Cryogenics at CERN

EuTuCHe
Symposium

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CERN
on behalf of the groups ACR and ECR (AT department)

Overview of Presentation

- As introduction; history of cryogenics at CERN
- Cryogenics for the LHC Collider
- Cryogenics for the LHC Experiments
- Non-LHC Cryogenic Experiments (a selection)
- Large Cryogenic Test Facilities (a selection)

A Brief History of Cryogenics at CERN

Cryogenics for Experiments

•Since ~1960 Cryogenics for a significant number of experiments (mainly superconducting magnets for fixed targets detectors and components testing)

•Since ~ 1960 Cryogenic Laboratory.

•-Early 1960 Bubble chambers for particle tracking. BEBC (Big European Bubble Chamber early 1970); particle experiment with a superconducting magnet and a track sensitive target with 30 m3 of liquid hydrogen until 1983

•Superconducting detector magnets for the LEP experiments ALEPH, DELPHI (LEP = Large Electron Positron Collider, 1989 until 2000)

•For the LHC (Large Hadron Collider) two very large cryogenic detectors CMS and ATLAS (in commissioning phase)

A Brief History of Cryogenics at CERN

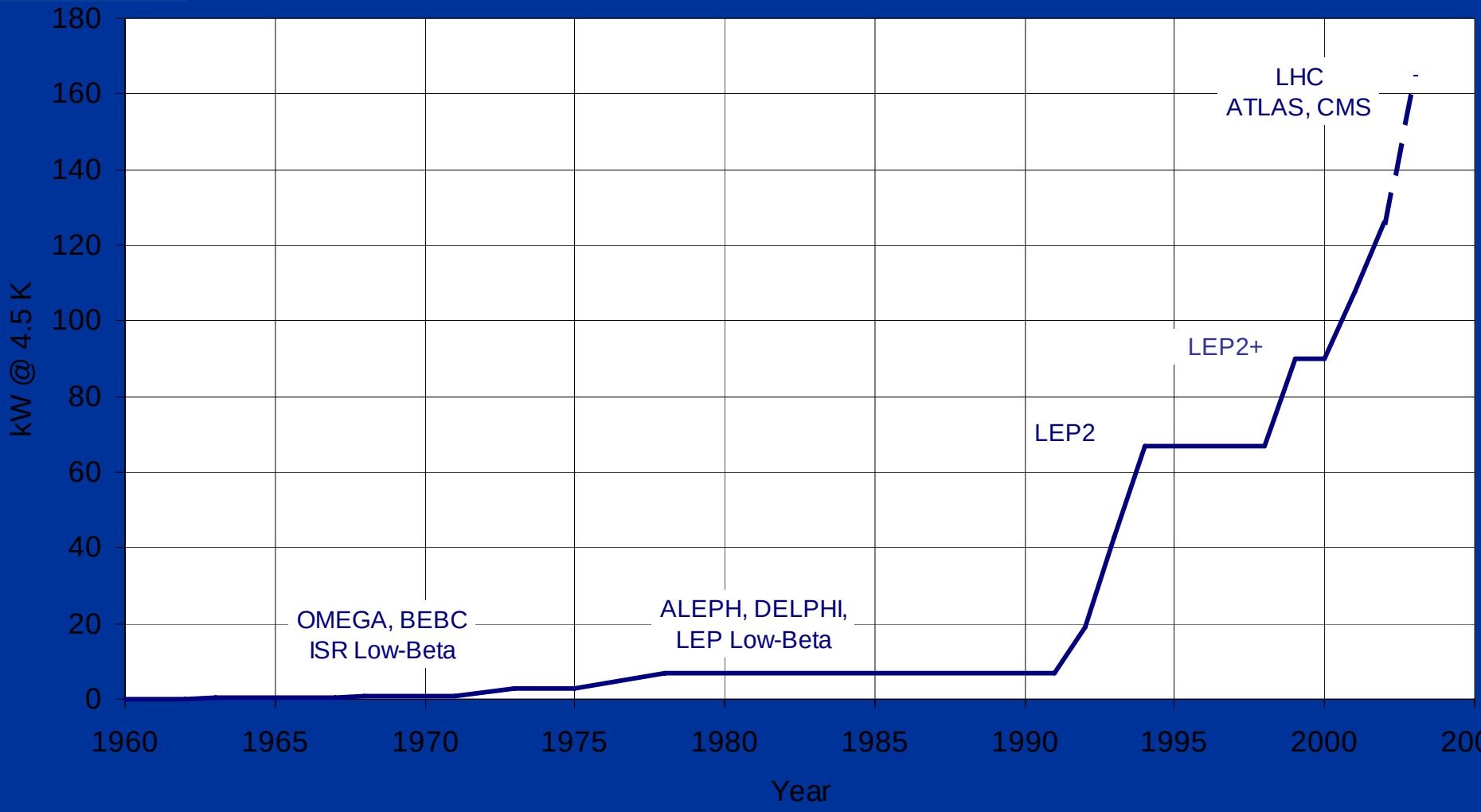
Cryogenics for Accelerators

•1975 ISR (Intersection Storage Ring); superconducting Low-Beta focusing magnets.

•1989 LEP; Cooling of the superconducting Low-Beta focusing magnets at the intersection points of the four experiments L3, ALEPH, OPAL, DELPHI
•1994 LEP2; superconducting accelerator cavities for energy upgrad. Four refrigerators 12 kW @ 4.5K
•1999 LEP2+ ; further energy upgrade with increased cooling capacity. In total 256 superconducting cavities.

•For the LHC 27 km circumference superconducting collider refrigeration capacity Eight refrigerators 18 kW @ 4.5K. (in commissioning phase)

Evolution of Cryogenic Refrigeration Capacity at CERN



The largest helium refrigeration center in the world!

Courtesy by Ph. Lebrun

The Cryogenic Groups

Accelerator Technology Department (AT)

Head Ph. Lebrun

Cryogenics for Accelerators (ACR)

GL Laurent Tavian

41 CERN personnel

+ industrial contracts for construction, operation, maintenance

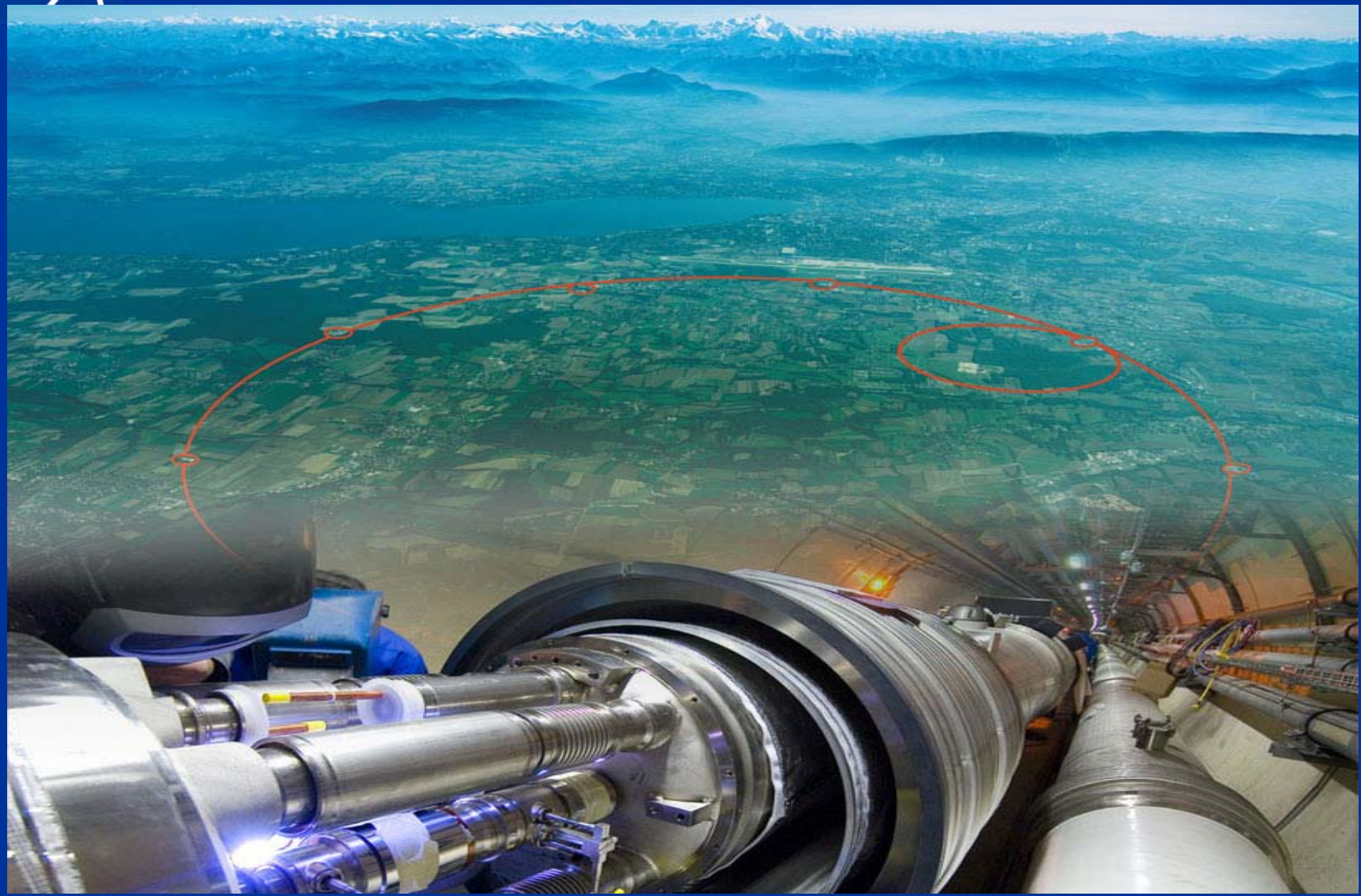
Cryogenics for Experiments (ECR)

GL Giorgio Passardi

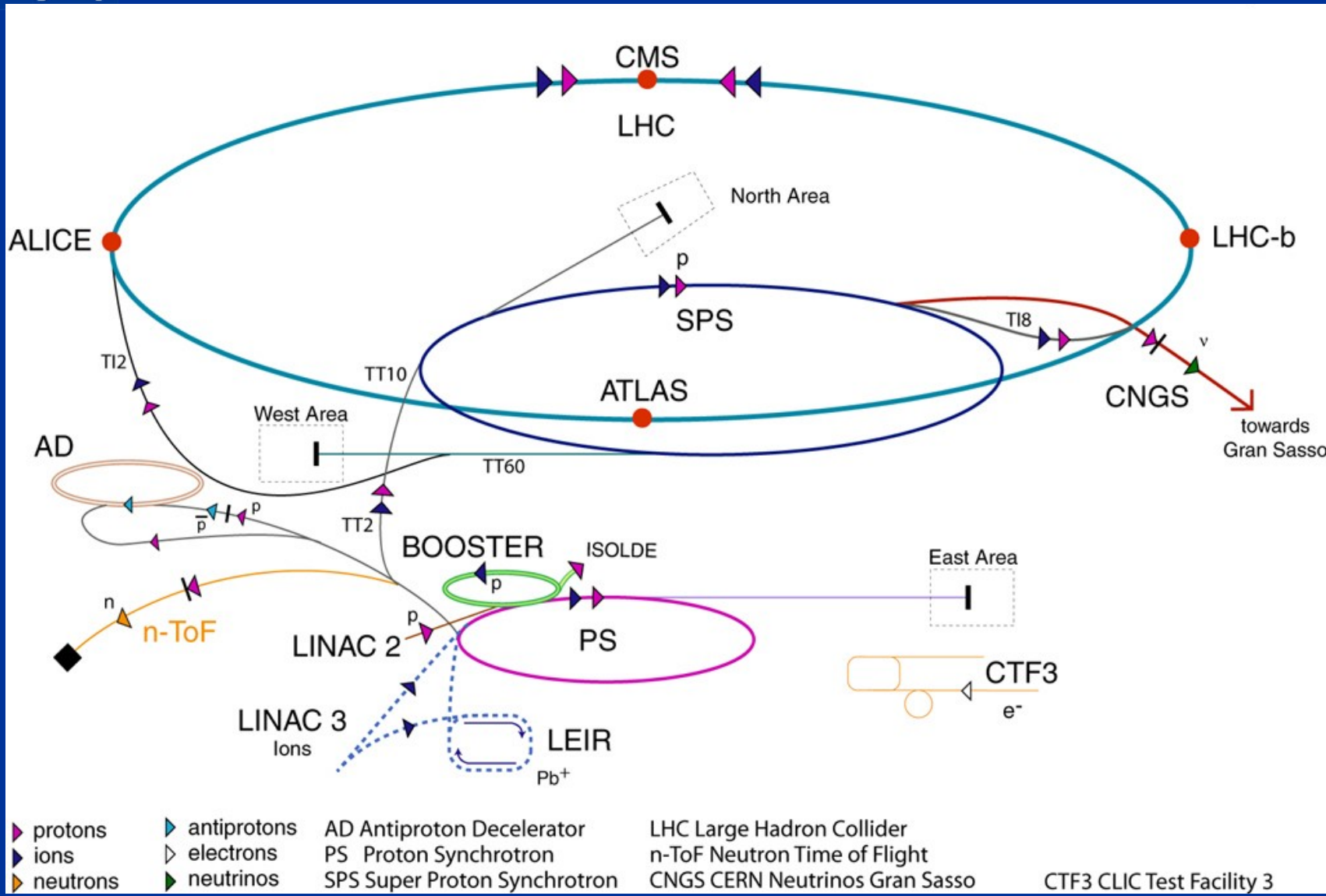
32 CERN personnel

+ industrial contracts for construction, operation, maintenance

Cryogenics for the LHC Collider



The CERN Accelerator Network



Overall Lay-out of the LHC with Detectors

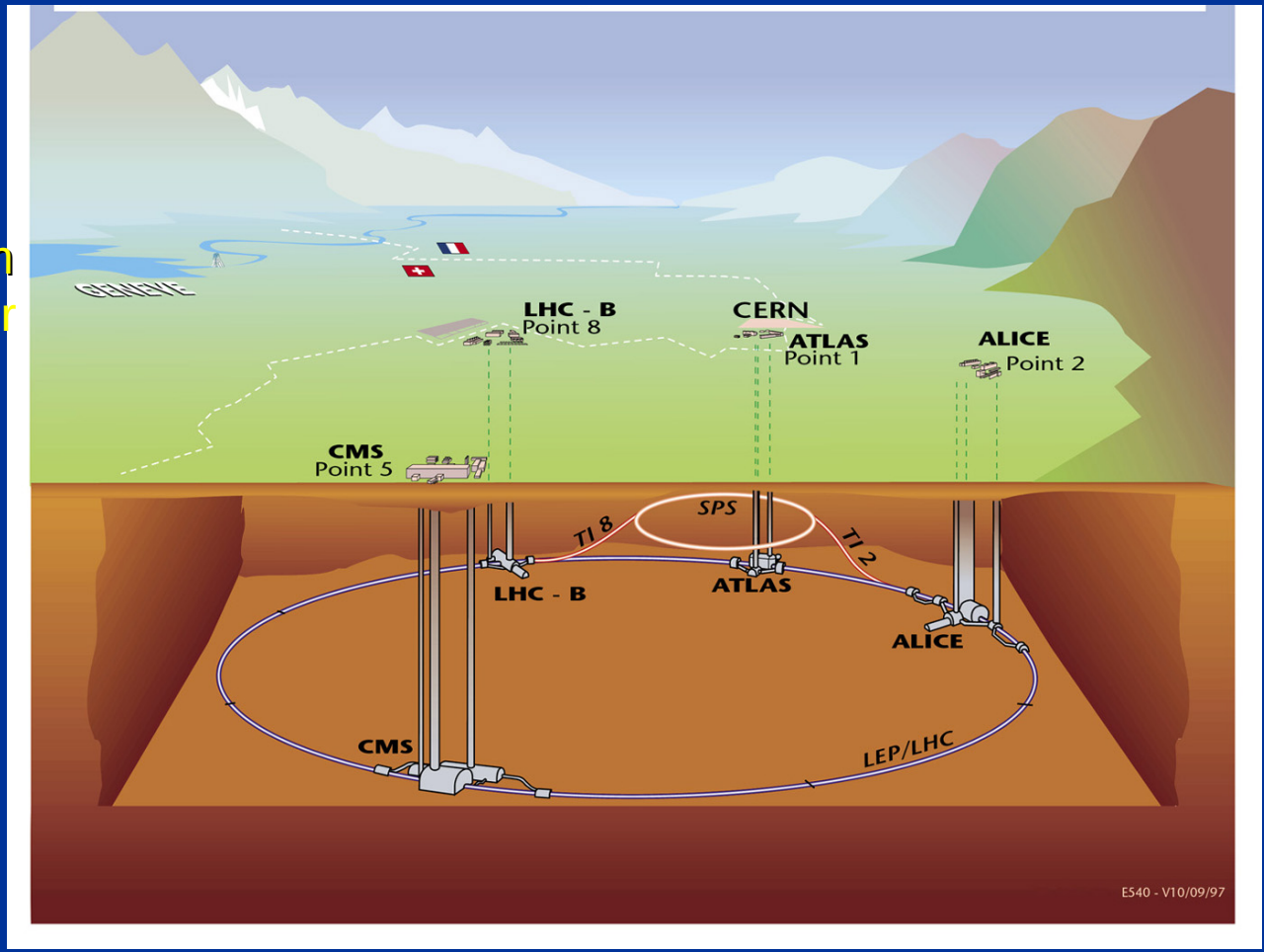
LHC – “Large Hadron Collider”.

