Conceptual design of the cryostat for a highly radiation transparent 2 T superconducting detector solenoid for FCC-ee+

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Contents:

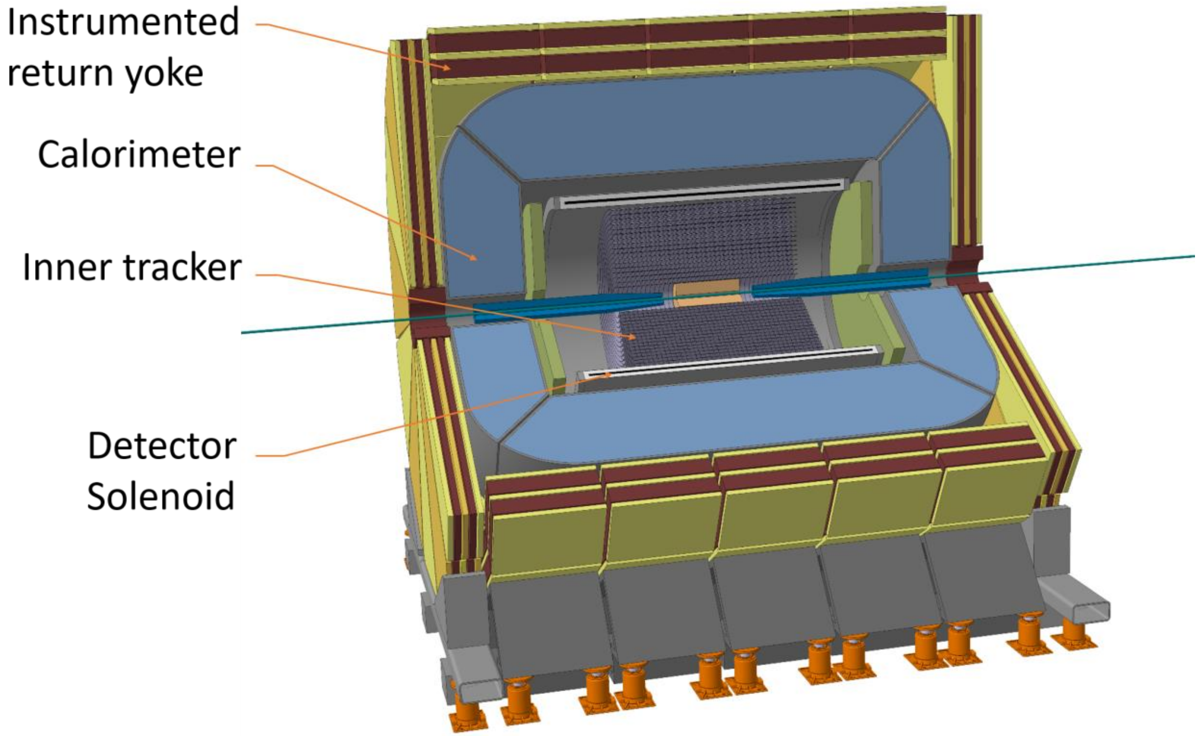
INTRODUCTION

- 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 would save:
  - **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

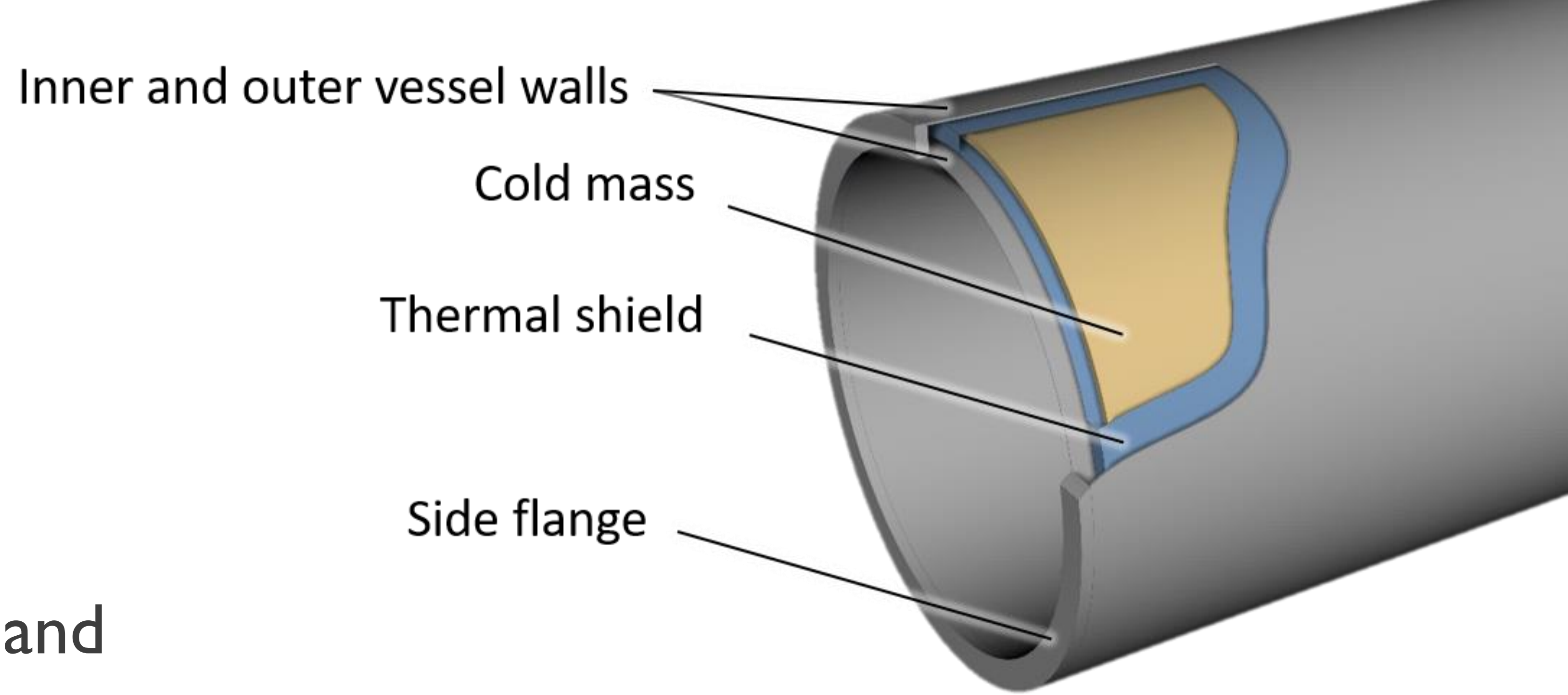
The same concept can be applied to the more demanding FCC-hh, with a 4T/4m bore main superconducting solenoid.



