Phase 2 silicon pixel-strip thermal mock-up module: building and testing

- *The pixel-strip module*
- *A realistic thermal mock-up*
- *Simulation and data results*
- *Conclusions & Outlook*

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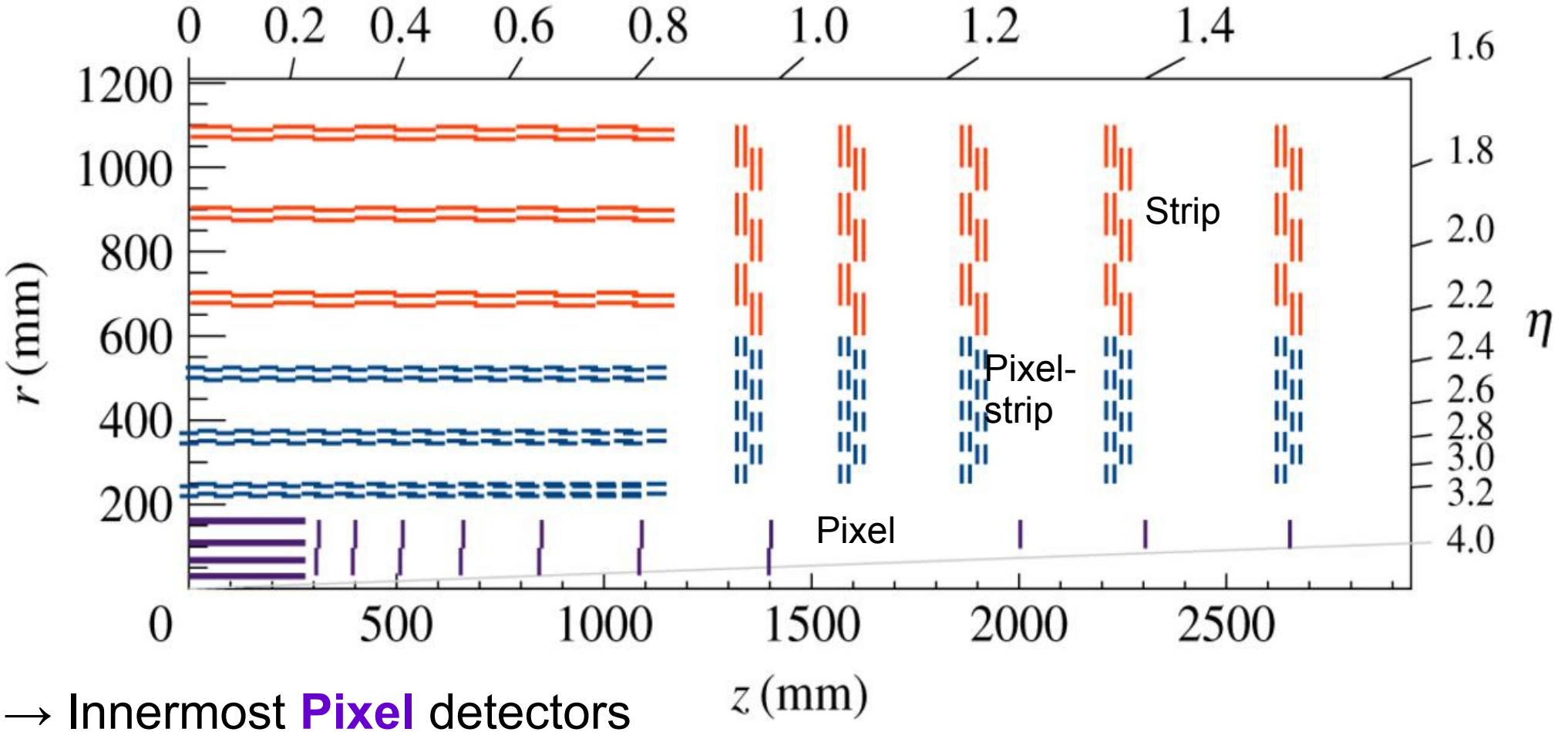
HL-LHC:Silicon detector upgrades

- Rebuild silicon detector for high luminosity running of the LHC
  - Less dead material, higher “granularity” & improve resolution by ~1.5



→ Innermost **Pixel** detectors

→ **Pixel-strip** and outermost **Strip-strip** detectors with intrinsic trigger capabilities at low p_T

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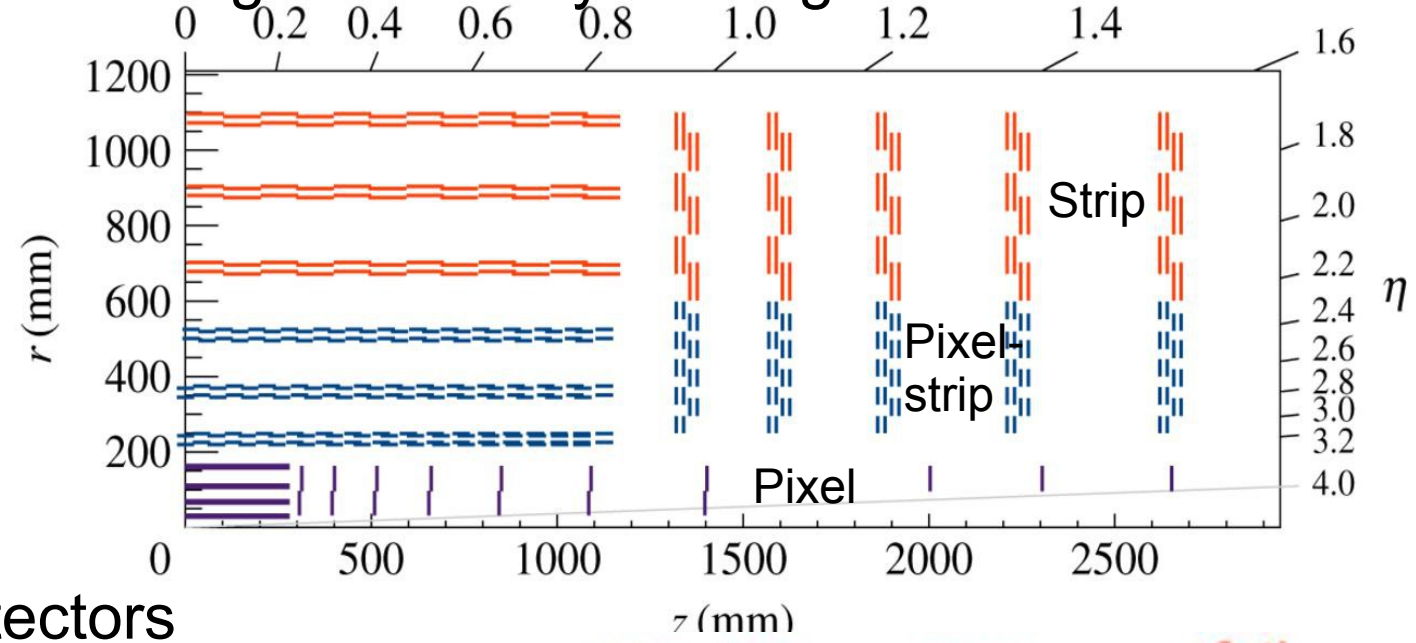

→ Innermost **Pixel** detectors

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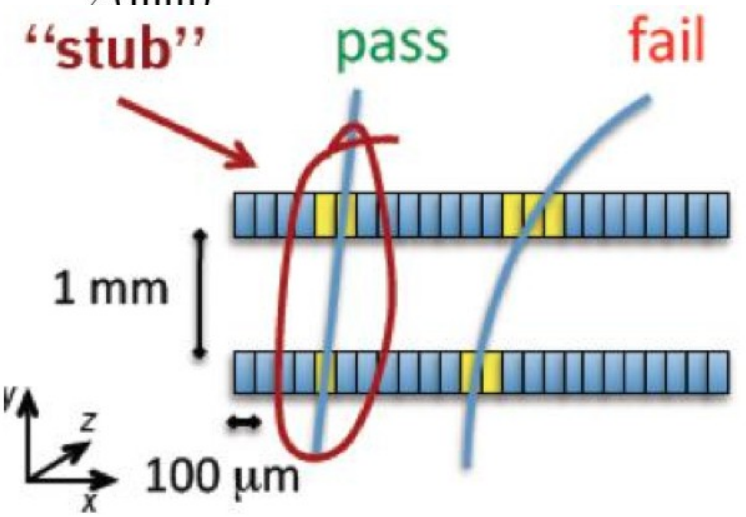
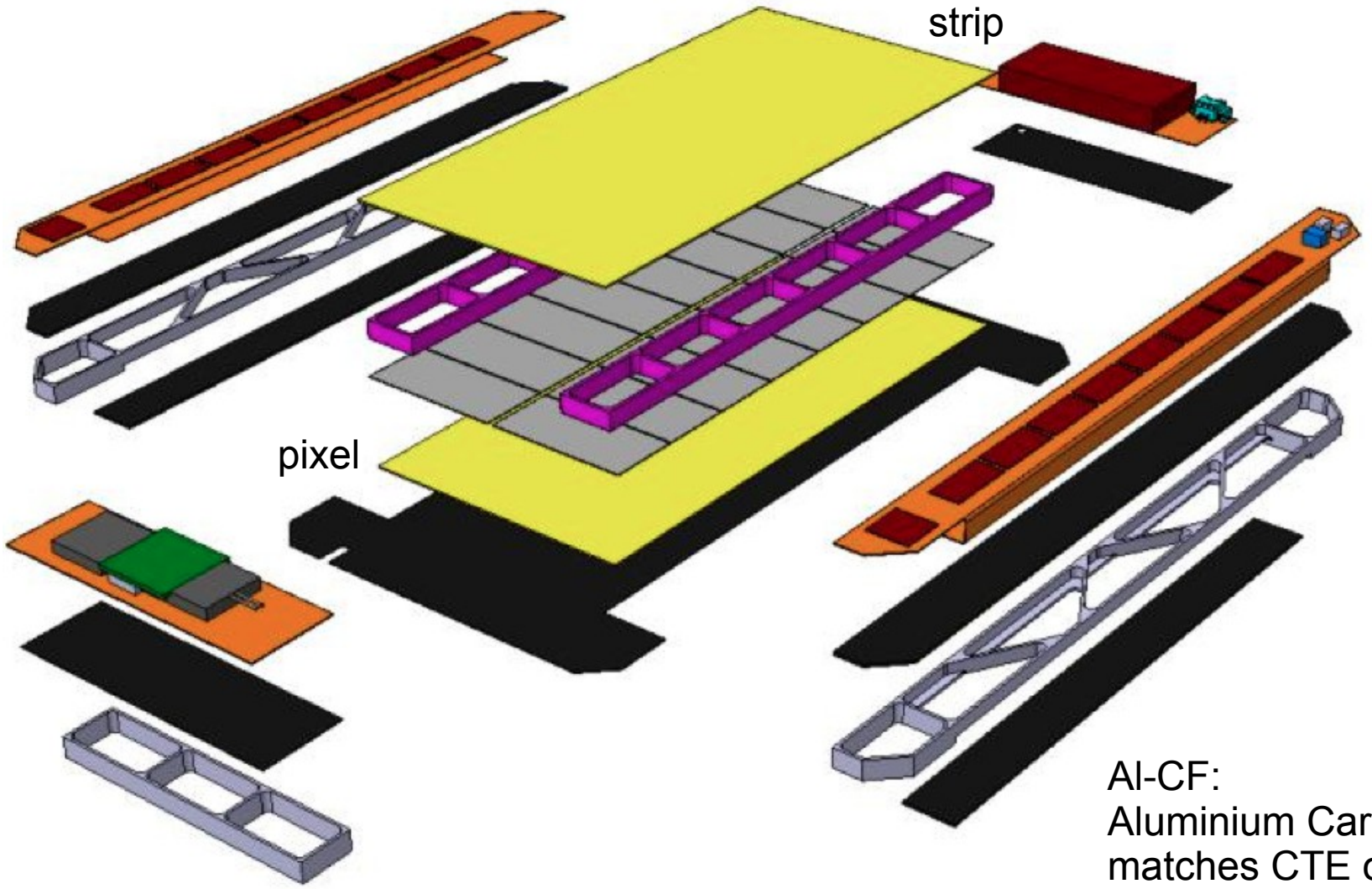


Add track info to trigger system:

- Allows track trigger at L1
- Can apply isolation to control trigger rates, etc.

