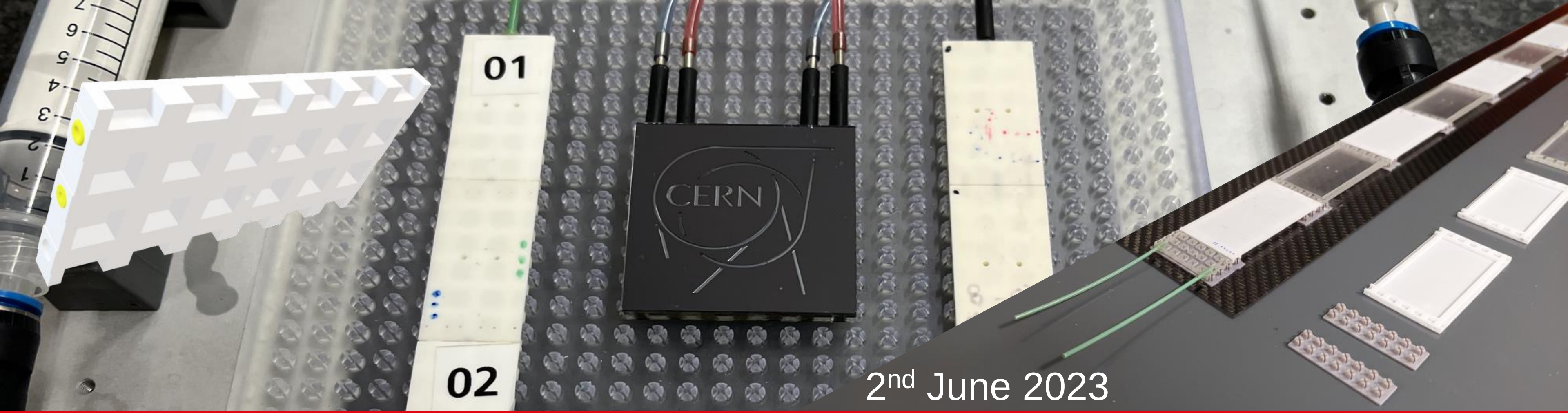


2nd June 2023

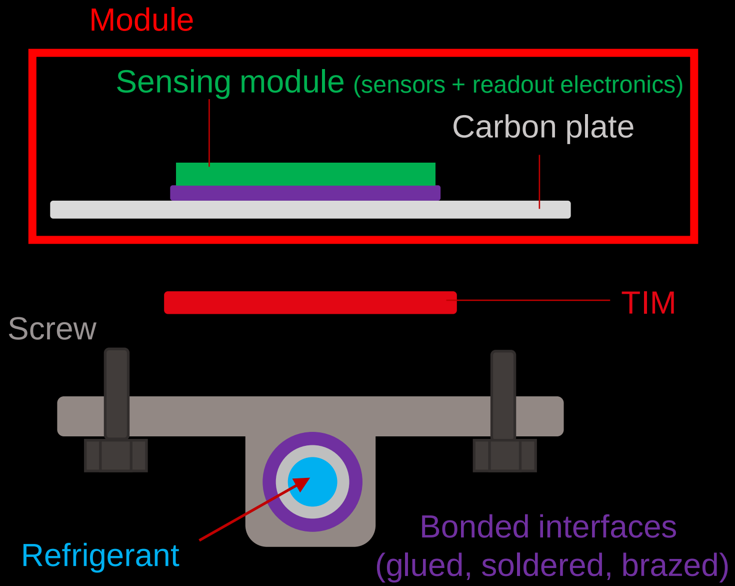
Interlocking modular microfluidic cooling substrate for future HEP experiments

ALICE
CERN EP-DT Detector Technologies
EP R&D
EPFL

Massimo Angeletti
CERN supervisor: Corrado Gargiulo

Forum on Tracking Detector Mechanics 2023
Eberhard Karls Universität Tübingen
https://indico.cern.ch/event/1228295/contributions/5390956/

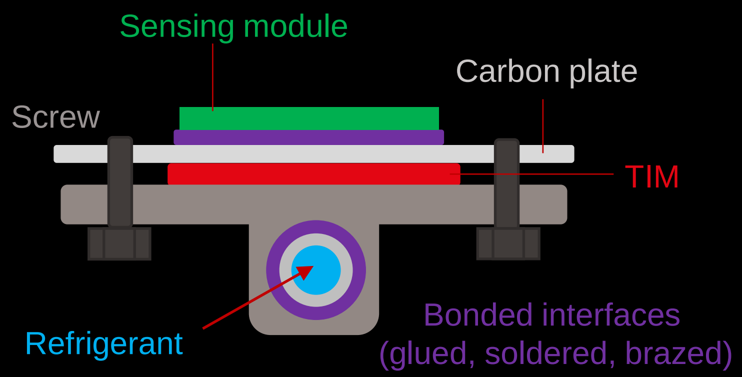
Replacement of modules



Thermal interface material (TIM) :

- thermal paste,
- thermal gap filler,
- compressible pyrolytic graphite sheet.

Replacement of modules



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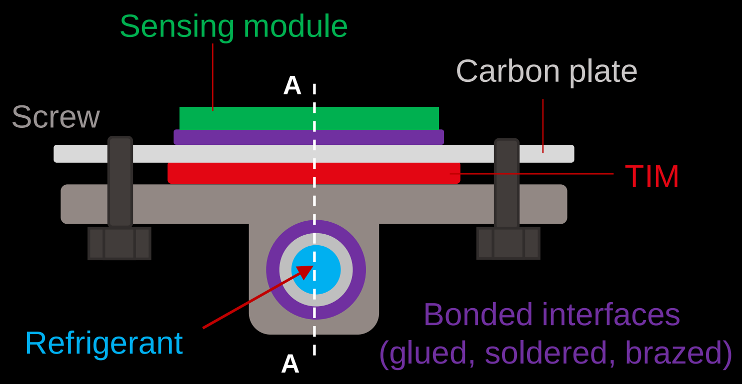
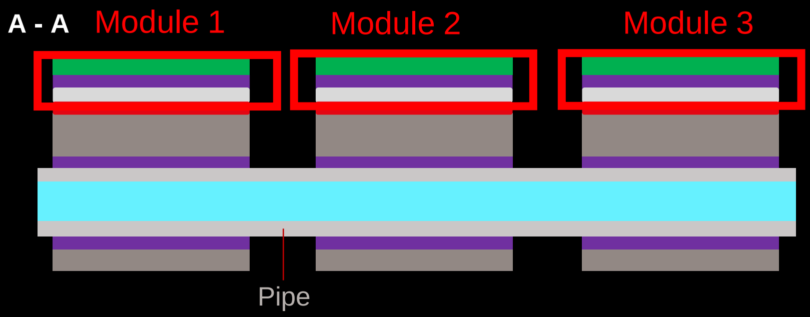
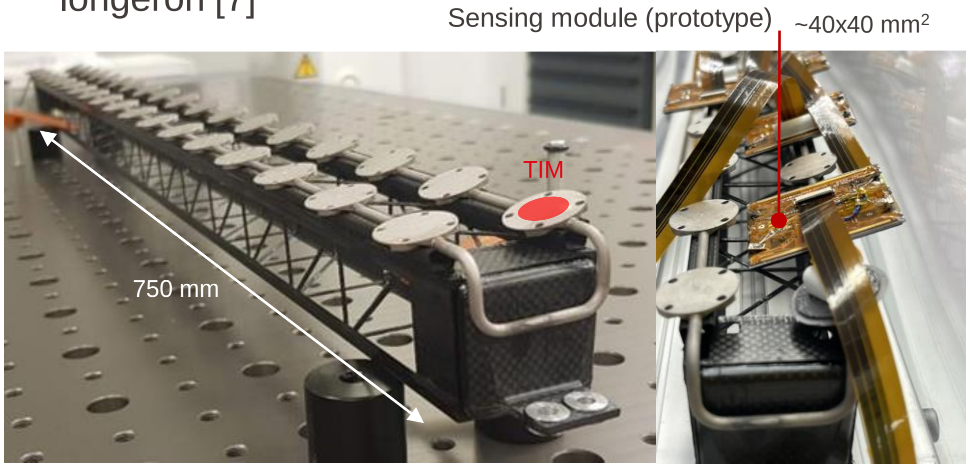




- **Example:** ATLAS Inner TracKer (ITK) central barrel longeron [7]

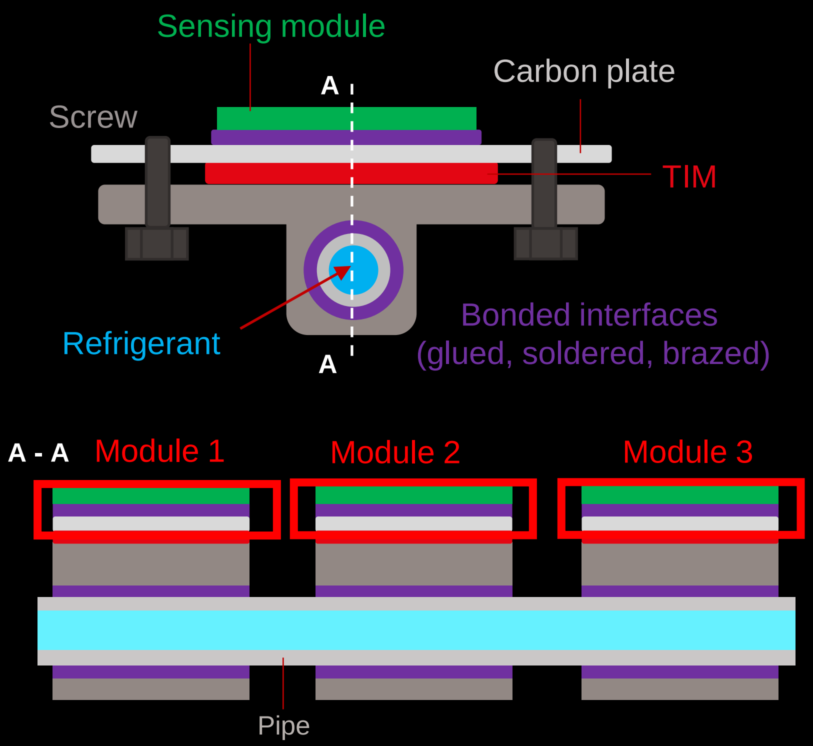


[7] D. Alvarez and et al., "Design Overview of the Bare Local Supports for the ITk Pixel Outer Barrel," Tech. Rep., 2021. https://edms.cern.ch/document/2632352.

