LHC status and commissioning plans

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10th September 2007

Acknowledgements: R. Bailey, M. Lamont

Outline

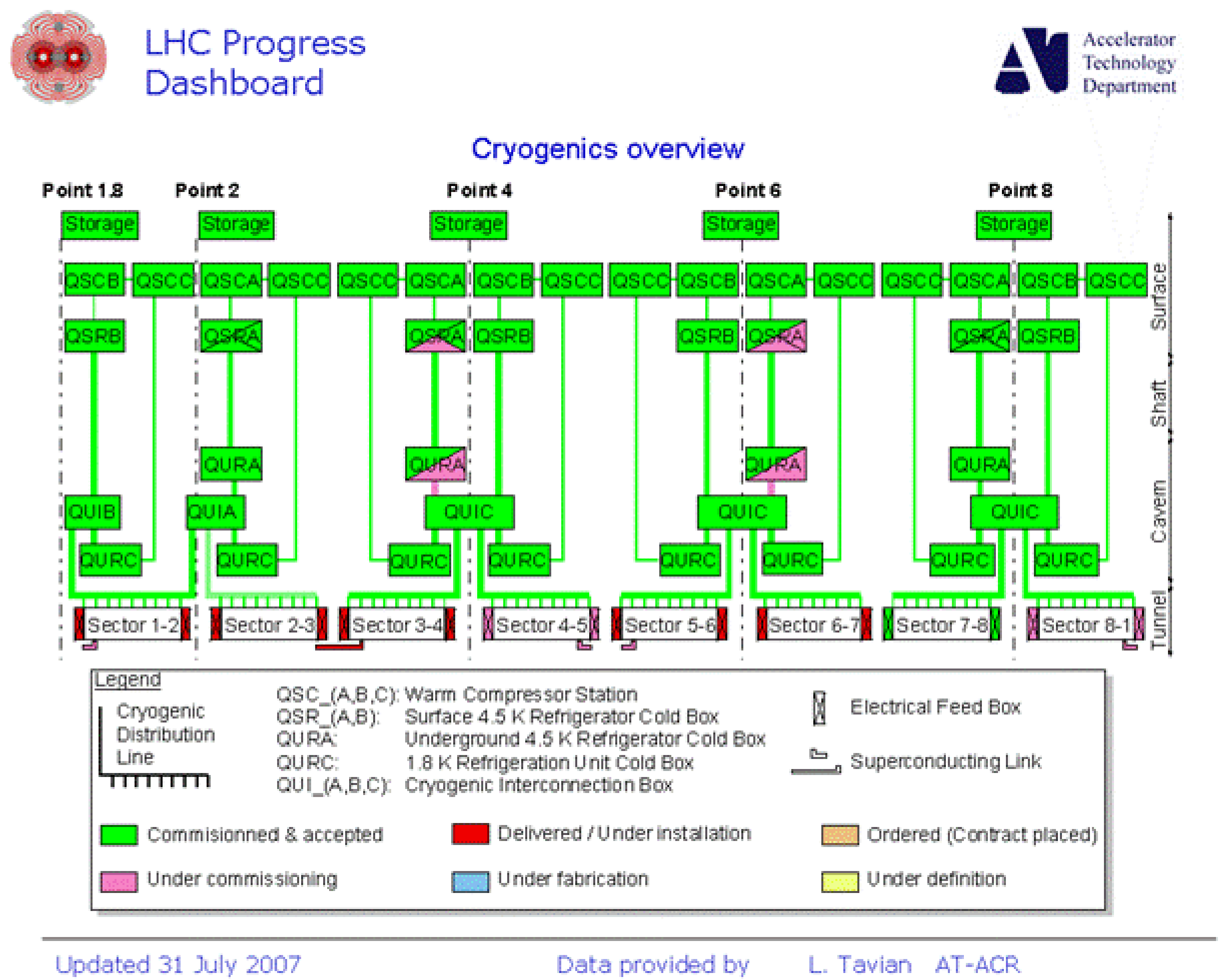
- Status of the main systems
- HW Commissioning status
- Progress to date
- Present schedule
- Commissioning plans

Cryogenic System (QRL)

3.3 km of QRL per sector
2100 internal welds
700 external manual welds

Installation started in sector 7-8 in July 2003
Geometry, weld quality, procedures, leaks, support tables …
Installation finished November 2006 (sector 7-8 by CERN)

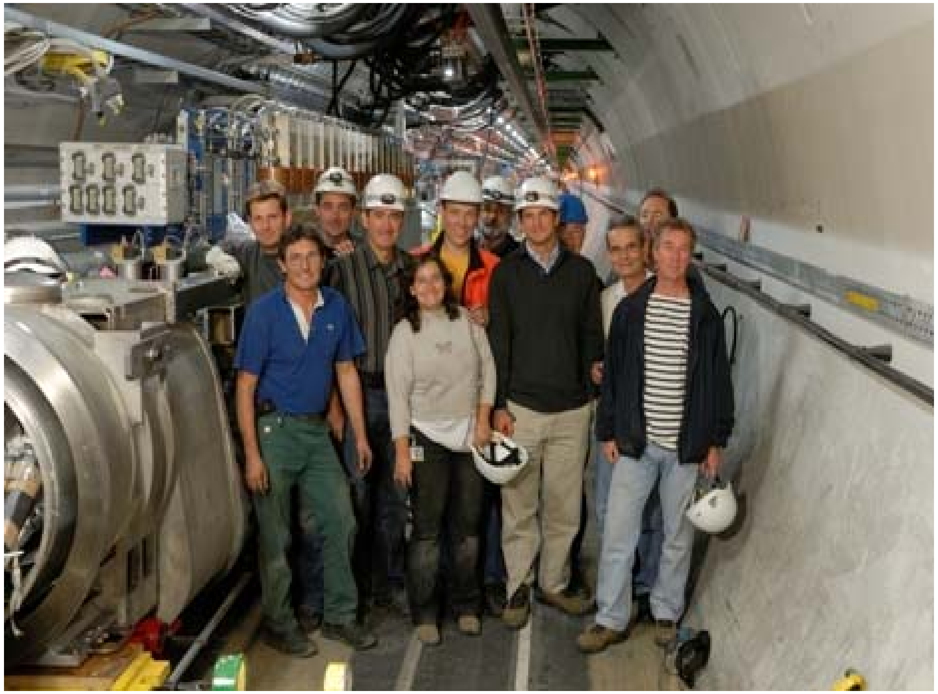
Cryogenic System



DFBs (feedboxes)

Function: feeding the room temperature cables into the cold mass.

Were on the critical path



DFBA - arcs
DFBM - quads
DFBL - links
DFBX – triplets

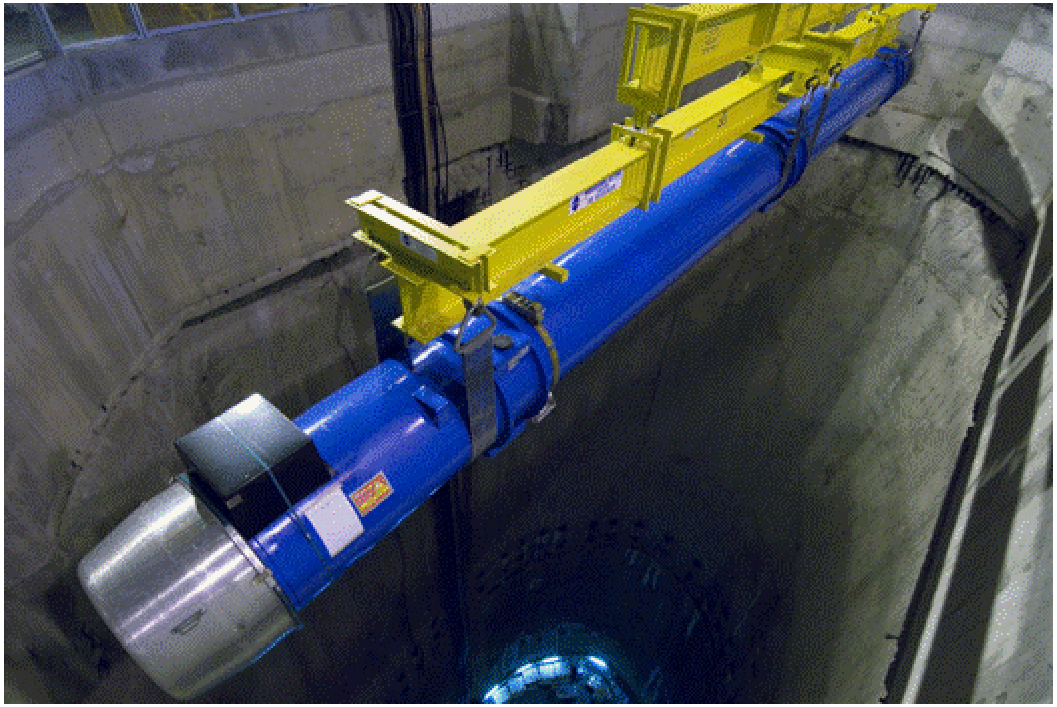
Main Magnets

First magnet installed March 2005

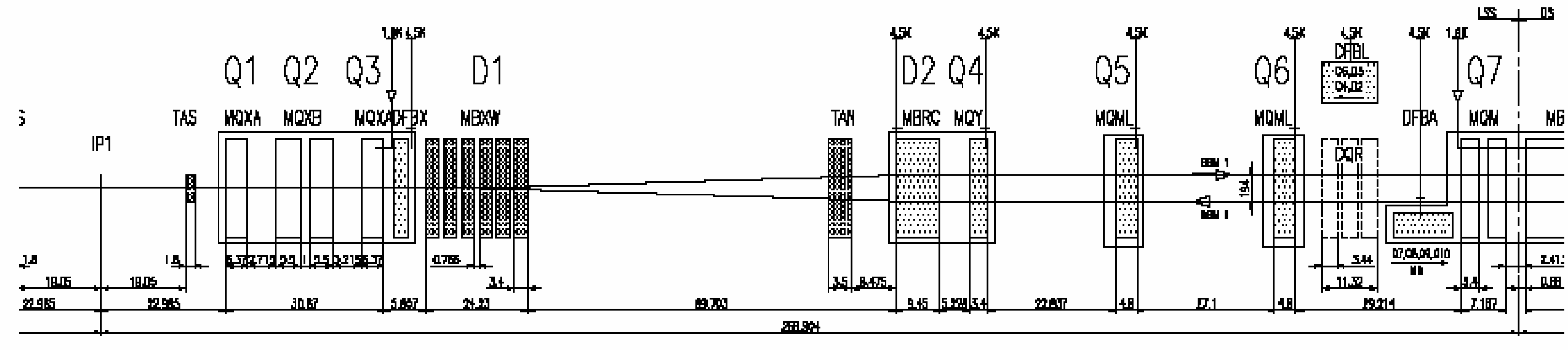
- Peak of ~1000 dipoles stored, allowed magnet sorting

