Istituto Nazionale di Fisica Nucleare
SEZIONE DI FERRARA

Università degli Studi di Ferrara

dRICH

Mechanical Design Status

Alessandro Saputi – 17 June 2025

Overview

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dRICH Mechanical Design
- Main requirements: position, clearance and envelope
- Components: vessel, detector box, aerogel
- Integration

PCB Cooling
- Main requirements

Prototype
- Design

Target R&D and Generic R&D
- Spectrometer Chamber
- High Pressure Chamber

Mechanical Design Team

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INFN FERRARA: mechanical design
- Alessandro Saputi
- Michele Melchiorri

INFN Torino: thermal simulations and cooling
- Carlo Mingioni
- Marco Nenni

JLAB: mirrors design
- Alex Eslinger

dRICH: main requirements

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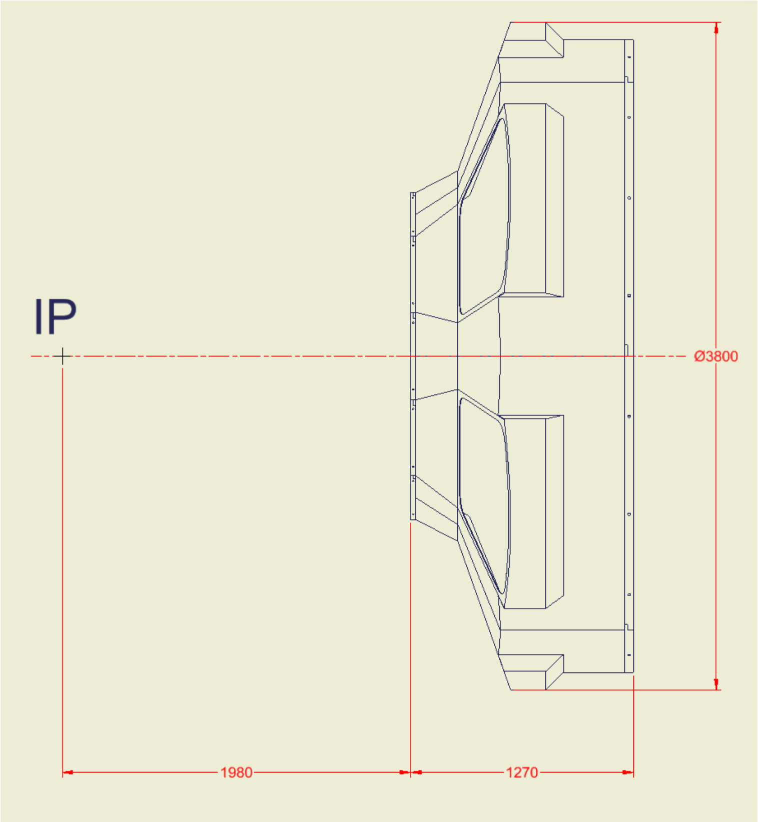
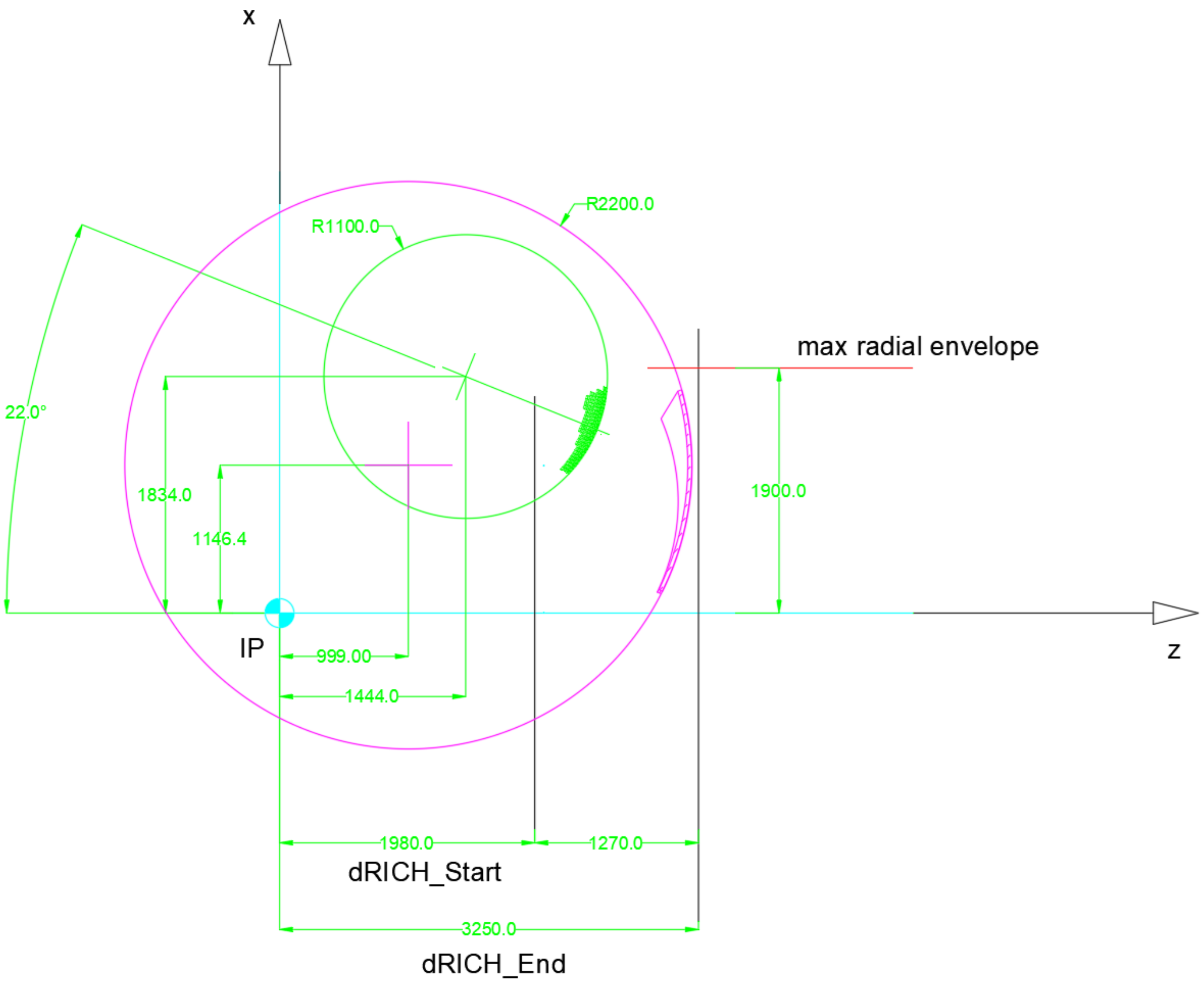
- **Envelope overall size**: Ø3800 mm × 1270 mm
- **Operating pressure**: Up to 3 - 10 mbar
- **Operating temperature**: 22 °C
- **Gas mixture**: C_2F_6 - Nitrogen

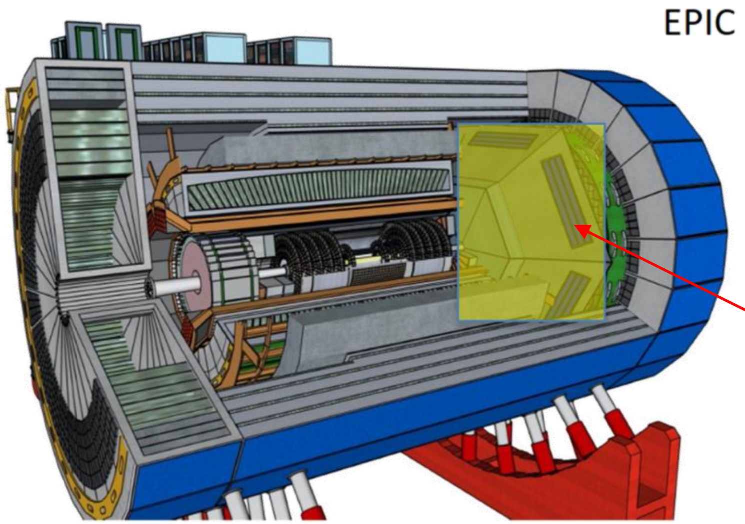


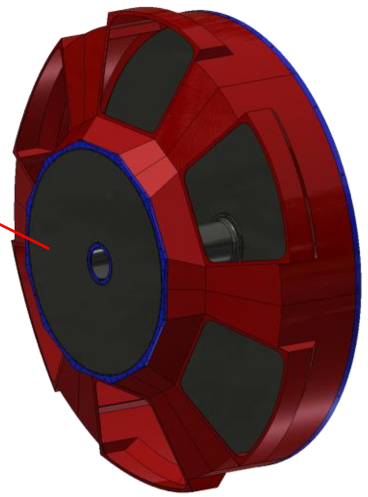


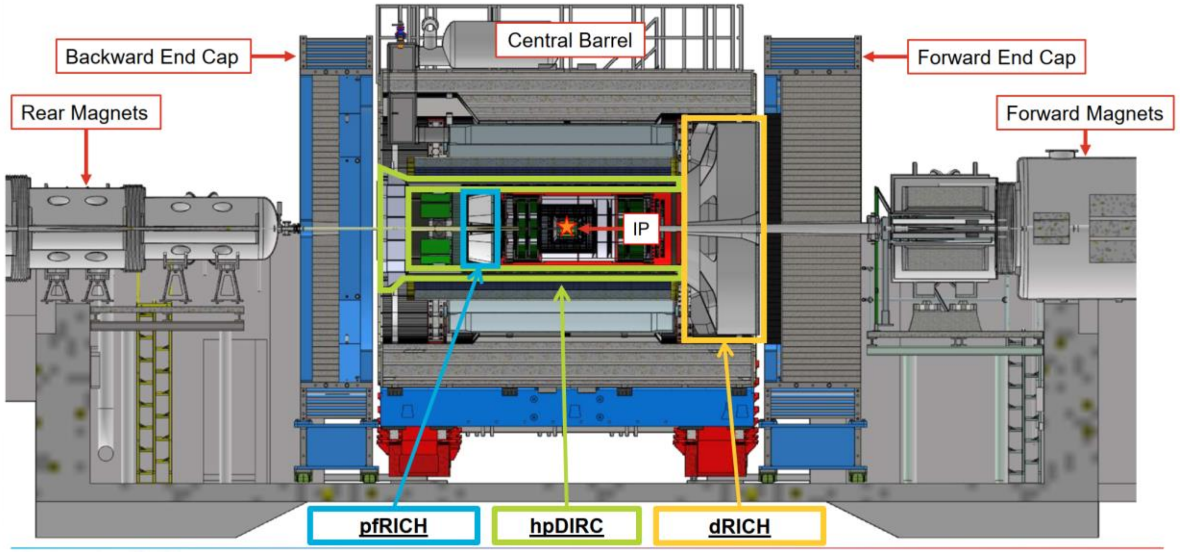
dRICH: main requirements

The major functions of the dRICH mechanical structure (gas enclosure) are to provide containment for the dRICH gas radiator and to act as a stable frame for the optical components (the mirrors and aerogel):

- It must be light-tight.
- It must ensure the stability of the structure under the influence of the magnetic field.
- The enclosure must withstand a differential pressure of 3-10 mbar without compromising the mirror alignment.
- The minimum amount of material must be placed within the ePIC experiment acceptance limits.







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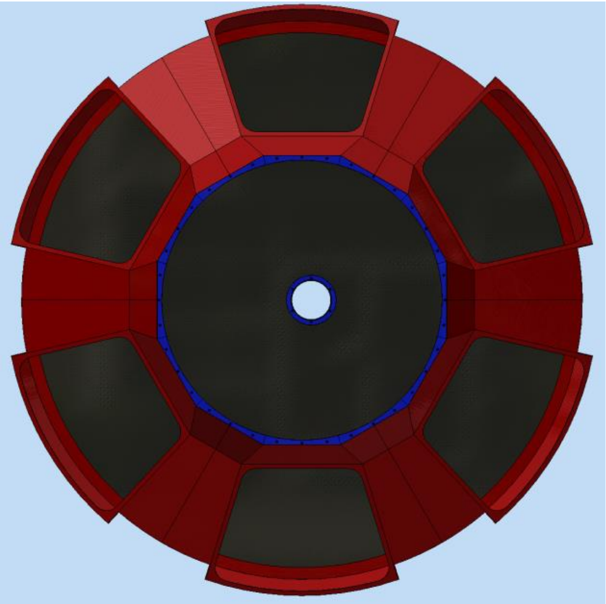
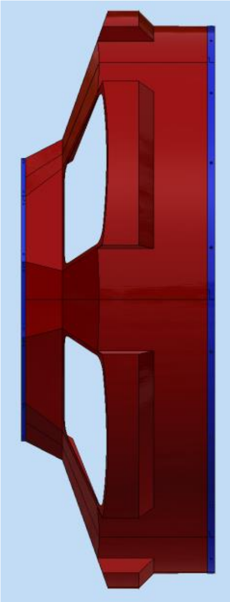
dRICH Gas Box: mechanical preliminary design

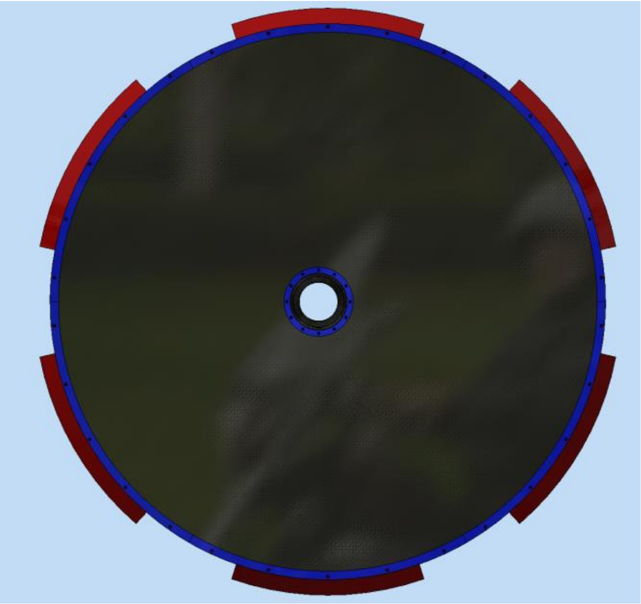
Front view

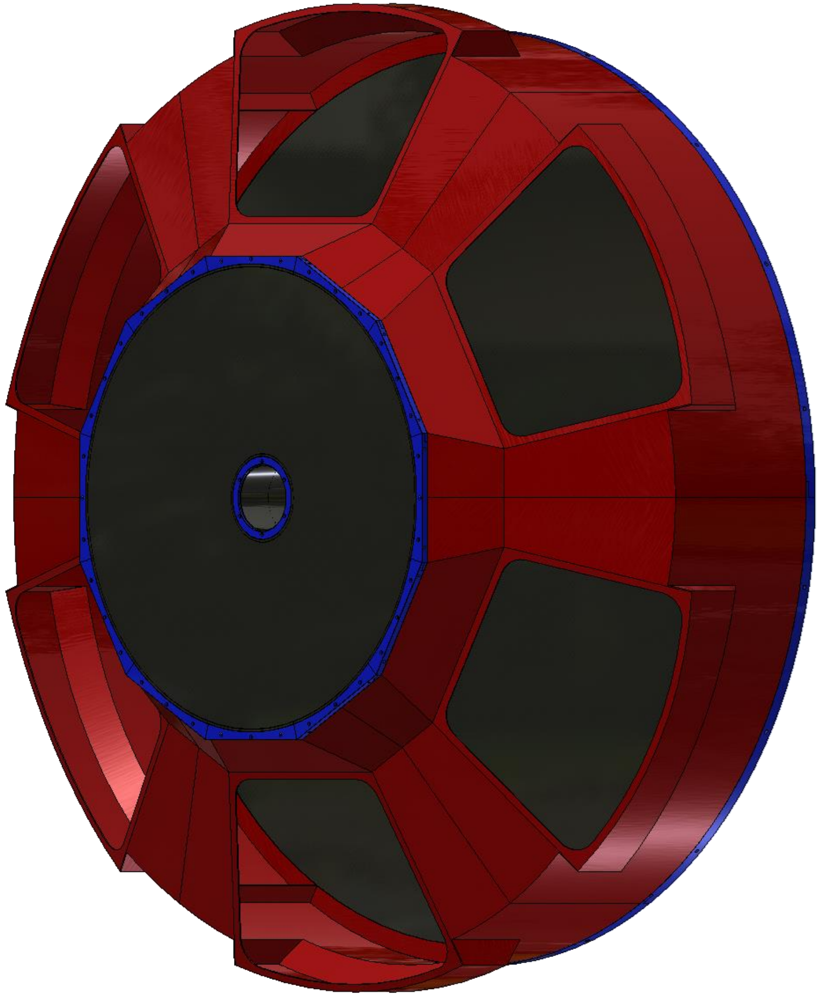


Side view



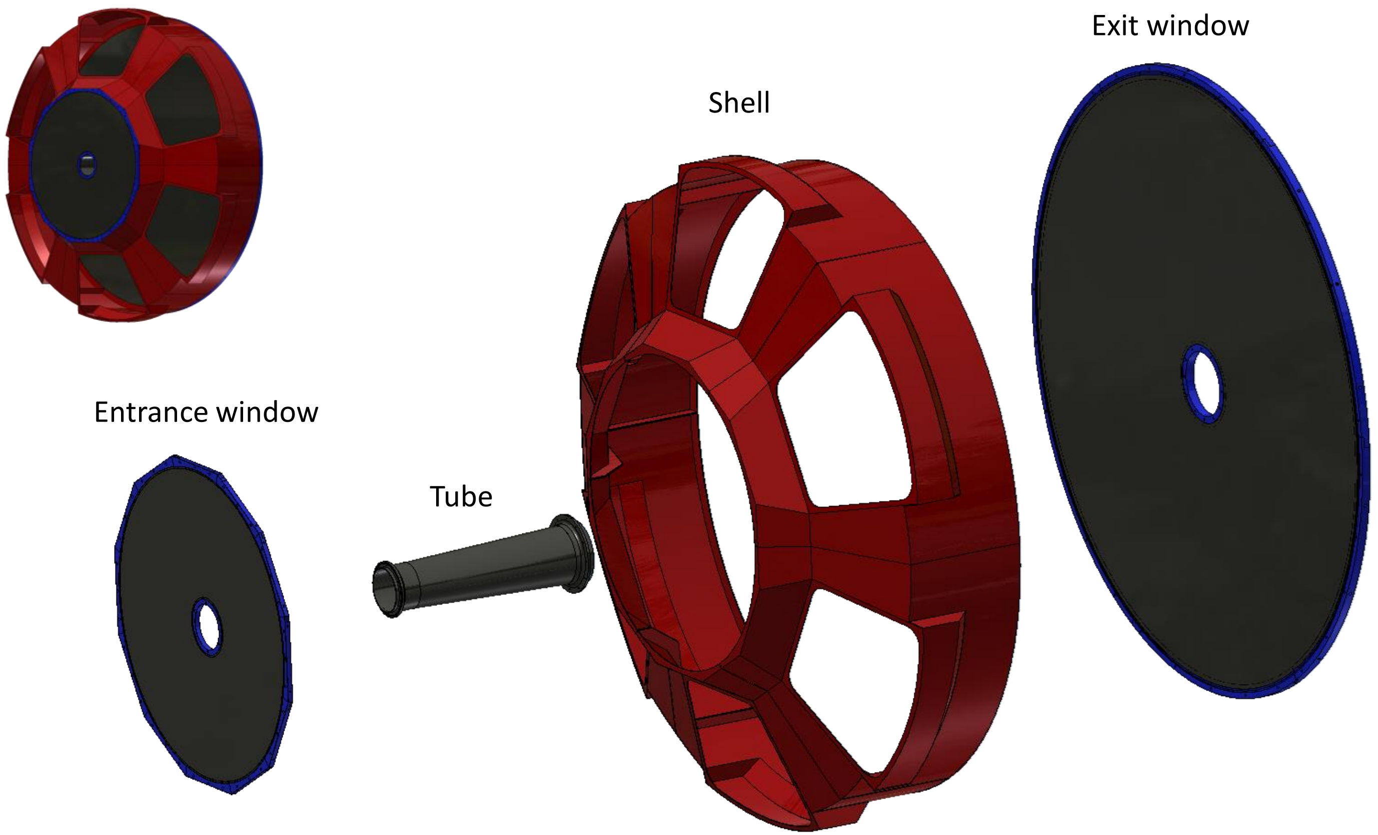
Back view

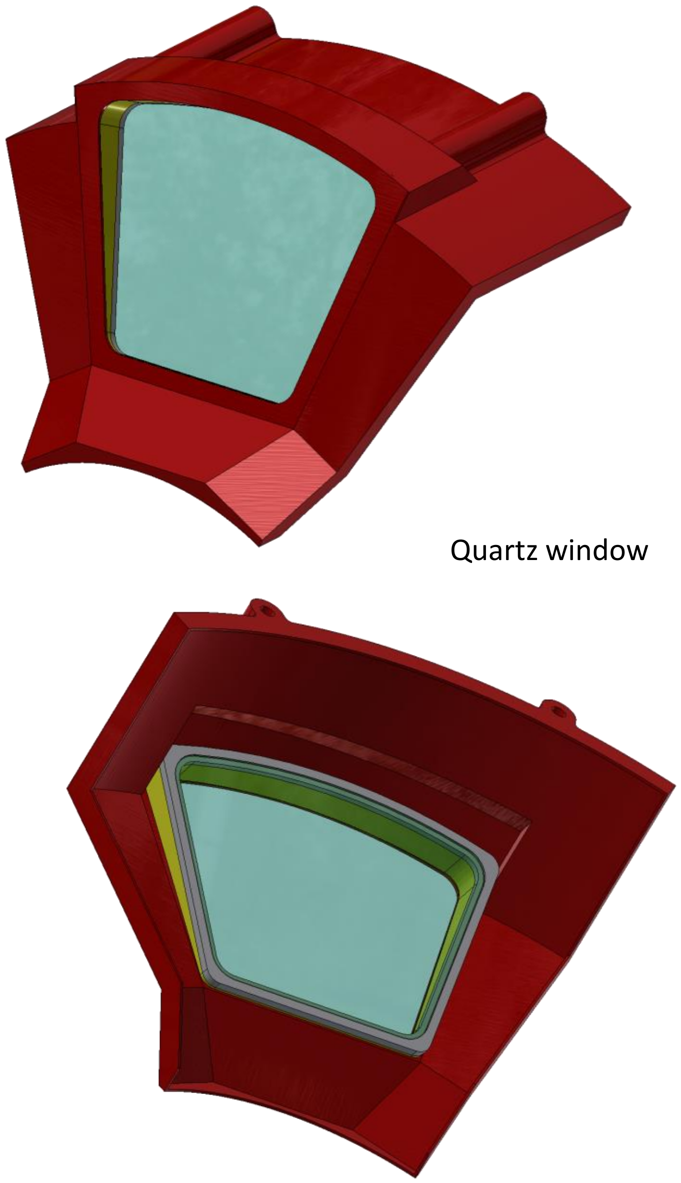




The gas box is essentially a cylindrical box made of carbon fibers, that hosts mirrors and aerogel tiles.

