GLA2011

The cryogenic systems of the LHC experiments

Johan Bremer on behalf of
TE/CRG, ATLAS collaboration and CMS collaboration

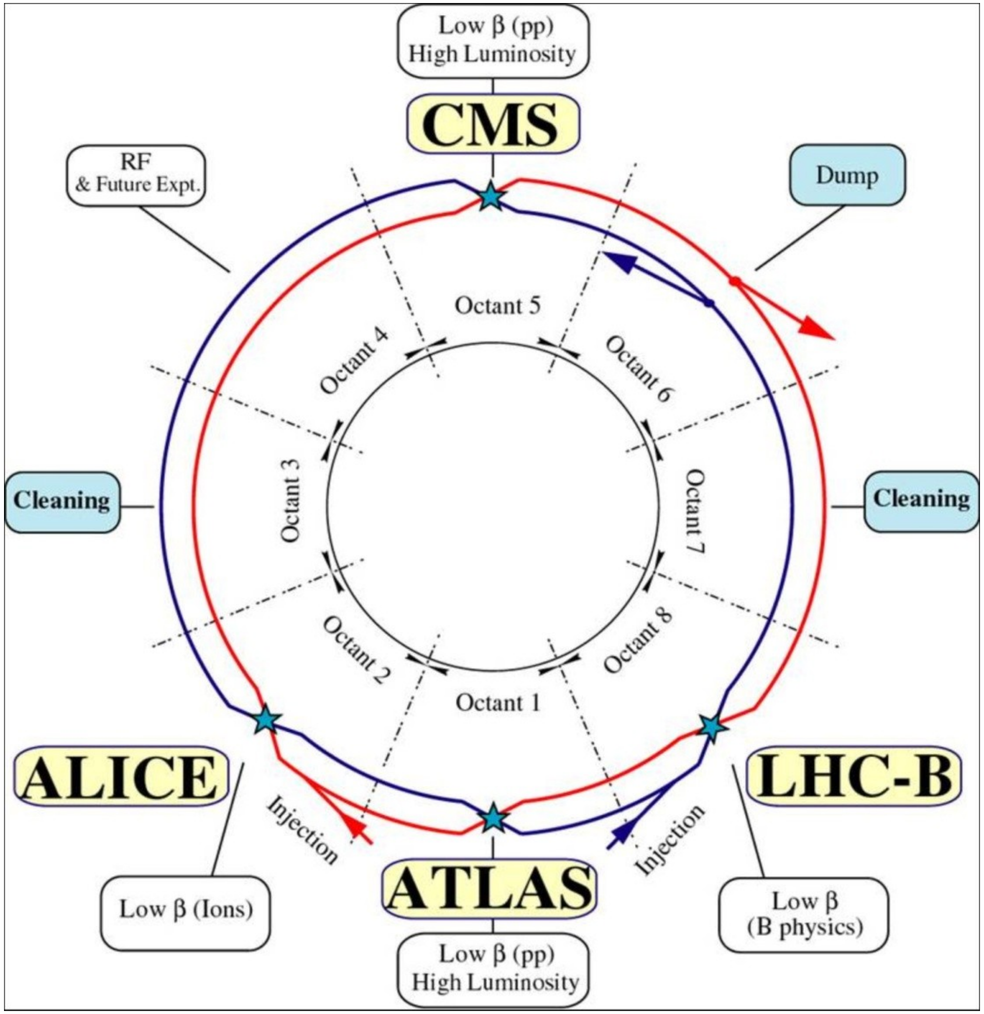
Content

Cryogenic system for the ATLAS magnets

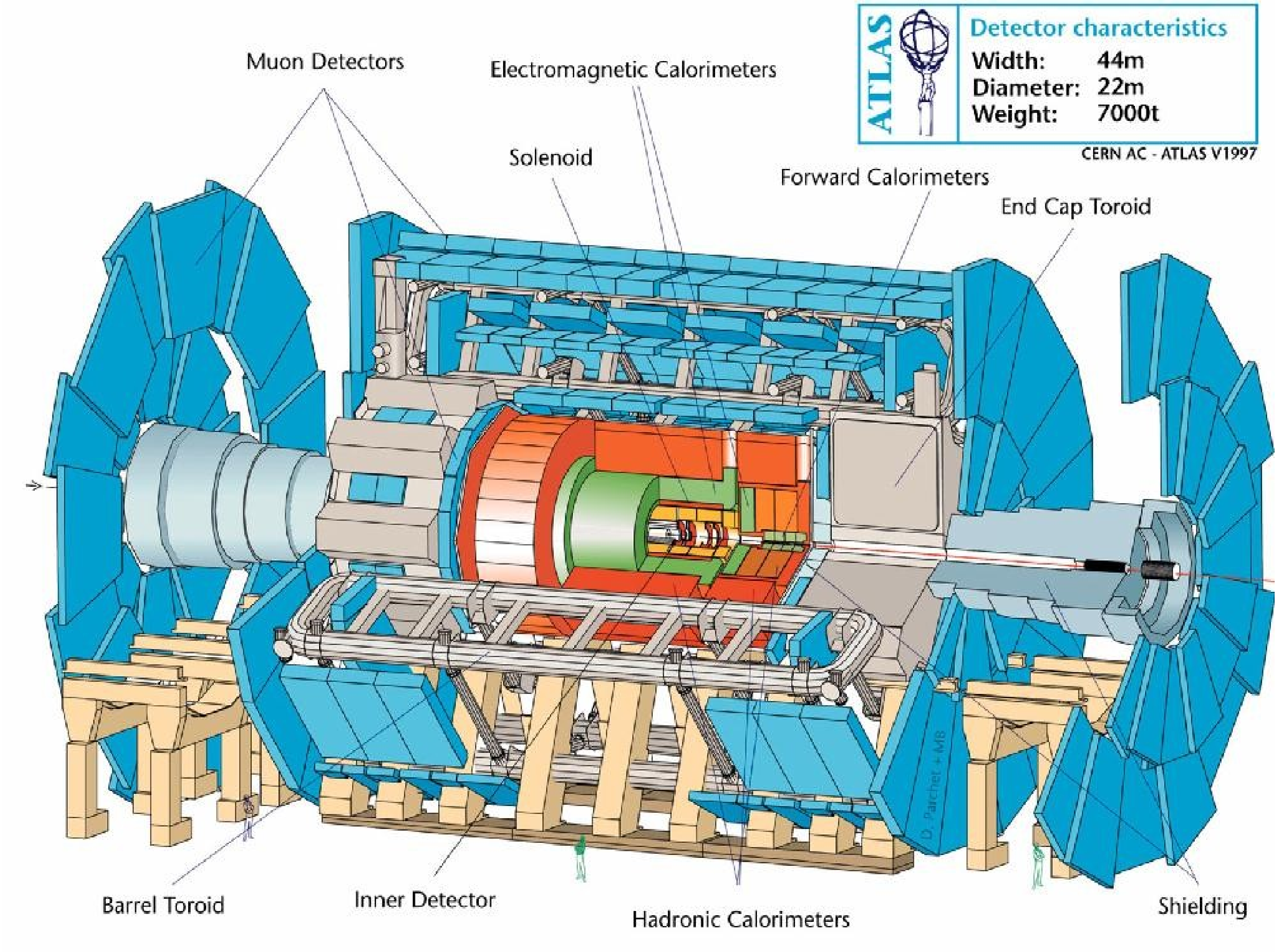
Cryogenic system for the CMS magnet

Cryogenic system for the ATLAS Liquid argon calorimeter

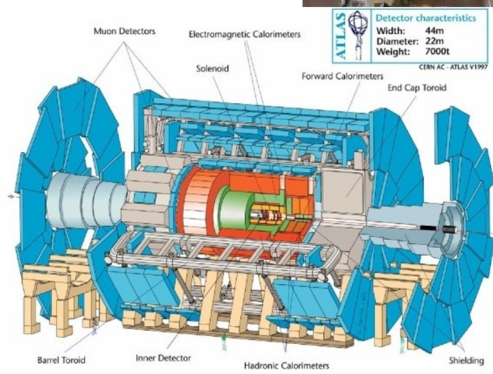
Large Hadron Collider

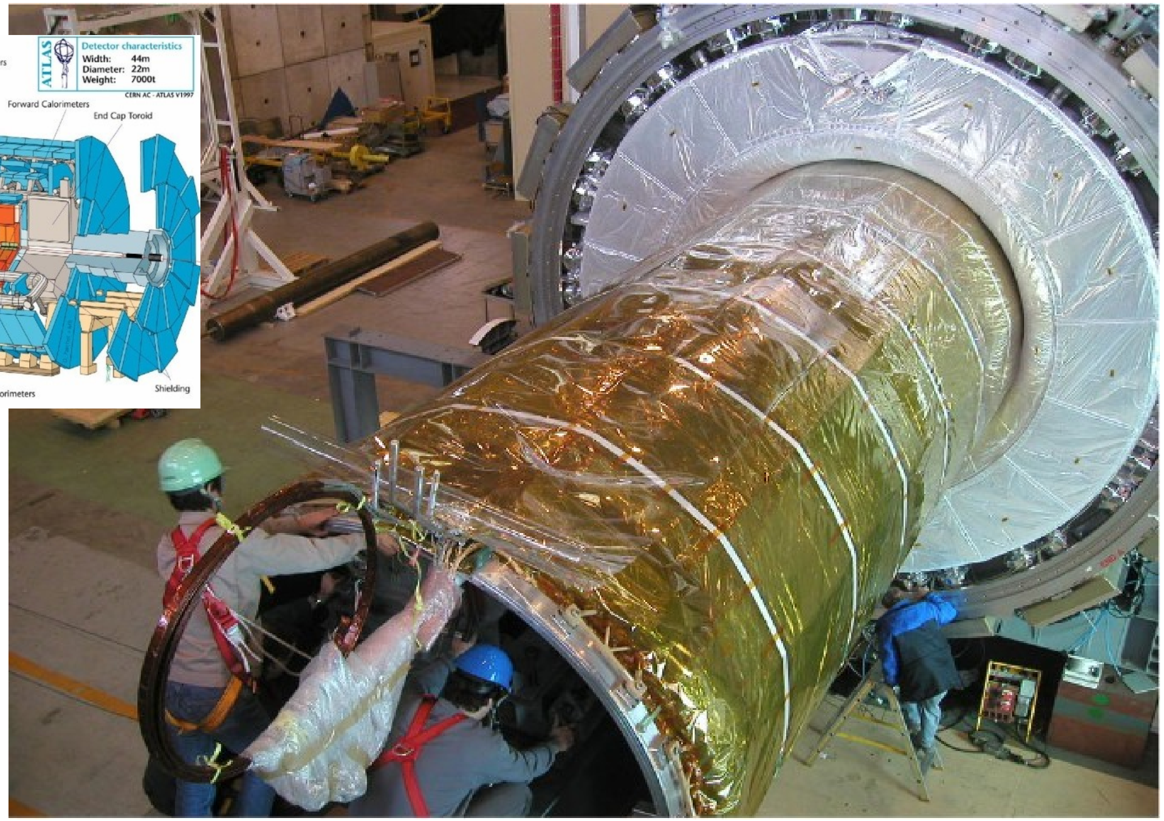


ATLAS


Detector characteristics
Width: 44m
Diameter: 22m
Weight: 7000t
CERN AC - ATLAS V1997
Muon Detectors
Electromagnetic Calorimeters
Solenoid
Forward Calorimeters
End Cap Toroid
Barrel Toroid
Inner Detector
Hadronic Calorimeters
Shielding

