LHC Machine Status

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2009 Meeting of the Division of Particles and Fields of the American Physical Society, Detroit on 27 July 2009

Paper presented at XXVII Int. Conf. on High Energy Physics: Session Pa-24
Glasgow, UK, 20–27 July 1994

The LHC Project Status and Plans

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Abstract

The Large Hadron Collider (LHC) project is based on a pair of superconducting storage rings to be installed in the LEP tunnel. The primary objective of the machine is to provide proton-proton collisions with a centre of mass energy of 14 TeV and an unprecedented luminosity of 10^{34} cm^{-2} s^{-1}. It will also provide colliding beams of Pb ions and a number of proposals are under study for B-physics experiments, either with colliding beams or in fixed-target mode. In a second phase, e-p collisions could be provided if desired by colliding the proton beam in one of the rings with LEP. The most critical elements of the LHC are the superconducting magnet system operating at a bending field of 8.65 Tesla and its associated cryogenic system. In order to reach this high field, the magnets must be cooled to below 2 degrees Kelvin over more than 24 km of its circumference. In addition, space limitations in the tunnel as well as cost considerations dictate a novel two-in-one magnet design where the two rings are incorporated into the same cryostat. An overview of the project status is given and the main technological and accelerator physics problems are discussed.

1. Introduction

The CERN Large Hadron Collider will provide proton-proton collisions with a centre of mass energy up to 14 TeV with a nominal luminosity of 10^{34} cm^{-2} s^{-1} and heavy ion (Pb-Pb) collisions with a luminosity of up to 10^{27} cm^{-2} s^{-1}. The reference design of the LHC has been presented at several conferences and two design reports exist [1, 2, and 3]. The main parameters of the machine for proton-proton operation are given in Table 1.

The basic layout of the LHC mirrors that of LEP, with eight long straight sections available for experimental detectors or utilities (Figure 1). The present experimental programme envisages two high luminosity proton-proton experiments (ATLAS and CMS), one heavy ion experiment (ALICE) and a possible B-physics initiative to be chosen from a number of proposals. Two major utilities, the beam cleaning and dump insertions also require long straight sections. The existing LEP experimental caverns at the even numbered points will be modified and reused as much as possible but the size and shape of the major proton-proton detectors, in particular ATLAS makes it economically sensible to open up a new experimental area at Point 1 of the machine.

Table 1. LHC main parameters

Energy	(TeV)	7.0
Dipole field	(T)	8.65
Luminosity	(cm^{-2} s^{-1})	10^{34}
Beam-beam parameter		0.0032
Injection energy	(GeV)	450
Circulating current/beam	(A)	0.53
Bunch spacing	(ns)	25
Particles per bunch		$1x10^{11}$
Stored beam energy	(MJ)	332
Normalized transverse emittance	(μm)	3.75
R.m.s. bunch length	(m)	0.075
Beta values at I.P.	(m)	0.5
Crossing angle	(μrad)	200
Beam lifetime	(h)	22
Luminosity lifetime	(h)	10
Energy loss per turn	(keV)	6.9
Critical photon energy	(eV)	45.6
Total radiated power per beam	(kW)	3.7

LHC layout, July 94

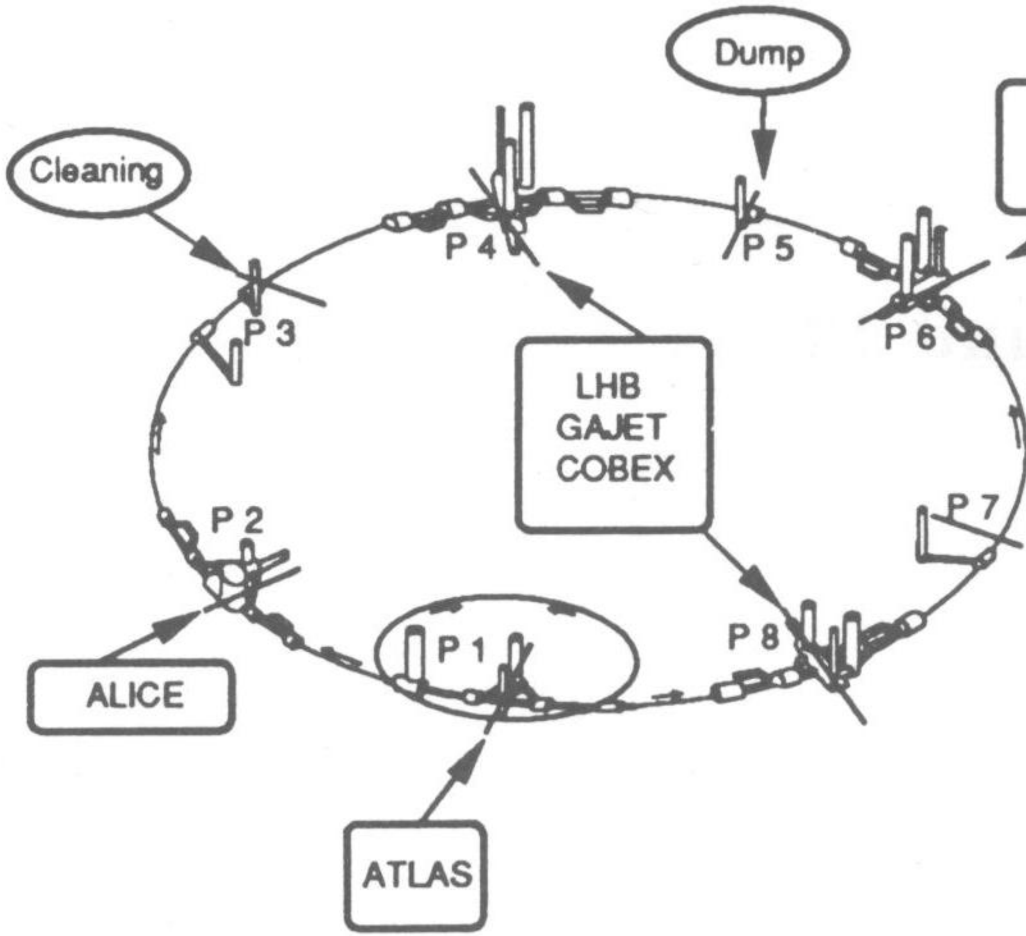
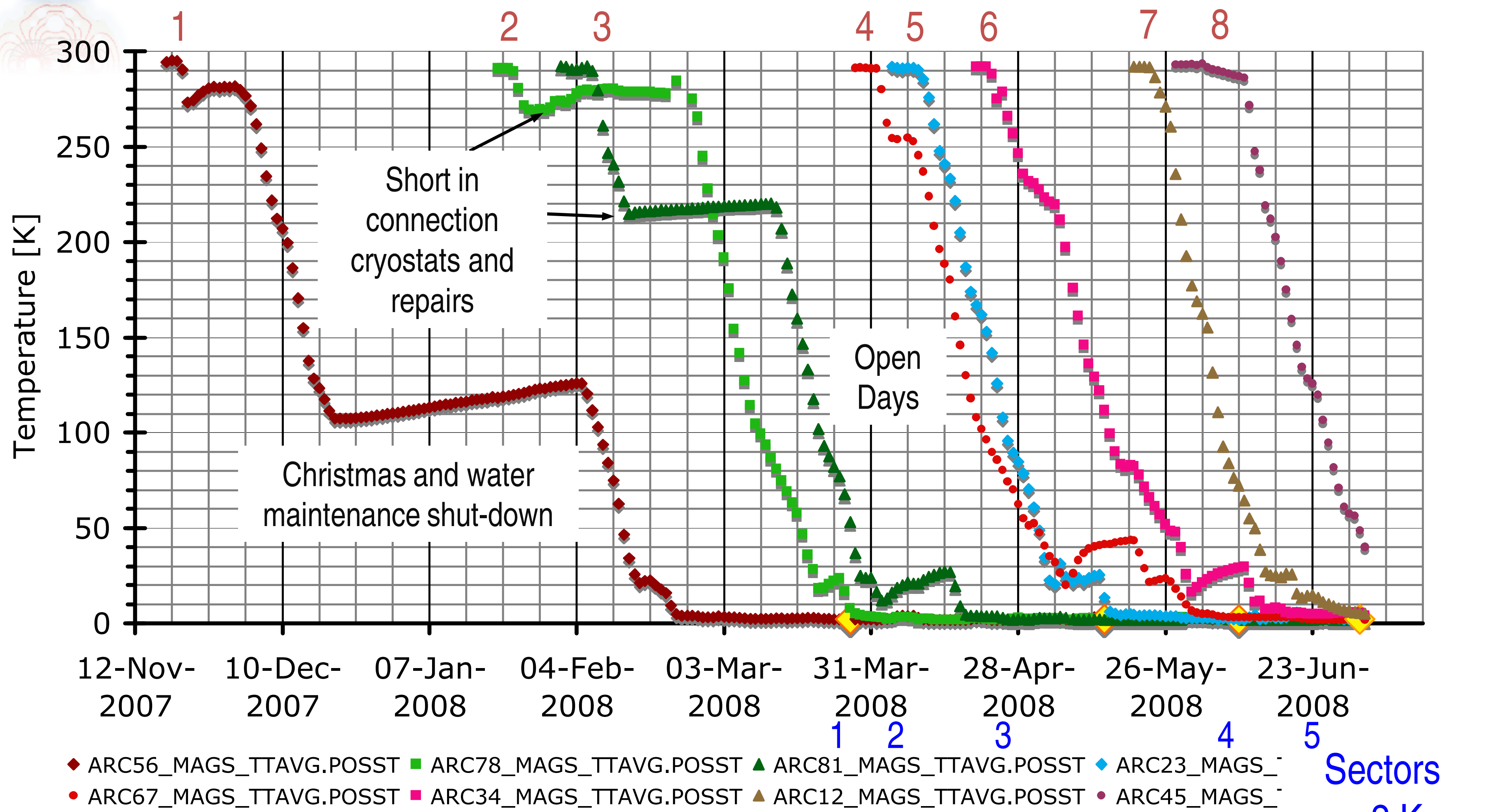


Figure 1. Layout of experimental areas.

