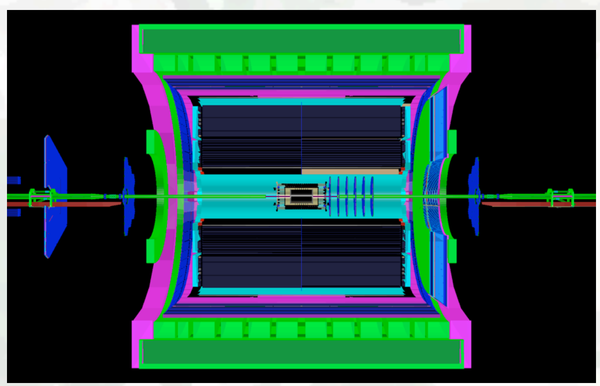
The STAR Forward GEM Tracker - R&D, Design and Assembly

Bernd Surrow

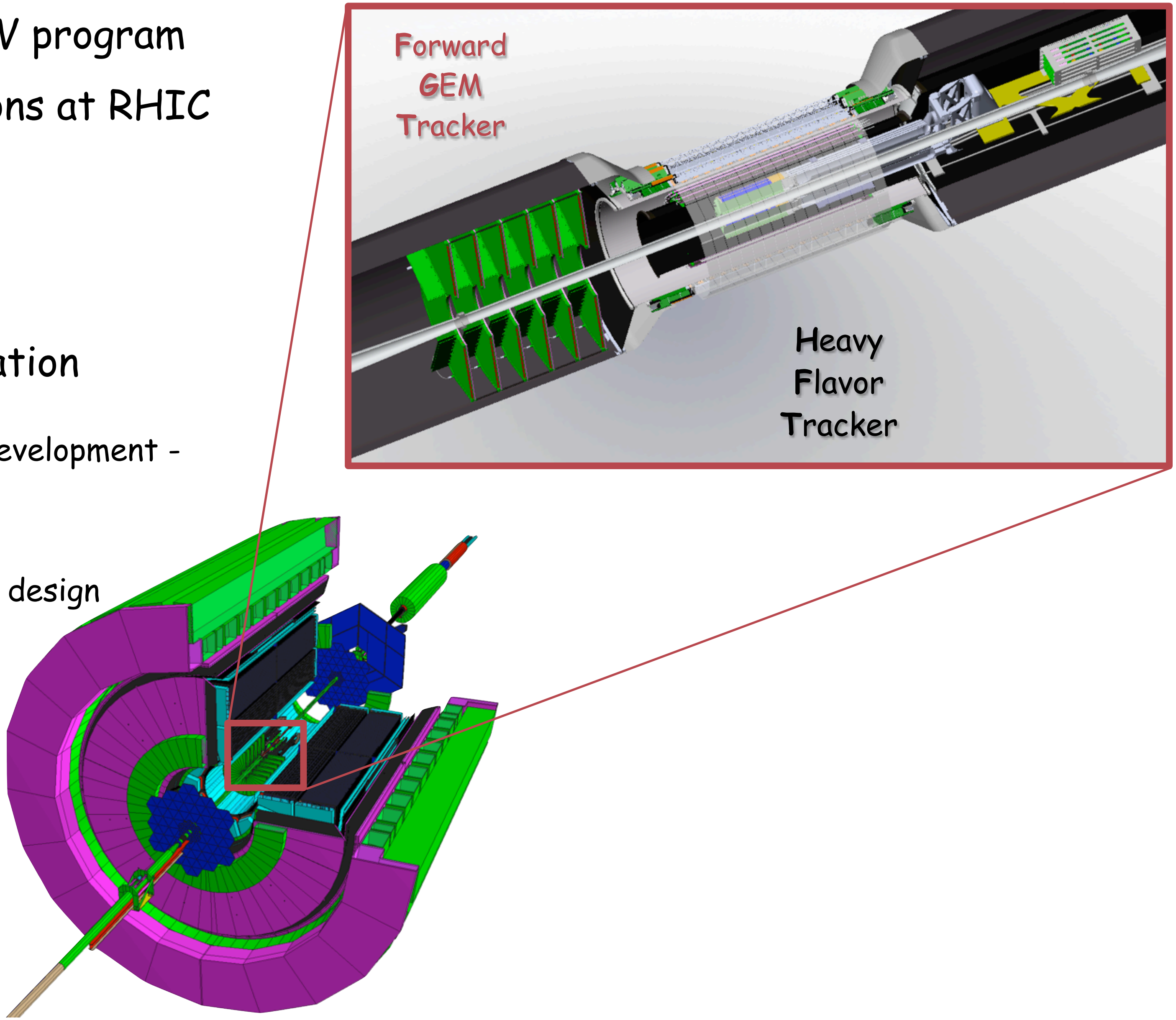
MIT

Massachusetts Institute of Technology



Outline

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



Physics motivation - W program at RHIC

STAR: Midrapidity A_L

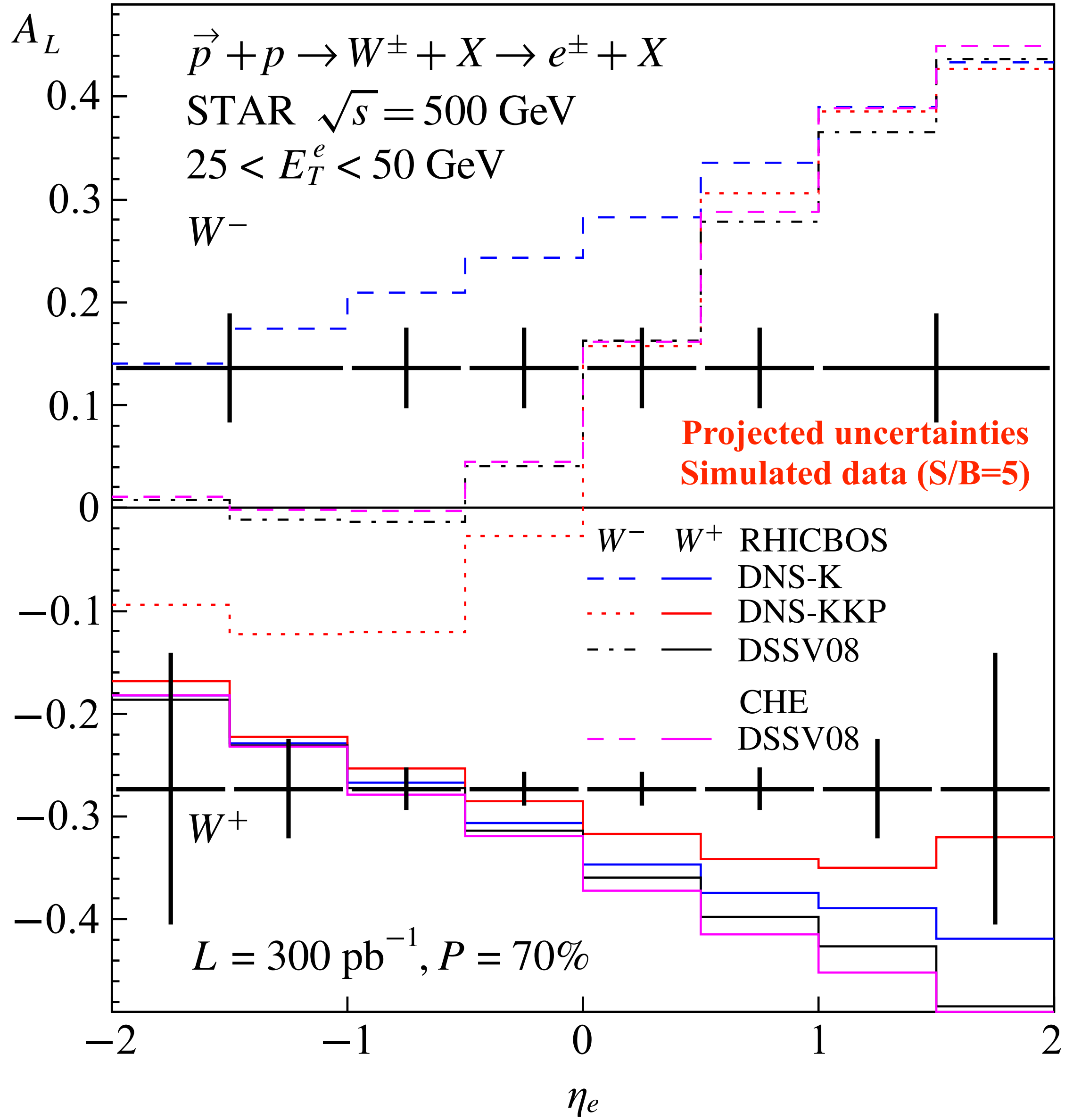
$$A_L^{W^-} = 0.14 \pm 0.19\,(\text{stat.}) \pm 0.02\,(\text{syst.}) \pm 0.01\,(\text{norm.})$$

$$A_L^{W^+} = -0.27 \pm 0.10\,(\text{stat.}) \pm 0.02\,(\text{syst.}) \pm 0.03\,(\text{norm}$$

STAR Collaboration, submitted to PRL,
arXiv: 1009.0326

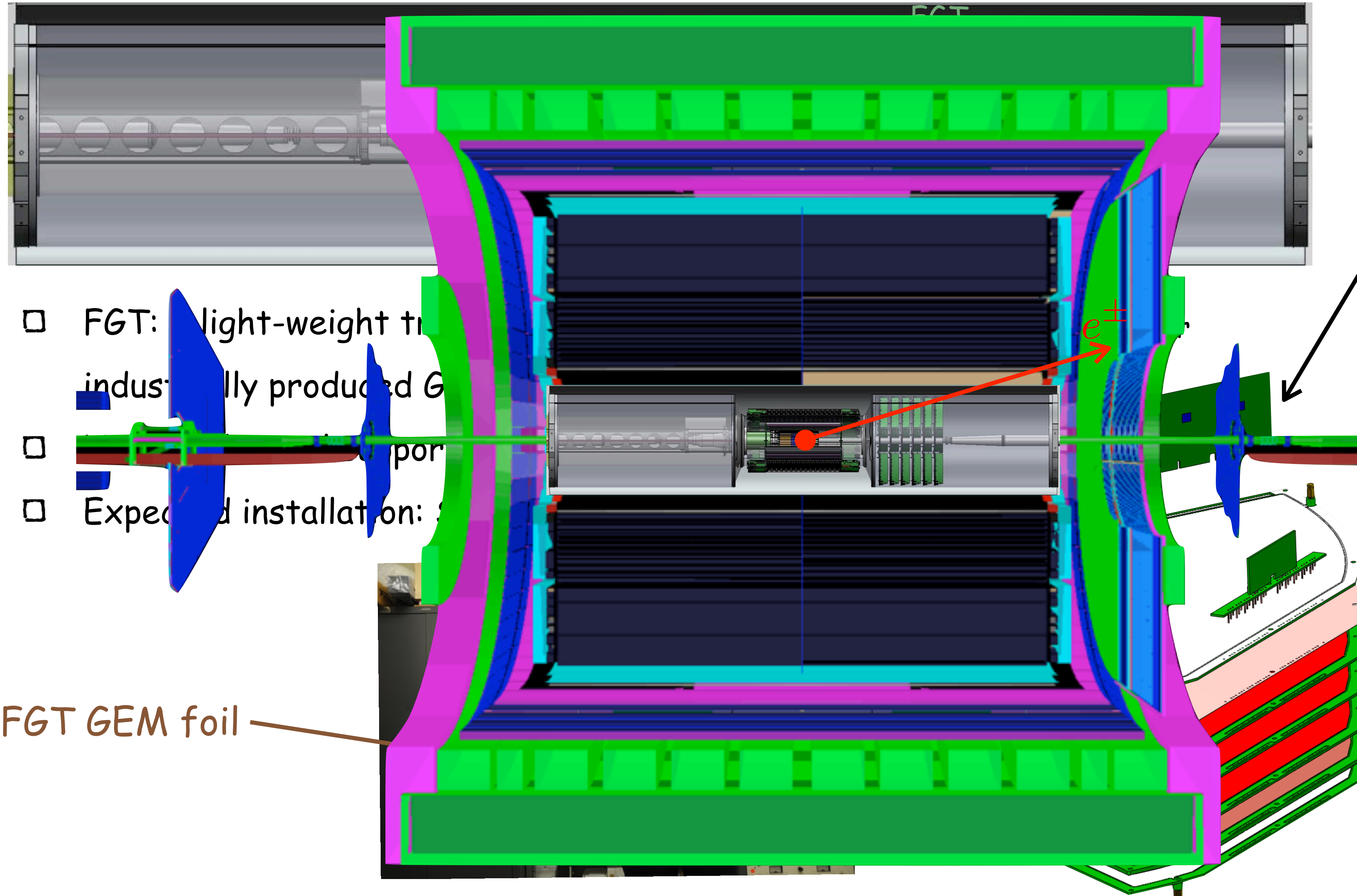
- $A_L(W^+)$ negative with a significance of ~3σ
- $A_L(W^-)$ central value positive
- Measured asymmetries are in agreement with theory evaluations using polarized pdf's (DSSV) constrained by polarized DIS data

  ⇒ Universality of helicity distr. functions!

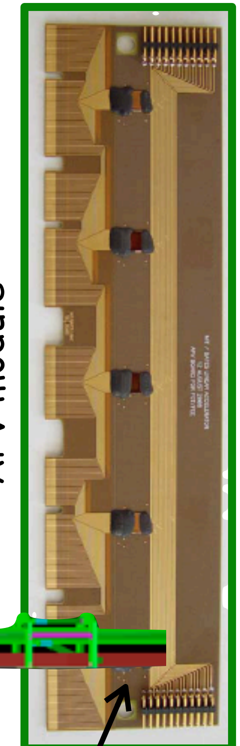


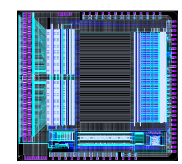
FGT Layout

- STAR Forward GEM Tracker



- FGT: light-weight tr
  indus lly produced G
- por
- Expec d installat on:





FGT Overview

- Institutional responsibility (1)
  - Mechanical
    - Mechanical design: MIT, LBL
    - Triple-GEM detector assembly and testing: MIT, Yale University
    - Cooling: MIT
    - Gas system: Valparaiso University
    - Installation: ANL, IUCF, LBL, MIT, University of Kentucky, Valparaiso University
  - Electronics
    - FEE design: MIT
    - FEE assembly and testing: MIT
    - DAQ design: ANL, IUCF
    - DAQ assembly and testing: ANL, IUCF, University of Kentucky
    - Other electronics needs (High-Voltage and Low-Voltage supplies): MIT, IUCF

FGT Overview

- Institutional responsibility (2)
  - System integration
    - Overall integration of mechanical system: BNL Operations Group, MIT, LBL
    - System test: ANL, IUCF, MIT, University of Kentucky, Valparaiso University
    - Operation and maintenance: ANL, IUCF, MIT, University of Kentucky, Valparaiso University
  - Software
    - Slow control: Valparaiso University
    - Simulations: MIT, IUCF
    - Calibration and tracking software: MIT
    - Physics analysis: ANL, MIT, IUCF, University of Kentucky, Valparaiso University

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

FGT Technical realization

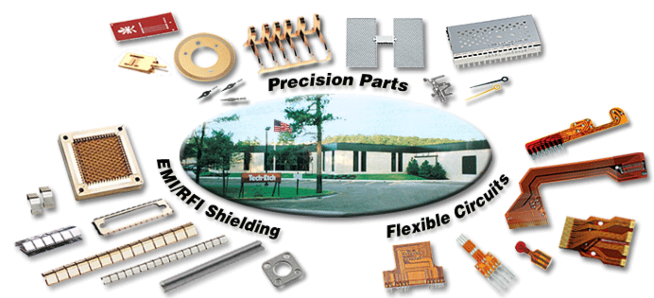
- SBIR proposal (2)

  - 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 / Successful production and performance of large GEM foils

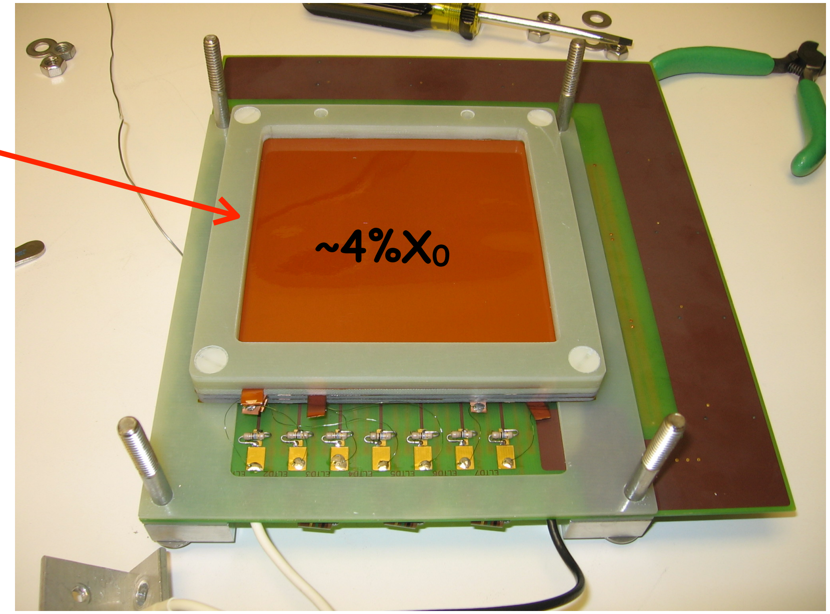
Tech-Etch Inc.

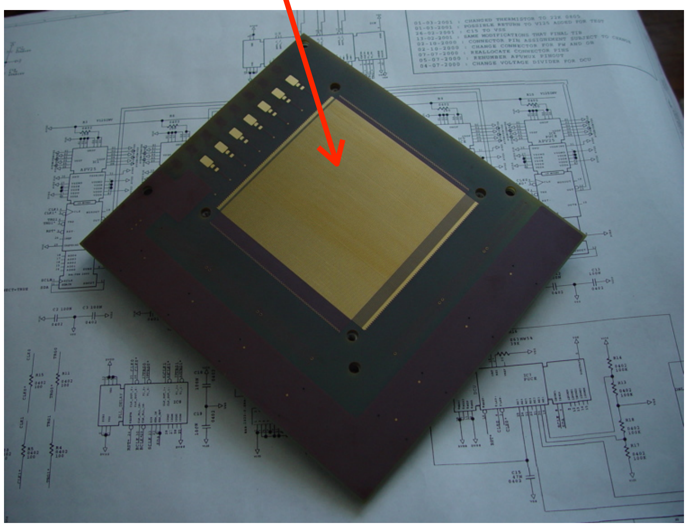


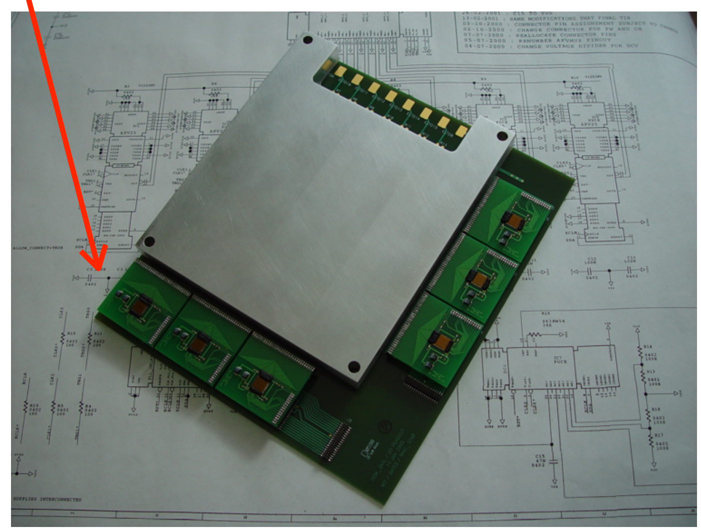
http://www.tech-etch.com

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

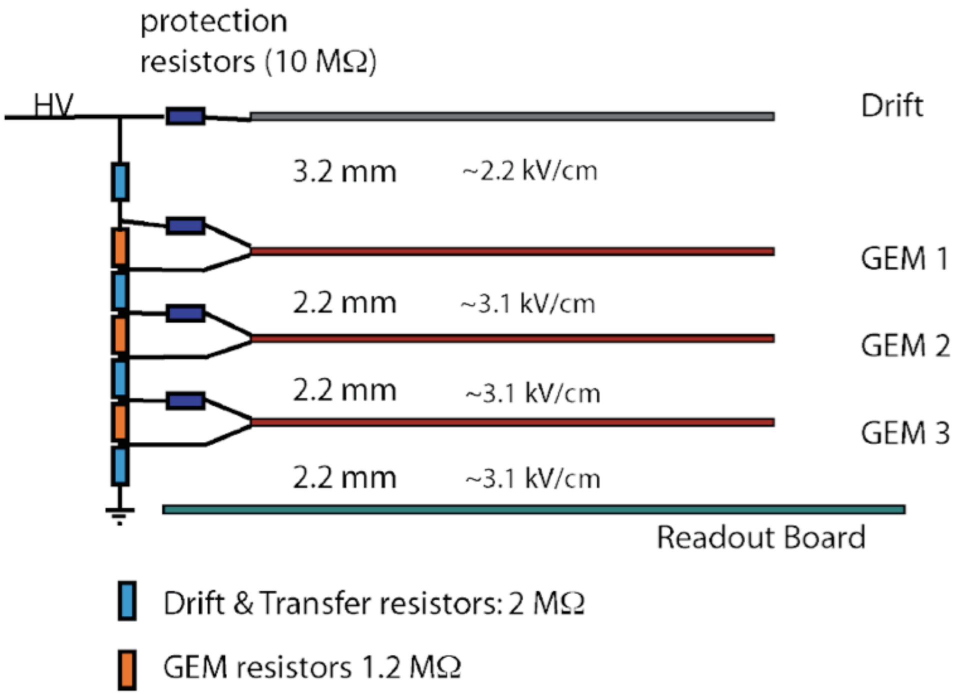


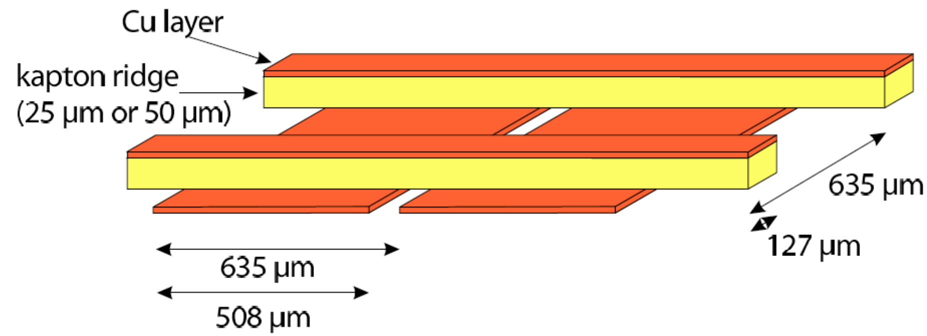




FGT Technical realization

Prototype triple-GEM configuration (2)



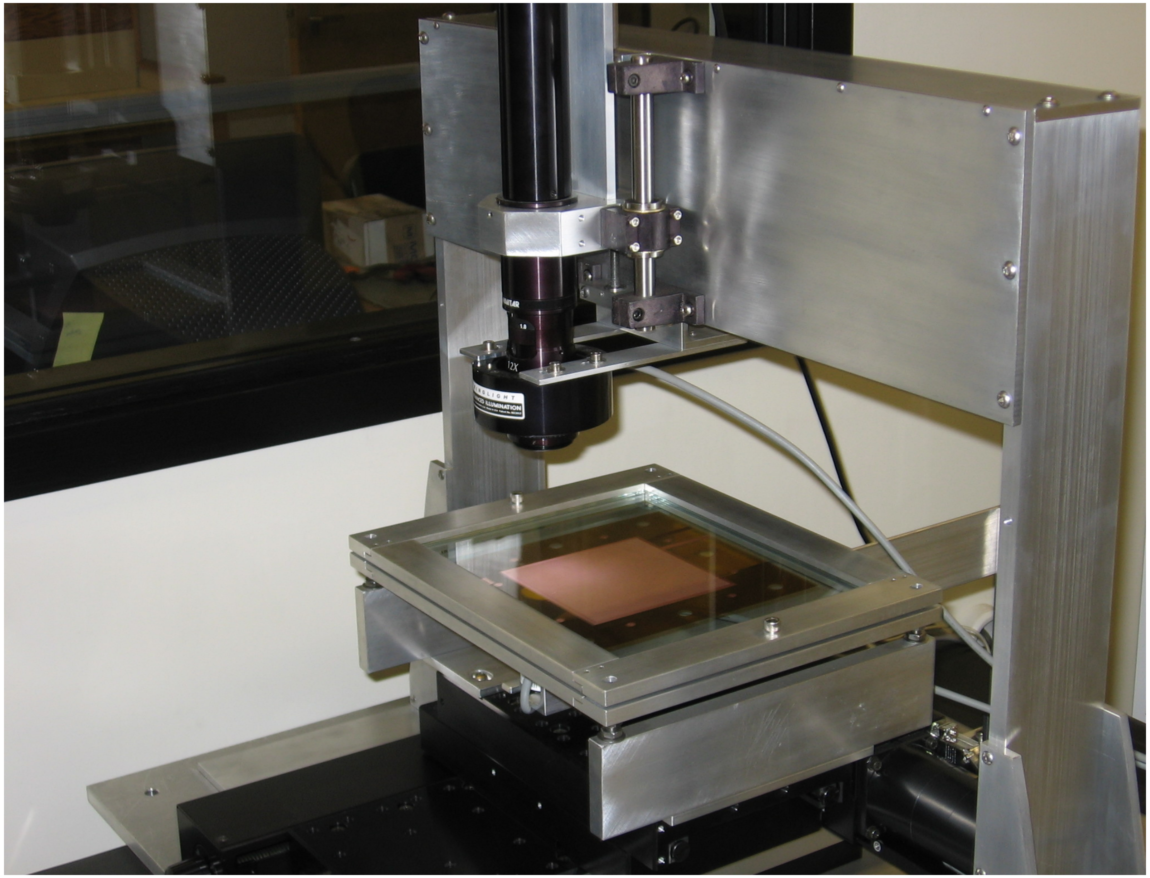


- Laser etched 2D readout board (Compunetics Inc.)
- Test beam configuration:
  Top strips (Y): ~127μm
  Bottom strips (X): 508μm
- Two separations: 25μm and 50μm

