LCD Solenoid Design
Reinforced Conductor R&D
Magnet Services

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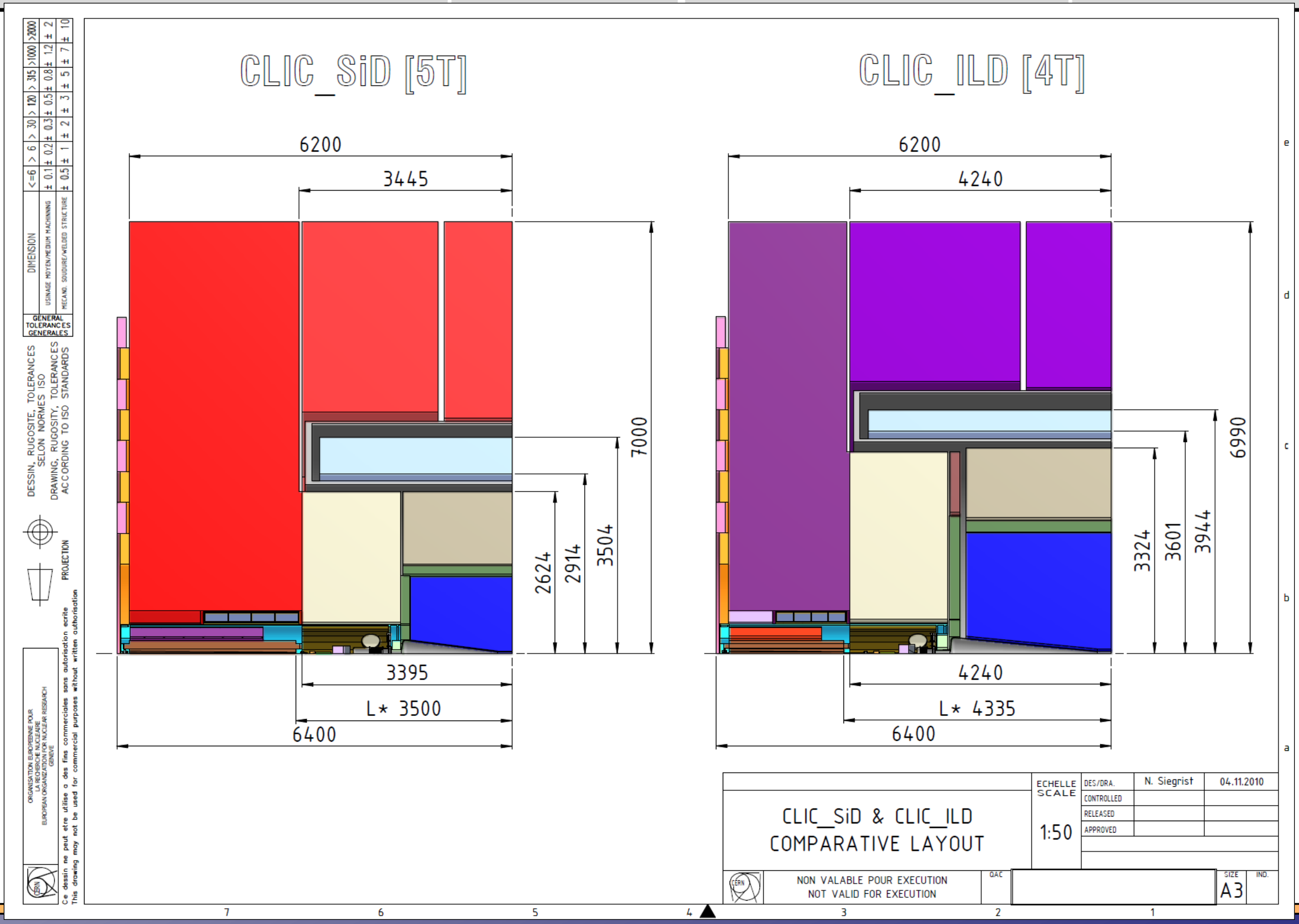
CLIC_Detector central solenoids main parameters.

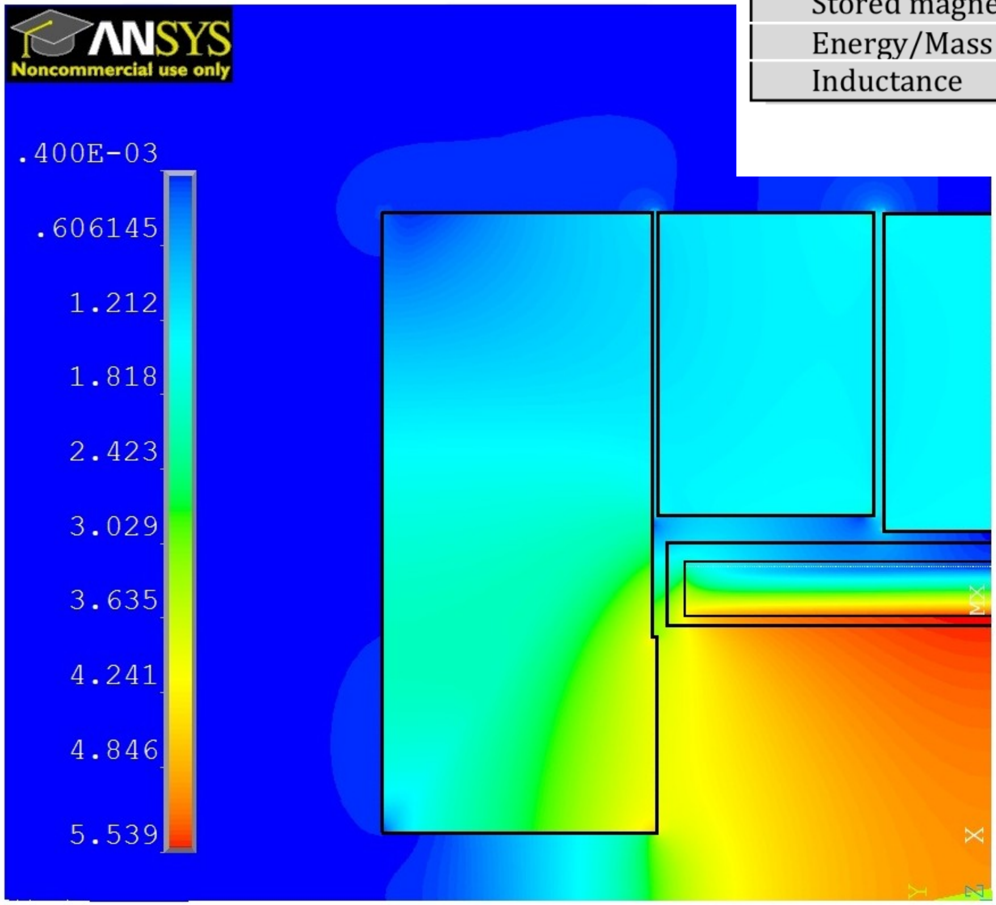
	Nominal magnetic field (T)	Free bore (mm)	Magnetic length (mm)	Cold mass weight (tons)
CLIC_SiD	5.0	5480	6230	170
CLIC_ILD	4.0	6850	7890	210



CLIC_SiD Simulated Magnetic Field.

Nota bene:
CLIC_SiD has been studied first because is the most challenging one. This study represents therefore a proof-of-principle for the CLIC_ILD case.

