EEEMCal | Backward Ecal

Final Design Review

Mechanical Design & Assembly

-

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Mechanical designer: Alexandre Migayron

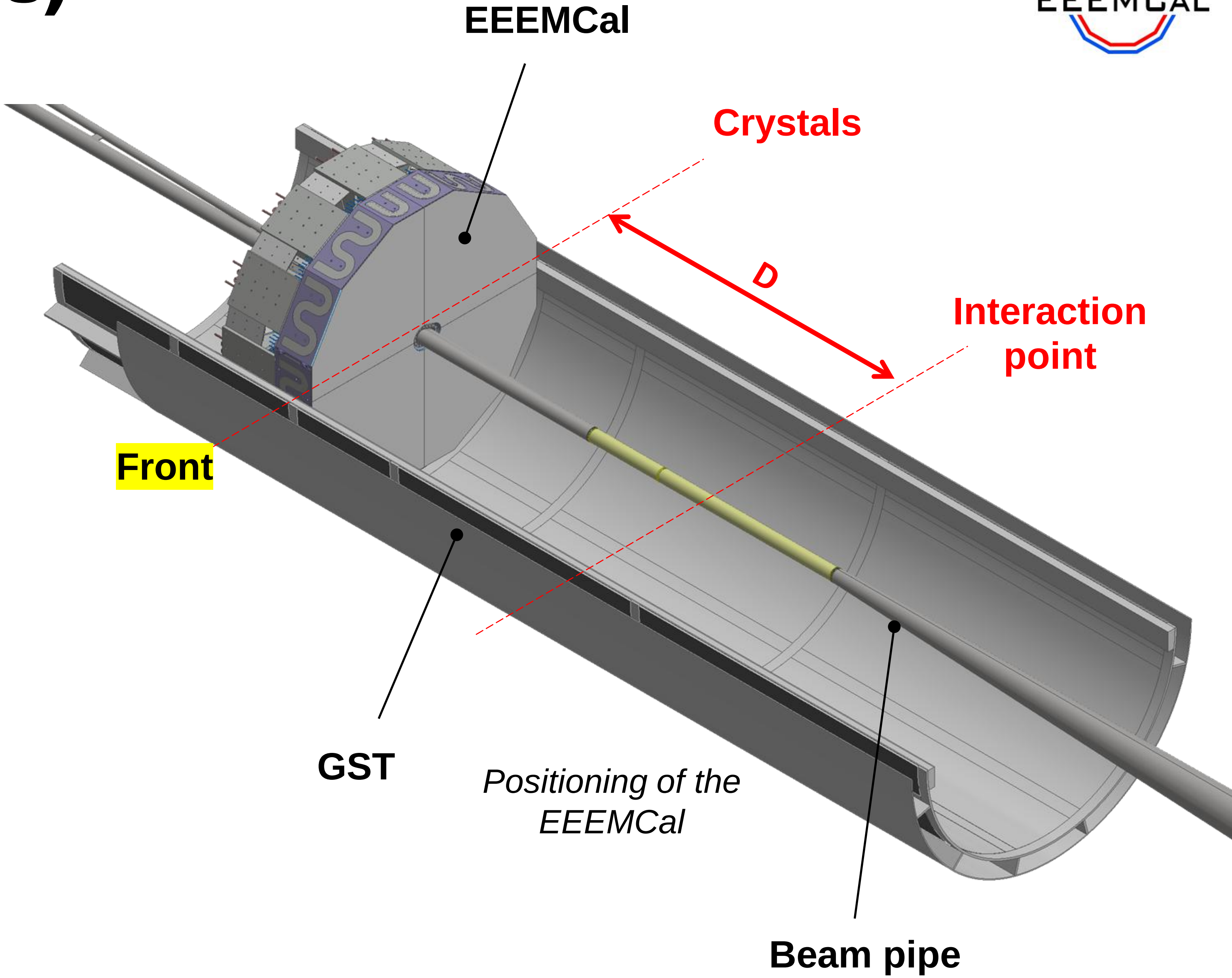
Outline

- ☐ Requirements
- ☐ Design validation
- ☐ Production & procurement
- ☐ Assembly
- ☐ Interfaces & integration
- ☐ Schedule

Requirements (Physics)

Physics specification guidelines

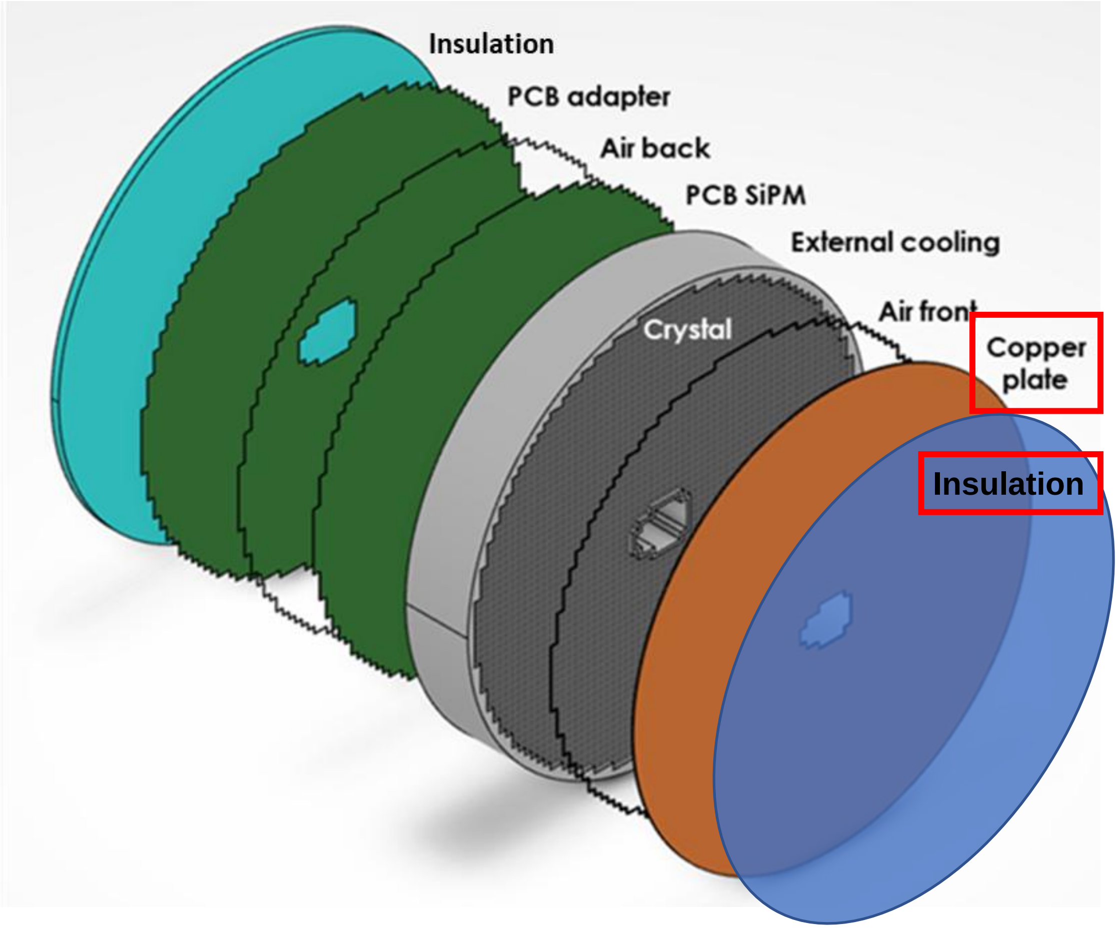
- ☐ Ensure distance **D** (interaction point / Crystals) between **176-178 cm**
- ☐ Minimize the material & space between crystals
- ☐ To be as close as possible to the beampipe
- ☐ Reduce material in **front** of the detector
- ☐ Ensure Temperature stabilty for the crystals to **+/- 0.1°C** at room temperature



Positioning of the EEEMCal

Design approach (Physics)

Material budget constraints in front of the calorimeter



Simplified design

☐ Material

- Copper
- Thickness max < 6 mm
- Mass = 4x15 Kg (easier for the handling)
- All material is included in simulations and detector performance meets physics requirements (Carlos' talk)

☐ Homogeneity

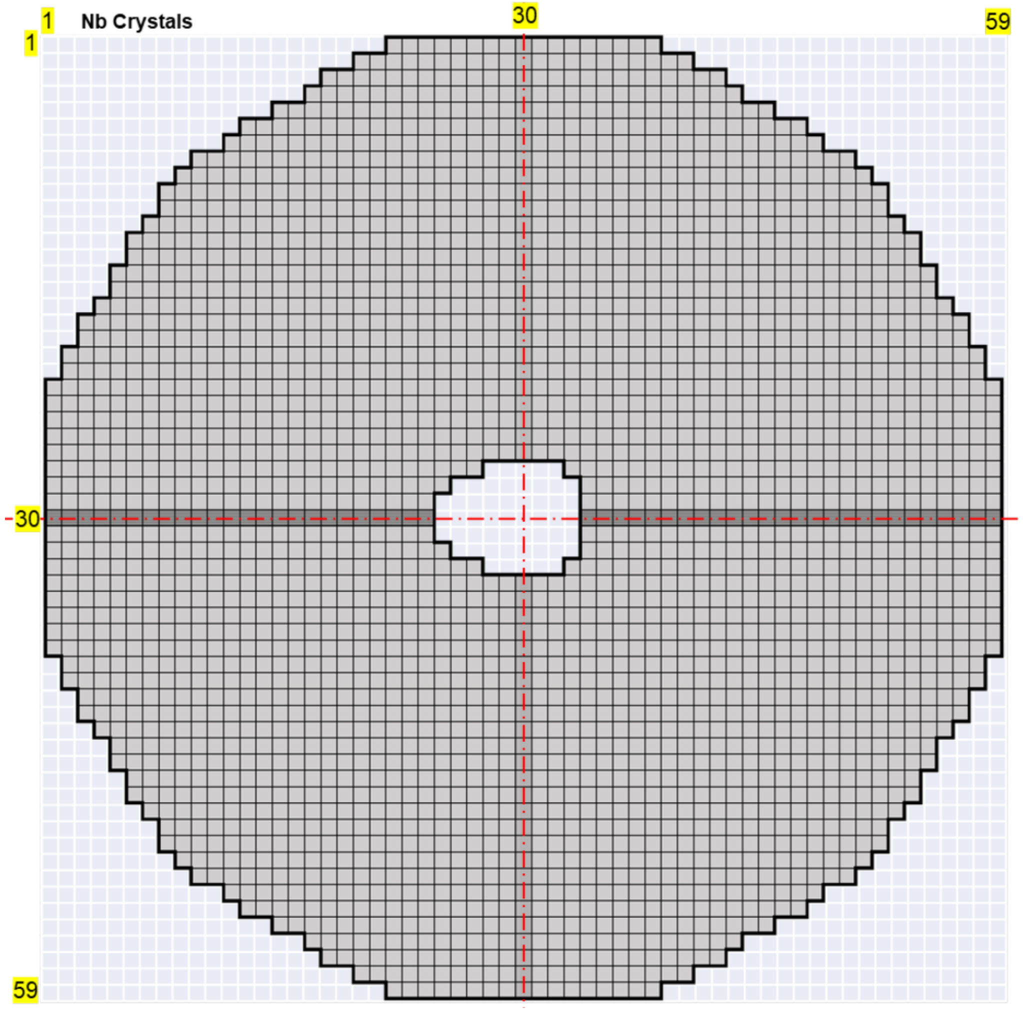
- No active cooling (without coolant)
- Cooling only by conduction

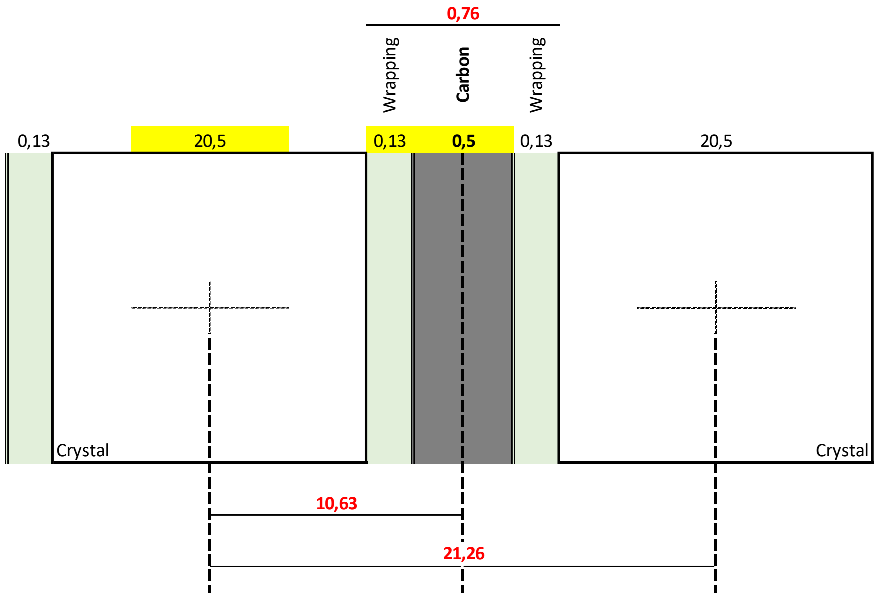
☐ Insulation

- Foam = 1 cm
- Depend on the dissipation of the power from the pfRICH

Design approach (Detector)

Detector architecture: crystal organization



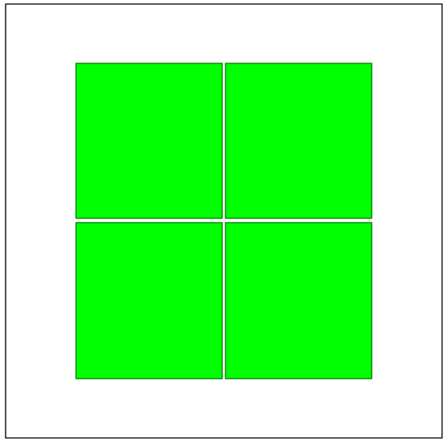


Crystals:

- Material: PWO ($PbWO_4$)
- Size = $20.5^{+0-0.5} \times 20.5^{+0-0.5}$ x 200 mm^3
- Mass = 0,7 Kg (8,28 $g.cm^{-3}$)
- Quantity = 2740
- Reflector: ESR® (3M) VM2000 = 0.65 µm
- Light insulation: Tedlar® = 0.65 µm
- Carbon plate = 0.5 mm

Design approach (Sensors)

Detector architecture: SiPM readout configuration

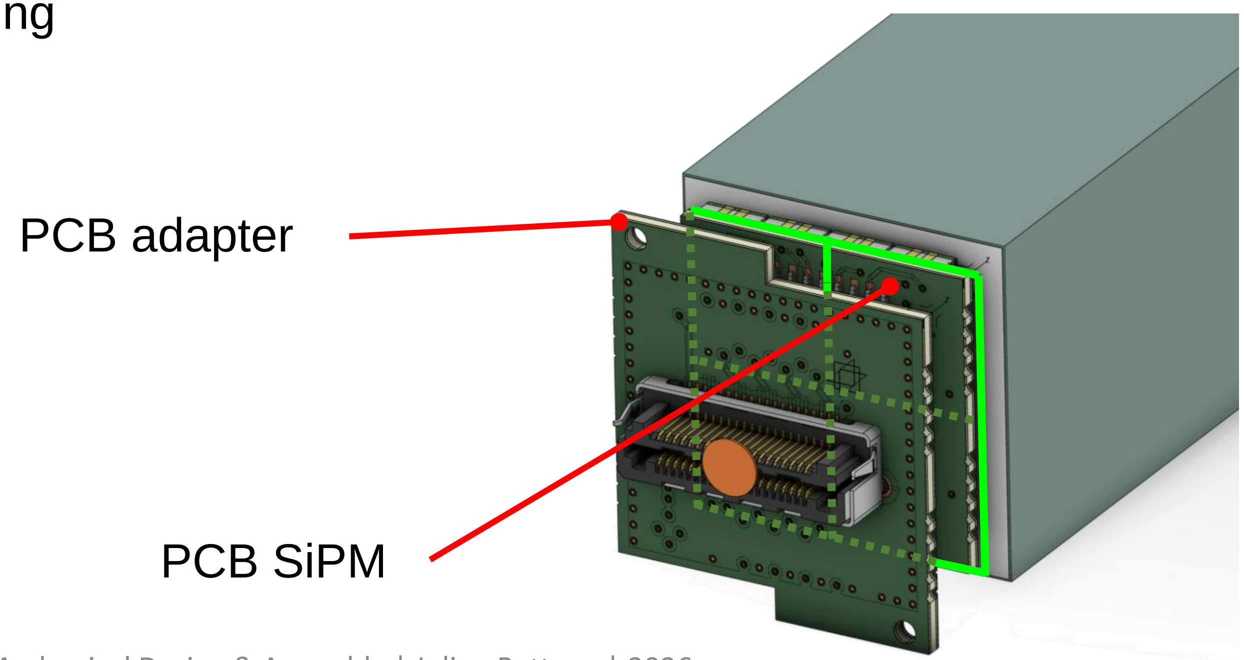


Hamamatsu S14160-6015PS (15 µm)	H 7,35
	L 6,85
	6 mm
	Active 6x6

Active surface SiPM		**34,27 %**
Distance SiPM / Cristal	H	2,800 mm
Distance SiPM / Cristal	L	3,300 mm

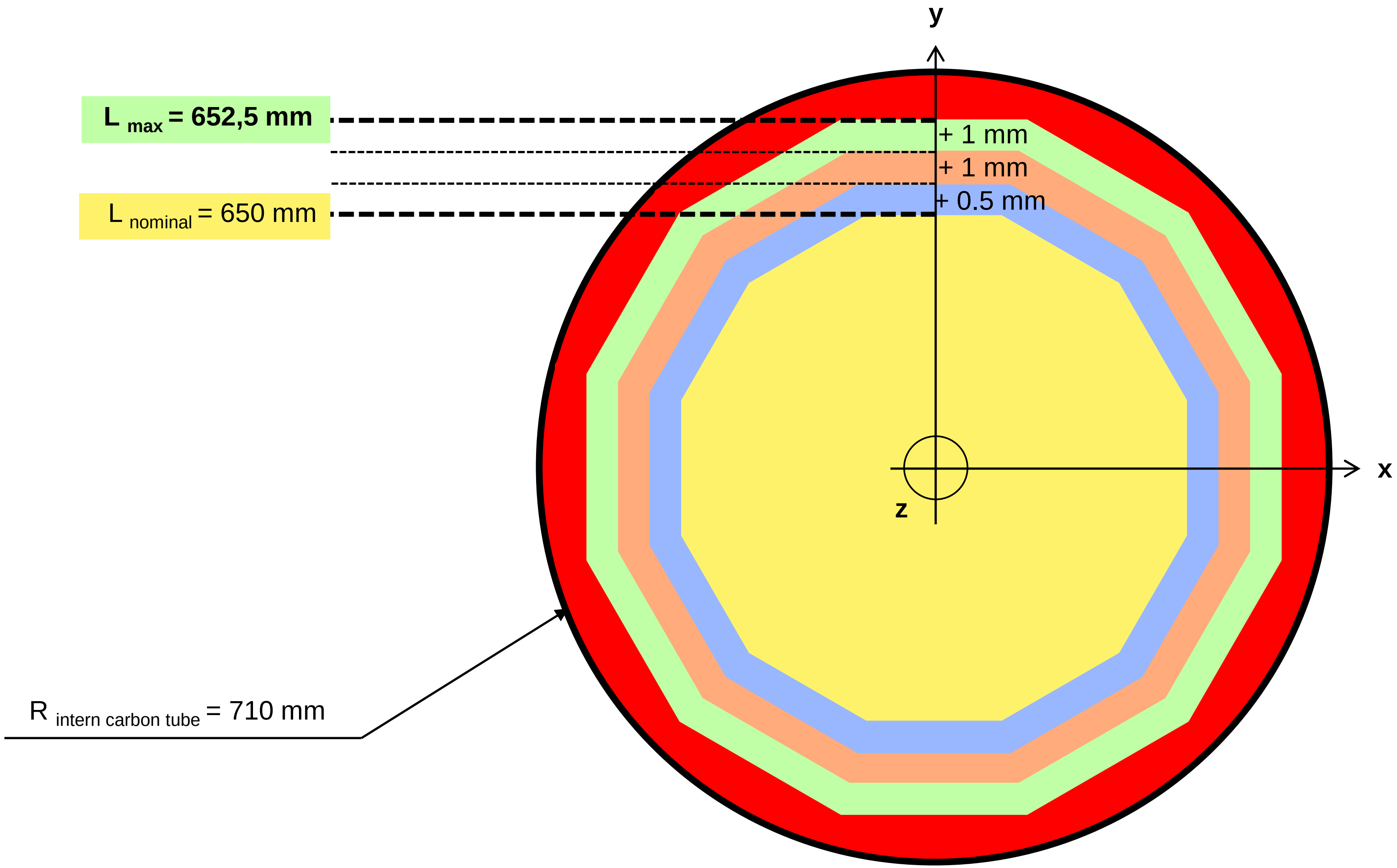
SiPM:

- Matrix 2x2 (Positionned at the center)
- 4 SiPM (6x6 mm^2) / crystal
- Optical coupling: Optical grease: DOWSIL™ Q2-3067 (same one used in NPS and the CMS ECal: https://cds.cern.ch/record/687014/files/note98_024.pdf
- No power to dissipate from the SiPM
- PCB adapter fastened on the grid to ensure the optical coopling



Requirements (Clearances)

Mechanical and integration constraints: detector envelope (clearances, carbon tube [x,y])



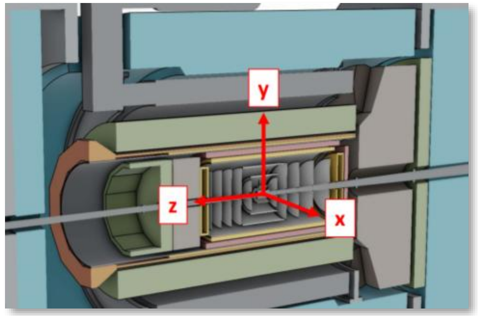
L_{max} = 652,5 mm

$L_{nominal}$ = 650 mm

$R_{\text{intern carbon tube}}$ = 710 mm

🟥 **31 mm < Clearance < 57,5 mm**

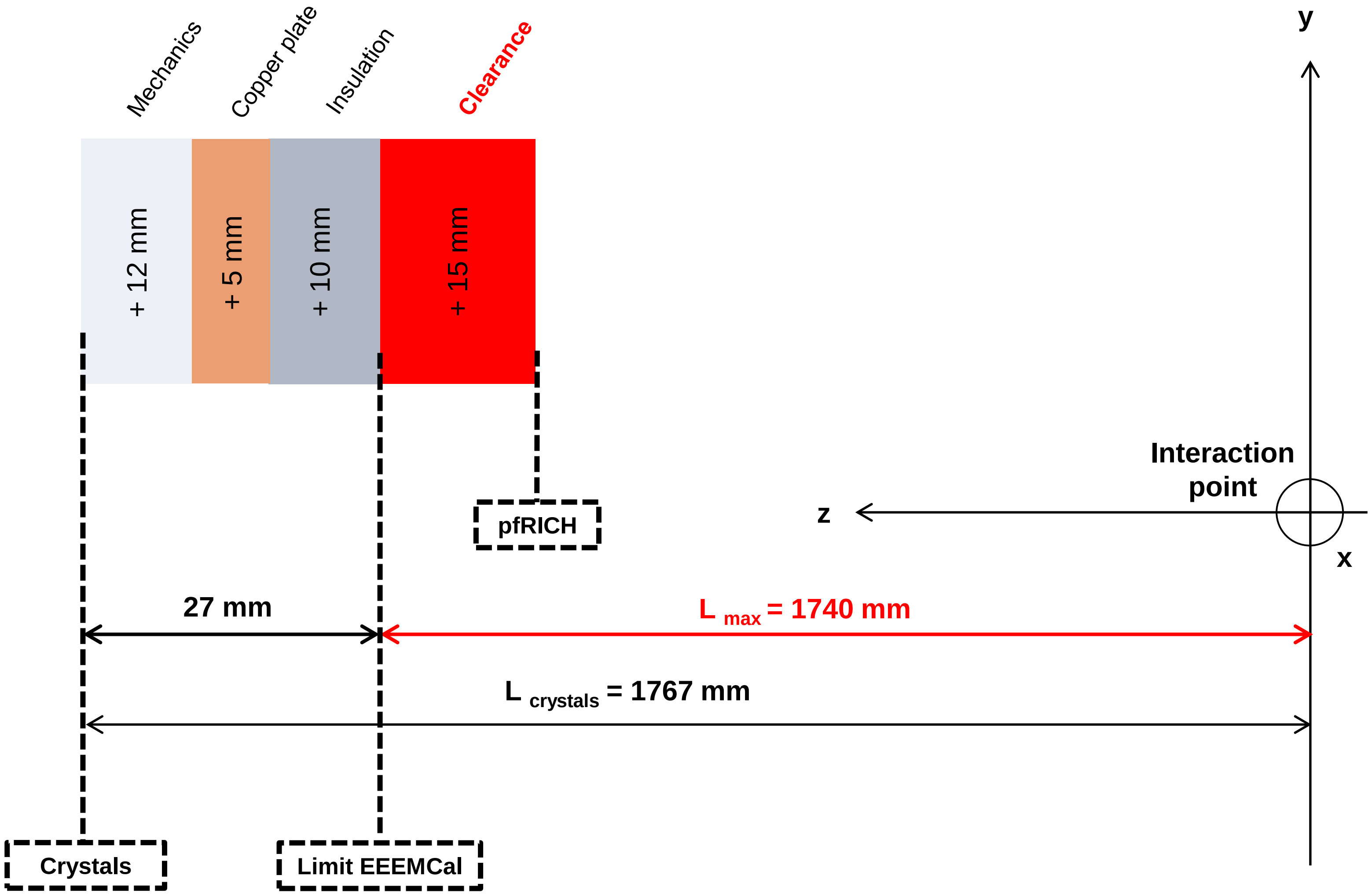
Clearance required for services from inner detectors



🟨 Nominal dimension
🟦 Machining dimension
🟧 Assembled dimension
🟩 Deflection dimension
🟥 **Clearance**

Requirements (Clearances)

Mechanical and integration constraints: detector envelope (clearances, pfRICH [y,z])



Mechanics
Copper plate
Insulation
Clearance

+ 12 mm
+ 5 mm
+ 10 mm
+ 15 mm

y
z
x
Interaction point

pfRICH

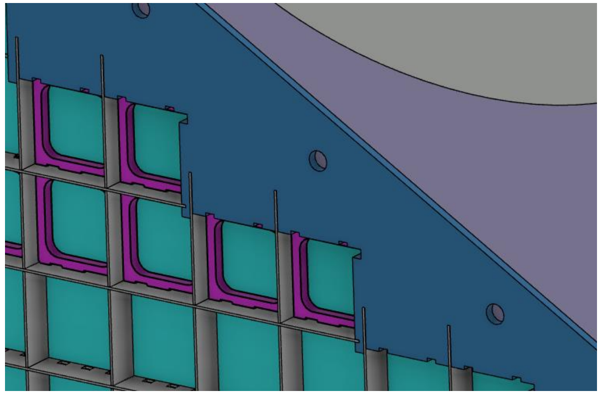
27 mm

L_{max} = 1740 mm

$L_{crystals}$ = 1767 mm

Crystals

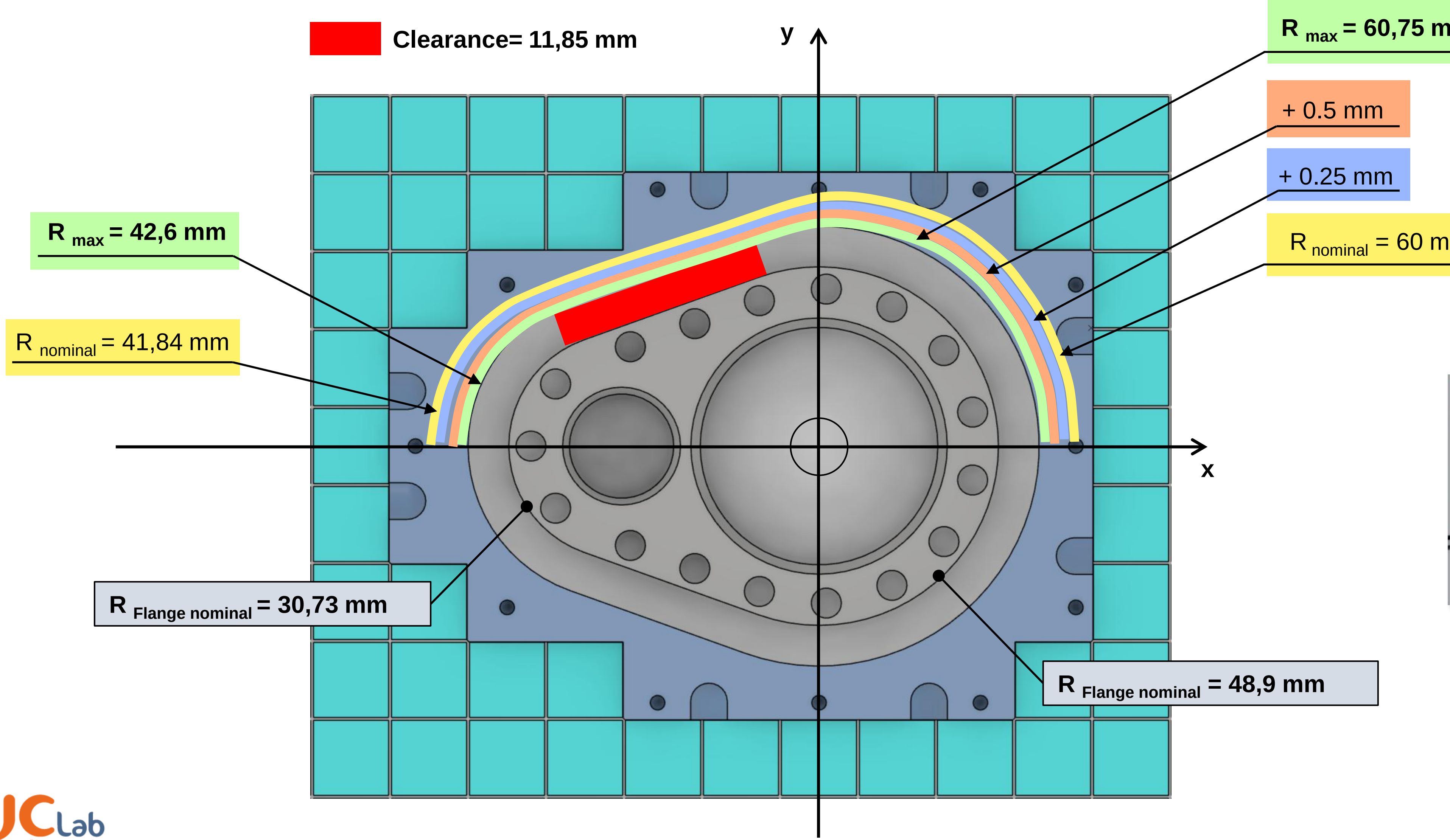
Limit EEEMCal



Mechanics = 12 mm
Including assembly and deflection

Requirements (Clearances)

Mechanical and integration constraints: detector envelope (clearances | Beam pipe flange)



🟥 **Clearance= 11,85 mm**

R_{max} = 60,75 mm

+ 0.5 mm

+ 0.25 mm

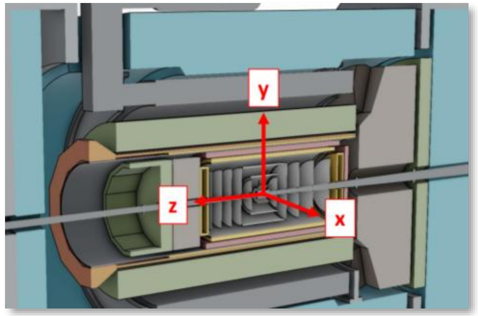
$R_{nominal}$ = 60 mm

R_{max} = 42,6 mm

$R_{nominal}$ = 41,84 mm

$R_{Flange\ nominal}$ = 30,73 mm

$R_{Flange\ nominal}$ = 48,9 mm



🟨 Nominal dimension

🟦 Machining dimension

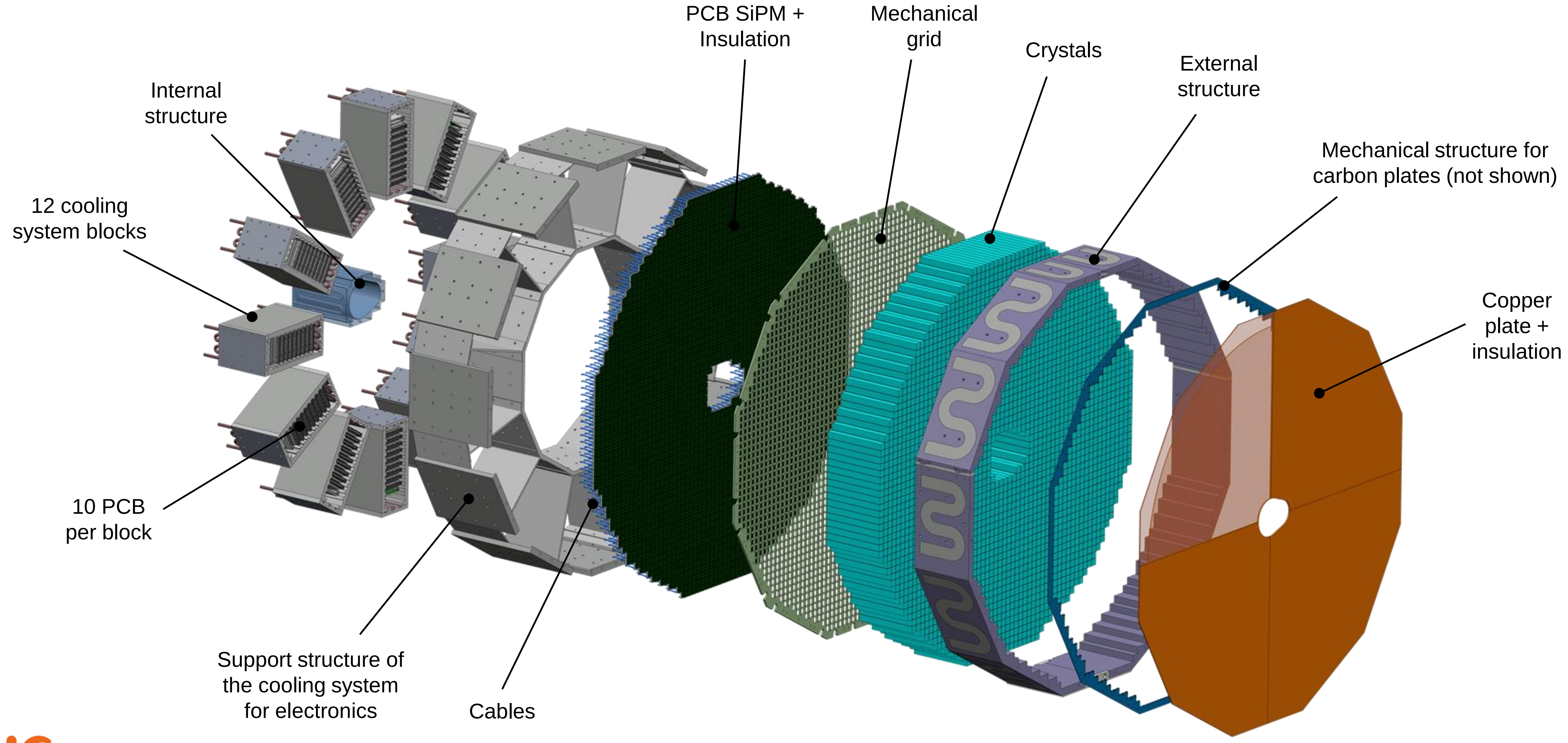
🟧 Assembled dimension

🟩 Deflection dimension

🟥 **Clearance**

Design validation (Overview)

Mechanical design: overview



PCB SiPM + Insulation

Mechanical grid

Crystals

External structure

Mechanical structure for carbon plates (not shown)

Copper plate + insulation

Internal structure

12 cooling system blocks

10 PCB per block

Support structure of the cooling system for electronics

Cables

Requirements (Integration)

Support and services: mechanical support structure

☐ Fastening of the detector:

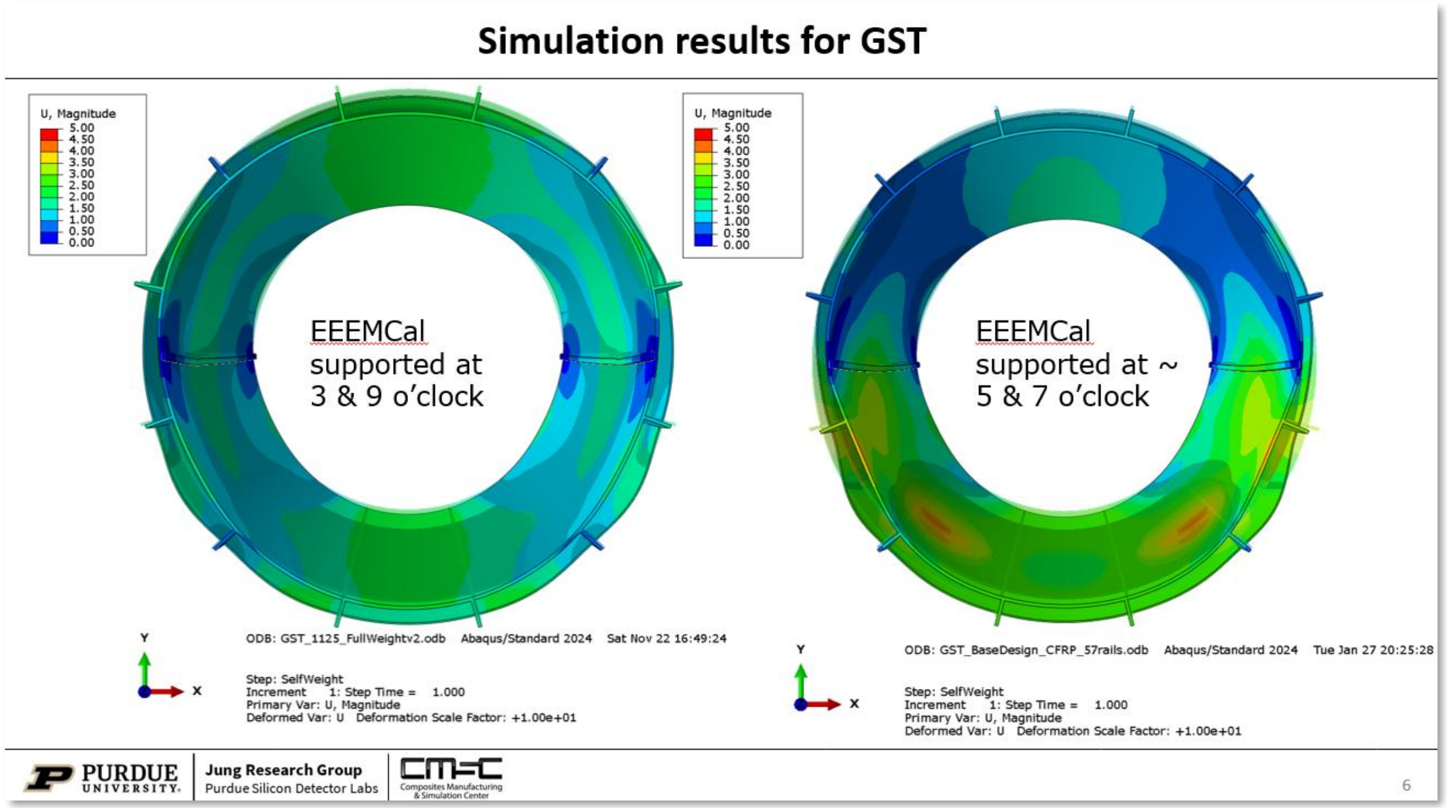
- The EEEMCal is fastened to the GST with guide rails
- At 3 and 9 o’clock
- In order to reduce the deflection with the services inside the carbon tube (compare to 5 and 7 o’clock)

☐ Eddy current:

- No monolithic circular structure
- Cut and isolate

☐ Clearances

- with the services inside the carbon tube
- With the beam pipe
- With the pfRICH



Simulation results for GST

EEEMCal supported at 3 & 9 o’clock

EEEMCal supported at ~ 5 & 7 o’clock

ODB: GST_1125_FullWeightv2.odb Abaqus/Standard 2024 Sat Nov 22 16:49:24

Step: SelfWeight
Increment 1: Step Time = 1.000
Primary Var: U, Magnitude
Deformed Var: U Deformation Scale Factor: +1.00e+01

ODB: GST_BaseDesign_CFRP_57rails.odb Abaqus/Standard 2024 Tue Jan 27 20:25:28

Step: SelfWeight
Increment 1: Step Time = 1.000
Primary Var: U, Magnitude
Deformed Var: U Deformation Scale Factor: +1.00e+01

PURDUE UNIVERSITY. | Jung Research Group Purdue Silicon Detector Labs | Composites Manufacturing & Simulation Center

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Results FEA (Sushrut Karmarkar)

Design validation (External structure)

