LHC cryogenics: First operational experience from cool-down to 1st beams

S. Claudet, Ch. Balle, K. Barth, V. Benda, J. Casas-Cubillos, D. Delikaris, G. Ferlin, G. Fernandez Penacoba, P. Gomes, F. Millet, C. Parente, A. Perin, M. Soubiran, L. Tavian, R. Van Weelderen & U. Wagner

(CERN)

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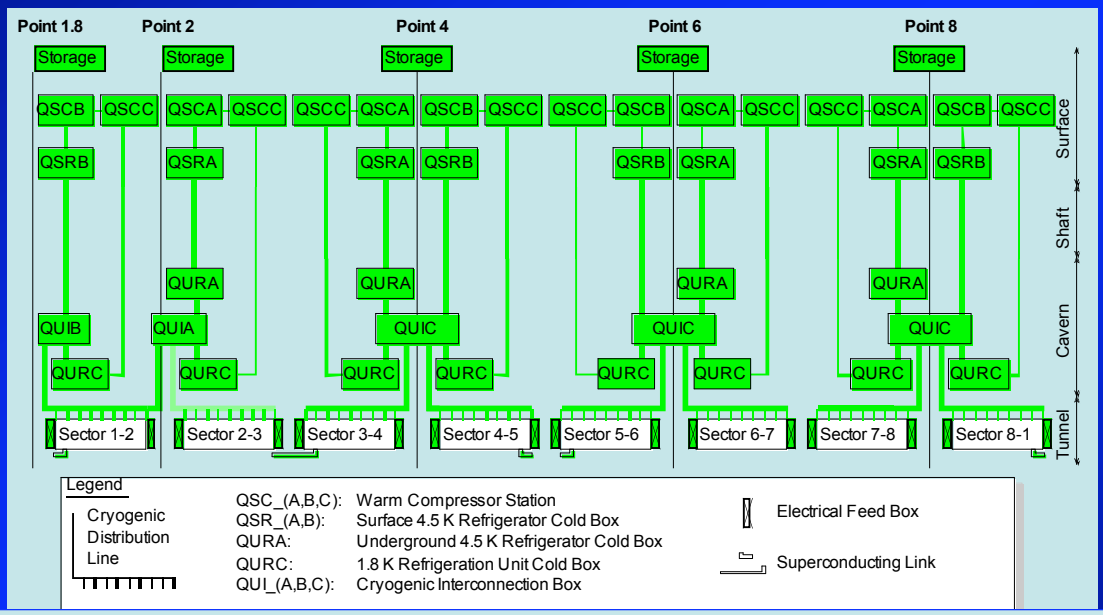
Outline

- Introduction
- Cool-down (and refrigeration issues)
- Cryogen fluids (logistics and perspectives)
- Cryogenic Hardware Commissioning
- Stability and availability
- Conclusion

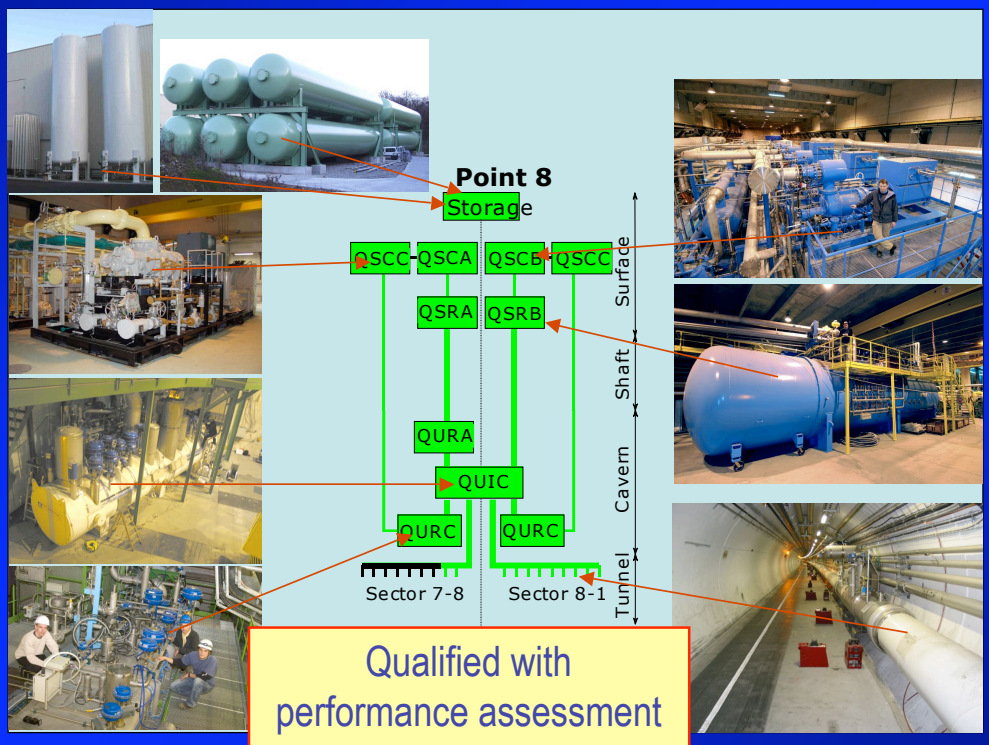
+ Part 2: Situation of LHC project and perspectives

LHC Cryogenics architecture



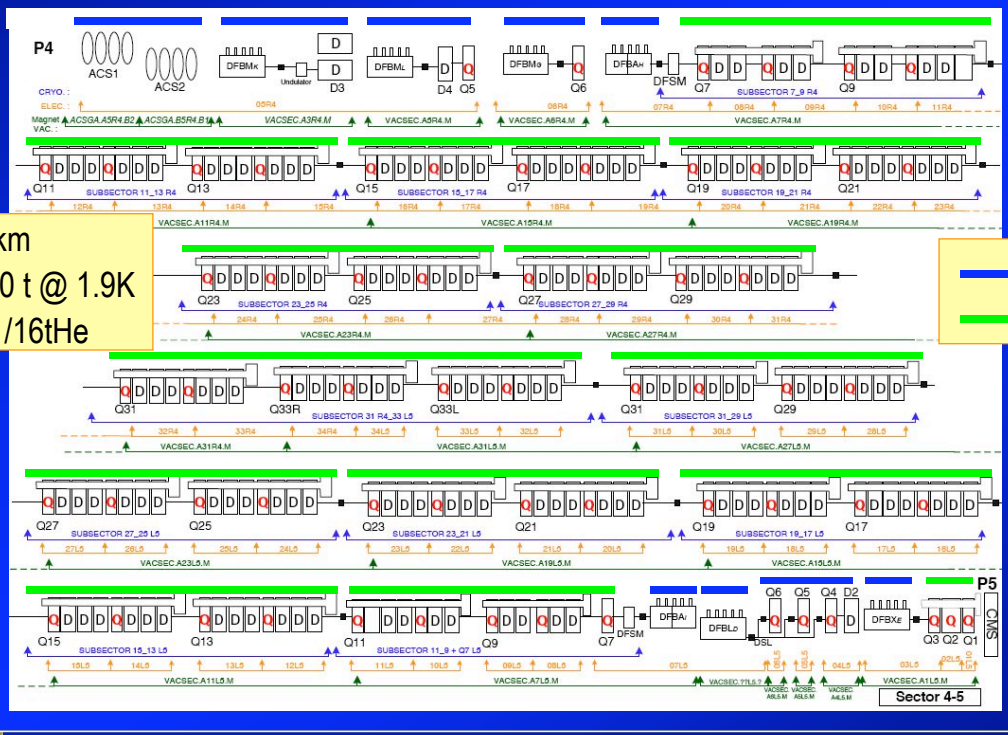
Large variety of large scale refrigerators,
AND
Large variety of valve boxes and large scale lines

