The LHC upgrades from a DTS Perspective

Doris Eckstein, DESY CMS group

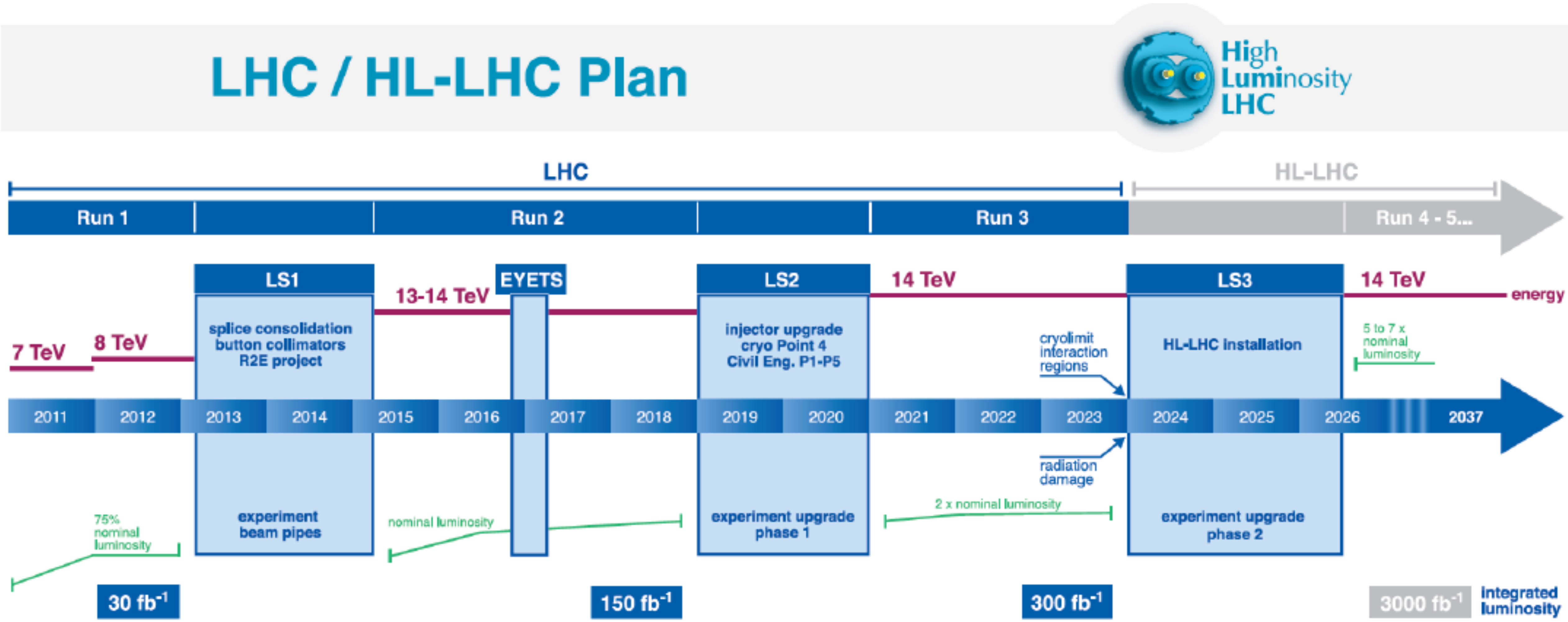
Disclaimer:

concentrate on what we do at DESY
the list ist not complete

HELMHOLTZ | ASSOCIATION

DESY

LHC Timeline



LHC (Run 1-3) until 2023 : 300fb^{-1}, Luminosity 1-2 x 10^{34} cm^{-2}s^{-1}

HL-LHC starting 2026 : 3000fb^{-1}, Luminosity 5-7,5 x 10^{34} cm^{-2}s^{-1}

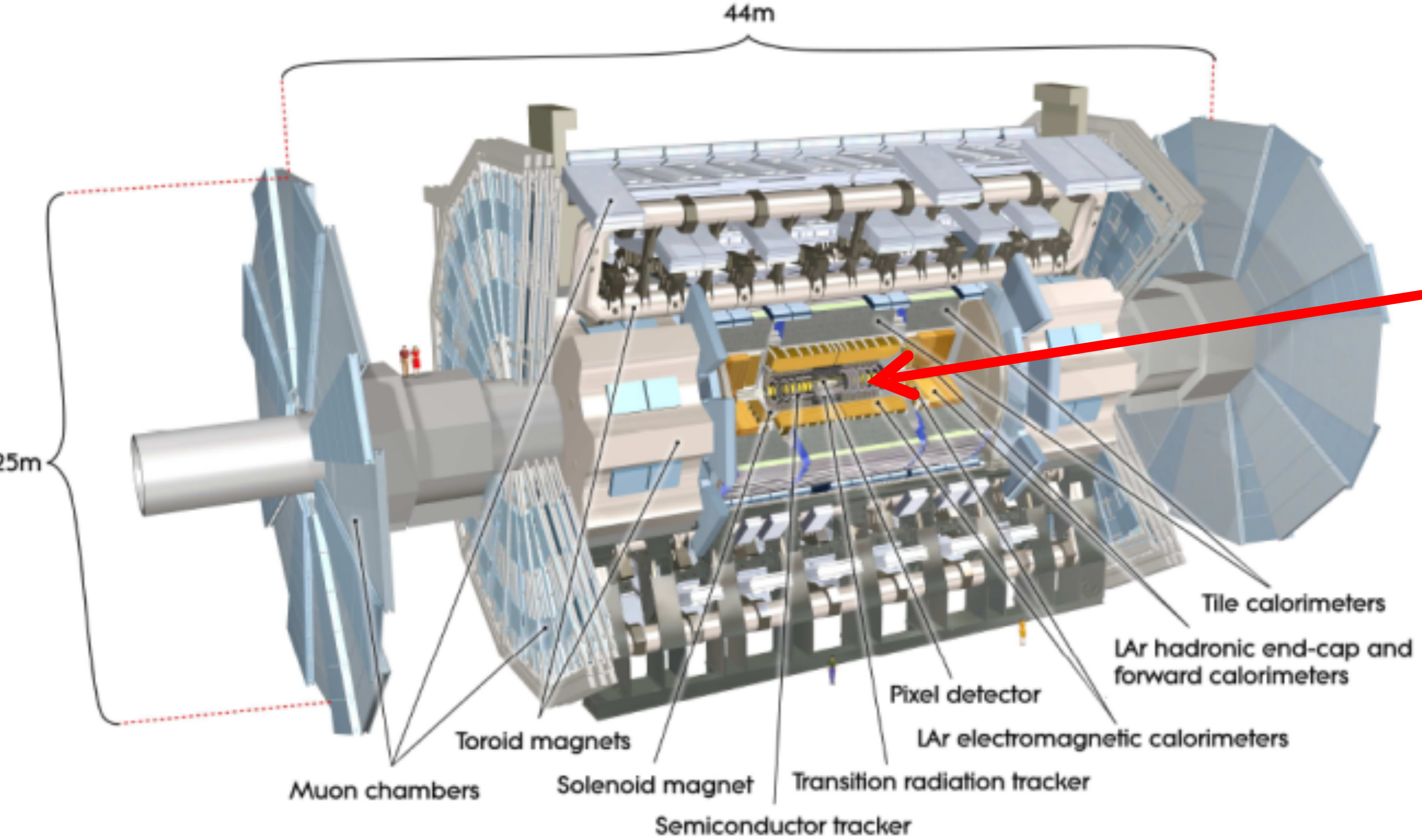
→ ~10 times higher trigger- and background rates

→ ~10 times higher radiation damage

Expect visible damage of the tracking detectors by end of Run 3

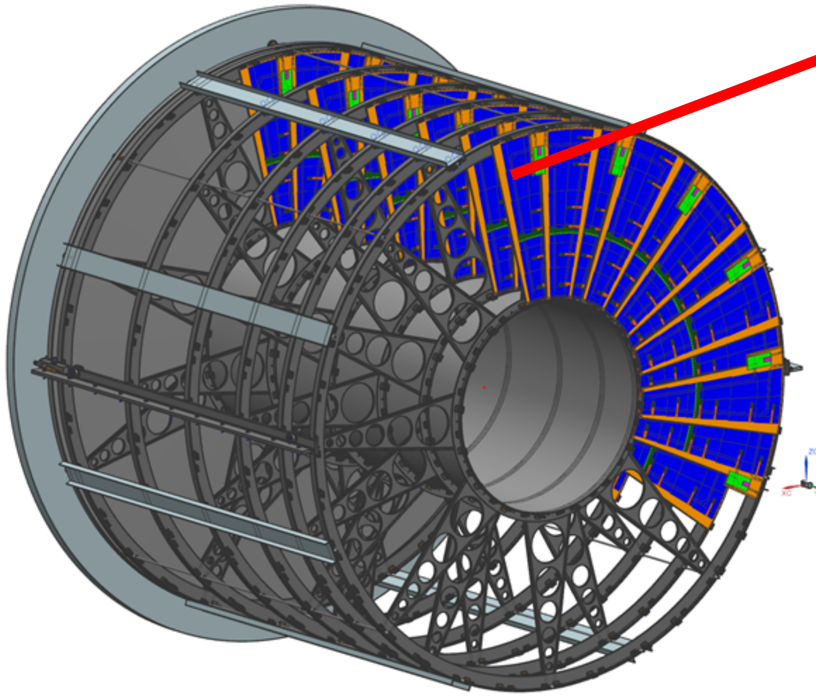
→ ATLAS and CMS need to build new Silicon-tracking-detectors for HL-LHC

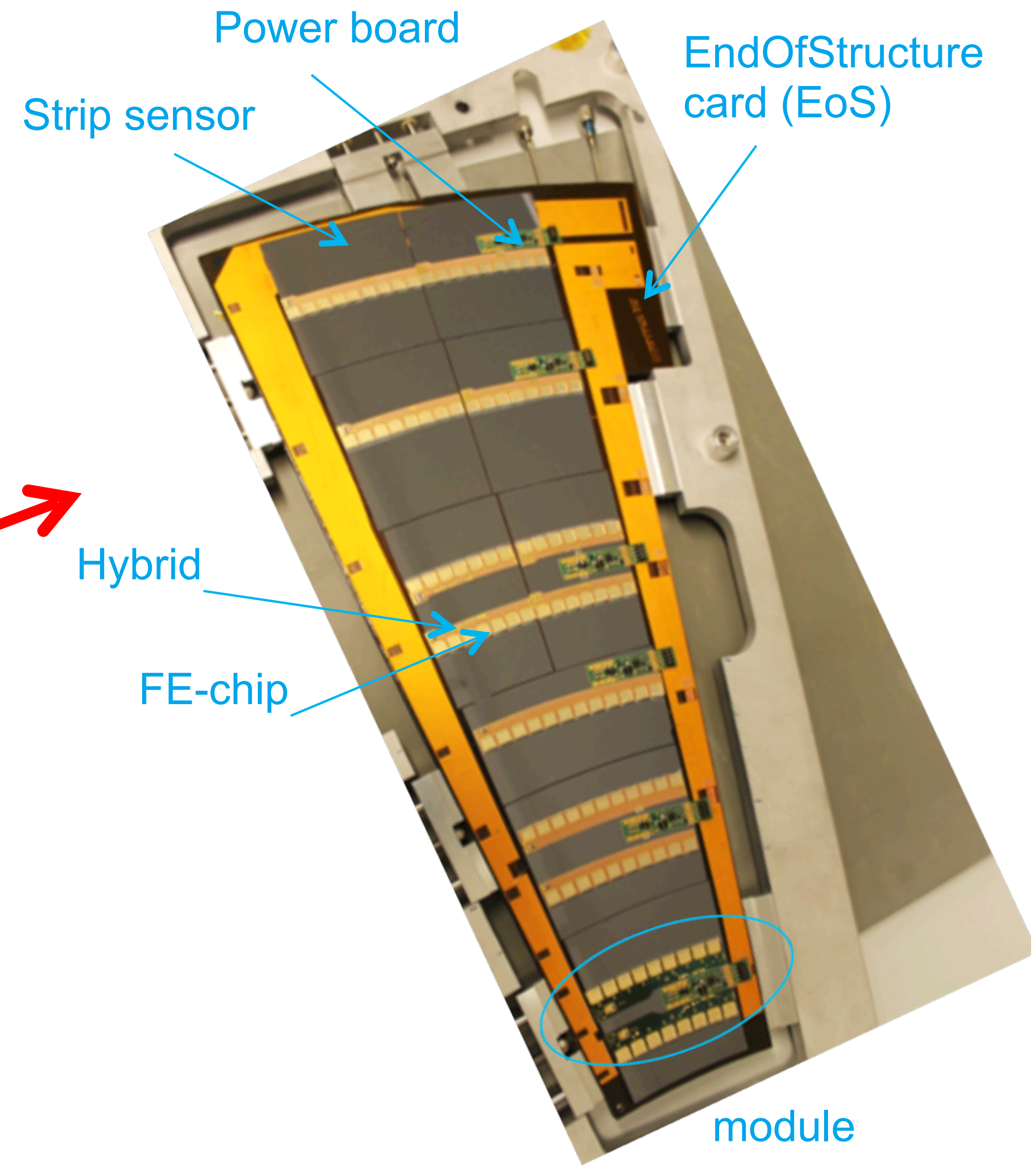
ATLAS Detector: Phase 2 Outer Silicon Tracker



New ATLAS silicon tracker
~165 m^2
~75M Channels

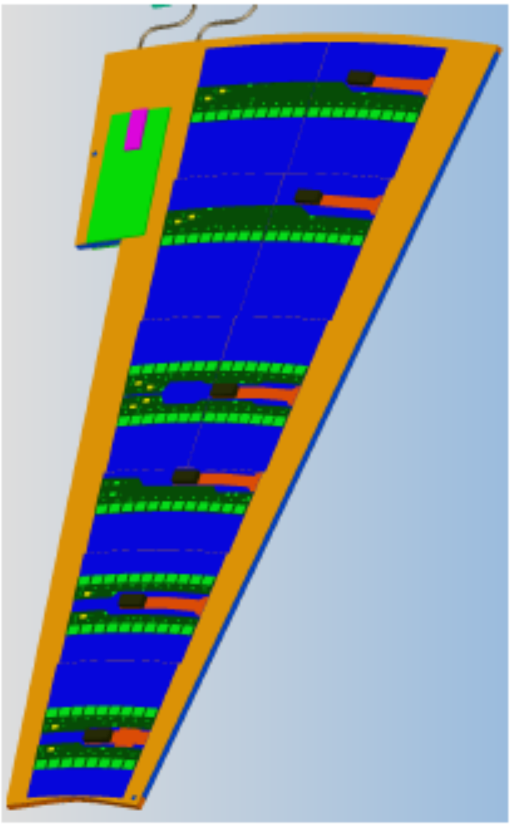
End cap : 6 disks
5000 silicon-sensor-modules



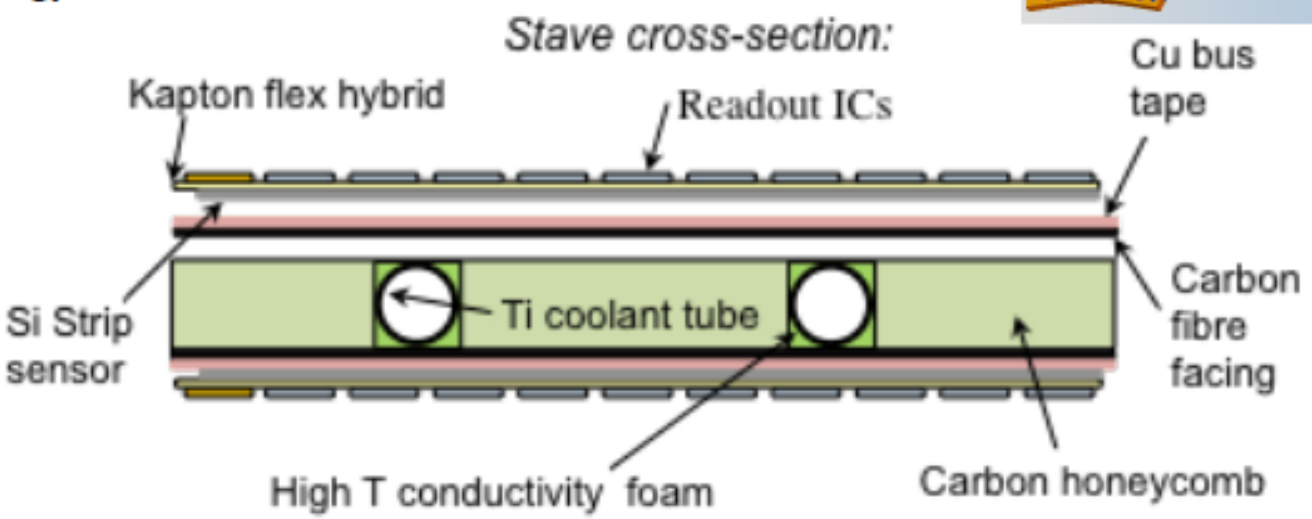


ATLAS Silicon Strip Tracker

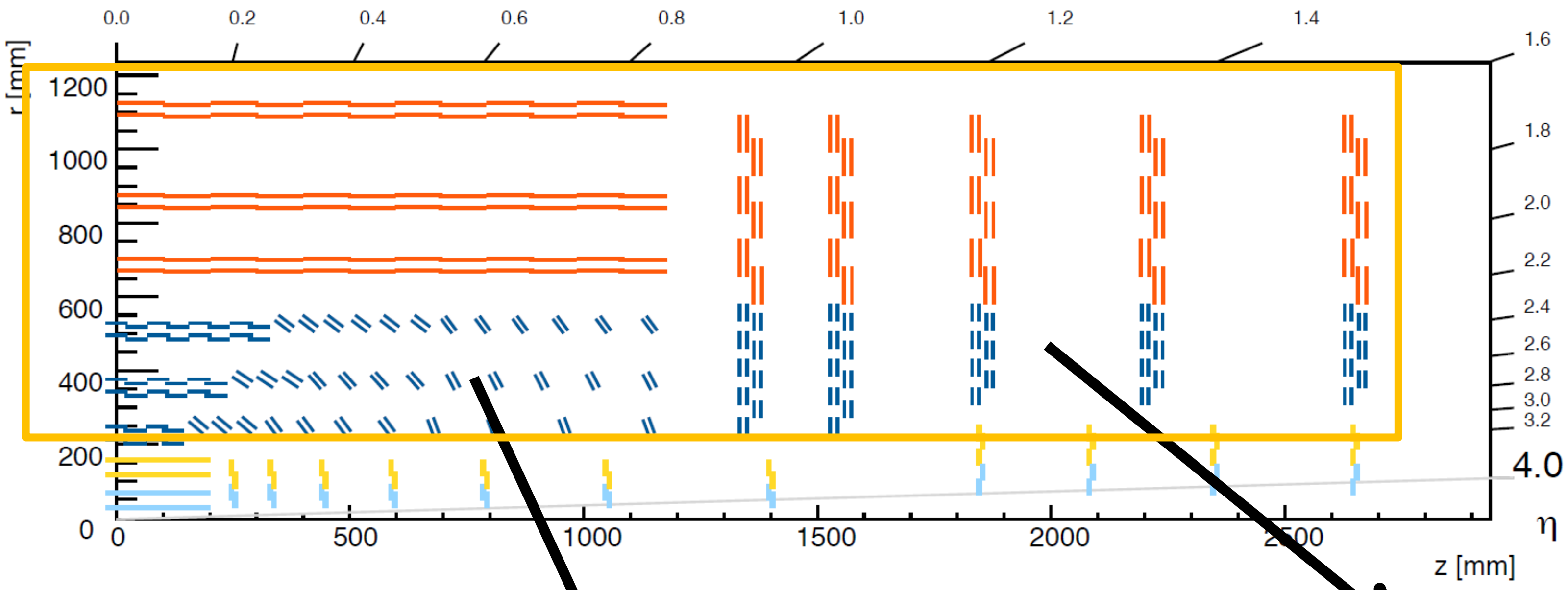
- Double-sided layers with implemented stereo angle (52mrad)
  - Short (~2.5 cm) and long strips (~5 cm) with 74.5 µm pitch in barrel
  - End-Cap with radial strips of different pitch (6 different module designs)
- Stave/petal one object; top and bottom side read out separately



- Silicon Modules directly bonded to a cooled carbon fibre plate.
- Services integrated into plate including power control and data transmission.