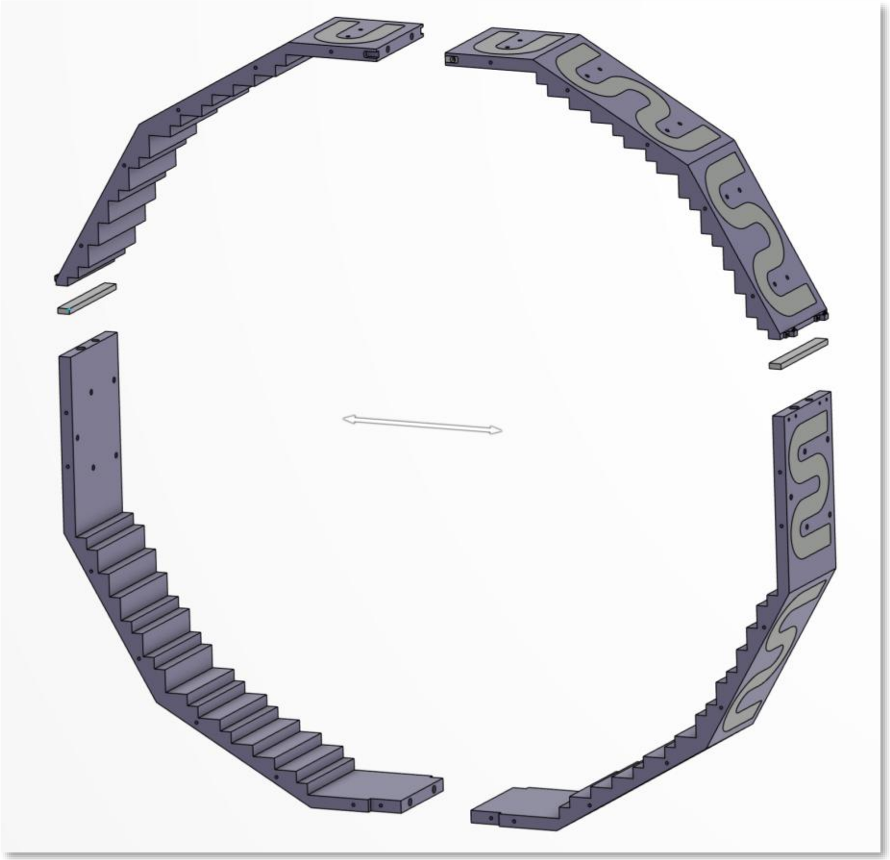
Mechanical design & simulations: deformation, stress

☐ External structure not machined in one block (4 parts)

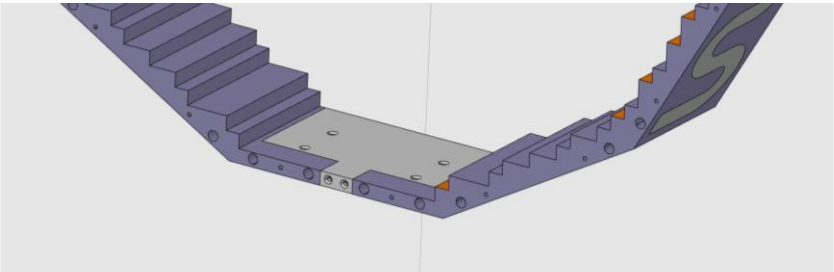
- Better for the cost
- Better for the Eddy current
- Better for the contact with crystals on the top (cooling)
- Better for the adjustments

☐ To ensure integrity of the structure

- Cover plate inside (5mm) on the top and the bottom to link
- To limit the deflection



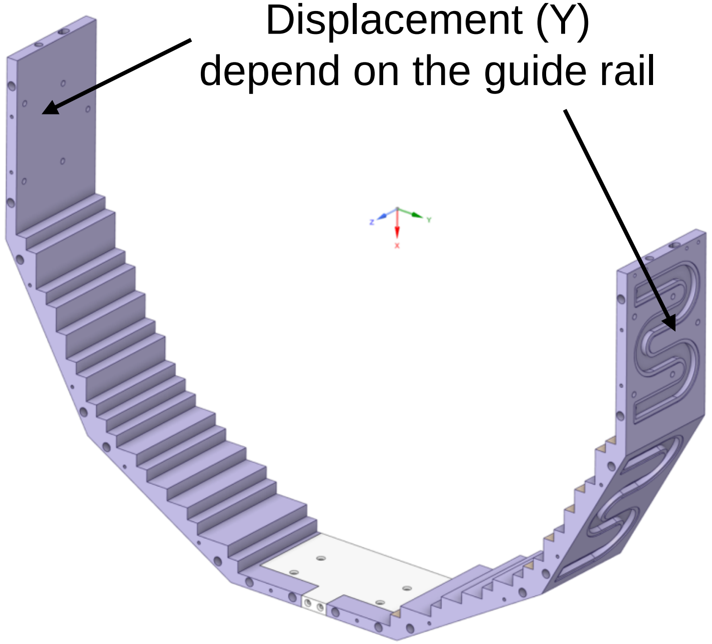
External structure in 4 parts



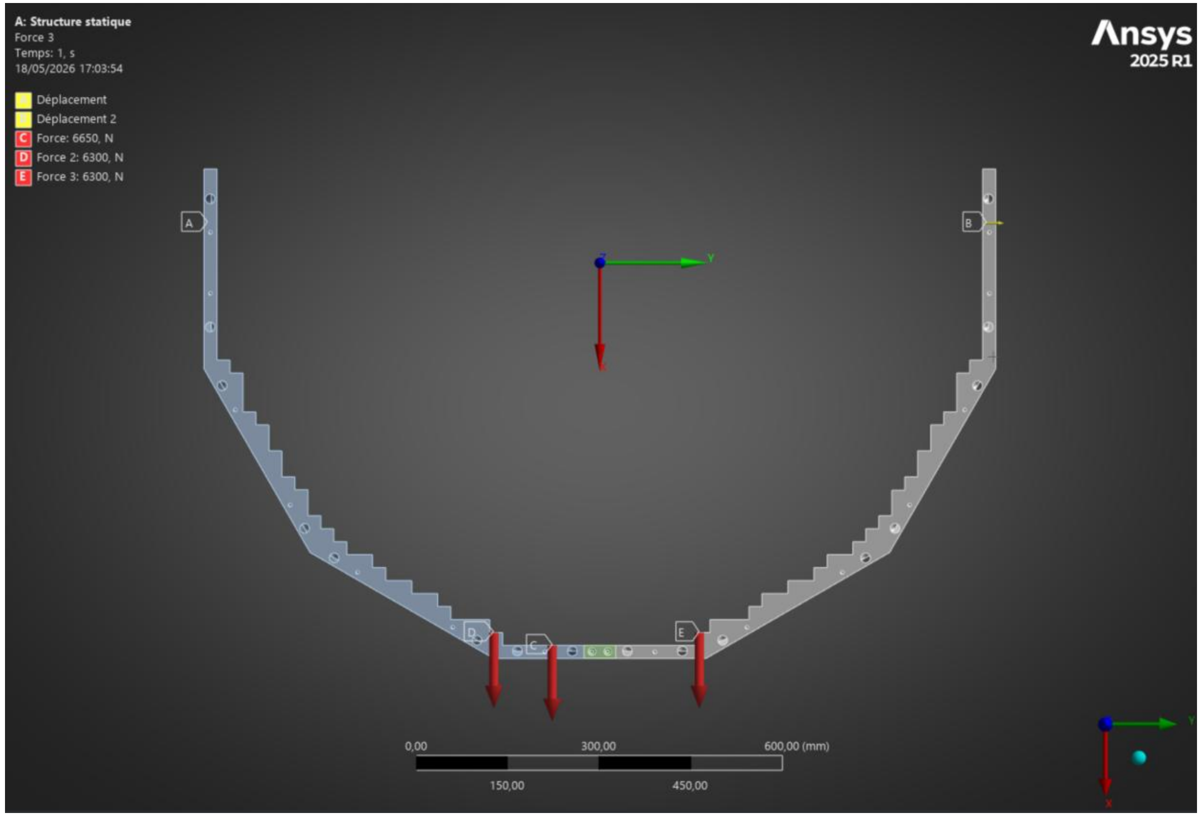
Aluminum Cover plate (Thermal conductivity = 185 W/m.K)

Design validation (External structure)

Mechanical design & simulations: deformation, stress



Displacement (Y) depend on the guide rail

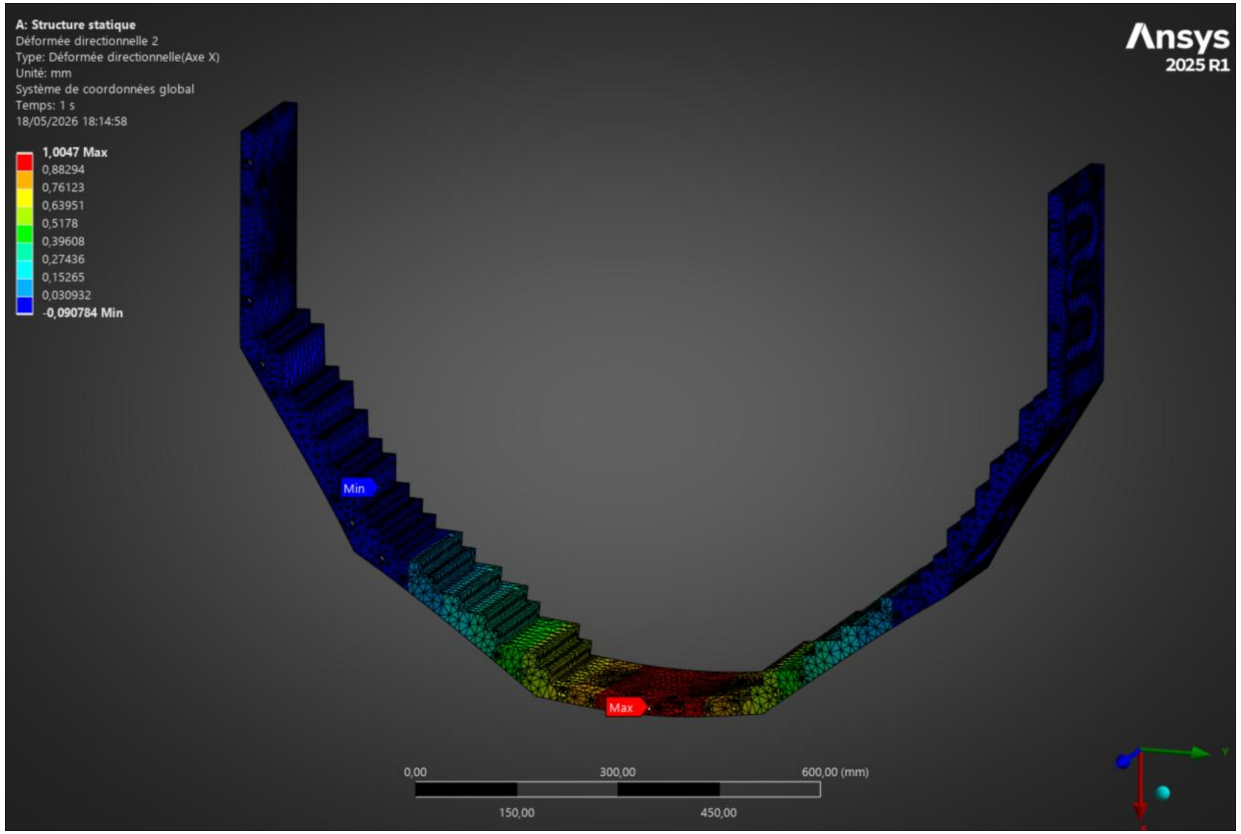


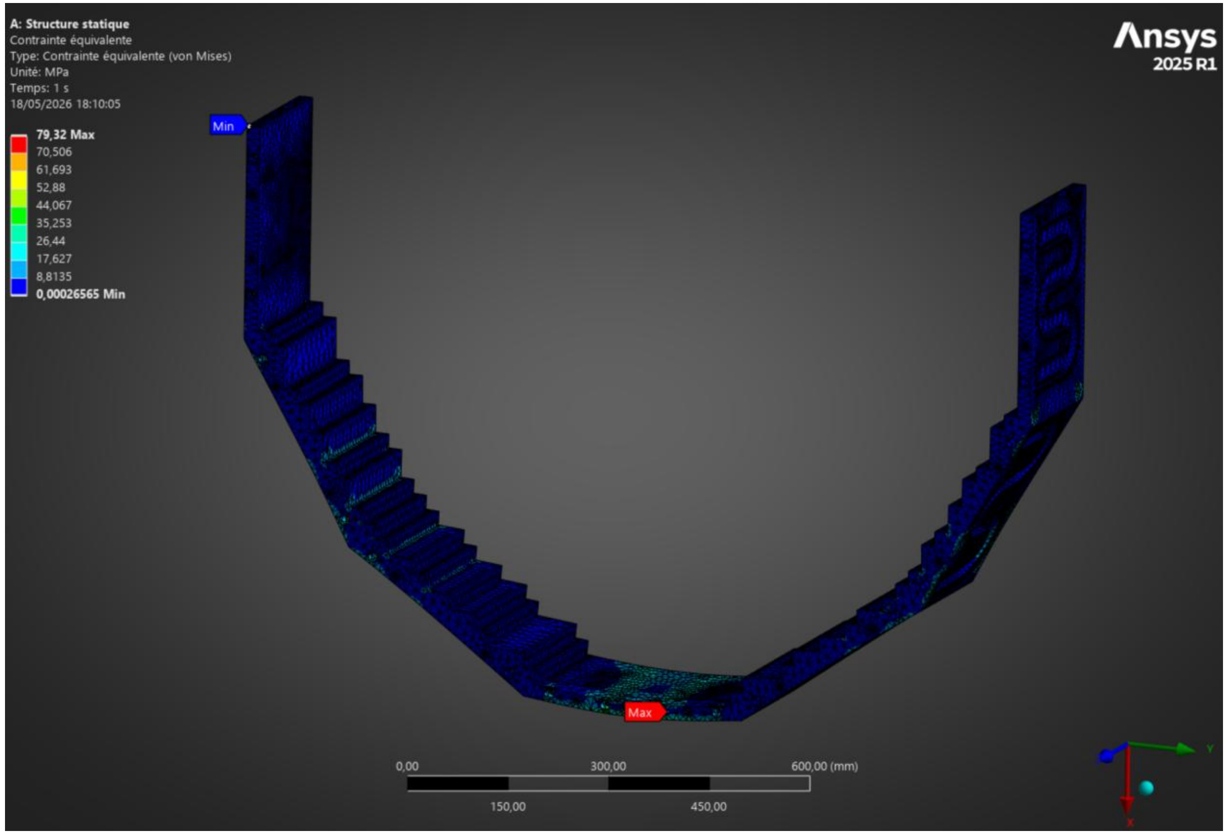
Boundary conditions

- Displacement in X = 0
- Displacement in Y estimated < 0,5 mm
- Force on bottom surfaces of the external structures (≈ 2 Tons)

Design validation (External structure)

Mechanical design & simulations: deformation, stress





*Displacement (1 mm) and stress (80 Mpa) of the structure in vertical (Y) direction with a **0,25 mm** displacement of the guide rails . Displacement (1,3 mm) and stress (80 Mpa) of the structure in vertical (Y) direction with a **0,5 mm** displacement of the guide rails .*

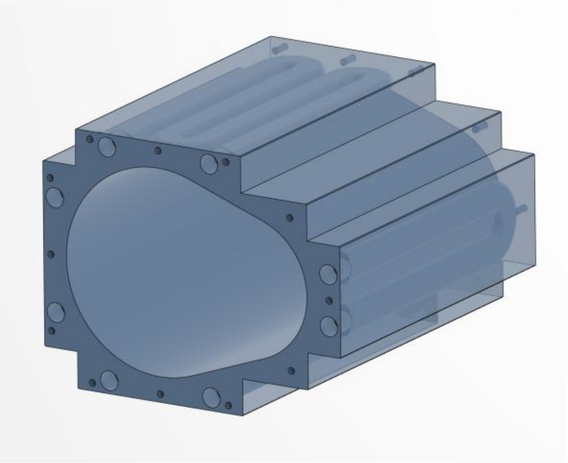
Total mass ≈ 2 Tons with the cover plate on the bottom.

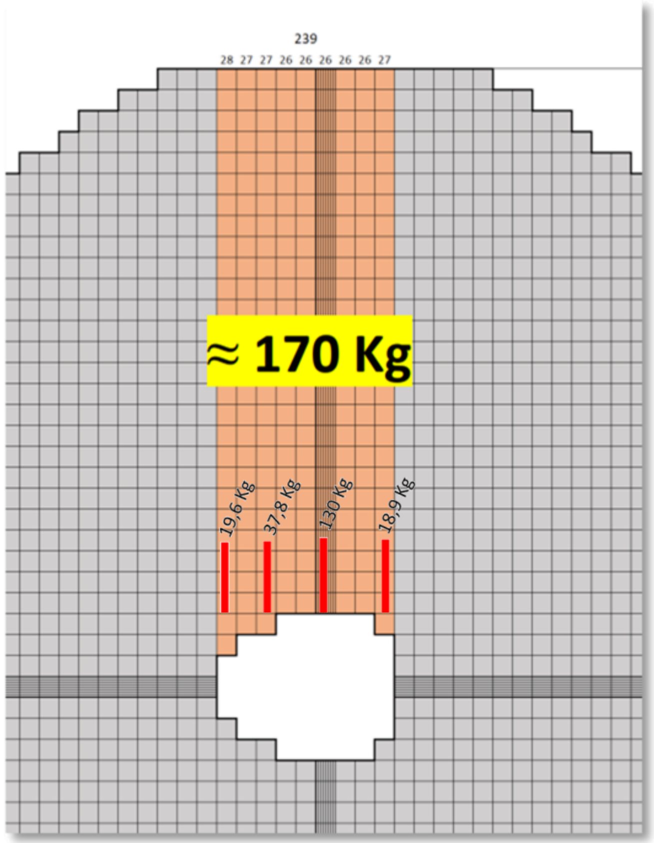
Design validation (Internal structure)

Mechanical simulations: deformation, stress

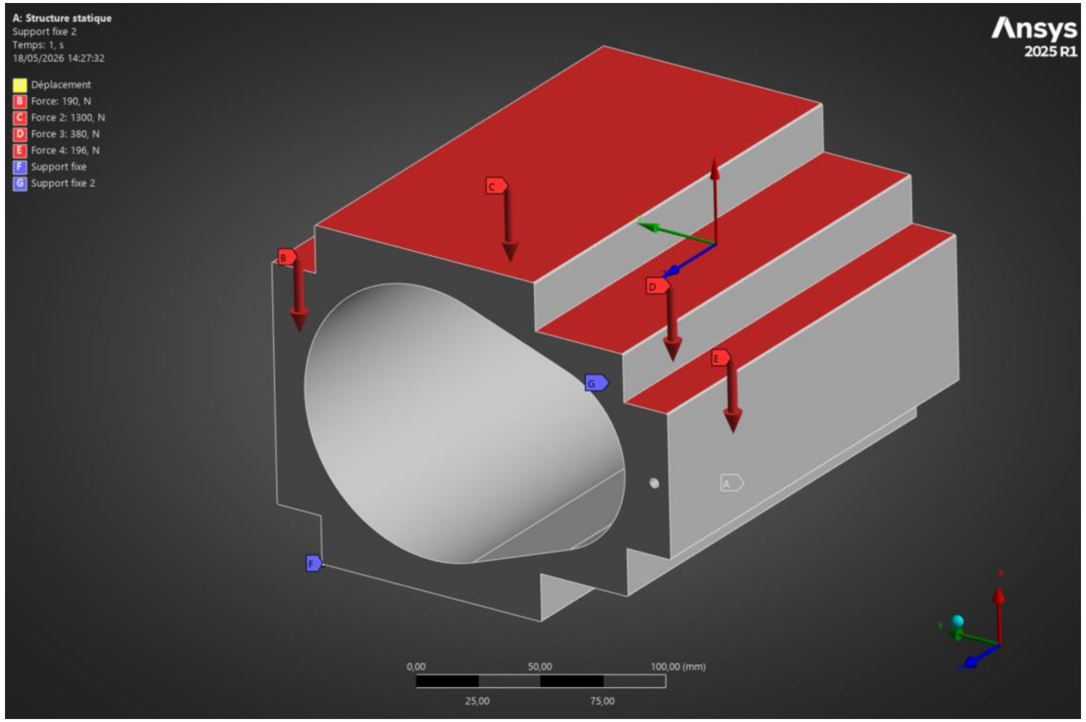
Design

- Very compact
- Very low deformation





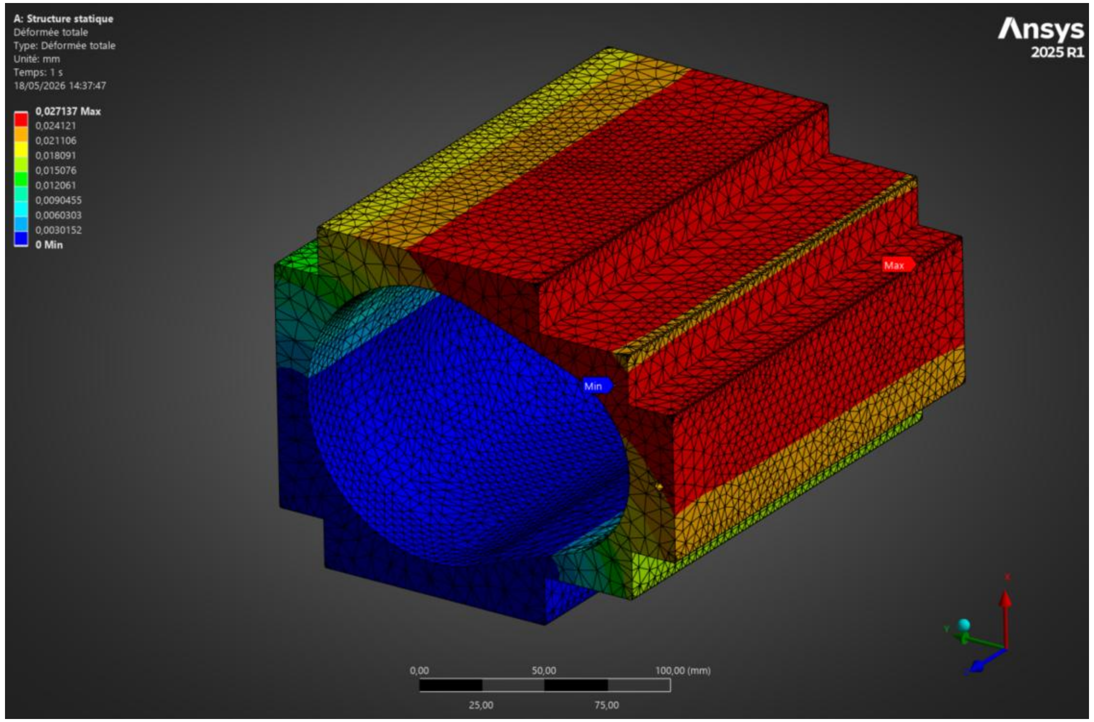
Distribution of the mass on the internal structure



