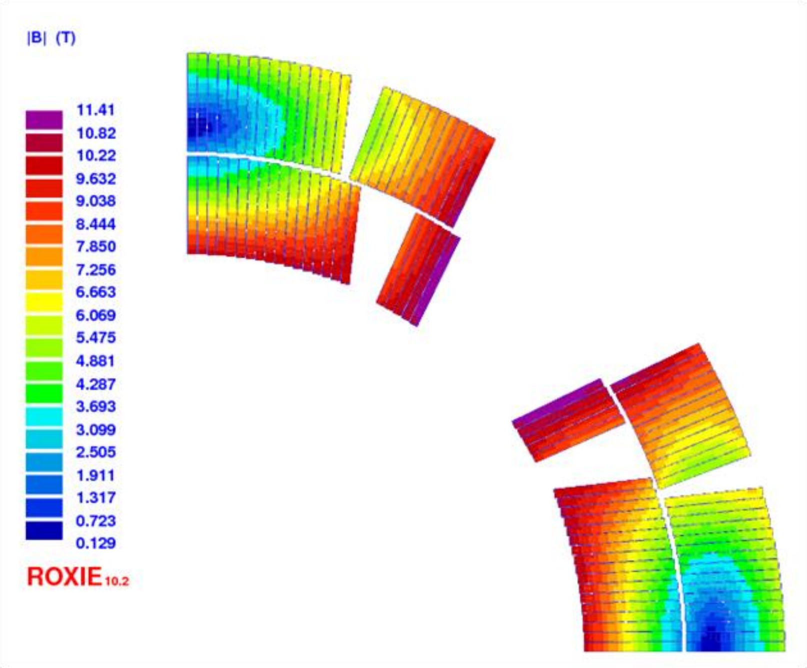
Summary:

- Introduction
- QLASA validation
- Protection heaters
- Assumptions in simulations
- Hot spot temperature
- Peak voltages

1. Introduction

Aperture diameter	150 mm
Gradient	132.6 T/m
Nominal current	16470 A
Magnetic stored energy	1.17 MJ/m
Inductance	8.3 mH/m
Magnetic length Q1/Q3	2 x 4.2 m
Magnetic length Q2a/Q2b	7.15 m
Conductor peak field	11.4 T
Operating temperature	1.9 K
Strand diameter	0.850 mm
Bare cable width	17.86 mm
Bare cable thin/thick edge thickness	1.462/1.588 mm
Insulation thickness	0.145 mm
Number of strands	40
Copper/non-copper ratio	1.2
Copper RRR	100