Nominal magnetic field at the IP	5.0 T
Peak magnetic field on the conductor	5.8 T
Free bore diameter	5.5 m
Magnetic length	6.2 m
Ampere.turns	34 MA.turns
Operating current	18 kA
Stored magnetic energy	2.3 GJ
Energy/Mass ratio	14 kJ/kg
Inductance	14 H



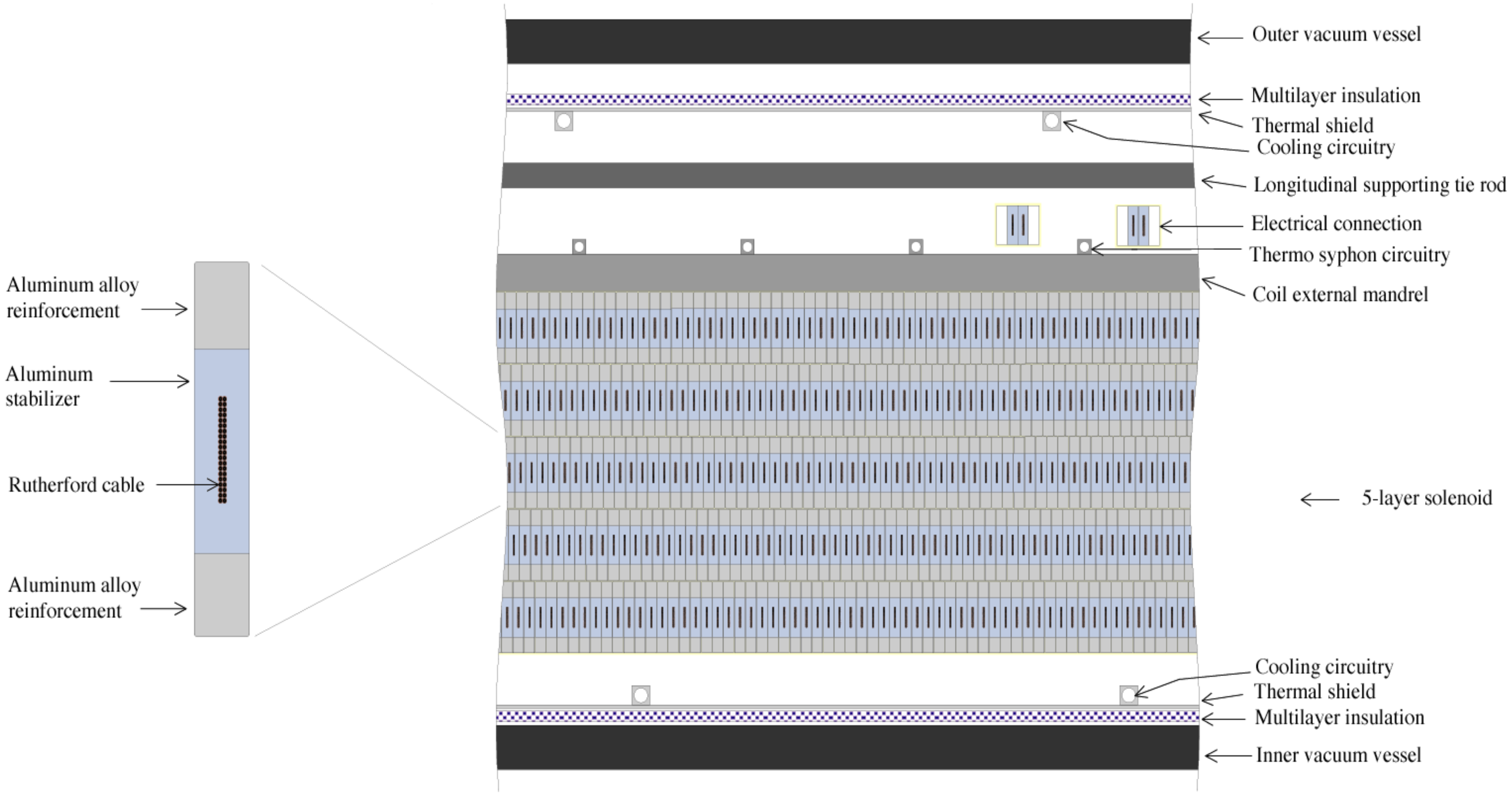
The field map displays the magnetic flux density vector sum in Tesla.

The model is made using the ANSYS magnetic vector potential formulation with the nodal-based method. Infinite boundaries are used.

The model is axis-symmetric. Taking into account the median transversal plan symmetry , only ¼ is modeled.

The iron yoke filling factor is 100%.
The iron properties are taken from CMS iron measurements.
The field is 5T at IP.

Coil Windings:



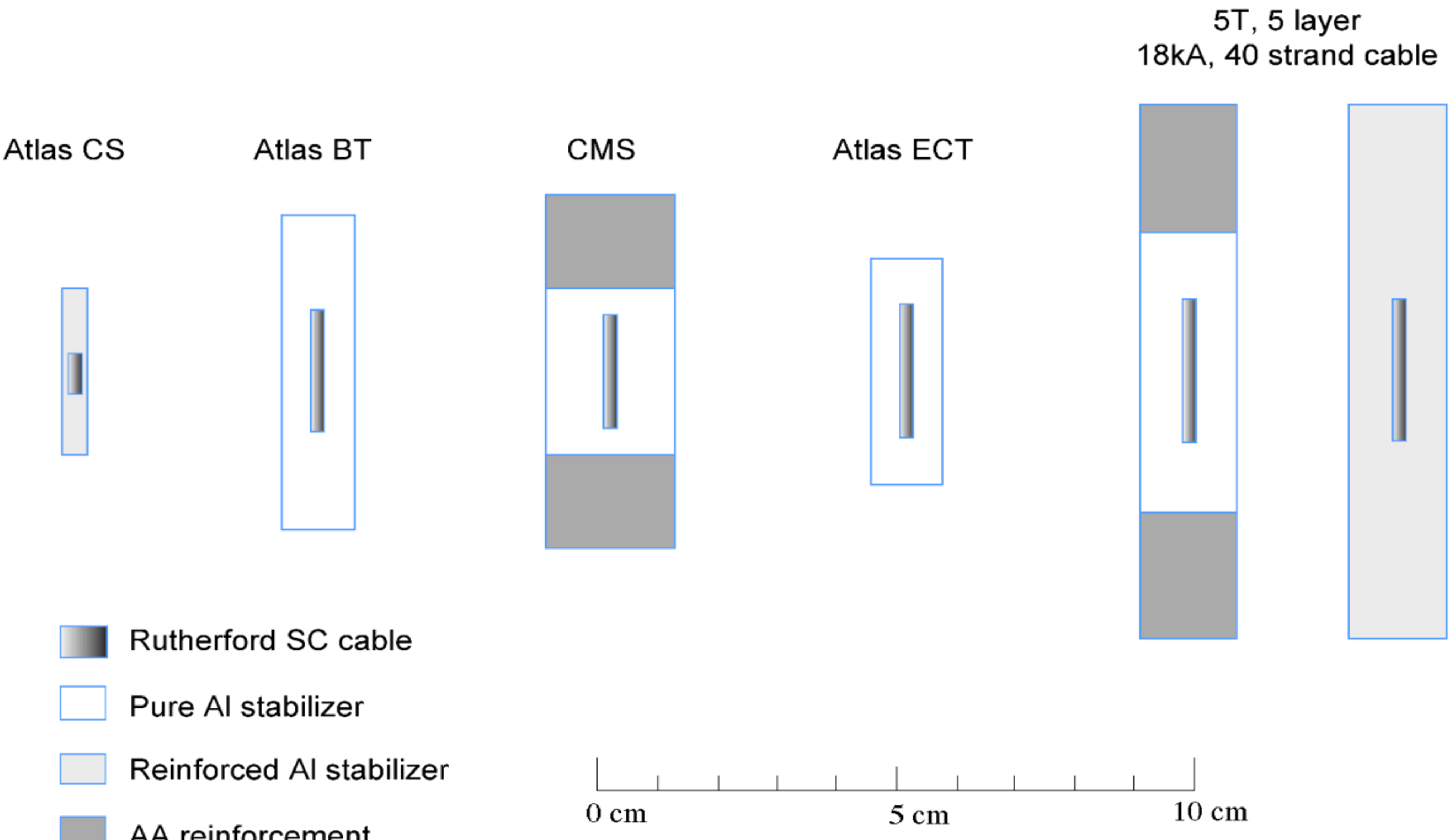
5-layers windings, split in 3 modules, following the CMS coil design by CEA/Saclay.