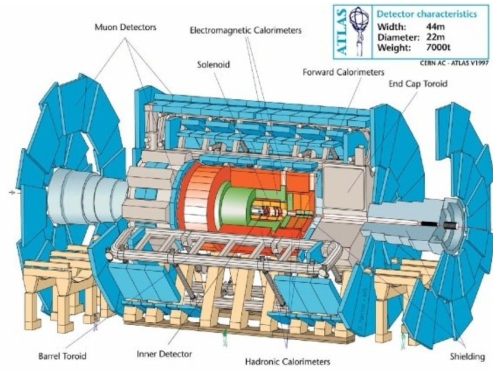
ATLAS Central Solenoid

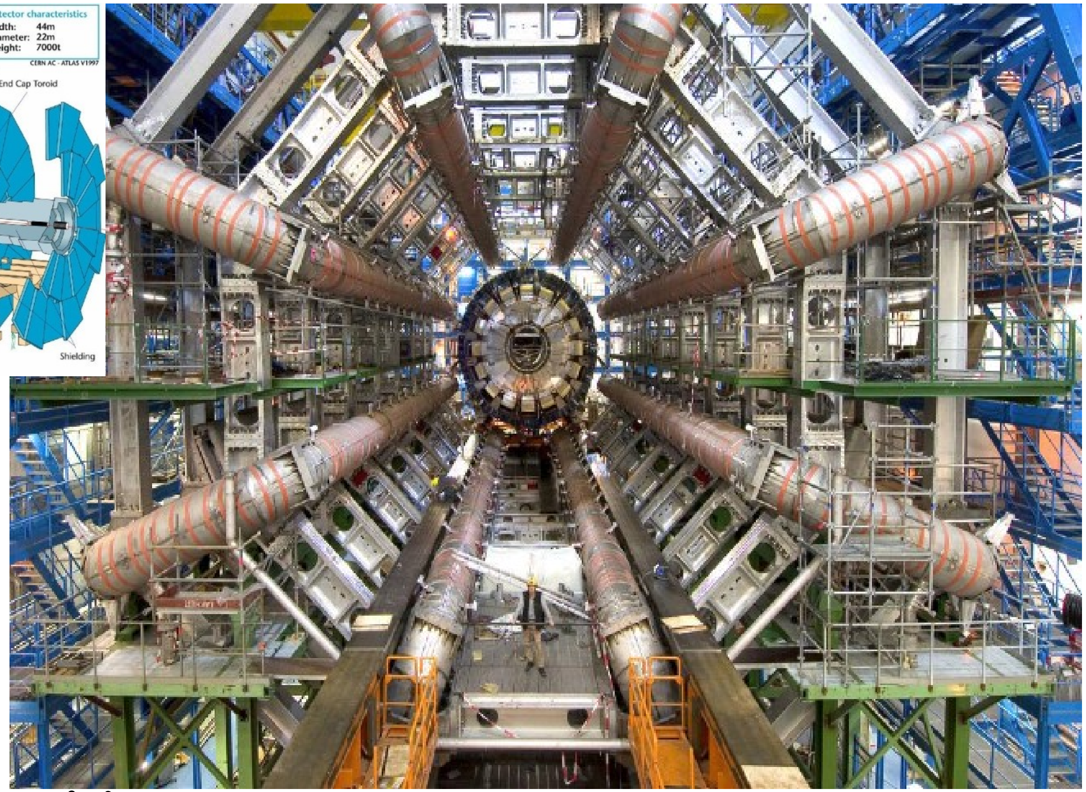




Cold mass:	5.5 tons
Current:	7.7 kA
Field:	2 T
Stored energy	39 MJ

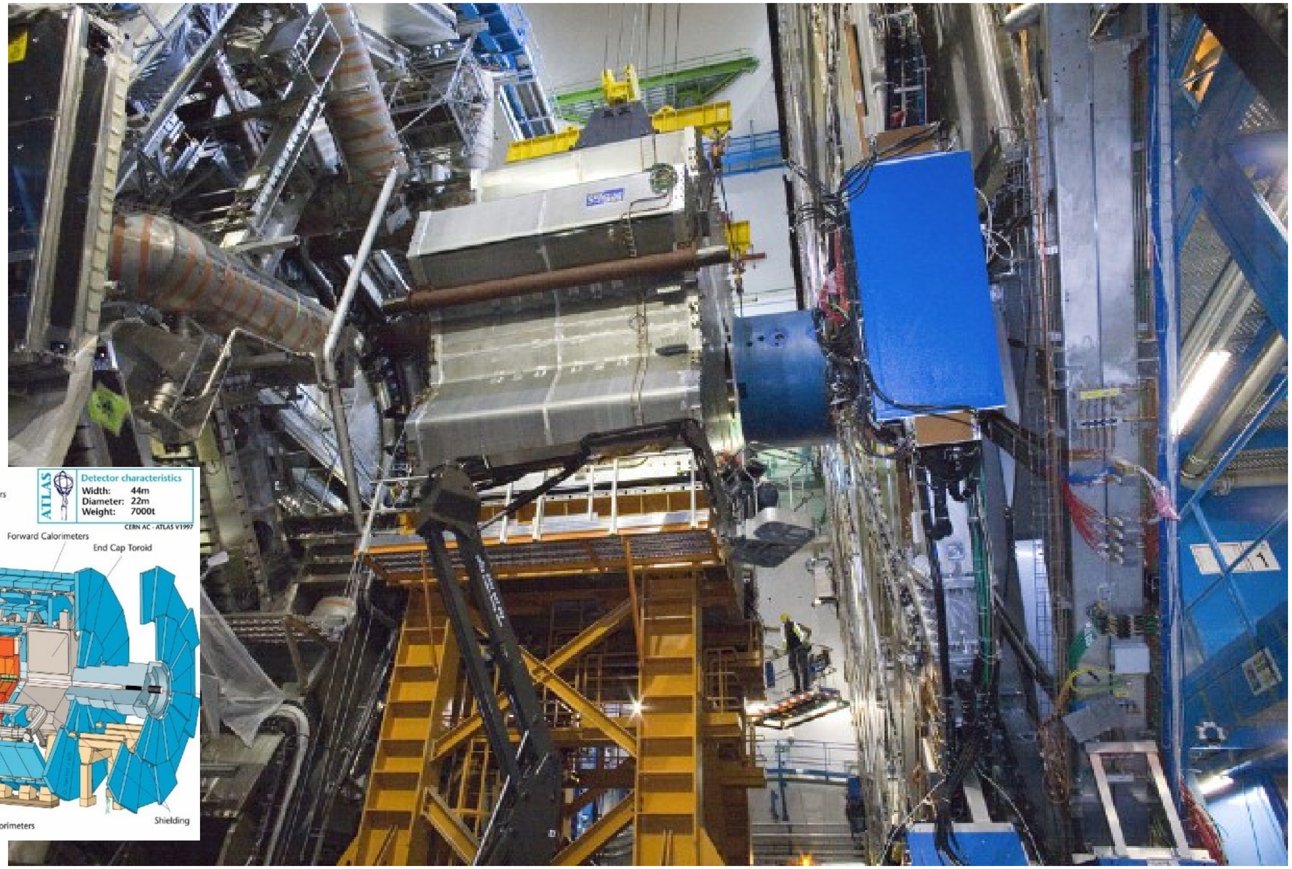
ATLAS Barrel Toroid

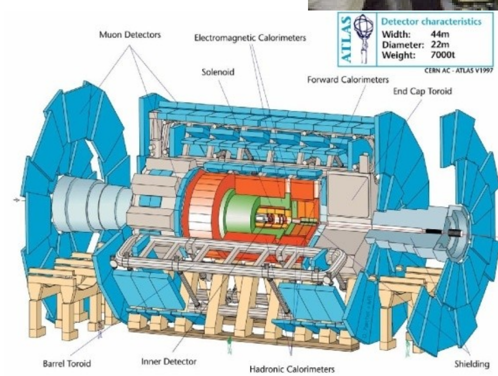




Cold mass	370 tons
Current	20.5 kA
Field	1 T (peak 4 T)
Stored energy	1.6 GJ

ATLAS End-Cap Toroid

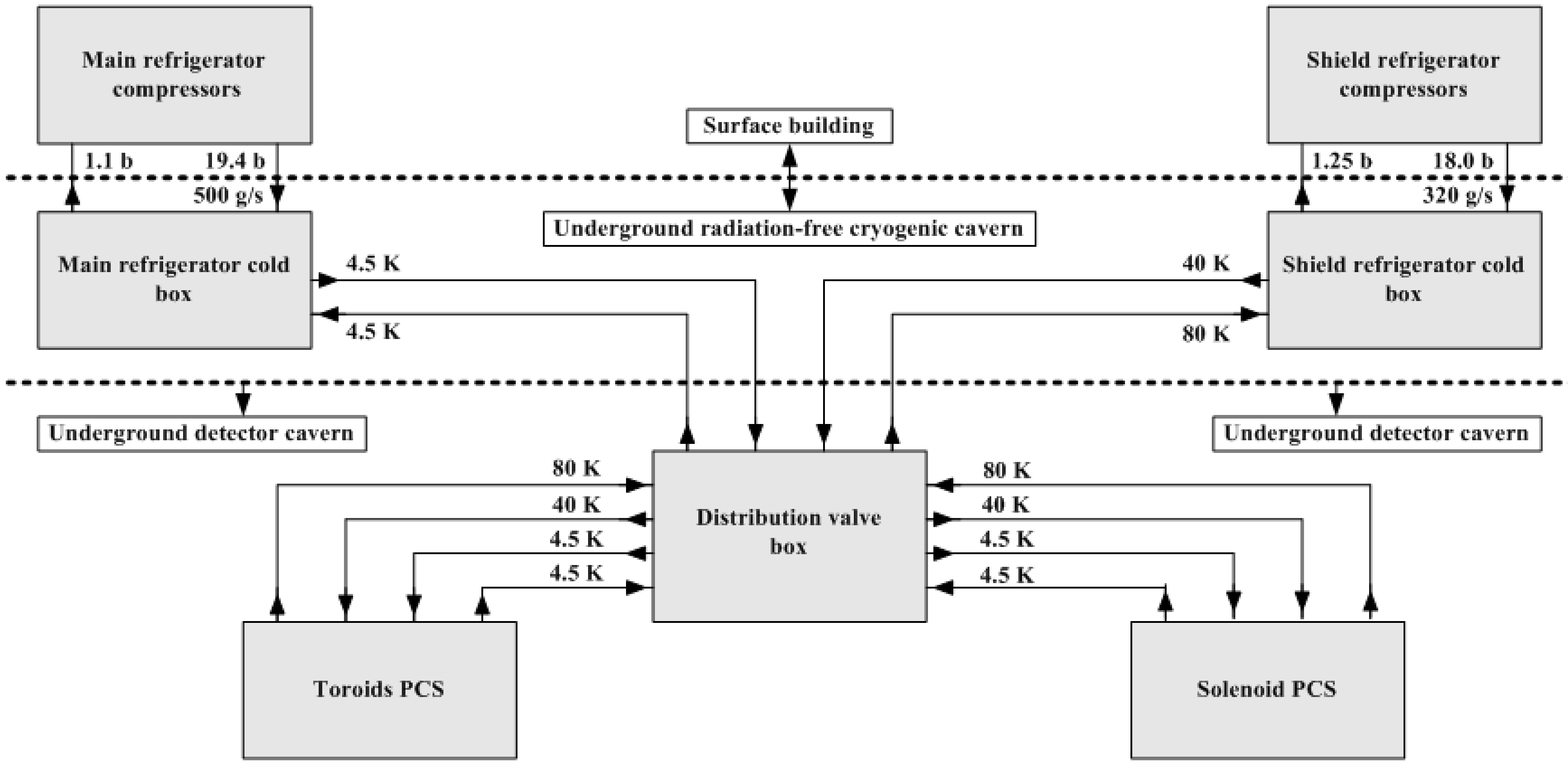




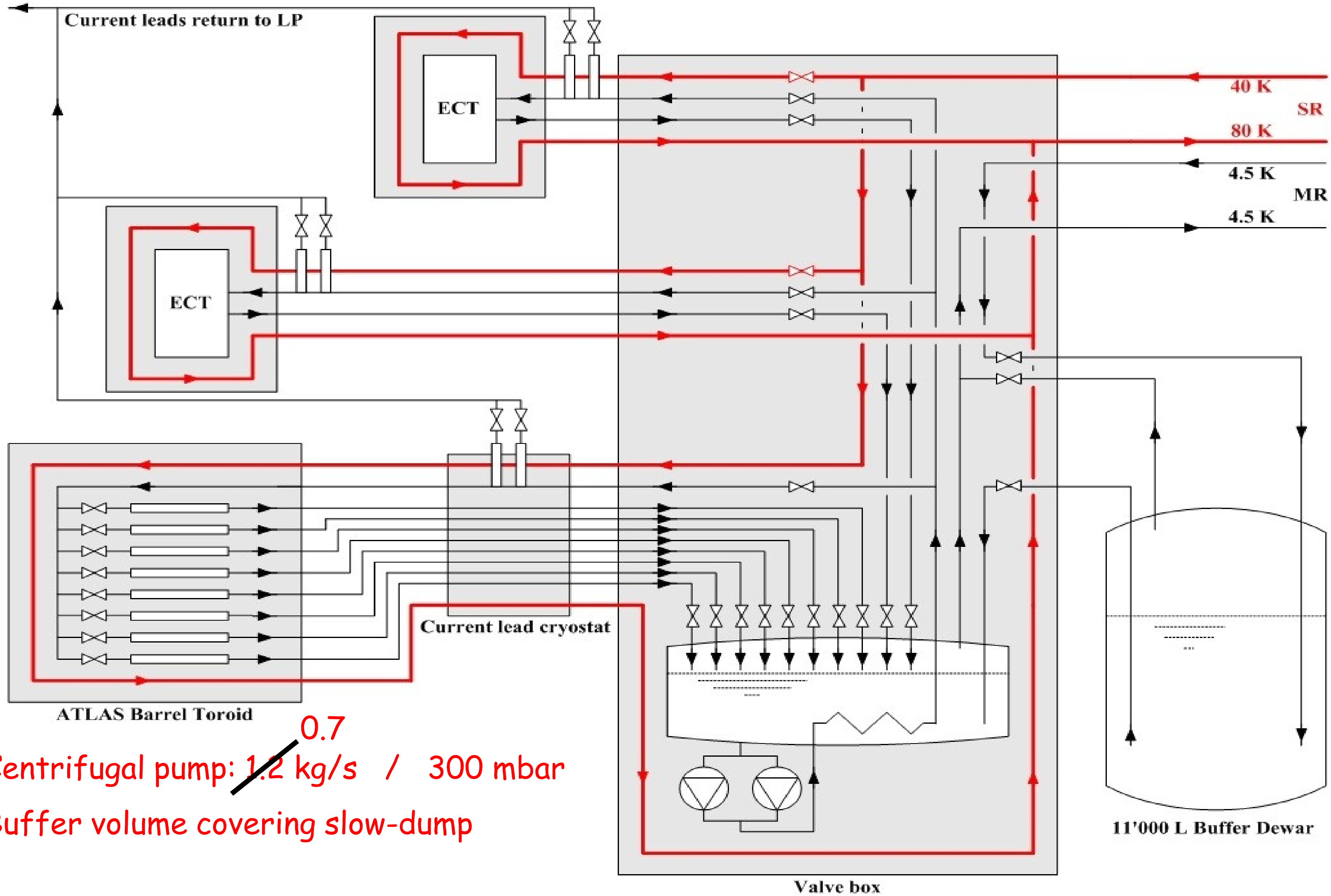
Cold	160 tons each
Current	20.5 kA
Field	1 T (peak 4 T)
Stored energy	0.25 GJ each

Basic flow scheme of the refrigerating system

6 kW @ 4.5 K **20 kW @ 60K**



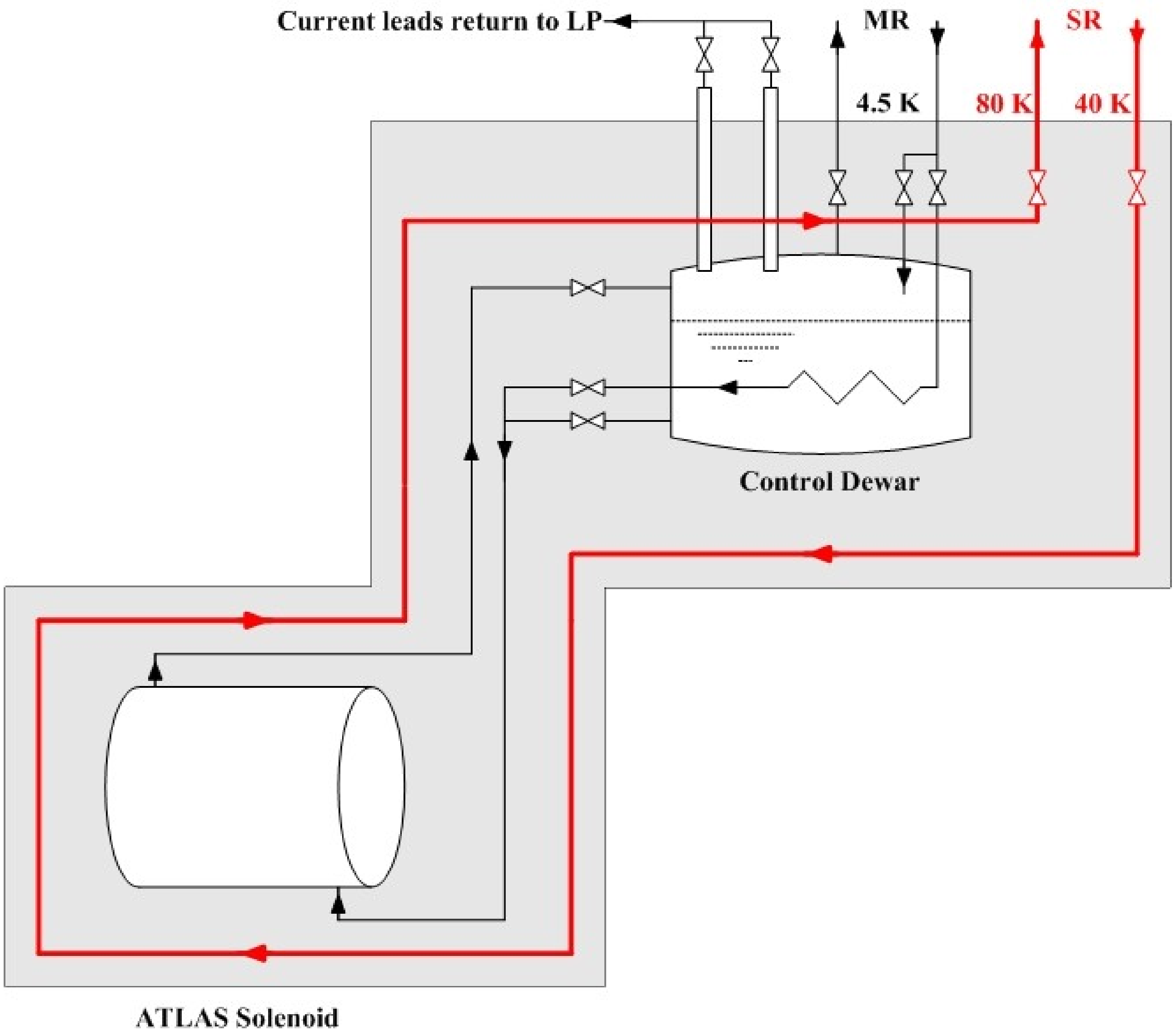
PCS of ATLAS Toroids



