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QuickTime™ and a
TIFF (Uncompressed) decompressor
are needed to see this picture.

# LHC Cryogenics

## *From cool-down to 1st beams*

*Serge Claudet (LHC Cryo OP),*
*On behalf of cryo teams involved*

# Content



- Introduction to LHC cryogenics
- Cool-down, cryo tuning for magnets HWC
- Functional analysis - Controls - Availability
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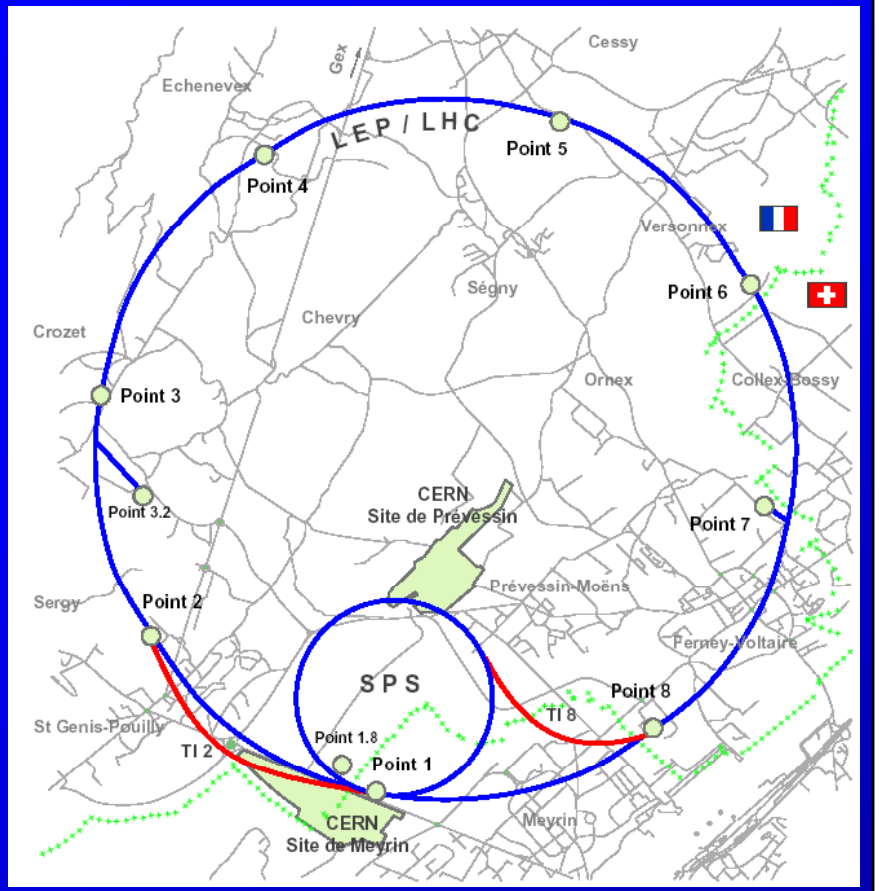
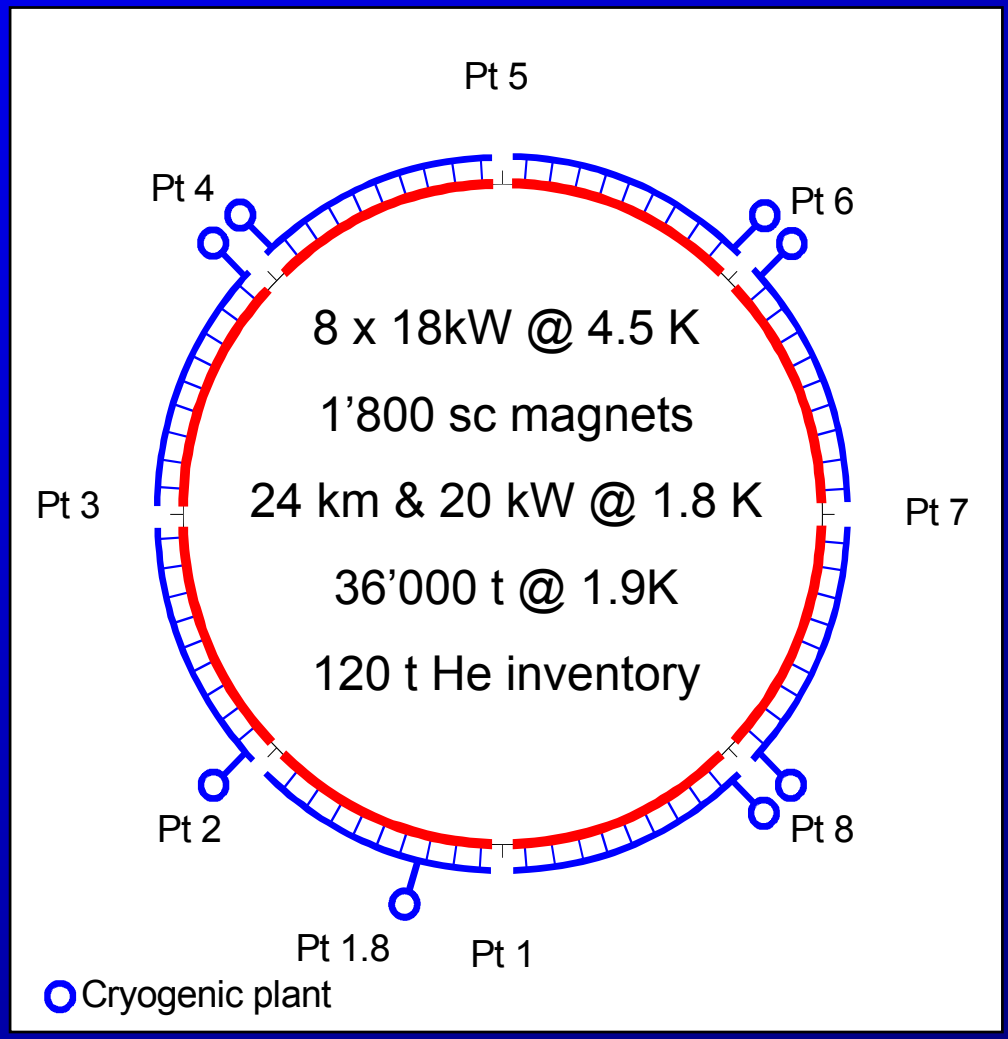
# Layout of cryogenics

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.



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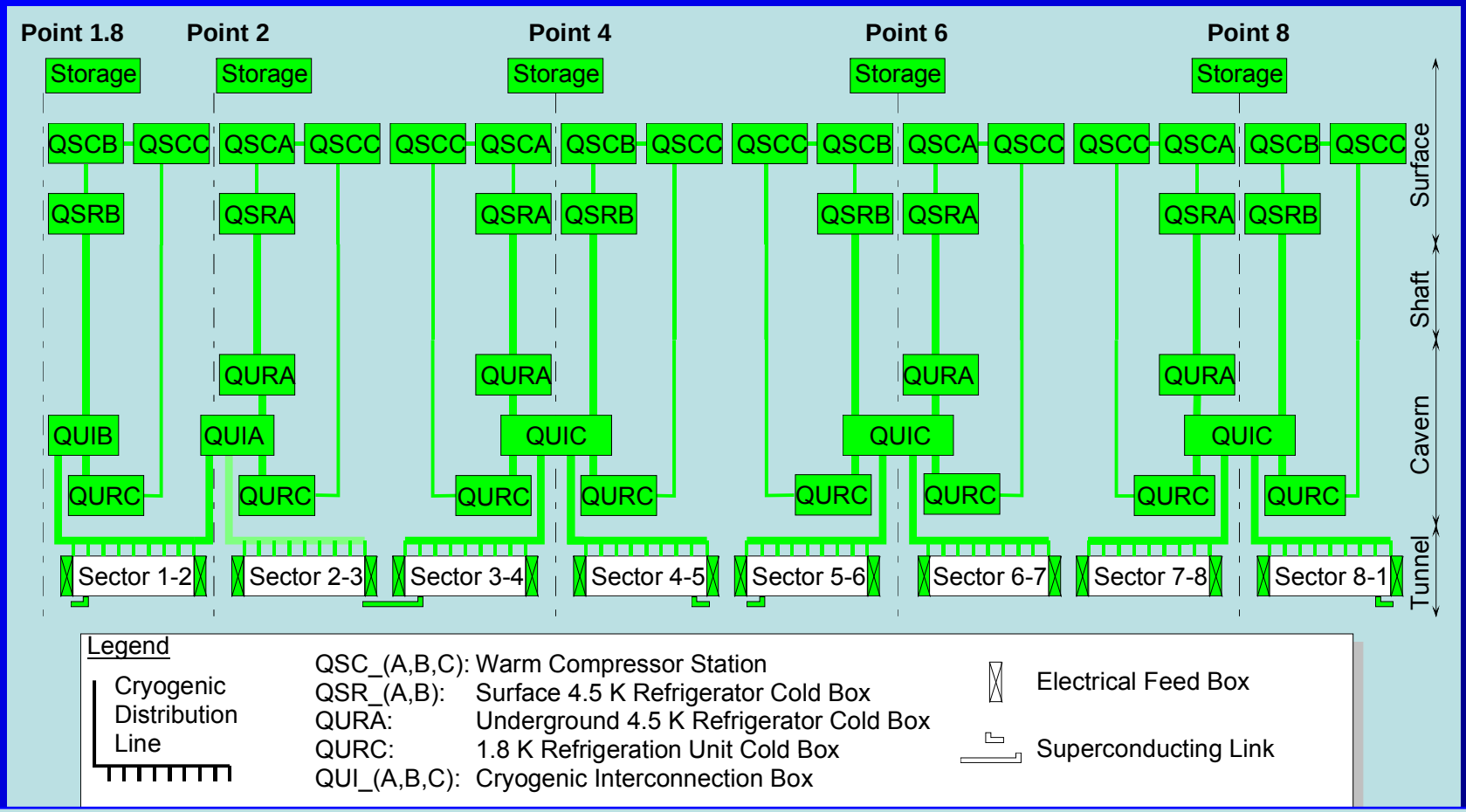
# LHC Cryogenics architecture



