Prototyping of large structures for the Phase-II upgrade of the pixel detector of the ATLAS experiment

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CERN EP-DT
On Behalf of the ATLAS Collaboration

2017 IEEE NSS and MIC
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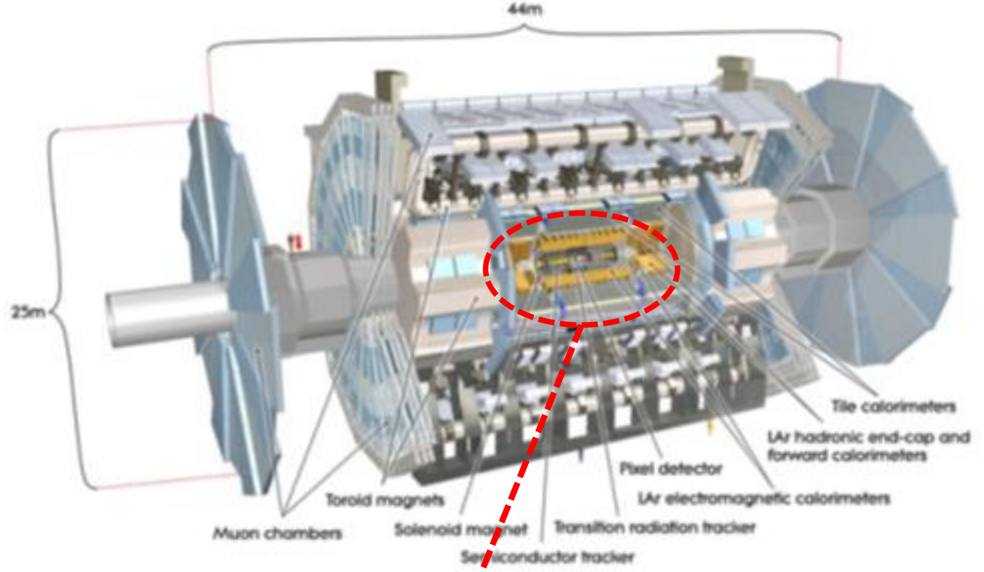
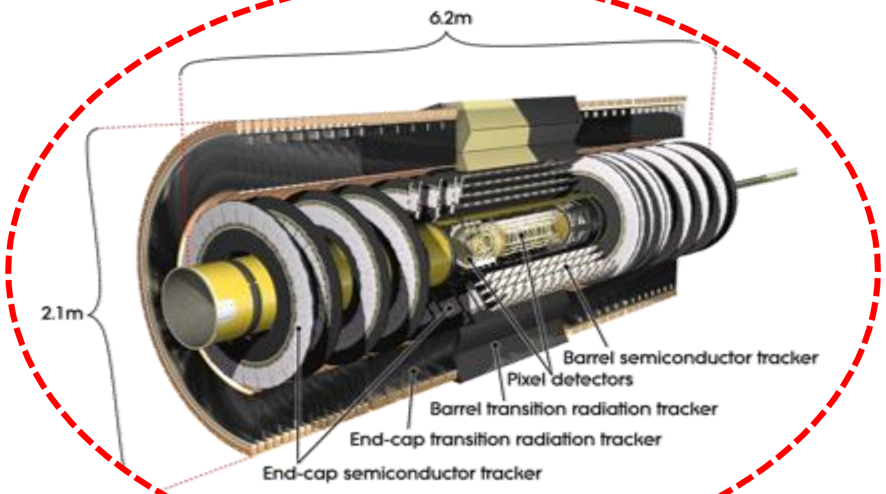
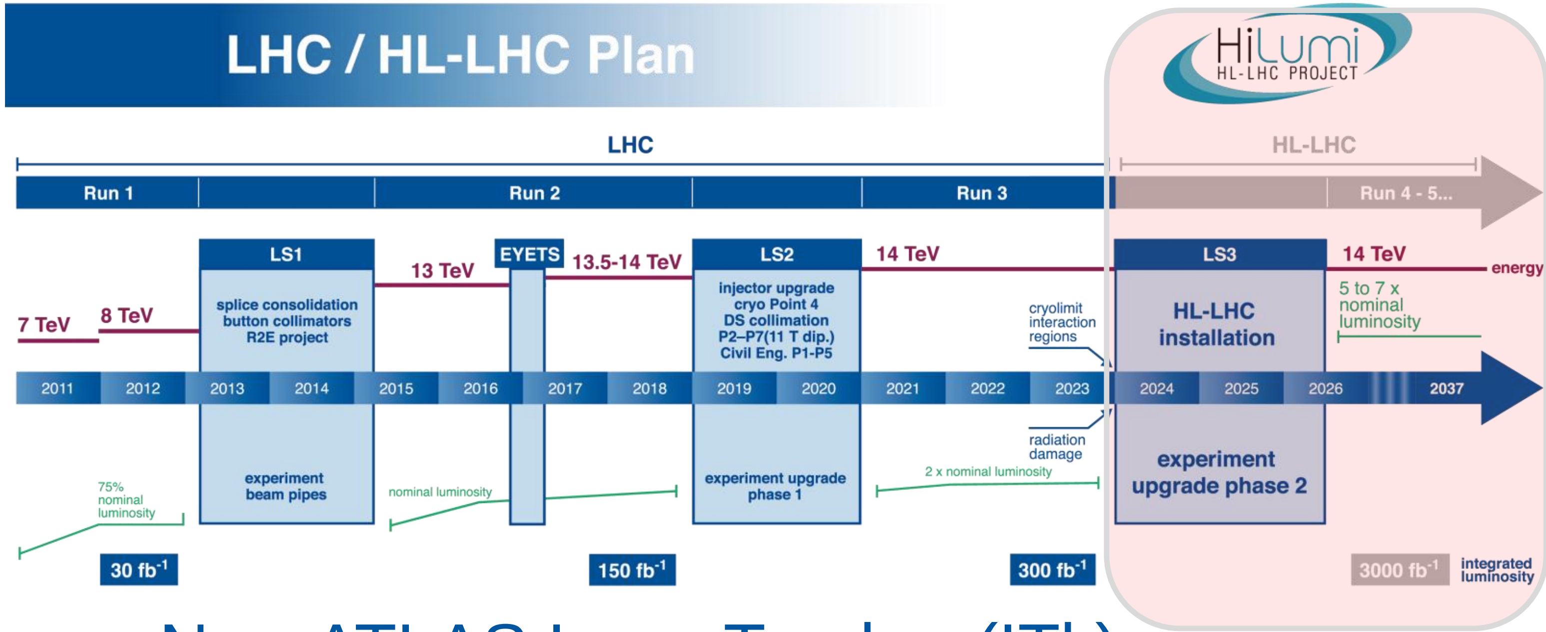
ATLAS Phase II Tracker Upgrade: ITk





Current ID



- New ATLAS Inner Tracker (ITk)
  - Finer segmentation
  - Faster readout and more storage
  - Increased radiation hardness

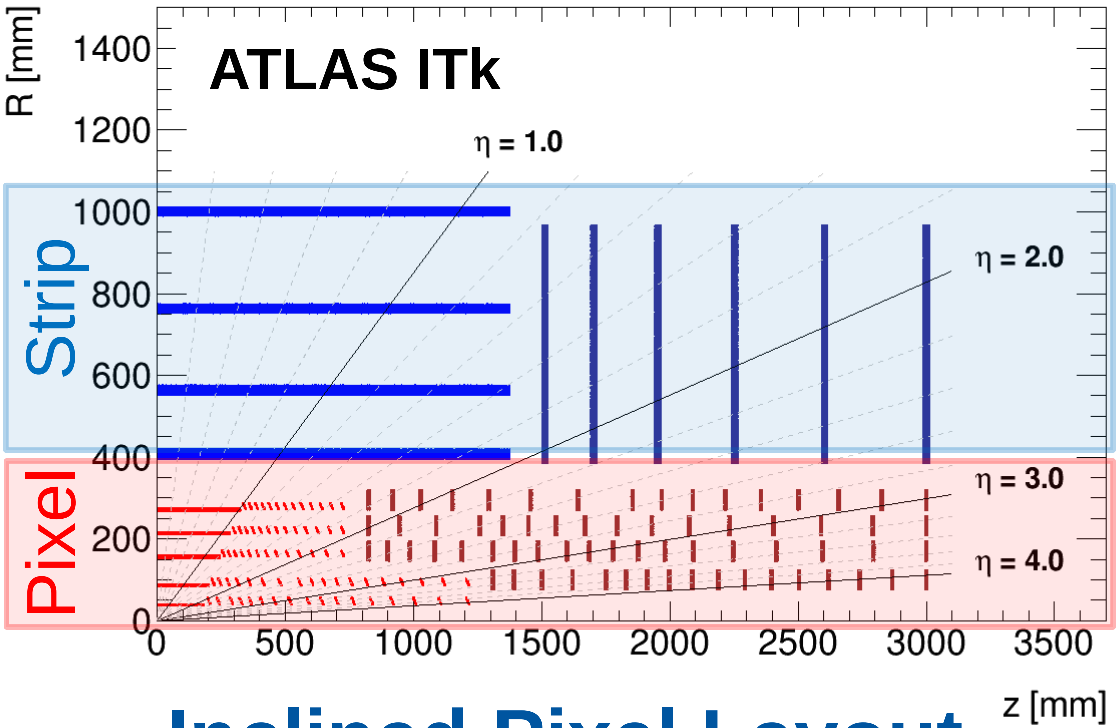
All-silicon detector with equivalent or better performance than current ID under HL-LHC Conditions

1 MeV n_{eq} fluence: $2 \cdot 10^{16}$ particles/cm^2 (20 times LHC nominal values);
Peak luminosity: 5 - $7.5 \cdot 10^{34}$ cm$^{-2} \cdot$s^{-1} (5-7.5 times LHC nominal values);
Integrated luminosity: 3000 – 4000 fb^{-1}

