Mechanical/Cooling Supports Based on Thermally Conducting Carbon Foam

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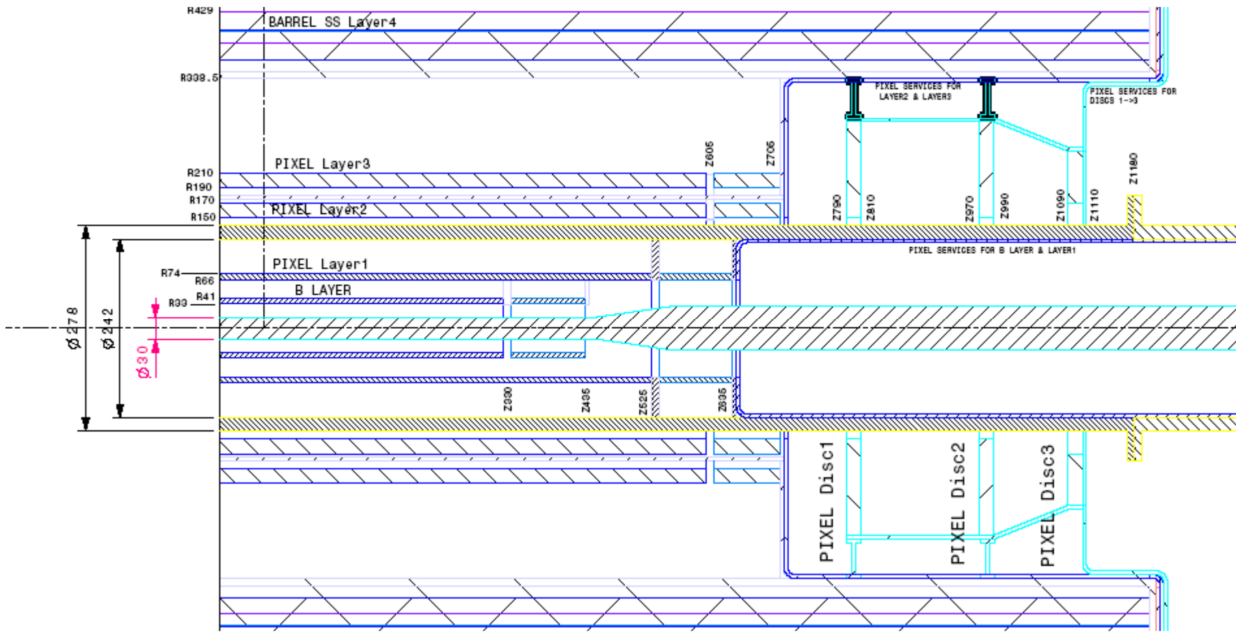
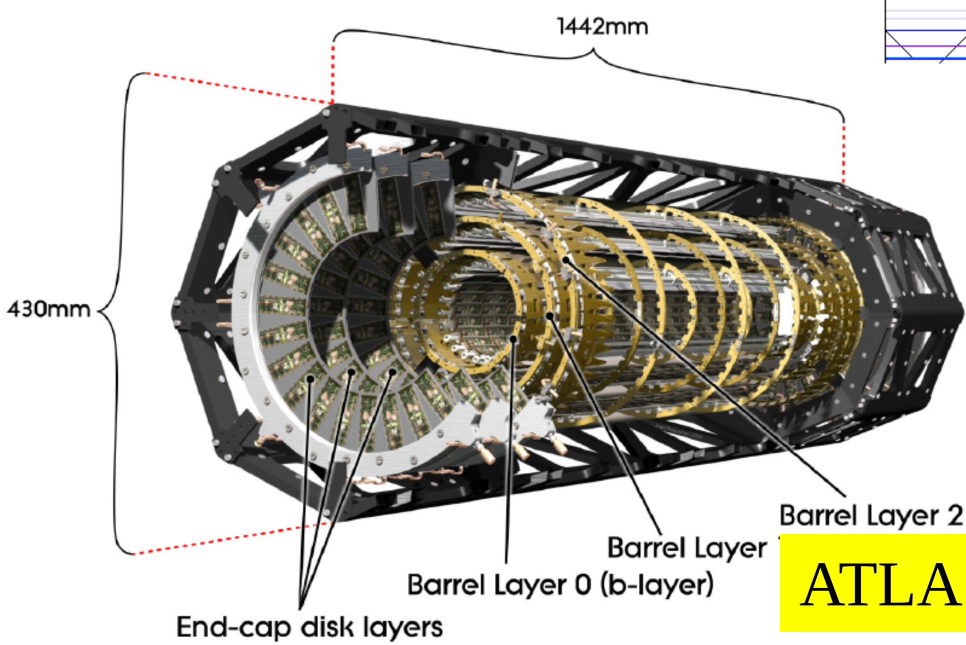
Motivation

- Next generation of detectors for upgrades to the LHC
- New mechanical structures



ATLAS Upgrade

- Scale increase factor of 3 or more for pixel upgrades
- Bigger pixel structures
- Possibly new cooling schemes