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:

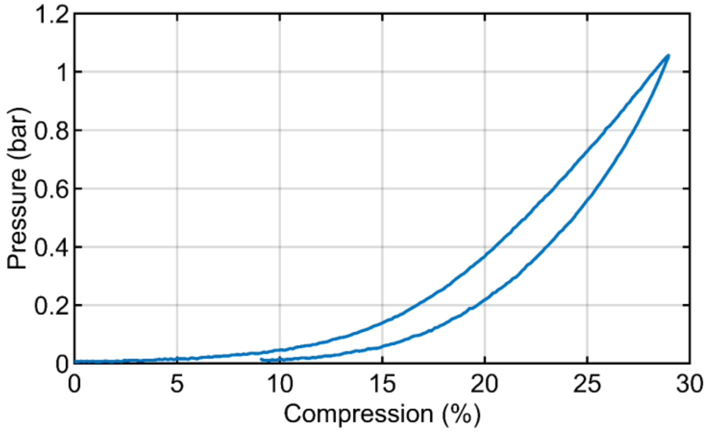
CHEMICAL NAME	PERCENTAGE
Synthetic amorphous silica	25-40%
Methylsilylated silica	10-20%
Polyethylene terephthalate (PET or polyester)	10-20%
Fibrous glass (textile grade)	10-20%
Magnesium hydroxide	0-5%
Aluminum foil	0-5%

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

COMPRESSION TESTS OF CRYOGEL® Z

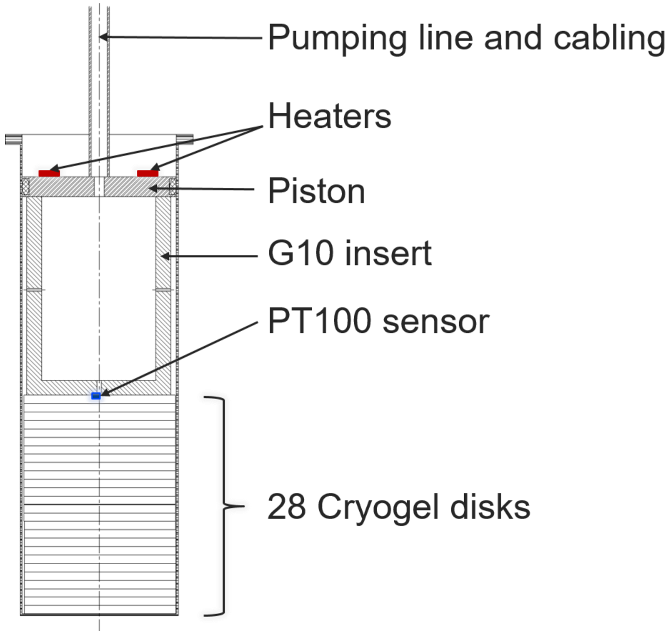
COMPRESSION TEST AT ATMOSPHERIC PRESSURE

- A compressive mechanical load equivalent to 1 bar is applied to a stack of 10 samples of Cryogel Z
- Dimension of the stack: 100x100x100 mm
- Measurements taken for 10 compressive cycles
- Maximum compression ≈30%, material recovered ≈20% (over the initial height, for every cycle)



COMPRESSION TEST UNDER VACUUM

- 28 Cryogel Z blankets of 155 mm diameter are placed inside a G10 cylinder, which is then vacuum pumped
- A differential pressure of 1 bar is applied to the stacks of Cryogel Z
- Maximum compression ≈ 30%, material recovered ≈ 24% (over the initial height)
- Setup used for a preliminary study of the thermal shrinkage of Cryogel Z as well



