The STAR Forward GEM Tracker (FGT)

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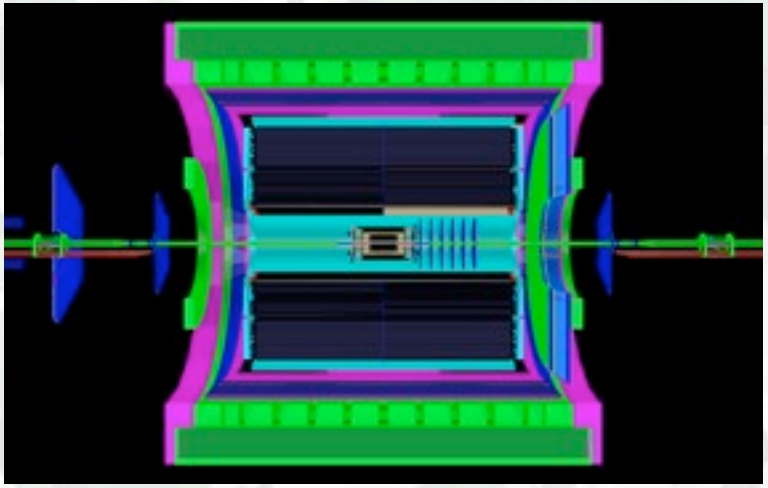
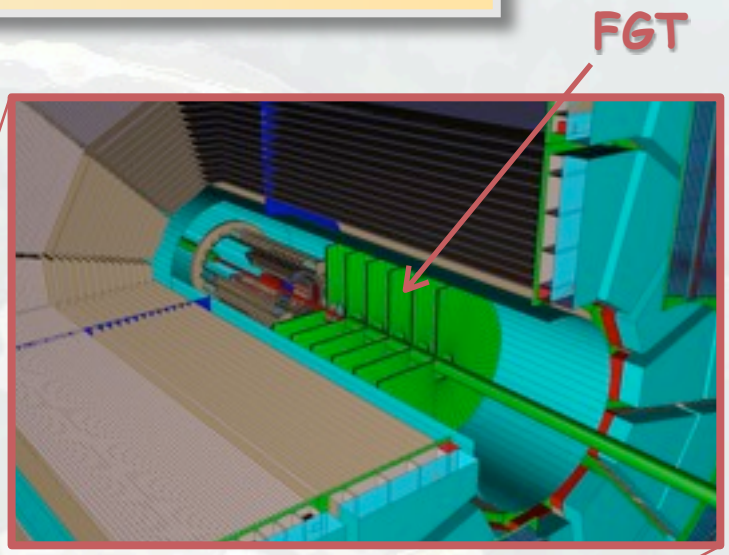
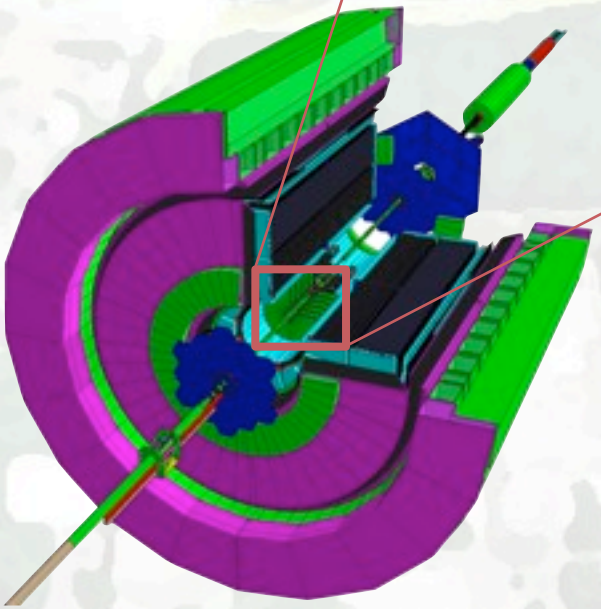


Outline

- 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

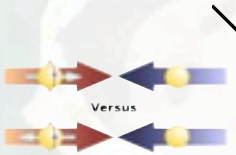




FGT Physics motivation - W program

Quark / Anti-Quark Polarization - W production

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



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

$$W^{\mp}$$

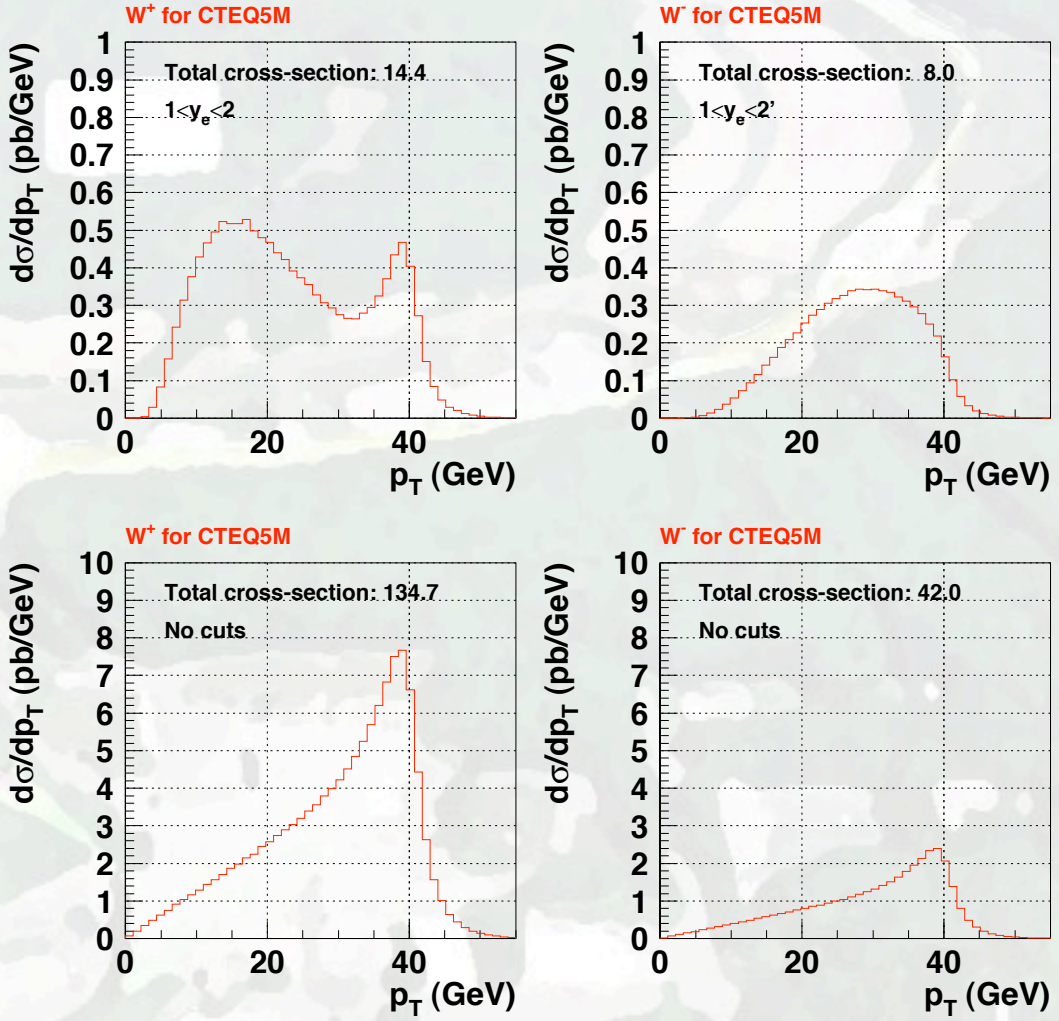
$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) - N^-(W)}$$

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

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

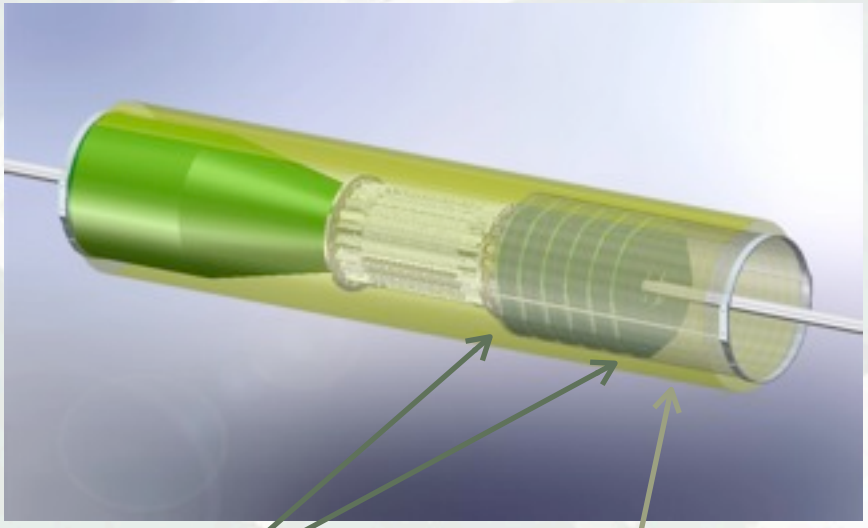
- Key signature: High p_T lepton (e^-/e^+ or μ^-/μ^+) (Max. $M_W/2$) - Selection of W^-/W^+ : Charge sign discrimination of high p_T lepton
- Required: Lepton/Hadron discrimination

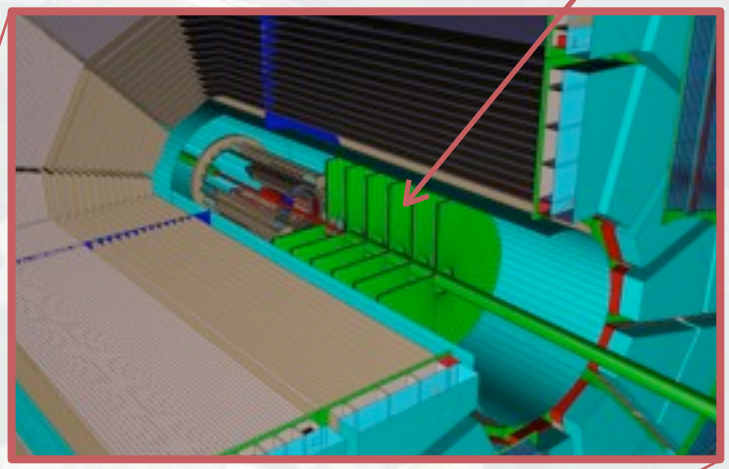
RHICBOS W simulation at 500GeV CME

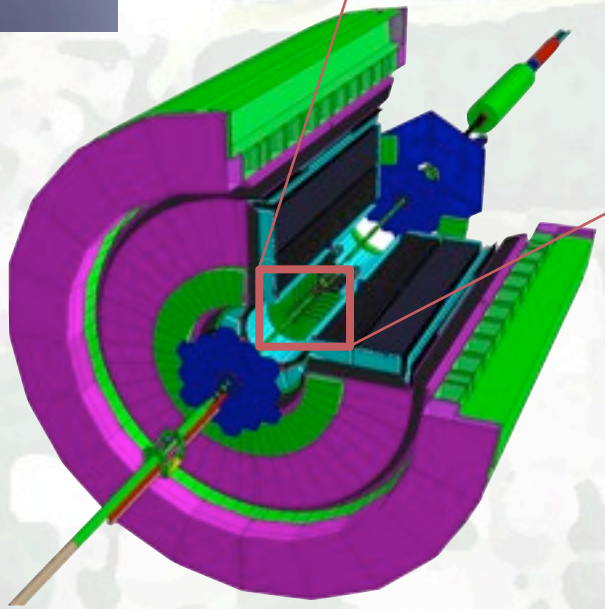


FGT Layout - Simulation results and optimization

- Layout







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

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.

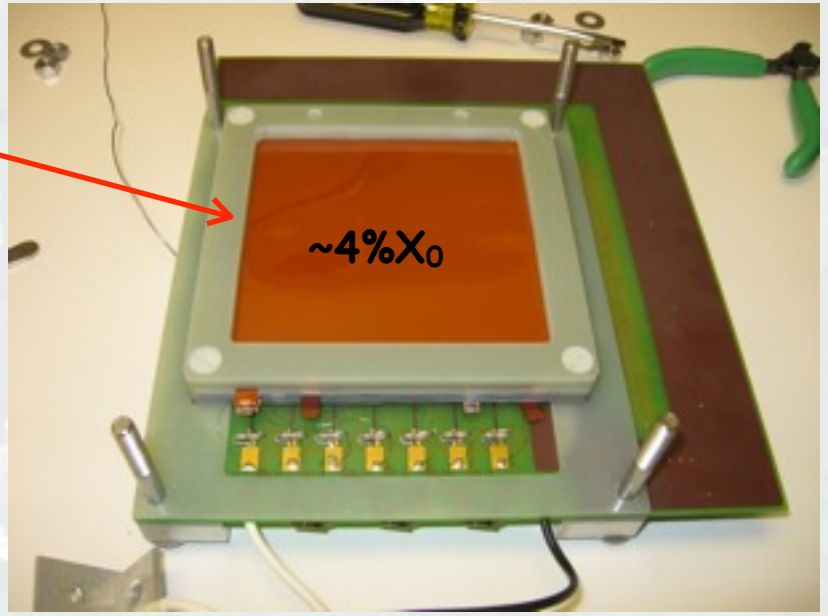
http://www.tech-etch.com

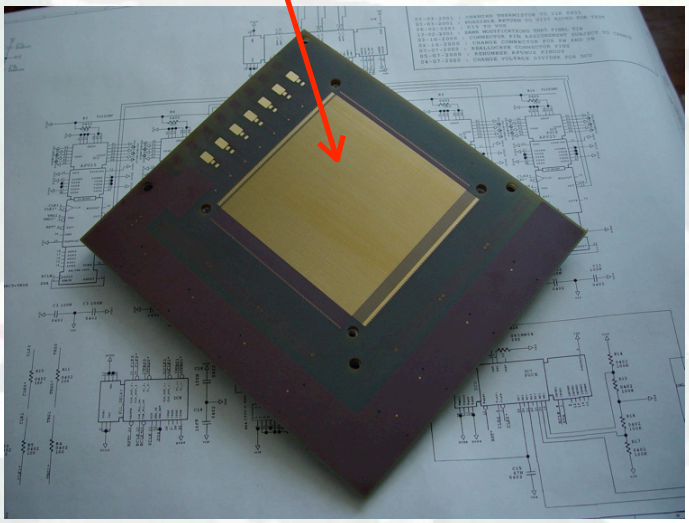
FGT Technical realization

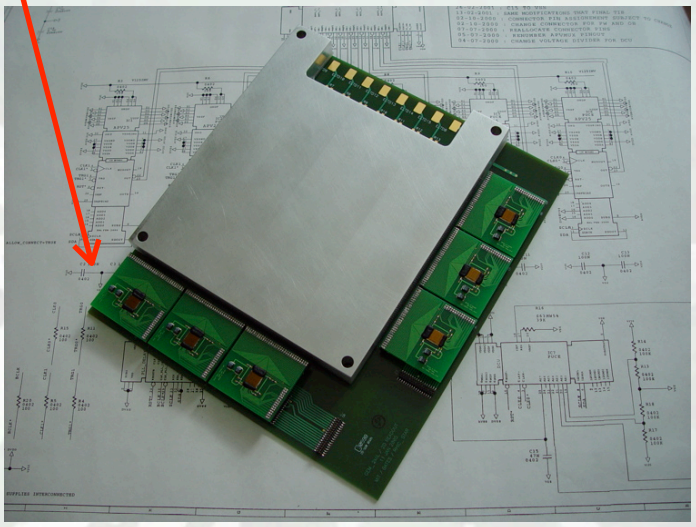
- R&D Development at MIT
  - Resources
    - 2 dedicated clean rooms (Class ~1000) (MIT Bates Laboratory / MIT Laboratory for Nuclear Science)
    - HV radioactive source setup / HV box / Light-microscope / Laminar flow hood / GEM foil CCD camera scanner
  - Activities based on 10cm X 10cm samples
 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

