FRESCA II Dipole review
March 28th, 2012 @ CERN

Magnet protection

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CEA Saclay / IRFU / SACM / LEAS

Outline

Dipole Conceptual Review January 2011

Magnet protection principles

New computations

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- dump resistor

2D FEM results: - quenched volume

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- dump resistor

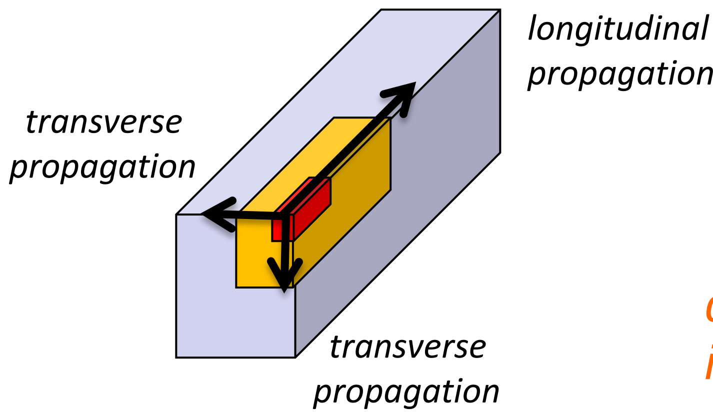
- current decrease

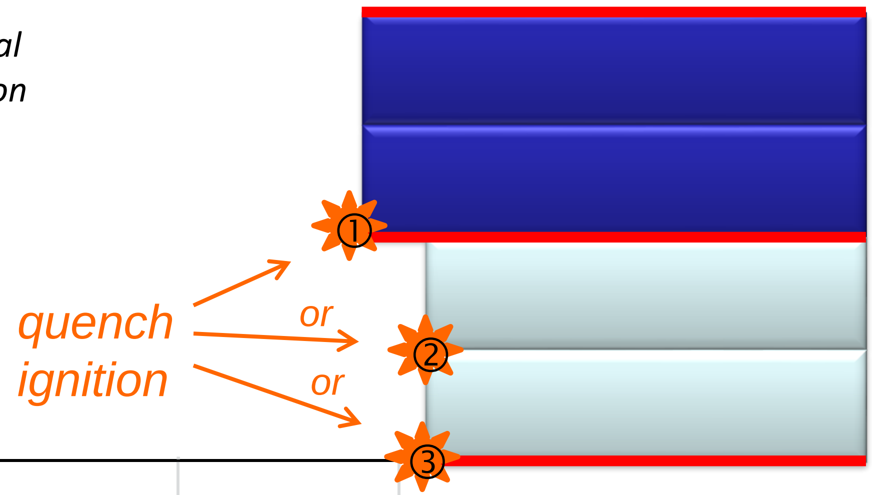
- hot spot temperature versus detection time

Conclusions and future actions

DCR January 2011

Results from computations made with the QTRANSIT fortran code had been presented : *3D simulation* of the quench thermal transient in the magnet was based on quench propagation velocities and the resistance growth with time.





Propagation			
Longitudinal velocity	*@ In = 10,5 kA*	*v (m/s) =*	*6,7*
Transverse velocity		*v (cm/s) =*	*25*
Detection			
Voltage		*U_d (mV) =*	*100*
Time		*t_d (ms) =*	*100*
Protection			
Dump resistor		*Rd (mΩ) =*	*95*
Heaters			

Computation hypothesis

DCR January 2011

To the question, « Is the quench protection for the dipole sufficient? », the recommendations had been :

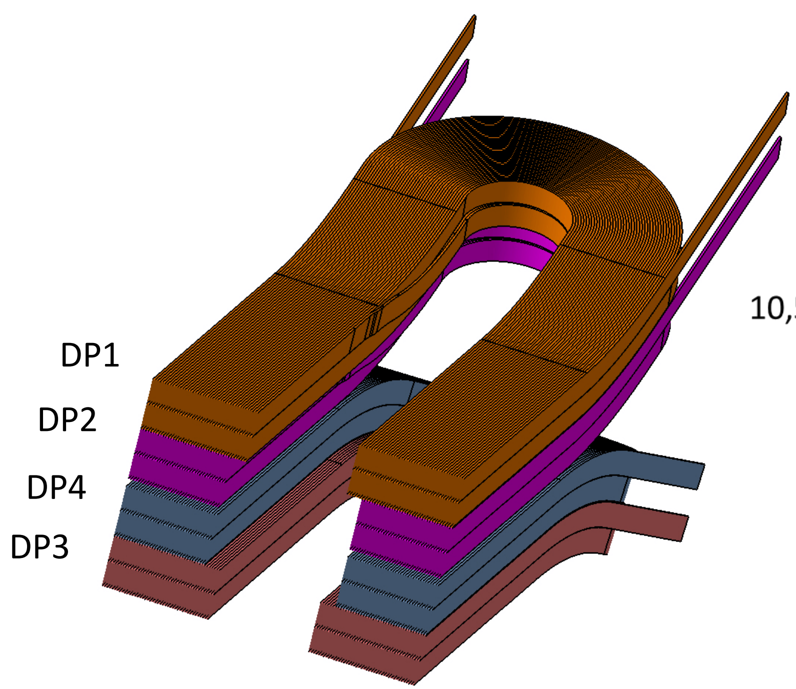
1. *The quench protection in case of a quench starting in the high field region is fine; although the transverse propagation (layer-layer, turn-turn) should be decreased in the simulations in order to make sure that computations are conservative. Specifically, as one of the worst scenario, the transverse normal zone propagation speed (in the presentation it was 25 cm/s) should be zero.*