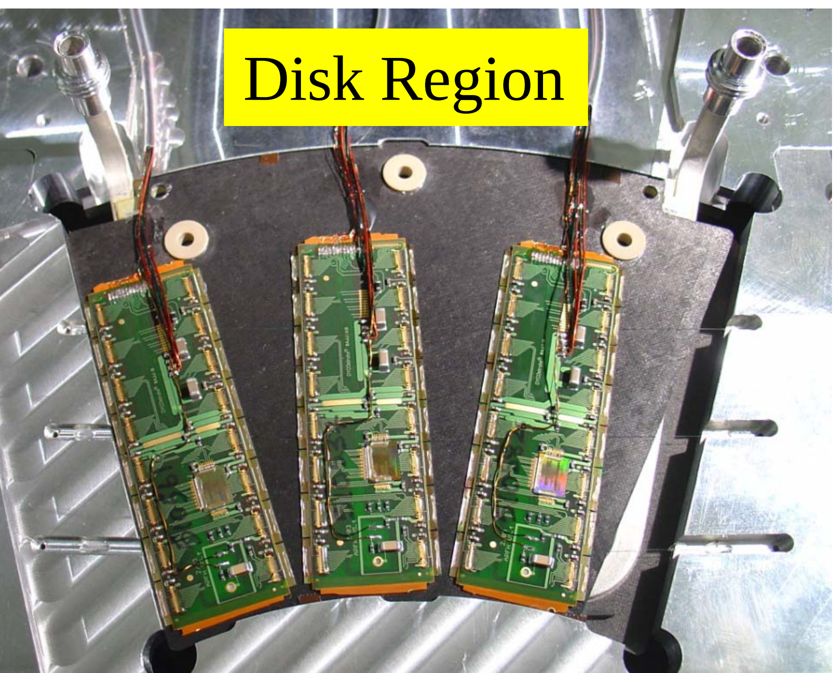


ATLAS

M. Gilchriese

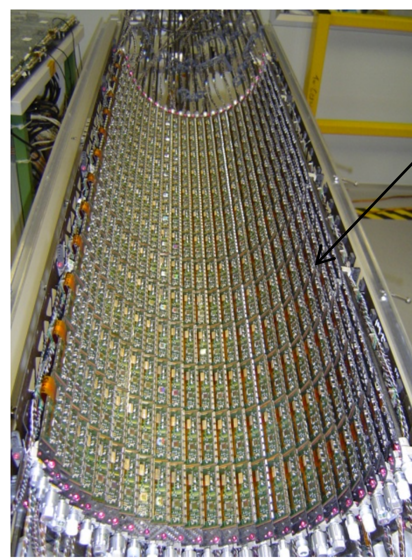
Pixel Mechanical/Cooling Supports

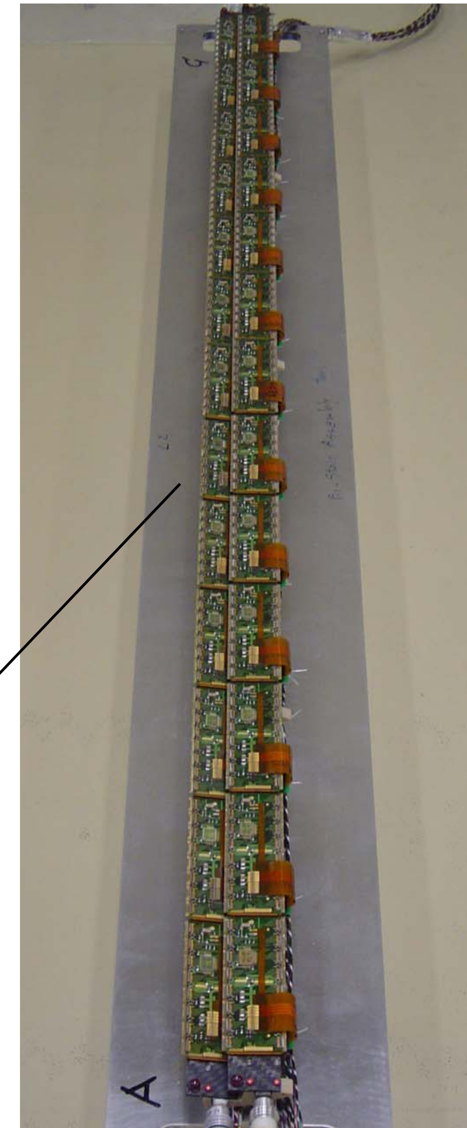
- Pixel modules mounted on mechanical supports with integrated cooling pipes
- Stable structures to allow accurate location of modules
- Power ~ 0.5 W/cm^2 (upgrade, currently higher)
- Silicon sensors in modules must operate cold ~ -10C
- Minimize material (radiation length)
- Radiation tolerant (up to ~ 1 GigaRad for upgrade)



Disk Region

Barrel Region

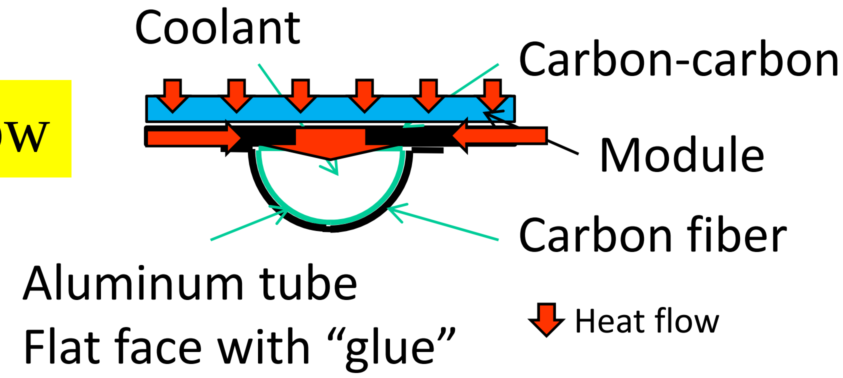




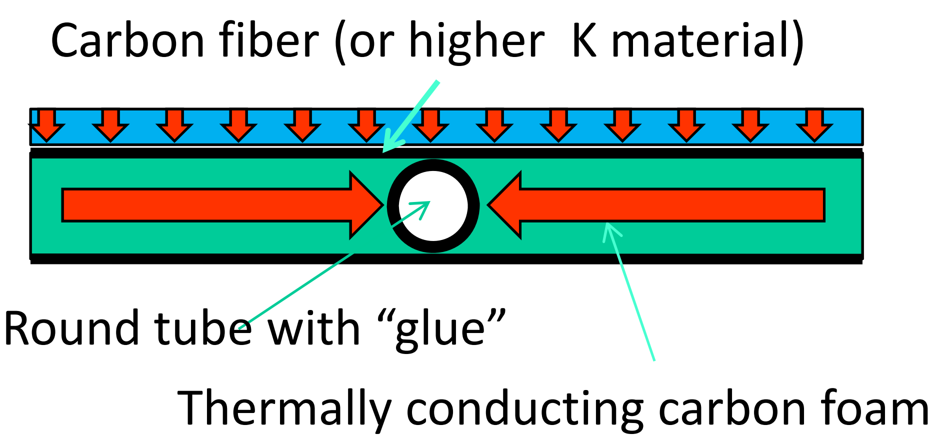
Thermal Basics

- Current concept (ATLAS example, but many others)
  - Heat flow into highly thermally conducting material that directs heat to coolant tube
  - Tube has flat face and contact made with thermal compound(grease/glue)
  - Structural support material additional
  - Different designs barrel and disk
- Foam concept
  - Heat into foam and then tube
  - Round tube allows use of high pressure coolants(eg. CO_2 at > 10 bar)
  - Foam also part of structural support
  - Use for ALL pixel regions(outer barrel, inner barrel, disks…keeping foam but adapt to geometrical constraints (not just rectangular structure) and thermal loads

Now



With foam



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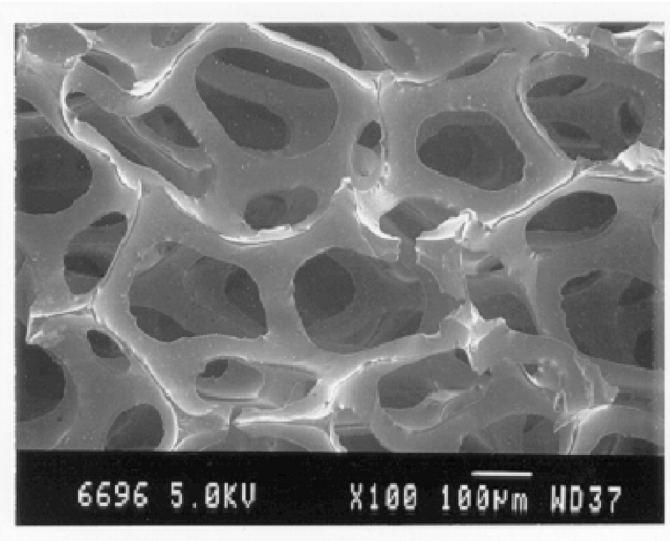
Carbon Foams – R&D