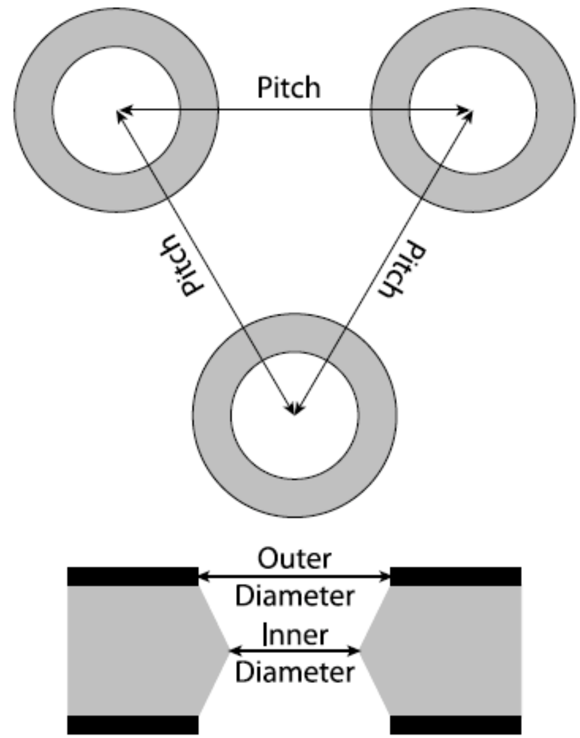
- Test beam operating voltage: ~3750V-3800V corresponding to ~385V-395V per GEM foil
- Testbeam effective gain: $\sim 3.5 \cdot 10^3$ ($\sim 2.5 \cdot 10^4$ bench tests)

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



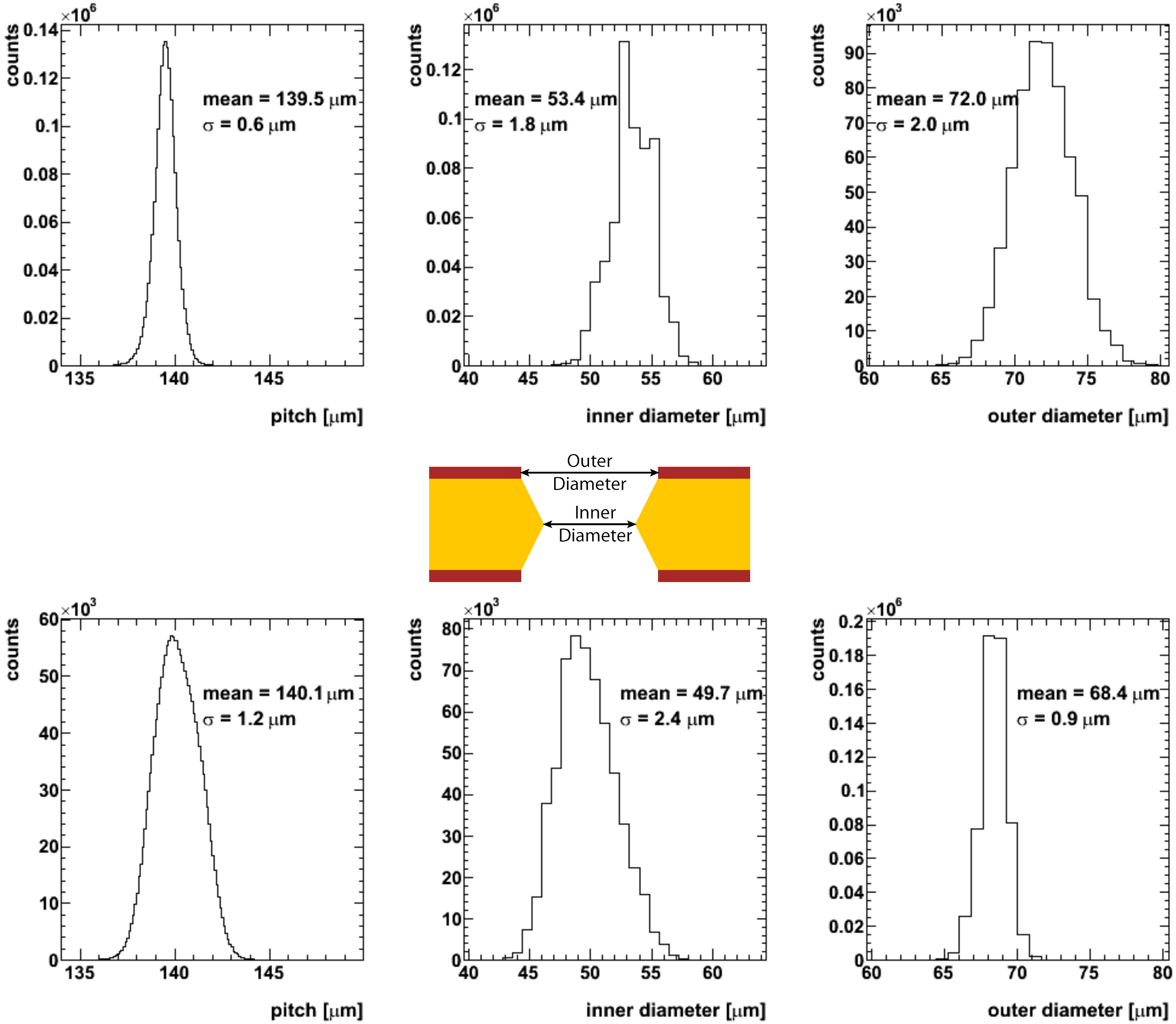
- Check for defects:
  - Missing holes, enlarged holes, dirt in holes and etching defects

FGT Technical realization

- Optical scans (2)

Tech-Etch

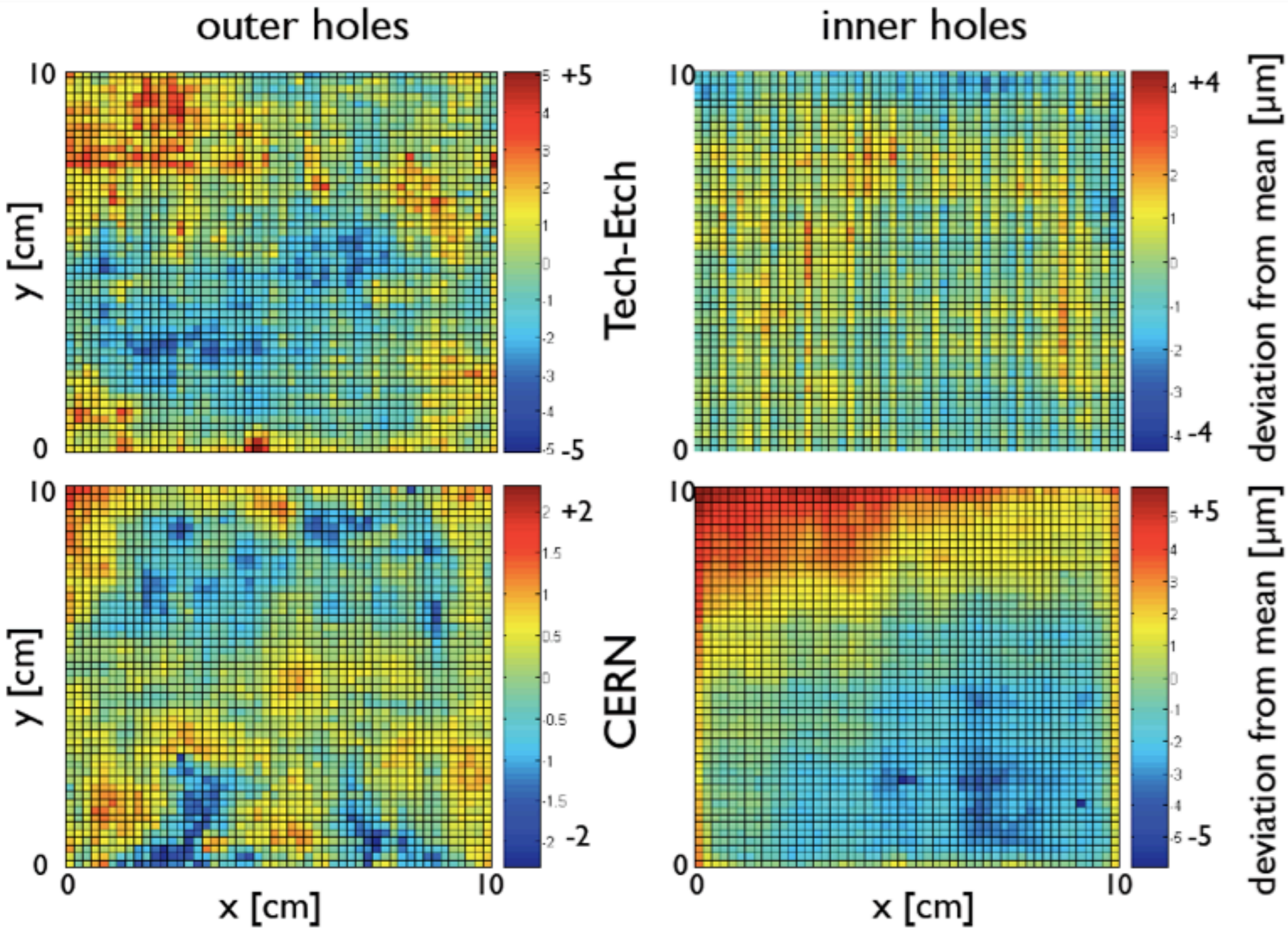
CERN

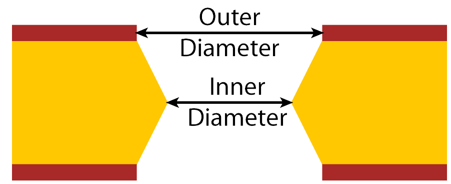


- Geometrical parameters are similar for Tech-Etch and CERN foils (10cm X 10cm samples)

FGT Technical realization

- Optical scans (3)



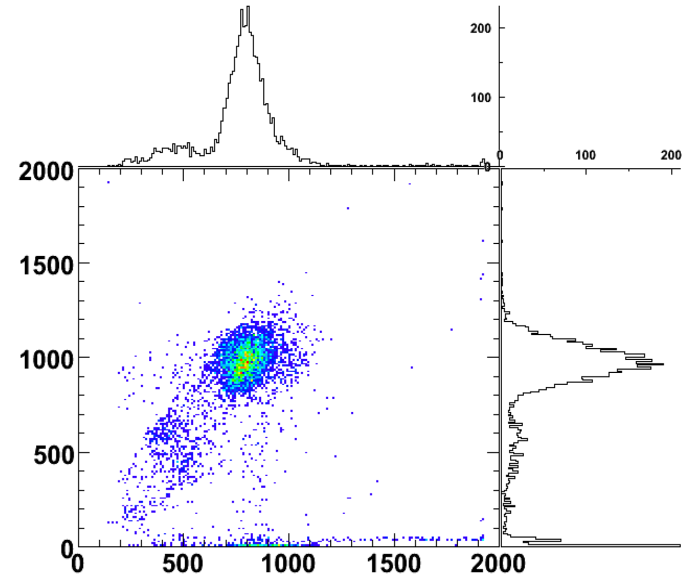


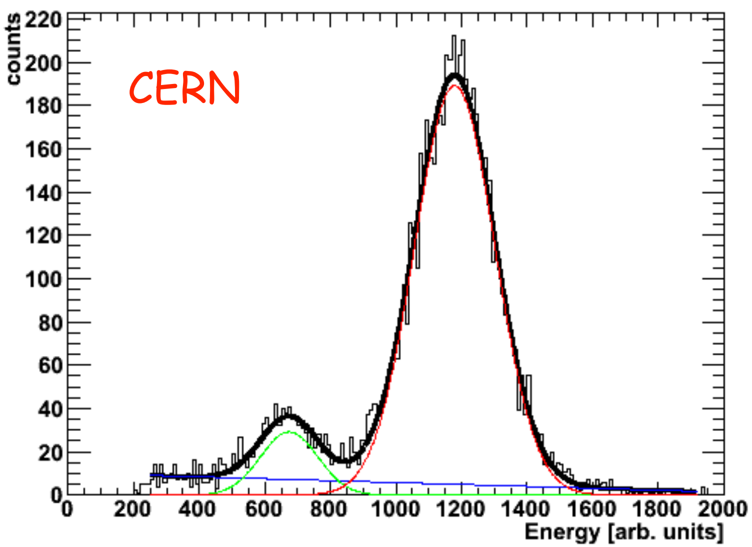
- Uniformity of outer/inner hole diameters for Tech-Etch and CERN foils (10cm X 10cm samples)

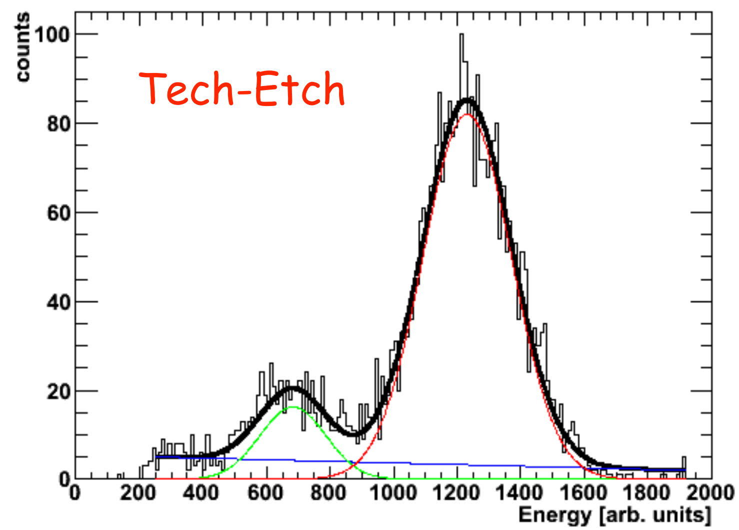
FGT Technical realization

- 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

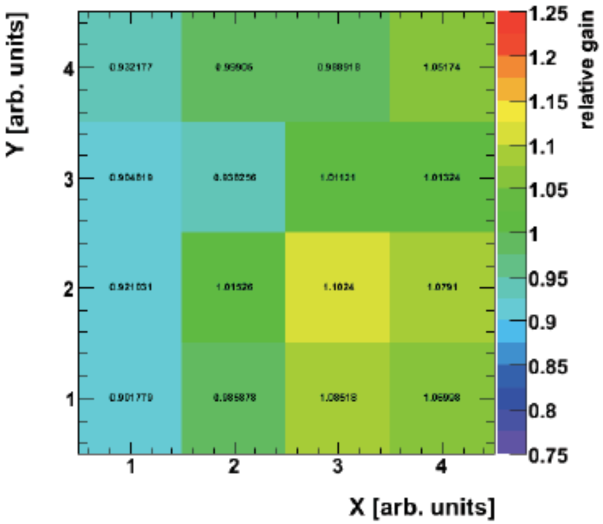


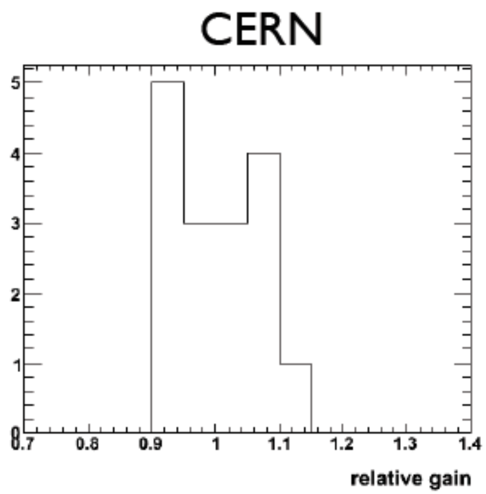


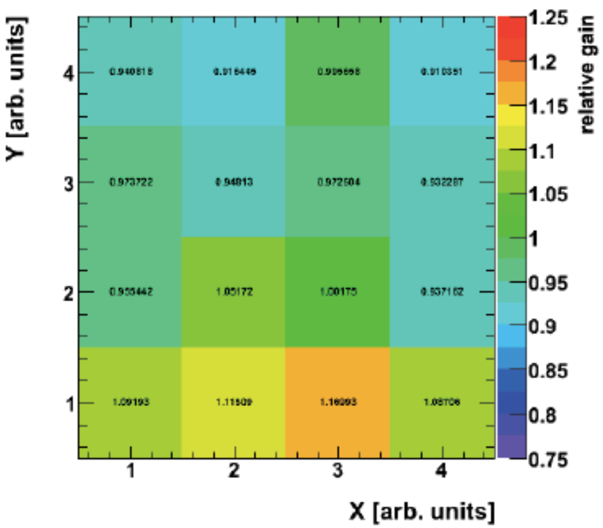


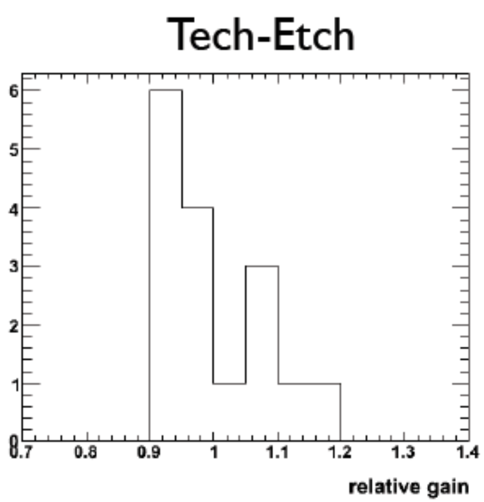
FGT Technical realization

- Source tests (2)





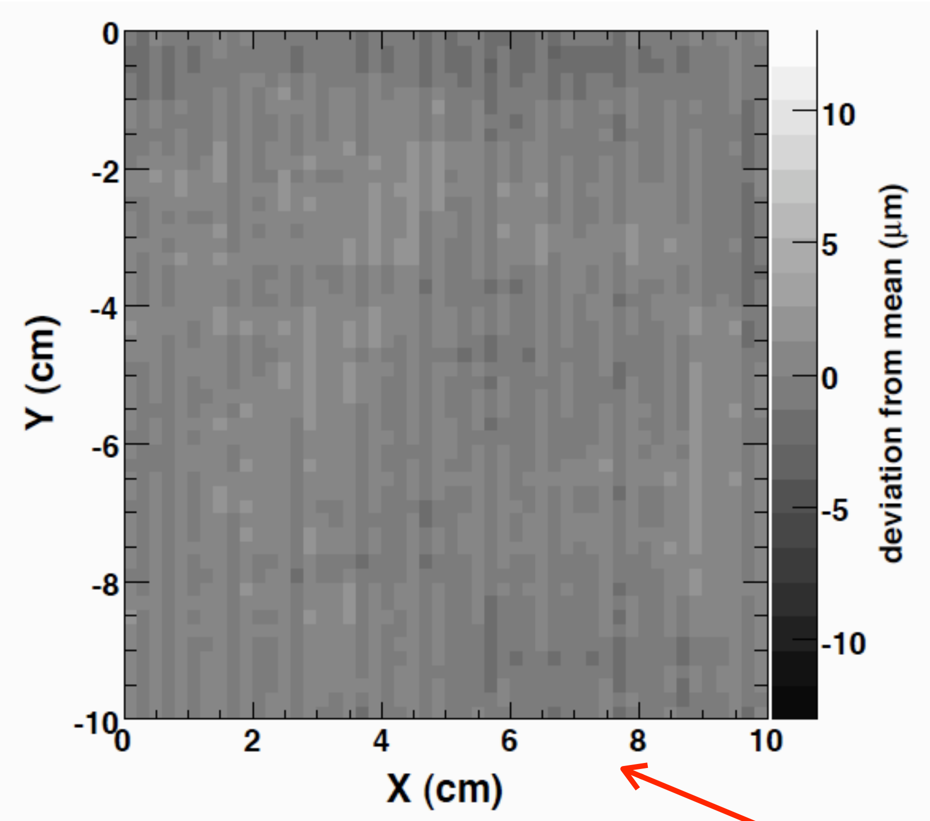


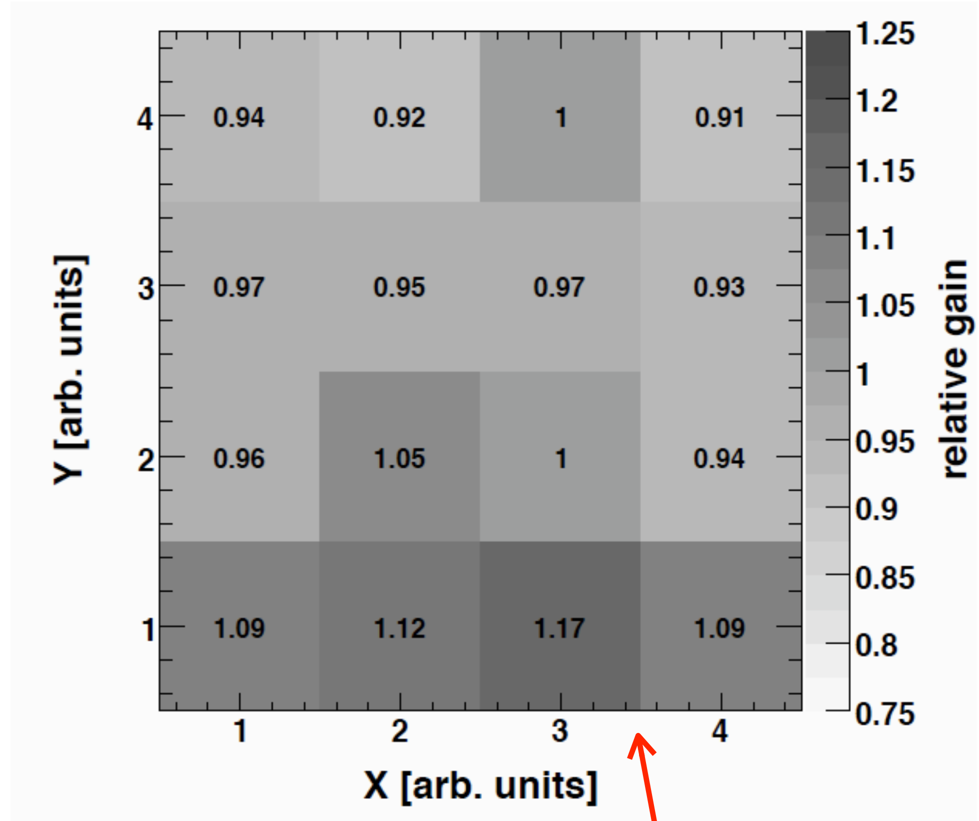


- Gain measured with low intensity ^{55}Fe source (~0.5Hz/mm^2)
- Good gain uniformity over full active area (Measured after charge built-up)

FGT Technical realization

- Source tests (3)



