AIDA Innova Second Annual Meeting

Challenges for advanced mechanics and cooling in High Energy Physics

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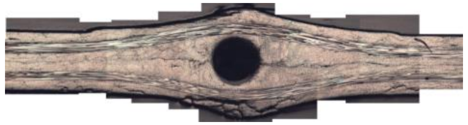
CERN EP-DT

Valencia 24-28 April 2023

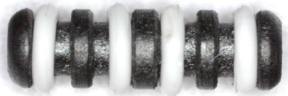
Challenges for mechanics and cooling in HEP

Mechanics for tracker

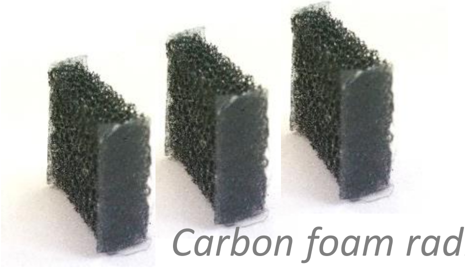


Carbon vascular

Ceramic Microchannels



interconnection



Carbon foam radiator

IRIS

Mechanics for cryostats

Leak tight winding

Sealed flanges

Wall
Carbon sandwich

ATLAS Cryostat

Low mass beampipe

Robotics

Confined space inspection

Environment mapping

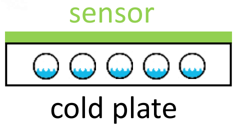
Inspection and first intervention

Mechanics for tracker

Mechanics & Cooling for a new silicon sensor generation

Air/gas cooling

Carbon foam radiators

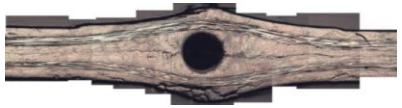


Liquid cooling

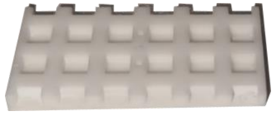
single-phase, two phase

Kapton pipes and CO_2

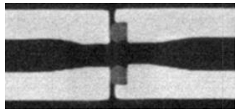
Pipeless coldplate



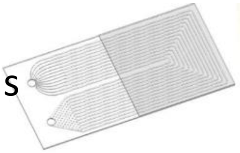
Ceramics **3D printed** coldplates



Modularity & **interconnection**

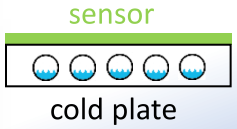


Silicon multi-micro-channels



New coolants

Challenges

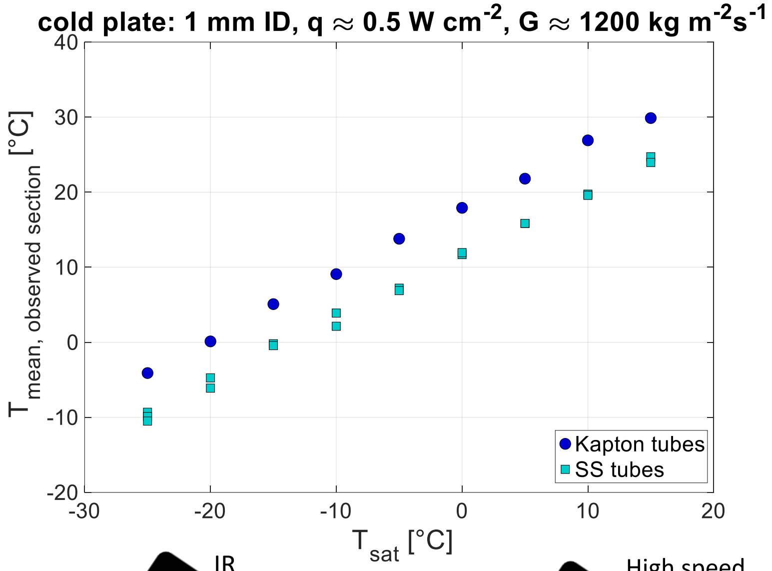


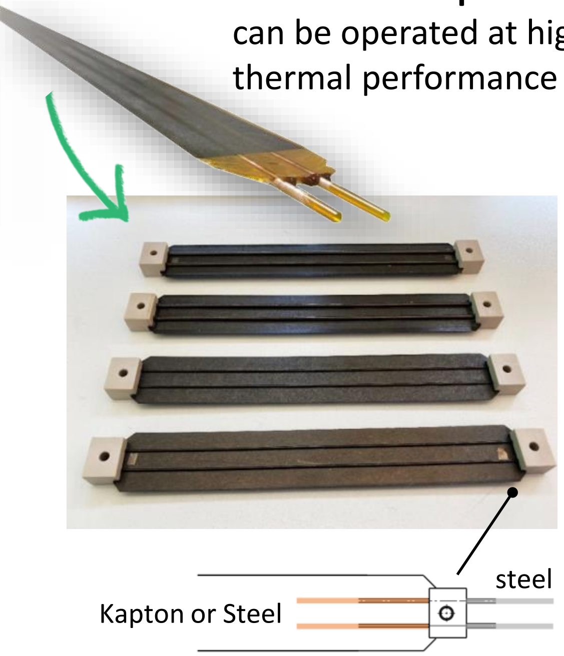
Kapton pipes and CO_2

Challenge

Extend use of low-mass cold plate with embedded Kapton pipes from water leakless to evaporative CO_2

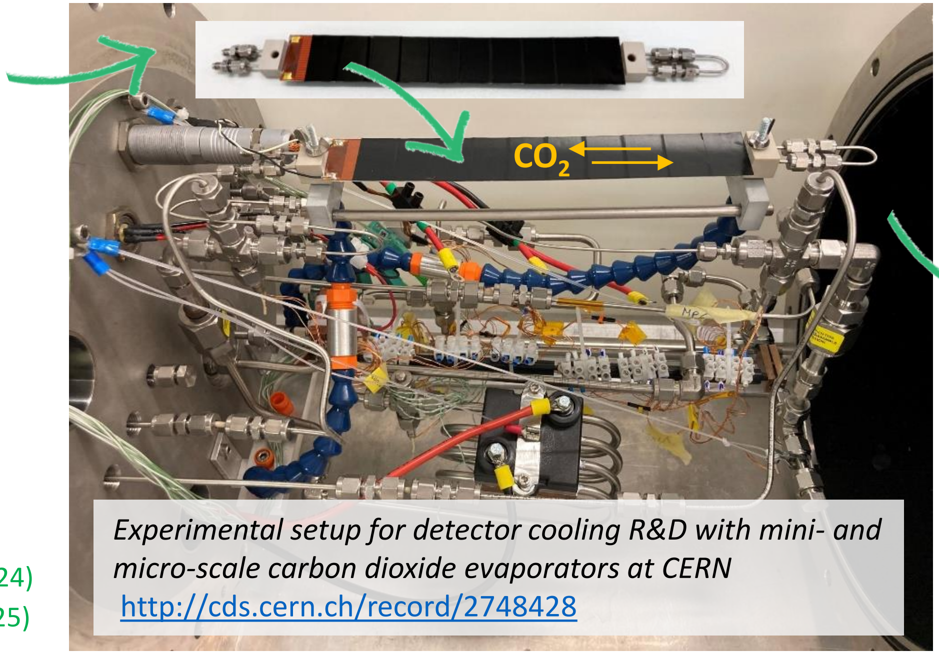
- **Carbon cold plates production**:
  with embedded **Kapton** and **stainless-steel** tubes (~ ID 2 mm & 1 mm)
- **Cold plates thermal characterization:**
  test setup/ procedure/ execution with IR camera and flow visualization with high-speed camera
- **Validation of Kapton version for CO_2** :
  can be operated at high CO_2 pressures
  thermal performance ↓ ($\Delta T_{KAPTON\text{-}SS}$ ~5°); low material budget ↑ with respect to steel pipe



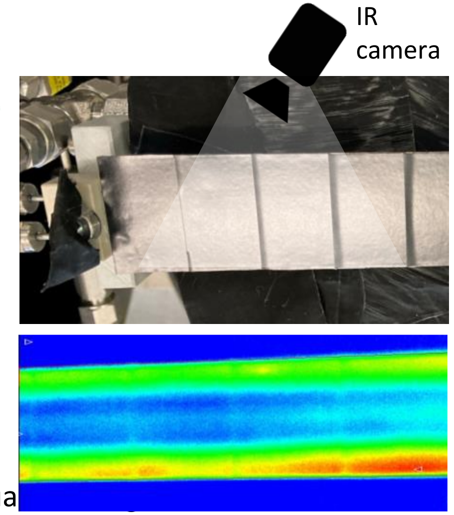


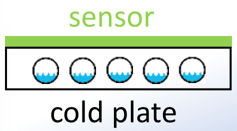
	Steel	Steel	Kapton	Kapton
ID [mm]	2.15	1	1.97(2.05)	1.024 (1.024)
WT [mm]	0.51	0.29	0.17(0.032)	0.076(0.025)

ALICE



Experimental setup for detector cooling R&D with mini- and micro-scale carbon dioxide evaporators at CERN
http://cds.cern.ch/record/2748428





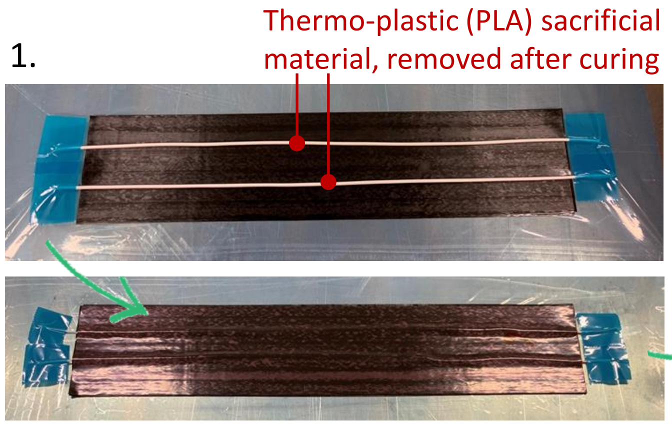
Pipeless coldplate

Challenge

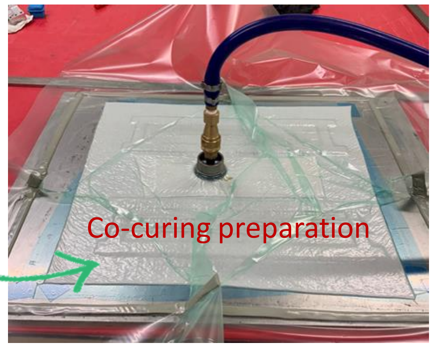
Build a PIPELESS coldplate with a vascular network system for liquid/air cooling

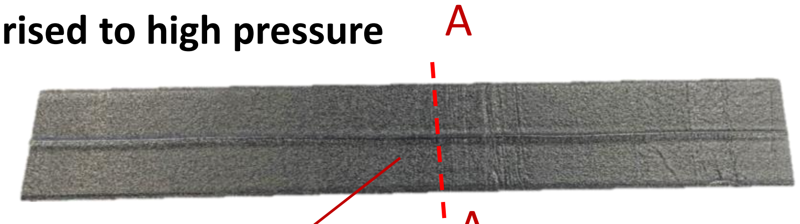
- **Process investigation - VaSC (Vaporization of Sacrificial Components)**
  1. Modified PLA embedded in CFRP preform
  2. Co-cured with CFRP part
  3. Vaporization step after curing (Vacuum oven 200°C for 15h)
- **Different methods to produce PLA preform**
  Filaments, Pre-cut sheets, 3D print network
- **Characterised to high pressure**

1.