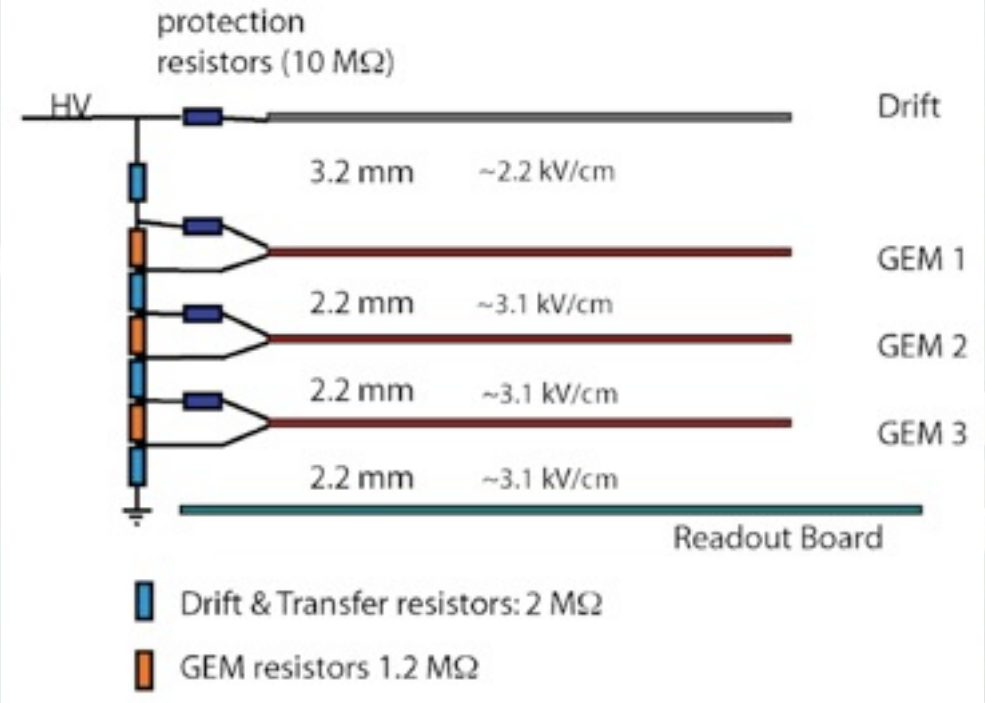


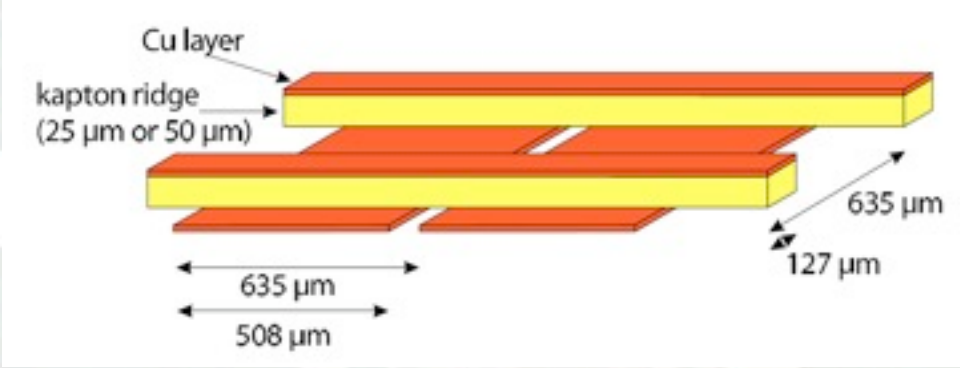




FGT Technical realization

- Prototype triple-GEM configuration (2)

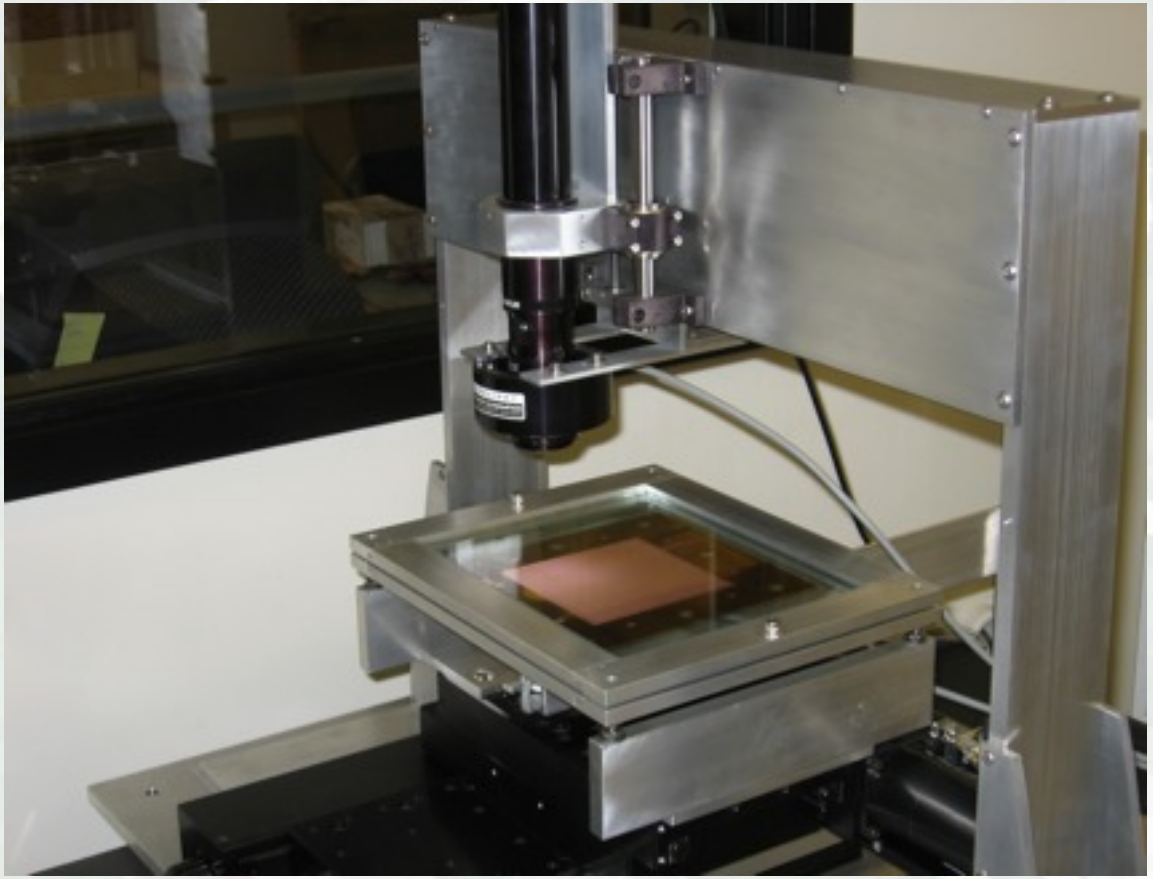




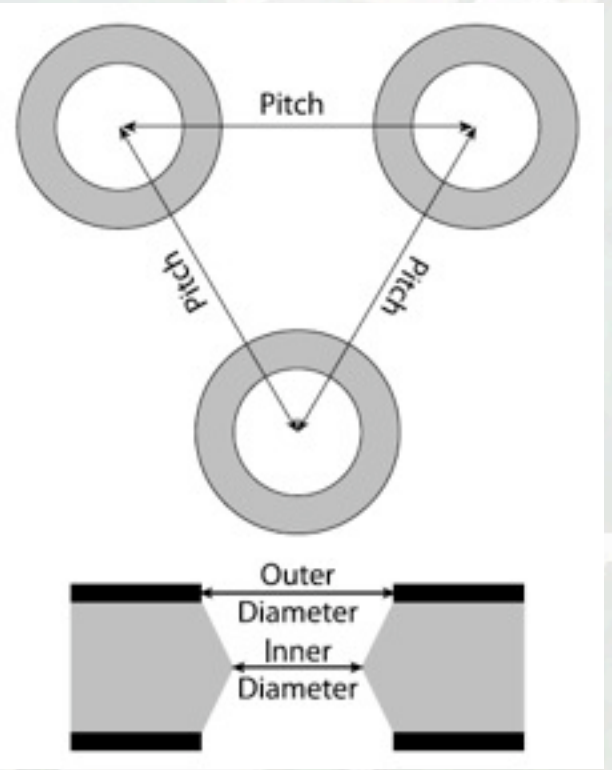
- Laser etched 2D readout board (Compunetics Inc.)
- Test beam configuration:
  Top strips (Y): ~127µm
  Bottom strips (X): 508µm
- Two separations: 25µm and 50µm
- Test beam operating voltage: ~3750V-3800V corresponding to ~385V-395V per GEM foil
- Testbeam effective gain: ~$3.5 \cdot 10^3$ (~$2.5 \cdot 10^4$ 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

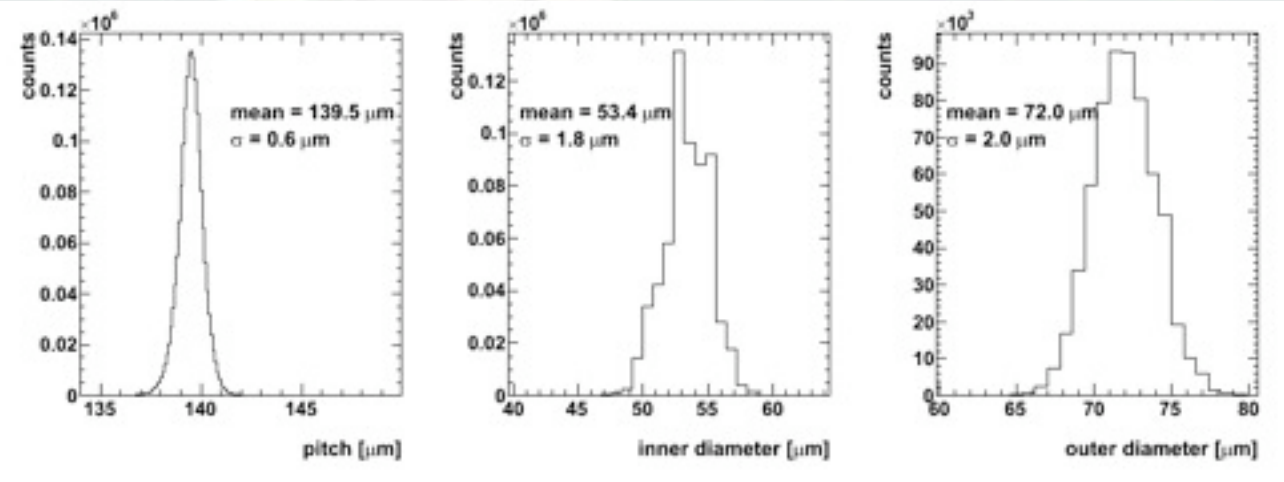


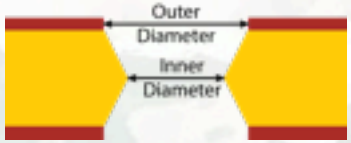
- Check for defects:
  - Missing holes, enlarged holes, dirt in holes and etching defects

FGT Technical realization

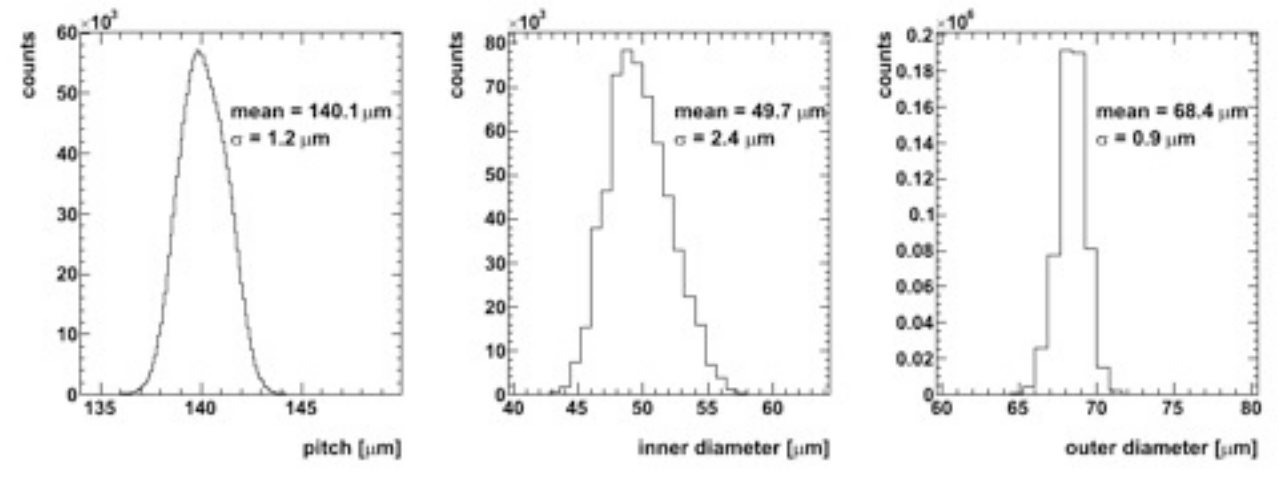
- Optical scans (2)