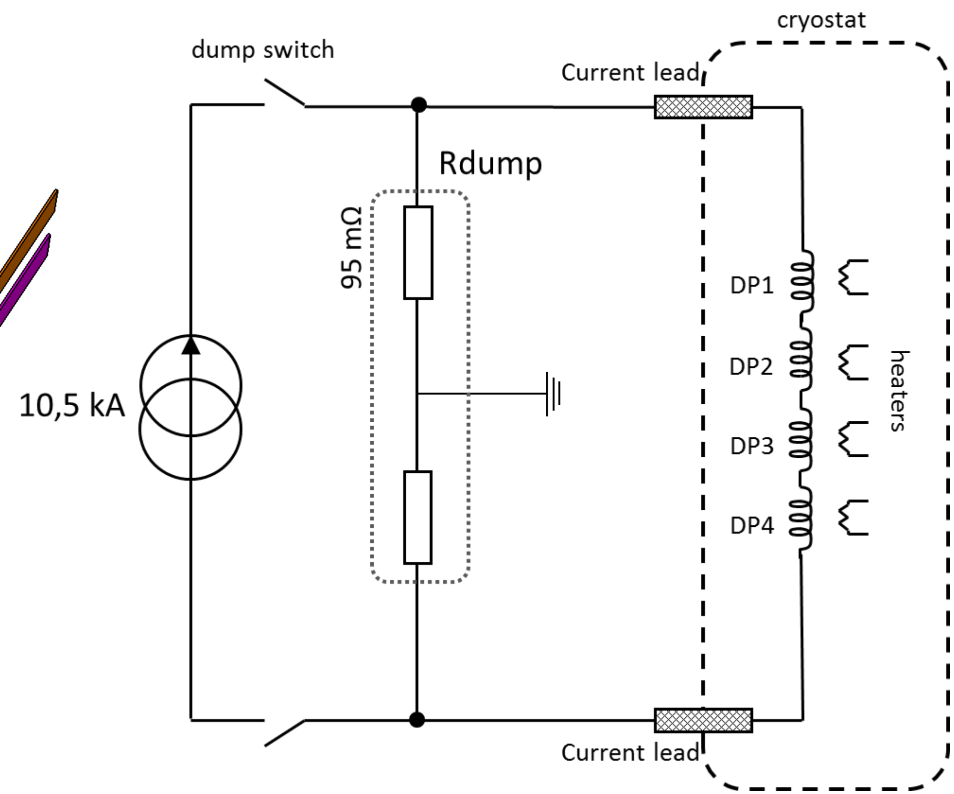
2. *The quench protection should be studied also in case of a quench starting in the low field region when the magnet is carrying its nominal operating current.*

3. *You may consider another protection technique in which the magnet is subdivided by shunt resistors, e.g., each of the four coils will be shunted by a resistor. This subdivision, however, must consider the unbalanced forces that might result from the non-uniform current flows in the four coils induced upon quenching.*

Magnet protection principles

- ✓ The protection technique is based on the extraction of the magnetic stored energy into a dump resistor, as well as on the development of coil internal resistance thanks to quench heaters
- ✓ Grounding circuit ± $V_{max}/2$ to ground,
- ✓ Inductances computed with ROXIE