Pixel-strip module (PS)



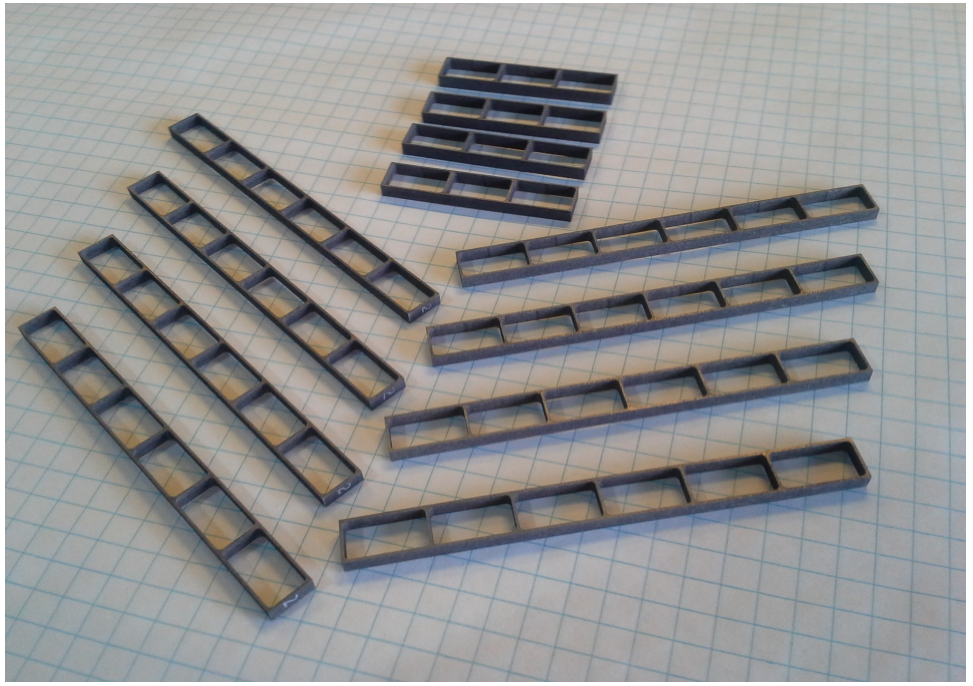
Al-CF:
Aluminium Carbon Fibre
matches CTE of silicon

Pixel-strip prototype to answer:

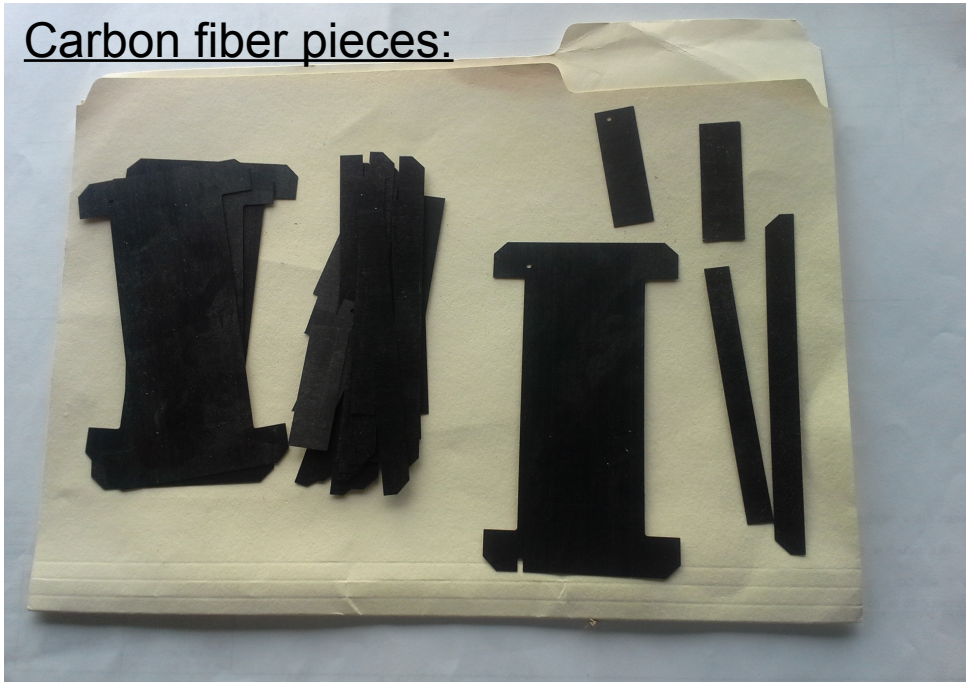
- Cooled from bottom – thin walled Al-CF structures – **sufficient** ?
- Complex module – test assembly ?

Module prototype

- Al-CF (Metgraf 4-230) has comparable CTE to silicon
  - Carbon fibers are randomly oriented in a plane
  - Test both orientations in terms of thermal performance
  - Machined with wire EDM
    - Precision of first test pieces: 100 μm



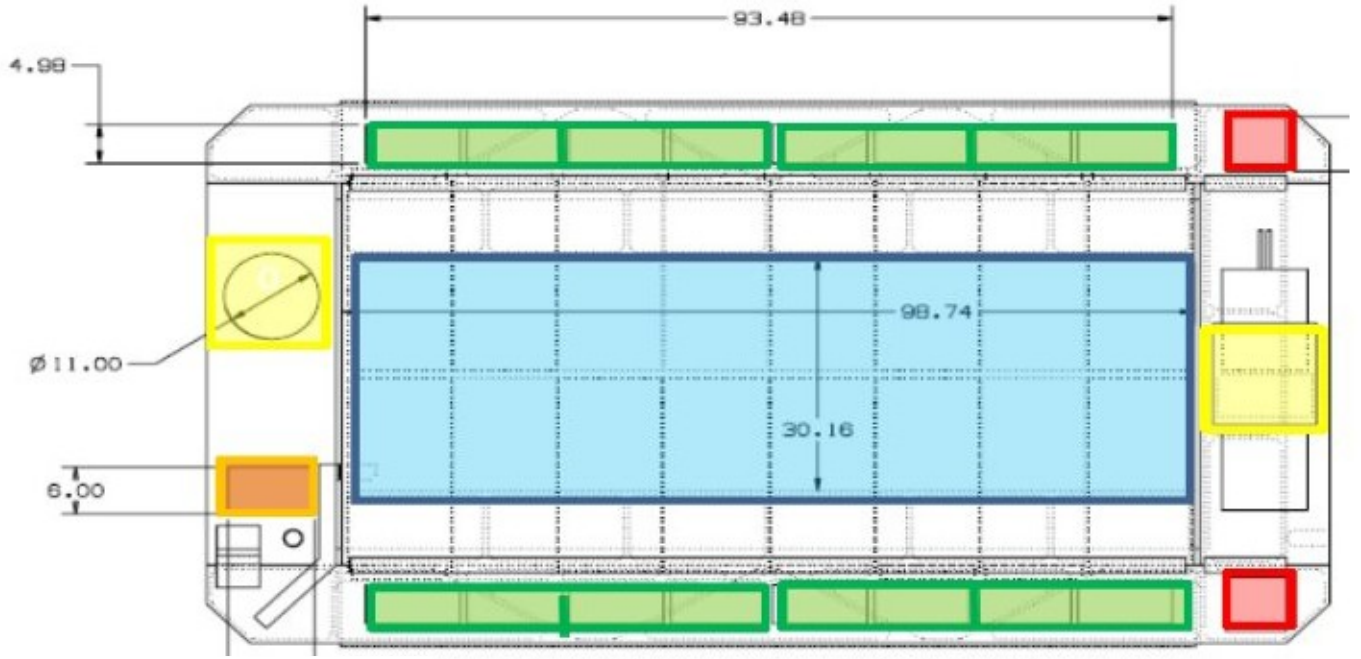
Carbon fiber pieces:



Realistic PS module heat loads

Heat source	"CERN"	"FNAL"
• 16 Pixel readout chips:	3 W	3 W
• 16 Strip readout chips:	0.5 W	0.5 W
• GBT:	0.5 W	0.8 W
• 2 Concentrator:	0.4 W	0.4 W
• DC-DC converter:	2 W	1.2+0.8 W
• Optical drivers:	0.3 W	added to GBT
• 2 Leakage current:	1.0 W	1.0 W
Total ("Nominal" or "1":	7.7 W	7.7 W

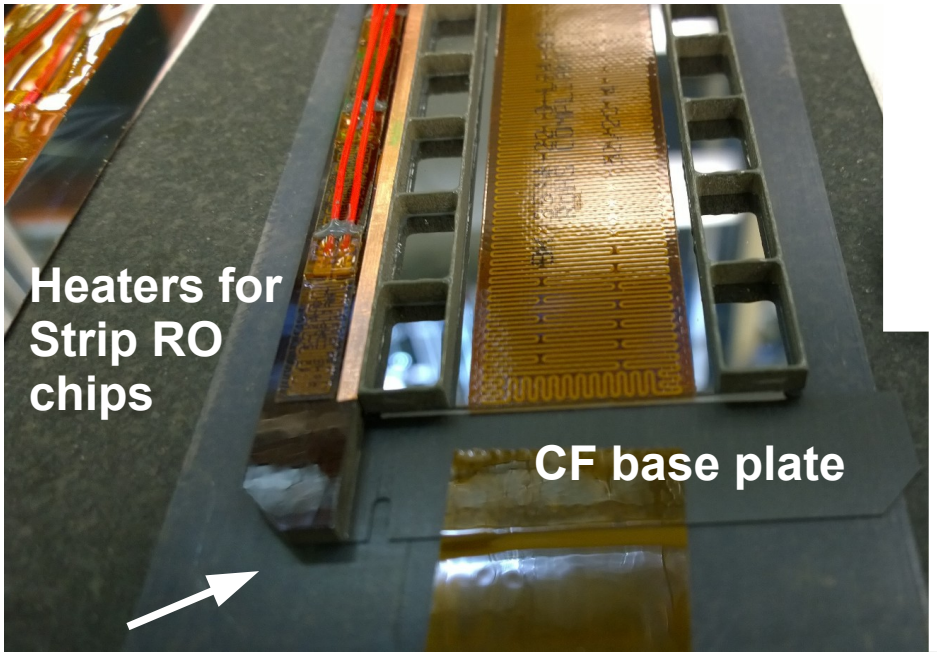
Remarks: Leakage currents corresponds to end of life conditions