Tech-Etch





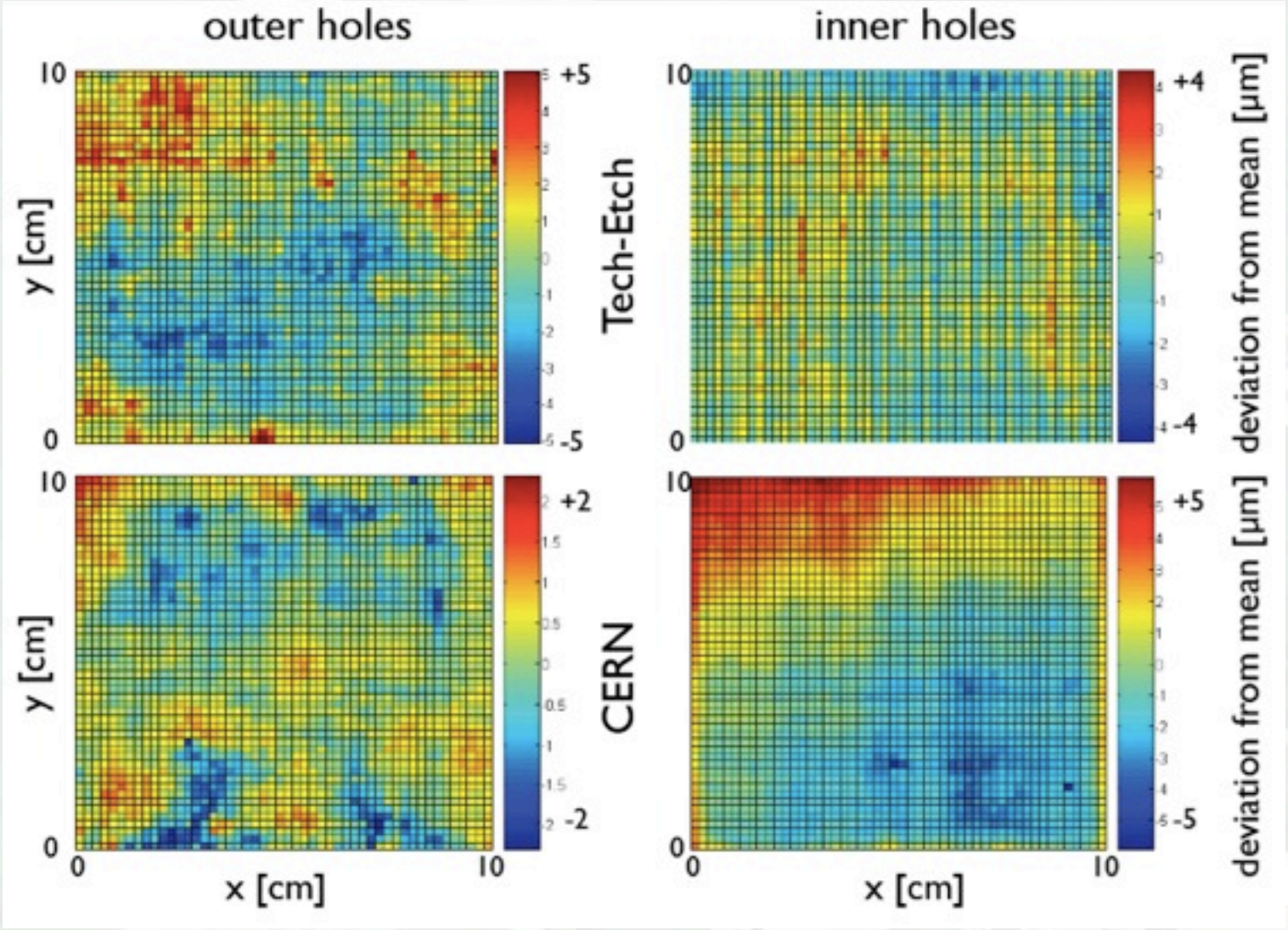
CERN

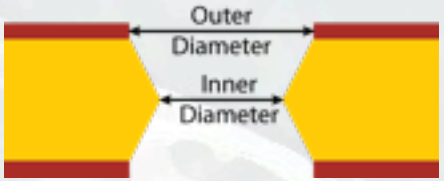


- Geometrical parameters are similar for Tech-Etch and CERN foils (10cm X 10cm samples)

FGT Technical realization

- Optical scans (3)



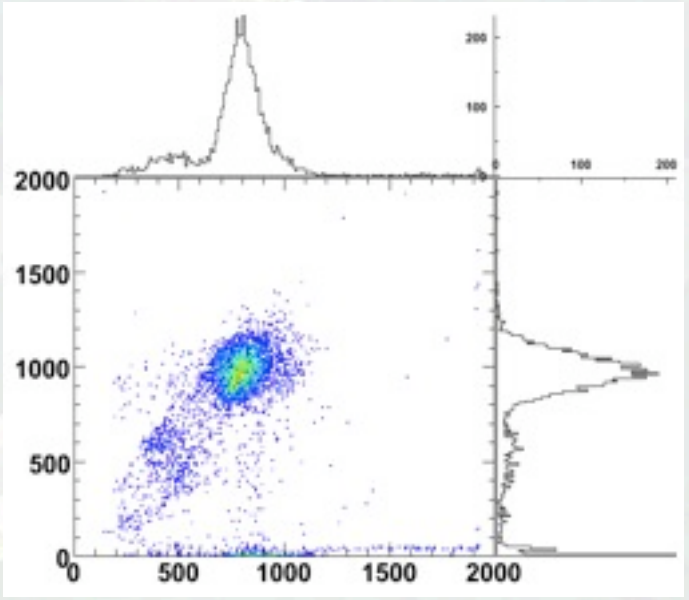


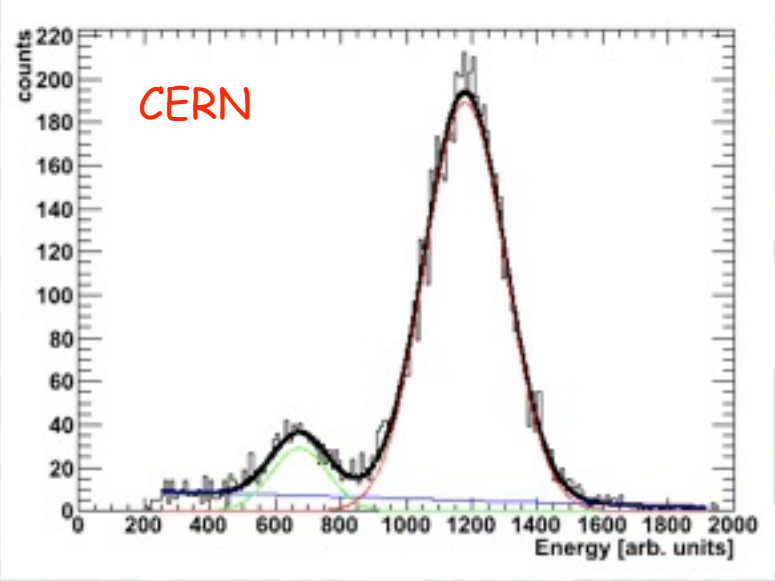
- Uniformity of outer/ inner hole diameters for Tech-Etch and CERN foils (10cm X 10cm samples)

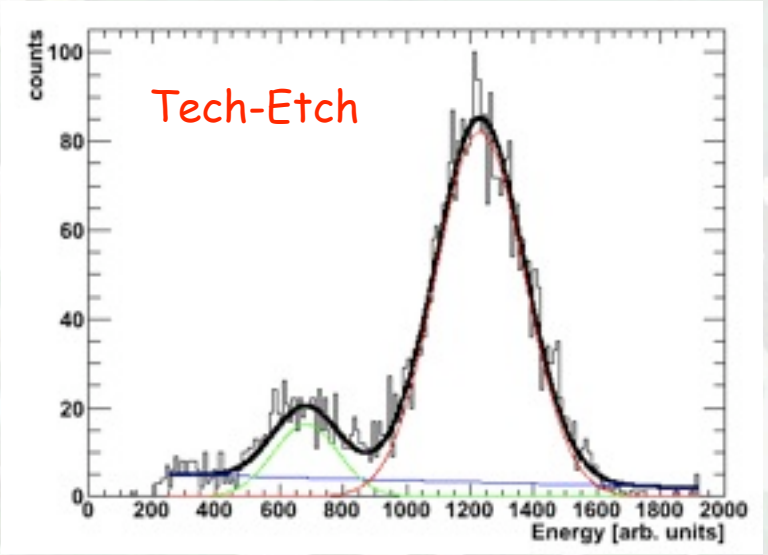
GEM foil test results

- 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

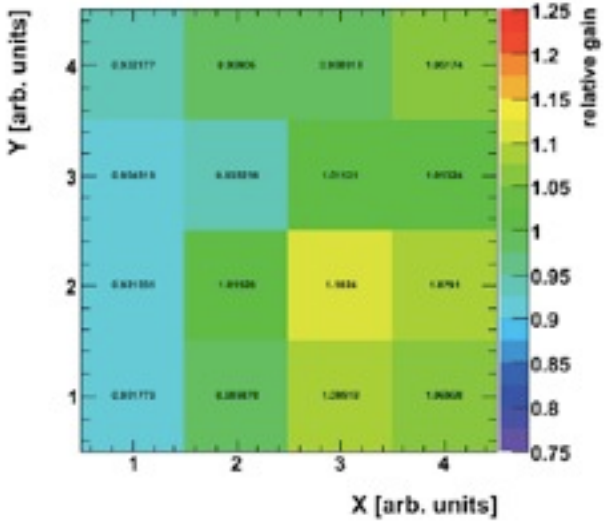


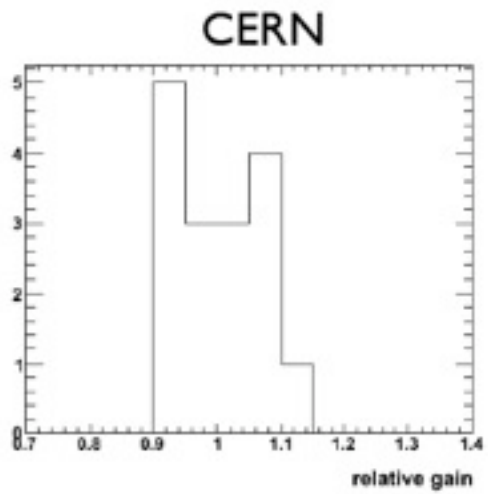


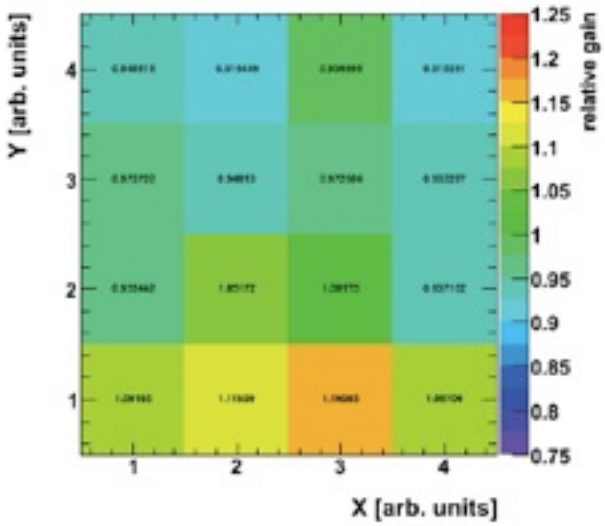


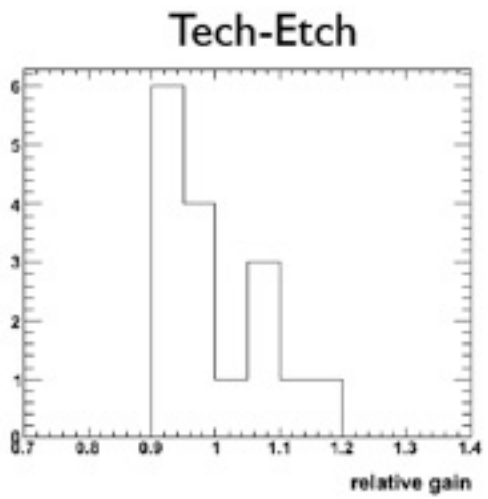
FGT Technical realization

- Source tests (2)





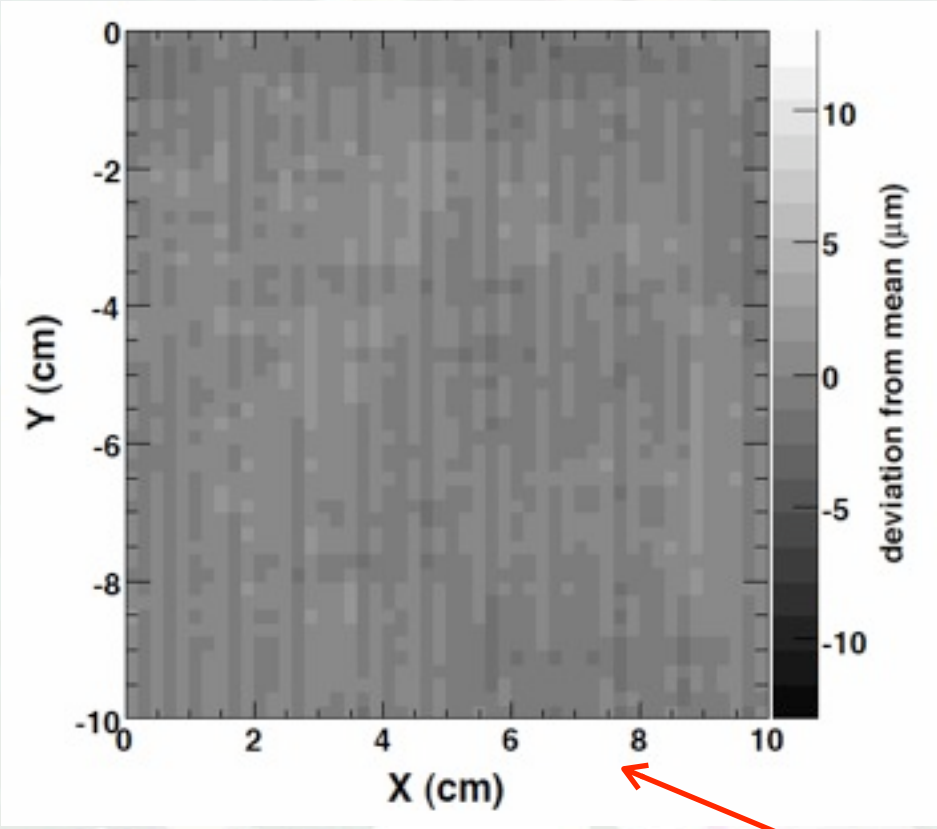


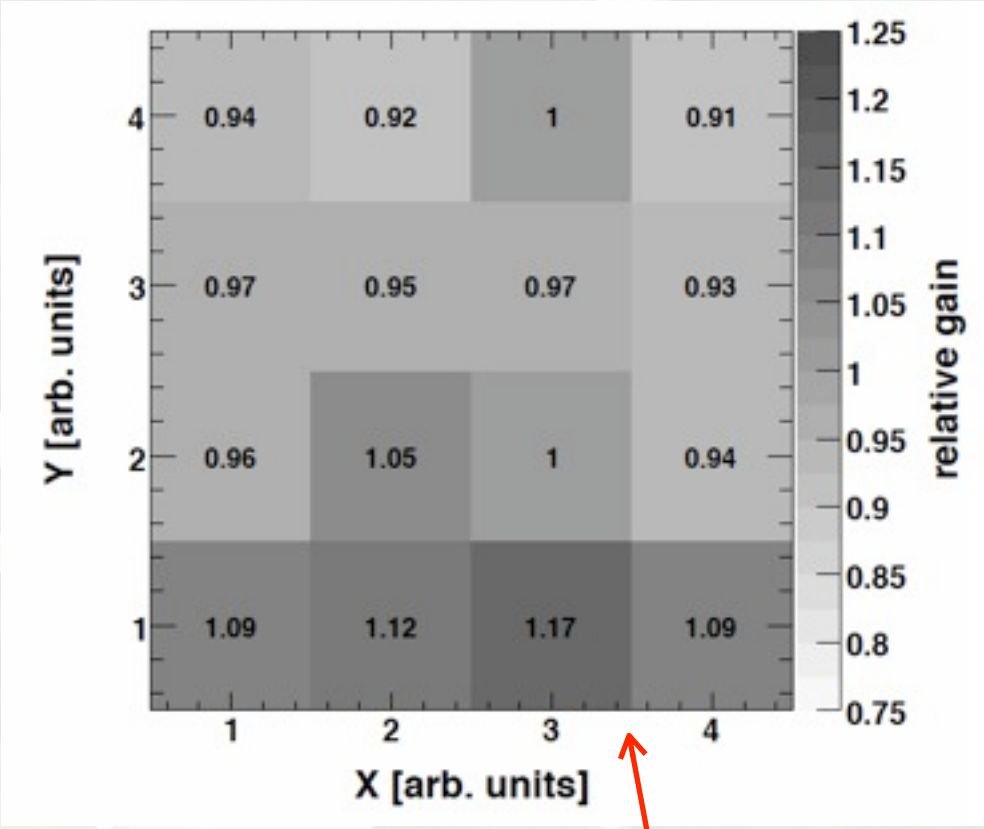


- Gain measured with low intensity ^{55}Fe source (~0.5Hz/mm^2)
- Good gain uniformity over full active area (Measured after charge built-up)

