Heat transfer in Cryogel® Z under compression for use in the ultra transparent cryostats of FCC detector solenoids

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Contents:

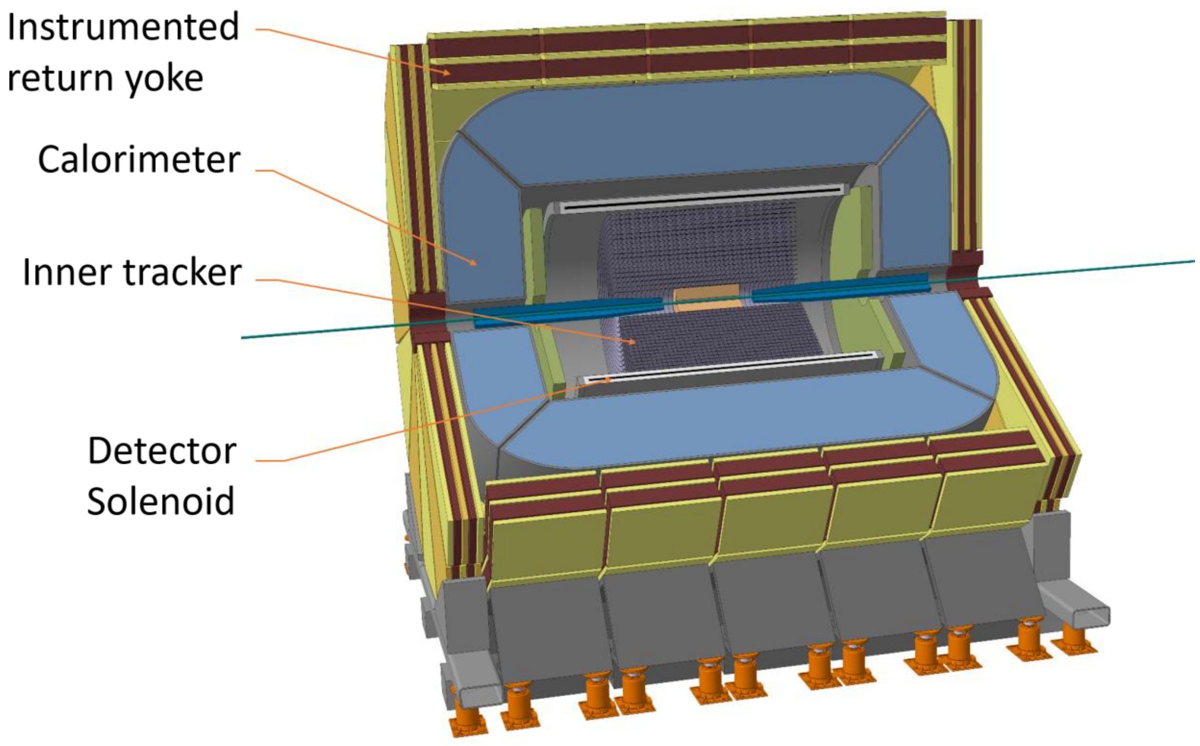
INTRODUCTION

- Conventional designs for FCC detector magnets show the superconducting solenoid around the inner tracker detector **and** calorimeter.
- Magnetic field is required in the tracker and in the muon chambers, **not** in the calorimeter.
- Most of the stored magnetic energy (~80%) is wasted in the calorimeter.
- Placing the solenoid inside the calorimeter, it is saving:
  - **factor ≅ 4 in stored energy,**
  - **factor ≅ 2 in cost.**

FCC-ee$^+$ 2 T Superconducting Solenoid

Inner bore: 7.6 m Length: 7.9 m	→	Inner bore: 4 m Length: 6 m

The same concept can be applied to the more demanding FCC-hh, with a 4T/4m bore main superconducting solenoid.