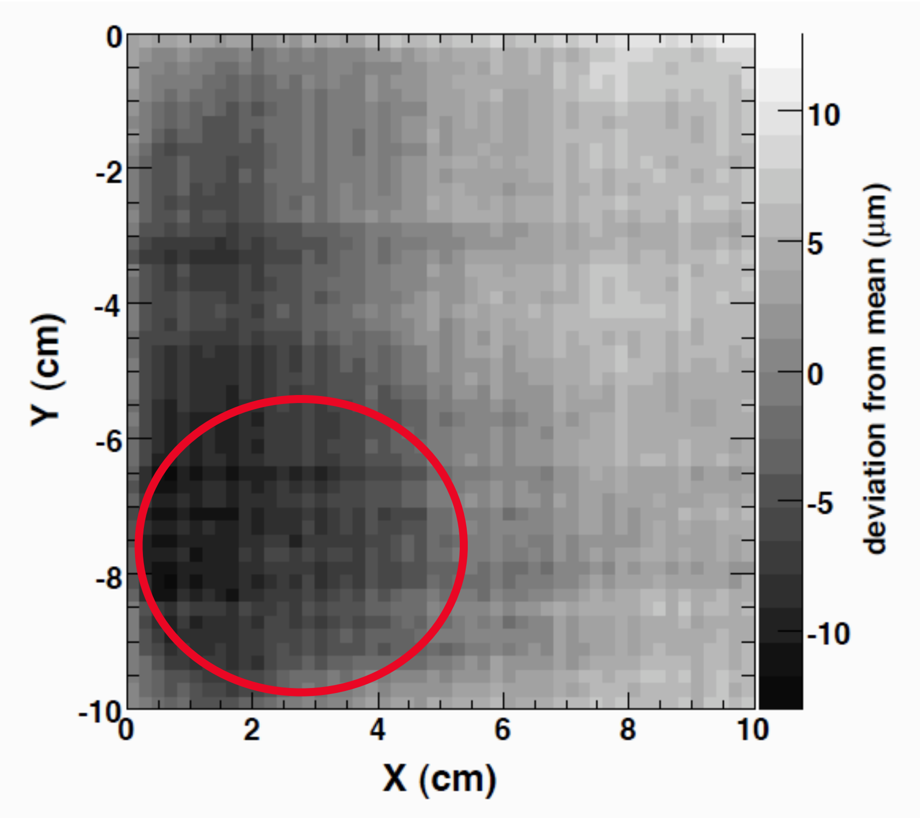


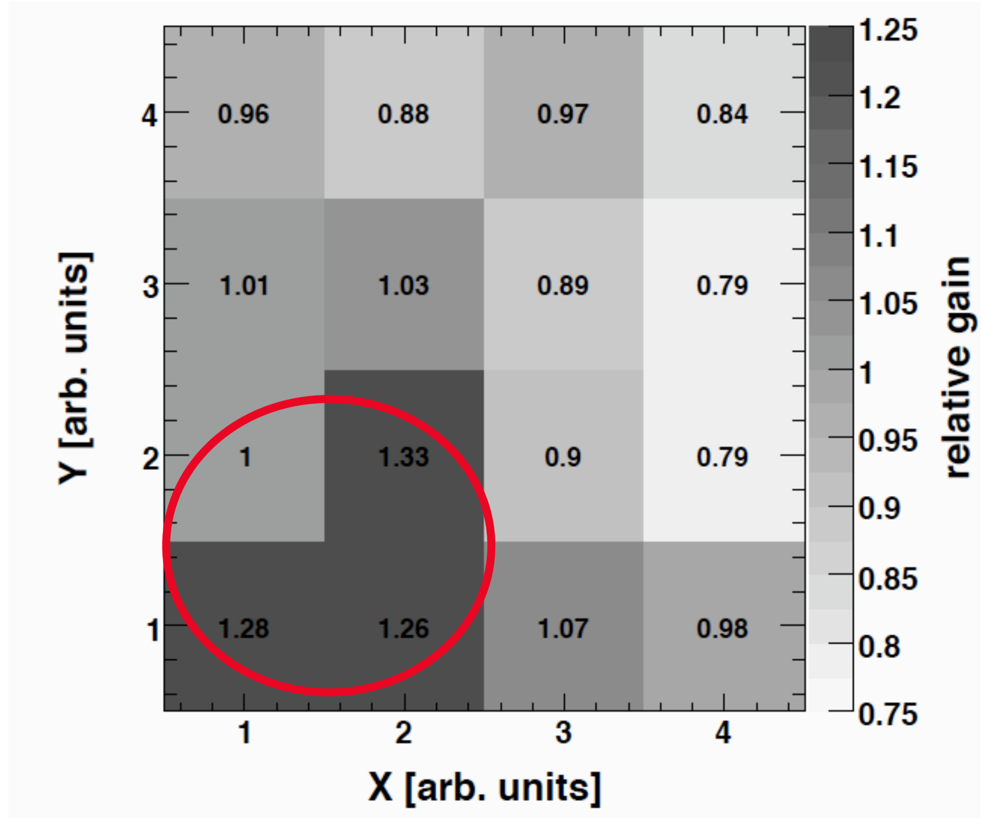
- Comparison of optical scans of inner hole diameter uniformity and gain uniformity

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

FGT Technical realization

Source tests (4)



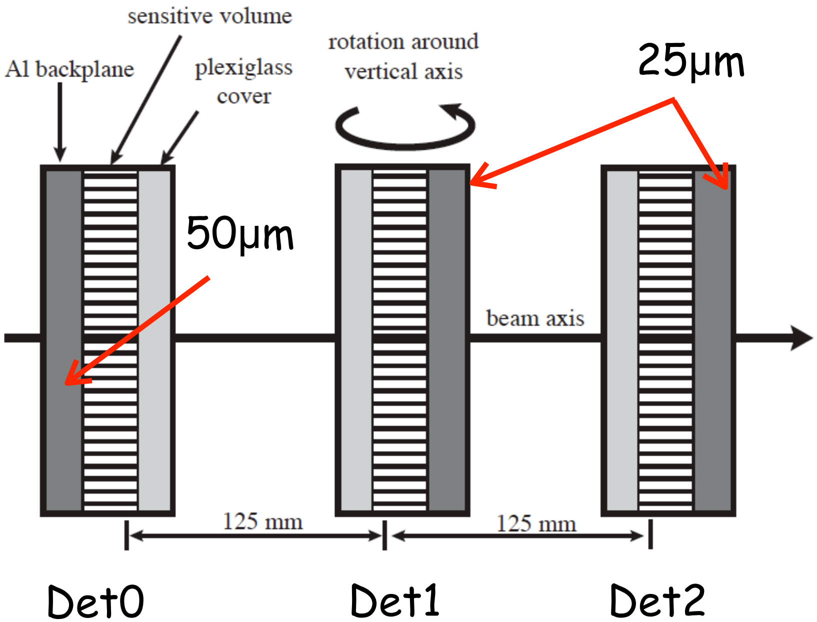


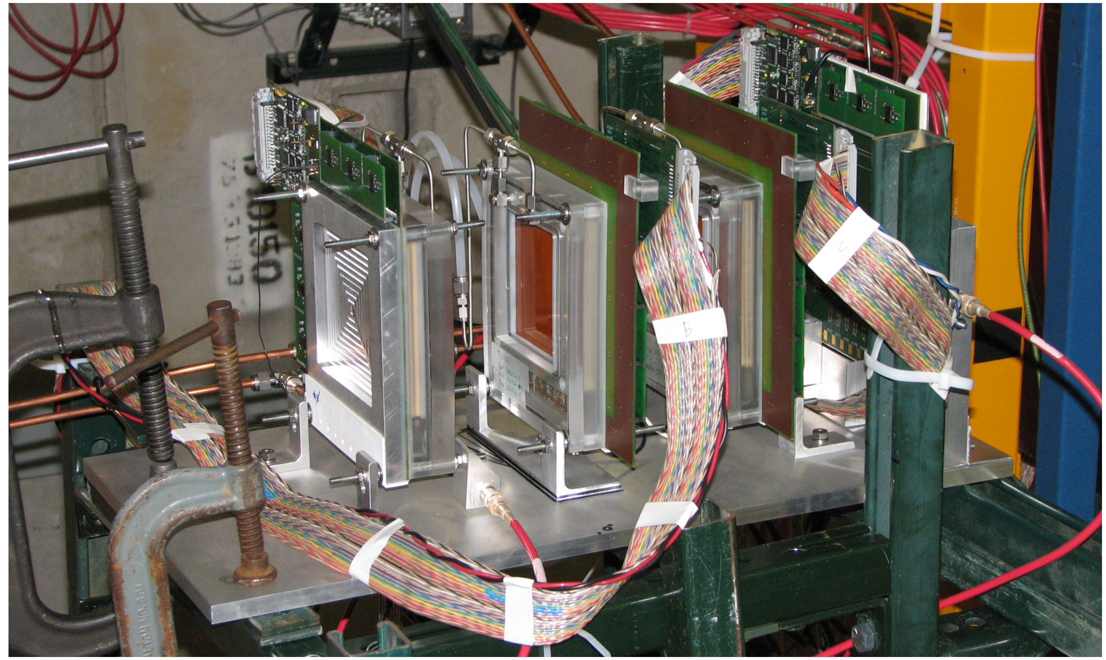
- Non-uniformity of inner hole diameter (~20µm smaller on left side compared to right side)

  reflected in large non-uniformity of source scan gain measurements

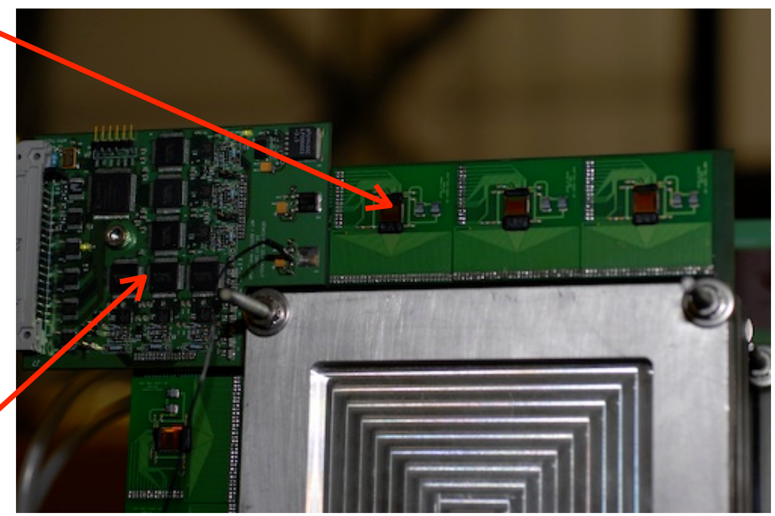
FGT Technical realization

- Testbeam results (1)





APV25-S1

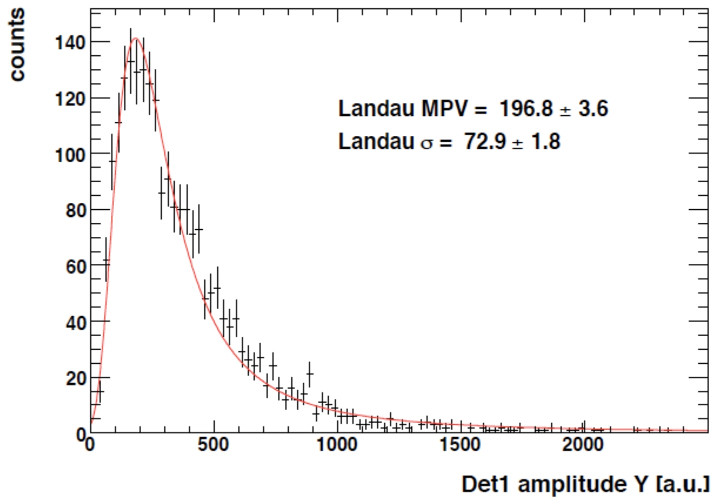


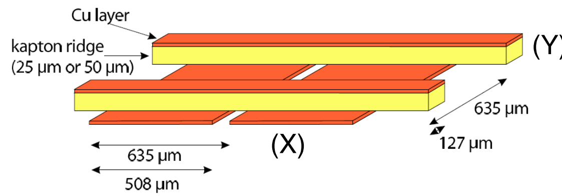
FPGA Readout System

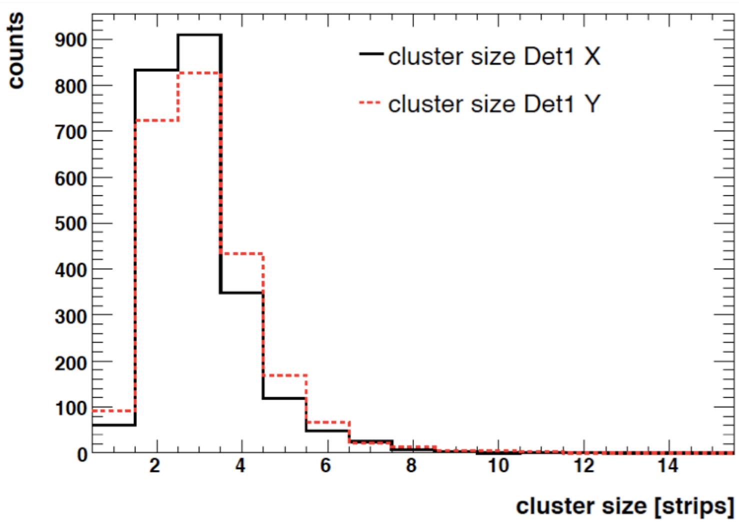
- FNAL Meson Test Beam Facility: Data taking with 4GeV-32GeV unseparated secondary beam and 120GeV primary proton beam

FGT Technical realization

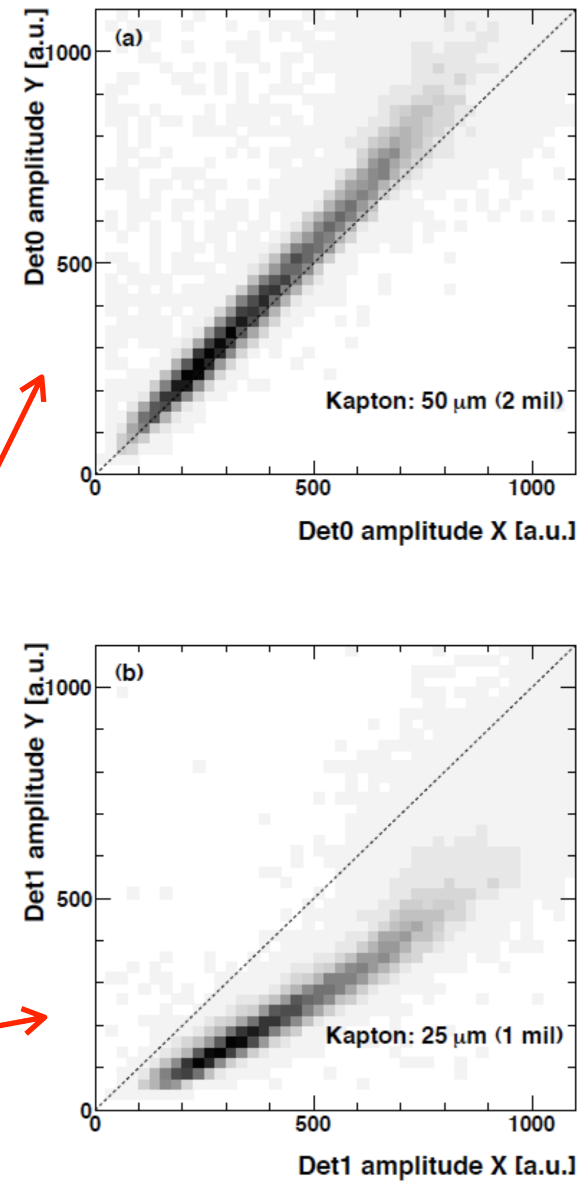
Testbeam results (2)





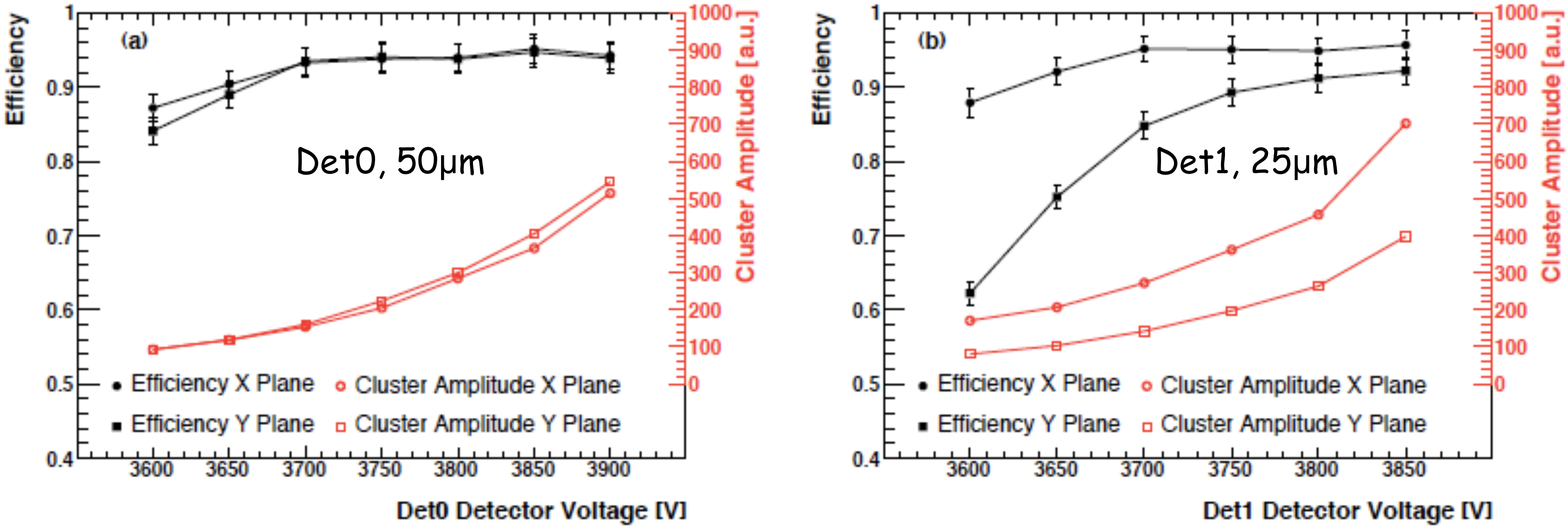


- Cluster charge follows expected distribution
- Two version of readout board (50μm and 25μm)



FGT Technical realization

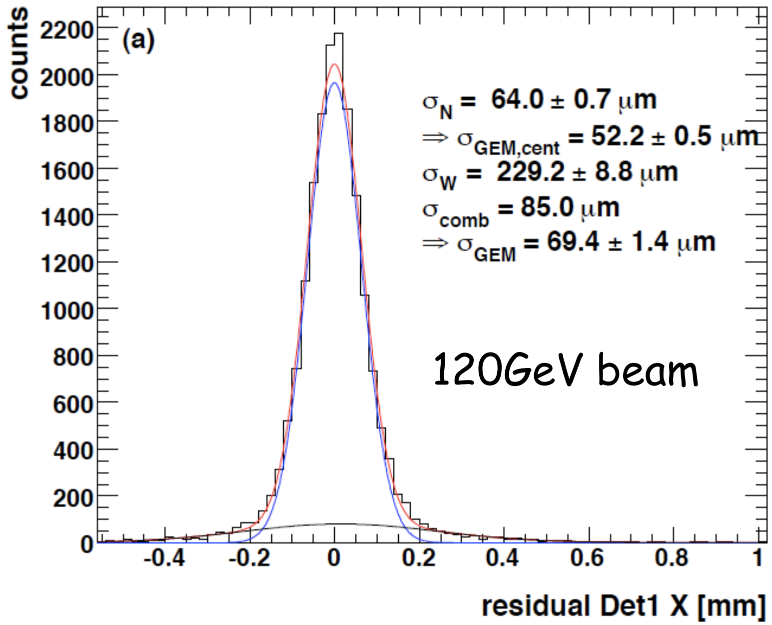
- Testbeam results (3)

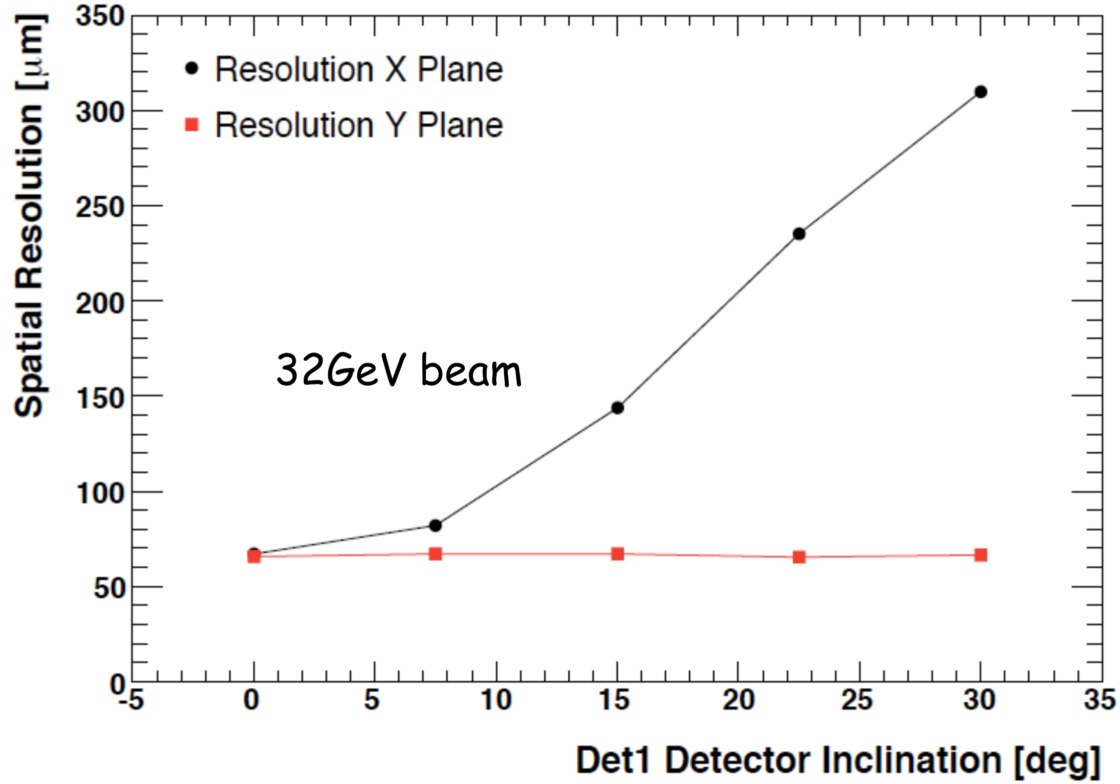


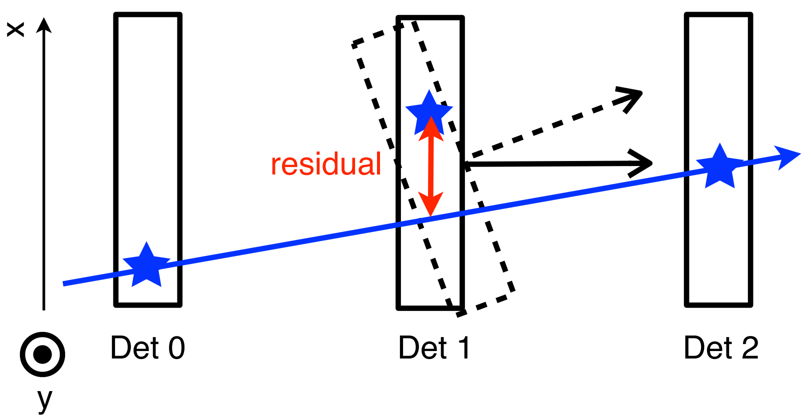
- Efficiencies at the level of ~95%-98% were reached in regions which limit the impact of noisy and dead regions with Tech-Etch GEM foils (Not affected by high intensity studies)
- Clear difference between Det0 (50µm) and Det 1 (25µm) for efficiency and cluster amplitude (Most probable value of Landau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

FGT Technical realization

Testbeam results (4)



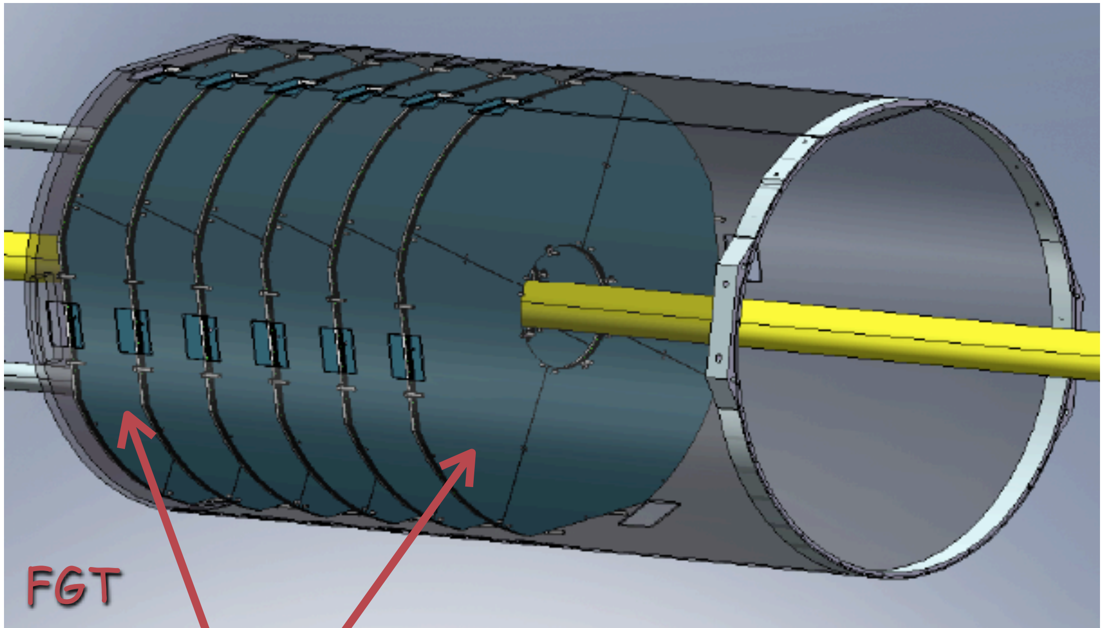


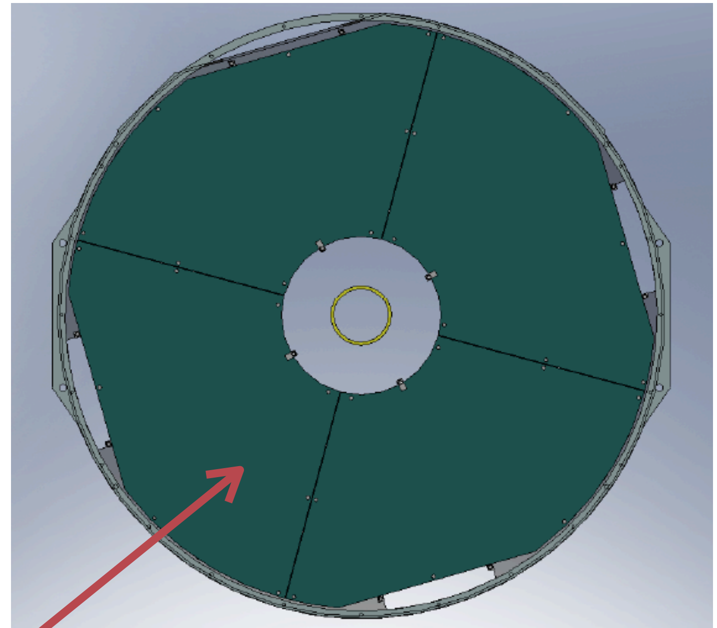


- Study of inclination by up to 30°: Only X (horizontal) resolution is affected, not so for Y (vertical) coordinate as expected!