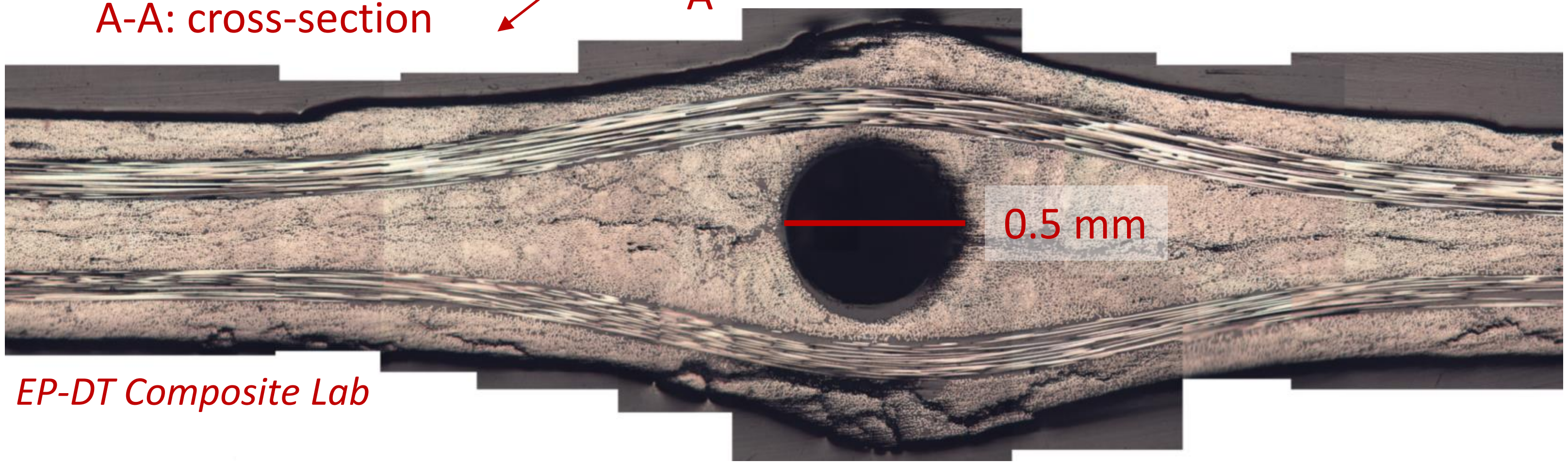

Thermo-plastic (PLA) sacrificial material, removed after curing

2.

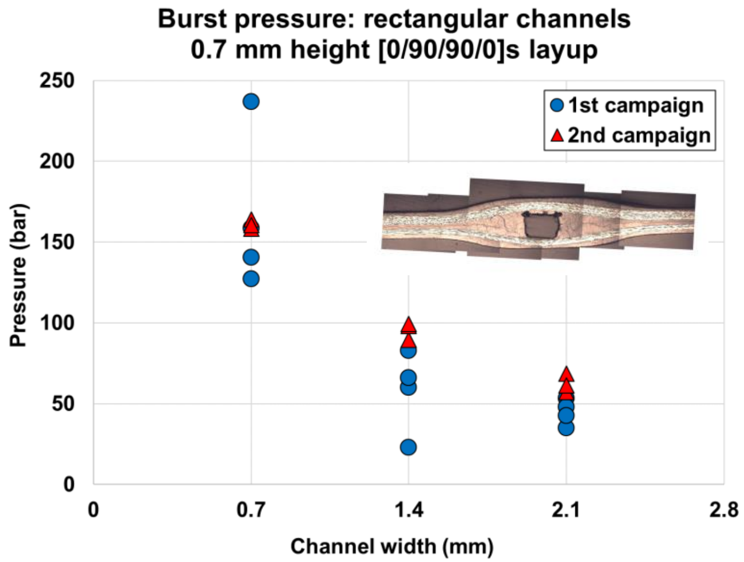

Co-curing preparation



A-A: cross-section



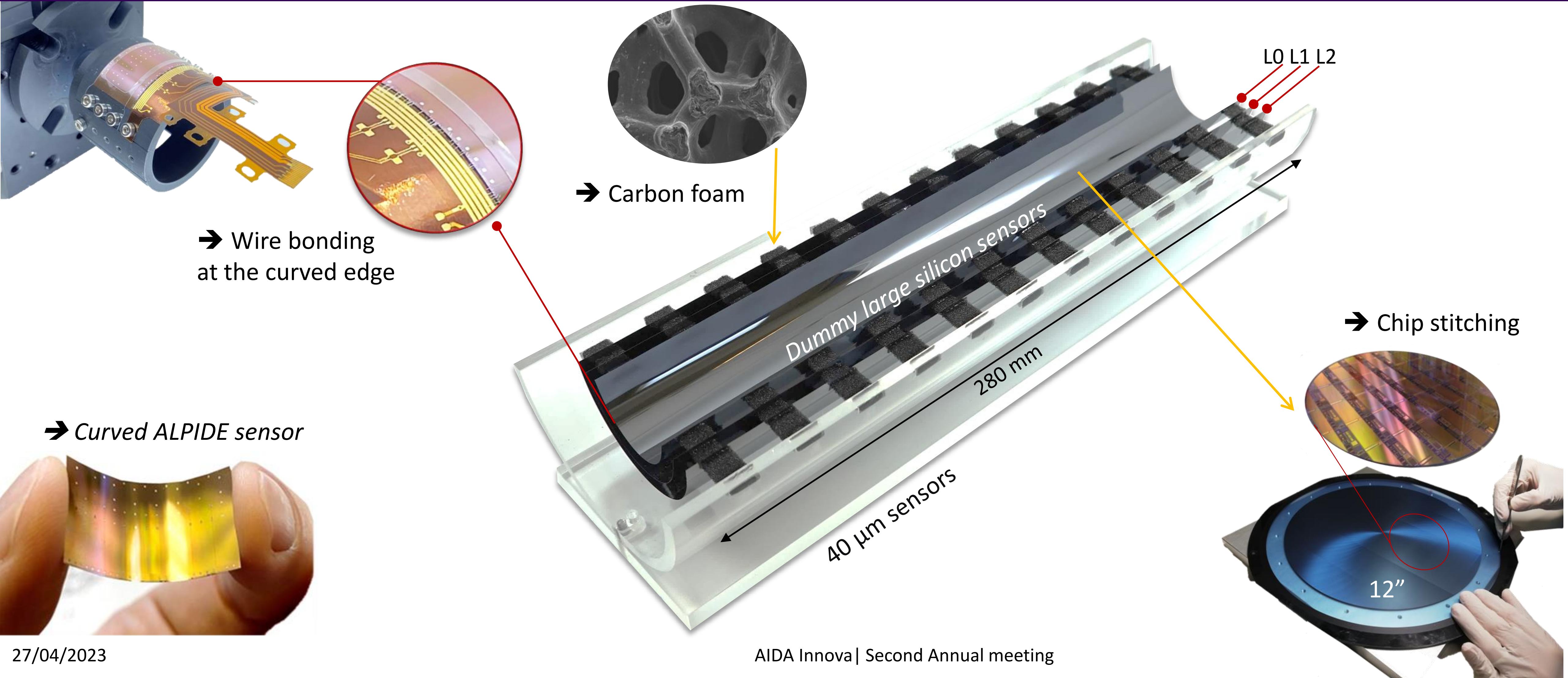
EP-DT Composite Lab



Carbon foam & Air cool

Challenge

Remove active liquid cooling and use air cooling ➔ Carbon foam acting as support & radiator



➔ Wire bonding at the curved edge

➔ Carbon foam

➔ Chip stitching

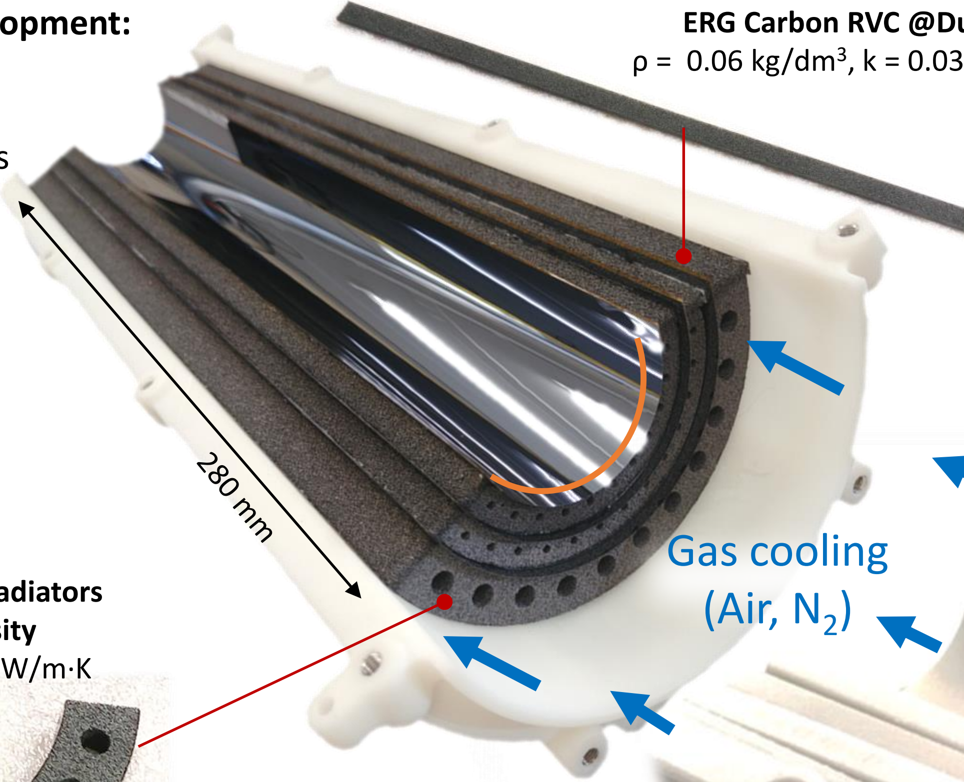
➔ *Curved ALPIDE sensor*

Carbon foam & Air cooling

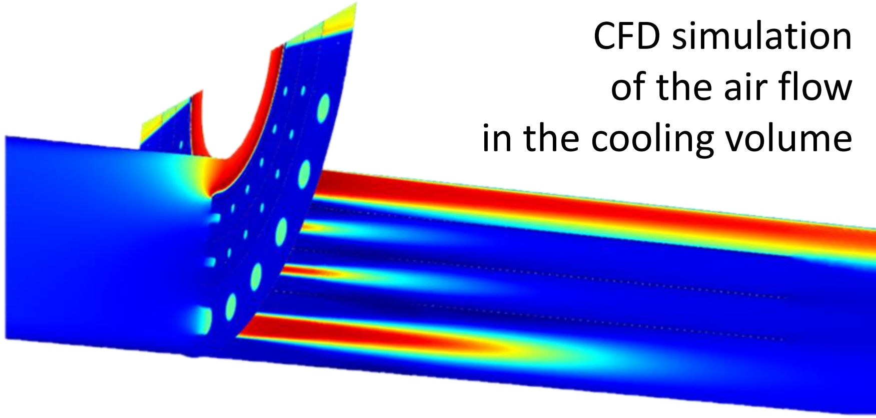
Challenge

Remove active liquid cooling and use air cooling → Carbon foam acting as support & radiator

- **Engineering Model Development:**
  3 silicon layers (40 µm thick)
  Layers radius 18, 24, 30 mm
  Carbon foam frames/radiators
- **Cooling performance**
  Pixel matrix ~ 0.05 W/cm^2
  Readout endcap 1 -2 W/cm^2
  ΔT across sensor < 5 °C
  ΔT Sensor and air <10 °C
  4m/s< Air speed <8m/sec



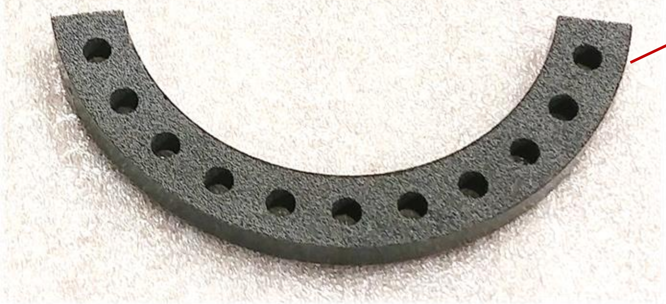
Support: Longerons
ERG Carbon RVC @Duocel
$\rho =$ 0.06 kg/dm^3, k = 0.033 W/m·K