FGT Technical realization

- Source tests (3)



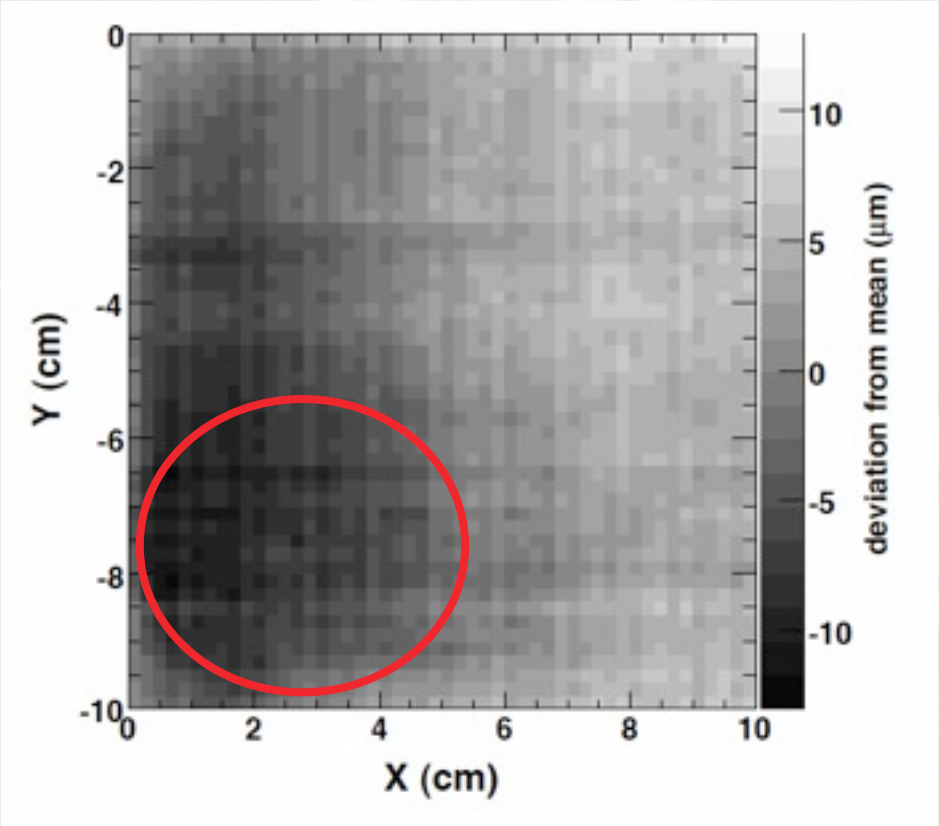


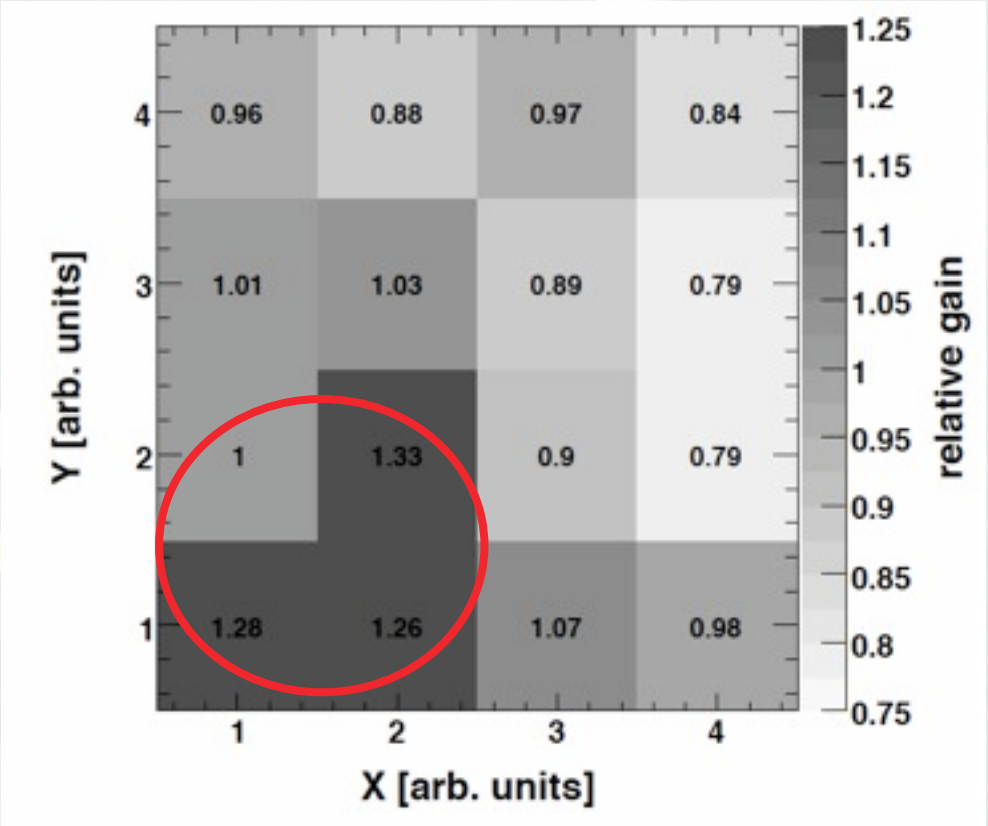
- Comparison of optical scans of inner hole diameter uniformity and gain uniformity

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

FGT Technical realization

- Source tests (4)



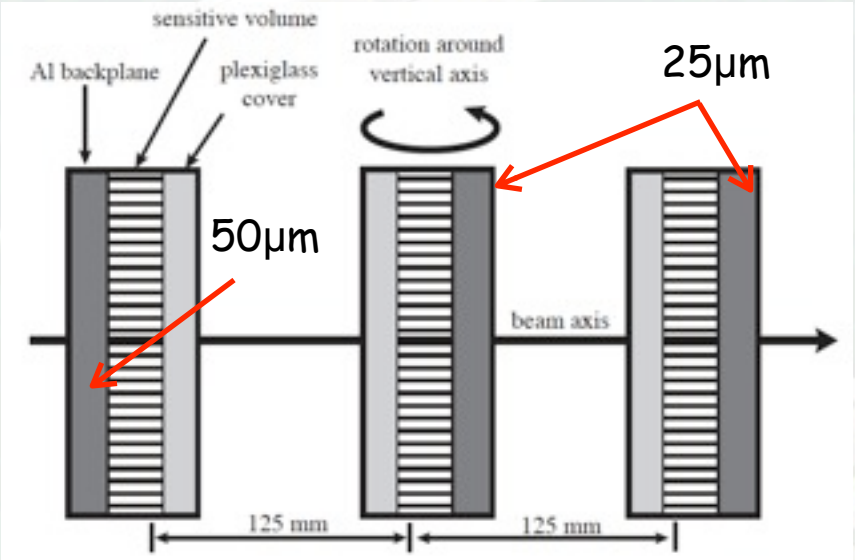


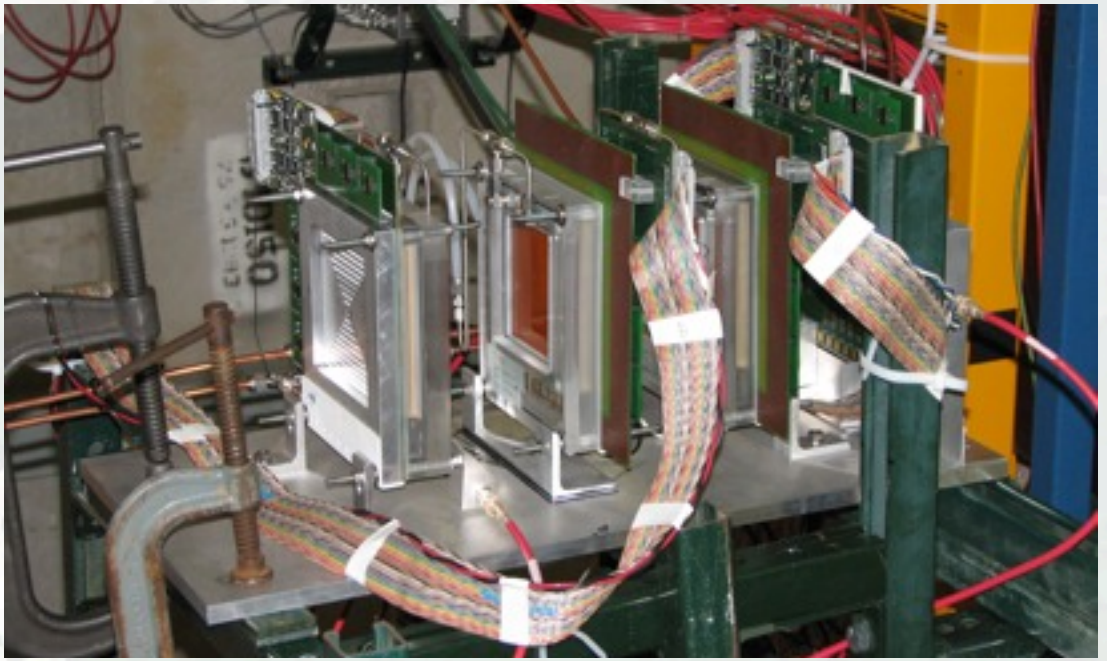
- Non-uniformity of inner hole diameter (~20μm smaller on left side compared to right side)

  reflected in large non-uniformity of source scan gain measurements

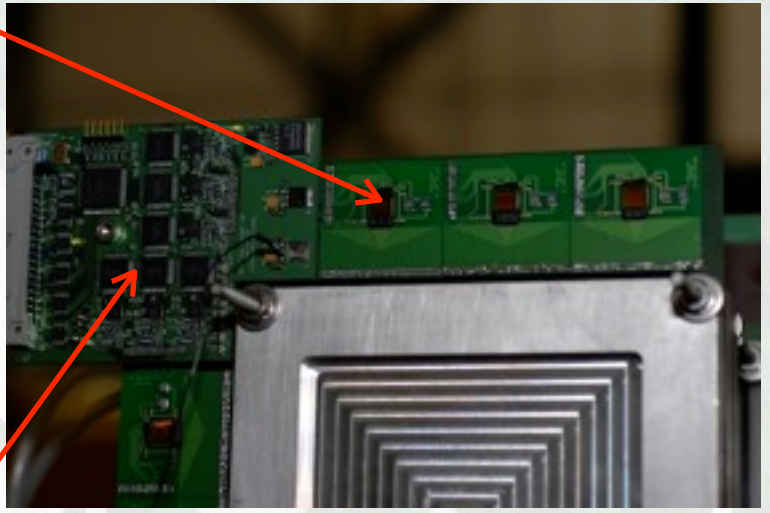
FGT Technical realization

- Testbeam results (1)





APV25-S1



GEM Control Unit

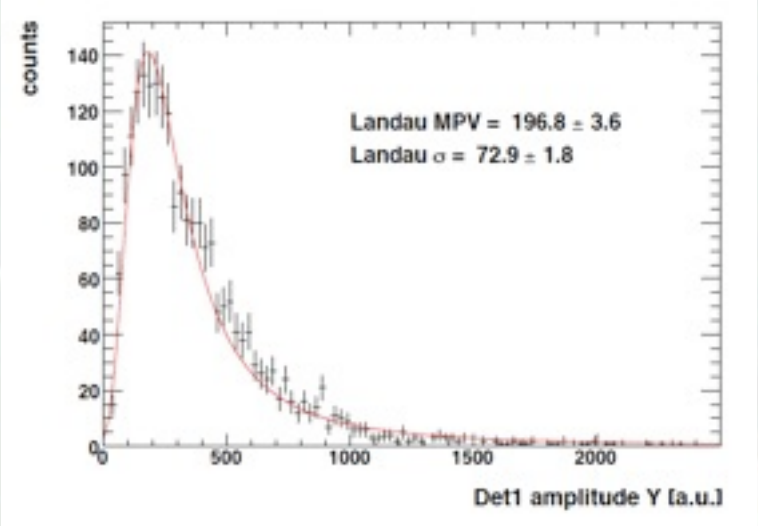
- FNAL Meson Test Beam Facility: Data taking with

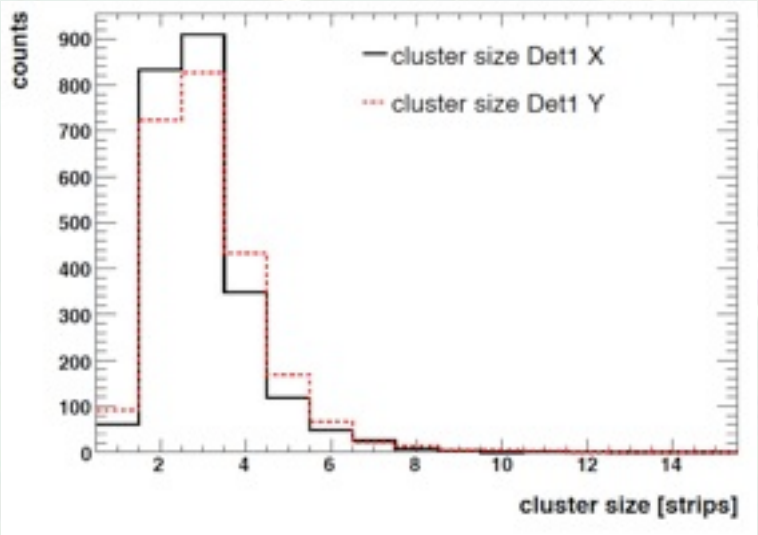
  4GeV-32GeV unseparated secondary beam and

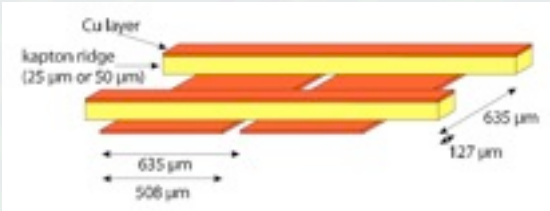
  120GeV primary proton beam

FGT Technical realization

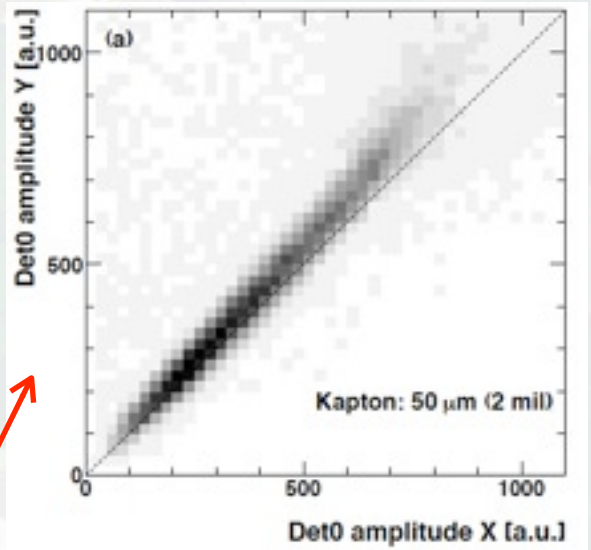
Testbeam results (2)

