Q4 cold mass
CERN CEA Collaboration meeting

02/06/2016
H. Felice, M. Segreti, D. Simon

STATUS OF THE MQYY DEVELOPMENT

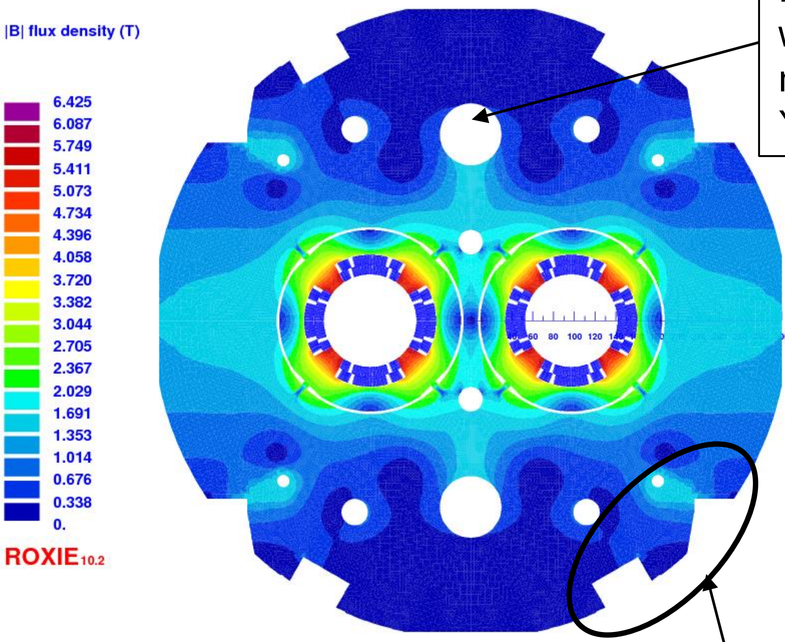
- **MQYYM: 1 short model, single aperture, 1,2 m magn length, 1,4m phys. length**
  - Design at CEA
  - MQM cable provided by CERN
  - Coil fabrication at CEA
  - Mechanical measurements on conductor (location TBD)
  - Collaring at CERN (vertical press in 927)
  - Yoking to be defined
  - Warm magnetic measurements to be defined
  - Cold test at CEA Saclay

- **2 prototypes** (double aperture) **designed** and built in industry (2016-2020)
  - QuaCo project (EU PCP): firms in competition (4/3/2), 2 prototypes from industry,

- **1 serie of 4 magnets + 2 spares built in industry**
  - After Quaco
  - Or started earlier than QuaCo

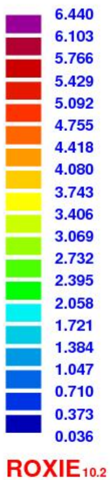
UPDATE OF THE CROSS-SECTION (V3)

- Different sources showed a slight difference in MQM conductor dimension
- **Cable Specification IT-2631**
  - **8,8 mm x 0,77 / 0,91 mm** (instead of 0,78/0,91 used so far)

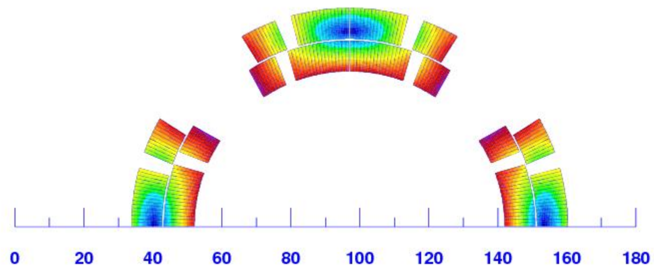


HEX position in agreement with corrector (180 mm, 60 mm in diameter)
Yoke diameter = 614 mm

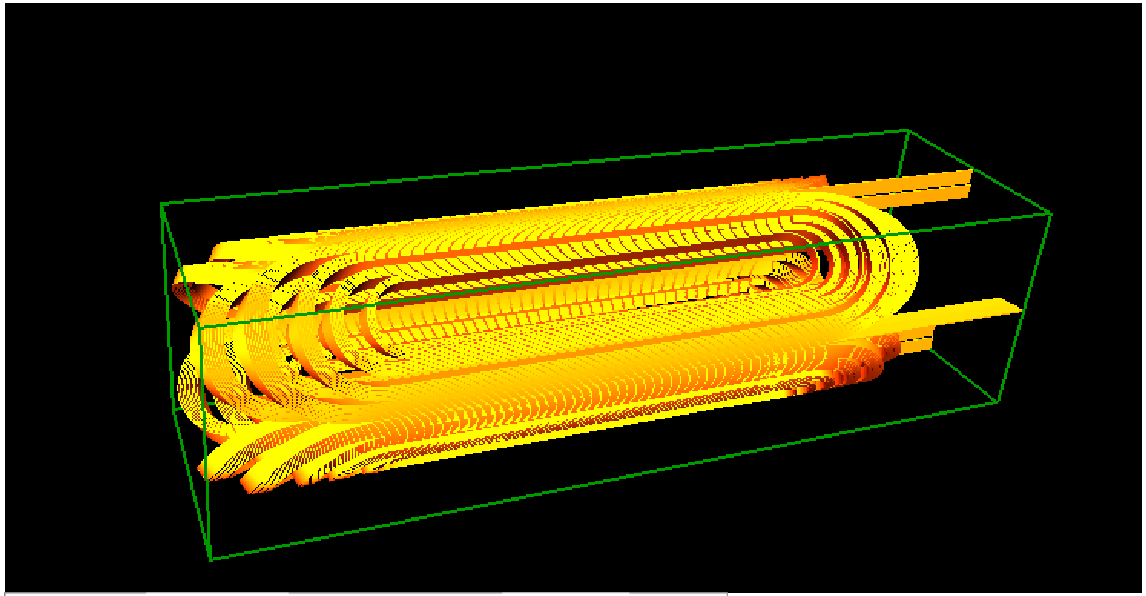
To be updated after discussion

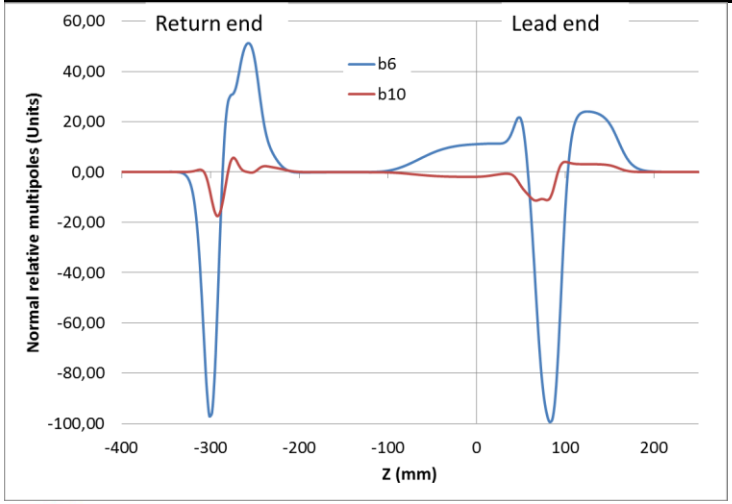


All b_n harmonics < 1 unit
b_{14} = 1,32

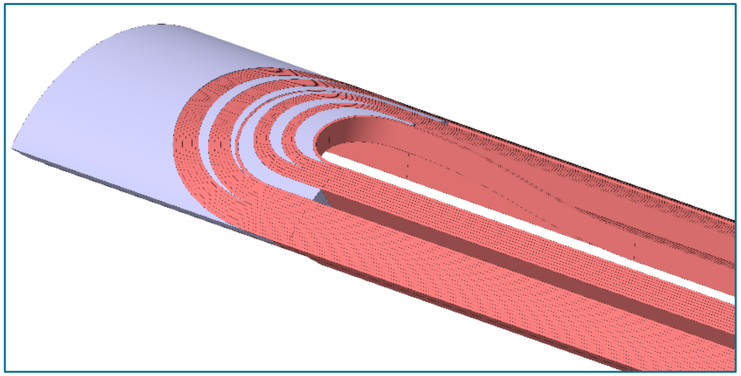


UPDATE OF THE COIL ENDS (V3)





- End optimisation on single aperture to minimize integrated b6
- Layer jump with bending radius of 300 mm (based on practice winding)
- Model Opera 3D started
  - Question on coil export from roxie to opera3D



CONDUCTOR NEEDS

- **Short model**
  - ULSM = 140 m including 10 m provision
  - 10 ULSM planned in the collaboration CERN-CEA
  - Insulated Conductor at CEA: december 2016

- **Prototypes**
  - ULP = 400 m including 10 m provision
  - 10 ULP per company (1 practice coil, 9 real coils)
  - 2 ULP for additionnal test (winding test)
  - 4 ULP for 1 aperture back-up

  ⇒ Total of 26 ULP

  ⇒ Insulated conductor at companies spring 2019 (according to preliminary QuaCo schedule)

- **Series**
  - ULS=ULP
  - 4 magnets + 2 spare magnets => 6x8= 48 ULS
  - 8 ULS for 2 aperture back-up
  - 2 ULS for practice coils

  => Total of 58 ULS

COLLARING OF MQYYM

- **MQYYM: 1 short model, single aperture, 1,2 m magn length, 1,4m phys. length**
  - Design at CEA
  - MQM cable provided by CERN
  - Coil fabrication at CEA
  - Mechanical measurements on conductor (location TBD)
  - Collaring at CERN (vertical press in 927) foreseen in spring 2017
  - Yoking to be defined
  - Warm magnetic measurements to be defined
  - Cold test at CEA Saclay (summer 2017)