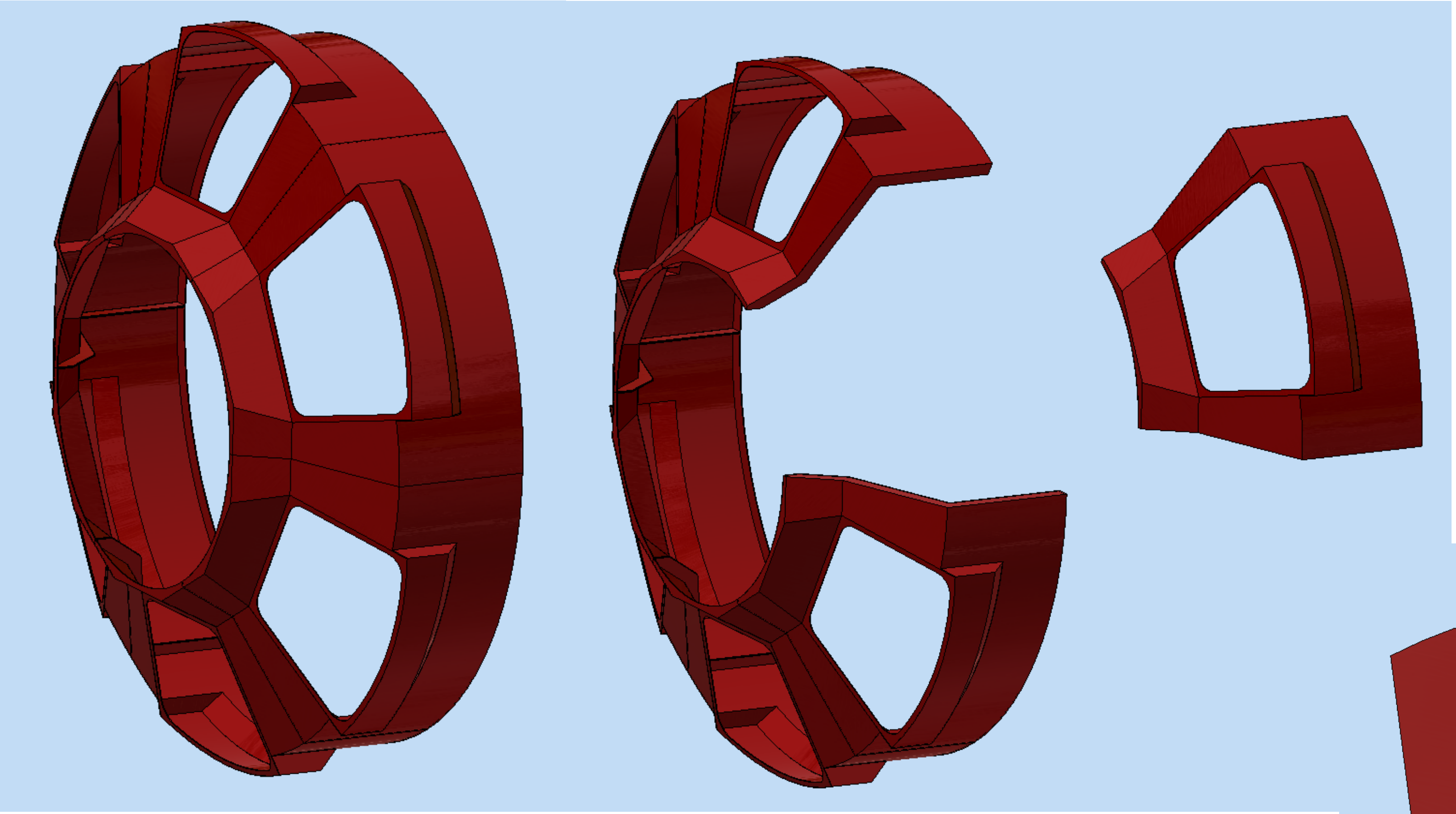
dRICH Gas Box: mechanical structure



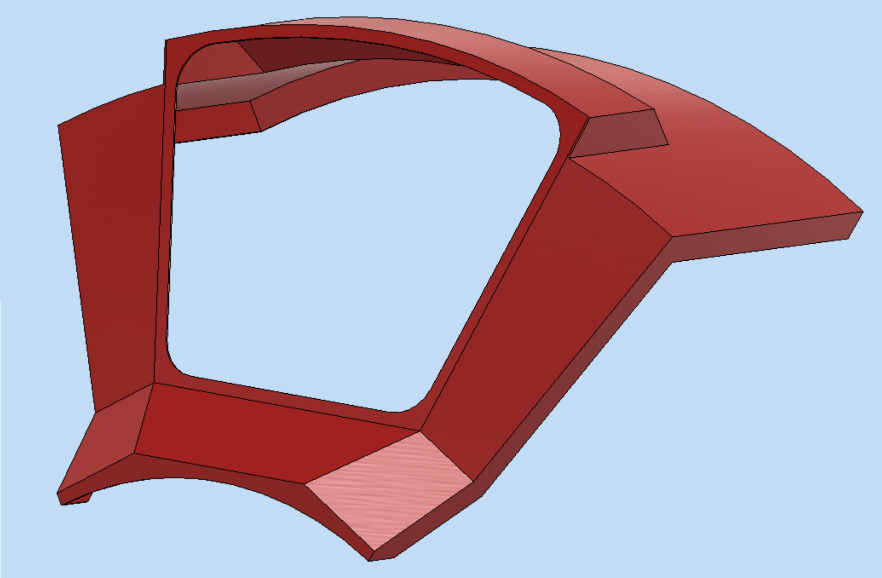


The mechanical structure (gas box) consists of six main components: the shell, the entrance and exit windows, the central tube, the detector boxes, and the quartz windows.
All components forming the gas box are bolted together.
Gas and light tightness are ensured by O-ring and gasket sealing.

dRICH: shell

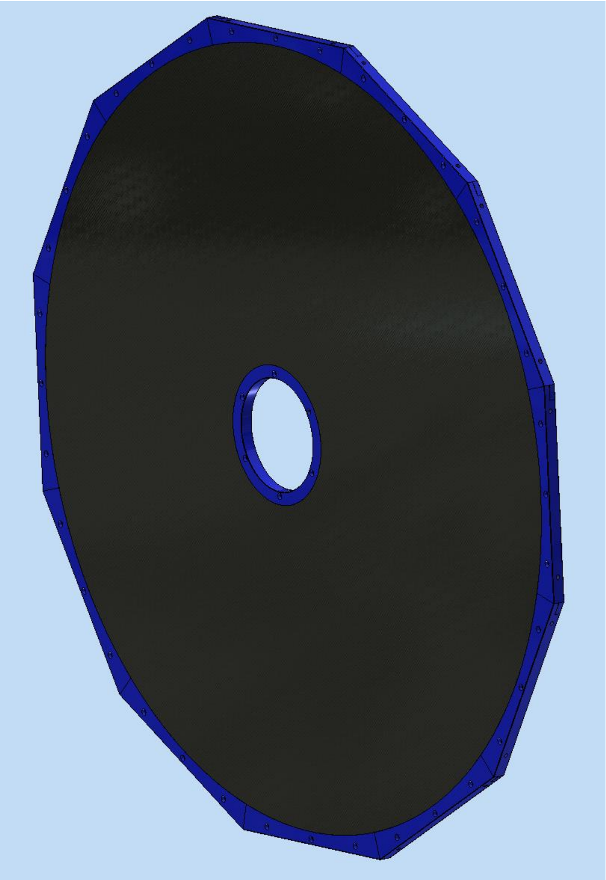


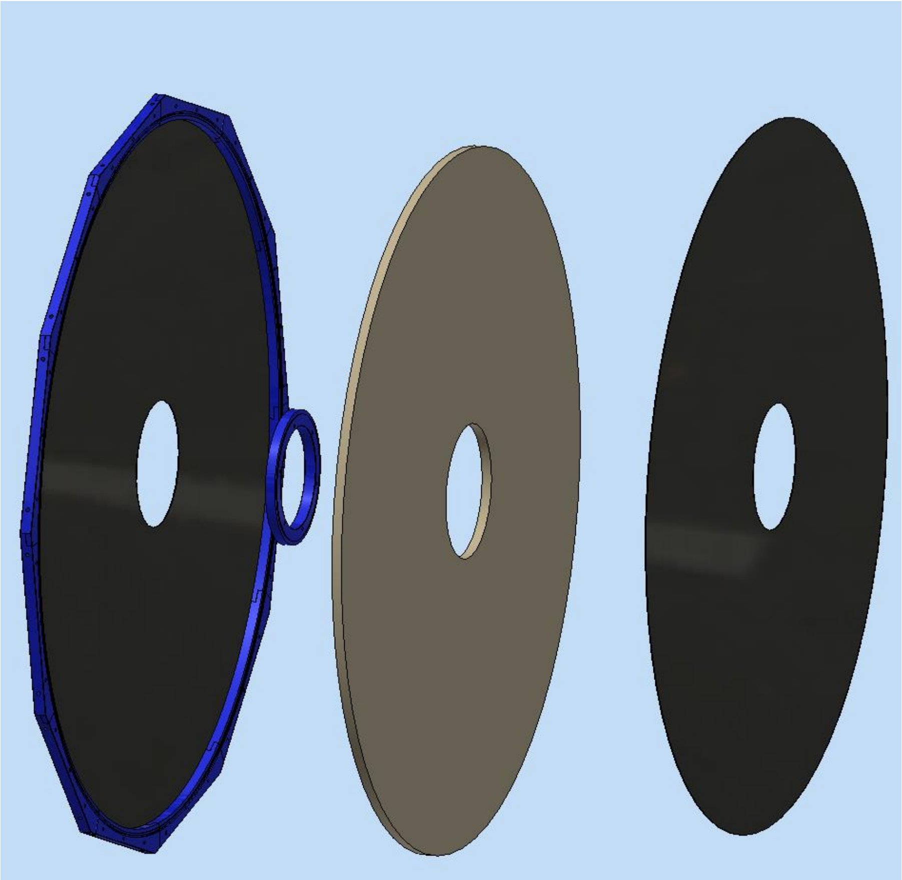
The shell will be made of an 10 mm thick carbon fibre epoxy composite. Each laminate will consist of six layers of balanced weave fabric, with fibres oriented at 0°/90° in one layer and ±45° in the adjacent layer.

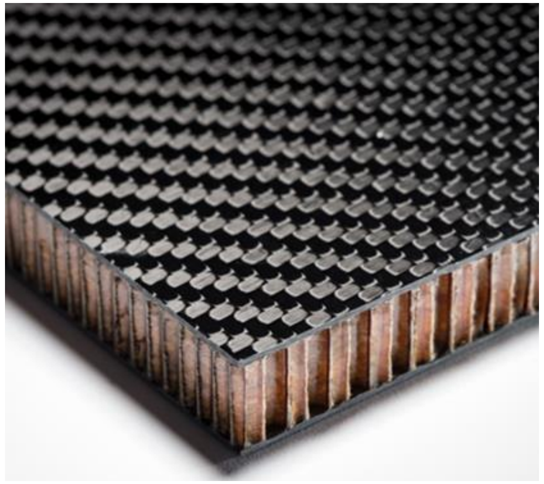


The shell is composed of six parts that are bolted and glued together to ensure structural integrity and the gas/light tightness.

dRICH: entrance windows







The Entrance Window will be a sandwich panel consisting of two carbon fiber-reinforced epoxy skins, each 2.28 mm thick, separated by a 25 mm thick Nomex honeycomb core. Each skin is composed of six layers of balanced weave laminate, with fibers oriented at 0°/90° in one layer and overlapped with ±45° in the adjacent layer.

The external sides are enclosed by two solid frames made of carbon fiber (CF) or aluminum.

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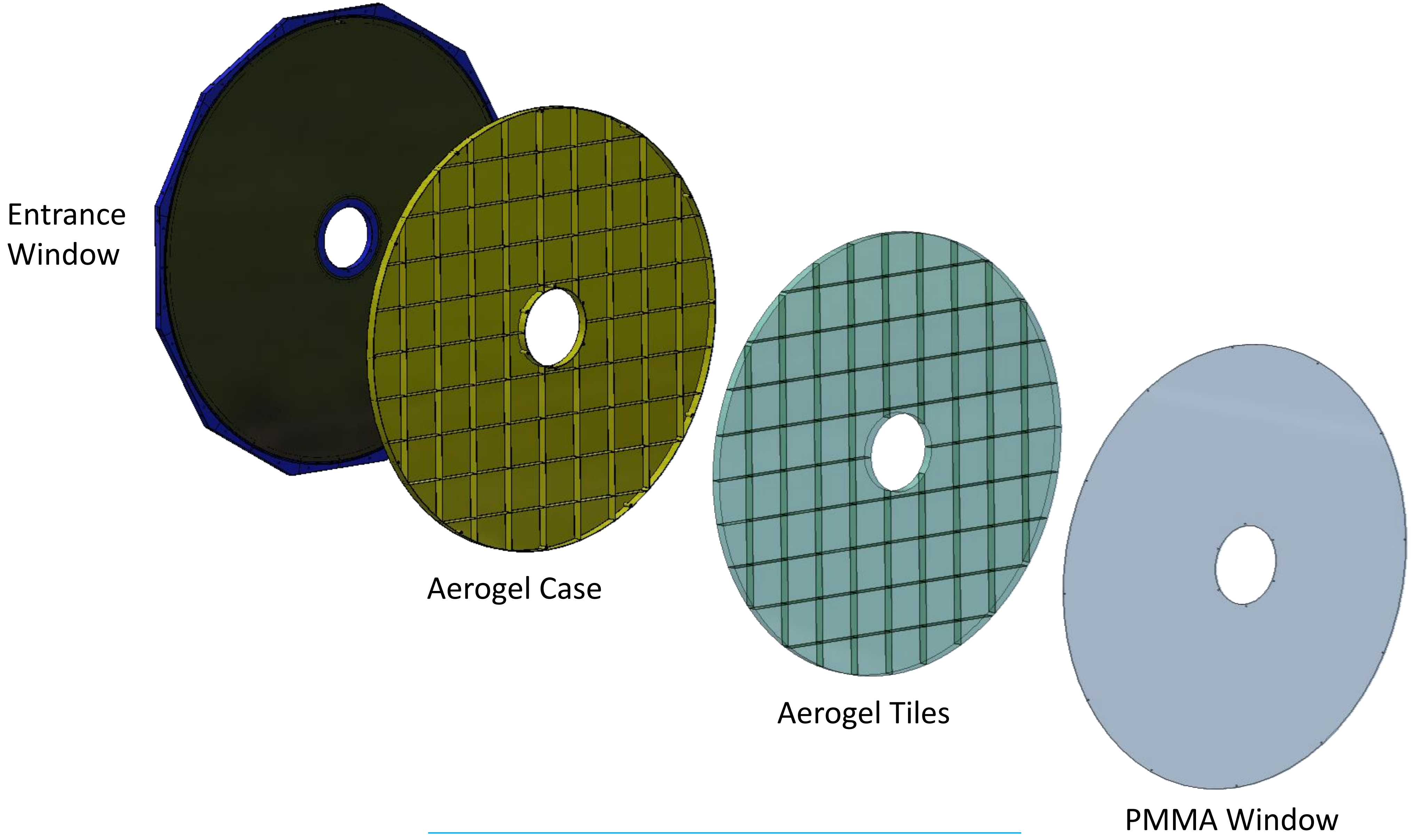
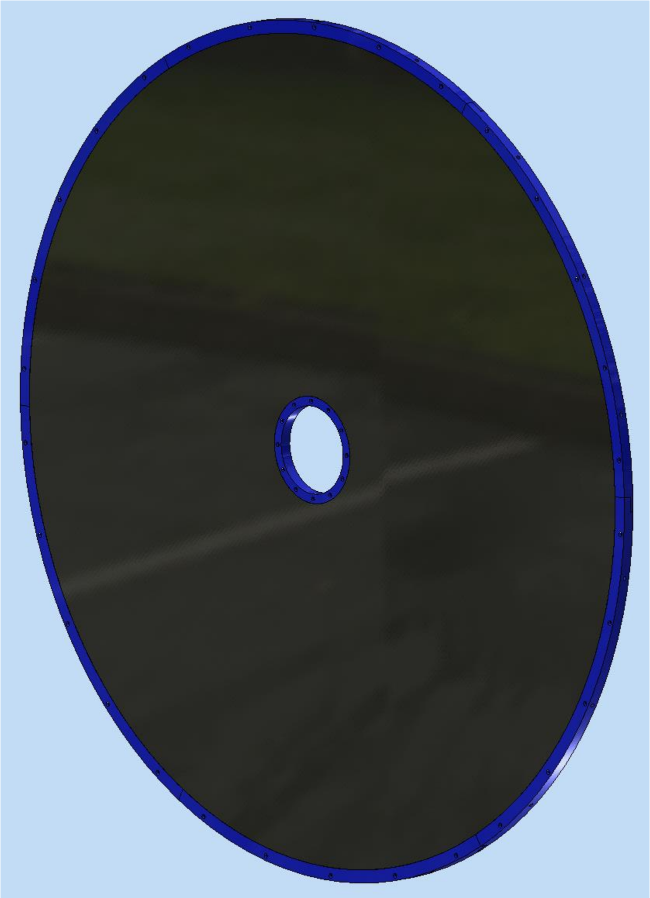
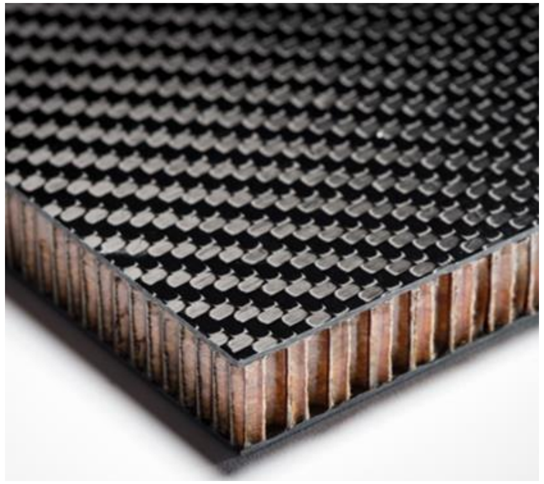
dRICH: aerogel support structure



dRICH: exit windows



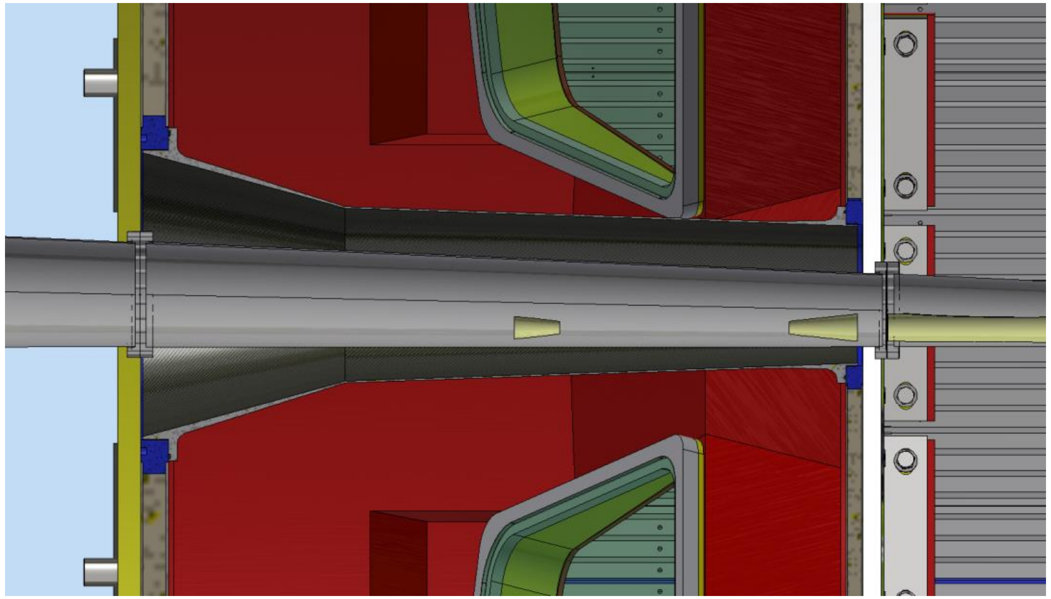


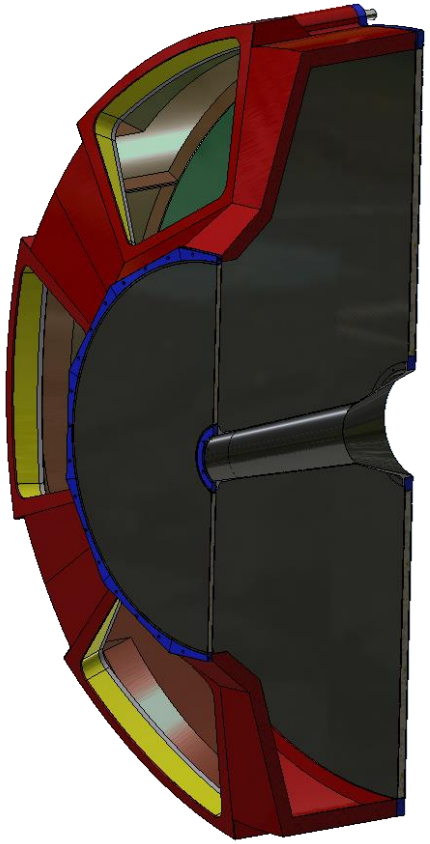
The Exit Window will be a sandwich panel consisting of two carbon fiber-reinforced epoxy skins, each 4.56 mm thick, separated by a 40 mm thick Nomex honeycomb core. Each skin is composed of six layers of balanced weave laminate, with fibers oriented at 0°/90° in one layer and overlapped with ±45° in the adjacent layer.

