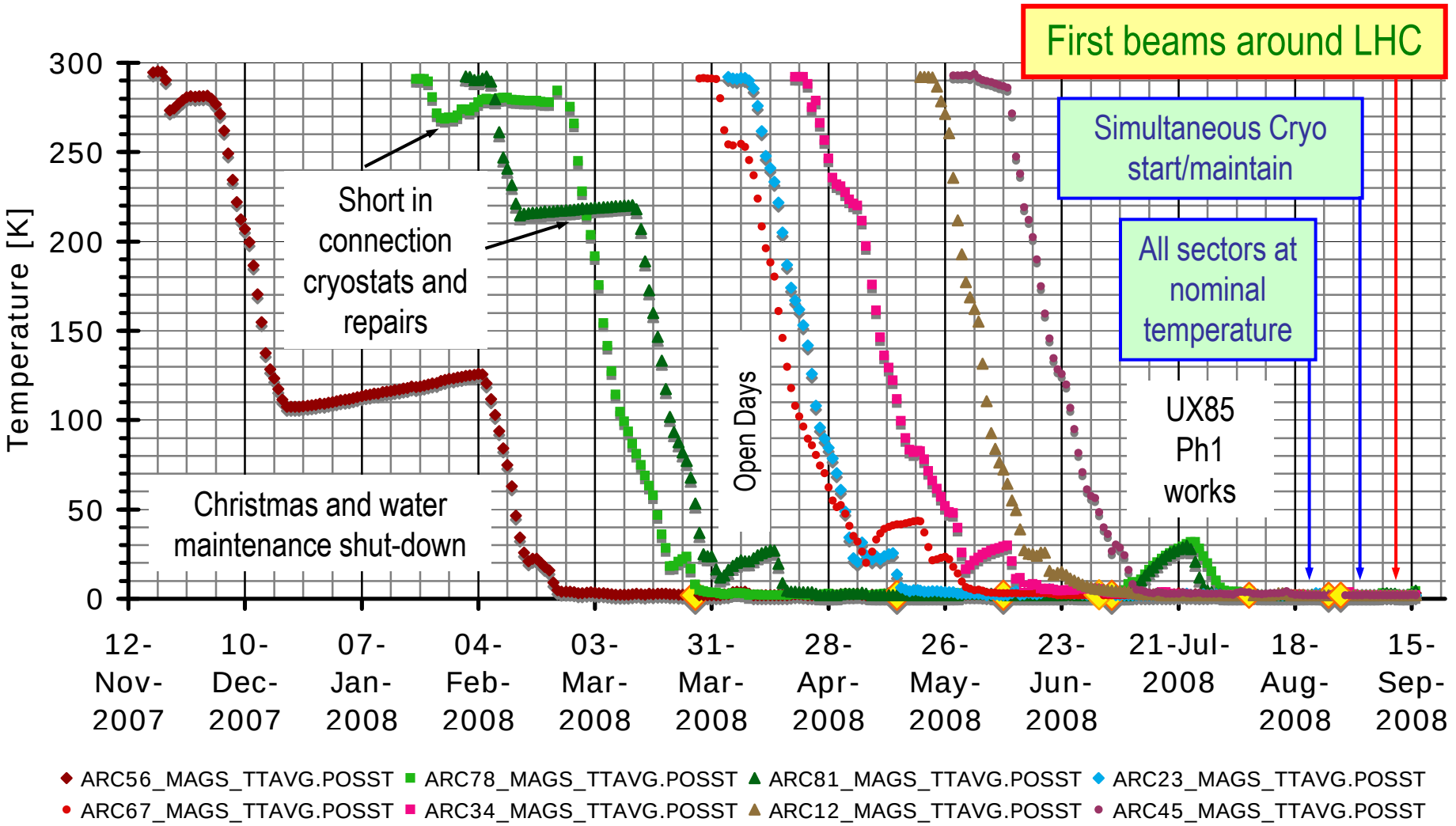
LHC Cryogenics:

What did we learn from cool-down to first beams ?

S. Claudet

on behalf of the Cryogenic team

First cool-down of LHC sectors



Cooling sectors + Cryo tuning + Powering activities

Content

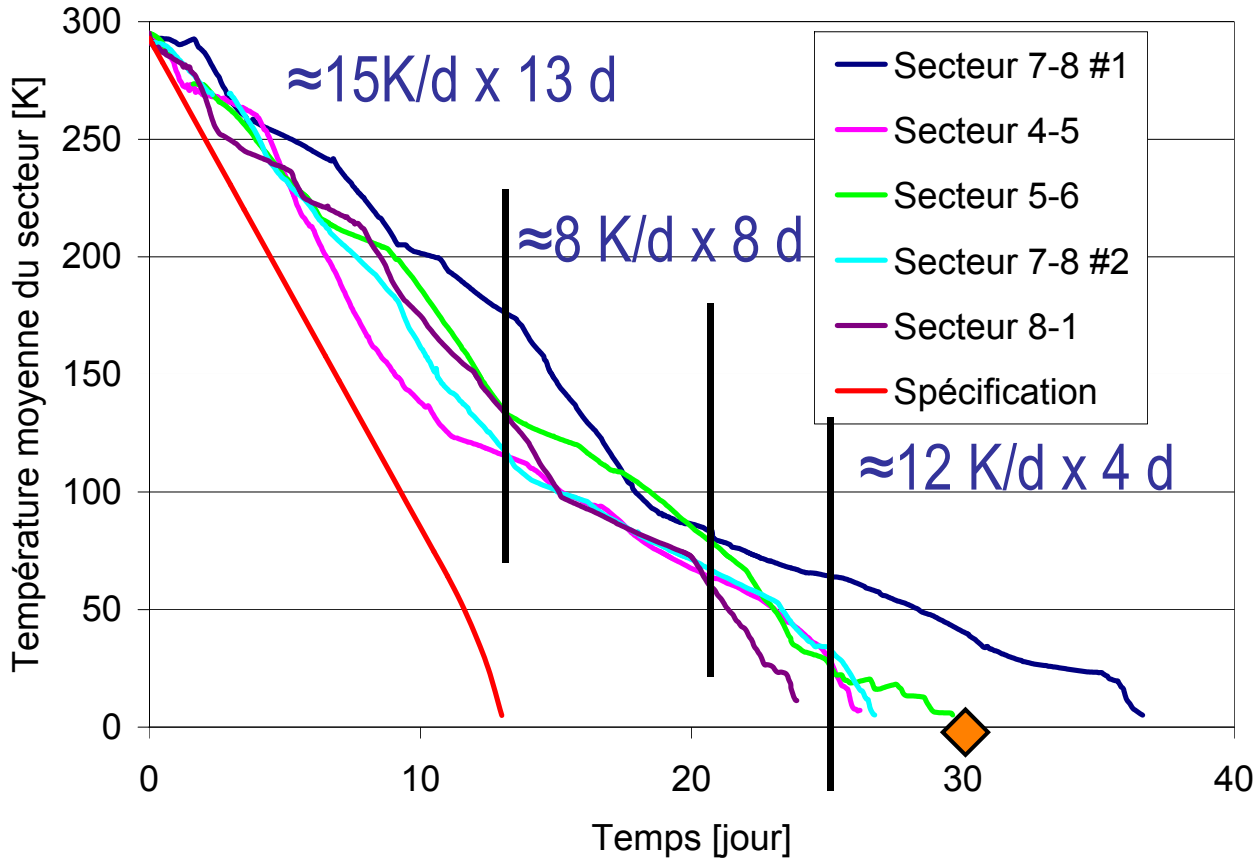
- Cool-down and refrigeration issues
- Cryogen management
- Tuning Long Straight Sections components
- Operational stability achieved
- Preliminary availability for beams
- Delays to recover quenches or failures
- Repairs and major consolidations
- Summary