Cryogenic sub-systems

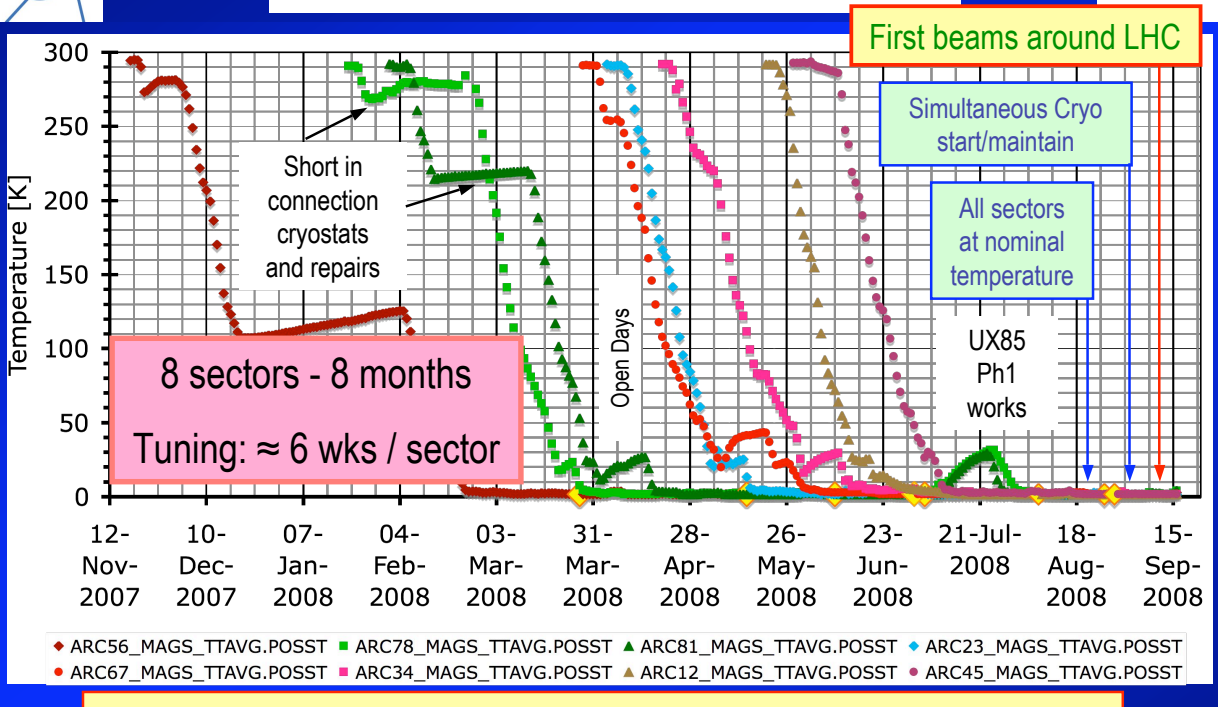


Qualified with performance assessment before being put together

LHC Sector 4-5 scheme

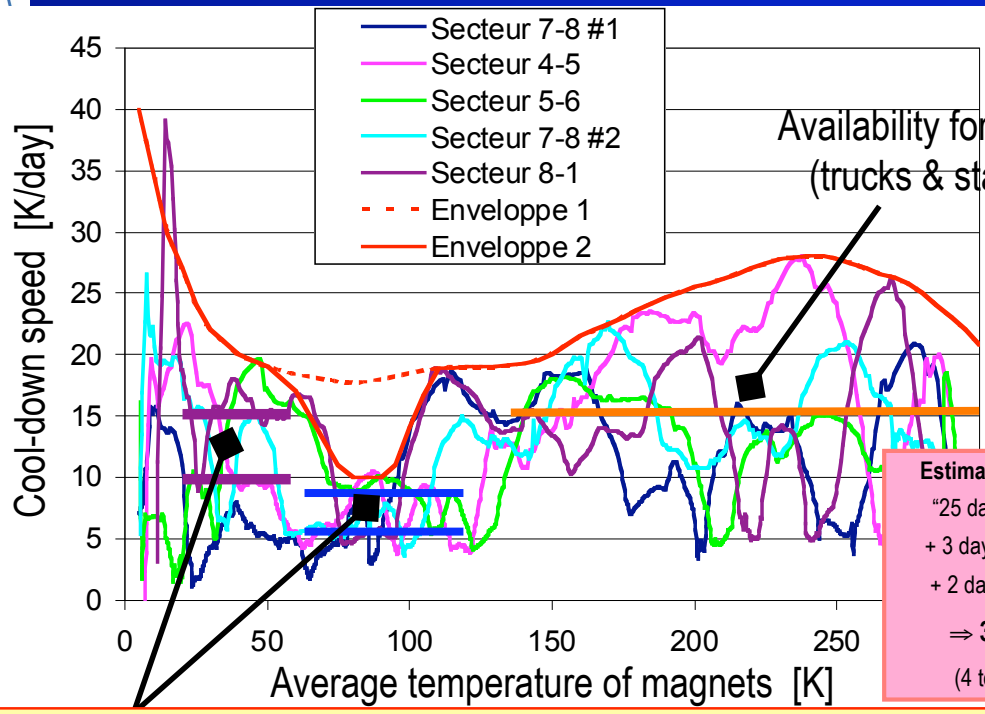


First cool-down of LHC sectors



Cooling sectors + Cryo tuning + Powering activities

Cool-down speed for LHC sectors

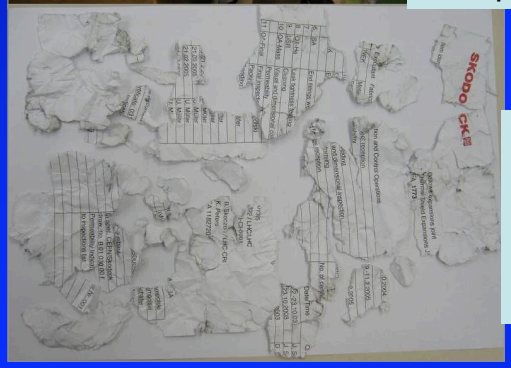


Estimate for 2009:
"25 days for 20K"
+ 3 days for Filling
+ 2 days for 1.9K
⇒ **30 days**
(4 to 5 wks)

Dispersion due to particular process (HX & Turbines) and timing for thermal shield/ Line B

Flushing sectors before cool-down

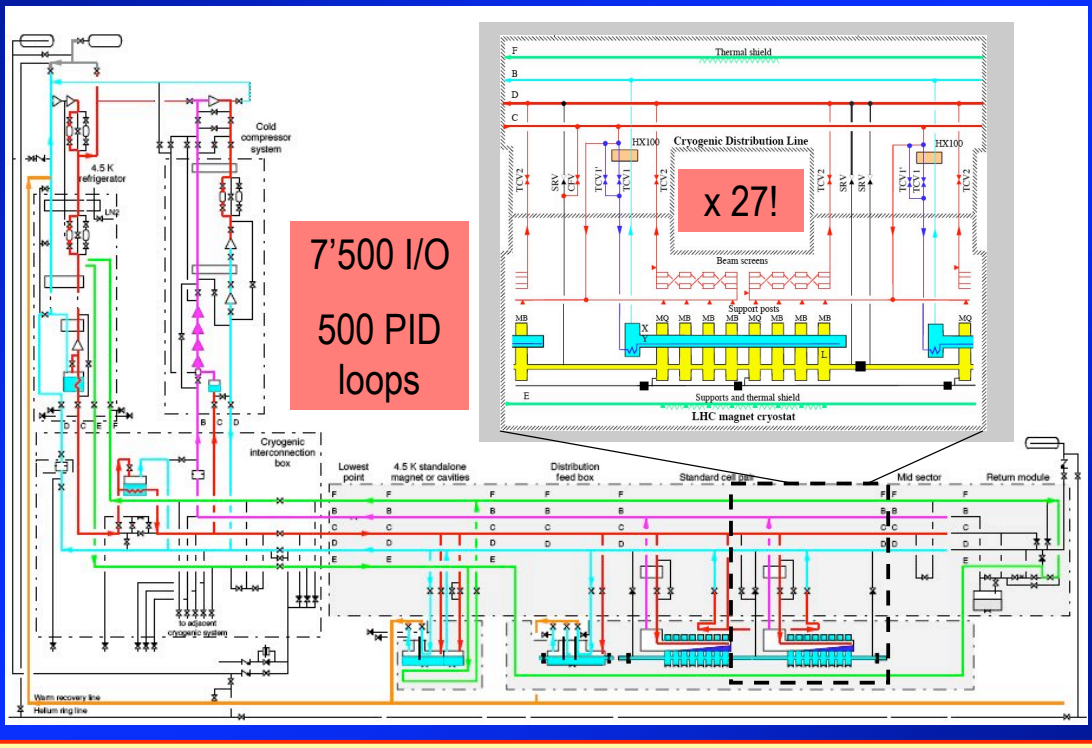
Dust
Debris
Kapton
Reports



And
possible
shorts in
diodes !