CERN | EP-DT Detector Technologies

ATLAS EXPERIMENT

ATLAS ITk: Pixel Upgrade



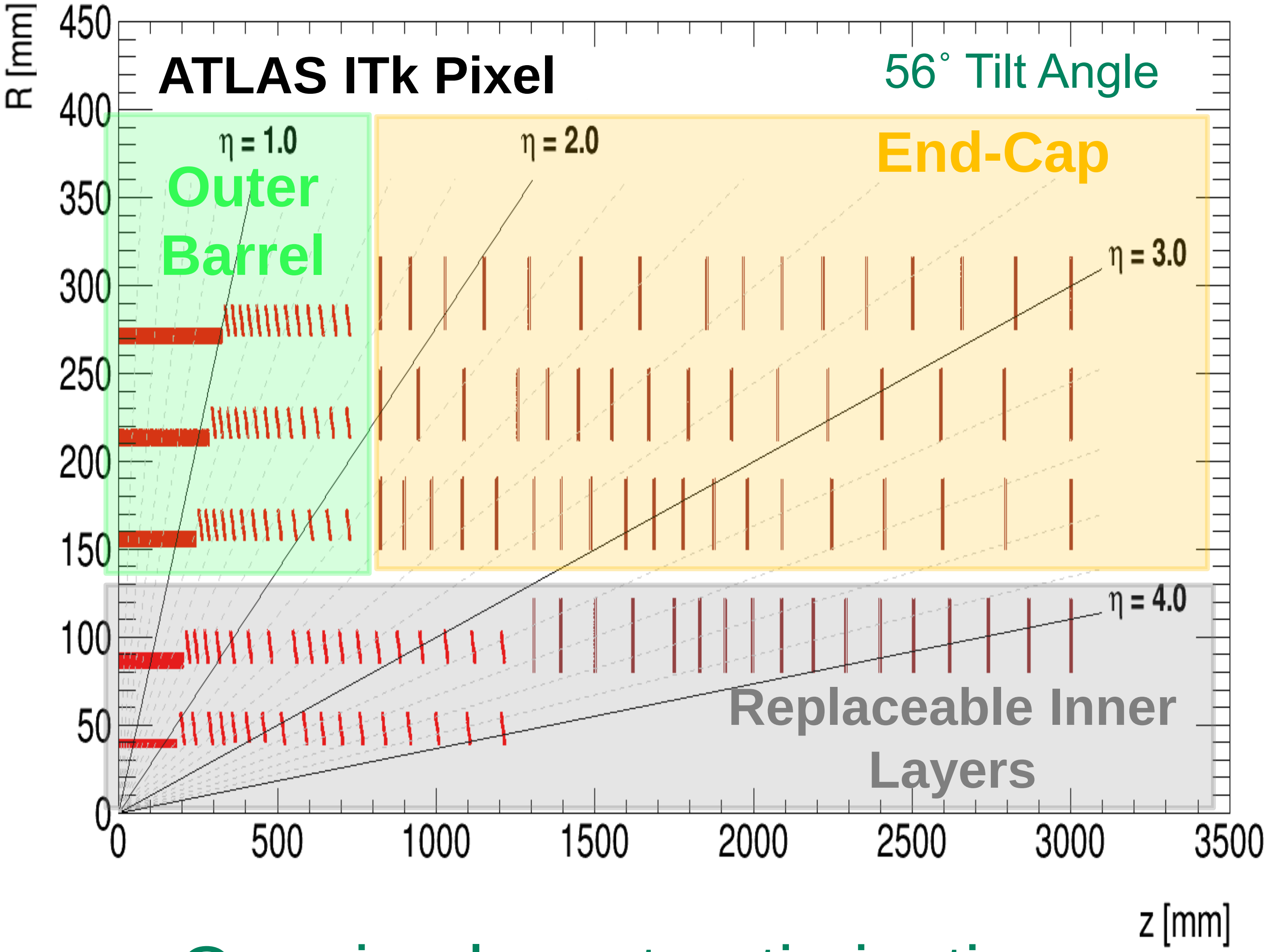
Inclined Pixel Layout

(reduce material budget & improve performance)

5 active layers

|η|~4 coverage

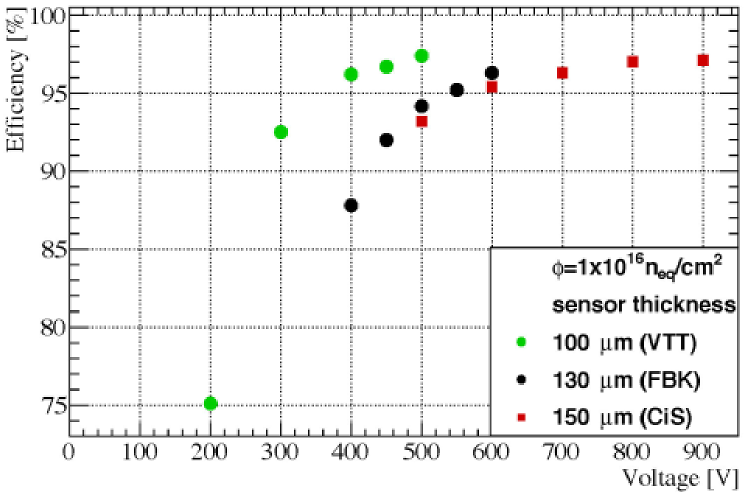
10,000 Pixel modules (~14m²)



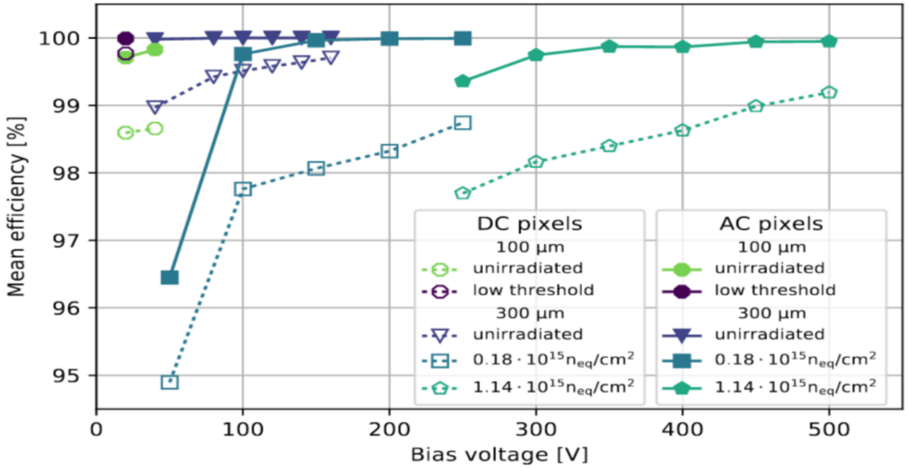
Ongoing layout optimisation

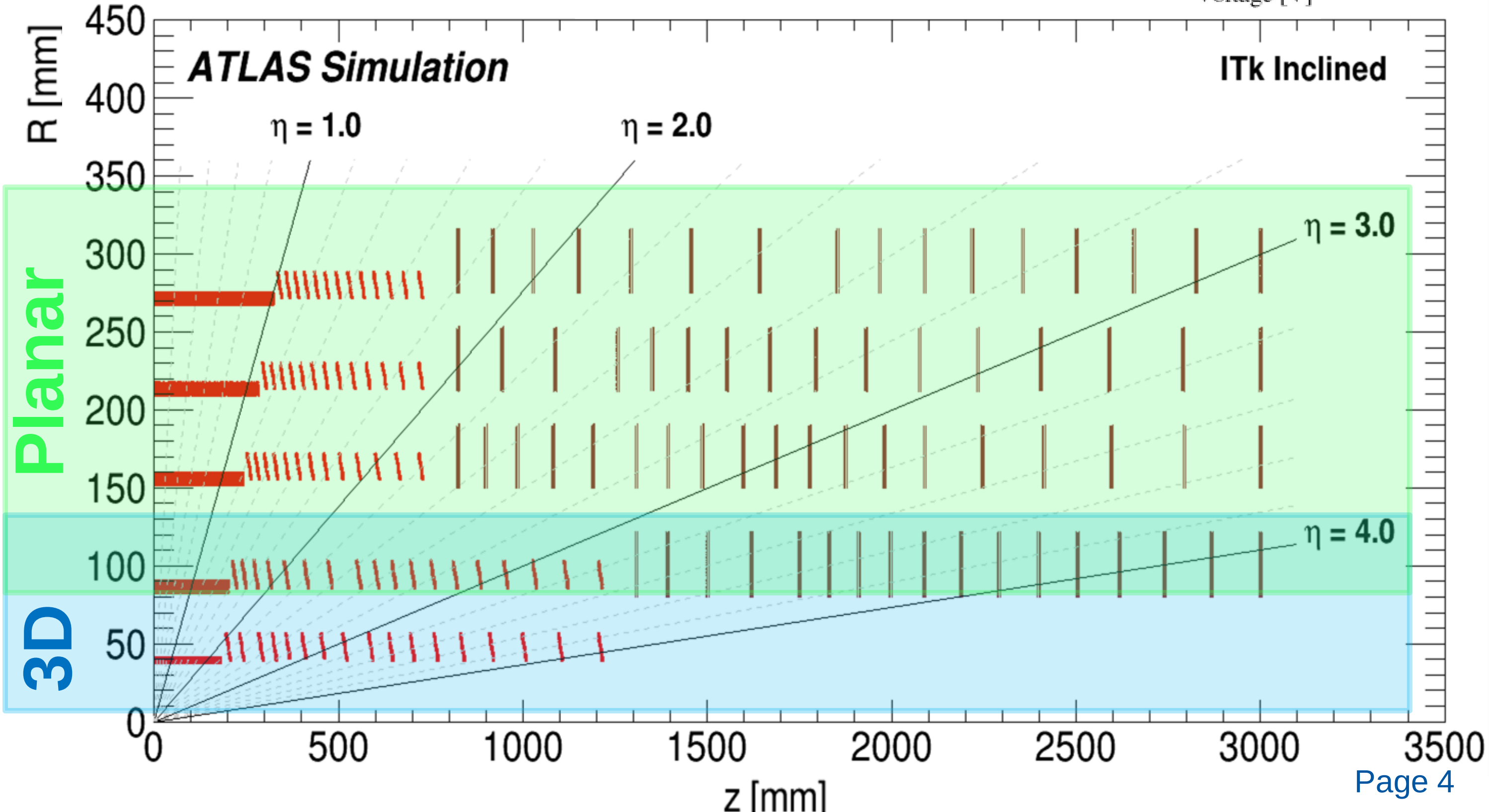
ATLAS Pixel Upgrade: Pixel Modules

- Pixel Sensors
  - 3D sensors (radiation hardness)
  - Planar (reduced cost)
  - CMOS (lower material budget, power consumption and cost)



