ICEC27-ICMC 2018
27th International Cryogenic Engineering Conference
International Cryogenic Materials Conference 2018
September 3-7 2018 Oxford England

Ultra thin and radiation transparent cryostats for FCC detector magnets

- First analyses of insulation materials -

Veronica Ilardi

H. Silva, A. Dudarev, T. Koettig, P. Borges de Sousa, L. N. Busch, T. Kulenkampff, E. R. Bielert and H.H.J. ten Kate

Content

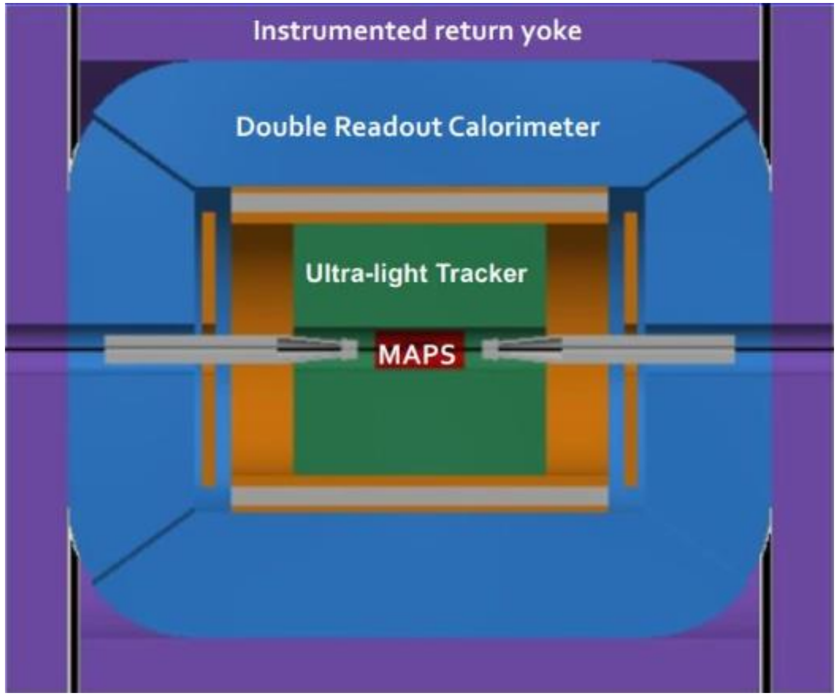
1. Requirements and design studies proposed
2. Innovative insulation materials
3. Thermal conductivity measurements on Cryogel
4. Heat load of cryostat using Cryogel
5. Model cryostat for thermal testing of Cryogel and glass spheres
6. Conclusion and outlook

Requirements and design studies proposed

FCC-ee detector designs proposed:
- A conventional 2 T/7.6 m bore solenoid around the calorimeter
- An ultra-thin and transparent 2 T/4 m bore around the tracker

FCC-hh detector designs proposed:
- A 4T/10m bore main solenoid around the calorimeter, plus two forward dipoles providing additional bending power
- An ultra-thin and transparent 4 T/4 m bore around the tracker

Motivation to develop a new, challenging FCC-ee design:
- Magnetic field only required in the tracker and in muon chambers
  → most of stored energy (~80%) is wasted in the calorimeter
- By placing the solenoid inside the calorimeter, it is possible to save:
  - Factor ≅ 4.2 in stored energy
  - Factor ≅ 2.1 in cost



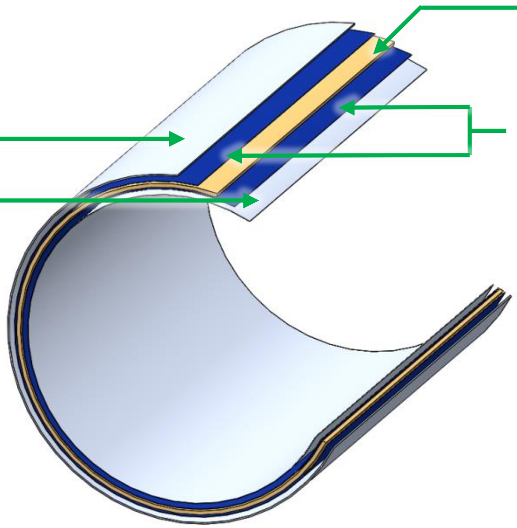
IDEA detector (International Detector Electron Accelerators), thin solenoid inside the calorimeter

