

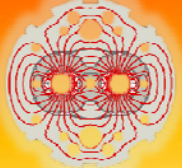
LHC Status Report

Lyn Evans



96th LHCC meeting, CERN 19th November 2008

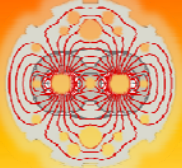




Situation on 10th September



- **7 out of 8 sectors fully commissioned for 5 TeV operation and 1 sector (3-4) commissioned up to 4 TeV.**



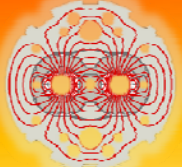
Interim Summary Report on the analysis of the 19th September 2008 incident at the LHC



Incident during powering

The magnet circuits in the seven other sectors of the LHC had been fully commissioned to their nominal currents (corresponding to beam energy of 5.5 TeV) before the first beam injection on 10 September 2008. For the main dipole circuit, this meant a powering in stages up to a current of 9.3 kA. The dipole circuit of sector 3-4, the last one to be commissioned, had only been powered to 7 kA prior to 10 September 2008. After the successful injection and circulation of the first beams at 0.45 TeV, commissioning of this sector up to the 5.5 TeV beam energy level was resumed as planned and according to established procedures.

On 19 September 2008 morning, the current was being ramped up to 9.3 kA in the main dipole circuit at the nominal rate of 10 A/s, when at a value of 8.7 kA, a resistive zone developed in the electrical bus in the region between dipole C24 and quadrupole Q24. The first evidence was the appearance of a voltage of 300 mV detected in the circuit above the noise level: the time was 11:18:36 CEST. No resistive voltage appeared on the dipoles of the circuit, individually equipped with quench detectors with a detection sensitivity of 100 mV each, so that the quench of any magnet can be excluded as initial event. After 0.39 s, the resistive voltage had grown to 1 V and the power converter, unable to maintain the current ramp, tripped off at 0.46 s (slow discharge mode). The current started to decrease in the circuit and at 0.86 s, the energy discharge switch opened, inserting dump resistors in the circuit to produce a fast power abort. In this sequence of events, the quench detection, power converter and energy discharge systems behaved as expected.



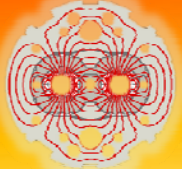
Interim Summary Report on the analysis of the 19th September 2008 incident at the LHC



Sequence of events and consequences

Within the first second, an electrical arc developed and punctured the helium enclosure, leading to release of helium into the insulation vacuum of the cryostat.

The spring-loaded relief discs on the vacuum enclosure opened when the pressure exceeded atmospheric, thus relieving the helium to the tunnel. They were however unable to contain the pressure rise below the nominal 0.15 MPa absolute in the vacuum enclosures of subsector 23-25, thus resulting in large pressure forces acting on the vacuum barriers separating neighboring subsectors, which most probably damaged them. These forces displaced dipoles in the subsectors affected from their cold internal supports, and knocked the Short Straight Section cryostats housing the quadrupoles and vacuum barriers from their external support jacks at positions Q23, Q27 and Q31, in some locations breaking their anchors in the concrete floor of the tunnel. The displacement of the Short Straight Section cryostats also damaged the “jumper” connections to the cryogenic distribution line, but without rupture of the transverse vacuum barriers equipping these jumper connections, so that the insulation vacuum in the cryogenic line did not degrade.

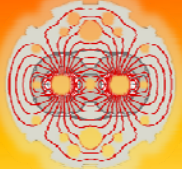


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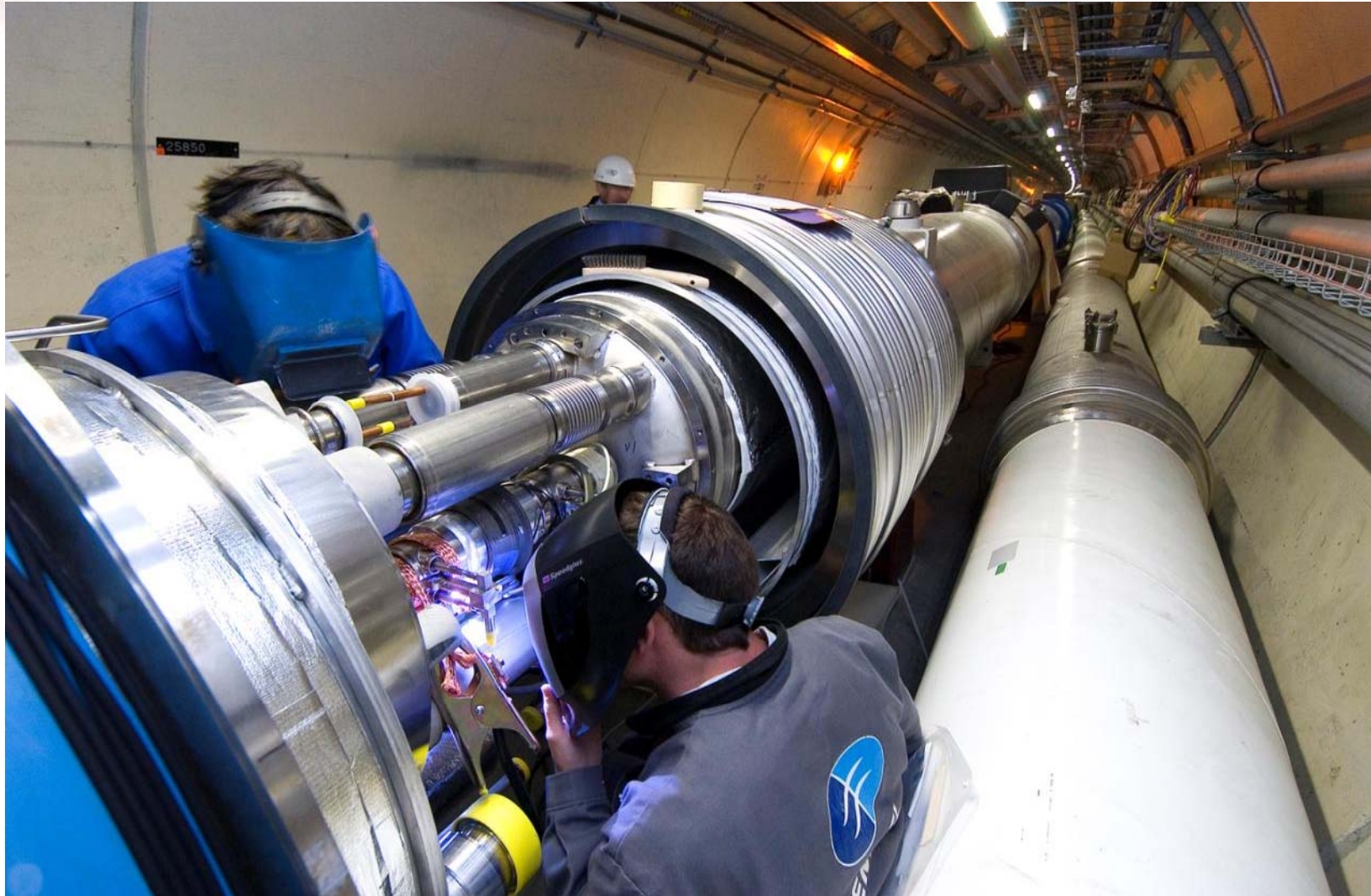