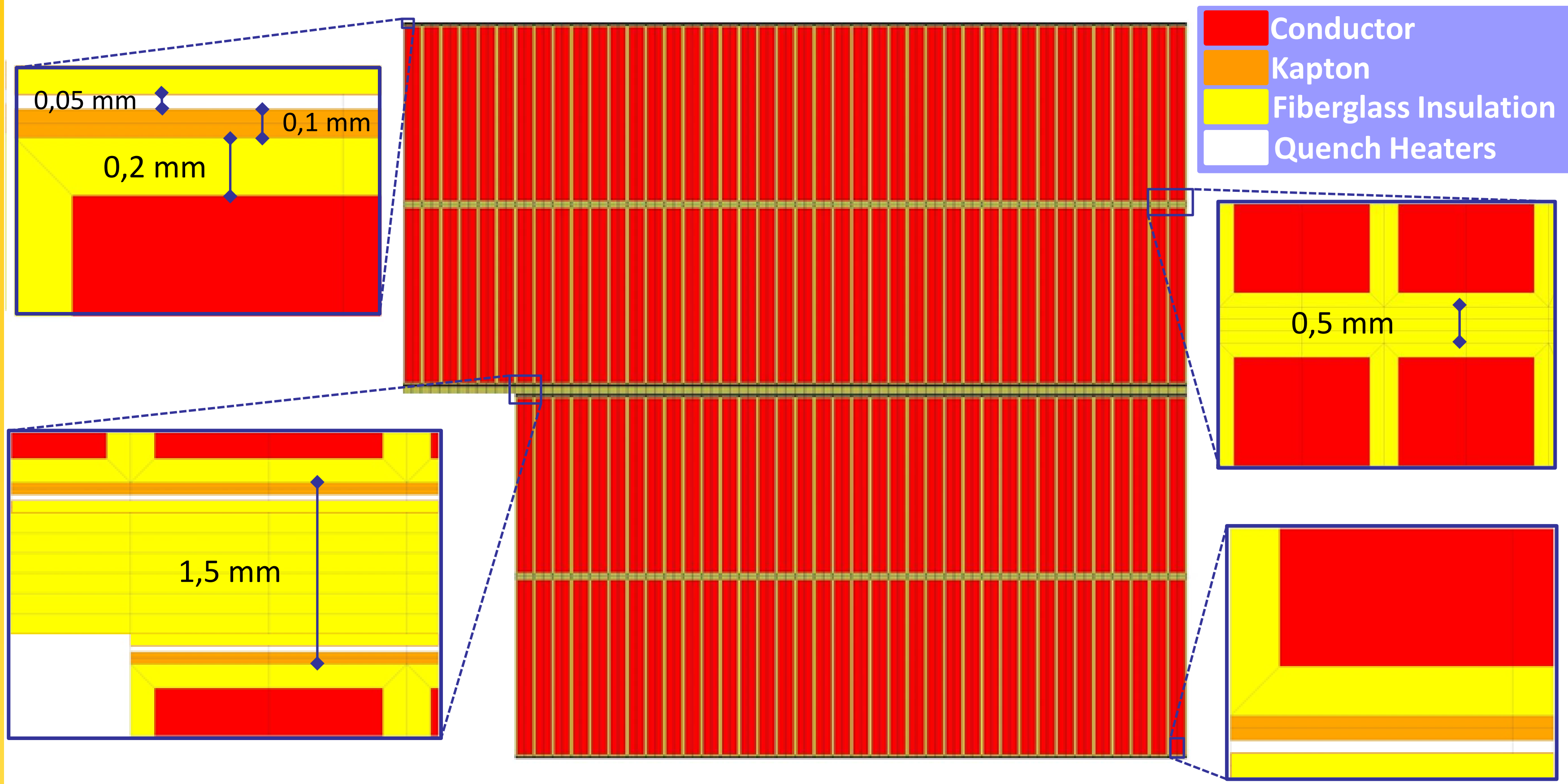
New computations

To *get rid of the propagation velocities*, we have decided to made new computations with the FEM code CAST3M, where only thermal and electrical properties of coil components are used.

⇨ **2D FEM computations have been led in order to evaluate temperature and current evolution with time following quench heater activation**

⇨ **3D FEM computations will be led in order to ascertain the behavior of the quench propagation before the activation of the heaters.**

2D FEM model



Quench heaters are activated and the code computes *the quench propagation*, **the current decrease** and **the temperature distribution within the dipole**.

Quench heaters

- Quench heater detailed design is not yet defined.

- We expect a heater power of *50 W/cm2* with a spatial distribution *as uniform as possible.*

- In 2D model , heater power is uniform on the coil surface.
- In order to take into account real spatial distribution, we decided to decrease heater power for computations: it was then set at **25 W/cm²**, which correspond to a power distribution on half of the coil surface.

- The pulse of power has been set to **50 ms**.

Dump resistor

- ✓ V_{max} = 1000 V, I = 10,5 kA
  → The value of the dump resistor was fixed to *95.4 mΩ*.

- ✓ Dump resistor volume has been set so that *the voltage at its terminals remains maximum as long as possible* :

$$V = \frac{d\rho}{dt} * \frac{LI^2}{\rho C_P}$$

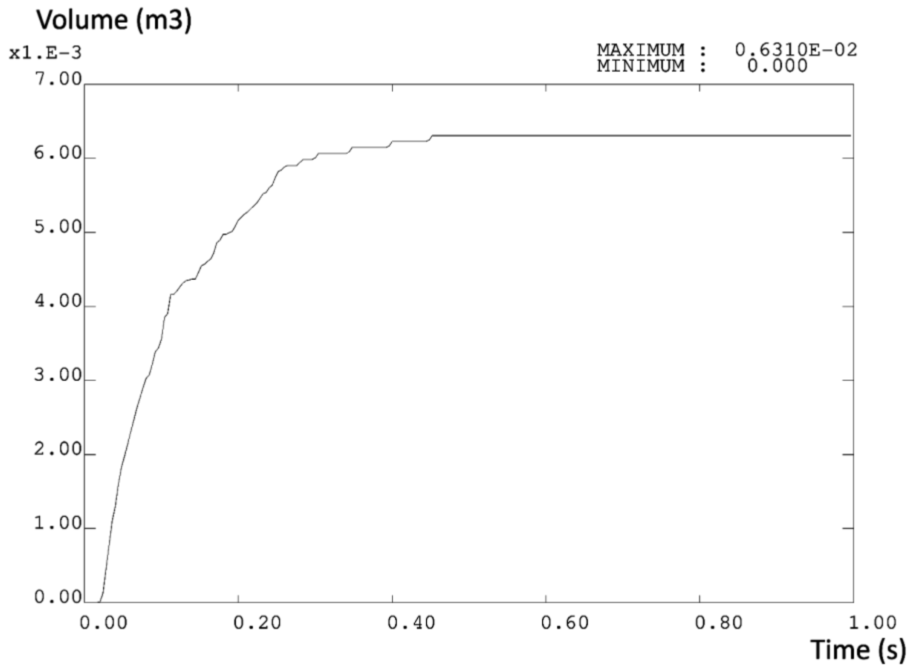
I : nominal current,
t : time,
L : magnet inductance,
ρ : overall resistivity,
C_P = specific heat.

This leads to a total volume of 2.63 liters.

- ✓ The code computes dump resistor temperature and resistance value with time (adiabatic computation)