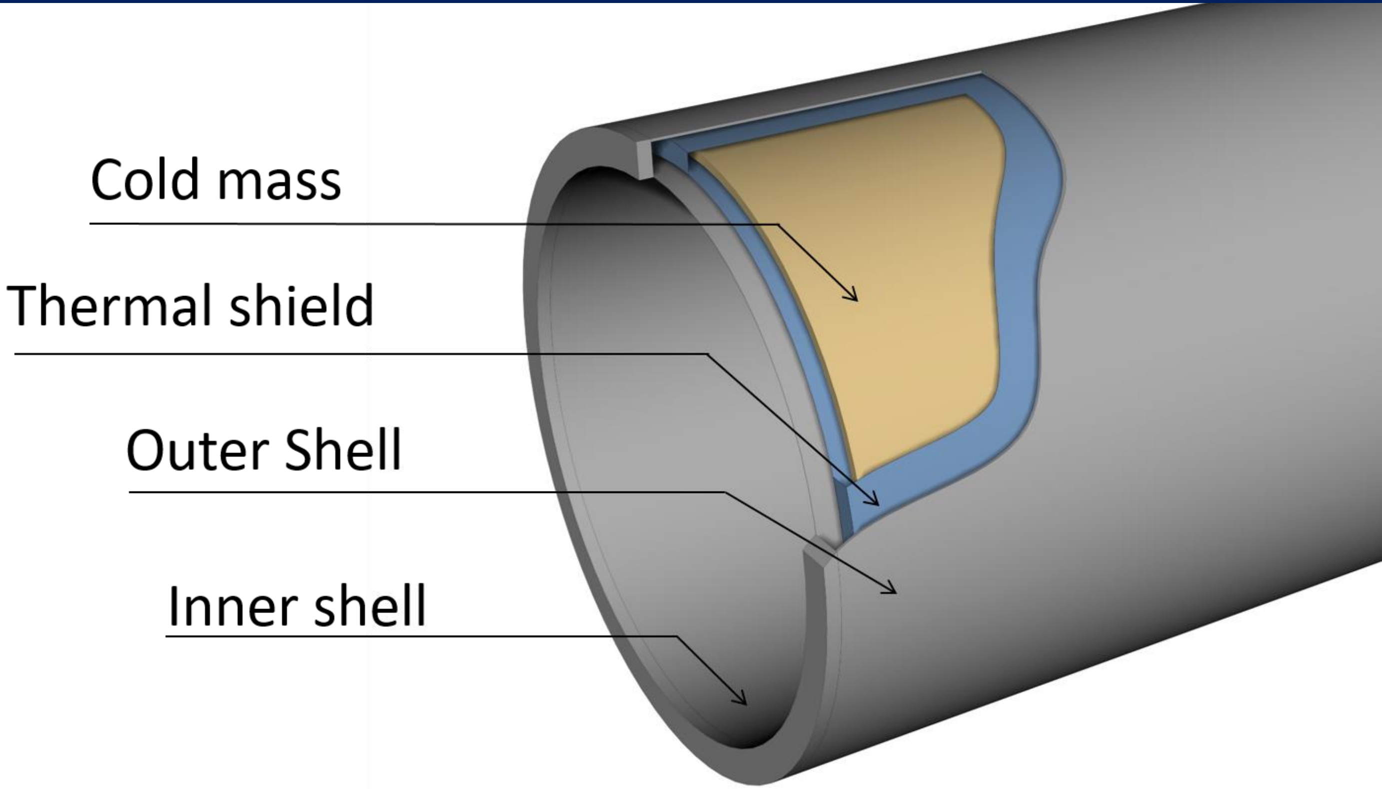


IDEA detector, International Detector Electron Accelerators

INTRODUCTION

SOLENOID REQUIREMENTS

- Highly particle radiation transparent cold mass and cryostat:
  $X_0 \leq 1$ in radial direction
- Lowest possible thickness and density:
  Radial envelope < 300 mm



- Structure of very thin metallic vacuum vessel walls, supported by an insulation material with sufficient mechanical resistance

CRYOGEL® Z SPECIFICATION

- Manufactured by Aspen Aerogels Inc.
- Shaped as a flexible aerogel composite blanket, with a layer of aluminum on top
- Combines silica aerogel with reinforcing fibers
- Density of 160 kg/m^3

Composition:

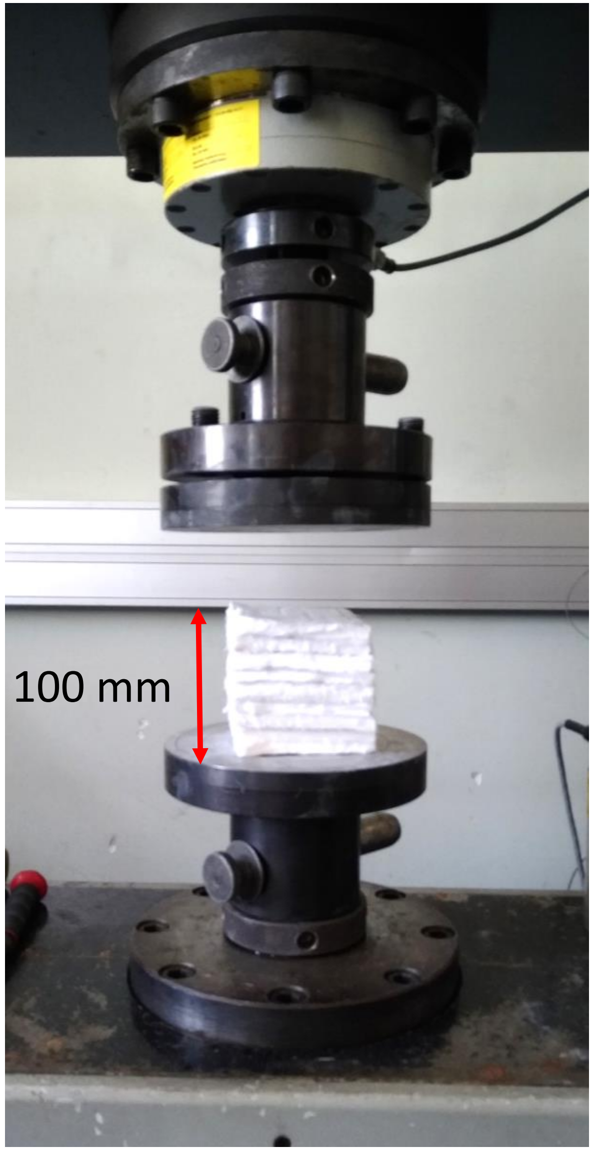
CHEMICAL NAME	PERCENTAGE
Synthetic amorphous silica	25-40%
Methylsilylated silica	10-20%
Polyethylene terephthalate (PET or polyester)	10-20%
Fibrous glass (textile grade)	10-20%
Magnesium hydroxide	0-5%
Aluminum foil	0-5%

The exact percentage (concentration) of composition has been withheld by Aspen Aerogels Inc. as a trade secret.