FGT Technical realization

- Overview FGT Layout

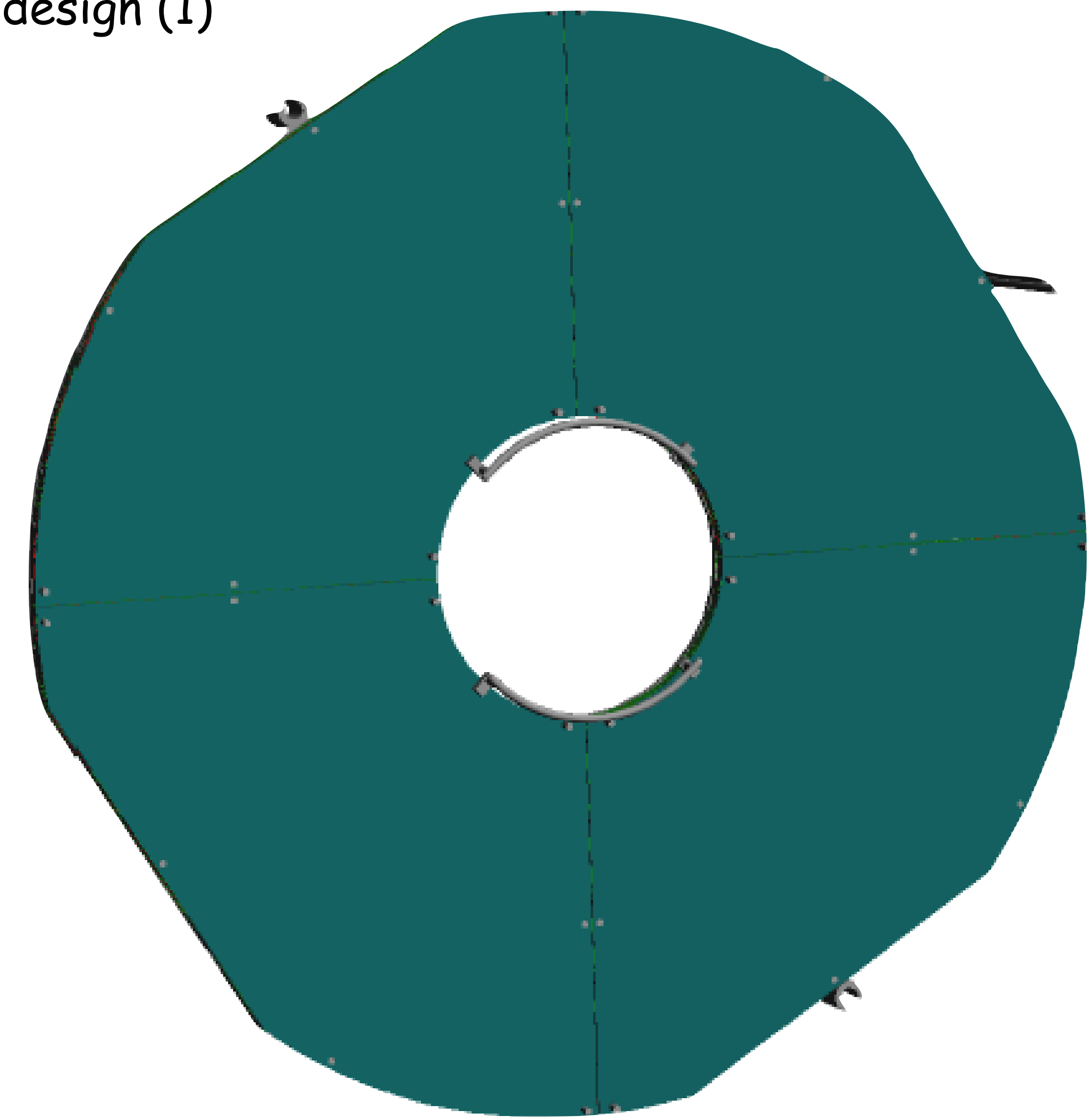




- FGT: 6 light-weight disks
- Each disk consists of 4 triple-GEM chambers (Quarter sections)

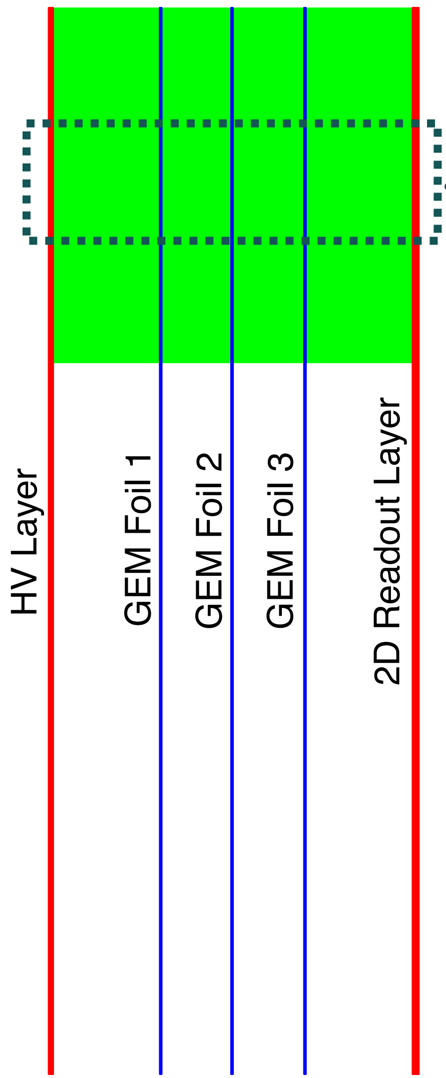
FGT Technical realization

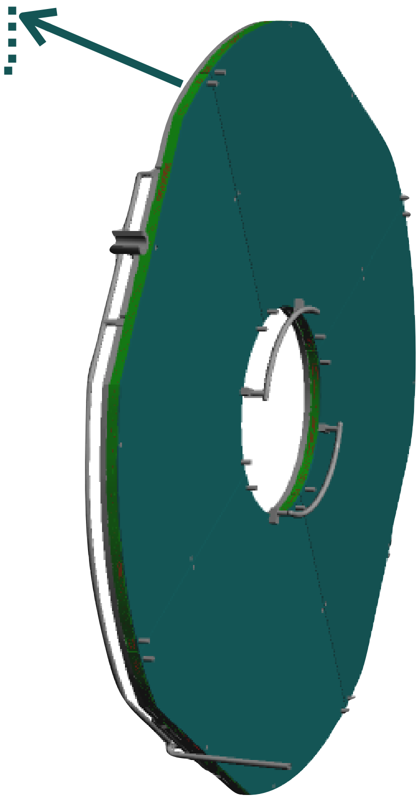
- Triple-GEM: Quarter section / Disk design (1)
  - Single disk
    - 5mm Nomex honeycomb
    - 0.25mm FR4 skins
    - Pins used as part of assembly and alignment
  - GEM quadrant
    - Pins define position
    - Pins preserve shape
  - Gas manifolds and rails



FGT Technical realization

- Triple-GEM: Quarter section / Disk design (2)

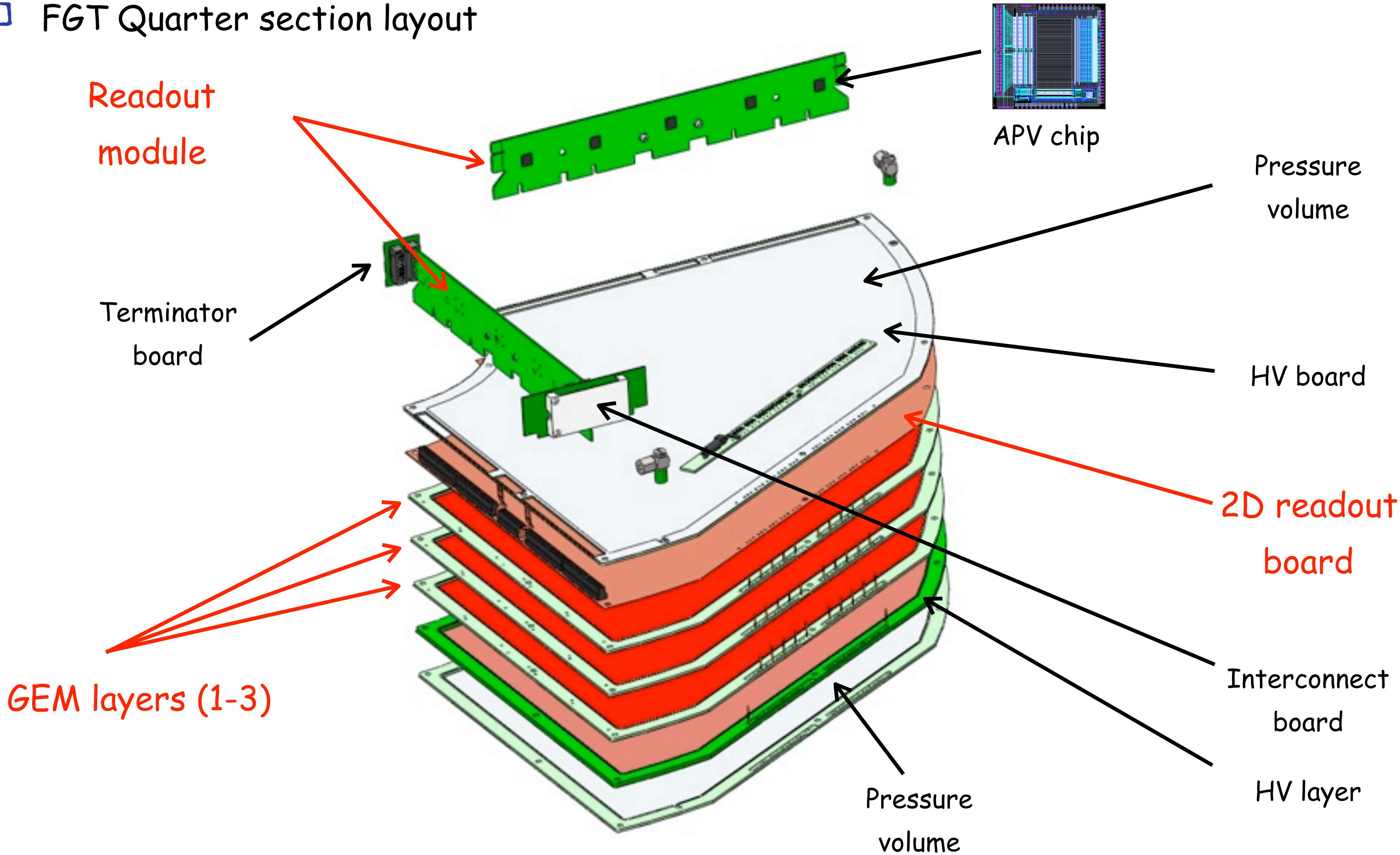




Component	Material	Radiation Length [%]
Support plate	5 mm Nomex	0.040
	2x250 μm FR4	0.257
HV layer	5 μm Cu	0.035
	50 μm Kapton	0.017
GEM foils	6x5 μm Cu (70%)	0.147
	3x50 μm Kapton (70%)	0.036
Readout	5 μm Cu (20%)	0.007
	50 μm Kapton (20%)	0.003
	5 μm Cu (88%)	0.031
	50 μm Kapton	0.017
	5 μm Cu (10%)	0.004
	5 μm Cu (10%)	0.004
Drift gas	10 mm CO_2 (30%)	0.002
	10 mm Ar (70%)	0.006
Total		0.606

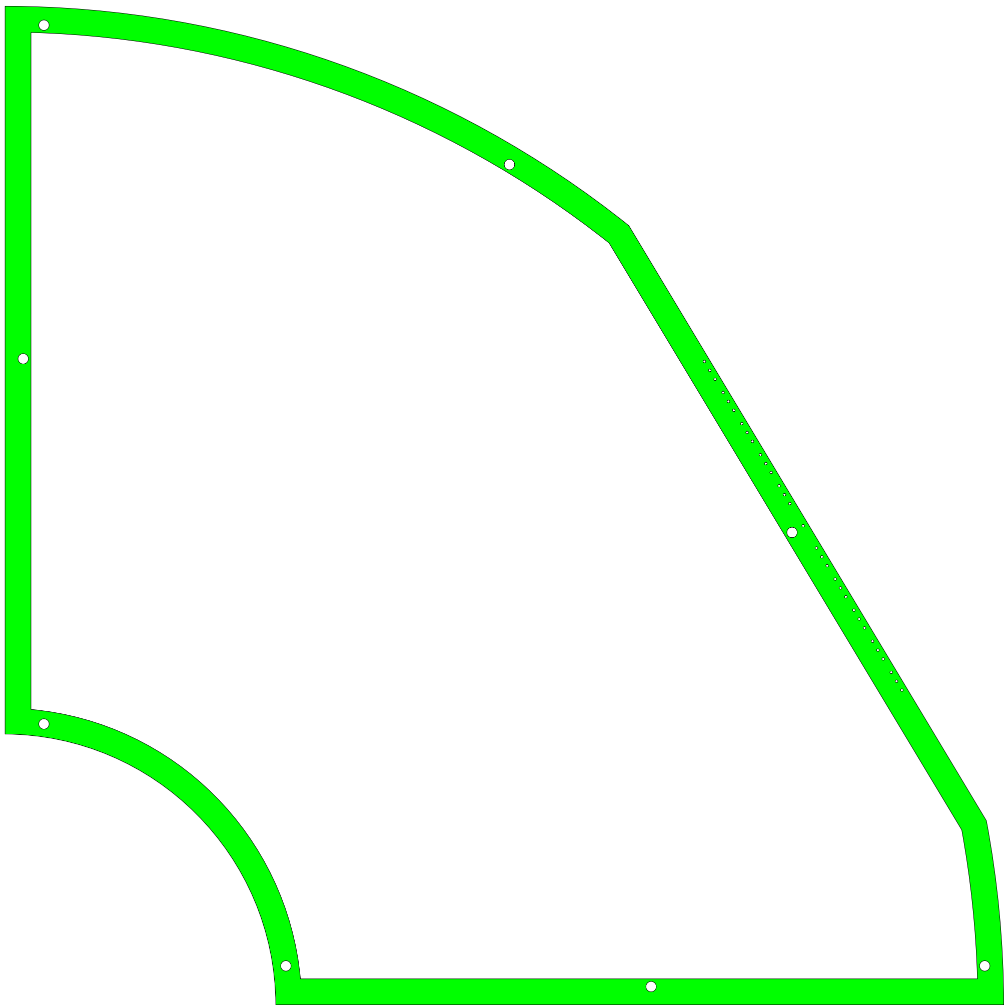
FGT Technical realization

- FGT Quarter section layout



FGT Technical realization

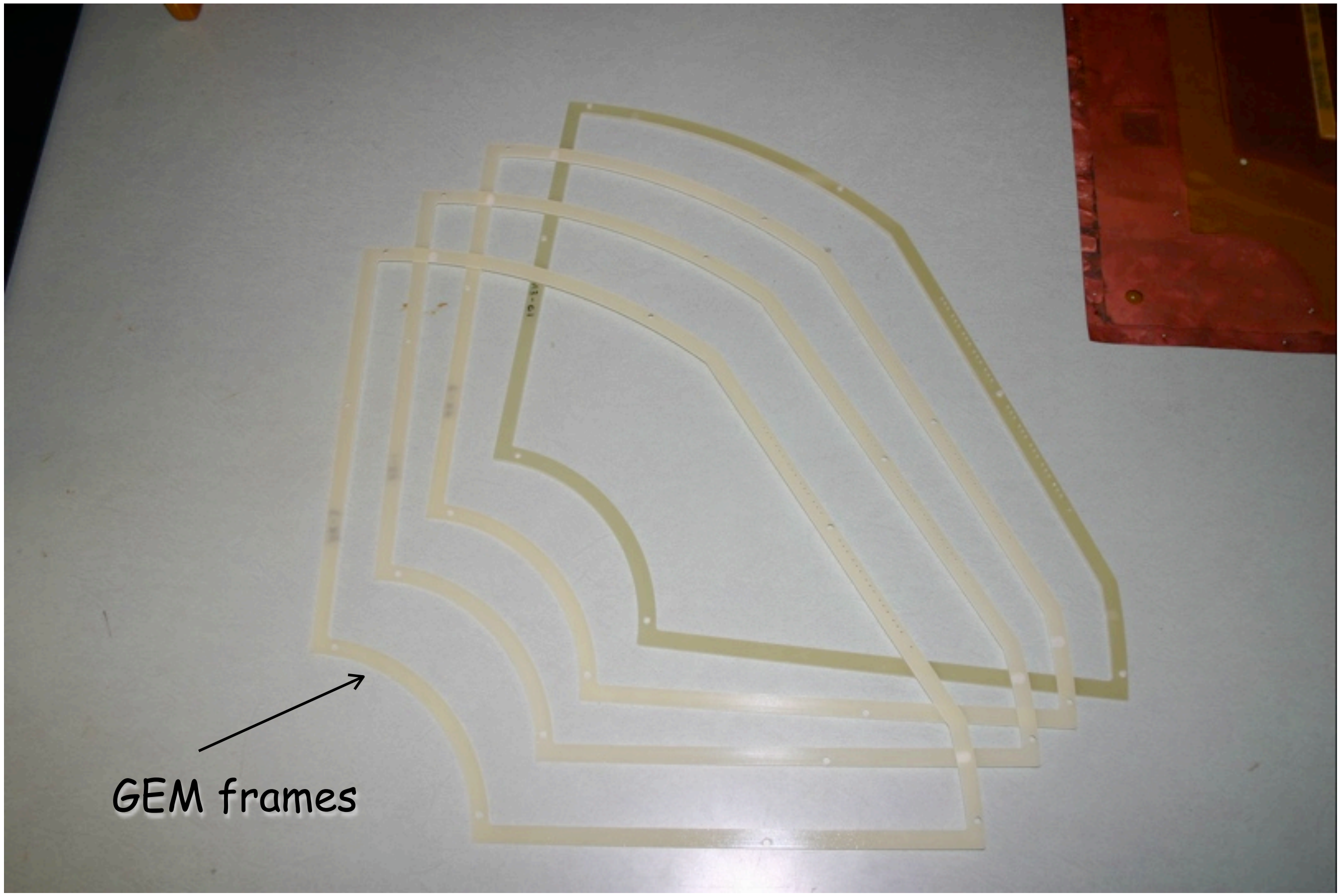
Triple-GEM: Frame layout (1)

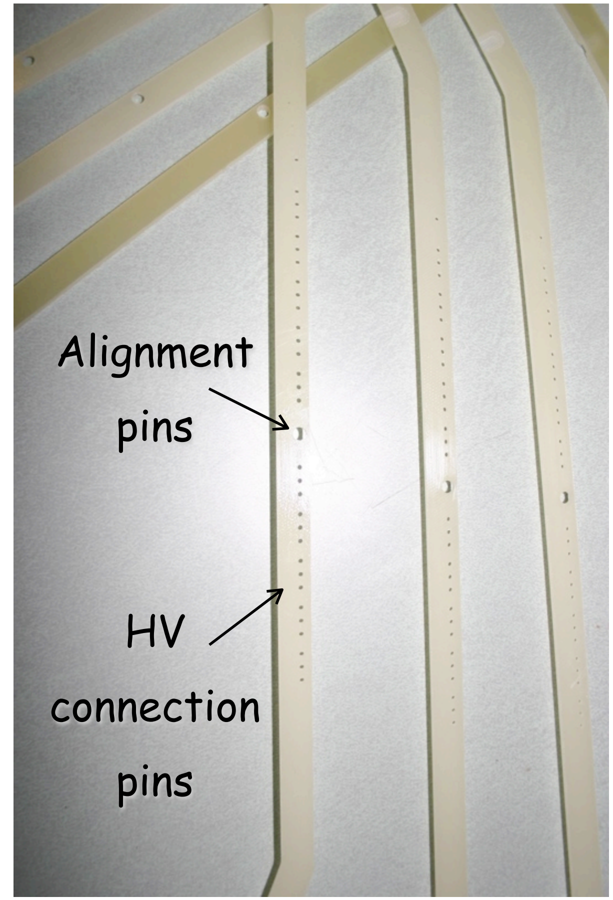


- 1cm wide frames of FR4
- 2-3mm thick
- Inner radius: 10.5cm
- Outer radius: 38.1cm
- Flat at 31°
- 1mm gap between quadrants
- 4mm FR4 pins
- 34 X 1mm holes for HV GEM foil connection

FGT Technical realization

- Triple-GEM: Frame layout (2)





FGT Technical realization

- Triple-GEM: Frame preparation (1)

Anne Holladay (MIT)

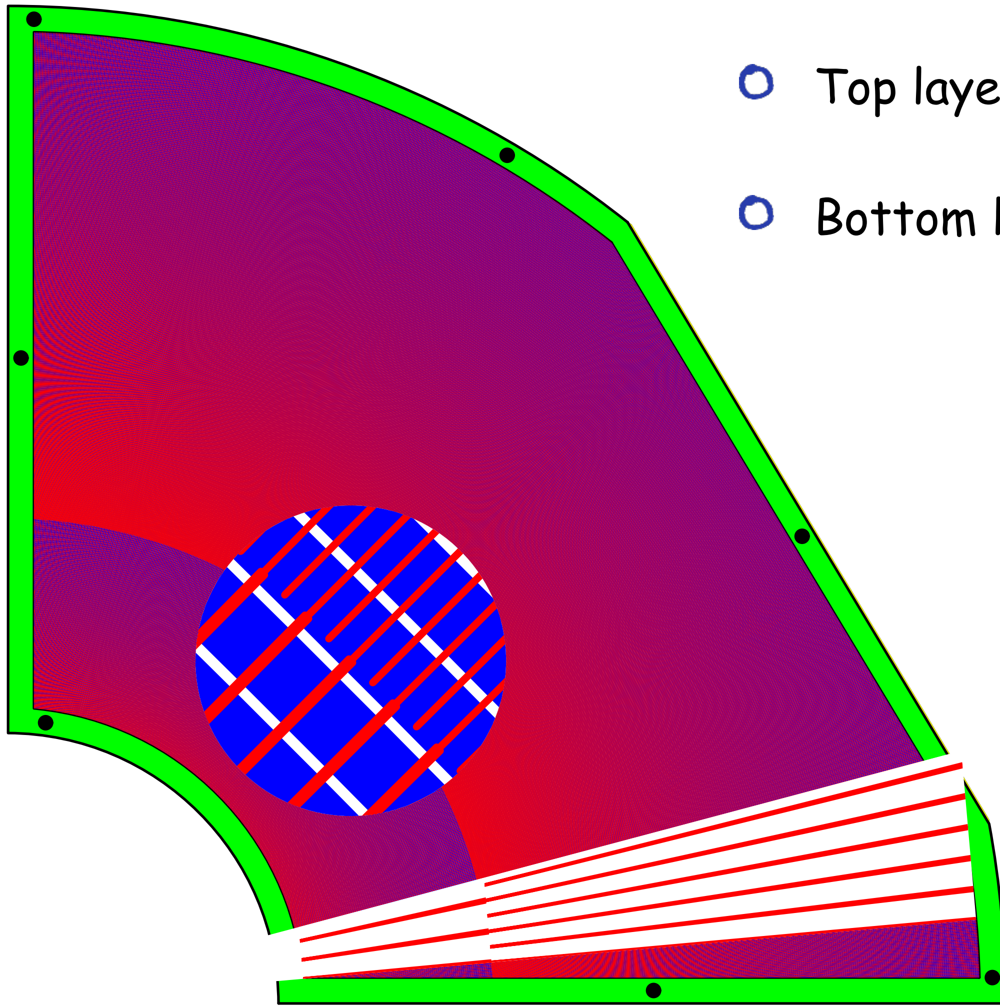
FGT Technical realization

- Triple-GEM: Frame preparation (2)

Anne Holladay (MIT)