Winding design & technology.

Radial temperature gradient within **0.1 K**.
Operating temperature of **4.5K** on the innermost layer .
Temperature margin at 5.8T of **1.5K** with 40 strand Rutherford cable with state-of-the-art NbTi conductor with Jc(4.2K, 5T)=3000 A/mm^2.
External mandrel with quench-back function.
Inter-layer & inter-module joints on the exterior of the mandrel.
Inner winding with resin impregnation under vacuum.

Number of turns	1880
[redacted]	
Ratio H / W	6.3
[redacted]	
$I_{operation}/I_{critical}$ (4.5K, 5.8T)	32%
[redacted]	
Coil total thickness	550 mm

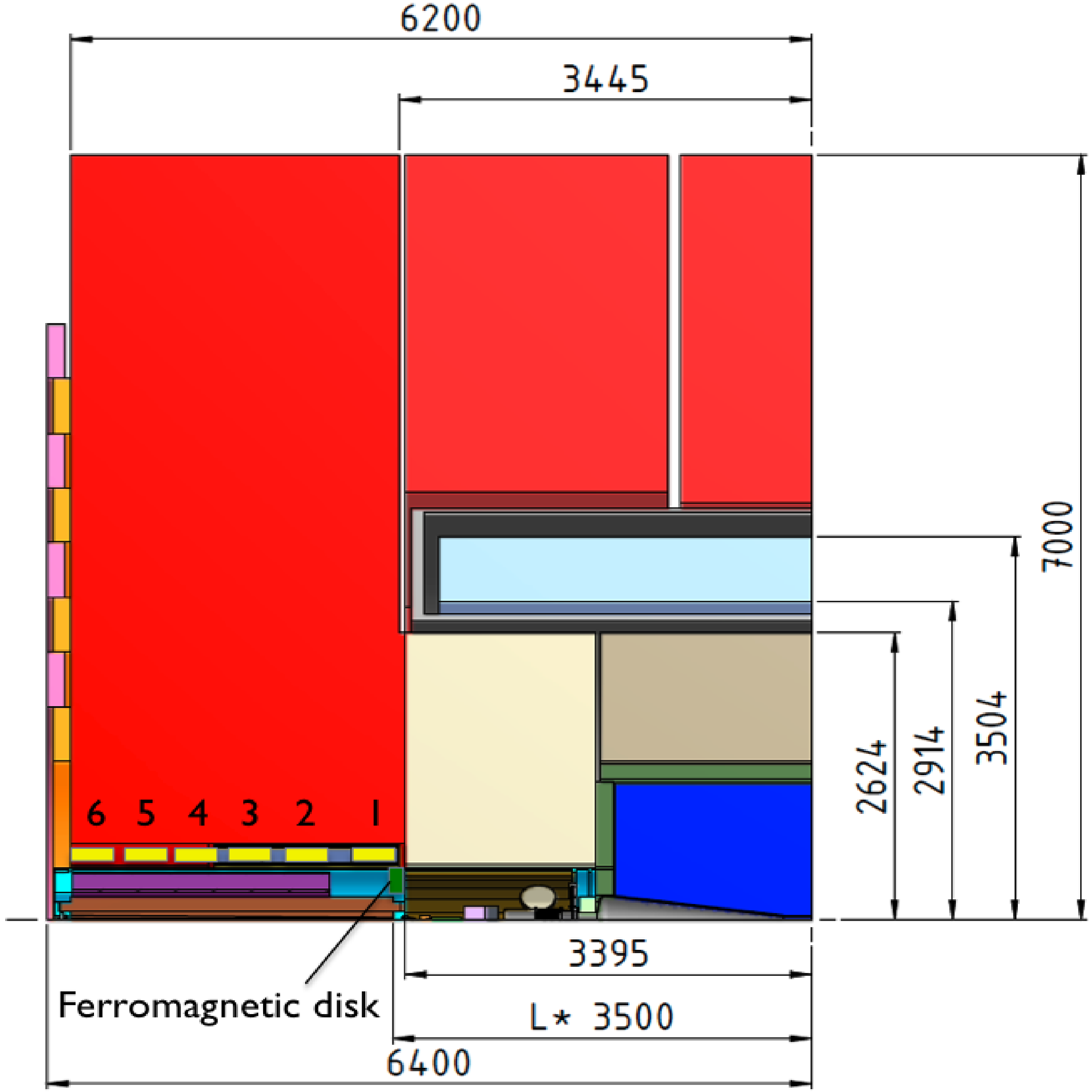
Superconductor options.



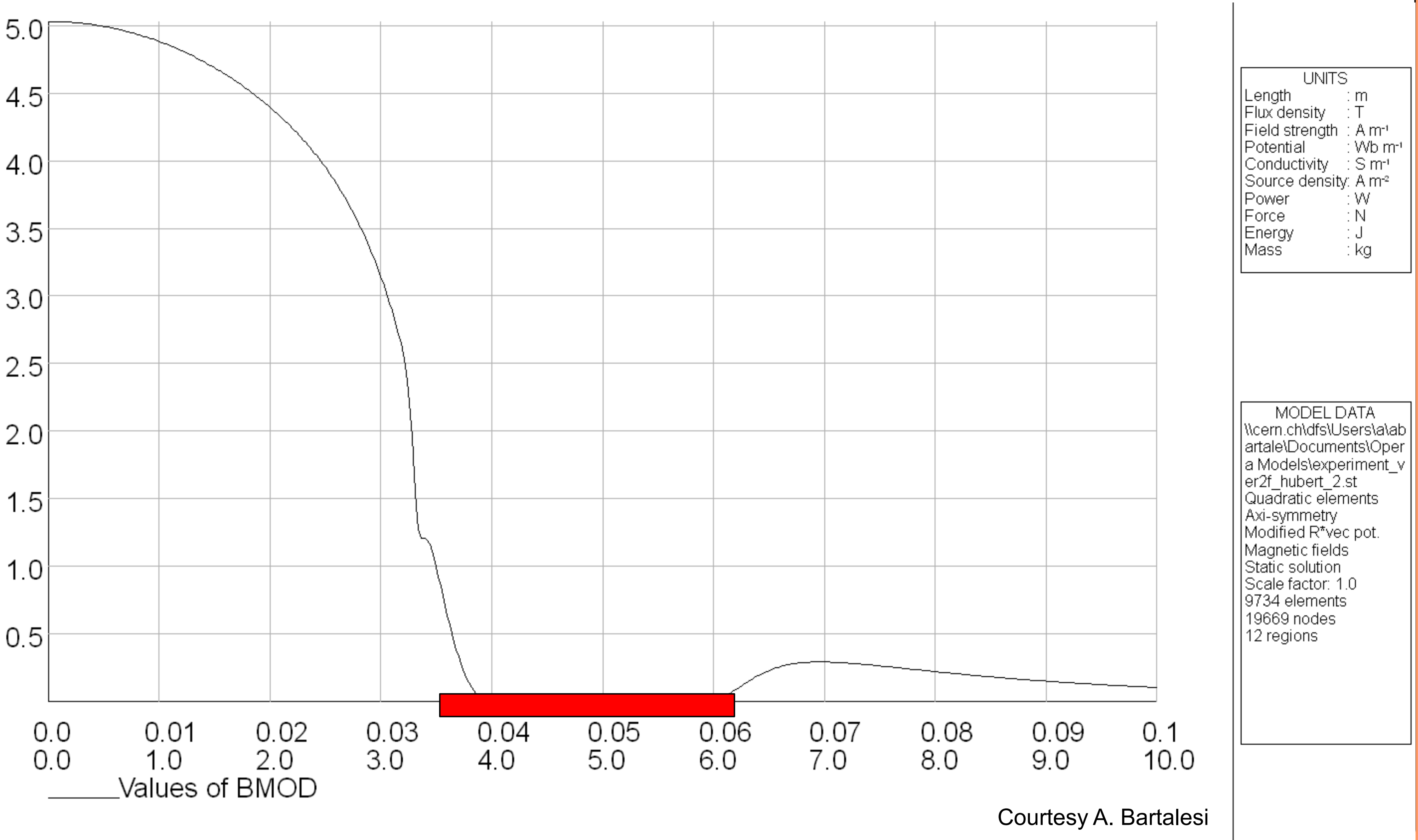
Anti-solenoid study.