Centrifugal pump: ~~1.2~~ 0.7 kg/s / 300 mbar

Buffer volume covering slow-dump

PCS of ATLAS Solenoid



Design & measured heat loads

Thermal loads at 4.5 K

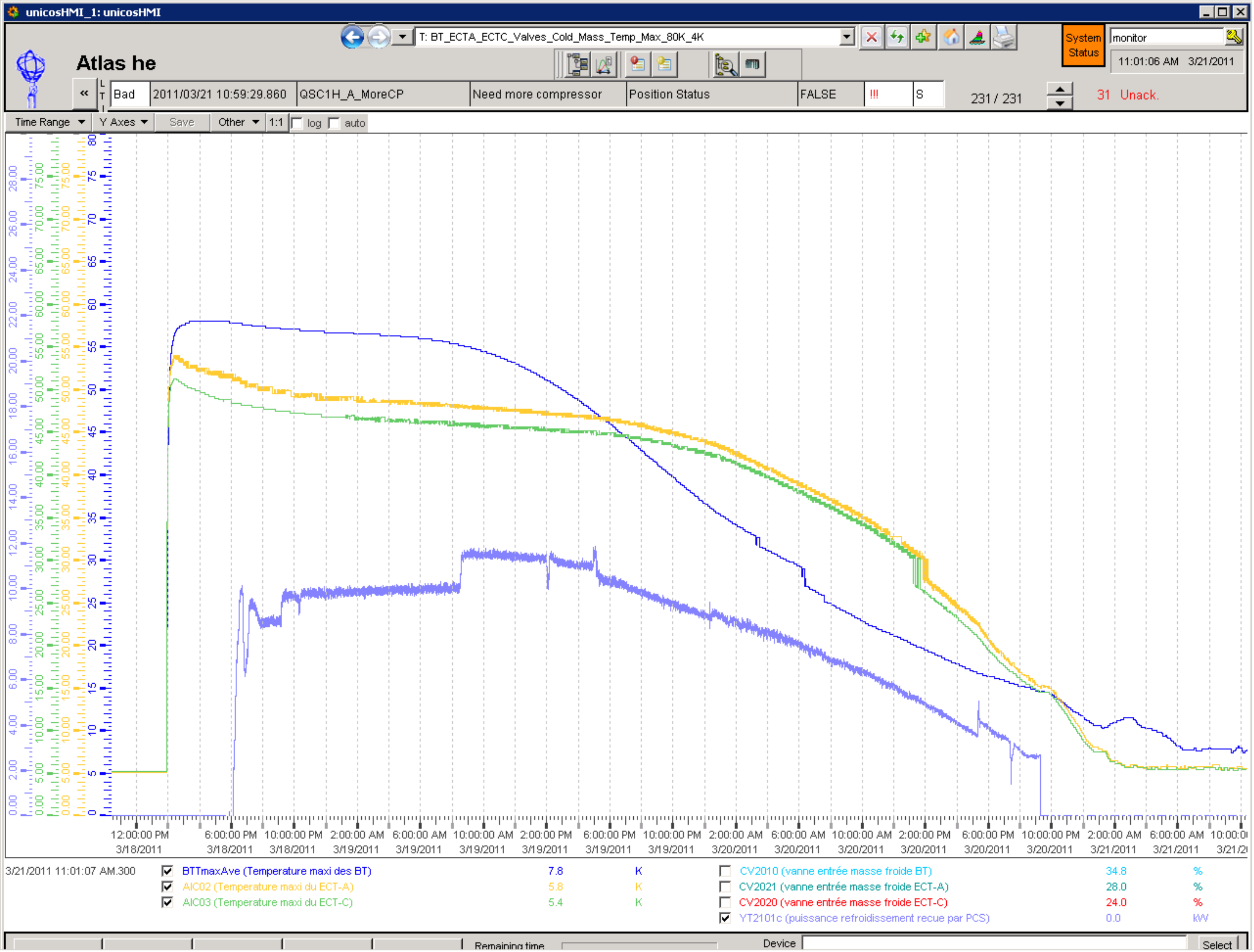
	design	measured
	static	
Barrel toroid	660 W	510 W
Both End-Cap toroid	360 W	290 W
Central solenoid	50 W	17 W
Pump	650 W	670 W
infrastructure	450 W	215 W
Total	2170 W	1702 W
	dynamic	
Barrel toroid (2 hr)	350 W	360 W
Both End-Cap toroid (2 hr)	220 W	140 W
Central solenoid (20 min)	20 W	25 W
Total	590 W	525 W

Liquefaction load

(1.6 x 6 + 1.2) *g/s* = 10.8 *g/s* (design)

(1.85 x 6 + 1.2) *g/s* = 12.3 *g/s* (measured)

Full system fast dump



Consolidation/Conclusion

Consolidations foreseen for:

Winterstop 2011:

installation of two compressor stations in the MR compressor chain;

Long shutdown 2013:

installation of extra helium storage volume in experimental underground area:

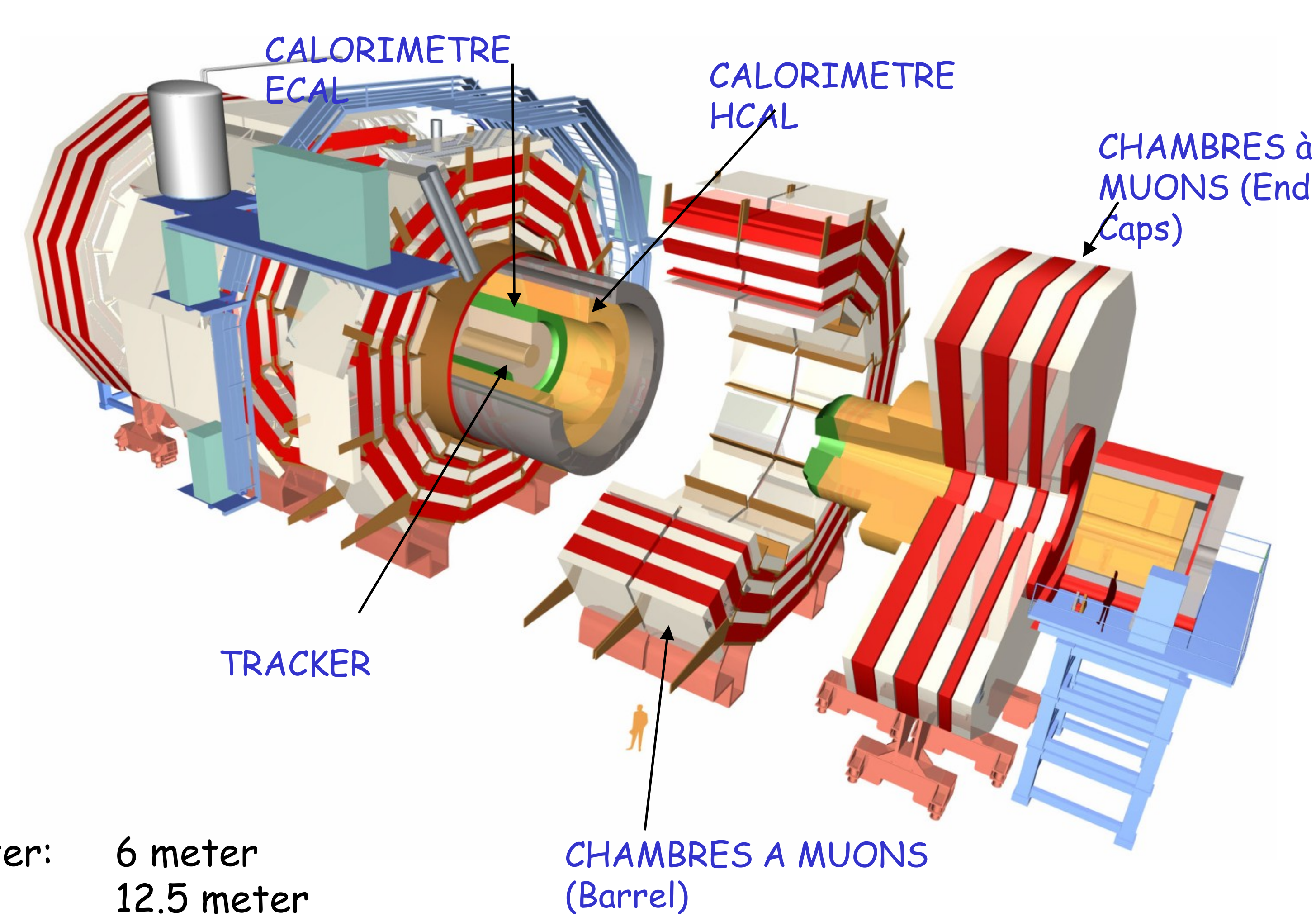
- Solenoid can (for some time) be driven independently from toroid system;

Conclusions:

ATLAS magnet system operational since 2008:

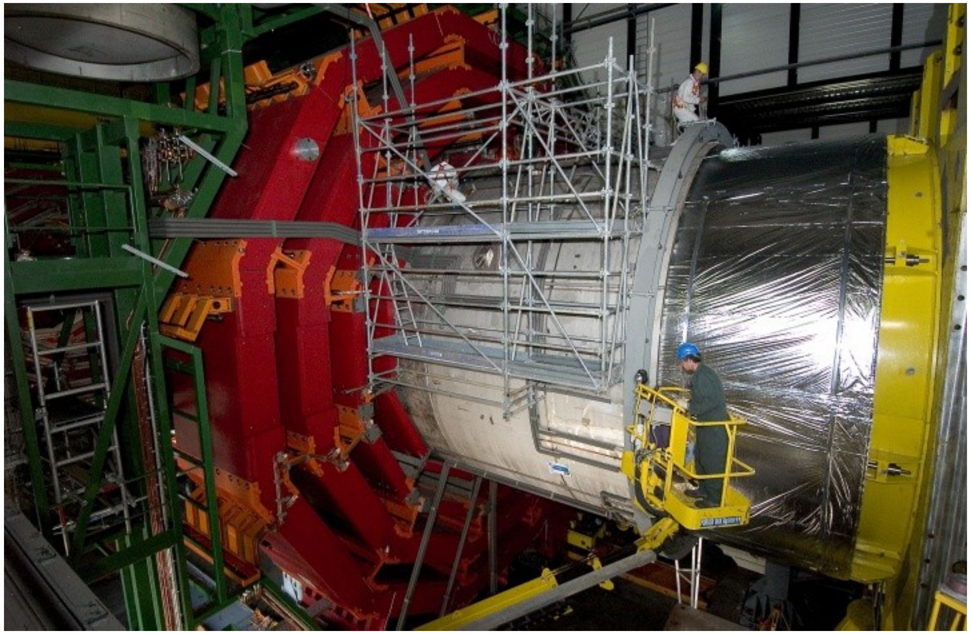
- Fast dumps only triggered by equipment failure (current lead valve, communication with PLC, not by failing pump)
- Slow dump caused by non-availability of refrigerator system works correctly
- Recuperation time after fast-dump now about 3 days;

CMS



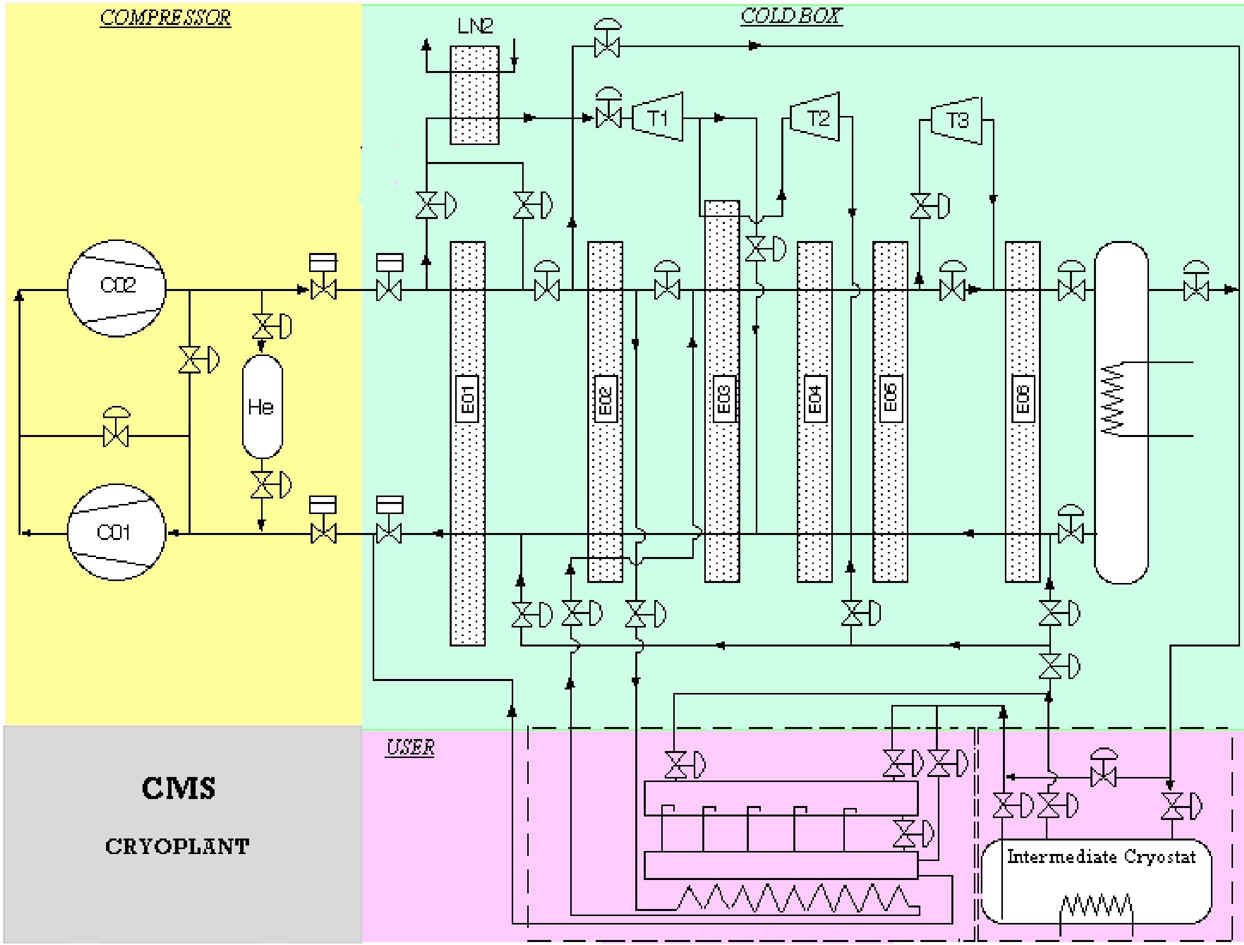
Solenoid:
Inner diameter: 6 meter
Length: 12.5 meter