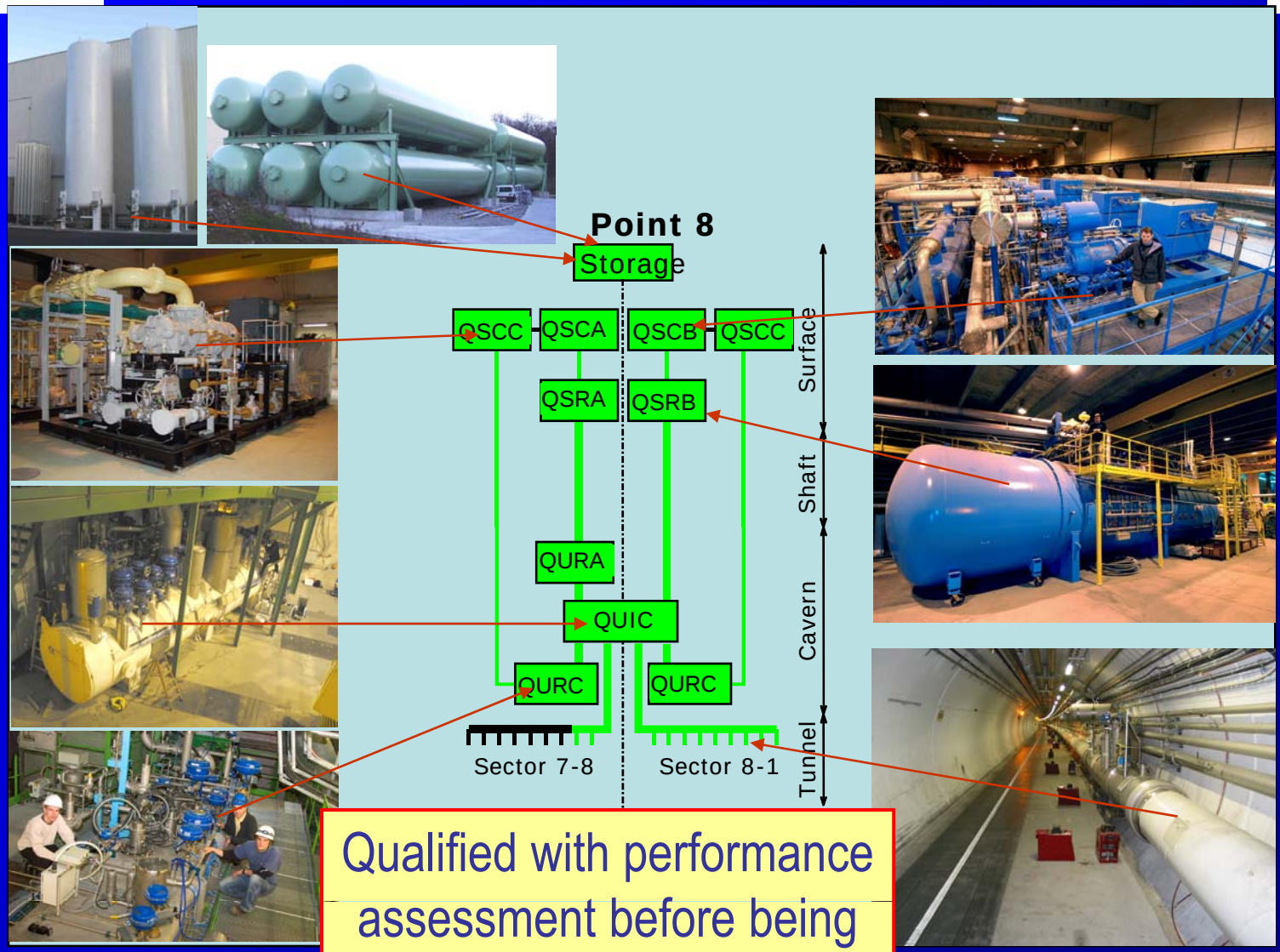

Large variety of large scale refrigerators,

AND

Large variety of valve boxes and large scale lines

# Cryogenic sub-systems






Qualified with performance assessment before being put together

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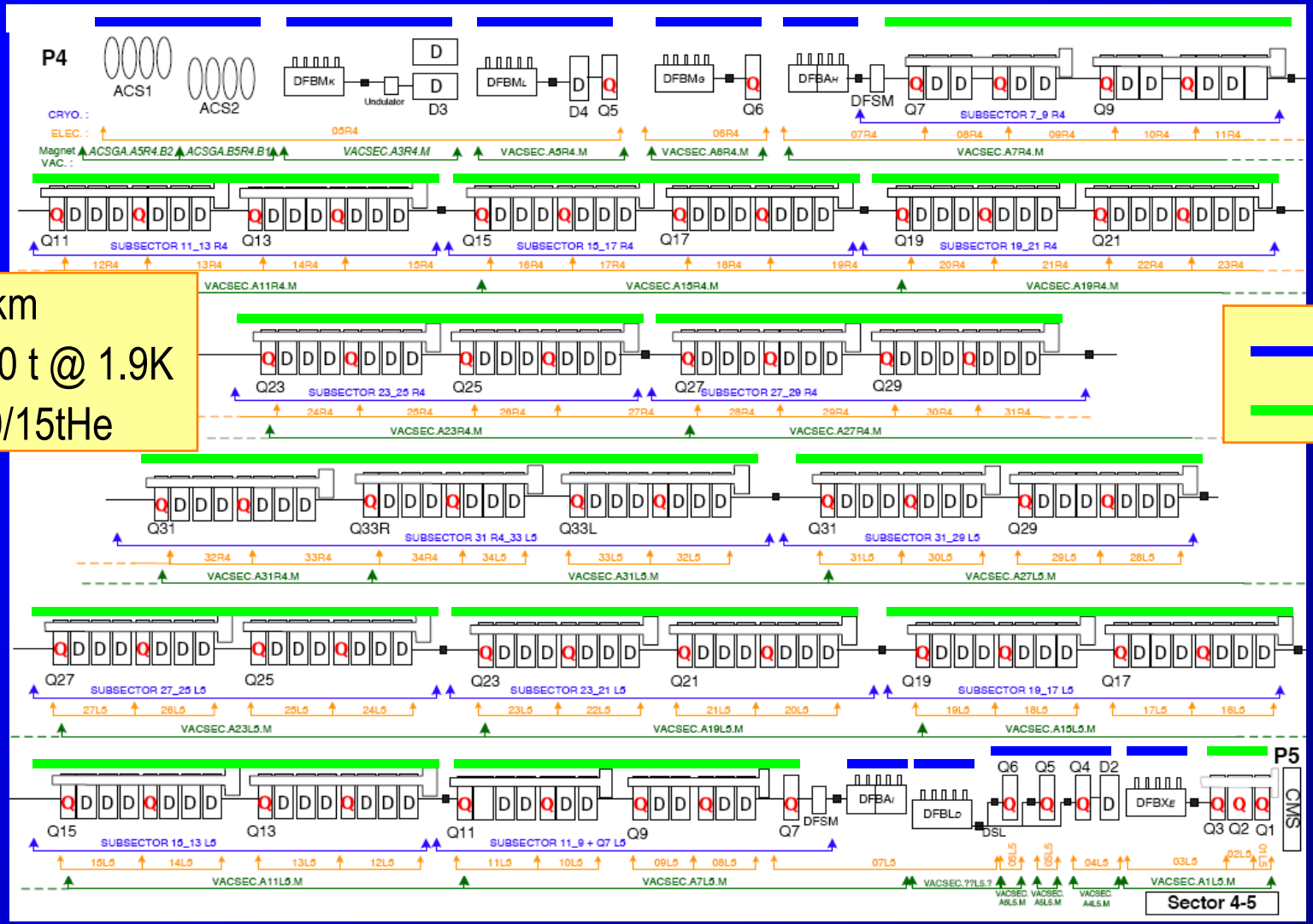
# LHC Sector 4-5 scheme

