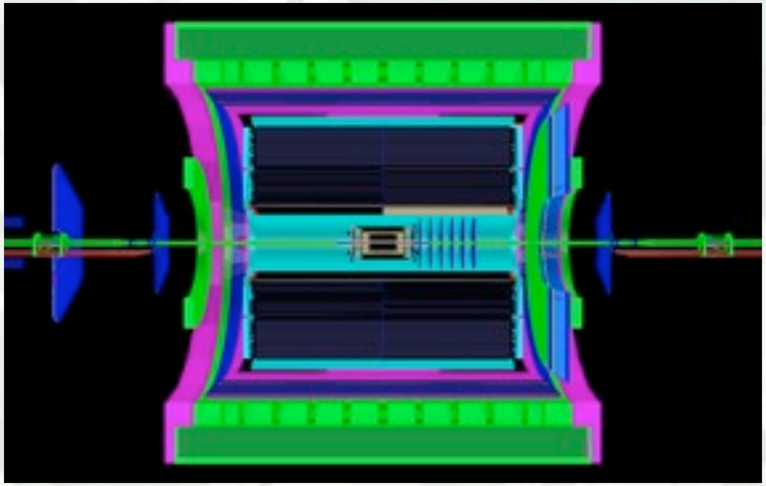
The STAR Forward GEM Tracker (FGT)

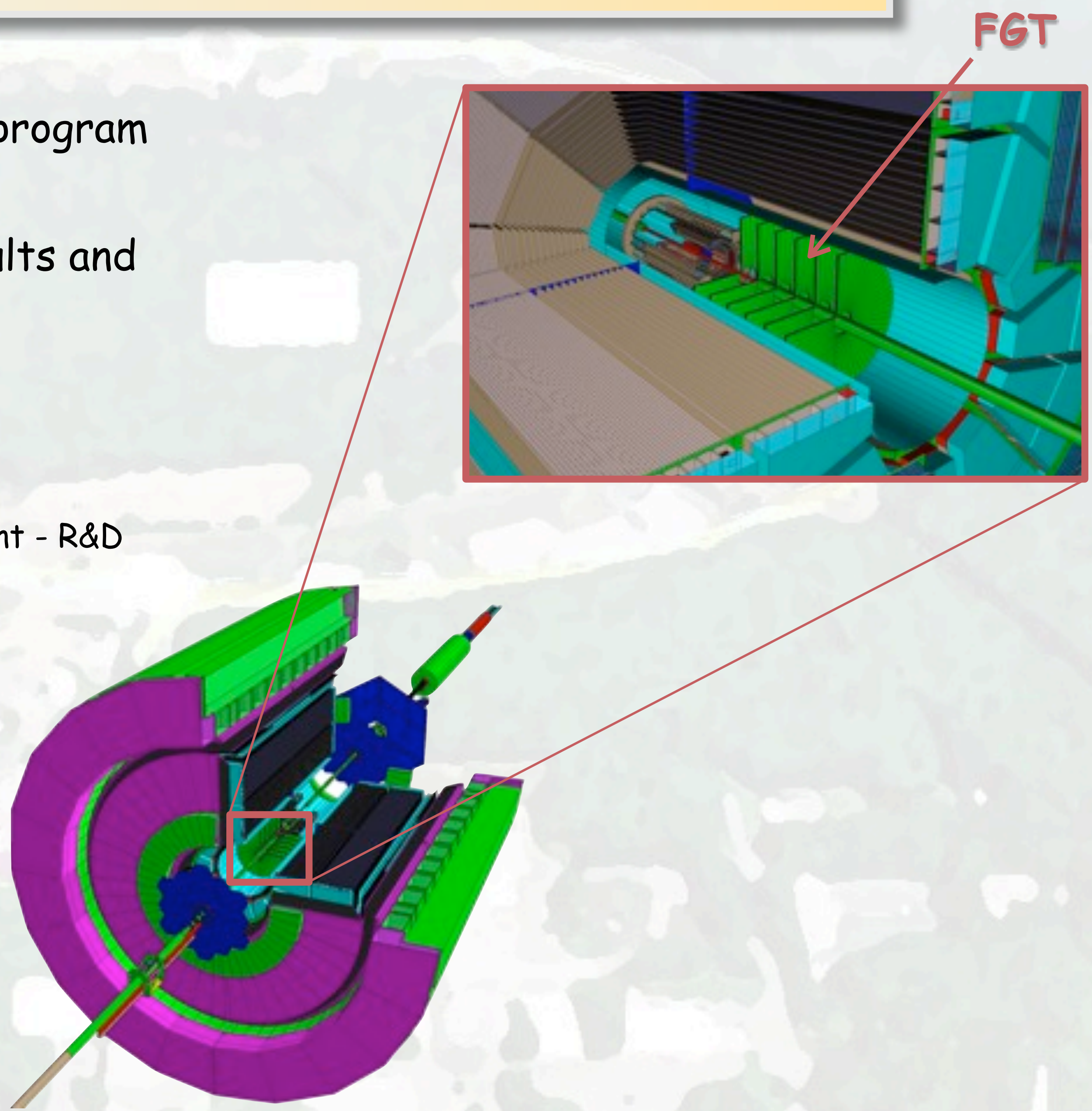
Bernd Surrow

Massachusetts Institute of Technology



Outline

- FGT Physics motivation - W program
- FGT Layout - Simulation results and optimization
- FGT Technical Realization
  - Triple-GEM detector development - R&D
  - Mechanical design
  - Front-End Electronics
  - DAQ
- FGT Schedule / Milestones
- Summary



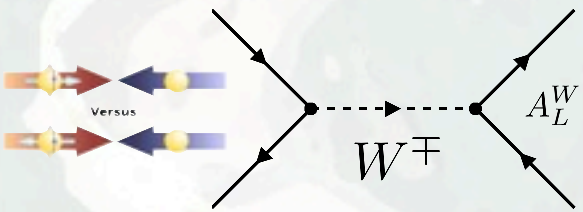
FGT Physics motivation - W program

Quark / Anti-Quark Polarization - W production

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

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

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



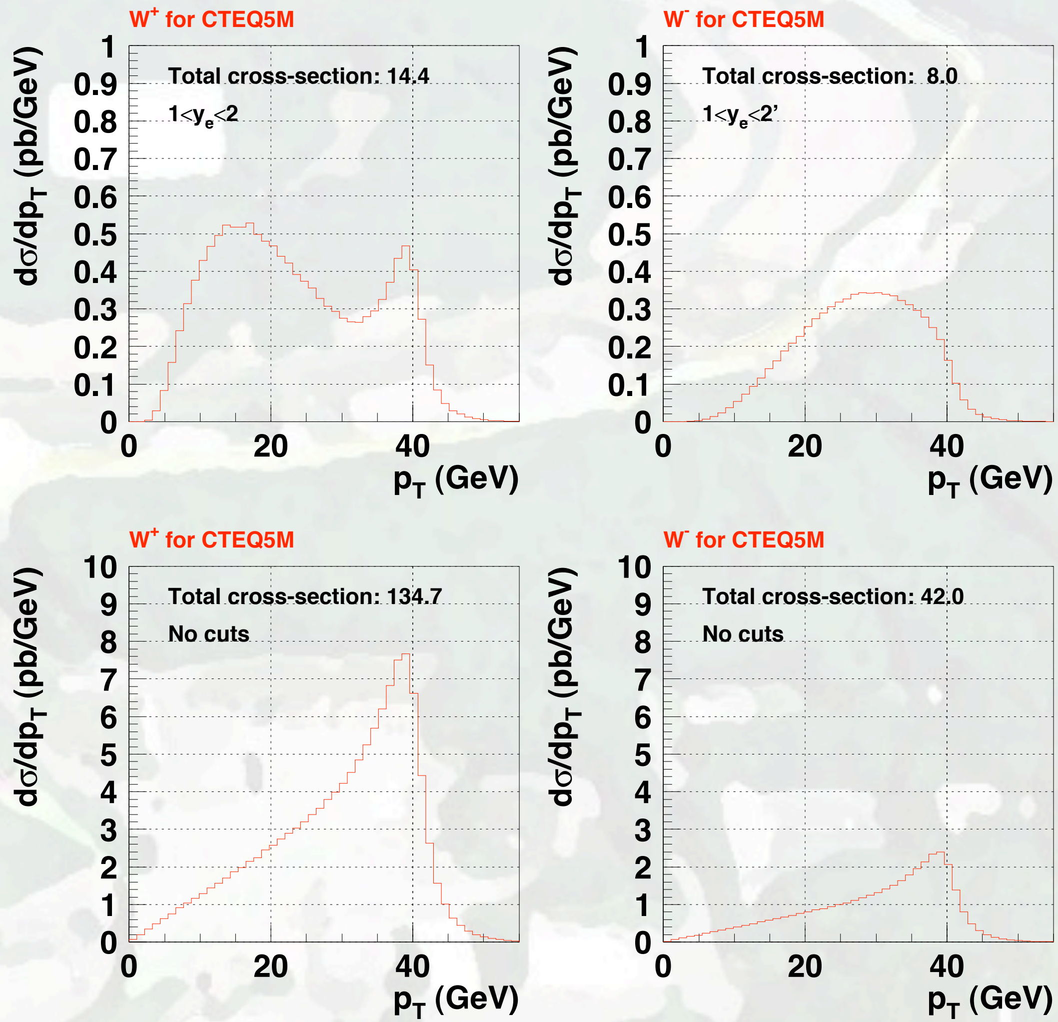
$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) - N^-(W)}$$

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

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

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

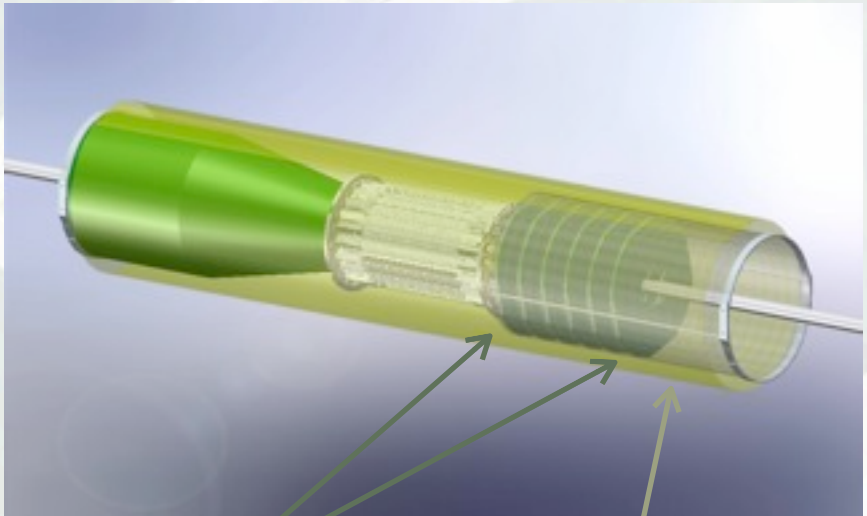
RHICBOS W simulation at 500GeV CME



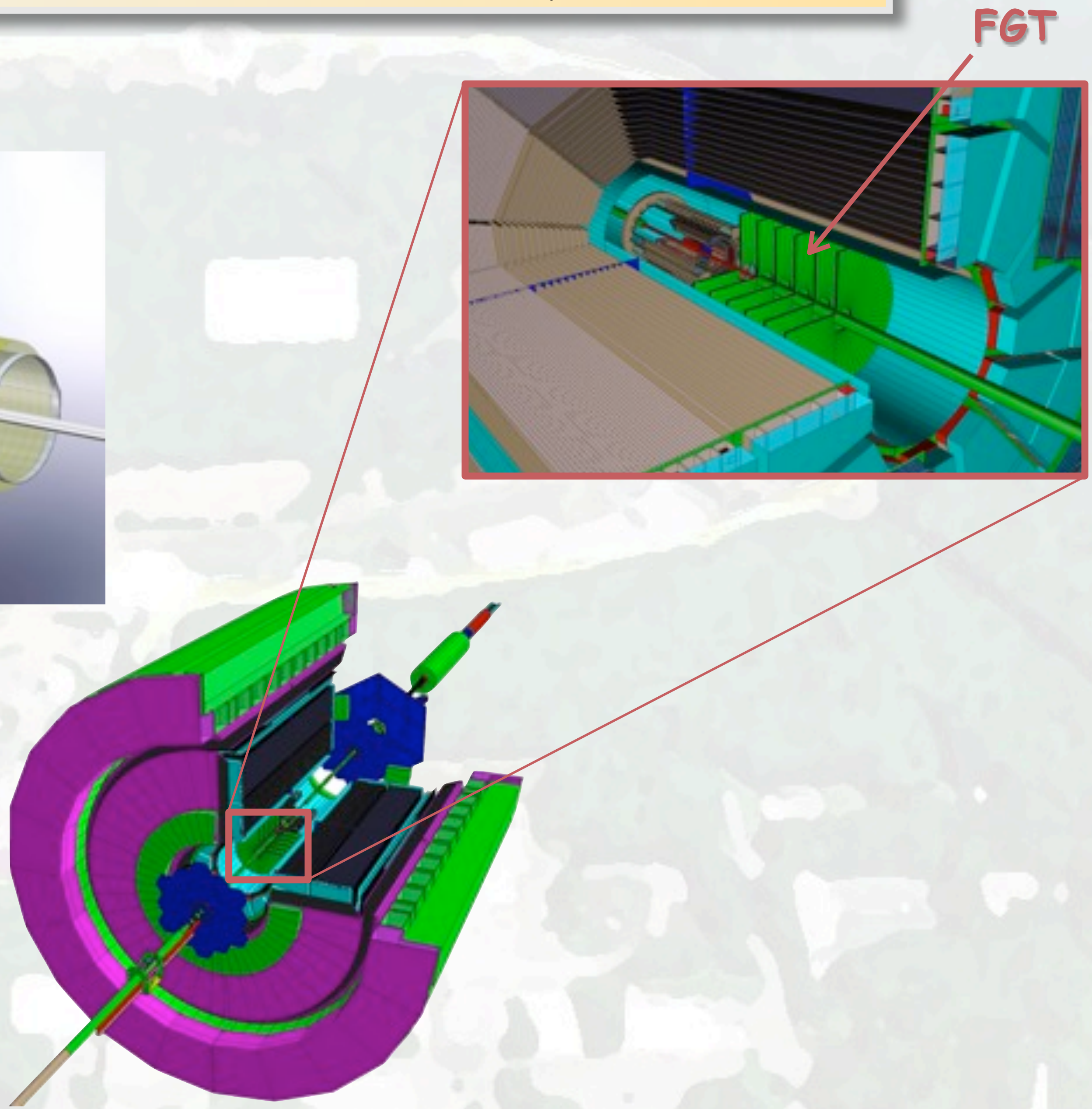
- **Key signature:** High p_T lepton (e^-/e^+ or μ^-/μ^+) (Max. $M_W/2$) - Selection of W^-/W^+ : Charge sign discrimination of high p_T lepton
- Required: Lepton/Hadron discrimination

FGT Layout - Simulation results and optimization

- Layout

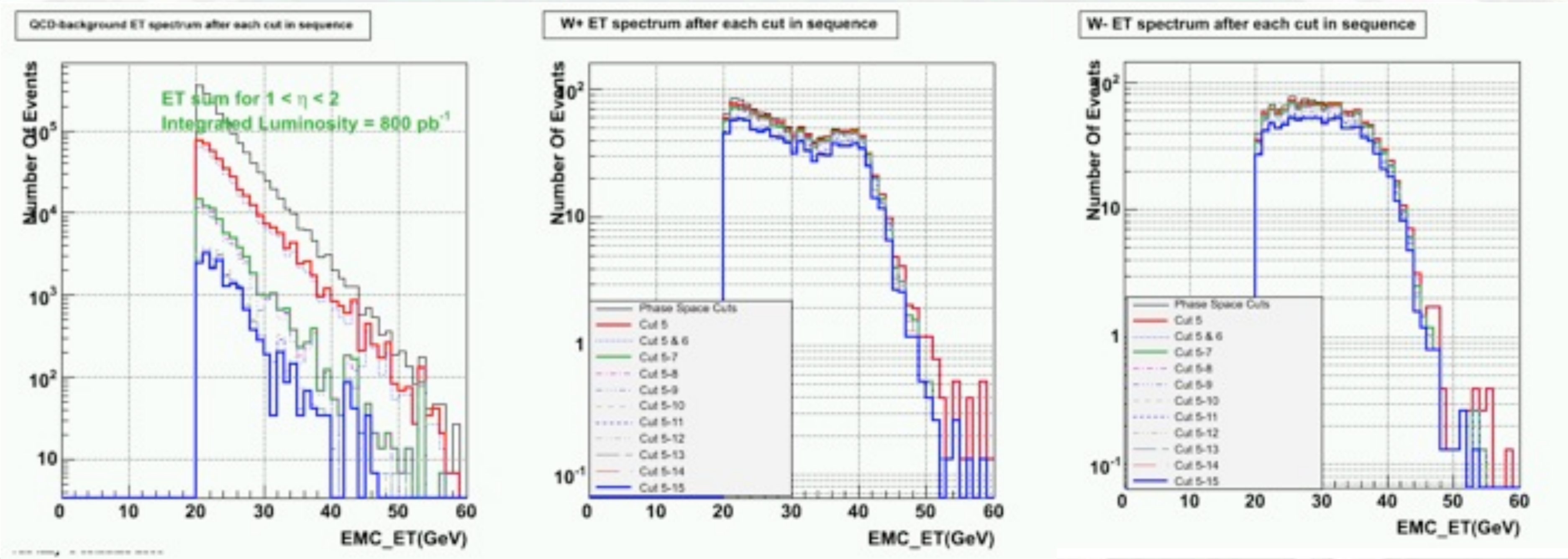


- FGT: 6 light-weight triple-GEM disks - WEST side of STAR
- New mechanical support structure



FGT Layout - Simulation results and optimization

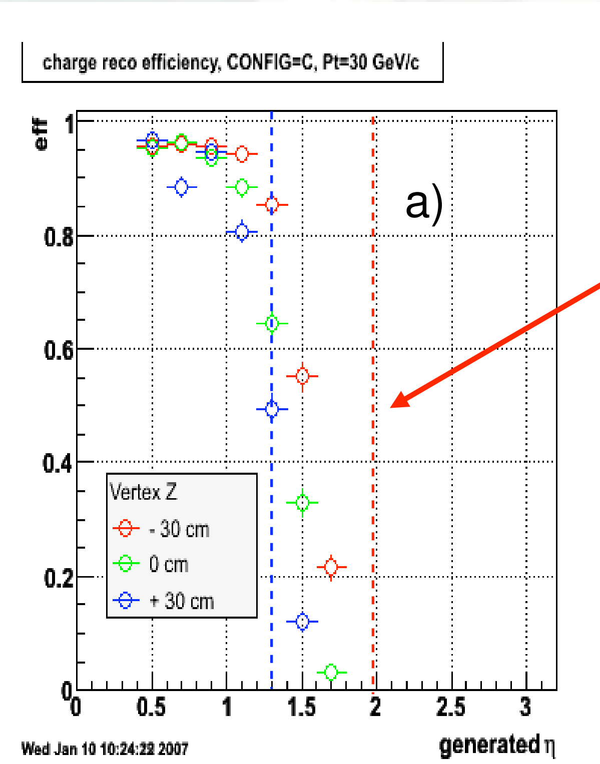
- Quark / Anti-Quark polarization program at STAR - e/h separation
  - Full PYTHIA QCD background and W signal sample including detector effects



  - e/h separation based on global cuts (isolation/missing E_T) and EEMC specific cuts as
  - With current algorithm: $E_T > 25$GeV yields S/B > 1 (For $E_T < 25$GeV S/B ~ 1/5) used for A_L uncertainty estimates

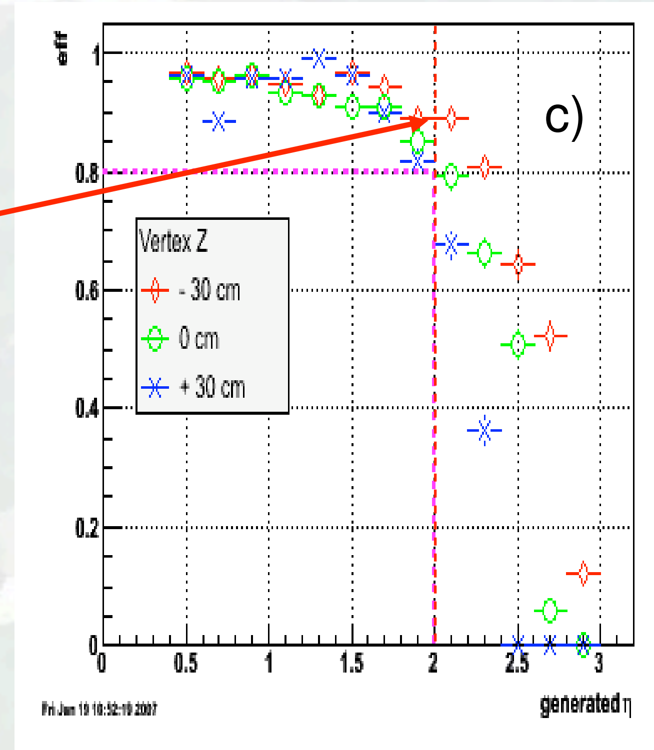
FGT Layout - Simulation results and optimization

- Quark / Anti-Quark polarization program at STAR



Reach of EEMC Acceptance

TPC + FGT Tracking, p_T = 30 GeV/c



6 triple-GEM disks, assumed spatial resolution 60μm in x and y (Fairly insensitive for 60-100μm)

Conclusion:

Charge sign reconstruction impossible beyond η = ~1.3

Charge sign reconstruction probability above 90% for 30 GeV p_T over the full acceptance of the EEMC for the full vertex spread

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 (submitted to DOE): 2D readout board using chemical etching

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
  - 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

Tech-Etch Inc.