Issues:

- TIM can **deteriorate over time** accelerated by **radiation damage**
  ➔ **Uncertainty and increase** of **thermal resistance.**
- Several thermal interfaces and materials
  ➔ ↓**thermal efficiency** (TFM=15-40), ↑**material budget**
- **Quality control** only at the final phase of the **detector integration**

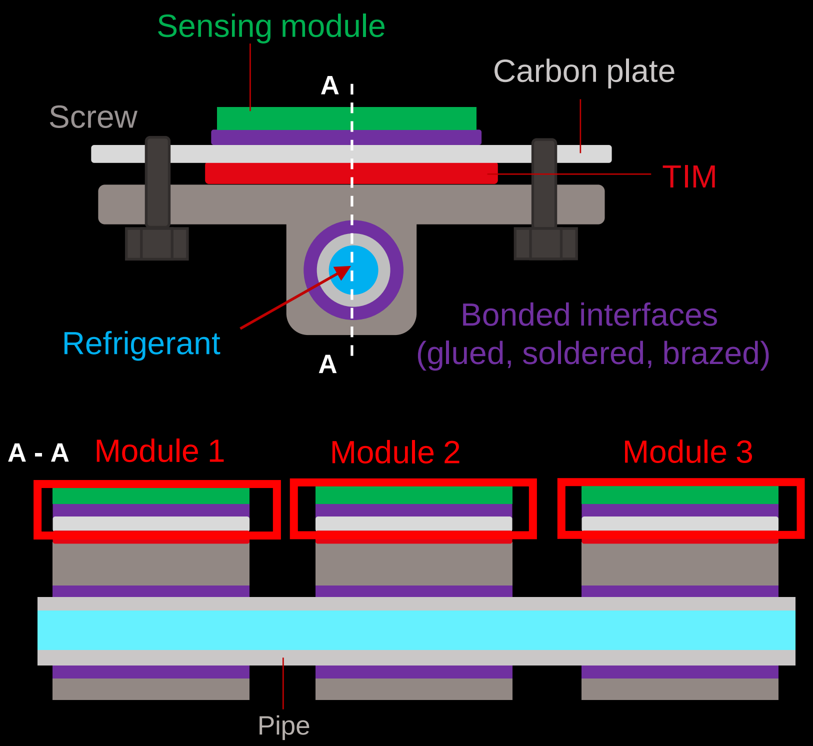
Present approach:



New approach:

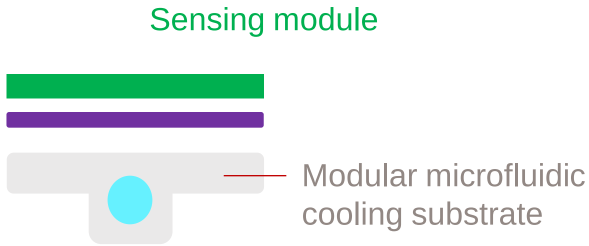
Objective of the research

Present approach:

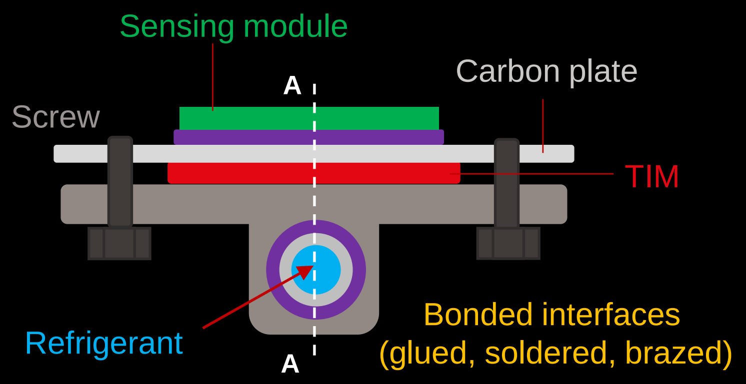


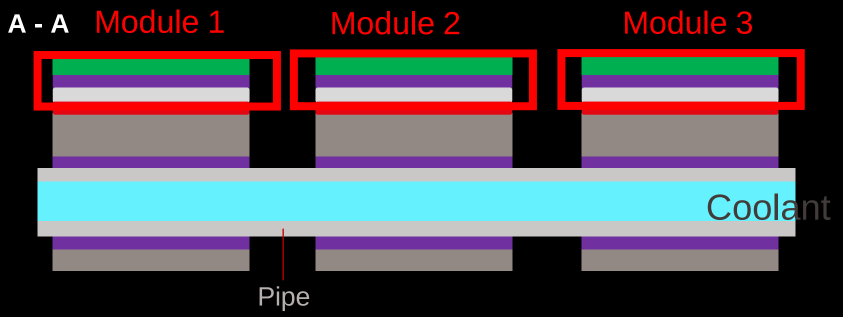
New approach:

- Cooling circuit as integral part of the module



Present approach:





New approach:

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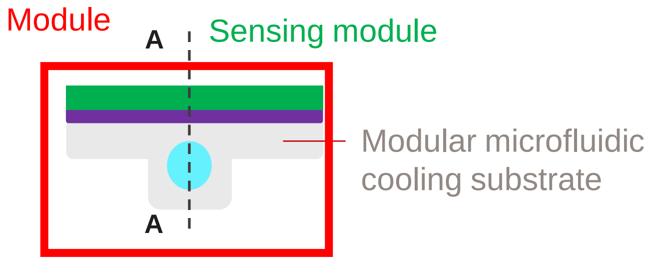
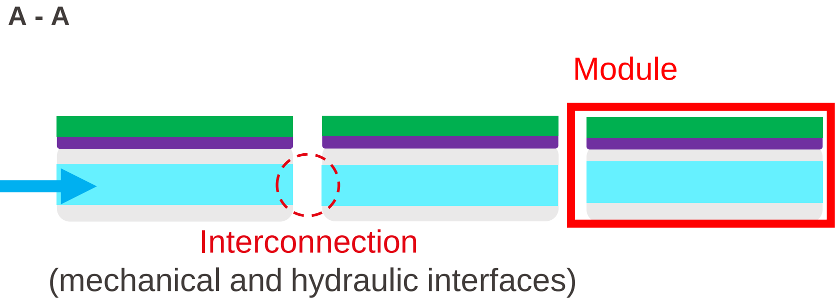
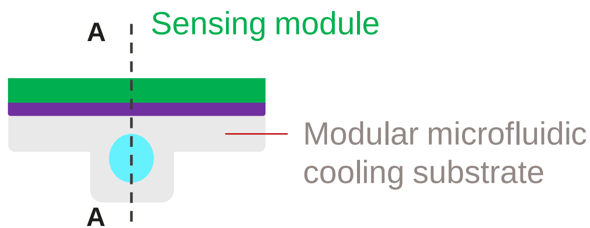


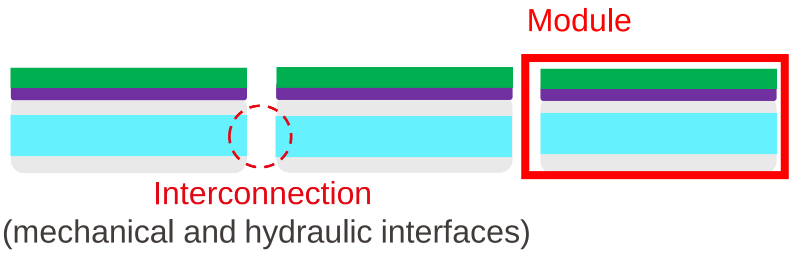


New approach: Modular microfluidic cooling substrate

- Cooling circuit as integral part of the module



A - A

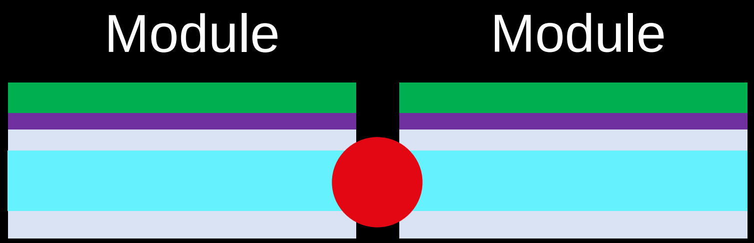


➔ **Advantages:**

- **Fully test a module** (electrical and thermal) **prior** the final detector integration
- Access **industrialised** and **distributed series production**
- ↑ **thermal efficiency**, ↓**material budget** (Minimization of thermal interfaces)

➔ **Main challenge: efficient**, **reliable mechanical** and **hydraulic interconnection** between microfluidic modules.