- Carbon foam has been around for many years, some ~ 40 years – see brief history here
- So why is R&D needed? Density ⇔ thermal conductivity (K)
- Readily available, good thermally conducting carbon foams have density (ρ) ≥ 0.5 g/cc. These are graphitic foams
- Readily available, low-density carbon foams (ρ ~ 0.05 g/cc) have very poor thermal conductivity. These are reticulated vitreous carbon (RVC) foams.
- Our R&D involves, primarily, lowering the density of the graphitic foams but keeping a reasonable K (and mechanical strength) and raising the K and the density (but not so much) of the RVC foams.
- This requires close collaboration with the manufacturers of these foams (currently working with three companies) but some techniques are proprietary.

Example of RVC-Based Foam

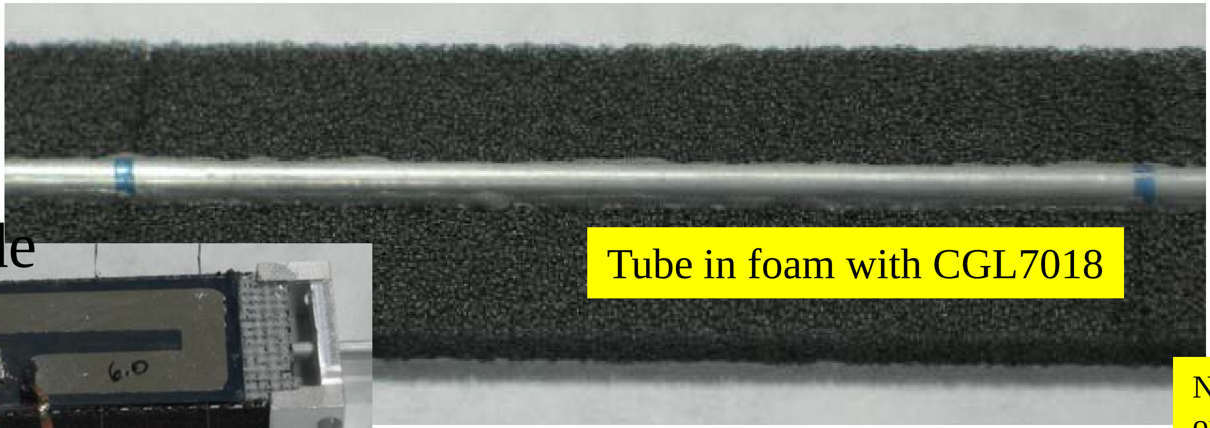
- Development work is being done by Allcomp, Inc supported by DoE SBIR
- The starting material is RVC foam of density ~ 0.05 g/cc
  - Porosity is typically 100 ppi (pores per inch) although lower porosity also being done for other applications
  - Highly thermally conducting carbon is added to the ligaments of the RVC precursor through a combination of chemical vapor deposition (CVD) and heat treatment
  - First examples for pixel structure prototypes raise density by factor ~ 4 but thermal conductivity by factor 100 – 200
  - Strength also enhanced. Readily machined.



Pixel Prototype Components

One prototype 20 cm long. The rest about 6 cm long

Tube OD ~ 2.8mm
Applicable to CO_2



~ 2.5 cm wide

~ 0.7 cm thick ~ 6cm long

Note can just use glue on foam to create surface for module mounting, if mechanics allow

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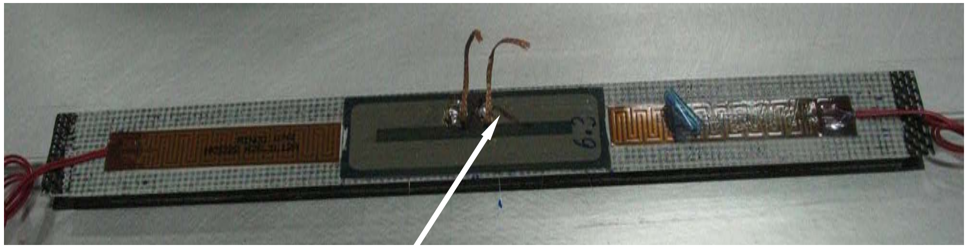
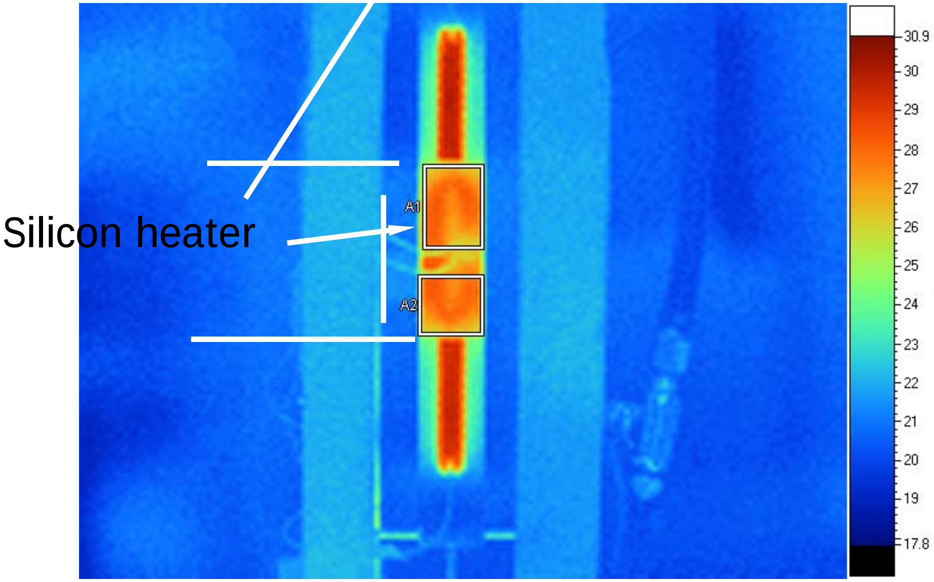
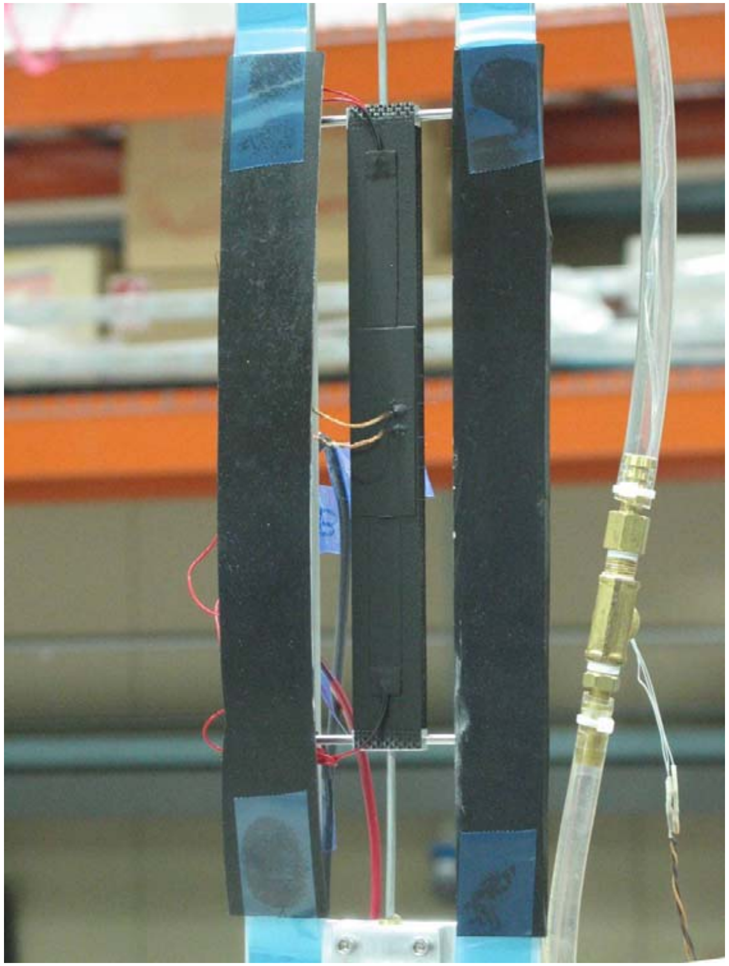
Simple Thermal Test Set-Up

