CLIC Detector Main Solenoid Design & Status Report

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Andrea Gaddi[1], Benoit Curé[1], Alain Hervé[2]
[1] Physics Dept. – CERN
[2] University of Wisconsin

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Main solenoid design for CLIC_SiD and CLIC_ILD detectors.
  winding design
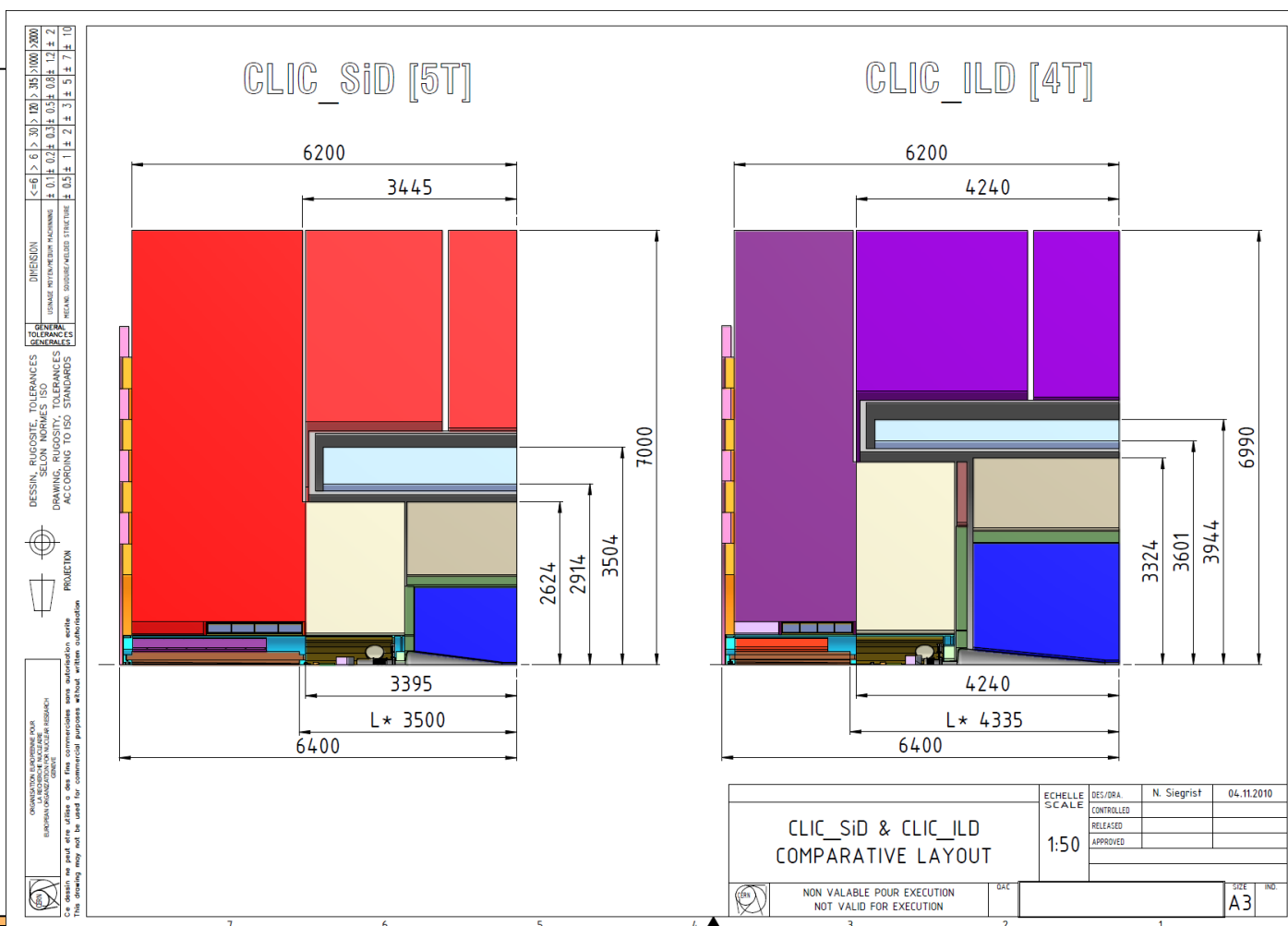 cable technology
  magnet services & infrastructures

R&D activity & collaborating Institutes.

Working plan & conclusions.

CDR and other documents.

CLIC_Detector central solenoids main parameters.

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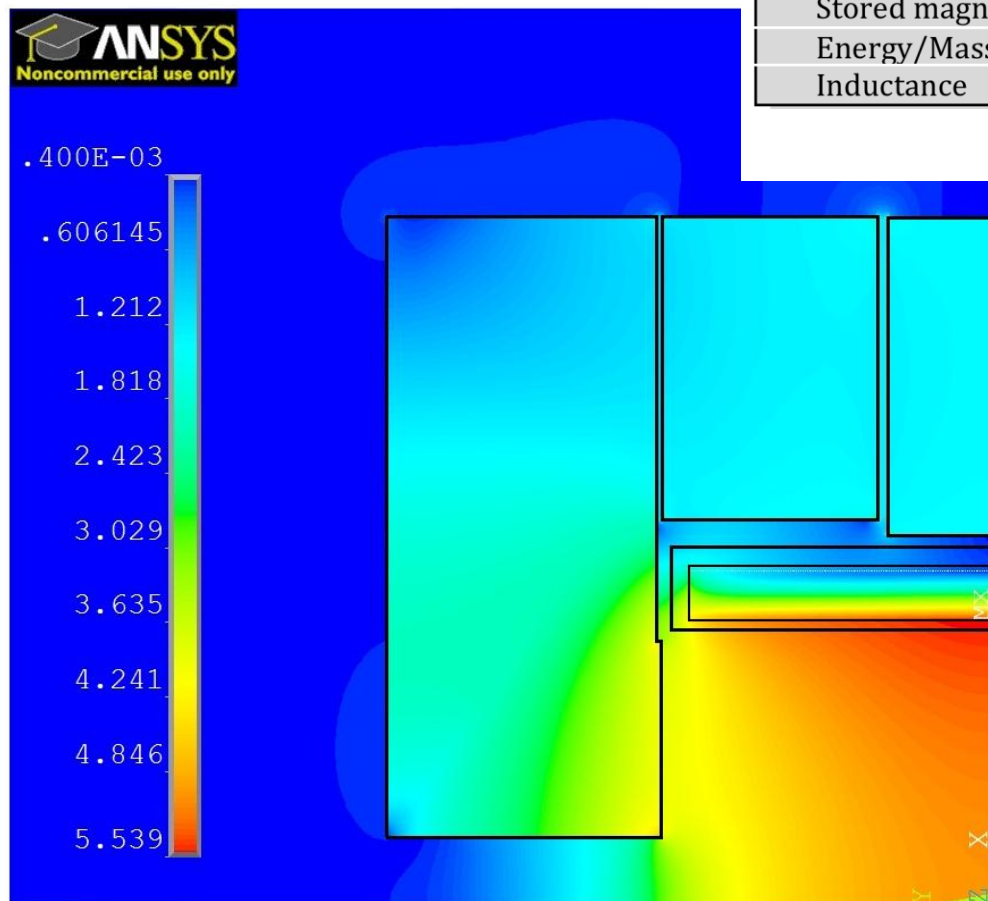
The field map displays the magnetic flux density vector sum in Tesla.

