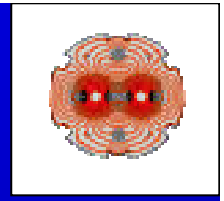
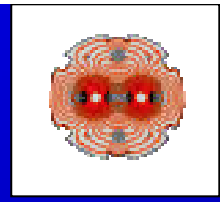


Design, Construction, Installation and first Commissioning Results of the LHC Cryogenic System

Serge Claudet (CERN, Geneva)

On behalf of the "Cryogenics for Accelerator" group and the hundreds of people involved

Thanks to contributors



- A. Ballarino
- Ch. Balle
- J. Casas
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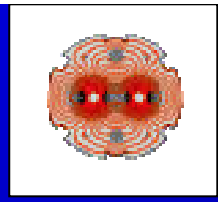
- F. Millet
- C. Parente
- G. Riddone
- L. Serio
- L. Tavian
- R. Van Weelderen
- B. Vullierme
- U. Wagner

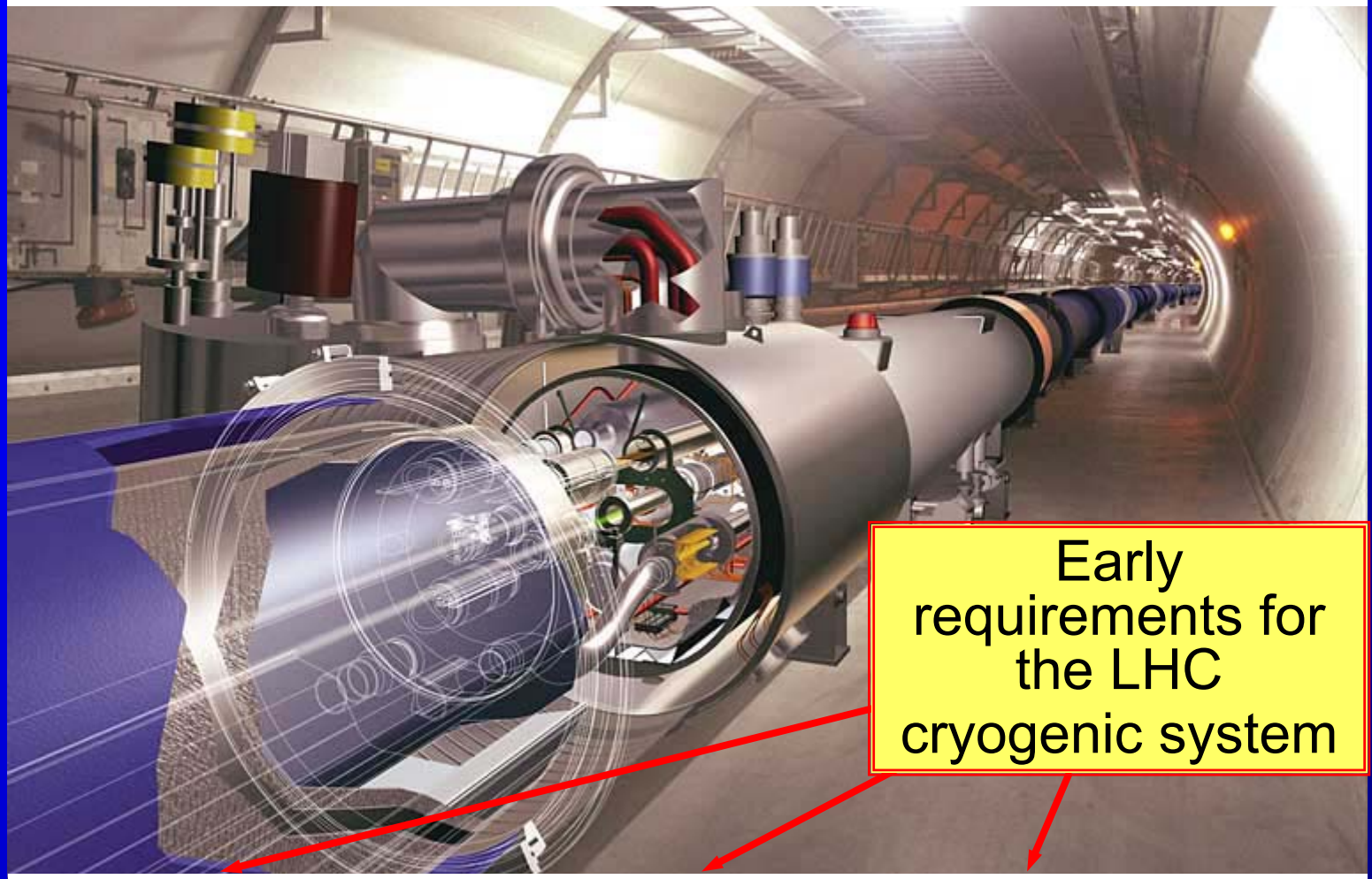
Content



- Introduction
- Design challenges and R&D outcome 90ies
- Procurement, Construction & Installation '98 - '06
- First commissioning experience '02 - '06
- Main problems encountered
- Considerations for new projects
- Conclusion

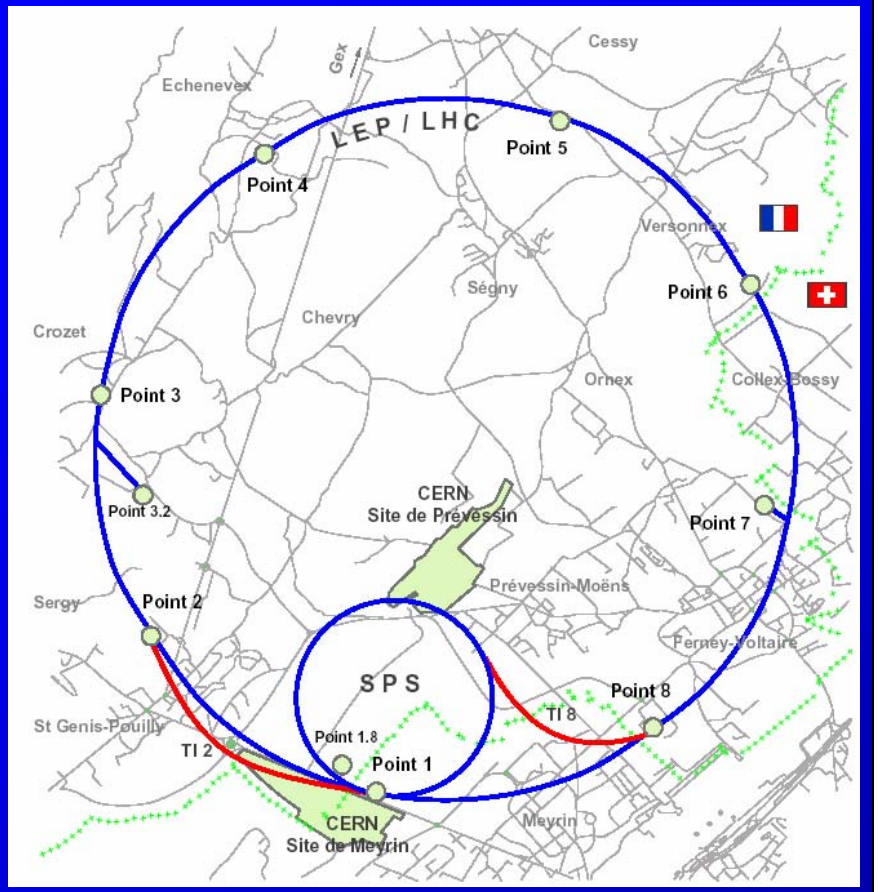
LHC accelerator

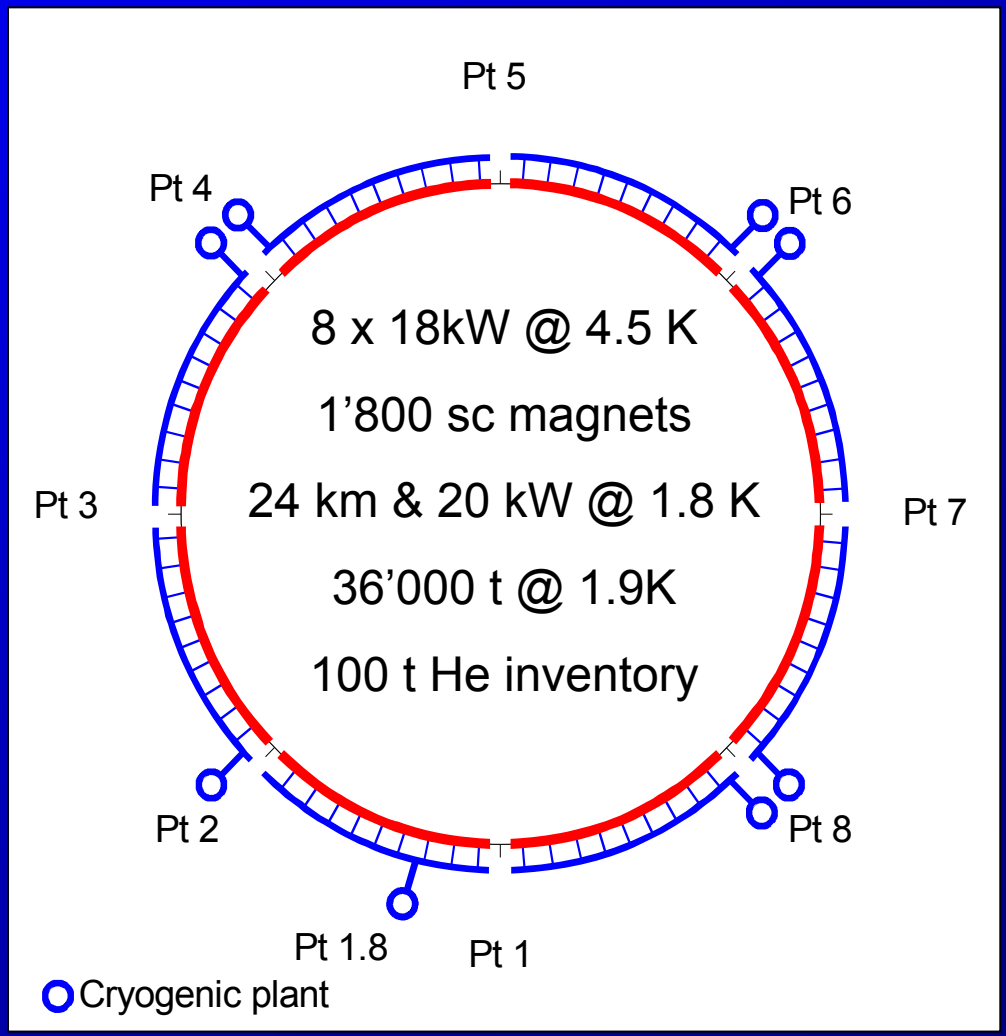
p-p collision 10^{34} $cm^{-2}.s^{-1}$, 14 TeV, 0.5 GJ stored energy



