# Thermal model for $Nb_3Sn$ Inner Triplet quadrupoles - 150 mm aperture option

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2nd HiLumi LHC/LARP Annual Meeting, LNF,
14th-15th-16th November 2012, Frascati

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

# Overview

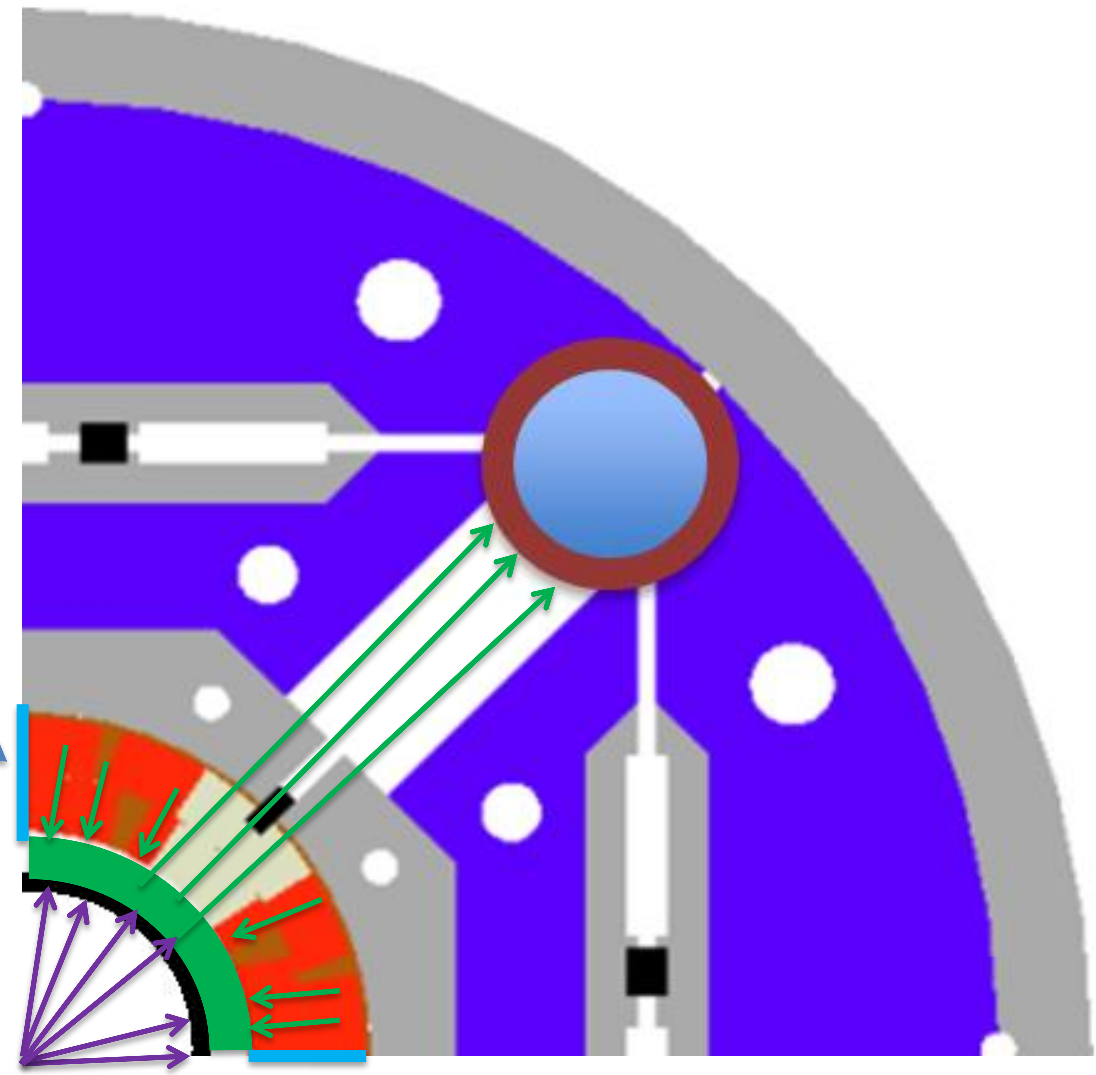
- General aspect
- Case considered – proposed features
- Coil insulations
- Helium channels through the pole
- Heat load considered
- Typical to be expected T-map for a coil with cooling at 1.9 K
- Heat flow distribution
- Typical to be expected T-map margin for a coil with cooling at 1.9 K under heat load
- Criticality analysis
- Main observations

# Coil cooling principle

- Heat from the coil area (green) and heat from the beam pipe (purple) combine in the annular space between beam pipe and coil and escape radially through the magnet "pole" towards the cold source → *"pole, collar and yoke" need to be "open"*

- Heat Conduction mechanism in the coil packs principally via the solids, except for dedicated helium channels deliberately machined in the mid-plane

- Longitudinal extraction via the annular space is in superfluid helium, with T close to $T_\lambda$ and with magnets up to 7 m long not reliable → *"pole, collar and yoke" need to be "open"*