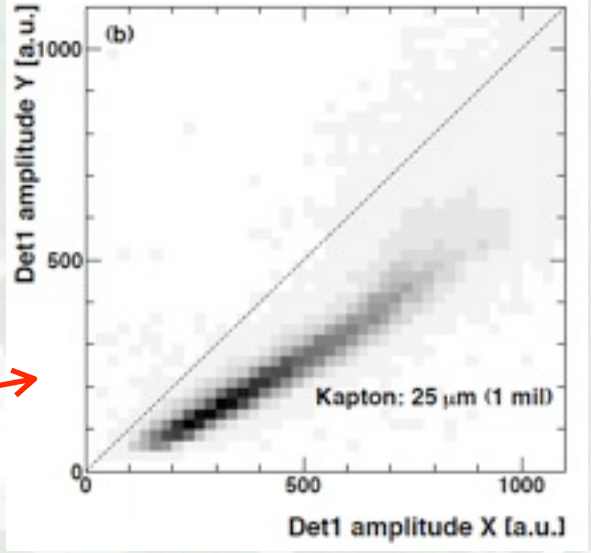






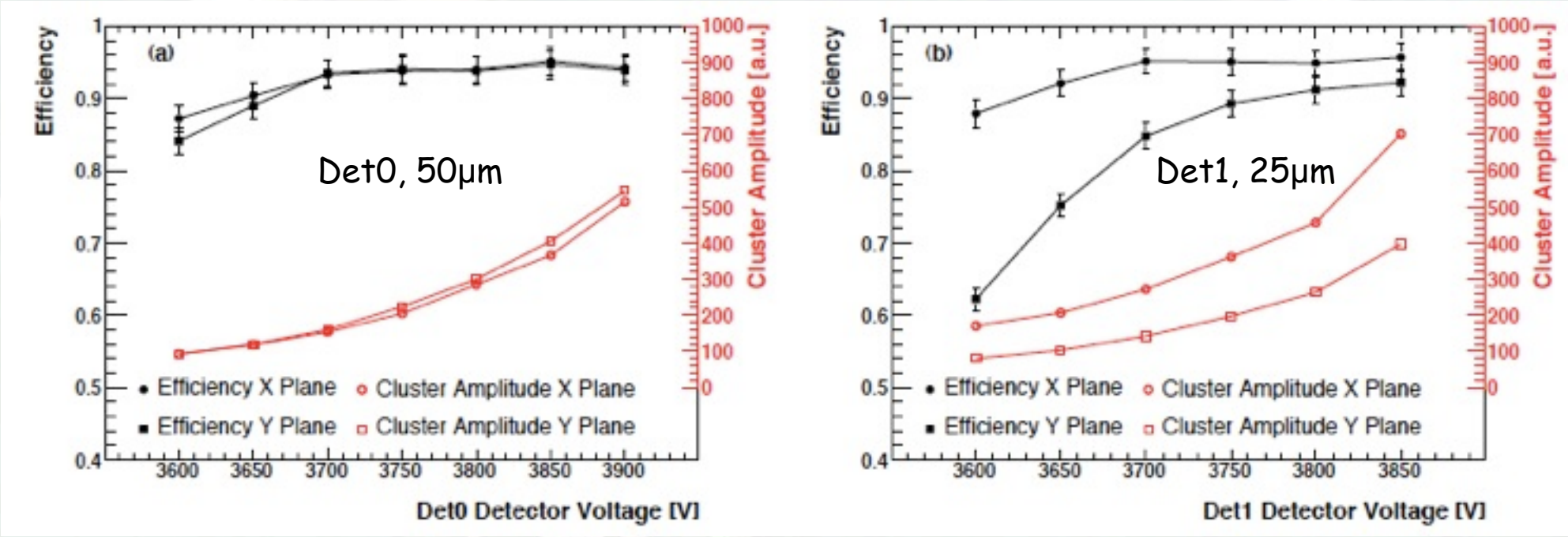
- Cluster charge follows expected distribution
- Two version of readout board (50µm and 25µm)





FGT Technical realization

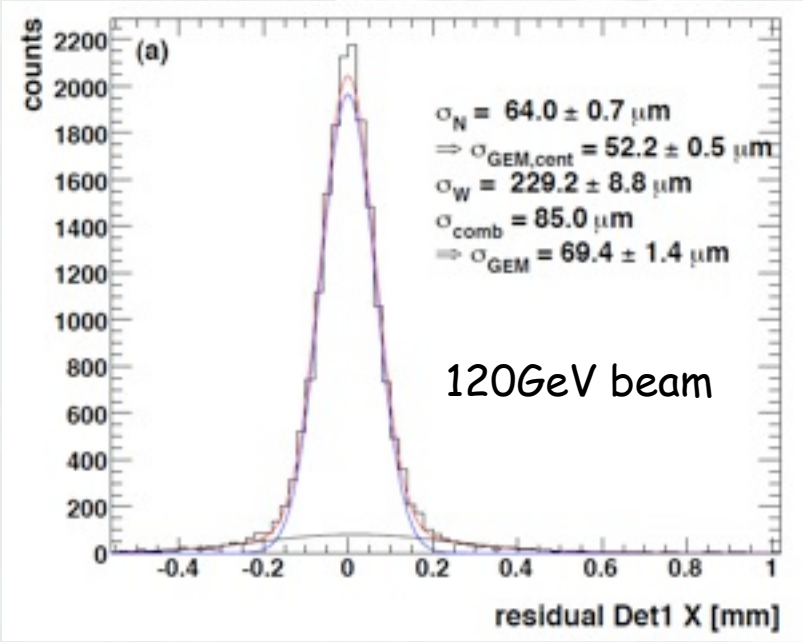
- Testbeam results (3)

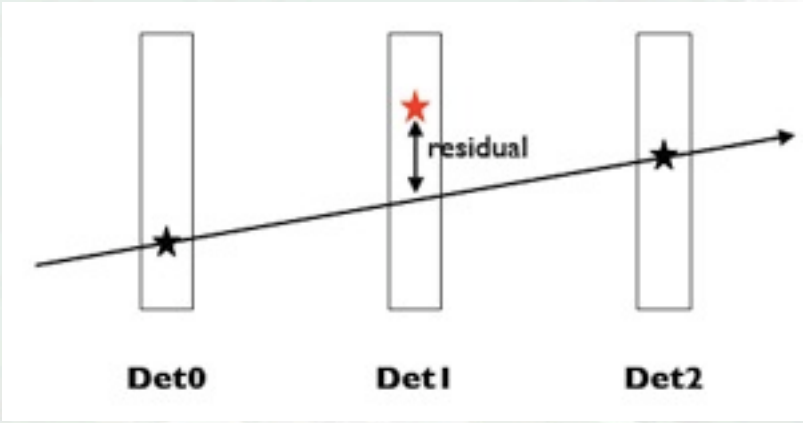


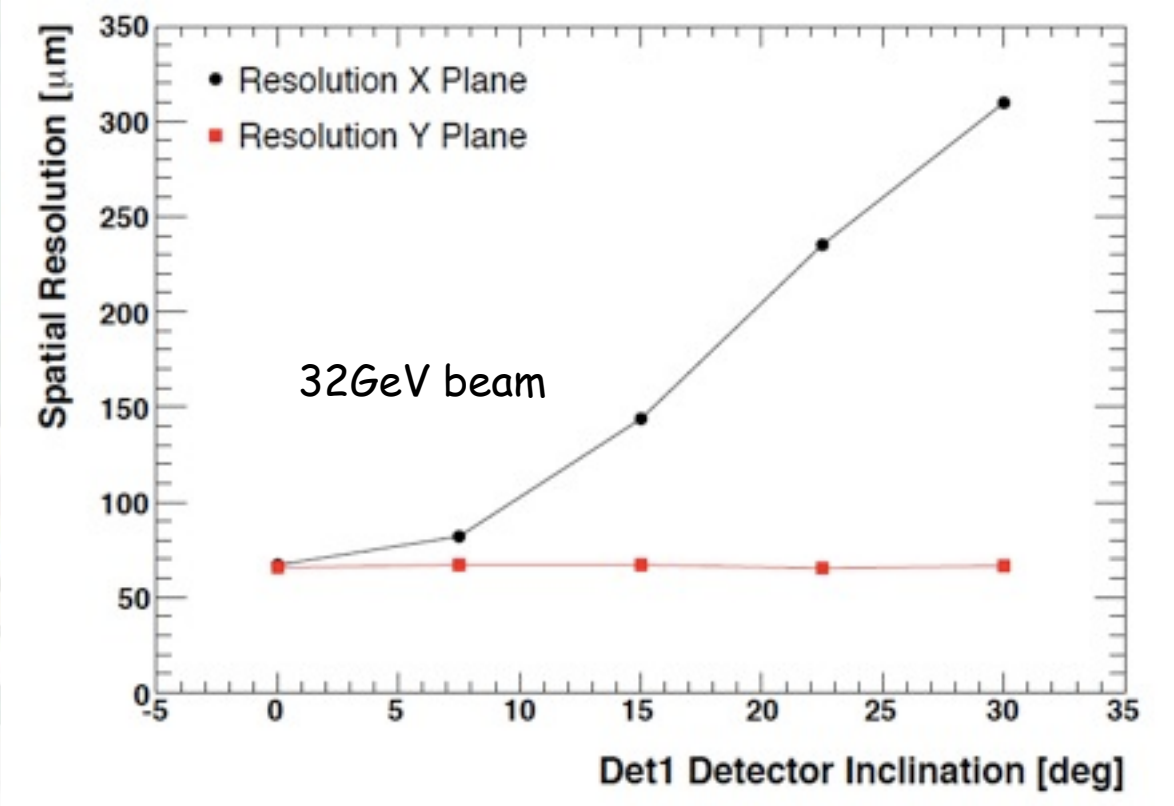
- Efficiencies at the level of ~95%-98% were reached in regions which limit the impact of noisy and dead regions with Tech-Etch GEM foils (Not affected by high intensity studies)
- Clear difference between Det0 (50µm) and Det 1 (25µm) for efficiency and cluster amplitude (Most probable value of Landau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

FGT Technical realization

- Testbeam results (4)



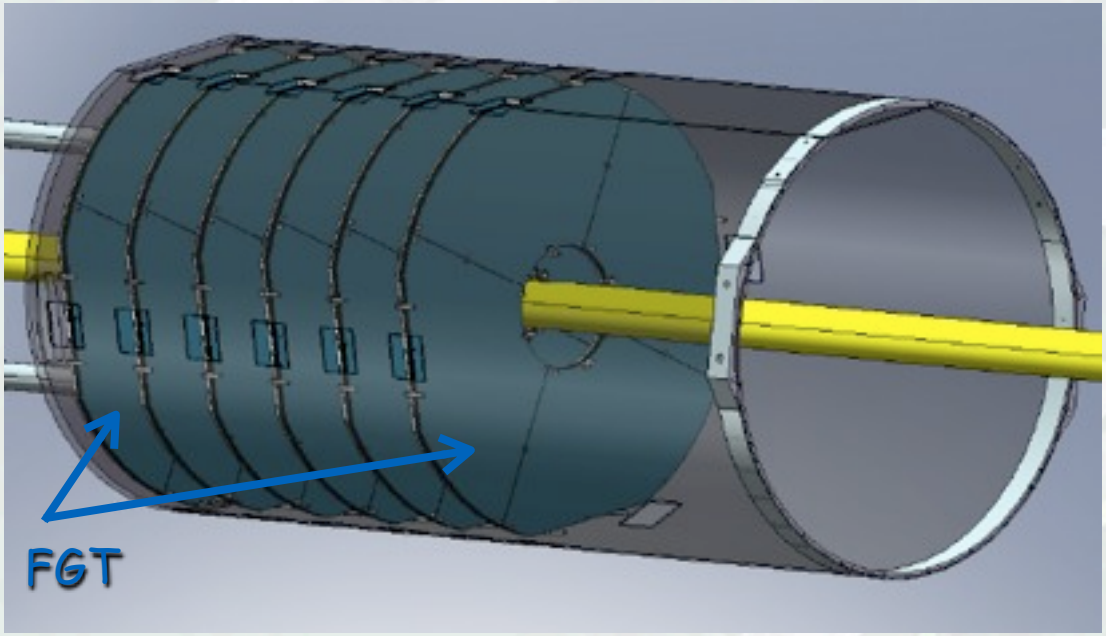


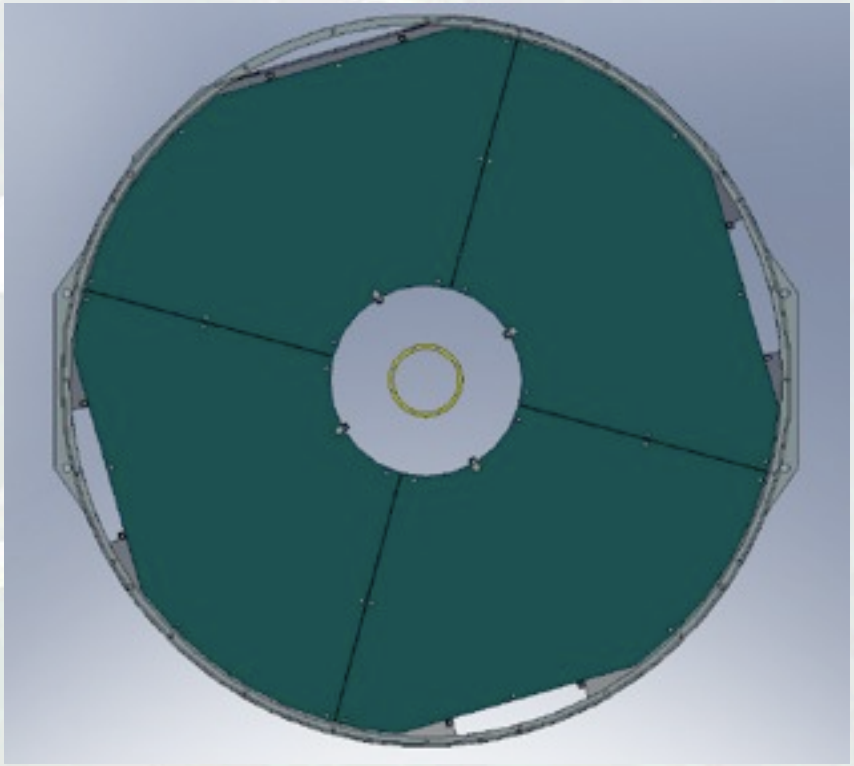


- Study of inclination by up to 30°: Only X (horizontal) resolution is affected, not so for Y (vertical) coordinate as expected!