Anti-solenoid coils

Coil	A/mm^2	Aturns
1	80	1,93x10^{6}
2	28	5,39x10^{5}
3	15	2,89x10^{5}
4	3,5	6,74x10^{4}
5	0,1	1,92x10^{3}
6	12	1,58x10^{5}



Anti-solenoid study.



Courtesy A. Bartalesi

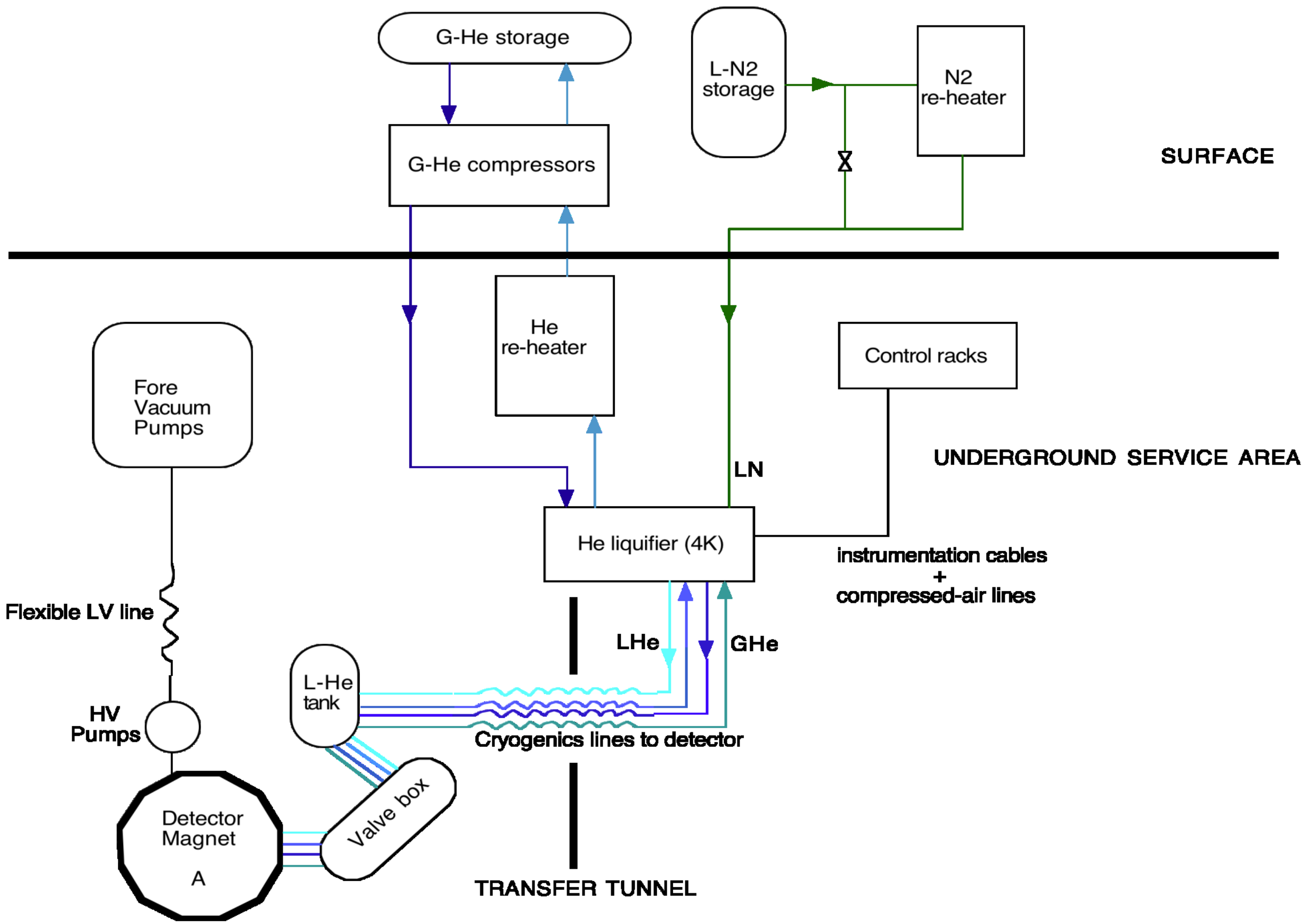
Magnet Services & push-pull scenario.

The two most challenging magnet services are the cryogenics & vacuum system and the powering & protection one.

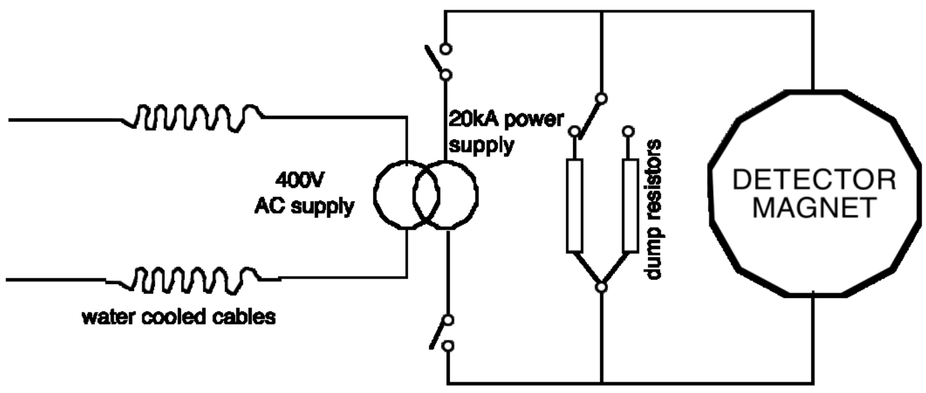
The He liquifier is an heavy and delicate components that cannot move with the detector, neither sit too close, due to the magnetic stray field. Its ideal location is the side service cavern, along with the fore vacuum pumps, that are noisy in terms of vibration and need easy access for maintenance.

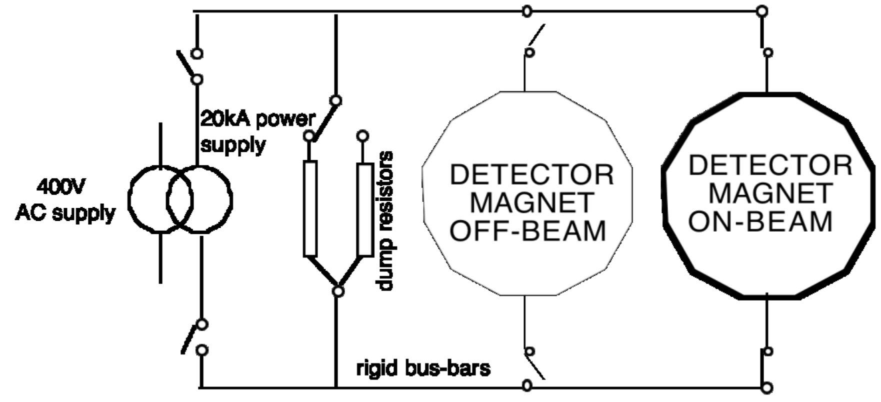
The power supply, and its associated breakers, is also a huge and heavy component whose location is better chosen in the service cavern. On the contrary, the dump resistors protecting the coil, should stay as close as possible to the magnet, but consideration on the total energy (> 1GJ) dissipated in the cavern may lead to move them away from the detector.

