HiLumi MQXF inner triplet magnets Thermal Modelling – T margin and Heat Extraction margin updates

Presenters

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Introduction

In this presentation are shown the last updates for the MQXF magnets thermal modelling, to take into account:

- Changes in insulation material thicknesses June 2015
- New (June 2015) T current sharing map due to reduction in field gradient.

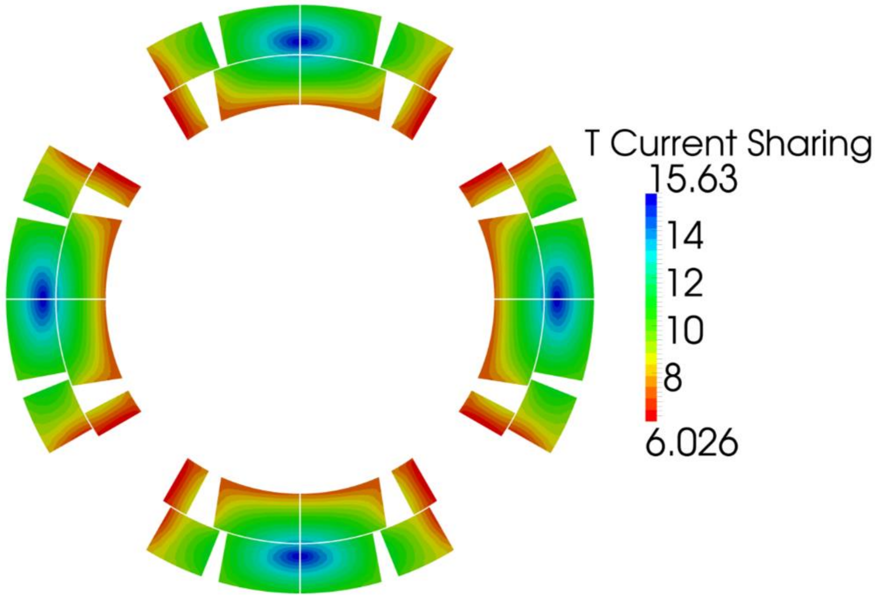
We present a study of the heat extraction margin with results scaled in terms of both maximum power density in the cross section [mW/cm^3] and maximum to ultimate luminosity ratio.

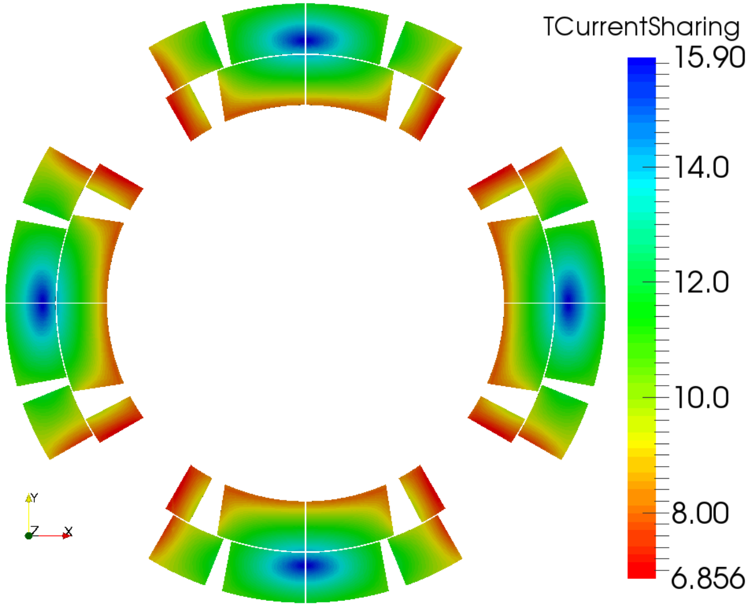
Changes in T Current Sharing

Previous T current sharing map

New T current sharing map June 2015, resulting from new operating conditions:

- Gradient = 132.6 T/m
- Nominal current = 16.47 kA
- Increased magnet length





Minimum Tcs improves from 6.0 K to 6.9 K

Changes in material thicknesses

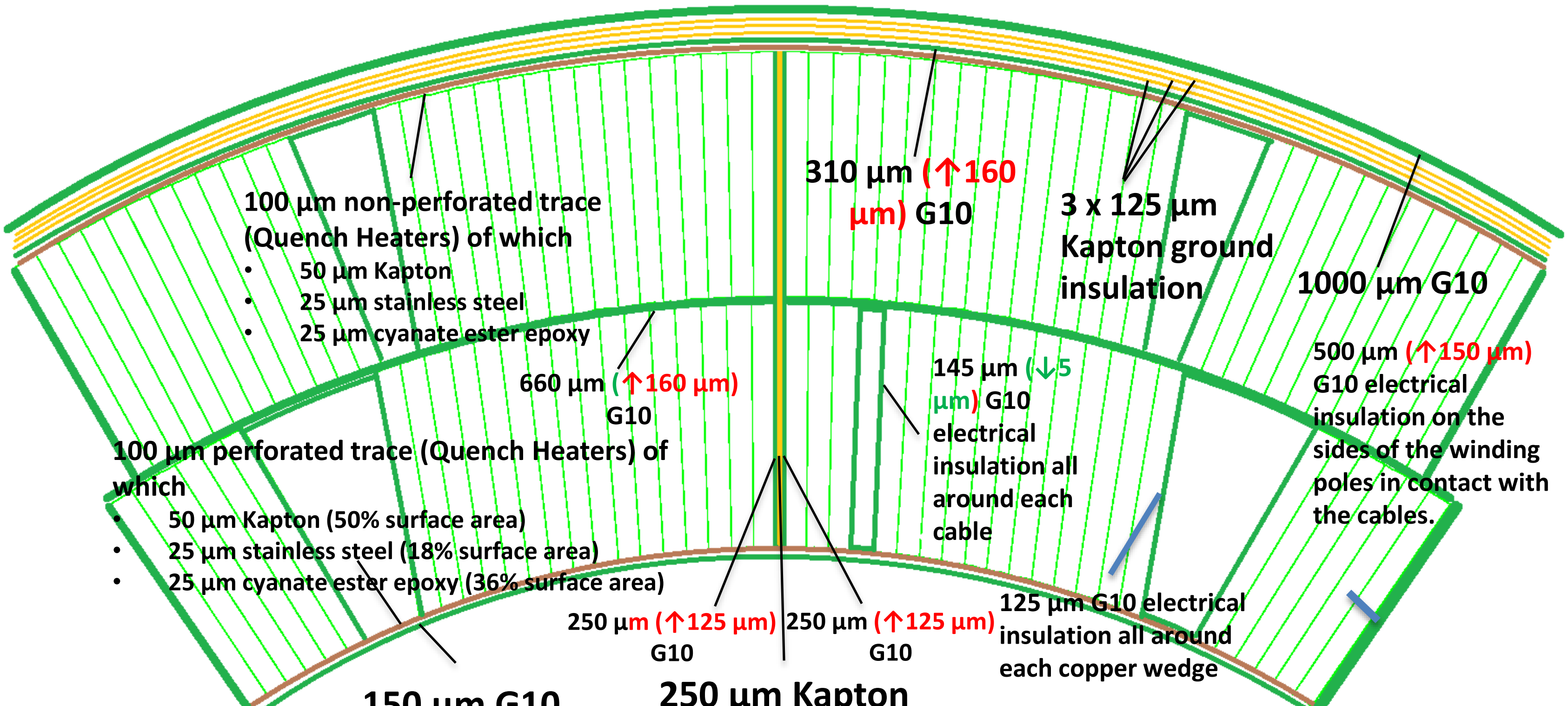
	Previous design	Updated design June 2015
Pole insulation	350 µm	500 µm
Mid-plane insulation	125 µm G10 + 250 µm Kapton + 125 µm G10	250 µm G10 + 250 µm Kapton + 250 µm G10
Inter-Layer insulation	500 µm	660 µm
Outer radius layer	150 µm	310 µm
Cable insulation	150 µm	145 µm

Simulation with 32% porous Inner Layer Quench Heaters

Helium passing through load keys
Energy Deposition Map Nov 2014
Bayonet heat exchanger temperature 1.9K

Changes in material thicknesses June 2015

↑x µm means that the thickness increased by x µm as compared to previous design

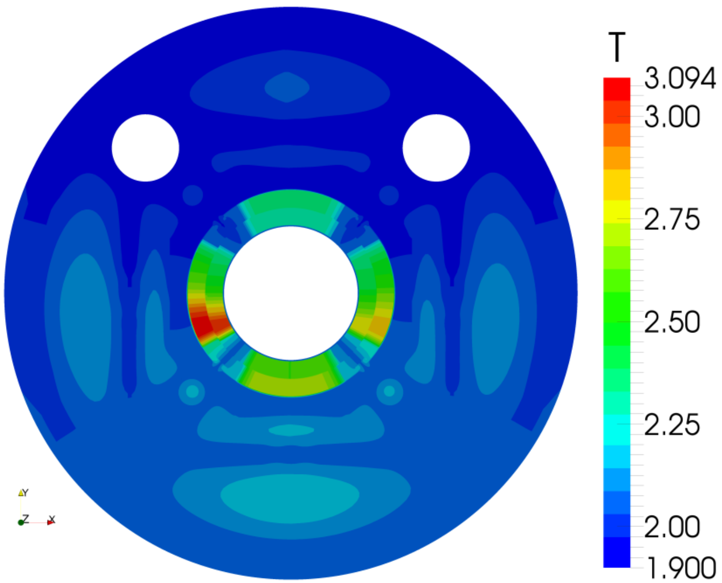


High Luminosity LHC

Temperature map of the magnet cross section

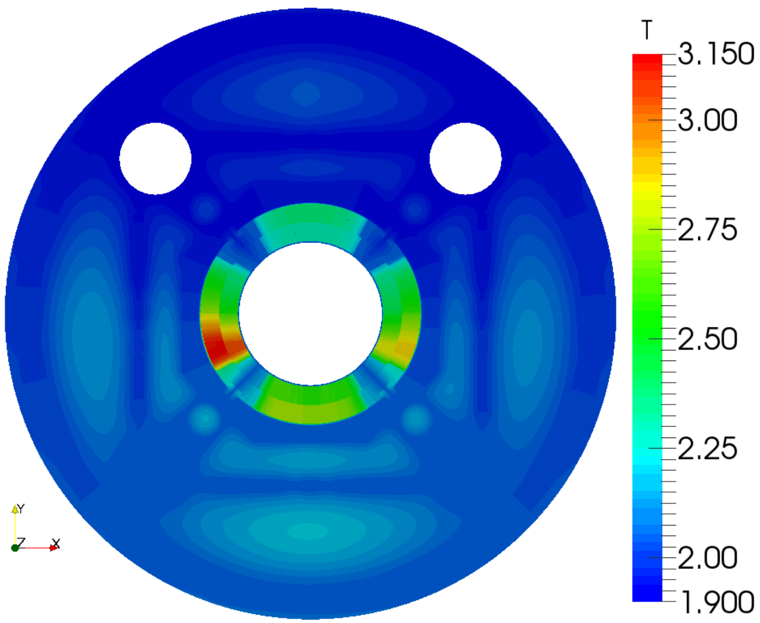
32% porous Inner Layer Quench Heaters
Helium passing through load keys
Energy Deposition Map Nov 2014
Bayonet heat exchanger temperature 1.9K

Previous insulation



Temperature map of the whole magnet cross section

New material thicknesses, June 2015



Maximum coil temperature increases slightly from 3.09 K to 3.15 K due to change in insulation