20 cm prototype

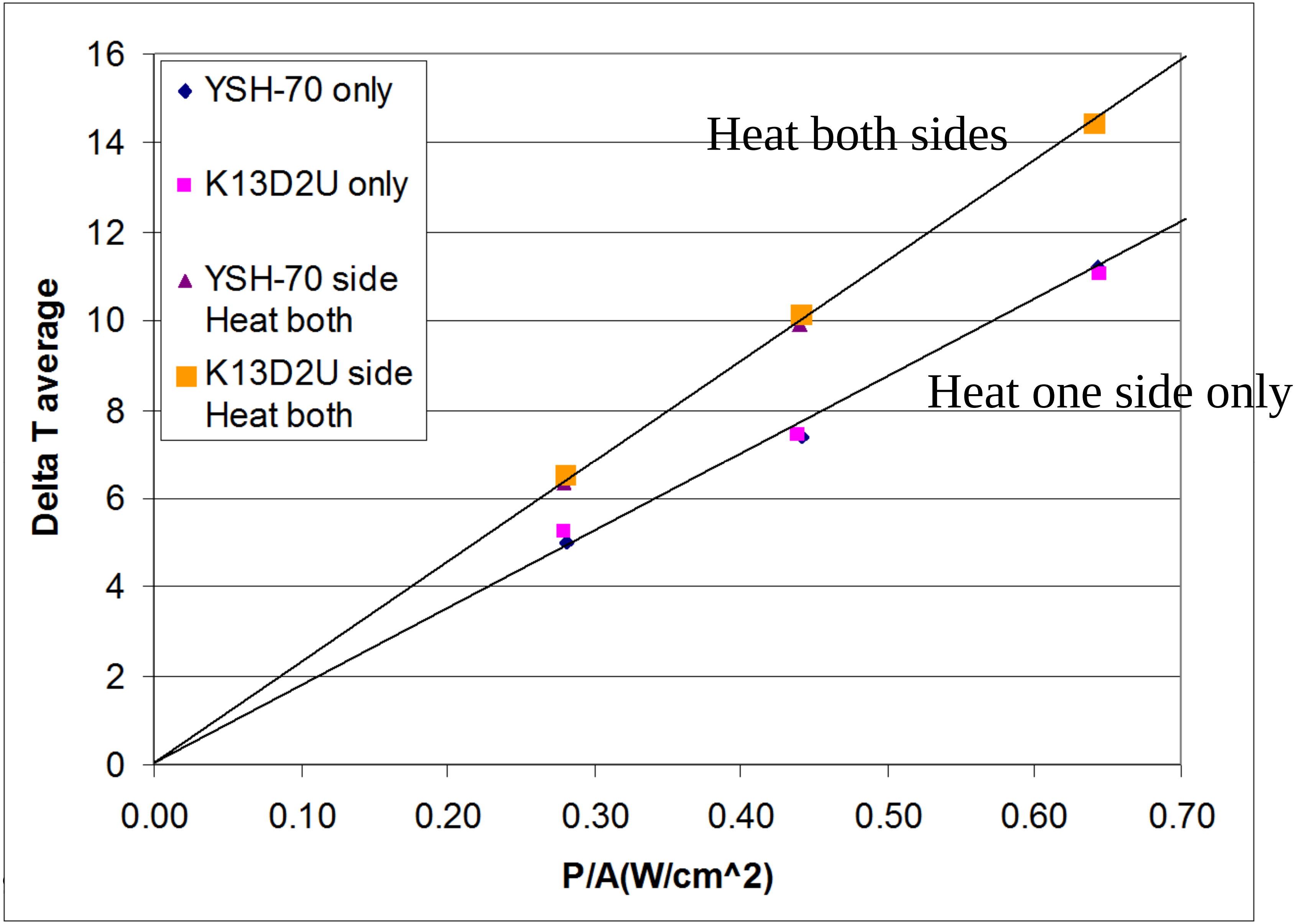






 Infrared image and water coolant at room temperature M. Gilchriese

Example Results



Comparison to Calculation

- Finite element analysis (FEA) estimates of thermal performance are essential overall design optimization.
- Example comparison shown below for 0.63 W/cm^2 double-sided heating (data on previous page) for foam with K=6 W/m-K. In reasonable agreement with results.