The external sides are enclosed by two solid frames made of carbon fiber (CF) or aluminum.

dRICH: central tube

Central tube

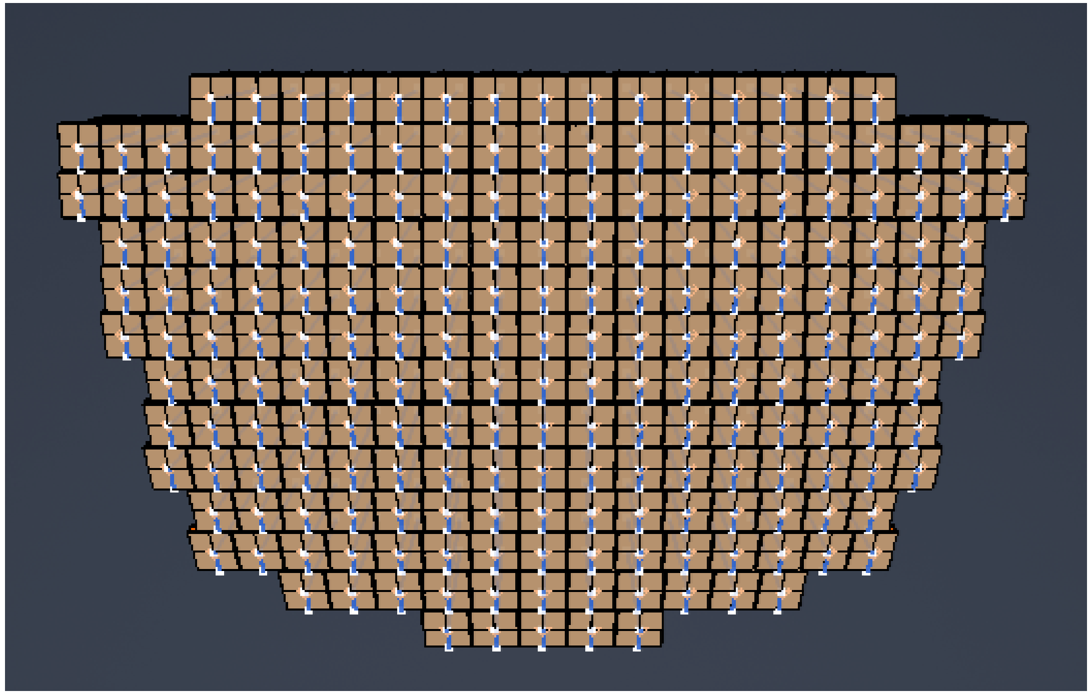


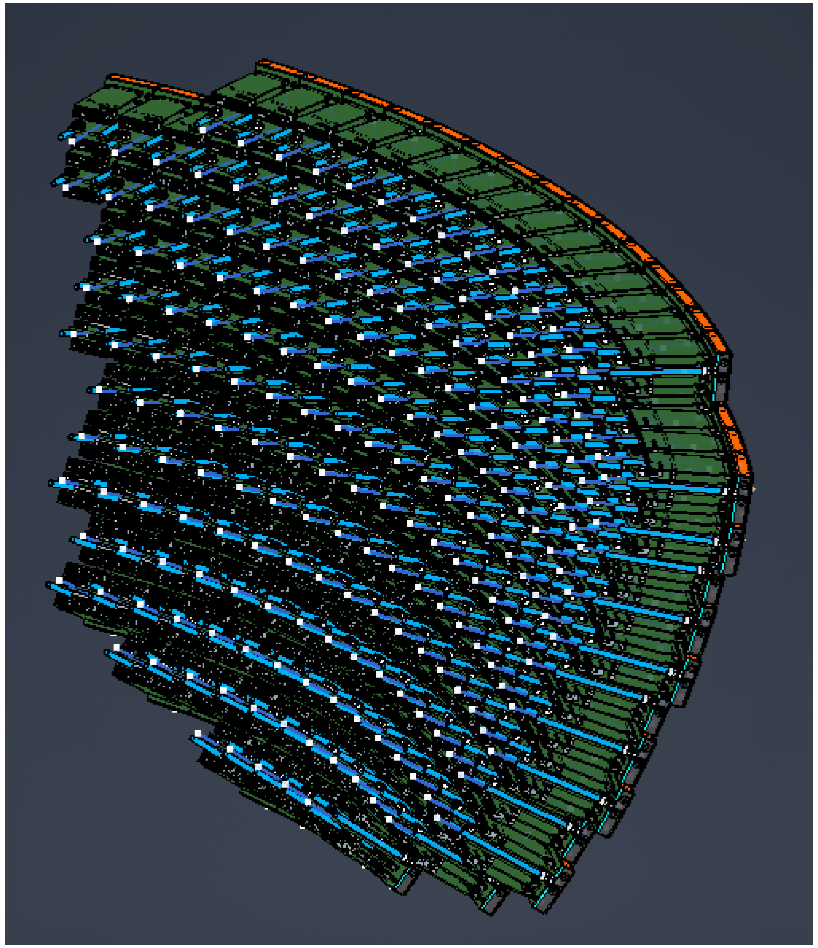


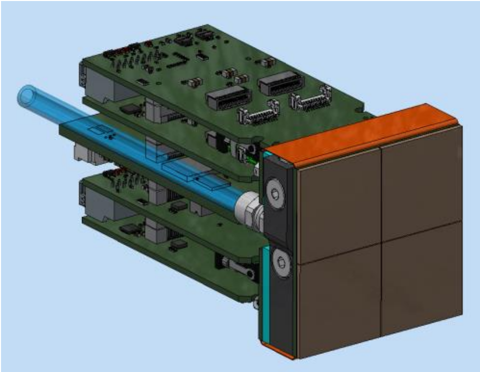
Both the entrance and exit windows are connected by the central tube. The central tube will be made of a 5 mm thick carbon fiber epoxy composite and will have an inside diameter of 242 mm at the entrance window, tapering to 500 mm at the exit window. This design ensures a radial separation between the vacuum chamber and the central tube.

dRICH: PDU - detector

The detector is composed of 211 PDUs arranged on a sphere with a radius of 1100 mm

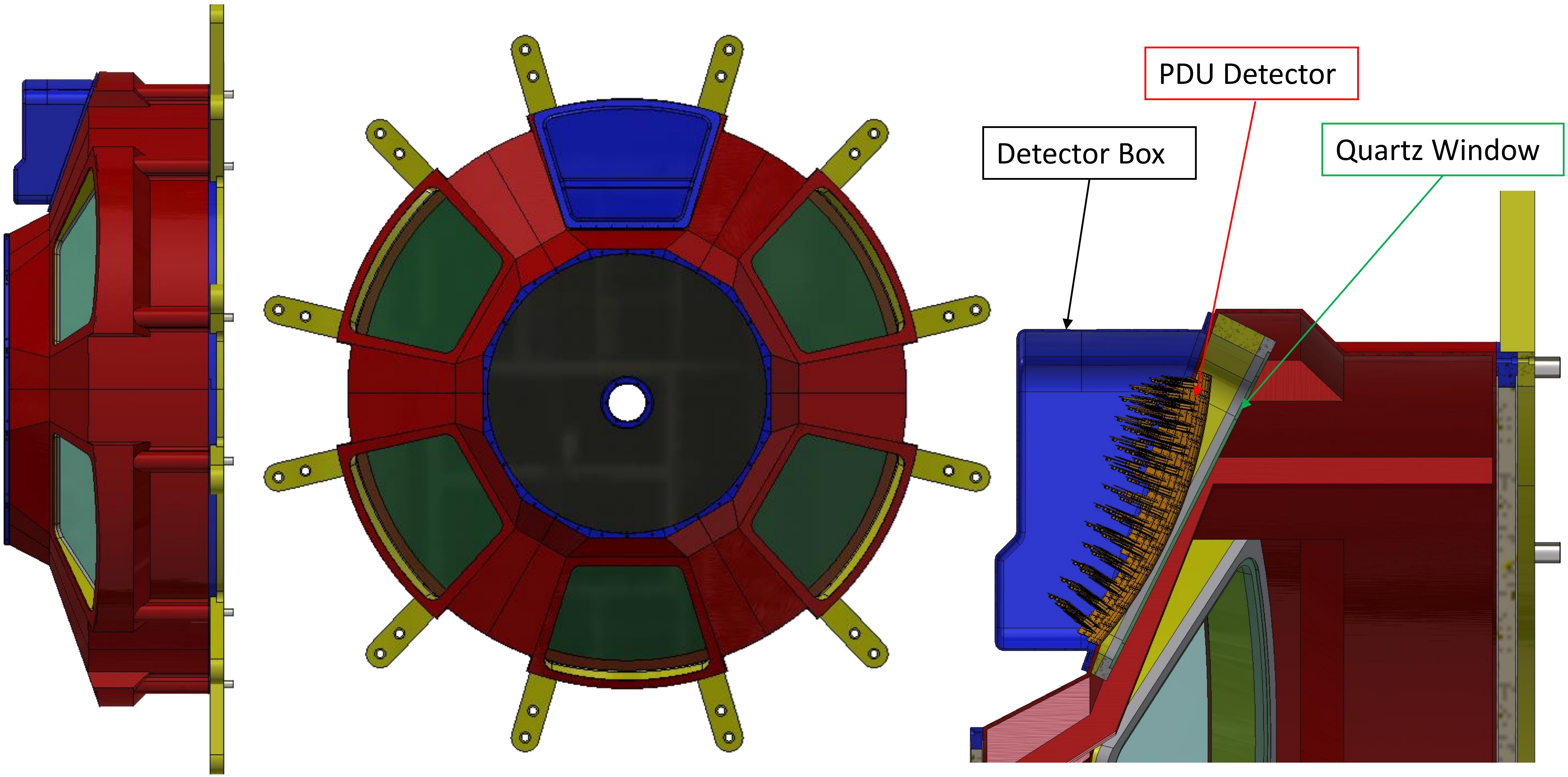




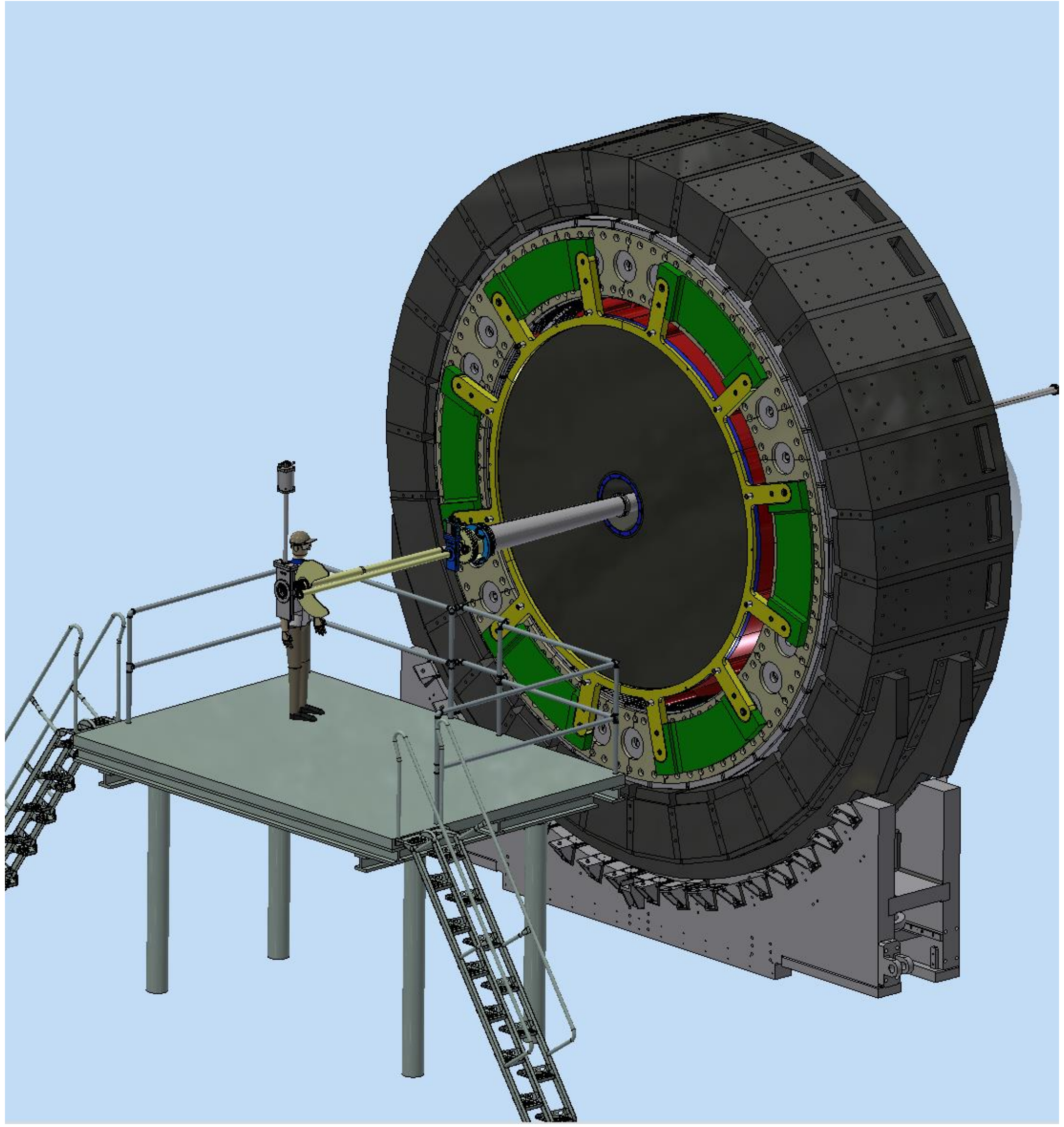


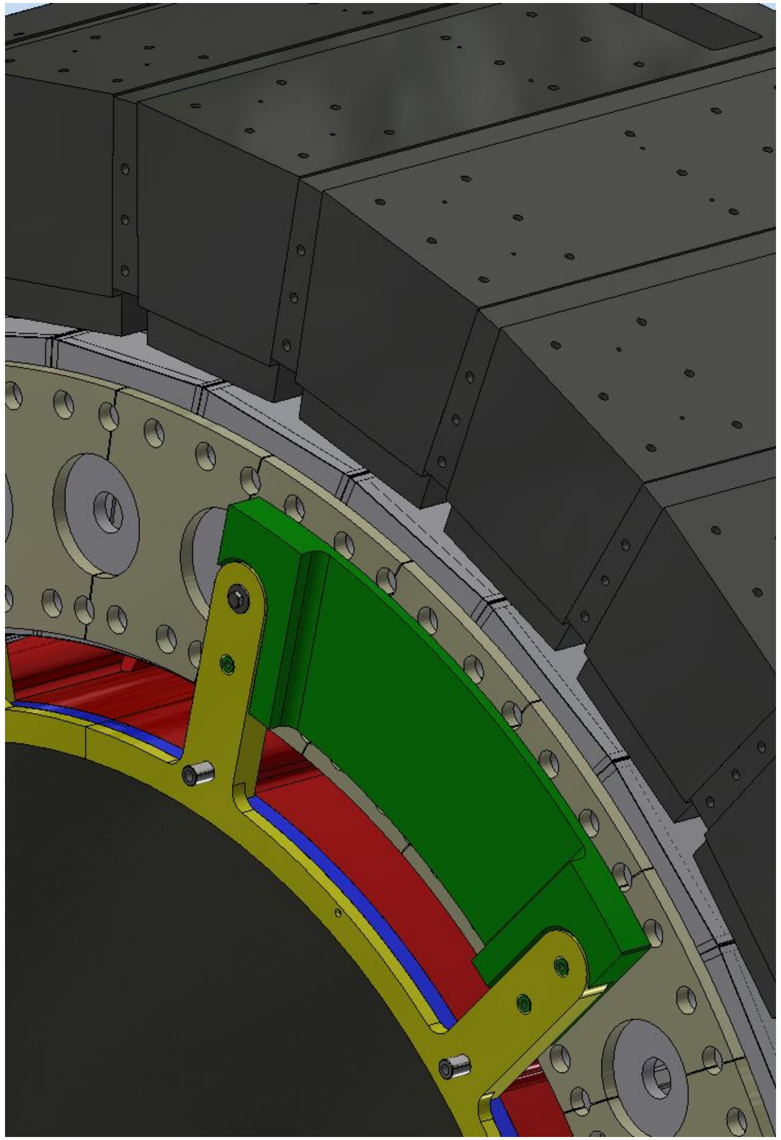
PDU designed by R.Preghenella

dRICH: detector box



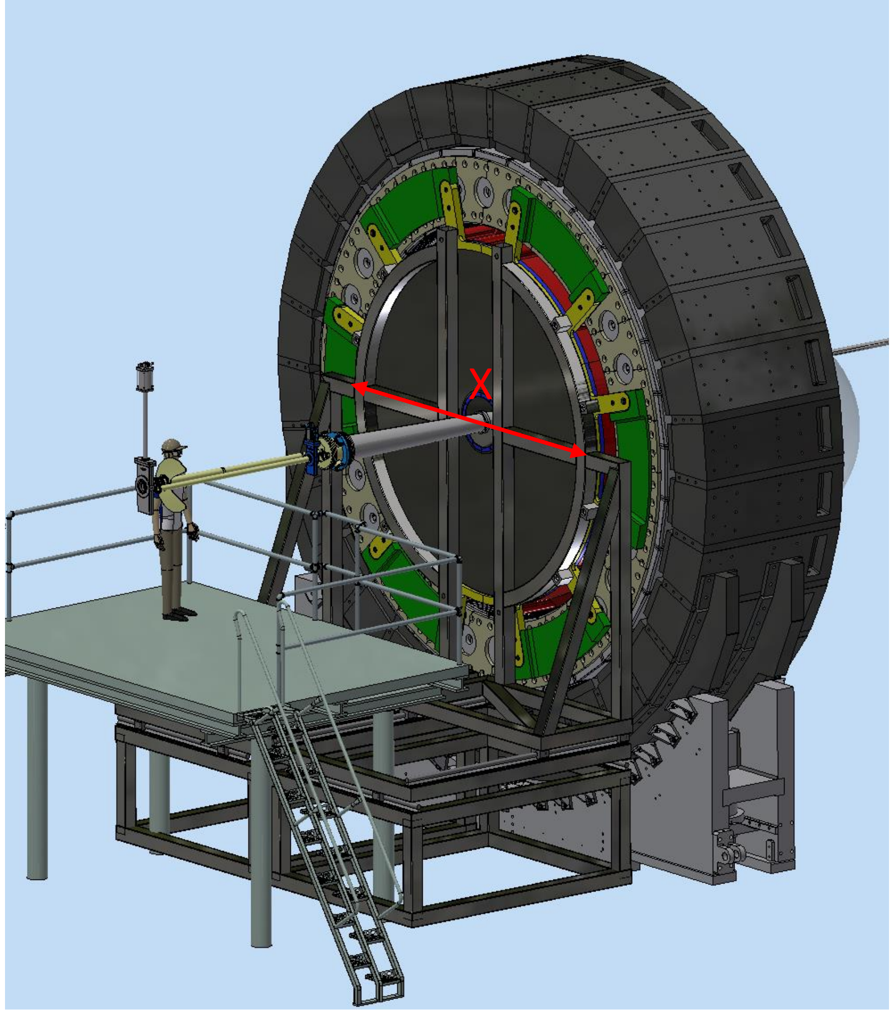
dRICH: integration with ePIC apparatus

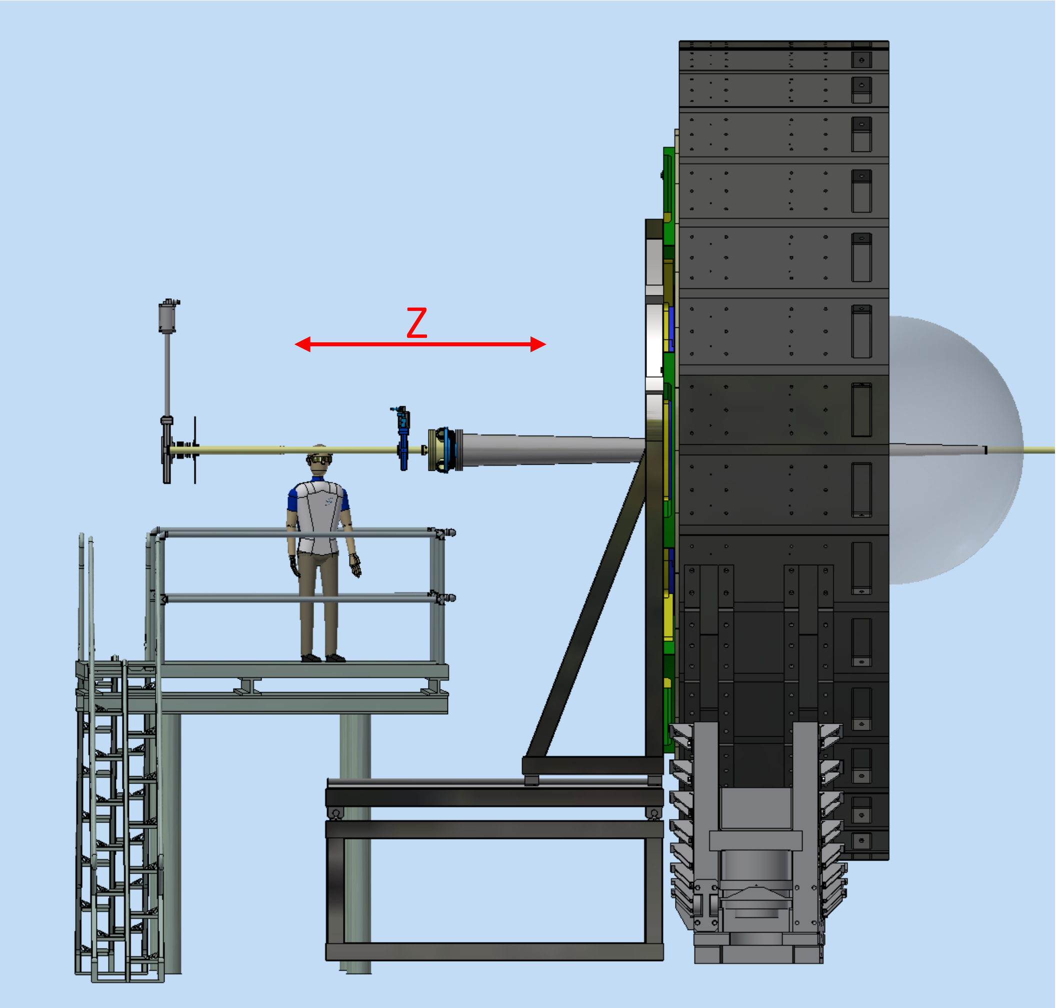




- dRICH (yellow harms) are bolted to the green plates.
- Green plates are bolted to the calorimeter structure.

dRICH: extractio/insertion tool





The extraction/insertion tool allows for moving the dRICH in and out, as well as shifting it in both the Z and X directions.