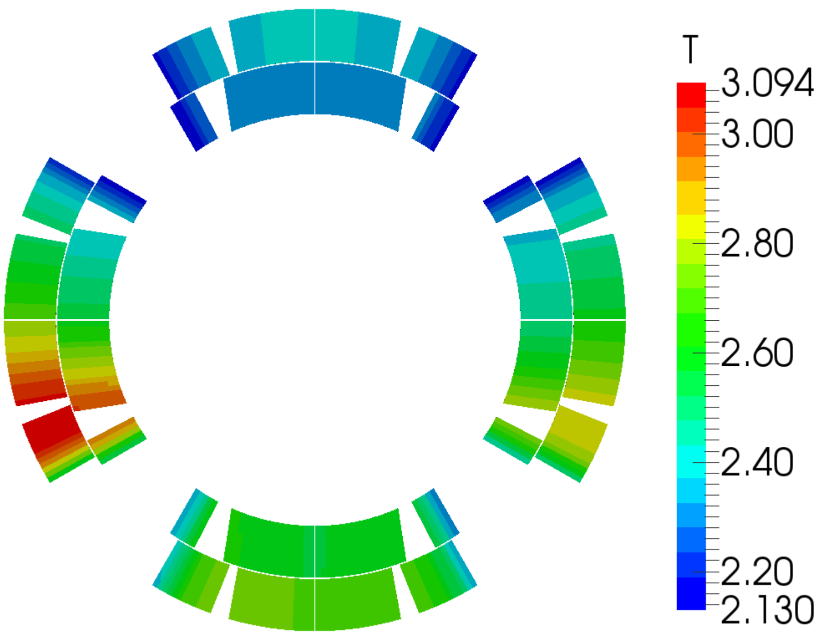
High Luminosity LHC

Temperature map of the magnet cross section

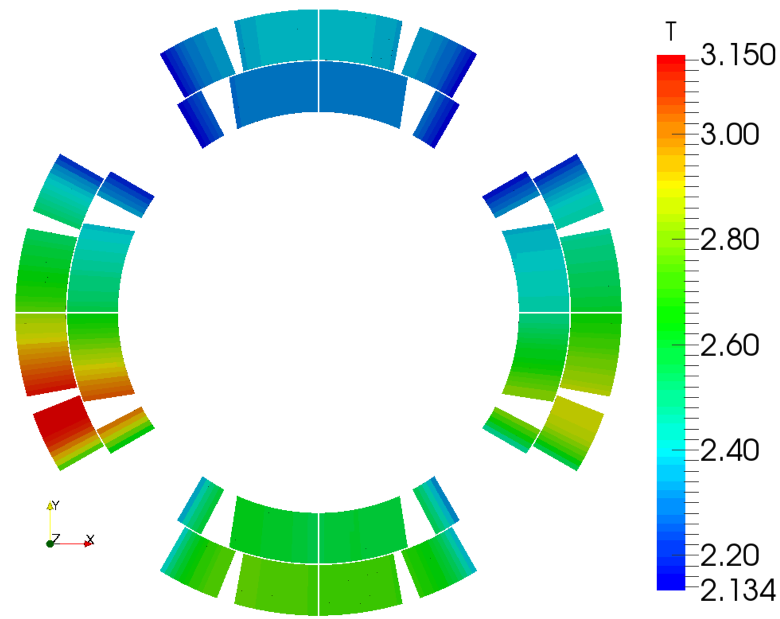
Zoom of previous slide

32% porous Inner Layer Quench Heaters
Helium passing through load keys
Energy Deposition Map Nov 2014
Bayonet heat exchanger temperature 1.9K