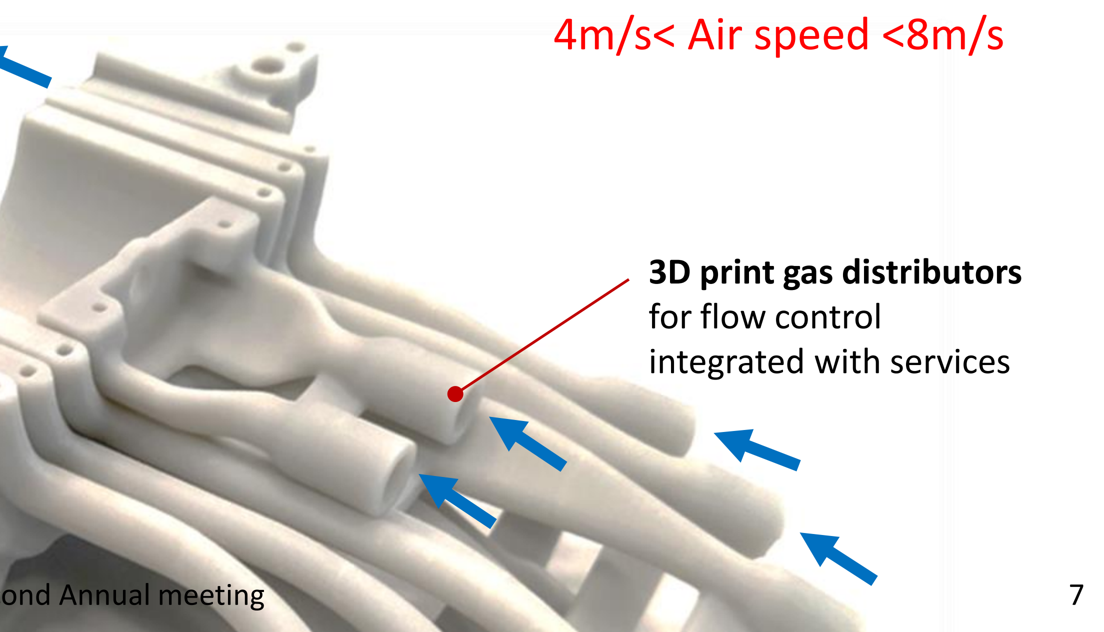

CFD simulation
of the air flow
in the cooling volume

4m/s< Air speed <8m/s

Gas cooling
(Air, N$_2$)

Support & cooling: Half ring radiators
Allcom K9 standard density
$\rho =$ 0.2-0.26 kg/dm^3, k = >17 W/m·K



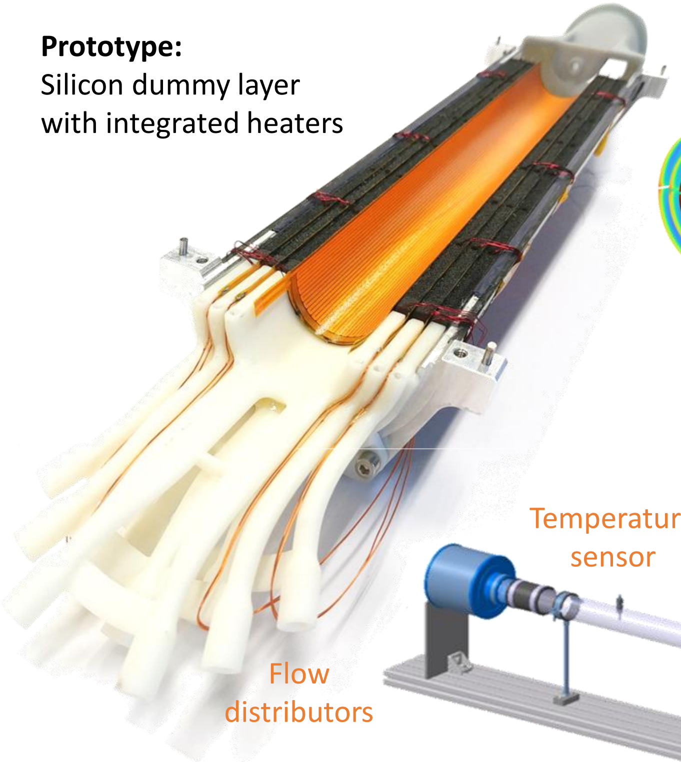

3D print gas distributors
for flow control
integrated with services

Carbon foam & Air cooling

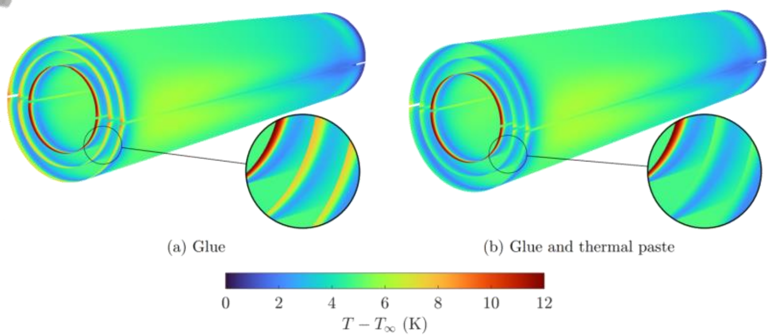
Challenge

Remove active liquid cooling and use air cooling ➔ Carbon foam acting as support & radiator

Prototype:
Silicon dummy layer
with integrated heaters

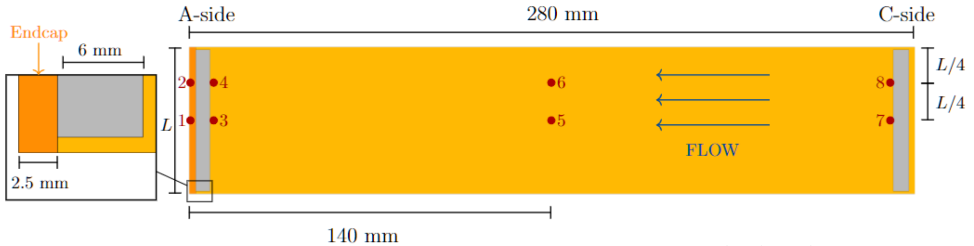


Temperature variation CFD simulation (sim.)



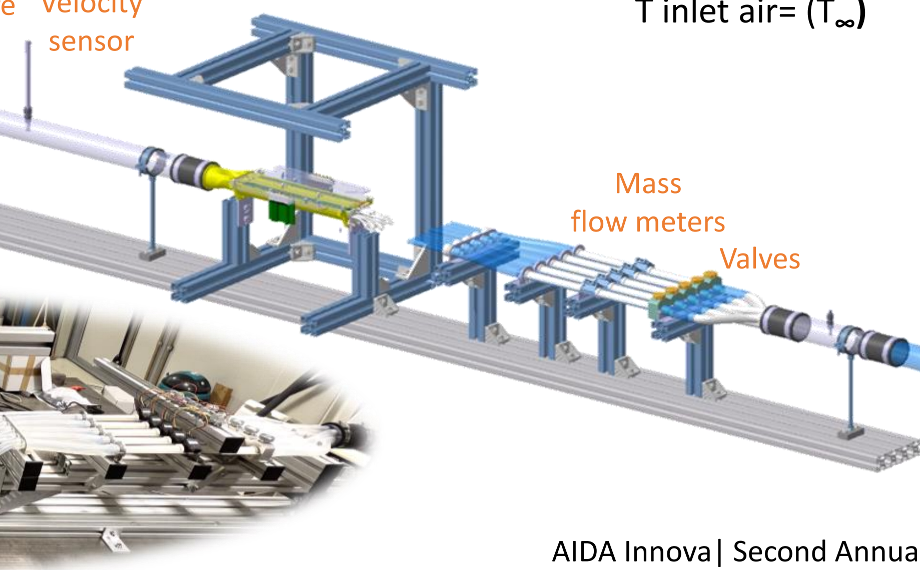
Boundary conditions

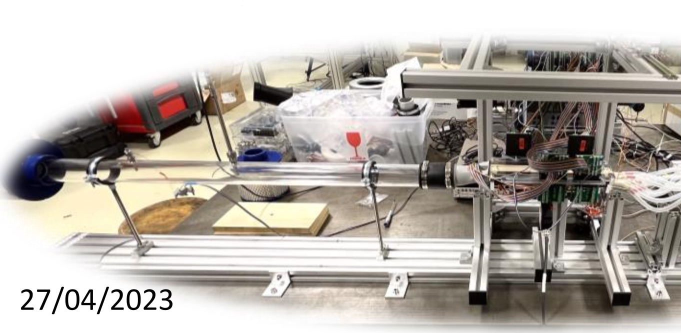
- Two zones of different power dissipation: endcap (e) and matrix (m)
- q_m = 25 mW/cm^2, q_e = 1000 mW/cm^2
- Same freestream velocity in all layers



Wind tunnel set-up

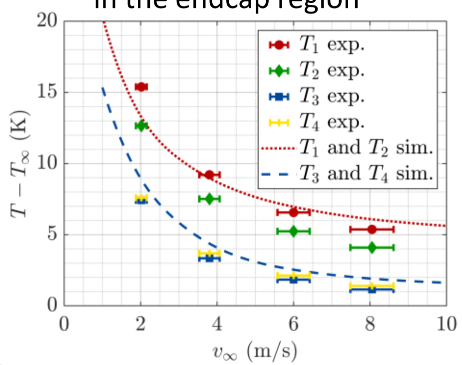
T inlet air= (T_∞)



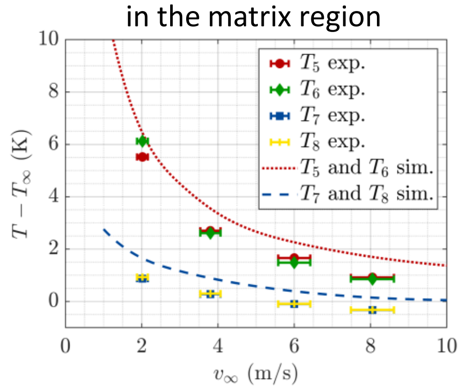


Temperature variation in Layer 0

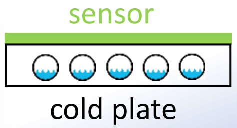
in the endcap region



in the matrix region



Outcomes
@ v_{air} > 4 m/s
Overall ΔT sensor < 5 °C
Sensor and air <10 °C

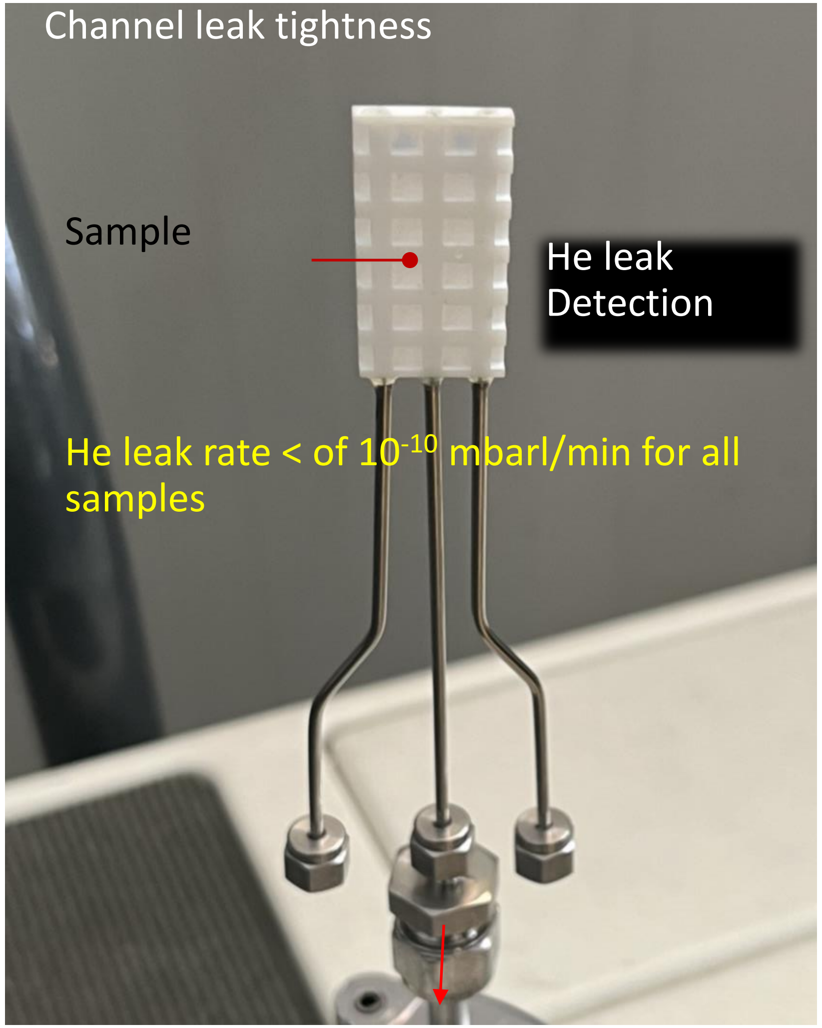


Ceramic 3d print microchannels

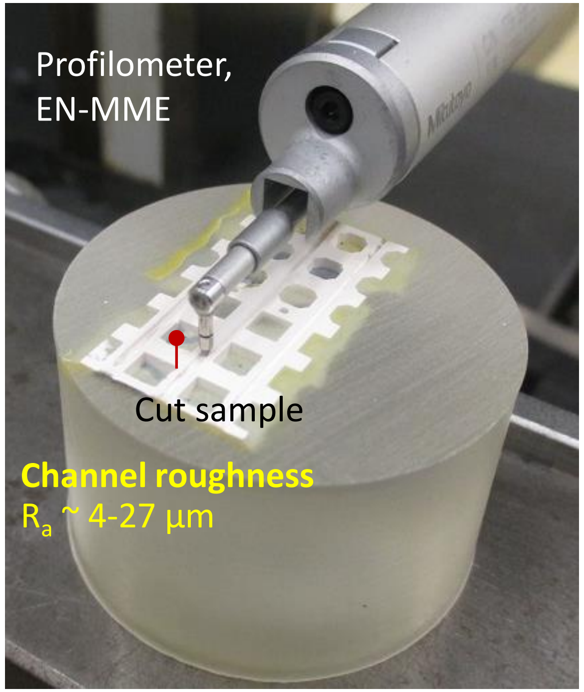
Challenge

Produce Coldplate in ceramic material with printing technologies (NPJ* and LCM)**

*Nanoparticle Jetting Technology, Xjet.,
** Lithography-based, Lithoz.