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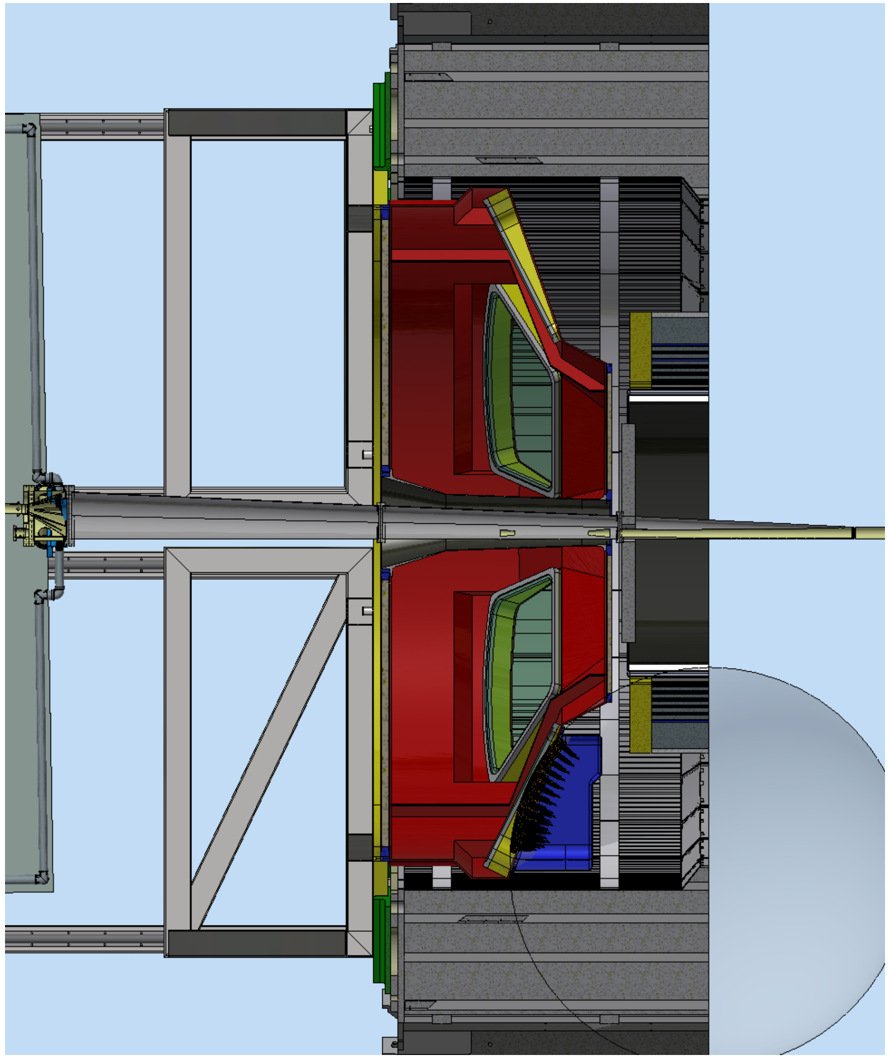
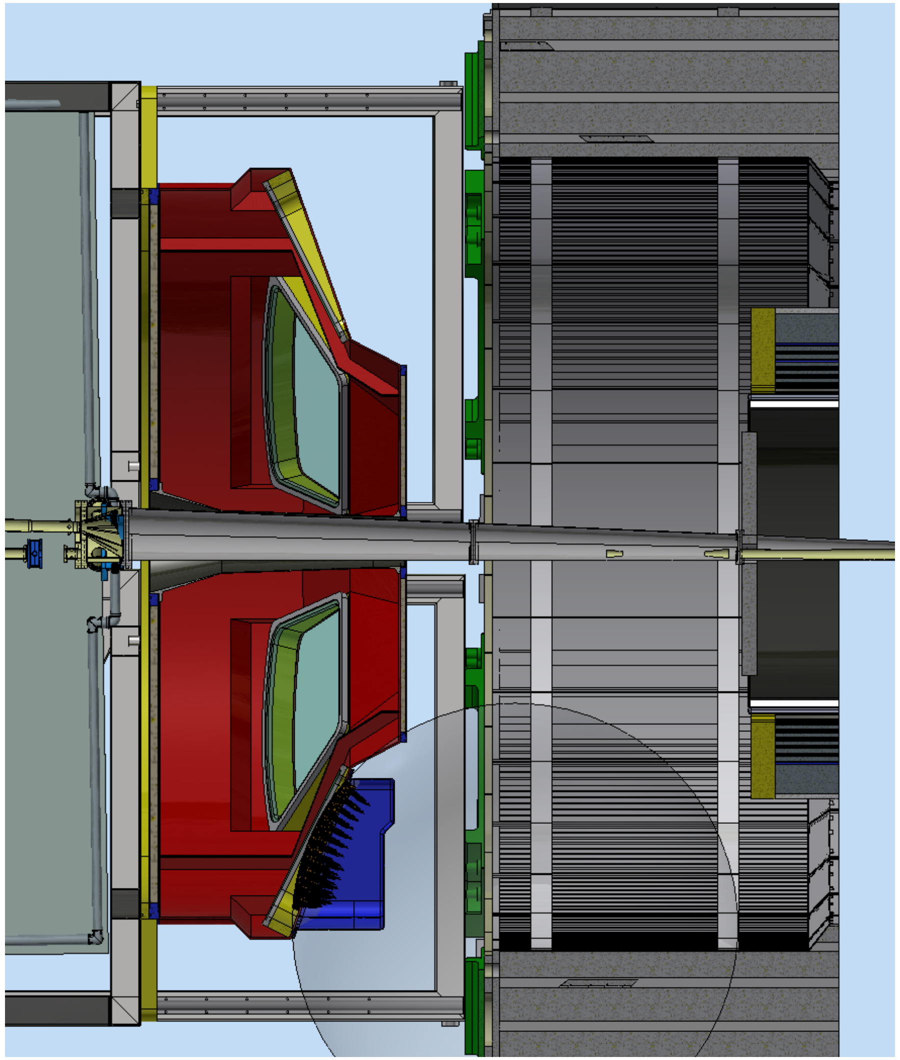
dRICH: closed and open position

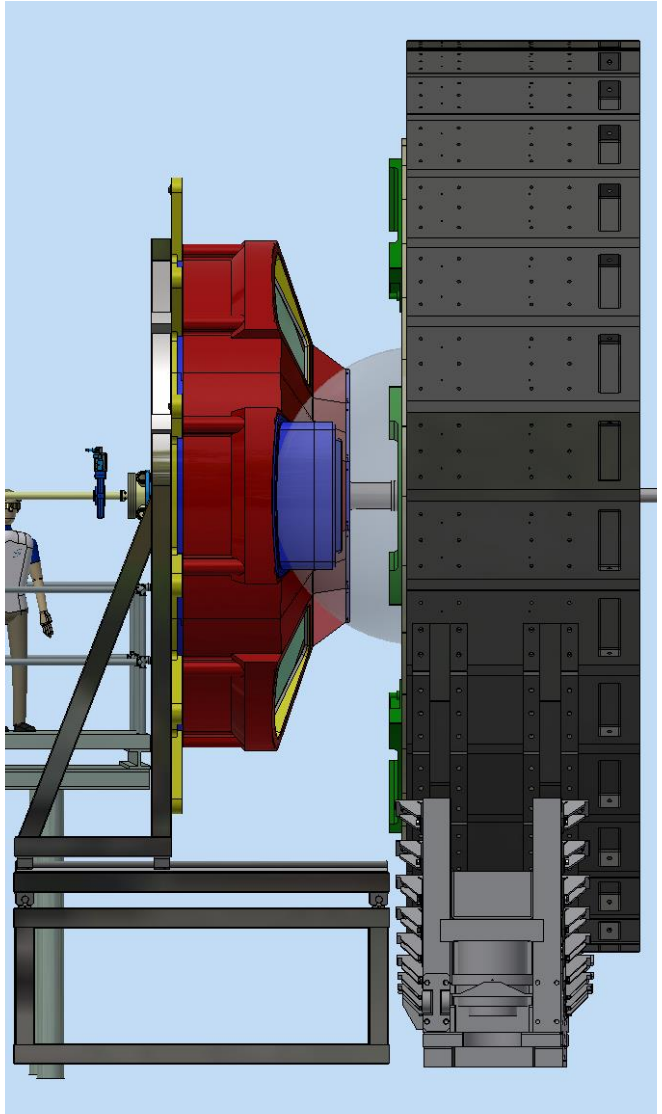


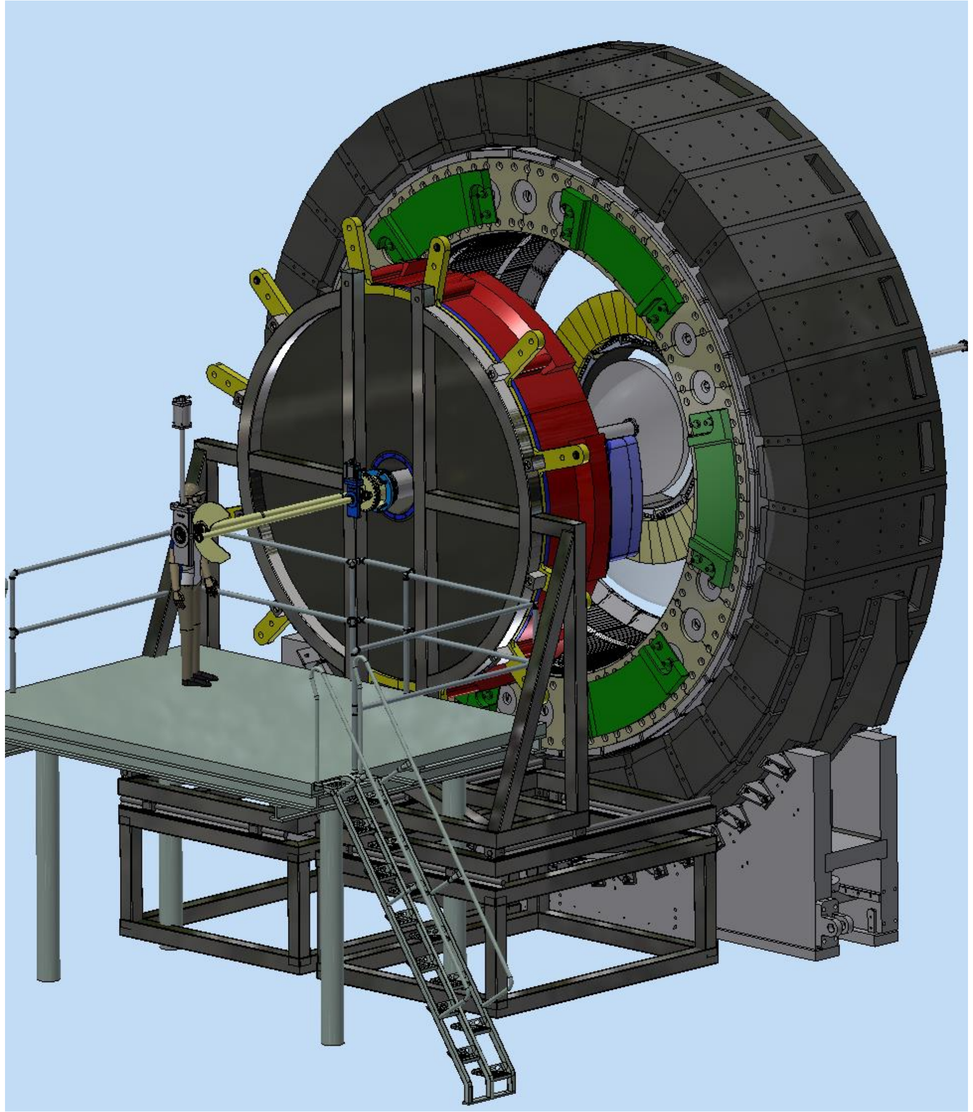
Closed position



Open position: no conflict with beam pipe

dRICH: open position





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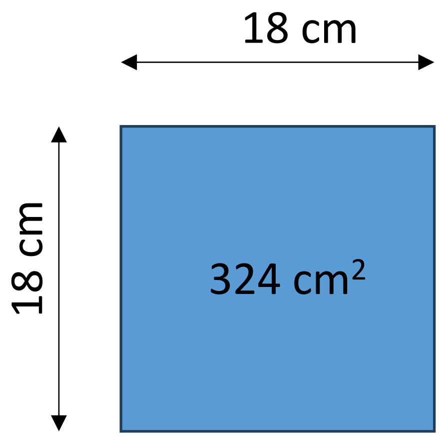
AEROGEL LAYOUT STUDIES

dRICH: aerogel layout

Aerogel Density ≈ 0.15 g/cm3.
Tile size = 180 mm x 180 mm - 20 mm thick

Requirements:
Aerogel Total Thickness 40 mm
Minimize dead space between the aerogel tiles
Light-tight material on the edges of the aerogel tiles



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AEROGEL – Layout_A: nesting_A

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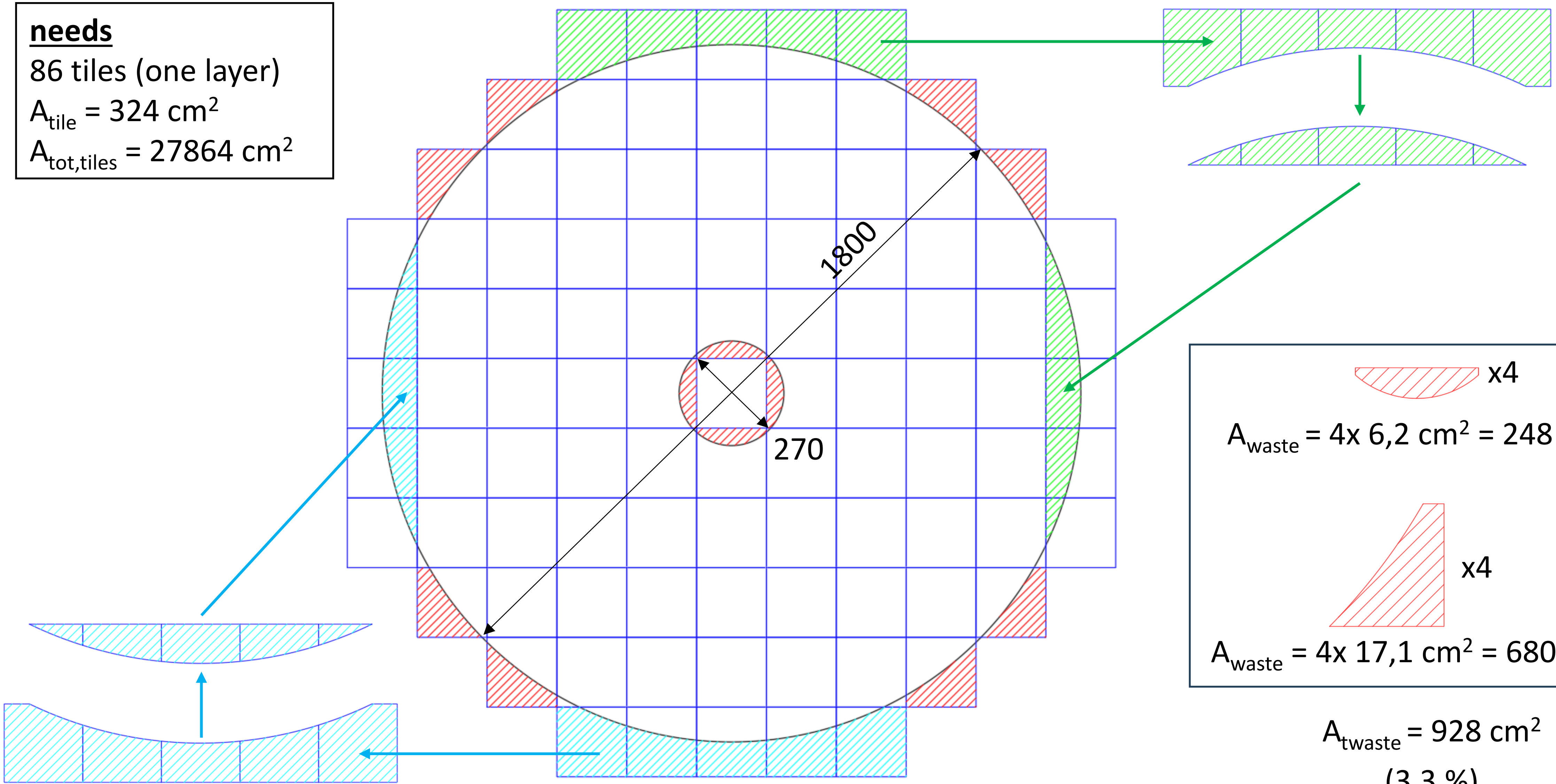
needs
86 tiles (one layer)
A_{tile} = 324 cm^2
$A_{tot,tiles}$ = 27864 cm^2



A_{waste} = 4x 6,2 cm^2 = 248 cm^2

A_{waste} = 4x 17,1 cm^2 = 680 cm^2

A_{twaste} = 928 cm^2
(3,3 %)

AEROGEL – Layout_A: Active Area and Dead Space

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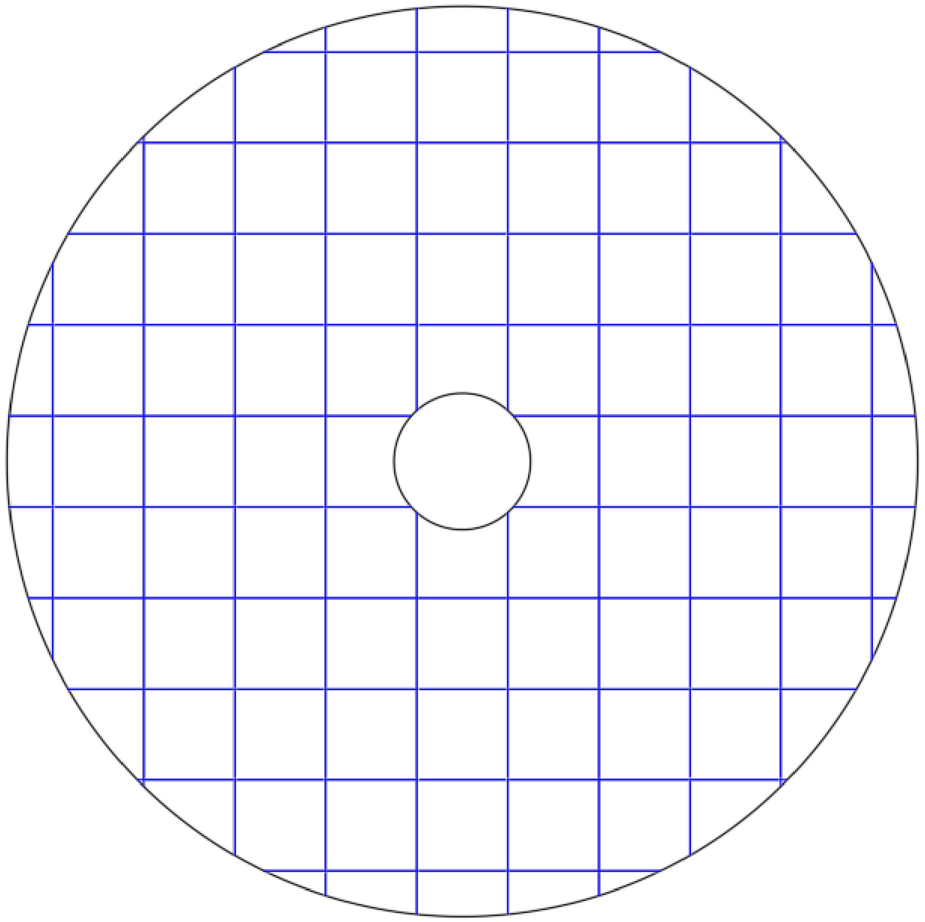
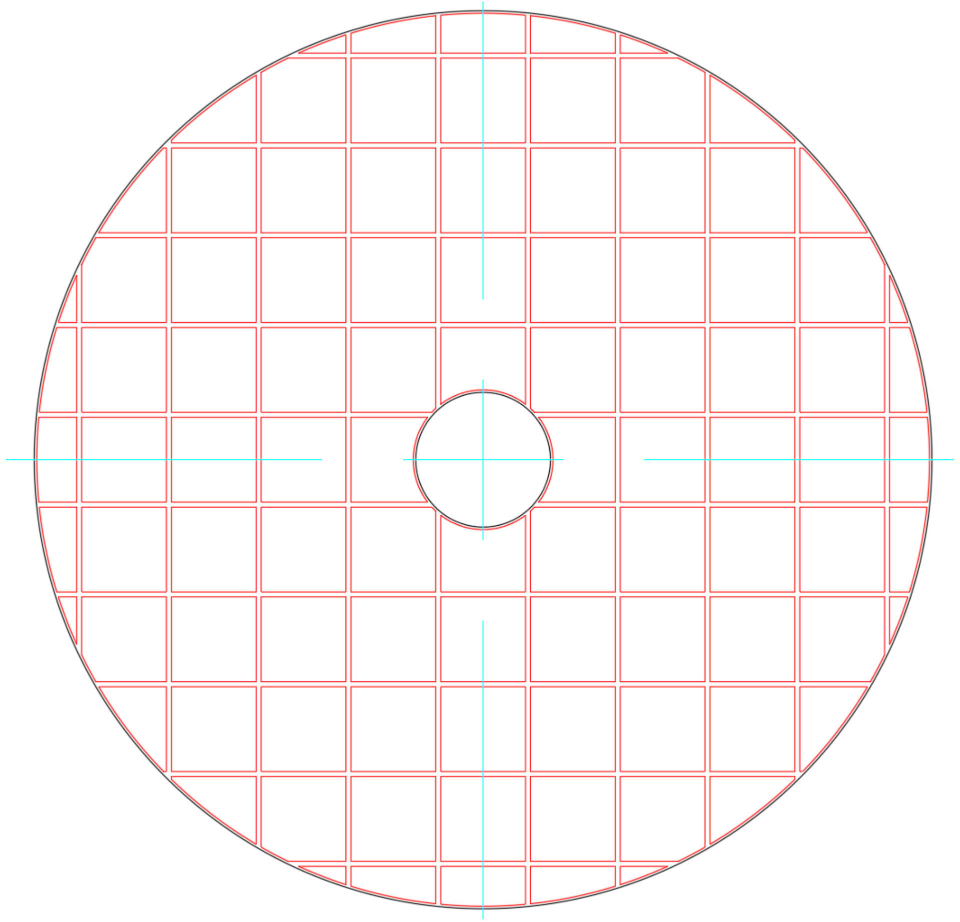