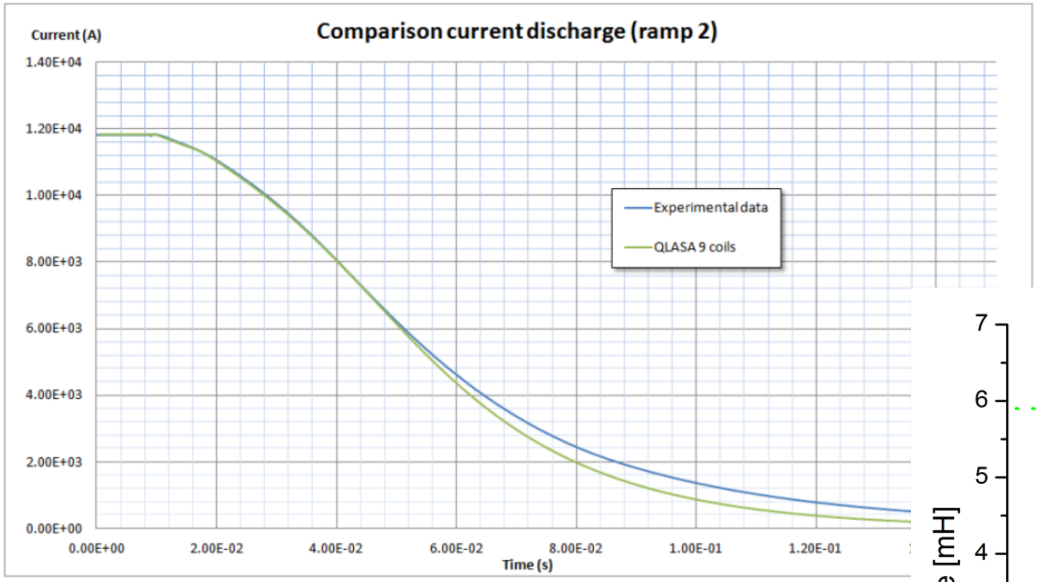


- ➢ High stored energy
- ➢ High peak field

- ➢ <u>Protection challenging!</u>

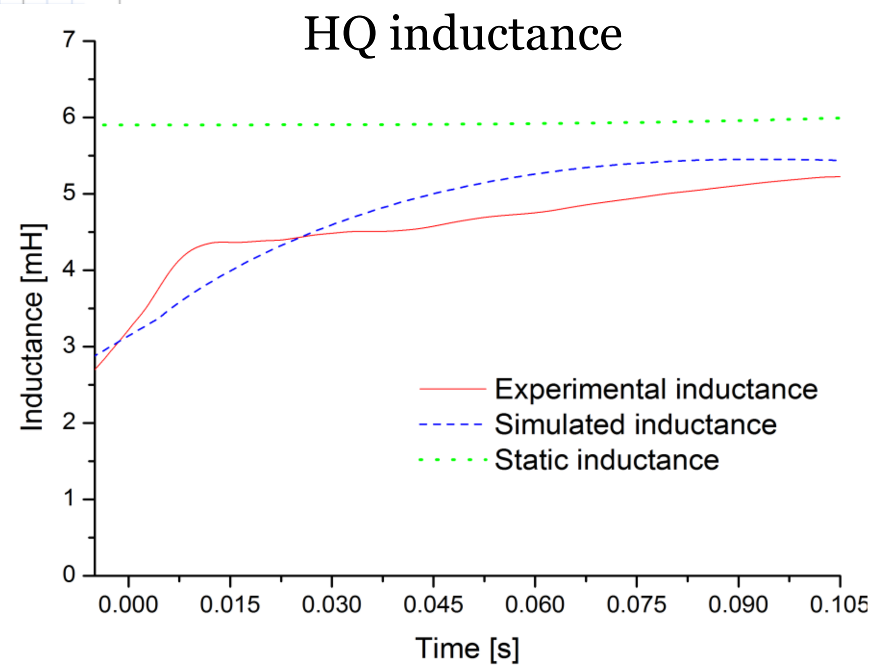
2. QLASA validation

- QLASA is a program for the quench simulation in solenoids.
- It has been experimentally validated with the LARP prototypes test results
- It can predict dynamic effects on the inductance