Last magnet lowered April 26th 2007

- Transport: 30’000 km underground at 2 km/h!
- Cryostating: 425 FTE.y
- Cold tests: 640 FTE.y



LSS: Inner Triplets



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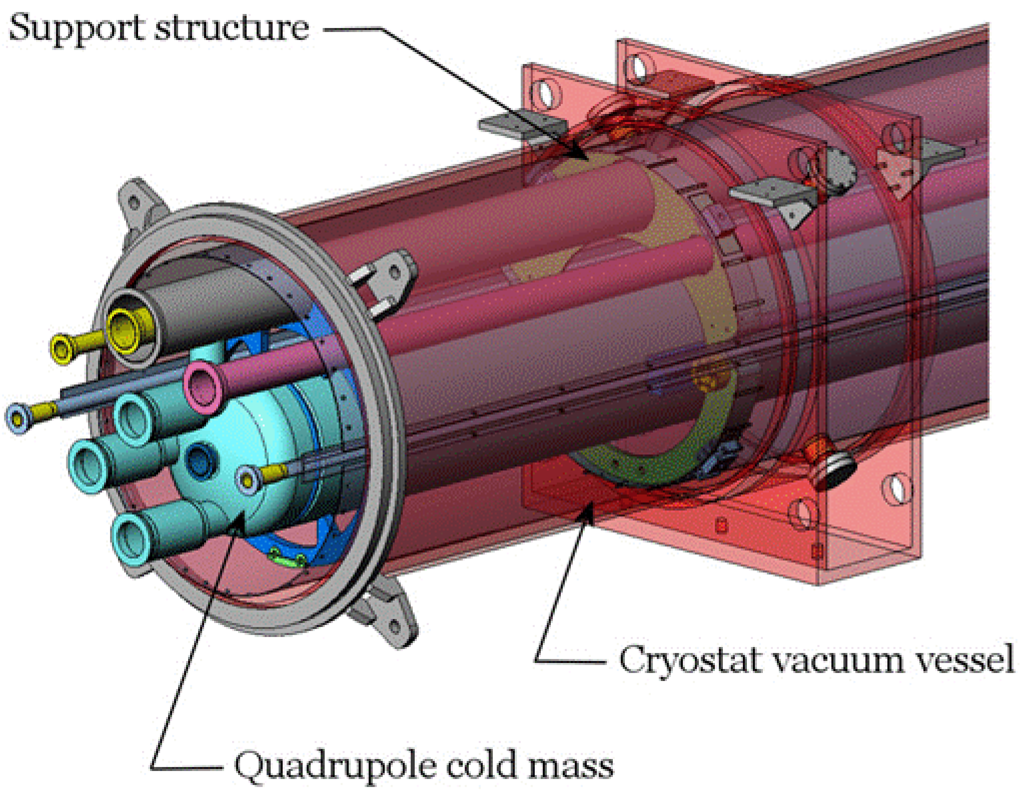
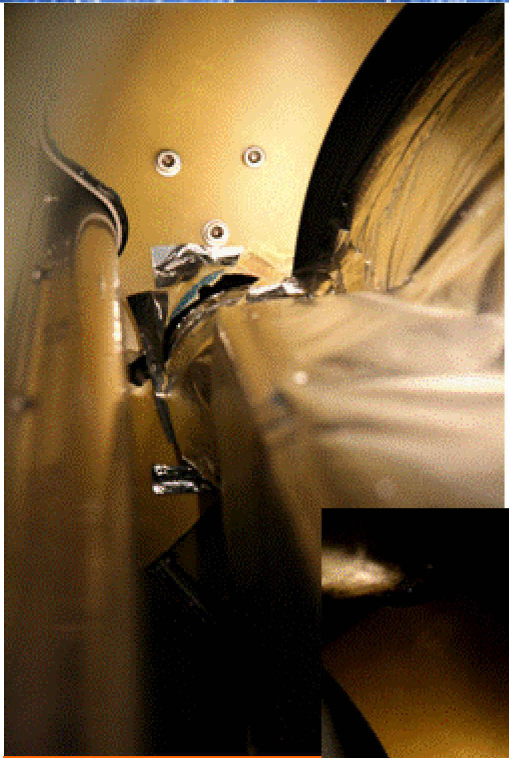
Triplets – Heat Exchanger problem

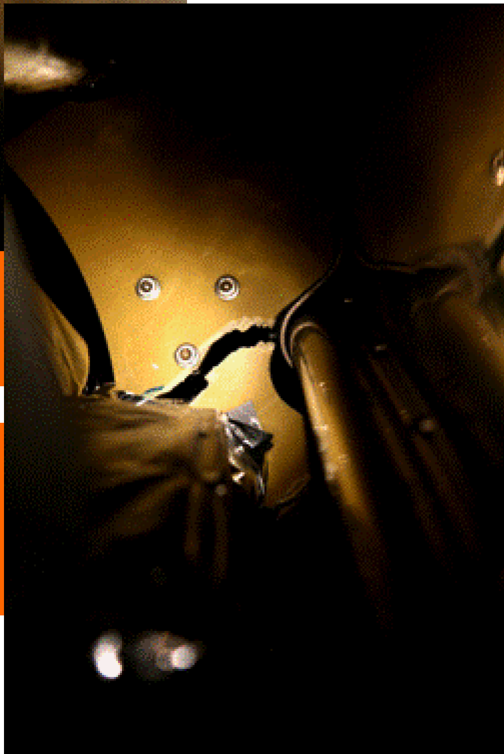
- During the pressure test of Sector 7-8 (25 November 2006) the corrugated heat exchanger tube in the inner triplet failed by buckling at 9 bar (external) differential pressure. It should stand Δp~20 bars (case of a quench).
- Reduced-height corrugations and annealing of copper near the brazed joint at the tube extremities accounted for the insufficient resistance to buckling.

- New tubes were produced with higher wall thickness, no change in corrugation height at ends, and e-beam welded collars to increase distance to the brazed joint.
- Installation of these tubes was made *in situ*.

Triplets Supports: problem



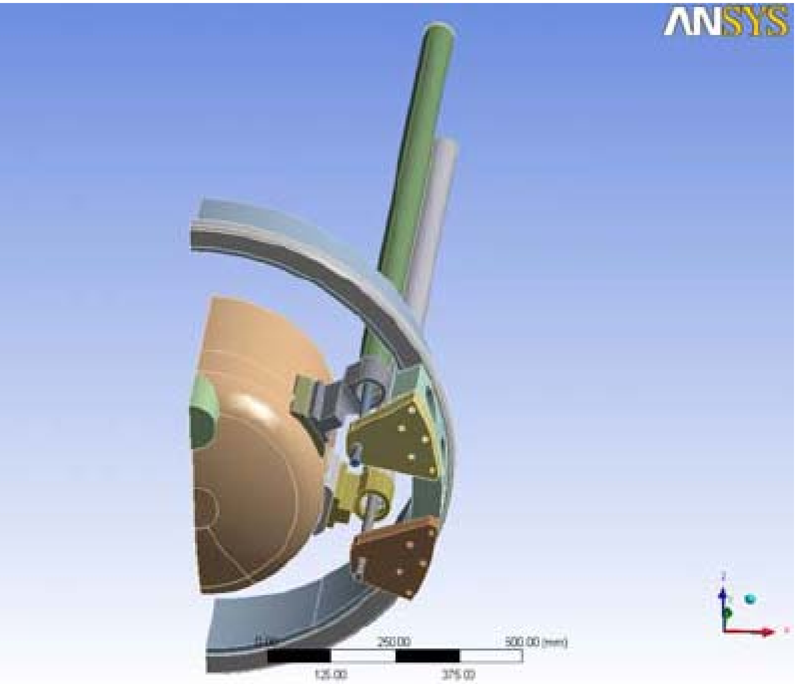




Q1 supports at IP 5L

On March 27 2007 serious failure in a high-pressure test at CERN of a Fermilab-built "inner-triplet" series of three quadrupole magnets with repaired Heat Exchanger

Triplets Supports: solution



Solution adopted

- Affixed at Q1 non-IP end and at Q3 IP end
- Transfer load at all temperatures
- Limits support deflections
- Compound design with Invar rod and aluminium alloy tube
- Attached with brackets to cold mass and cryostat outer vessel
- Successful pressure test (25 bars for 1hour) on Triplet – right of point 8 on 13/7

