Karlsruhe Institute of Technology

suprapower

Conceptual design and thermal analysis of a modular cryostat for one single coil of a 10 MW offshore superconducting wind turbine

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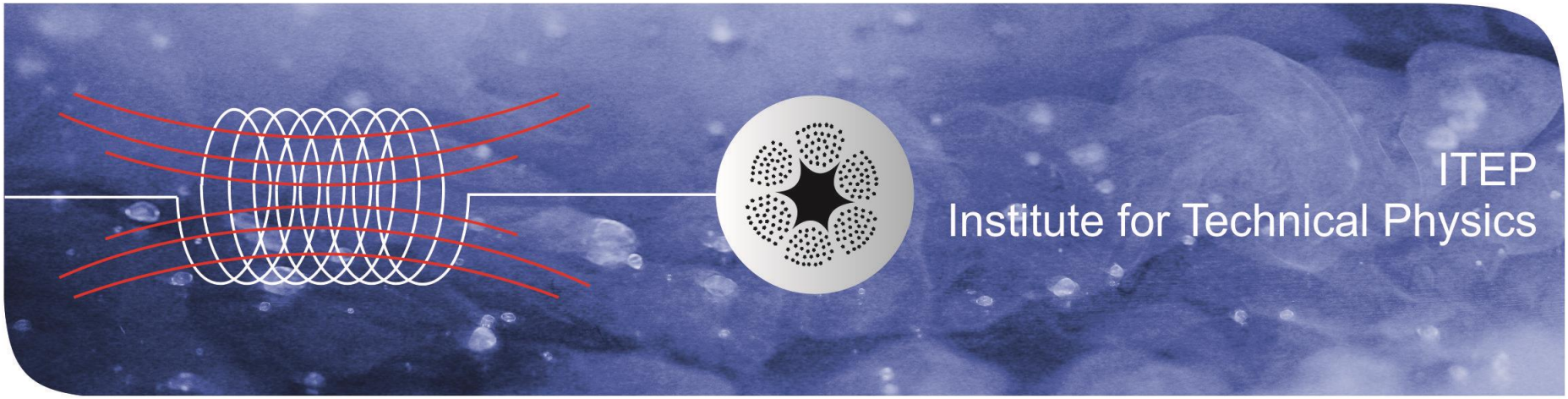
CEC-ICMC, Tucson, USA

Institute for Technical Physics | Cryogenics



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Offshore Wind

Market Perspectives

	2020	2030	2050
Europe	40 GW	150 GW	460 GW
World	100 GW	375 GW	1150 GW
Cost per MW	4,5 M€	3,5 M€	2,5 M€

	2020	2030	2050
Europe	180,000 M€	565,000 M€	1.34 B€
World	450,000 M€	1.412 B€	3.35 B€

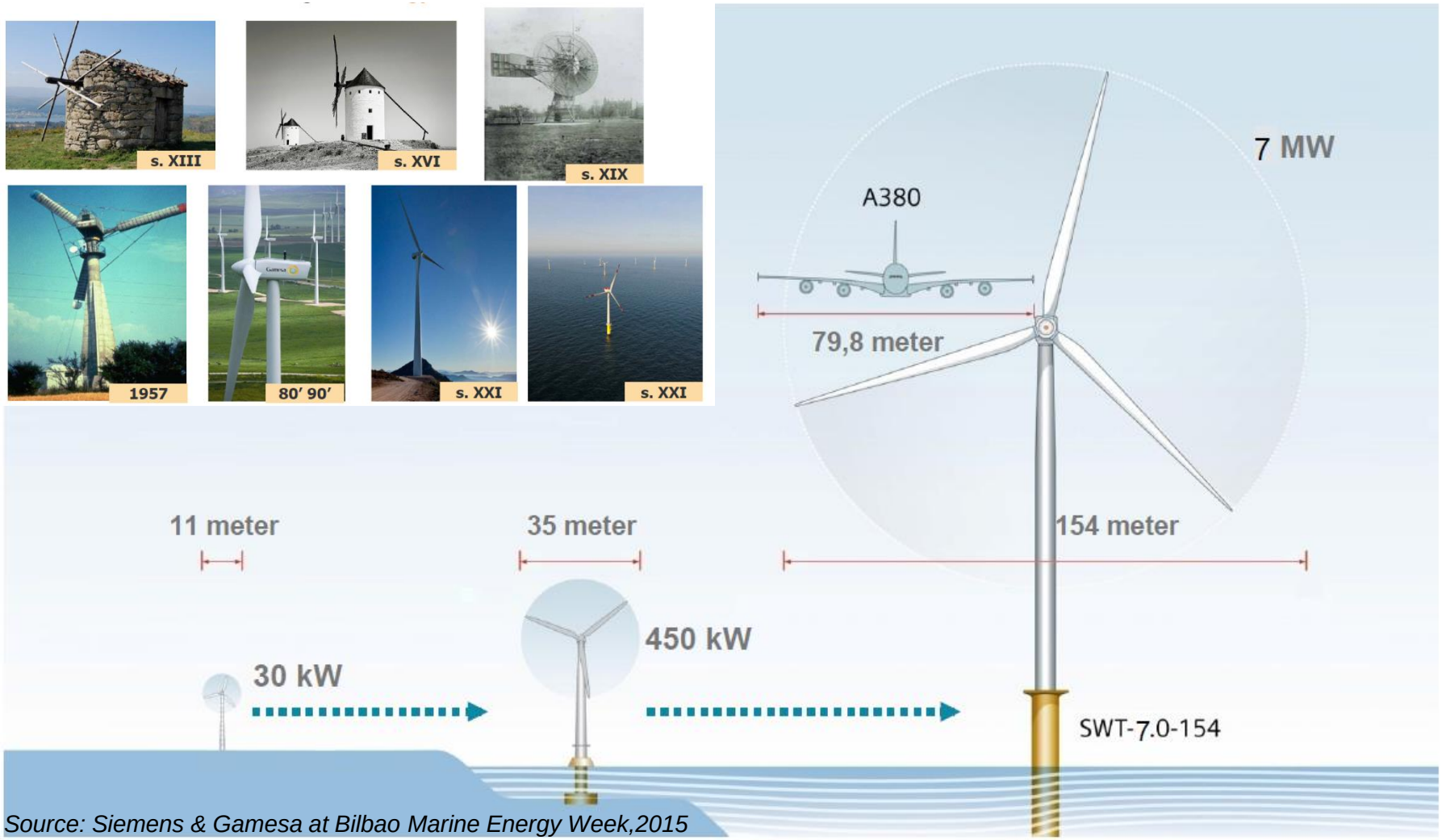
Source: EWEA and IEA

$1M€=10^{6}€$

$1B€=10^{12}€$

Huge offshore wind market is expected for the upcoming years. Cost reductions are highly required to reach these predictions.