THERMAL CONDUCTIVITY TESTS OF CRYOGEL® Z

$$I = Q\,\frac{L}{A} = \int_{T_c}^{T_h} \lambda(T)\,\mathrm{d}T$$

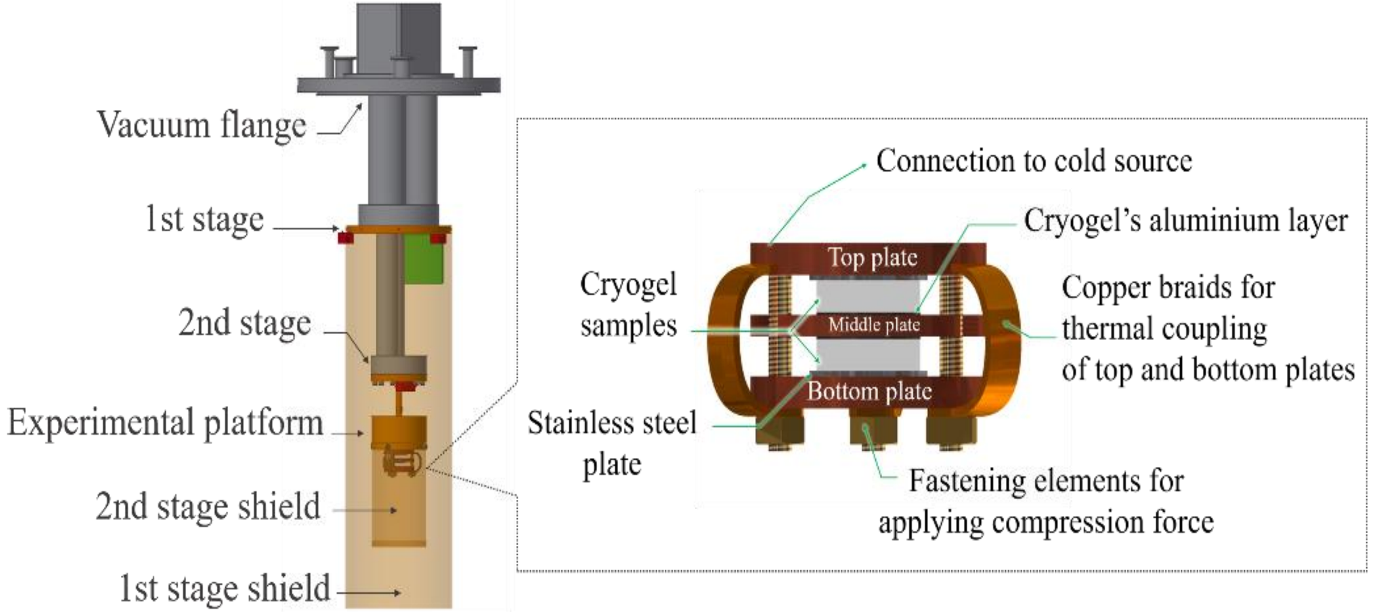
INTEGRAL METHOD

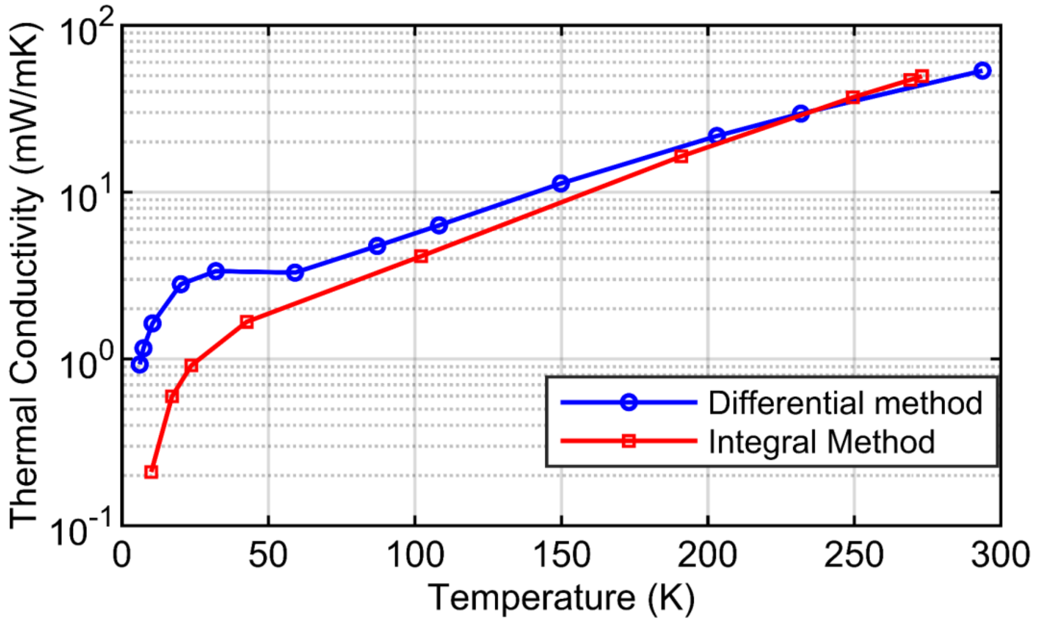
$$\nabla I(T_c, T_h) = \frac{\partial}{\partial\, T_c} I(T_c, T_h) + \lambda(T_h) - \frac{\partial}{\partial\, T_h} \int \lambda(T)\, dT\Big|_{T_c} = \lambda(T_h)$$

