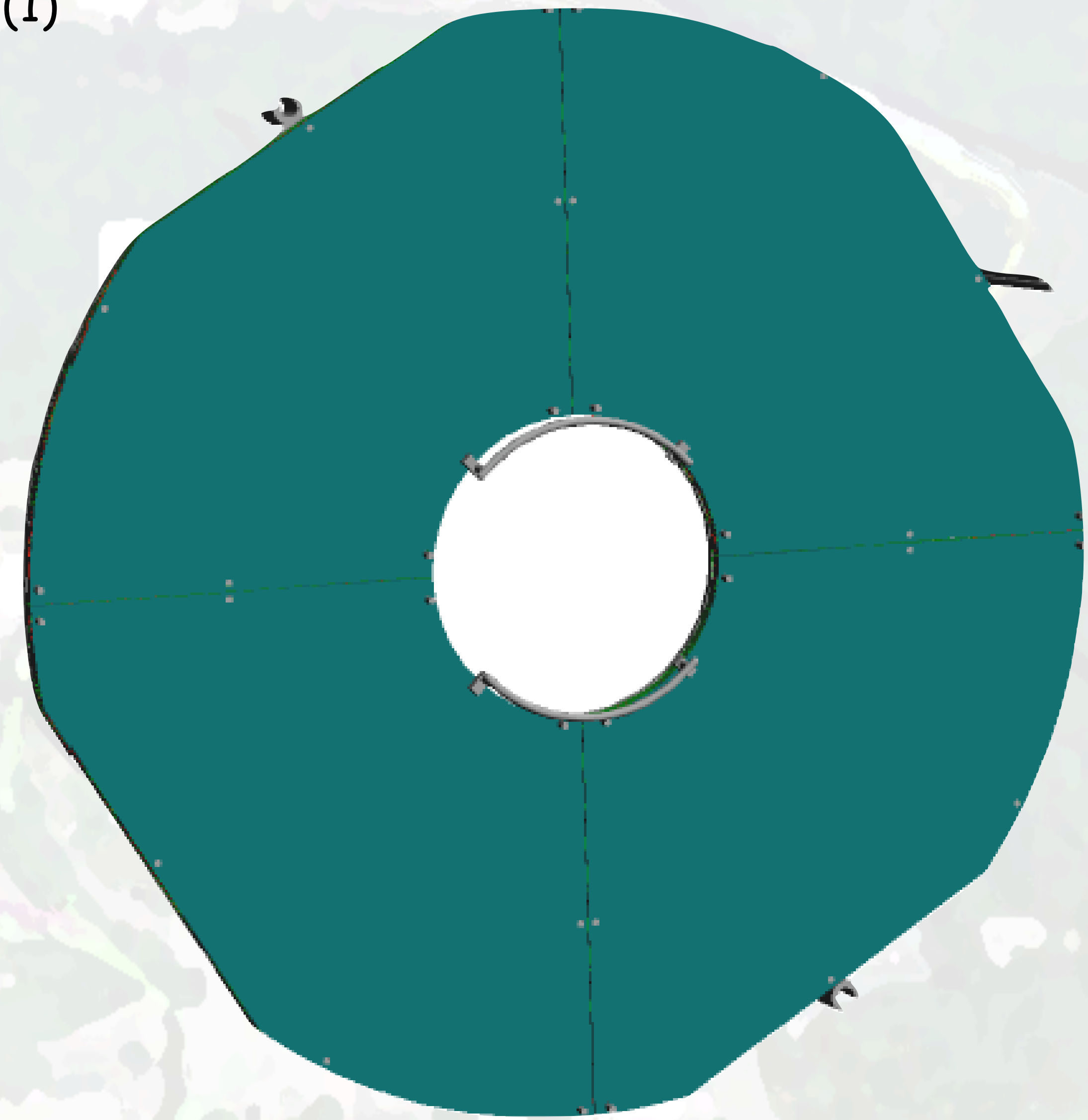




- FGT: 6 light-weight disks
- Each disk consists of 4 triple-GEM chambers (Quarter sections)
- Procurement and assembly of full quarter section prototype in preparation

