WP 8.1 & 8.4 – DETECTOR MAGNETS R&D
EP R&D DAYS 2021

SHUVAY SINGH – EP/ADO/SO

11 NOVEMBER 2021

PROJECTS – WP 8

NEW 4-T MAGNET FACILITY

ADVANCED MAGNET POWERING

WP 8 Team

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NEW 4-T MAGNET FACILITY

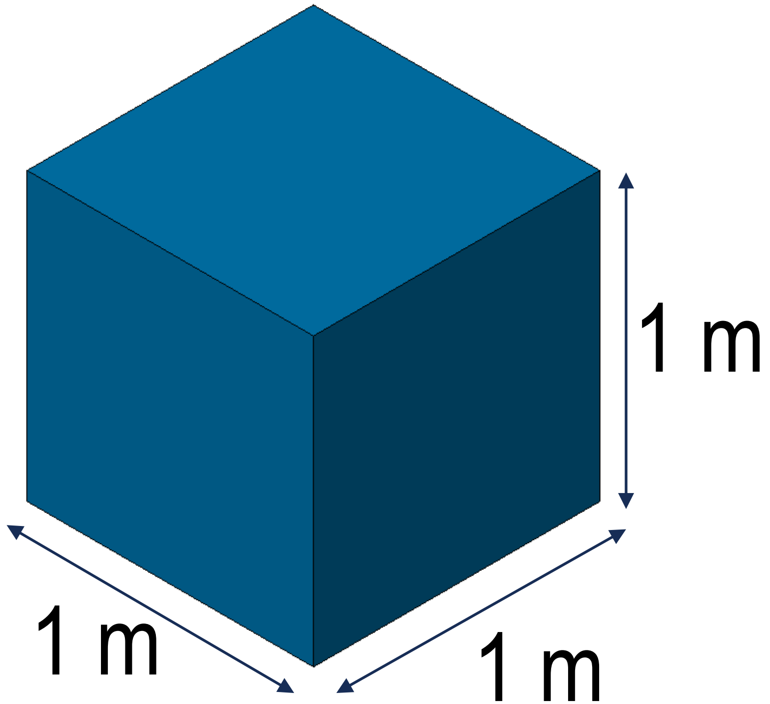
EXISTING GENERAL PURPOSE NORTH AREA MAGNETS

- 3 T M1 Magnet
- Dipole and Solenoidal function (split solenoid)
- 1.4 m free bore diameter

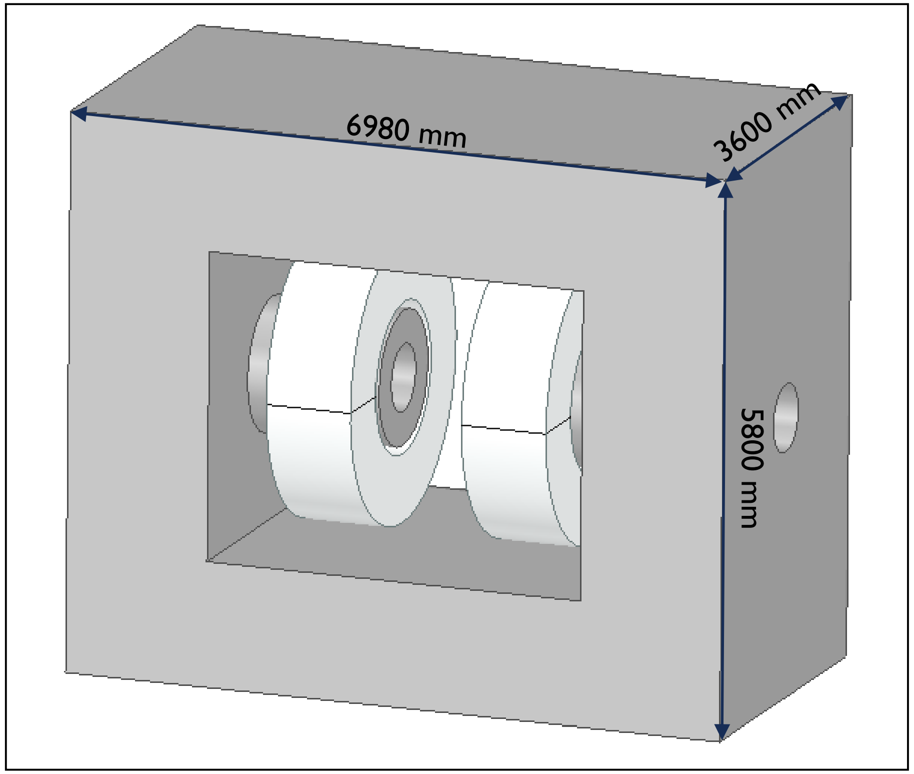
- 1.6 T Morpurgo Magnet
- Dipole function (saddle)
- 1.6 m free bore diameter

NEW NORTH AREA MAGNET REQUIREMENTS

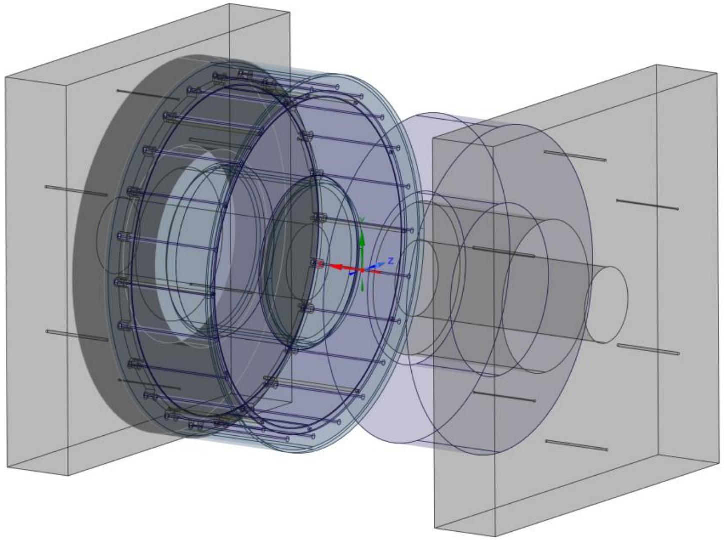
1) 4 T central field
2) 1 m^3 free volume target
3) Minimised stray field
4) 4.5 K operation temperature
5) 8 kA power convertor (available at CERN)



SPLIT COIL SOLENOID MAGNET

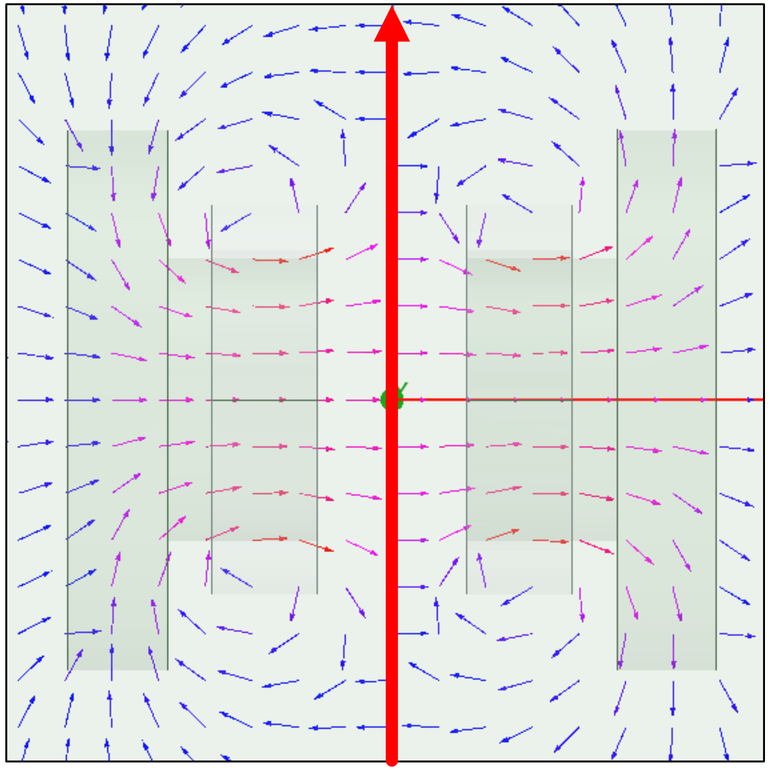


Specifications	
Field at Center	4 T
Free gap	1000 mm
Free bore diameter	700 mm
Total Stored Energy	130 MJ
Axial coil length	900 mm
Peak field in conductor	5.68 T
Stray field at 5 m	8.4 mT