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

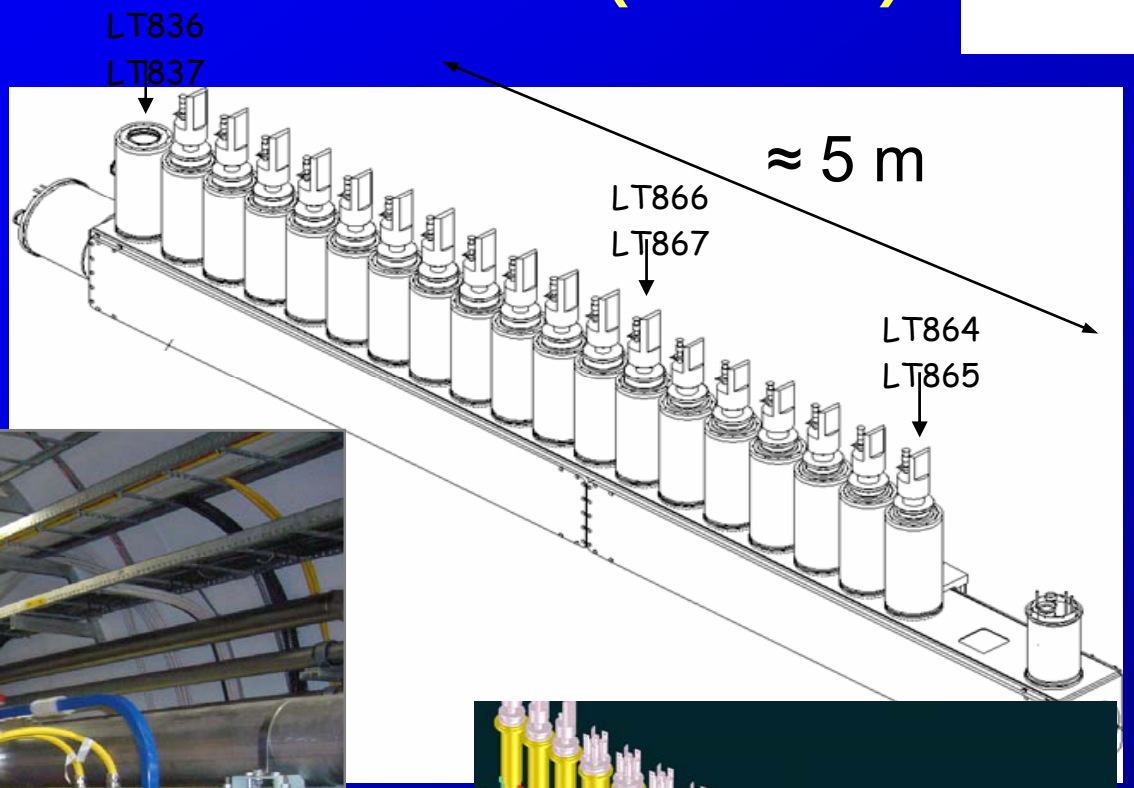


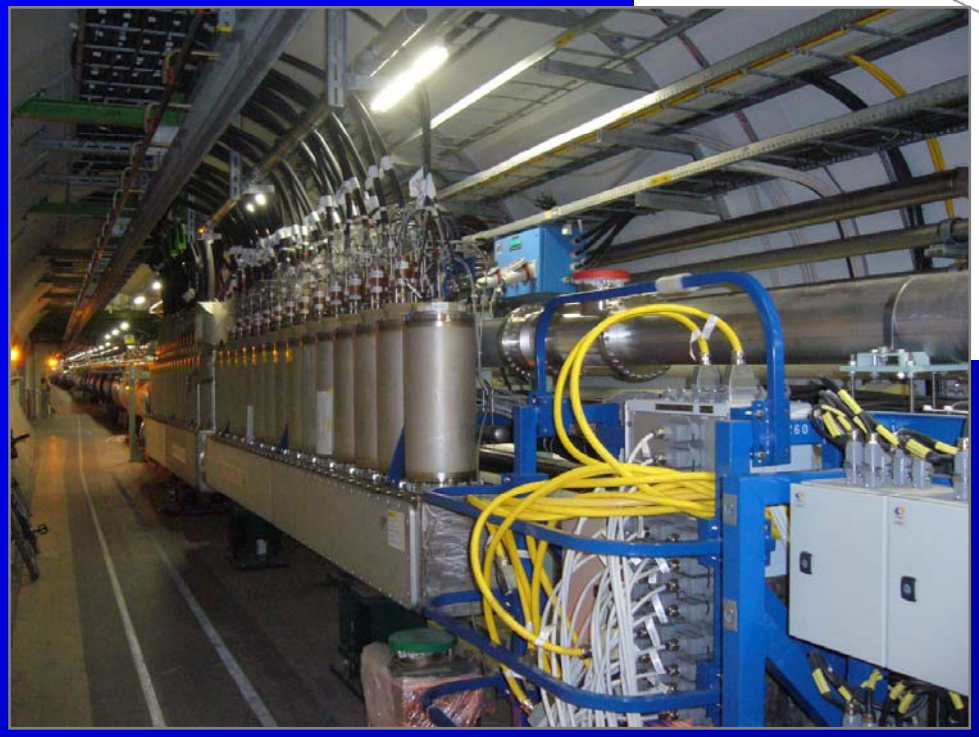

3.3 km
4'700 t @ 1.9K
≈ 10/15tHe

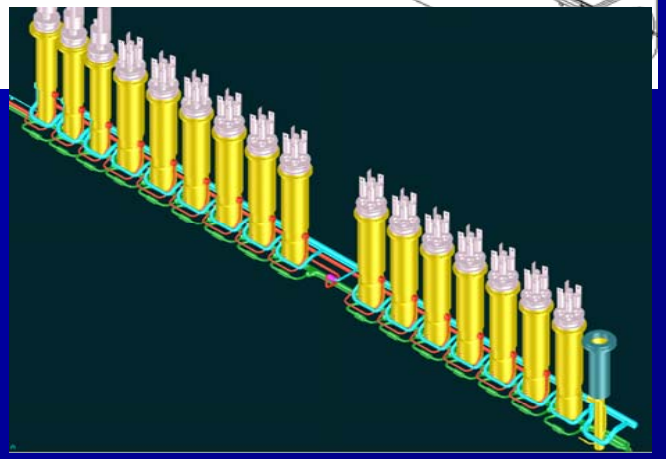
4.5 K
1.9 K

# Electrical Feed Boxes (DFB's)

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.





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# Flushing sectors before cool-down

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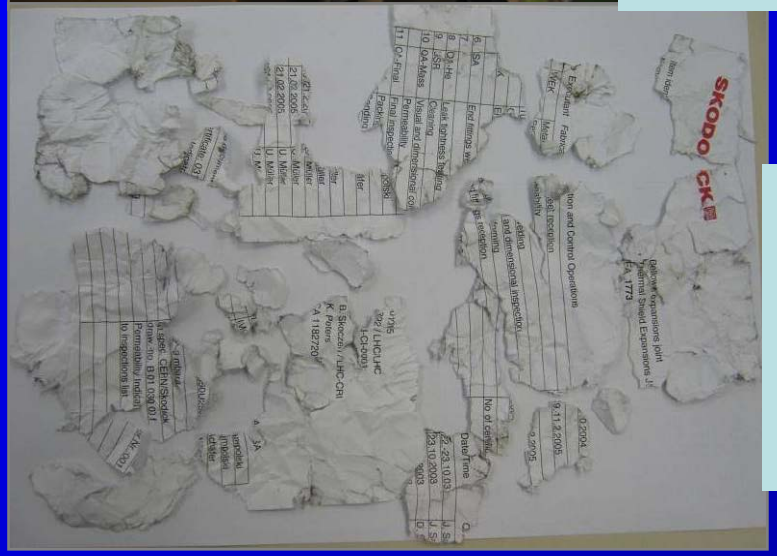
Dust Debris
Kapton
Reports



And
possible
shorts in
diodes !

But the sooner the best !!!