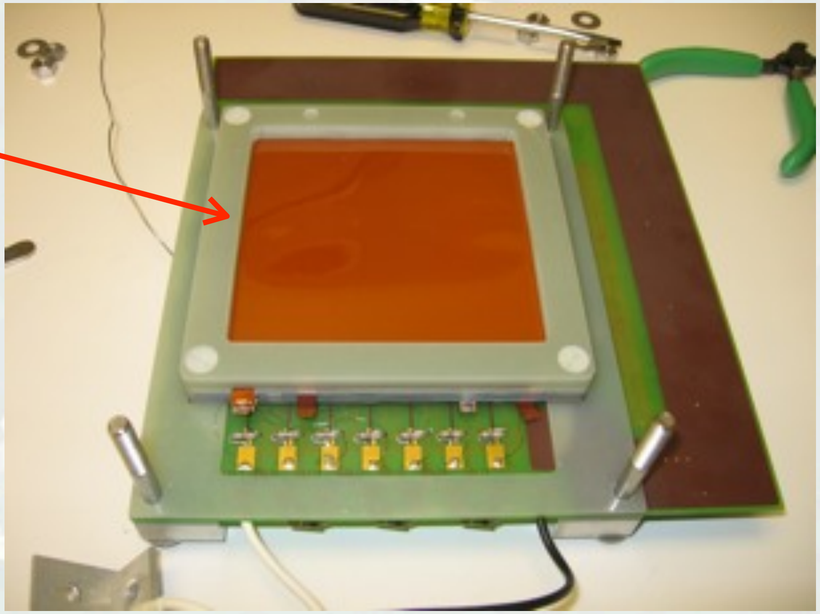
http://www.tech-etch.com

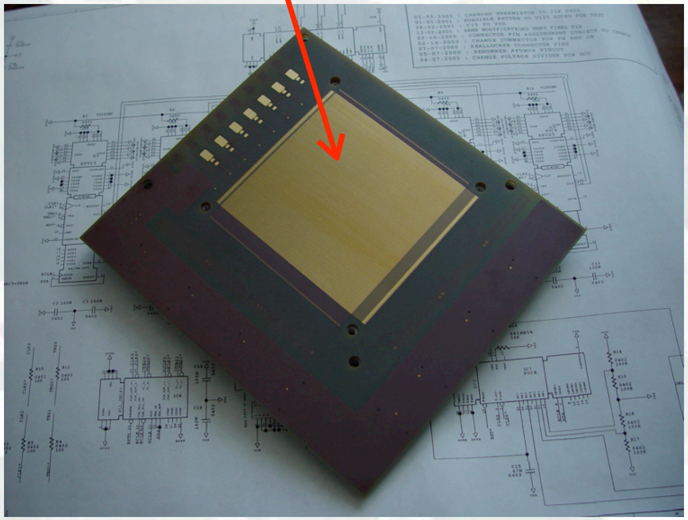
FGT Technical realization

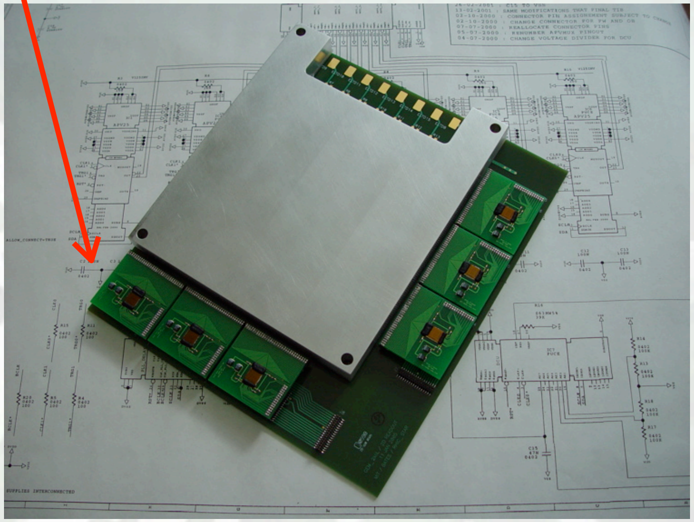
- R&D Development at MIT
  - Resources
    - 2 dedicated clean rooms (Class ~100/1000) (MIT Bates Laboratory / MIT Laboratory for Nuclear Science)
    - HV radioactive source setup / HV box / Light-microscope / Laminar flow hood / GEM foil CCD camera scanner
  - Activities based on 10cm X 10cm samples
    - 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

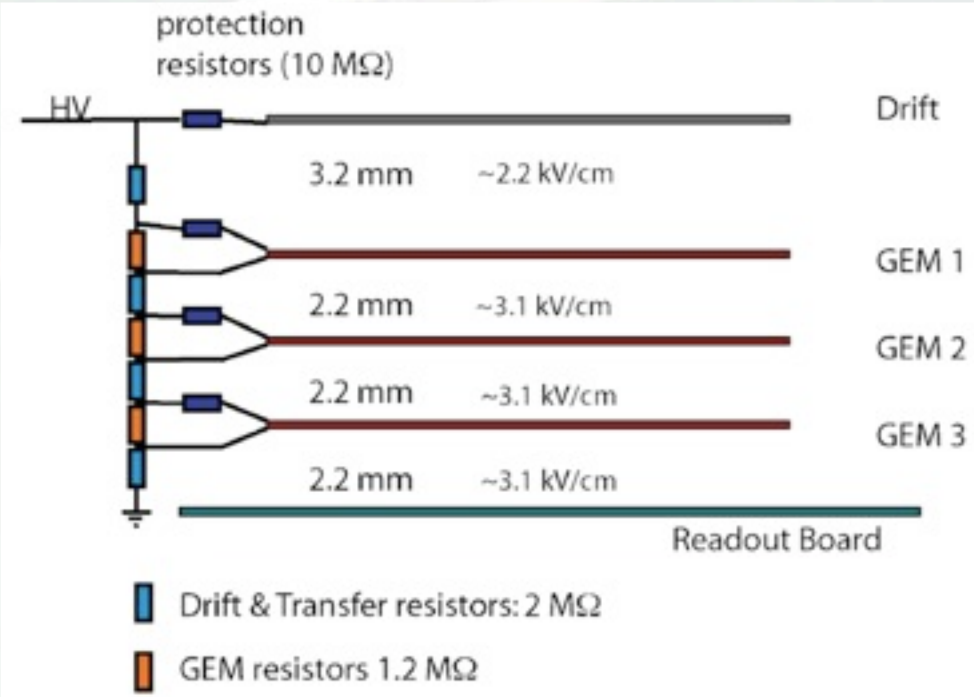


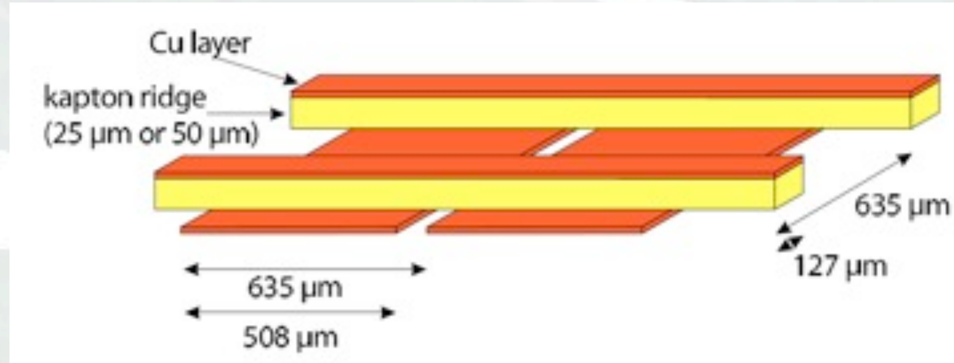




FGT Technical realization

- Prototype triple-GEM configuration (2)



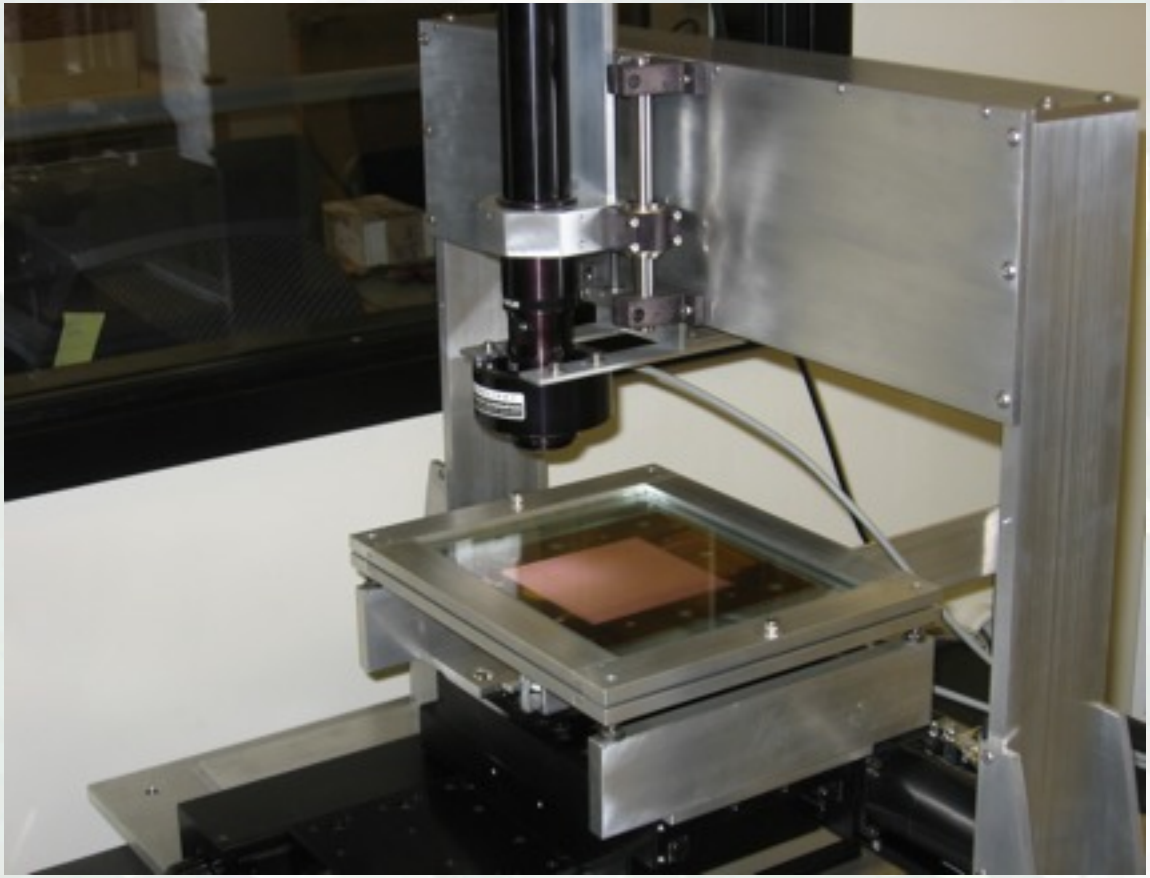


- Laser etched 2D readout board (Compunetics Inc.)
- Test beam configuration:
  Top strips (Y): ~127µm
  Bottom strips (X): 508µm
- Two separations: 25µm and 50µm

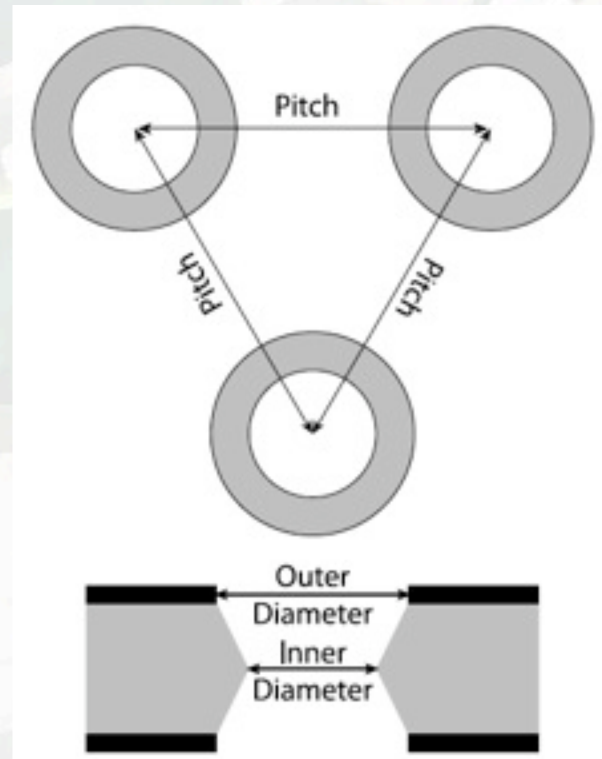
- Test beam operating voltage: ~3750V-3800V corresponding to ~385V-395V per GEM foil
- Testbeam effective gain: $\sim 3.5 \cdot 10^3$ ($\sim 2.5 \cdot 10^4$ bench tests)

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

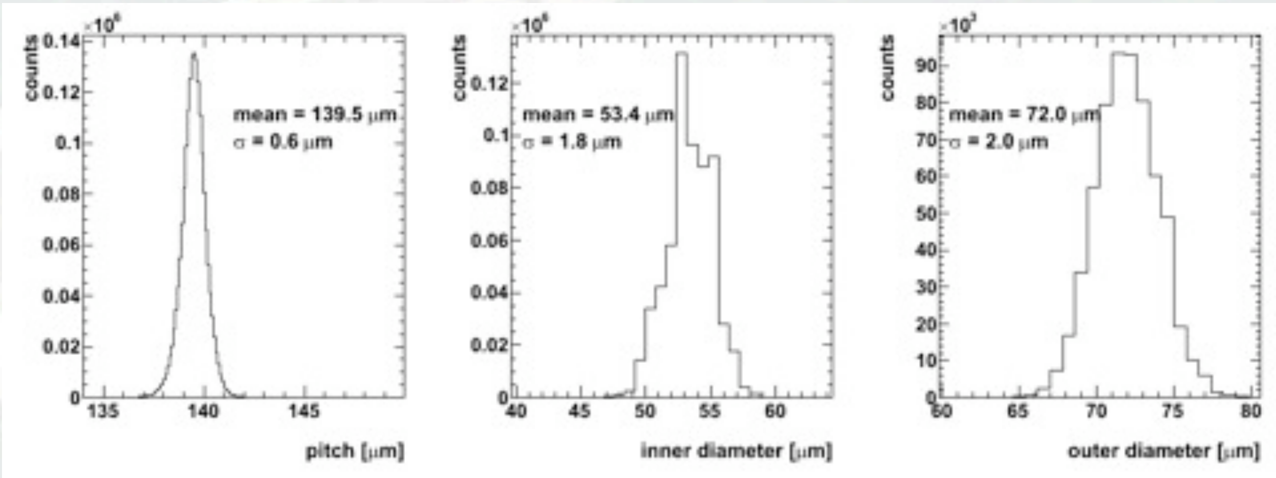


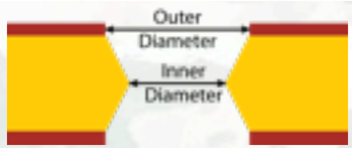
- Check for defects:
  - Missing holes, enlarged holes, dirt in holes and etching defects

FGT Technical realization

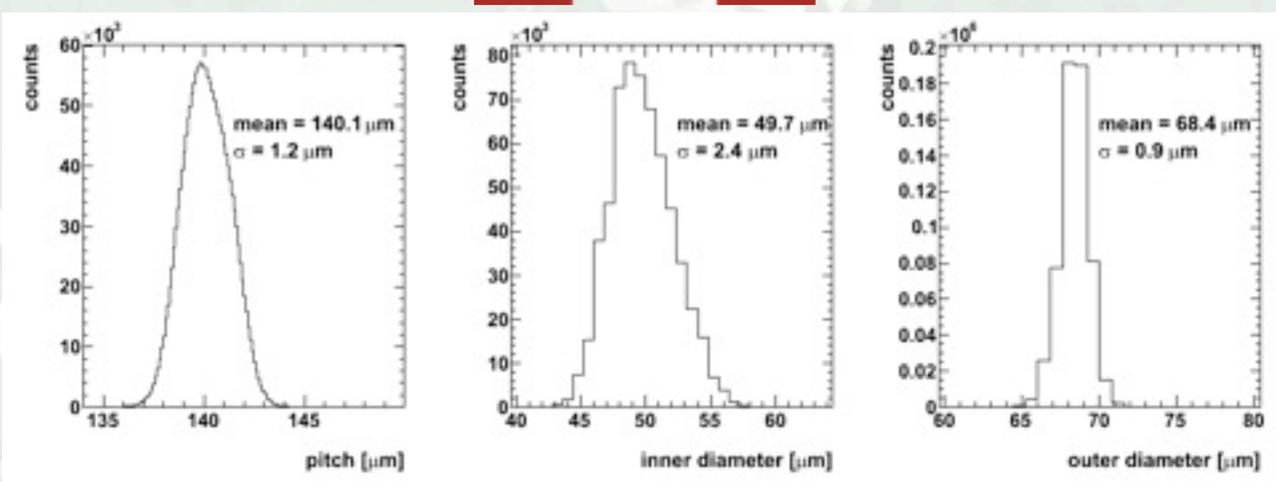
- Optical scans (2)