Wind Turbine Dimension



Source: Siemens & Gamesa at Bilbao Marine Energy Week,2015

Offshore wind power market shows the tendency of large-scale wind turbines

Large-scale wind turbines

8MW

8MW

GEARED

Large-scale conventional wind turbines are under development in the market

6MW

6 - 7 MW

GEARLESS

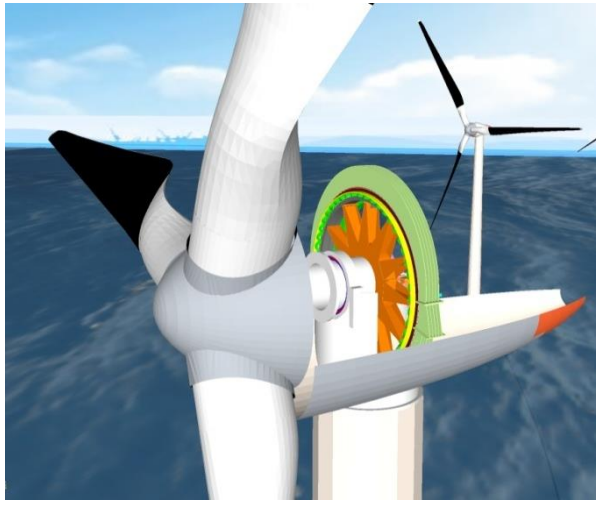
Source: Companies website

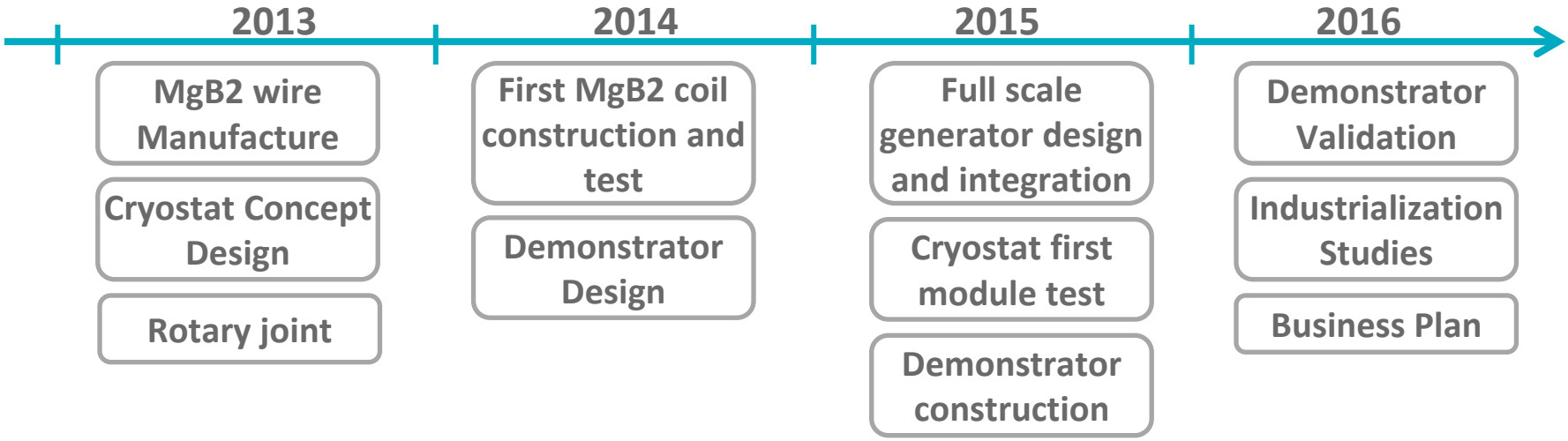
How to develop large-scale wind turbines up to 10 MW and even 20 MW?

SUPARPOWER Project

Aims:

- Suprapower aims to develop a new concept of innovative, **lightweight, robust and reliable wind turbine for offshore applications** by use of superconductivity
- **10 MW class generator**. Objective: 30% weight and size reduction
- Validation of generator concept through **a scale machine**





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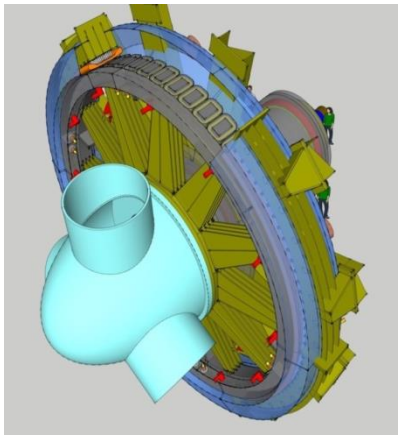
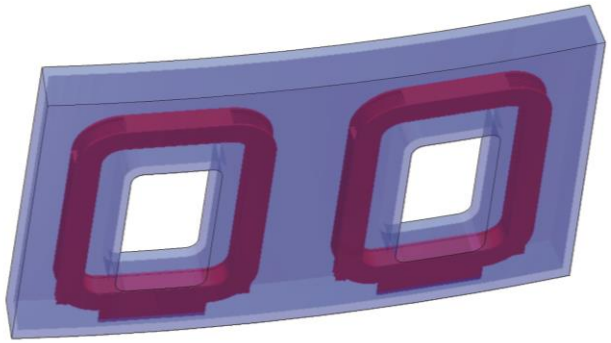
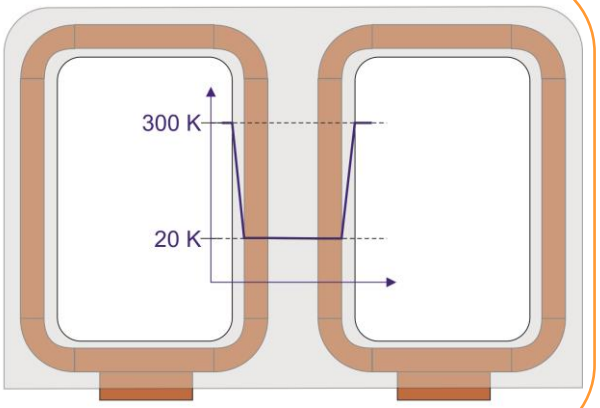
Modular concept