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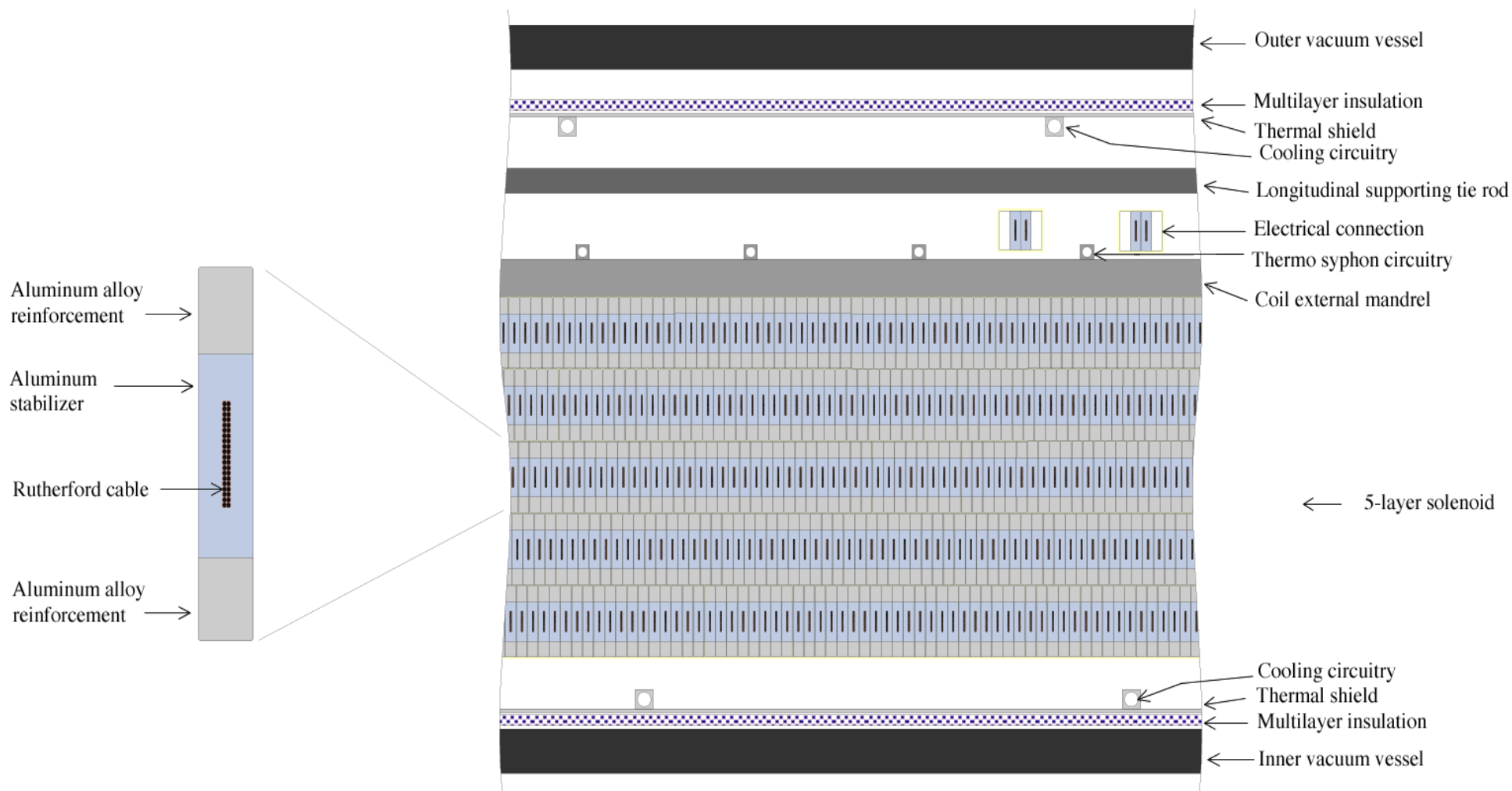
5-layers windings, split in 3 modules, following the CMS coil design by CEA/Saclay.