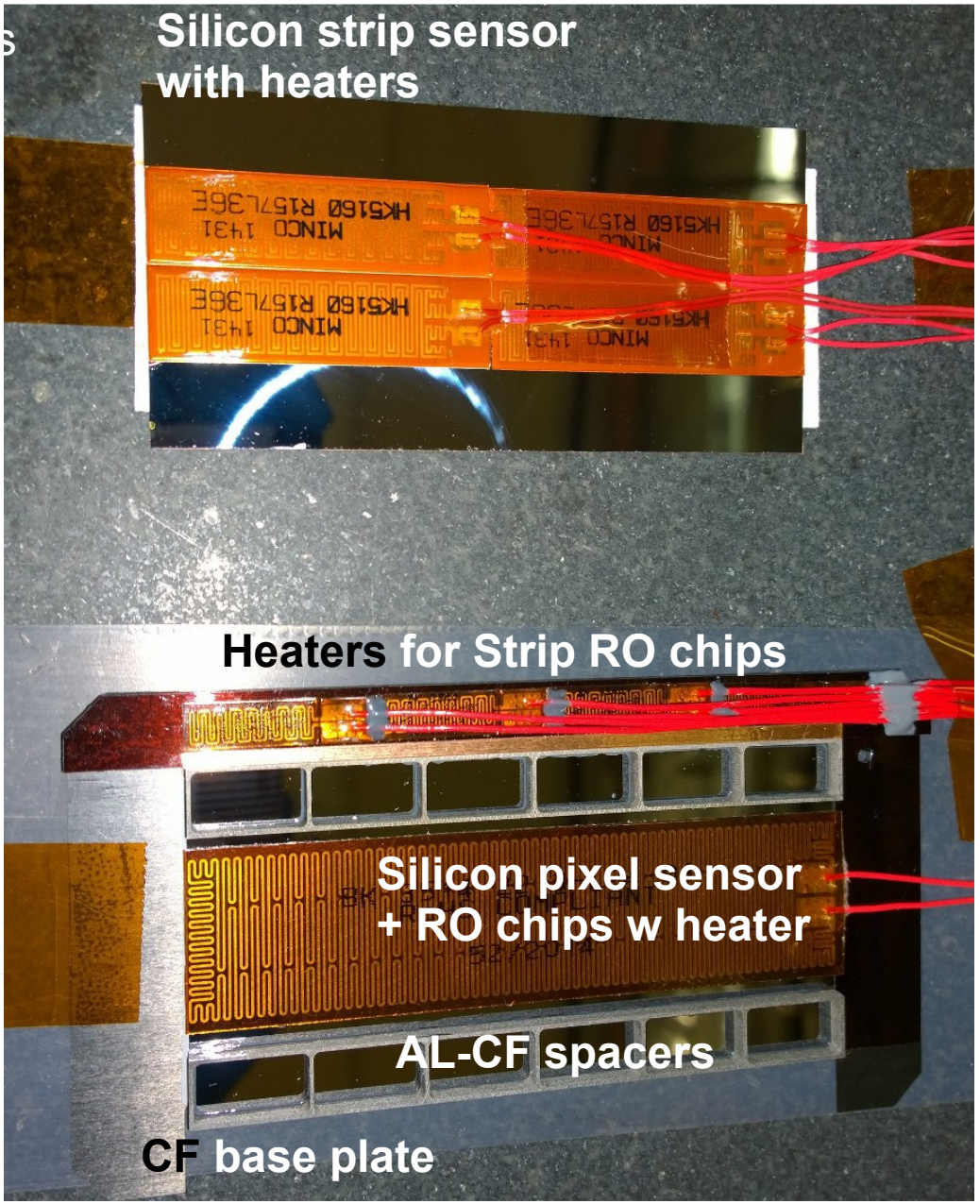


Pixel-strip prototype

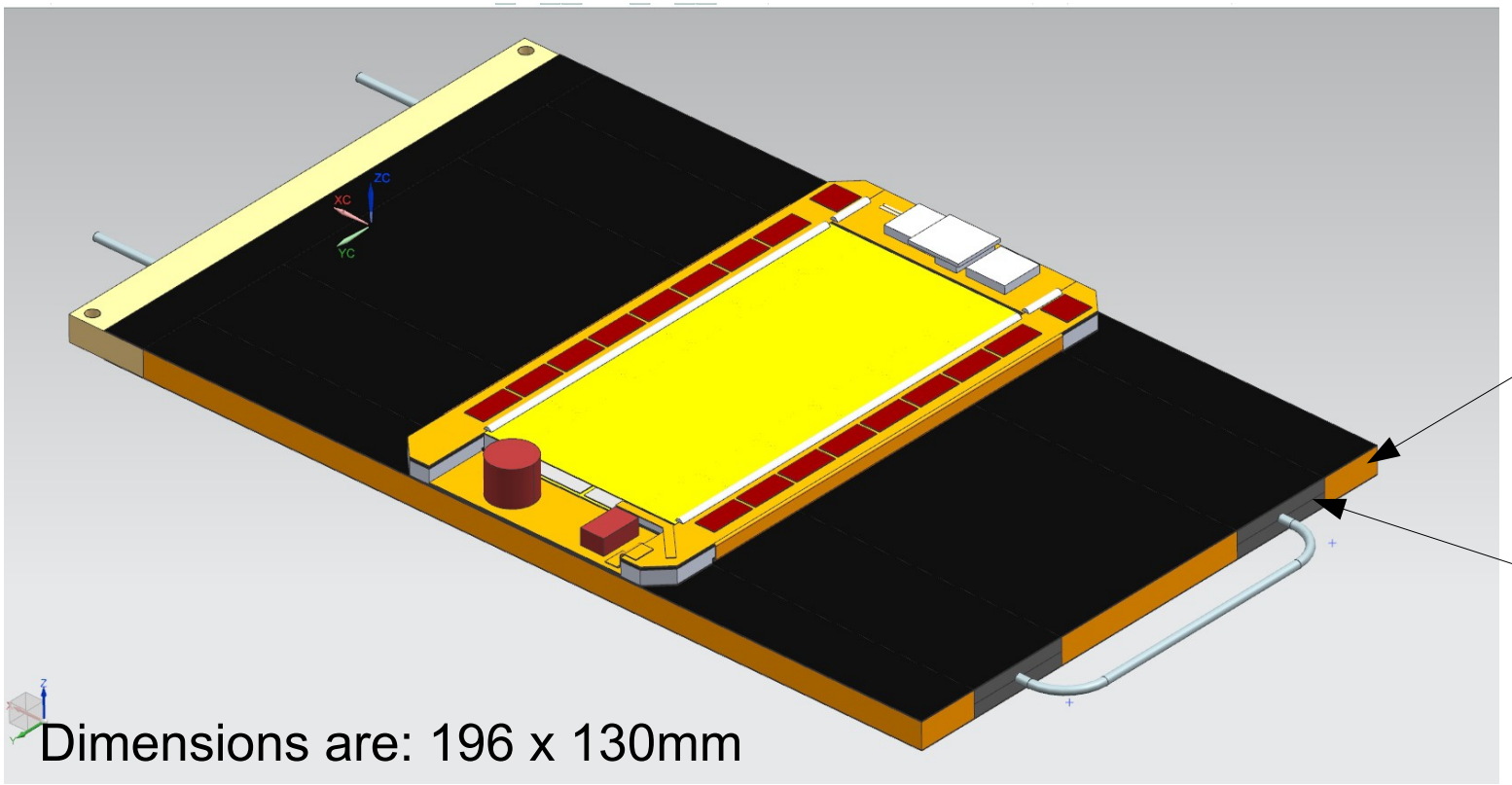
Complex Pixel-Strip assemply:

- Using Al-CF (good CTE in x-y plane)
- Carbon f ber (3 layers, total is 200 μm)
- Raw silicon (2-side polished, 200 μm)
- Added ~880 wire-bonds (reality: 1000)





PS module & support structure

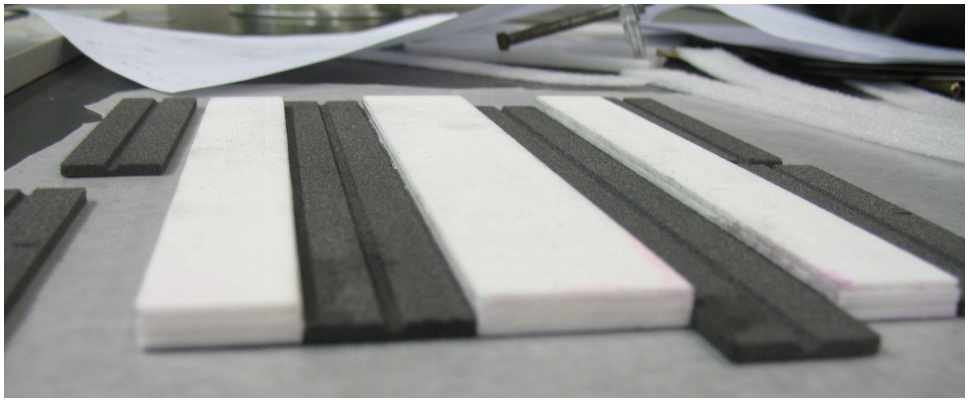


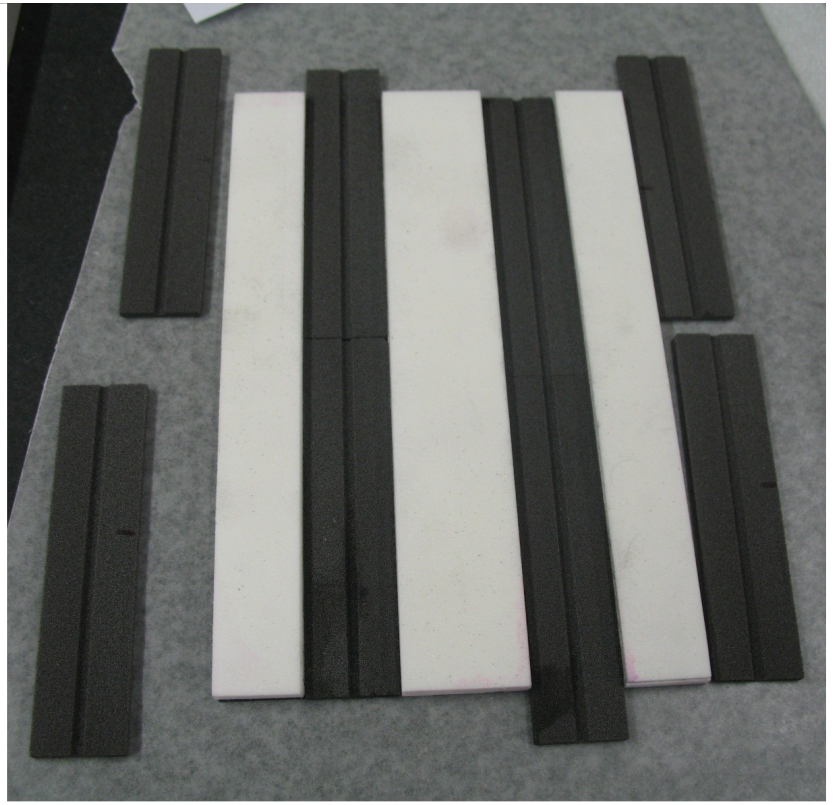
Custom built support (rod) structure:

- Based on Carbon foam, Rohacell, Carbon fibre sheet
- 3.2mm pipes w TC5022 (1st iteration)
  - Future rod will use smaller pipe diameter & Carbon hex-cell or Airex foam since Rohacell is not radiation hard
- PS module mounted with “re-workable” Laird film

Rod support structure

- Small rod structure to test PS mock-up module
  → 130 x 200 mm size

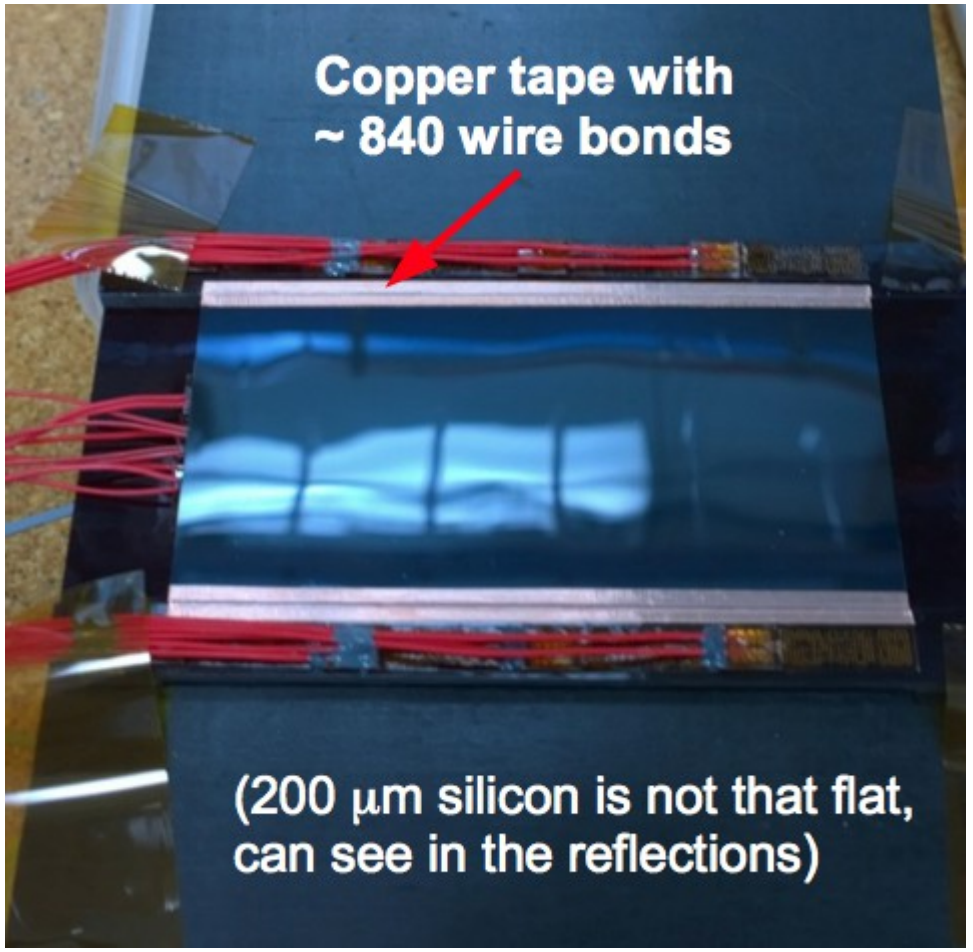




Remarks:

- Carbon Fiber sheets are 200μm
- Stress relief for 3.2mm pipes
- For now used Rohacell, needs to replaced (not rad. hard)
- Carbon foam is 25mm wide:
  - Difficult to machine the grooves
  - Use TC5022 in grooves

Cross section through PS module



Materials used:

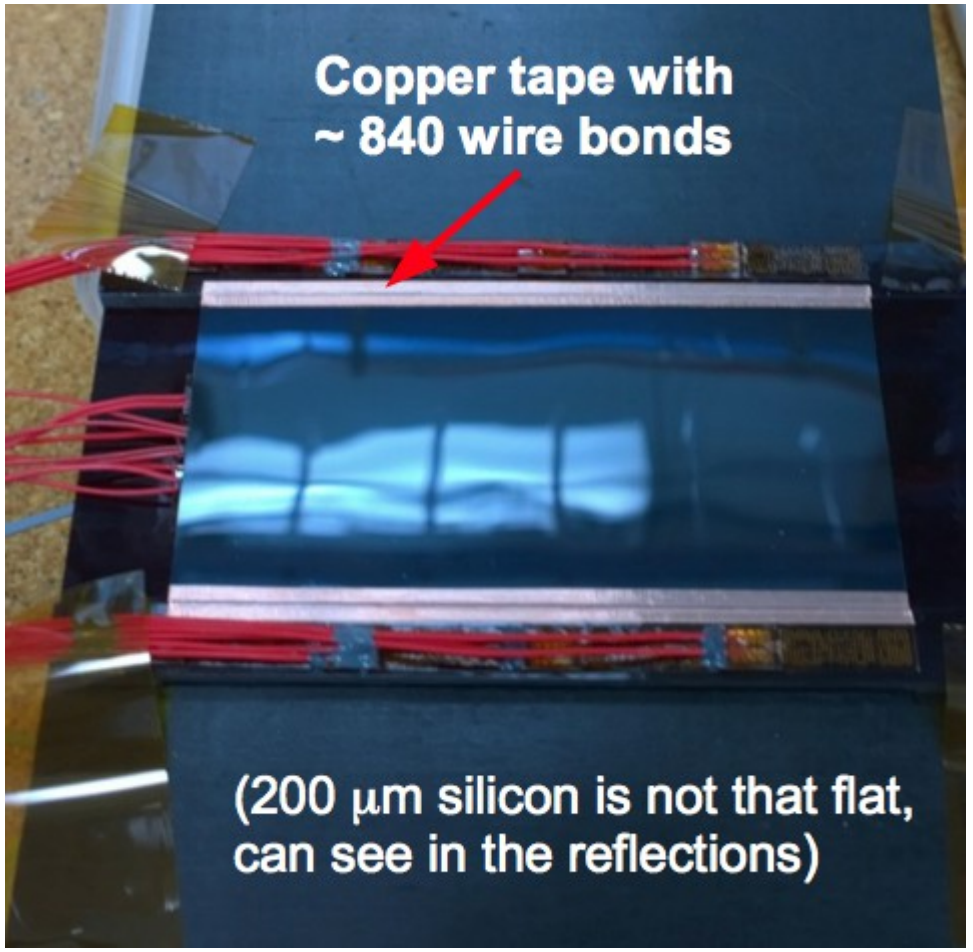
- CF sheets 4 layers, 200 mu thick
- Raw silicon, 200 mu thick
- Al-CF spacers
- Heaters
- Kapton representing Flex circuits
- 3mm self-adhesive copper tape