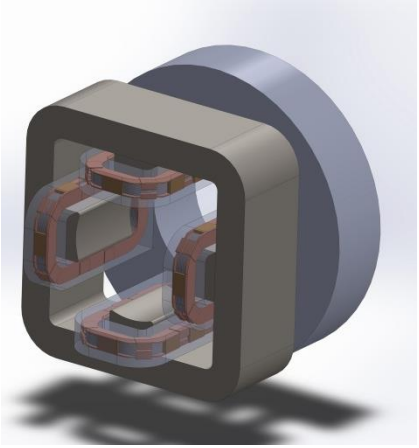


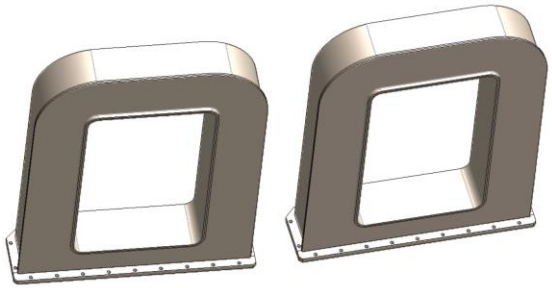


one cryostat for several coils

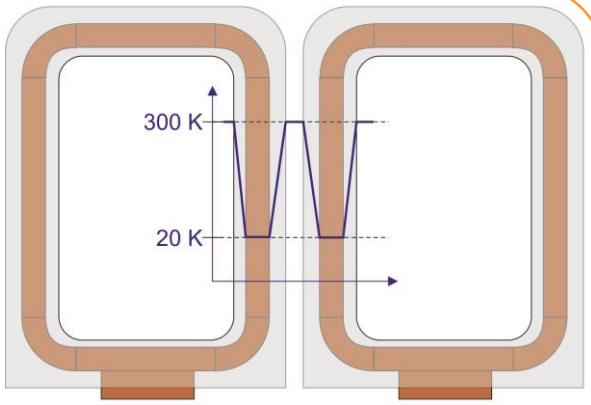


Source: TECNALIA



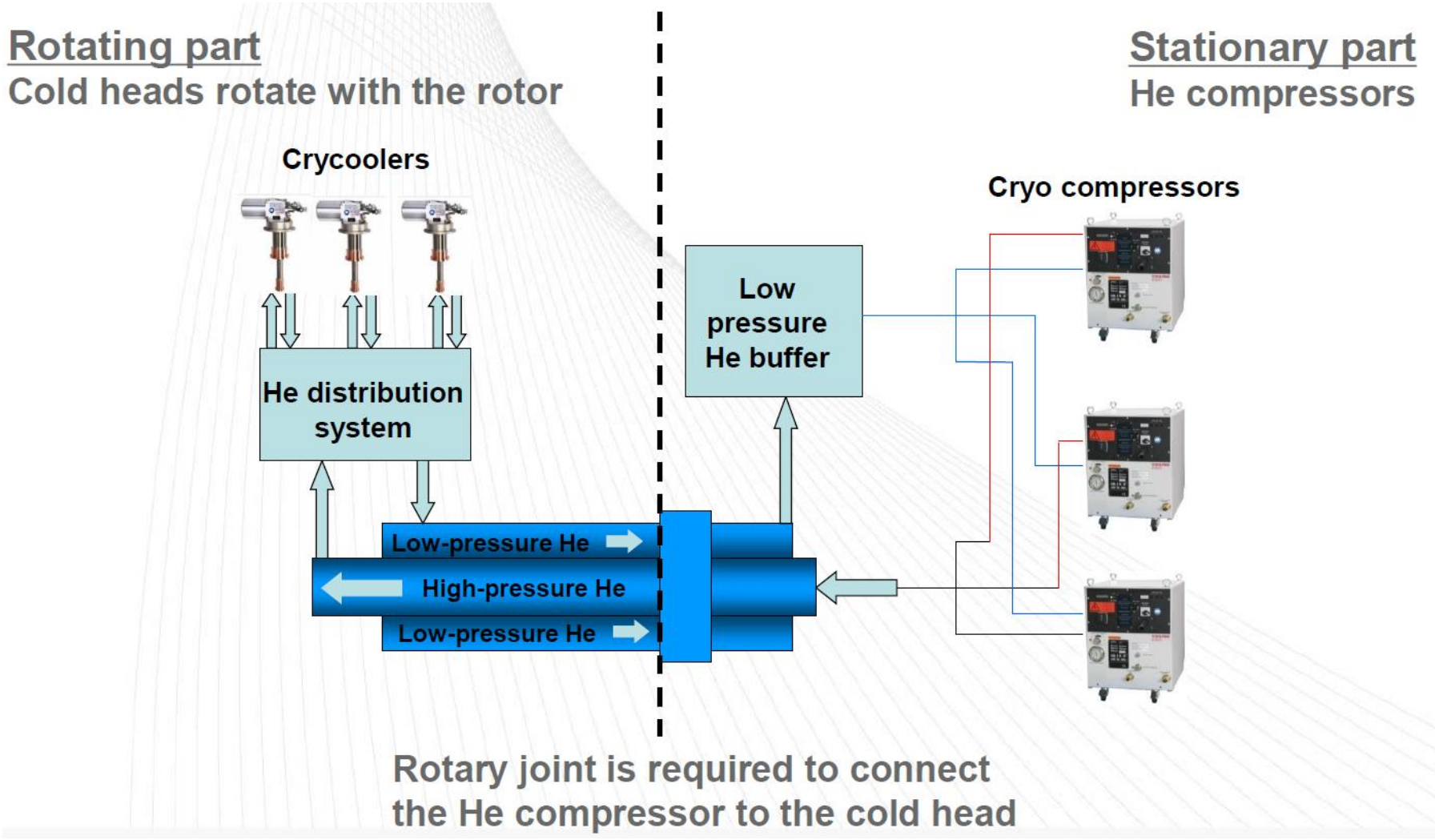


one cryostat for one coil

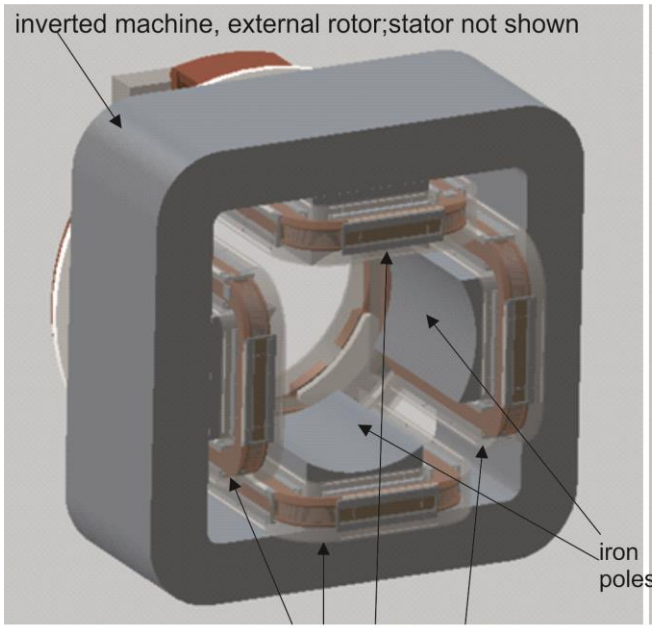


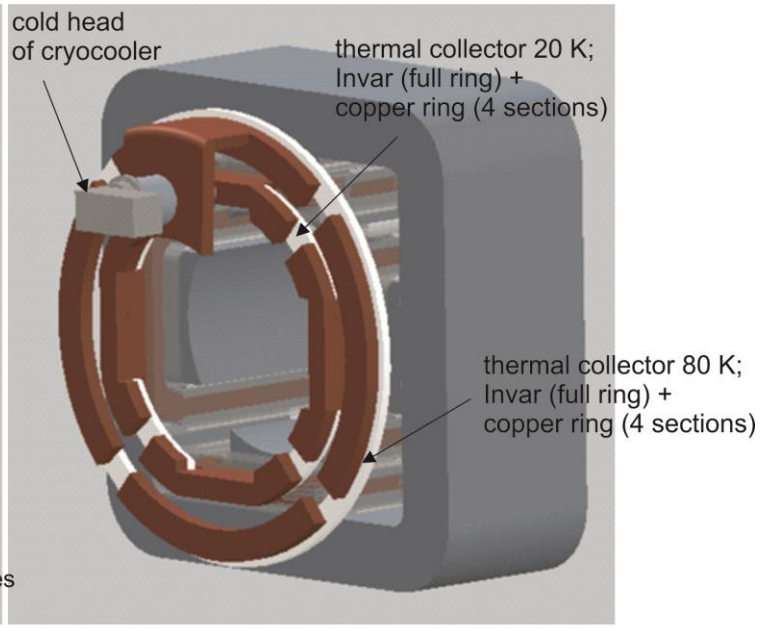
Modular cryostat are proposed to ease installation and maintenance