≥ 1.5 mm annular space

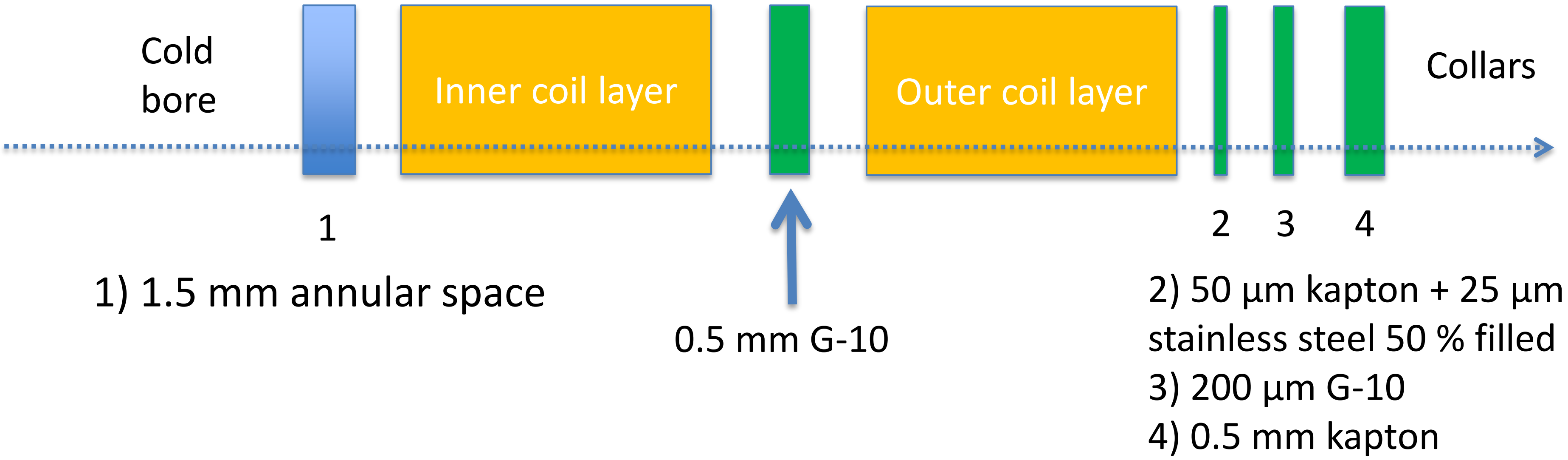
Superfluid helium cooling, 150 mm aperture, 1 case considered:

3.7 mm cold bore + 2 mm beam screen + 6 mm W absorbers

***Proposed features***

| Feature | Value | comments |
|---|---|---|
| Annular gap | 1.5 mm | Safest choice for cooling and pressure rise due to quench (to be verified) |
| collar open | 2 % | Can be lower in steady state Dynamic to be verified |
| Yoke open | 2 % | Can be lower in steady state Dynamic to be verified |
| Titanium piece open | 4 % | |
| Aluminium collar keys | 4 % | More investigation needed with the real holes |
| Mid-plane open | **> 7 %** | |
| Beam screen actively cooled by helium channels | 4 x 4.5 – 4.7 mm ID or 8 x ~ 3.4 mm ID | estimated for ~ 400 W total |
| 2 heat exchangers | 68 mm ID | calculated for ~ 500 W total |
| Some Materials thermal properties need to be measured | | |

# Coil magnet configuration assumed for calculations




- Cable: 0.15 mm G-10 insulated
- 2-3-4 have been homogenized to form one mono layer
- Lack of some material thermal properties: need to be measured