Previous insulation



New material thicknesses, June 2015

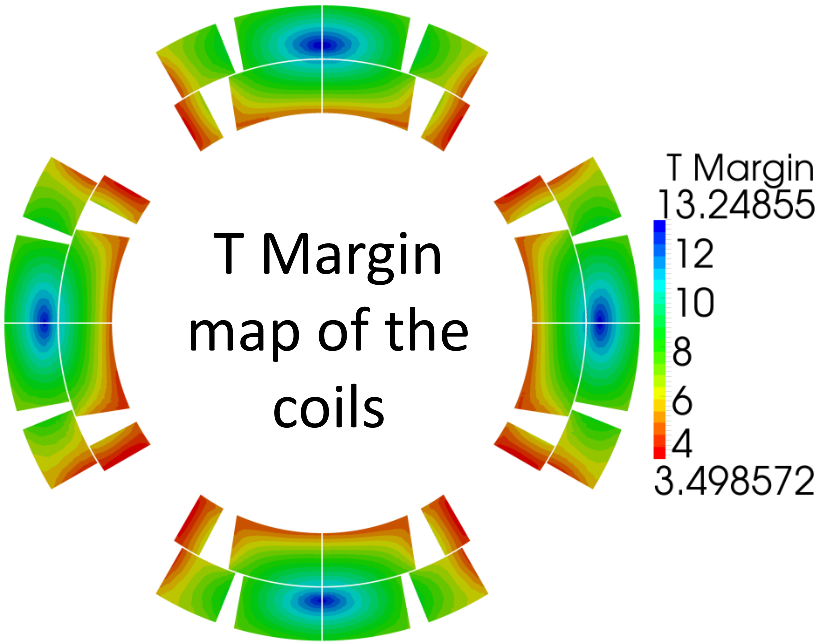


Temperature map of the coils

Maximum coil temperature increases slightly from 3.09 K to 3.15 K

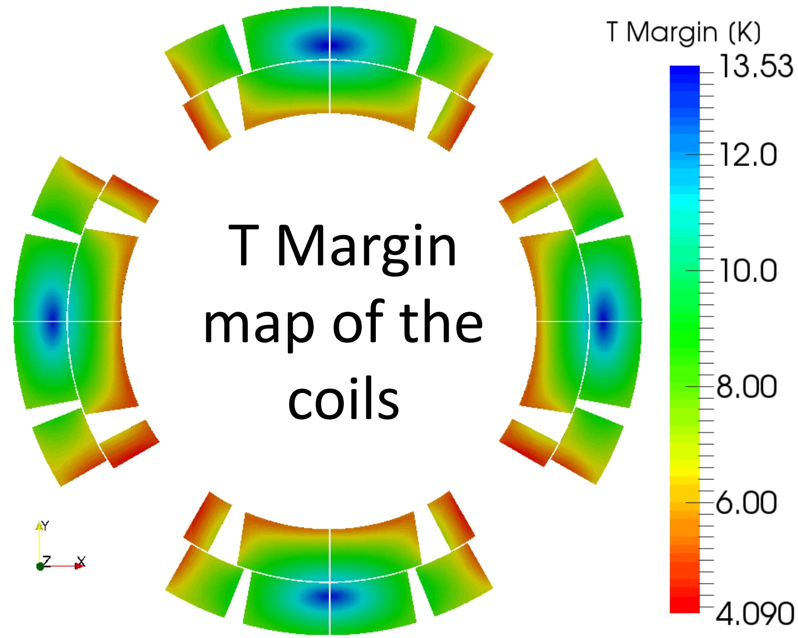
T margin map of the coils

Previous insulation & Field gradient



32% porous Inner Layer Quench Heaters
Helium passing through load keys
Energy Deposition Map Nov 2014
Bayonet heat exchanger temperature 1.9K

New material thicknesses & Lower field gradient, June 2015



An increase from 3.5 K to 4.09 K of T margin

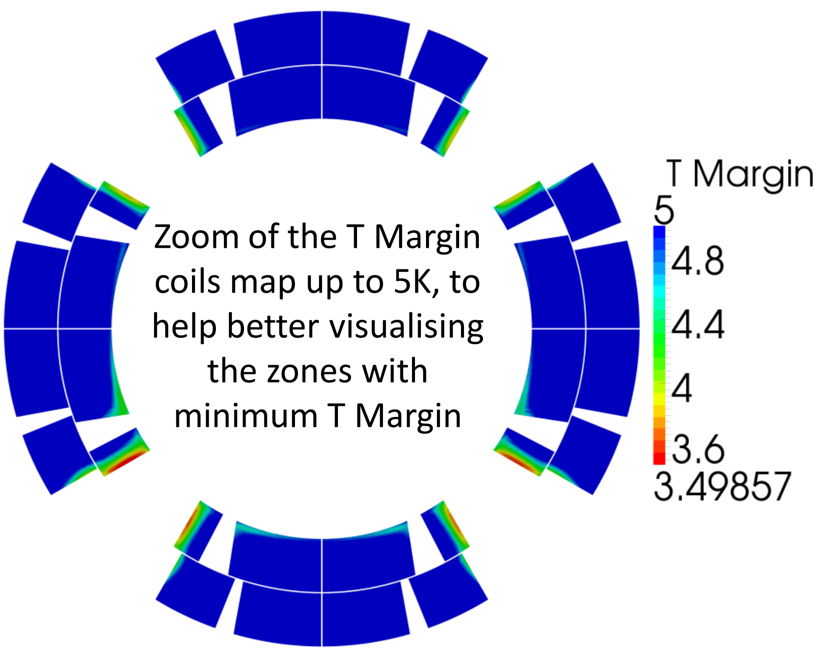
Thanks to the reduction in field gradient which largely compensates the increased electrical insulation effects

T margin map of the coils

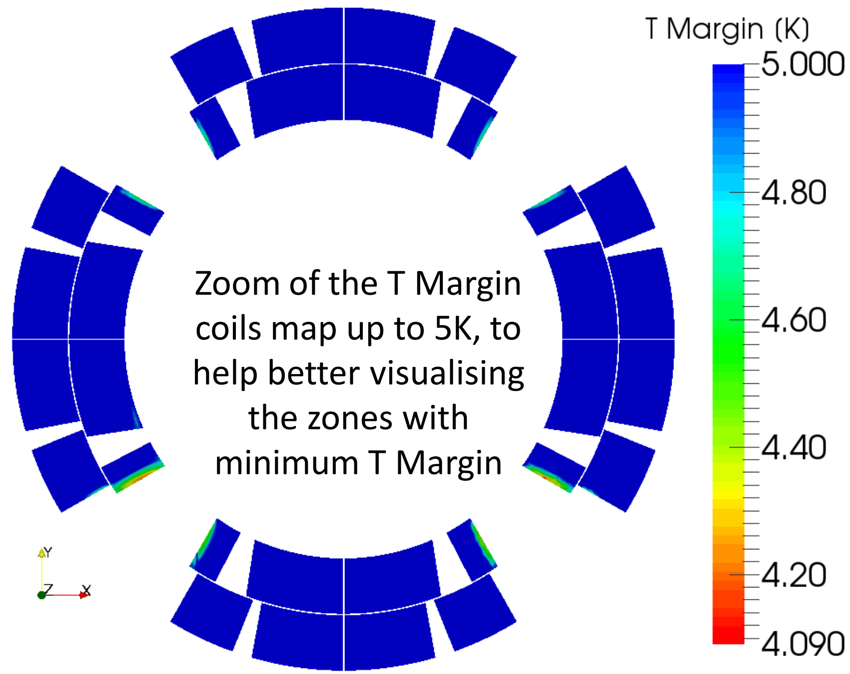
Zoom of previous slide

32% porous Inner Layer Quench Heaters
Helium passing through load keys
Energy Deposition Map Nov 2014
Bayonet heat exchanger temperature 1.9K

Previous insulation & Field gradient



New material thicknesses & Lower field gradient, update June 2015



An increase from 3.5 K to 4.09 K of T margin

Thanks to the reduction in field gradient which largely compensates the increased electrical insulation effects

