Report from Forum on Tracking Detector Mechanics

An incomplete personal summary

https://indico.cern.ch/event/1336746/

Moritz Guthoff
SiDet Meeting 24.09.2024

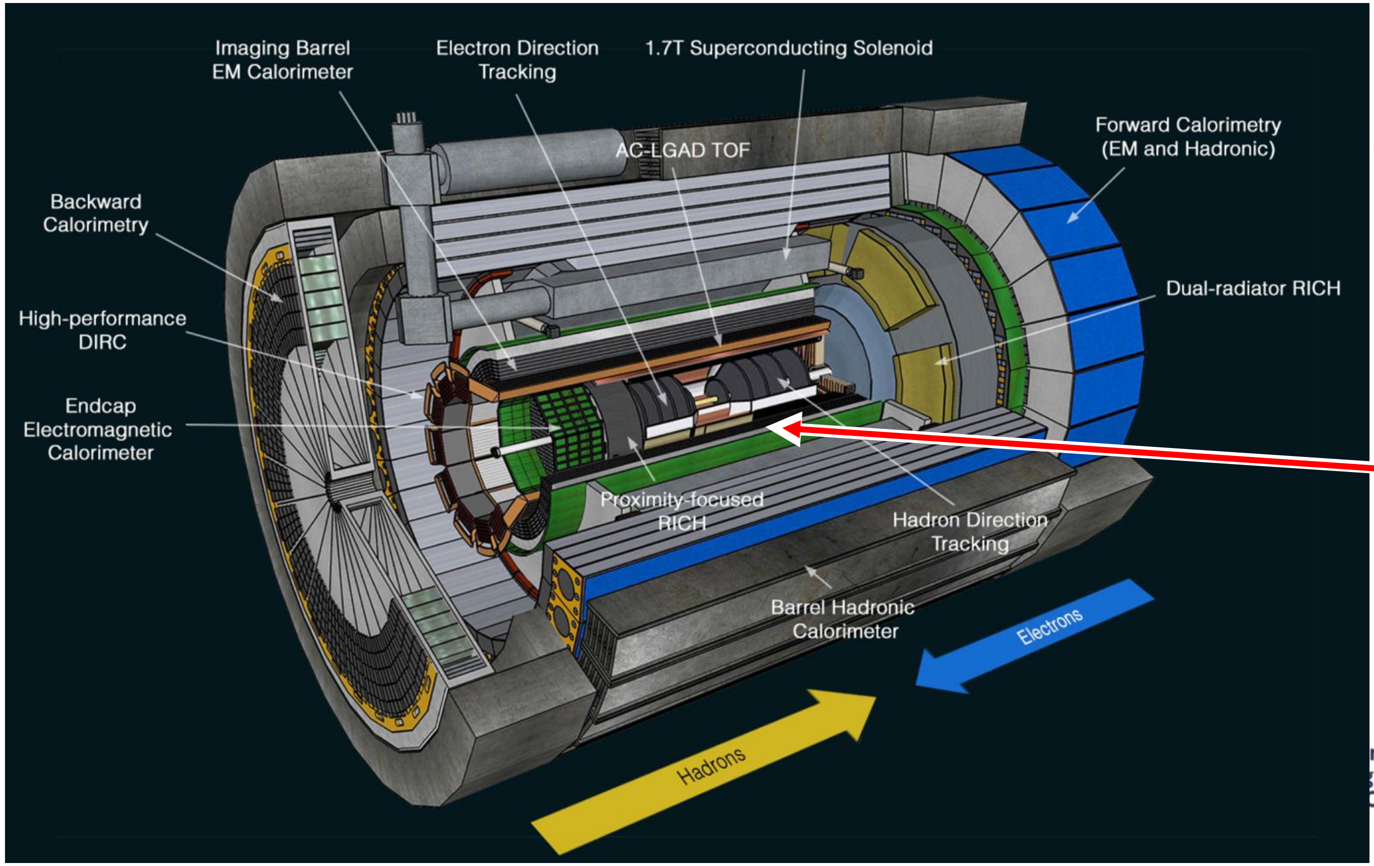
HELMHOLTZ

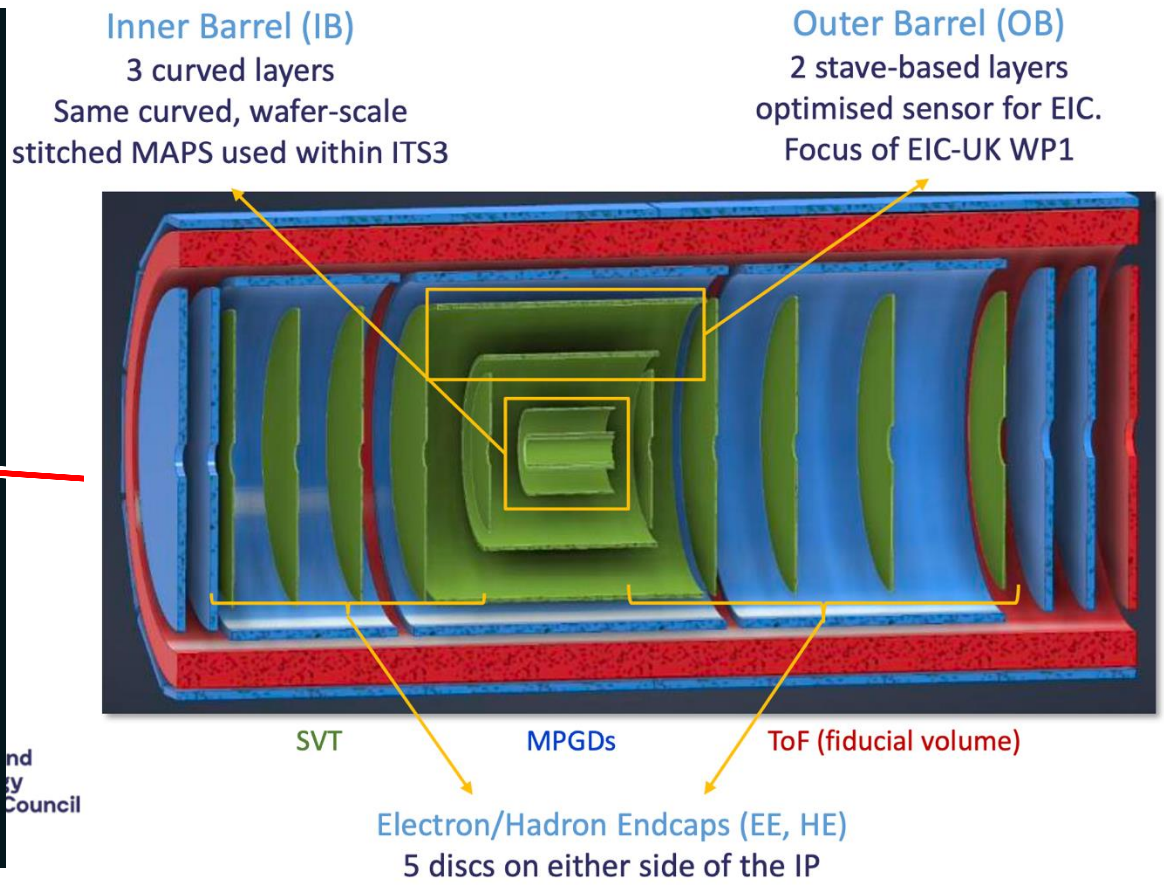
DESY.

Forum topics

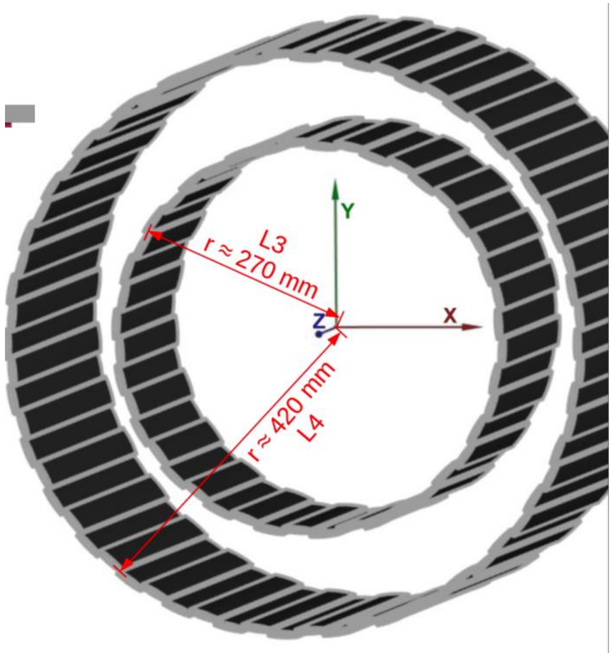
- Detector cooling
- Deflection, stability and precision of the structures, achieved and revisited requirements for the next generation
- Thermal expansion differences inside the detector
- Mass and therefore radiation length of mechanics, cables and pipes
- Humidity control, including gas flushing inside detector volume and along services
- Structural issues concerning humidity or outgassing
- Choices of construction materials
- Rails for support and guidance
- Alignment systems, requirements and "weak modes" of the system, in-situ adjustments, sensors including load sensors
- Pipe materials, pipe connection techniques and fittings
- Shock and vibration issues such as bond wire vibration during transport and in operation
- Effects on mechanics during fast discharge of magnet coils
- Tracker to beam-pipe interfaces and bakeout scenarios
- Failure management: What do we do to achieve a tracker with maximum duty cycle
- Service management: What strategies do we have to deal with services? How can we minimize installation and testing times?
- Radiation and mechanics: A discussion about the impacts of radiation on the design, materials and also issues like access constraints
- Maintenance scenarios and the required special tooling
- FEA and its comparison to real objects

