Symposium for the inauguration of the LHC cryogenics
31 May to 01 June 2007

LHC experiment cryogenics

Cooling methods of the large super-conducting magnets for LHC experiments

Goran Perinić, AT-ECR 30.05.2007

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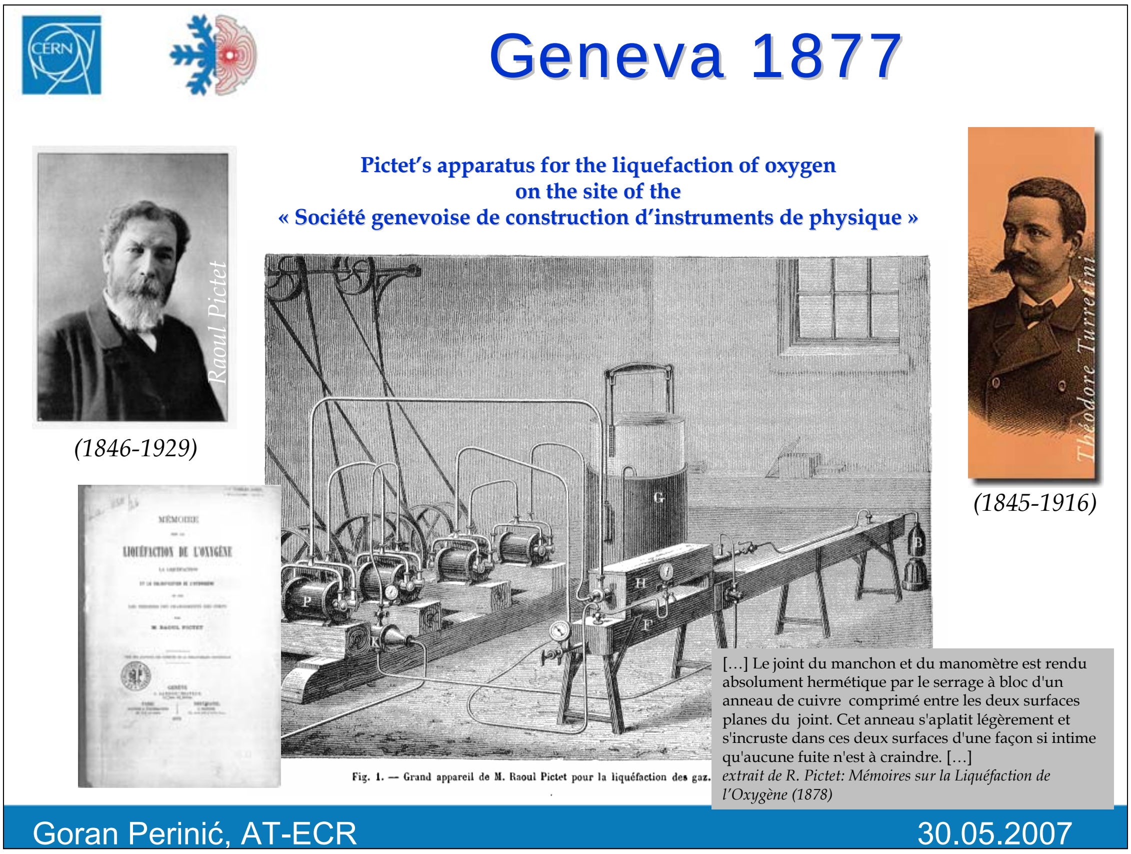
Dear colleagues,

We are united here to celebrate the achievement of a collaboration in between science and industry. A collaboration for the construction of the world's larges cryogenic installation. An installation that is breaking many records!

However, before I talk about THIS collaboration, I should like to honour the achievements of ANOTHER collaboration that took place almost exactly 130 years ago:



It was back in 1877 here in Geneva that Raoul Pictet, professor at the University of Geneva managed to liquefy oxygen. Pictet had in fact for the first time reached temperatures below 120 K … CRYOGENICS WAS BORN.

The race for the liquefaction of the permanent gases and therefore the competition for ever lower temperatures in the second half of the 19th century must have been as exciting as the search for the Higgs Boson today.