24 km of superconducting magnets @1.8 K, 8.33 T

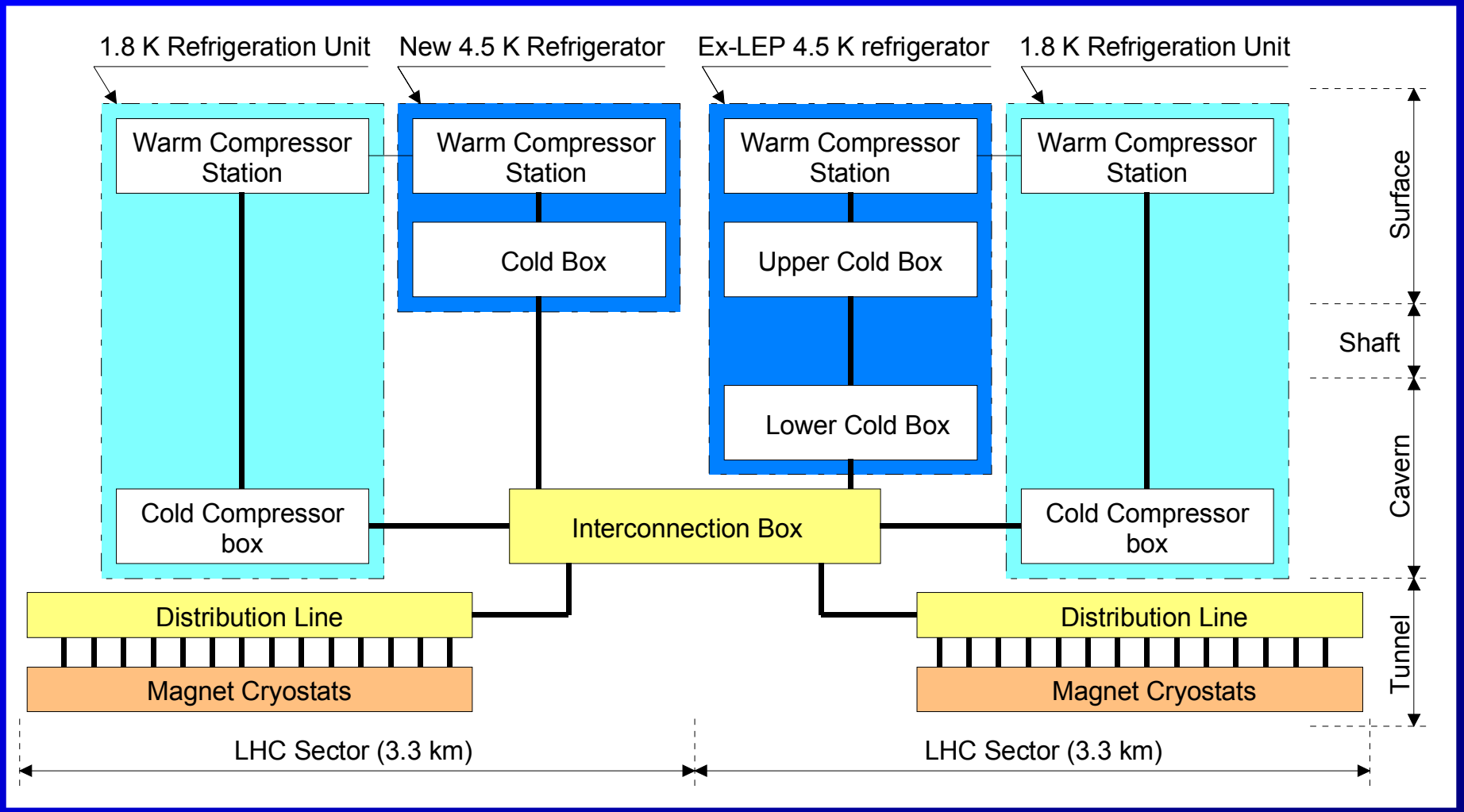
Layout of cryogenics



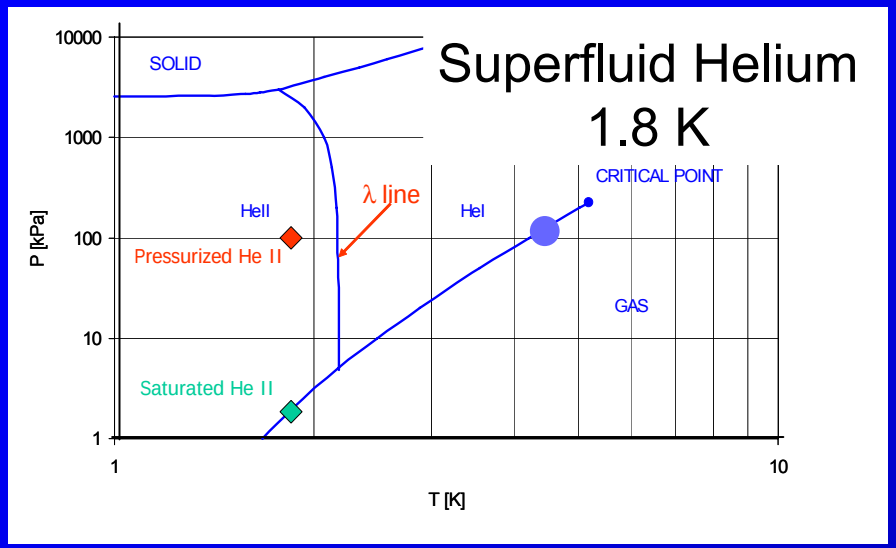


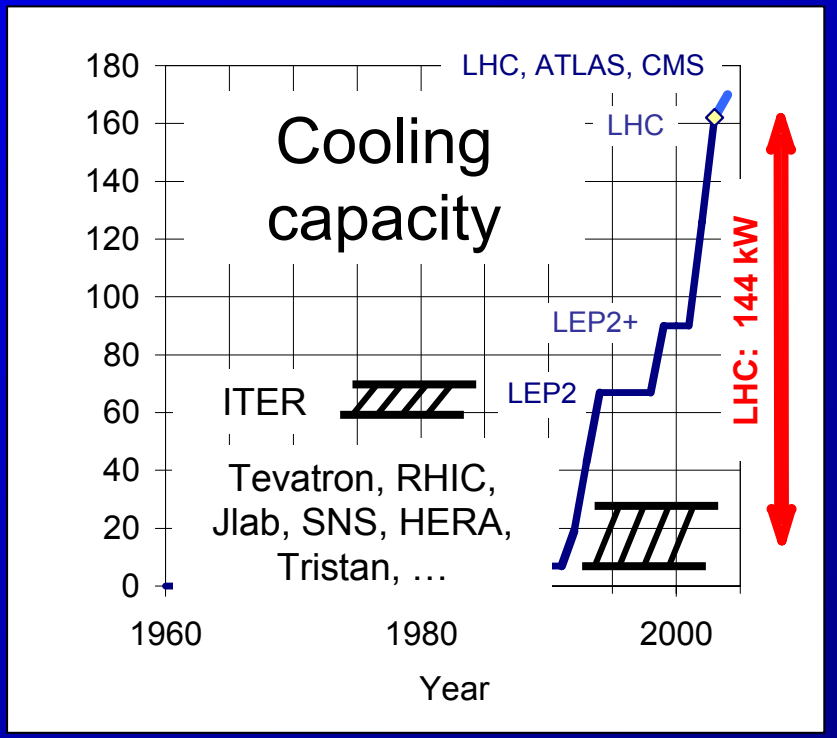
Cryogenic architecture

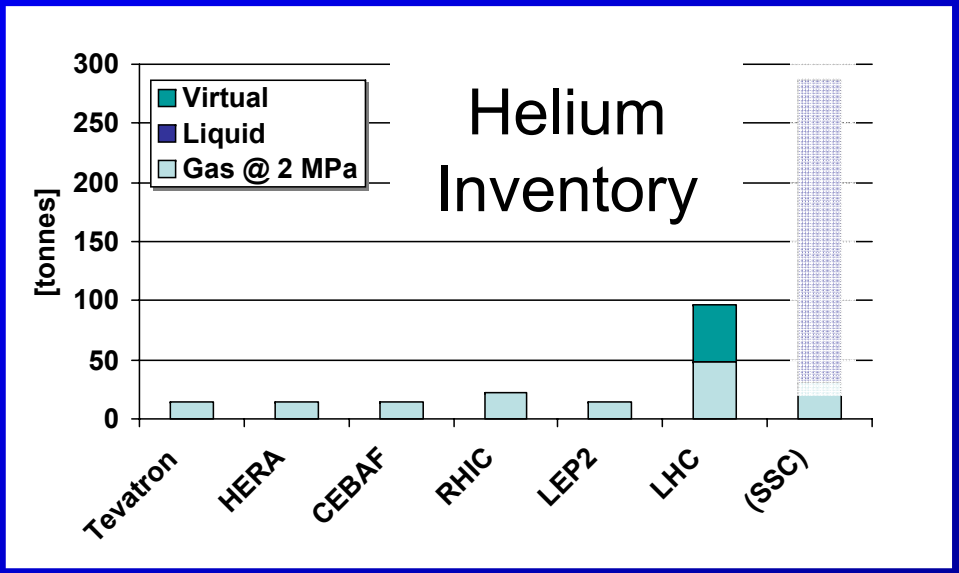
Typical LHC even point



How does it compare ?

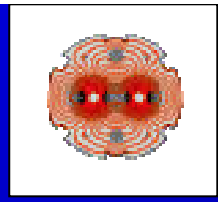






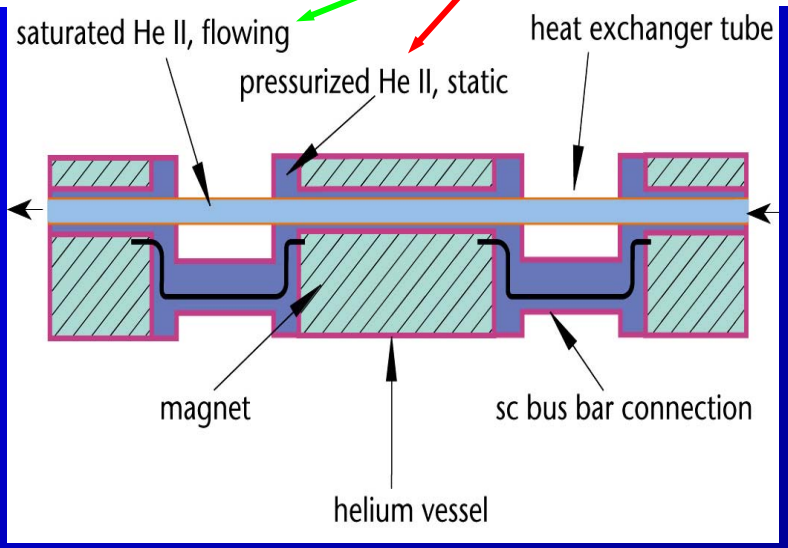
Unprecedented !