COMPRESSION TESTS OF CRYOGEL® Z

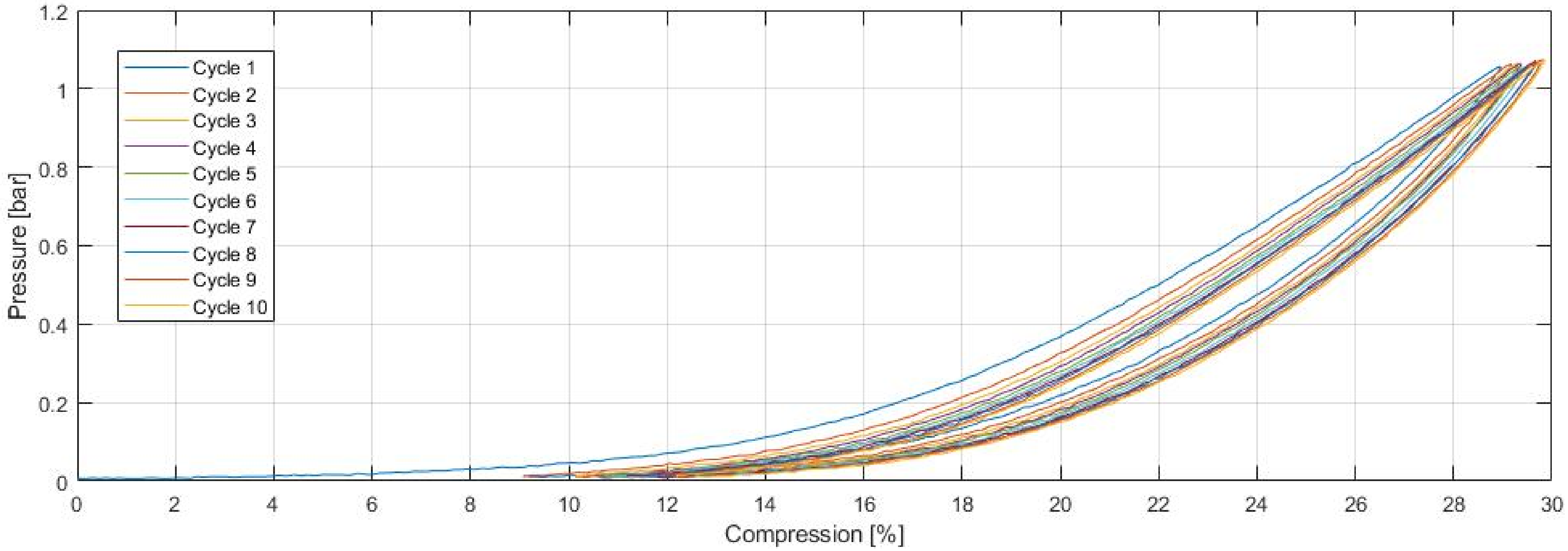
COMPRESSION TEST AT ATMOSPHERIC PRESSURE AND ROOM TEMPERATURE

- A compressive mechanical load equivalent to 1 bar is applied to a stack of 10 samples of Cryogel Z.
- The dimension of the stack is 100 mm x 100 mm x 100 mm.
- The measurements are taken for 10 compressive cycles.