Nominal Active Area (A_n)= 24874 cm^2

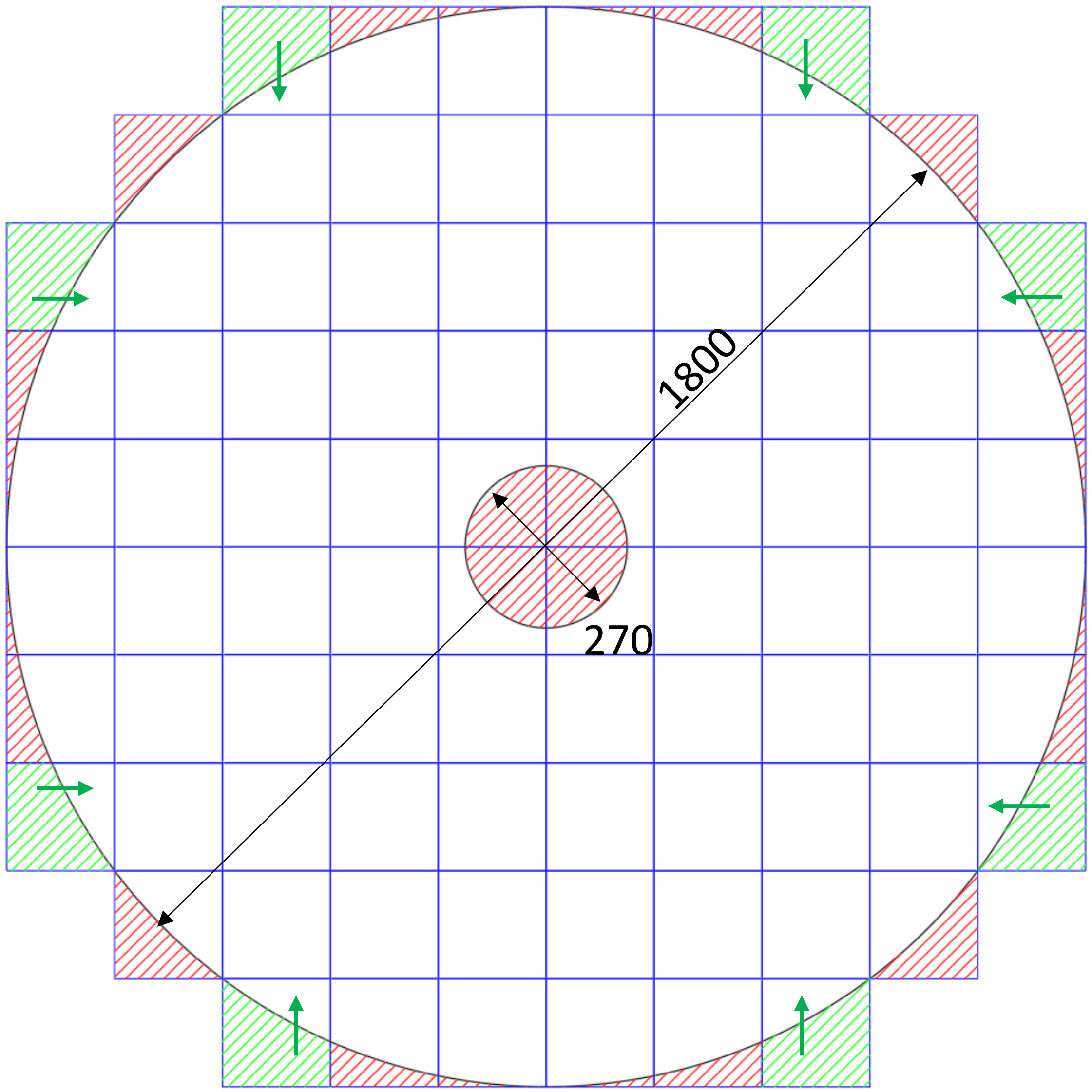


Active Area (A_a) = 21883,5 cm^2

Dead Active Area (A_{da}) = $A_n - A_a$ = 2990,5 mm^2 (12%)

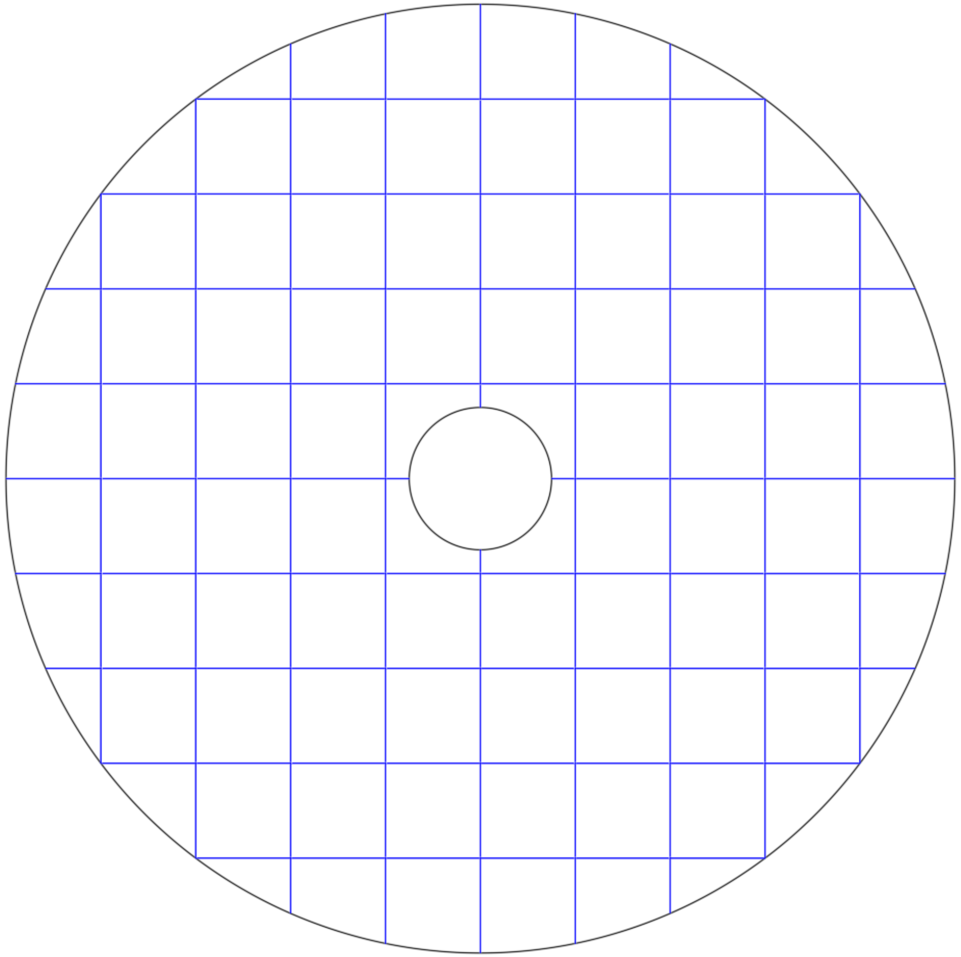
AEROGEL – Layout_B: nesting_B

84 tiles (one layer)
A_{tile} = 324 cm^2
$A_{tot,tiles}$ = 27216 cm^2

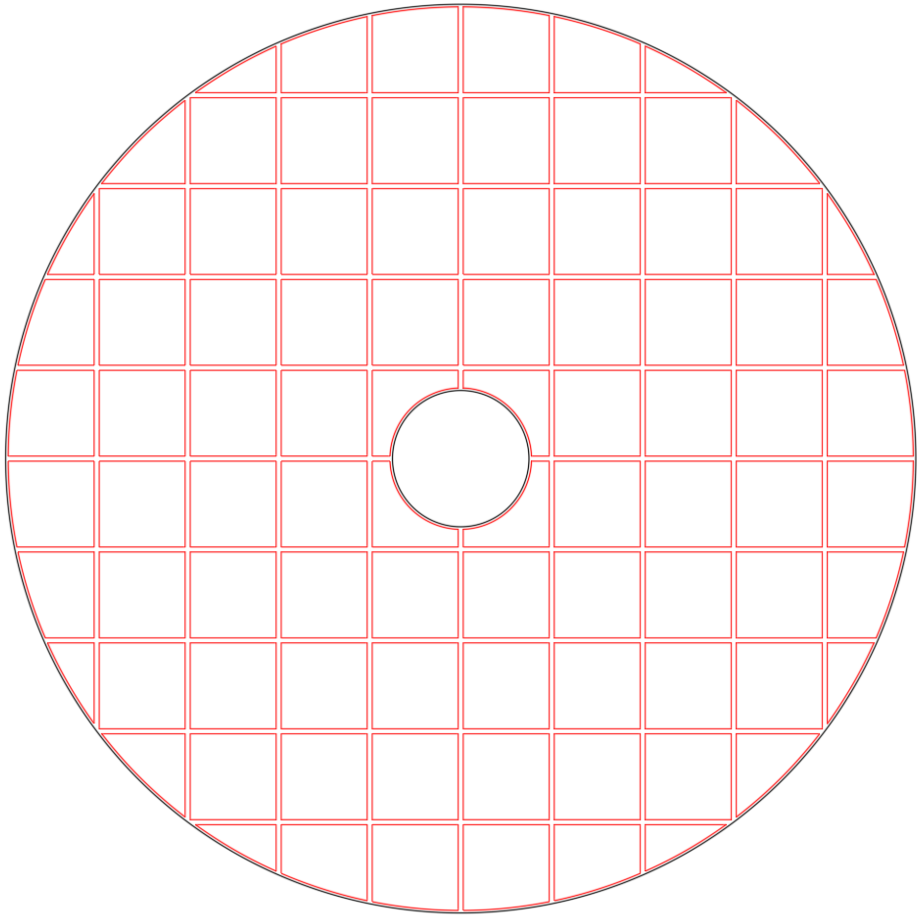


A_{twaste} = 1868 cm^2
(6,8 %)

AEROGEL – Layout_B: Active Area and Dead Space



Nominal Active Area (A_n)= 24874 cm^2



Active Area (A_a) = 21368 cm^2

Dead Active Area (A_{da}) = $A_n - A_a$ = 3506 cm^2 (14%)

AEROGEL – Layout_C: nesting_C

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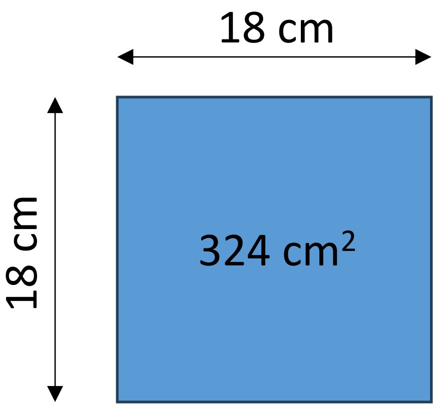
needs

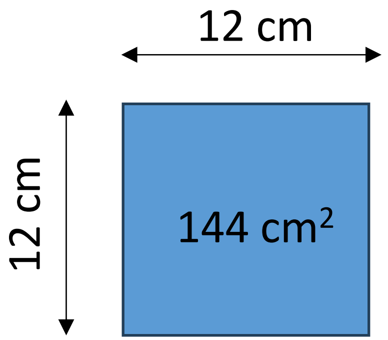
116 tiles (one layer)

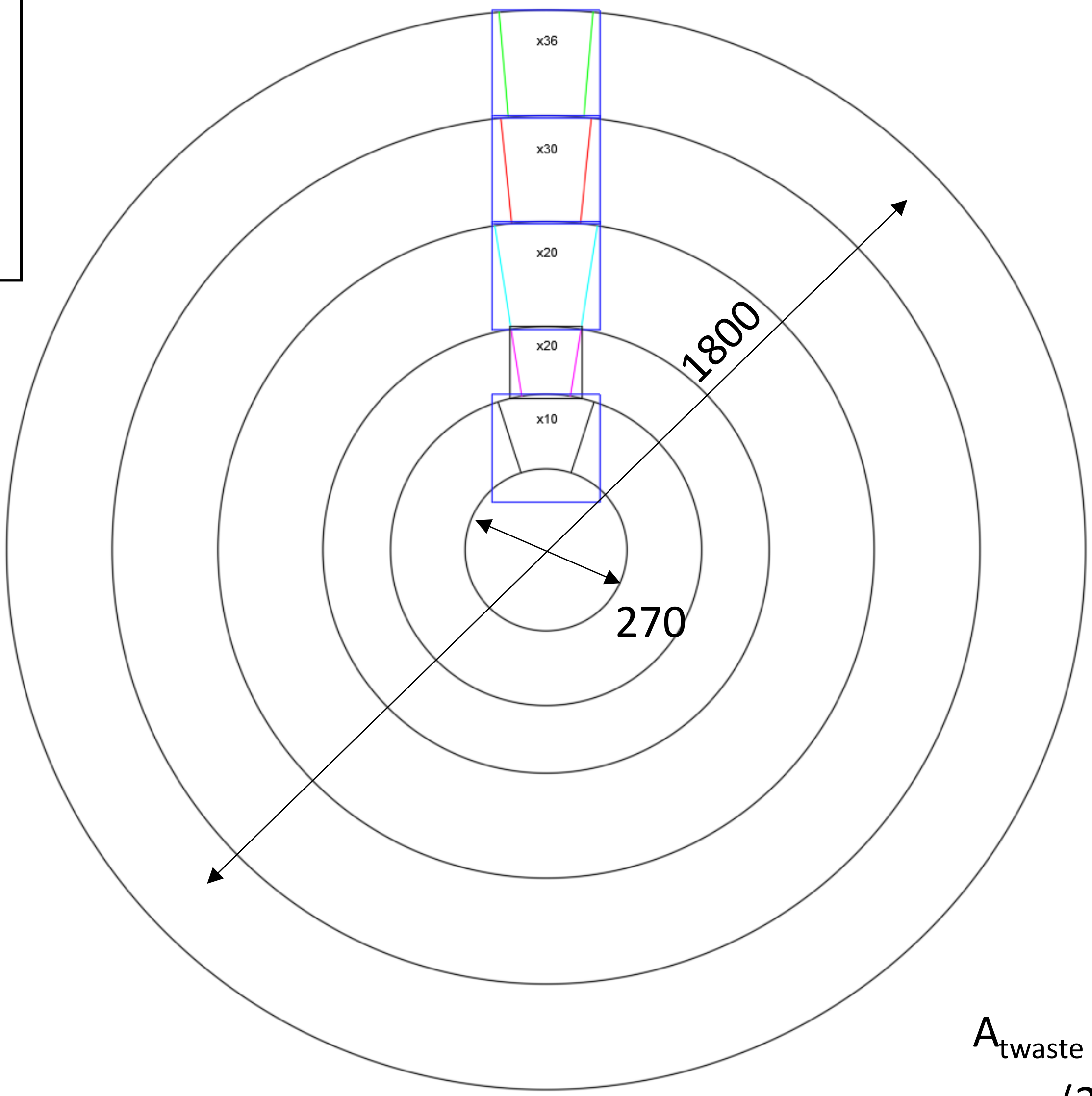
A_{tile} = 18cmx18cm = 324 cm^2

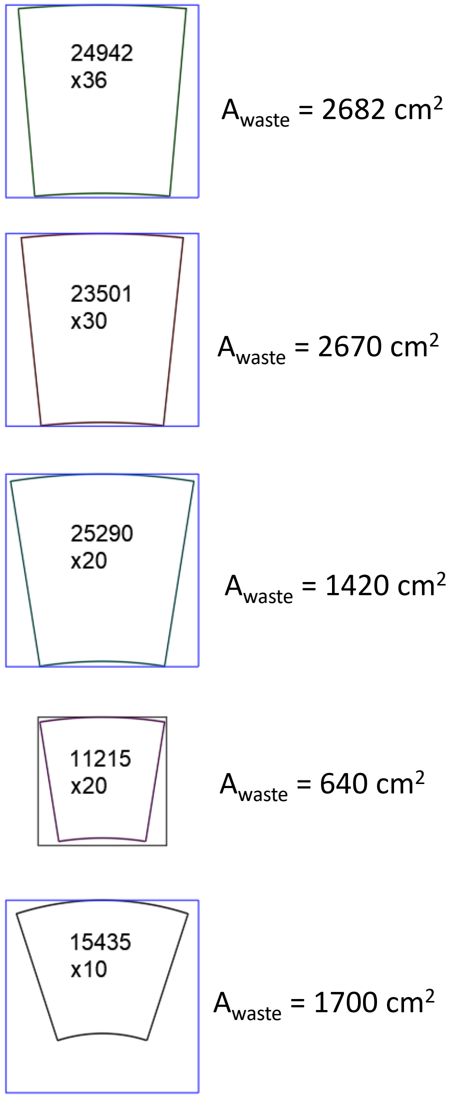
A_{tile} = 12cmx12cm = 144 cm^2

$A_{tot,tiles}$ = 33984 cm^2









A_{twaste} = 9112 cm^2

(26,8 %)

