The STAR Forward GEM Tracker (FGT)

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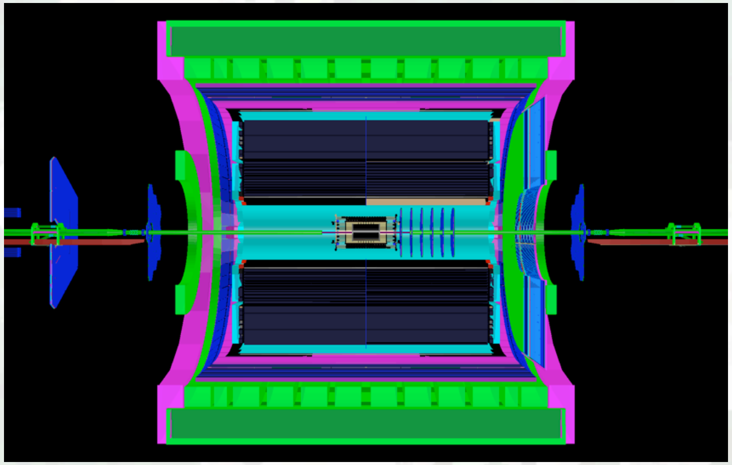
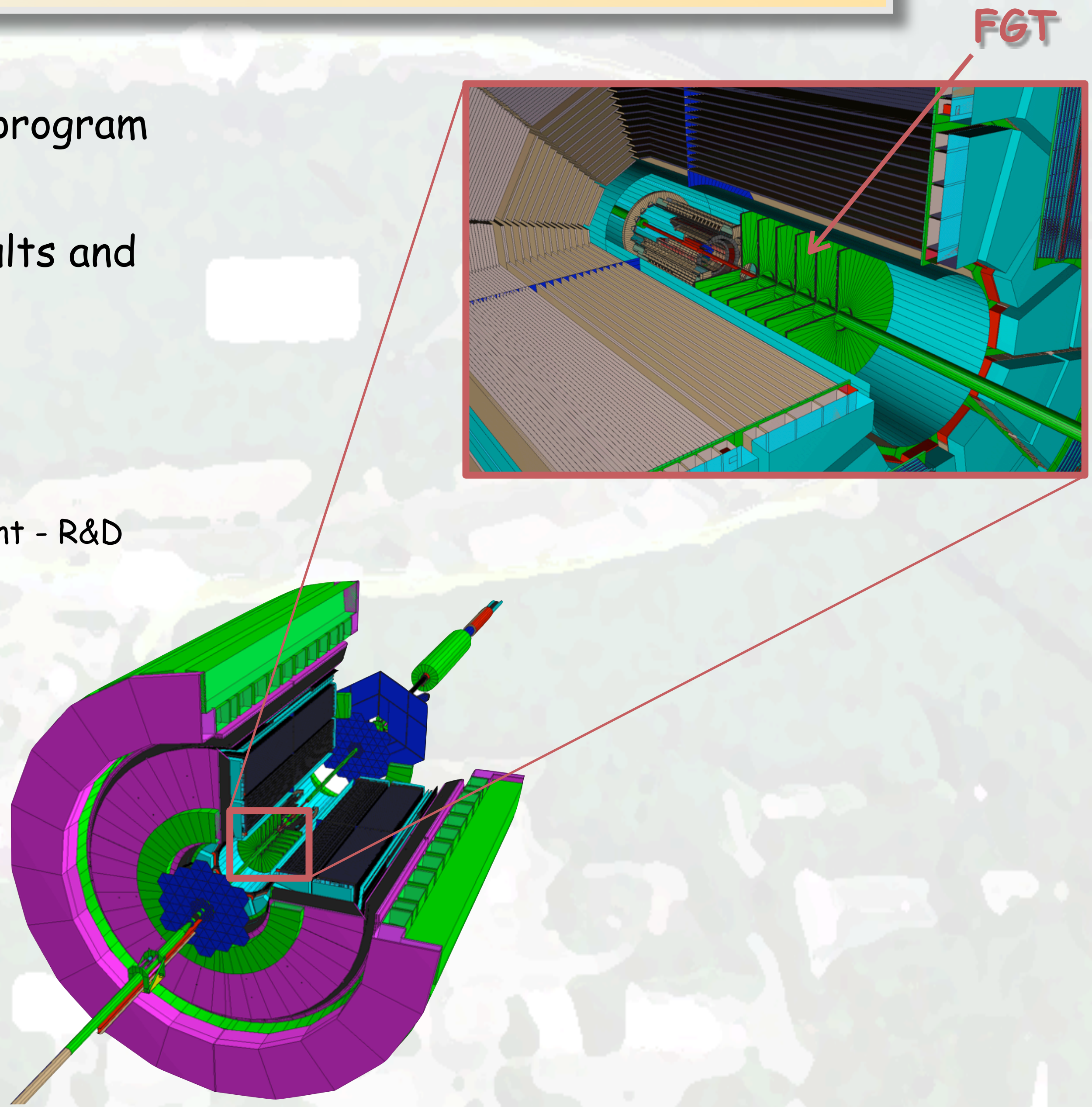


AGS-RHIC Users Meeting, Workshop Session 3 - Upgrades
Upton, NY, May 27, 2008

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

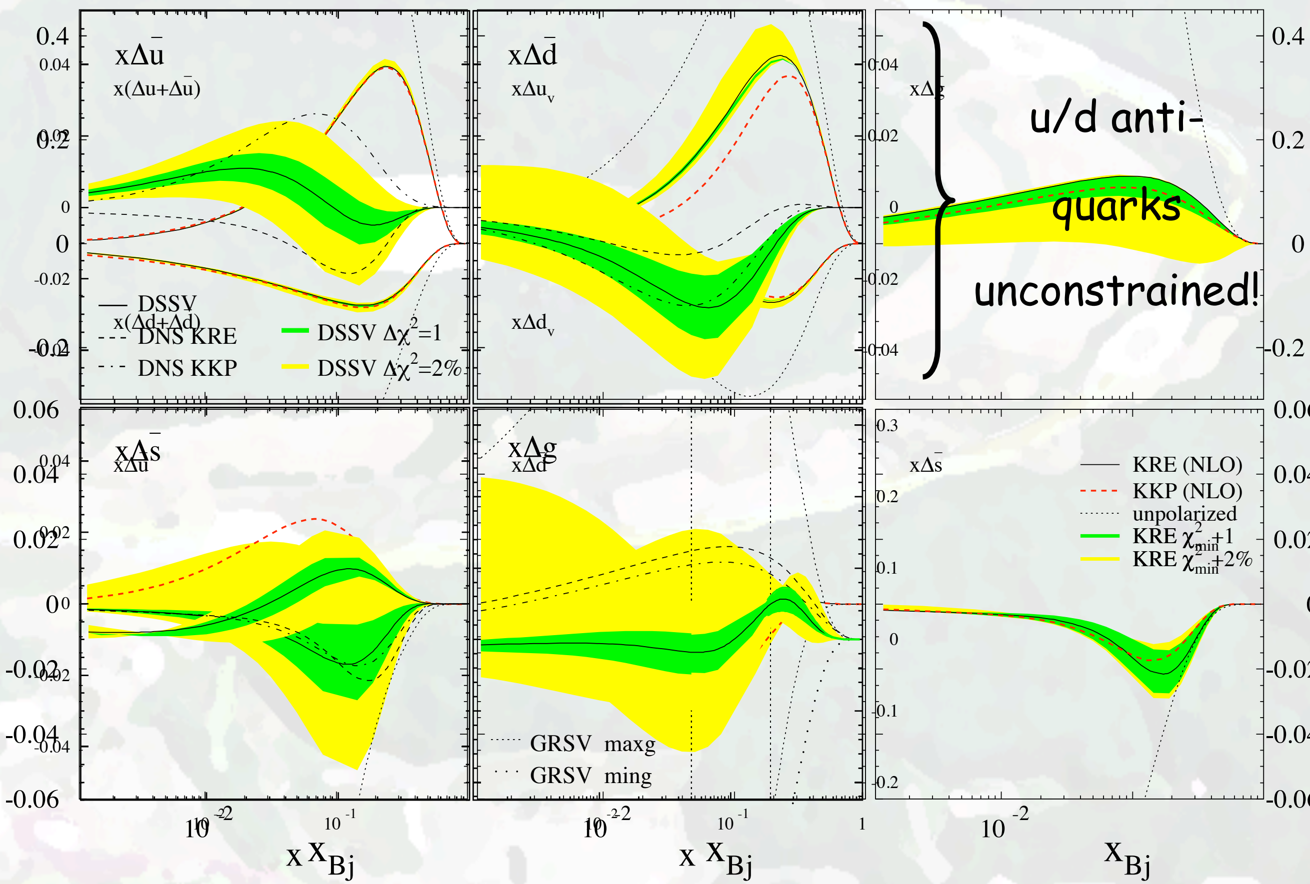
- What do we know about u/d anti-quark polarization?
  - Spin carried by quarks is very small ($\Delta\Sigma \sim 0.4$)!