Collision machine installed in the 27 km circumference former LEP underground tunnel

Acceleration of protons and heavy ions

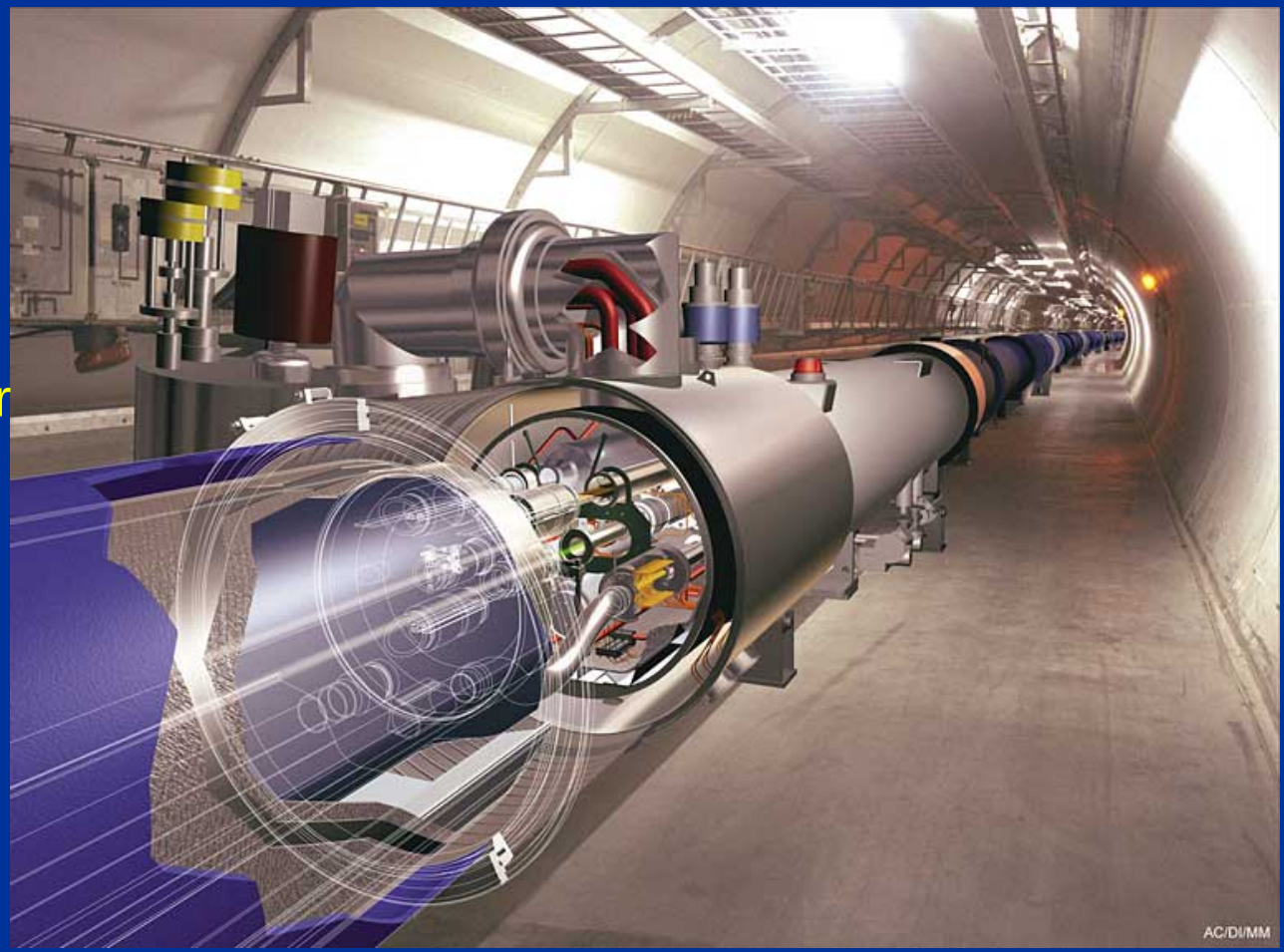
Proton / proton collisions at 7 TeV / 7 TeV

Four large detector experiments



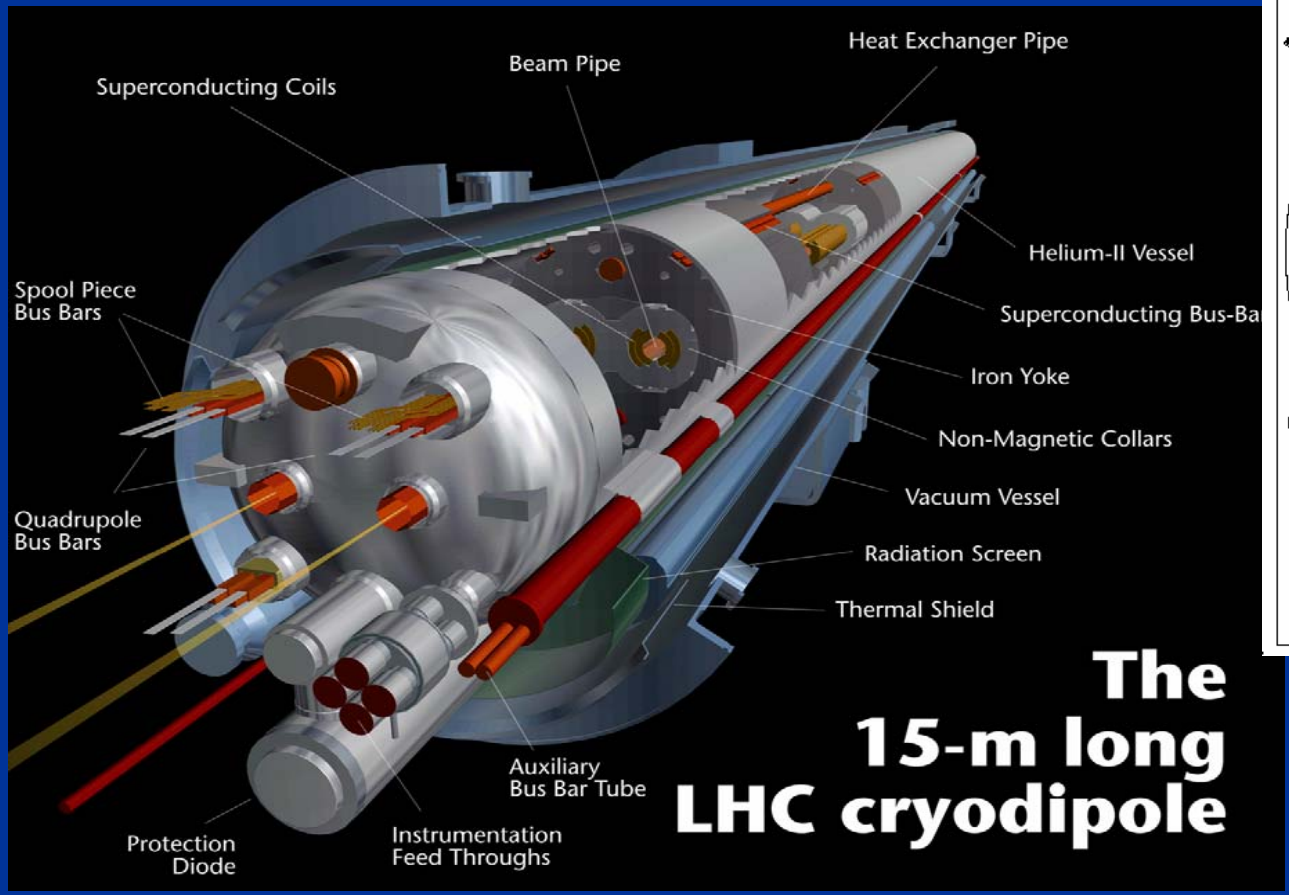
Lay-out of the LHC Collider

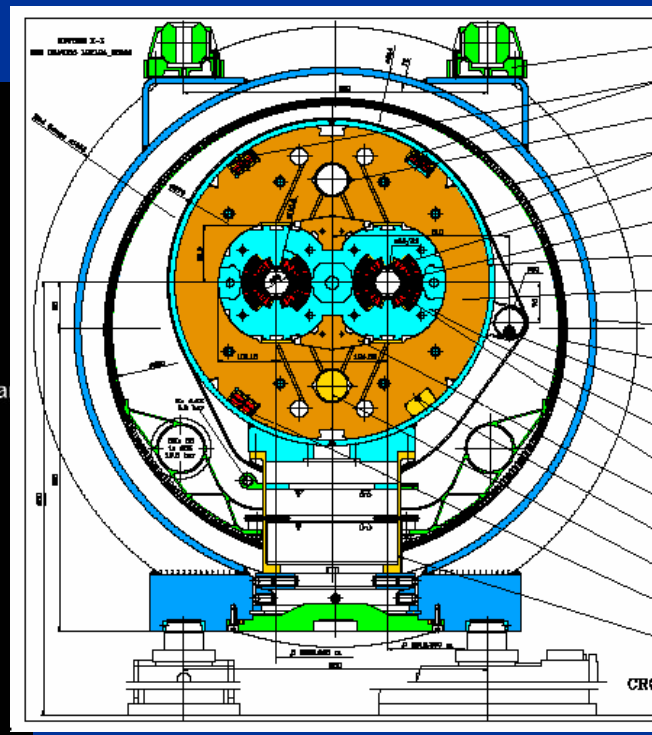
- Approx. 1800 superconducting magnets operating at 1.9 K
- Distribution transfer line
- Particle beams circulate counter-rotating in two separate vacuum beam pipes



Artists view of the LHC tunnel

The Dipol Magnets





Cross section of a dipol and cryostat.

The «bending » dipole magnets keep particle beams on their trajectory.