Design



- Site constraints and general concerns
- Early heat load inventory and follow-up, periodic update of cryogenic architecture
- Components and system R&D:
  - Early industry involvement
  - Dedicated tests facilities

Magnet cooling scheme

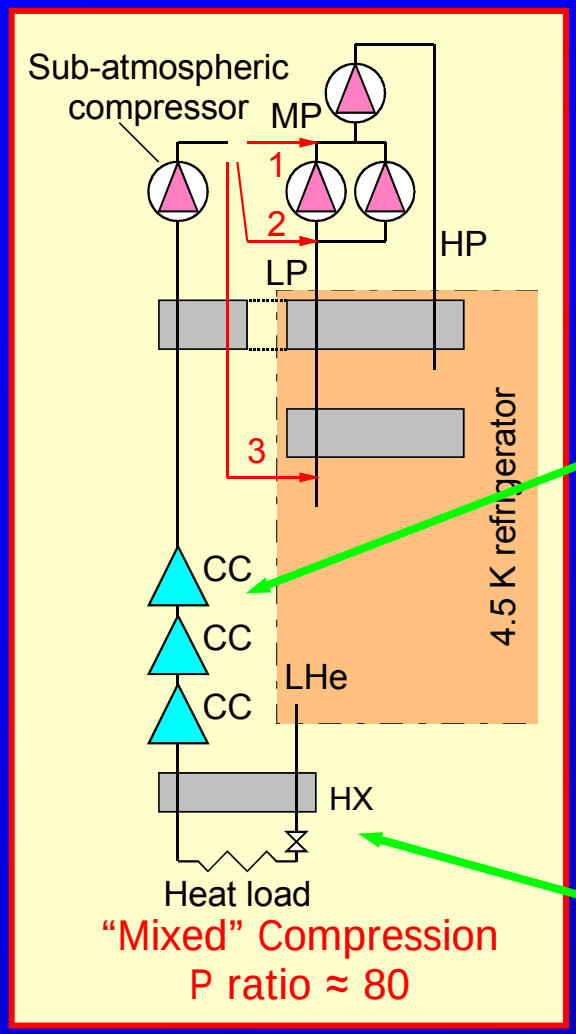


Thermo-hydraulics of two-phase flow in He II

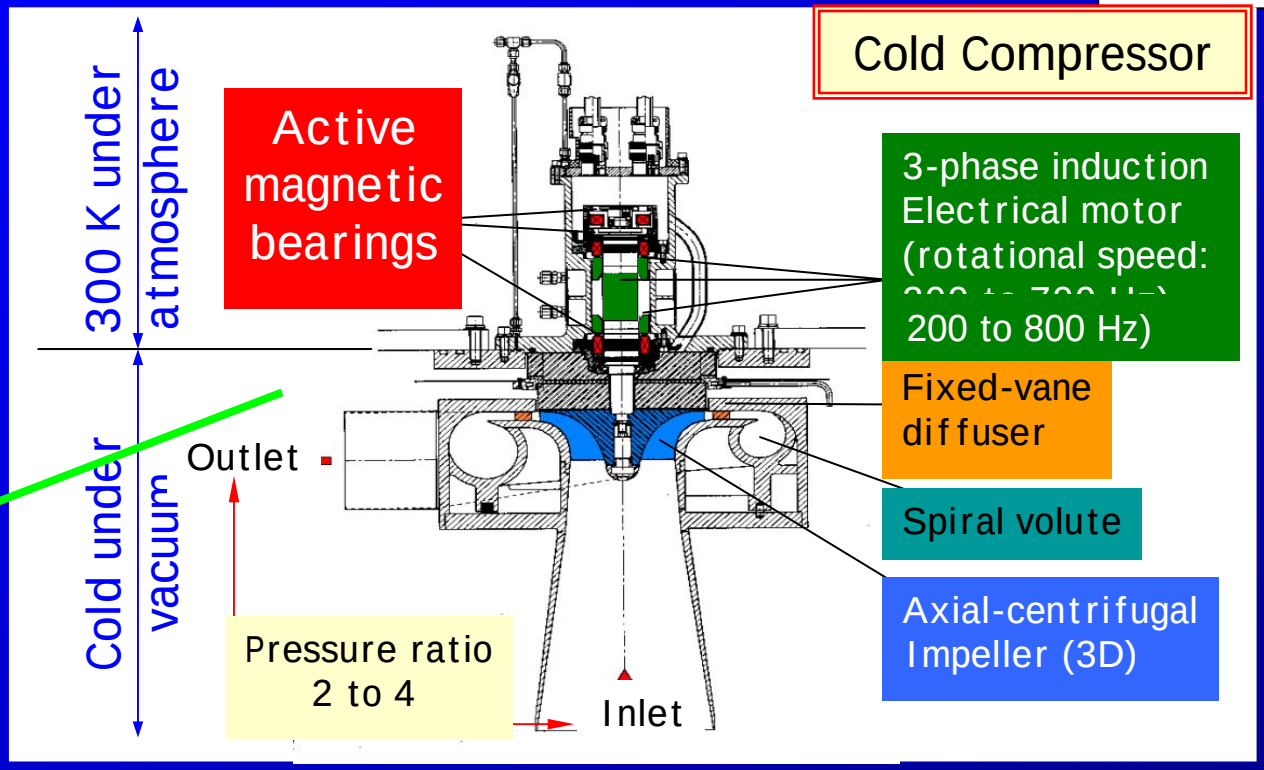
(and limitations!)

(≈ 1W/m)

1.8 K issues



"Mixed" Compression
P ratio ≈ 80



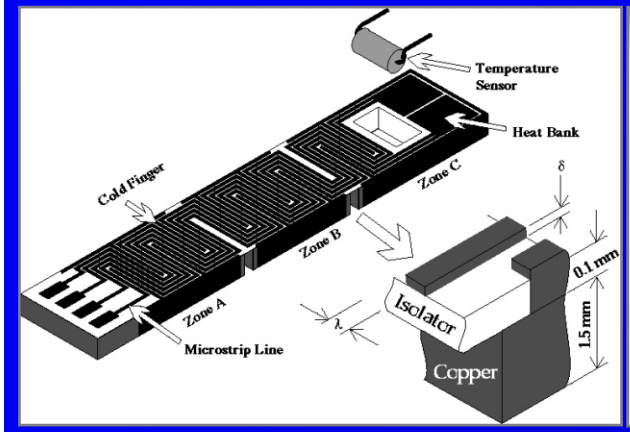
Stainless Steel Plate

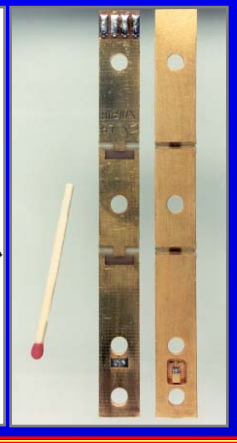
CC:
- 3D wheels
- Bearings (300K)

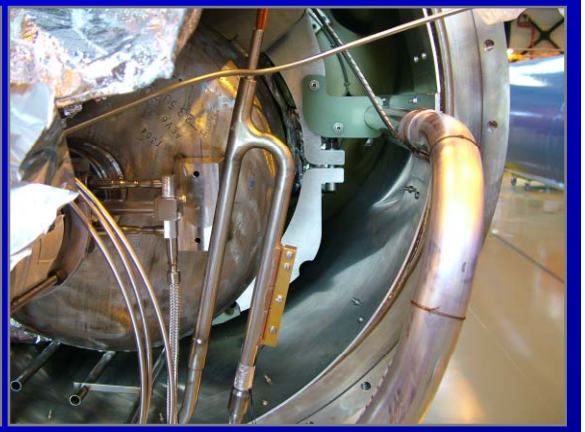
HX:
- Very Low Pressure

Thermometry

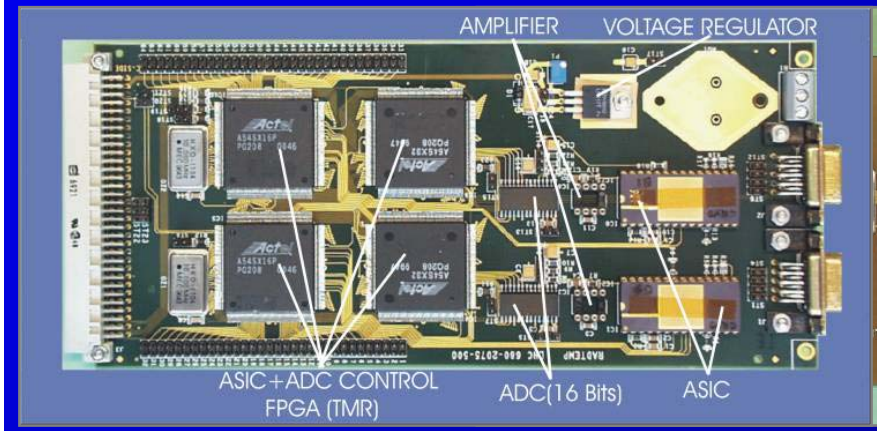
6’000 units, +/- 10 mK @ 2K in LHC radiation conditions