FGT Technical realization

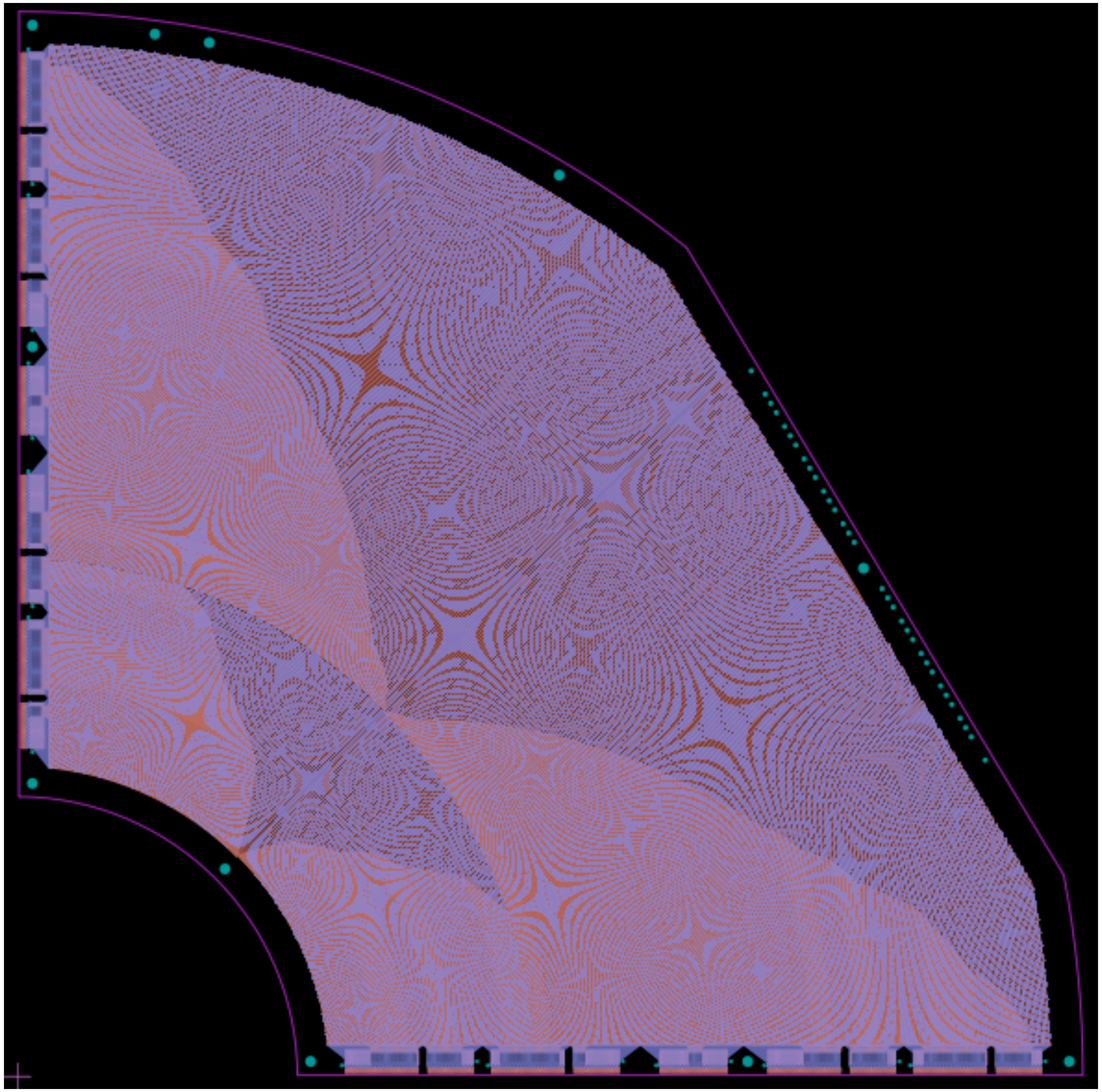
- Triple-GEM: Quarter section design



- 2D readout board
- Top layer: Φ-readout layer
- Bottom layer: R-readout layer

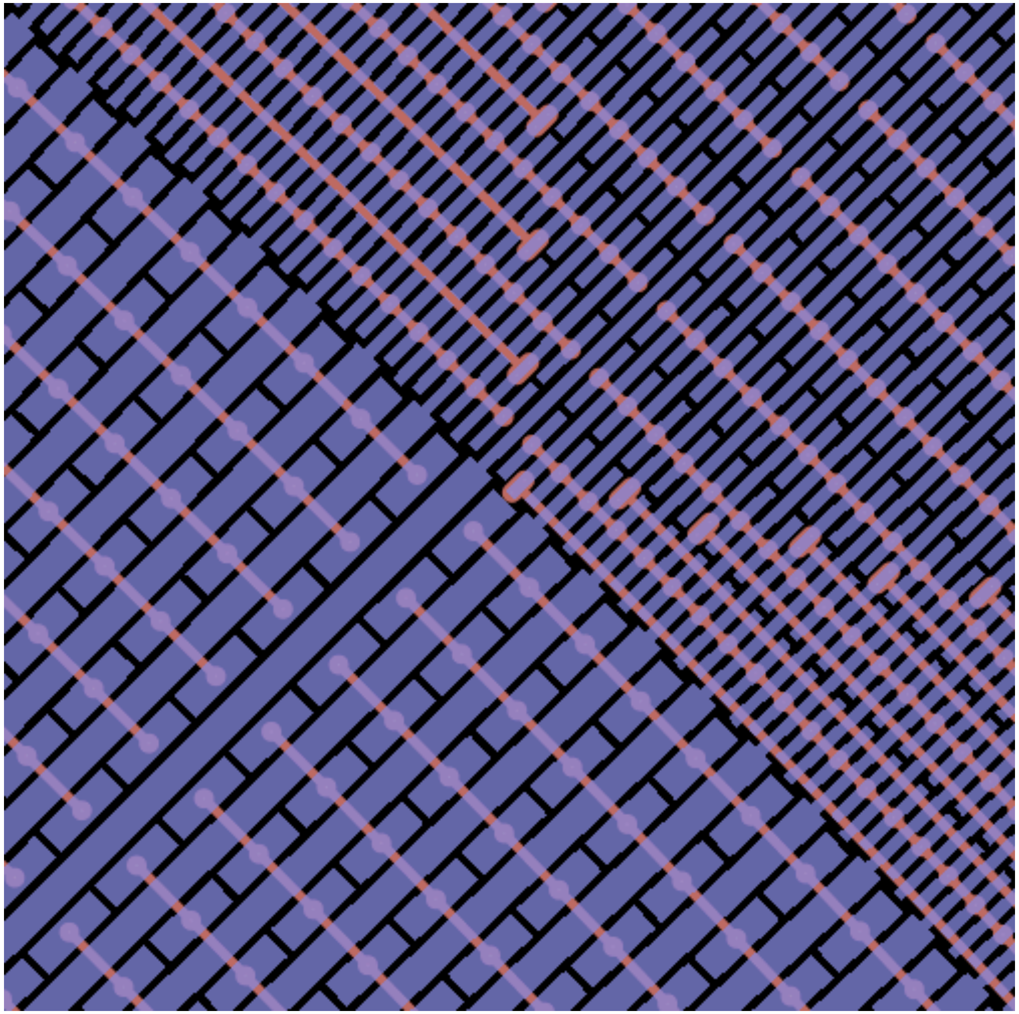
FGT Technical realization

- Triple-GEM: 2D readout board - Gerber layout



FGT Technical realization

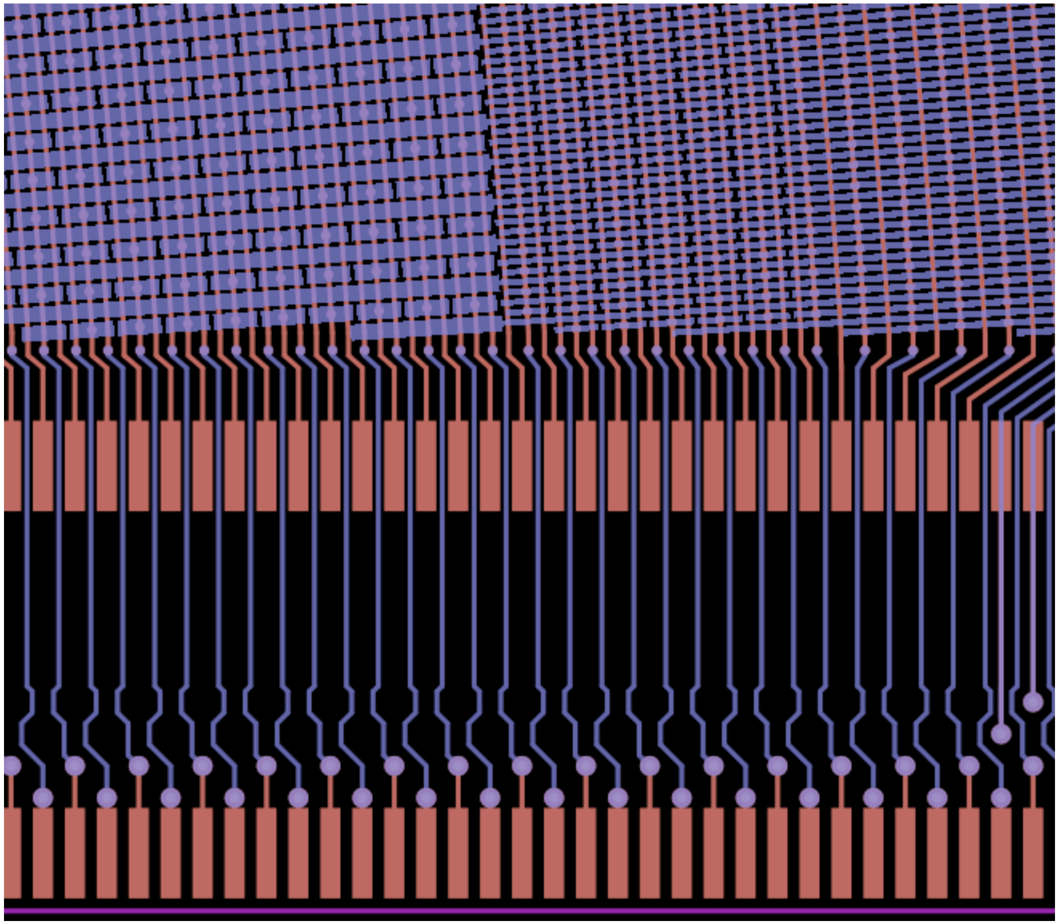
- Triple-GEM: 2D readout board (1)



- Active layer in blue
  - Collects charge from shower
  - Lines at constant angle
  - Pads at constant radius
- Routing layer in orange
  - Each line separately read out
  - Pads at each radius connected together
- 400-800 micron pitch design
  - Each line has 2 vias for more reliable connection
  - Pad readout extends only half way across quadrant
    - Shorter lines (less capacitance)

FGT Technical realization

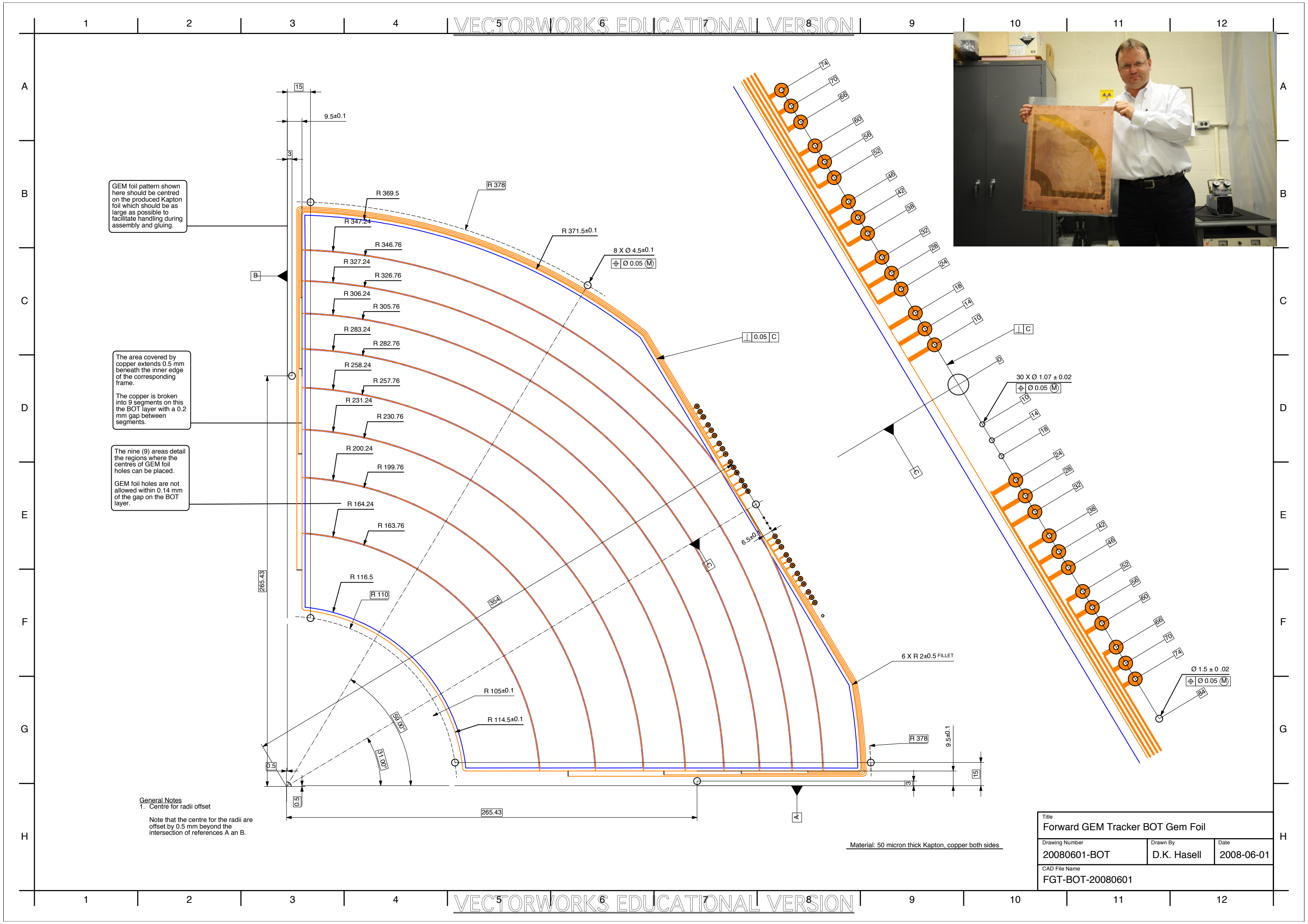
Triple-GEM: 2D readout board (2)



- 400-800 micron pitch design
  - 800 micron pitch region (left)
    - 325 micron wide lines and pads
    - 75 micron wide gap
  - 400 micron pitch region (right)
    - 125 micron wide lines and pads
    - 75 micron wide gaps
  - Fewer Φ lines
    - Routing simpler, more space between routing lines (less capacitance)
- 300-600 micron pitch design
  - 600 micron pitch
    - 250 micron wide lines and pads
    - 50 micron wide gaps
  - 300 micron pitch
    - 100 micron wide lines and pads
    - 50 micron wide gaps
  - Longer routing lines, closer together (higher capacitance)

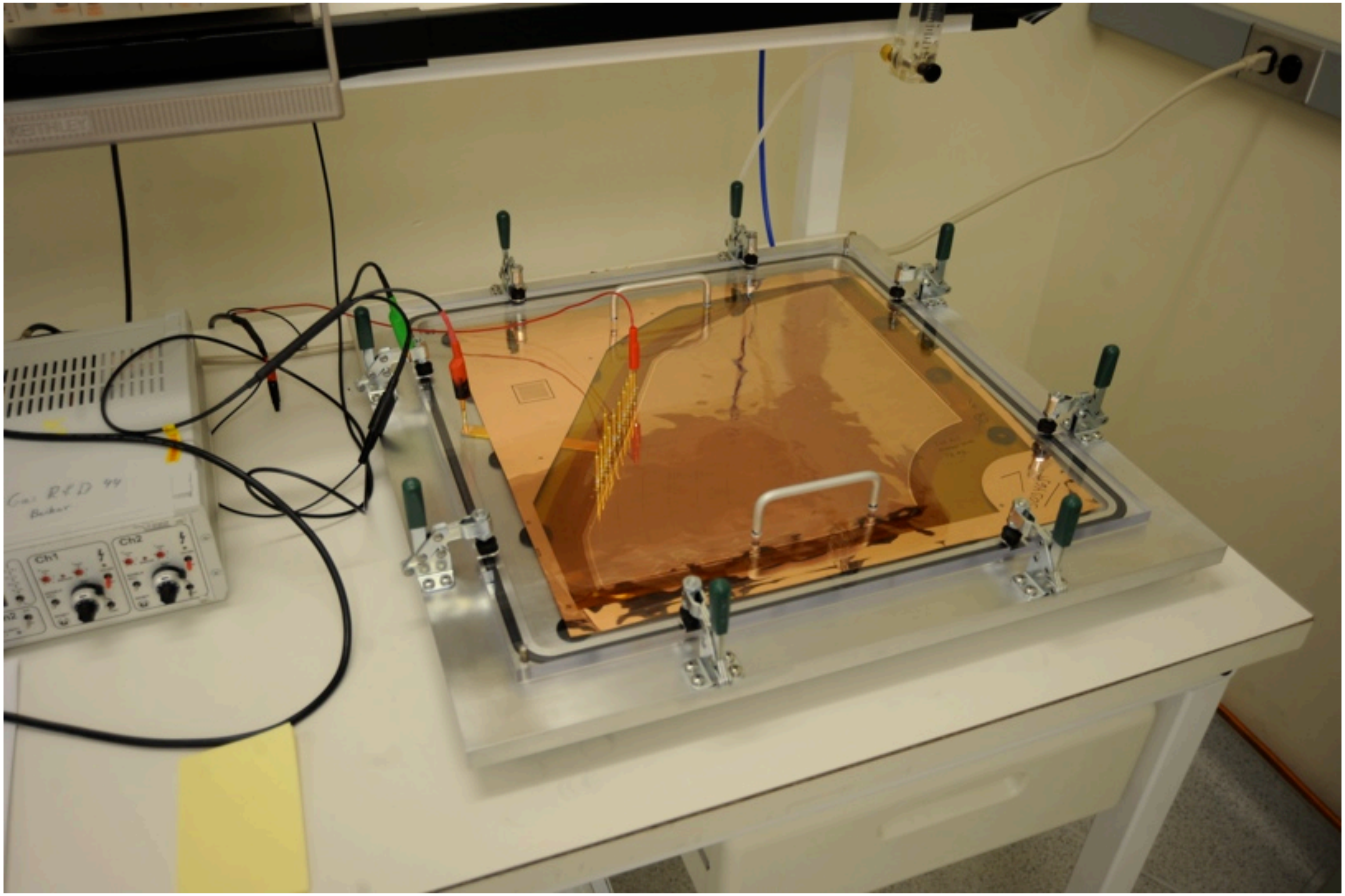
FGT Technical realization

- Triple-GEM: GEM foil design



FGT Technical realization

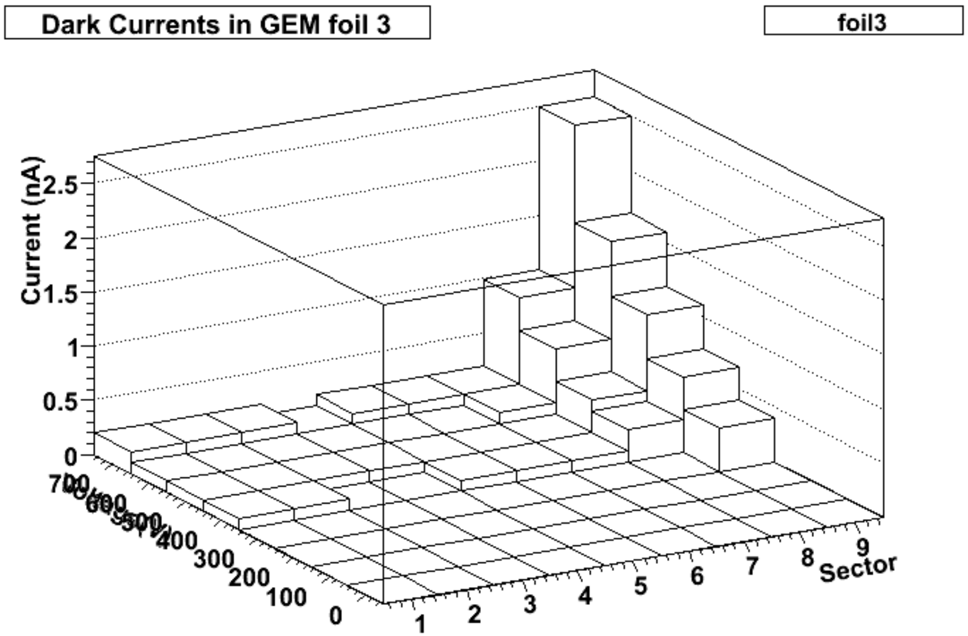
- Triple-GEM: GEM foil - Leakage current tests



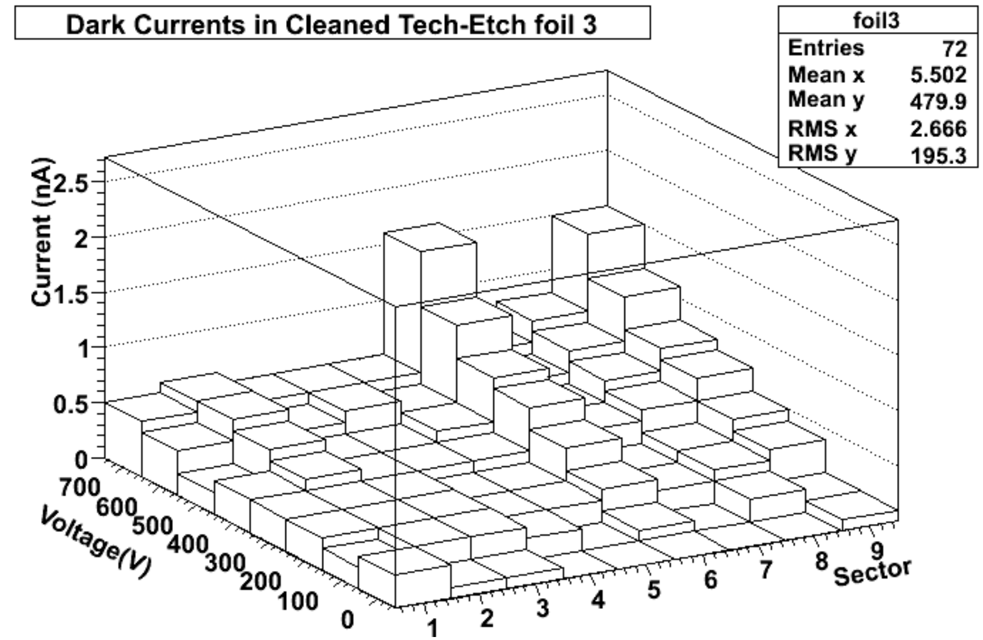
HV box for GEM foil leakage current tests