CMS solenoid



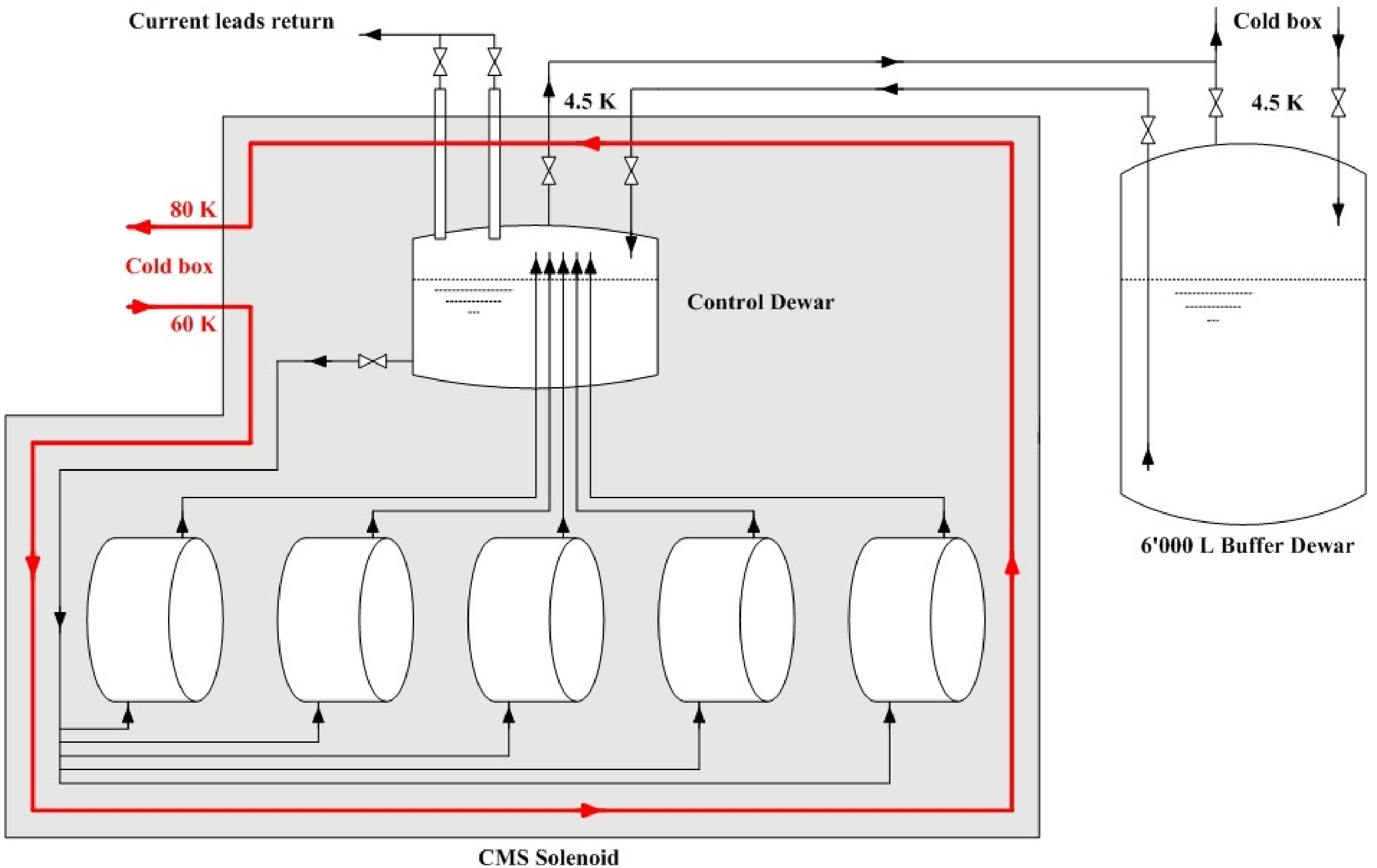
Cold mass	234 tons
Current	18.1 kA
Field	3.8 T
Stored energy	2.7 GJ

CMS basic flow scheme

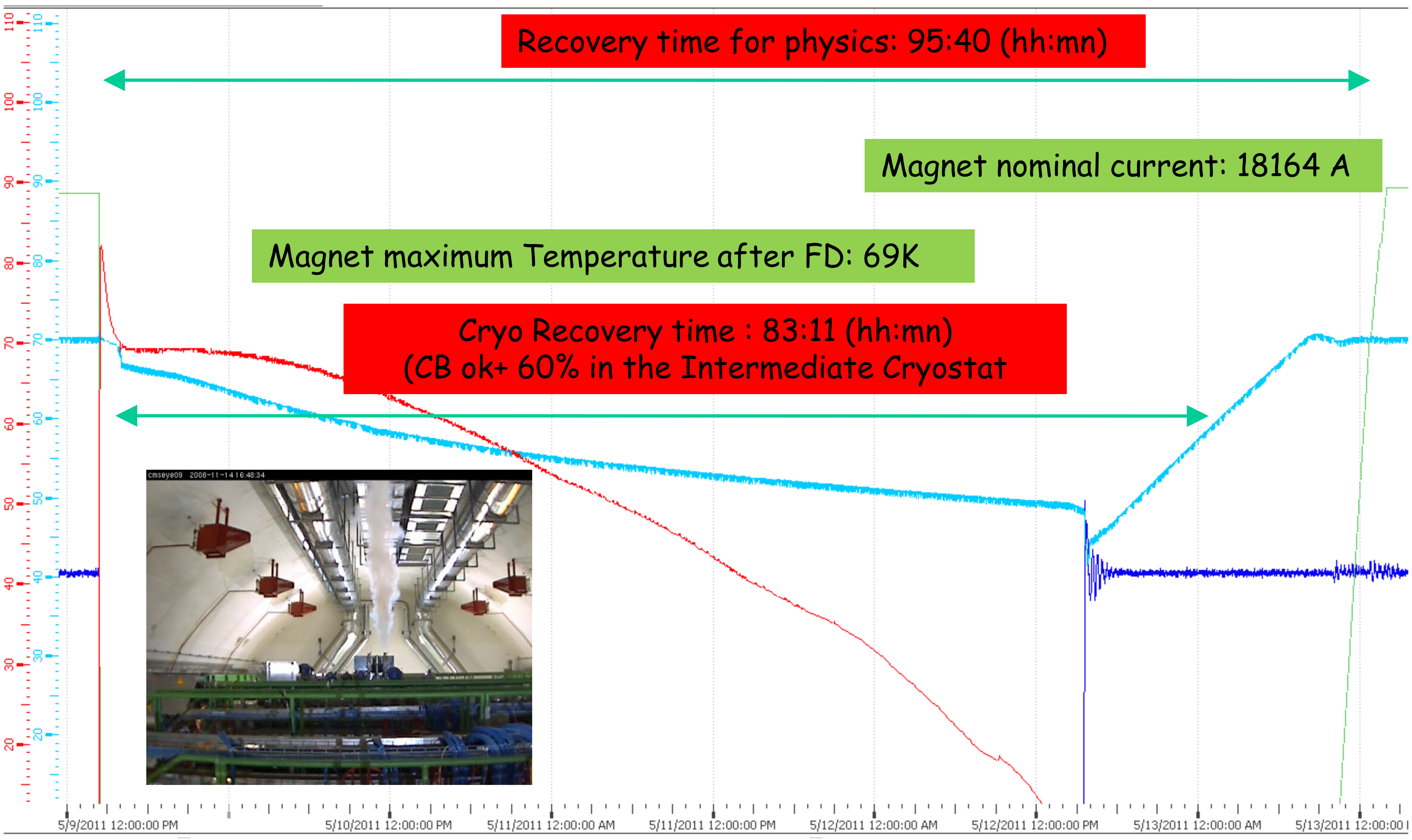


Thermal load going into 4.2 K system	800 W
Thermal load on thermal screen system (60K - 80 K)	4500 W
Liquefaction load	2x2 g/s

CMS basic flow scheme



Fast Dump recovery



Consolidation/Conclusion

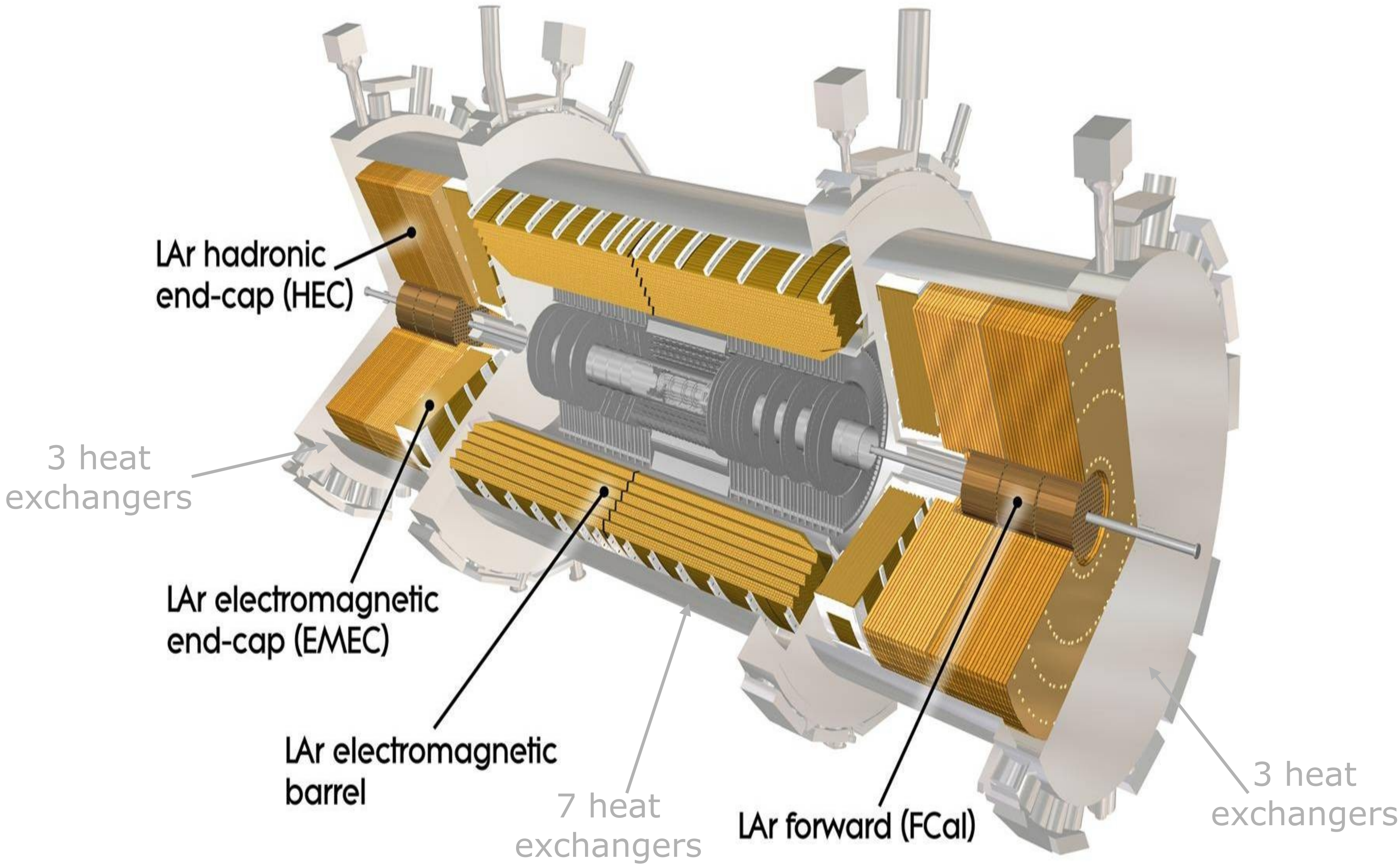
Consolidation

The two compressor stations (low and high pressure) will be backed-up by a complete redundant system.

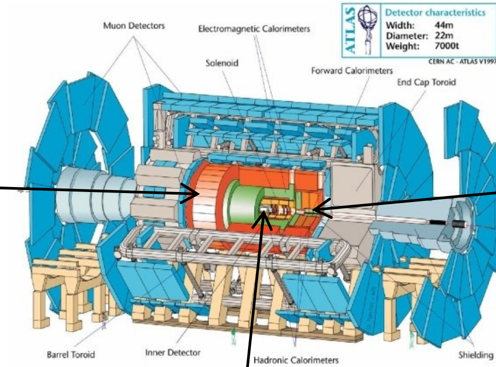
Conclusion:

- Fast dumps only triggered by equipment failure (for example current lead valve);
- Slow dump caused by non availability of refrigerator system works correctly;
- Recuperation time after fast-dump about 3.5 days;