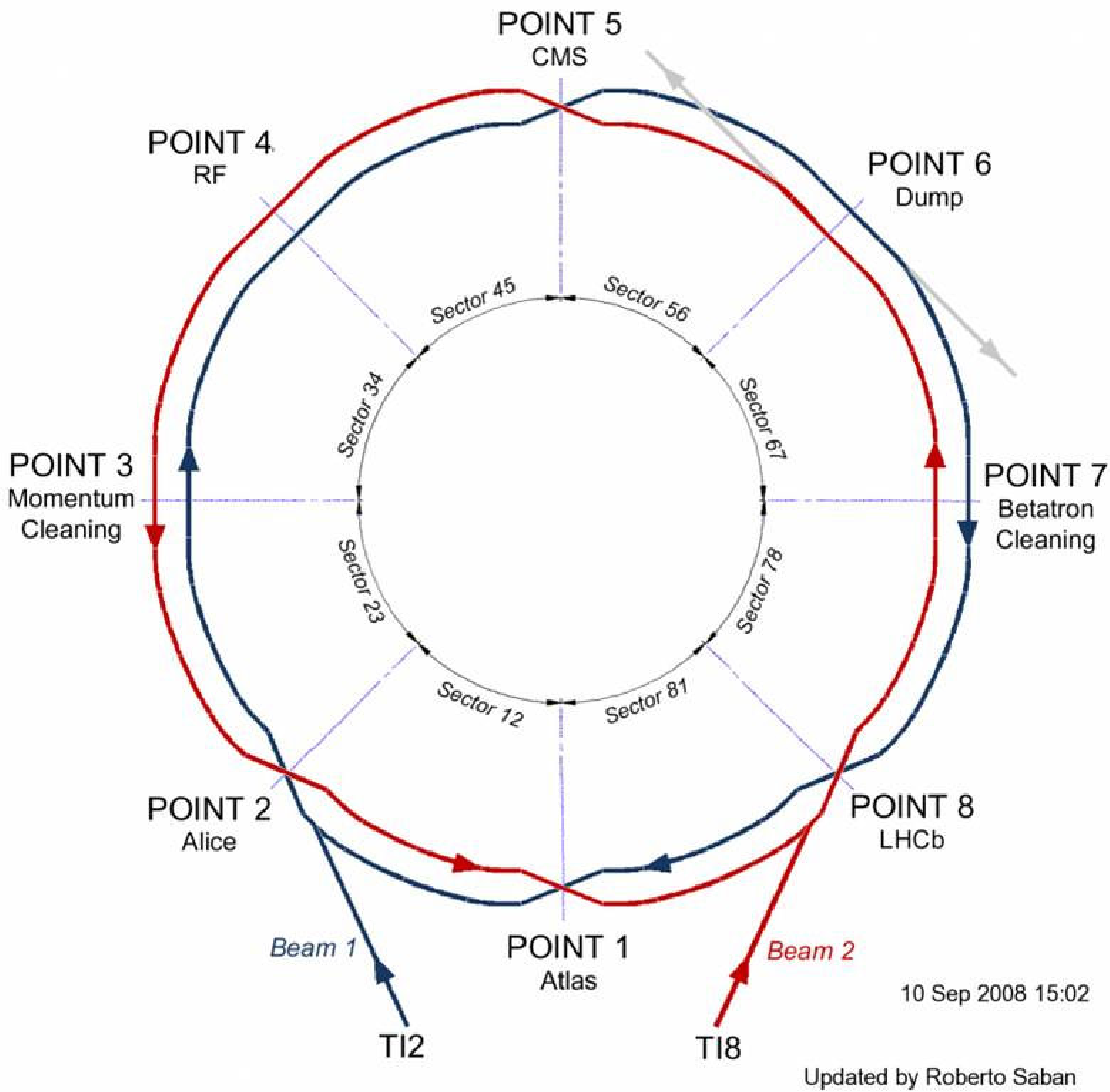
Cooldown of LHC sector



Cooling sectors + Cryo tuning + Powering activities

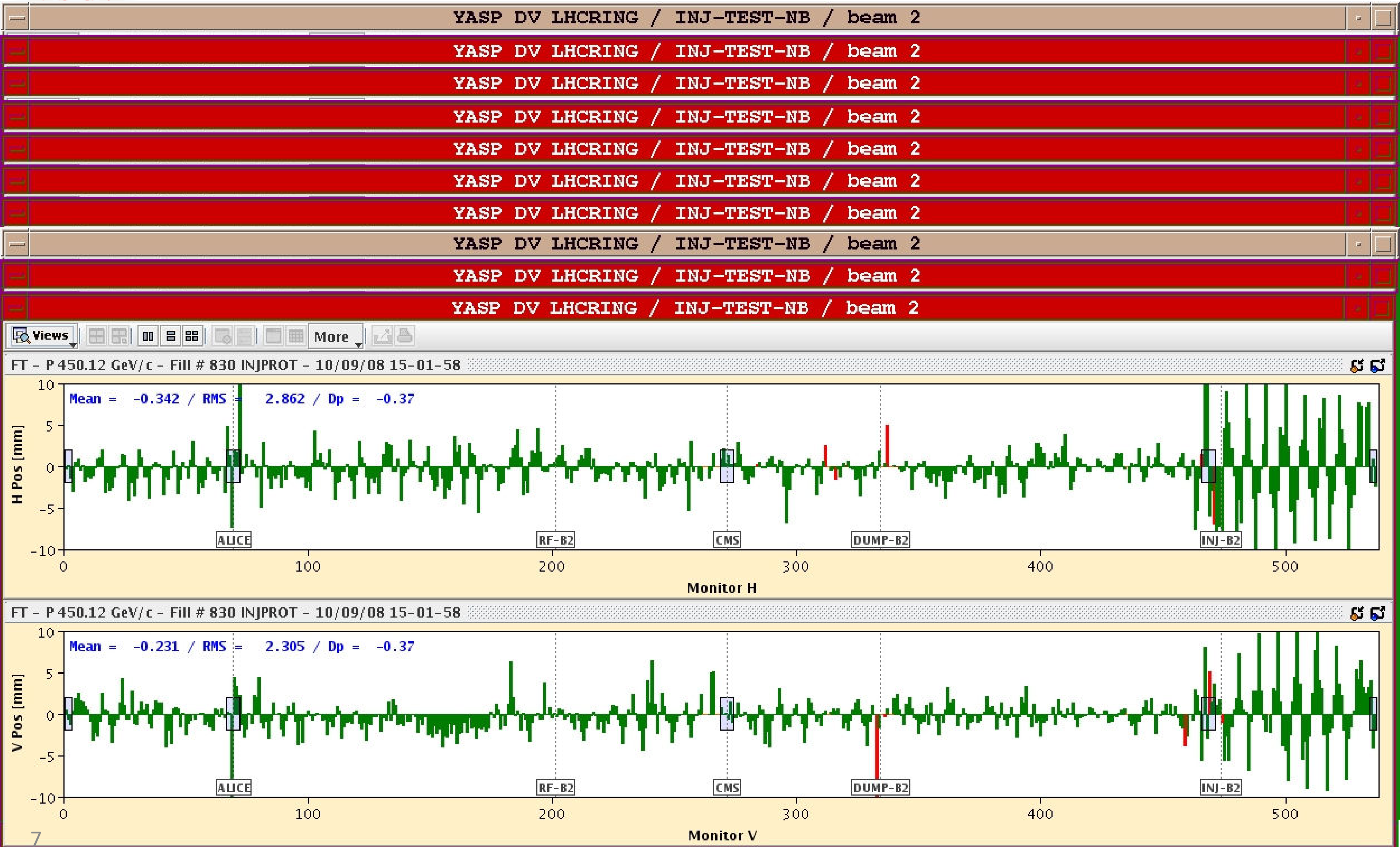
Situation on 10th September

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

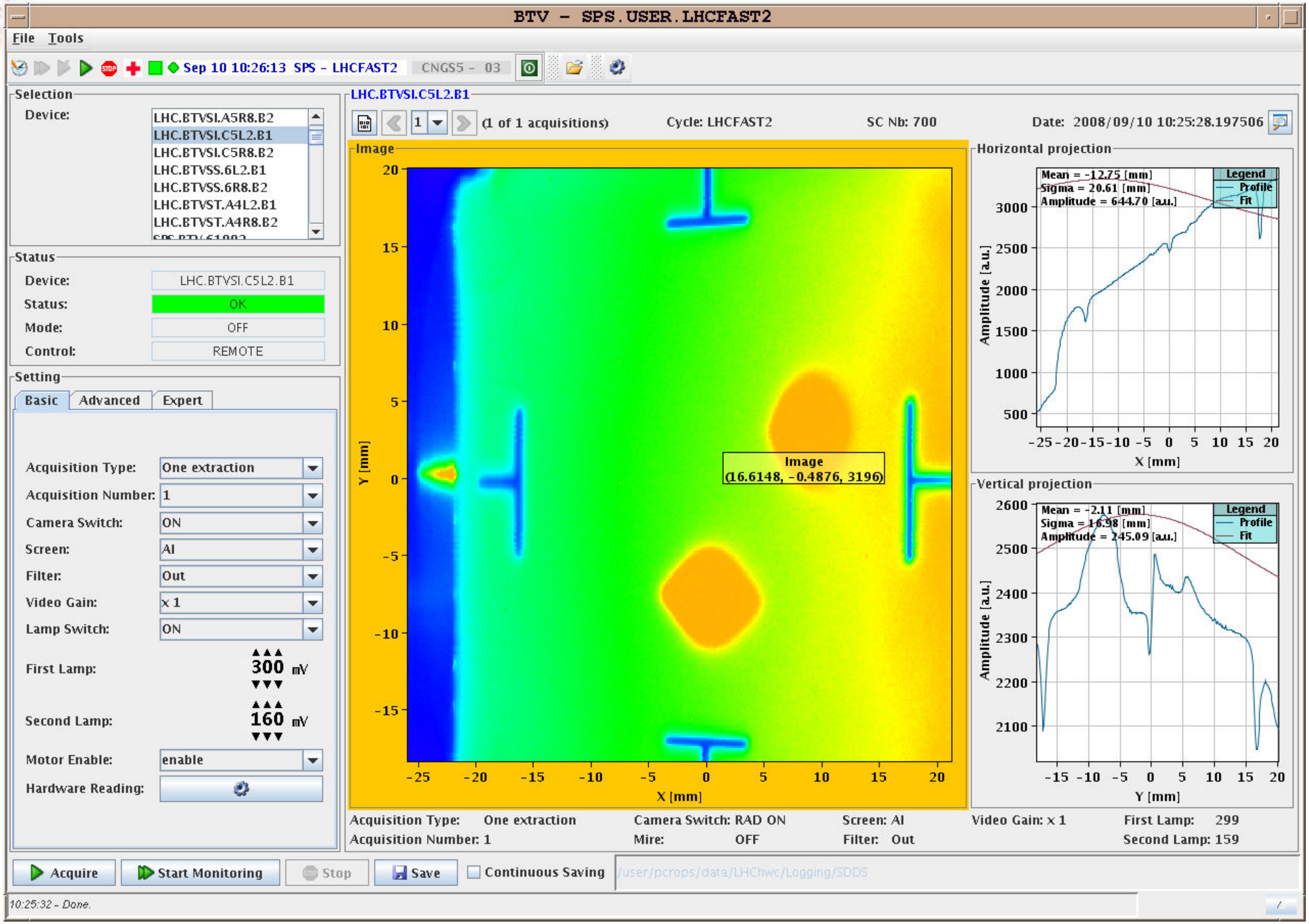


POINT 5
CMS
POINT 4
RF
POINT 6
Dump
Sector 45
Sector 56
Sector 34
Sector 67
POINT 3
Momentum
Cleaning
POINT 7
Betatron
Cleaning
Sector 23
Sector 78
Sector 12
Sector 81
POINT 2
Alice
POINT 8
LHCb
Beam 1
POINT 1
Atlas
Beam 2
10 Sep 2008 15:02
TI2
TI8
Updated by Roberto Saban