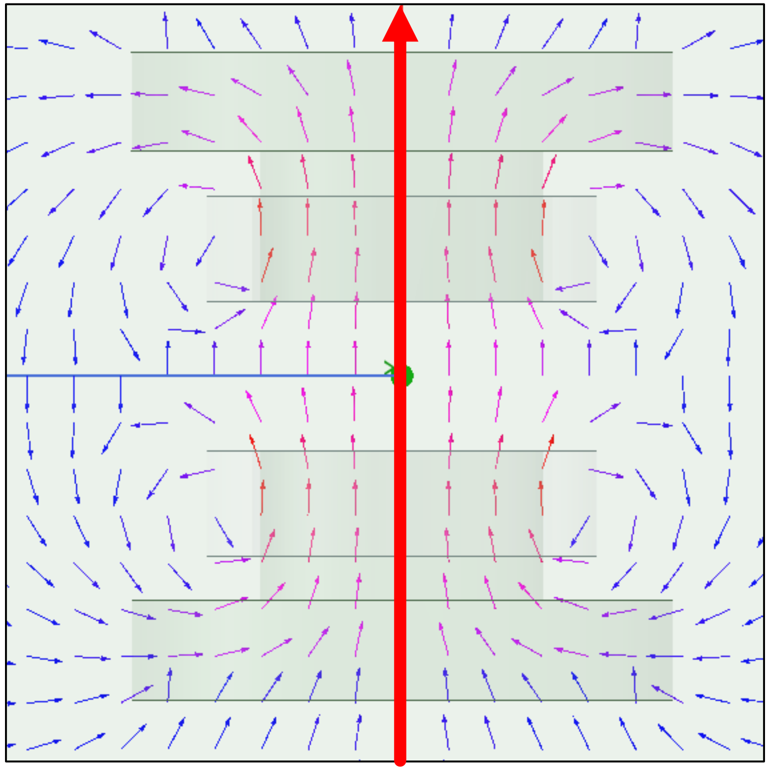
- Split Coil Solenoid (SCS) similar in design and functionality of M1
- Iron yoke allows for beam in 2 directions
- Coils supported by titanium tie-rods

BENEFITS OF A SPLIT COIL SOLENOID MAGNET



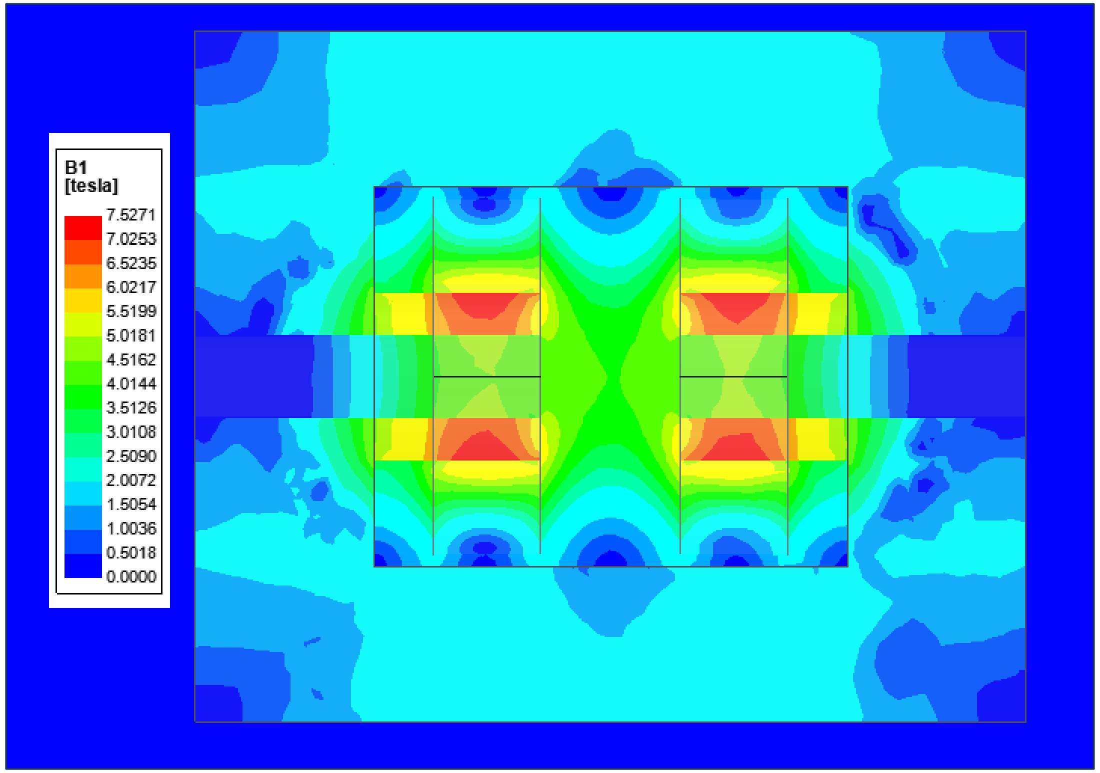
Dipole function

- Two different testing orientations are possible relative to beam axis
- Maintains dual M1 functionality



Solenoidal function

SPLIT COIL SOLENOID MAGNET CHALLENGES

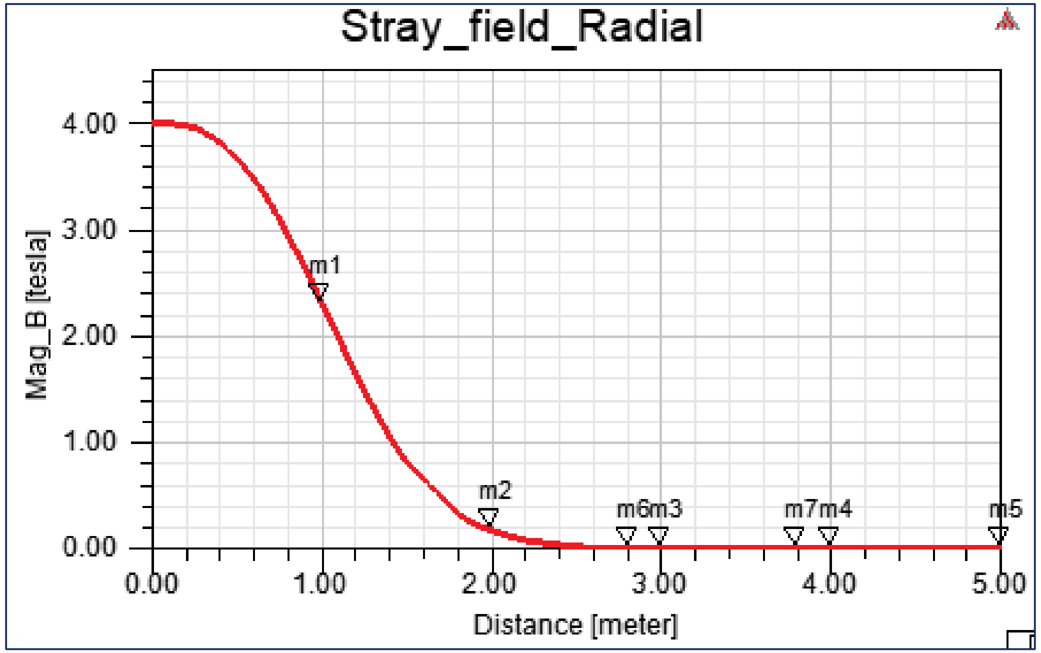


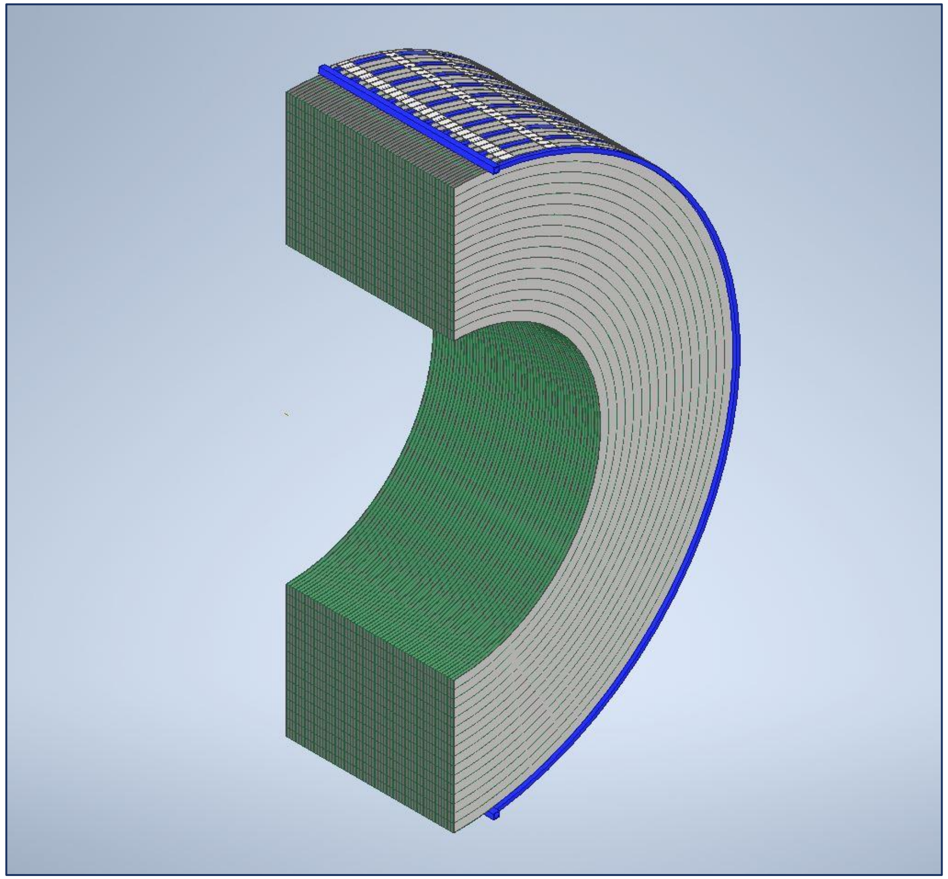
Peak fields occur outside conductor

- Keeping **peak fields in the conductor** below critical value
- **Reducing stray field** to lower than M1 values
- Maintaining energy density to a low level for **reduced internal conductor stresses**
- A **solid plug** insert version exists with much lower conductor peak fields and coil size, however dual functionality is lost (only operates as a dipole)