$$\underbrace{\frac{1}{2}\Delta\Sigma}$$

$$\frac{1}{2} = \langle S_q \rangle + \langle S_g \rangle + \langle L_q \rangle + \langle L_g \rangle$$

$$\underbrace{\Delta G}$$

$$\Delta\Sigma = \Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}$$



D. de Florian et al., Phys. Rev. D71, 094018 (2005). arXiv:0804.0422

$$\Delta q_i(Q^2) = \int_0^1 \Delta q_i(x, Q^2)dx$$

$$\Delta G(Q^2) = \int_0^1 \Delta g(x, Q^2)dx$$

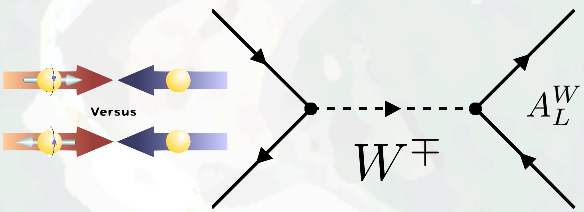
FGT Physics motivation - W program

Quark / Anti-Quark Polarization - W production

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

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

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



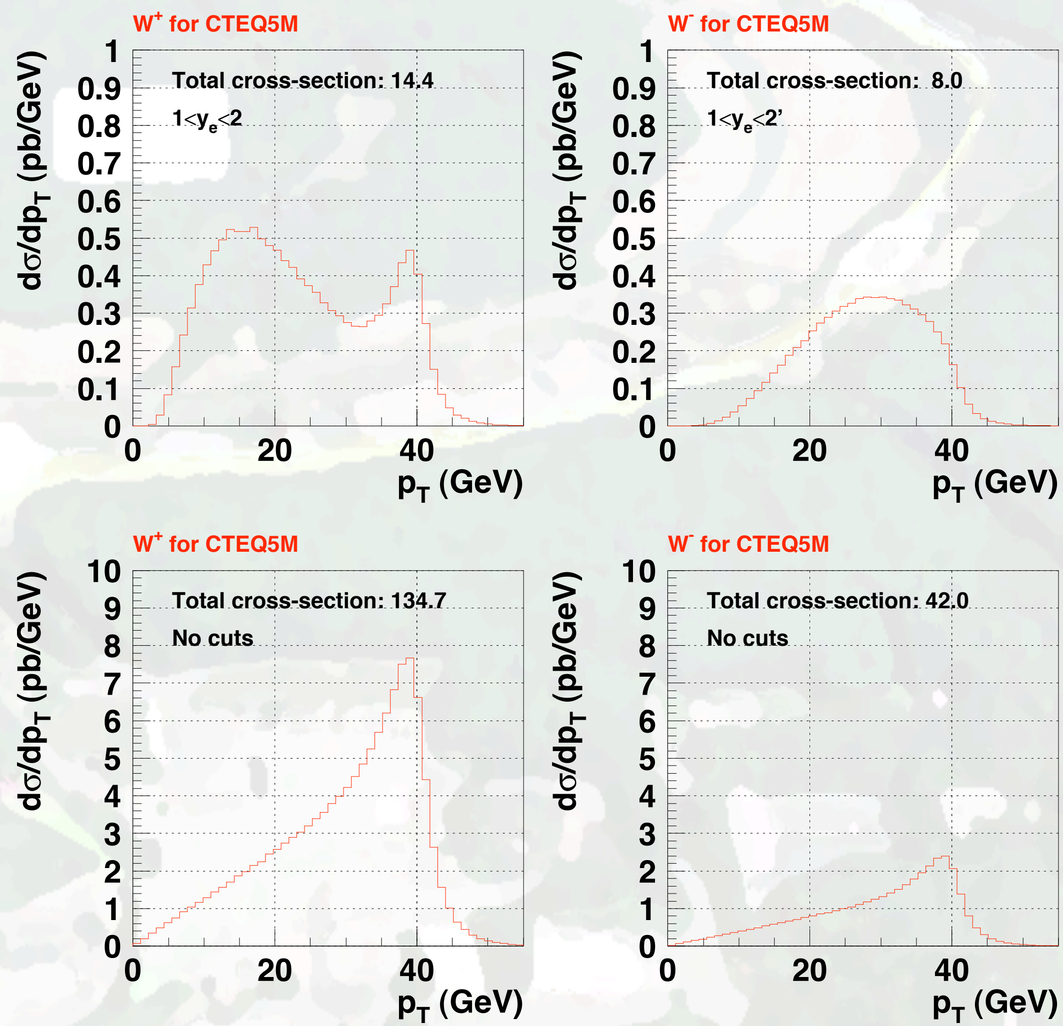
$$A_L^W = \frac{1}{P}\frac{N^+(W) - N^-(W)}{N^+(W) - N^-(W)}$$

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

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

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

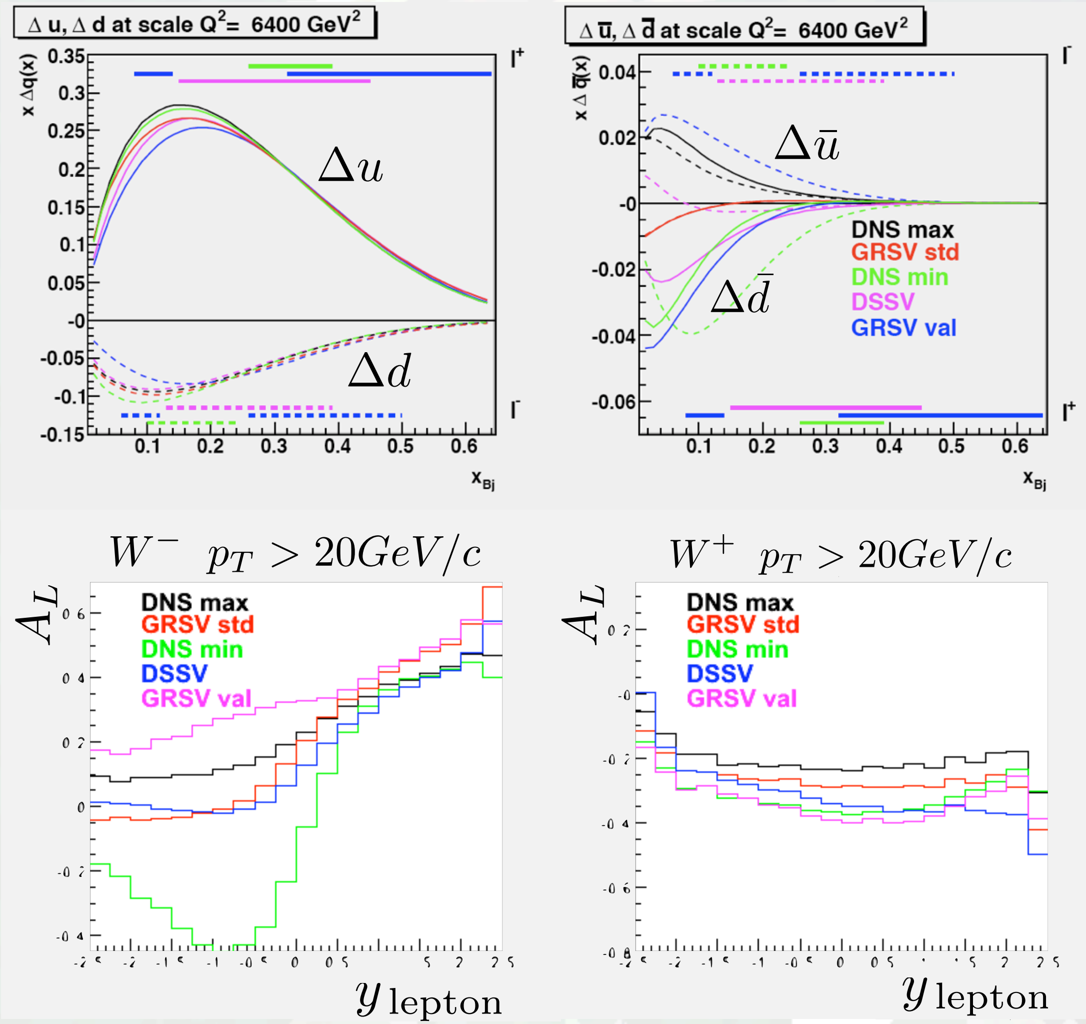
RHICBOS W simulation at 500GeV CME



- **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 Physics motivation - W program

Quark / Anti-Quark Polarization - Sensitivity in W production



- Theoretical framework for leptonic asymmetries exists (RHICBOS) ⇒ Basis for input to global analysis!
- Reconstruction of W-rapidity only possible in approximative way in forward direction
- Important contribution from forward and mid-rapidity region

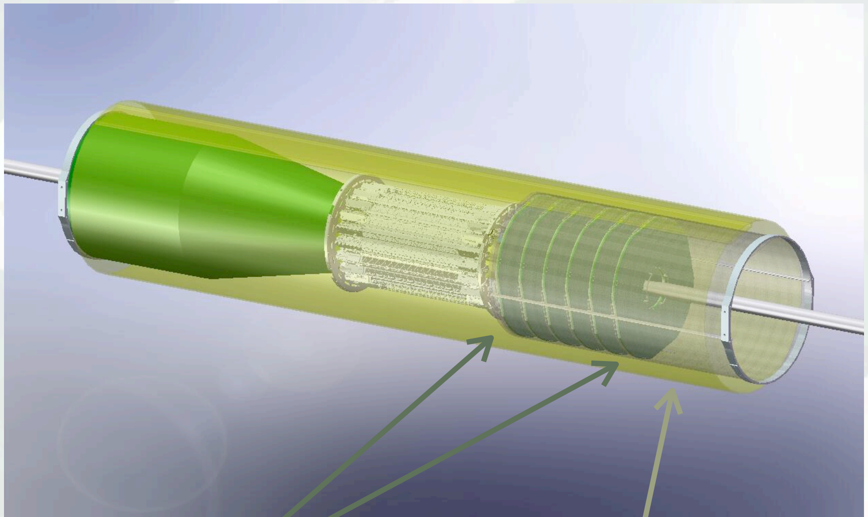
$$A_L^{W^-} = -\frac{\Delta d(x_1)\bar{u}(x_2) - \Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2) + \bar{u}(x_1)d(x_2)}$$