Argon calorimeters

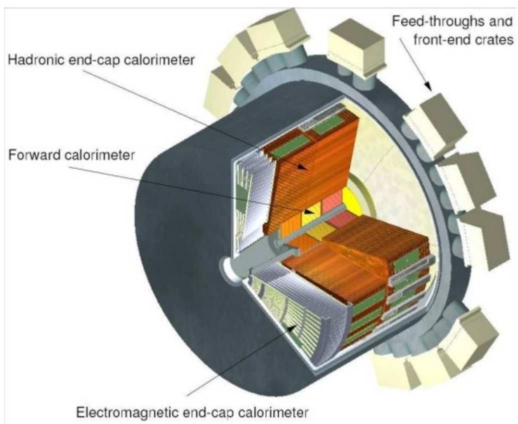


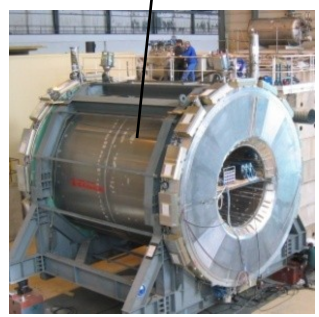
Argon calorimeters

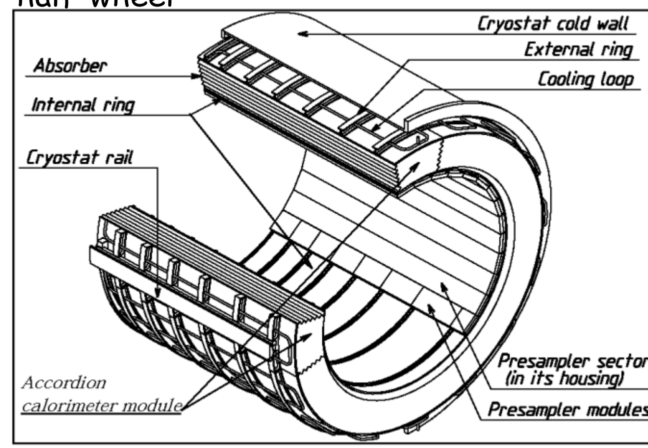


Equipped End-Cap cryostat

Electromagnetic barrel half-wheel







Cryostat diameter	4.3 meter
length	3 meter
Argon volume	19 m^3
Detector weight	219 t
Heat load	2.5 kW

Cryostat diameter	4.3 meter
length	6.5 meter
Argon volume	40 m^3
Detector weight	120 t
Heat load	1.9 kW

Functional requirements (1)

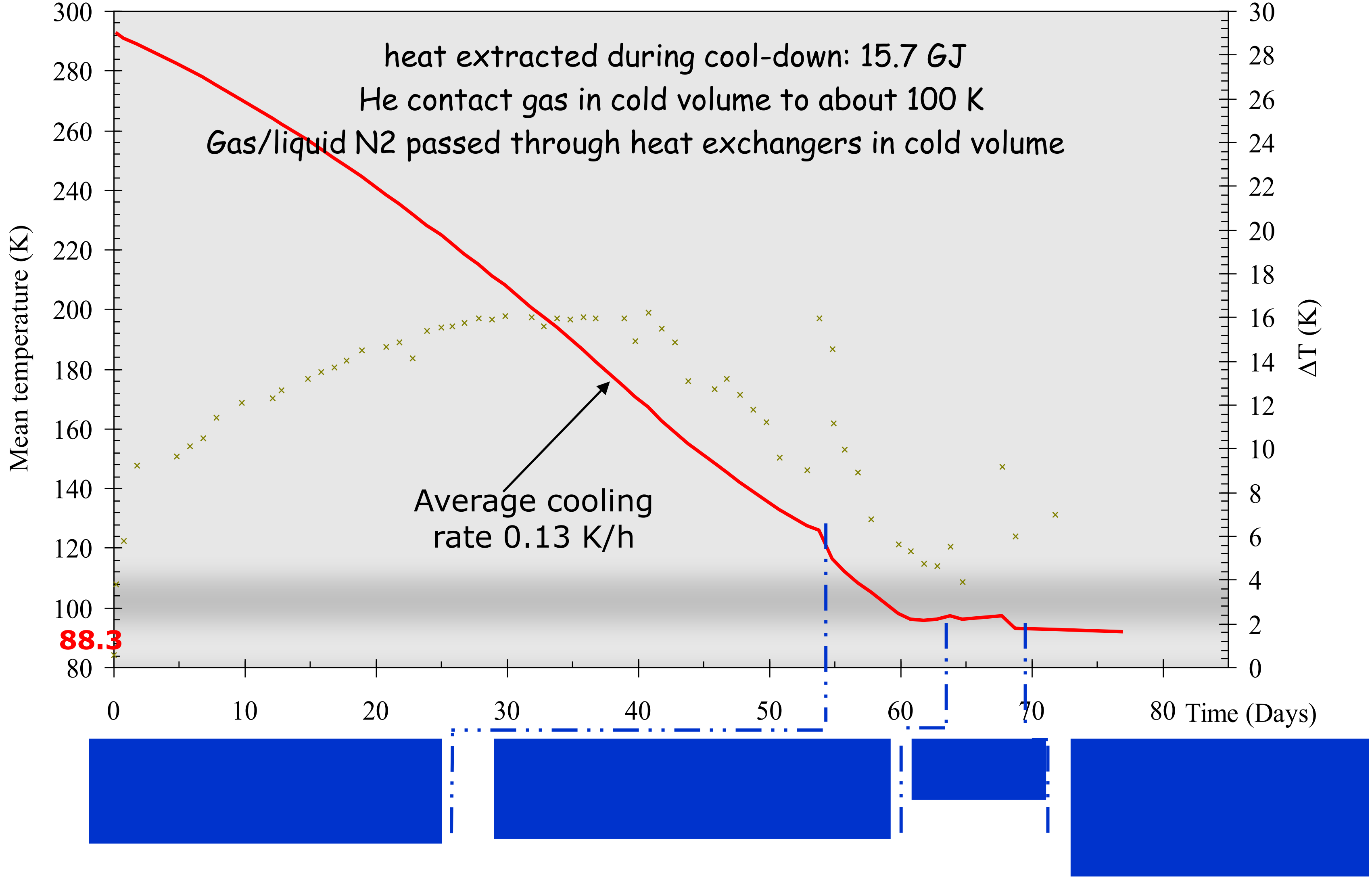
- Maximum temperature gradients during cool down (< 6K..45K)
- No argon gas bubble formation in liquid bath
- Temperature distribution in argon bath < 0.6K
- Temperature stability not well defined in TDR
- Argon purity < 1000 ppb O_2 equivalent (volume)

Functional requirements (2)

Safe continuous operation of the ATLAS LAr cryogenic system:

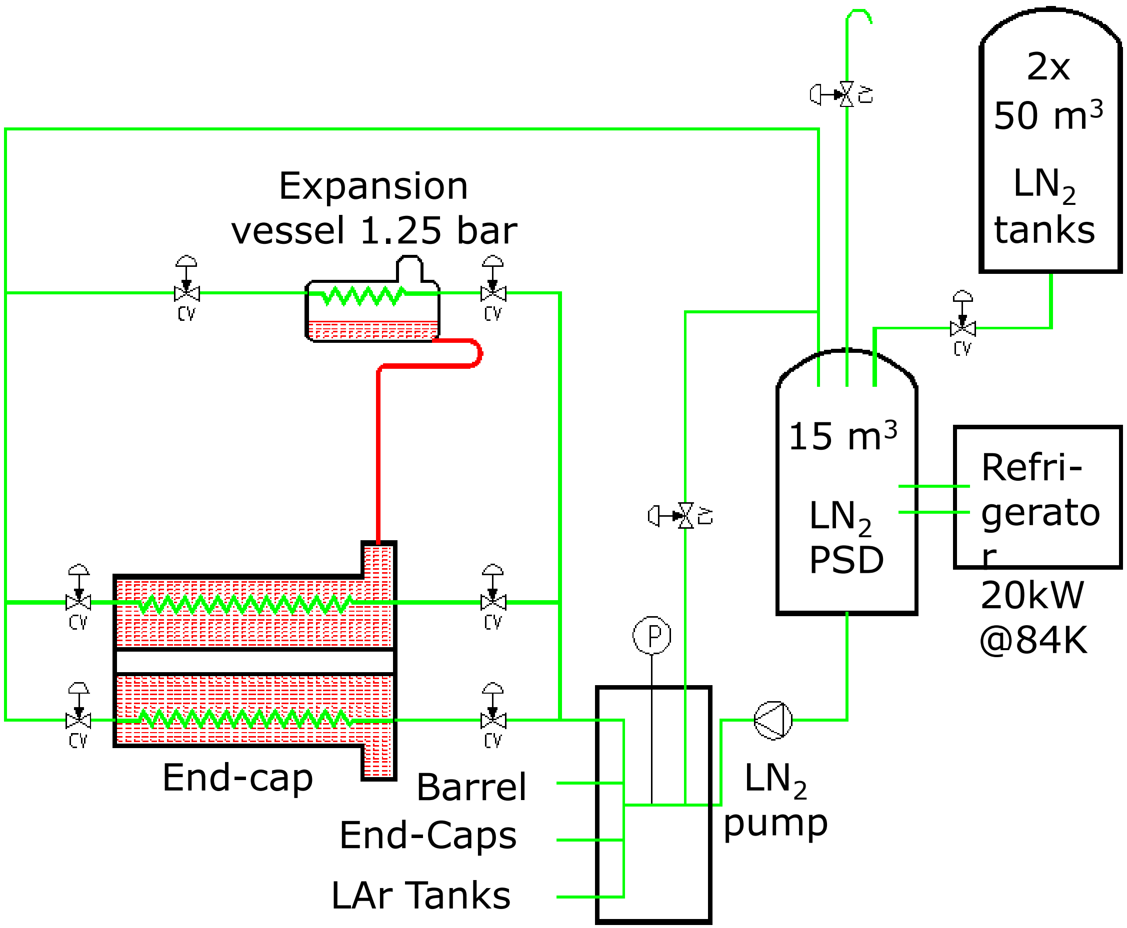
- Foresee that calorimeters shall not be emptied over their lifetime
- Foresee an emergency evacuation of the argon (in case emptying is needed)
- Foresee that End-Cap calorimeters can be displaced longitudinally over 12 meters to give access to the inner part of the ATLAS detector
- Foresee that no condensing (of water) will find place on the signal feed-throughs

End-Cap cool down



- Do not pass temperature gradients during cool down (< 6..45K) OK

Nitrogen circulation



Nitrogen is circulated through heat exchanges via a nitrogen pump;

The 2-phase nitrogen flow is regulated to the same pressure in all 12 heat exchangers placed in the baths;

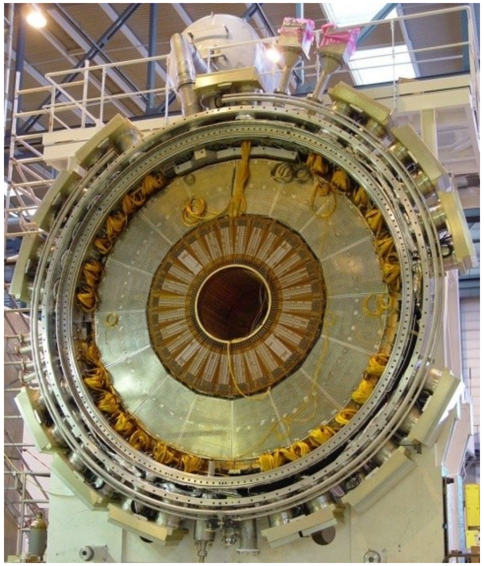
Nitrogen re-liquefied by refrigerator;

System backed up by 100 m^3 N_2 storage at the surface;