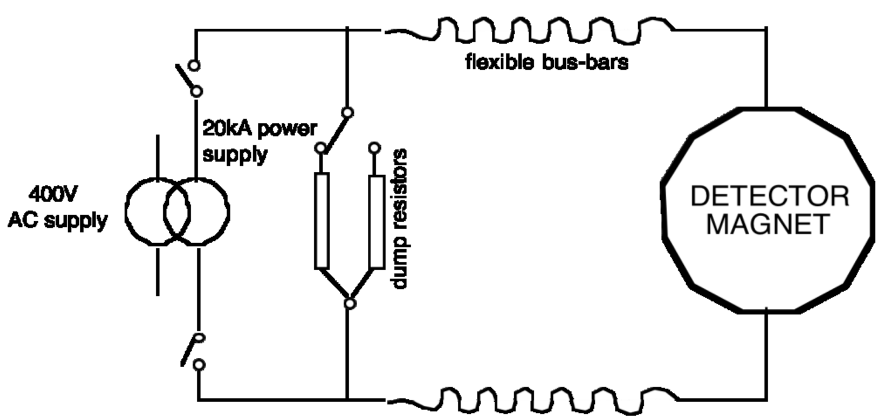
Cryogenics & vacuum block diagram

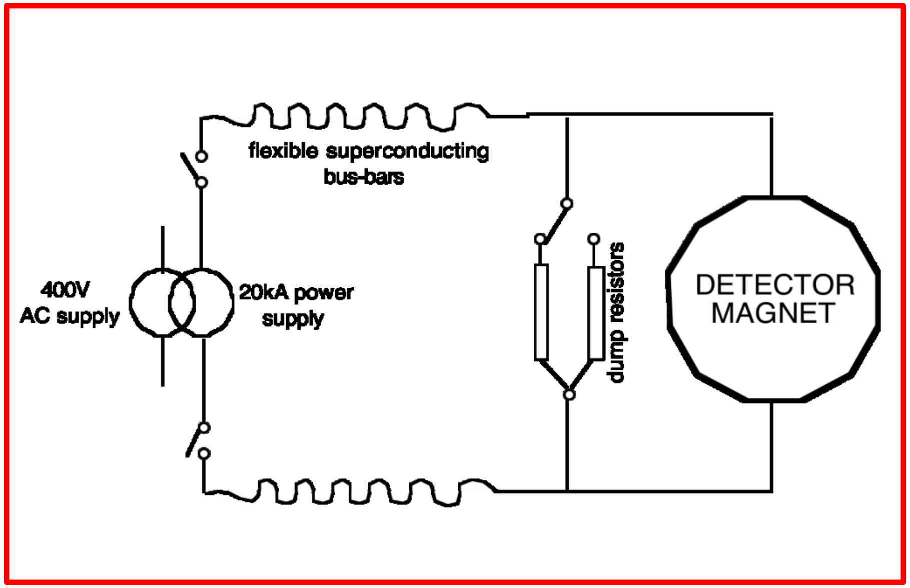


LCD Solenoid, Conductor R&D, Magnet Services









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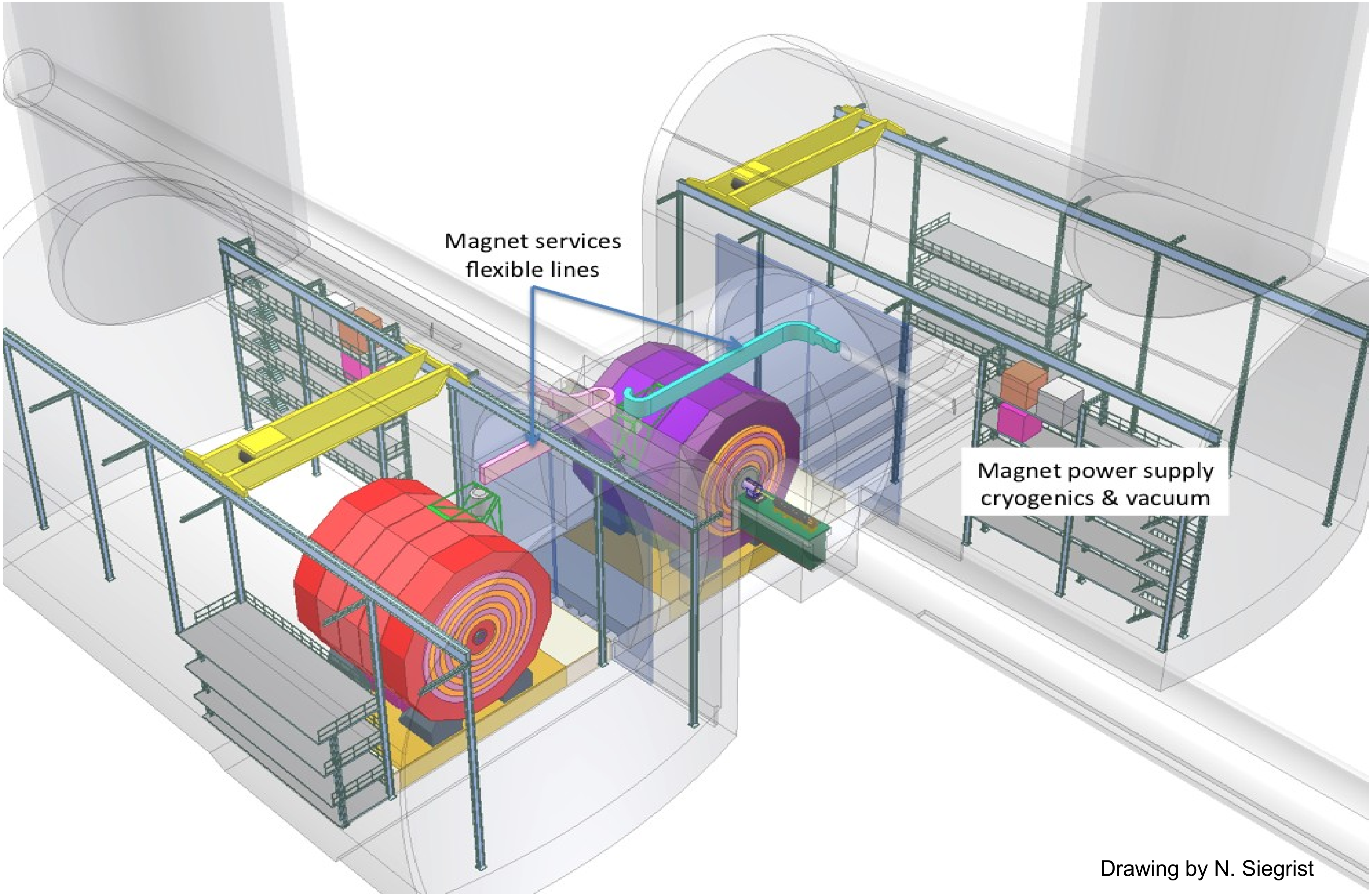


Drawing by N. Siegrist

Flexible cryo & vacuum lines.

The detector solenoid has to stay cold during the push-pull period, i.e. liquid Helium has to be guaranteed via flexible transfer lines. Vacuum inside the coil cryostat could be kept by simple cryo-pumping during push-pull, but a flexible rough vacuum line is necessary anyhow.