FGT Technical realization

- Layout

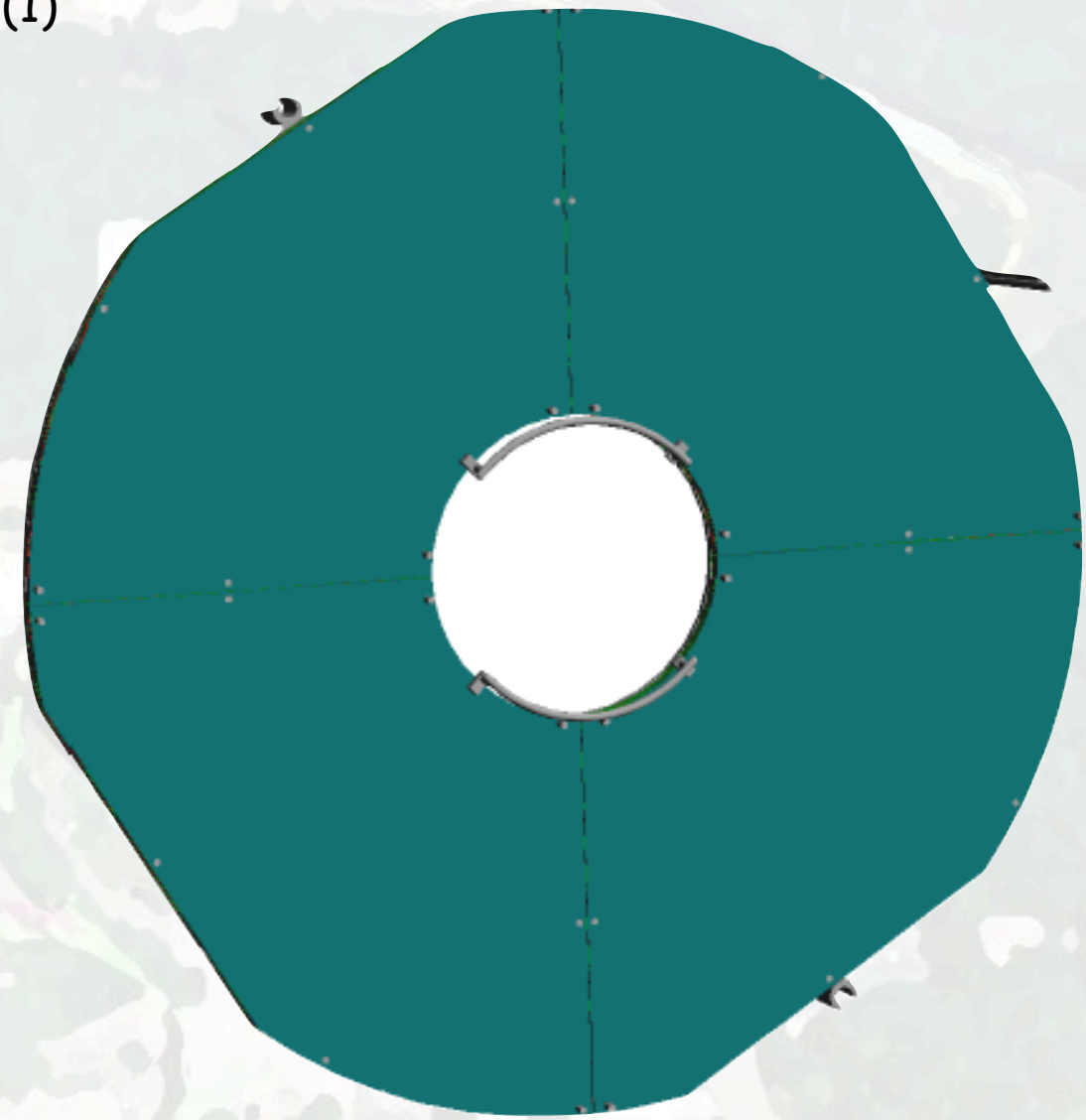




- FGT: 6 light-weight disks
- Each disk consists of 4 triple-GEM chambers (Quarter sections)
- Procurement and assembly of full quarter section prototype in preparation

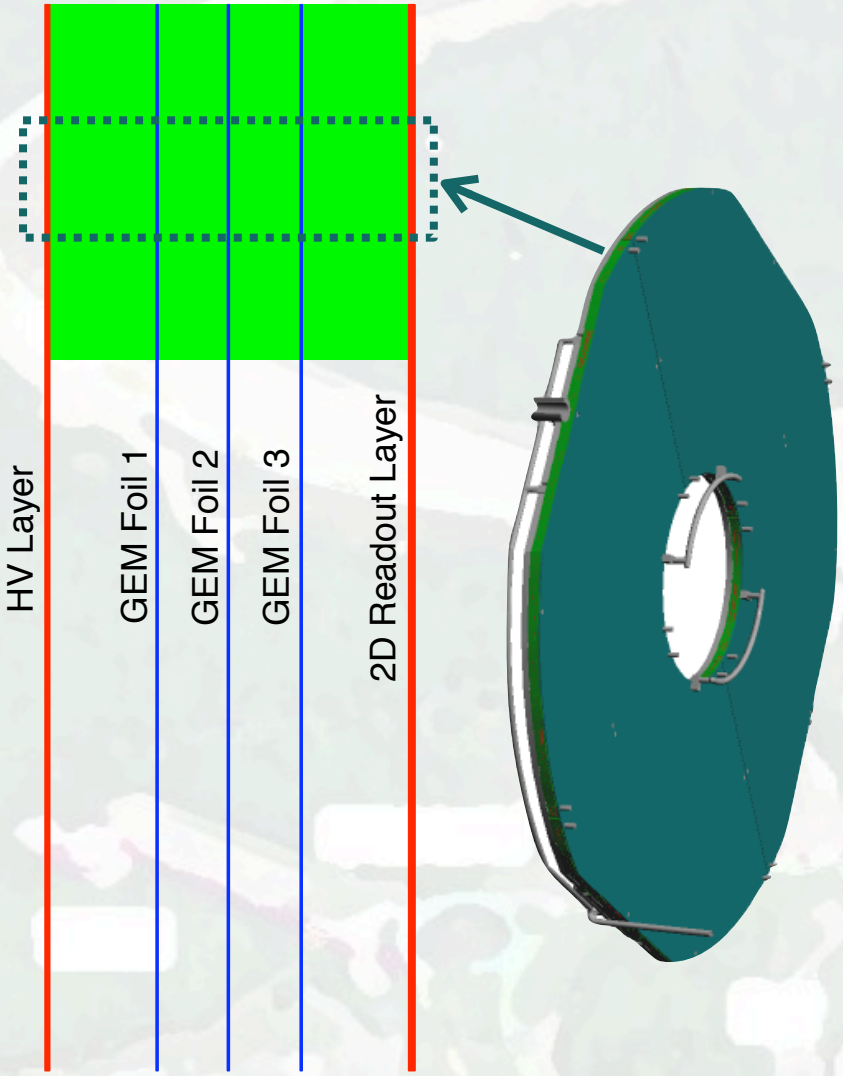
FGT Technical realization

- 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

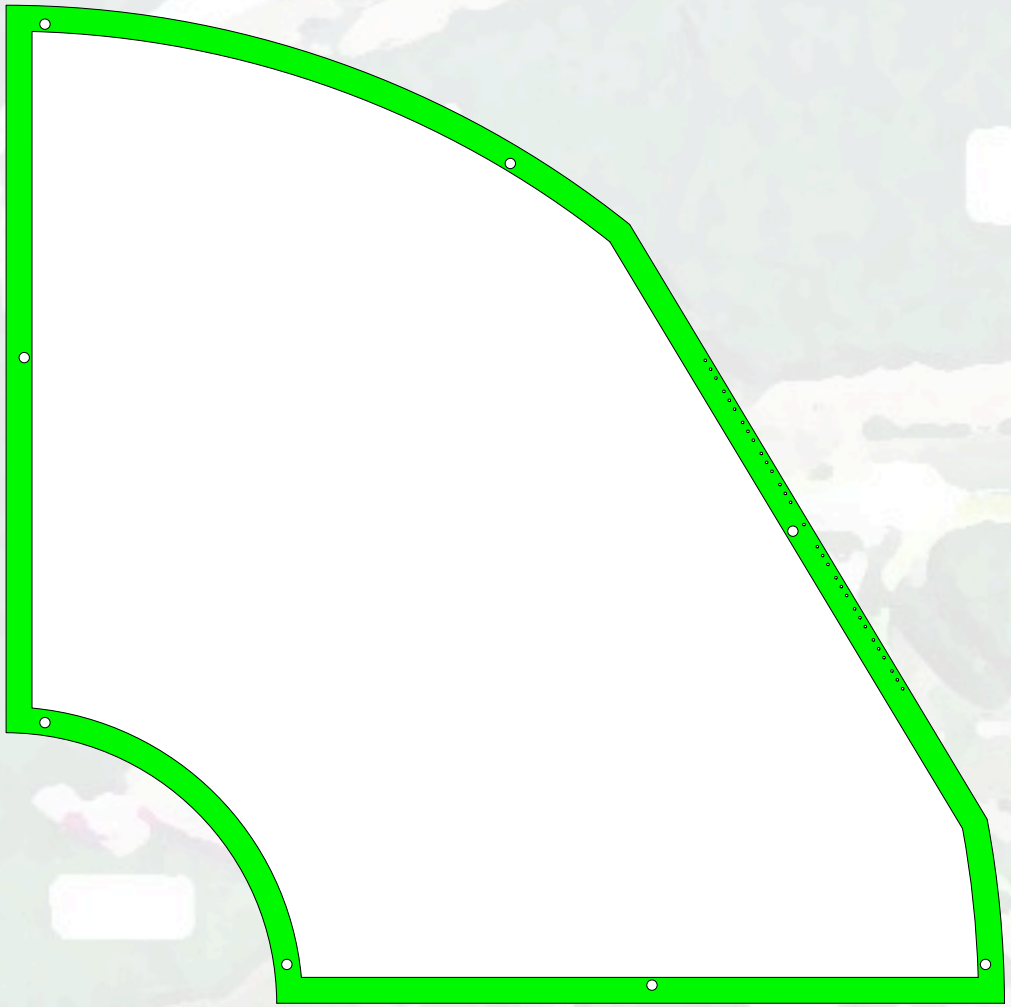
Triple-GEM: Quarter section design (2)



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)

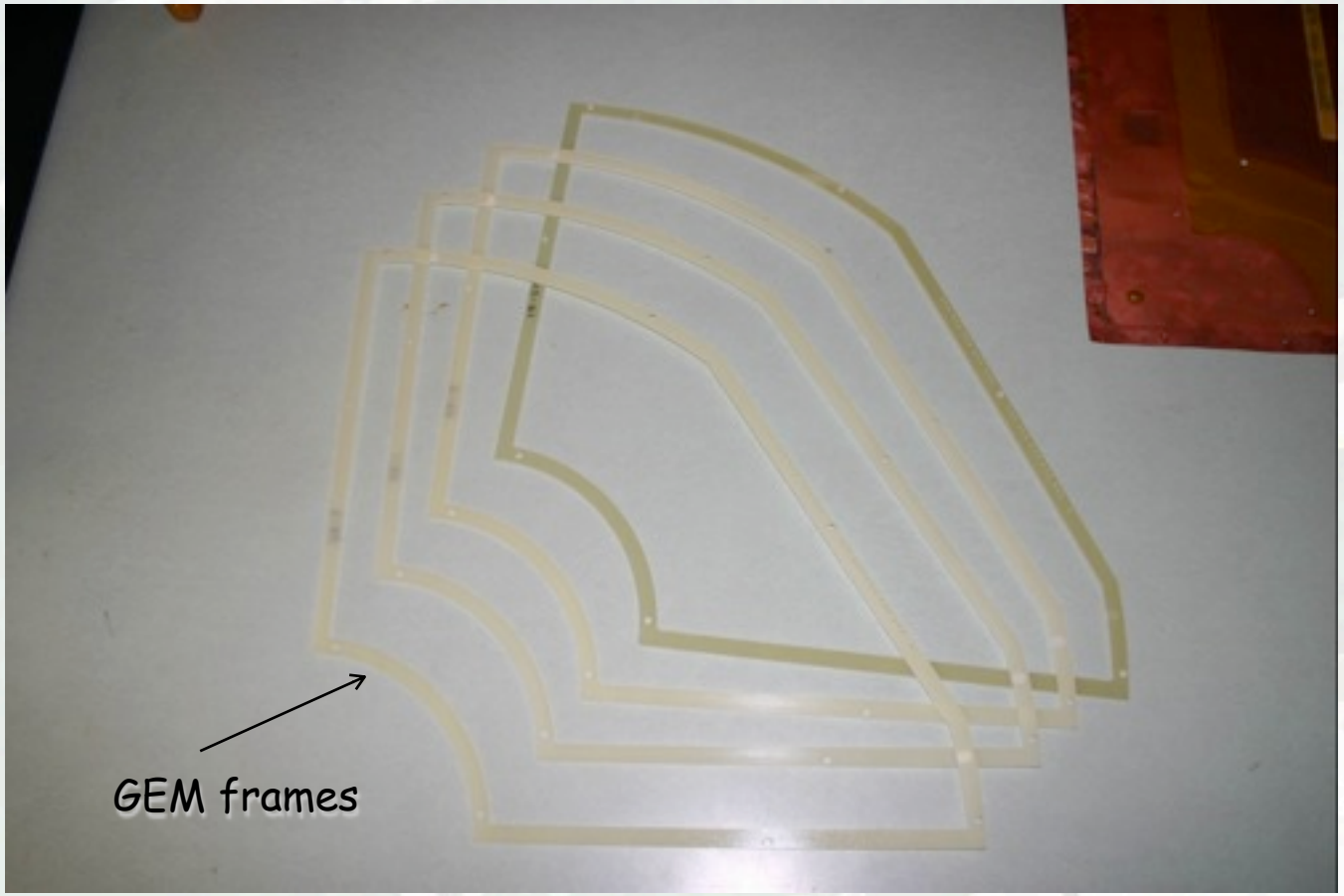


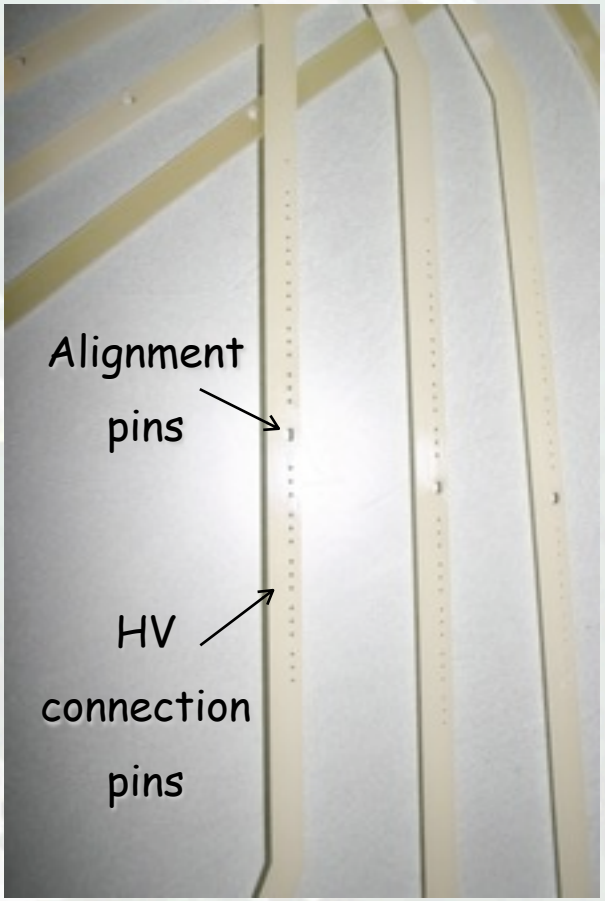
- 1cm wide frames of FR4
- 2-3mm thick
- Inner radius: 10.5cm
- Outer radius: 38.1cm
- Flat at 31°
- 1mm gap between quadrants
- 4mm FR4 pins
- 34 X 1mm holes for HV GEM foil connection

View at readout layer from downstream!

