Operation of the LHC Cryogenics system and interface with beam & machine operation

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on behalf of the "Cryogenics Group"
Technology Department

Workshop on Accelerator Operations
August 6-10, 2012

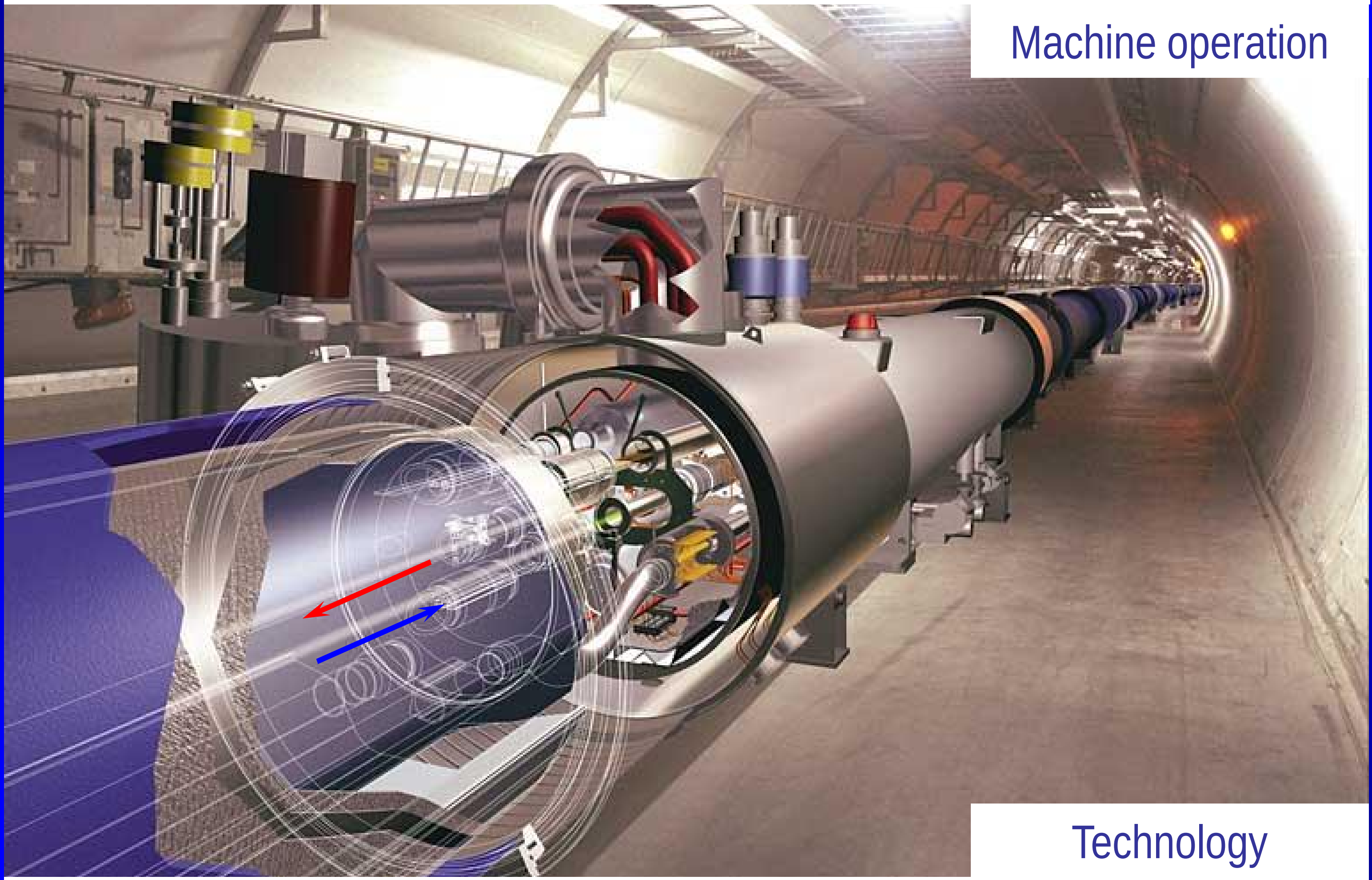
Outline

- Introduction to LHC Cryogenics
- Operation, organisation and results
- Availability and interaction with beam operations
- Summary