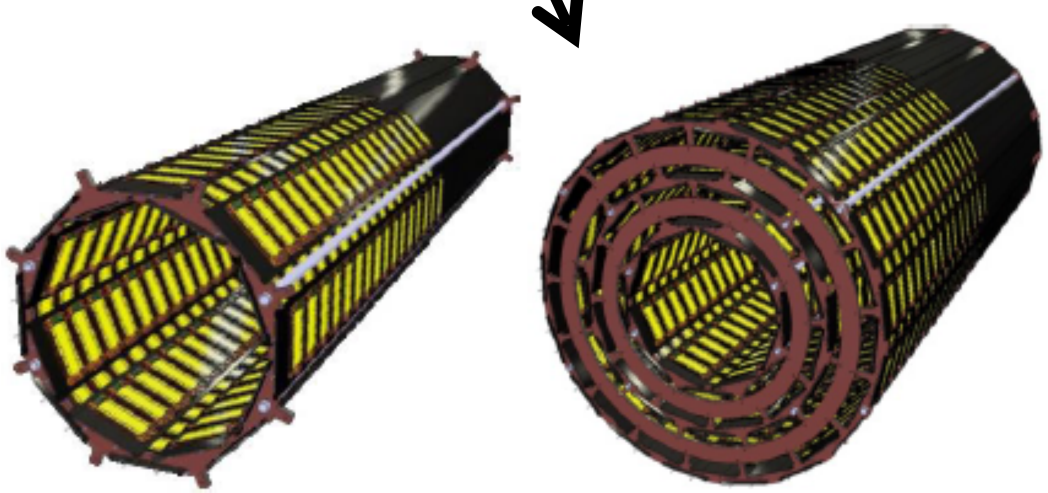


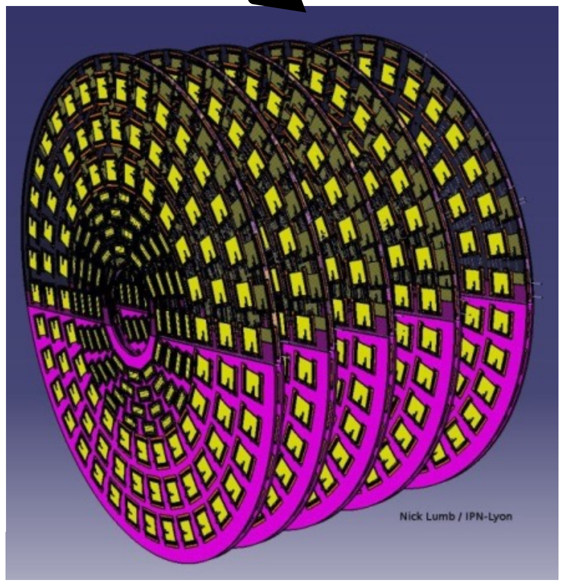
Outer Tracker



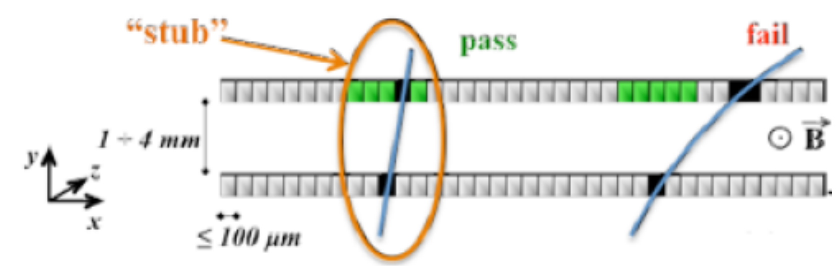
6 barrel layers
2x5 disks (Endcap)

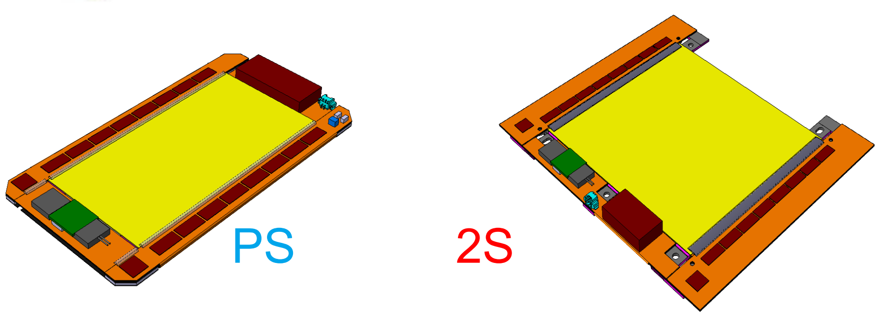
2 Module types :
double layer of silicon sensors
r > 60 cm: 2Strip (2S)
r < 60 cm: Pixel-Strip (PS)



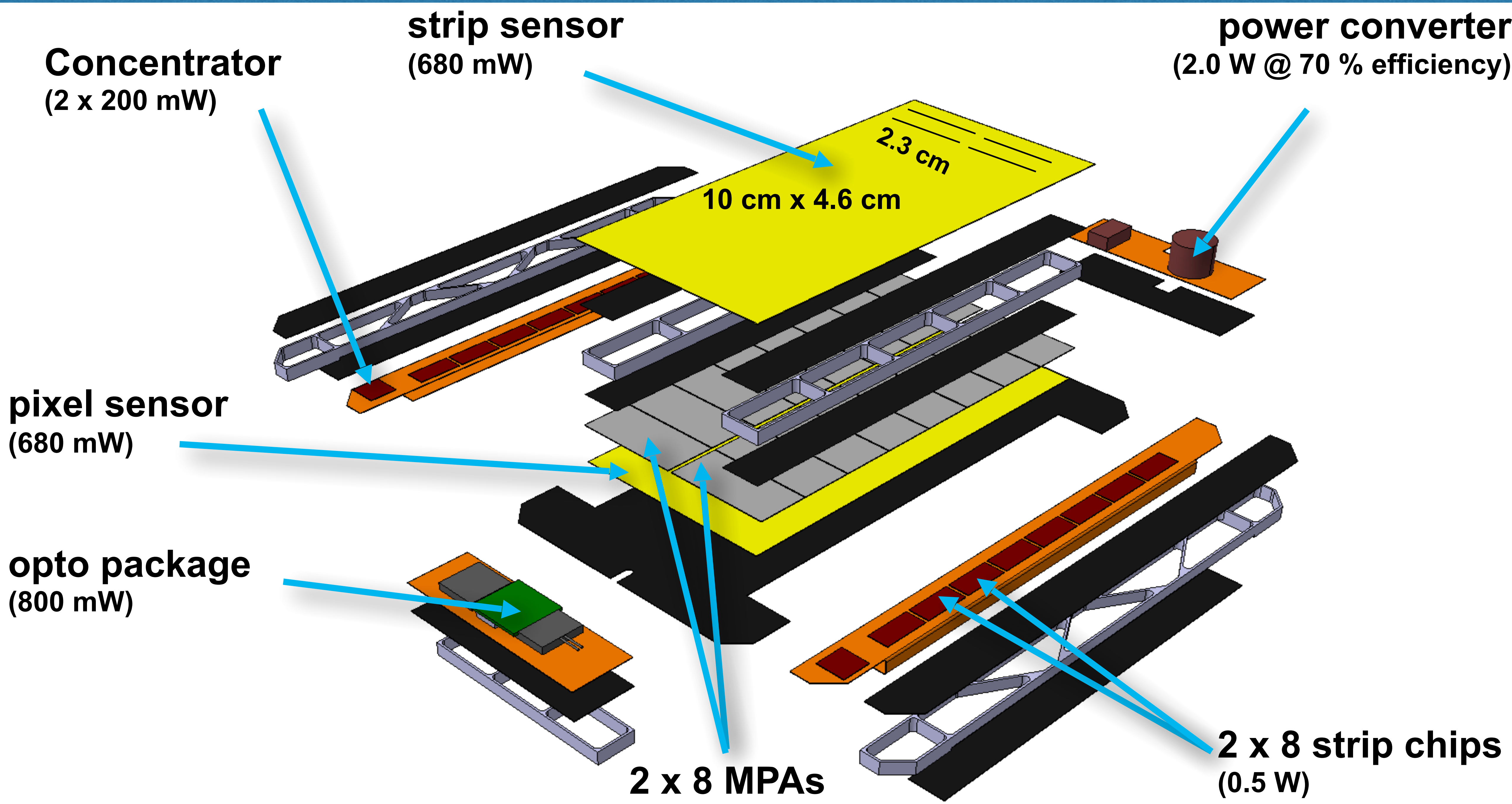


Radius ~ 110 cm
Length ~ 140 cm



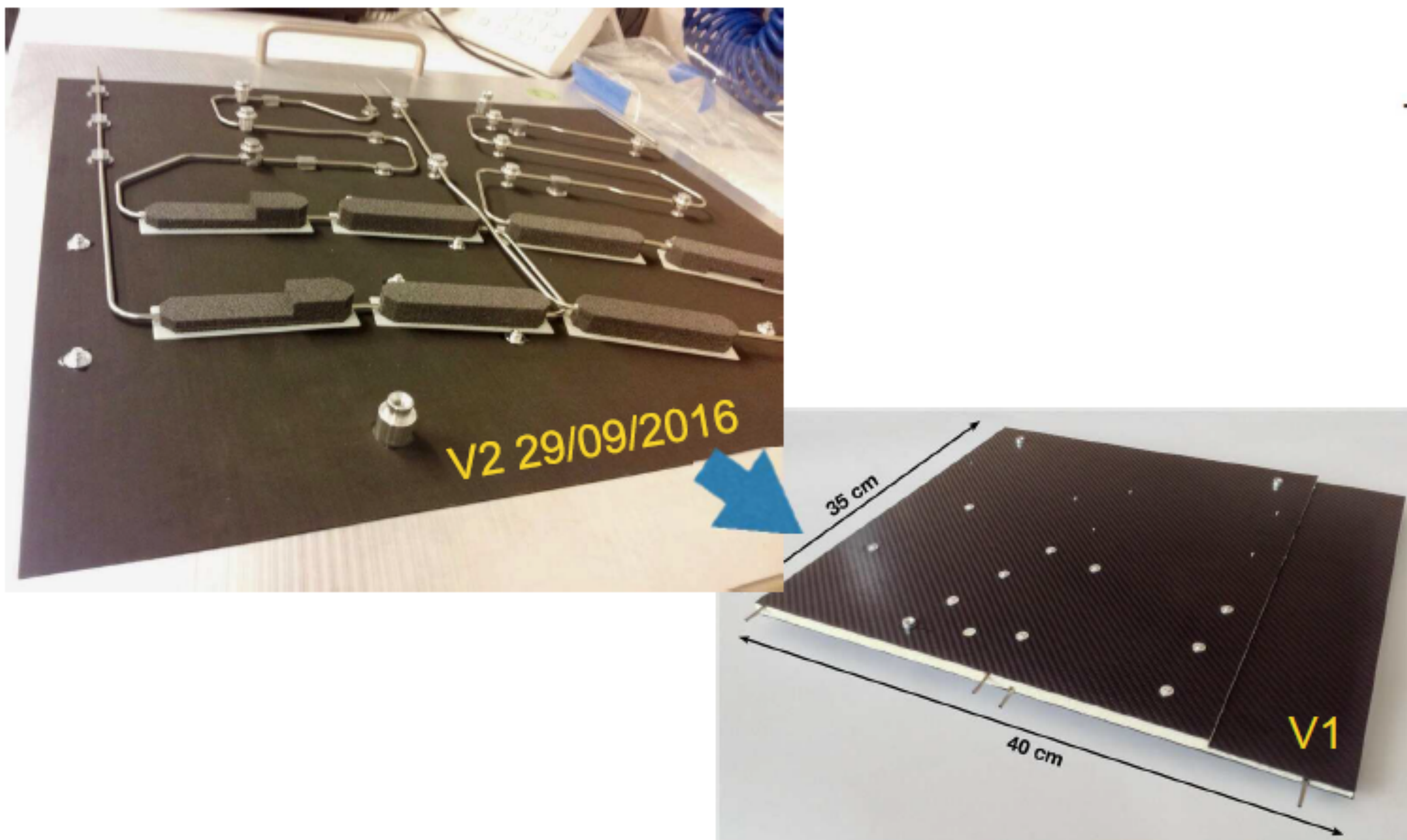


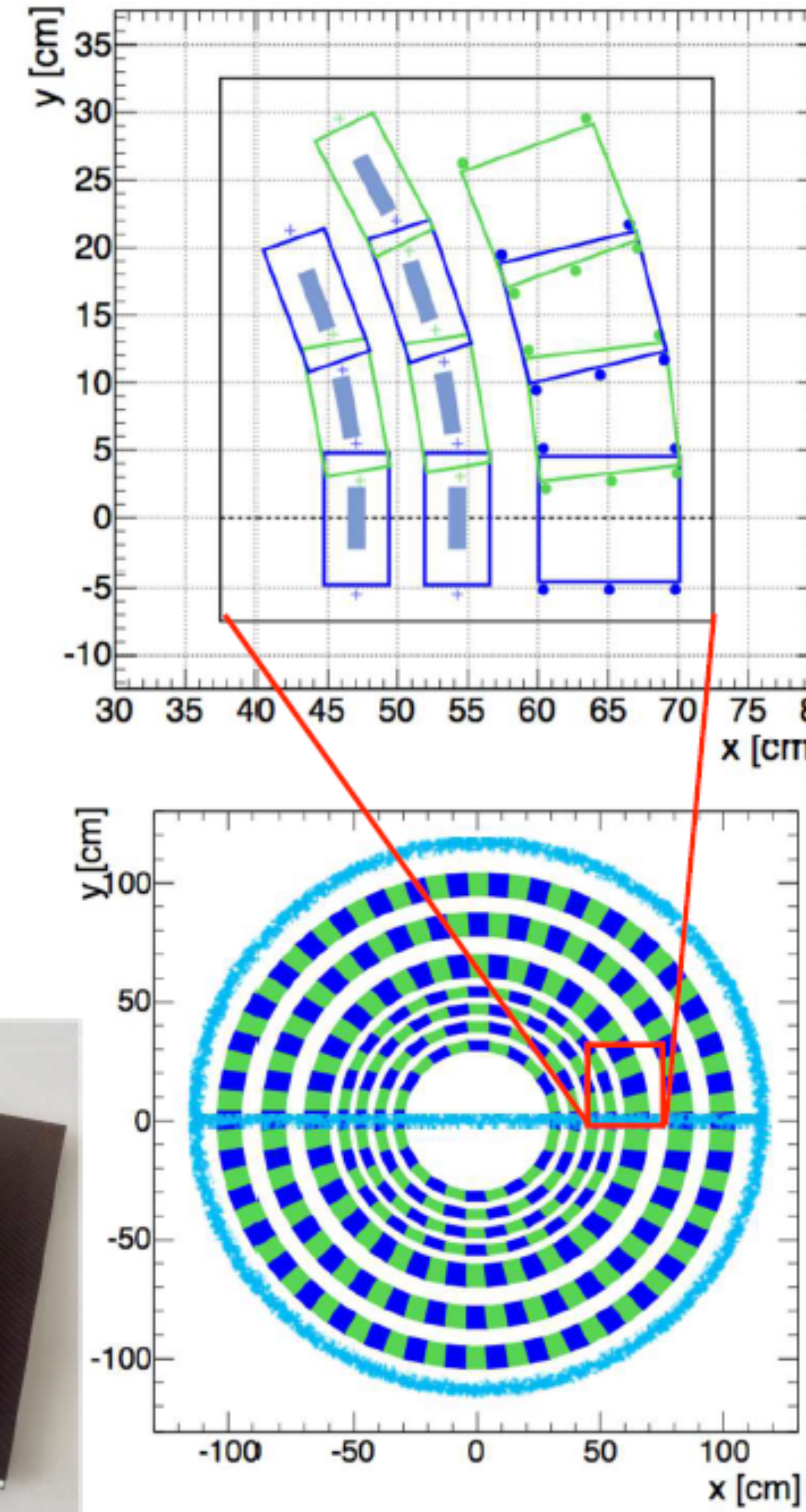
local p_t-discrimination
providing L1 trigger input



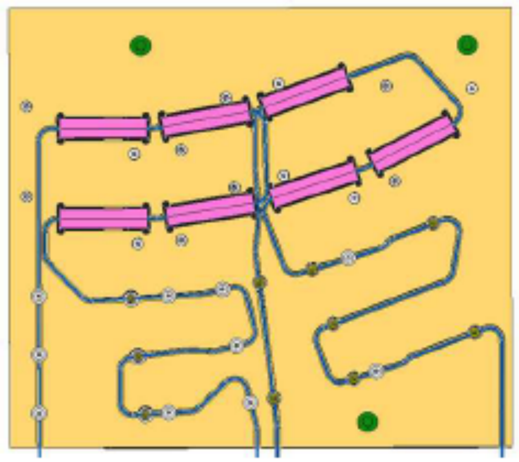
- Macro Pixel Asic
- performs correlation and produces stubs
- 3.0 W

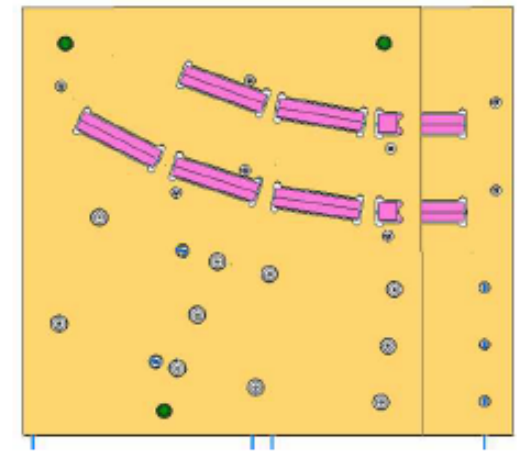
- small (35 cm x 40 cm) part of a dee with all features
  - transition between PS and 2S regions
  - edge of dee
  - two small cooling sectors
- lessons learned from first version are currently being implemented in second version
  - with a few changes in the design
  - geometrical precision expected to be within specs