Inspection and diagnostics

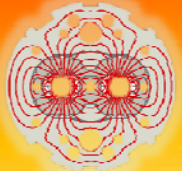
The number of magnets to be repaired is at maximum of 5 quadrupoles (in Short Straight Sections) and 24 dipoles, but it is likely that more will have to be removed from the tunnel for cleaning and exchange of multilayer insulation. The exact numbers will be known once the ongoing inspections are completed. Spare magnets and spare components appear to be available in adequate types and sufficient quantities for allowing replacement of the damaged ones during the forthcoming shutdown. The extent of contamination to the beam vacuum pipes is not yet fully mapped, but known to be limited; in situ cleaning is being considered to keep to a minimum the number of magnets to be removed. The plan for removing/reinstallation, transport and repair of magnets in sector 3-4 is being established and integrated with the maintenance and consolidation work to be performed during the winter shutdown. The corresponding manpower resources have been secured.



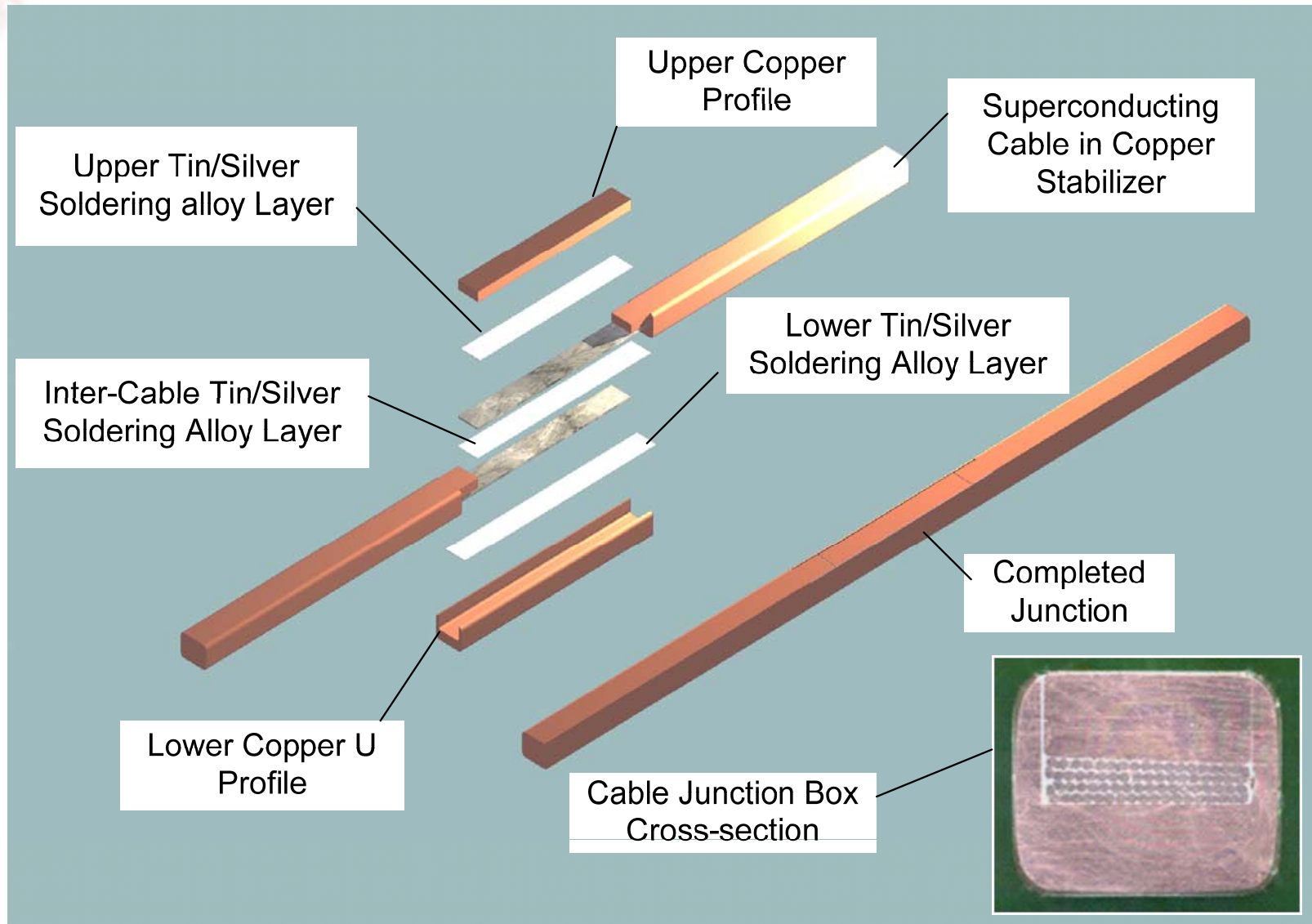
19th september incident

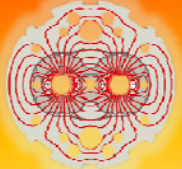


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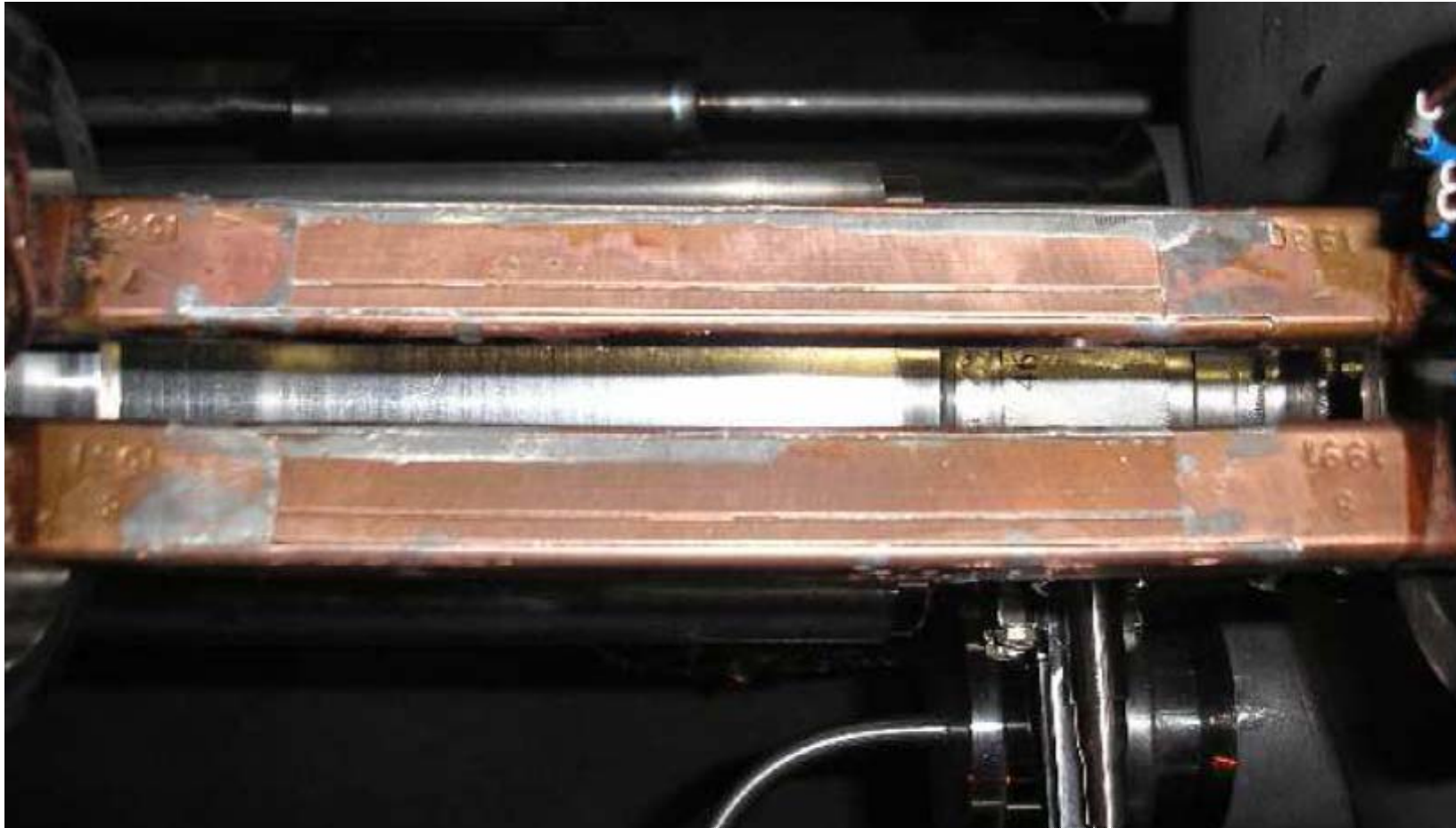