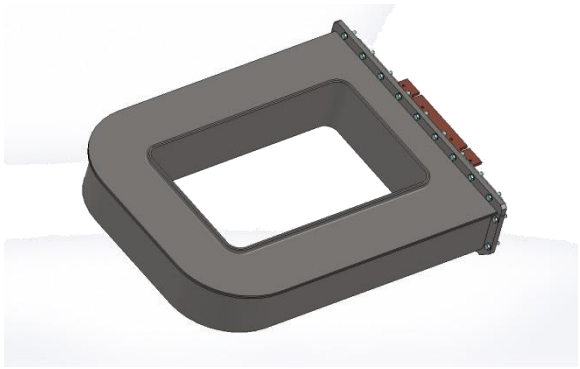
Cooling source-Cryocooler

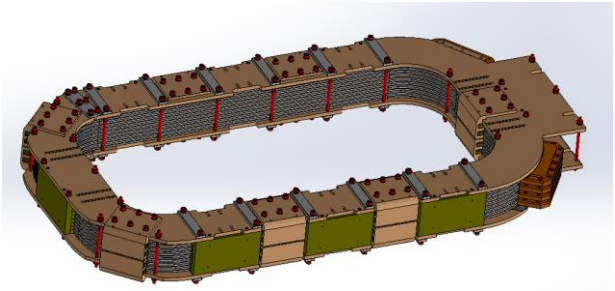


Modular cryostat

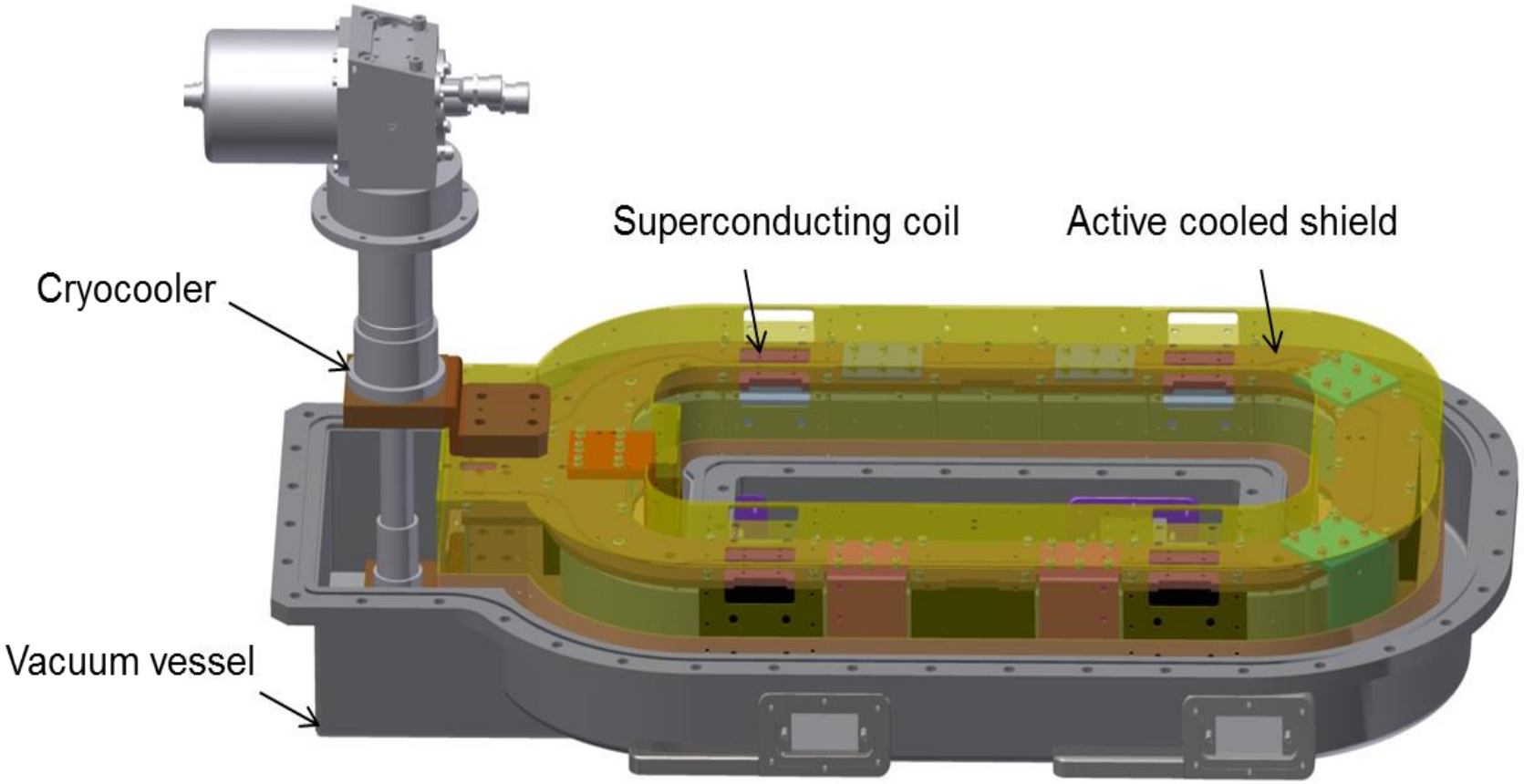




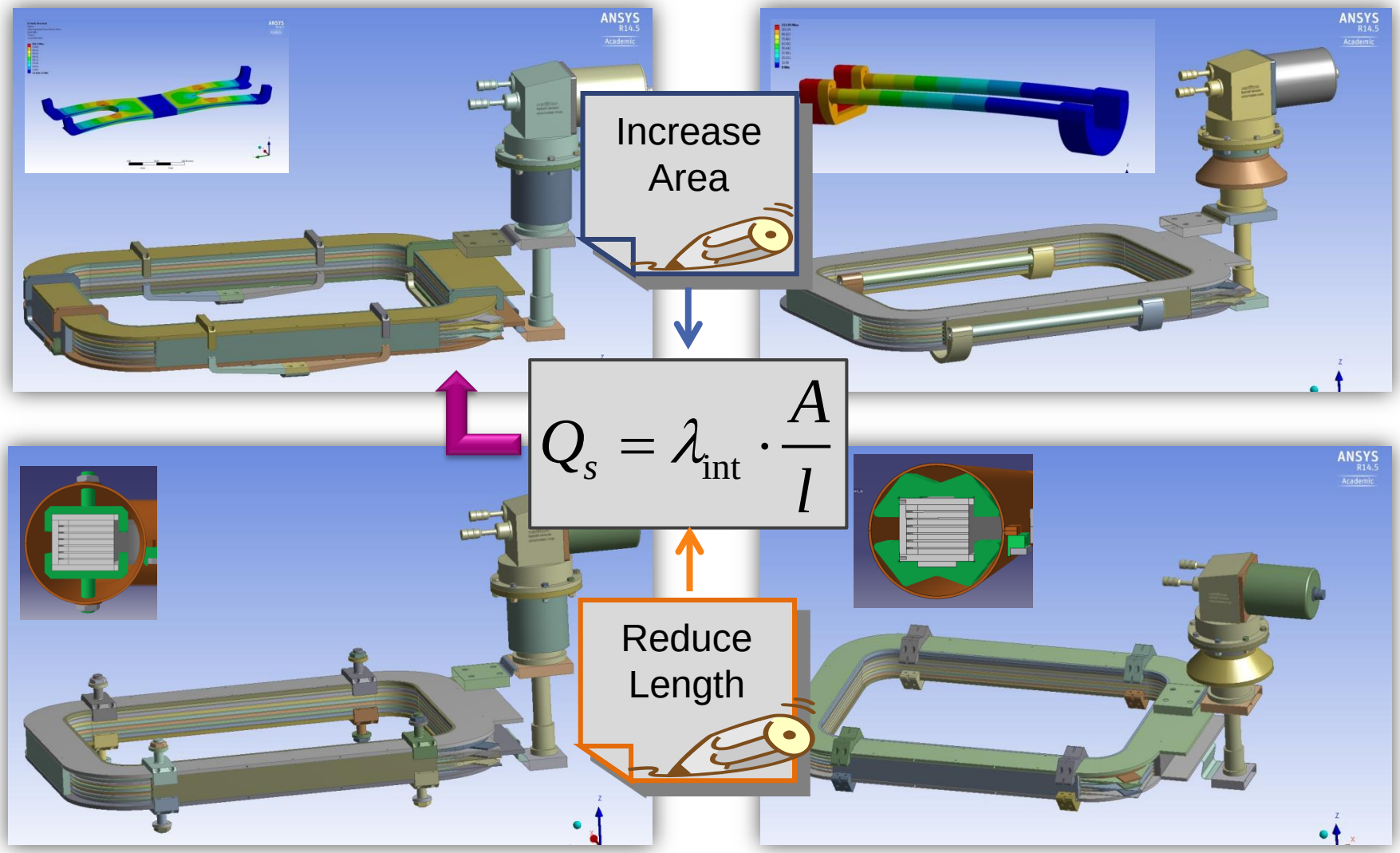




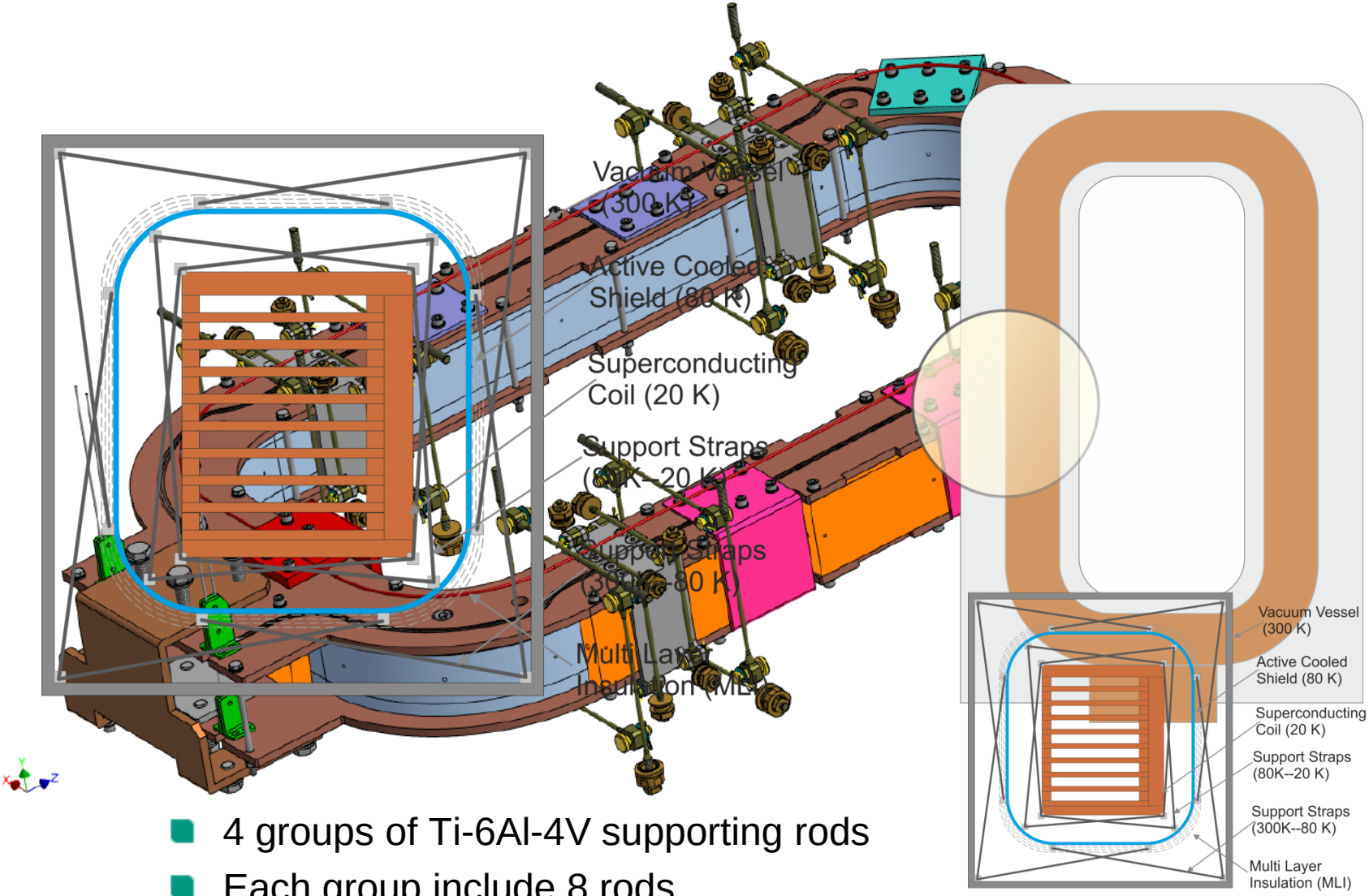
Modular cryostat