- **Collaring**: Drawings of the vertical press from CERN received today

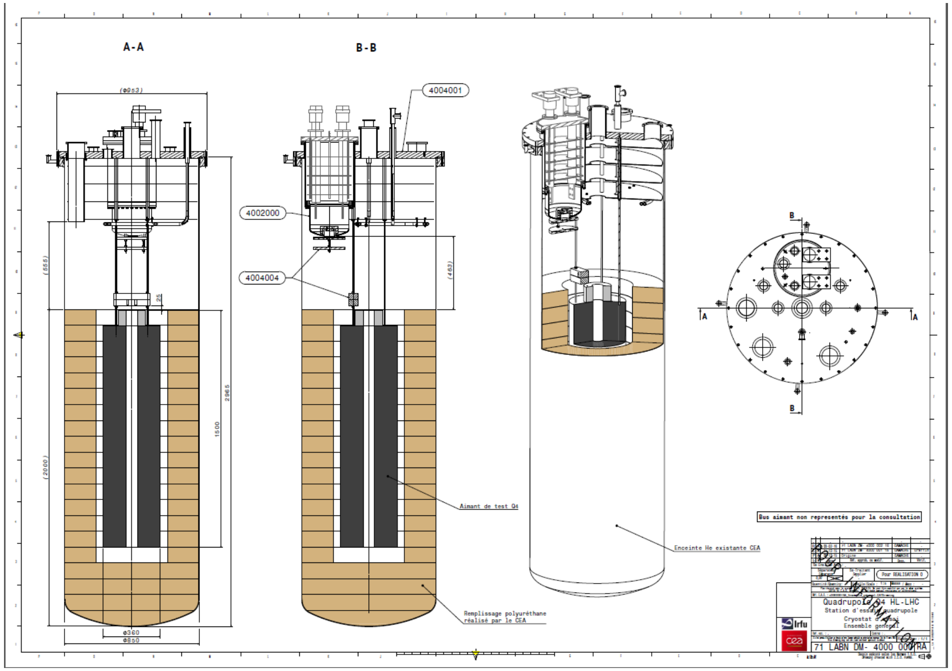
⇒ compatibility with the design of the collars will be checked.

⇒ Meeting at CERN will be planned as soon as strike will be over… so we can have a face-to-face meeting in 927.

- **Yoking:** discussion to be postponed to next meeting

MAGNETIC MEASUREMENT FOR MQYYM

- For the short model: MQYYM
  - Warm measurements
    - Horizontally
    - Type of probe:
      - Is the warm probe different from the cold measurement probe?
  - Measurements at cold
    - Compatibility with the vertical test station
      - Type of probe (rotating in LHe, need for anticryostat?)
      - Positionning system
      - Status of the design at CERN?
      - How to move forward?



MAGNETIC MEASUREMENT FOR MQYYM

- Name of the engineer at CERN technically in charge of the project: E. Todesco/ A Foussat
- Name of the engineer at CEA technically in charge of the project: H. Felice
- Official name of the magnet : MQYYM
- Magnet type : Quadrupole
- Number of magnets to be measured 1 single aperture
- Aperture diameter (total and free) 90 mm, *70 mm free?*
- Length (magnetic and total (physical)) 1.2 m magnetic, 1.5 m total
- Nominal and max. field or gradient 120 T/m nominal
- Location of the measurements:
  - To be discussed for the collared coil
  - CEA Saclay, summer 2017 at room temperature and 1,9 K
- Foreseen date of arrival of first magnet at CERN : NA
- A clear indication in case the magnet should be measured outside of CERN (partner institute) together with information about the measurement equipment to be provided (probe only or complete system) complete system needed
- Measurements at warm and/or at cold: both room temperature (collared coil and magnet) and 1.9 K
- Tests and measurements to be performed: Gradient and field multipoles

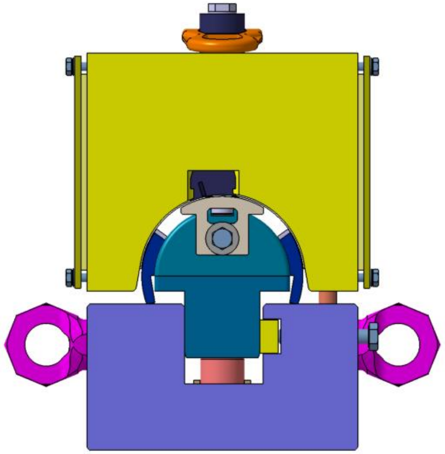
MAGNETIC MEASUREMENT FOR MQYY PROTOTYPE (WITHIN QUACO)

- Name of the engineer at CERN technically in charge of the project: E. Todesco/ A Foussat
- Name of the engineer at CEA technically in charge of the project: H. Felice
- Official name of the magnet : MQYY?
- Magnet type : Quadrupole
- Number of magnets to be measured 1 double aperture
- Aperture diameter (total and free) 90 mm, *70 mm free?*
- Length (magnetic and total (physical)) 3,67 m magnetic, m total
- Nominal and max. field or gradient 120 T/m nominal
- Location of the measurements:
  - Warm: At the two company premises
  - Cold: at CERN or CEA Saclay
- Foreseen date of arrival of first magnet at CERN / CEA: Spring 2020
- A clear indication in case the magnet should be measured outside of CERN (partner institute) together with information about the measurement equipment to be provided (probe only or complete system) warm system TBD / cold complete system needed
- Measurements at warm and/or at cold: both room temperature (collared coil and magnet) and 1.9 K
- Tests and measurements to be performed: Gradient and field multipoles

CAD STATUS

MQYYM

- Coil fabrication Tooling (mandrel, side pushers, curing cavity…)
  - 2D drawings are ready
  - Layer jump is being updated
  - Waiting to hear from CERN about the procurement of the components (who does what and how)
- Collars are updated with MQM cable based design
  - ⇒ Need to check the compatibility with the press (drawings received 02/06)
- Coil V3 is being worked on right now
- Connection box is next
- Yoke: to be done. Assembly concept to be worke



Prototype CAD model

- DRAFT model of the double aperture for integra purpose should be ready by the end of June

- Action item CEA: Review and approval process to be defined

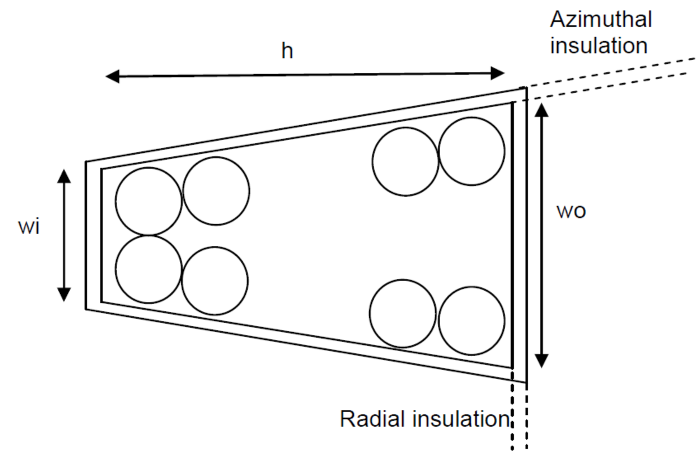
Status on Magnet Protection Study

D. Simon

INTRODUCTION

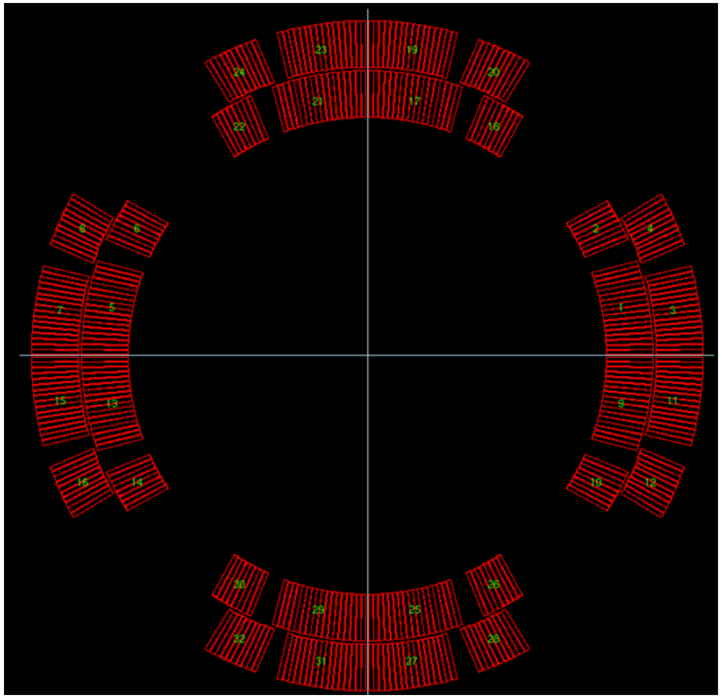
- This presentation talks about the protection of the Q4 quadrupole.
- A first study of the quench protection for the current design of the quadrupole is proposed. Results are shown for **one aperture**
- The study is performed with the ROXIE and Qtransit softwares
- The Qtransit code is based on the M.N.Wilson quench code and which have been developed by CEA for performing quench simulation

INPUTS

Q4 Cable		
h	8.8 mm	
wi	0.78 mm (V2)	
wo	0.91 mm	
Strand diameter (d)	0.475 mm	
N strand	36	
Radial insulation (e)	0.08 mm	
Azimuthal inslation (e)	0.08 mm	
Insulated cable crosss section	8.960 mm^2	
Detection threshold	0,1 V	These values have been confirmed by CERN (Email from E.Todesco 08/03/2016)
Validation time	10 ms	
Maximum Hotspot temperature allowed	< 250K	These values are conservatives (Email from B. Auchmann 09/03/2016)
Maximum voltage to ground allowed	800 V	

2D CROSS SECTION WITH ROXIE

- The ROXIE software has a module that allows the quench simulation. To perform the “2D” quench simulation on ROXIE the cross section of the magnet has to be built in order to describe the quench propagation in the coil (ie the number of the blocks and the conductor that follow the winding)