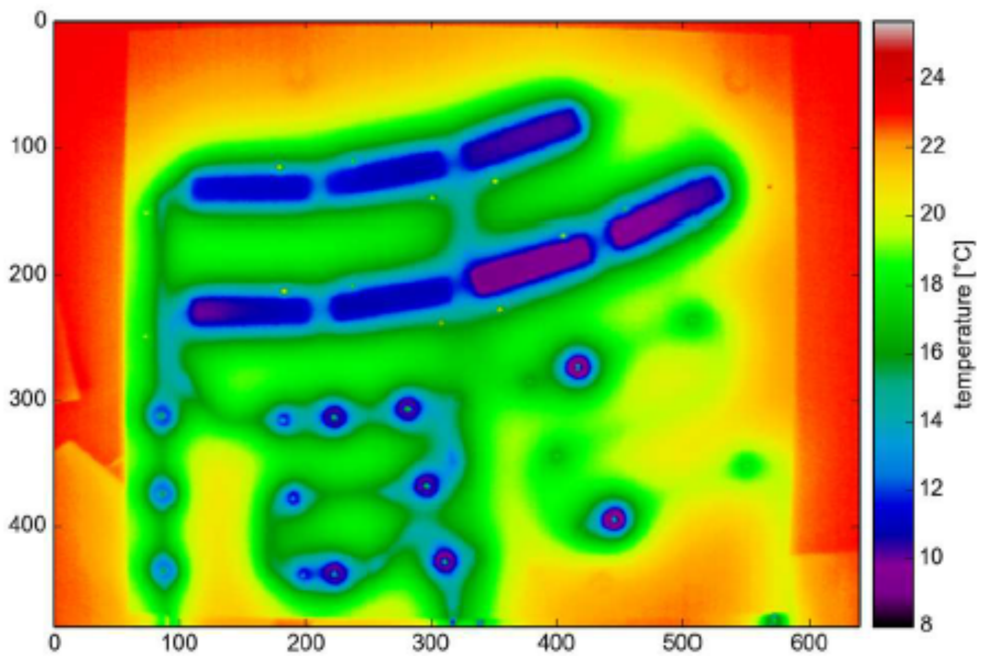


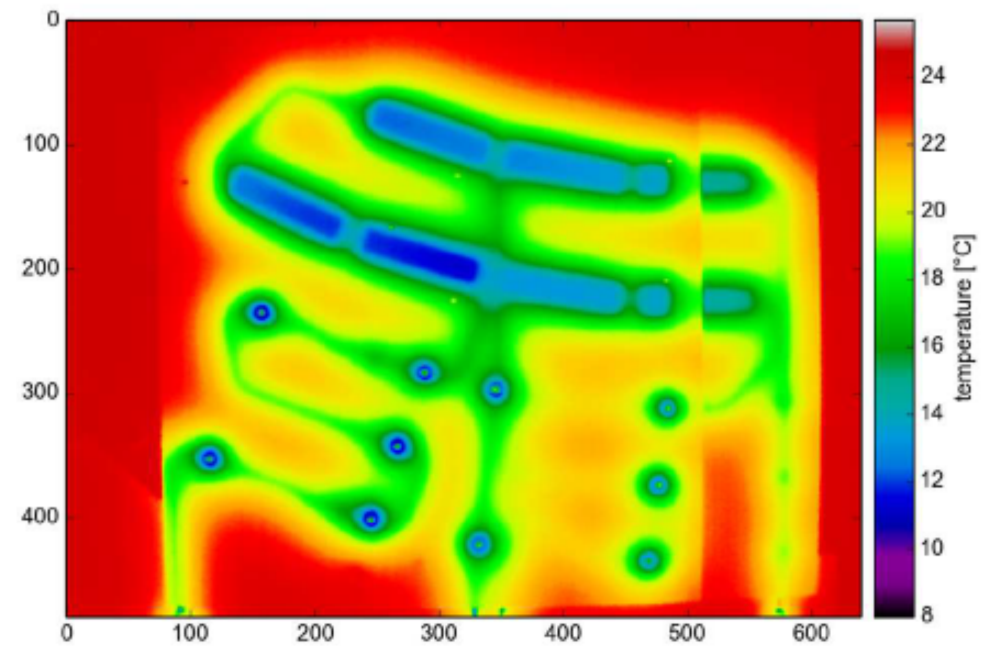


CMS: Dee Prototype - Thermal Testing



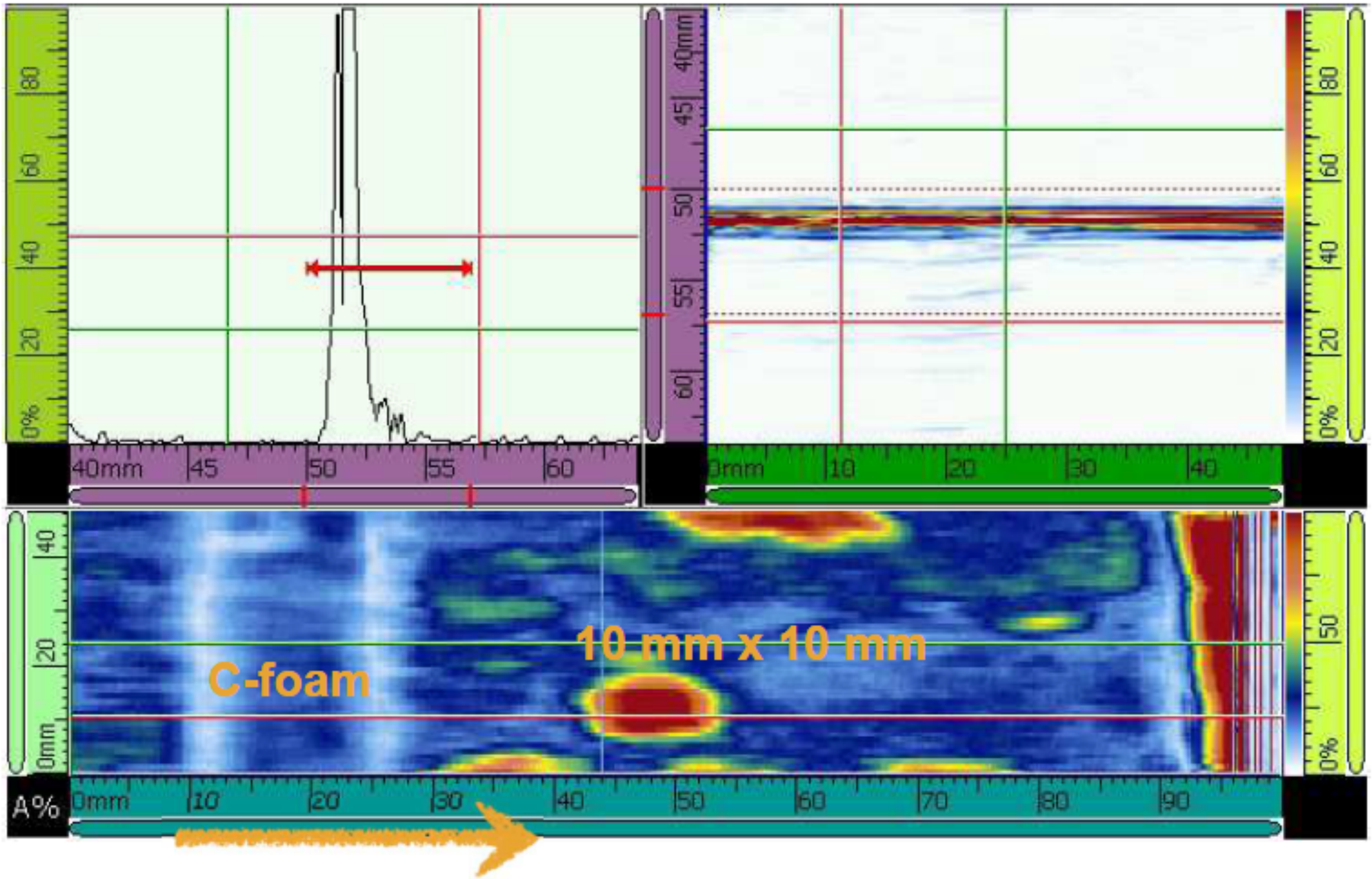


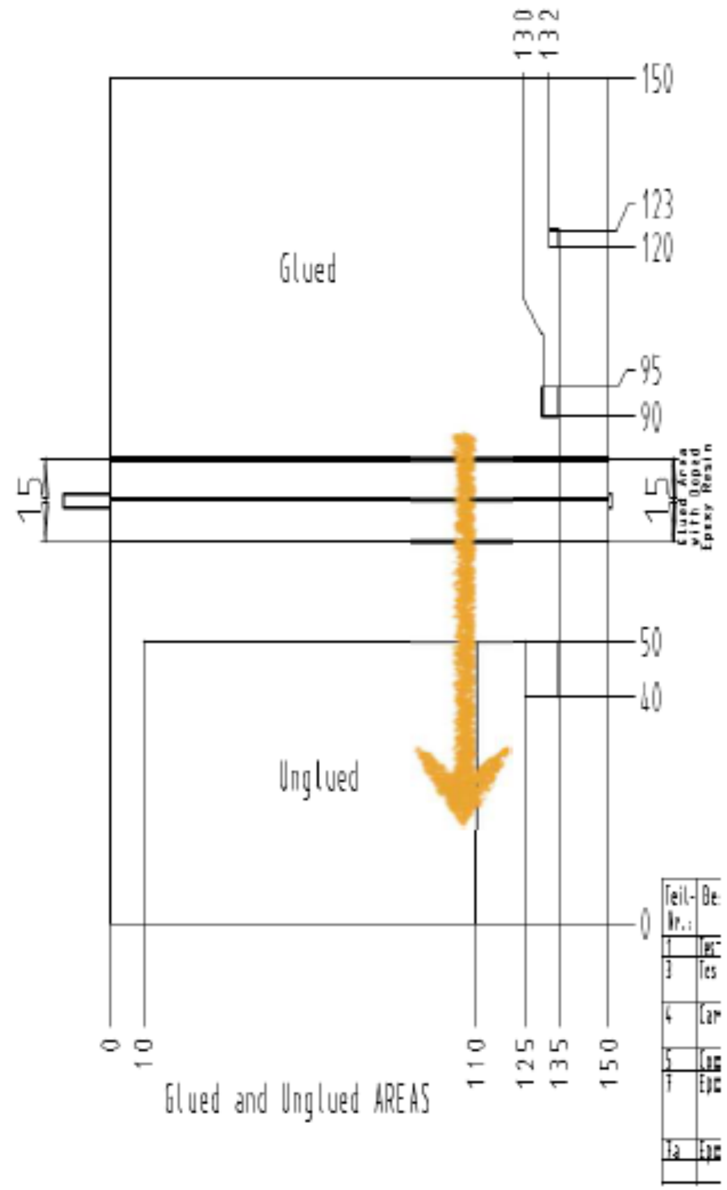




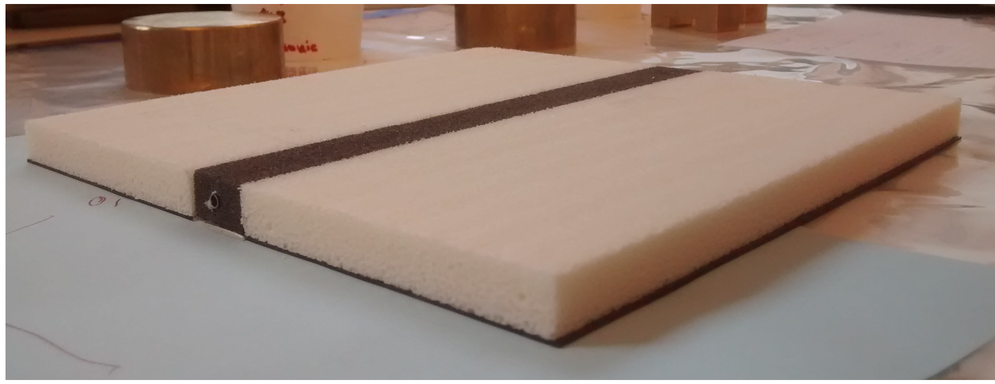
- prototype connected to conventional cooling system
- feasibility studies of IR measurements as diagnostic tool
  - check thermal interface between C-foam and facing
- looks promising as a tool for QA

CMS: Ultrasonic Testing



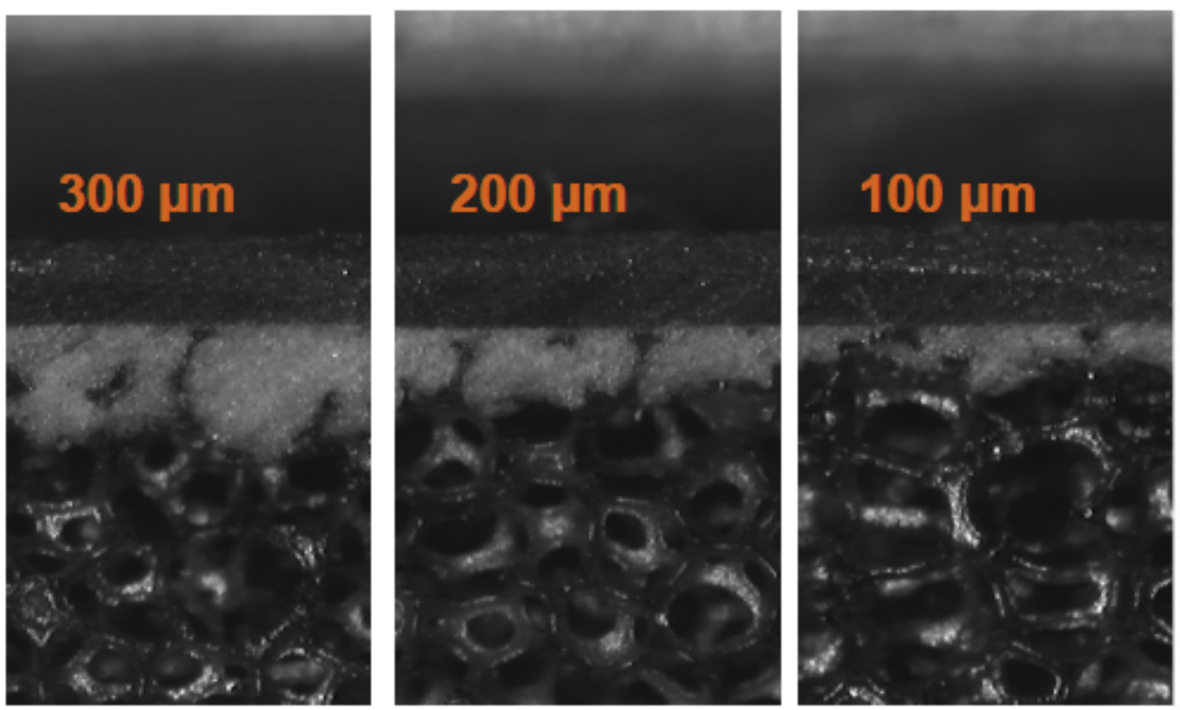


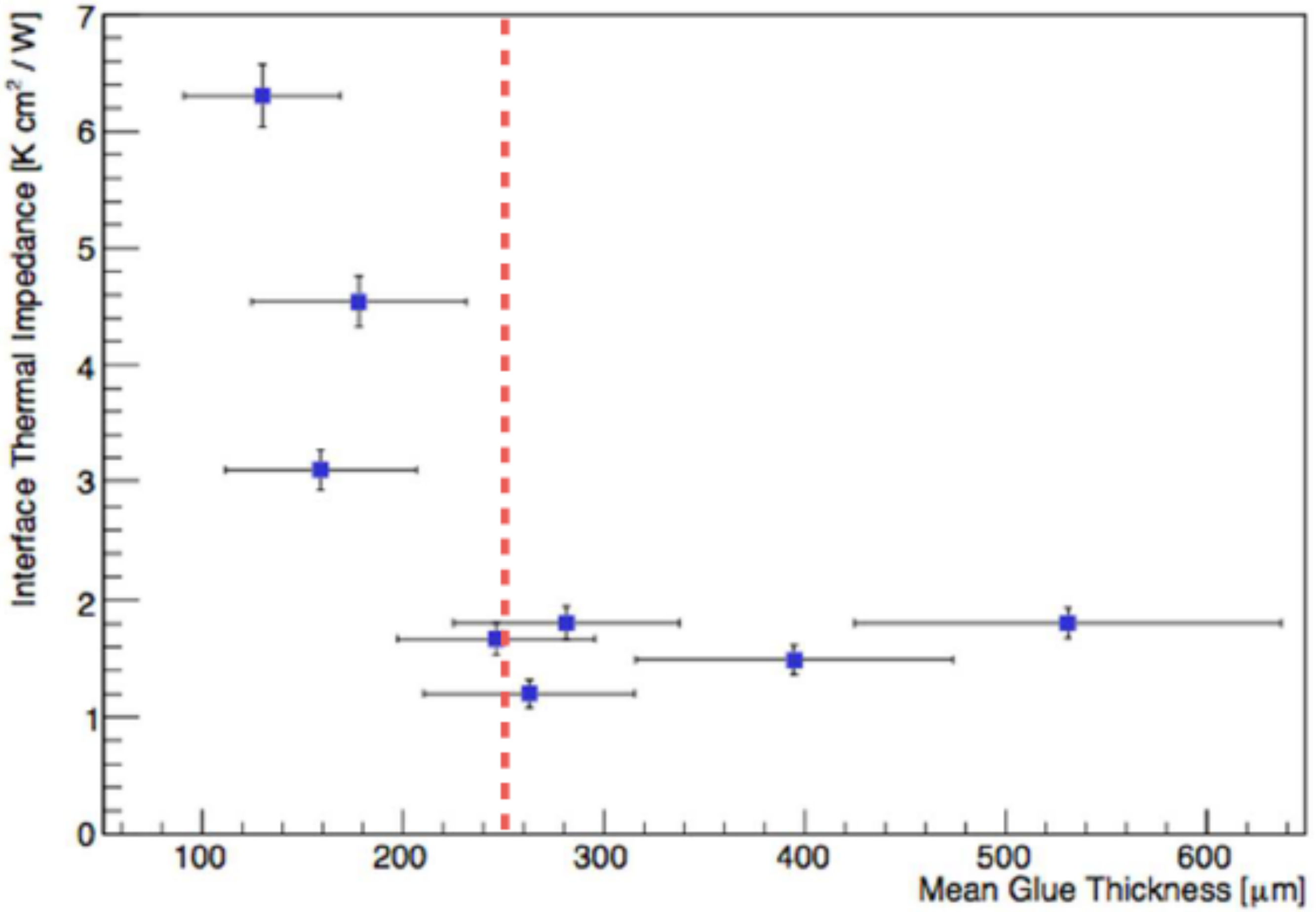
- feasibility studies of ultrasonic measurements as diagnostic tool
  - check glue joints, especially thermal interface between C-foam and facing
- several test samples with dedicated imperfections produced
  - grooves in airex and C-foam
  - oil and water spots
  - un-bonded areas of sizes 3 mm x 3 mm, 5 mm x 5 mm and 10 mm x 10 mm