LHC accelerator

p-p collision 10^{34} $cm^{-2}.s^{-1}$, 14 TeV, 0.5 GJ stored energy

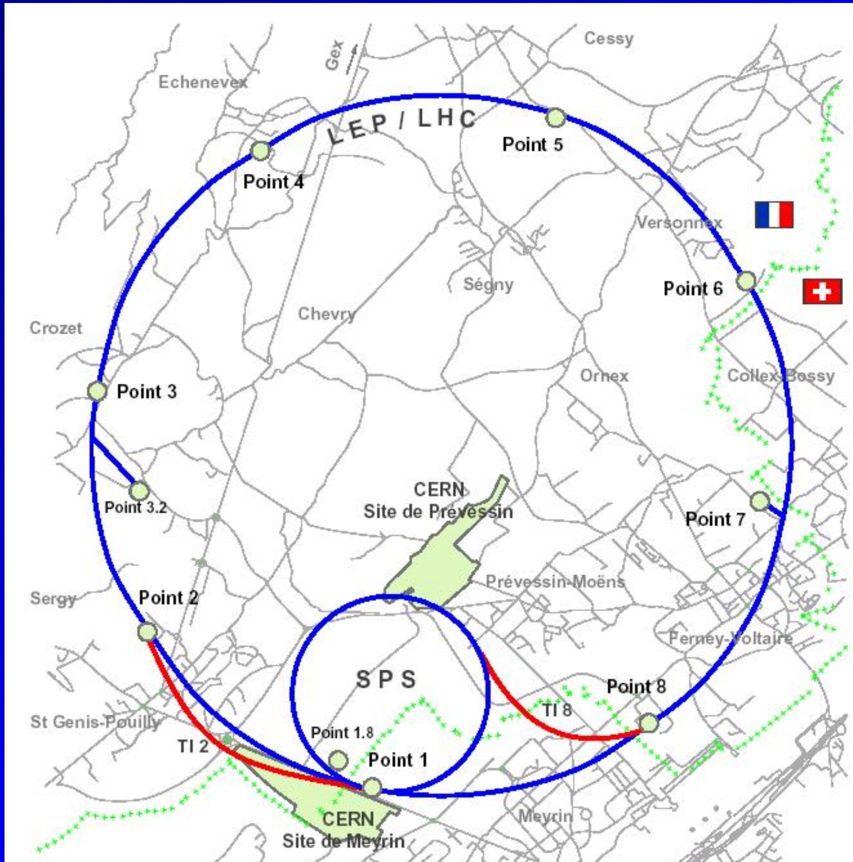
Machine operation



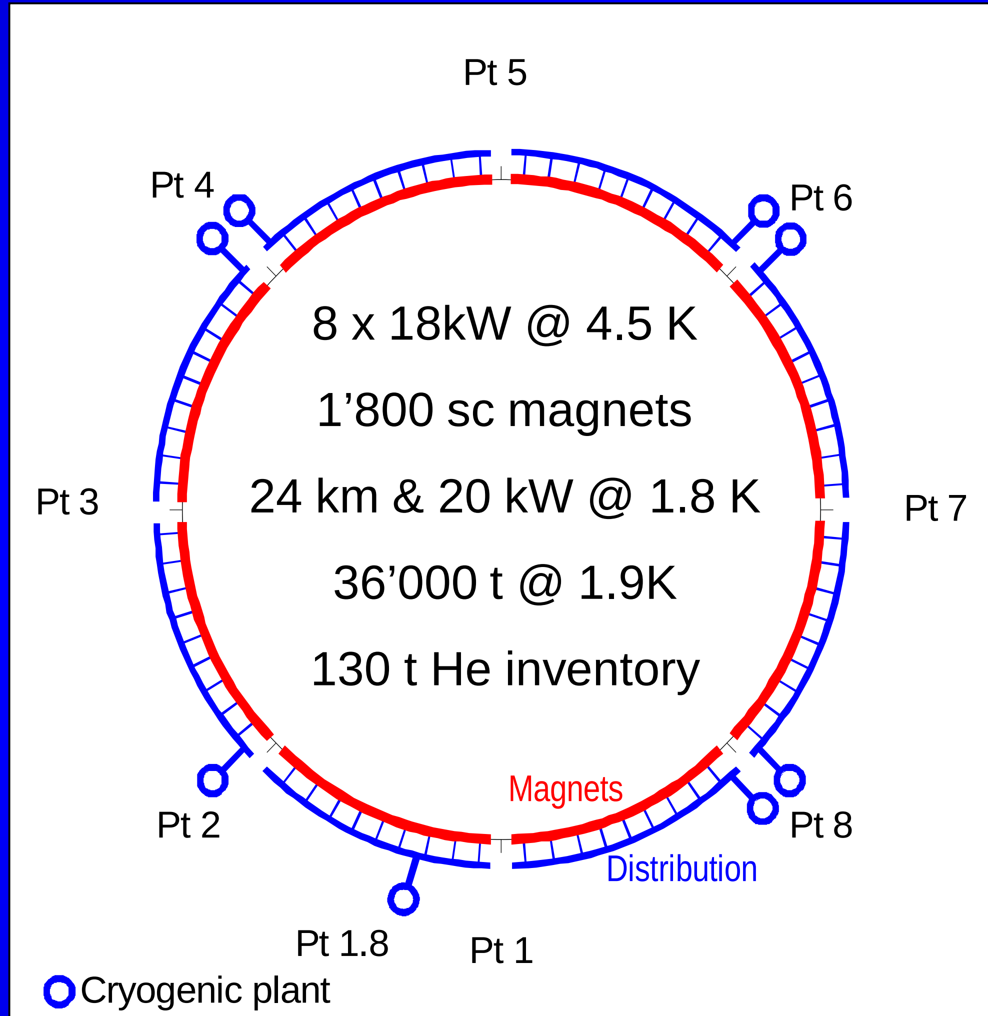
Technology

24 km of superconducting magnets @1.8 K, 8.33 T

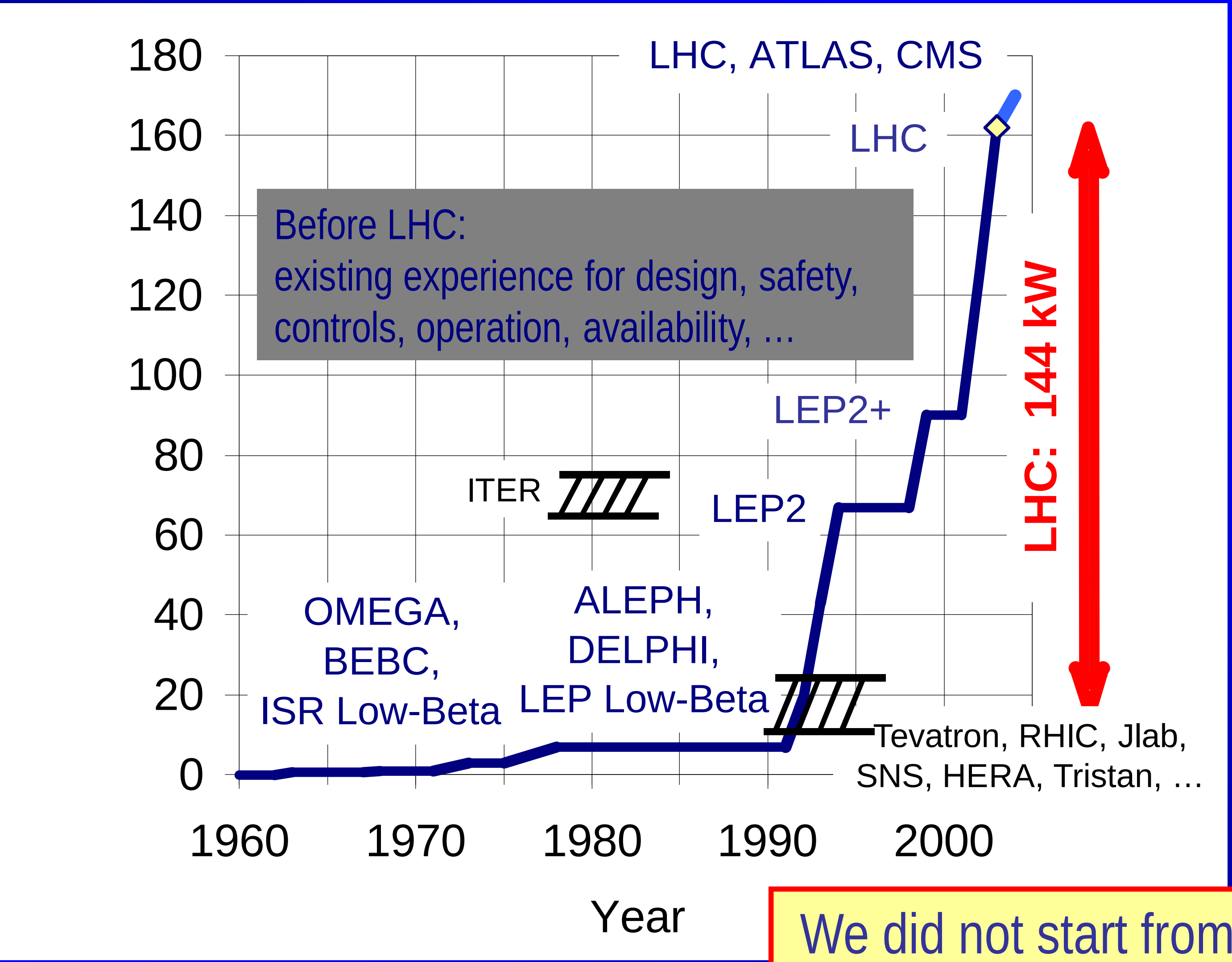
Layout of LHC cryogenics



LHC cryogenics is the largest, the longest and the most complex cryogenic system worldwide

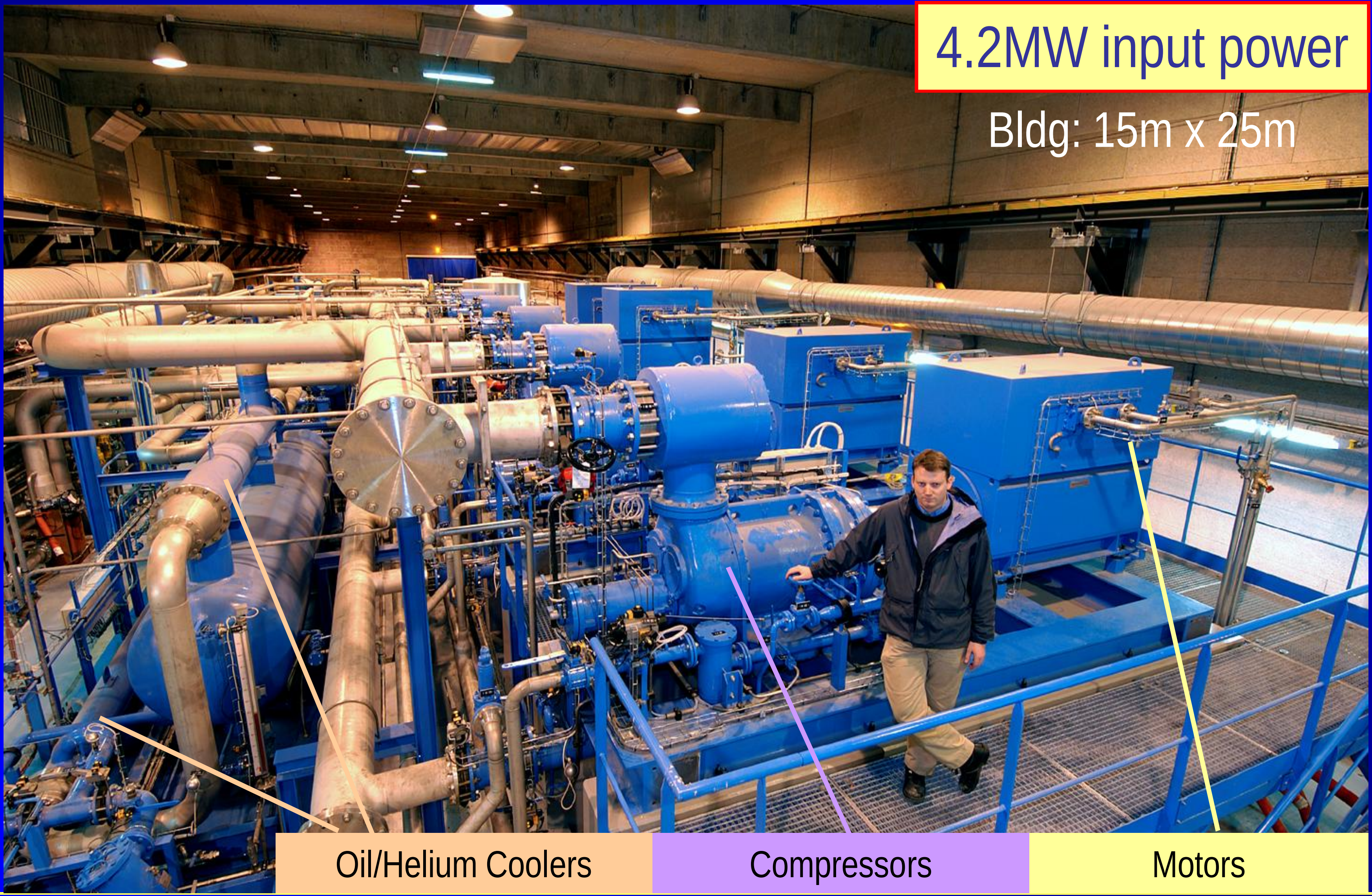


How does it compare ?



We did not start from scratch!

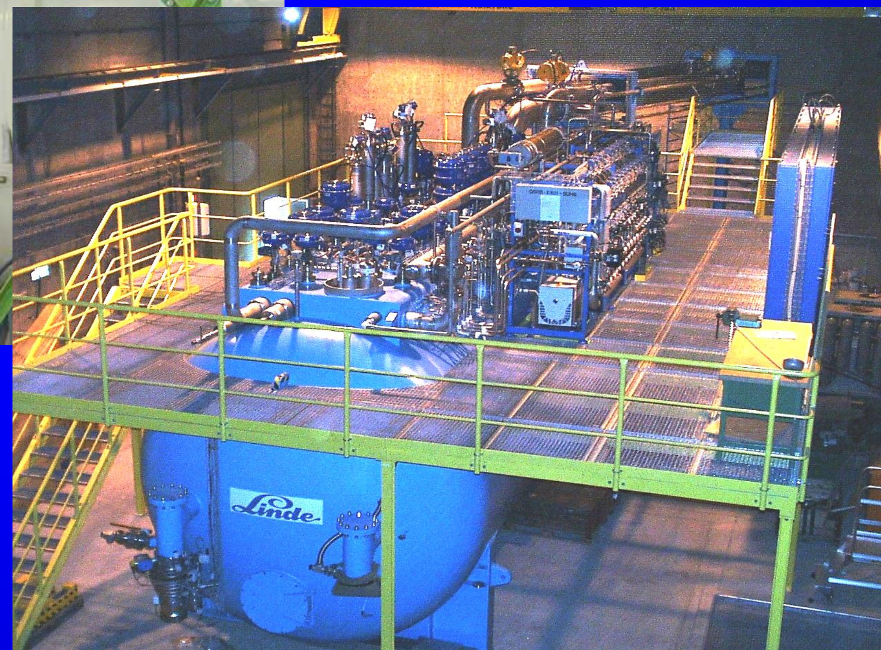
LHC compressor station (x8)



18 kW @ 4.5 K Refrigerators (x8)