DIFFERENTIAL METHOD

$$\lambda = Q\,\frac{L}{A}\frac{1}{(T_h - T_c)}$$

Thermal conductivity ranging from 0.2 mW/mK at 10 K to 50 mW/mK at 275 K



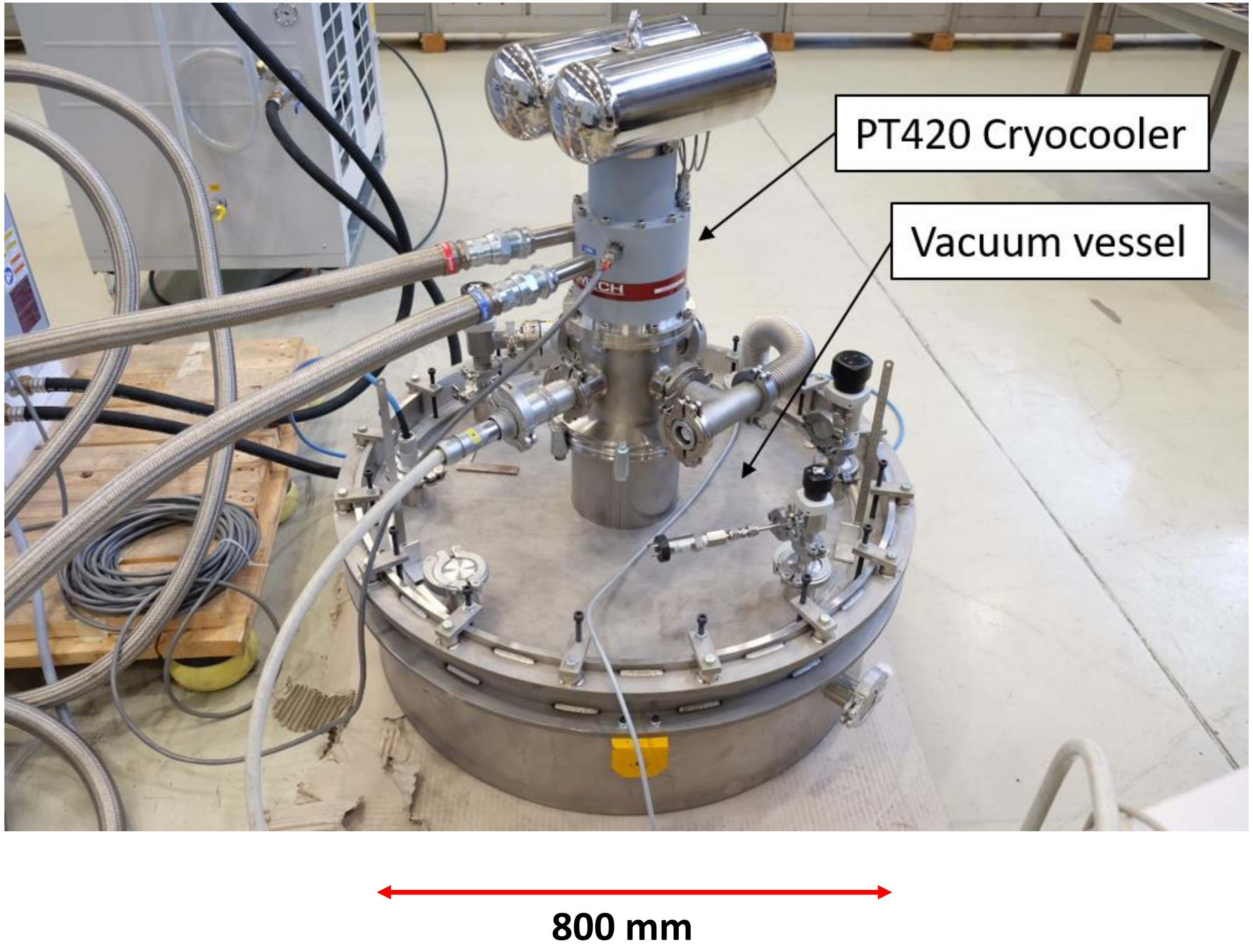


HEAT TRANSFER IN A LARGE-SCALE CRYOGEL® Z SAMPLE

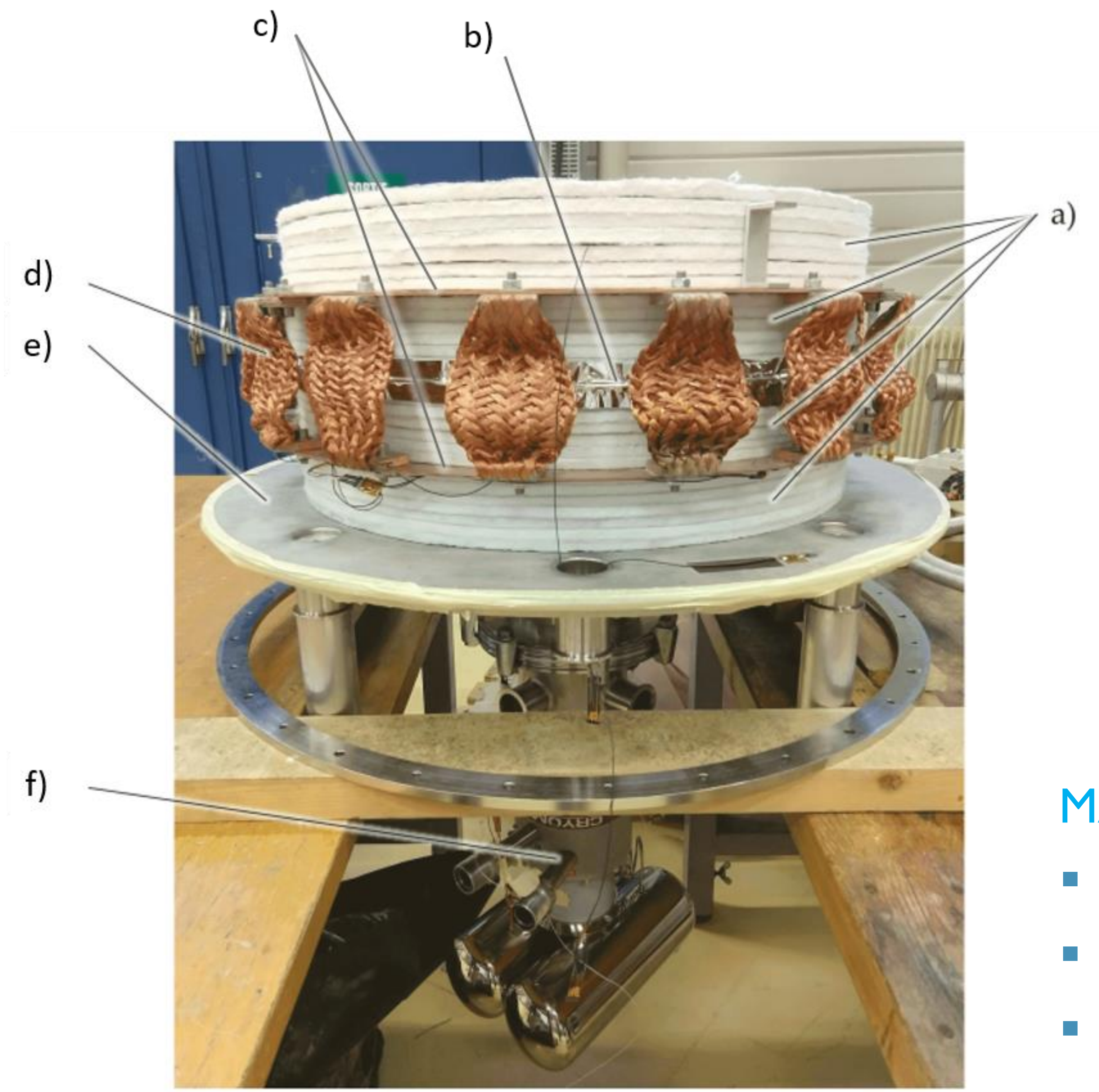
GOAL

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