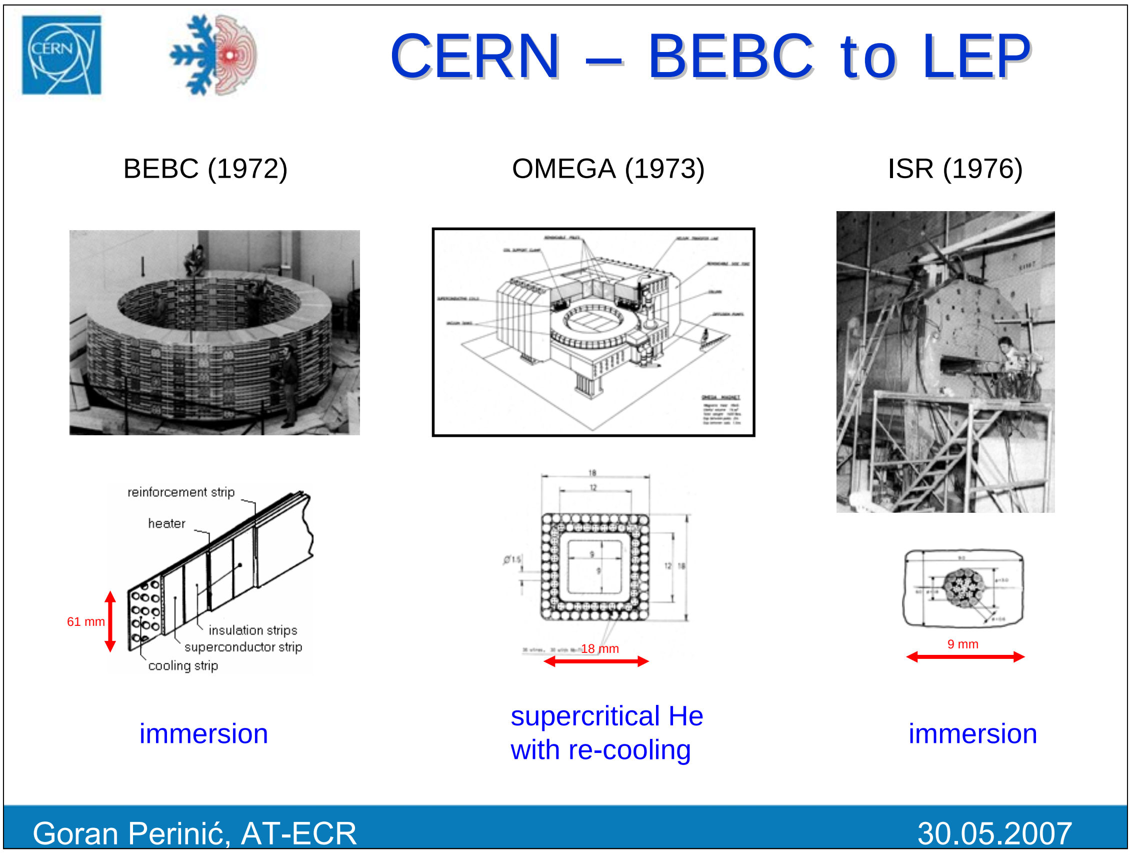
As you imagine, Pictet did not build the apparatus for the liquefaction, that is shown on the drawing, himself. He contracted the construction to the engineer Théodore Turrettini who was the director of the Geneva society for the construction of physics instruments. The apparatus was built on the site of the "Geneva society for the construction of physics instruments" and used their steam engine as power source.

You will actually meet Théodore Turrettini again this evening: The Mandarin Oriental Hotel where tonight's reception takes place,is located on the Quai Turretttini. Once at the hotel, please do have a look across the Rhone to admire the « Bâtiment des Forces Motrices », Turrettini's most known oeuvre: the water pumping station of Geneva.

These guys, however fruitful their collaboration, did certainly not yet imagine the possible uses of low temperatures. They had just opened the door to a NEW WORLD …,

but I must come to CERN!

Let me make a leap of almost 100 years – a leap to our fathers and their collaborations:

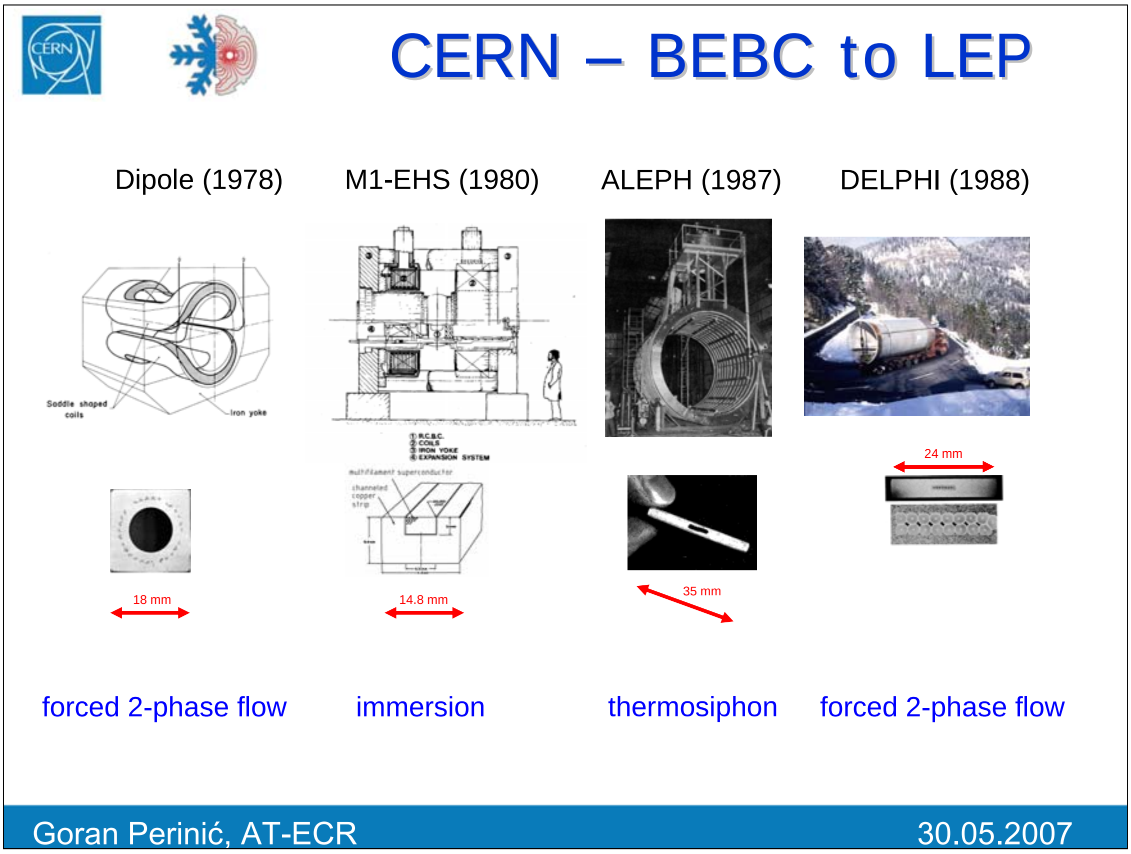


And I come to the historic of large superconducting coils at CERN.

These large superconducting coils that have been built by the collaborations of our fathers and I am sure that there are quite a few present here in the auditorium that have made those magnets work.

The refrigeration method is noted in blue. In those days it was very common to immerse the magnet into a liquid helium bath. This was advantageous for the refrigeration, but it required quite a considerable amount of helium. The first cool-down of the BEBC coil was in fact delayed due to a helium shortage. There were also other modes of refrigeration like the supercritical helium flow inside the OMEGA conductor.

