CERN

Academia Meets Industry on Cryogenics

HEPTech

EUROPEAN CRYOGENICS DAYS

June 9-10, 2016

Geneva | SWITZERLAND

LHC machine operation: what did we learn?

CERN, Technology department – Cryogenic group – Operation for accelerator section

Gerard FERLIN on behalf of the Cryogenic operation team

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Special thanks to L. Tavian, S. Claudet… for slides

Agenda

- Introduction CERN - LHC
- Architecture of LHC cryogenic system
- Large scale Helium Refrigeration
- Installation & Commissioning
- As time goes (from commissioning to today)
- LHC Cryogenics operating results
- Conclusion

CERN in Brief

Founded in 1954

21 Member States + Associates

Annual budget: ≈ 1,110 MCHF

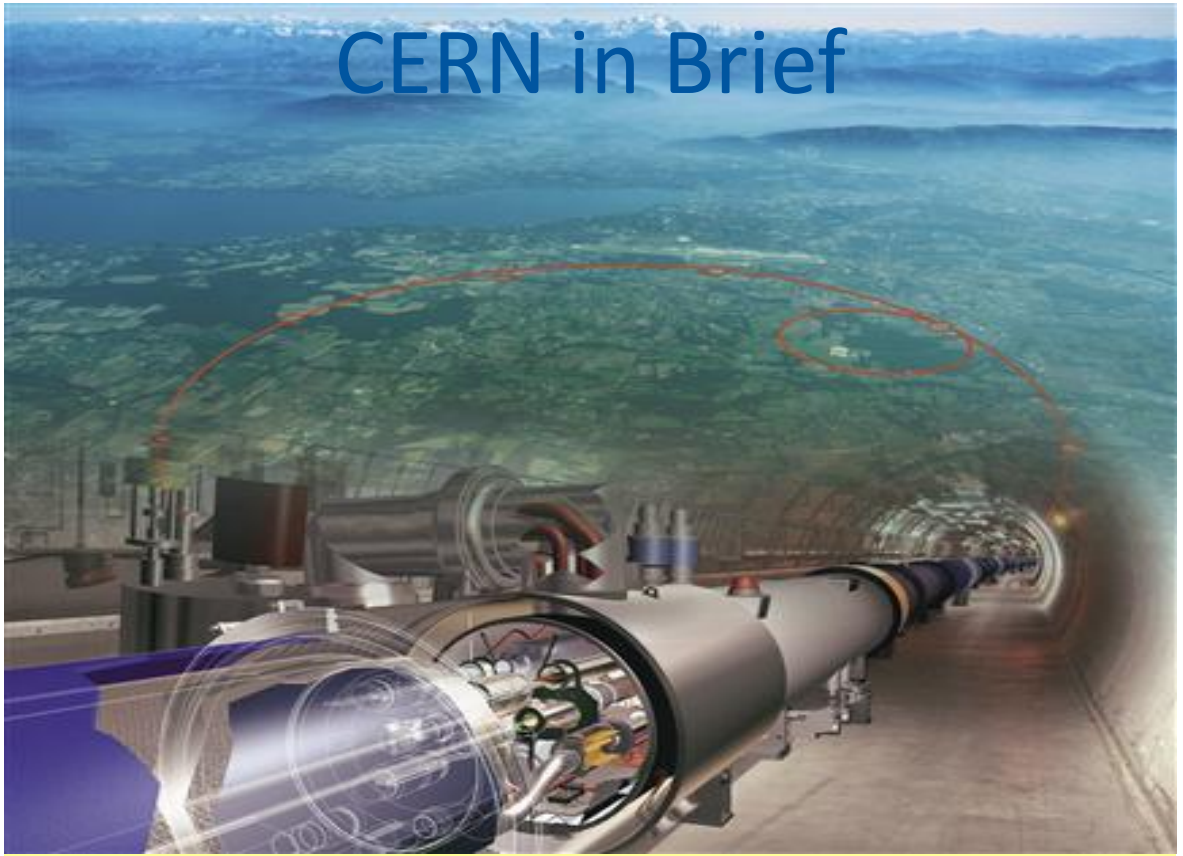
Around 2’500 staffs

About 11’500 users

LHC: p-p collisions

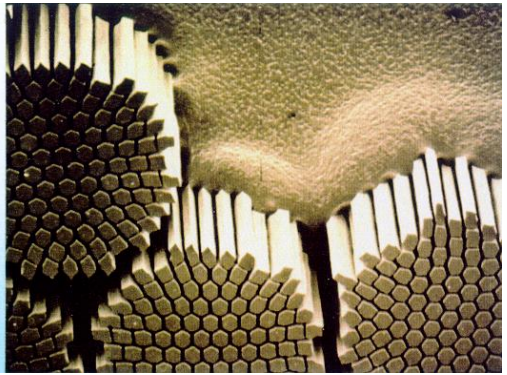
10^{34} $cm^{-2}.s^{-1}$, 14 TeV

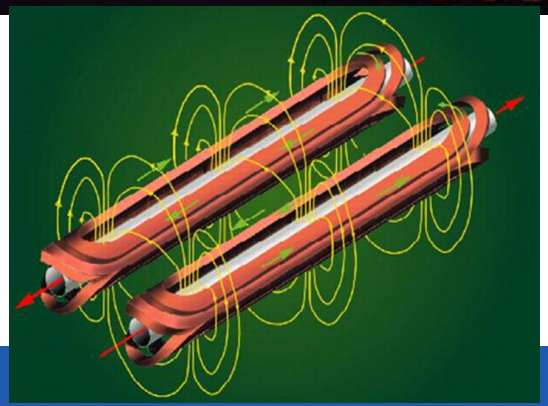
500 MJ beam energy



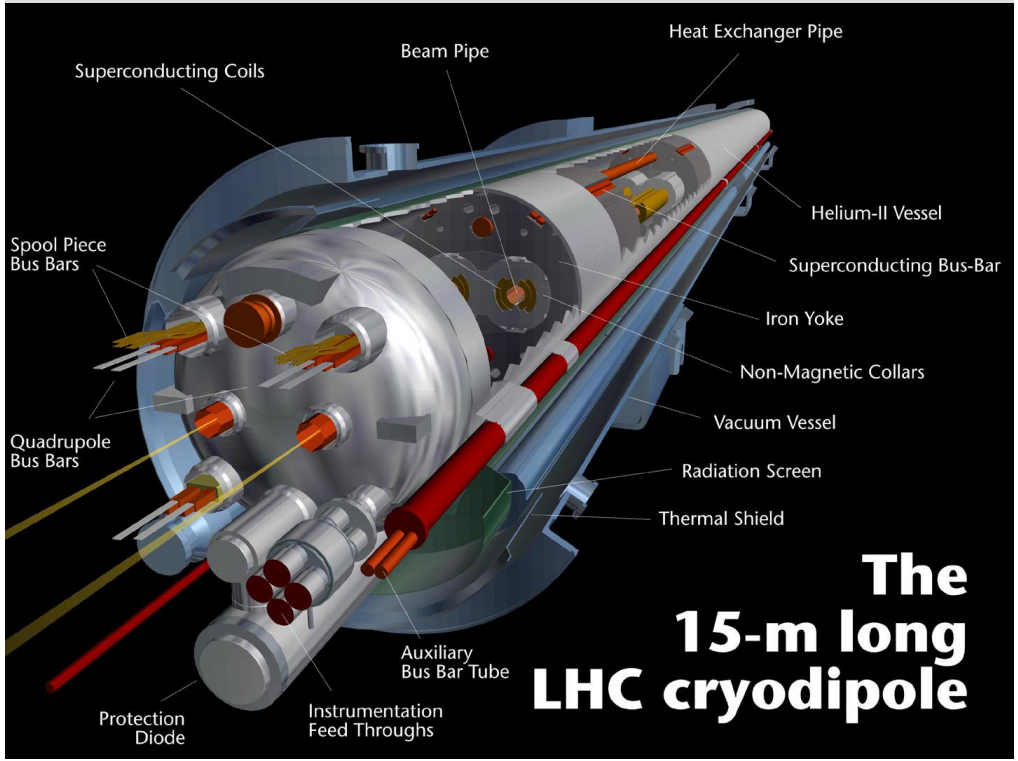
24 km (36000 T) of superconducting magnets @1.9 K, 8.33 T