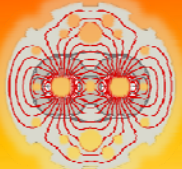
Busbar splice





Busbar splice

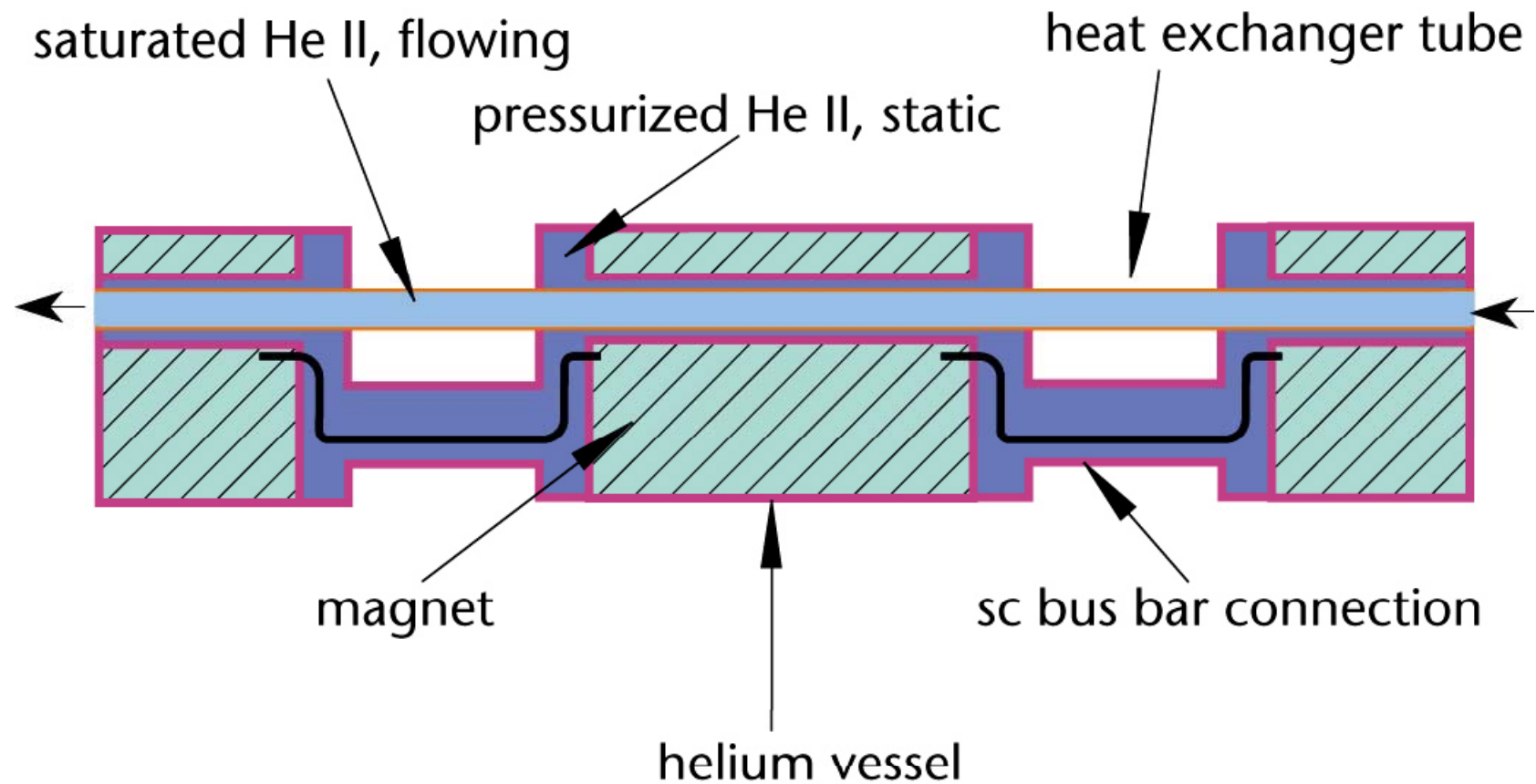


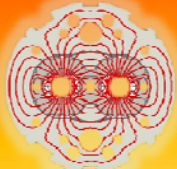


Magnet cooling scheme



LHC magnet string cooling scheme





Cryostat and cold masses longitudinal displacements

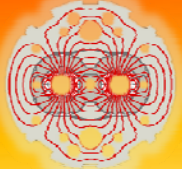


Displacements status in sector 3-4 (From Q17R3 to Q33R3) : P3 side

Based on measurements by TS-SU, TS-MME and AT-MCS

	Q17	A18	B18	C18	Q18	A19	B19	C19	Q19	A20	B20	C20	Q20	A21	B21	C21	Q21
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	?	?	?	?	?	?	?	?	?	?	<5	<5	<5	<5	<5	<5	<5
	Q21	A22	B22	C22	Q22	A23	B23	C23	Q23	A24	B24	C24	Q24	A25	B25	C25	Q25
Cryostat	<2	<2	<2	<2	-7	<2	<2	<2	-187	<2	<2	<2	<2	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	-25	-67	-102	-144	<5	-190	-130	-60	<5	<5	<5	<5	<5
	Q25	A26	B26	C26	Q26	A27	B27	C27	Q27	A28	B28	C28	Q28	A29	B29	C29	Q29
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	474	-4	<2	<2	11	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	57	114	150?	-45	230	189	144	92?	50	35	<5	<5
	Q29	A30	B30	C30	Q30	A31	B31	C31	Q31	A32	B32	C32	Q32	A33	B33	C33	Q33
Cryostat	<2	<2	<2	<2	<2	<2	<2	<2	188	<2	<2	<2	5	<2	<2	<2	<2
Cold mass	<5	<5	<5	<5	<5	19	77	148	<5	140	105	62	18	<5	<5	<5	?

>0 [mm]
 ? Not measured yet
 Cold mass displacement
 Cryostat displacement
 SSS with vacuum barrier
 Electrical interruptions
 Dipole in short circuit
 Electrically damaged IC
 Buffer zones
 Disconnected