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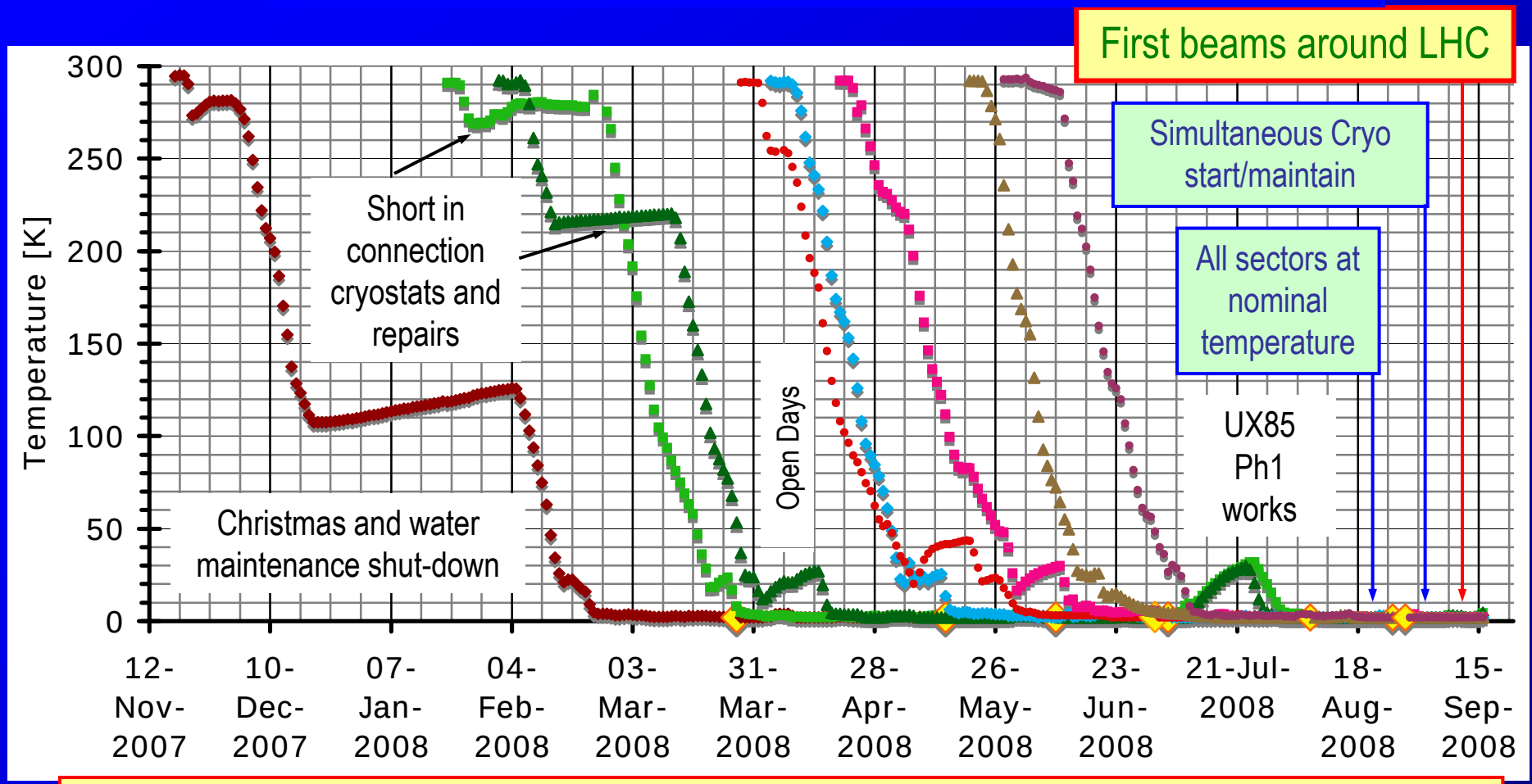
# First cool-down of LHC sectors




Cooling 8 sectors + Cryo tuning + Powering tests activities

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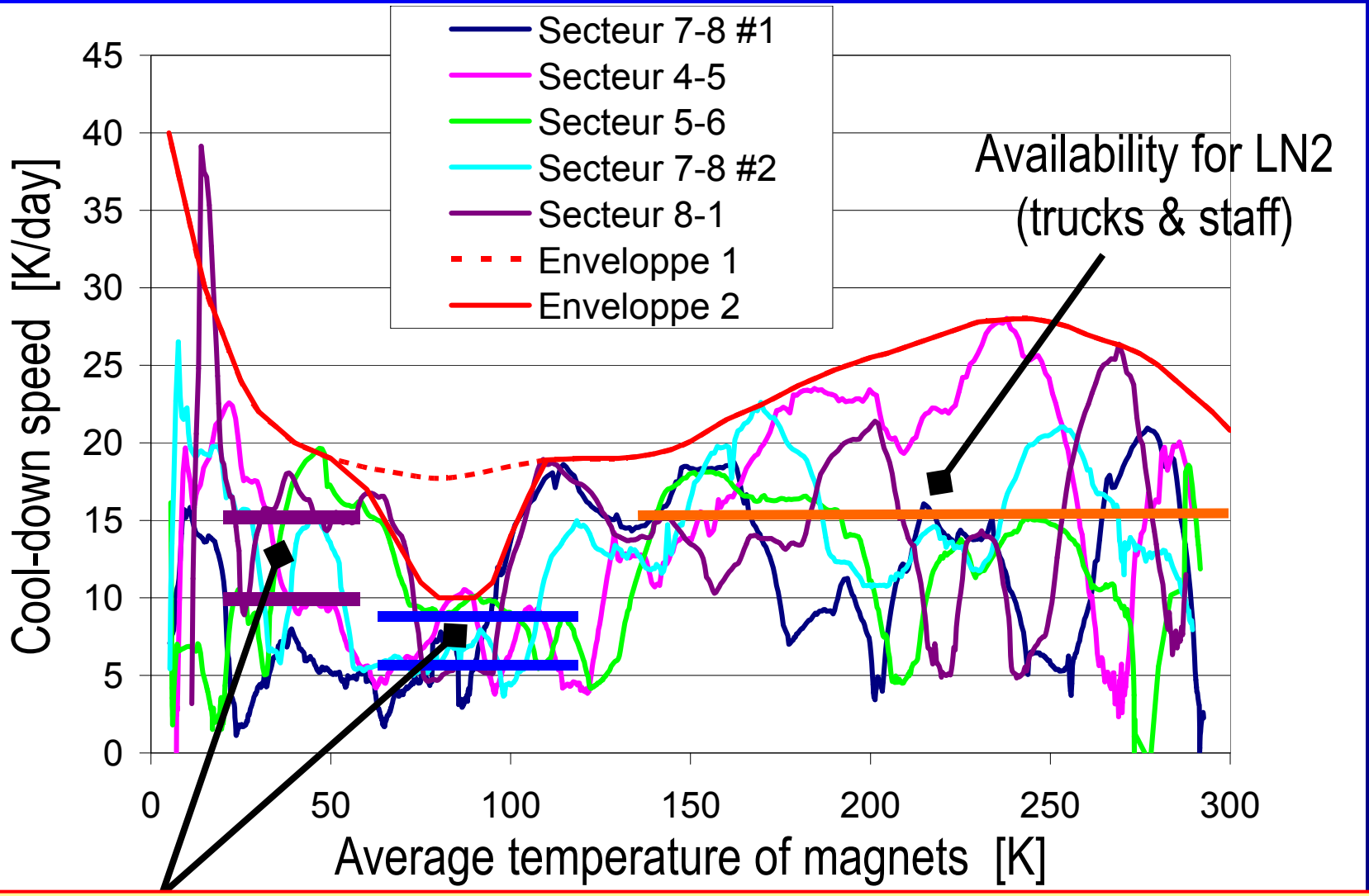
# Cool-down speed for LHC sectors

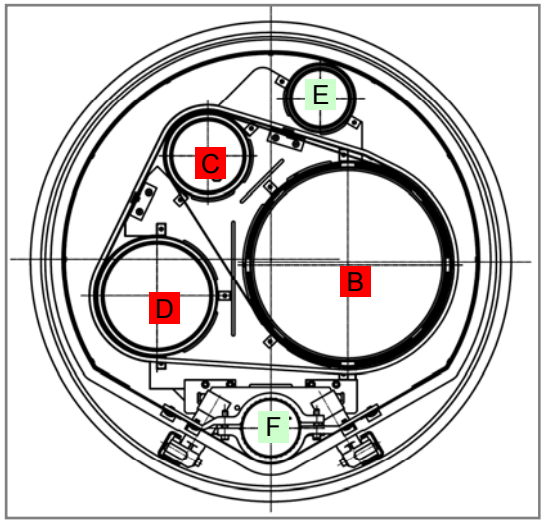





Dispersion due to particular process (HX & Turbines) and timing for thermal shield/ Line B