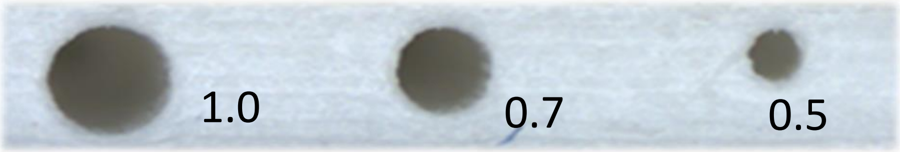

Channel leak tightness

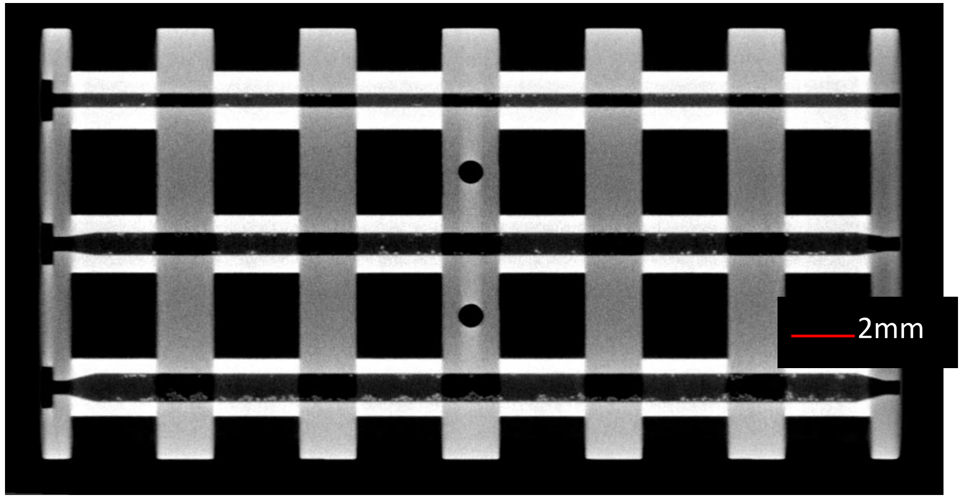
He leak rate < of 10^{-10} mbarl/min for all samples



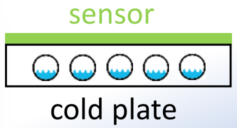
Channel roughness
R_a ~ 4-27 µm

Holes diameter





Ceramics 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)

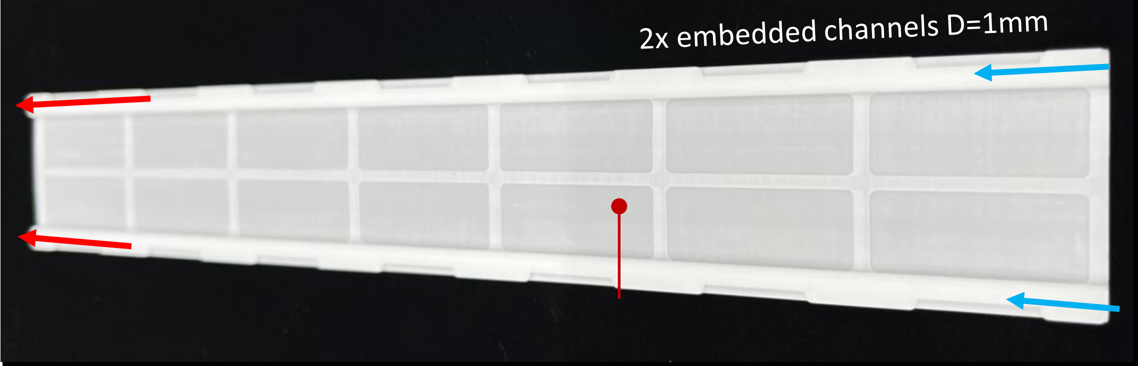


Ceramic 3d print microchannels

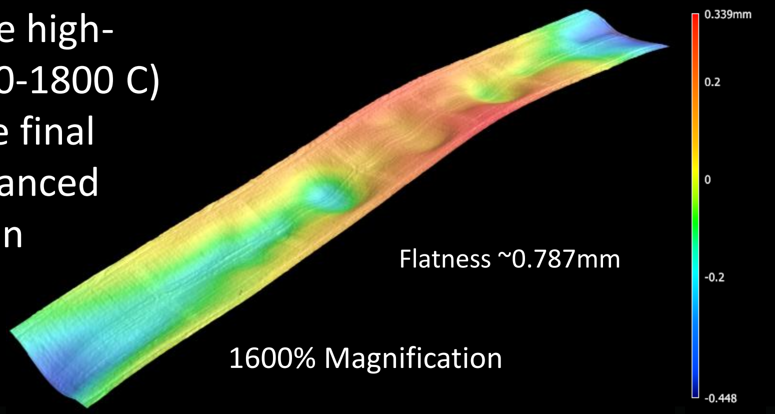
Challenge

Produce Coldplate in ceramic material with printing technologies (NPJ* and LCM)**

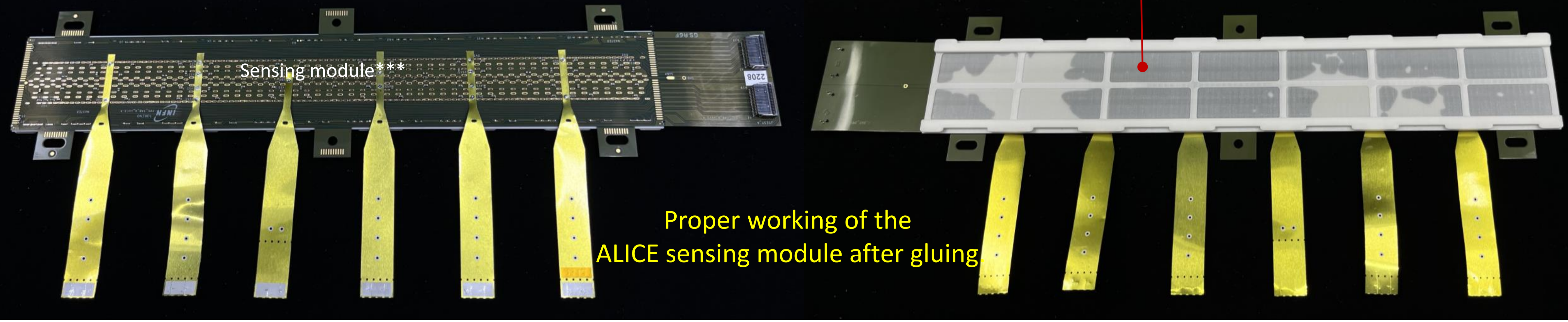
Large-scale 3D printed ceramic cold plate



key aspect specific to ceramics is the high-temperature sintering process (1500-1800 C) of the "green part"; this impacts the final accuracy of the part due to non-balanced thermoplastic expansion/contraction



use of the "green part" without sintering as the final material is also being considered



Proper working of the ALICE sensing module after gluing

*** ALICE ITS2 OB sensing module

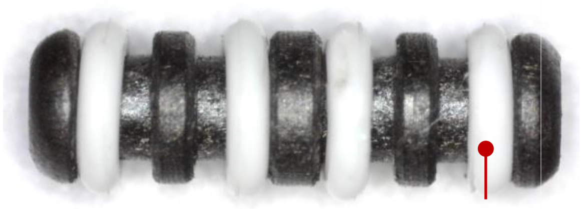
Modularity & Interconnection

Challenge

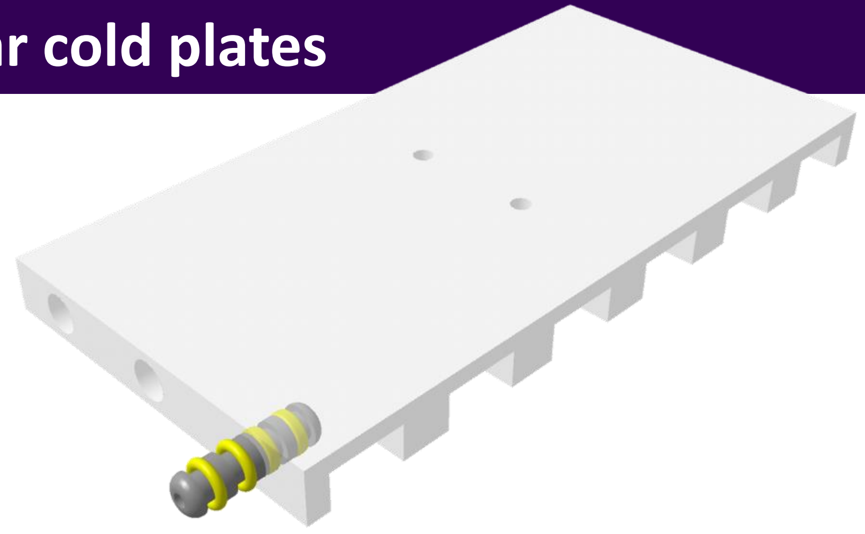
Reliable hydraulic and mechanical interconnection for modular cold plates

- **Hydraulic interface: Radial seal-based**
  High pressure cooling systems (>20 MPa)
  Leak-tightness (He leak rate 10^{-10} mbarl/s)

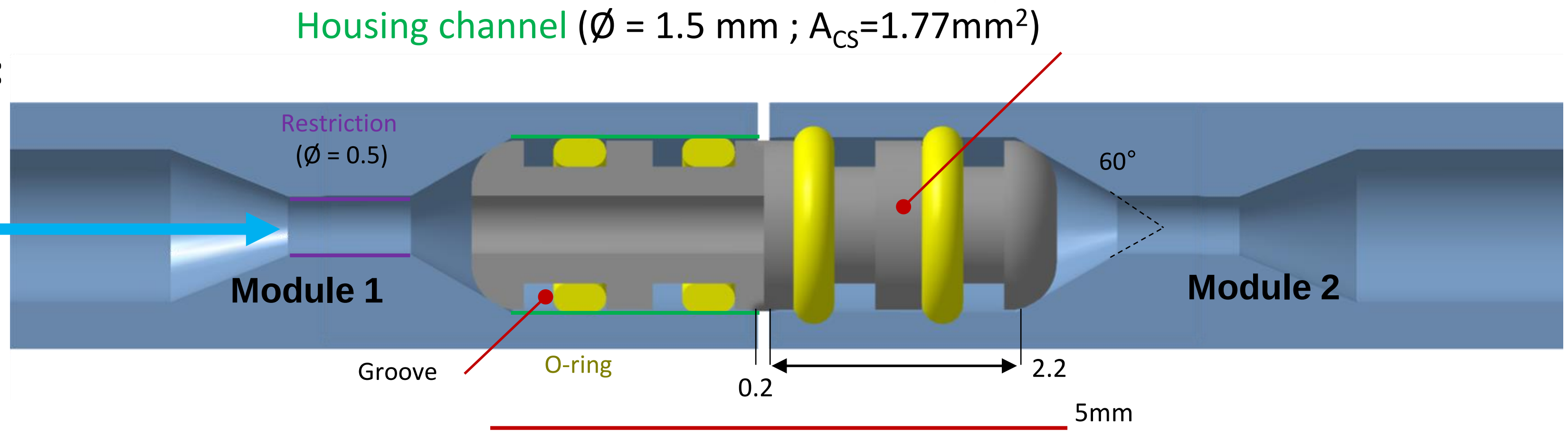
Seal fitting, CNC carbon PEEK



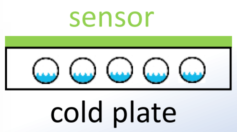
Micro O-rings (NBR material)