Conceptual design of support structure



Support structures



- 4 groups of Ti-6Al-4V supporting rods
- Each group include 8 rods

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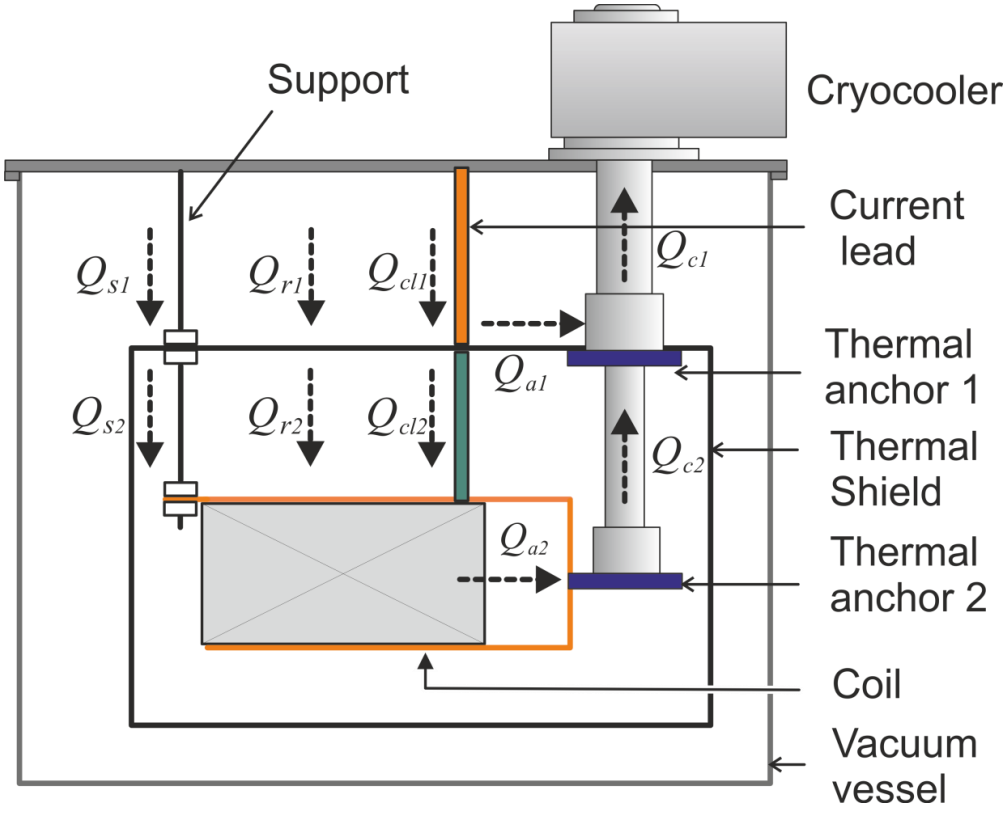
Thermal analysis- Analytical model