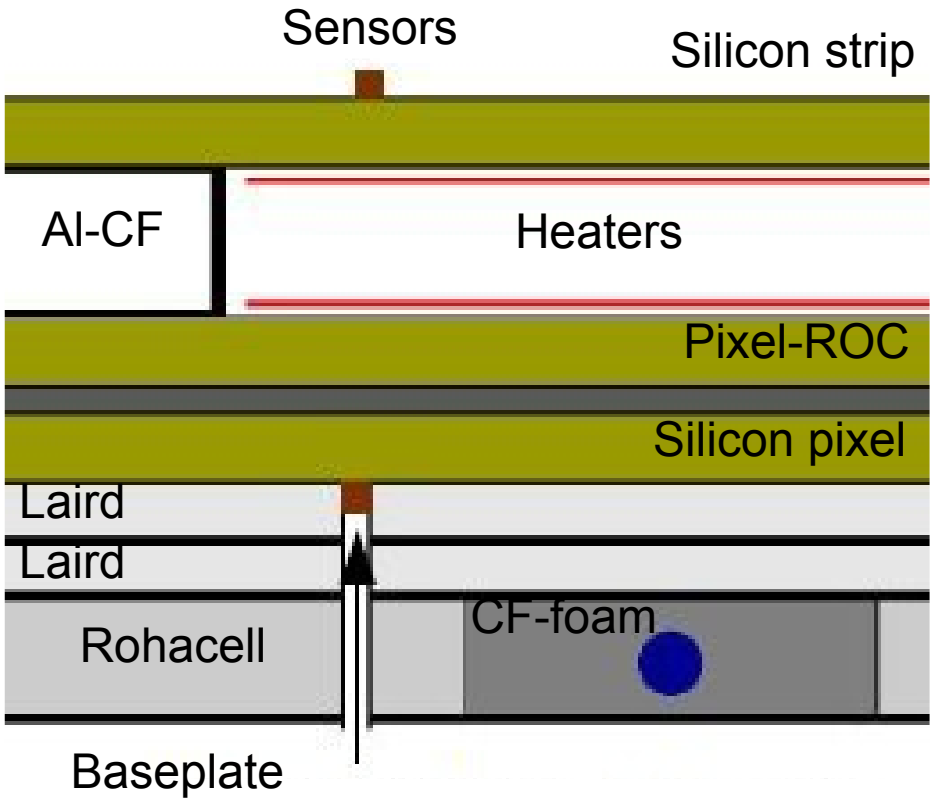
Assembly:

- Laird film between base plate and silicon Pixel sensor
- Silicon “RO chips” glued with “Alcad” to silicon “Pixel” layer
- Al-CF structures glued with Epoxy DP110 (or DP190)
- PS module to support structure: Laird film

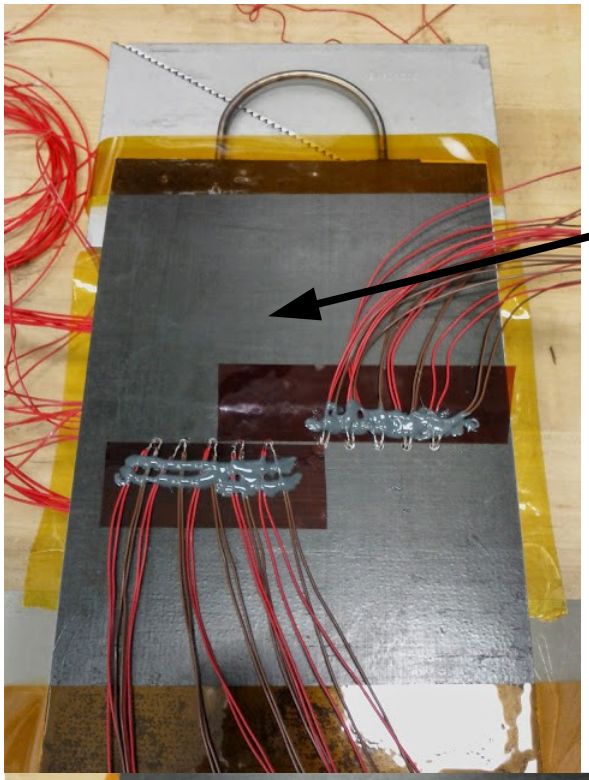
Cross section through PS module

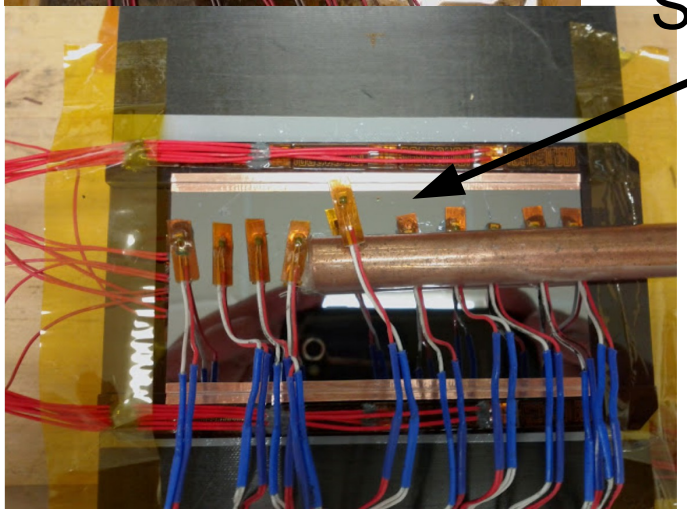
Cross section through entire “stack”:





Complete test structure

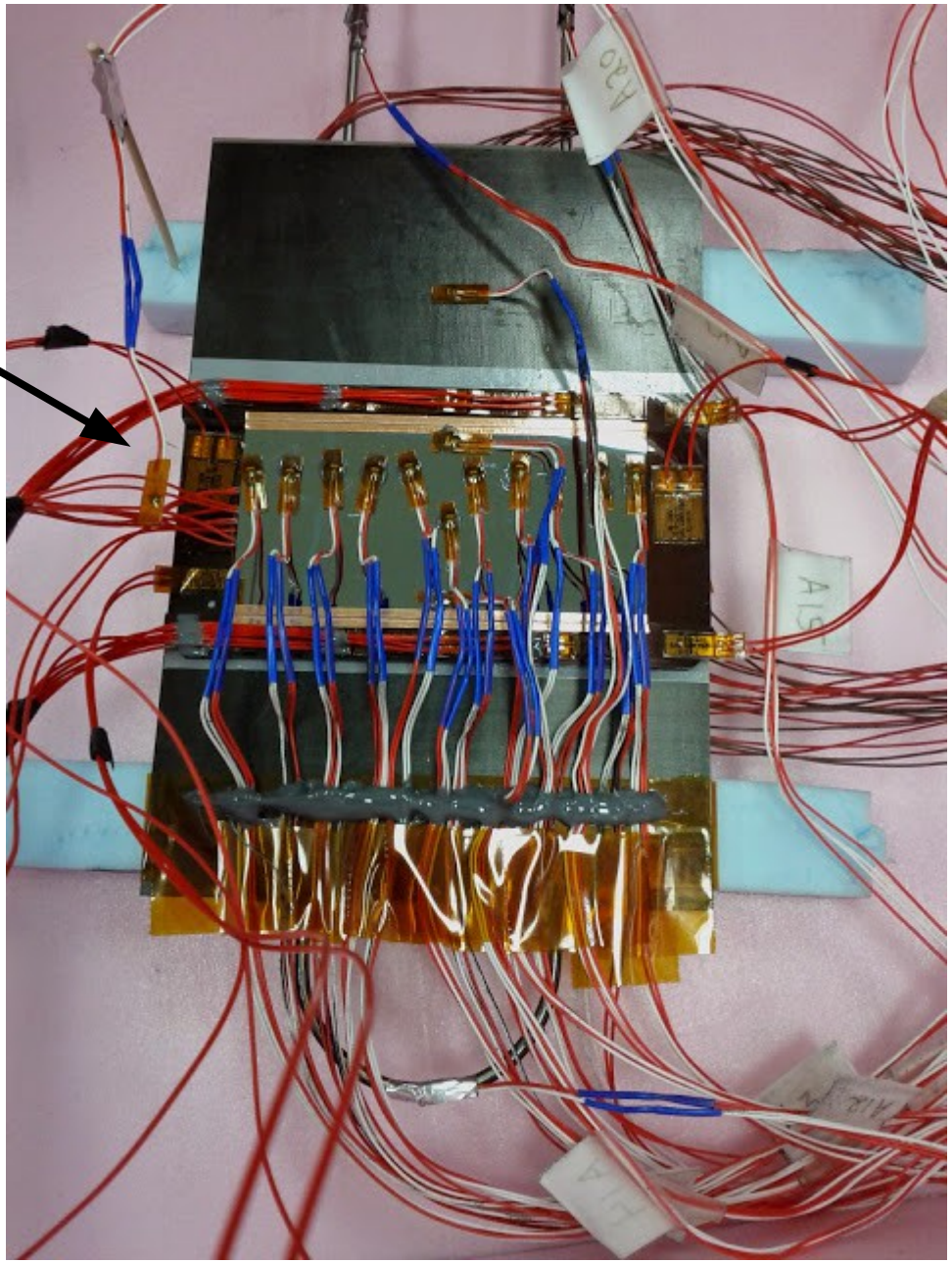




Bottom side
"Pixel holes"

Completed setup:
30 RTDs + 18 heaters

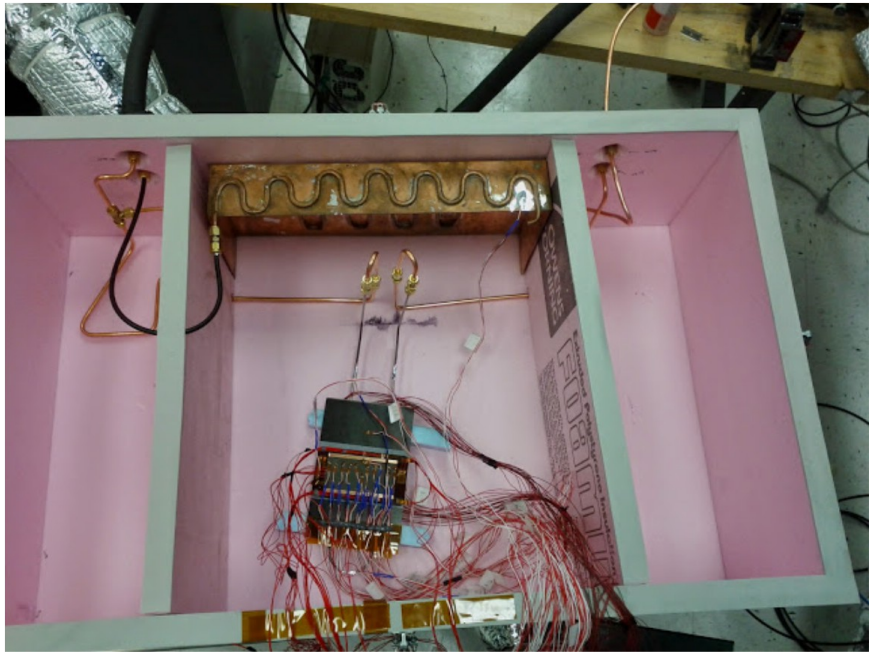
Putting down Top side RTDs "Strip"

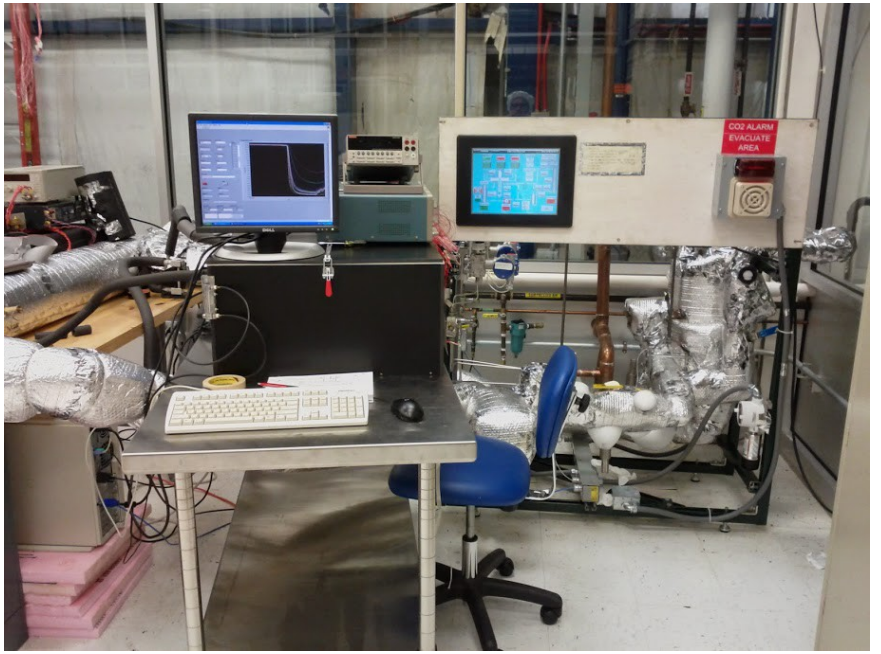


CO2 test setup

System modified for Phase II tests and FPIX production system:

- Existing setup allowed for large flows of 3.5g/s at 0.5 bar
  - But difficult to ensure 2-phase
  - Coolant is -20ºC – presented results are using this setup



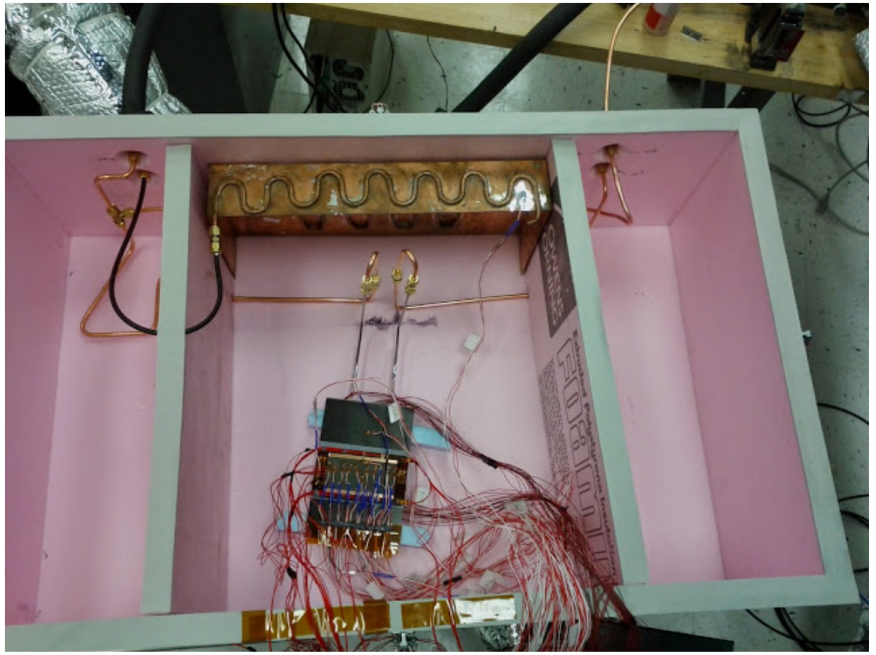


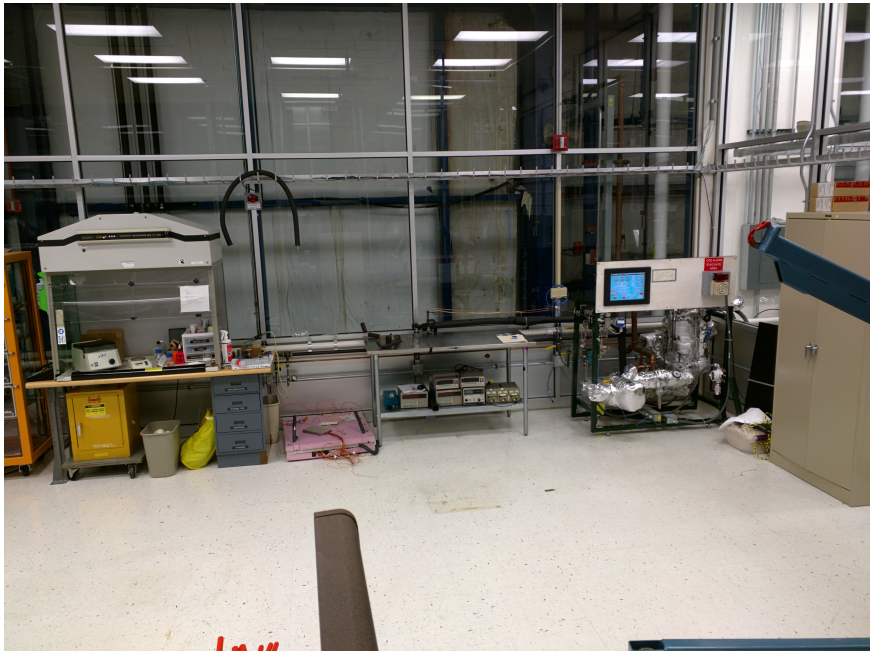
CO2 test setup

→ **Change rod pipe to 2.2mm → ensure 2-phase cooling**

System modified for Phase II tests and FPIX production system:

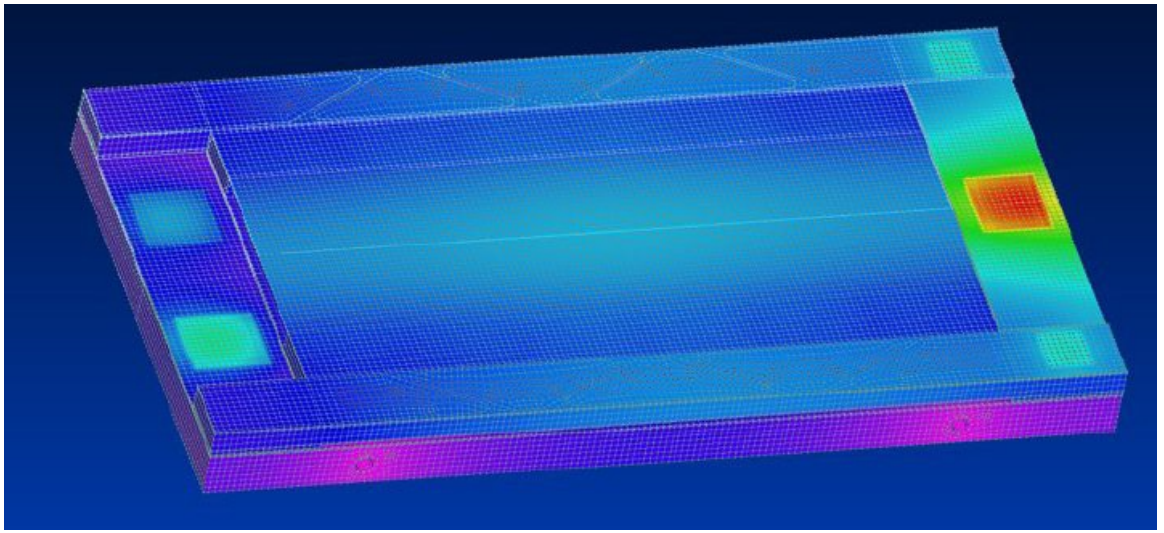
- Existing setup allowed for large flows of 3.5g/s at 0.5 bar
  - But difficult to ensure 2-phase
    → Modifications to existing CO2 test setup:
    - More space for at least 2 setups at same time
    - Allow higher pressure drops: Needed to connect similar test systems
    - Allows lower flows → **Can now ensure 2-phase cooling**

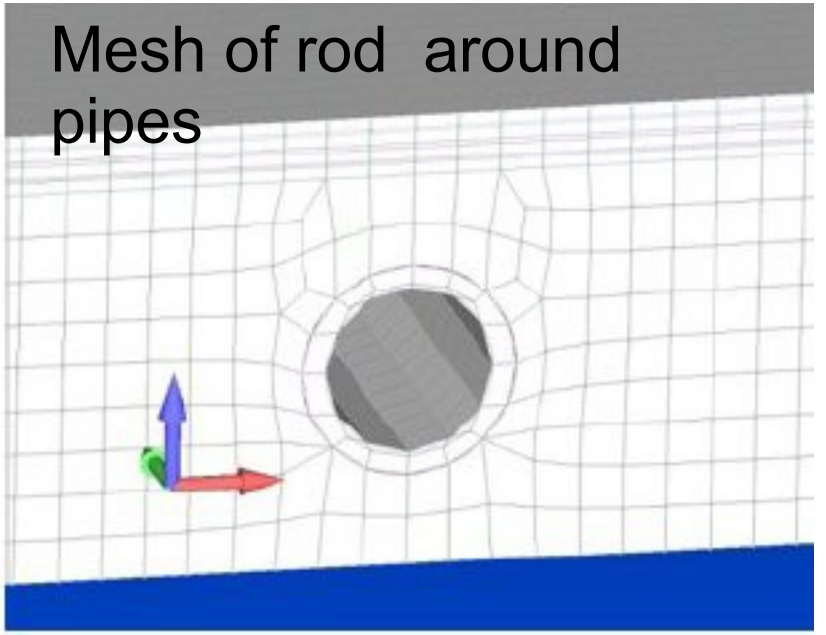




Simulations

- FEA model uses hexagons (bricks) instead of tetrahedrons (pyramids)
- Meshing is complex – use SolidWorks with slightly simplified structure
- Typically model half the module (symmetric along “long axis”)
  - In reality slightly asymmetric but very small effect
- Inside of pipes is held at -20 ºC
- **Most of the losses at epoxy joints !**





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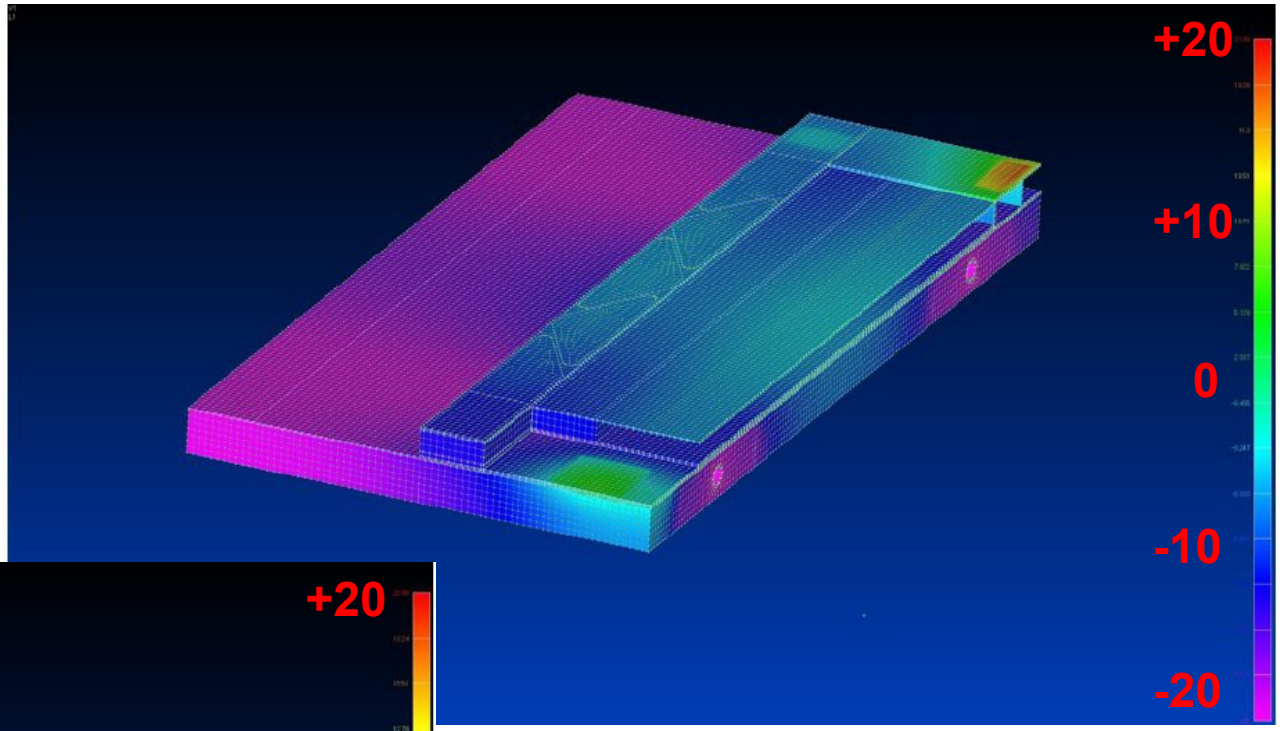
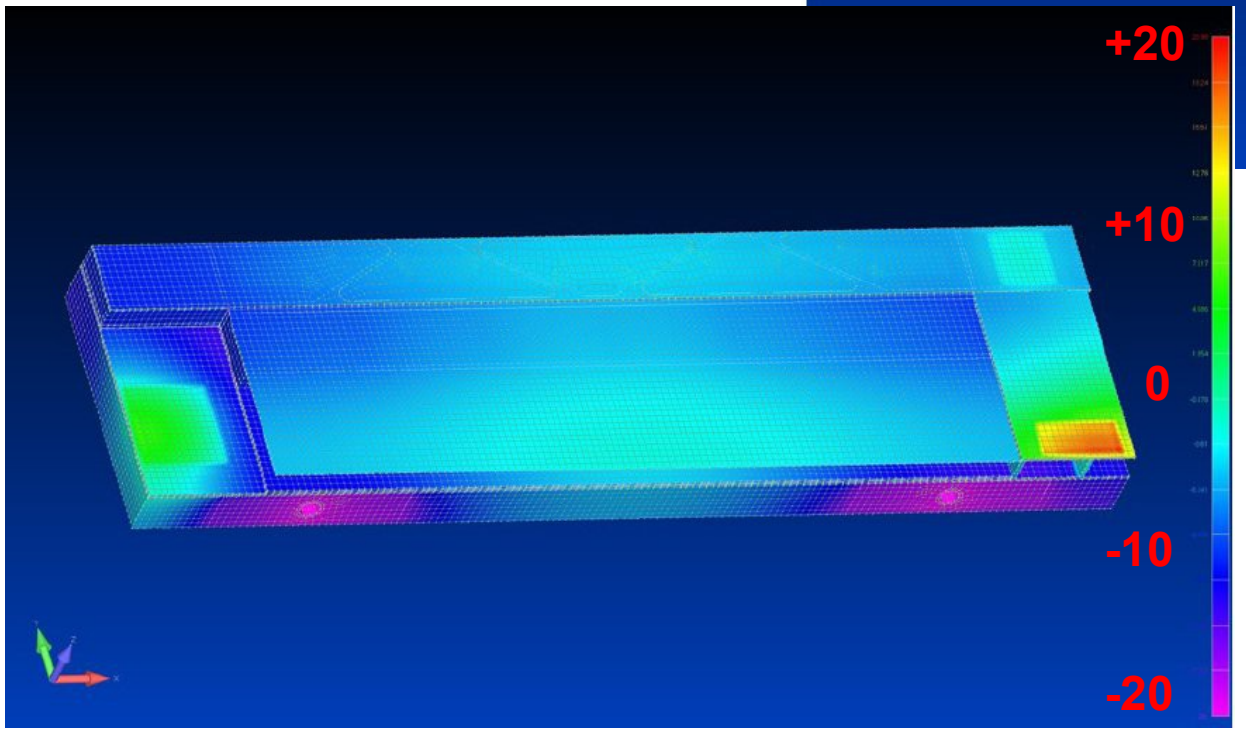
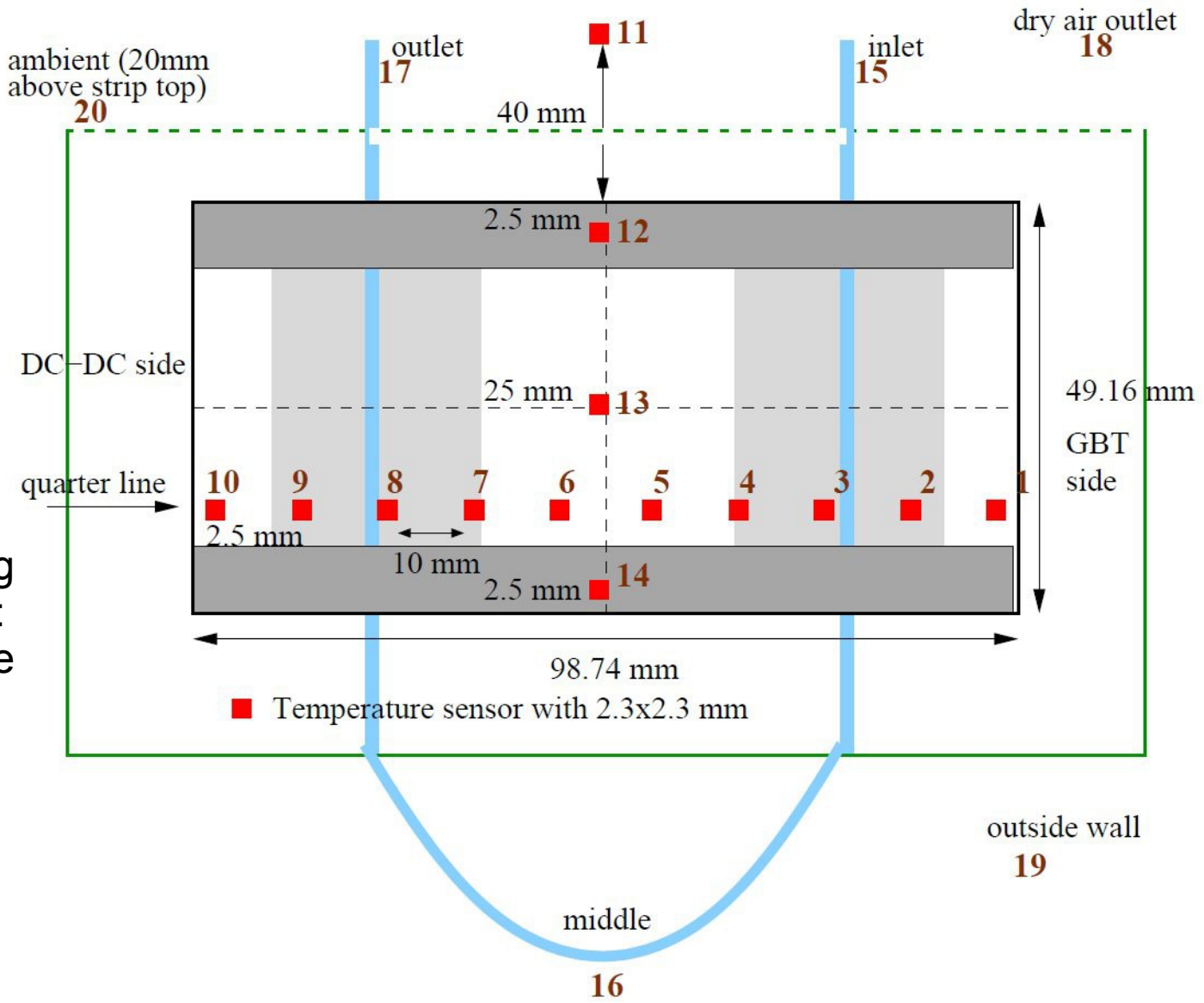