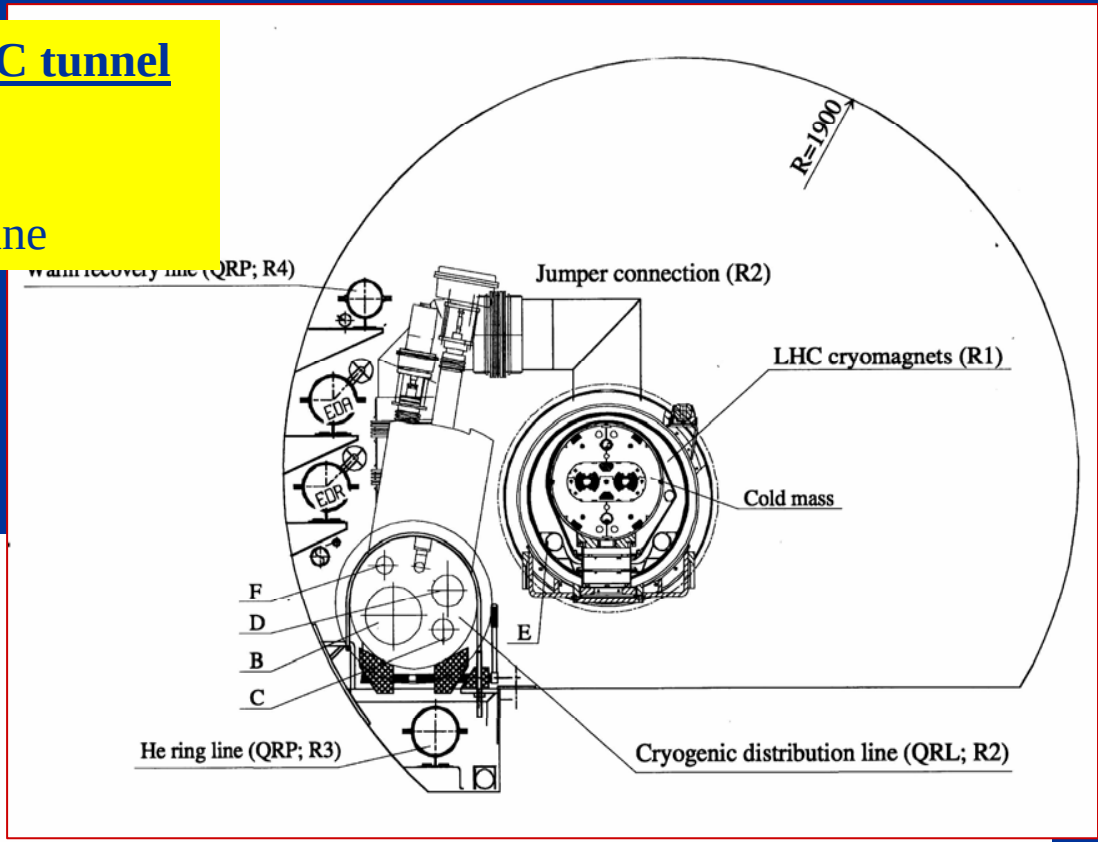
Lay-out of the LHC Collider

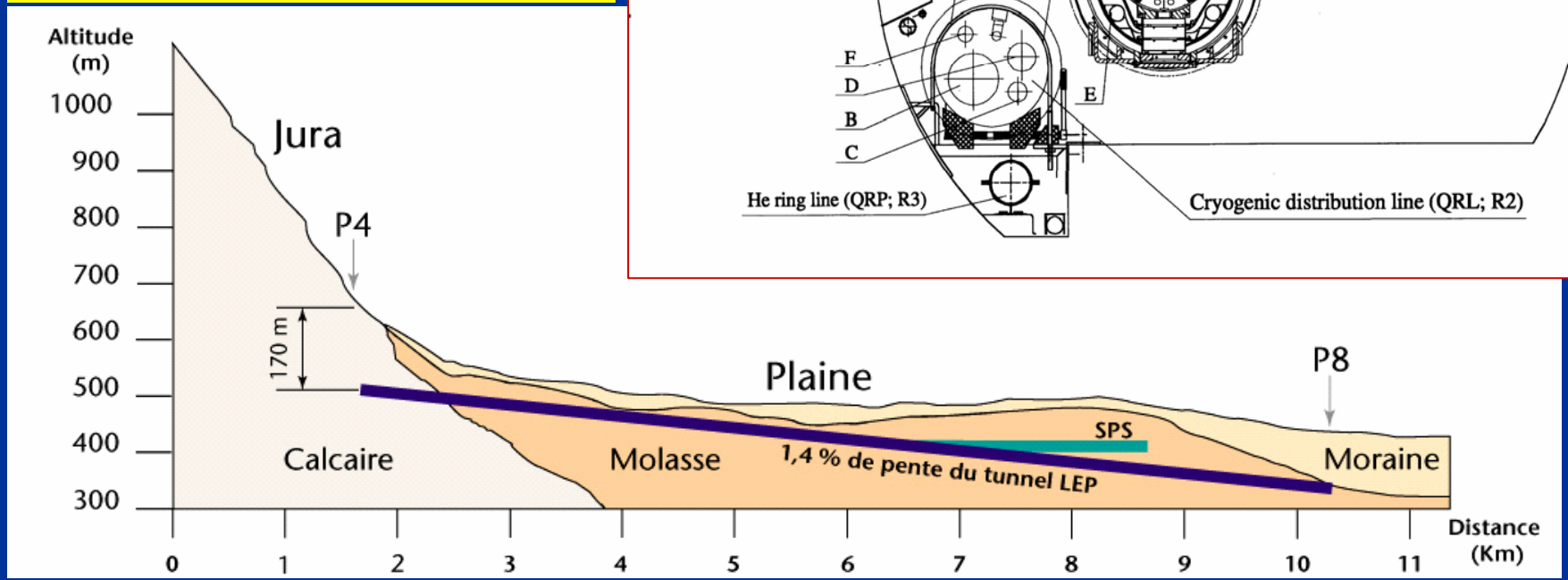
Cross section of the LHC tunnel

- 3.8 m diameter tunnel
- LHC Cryo-magnets
- Cryogenic distribution line

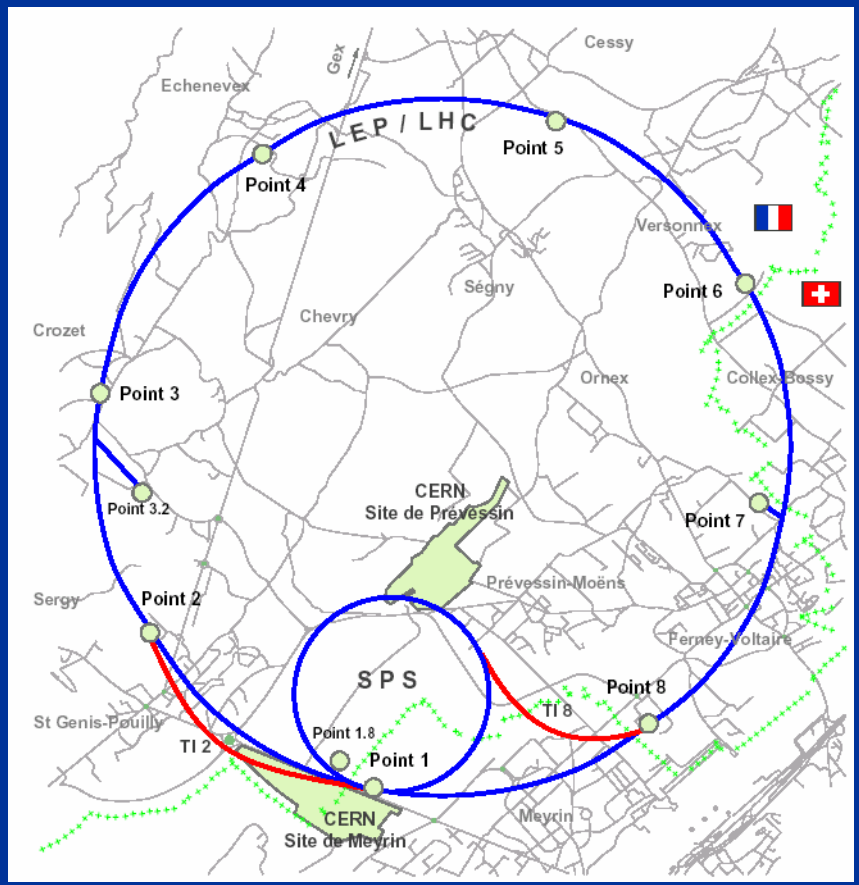
LHC tunnel

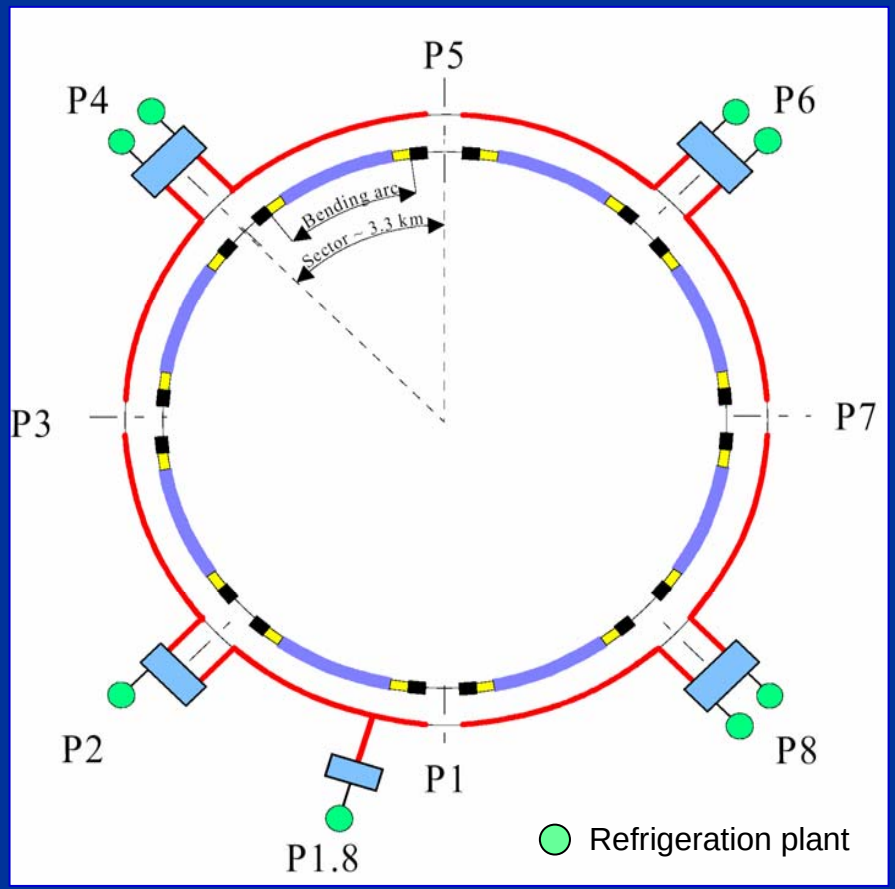
- deep underground
- 1.4 % slope of the tunnel





Distribution of Cryogenic plants





8 Cryogenic plants provide the cooling capacity for the superconducting magnets. One for each arc of 3.3 km length .

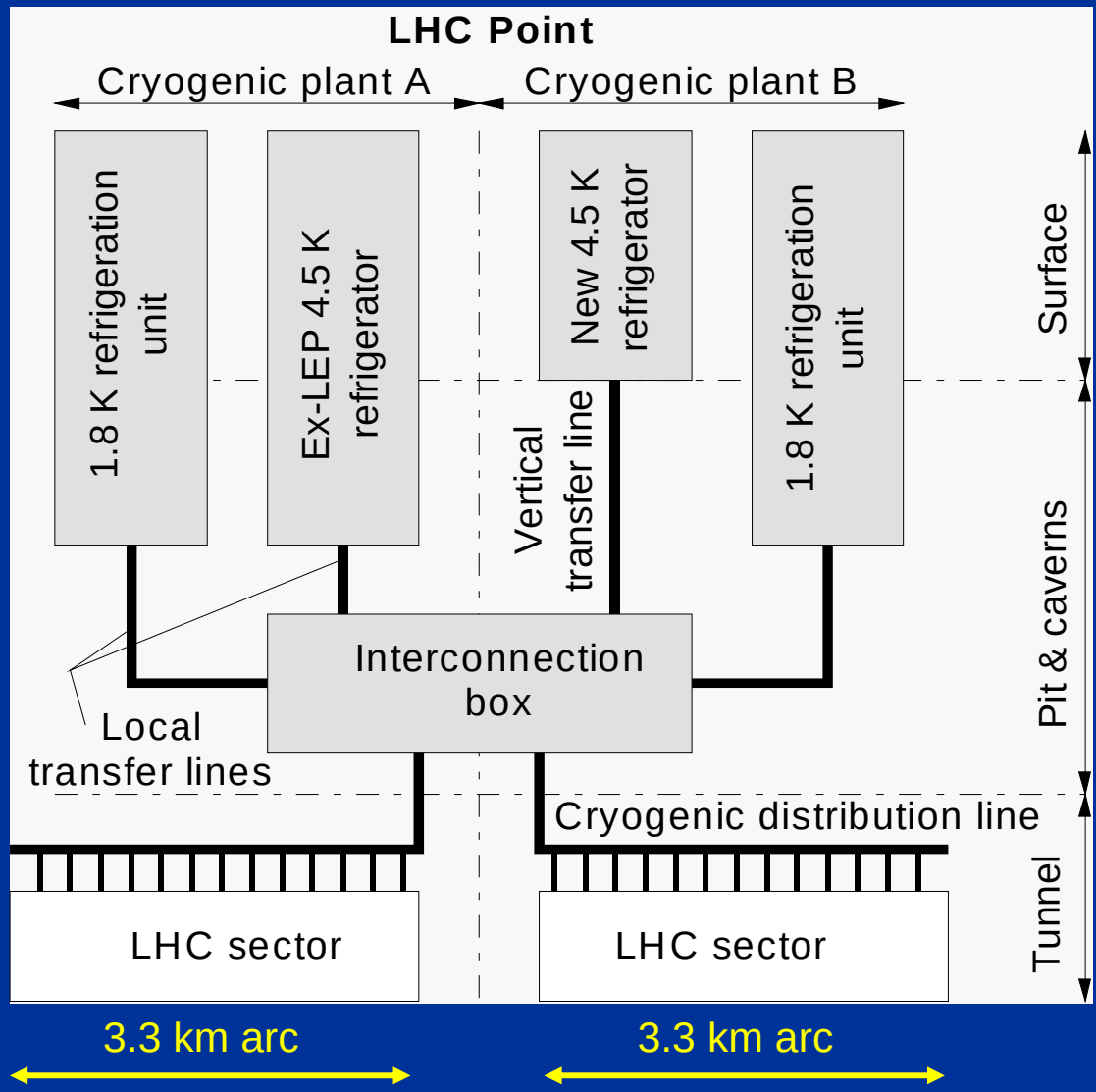
Cryogenic architecture at a LHC point

The cryogenic plants comprise each a 4.5 K refrigerator and a 1.8 K refrigeration unit installed in surface buildings and, underground in pits and caverns. Links via large transfer lines.

The interconnection box distributes the cryogen to and from the magnet via the cryogenic distribion line

This cryogenic architecture is valid for points 4,6,8 only. (Points 2 and 1.8 are different)

The difference between A plant and B plant derives from the adaption of the former 12 kW LEP refrigerators for re-use at LHC and new units.



The 18 kW @ 4.5K Refrigerators

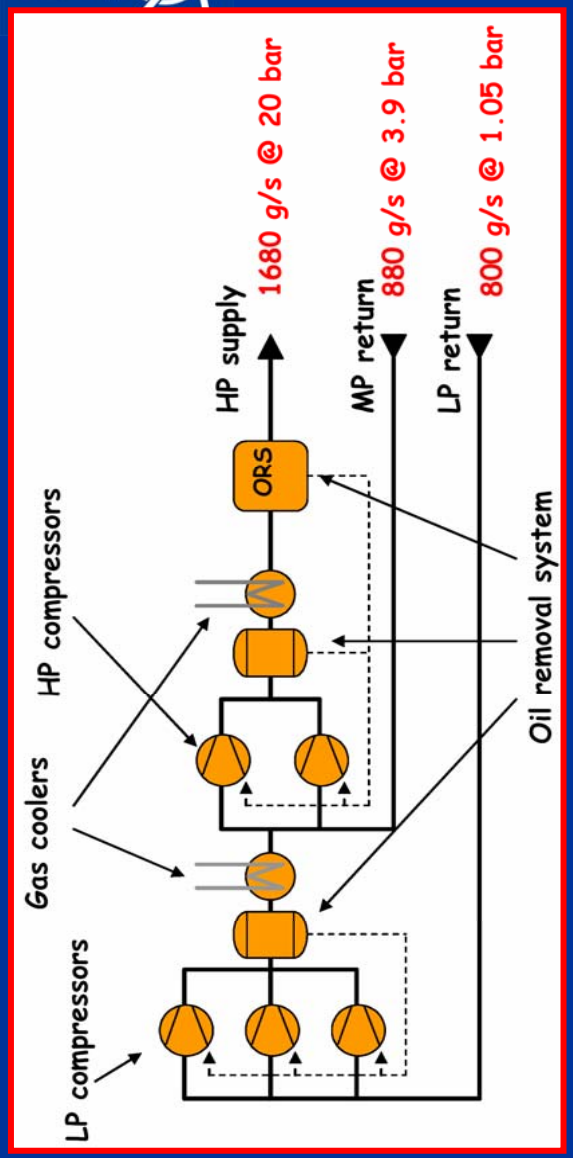
Specific refrigeration capacity
33 kW @ 50 K to 75 K
23 kW @ 4.6 K to 20 K
41 g/s liquefaction (current leads)

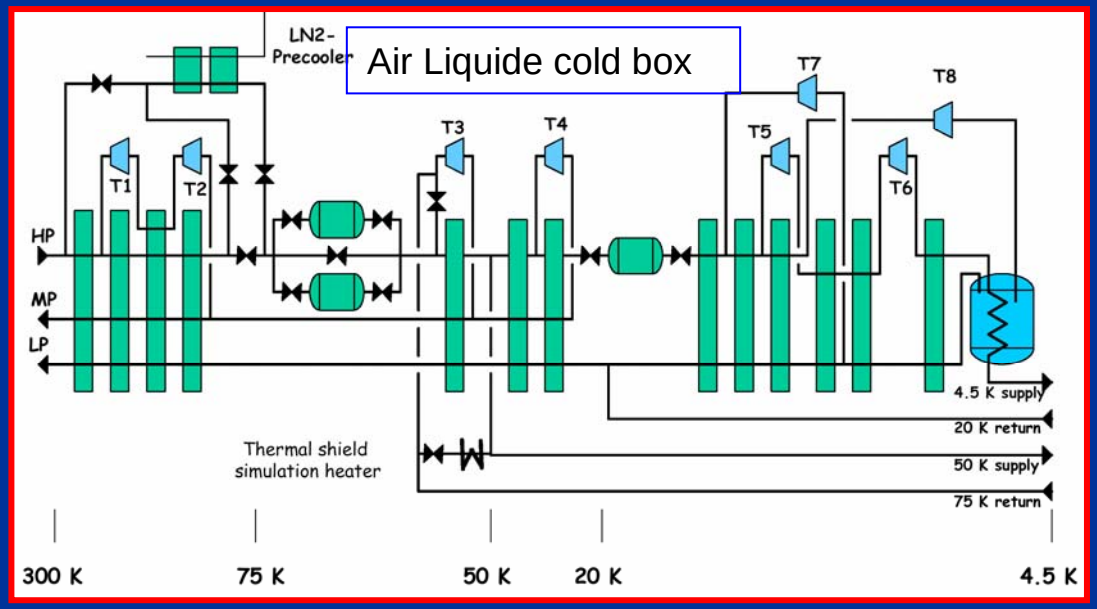
Warm compressor station (4 MW el. input)