33 kW @ 50 K to 75 K - 23 kW @ 4.6 K to 20 K - 41 g/s liquefaction

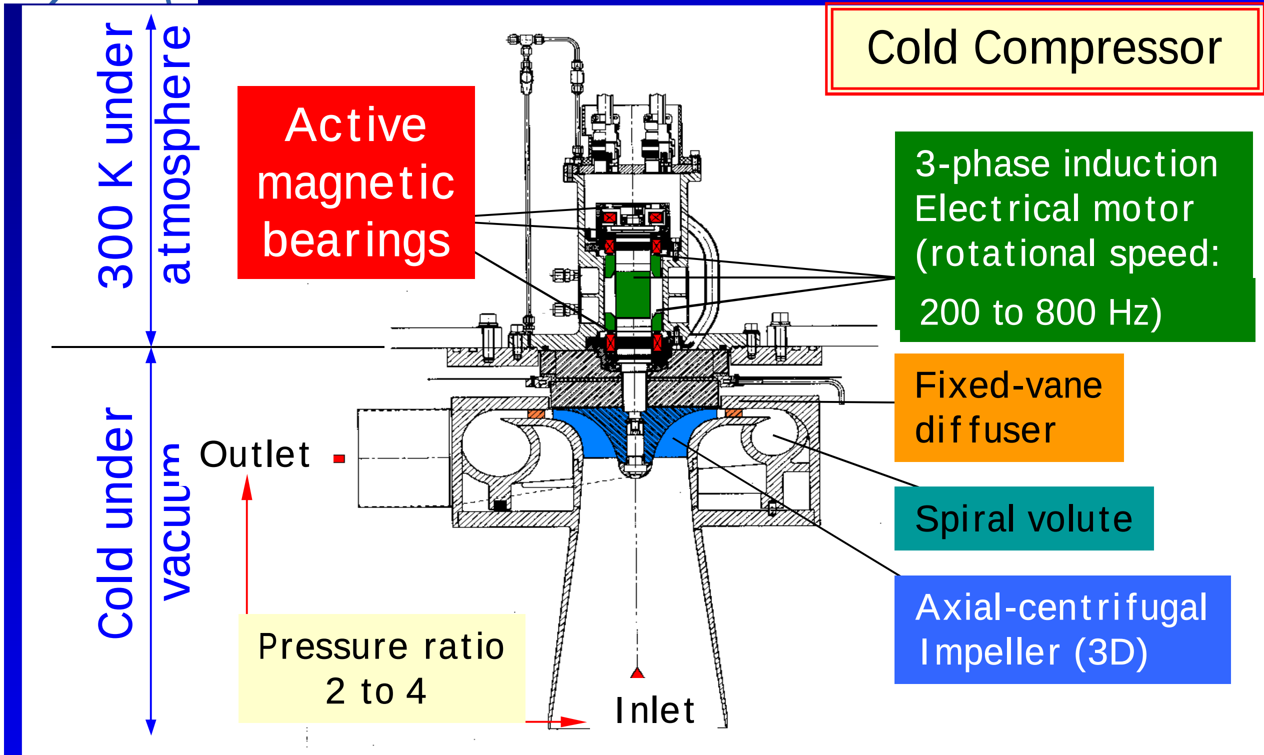
LHe: 3'600 l/h

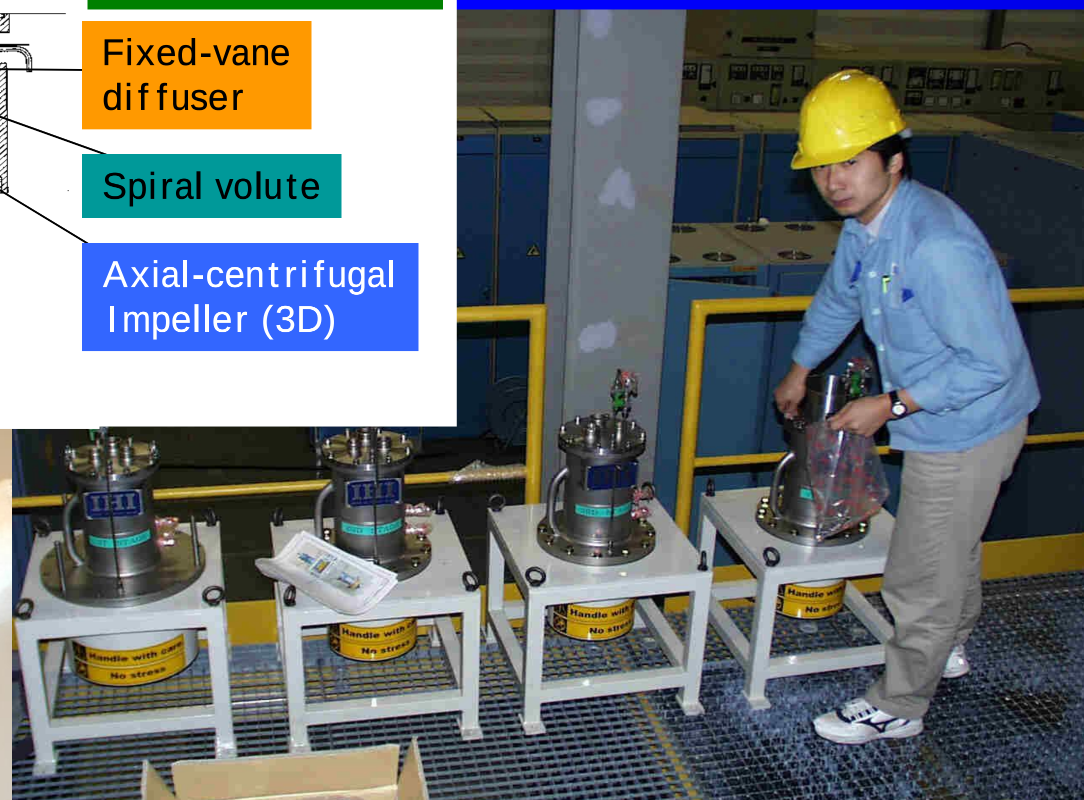


4m diam, 20m long, 100tons

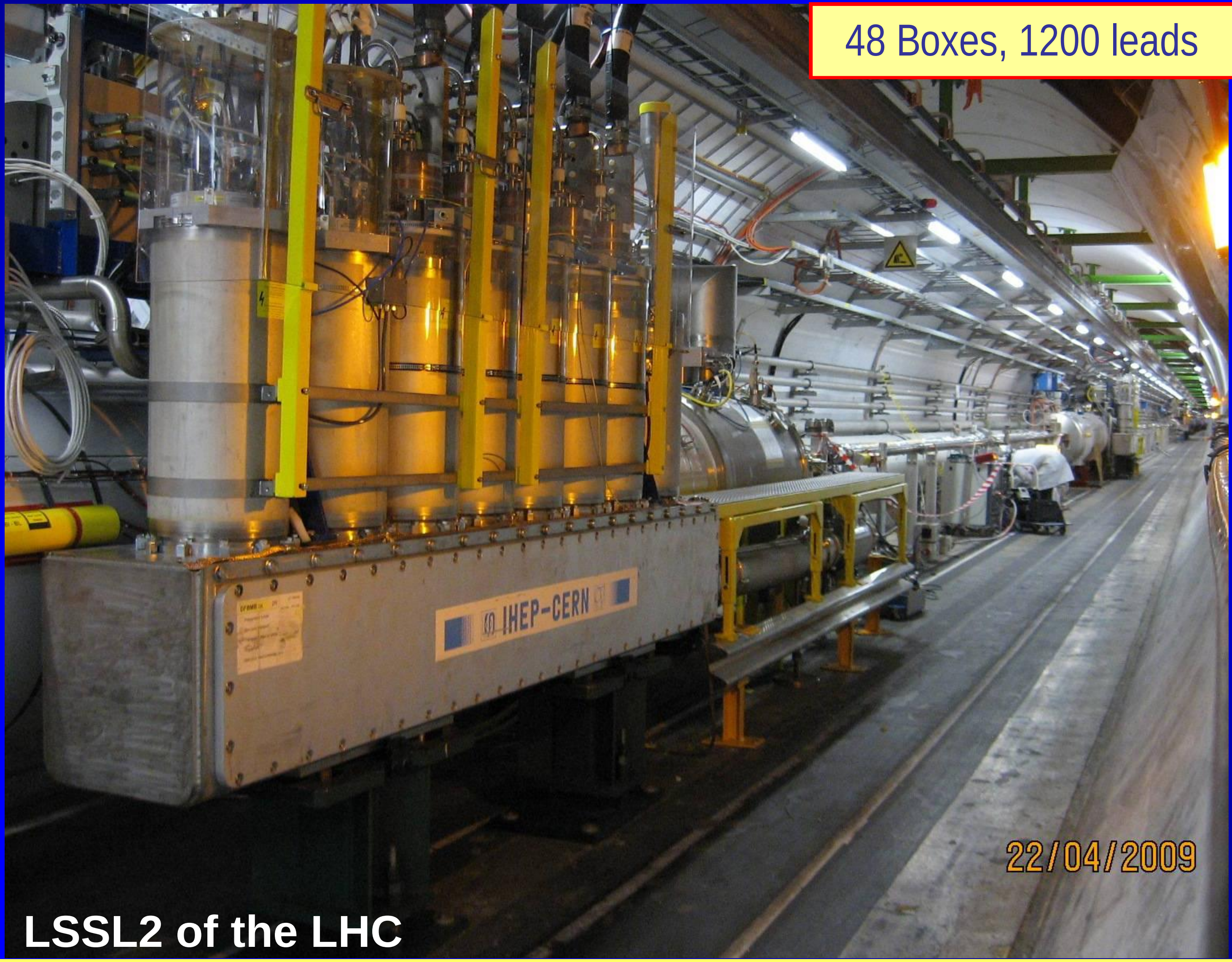
1.8K Units with cold compressors (x8)