Two approaches for the ultra-light cryostats:
- Minimize material thickness in metallic cryostat using honeycomb-like structures or corrugated plates (not presented here)
- Use an insulating material with sufficient mechanical resistance paired with lowest thermal conductivity

2 T/4 m solenoid cryostat - Innovative insulation materials

Design drivers:

- 4 m bore, 6 m length
- Radiation length $X_0 < 1$ in radial direction
- Radial envelope < 300 mm

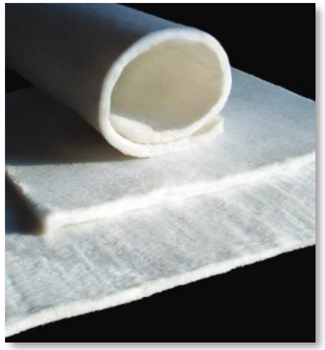
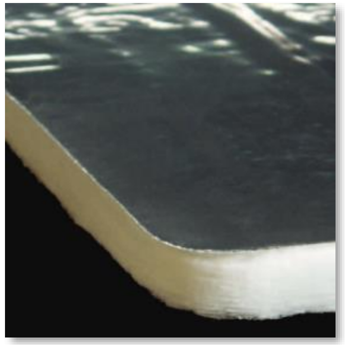


Concept:

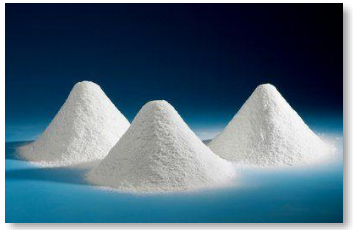
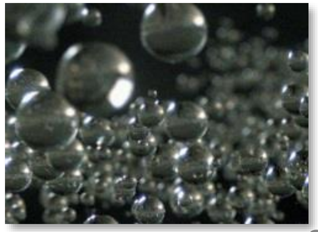
- Classical sandwich of vacuum vessel, radiation shield, MLI and cold mass is replaced
- Thin cryostat walls supported by a material providing thermal insulation and structural support

Materials of interest:

- Cryogel Z (Aspen Aerogels)
  Density: 0.16 g/cm^3
  Thermal conductivity measured: 0.017 W/mK@24°C, 0.1 bar compression

- K1 glass spheres (3M)
  Density: 0.125 g/cm^3
  Calculated thermal conductivity: 0.047 W/mK@21°C, no compression
  Particle size: 65 micron (by volume)

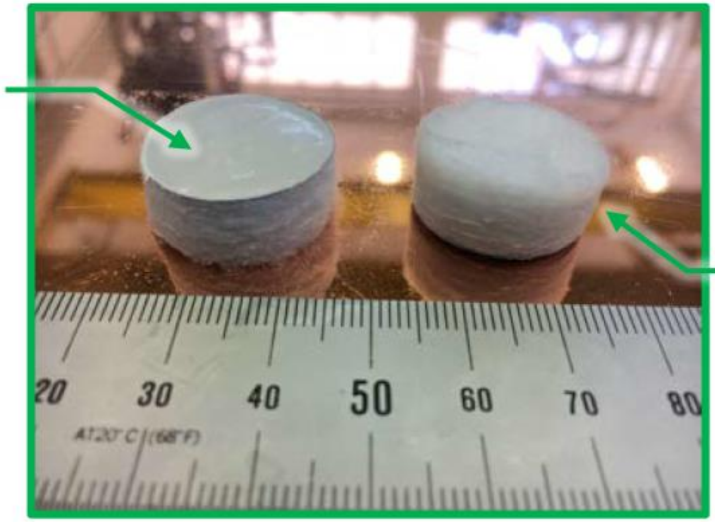



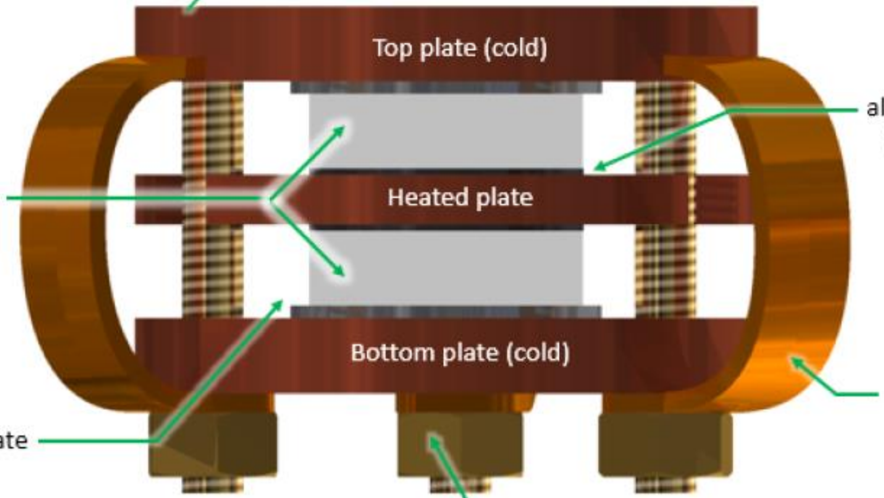
Thermal conductivity measurements on Cryogel