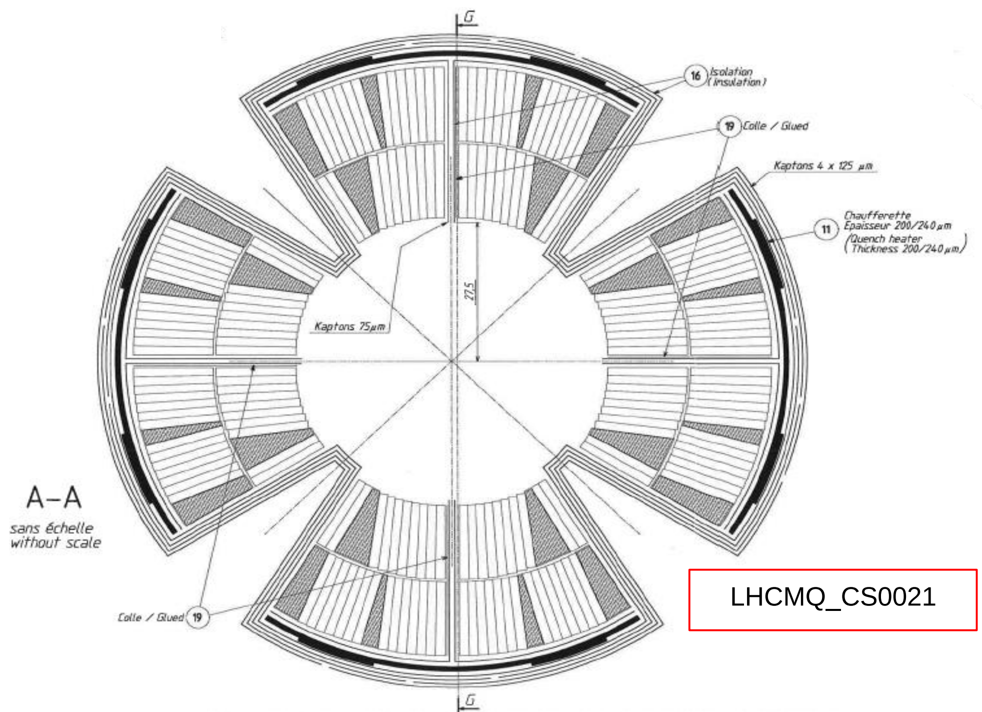
HYPOTHESIS

- The ROXIE quench's simulations have been made for **two different cases**. The first case simulate a the behavior of the magnet if a quench occur in the magnet **without protection** (ie without quench heaters). The second case simulate the behavior of the magnet with **quench heaters**.

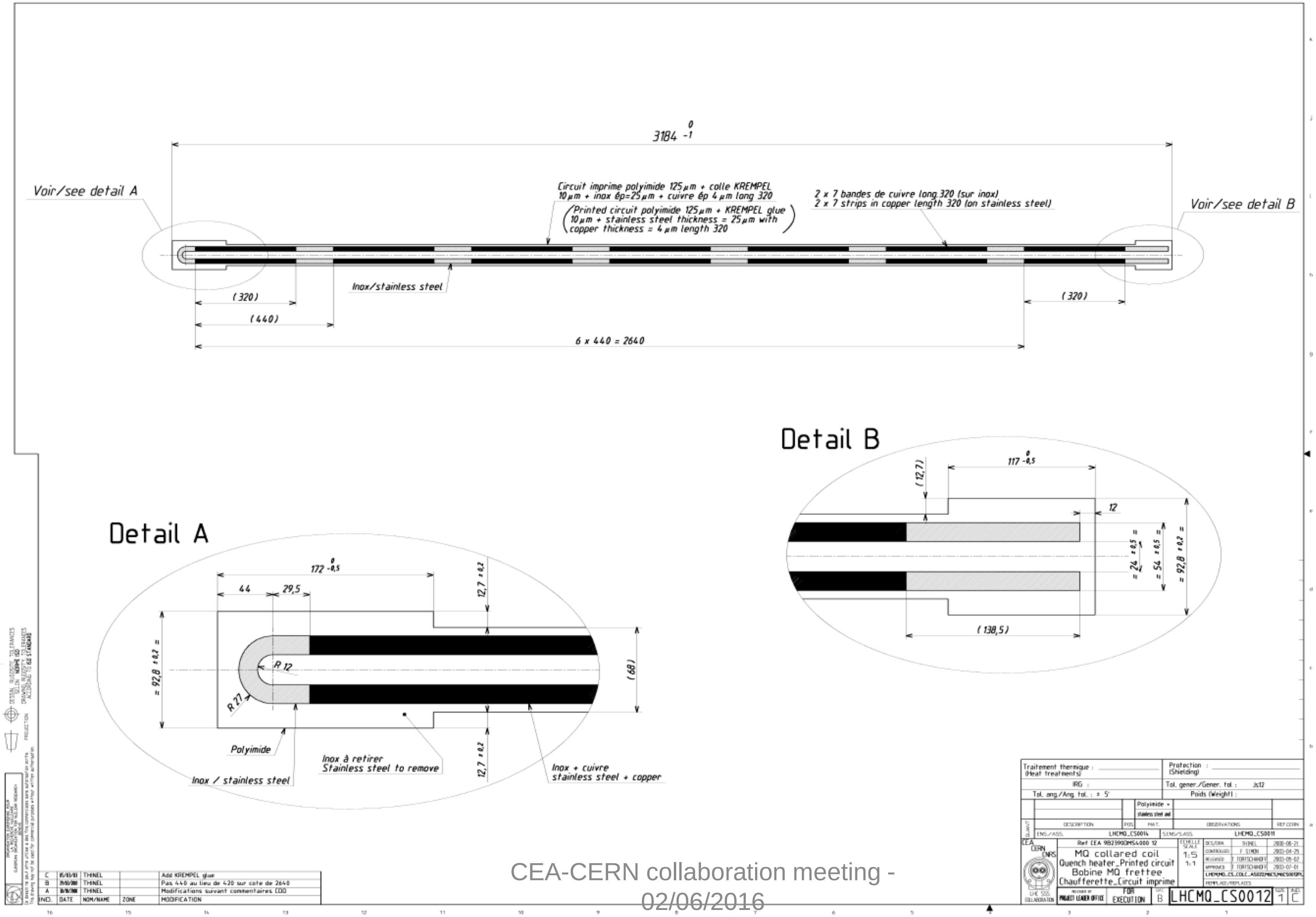
- The Qtransit's simulation have been made for the two past cases in order to check the ROXIE results

HYPOTHESIS

- To be in agreement with operating condition in LHC, the protection system of the MQYY will be carried out with Protection Heaters (and no dump resistor)
- The design of the Protection Heaters will be inspired by the MQ Protection Heaters: outer layer



LHCMQ_CS0021


3184 -1
Voir/see detail A
Circuit imprime polyimide 125µm + colle KREMPEL
10µm + inox ép=25µm + cuivre ép 4µm long 320
(Printed circuit polyimide 125µm + KREMPEL glue
10µm + stainless steel thickness = 25µm with
copper thickness = 4µm length 320)
2 x 7 bandes de cuivre long 320 (sur inox)
2 x 7 strips in copper length 320 (on stainless steel)
Voir/see detail B
Inox/stainless steel
(320)
(440)
6 x 440 = 2640
Detail A
172 -0,5
44
29,5
12,7 ±0,2
92,8 ±0,2
R 12
R 27
(68)
Polyimide
Inox / stainless steel
Inox à retirer
Stainless steel to remove
Inox + cuivre
stainless steel + copper
Detail B
117 -0,5
(12,7)
12
24 ±0,5
54 ±0,5
92,8 ±0,2
(138,5)
C Add KREMPEL glue
B THINEL Pas 440 au lieu de 420 sur cote de 2640
A THINEL Modifications suivant commentaires CDD
IND. DATE NOM/NAME ZONE MODIFICATION
Traitement thermique : (Heat treatments)
Protection : (Shielding)
IRG :
Tol. gener./Gener. tol. : Js12
Tol. ang./Ang. tol. : ± 5'
Poids (Weight) :
Polyimide + stainless steel and
DESCRIPTION POS MAT. OBSERVATIONS REF.CERN
ENS./ASS. LHCMQ_CS0014
S.ENS/S.ASS. LHCMQ_CS0011
CEA CERN CNRS
Ref CEA 9B2390DMS4000 12
MQ collared coil
Quench heater_Printed circuit
Bobine MQ frettee
Chaufferette_Circuit imprime
ECHELLE SCALE 1:5 1:1
F. SIMON
T. TORTSCHANOFF
LHC SSS COLLABORATION
PROJECT LEADER OFFICE
FOR EXECUTION
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LHCMQ_CS0012
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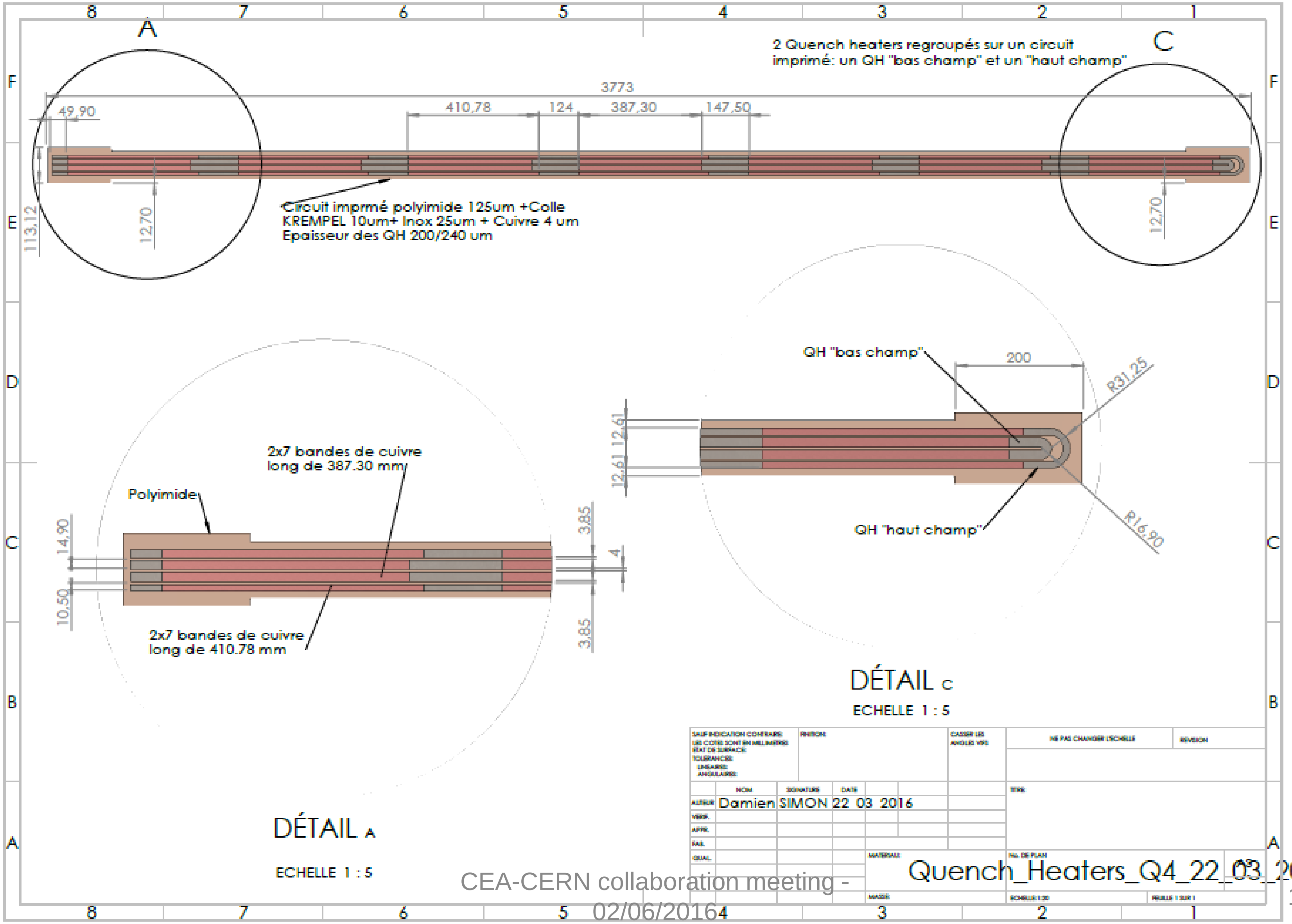
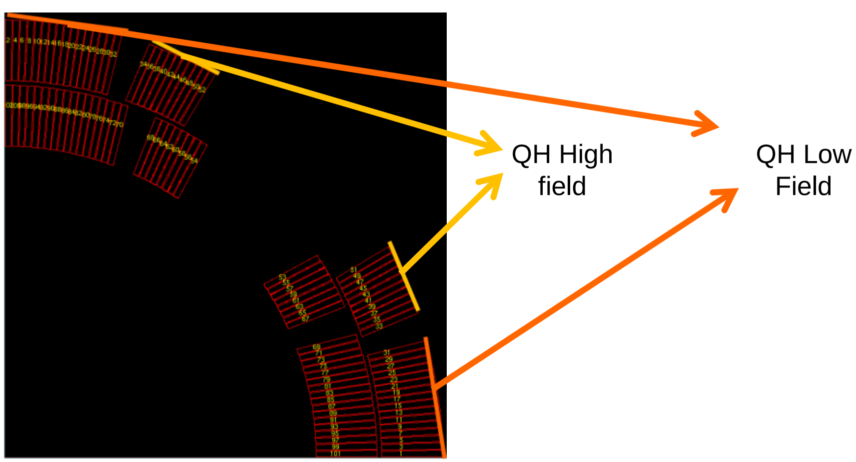
C