Sensor equipment

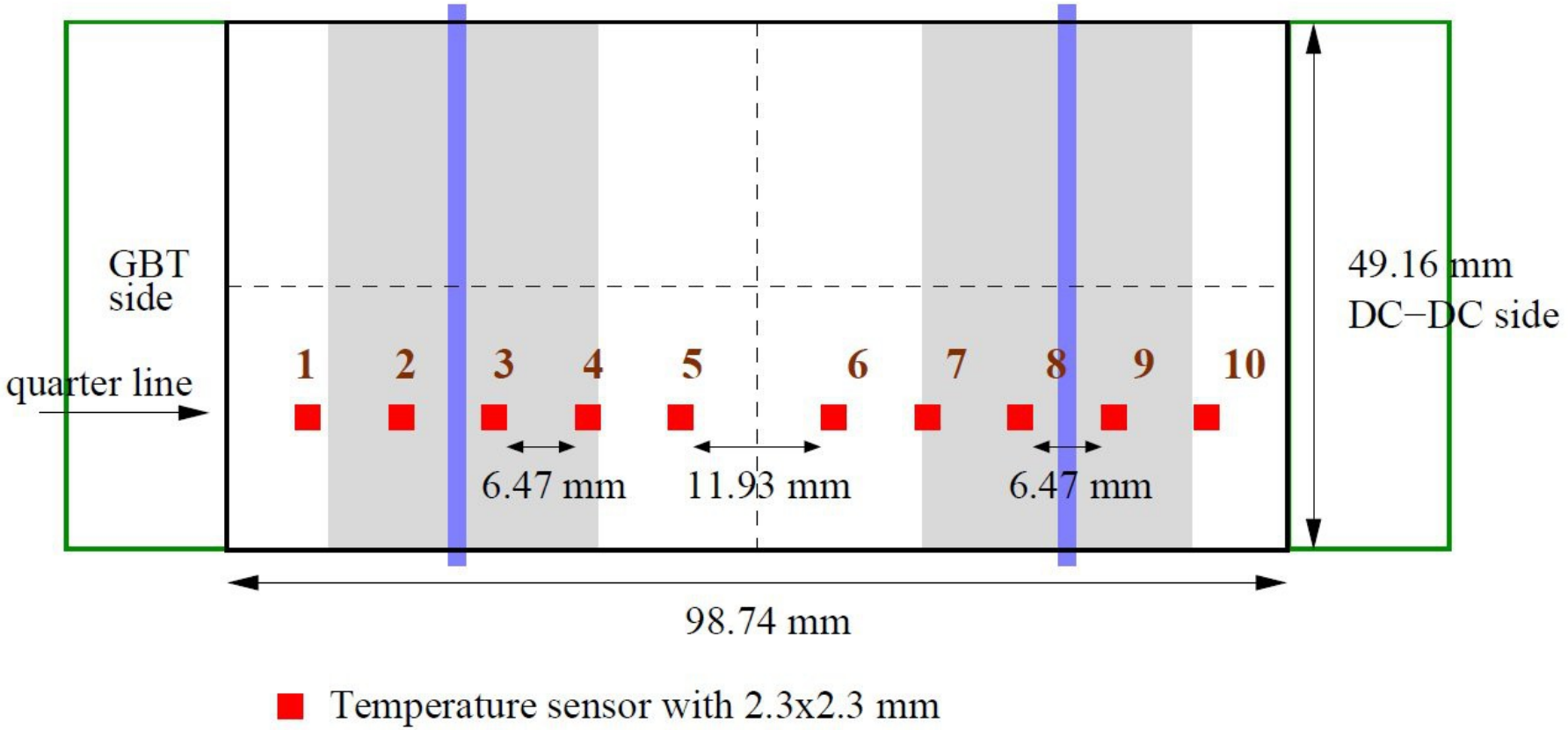
Strip−sensor (top side):



Sensor spacing on quarter line: 10mm, first one at 2.5mm

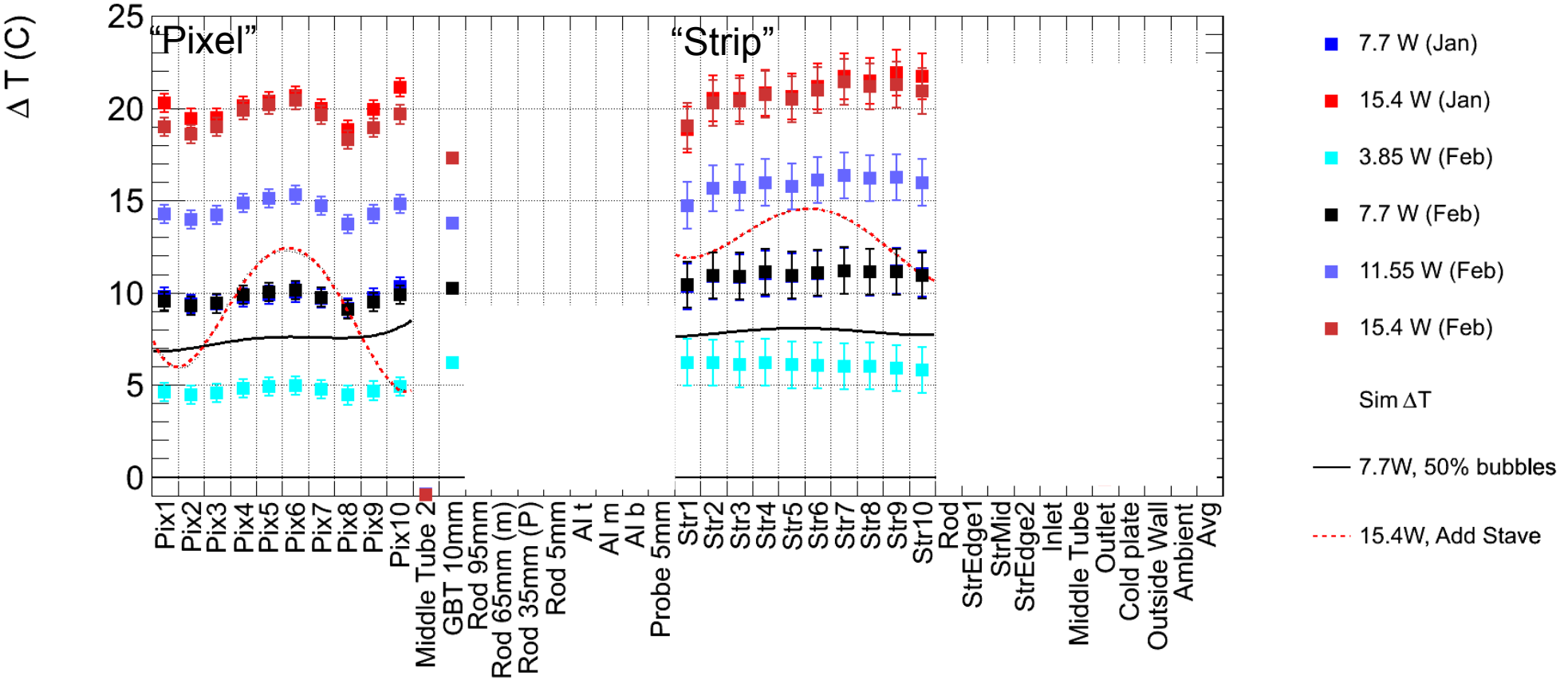
Sensor equipment

Pixel−sensor (bottom side):