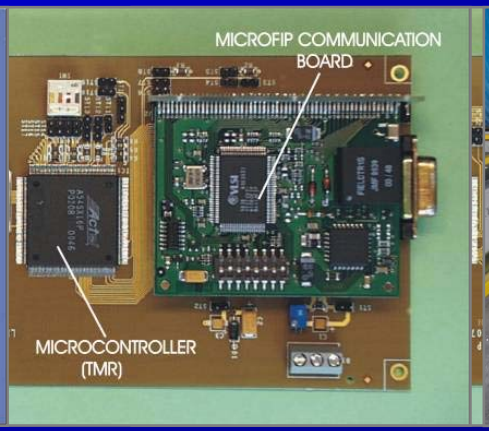






From ‘sensor’ to ‘thermometer’ with signal processing





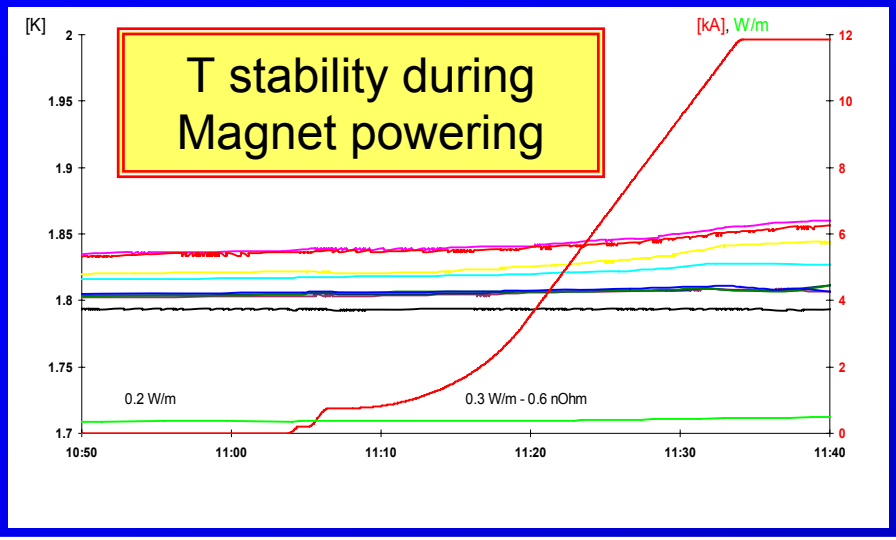
Other R&D examples

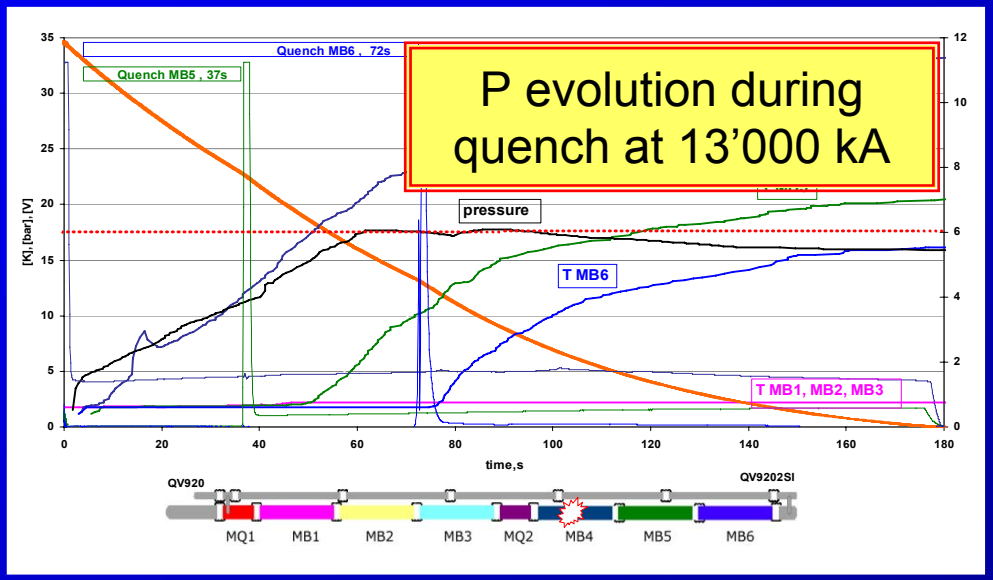
- HTS current leads

Total: 3.4 MA
1200 units
600-6000-13000 A
BSCCO 2223

- Thermal design:
  - Low temperature insulation
  - Heat intercept techniques
- Safe cryo-magnets resistive transition:
  - Cascade: cryostat - cold recovery header - MP tanks
  - Specific cold safety relief valves

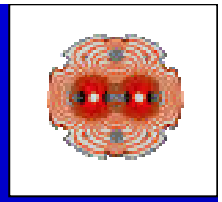
LHC test string





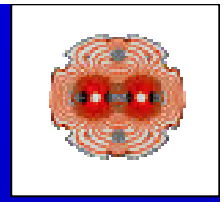
More than 20'000 hours of operation of the LHC Test Strings

Procurement

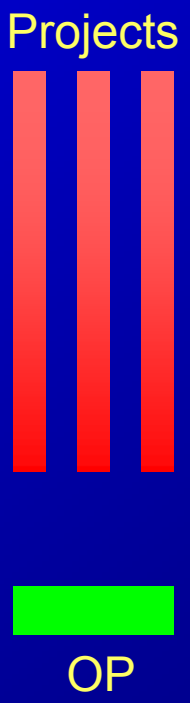


- Sub-systems by type of functionality:
  - CERN to define interfaces and required performance
- Great majority procured from industry:
  - Competitive performance based tendering
  - Detailed studies, manufacturing, site installation, commissioning, performance assessment
- Separate management of general services:
  - Interconnecting piping, controls

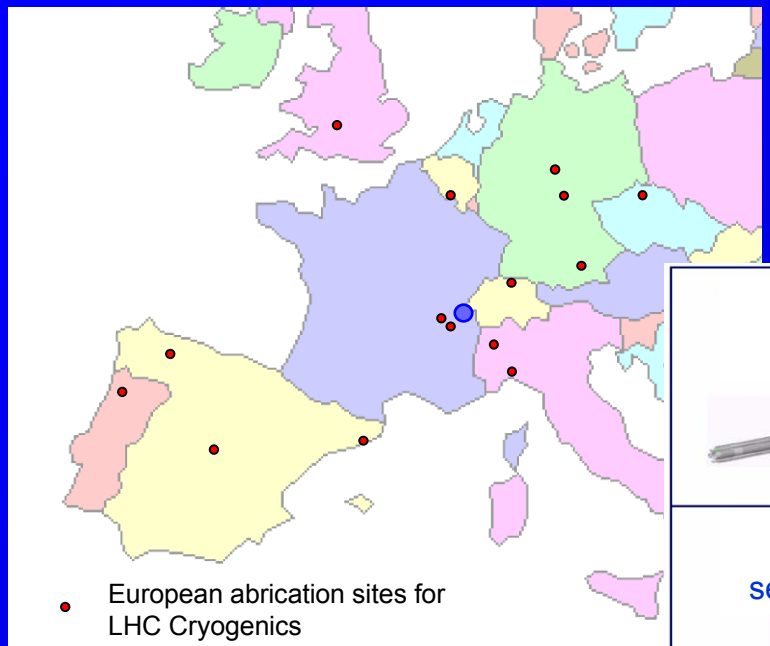
Construction phase



- Industry available products:
  (storage tanks, piping, 4.5K refrigerators)
  – Functional technical specifications adapted (tests)
- Extension of existing products
  (1.8K units, cryogenic lines, electrical feed boxes)
  – Complex performance & possible impacts
  – CERN add. design & support to fabrication
- Totally new products
  (Rad. tol. cryo thermometry - superconducting links)
  – CERN with full responsibility for developments and "built to print" fabrication contracts



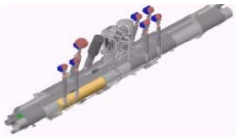
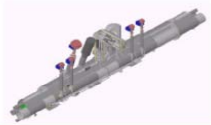
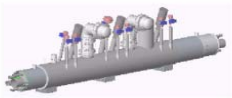
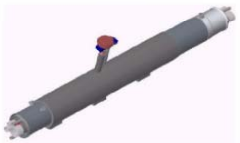
Industrial fabrication sites



European abrication sites for LHC Cryogenics

And from USA, Russia, Japan, …

Important issues:
Qualification, procedures, supply chain, follow-up, Quality assurance

215 standard pipe elements 	30 fixed points & vacuum barriers 	17 special service mod. + 1 return mod. 
18 standard service modules 	2 double-jumper service module 	30 special pipe elements 
2 steps 	6 elbows 	1 test module 

Main distribution line:

Dedicated assembly sites to cope with ''relative'' modularity

Electrical feed boxes

CL cartridges assembly area

Mechanics - Electricity - Cryogenics

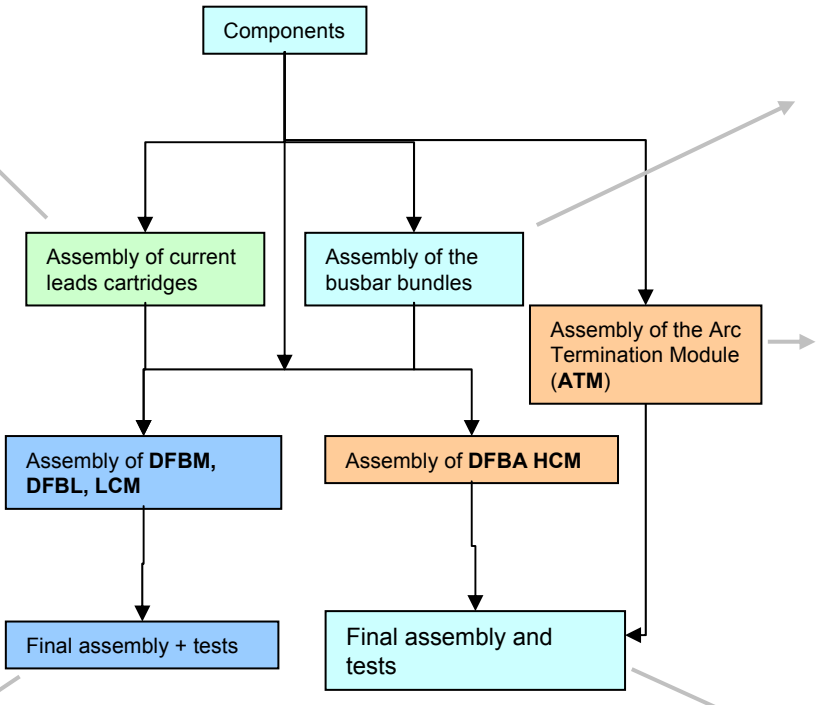
CL modules assembly stands

Global leak test of DFBM

DFBA busbar bundles lambda plates

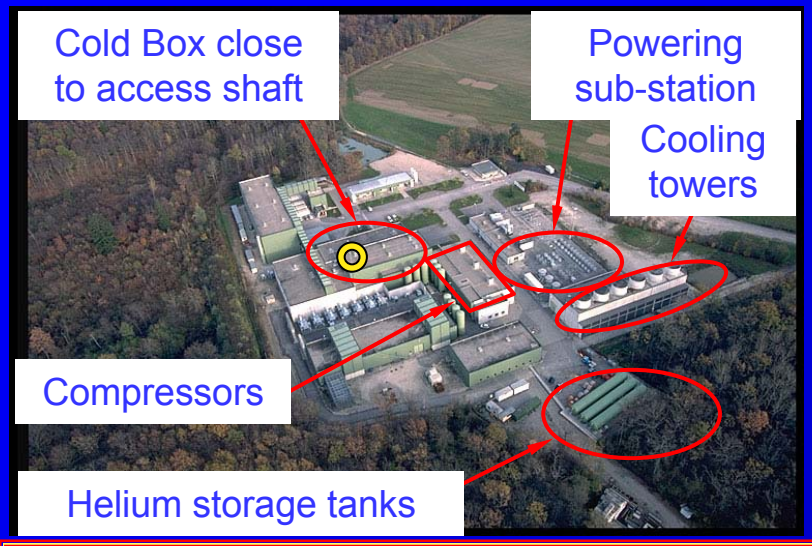
Assembly of DFBA shuffling boxes

Pressure test area for DFBAs



Towards an integrated factory !