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
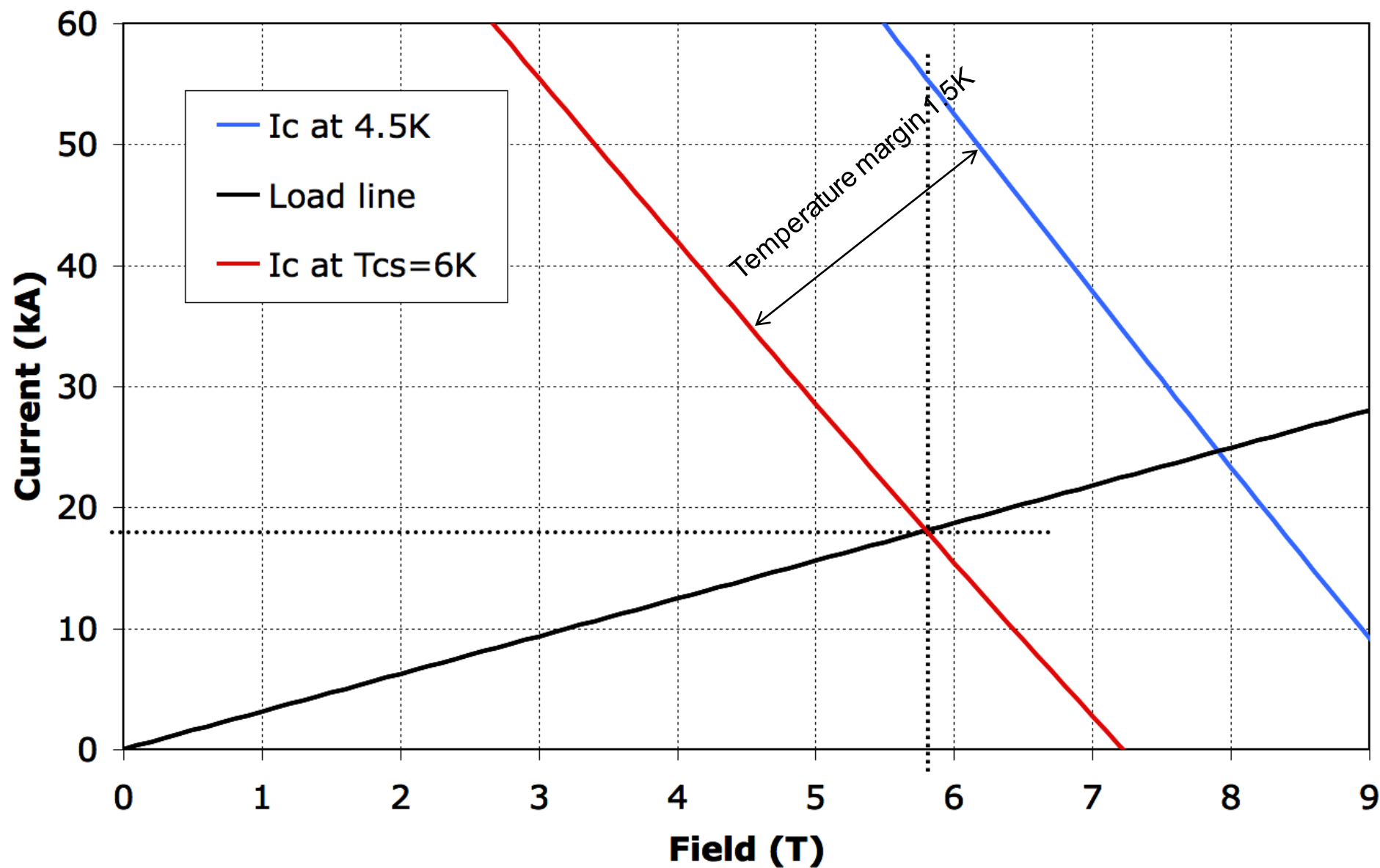   with state-of-the-art NbTi conductor with Jc(4.2K, 5T)=3000 A/mm^2.
External mandrel with quench-back function.
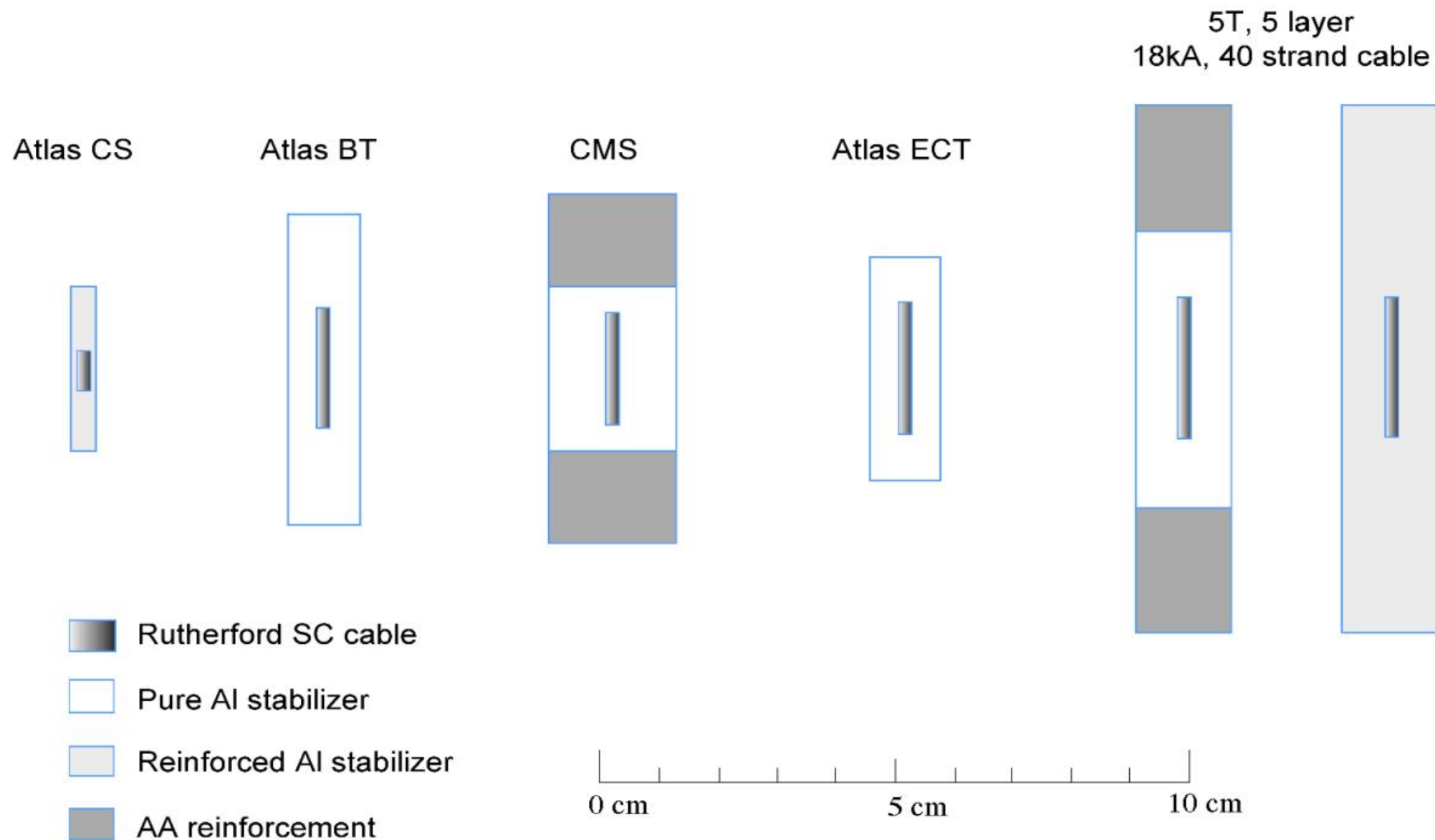Inter-layer & inter-module joints on the exterior of the mandrel.
Inner winding with resin impregnation under vacuum.