$$\frac{d}{dt}(\rho V c_p T)_S = Q_H - Q_L - Q_{A_1}$$

$$\frac{d}{dt}(\rho V c_p T)_{SC} = Q_L - Q_{A_2}$$

$$\frac{d}{dt}(\rho V c_p T)_{A_1} = Q_{A_1} - Q_{C_1}$$

$$\frac{d}{dt}(\rho V c_p T)_{A_2} = Q_{A_2} - Q_{C_2}$$

$$0 = Q_H - Q_L - Q_{c_1}$$

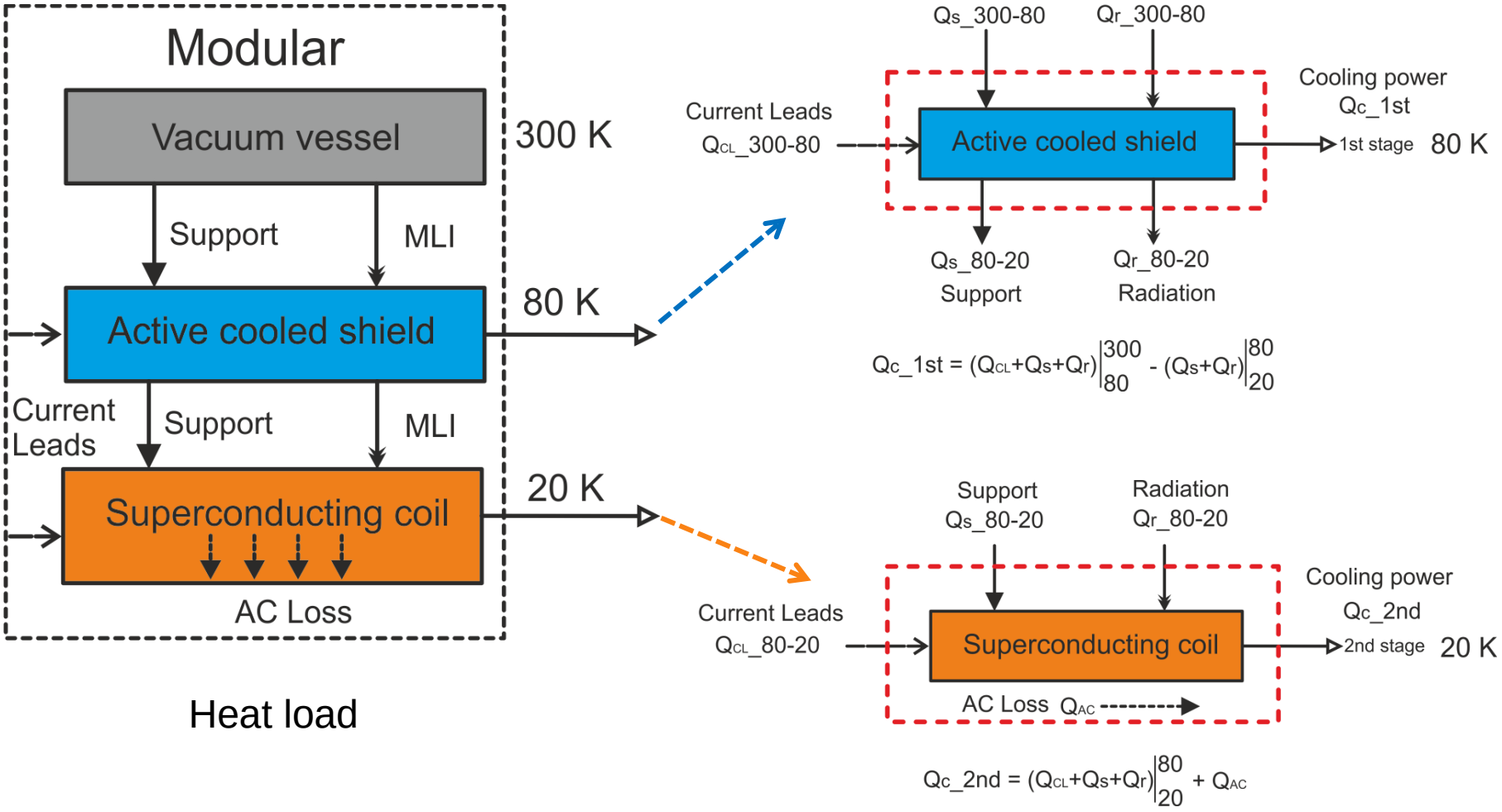
$$0 = Q_L - Q_{c_2}$$

$$Q_H = Q_{s1} + Q_{r1} + Q_{cl1}$$

$$Q_L = Q_{s2} + Q_{r2} + Q_{cl2} + Q_{AC}$$

- Steady state
- Zero dimension
- Neglect thermal anchor

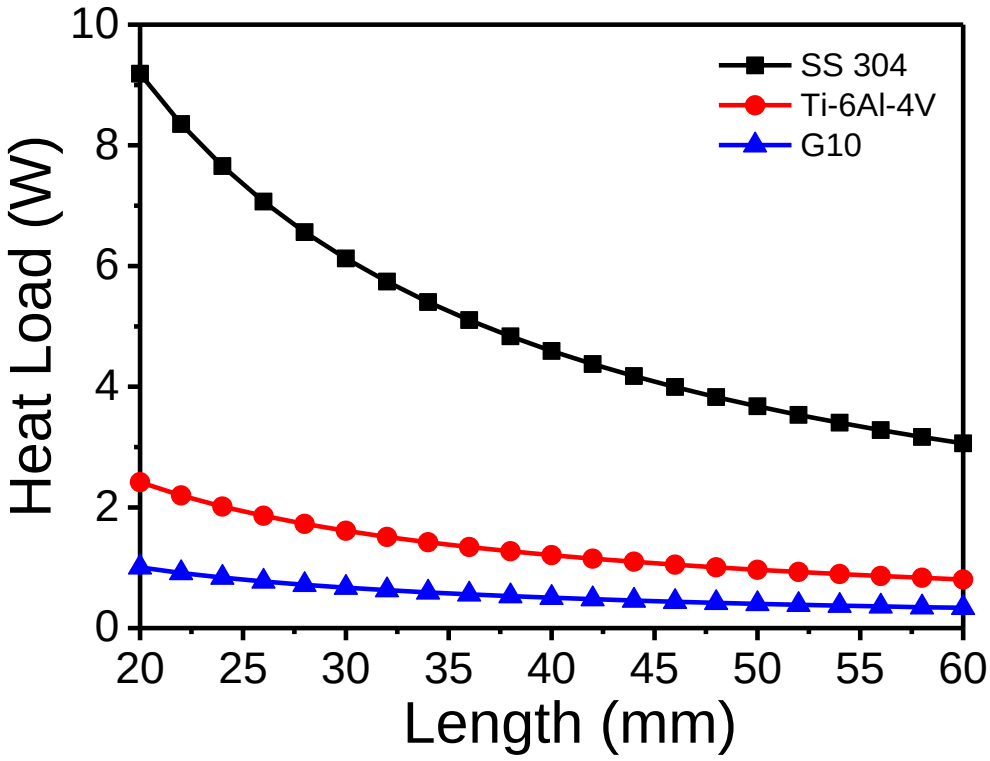
First law of thermodynamics



Conduction via support-Material selection

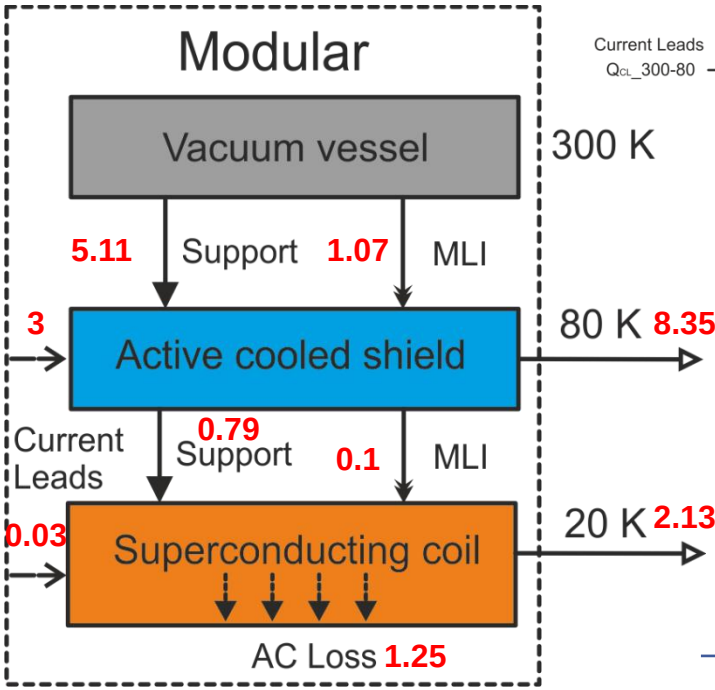
$$A_{strap} = \frac{F_{strap} \cdot s}{\sigma}$$

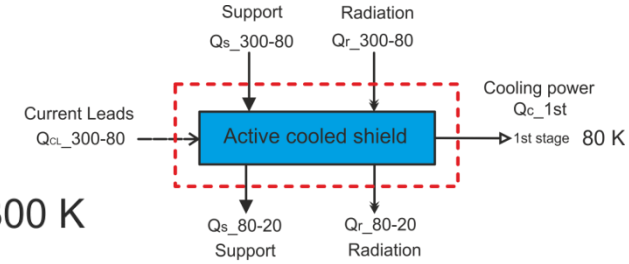
$$Q_{strap} = \lambda_{\text{int}} \frac{A_{strap}}{l} \cdot n$$

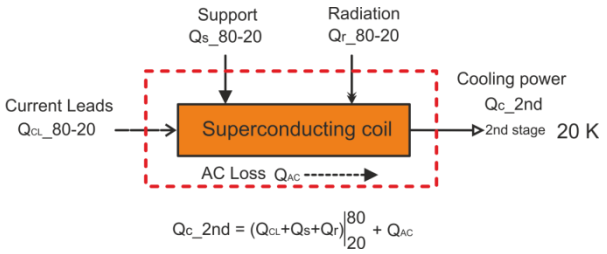


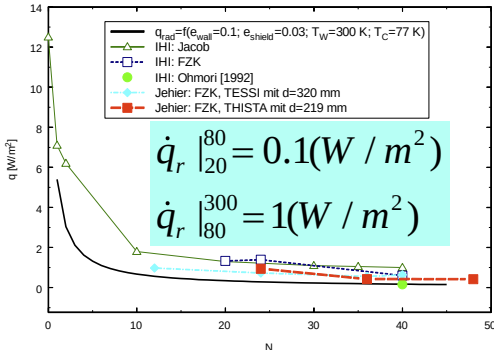
- The material G10 has the best thermal performance---lowest conduction
- G10 also has the largest cross sectional area & gas exhausting effect
- Titanium alloy Ti-6A1–4V is finally chosen for the cryostat straps

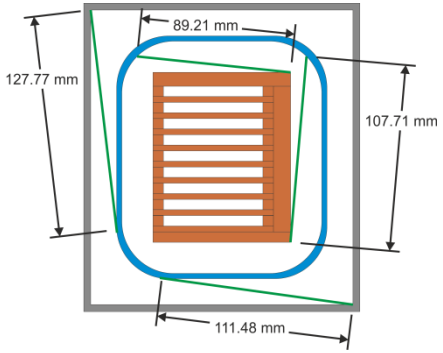
Heat load calculation







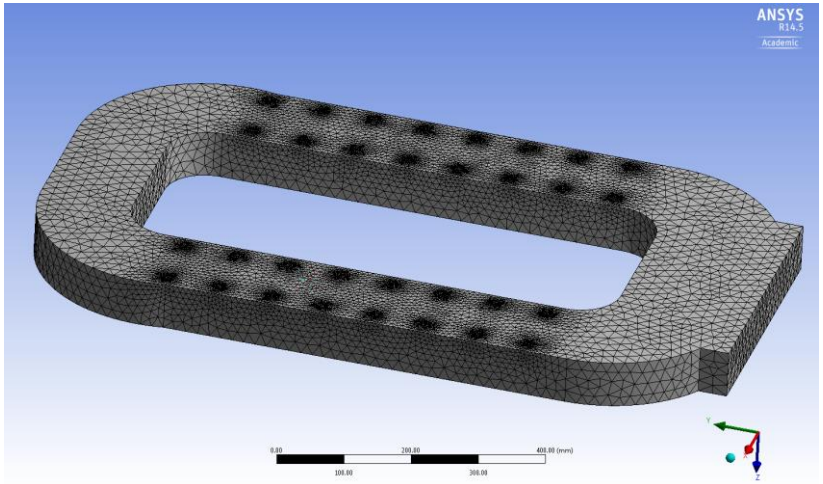




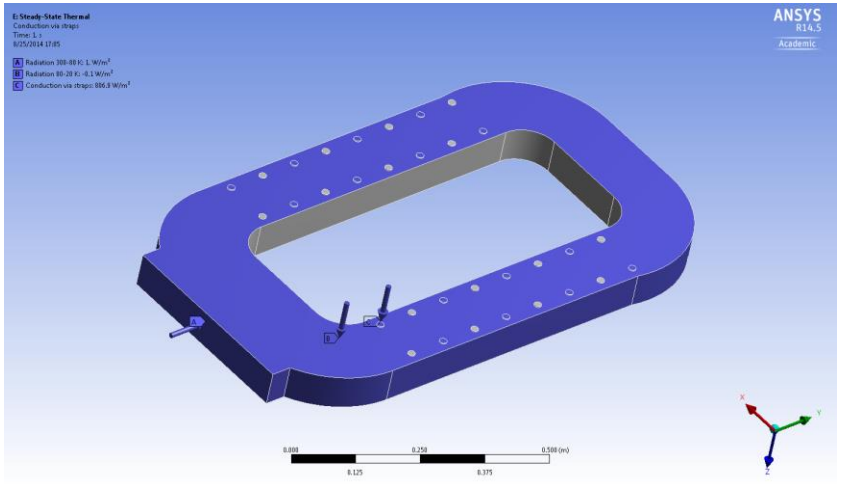
Assumption
Uniform temperature
coil(20 K) shield(80 K)
vessel(300 K)