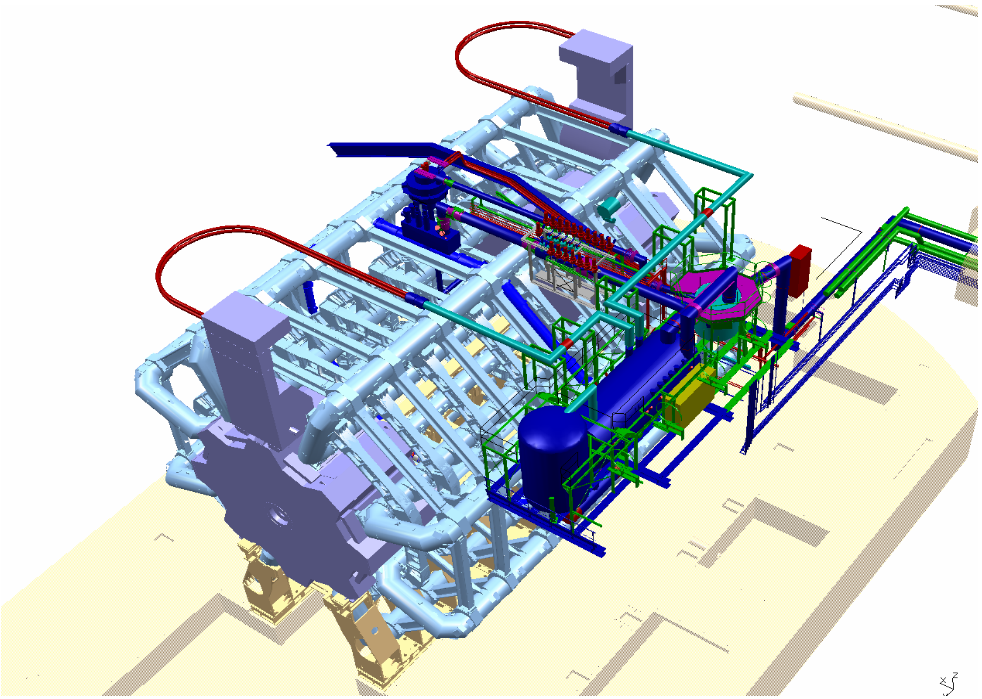
CMS has 30m long rigid cryo transfer line, vacuum insulated
+ 50m long rigid Φ230mm primary vacuum line (10^{-3} mbar)
Not applicable to push-pull.

Flexible cryolines have been successfully installed to cool Atlas Endcap Toroids

LHe lines diameter	*58mm*
Outer shielding	*110mm*
Vacuum envelope	*143mm*

SiD foresees a flexible cryoline Φ160mm, vacuum insulated

Atlas flexible cryo-lines.



Courtesy A. Dudarev

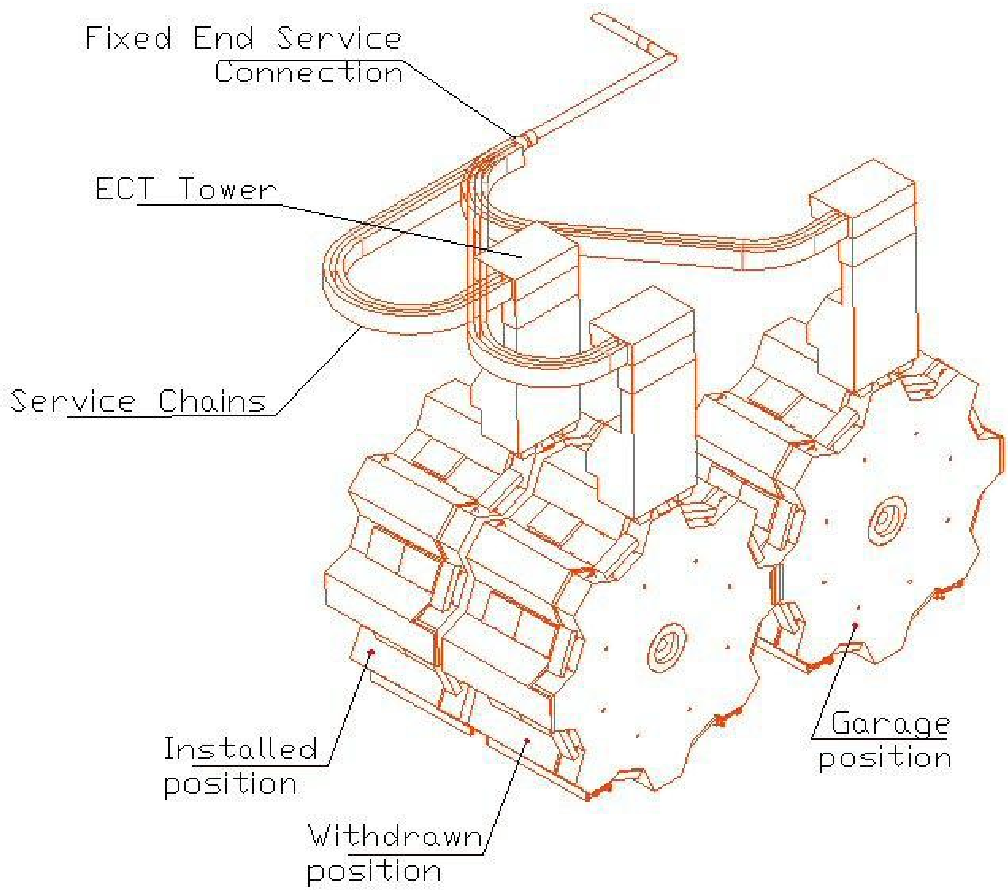
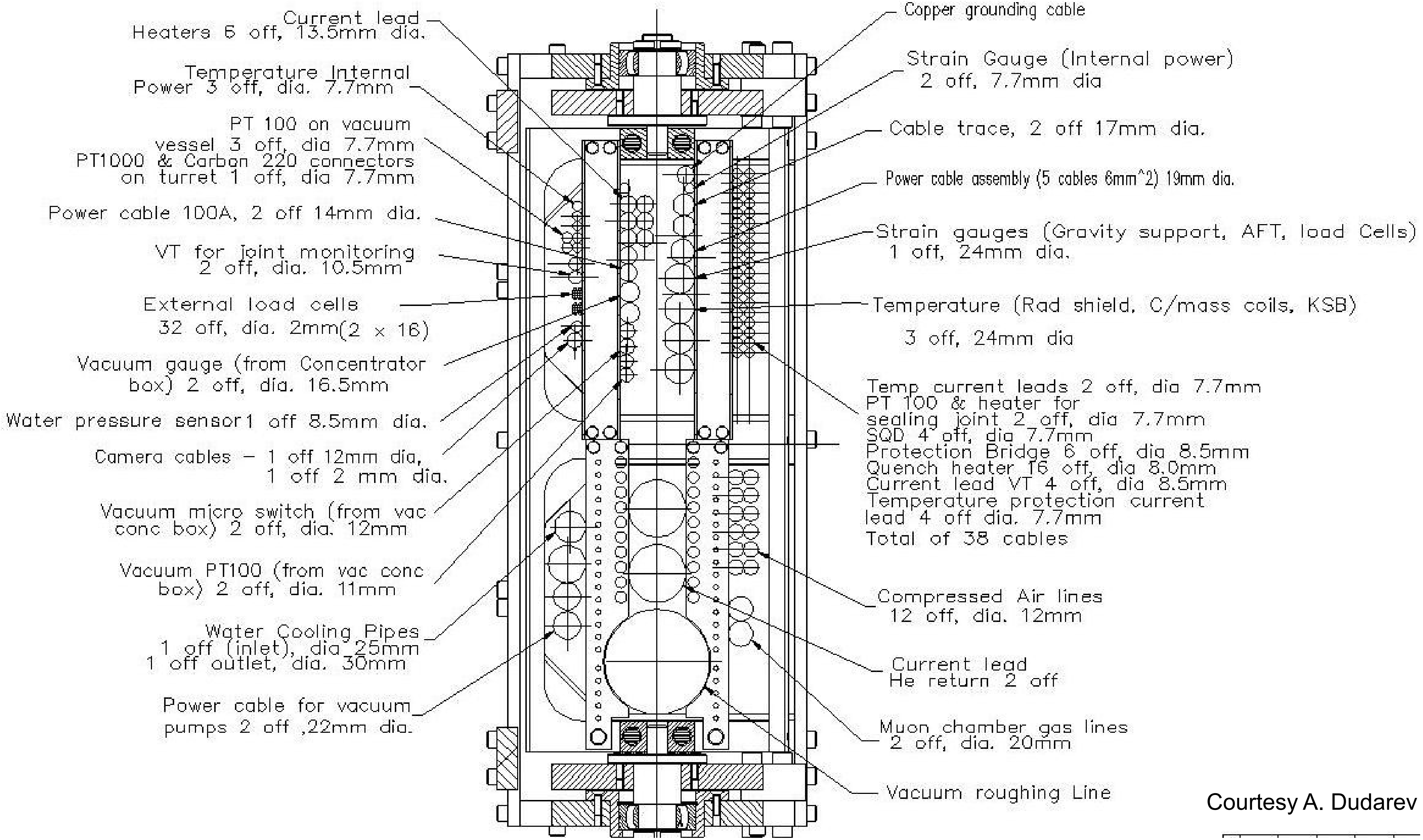