Interconnection



Interconnection
(mechanical and hydraulic interfaces)

- Reliable
- Low mass
- Small size
- Dismountable

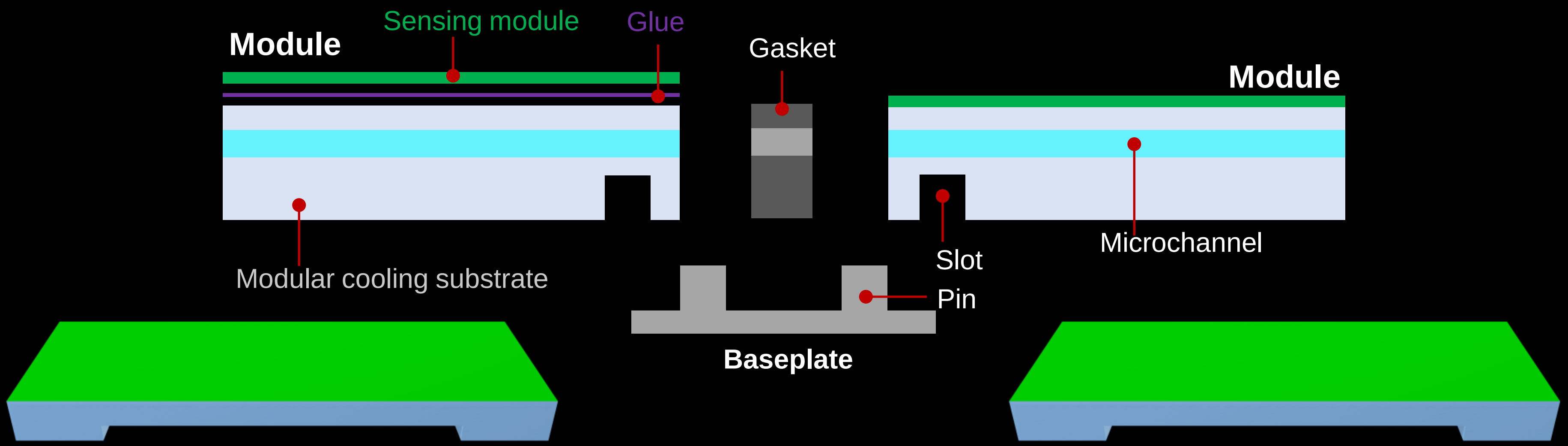
As **simpler as possible**.
➔ there is always time to complicate it...

Independent (or almost) **on selected material and manufacturing process** of the cooling substrate.

Minimum diameter= 0.5mm.

Interlocking concept

- **Mechanical interface ➔ Pin-based ➔** LEGO-like, pin and slot anchoring (out-of-plane mechanical interface)
- **Hydraulic interface ➔ Face seal ➔** Compressed gasket (in-plane hydraulic interface)



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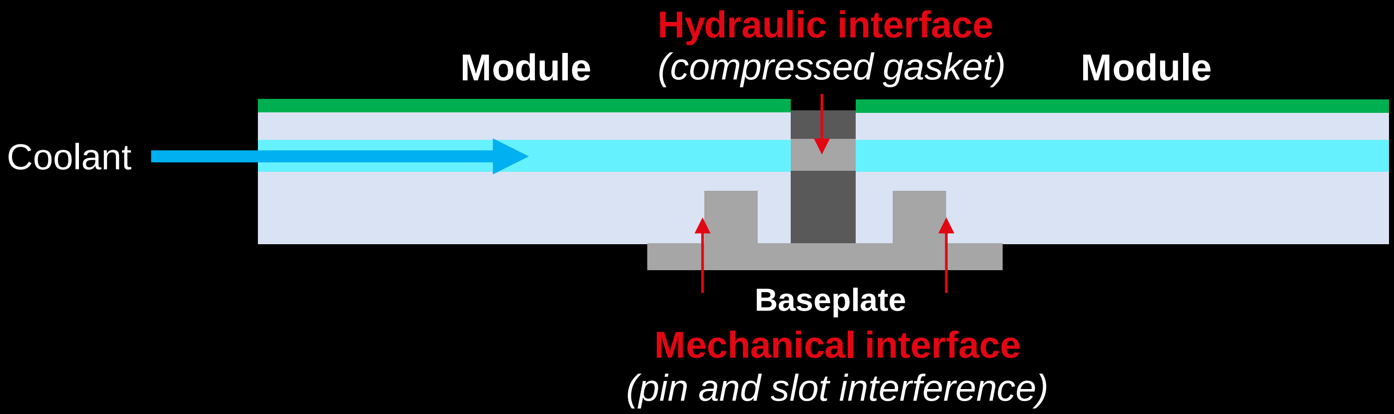
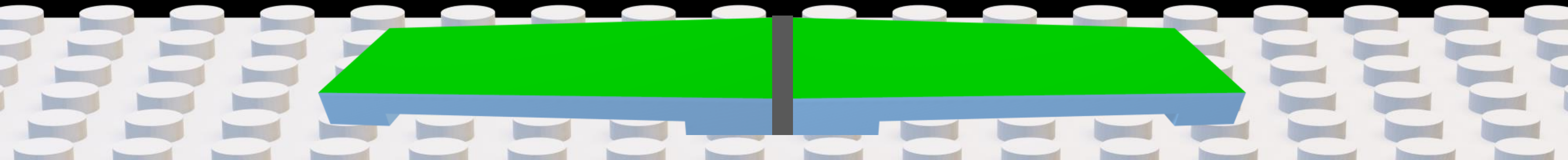
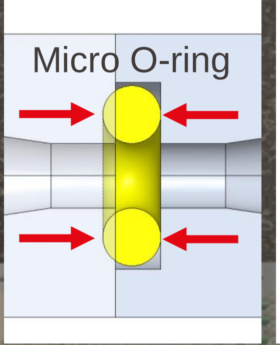
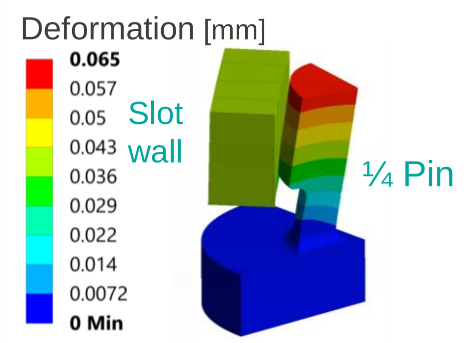