Boundary conditions for the ANSYS FEA (displacement in X for the bottom plane = 0)

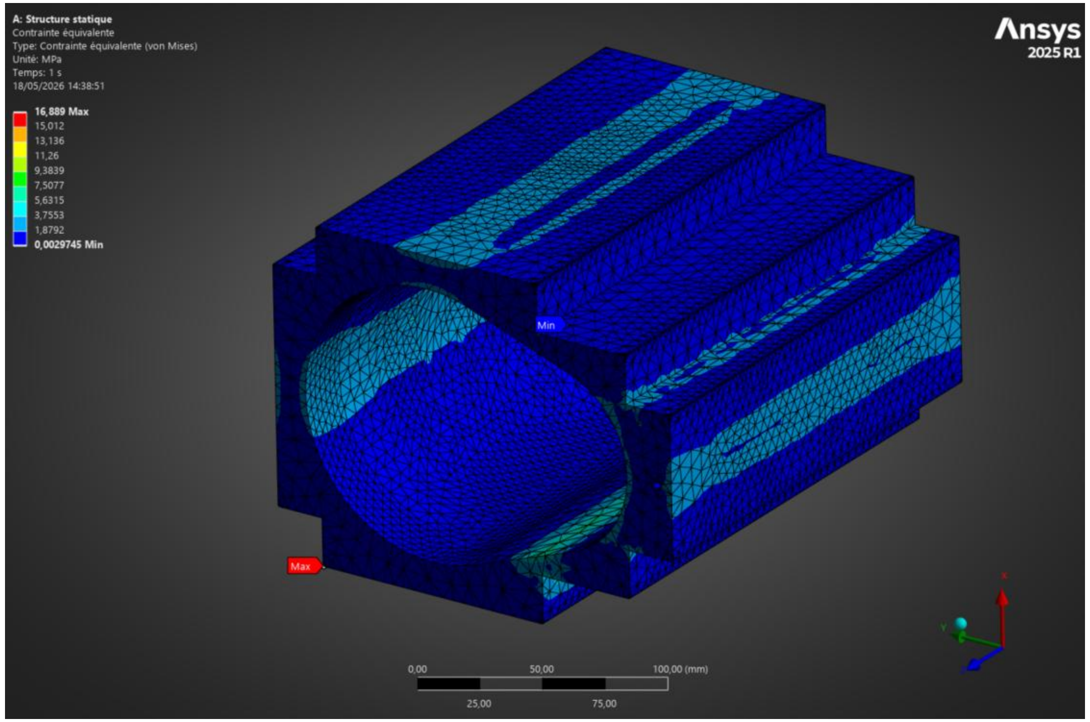
Design validation (Internal structure)

Mechanical simulations: deformation, stress



A: Structure statique
Déformée totale
Type: Déformée totale
Unité: mm
Temps: 1 s
18/05/2026 14:37:47

Deflection < 0,03 mm



A: Structure statique
Contrainte équivalente
Type: Contrainte équivalente (von Mises)
Unité: MPa
Temps: 1 s
18/05/2026 14:38:51

Stress < 17 Mpa

Requirements (Temperature)

Temperature stability and cooling constraints

❑ Experimental hall (based on RHIC/STAR):

- The amplitude of the temperature variations in the experimental hall → ΔT= 3°C
- The frequency/period of the temperature variations in the experimental hall → 6 hours < T < 12 hours

❑ Temperature stability for the crystals:

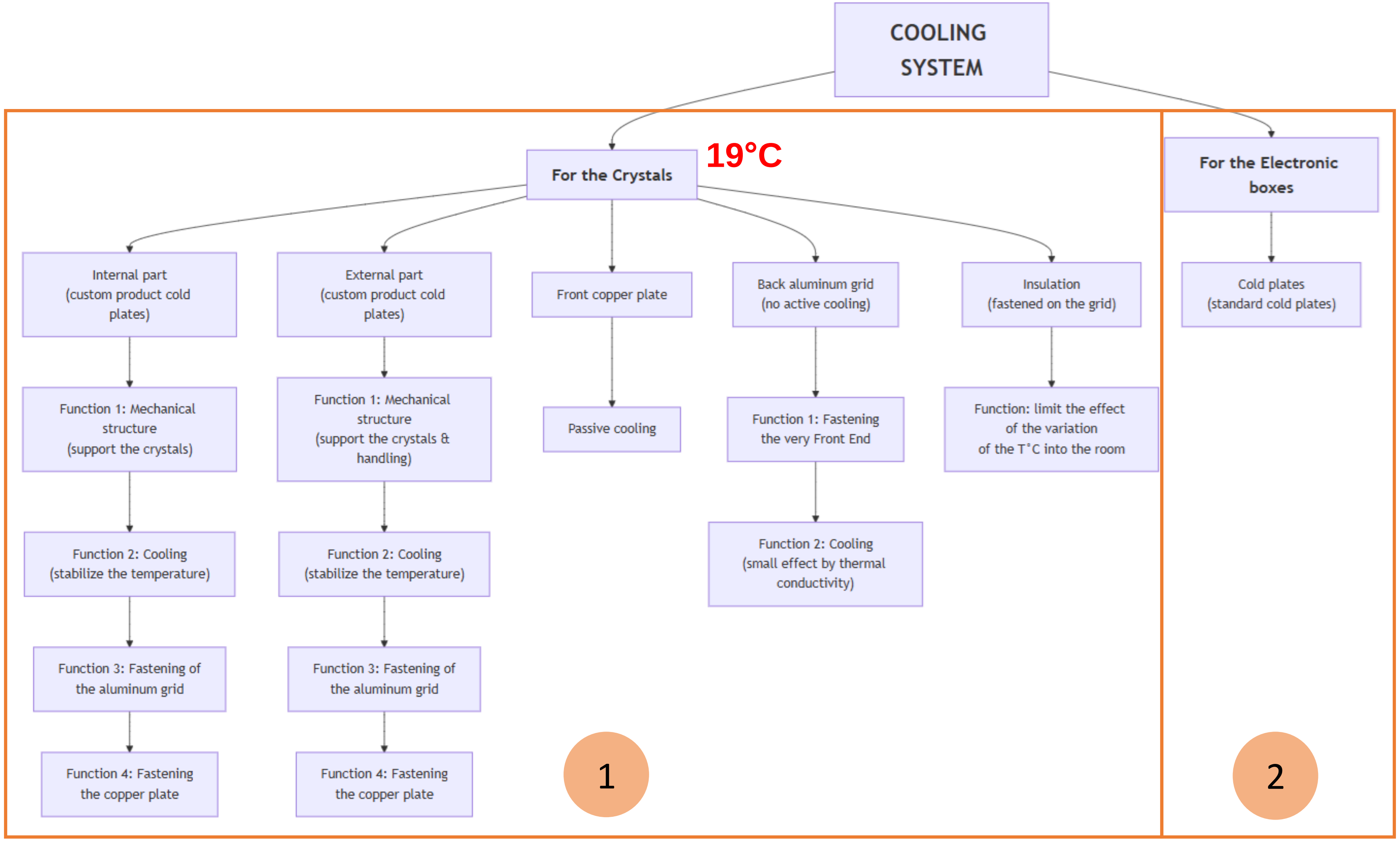
- +/- 0.1°C @ 1 σ

❑ Power of the electronics to dissipate:

- Not in front of the crystals
- ≈ 350 W

Requirements (Cooling)

Support and services: cooling scheme and front-end electronics location



- COOLING SYSTEM
  - For the Crystals — 19°C
    - Internal part (custom product cold plates)
      - Function 1: Mechanical structure (support the crystals)
      - Function 2: Cooling (stabilize the temperature)
      - Function 3: Fastening of the aluminum grid
      - Function 4: Fastening the copper plate
    - External part (custom product cold plates)
      - Function 1: Mechanical structure (support the crystals & handling)
      - Function 2: Cooling (stabilize the temperature)
      - Function 3: Fastening of the aluminum grid
      - Function 4: Fastening the copper plate
    - Front copper plate
      - Passive cooling
    - Back aluminum grid (no active cooling)
      - Function 1: Fastening the very Front End
      - Function 2: Cooling (small effect by thermal conductivity)
    - Insulation (fastened on the grid)
      - Function: limit the effect of the variation of the T°C into the room
  - For the Electronic boxes
    - Cold plates (standard cold plates)

❑ Pressure drop

- Cooling system at the same level to reduce the gravitationnel losses
- Pressure drop = 2,5 bars

❑ Galvanic corrosion

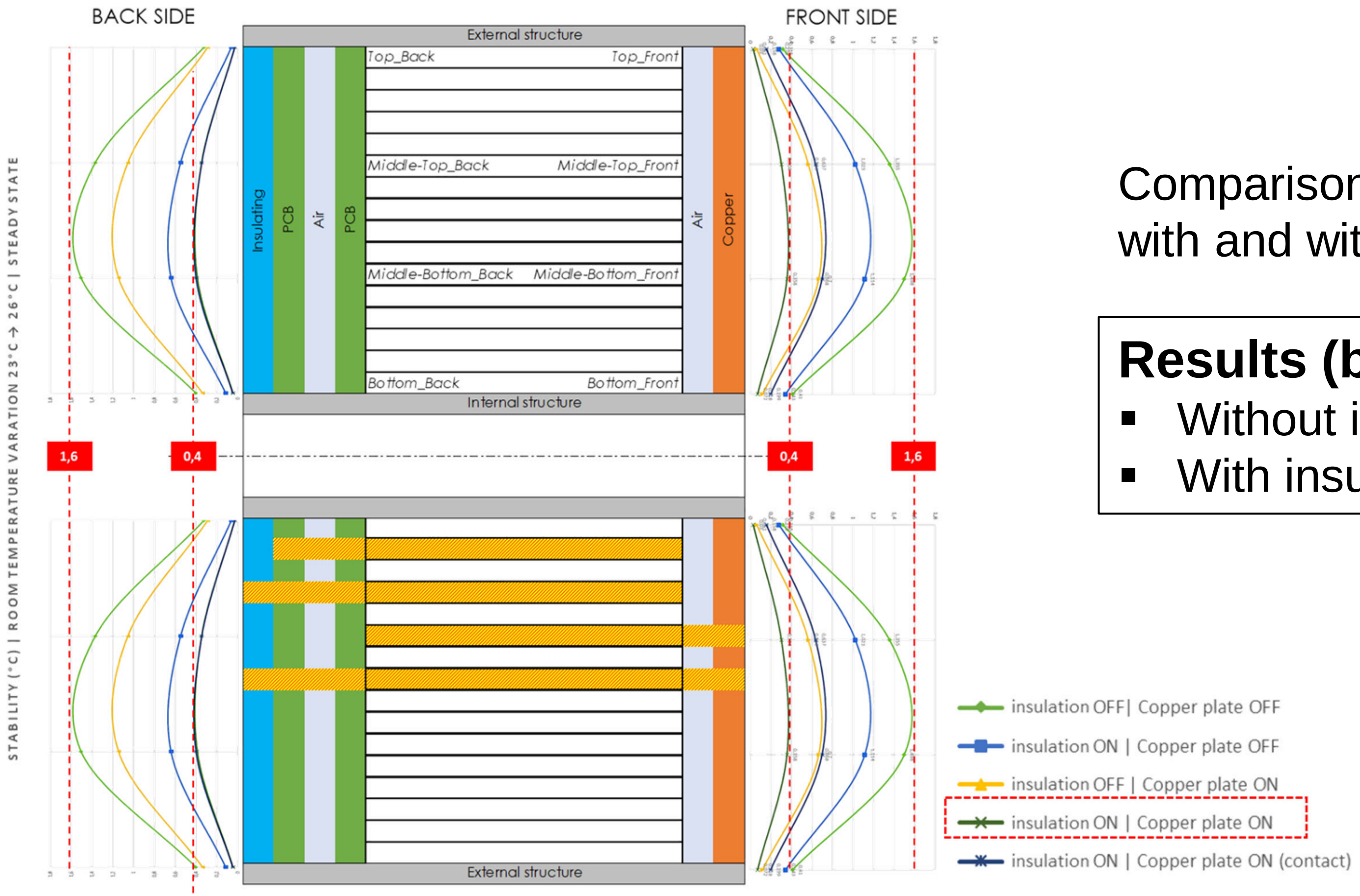
- No copper for the cooling system « For the crystals »
- Use Aluminum

❑ Leak less system

- To reduce risks for electronics
- Reduce the need for maintenance

Design validation (Cooling system crystals)

Thermal simulations: temperature gradients and cooling performance



Summary of the different configurations tested

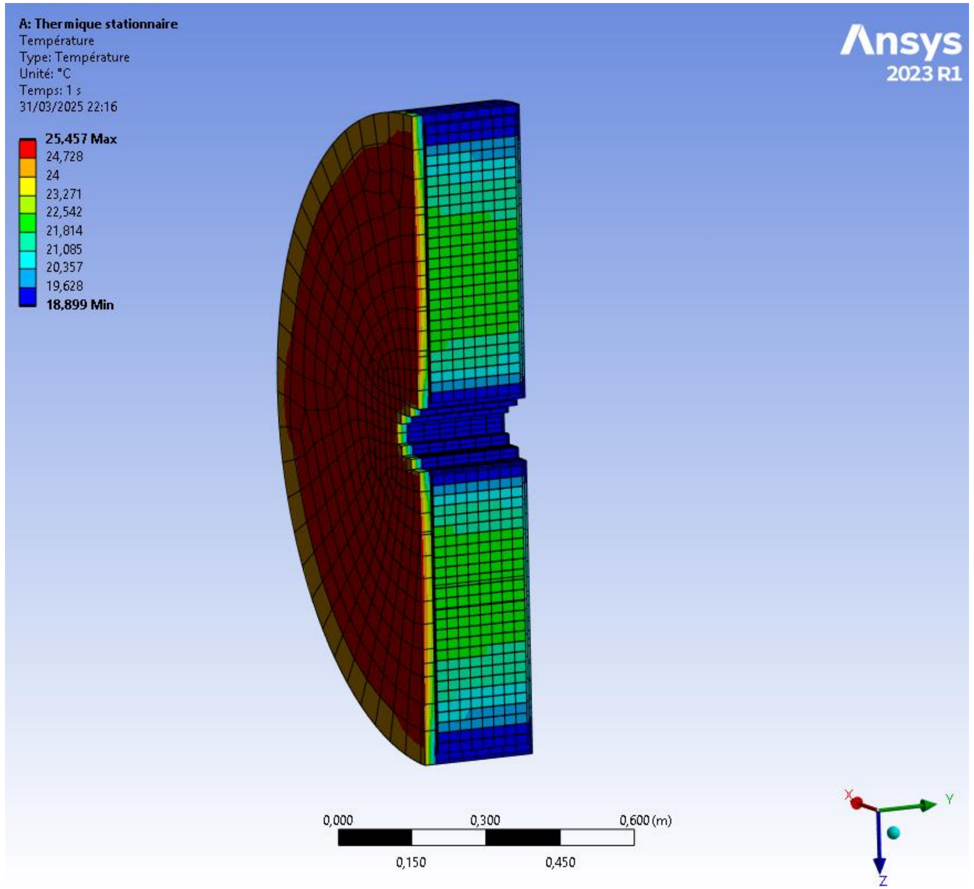
Comparison between **two steady states** (23°C and 26°C) with and without insulation

Results (between 23°C & 26°C):

- Without insulation: Difference = **1,6°C**
- With insulation (foam, air, copper): Difference = **0,4°C**

Design validation (Cooling system crystals)

Thermal simulations: temperature gradients and cooling performance



Case: Room temperature = 26°C with insulation

Hypotheses

- Electronics all around the calorimeter, not in front of the crystals
- Power of the other detectors totally dissipated
- pfRICH estimated power = 700 W

Boundary conditions

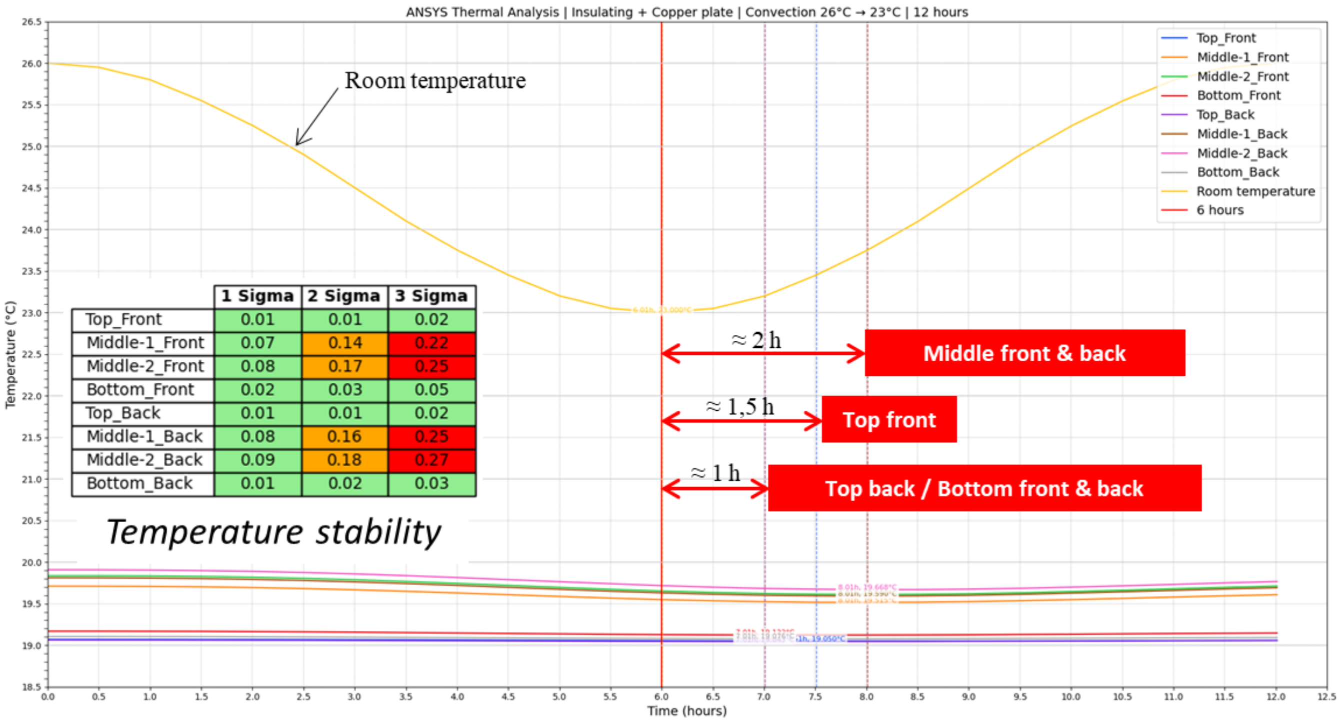
- Temperature on the external structure & internal structure = 19 °C
- Convection on all faces (stagnant air, simplified case) with Temperature = 26 °C

Results steady state :

- Gradient = **4°C**

Design validation (Cooling system crystals)

Thermal simulations: temperature gradients and cooling performance



	1 Sigma	2 Sigma	3 Sigma
Top_Front	0.01	0.01	0.02
Middle-1_Front	0.07	0.14	0.22
Middle-2_Front	0.08	0.17	0.25
Bottom_Front	0.02	0.03	0.05
Top_Back	0.01	0.01	0.02
Middle-1_Back	0.08	0.16	0.25
Middle-2_Back	0.09	0.18	0.27
Bottom_Back	0.01	0.02	0.03