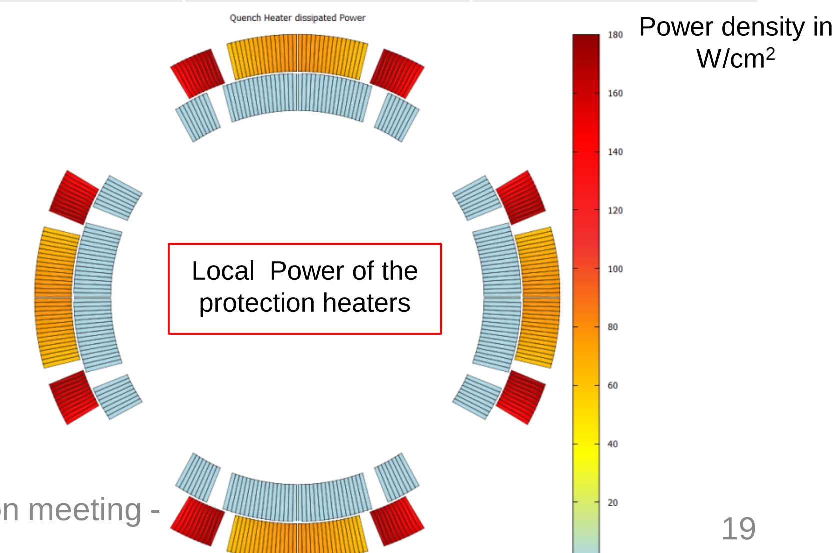
PRELIMINARY DESIGN OF THE QUENCH HEATERS FOR THE MQYY



COMPARISON OF MQ AND MQYY PROTECTION HEATERS

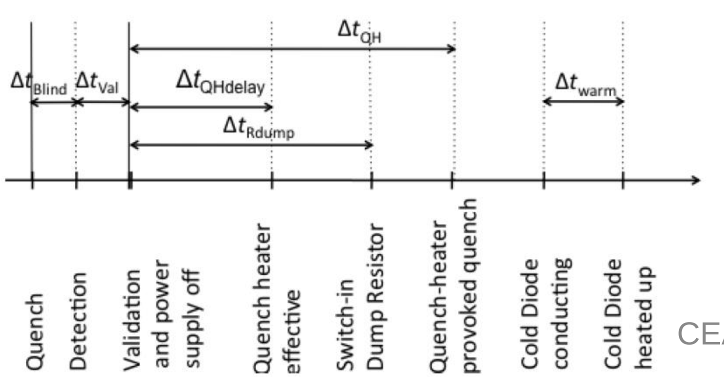
	MQ	MQYY LF v1	MQYY HF v1
I (A)	80	80	80
U (V) (for 4 QH)	900	900	900
R1/m (no copper = stainless steel) à 1,9K (Ω/m)	1,5	1,5	1,5
R2/m (copper plated) à 1,9K (Ω/m)	0,43	0,38	0,38
Local power of the heating stations (W/cm^2)	64	63	125
Surface of the heating stations (mm^2)	1800	2003	998

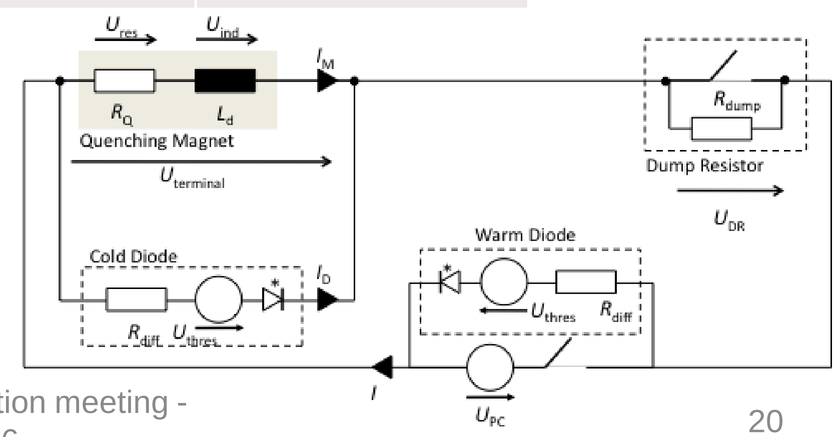




HYPOTHESIS

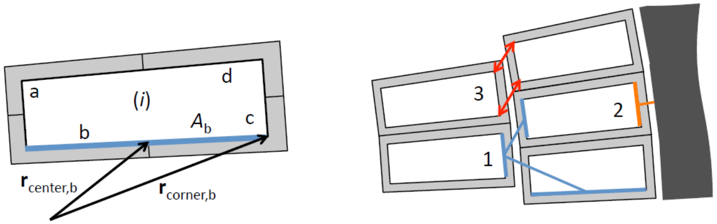
	MQYY
I_0	4590A
QMDCC	0,00085m
MAGLEN	3,744m
MAGMLE	3,671m
WARMDIO	$U_{threshold}$ = 1V; R_{diff} = 0
PCREGUL	V_{max} = 8V
Δt (BLINDTIME)	6 ms
Δt_{val}	10 ms





THERMAL CONTACT

- Transversal heat transfer
  - QMDCC: $d_{\alpha,\beta}^{i,n} = \left| r_{center,\alpha}^{i} - r_{center,\beta}^{n} \right|$ *(0,00085 m)*