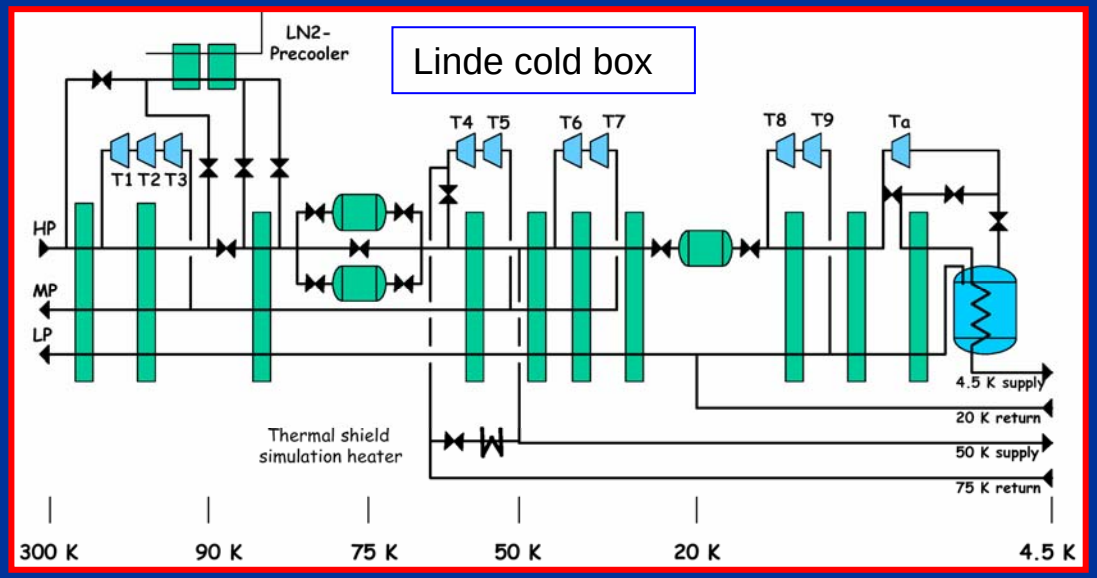
Air Liquide cold box

Linde cold box

Process cycle of the 18 kW @ 4.5K cryoplants

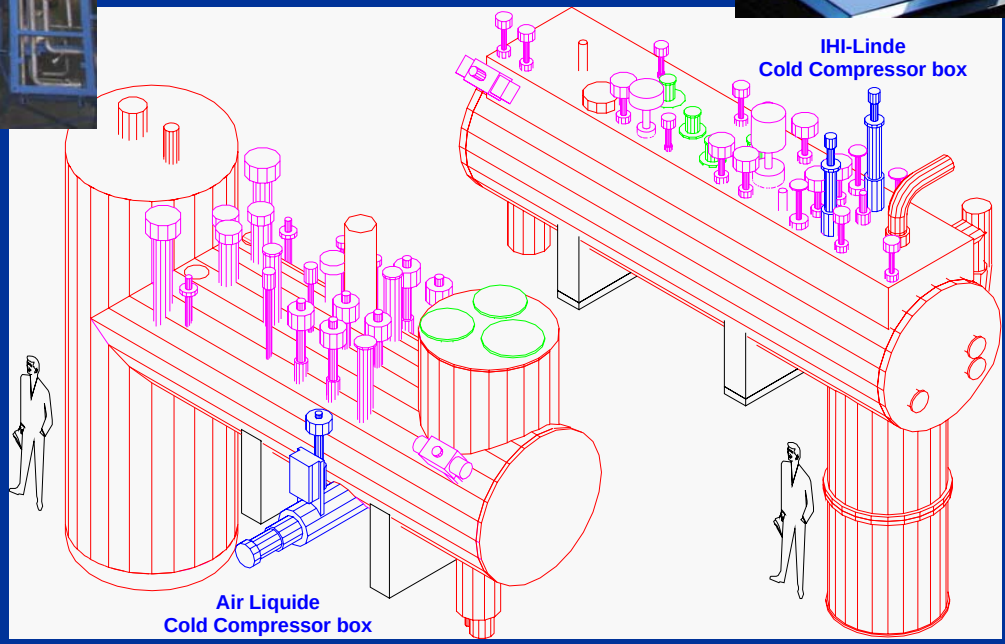






1.8 K Refrigeration cold boxes

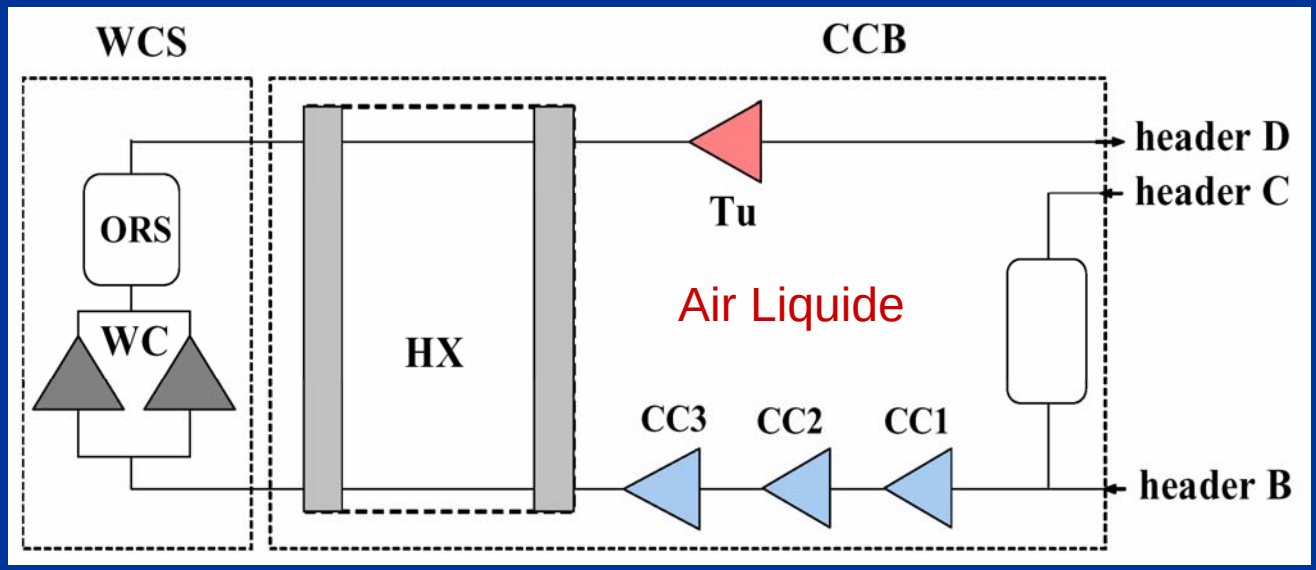
- 1.8 K cold boxes (Air Liquide, IHI-Linde) with
- cold compressor units

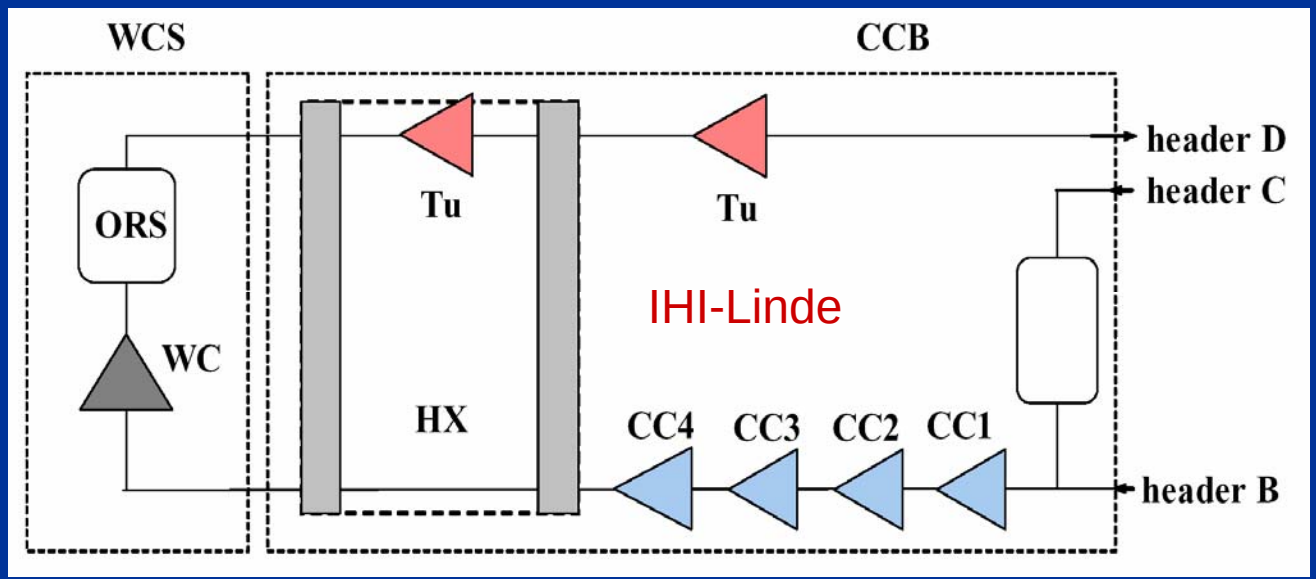


1.8 K Refrigeration cycles

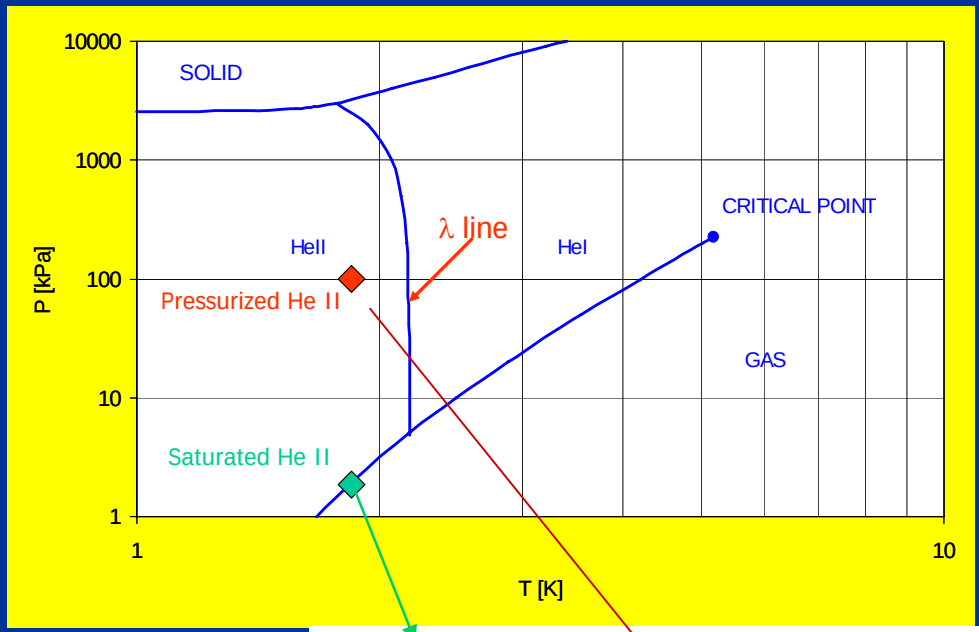
The 1.8 K refrigeration is produced by pumping on a superfluid helium bath heat exchanger in the magnets reducing its boiling pressure to 15 mbar.

Compression is done with cold and warm compressors



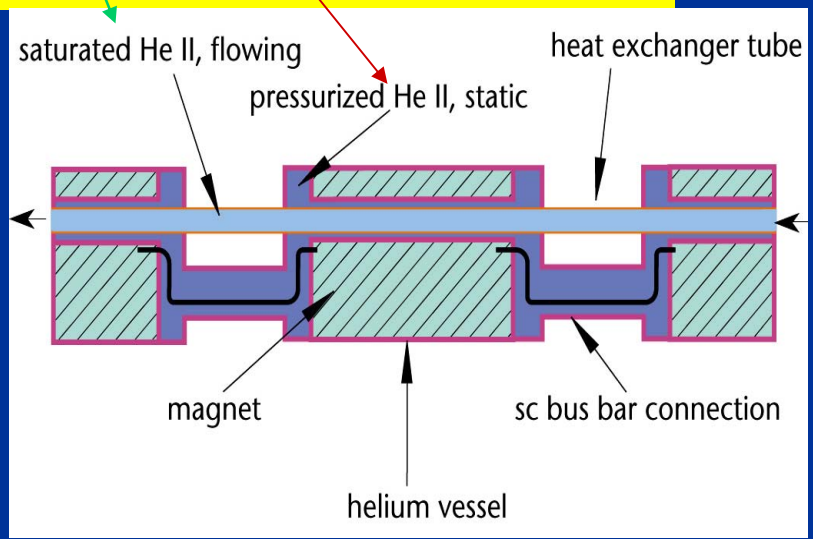


The magnets cooling principle



The magnet cold mass are immersed in a static superfluid helium bath

Cooling via a heat exchanger tube with saturated helium boiling under reduced pressure (15 mbar).

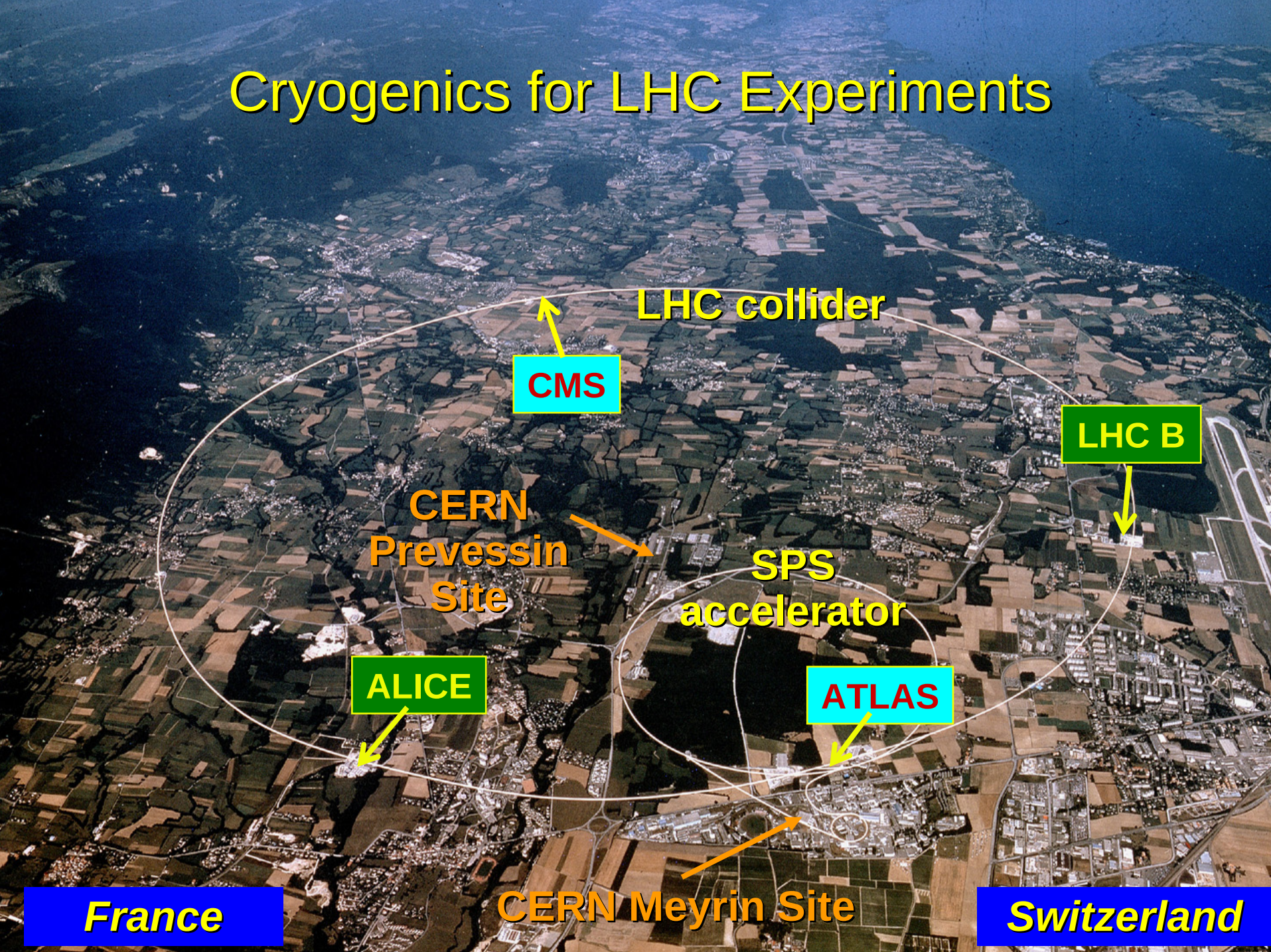


Extraction of vaporized helium by cold and warm compressors of the 1.8K refrigerator