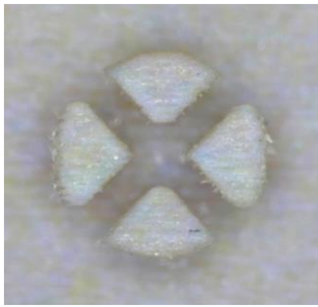


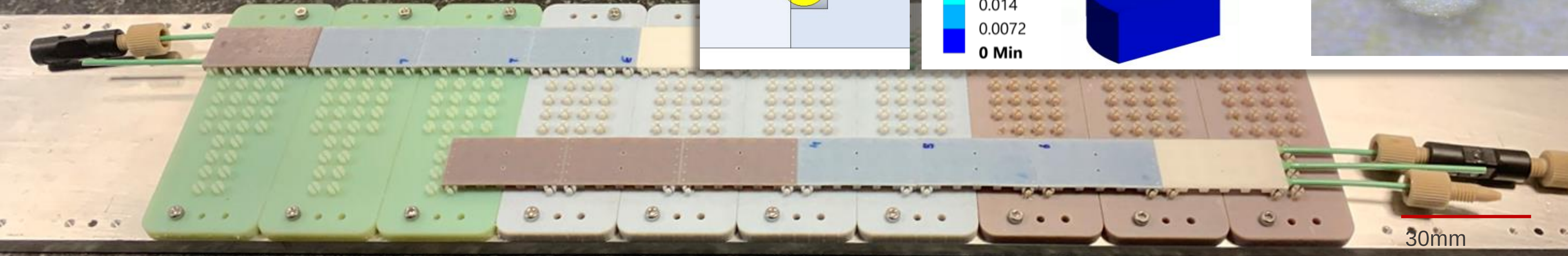
Interlocking concept

- **Breadboard model:** 15x30x2.2 mm^3 samples

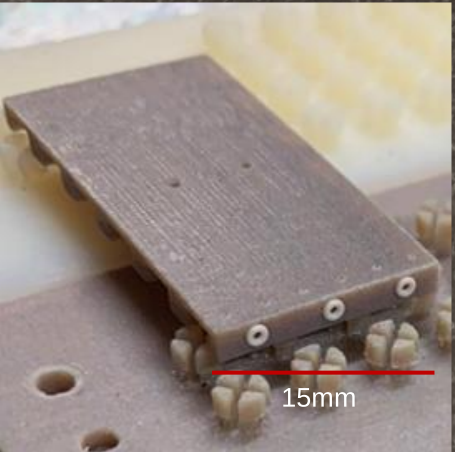


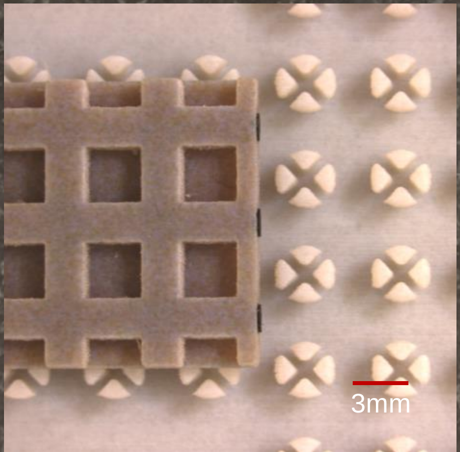


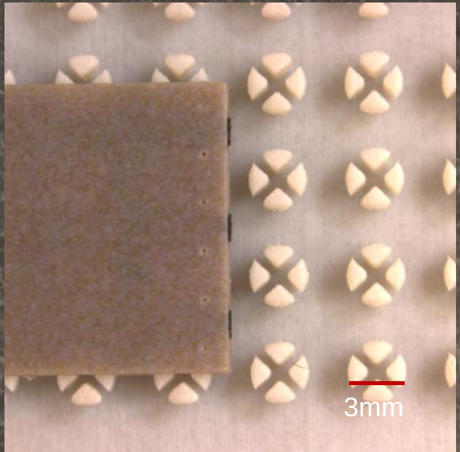


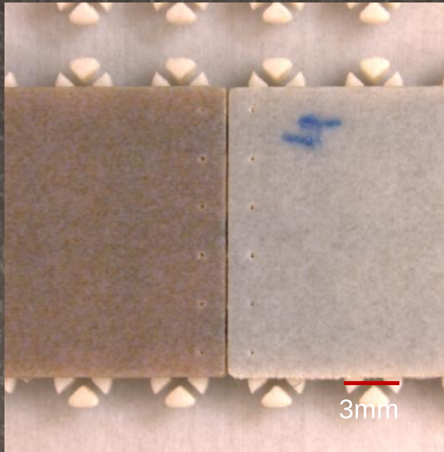


- **Design flexibility** based on a mechanical interface that can be tuned based on substrate material

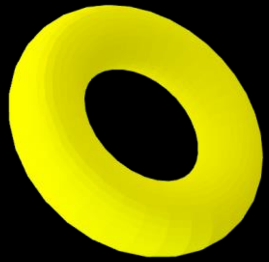






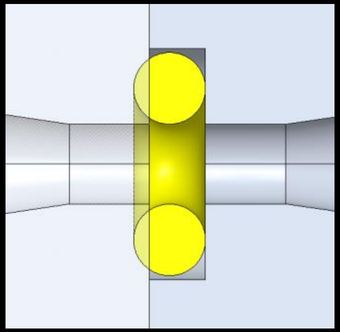


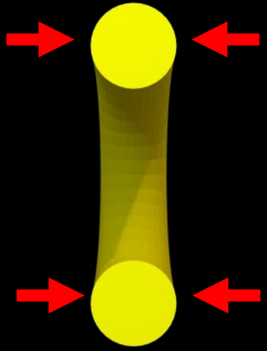
Interconnection alternatives



- **Hydraulic interface →** from **Face seal** to **Radial**

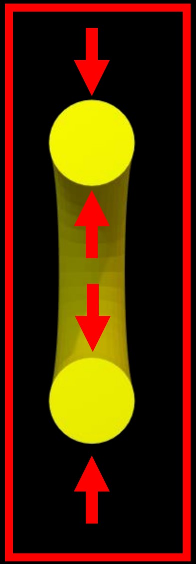
Axial compression





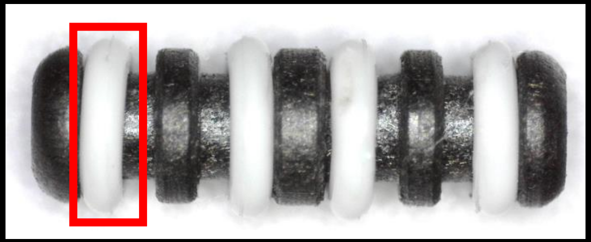
- Minimise dependence on module positioning

Radial compression



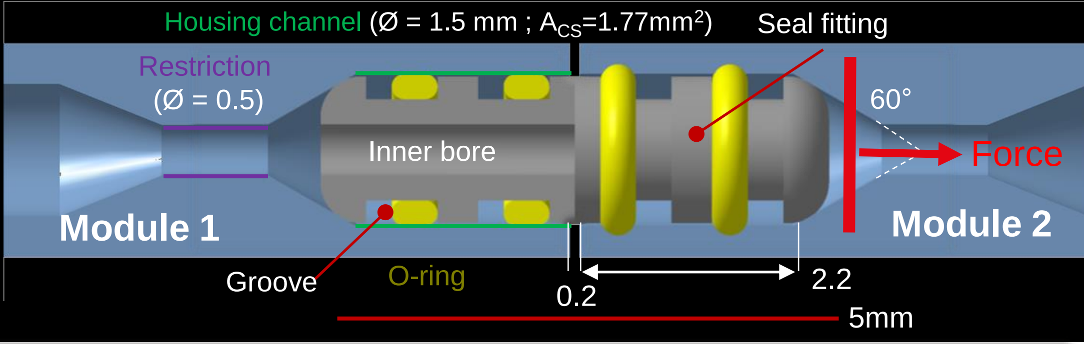
- **Additional component:**

Seal Fitting



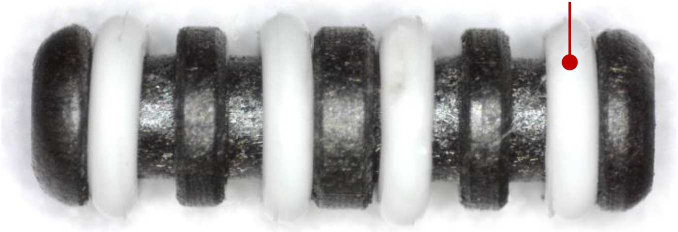
Interconnection alternatives

- Hydraulic interface → Radial seal
  - Redundancy

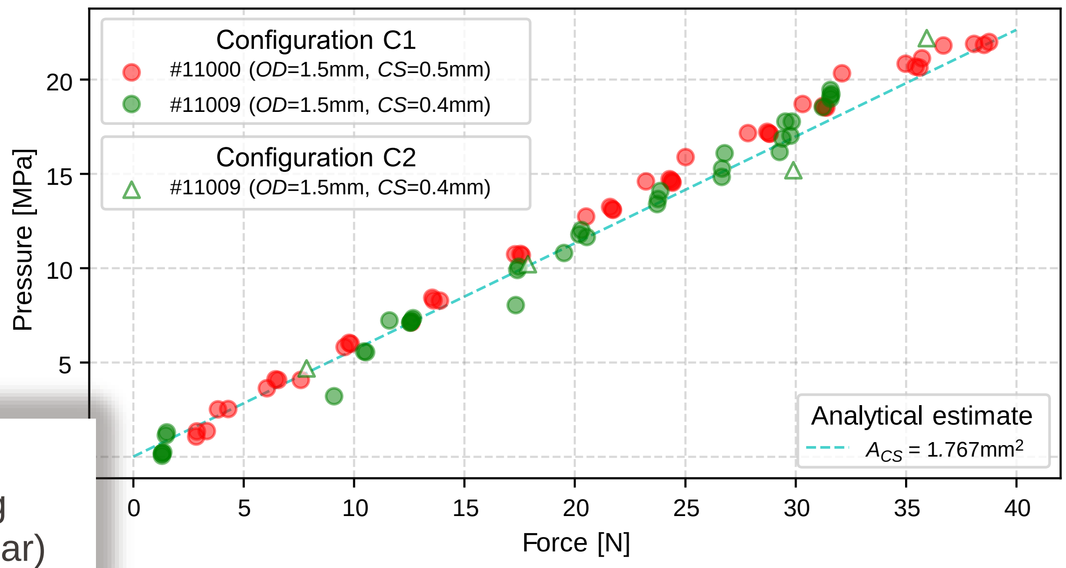


Pressure tests

Micro O-rings (NBR material)