Superconducting Magnet

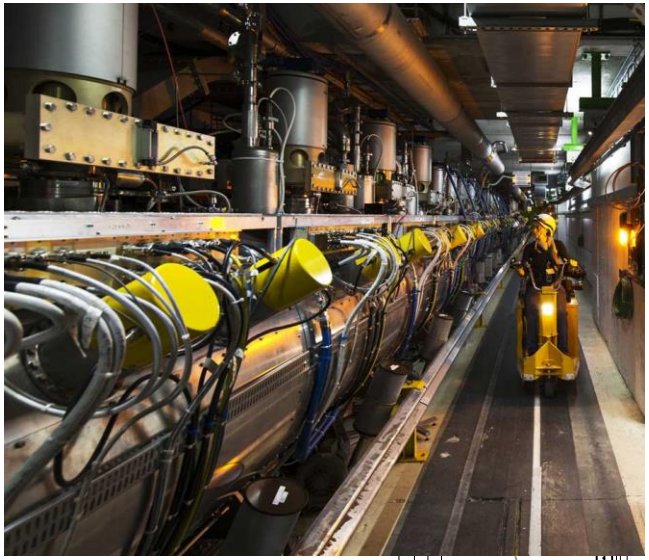




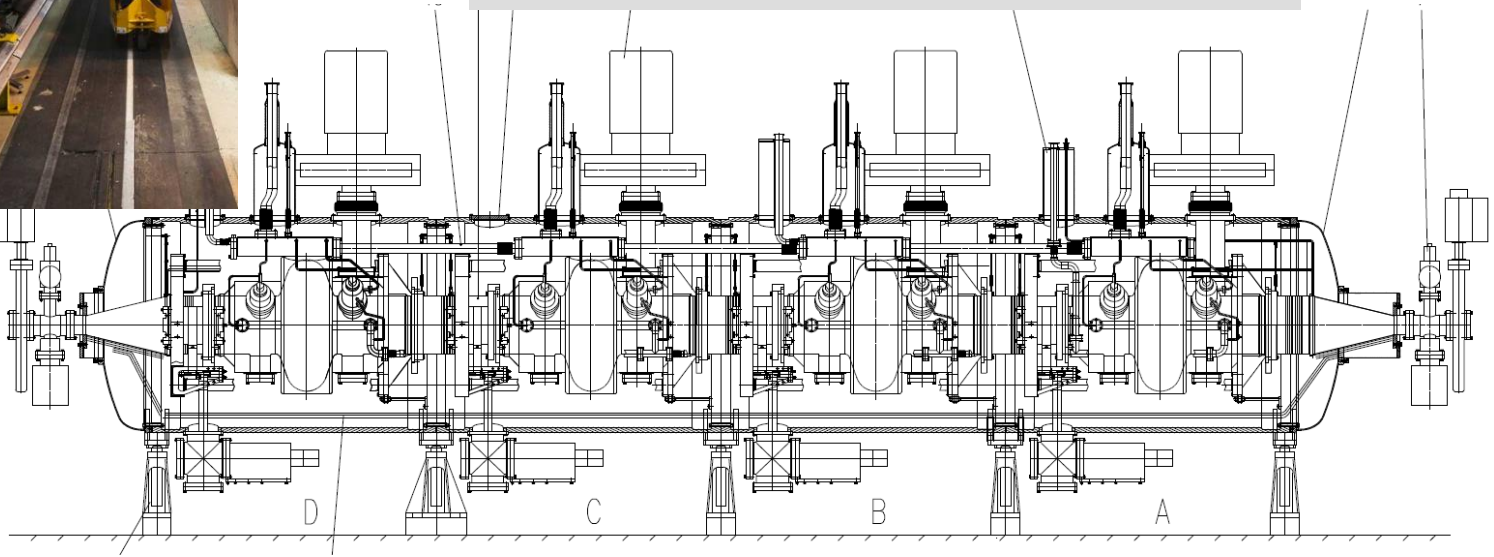
LHC: 9593 superconducting magnets, whose 1232 dipole magnets



Superconducting Radio Frequency cavities (SRF)



LHC: 4 modules of 4 SRF cavities



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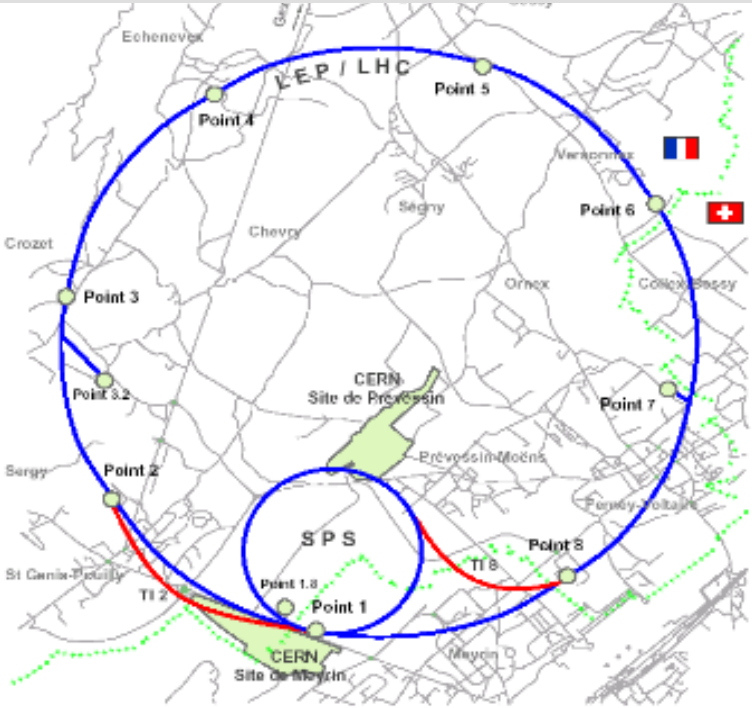
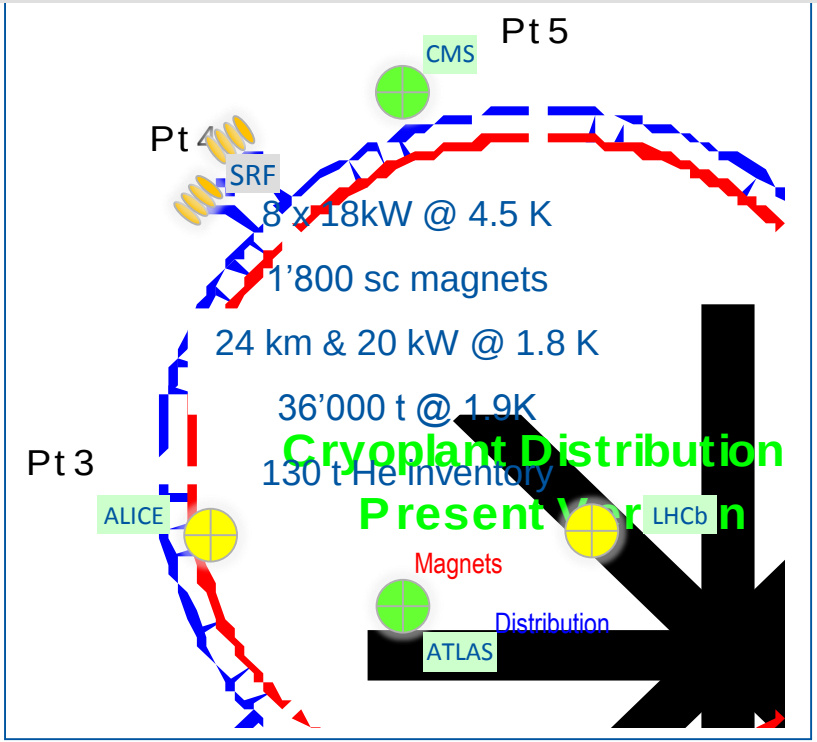
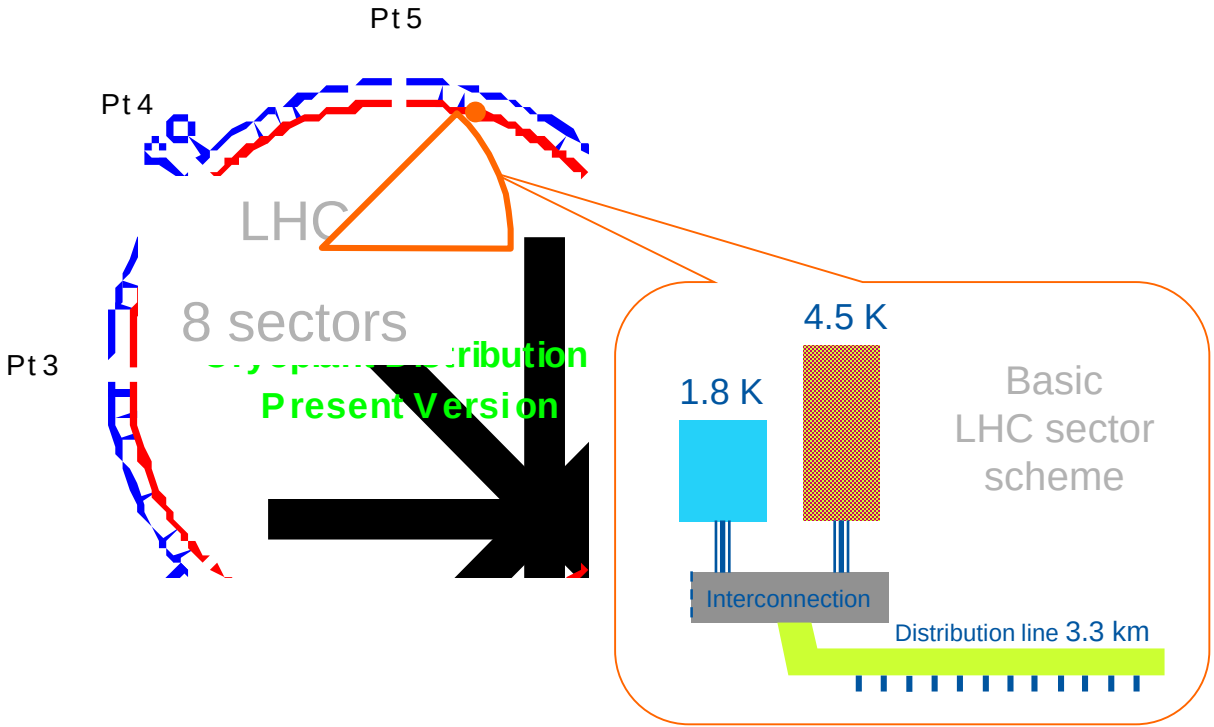
Layout of LHC cryogenics

LHC: 24 km of high-field superconducting magnets operating in superfluid helium at 1.9 K