2D results: quenched volume

FEM code computes the evolution of the *quenched volume with time*

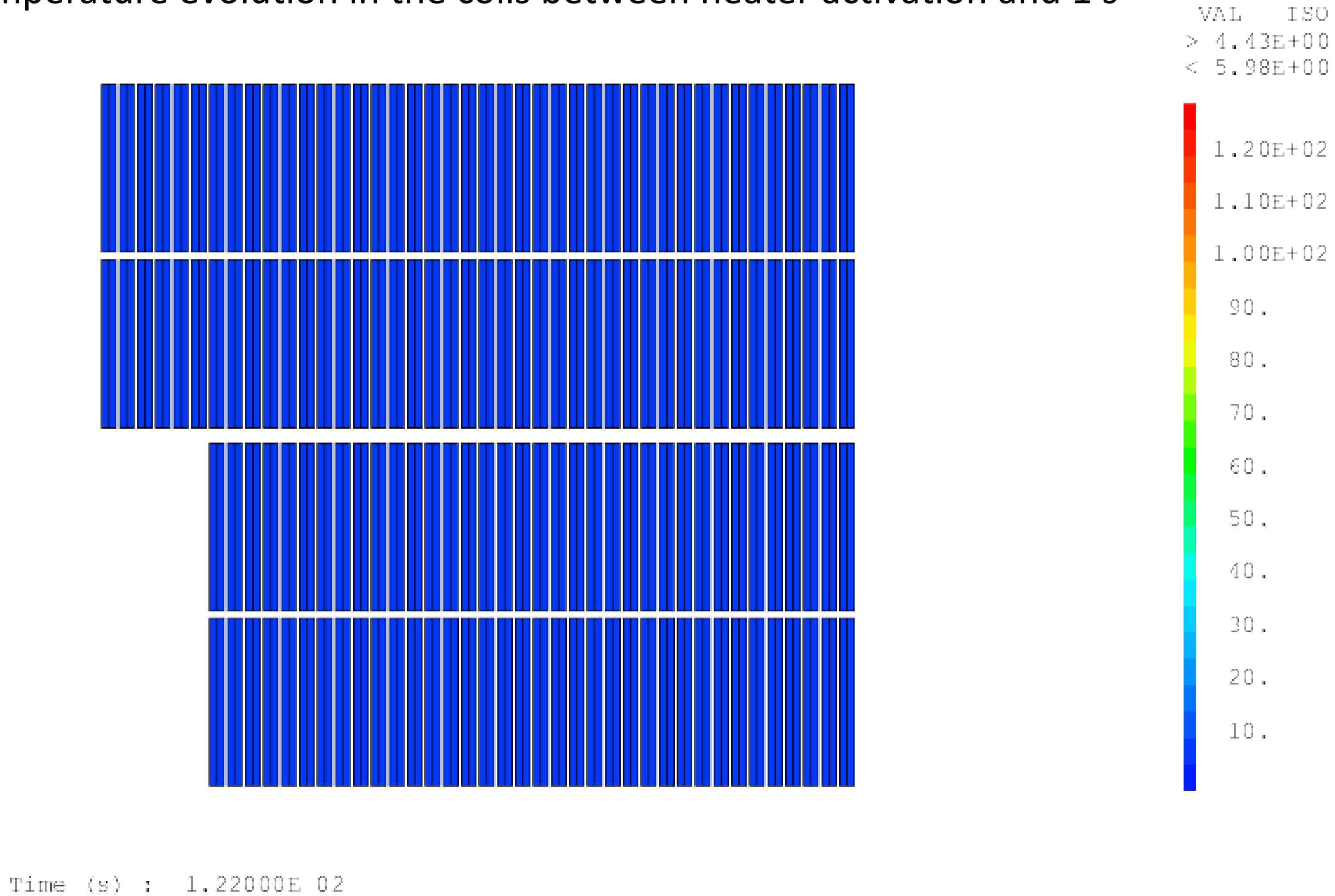


It takes *457 ms to totally quench the dipole*.

The *time delay* between the activation of the heaters and the quench ignition in the dipole is *20 ms*.