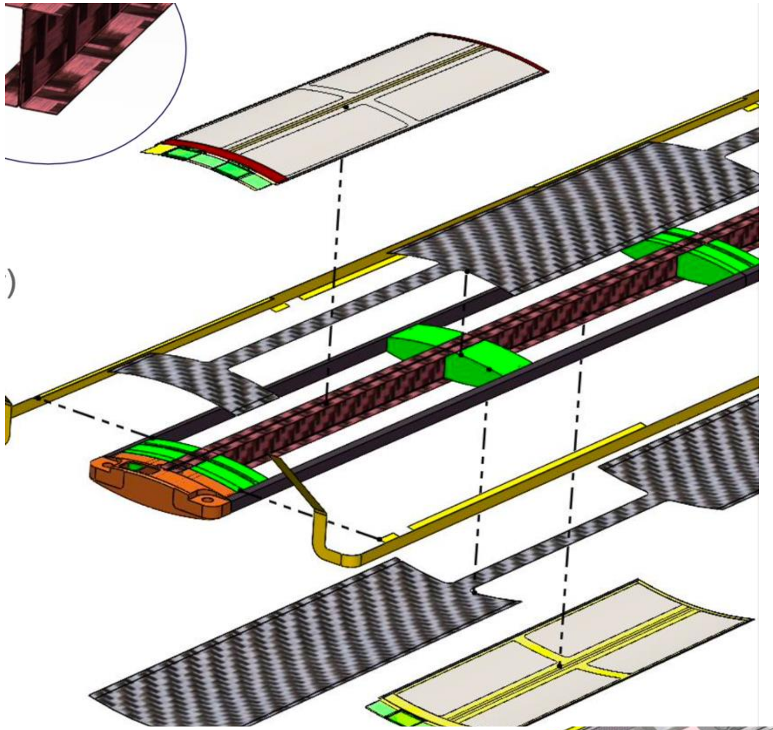
ePIC detector at the EIC

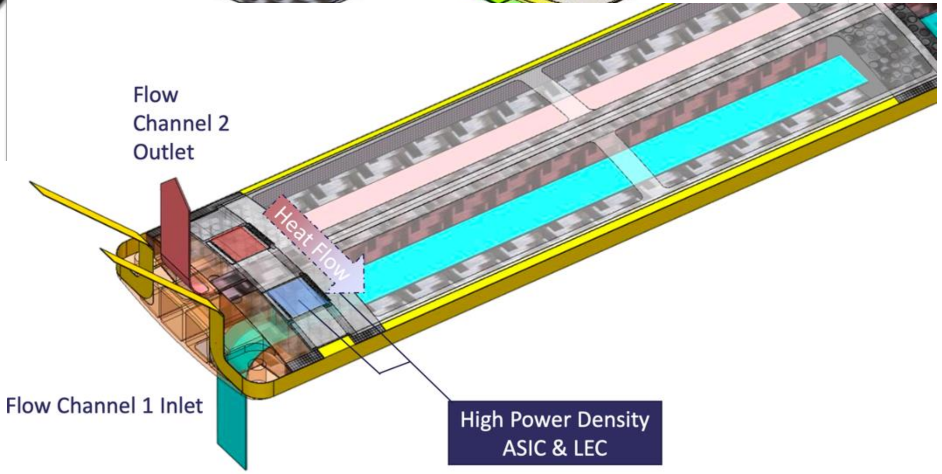


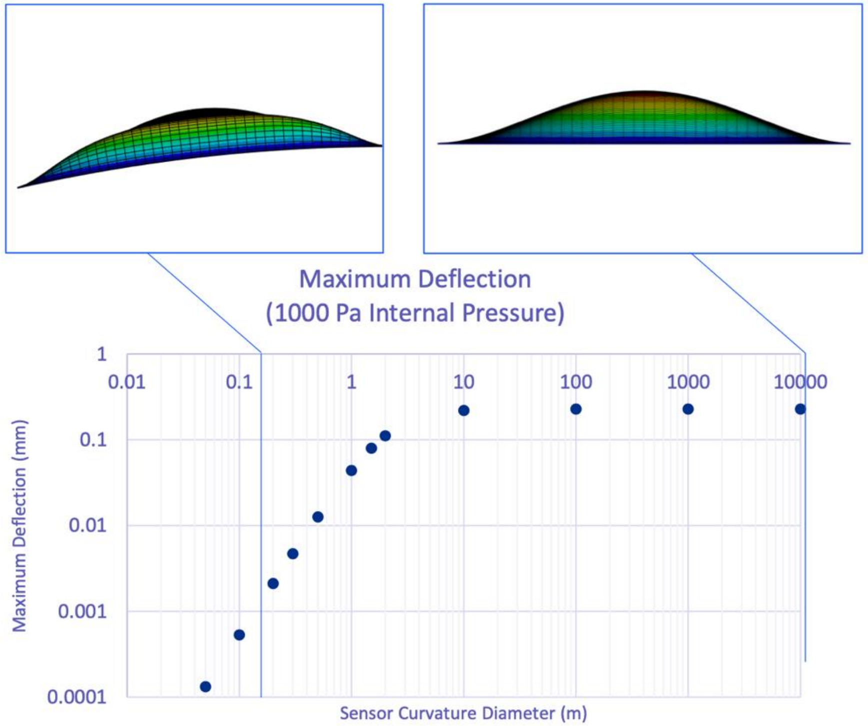


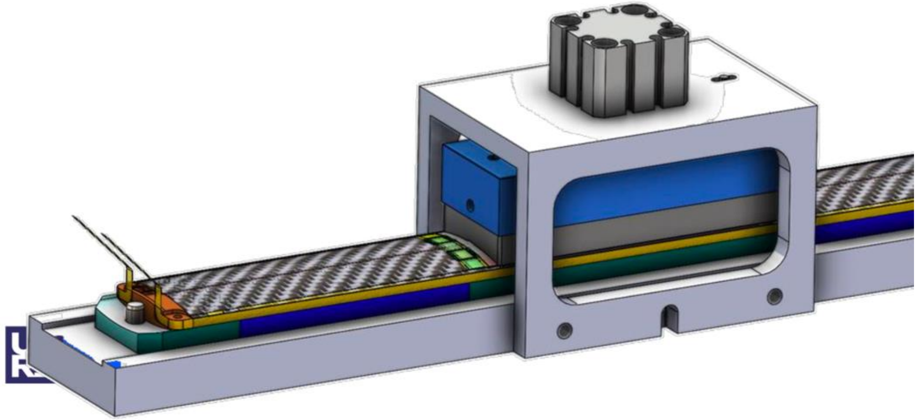
ePIC SVT Barrel staves



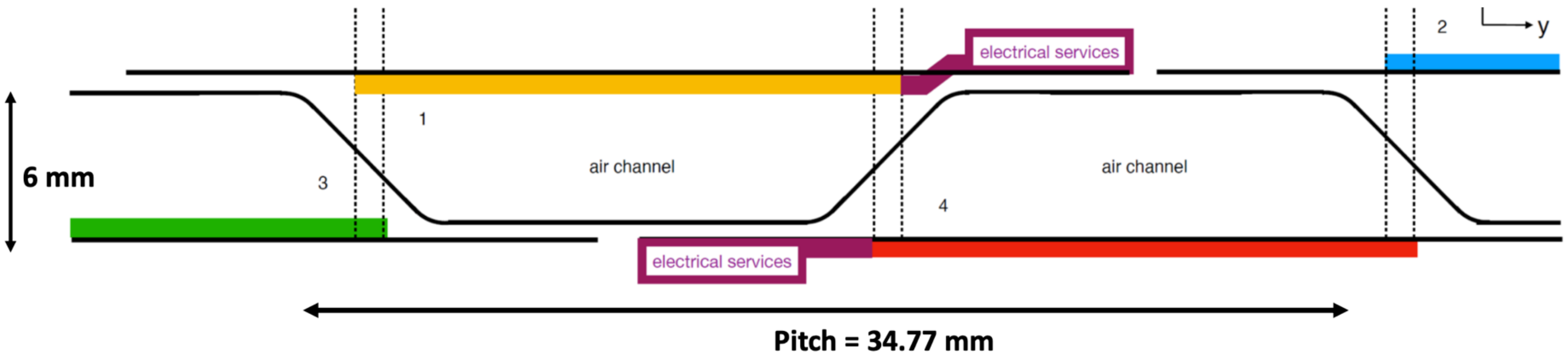


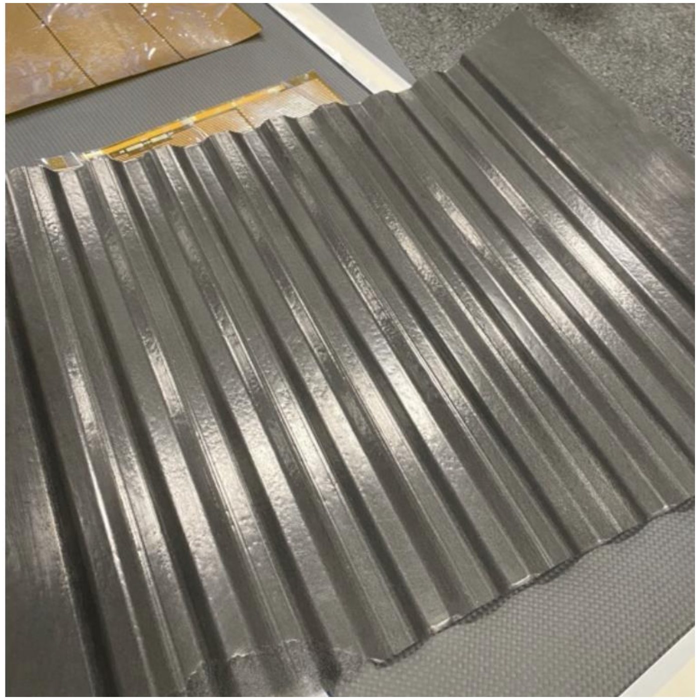






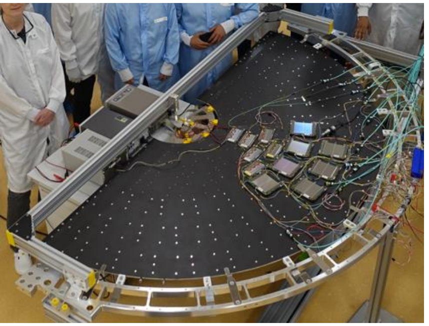
ePIC SVT endcaps

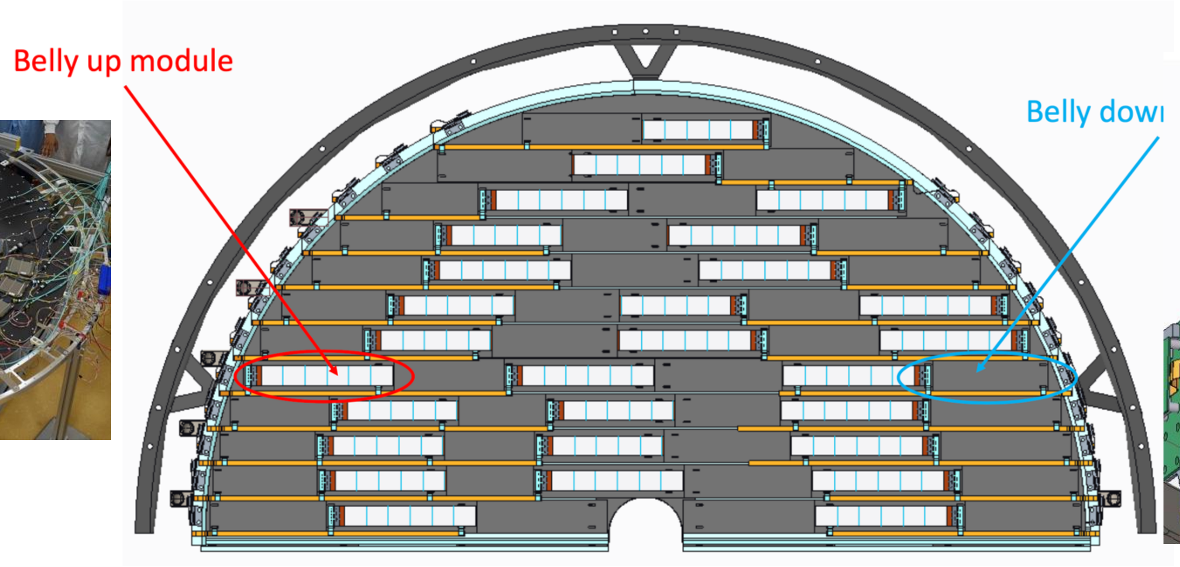


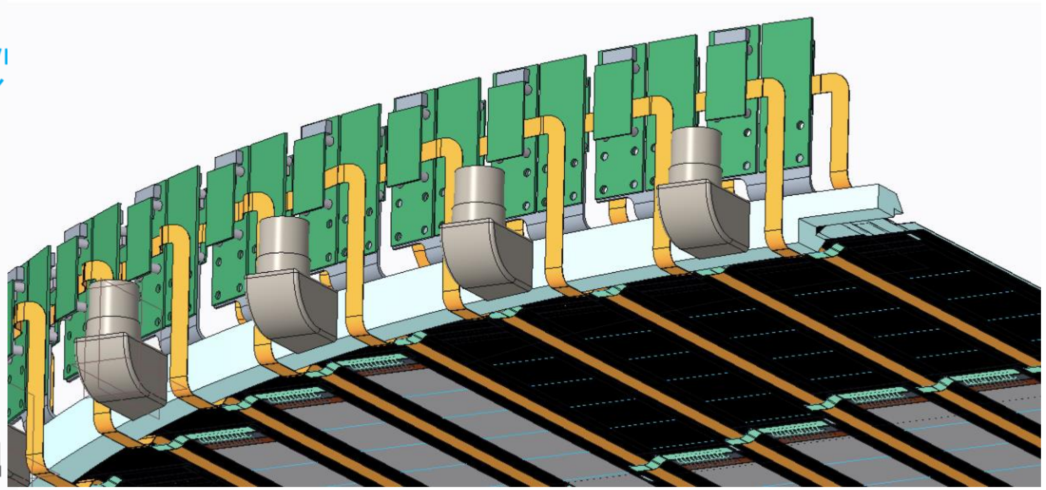


Sensor layout

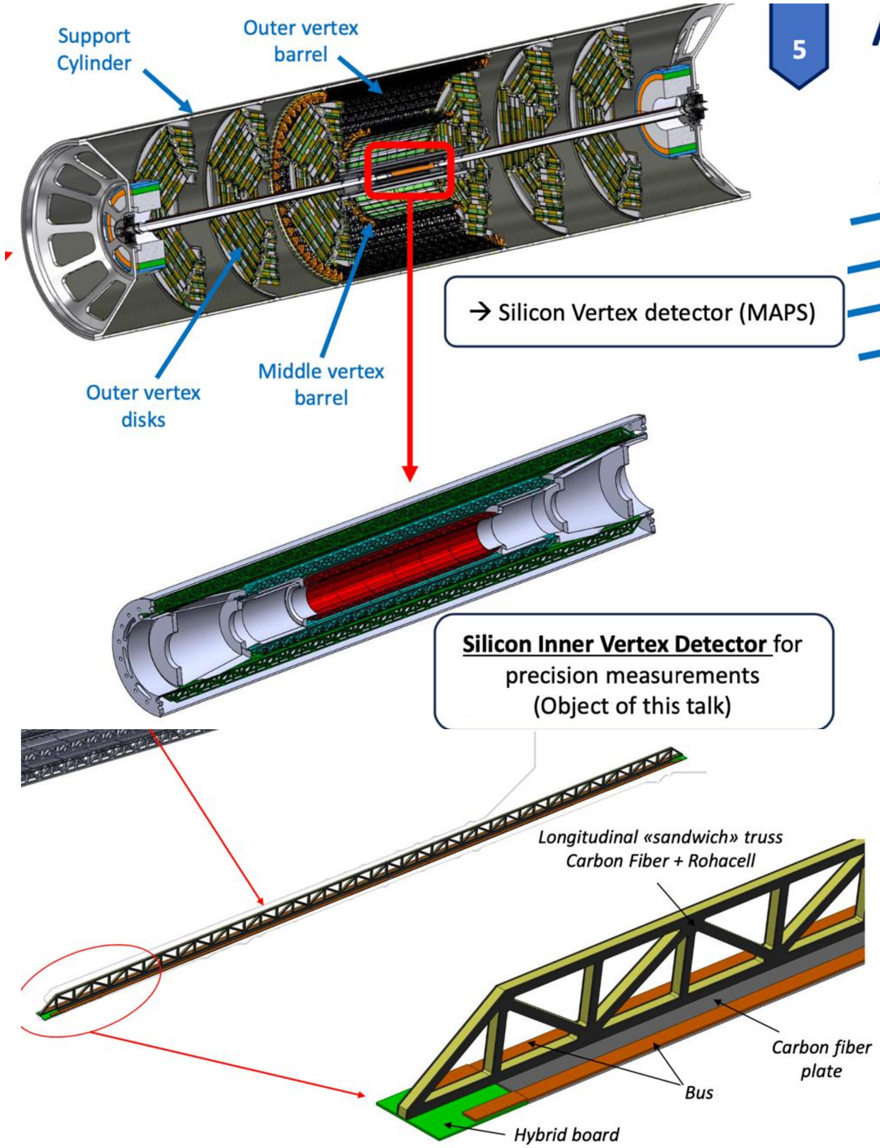
”Front” face of disc (facing in towards interaction region)