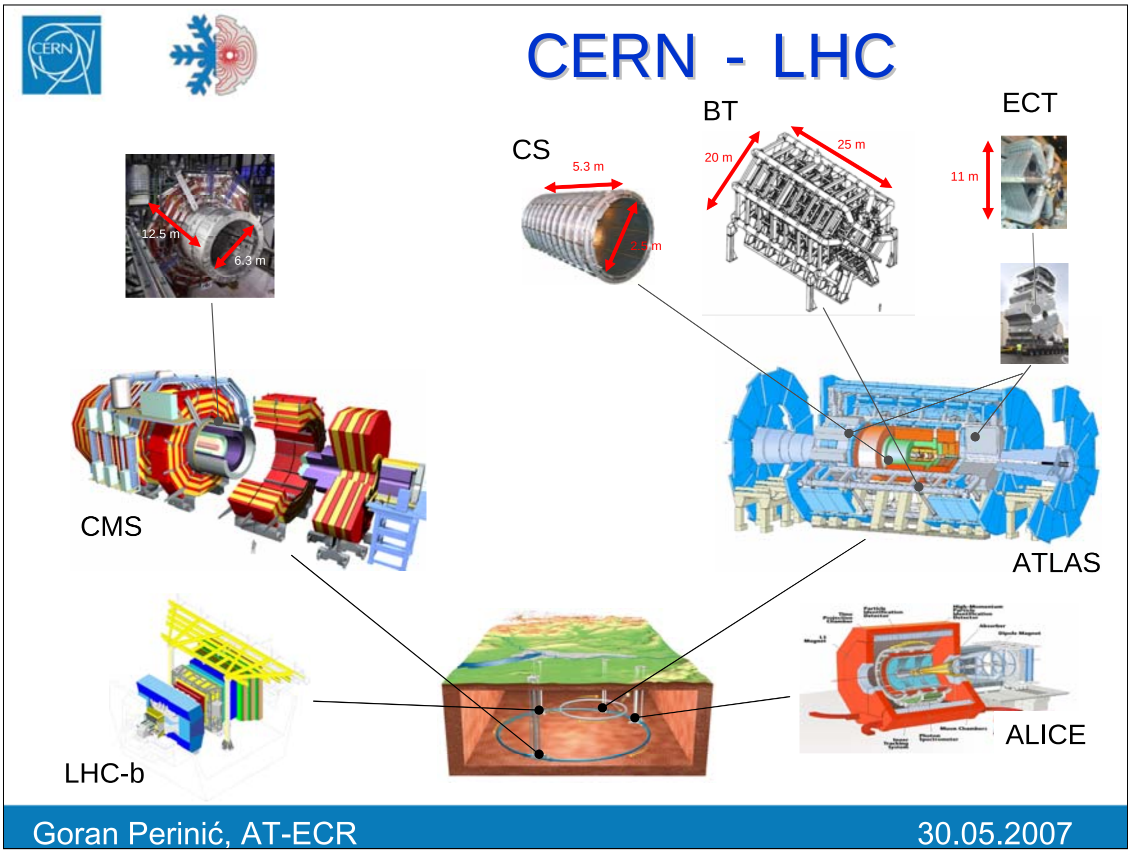
From the 1970s to the 1980s:



Two of these magnets, the DIPOLE and the M1-EHS magnet are still operational at CERN.

The ALEPH and DELPHI magnets of LEP were the models for the new magnets.

As you can see, CERN has collected quite a lot of experience in the field of large superconducting magnets before attacking the LHC project:



For LHC, as you know, four new detectors are being built. Two of them, Alice and LHC-b, are built with conventional magnets.

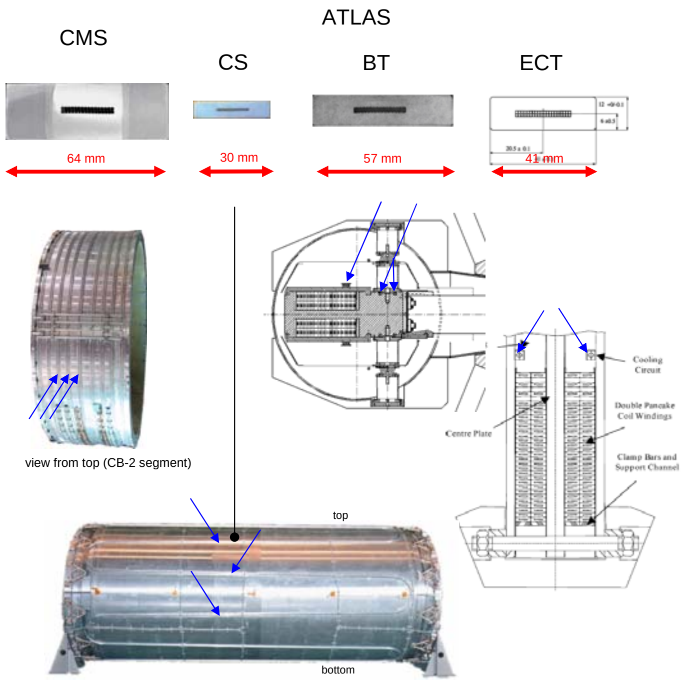
CMS comprises a large superconducting solenoid and

ATLAS contains a solenoid in the centre and a complex magnet system consisting of 24 toroidal coils.

What are the similarities and what are the differences in between these cooling systems for these coils?:

What is similar? I

- composite Al-stabilized conductors
- indirect cooling via the coil support
- operation temperature 4.5-4.8K
- cool-down with a maximum temperature gradient of 40K



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I start with the similarities:

All coils are built using similar composite aluminium stabilized conductors.