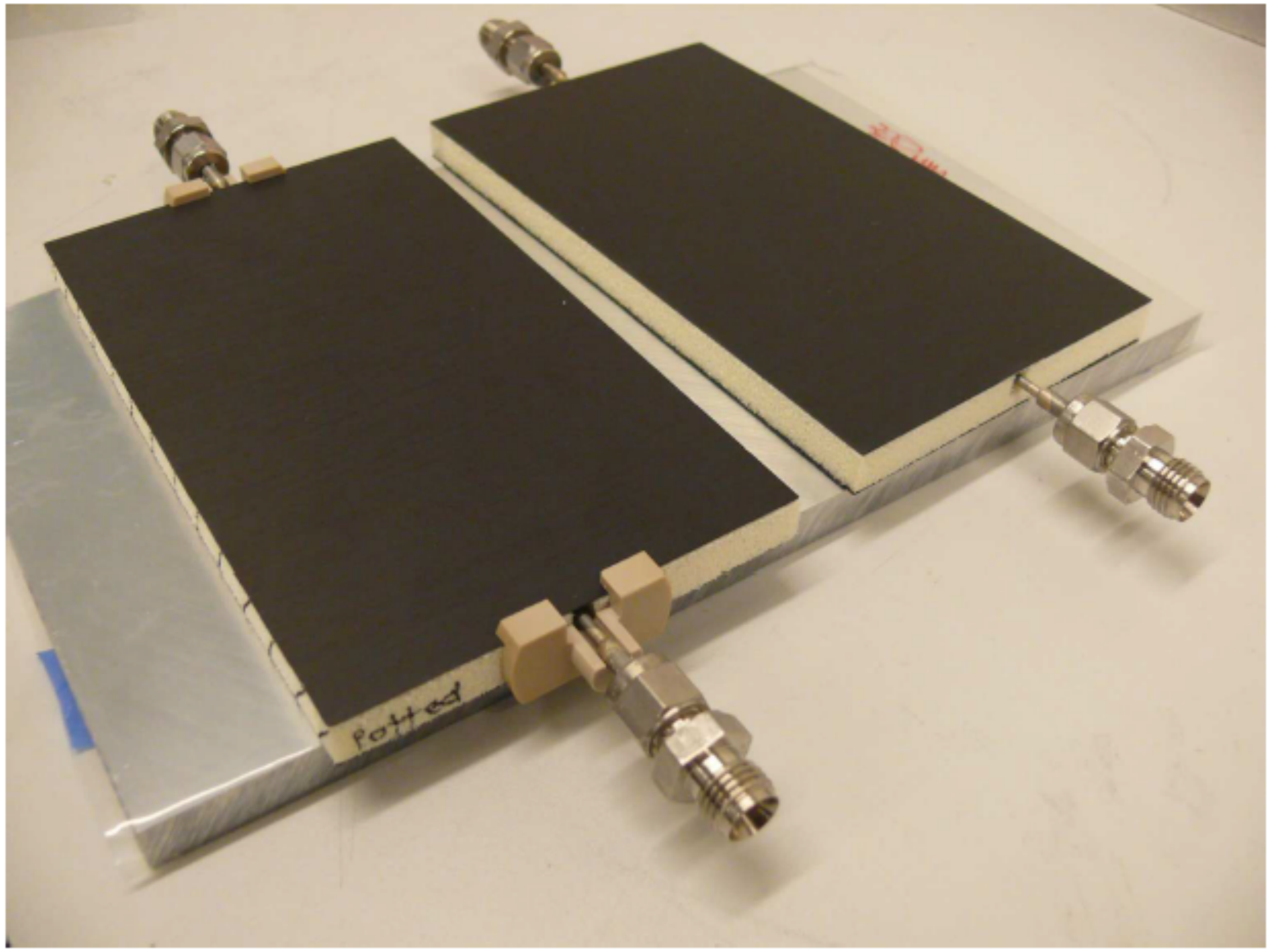
CMS: Generic R&D - CVD Carbon Foam

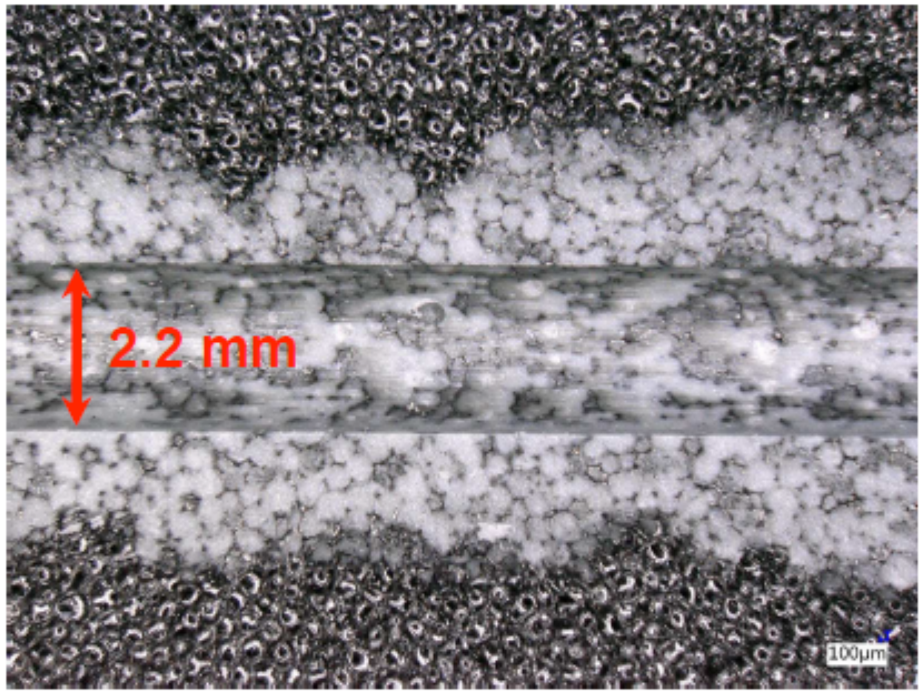
- high thermal conductivity at low density
  - thermal conductivity: 10 W/m/K - 75 W/m/K
  - density: 0.09 g/cm^3 - 0.35 g/cm^3
- thermal contact between foam and pipe / CFRP / … depends on amount of glue
  - glue is pushed into foam and increases contact surface area
  - not enough glue: large thermal impedance
  - too much glue: extra mass with no benefit in terms of thermal impedance
  - in any case: distance between foam and other part has to be as small as possible
- thermal impedance as function of glue thickness that is pushed into foam
  - at around 250 μm a minimum is reached





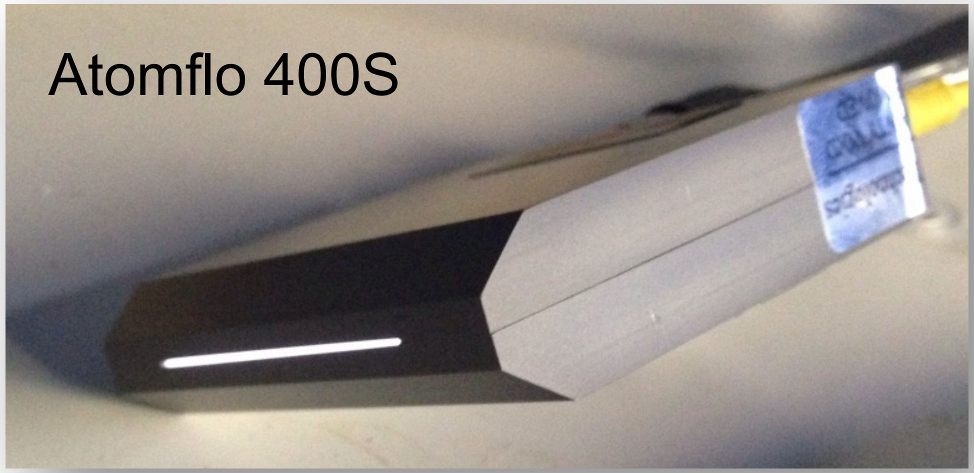
CMS: TEDD Thermal Mockup

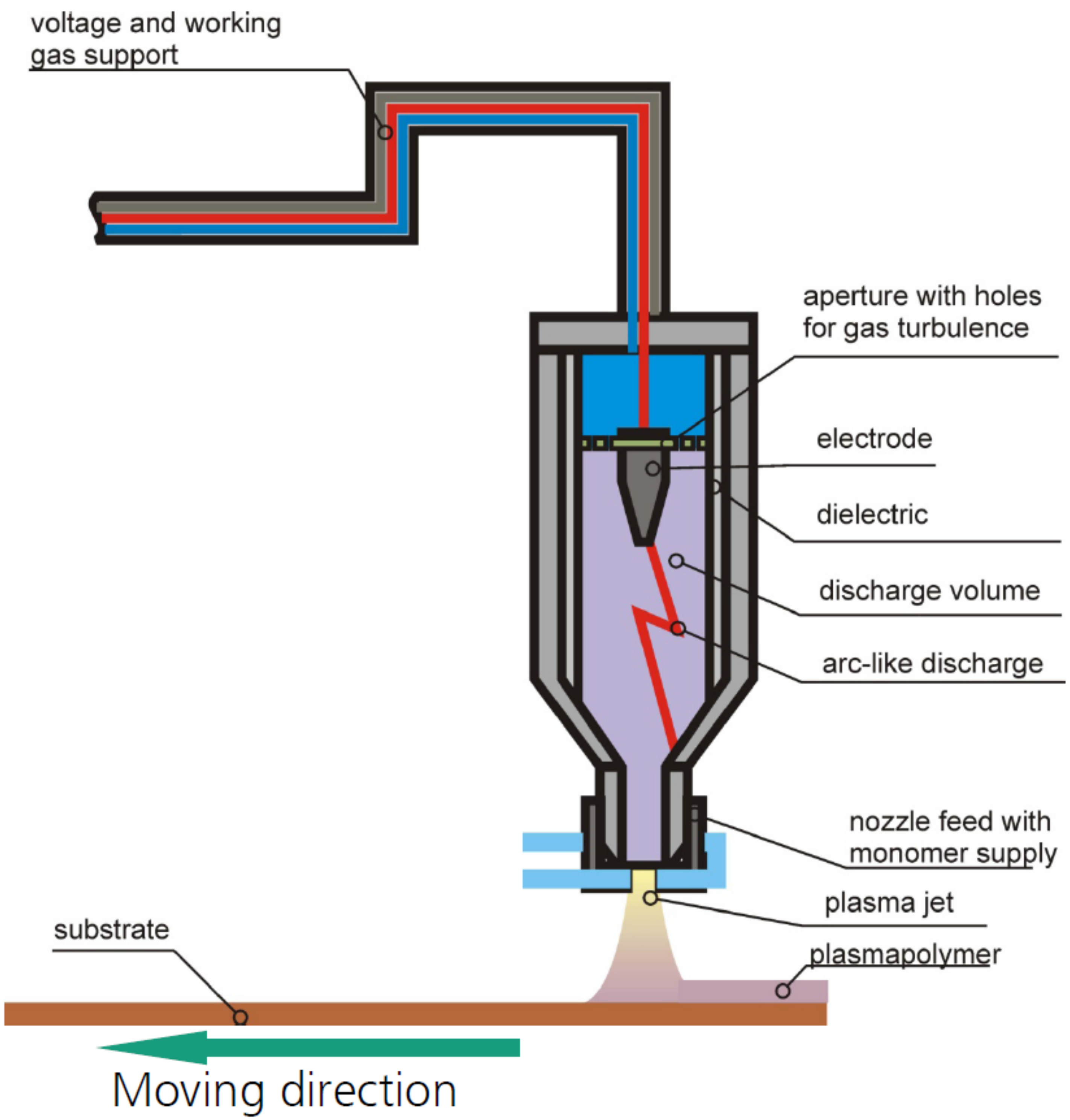




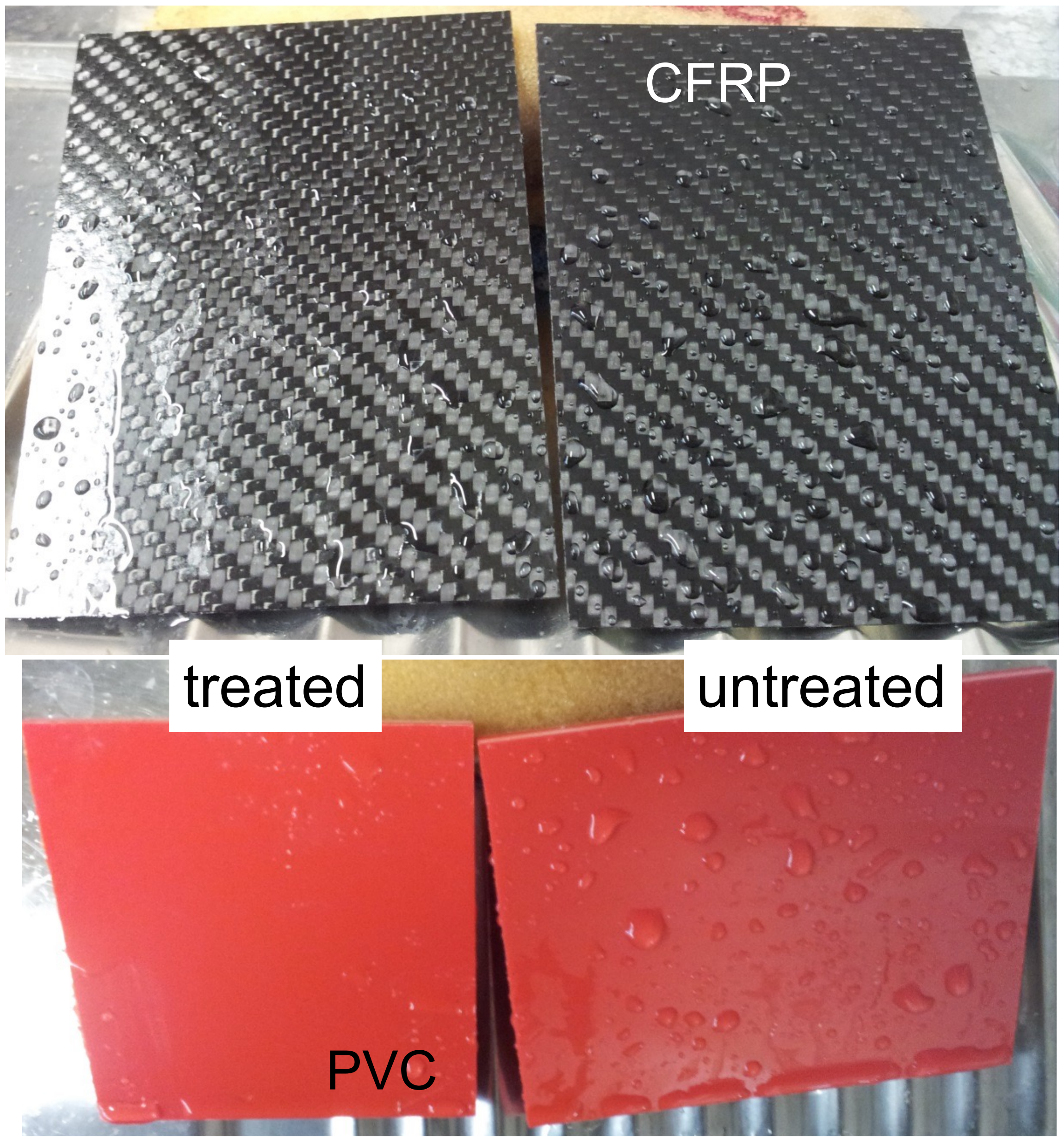
- thermal mockups for one PS module build and ready for testing
  - two different types of pipe gluing techniques used
    - pipe directly glued into carbon foam
    - groove in carbon foam potted with glued and re-machined (see image)
- structures will be sent to Lyon for qualification with thermal mockup PS module

- clean and activate surfaces before glueing for better adhesion
- No chamber needed
- Our plasma device
  - RF-discharge
  - Helium as primary gas
  - Oxygen as secondary gas
  - 2 inches linear head

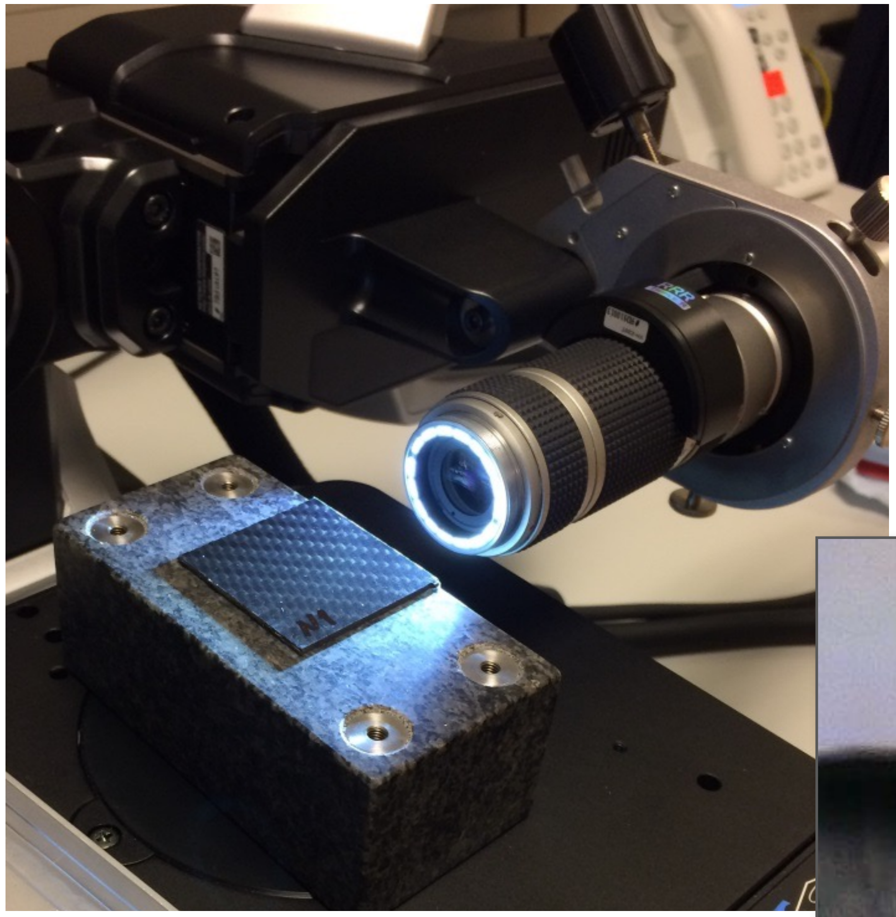


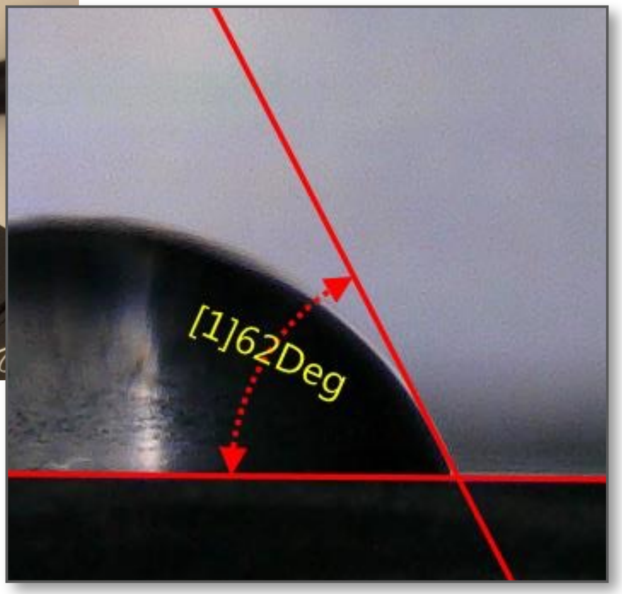


- Surface energy test with water drops
- Better wettability in left samples



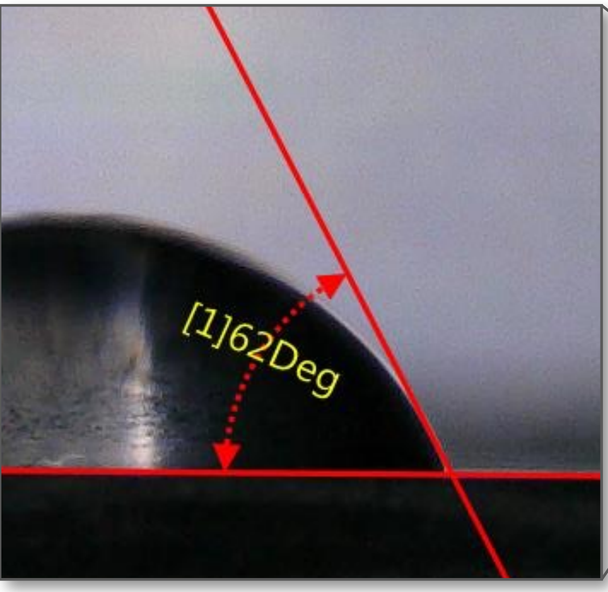
- Quantify:
- apply water drop (defined amount)
- measure contact angle
- verify dependence on plasma treatment