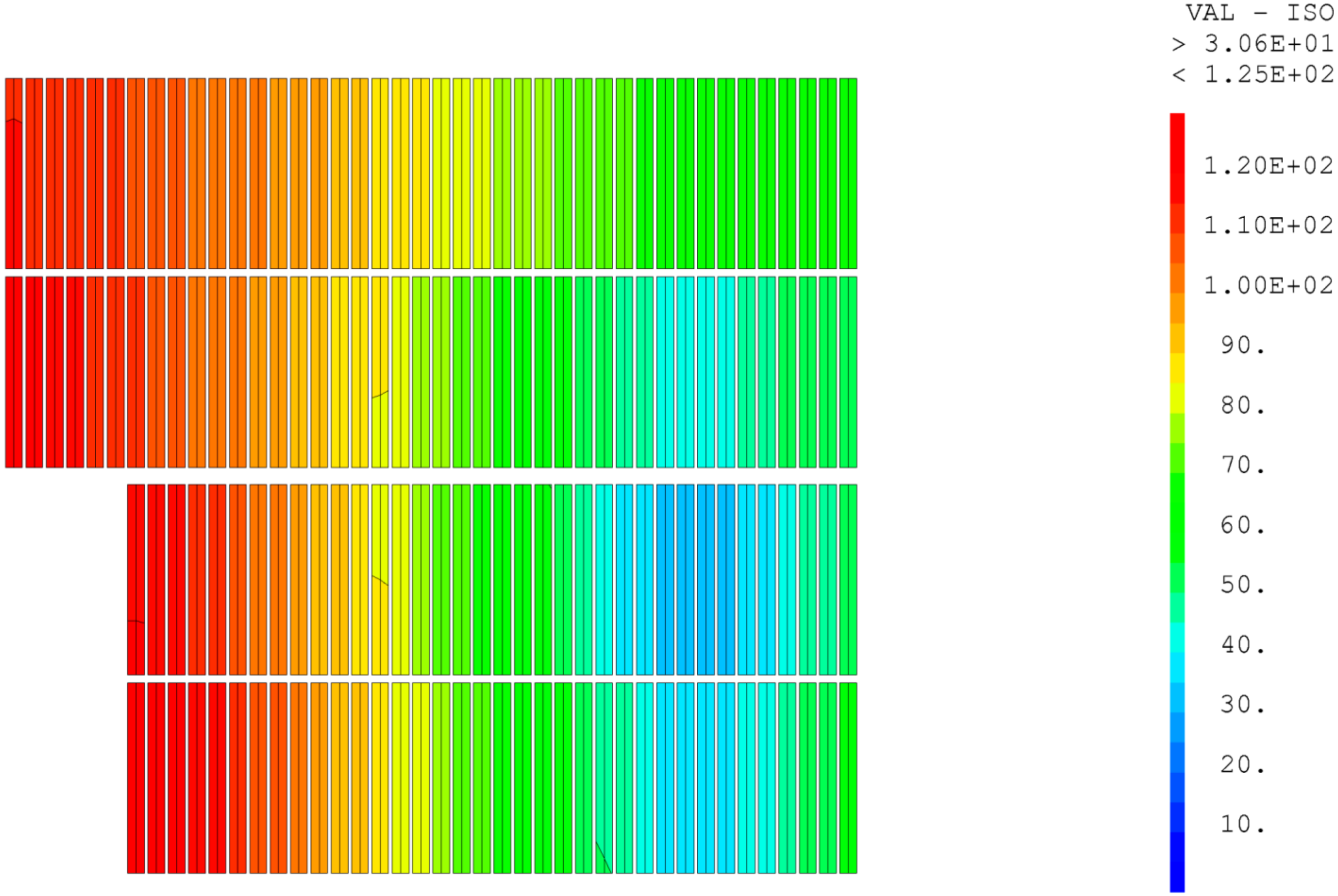
2D results: coil temperature

Temperature evolution in the coils between heater activation and 1 s



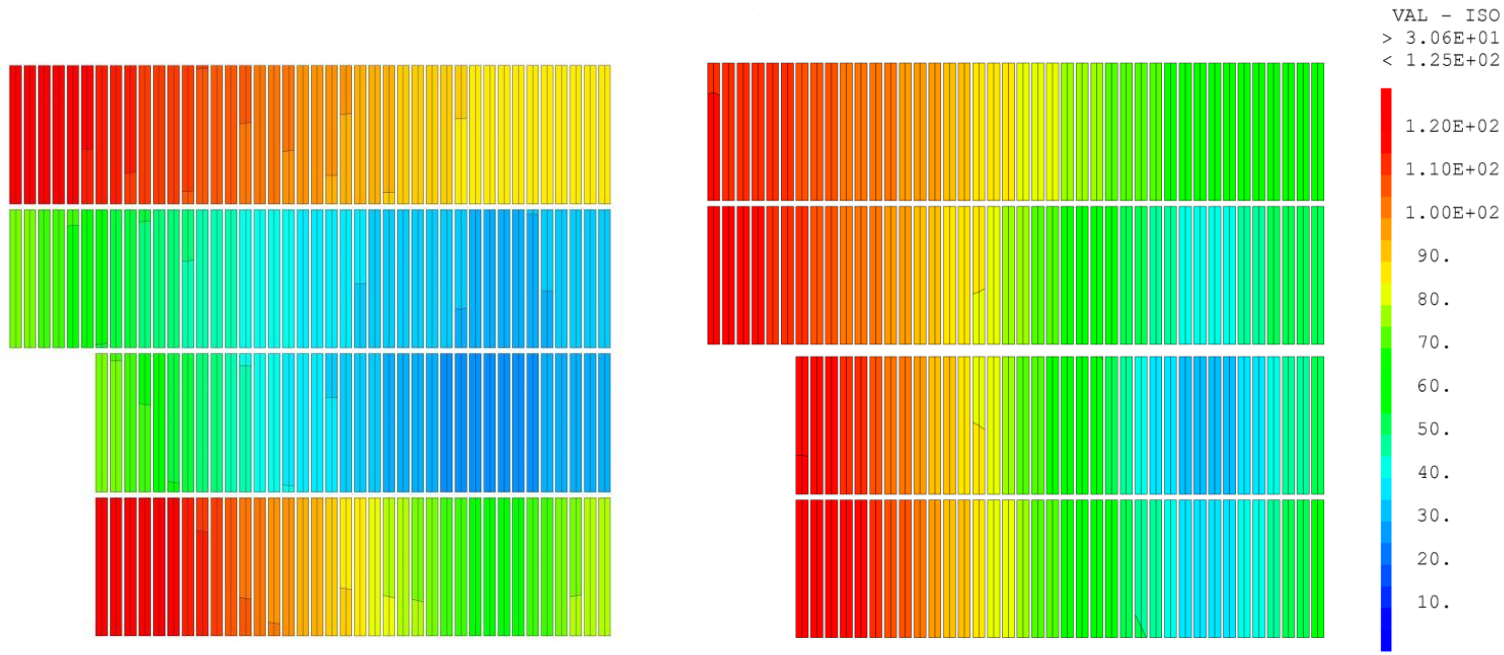
2D results: coil temperature

Temperature distribution at t = 0.98 s



Due to the heaters, the *temperature is well distributed* and the thermal gradients are kept low.