Beam 2 first beam – D-day

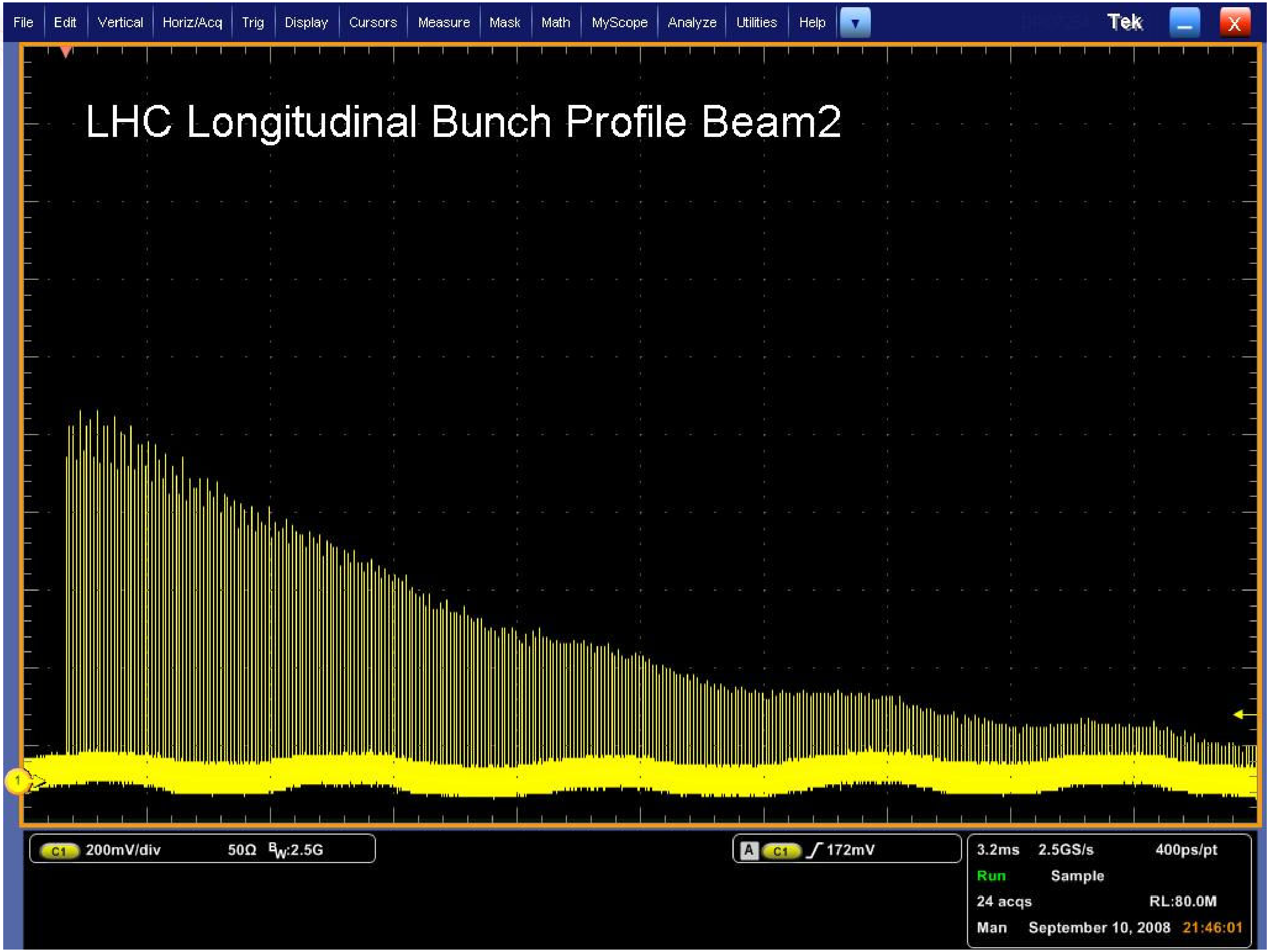


Beam on turns 1 and 2



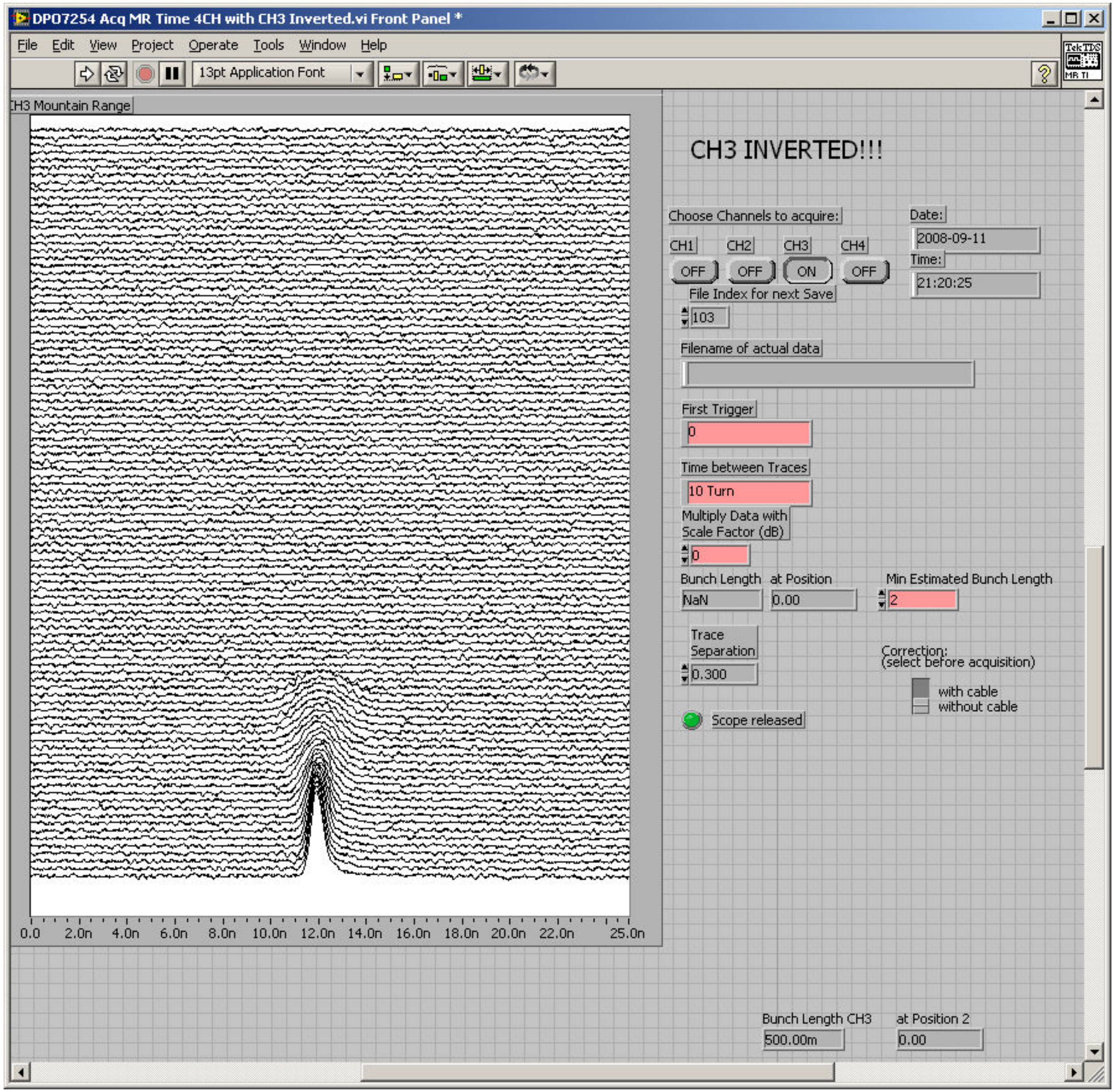
Courtesy R. Bailey

Few 100 turns



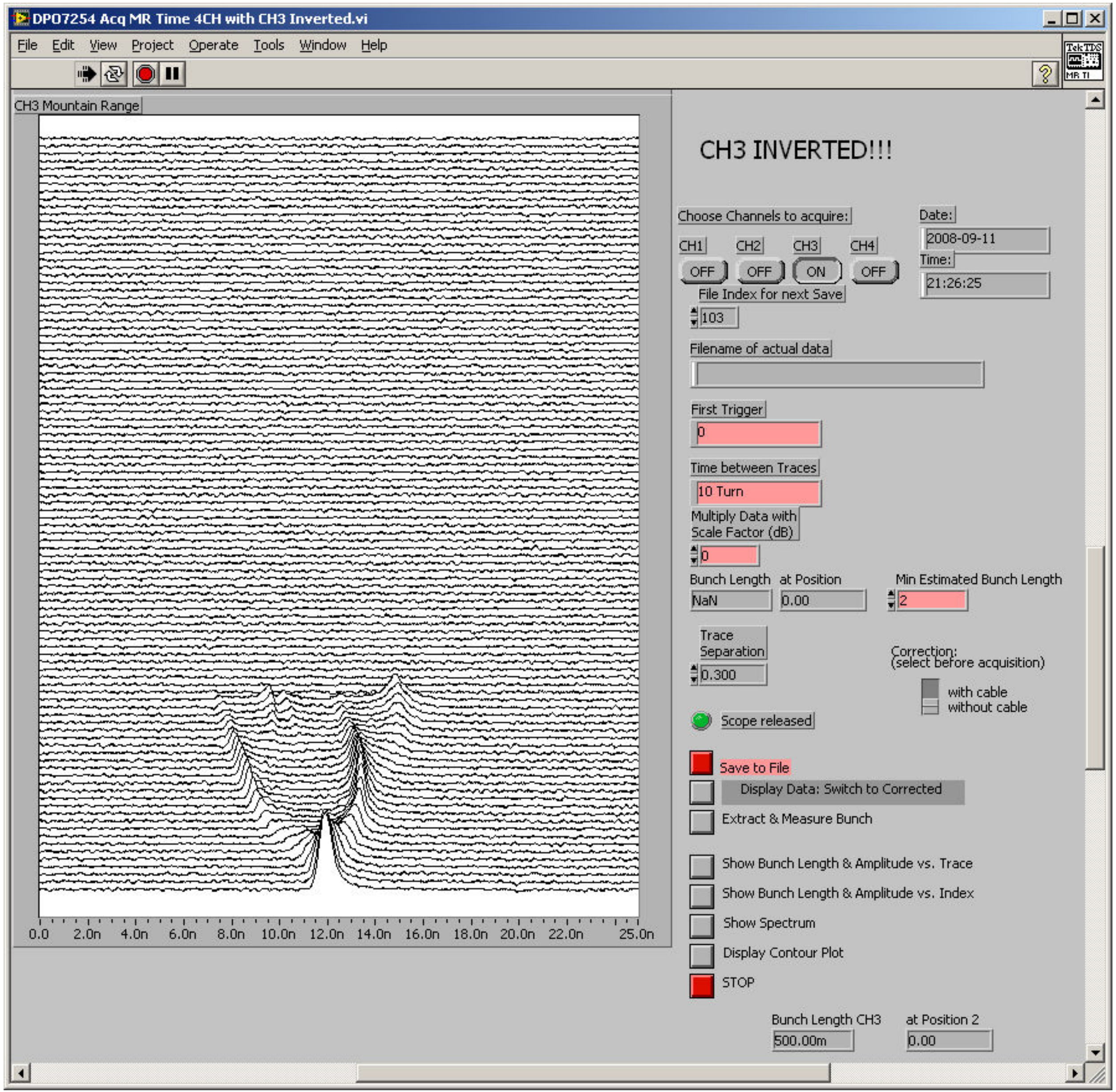
Courtesy R. Bailey

No RF, debunching in ~ 25*10 turns, i.e. roughly 25 mS



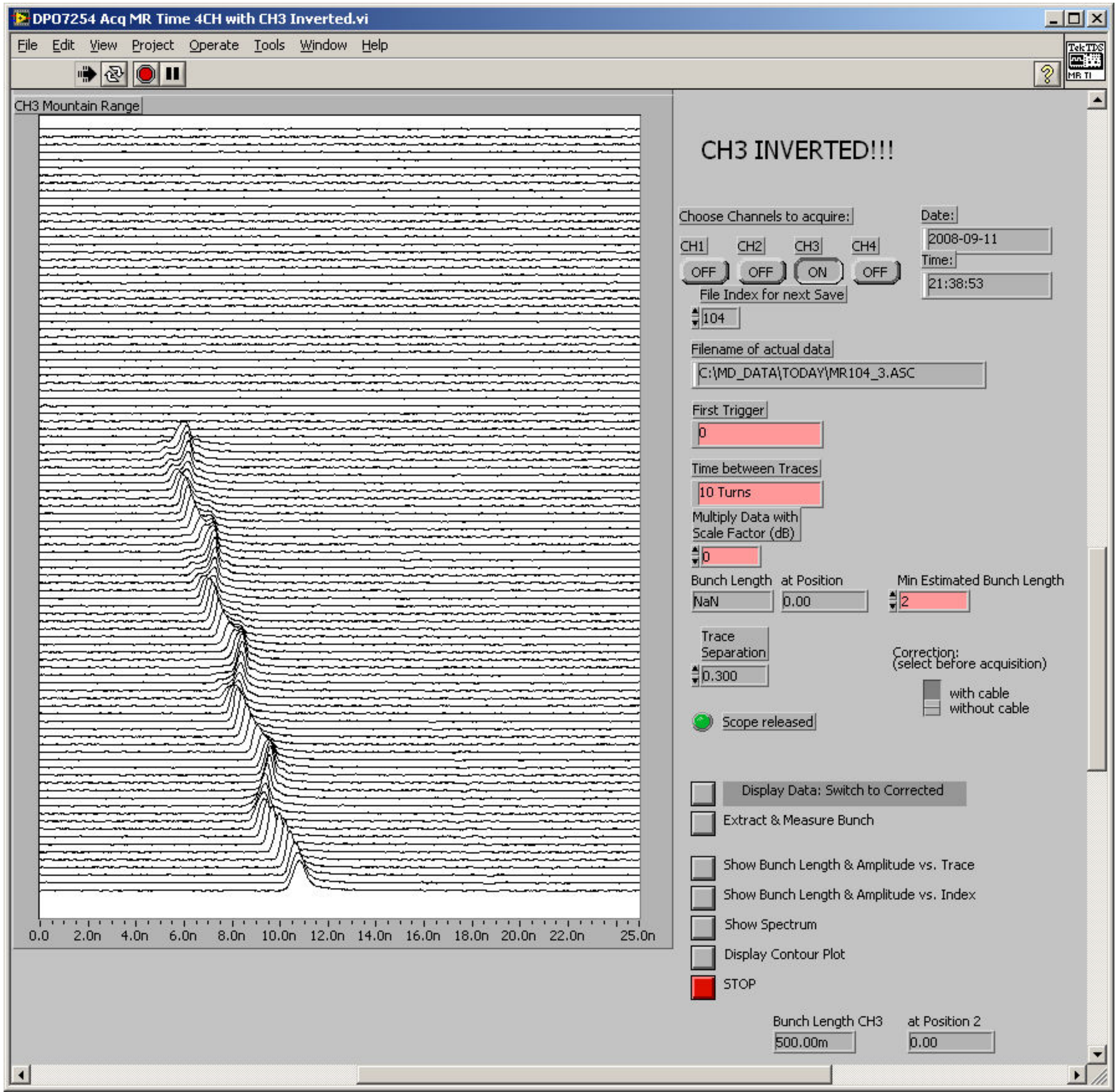
Courtesy E. Ciapala

First attempt at capture, at exactly the wrong injection phase…



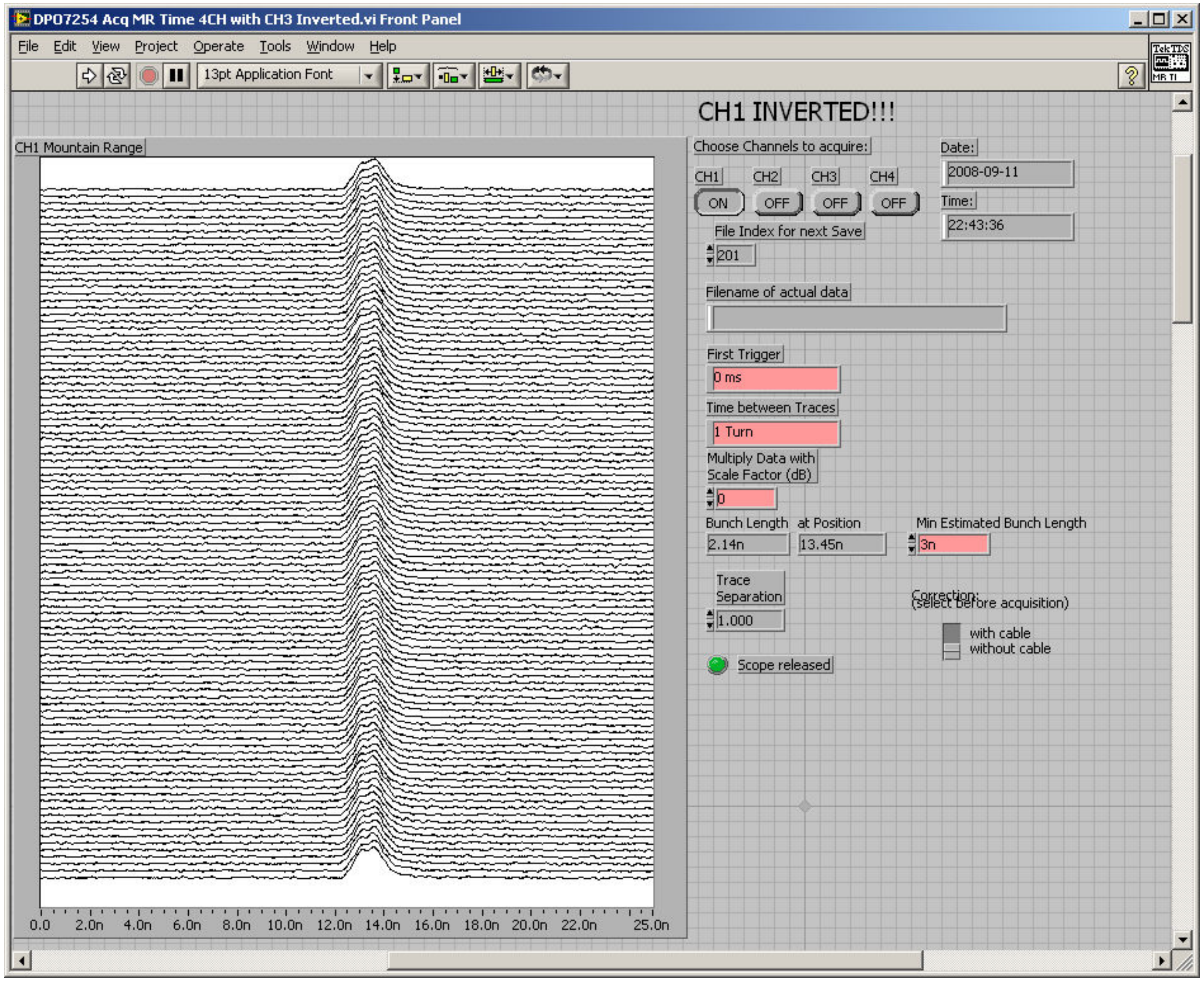
Courtesy E. Ciapala

Capture with corrected injection phasing



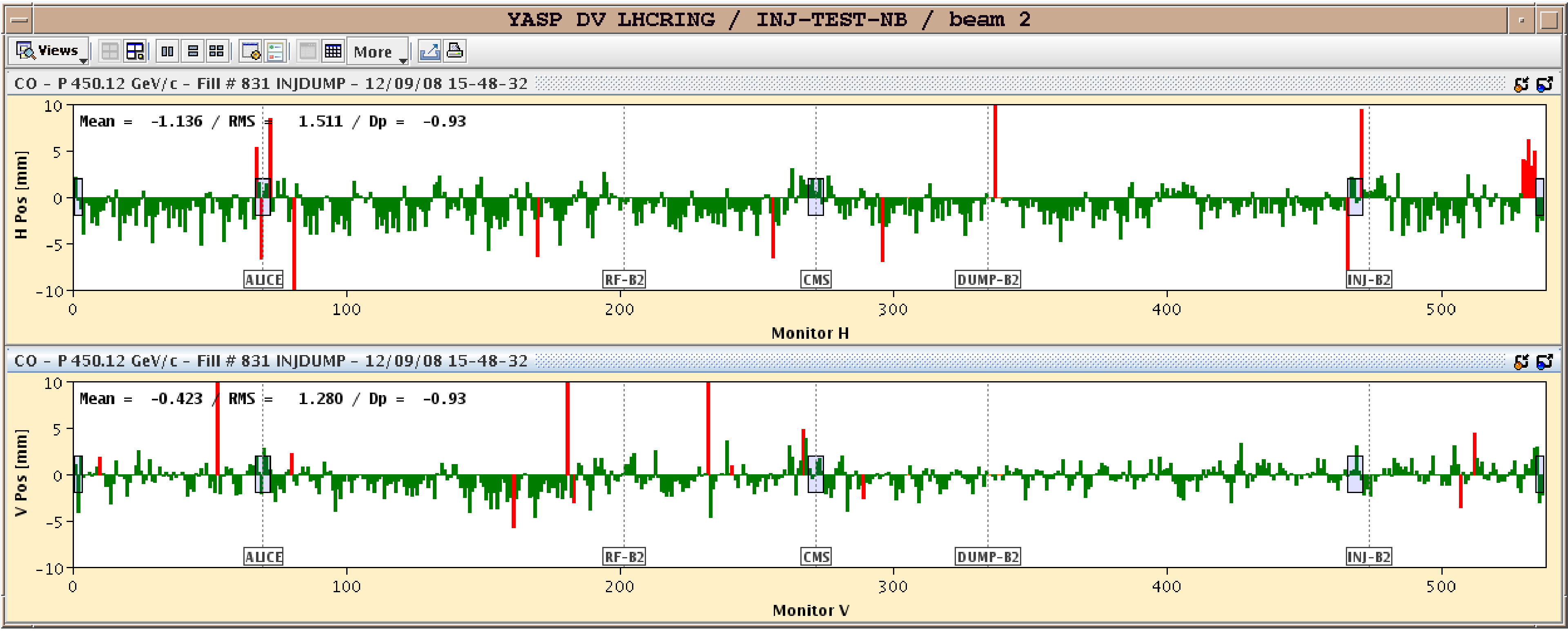
Courtesy E. Ciapala

Capture with optimum injection phasing, correct reference



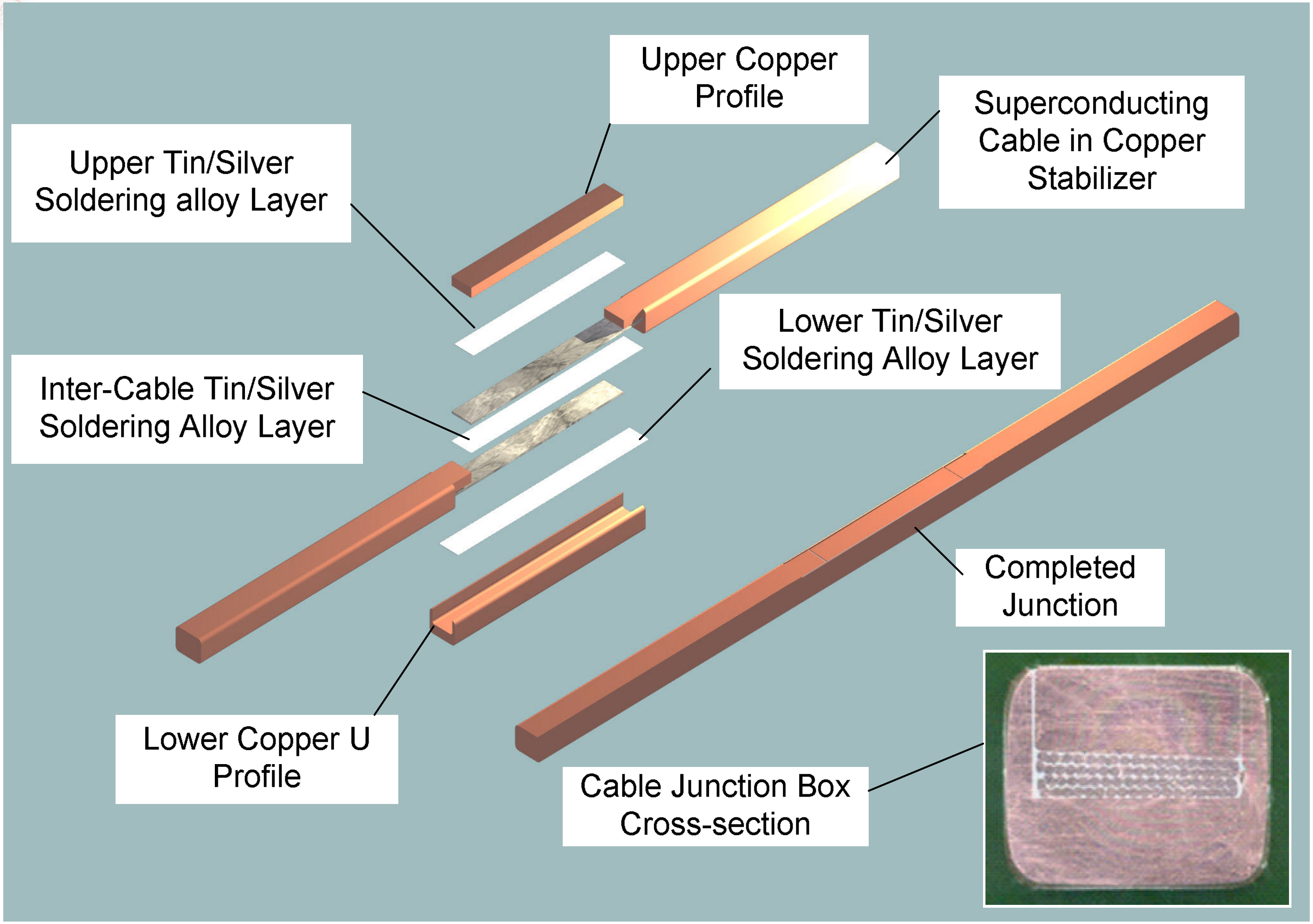