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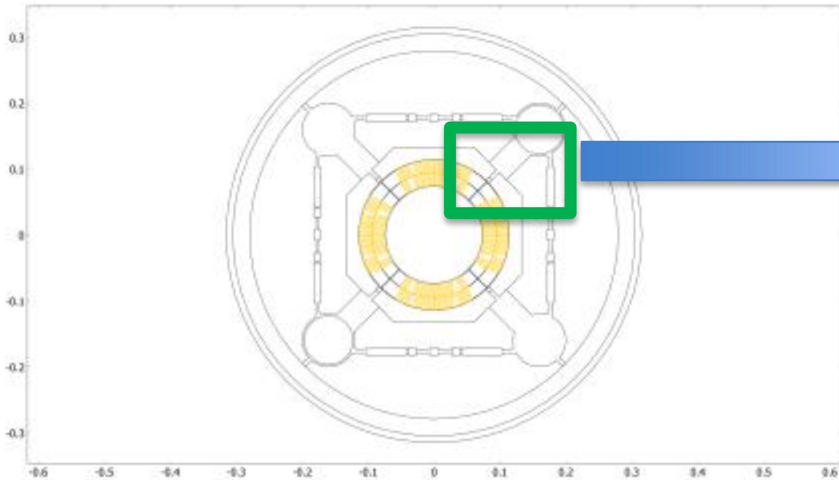
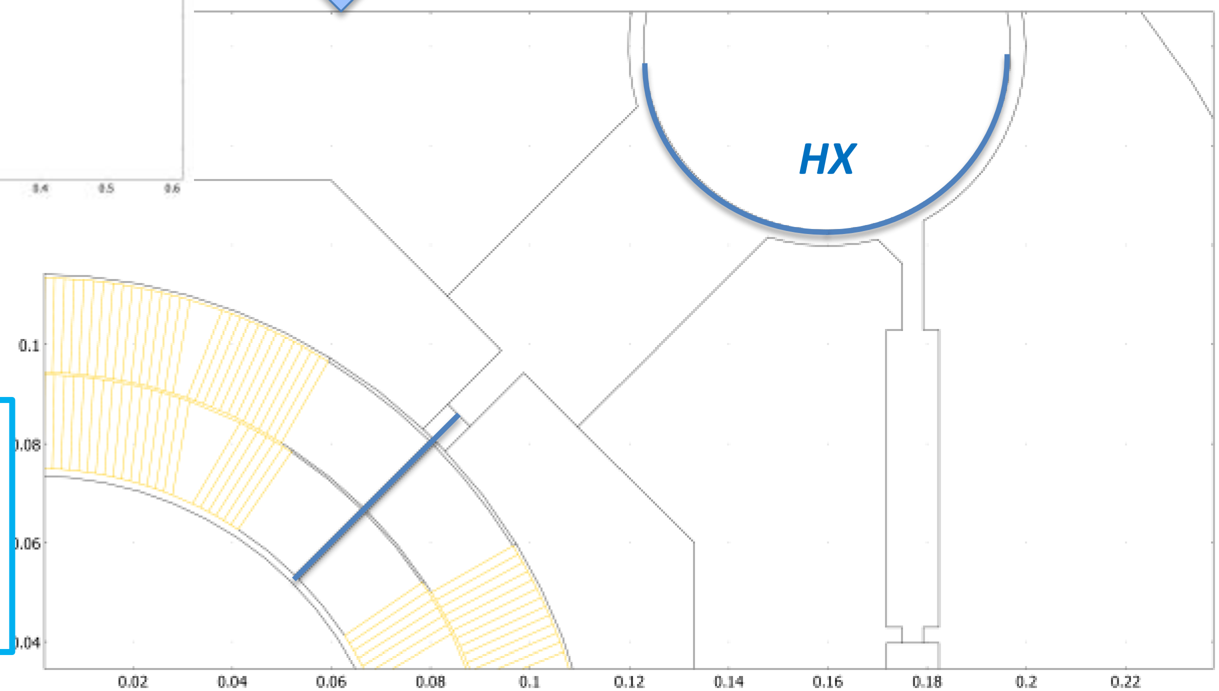
# Heat escape through the pole

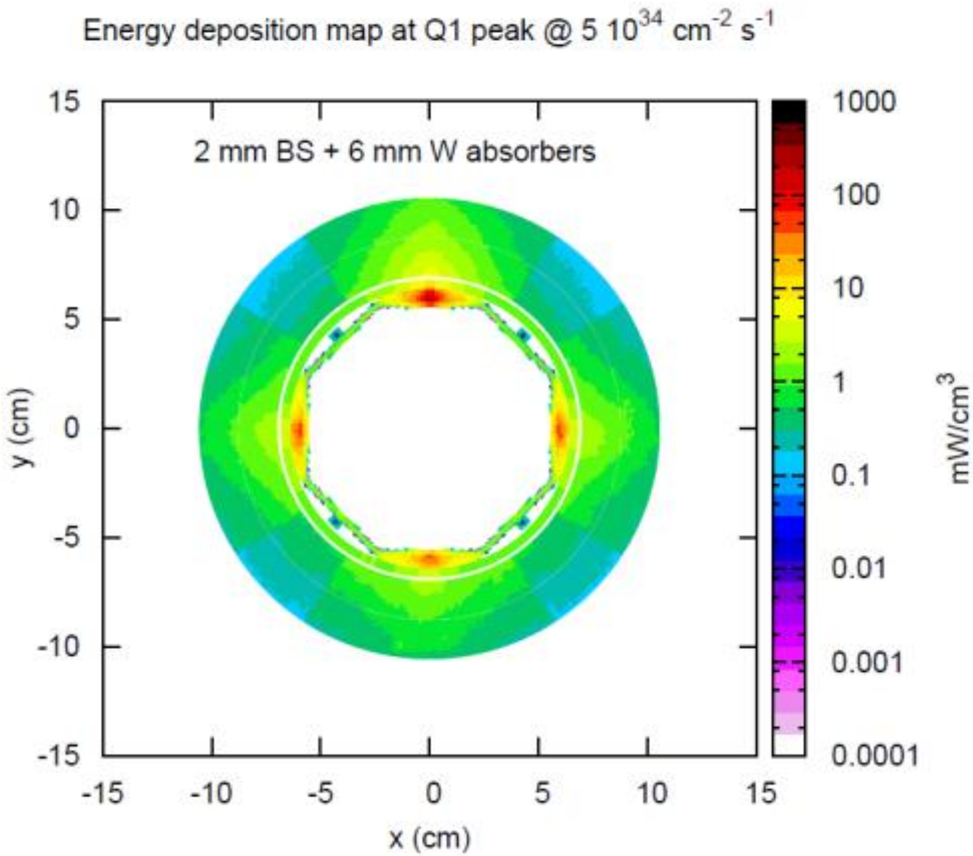


Previously: pole homogenously 4 % open to He II




Now: pole with channels 4 % (1.2 mm) open to He II
Communicating from the annular space to the HX