AEROGEL – Layout_C: Active Area and Dead Space

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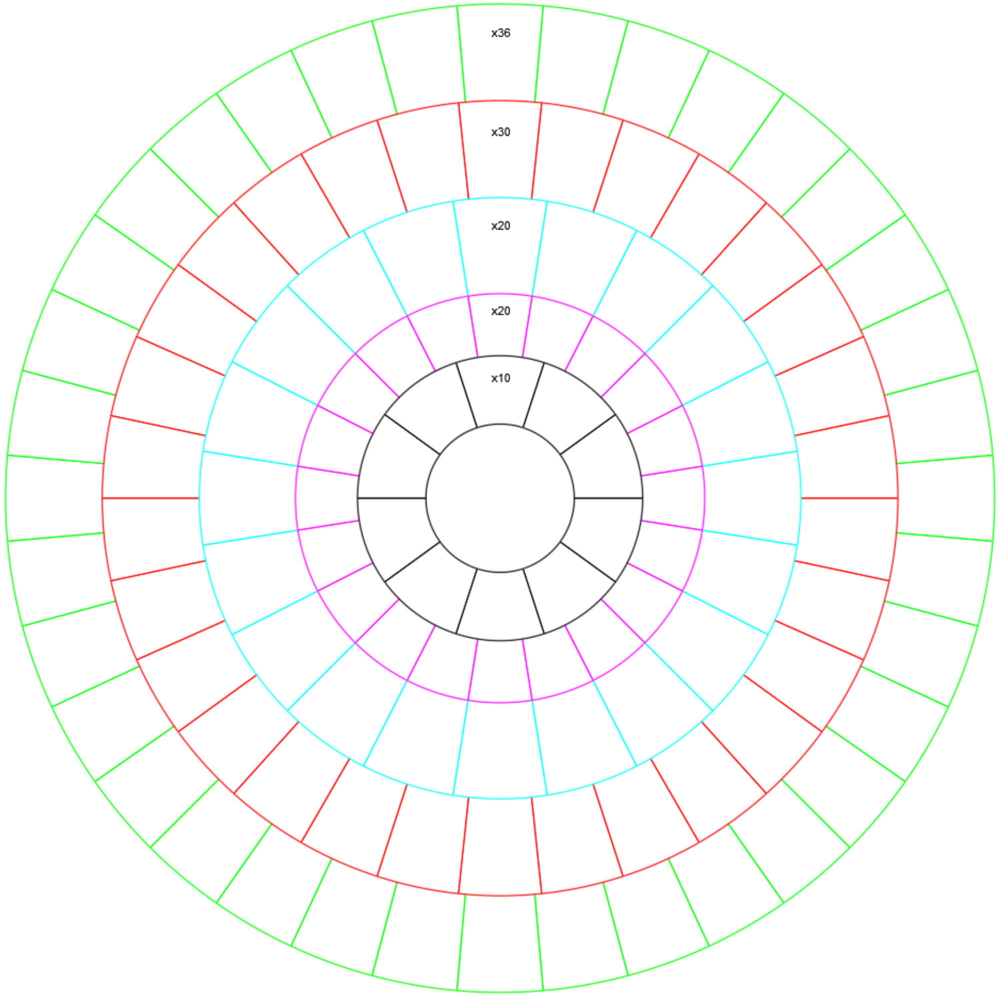
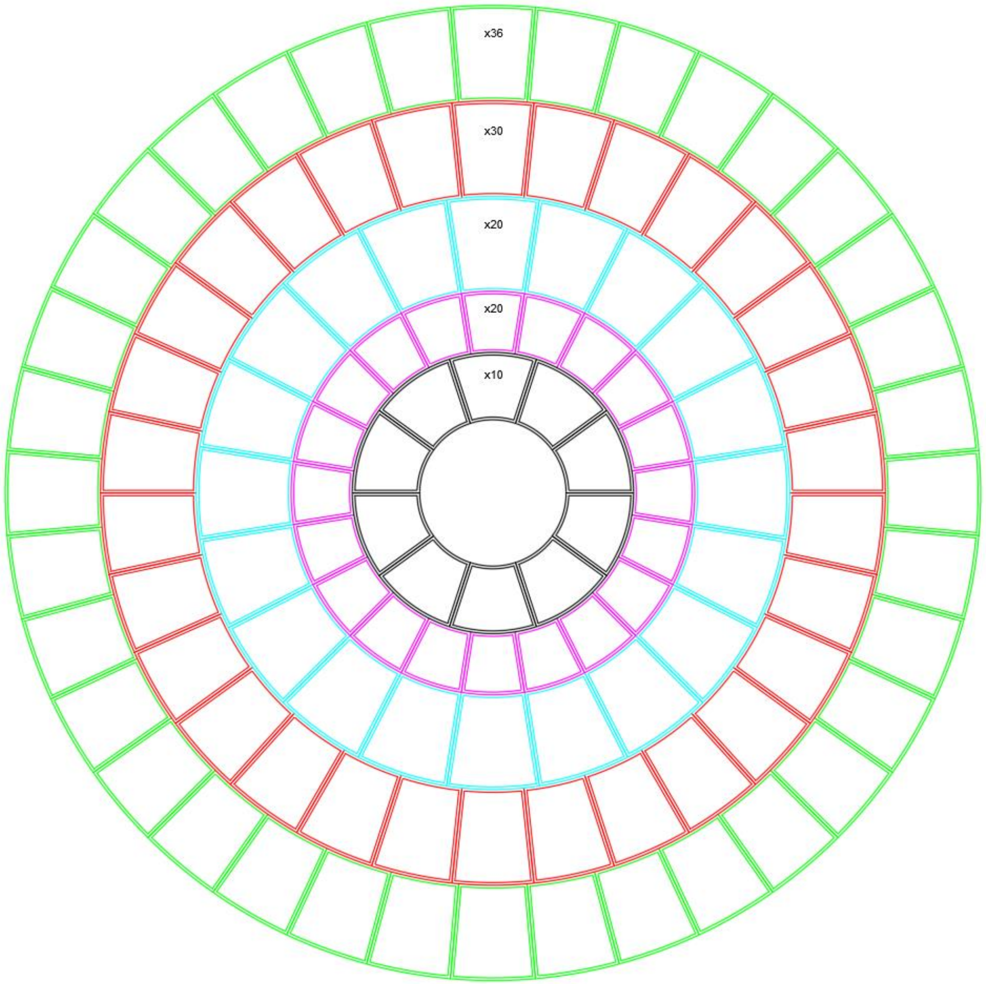


Nominal Active Area (A_n)= 24874 cm^2



Active Area (A_a) = 21605 cm^2
Dead Active Area (A_{da}) = $A_n - A_a$ = 3269 cm^2
(13,1%)

PCB COOLING STUDIES

PDU and boards: cooling and thermal power

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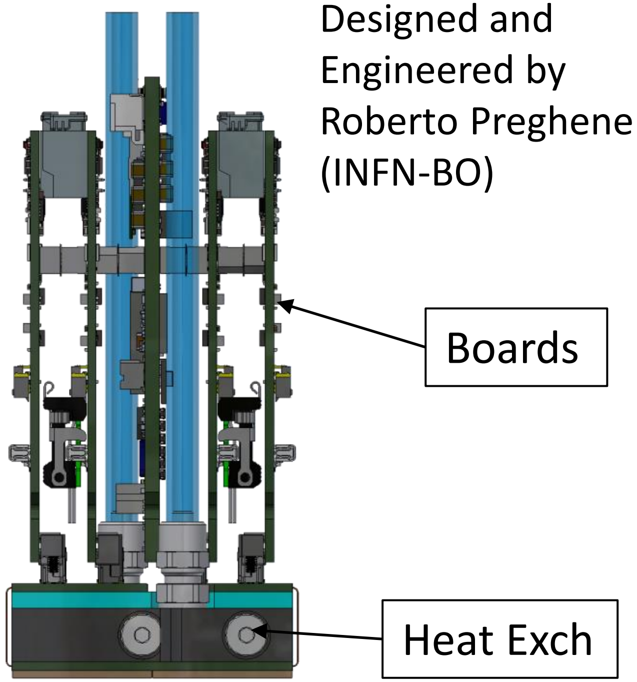
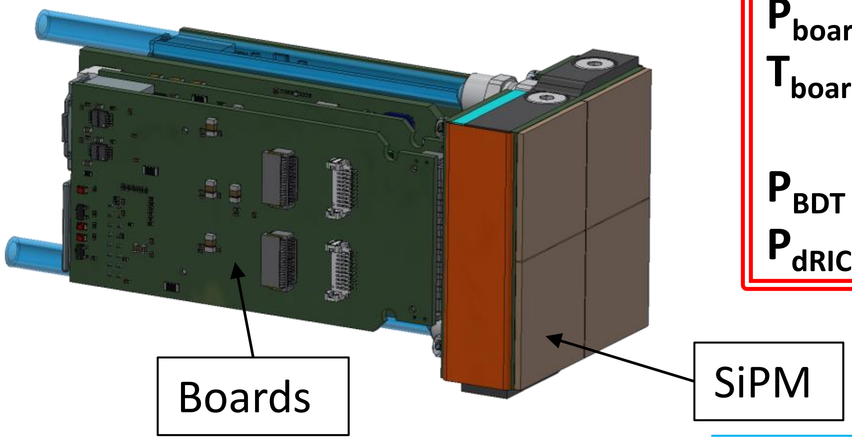


Designed and
Engineered by
Roberto Preghenella
(INFN-BO)



dRICH PDU = 1200
Detector Box PDU = 211
dRICH Detector Boxes = 6

<u>SiPM</u>

$\mathbf{P_{PDU}}$ **= 5 W** (cooling power to be supplied to each PDU unit)
$\mathbf{T_{SiPM}}$ **= -40°C** (SiPM temperature)

$\mathbf{P_{DT}}$ **= 211 × 5 W = 1055 W** (cooling power to be supplied to each detector box)
$\mathbf{P_{dRICH}}$ **= 6 x 1055 W = 6330 W** (cooling power to be supplied to dRICH)

<u>Electronic Boards</u>

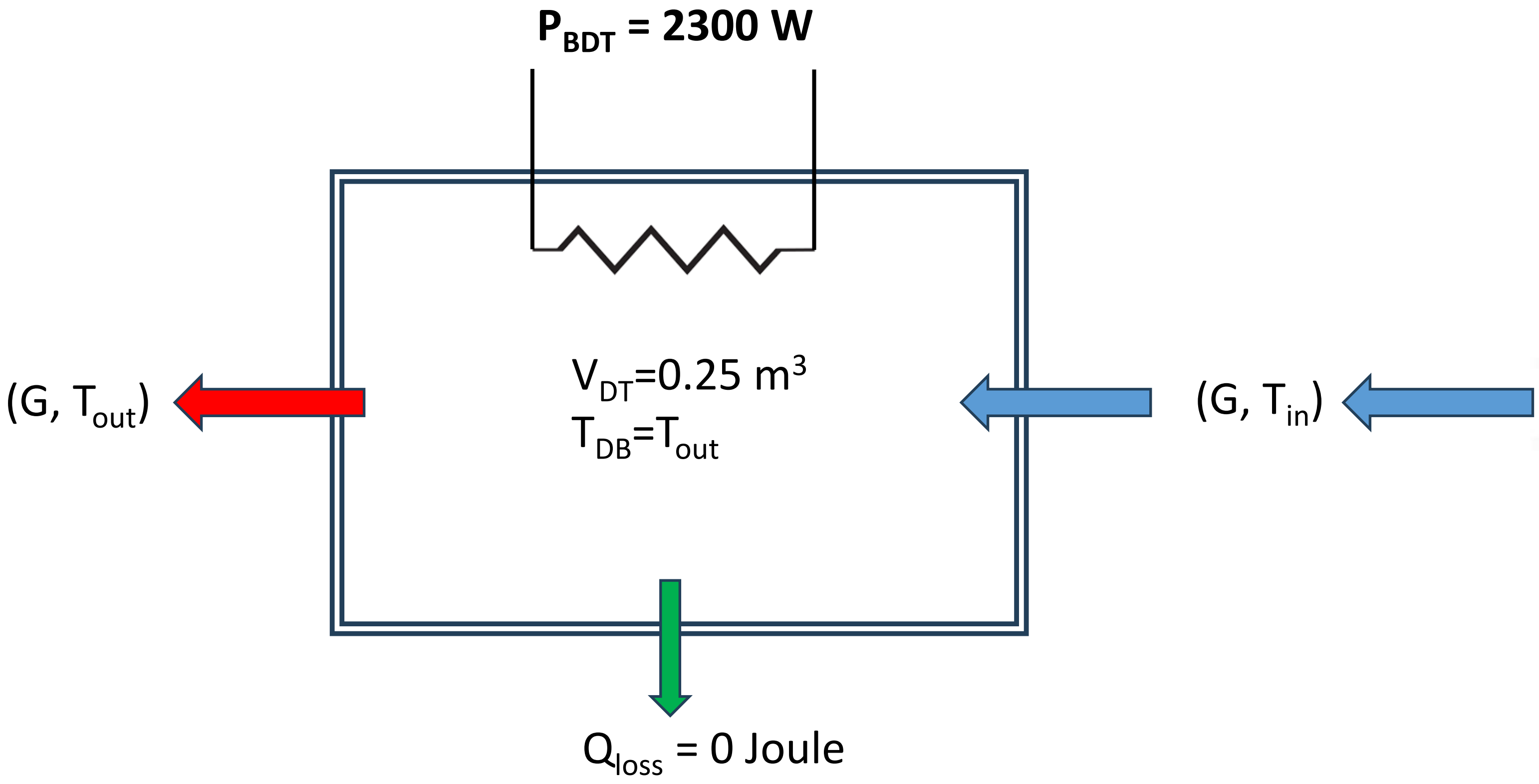
$\mathbf{P_{boards}}$ **= 11 W** (thermal power generated by each PDU unit)
$\mathbf{T_{boards}}$ = **30°C** (maximum admissible boards temperature)

$\mathbf{P_{BDT}}$ **= 211 × 11 W = 2321 W** (thermal power generated by each detector box)
$\mathbf{P_{dRICH}}$ **= 6 x 2321 W = 13926 W** (thermal power generated by dRICH)

Detector Box: board’s air cooling

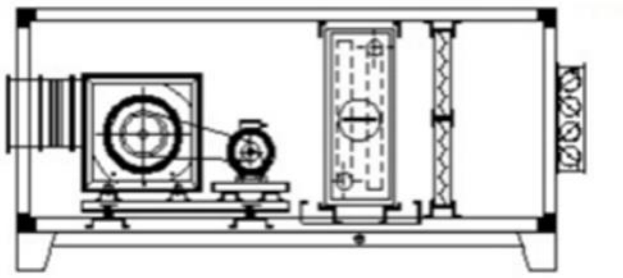
Hypothesis:

- Detector box perfectly insulated
- Thermal interaction with the SiPM cooling system not considered



Disadvantages:

- Risk of condensation
- High noise
- High vibrations
- Big size of ducts



- External air intake
- Bag filter
- Cold coil
- Fan

Detector Box: FEE cooling

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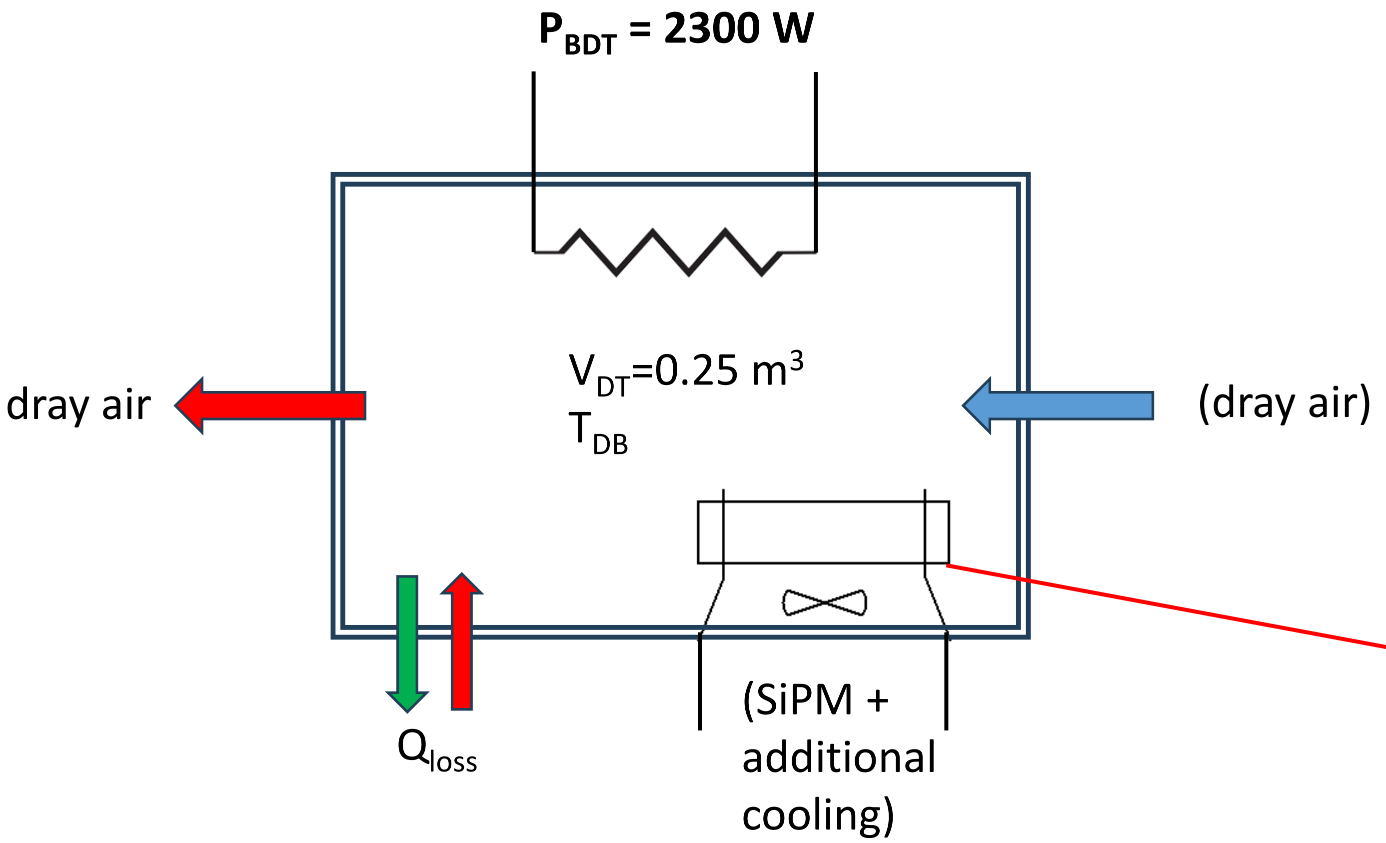
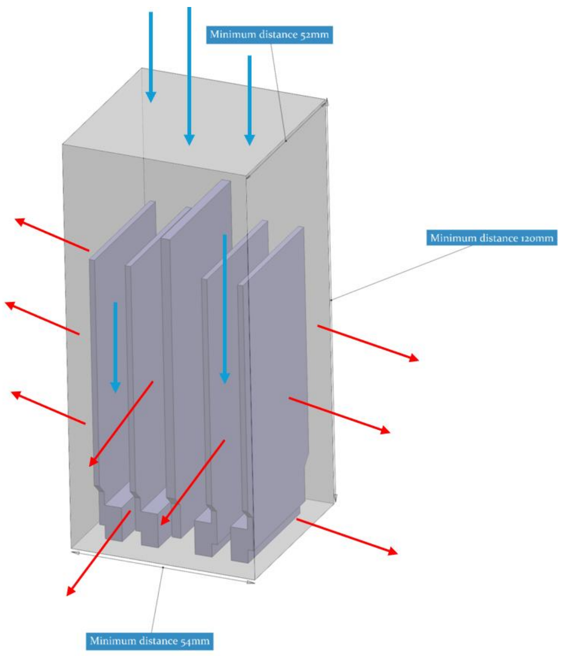
Hypothesis:

- Detector box no perfectly insulated
- Thermal interaction with the SiPM cooling system considered



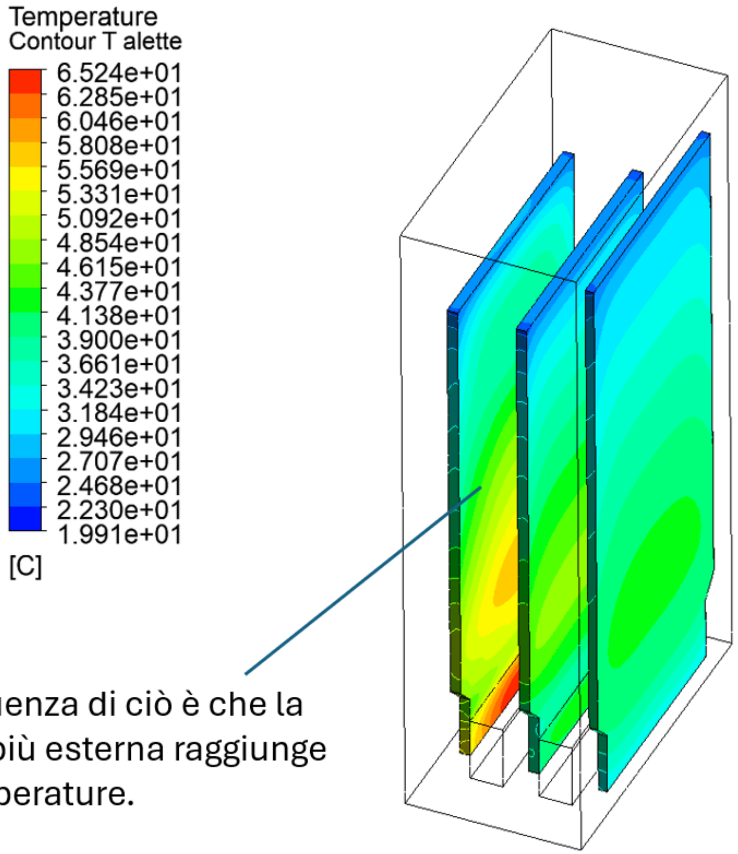
Inlet/Outlet pipe diameter: 15/20 mm

Detector Box: FEE cooling

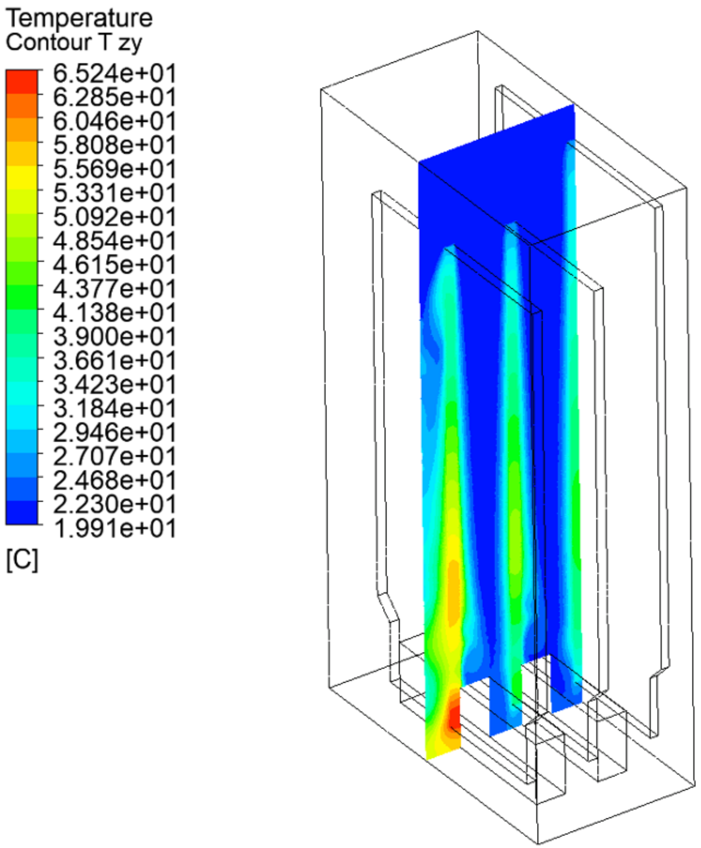


Condizioni su sezione inlet: v = 1 m/s, T = 20° C.