Tech-Etch





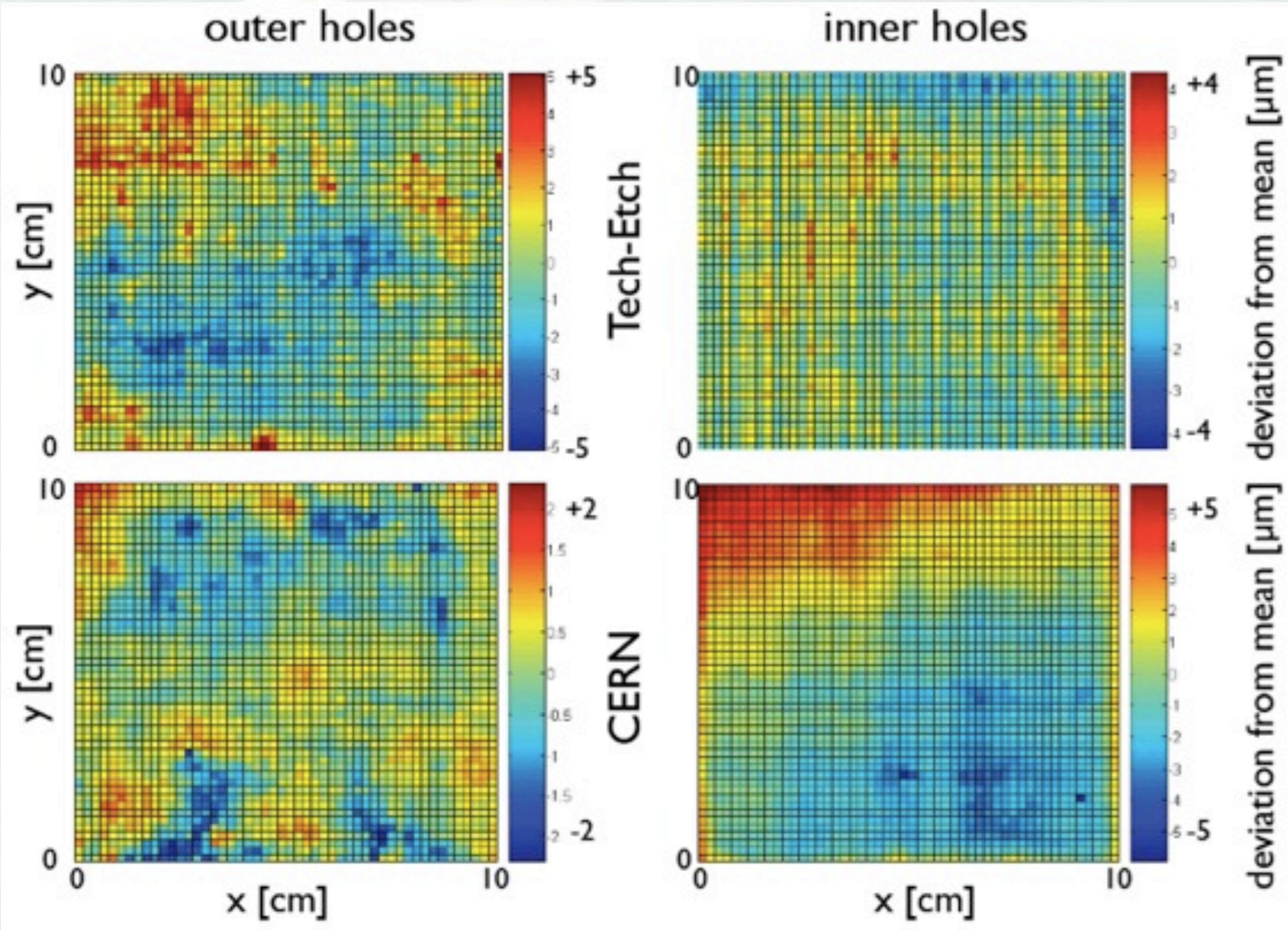
CERN



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

FGT Technical realization

- Optical scans (3)

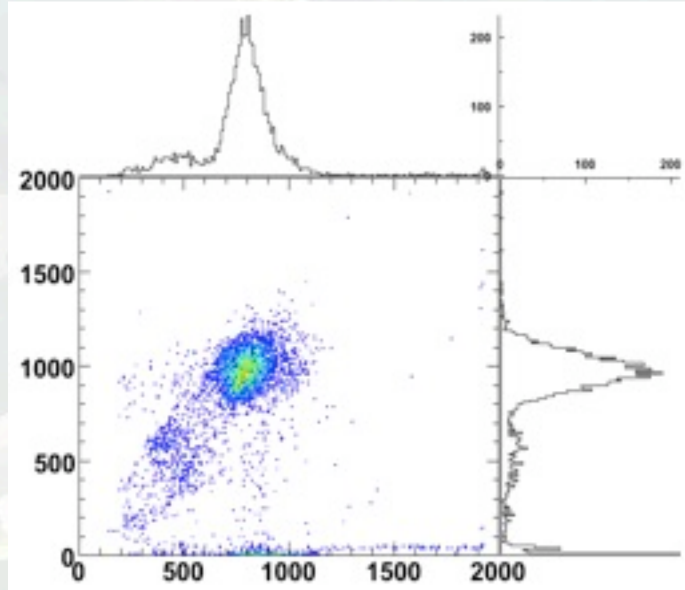


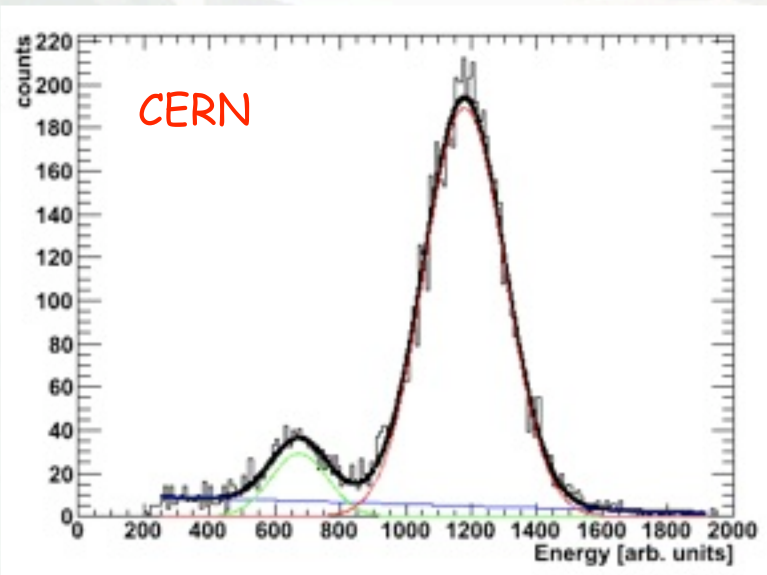
- Uniformity of outer/ inner hole diameters for Tech-Etch and CERN foils (10cm X 10cm samples)

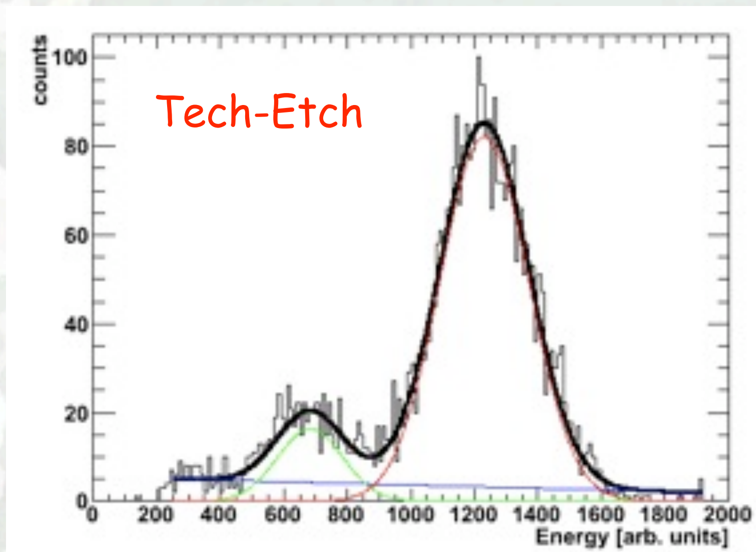
GEM foil test results

- 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%)

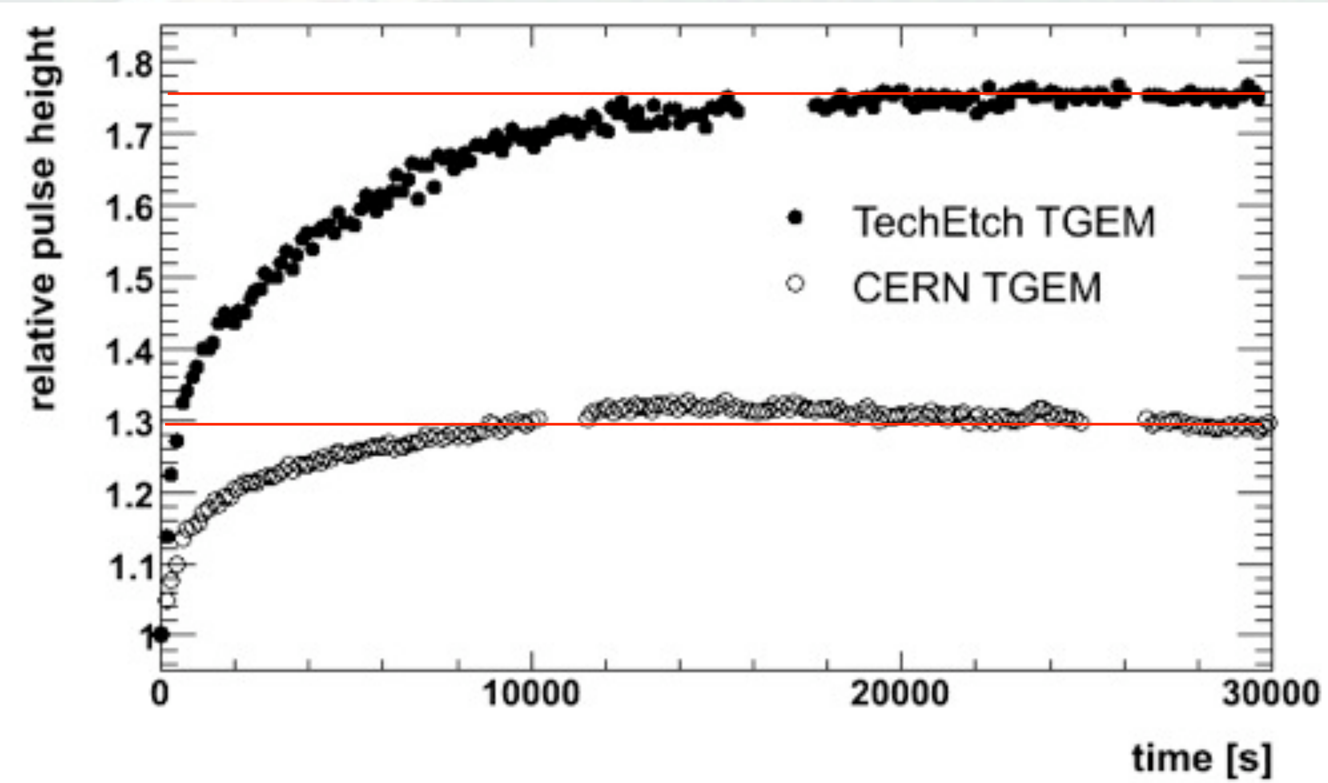
Correlation of X-Y readout plane







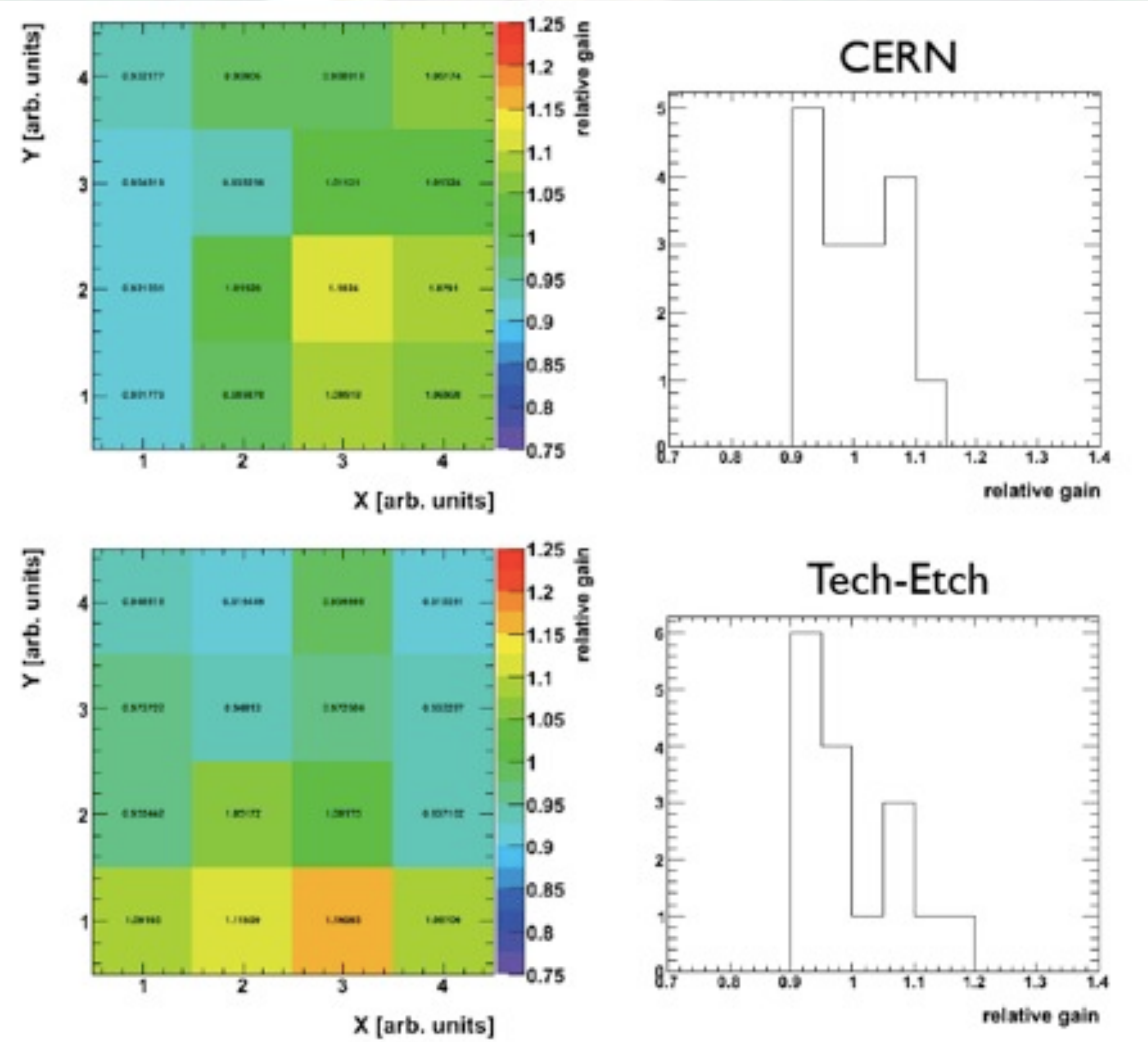
Source tests (2)



- Evolution of relative gain for Tech-Etch and CERN GEM foil based triple-GEM prototype detector as a function of time
- Irradiation: Low intensity ^{55}Fe source (~0.5Hz/mm^2)

FGT Technical realization

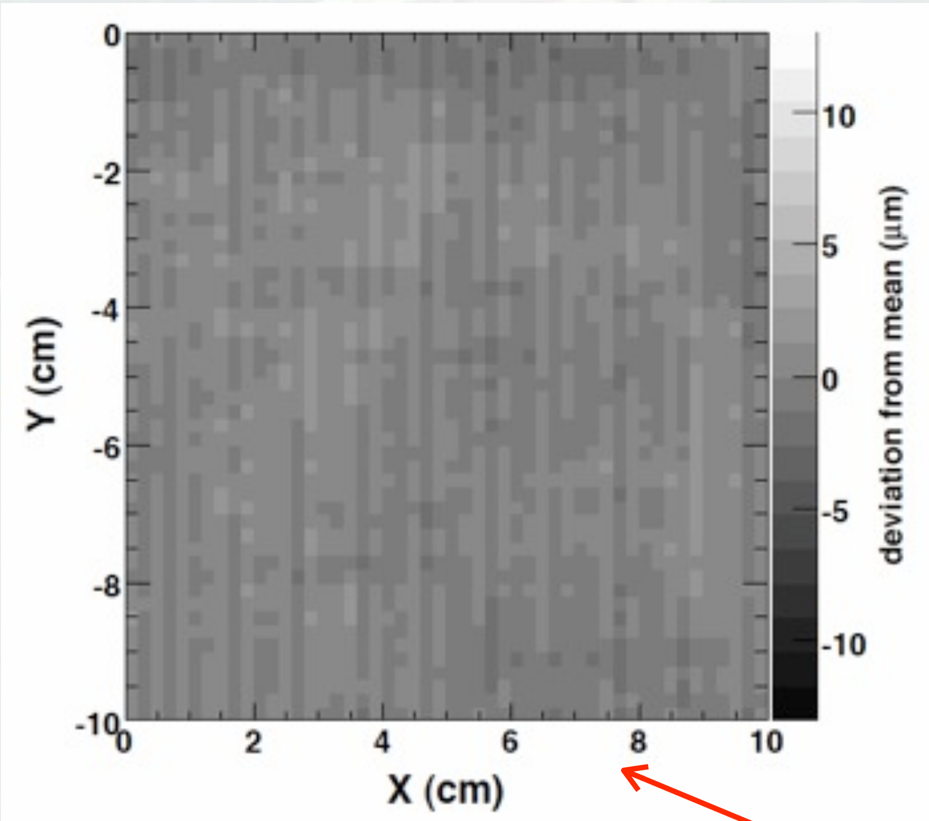
- Source tests (3)

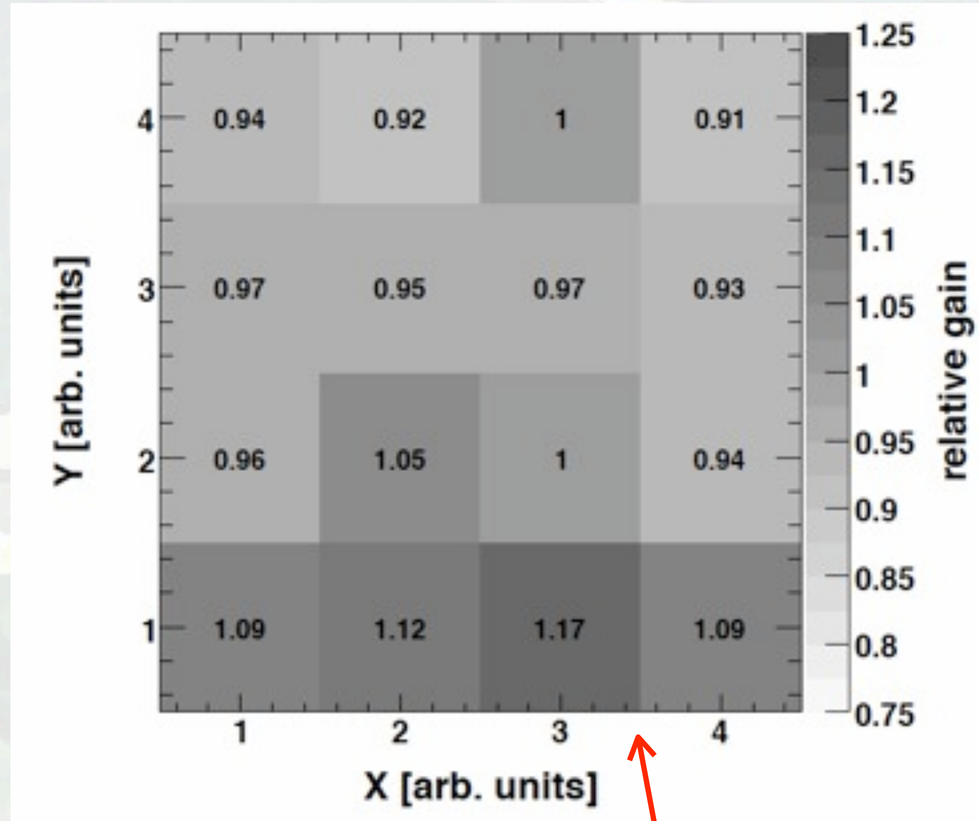


- Gain measured with low intensity ^{55}Fe source (~0.5Hz/mm^2)
- Good gain uniformity over full active area (Measured after charge built-up)

FGT Technical realization

- Source tests (4)