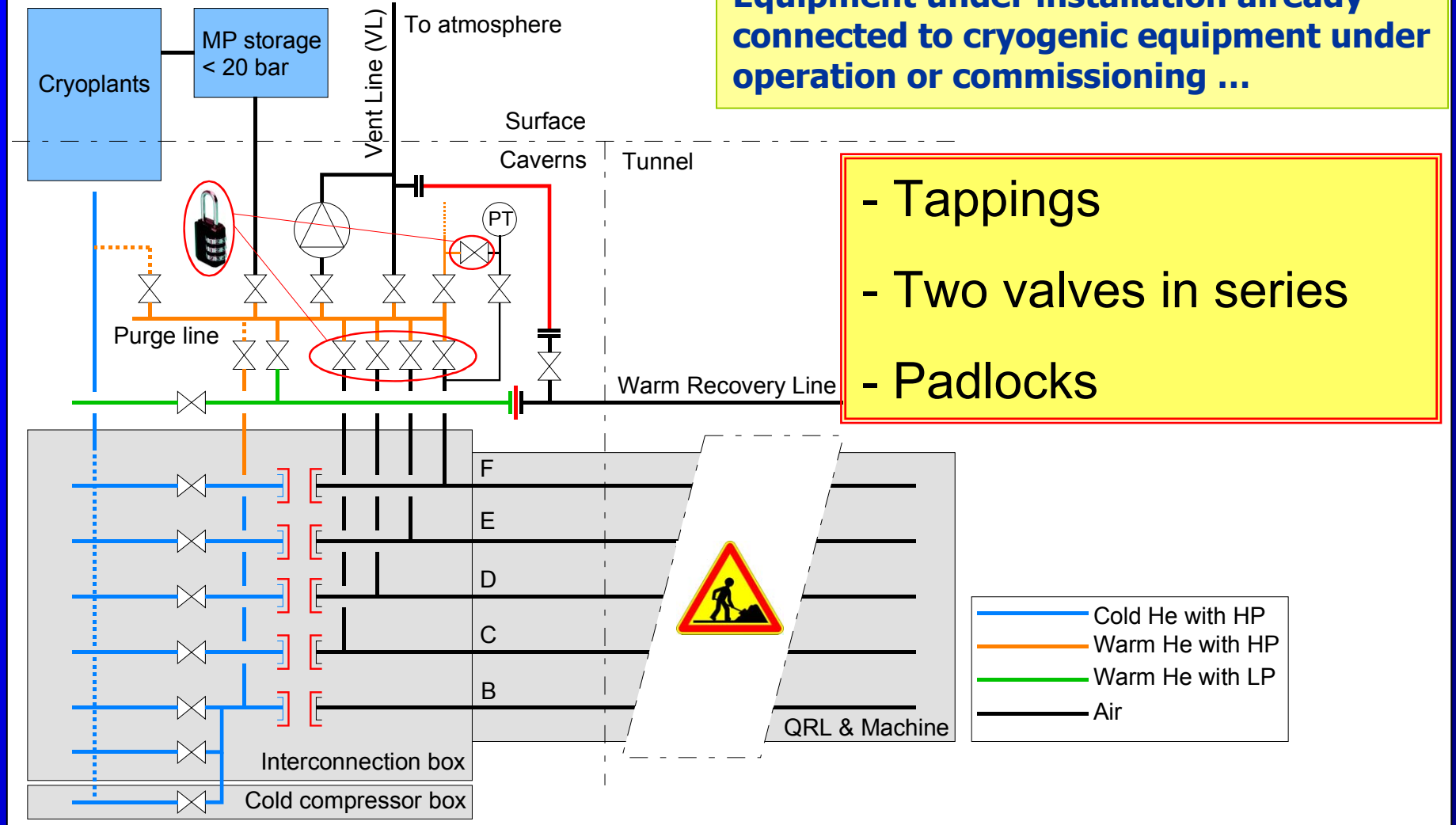
Installation phases



Important issues: logistics, handling, co-activity, quality

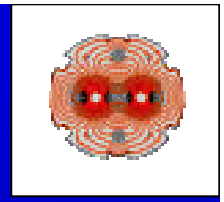
Installation & tests

Equipment under installation already connected to cryogenic equipment under operation or commissioning …

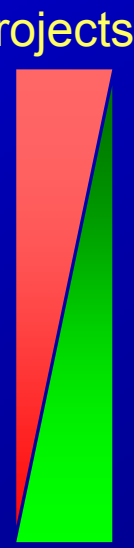


- Tappings
- Two valves in series
- Padlocks

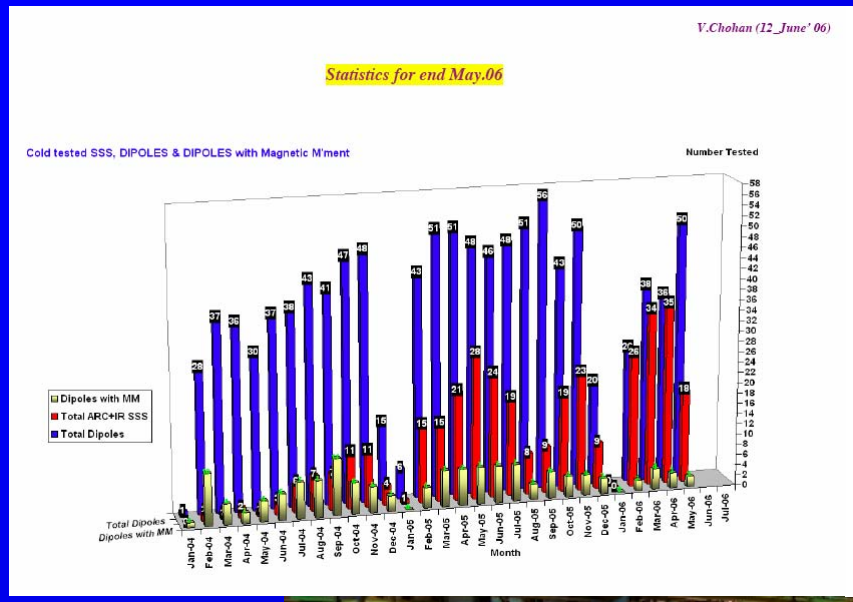
Commissioning

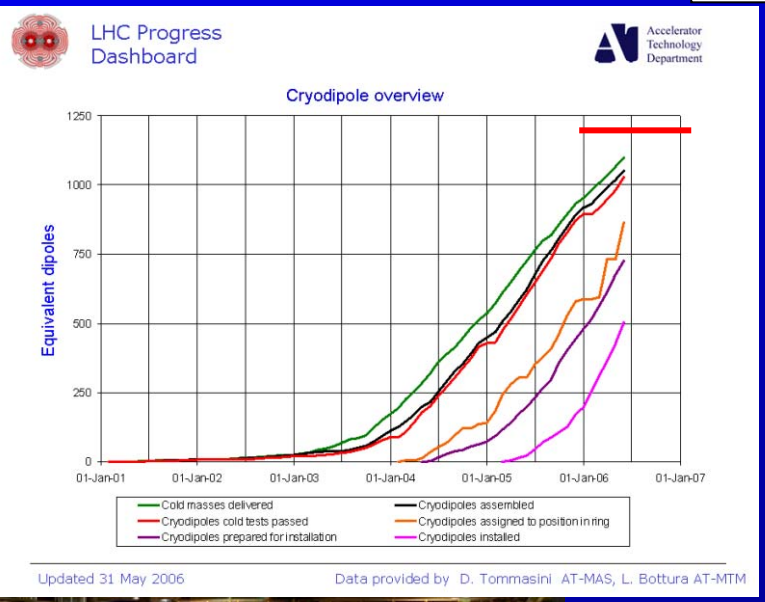


- Commissioning of each sub-system:
  - Mechanical pressure test, helium leak test
  - Input/output signal tests
  - Operational tests to demonstrate all functions
  - Performance measurements (ref. capacity, thermal losses)
- Subsequent commissioning in cascade:
  - Potential problems identified early and clearly
  - Possible actions before it becomes critical
- Global LHC Hardware Commissioning:
  - A Crucial test for many systems, incl. cryogenics
  - Project wide coordination efforts, incl cryogenics