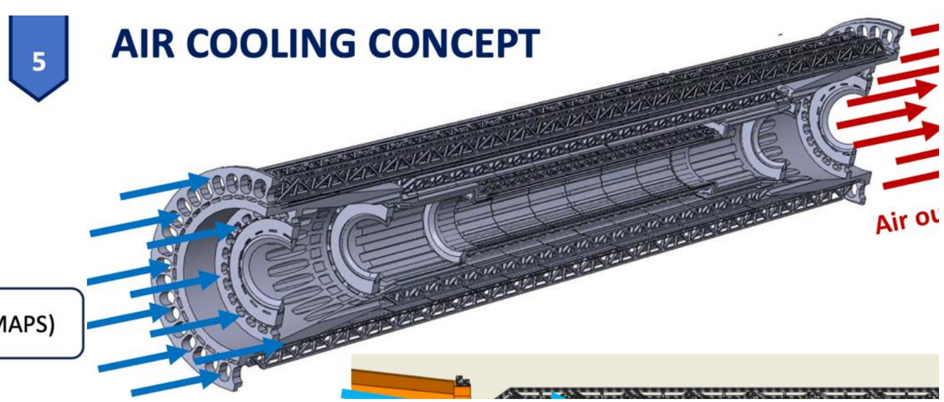


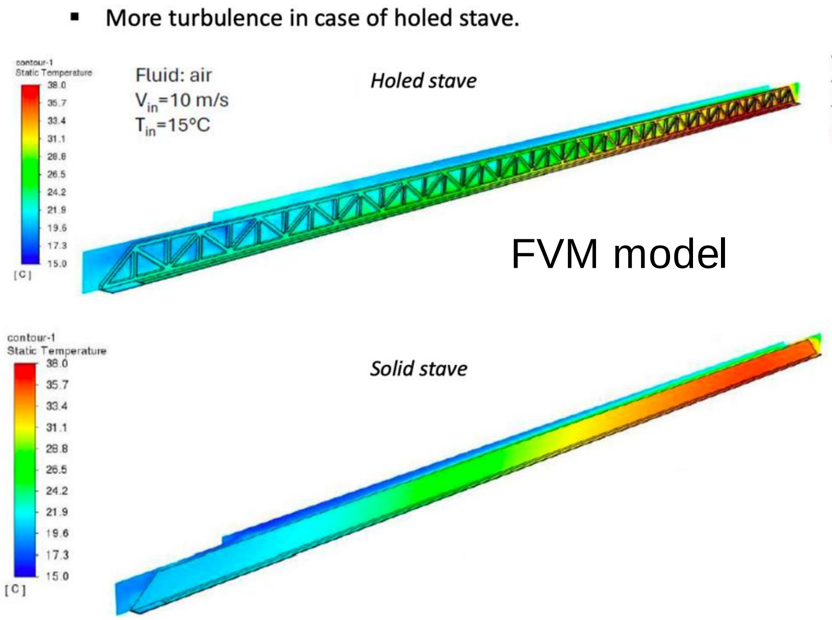


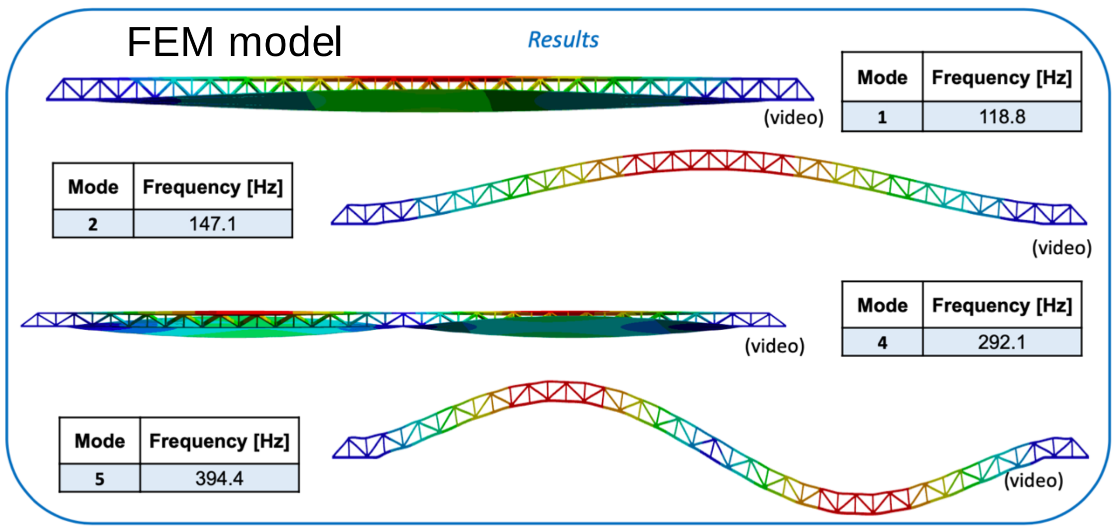


Thermal simulation of air cooled IDEA vertex detector









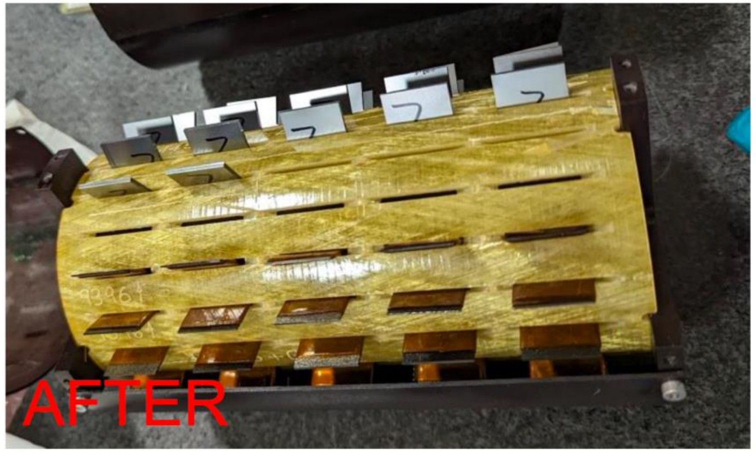
Mode	Frequency [Hz]
1	118.8

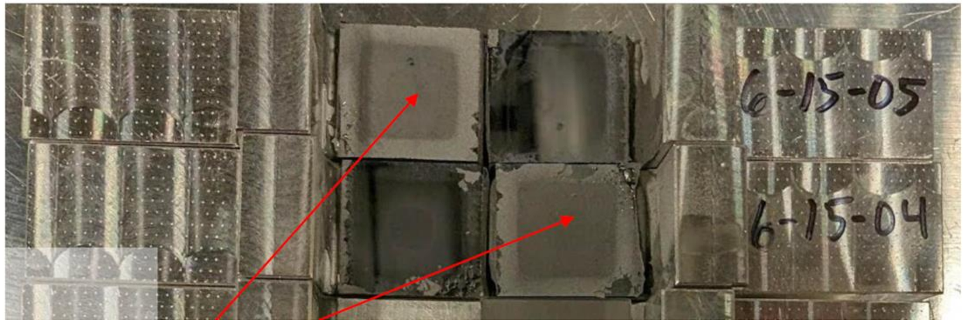
Mode	Frequency [Hz]
2	147.1

Mode	Frequency [Hz]
4	292.1

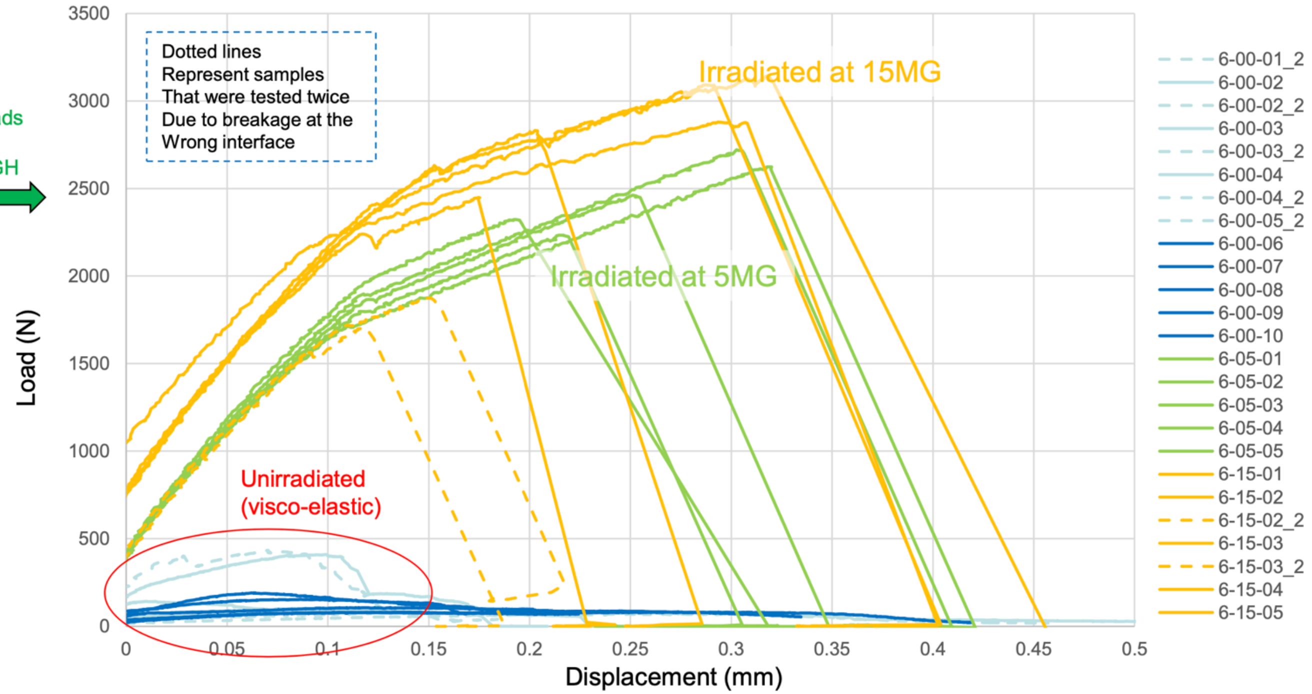
Mode	Frequency [Hz]
5	394.4

Mechanical Performance of Irradiated Adhesive Samples for ATLAS ITk



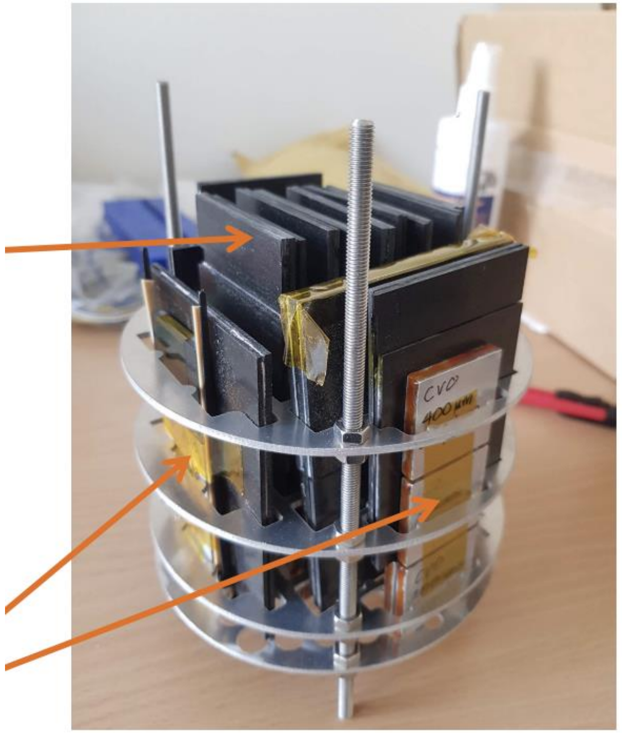


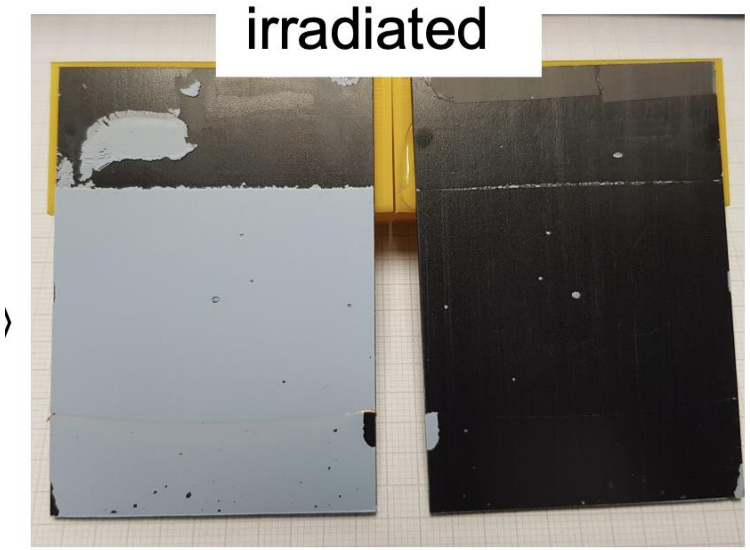
Loads Are HIGH

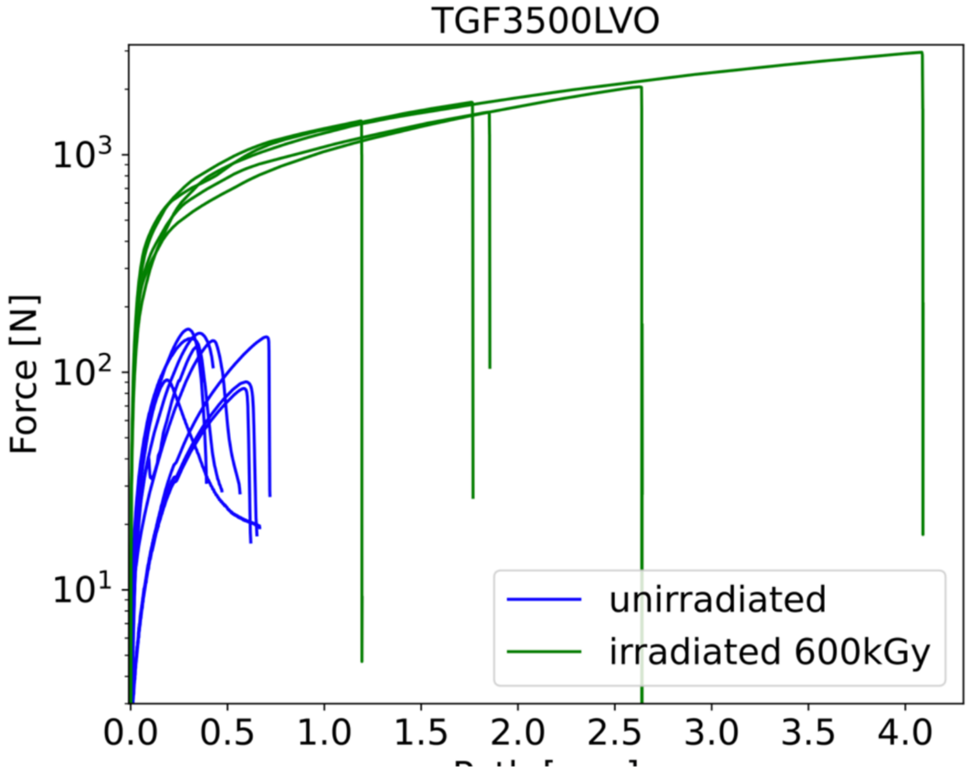


SE4445 strength does not degrade after irradiation, in fact, it acts more like a true adhesive