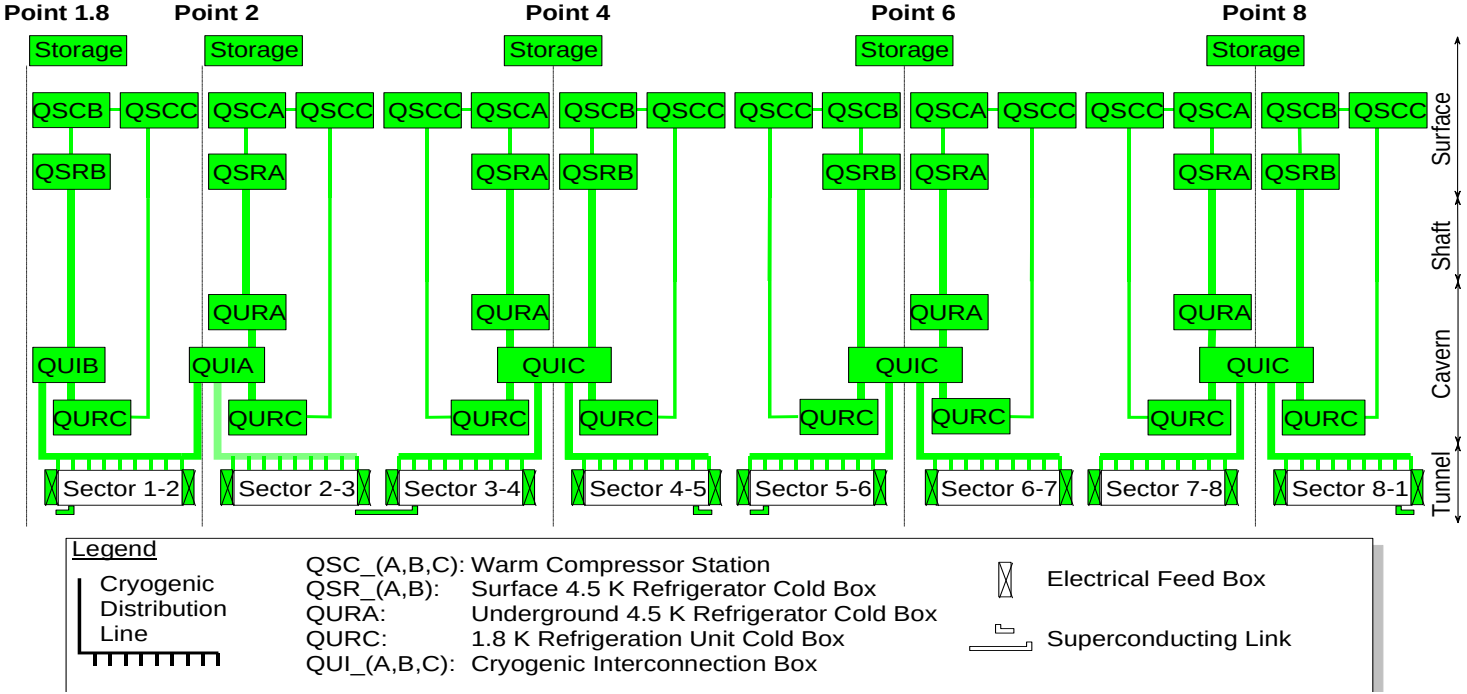




LHC cooling system

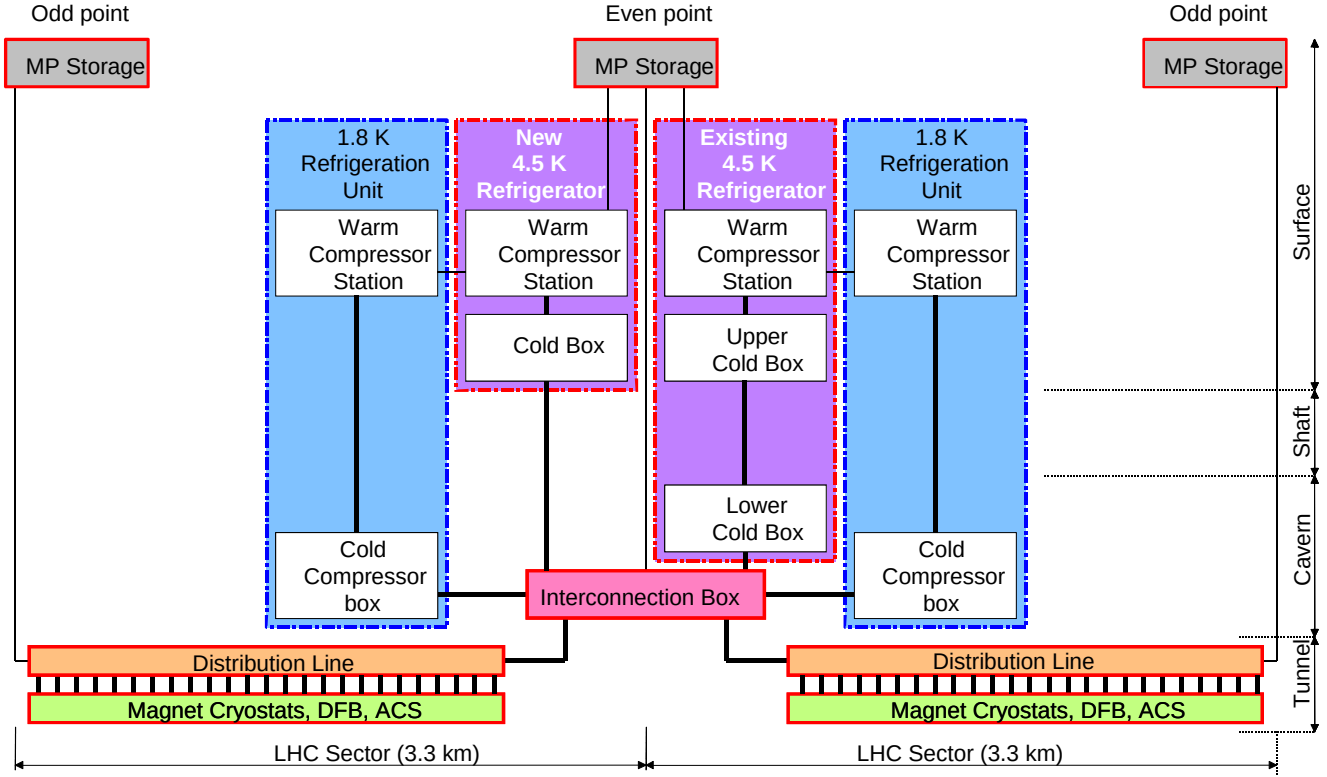


LHC Cryogenics architecture

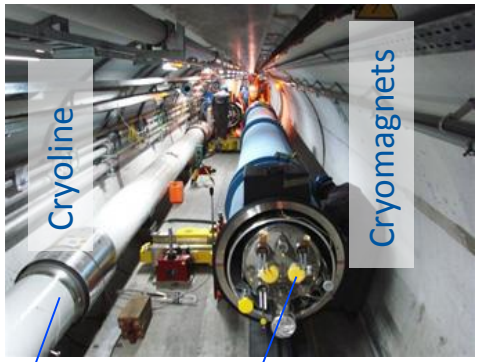


Large variety of operational configurations are available, including the use of one cryogenic plant for two sectors in case of emergency configuration for securing the helium inventory, ensure the sectors cold stand-by or perform "low-intensity physics"

Cryogenic island architecture

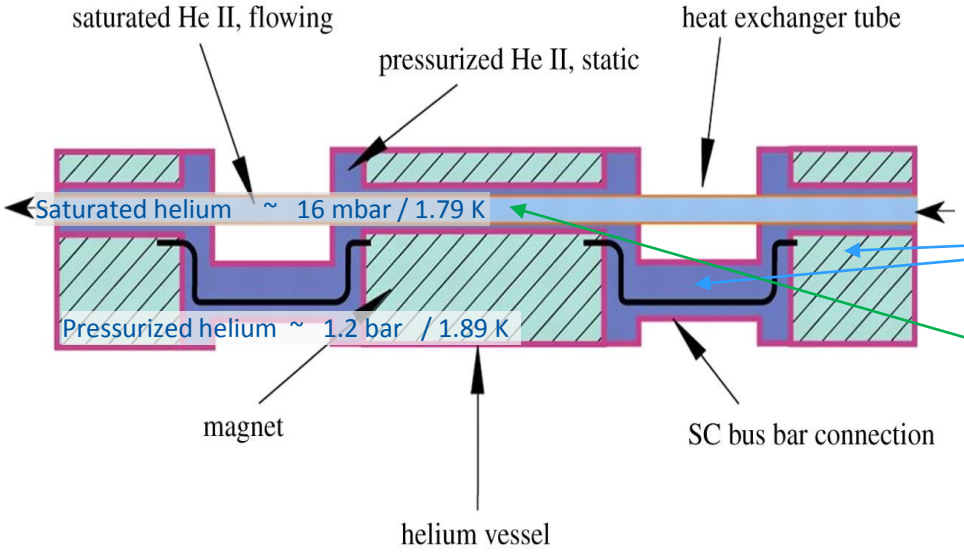


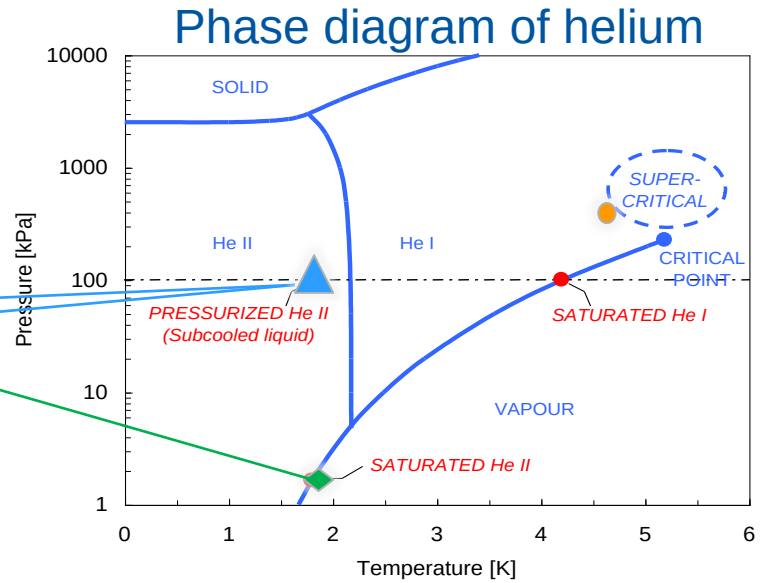
1/8e of LHC: production-distribution-magnets