See F. Hügging, Upgrade of ATLAS ITk Pixel Detector, VERTEX 2017

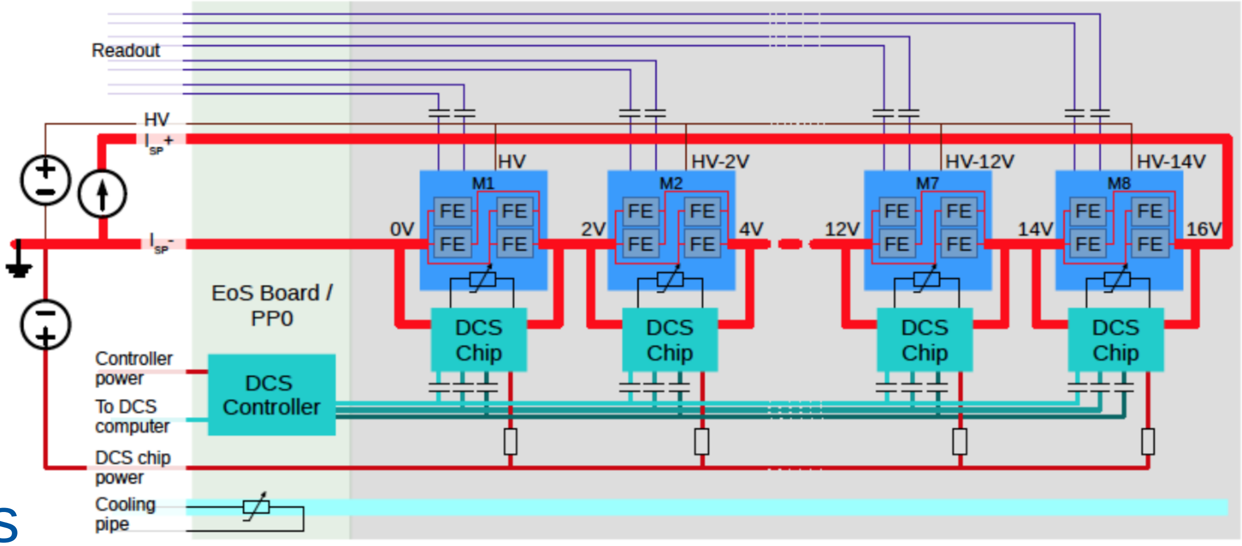


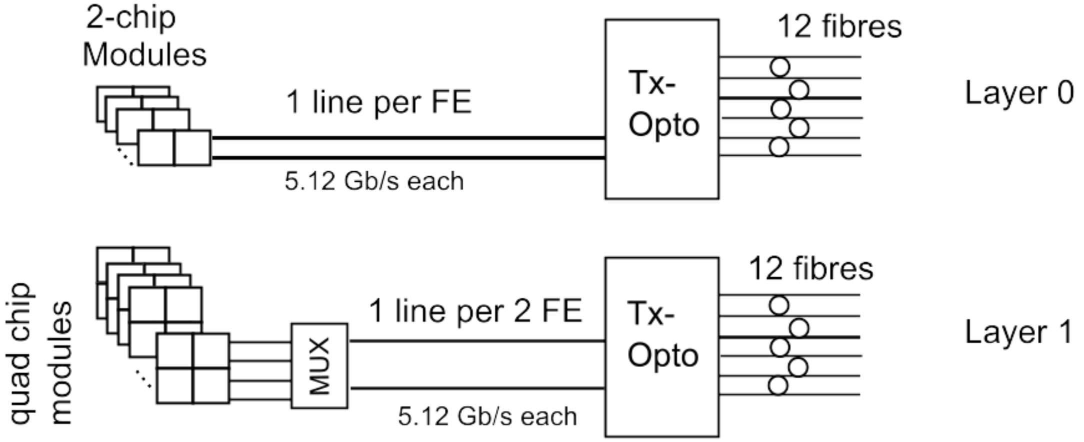


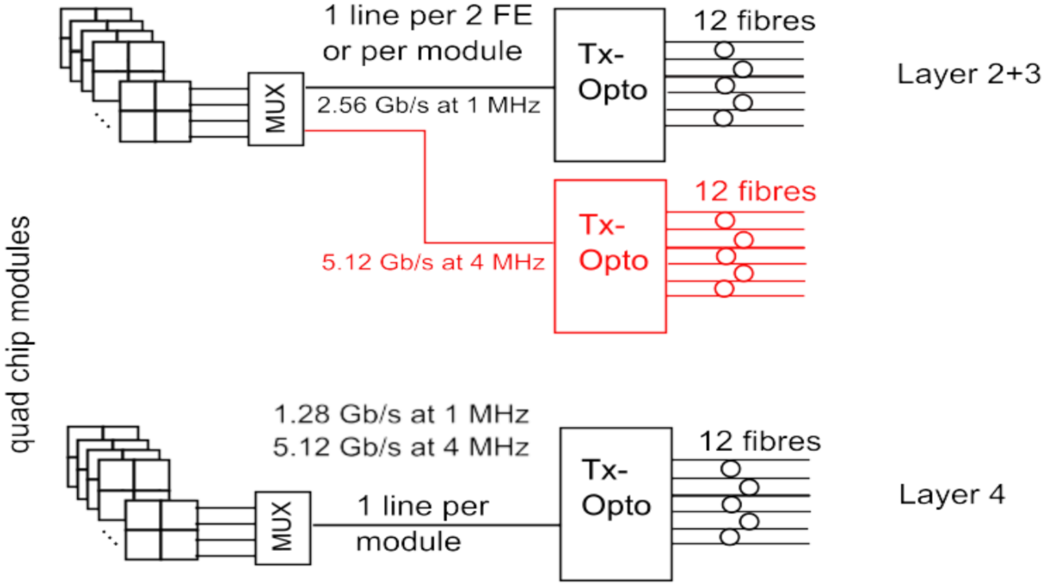
- New Front-End R/O Chip
  - RD53 Collaboration (joint ATLAS & CMS development)
  - 65nm technology
  - 50x50µm2 pixels

ATLAS Pixel Upgrade: Service Scheme

- Module serial powering
  - Constant current source
  - Shunt low-dropout regulator to control voltage across pixel module
  - DCS chip (monitor and control module)
- Aggregator chip to multiplex the output of several FEs to generate a single 5.12Gb/s (use the full bandwidth of data cables)