Courtesy E. Ciapala

Corrected closed orbit on B2.
Energy offset of ~ -0.9 permill due to the capture frequency.



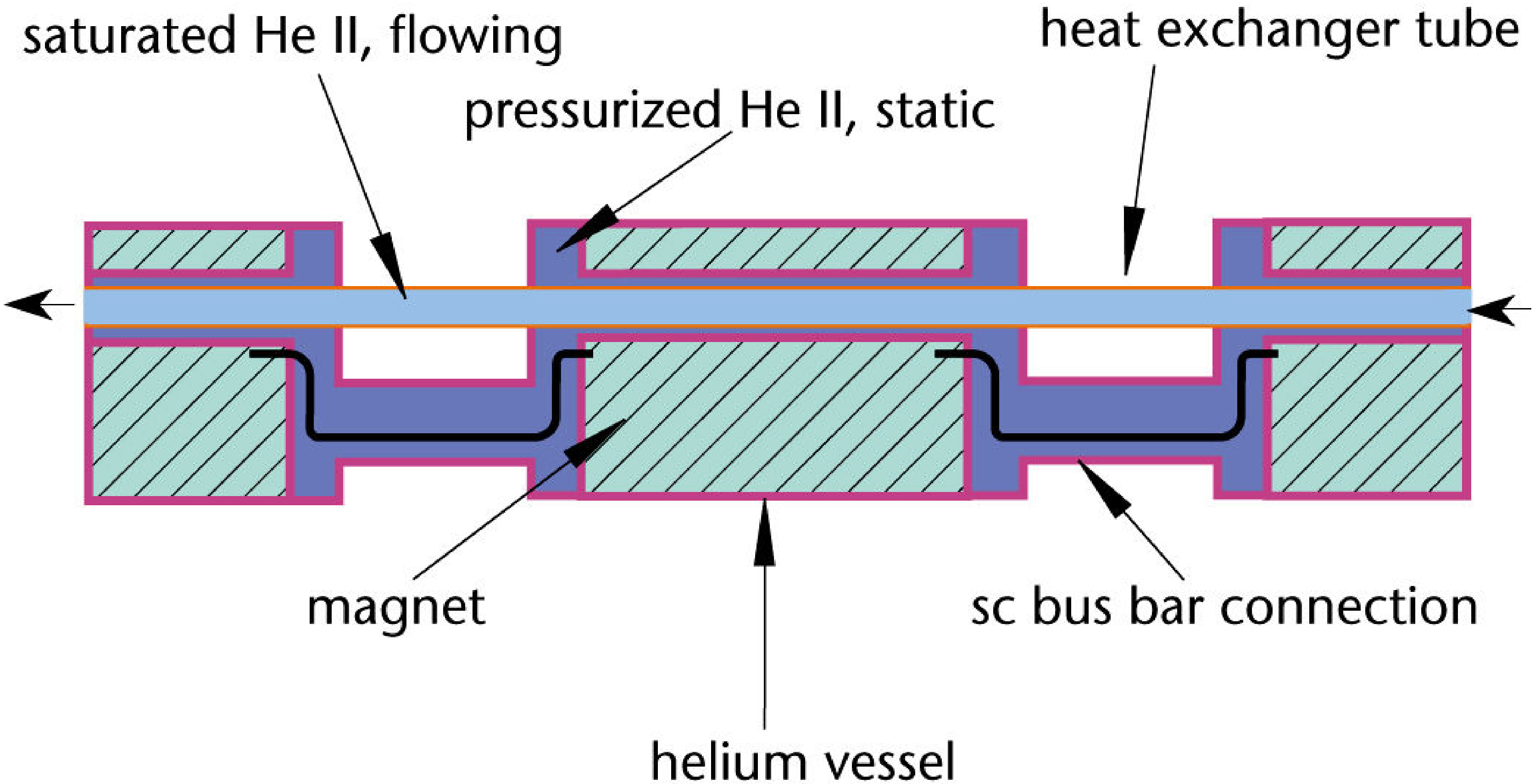
Courtesy J. Wenninger

Busbar splice



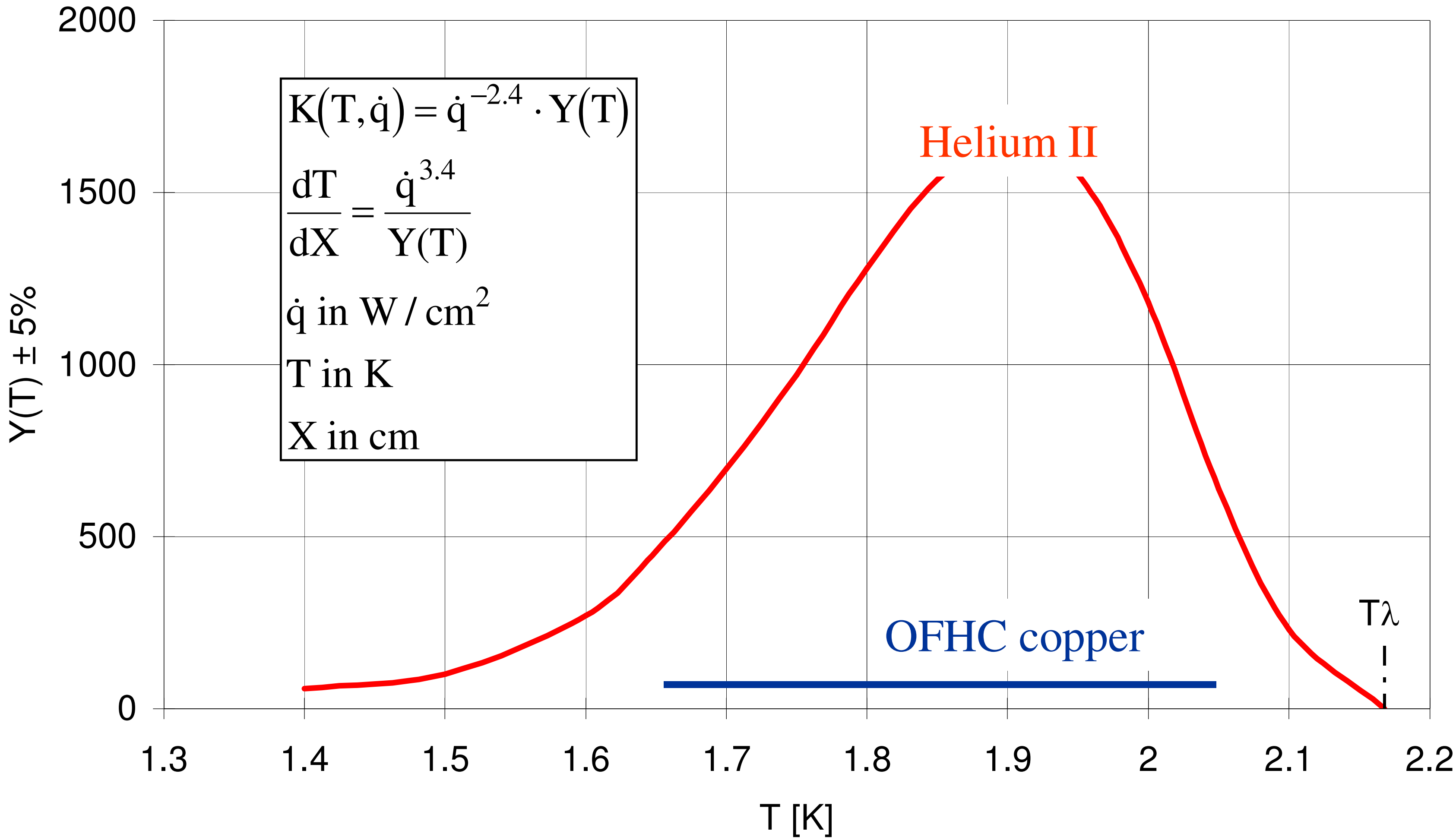
Magnet cooling scheme

LHC magnet string cooling scheme



CERN AC _ EI2-12 VE _ V9/9/1997

Equivalent thermal conductivity of He II



$$K(T,\dot{q}) = \dot{q}^{-2.4} \cdot Y(T)$$

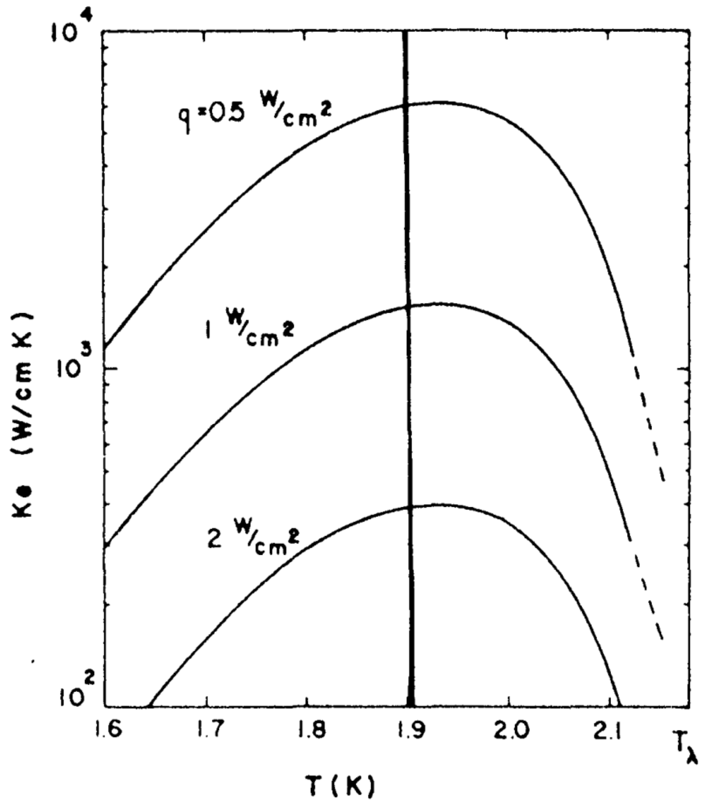
$$\frac{dT}{dX} = \frac{\dot{q}^{3.4}}{Y(T)}$$

$\dot{q}$ in W / cm^2

T in K

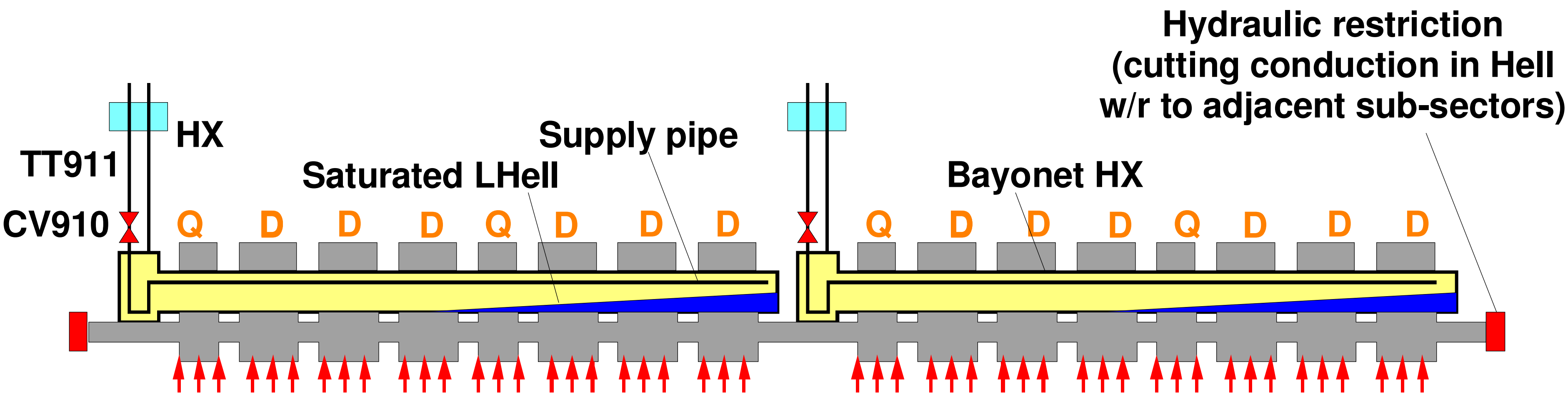
X in cm

Equivalent thermal conductivity of He II



Effective thermal conductivity of He II.