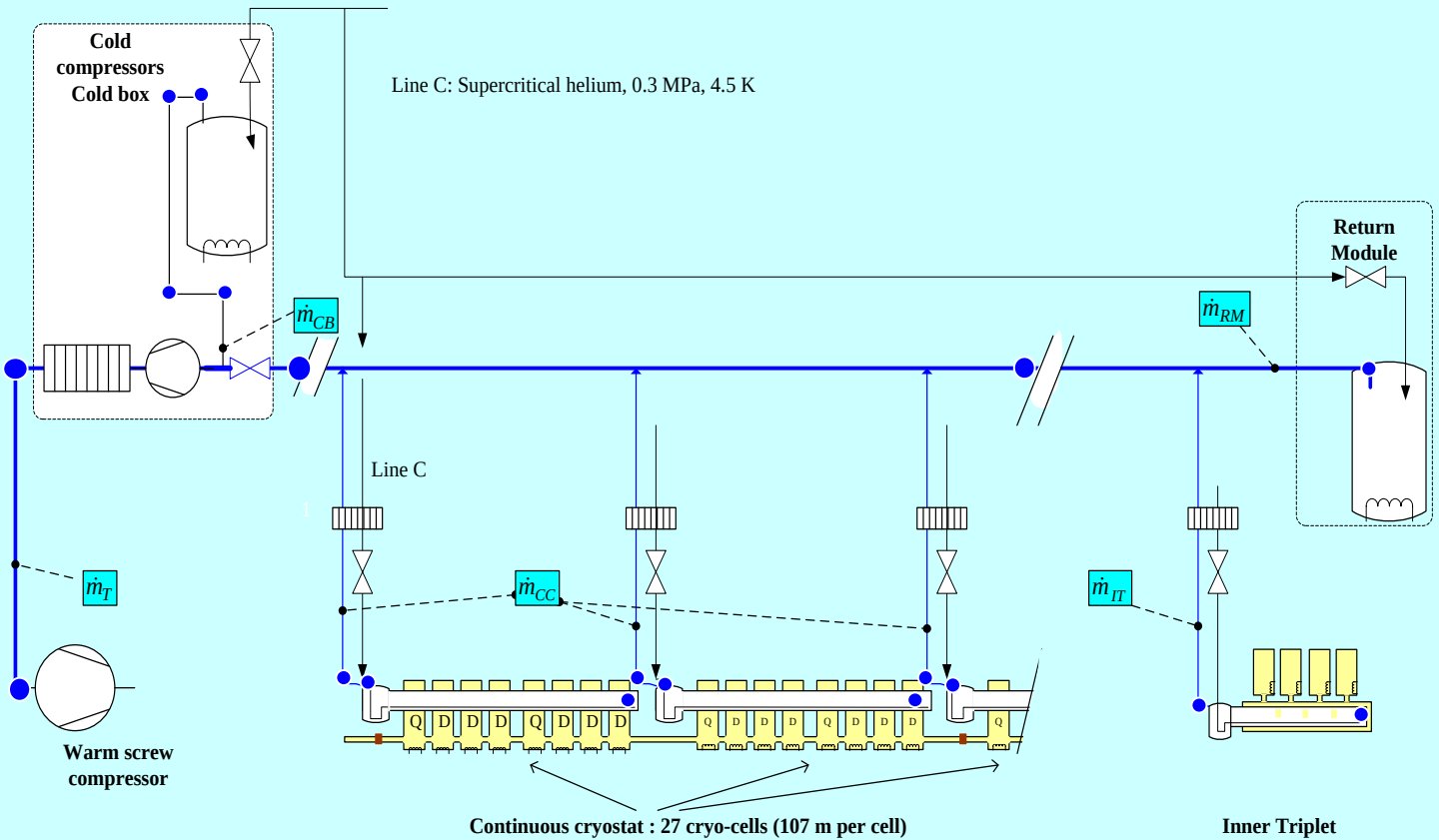
Total 8 sectors:	
Warm Compressors:	64
Turbines:	74
Cold Comp.:	28
Leads:	1’200
I/O signals:	60’000
PID loops:	4’000

1.9 K Cryomagnet cooling scheme





1.9 K Cryomagnet cooling system: how does it works?



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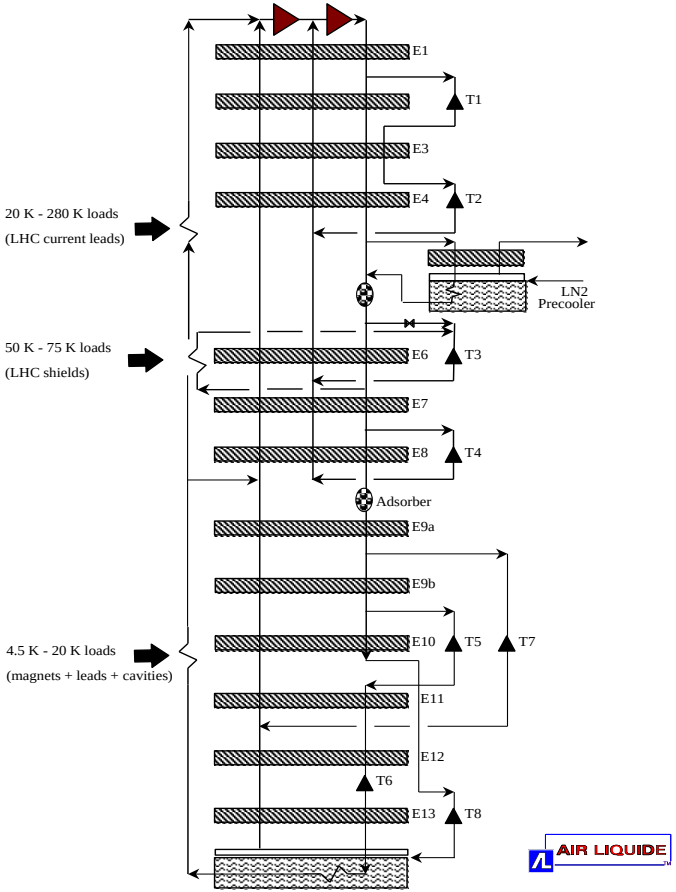
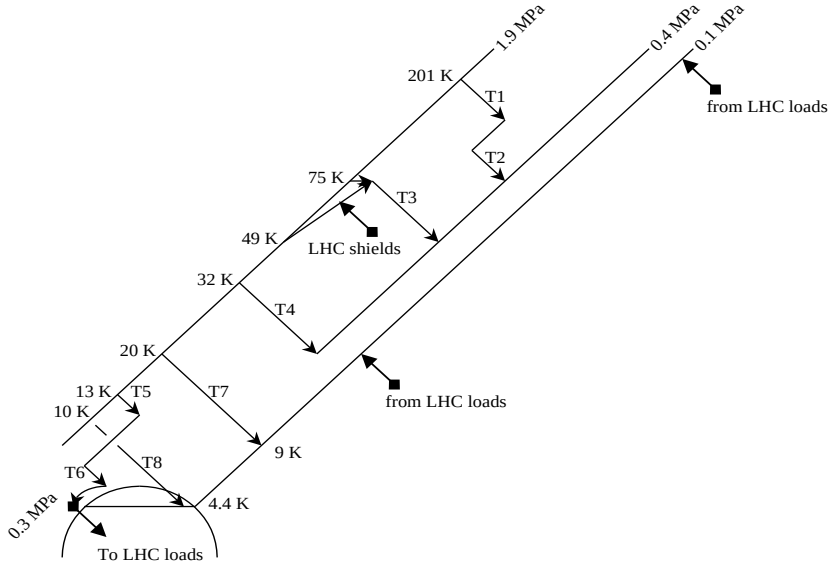
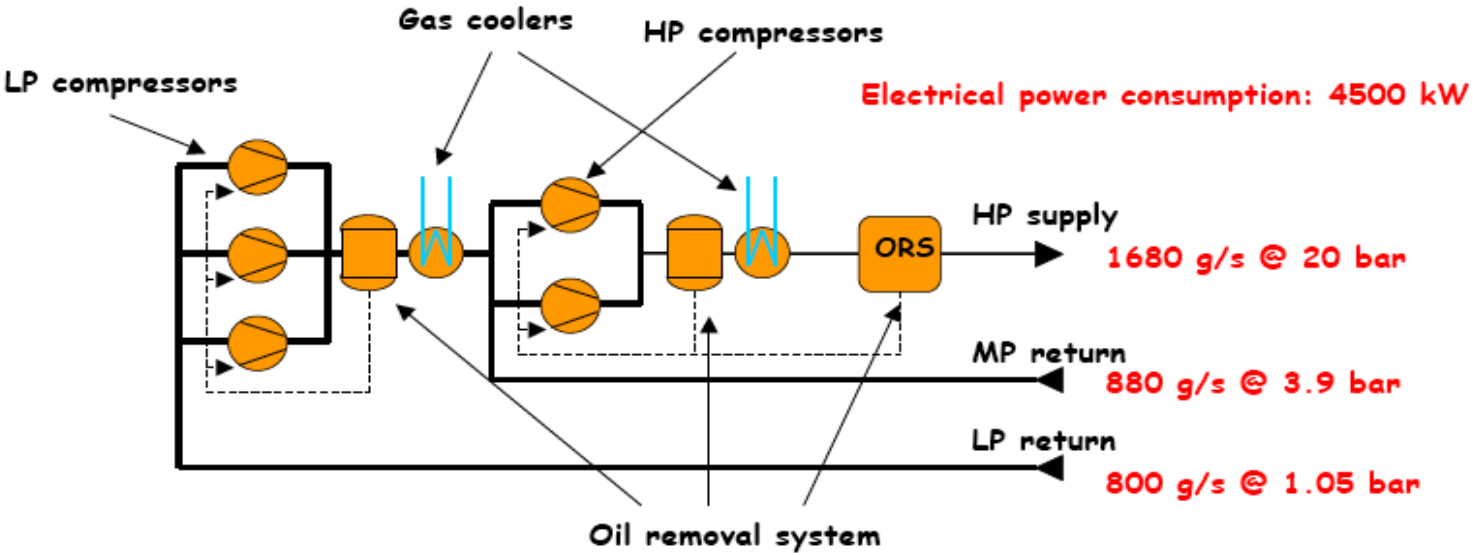
Process cycle & T-S diagram of LHC 18 kW @ 4.5 K cryoplant