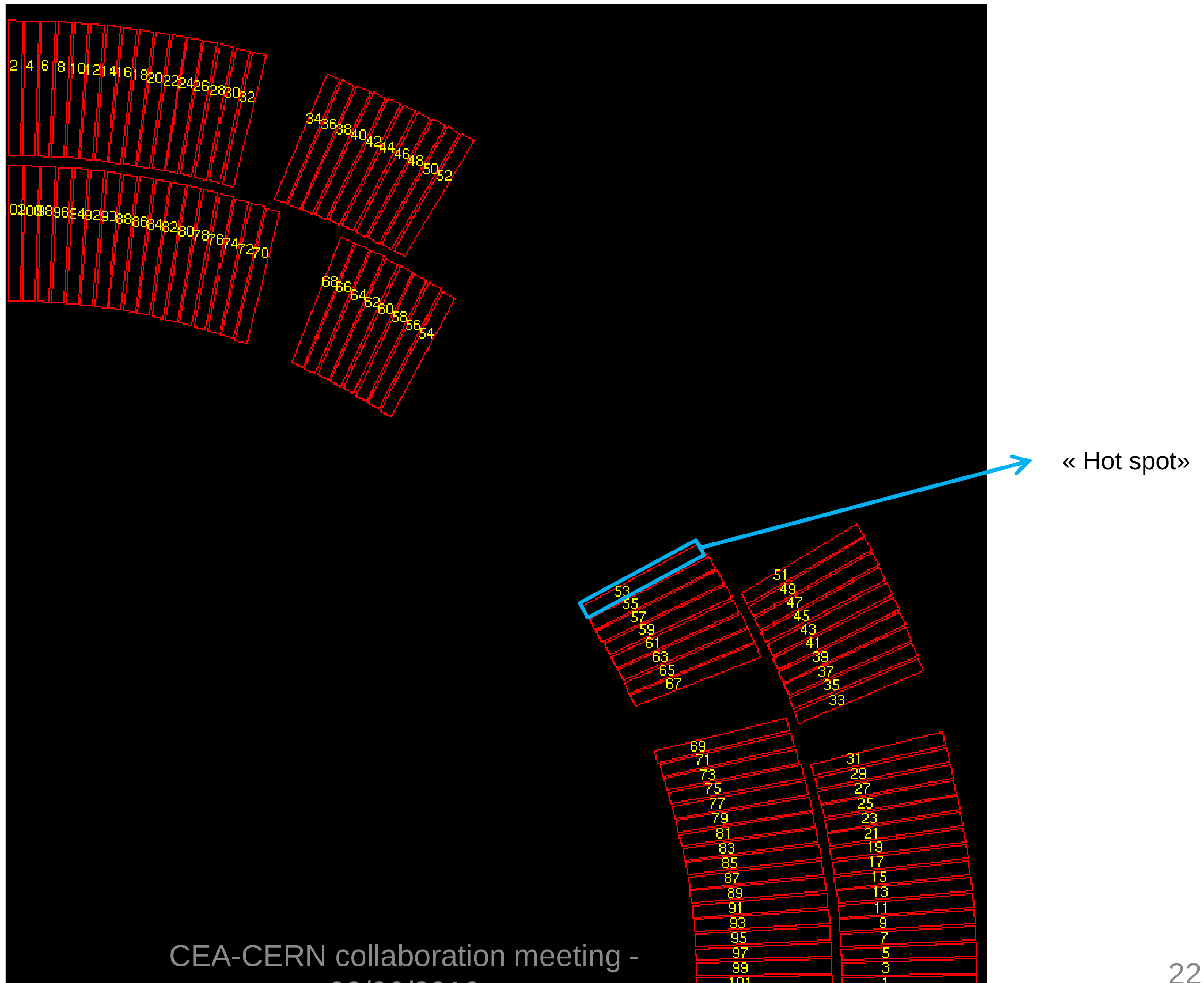


Extracted from Juljan Nikolai Schwerg's thesis

  - HETRTR: Scaling of transversal heat transfer coefficient *(20 based on Bernhard Auchman's input)*

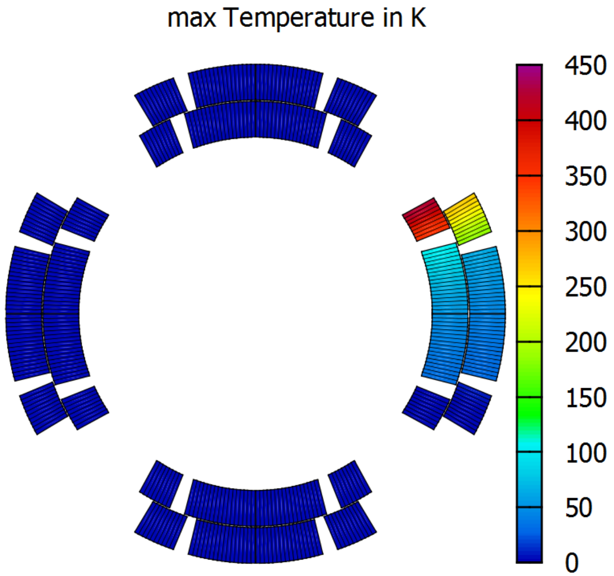
- Longitudinal heat transfer
  - HETRLO: Scaling of longitudinal heat transfer coefficient *(2 based on Bernhard Auchman's input)*

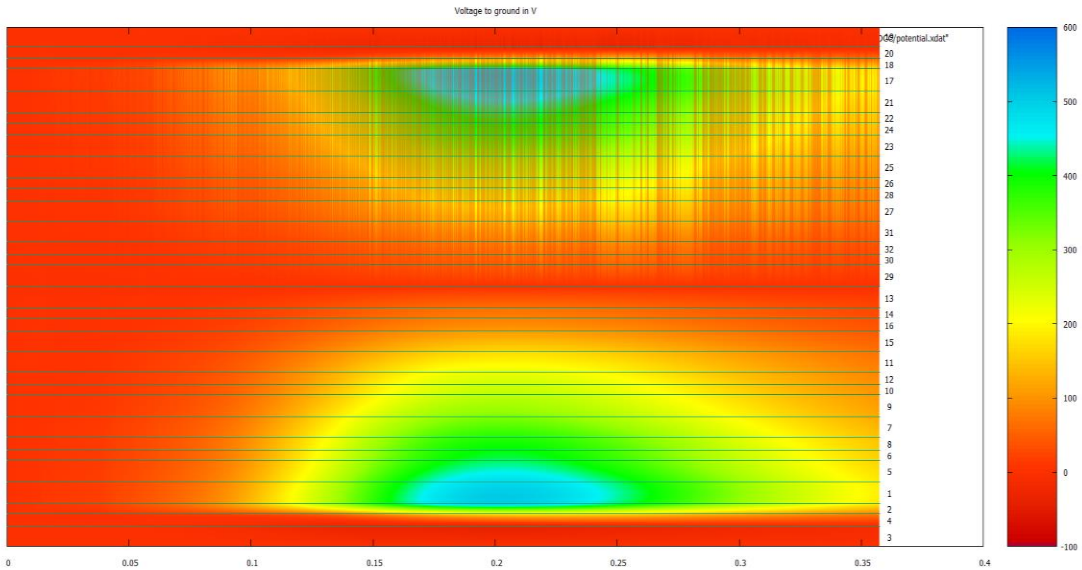
- Case n°1: Without QH



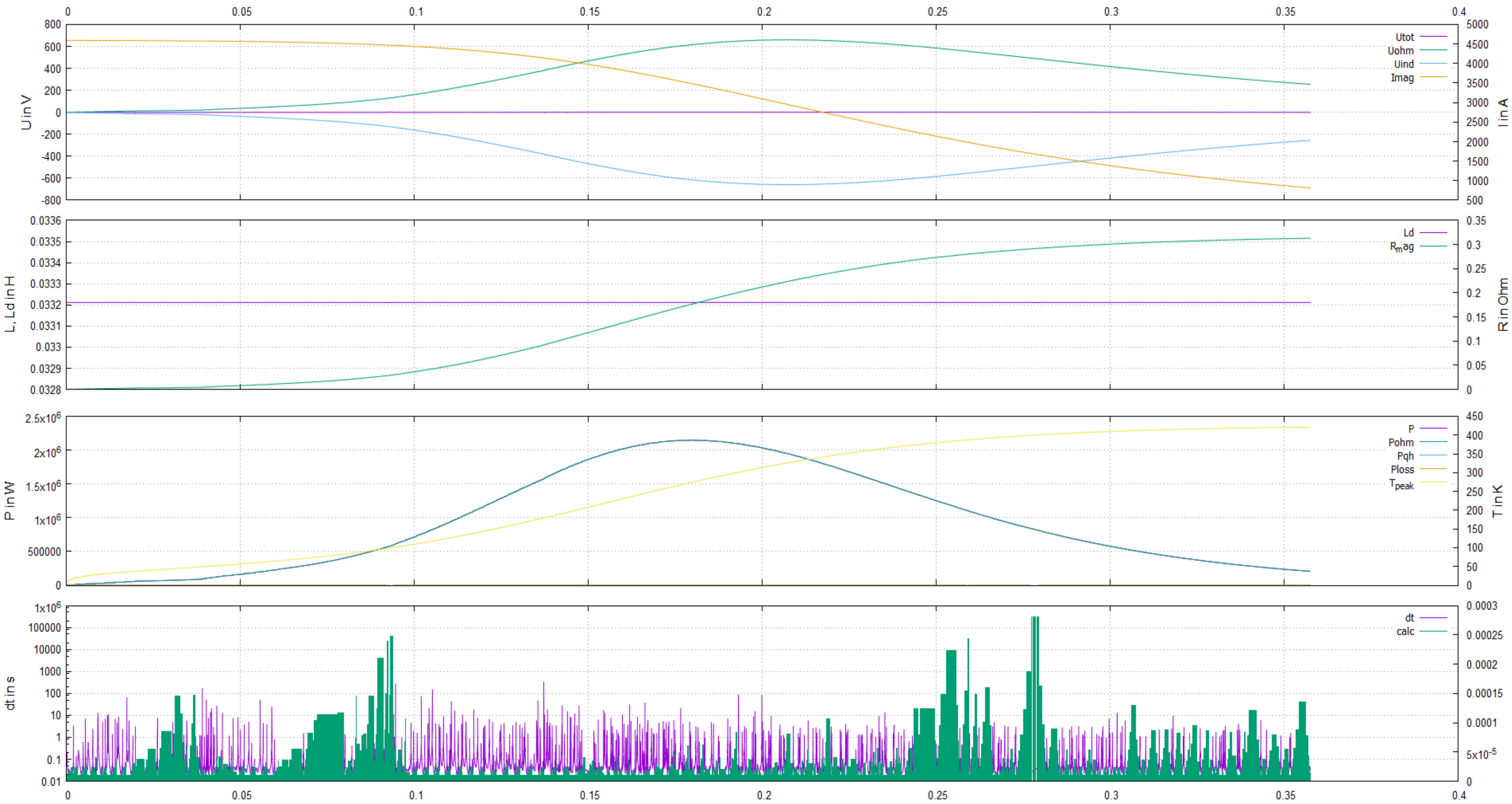
PRELIMINARY RESULTS

- Temperature Maximum: 450 K
  - Anomaly in the temperature distribution (absence of longitudinal propagation in the symmetric block of the coil)
- Max Voltage to ground: 600 V
- Max voltage in the coil: 700 V