But the sooner the best !!!

Tuning one of 8 LHC sectors

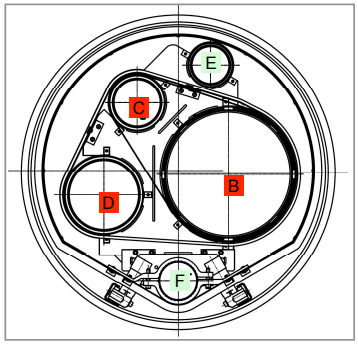


7'500 I/O

500 PID loops

Preparation, Methodic and systematic approach, a bit of time

An idea of time constants !



	Diam. [mm]	Volume [m3]
C	100	25.9
D	150	58.3
B	250	162.0

$$m' = Ro \cdot V \cdot S$$

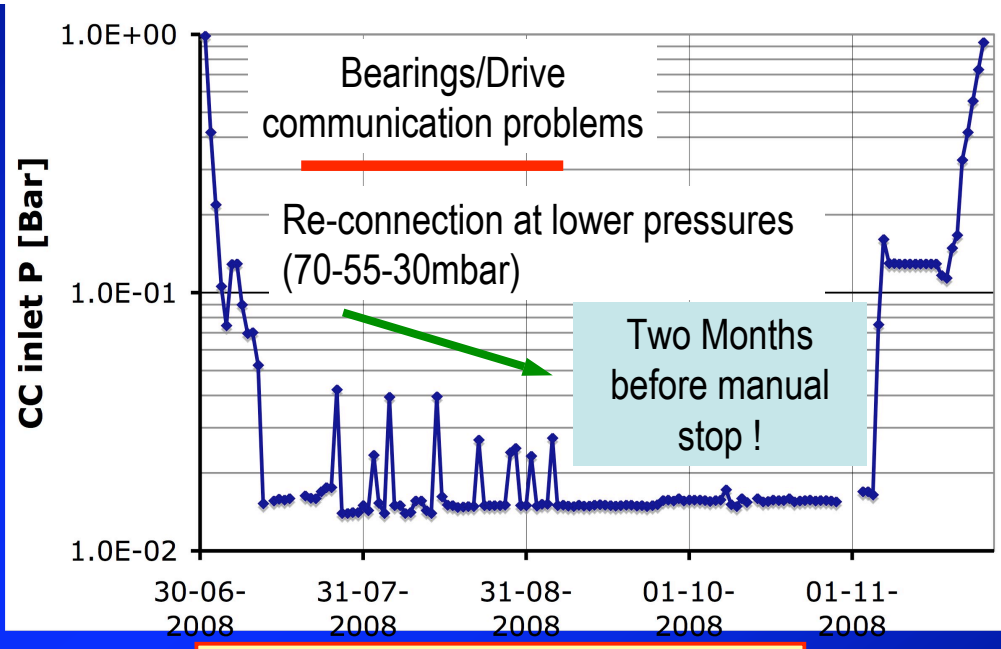
From QUI to QRL_RM

≈ 3300m

	Density [g/l]	Mass [kg]	Time flight
C [3B, 5K]	118	3058	5 - 12h
D [1.3, 8K]	8	467	1 - 4h
B [0.015, 4K]	0.18	29	4 - 12'

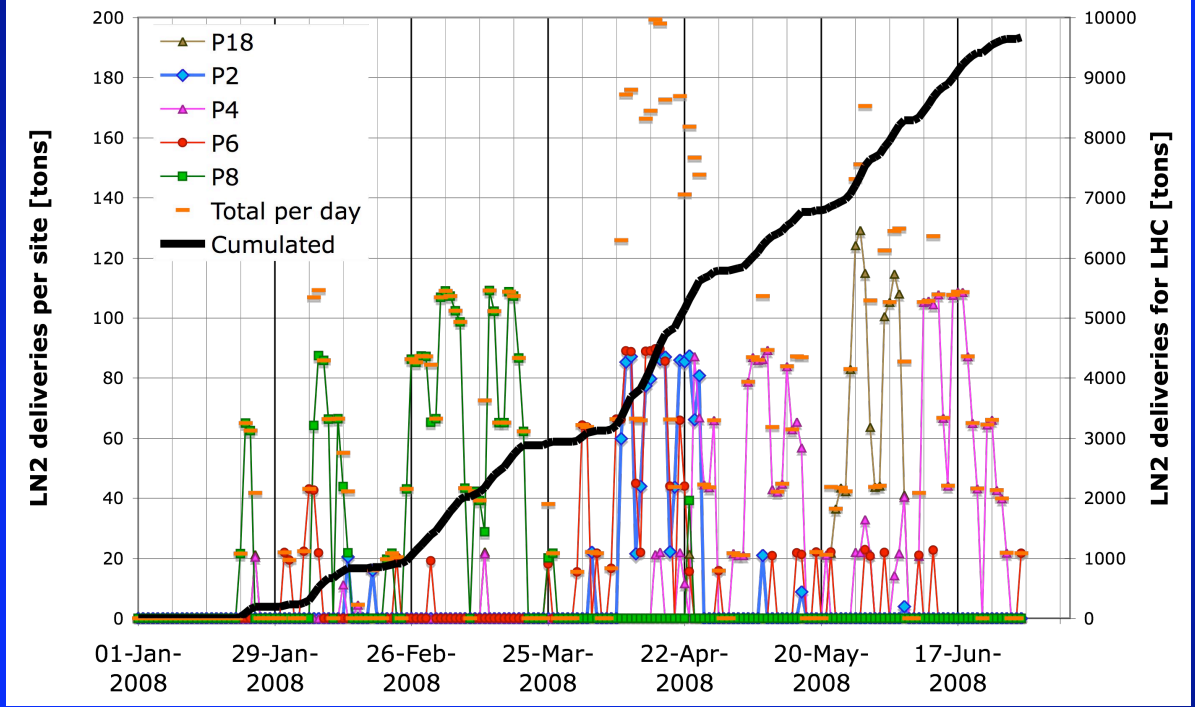
Changes on « supply conditions » may have an effect some hours later …

1.8K Units: Global significant progress !

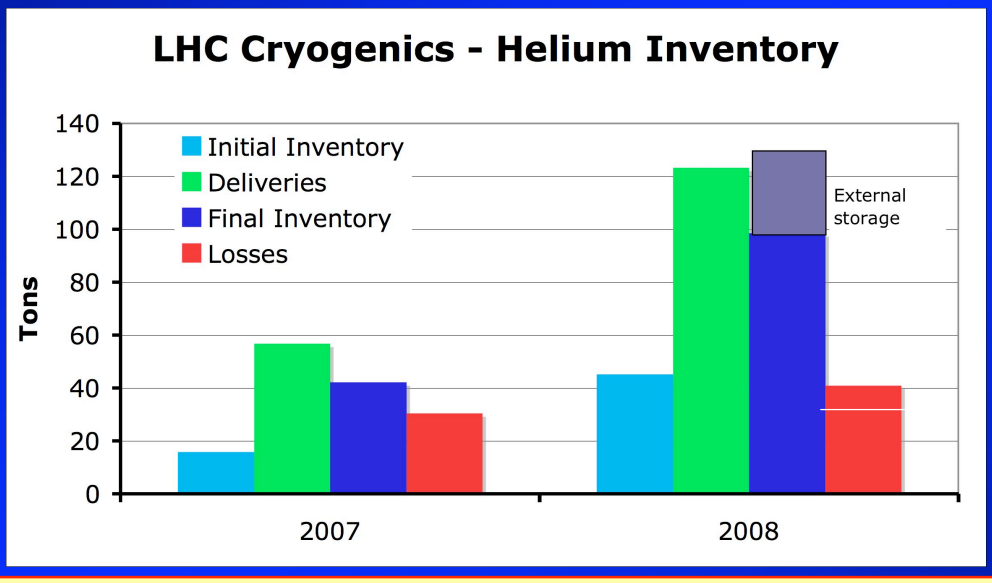


Better than 2wks MTBF Spring'08 !