Singola PDU, aria dall’alto

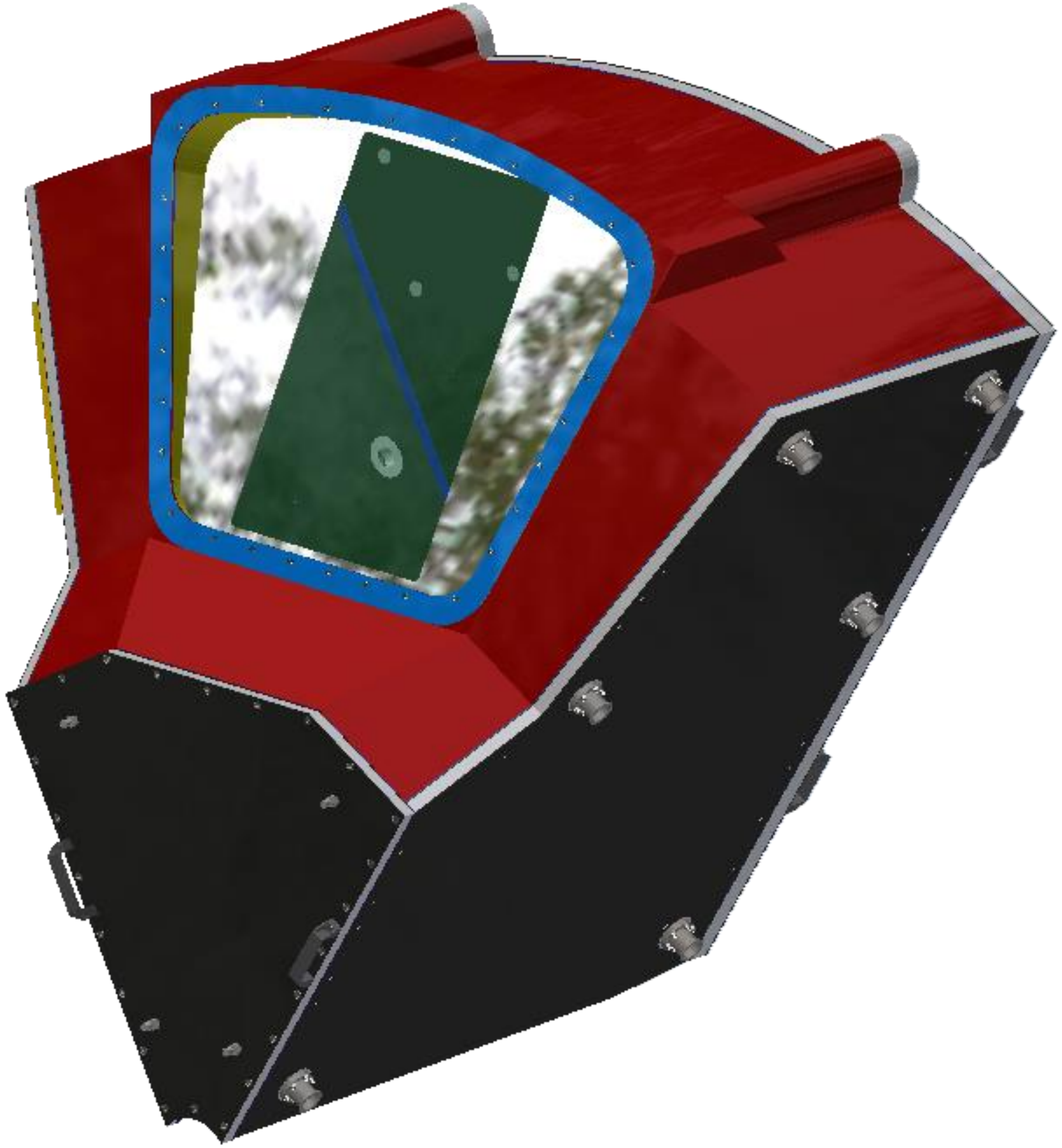


Conseguenza di ciò è che la scheda più esterna raggiunge alte temperature.



PROTOTYPE and R&D projects

dRICH: prototype

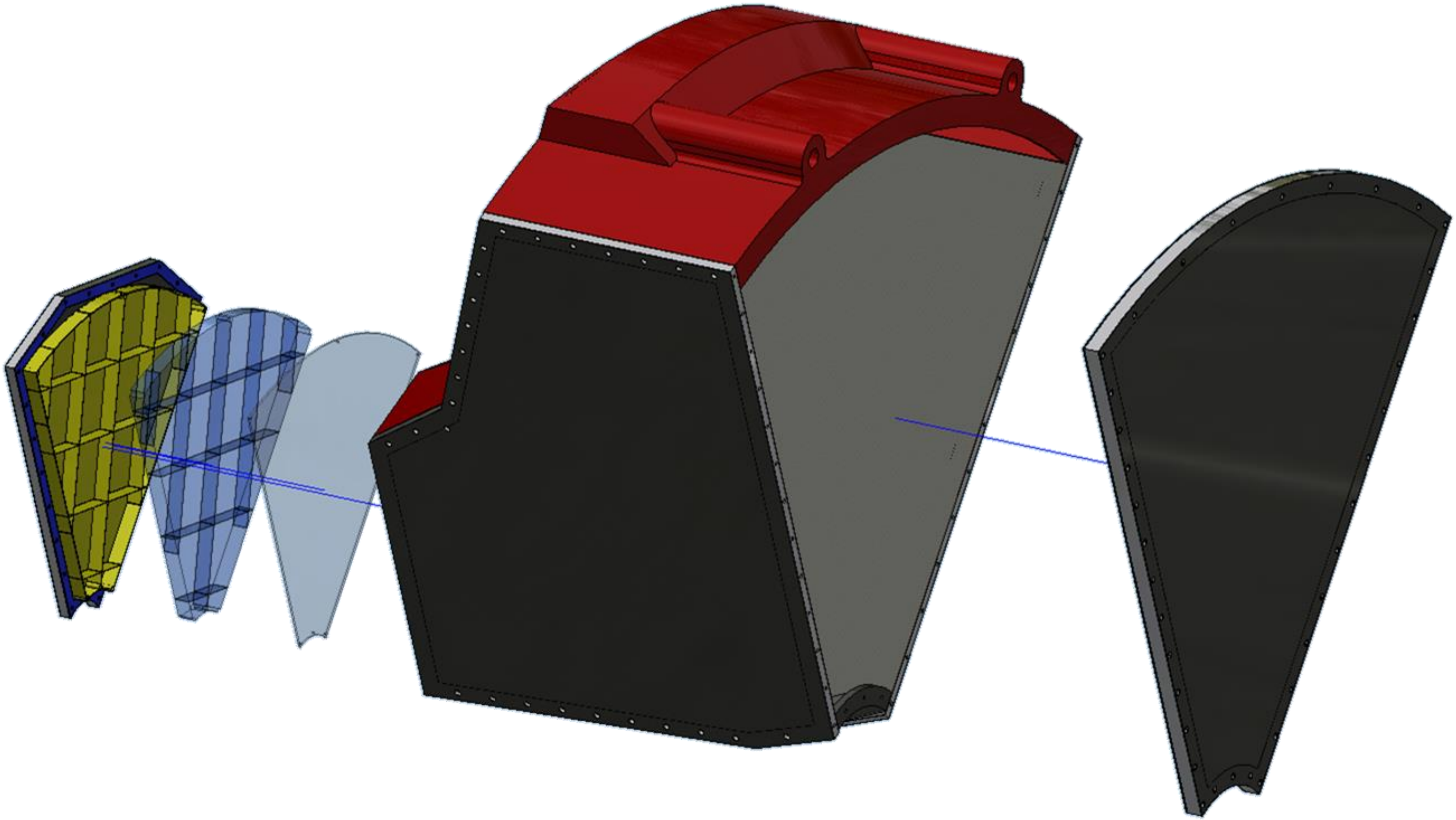


Full-scale (1:1) prototype representing one-sixth of the complete dRICH detector.

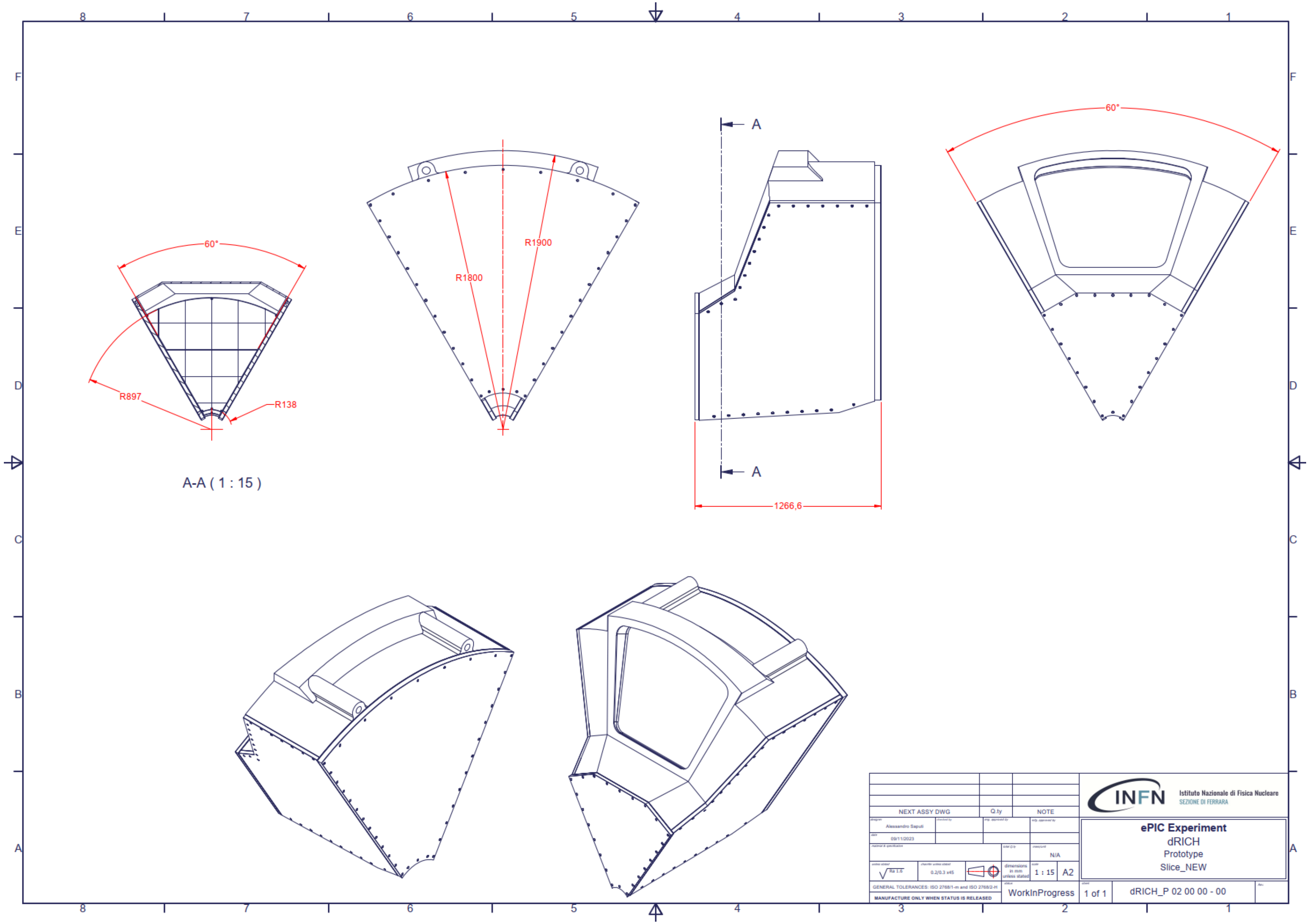
Status:

- The drawings are ready.
- The tender has been completed.
- Construction should start before the end of June 2025.

dRICH: prototype



dRICH: prototype



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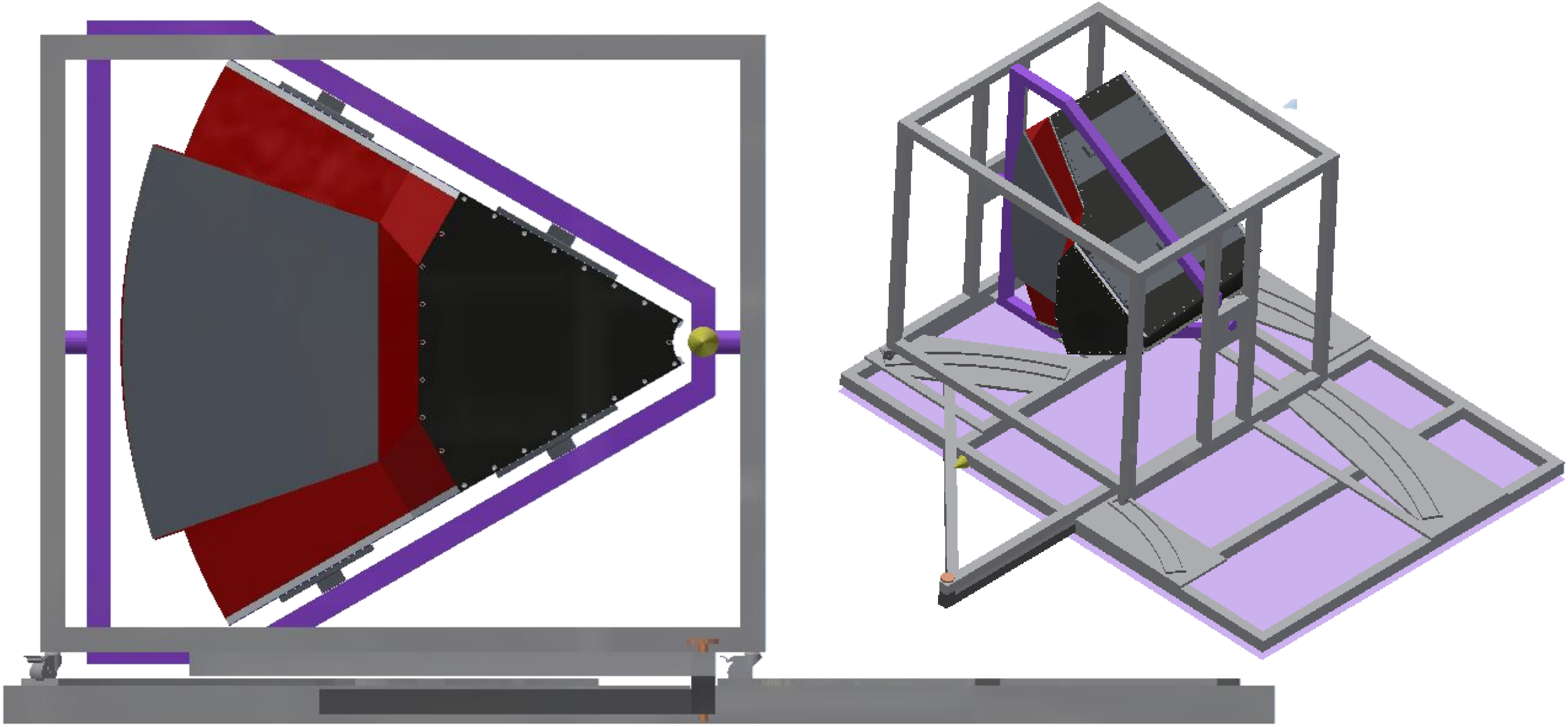
dRICH: test beam setup



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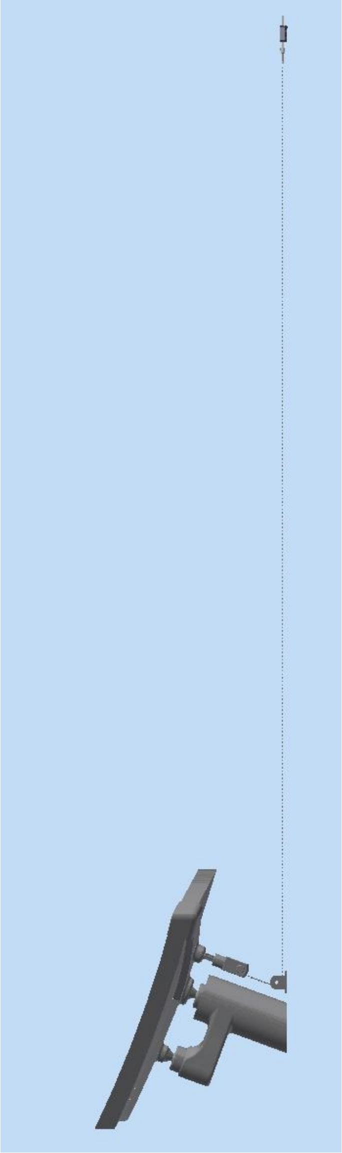
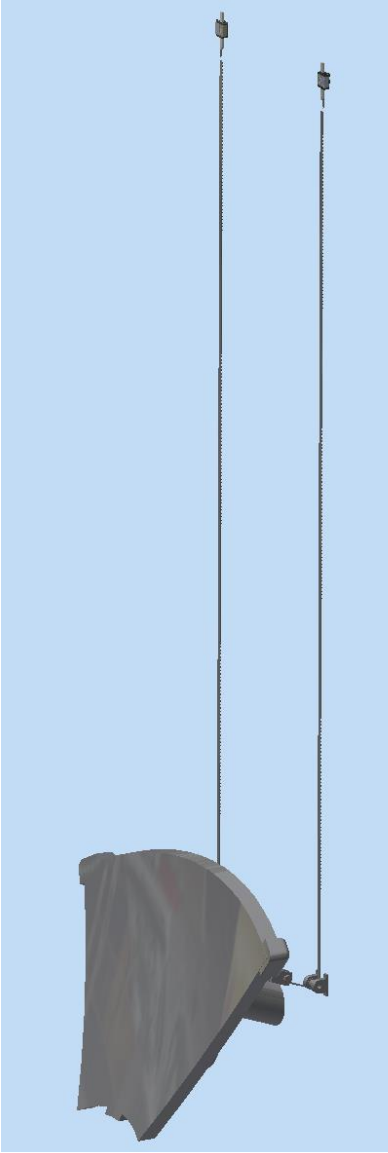
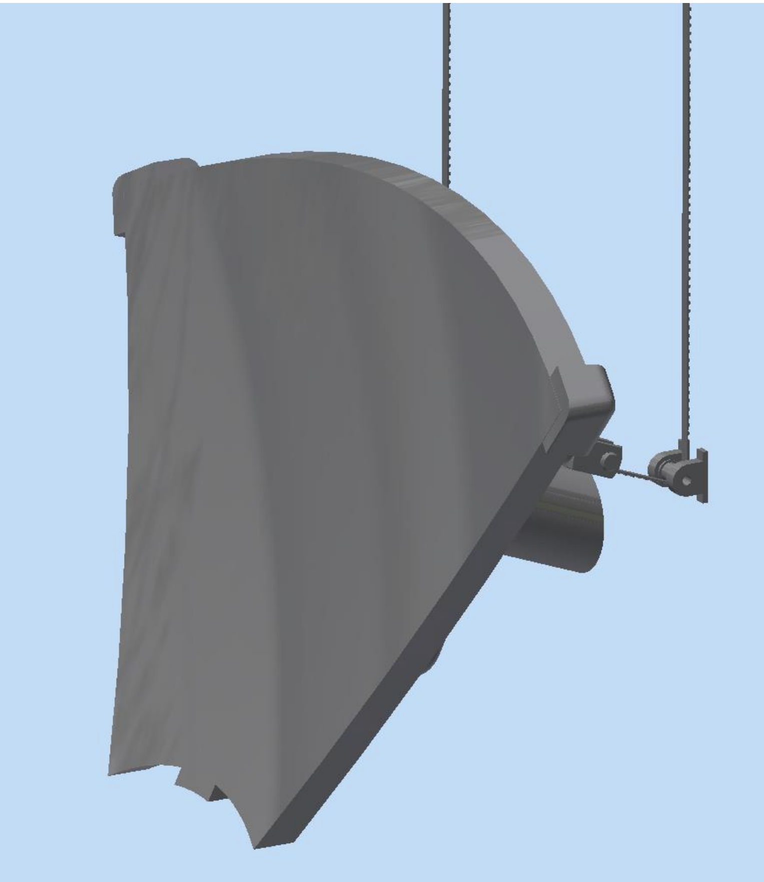
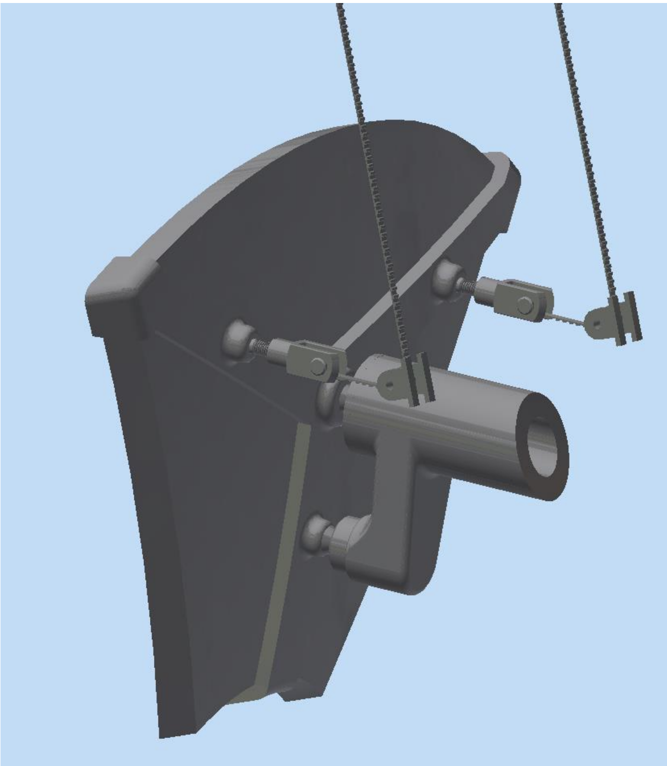
dRICH: mirror for prototype