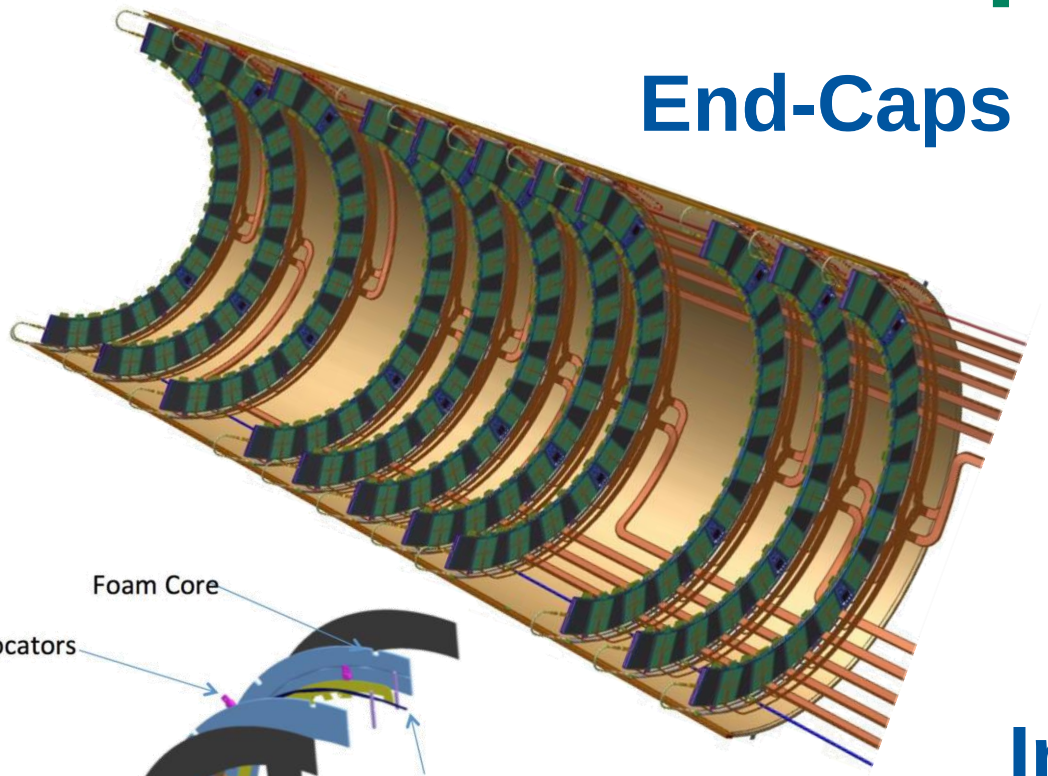


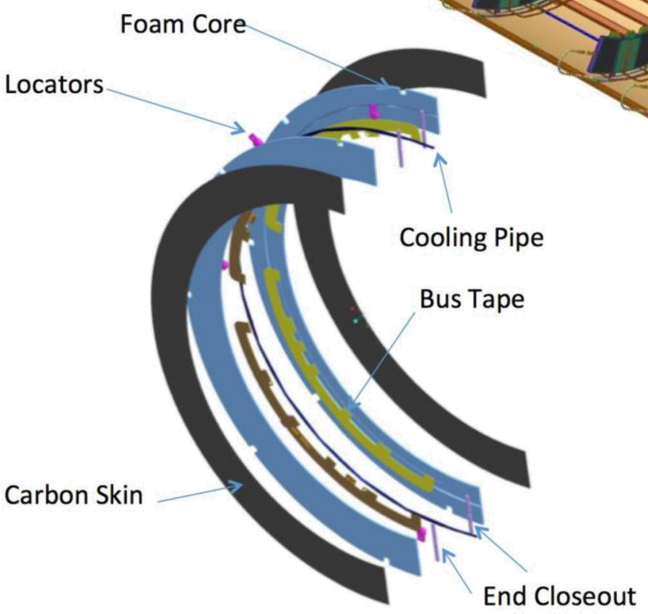


See F. Hügging, Upgrade of ATLAS ITk Pixel Detector, VERTEX 2017

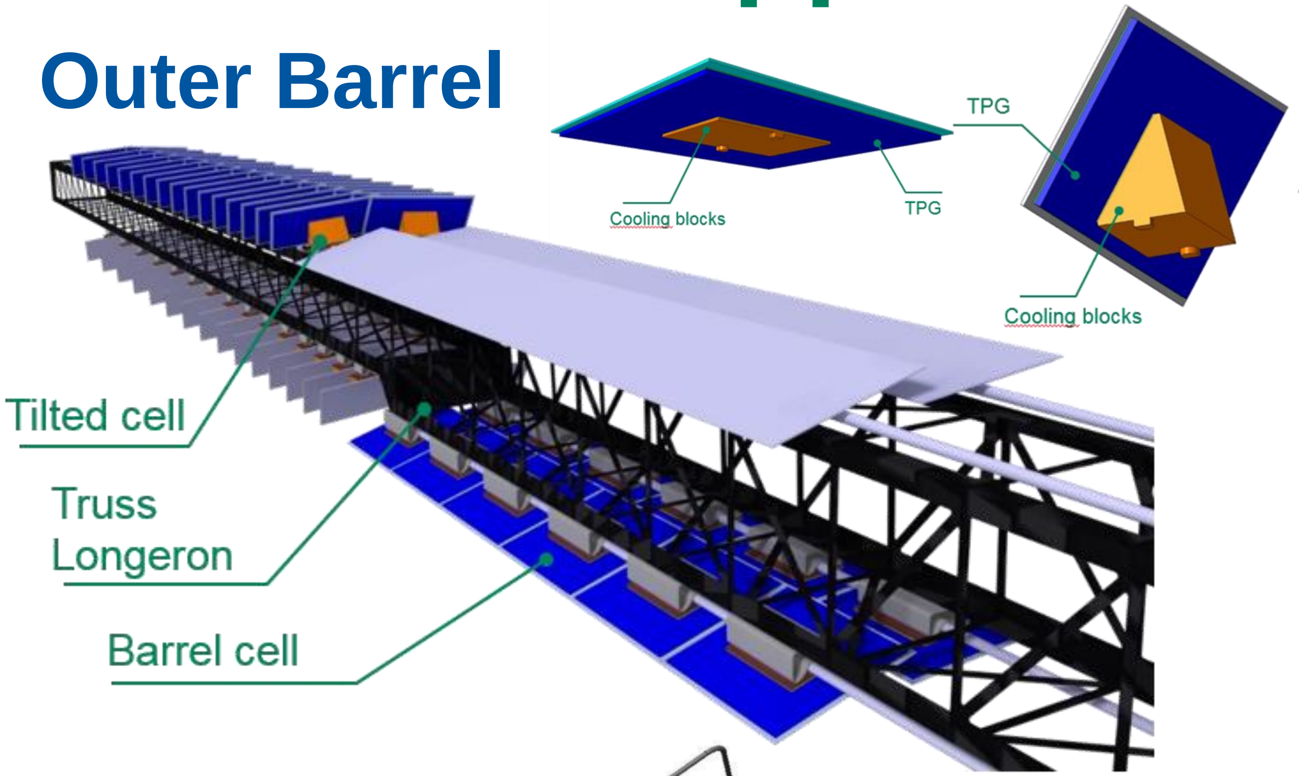
ATLAS Pixel Upgrade: Local Supports

End-Caps

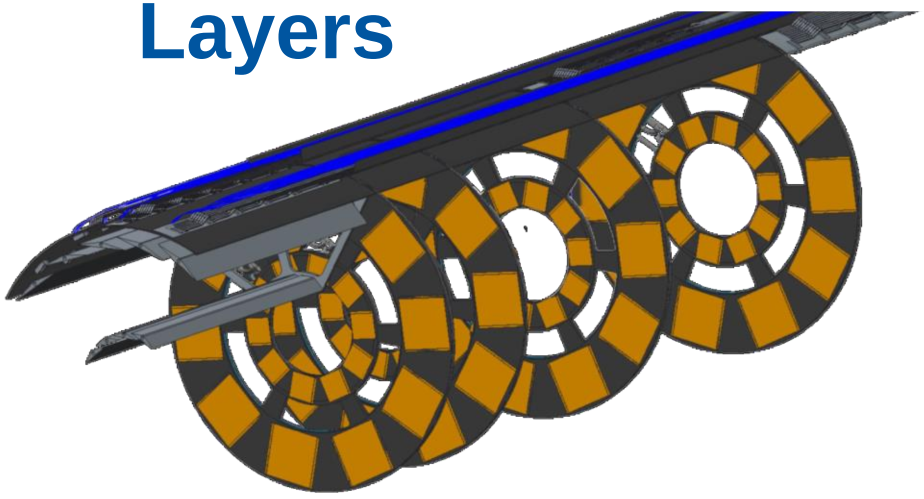


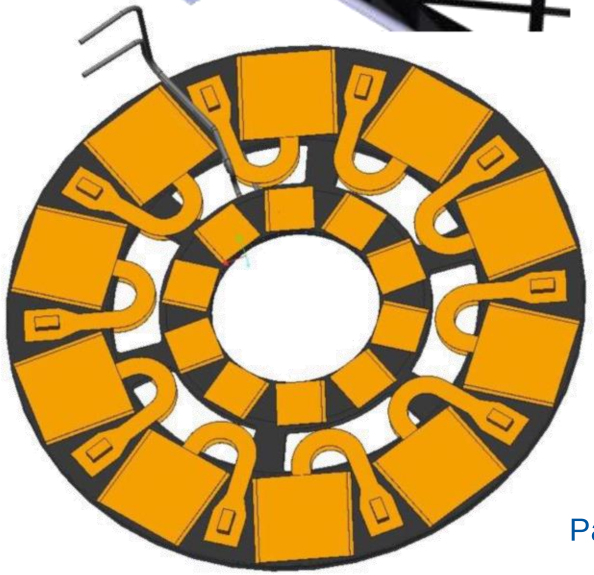


Outer Barrel



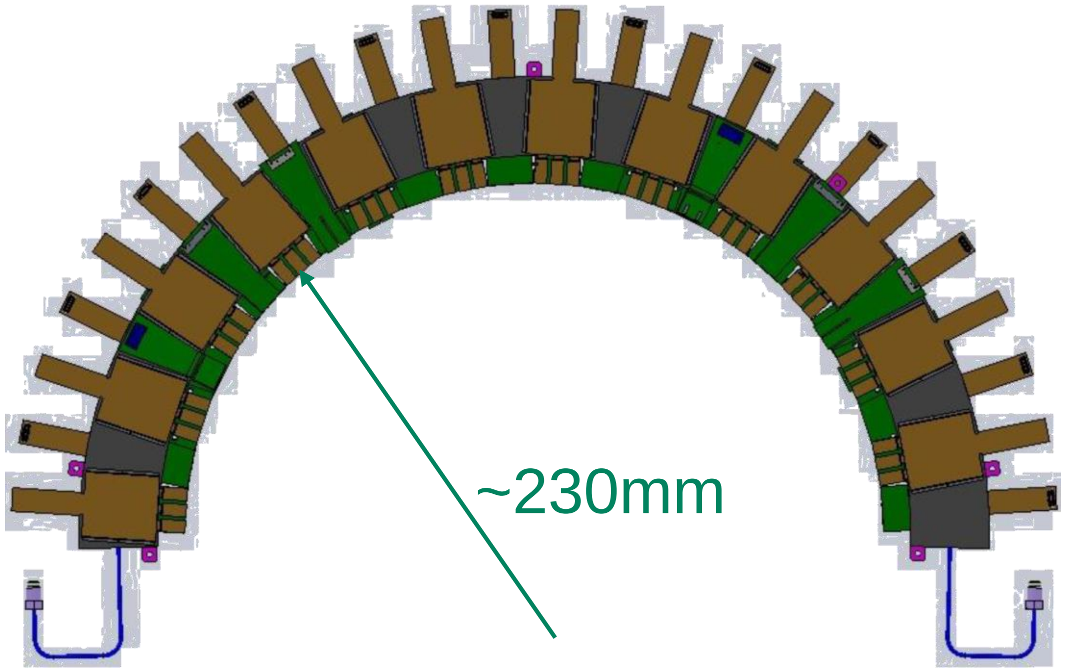
Inner Layers





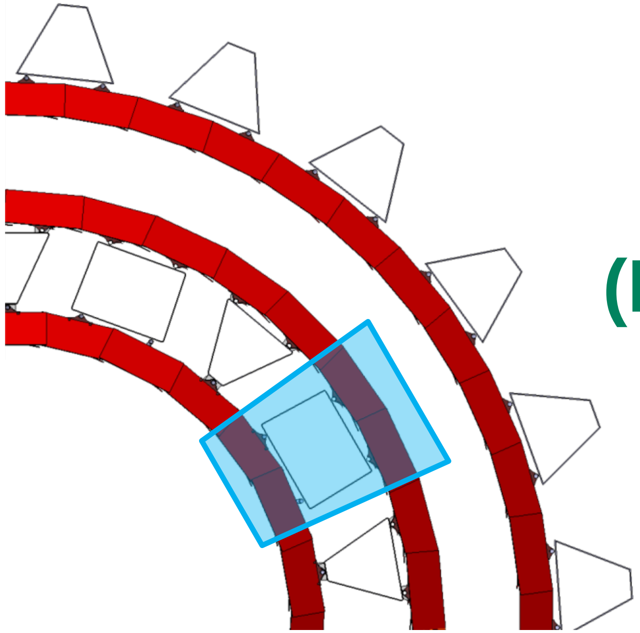
Pixel Outer Layers: Prototyping

- Validation thermal and mechanical performance of local support concepts
- Qualify procedures for loading, integration and re-workability
- Electrical tests for serial powering, readout and multi-module operation (system testing)



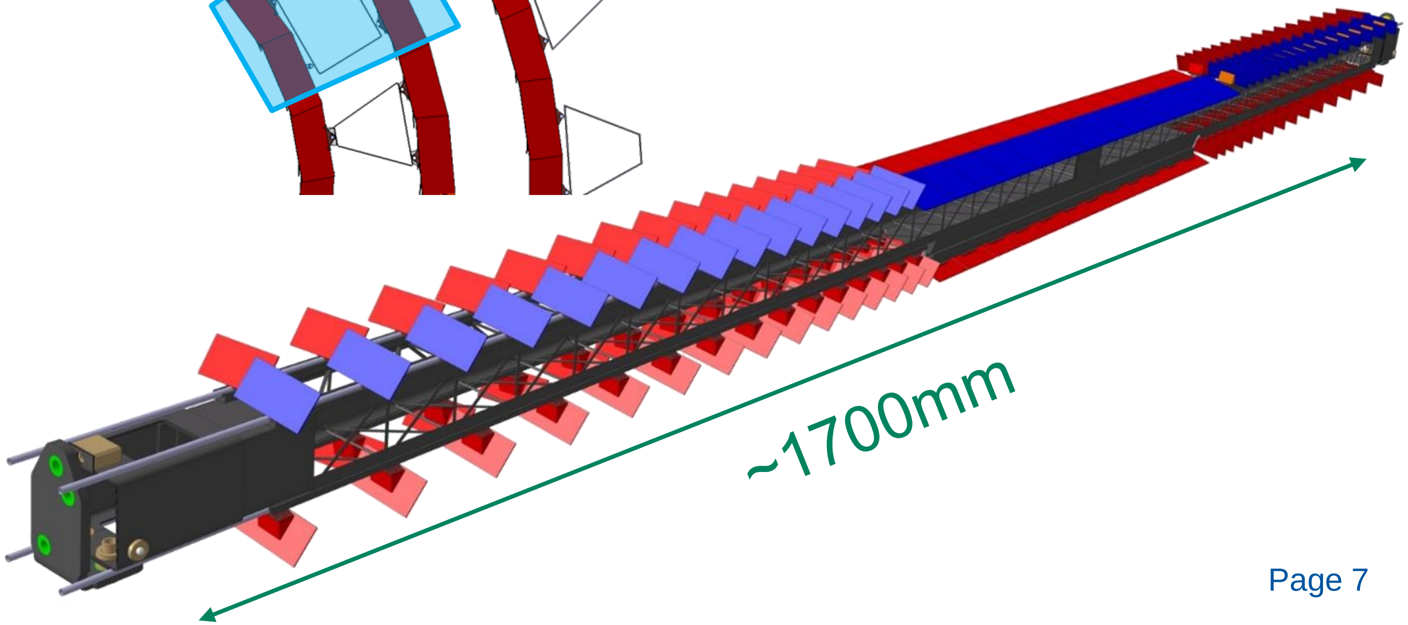
End-Caps

(Ring-0 L3)



Outer Barrel

(Demonstrator L23)

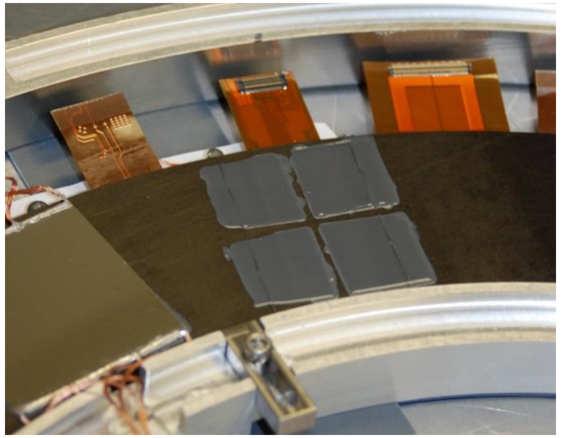


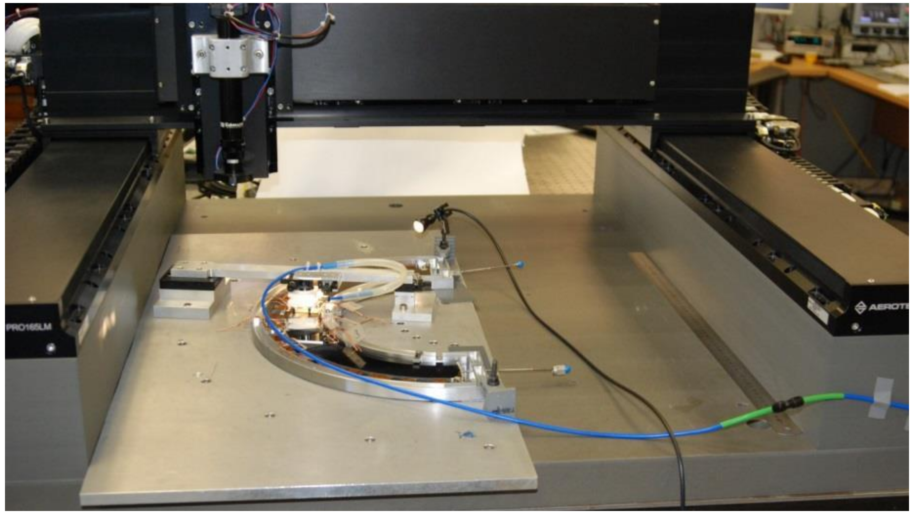
Pixel End-Cap: Ring-0

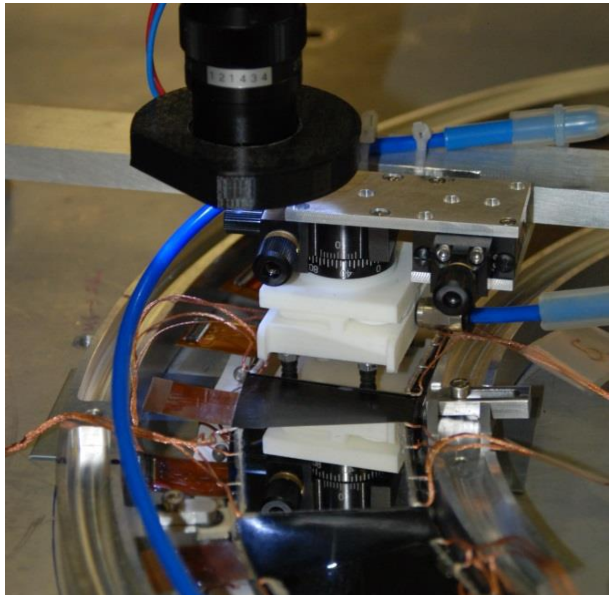
- 4 x End-Cap Rings (L3)
  - Thermal performance
  - Thermo-mechanical response
  - Development of QC procedures
  - **<u>“Ring-0”</u>**: System tests)