Sample characteristics:
- 22 mm diameter
- 10 mm initial thickness
- 7 mm thickness after compression
  → Sample height reduction of 30%

Test conditions:
- Temperature between 3 and 300 K
- Pressure between 10^{-7} and 10^{-8} mbar

Test set-up and instrumentation:
- 100 Ω electric heater on center plate
- TVO temperature sensor on bottom plate
- Two Cernox sensors, on top and middle plates
- Sumitomo two-stage PTR (up to 1 W @ 4.2 K on 2nd stage)





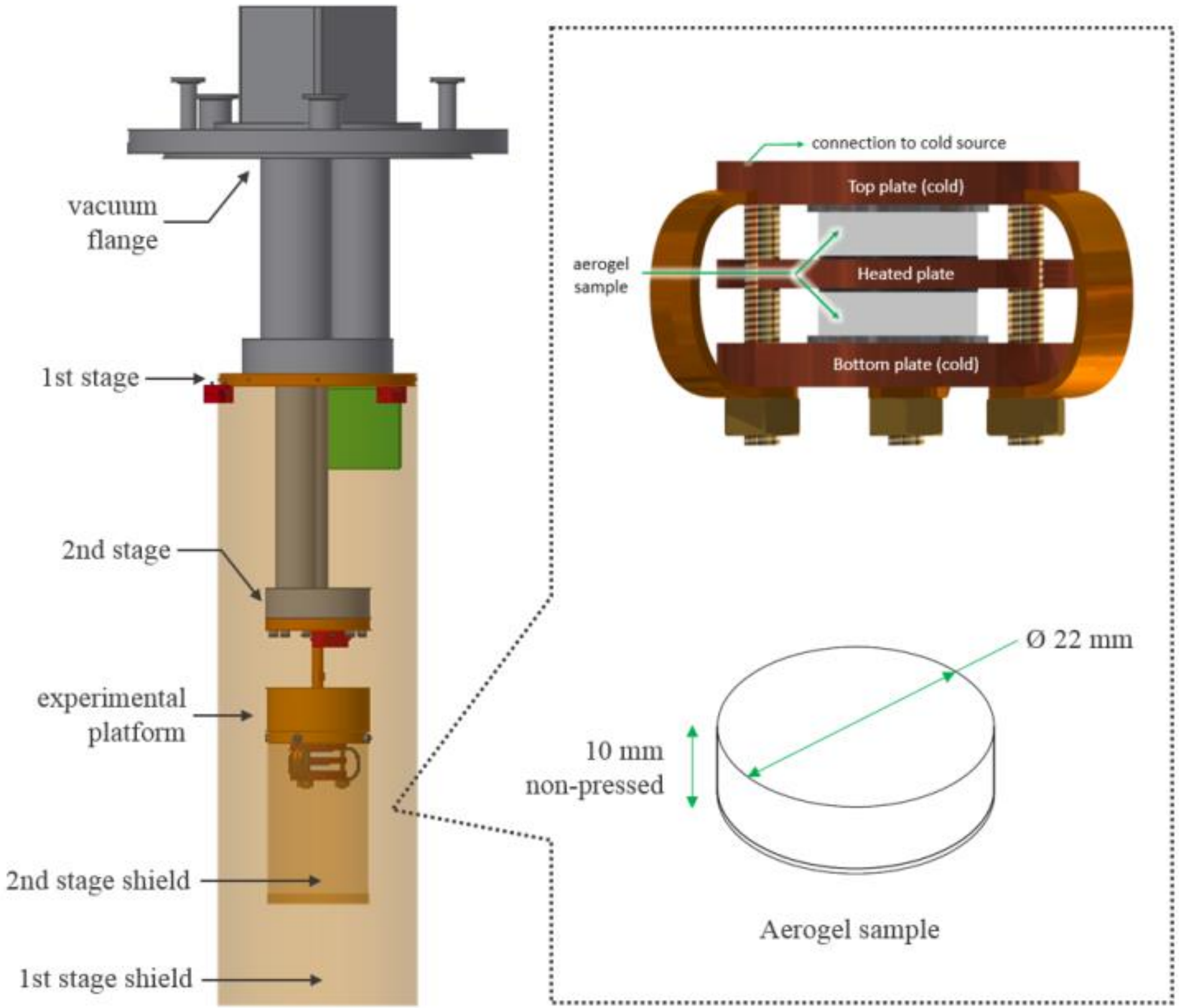
Thermal conductivity measurement of Cryogel