Fig 1.

Atlas flexible service-lines.



Courtesy A. Dudarev

Flexible HTS bus-bars.

Despite the fact that during push-pull, the detector magnet is obviously off, a permanent connection of the solenoid power supply to the coil current leads would save precious time and avoid risks associated with manipulation.
This line shall be able to carry 20kA in a self-field of about 0.6T, over a length of some 60m. A flexible resistive line would take too much space in the cavern and have a significant voltage drop ΔV (in addition to the power dissipated $P=\Delta V x I$).

*CERN is actually developing the design of a semi-flexible, vacuum insulated, HTS (**MgB_2**) line for the LHC upgrade.*
The characteristics of this powering line are the following:

- ❑ *Nominal current: 110kA at 20K and 0.8T*
- ❑ *Maximum current: 130kA at 20K and 0.8T*
- ❑ *Cooling: GHe, from 5 to 20K*
- ❑ *Length: 100m*
- ❑ *Vacuum envelope: Φ90mm*
- ❑ ***Minimum bending radius: 1.5m***

Proposal for powering lines : flexible HTS bus-bars.

Prototypes of the multi-cables HTS powering line (courtesy A. Ballarino)

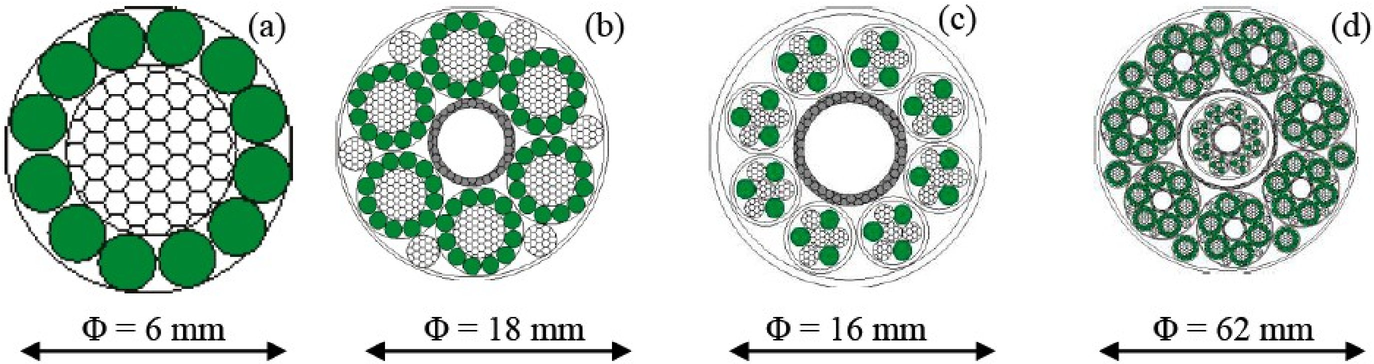


Figure 1. Layout of: 3 kA cable (a), 14 kA cable (b), group of 8 × 0.6 kA cables (c), configuration of 7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables (d). The MgB_2 is shown solid, the copper is shown hatched.