Sub-sector magnet cooling scheme

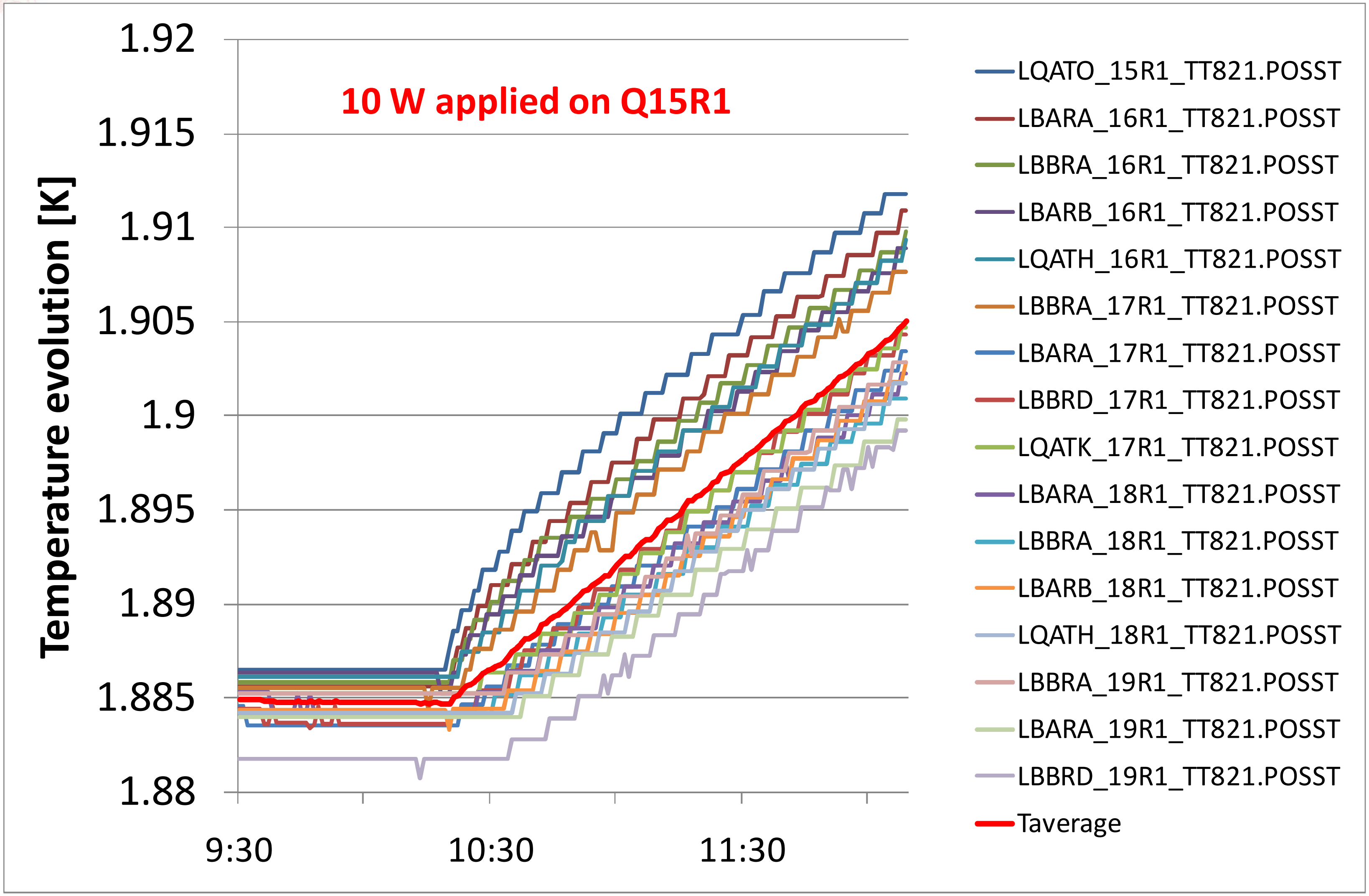


Principle:

→ Blocking of the JT valve (CV910) at a value to extract the static heat inleaks before the powering

→ Then, the temperature drift is mainly due to electrical resistive heating dissipated during the powering

Experimental validation: temperature evolution



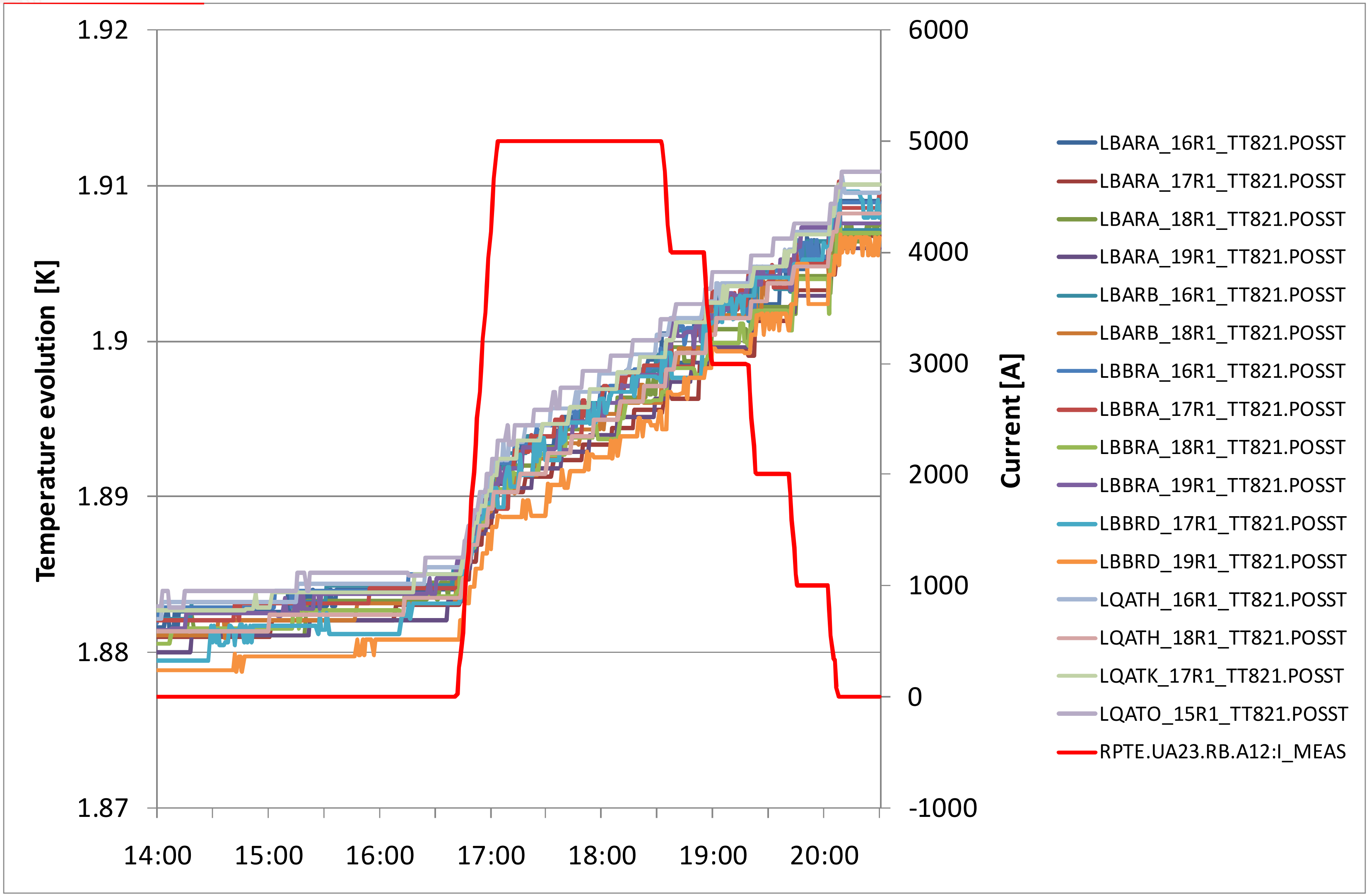
Experimental validation: calorimetry

	Before heating	With heating
ΔU [J/kg]	-1.1	78
M [kg]	823	
ΔU [kJ]	-0.92	64.2
t [s]	2880	6600
W [W]	-0.3	9.7
ΔW [W]	**10**	

→ **The power variation calculated by calorimetry is 10 W and is corresponding to the applied electrical power**

→ **Validation of the method !**

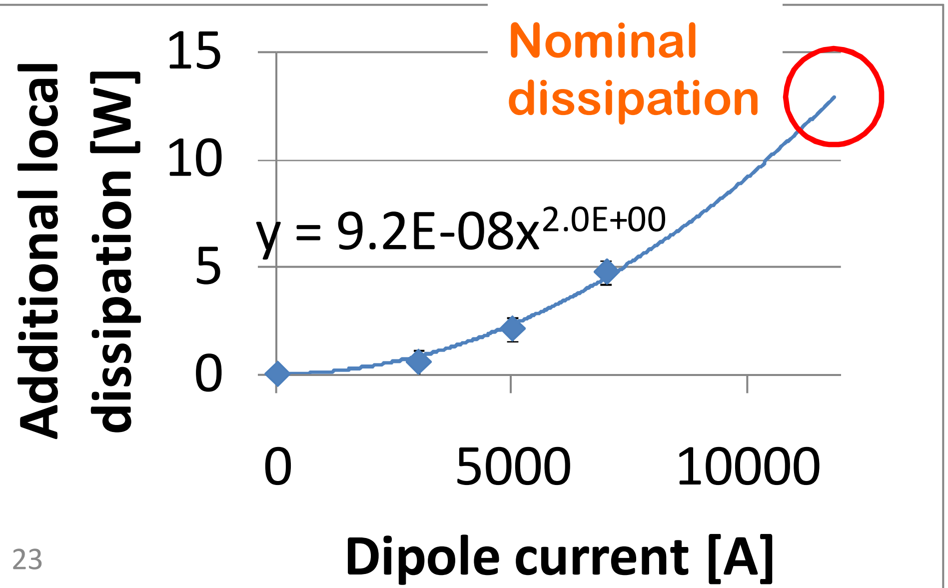
Powering example: 15R1 powering @ 5000A



The 15R1 case: additional heat dissipation due to a bad splice in B16R1

Current	Total (measured)		Nominal Splices*	Add. local dissipation	Uncertainty
[A]	[mW/m]	[W]	[W]	[W]	[W]
3000	4.4	1.0	0.4	0.6	0.6
5000	14.9	3.2	1.1	2.1	0.6
7000	32.2	6.9	2.1	4.8	0.6

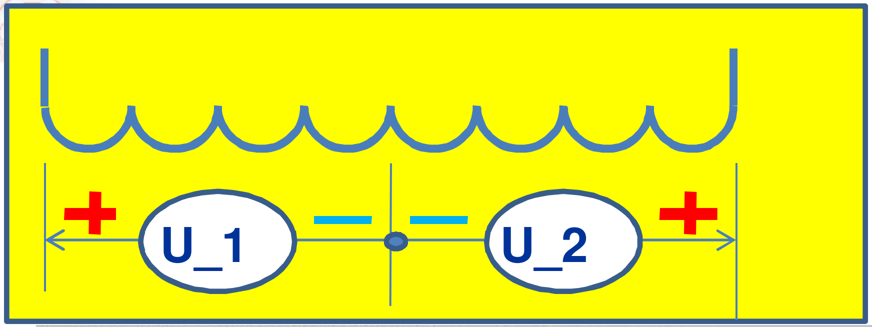
*: Calculated on the basis of 0.33 nW per splice and verified with the 5000 A plateaus



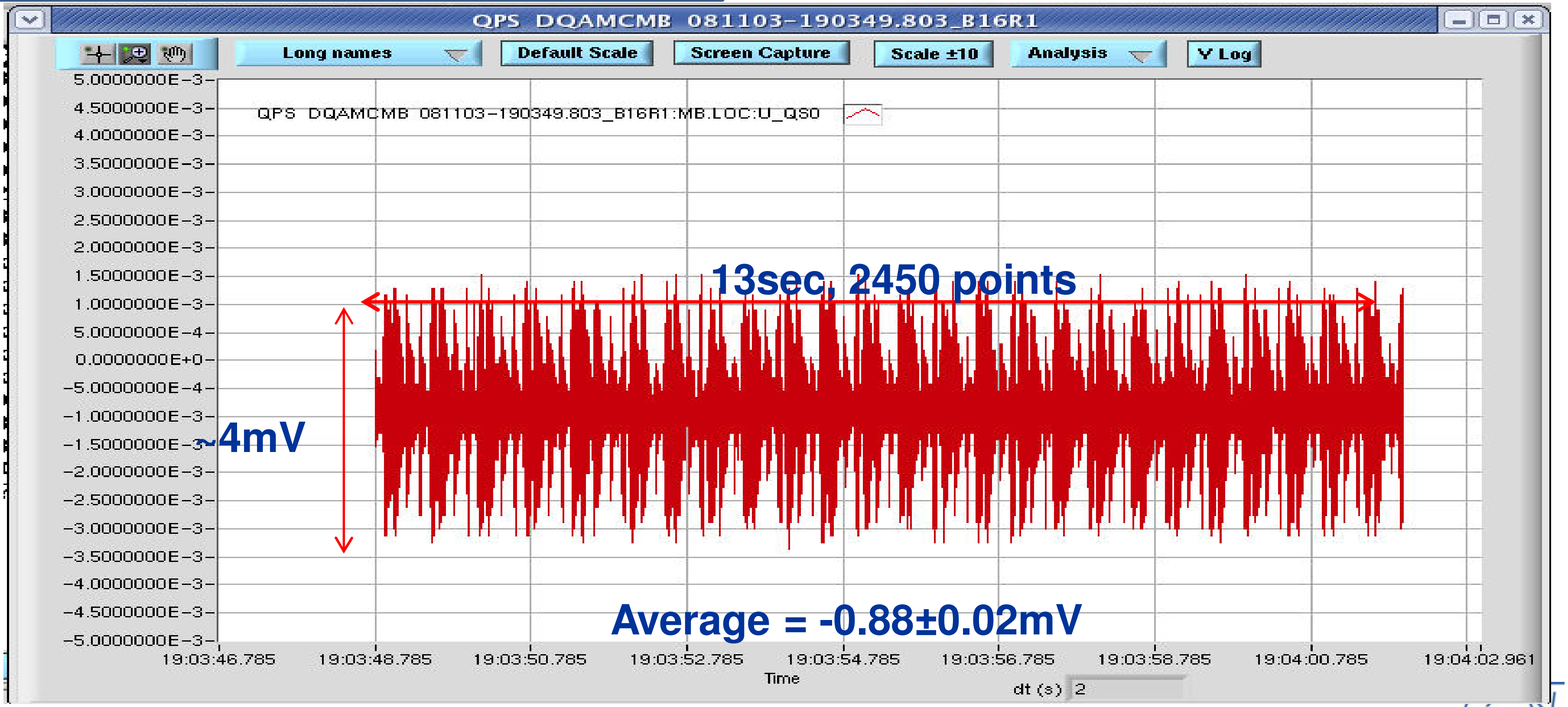
→ Local resistance: ~90 nohms confirmed by electrical measurement !