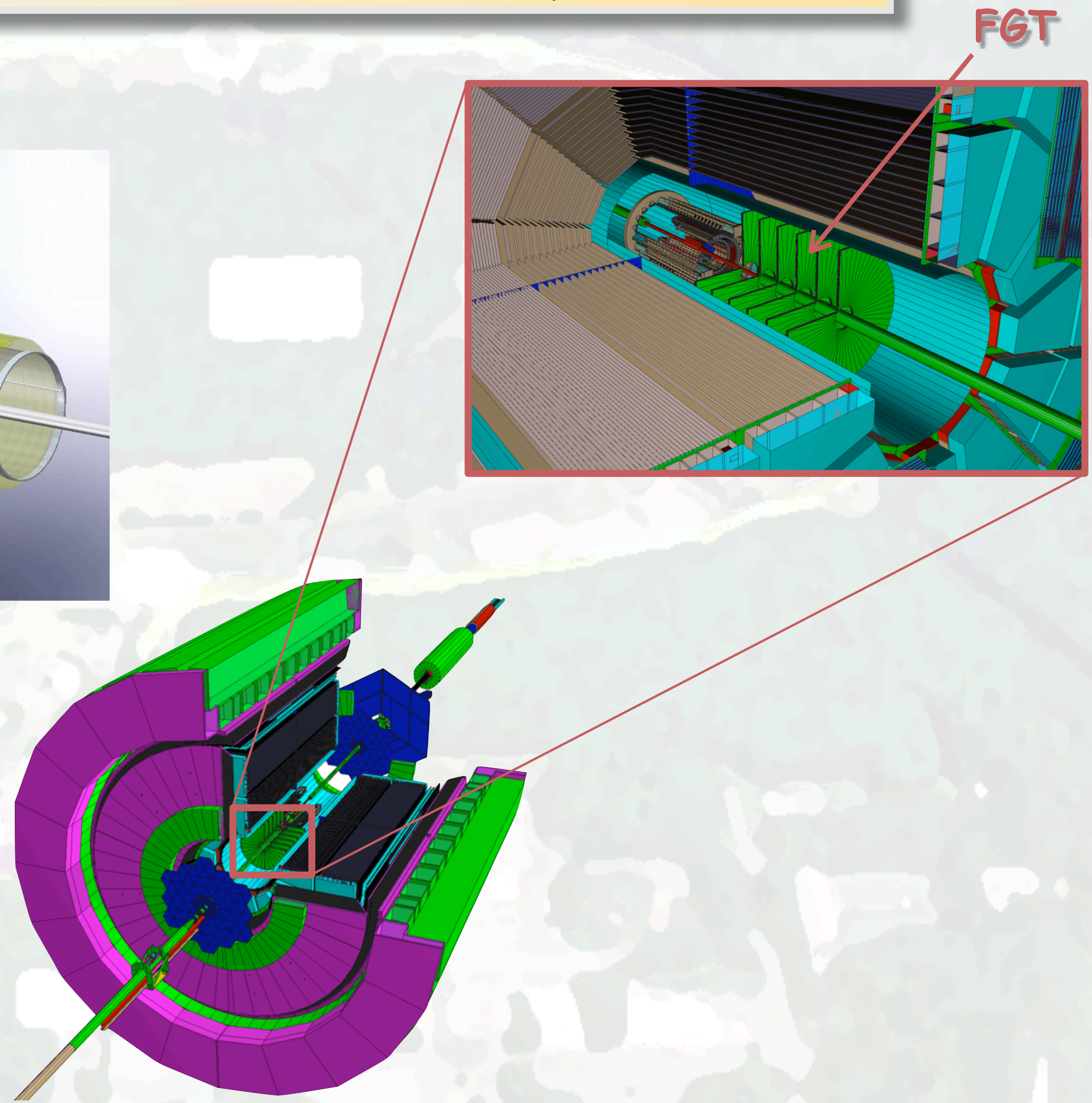
$$x_1 = \frac{M_W}{\sqrt{s}} e^{y_W} \qquad x_2 = \frac{M_W}{\sqrt{s}} e^{-y_W}$$

- Large uncertainties for polarized anti-quarks reflected in leptonic asymmetries!

FGT Layout - Simulation results and optimization

- Layout

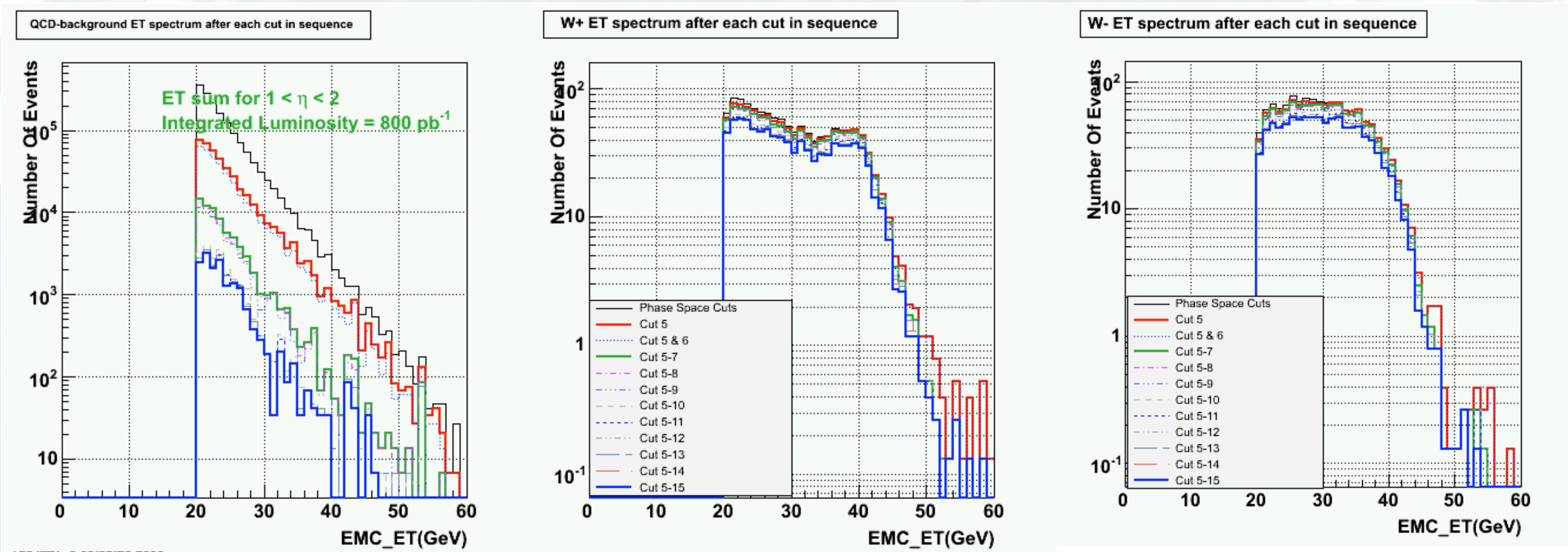




- FGT: 6 light-weight triple-GEM disks - WEST side of STAR
- New mechanical support structure

FGT Layout - Simulation results and optimization

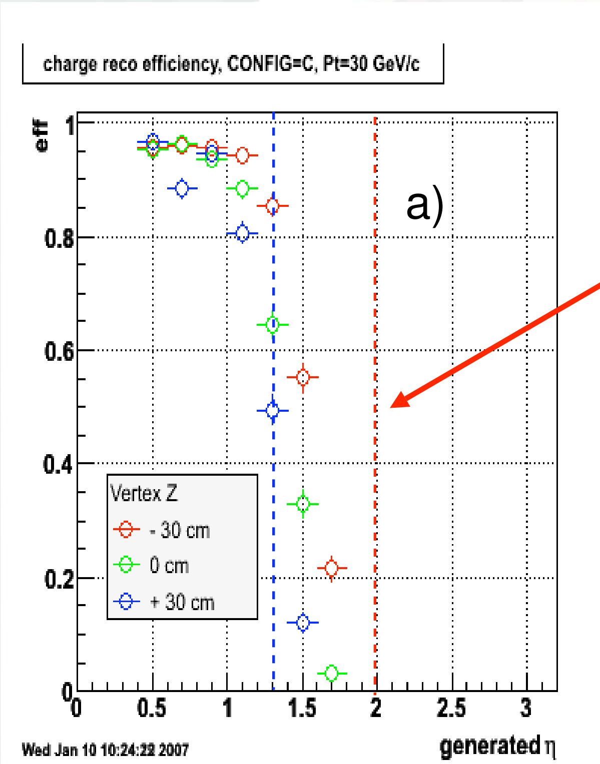
- Quark / Anti-Quark polarization program at STAR - e/h separation
  - Full PYTHIA QCD background and W signal sample including detector effects



- 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

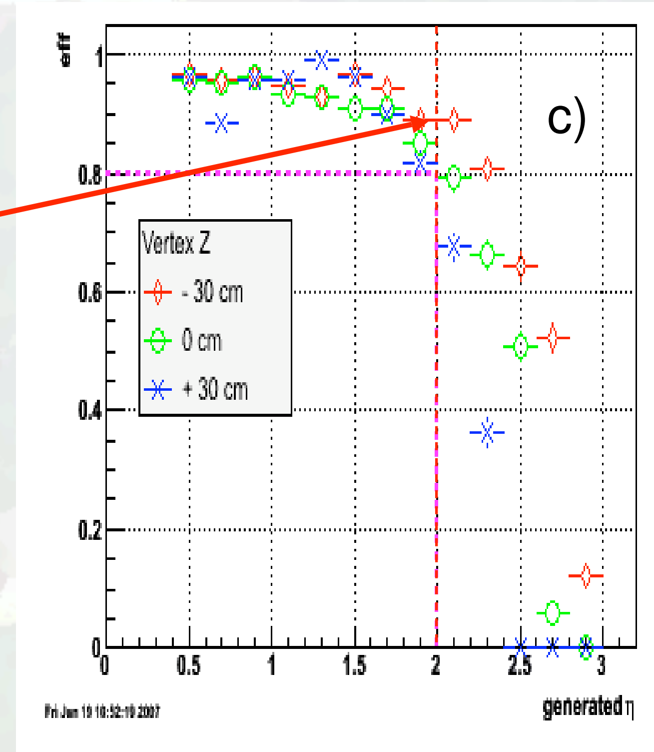
FGT Layout - Simulation results and optimization

- 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)