Sample under compression

COMPRESSION TESTS OF CRYOGEL® Z

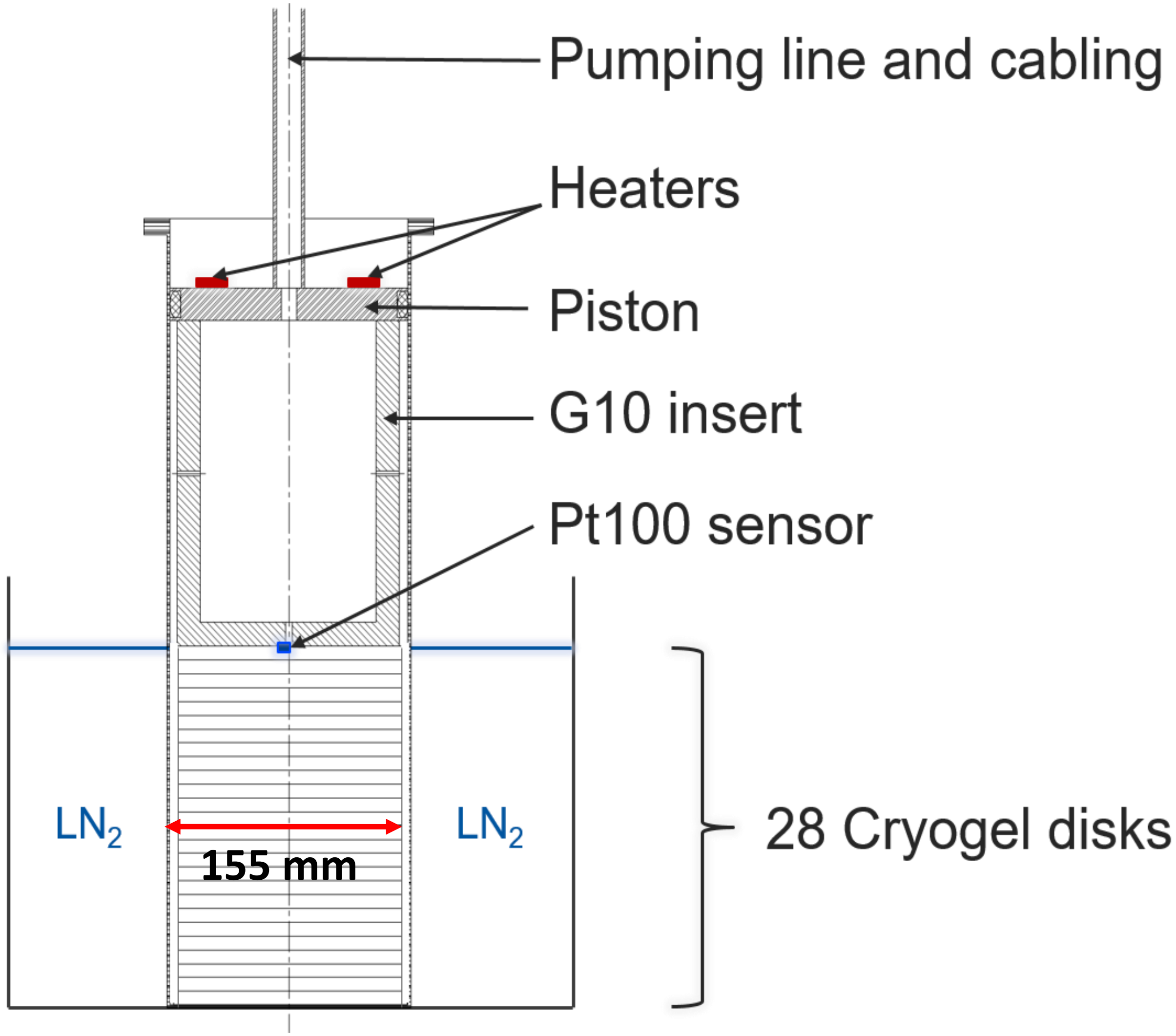


- Maximum compression ranging from 29.0% of the initial thickness at the first cycle and 29.8% at the last cycle.
- Compression hysteresis: percentage of material recovered ranging from 20% of the initial thickness at the first cycle and 17% at the last cycle.

COMPRESSION TESTS OF CRYOGEL® Z

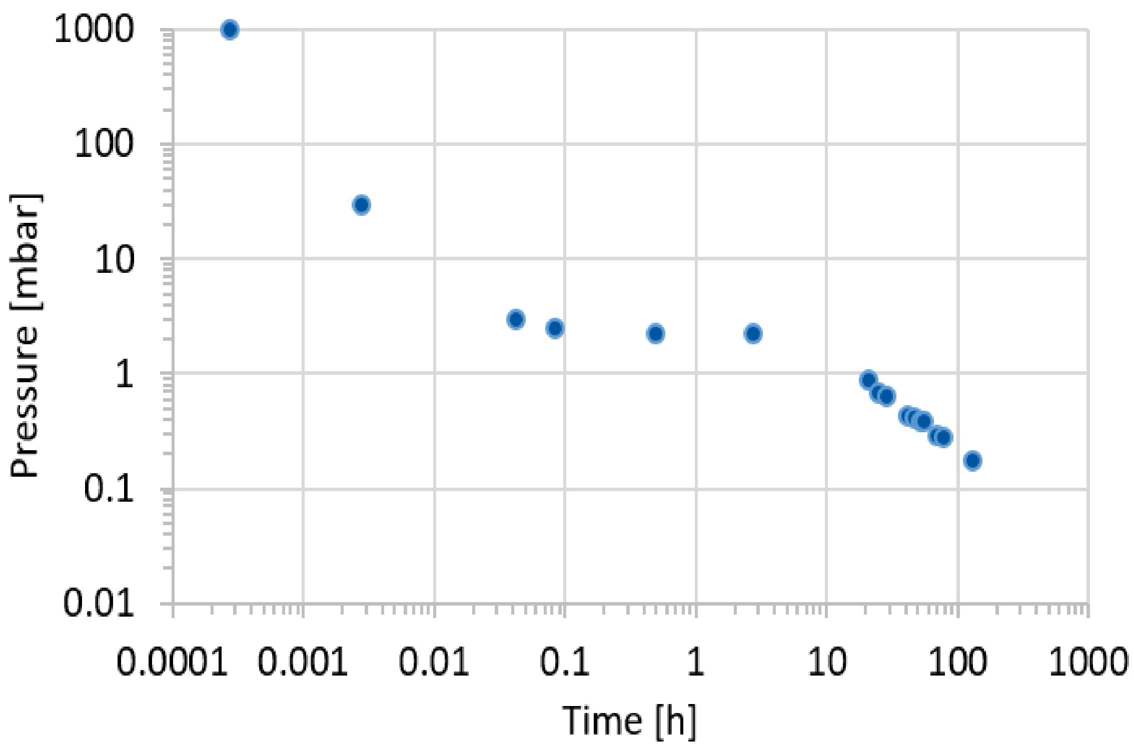
THERMAL SHRINKAGE TEST OF COMPRESSED CRYOGEL Z

- A G10 cylinder of 484 mm is vacuum pumped and placed in liquid nitrogen.
- 280 mm of Cryogel Z blankets of 155 mm diameter filling the cylinder.
- A stainless steel piston with an O-ring seal is ensuring the leak tightness of the setup.
- The O-ring is kept at room temperature by using two electric heaters on the piston and a 210 mm G10 insert between the O-ring and the stack of Cryogel Z.
- A Pt100 temperature sensor is placed on top of the Cryogel discs.