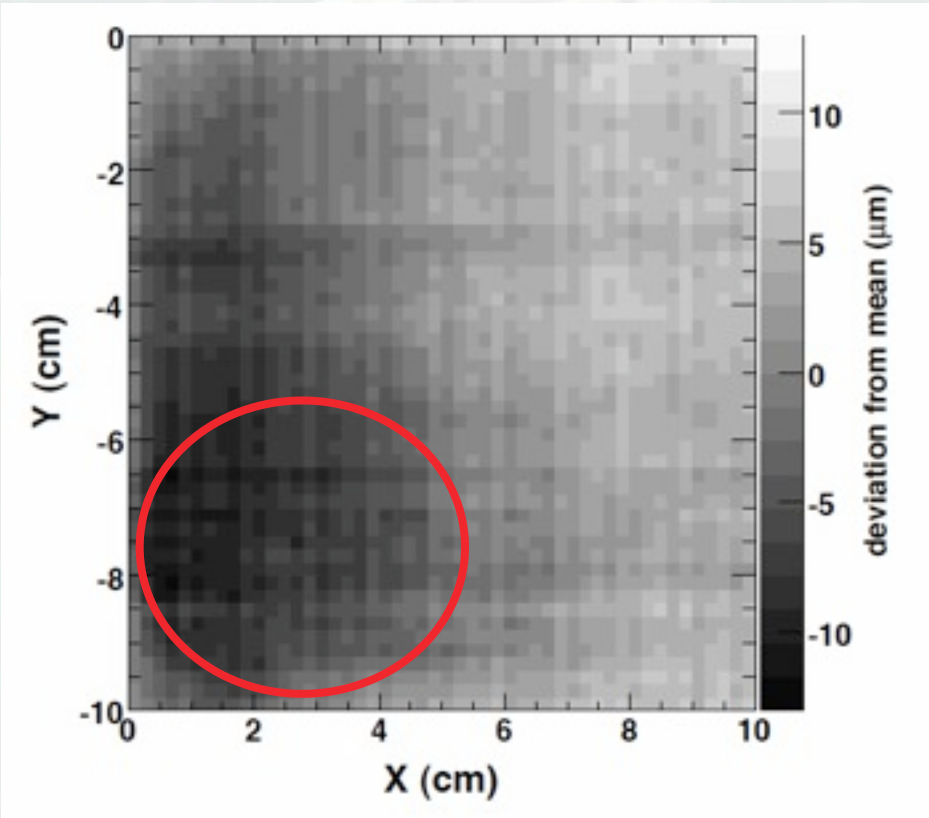


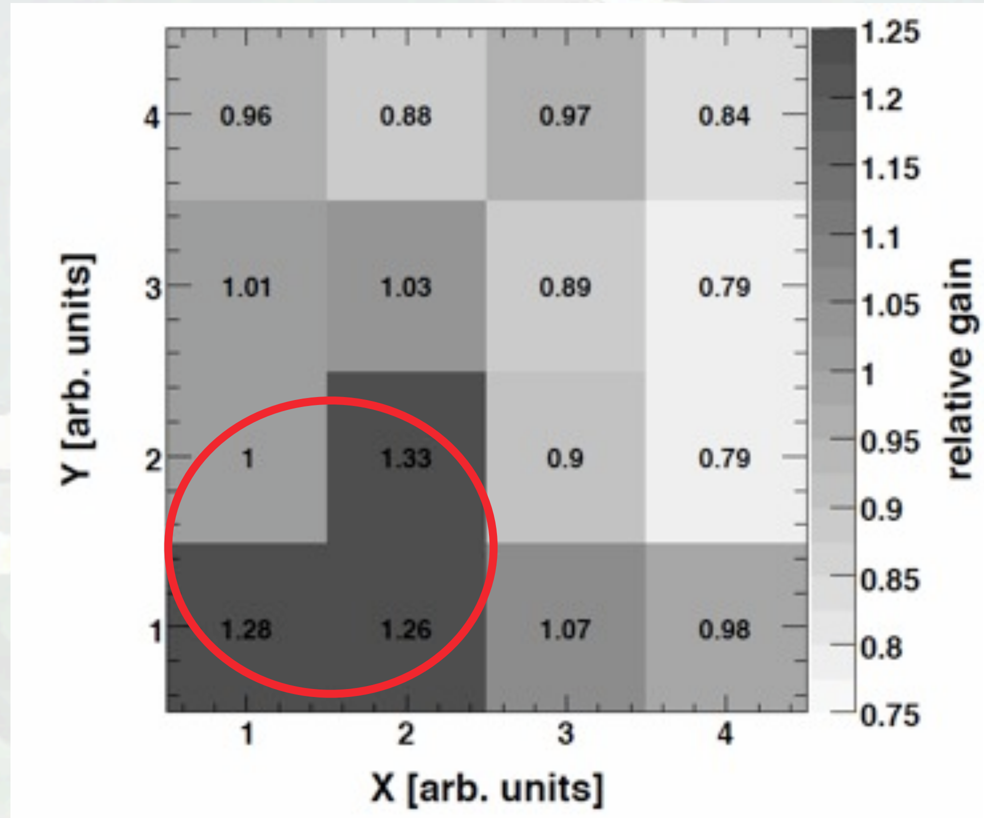
- Comparison of optical scans of inner hole diameter uniformity and gain uniformity

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

FGT Technical realization

- Source tests (5)



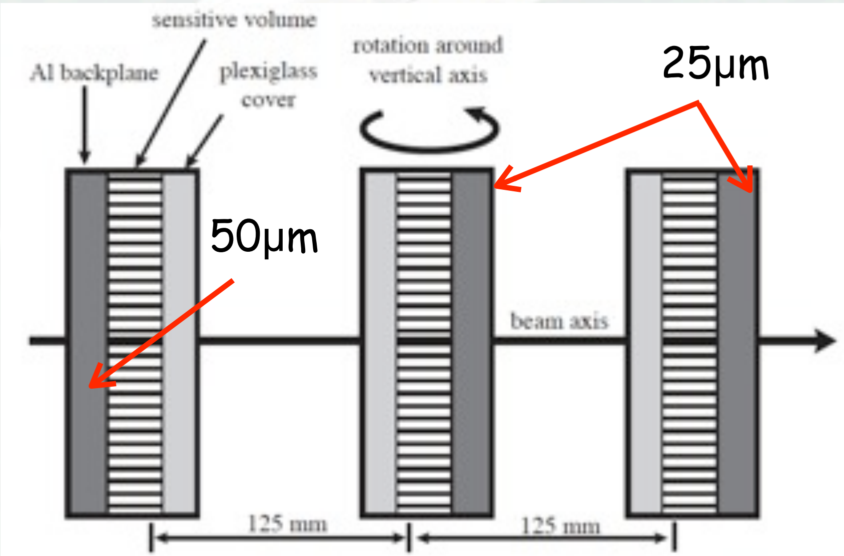


- Non-uniformity of inner hole diameter (~20µm smaller on left side compared to right side)

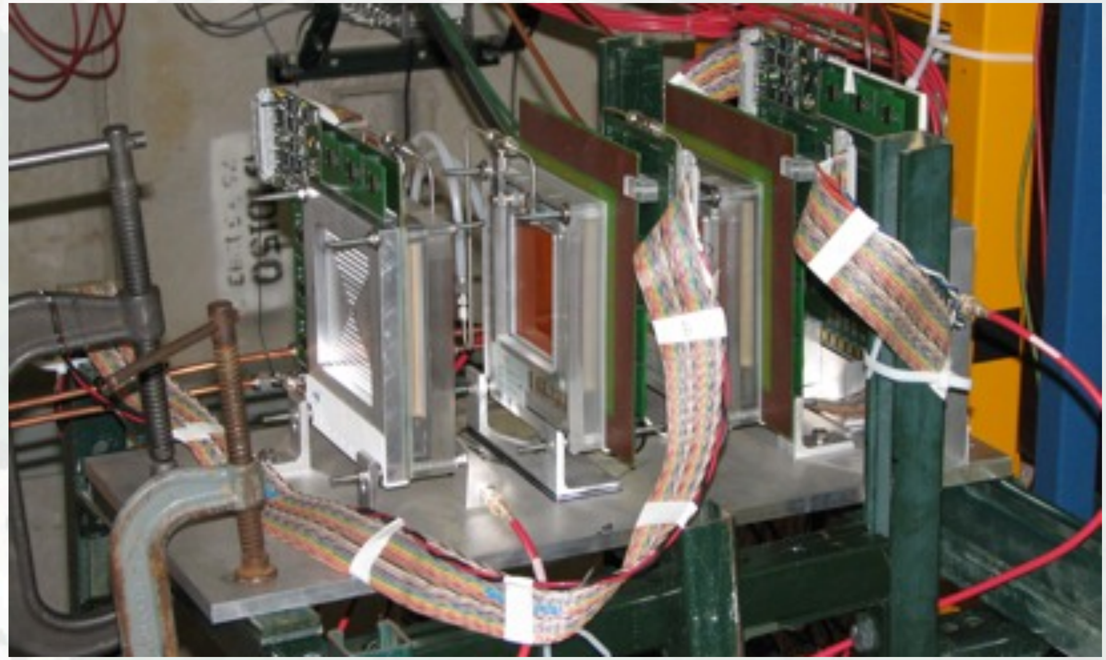
  reflected in large non-uniformity of source scan gain measurements

FGT Technical realization

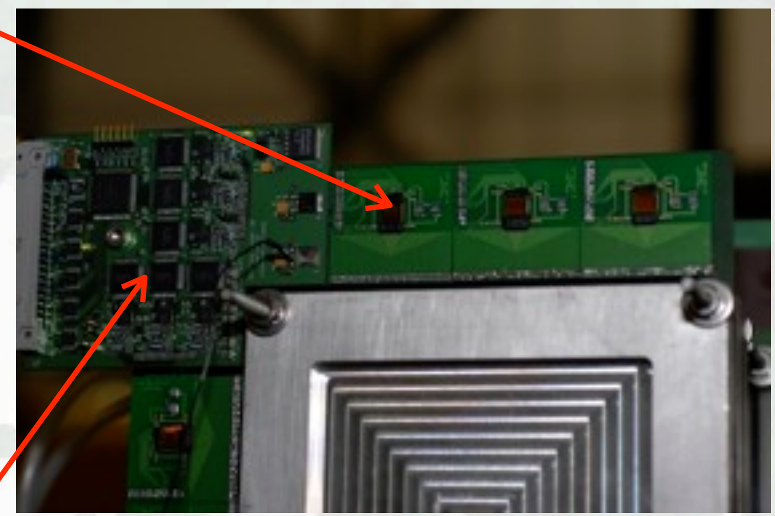
- Testbeam results (1)



Det0 Det1 Det2



APV25-S1

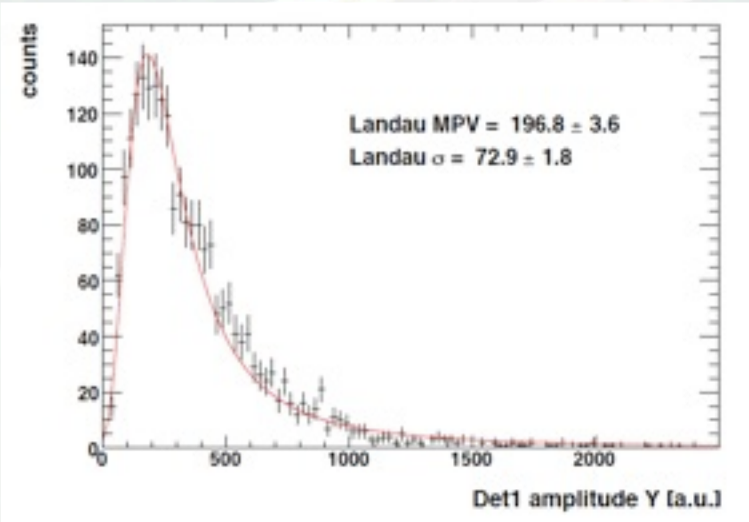


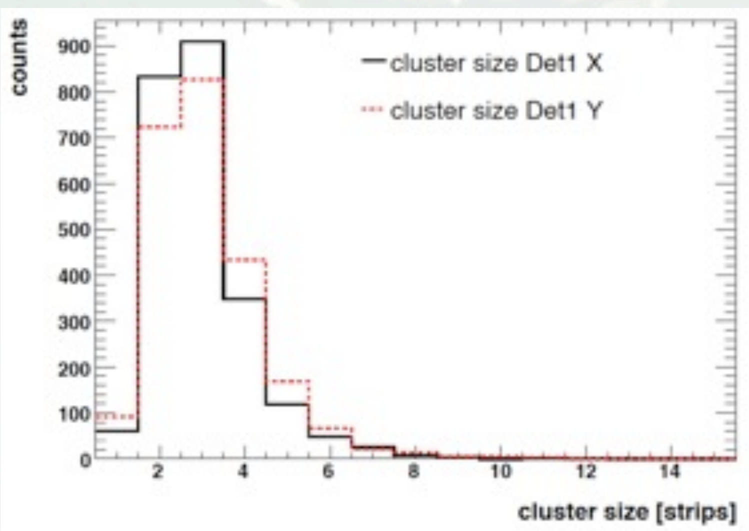
GEM Control Unit

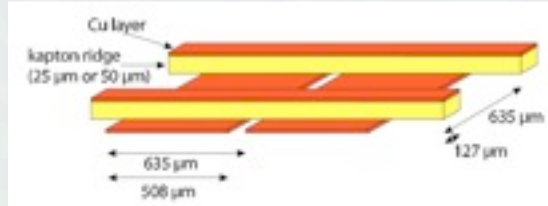
- FNAL Meson Test Beam Facility: Data taking with 4GeV-32GeV unseparated secondary beam and 120GeV primary proton beam

FGT Technical realization

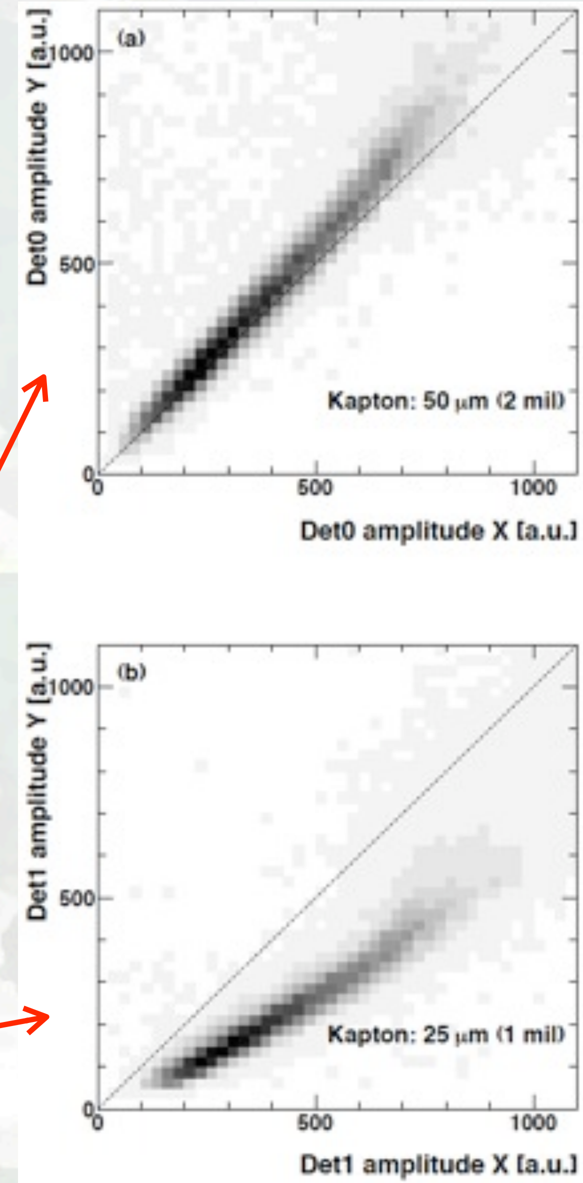
Testbeam results (2)





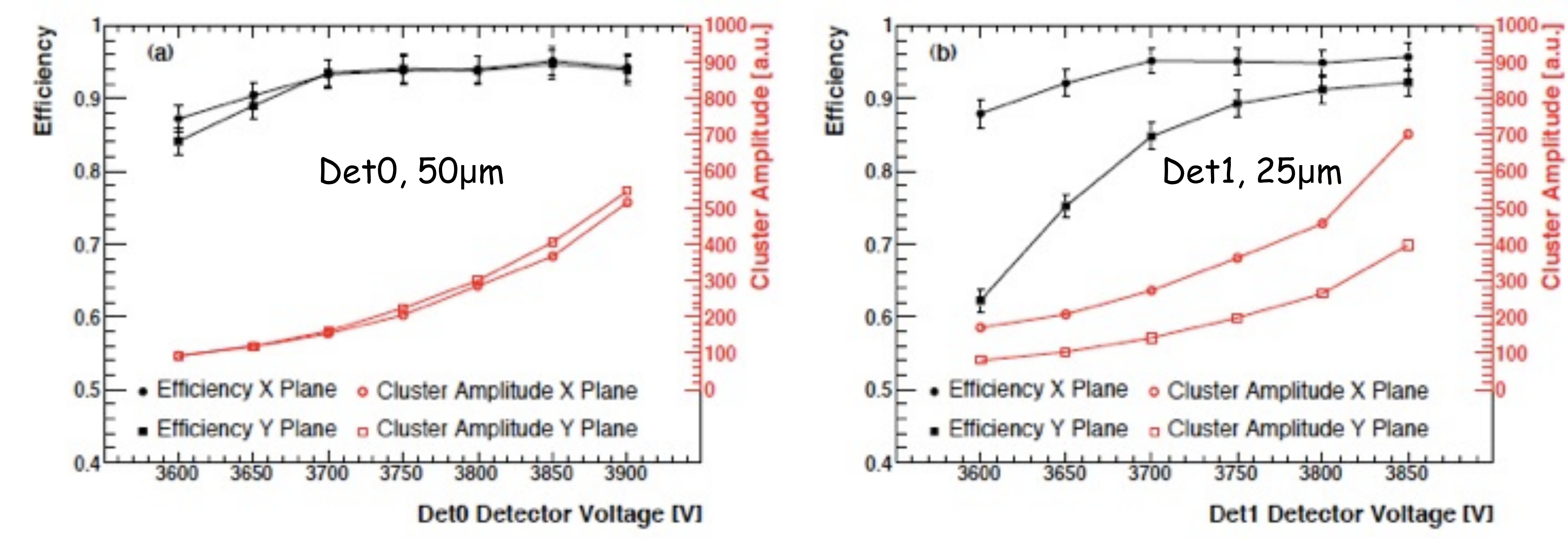


- Cluster charge follows expected distribution
- Two version of readout board (50μm and 25μm)



FGT Technical realization

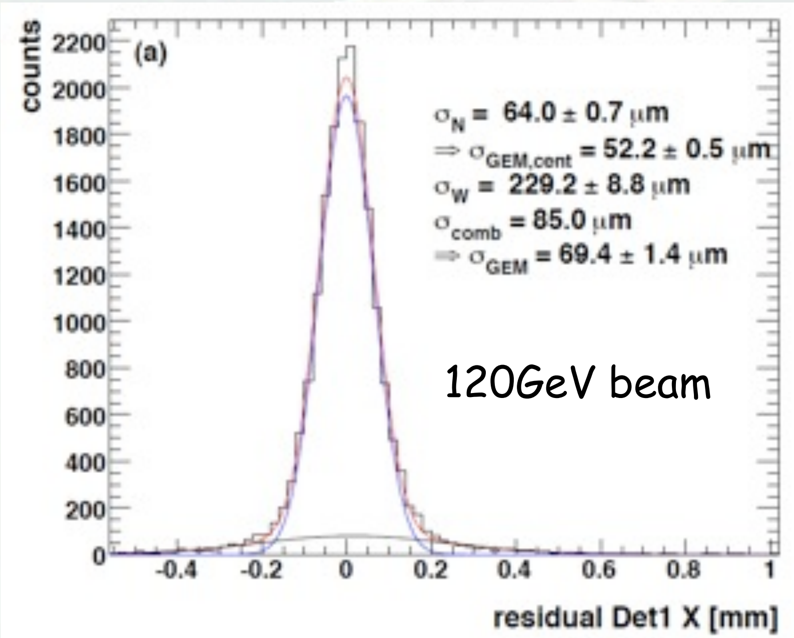
- Testbeam results (3)