2D results: coil temperature

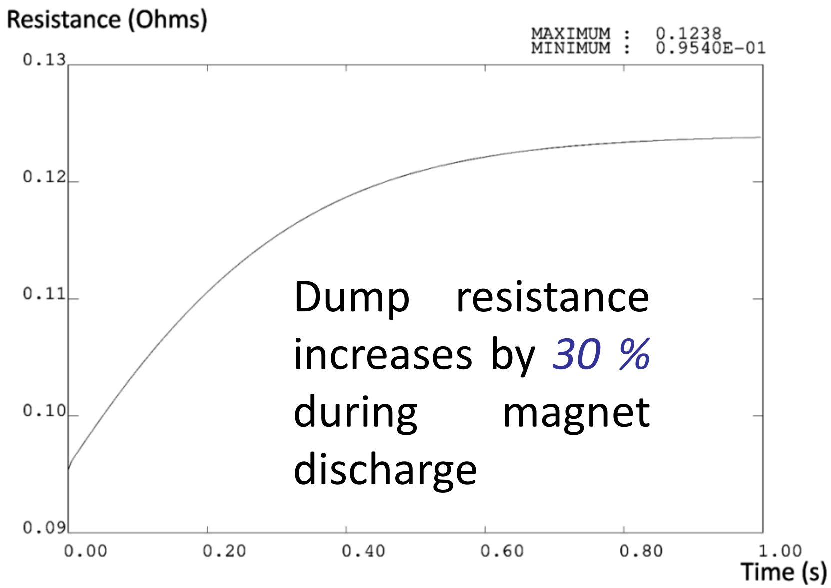


Temperature distribution in the case of 2 external heaters

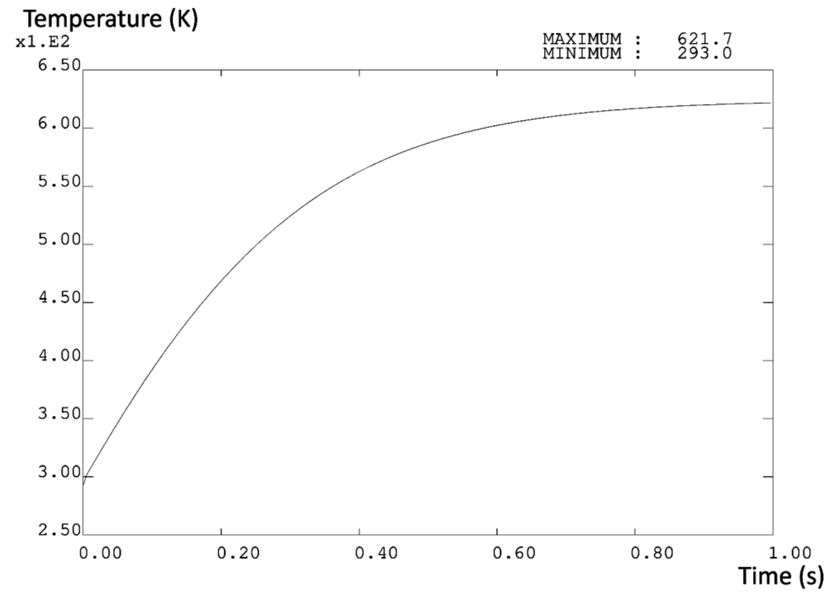
Temperature distribution in the case of 4 heaters

The use of 4 heaters helps to distribute more uniformly the temperature (lower temperatures gradients).

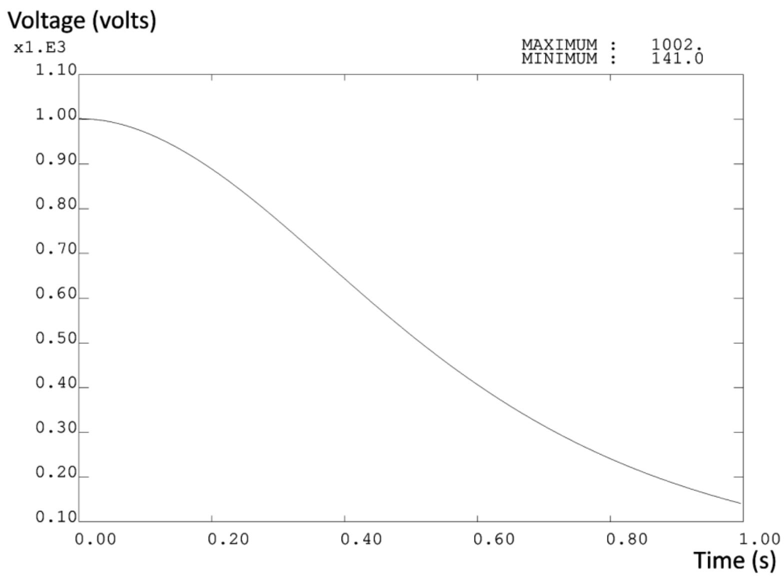
2D results: dump resistor



Dump resistance increases by *30 %* during magnet discharge



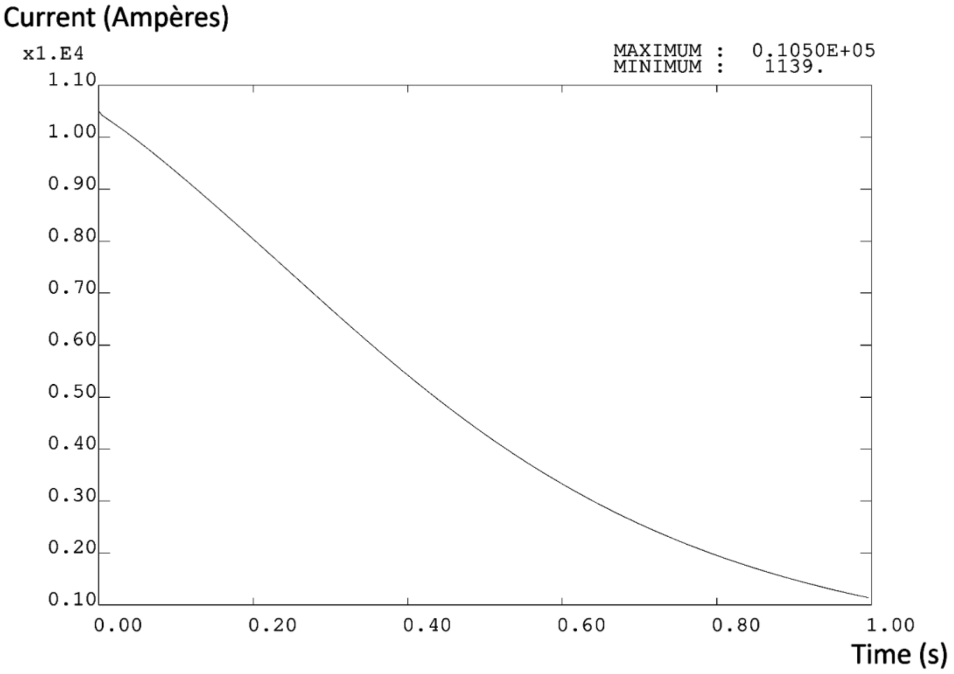
The temperature of the dump resistor at the end of the discharge is *622 K*, which is an acceptable value.