Status

- All low-β have been repaired, interconnection work proceeding as scheduled

Vacuum System

Shutdown 7-8

Status of insulation vacuum global leak testing - 31/07/07

Found wk 30

Sector	1R	4R	5R	6R	7R	11R	15R	19R	23R	27R	31R	31L	27L	23L	19L	15L	11L	7L	6L	5L	4L	1L
SECTOR 7-8	-	-	-		lk,c'k							lk,m						n/a				
SECTOR 4-5	-	D3			lk,m		lk,c'k?												n/a	n/a		
SECTOR 8-1							lk,m		lk,c'k										n/a	n/a		
SECTOR 3-4	-	-	-						lk,m		lk,x										D3	-
SECTOR 5-6							lk,m		lk,m			lk,m							-			-
SECTOR 6-7	-			-																-	-	-
SECTOR 2-3										T		T	T	T						-	-	-
SECTOR 1-2																						

(VACSEC. spans columns 1R to 1L)

repaired & re-pumping

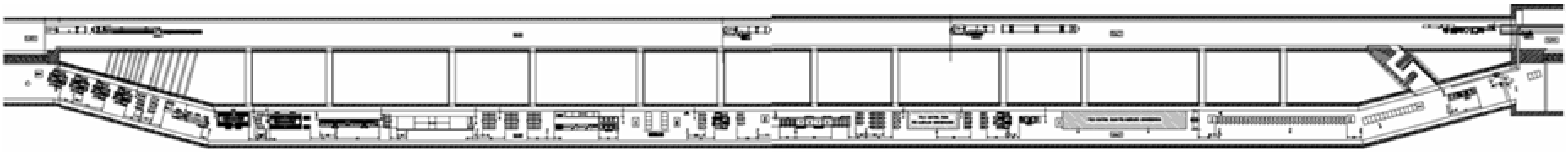
- Subsector pressure & leak tested
- Subsector leak tested at 1 bar
- Subsector evacuated (T - on turbo)
- Subsector to be delivered < 1 week
- lk On-going leak repairs
- Subsector mechanical assembly postponed

Found 1/8/07

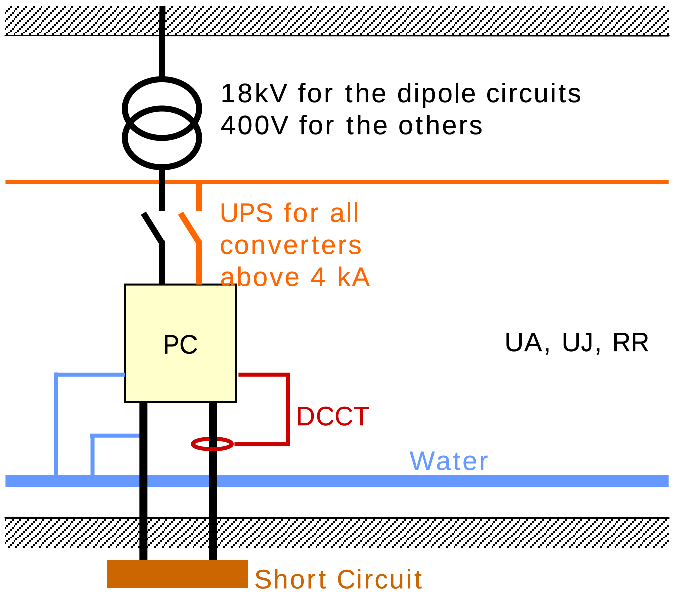
Found 2/8/07

10^{-3} mbar l/s near Q17R8 – problems to precisely locate
Go ahead with sector flushing in September (3 weeks)
Refine leak localisation techniques and try to fix in situ

Power Converters



1720/1720 installed



Commissioning campaign on short circuit
From mid 2006 to now ~100% commissioned

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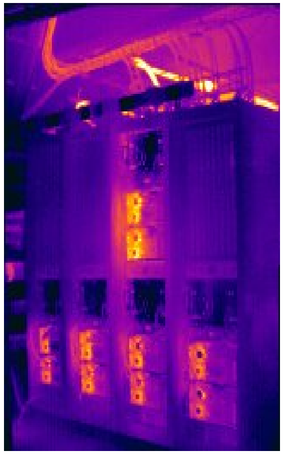
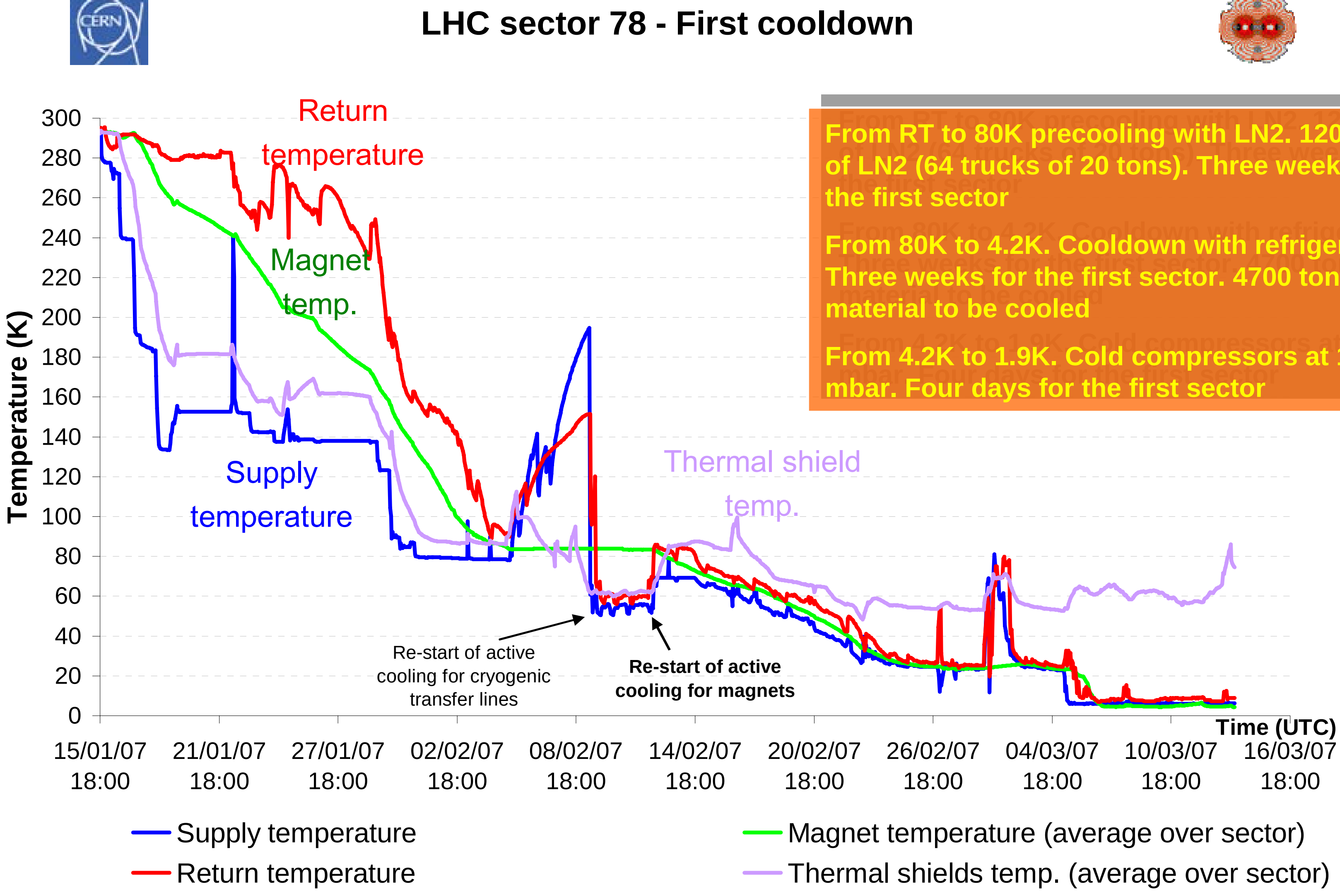