Heat load measurements for different temperatures while compressing Cryogel Z by 1 bar, corresponding to the differential pressure of the cryostat under vacuum.



HEAT TRANSFER ANALYSIS - TEST SETUP

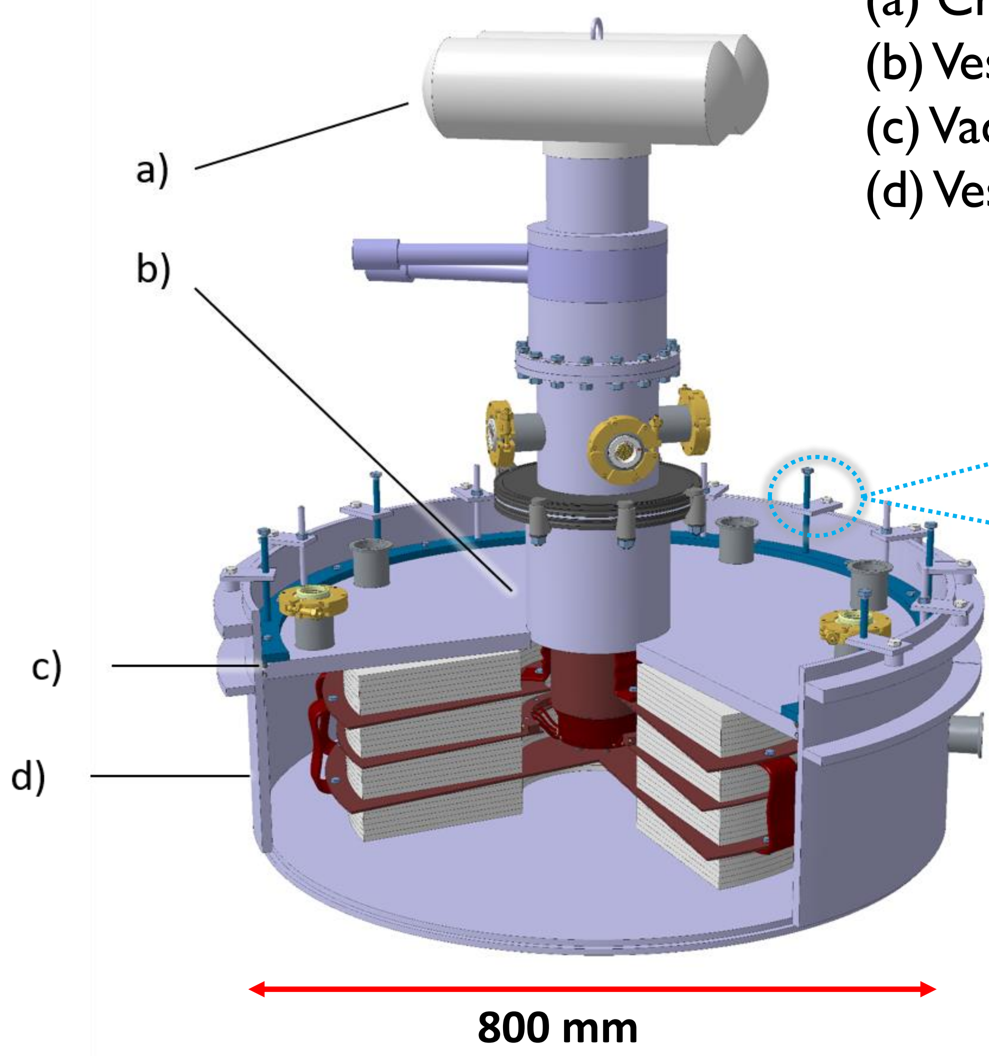


(a) Cryogel Z stacks
(b) Cold mass
(c) Thermal Shield
(d) Copper braids
(e) Vessel top flange
(f) Cryocooler's head