125 g/s GHe from 15 mbar to P atm with 3 or 4 stages





Electrical feed boxes for current leads



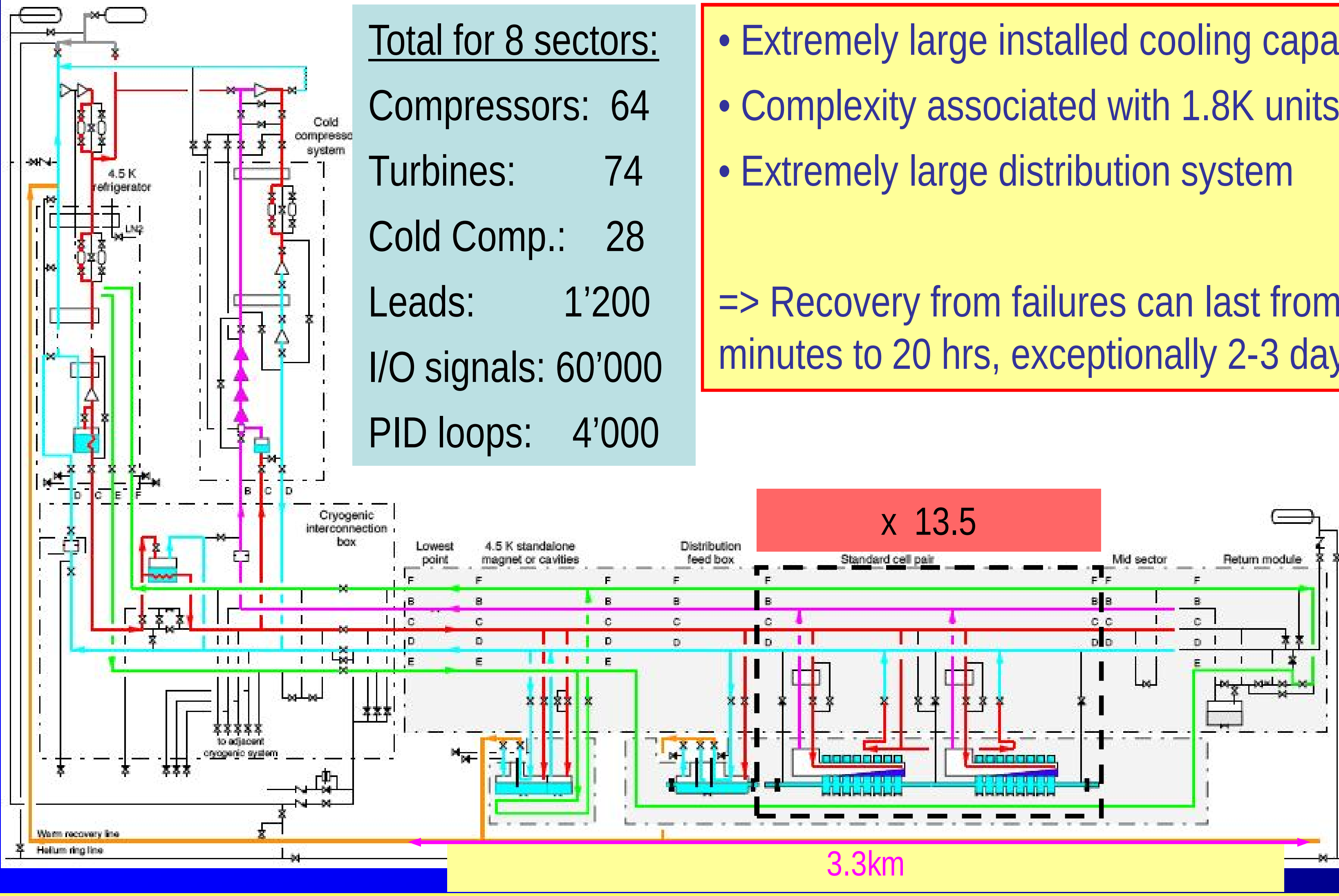
One LHC sector: production-distribution-magnets

Total for 8 sectors:

Compressors: 64
Turbines: 74
Cold Comp.: 28
Leads: 1’200
I/O signals: 60’000
PID loops: 4’000

- Extremely large installed cooling capacity
- Complexity associated with 1.8K units
- Extremely large distribution system

=> Recovery from failures can last from few minutes to 20 hrs, exceptionally 2-3 days



Interfaces: follow-up electrical perturbations

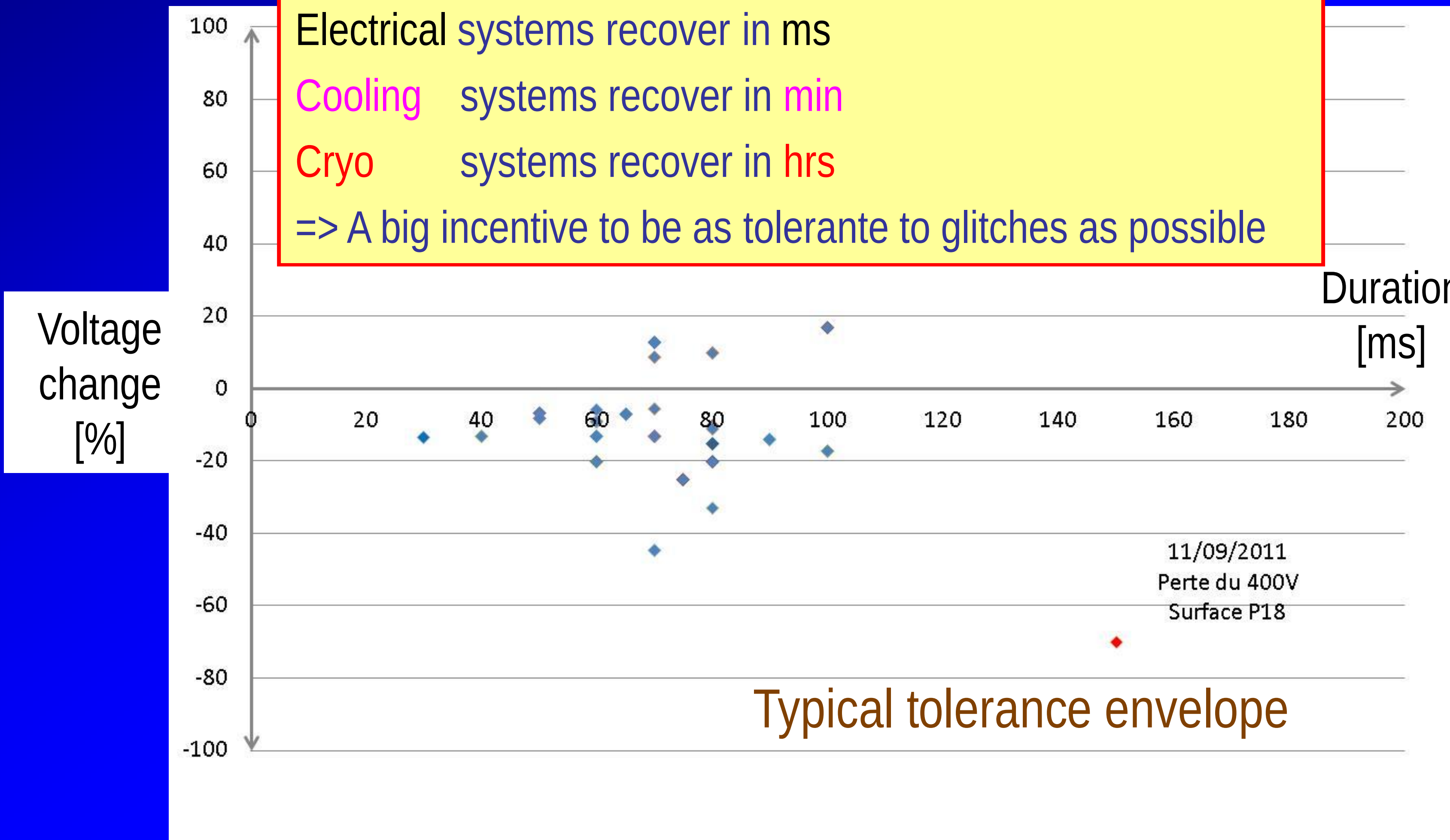
EL perturbations and their impact on our LHC Cryo system

Electrical systems recover in ms

Cooling systems recover in min

Cryo systems recover in hrs

=> A big incentive to be as tolerante to glitches as possible



Main reasons to superconducting

For accelerators in high energy physics

Capital Cost

- Compactness through higher fields

$E_{beam} \approx 0.3 \,.\, B \,.\, r$ — [Gev] [T] [m]

$E_{beam} \approx E \,.\, L$ — [Gev] [MV/m] [m]

Be sure that at design stage, working at higher temperature was considered, but not selected to maximise LHC beam energy

=> Cryogenic systems takes longer to recover from failures than conventional ones (but we work on it!)

Operating Cost

- Saving operating energy

Electromagnets:

Resistive: $P_{input} \approx E_{beam}$

Superconducting: $P_{input} \approx Pref$

Acceleration cavities

$P_{input} \approx Rs.L.E^2/w$

$R_s \approx R_{BCS} + R_o$

$R_{BCS} \approx (1/T)\exp(-BT_c/T)$

Interactions between LHC systems

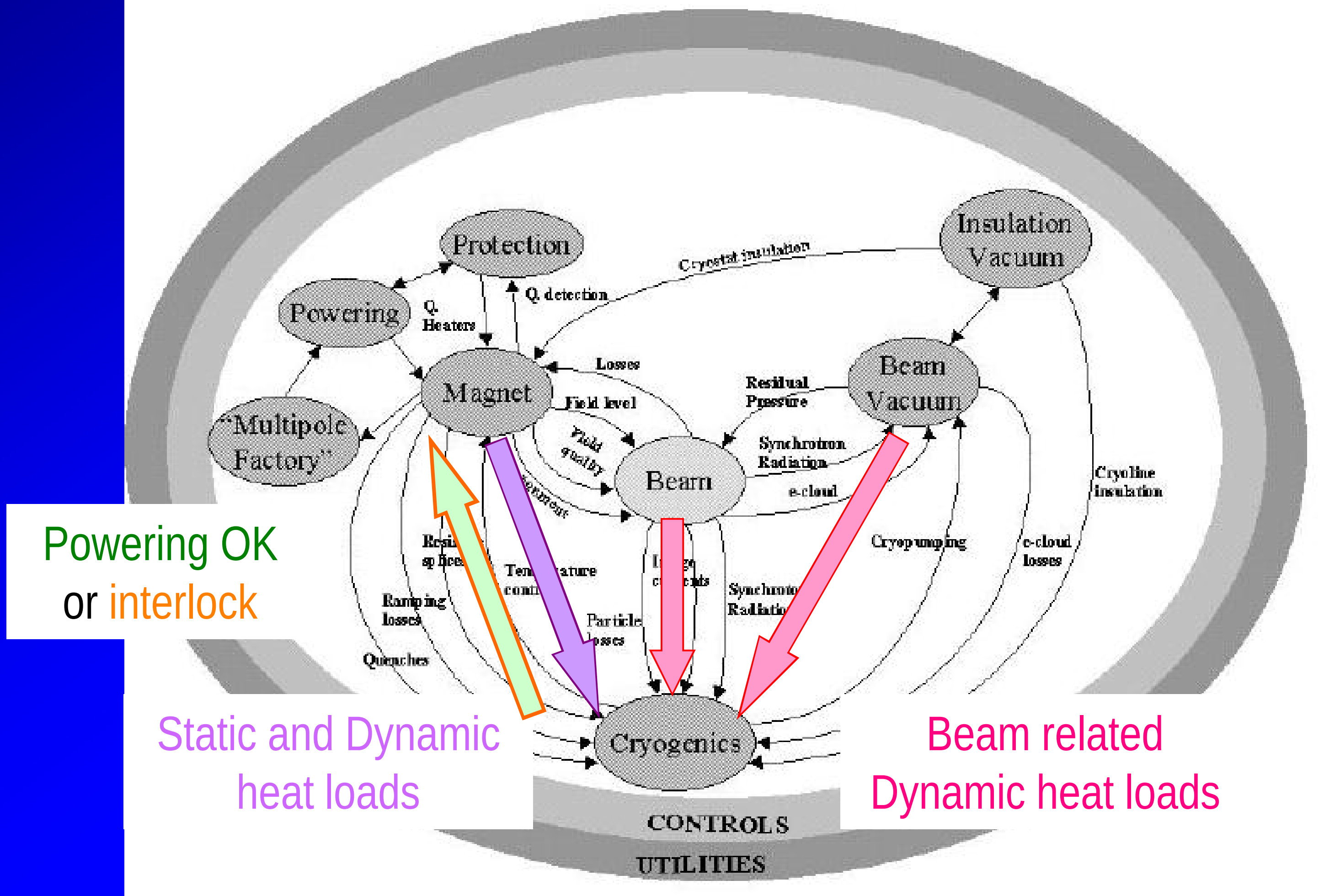


Figure 1: Interdependence of LHC main accelerator systems and beam.