Temperature stability

Evolution of the temperature for a variation of the room temperature from 26°C to 23°C in 6 hours and 23°C to 26°C in 6 hours

Hypotheses

- 3°C of variation in 6 hours
- With insulation
- No electronics in front of the crystals

Results transient state (stability):

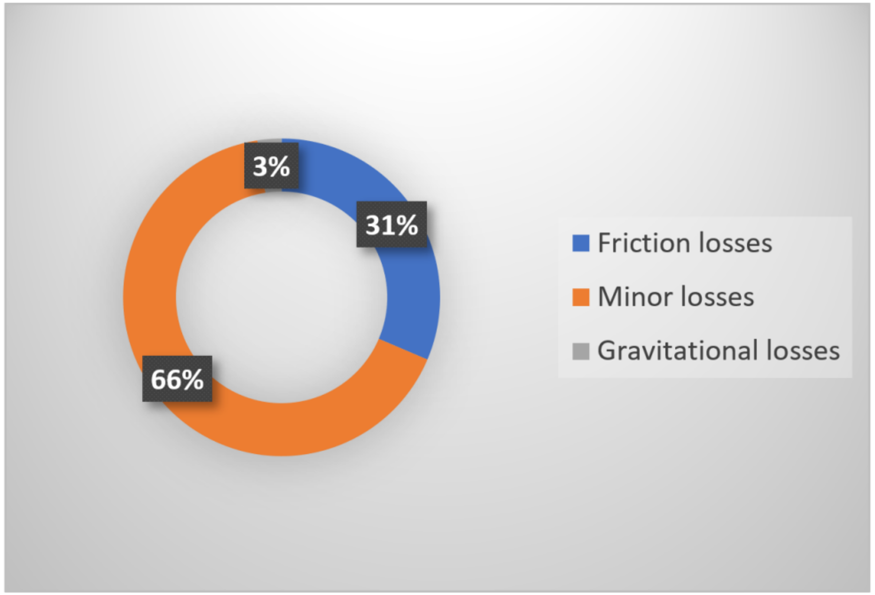
- ΔT (stability at 1 σ) < 0,1°C
- 1 hour < Shift (inertia) < 2 hours
- In the same range as the NPS experiment (Jlab, 1000 PWO crystals)

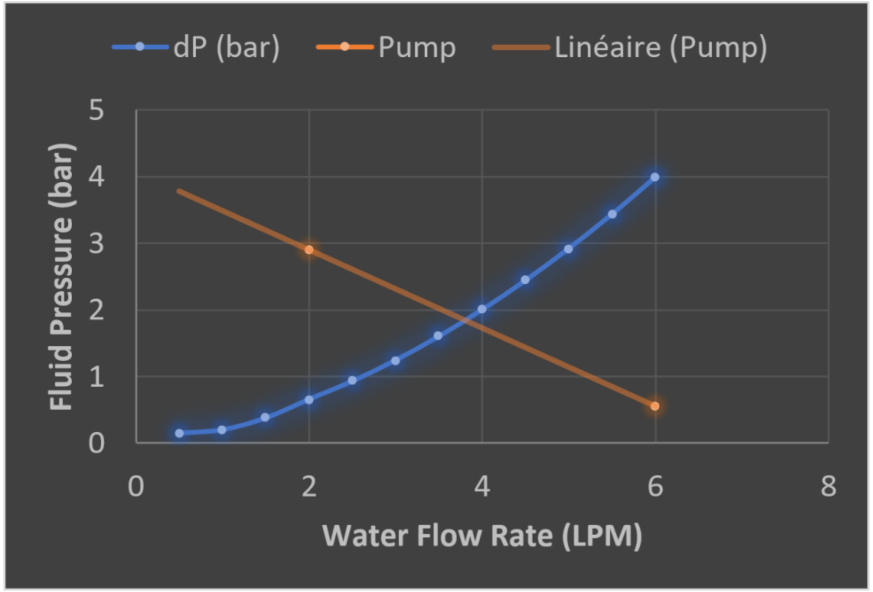
Design validation (Cooling system crystals)

Thermal simulations: temperature gradients and cooling performance

System

- Dedicated cooling system → because of the 0,1°C stability required for the crystals
- Leak less and Aluminum compatible
- « Novec » like





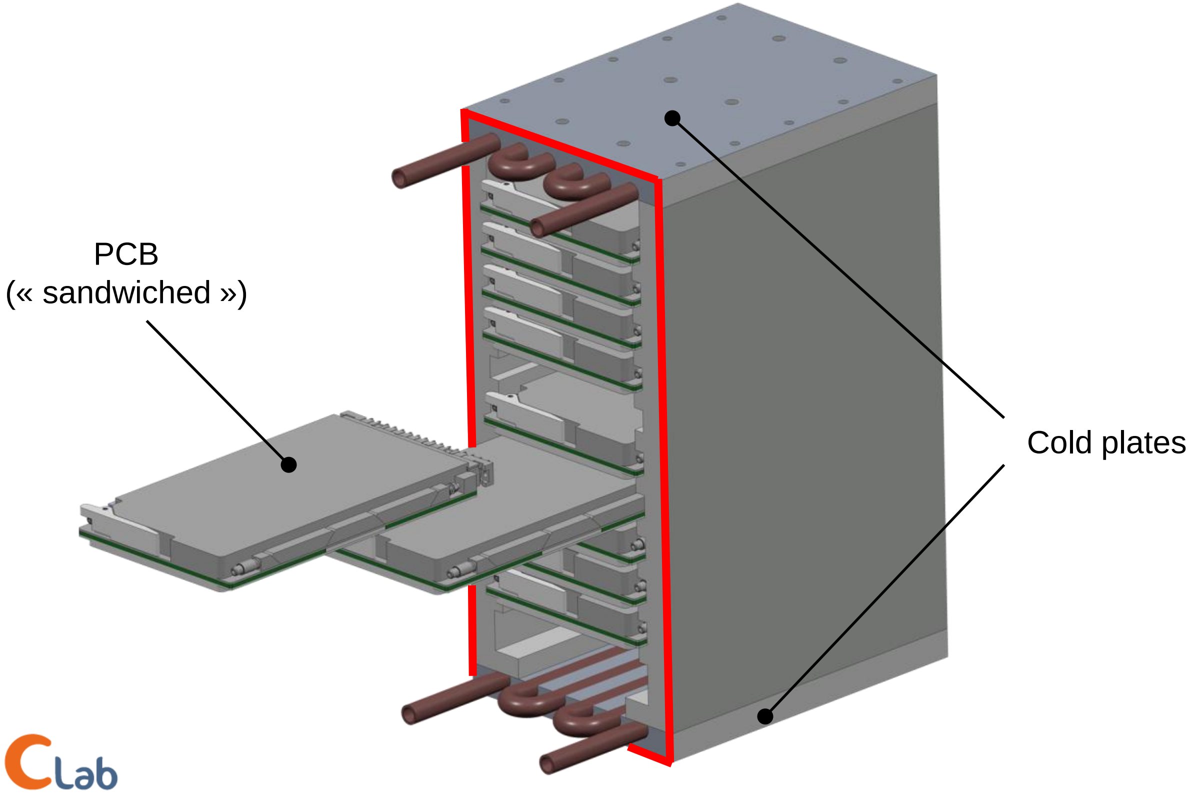
Most of the pressure drop come from minor losses. The pressure drop is around 2 bar (+ 0,5 bar) with the internal structure

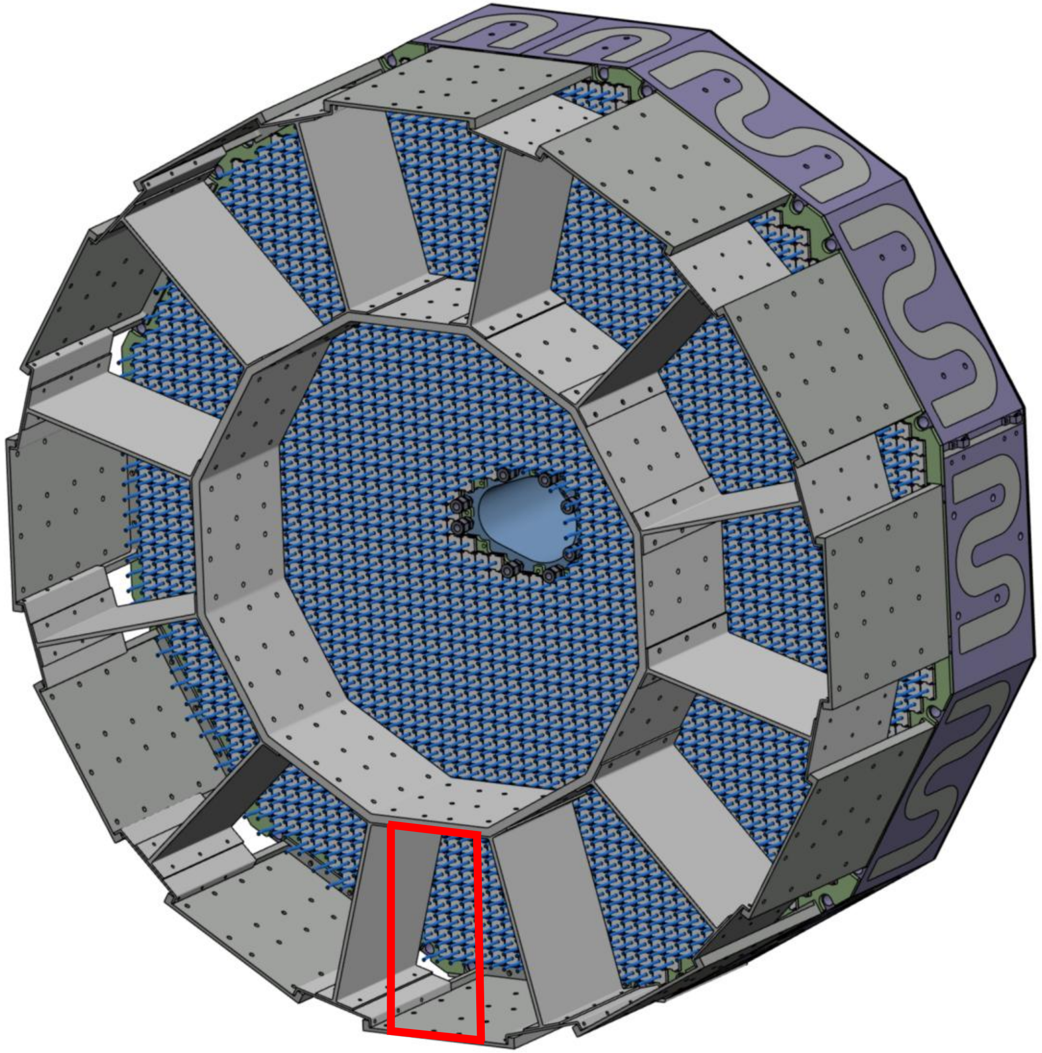
Design validation (Cooling electronics)

Thermal simulations: temperature gradients and cooling performance

Total power = 350 W (12 blocks)

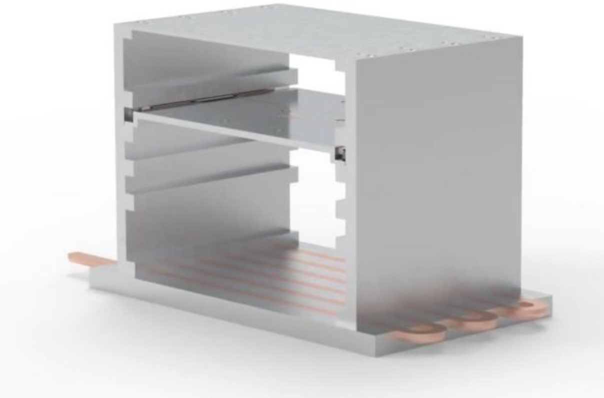
- 1 block ≈ 30 W (10 PCB)
- 1 PCB ≈ 3W (24 Channels x 120 mW)
- Size = 18 cm x 12 cm

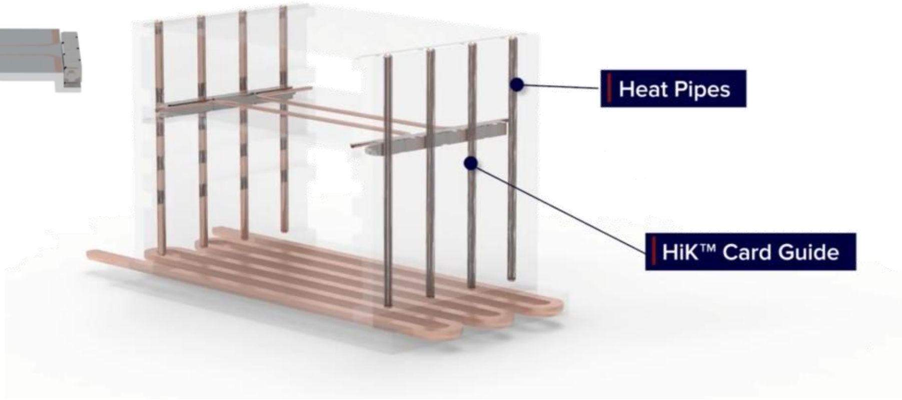




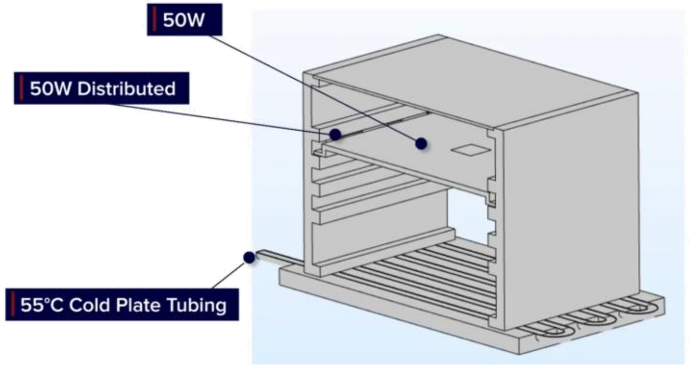
Design validation (Cooling electronics)

Thermal simulations: temperature gradients and cooling performance / Wedgelock datasheet

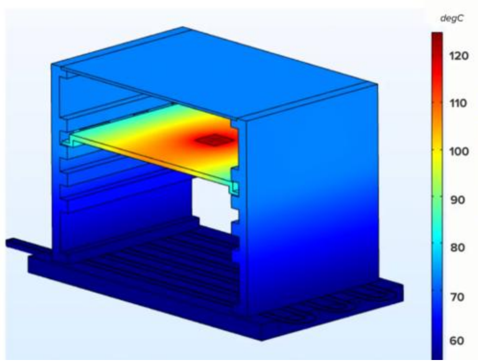




BOUNDARY CONDITIONS

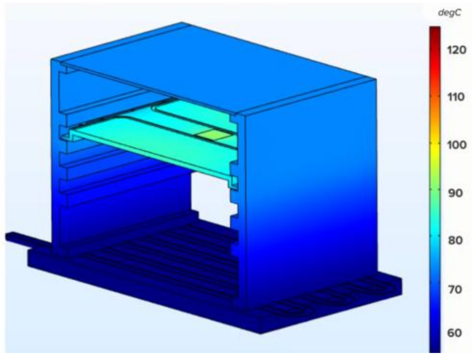


NORMAL CHASSIS WITH NORMAL CARD AND COTS WEDGELOCK



ITEM	TEMPERATURE(°C)
Cold Plate	55
Card Max	124
Total Delta T	69

NORMAL CHASSIS WITH HIK™ CARD AND ICE-LOK™



ITEM	TEMPERATURE(°C)	BASE TEMP
Cold Plate	55	55
Card Max	92	124
Total Delta T	37	69

Design validation (Cooling electronics)

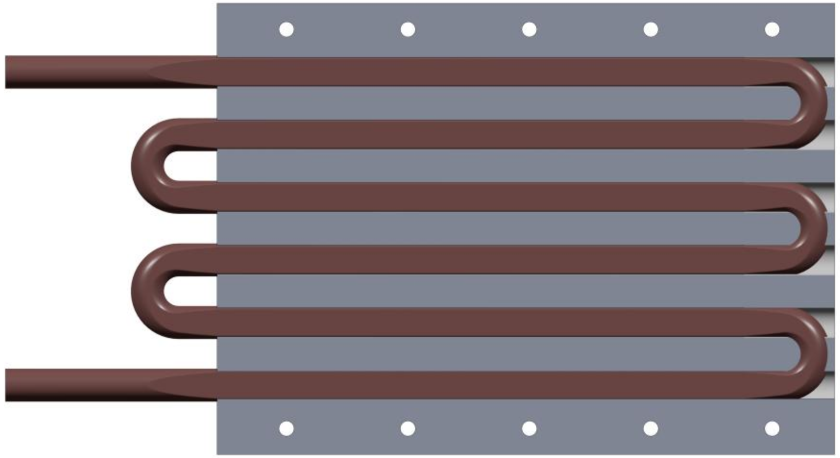
Thermal simulations: temperature gradients and cooling performance

System

- BNL global cooling system unit
- Not specific temperature stability required
- Compatible with copper tubes

Drop pressure (2,5 bars max)

- 12 blocks → 24 cold plates
- **Cold plate:**
  - 5 « U-turn »
  - 6 lines 20 cm = 120 cm
  - 5 bends 180°
  - Diameter of the copper tube = 8 mm
- **Between each cold plates:**
  - 22 bends 90°
  - Copper tube = 2 x 11 x 20 cm ≈ 5 m
- **From the cooling system to the detector:**
  - Length ≈ 5 m

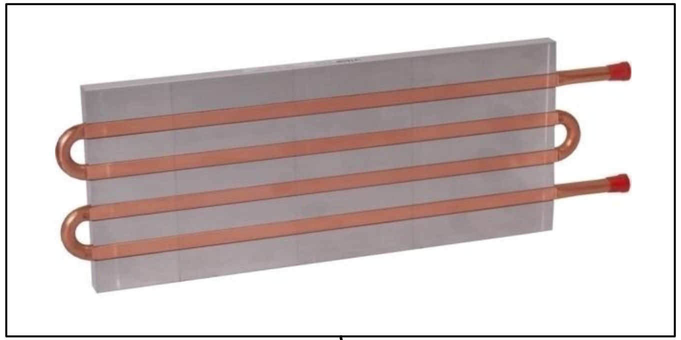


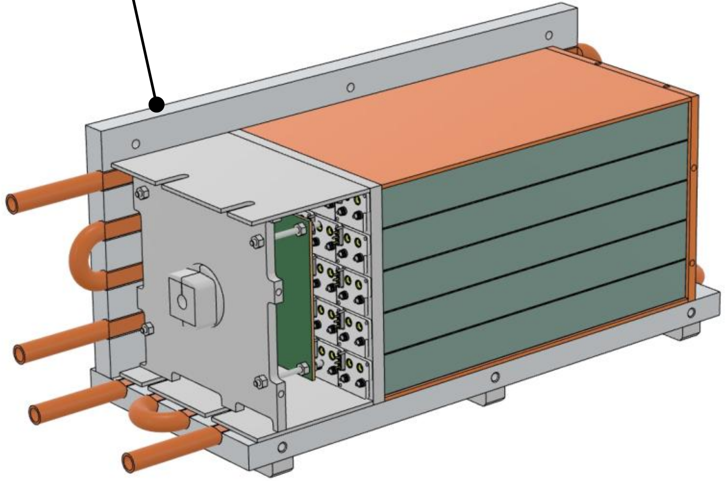
Two cold plates per blocks

Design validation (Prototype 5x5)