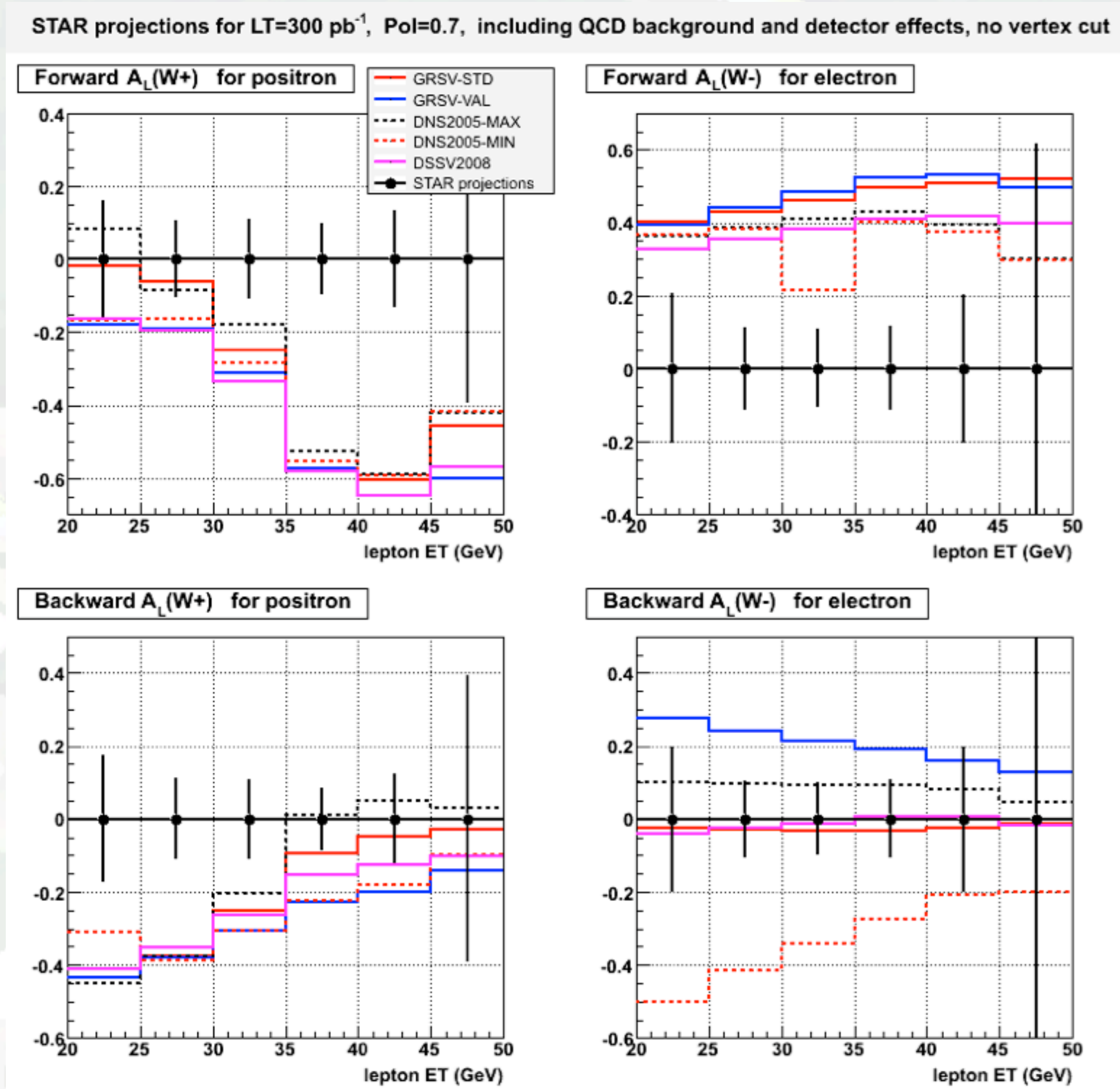
Conclusion:

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

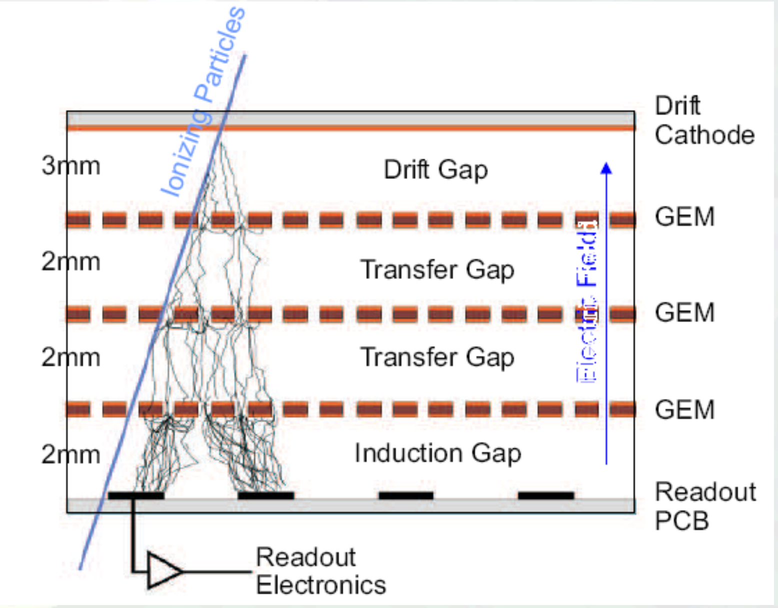
FGT Layout - Simulation results and optimization

- Quark / Anti-Quark polarization program at STAR - Projections
  - Large asymmetries dominated by quark polarization - Important consistency check to existing DIS data with 100pb^{-1} (Phase I)
  - Strong impact constraining unknown antiquark polarization requires luminosity sample at the level of 300pb^{-1} for 70% beam polarization (Phase II)



FGT Technical realization

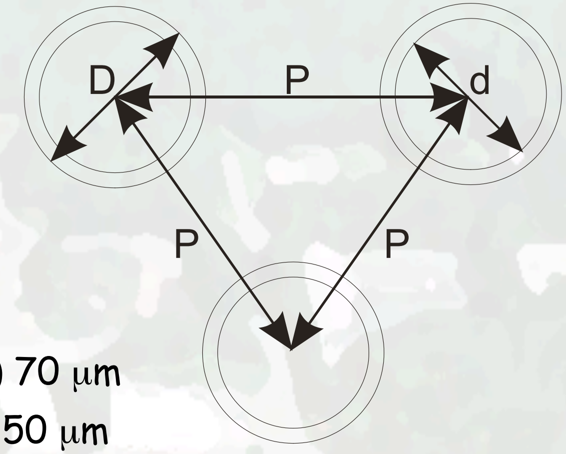
- GEM technology
  - Example: Triple-GEM application at COMPASS
  - Advantages:
    - Reliable (COMPASS, multi-year experience)
    - High gas amplification (Multiple GEMs: up to ~10^6)
    - Fast (< 20 ns FWHM, rate capability up to 10^5 Hz/mm)
    - Low mass (50μm Kapton + 10μm Cu; Thin low Z read-out plane)
    - Good spacial resolution (1D and 2D) (~60μm)
    - Simple construction and in-expensive



F. Sauli, Nucl Instr. and Meth. A386 (1997) 531.

C. Altunbas et al., Nucl Instr. and Meth. A490 (2002) 177.

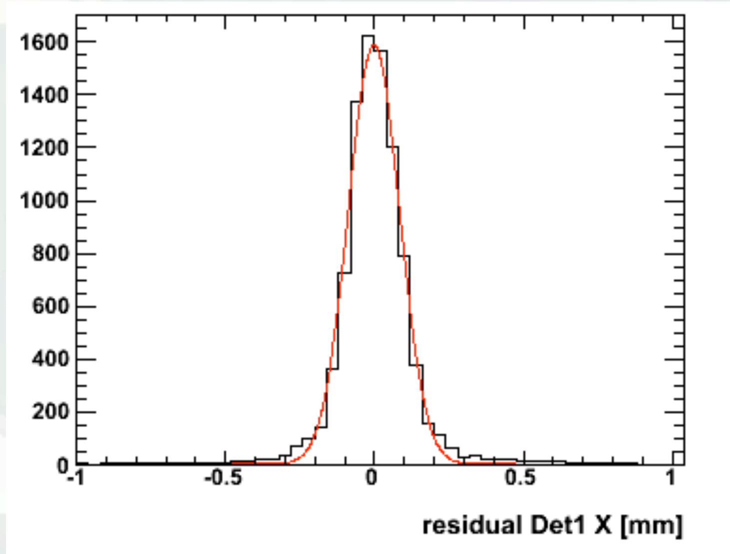
Standard layout:
- Pitch (P) 140 μm
- Outer diameter (D) 70 μm
- Inner diameter (d) 50 μm