# Energy deposition 2D map for Q1 at peak power (140 mm aperture option)




*Courtesy of F. Cerutti and L. Salvatore*

**Rescaled** to have the same **heat load** in **W/m** for the **150 mm aperture option**

# Corresponding Energy deposition used for the model on the coil

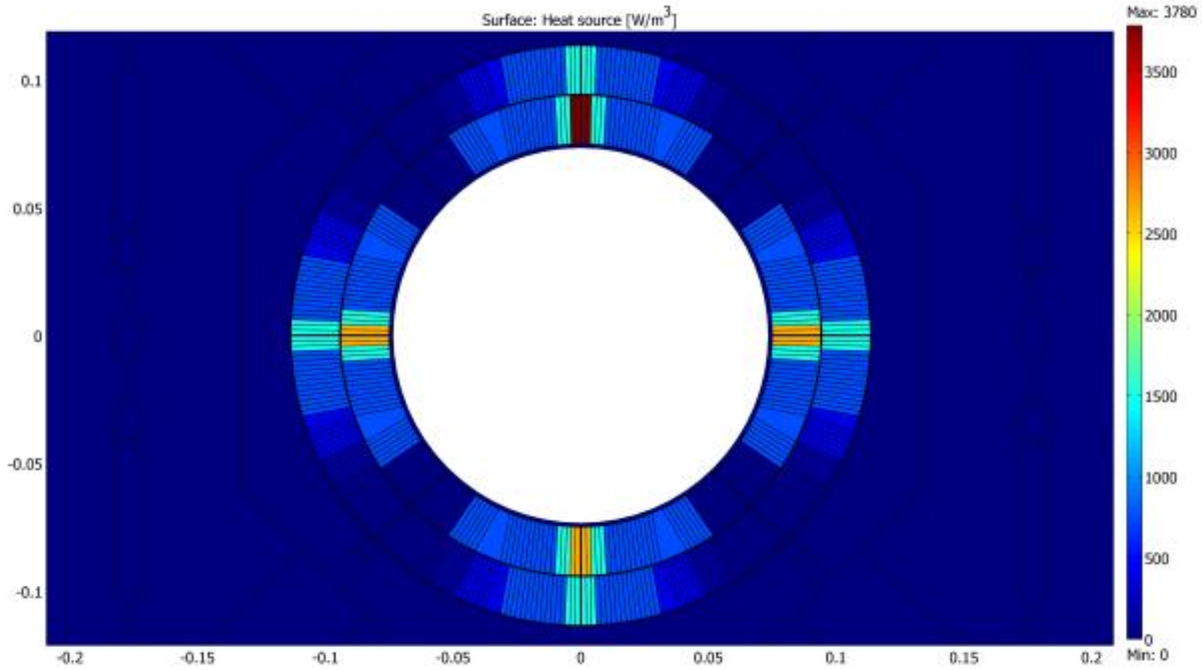
**1**) 3.7 mm cold bore + 7 mm W inserts
**2**) 3.7 mm cold bore + 6 mm W inserts + Beam Screen

} Same heat load on the coil (~13 W/m) peak at 3.78 mW/cm$^3$

Difference between 1 and 2: heat load on the cold bore -> 55.6 W/m$^2$ for **1** and 6.8 W/m$^2$ for **2**