Cool-down & Refrigeration issues

- Efficient purge/flushing before 1st cool-down, as no filter clogging or valves perturbated by dust during operation, even after 56 training quench campaign!
- Cool-down time: target at 8-6-5-4 weeks, updated installed capacity at 3 wks
- Cold compressors and 15 mbar operation: more or less mastered and recovery time improved, but 3 sectors will not yet profit from it (45-78-81) until warm-up of sectors
- Many mechanical components not always in nominal conditions (100s Vac vessels, 64 CP, 2000s PV/CV, 76 Tu, 28 CC), spares not always the solution
- Operation mode “2 sectors on one cryoplant” tested with enough capacity for early beams in some cases

Corrected cool-down curves

Cool-down curves corrected from external aleas or cryo failures



"25 days for 20K"

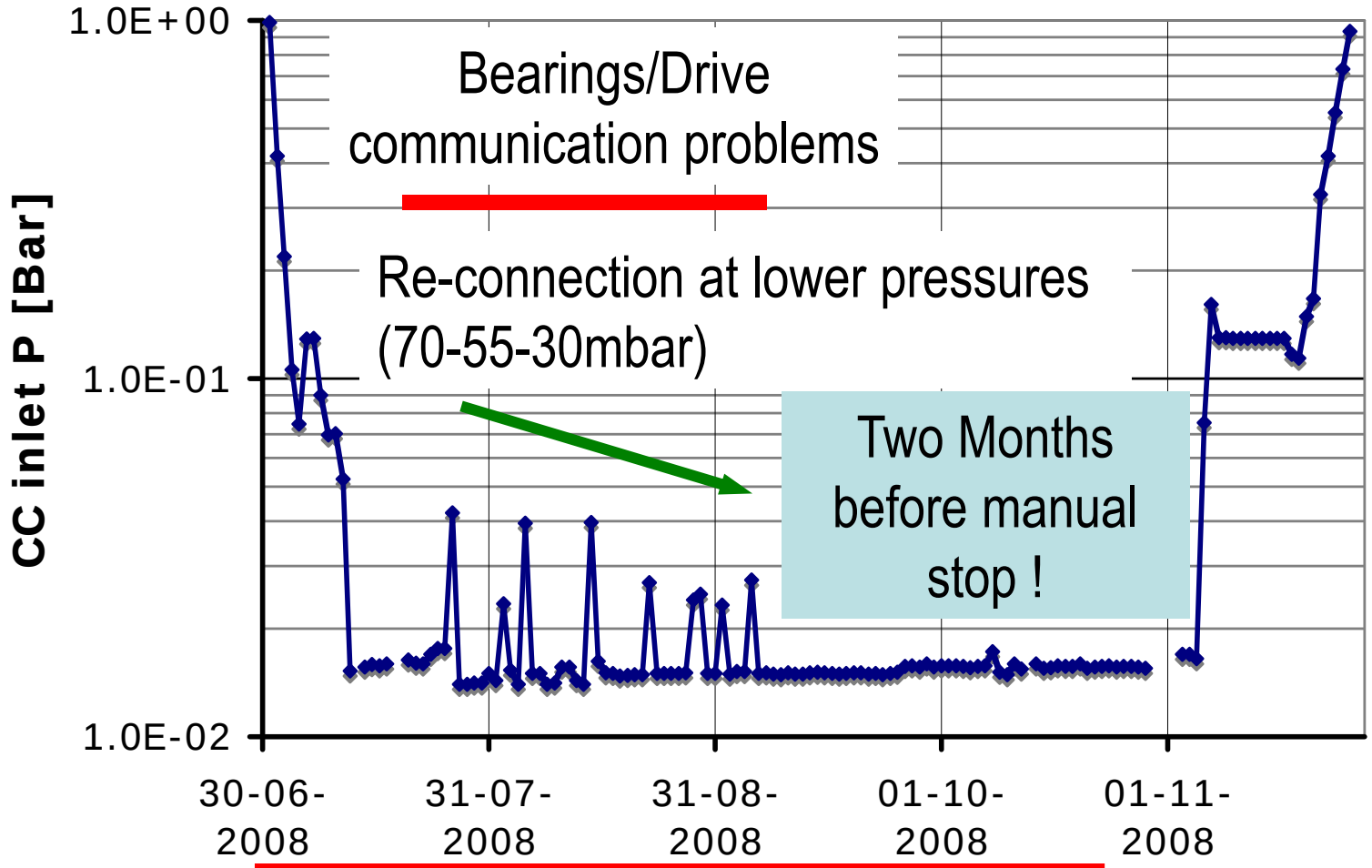
+ 3 days for Filling

+ 2 days for 1.9K

⇒ 30 days

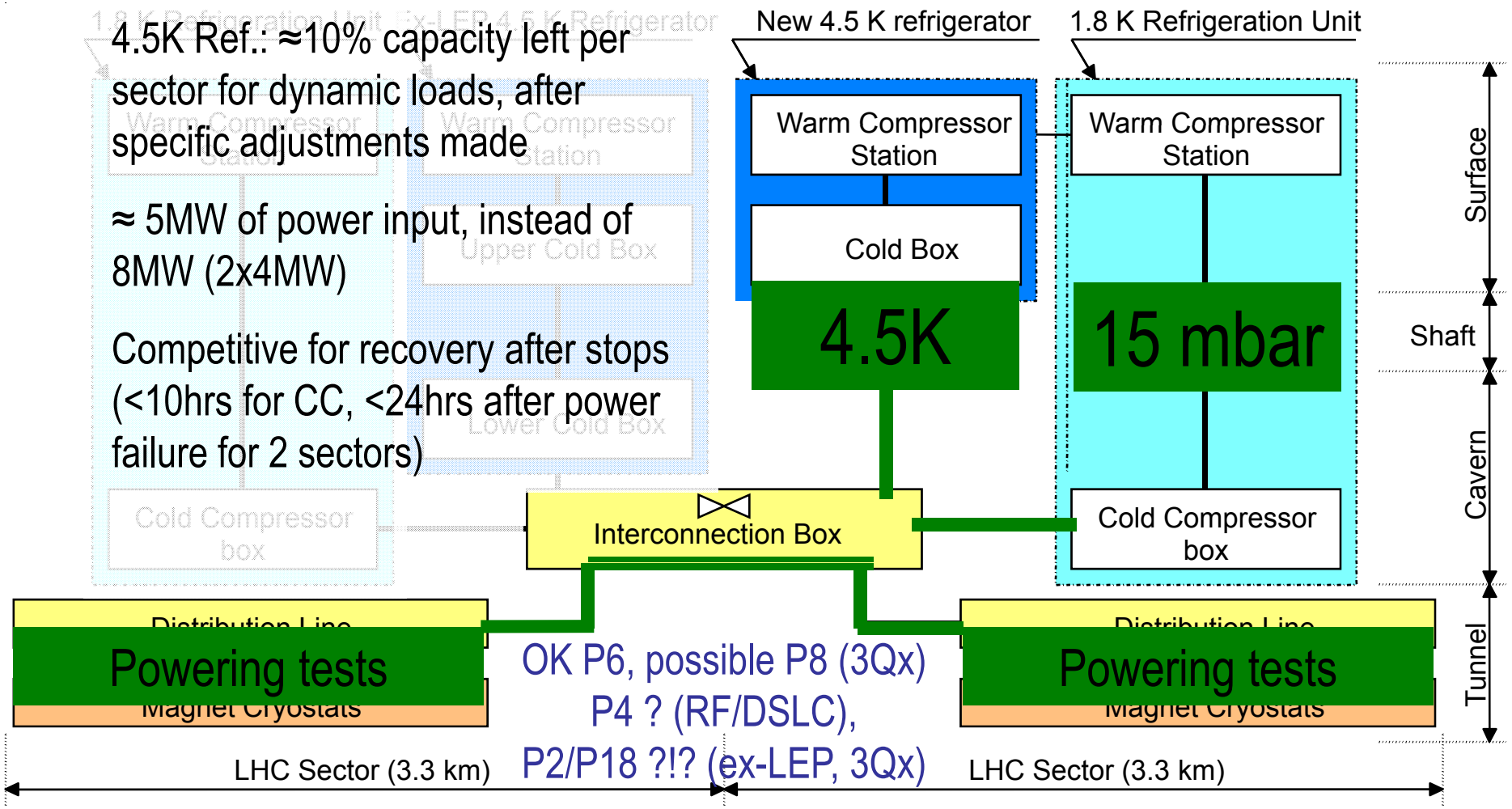
(4 to 5 wks)

1.8K Units: Global significant progress !



Better than 2wks MTBF Spring'08 !

Two sectors on one cryoplant



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

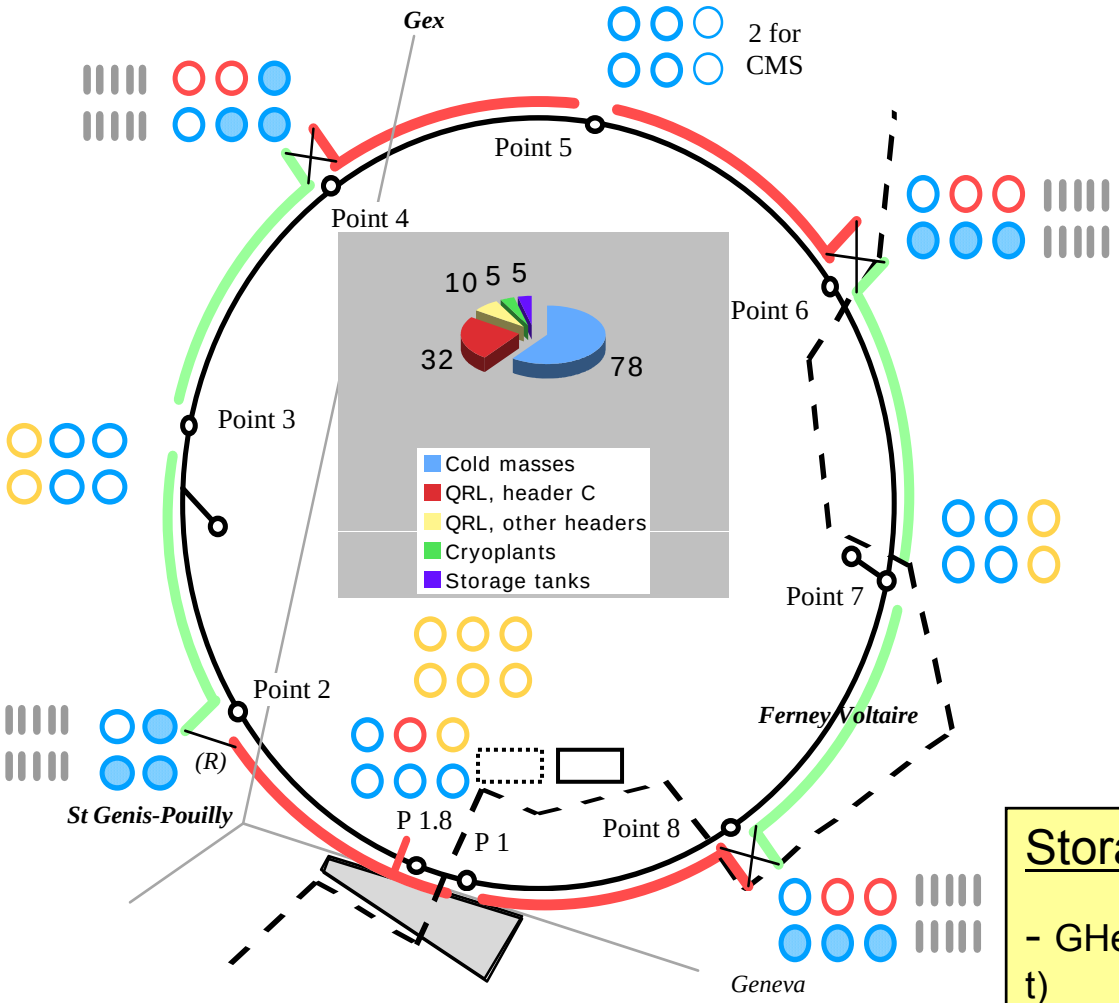
Cryogen management

- Nitrogen: 10’000t for cool-downs, 55 to 60 trucks (20t) per sector, 5 to 6 trucks (20t) / day and /site, up to 9-10/day achieved, reduced rates for sundays