First cool down: Sector 7-8

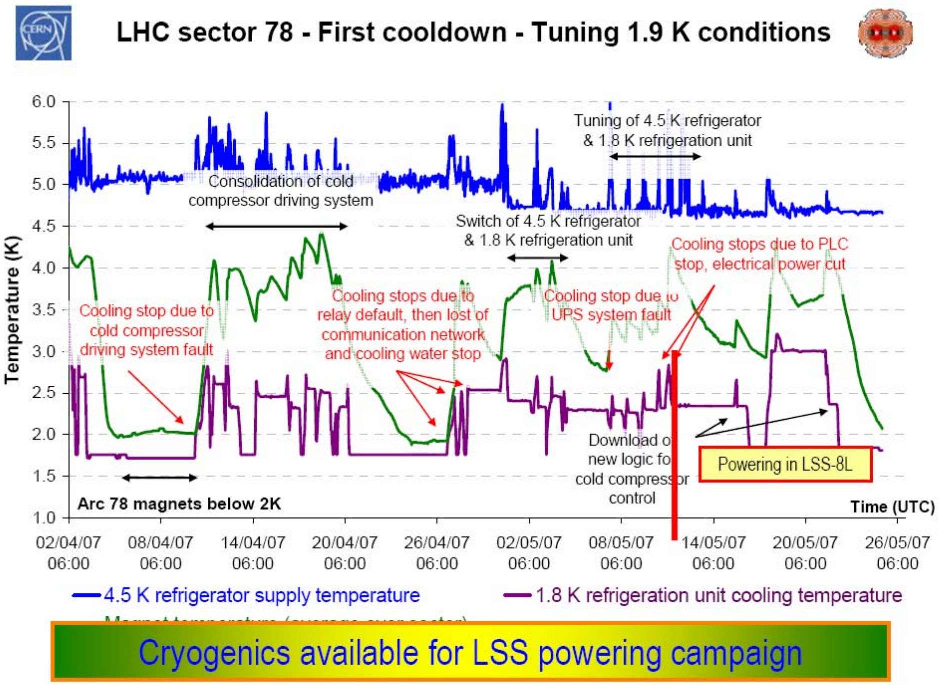


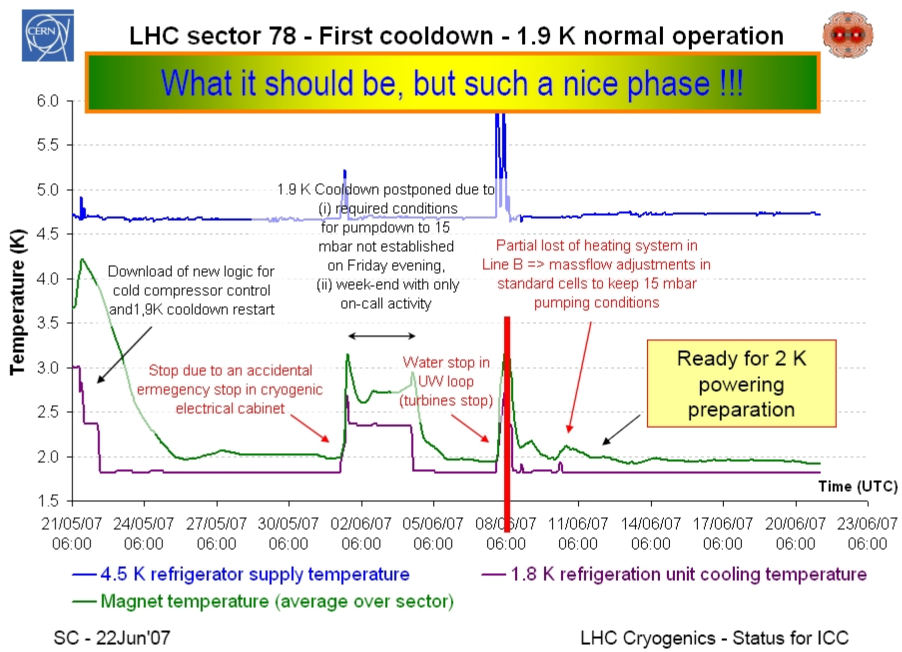
From RT to 80K precooling with LN2. 1200 tons of LN2 (64 trucks of 20 tons). Three weeks for the first sector

From 80K to 4.2K. Cooldown with refrigerator. Three weeks for the first sector. 4700 tons of material to be cooled

From 4.2K to 1.9K. Cold compressors at 15 mbar. Four days for the first sector

First cool down: Sector 7-8





- 4.5 K systems available for powering late May
- 1.9 K systems available for powering mid June
- Teething problems with cold compressor operation
- Series of failures on the technical services
- Initially using an upgraded LEP cryo-plant
- ~40 % more He required than expected (exact reason being investigated)

Power tests

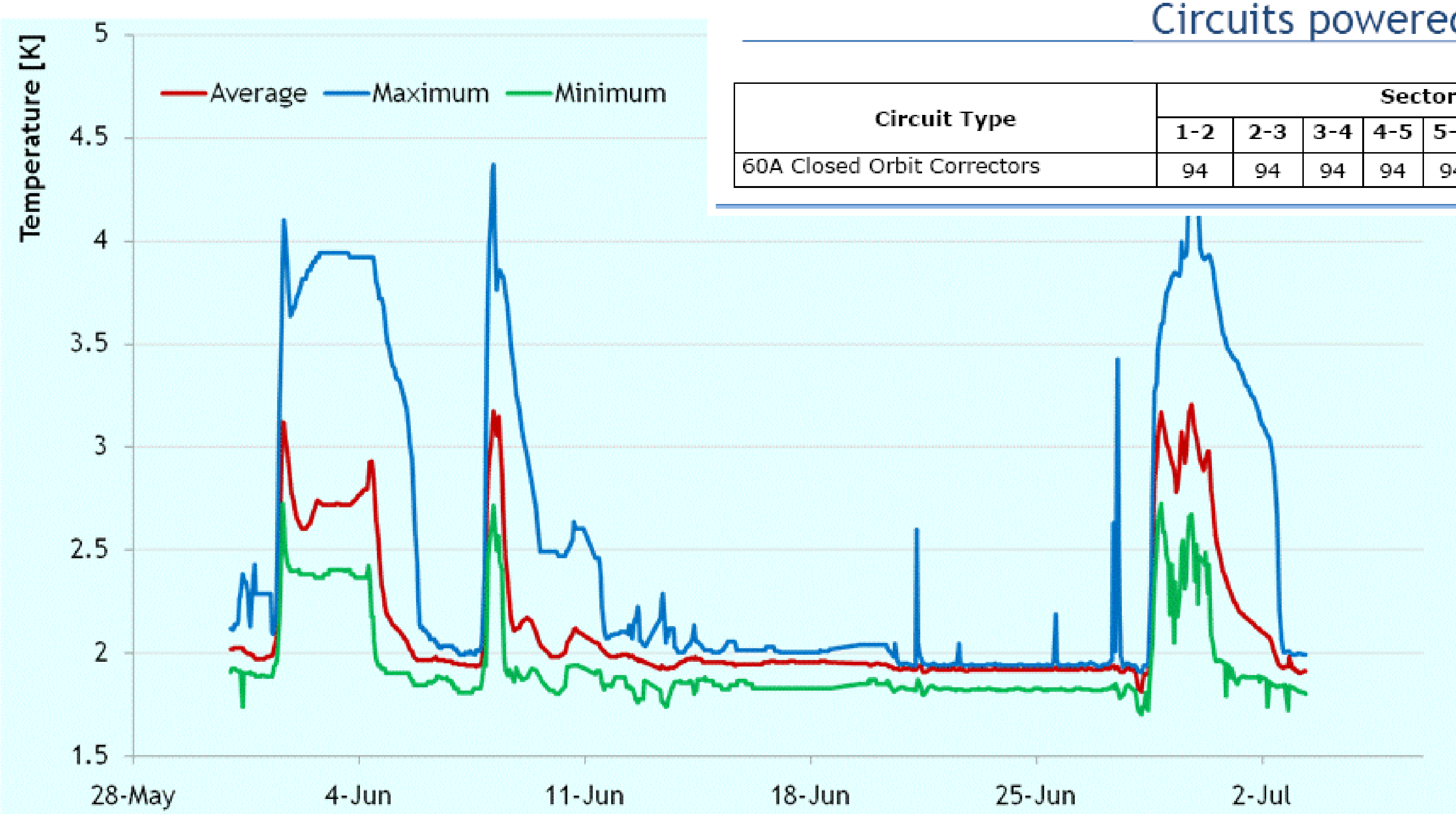
Reduced scope due to reduced time and suspected inter-turn short on dipole 1055

Circuit Type	Sector								LHC
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1	
13 kA							3	3	24
Indipendently Po							2	3	16
Indipendently Po							7	14	78
600A with Energy							27	23	202
600A Energy Extr							20	14	136
600A no Energy E							9	16	72
80-120A Correcto							37	50	284
TOTAL							**105**	**123**	**812**

Limited Current: RB (2 kA), RQD (6.5 kA), RQF (350 A)	3
Only RD2, Inner triplet dipole not available	1
Only RQ4 and RQ5	2
14 Line-N Circuits, 3 spool piece correctors & 2 MQTLH	19
Three Line-N Circuits	3
RCO and inner triplet correctors not available	0
Q4 and Q5 available correctors	7
Minimum Total Required	**35**

Circuits powered from the arc

Circuit Type	Sector								LHC
	1-2	2-3	3-4	4-5	5-6	6-7	7-8	8-1	
60A Closed Orbit Correctors	94	94	94	94	94	4	94	94	752



Power tests – achieved

Main Circuits at 1.9 K	RB (main dipole circuit)	Powered successfully up to 2kA
		Provoked quenches at 760A and 2kA
	RQF & RQD (main quads)	Powered successfully up to 6.5kA
		Provoked quenches at 760A and 2kA and 6.5kA
Circuits in the Matching Section Left of Point 8 at 4.5 K	RD2	Powered successfully up to 6kA
		Provoked and training quenches at different current levels
	RQ4 and RQ5	Powered successfully up to 3590A and 4210A respectively
		Provoked and training quenches at different current levels
	RCBYH4.L8B2 RCBYV4.L8B1 RCBYHS4.L8B1 RCBYVS4.L8B1 RCBYVS4.L8B2 RCBCH5.L8B1 RCBCV5.L8B2	Powered successfully up to nominal current
600 A Circuits at 1.9 K	Line-N: RQT12.L8B1 RQTF.A78B1 RQTD.A78B2 RQTF.A78B1 RQTF.A78B2 RQS.L8B1 RSD2.A78B1	Powered successfully up to 200A (RQS.A78 up to 550A)
		None bad splice found so far
	Spool Pieces: RCO.A78B1 RCS.A78B1 RCS.A78B2	Powered successfully up to 200A
60 A 1.9 K	32 Closed Orbit Correctors	Powered successfully up to 55A
		Two circuits experienced natural quenches