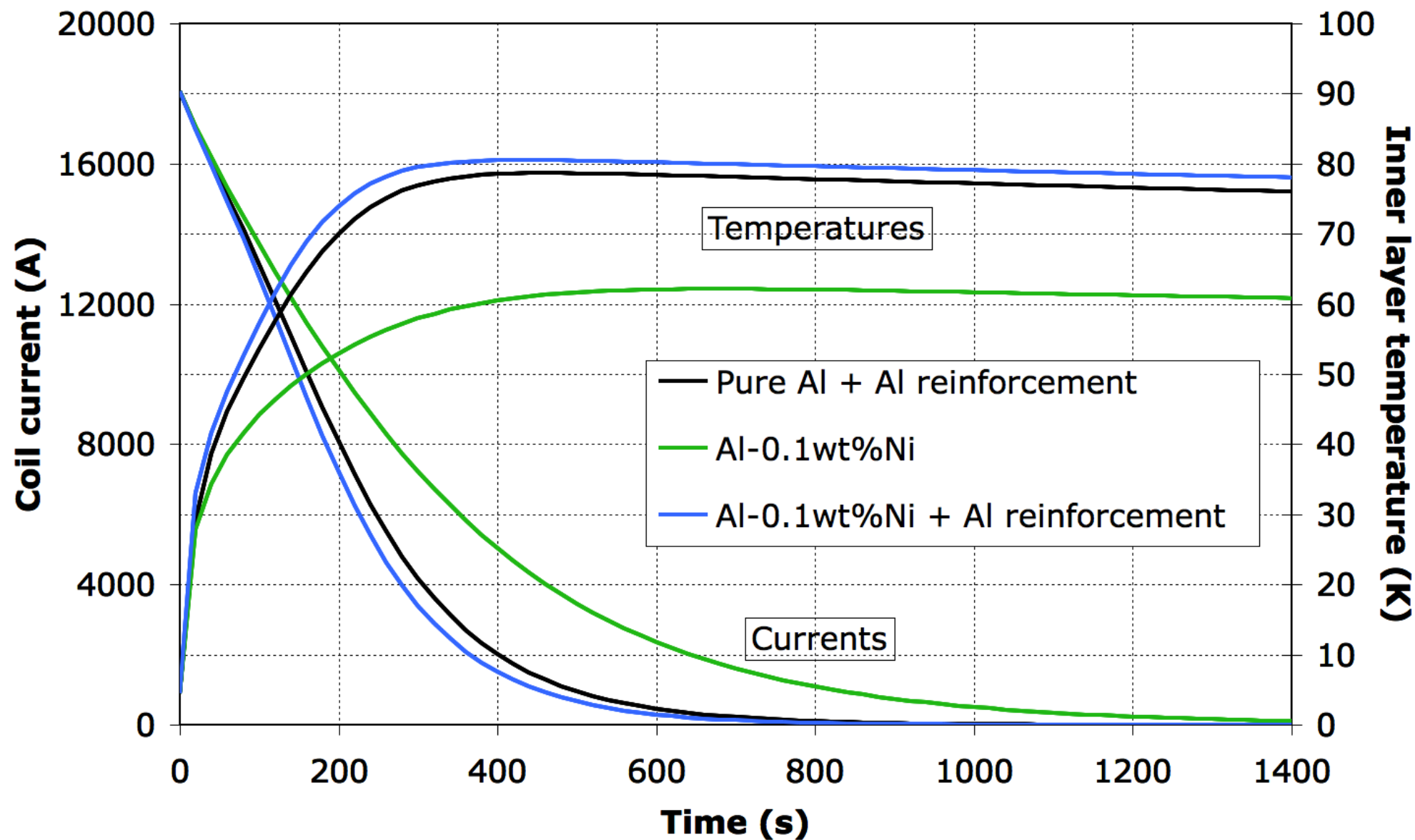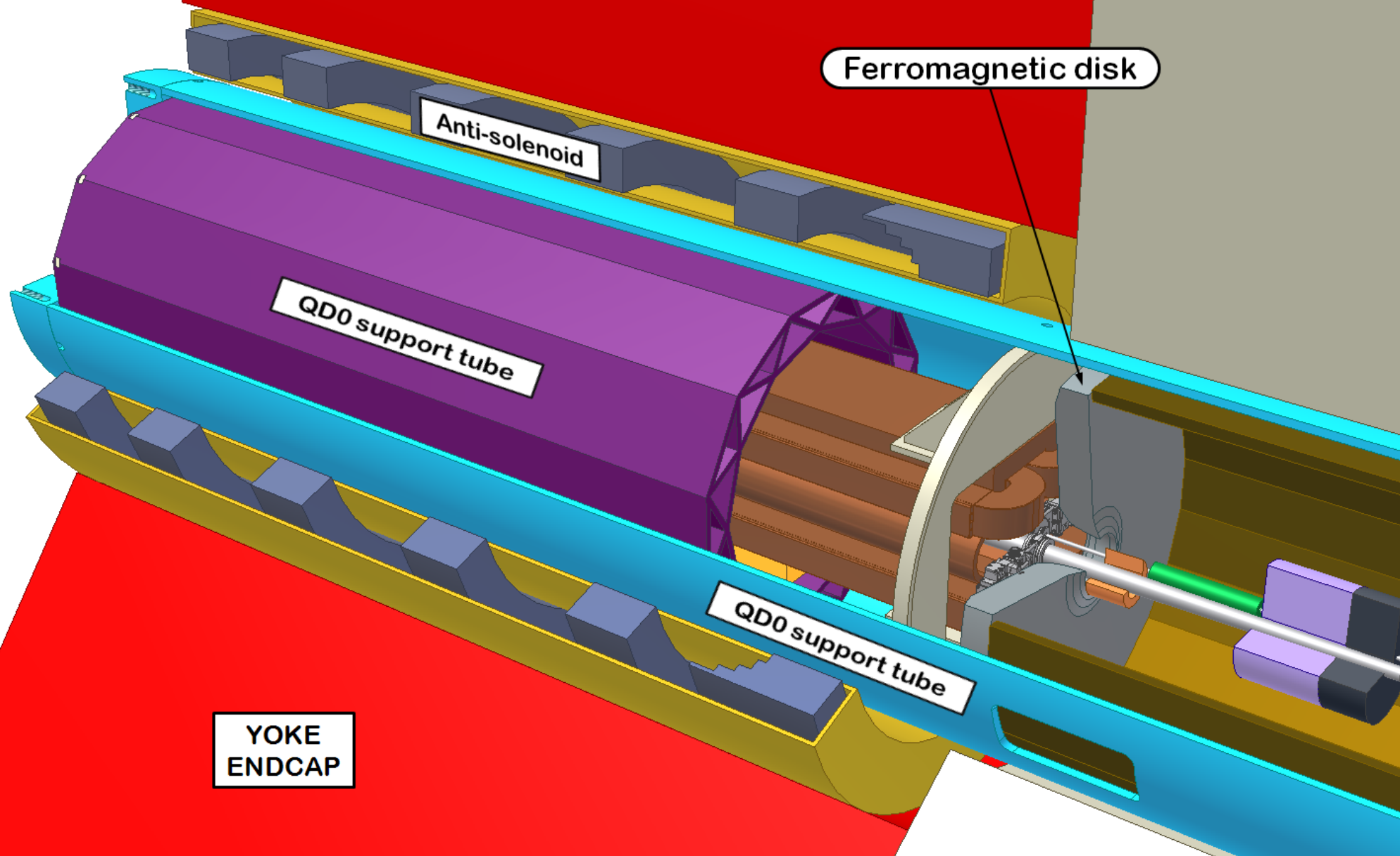|	
Number of turns	1880
Conductor dimensions H x W	97.4A mm x 15.6 mm
Ratio H / W	6.3
Conductor unit length	2.7 km
$I_{operation}/I_{critical}$ (4.5K, 5.8T)	32%
External cylinder thickness	50 mm
Coil total thickness	550 mm

Load line 40-strand cable.

Superconductor options.

5T, 5 layer
18kA, 40 strand cable

Atlas CS   Atlas BT   CMS   Atlas ECT

Rutherford SC cable

Pure Al stabilizer

Reinforced Al stabilizer

AA reinforcement

0 cm   5 cm   10 cm

Fast dump simulation.

Legend within figure:
- Pure Al + Al reinforcement
- Al-0.1wt%Ni
- Al-0.1wt%Ni + Al reinforcement

Temperatures

Currents

Axis labels: Coil current (A), Inner layer temperature (K), Time (s)

Anti-solenoid study.