Normal operation

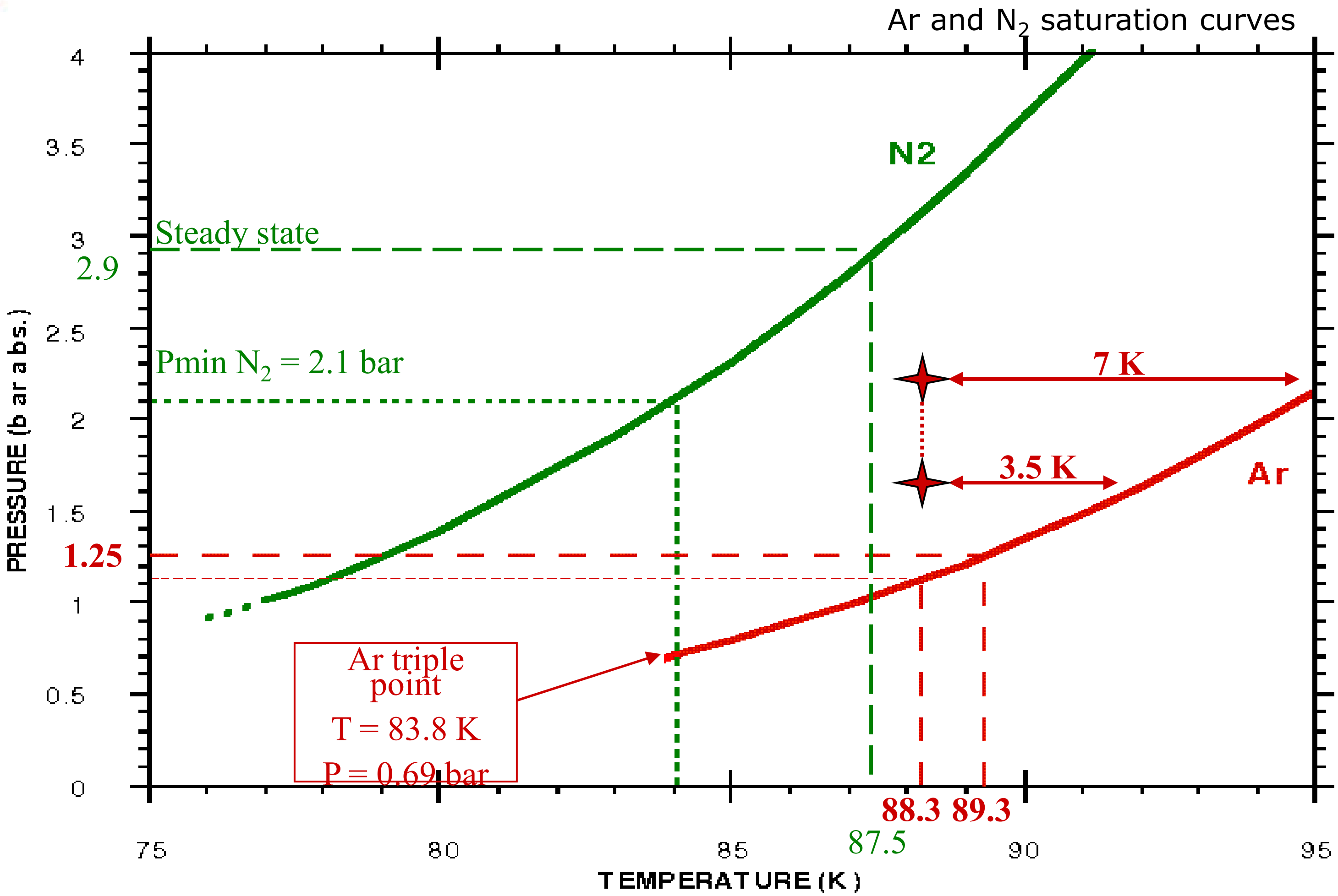
Each of the cryostats equipped with expansion vessel:

Liquid level in expansion vessel;
Expansion vessel placed above level of cryostat;
Expansion vessel distanced from cryostat



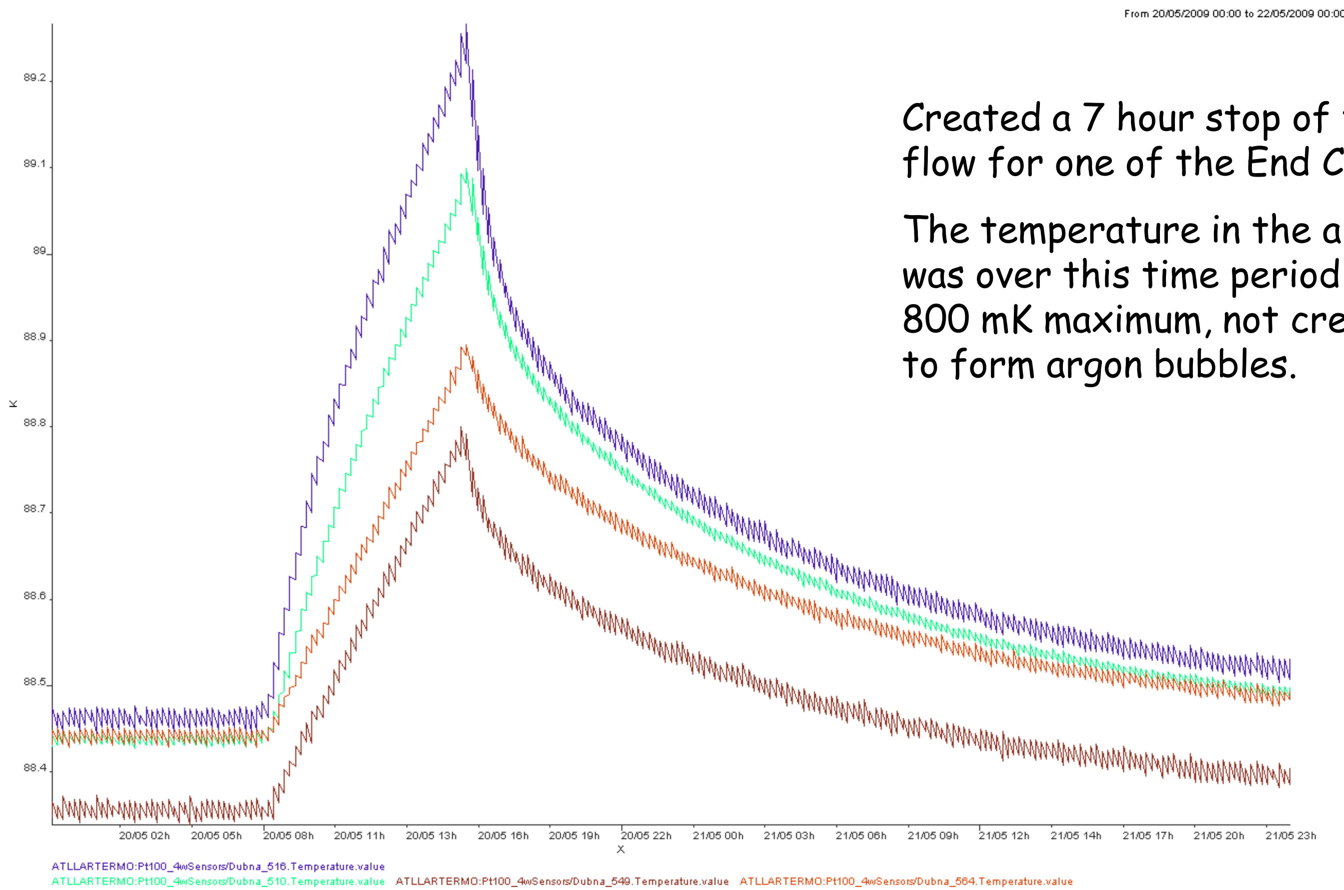
Argon in expansion vessel is regulated to saturated conditions at 1.25 bar (89.3K). The bath temperature is regulated to 88.3 K, creating a liquid which is sub-cooled between 3 K and 7 K in the sensitive volume

Cooling principle



Sub-cooled liquid:
No boiling (no gas production, no noise)
Time to recuperate from cooling failure

Calorimeter cooling stop



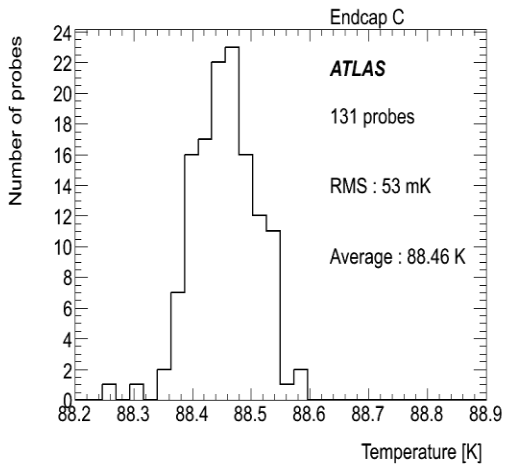
Created a 7 hour stop of the nitrogen flow for one of the End Caps.

The temperature in the argon bath was over this time period rising with 800 mK maximum, not creating a risk to form argon bubbles.

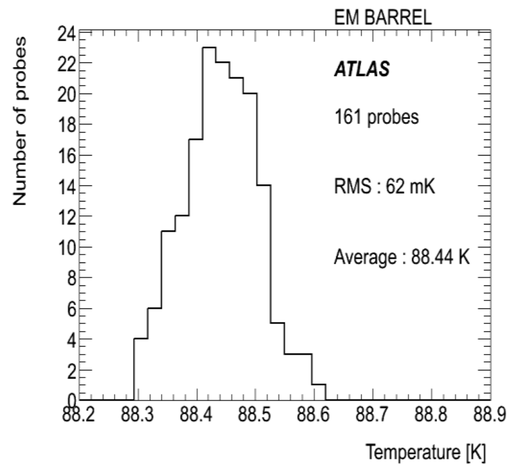
No argon gas bubble formation OK

Result 2010 data taking period

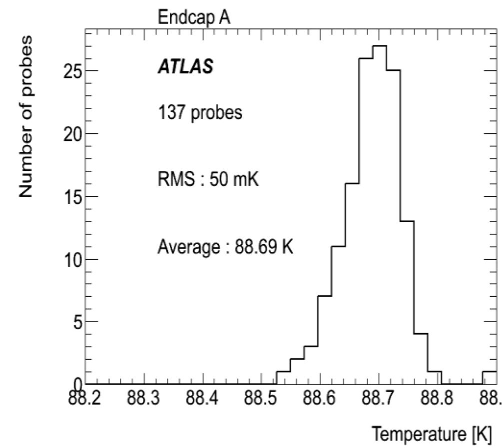
Homogeneity in space



C-side end-cap



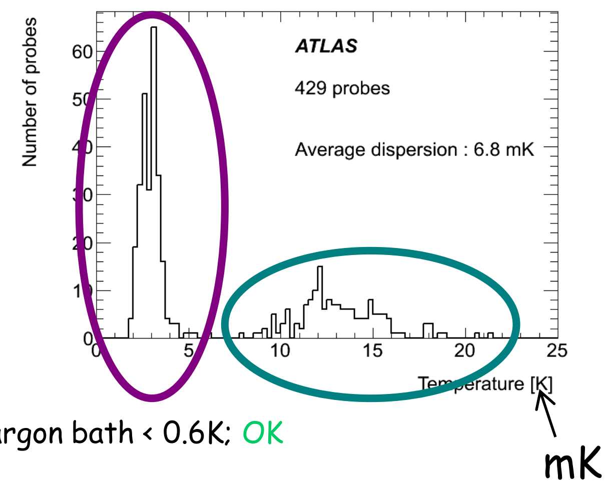
Barrel



A-side end-cap

Stability in time

Endcaps probes
→ Very good stability !
(~3.5 mK)

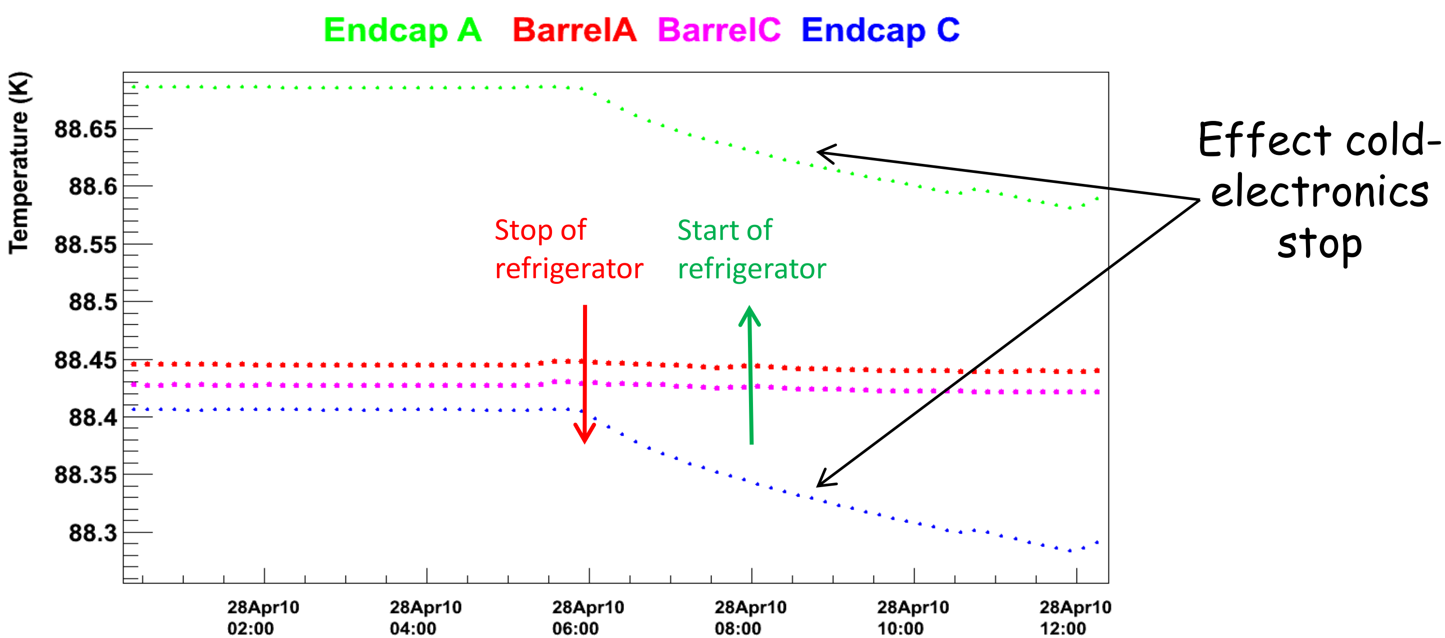


Barrel probes :
Due to the 50 mK step in august (~5 mK without this 2 weeks)