Seal fitting, CNC carbon PEEK

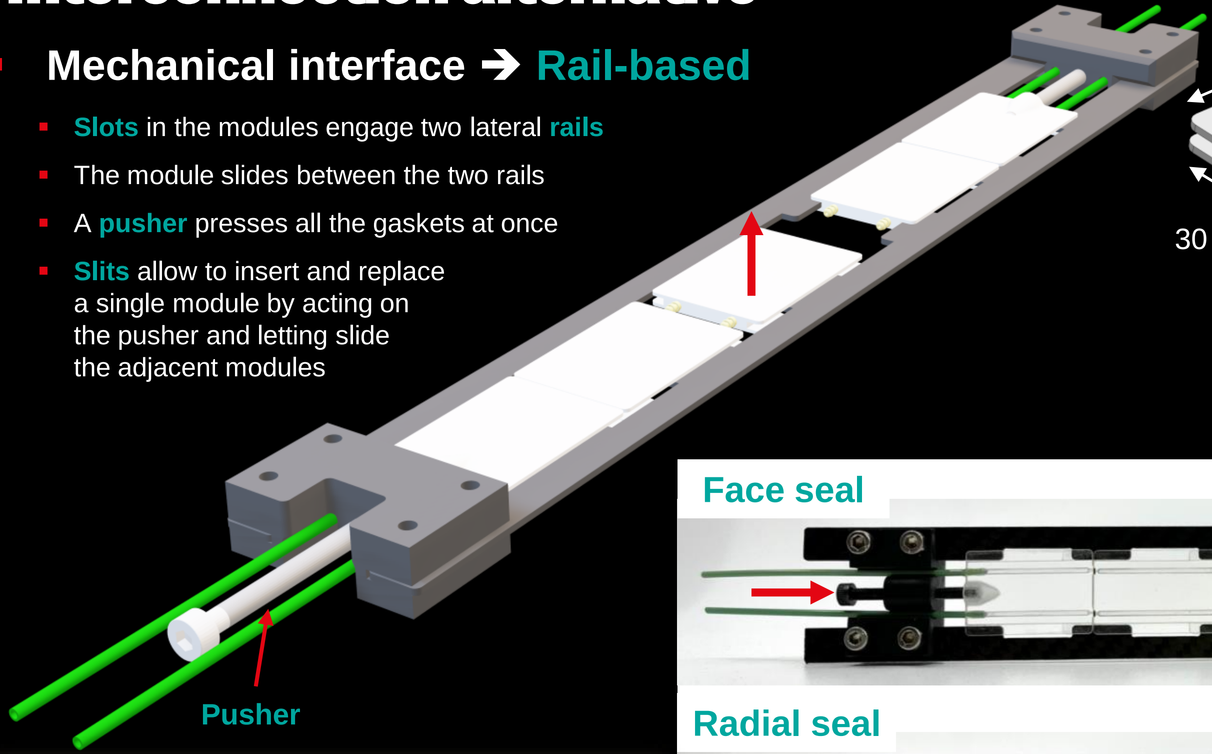


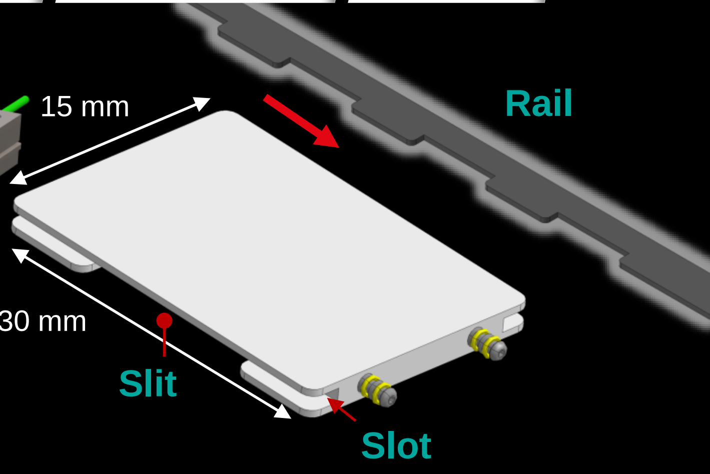
Outcomes

- Minimum dependence on module positioning
- Applicable to high pressure systems (>200 bar)

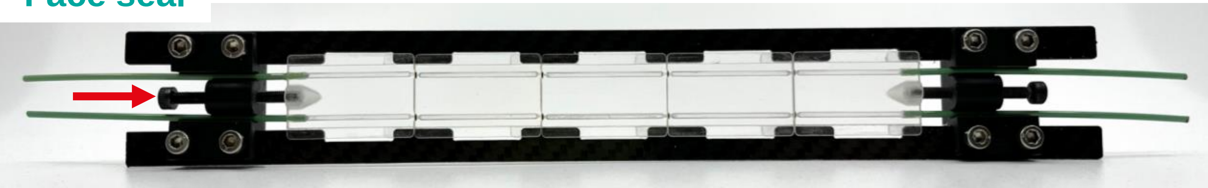
Interconnection alternative

- **Mechanical interface → Rail-based**
  - **Slots** in the modules engage two lateral **rails**
  - The module slides between the two rails
  - A **pusher** presses all the gaskets at once
  - **Slits** allow to insert and replace a single module by acting on the pusher and letting slide the adjacent modules

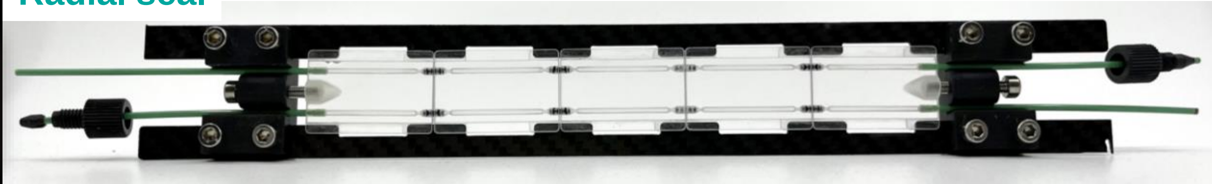




Face seal



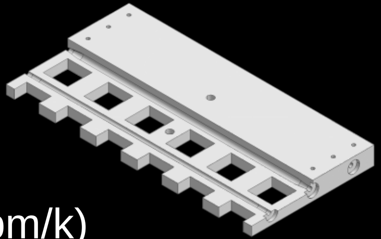
Radial seal



Outcomes

- good alternative for its simplicity

Ceramics 3D printed



- **Advantages:**
  - (CTE) matching with the silicon sensors (2-6 ppm/k)
  - Good thermal conductivity (12-200 W/m K)
  - Radiation hardness (>100 MGy for Al2O3)
  - Low outgassing
  - Arbitrary shape (real 3D envelope by 3d print)

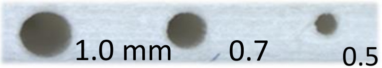
- **Materials:**
  - Zirconia (ZrO)
  - Alumina (Al_2O_3)
  - Aluminum nitride (AlN) (ongoing)

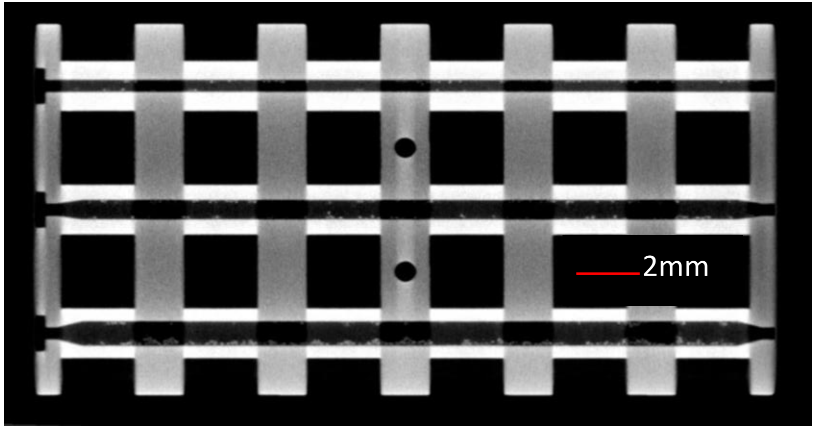
- **Selected AM:**
  - **Nanoparticle jetting technology (NPJ) ***
  - **Lithography-based Ceramic Manufacturing (LCM) ****

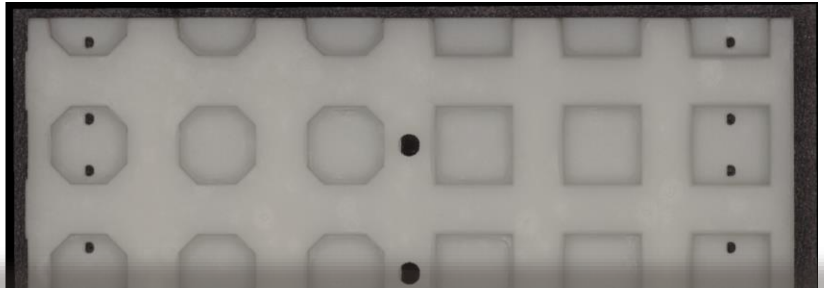
*Xjet company **Lithoz company

Samples

Hole diameter







Outcome of cold plate inspection

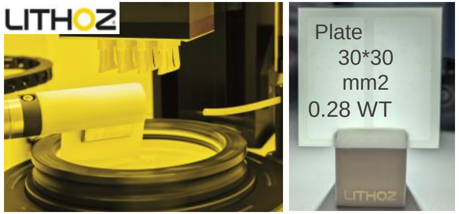
- Both technology suitable for cold plate prodution

Collaboration with EP R&D

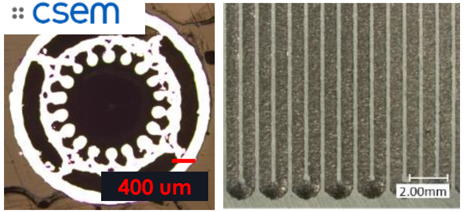
- **Network with industrial partners**.
- **Task objective:** Generation of new **standards to produce micro-structured cold plates** by **additive manufacturing** (ultra-thin wall).
  - 3D Printed **ceramics** (Al_2O_3, AlN, ceramics composites) and **metals** (AlSi12, COVAR).