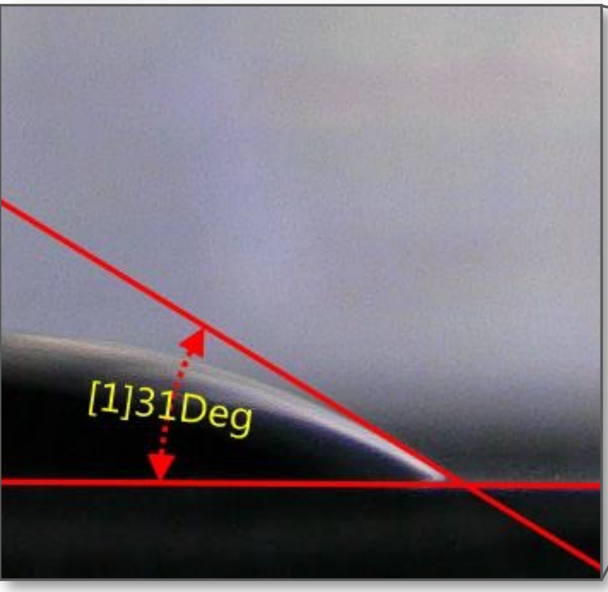


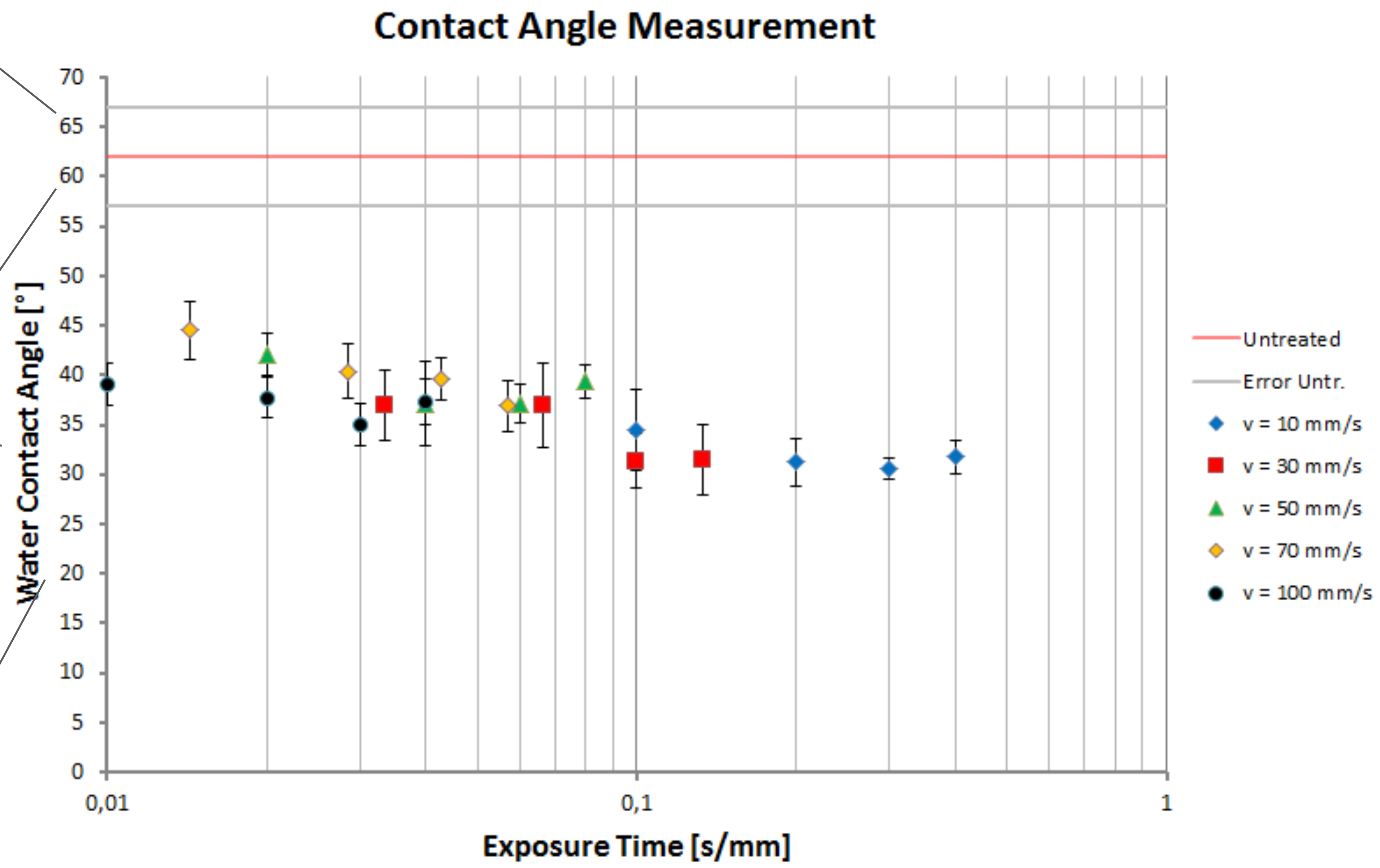


> Drop size of 6µl distilled water applied on samples (CFRP)

- Treated sample parameters: 180W, 4.5mm distance, several speed and scan values



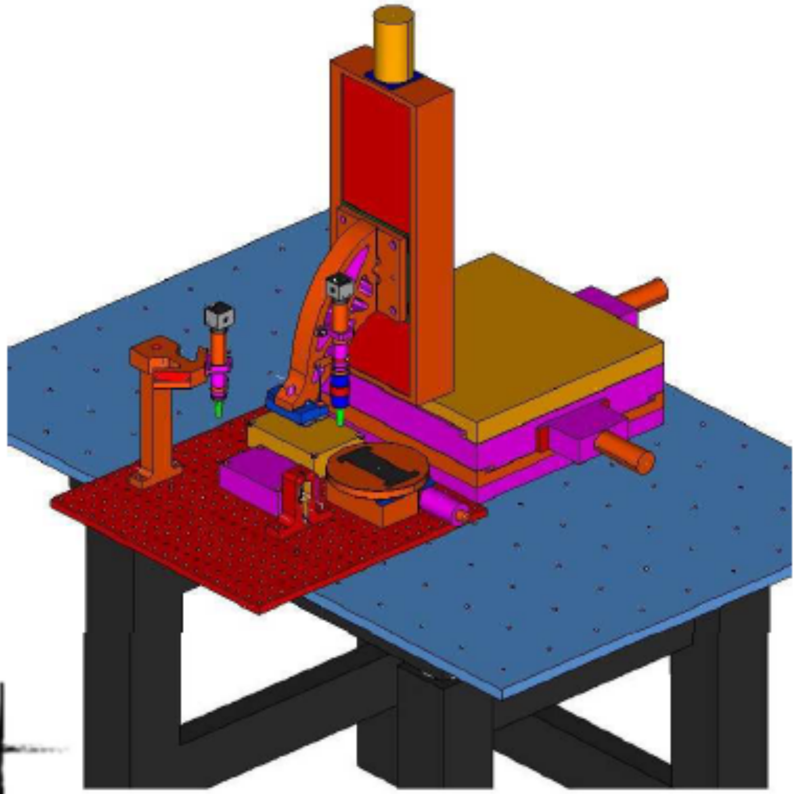


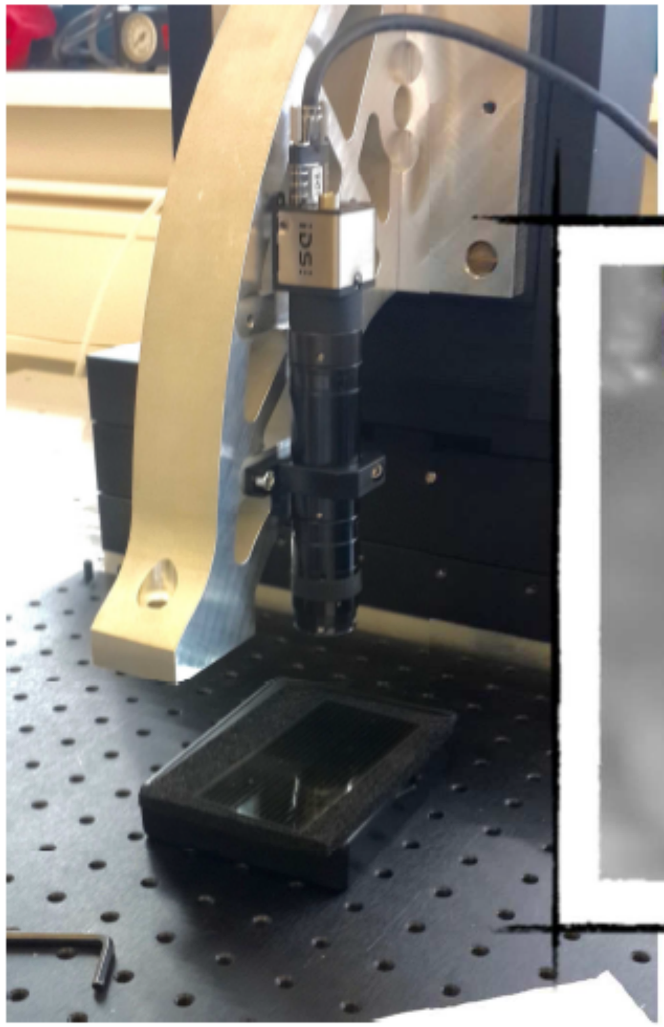


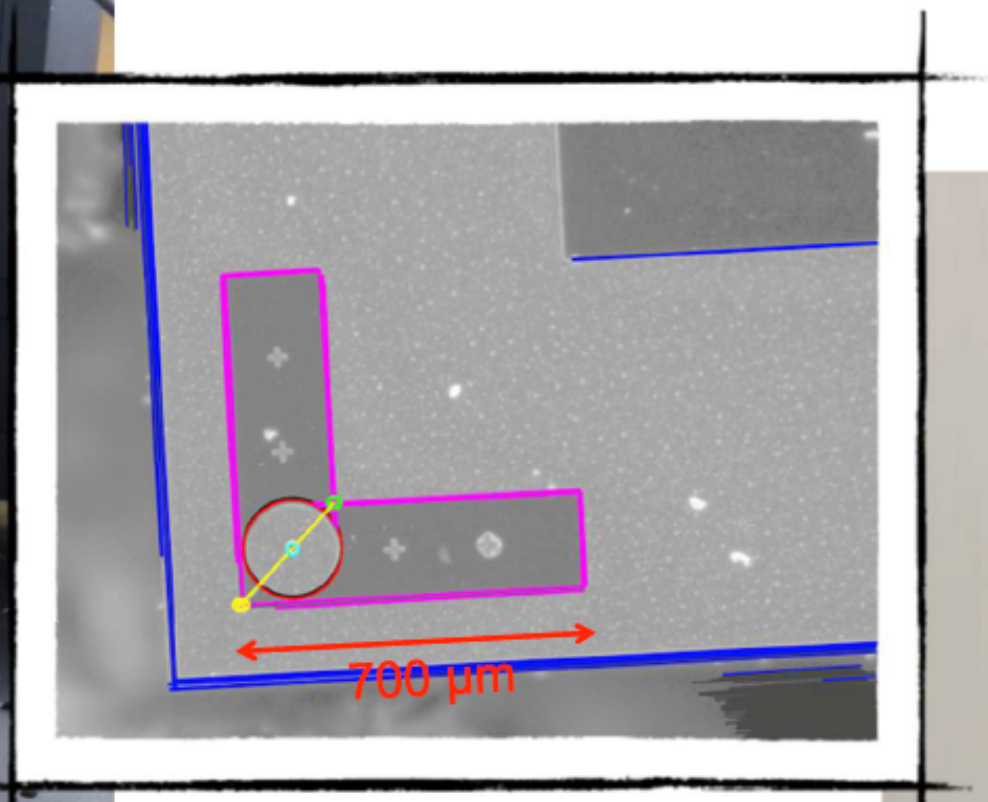
Talk by J. Keaveney today morning

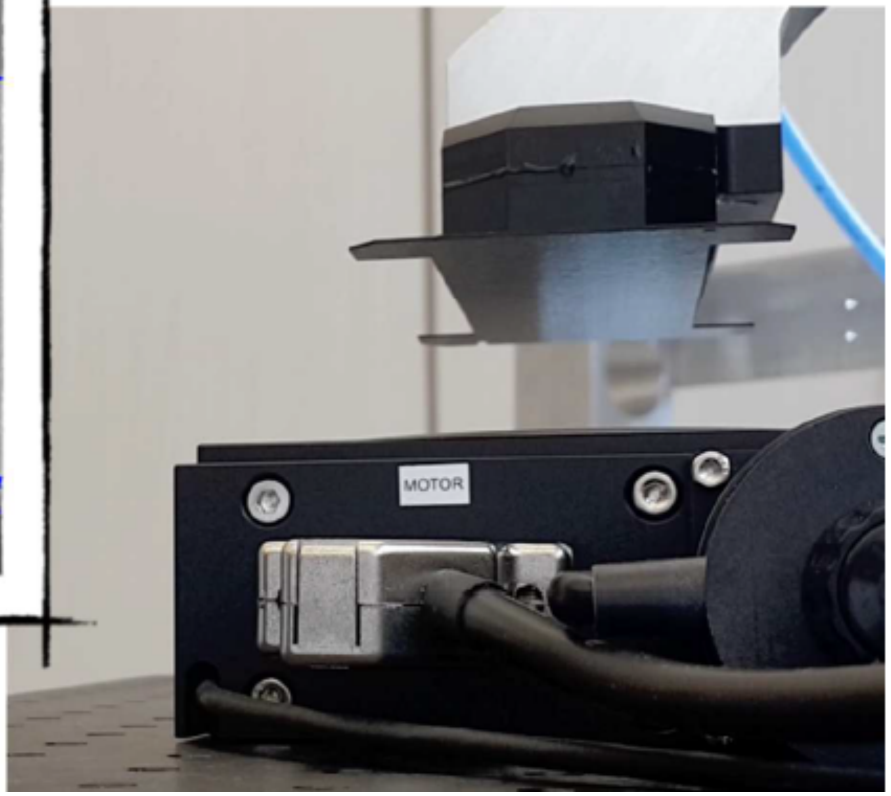
Automated Module Assembly

- precise sensor-to-sensor alignment essential for trigger performance of module
- automation of parts of the production could aid in precision mass production
- feasibility study uses existing X-Y-Z stage extended by cameras and a rotation stage





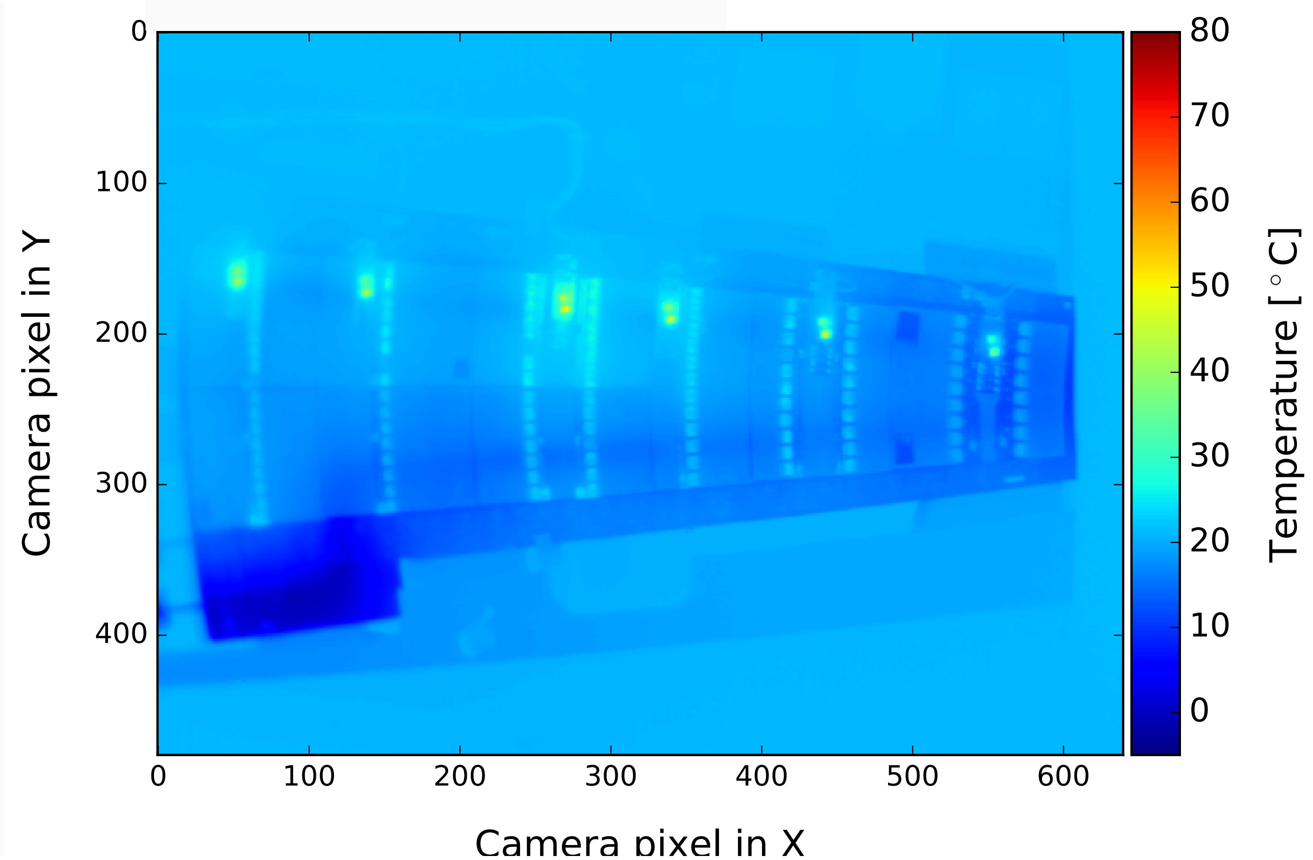


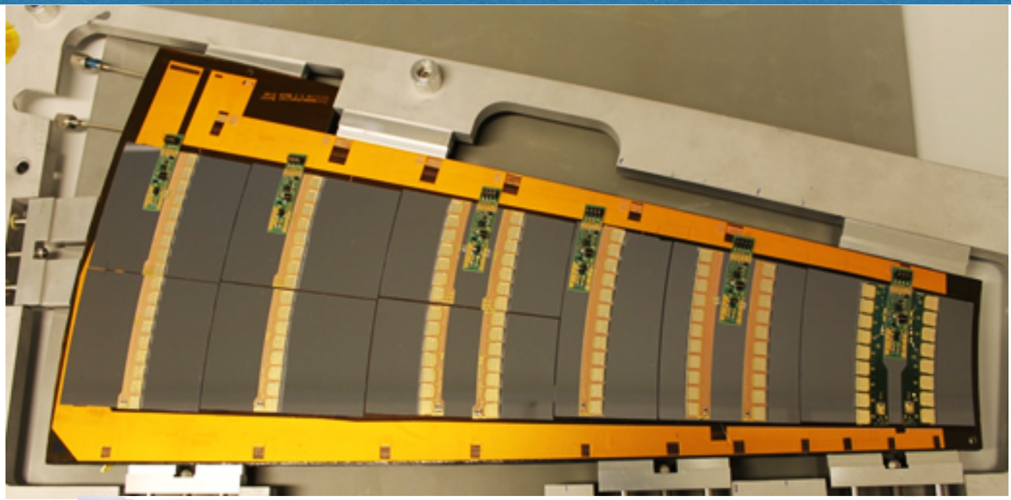


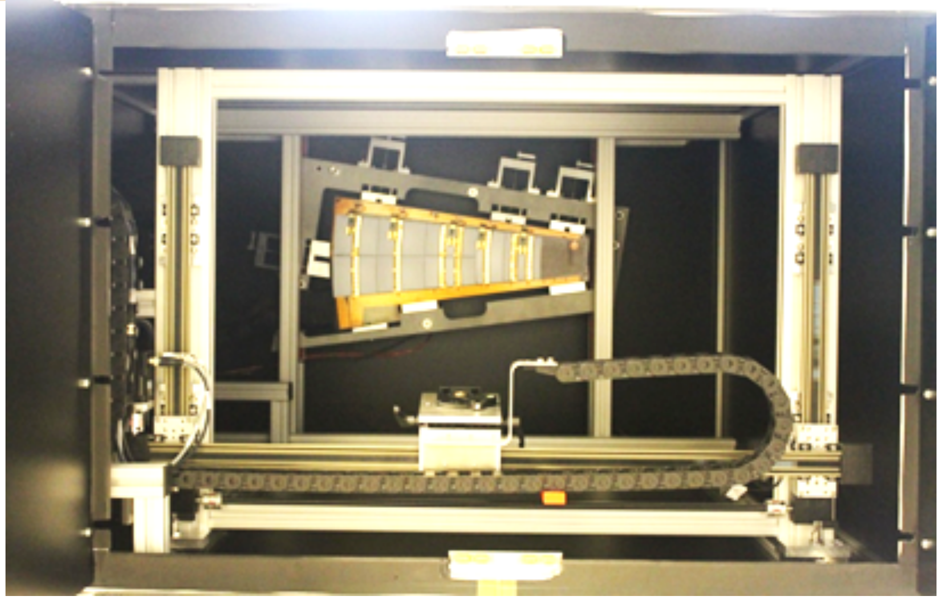
Both sides of TM Petal populated

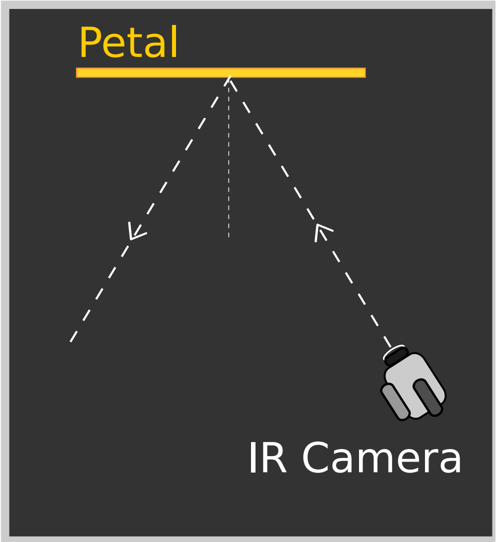
- TM modules built in Zeuthen, Petal assembly and test in Hamburg
- Custom thermal chamber for automated IR measurements and core QC
- First preliminary IR measurements, detailed tests ongoing