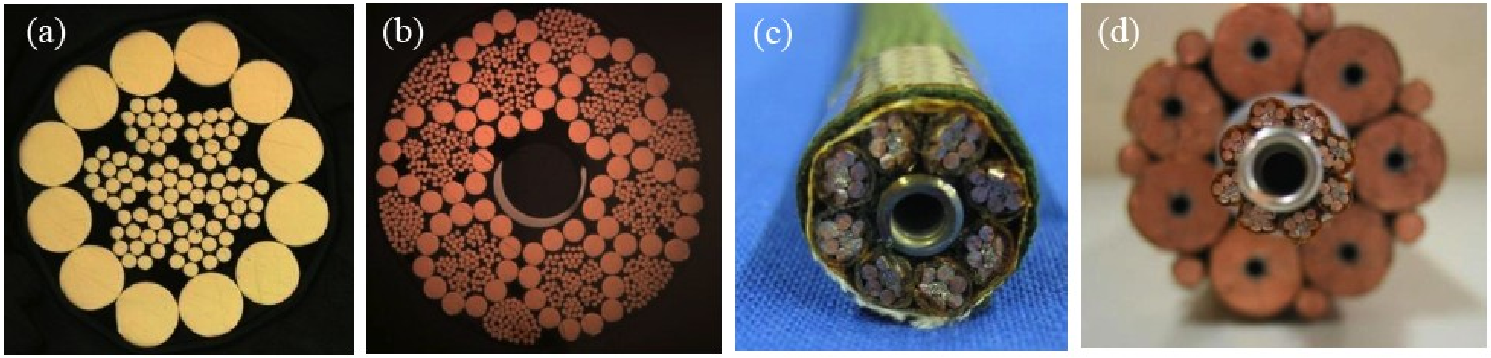
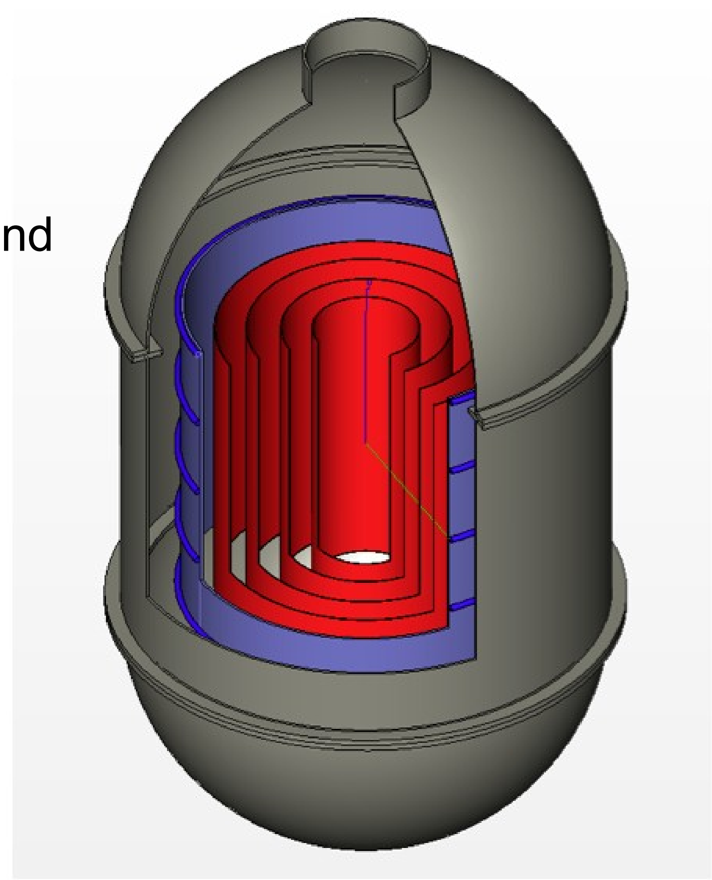
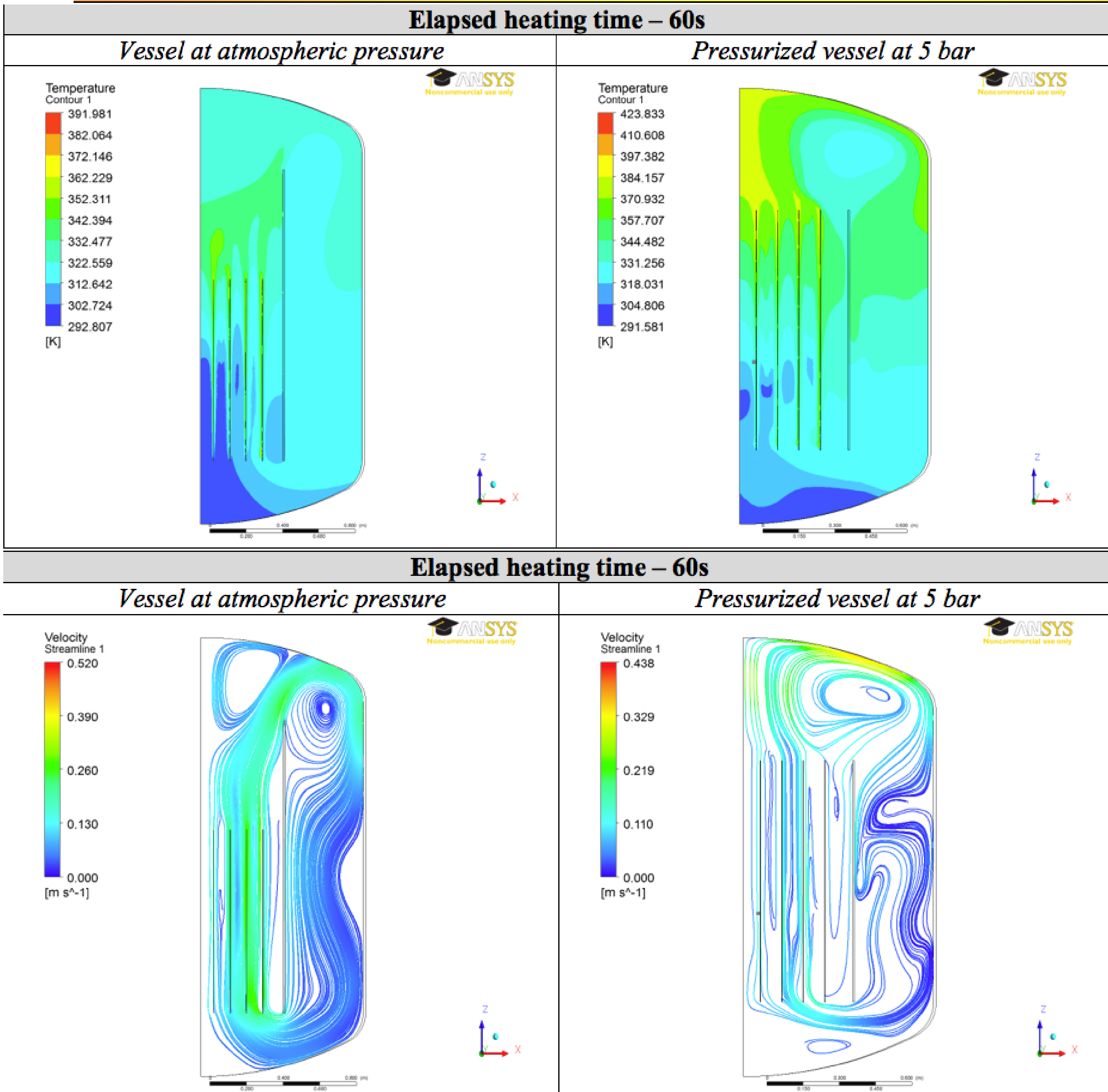


Figure 2. Mock-up of: 3 kA cable (a), 14 kA cable (b), group of 8 × 0.6 kA cables (c), configuration of 7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables (d). The external diameter of each assembly is reported in Figure 1.

Proposal for dump-system : compact water-cooled resistors.

Total stored magnetic energy	≈ 2.50 GJ
Energy extracted by dumping system	≈ 1.25 GJ
Solenoid reference current (I)	≈ 20 kA
Solenoid inductance ($L = 2E/I^2$)	≈ 12.5 H
Dump resistance (R)	≈ 30 mΩ
Discharge voltage	≈ ±300 V wrt ground
Peak discharge power ($Ppeak = I^2R$)	≈ 12 MW
Discharge time constant ($t = L/R$)	≈ 416 s





Simulation done by F. Ramos

Stray field considerations.

- Requirement for the magnetic field outside of detector is an important factor which defines the amount of iron in the detector (or degree of compensation for endcap hybrid-design).
- Effects of any field outside of detectors on the beam shall be corrected, and the requirements should come from human safety factor, from the limit of field map distortion due to off-beamline detector and from effects on cavern equipment.
- From personnel safety considerations, field on any external surface of the detector shall be less than 200mT, while the field in non-restricted area (including near the off-beamline detector) shall be less than 10mT.
- The magnetic field effect from the off-beamline detector onto the on-beamline detector must limit distortion of magnetic field map of the latter, anywhere inside its tracking volume.
- The design criteria assumed for LCD Magnets is to have less than <u>5mT magnetic field induction at 15m</u> distance from the detector axis.

Conclusion & work-plan for the future.

- Further studies on coil winding, thermosyphon flow, quench protection. We can run the same study for CLIC_ILD and eventually adapt drawings and tables to make this work compatible with ILC_DBD.
- Conductor R&D: trial extrusion & cold working of a large cross-section conductor, with Ni doped stabilizer (CERN/KEK collaboration). Measurements of mechanical & electrical characteristics at room and liquid He temperature (CERN/KEK/INFN).
- Coil instrumentation: development of optical fiber based temperature, strain & B-field sensors, to be embedded into the coil windings.
- Anti-solenoid: further study on current optimization and possibly construction of a short length prototype.
- The effects of the stray-field will be carefully looked. Any effort to limit the stray-field via an optimized yoke design and/or the use of tunable coils on the yoke endcaps will be pursued.

Conclusion & work-plan for the future.

- The push-pull scenario leads to an integrated design of detector infrastructures. Integration of magnet services with cavern layout requires a close collaboration with the civil engineering group.
- A compromise between on-board services and a remote “service block” has to be found, making use of cable-chains that assure permanent connections with the service block, allowing a smooth movement of the detector during the push-pull operation.
- Cryogenics and vacuum flexible lines have been already successfully used at Atlas. Need to be adapted to CLIC detector magnet. An existing R&D program for a HTS powering line for LHC upgrade could give good indications for a 20kA HTS line cooled with GHe between 5 and 20K, to be employed for detector magnet power-lines.
- The problem of a compact on-board dump-system could be solved with a water-cooled resistor-bench. A 1/10 scale prototype could be useful to validate our simulations.