Radiation qualification of Thermal Interface Material in CMS

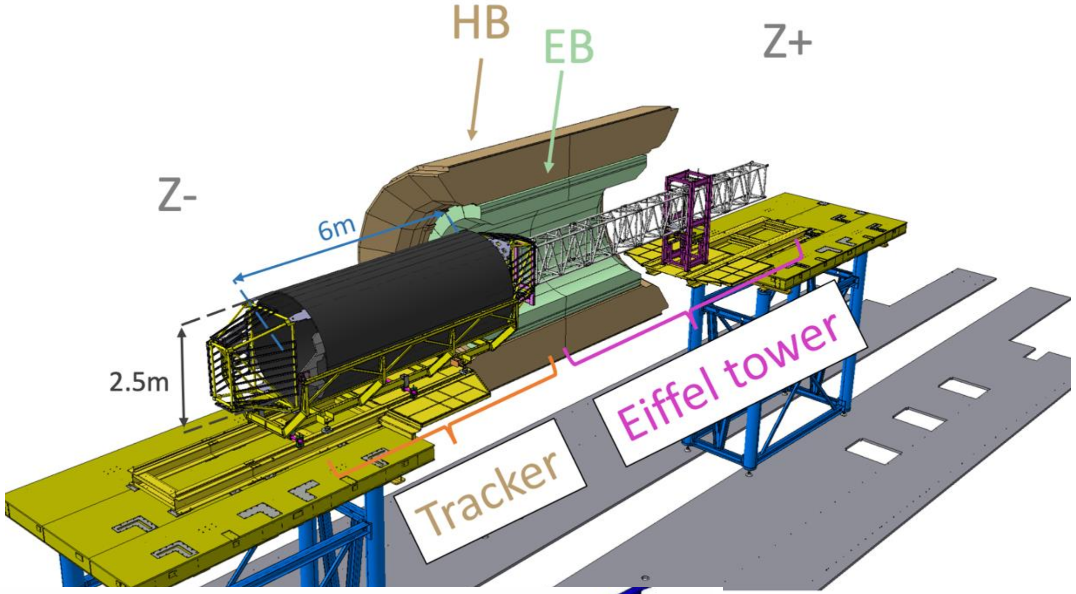




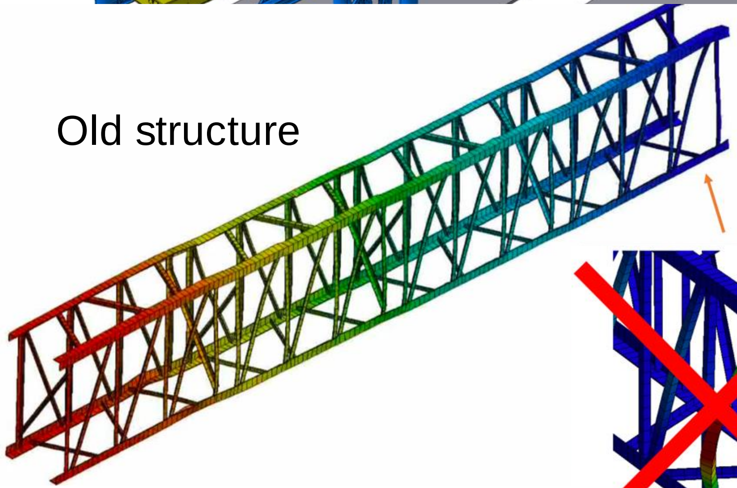


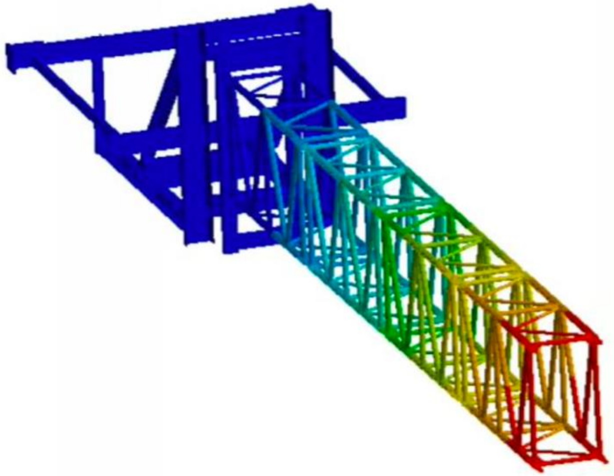
Significantly increased adhesive strength, mostly seen in shear test.
(about x10 breaking force)