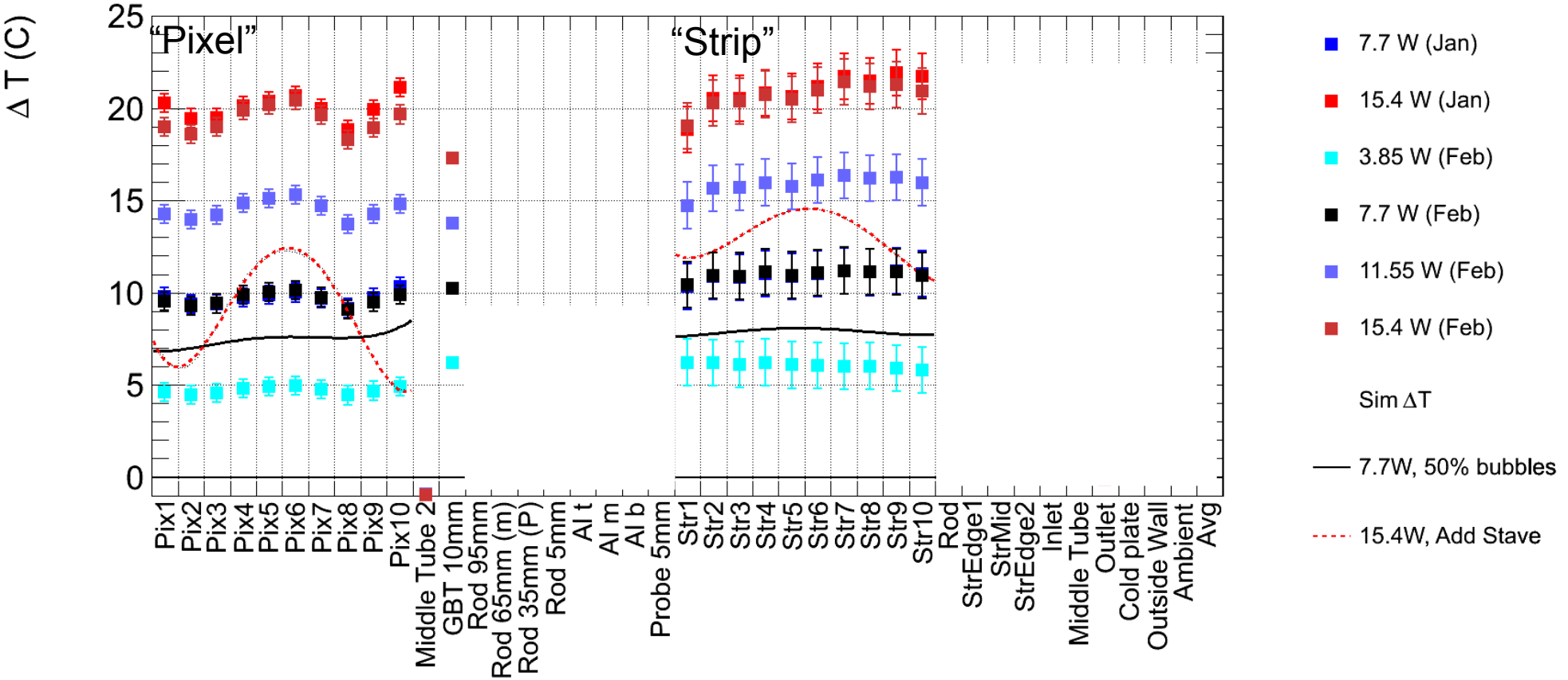
Sensor spacing
on quarter line:
8.5 mm, first one
at 7.5mm

Data results & simulations



- **Observed 10ºC ΔT is according to specifications/design**
- Linear response of the PS module: 2x heat load → 2x temperature

Data results & simulations



- **Observed 10ºC ΔT is according to specifications/design**
- Linear response of the PS module: 2x heat load → 2x temperature

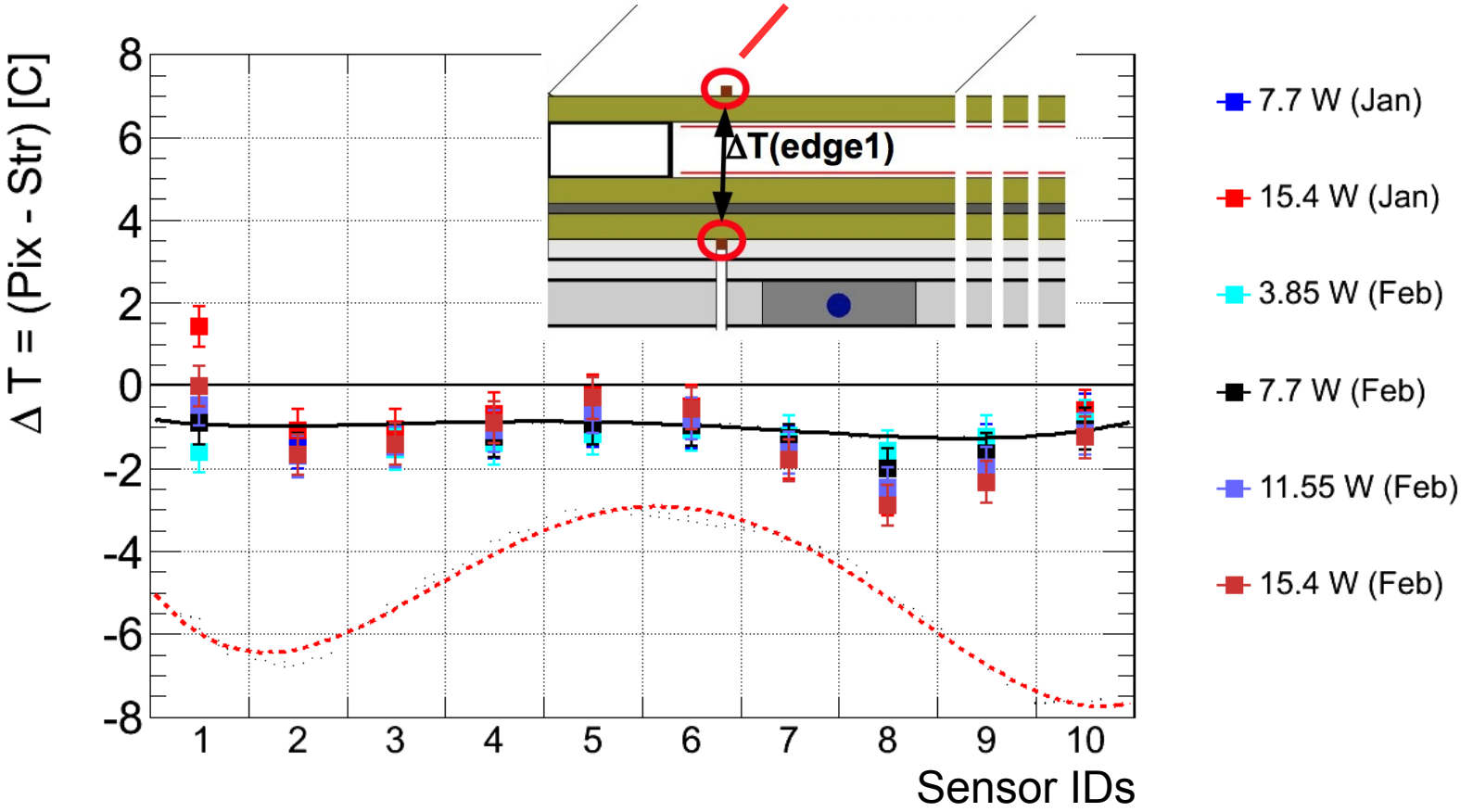
Simulations (straight lines) by M. Johnson:

- "**15.4W Sim**" has perfect connection between pipe and foam
- "**7.7W Sim**" has 50% air bubbles with diameter of 50 I m

→ "Shape" is close to data, bad pipe – foam connection

→ About a constant 2ºC offset for pixel and strip, thickness of epoxy layers

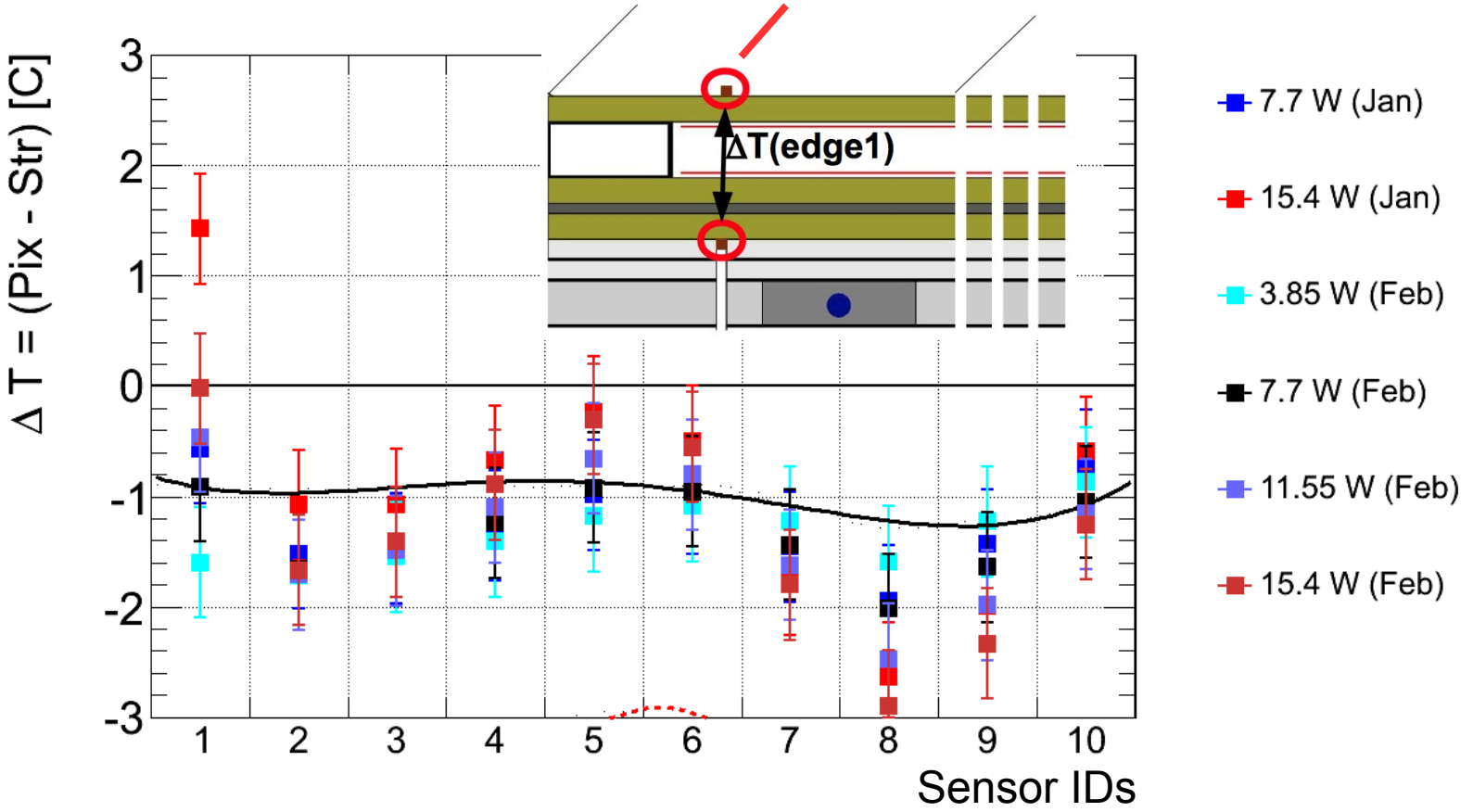
Temperature difference



Temperature differences of 10 “Pixel” RTDs to 10 “Strip” RTDs:

- Differences of about 1-2 ºC, **efficient cooling** of strip layer
- Optimistic simulation (perfect tube-foam connection) off
- More realistic simulation (50 μm air gaps) matches quite well

Temperature difference



Temperature differences of 10 “Pixel” RTDs to 10 “Strip” RTDs:

- Differences of about 1-2 ºC, **efficient cooling** of strip layer
- More realistic simulation (50 μm air gaps) matches quite well
- **No significant dependence on heat load**

Summary

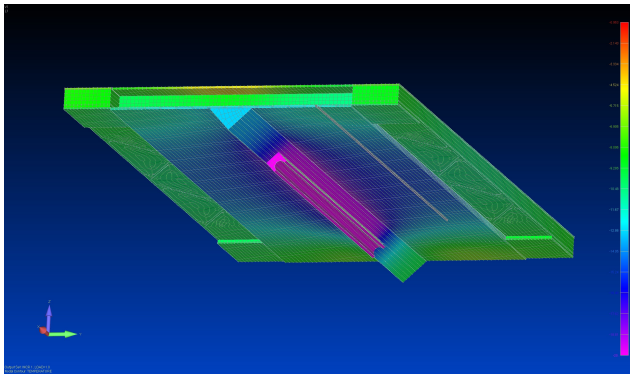
- Built realistic PS modules, good thermal behavior according to specifications
- Simulations are encouraging in their agreement to data
  - Pipe-foam connection crucial (more of a topic with 2mm pipe)

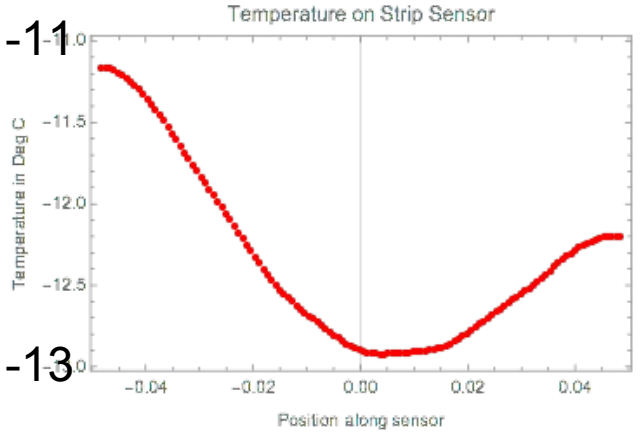
Summary & Outlook

- Built realistic PS modules, good thermal behavior according to specifications
- Simulations are encouraging in their agreement to data
  - Pipe-foam connection crucial (more of a topic with 2mm pipe)

<u>Now working on & next steps:</u>

- Modified CO2 system to reduce flow (ensure 2 phase)
- Improved rod support structure with 2.2 mm pipes
- Building more PS modules for other institutes (for Lyon)
- Test single cooling pipe mounting structures (from CERN)