The voltage at the terminals of the dump resistor remains maximum at the beginning of the discharge (nul slope).

2D results: current decrease

FEM code computes the evolution of the *current decrease with time*



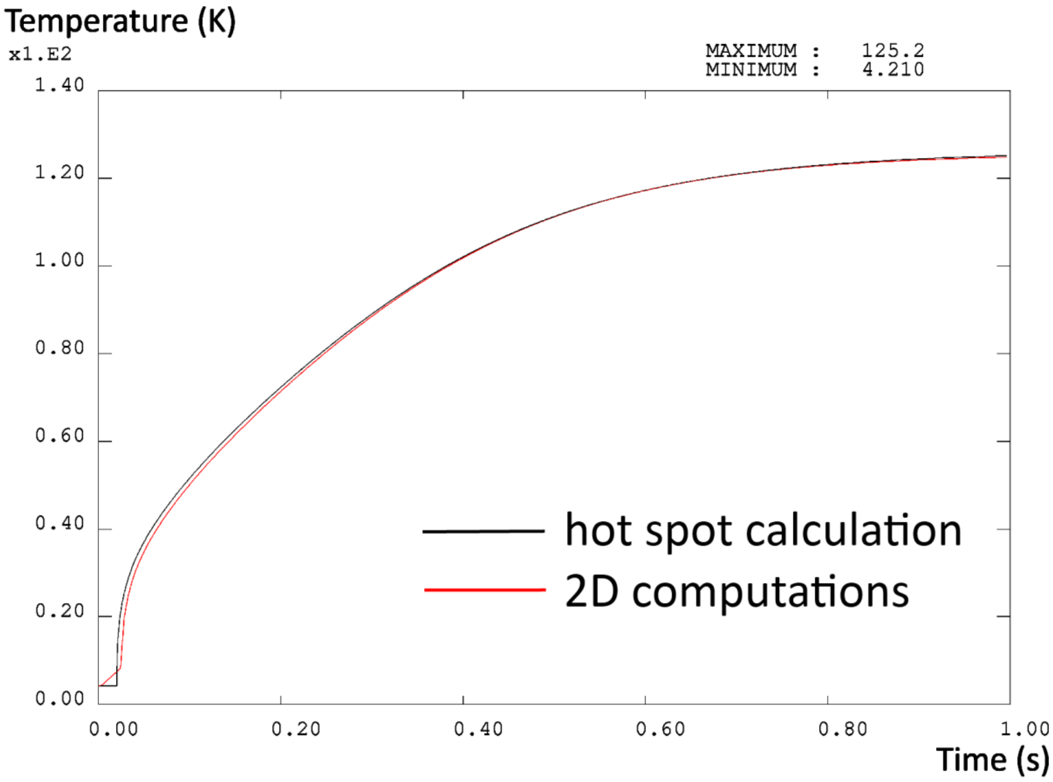
The time constant (I/e) is 520 ms.

2D results: hot spot temperature

From *the current evolution,* the adiabatic hot spot temperature is calculated and *compared* to the maximum temperature computed by the FEM code.

$$\int_0^{\infty} J^2(t)dt = \int_{\theta_0}^{\theta_{max}} \frac{\gamma C(\theta)}{\rho(\theta)} d\theta$$

J(t) : overall current density,
t : time,
$\rho(\theta)$: overall resistivity,
γ : density, θ : temperature,
$C(\theta)$ = specific heat.



The *good accordance* between the two curves allows us to use current evolution to evaluate the maximal temperature