Summary of main characteristis

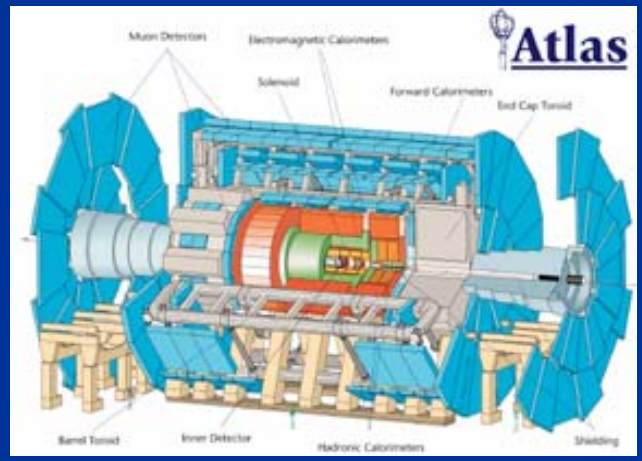
- 27 km circumference superconducting collider with 1800 magnets at 1.9 K
- Eight 4.5 K refrigerators
- Eight 1.8 K refrigerators
- Complex cryogenic process at very large scale
- A complex distribution system with transfer lines « around » the tunnel
- 800.000 liters of liquid helium in magnets and cryo-systems

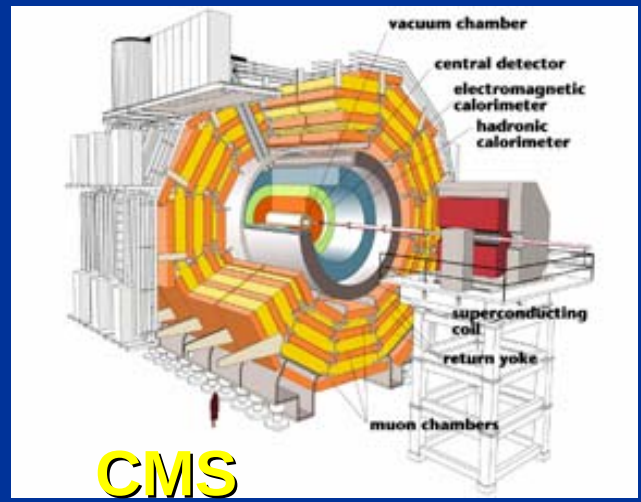
Cryogenics for LHC Experiments

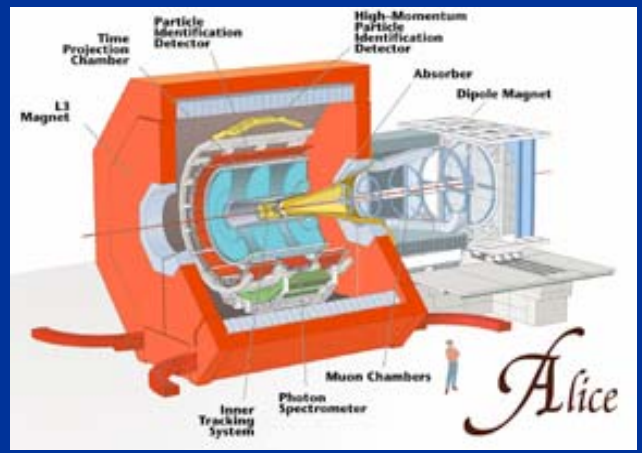


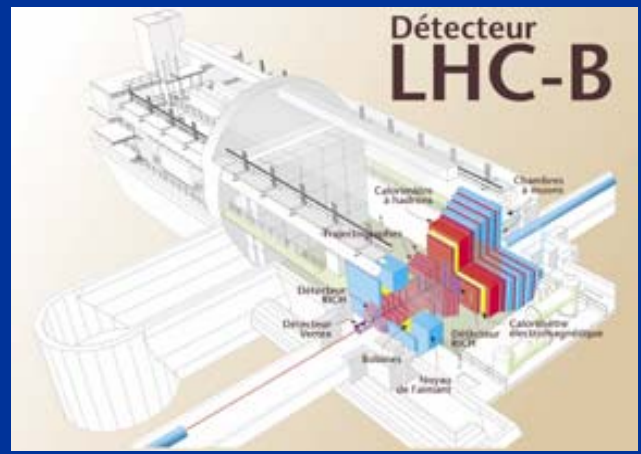
LHC Experiments

Two of the four detector experiments use cryogenic technology for their particle spectrometrie

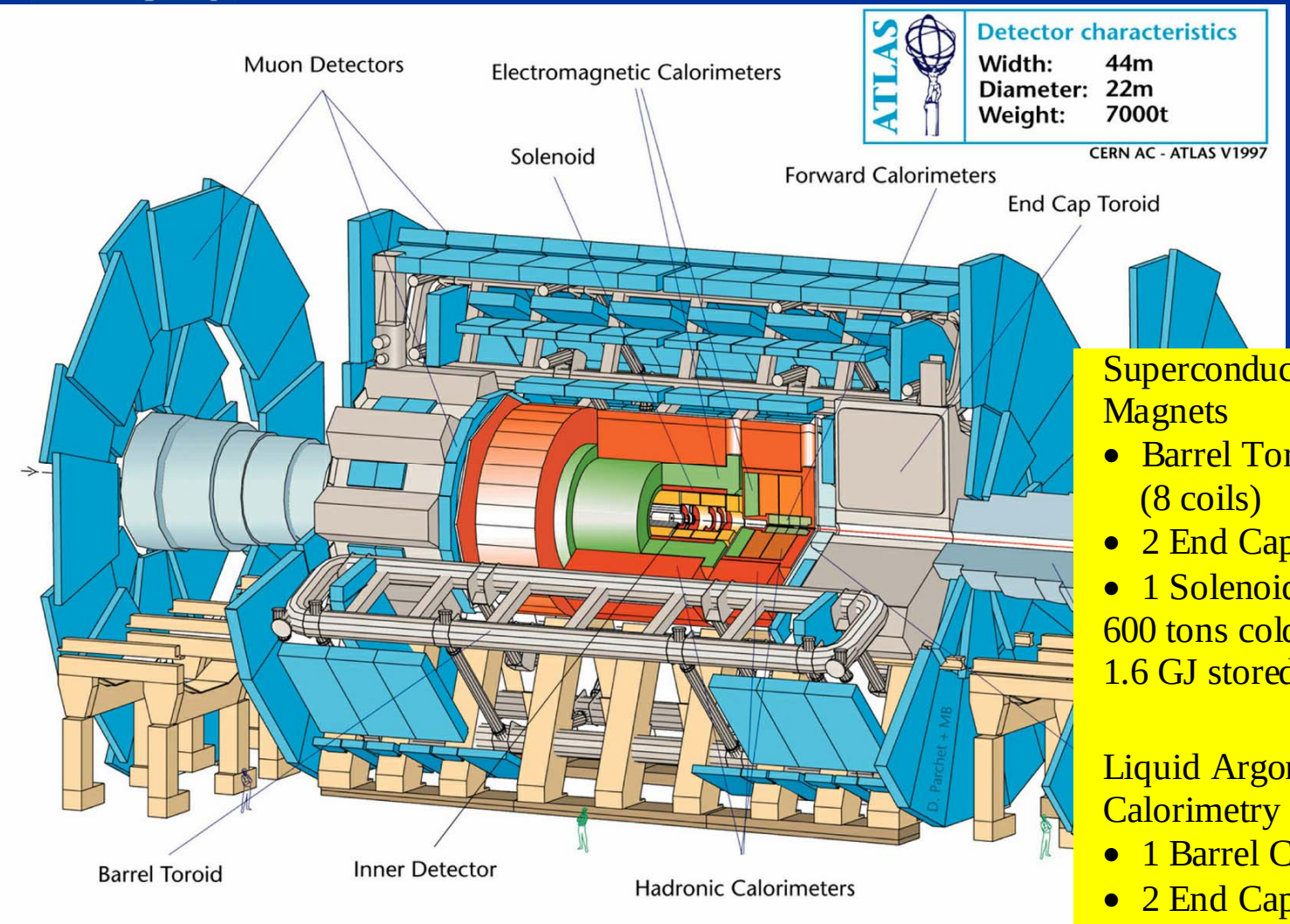








ATLAS and Cryogenics



Superconducting Magnets — Helium Cryogenic Systems

- Barrel Toroid (8 coils)
- 2 End Cap Toroids
- 1 Solenoid

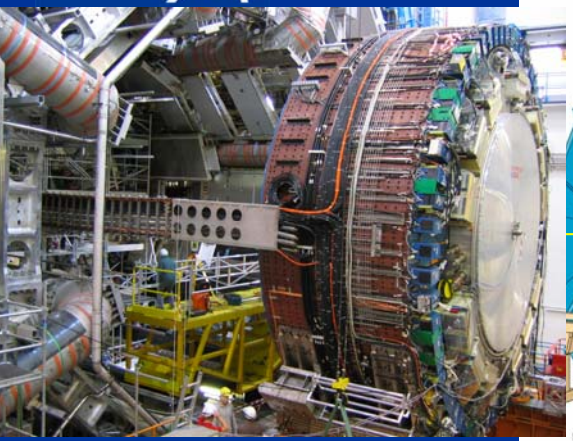
600 tons cold mass
1.6 GJ stored energy

Liquid Argon Calorimetry — Nitrogen & Argon Cryogenic Systems

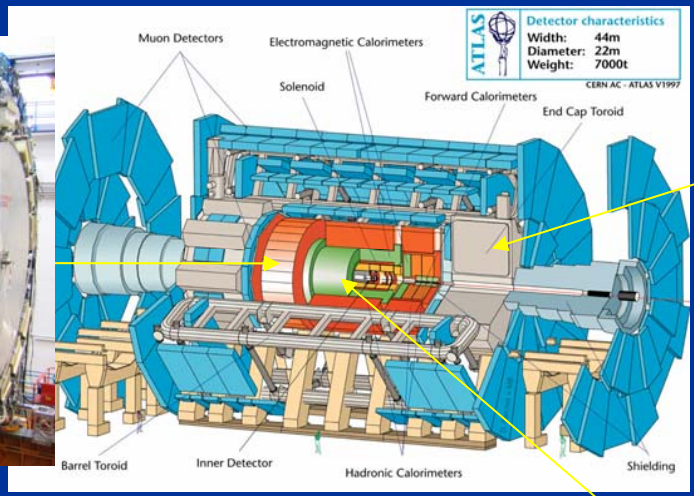
- 1 Barrel Cryostat
- 2 End Cap Cryostats

600 tons cold mass
82 m3 liquid Argon

The magnets and Liquid argon calorimeters

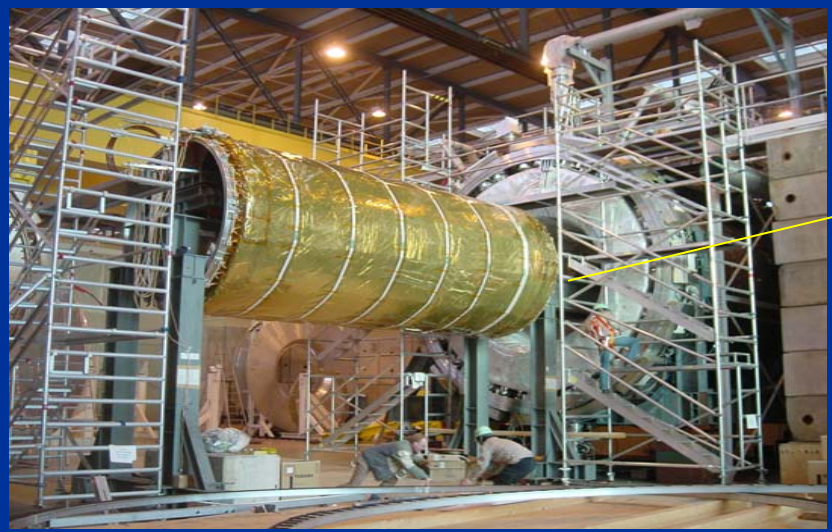


End Cap calorimeter during integration



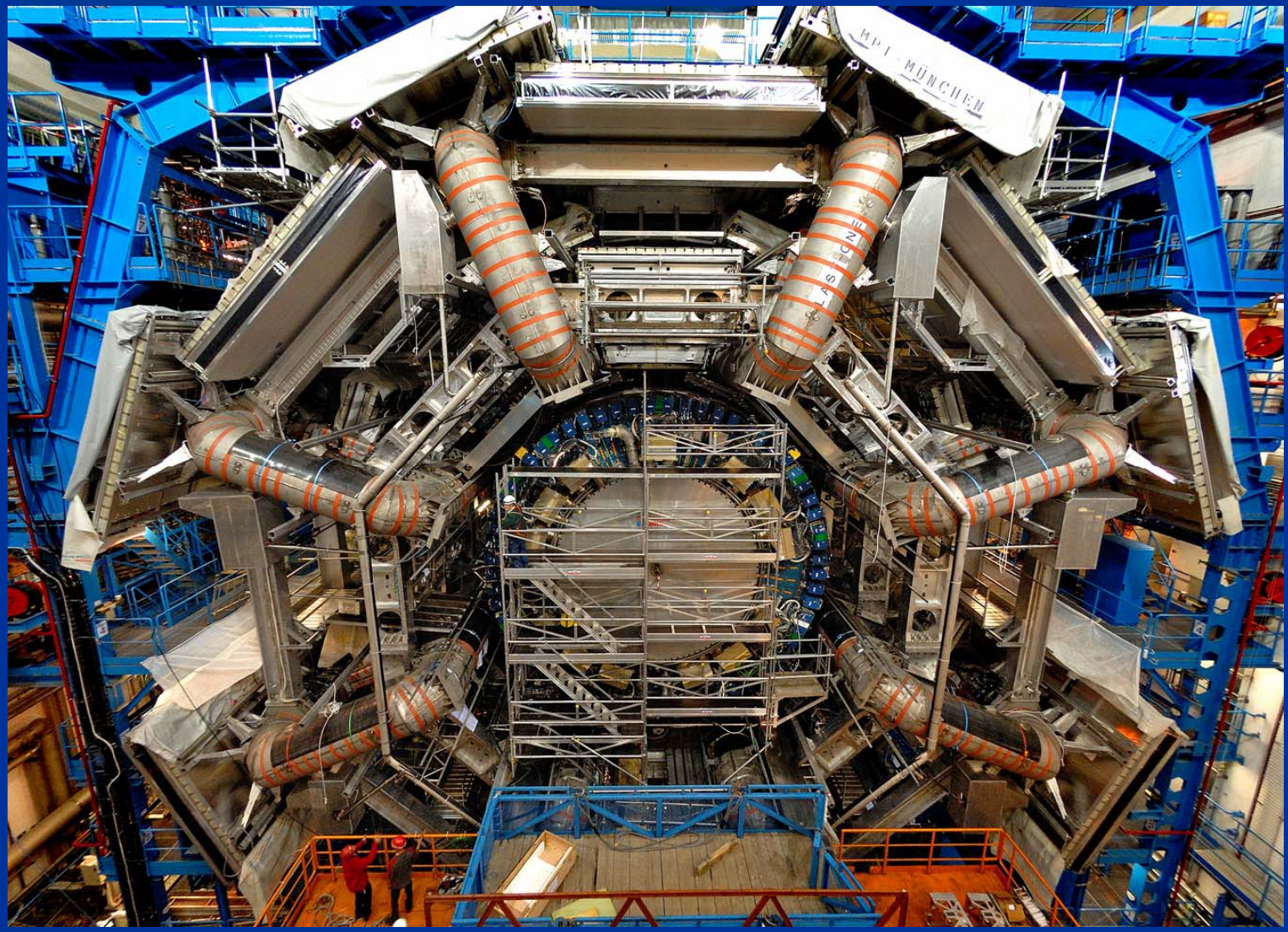
End Cap Toroid magnet (assembly)

Central Solenoid during integration in the common cryostast of the Liquid Argon Barrel detector at hall 180



Liquid argon barrel calorimeter cryostat during lowering in the pit

The magnets and helium cryogenics



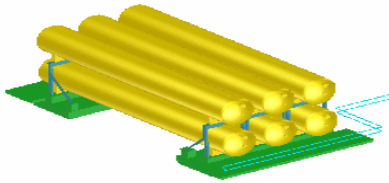
Barrel Toroid; The eight coils assembled form a barrel with length 25 m and diameter 20 m.