Hydraulic interface:
Radial seal-based



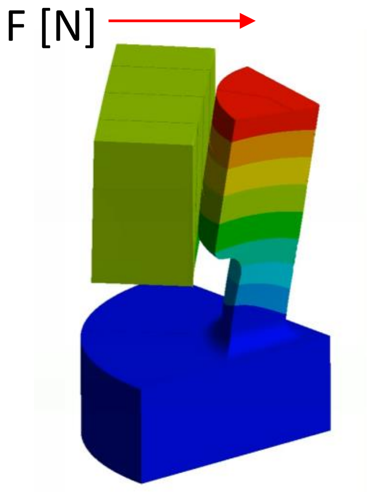
High pressure cooling systems (>20 MPa)
Leak-tightness (He leak rate 10^{-10} mbarl/s)



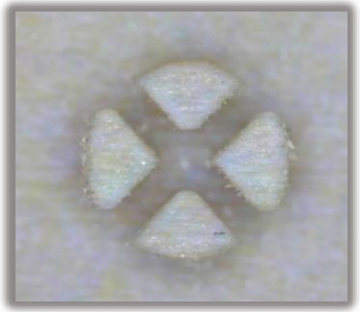
Modularity & Interconnection

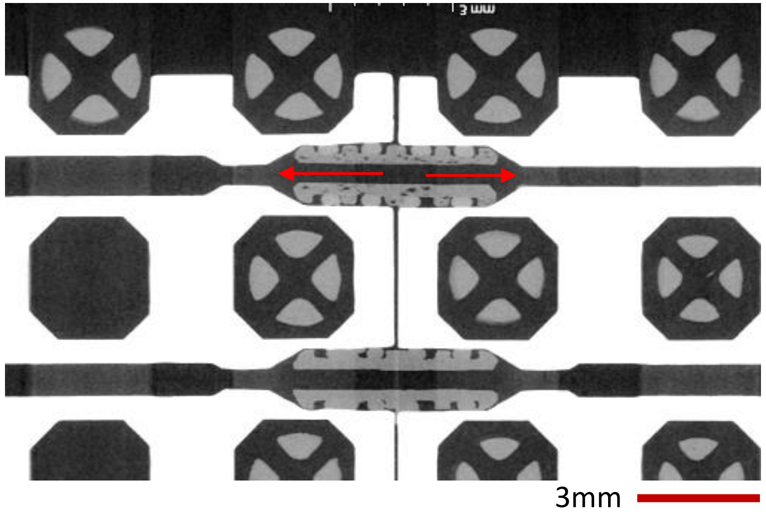
Challenge

Reliable hydraulic and mechanical interconnection for modular cold plates

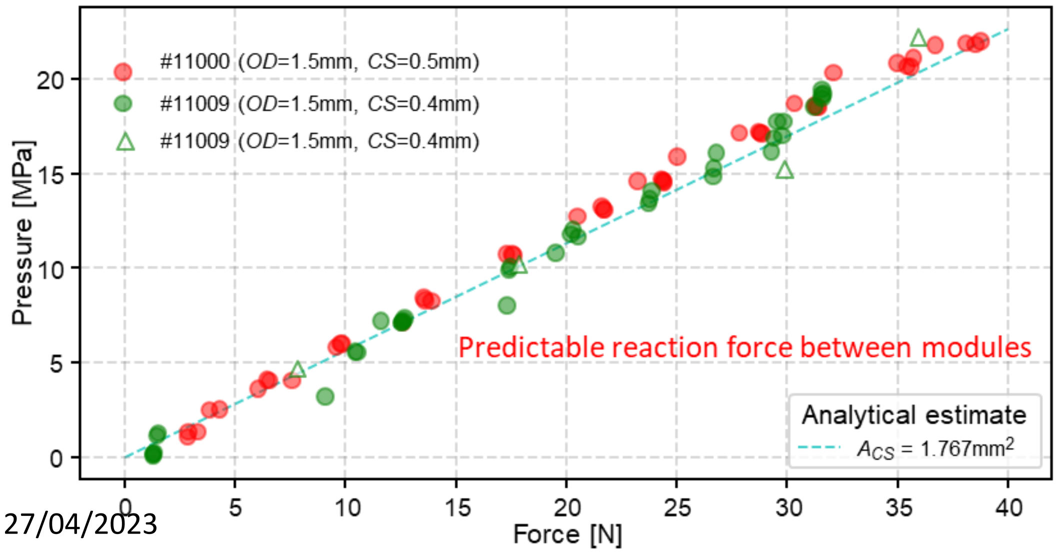


Mechanical interface:
Pins/Slots (LEGO-like)

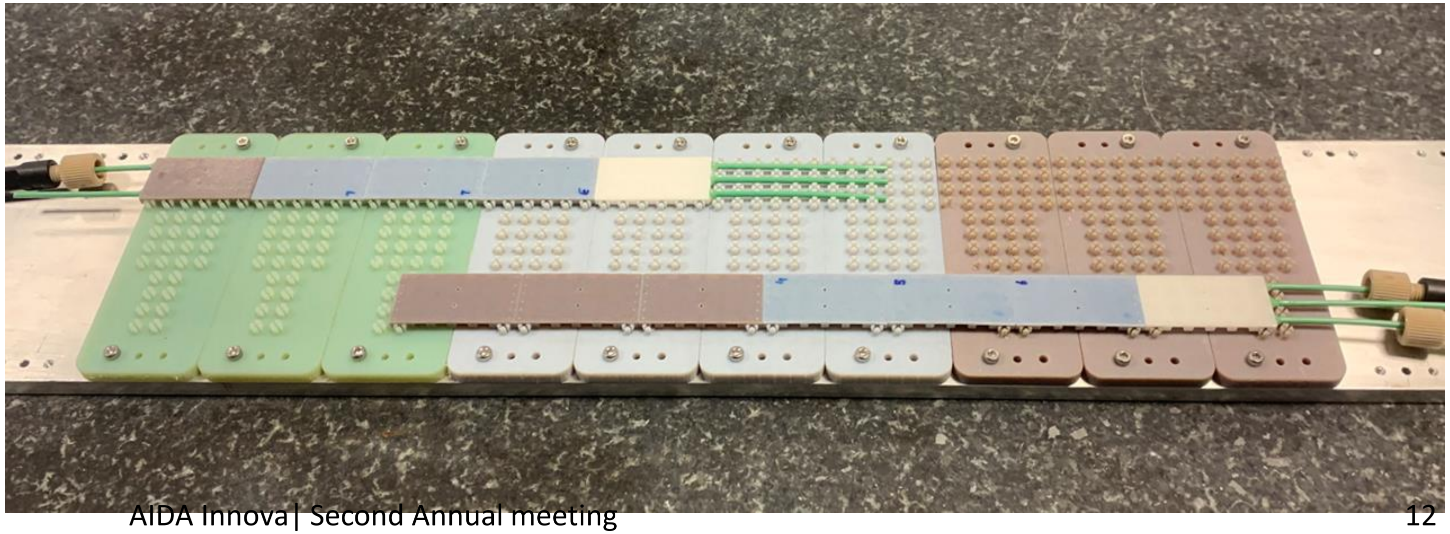




Hydraulic interface:
Pins/Slots (LEGO-like)



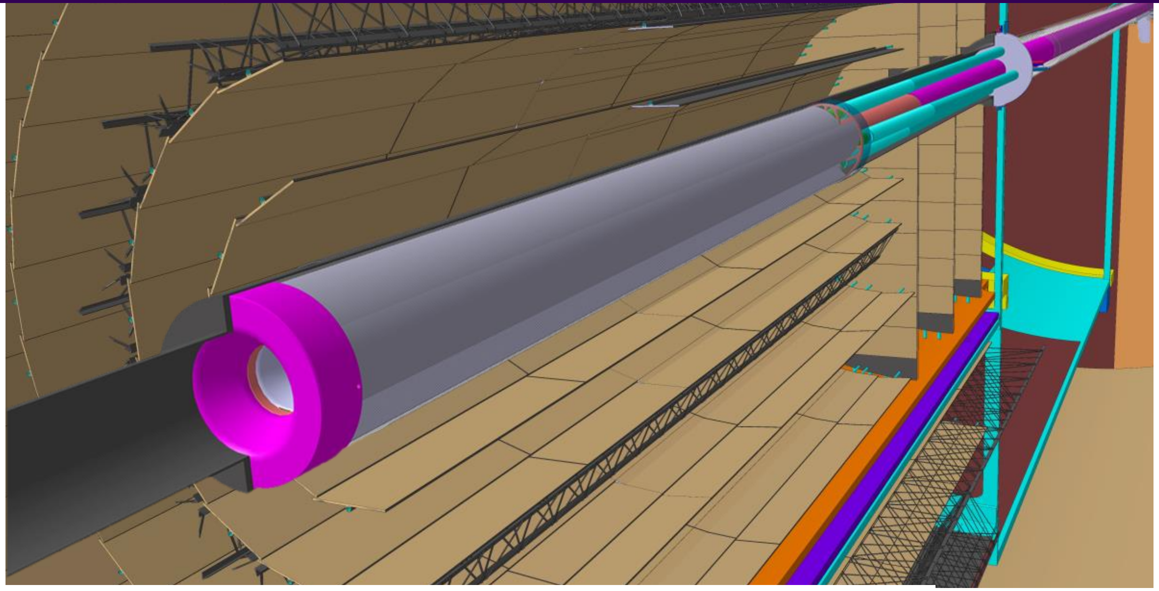
Predictable reaction force between modules

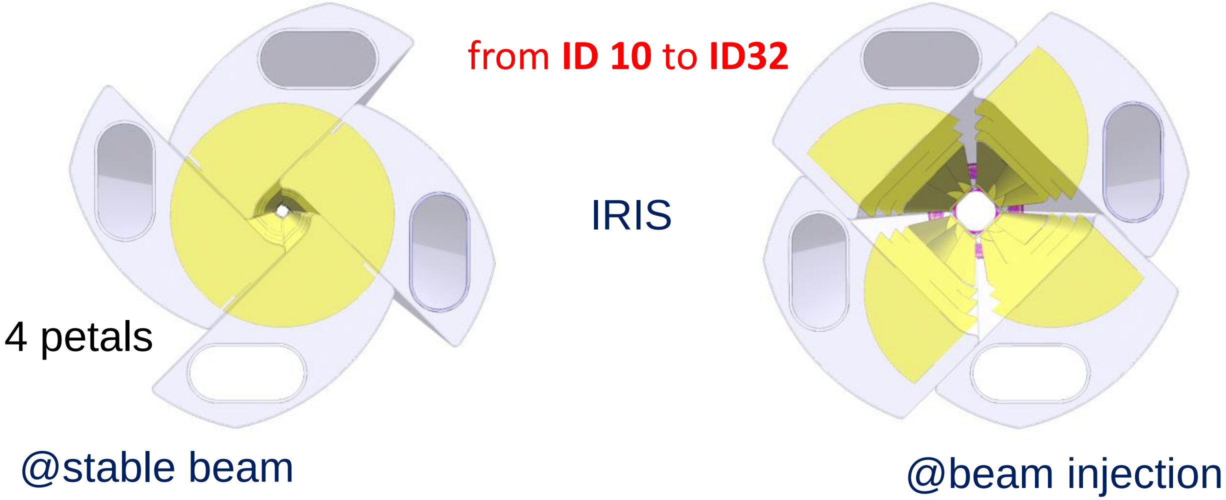


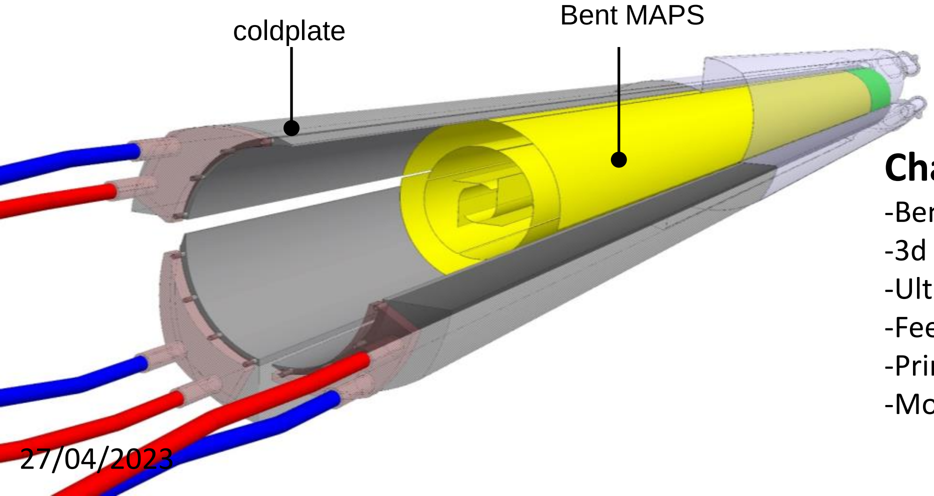
Challenge

Get close to the IP: Future retractable Vertex Detector in primary vacuum

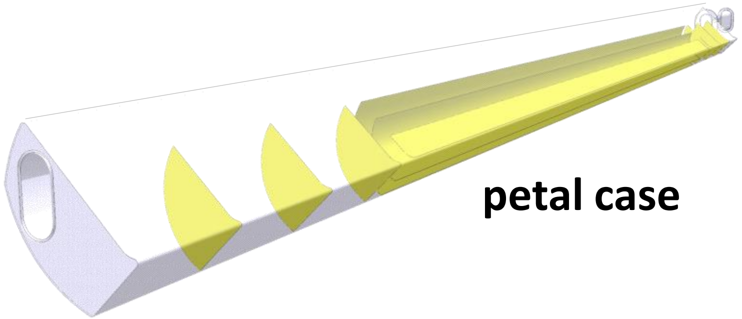
See Corrado Gargiulo link







Challenges:
- -Bent MAPS
- -3d printed Ceramic coldplate (CO2?)
- -Ultrathin petal case (Be 0.15mm)
- -Feed throughs to bring services inside the petals
- -Primary/secondary vacuum
- -Movement in a primary vacuum



New Coolant < -45°C

Challenge

New environmental-friendly refrigerant -60 to -80°C (Current CO_2 coolant limit -45°C)

-35 °C

-45 °C

-? °C

Selection?