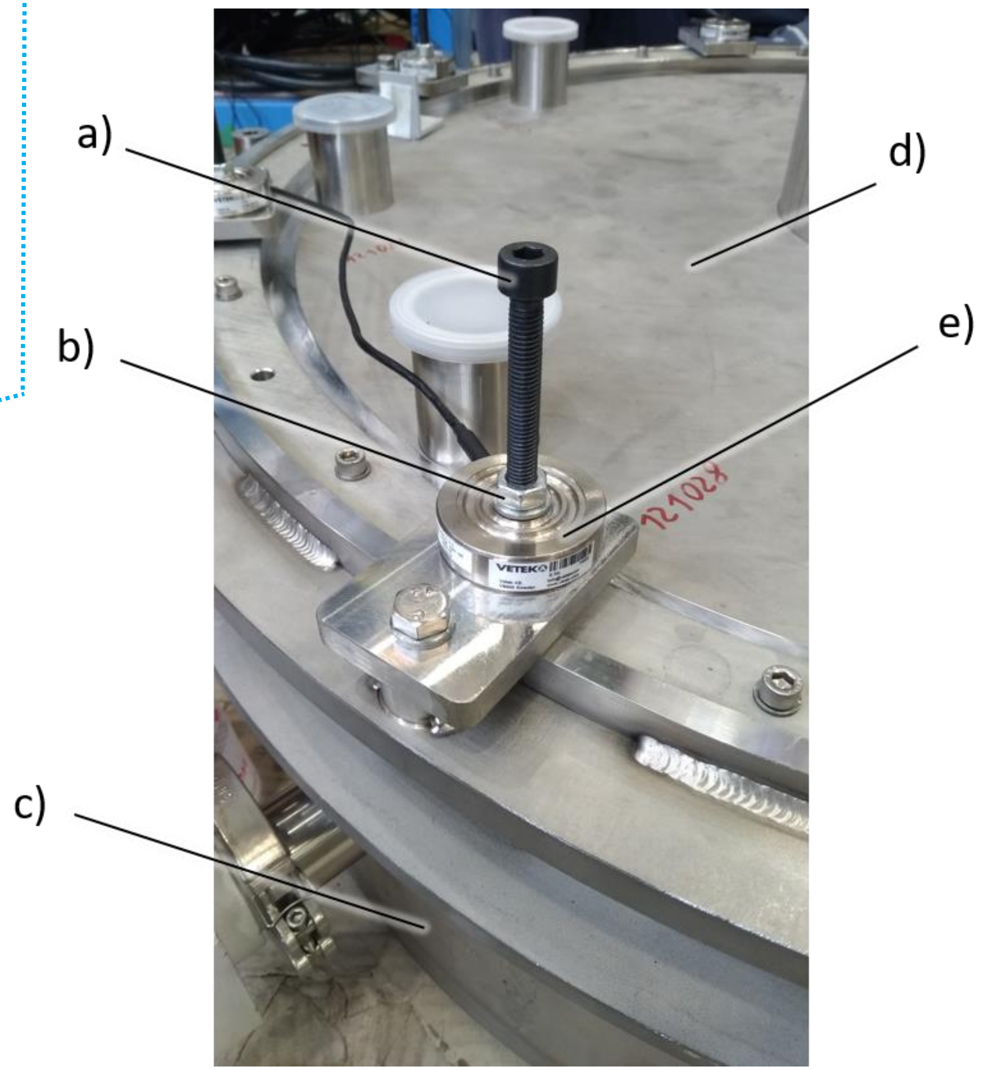
MAIN DIMENSIONS

- Vacuum vessel: 800 mm diameter, 290 mm height
- Thermal shield: 660 mm diameter
- Cold mass: 620 mm diameter
- Cryogel stacks: 600 mm diameter, 4x70 mm height

HEAT TRANSFER ANALYSIS - TEST SETUP



(a) Cryocooler cold head
(b) Vessel top flange
(c) Vacuum sliding interface
(d) Vessel walls