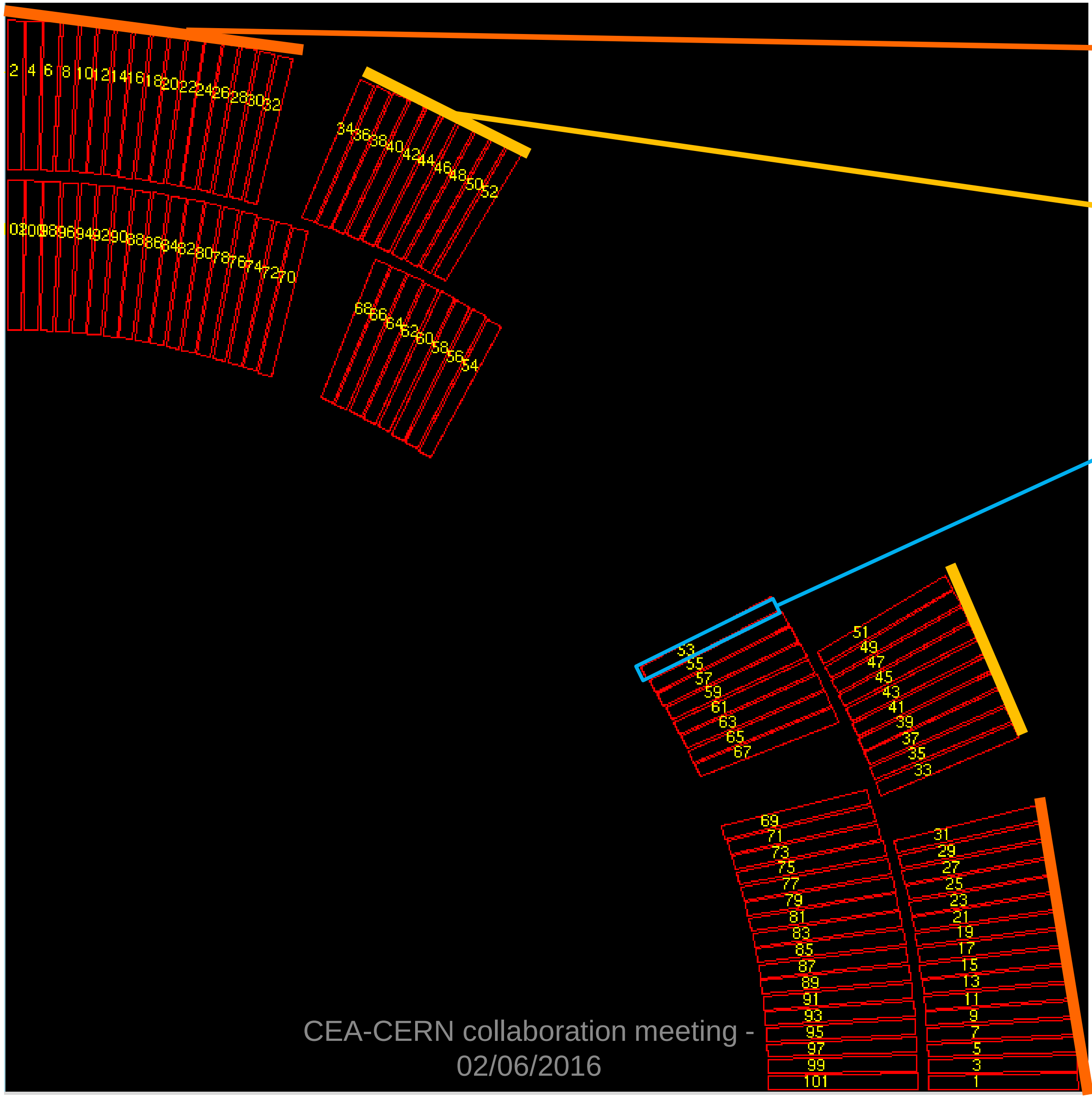


RESULTS



U in V
I in A
Utot
Uohm
Uind
Imag
L, Ld in H
R in Ohm
Ld
Rmag
P in W
T in K
P
Pohm
Pqh
Ploss
Tpeak
dt in s
Stepping Info
dt
calc

2D CROSS SECTION WITH QH

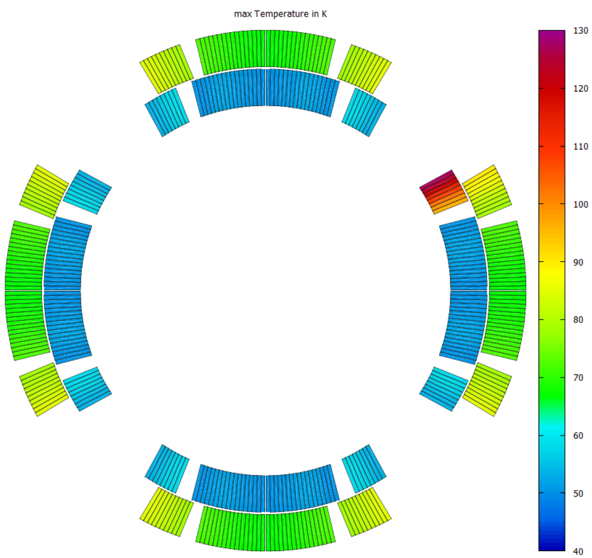


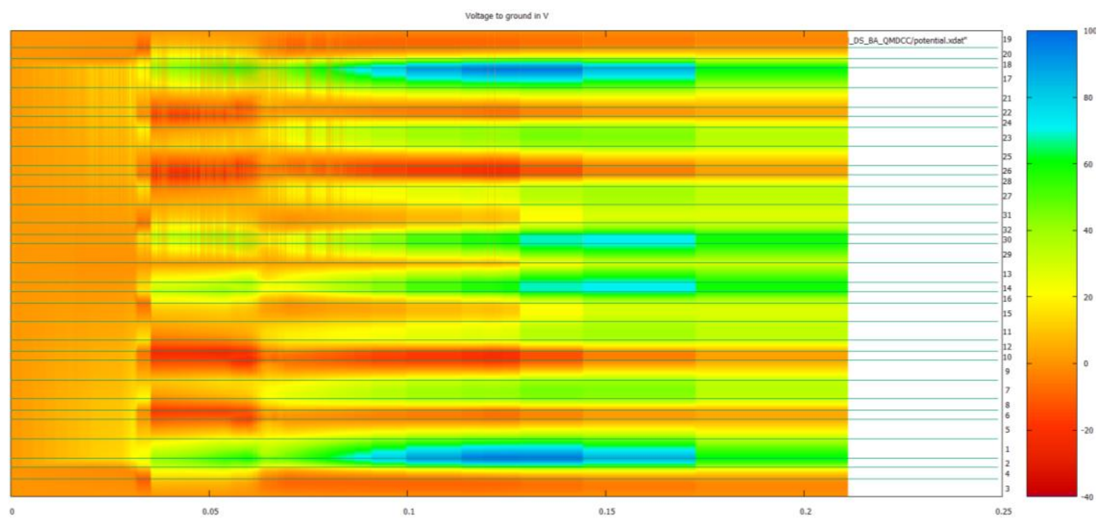
QH low field

QH high field

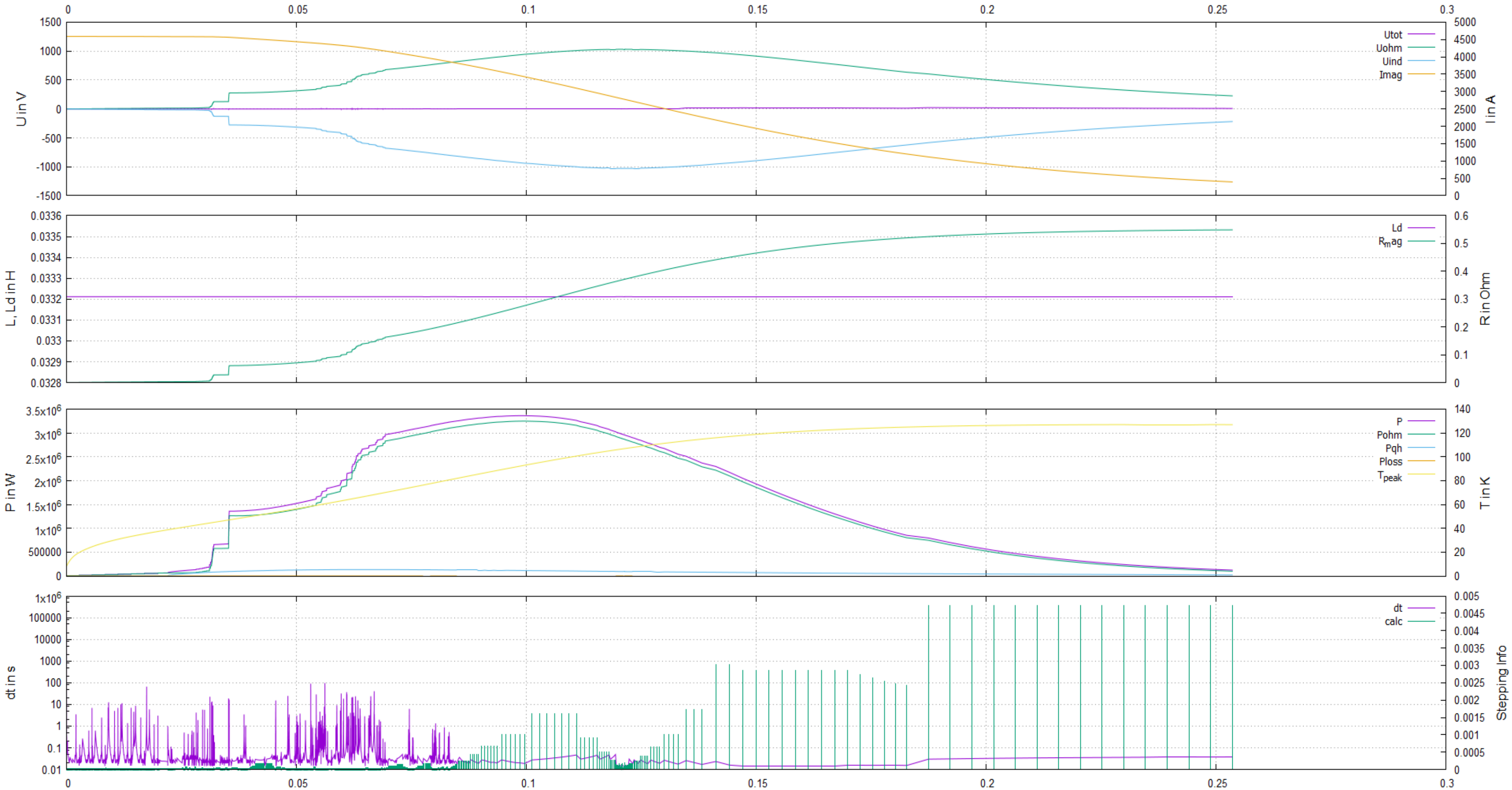
« Hot spot »