Petal cooled down at -20°C (chiller), inlet cooling pipe at -6°C, $\varepsilon = 0.64$
Power on!: 10.5 V ; 2.40 A on both sides



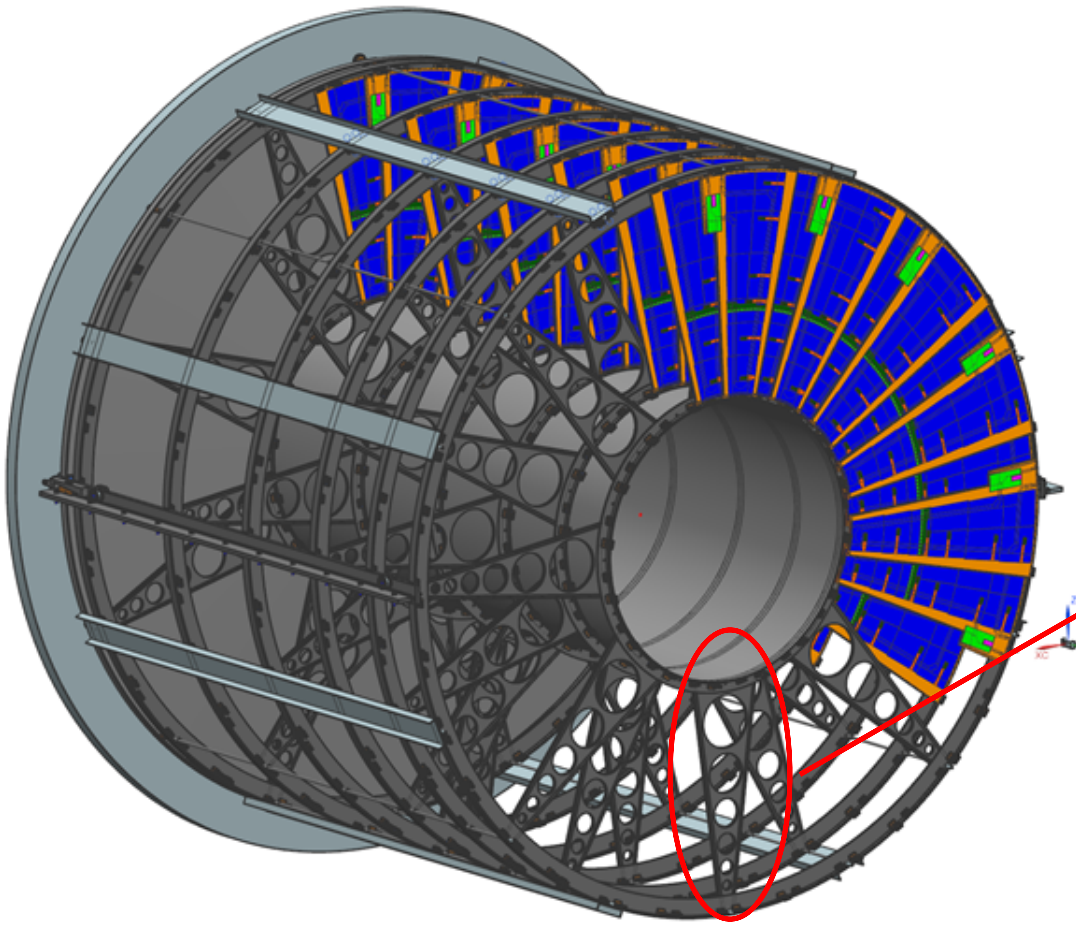


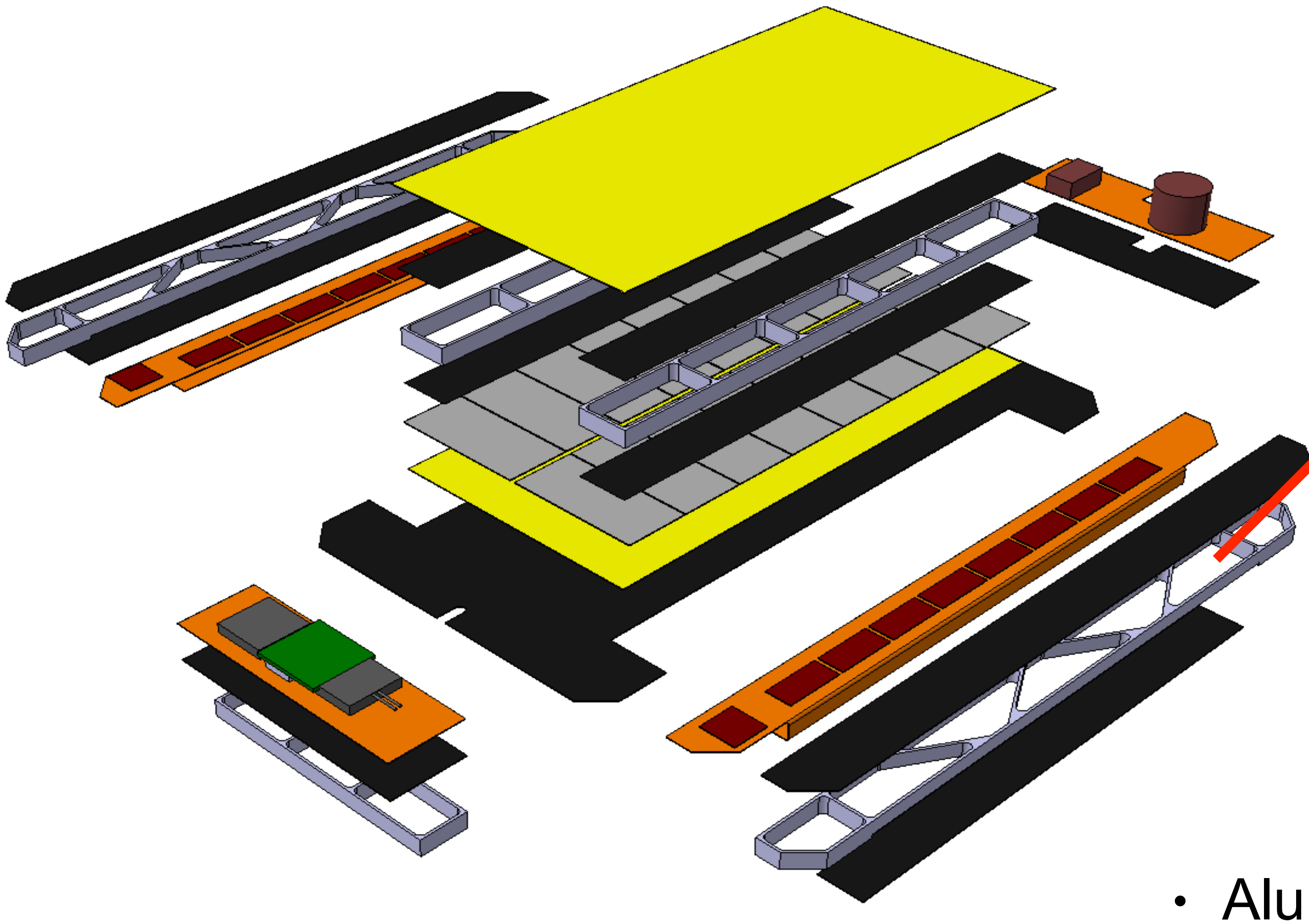




Manufacture of first blades for new EC structure

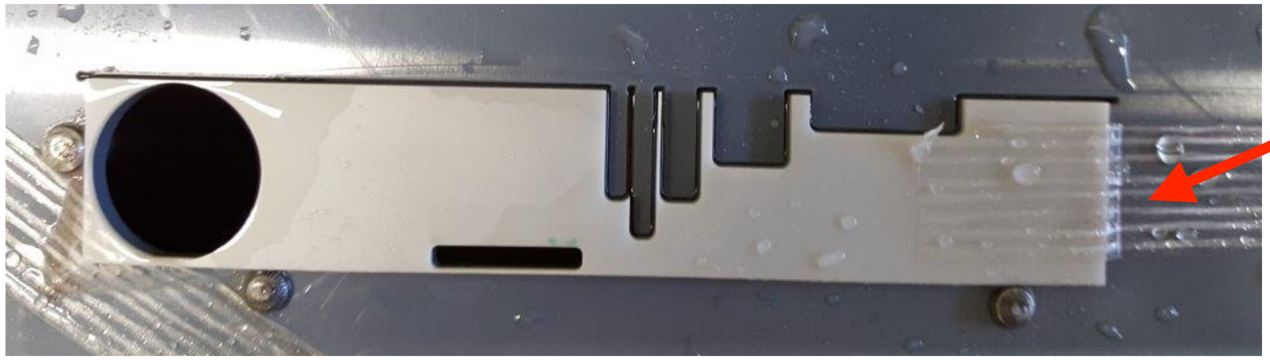
- Manufactured using standard commercial materials (availability and delivery time)
- 2 blades finished, 2 ongoing, avg weight: ~ 107 g
- Flatness measurements ongoing





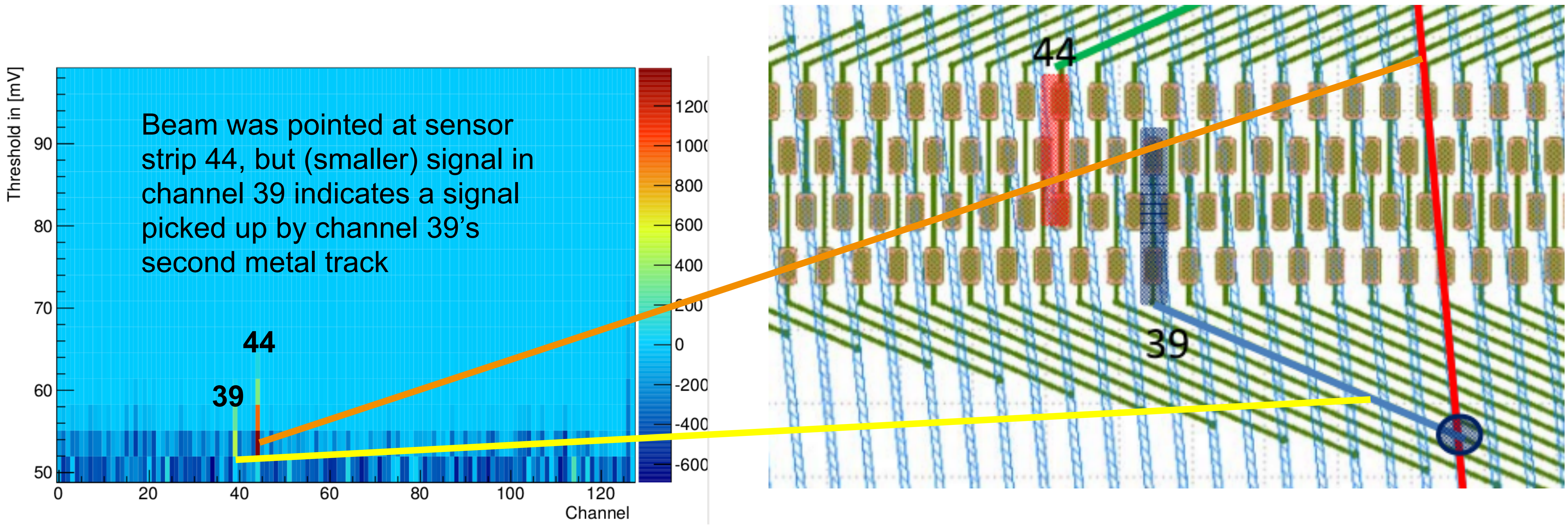
- spacers:
  - heat conduction
  - electrical conductivity
  - so far: AlCF used
  - alternative materials ?

- Aluminium Nitride AlN
  - how to machine complicated structure
  - investigate sawing, drilling, microwaterjet cutting, losing, additive manufacturing



Studies of irradiated sensor modules in X-ray beam

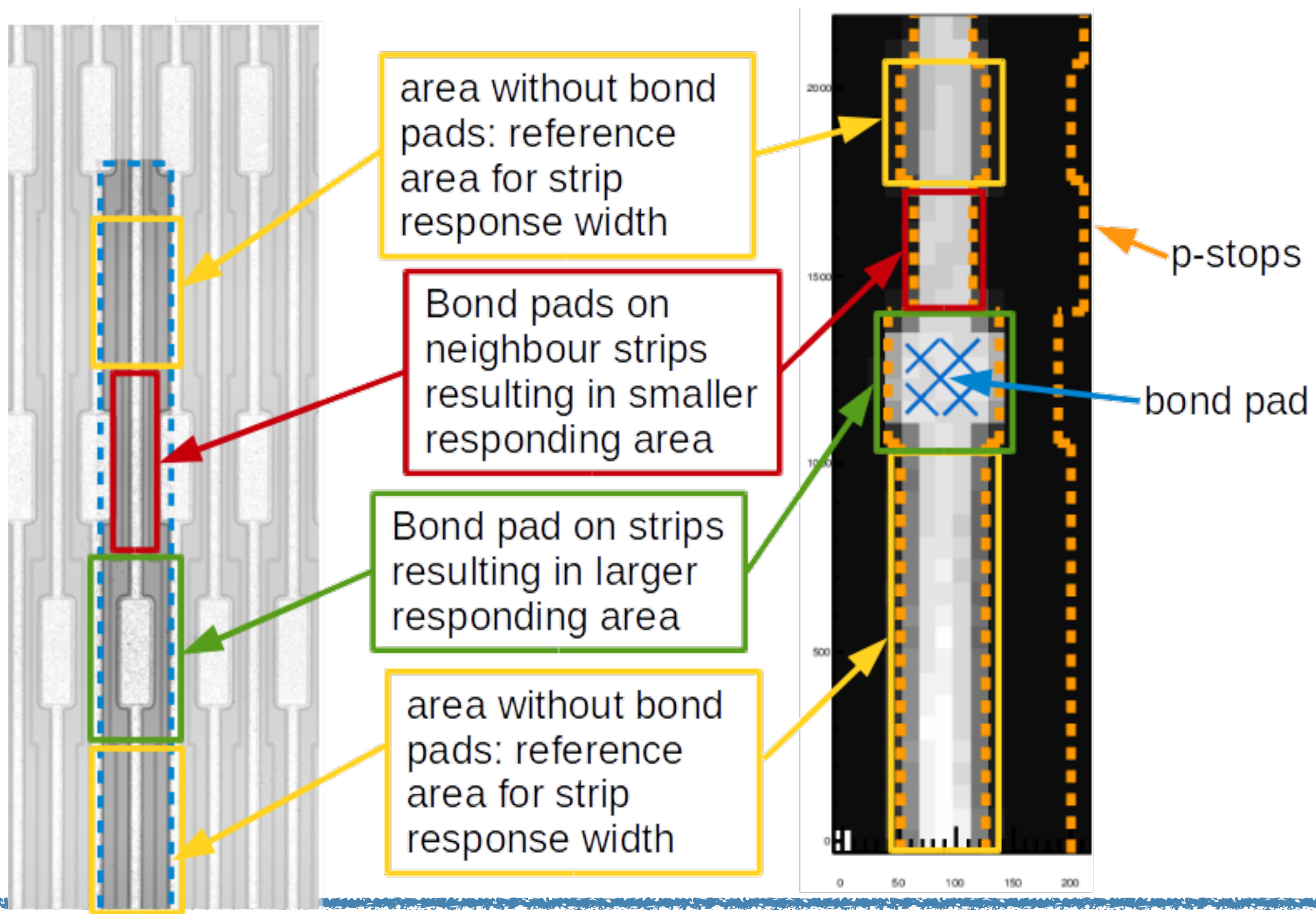
- Collaboration with CNM to investigate alternative sensor layouts with second metal layer
- Investigate impact of second metal layer on sensor performance (pick-up, cross-talk) as seen for similar sensors (e.g. LHCb Velo)