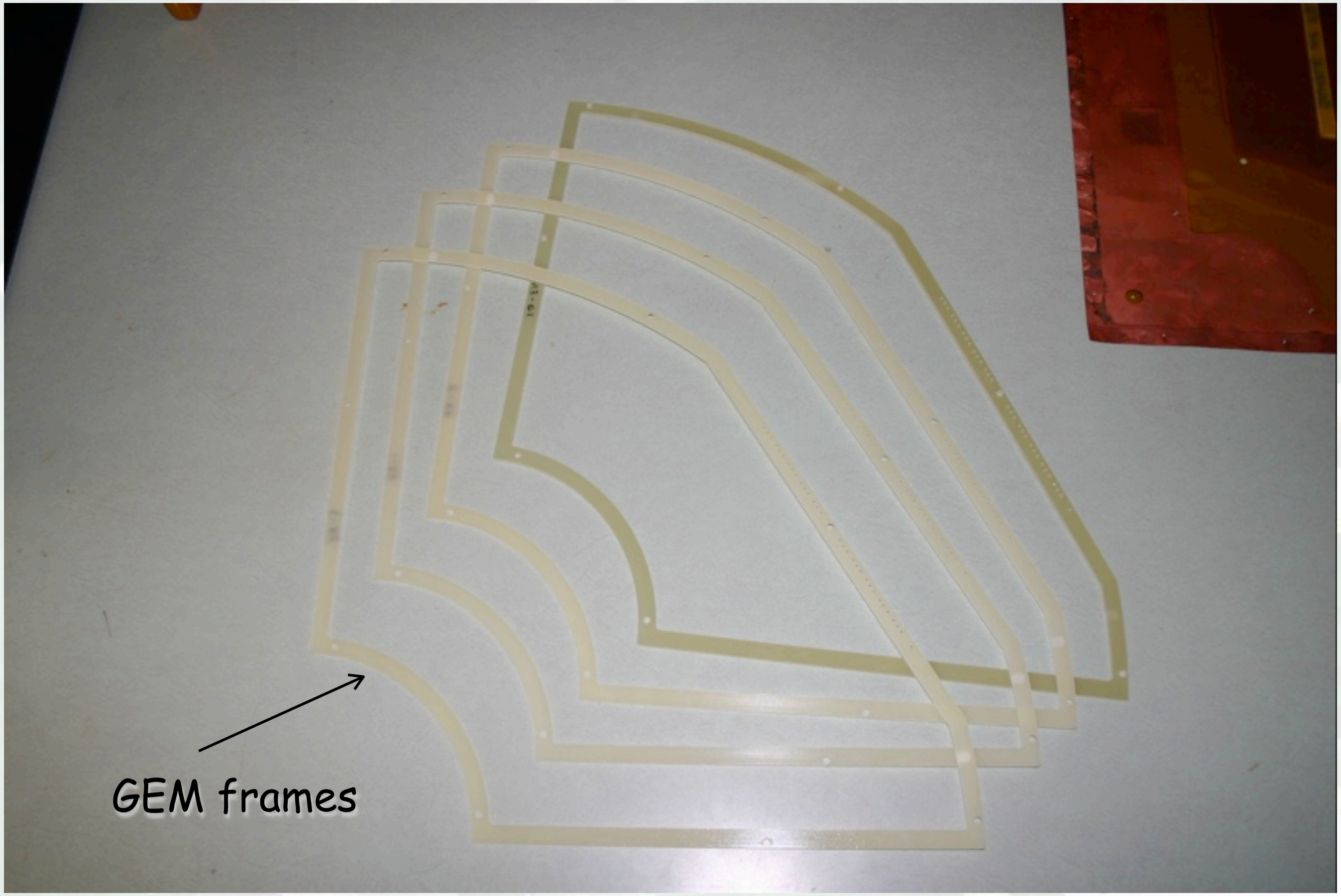
FGT Technical realization

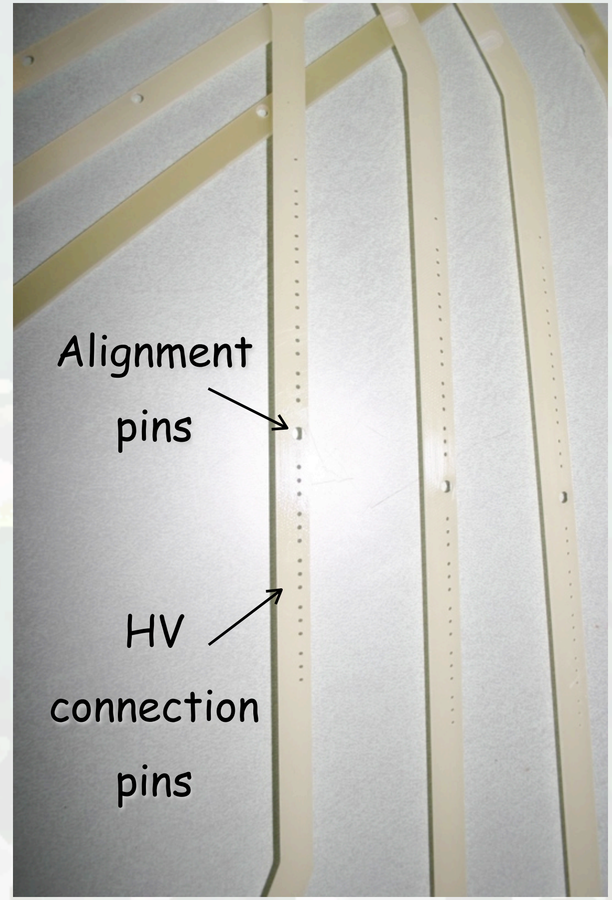
- Triple-GEM: Quarter section design (1)
  - Single disk
    - 5mm Nomex honeycomb
    - 0.25mm FR4 skins
    - Pins used as part of assembly and alignment
  - GEM quadrant
    - Pins define position
    - Pins preserve shape
  - Gas manifolds and rails



FGT Technical realization

- Triple-GEM: Quarter section design (2)

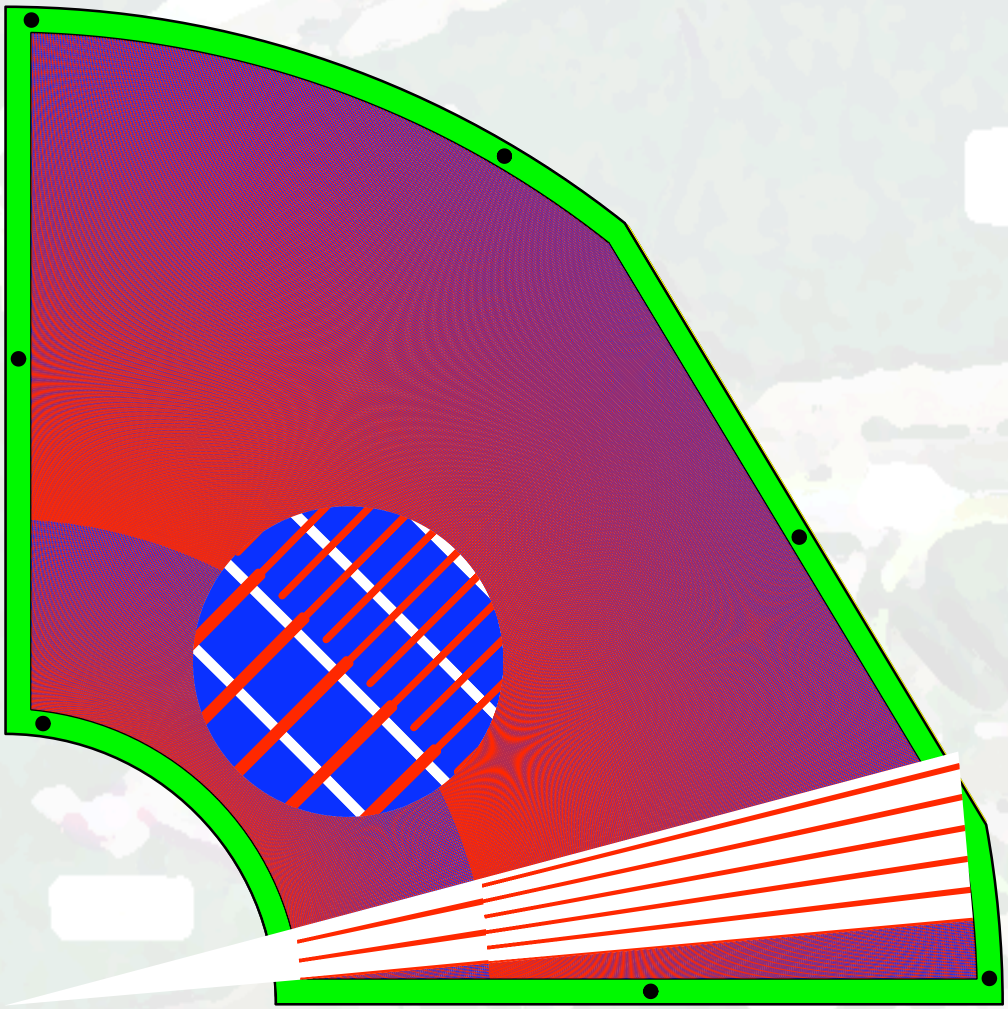




- Dimensions close to final design (WSC dimensions)
- Verify mechanical detail
- Develop stretching and assembly fixtures / Test flatness of GEM foils

FGT Technical realization

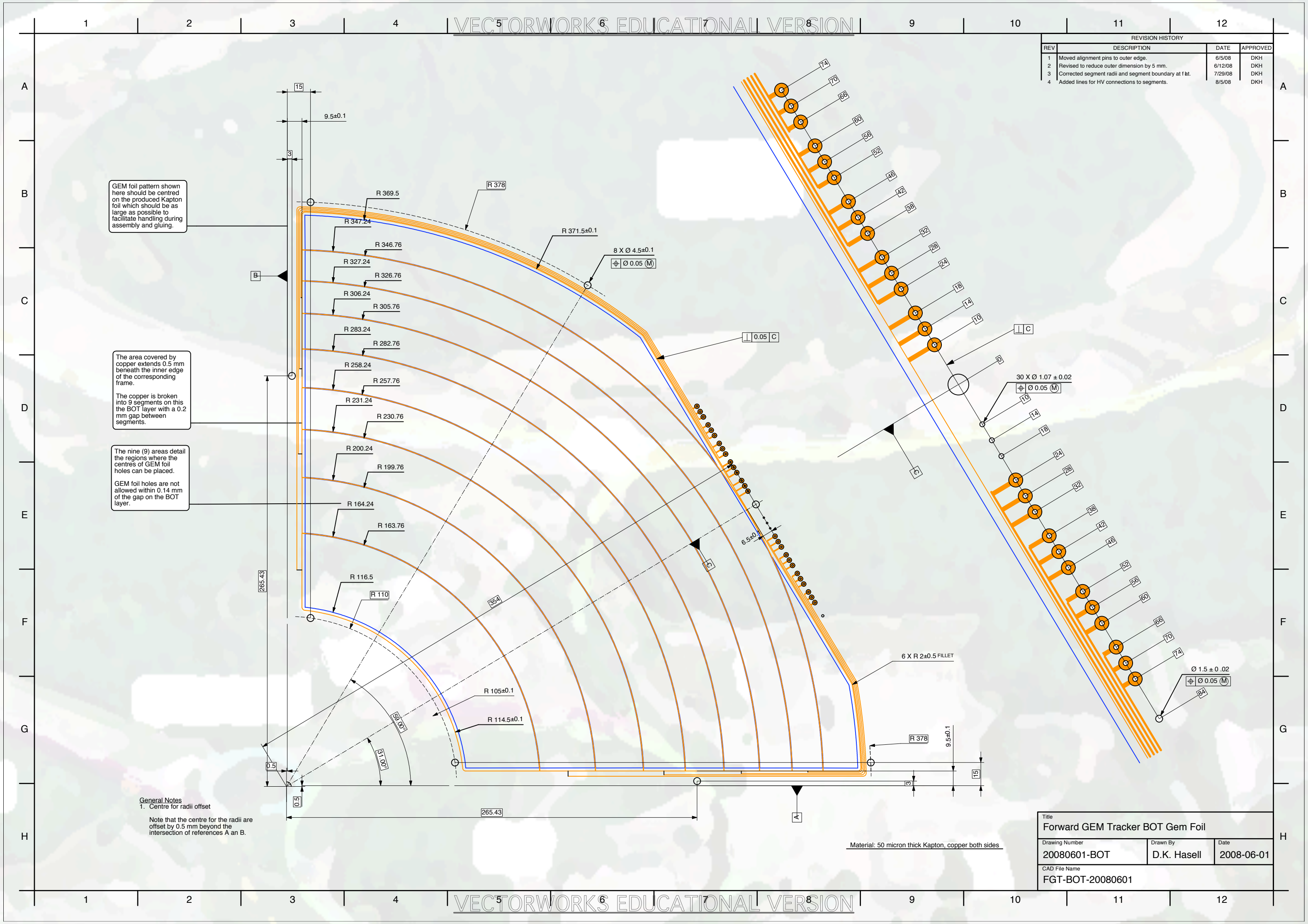
- Triple-GEM: Quarter section design (3)