CMS Tracker insertion

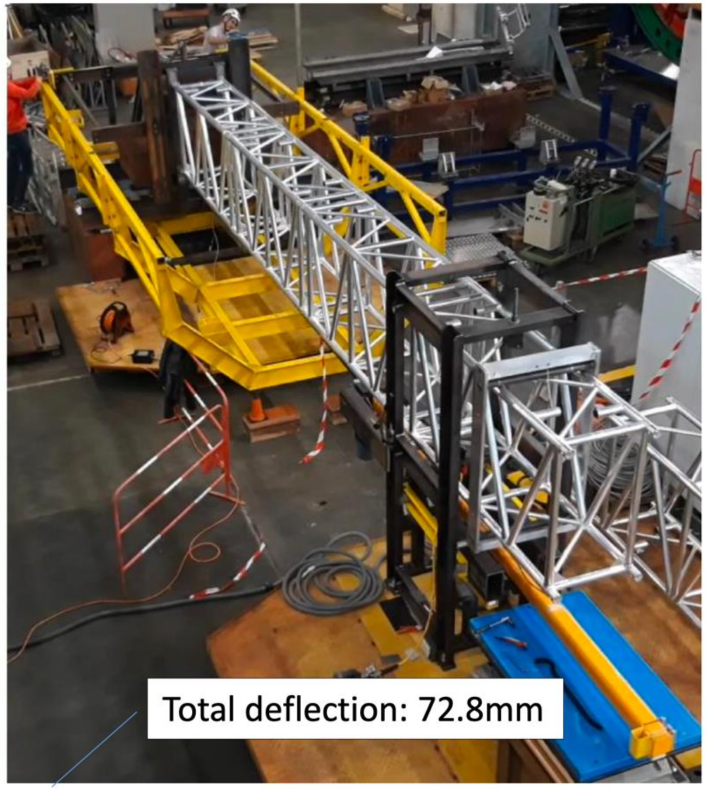


Old structure





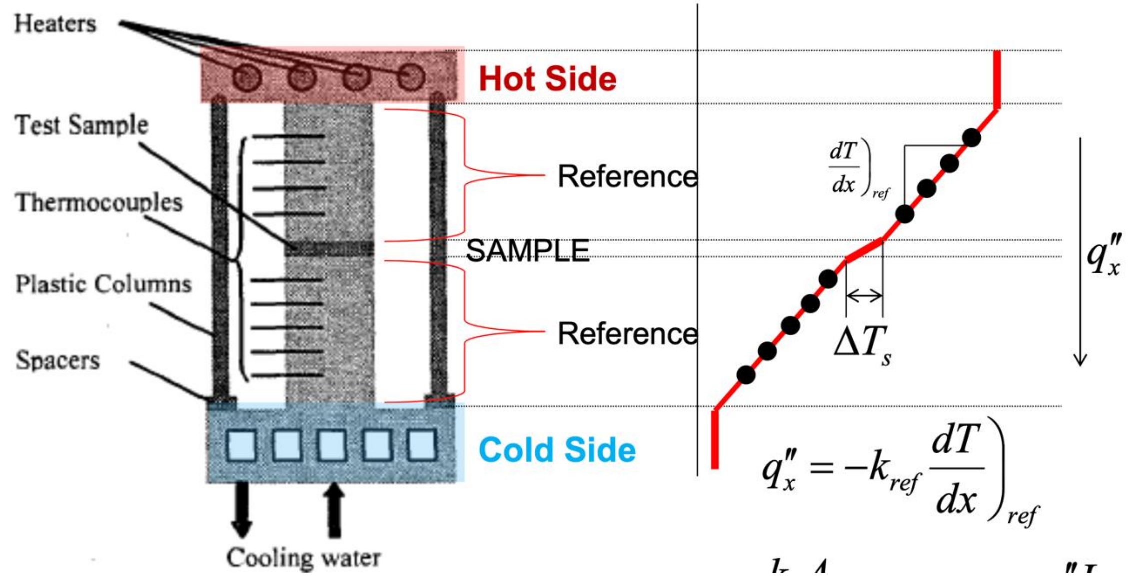
Total deflection: 68.0mm

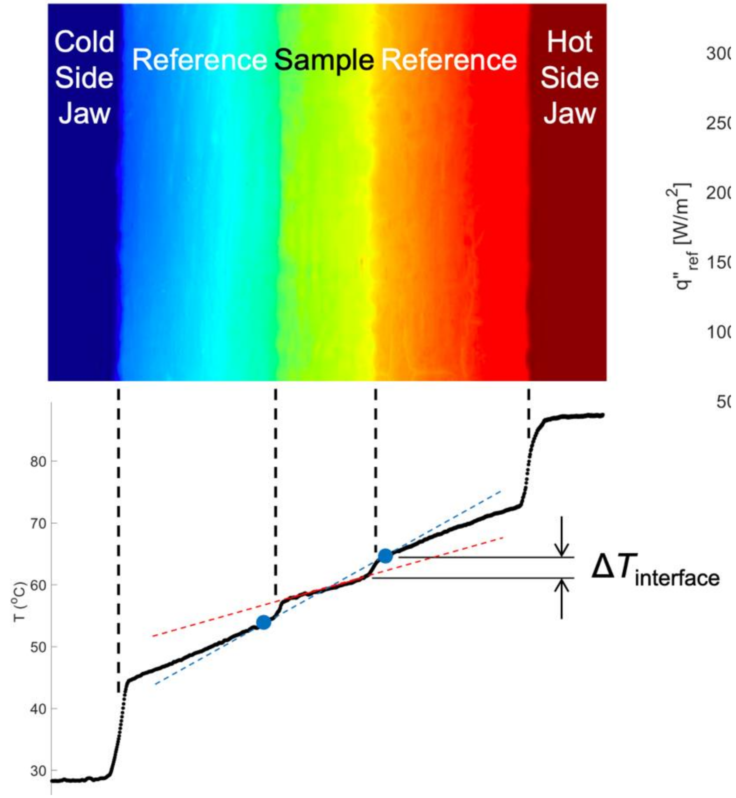


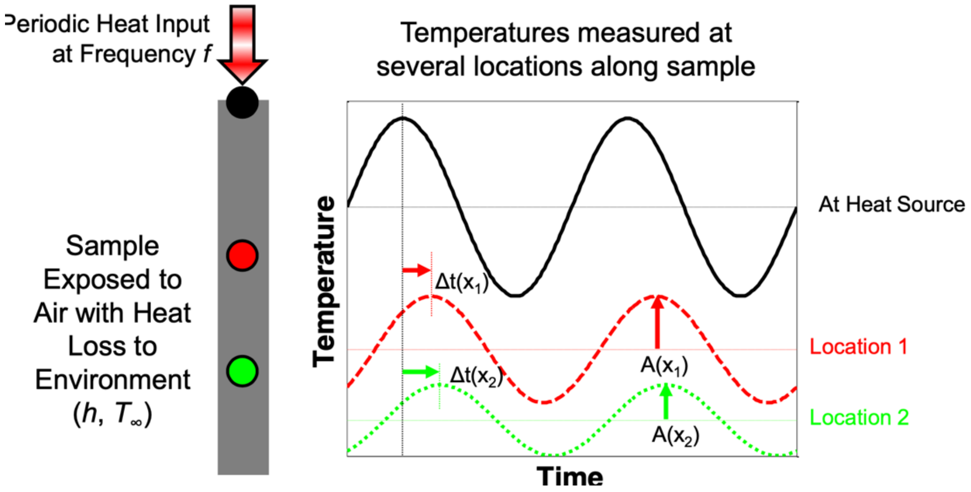
Total deflection: 72.8mm

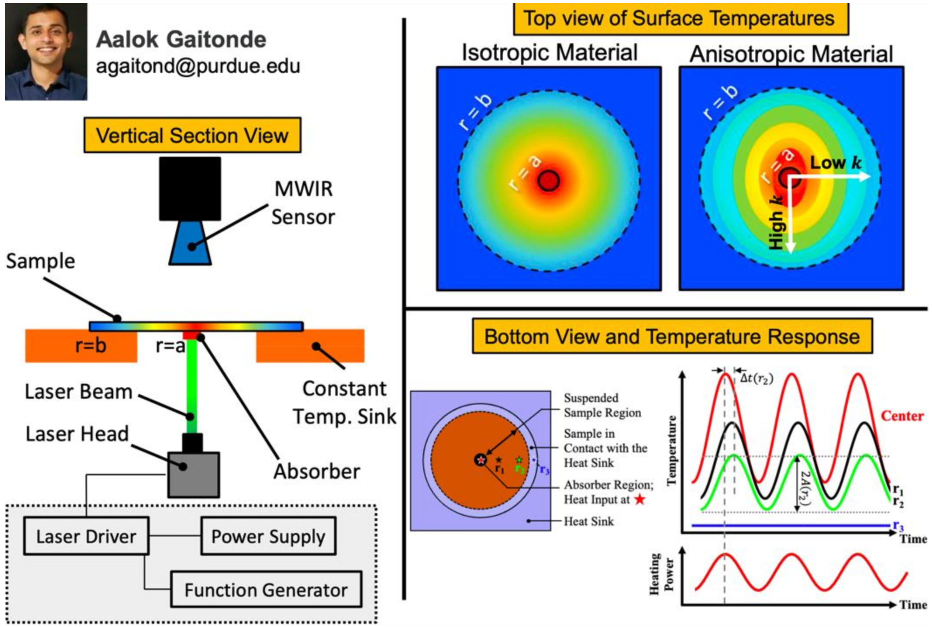
Thermal metrology

ASTM D5470 Reference Bar Method

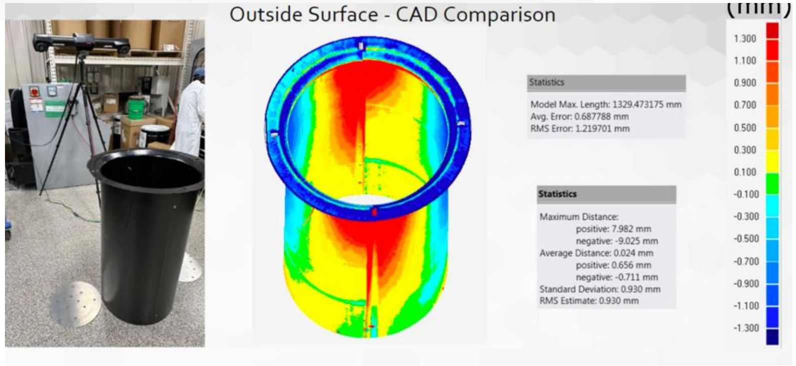


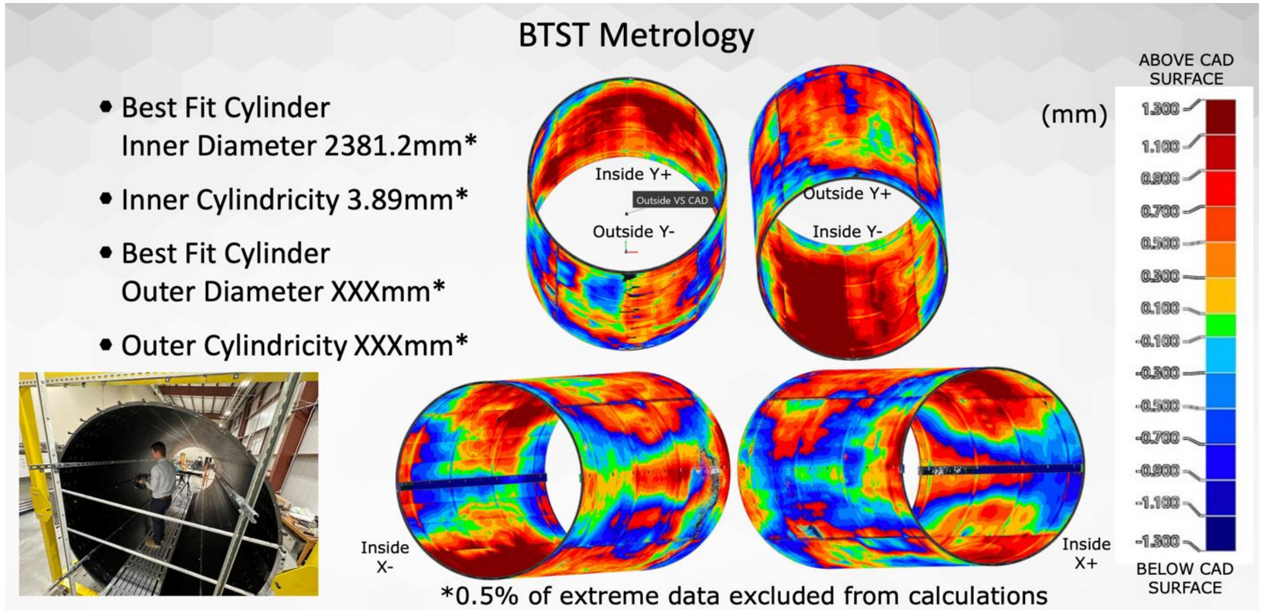






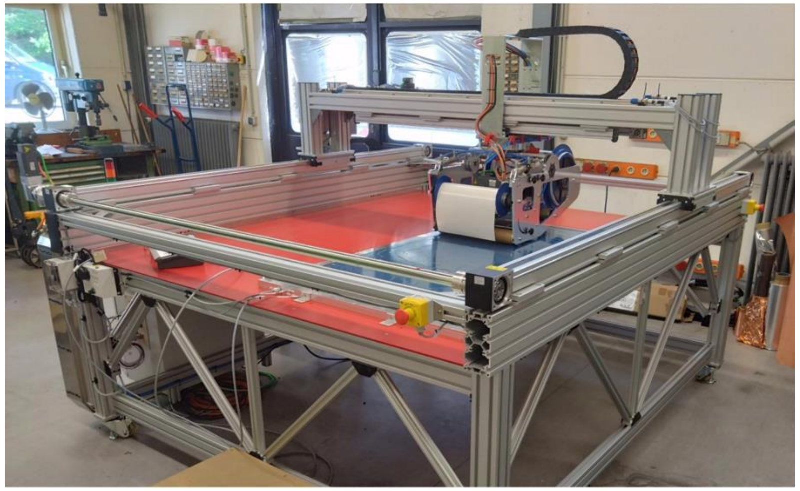
Composite support structures for the CMS Tracker



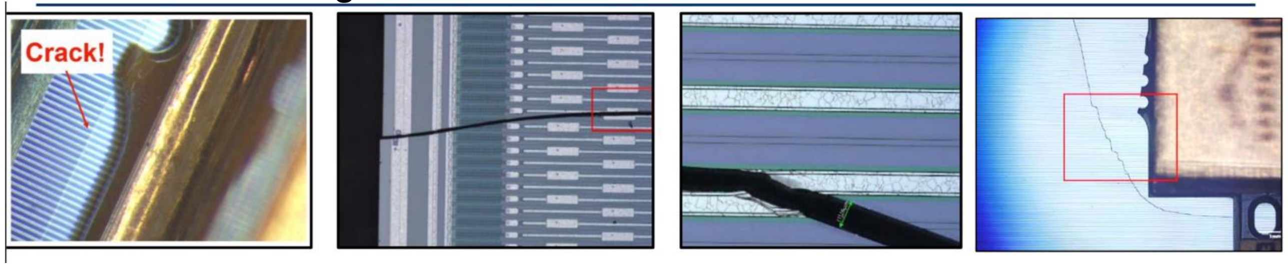


What else?

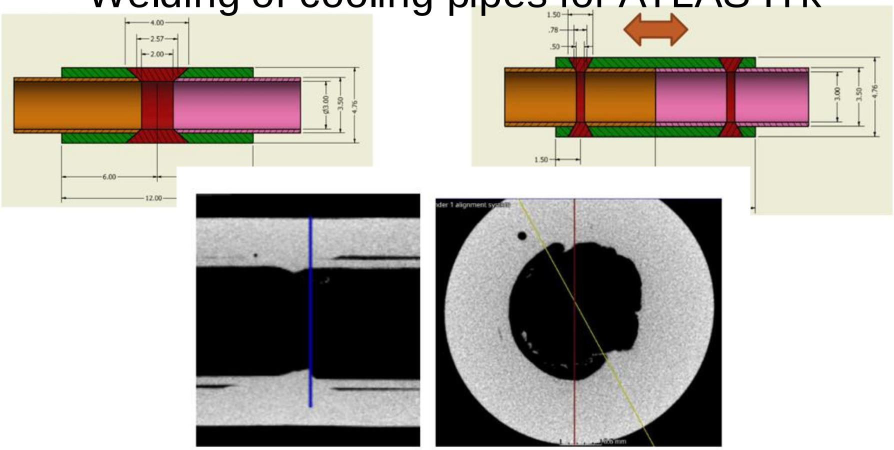
Robotic system for automatic prepreg layup



Cracking Silicon sensors



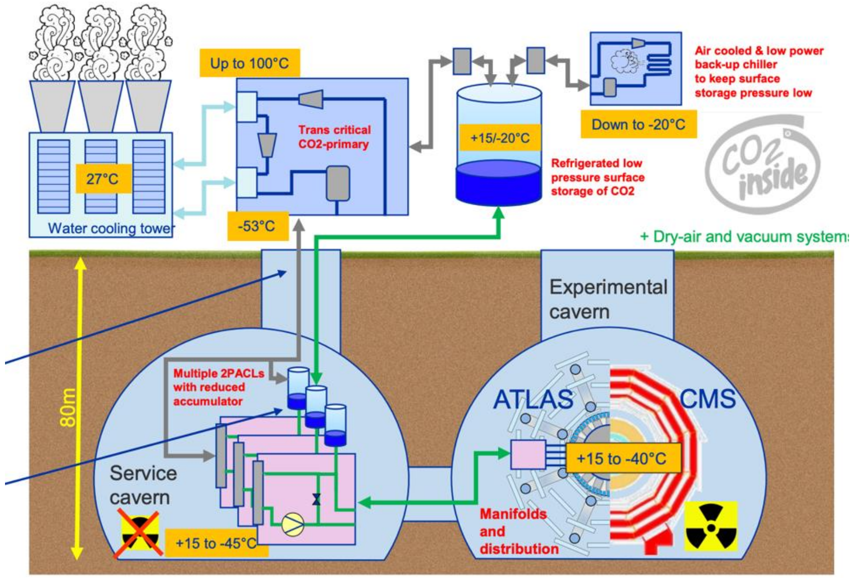
Welding of cooling pipes for ATLAS ITk



Loose ID tolerance

ATLAS ITk System test

ATLAS & CMS CO2 cooling systems



DRD 8 session

DRD8 structure