- **Process tailoring** of new materials for HEP application and **test campaign**.
  - Geometrical limits
    - Leak tightness & pressure tests Vs wall thickness
    - Flatness Vs plate thickness/dimension
  - Materials properties (irradiated material and non-)
    - Flexural modulus/strength (DIN EN 843-1/5)
    - Thermal conductivity (ASTM D5470 - 12)

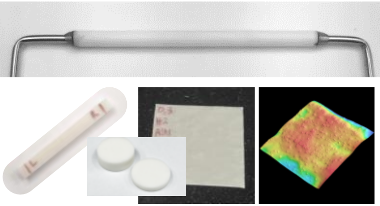
Lithography based Ceramic Manufacturing (LCM)



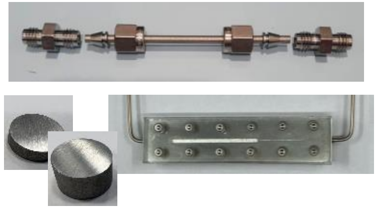
Laser powder bed fusion (LPBF) technology



- Ceramic samples (AIN, Al_2O_3)



- Metal samples (AlSi12)



- Irradiation campaign

Non-irradiated

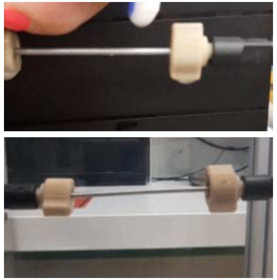
Irradiated (1MGy)

- Test campaign

Flexural (DIN EN 843-1/5)

Burst pressure

Leak tightness



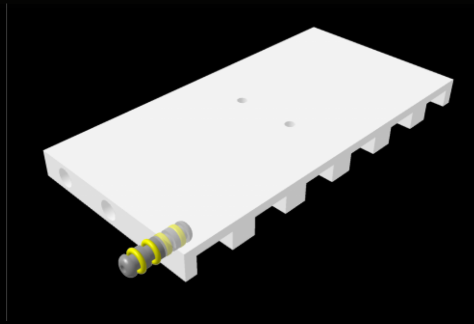
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 101004761.

Interconnection

- Mechanical interface → Pin-based
- Hydraulic interface → Radial seal

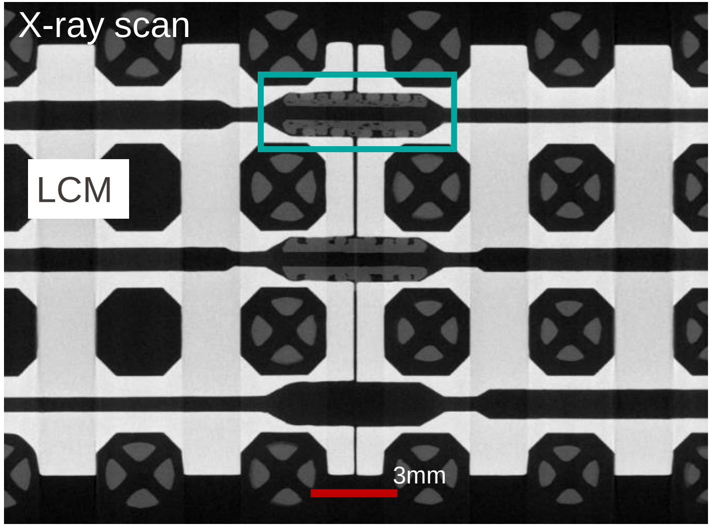
Outcome of the interconnection validation

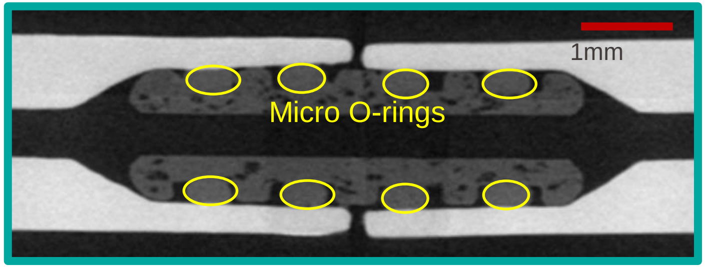
- Sample positioning within printing accuracy (± 50 µm)
- Leak-tightness (He leak rate $<10^{-10}$ mbar l/s)
- Pressure >300 bar



Optimisation, Inspection, validation

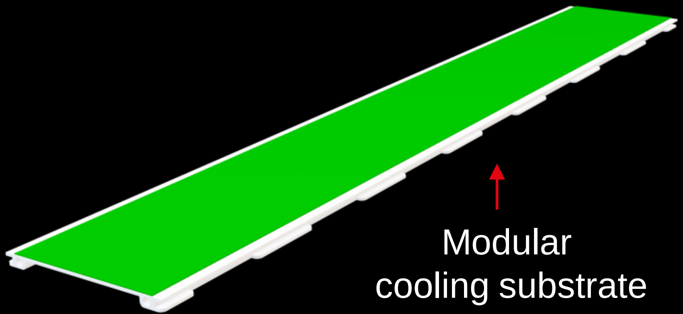
- Hydraulic interface: Radial seal,





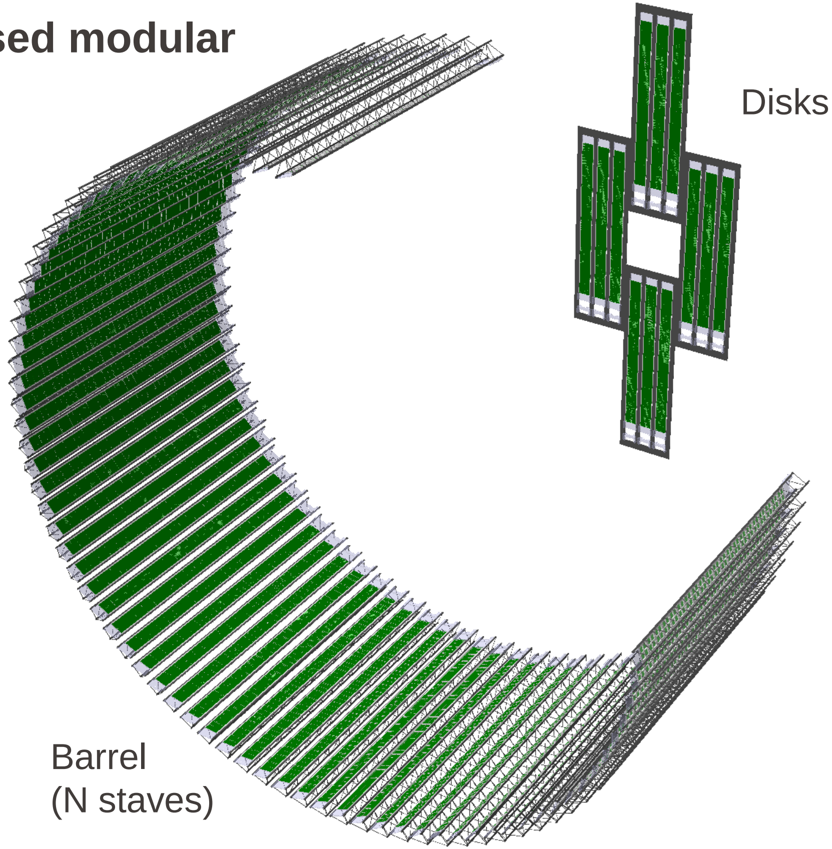
Implementation

- In a real **detector layout**
- Ceramic AM
  - **Flatness**
  - **Gluing interface**
  - **Hydraulic and thermal performances**