- 50 μm Kapton
  - Copper on both sides
  - Laser etching exposes bottom layer
- Top layer
  - Φ-readout layer
  - Alternate lines end at 18.8cm
  - Pitch: 300-600 μm
  - Line width: 80-120μm
- Bottom layer
  - R-readout layer
  - Pitch: 800μm
  - Line width: 700μm

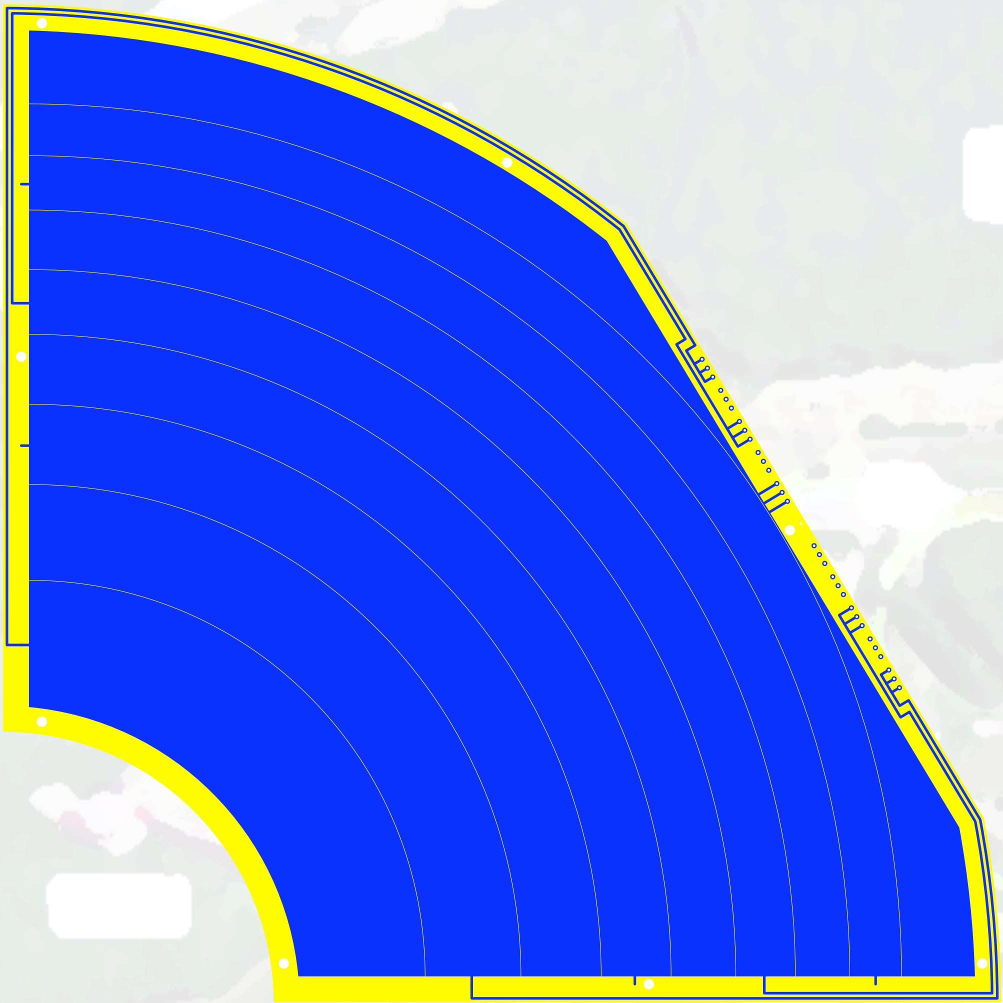
FGT Technical realization

- Triple-GEM: GEM foil design (1)



FGT Technical realization

- Triple-GEM: GEM foil design (2)

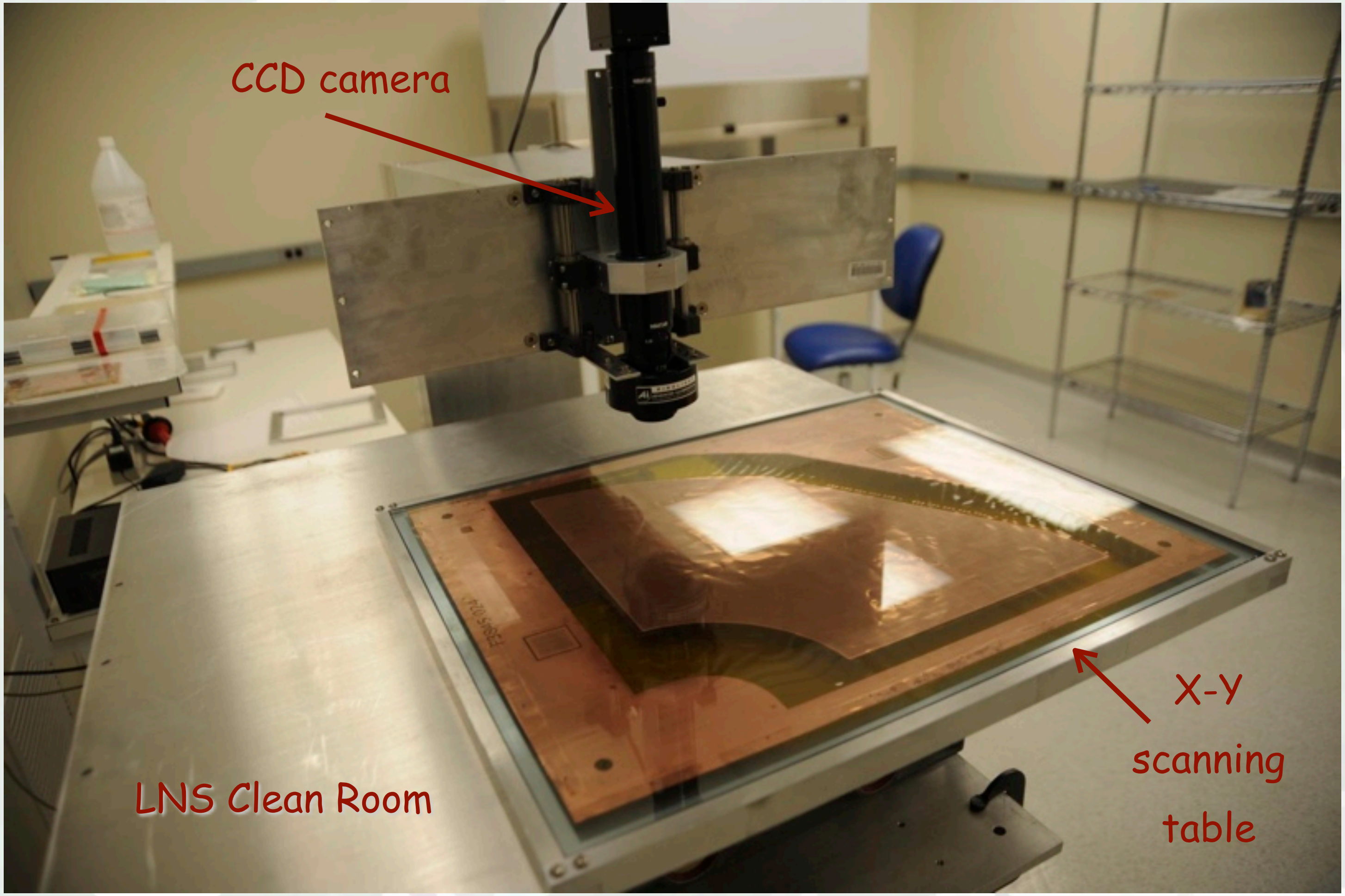


Segmented GEM foils:

- Minimize damage in case of breakdown
- 9 segments in radial direction with ~100cm^2 each
- Gap: 200μm
- Hole pitch (~ 140μm) and diameter (I: ~50μm / O: ~60μm) similar to prototype!
- Routing and vias distribute HV to segments

FGT Technical realization

- Triple-GEM: GEM foil testing (1)