→ Nominal dissipation 13 W: OK w/r to the cooling loop capacity margin

Sector A12: A15R1 – C19R1: “splice” measurements on 03.11.08



U_QS0 => -(U_1+U_2)
Sampling Rate = 5ms
Resolution = 0.125mV
Quench Threshold = 100mV@10ms



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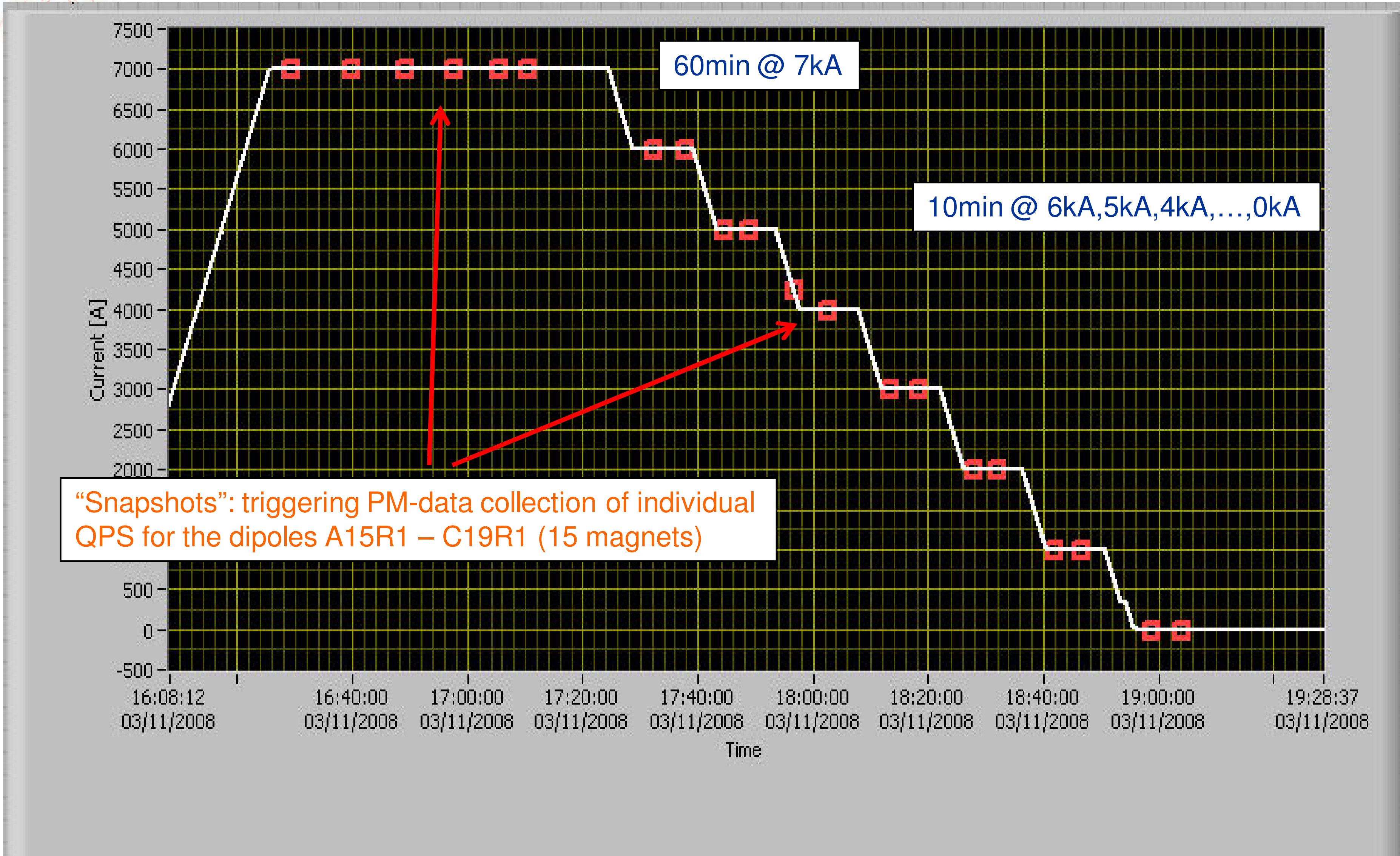
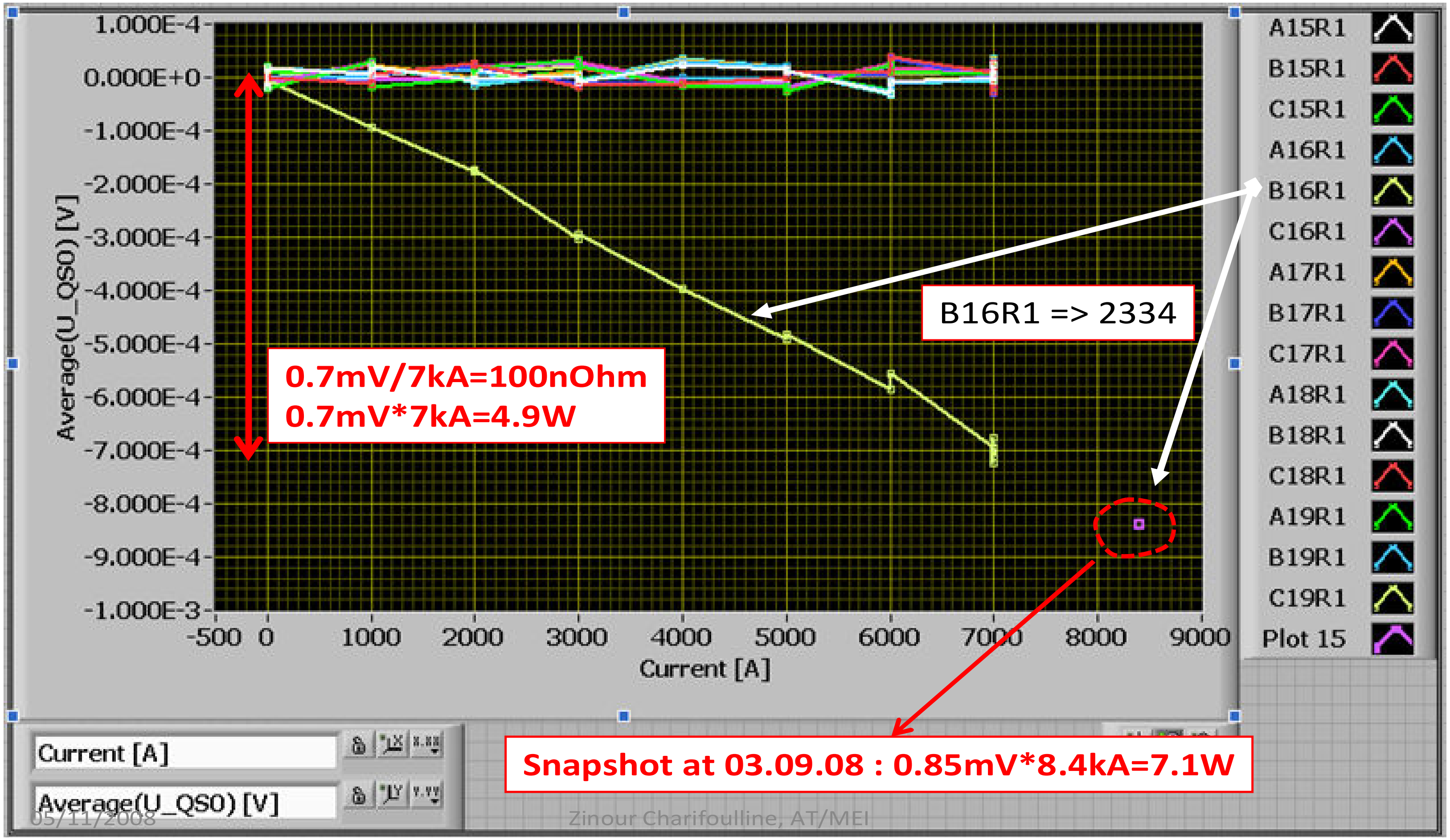
Sector A12: A15R1 – C19R1: measurements on 03.11.08



Courtesy Z. Charifoulline

Proof of the missing source of heating, representing 100 nΩ, located in dipole B16.R1 (in the joint between the two apertures).

Sector A12: A15R1 – C19R1: Dipole Measurements made on 03.11.08



Compatible with SM18 data (resolution ±20 nΩ)

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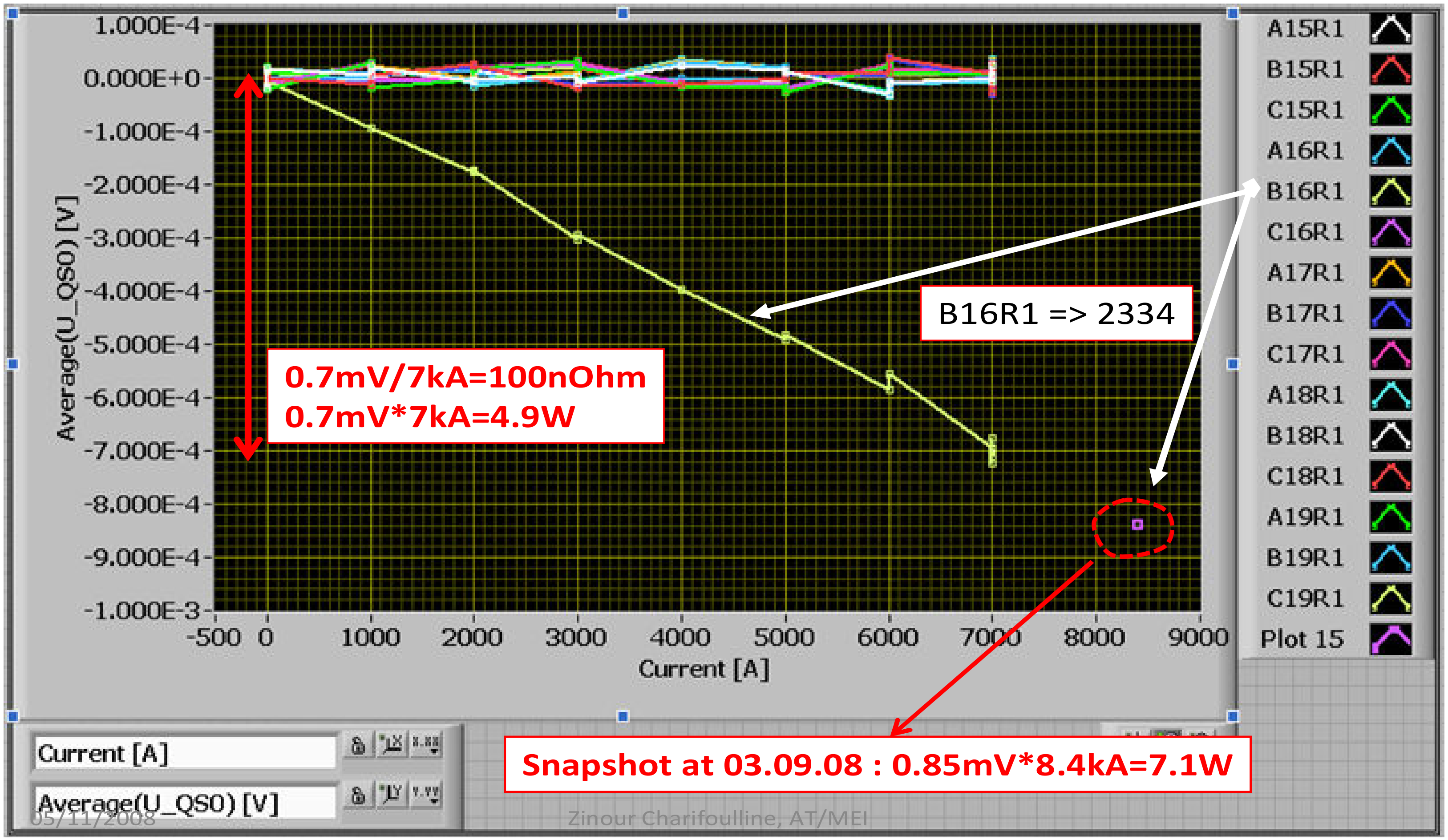
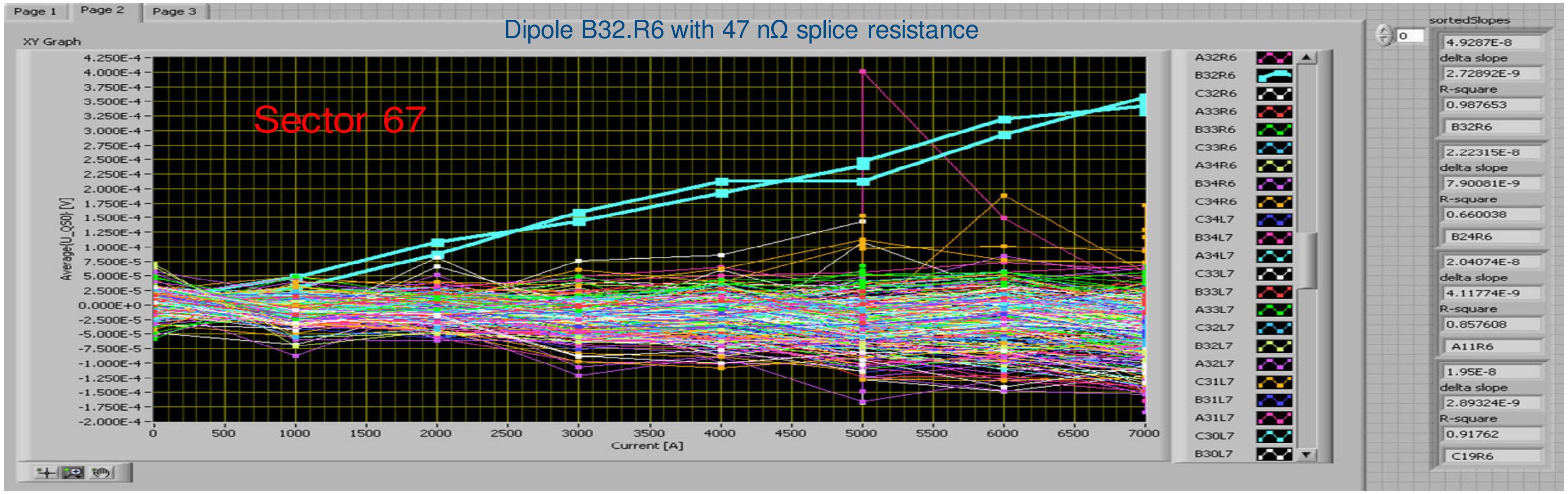
Sector A12: A15R1 – C19R1: Dipole Measurements made on 03.11.08