- The LoI proposes 4 Working Groups (WGs):

	FTEs
WG 8.1: Global/System Design and Integration	5.3
WG 8.2: Low Mass Mechanics and thermal management:	16.0
WG 8.3: Detector Cooling	7.3
WG8.4 Design and Qualification Tools	3.8

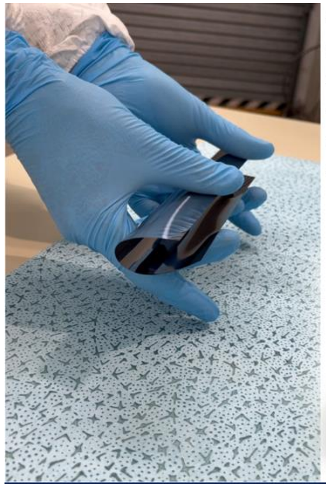
The LoI mentions also **targeted and collaborative R&D work** which includes (besides mechanics and cooling) sensors, front-end electronics, and electrical and readout services, for two application frameworks

Low intensity (LI): In this framework the mechanics and cooling will support sensors and electronics that have been designed for low power densities. The number and cross-section of electrical services will be small. Radiation damage levels will be low, and thus there will be no need to operate these systems cold (< 15 °C). Where possible, gas cooling will be an appealing solution. Radiation hardness levels of materials will be moderate.