↳ ***Absorbed by the heat exchanger***

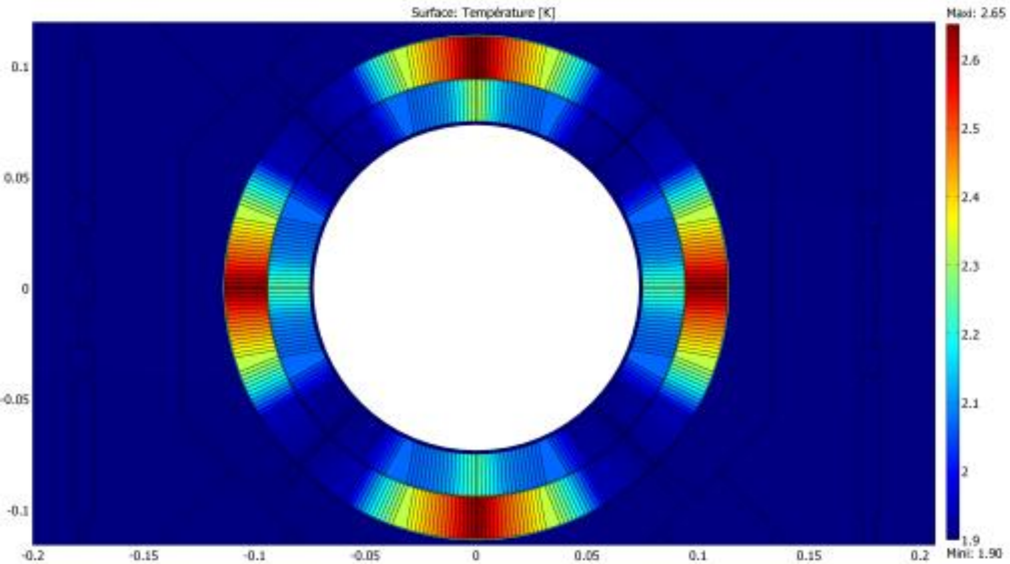
- ***Simulations: case 2 considered***



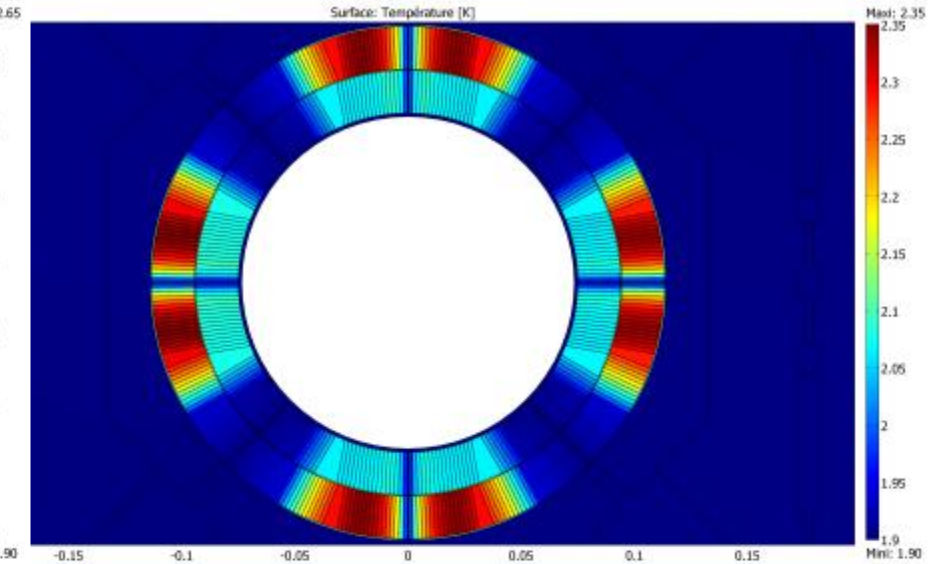

**heat load** in **W/m$^3$**

# Simulated T-distribution in a He II bath at 1.9 K

Coils **without** helium channels in the mid-plane




Coils **with** helium channels in the mid-plane




| Mid-plane He II channels | closed | 1 or 2 sides open |
|---|---|---|
| $T_{max}$ (K) coils in magnet configuration - HX at 1.9 k | 2.65 | 2.35 |
| $\Delta T_{max}$ (K) | 0.750 | 0.450 |

For the **140 mm** aperture option, **700 mK** gained with He channels in the mid-plane on $T_{max}$
For the **150 mm** aperture option, **300 mK** gained with He channels in the mid-plane on $T_{max}$

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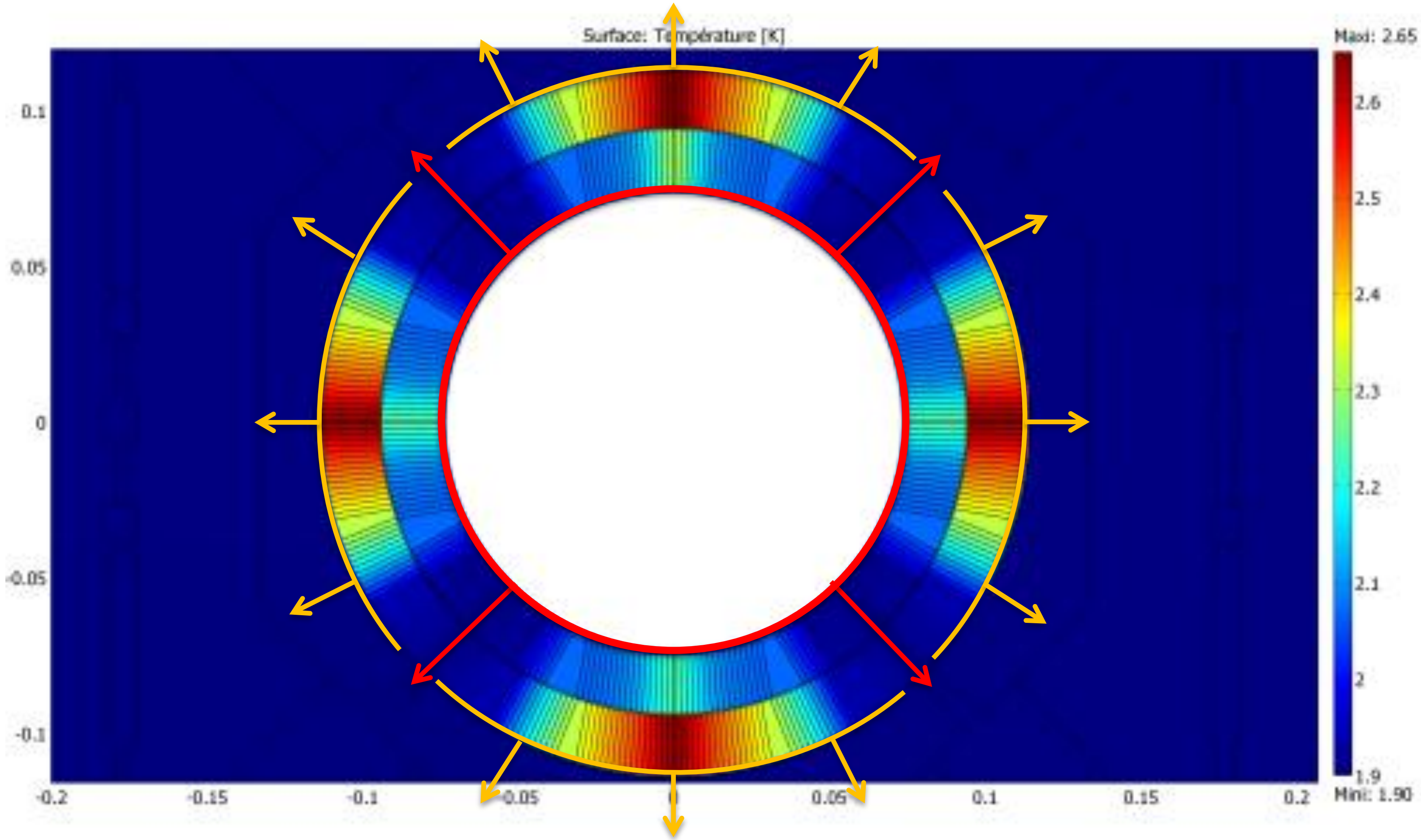
# Heat flow distribution - no helium channel in the mid-plane