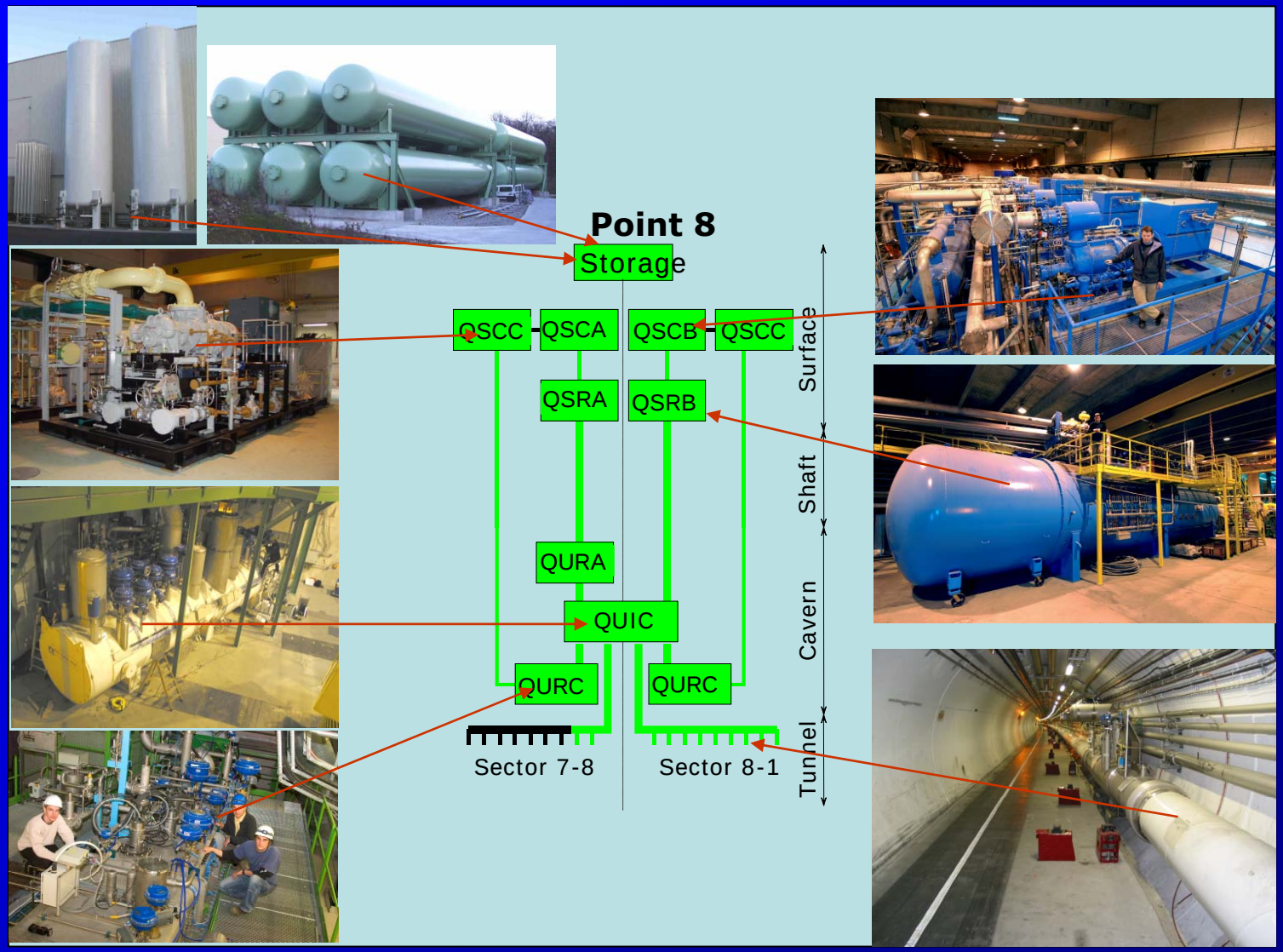


Magnet cold tests



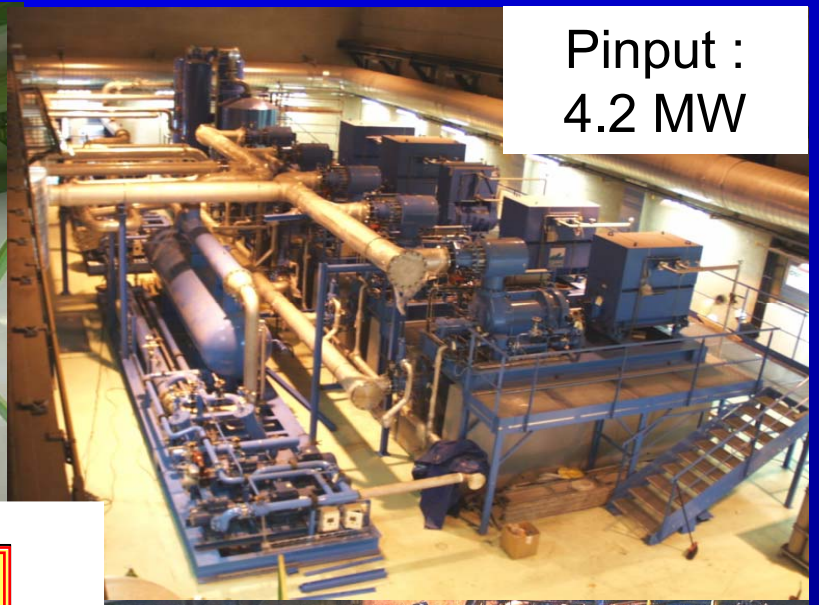


Cryogenic sub-systems

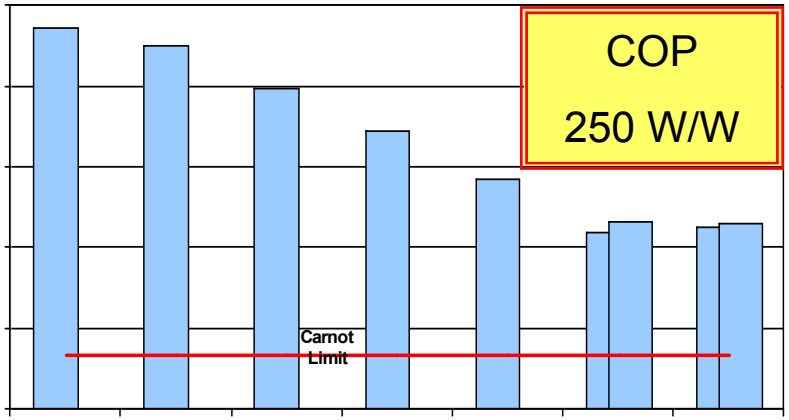


18 kW @ 4.5 K Refrigerators

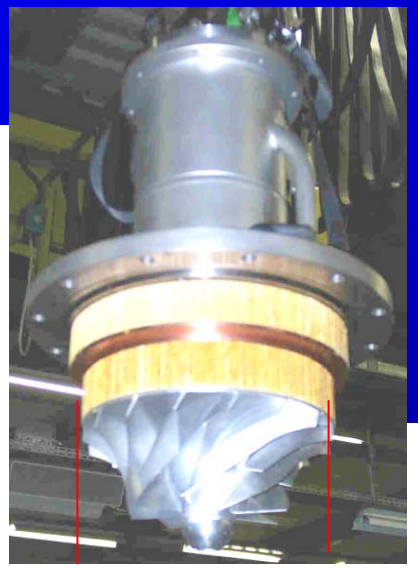
33 kW @ 50 K to 75 K - 23 kW @ 4.6 K to 20 K - 41 g/s liquefaction