Analysis of local heat extraction margin

The energy deposition map at a luminosity of **7.5x10^{34} cm^{-2}s^{-1}**

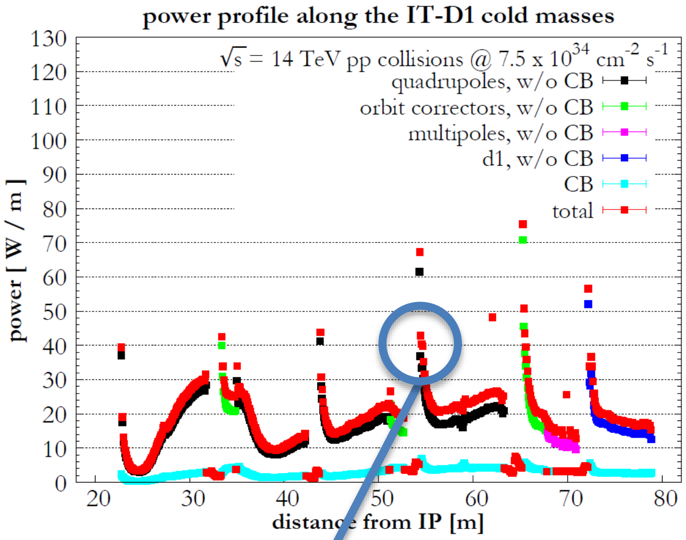
In this analysis we searched how much we can increase luminosity before quenching for different temperatures of the bayonet heat exchangers

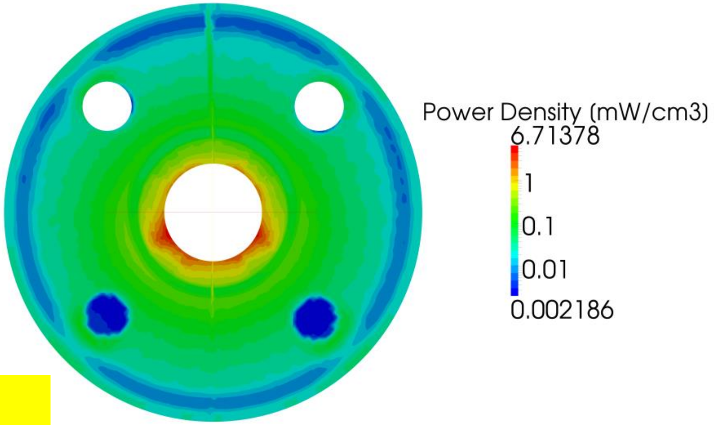
The analysis was done for **steady state.**

In this analysis quench occurs due to **breakdown of global cooling** rather than for 0 temperature margin.

In case of unsteady state it is possible to reach higher luminosity peaks for sufficiently short timescales (diffusion time).

- **Energy deposition map** in **Q3** from simulations made in **Nov 2014 (short tungsten absorbers)**, expressed in mW/cm^3, for a ultimate luminosity of **7.5x10^{34} cm^{-2}s^{-1} .**
- Energy deposited **not only in the coils** (58.6%) but also in the rest of the magnet (42.4%)
- This energy map doesn't show averaged values but actual values, and it's implemented in OpenFOAM without approximations.
- Energy deposited in this cross section: **32.4 W/m**
- Heat flux from the cold bore in this cross section: **15.73 W/m^2**





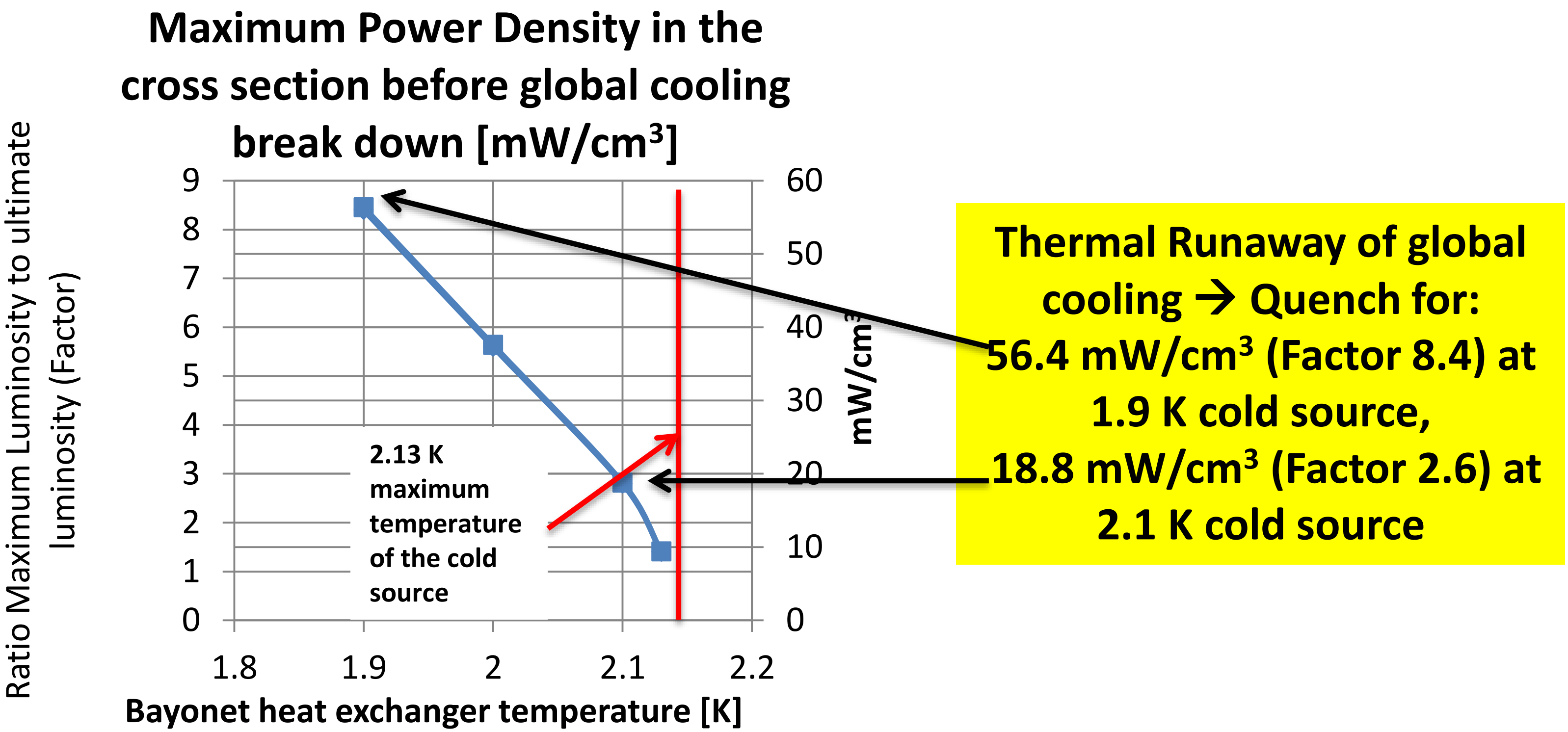
The peak power density at a ultimate luminosity of 7.5x10^{34} cm^{-2}s^{-1} is **6.71 mW/cm^3.**