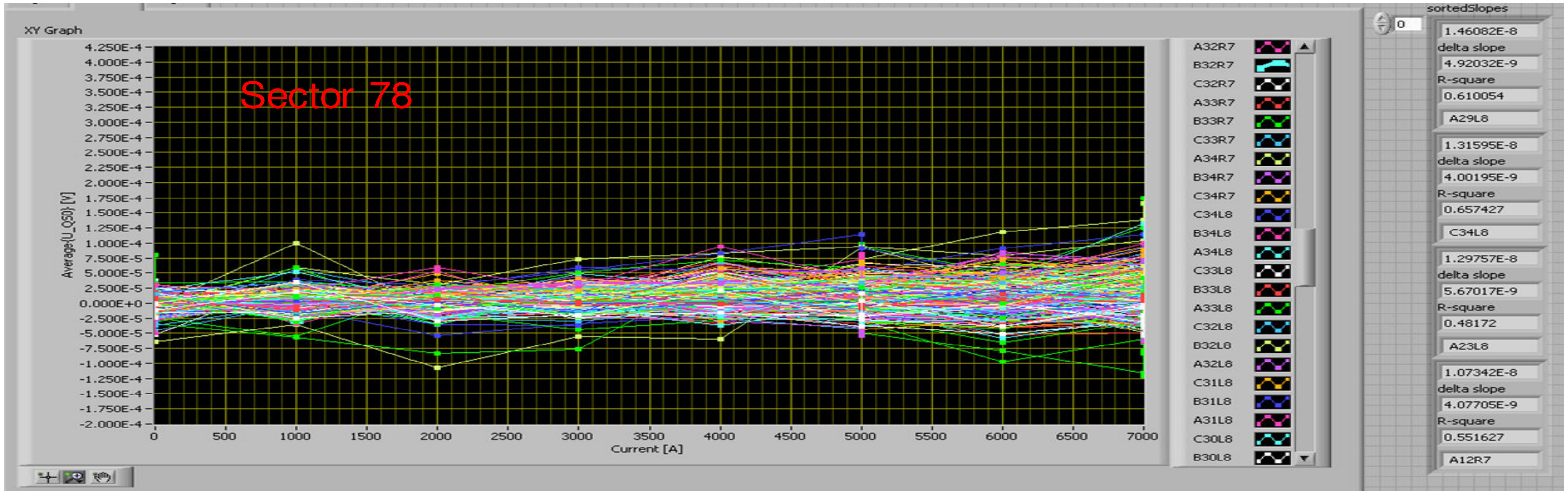


Compatible with SM18 data (resolution ±20 nΩ)

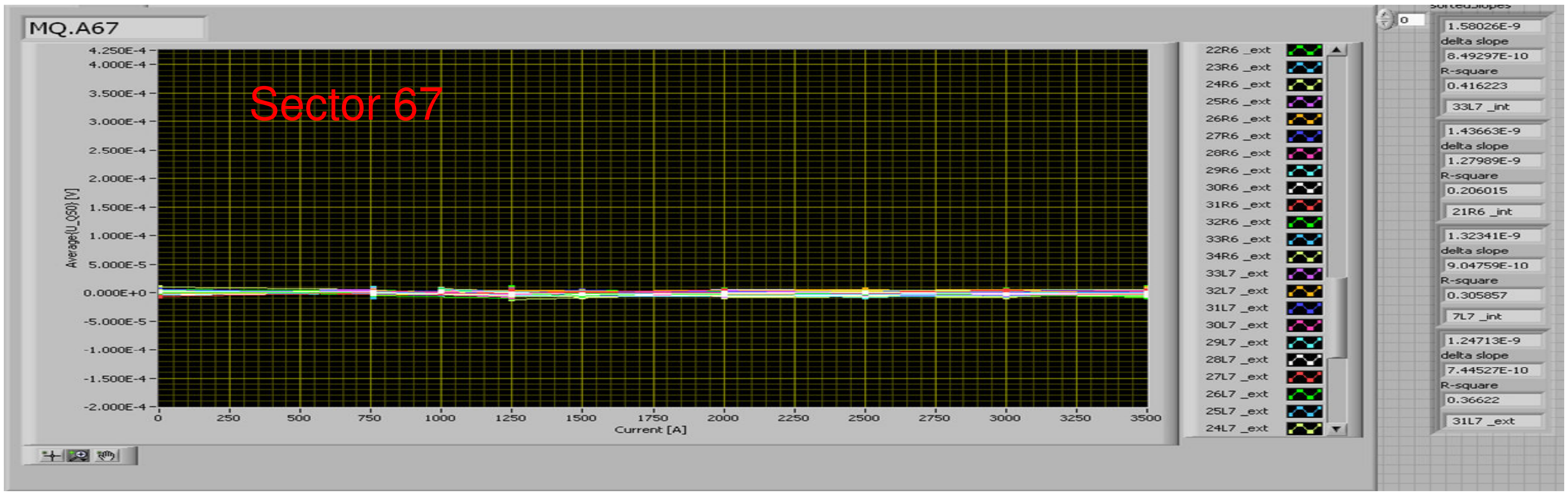
Snapshots in S67 and S78 on all 154 dipoles - B32.R6 with a high (47 nΩ) joint resistance between the poles of one aperture

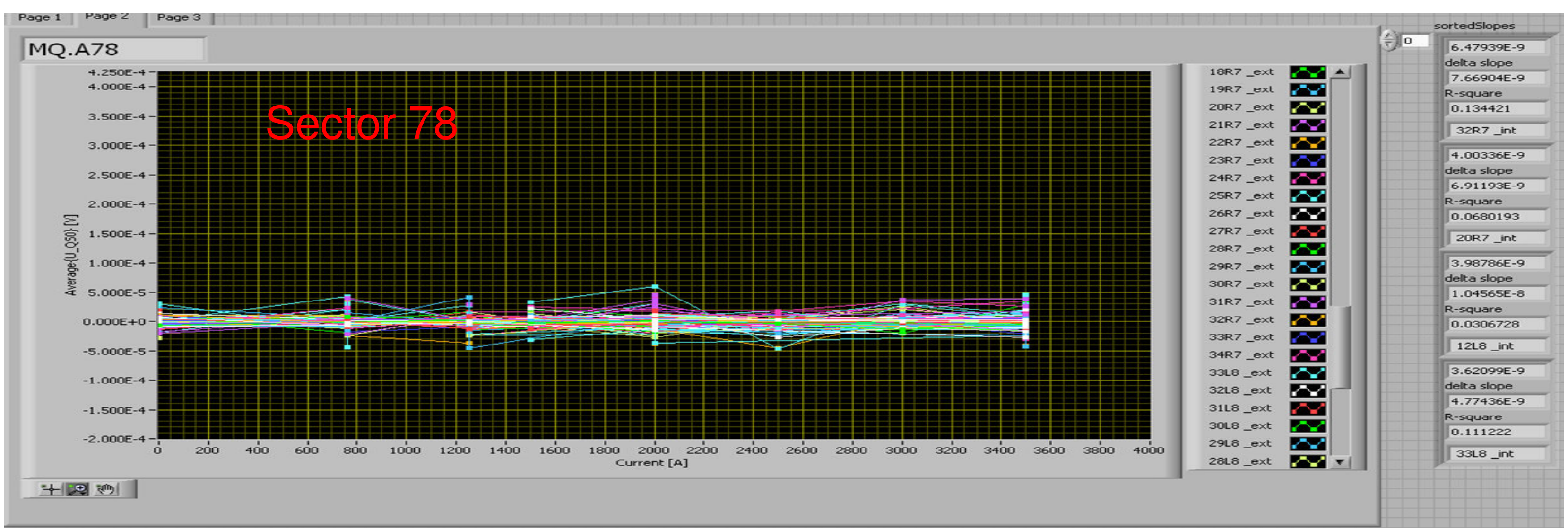
Results from provoked massive Post-Mortem of all dipoles in sectors 67 & 78