- Helium: 120t received, 29t back in 2008 (cont’d), 1 to 2 trucks (4.5t) / week achieved, 9t/week (2 trucks) possible in 2009 thanks to additional HW, moderate losses (41t incl. purge & leak tests)

Some flexibility (Nb sectors to be kept cold or time to handle inventory) if more LHe tanks at CERN !

Helium inventory



Quench Tanks (new)
Quench Tanks (existing)
Refrigerator Tanks (New)
Storage Tanks compatible with the "Impact Study"
Exist. vertical Tanks 75 m3

LHC Inventory:

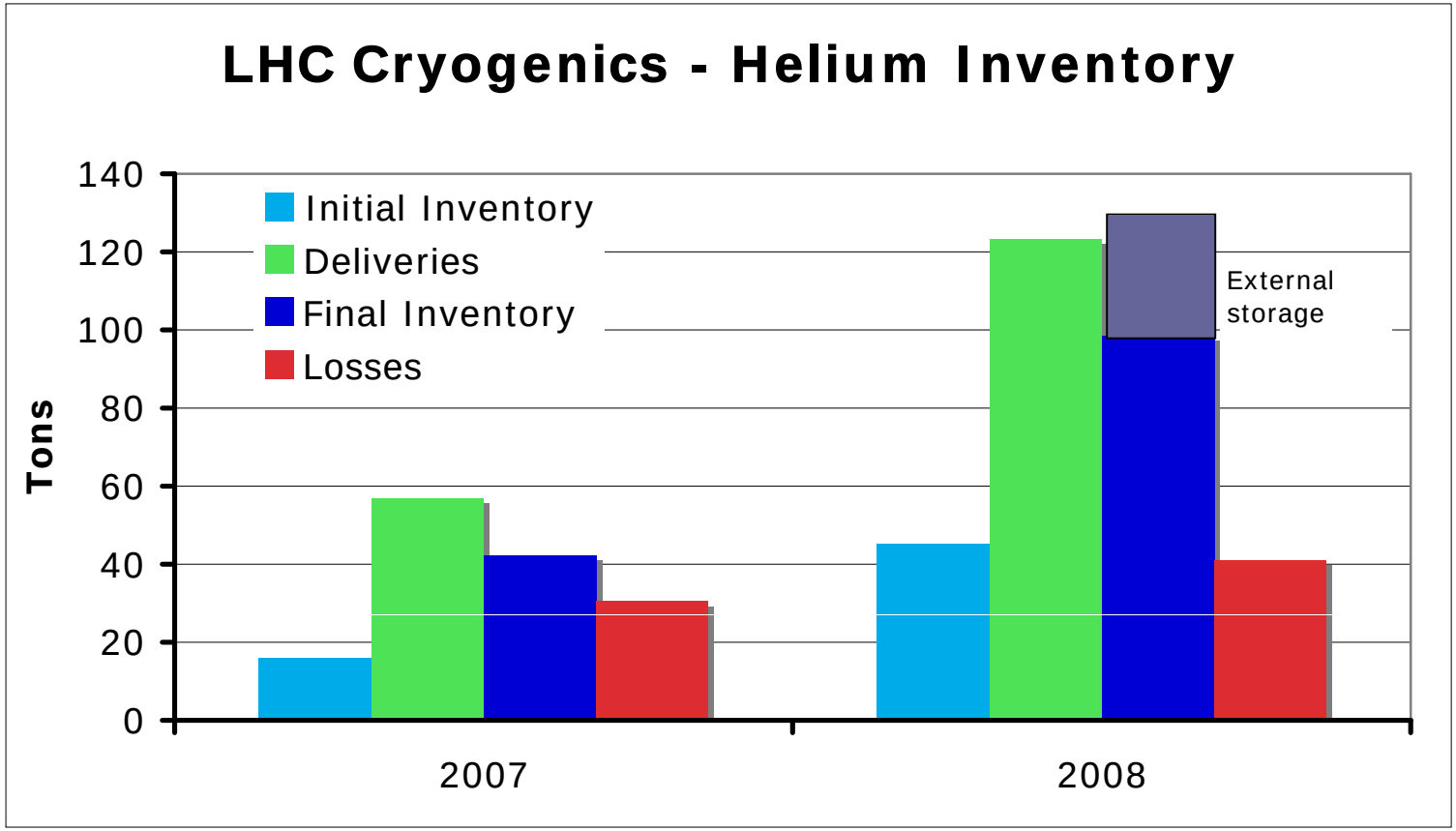
- LHC + Cryo: 125 t (= 8 x 16t)
- Required for P control: ≈ 5 t
- Total: 130 t

Storage capacity:

- GHe tanks (300K-20B): 45 t (vol. = 51 t)
- LHe P18 (4.5K): 15t end'08, 30t spring'09
- External storage: Maxi 55 t