In a detector cooling application the choice of the coolant is twofold:

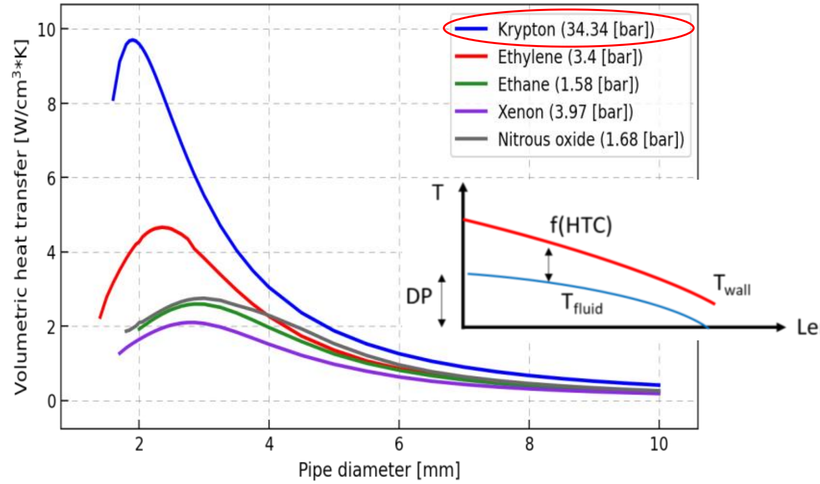
- Having the best thermal performance with the smallest possible cooling pipe
- Avoid an uneven temperature distribution along the silicon sensors

*[11] FTDM 2022 Frascati – Hybrid cycle with Krypton for cooling of future silicon detectors in HEP – Luca Contiero – link

Fluid comparison [10]

- **Krypton ➔** a possible option under consideration
- Same **pressure level of CO_2** - diameter expected to be in the same range

Volumetric Heat Transfer Coefficient (VHTC) $= \frac{Q}{Volume*DT(HTC+DP)}$



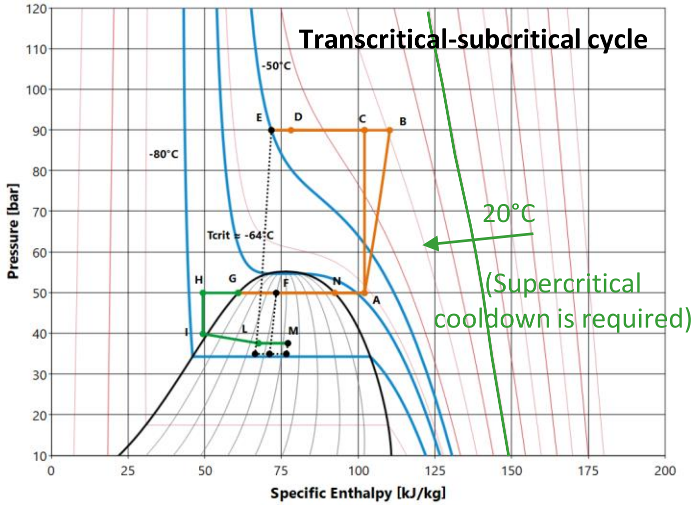
Length = 2 [m]; Q = 200 [W] ; Vapor quality change = 0-35%; T = -80 [°C]

*[10] FTDM 2019 Cornell – R&D for a colder future in HEP– B.Verlaat, P.Petagna– link

Purpose of the research: *[11]

Design a special hybrid cycle with Krypton (Kr)

Krypton P-h



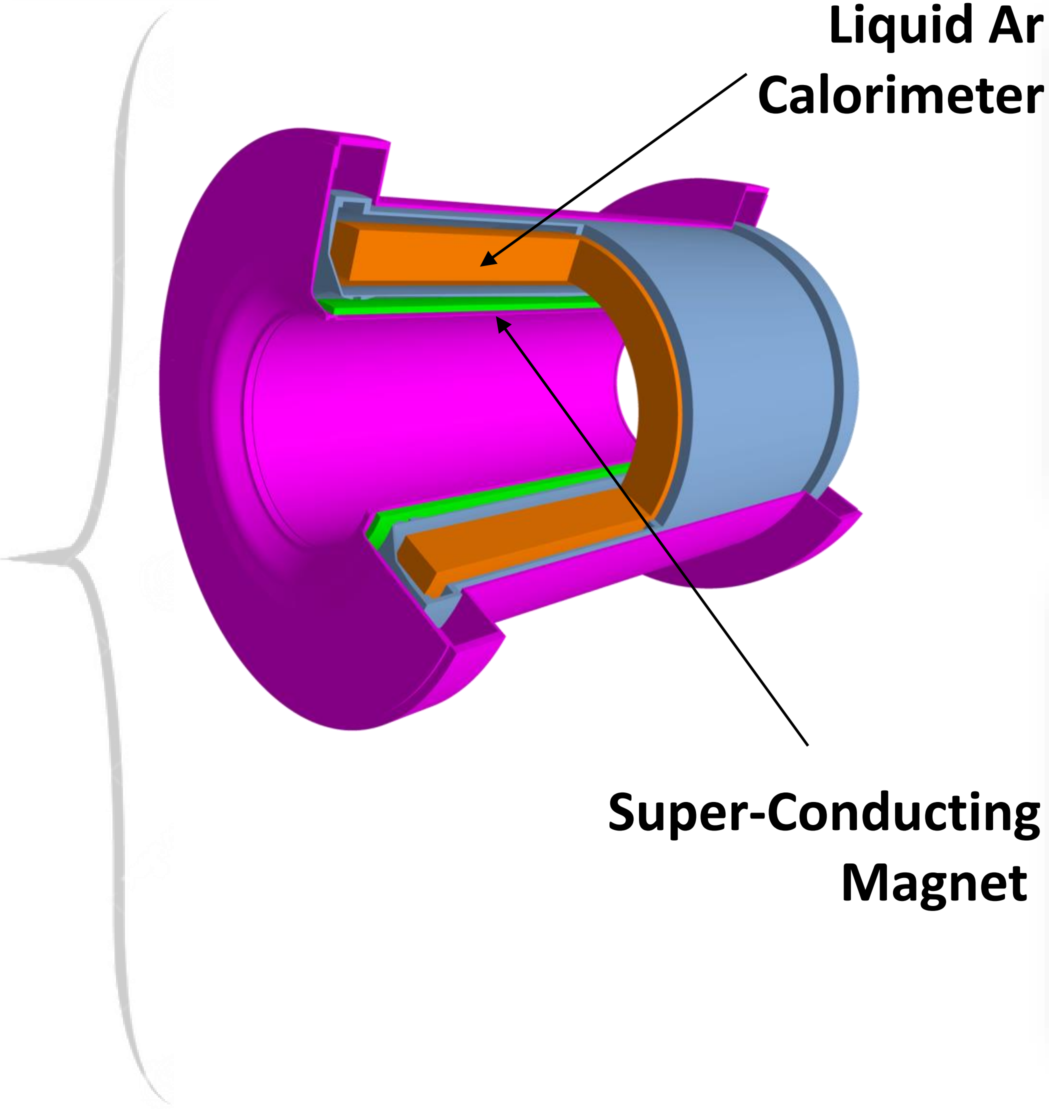
- Starting in gas phase (room temperature) requires a special cycle
- Supercritical cooldown to avoid thermal shock inside the detector
- Delicate components must be cooled down slowly
  - → at high pressure nearly vertical isothermal lines.
- Oil-free machine must be used (turbocompressors)
- Transcritical-subcritical cycle

➔ Test on supercritical Kr will be performed at NTNU

➔ Design and procurement of a test rig to compare supercritical CO2 and supercritical Kr thermal performances

Mechanics for cryostats

Detector Cryostat




LAr tightness: 3.5 bar, 87 K


Thermal insulation: 10e-5 mbar, 293 K

Challenges

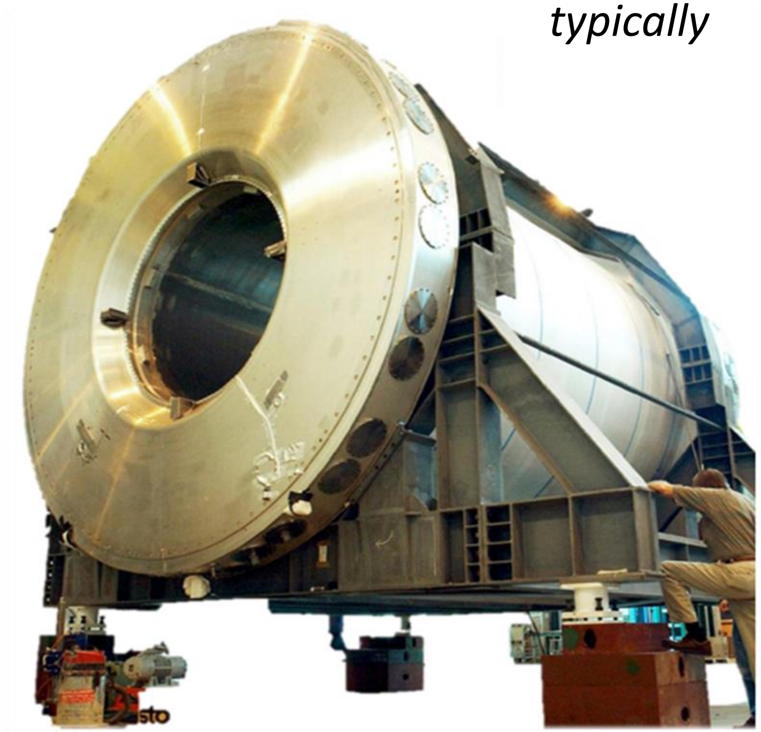
Mechanics for cryostats

Challenge

Carbon composite design to scope lighter cryostat with lower material budget in future experiments

HEP Detector Cryostats

Up to now, cryostat have been designed with SS316 and Al 5083 typically



Cryo-Tank Aerospace

Replacement of metal with Carbon could reduce material and thickness of future cryostats

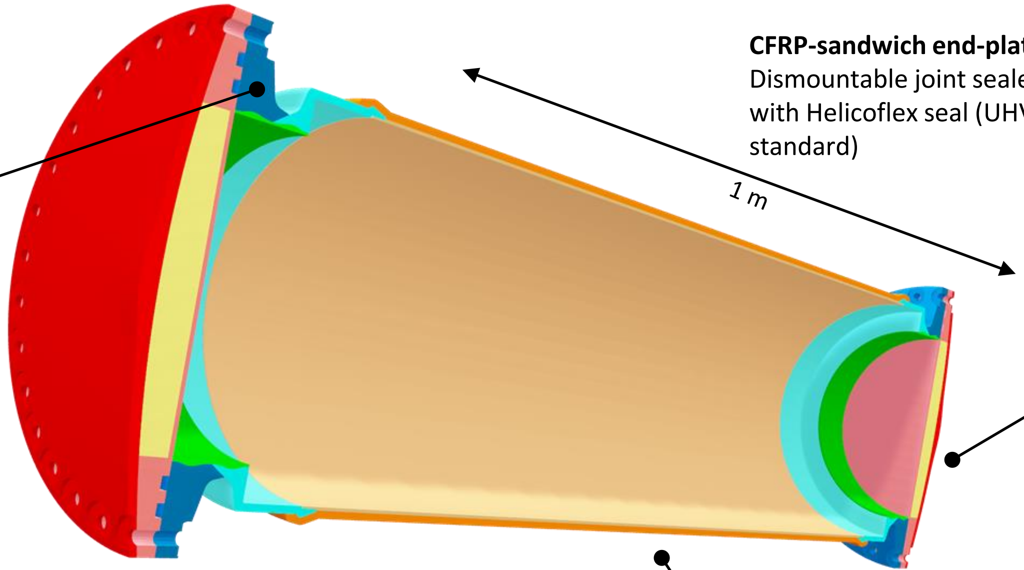
Full-carbon composite Engineering Model

Mechanics for cryostats

Challenge

Carbon could bring to 70% X_0 and 20% thickness saving

CFRP end-flanges:
Complex geometries to design interfaces with end-plates, feedthroughs, detector, magnet, … in future cryostat.