Cryogenic Systems Lay-out at ATLAS

Underground detector cavern,

Underground technical side cavern

Warm Helium gas storage (6x250m3)

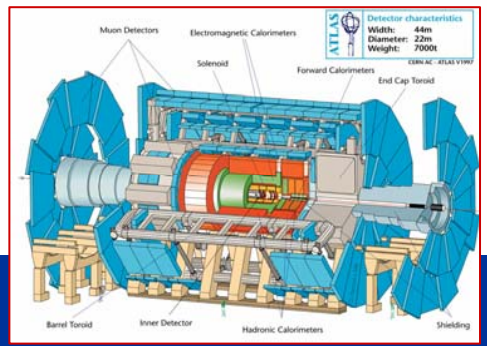


3 Compressor units on surface

LN2 dewars

3 Refrigerators

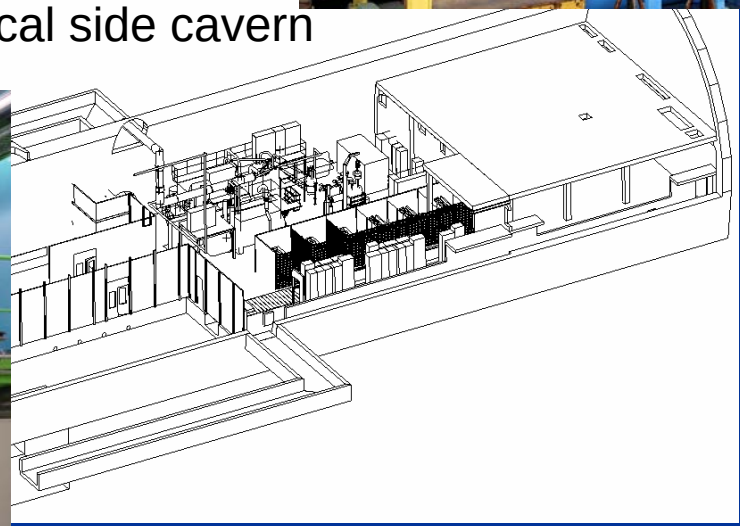
Proximity Cryogenic Systems for the magnets and calorimeters



The 3 refrigerators

Shield refrigerator (20 kW @ 40-80K and 60 kW for cool down from ambient)

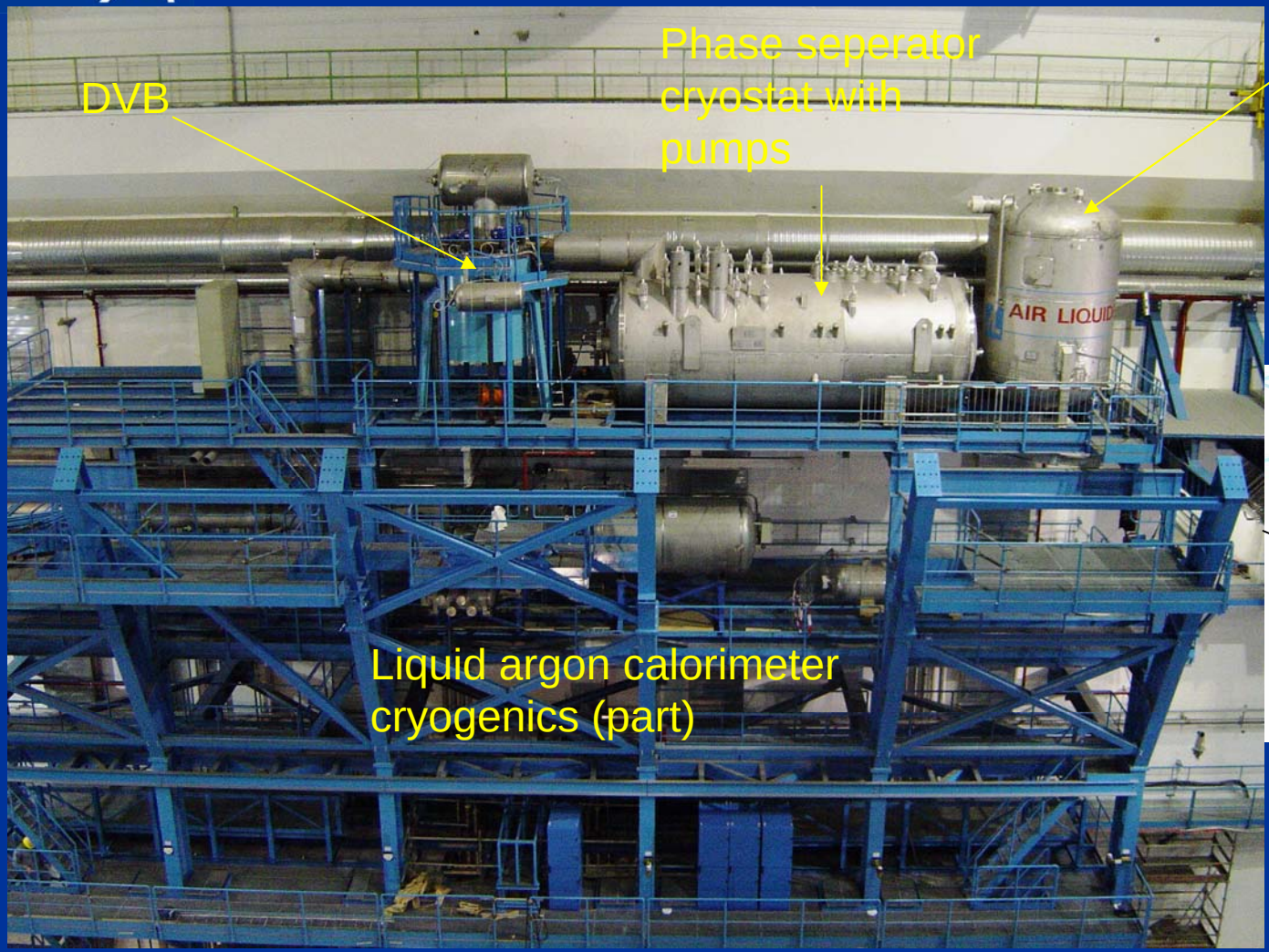
Technical side cavern

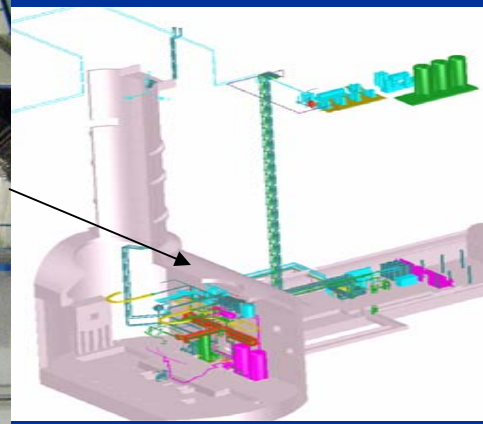


Main refrigerator (6 kW @ 4.5K)

LN2 refrigerator (20 kW @ 80 K)

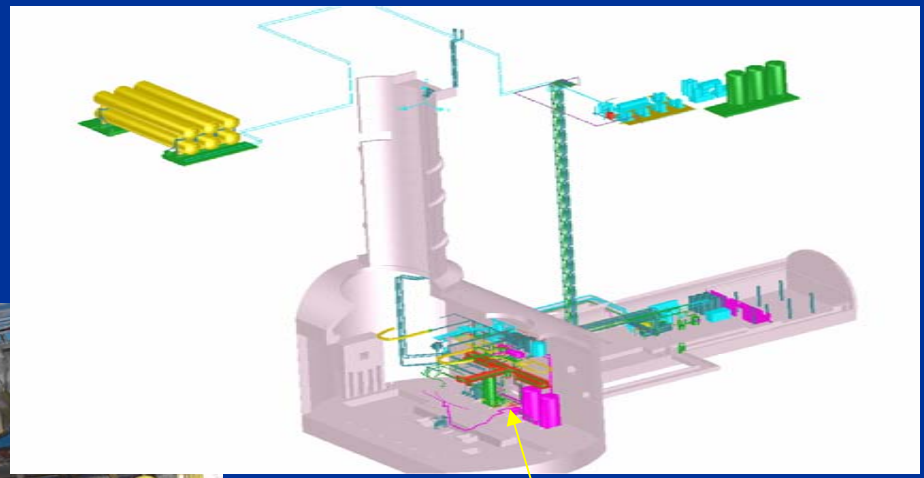
The proximity cryogenics





The proximity cryogenics on 4 story high « wall »

The magnet and argon (proximity) cryogenics



Phase seperator cryostat for Toroids

Impeller of the 1200 g/s centrifugal liquid helium pump

Helium cryogenics

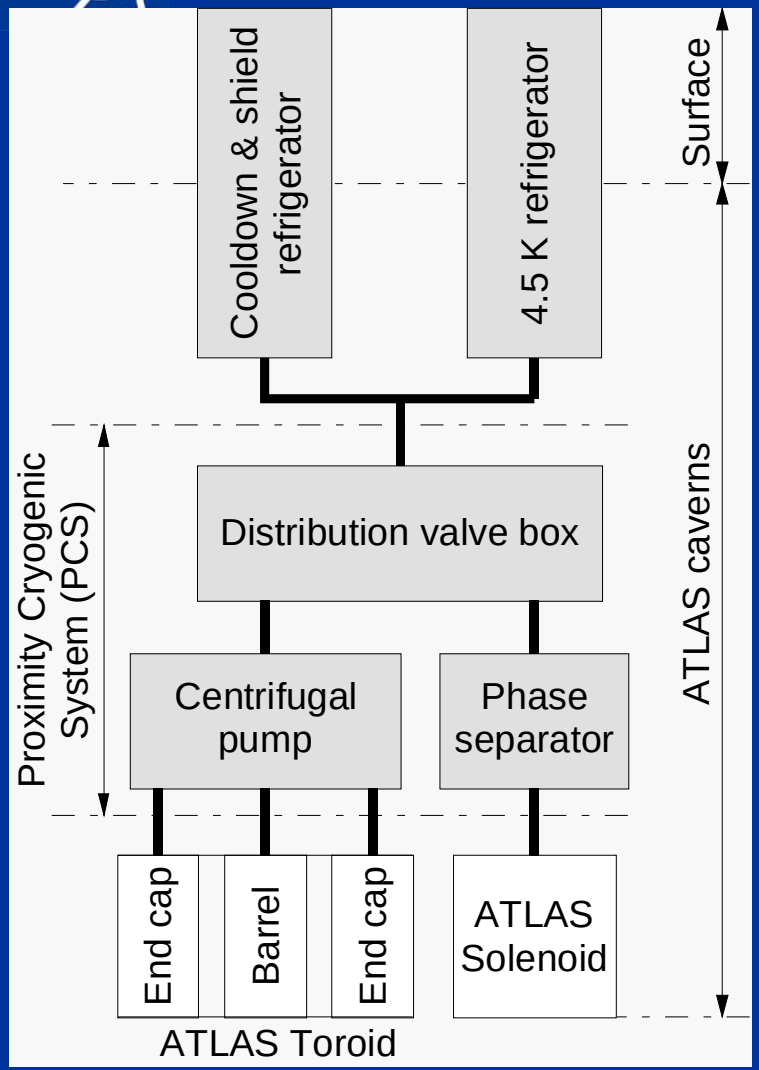
LN2 distribution system with centrifugal pumps.

2 x 50 m3 liquid argon dewars.