FGT Technical realization

- Triple-GEM: GEM foil testing: Tech-Etch - Initial results



Before re-cleaning

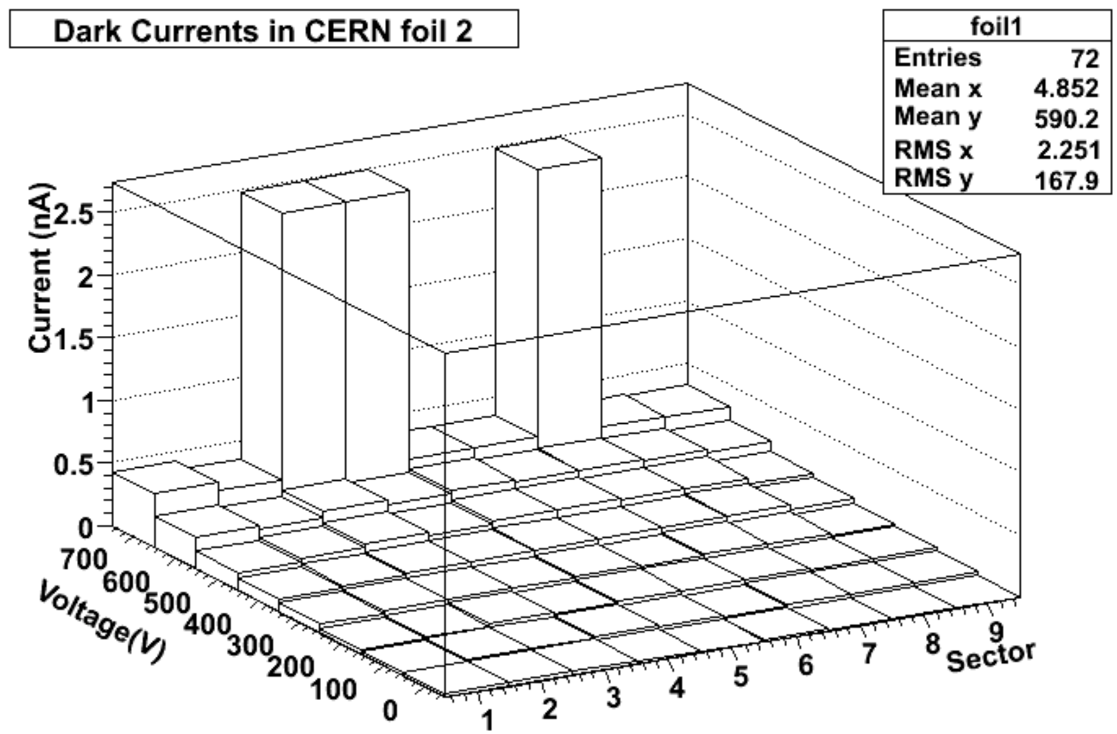


After re-cleaning

FGT Technical realization

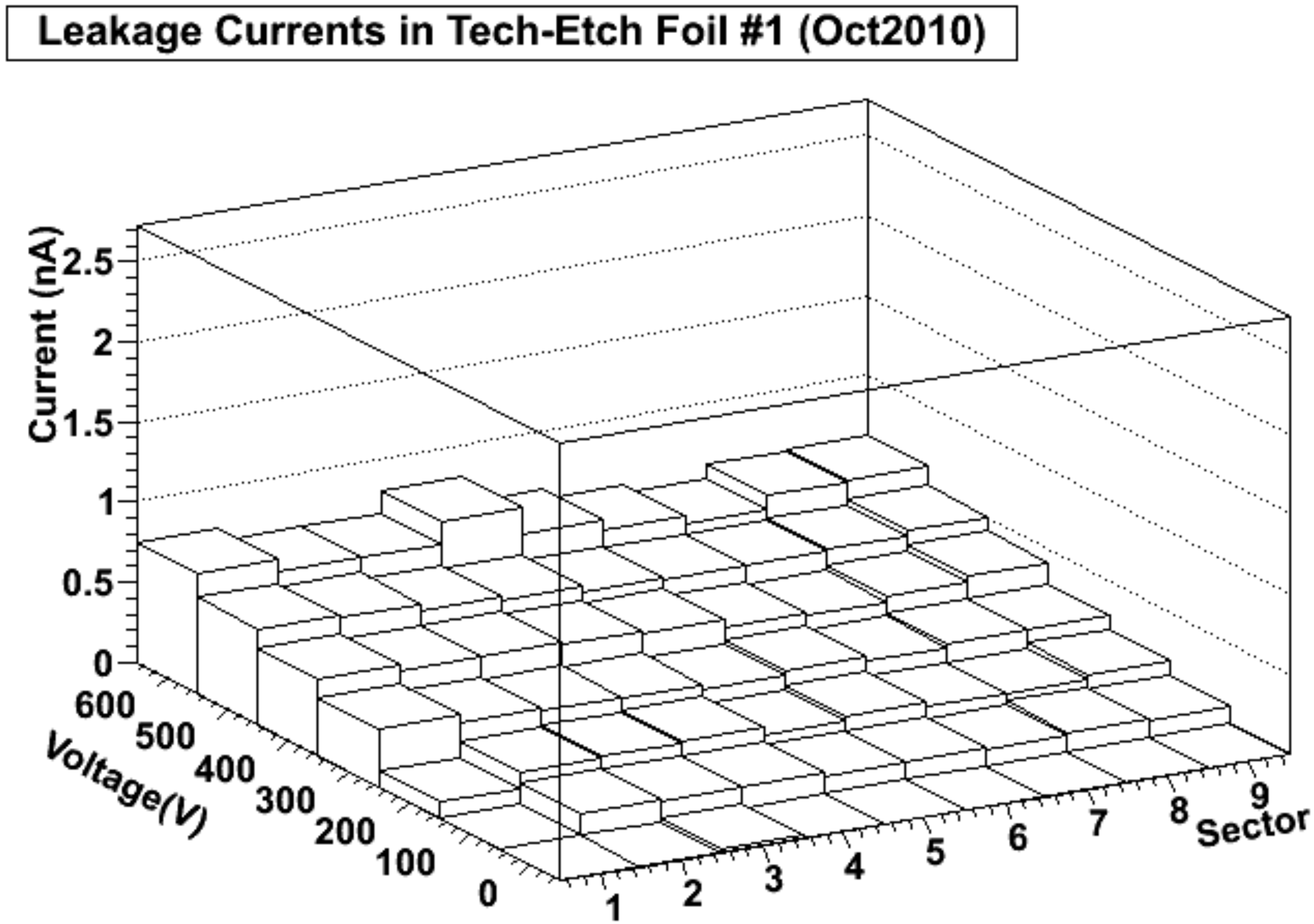
- Triple-GEM: GEM foil testing: CERN - results

  - Tested up to 700V at MIT (CERN performs tests only up to 600V)
  - Higher currents at 700V
  - Often unstable above 600V



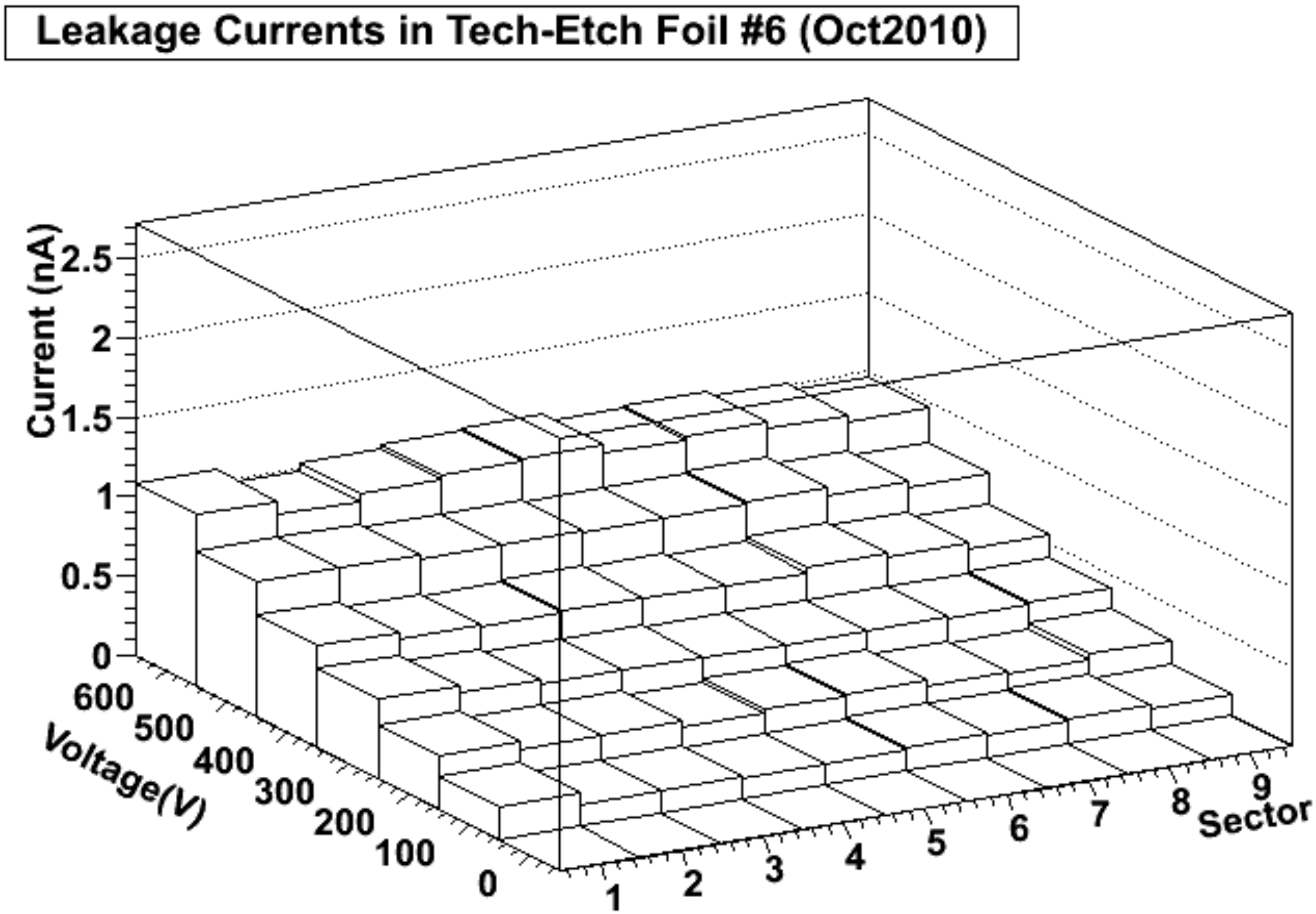
FGT Technical realization

- Triple-GEM: GEM foil testing: Tech-Etch production foil results (1)



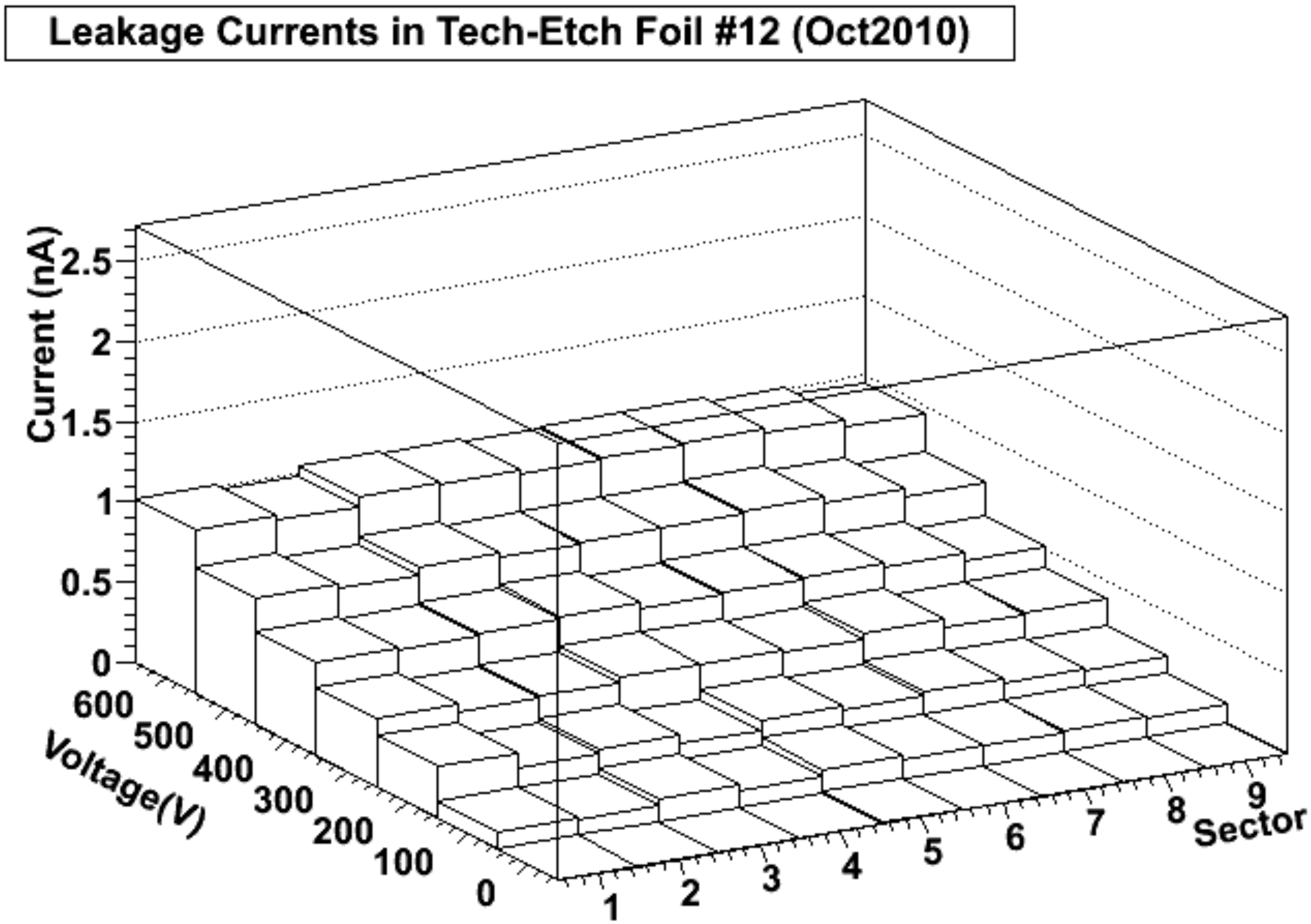
FGT Technical realization

- Triple-GEM: GEM foil testing: Tech-Etch production foil results (2)



FGT Technical realization

- Triple-GEM: GEM foil testing: Tech-Etch production foil results (3)



FGT Technical realization

Triple-GEM: GEM foil testing - CCD Scans (1)

CCD camera setup for optical GEM foil scans

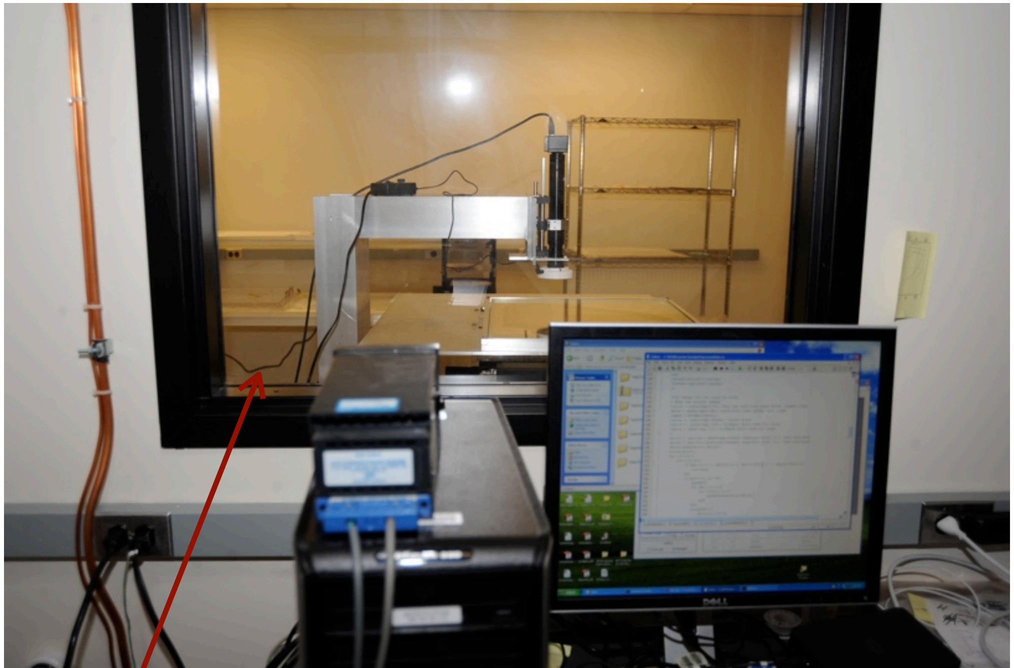
Will Leight (MIT) and Arvin Shahbazi Moghaddam (MIT)

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 - CCD Scans (2)

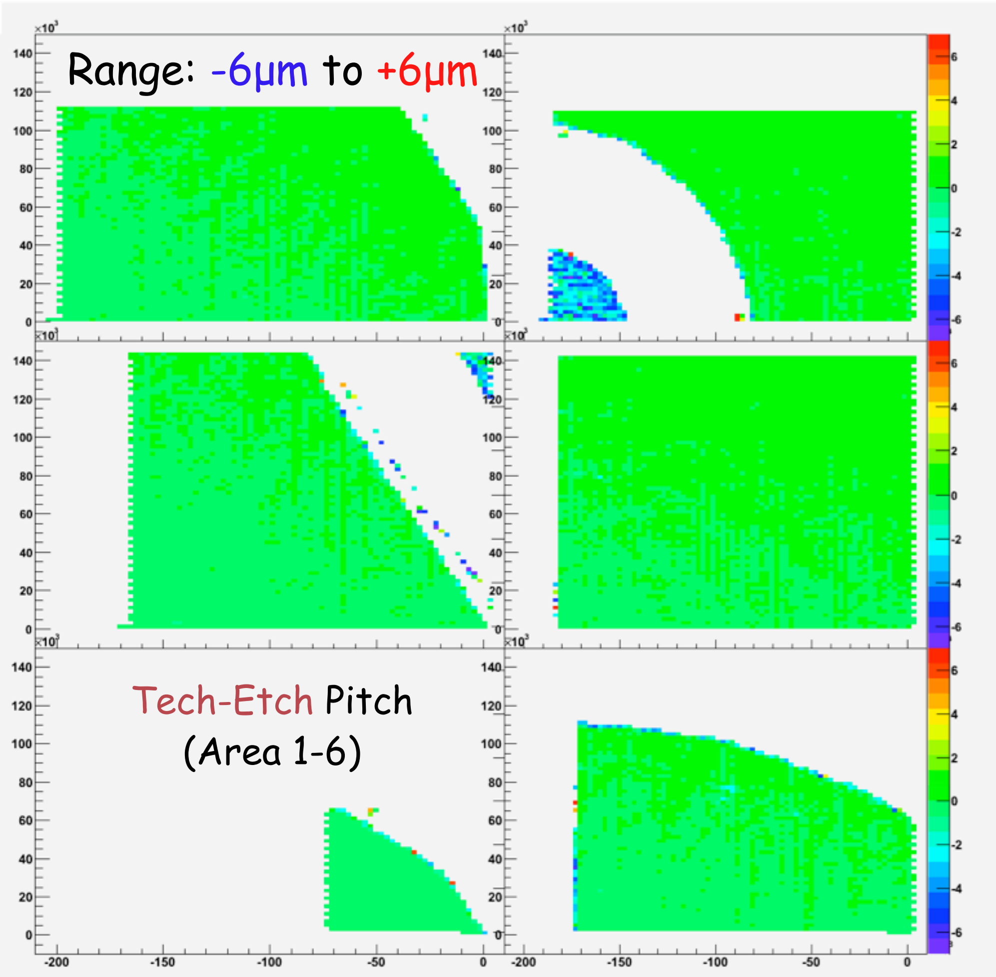


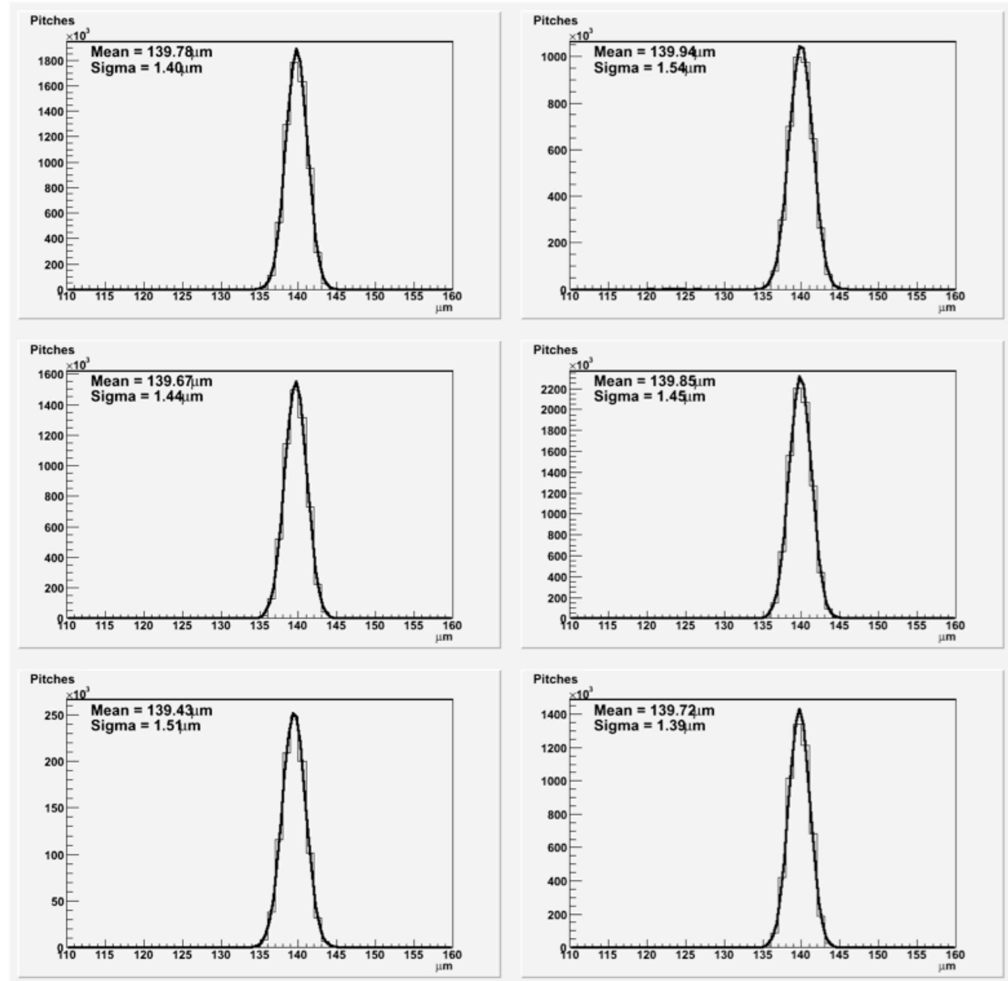
LNS Clean Room

FGT Technical realization

- Triple-GEM: GEM foil testing - Tech-Etch / Pitch distribution

RMS ~1.5µm (Area 1-6)

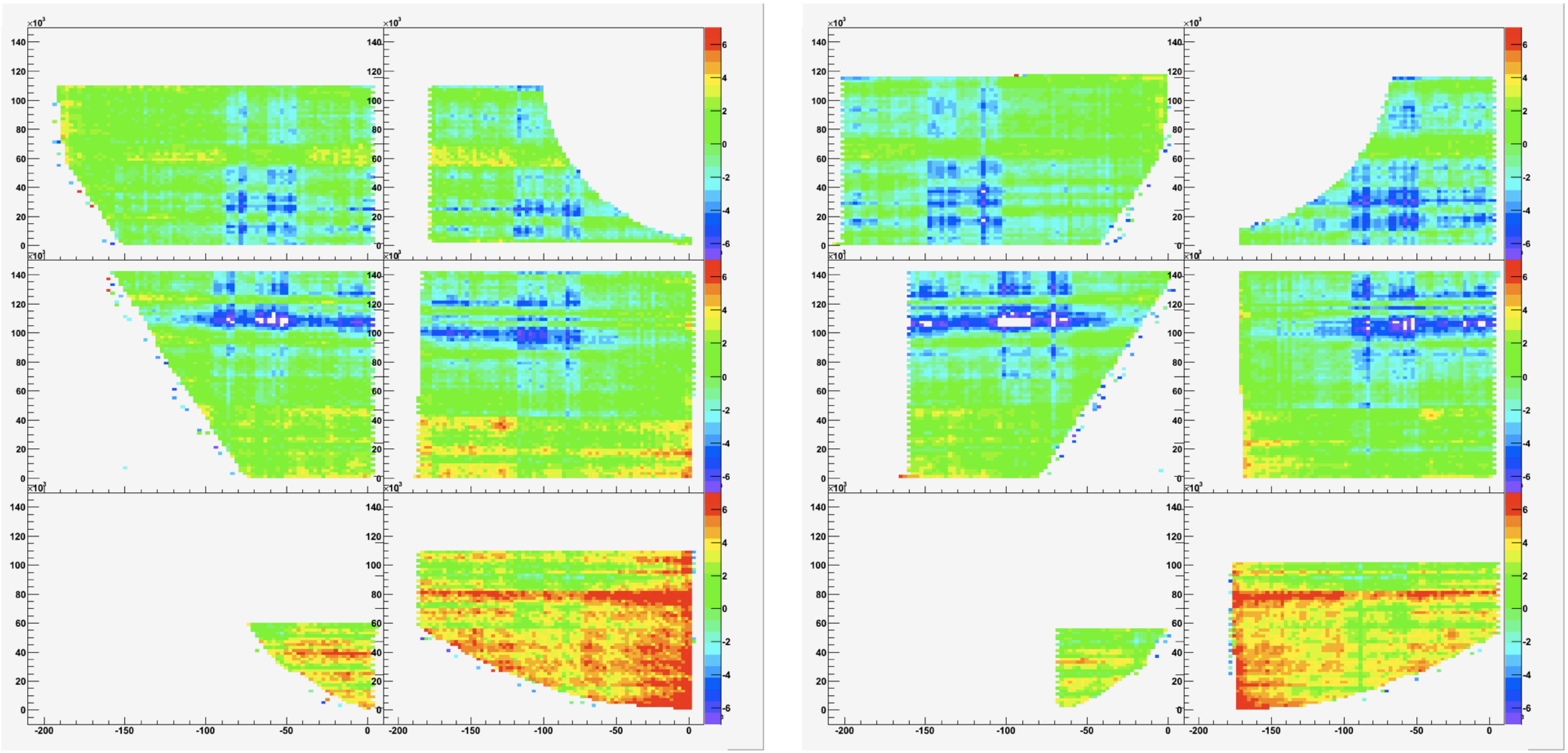




- Tech-Etch and CERN (Uniform pitch / Using glass masks critical for inner hole diameter uniformity!)