    ↳ To be loaded with 11 pixel modules (FE-I4)

- Module loading & survey using custom linear gantry system equipped with camera

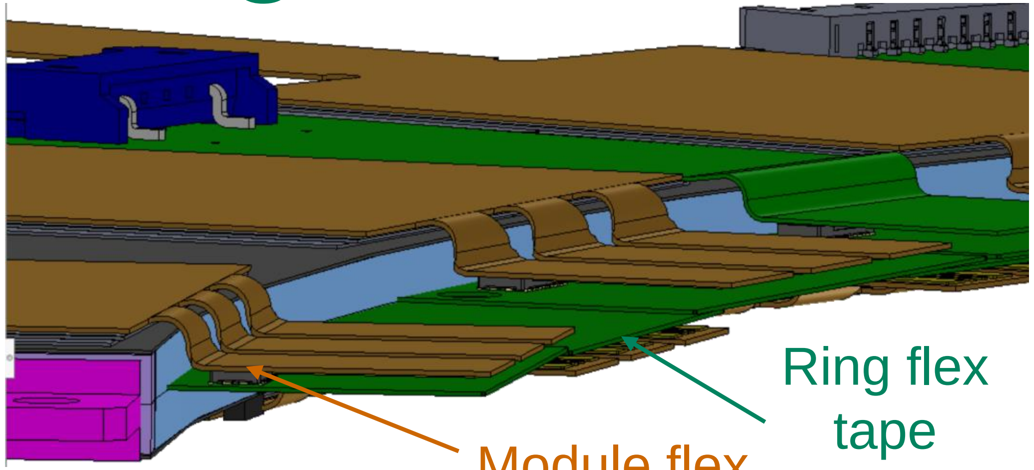






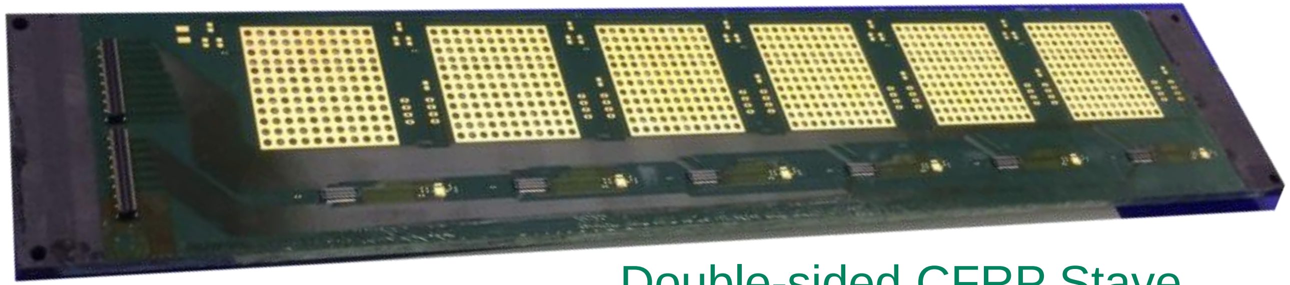
Pixel End-Cap: Ring-0

- Ring flex tape for serial powering integrated within the sandwich structure
  (connected to services via EoS cards – DCS, HV&LV)
- Data, command & clock cables directly connected to the individual modules



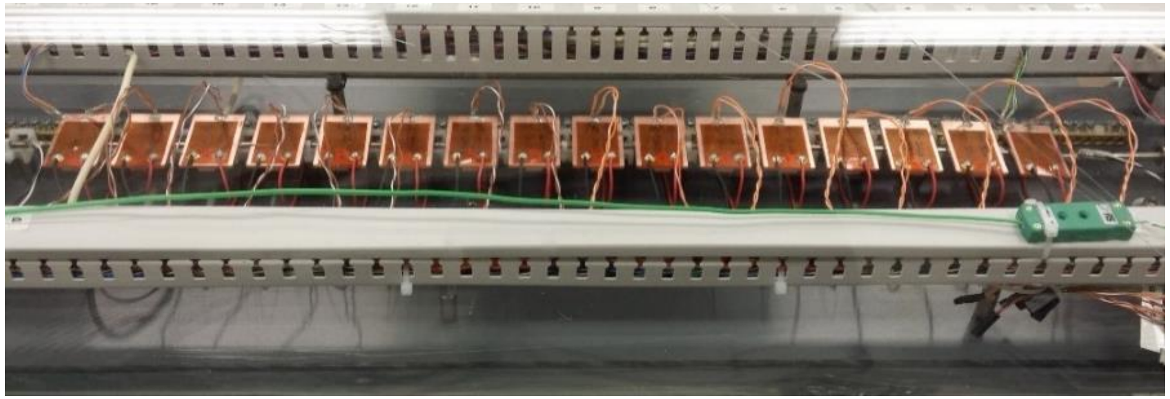
- Double-sided CFRP stave for serial powering testing (up to 12 modules)
  - Cooling + irradiated modules
  - Cross-talk, tuning and noise studies

Ring Flex Tape Prototype (6 x module chain)

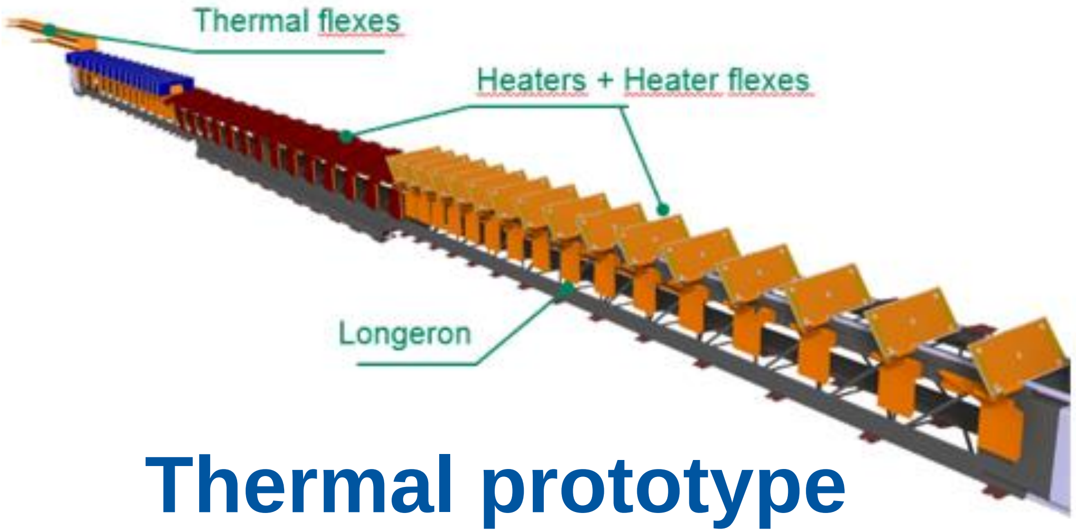


Double-sided CFRP Stave

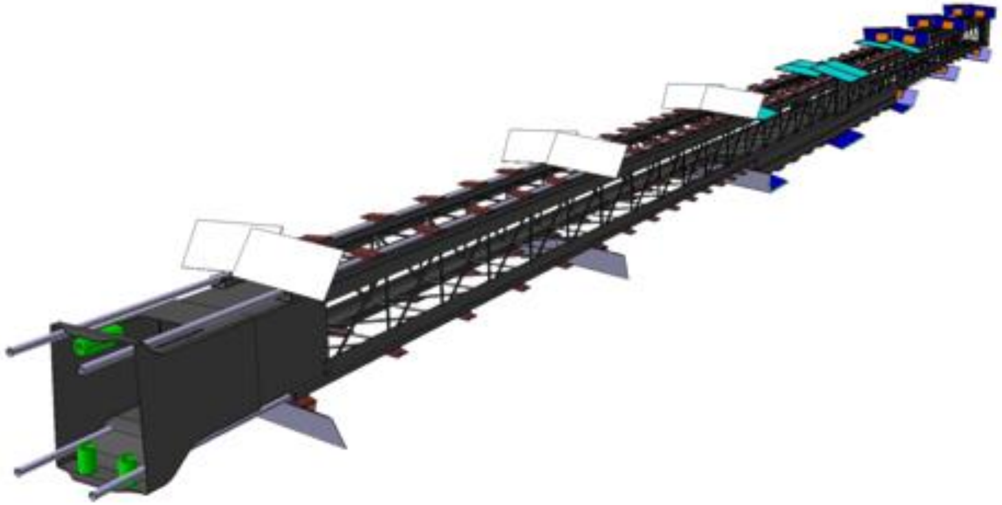
Pixel Outer Barrel: Large-Scale Prototypes