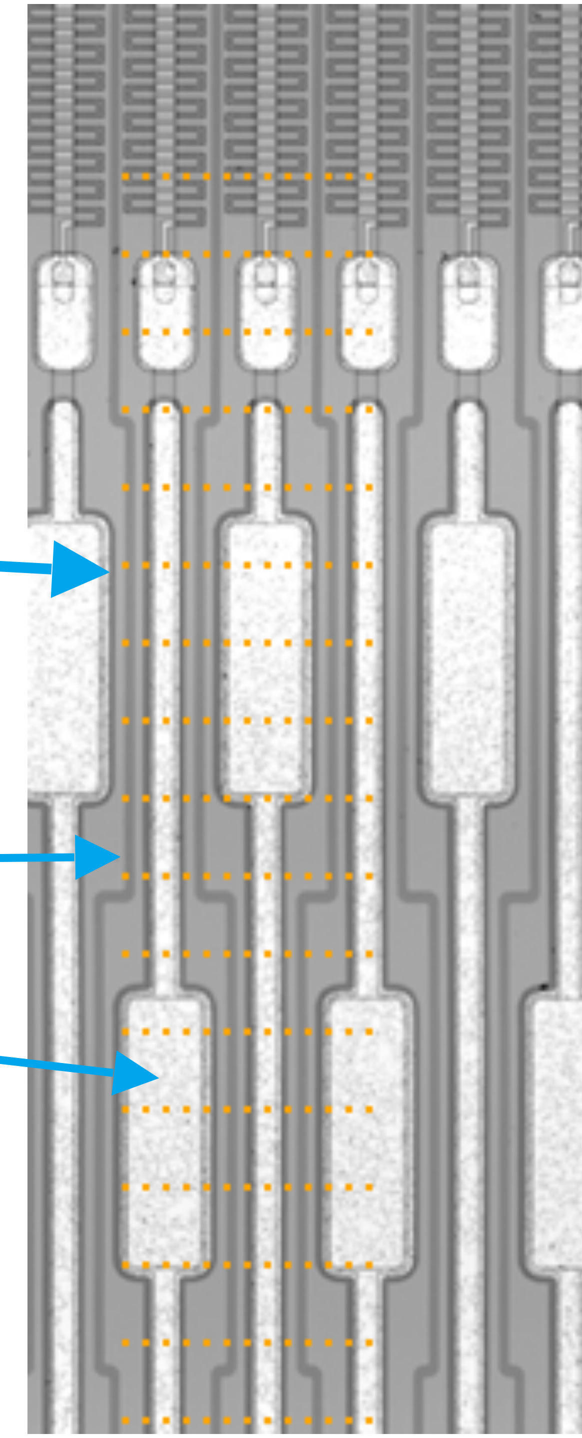


ATLAS: Particle Response Studies: Impact of sensor bond pads on strip response

Measurements at Diamond Light Source

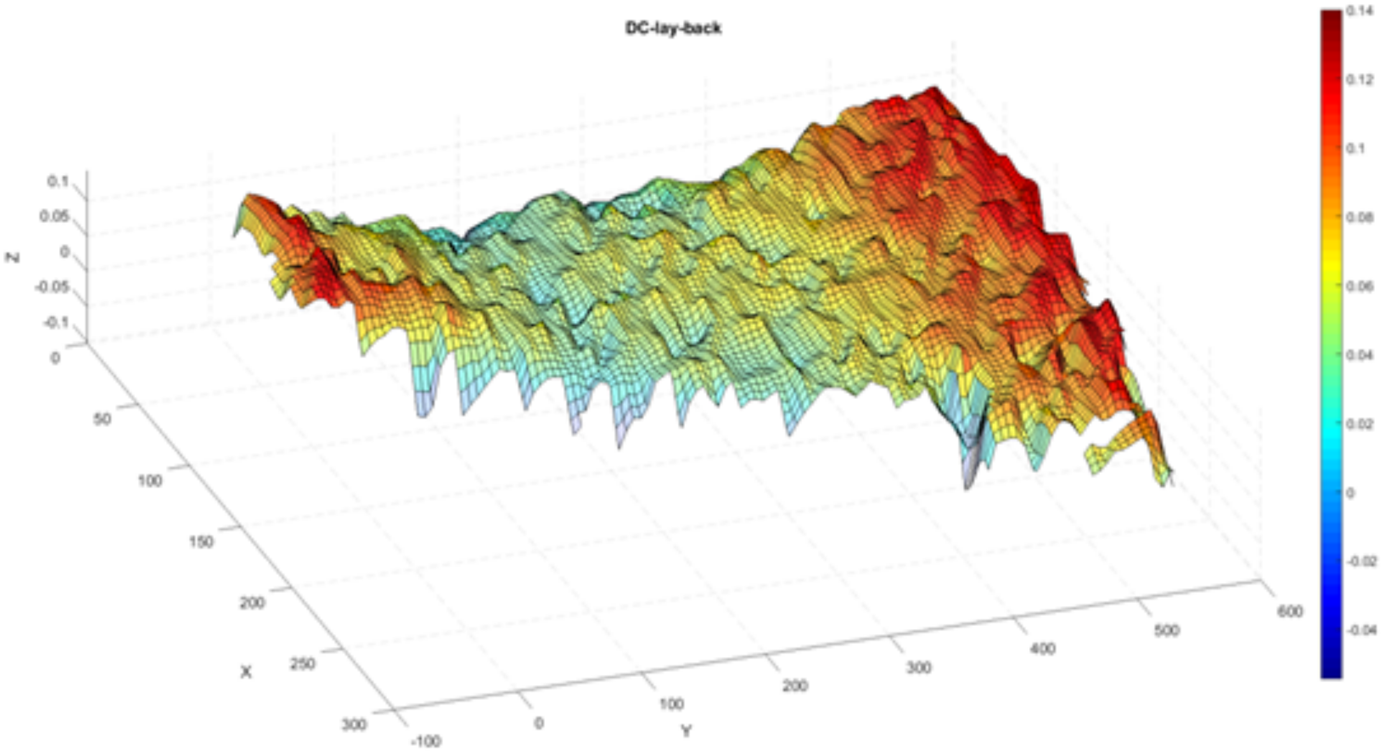
- Study sensor strip response in a sensor region with bond pads
- Micro-focused X-ray beam (2 x 3 μm) pointed at sensor, number of hits collected for constant number of triggers
- Collected hits over a grid of (0.2 x 20 mm)

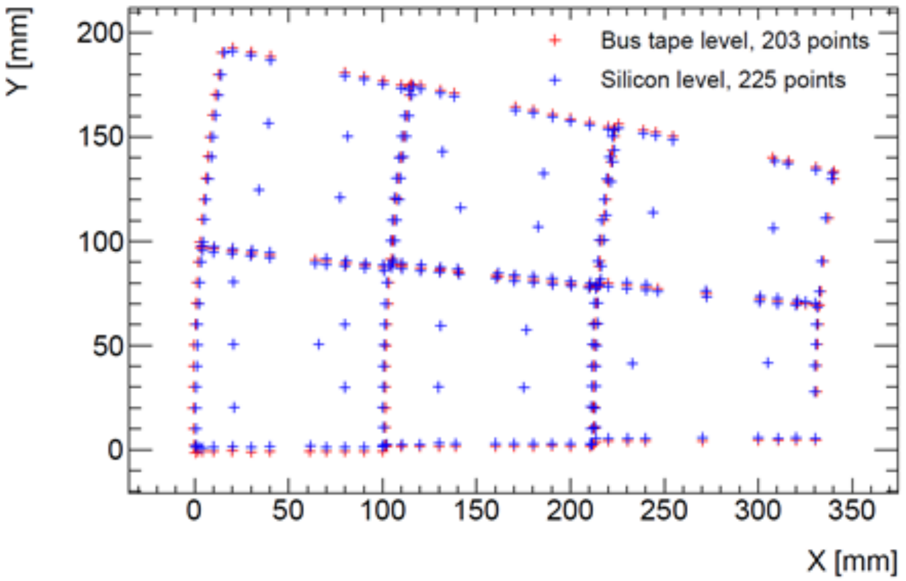




New CNC 670 SmartScope for mechanical QC of cores and petal components

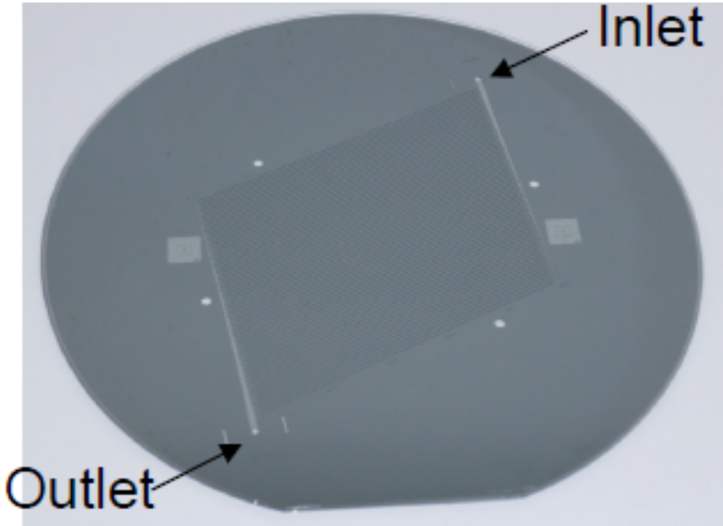
- Location of modules on core
- Module-to-core glue thickness
- Petal core flatness
- C-channels thickness, planarity



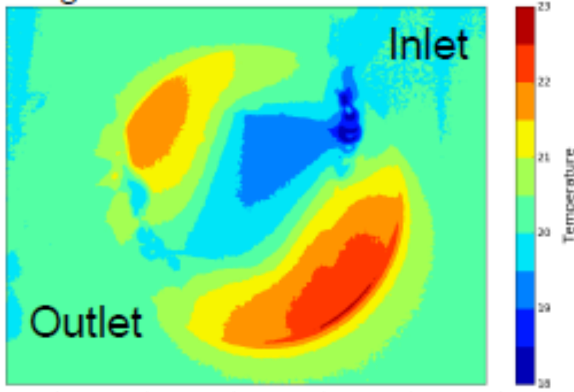


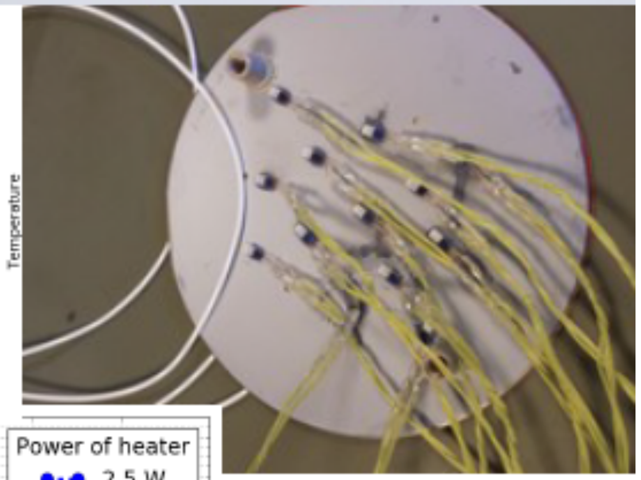
DESY and CNM (Barcelona) investigating micro-channel cooling as an option for cooling system for silicon during HL-LHC

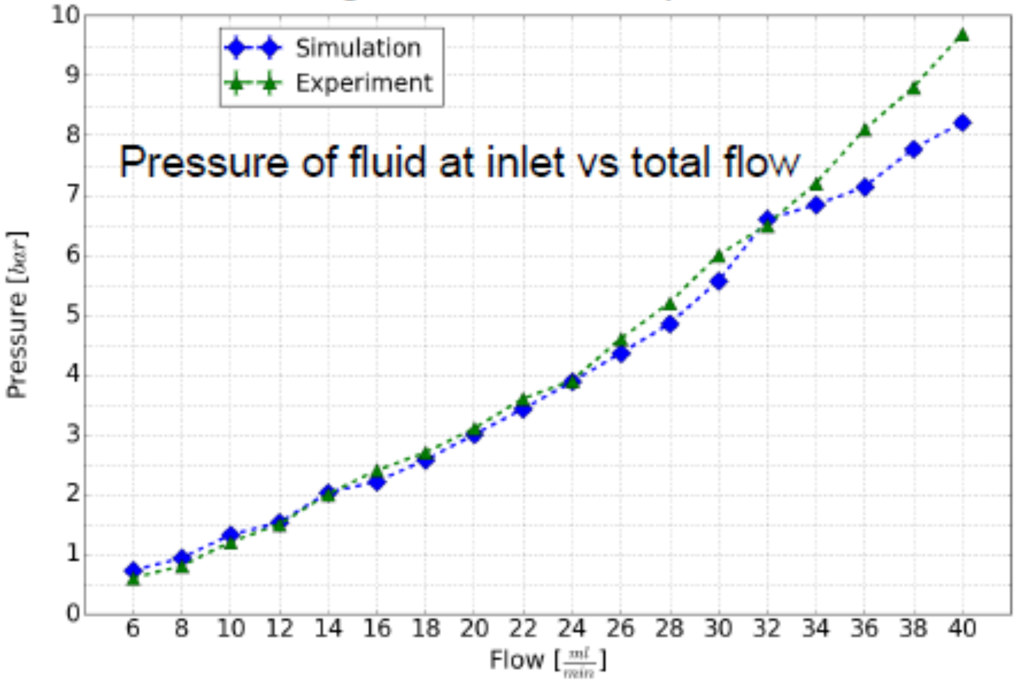
- Micro-channels etched into 4” silicon wafer of 300-500 µm thickness
  - 2 manifolds (inlet and outlet) with 60 channels (100 µm x 100 µm)
  - covered with 500 µm pyrex
- Wafer heated with 4” heater
- Sensors setups for temperature, pressure and flow measurements
- Simulation with ANSYS/CFX software
  - Good agreement with experiment

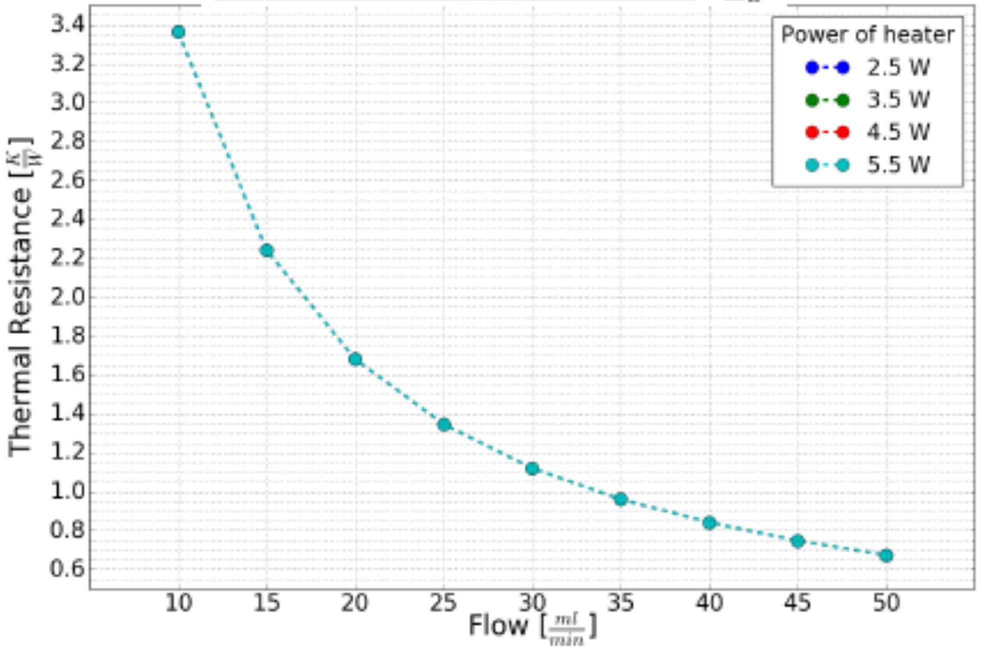


temperature measurement using thermal camera







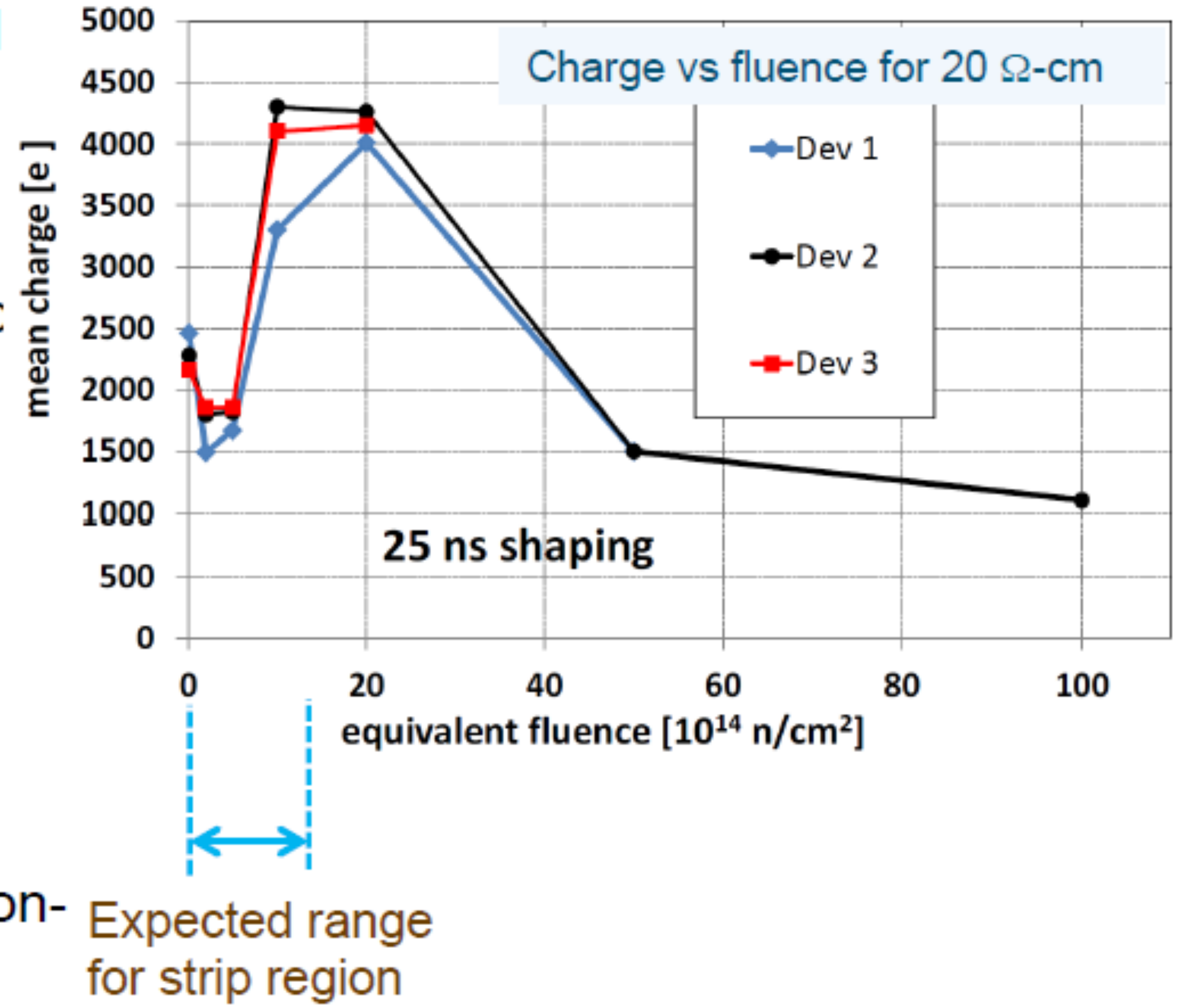


Paper soon to be submitted

ATLAS: Generic R&D - ATLAS Strip CMOS Program

DESY is strongly involved of developing rad-hard CM sensors as a drop-in solution for the Strip Tracker

> <u>Better performance</u>: less material, ~x2 better hit resolution in **r-ϕ** and **z**, single-bucket **time** resolutic
  - pixelization with x20 less **area** than a strip to reduce noise
  - very competitive cost
  - <u>faster construction</u>: a lot fewer wirebonds, faster fabrication