Pinput :
4.2 MW



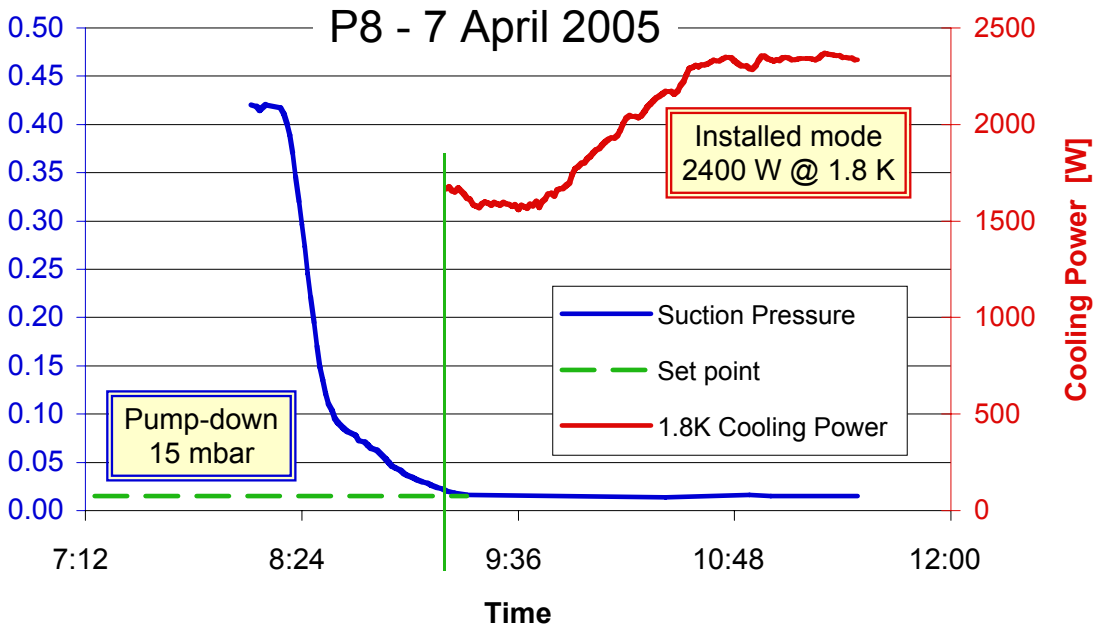
2400 W @ 1.8K units

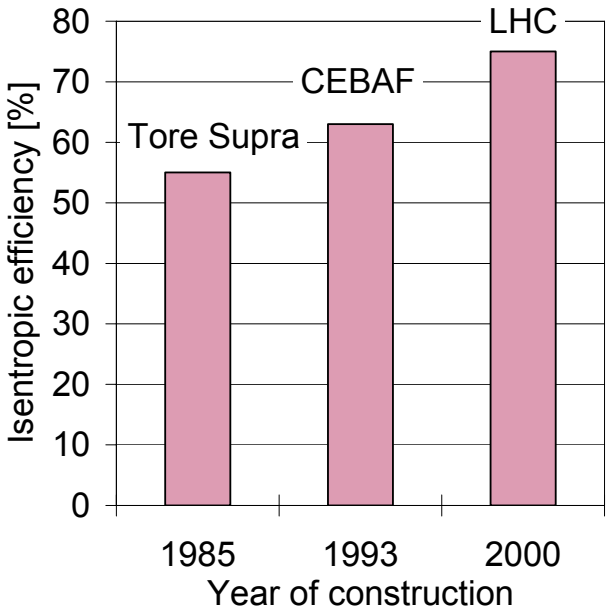


Diam: 250mm

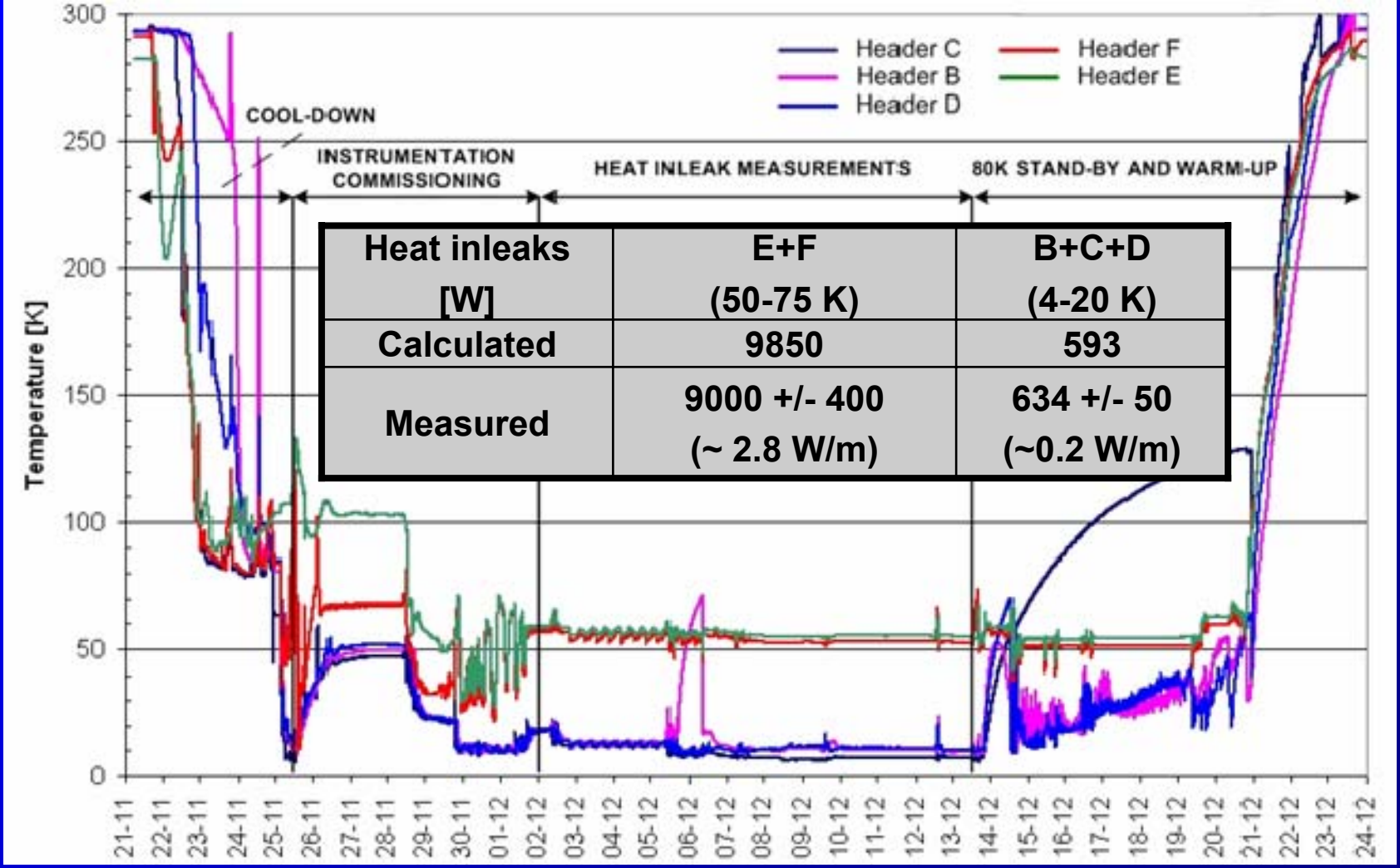
1.8K refrigeration units

1st Pump-down in final LHC configuration



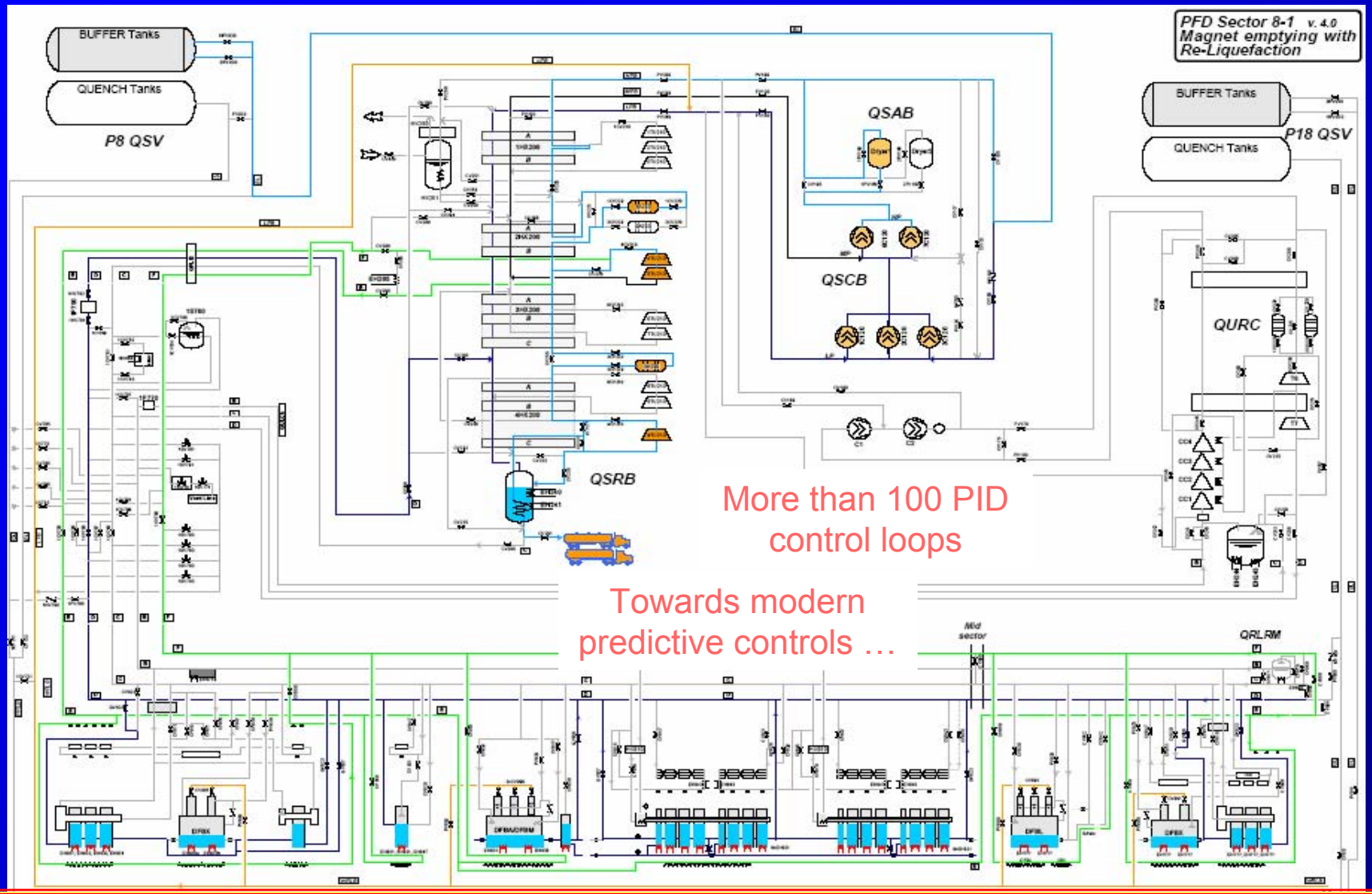


Main cryogenic line



Heat inleaks [W]	E+F (50-75 K)	B+C+D (4-20 K)
Calculated	9850	593
Measured	9000 +/- 400 (~ 2.8 W/m)	634 +/- 50 (~0.2 W/m)

Cryogenics P&F diagram



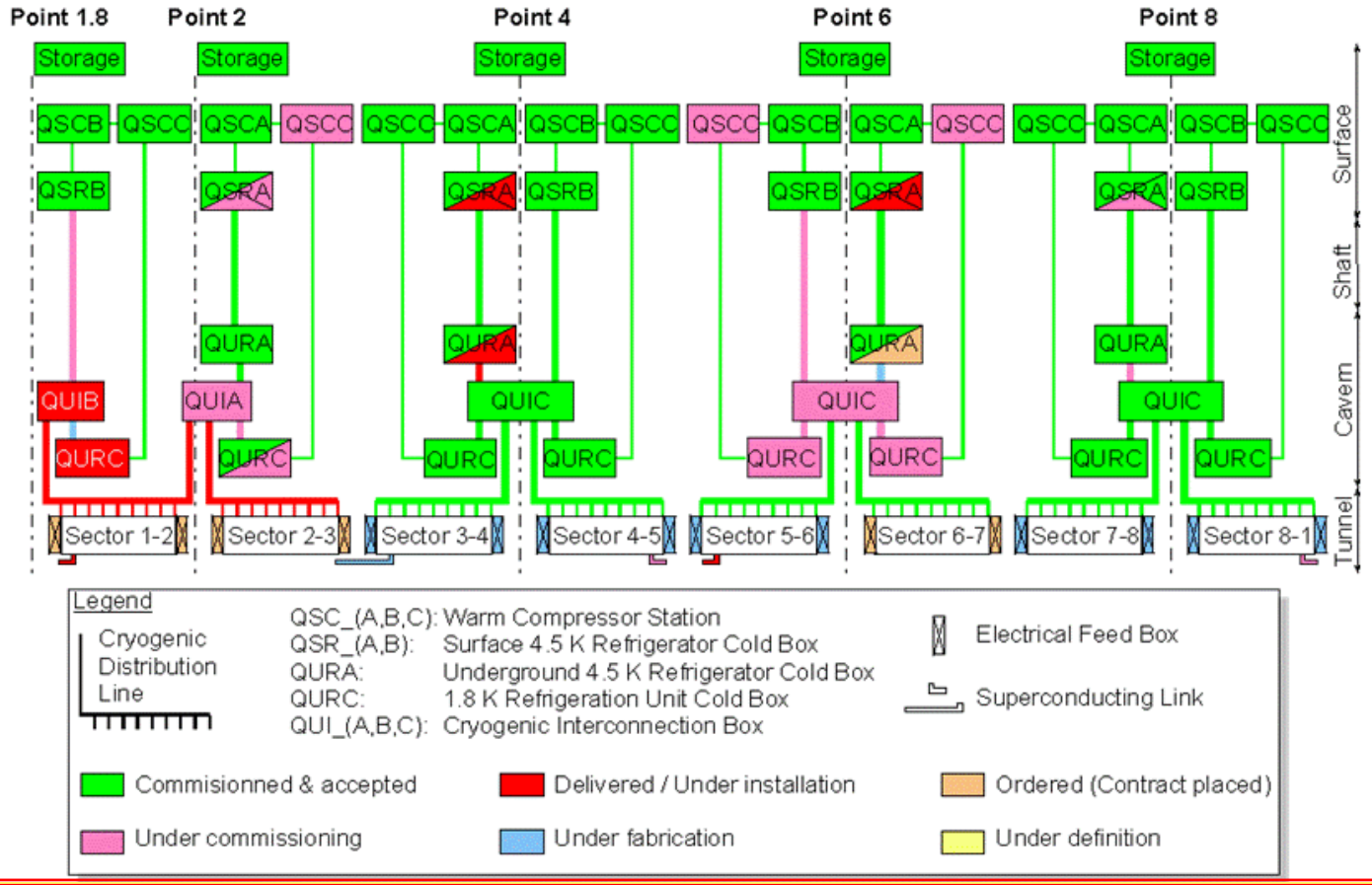
A large and complex fluid distribution system

Progress overview

LHC Progress Dashboard

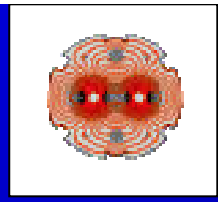
Accelerator Technology Department

Cryogenics overview



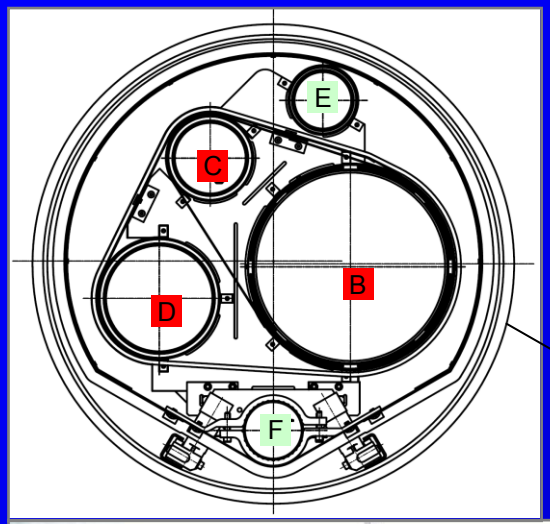
Staggered progress by "LHC Point" then by sub-system

Main problems !