			Temperature differentials		
	Silicon surface	35.49	YSH50 Side		
	77	35.379	0.111	silicon	
	8	34.309	1.07	SE4445 Adhesive	
	1	33.073	1.236	YSH70 Facing	
	76	32.891	0.182	YSH70 Facing Adhesive	
	33	23.303	9.588	Foam Delta	
	78	20.893	2.41	Al tube adhesive	
	34	20.831	0.062	Al tube	
	coolant	20.25	0.581	Convective film	
	45	20.84	0.59	Convective film	
	48	20.894	0.054	Al tube	
	82	23.381	2.487	Al tube adhesive	
	37	32.872	9.491	Foam Delta	
	79	33.054	0.182	K13D2U adhesive	
	50	34.562	1.508	K13D2U facing	
	69	35.631	1.069	SE4445 Adhesive	
	Silicon Surface	35.725	0.094	silicon	
			K13D2U side		

Simple Summary of Prototypes

20 cm

Foam	ρ(g/cc)	K(W/m-K)	ΔT@8.3W	ΔT_{ave}/Watt
Allcomp 1 (RVC)	0.18	~ 6 Measured	~ 10	~ 1.2
Allcomp 2 (RVC)	0.21	~8 Measured	~ 8.5	~ 1.0
POCO 1 (Graphitic)	0.09	~ 17(z) ~ 6(x-y) Vendor guess	~ 11	~ 1.3
POCO 2 (Graphitic)	0.13	Not known yet	~ 9	~ 1.1
Koppers (Graphitic)	0.21	~ 15? Extrapolation	~ 8	~ 1.0

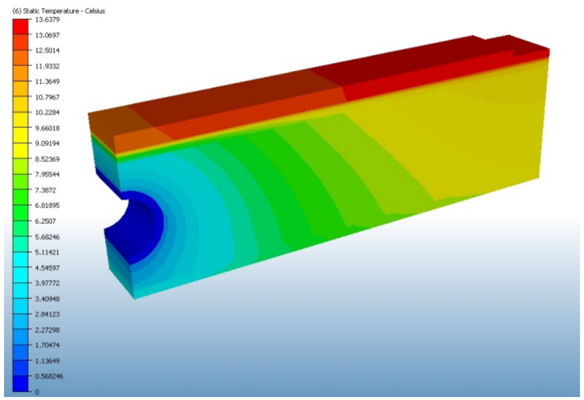
- Results are for single-sided heating. Same after thermal cycling from +25C to -30C (50 times)
- Results already improvement in ΔT_{ave}/Watt compared to existing ATLAS barrel structures (1.5-2)

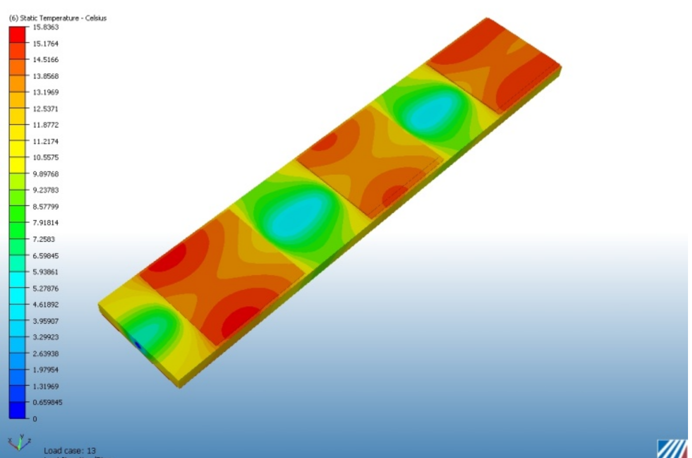
Near-Term Plans

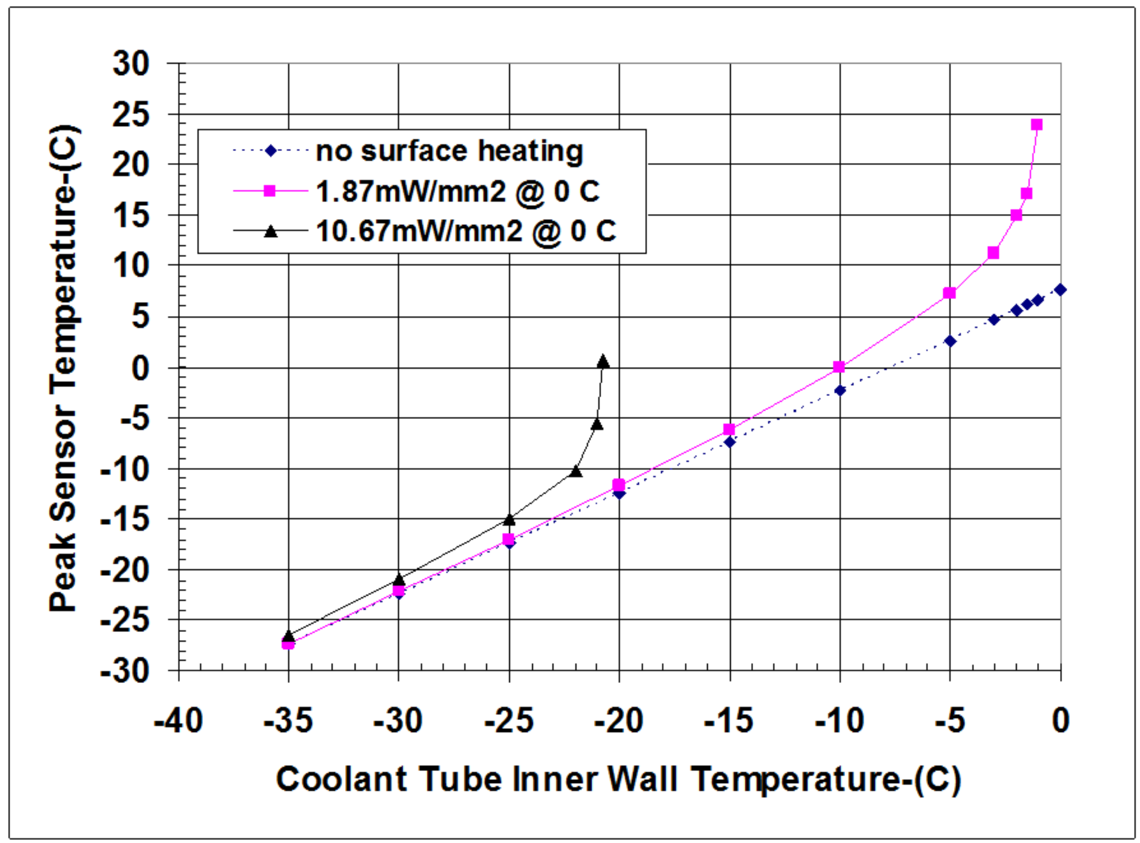
- Additional foam candidates (RVC-based) have been made with higher K (~ 17 for $\rho \sim 0.17$ g/cc) and small prototype is being made to compare with previous results.
- Planning to make 1-m scale prototype(s) over next few months with this foam candidate.
- Additional foam candidates being made, primarily RVC-based but also graphitic foams.
- Mechanical properties of foams, including the high density graphitic foam, are not well known. Program underway to measure moduli and strengths so that reliable mechanical modeling can be done.
- Principal mechanical issue is thermally induced stress resulting from cooldown