Ferromagnetic disk

Anti-solenoid

QD0 support tube
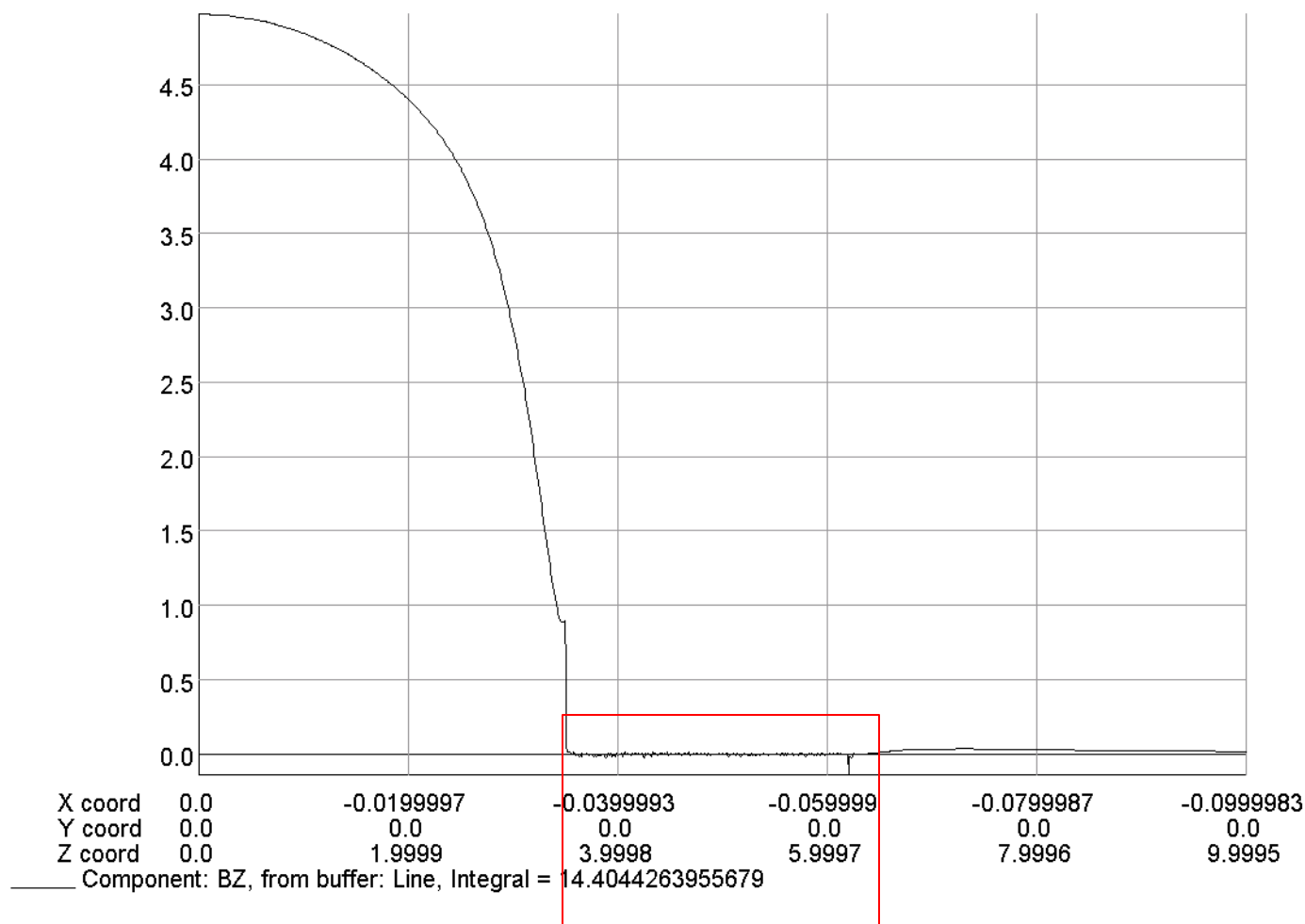
QD0 support tube

YOKE
ENDCAP

Anti-solenoid function.

The main detector solenoidal field has an impact on the in-coming beam that has to be kept to a minimum. Also, the QD0 permanent magnet bricks need to be protected from the main detector field to avoid saturation and de-magnatization in the long term. The anti-solenoid is designed to reduce to a minimum value the field in the forward detector region at 3.5 < z < 6.5 m and r < 1 m.

More details on the magnetic analysis of the CLIC MDI region in the talk from A. Bartalesi on Thursday am.

Effect of anti-solenoid on Bz field component.

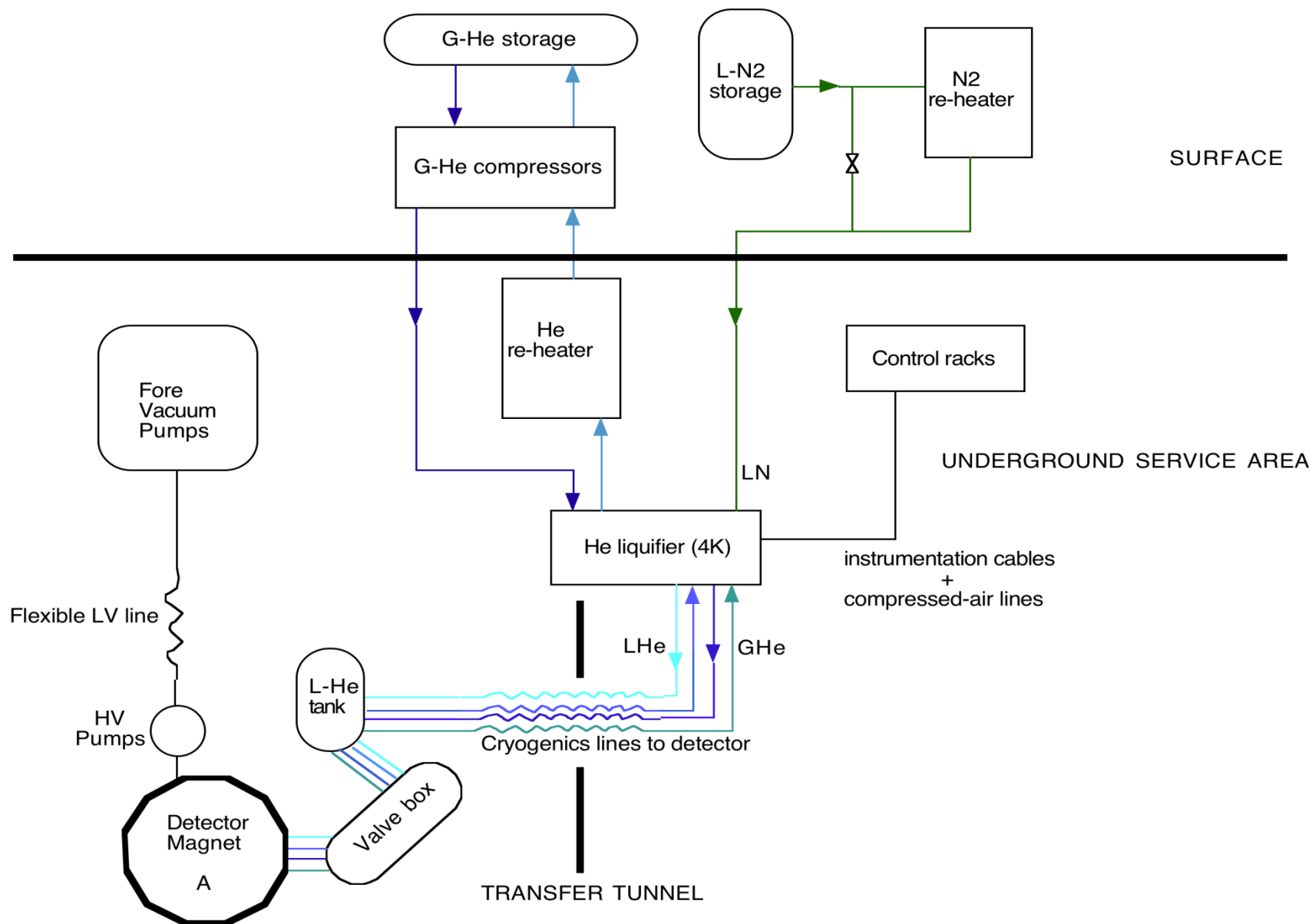Courtesy A. Bartalesi – M. Modena / CERN TE Dept.

Magnet Services & push-pull scenario.

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

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.