COMPRESSION TESTS OF CRYOGEL® Z

- Compression result consistent with the previous result: compression of the 29% over the initial height, 24% recovered material.
- The pressure, decreasing at the first pumping cycle shows a clear holding level at 2.2 mbar, indicating outgassing of the material.
- No relevant displacement of the piston observed, given the accuracy of ± 0.5 mm. The contraction of G10 parts is 0.5 mm.
- Thus, thermal shrinkage of Cryogel Z may occur within our measurement accuracy of 0÷1 mm (0÷0.5% of the compressed height of Cryogel Z stack).



First pump down of a stack of Cryogel Z compressed layers at 293 K, pressure versus time

HEAT TRANSFER IN A LARGE-SCALE CRYOGEL® Z SAMPLE

GOAL

To analyse the heat load expected in a large cryostat when using Cryogel Z as thermal insulator.

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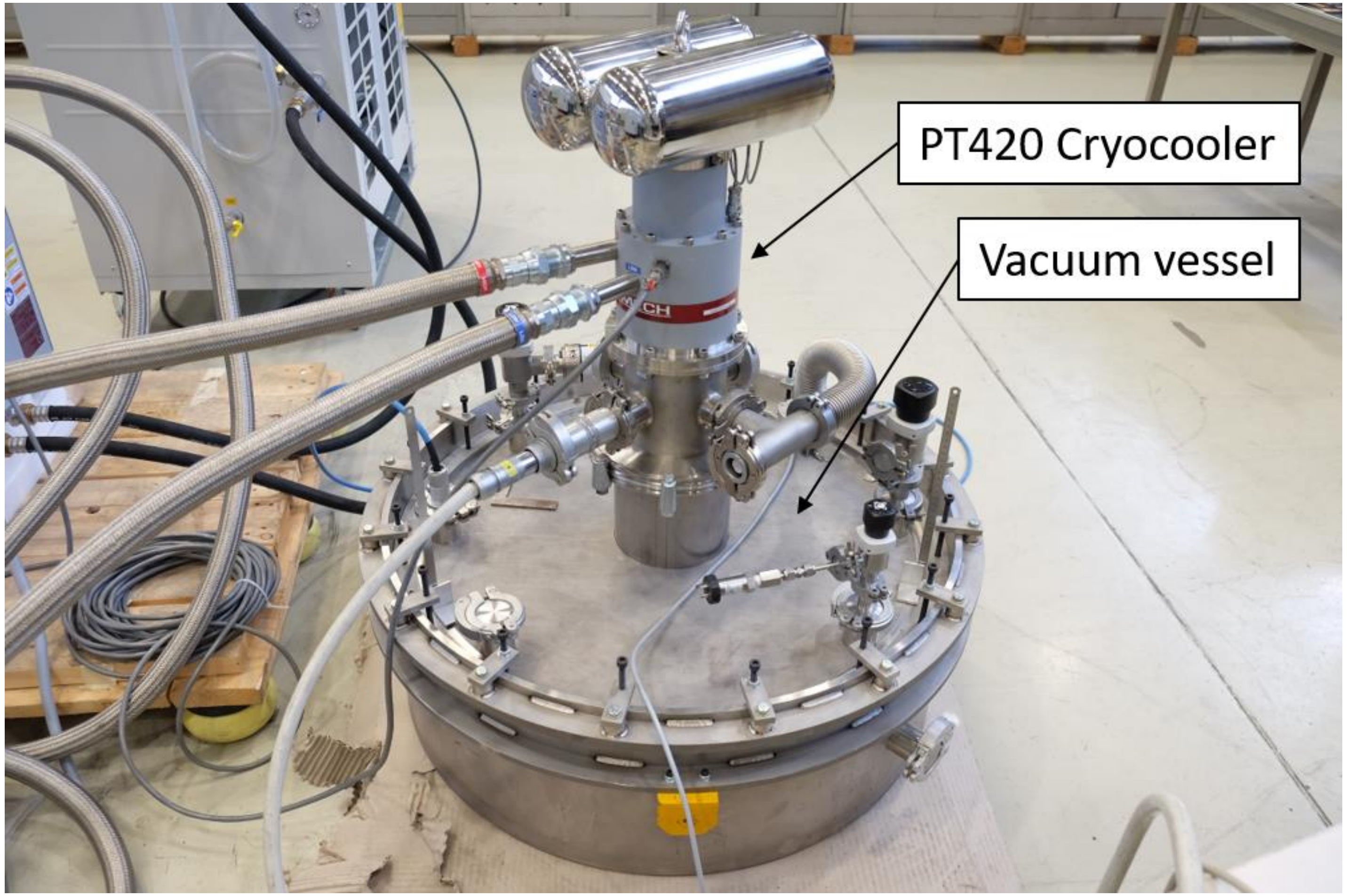
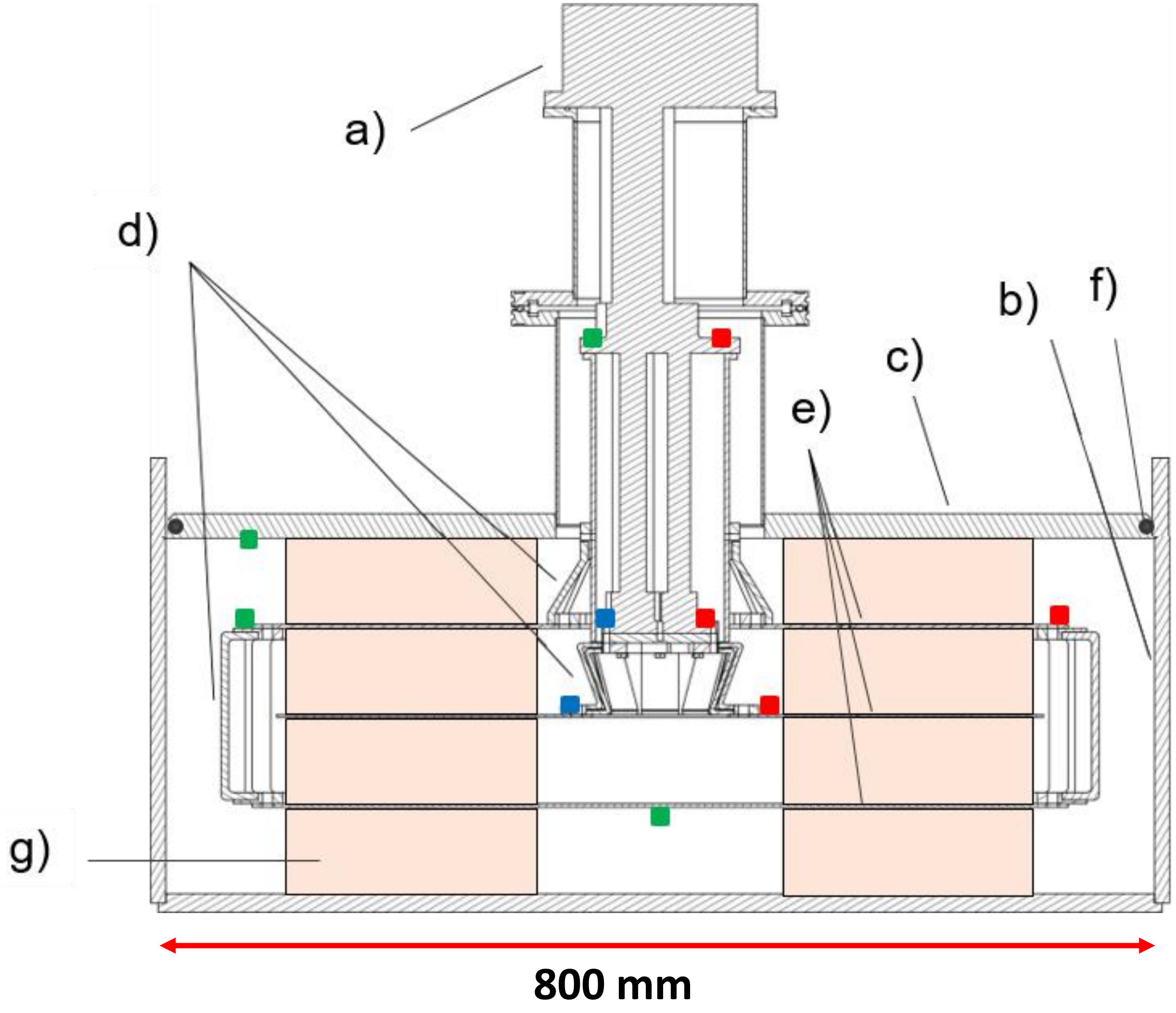
Heat load measurements from 4 K to room temperature while compressing Cryogel Z by 1 bar, corresponding to the differential pressure of the cryostat under vacuum.