Argon Cryogenics

15000 liter nitrogen phase seperator

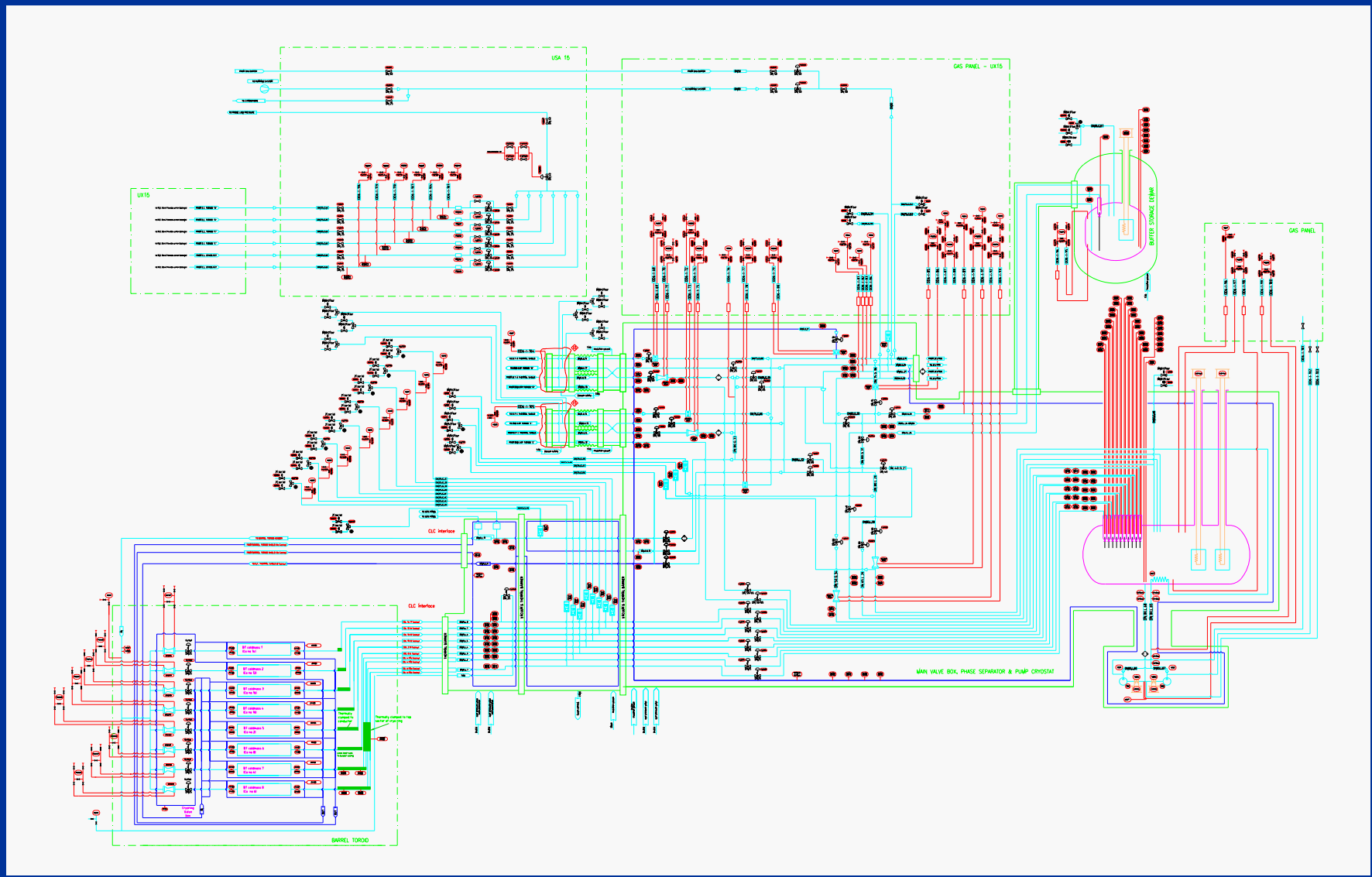
Helium Cryogenic System



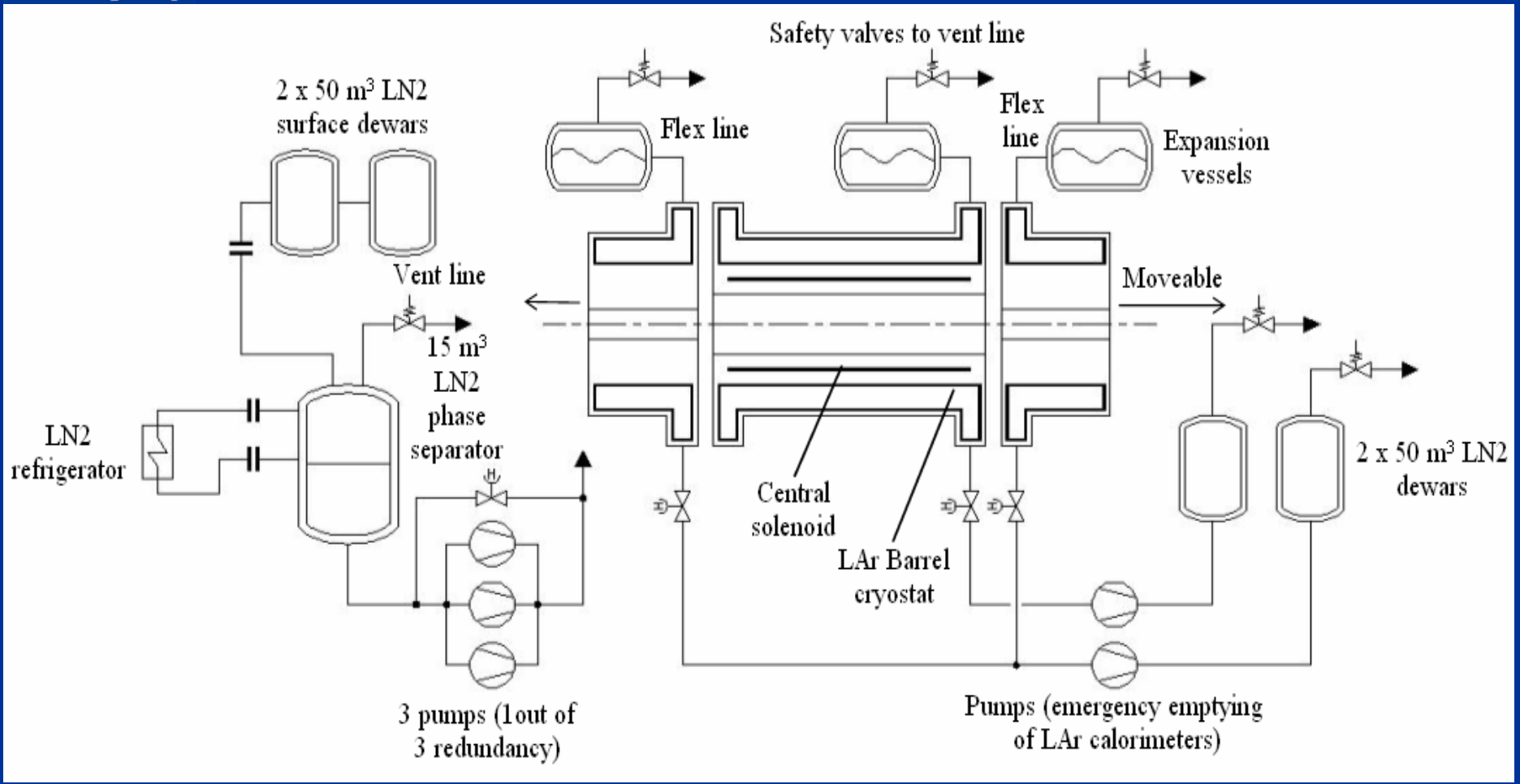
Simplified process scheme

- Main Refrigerator (6 kW @ 4.5K)
- Shield Refrigerator (20 kW @ 20 K). Serves also for cool down of the 600 tons cold mass (LN2)
- Proximity Cryogenics for the Toroid magnets with 1200 g/s centrifugal pump, phase seperator cryostat and 11000 liter of stored liquid helium for emergency discharge of the magnets (1.7 GJ stored energy)
- Proximity Cryogenics (phase seperator) for the Central Solenoid
- Two-phase flow in cooling pipes attached to cold mass (indirect cooling)

The Toroid PCS flow scheme



Liquid argon cryogenic system



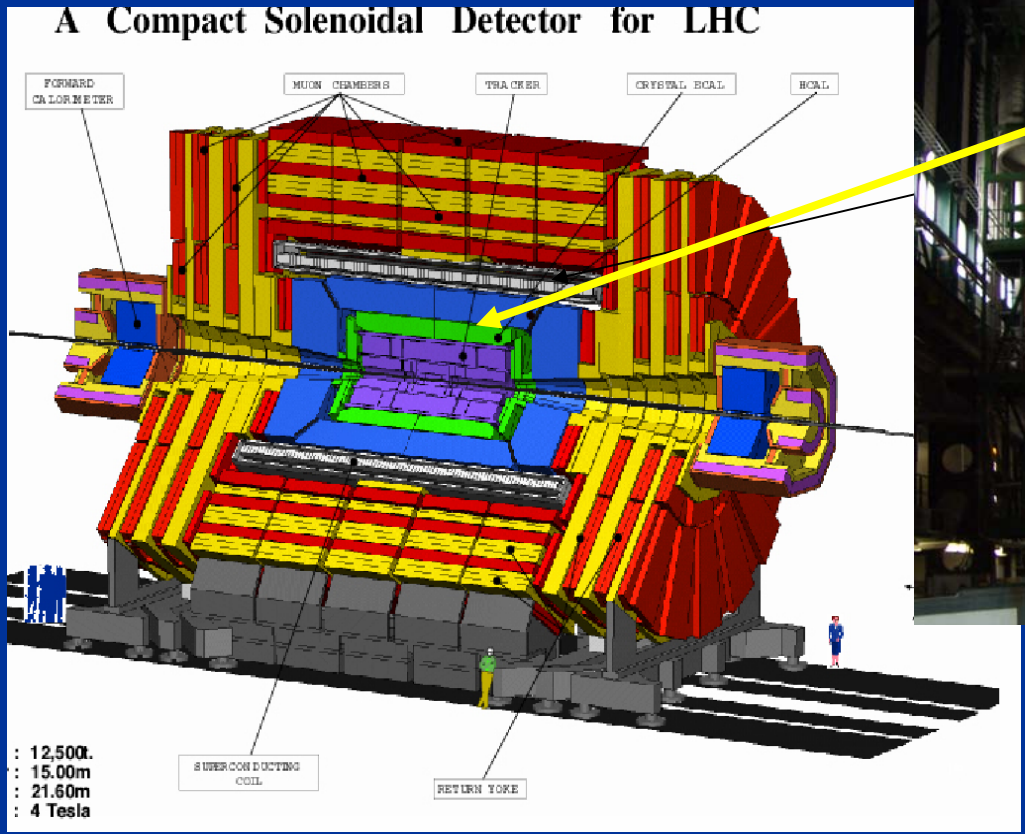
Simplified flow principle. The three cryostats contain 82 m3 of liquid argon. Permanent cooling with liquid nitrogen (either produced by refrigerator or provided via surface LN2 dewars).

The CMS detector and cryogenics

CMS = Compact Muon Solenoid

Solenoid magnet: 13 m long, 5.6 m diameter

20 kA, 4 Tesla, stored energy 2.5 GJ



Cross section of the detector

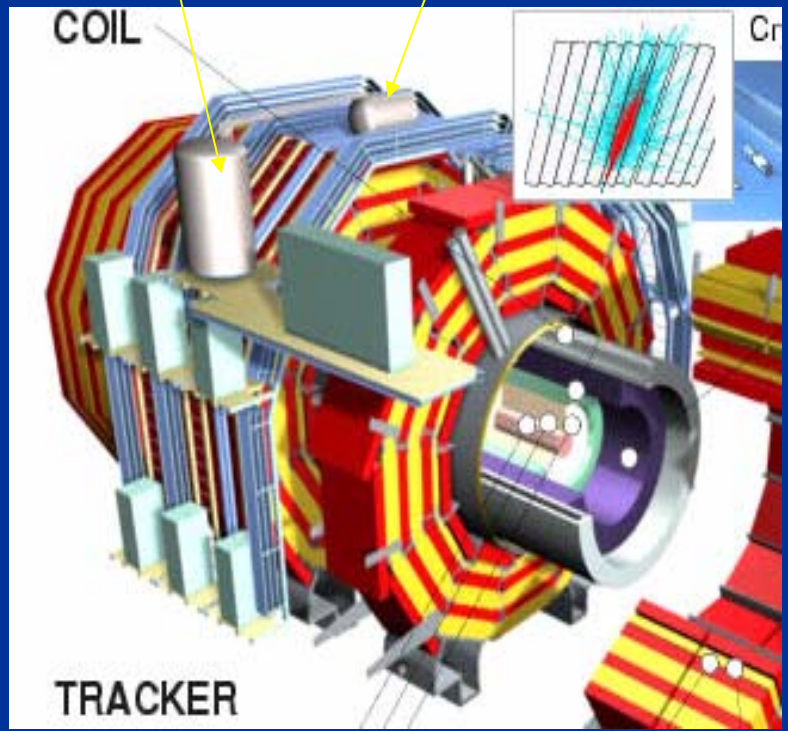
Solenoid coil during integration in cryostat

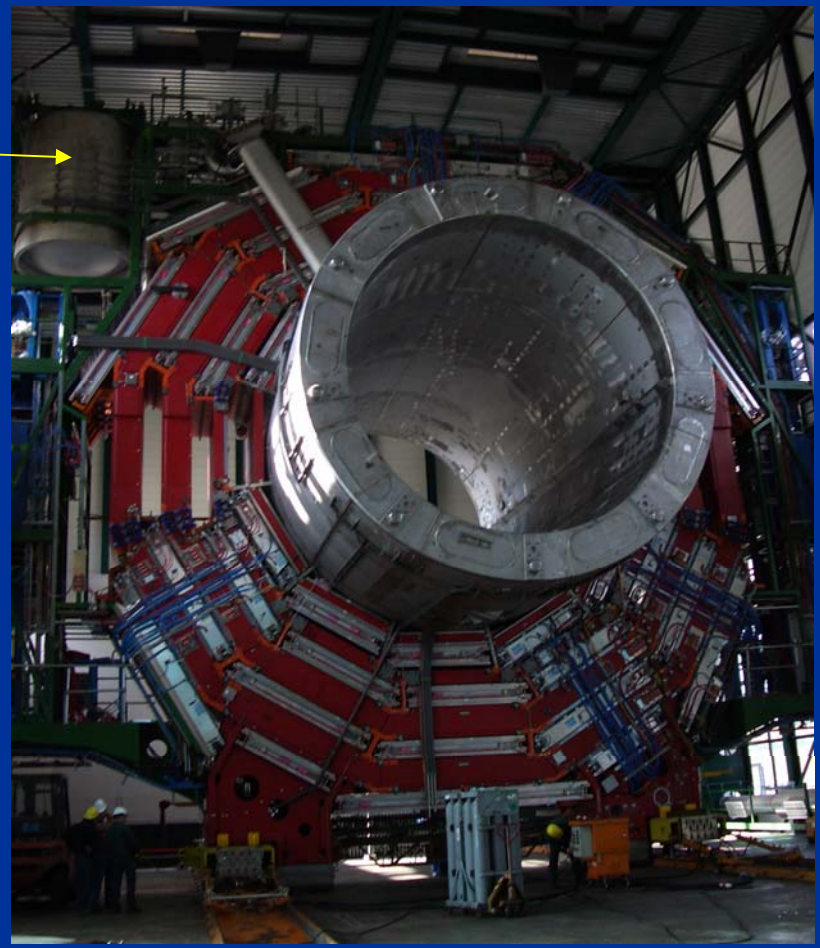
The CMS detector and cryogenics

Cooling principle: two-phase thermosyphon flow

6000 liter storage dewar

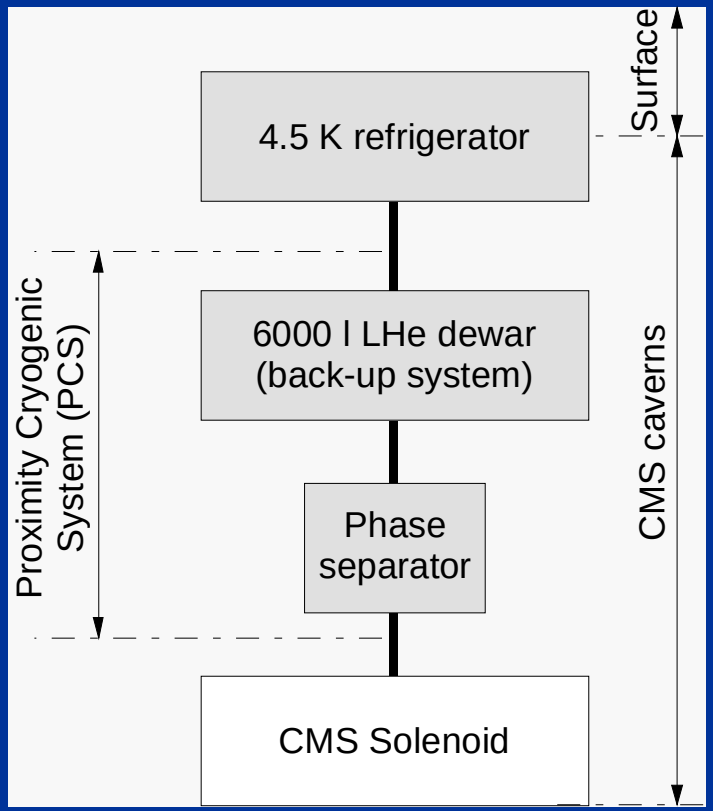
Phase seperator cryostat





Central barrel with integrated solenoid cryostat

The CMS detector and cryogenics



Simplified cryogenic architecture.

1.5 kW @ 4.5 K Refrigerator cold box installed in underground cavern

3) Non-LHC cryogenic experiments (a selection)

Prevessin site

Fixed target experiments
NA48, NA49, RD5,
Compass, ATLAS H8

At LHC Point 8

CAST (solar axion experiment)

Meyrin site

Antimatter experiments (Atrap, Asakusa, Alpha)

Gravitational antenna Explorer

Merit

The Compass experiment

Compass is a low temperature fixed target experiment using a polarized target of solid ammonia or 6LiD at 50 mK in a magnetic field of 2.5 T

Dilution refrigerator (20 mK) designed and built in the 1990's for SMC is still in use for Compass.

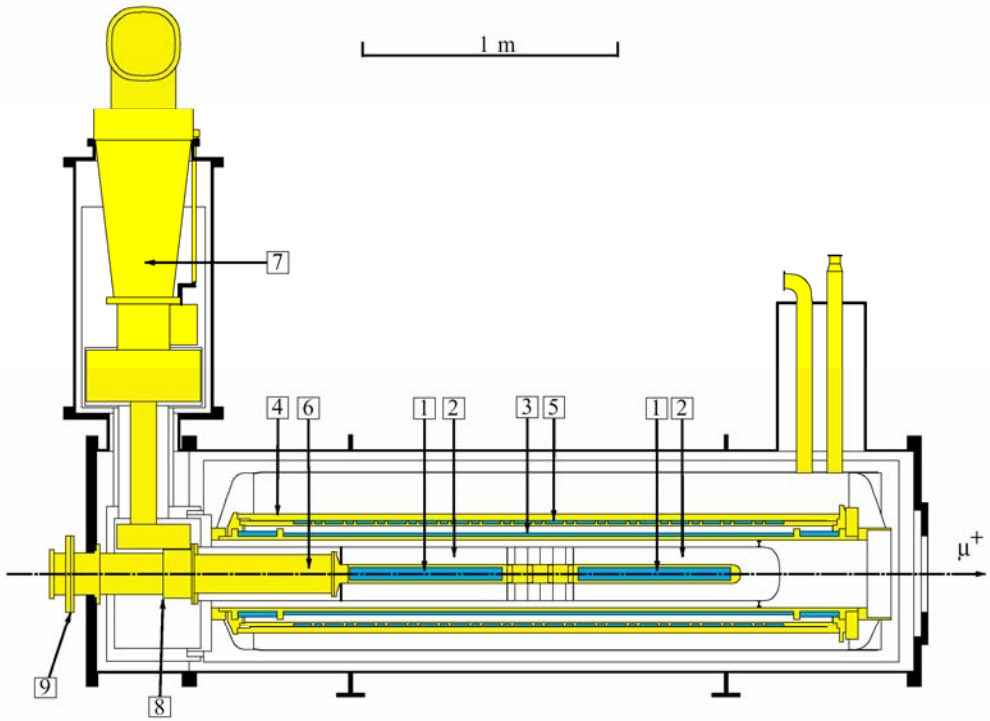


Fig. 5: The SMC target cryostat with the target holder as used in 1993 (from Ref. [3]). (1) target cells, (2) microwave cavity, (3) solenoid coil, (4) dipole coil, (5) correction coils, (6) dilution refrigerators, (7) precooler of ^{3}He, (8) indium seal, and (9) external seal.