SPLIT COIL SOLENOID STRAY FIELD AND CRYOGENICS

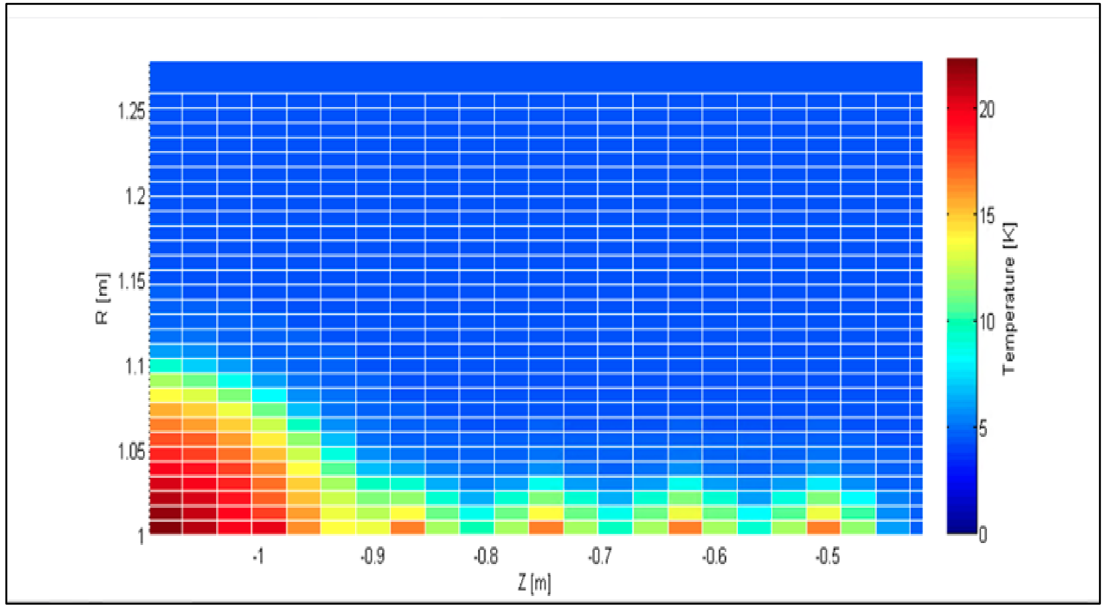
- Current stray at 5 m is 8.4 mT, lower than M1 magnet
- **Shaping of iron** to reduce stray field
- **Active shielding** has also been investigated however, due to small margin in maximum allowable peak field, reduction in stray field is **negligible**





Thermo-siphon concept for cooling of stacked double pancakes of each coil

SPLIT COIL SOLENOID MAGNET QUENCH BEHAVIOUR

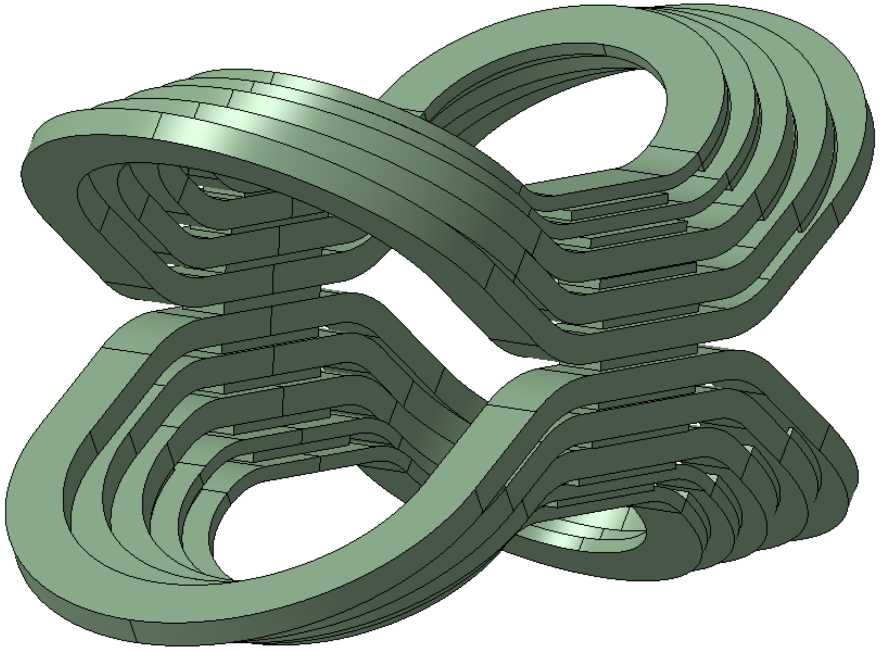


- Preliminary split coil simulations done with updated "**Quench 2.7**"
- Quench heater concept showed satisfactory results with a good safety margin
- With the quench heater variant the coil reaches a temperature of approximately **100 K**, but with a relatively small temperature gradient below **25 K**
- It shows the feasibility with a reduced temperature gradient across the coil, without the need for energy-extraction systems

[2]