85 % through the helium channels in the pole

15 % through the external insulation

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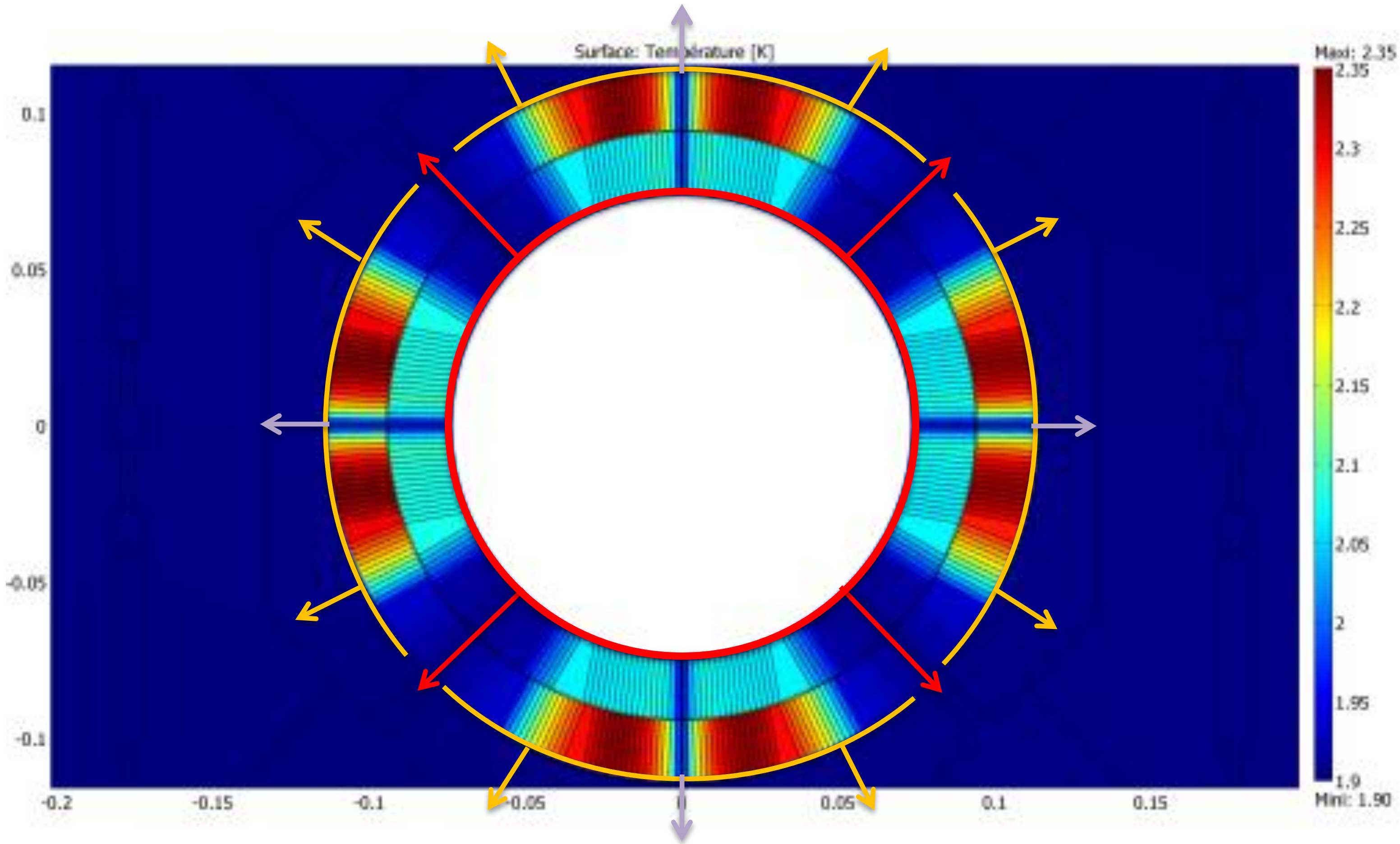
# Heat dissipation - helium channels in the mid-plane