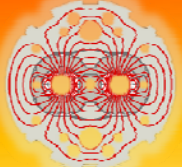


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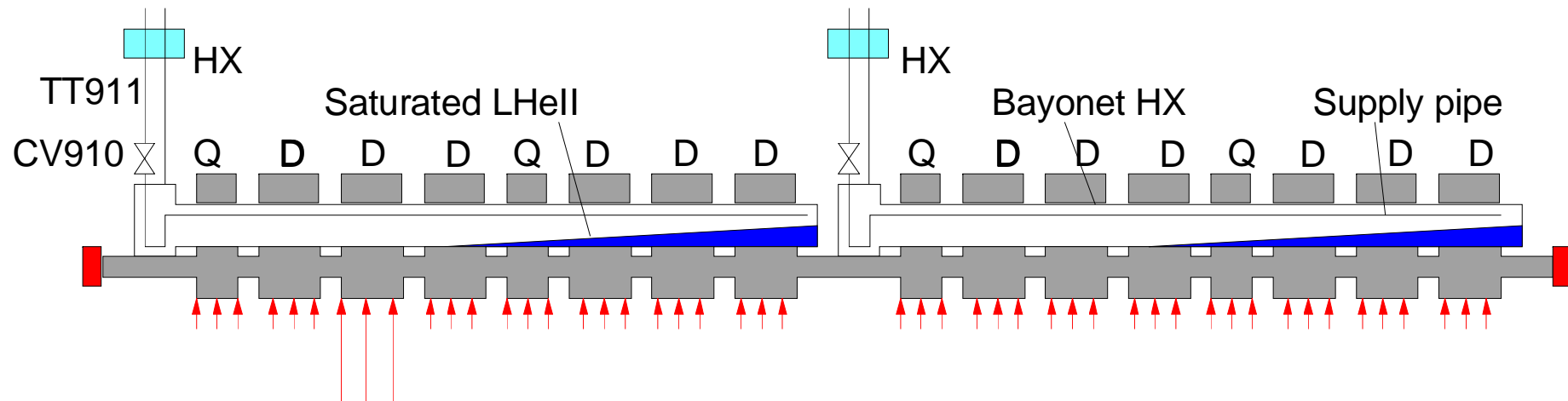


Preliminary recommendations

Recommendations made by the task force aim at two different goals, namely to prevent any other occurrence of this type of initial event, and to mitigate its consequences should it however reproduce accidentally. Possible precursors of the incident in sector 3-4 are being scrutinized in the electrical and calorimetric data recorded on all sectors, in order to spot any other problem of the same nature in the machine. An improvement of the quench detection system is under way, to generate both early warnings and interlocks, and to encompass magnets, bus bars and interconnects. The relief devices on the cryostat vacuum vessels will be increased in discharge capacity and in number, so as to contain a possible pressure rise to below 0.15 MPa absolute even in presence of an electrical arc. The external anchoring of the cryostats at the locations of the vacuum barriers will be reinforced to guarantee mechanical stability.

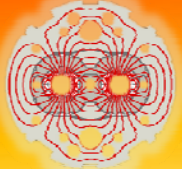


Sub-sector magnet cooling scheme

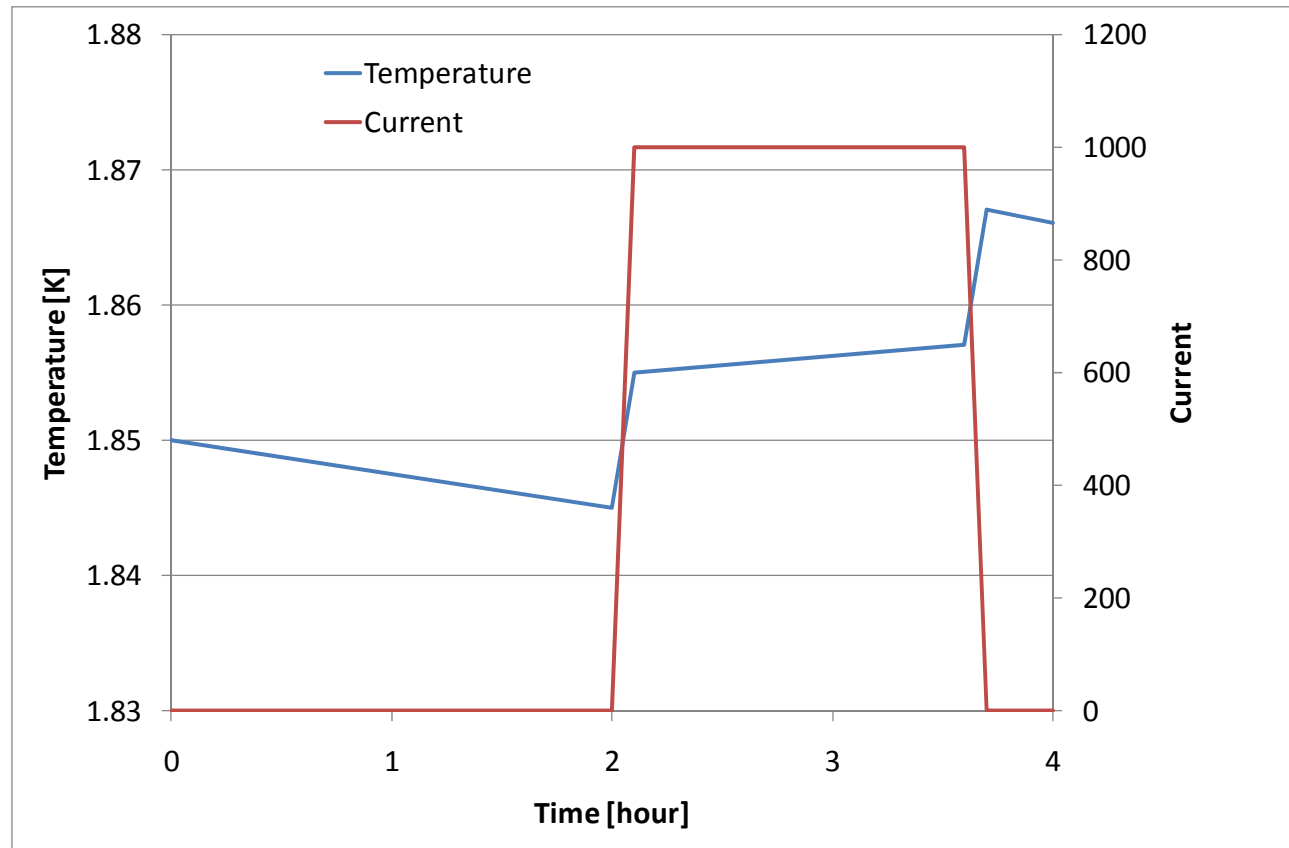


Principle

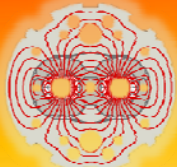
- Blocking of the JT valve at a value to extract the static heat inleaks before the powering
- Then, the temperature drift is due to electrical resistive heating dissipated during the powering