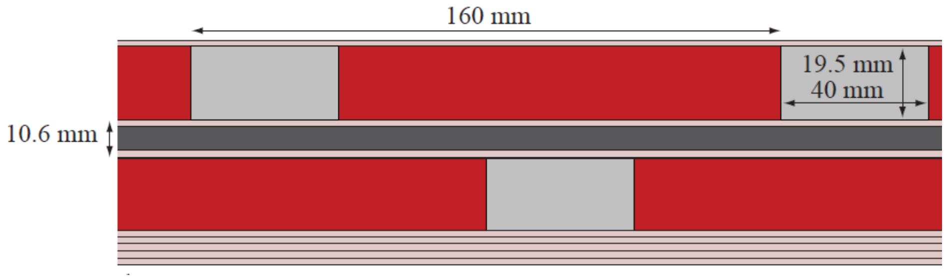


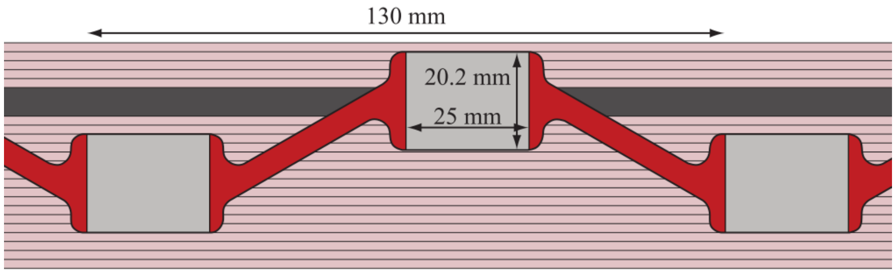
Validation on LQ data

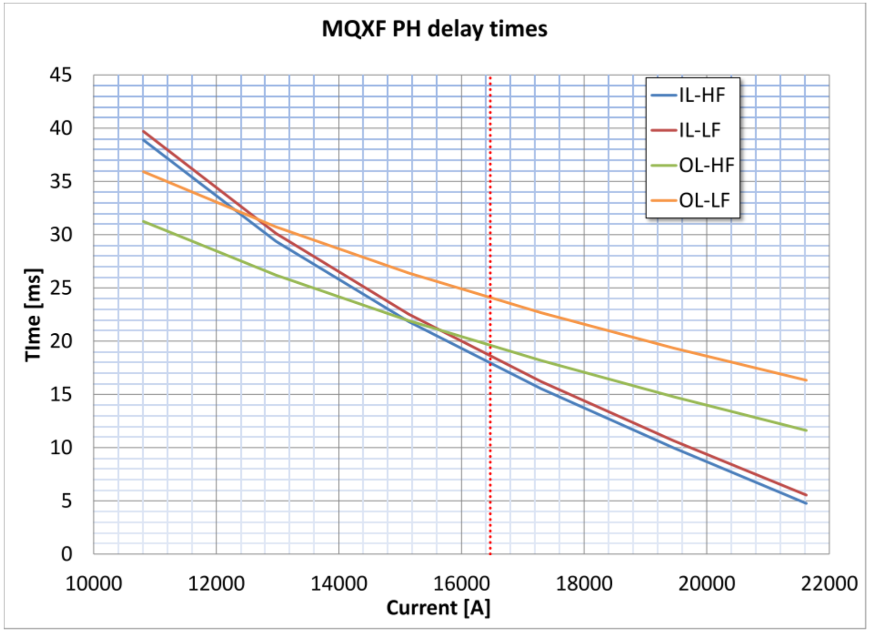
- Right detection time
- Right resistance development simulation



3. Quench heaters design







Quench heaters have been designed for **inner** and **outer** layer

4. Assumptions in simulations

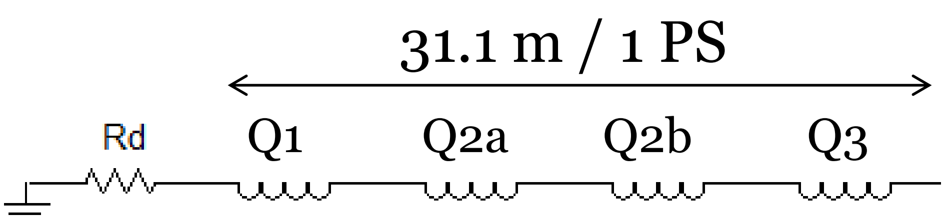
- the initial quench is a point (initial size equal to 0) located in the peak field zone (pole turn);
- the detection time is computed according to the propagation velocities computed by QLASA (~7 ms)
- Heaters-induced quench occurs at a different average time in the high-field and in the low-field blocks of each layer. The heating stations are simulated, but pre-heat from the copper-bridges is not considered;
- heat exchange between layers is neglected;
- dynamic effects on the magnet inductance due to the inter-filament coupling currents are taken into account. These effects have been experimentally observed in the HiLumi experience;
- quench-back is neglected.