Pre-cooling to 80K with LN2



Follow-up of Helium inventory



Similar (reduced ?) losses expected for 2009 due to purges/leak tests

Pre-defined program of increased LHe storage now launched !

LHC Cryogenic commissioning

- 2 K magnets in ARC
  - LT/EH at return modules
  - LT of SSS in ARC
  - EH at lowest point
  - EH of cold masses & beam screens
  - ⇒ Possible pump-down and cool-down of magnets, including tests with cold compressors

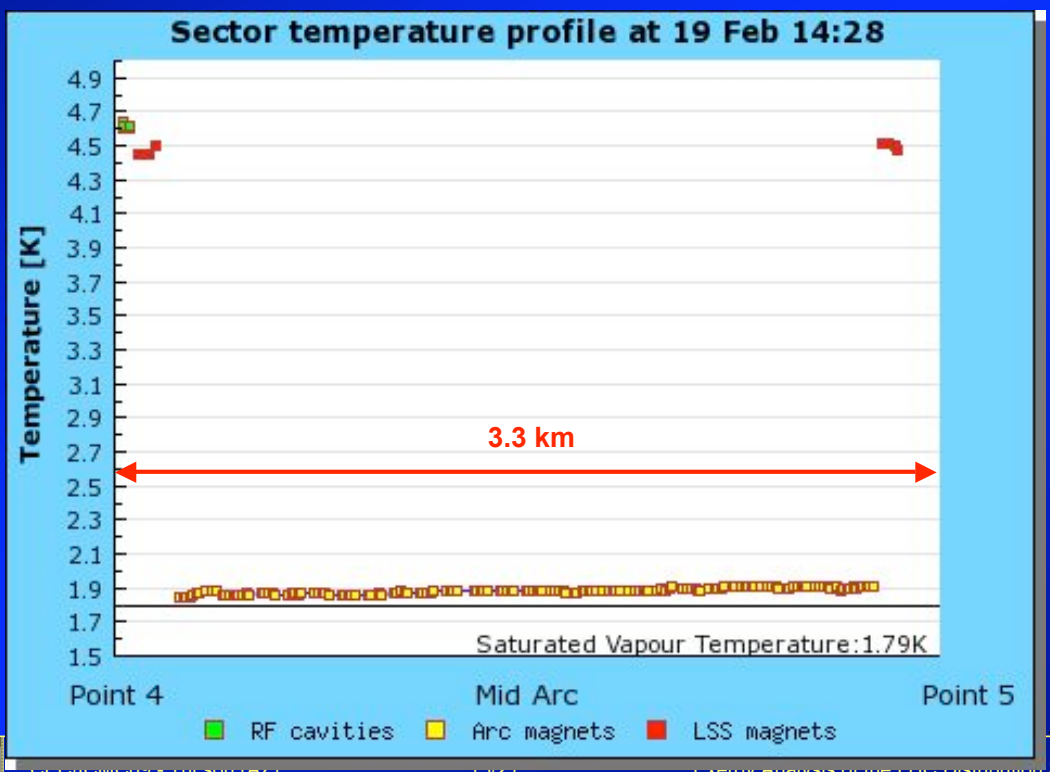
Identified and tuned in 2007,

Foreseen during the (target =two) weeks after ARC magnets @ 4.5K, some 6 weeks required each sector

2 weeks OK June 2009 for 1st time !

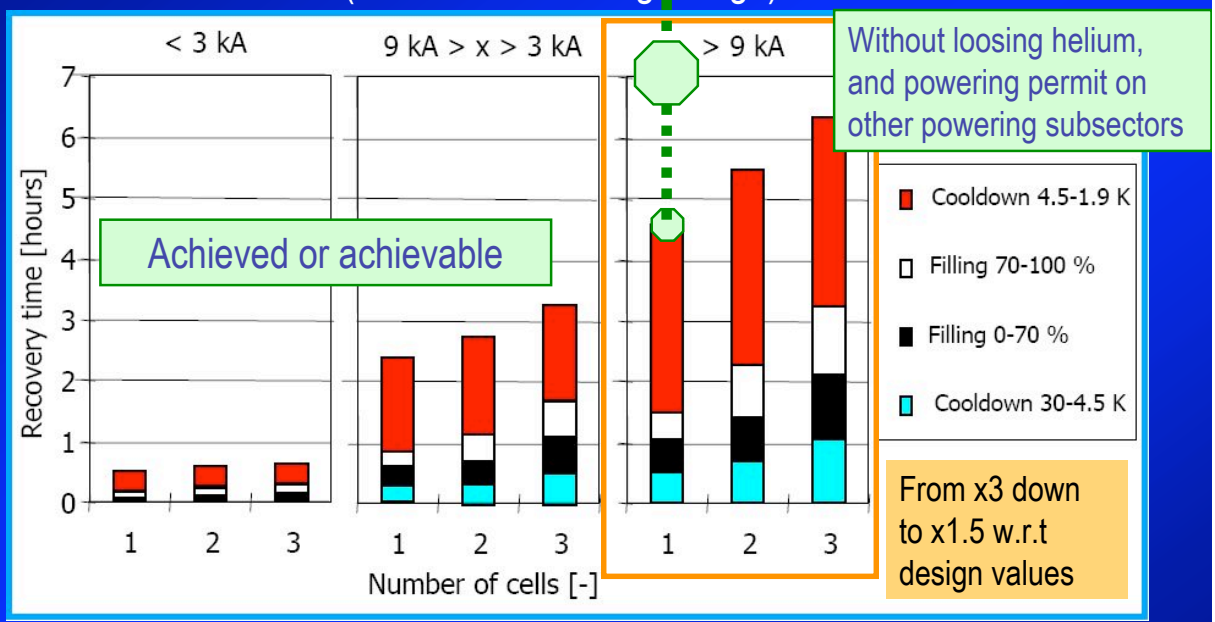
- 4.5K stand-alone magnets
  - Cool-down to < 10K
  - Adjust instrumentation LT/EH
  - Control LHe at 50%
  - ⇒ Fill-up and boil-off to determine appropriate set-point
- Electrical Feed Boxes (DFB's)
  - Cool-down shield (if any)
  - Cool-down leads at 150K, then cool-down phase separator
  - Adjust instrumentation LT/EH
  - Control LHe at nominal
  - ⇒ Fill-up and boil-off to determine appropriate set-point
  - ⇒ Tuning of Temp. control loops

Typical LHC sector temperature profile



Recovery Time after Limited Resistive Transitions

(Predictions at design stage)



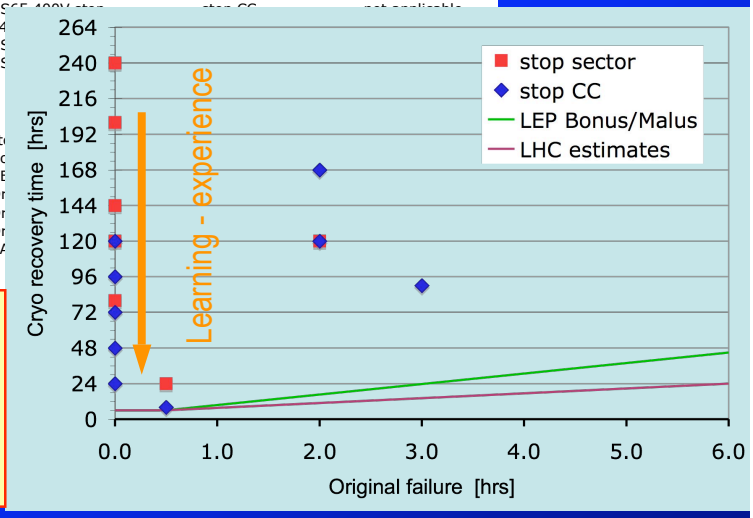
- More than 14 cells or full sector: recovery up to 48 hours
- In case of fast discharge (even w/o quench): 2 h recovery (heating due to eddy currents)