FGT Technical realization

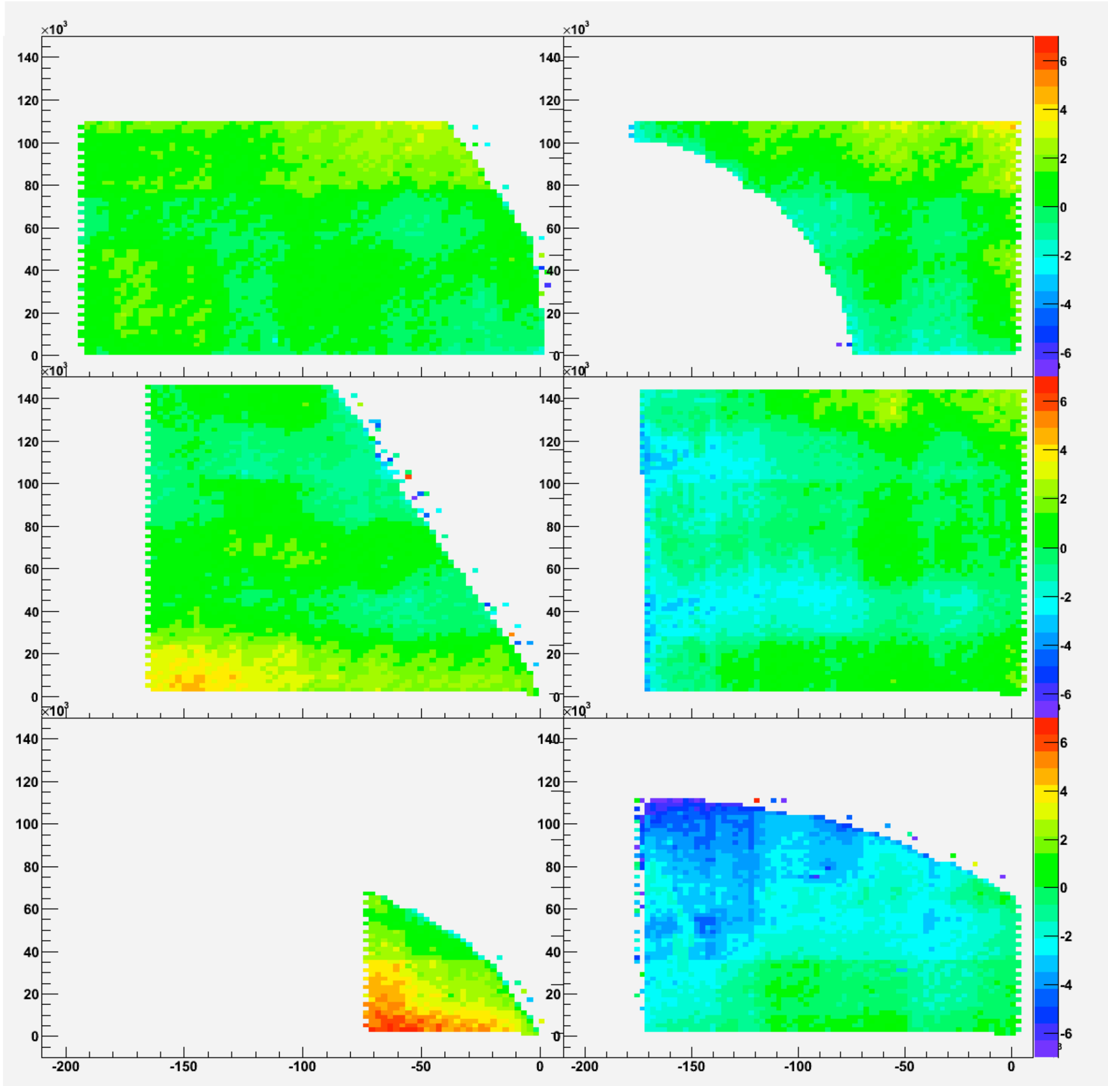
- Triple-GEM: GEM foil testing - Tech-Etch / Inner hole diameter distribution
  - Striped pattern understood: Misalignment of Mylar foil masks ⇒ Glass masks important!



Range: -6μm to +6μm

FGT Technical realization

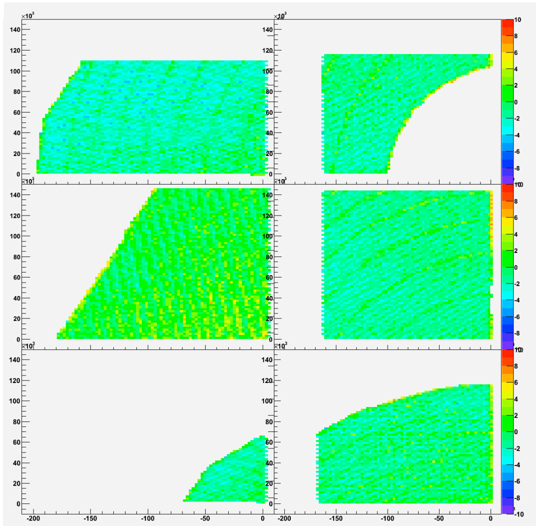
- Triple-GEM: GEM foil testing - CERN / Inner hole diameter distribution



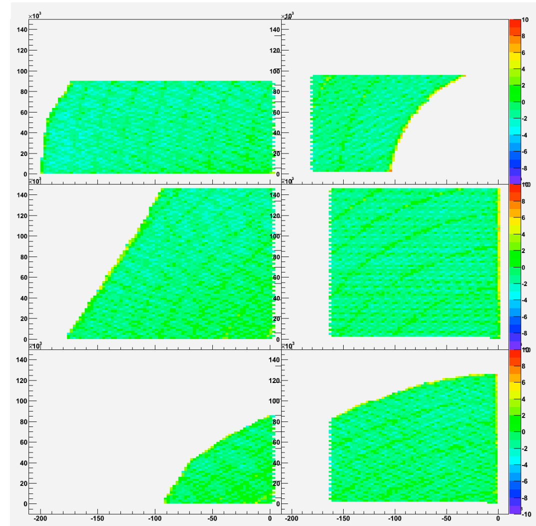
FGT Technical realization

- Triple-GEM: GEM foil testing - Tech-Etch / Inner hole diameter distribution

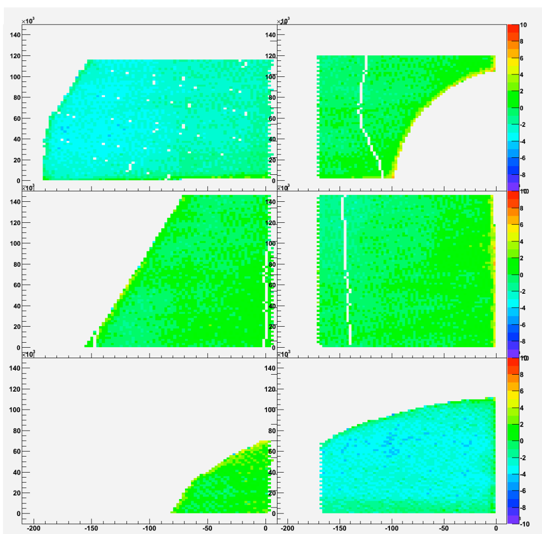
15 mins



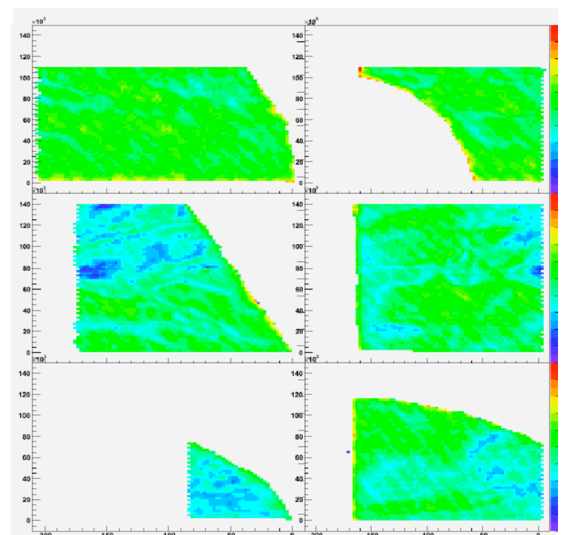
10 mins



7 mins

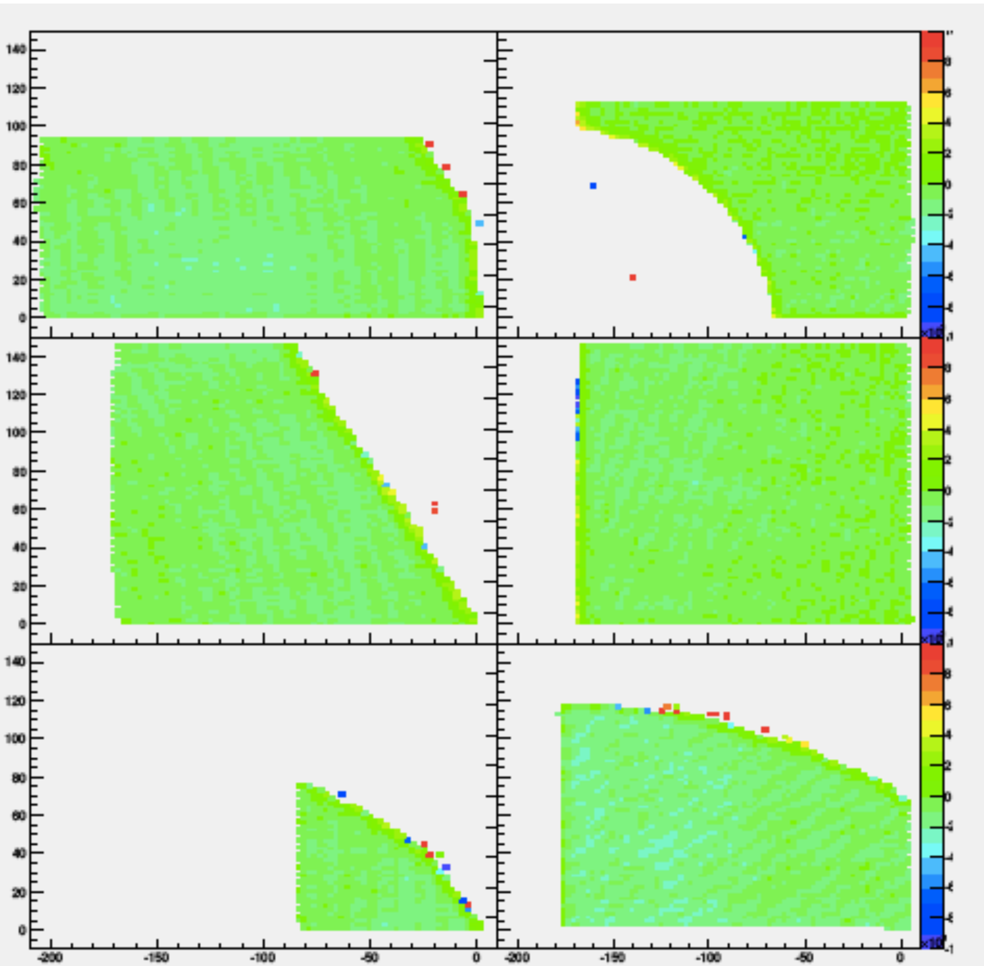


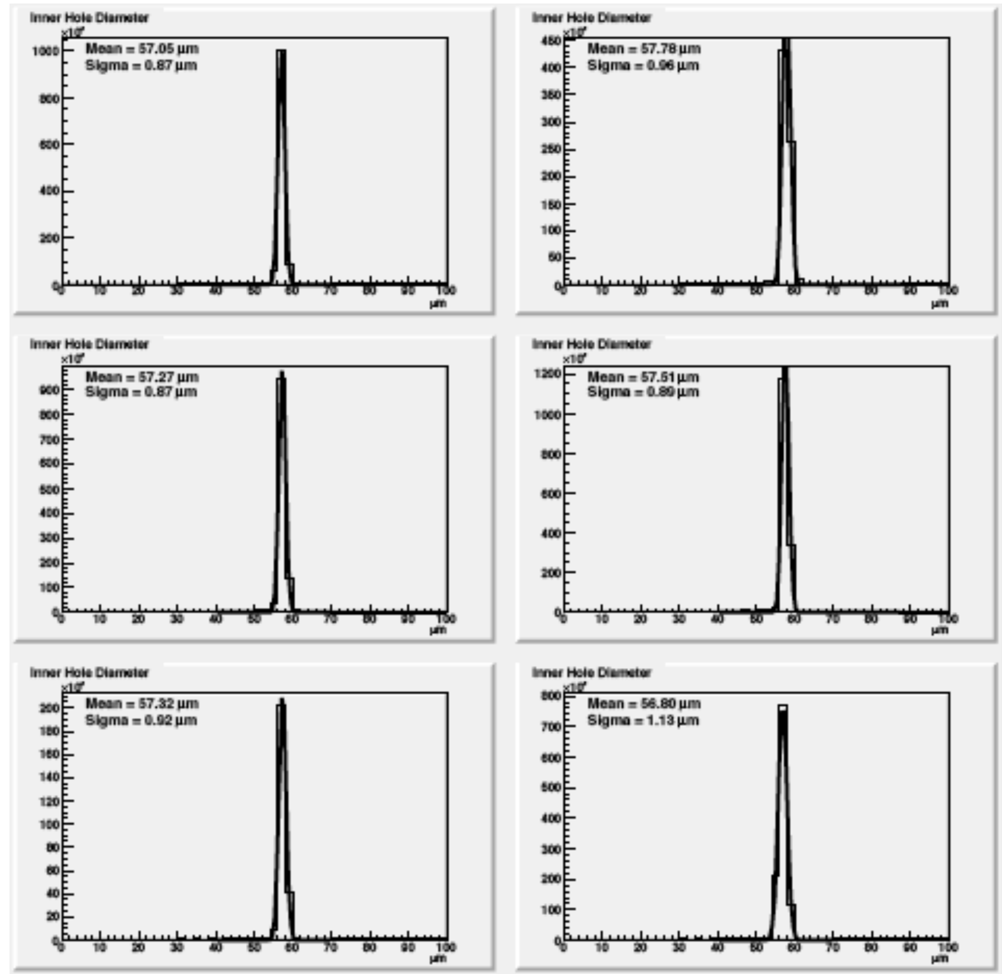
2 mins



FGT Technical realization

- Triple-GEM: GEM foil testing - Tech-Etch / Inner hole distr. - Production foil (1)

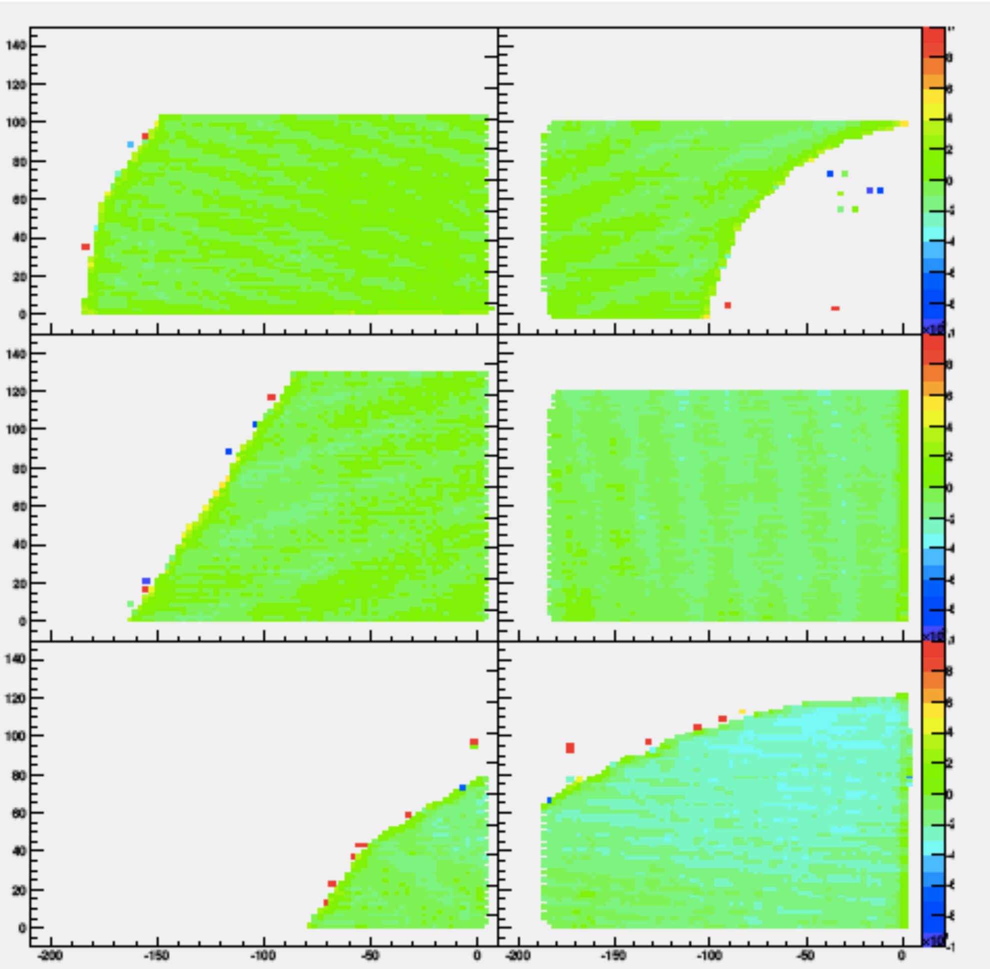


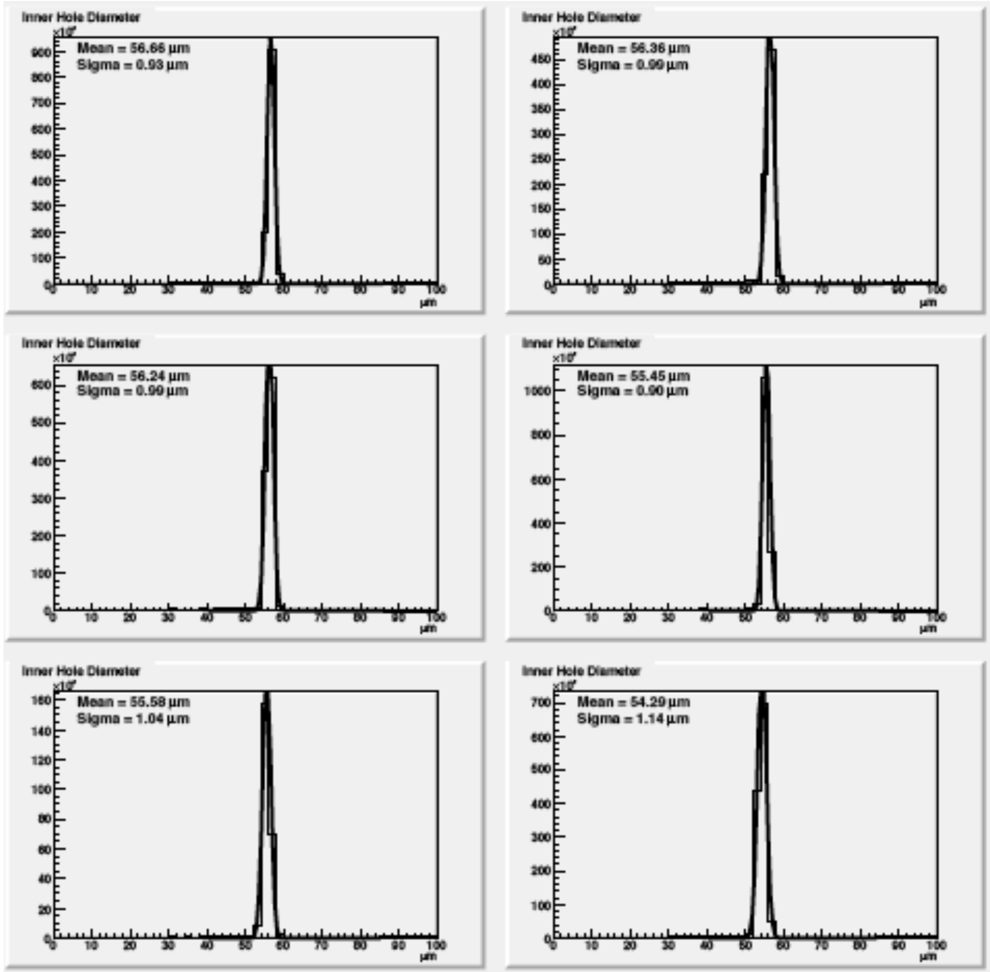


Typical values: Mean ~55µm and Sigma ~1µm

FGT Technical realization

- Triple-GEM: GEM foil testing - Tech-Etch / Inner hole distr. - Production foil (2)

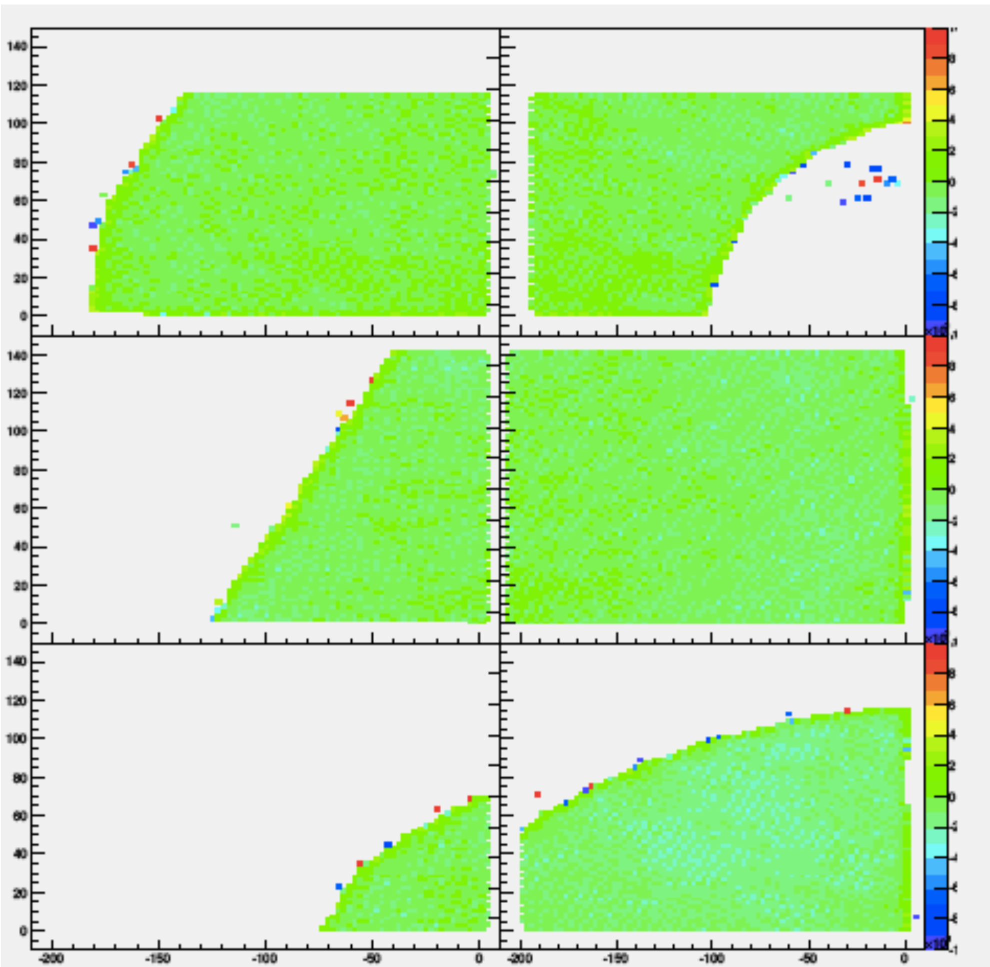


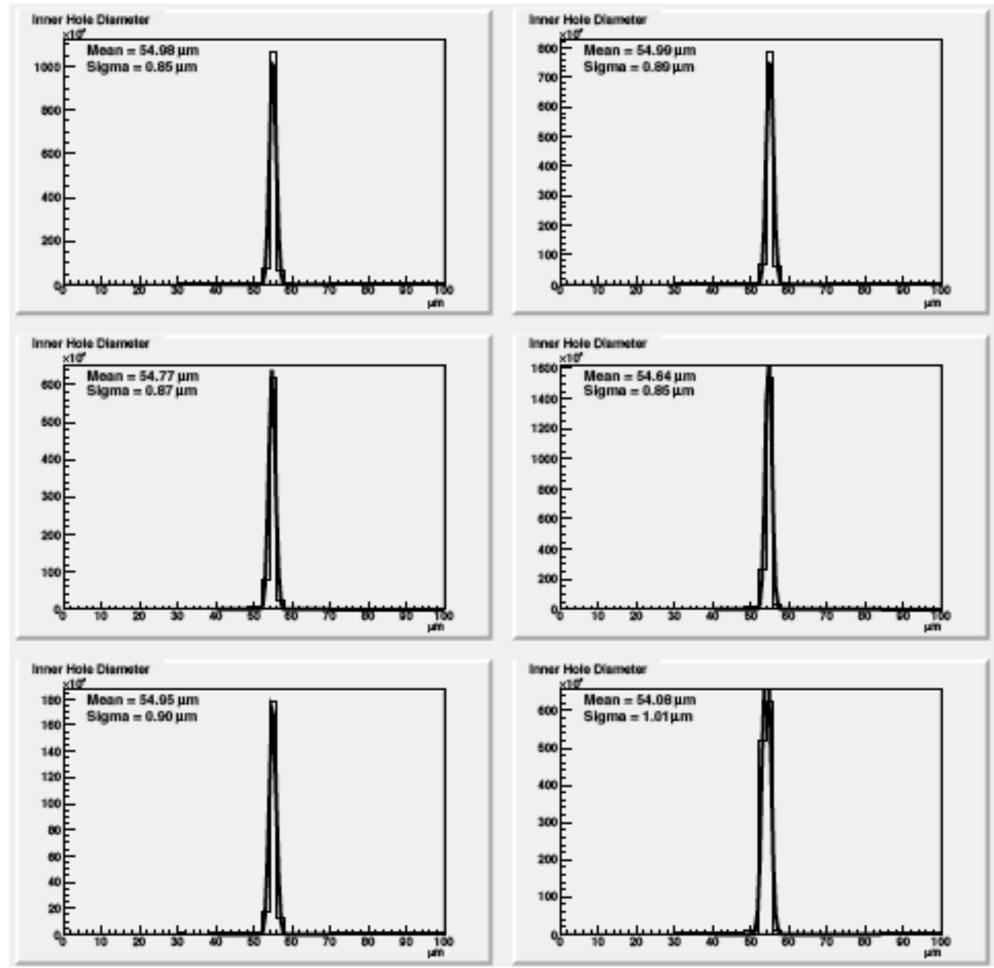


Typical values: Mean ~55µm and Sigma ~1µm

FGT Technical realization

- Triple-GEM: GEM foil testing - Tech-Etch / Inner hole distr. - Production foil (3)