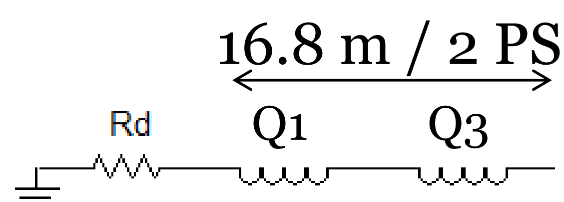
Main protection parameters	
Dump resistor (maximum voltage between ends)	46 mΩ (800 V)
Voltage threshold	100 mV
Validation time	10 ms
Switch opening delay time	5 ms

5. Hot spot temperature

31.1 m (**1 PS**)	Hot spot temperature [K]	MIITs [MA²s]
Nominal	261	28.3
Only outer layer PH	346	33.6
Failure HF OL-PH (20 % less resistance)	299	30.7
16.8 m (**2 PS**)	Hot spot temperature [K]	MIITs [MA²s]
Nominal	257	28.1
Only outer layer PH	341	33.3
Failure HF OL-PH (20 % less resistance)	299	30.7

- Protection and redundancy are **ensured** only with IL heaters
- The two scenarios are very similar on the hot spot temperature point of view





6. Peak voltages

Voltages simulations made using **ROXIE**

2 PS Scenario

	TG [V]	TG (sc) [V]	T-T [V]	L-L [V]	M-M [V]
Nominal	638	838	46	454	148
Coil 1 IL fail	662	872	49	522	356
Coil 3 IL fail	663	873	50	527	482
Coil 1 OL-HF fail 1 side	608	813	48	487	159
Coil 3 OL-HF fail 1 side	608	813	47	490	275
Coil 1 OL-LF fail 1 side	597	802	47	472	147
Coil 3 OL-LF fail 1 side	582	787	47	472	176
Coil 1 fail	1862	2092	62	1734	1701
Coil 3 fail	1463	1693	63	1747	1832
OL-HF fail	738	958	66	239	148
OL-QH only	385	635	60	516	146

1 PS Scenario

	TG [V]	TG (sc) [V]	T-T [V]	L-L [V]	M-M [V]
Nominal	659	859	44	421	313
Coil 1 IL fail	754	964	47	486	342
Coil 3 IL fail	755	965	47	490	494
Coil 1 OL-HF fail 1 side	704	909	45	452	314
Coil 3 OL-HF fail 1 side	704	909	45	455	314
Coil 1 OL-LF fail 1 side	680	885	45	439	312
Coil 3 OL-LF fail 1 side	681	886	45	439	313
Coil 1 fail	1810	2020	59	1674	1513
Coil 3 fail	1335	1565	59	1686	1769
OL-HF fail	833	1053	62	223	312
OL-QH only	494	744	56	478	311

- Peak voltage to ground is < 1kV in the most realistic failure scenarios
    - It is <2 kV in the 3 less realistic cases
- The two scenarios are very similar also on the peak voltages point of view
    - Only midplane-midplane voltage doubles in the 1 PS scenario, in some cases

7. Assumptions for voltage to ground

- Roxie allows simulating only one magnet, and not the whole chain
  - This affects the voltage to ground computation

- The computation has been performed as following:

  1. Simulation of only one magnet, with a dump resistor dimensioned in order to obtain a voltage drop between the ends the same as the voltage across the magnet inserted in the chain.
     - It is assumed that all the protection heaters in the chain work well. This causes an error on the voltage to ground evaluation, on the order of the resistance difference.

  2. The input voltage of the magnet inserted in the chain is added to the obtained voltage to ground.
     - In this case too it is assumed that for the calculation of the input voltage all the protection heaters in the chain work well. This causes another error on the voltage to ground on the order of the resistance difference.

- In most of the failure scenarios, resistance difference is few %, therefore the voltages to ground are sufficiently reliable.