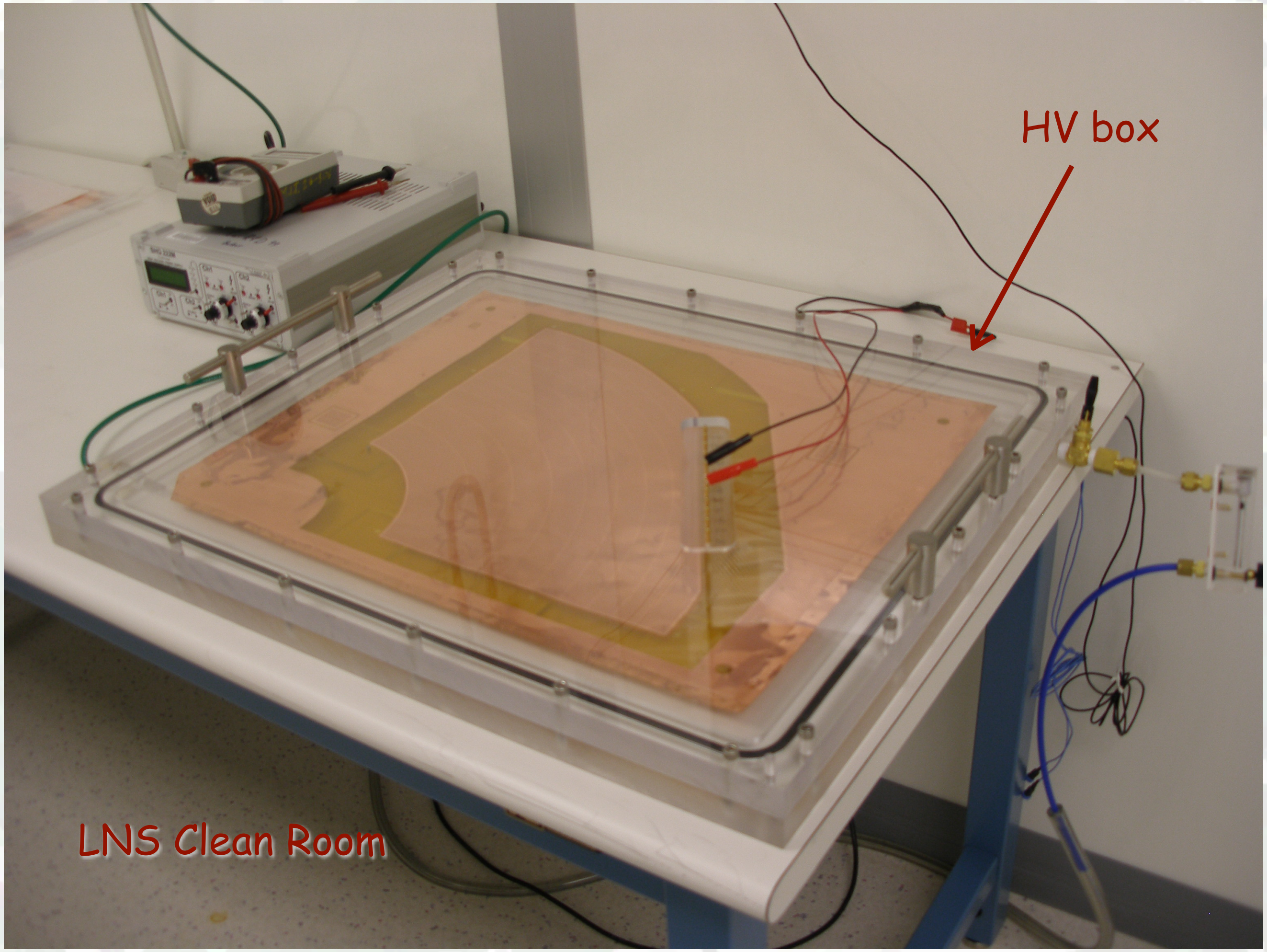
CCD camera setup for optical GEM foil scans

Optical scans:

- Measure inner and outer hole diameter / Uniformity across full surface (Important for gain uniformity) - Ongoing
- Systematic Tech-Etch and CERN comparison

FGT Technical realization

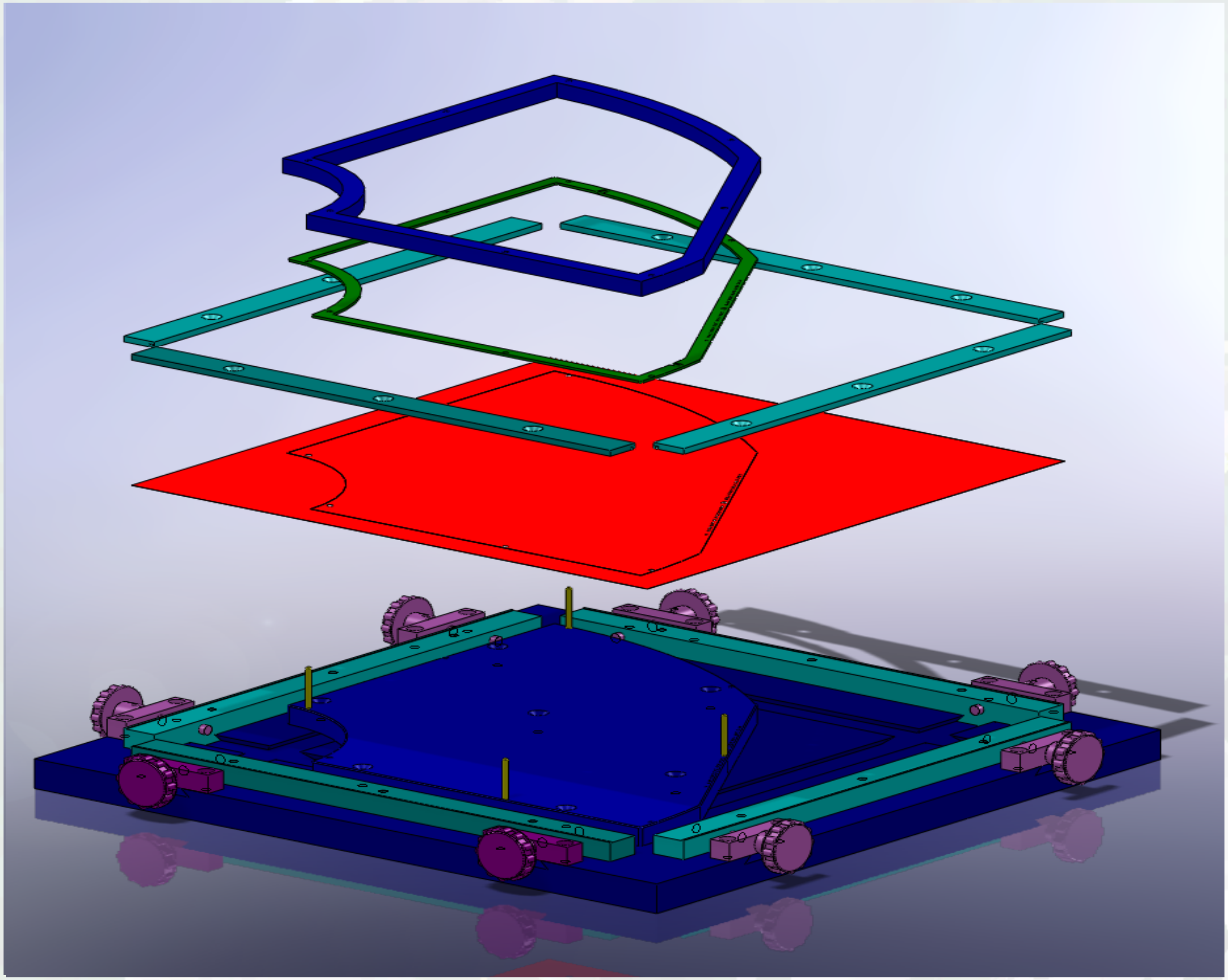
- Triple-GEM: GEM foil testing (2)



HV box for GEM foil dark current tests

FGT Technical realization

- Triple-GEM: GEM foil stretching and assembly tooling



Stretching jig:

- Stretch GEM foil
- Clamp 2mm spacer for single glue operation

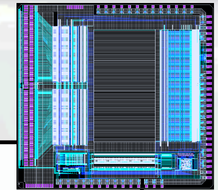
Assembly jig:

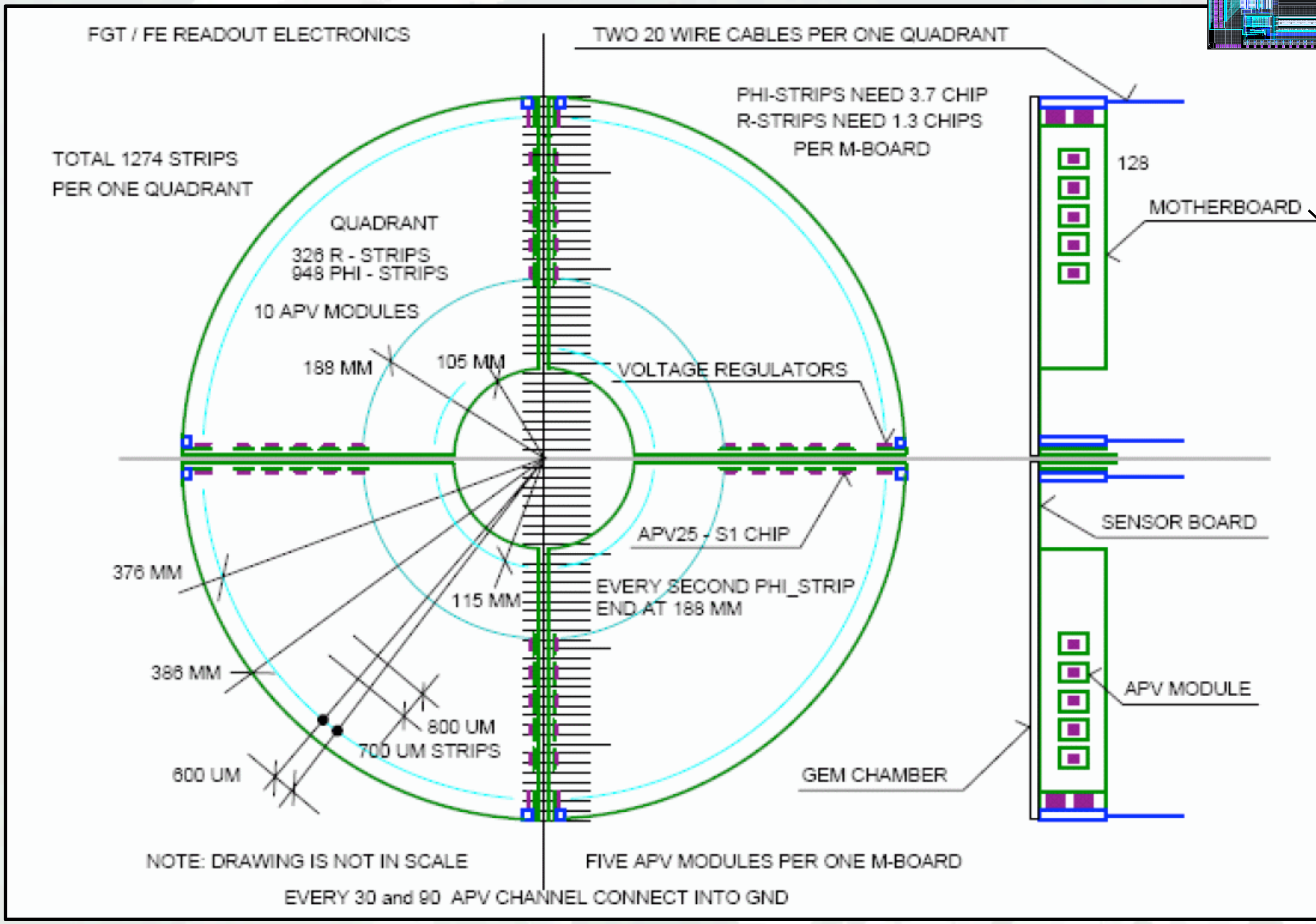
- Align frames to each other and to SIMM pins
- Hold frames flat with clamps
- Hold SIMM pins in place for soldering
- Clamp frames together for gluing operation