Process diagram, LHC compressors 18 kW @ 4.5 K

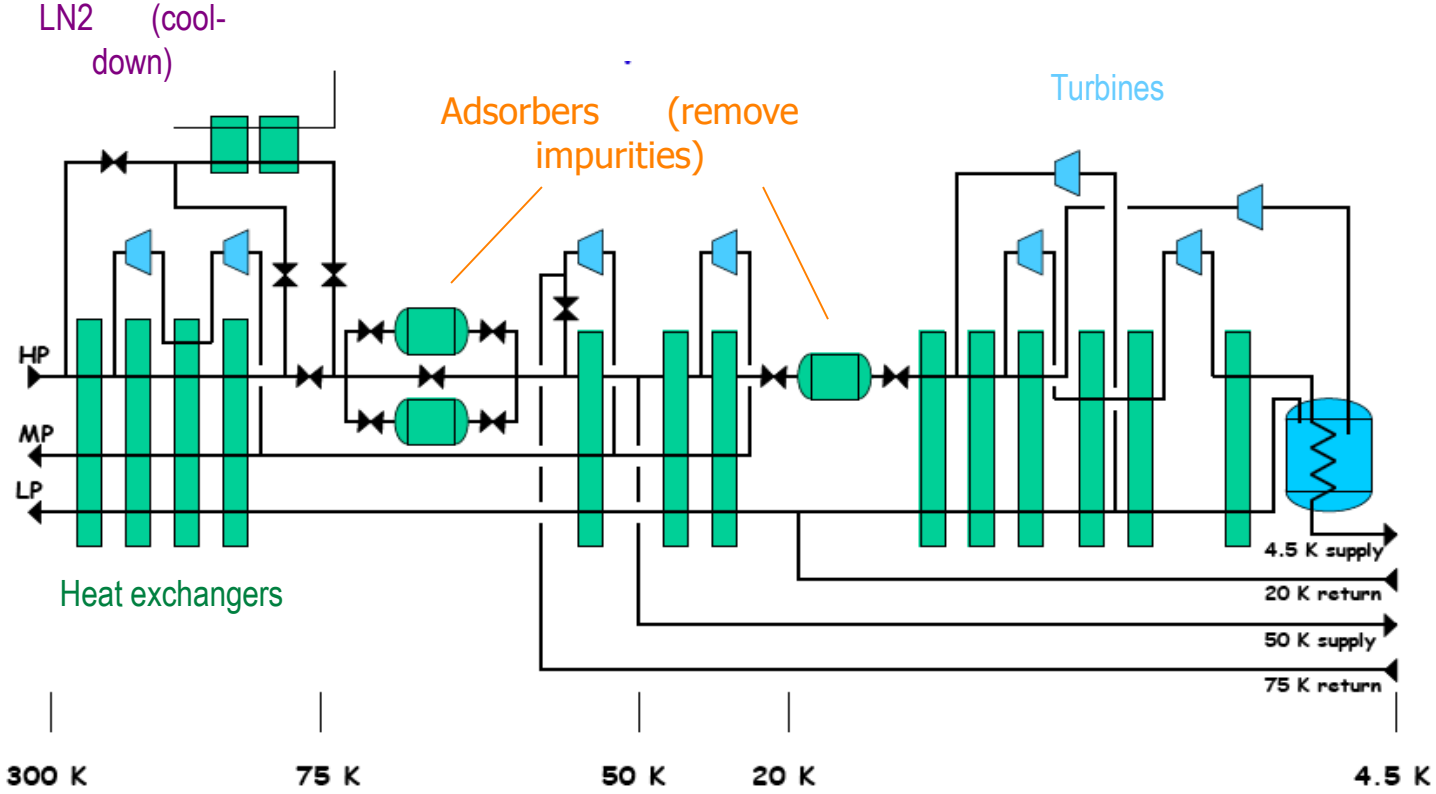
Oil lubricated screw compressors, water cooled, oil separation included



Machine derived from industrial refrigeration (or compressed air)

No more piston (high PR, low flow), not yet centrifugal (high flow, low PR)

Process diagram, LHC refrigerator 18 kW @ 4.5 K



Interconnection box

4.5 K refrigerators
(18 kW @ 4.5 K)

1.8 K refrigeration units
(2.4 kW @ 1.8 K)

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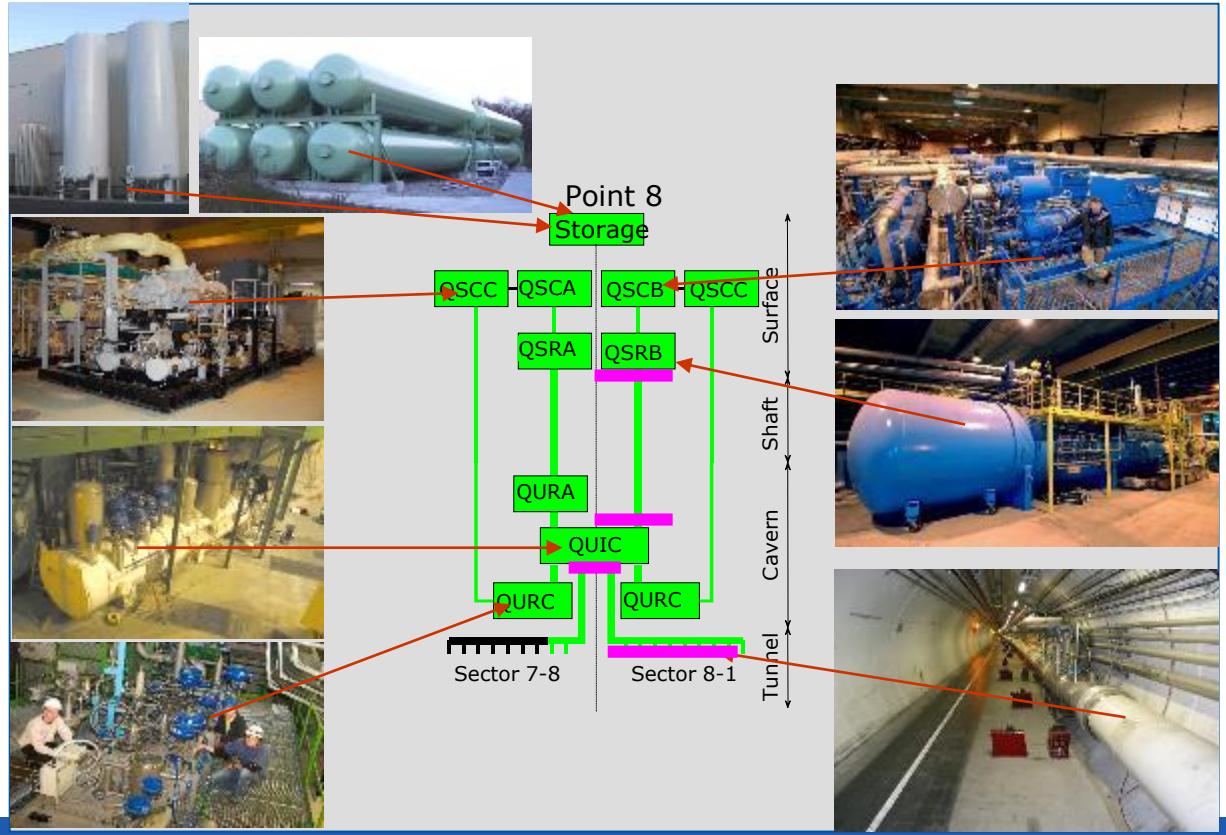
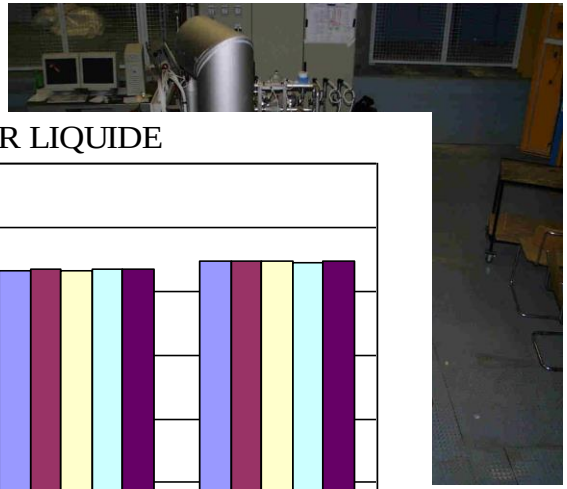
Testing the cryogenic sub-systems

Performance assessment of all sub-system (at least a type test) before connection to the next sub-system

Challenging devices such cold compressor units tested with a specific scheme



Test station for cold compressor units



35 cold compressor cartridges qualified

Reproducible performances for Cold Compressors cartridges and validation of the 2 set of prototypes for the 1.8 K cold boxes

From test facility to final area

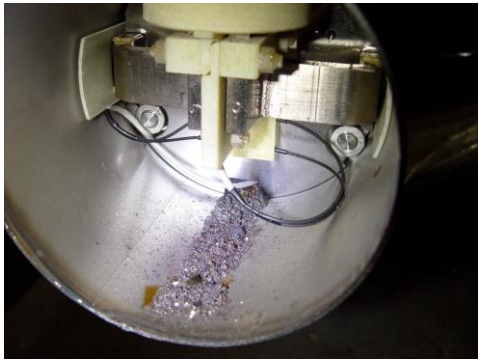
- Prototype 1.8 K cold boxes moving to their final position

Problems encountered: solid pollution

Huge amount of Solid particles such as :

-Fine dust

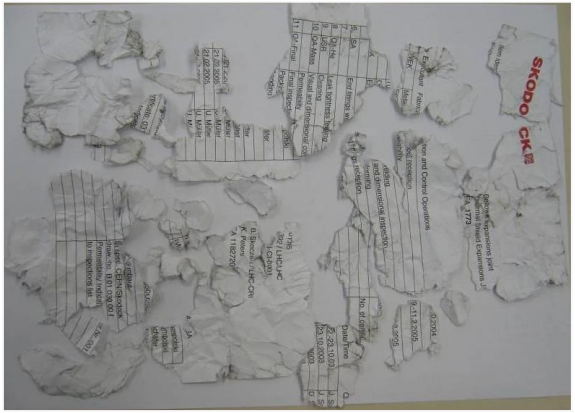
-Metallic chips with possible shorts in diodes



Non exhaustive list!

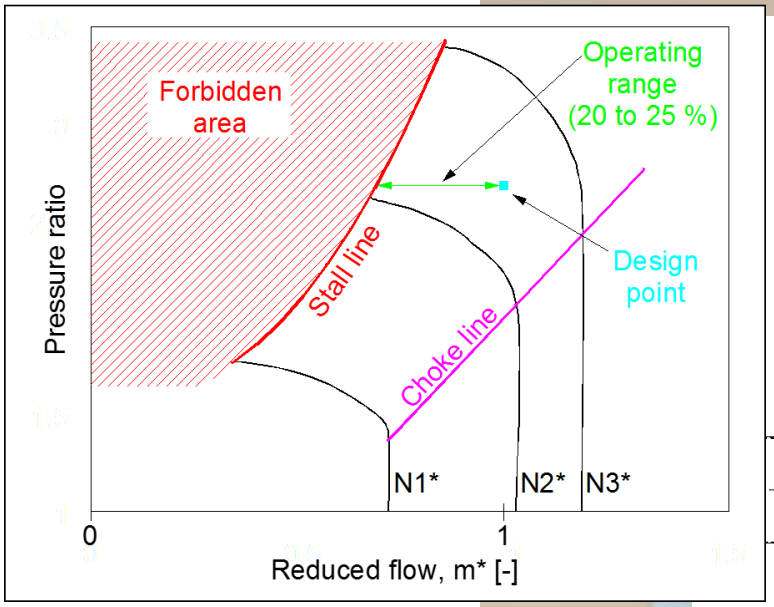
-Kapton ™

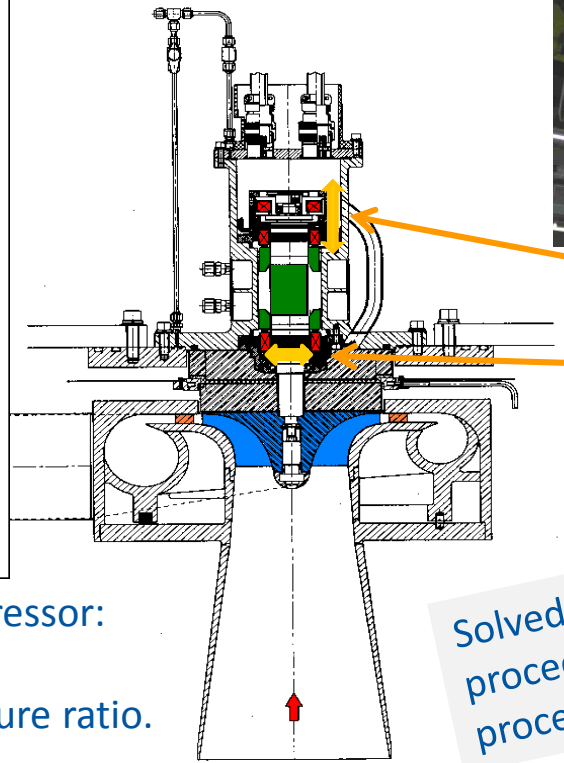
-QA documents !