THE MAGNADON

- **MAG**net for **N**orth **A**rea with a **D**ipole **CON**cept

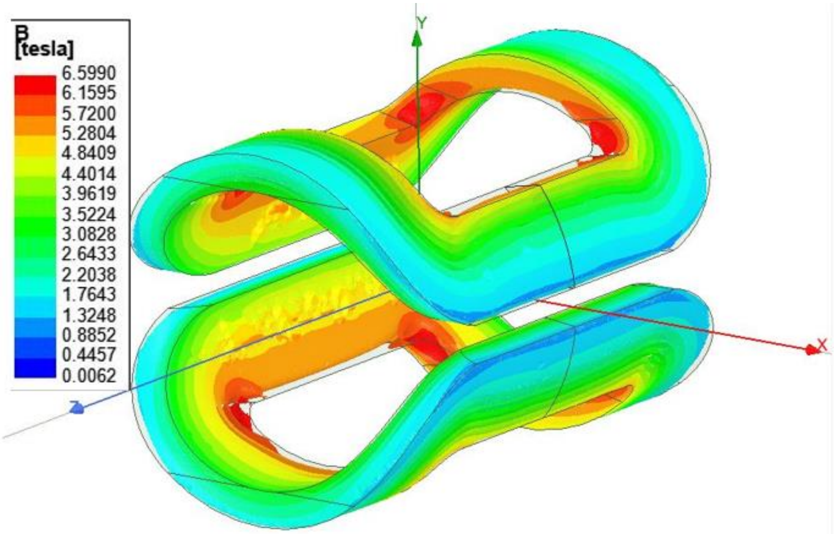


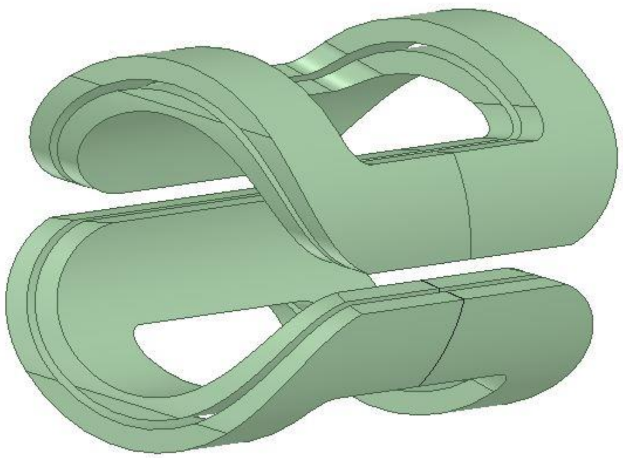
~ 2 m bite radius / outer bore

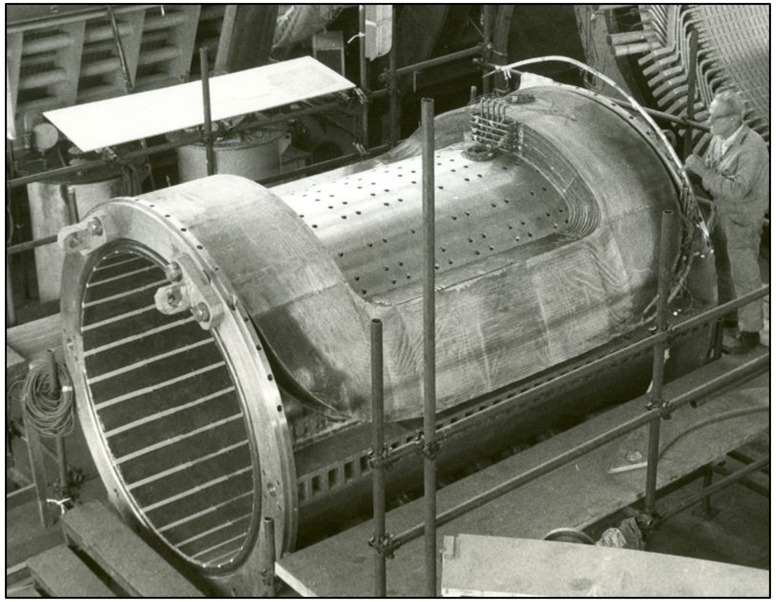
- Similar to the MADMAX magnet design
- Special thanks to CEA - IRFU Saclay for fruitful discussions

THE MAGNADON

- Alternative saddle shape first considered and studied





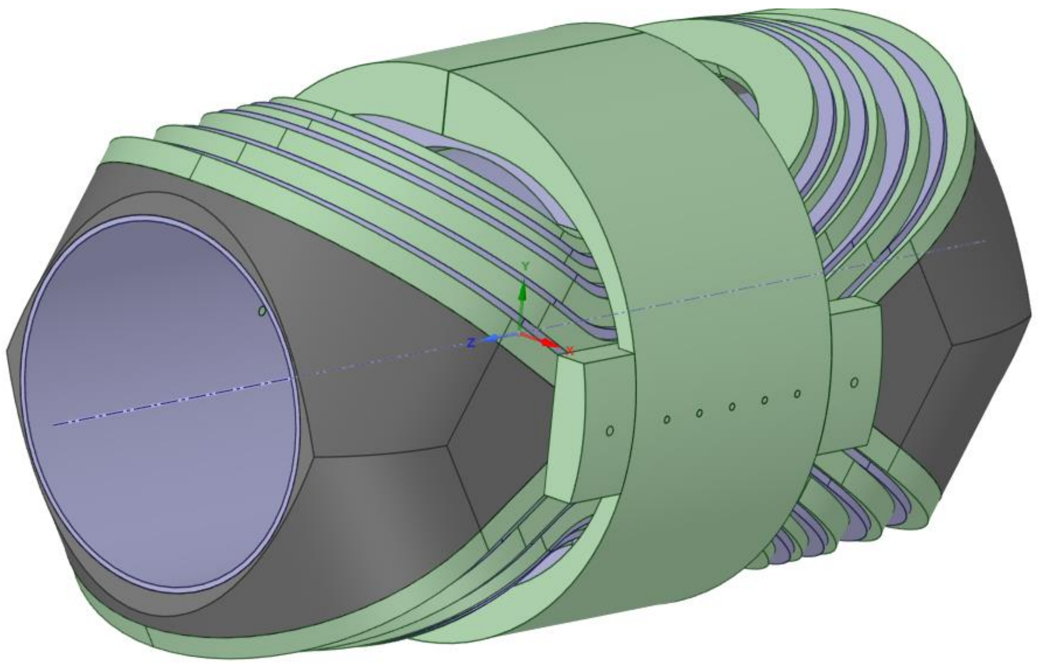


Construction of Morpurgo magnet

- Similar to H8 Morpurgo magnet
- Peak field concerns lead focus to Magnadon

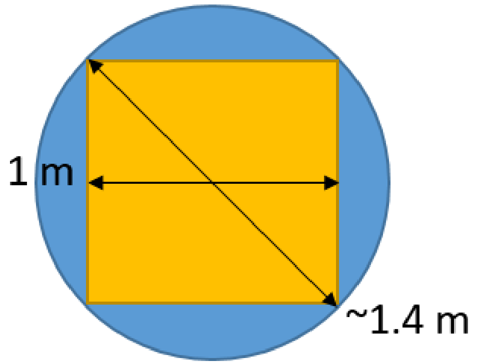
MAGNADON MAGNET SPECIFICATIONS

Preliminary design of support

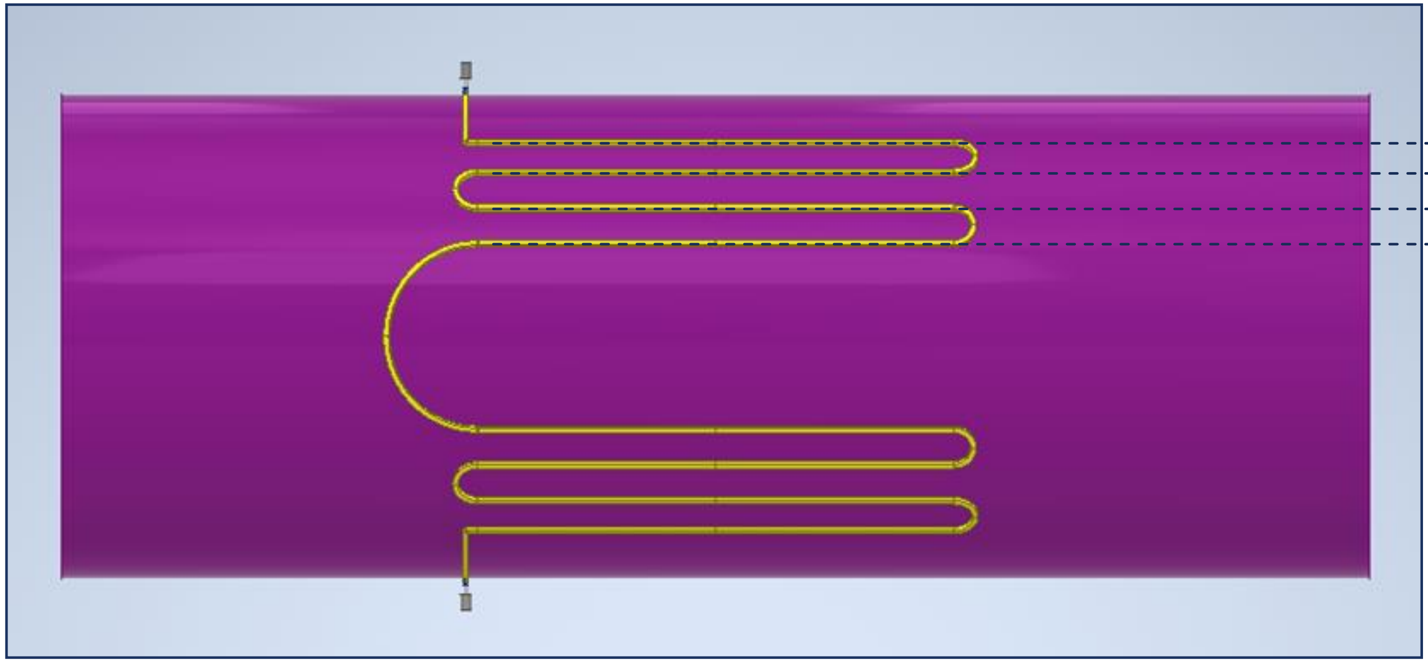


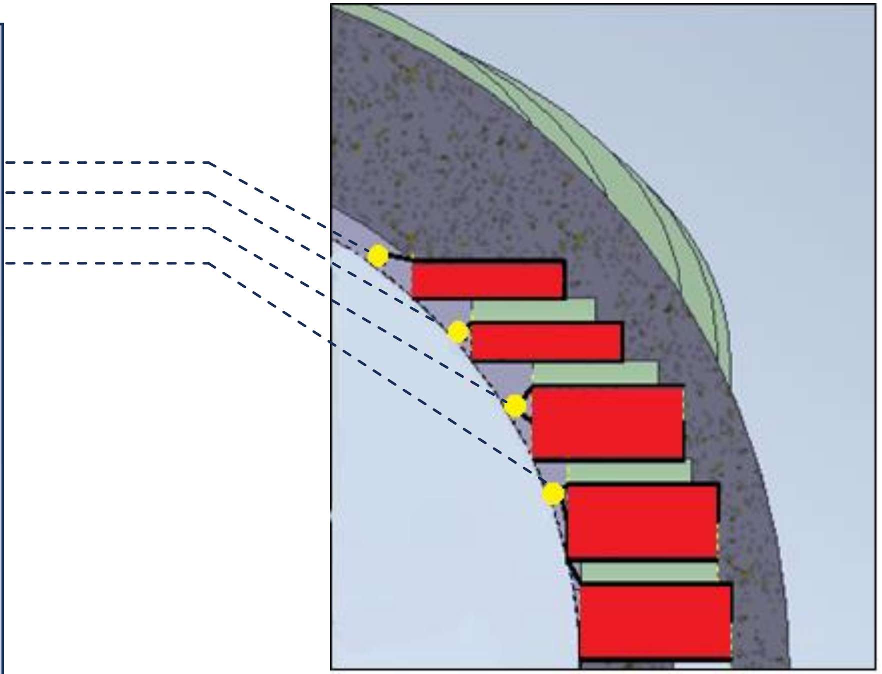
- New design used a tilted racetrack "skateboard" design
- Compatible with Morpurgo iron yoke