Analysis of stops & Recovery time

sector 56			origin (hrs)			stop (hrs)
1	29-Feb-08	Elec	2.0	Stop 400V (Pb AUG loop)	stop CC	168
2	12-Mar-08	Cryo	0.0	Controls CC (AL)	stop CC	not applicable
3	14-Mar-08	Cryo	48.0	Leak in 18kW Cold Box	stop CC	240
4	02-Apr-08	Cryo		Controls CC (AL)	stop CC	not applicable
5	04-Apr-08	Cryo		Stop 18kW Comp. (LS oil)	**stop entire sector**	not applicable
6	04-Apr-08	Water		Stop 400V P5 (water)	partly blind	not applicable
7	06-Apr-08	Cryo		Stop 18kW Comp. (LS oil)	**stop entire sector**	not applicable
8	18-Apr-08	Elec	0.0	Low 400kV	stop CC	96
9	30-Apr-08	Elec	0.0	CERN 400kV failure	**stop entire sector**	120
10	04-May-08	Elec		US65 400V stop	stop CC	not applicable
11	10-May-08	Elec		US65 400V stop	stop CC	not applicable
12	10-May-08	Elec		US[illegible]		
13	11-May-08	Elec	0.0	24		
14	22-May-08	Elec	0.0	US		
15	30-May-08	Elec	2.0	US		

sector 78				
1	18-Apr-08	Controls	3.0	st
2	26-Apr-08	Cryo	0.0	Cc
3	30-Apr-08	Elec	0.0	CE
4	09-May-08	Cryo	0.0	Dr
5	25-May-08	Cryo		Dr
6	26-May-08	Cryo		Dr
7	29-May-08	Elec + Water	2.0	VA

sector 81

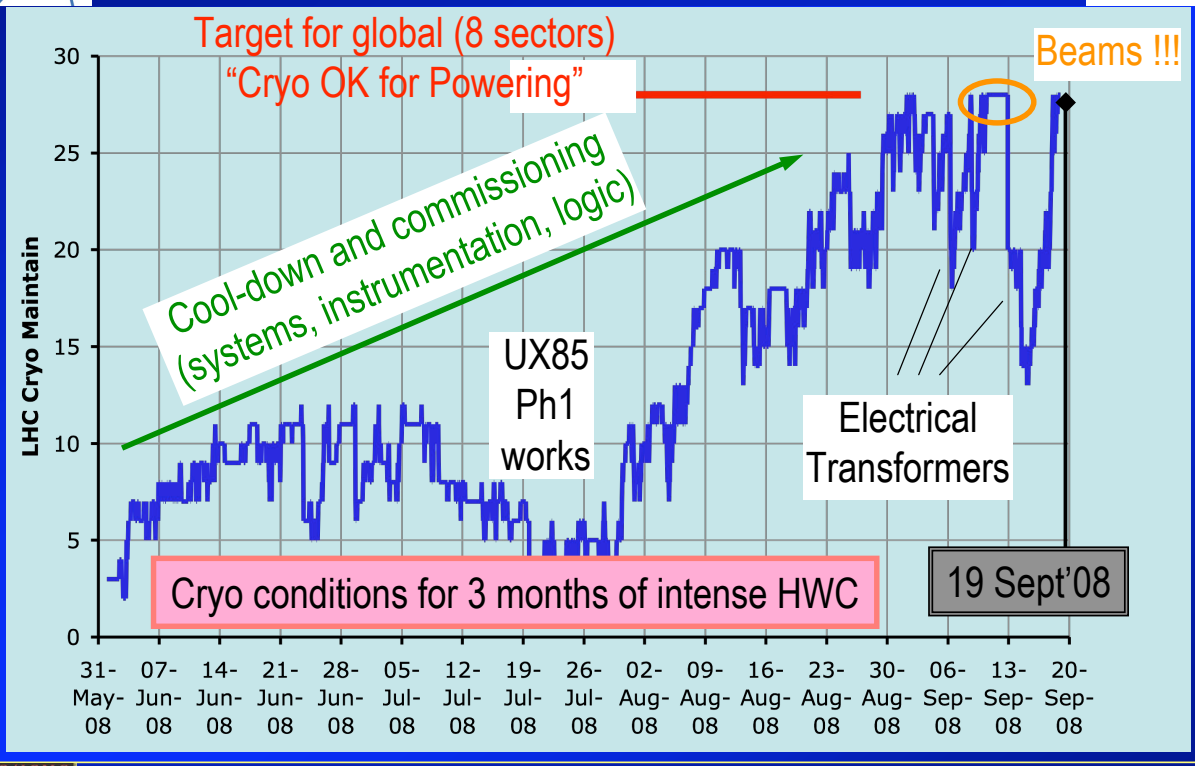


Recovery done Autumn'08:

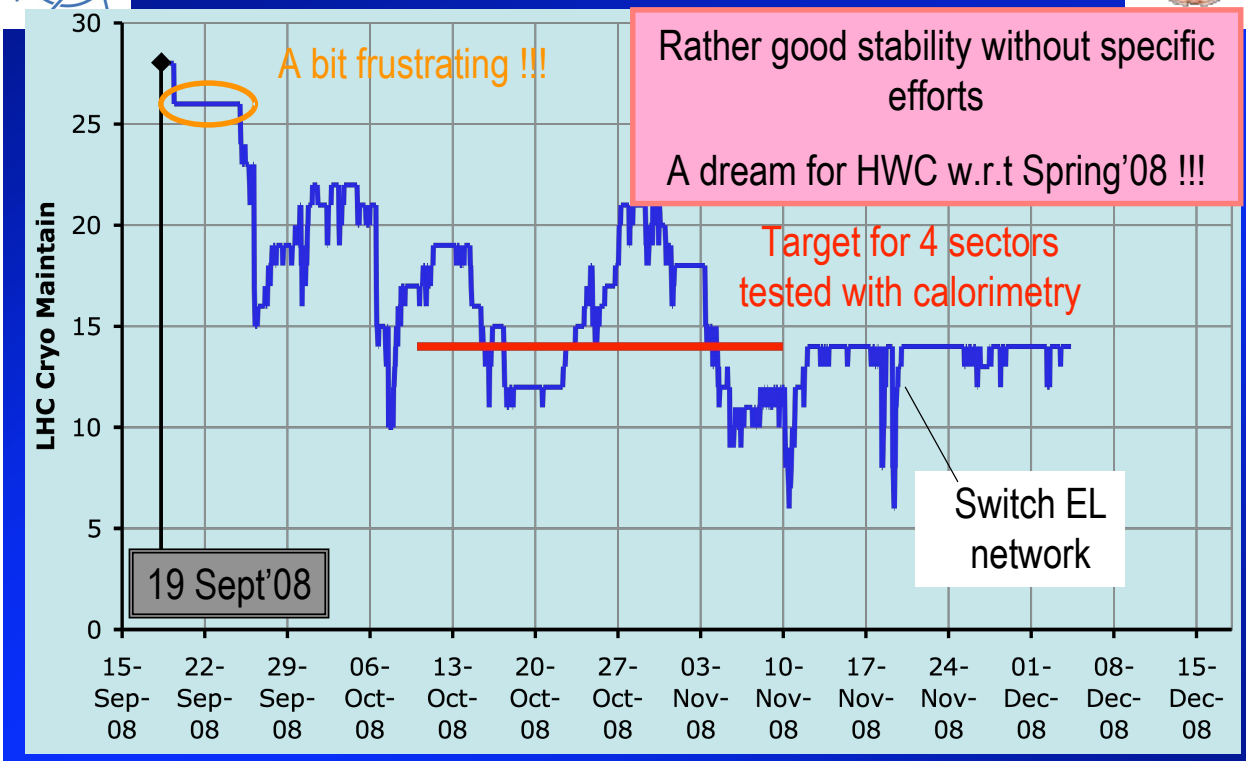
Stop CC: < 6-12 h

Stop 4.5K: < 12-24 h

LHC Cryogenics: towards beams



LHC Cryogenics: just after beams



Rather good stability without specific efforts

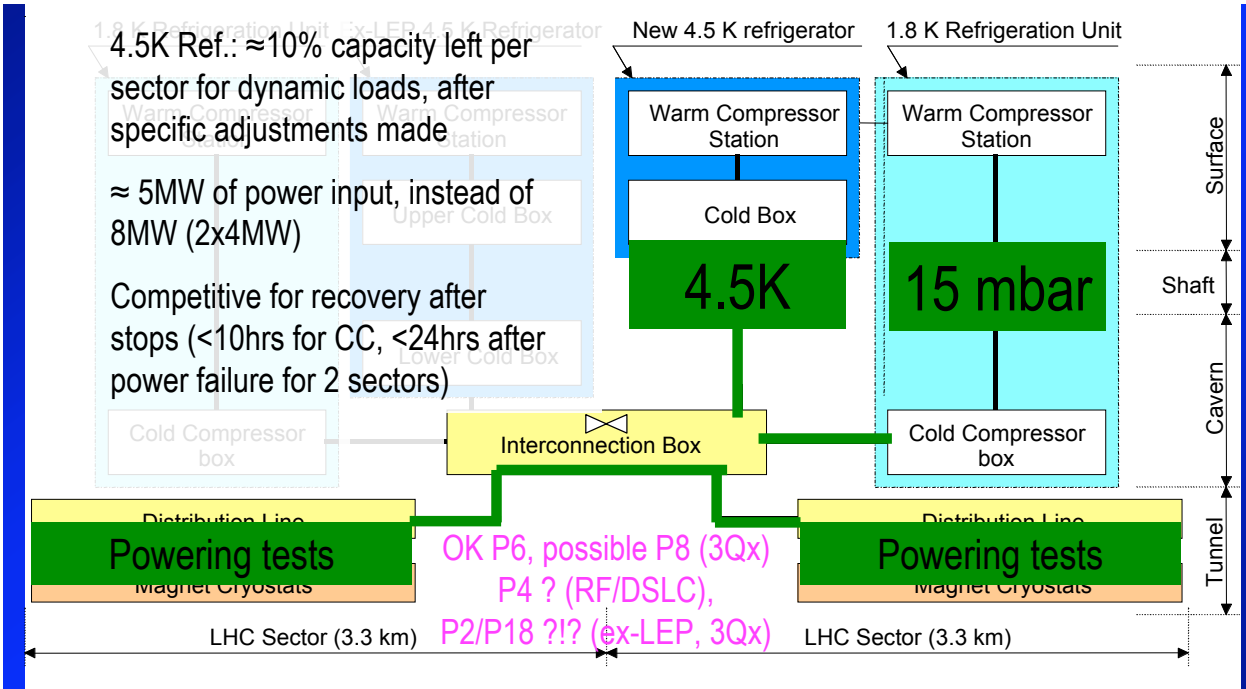
A dream for HWC w.r.t Spring'08 !!!

Two sectors on one cryoplant

4.5K Ref.: ≈10% capacity left per sector for dynamic loads, after specific adjustments made

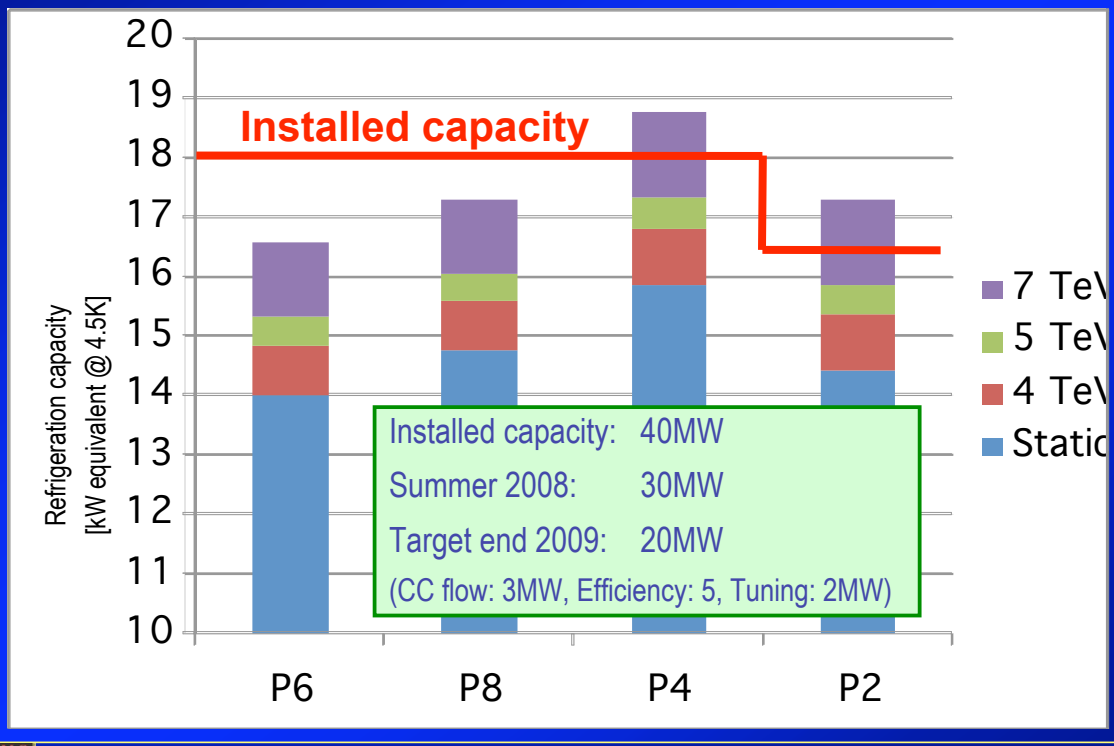
≈ 5MW of power input, instead of 8MW (2x4MW)

Competitive for recovery after stops (<10hrs for CC, <24hrs after power failure for 2 sectors)



Not valid for large transients, but an interesting feature for low beam loads, or validated fall-back scenario if serious problems with a refrigerator

Static heat inleaks and resistive heating



Summary

- LHC Cryogenic system has been put in operation with success and was “ready” for D-day
- With static heat loads and effect of resistive heating lower than specified, we have the foreseen global budget for expected dynamic loads, to be further checked at local levels
- Test programs were conducted to improve our understanding and tuning of sub-systems
- Nominal preventive maintenance and consolidation programs Services-Cryo-Machine are being implemented during this winter shut-down
- Operation with shift (1 x 5x8) to start spring’09, industrial support to help for big transients and possible others for specific cases

2009: from commissioning to real operation !

Part 2

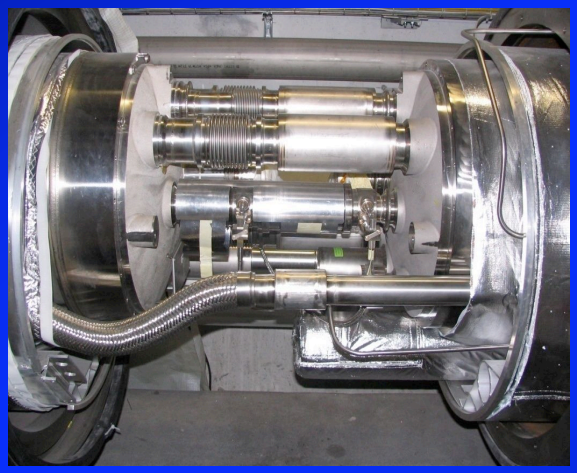
Situation of LHC project and perspectives

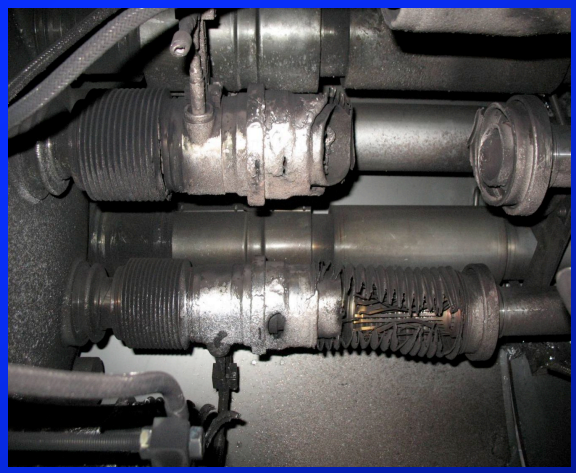
(Presented at the end of "LHC Session")