High Luminosity LHC

Analysis of local heat extraction margin

By which factor can we increase the luminosity before thermal runaway of the general cooling?

This analysis was performed for different temperatures of the bayonet heat exchangers



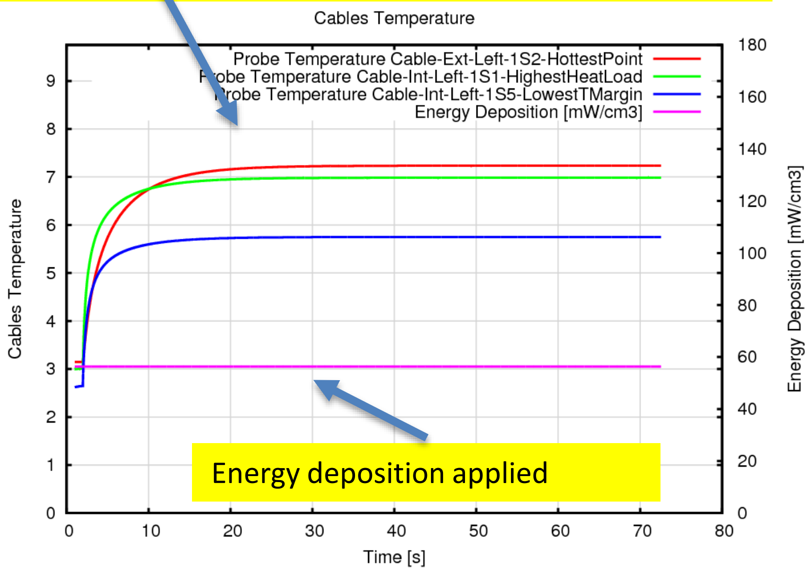
6.71 mW/cm^3: power density peak at ultimate luminosity of $7.5X10^{34}$ $cm^{-2}s^{-1}$

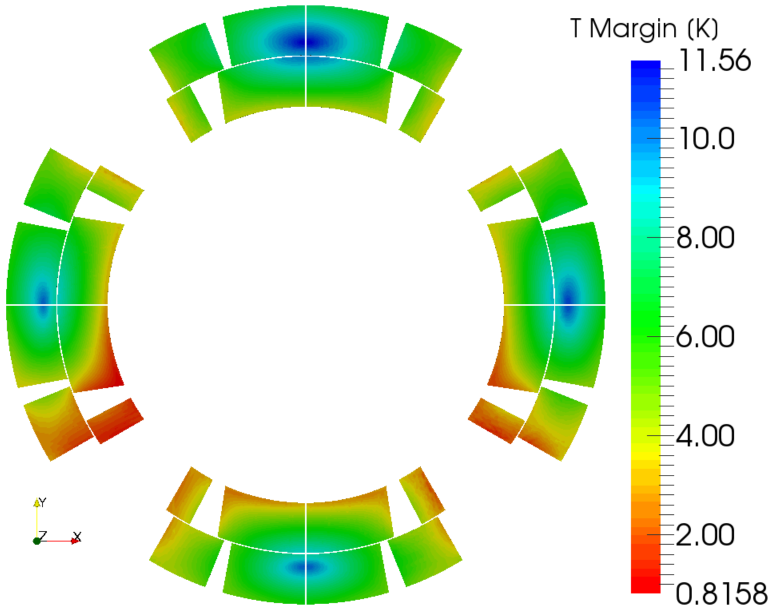
Analysis of local heat extraction margin

By which factor can we increase the luminosity before thermal runaway of the general cooling?

T Margin map before global cooling break down (56.4 mW/cm³ – Factor 8.4)

Although at its limits, the system doesn't quench



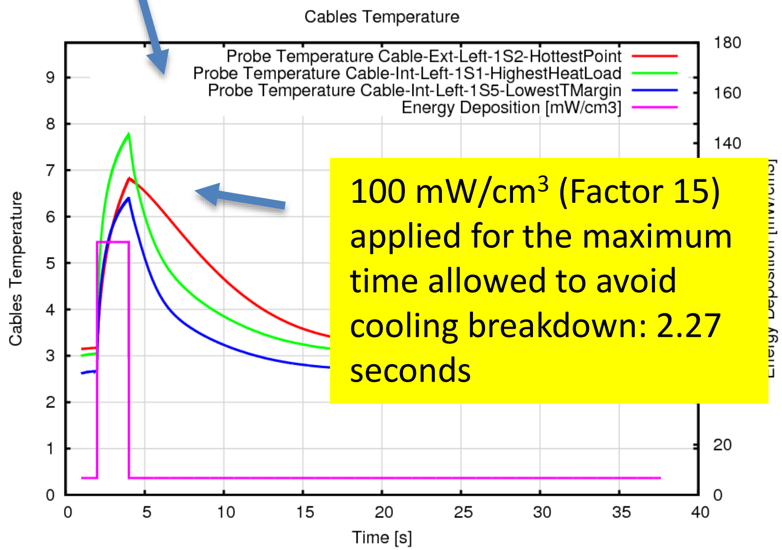


The minimum T Margin that is present in the domain before global cooling breakdown is 0.82K