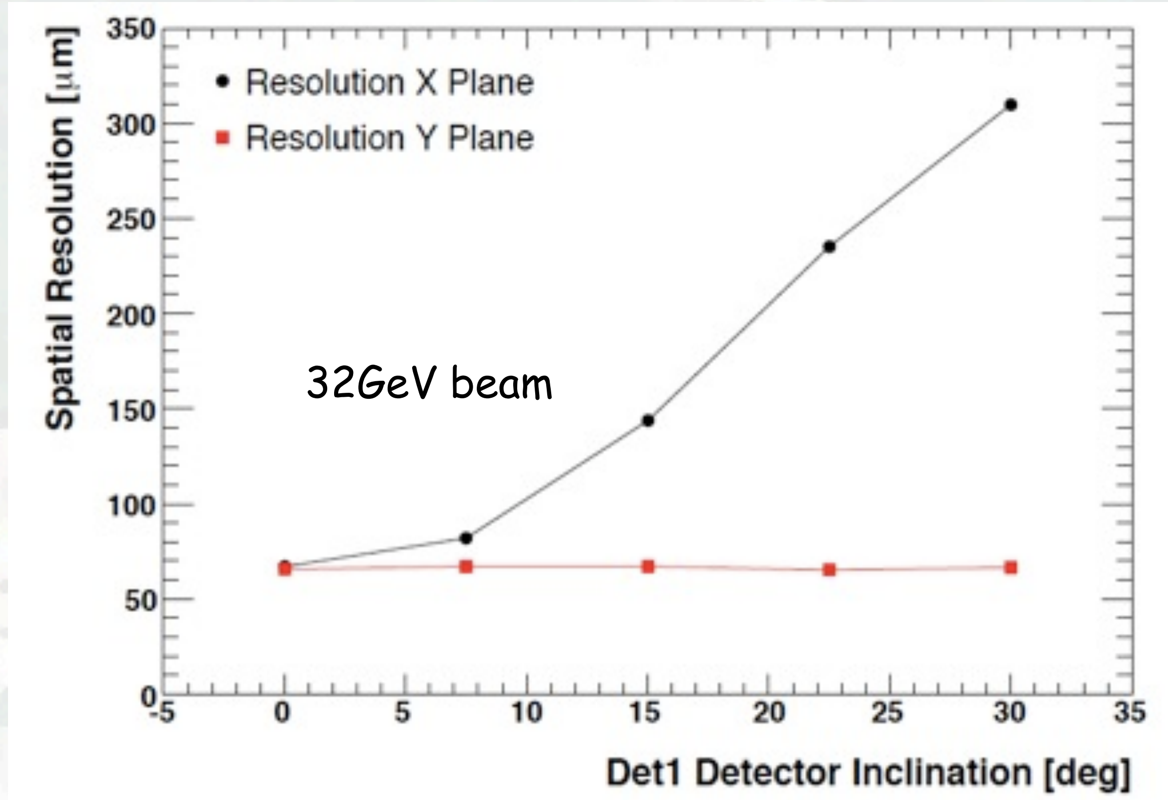


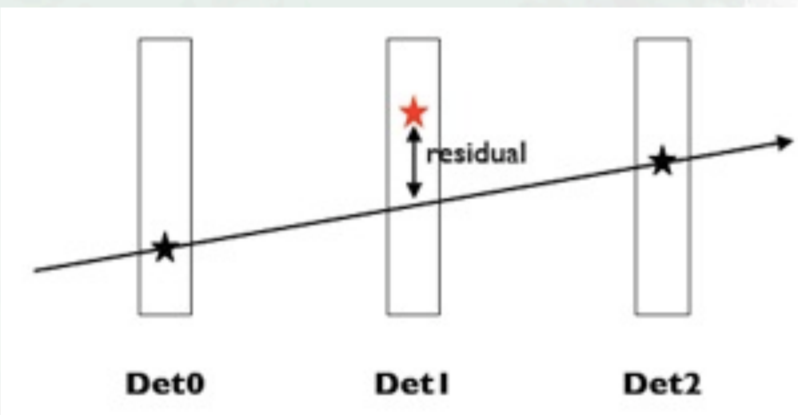
- Efficiencies at the level of ~95%-98% were reached in regions which limit the impact of noisy and dead regions with Tech-Etch GEM foils (Not affected by high intensity studies)
- Clear difference between Det0 (50µm) and Det 1 (25µm) for efficiency and cluster amplitude (Most probable value of Landau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

FGT Technical realization

- Testbeam results (4)



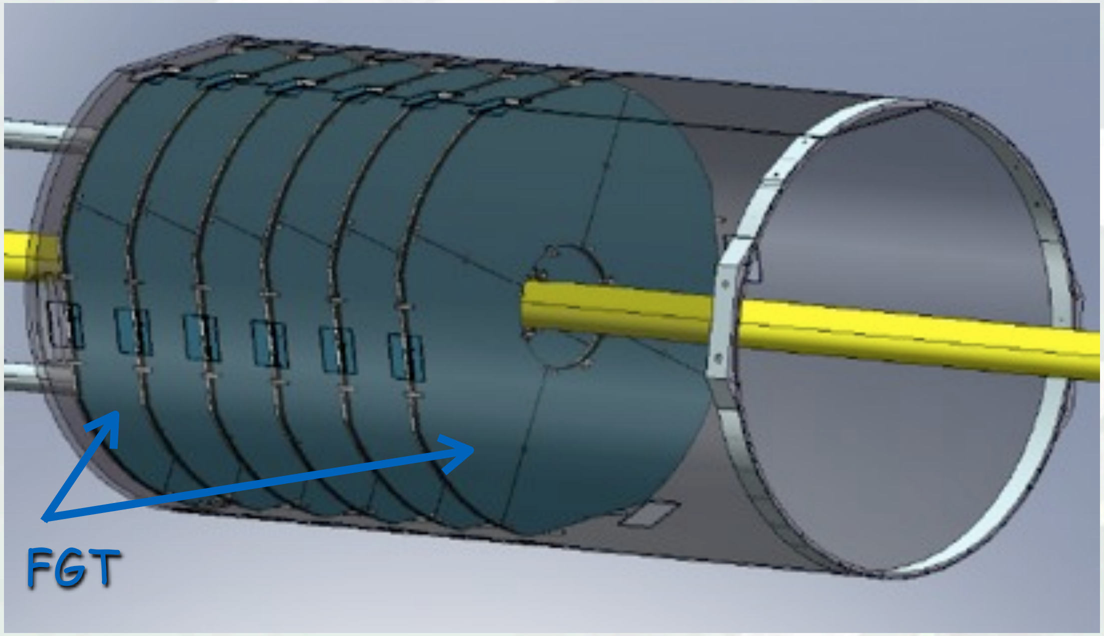


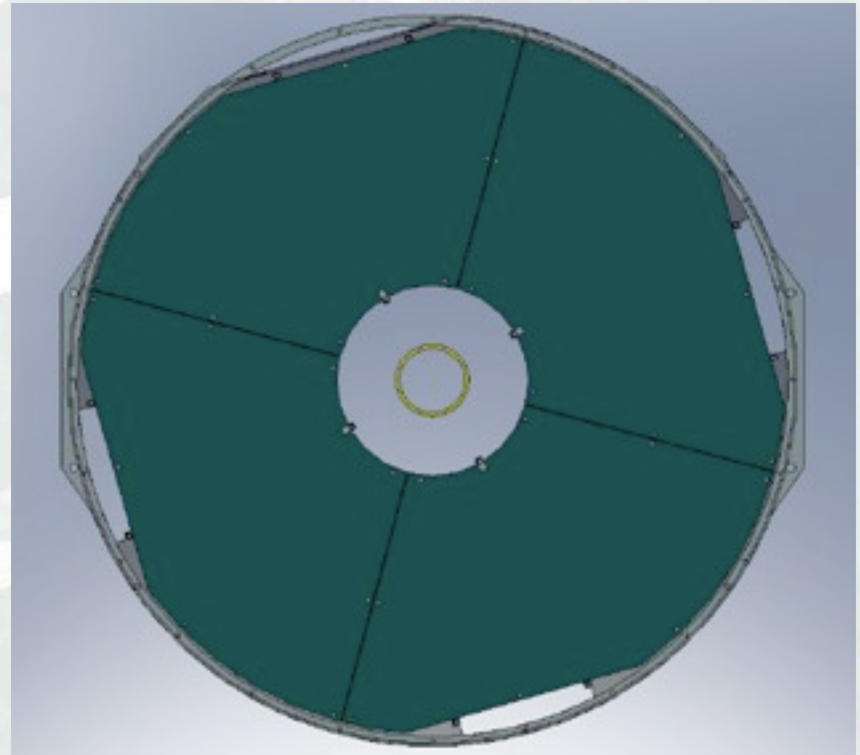


- Study of inclination by up to 30°: Only X (horizontal) resolution is affected, not so for Y (vertical) coordinate as expected!

FGT Technical realization

- Layout

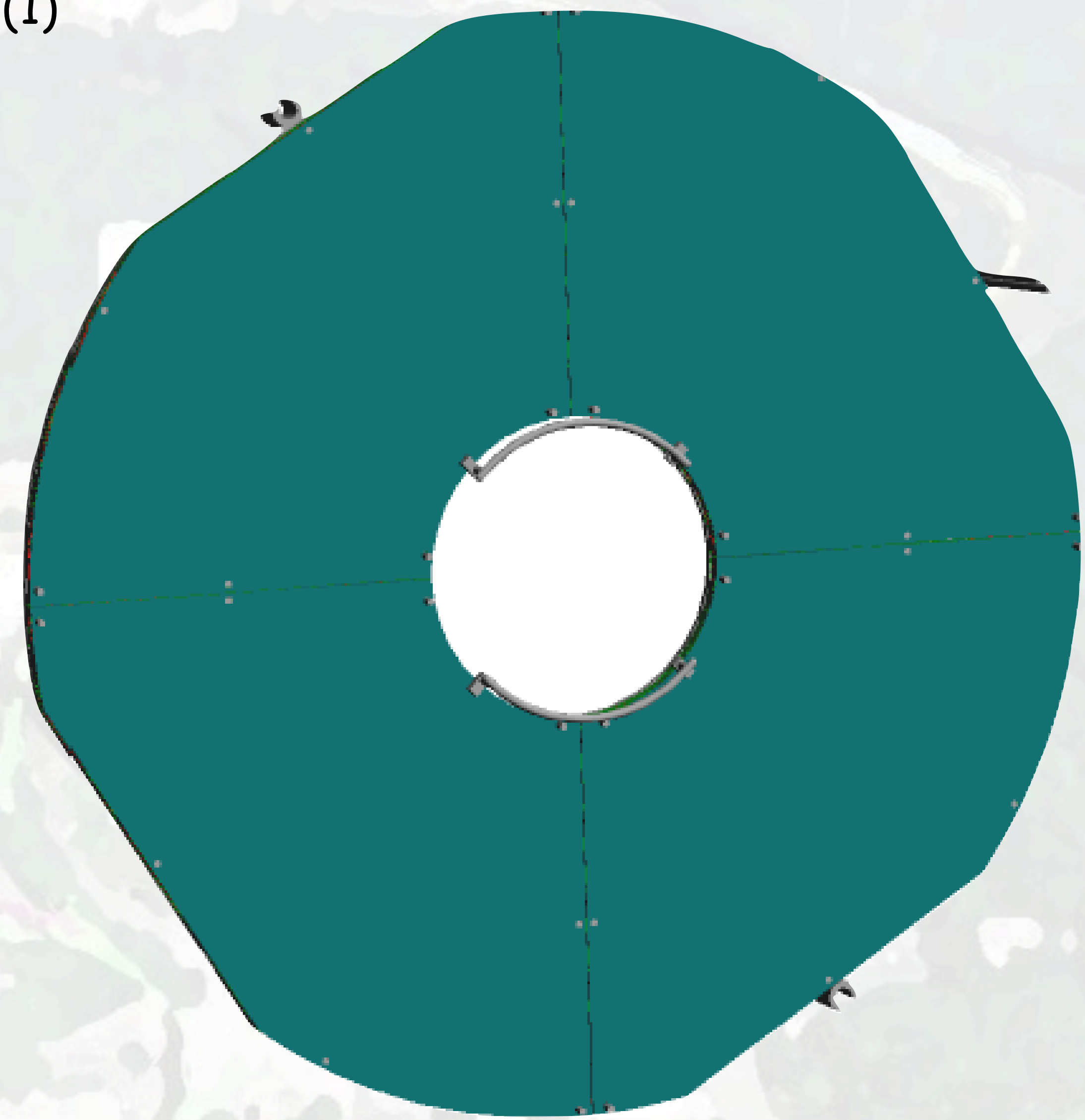




- FGT: 6 light-weight disks
- Each disk consists of 4 triple-GEM chambers (Quarter sections)
- Procurement and assembly of full quarter section prototype in preparation

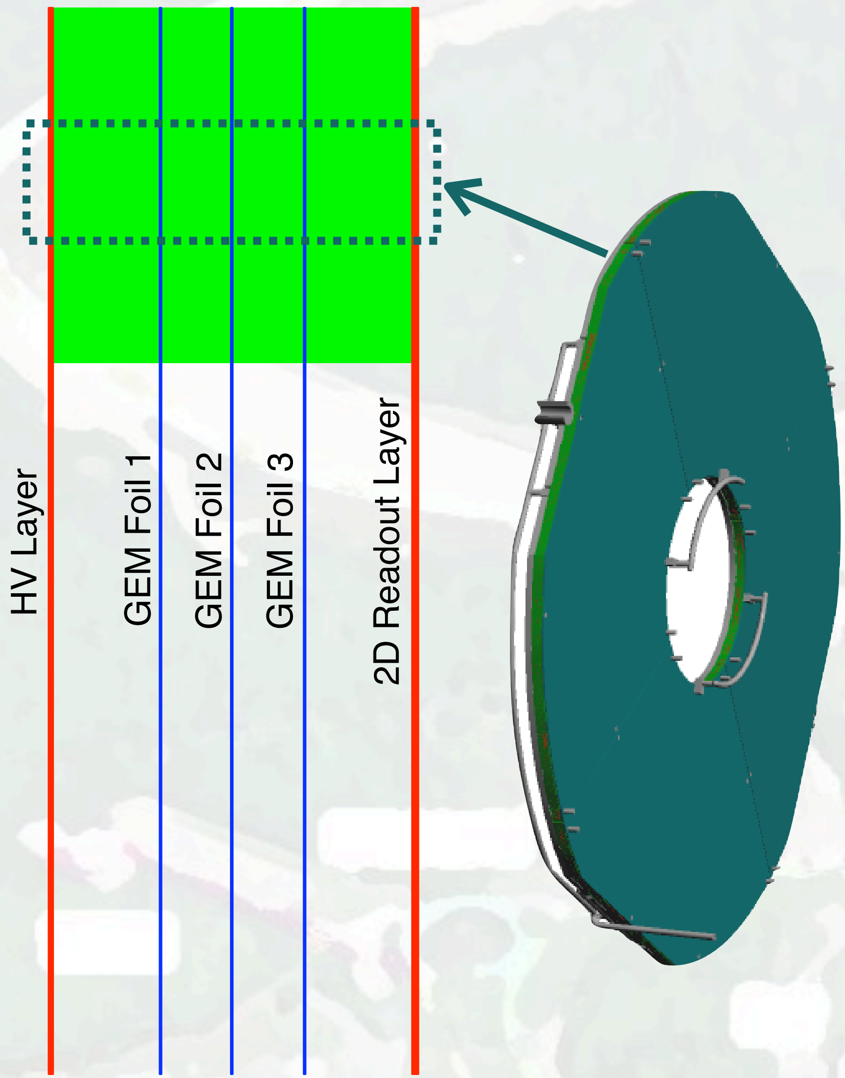
FGT Technical realization

- 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

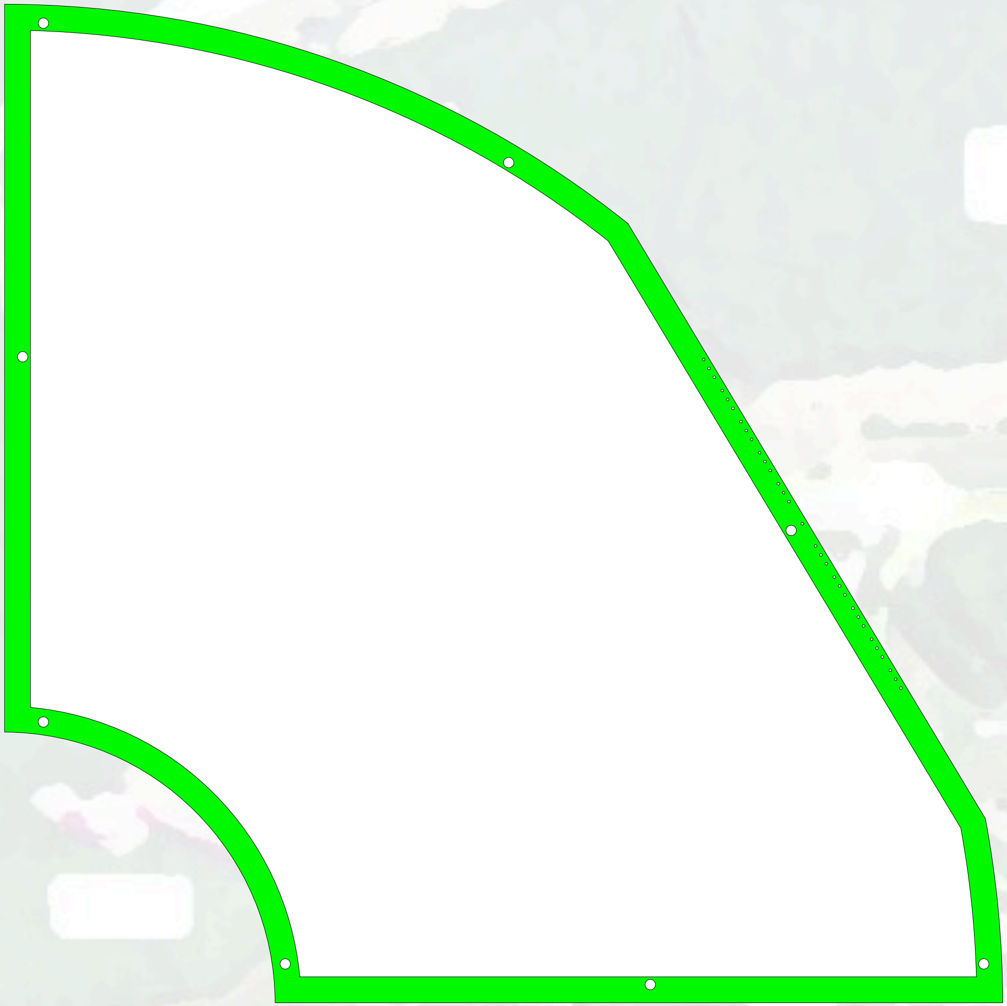
- Triple-GEM: Quarter section design (2)



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

FGT Technical realization

- Triple-GEM: Quarter section design (3)