Heat	Qs	Qr	QAC	QCL	Sum
unit	W	W	W	W	W
Shield	5.11	1.07	0	3	8.26
Coil	0.79	0.1	1.25	0.03	2.17

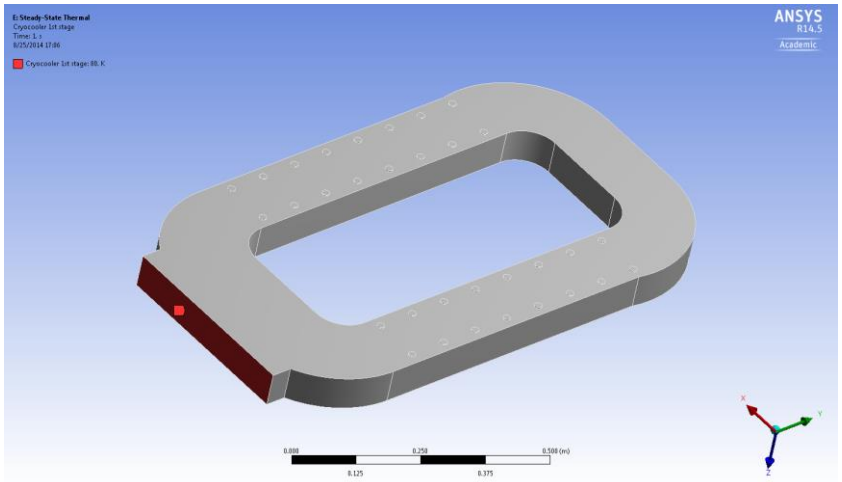
Design of active cooled shield- FEM simulation