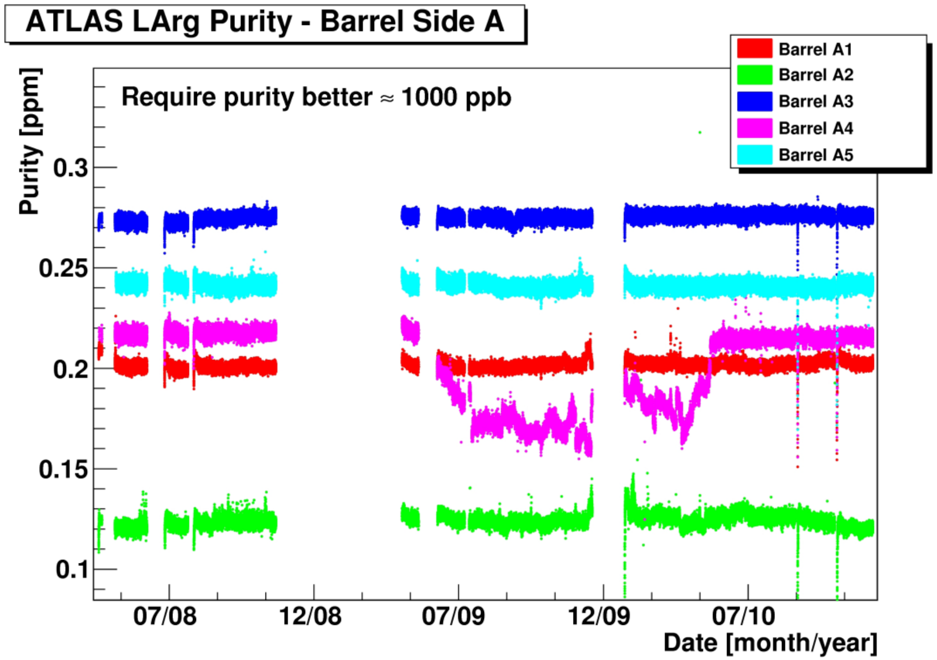
GLA2011 Temperature distribution in argon bath < 0.6K; OK

Result 2010 data taking period

Effect of refrigerator stop on temperature stability of argon baths



Result purity measurements



Results over more than 2 years

(Systematic error approx. 100 ppb)

Argon purity < 1000 ppb O_2 equivalent (volume) OK

Precautions taken against failures of services

• If stop of refrigerator, nitrogen supplied via surface. Spare buffer of 10000 liter in experimental cavern

• Electrical power: EDF/EOS/Diesel 1/ Diesel 2/ UPS

• Compressed air backed-up by nitrogen buffer and by batteries

• Cooling water supply switched to tap water in case of problems with standard cooling water system

• One nitrogen pump is running, two are in stand-by. When supplied via surface, system can even run without pumps

• Warm back-up for each of the PLCs (not really redundant)

• Very slow rise in evacuation vacuum once diffusion pumps are stopped (more than 6 hours till 10^{-4} mbar)

Pre-cautions taken not having to empty the calorimeters OK

Emergency evacuation of liquid argon

Two 50 m3 permanently cooled argon storage tanks have been placed in the experimental cavern

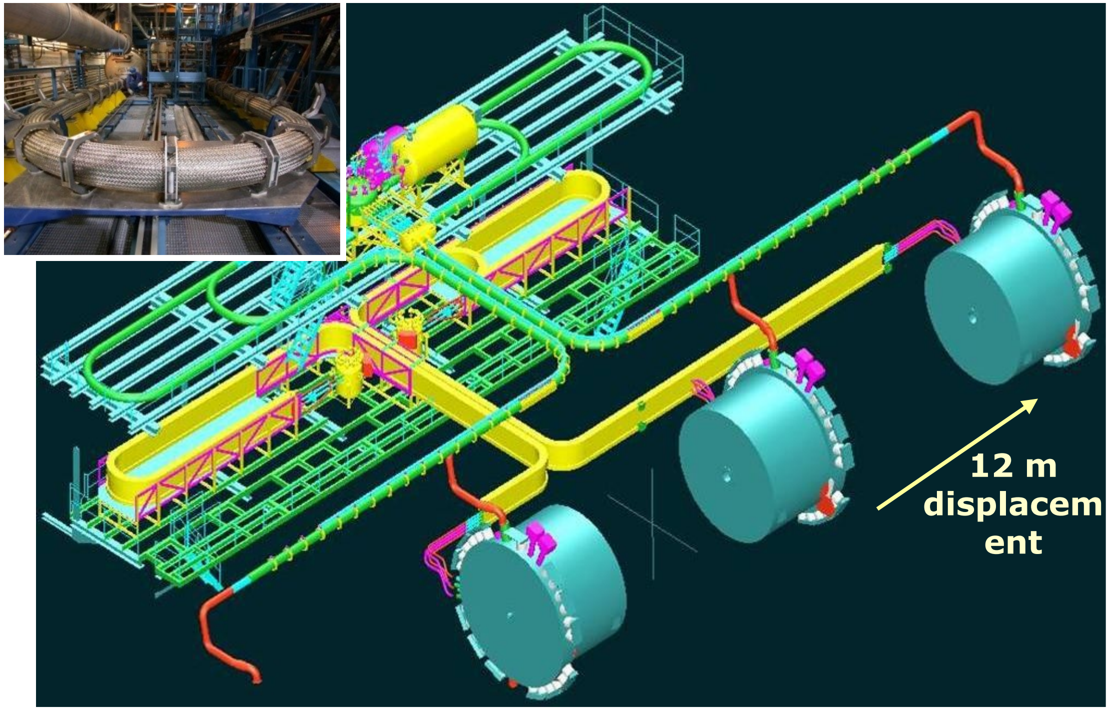
Top of tank is situated at a lower level than bottom of calorimeters

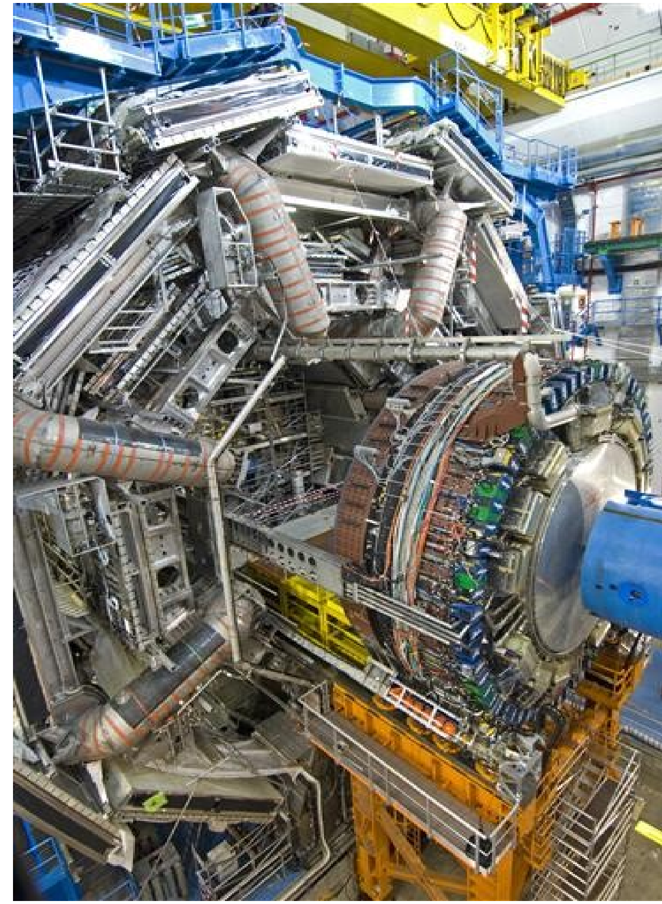
In case of emergency calorimeters can be emptied by gravity into these tanks

First collision in cavern: Emptying system successfully operated

GLA2011 Foresee an emergency evacuation of the argon OK

End Cap displacements





End-Cap displacement OK

Feed-through anti-condense

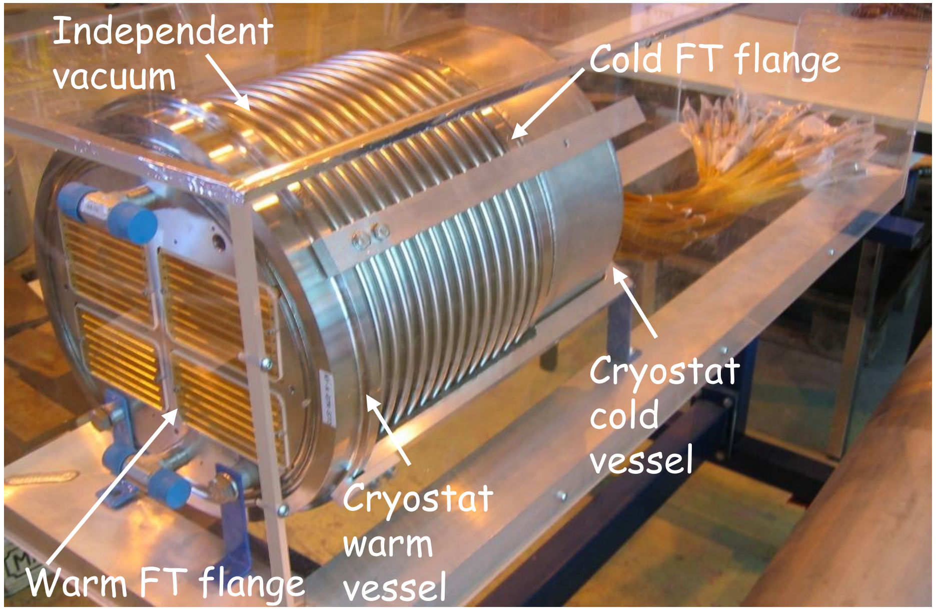
Total of 114 signal feed-throughs

Feed-through: pass signal cable from liquid argon bath to room temperature

Each warm flange independently regulated at 20 °C

Heat load per feed-through into liquid argon bath ~ 15 W

After heating failure about 30 minutes down-to dew point



no condensing on the signal feed-throughs OK

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Conclusions

Argon calorimeters:

- The three ATLAS liquid argon cryostats are operational since beginning 2006
- Temperature gradient and stability are well within the foreseen limits
- Emergency system to empty the cryostats is operational
- System to displace full End-Cap cryostats is operational
- Signal feed-through system is functioning well within the foreseen limits

General:

Cryogenic systems for the experiments function well, data-taking with 3,5 TeV beams and luminosity of > 1 10^{33} $cm^{-2}s^{-1}$ ongoing.