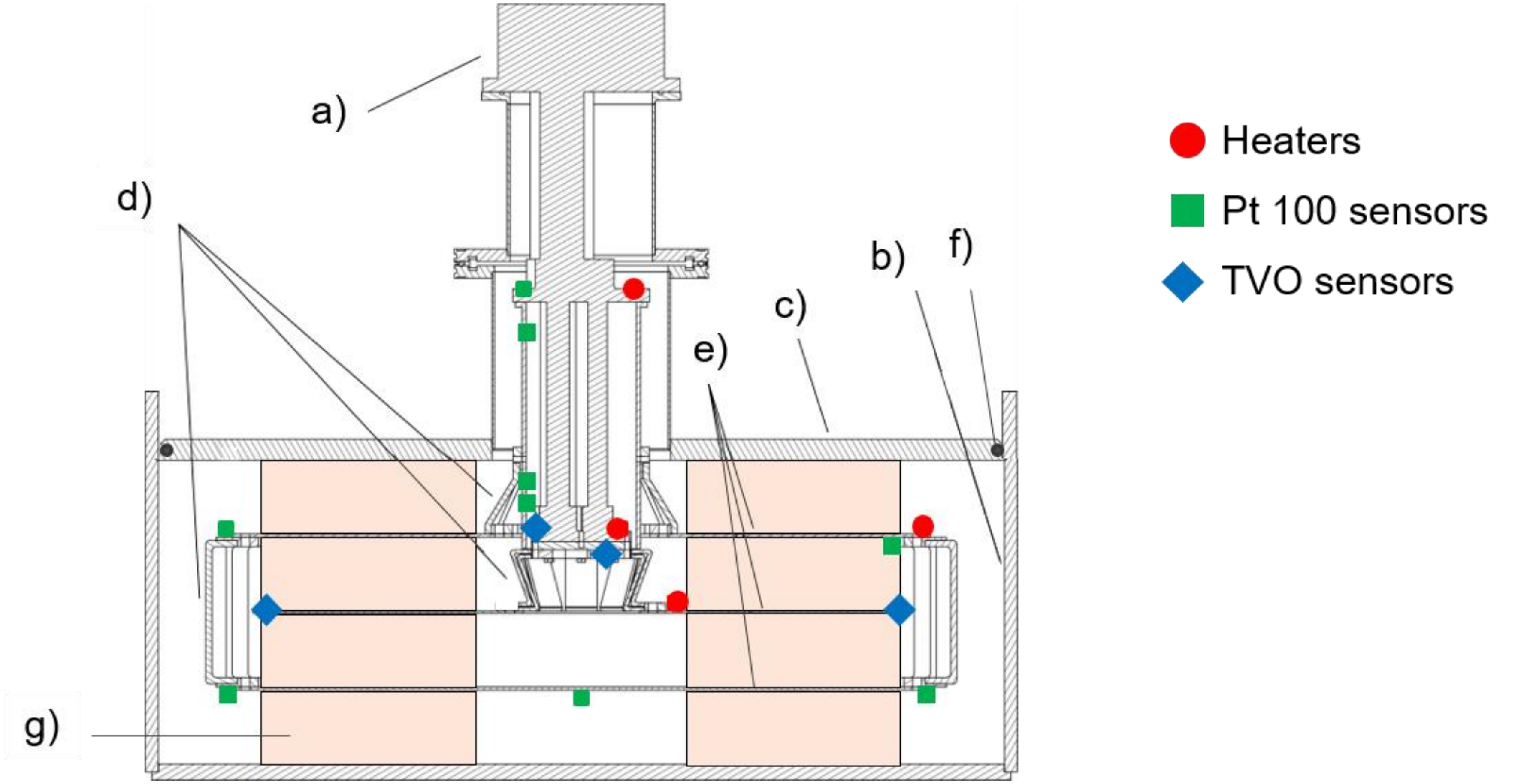


(a) Sliding screw, (b) Locking bolts, (c) Vessel side wall, (d) Vessel top flange, (e) Load cells

HEAT TRANSFER ANALYSIS - TEST SETUP

INSTRUMENTATION

- nine Pt100 sensors and two electrical heaters on the cryocooler's first stage and thermal shield;
- four TVO sensors and two heaters on the second stage and cold mass.

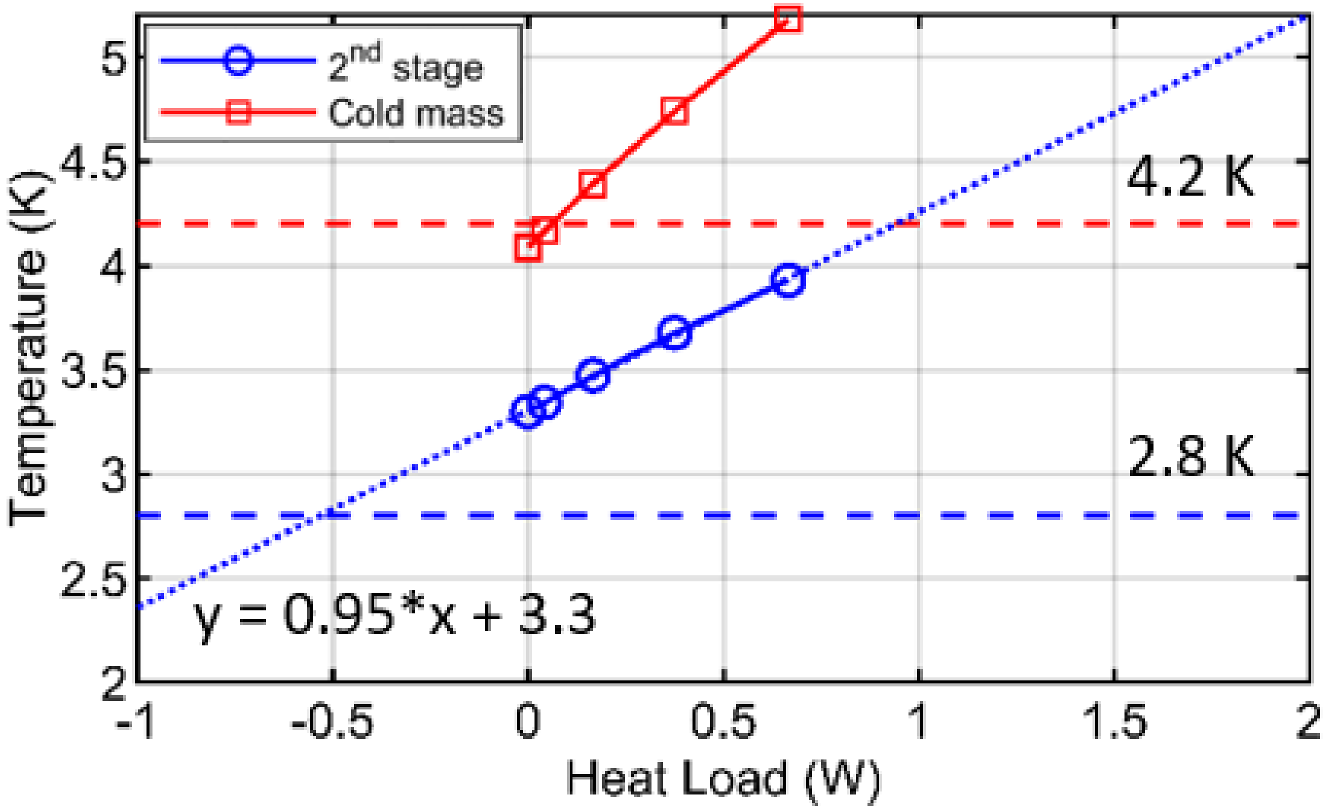


(a) Cryocooler cold head
(b) Vessel side wall
(c) Vessel top flange
(d) Copper braids
(e) Thermal shield and cold mass
(f) O-ring
(g) Stack of Cryogel Z