# An idea of time constants !






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

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

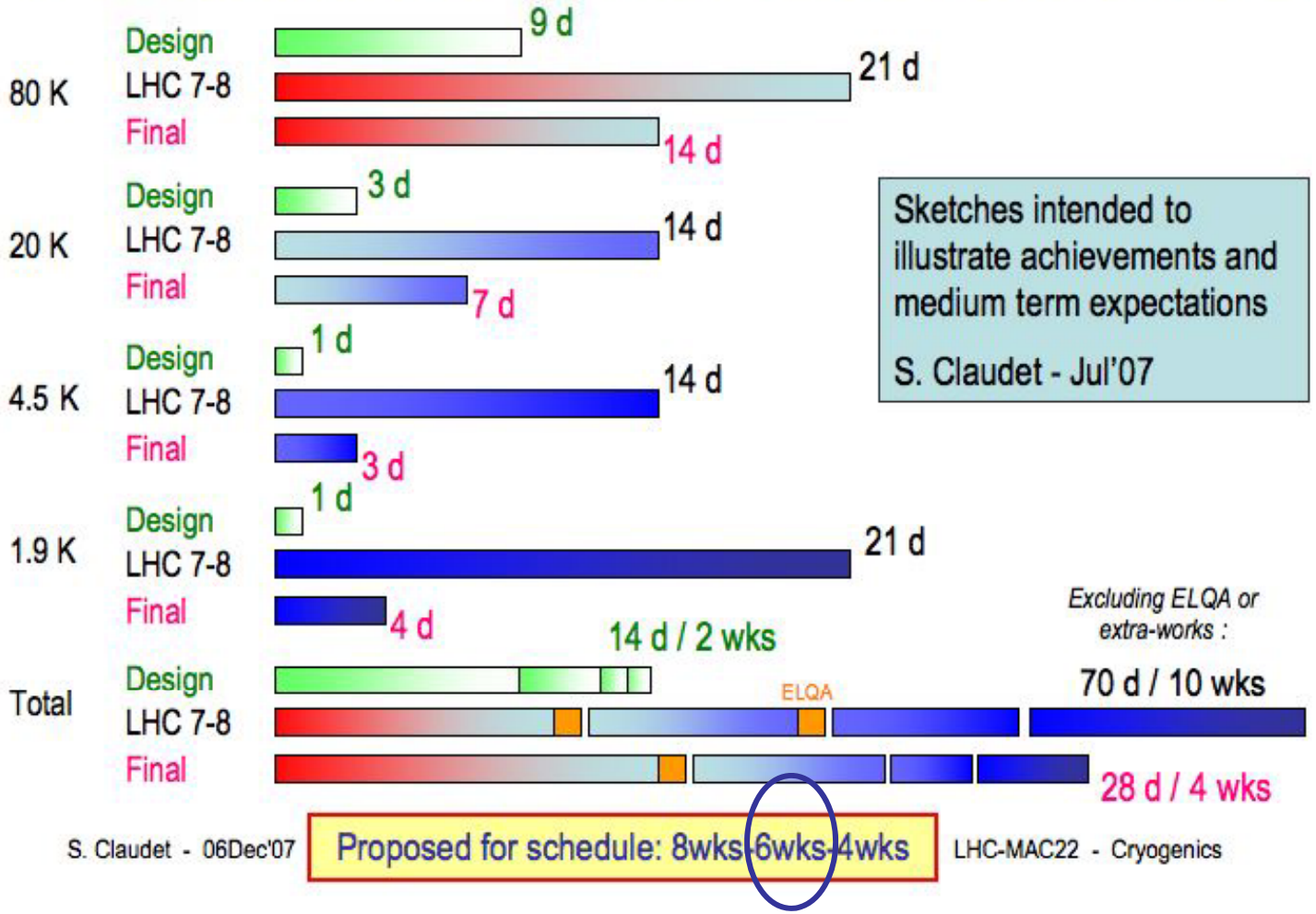
*From QUI to QRL_RM*

*≈ 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 …

# LHC Cryogenics: duration of cool-down phases




Updated installed capacity

25 d 18 d

LHe 3 d 2 d

2 d 1.5 d

Duration of phases

Present reference with Jun'08 constraints (staff, LN2, controls)

Target 2008: 5 wks

At best: 21.5 d

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# LHC Cryogenic commissioning

QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

- 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 for sector 4-5,

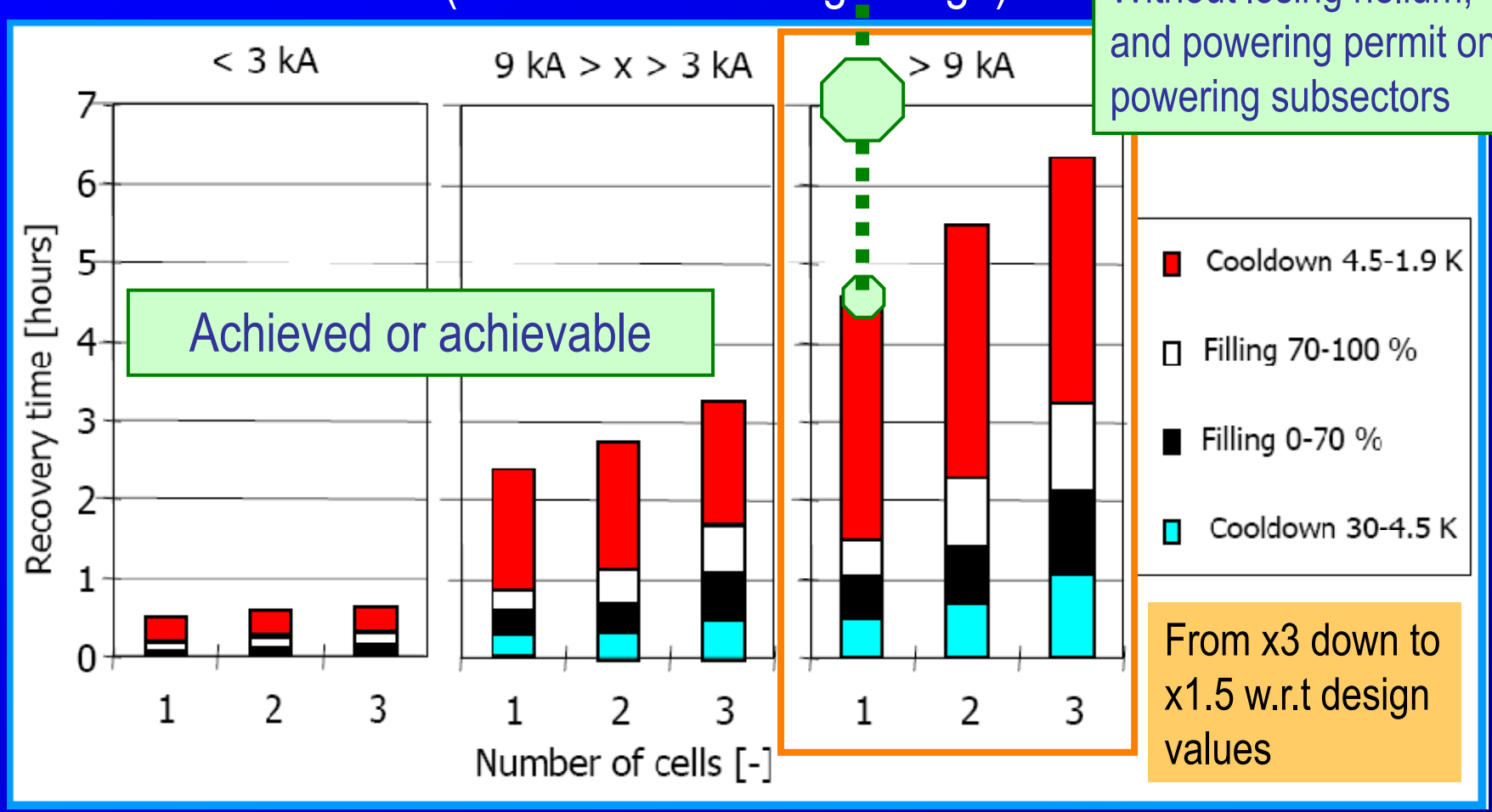
Implemented for sector 5-6, 7-8, and now in 8-1, 2-3, 6-7 during the (target =two) weeks after ARC magnets @ 4.5K

- 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

# Recovery Time after Limited Resistive Transitions

(Predictions at design stage)

Without losing helium, and powering permit on othe powering subsectors




Achieved or achievable

From x3 down to x1.5 w.r.t design values

- 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)