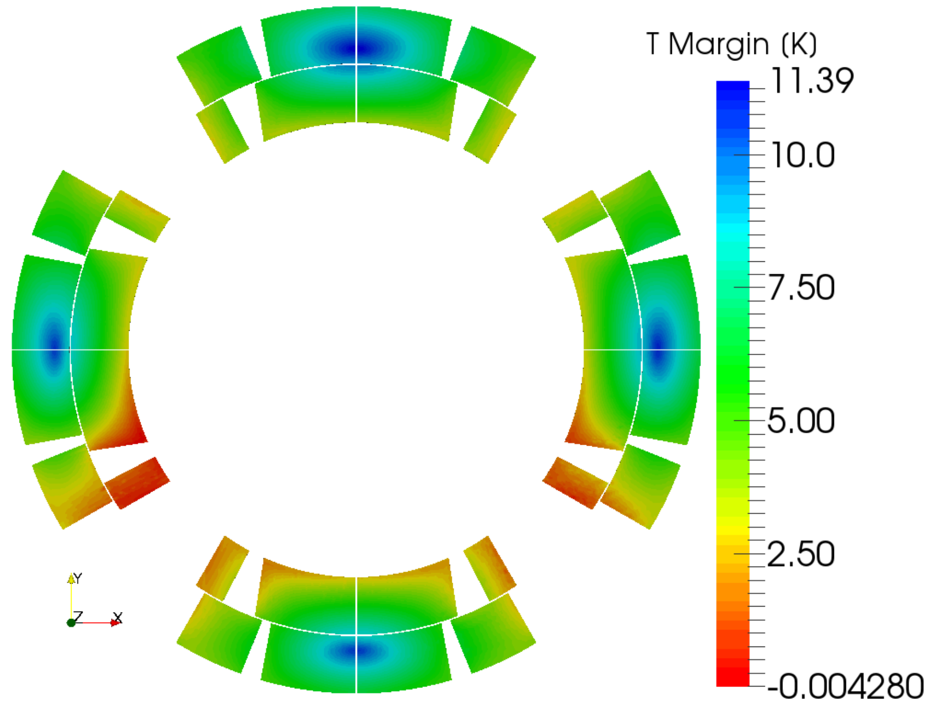
Analysis of local heat extraction margin

Transient study: how long can the system bear energy deposition values beyond 56.4 mW/cm^3?

The system would quench if 100 mW/cm^3 (Factor 15) were applied for longer than 2.27 seconds



100 mW/cm^3 (Factor 15) applied for the maximum time allowed to avoid cooling breakdown: 2.27 seconds



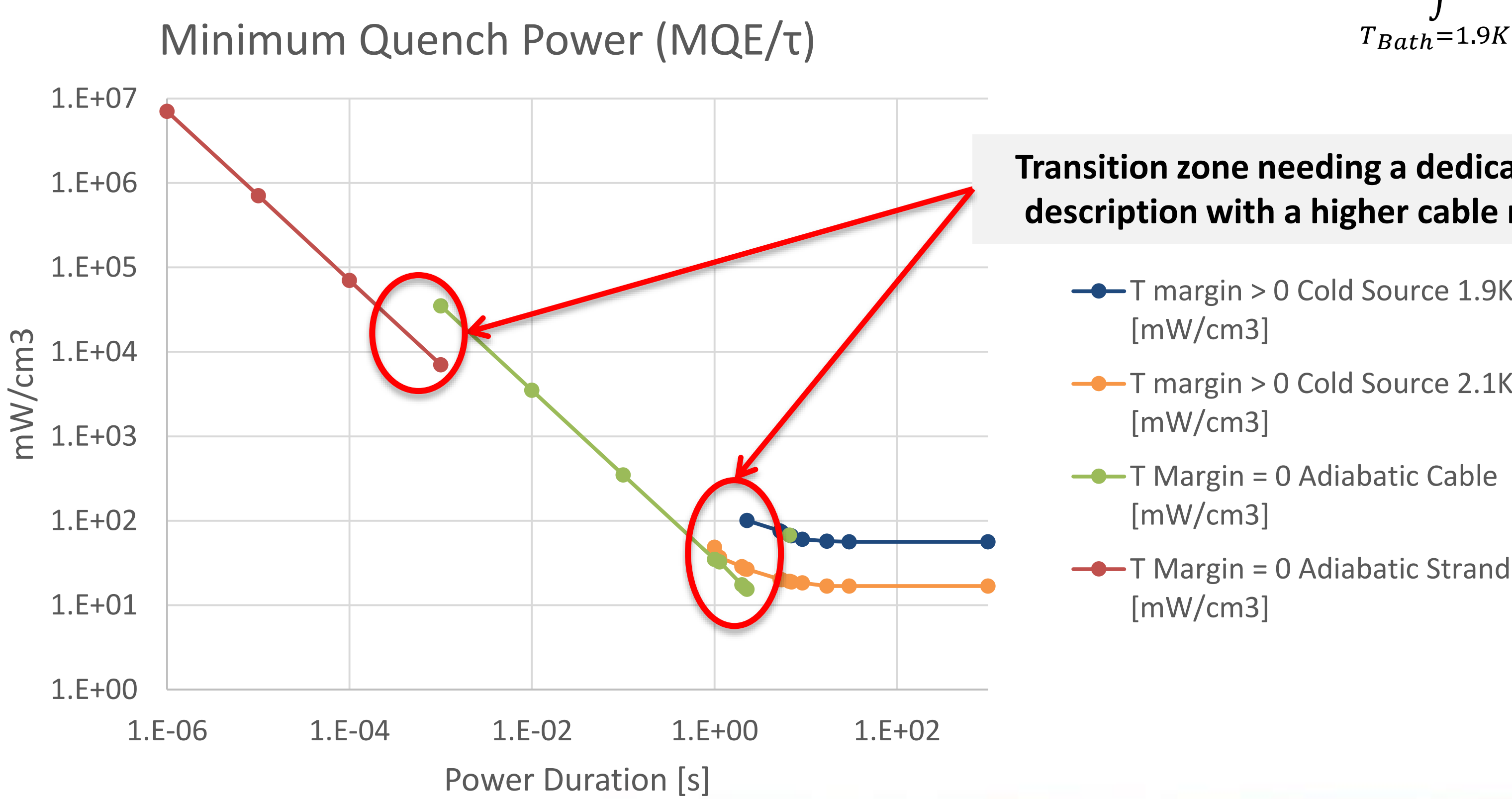
For a transient with 100 mW/cm^3 , the minimum T Margin that is present in the domain before global cooling breakdown is **0 K**