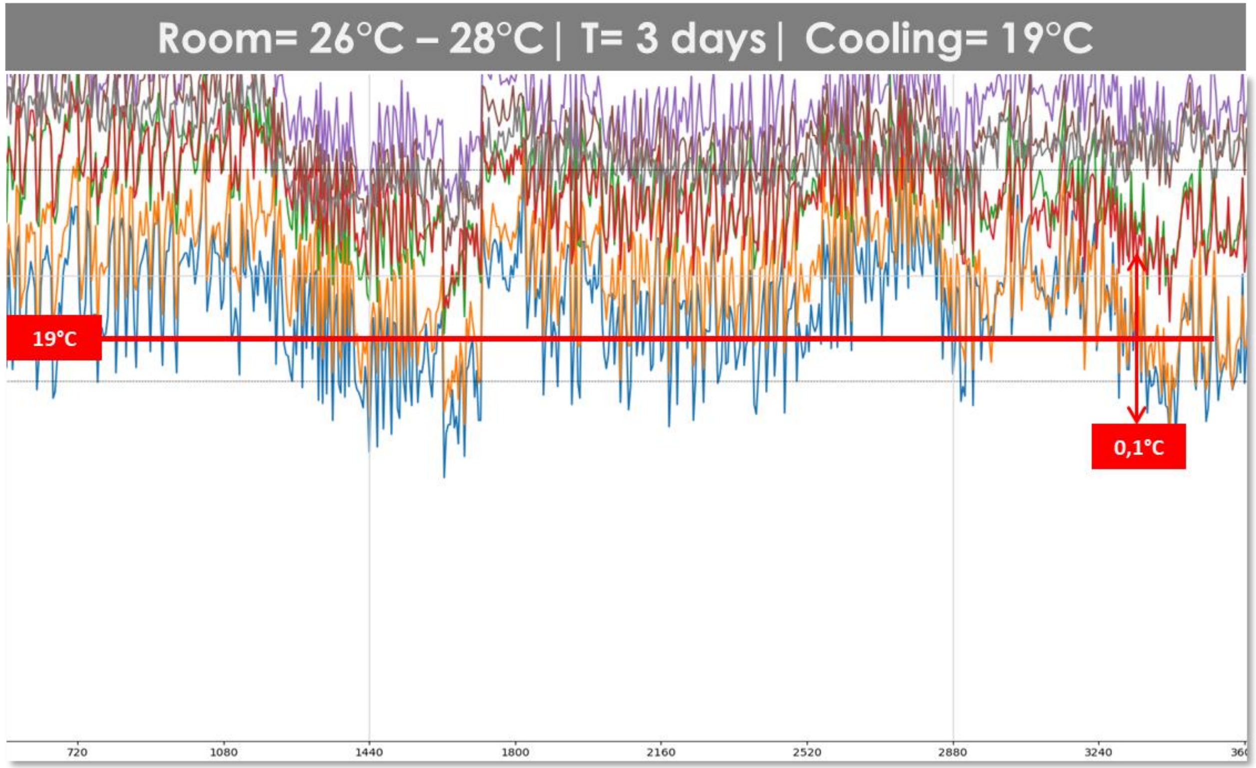
Prototype tests (modules, cooling, mechanics)

4 standard cold plates





Assembly with 25 crystals



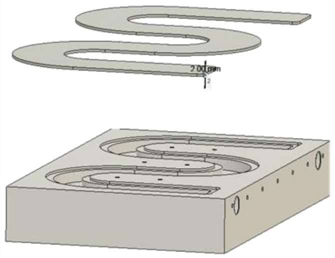
Evolution of the temperature of the crystals during the beam test at CERN

Beam test @ CERN (26 °C < T < 28°C):

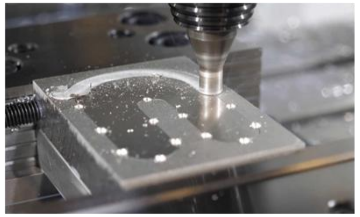
Temperature stability under +/- 0,1°C

Design validation (Prototypes FSW)

Prototype tests (modules, cooling, mechanics)

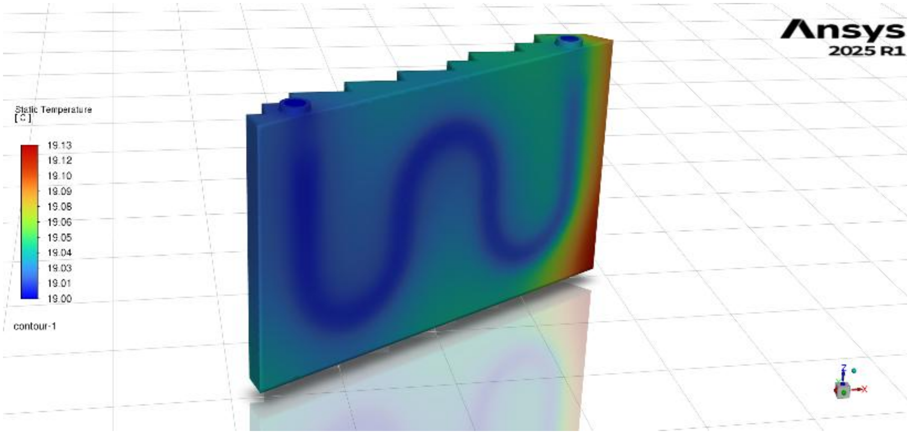


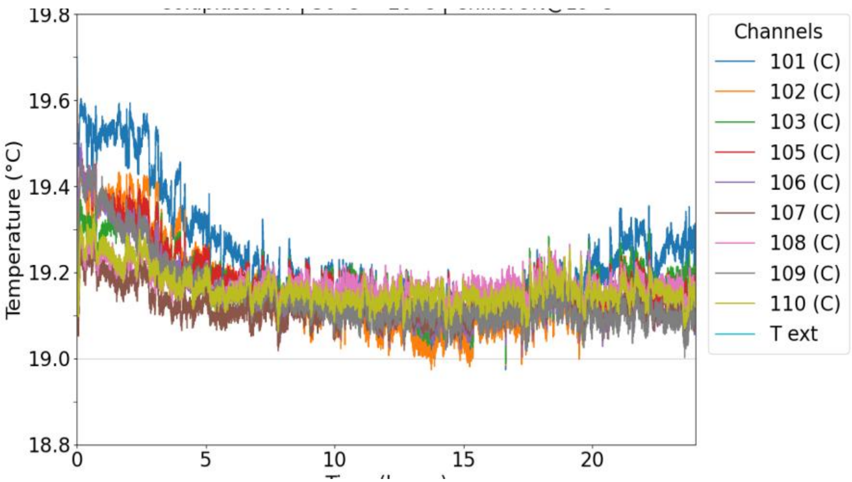
Raw bloc machined



FSW

Dimensional inspection
→ OK (< 0,1 mm)



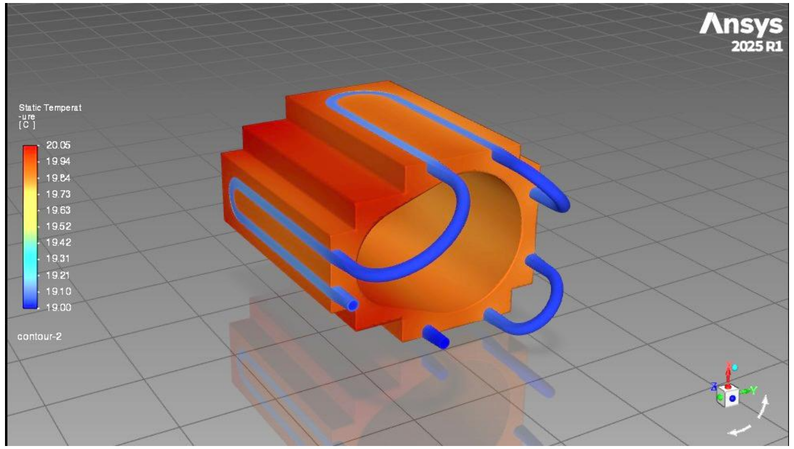


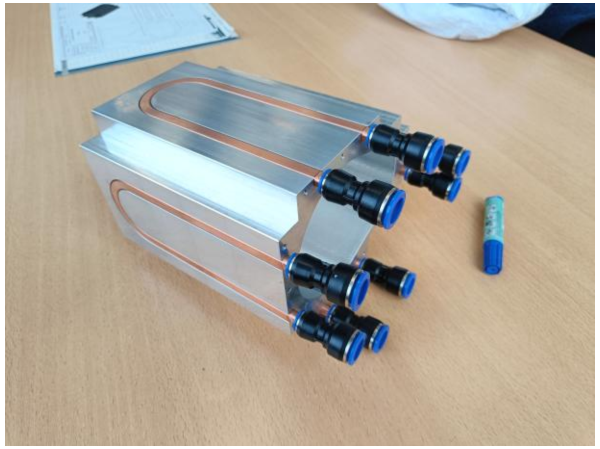
Results

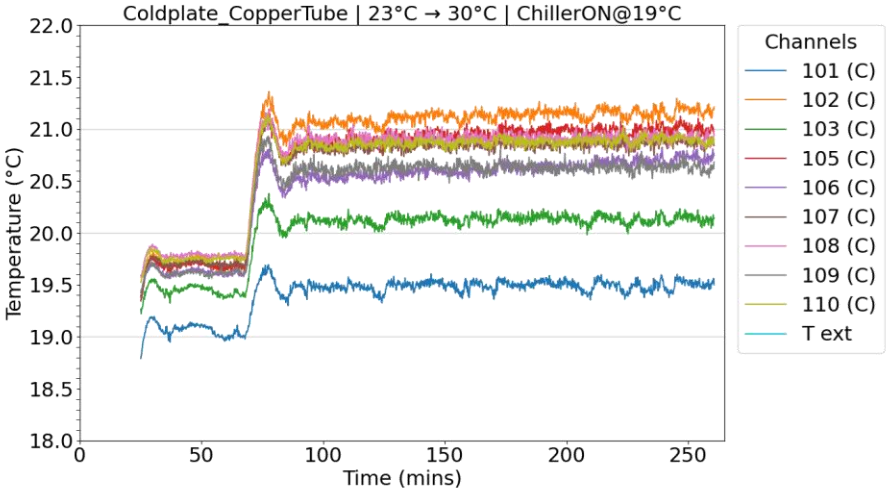
The measured temperature stability met the design requirement of **± 0.1 °C**.

Design validation (Prototype copper tubes)

Prototype tests (modules, cooling, mechanics)

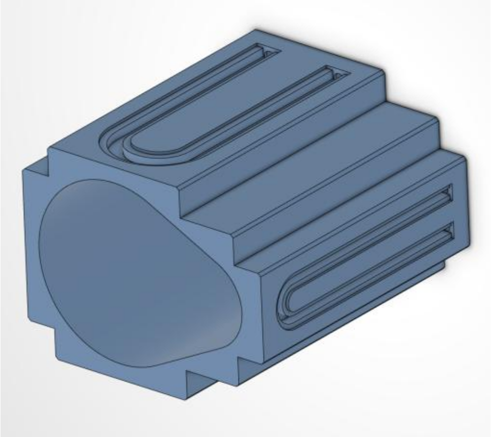






Results

- Material between copper and alumimun unknown
- Gradiant on the structure could be reduced
- Stability with a rapid variation of the temperature into the room ≈ 0,5 °C
- Stability when the temperature into the room still stable ≈ 0,1 °C

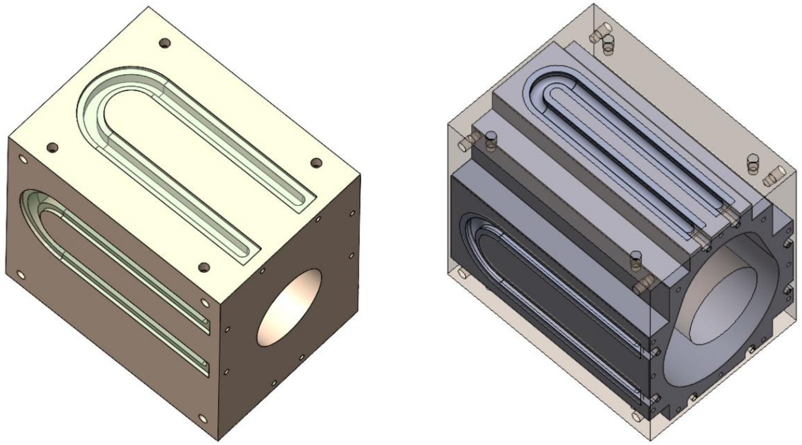


New design in 3D printing or FSW

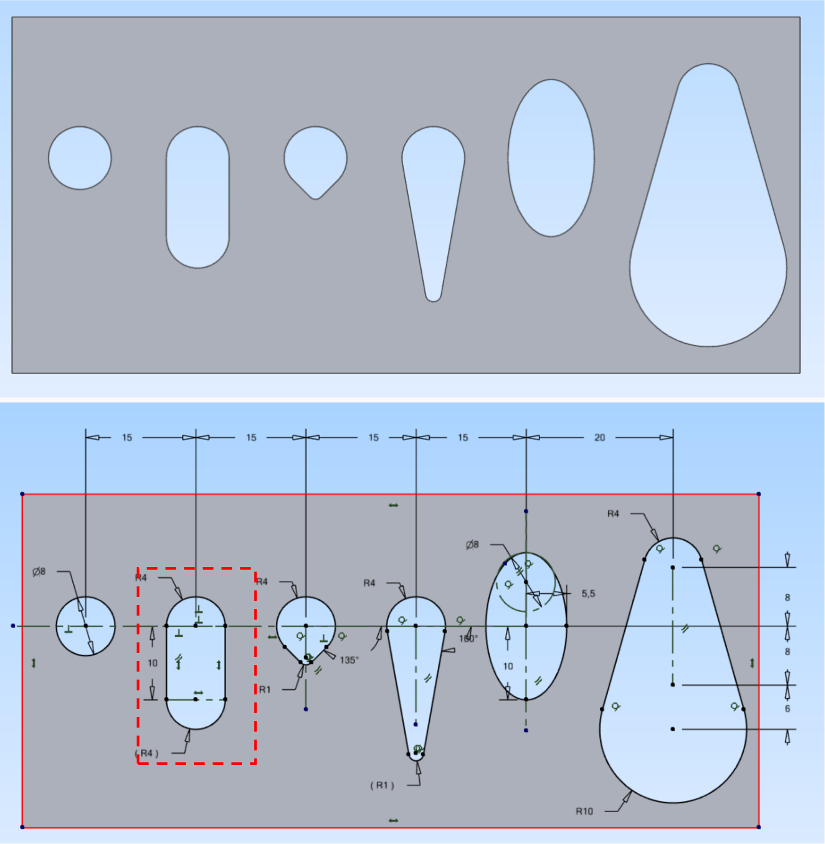
Production & procurement (Internal structure)

Production capacity, delivery assumptions and industrial feasibility

Stirweld company (FSW) or AFU (3D printing):



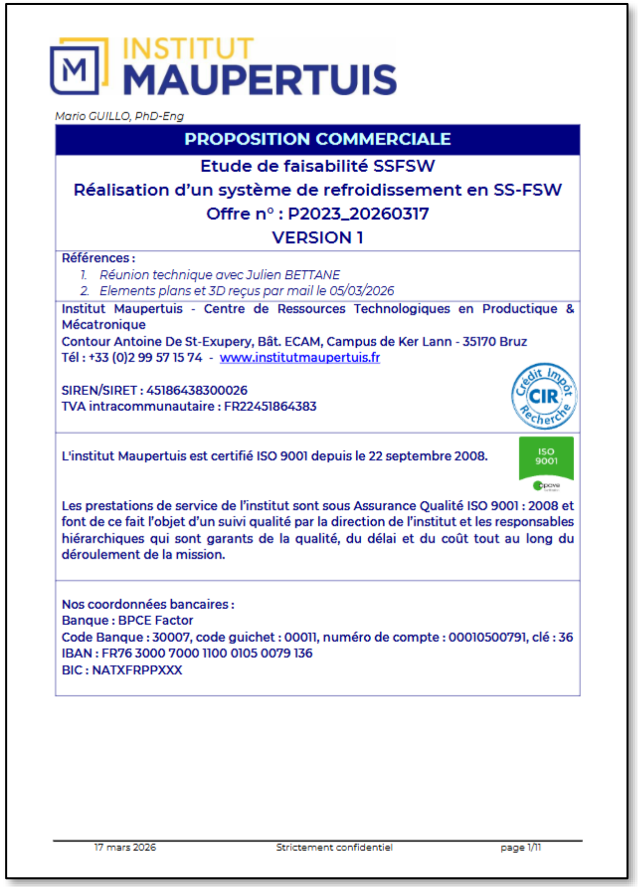
Option without copper tubes. Using FSW technology or 3D printing



Current optimization for the shape of the canal of the internal structure with the company

Production & procurement (External structure)

Production capacity, delivery assumptions and industrial feasibility



INSTITUT MAUPERTUIS

Mario GUILLO, PhD-Eng

PROPOSITION COMMERCIALE

Etude de faisabilité SSFSW
Réalisation d'un système de refroidissement en SS-FSW
Offre n° : P2023_20260317
VERSION 1

Références :

1. *Réunion technique avec Julien BETTANE*
2. *Elements plans et 3D reçus par mail le 05/03/2026*

Institut Maupertuis - Centre de Ressources Technologiques en Productique & Mécatronique
Contour Antoine De St-Exupery, Bât. ECAM, Campus de Ker Lann - 35170 Bruz
Tél : +33 (0)2 99 57 15 74 - www.institutmaupertuis.fr

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TVA intracommunautaire : FR22451864383

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Les prestations de service de l'institut sont sous Assurance Qualité ISO 9001 : 2008 et font de ce fait l'objet d'un suivi qualité par la direction de l'institut et les responsables hiérarchiques qui sont garants de la qualité, du délai et du coût tout au long du déroulement de la mission.

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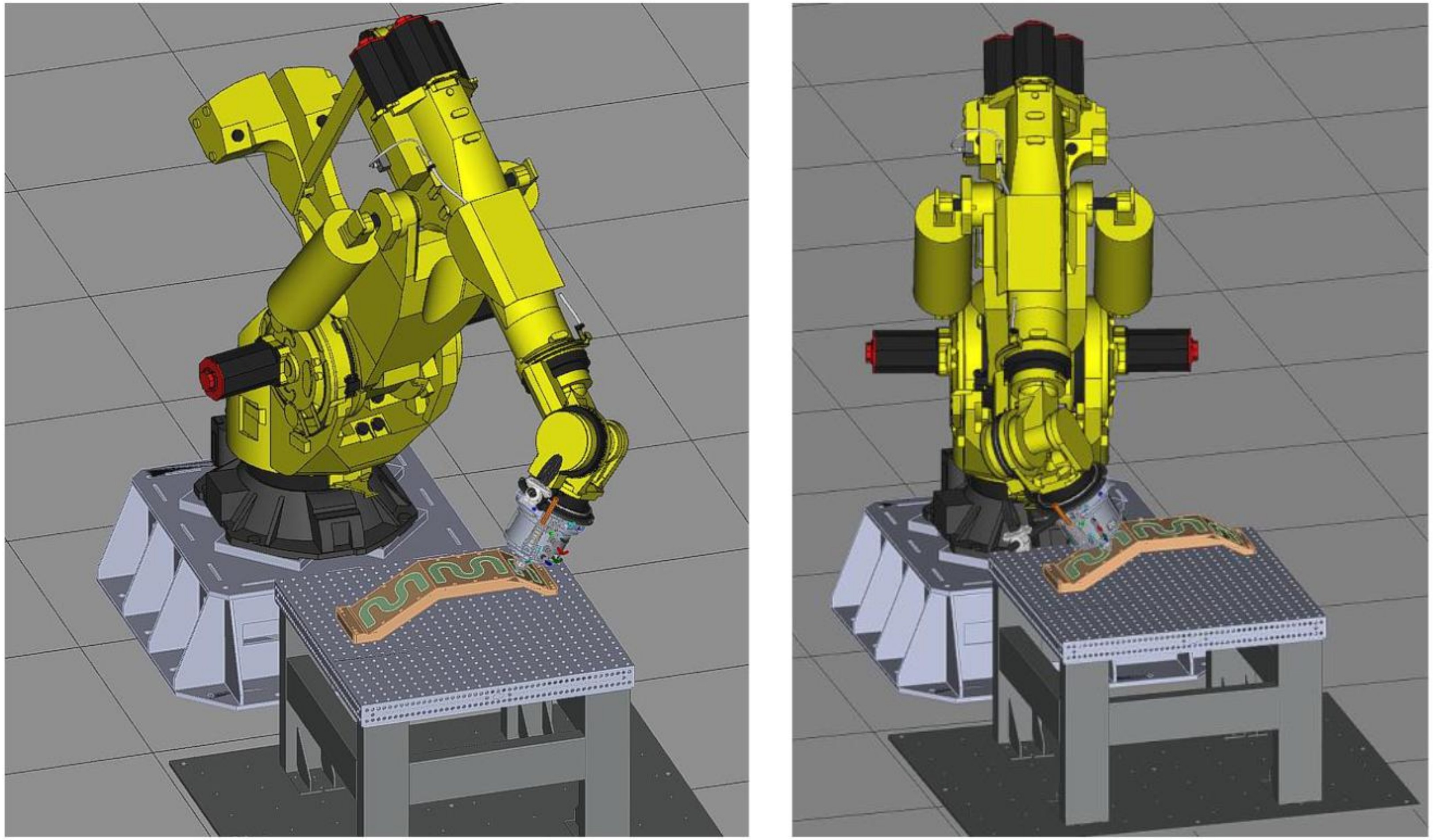
BIC : NATXFRPPXXX