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Key factors for operation

- Equipment architecture:
  - Central liquefier to intermediate buffer, distribution decoupled
  - Cooling capacity production in line with demands

On-call adapted

- Type of operation
  - Transients (cool-down / warm-up) or various recovery
  - Alarm monitoring, simple reset actions, calling for experts
  - Detection of process degradation and curing action
  - HW checks and preventive treatment of slow evolving problems
- Frequency of required actions:
  - Once per month, once per week
  - Once per 1-2 days

LHC: A huge and complex system without significant buffer and frequent operator actions required

Dedicated 24/7 required so far !!!

Structure - Coordination - Outils

Management

- Mechanics
- Electricity-Controls
- Instrum-Cryolab
- Methods - Logistics
- Operation Accel.
- Operation Detect.

Coordinations:

- Team Leaders + Management (1/wk)
- Performance panel (1/2wks)
- Operation / Maintenance panel
- Methods & Tools panel

Tools (web interface DB oracle):

- e-logboog operation for any change of configuration (wanted or not) or observation and diagnostic request
- Diagnostic tables, work-orders, intervention reports
- Asset & spares management, intervention procedures
- Maintenance plan
- Scheduling

Staff & team evolution

People should be able to quit, newcomers should be integrated

- High level requirements for recruitment (Bachelor & Masters)
- Formalised induction process:

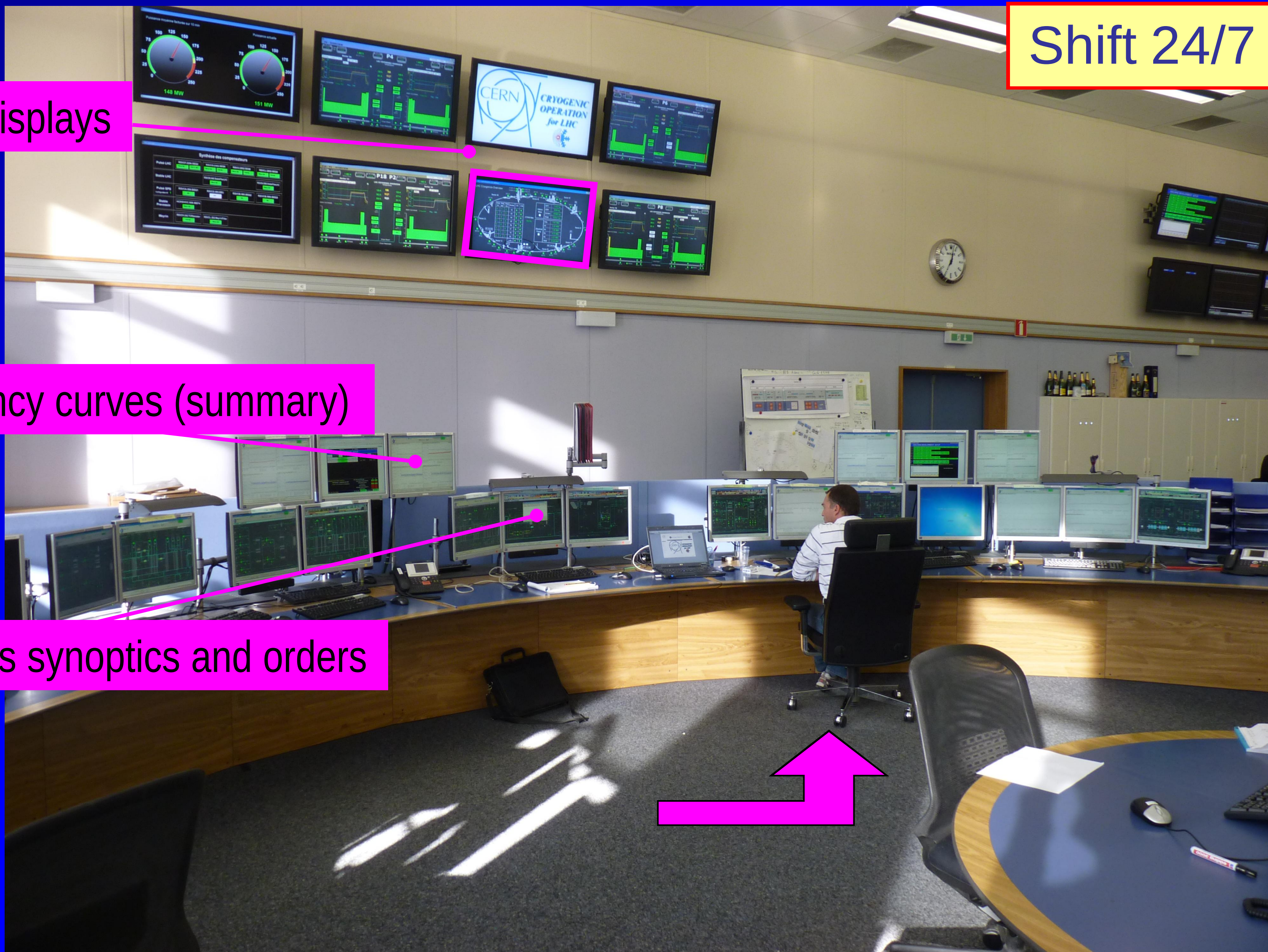
  Academic training - On the job training - Shadow shifts

  => Certification after ≈ 10 months as shift operator (alone!)
- Senior operator (>3 yrs):

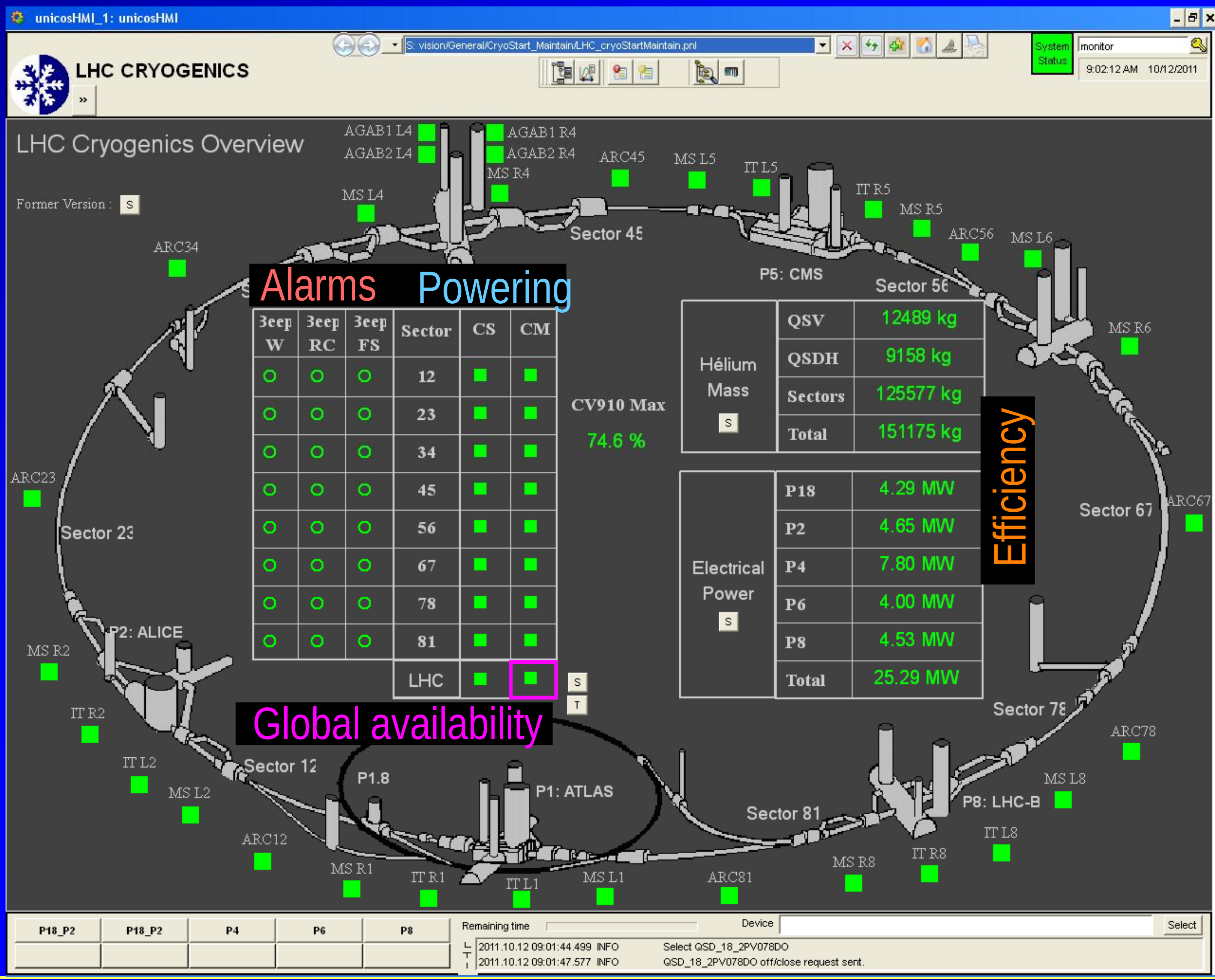
  Able with all sub-systems, ability to optimise production-needs-time
- Certification diploma:

  Written - Site - Simulator - Improvement study (report + presentation)
- If selected for indefinite contract:
  - Operation for 5 to 10 years
  - Ability to become “production Eng.” as site responsible
  - Ability to switch to support teams or another activity at Cern