Sector 7-8 Consolidation

Arc/non recurrent	
Replacement of wrong Plug in Modules	Removal complete - First adapted ones available
Replacement of cryodipole 1055	New dipole installed
Inspection of line N splices	Several non conformities found 5 to be fixed
Repair of bus bars on the SSS 500 series	Progressing on schedule
Improve CC splices on instrumentation	OK
Replace damaged X line bellows	OK
LSS/non recurrent	
Triplet repair	Q1 had to removed; broken spider
Replace O rings on DFBA	Vulcanised seal available in September
Improve electrical insulation of DFBAO	Will be opened on August 20
Q4-D2 opened for inspection	Support to be reinforced
Arc/potentially recurrent	
Short on MBB circuit at dipole 3006	Defect found and repaired
Short on MQD circuit	Defect found and confirmed as source
Leaks at 32L8 and 7R7	32L8 found. 7R7 not yet localised.
Cryogenic heaters; burnt MLI	Discovered during 1055 intervention
Check and repair of Y line interconnection	Badly soldered line Y to phase separator
LSS/ potentially recurrent	
DFBMC non conformities on 120A circuits	HV breakdown repaired. High resistance on Q5 side

Shielded Bellows (PiMs)

Function: guarantee electrical continuity for image currents induced by the beam to avoid instabilities

Plug in Module (PiM) in equivalent cold position

Shielded Bellows (PiMs)

QQBI.26R7 line V2

Shielded Bellows (PiMs)

Quadrupole-Dipole interconnects in the DS

- 15 PIMs were wrongly installed and cut out for replacement
- Of these, 7 PiMs had fingers buckled into the beam aperture
- These PIMs were all working outside their specified range

Expected

Q11-Connection cryostat in 8L (QQEI.11L8)

- 2 fingers in the V2 line buckled into the beam aperture
- 8L was equipped with a standard SSS-MB PIM
- However, Q11 is 20% longer than a standard SSS, so the PIM was operating under different conditions to the arc
- The working conditions are being revised

Surprise

Quadrupole-Dipole in 26R7 (QQBI.26R7)

- 1 finger in V1 line and 8 fingers in V2 buckled into the aperture
- This is a standard arc interconnect by design
- There were at least 2 particularities noted
  - The installed length of the PIM was ~4 mm longer than nominal
  - The contact finger bending angles were out of tolerance

Surprise

PiMs summary (September 5th)

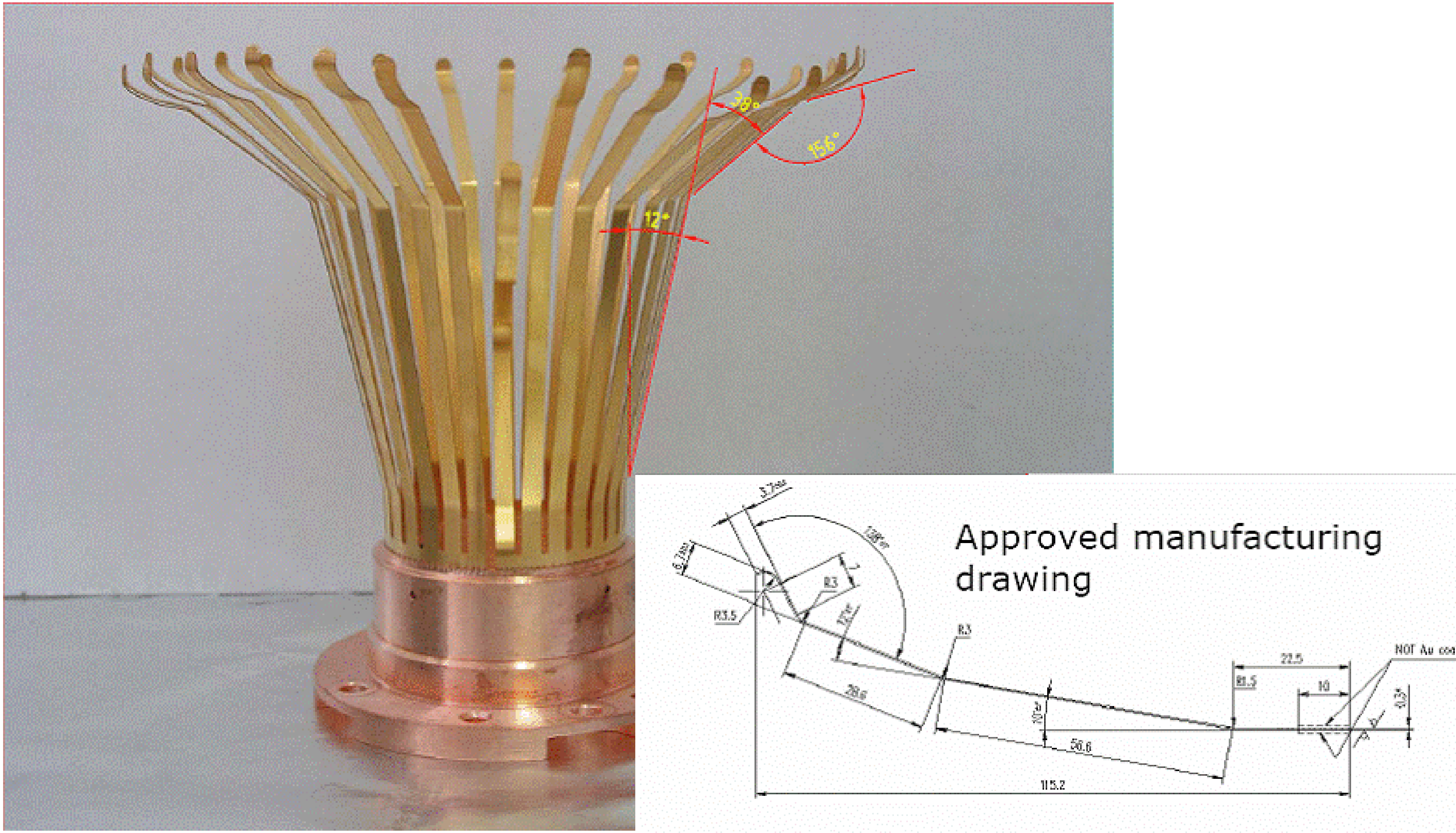
The problem

- Contact fingers in an arc interconnect have buckled into the beam aperture
- Post-mortem examination shows this took place during sector warm-up

Possible causes

- Design: friction coefficient, cold welding, working range
- Manufacture: contact finger geometry tolerance errors, roughness of coatings
- Environment: Damage during installation, error in installed length, cryogenic or mechanical errors

Shielded Bellows (PiMs)

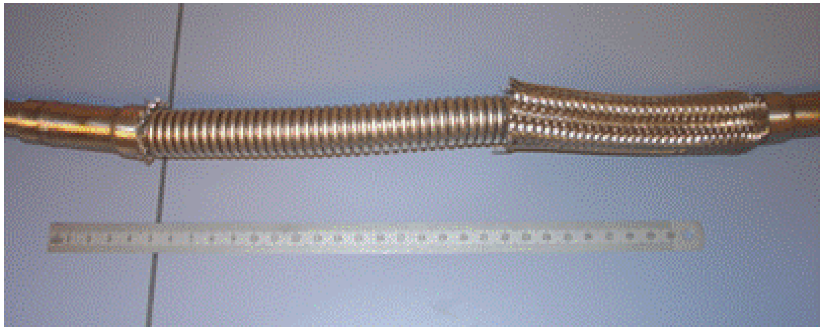


PiMs summary (September 5th)

Actions under-way

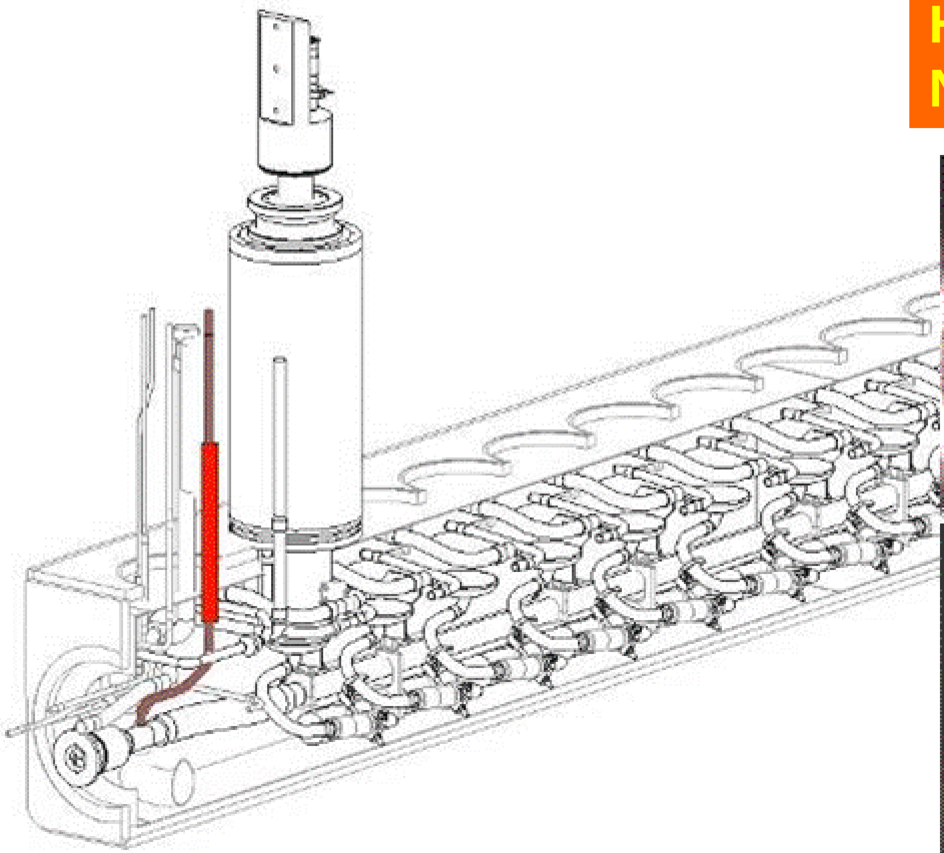
- Verification of design – detailed calculation and measurement of friction
- Systematic control on contact finger stock, verifications with supplier
- Detailed analysis of magnet, interconnect and cryogenic NCs
- Systematic X-ray of sector 7-8 PiMs
  - Requires to open all outer bellows
  - Divert IEG teams from sector 1-2 (which delays interconnect work there)
  - ~250 PiMs measured so far (out of 400) ➔ 5 faulty PiMs observed in the arc
- Investigation of diagnostic methods for finding buckled fingers (AT)
- Investigation of diagnostic methods for verification of clear aperture (AB)