Specifications	
Field at Center	4 T
Free warm bore diameter	1400 mm
Total Stored Energy	80 MJ
Peak field in conductor	5.5 T
Stray field at 5 m	11 mT



MAGNADON MAGNET THERMOSIPHON CONCEPT

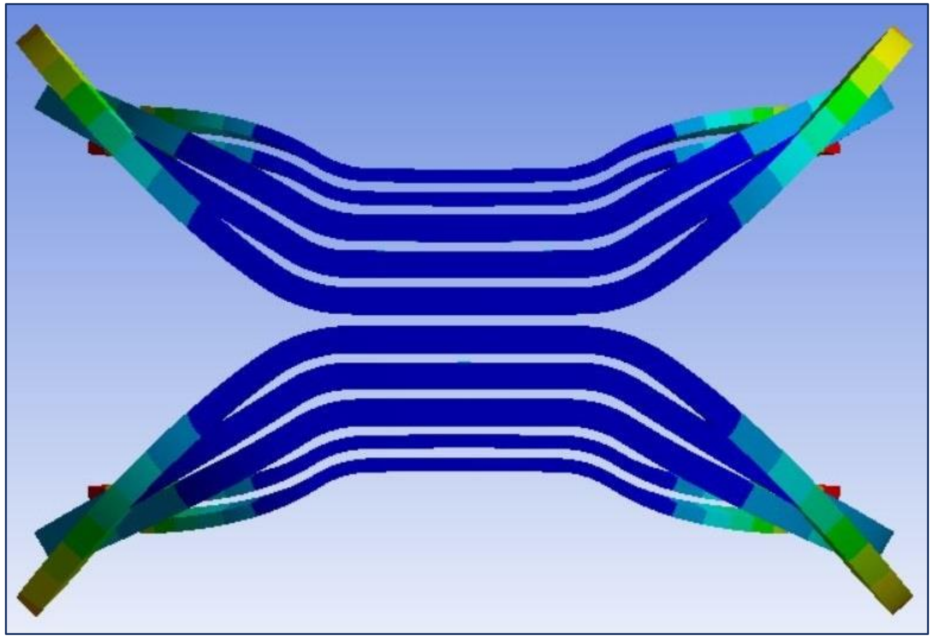


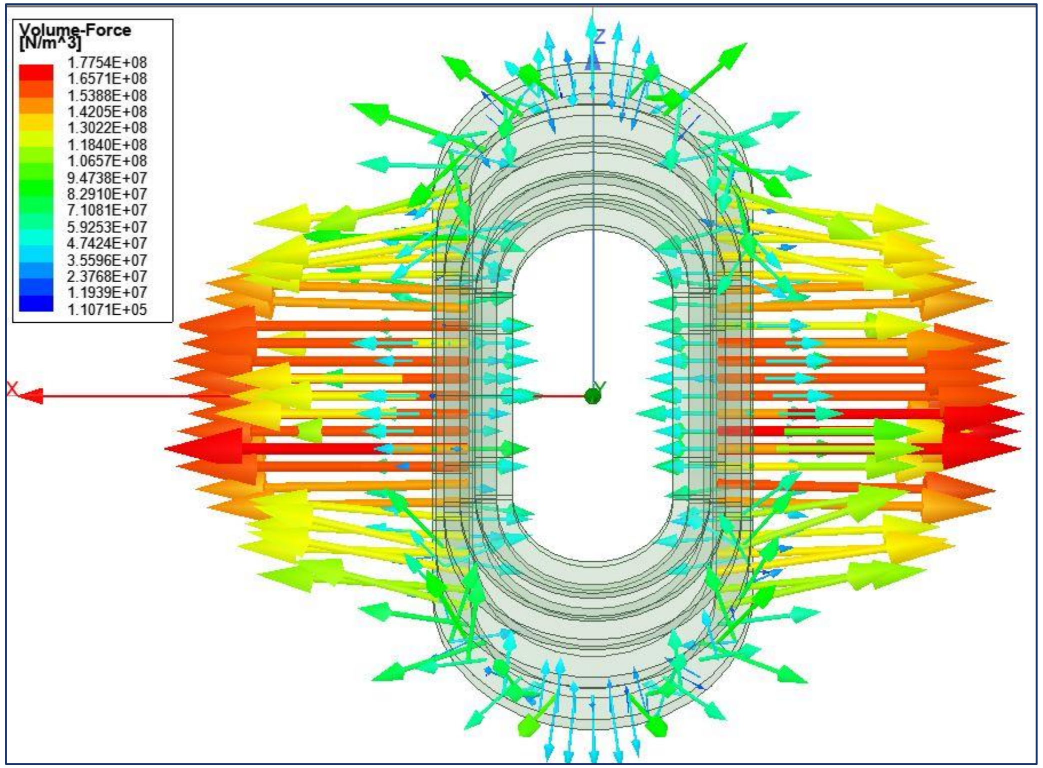


Cross-section of Magnadon assembly

- New code developed (Thermo-ronika) to compute all design parameters and behaviour for thermosiphon of Magnadon and SCS
- Fully passive system without the need of pumps