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# Cryogenics P&F diagram

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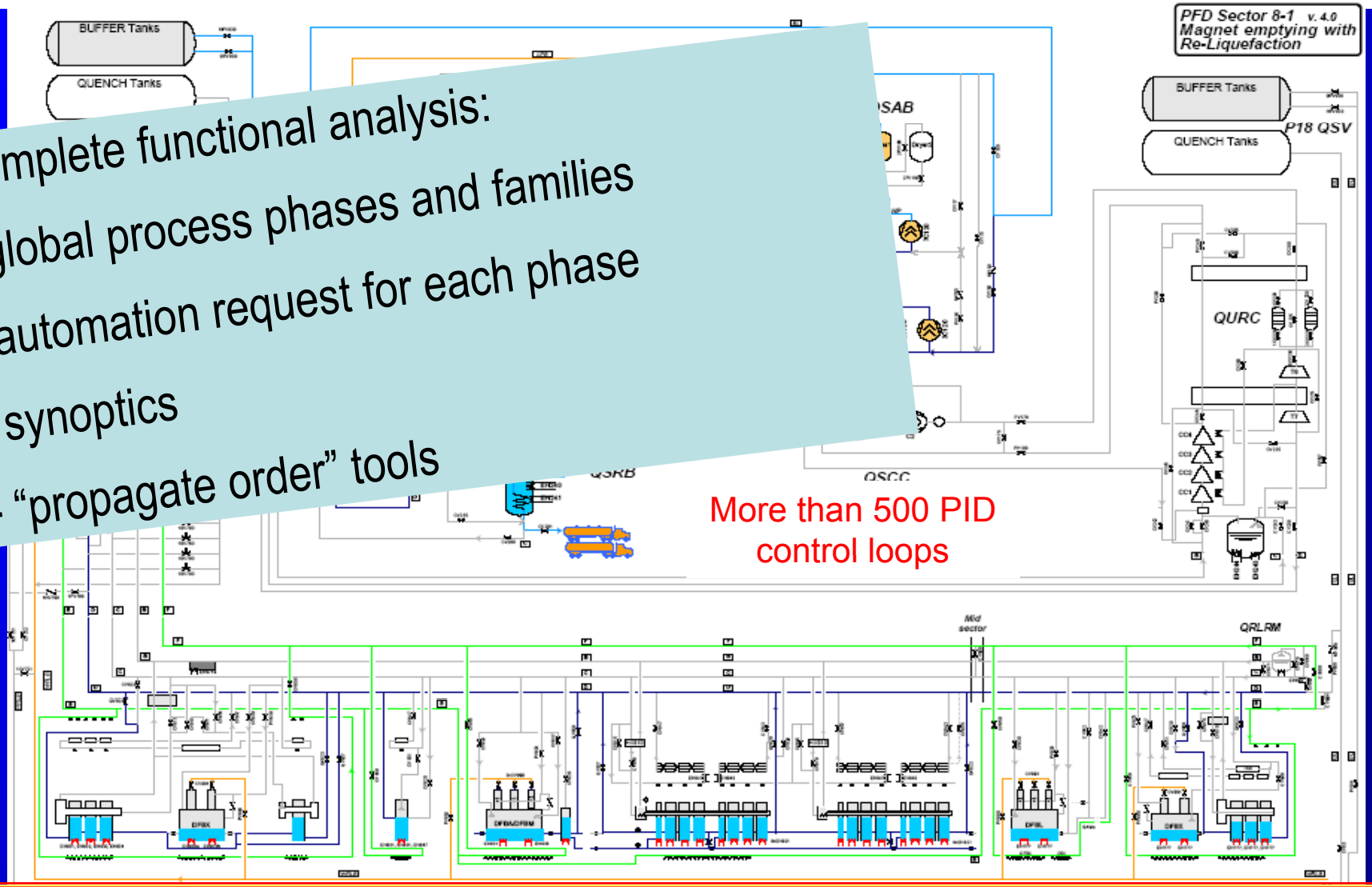
Complete functional analysis:

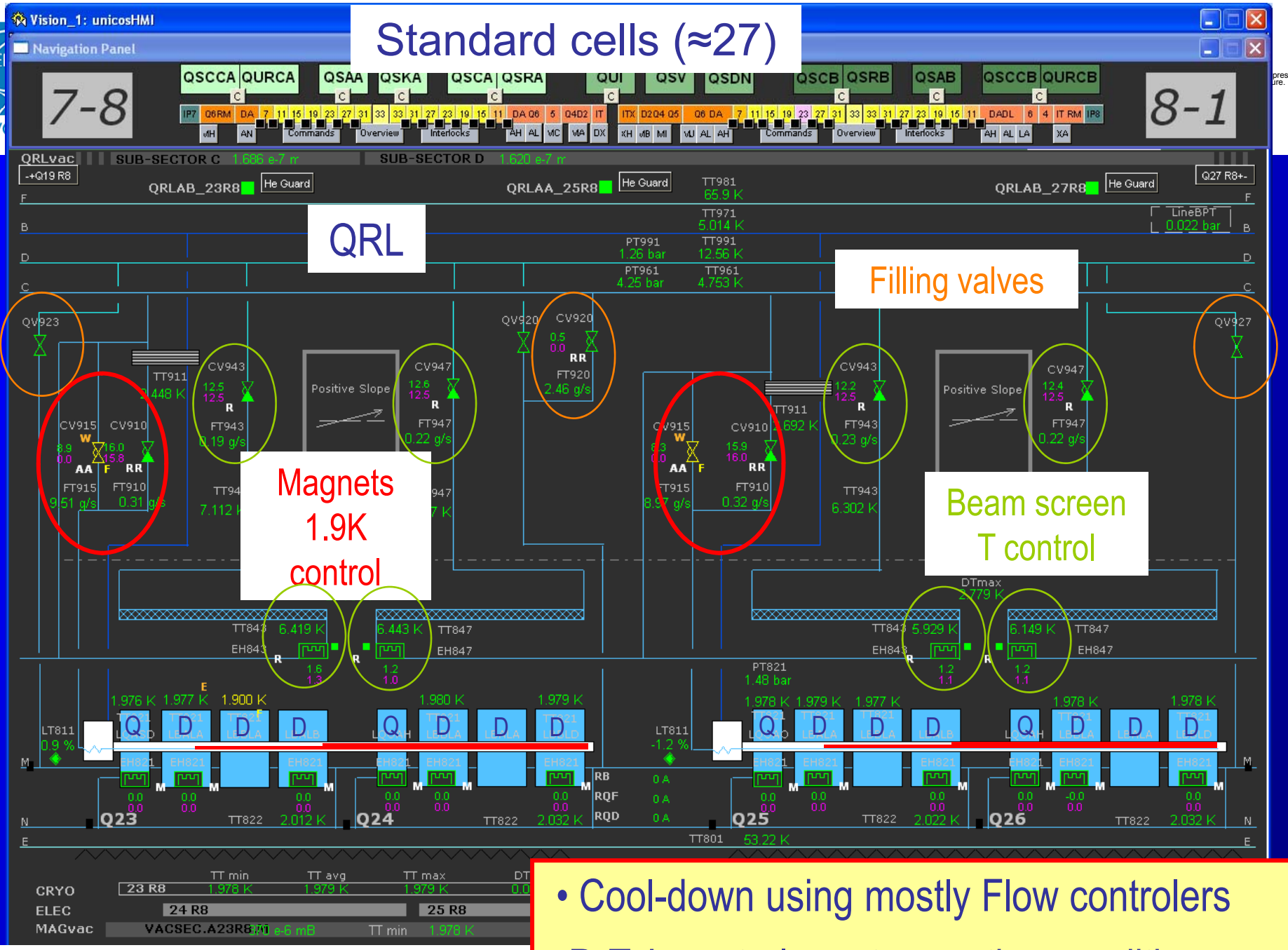
- global process phases and families
- automation request for each phase
- synoptics
- “propagate order” tools




More than 500 PID control loops

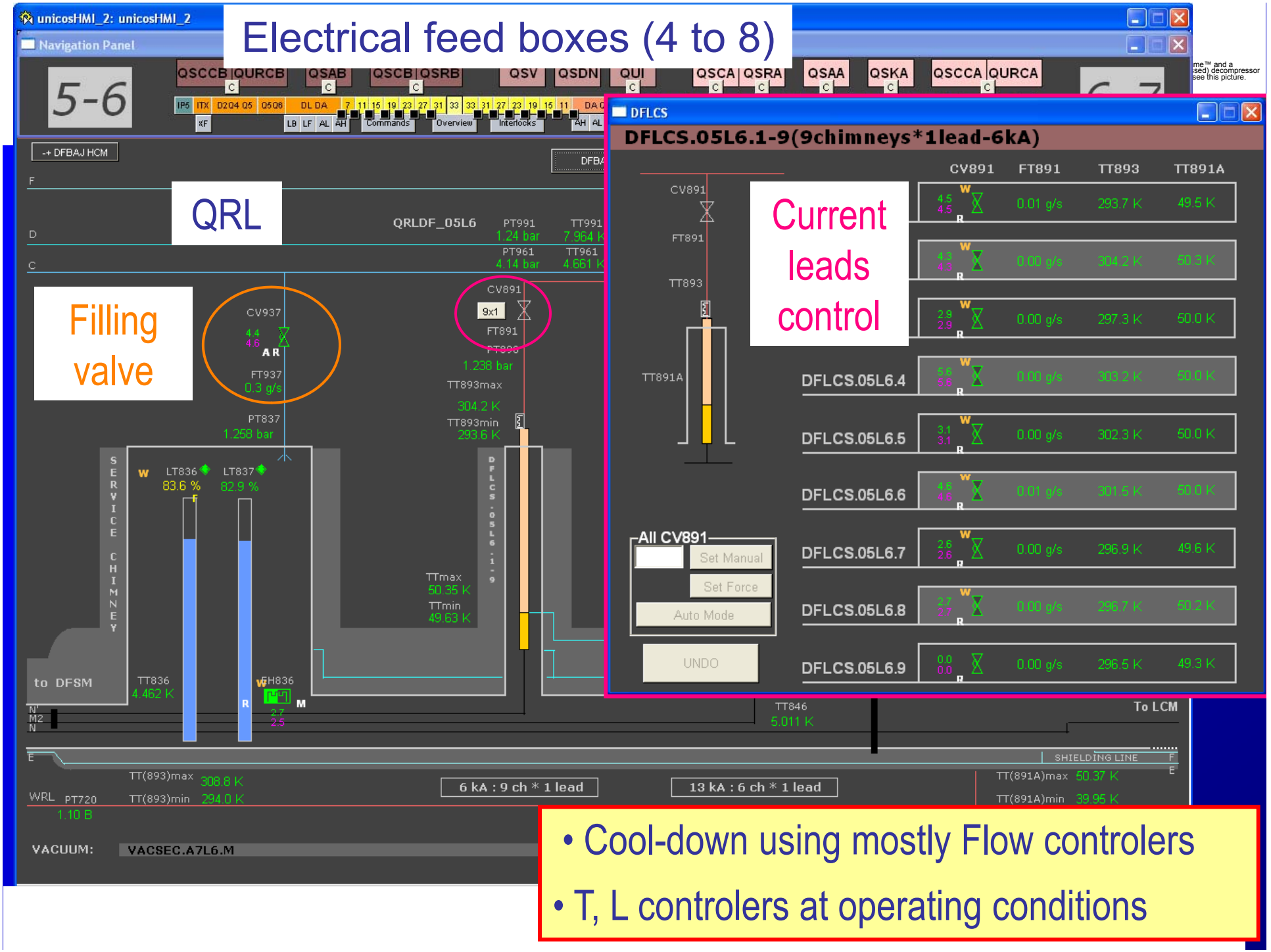
A large and complex fluid distribution system !