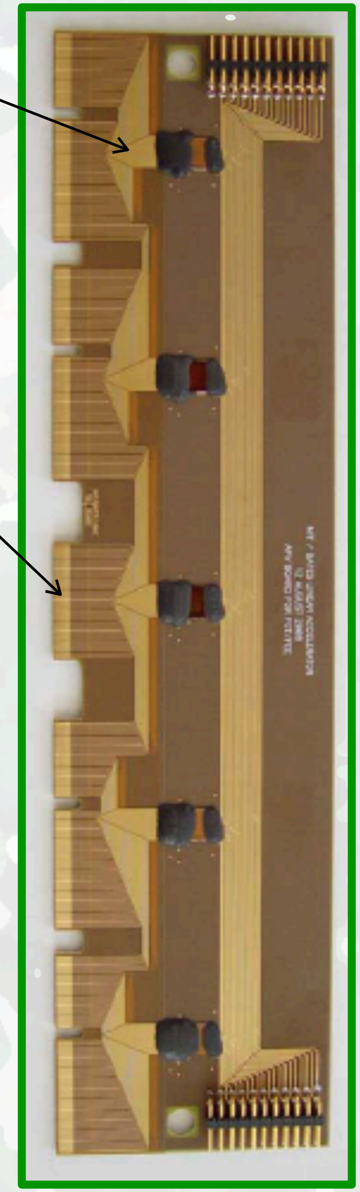
FGT Technical realization

- FEE: Overview

APV25-S1 chips

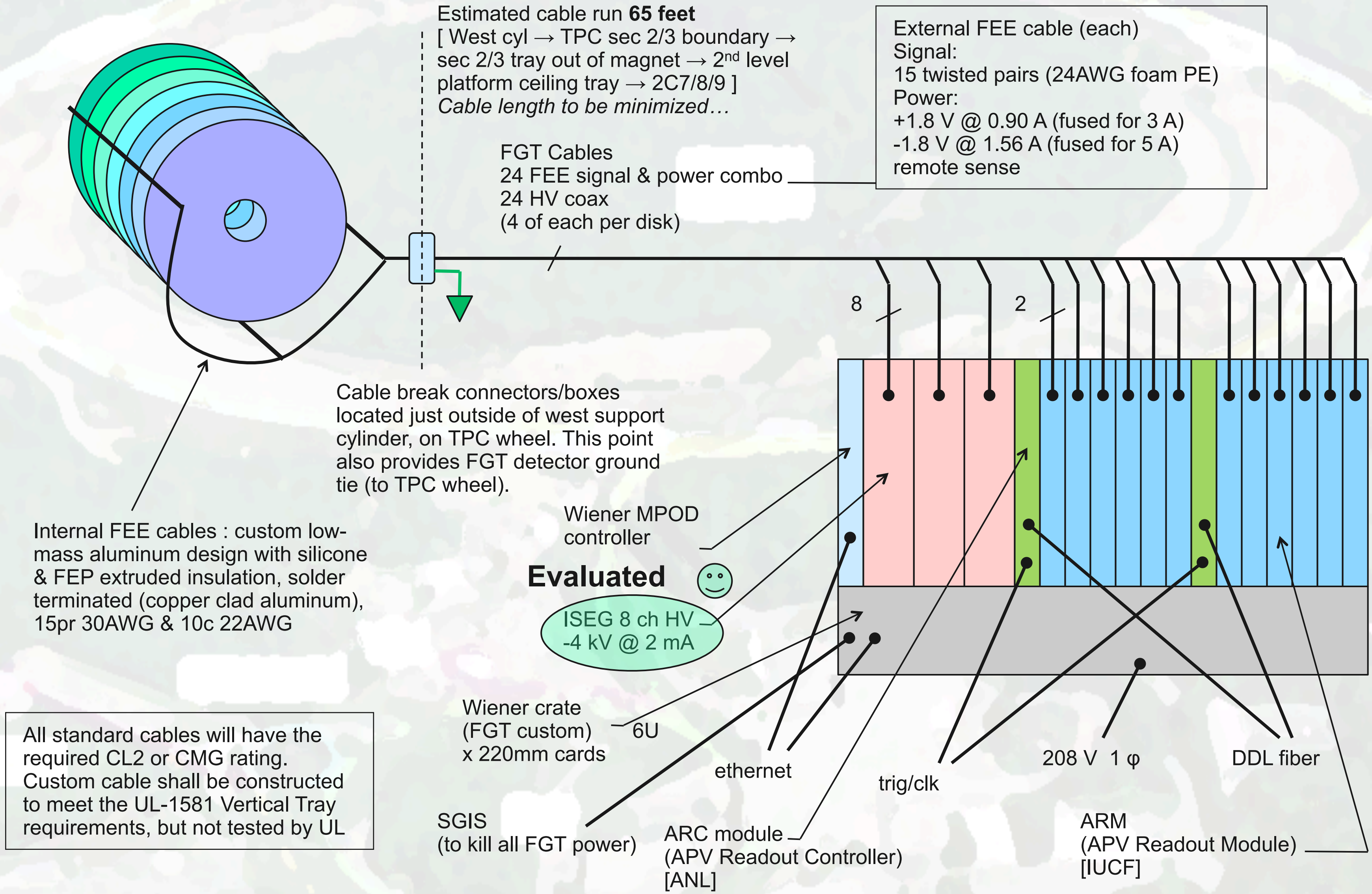






FGT Technical realization

DAQ: Overview



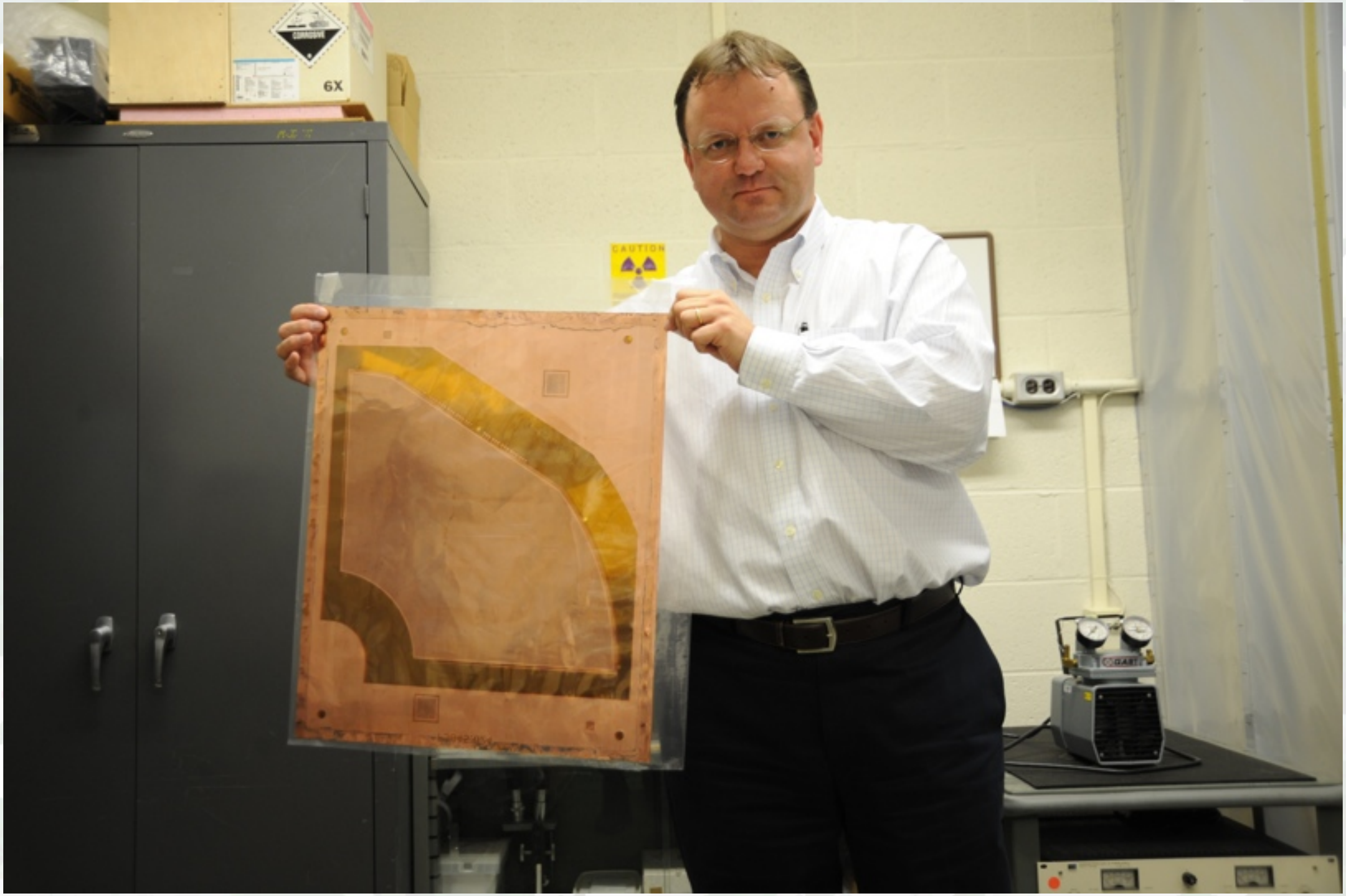
Summary

- Milestones / Schedule
  - Goal: Complete FGT construction in ~fall 2010 followed by full system test and subsequent full installation in ~summer 2011

    ⇒ Ready for anticipated first long 500GeV polarized pp run in FY12
  - Review: Successful review January 2008 / Beginning of construction funds FY08
  - Cost estimate / planing / milestones: R&D and pre-design work: FY07 / FY08
    - Triple-GEM Detector: Complete prototype tested (Bench and FNAL testbeam)
    - Front-End Electronics (FEE) System: Complete prototype tested / FEE design completed
    - Data Acquisition (DAQ) System: Layout exists based on similar DAQ sub-detector systems with extensive experience (ANL/IUCF)
    - Mechanical pre-design completed: Triple-GEM detector and new support structure
    - GEM foil development: Successful development of industrially produced GEM foils through SBIR proposal in collaboration with Tech-Etch Inc. (BNL, MIT, Yale University)

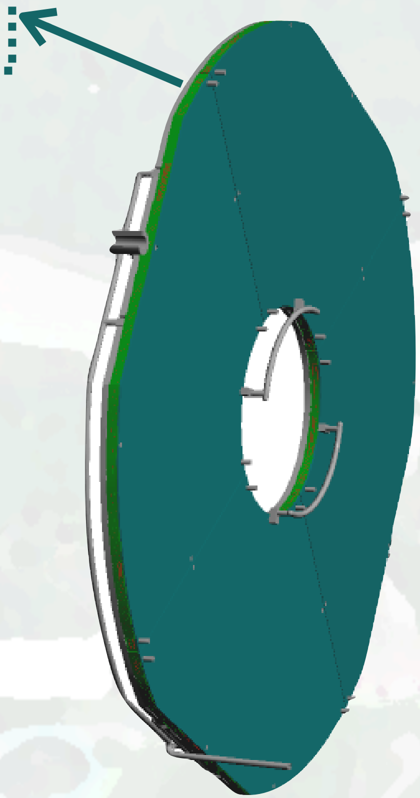
Backup

- Triple-GEM: GEM foils at MIT



Backup

- Triple-GEM: Quarter section design



Component	Material	Radiation Length [%]
Support plate	5 mm Nomex	0.040
	2x250 μm FR4	0.257
HV layer	5 μm Cu	0.035
	50 μm Kapton	0.017
GEM foils	6x5 μm Cu (70%)	0.147
	3x50 μm Kapton (70%)	0.036
Readout	5 μm Cu (20%)	0.007
	50 μm Kapton (20%)	0.003
	5 μm Cu (88%)	0.031
	50 μm Kapton	0.017
	5 μm Cu (10%)	0.004
	0.125 mm FR4	0.064
	5 μm Cu (10%)	0.004
Drift gas	10 mm CO_2 (30%)	0.002
	10 mm Ar (70%)	0.006
Total		0.670