FGT Technical realization

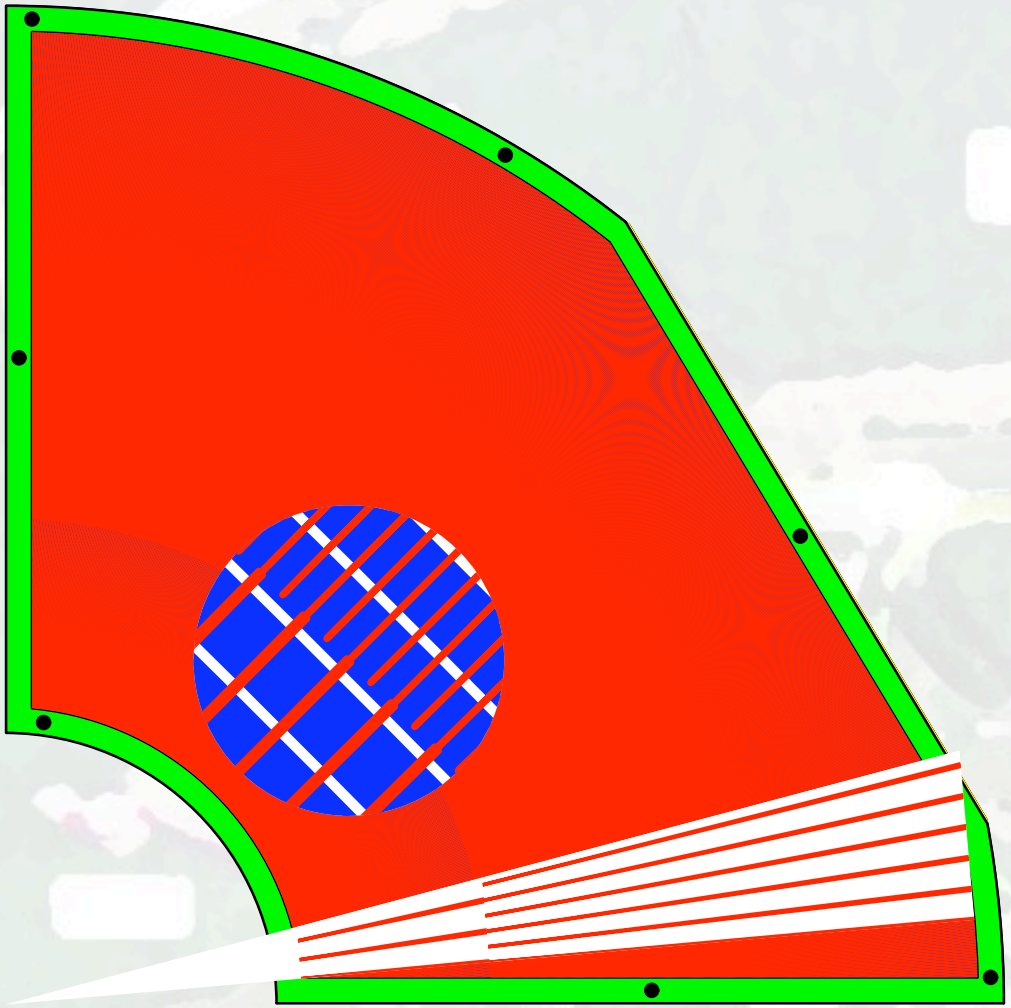
- Triple-GEM: Quarter section design (4)





FGT Technical realization

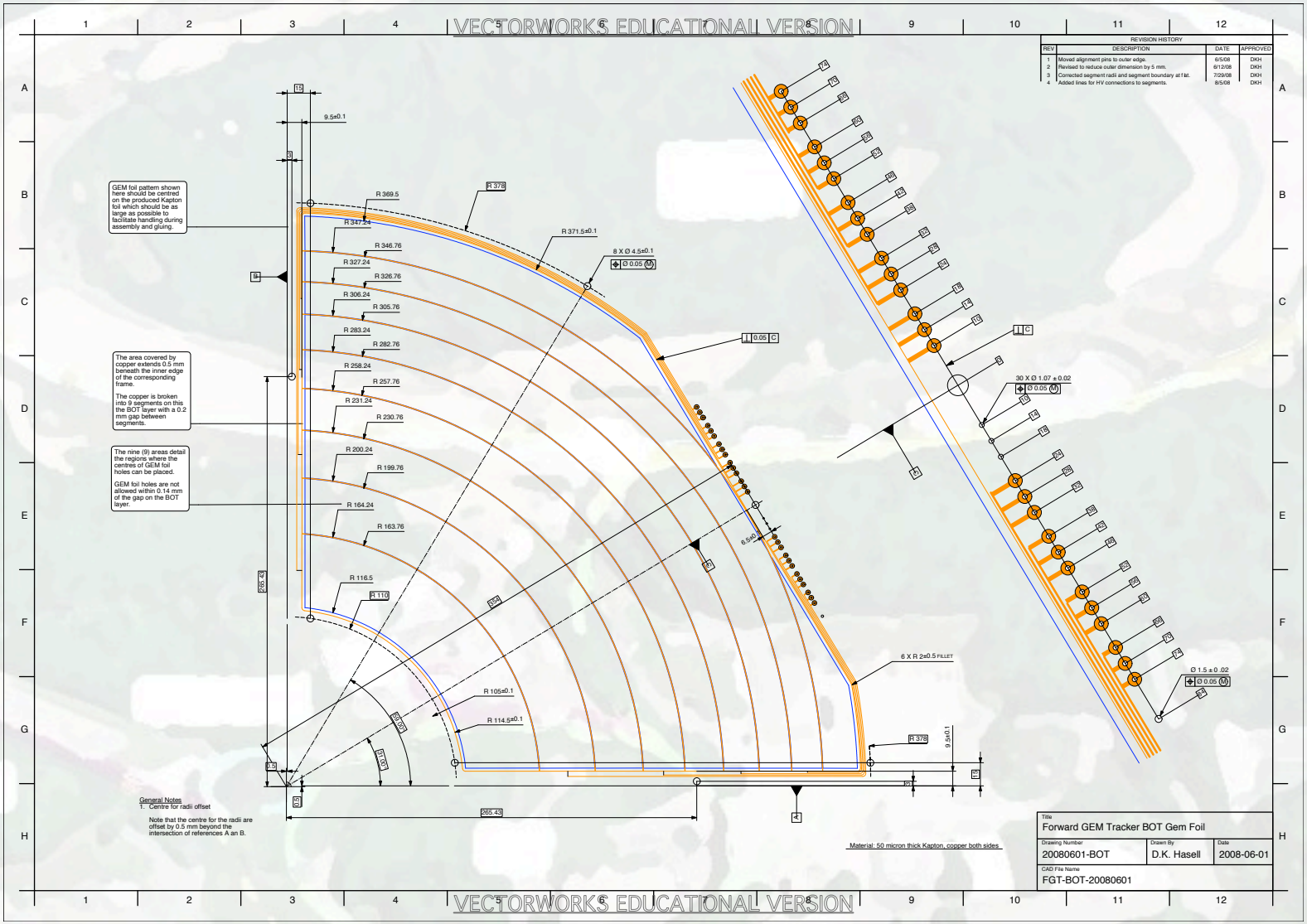
- Triple-GEM: Quarter section design (5)



- 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

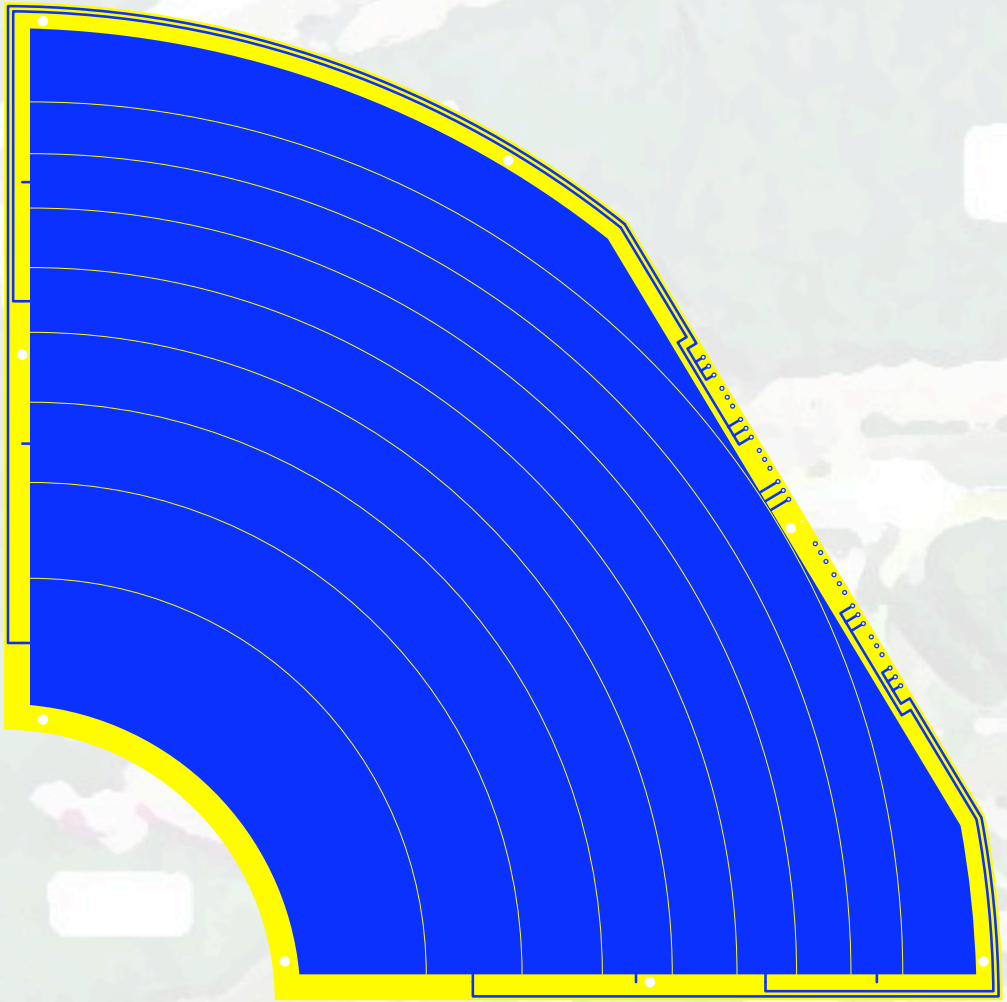
FGT Technical realization

- Triple-GEM: GEM foil design (1)



FGT Technical realization

- Triple-GEM: GEM foil design (2)



Segmented GEM foils:

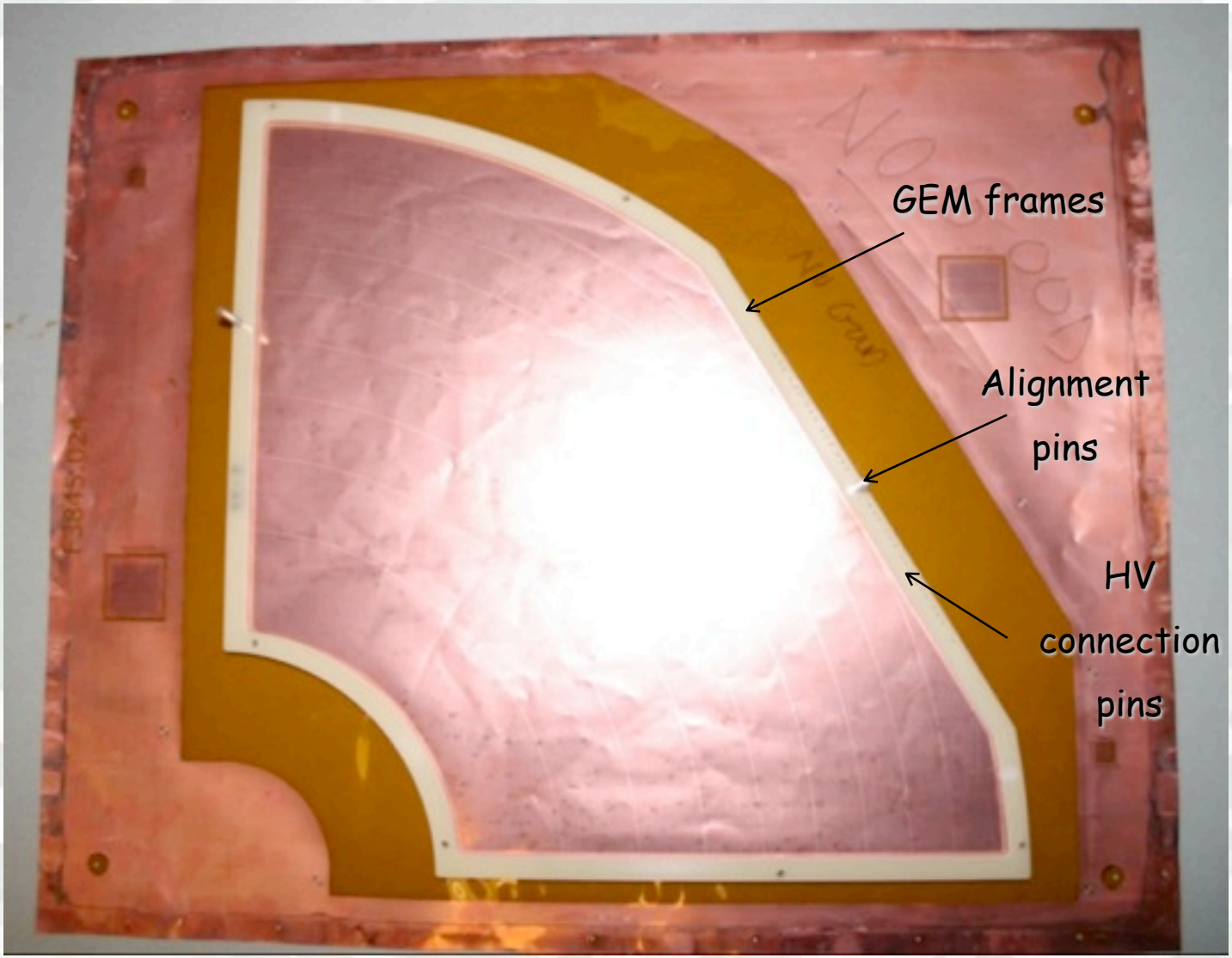
- Minimize damage in case of breakdown
- 9 segments in radial direction with ~100cm^2 each
- Gap: 200μm
- Hole pitch (~ 140μm) and diameter (I: ~50μm /O: ~60μm) similar to prototype!
- Routing and vias distribute HV to segments

FGT Technical realization

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

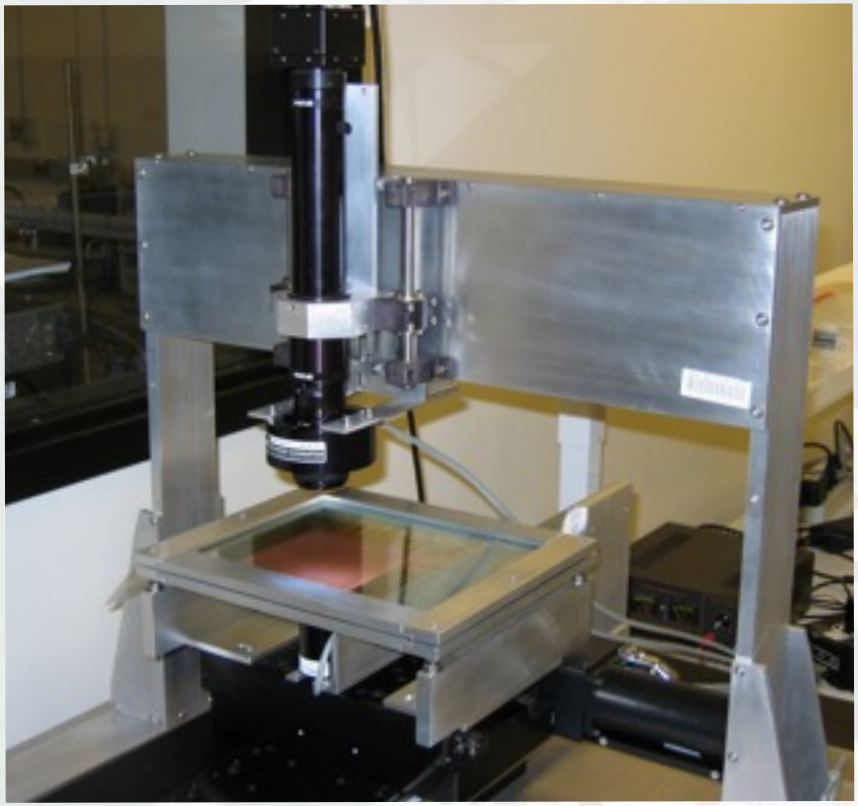
FGT Technical realization

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



FGT Technical realization

- Triple-GEM: GEM foil testing (1)