# Standard cells (≈27)




- Cool-down using mostly Flow controlers
- P, T, L controlers at operating conditions

# Electrical feed boxes (4 to 8)




- Cool-down using mostly Flow controlers
- T, L controlers at operating conditions

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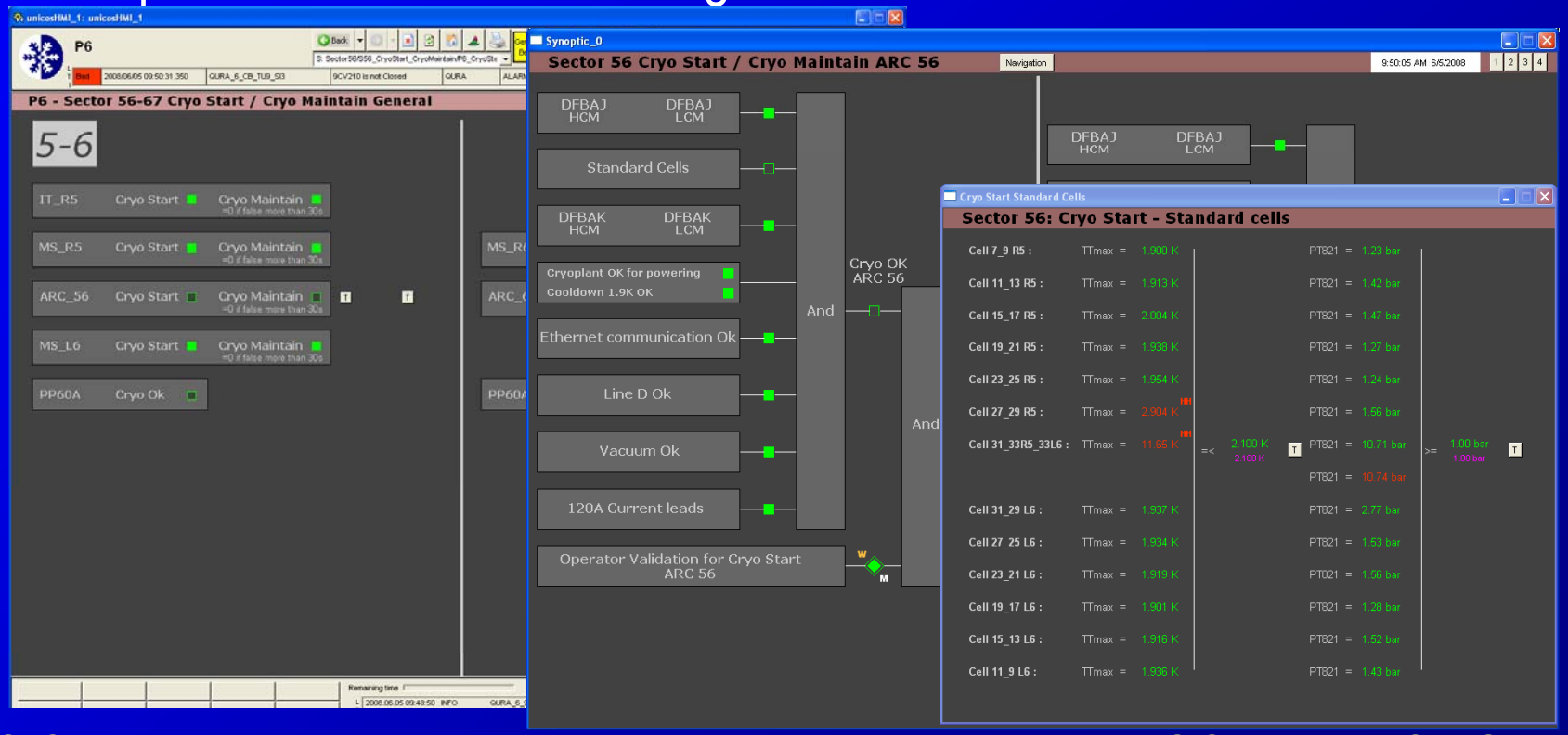
# Cryo conditions for powering

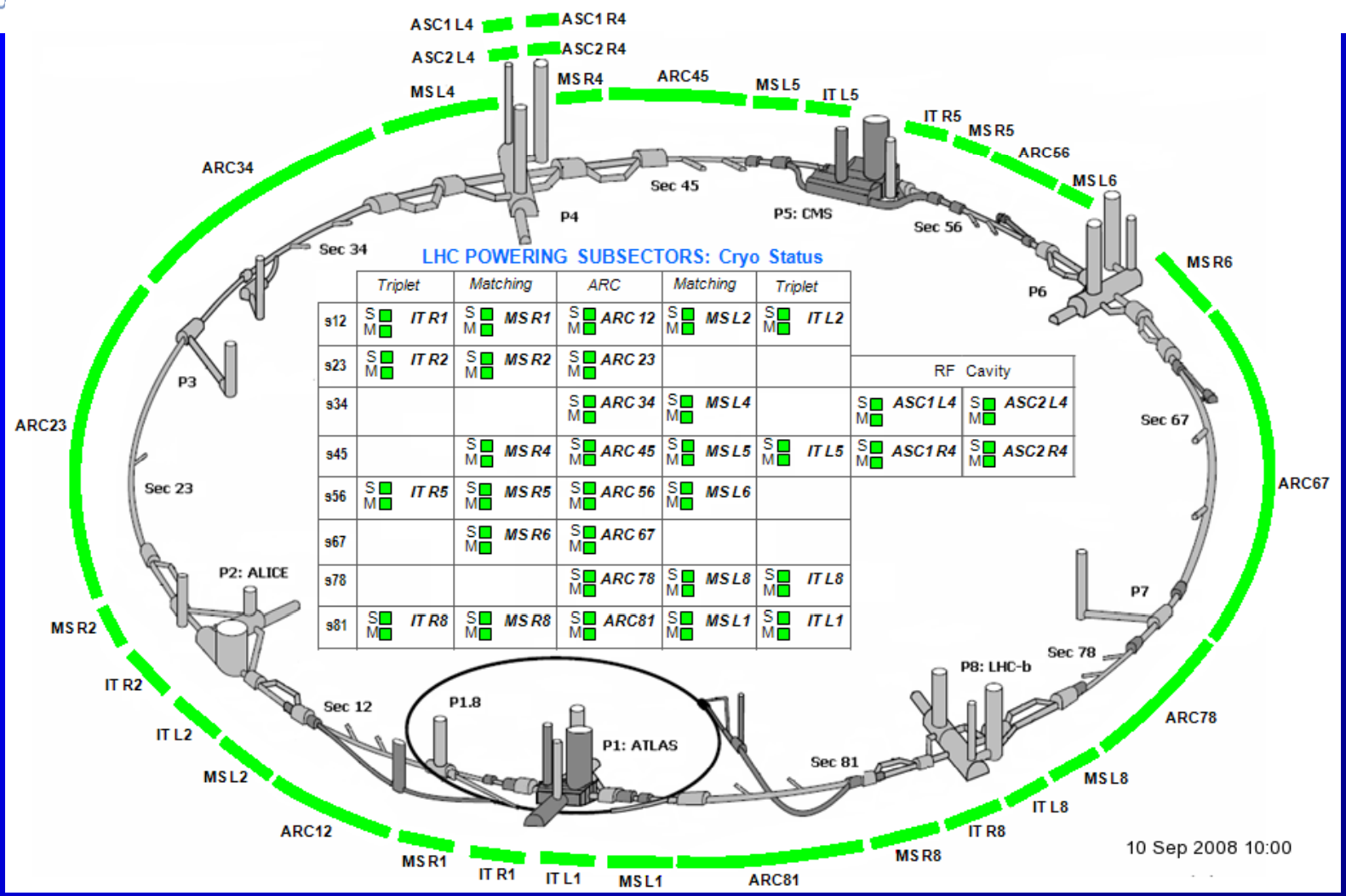
QuickTime™ and a TIFF (Uncompressed) decompressor are needed to see this picture.