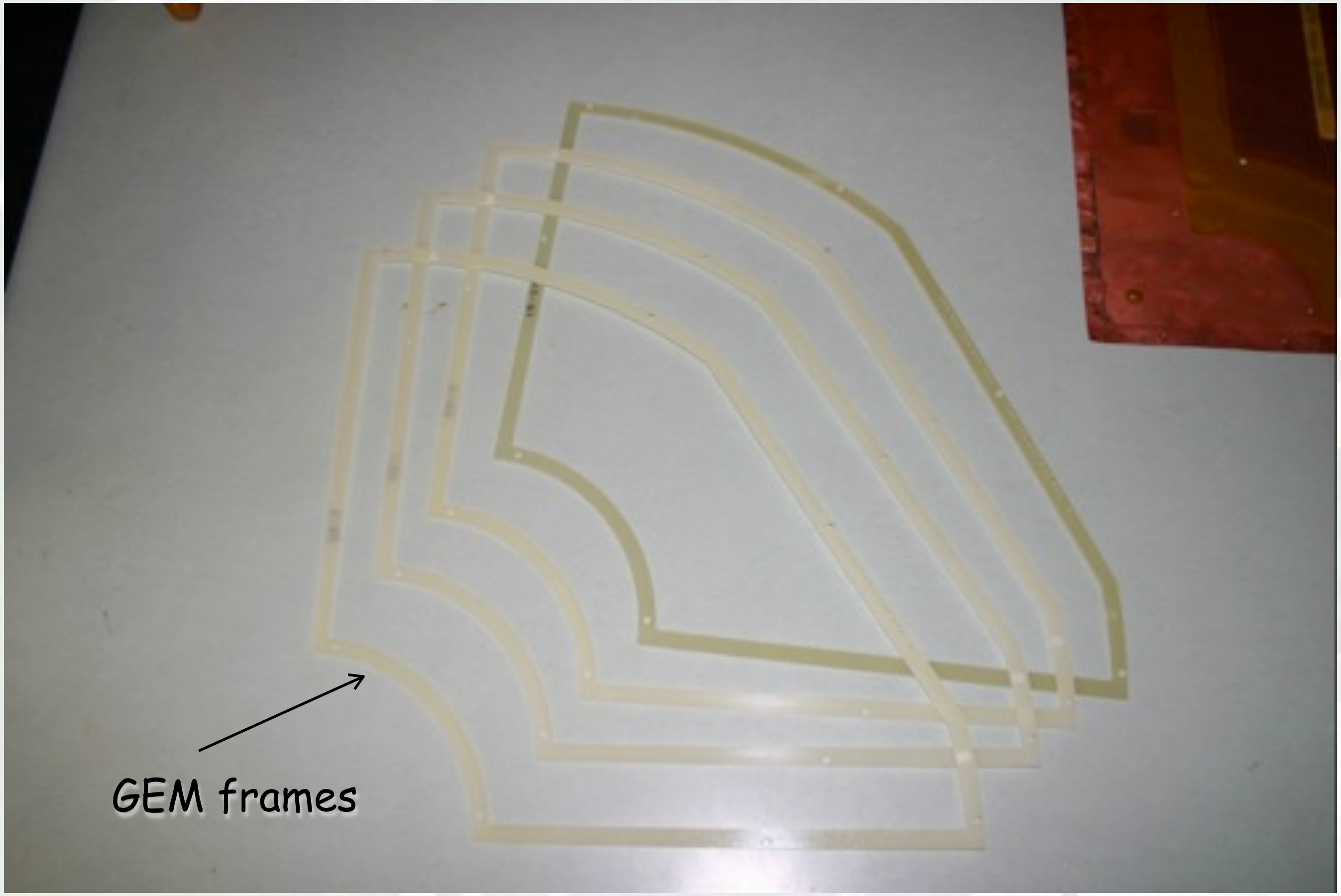


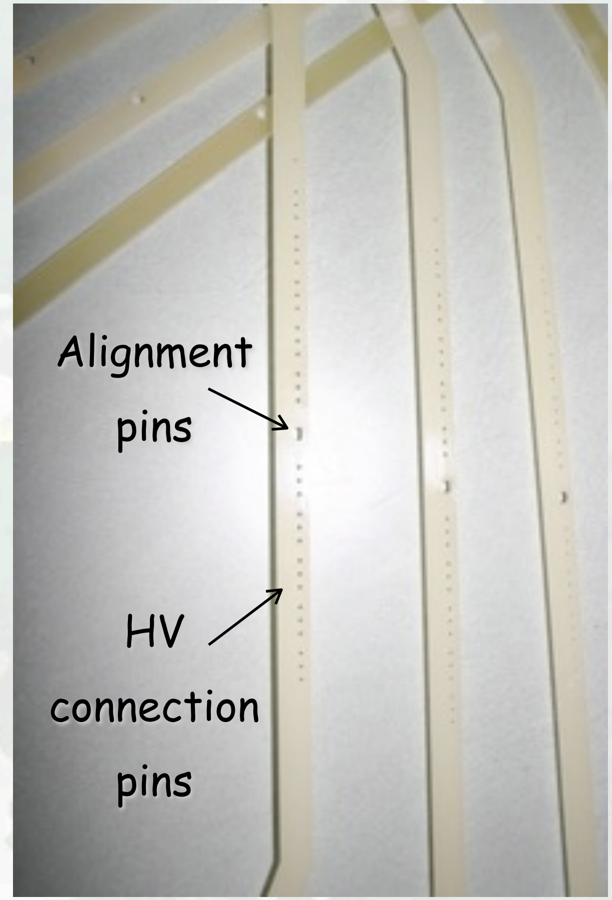
- 1cm wide frames of FR4
- 2-3mm thick
- Inner radius: 10.5cm
- Outer radius: 38.1cm
- Flat at 31°
- 1mm gap between quadrants
- 4mm FR4 pins
- 34 X 1mm holes for HV GEM foil connection

View at readout layer from downstream!

FGT Technical realization

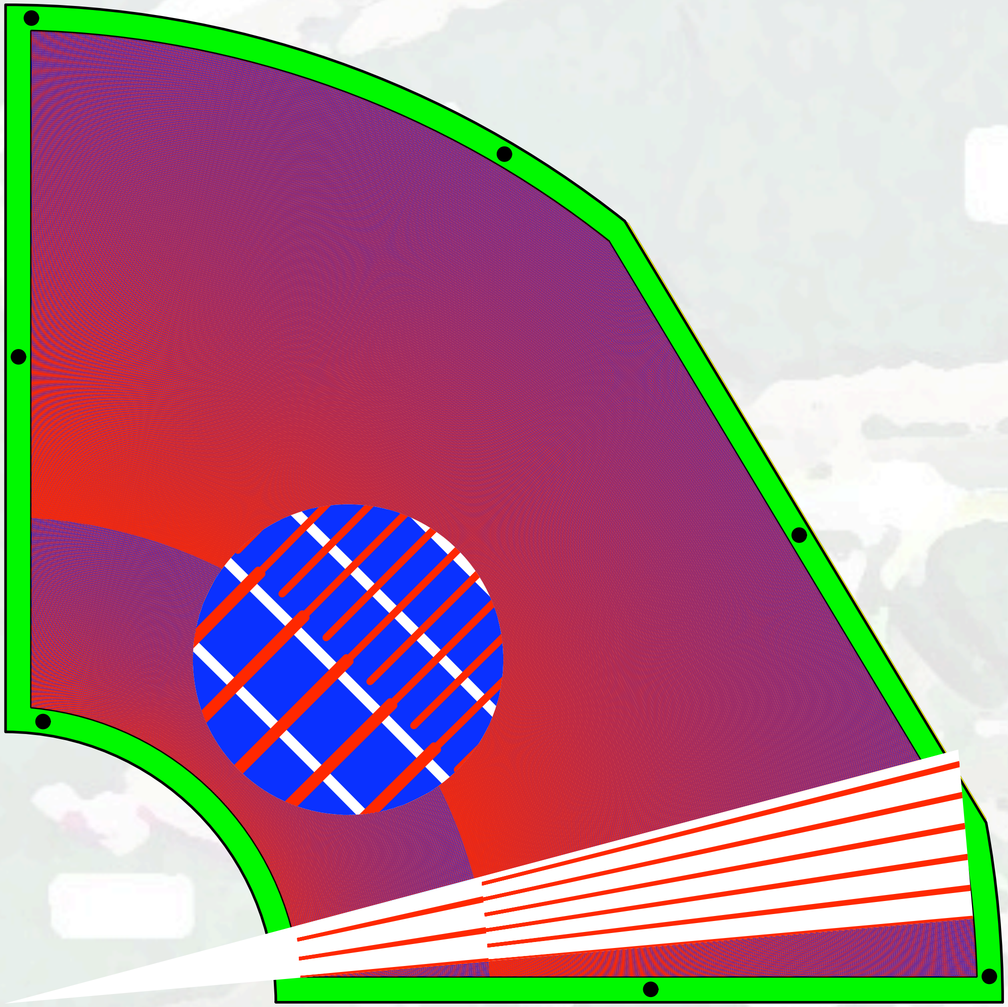
- Triple-GEM: Quarter section design (4)





FGT Technical realization

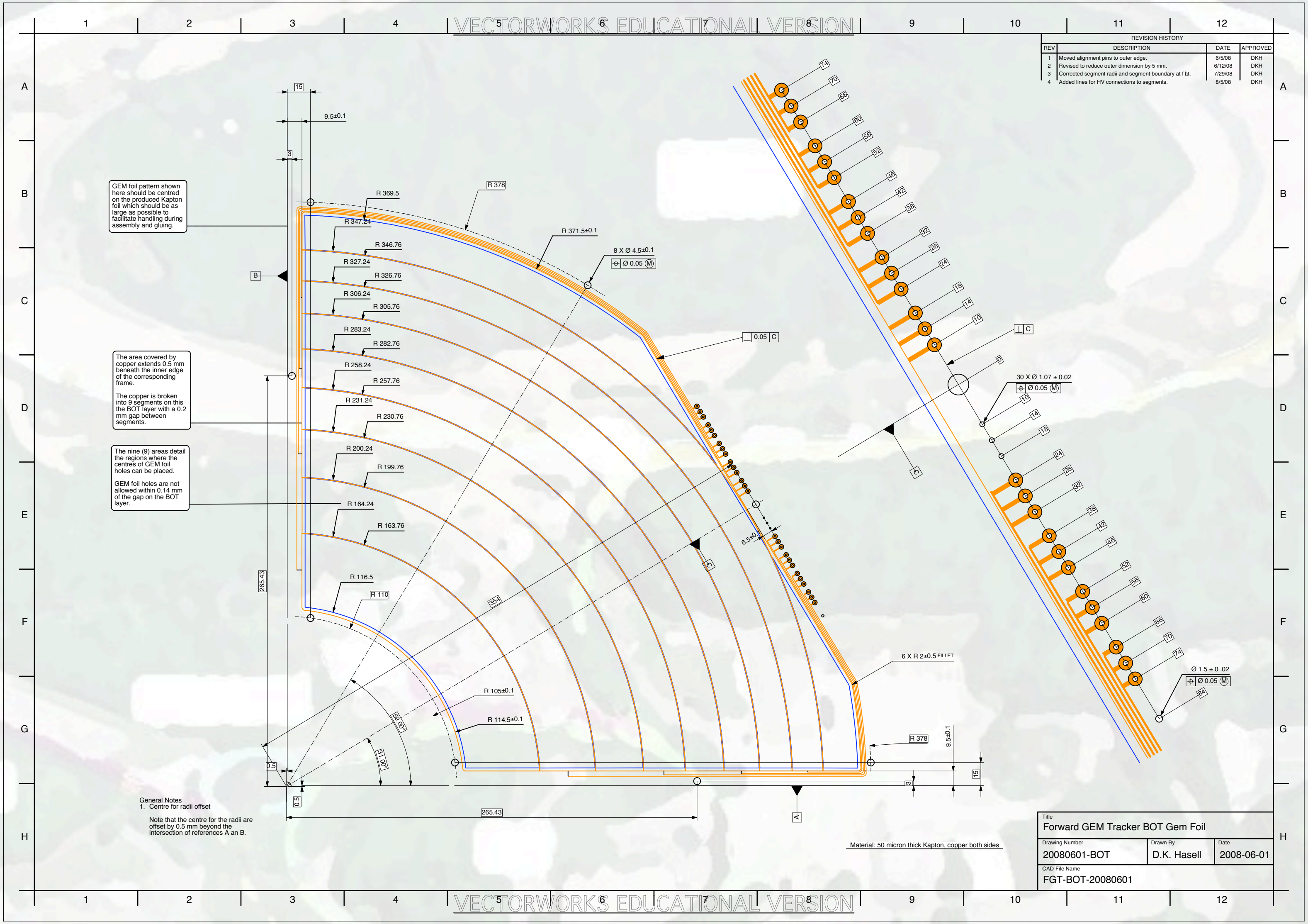
- Triple-GEM: Quarter section design (5)



- 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

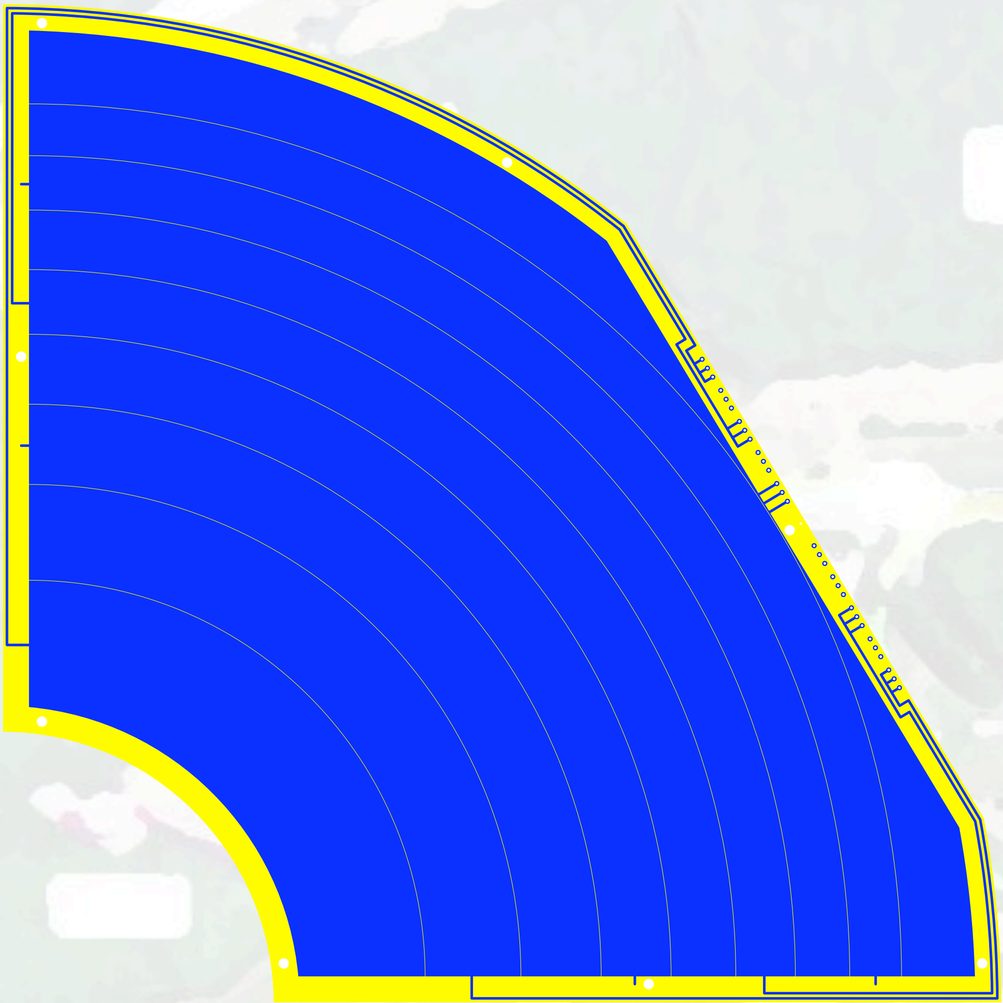
FGT Technical realization

- Triple-GEM: GEM foil design (1)



FGT Technical realization

- Triple-GEM: GEM foil design (2)



Segmented GEM foils:

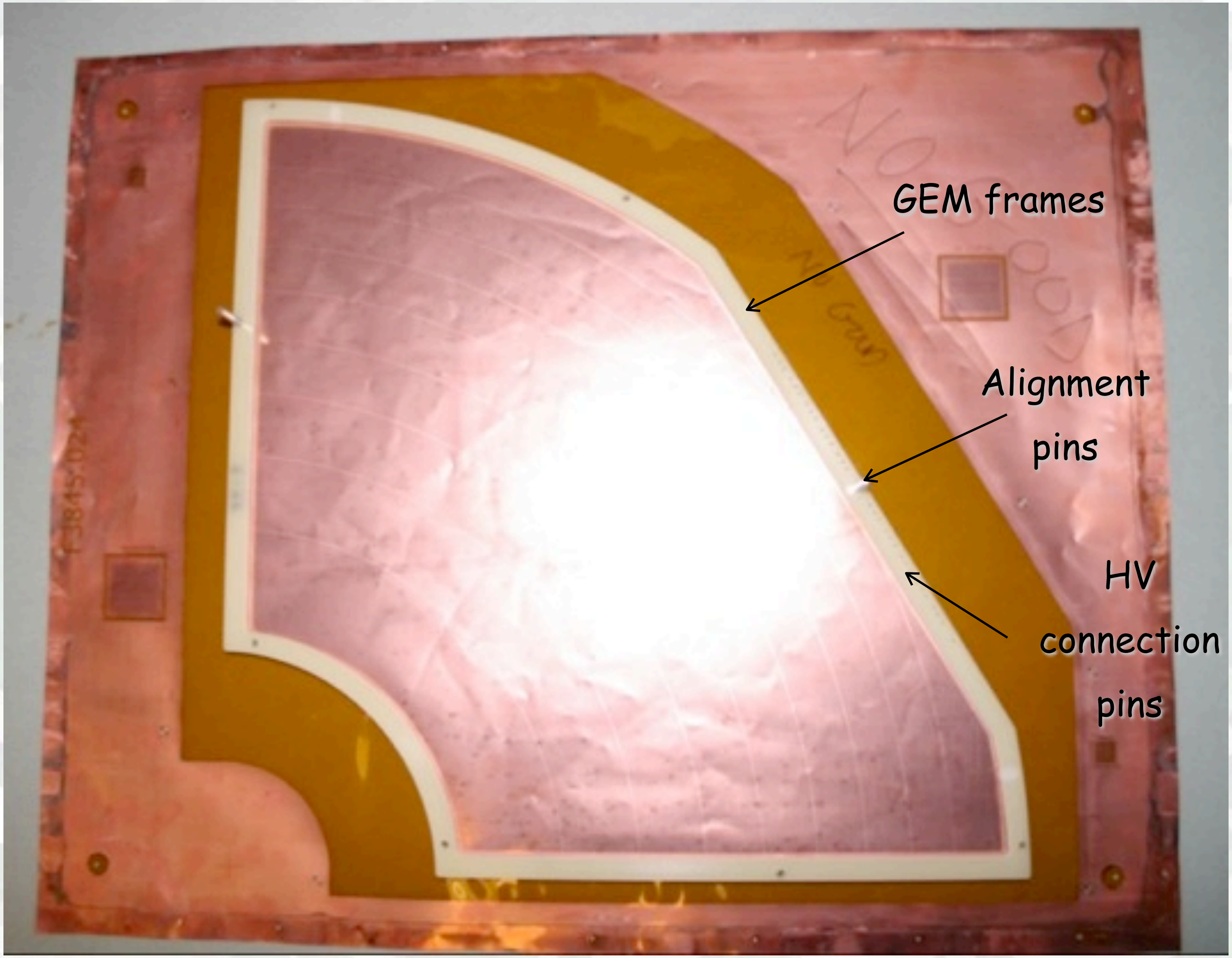
- Minimize damage in case of breakdown
- 9 segments in radial direction with ~100cm^2 each
- Gap: 200μm
- Hole pitch (~ 140μm) and diameter (I: ~50μm /O: ~60μm) similar to prototype!
- Routing and vias distribute HV to segments

FGT Technical realization

- Triple-GEM: GEM foils at MIT (1)

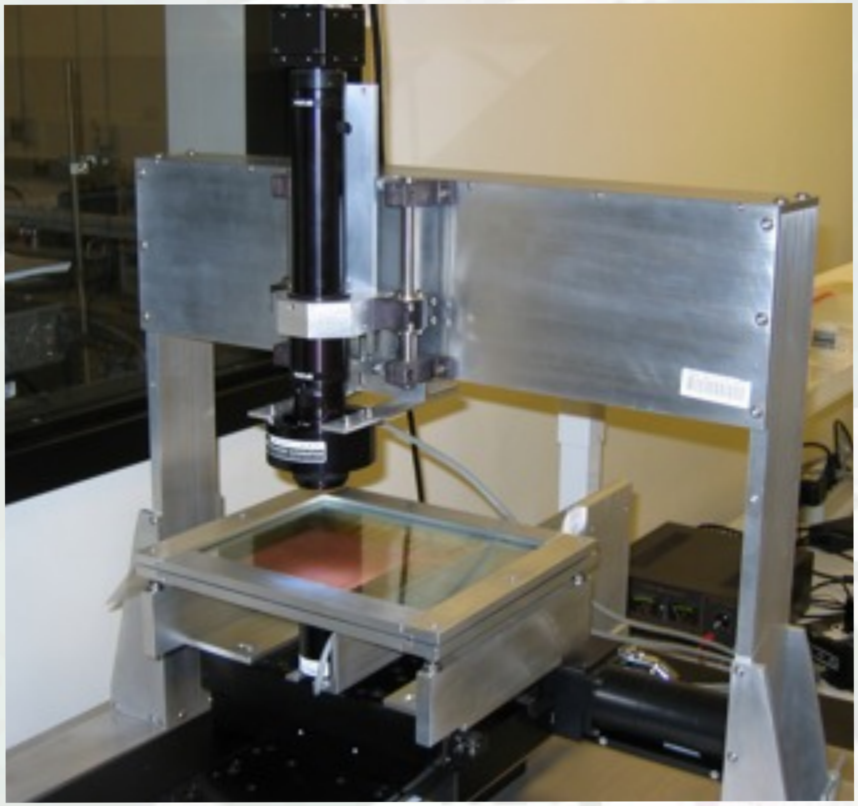
FGT Technical realization

- Triple-GEM: GEM foils at MIT (2)