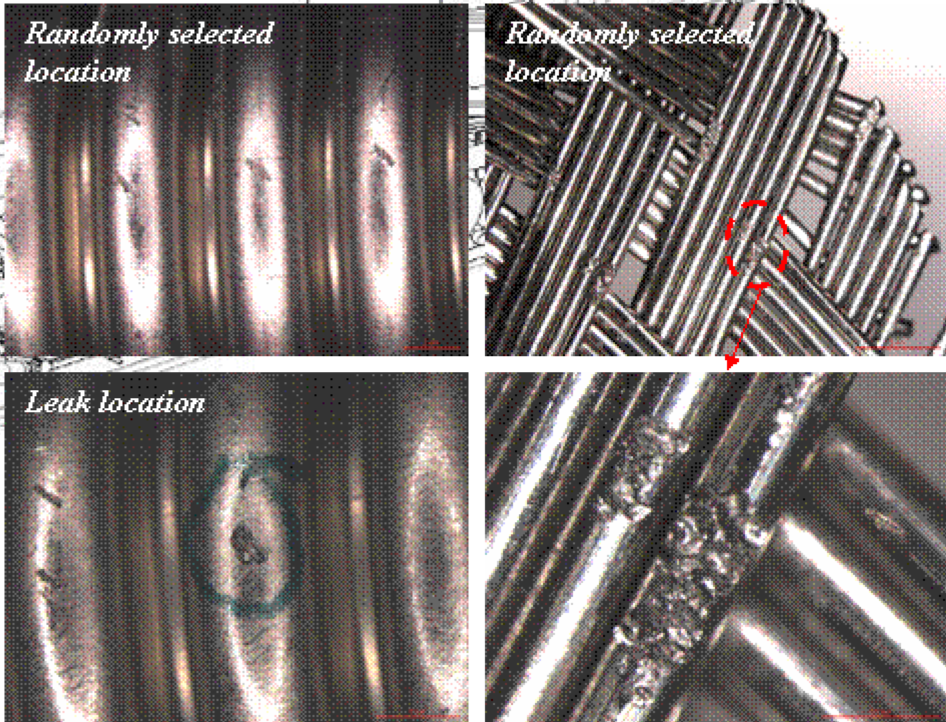
Cool-down Sector 4-5



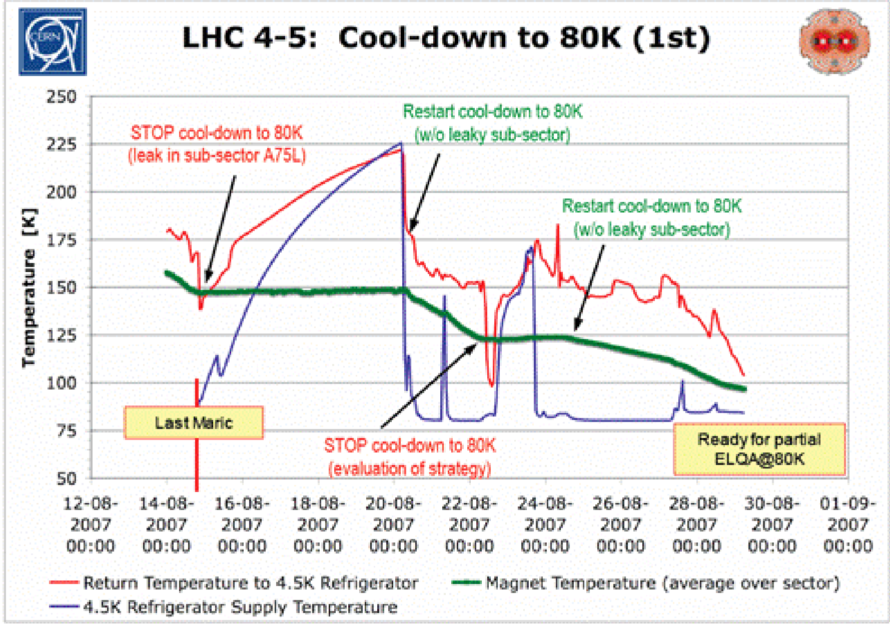
Leak on DFBAH flexible

Due to fusion of the metal
Heating of an electrical origin
Free of oxidizations
Happened under vacuum
No consensus about how





Cool-down Sector 4-5



Leak in cold mass circuits including some DFBAI piping

Decided to continue to cool as much as possible and do (limited) ELQA and power tests, followed by warm up, repairs in parallel with triplet interconnect, then cool down

Summary by Sector

Arc 1-2 and 2-3: interconnection on-going, closure in September

- Closure of sector 1-2 presently at stand-still (IEG teams in 7-8)

Arc 3-4: closed, leak tests of individual sub-sectors in progress

Arc 4-5: cooled at 80K, ELQA tests on going

- Leak appeared in DFBA at 4R, now fixed ➔ 3 weeks delay
- New leak appeared in 5L, need to be localised and fixed…

Arc 5-6 and 6-7: closed, leak tests of individual sub-sectors on-going

Arc 7-8: warmed-up after partial power tests (no low-β)

- Replacement of MB1055 done, repair in progress and on schedule
- Problems with Plug in Modules

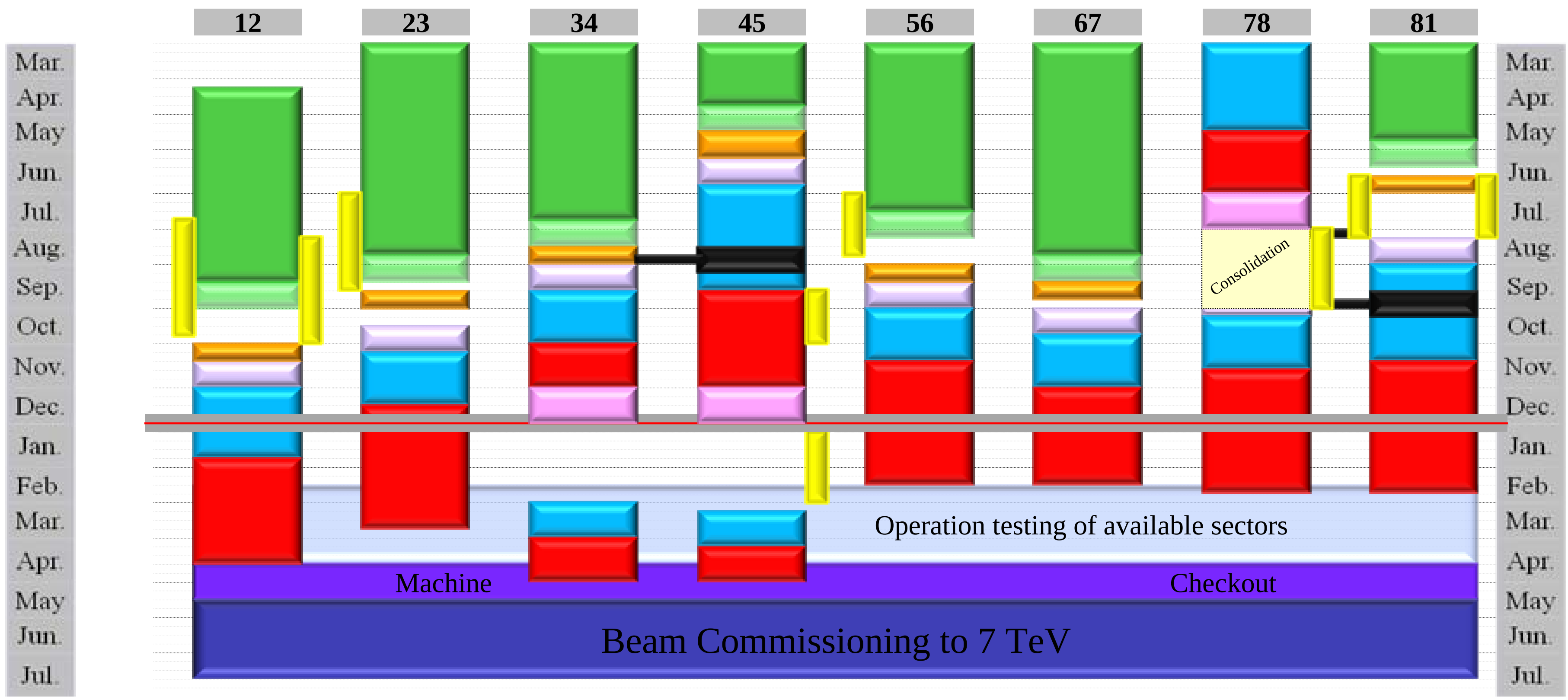
Arc 8-1: closed and pressure tested, flushing starts next week