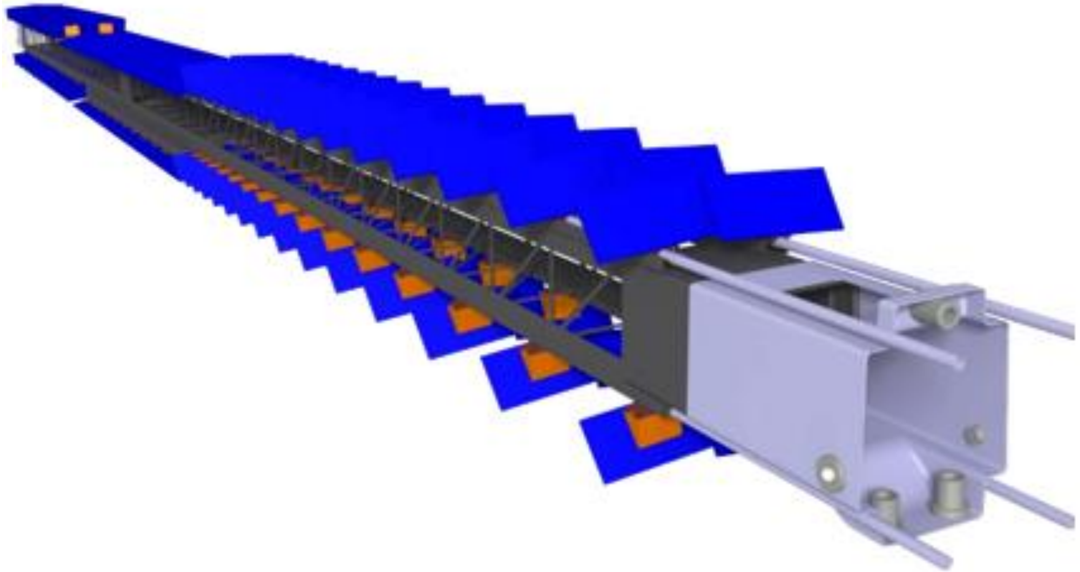
Thermo-fluidic prototype



Thermal prototype



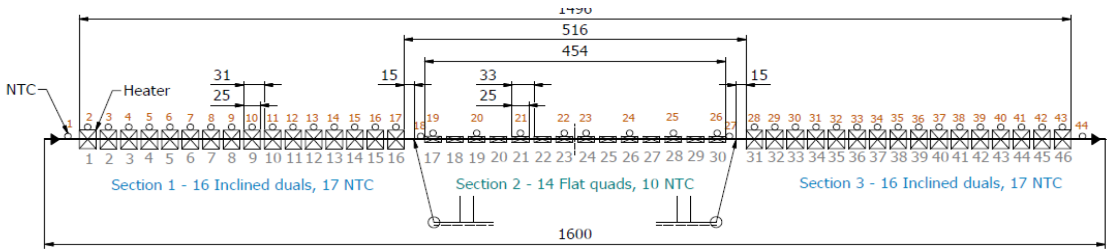
Thermo-mechanical Prototype

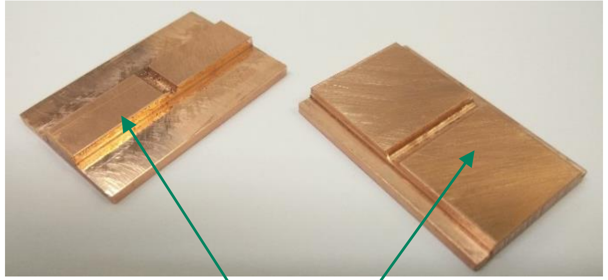


Final Demonstrator

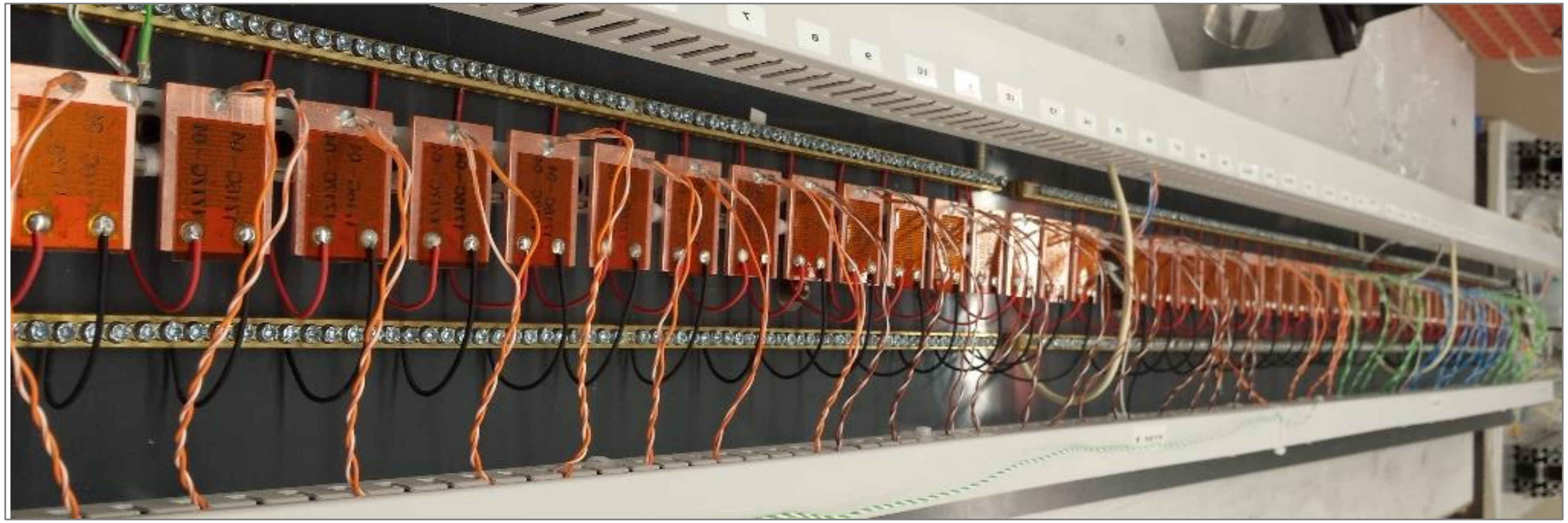
OB Prototyping: Thermo-Fluidic Response

- 1.6m long CO_2 cooling pipe with localised heat loads (soldered copper blocks - 14 flat, 32 inclined)
  - End-of-life power dissipation (~0.7W/cm^2) and with 40% safety factor (~1W/cm^2)
  - Various mass flow rates (3-6g/s) and azimuthal orientations (0˚-180˚)





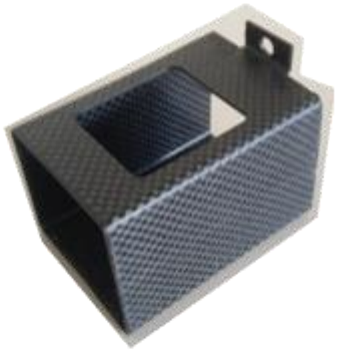
Block geometry selected to replicate heat flux at the pipe surface



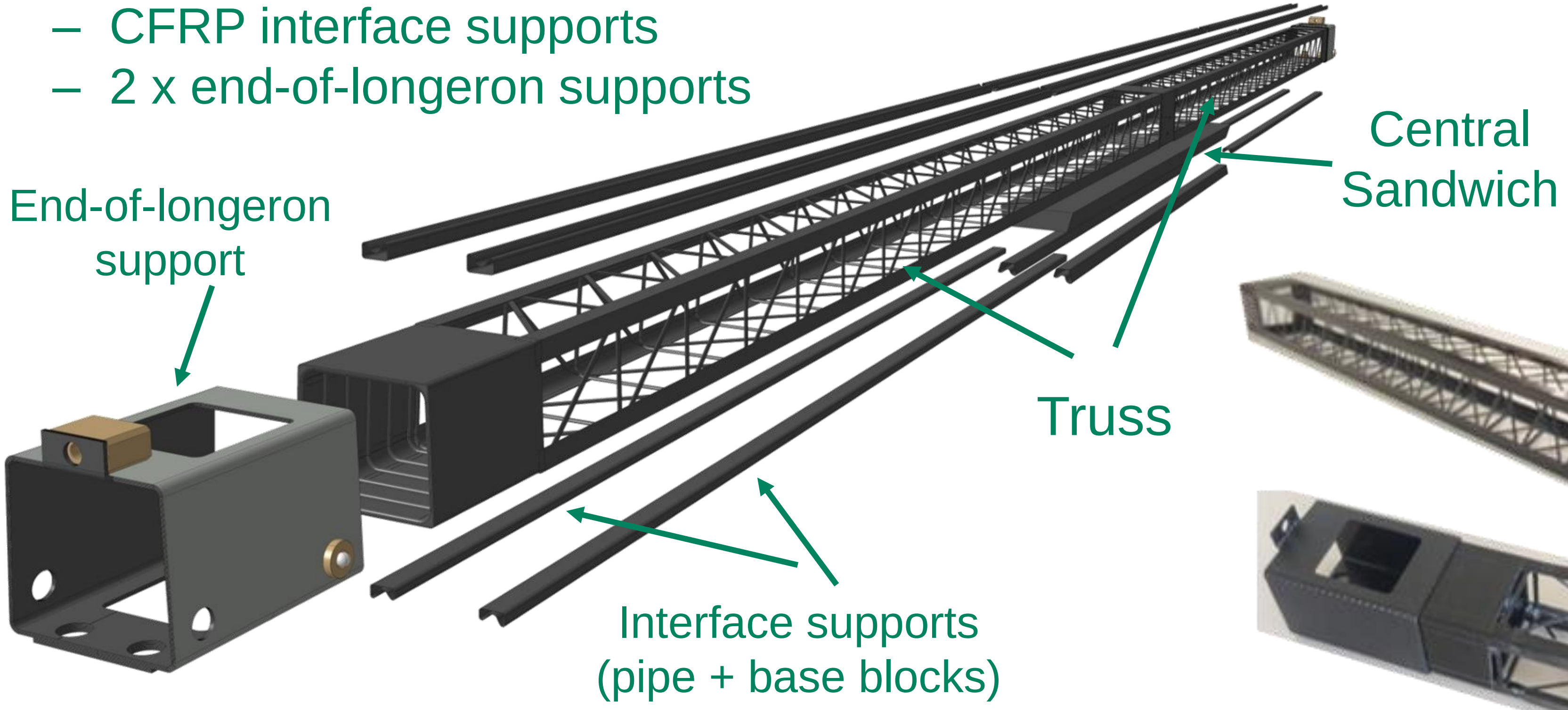
Sustained performance (ΔT, HTC) along the full length of the pipe for the different testing conditions

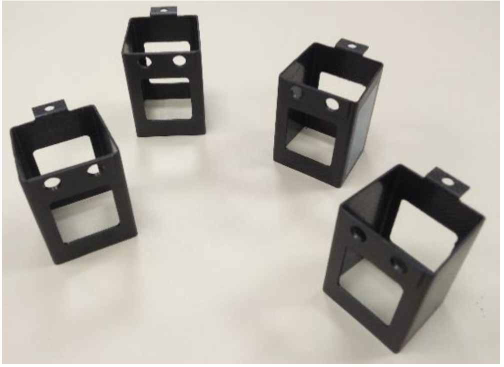
See R. Gomez, Novel low material-budget detector cooling strategies for inclined modules in silicon tracker detectors, Forum on Detector Tracking Mechanics 2017

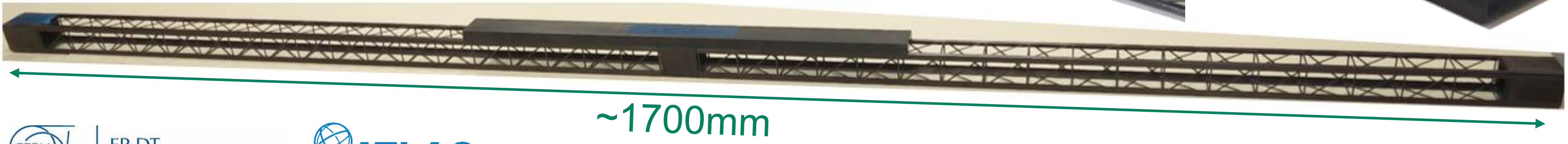
OB Prototyping: Truss Structure



- CFRP Truss Structure (filament winding construction)
  - 2 x TRUSS + Central sandwich step
  - CFRP interface supports
  - 2 x end-of-longeron supports