- Maximum Temperature : 130K
  - Anomaly in the temperature distribution (absence of longitudinal propagation in the symmetric block of the coil)
- Max voltage to ground: 100 V





RESULTS


U in V
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R in Ohm
Ld
Rmag
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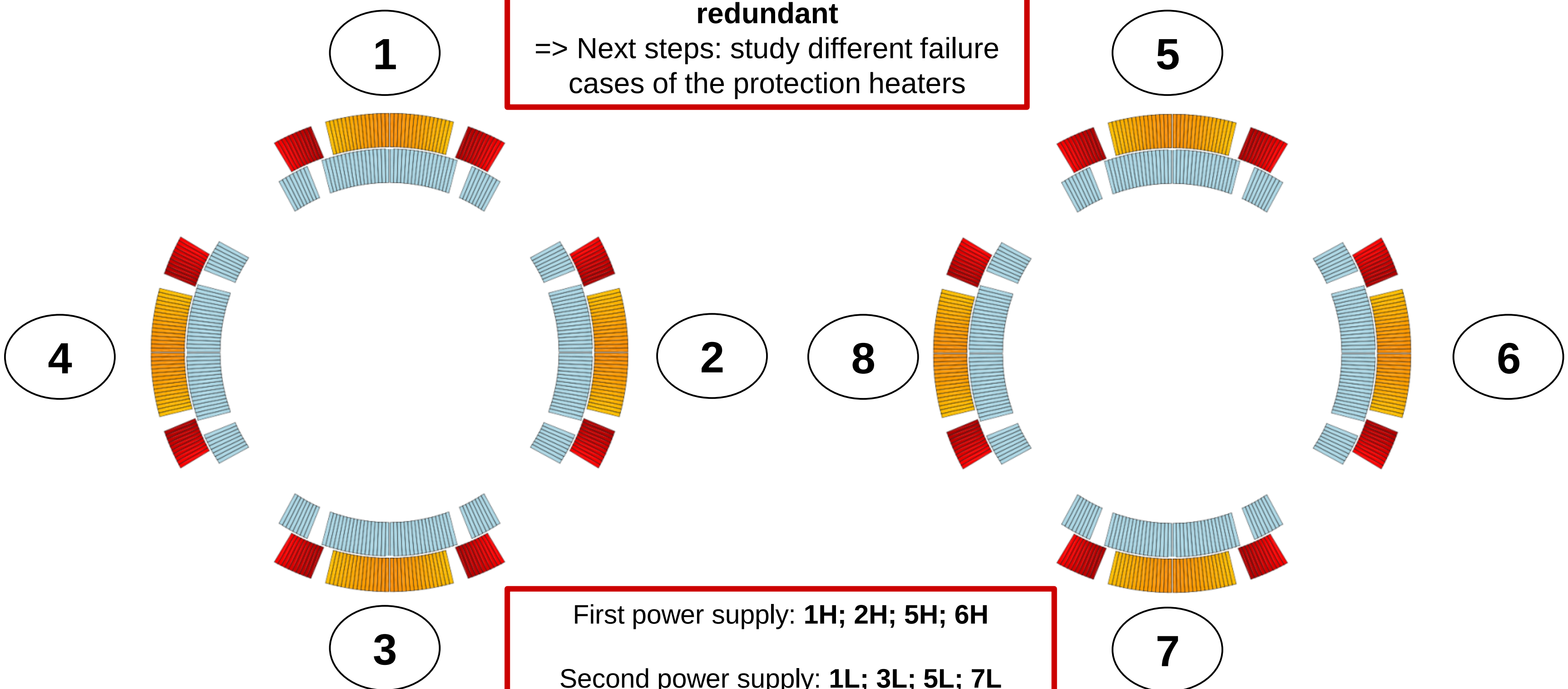
P
Pohm
Pqh
Ploss
Tpeak
dt in s
Stepping Info
dt
calc

QUENCH HEATERS CONNECTION

Main principle: Make the system **redundant**
=> Next steps: study different failure cases of the protection heaters



First power supply: **1H; 2H; 5H; 6H**

Second power supply: **1L; 3L; 5L; 7L**

Third power supply: **3H; 4H; 7H; 8H**

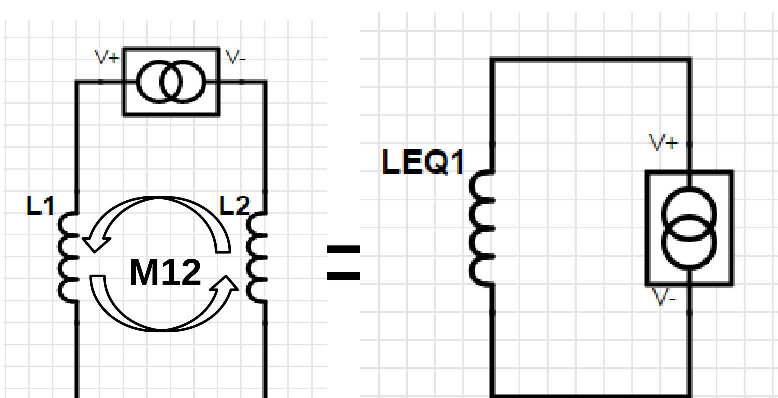
Fourth power supply: **2L; 4L; 6L; 8L**

H: High field protection heaters
L: low field protection heaters

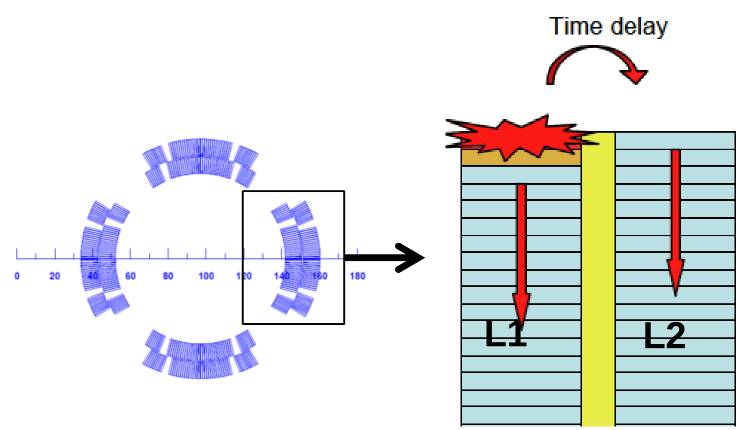
Under discussion

COMPARISON WITH QTRANSIT

- To simulate the quench propagation for the Q4 magnets we used a model of two coils where the first coils represent the inner layer of the 4 coils and the second coils represent the outer layers.
- The two layers are separated by a G10 shim of 0,5 mm which delays the thermal conduction between the two layers.
- The total volume of the 4 coils and the total energy are accounted for. QH are fired on all coils.



$$L_{eq1} \approx L_1 + L_2 + 2M_{12}$$



COMPARISON WITH QTRANSIT

	ROXIE	Qtransit
Without protection heaters		
Hot Spot	≈445K	≈300K
Voltage to ground	≈600V	≈634V
With protection heaters		
Hot Spot	≈130K	≈180K
Voltage to ground	≈100V	≈340V

CONCLUSION

The **QTRANSIT and ROXIE** codes have been used to perform preliminary Quench simulation.

Simulations **with and without protection heaters** have been carried out.

The highest hot spot temperature in absence of protection heaters is around 450K with ROXIE (conservative).

With QH:

the hotspot is limited to ~180K with ROXIE.

The max V to ground is ~100 V with ROXIE.

A preliminary design of the protection heaters for the MQYY have been made.

NEXT STEPS

Continue to **fine tune** the ROXIE inputs.

Study different **failure cases of the protection heaters**.

Perform **2+1D simulation** with ROXIE (discretisation of MAGLEN).

Perform ROXIE simulation with **coupling-current losses** in the coil.

Perform simulation for the **2 apertures with the yoke**.