G-He storage

L-N2 storage

N2 re-heater

G-He compressors

SURFACE

Fore Vacuum Pumps

He re-heater

Control racks

Flexible LV line

LN

UNDERGROUND SERVICE AREA

HV Pumps

L-He tank

LHe

GHe

instrumentation cables + compressed-air lines

He liquifier (4K)

Cryogenics lines to detector

Detector Magnet

A

Valve box

TRANSFER TUNNEL

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

Magnet powering block diagram / different options.

Magnet services flexible lines

Magnet power supply cryogenics & vacuum
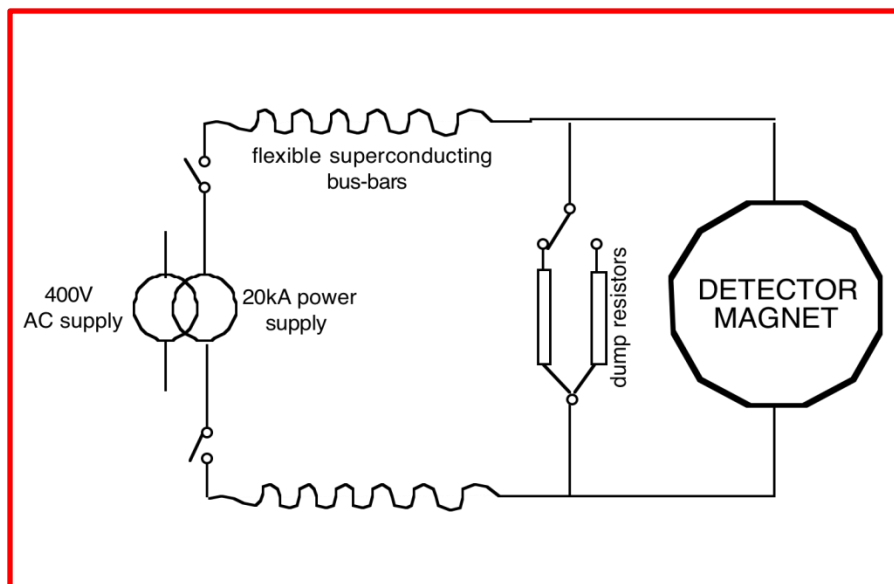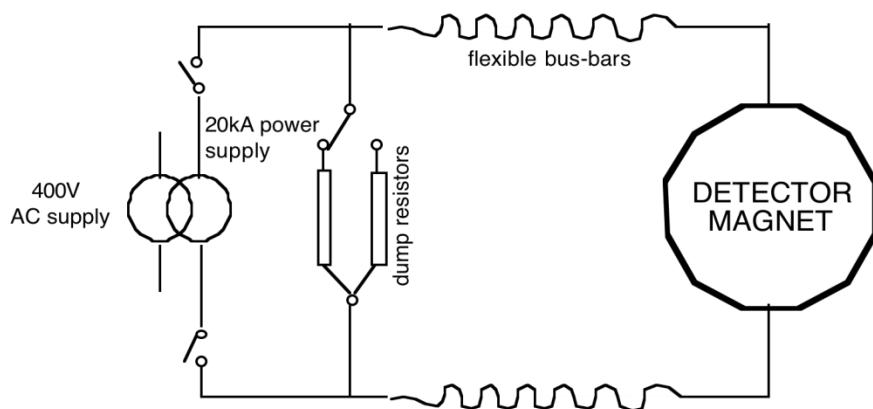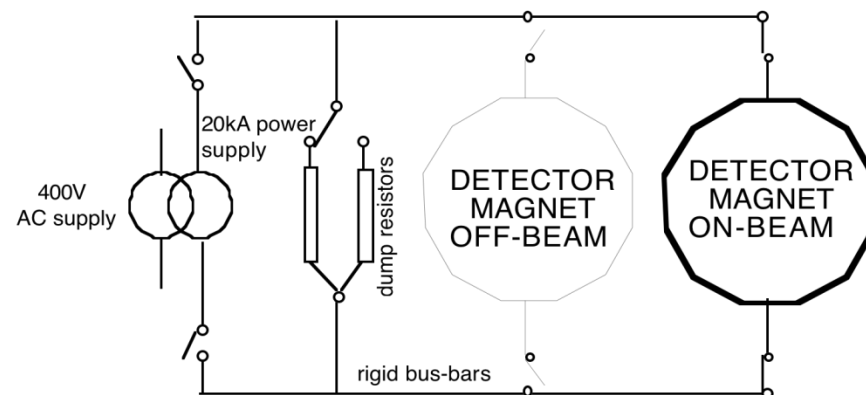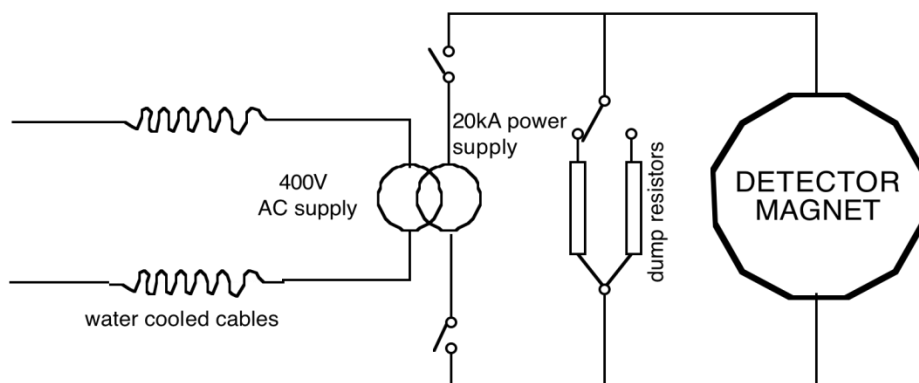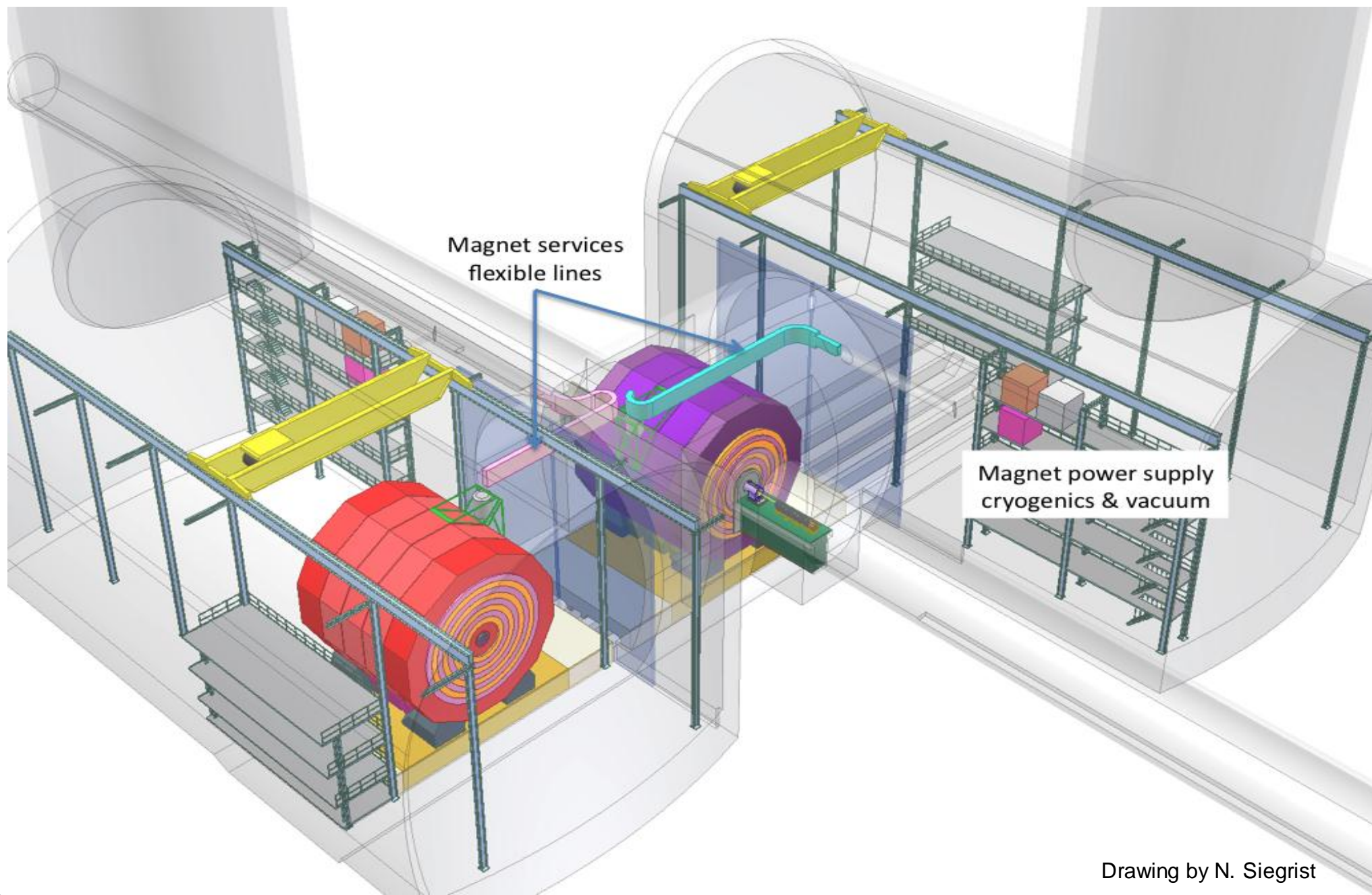
Drawing by N. Siegrist