CFRP-sandwich end-plates:
Dismountable joint sealed with Helicoflex seal (UHV standard)

-He leak tightness: 10e-9 mbar x l /s (293-87K)
-LAr tightness: 3.5 bar and 87 K

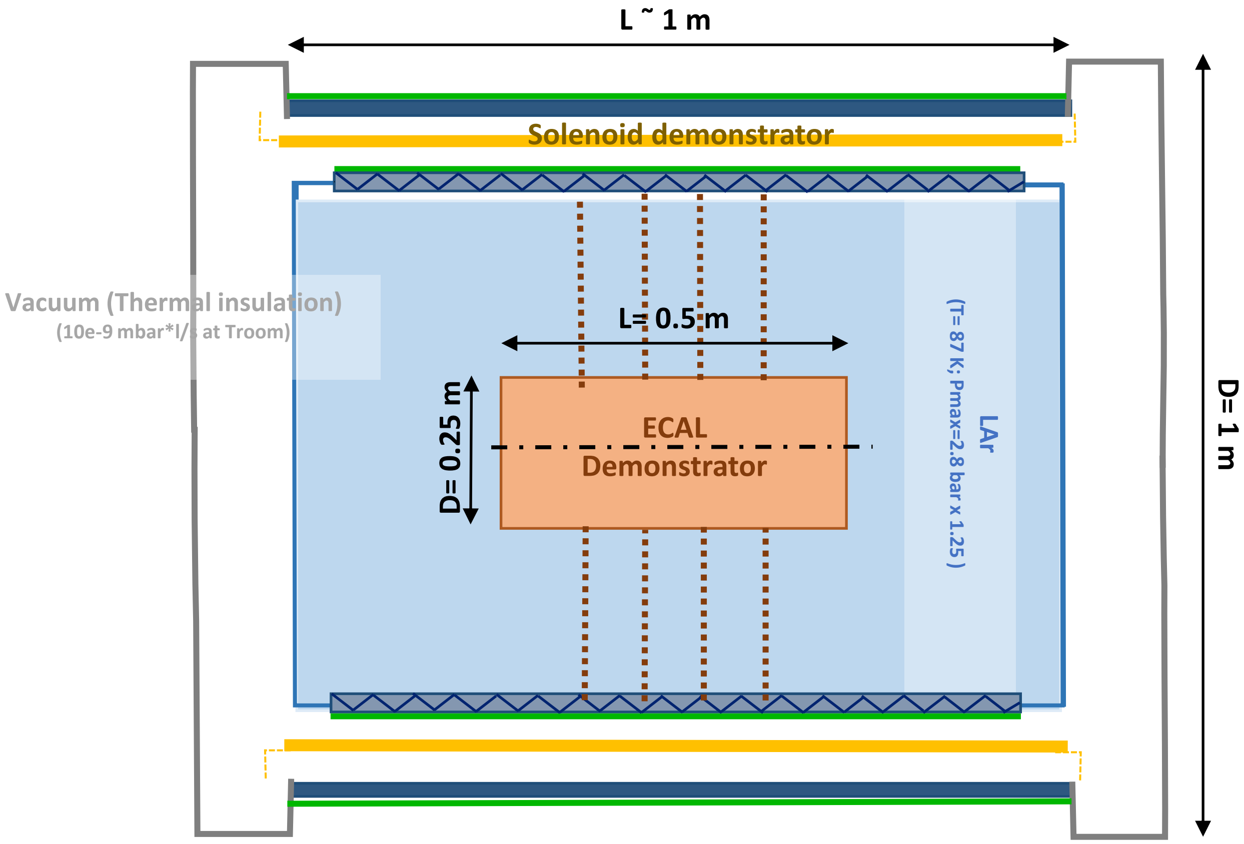
CFRP structural inner shell
+ non-crossing laminate on top:
Leak-tight shell without metallic liner

-Full Carbon Sandwich for Cryo temperature

Mechanics for cryostats

Challenge

Go to 1m³ demonstrator for Cryostat for LAr and Super-Conducting magnet



Cryostat Concept Demonstrator 1mD:

- Production of CFRP sandwich shell (multipiece structural inner shell)
- Support/Interfaces with LArCal and SC magnet
- Design of a double-cryostat for WP3 and WP4 demos
- Transition piece to connect metallic feedthroughs*

Test Campaign:

- He leak-tightness, 293-87 K
- LAr tightness, 3.5 bar
- Radiation Hardness (0.1 MGy)
- Mechanical Characterization of material (77 K)

BeamPipe Concept Demonstrator*, test campaign*

Design of:

- Full scale CFRP cryostat for LArCal and SC magnet (FCCee, FCChh)
- BeamPipe

Robotics

ROBTICS
for
HEP Experiments

Development of robotic platforms for motion in the detector environment

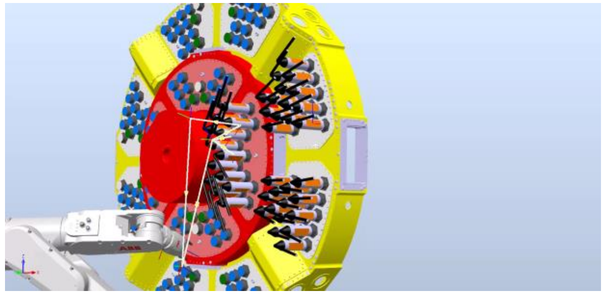
-Motion in the detector **cavern ground**
-Motion in **confined and cluttered spaces**
-**Aerial motion** for environmental mapping of the whole cavern

Inspection and manipulation payload design for the robotic platform

-Inspection
-Manipulation (Teleoperated)

Design of detector interfaces for robotic operation.

-Development of automated systems for detector opening closing insertion/extraction and maintenance

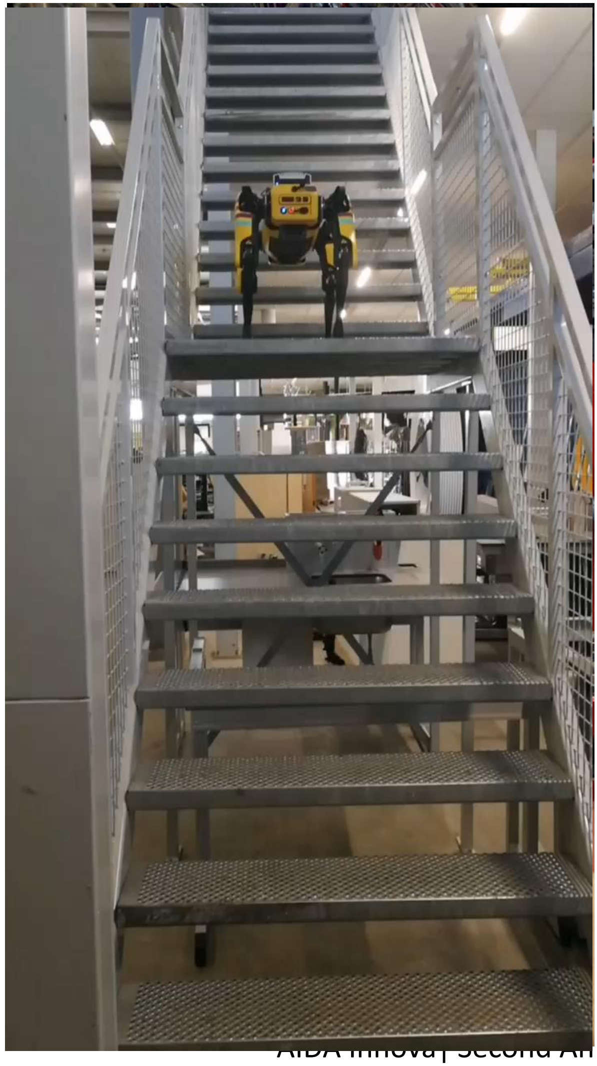


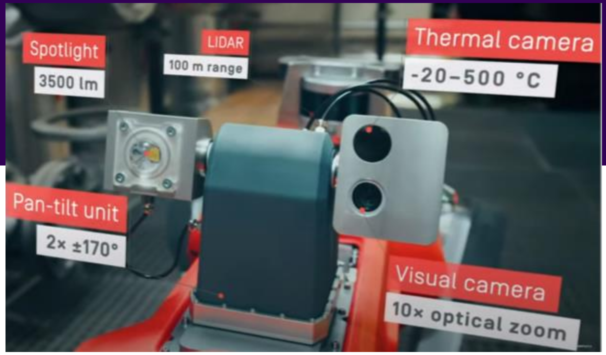
Challenges

robotic motion platforms for inspection and manipulation

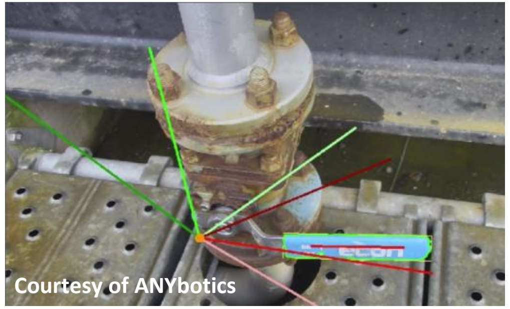
Challenge

Identify a robotic platform that can move in cavern (GROUND)



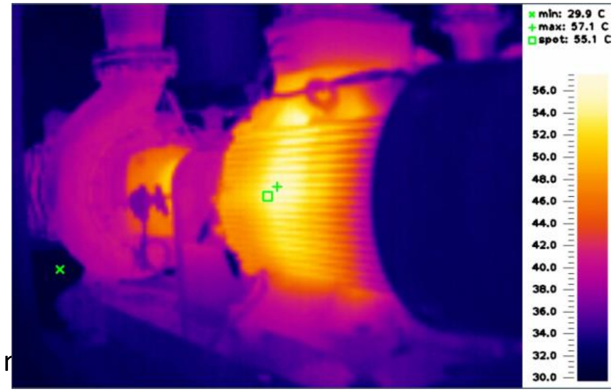


VALVES CHECKING


Courtesy of ANYbotics

RADIATION MEASUREMENT

THERMAL INSPECTIONS

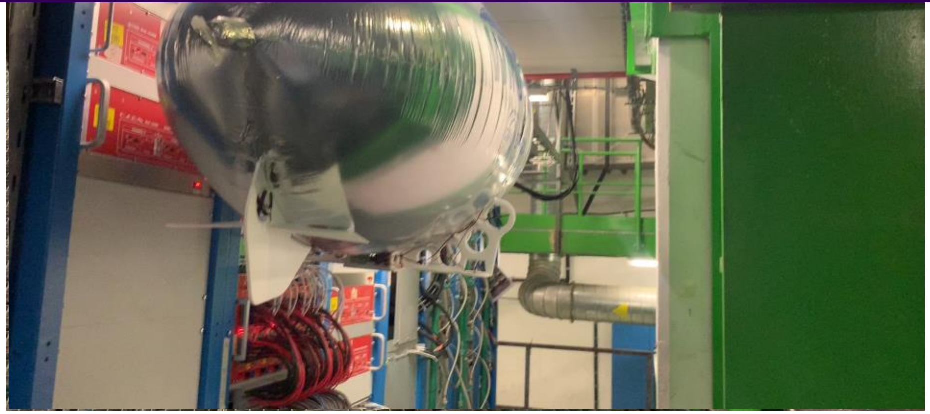


Aerial motion for environmental mapping

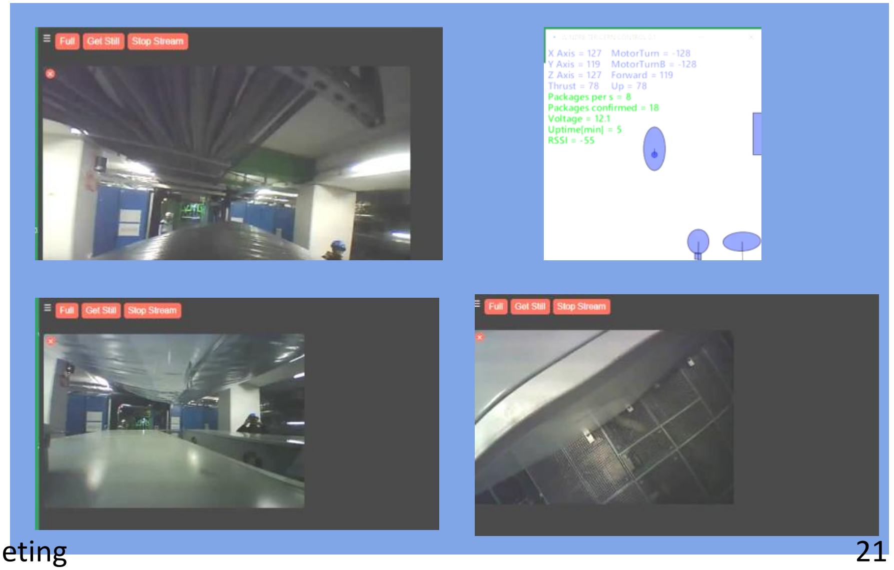
Challenge

Identify a robotic platform that can move in cavern environment (AERIAL)