FGT Technical realization

- Triple-GEM: GEM foil testing (1)



CCD camera setup for optical GEM foil scans

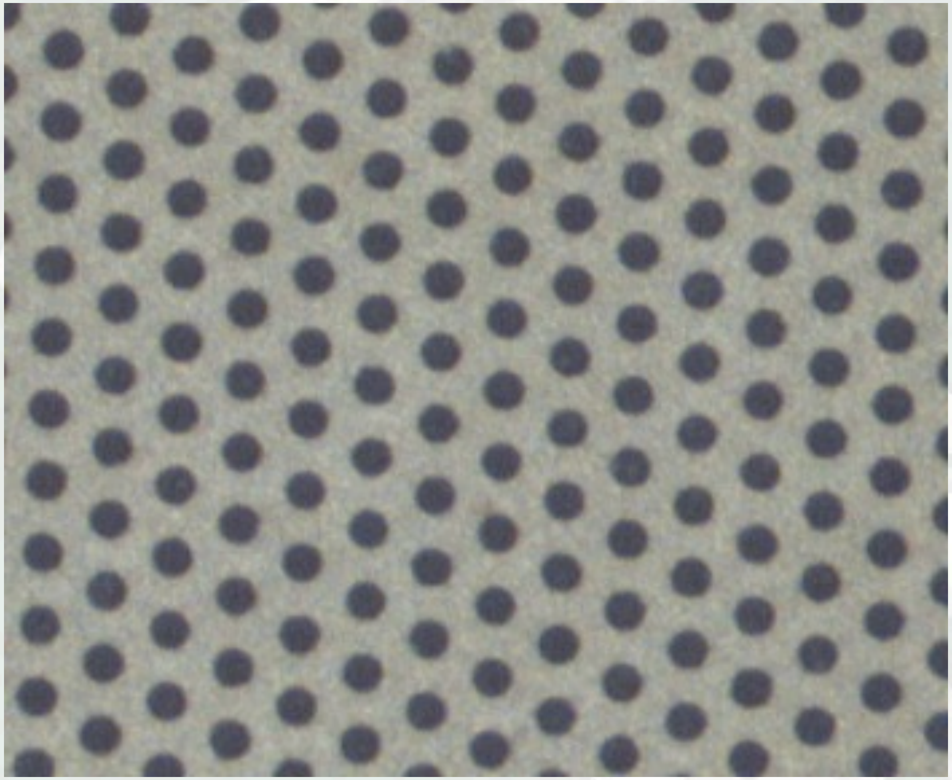
(Glass plate modifications in progress)

HV Vacuum / Nitrogen box for GEM foil dark current tests

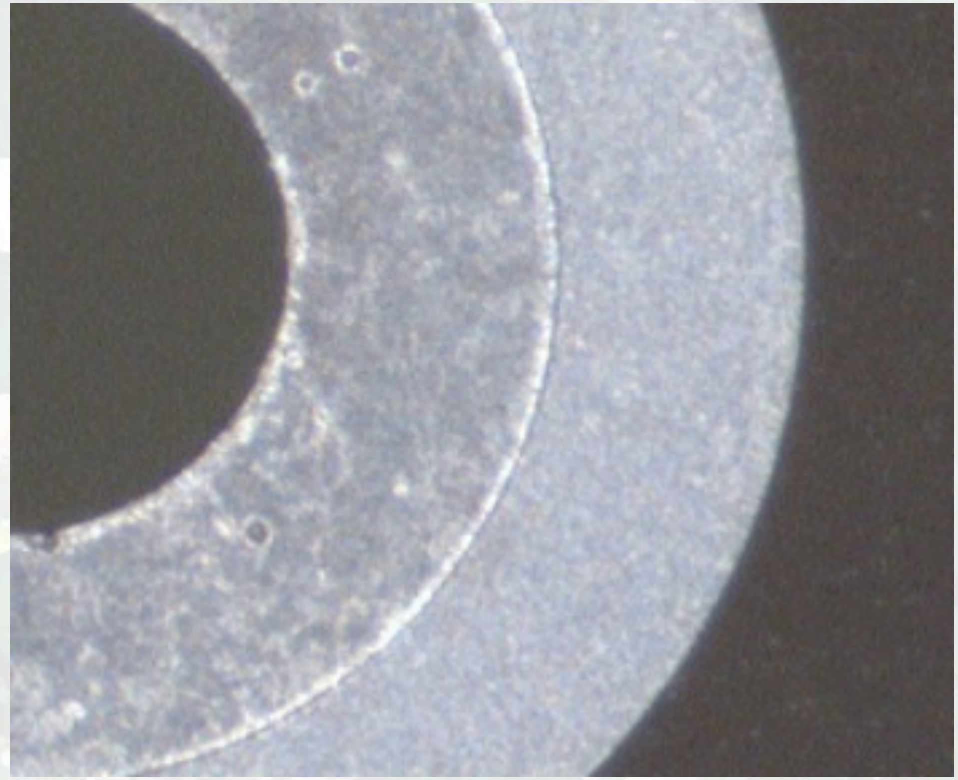
(Minor modifications necessary - In progress)

FGT Technical realization

- Triple-GEM: GEM foil testing (2)



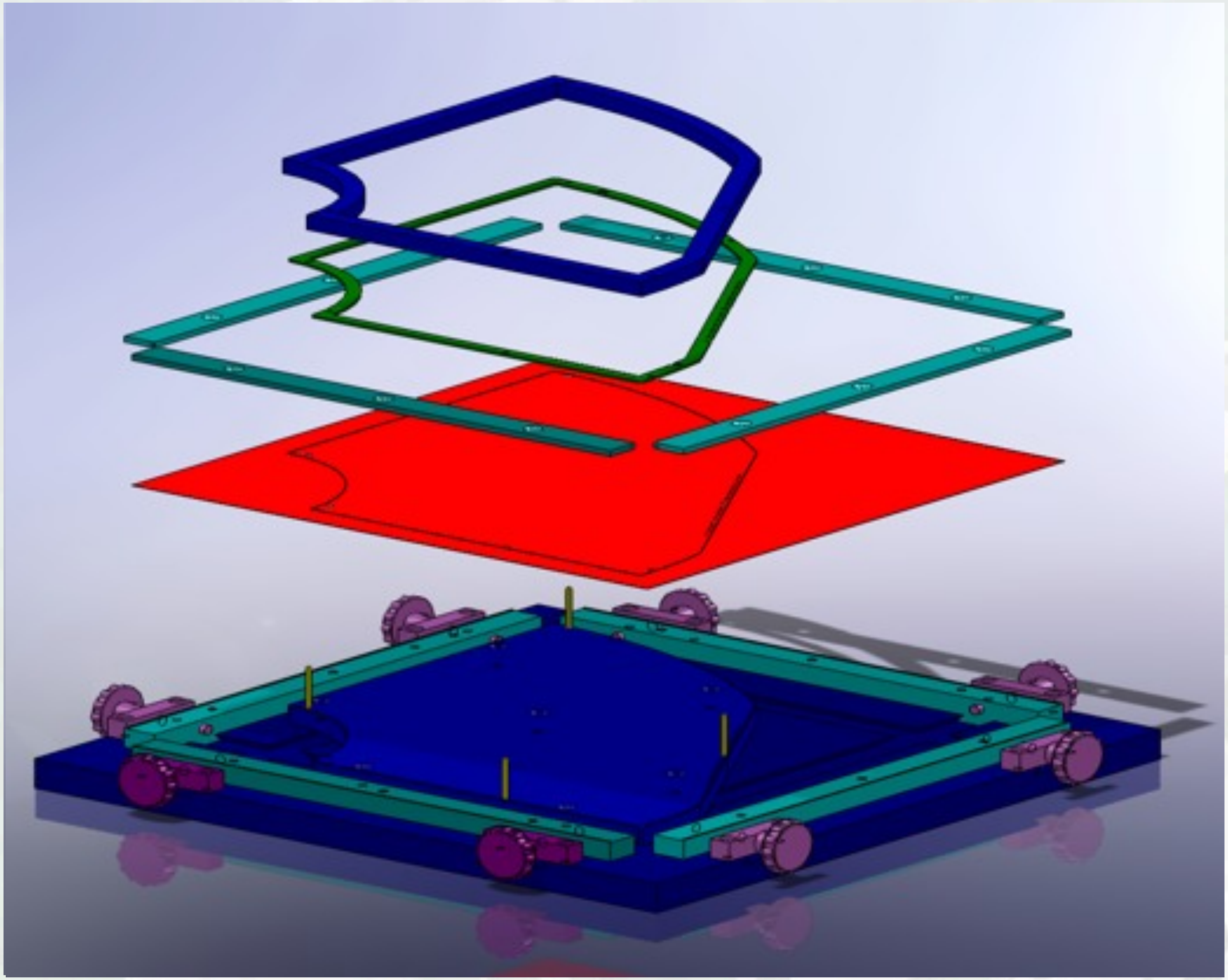
First scan for large GEM foil
(Hole arrangement)



First scan for large GEM foil
(HV connection)

FGT Technical realization

- Triple-GEM: GEM foil stretching and assembly tooling



Stretching jig:

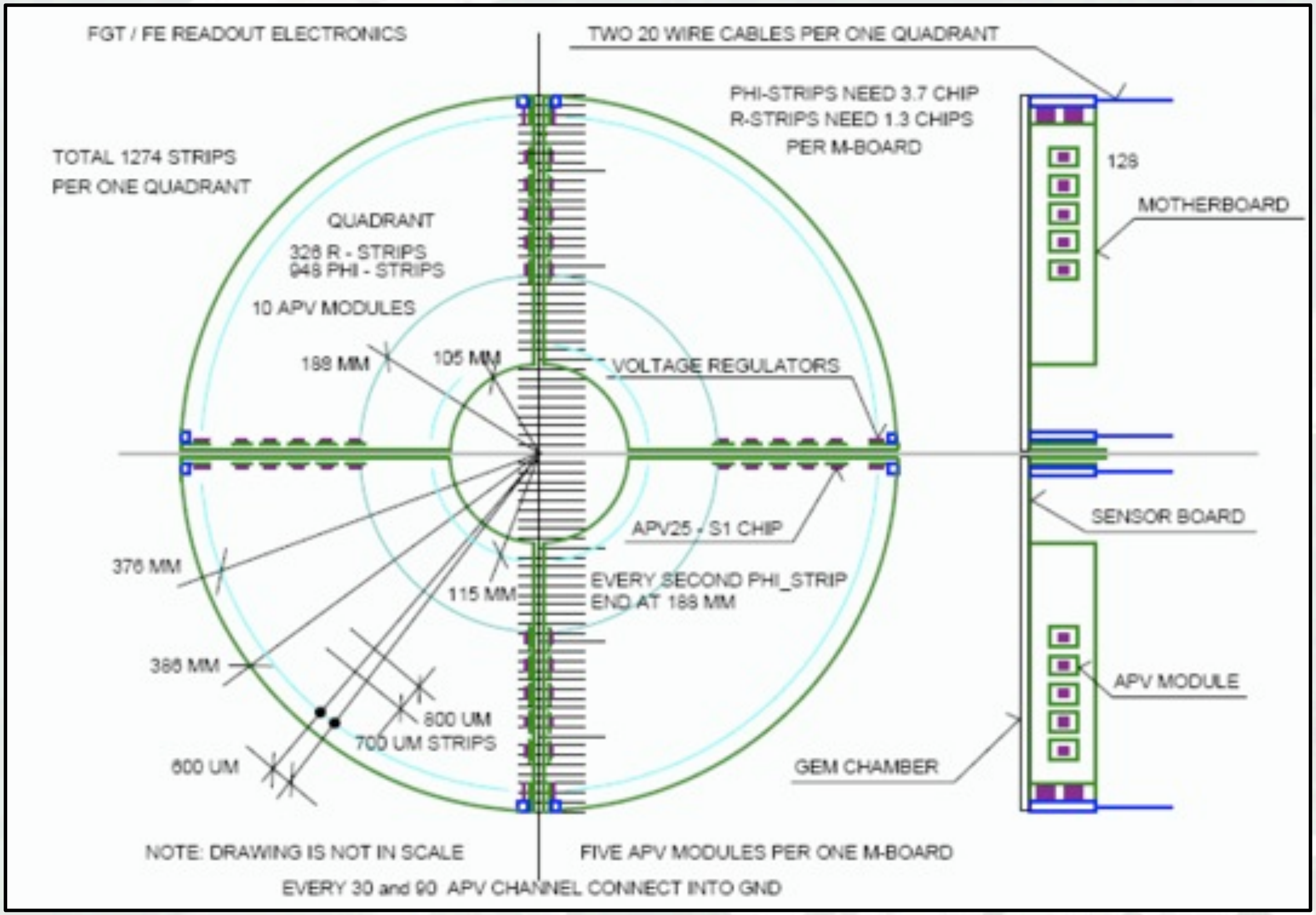
- Stretch GEM foil
- Clamp 2mm spacer for single glue operation

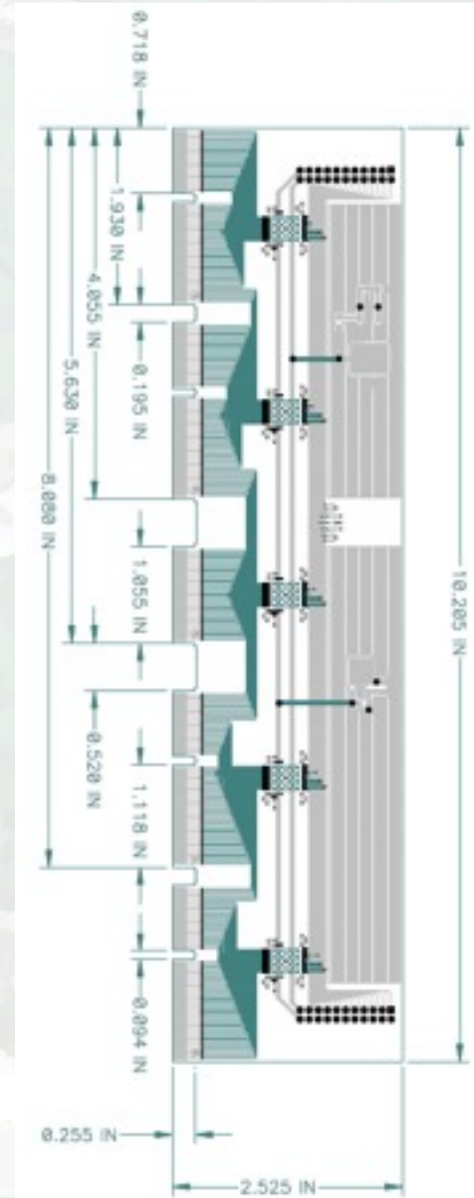
Assembly jig:

- 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

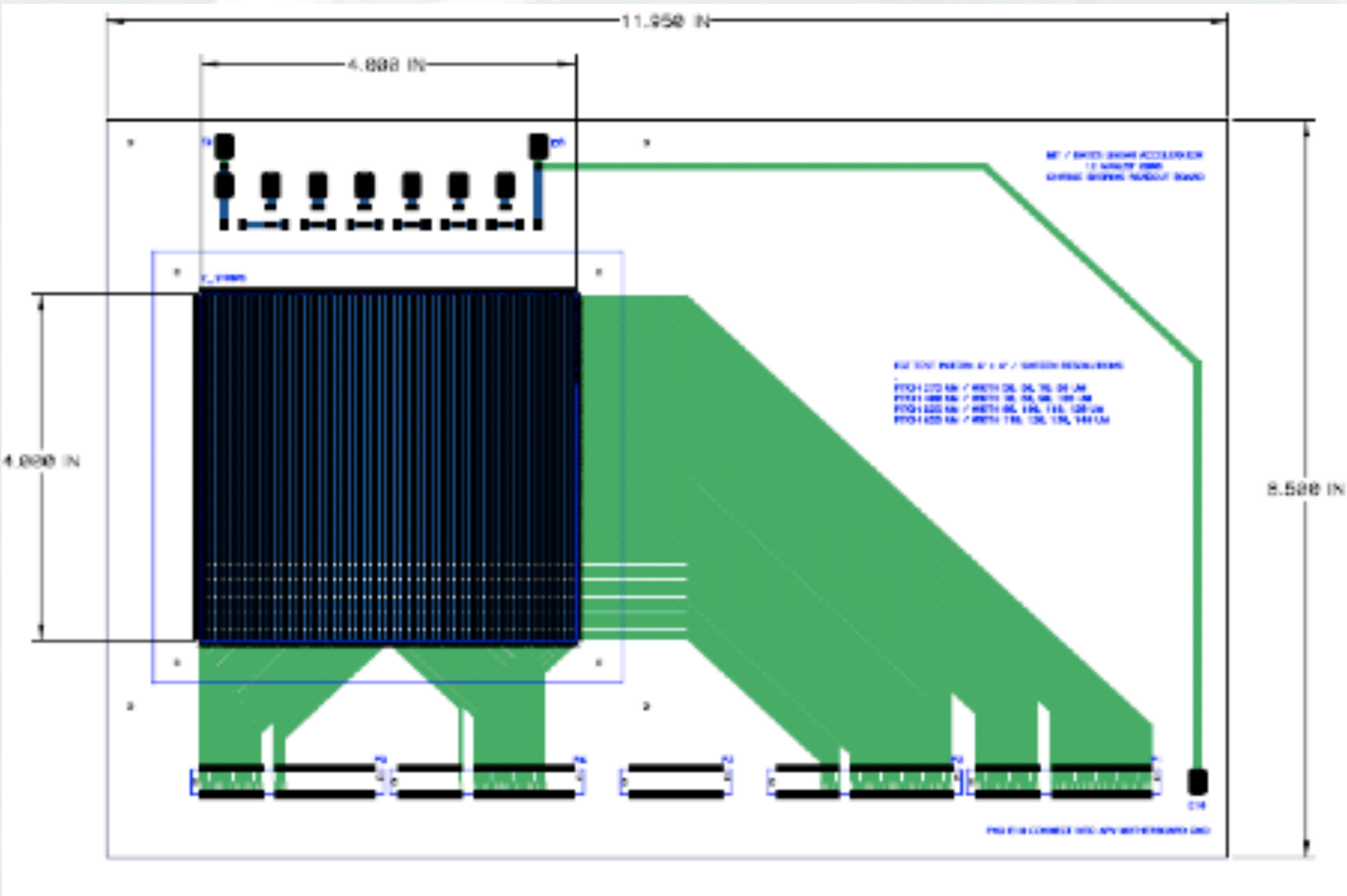
- Triple-GEM: 2D readout board design (1)