REFERENCE

- **ROXIE USER CASE: QUENCH SIMULATIONS** « Susana Izquierdo Bermudez »
- **Numerical Calculation of Transient Field Effects in Quenching Superconducting Magnets** « Juljan Nikolai Schwerg »
- **ROXIE User's Documentation** « Bernhard Auchmann »

HYPOTHESIS

- MAGLEN: Average half-turn length (m), i.e. length of the windings (electrical, thermal and magnetical)
- MAGMLE: Magnetic length of the magnet at nominal current (m) (used for inductance voltages and inductance)
- QUENCH:
  - Time: Time when a conductor quenches
  - Cond: Conductor where quench starts
  - Piece: Longitudinal position where quench starts for 3D simulations

General :

No	String	N/a	N/a	N/a
1	QUENCH	0	25	0
2	MAGLEN	3.744	0	0
3	MAGMLE	3.671	0	0

- The magnetic length have been made determined with ROXIE by the CEA team (Michel Segreti & Hélène Felice)

HYPOTHESIS

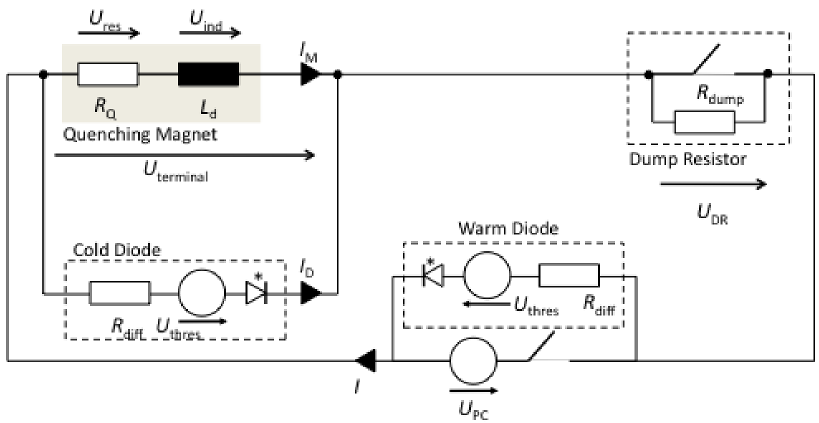
- QMDCC: Max. radius of effective inter-cable heat transfer (m) (default: 0.0005). The QMDCC plays an important role on the results of the quench simulation
- HETRQC: Scaling of radial transfer coefficient from the quench heater to conductor (default: 1)
- HETRTR: Scaling of transversal transfer coefficient (20)
- HETRLO: Scaling of longitudinal transfer coefficient (2)

Thermal model :

No	String	Radius	N/a	N/a	N/a
1	QMDCC	0.00085	0	0	0
2	HETRQC	0.43	0	5	1 3 5 7 9 11 13 15
3	HETRQC	0.43	0	5	2 4 6 8 10 12 14 16
4	HETRTR	20	0	0	0
5	HETRLO	2	0	0	0

HYPOTHESIS

- WARMDIO: Warm diode definition
- PCREGUL: Maximum output voltage for the power converter



Electrical network :

No	String	N/a	N/a	N/a	N/a
1	WARMDIO	1	0	0	0
2	PCREGUL	8	0.1	0.1	0

HYPOTHESIS WITHOUT QH

- DETECT: Detection voltage (LHC circuits 0.1V-0.5V) and validation delay Δtval (LHC circuits 10 ms)

- BLINDTIM:Time to get over the threshold (Δtblind). Delay of detection blindness after quench start (s), useful in case of 2 r

Quench protection :

No	String	N/a	N/a	N/a	N/a	N/a	N/a	N/a
1	DETECT	0.1	0.01	0	0	0	0	0
2	HEATDEF	1	0.064	2.5E-05	0	3	3	3
3	HEATDEF	2	0.04	2.5E-05	0	3	3	4
4	HEATDEF	3	0.064	2.5E-05	0	3	3	7
5	HEATDEF	4	0.04	2.5E-05	0	3	3	8
6	HEATDEF	5	0.064	2.5E-05	0	3	3	11
7	HEATDEF	6	0.04	2.5E-05	0	3	3	12
8	HEATDEF	7	0.064	2.5E-05	0	3	3	15
9	HEATDEF	8	0.04	2.5E-05	0	3	3	16
10	HEATDEF	9	0.064	2.5E-05	0	3	3	19
11	HEATDEF	10	0.04	2.5E-05	0	3	3	20
12	HEATDEF	11	0.064	2.5E-05	0	3	3	23
13	HEATDEF	12	0.04	2.5E-05	0	3	3	24
14	HEATDEF	13	0.064	2.5E-05	0	3	3	27
15	HEATDEF	14	0.04	2.5E-05	0	3	3	28
16	HEATDEF	15	0.064	2.5E-05	0	3	3	31
17	HEATDEF	16	0.04	2.5E-05	0	3	3	32
18	HEATPOW	627358	0.0275	0.006	0	0	5	1 3 5 7 9 11 13 15
19	HEATPOW	1.24603E+06	0.0275	0.006	0	0	5	2 4 6 8 10 12 14 16
20	HEATINS	0.000135	4	4E-05	4	0	5	1-16
21	BLINDTIM	0.006	0	0	0	0	0	0
22	HEATLO	0.13441	0.40307	0	0	0	5	1
23	HEATLO	0.09503	0.44621	0	0	0	5	2

HYPOTHESIS WITH QH

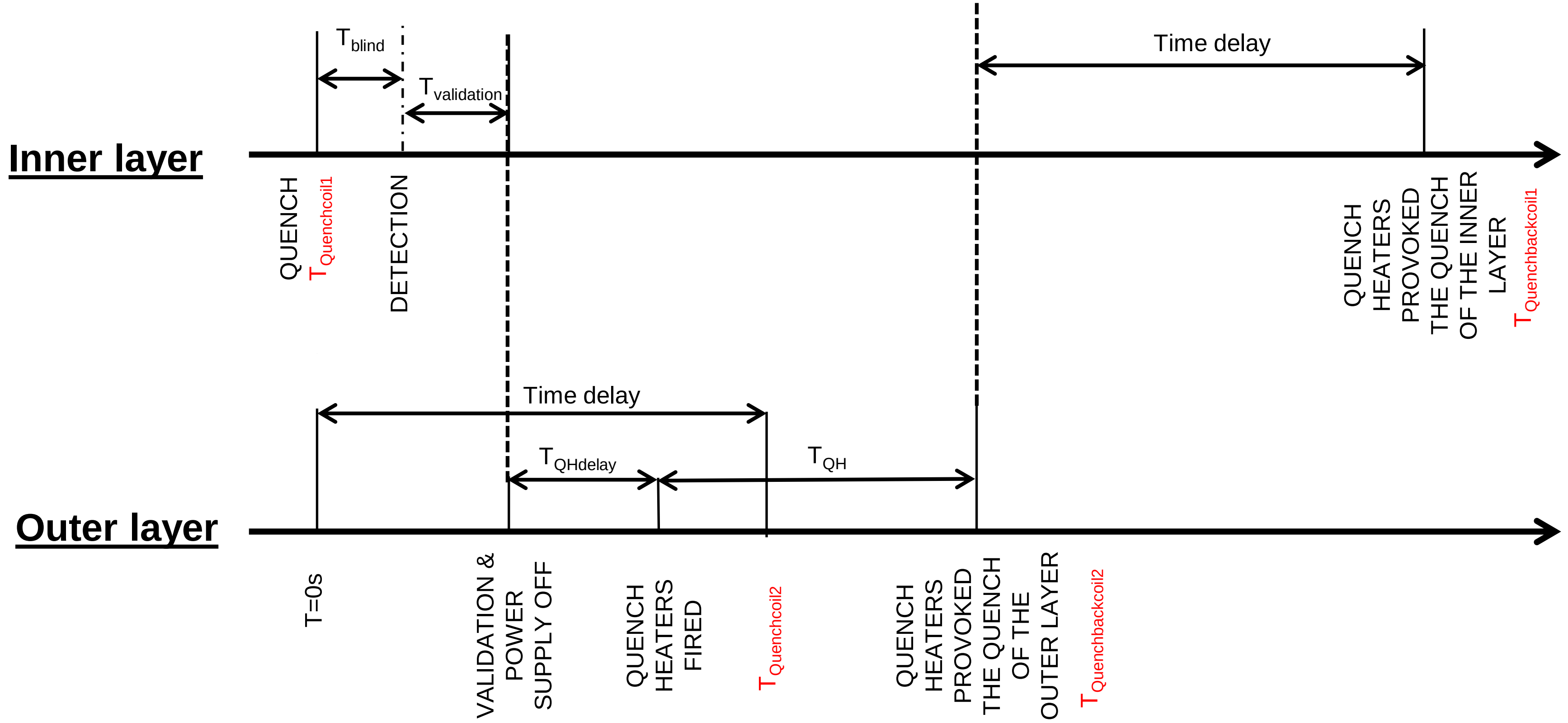
HEATDEF: Definition of the heater geometry and placing in the coil

HEATLO: Heater layout. In case of heater stations, defines the length covered by the heating station (cov) and the distance between heater stations (dist).

Quench protection :

No	String	N/a	N/a	N/a	N/a	N/a	N/a	N/a
1	DETECT	0.1	0.01	0	0	0	0	0
2	HEATDEF	1	0.026035	2.5E-05	0	4	3	3
3	HEATDEF	2	0.012971	2.5E-05	0	4	3	4
4	HEATDEF	3	0.026035	2.5E-05	0	4	3	7
5	HEATDEF	4	0.012971	2.5E-05	0	4	3	8
6	HEATDEF	5	0.026035	2.5E-05	0	4	3	11
7	HEATDEF	6	0.012971	2.5E-05	0	4	3	12
8	HEATDEF	7	0.026035	2.5E-05	0	4	3	15
9	HEATDEF	8	0.012971	2.5E-05	0	4	3	16
10	HEATDEF	9	0.026035	2.5E-05	0	4	3	19
11	HEATDEF	10	0.012971	2.5E-05	0	4	3	20
12	HEATDEF	11	0.026035	2.5E-05	0	4	3	23
13	HEATDEF	12	0.012971	2.5E-05	0	4	3	24
14	HEATDEF	13	0.026035	2.5E-05	0	4	3	27
15	HEATDEF	14	0.012971	2.5E-05	0	4	3	28
16	HEATDEF	15	0.026035	2.5E-05	0	4	3	31
17	HEATDEF	16	0.012971	2.5E-05	0	4	3	32
18	HEATPOW	627358	0.0275	0.006	0	0	5	1 3 5 7 9 11 13 15
19	HEATPOW	1.24603E+06	0.0275	0.006	0	0	5	2 4 6 8 10 12 14 16
20	HEATINS	0.000135	4	4E-05	4	0	5	1-16
21	BLINDTIM	0.006	0	0	0	0	0	0
22	HEATLO	0.13441	0.40307	0	0	0	5	1
23	HEATLO	0.09503	0.44621	0	0	0	5	2

Case 1:The outer layer quenches before the quench heaters provok a quench



Case 2: The outer layer quenches when the quench heaters provok a quench