78 % through the helium channels in the pole

13 % through the external insulation

9 % through the mid-plane helium channels

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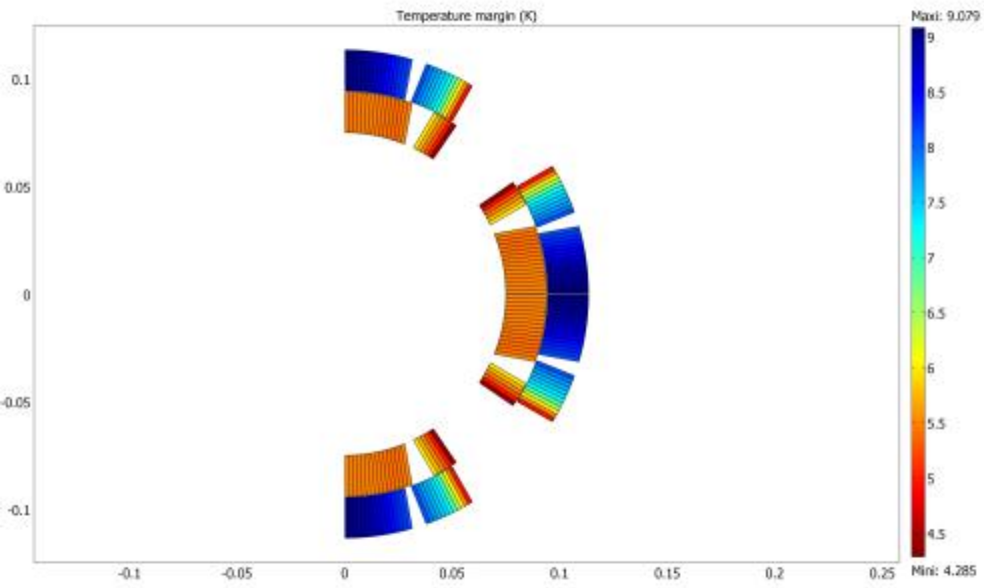
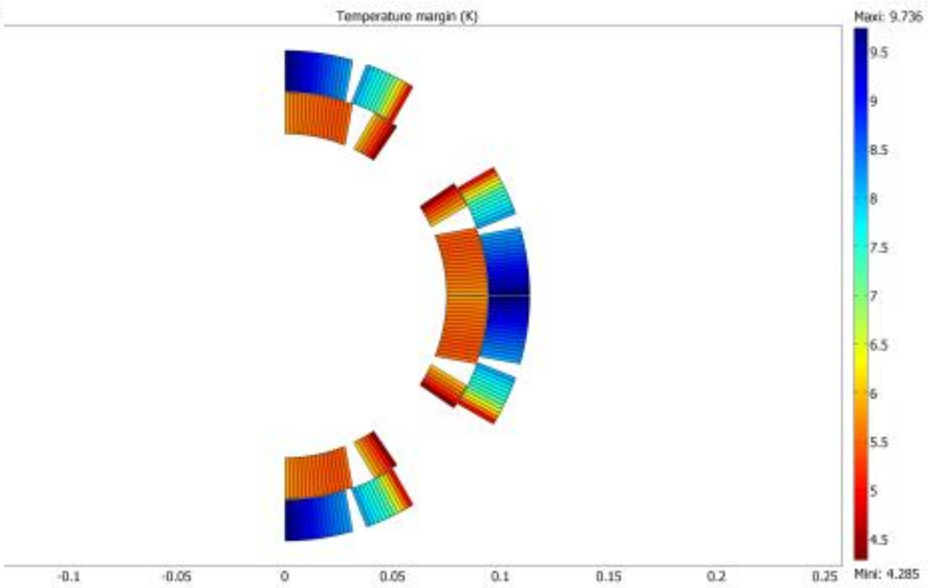
# Temperature margin under heat load

- Nominal current considered
- Worst case considered for each cable
- Heat load at peak power deposition considered