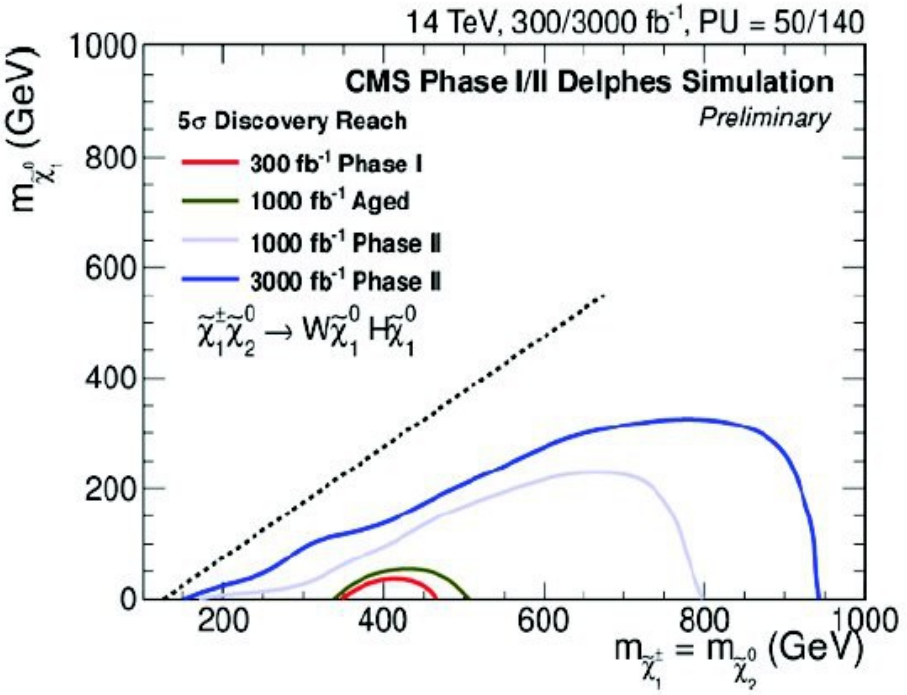




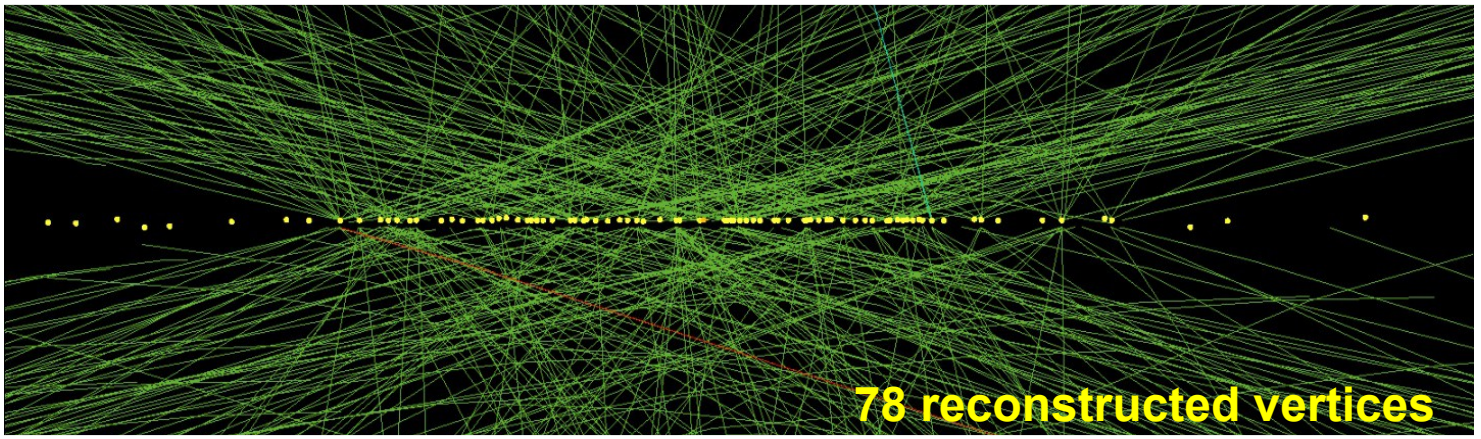
Backup

HL-LHC upgrades

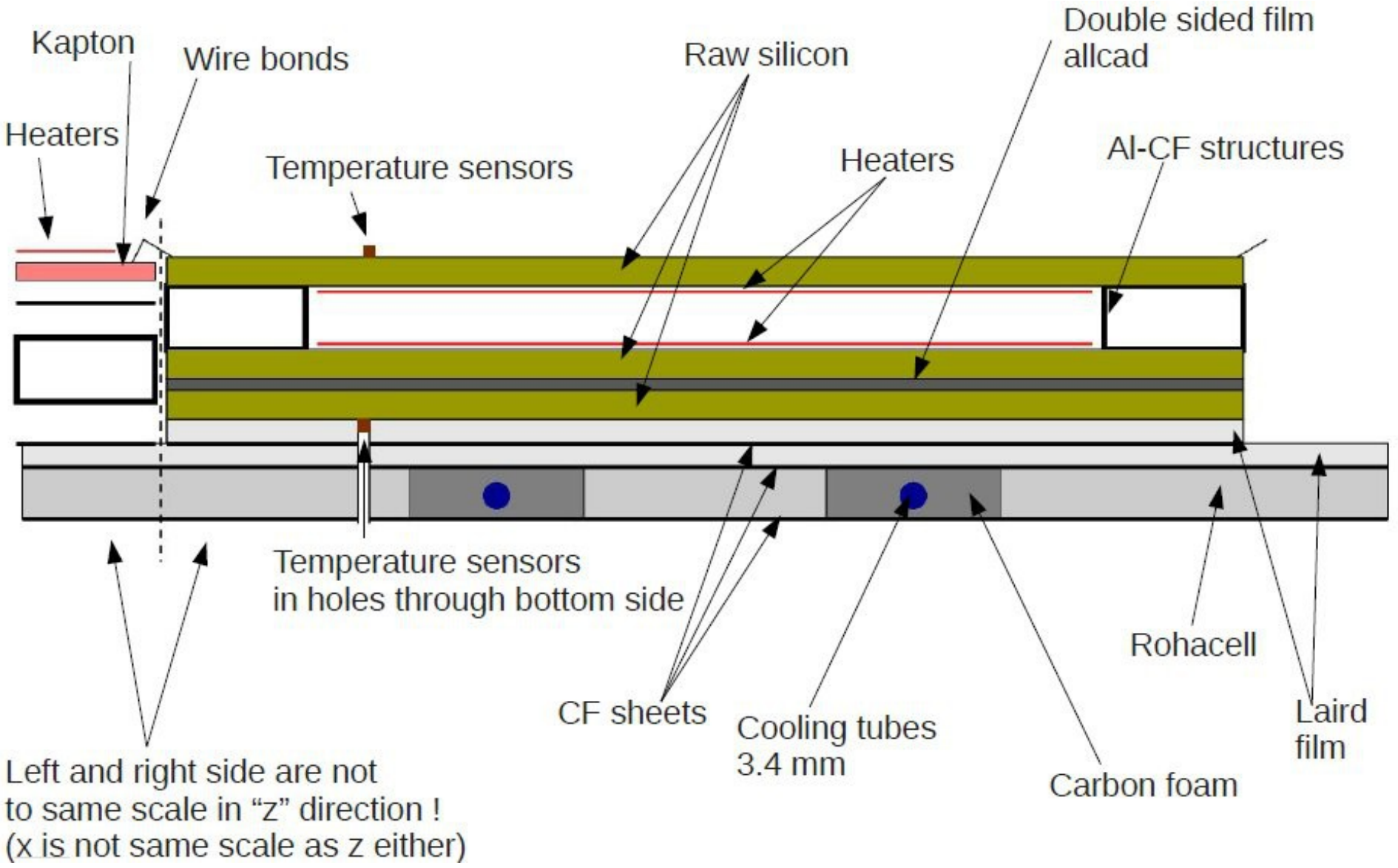
- Diff cult to project, depends on physics outcome of Run II:
  - SM precision tests & BSM scenarios
- “Keep running” does not work
  Need improved detectors



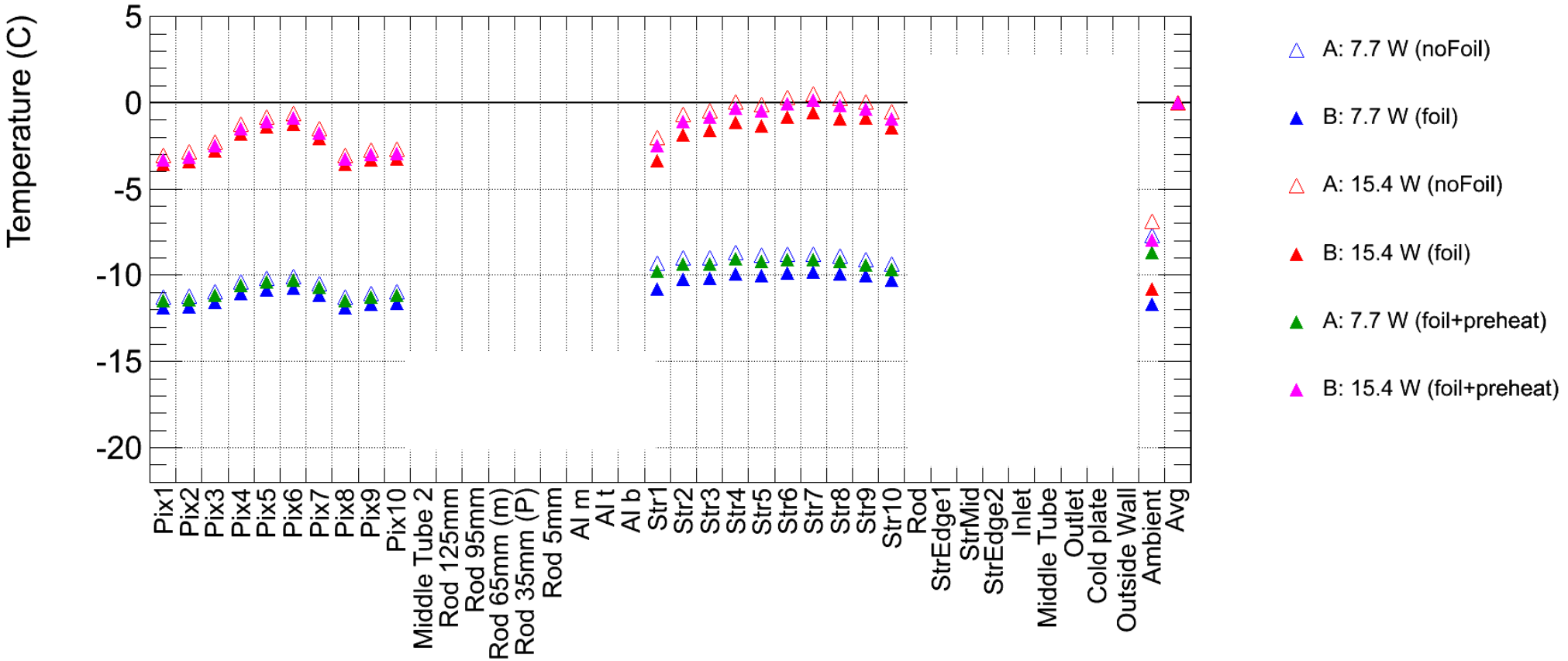
- Need very precise information from tracking devices in the trigger



Cross section through PS module



Effect of “ambient”

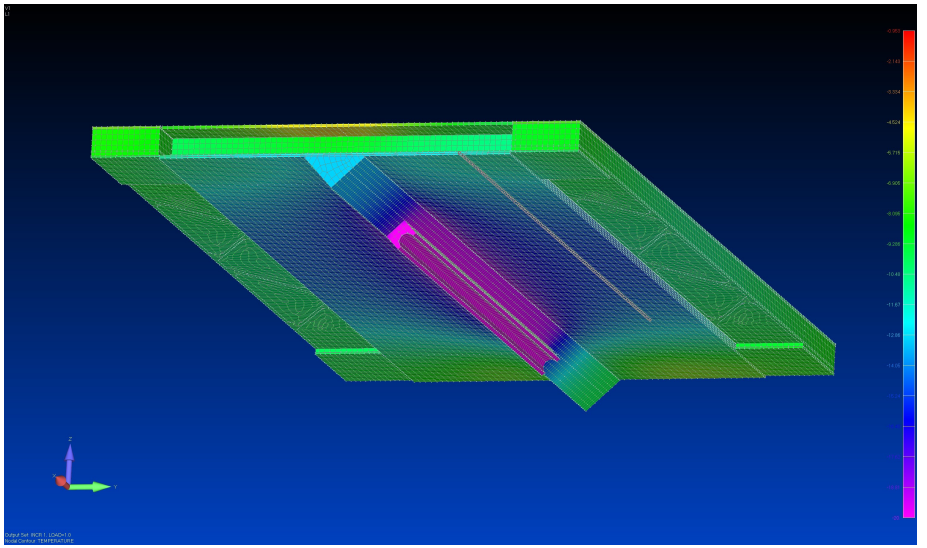


<u>February 02/17 data taking:</u>

- Same settings, but with “foil”, “noFoil”, “foil+preheat”
- Derive “ambient effects” and use as systematic uncertainty in the following
- Differences of 0.5 degree for Pixel and 1.25 degree for strip (sort of expected)

Tilted barrel PS support structure

- Geometry is not symmetric so modeled full structure
- Cooling pipe is at 90 degrees compared to slotted stave
- No pipe and epoxy in slot so not completely comparable to previous plot
- Inside of slot at -20 C



1-3 degree warmer than PS module