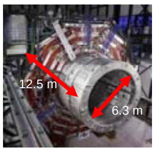
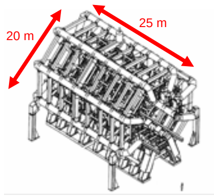
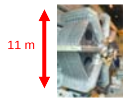
In all cases the heat removal is achieved via the coil support.

All coils are operated at temperatures in the range from 4.5 K to 4.8 K.

And in all cases a maximum thermal gradient of 40 K is allowed during the cool–down.

What is similar? II

- **materials and bonding**

	CMS	ATLAS-CS	ATLAS-BT	ATLAS-ECT
				
Coil support	Al 5083 H321	Al 5083	Al 5083	Al 5083
Cooling channels	Al 6060 T5 welded on	Al 6063 welded on	Al 1070 glued on	Al 6061 T4 glued on
Shield	Al 3003 H22	Al	Al 3003 H22	Al 5083
Shield cooling channels	Al 6082 welded on	Al 6063 welded on	Al 1070 welded on	Al 1070 welded on

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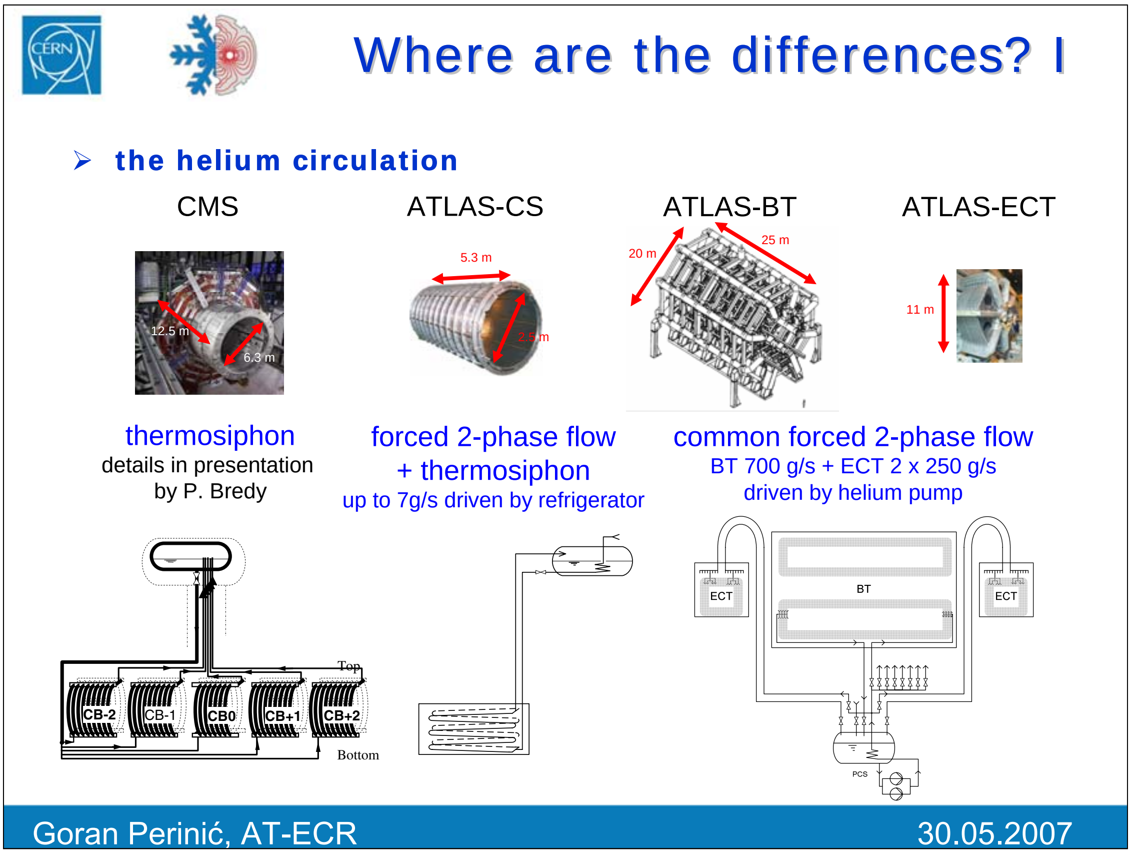
Another point where the coils have many similarities are the materials chosen for the coil supports, the cooling pipes and the shields. All are in fact aluminium alloys. Why is it aluminium – because aluminium is more transparent to muons than copper or stainless steel.

The choice of the alloy depends on factors like heat conductivity, yield strength, weldability, extrudability.