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 $P=\Delta V \times I$).

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: $\Phi 90mm$*
- *Minimum bending radius: 1.5m*

Proposal for powering lines : flexible HTS bus-bars.

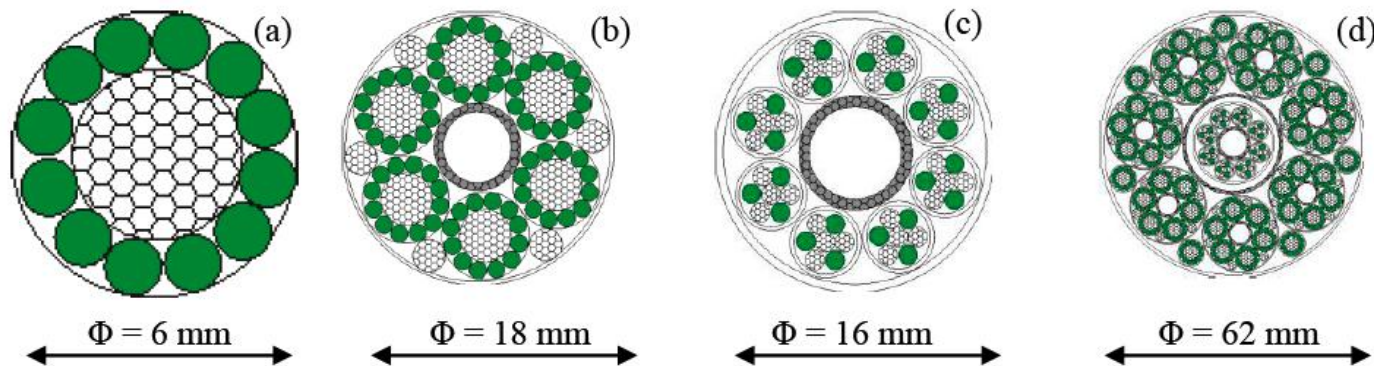Prototypes of the multi-cables HTS powering line (courtesy A. Ballarino)

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.
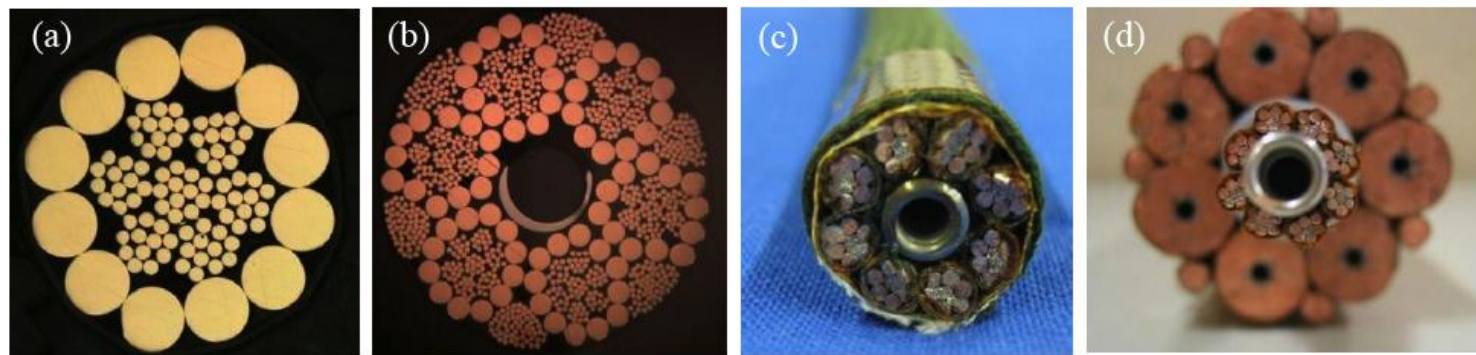

Figure 2. Mock-up of: 3 kA cable (a), 14 kA cable (b), group of 8 × 0.6 kA cables (c), configuration of 7 × 14 kA, 7 × 3 kA and 8 × 0.6 kA cables (d). The external diameter of each assembly is reported in Figure 1.
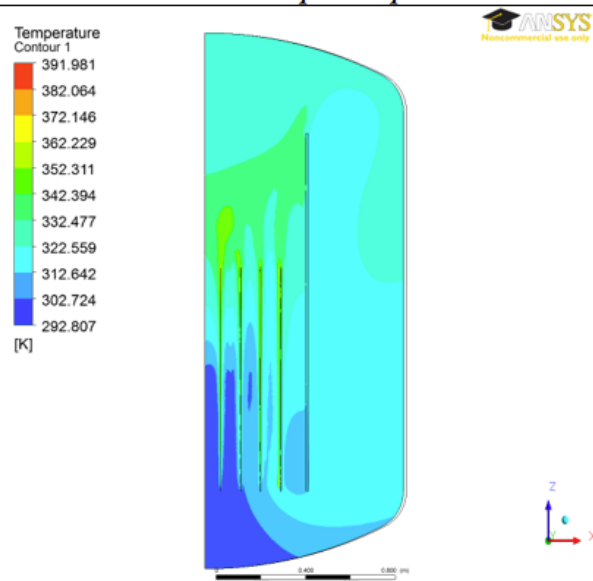
Proposal for dump-system : compact water-cooled resistors.