Analysis of local heat extraction margin

Transient study: the Minimum Quench Power (MQE/τ) as a function of deposition time τ

For τ > ~ 10 s, thermal runaway due to break down in global cooling
2.1 K steady state MQE/ τ: 19 mW/cm3
1.9 K steady state MQE/ τ: 56 mW/cm3

$$MQE_{Adiabatic} = \int_{T_{Bath}=1.9K}^{T_{CS}=6.857K} \rho C_p(T)dT$$

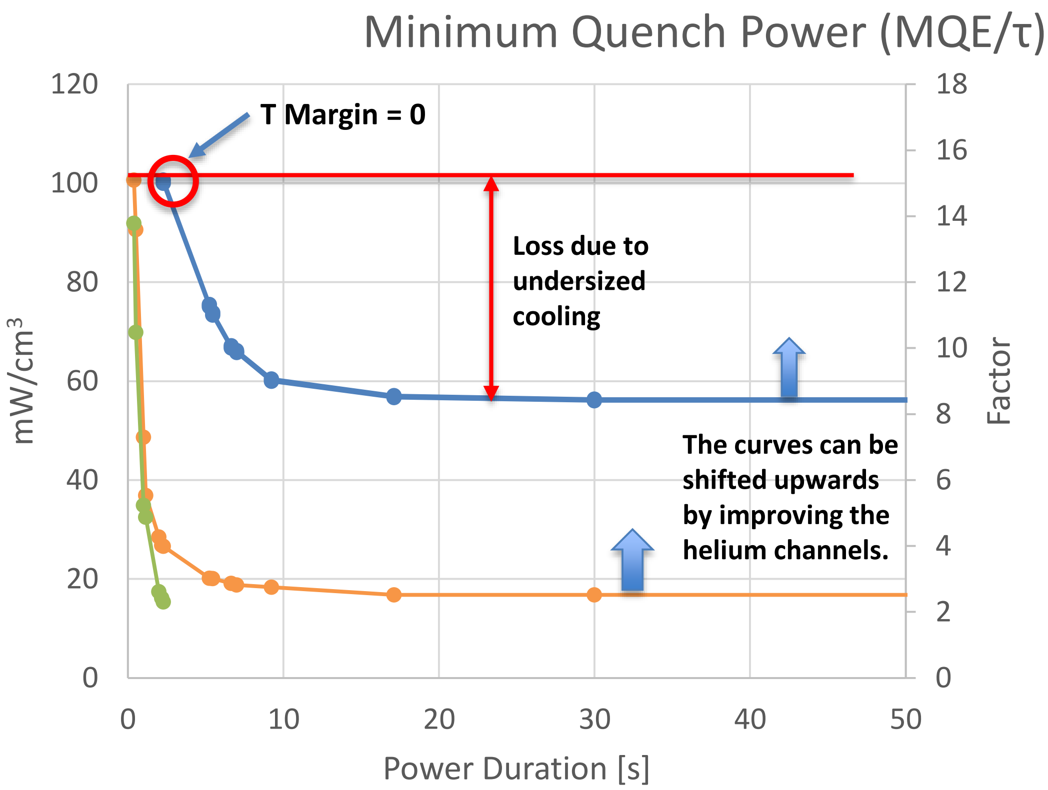


High Luminosity LHC

Analysis of local heat extraction margin

Transient study: the Minimum Quench Power (MQE/τ) as a function of deposition time τ

For τ > ~ 10 s, thermal runaway due to break down in global cooling (i.e. Tmargin > 0 K)
2.1 K steady state MQE/ τ: 19 mW/cm3
1.9 K steady state MQE/ τ: 56 mW/cm3



$$MQE_{Adiabatic} = \int_{T_{Bath}=1.9K}^{T_{CS}=6.857K} \rho C_p(T)dT$$

- At 1.9 K we reach Tmargin = 0 K for τ=2.3 s at 100 mW/cm3 determined by the cable insulation → room for improvement by adapting He-channels: estimated factor 100/56

Conclusions and future development

- This analysis shows that while the energy deposition peak (power density peak) at a ultimate luminosity of $7.5x10^{34}$ $cm^{-2}s^{-1}$ is **6.71 mW/cm^3**, the energy deposition peak that can be tolerated at *steady state* before global cooling breakdown is around **56 mW/cm^3** (that is, at a luminosity 8.4 times higher), at a cold source temperature of 1.9 K, and around **18.8 mW/cm^3** (that is, at a luminosity 2.6 times higher), at a cold source temperature of 2.1 K
- When the global cooling breakdown occurs at steady state, *the T margin is still > 0 K!*
- Since T margin is still > 0 K especially for a cold source temperature of 2.1K, one could envisage to *increase the maximum steady state* power density by increasing the global cooling paths: Particularly *the size and/or number of winding pole cooling holes*. On the other hand *increasing T margin* as per slides 8 and 9 *would not reduce global cooling breakdown*, as shown in slide 15.
- Transient simulations with short-time energy deposition peaks were performed in order to evaluate the MQE by probing when we reach T margin = 0 K as function of power deposition times: 100 mW/cm3 during 2.3 s (after which we move into the fully adiabatic region).
- The transition zone needs a dedicated model description with higher cable resolution

Any questions?

Thanks for your attention