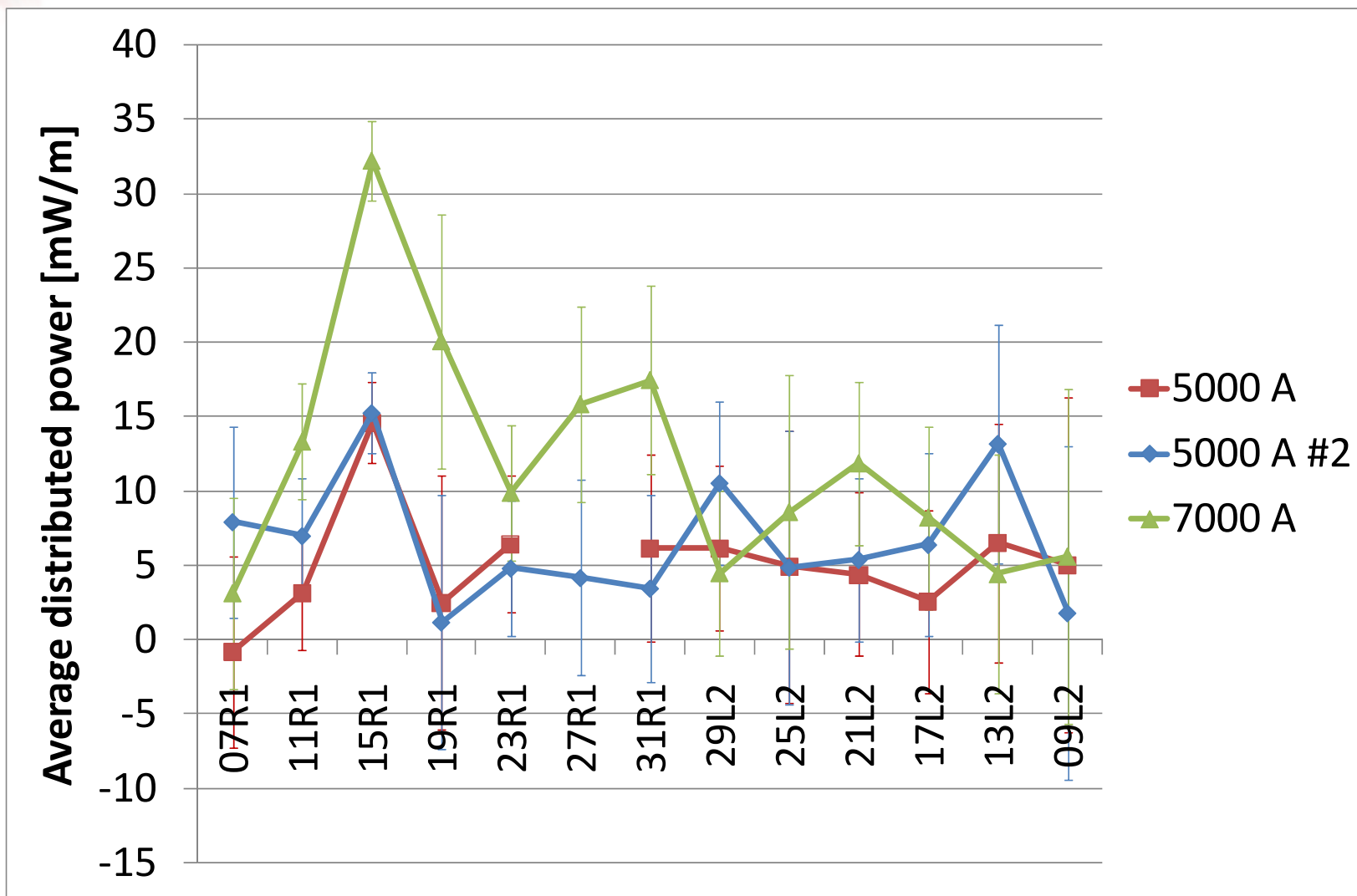
Methodology

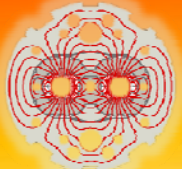


1. Assessment of the baseline slope (remaining CV opening mismatch w/r to static HL)
2. Assessment of the temperature increase during powering plateau
3. Assessment of the internal energy variation (J/kg)
4. Assessment of the deposited energy assuming a mass of 26 l/m of LHell