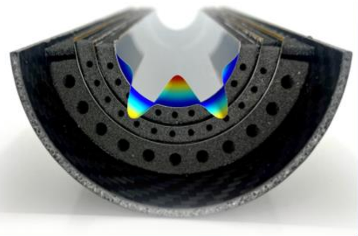
High intensity (HI): Detector systems within this framework will have to cope with large fluxes of signal and background particles. The high channel density and complexity of the front-end electronics will result in high power densities, which will need to be supplied by advanced powering systems. For the removal of the dissipated power further developments of evaporative cooling systems will be needed. Significant radiation damage will require cold (< -35 °C) operation to keep leakage currents under control. Materials will need to be qualified for the high radiation environment.

WG 8.1: Global/System Design and Integration:

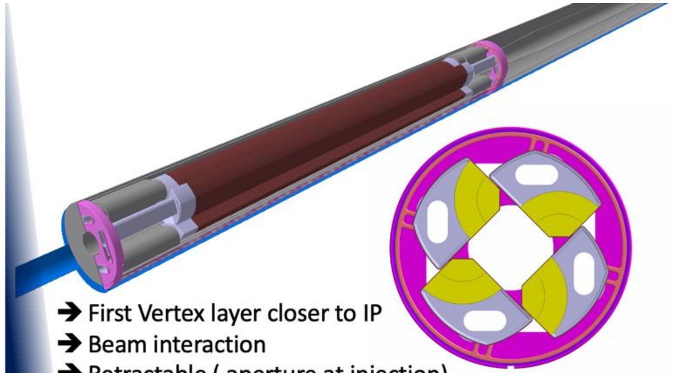
- Mechanics for advanced layouts, including curved and tilted sensors, low radii vertex systems and retractable detectors;
- Service integration;
- Environmental and structural health monitoring;
- Life-Cycle design of trackers;
- Fostering links with the accelerator community to understand the Machine Detector Interface (MDI) for future colliders;
- Robotics and remote operation, maintenance and handling;
- Scalability and industrialisation.



- ➔ Silicon stitching
- ➔ Silicon bending
- ➔ Air cooling
- ➔ Carbon foam
- ➔ Low mass mechanics
- ➔ Short term mechanical stability (vibration)



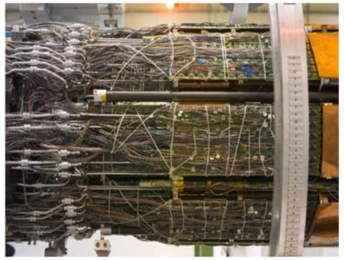
➔ ALICE ITS3 as vertex precursor for FCC ee?



- ➔ First Vertex layer closer to IP
- ➔ Beam interaction
- ➔ Retractable (aperture at injection)
- ➔ Beam impedance (dissipated power)
- ➔ Reliable precise rotation
- ➔ Reliable extraction

➔ ALICE IRIS, LHCb Velo as case study to go closer to IP

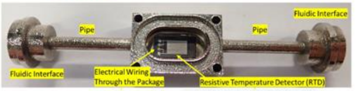
Service integration



carbon-nanotube cables. *Common* ***coaxial cables*** *could be made 50 percent lighter with a new nanotube-based outer conductor.*

- ➔ Service architecture
- ➔ Integrated and reduced services mass
- ➔ Integrated sensors in cooling lines
- ➔ ...

C. Manoli, P. Petagna

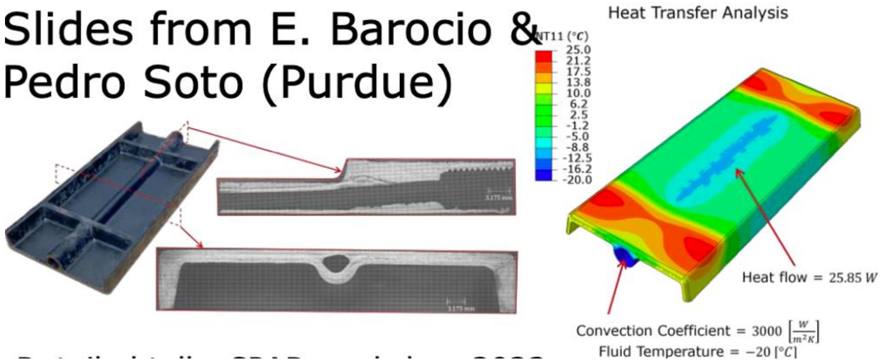


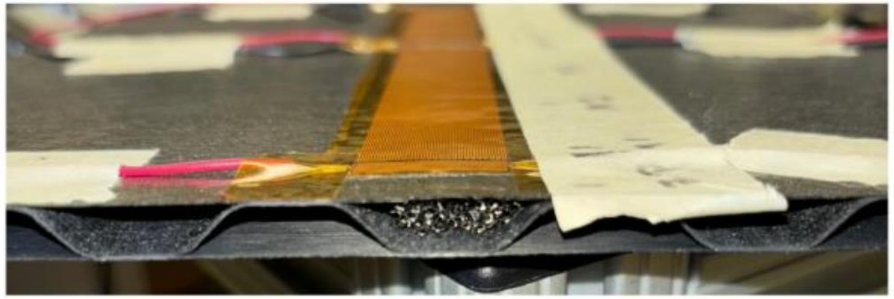
Smart Wall Pipes

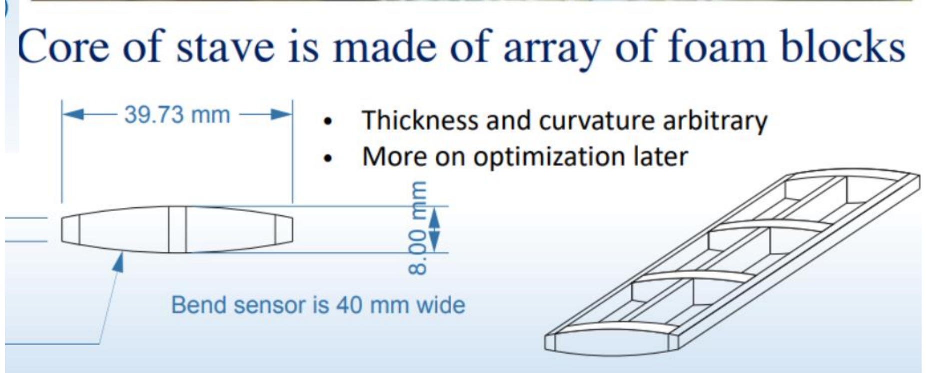
WG 8.2: Low Mass Mechanics and thermal management:

- Novel materials for structural and thermal management applications, including qualification for operation in harsh environments;
- Advanced manufacturing techniques, including additive manufacturing;
- Support structures with integrated cooling circuits, including silicon or ceramic substrates with embedded microchannels, composite substrates with embedded pipe-less networks and cold plates with thin-walled pipes;
- Modular, scalable designs for detectors with large surface areas;
- Vacuum-tight composite structures.

Slides from E. Barocio & Pedro Soto (Purdue)







Radiation Resistance

Effect of radiation on –
- Thermal Conductivity
- Elastic modulus
- Poisson's ratio
- Coefficient of thermal expansion (CTE)

Heat Transfer

- Thermal Conductivity
- Specific Heat
- Emissivity
- Performance at sub-zero temperatures

Thermo-mechanics

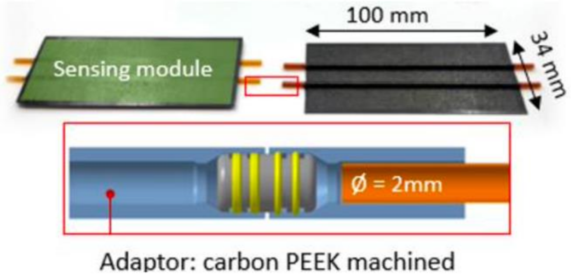
- Crystallization / Melting
- Coefficients of Thermal Expansion
- Bonding