Measurement procedure:

- PTR 1st stage kept between 25 and 35 K
- PTR 2nd stage initially set at 2.6 K
- Heated plate temperature incrementally increased up to 273 K
- Temperature on top and bottom plates kept constant

Heat loss considered:

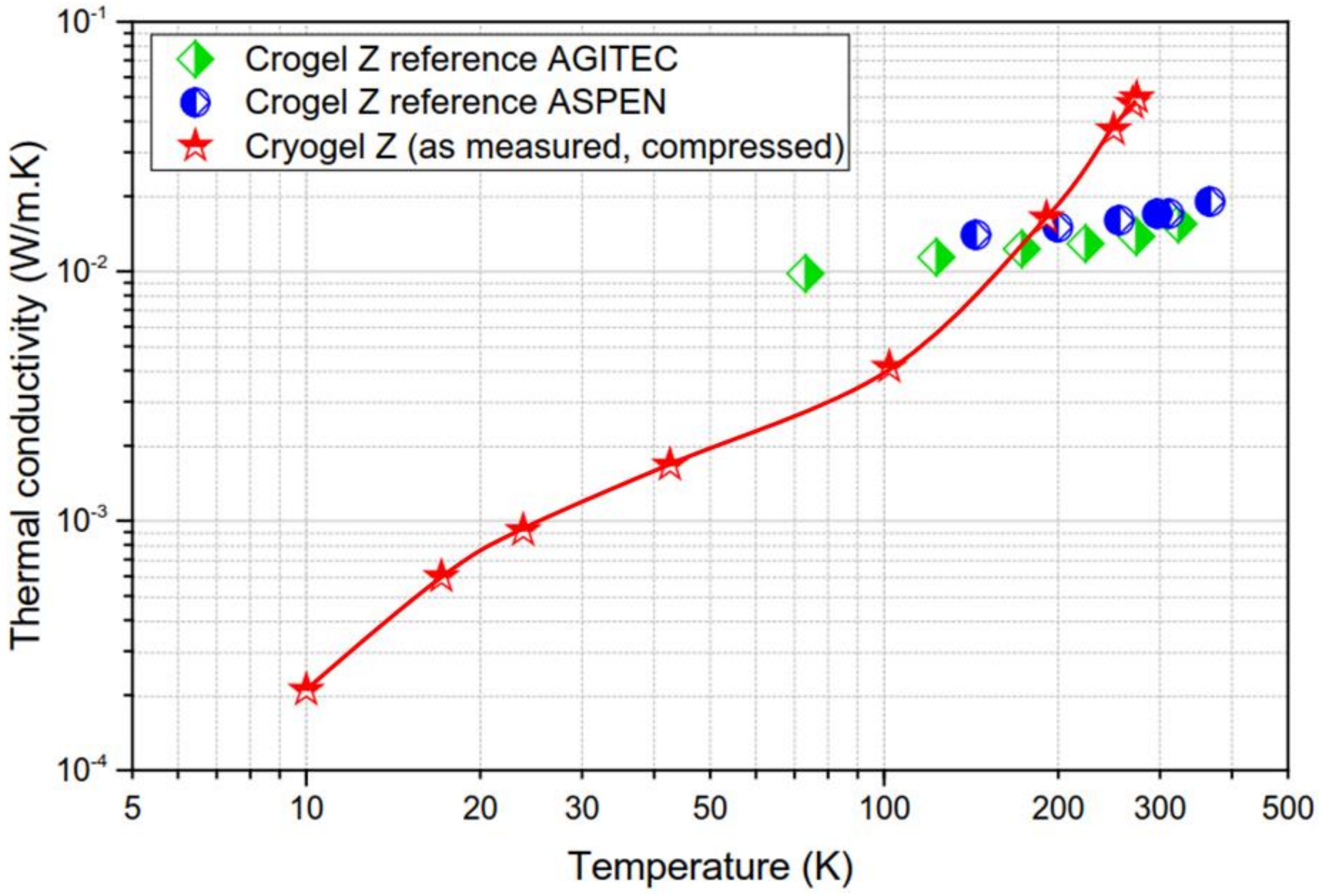
- Radiation loss of the middle plate to the environment: 8.2% of total applied heating power for the highest temperature gradient
- Conduction loss through the Cernox sensor and the electric heater on the center plate: 3% of total applied heat load for the measured range