Design Optimization

- Extensive FEA work underway to understand optimal thermal design, taking into account not only steady-state power but also silicon detector thermal runaway (exponential dependence of leakage current => self-heating that can lead to runaway)

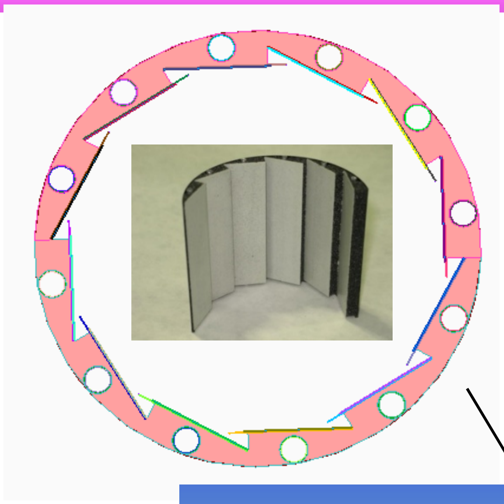


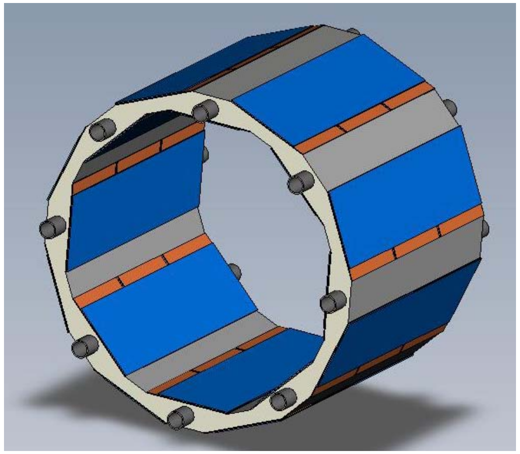


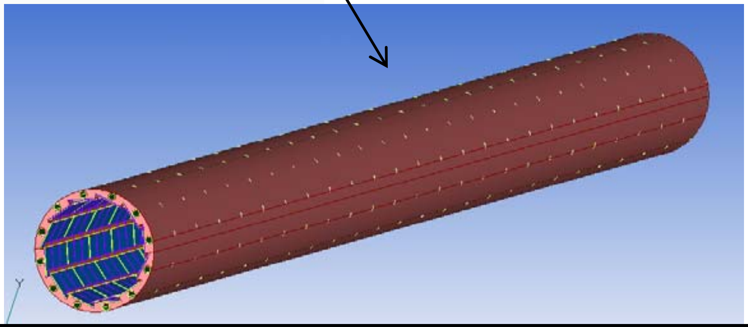


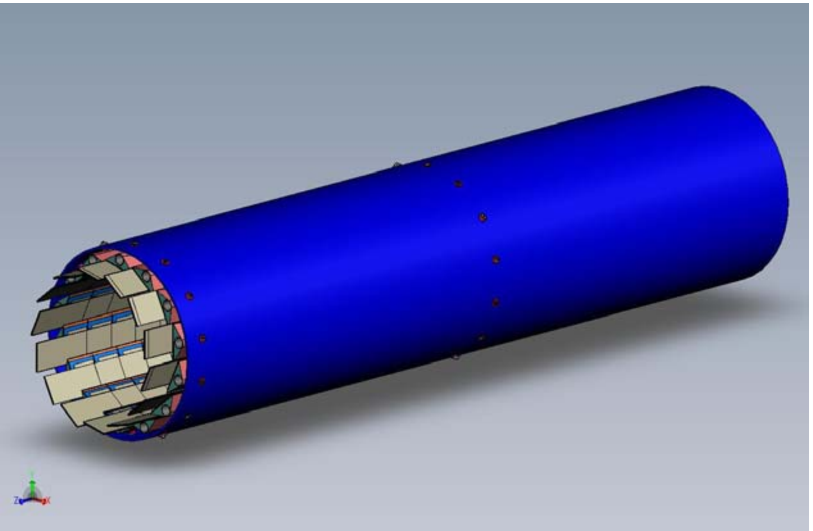
Pixel Upgrade Inner Layers - Examples

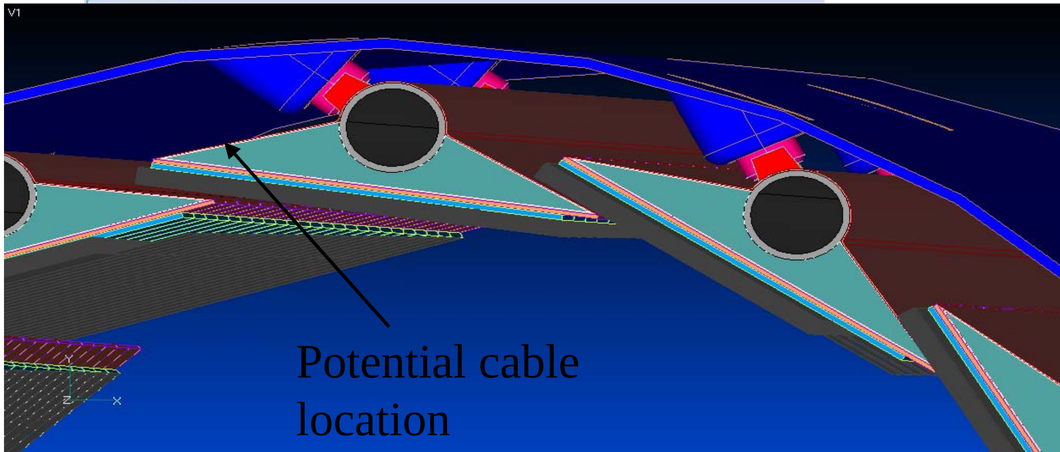
- Monolithic structures
  - R ~ 4 cm only
  - Modules one side
  - Modules alternate sides
- Single-sided staves
  - R ~ 4 cm
  - R ~ 10 cm
- Single-chip modules(e.g. 3D)