800 mm

HEAT TRANSFER IN A LARGE-SCALE CRYOGEL® Z SAMPLE



- Heaters
- Pt 100 sensors
- TVO sensors

(a) cryocooler cold head
(b) cryostat wall
(c) cryostat top flange
(d) flexible thermal links
(e) thermalized copper plates
(f) O-ring
(g) Cryogel Z stacks

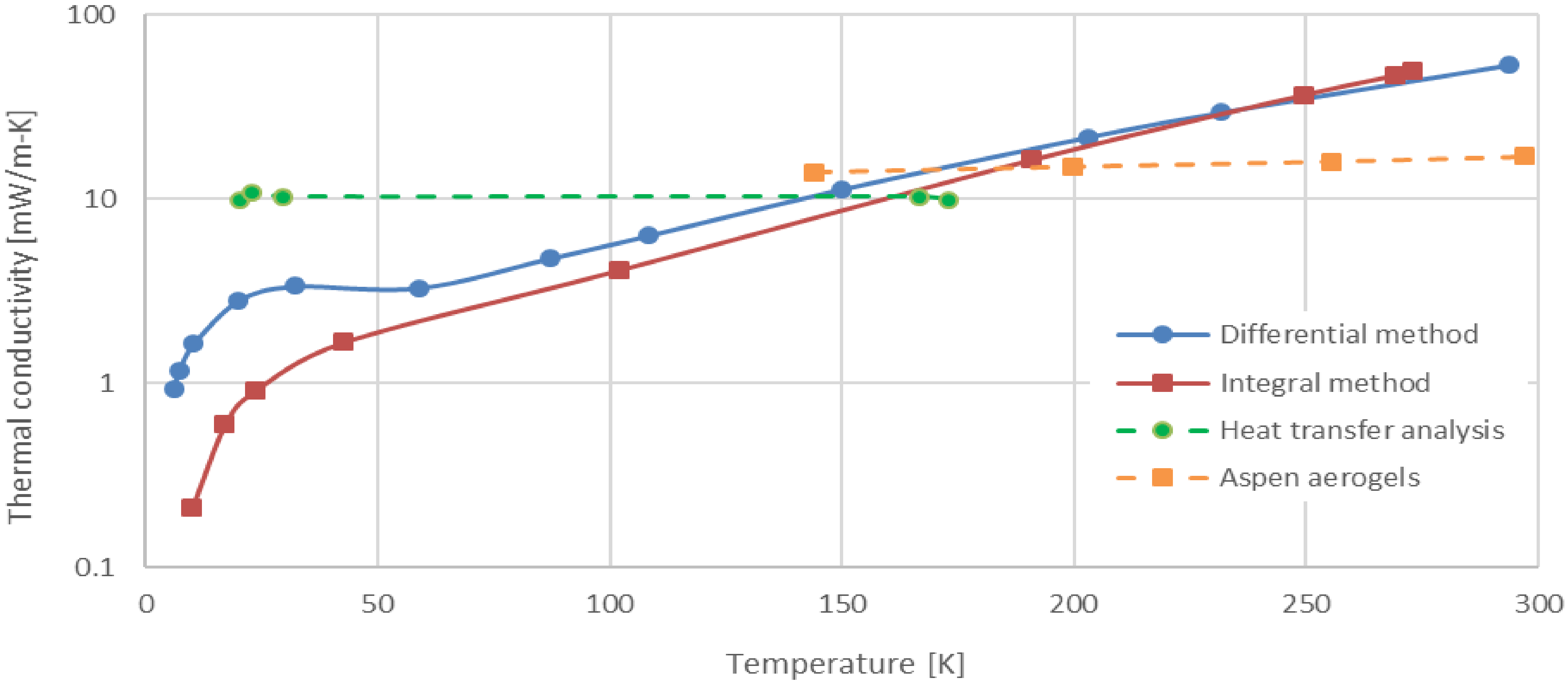
$T_{SCHIELD}$ ranging from 40 to 80 K
T_{COLD_MASS} maximum 5 K

Main dimensions:

- Vacuum vessel:
  800 mm diameter, 293 mm height
- Thermal shield: 660 mm diameter
- Cold mass: 620 mm diameter
- Cryogel stacks:
  600 mm diameter, 4x70 mm height

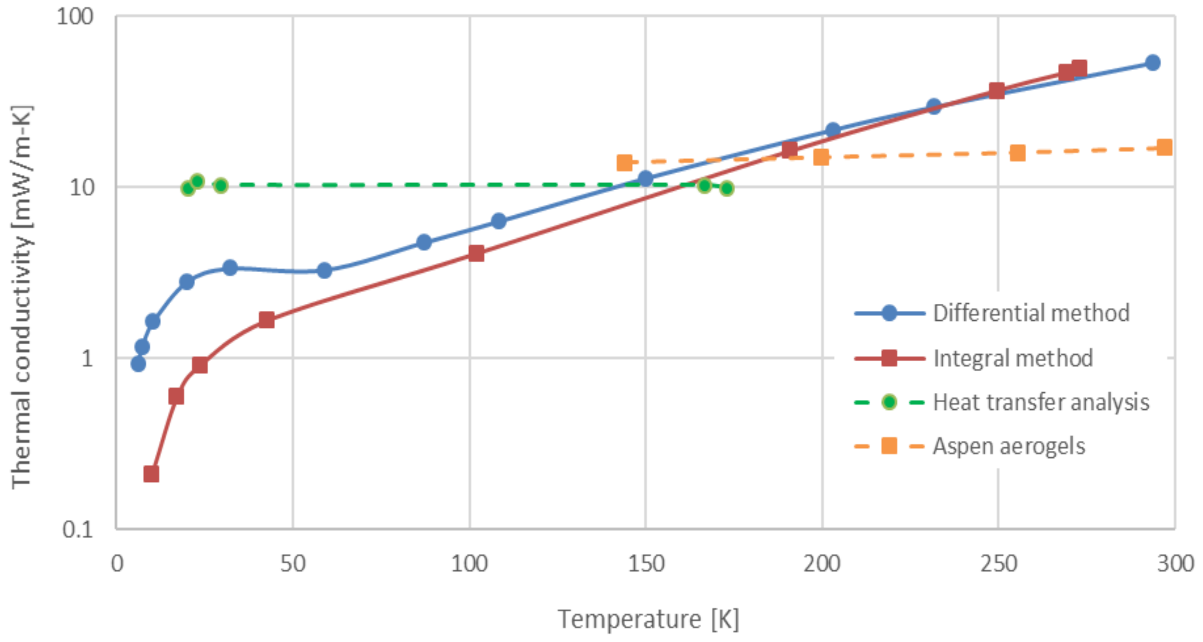
HEAT TRANSFER IN A LARGE-SCALE CRYOGEL® Z SAMPLE

- From the heat flow values obtained for various combinations of temperature on the first and second stages, we determined the thermal conductivity of Cryogel Z in this large scale setup assumed representative for a real cryostat.



HEAT TRANSFER IN A LARGE-SCALE CRYOGEL® Z SAMPLE

- We can justify the different thermal conductivity values between the small scale and large scale tests by considering that:
  - The small sample dimensions of the first (22 mm diameter, 10 mm thickness) radically increase the measurement error (maximum 30%).
  - The heat transfer analysis takes into account the various interfaces between Cryogel Z blankets, copper plates and vessel.



- The thermal conductivity data between 150 and 200 K are fairly consistent with the one provided by Aspen Aerogels Inc. (acquired according to ASTM C177, under 140 mbar compression) despite the different test conditions.