Thermal conductivity measurements on Cryogel

Results:

Temperature (K)	Thermal conductivity $\times 10^{-4}$ (W/mK)
10.0	2.10
17.1	5.97
23.7	9.15
42.6	16.7
102.1	41.3
190.9	164
249.5	370
269.1	471
273.6	496



Significant differences justified by different test conditions!

- No compression on the samples measured by the manufactures
- Different gaseous environments

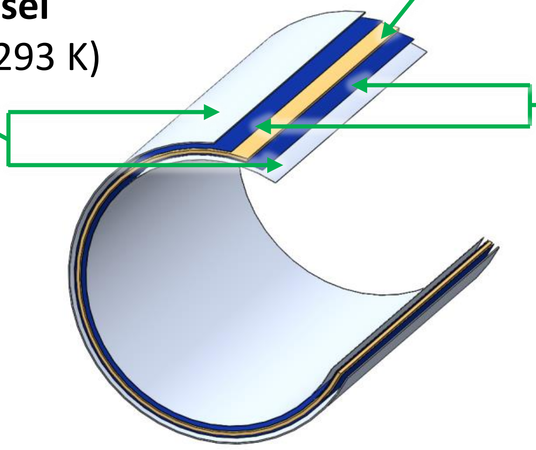
2 T/4 m solenoid cryostat – Heat load of cryostat using Cryogel

4 m bore, 6 m long cryostat model realized in ANSYS:

- Sandwich of vacuum vessel walls, thermal shield, cold mass
- Gaps filled with Cryogel Z
- Cryostat wall thickness between 15 and 105 cm

Analized aspects:

- Expected heat loads on cold mass and thermal shield
- Running power cost to cool the cryostat
- Thermal shield optimum position to minimize the energy cost
- Eventual use of outer surface heaters



Total heat load on the cold mass (W)	Total heat load on the thermal shield (kW)	Energy cost (kW)
400	10	400

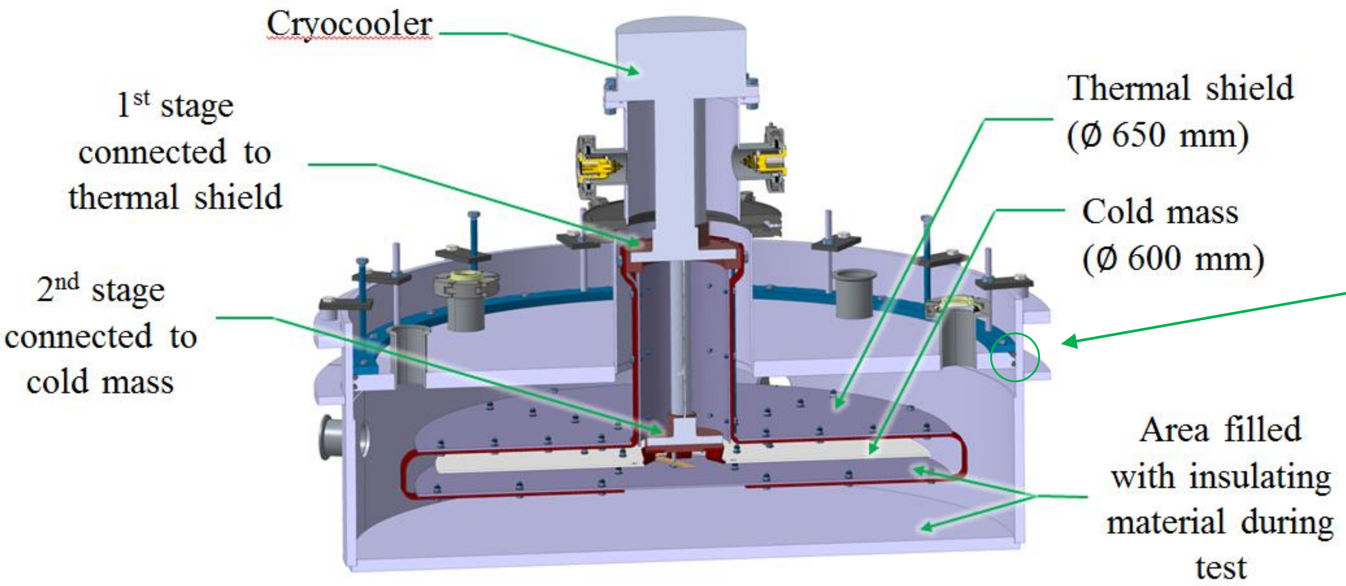
Results:

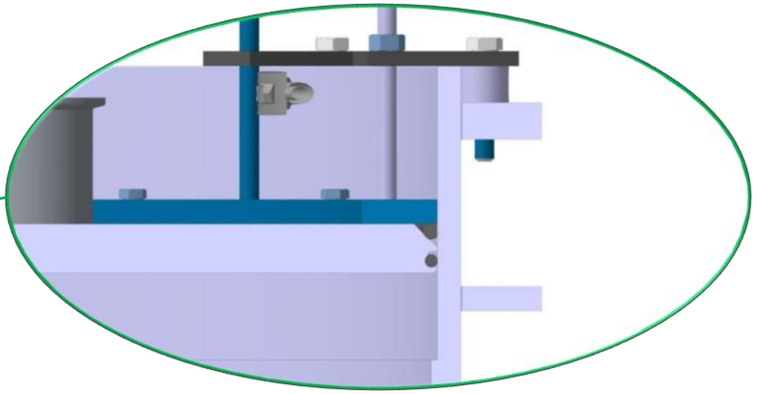
- A 250 mm thick cryostat combines low thickness and lowest possible thermal load
- Thermal shield at 25 mm from the cold mass to minimize the power cost

- Maximum heat load allowed on outer skin to avoid condensation: 4 kW (T_{air}=27°C, humidity 35%, dew point: 10°C)

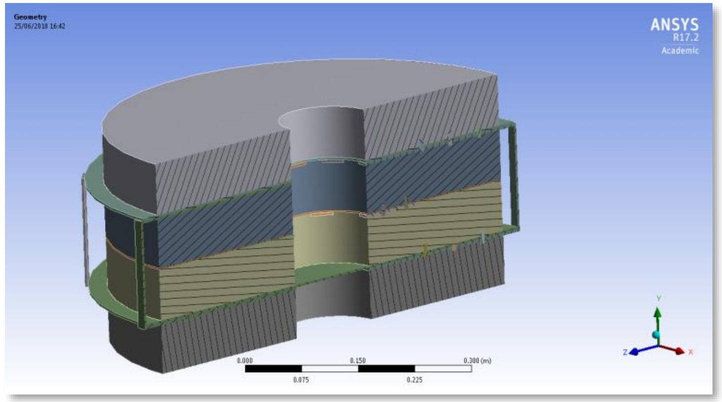
→ **The use of heaters is necessary!**

Model cryostat for thermal testing of Cryogel and glass spheres





Detail of the O-ring and bolts



Test set up:

- Stainless steel vacuum vessel, aluminum thermal shield and cold mass
- Free space to be filled with insulating material (Cryogel / glass spheres)
- CRYOMECH 420 pulse tube cooler (up to 2 W @ 4.2 K)

Test conditions:

- Temperature between 4 and 300 K, Pressure between 10^{-7} and 10^{-8} mbar
- 1st test with no compressive load → Cryostat is subjected to p_{atm} = 1 bar as in the real case
- 2nd test with a 2 bar compressive load

Conclusion and outlook

As part of the FCC study for detector magnets, the option of using highly radiation transparent and light cryostats is under investigation

- ✓ Cryogel Z and K1 glass spheres under vacuum are being considered as innovative insulating material with acceptable mechanical properties to be used for both FCC detector magnets cryostats
- ✓ A first test on Cryogel shows a thermal conductivity of 2.10×10^{-4} W/mK at 10 K and 10^{-8} mbar
- ✓ Thermal simulations for the 2T, 4 m bore, 6 m long FCC-ee case lead to a 250 mm thick cryostat, with the thermal shield positioned at 25 mm from the cold mass
  Total heat loads of 400 W on cold mass and 10 kW on thermal shield are expected
- ✓ The new set-up for a larger scale, more representative thermal conductivity tests on Cryogel and glass spheres was described
- ✓ The upcoming tests will show, to good approximation, whether the thermal and mechanical properties of the proposed insulating materials can satisfy the requirements imposed by the FCC project