A good basis, but "rather long" logistics

Follow-up of Helium inventory



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

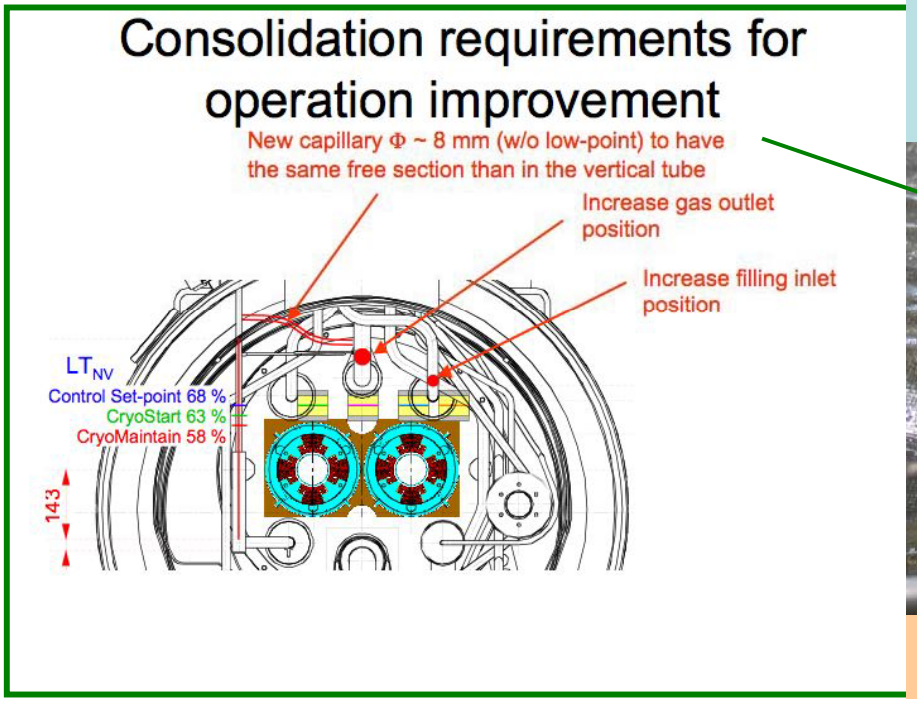
Tuning LSS components

- Electrical Feed Boxes (DFBs):
  - We could operate all of them close to nominal conditions (maximum scenario required so far during HWC)
  - Few delicate cases (heat loads, levels measurements, levelling of sc link to magnets, valves for cooling current leads, thermometers and noise, High Voltage perturbation on instrumentation cards)

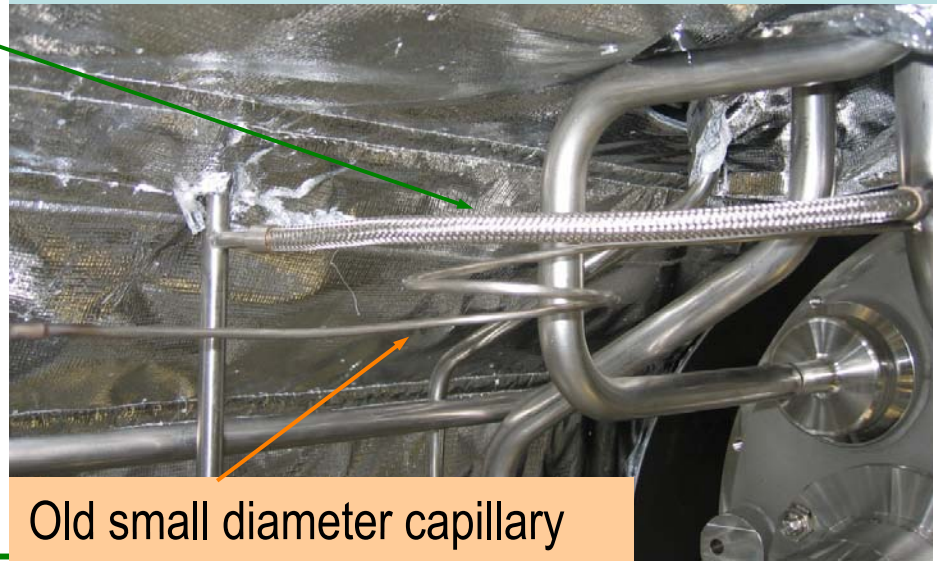
Might come back !

- Stand alone Magnets (SAM):
  - Difficult Level measurements due to Cold GHe capillary with too small diameter and possible low points, most delicate cases being treated
- Triplets:
  - DFBX: Commissionned with moderate ramp rates on some leads (Cu)
  - NC found on some Q1 (Missing Cu braid), being treated on critical cases in R1 and 5L
- Superconducting links (DSLs):
  - No problem encountered on four DSLs (<80m), except for DSLC_P3
  - DSLC design/installation weak point being treated

Levels for stand-alone magnets



Reference: P6 already conform, due to specific design due to beam dump line



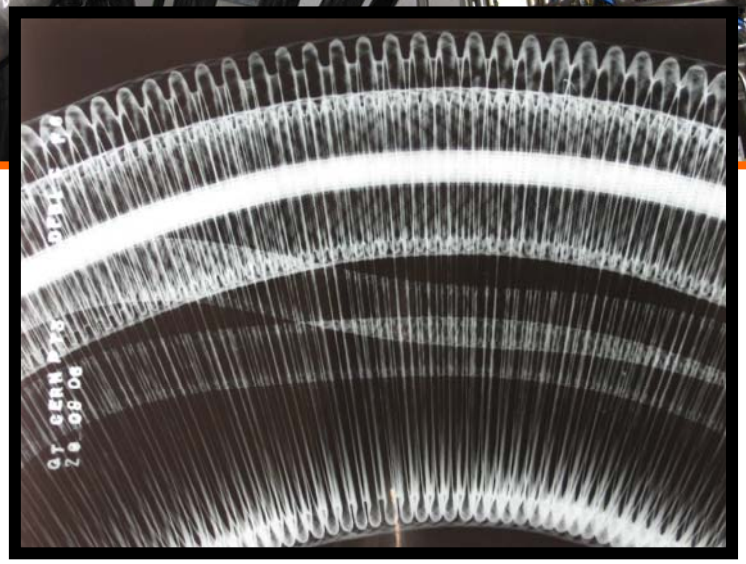
Since spring 2008:

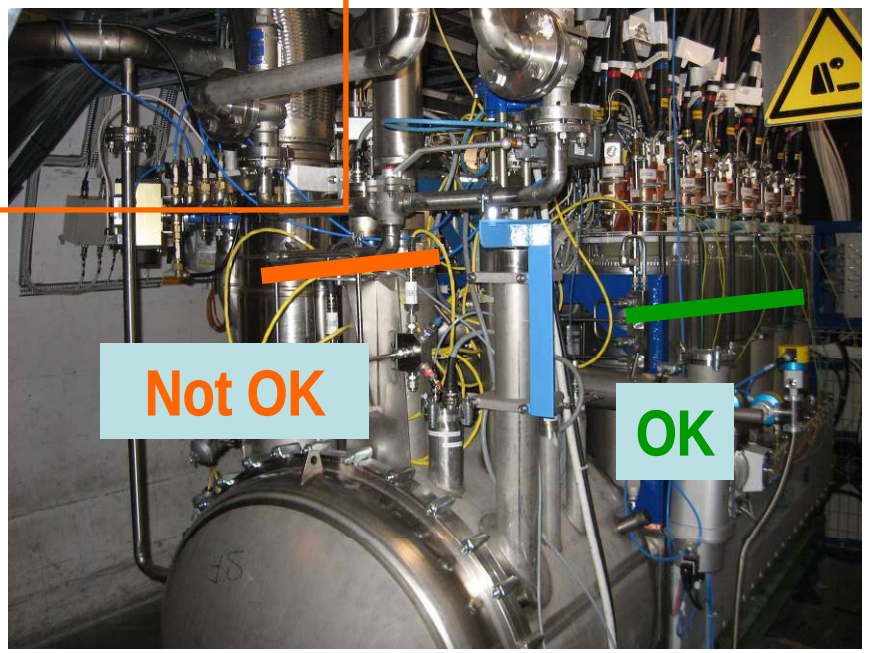
- Case by case lengthy tuning AND global QRL_line_D pressure stability required