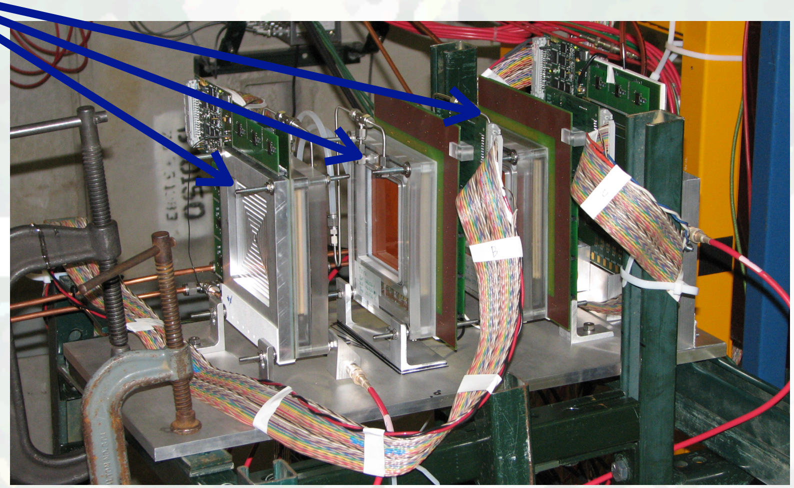
FGT Technical realization

- GEM technology development

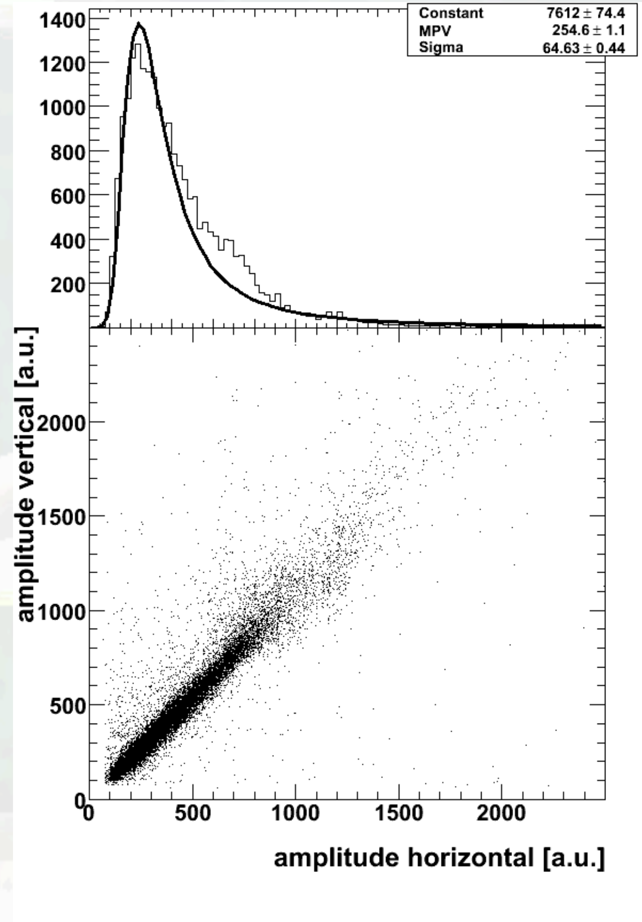
  - SBIR proposal (Phase I/II): Established commercial GEM foil source (Tech-Etch Inc.)



  - FNAL testbeam of three prototype triple-GEM chambers including APV25 chip readout



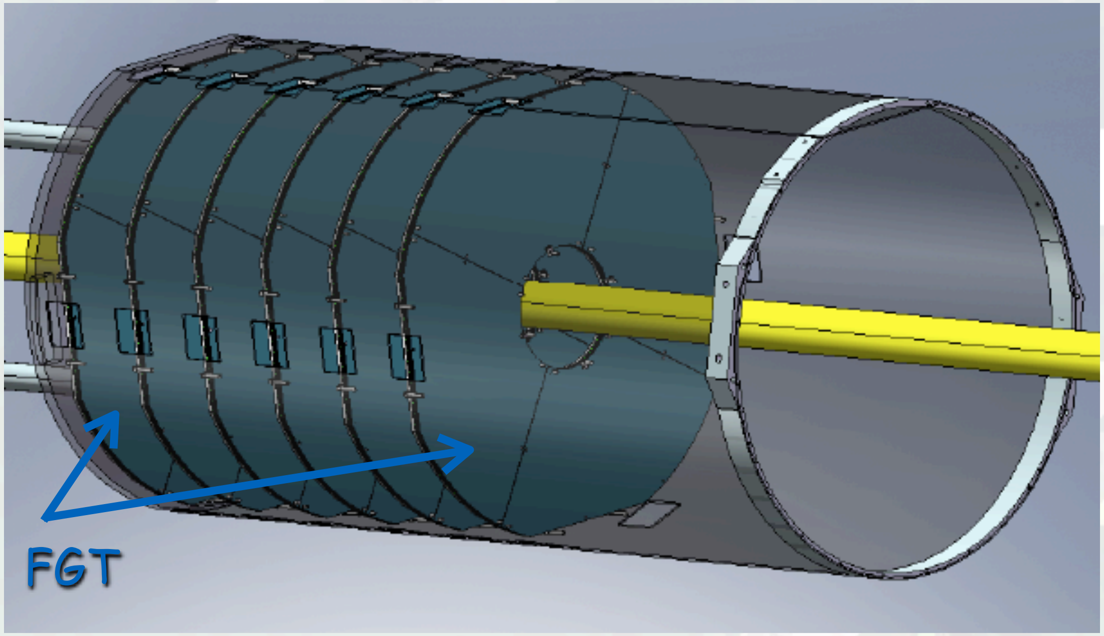
  - Performance meets requirements!

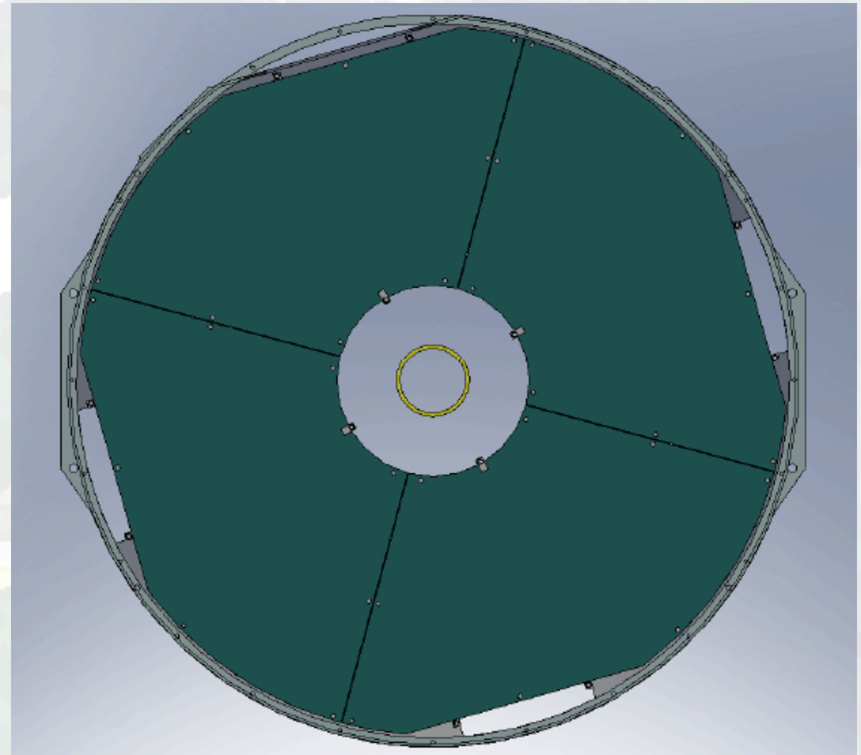


  - Hit resolution: ~60 μm
  - Good charge sharing!

FGT Technical realization

- Mechanical design

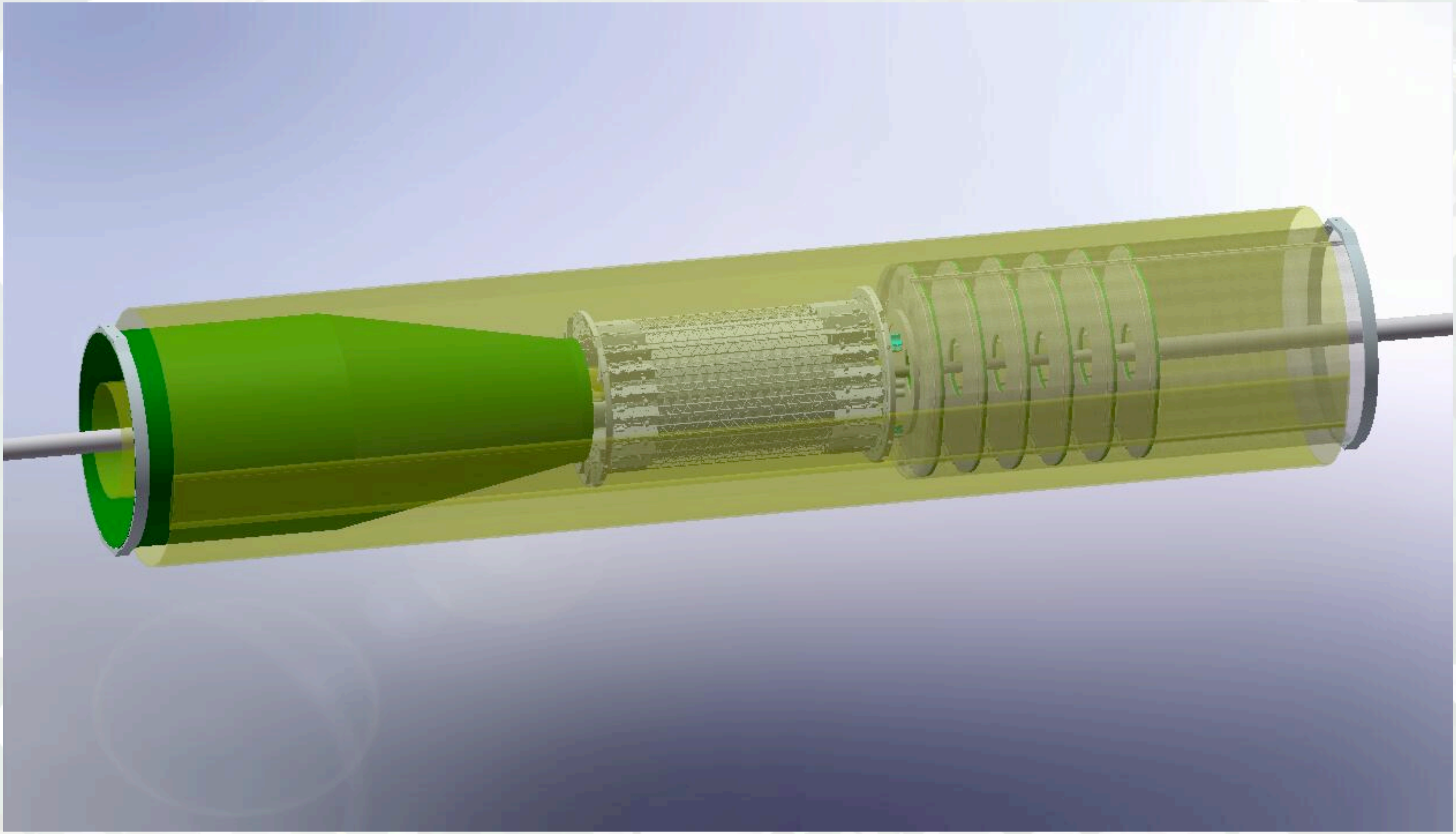




- FGT: 6 light-weight disks
- Each disk consists of 4 triple-GEM chambers (Quarter sections)
- Procurement and assembly of full quarter section prototype in preparation