- Leak in cold mass of Q17.R8 (still not fixed) ➔ quadrupole need to be replaced if it cannot be repaired in situ ➔ ~8 weeks
- TI8 high intensity tests (scheduled end of August) postponed

Summary of installation and commissioning

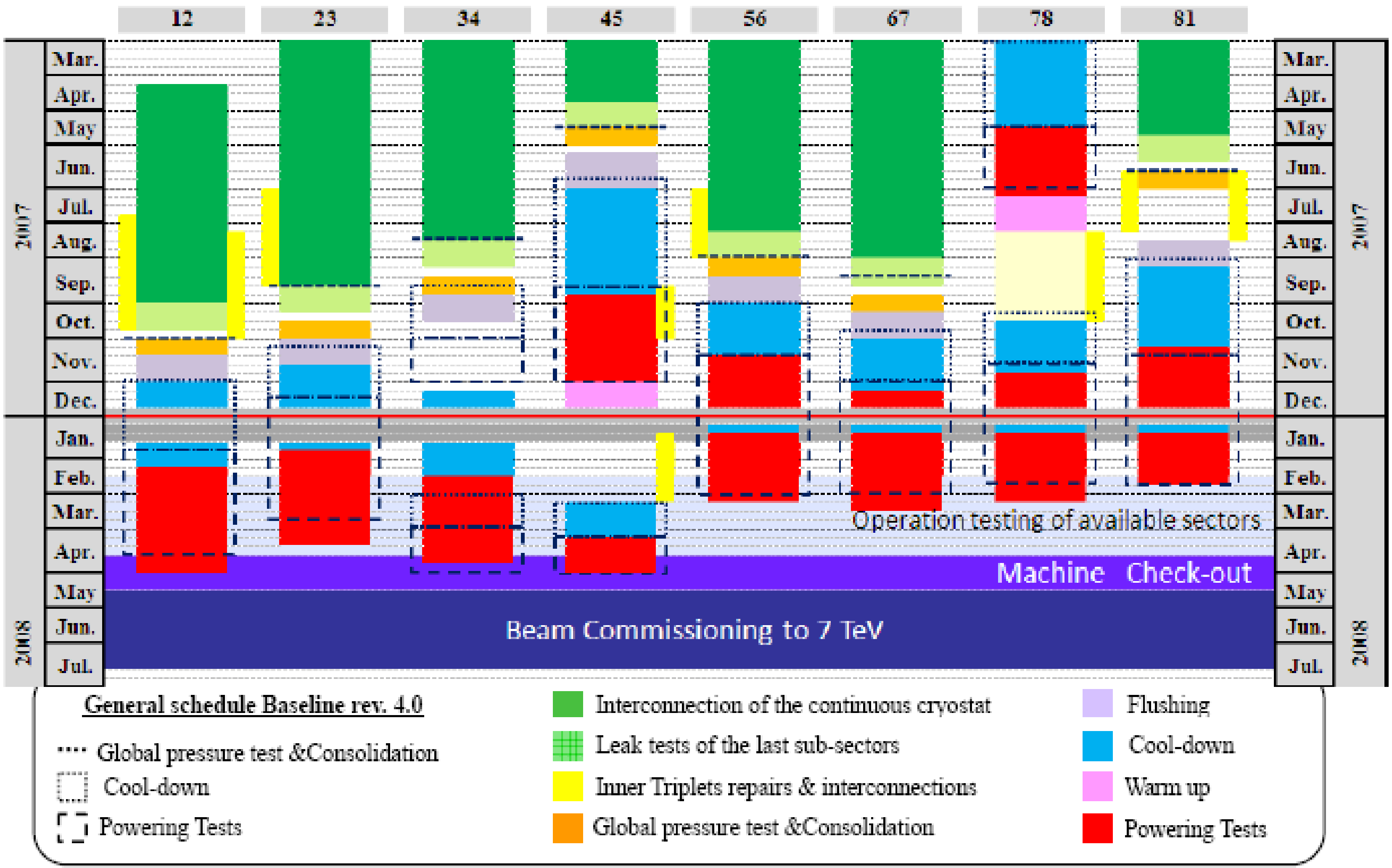
- Procurement problems of remaining components (DFBs, collimators) now settled
- Good progress of installation and interconnection work, proceeding at high pace in tunnel
- Numerous non-conformities intercepted by QA program, but resulting in added work and time
- Technical solutions found for inner triplet problems, but repair of already installed magnets will induce significant delays
- Commissioning of first sectors by isolating faulty triplets, but will have to be re-done with repaired triplets (needing additional warm-up/cool-down cycles)
- First sector cooled down to nominal temperature and operated with superfluid helium. Teething problems with cold compressor operation have now been fixed
- Partial power tests performed in sector 7-8
- Sector 7-8 consolidation ongoing (with a few surprises, notably PiMs)
- Second sector 4-5 cool down started but problems
- Sector 8-1 leak must be localised and fixed in situ or quad comes out

Schedule – rev 4.0 – June Council



- Interconnection of the continuous cryostat
- Leak tests of the last sub-sectors
- Inner Triplets repairs & interconnections
- Global pressure test &Consolidation
- Flushing
- Cool-down
- Warm up
- Powering Tests

Schedule 03/08 – LHC Project web page



Comments on the schedule

Present uncertainties (end of August)

- PiMs
- Sector 4-5 strategy
- Sector 8-1 leak localisation/repair
- Sector 1-2 presently at stand-still
- Helium inventory issues:
  - Procurement of the additional He (20 to 40 t more)
  - Logistics (load rate vs. storage space = ~50 t, +25 t at the end of 2007)

Priority is to get the machine cold and leak tight

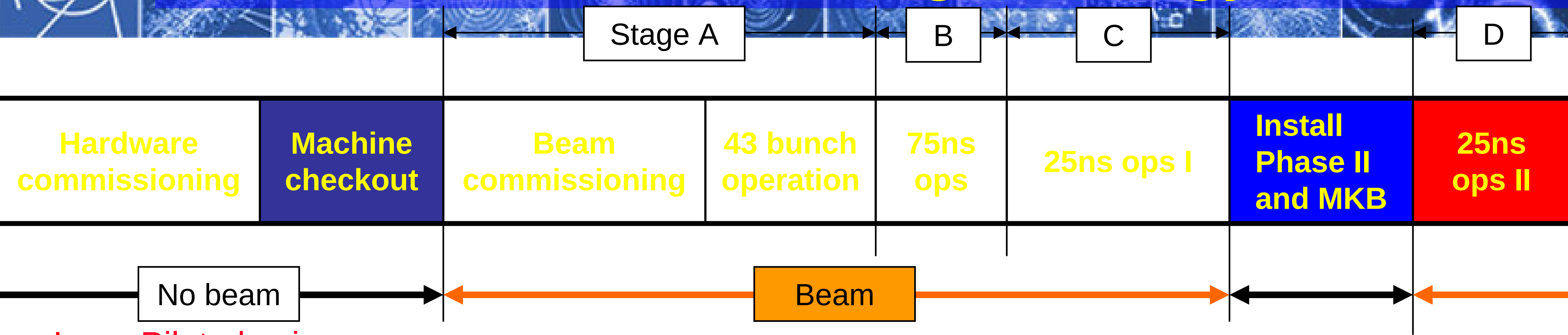
High parallelism for the power tests (HW commissioning)

Problems found at cold cost at least 3 months to fix

With the present experience changes might occur

Injection test into point 8 may come back on the scene

Overall commissioning strategy



I. Pilot physics run
- First collisions
- 43 bunches, no crossing angle, no squeeze, moderate intensities
- Push performance and go to 156 bunches
- Performance limit 10^{32} cm^{-2} s^{-1} (event pileup)

II. 75ns operation
- Establish multi-bunch operation, moderate intensities
- Relaxed machine parameters (squeeze and crossing angle)
- Push squeeze and crossing angle
- Performance limit 10^{33} cm^{-2} s^{-1} (event pileup)

III. 25ns operation I
- Nominal crossing angle
- Push squeeze
- Increase intensity to 50% nominal
- Performance limit 2 10^{33} cm^{-2} s^{-1} (beam dump diluters and collimators)