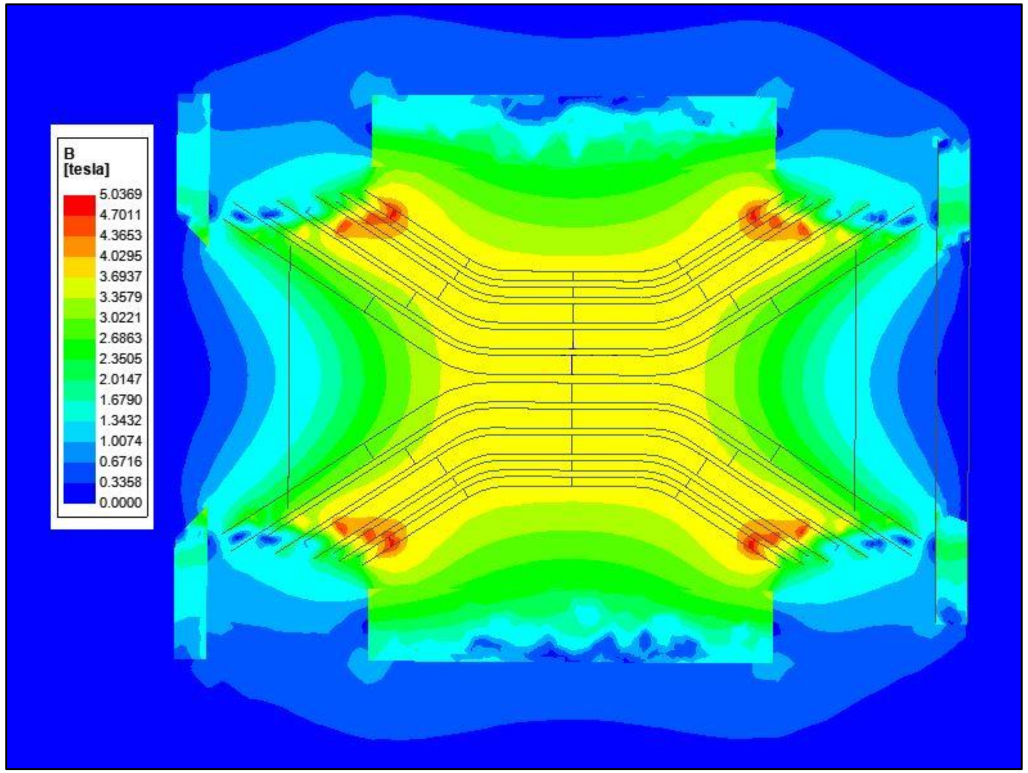
MAGNADON MAGNET LORENTZ FORCES AND DEFLECTION

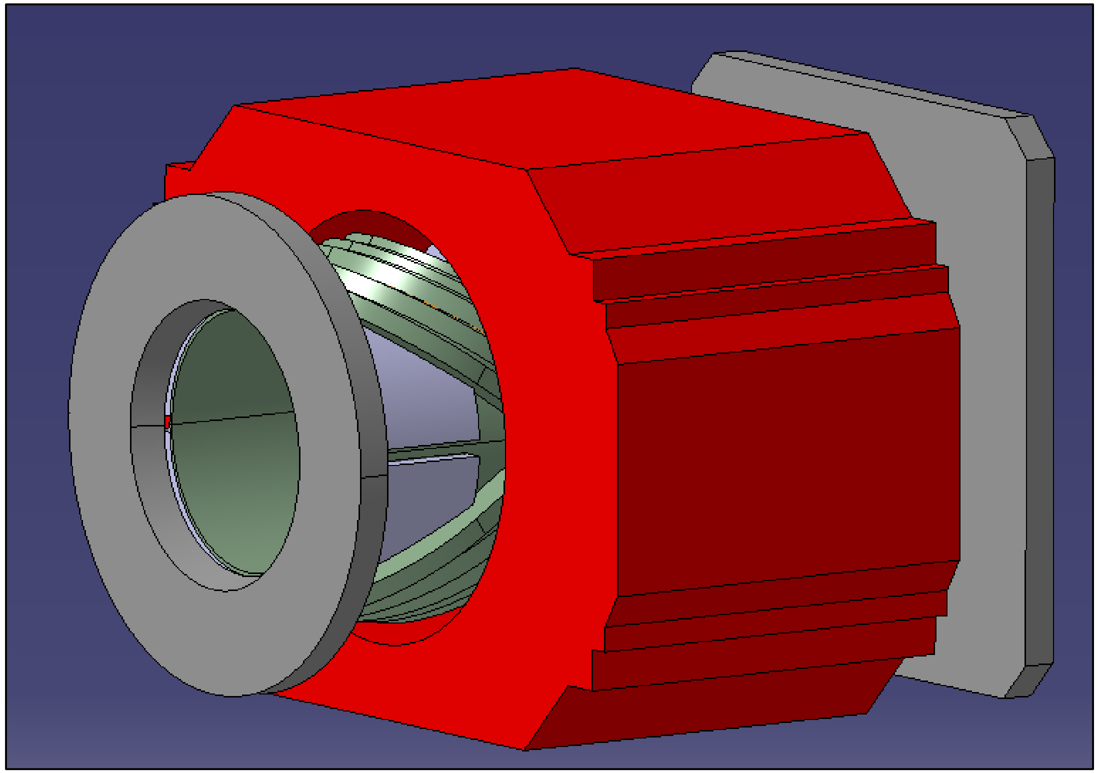




- Coils attempt to "open" and "close" during current ramp up requiring a robust and complex mechanical support structure
- Bursting force along X-Axis : 2.5 MN

BENEFITS OF THE MAGNADON MAGNET





- The Magnadon magnet has the possibility to **reuse the iron yoke of Morpurgo**, reducing manufacturing complexity and cost of making a new yoke
- Thanks to the iron yoke, stray fields are low, approximately 11 mT at 5 m

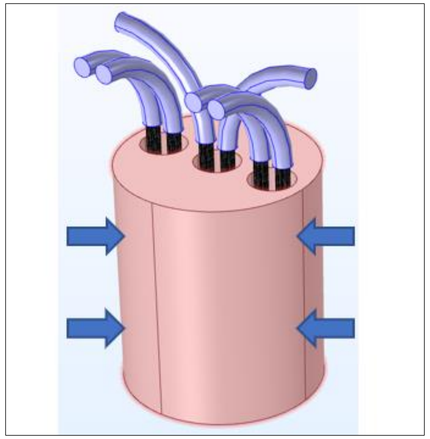
NORTH AREA MAGNETS SUMMARY AND BENEFIT COMPARISON

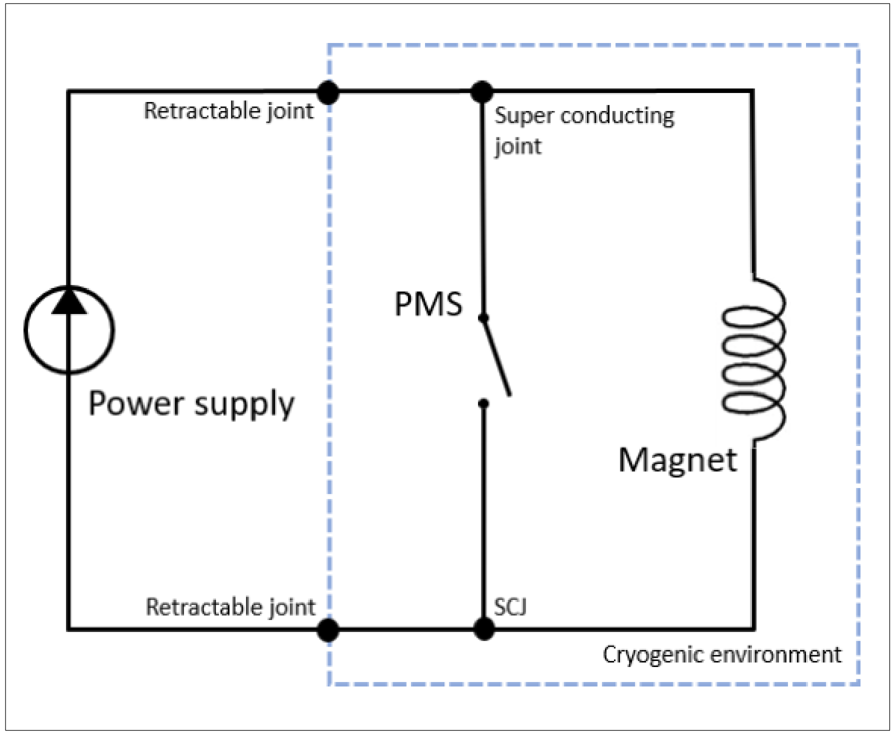
Split Solenoid Coil	The Magnadon
▪ Simple mechanical layout and supports ▪ Dual orientation of testing ▪ Simplicity of manufacture	▪ Compatible with Morpurgo yoke ▪ Better field homogeneity ▪ Larger aperture of 1.4 m

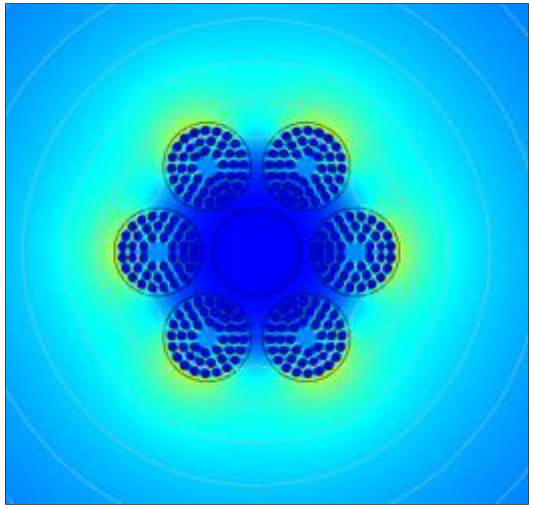
- Both magnets have a 4 T central field
- Double/Single pancake winding technique
- 4.5 K operation temperature (with 2 K of margin)
- NbTi with Aluminium stabiliser
- Fully passive thermo-siphon helium cooling feasible
- Magnadon has a more complex winding process and mechanical structure to be further developed, so it has been decided to continue with the SCS at this stage, with its conventional double pancake, which has no showstoppers

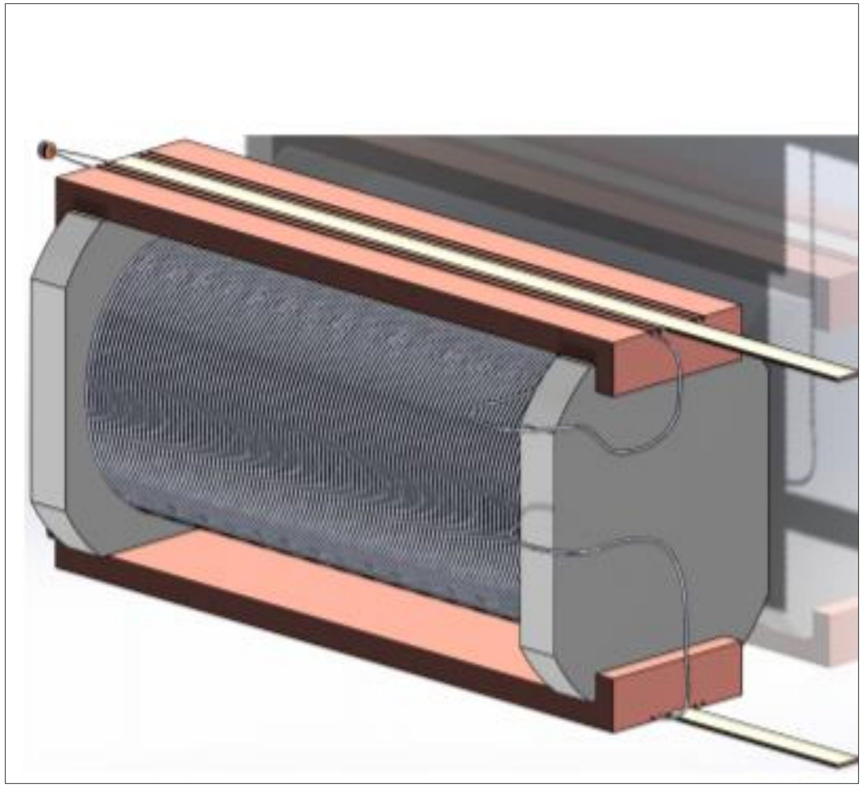
PERSISTENT MODE SWITCH STUDIES

- Investigations of including a PMS for the magnet
- Allows for power supply to be switched off after initial ramping up, represents potential future return
- Questions of joints, specific welding technologies investigated and considered