Cryo operator in Cern Central Control room



Operation, indicators



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Availability: a signal Yes/No is required

T2 = Achieved up time during required time / Required time x 100 (operational availability)

T2 indicator w.r.t EN 15341

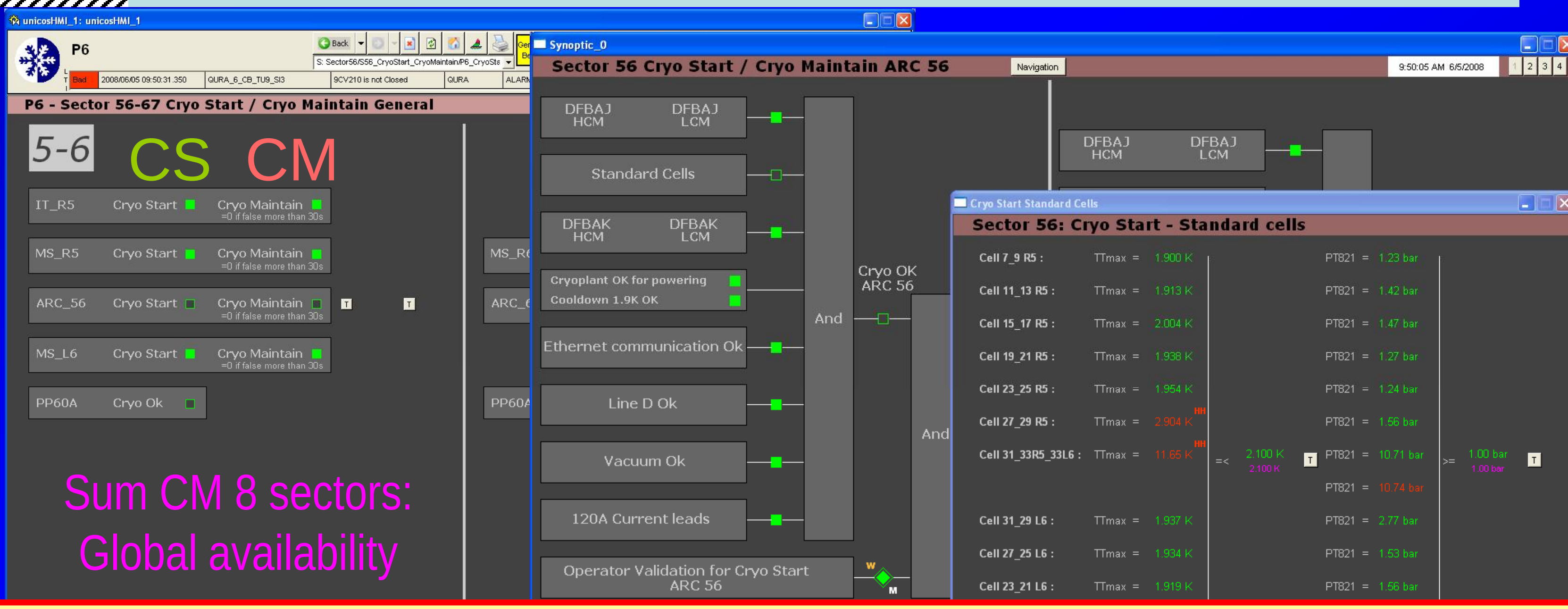
CM

CM
CS
SP
CS
CM

Cryo Maintain: Few important conditions checking integrity of HW, with slow power abort in case this signal is lost (leading to beam dump!)

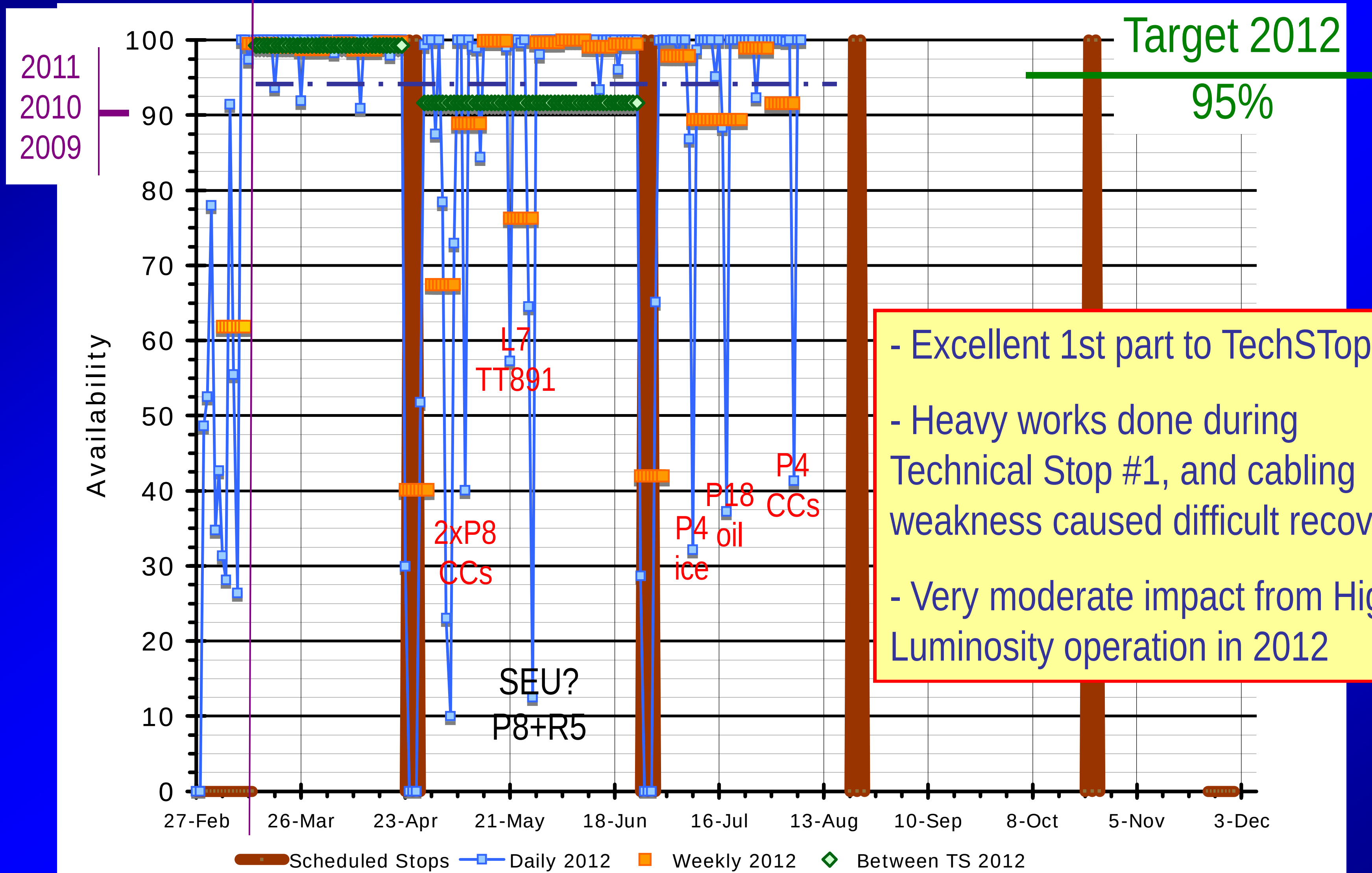
set-point

Cryo Start: set of conditions to allow powering of concerned sub-sector, with no action if powering started (illustrates good stability of process)



Possibility to treat thousands of channels in a structured way to match at best the LHC powering sub-sectorisation and the cryo sub-sectorisation

LHCCryo global availability 2012

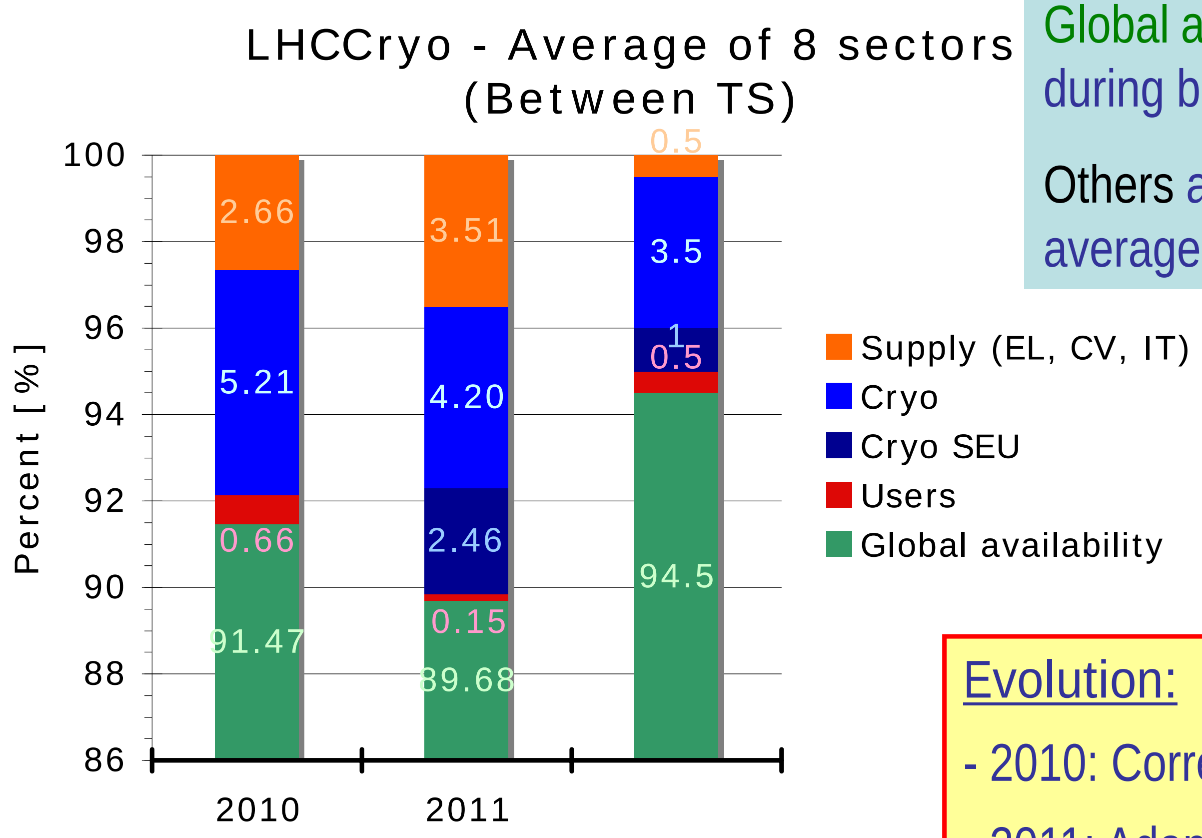


- Excellent 1st part to TechSTop

- Heavy works done during Technical Stop #1, and cabling weakness caused difficult recovery