Backup

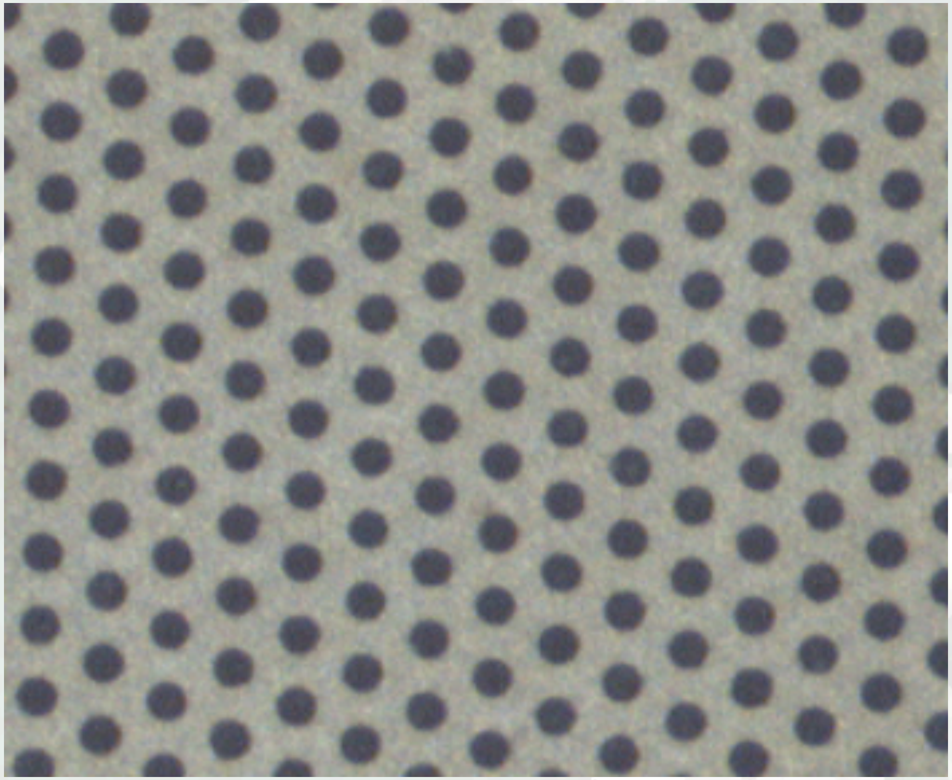
- Triple-GEM: GEM foil testing (1)
  - HV test of GEM foils
    - Verify continuity and isolation
    - Measure leakage current up to 600V
  - Tech-Etch QA procedure: Resistance > 10GOhms / Leakage current < 5nA at 10% RH
  - MIT tests
    - Isolation between segments
    - Quick HV test to 600V
      - Ramp HV to 100V/minute
      - Segment currents < 1nA
      - Segment 8/9 problematic (Trip at 600V)
    - Longer conditioning reduces leakage current, but segments 8/9 still trip at 600V

Note:

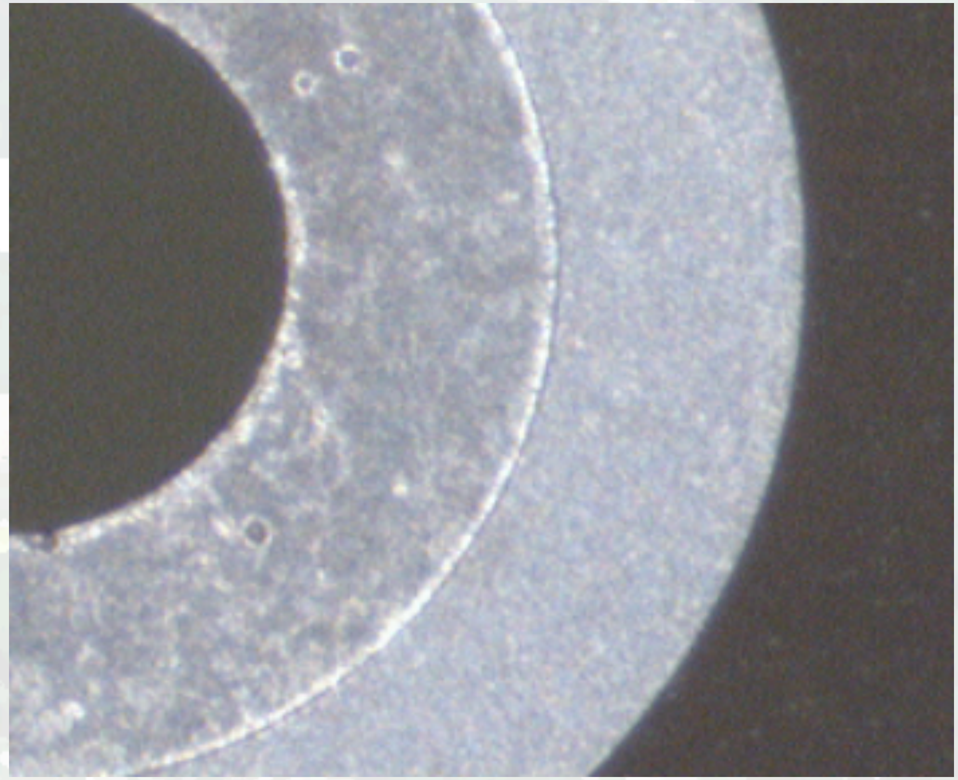
CERN production QA criteria:
10nA max at 600V 35% Hr max

Backup

- Triple-GEM: GEM foil testing (2)



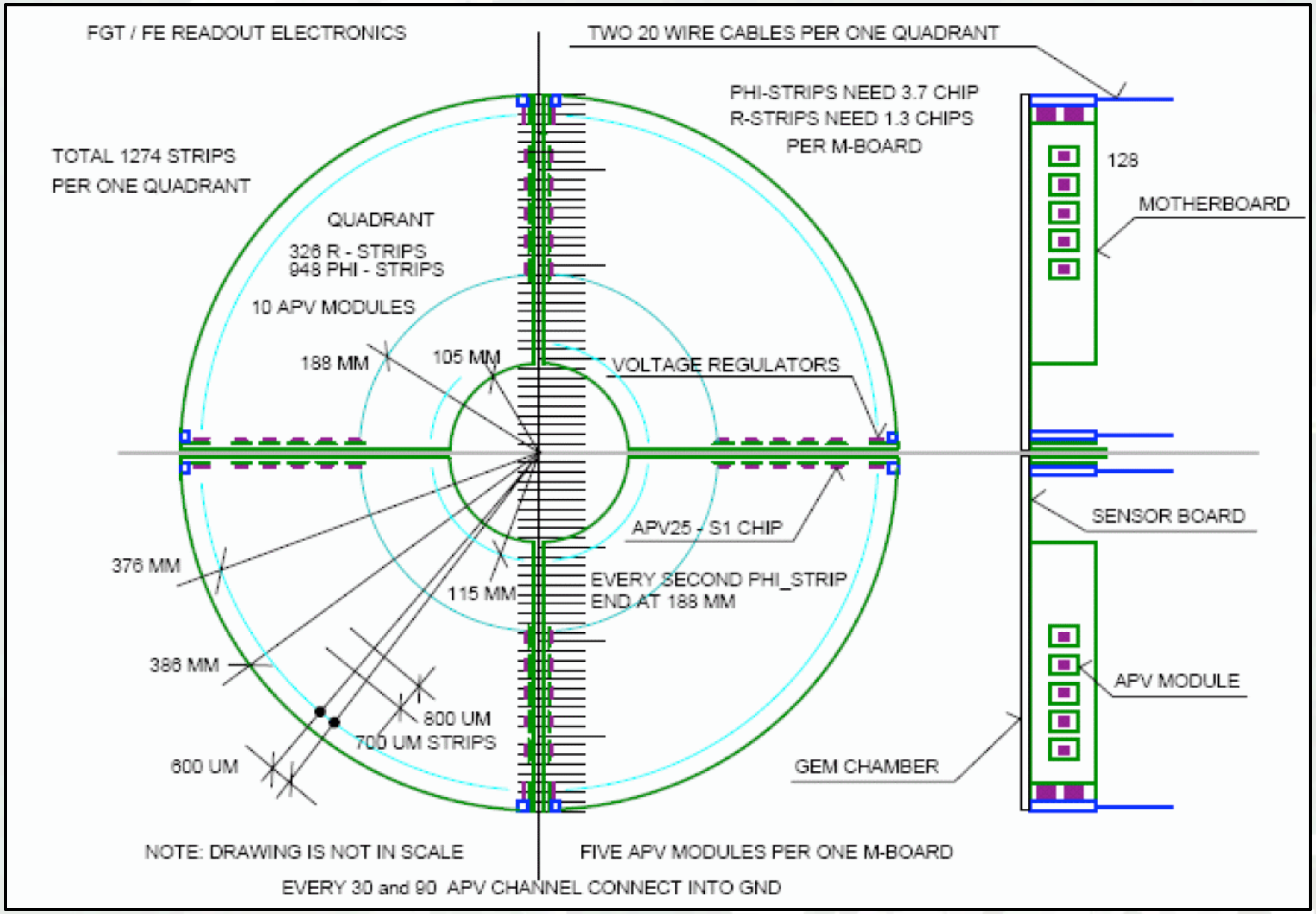
First scan for large GEM foil
(Hole arrangement)