- Very specific “troubles” not even mentioned
- Design & sub-system concerns
  - Cryogenic lines (x 3)
  - Electrical heaters for cryogenic flows (x 2)
  - Impurities (dust) remaining from fabrication
  - Controls
  - Coordination for “built to print” sub-systems (x 2)
- General concerns
  - 3D models, transport items to place, QA tools
  - “Time is contingency” to “Keep on schedule” takes time!

Main cryogenic line (1/2)



Φ= 650 mm
E-F= 50-75
B,C,D = 4-20 K

Weak mechanical approach and quality assurance

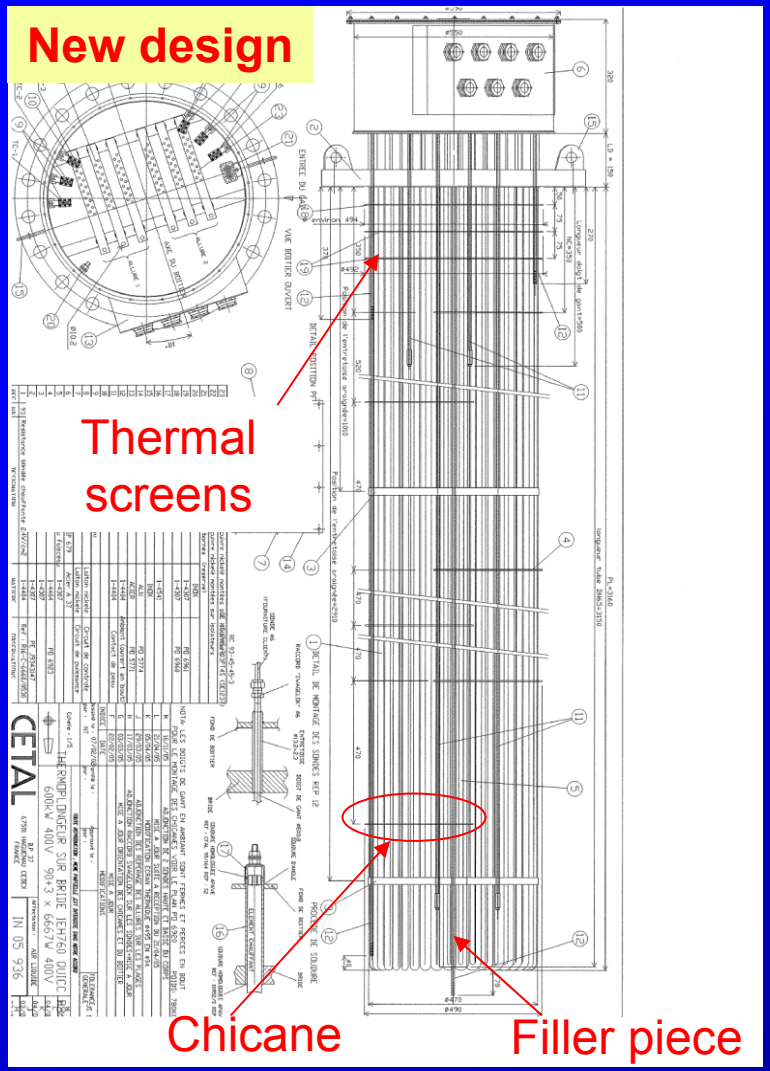
Main cryogenic line (2/2)

2nd start has been the good one, after complements by CERN

Double sourcing ?

Electrical heaters

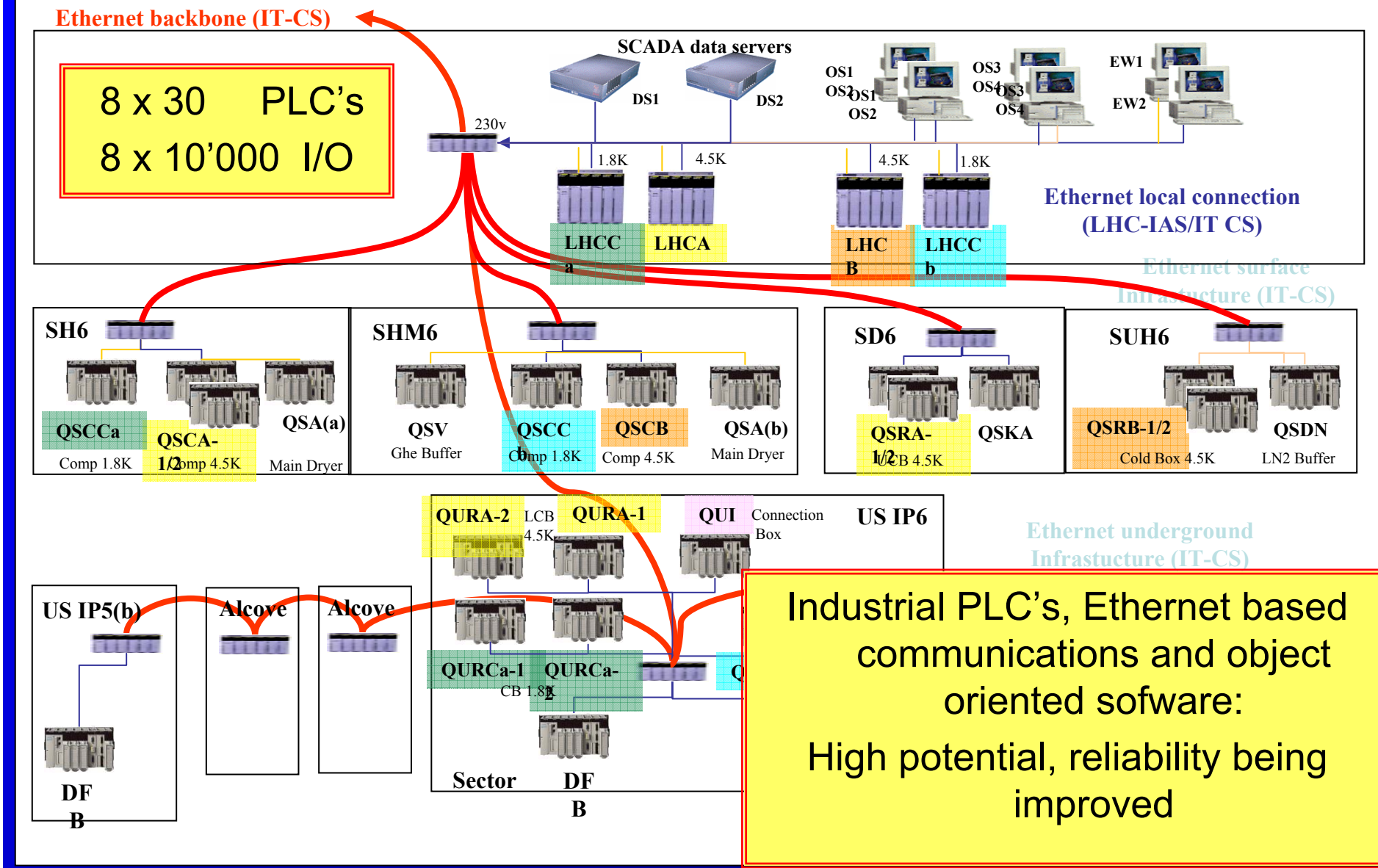
New design



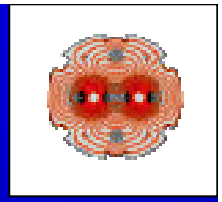
600 kW Electrical Heater

Combination of heat exchange, flow patterns, electrical and integration analysis

Controls


Ethernet backbone (IT-CS)
8 x 30 PLC's
8 x 10'000 I/O
SCADA data servers
DS1
DS2
OS1
OS2
OS3
OS4
EW1
EW2
230v
1.8K
4.5K
4.5K
1.8K
LHCC a
LHCA
LHC B
LHCC b
Ethernet local connection (LHC-IAS/IT CS)
Ethernet surface Infrastucture (IT-CS)
SH6
QSCCa
Comp 1.8K
QSCA-1/2
Comp 4.5K
QSA(a)
Main Dryer
SHM6
QSV
Ghe Buffer
QSCC
Comp 1.8K
QSCB
Comp 4.5K
QSA(b)
Main Dryer
SD6
QSRA-1/2
QSKA
SUH6
QSRB-1/2
Cold Box 4.5K
QSDN
LN2 Buffer
QURA-2
LCB 4.5K
QURA-1
QUI
Connection Box
US IP6
Ethernet underground Infrastucture (IT-CS)
US IP5(b)
Alcove
Alcove
QURCa-1
CB 1.8K
QURCa-2
Sector DF B
DF B
Industrial PLC's, Ethernet based communications and object oriented sofware:
High potential, reliability being improved

Considerations for new projects

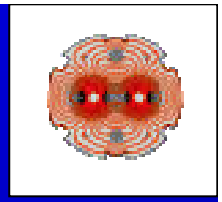


www.cern.ch/lhc
> LHC Design Report > Cryogenics
> LHC Project Reports : Papers

- LHC public documentation:
- Each new project has its own constraints!

  Identification of boundary conditions and technological evolution since last project:
  - Partnership: an efficient way to catch faster
  - If necessary, R&D and components validation
- For design & installation: solid references completed by flexibility
- Take advantage of experienced teams while they exist!

Conclusion



- Installation of various cryogenic sub-systems and cold tests of LHC cryo-magnets will be mostly completed by end of 2006
- All cryogenic sub-systems commissioned so far fulfil their requirements
- First LHC sector cool-down and commissioning end 2006:

  Confident, and aware that it represents an enormous challenge with learning process, efforts and surprises!