Cryo Start: set of conditions to allow powering of concerned sub-sector (rather strict = good stability of process)

Cryo Maintain: Few important conditions checking integrity of HW, with slow power abort in case this signal is lost



# LHC Cryogenics power permit




LHC POWERING SUBSECTORS: Cryo Status

| | Triplet | Matching | ARC | Matching | Triplet | RF Cavity | |
|---|---|---|---|---|---|---|---|
| s12 | IT R1 | MS R1 | ARC 12 | MS L2 | IT L2 | | |
| s23 | IT R2 | MS R2 | ARC 23 | | | | |
| s34 | | | ARC 34 | MS L4 | | ASC1 L4 | ASC2 L4 |
| s45 | | MS R4 | ARC 45 | MS L5 | IT L5 | ASC1 R4 | ASC2 R4 |
| s56 | IT R5 | MS R5 | ARC 56 | MS L6 | | | |
| s67 | | MS R6 | ARC 67 | | | | |
| s78 | | | ARC 78 | MS L8 | IT L8 | | |
| s81 | IT R8 | MS R8 | ARC81 | MS L1 | IT L1 | | |

The cherry on the cake ! 20 months after start of cool-down

# Downtime - Availability

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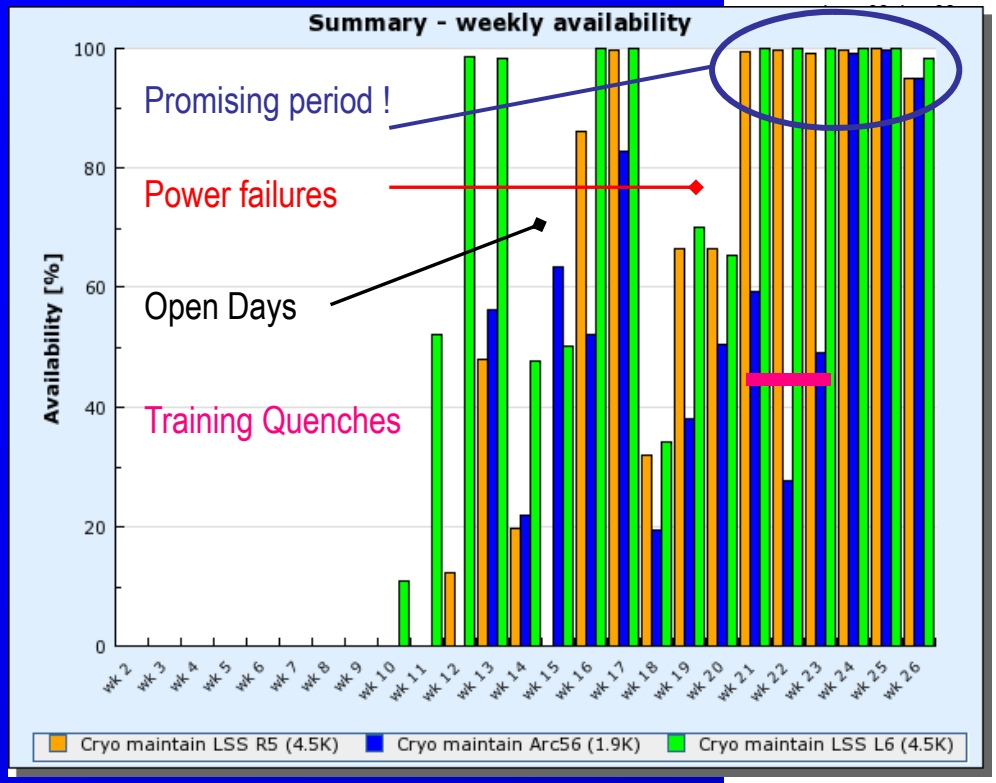
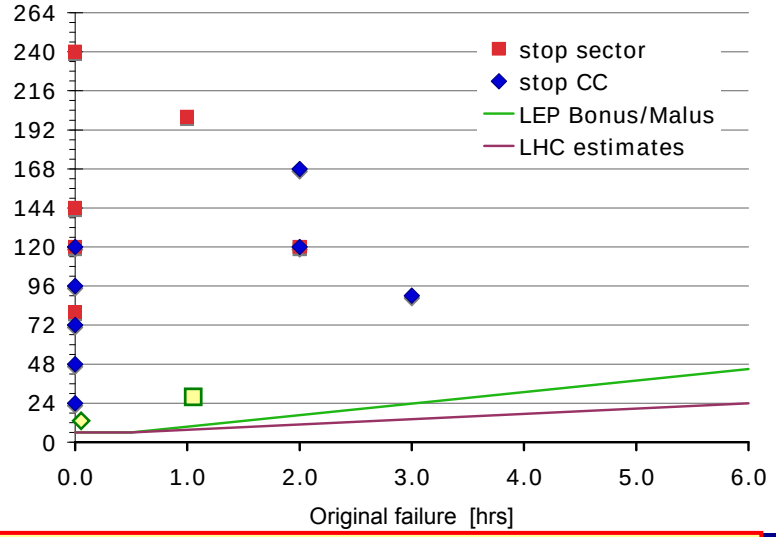



| sector 56 | | | origin (hrs) | | | stop (hrs) |
|---|---|---|---|---|---|---|
| 1 | 29-Feb-08 | Elec | 2.0 | Stop 400V (Pb AUG loop) | stop CC | 168 |
| 2 | 12-Mar-08 | Cryo | 0.0 | Controls CC (AL) | stop CC | not applicable |
| 3 | 14-Mar-08 | Cryo | 48.0 | Leak in 18kW Cold Box | stop CC | 240 |
| | | Cryo | | Controls CC (AL) | stop CC | not applicable |
| | | Cryo | | Stop 18kW Comp. (LS oil) | **stop entire sector** | not applicable |
| | | Water | | Stop 400V P5 (water) | partly blind | not applicable |
| | | Cryo | | Stop 18kW Comp. (LS oil) | **stop entire sector** | not applicable |
| | | Elec | 0.0 | Low 400kV | stop CC | 96 |
| | | Elec | 0.0 | CERN 400kV failure | **stop entire sector** | 120 |
| | | Elec | | US65 400V stop | stop CC | not applicable |
| | | Elec | | US65 400V stop | stop CC | not applicable |
| | | Elec | | US65 400V stop | stop CC | not applicable |
| | | Elec | 0.0 | 24 VDC power unit down | **stop entire sector** | 80 |
| | | Elec | 0.0 | US65 400V stop | stop CC | 24 |
| | | Elec | | | | |
| | | Water | | | | |




⇒ Rather good availability already a few weeks after 5 TeV qualification

⇒ Failure rates of services to be improved

⇒ Cryo recovery time to be improved with more robust automation

Target Autumn'08: < 12 h for stop CC [OK] < 36 h for full sector stop [24h]

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# Organisation of resources

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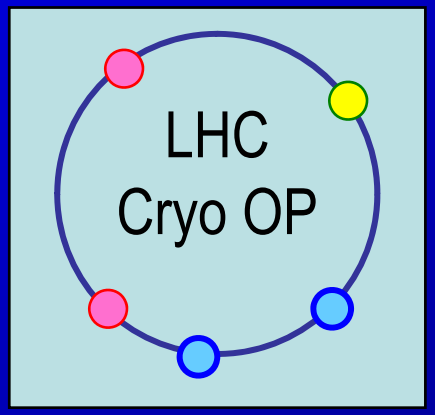


- Cool-down of 8 sectors:
  - Performed with “cryo island” based teams
- HWC of many sectors in parallel:
  - Since mid Jan’08, operators up to 22h and Saturdays
  - Since Spring’08, two shifts (week) and Saturdays (day)
- First beams:
  - We do not have CERN staff (alone) for any kind of shift
  - Various type of shifts possible via our industrial partner, with CERN experts and local control rooms (day time) in back-up

Sept. to Nov’08: 2 x (3x8h-7d/7d) in CCC

- After July 2009:
  - End of present operation contract, with in-sourcing plus “Field Support Unit” as reference solution, to be re-evaluated end 2008

Learning to master LHC cryogenics, education of teams while updating controls based on ecperience, towards sites-machines-operations duties

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# Summary



- Confirmation of cooling principle, heat loads, thermometry channels, machinery, global system behaviour
- The LHC cryogenic system has been progressively put into service with obvious signs of “learning curve”, and promising periods for possible beams
- Consolidation program started and continued (valves, DFB’s, instrumentation & controls, helium guards) now extended as well to services
- Slowly preparing the switch from HWC to operation for beam, with reasonable confidence but with minimal tools and staff