HEAT LOAD MEASUREMENTS

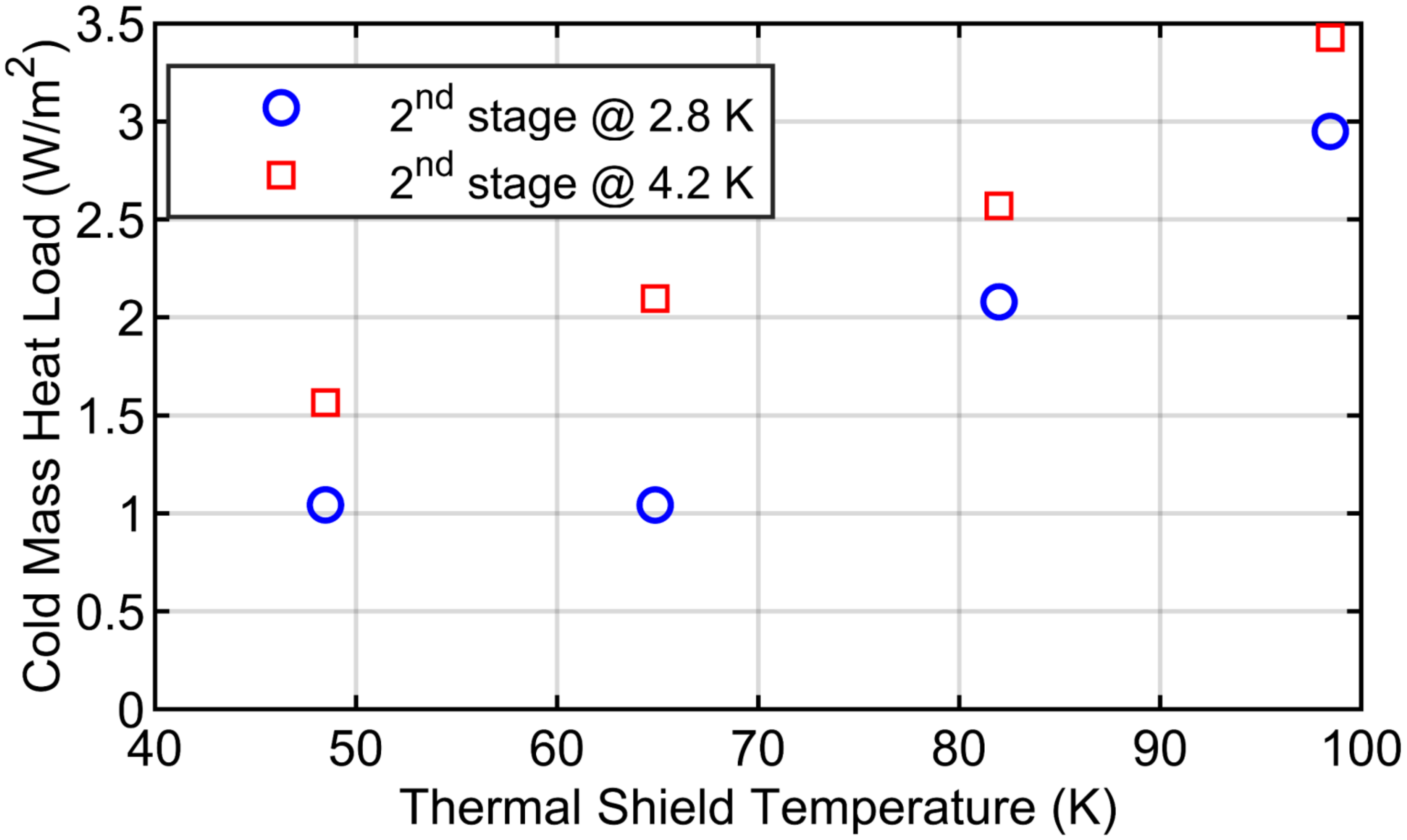
- The first test run focuses on measuring the heat load between the cold mass and the thermal shield;
- A heat load is applied to the thermal shield through the electric heaters and its temperature is then allowed to stabilize;
- Once reached the equilibrium, the temperature of the cold mass is incrementally increased and five measurement points are taken;
- A linear fit to the experimental data is used to extrapolate the heat load at 2.8 K and 4.2 K, which correspond to the known cryocooler's cooling capacity of respectively 0 W and 2 W;
- The procedure is repeated for different temperatures of the shield, between 40 K and 100 K.

Thermal Shield Temperature = 65 K



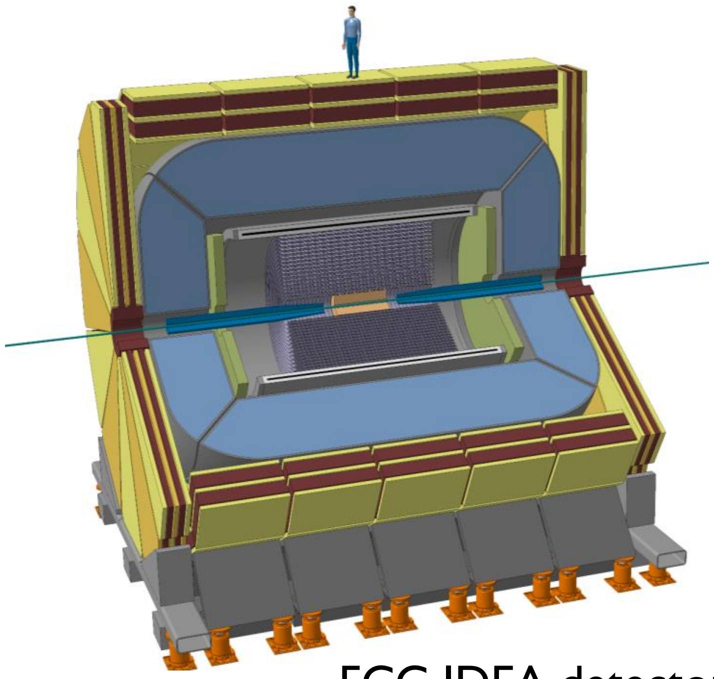
HEAT LOAD MEASUREMENTS

- The heat load on the cold mass is obtained for different thermal shield temperatures, with the cryocooler second stage at 2.8 K and 4.2 K.
- The losses in heating power through both radiation and solid conduction are negligible, while a correction is applied for the radiation between thermal shield and cold mass.



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.
- The heat transfer analysis shows a heat load on the cold mass of 1 W/m^2, for a thermal shield temperature of 65 K.
- Cryogel Z is a promising insulation material for ultra-thin cryostats of the FCC detector magnets.



FCC IDEA detector