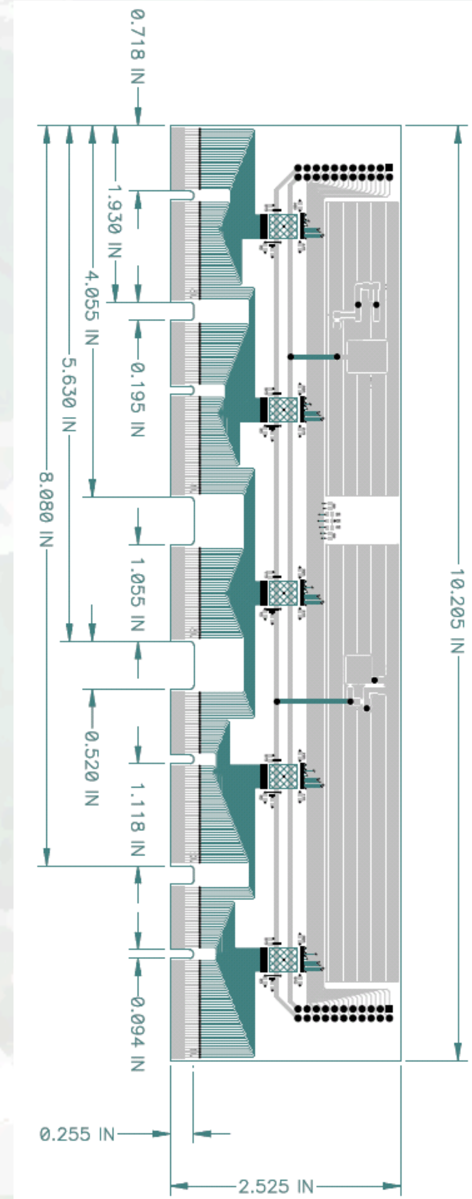


First scan for large GEM foil
(HV connection)

Backup

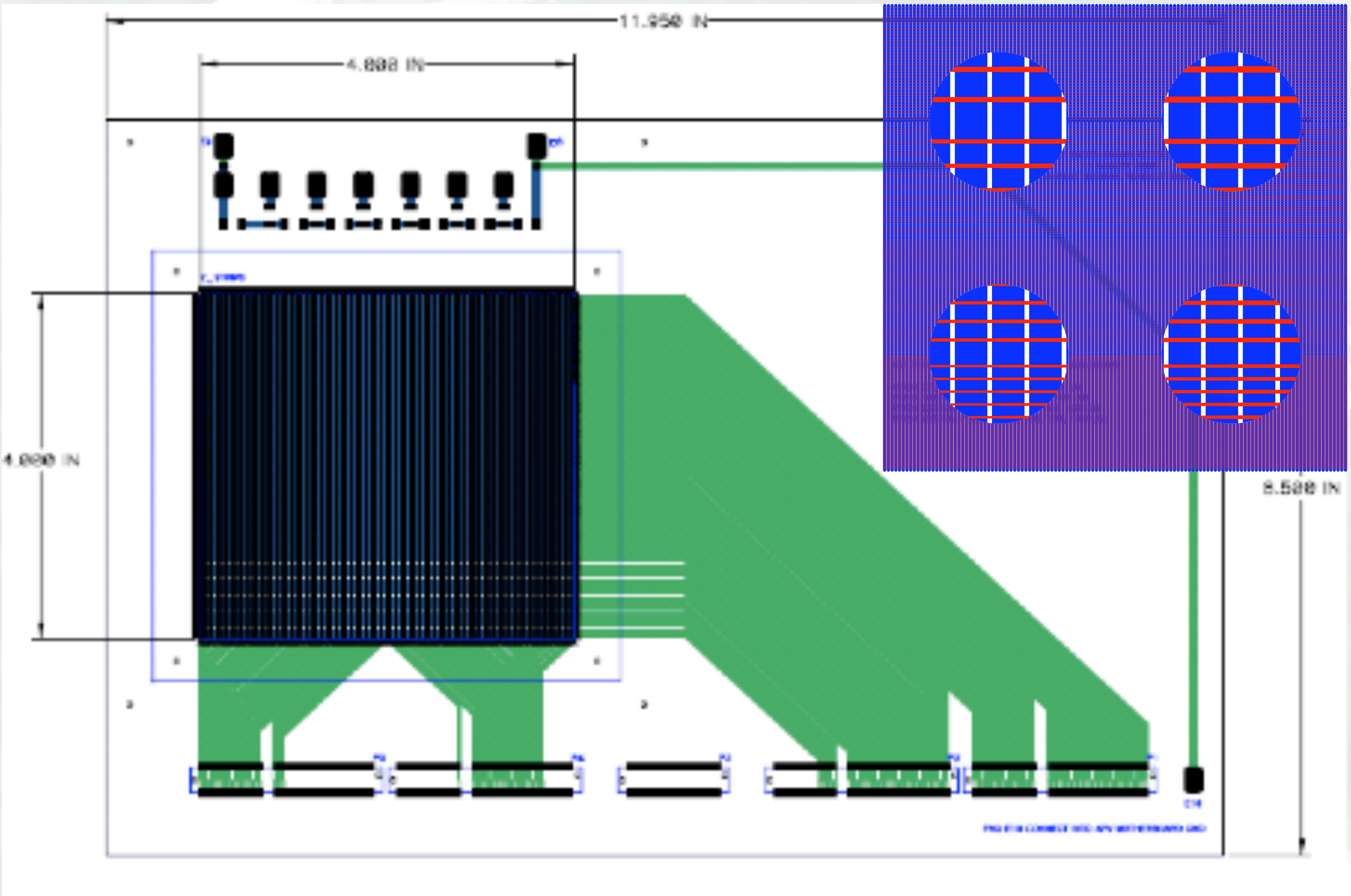
- Triple-GEM: 2D readout board design (1)





Backup

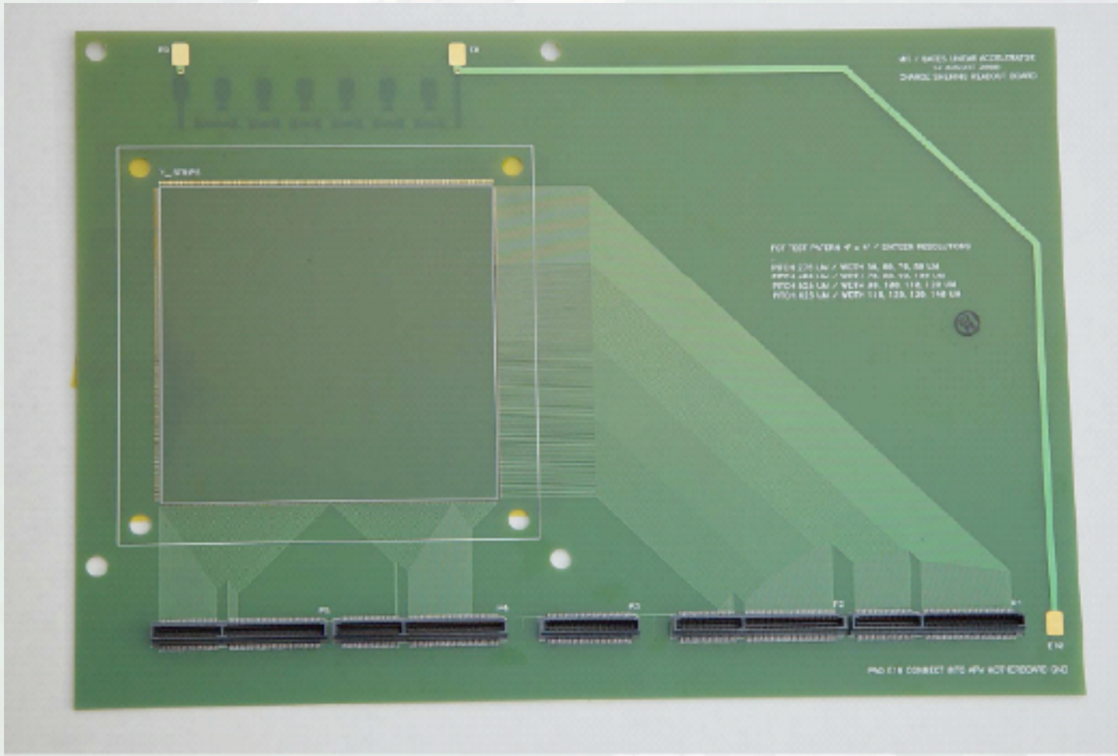
- Triple-GEM: 2D readout board design (2)



- Special 2D readout board designed (Suitable for 10 X 10 cm^2 prototype arrangement)
- 4 X 4 separate regions of different strip pitch/width

Backup

Triple-GEM: 2D readout board design (3)



- Manufactured by Compunetics Inc.
- Delivered to MIT-Bates, December 2009
- Assembly in progress using existing 10 X 10 cm^2 prototype
- Uniformity tests with ^{55}Fe source

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