During present shut-down:

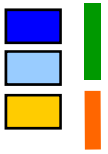
- Pipe work being consolidated, at least for MQY critical cases, 1/3 might not be treated

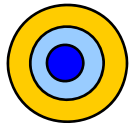
The DFBLC and DSLC in UJ33





Cable layout
Layer 1 (inner) Wires 1-10:
Layer 2: 11-26:
Layer 3 (outer layer) 27-48:





Cryo instrumentation tuned for larger Helium mass-flow

=> Stable operation now at 9-10 g/s (w.r.t 4.5 g/s before)

SC - 02Feb'09

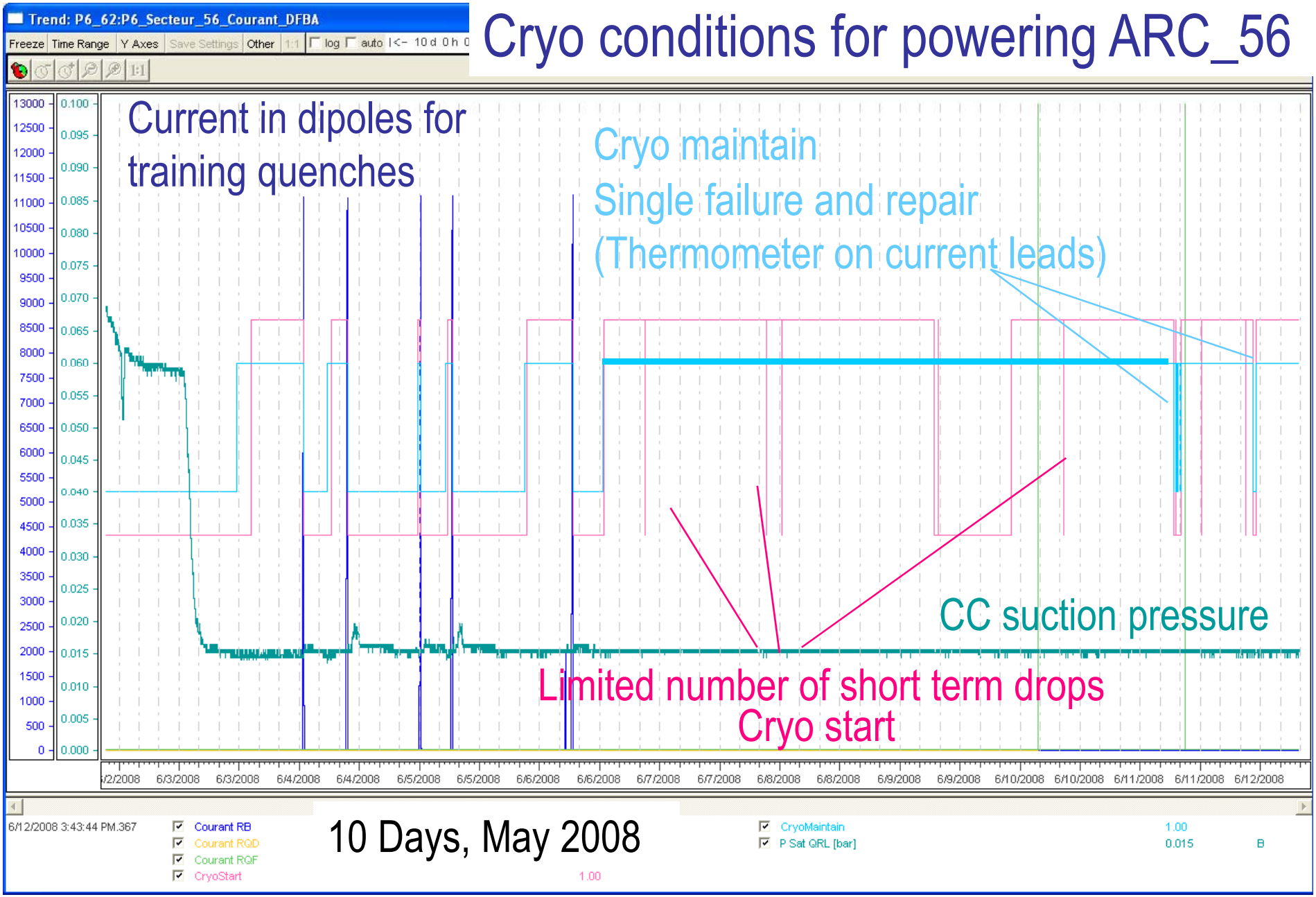
Consolidations underway on flexible hoses and supports

Stability achieved

- Issues to be treated:
  - Stable services
  - Global refrigeration mastered
  - 15mbar established
  - DFB's and current leads stabilised
  - Beam screen cooling loops stabilised

- Once critical points listed above had been treated, we had "rock solid" cryo conditions for powering of a given sector !