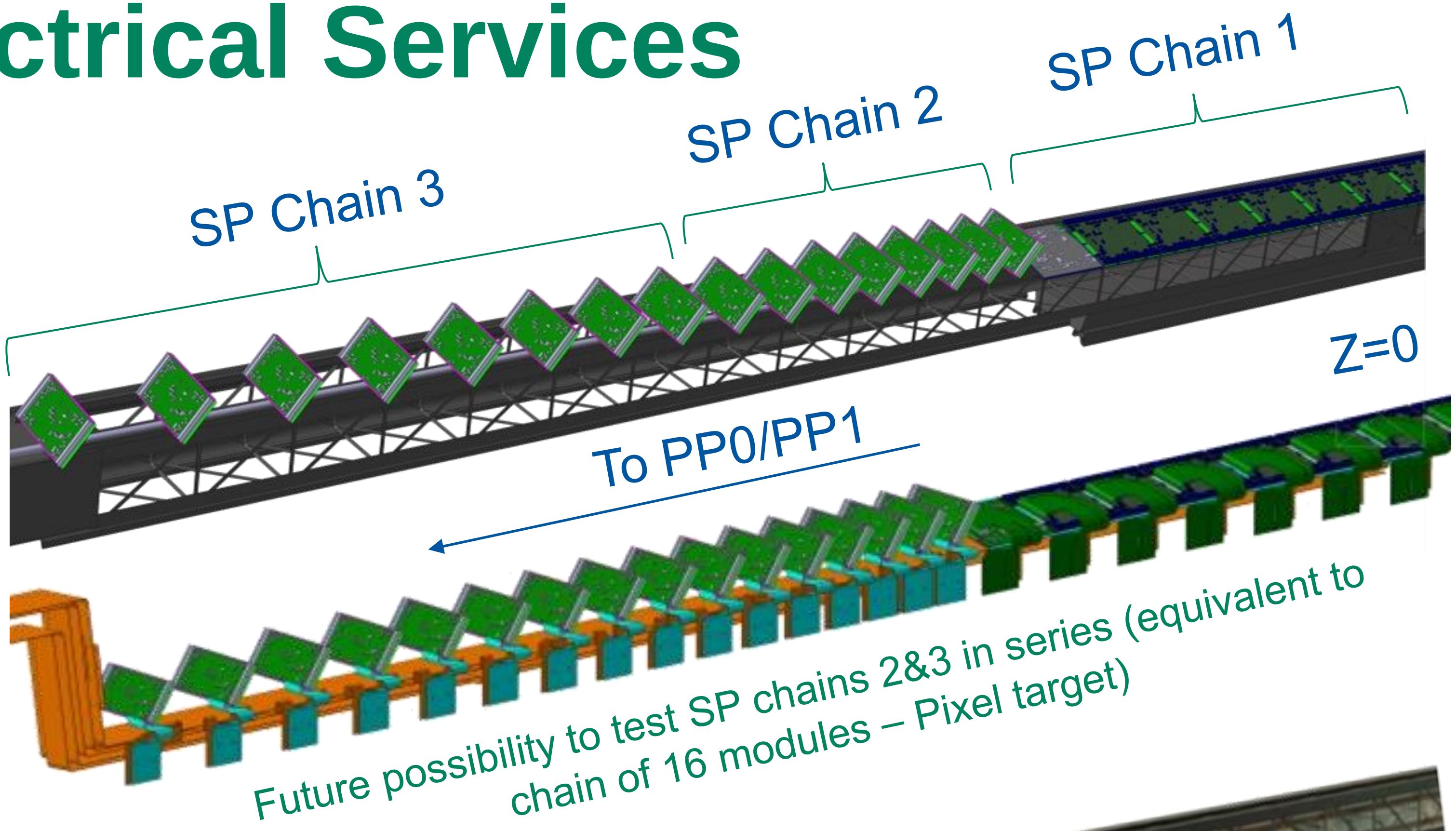




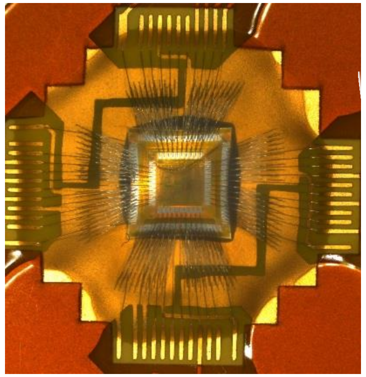


OB Prototyping: Electrical Services

- Stave flexes (power & data) integrated within the Truss
  (3SP chains per side for each CL)

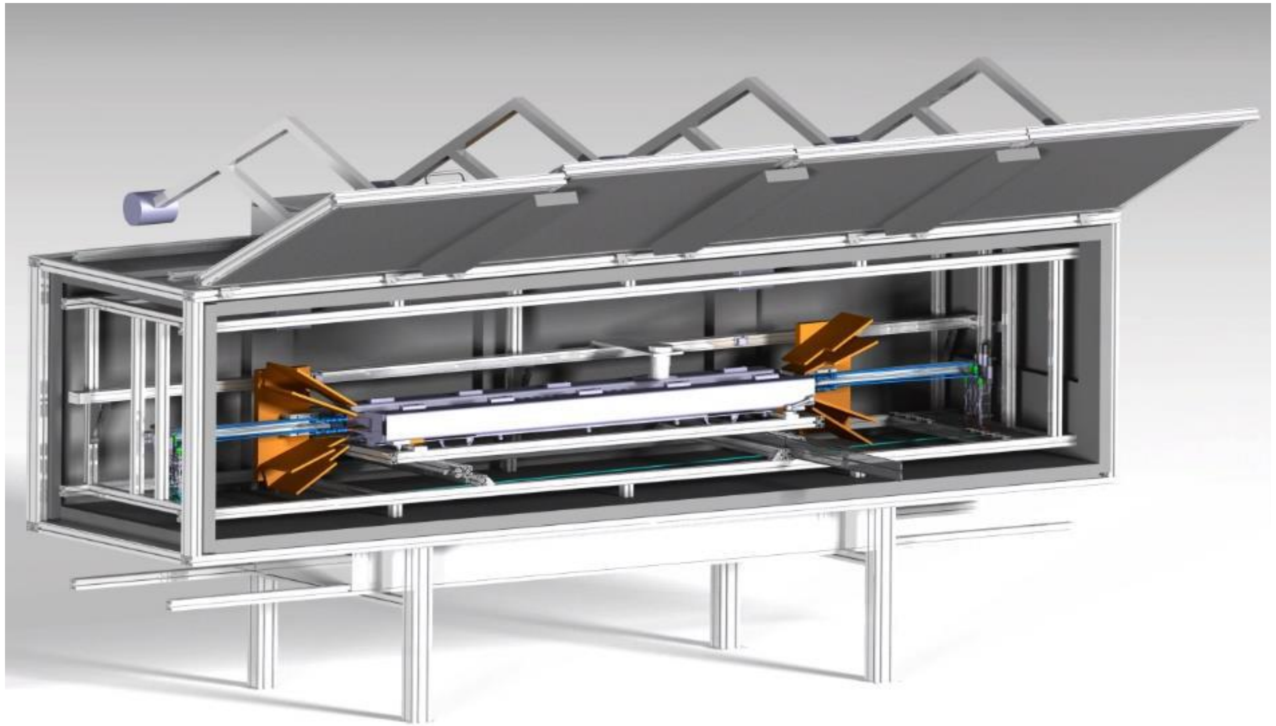


- DCS serial powering control chip integrated on power stave flexes



Prototyping: Future System Tests

- Multi-module readout tests
- Powering and Detector Control System (DCS)
  (serial powering, DCS bypass tests, DCS controller)
- Grounding and shielding and cross-talk
  (HV tests, noise injection tests, RF shielding)
- Source tests
- CO_2 Cooling
  (boiling trigger, manifolds, dry out tests)



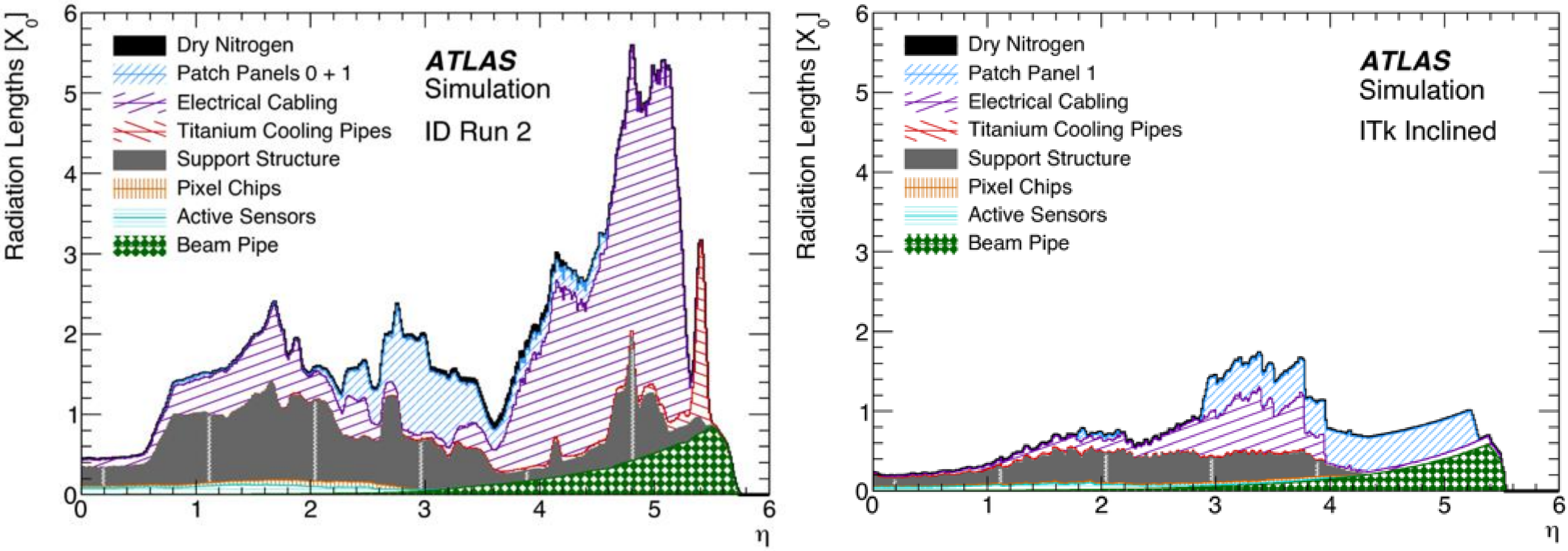
Conclusions

- A replacement for the current ATLAS Inner Detector is needed to cope with the demands and maximise the potential for discoveries of the HL-LHC
- The future silicon tracker will feature 5 layers of pixel detectors covering up to $|\eta|$~4
- New solutions for sensors, FE electronics, services and mechanics are under development to maximise the performance of the future detector
- The adoption of a pixel inclined layout poses further design and integration challenges
- The ongoing demonstrator programmes will help validating the pixel local support concepts using large-scale prototypes
- They also comprise the development of procedures for loading, integration and re-workability
- Further system testing with large structures will allow to evaluate the future service scheme and assess different readouts

Additional Material

ATLAS Pixel Upgrade

- Maximum radiation length reduced from $5.5X_0$ (ID Run 2) down to $2X_0$ (ITk Inclined)