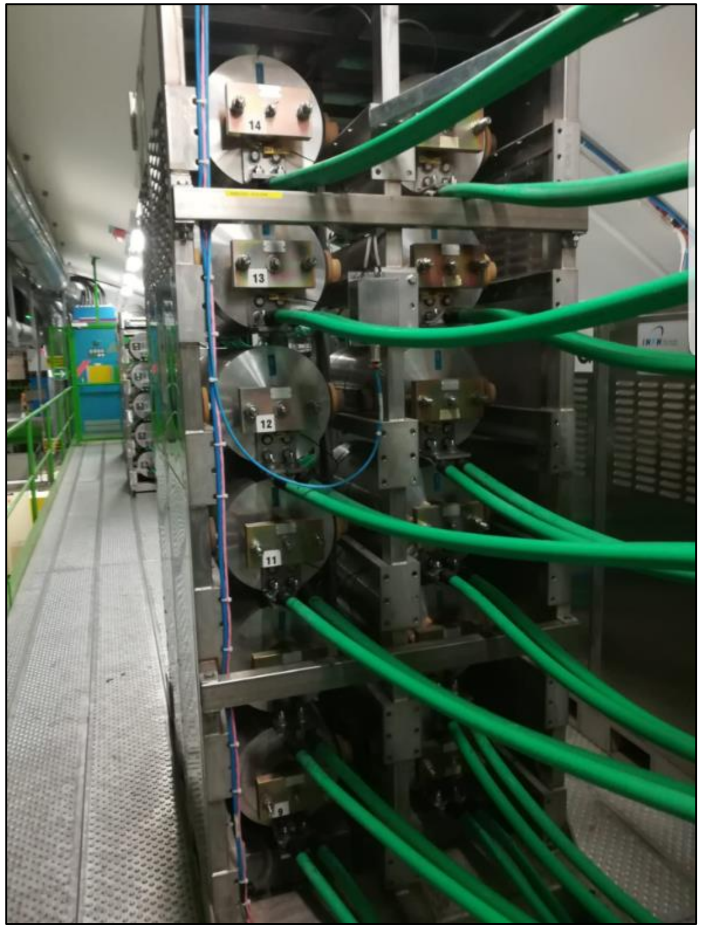




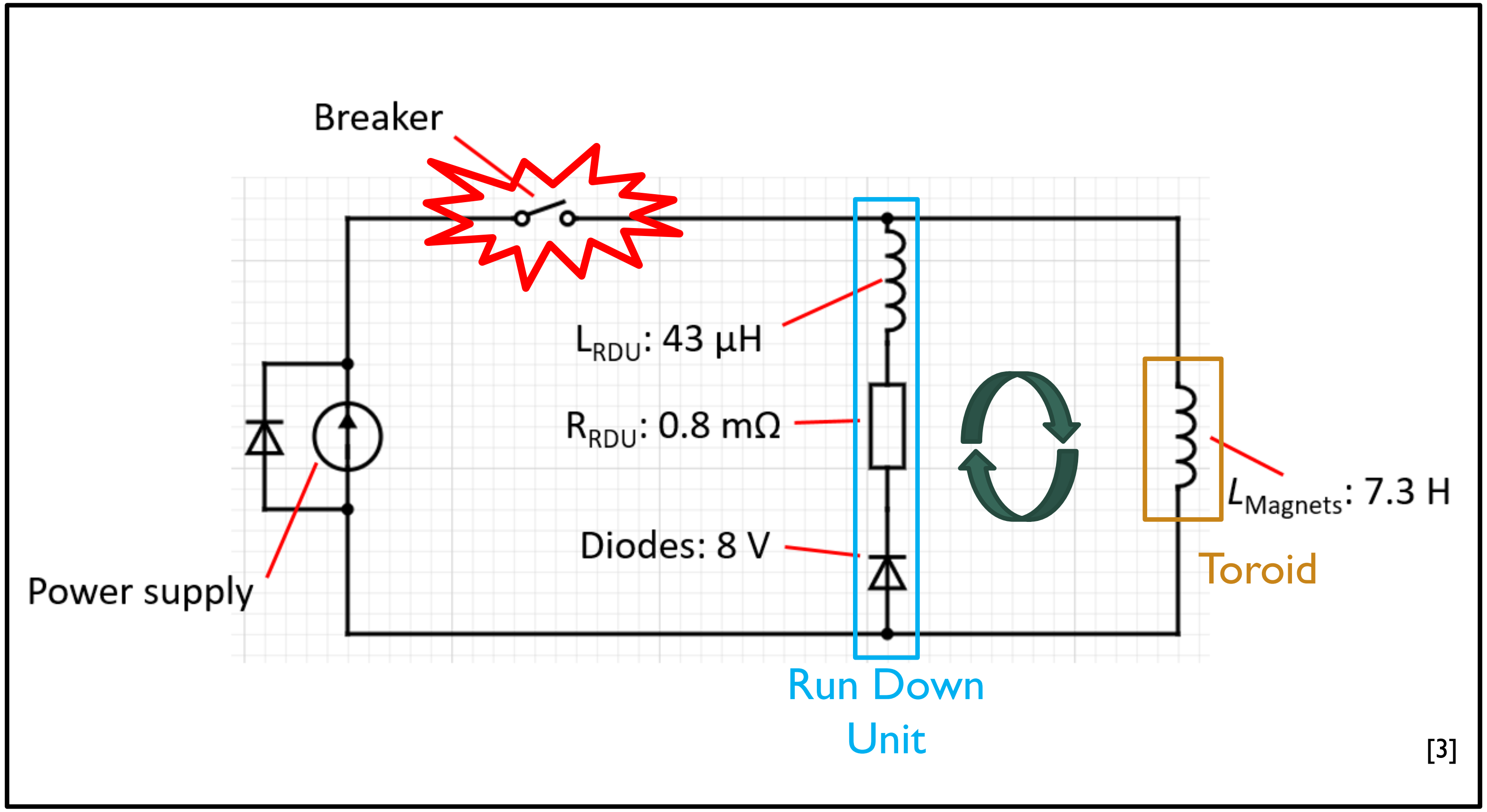
ADVANCED MAGNET POWERING

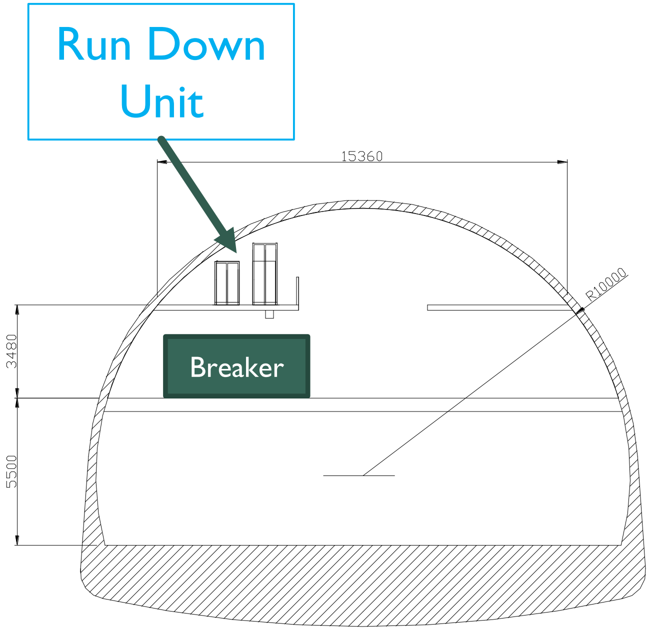
DETECTOR MAGNET POWERING SYSTEM: SNUBBER

- Detector magnets experience arcing across its breakers during powering down due to parasitic inductance in the Run Down Unit
- An arc suppression system, or Snubber, has been proposed to remedy this issue which causes accelerated wear to the main breakers
- This problem occurs on the ATLAS toroid magnet