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 ($P_{peak}=I^2R$)	≈ 12 MW
Discharge time constant (t=L/R)	≈ 416 s
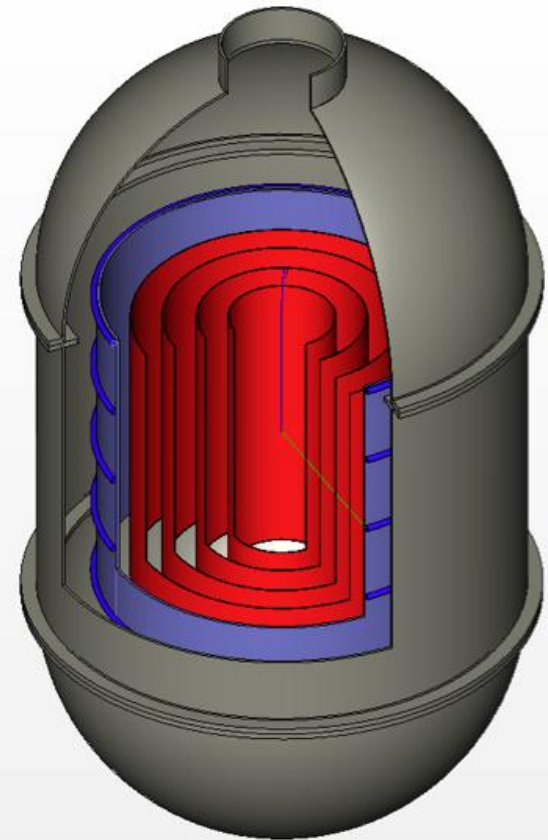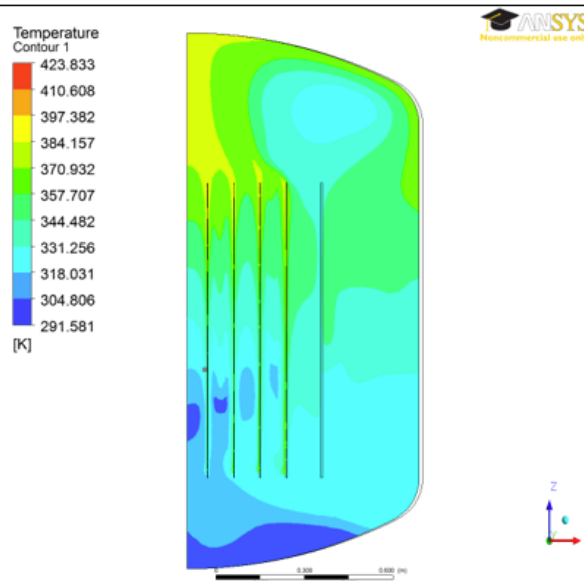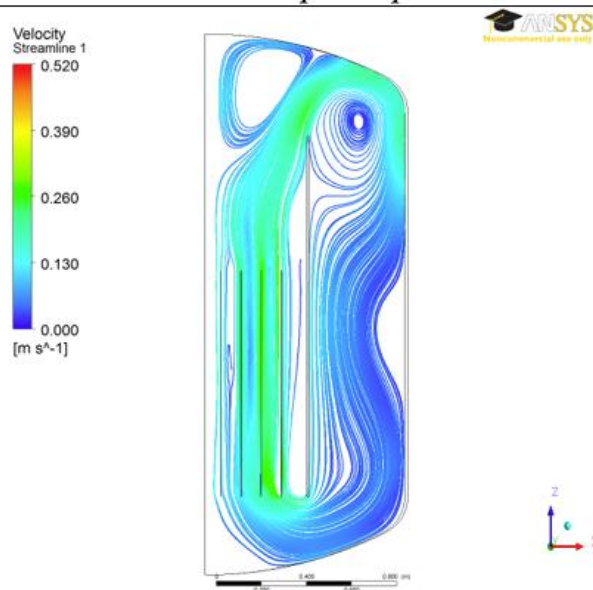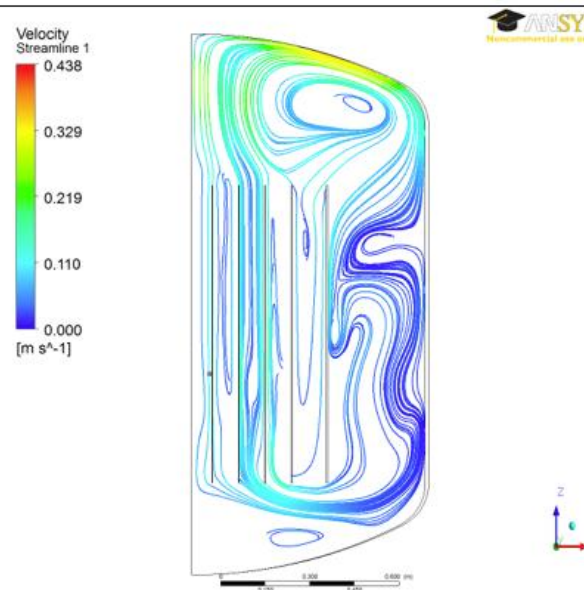
Simulation done by F. Ramos

R&D activities *(see also CDR-Vol.2-Chapt.13.2.9)* and collaborating Institutes.

- Conductor R&D: trial extrusion & cold working of a large cross-section conductor (57x12mm) with 40-strands Rutherford cable and Ni-doped stabilizer. Cold-working test bench and measurements of mechanical & electrical characteristics at room and liquid He temperature (CERN / KEK collaboration). Winding technique for large cross-section cables.

- Coil instrumentation: development of optical fiber based temperature, strain & B-field sensors, to be embedded into the coil windings (CERN and Optosmart collaboration).

- 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 (CERN TE Dept. R&D).

- Interest on superconducting cable R&D has been expressed by Fermilab (Mu2e project) and INFN.

Conclusion & work-plan for the future.

- Further studies on coil winding, thermosyphon flow, quench protection. Run the same study for CLIC_ILD.

- R&D on superconducting cable, coil instrumentation and flexible superconducting power lines, as mentioned in the previous slide.

- 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.

- 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.

- 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.

CLIC - CDR & other documents.

- CLIC-CDR Volume 2 – Chapter 7 gives a good description of the two detector Magnet Systems.

- « Considerations about an improved superconducting cable for LCD », by A. Gaddi – LCD-Note-2009-001.

- A technical note written by B. Curé under the title « Study of a 5-T large aperture coil for the CLIC detector », LCD-Note-2011-007 gives an inside view of the design parameters and related technology issues. A paper has been presented to the last Magnet Technology conference (MT-22) in Marseille.

- The CLIC-Note-2010-003 « Design of a compact dump resistor system for LCD magnet » describes the preliminary study of a water cooled dump resistor, following a first proposal from W. Craddock (SLAC) for ILC-SiD.

- S. Sgobba et al. have pubblished the note « Towards an improved high strength high RRR CMS conductor » in IEEE Trans. Applied Supercond. 16/2 – 2006.

- The reference document for Ni-doped stabilizer cold-working has been published by A. Yamamoto et al. « Development towards ultra-thin superconducting solenoid magnets for HEP detectors », in Nuclear Physics B, 78 – 1999.

CLIC-Notes can be found at the URL: http://lcd.web.cern.ch/LCD/Documents/Documents.html