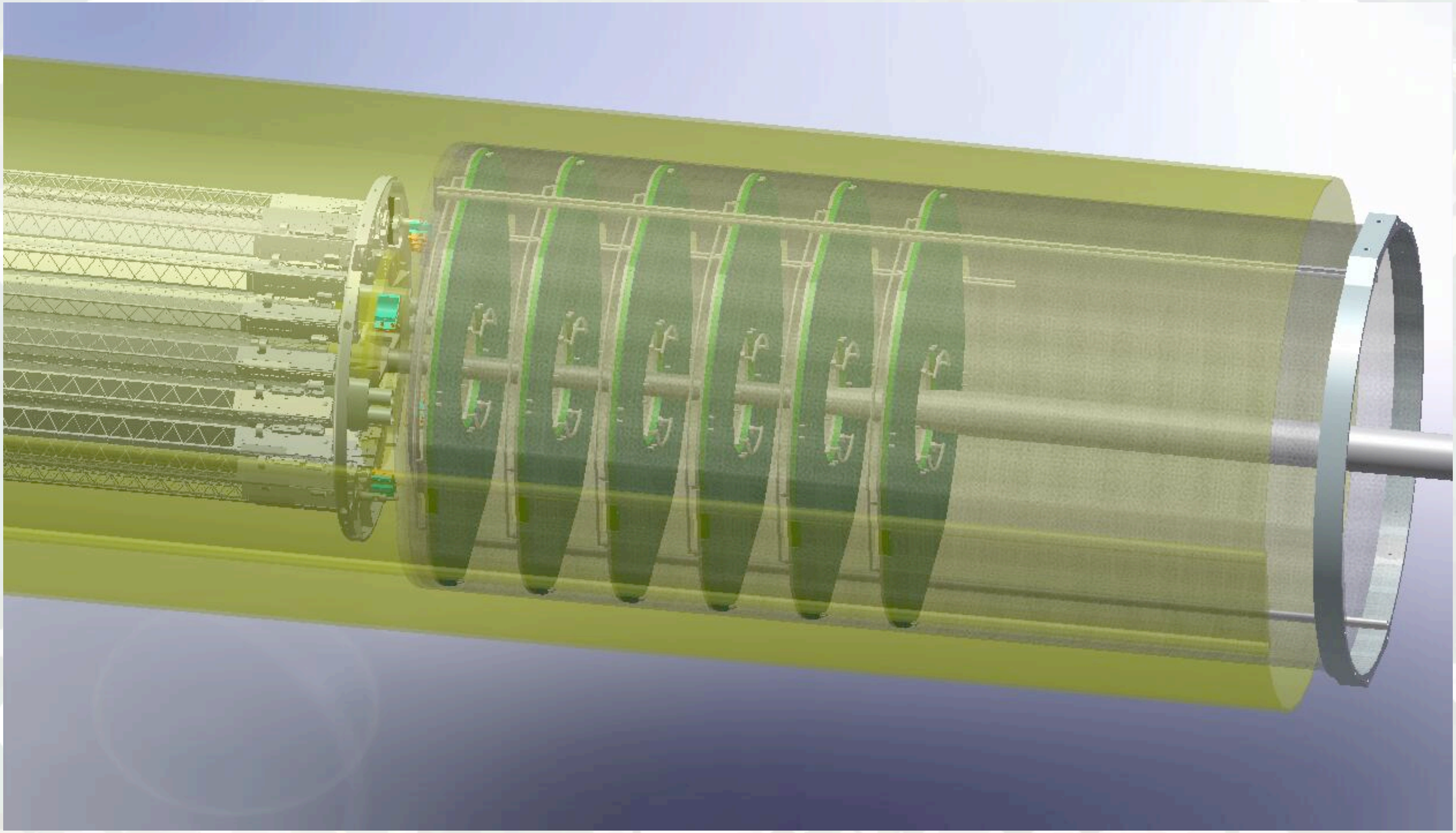
FGT Technical realization

- Mechanical support structure (1)



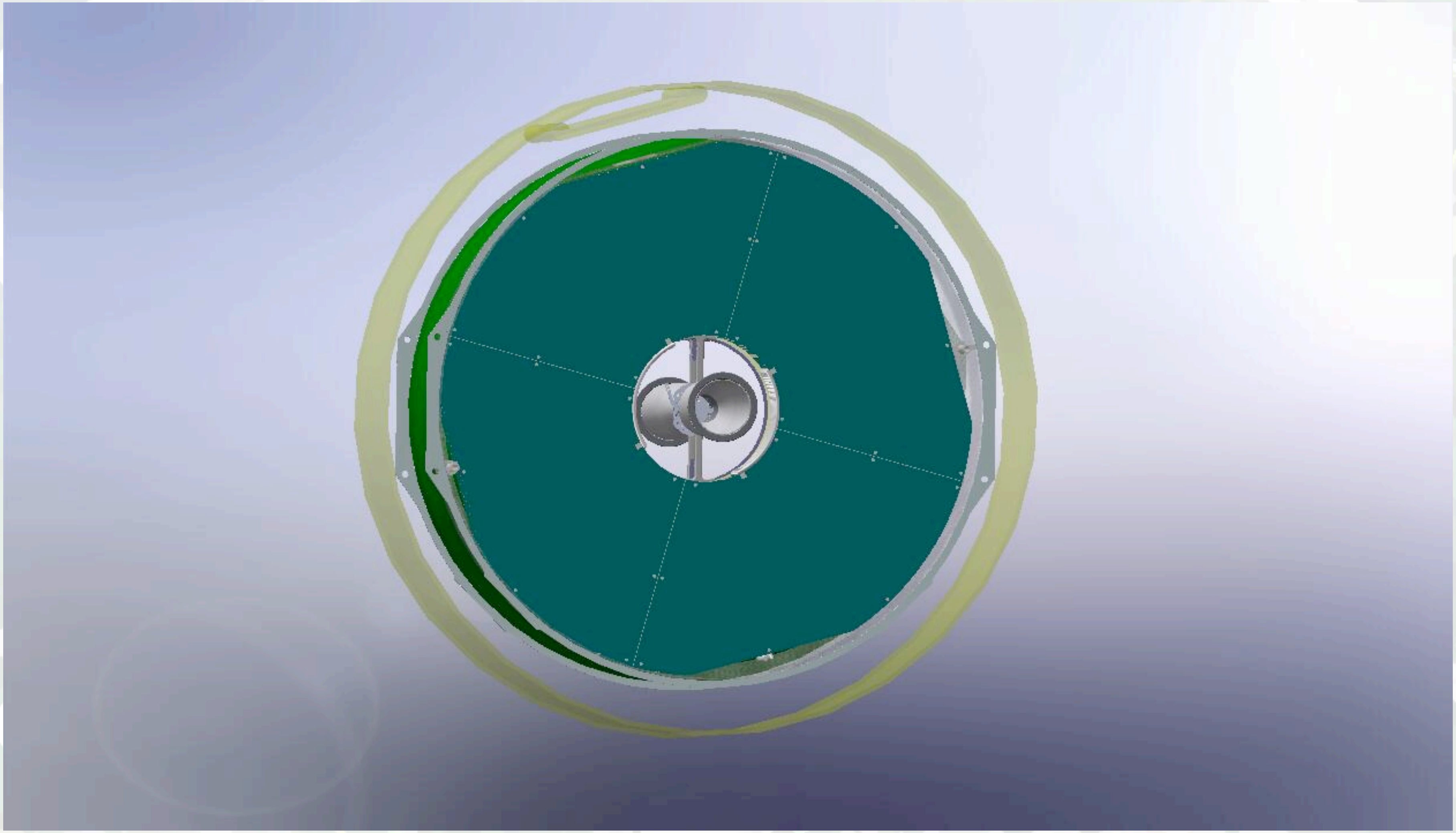
FGT Technical realization

- Mechanical support structure (2)