IV. 25ns operation II
- Push towards nominal performance

Minimise
- *Complexity*
- *Beampower*
- *Losses* (β^*)
- *Pileup*

Optimise
- N
- k_b
- β^*

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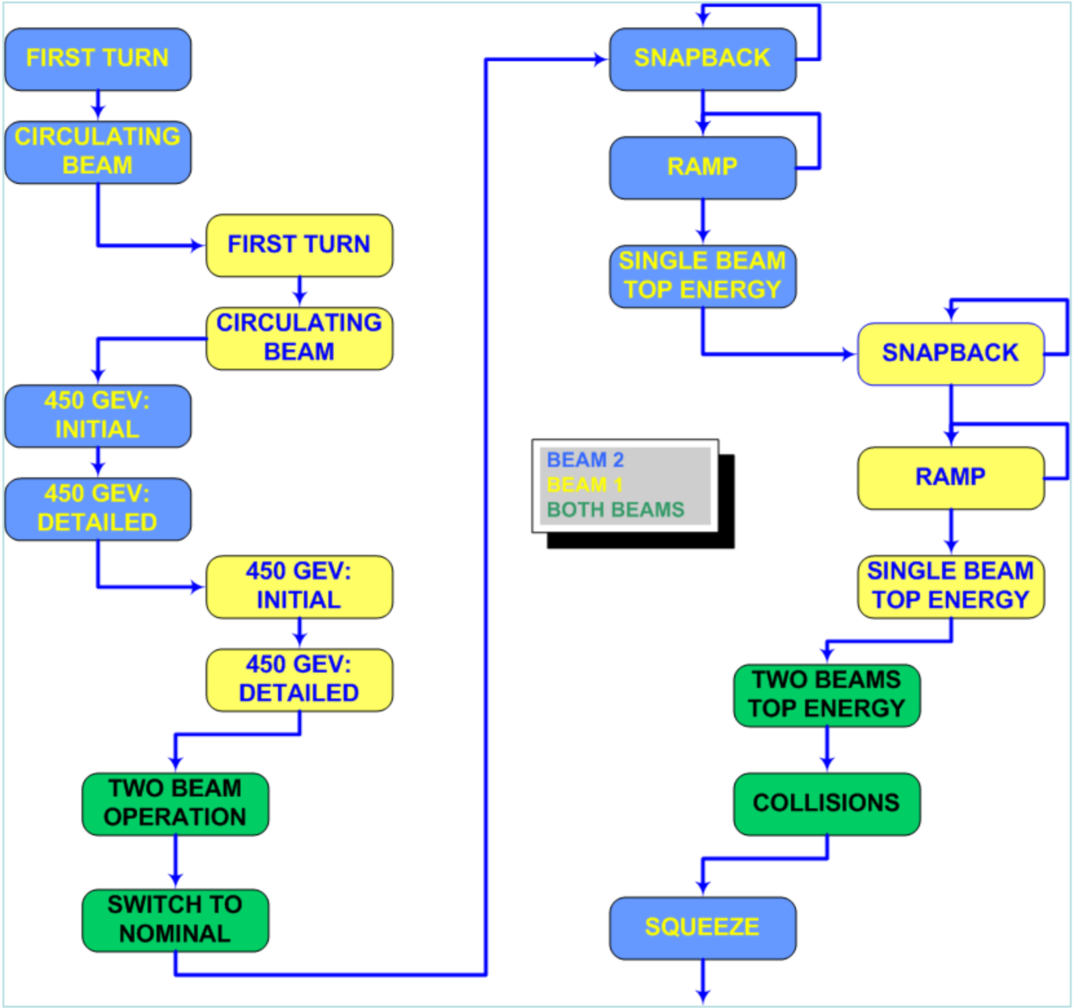
Stage A: Commissioning Phases



Have to commission:

Hardware: RF, beam Dump, Collimators, Kickers etc

Instrumentation: BPMs, BLMs, BCT, Beam size, luminosity etc.

Controls

Machine Protection

Measure optics, energy, aperture etc. etc. etc.

Procedures: Injection, snapback, ramp, squeeze, recover etc.

Details available…http://lhccwg.web.cern.ch/lhccwg/

Beam commissioning to 7 TeV

		Rings	Total [days]
1	Injection and first turn	2	4
2	Circulating beam	2	3
3	450 GeV – initial commissioning	2	4
4	450 GeV – detailed optics studies	2	5
5	450 GeV increase intensity	2	6
6	450 GeV - two beams	1	1
7	450 GeV - collisions	1	2
8a	Ramp - single beam	2	8
8b	Ramp - both beams	1	2
9	7 TeV – top energy checks	2	2
10a	Top energy collisions	1	1
	TOTAL TO FIRST COLLISIONS (beam time)		30
11	Commission squeeze	2	6
10b	Set-up physics - partially squeezed	1	2
	TOTAL TO PILOT PHYSICS RUN (beam time)		44

Stage A: First collisions

Approx 30 days of beam time to establish first collisions

- Un-squeezed
- Low intensity

Approx 2 months elapsed time

- Given optimistic machine availability

Continued commissioning thereafter

- Increased intensity
- Squeeze

RHIC (2000):
- First beam April 3rd
- First successful ramp: June 1st
- First collisions June 12th

Stage A physics run

Start as simple as possible

Head-On

Change 1 parameter (k_b, N, $\beta^*_{1,5}$) at a time

All values for

- nominal emittance
- 7TeV

$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*}$$

$$Eventrate / Cross = \frac{L\sigma_{TOT}}{k_b f}$$

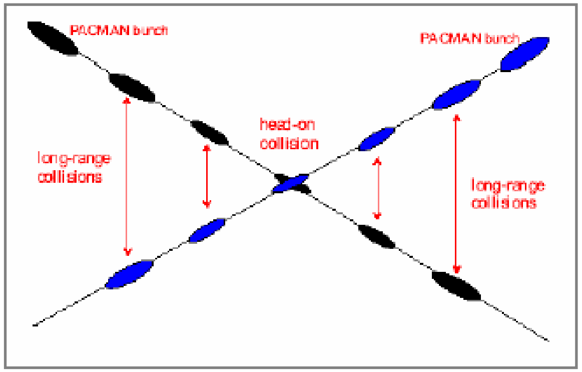
Protons/beam ≲ 10^{13}
(LEP beam currents)

Stored energy/beam ≲ 10MJ
(SPS fixed target beam)

Parameters			Beam levels		Rates in 1 and 5	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
1	10^{10}	11	$1\ 10^{10}$	10^{-2}	$1.6\ 10^{27}$	<< 1
43	10^{10}	11	$4.3\ 10^{11}$	0.5	$7.0\ 10^{28}$	<< 1
43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	2	$1.1\ 10^{30}$	<< 1
43	$4\ 10^{10}$	2	$1.7\ 10^{12}$	2	$6.1\ 10^{30}$	0.76
156	$4\ 10^{10}$	2	$6.2\ 10^{12}$	7	$2.2\ 10^{31}$	0.76
156	$9\ 10^{10}$	2	$1.4\ 10^{13}$	16	$1.1\ 10^{32}$	3.9

Stage B physics run (75 ns)

- Relaxed crossing angle (250 μrad)
- Start un-squeezed
- Then go to where we were in stage A
- All values for
  - nominal emittance
  - 7TeV



$$L = \frac{N^2 k_b f \gamma}{4\pi \varepsilon_n \beta^*} F$$

$$F = 1 / \sqrt{1 + \left(\frac{\theta_c \sigma_z}{2\sigma^*}\right)^2}$$

Stored energy/beam ≤ 100MJ

Protons/beam ≈ few 10^{13}

Parameters			Beam levels		Rates in 1 and 5	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
936	4 10^{10}	11	3.7 10^{13}	42	2.4 10^{31}	<< 1
936	4 10^{10}	2	3.7 10^{13}	42	1.3 10^{32}	0.73
936	6 10^{10}	2	5.6 10^{13}	63	2.9 10^{32}	1.6
936	9 10^{10}	1	8.4 10^{13}	94	1.2 10^{33}	7

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Stage C physics run (25 ns)

Nominal crossing angle (285 μrad)

Start un-squeezed

Then go to where we were in stage B

All values for

- nominal emittance
- 7TeV

Protons/beam ≈ 10^{14}

Stored energy/beam ≥ 100MJ

Parameters			Beam levels		Rates in 1 and 5	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
2808	$4\ 10^{10}$	11	$1.1\ 10^{14}$	126	$7.2\ 10^{31}$	<< 1
2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72
2808	$5\ 10^{10}$	2	$1.4\ 10^{14}$	157	$5.9\ 10^{32}$	1.1
2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1
2808	$5\ 10^{10}$	0.55	$1.4\ 10^{14}$	157	$1.9\ 10^{33}$	3.6
Nominal			$3.2\ 10^{14}$	362	10^{34}	19

Suggested parameter evolution in the first 2 years of operation

Parameters			Beam levels		Rates in 1 and 5	
k_b	N	β* 1,5 (m)	I_{beam} proton	E_{beam} (MJ)	Luminosity ($cm^{-2}s^{-1}$)	Events/ crossing
43	$4\ 10^{10}$	11	$1.7\ 10^{12}$	2	$1.1\ 10^{30}$	<< 1
43	$4\ 10^{10}$	2	$1.7\ 10^{12}$	2	$6.1\ 10^{30}$	0.76
156	$4\ 10^{10}$	2	$6.2\ 10^{12}$	7	$2.2\ 10^{31}$	0.76
936	$4\ 10^{10}$	11	$3.7\ 10^{13}$	42	$2.4\ 10^{31}$	<< 1
936	$4\ 10^{10}$	2	$3.7\ 10^{13}$	42	$1.3\ 10^{32}$	0.73
2808	$4\ 10^{10}$	2	$1.1\ 10^{14}$	126	$3.8\ 10^{32}$	0.72
2808	$5\ 10^{10}$	2	$1.4\ 10^{14}$	157	$5.9\ 10^{32}$	1.1
2808	$5\ 10^{10}$	1	$1.4\ 10^{14}$	157	$1.1\ 10^{33}$	2.1

G. Arduini – 10/09/2007

Looking forward for…

— ** STABLE BEAMS ** —

E=7.0 TeV/c	Beam	In Coast	0.5 h
Beams	Beam 1	Beam 2	
#bun	43	43	
Nprot(t)	0.41e12	1.73e12	
tau(t) h	121	140	

Luminosities	ATLAS	ALICE	CMS	LHC-B
L(t) 1e28 cm-2s-1	7.32	6.23	7.13	5.21
/L(t) nb-1	0.78	0.68	0.78	0.52
BKG 1	0.70	0.52	0.90	0.43
BKG 2	0.45	0.82	0.50	0.80

COLLIMATORS in coarse settings
Separation Scan in IR1/Atlas