The CAST experiment

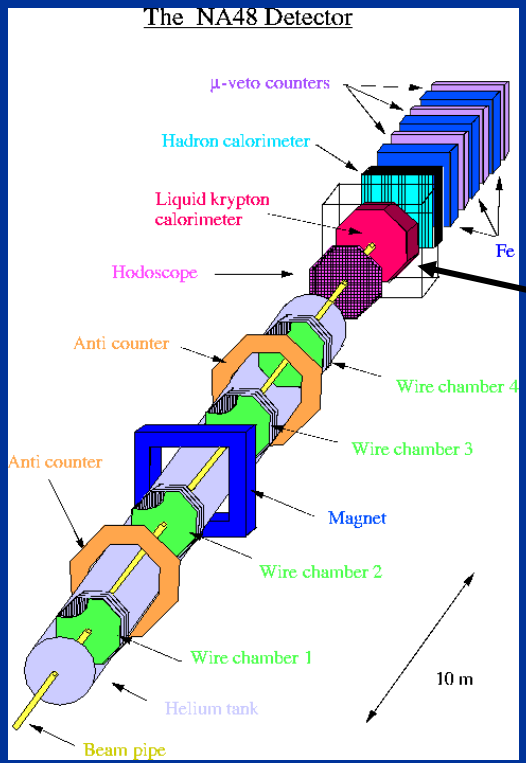
CERN Axion Solar Telescope

CAST is a solar telescope aiming to detect Axions particles hypothetically produced in stars. The set-up permits to follow the path of the sun.

Use of a de-commissioned LHC dipole test magnet to catalyze the axions into photons in the 9.5 Tesla field. Operating temperature 1.9 K.

Use of the de-commissioned 0.8 kW @ 4.5 K former DELPHI refrigerator

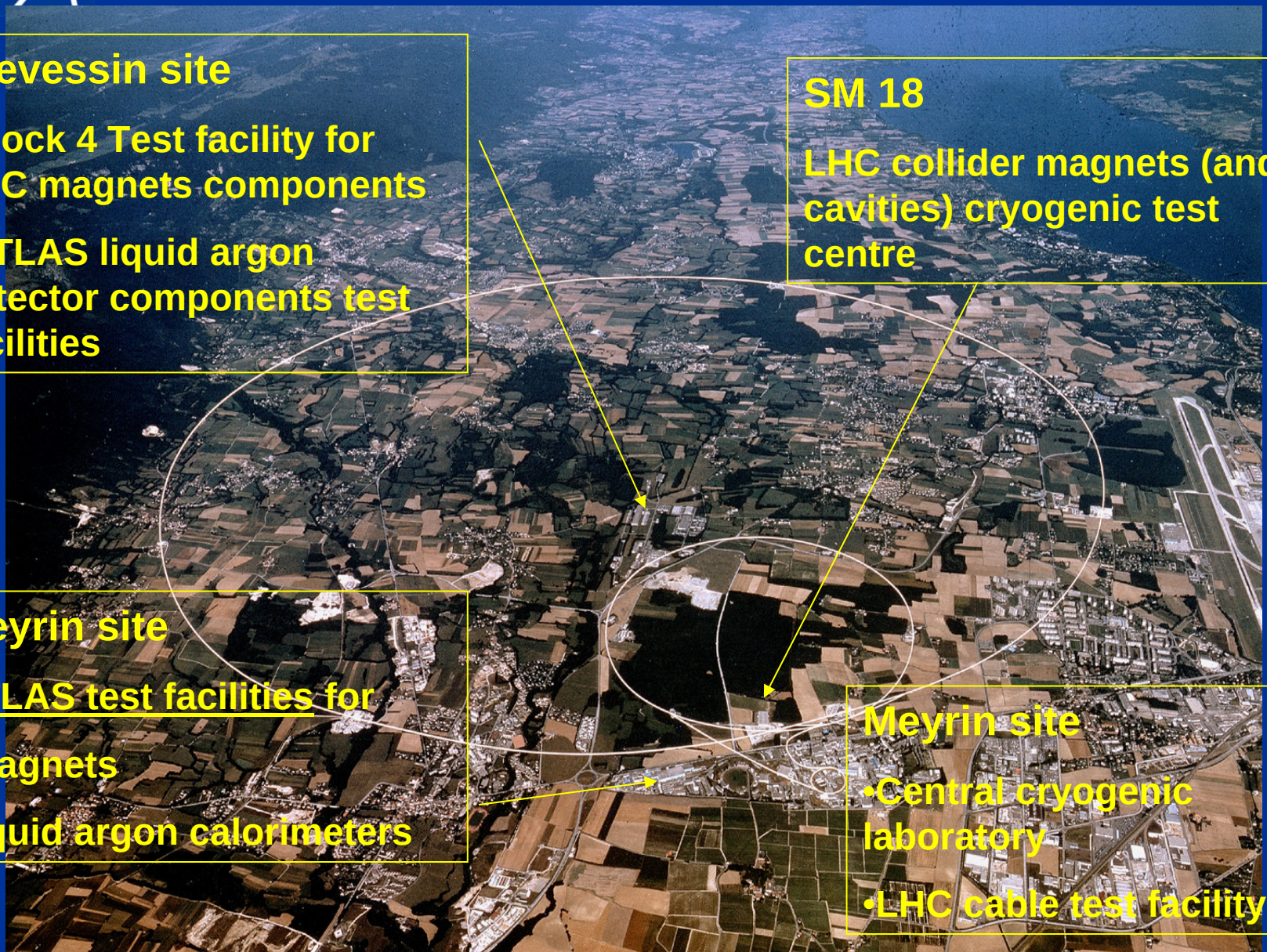
The NA48 experiment



Calorimeter with 10.000 liter of liquid Krypton

Cooling system particularity; Cascade principle with LN2 cooling an argon bath. Argon cools liquid krypton.

Cryogenic test facilities + labs (a selection)



Prevessin site

- **Block 4 Test facility for LHC magnets components**
- **ATLAS liquid argon detector components test facilities**

SM 18

LHC collider magnets (and cavities) cryogenic test centre

Meyrin site

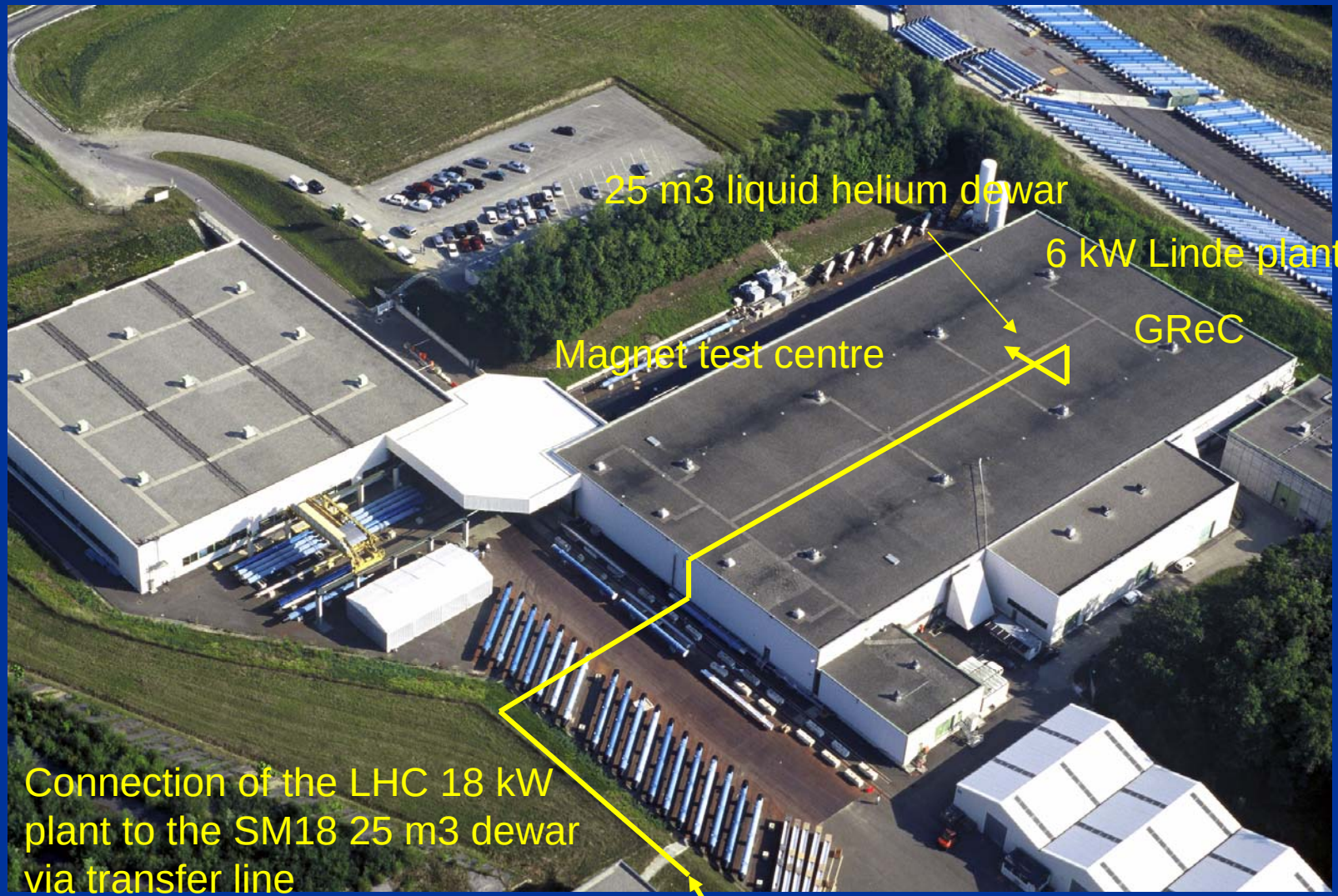
ATLAS test facilities for

- **magnets**
- **liquid argon calorimeters**

Meyrin site

- **Central cryogenic laboratory**
- **LHC cable test facility**

The SM18 cryogenic test centre



The SM18 cryogenic test centre

Test facility for the LHC main magnets
Test of <2000 magnets at 1.9 K
12 test benches
7000 m2 floor space

The hall 180 ATLAS assembly + test area

After assembly magnets and liquid argon calorimeters were (are) individually tested under cryogenic conditons at hall 180

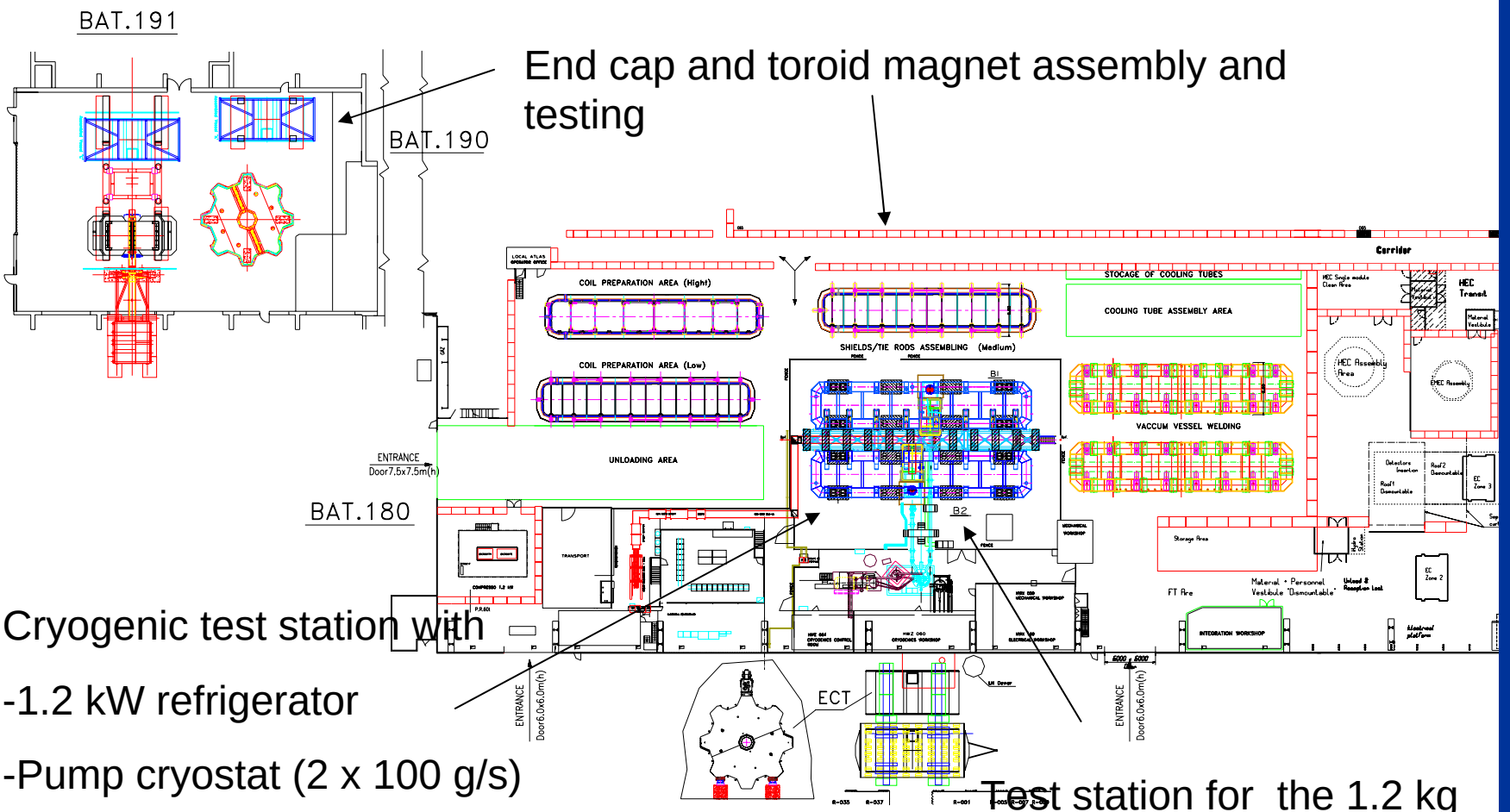
8 toroid coils

2 end cap magnets

1 central solenoid

3 liquid argon calorimeters

The hall 180 ATLAS magnet test area



Cryogenic test station with

-1.2 kW refrigerator

-Pump cryostat (2 x 100 g/s)

-Distribution system

Test station for the 1.2 kg ATLAS pumps, High Reynolds…

The CERN central cryogenic laboratory

Mission;

- LHC prototypes and components testing
- Quality assurance for LHC and other « clients »
- Developments for experiments and technical departments
- Instrumentation qualification

Particularities;

- Cryogenic infrastructure with several cryostats and test benches
- Dilution refrigerator development and construction (7 mK)

Instead of a conclusion; Cryogenic Inventory

He Refrigerators	
Number	kW@4.5 K
8	18
2	6
1	1.5
1	1.2
2	0.8
9	0.4
1	0.1

Helium gas storage	
(1.5 & 2.1 MPa)	
Number	capacity (m3)
65	80
60	250

Liquid N2 storage	
Number	capacity (m3)
16	50
1	40
2	27
2	20
2	15
1	7
9	6

Superconducting collider machine with 800,000 liter of liquid helium inventory

Experiment with 90,000 liter of liquid Argon

Experiment with 10,000 liter of liquid Krypton