2D results: hot spot temperature

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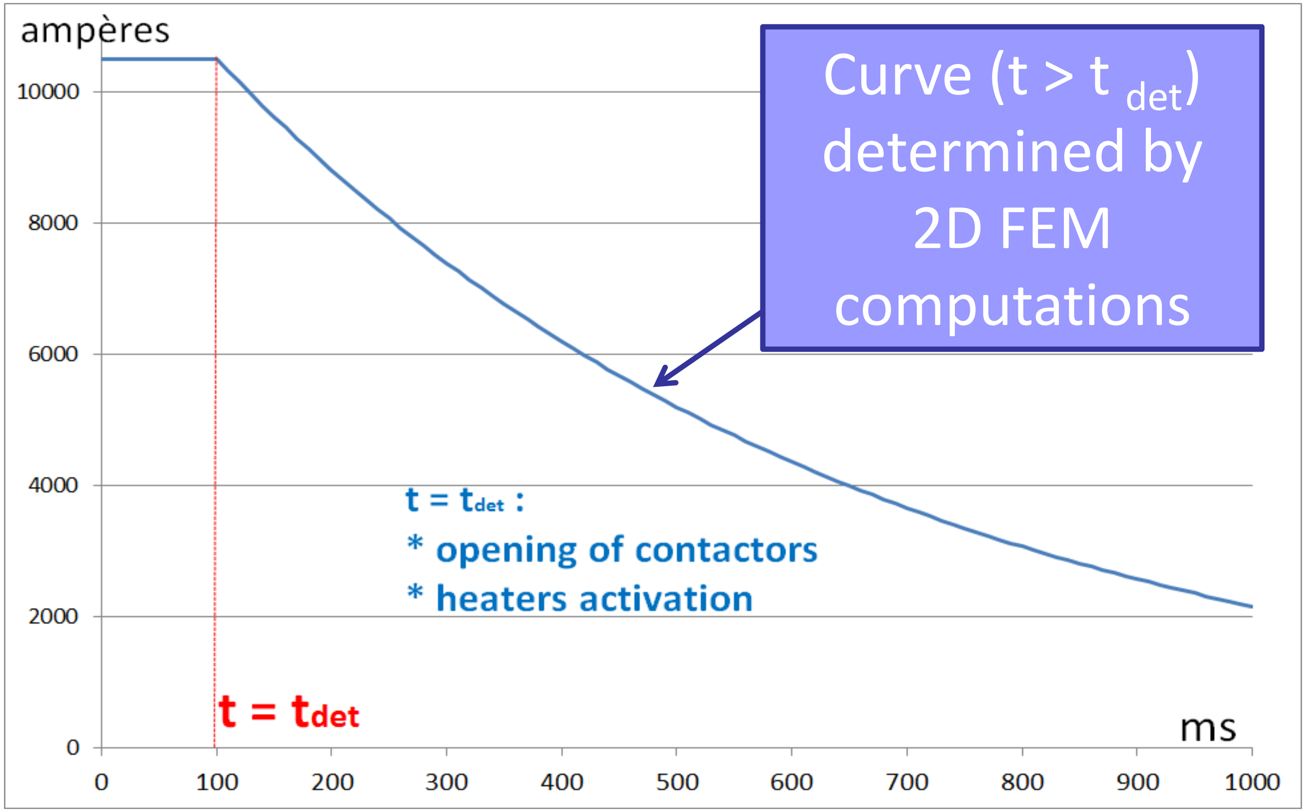
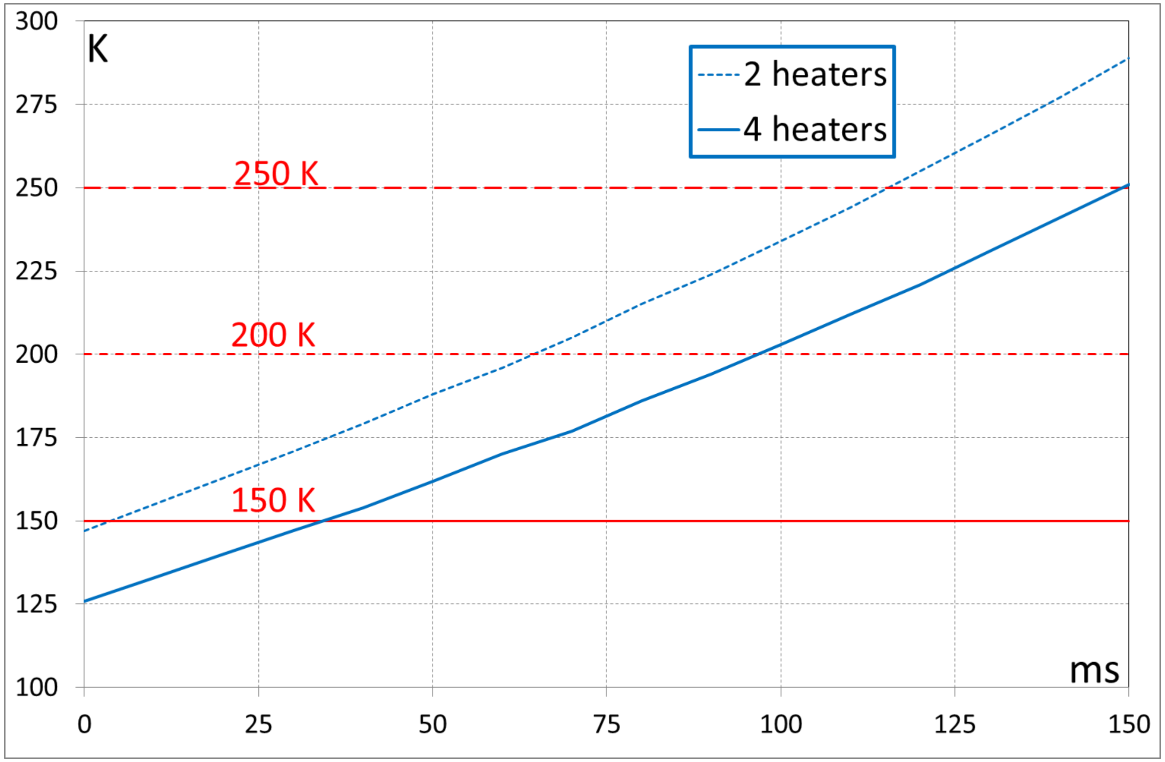
The hot spot temperature can then be calculated in function of the *detection time* by assuming the magnet current equal to nominal current during t_{det} and using the current decrease given by FEM calculations for $t > t_{det}$.



2D results: hot spot temperature

The following figure gives the *hot spot temperature* in the dipole, in function of the *detection time t_{det}*.



If we want a maximal temperature in the coils below 150 K, the detection time should be *lower than 30 ms*.

We expect a *t_{det} of 100 ms* : this lead to a maximal temperature of **203 K for 4 heaters** and 230 K for 2 heaters.

The use of 4 heaters decreases the maximal temperature in the dipole
The maximal temperature difference between the cases with 2 and 4 heaters is of about 30 K.

Conclusions and future actions

The 4 heaters 2D FEM study shows a good protection of the magnet in the case the quench detection occurs within 100 ms.
3D FEM computations must be led in order to evaluate the behavior of the quench propagation before the activation of the heaters.

2. *The quench protection should be studied also in case of a quench starting in the low field region when the magnet is carrying its nominal operating current.*

3D computations of detection time will be led in the low field region where propagation velocities are lower; the MQE will also be computed.

3. *You may consider another protection technique in which the magnet is subdivided by shunt resistors, e.g., each of the four coils will be shunted by a resistor.*

If 3D study shows detection time consistent with 100 ms, the protection system based on dump resistor and heaters is adequate for the dipole.
If the 3D study shows a detection time too large, a complementary protection technique must be considered.