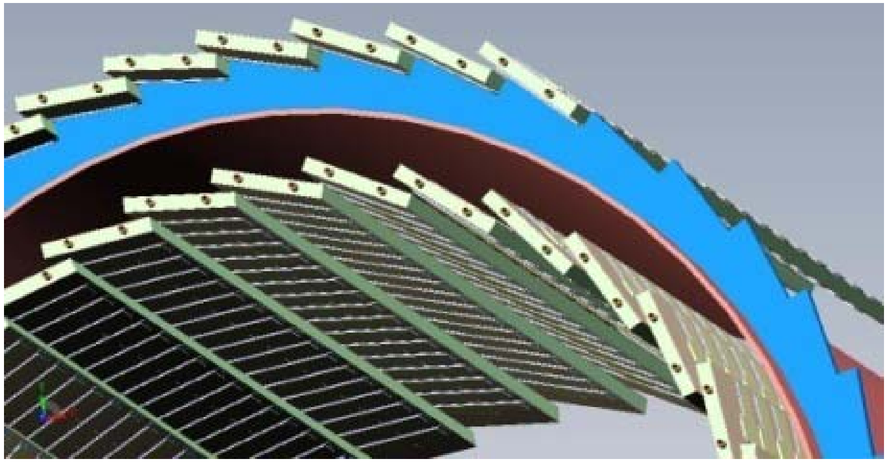


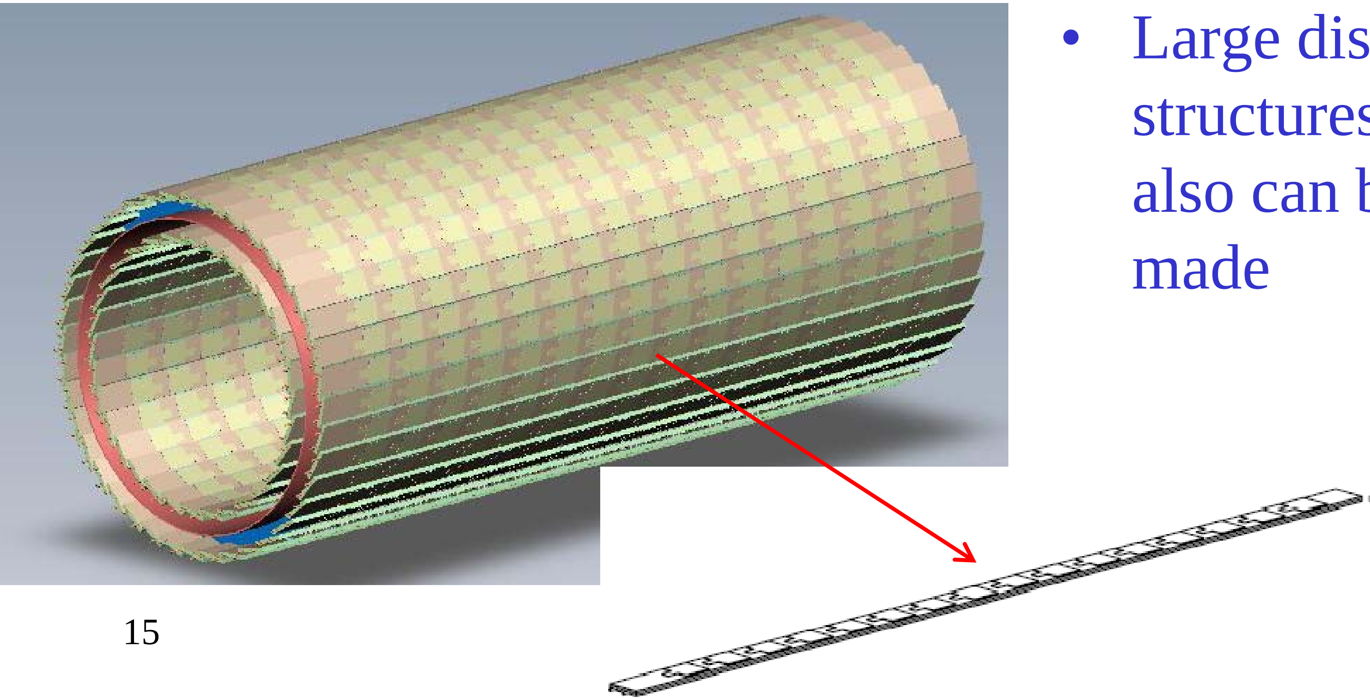




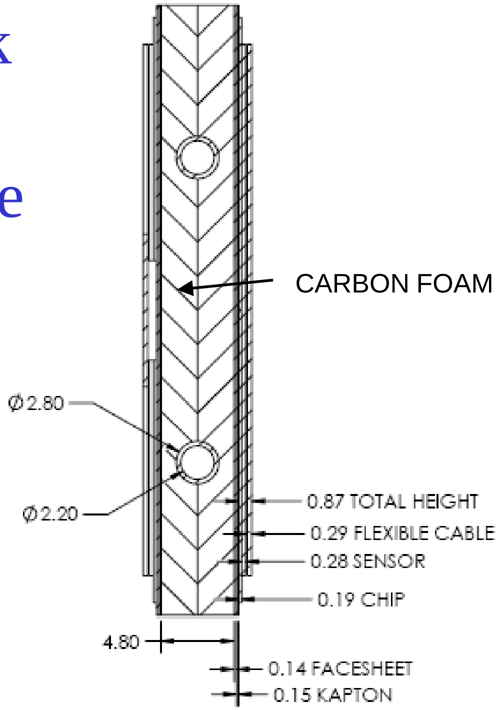
Outer Layers - Example

- Meter-scale staves
- Modules on both sides
- Staggered for coverage
- Large area, simple, fast and cheaper for larger R pixels