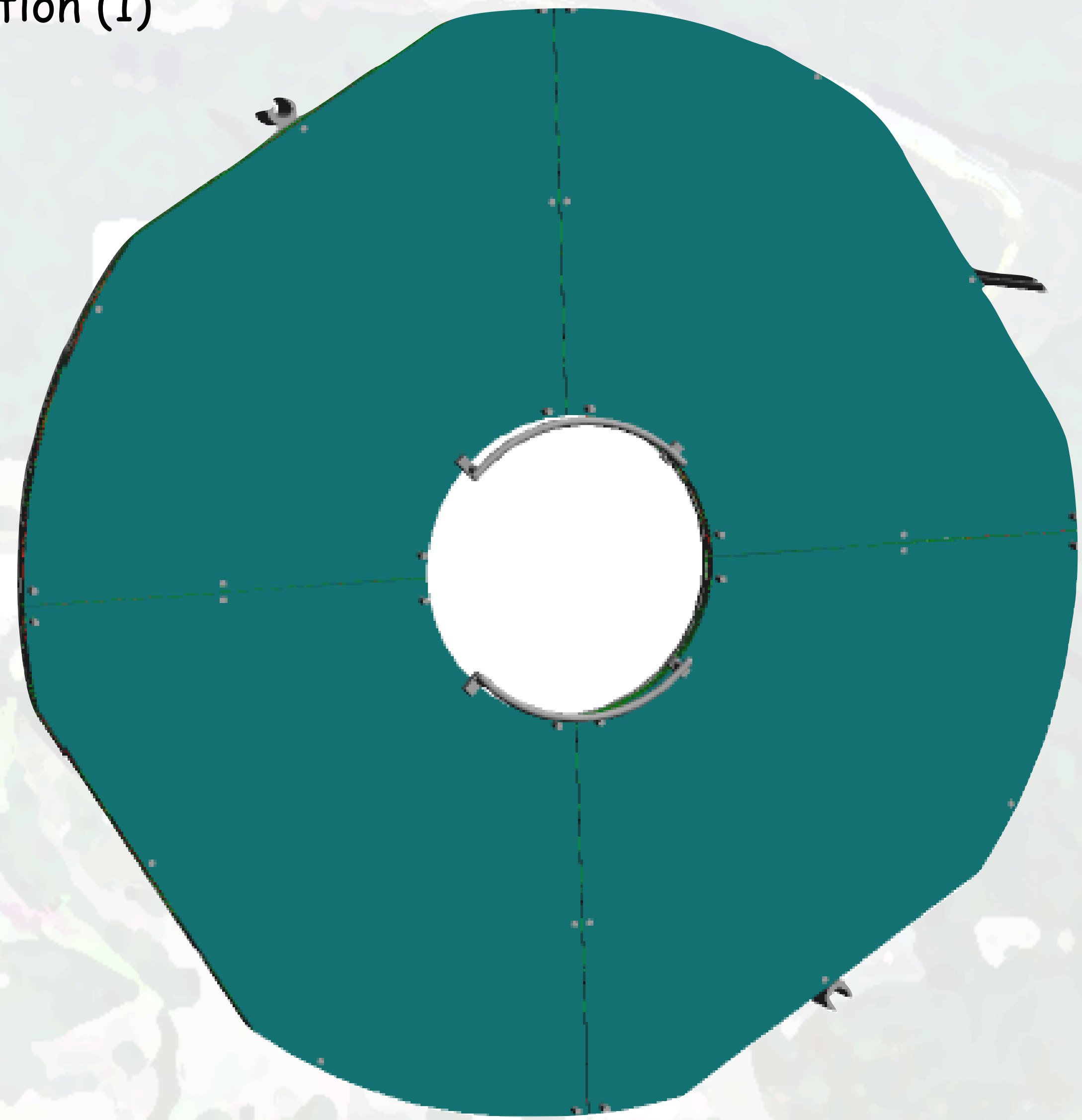
FGT Technical realization

- Mechanical support structure (3)



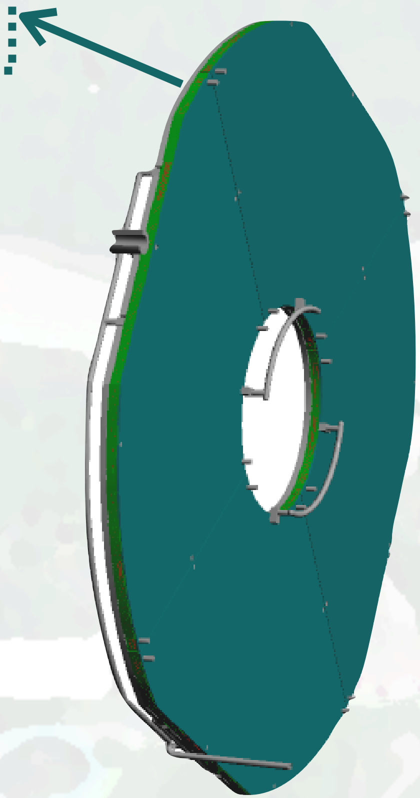
FGT Technical realization

- Triple-GEM detectors - Quarter section (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

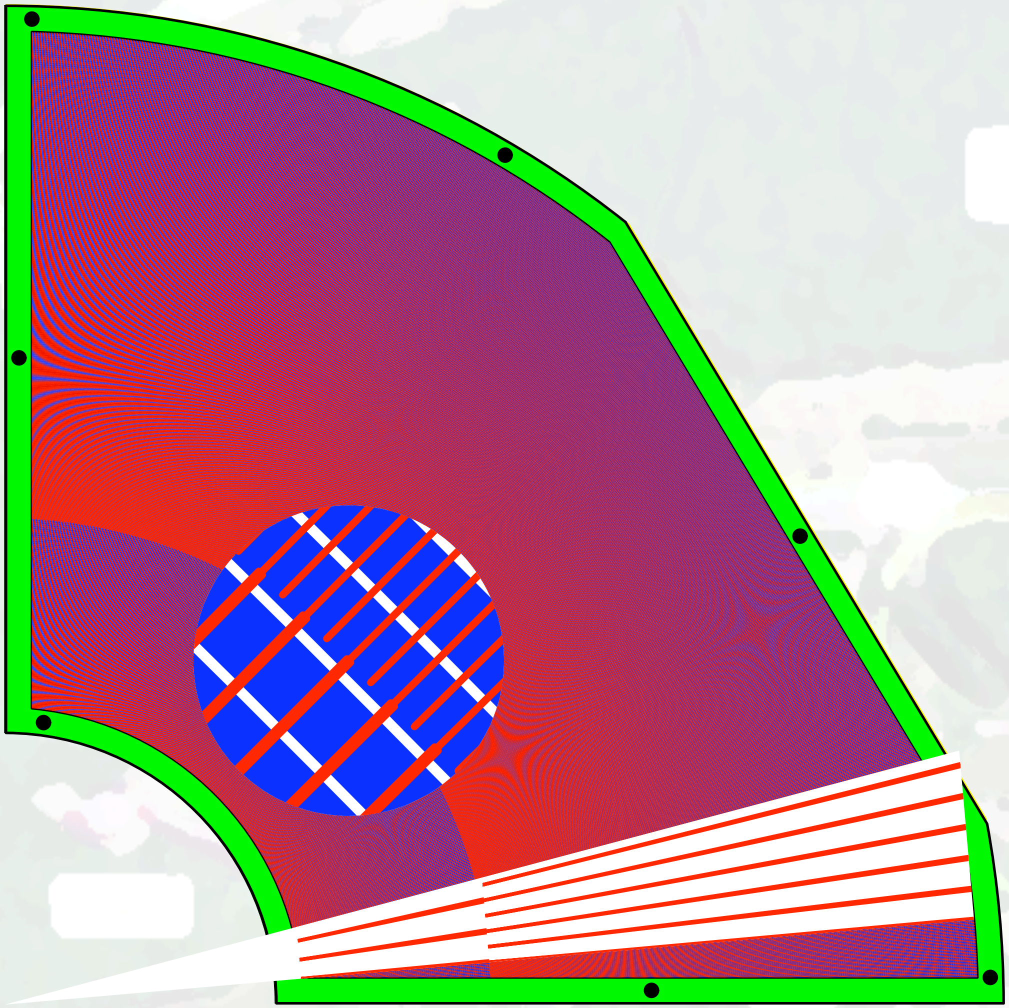
Triple-GEM detectors - Quarter section (2)



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

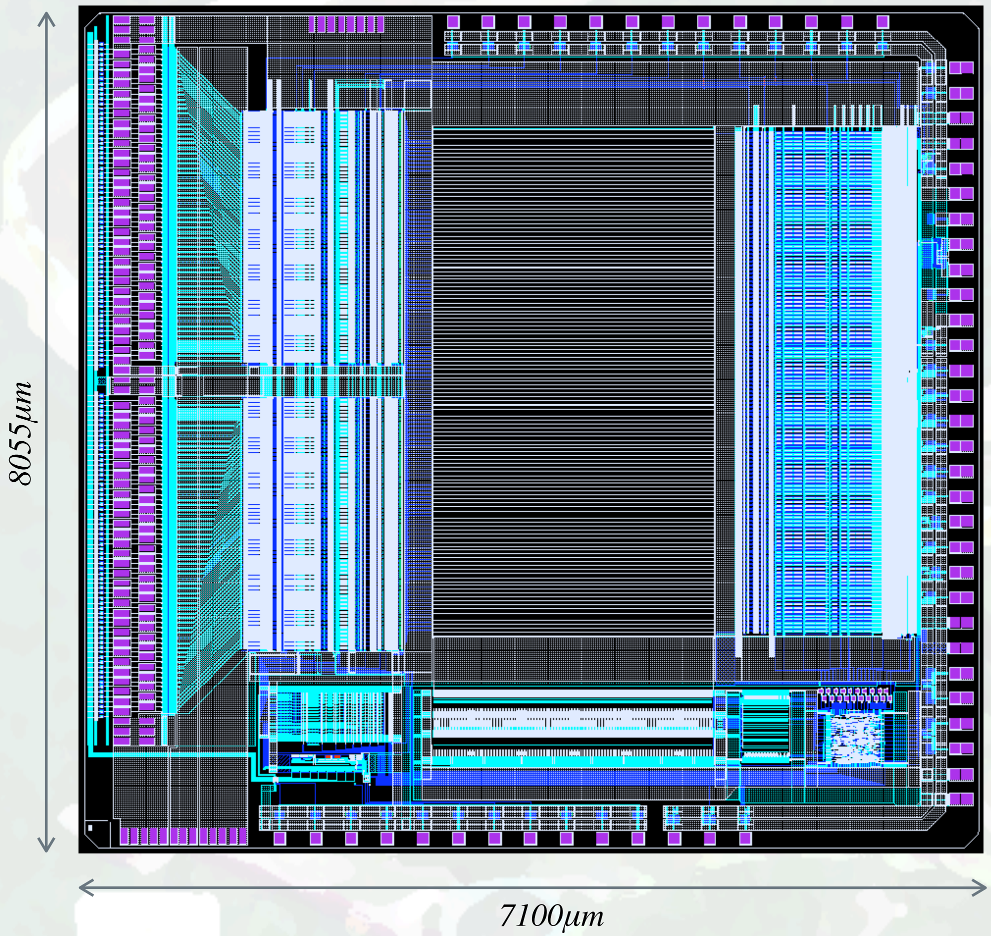
- Triple-GEM detectors - Assembly



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

FGT Technical realization

Front-End Electronics (1)