FGT Technical realization

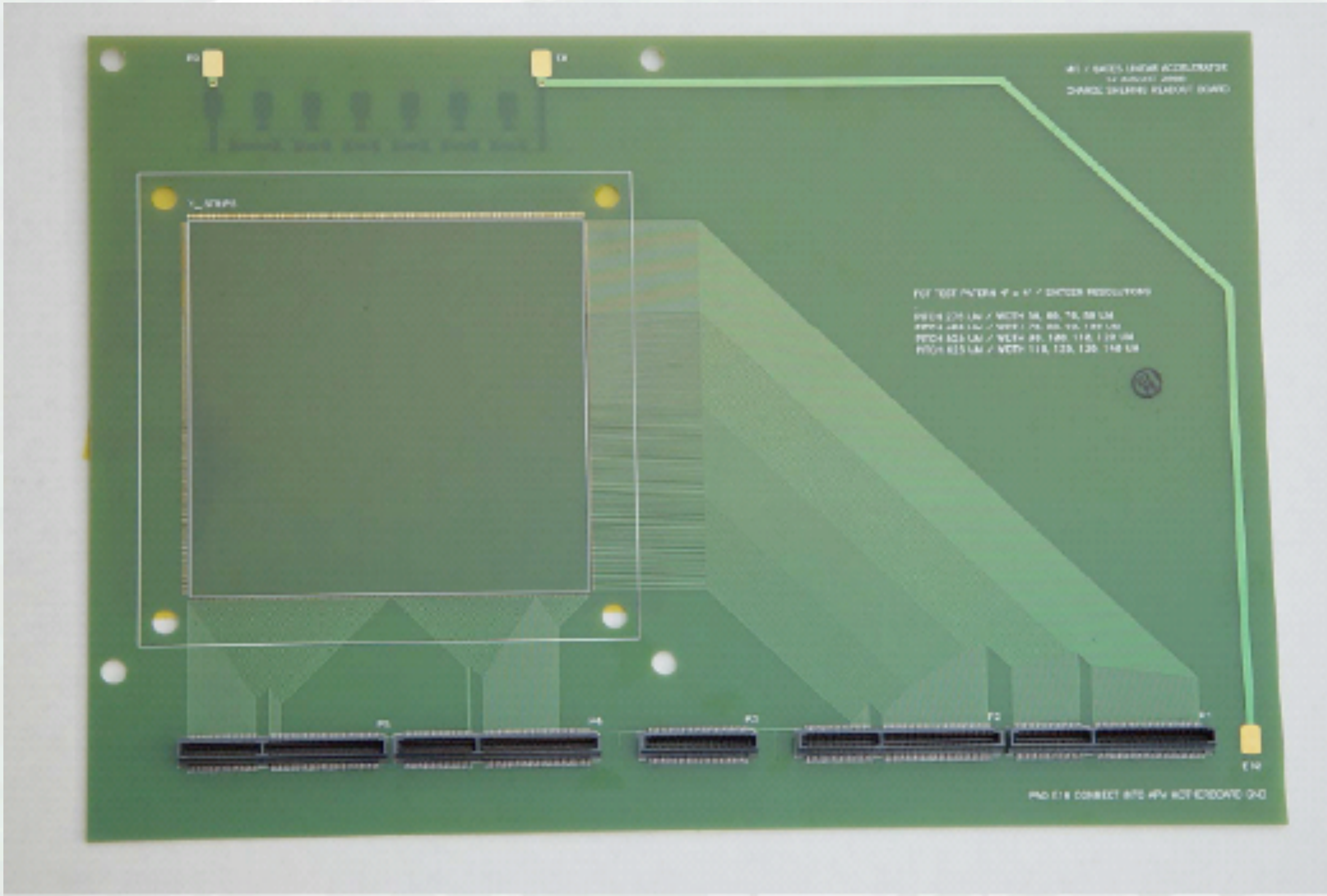
- Triple-GEM: 2D readout board design (2)



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

FGT Technical realization

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



- Manufactured by Compunetics Inc.
- Delivered to MIT-Bates, December 2009
- Assembly in progress

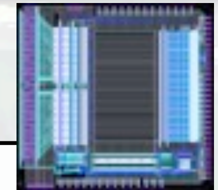
FGT Technical realization

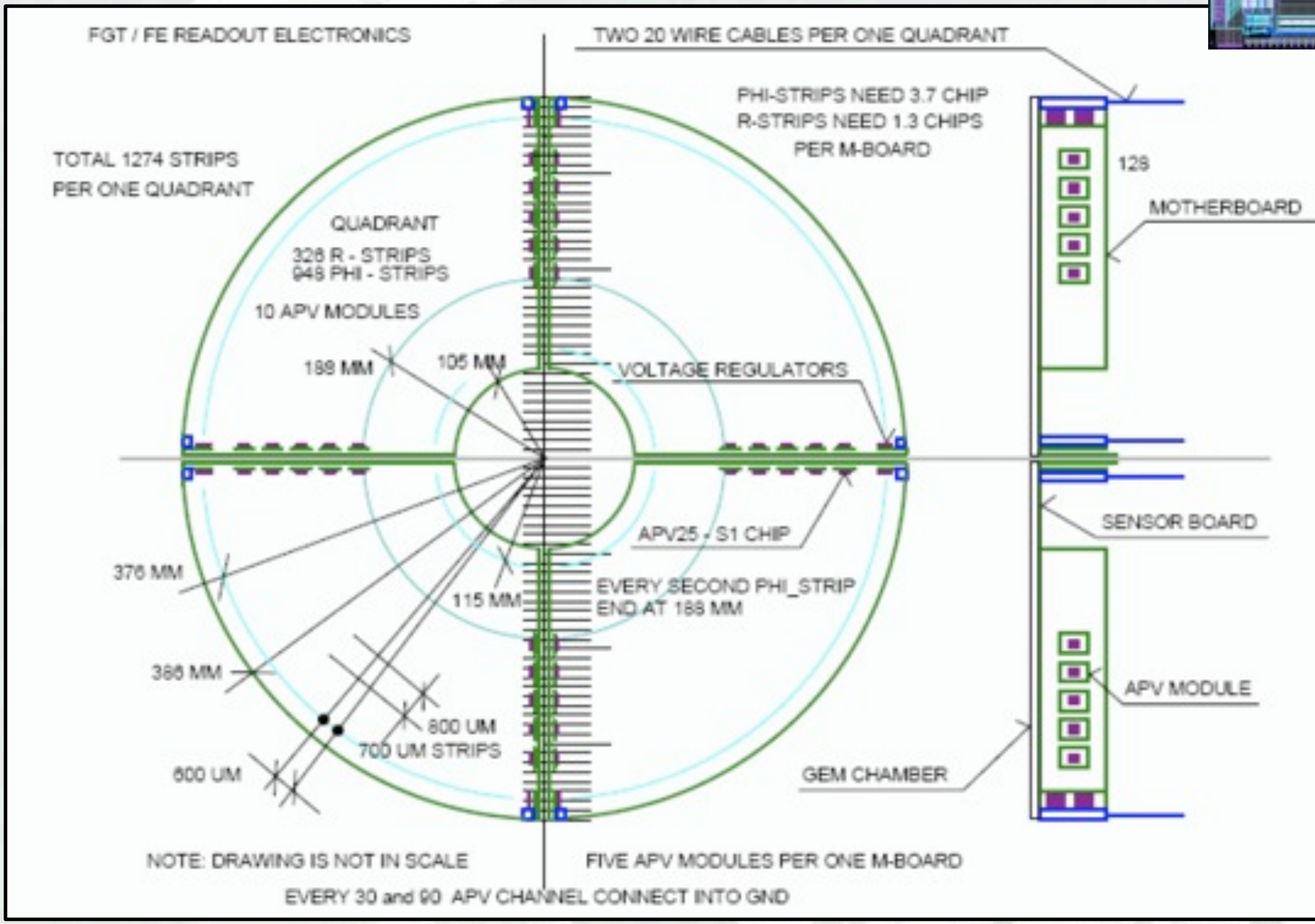
- Triple-GEM: Plans / Issues (Until June 2009)
  - Finish tests of large GEM foils
  - Charge sharing board assembly and test
  - Finalize design of 2D readout board and order full scale 2D readout board prototype
  - Assembly and test of full scale prototype (Source test and cosmic ray test setup)
  - Order of GEM foils and beginning of testing

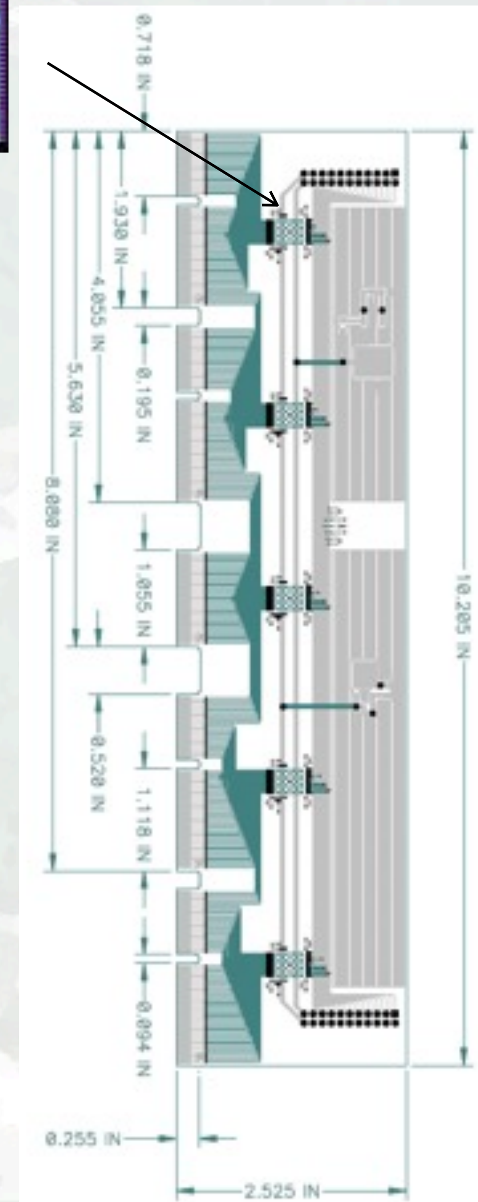
FGT Technical realization

- FEE: Overview

APV25-S1 chips

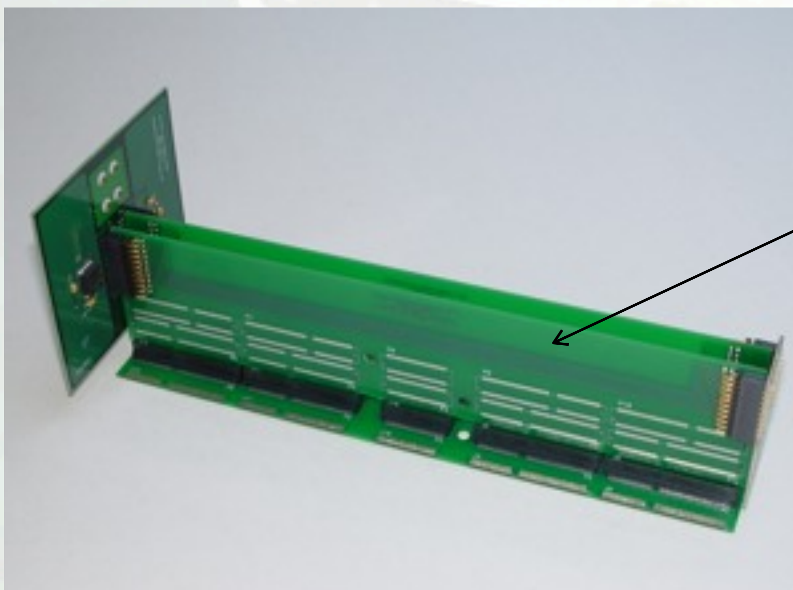




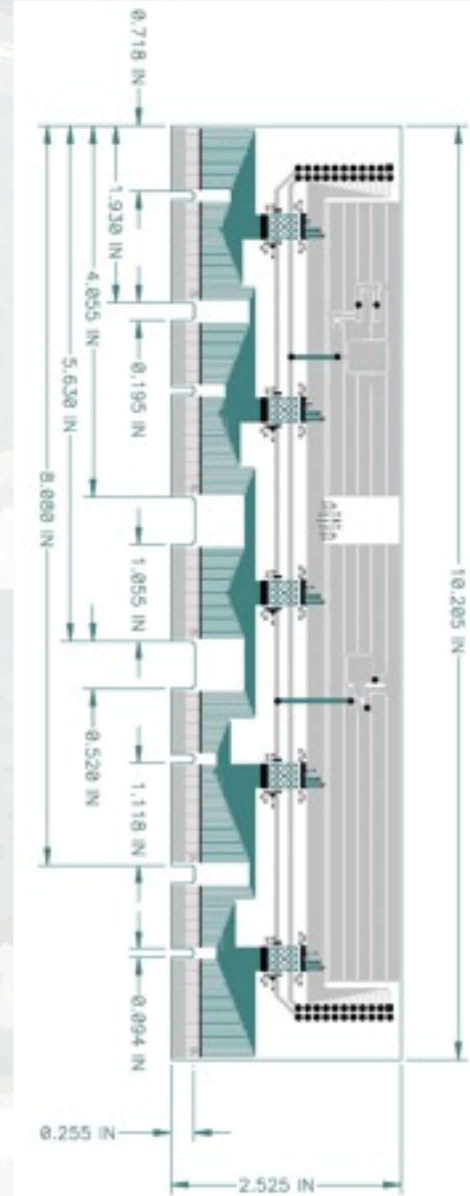


FGT Technical realization

- FEE: APV module
  - Design of APV module completed
  - Fabrication of APV module ongoing by Compunetics Inc.
  - APV module will be used for test-charge board and full-scale prototype

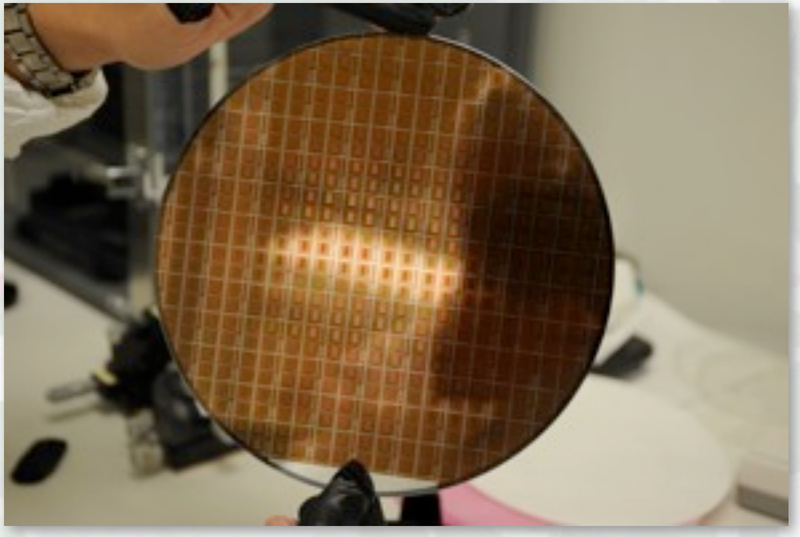


APV test module for multi-pin connector tests



FGT Technical realization

- FEE: APV25-S1 chips at MIT



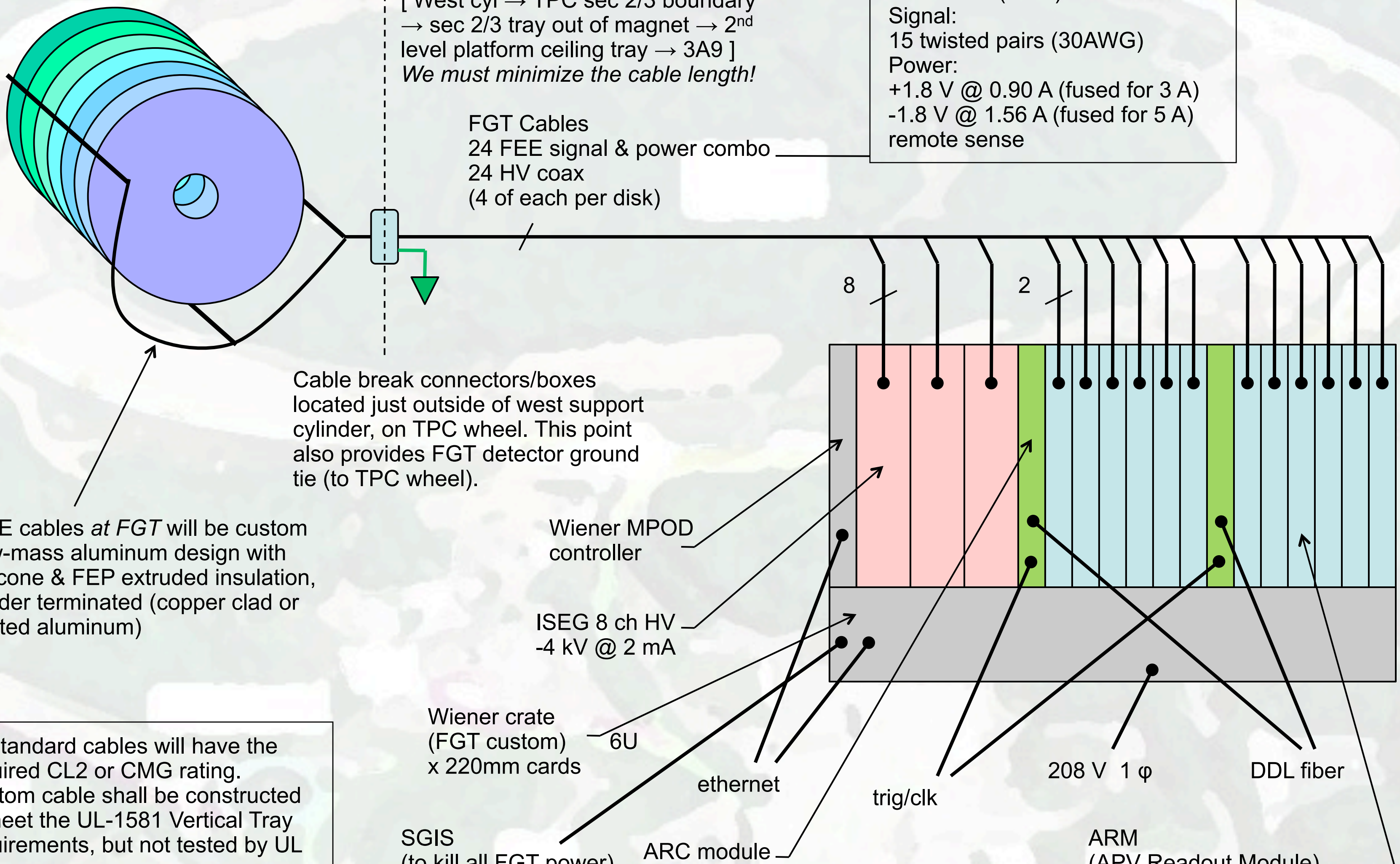
FGT Technical realization

DAQ: Overview

MEASURED (GV) cable run **37 feet**
[West cyl → TPC sec 2/3 boundary → sec 2/3 tray out of magnet → 2nd level platform ceiling tray → 3A9]
We must minimize the cable length!

FEE cable (each)
Signal:
15 twisted pairs (30AWG)
Power:
+1.8 V @ 0.90 A (fused for 3 A)
-1.8 V @ 1.56 A (fused for 5 A)
remote sense

FGT Cables
24 FEE signal & power combo
24 HV coax
(4 of each per disk)



Cable break connectors/boxes located just outside of west support cylinder, on TPC wheel. This point also provides FGT detector ground tie (to TPC wheel).

FEE cables *at FGT* will be custom low-mass aluminum design with silicone & FEP extruded insulation, solder terminated (copper clad or plated aluminum)

All standard cables will have the required CL2 or CMG rating. Custom cable shall be constructed to meet the UL-1581 Vertical Tray requirements, but not tested by UL

FGT Schedule / Milestones

- Overview - Planing

  - Goal: Installation in summer 2010 ⇒ Ready for anticipated first long 500GeV polarized pp run in FY11 consistent with STAR 5-year Beam Use Request
  - Review: Successful review January 2008 / Beginning of construction funds FY08
  - Cost estimate and planing relies on the R&D and pre-design work:
    - Triple-GEM Detector: Complete prototype tested on the bench and during FNAL testbeam experiment with extensive experience in mechanical design work (MIT-Bates) and assembly including previous experience at COMPASS
    - Front-End Electronics (FEE) System: Complete prototype tested on the bench and during FNAL testbeam experiment based on existing APV25-S1 readout chip (MIT-Bates)
    - Data Acquisition (DAQ) System: Conceptual layout is based on similar DAQ sub-detector systems with extensive experience (ANL/IUCF)
    - GEM foil development: Successful development of industrially produced GEM foils through SBIR proposal in collaboration with Tech-Etch Inc. (BNL, MIT, Yale University)

Summary and Outlook

- Summary
  - Exciting program of W production in polarized proton-proton collisions at RHIC constraining unknown u/d anti-quark distributions - Clear sensitivity in particular at forward rapidity
  - STAR experiment requires upgrade of forward tracking system for charge sign discrimination of electrons/positrons
  - Triple-GEM technology provides a cost effective way for a forward tracking upgrade solution
  - Successful development of industrial production of GEM foils (SBIR proposal with Tech-Etch Inc.) - Test of large GEM foils ongoing
  - Successful beam test at FNAL demonstrates that performance meets requirements
  - Design work being finalized - Pre-production underway
  - Goal: Installation summer 2010 to be ready for Run 11