In a real detector layout

- **Proposed modular design**



Implementation

- In a real **detector layout**
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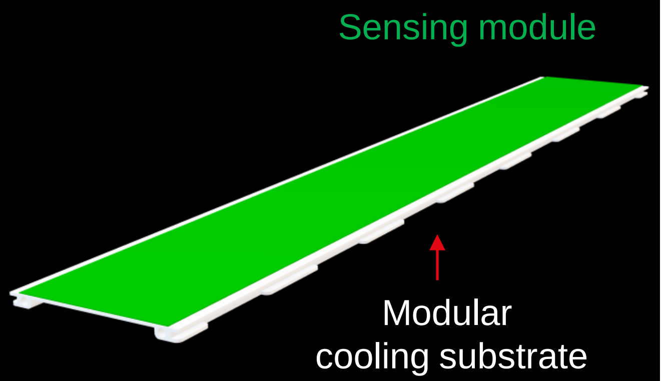
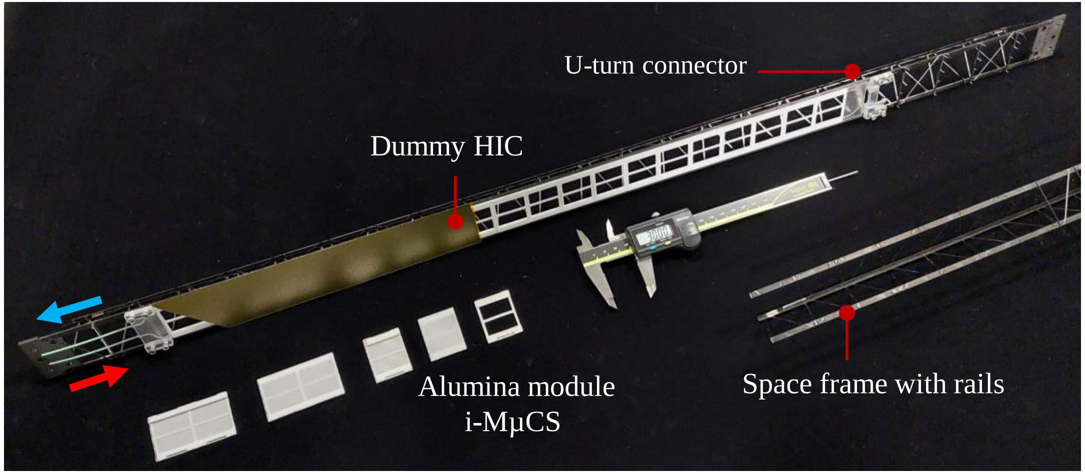


In a real detector layout

- **Prototypes**

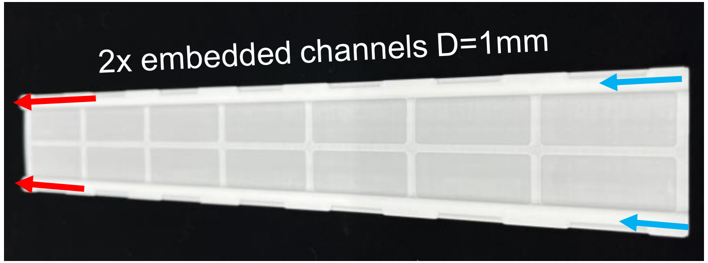


Implementation

- In a real **detector layout**

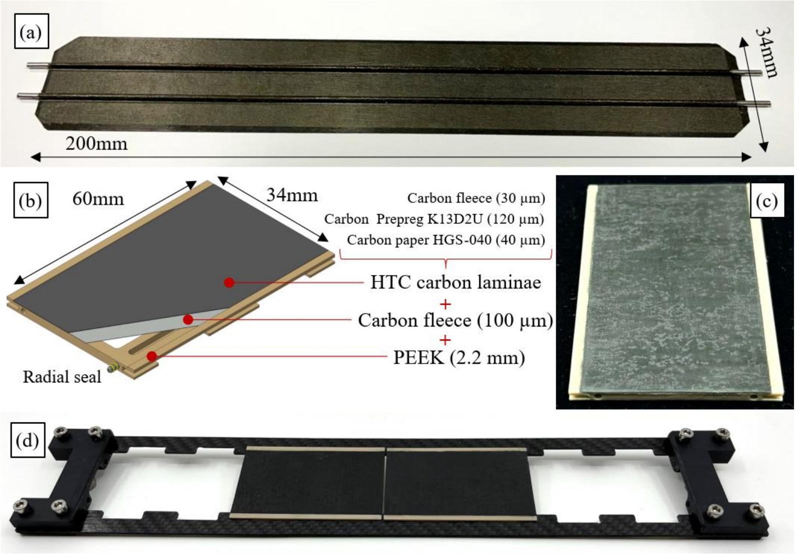
Different materials and manufacturing

- **Ceramic cold plate**

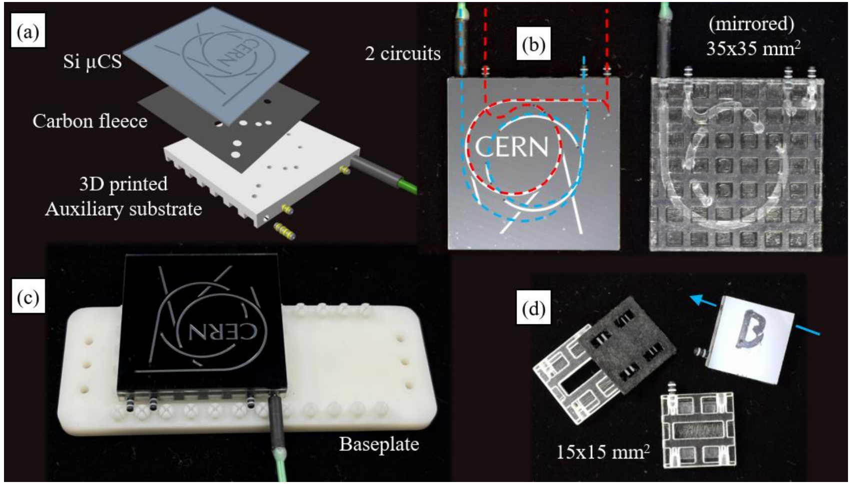


~30x210 mm^2, wall thickness 0.2 /0.7 mm, Alumina

- **CFRP modular cold plate**

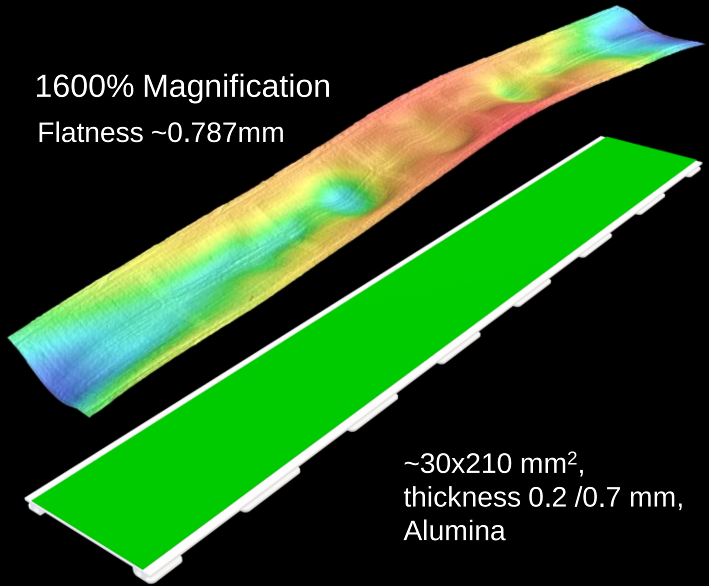


- **Silicon microchannel cold plate**



Implementation

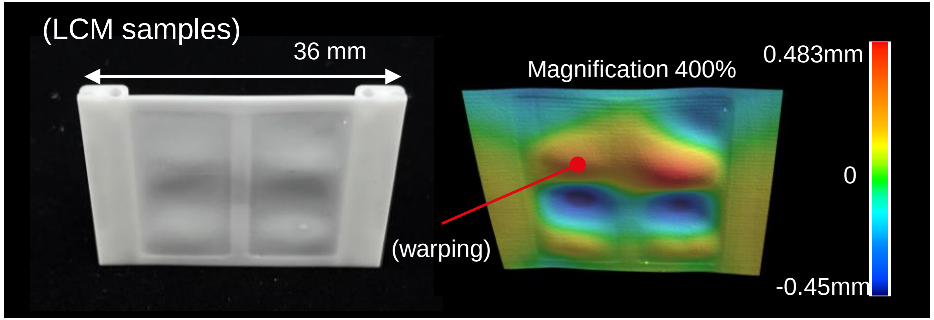
- In a real **detector layout: ALICE 3**
- Ceramic AM
  - **Flatness**
  - **Gluing interface**
  - **Hydraulic and thermal performances**



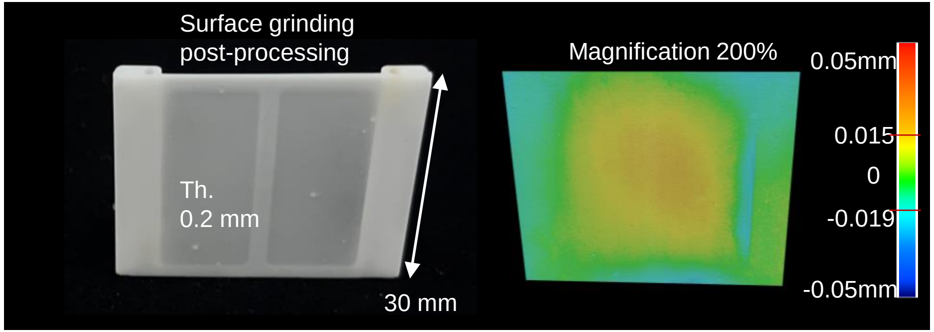
Flatness

- **Requirement:** flatness <100µm
- Deformation (**warping**) of thin plate (0.2mm) due to sintering.