17 mars 2026 Strictement confidentiel page 1/11

POC and quote received



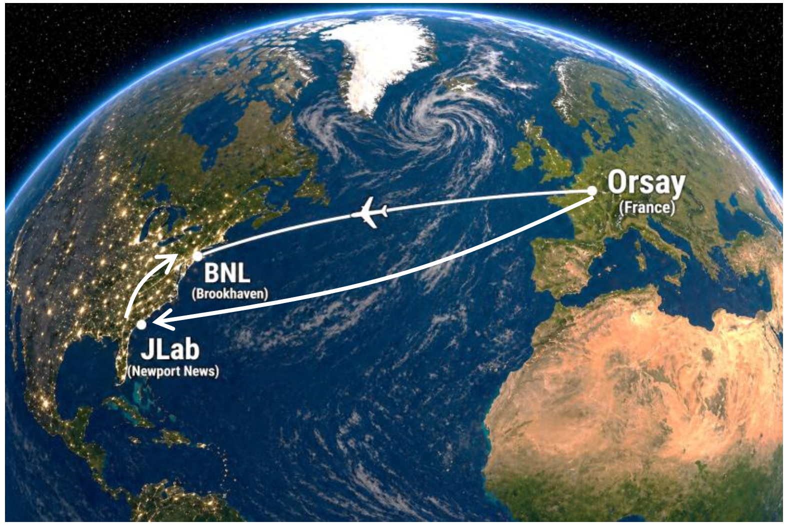
Robot for the FSW

Production & procurement

Packaging for shipment to the US (JLab/BNL), with coordination for reception and integration

Preparatory work (France)

- Mechanical tests with a mockup
- Pre testing of the assembly
- Dimensional control, Validation of the clearances
- Pre assembly of the module sensors + PCB
- Pre assembly of the carbons plates
- Pre-shaping of the wrapping



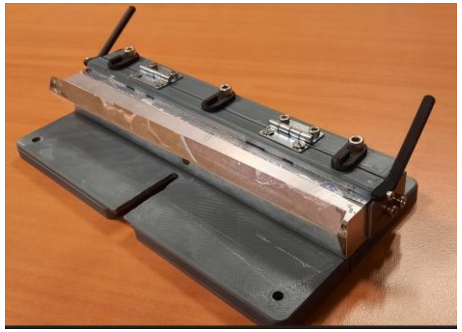
Detector assembly performed at BNL

Fabrication in France and shipped to BNL

- External and internal structures
- Grid and mechanical structure with carbon plates
- Module sensors + PCB

PWO crystals

- Currently being received at JLab (Josh’s talk)
- Crystal wrapping material prepared in France (pre-shaped) and shipped to JLab
- Crystal wrapping made at JLab; wrapped crystals shipped to BNL



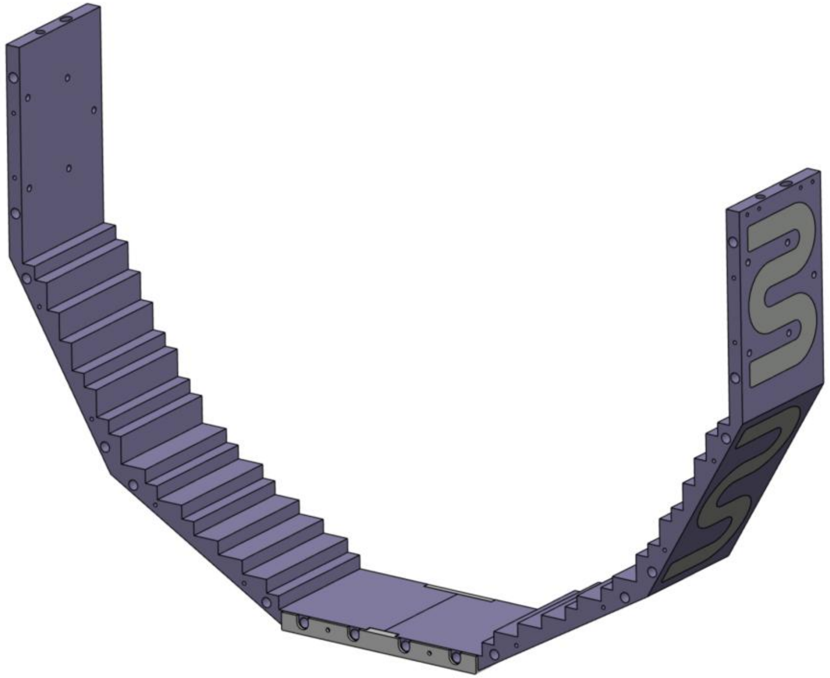
Pre-shaped tooling

Assembly

Assembly sequence of calorimeter modules and required tooling

1 Back side

Assembly of the bottom of the **external structure** with tools (dimensionnal checking)

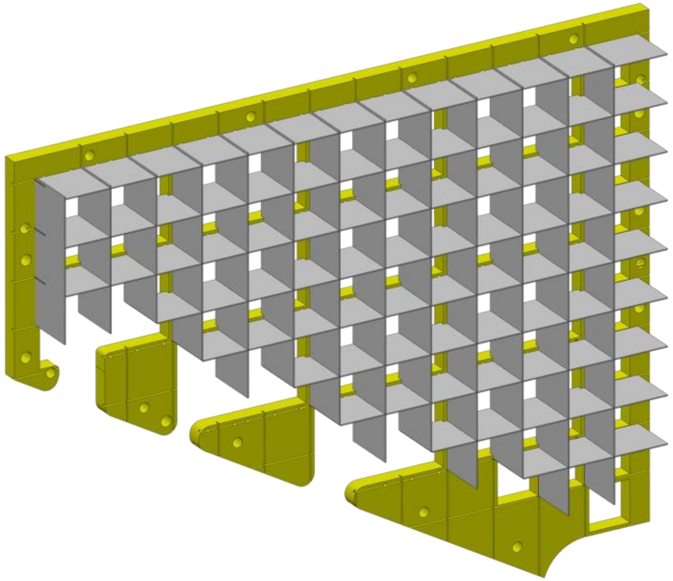


Assembly

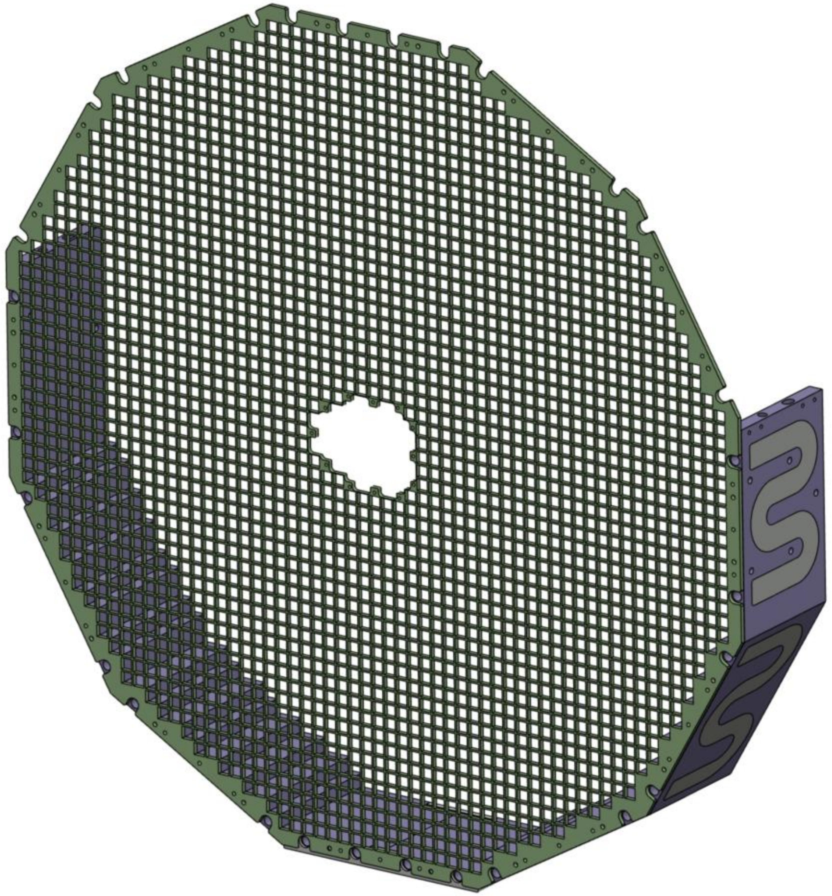
Assembly sequence of calorimeter modules and required tooling

2 **Back side**

Assembly of the **grid** and positioning of the **carbon plates** (with glue)



On marble, pre-assembly of the carbon plates on the grid

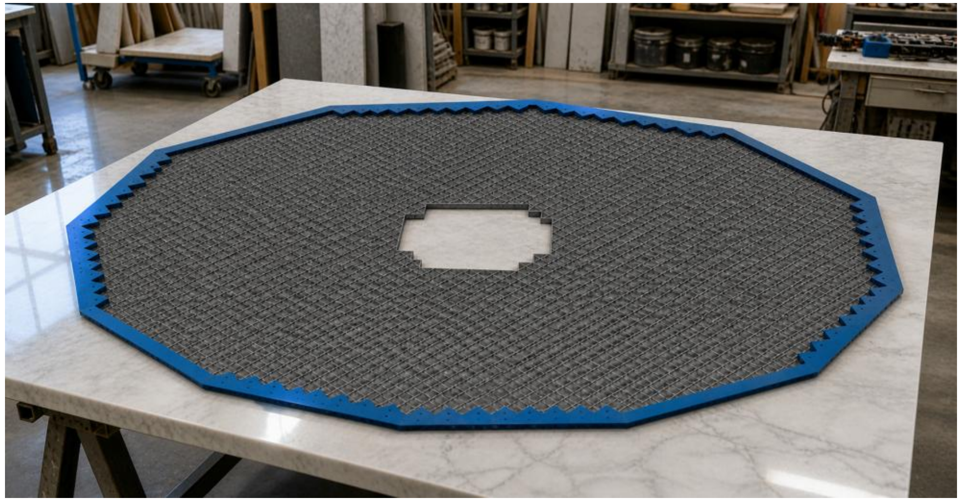


Assembly

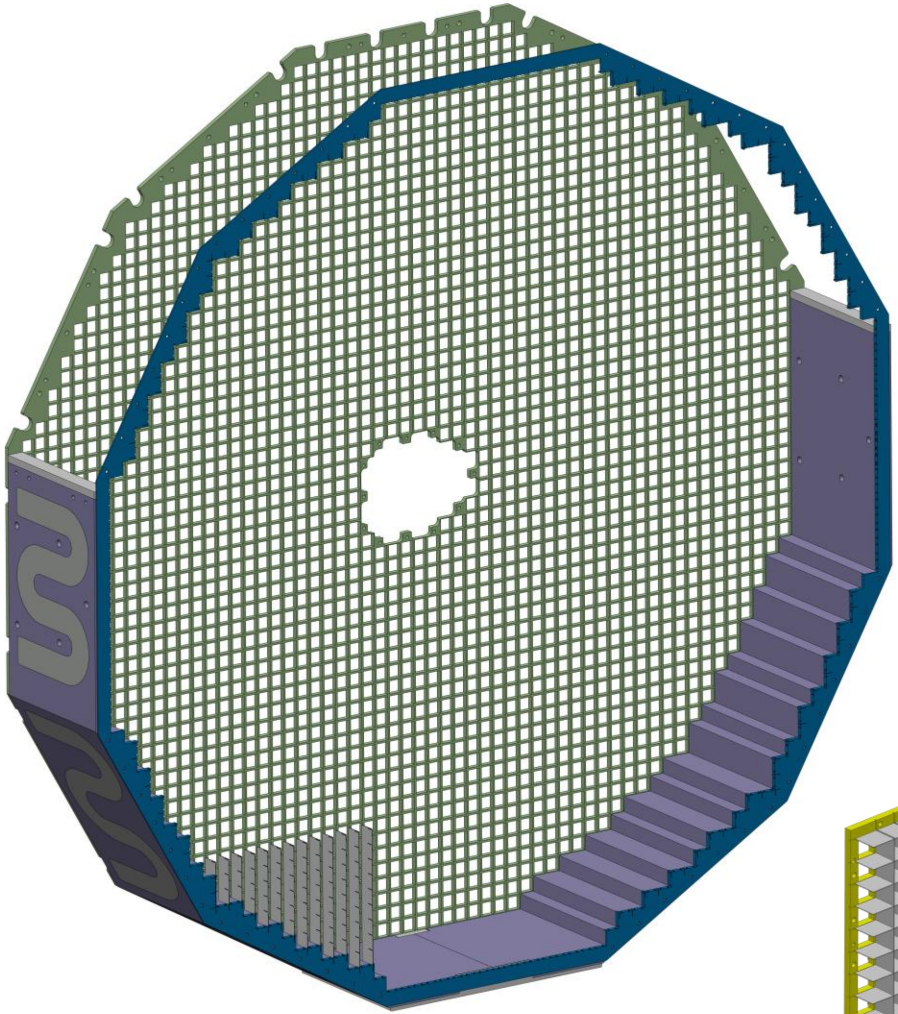
Assembly sequence of calorimeter modules and required tooling

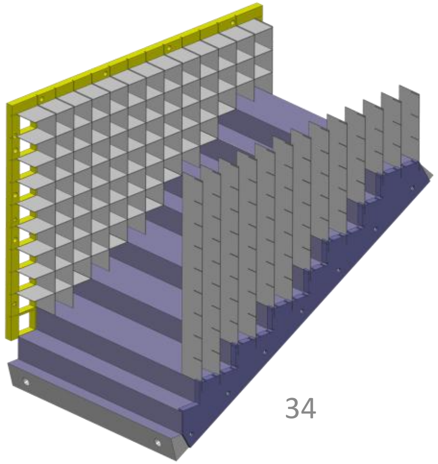
3 **Front side**

Positioning of the **mechanical structure for the carbon plates** (with glue)



*On marble, pre-assembly of the **vertical** carbon plates on the « mechanical structure for the carbon plates »*

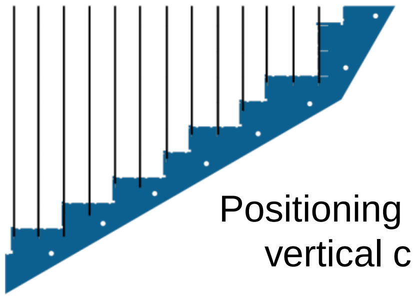




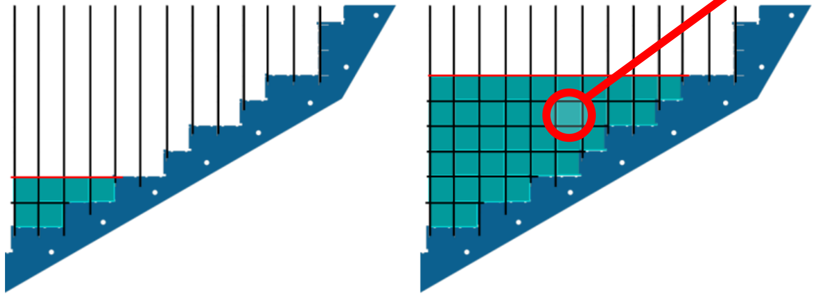
Assembly

Assembly sequence of calorimeter modules and required tooling

4 **Front Side | Stacking sequences**

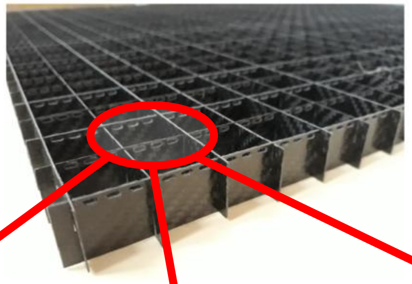


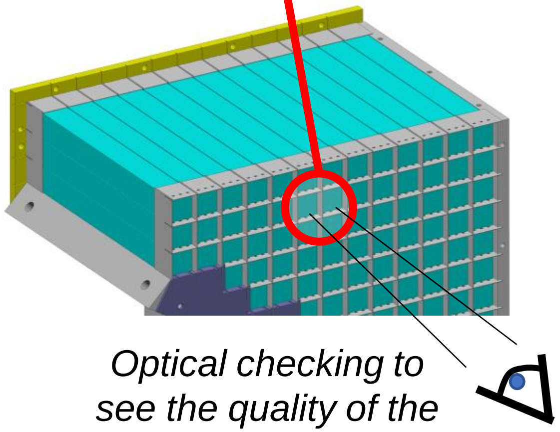
Positioning of the all vertical carbon



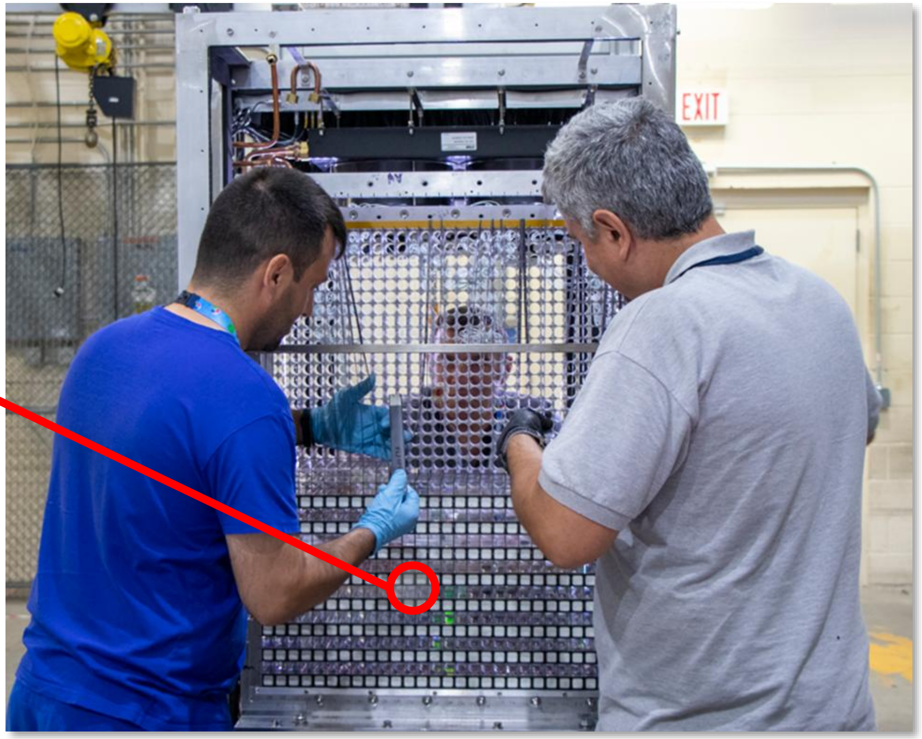
Addition of the horizontal carbon plates at **each** layer (**red line**)

Carbon plates slotted





Optical checking to see the quality of the optical coupling



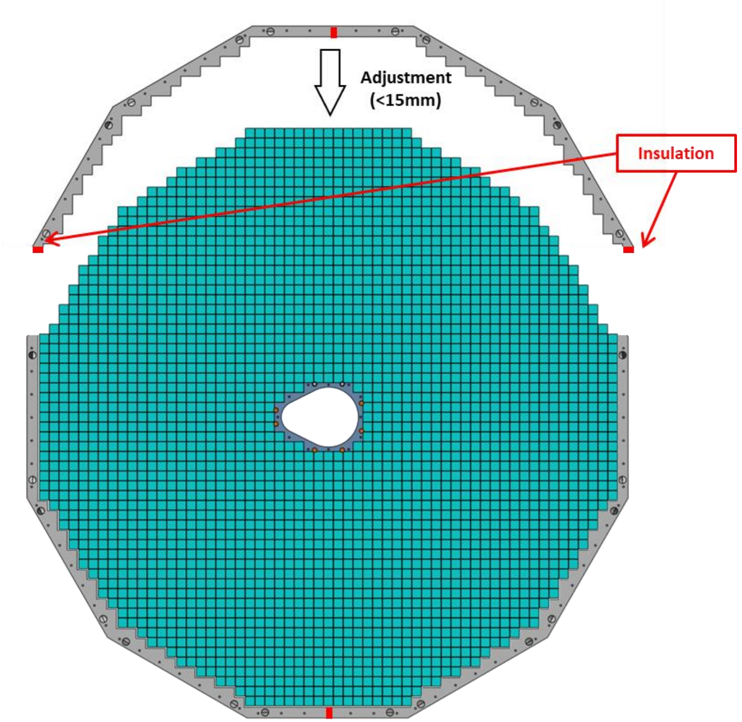
Stacking of previous PWO-based calorimeter (NPS) took 1-2 weeks (1080 crystals)