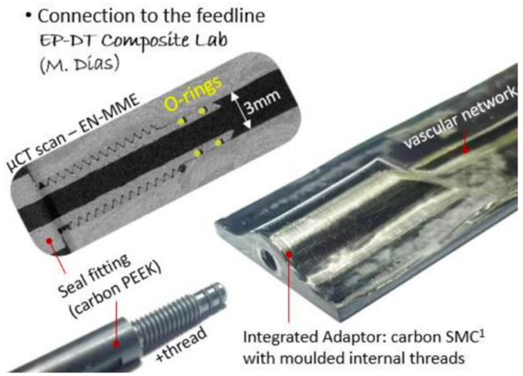
Viscoelasticity

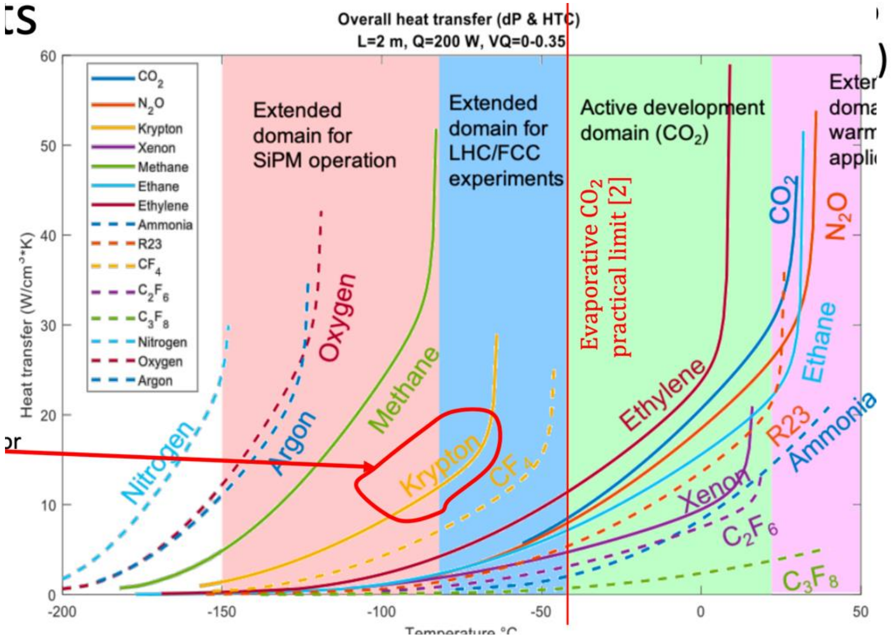
- Prony Series model

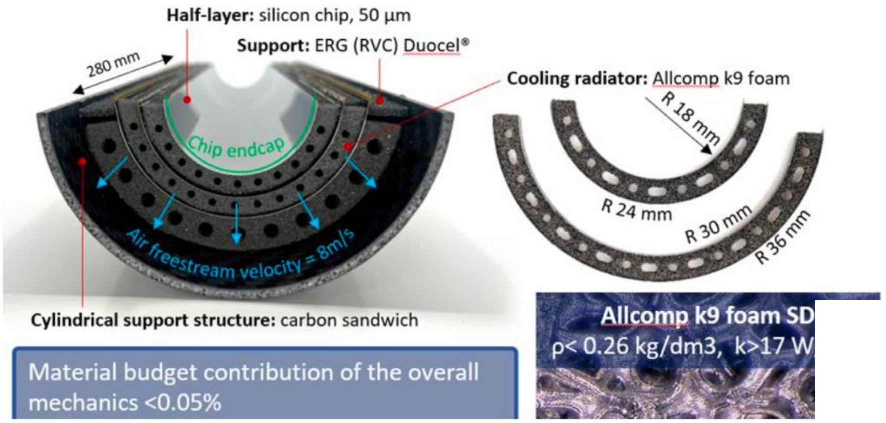
WG 8.3: Detector Cooling:

- Evaporative and liquid cooling for both low and warm temperatures, based on natural or eco-friendly refrigerants and new cycles;
- Gas cooling solutions for detectors, including flow design and heat transfer through porous media;
- Connection technologies for cooling circuits, including leak repair methods;
- Instrumentation, including flow measurements for gases and liquids.

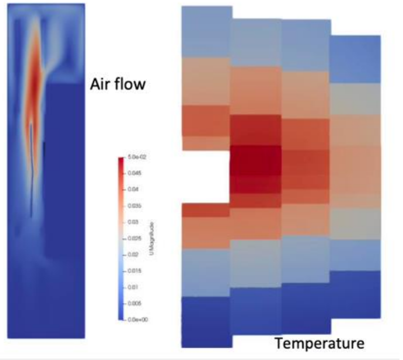








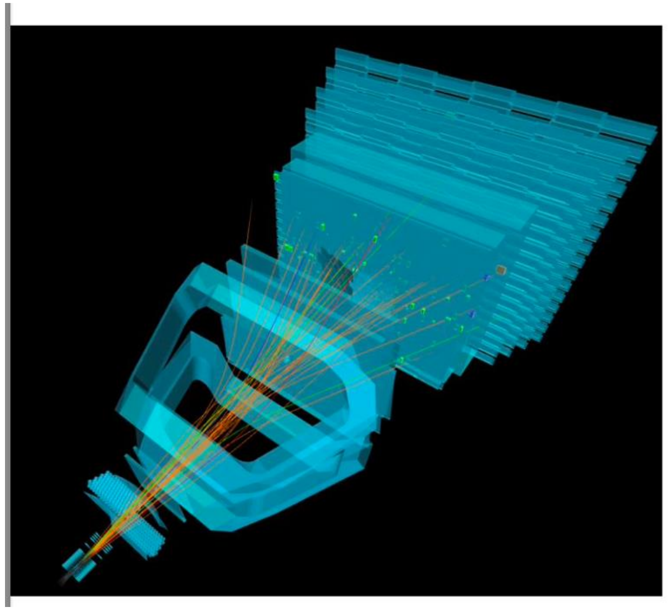
Open source Air flow simulation(OpenFoam) GSI-Darmstadt, M. Teklishyn

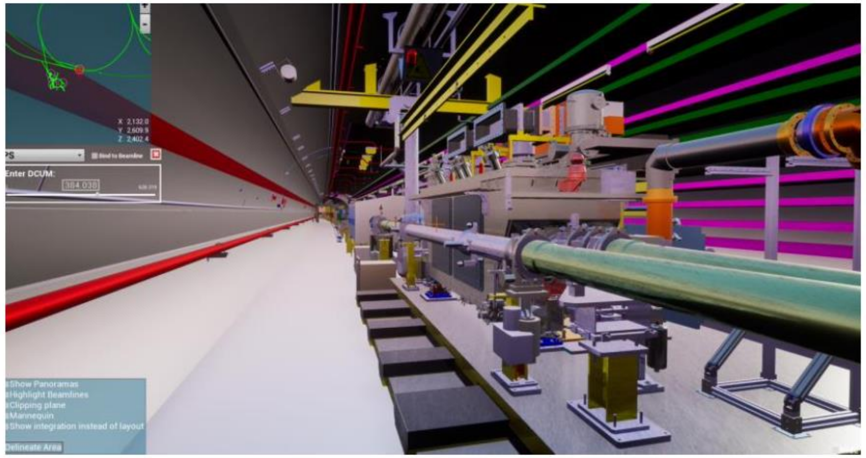


WG8.4 Design and Qualification Tools:

- Open-source software and high-performance parallel computing numerical simulation tools for structures and fluids;
- Machine learning enhanced topology optimisation;
- Virtual reality aided design;
- Methods for using 3D design of complex service geometries and linking of schematics and 3D models;
- Connection of CAD tools and GEANT.

Virtual reality: display of a real event
http://cds.cern.ch/record/2745563



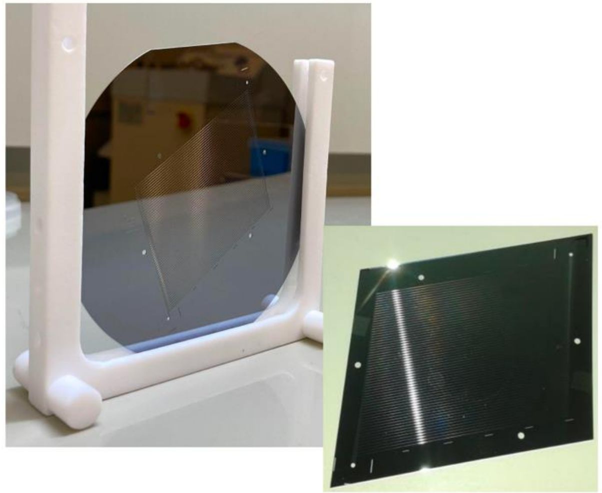


Digital twins: SPS CERN
https://indico.cern.ch/event/1304817

DRD7 microchannel cooling

Microchannel cooling and active interconnection developments

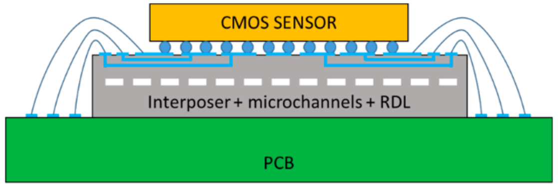
- **Miguel Ullán (IMB-CNM, CSIC)**, Carlos Mariñas (IFIC-UV, CSIC), Marcel Vos (IFIC, CSIC-UV), Ingrid Gregor (DESY), Sergio Díez (DESY) and Jonathan Correa (from DESY)
- In the past, we developed a technology of micro-channel cooling for High Energy Physics detectors
  - N. Flaschel, et al. “Thermal and hydrodynamic studies for micro-channel cooling for large area silicon sensors in high energy physics experiments”, NIMA, vol. 863, pp. 26-34, 2017. (link)
  - Ph.D Thesis: Micro-channel Cooling For Silicon Detectors. Nils Flaschel. Hamburg University. 2017 (link)



Microchannel cooling and active interconnection developments

DRD7: AN R&D COLLABORATION ON ELECTRONICS AND ON-DETECTOR PROCESSING

- Main Objective I: Integration of micro-channels in silicon interposers with integrated signal and power routing (RDL)



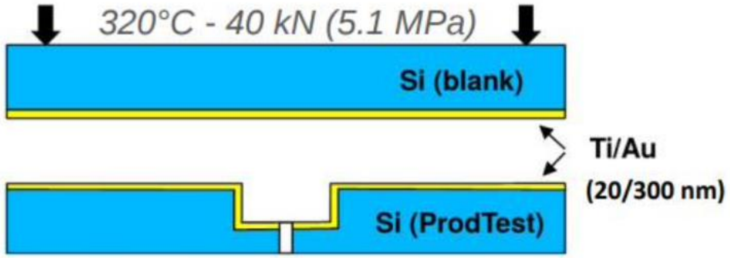
Main Objective II: Full integration of the sensor (CMOS technology) with the microchannel cooling in a single silicon piece

- Full integration of DMAPS chip with the microchannels in a single monolithic piece
- Post-processing at wafer level with a CMOS compatible process
- Following the “post-processing” technique developed previously
- Additional technological developments
  - ✓ Low temperature (350°C) anodic bonding
  - ➢ Microchannels created on glass substrates (isotropic wet etching)
  - ➢ Eutectic and/or fusion bonding
  - ➢ Improve post-processing compatibility
  - ➢ Full demonstrator

Conclusion

DRD7: AN R&D COLLABORATION ON ELECTRONICS AND ON-DETECTOR PROCE

- Microchannel cooling and active interconnection developments (CNM, DESY, IFIC)
  - Aiming to bring more functionalities to the cooling plate
    - Redistribution layer could be an interesting solution for ASICs with through-silicon vias
  - CMOS compatible process to integrate the cooling to the sensor
- Microchannel cooling manufacturing via thermocompression (CPPM)
  - Main motivation to reduce the manufacturing cost
    - Very promising results “hyperbar” chamber (resistance to high pressure)
  - Techniques developed can be also explored for integration (chips and connecturization)
- Ceramics
  - It has also the potential to include electronic features
  - Fully validated initial prototypes in the coming years to high pressure, leak tightness and cooling performance in the following years
  - LHCb VELO Upgrade 2 as benchmark requirements (High pressure, CO_2 evaporative cooling)
- Metal 3D printing
  - X-ray tomography indicates issue with the fill factor
  - Distortion observed created a choke point
  - Next run: focus on improving distortion and fill factor and investigation of electropolishing (material reduction/easier integration?)

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