- This solid pollution has been anticipated by carrying out an exhaustive pipe flushing

Hydrodynamic cold compressors for 1.8 K units





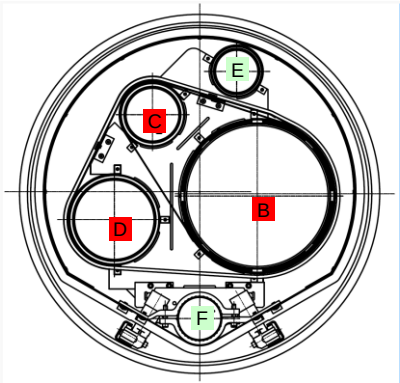
Axial Displacement

Radial Displacement

Complex operation of hydro-dynamic compressor:
- high rotational speed: up to 800 Hz,
- reduced operation range at constant pressure ratio.

Solved by training and updated procedures to avoid uncontrolled process oscillations

Hydraulic time constant



From valve box to Return modul

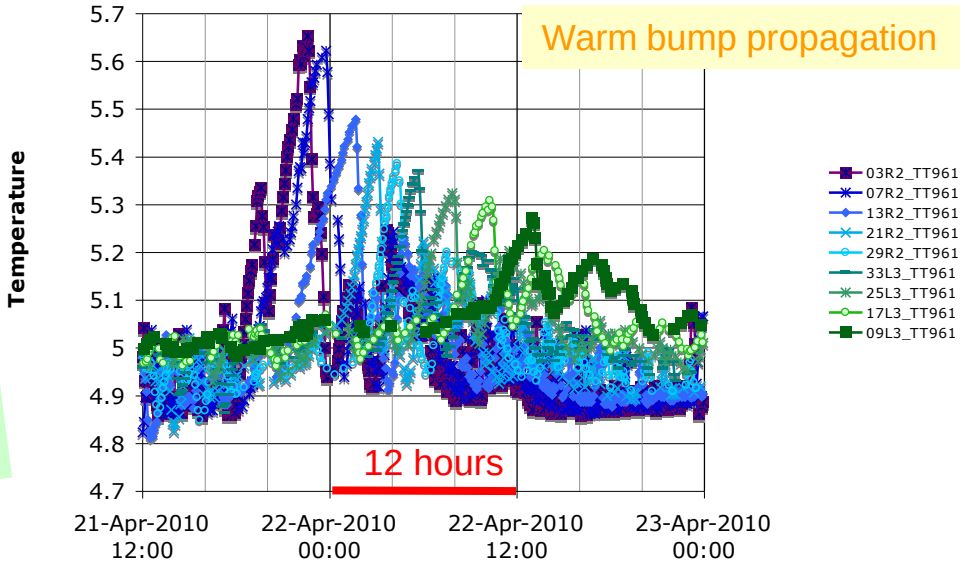
≈ 3300m

	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'

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

Change on "supply conditions" may have an effects some hours later!

Warm bump propagation



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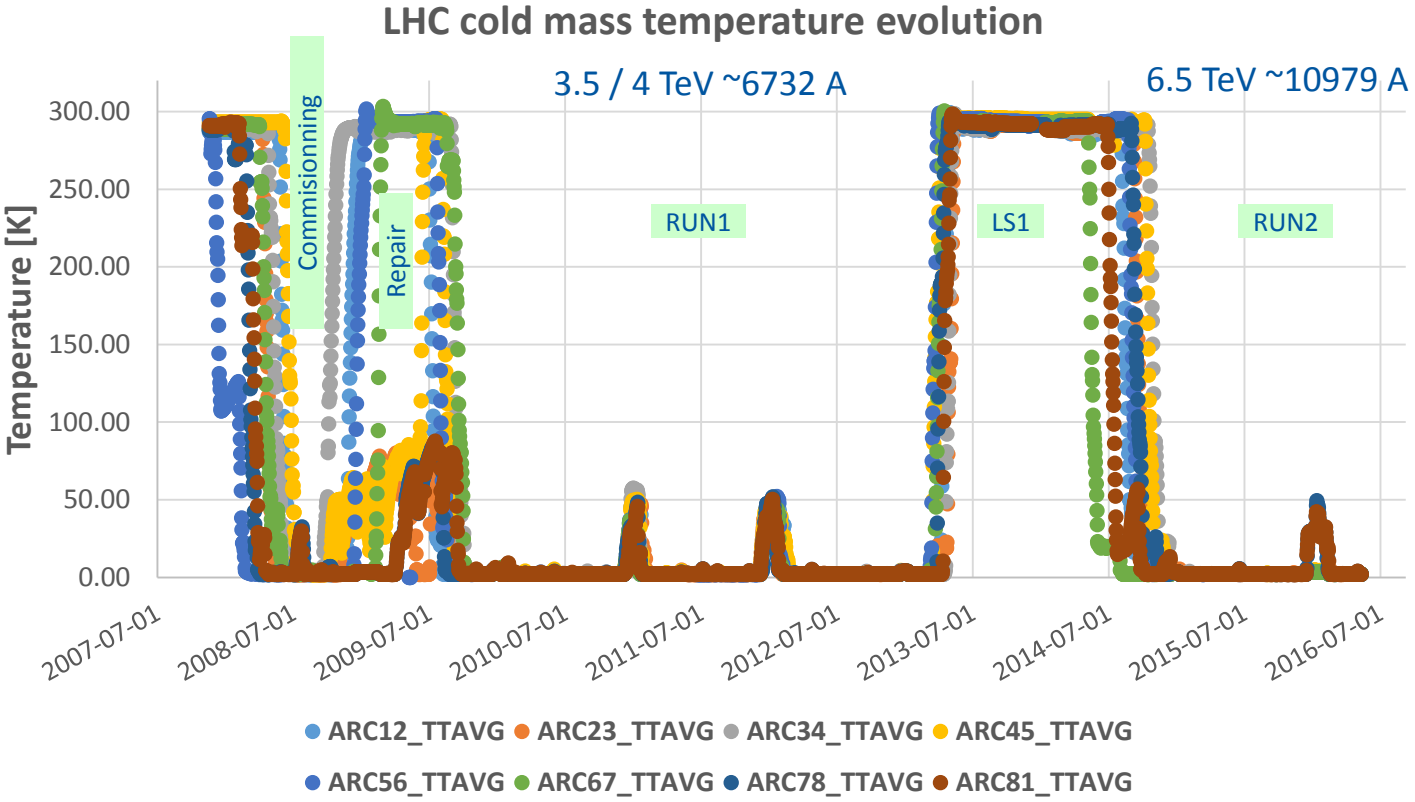
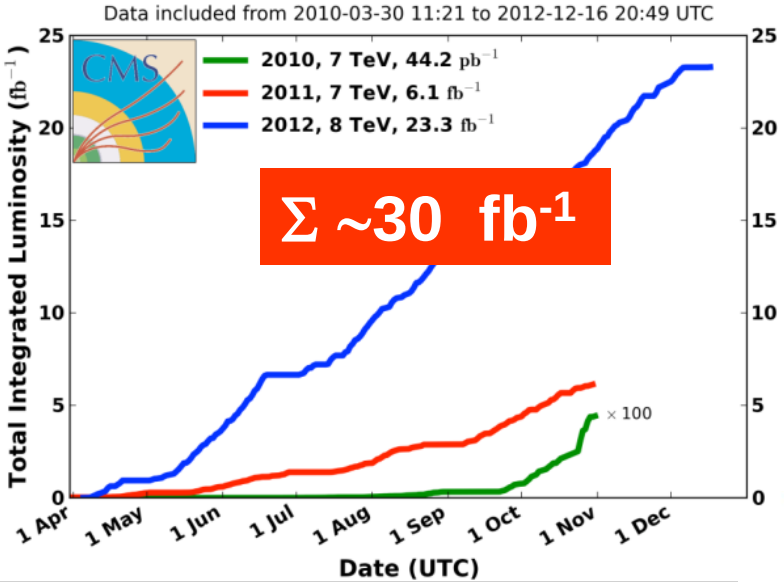
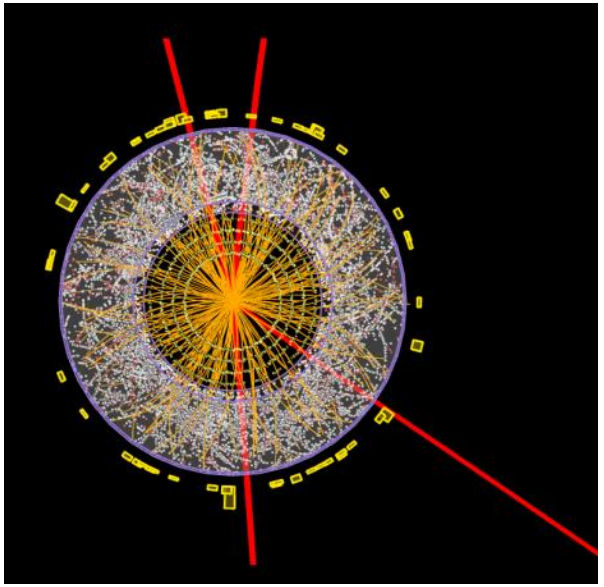
From 1st commissioning to today