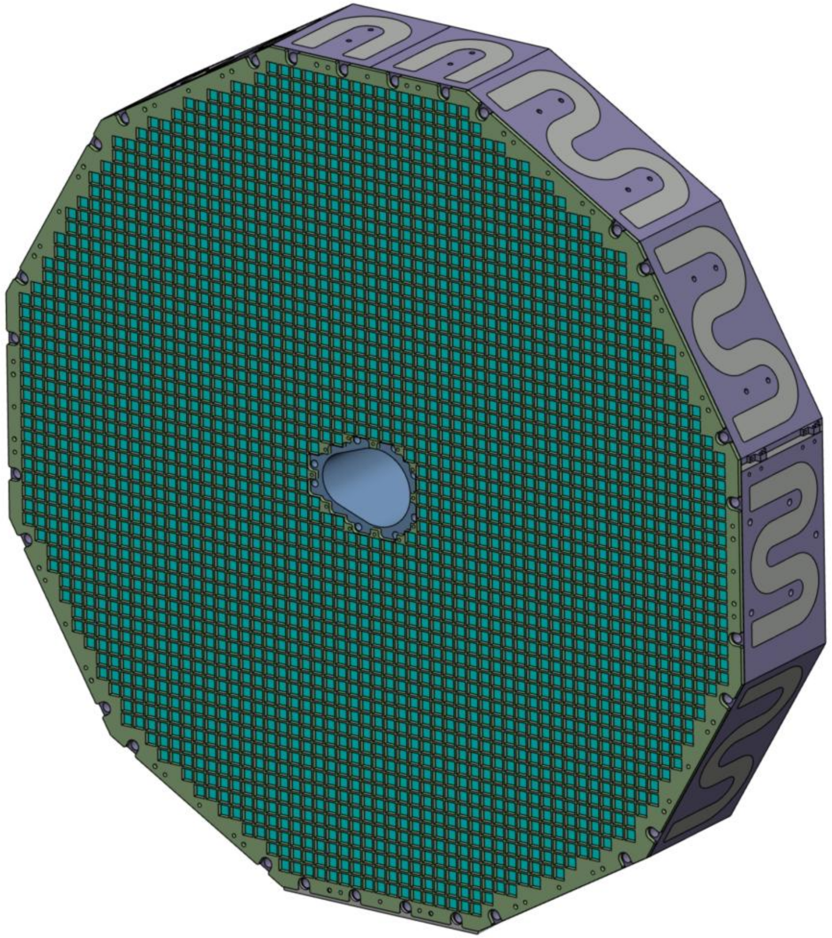
Assembly

Assembly sequence of calorimeter modules and required tooling

5 **Back side**

Assembly of the **top of the external structure**





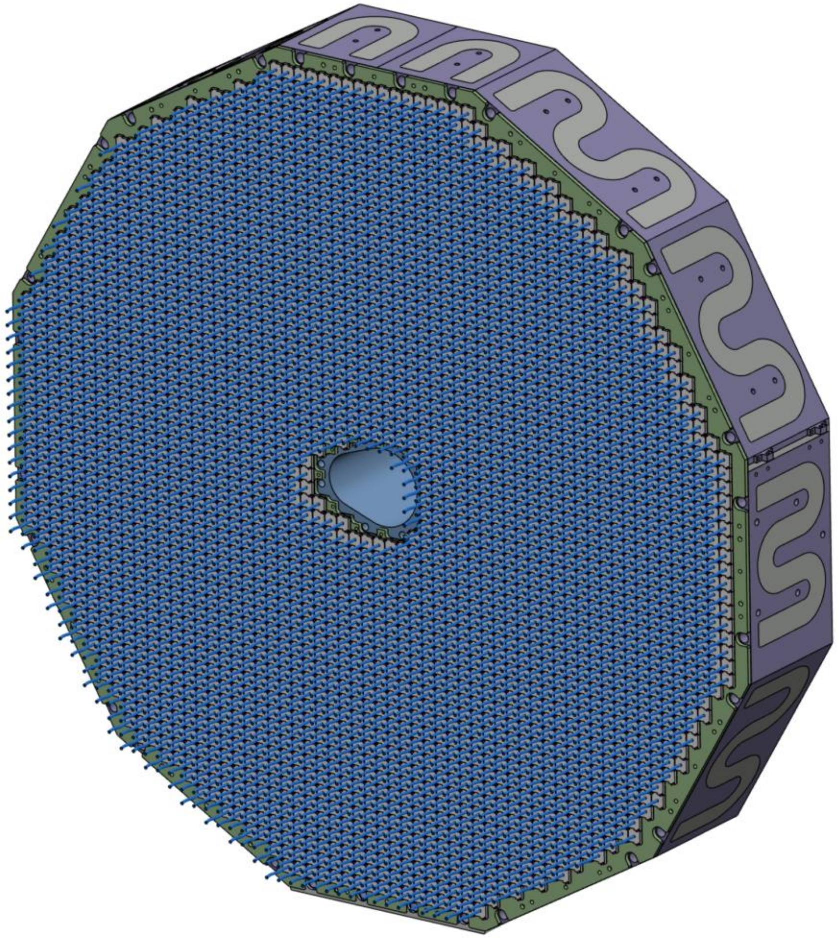
Assembly

Assembly sequence of calorimeter modules and required tooling

6

Back side

Positioning of the **PCB SiPM** and the **insulation**

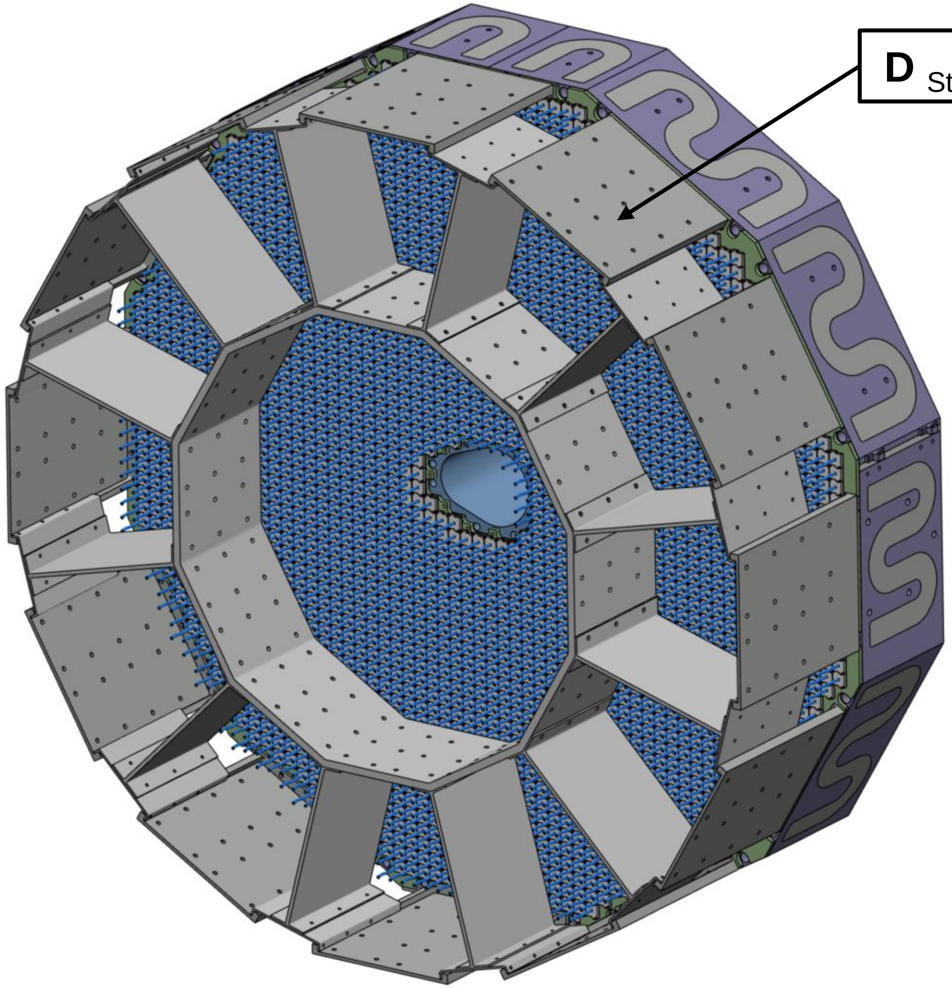


Assembly

Assembly sequence of calorimeter modules and required tooling

7 **Back side**

Assembly of the **mechanical structure of the electronics**



$D_{\text{Structure of the electronics}} < D_{\text{External structure}}$

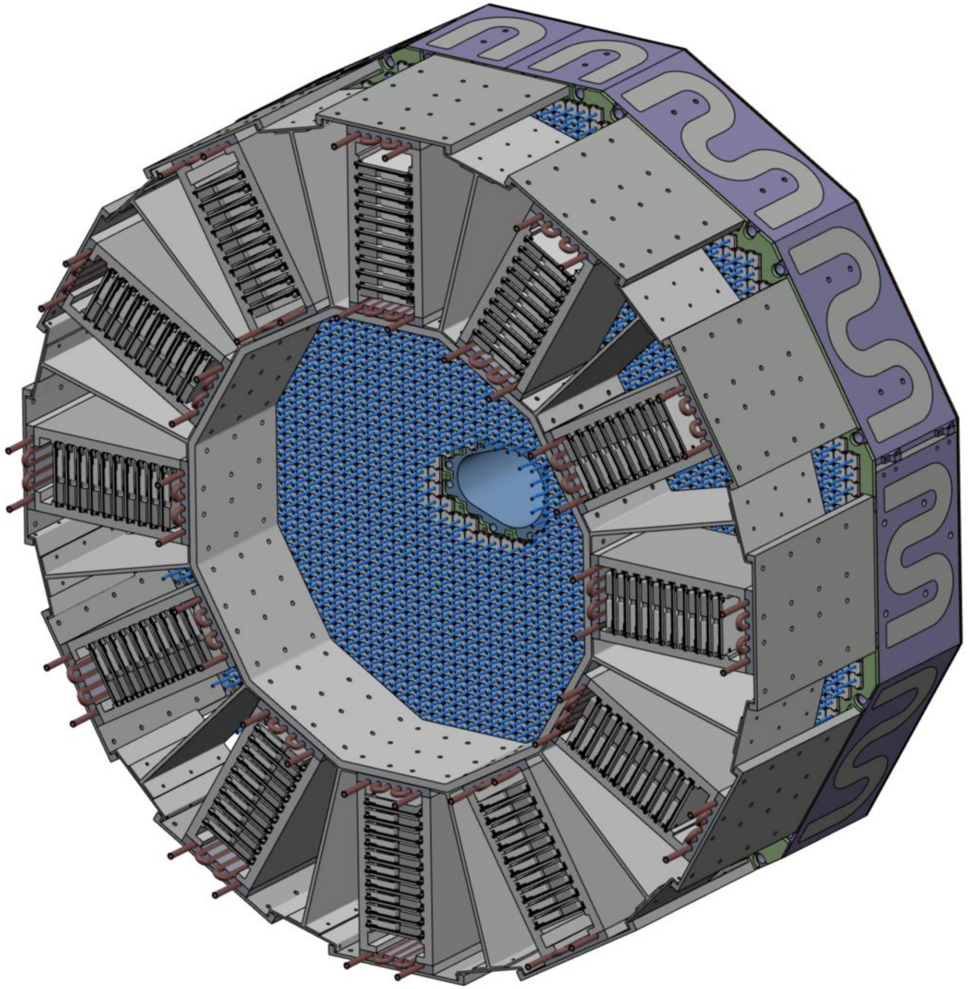
Assembly

Assembly sequence of calorimeter modules and required tooling

8 **Back side**

Inserting of the **cooling blocks**

Mass structure = 50 Kg
Cooling box = 10 Kg x12
Total = 170 Kg max



Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

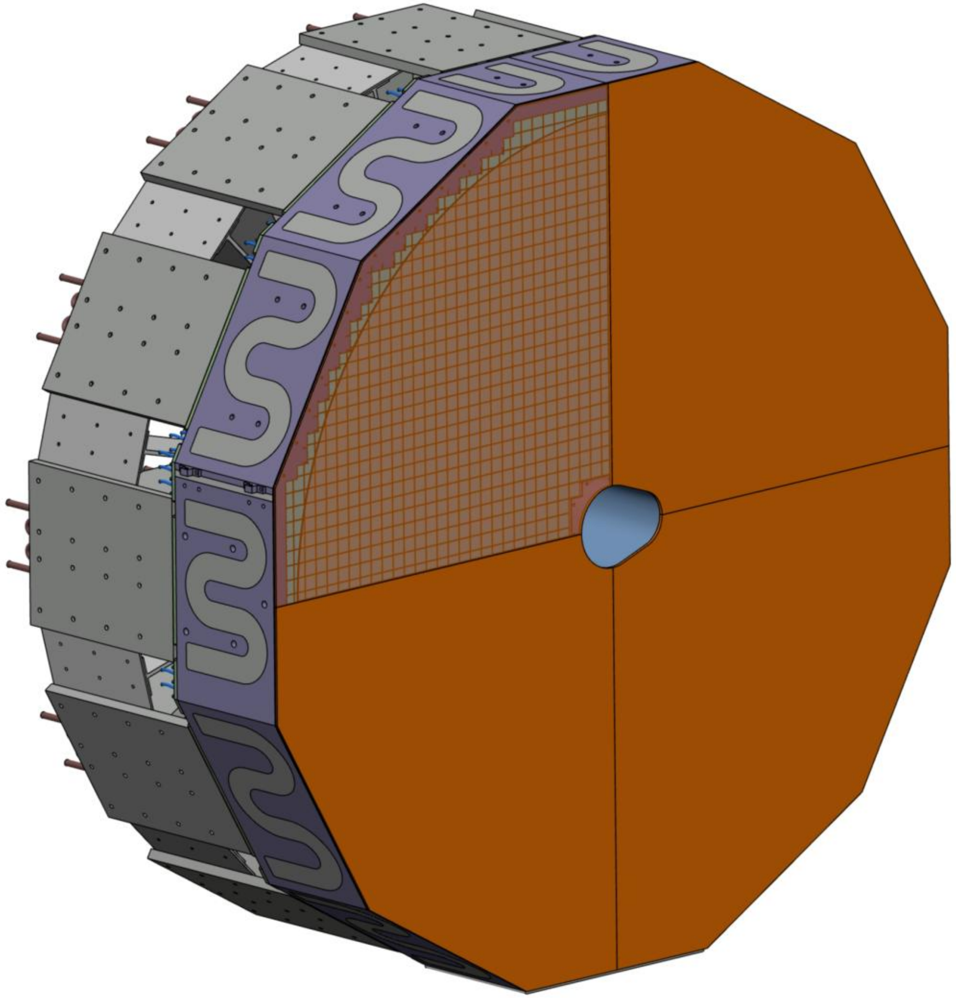
Assembly

Assembly sequence of calorimeter modules and required tooling

9 **Front side**

Assembly of the **copper plates** (4 plates), in contact with the external and internal structures

+ Assembly of the **insulation** (foam or thin film ROHACEL)

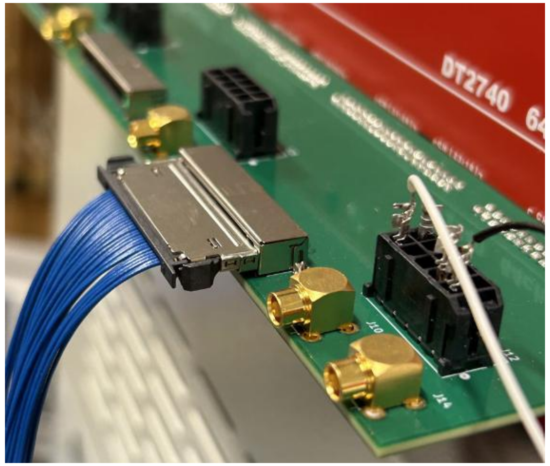


Assembly

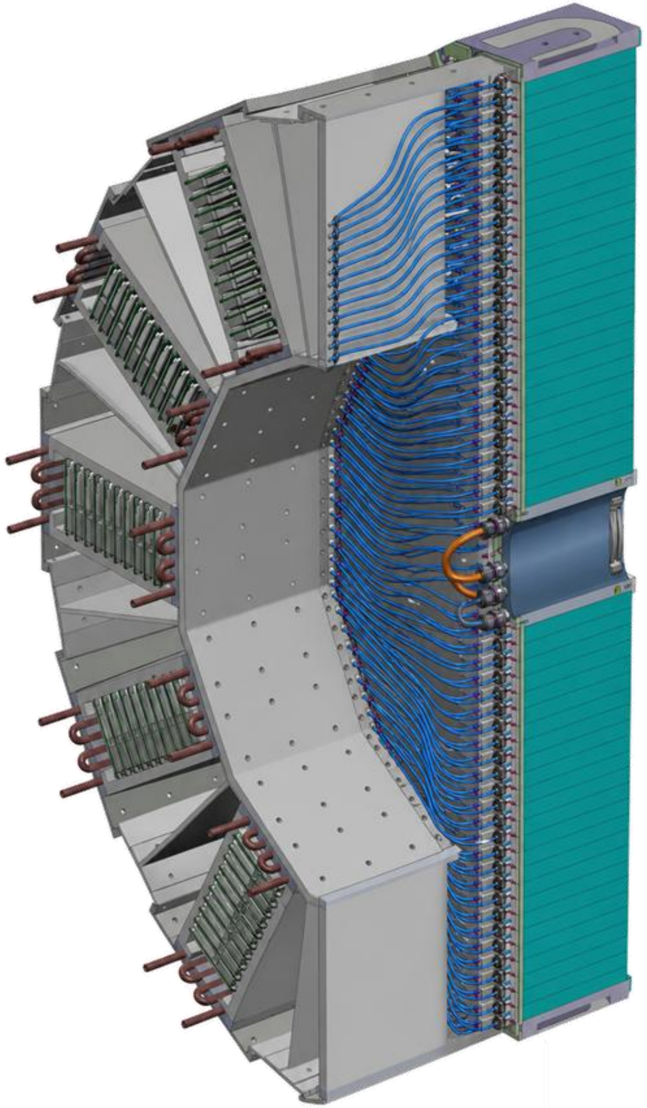
Assembly sequence of calorimeter modules and required tooling

10 **Front side**

Cabling with **single or multi-channels connectors/cables**
→ **1 cable per crystal**
→ **1 cable per 8 crystals (≈ 4 cables per FEB)**



Exemple of flat cable



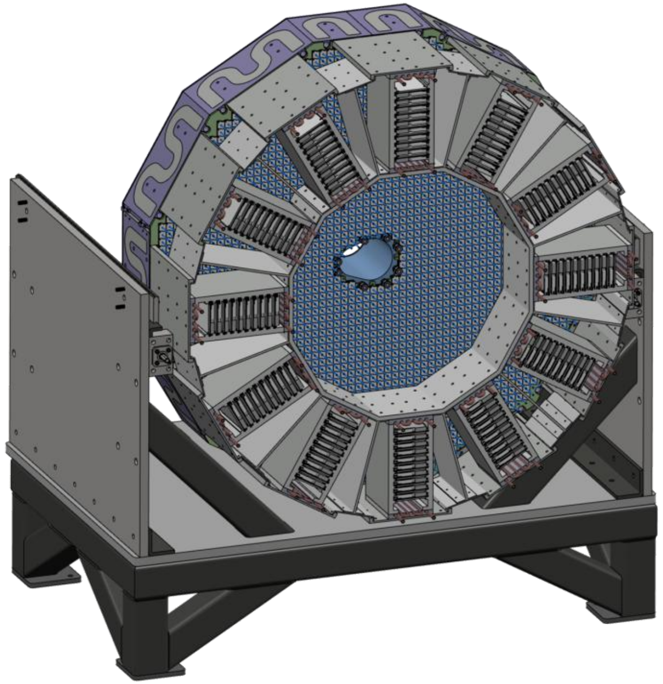
Cabling design

Interfaces & integration (survey & safety)

Handling procedures into the experimental room

Control and aligment on the temporary tool

- Specific ressources required
- **Sights or others** placed at specific location to check the positioning of the detector



Handling with bridge crane into the experimental room (see Roland's slides)

- Landyards (or others) not directly fastened to the external structure of the calorimeter
- Interface tooling required
- Positioning into the temporary tool (with the guide rails)

Example of device or tool

ESH&Q (risks, safety) / QA (prototypes)

QA, prototypes

Mechanical Design / ESH&Q

- The main risks have been identified and addressed from the early mechanical design phase: interferences, thermal stability, transport/handling, assembly, and operational safety.
- The detector design is compatible with integration constraints and interfaces (beam pipe, support structure, cooling, available space).
- Thermal stability is ensured through validated design choices and prototype testing, targeting a stability of ±0.1 °C.
- ESH&Q risks are mitigated through dedicated design choices, documented procedures, and controlled transport, pre-assembly, and installation steps.

QA / Validation

- The QA strategy relies on prototyping, dimensional inspection, and controlled assembly procedures.
- A 5×5 thermal/mechanical prototype validated the cooling and assembly concepts, with performances meeting the requirements.
- Assembly sequences are documented to ensure repeatability, inspection capability, and traceability.
- Production includes part inspection, process validation, mock-up/clearance tests, and validation of critical steps before shipment.

The design is considered ready for construction, with a complete verification and validation strategy already defined.

Schedule

WBS for components and detector structures

Assembly milestones and detector integration phases

Detector ready for integration into ePIC

Planning

	2026				2027				2028				2029				2030				2031				2032				2033				2034			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Prototype & validation	🟩	🟩																																		
Production drawings			🟩	🟩	🟩	🟩	🟩	🟩																												
Procurement / Fabrication					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																				
Test / QA													🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩																
Assembly																	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩												
Integration																									🟩	🟩	🟩	🟩								

R&D → **Production drawings** → **Procurement & Fabrication** → **Shipping** → **Assembly** → **Integration**

Now