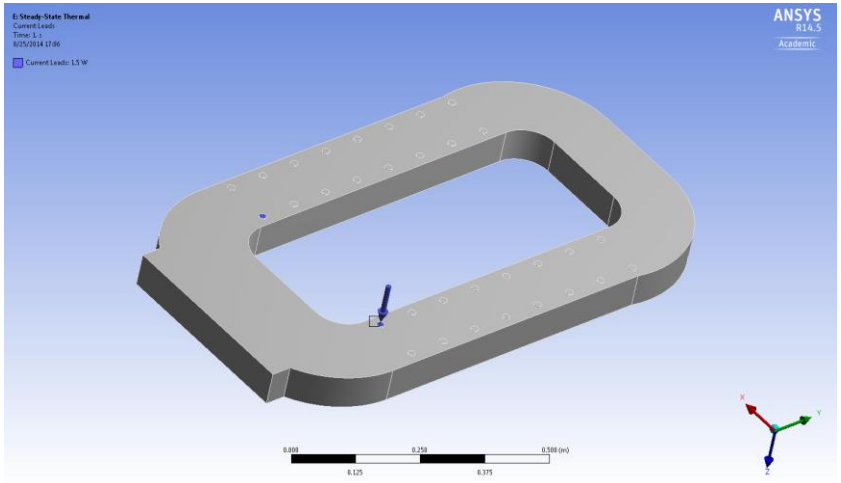
72,201 Elements and 140,040 Nodes



Conduction and radiation to shield

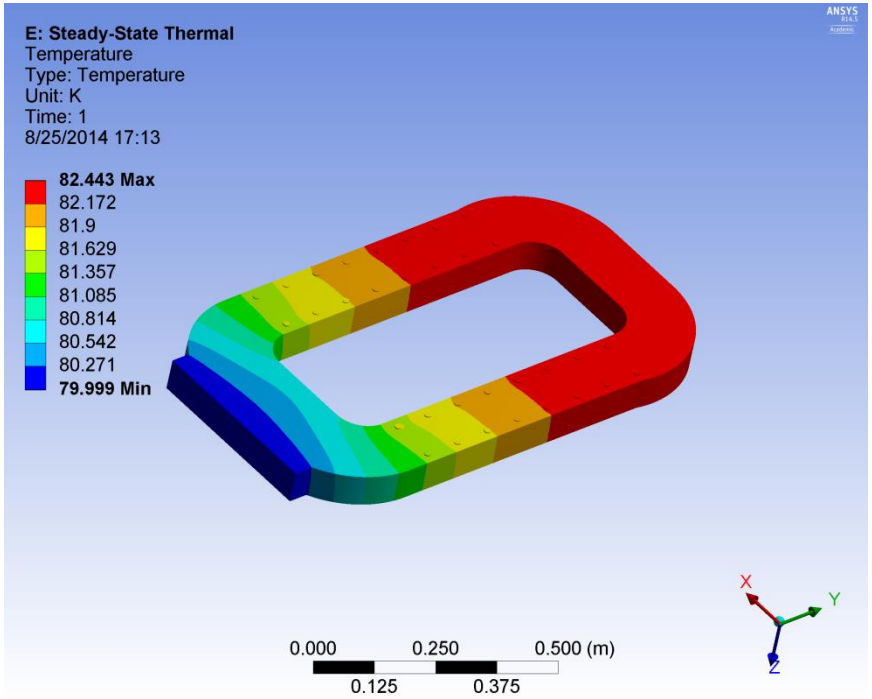


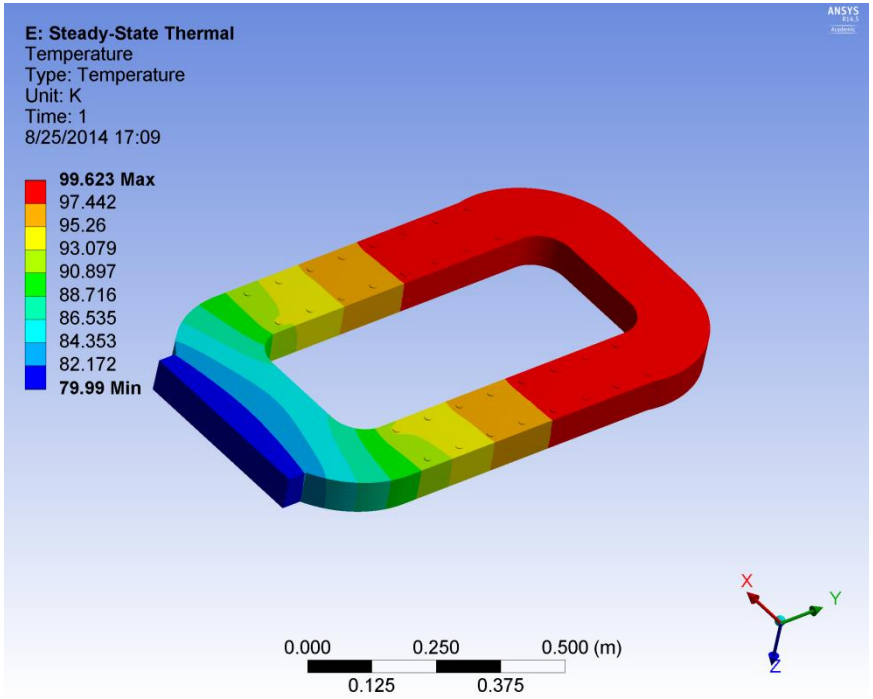
Cold end-Connect with cryocooler



Current leads loss

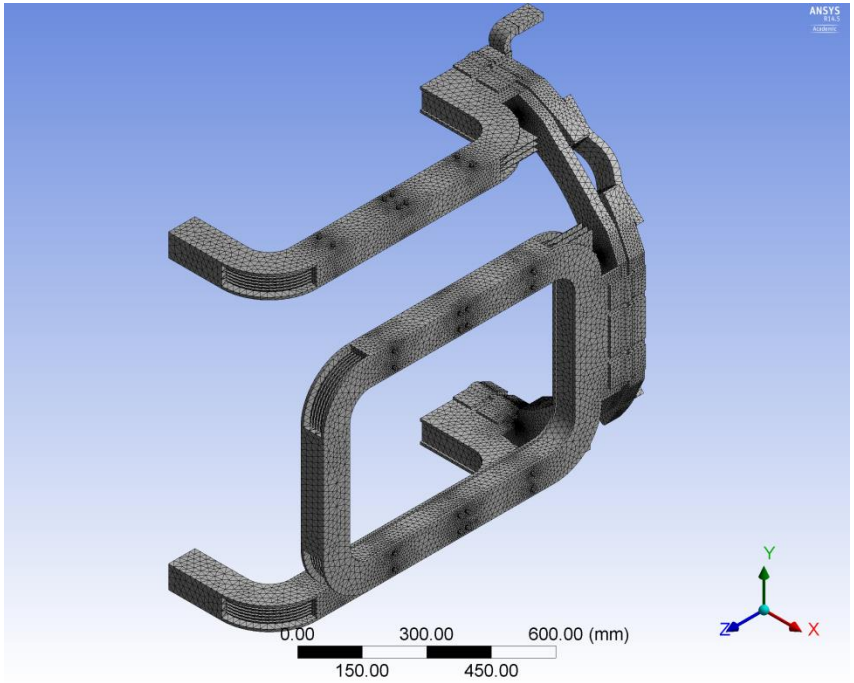
Design of active cooled shield

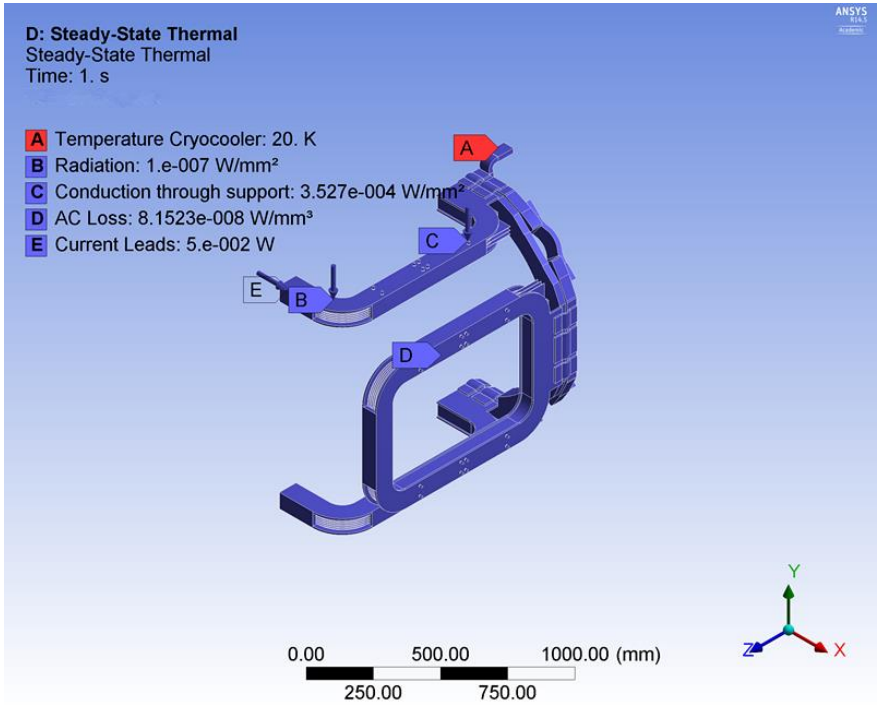




- The temperature distribution of active cooled shield is not uniform
- The maximum temperature difference is 2.44 K and 19.62 K for copper and Al respectively
- Temperature change will influence the heat conduction on support straps

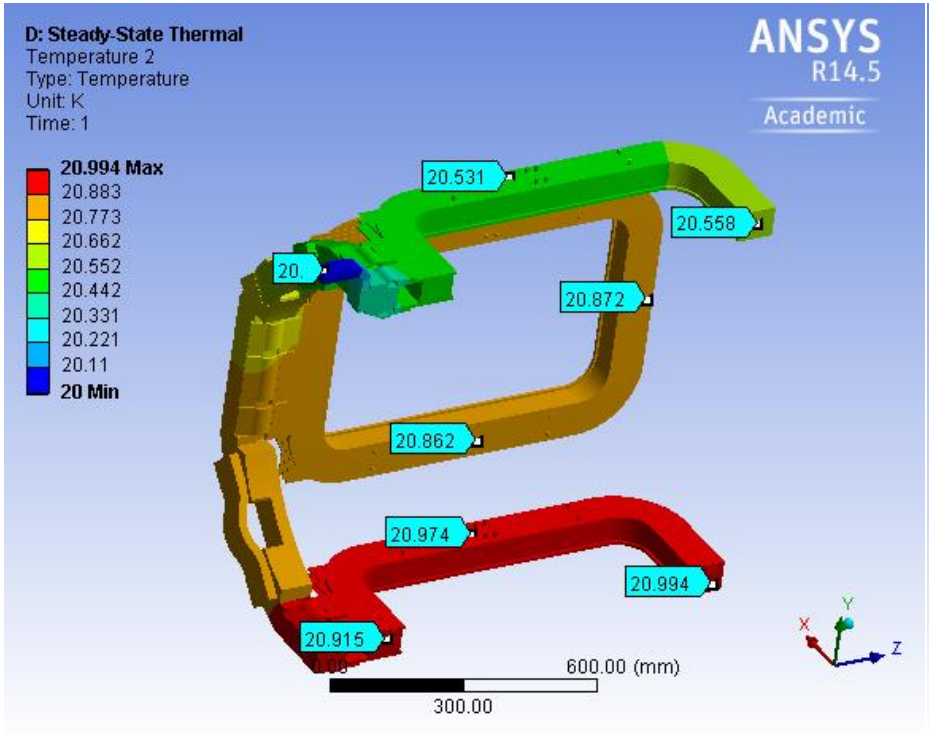
Ansys-numerical model

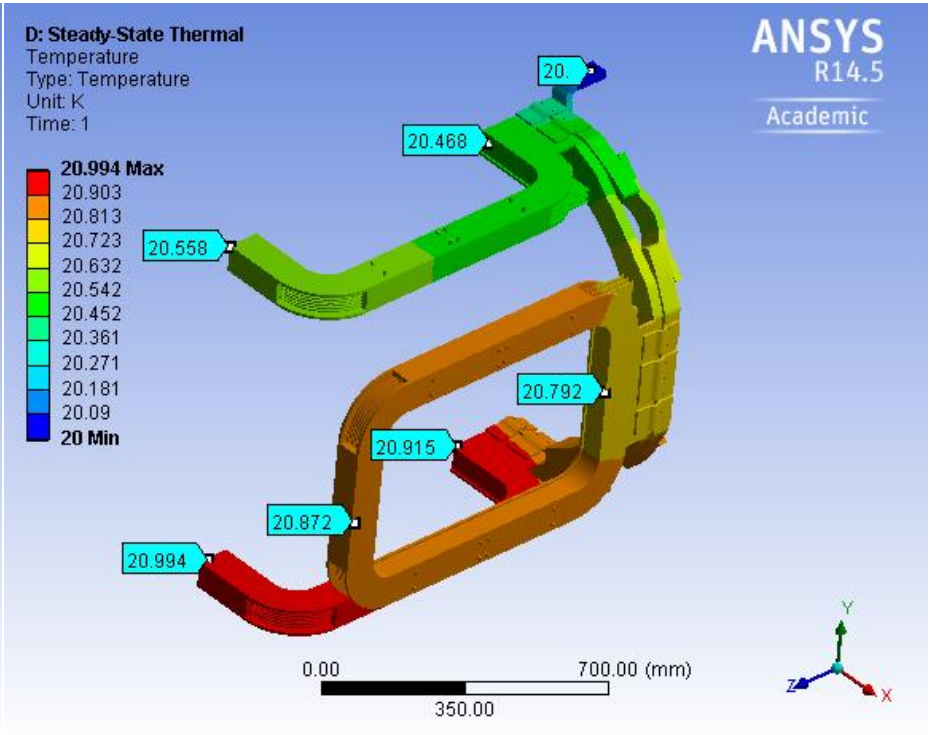




- The grid resolution gives a mesh with tetrahedrical elements, resulting a total of 4,839,088 nodes and 3,511,053 elements.
- Because of the symmetry boundary condition only the half structure has been studied.
- Different heat loads are applied to the model accordingly

Temperature distribution





- The maximum temperature difference along the coil is around 1 K
- Reducing AC loss could further reduce this temperature variation

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Summary

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  - MgB2 superconducting wires
- 2. Modular cryostat concept
  - Modular cryostat
  - Two stage G-M cryocooler & Conduction cooling
  - Titanium alloy supporting rods
- 3. Thermal performance of cryostat
  - 2.17 W @ 20 K heat load per supercomputing coil
  - 1 K temperature variation along the superconducting coil

Thanks for your interest

More info at

www.suprapower-fp7.eu

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