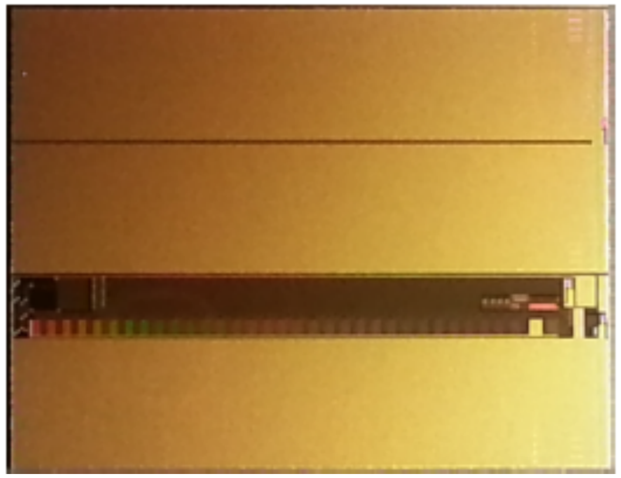


Current results for rad-hardness are encouraging

> HV-CMOS AMSHV35 seems to be suitably radiation-hard

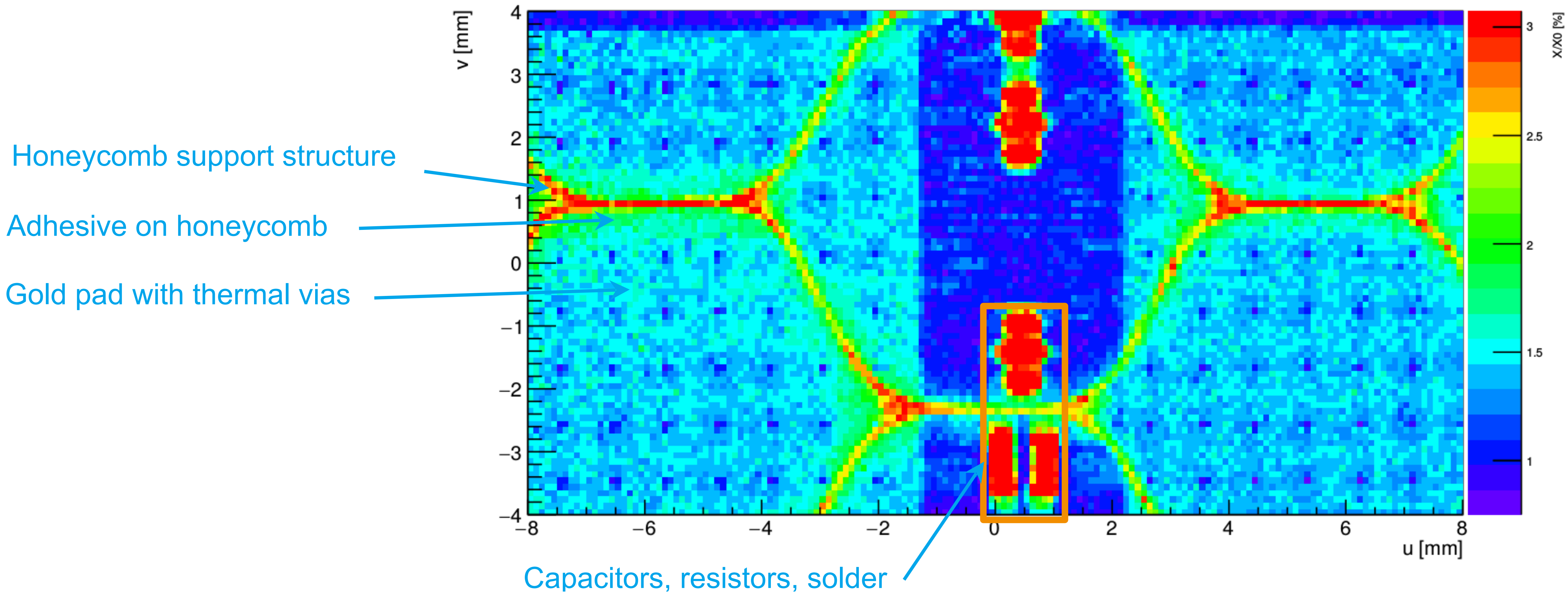
> CHESS-2:
  - full reticle-size chip (2.5 x 2 cm)
  - biggest chip in AMSHV35 so far
  - designed to be the building block for a real module (10 x 10 cm)
  - chip just back from foundry, test preparations on-going
  - DESY-II Test Beam Facility will play key role in testing

Photo of CHESS-2 chip:



DESY testbeam: Measurements of radiation lengths

- Using beam telescope to determine X0 of
  - Material with unknown radiation length (carbon foam, carbon fibre sheets)
  - Petal-like structure (silicon strip module on mechanical support structure)



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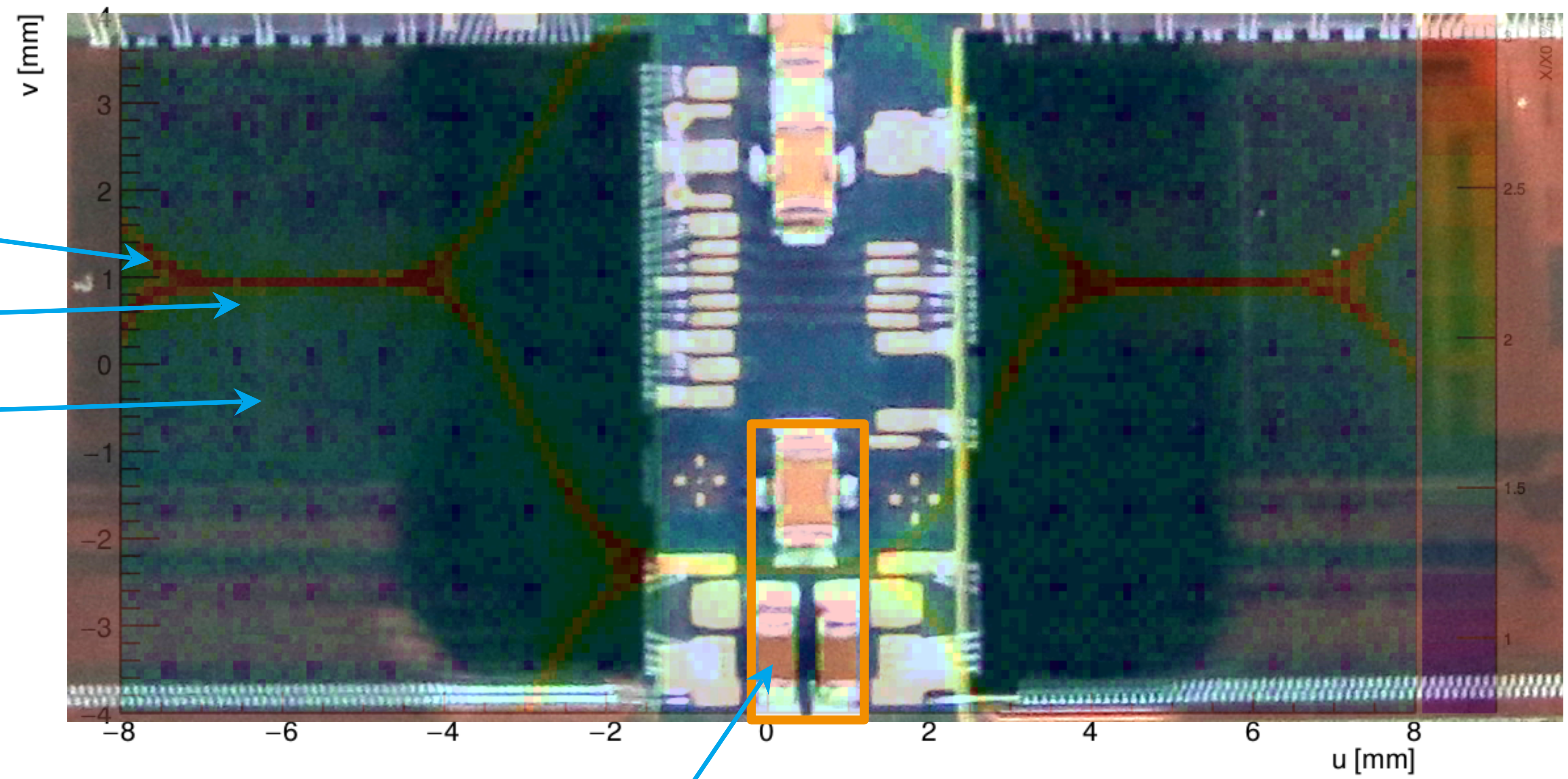


Honeycomb support structure

Adhesive on honeycomb

Gold pad with thermal vias

Capacitors, resistors, solder

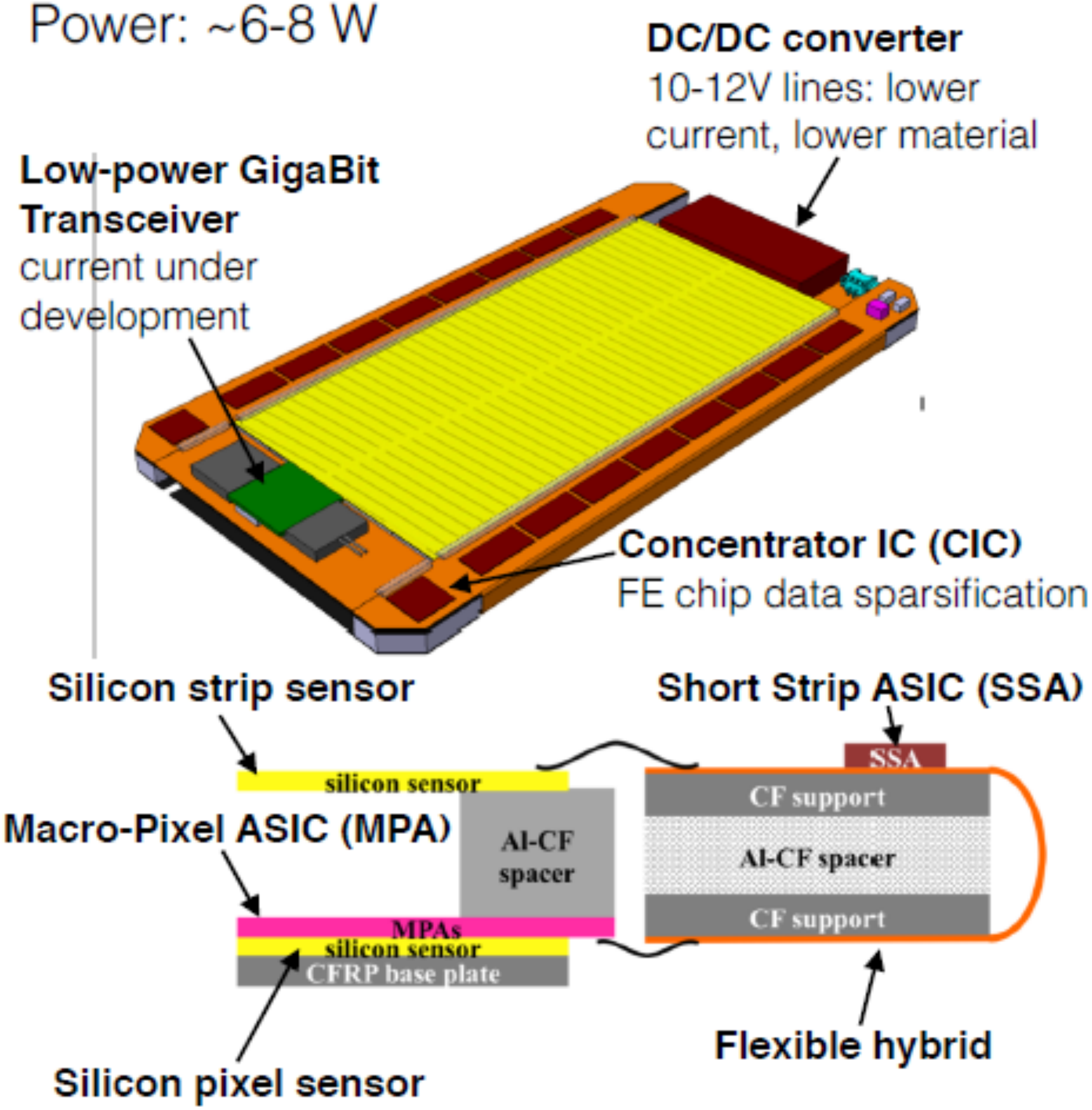
Summary

- ATLAS and CMS groups are preparing for the production
- While moving towards production: ample opportunity for R&D useful also for other projects
- Glueing studies, diagnostics tools, highly integrated structures, automation, matching, and the like are common to many projects

—> share knowledge

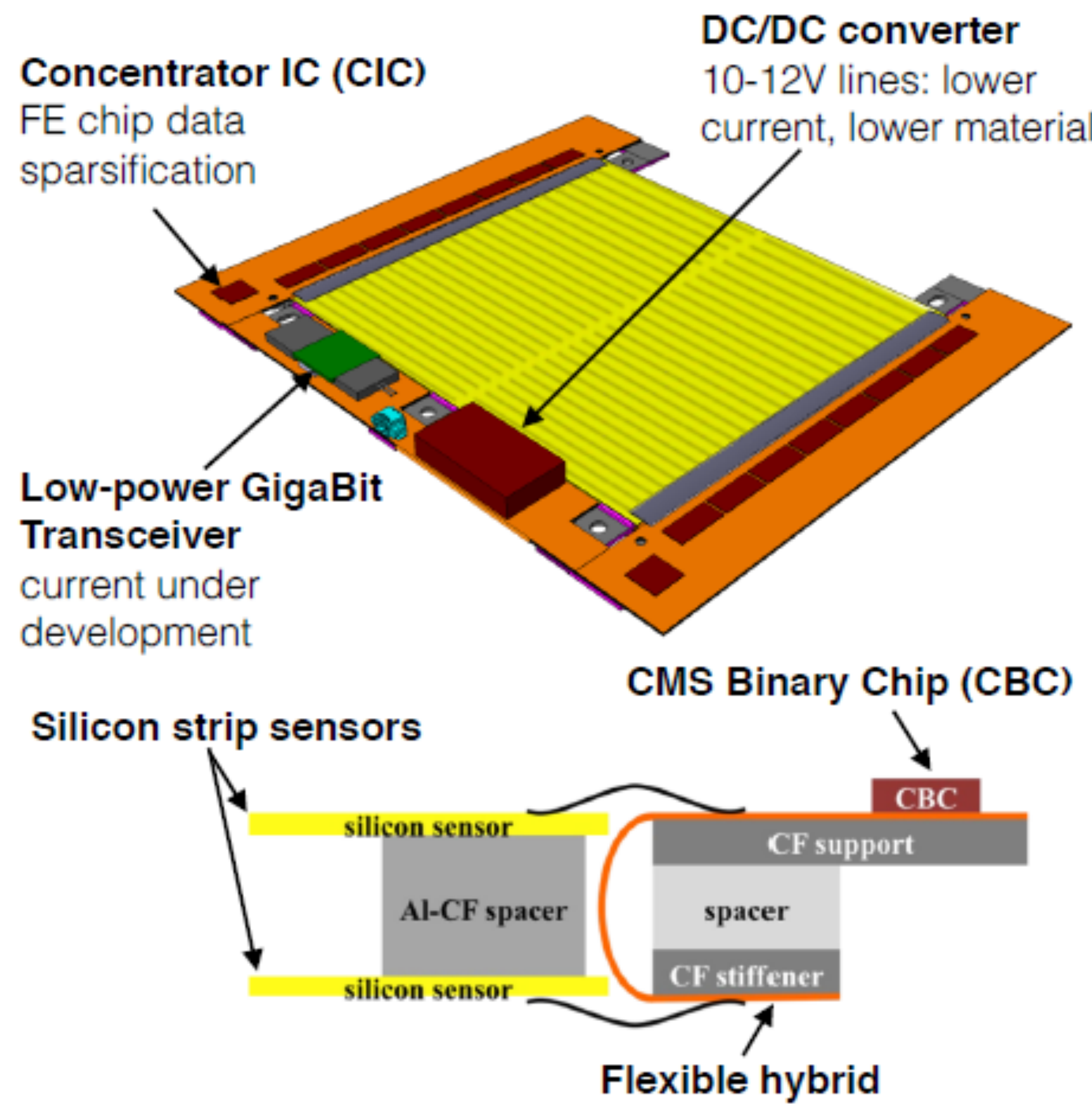
PS modules: Macro Pixel + Strip

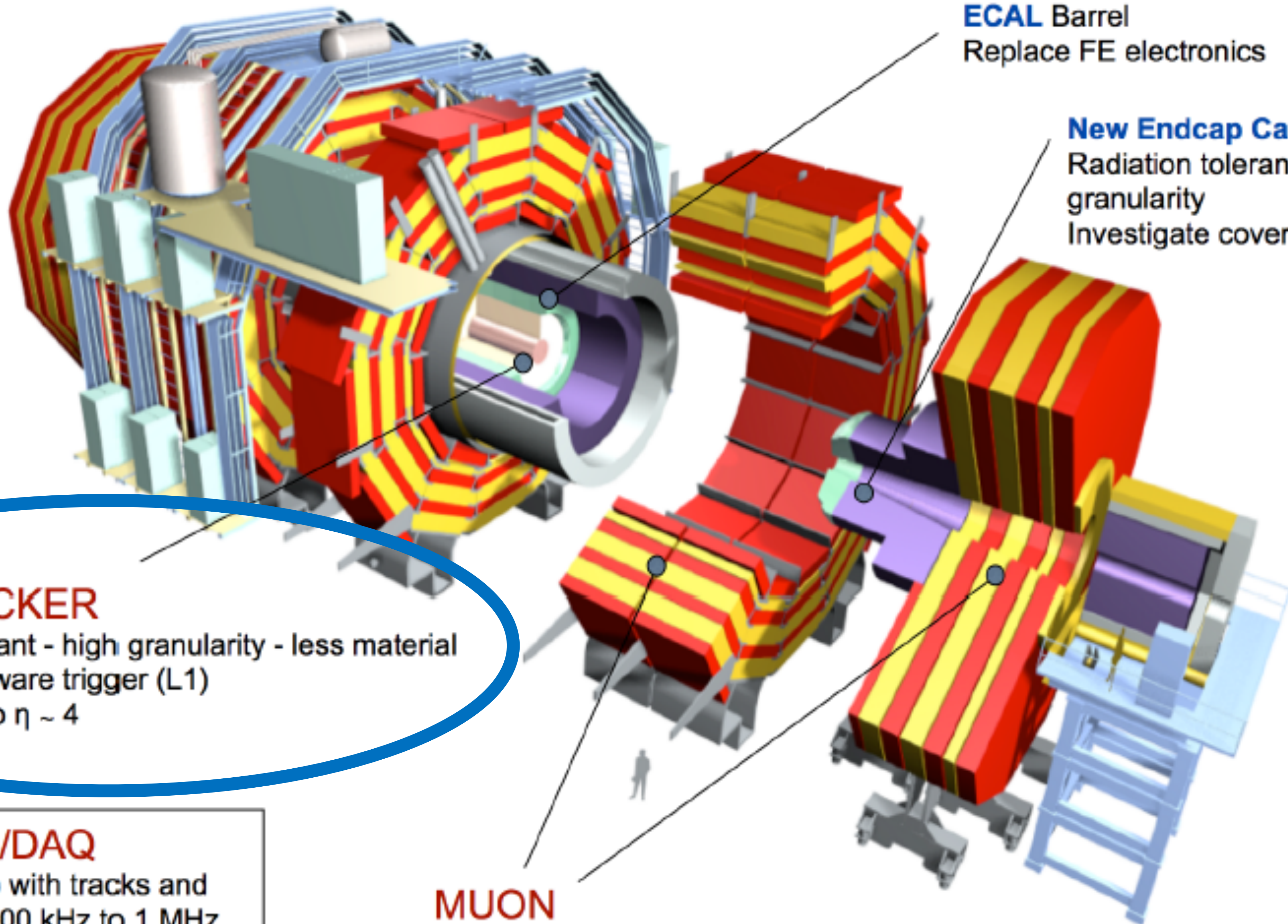
Macro Pixel: 1.5 mm × 100 µm DC coupled
Strip: 2.4 cm × 100 µm AC coupled
Module area: ~5 × 10 cm^2
Power: ~6-8 W



2S modules: Strip + Strip

Strip: 5 cm × 90 µm AC coupled (both sides)
Module area: ~10 × 10 cm^2
Power: ~4-5 W





CALORIMETERS

ECAL Barrel
Replace FE electronics

New Endcap Calorimeters
Radiation tolerant - high granularity
Investigate coverage up to η ~ 4

NEW TRACKER

Radiation tolerant - high granularity - less material
Tracks in hardware trigger (L1)
Coverage up to η ~ 4

TRIGGER/DAQ

L1 (hardware) with tracks and rate up ~ 500 kHz to 1 MHz
Latency ≥ 10 µs
HLT output up to 10 kHz

MUON

Replace DT FE electronics
Complete RPC coverage in forward region (new GEM/RPC technology)
Investigate Muon-tagging up to η ~ 4

The Phase-II Inner Tracker (ITk) of ATLAS

- Replacement of ATLAS inner detector (pixel, SCT, TRT) by an **all-silicon tracker**
  - Baseline (shown below) covers up to $\eta = 3.2$ on the pixel region, with a minimum of 9 hits
- 5 barrel pixel layers, 16 endcap pixel "layers"
- 4 barrel strip cylinders
  - Short strips and long strips modules
- 6 endcap strips disks per endcap
  - 9 types of modules, of varying pitches and length
- **DESY is building one of the strip endcaps**

~ 21000 modules required for the strip tracker