Large 3D scan (Keyence VR5200)

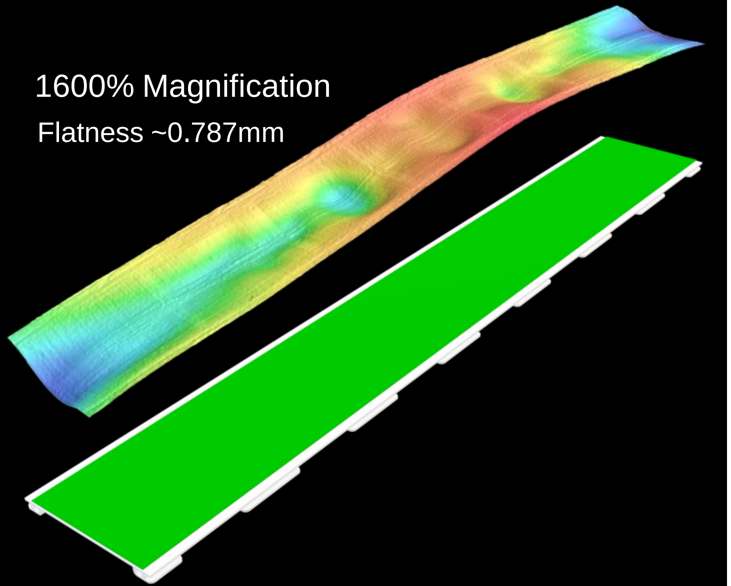


- Printing **thicker** cooling substrate and **post grinding**



Implementation

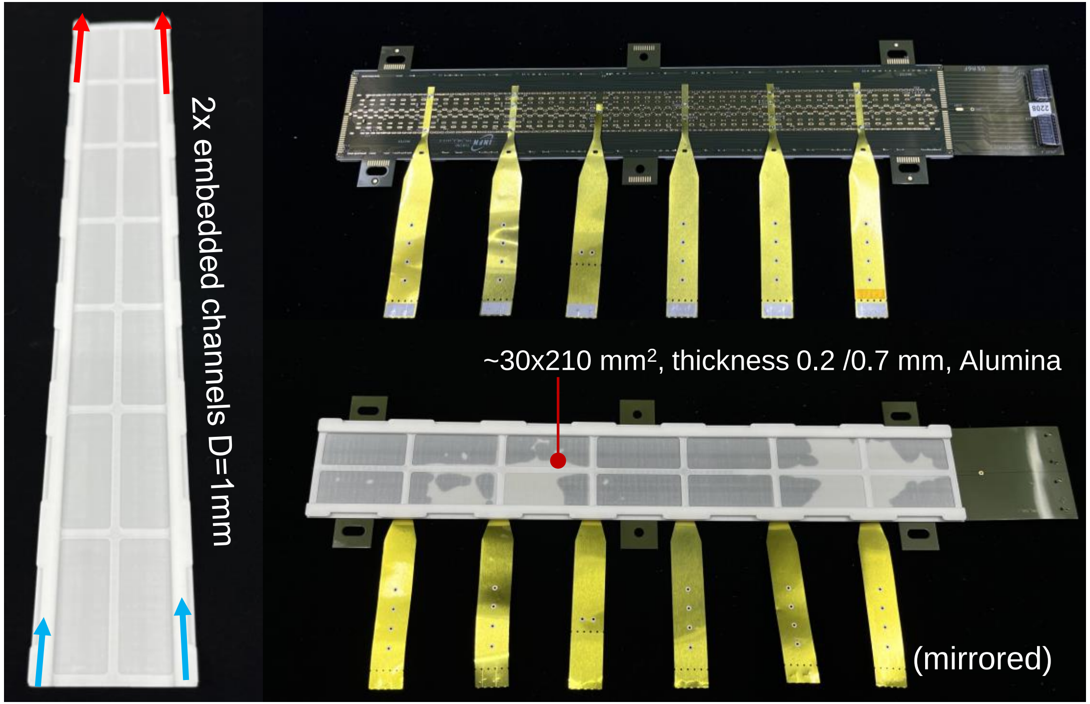
- In a real **detector layout: ALICE 3**
- Ceramic AM
  - **Flatness**
  - **Gluing interface**
  - **Hydraulic and thermal performances**



Gluing interface

- Similar gluing procedure followed for the ALICE ITS2

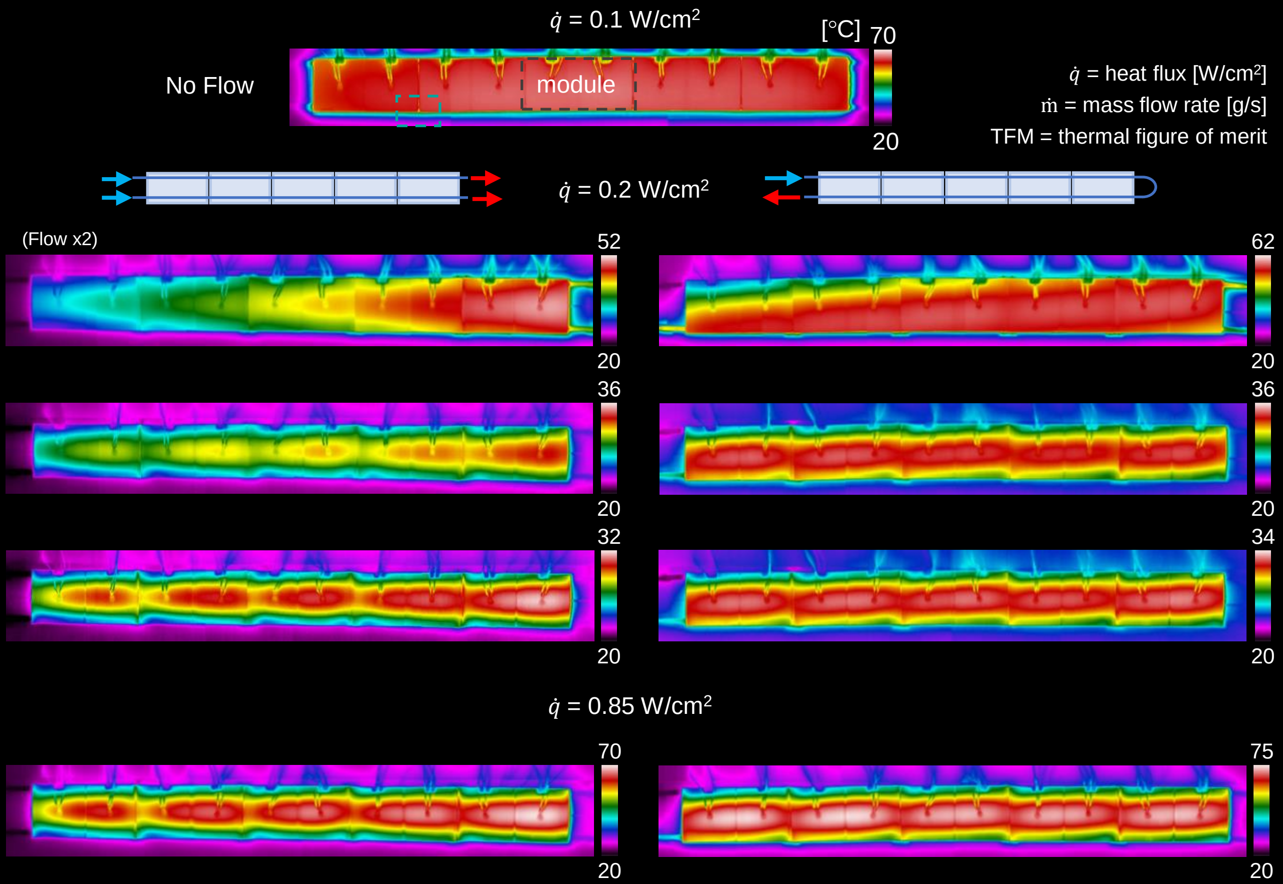
  Large-scale 3D printed ceramic cold plate



Implementation

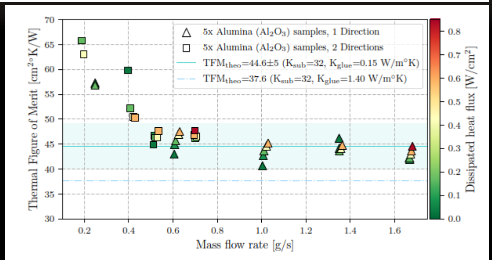
Hydraulic and thermal performance:

- In a real **detector layout: ALICE 3**
- Ceramic AM
  - **Flatness**
  - **Gluing interface**
  - **Hydraulic and thermal performances**



Outcomes of thermal analysis:

- Predictable TFM
- TFM ~ 45 cm^2 k/W for AL2O3 (tested)
- TFM ~ 11 cm^{2}k/W for AlN (extrapolated)



Conclusion

- An **innovative** re-workable **interlocking microfluidic** interconnection between cooling substrates for electronic dissipating components was developed.

- The modular interlocked substrate design has been tuned to allow its manufacturing in **Ceramics,** a material suitable for HEP application based on its thermal and mechanical properties.

- **Future** developments will have to bring the Ceramics modules to a maturity level that allow its use in HEP detectors. Design optimisation, alternative industrialised manufacturing processes, large scale integration, are the key aspects.

- (Carbon and Ceramic) **modular microfluidic cold plates** are now considered for the future **ALICE3 Outer Tracker**.