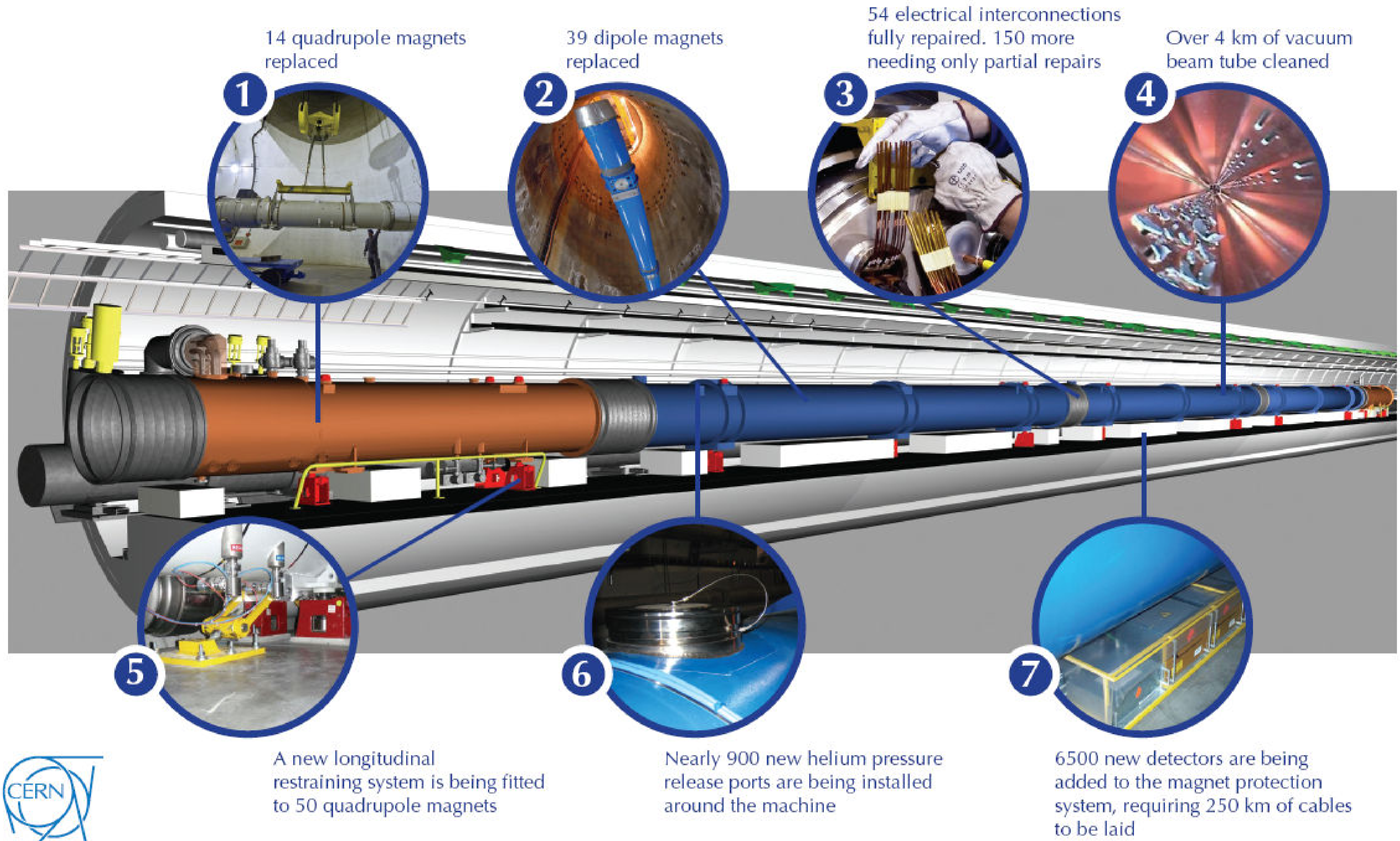


Main quadrupoles in S67 and S78
Results of global snapshots





The LHC repairs in detail



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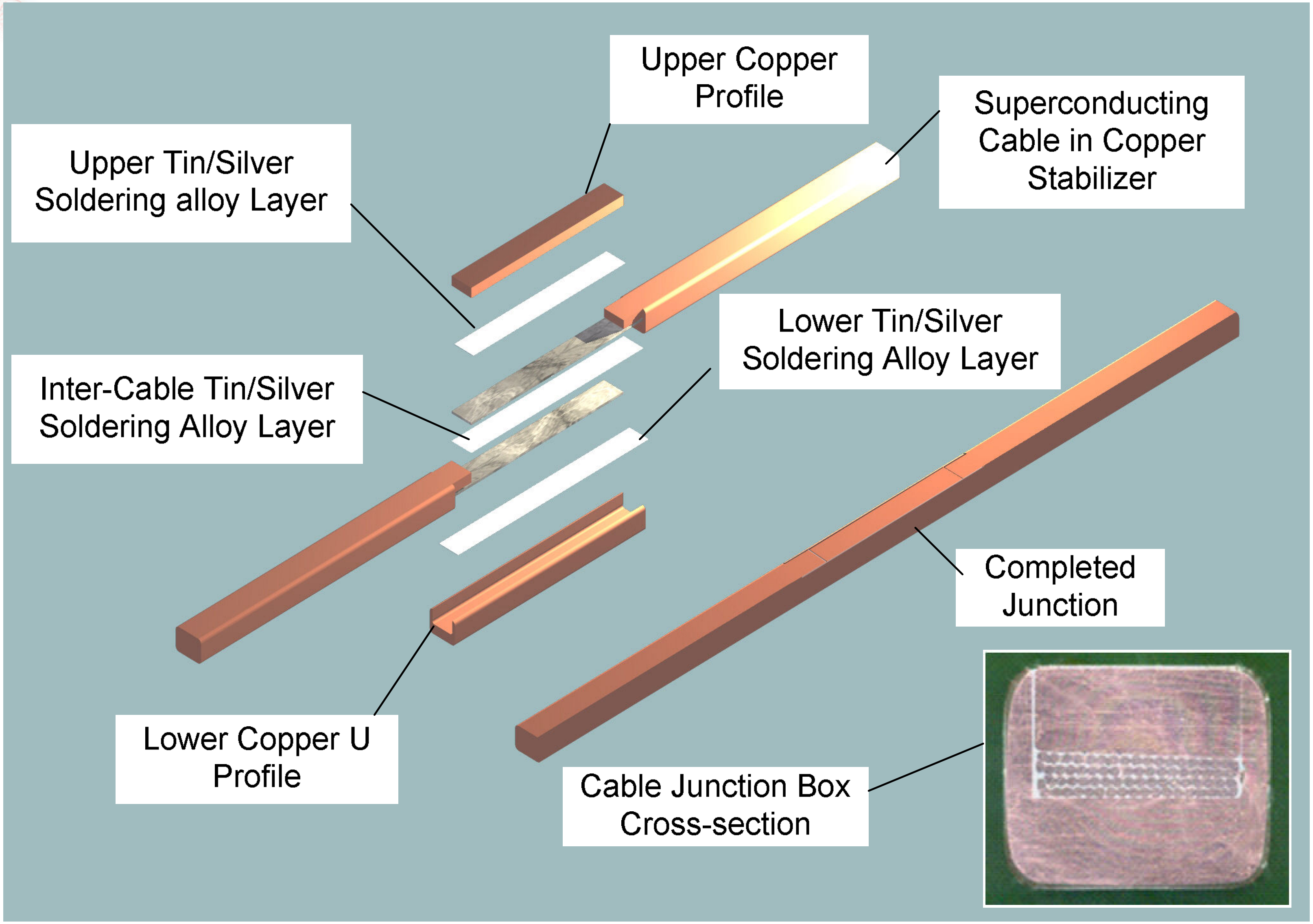
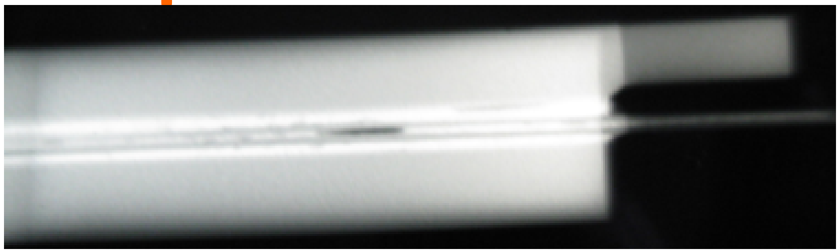
Busbar splice

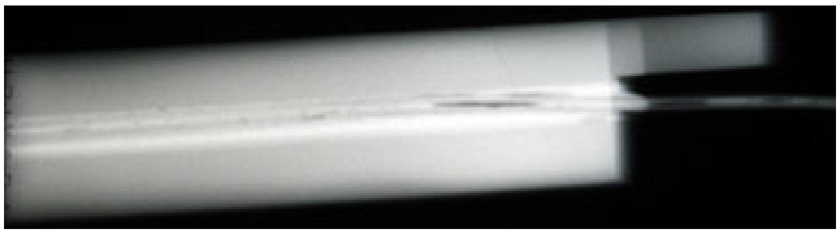


What did we observe?

Dipole extremities in SMa18 (March 2009)

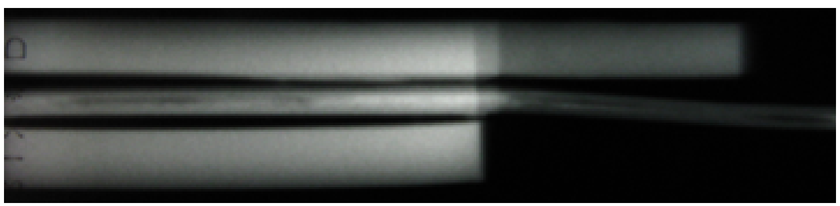


MB2690 M2

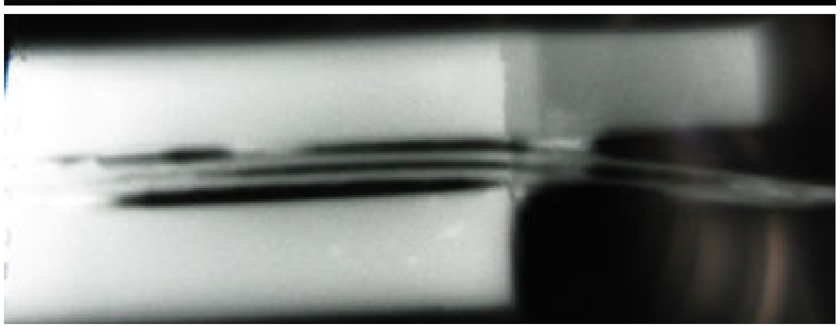


MB2690 M3

Spare magnet



MB3118 M2

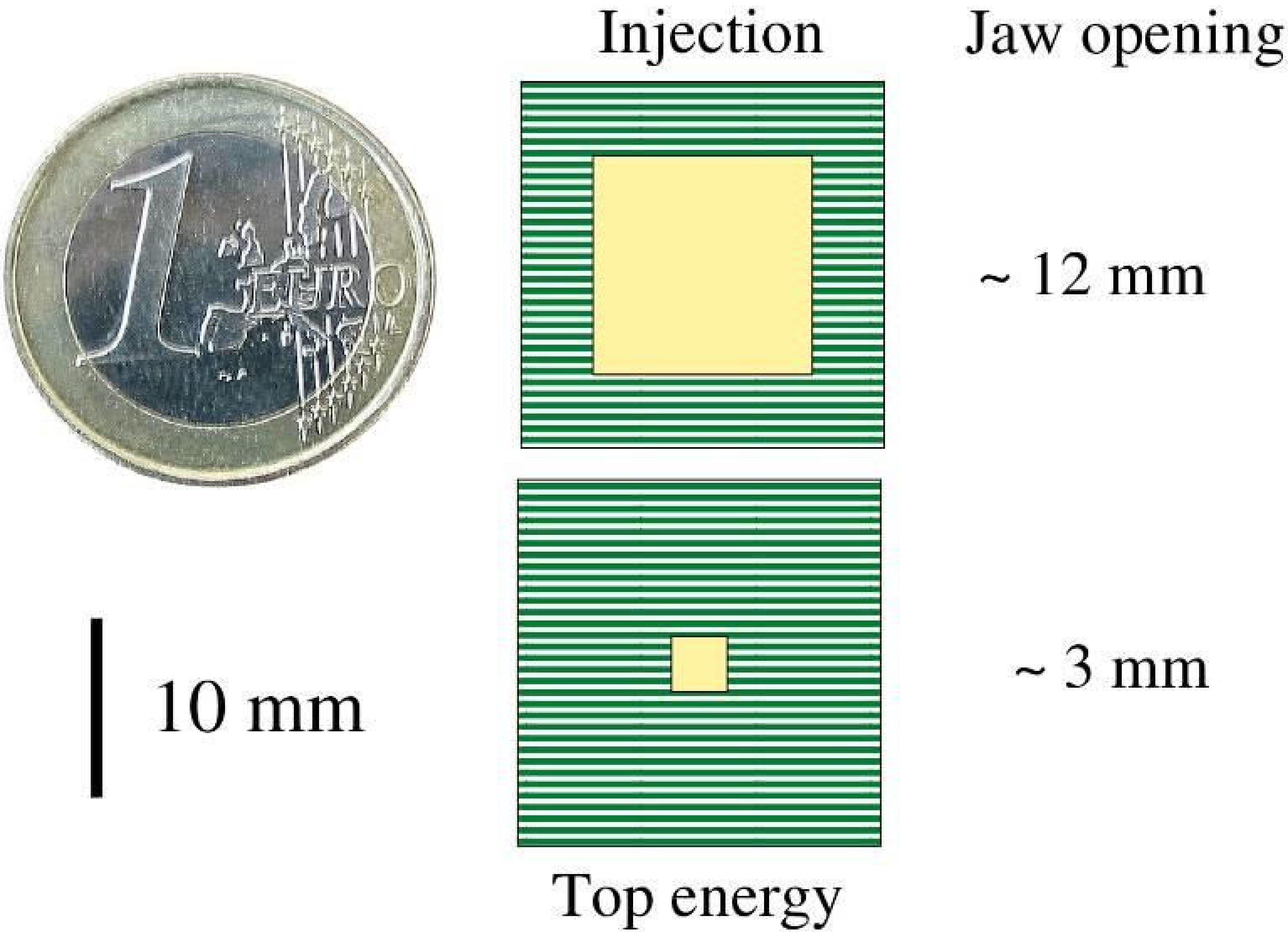


MB3118 M3

Magnet coming from the tunnel

Courtesy H. Prin

Collimation



Modification of dump resistors

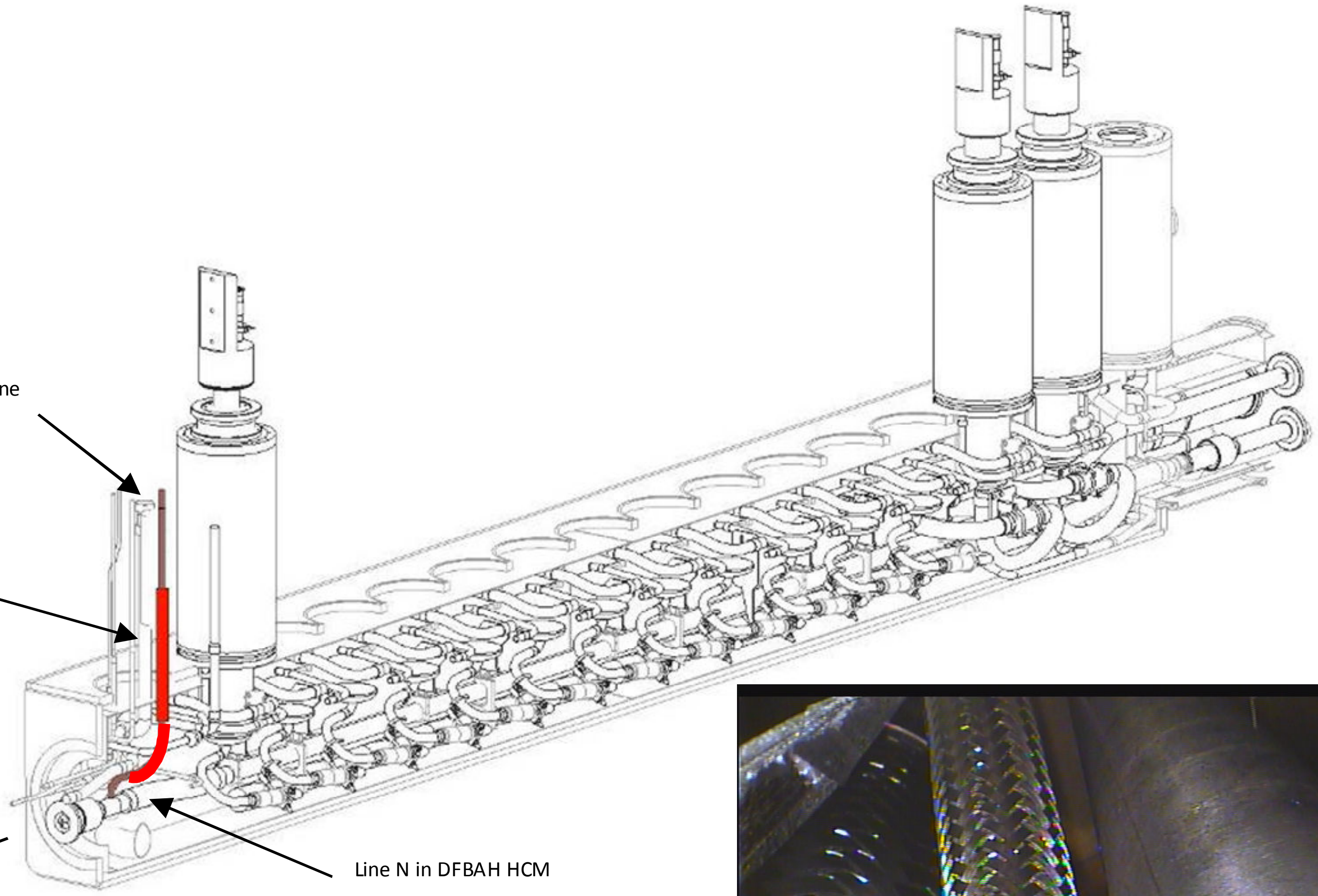
- Reconfiguration of dump resistors allows the current to be brought down faster in case of a magnet quench.

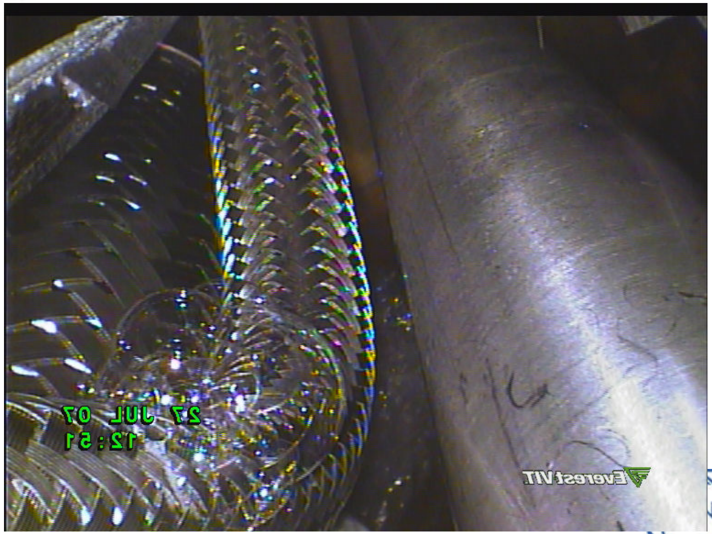
- For the dipole, 104 sec ⟹ 68 or 53 sec.
- For the quadrupole, 25 sec ⟹ 15 or 12 sec.

Vacuum problems

- In two sectors, vacuum leaks have appeared in current feed boxes. The cause of these leaks is almost certainly due to flexible hoses. The reason is now understood: operation outside design under some transient cooldown conditions.

- The two sectors concerned will have a partial warmup to change the hoses. Operational procedures in the other sectors will be changed to avoid such transients.


CL line
Flexible hose LHCDFBA_0114
Fixed point
approx 3.2 m
Line N in DFBAH HCM



Schedule

- The machine will start up in November 2009 after repair of the vacuum leaks in two sectors.
- The energy of operation in 2010 will be chosen once all data on splice resistance is available. It will be as close as possible to, but not above 5 TeV.
- The ion injector chain will be made ready for a possible ion run at the end of 2010.