Control/ Propeller
Camera/Payload



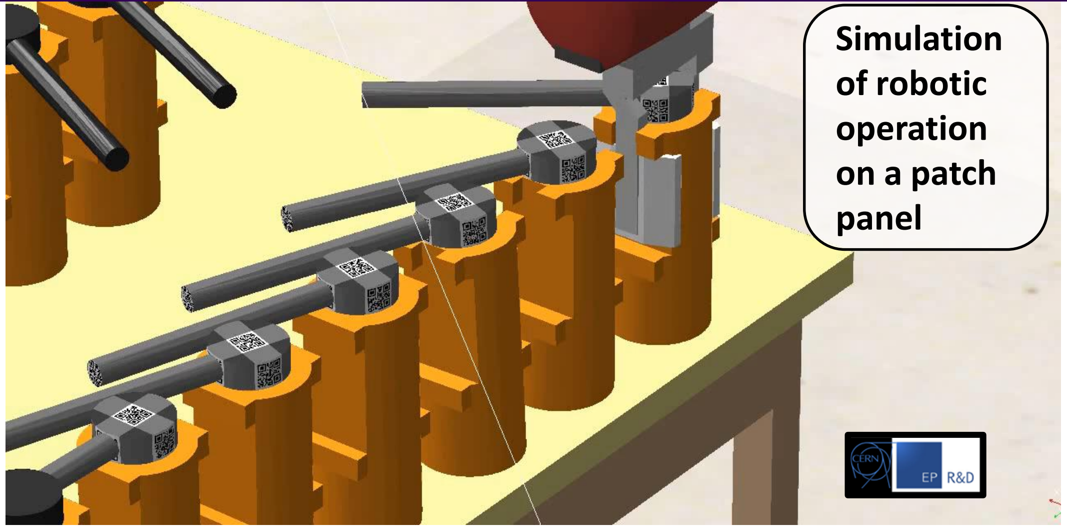
CONTROL ROOM (Ground Level) VIEW



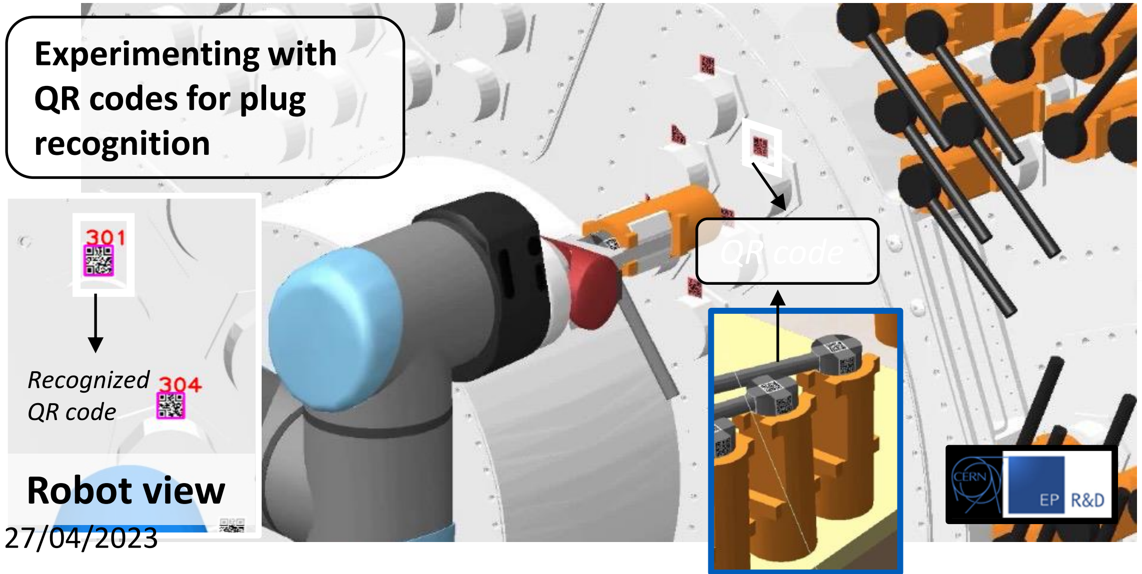
```
X Axis = 127   MotorTurn = -128
Y Axis = 119   MotorTurnB = -128
Z Axis = 127   Forward = 119
Thrust = 78    Up = 78
Packages per s = 8
Packages confirmed = 18
Voltage = 12.1
Uptime[min] = 5
RSSI = -55
```

Challenge

Design of detector interfaces for robotic operation.

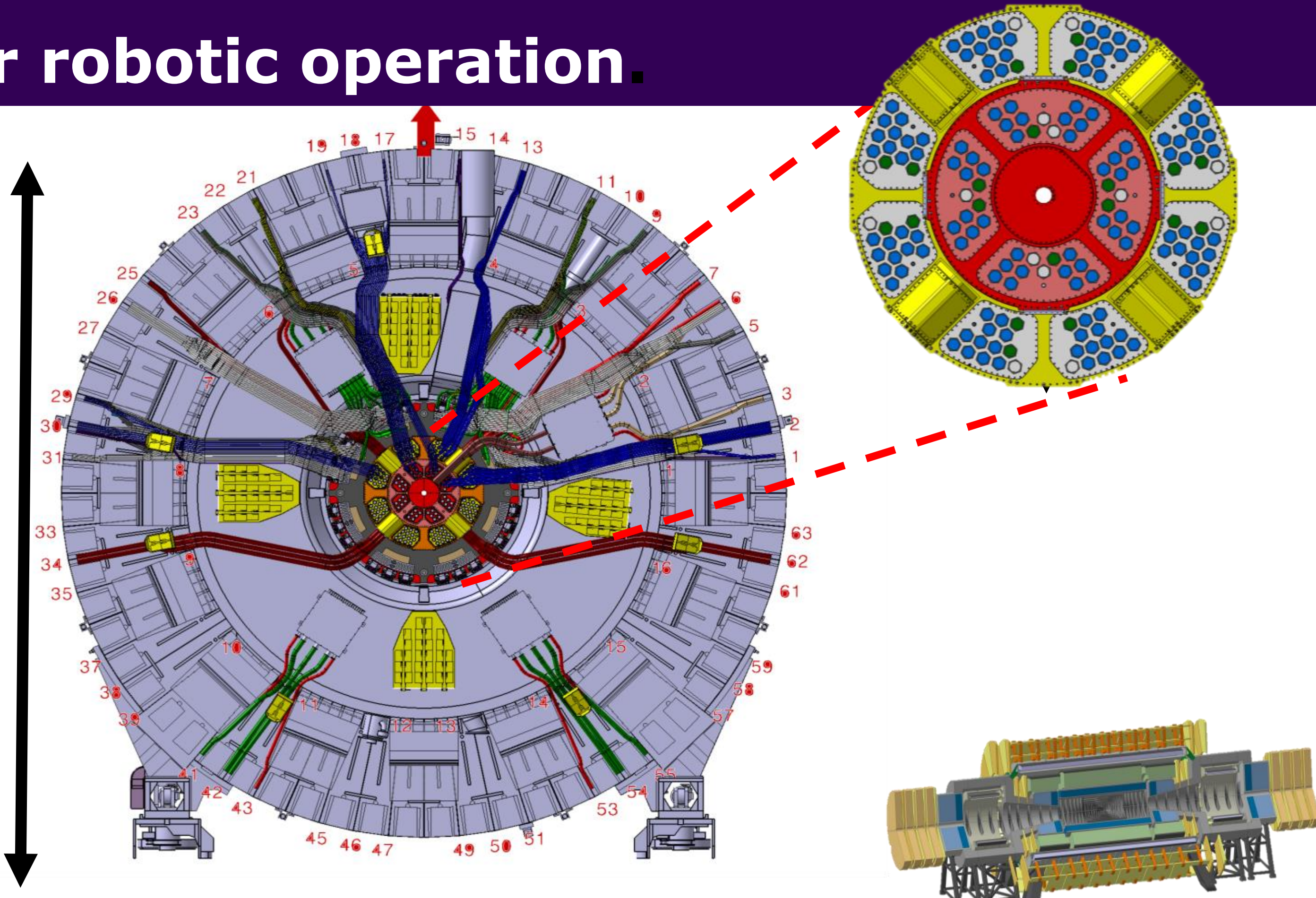


Simulation of robotic operation on a patch panel



Experimenting with QR codes for plug recognition

Robot view



Optimization of the connector design to be manipulated by a robot

Tests on the effective manipulation (both kinematics and dynamics)

Next steps

Air cooling **based on** **Carbon foam**

- Implementation into real detector
- Manage local air distribution for large scale application
- Validate sensor stability vs. gas speed

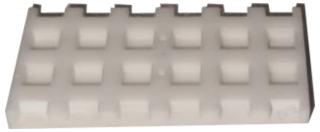
Pipeless **Carbon cold plate with microvascular network**

- Experimental fluidic tests
- Long-term fluid compatibility
- Apply planar interconnections

Carbon cold plate with embedded **Kapton pipes for CO2**

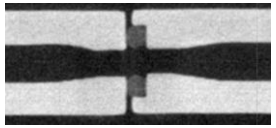
- Produce large-scale demonstrator
- Ensure absolute tube tightness (e.g. add coating)
- Long-term compatibility with CO_2

Ceramic **3D printed** **cold plates**



- More complex 3D shape for real detector
- Proposal for application in primary vacuum due to low outgassing (IRIS, LHCb Velo)

Modularity & **interconnection**



- Apply to different cold plate concepts
- Explore variants in metal/PEEK/HNBR for better radiation hardness and compatibility with CO_2

Next goals

Challenges

Manufacturing process and material choice

Leak tightness to vacuum/ LAr

Leak tightness of dismountable carbon joints

Leak tightness Long term

Services Feed trough

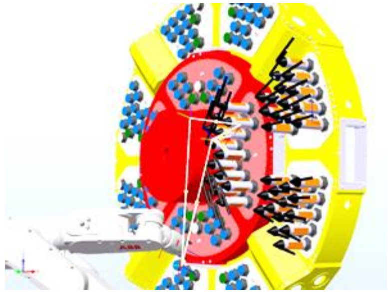
next

- Filament winding for large scale and microcrack resistant resin system for Out of Autoclave
- Test campaign on demonstrators to validate liner-less design and resin system and process
- Develop Helicoflex/equivalent solution for large scale
- Permeability and radiation effects
- Transition pieces between carbon and metallic feedthrough

Challenges

GROUND robotic platforms for motion in the detector environment

Aerial robotic platforms for motion in the detector environment



Detector interfaces for robotic operation

next

Develop of a **CERN-focused mobile platform** in collaboration with BE-CEM-MRO
Develop **Platform Payloads** for inspection/manipulation

Improve **Blimps control system**
Investigation of new motion possibilities
Payload development, **Autonomous Motion**
Self-Recharge Platform Development

Detector interfaces to **robotic arm** for handling
(Exp. area, test beam, irradiation facilities)