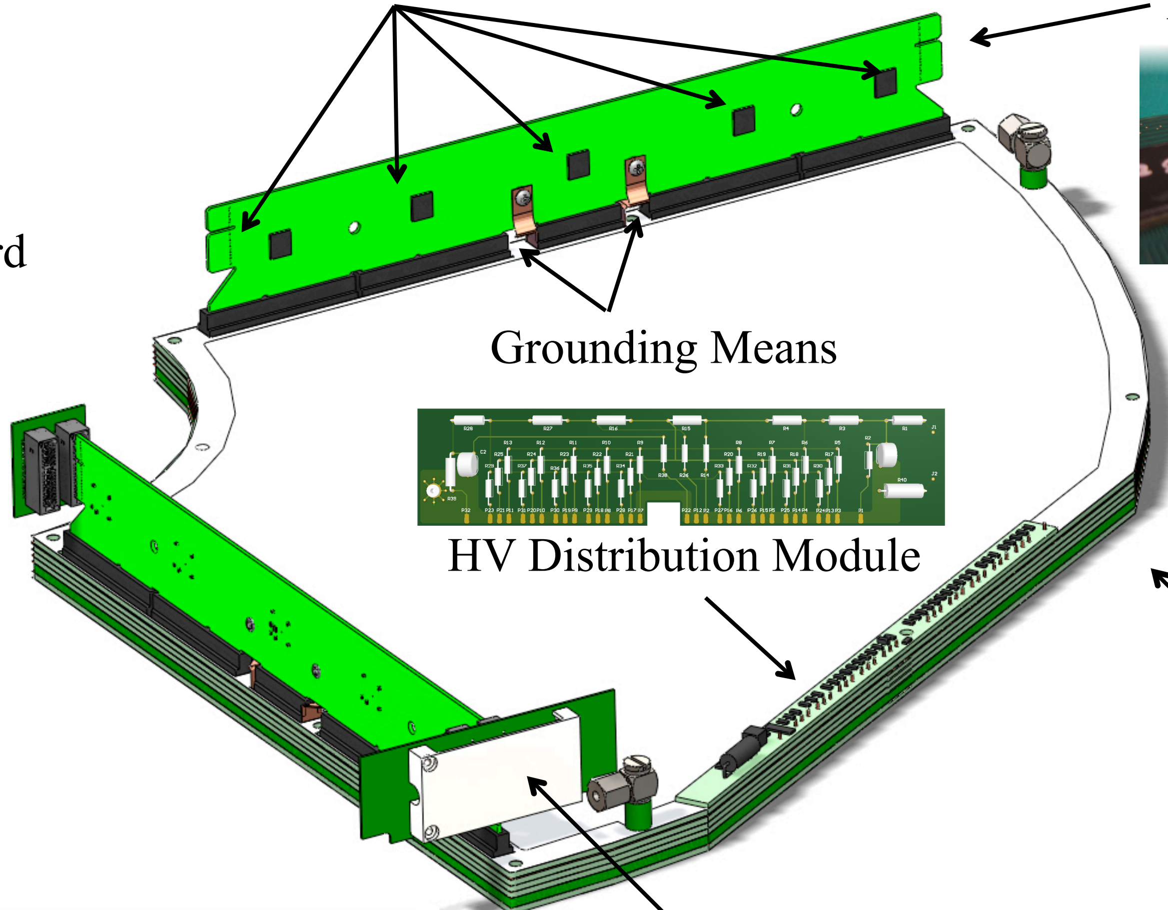


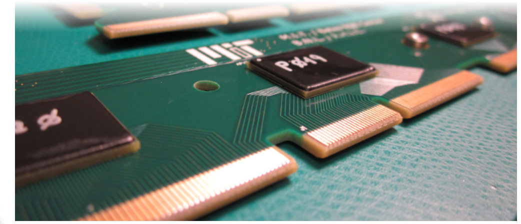


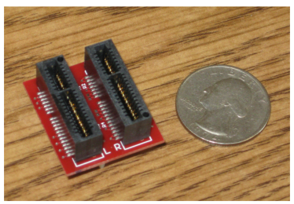
Typical values: Mean ~55µm and Sigma ~1µm

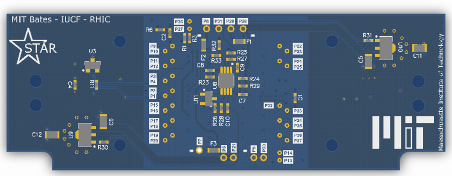
FGT Technical realization

- FEE: Overview



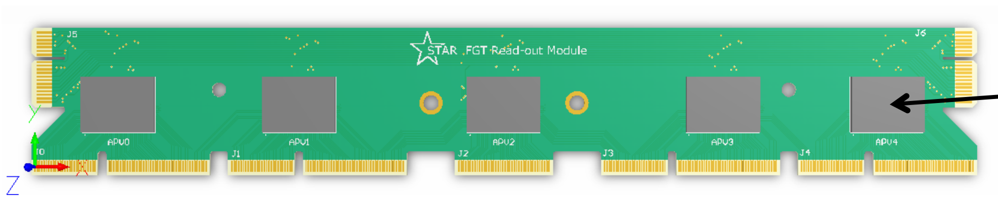




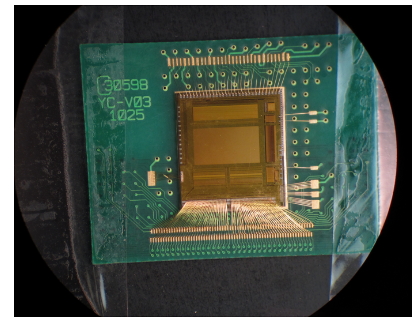


FGT Technical realization

- FEE: Design and prototype options
  - Two concepts for readout module:
    - Default design version: Packaged chip option (Cheaper / More flexible)

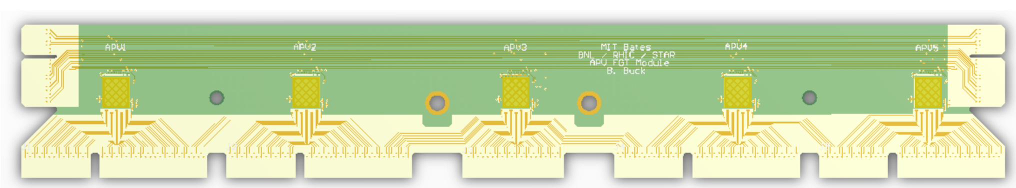


- Chip carrier design completed by Compunetics
- Assembly and bonding performed by Corwil (Successful APV packaging for NASA)



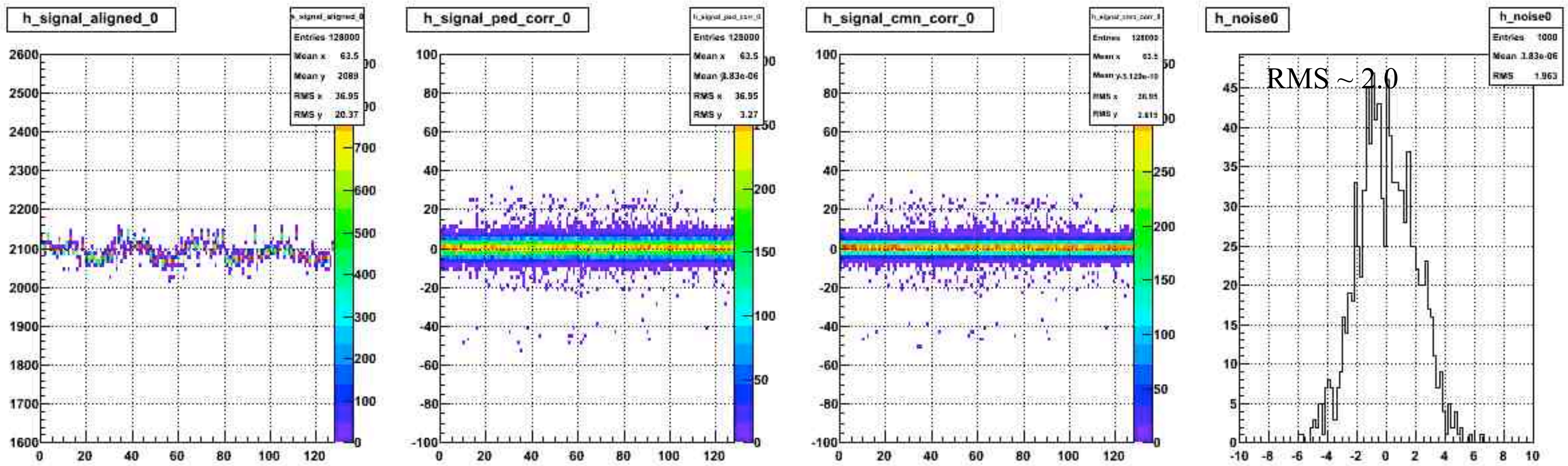
- First prototype produced in late 2008 and tested / Second prototype delivered beginning of June 2009

    - Earlier design: Chip on board option (More expensive / Difficult production)



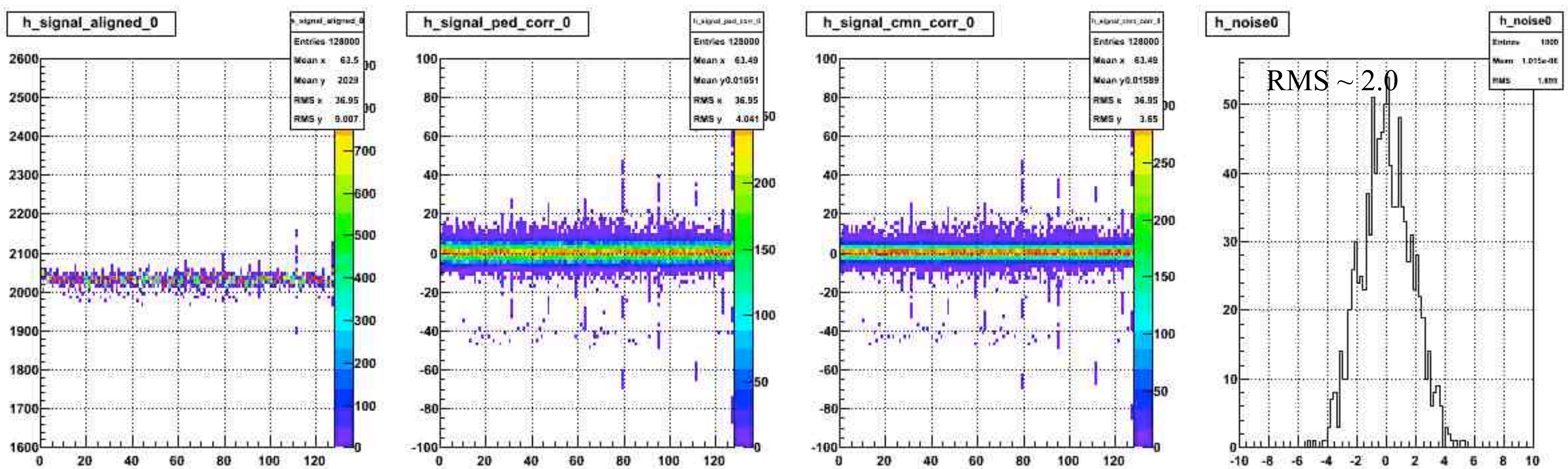
FGT Technical realization

- FEE: Test results for both readout concepts



Raw-data | Ped. subtr. data | Ped./CM subtr. data | Projection of Ped./CM subtr. data

BGA on Board

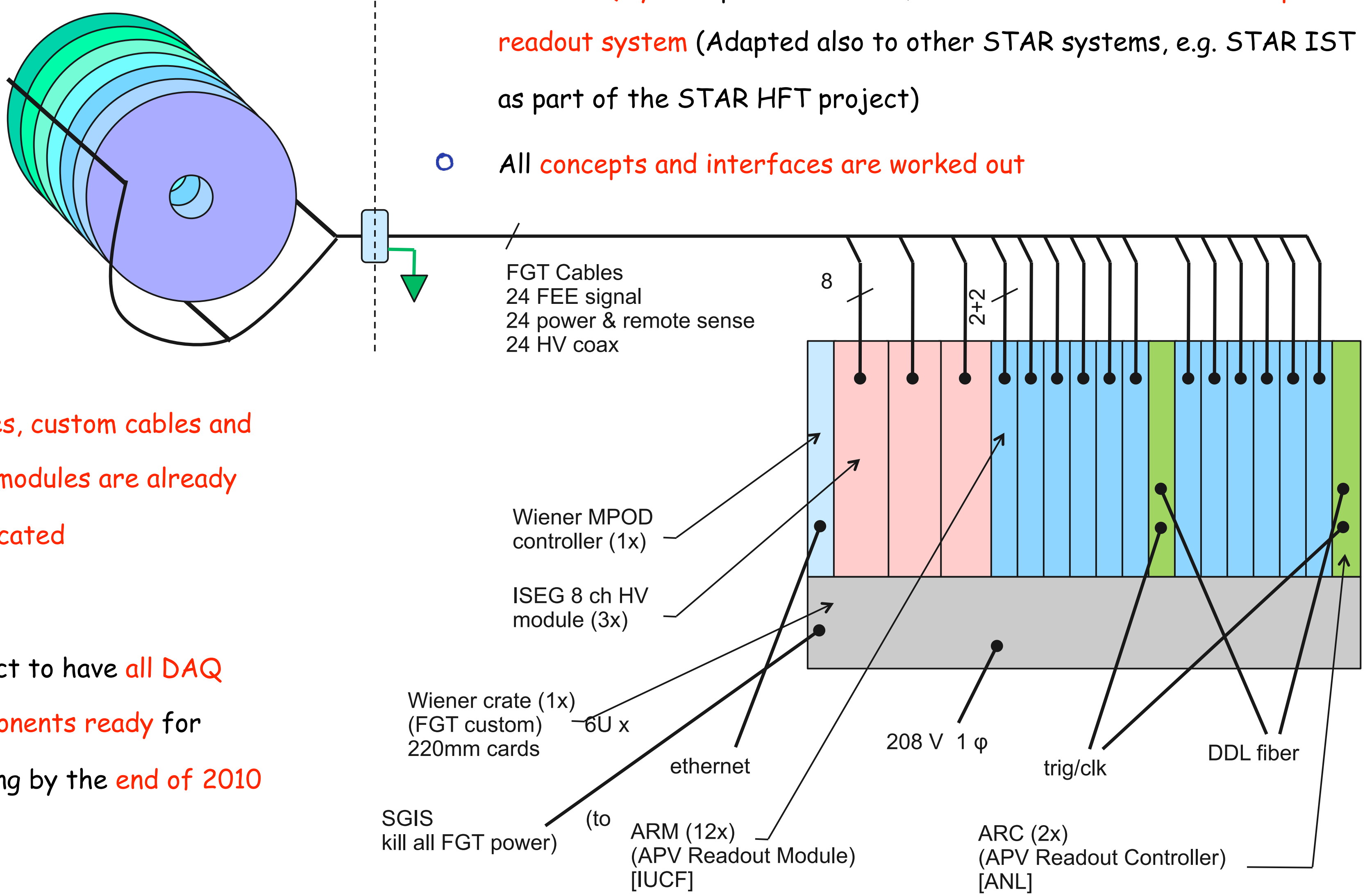


Chip on Board

FGT Technical realization

DAQ: Overview

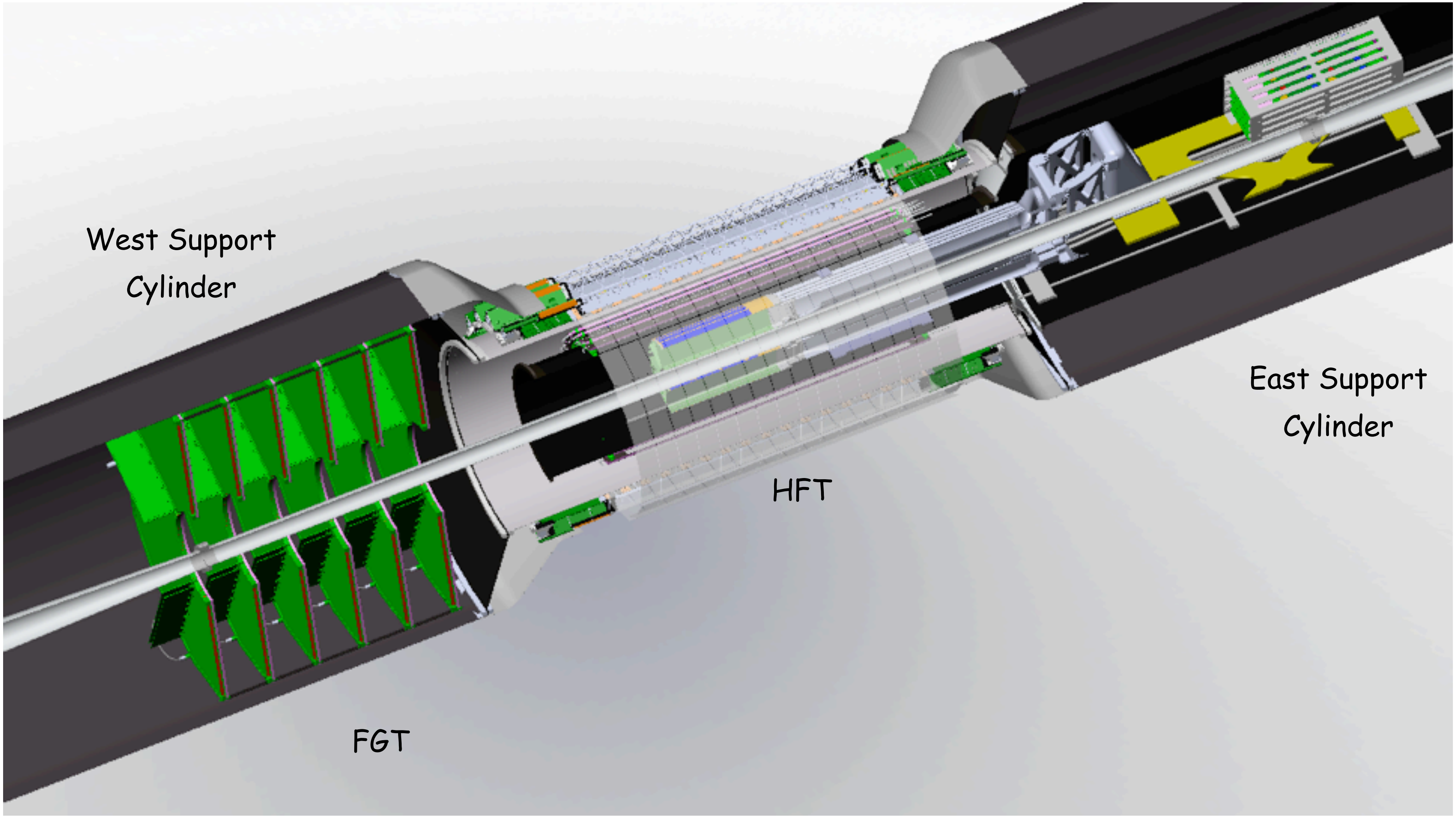
- FGT DAQ system provides a fast, reliable and efficient APV chip readout system (Adapted also to other STAR systems, e.g. STAR IST as part of the STAR HFT project)
- All concepts and interfaces are worked out



- Crates, custom cables and ARC modules are already fabricated
- Expect to have all DAQ components ready for testing by the end of 2010

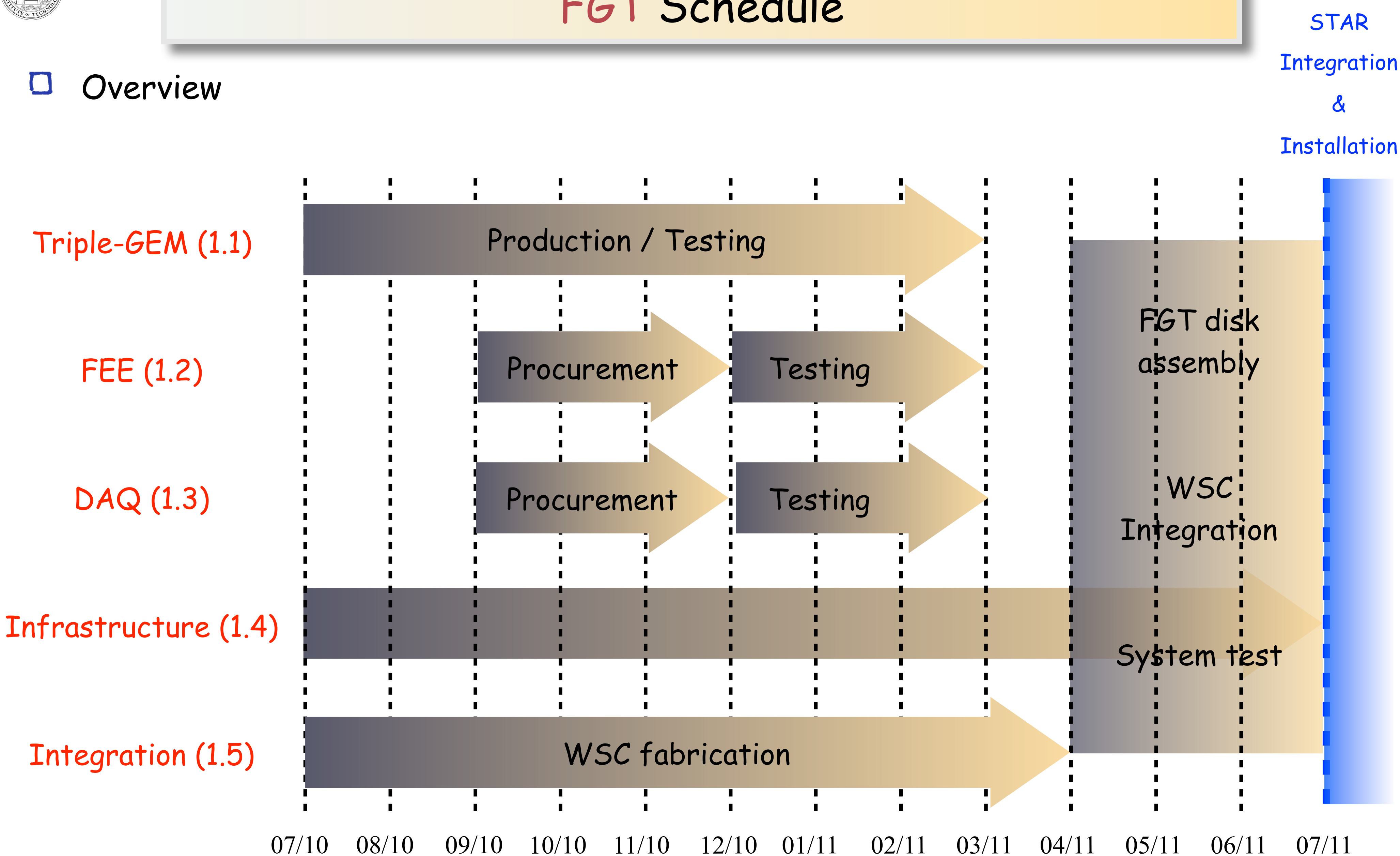
FGT Technical realization

- Integration



FGT Schedule

- Overview



Summary

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

    ⇒ Ready for anticipated first long 500GeV polarized pp run in FY12 (Run 12)
  - Tech-Etch foil performance satisfactory: Leakage current / Optical uniformity of inner hole diameter
  - 2D readout board / FEE / DAQ : Assembly in progress
- New SBIR initiatives in collaboration with Tech-Etch Inc.:
  - Commercial fabrication using chemical etching of 2D readout board : Basis of FGT boards
  - In preparation: Large GEM production (~1 X 1 m^2) using single-mask etching - Strong impact for various future applications in Nuclear and Particle Physics / Major RD51 focus