**No helium channel in the mid-plane**




**Helium channels in the mid-plane**

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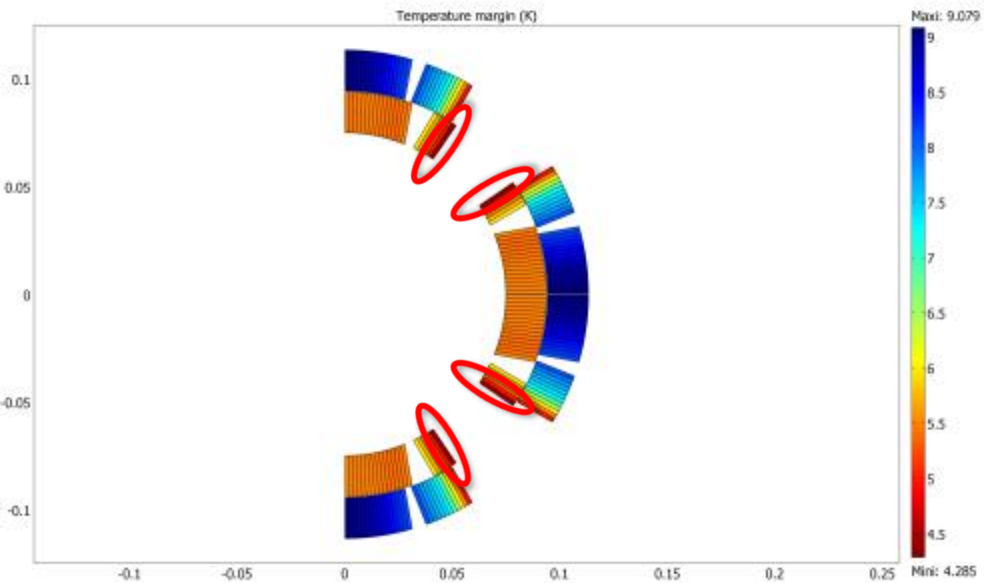
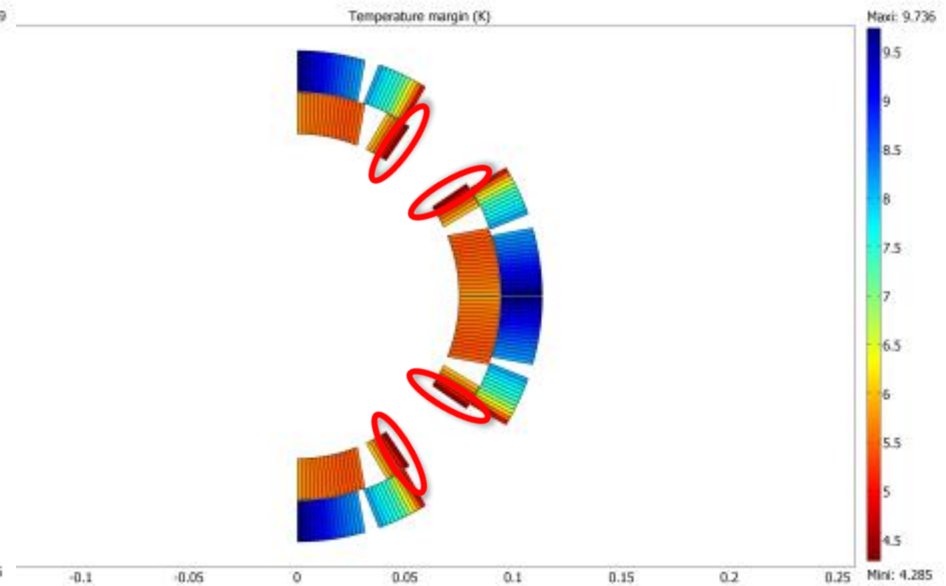



**Helium channels in the mid-plane**




For both cases, the **lowest T-margin** is for the **inner coil cables adjacent to the pole piece**
**Temperature margin** is **4.29 K** at this point (mid-plane T-margin ~5.46 K)

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# Criticality analysis

| | $T_{max}$ (K) (position) | Lowest T margin (K) (position) |
|---|---|---|
| HX - 2.05 K – no He channel in the mid-plane – collars/yoke open | 2.75 (mid-plane) | 4.18 (pole) |
| HX - 2.05 K – no He channel in the mid-plane – collars/yoke closed | 2.76 (mid-plane) | 4.17 (pole) |
| HX – 1.9 K – no He channel in the mid-plane – collars/yoke closed | 2.66 (mid-plane) | 4.3 (pole) |
| HX - 2.05 K – He channel in the mid-plane – collars/yoke open | 2.47 (~± 20° axis) | 4.18 (pole) |
| HX - 2.05 K – no He channel in the mid-plane – collars/yoke closed | 2.47 (~± 20° axis) | 4.17 (pole) |
| HX – 1.9 K – He channel in the mid-plane – collars/yoke closed | 2.36 (~± 20° axis) | 4.3 (pole) |

# Criticality analysis

| | $T_{max}$ (K) (position) | Lowest T margin (K) (position) |
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| HX – 1.9 K – no He channel in the mid-plane – collars/yoke closed | 2.66 (mid-plane) | 4.3 (pole) |
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| HX – 1.9 K – He channel in the mid-plane – collars/yoke closed | 2.36 (~± 20° axis) | 4.3 (pole) |

***All results scale ~ linearly with bath temperature***
***Lowest T-margin always at the pole***
***No real criticality for yoke and collar packing***

# Main Observations

***Midplane not opened:***

- Temperature field : **750 mK** < $T_{max\ coil} - T_{HX}$
- Lowest temperature margin: **4.3 K**
- **85 %** of heat evacuated via annular space & channels through pole

***Midplane opened:***

- Temperature field : **450 mK** < $T_{max\ coil} - T_{HX}$
- Lowest temperature margin: **4.3 K**
- **78 %** of heat evacuated via annular space & channels through pole

***Conclusion:***

- Helium channels in the pole: very important since ~ **80 %** of the heat flows through
- **Lowest temperature margin** (cable adjacent to the pole): **4.3 K**

**All of these results must be verified with the real heat load for this option when available**

# References

1. “Investigation of Suitability of the Method of Volume Averaging for the Study of Heat Transfer in Superconducting Accelerator Magnet Cooled by Superfluid Helium”, H. Allain, R. van Weelderen, B. Baudouy, M. Quintard, M. Prat, C. Soulaine, Cryogenics, Available online 14 July 2012.