Cryo conditions for powering ARC_56



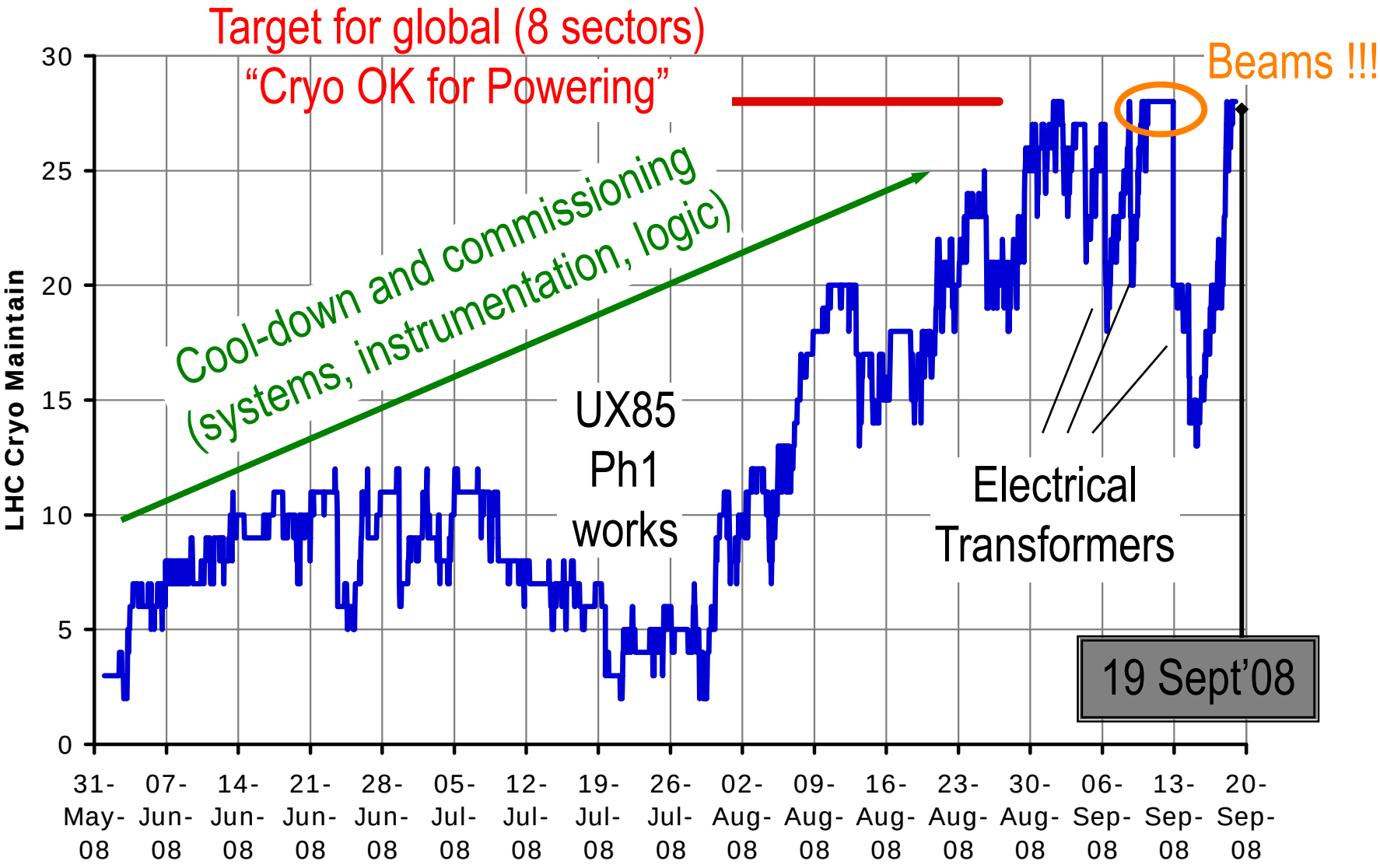
Preliminary availability for beams

- Not much experience before D-day
- With “skilled-operator” help during D-day
- Promising periods of 4-5 days in a row after D-day for 4 to 7 sectors

- We have now already reached a situation with several days of availability between minor perturbations, and a more serious perturbation after a few weeks

- Some 4000 PID control loops (8x500) to work simultaneously, some efforts to be put on:
  - DFB and current leads control tolerances
  - Selection of magnets to be considered for “Cryo Maintain”