- Very moderate impact from High Luminosity operation in 2012

Performance and origin of downtine



(260 days) (271 days) *(137/290)*

(Full days, Mondays & Fridays of Technical Stops not counted here)

Global availability as seen by LHC during beam operation periods

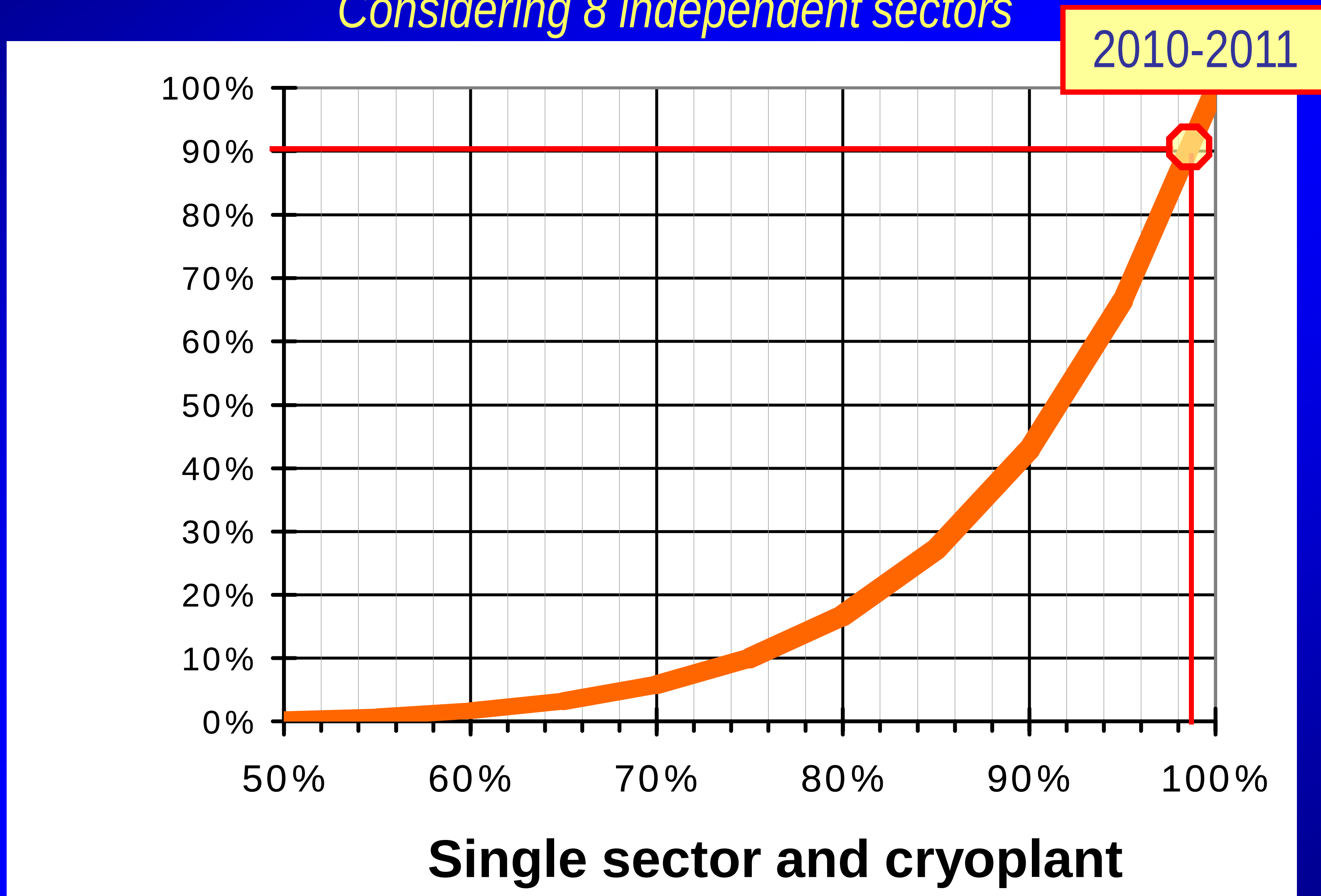
Others according to relative ratio of their average for the 8 sectors

Evolution:

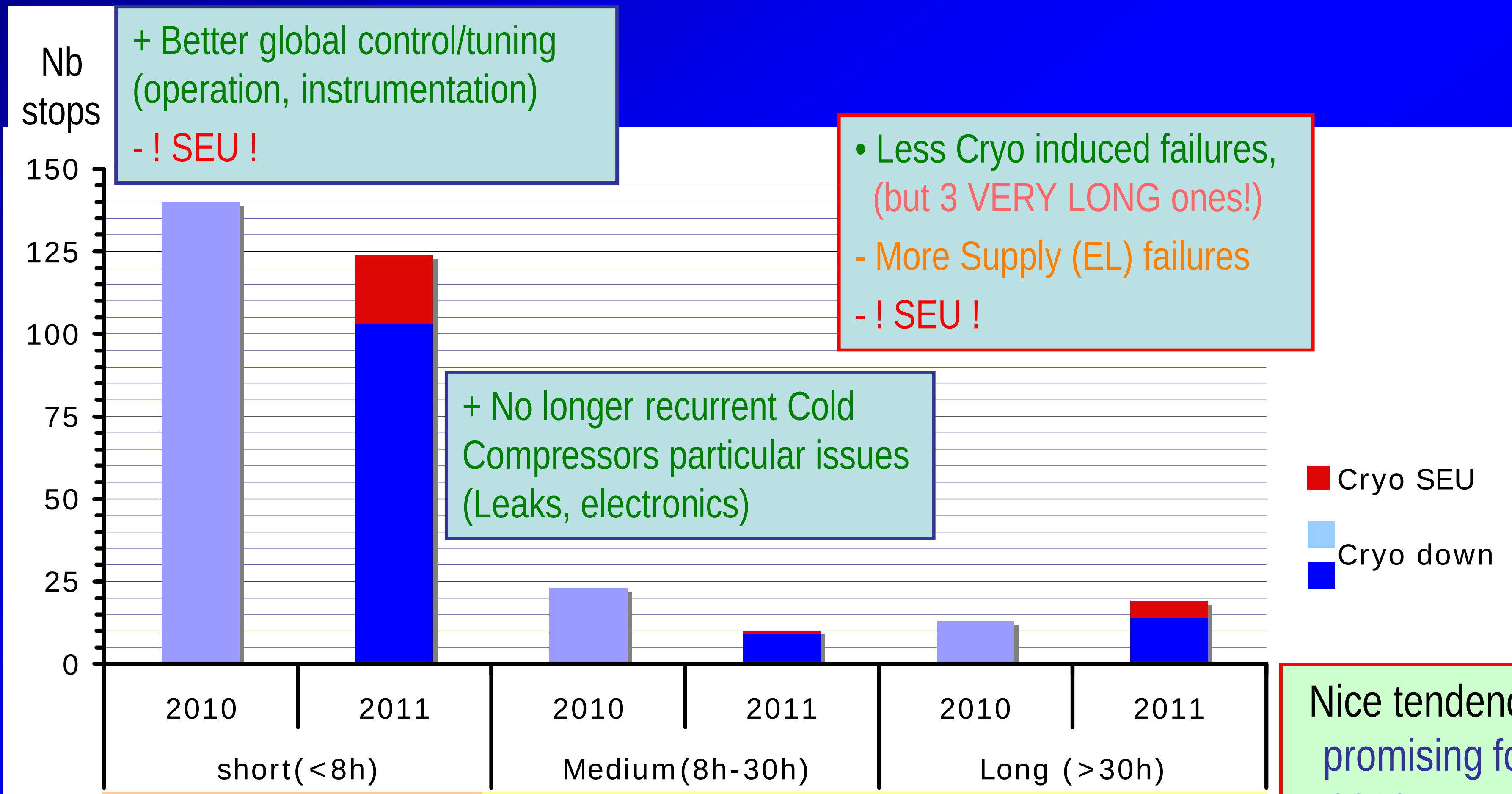
- 2010: Correcting early Cryo bugs
- 2011: Adapting to SEU (corrected @Xmas)
- 2012: So far rewarding !!!

Availability: from global to single plant

Considering 8 independent sectors



Indicators: recovery categories & tendency



From the books:

Immediate effect of (good!) practice	Annoying if frequent, to be kept low with moderate efforts	Serious cases requiring specific monitoring and significant efforts

Nice tendency, promising for 2012 or new surprises to come up?