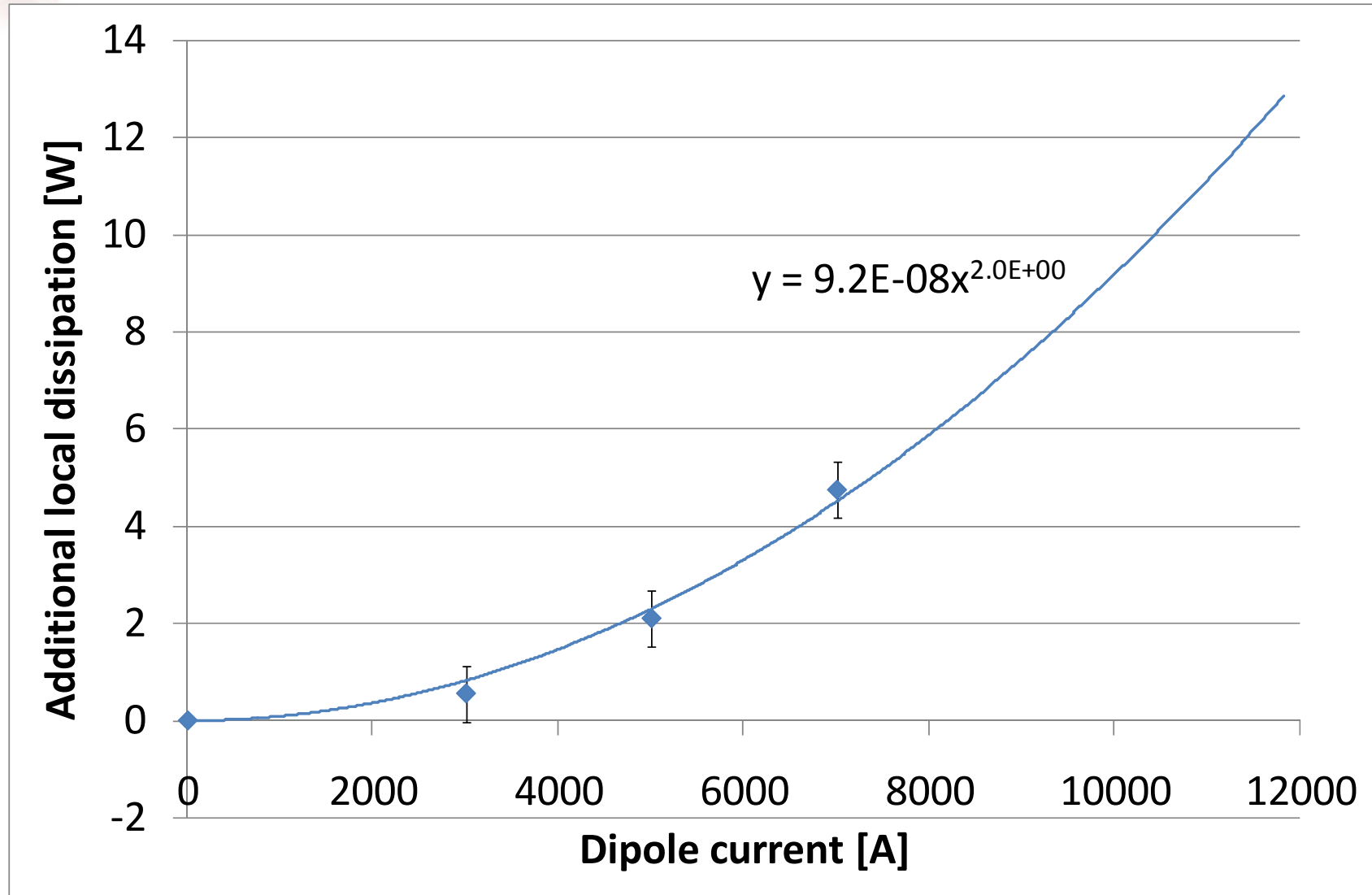


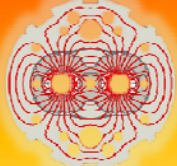
Distributed power dissipated during the current plateaus





Additional local dissipation in 15R1

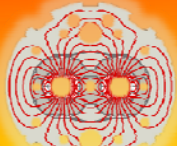




Conclusion on calorimetry



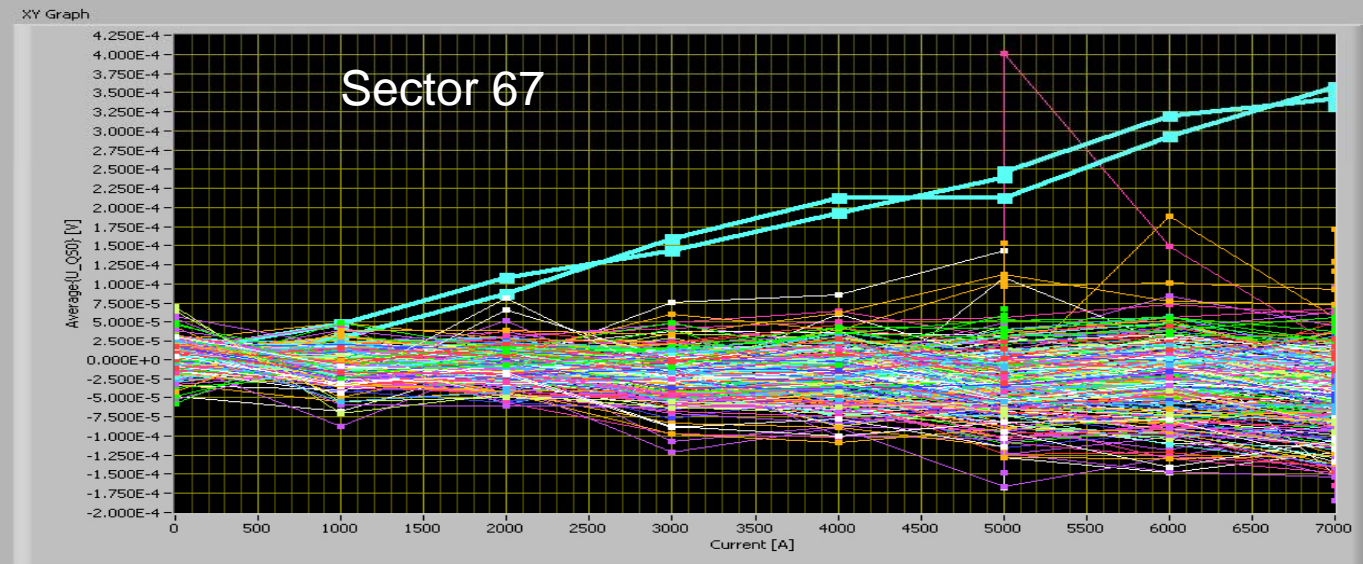
- **Calorimetric measurement during the repowering of sector 1-2 has confirmed an additional resistive heating in the sub-sector 15R1**
 - The corresponding electrical resistance is about 90 nW
 - At nominal current the additional heat dissipation will be about 13 W (not an issue for cryogenic system)
- **The present calorimetry measurement is impressively good thank to:**
 - the excellent quality of the thermometry.
 - The excellent stability of the cryoplants and overall system.
 - The cooling with pressurized superfluid helium.
- **Room for improvement is existing, especially for the stability of the incoming cooling flow:**
 - Operate with minimum valve opening (around 20 %) by suppression of all the electrical heating added in the cold-masses to generate additional flow for the cold compressors (generation of this flow in the QRL return module).
 - Reduction of the valve-positioner dead-band.
 - Diagnose and suppress the instabilities observed in the sub-cooled temperature (upstream the JT valve).
 - The accuracy of a calorimetric measurement could then become less than 1 W per sub-sector.
- **Due to the high thermal conductivity of Helium, the calorimetry will not allow to locate the position of a local dissipation below 15 W within a sub-sector.**