CCD camera setup for optical GEM foil scans

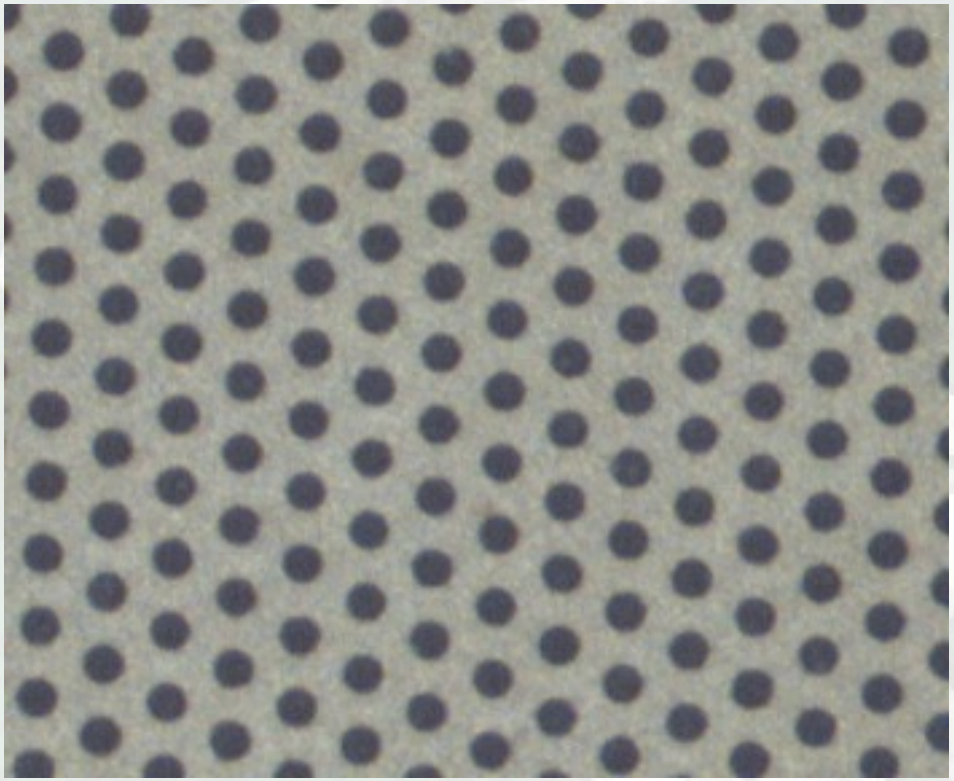
(Glass plate modifications in progress)

HV Vacuum / Nitrogen box for GEM foil dark current tests

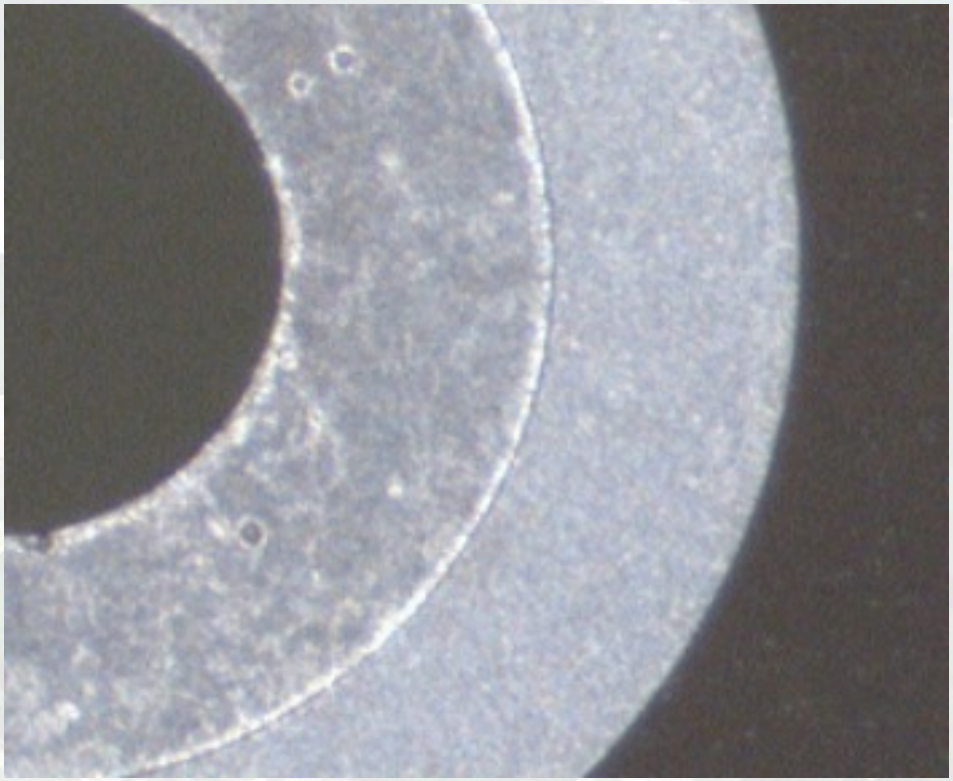
(Minor modifications necessary - In progress)

FGT Technical realization

- Triple-GEM: GEM foil testing (2)



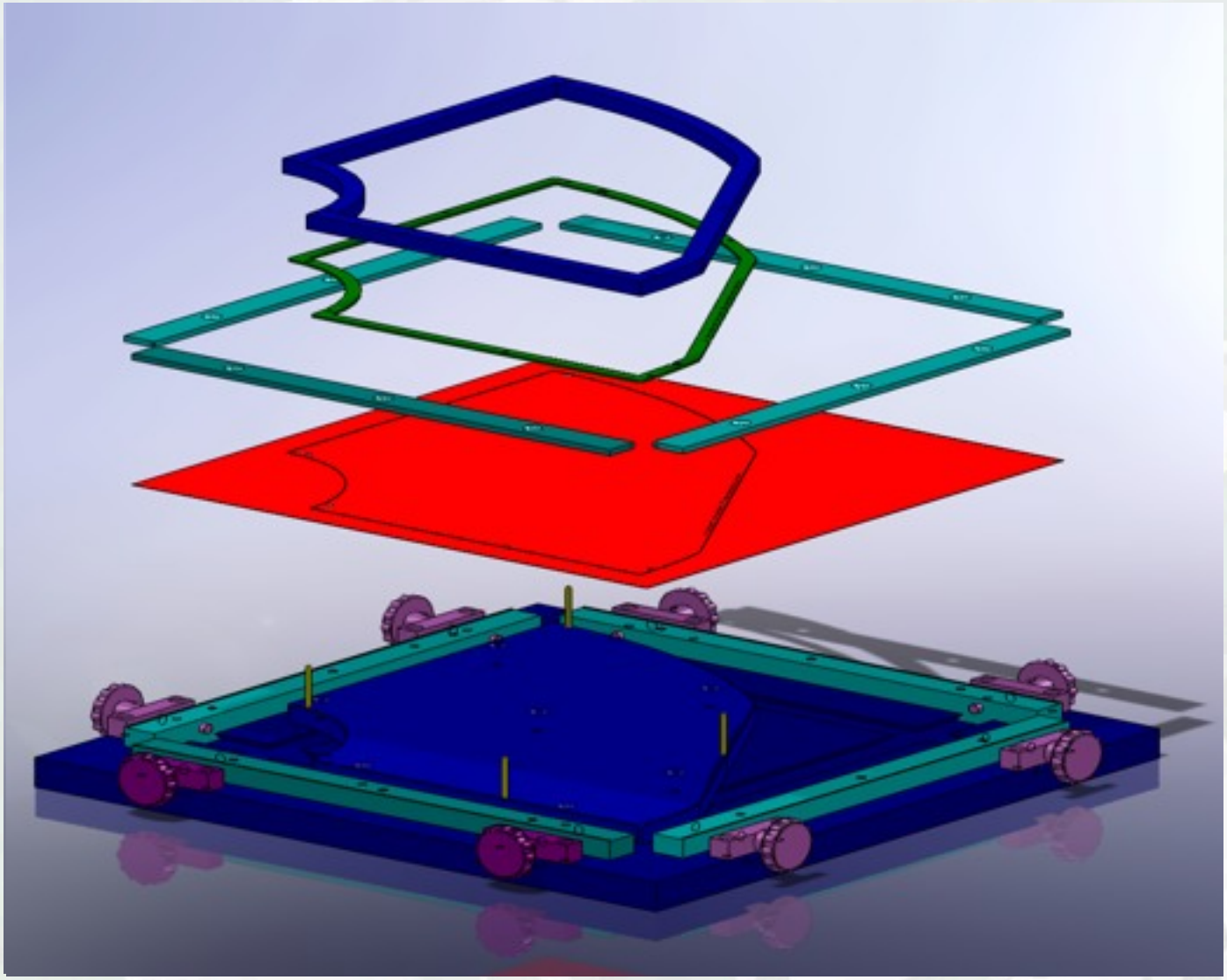
First scan for large GEM foil
(Hole arrangement)



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

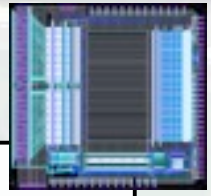
Assembly jig:

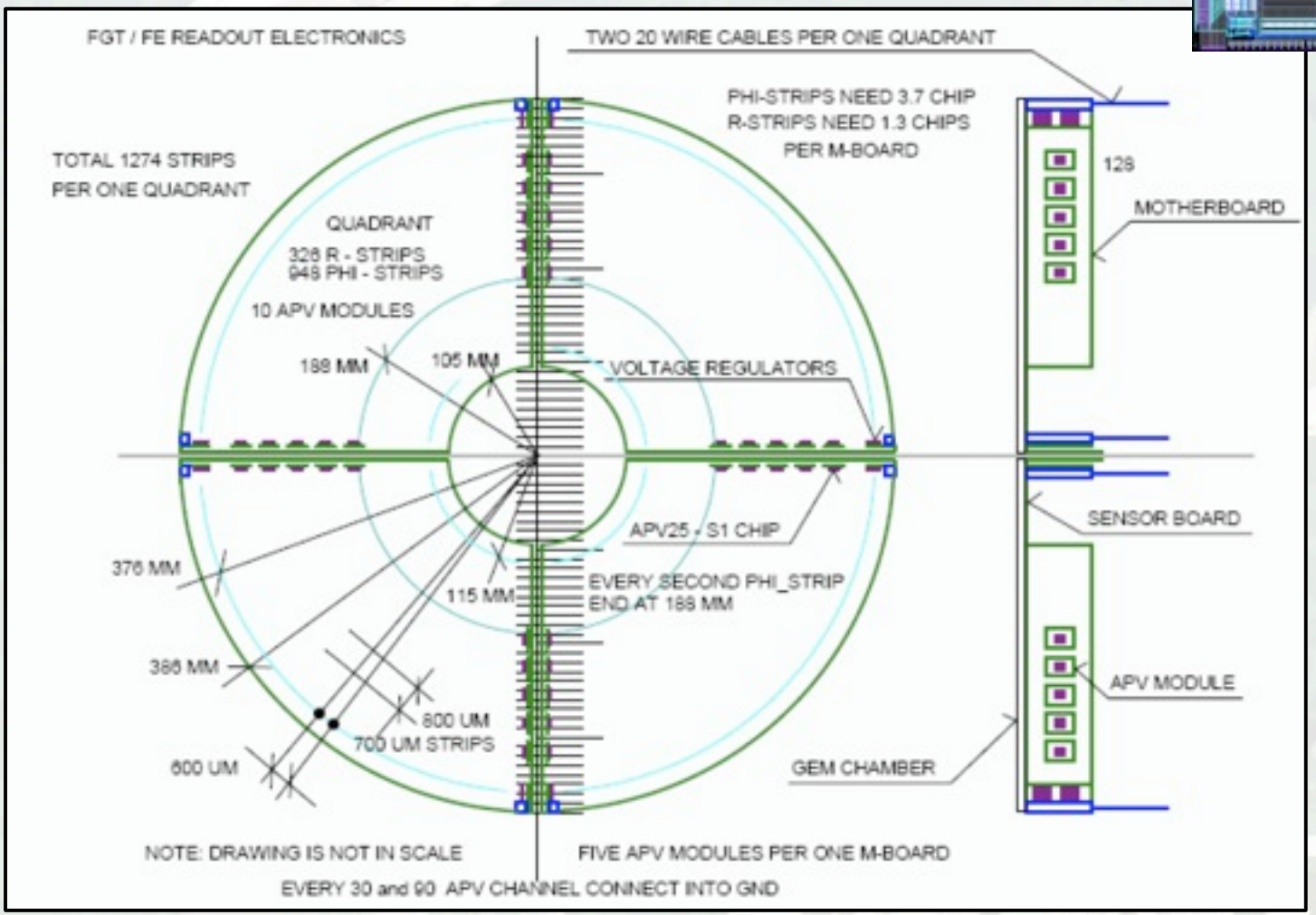
- Align frames to each other and to SIMM pins
- Hold frames flat with clamps
- Hold SIMM pins in place for soldering
- Clamp frames together for gluing operation

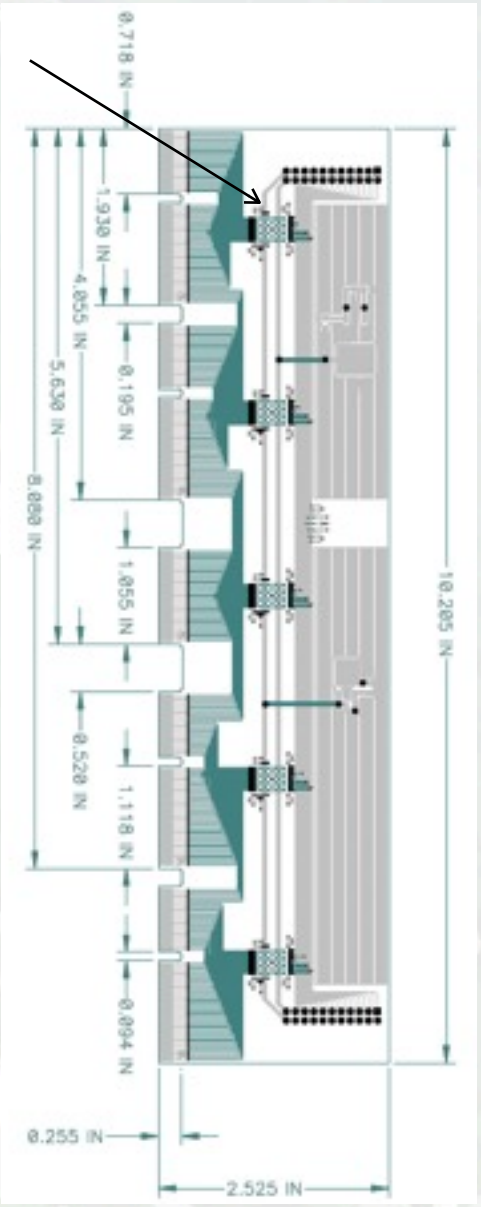
FGT Technical realization

- 2D readout board design and FEE

APV25-S1 chips







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