19 septembre incident in sector 3-4
Electrical arc between two dipoles

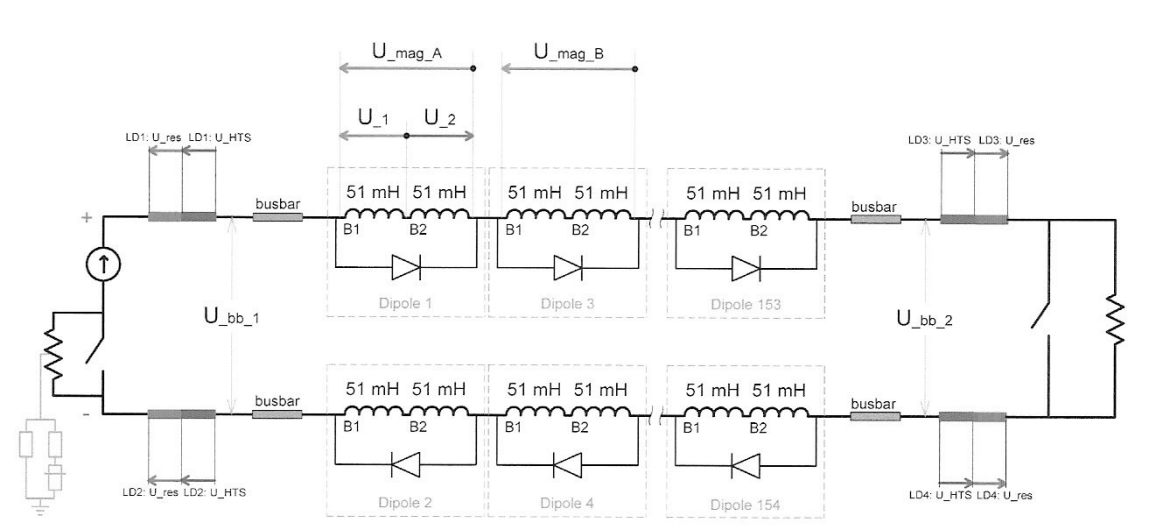
Dipole circuit of sector 34 already powered up to 7 kA

During a ramp to 9,3 kA (corresponding to 5,5 TeV), an arc occurred at 8.7 kA, melting busbars and destroying the helium vessel and beam pipes

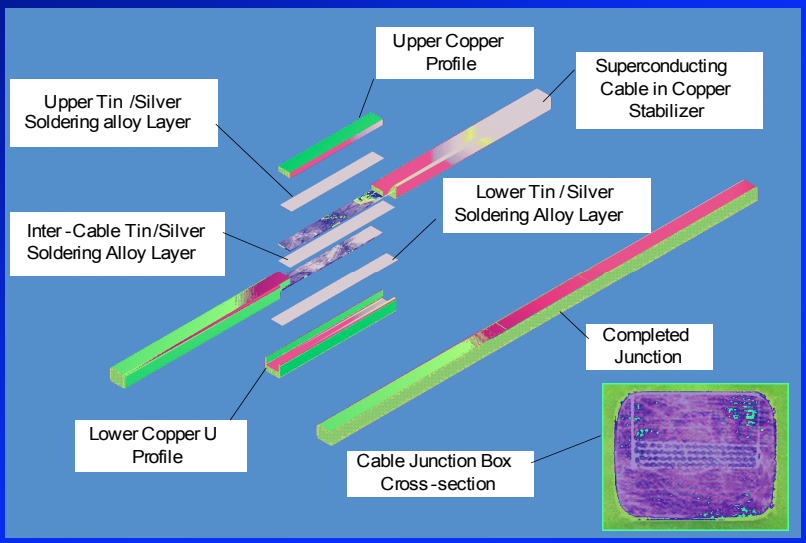




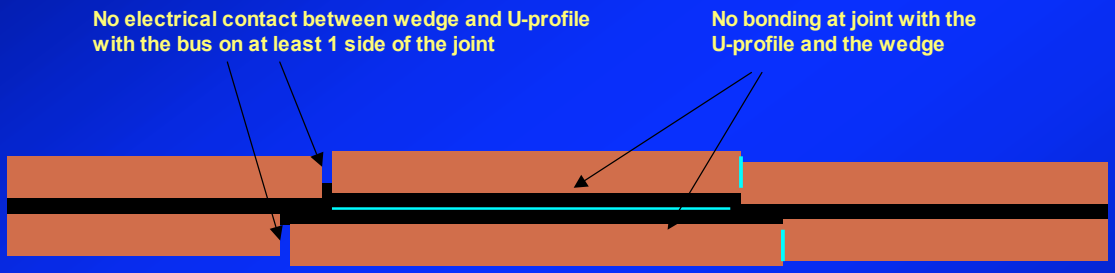
Dipoles powering circuit scheme



12 kA busbar junction



Busbar junction between dipoles at 220 nΩ with bad electrical and thermal contacts with Cupper stabilizer !

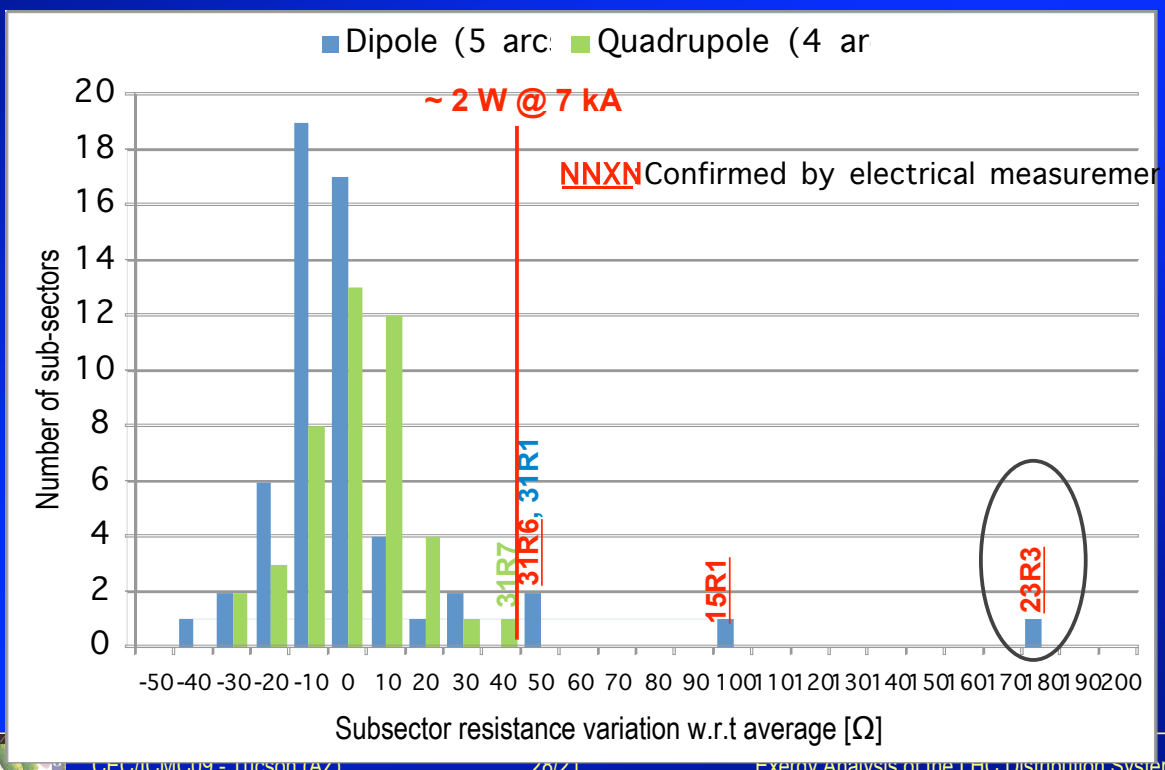


⇒ Loss of clamping pressure on the joint, and between joint and stabilizer

⇒ Degradation of transverse contact between superconducting cable and stabilizer

⇒ Interruption of longitudinal electrical continuity in stabilizer

Arc sub-sector resistance variation assessed by calorimetry



LHC recovery baseline

Cu resistivity measurements:

- 300 K (done RBx4, underway RQ)
- 80 K (done 45, interpretation?)