Results from provoked massive Post-Mortem of all dipoles in Sectors 67 & 78

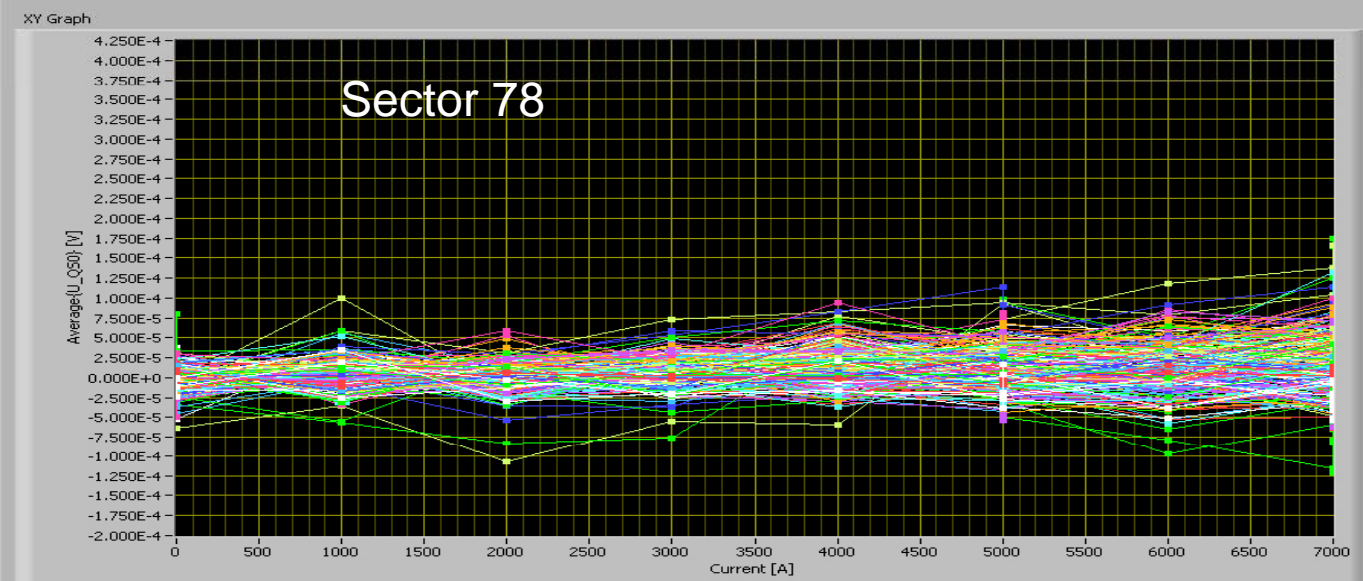


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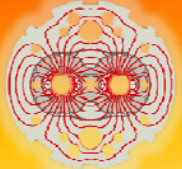
- A32R6
- B32R6
- C32R6
- A33R6
- B33R6
- C33R6
- A34R6
- B34R6
- C34R6
- C34L7
- B34L7
- A34L7
- C33L7
- B33L7
- A33L7
- C32L7
- B32L7
- A32L7
- C31L7
- B31L7
- A31L7
- C30L7
- B30L7

sortedSlopes
4.9287E-8
delta slope
2.72892E-9
R-square
0.987653
B32R6
2.22315E-8
delta slope
7.90081E-9
R-square
0.660038
B24R6
2.04074E-8
delta slope
4.11774E-9
R-square
0.857608
A11R6
1.95E-8
delta slope
2.89324E-9
R-square
0.91762
C19R6



- A32R7
- B32R7
- C32R7
- A33R7
- B33R7
- C33R7
- A34R7
- B34R7
- C34R7
- C34L8
- B34L8
- A34L8
- C33L8
- B33L8
- A33L8
- C32L8
- B32L8
- A32L8
- C31L8
- B31L8
- A31L8
- C30L8
- B30L8

sortedSlopes
1.46082E-8
delta slope
4.92032E-9
R-square
0.610054
A29L8
1.31595E-8
delta slope
4.00195E-9
R-square
0.657427
C34L8
1.29757E-8
delta slope
5.67017E-9
R-square
0.48172
A23L8
1.07342E-8
delta slope
4.07705E-9
R-square
0.551627
A12R7



Conclusions



- The repair is now well underway with approximately 100 people from CERN and contractors working on it.
- All damaged magnets will be removed before the end of the year and about 20 new dipoles will be installed.
- Powerful techniques have been developed to spot resistive splices at low current.
- Steps are being taken to improve the busbar protection and to avoid collateral damage in the unlikely event of another incident of this kind.