Operation structure & approach

- 2007/2008 cool-down & HWC: *Control rooms: site - CCC- office*

  Per site, one experienced engineer with agreed minimum protocol to guide a local team of operators, with help of support teams (instrumentation, experts, controls)

- Since 2009 and operation with beam:

  One operator in shift 24h/7d, more transverse structure site/CernControlCenter, procedures & operation tools

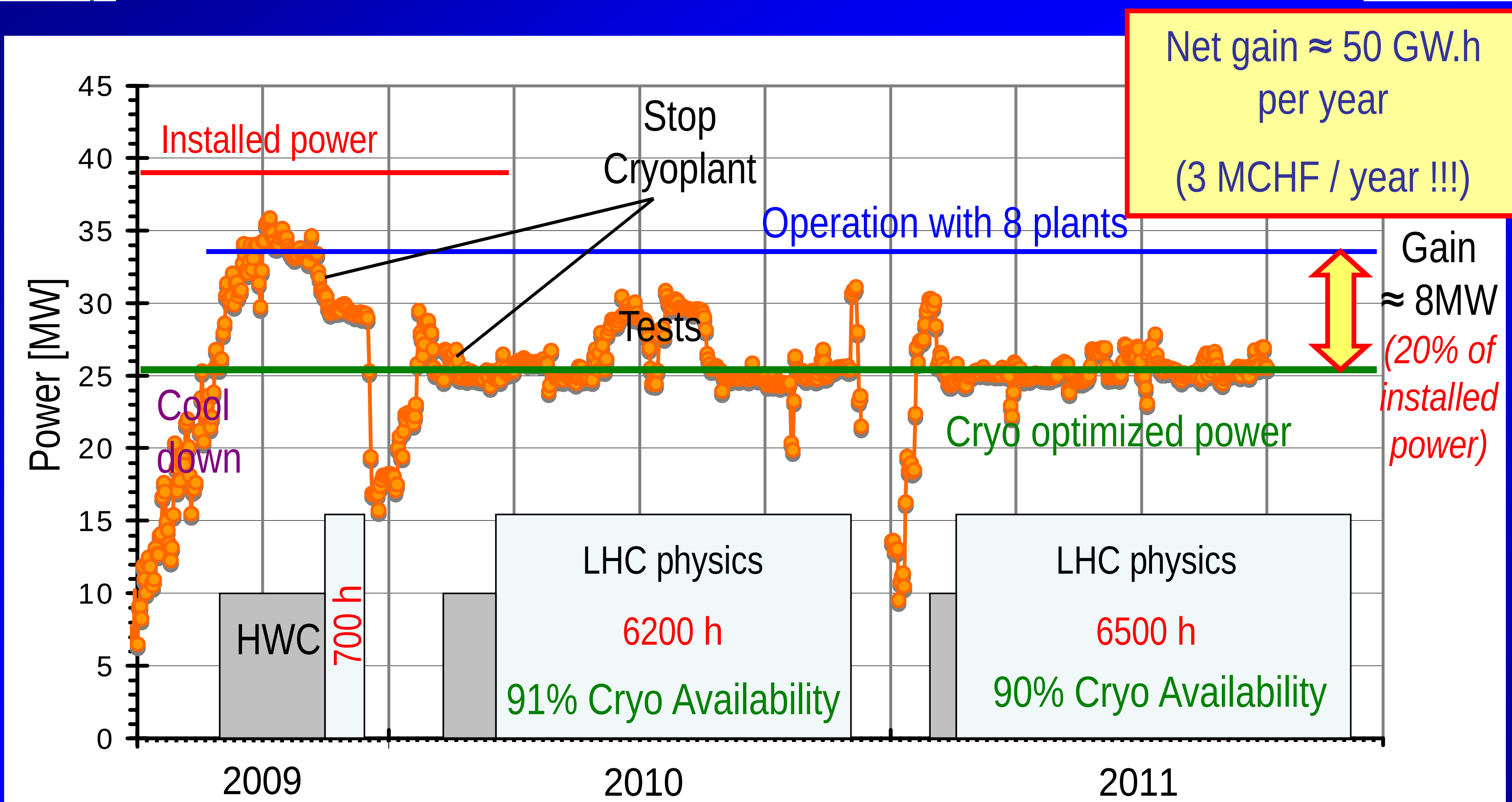
- For machine controls (temperature, level, pressure):

  Basic interlocks and simple PID loops with generic tools for fast orders, now completed with automated sequences & procedures

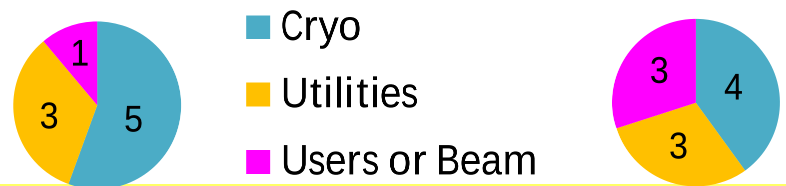
- Indicators:

  From temperature stability to daily availability
  on-line cool-down curves to on-line cryo-status

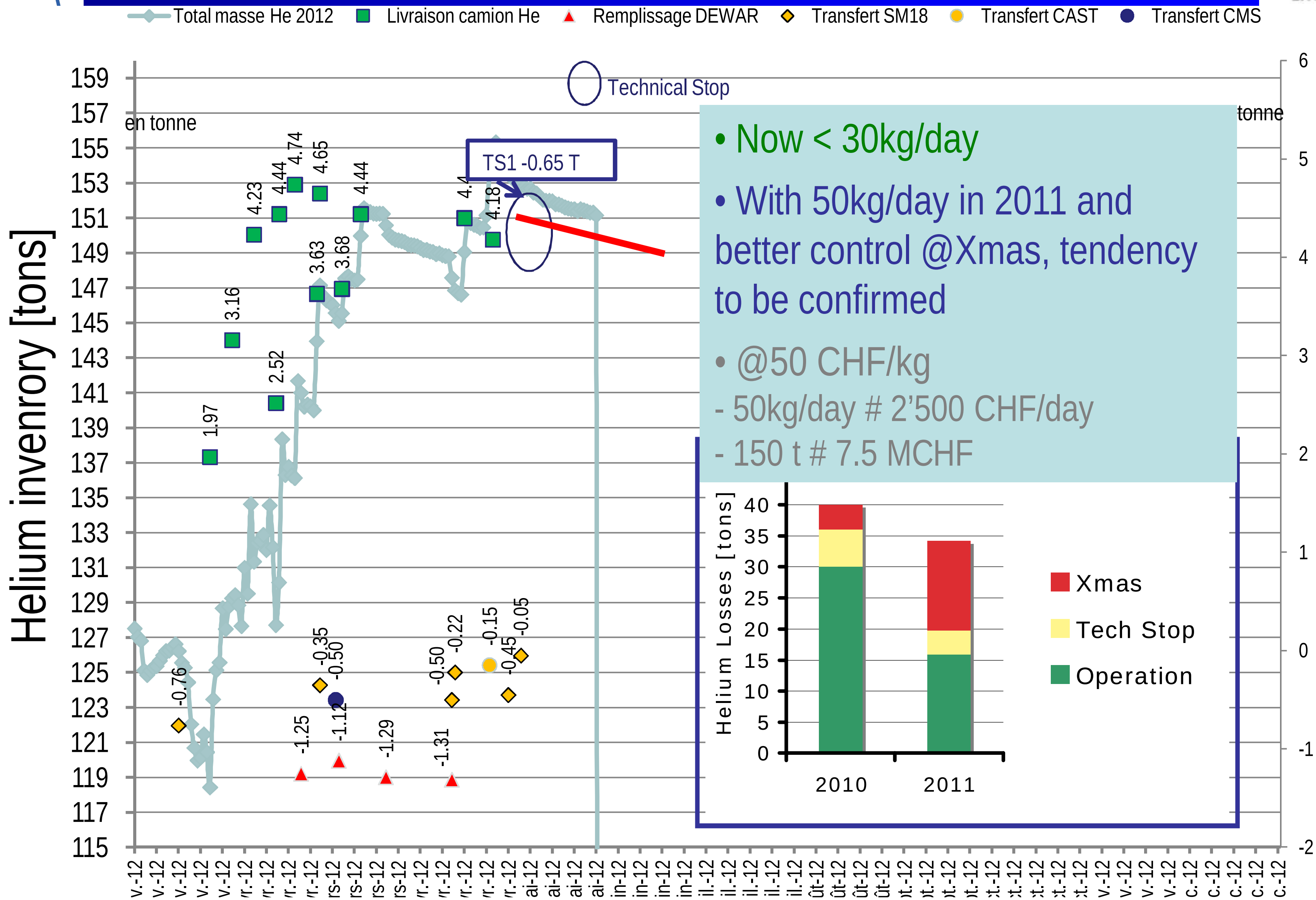
Power Consumption for LHC Cryogenics



Cryo unavailability breakdown



Helium inventory follow-up

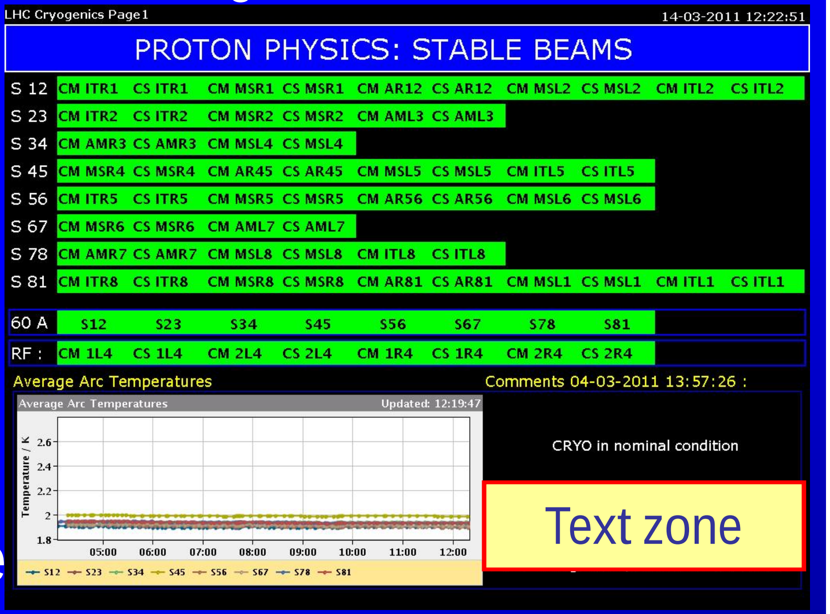


- Now < 30kg/day
- With 50kg/day in 2011 and better control @Xmas, tendency to be confirmed
- @50 CHF/kg

- 50kg/day # 2'500 CHF/day
- 150 t # 7.5 MCHF

Interfaces with Beam-OP

- HW signals:
  - Cryo Start and Cryo Maintain towards Powering Interlock module
- SW panels:
  - Cryo web page
- People in Control Room (LHC):
  - 1 Eng in charge + 1 operator
  - 1 Cryo operator
  - 1 operator for technical infrastructure



- *Possible evolutions ?*
  - *Closer discussions with Eng. In charge in case of cryo problem*
  - *Other operators involved to help diagnostics/recovery*
  - *No longer cryo operators at night (on call only)*

Summary

- LHC cryogenics is the largest, the longest and the most complex cryogenic system worldwide. We could achieve a reasonable availablity (> 90 %) so far with beams. This demonstrates that there are no big issues in concept, technology or global approach for operation.
- Despite all our efforts, we had very hard time and lengthy commissioning to learn how to tune all these sub-systems together while permanently consolidating what was not conform. Experience has been converted into automatism, procedures, tools, training
- Cryogenics operation is well integrated in central control room with LHC main systems, but operated/supported independently (about 50 people)
- Maintenance is as well reaching an efficient preventive/corrective ratio, with efforts to be made for non-standard cases. We have to prepare for higher energies and intensities with continued gain in reliability !