LHC Cryogenics: towards beams



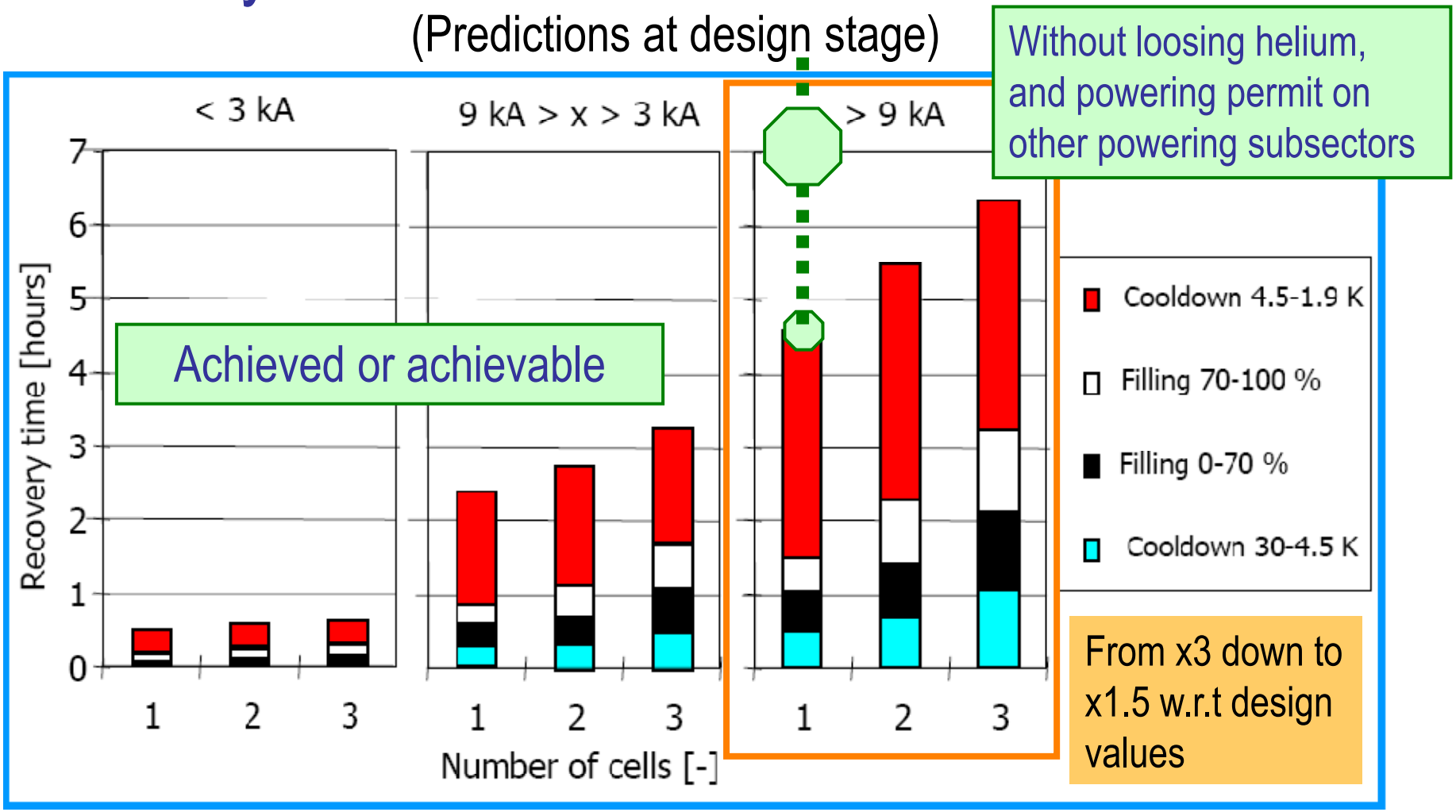
LHC Cryogenics: just after beams

Recovery from quenches or failures

- Quenches:
  - Better understanding of their effects on P, T, m'
  - Procedure established for efficient recovery
  - Procedure being introduced in automatism
- Services:
  - Difficult periods by turns with EL, CV, CO, VAC
  - All being addressed with appropriate studies and mostly followed by consolidation programs

Recovery Time after Limited Resistive Transitions

(Predictions at design stage)

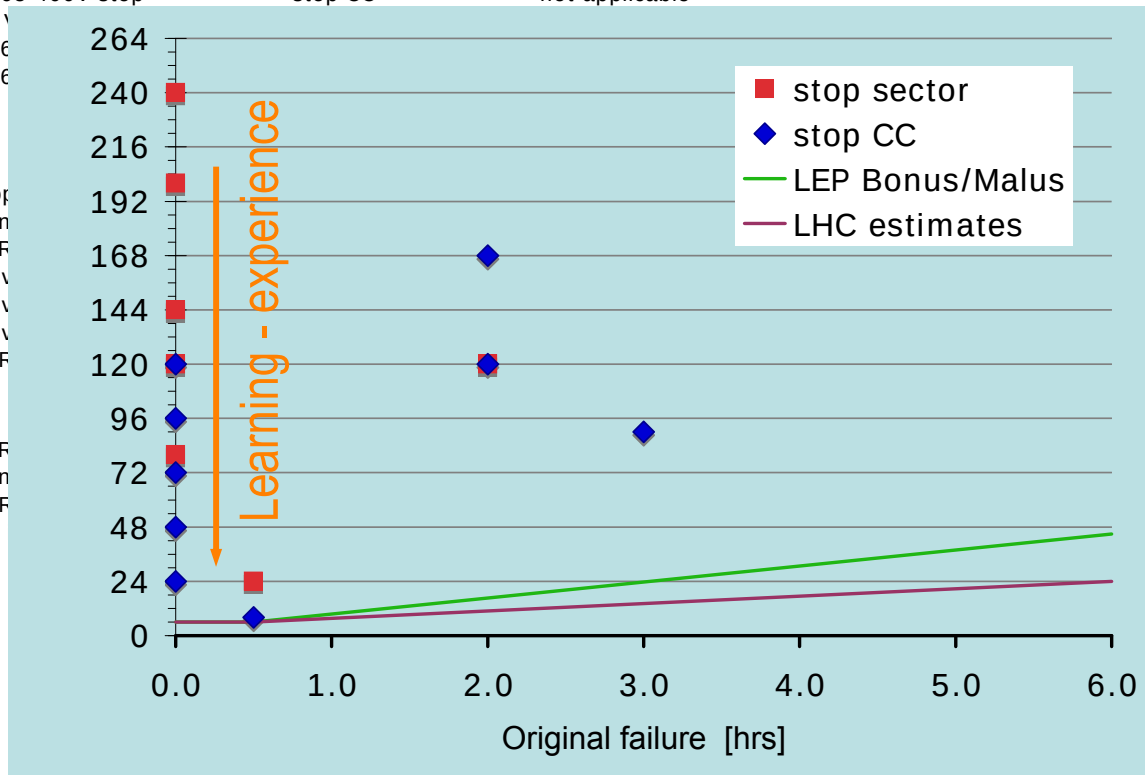


- More than 14 cells or full sector: recovery up to 48 hours
- In case of fast discharge (even w/o quench): 2 h recovery (heating due to eddy currents).

Analysis of stops

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		US65 400V stop	stop CC	not applicable
13	11-May-08	Elec	0.0	24 V		
14	22-May-08	Elec	0.0	US6		
15	30-May-08	Elec	2.0	US6		

sector 78				
1	18-Apr-08	Controls	3.0	stop
2	26-Apr-08	Cryo	0.0	Con
3	30-Apr-08	Elec	0.0	CER
4	09-May-08	Cryo	0.0	Driv
5	25-May-08	Cryo		Driv
6	26-May-08	Cryo		Driv
7	29-May-08	Elec + Water	2.0	VAR



Target Autumn'08:

< 12 h for stop CC

< 36 h for full sector stop

Towards more stable services

- Electricity:
  - 3.3kV input Power, 400V distribution, 24VDC units
  - Spares or fall-back solutions being studied, some implemented (budget tbc)
  - *Specific case of Cold Compressor drives (70-100ms) on UPS to be monitored and evaluated*
- Cooling water:
  - Many consolidations identified and launched
  - Main water pumps MTTR ≈ Cryo tolerance, Test program + study going on
- Controls:
  - Communication cards, PLC arrangement and network being consolidated, always sensitive to IT routers/switches
- Insulation vacuum:
  - Interlocks for “catastrophic rupture” to be simplified: 1 volume <=> 1 signal
  - Gauges to PLC’s to be put on UPS

Cryo repairs and major consolidations

- Mecanics:
  - Repairs of few leaks into cold-boxes insulation vacuum (P2, P6, P8)
  - DSLC_P3
  - Change of 1 control valve for 1.8K units when possible (not for 45-78-81)
  - Change of about 100/2200 valve popets of QRL & QUI
- Instrumentation:
  - Instrumentation on electrical feed boxes (TTs, CVs for current leads)
  - Tuning of valve positioner dynamics
  - Correction of Non-Conformities (LTs, TTs, …)
  - High Voltage compatible instrumentation cards ready for review
- Automatisms:
  - 2nd generation of logic (simplified) for tunnel
  - Standardisation of procedures for interconnection of sub-systems
  - 1.8K units and pump-down

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