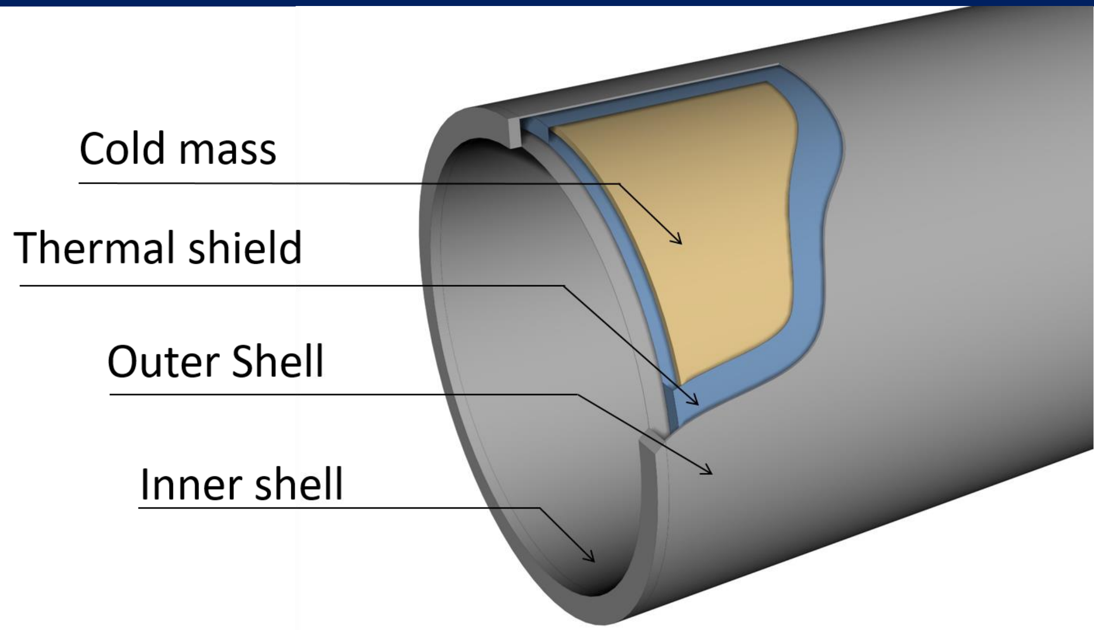
ESTIMATED HEAT LOAD IN A CRYOSTAT WITH CRYOGEL® Z

HEAT LOADS IN THE CRYOSTAT OF THE 4 m BORE, 6 m LONG FCC-ee+ SOLENOID

- Cryostat's total thickness: 250 mm
- Thermal shield at 70 mm from the cold mass.
- $T_{SCHIELD}$ = 40 K
- T_{COLD_MASS} = 6 K

Fourier law for a steady-state one-dimensional conduction in a cylindrical layer:

$$Q = 2 \cdot \pi \cdot \lambda \cdot L \cdot \frac{T_1 - T_2}{ln\left(\frac{r_2}{r_1}\right)}$$



Heat load on the thermal shield:

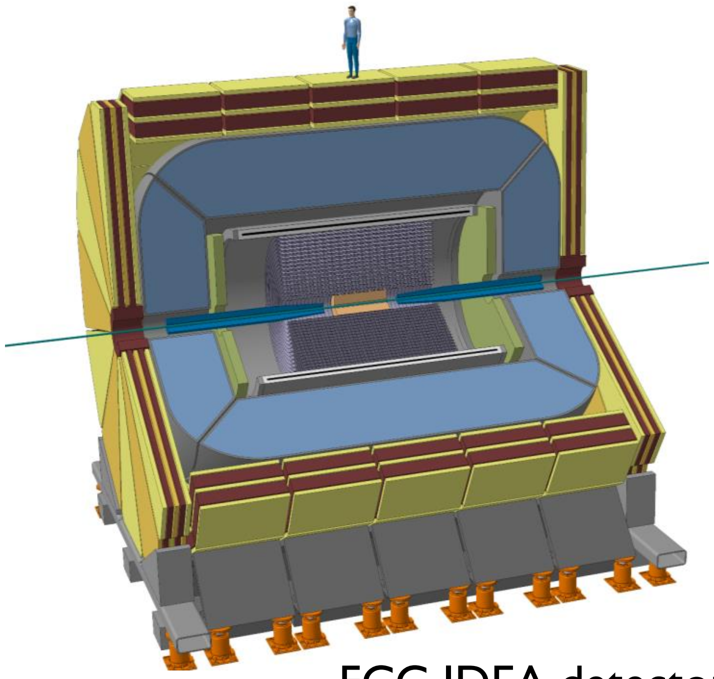
Q_1 = 13 kW

Heat load on the cold mass:

Q_2 = 900 W

CONCLUSION

- Cryogel Z shows fairly stable mechanical behavior under 1 bar mechanical pressure with some 30% height reduction.
- Thermal conductivity for Cryogel Z, measured on a small-scale setup, is 0.2 mW/mK@10 K to 50 mW/mK@273 K.
- Thermal conductivity results in the 150-200 K range are comparable to the data given by Aspen Aerogels Inc.
- For the FCC-ee+ solenoid, a 250 mm thick cryostat with 13 kW on the shield and 900 W on the cold mass would work.
- Cryogel Z is a promising insulation material for ultra-thin cryostats of the previously mentioned FCC detector magnets.


FCC IDEA detector


Cryogel Z blankets