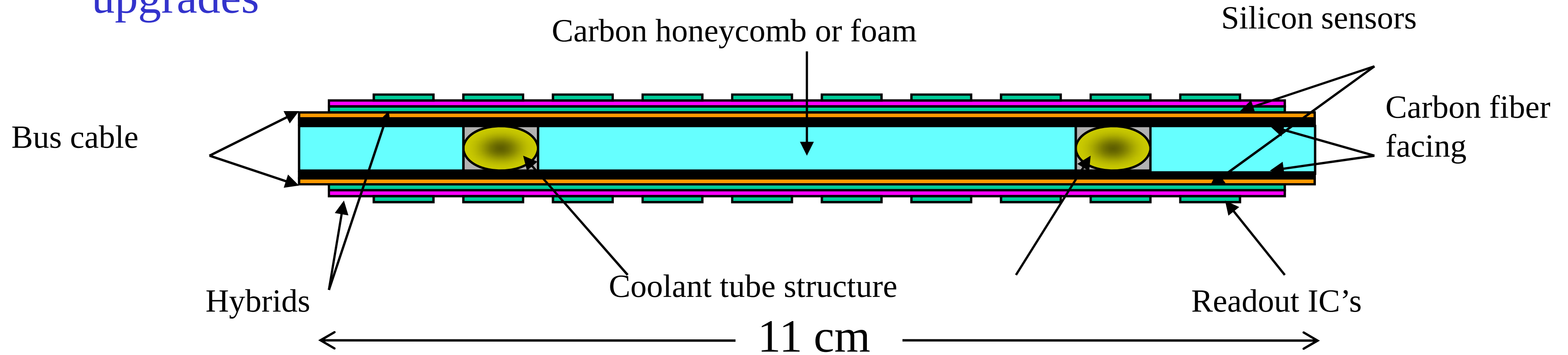


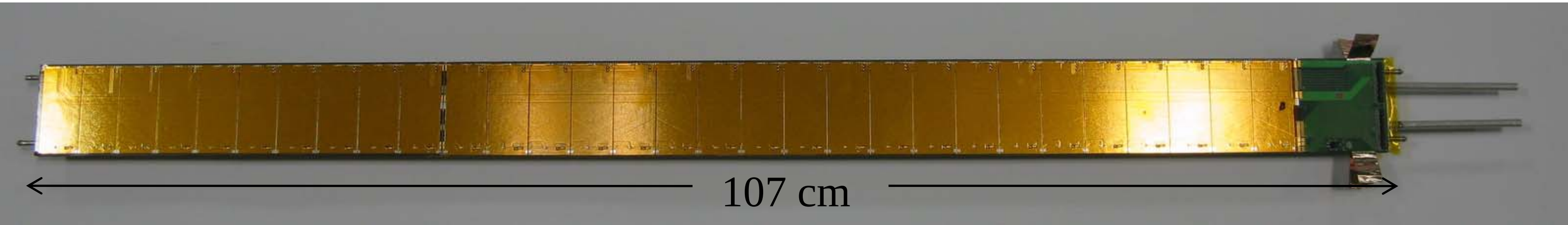
- Large disk structures also can be made



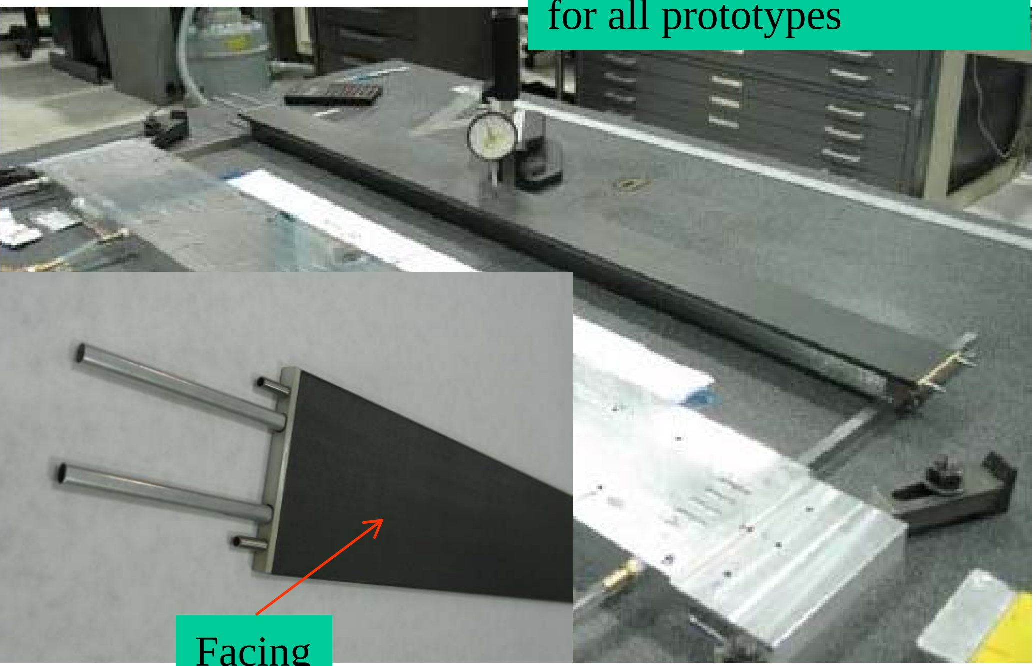
Non – Pixel Applications

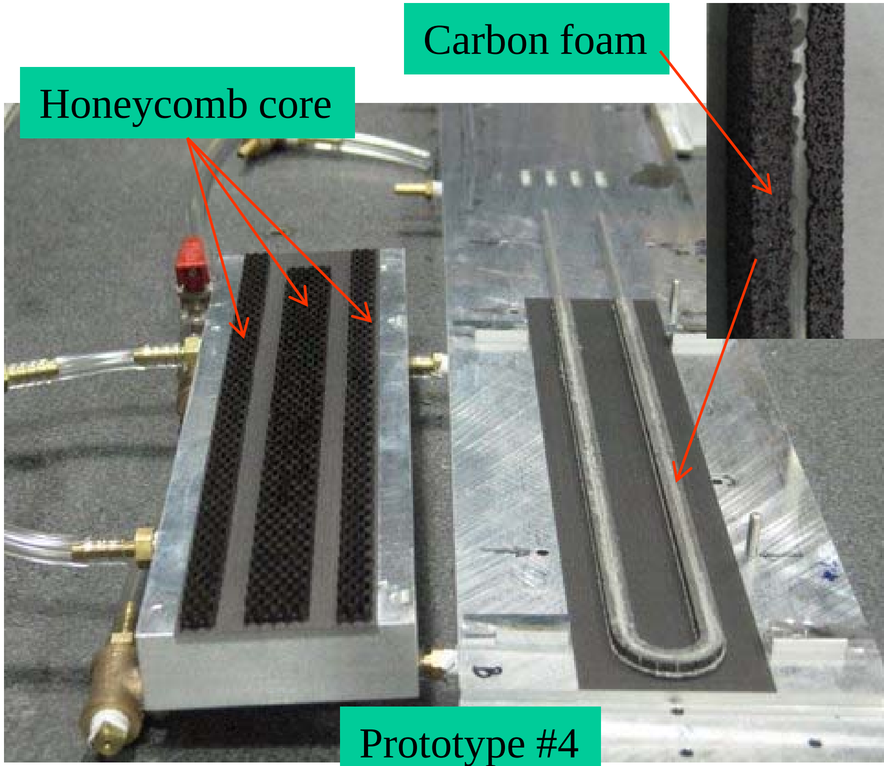
- We have also designed and made prototypes over the last two years for “local supports” for silicon strip detectors, also for potential use in LHC upgrades.
- In this case, the power density is lower than for pixels and we have so far chosen to use conventional graphitic foam($\rho \sim 0.5$ g/cc) along with low-density honeycomb. Using all foam is option if better thermal performance is needed.
- Additional prototype fabrication and design is now underway with BNL, Yale and Valencia and a variant of this concept is under consideration for STAR upgrades





Prototype Construction





Summary and Outlook

- The use of carbon foam in mechanical/cooling structures for future silicon pixel and silicon strip detectors is a promising approach to improving thermal performance and to meet mechanical stability and radiation length goals.
- Relative simple fabrication, can be applied to ALL regions of upgraded pixel detector.
- The development of low-density, thermally conducting carbon foams is underway with encouraging results and small prototypes with such foams have been made and tested successfully.
- Full-size pixel prototypes will be made and tested over the next six months.
- Design and analysis for future implementation of structures based on carbon foam is underway to help guide the R&D.