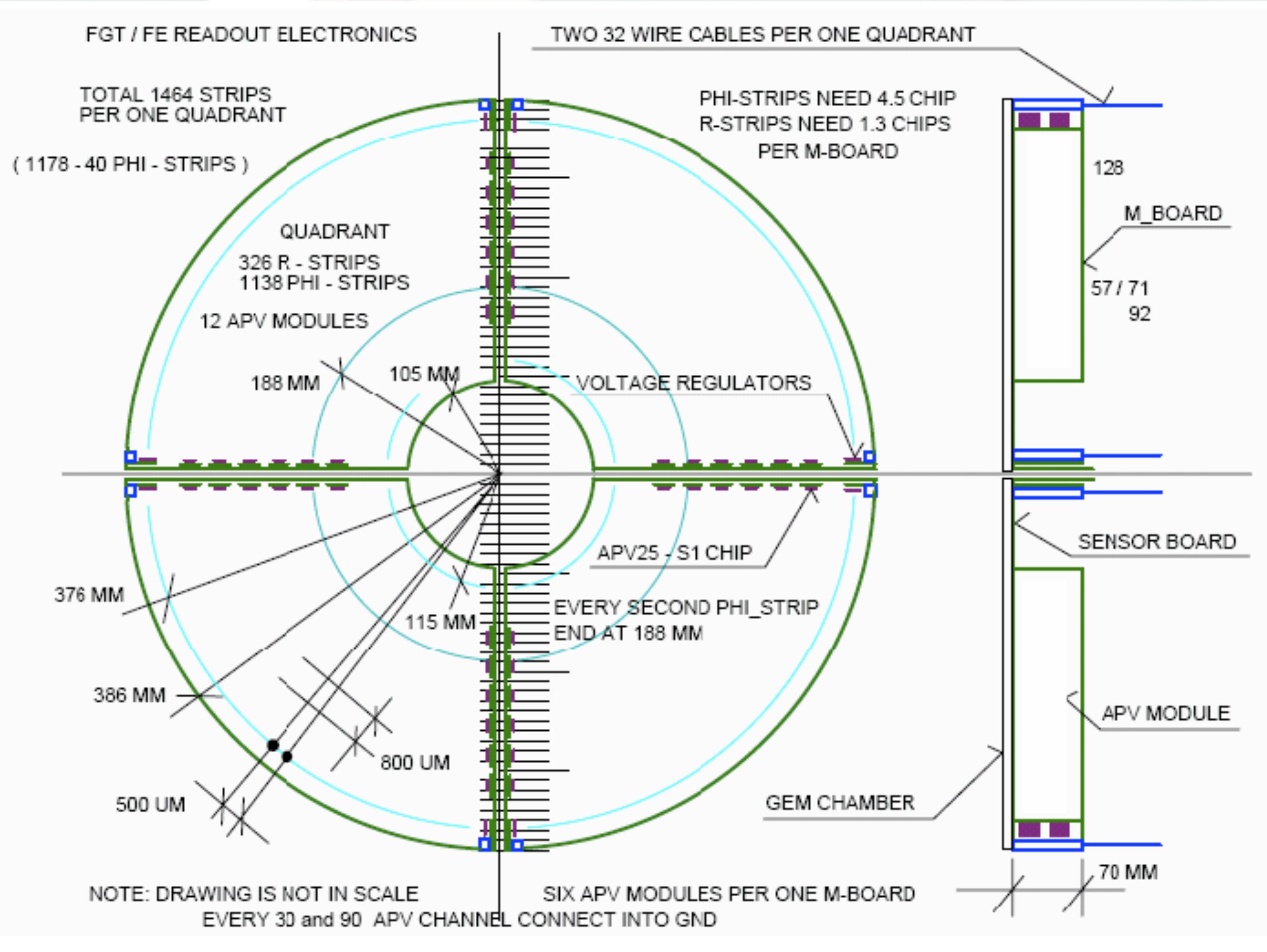


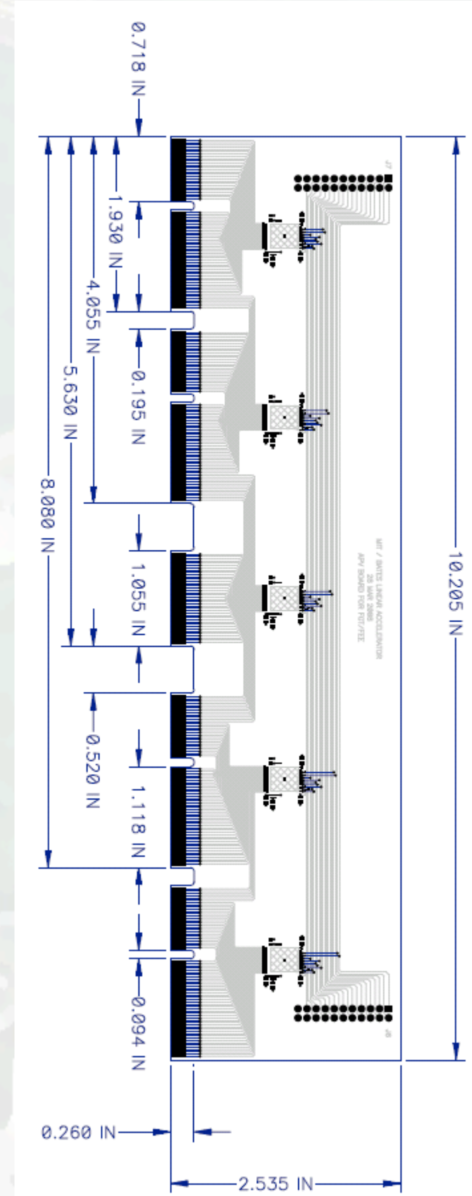
- Off-the shelf readout chip: APV25-S1
- Used for STAR IST and FGT (1 readout system)!

- Developed for CMS (75000 in CMS tracker) and also used by COMPASS for triple-GEM detector readout
- 0.25µm CMOS
- 128 channels
- 40 MHz sampling rate
- 4µs analogue pipeline
- 11:1 Signal / Noise
- 0.25Watt/chip
- Radiation hard

FGT Technical realization

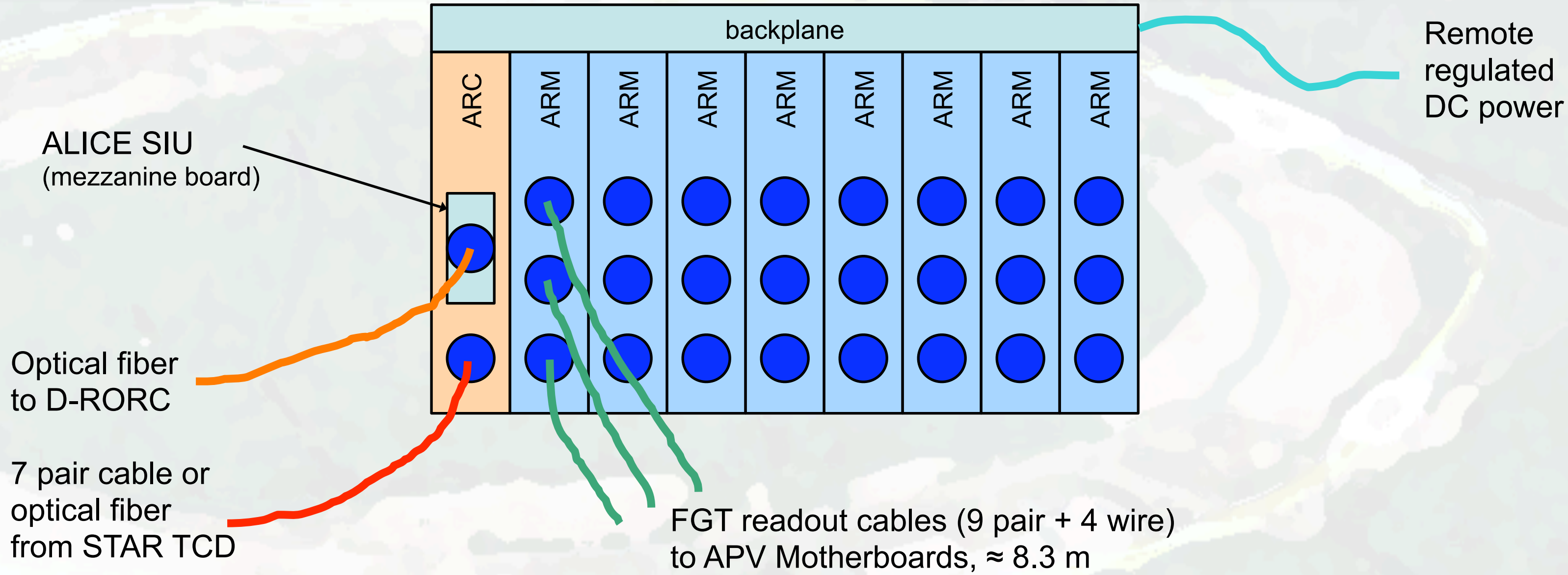
Front-End Electronics (2)





FGT Technical realization

- DAQ
  - Conceptual design of STAR specific DAQ system for APV25-S1 readout of FGT developed
  - Focus on similar design for STAR DAQ system for IST



- Two crates, each handles 12 cables, OR 3 crates each handles 8 cables, 10 APV's per cable, a total of 15360 (10240) detector channels per crate
- ARM (APV Readout Module): 20 OR 10 ADC channels and data processing FPGA's (zero suppression, pileup rejection); power for APV on ARM or separate new board (4/crate)
- ARC (APV Readout Controller): control FPGA's, STAR clock/trigger interface and ALICE SIU (data/control link)
- Connected by passive backplane, 30 MHz synchronous 24 bit datapath
- Uses commercial hardware (6U crate, VME P1 backplane)

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 this summer
  - 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