See TDR for the ATLAS Inner Tracker Strip Detector, 2017

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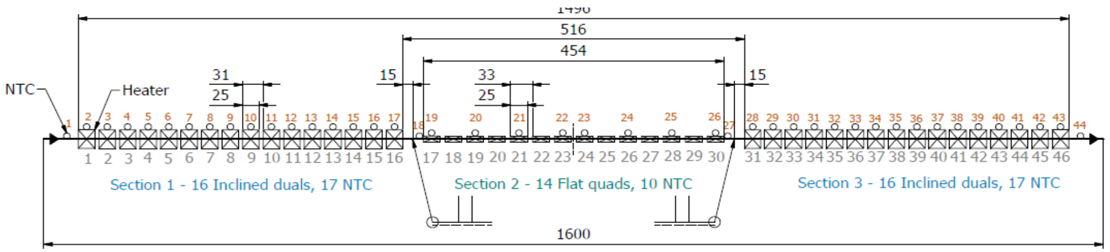
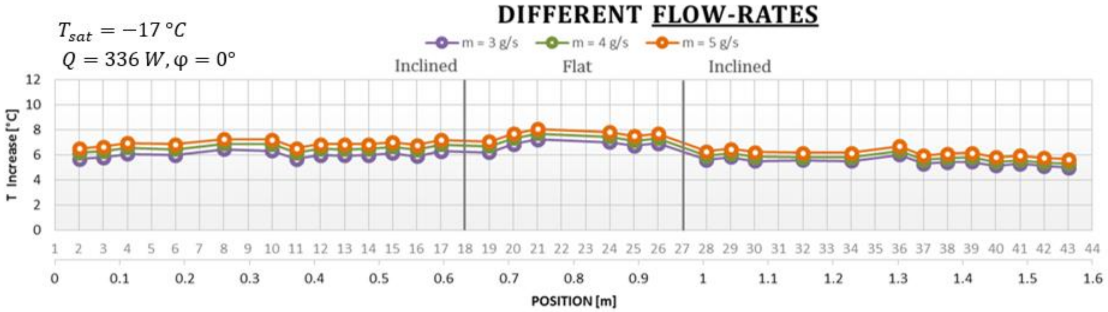
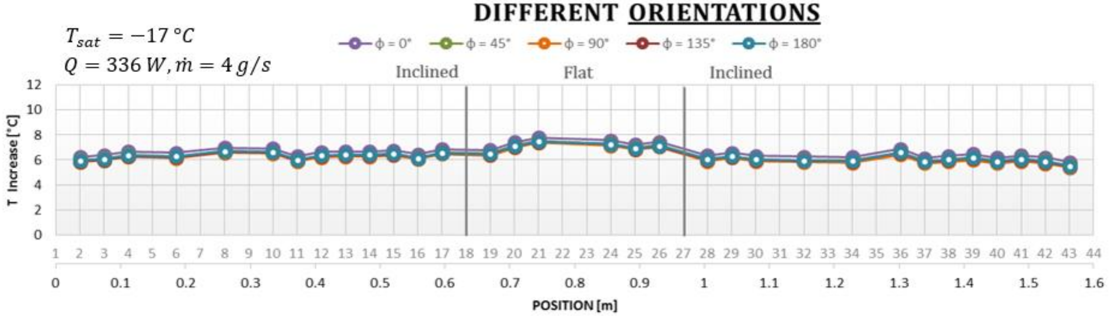
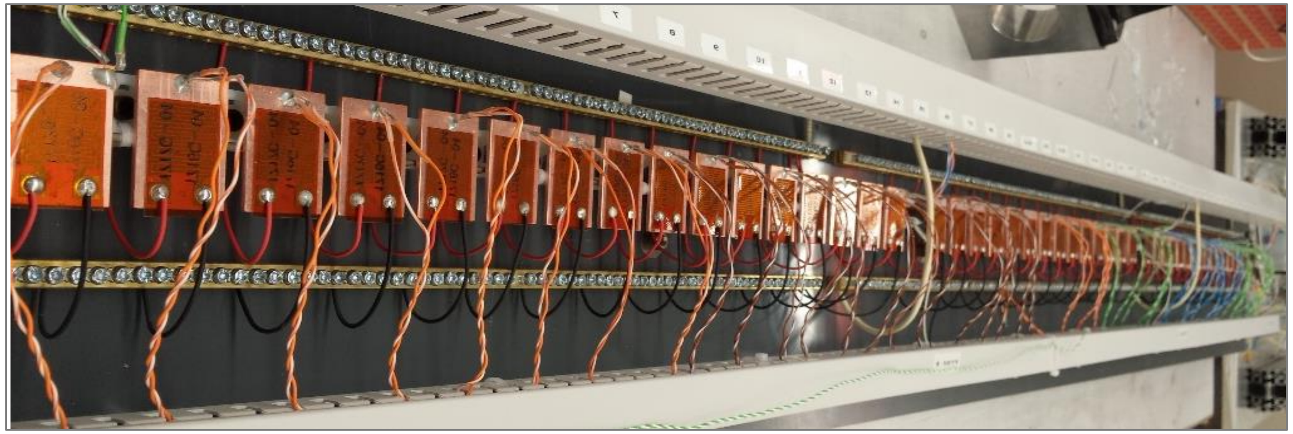
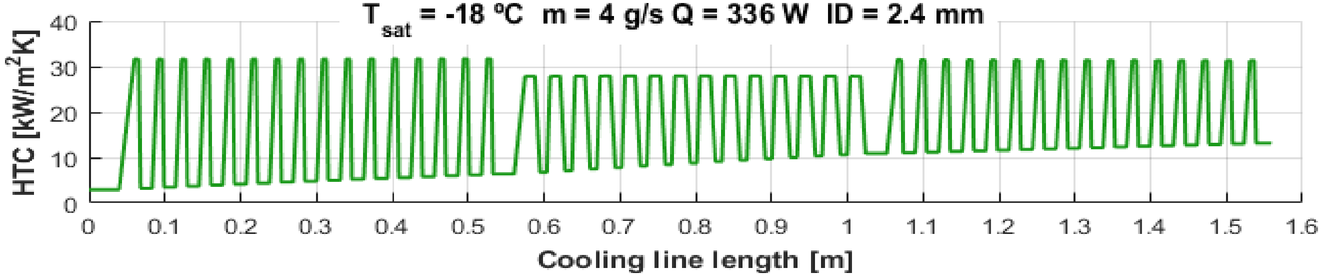








Sustained performance (ΔT, HTC) along the full length of the pipe for the different testing conditions

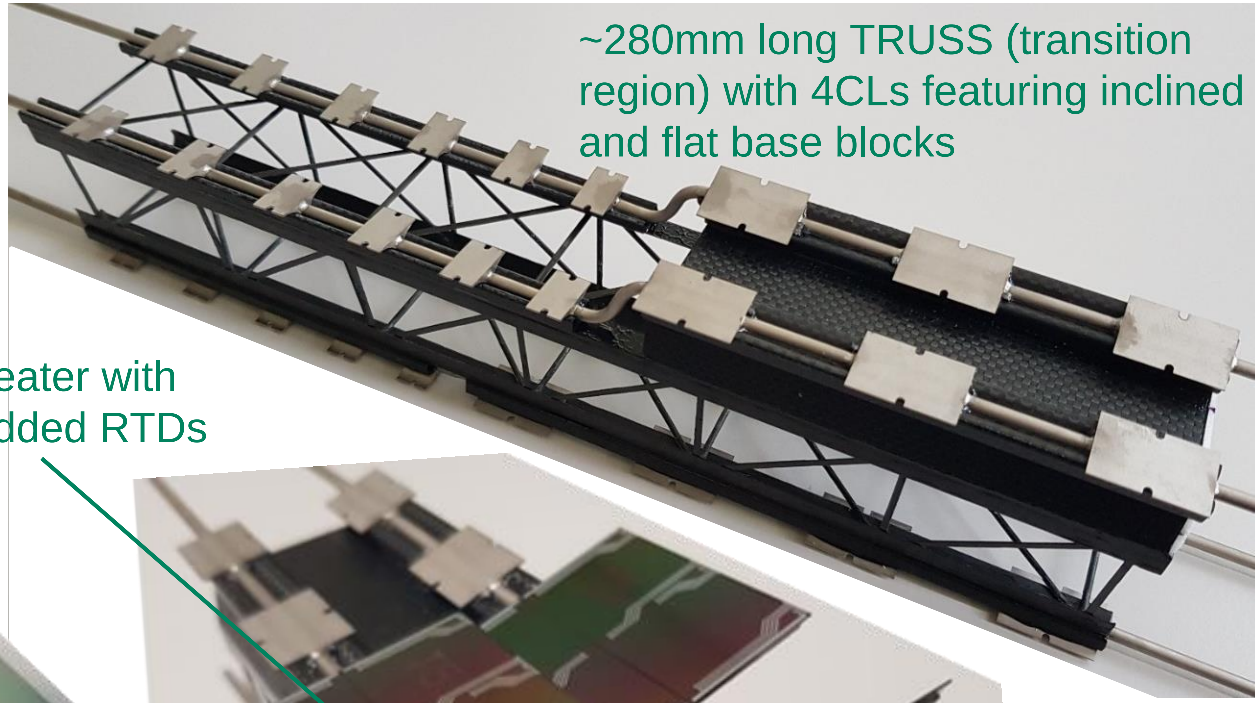


Good agreement with CO_2 semi-empirical models

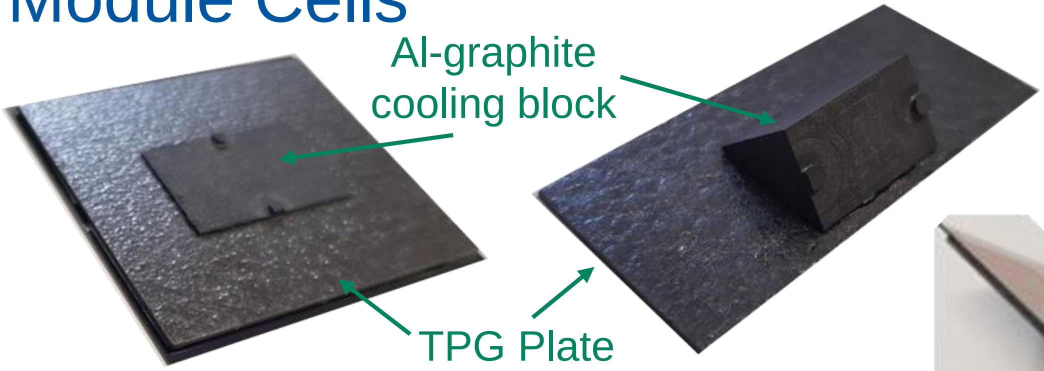
Prototyping: Functional Longeron & Module Cells

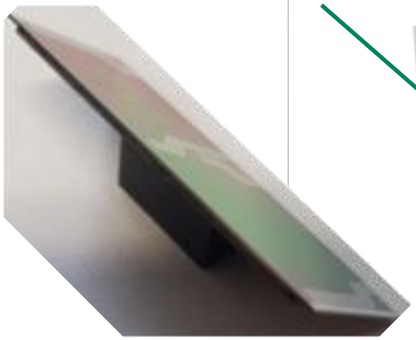
- Ti cooling pipes
- Base blocks
- Truss longeron

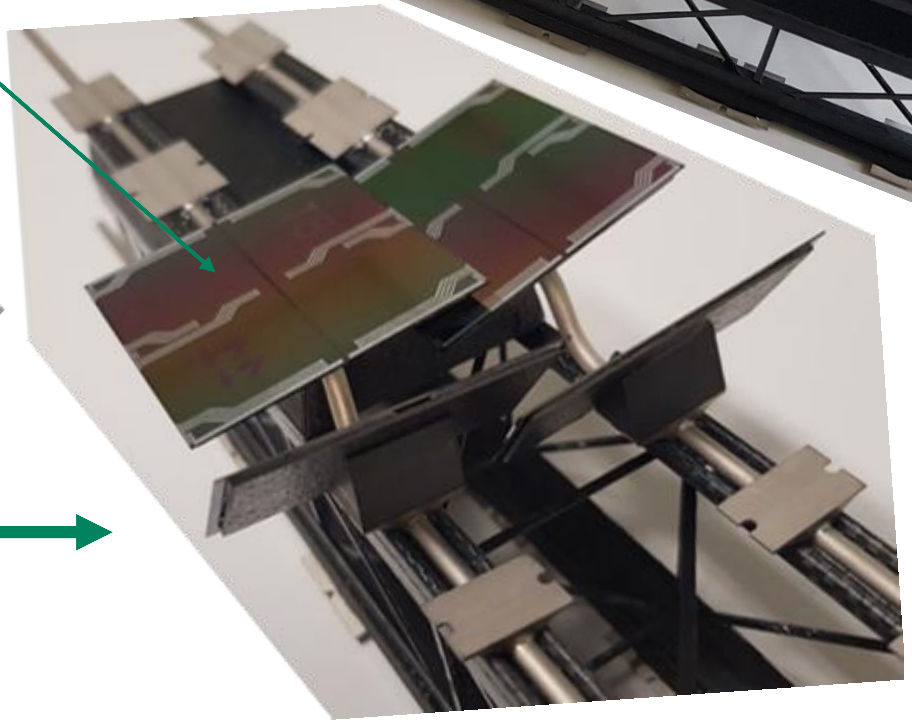
Ti cooling pipes and Base blocks: Soldered (Ni-coating); all three: Bonded → **Functional Longeron**



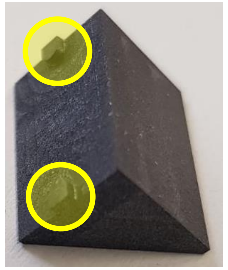
- Module Cells







- Loading is a two-step process
  - Cell Loading
  - Longeron Integration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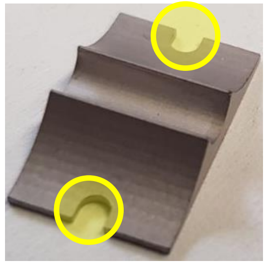
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