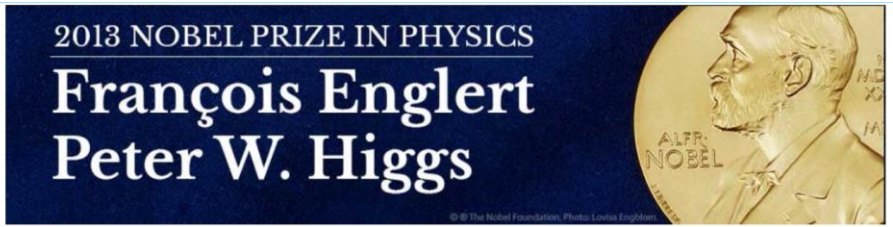


LHC Run 1 (2010-2012 @ 3.5 et 4 TeV)



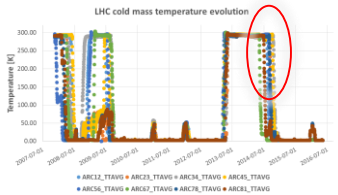


Despite all, thanks to the efforts of all staff, the first campaign has been awarded by a Premium price

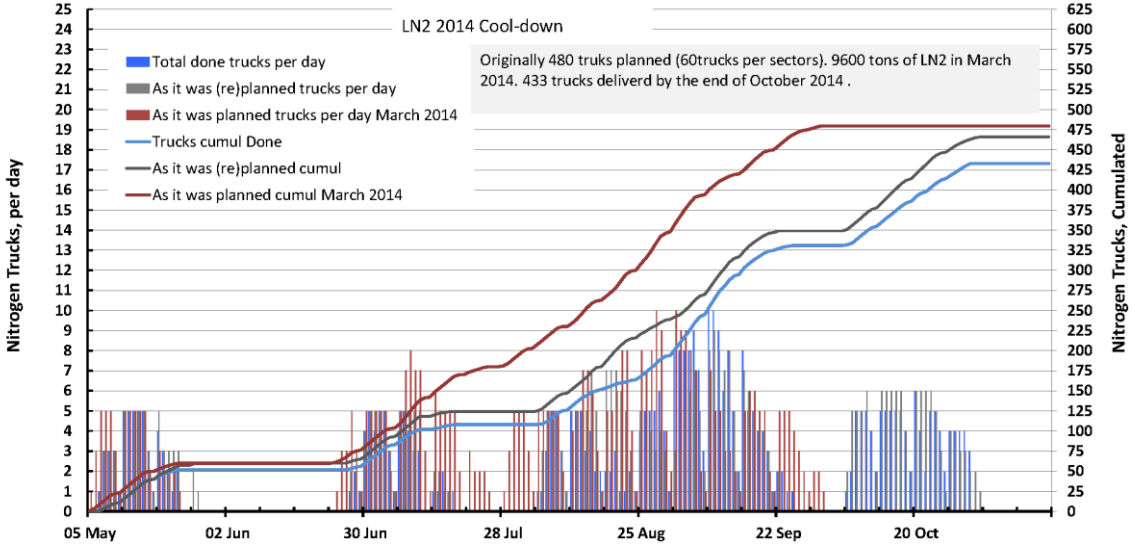


for the theoretical discovery of a mechanism that contributes to our understanding of the origin of mass of subatomic particles, and which recently was confirmed through the discovery of the predicted fundamental particle,
by the ***ATLAS and CMS experiments at CERN's Large Hadron Collider"***

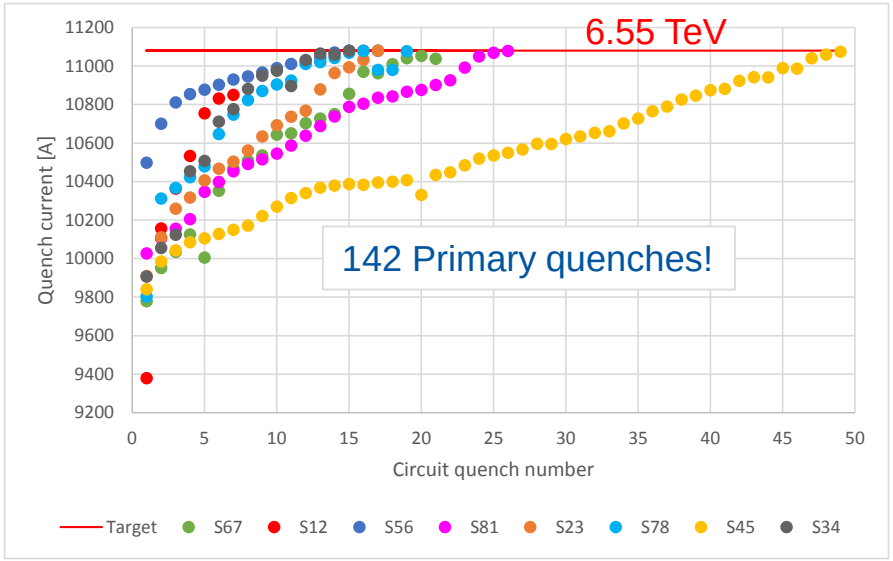
Cooling down of LHC: Nitrogen phase



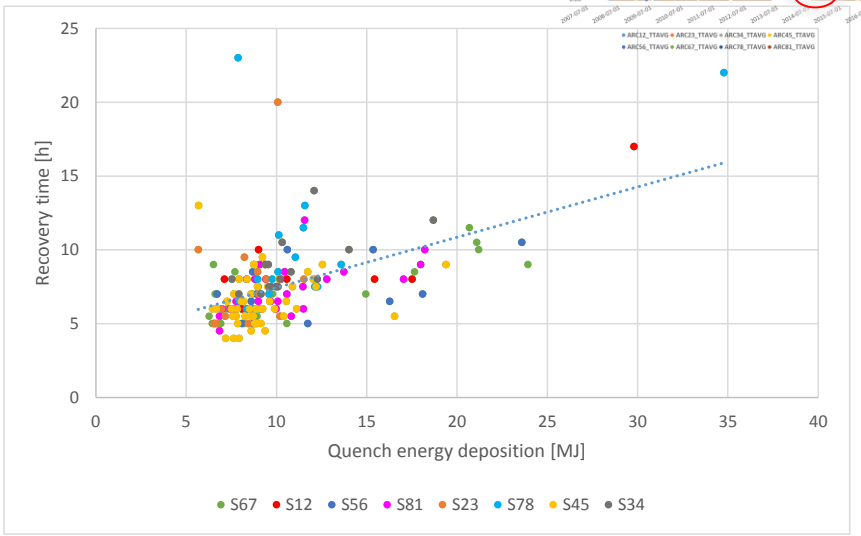
LHC cooling down use 8660 Tons of LN2, in average 54 trucks per sector



Training for sectors towards 6.5 TeV



Cryodipoles training



Cryogenic recovery time after quench

The cryodipoles training phase up to 6.5 TeV last more time than expected (142 done vs 80 expected)