Quartz Window: FEA

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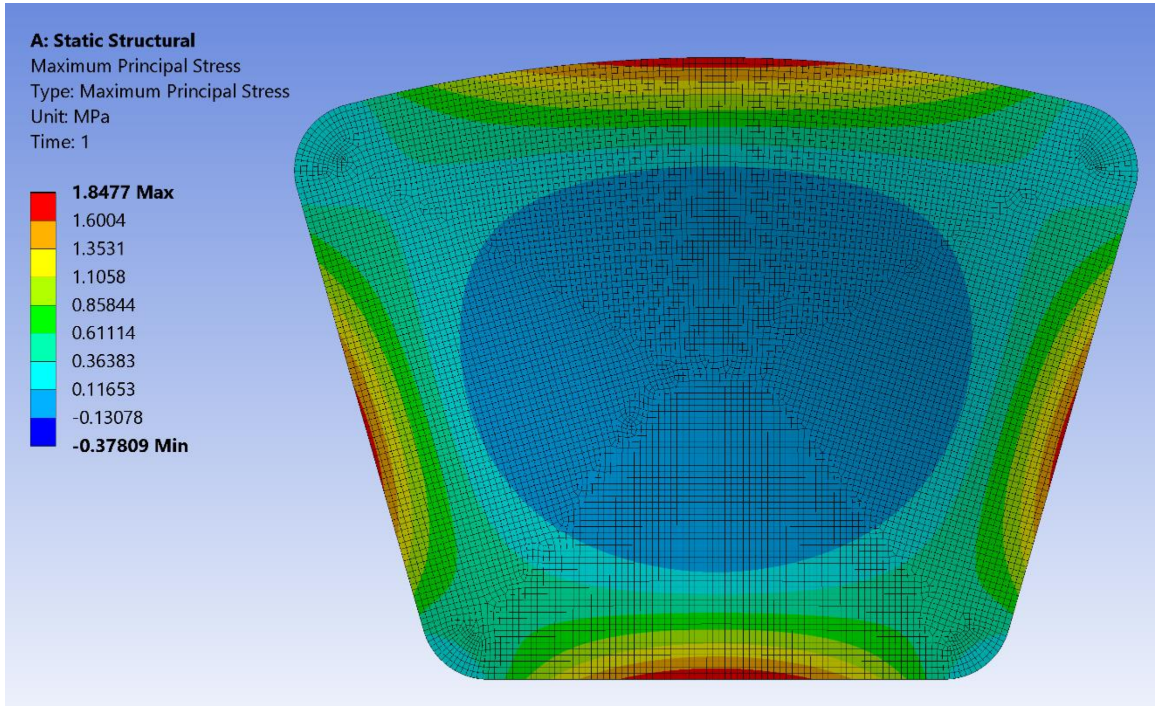
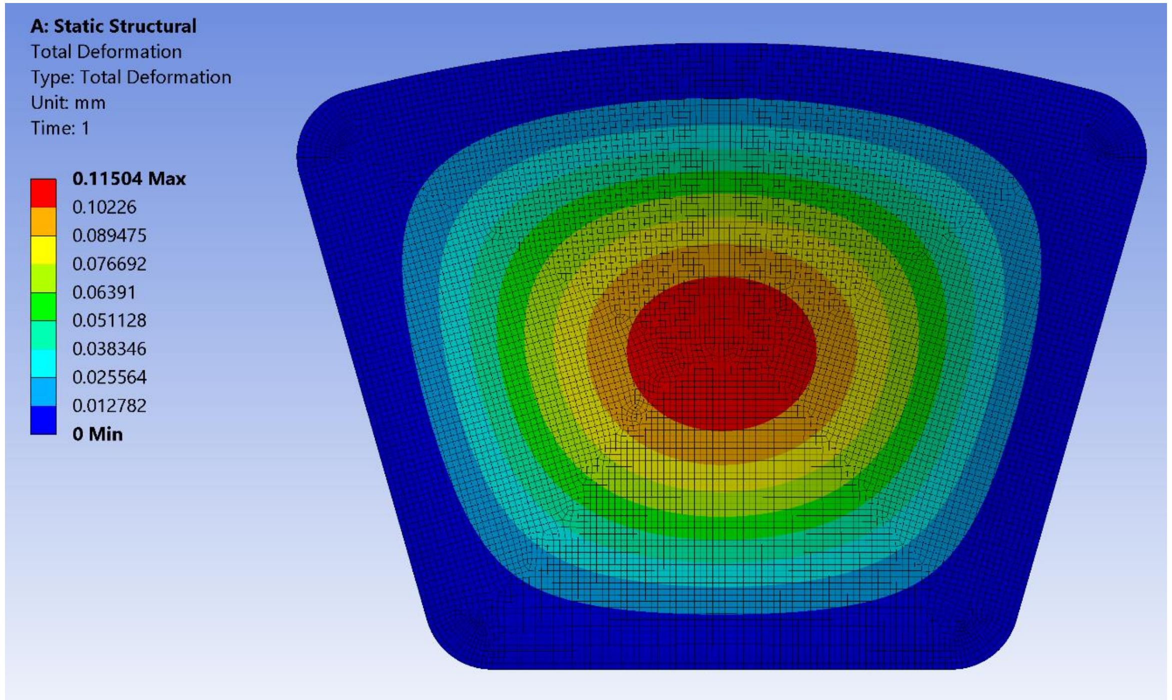
Maximum Principal Stress (S1)



- Thickness: **t_1=8 mm**;
- Uniformly distributed (absolute) pressure over the entire surface: 0,0005 MPa (5 mbar)
- Constrains: Fixed along the edge surface

Deformation along Z Axis

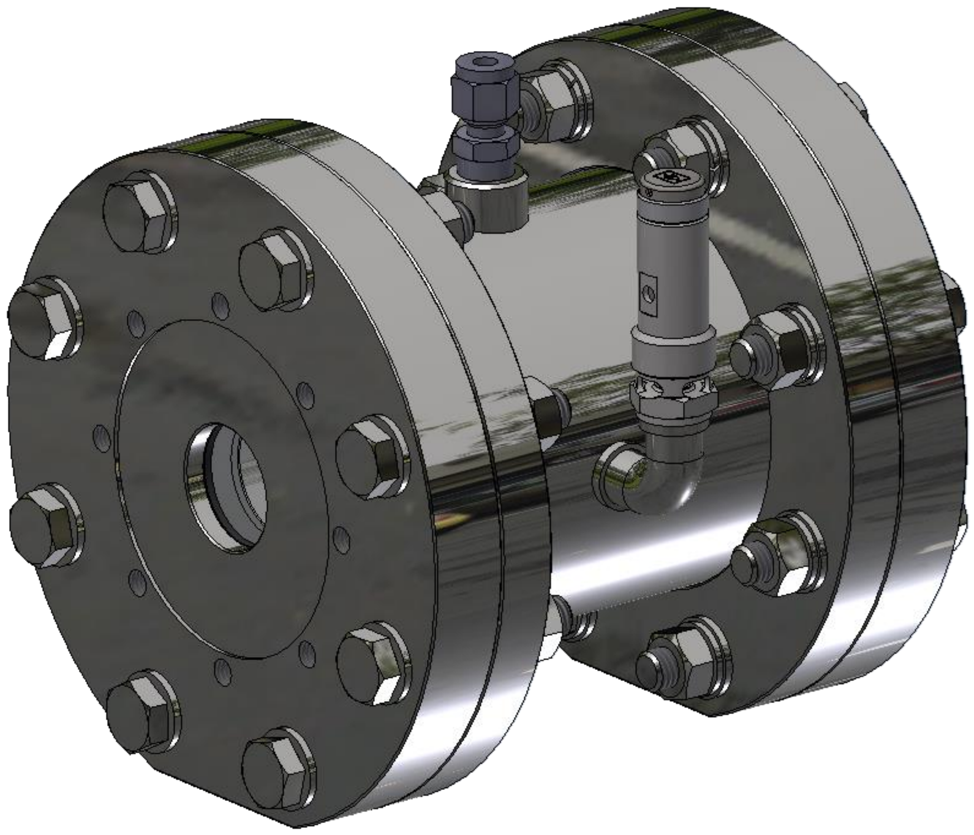


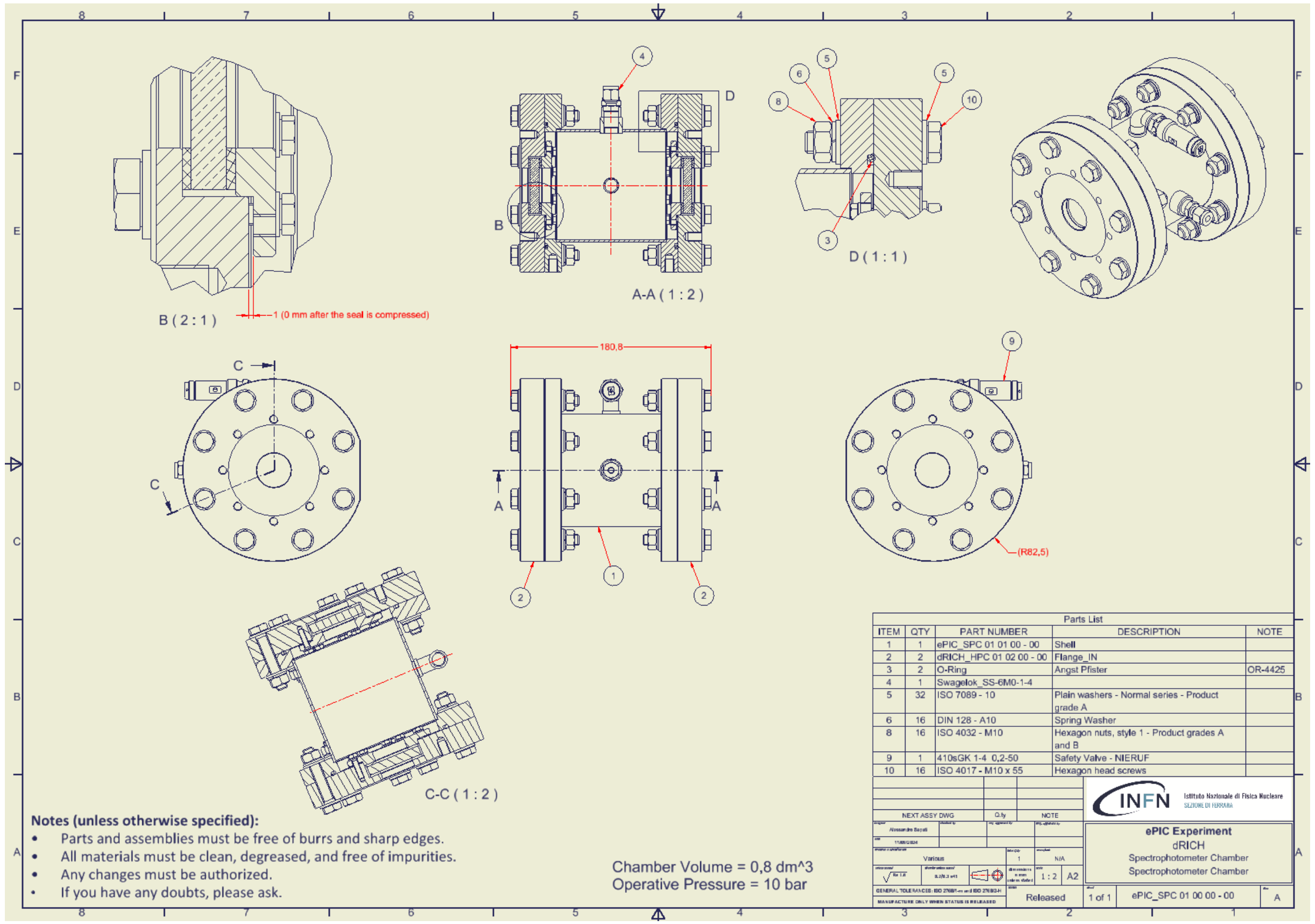
- Maximum Principal Stress S1=1,9 MPa;
- Maximum Deformation along Z Axis = -0,11 mm
- Minimum Calculated Safety Factor SF_c = 15

$\boxed{SF_c > 7}$ ⟶ checked

Spectrophotometer Chamber: target R&D

Design Pressure: 1,43 Mpa
Operative Pressure: 1 MPa





This chamber has been designed to study:

- Gas permeability of carbon fiber
- Gas transparency in the visible spectrum
- Gas-aerogel interactions

High Pressure Chamber: generic R&D

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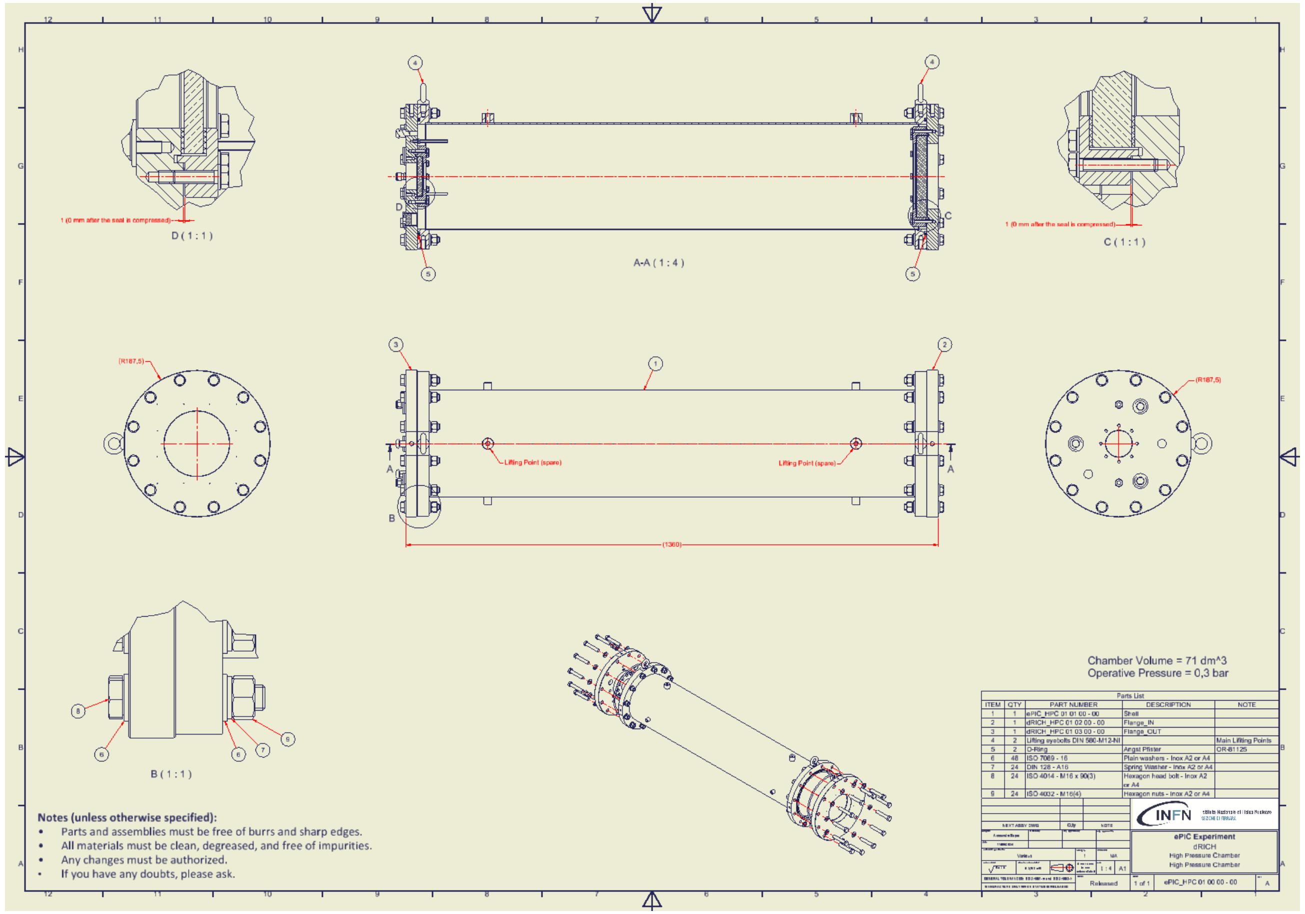
Design Pressure: 0,5 Mpa
Operative Pressure: 0,3 MPa



This chamber has been designed to study risk mitigation strategies for greenhouse gases.

Quartz Window: stress&strain calculation - t_1=8 mm

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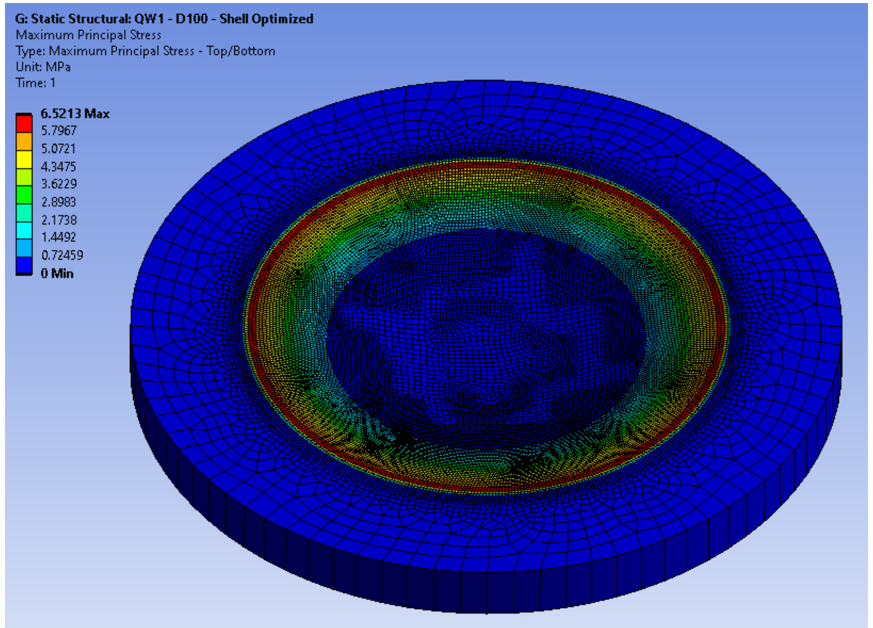
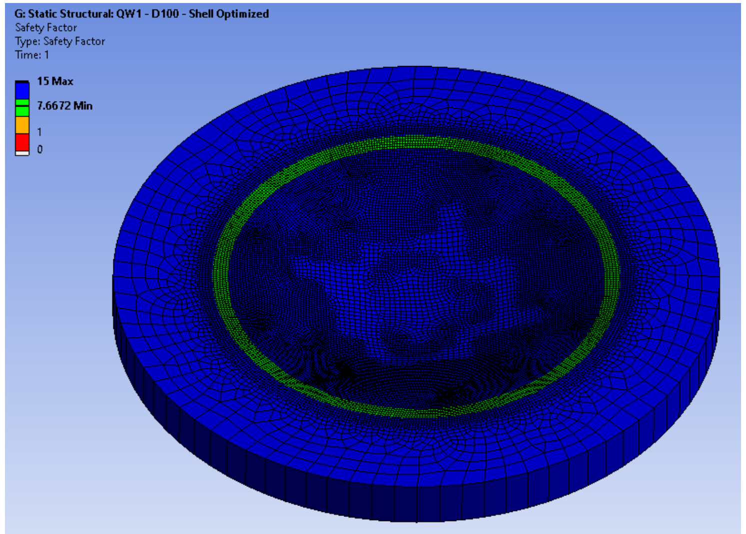
- Thickness: **t_1=8 mm**;
- External diameter: D_1=100 mm
- Uniformly distributed (absolute) pressure over the entire surface (d_1=68mm): 0,5 MPa
- Constrains: Fixed along the edge surface

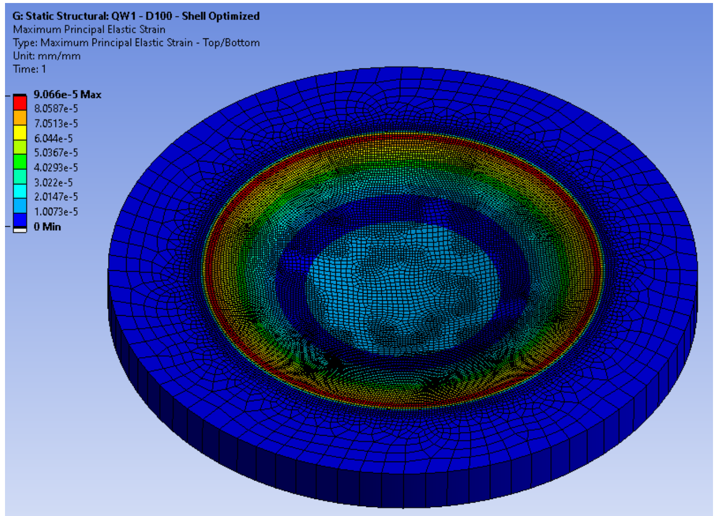
Maximum Principal Stress (S1)



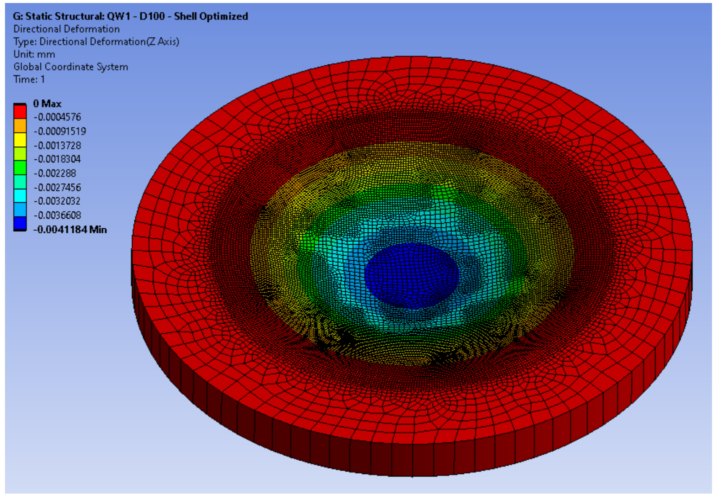
Safety Factor



Maximum Principal Strain



Deformation along Z Axis



- Maximum Principal Stress S1=6,5 MPa;
- Maximum Principal Strain = 0,00009
- Maximum Deformation along Z Axis = -0,004 mm
- Minimum Calculated Safety Factor SF_c = 7,6

$SF_c > 7$ ⟶ checked

Conclusions and NEXT Steps

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- **Consolidation of the dRICH mechanical design and cooling design**: refining and finalizing the mechanical design of the dRICH……
- **Integration study of dRICH into the ePIC Apparatus:** fixing system, service integration……….
- **Study of the Extraction and Insertion System (Moving System):** design and optimization of the moving system used for the extraction and insertion of the dRICH detector within the ePIC apparatus
- **Structural Study of dRICH:** A detailed structural analysis of the dRICH detector will be conducted using Finite Element Method (FEM) simulations.

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