Simulations / Tests to define tolerated resistivity w.r.t magnet current and discharge constant

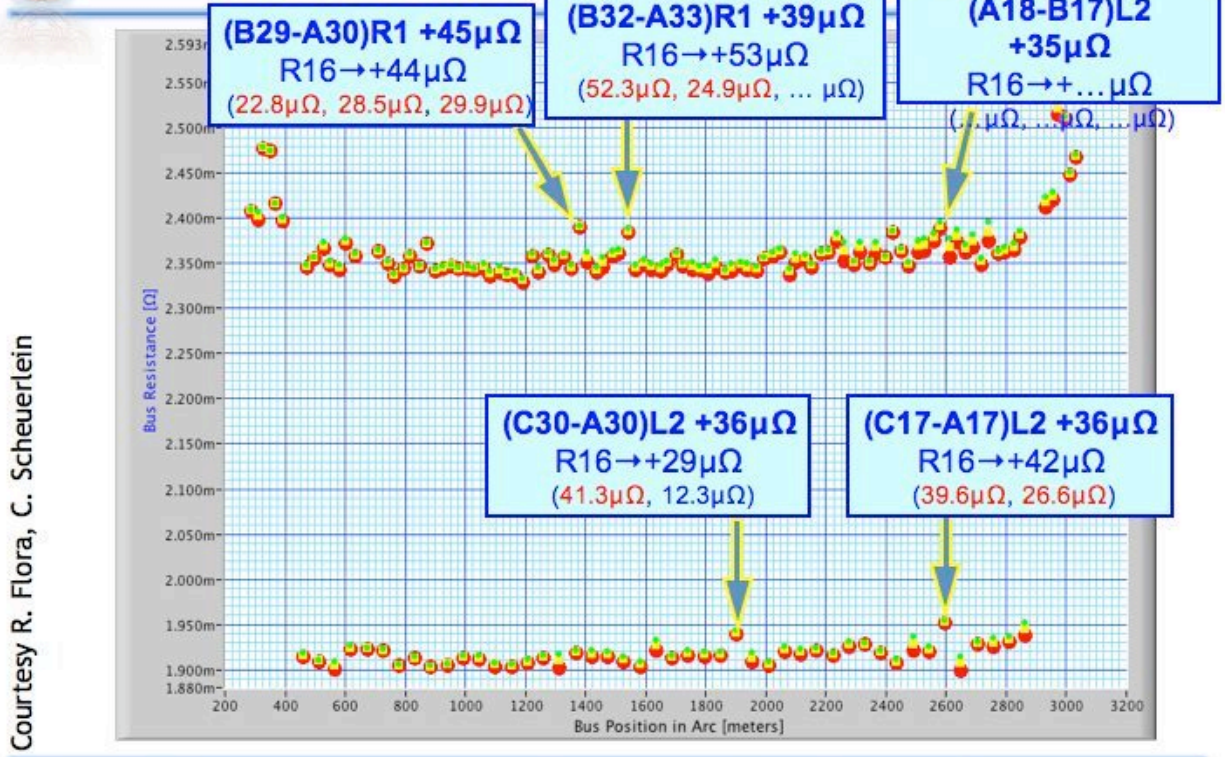
Possible scenarii:

- ø reparation => ≈ 3 Tev
- 1, 2, 3, … reparations => 4 - 5 Tev

To be done:

- Correlation 80K-300K on sector 45 (warmed-up), repair strong cases
- Prepare to measure 23-78-81 at 80K for decision end July 2009

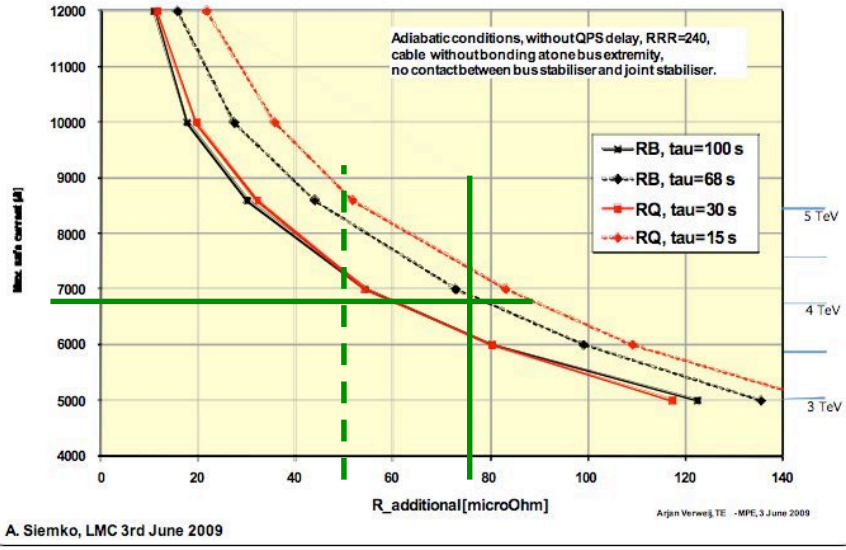
1-2 M3 splice resistance (copper)

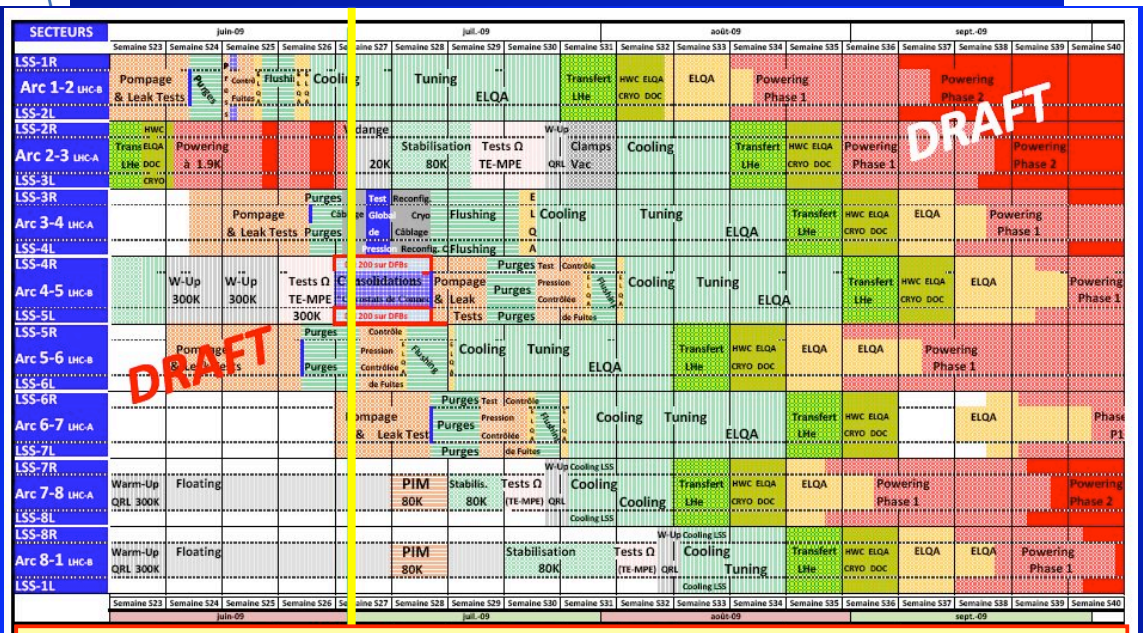


Courtesy R. Flora, C. Scheuerlein

Input B: Thermal runaway current

Ongoing calculations





The present schedule should allow beams circulating Oct - Nov 09, with tuning for physics and run until Autumn 2010