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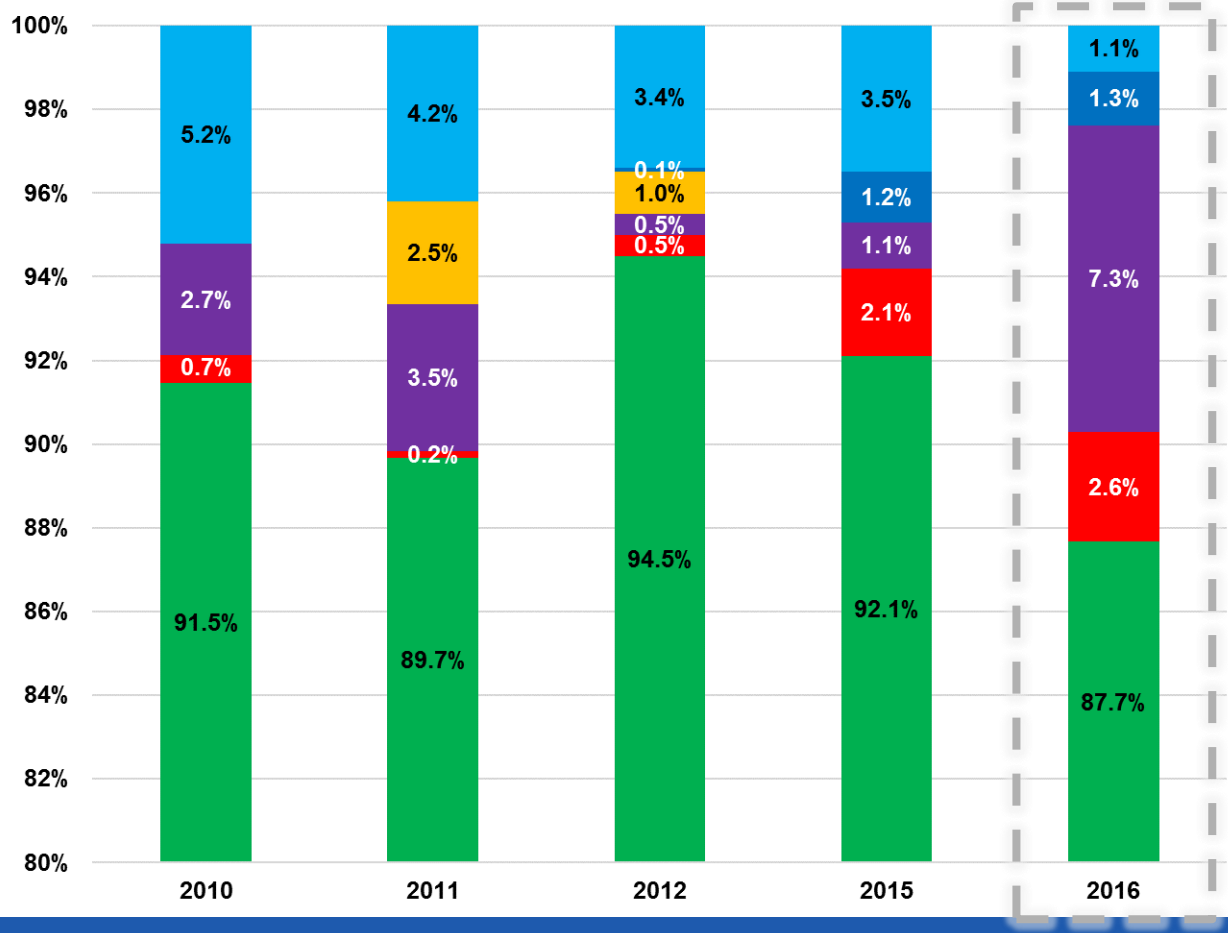
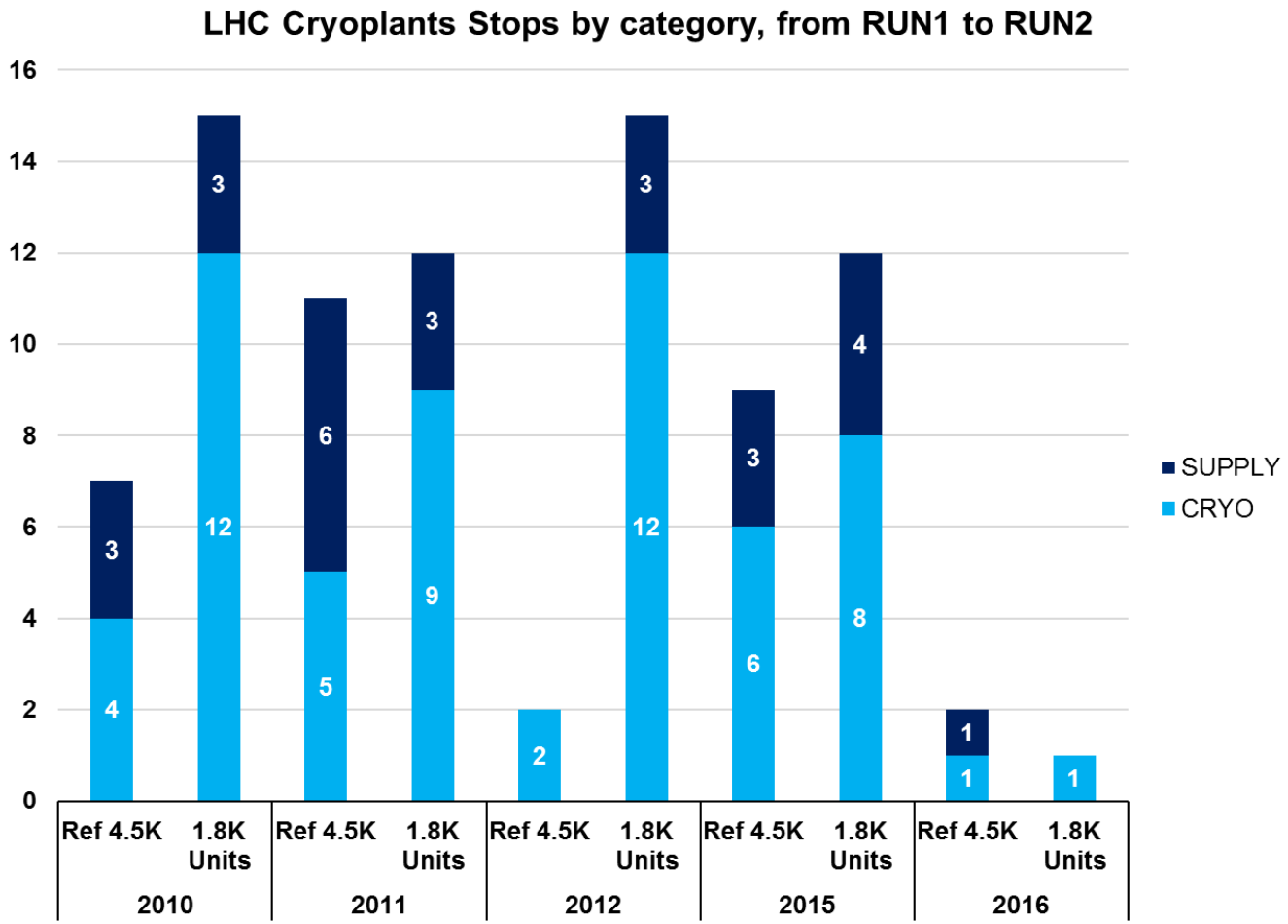
LHC CRYO AVAILABILITY SUMMARY FROM RUN 1 TO RUN 2



Preliminary

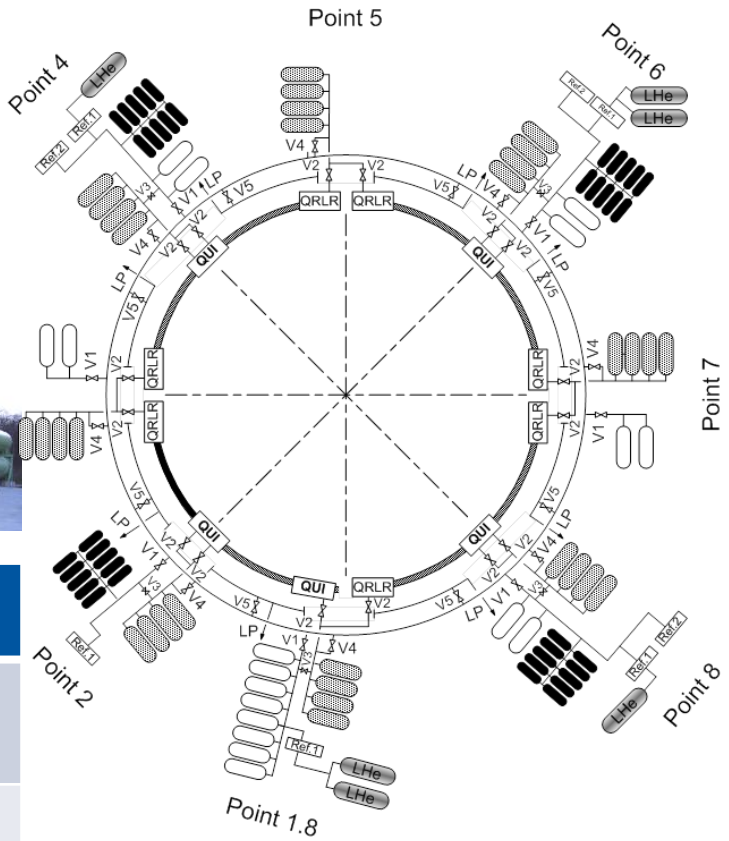
Availability: Cryoplants unexpected stops



Helium storage & inventory

He storage at CERN

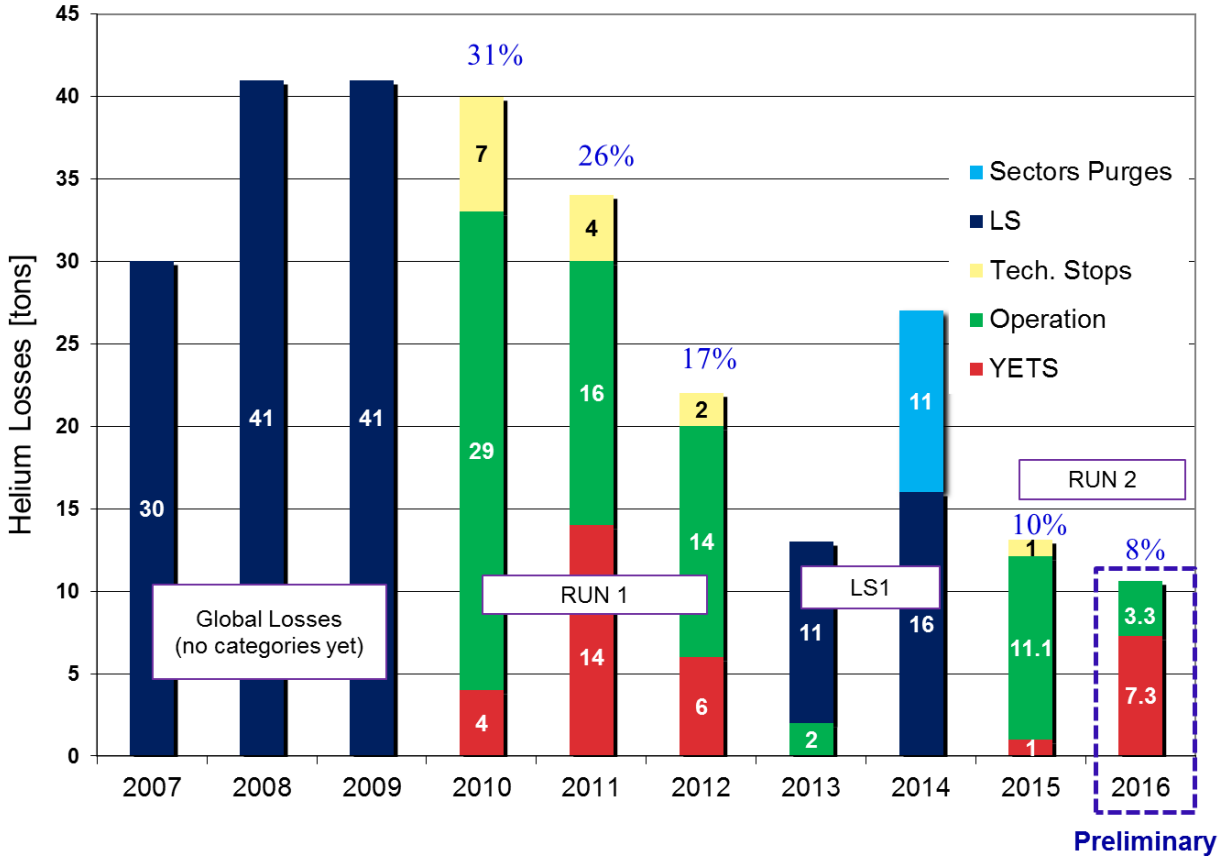
	LHC machine	Liquid storage	Gaz storage
Helium Storage [T] for LHC at CERN	130	90 T ; not equipped with permanent re-liquefiers	45



He inventory

	LHC inventory	Strategic inventory	Balance for deliveries	Virtual inventory
LHC Steady state operation	130 T	15 T	5 T	0
LHC stopped for 1 year shut down	0 T	40 T to 80 T	10 T	From 40 to 80 T

Helium losses



Summary

- LHC cryogenics is the largest, the longest and the most complex cryogenic system worldwide. After 5 years of beam operation, we could achieve an availability in the 95 % range.
- Even with step by step methodical approach, we had very hard time and lengthy commissioning to learn how to tune all these sub-systems together.
- A stable operation under high thermal load is now our new goal. The target is now to improve availability to the challenging 98 % range.

Thanks you