The main difference in between the magnet coils is the method how the liquid helium is circulated:

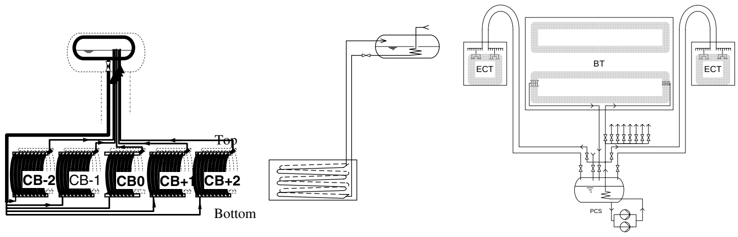
CMS uses a thermosiphon system. It will be explained in detail in the next presentation by Philippe Bredy.

The ATLAS central solenoid uses directly the flow provided by the refrigerator. However, the cooling channels have been built in a way that thermosiphon cooling is possible in emergency cases too.

The ATLAS barrel toroid and end cap toroids are cooled in parallel with a forced two-phase flow driven by a dedicated liquid helium pump that has been specially developed.

Where are the differences? II

➢ **the helium circulation**



	CMS	ATLAS-CS	ATLAS-BT / ECT
static heat load	180 W	11 W	BT 8x 80 W+ ECT 2x 200W
max. height difference	12 m	13 m	20 m
cooling pipe dimensions	14 / 20 mm	18 / 24 mm	BT 14 / 20 mm ECT 15.7 /24 mm
phase separator vol.	800 l	280 l	4600 l
LHe inventory – phase sep.	150 l	180 l	2700 l
LHe inventory – cool. pipes	355 l	30 l	BT 800 l + ECT 500 l

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Let me summarize some characteristic data:

1. The static heat loads are different as they depend on the size and shape of the coils.

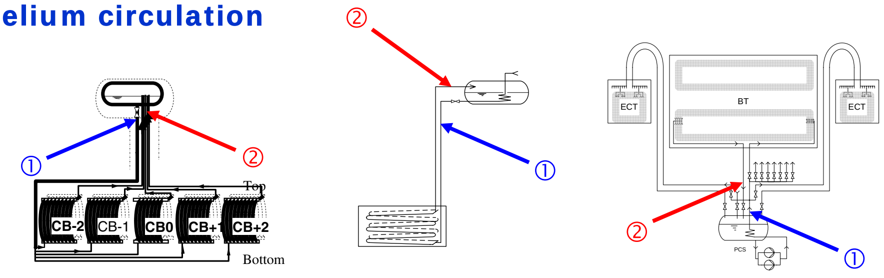
2. All three cooling systems have to deal with height differences of more than 10 m.

And if you look at the last line:

3. The He inventories of the coils are comparatively small.

Where are the differences? III

- the helium circulation



	CMS	ATLAS-CS	ATLAS-BT / ECT
① p_1; T_1; X_1	1,25 bar; 4,4 K (sat.) 0 %	1,35 bar; 4,5 K (2-ph.) 5 %	1,7 bar; 4,65 K (subc.) 0 %
mass flow	200-400 g/s	< 7 g/s	700 g/s + 500 g/s
② p_2; T_2; X_2	1,25 bar; 4,4 K (2-ph.) up to 10 %	1,3 bar; 4,5 K up to 33 %	1,67 bar; 4,8 K up to 8 %

- values variate in dependency of the heat load (static load, dynamic load)

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Here are the conditions at the inlet and at the outlet of the coil cooling circuits.

What are the thermodynamic differences of the three cooling methods?

In the case of CMS the refrigeration starts with a saturated liquid. Variations in the heat load, i.e. when a coil is charged or discharged, make vary the helium flow.

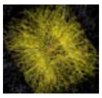
In the ATLAS central solenoid the starting point is two-phase helium and the vapour content at the outlet varies in dependency of the heat load.

In the barrel toroid and the end cap toroid the situation is similar only that the starting point is sub-cooled helium at 1.7 bar.

Conclusion

Four new superconducting magnets have been built for the LHC experiments thanks to an extensive collaboration in between CERN, external institutes and industrial suppliers. The new magnets surpass anything built before at CERN and elsewhere.

The magnet cooling methods have been chosen in dependency of the magnet design. They represent a consistent development of the technologies and experiences gained from previous projects at CERN.



The cooling systems have been designed and built for the long term operation.

Thank you!