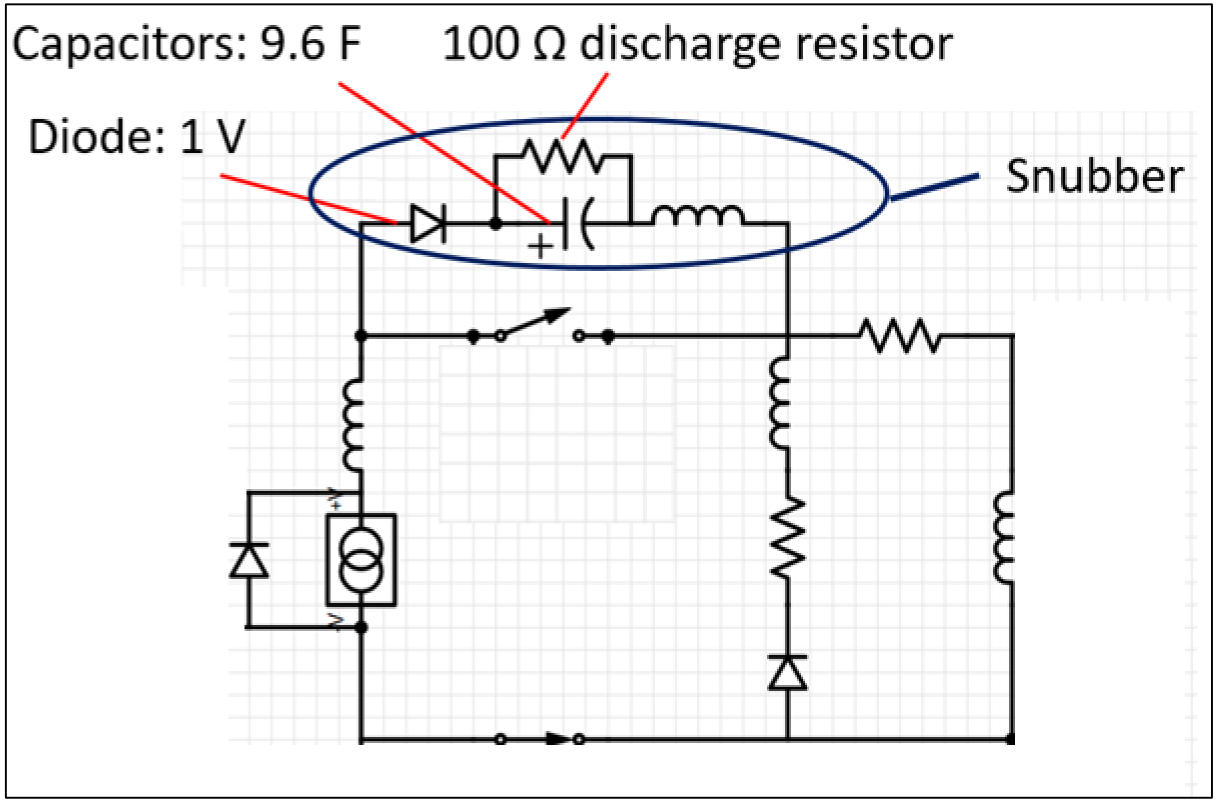
DETECTOR MAGNET ARCING DURING POWERING DOWN





RDU relative to Breaker position

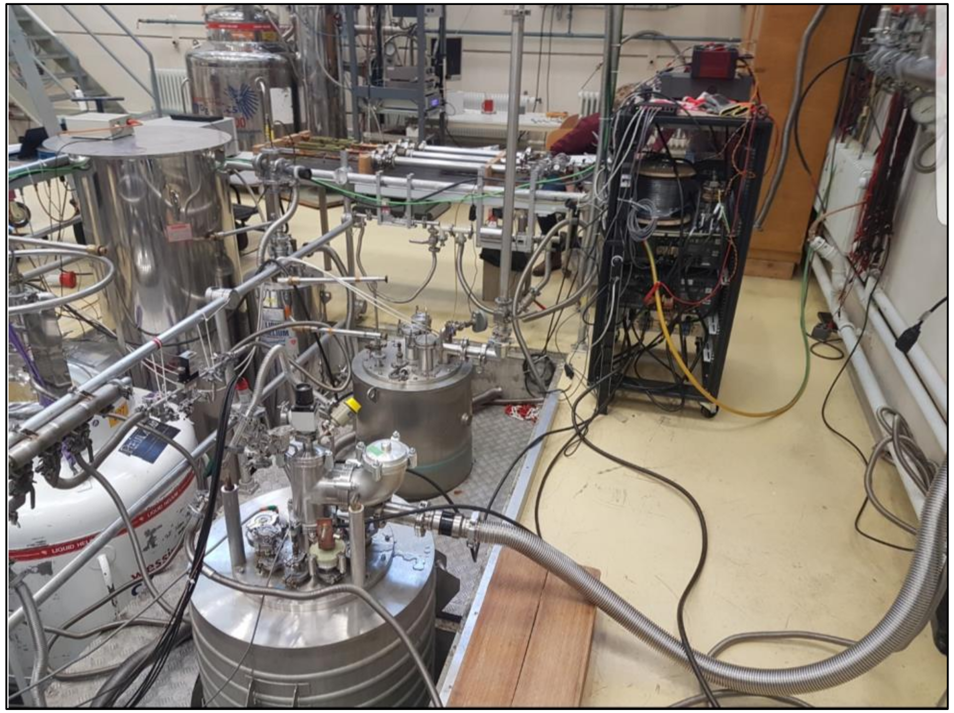
DETECTOR MAGNET SNUBBER SCHEMATIC

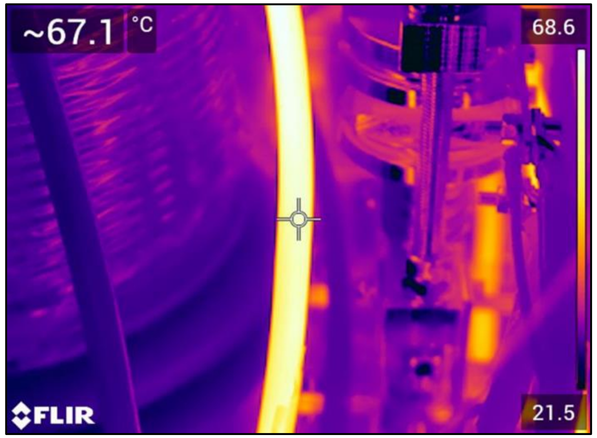


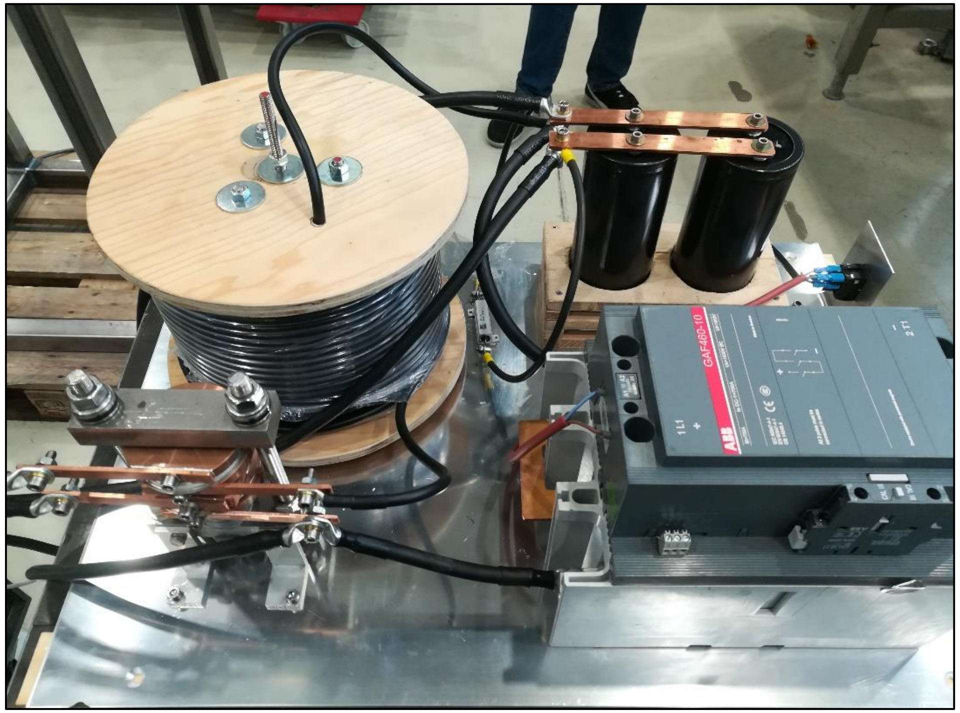
- RC circuit used for arc suppression
- During discharge, snubber temporarily conducts current, thus allowing the RDU to slowly ramp up
- With electrolytic capacitors a Diode is needed to guarantee correct polarity
- 100 Ω resistor slowly discharges capacitors that hold stored parasitic magnetic energy (~10 kJ)

[3]

DETECTOR MAGNET SNUBBER DEMONSTRATOR







- A 1/50th scale snubber tested at TE-CRG Cryolab to determine proof of concept, degree of effectiveness and repeatability of operation in December 2020
- Testing was successful on reducing voltage spike across breaker

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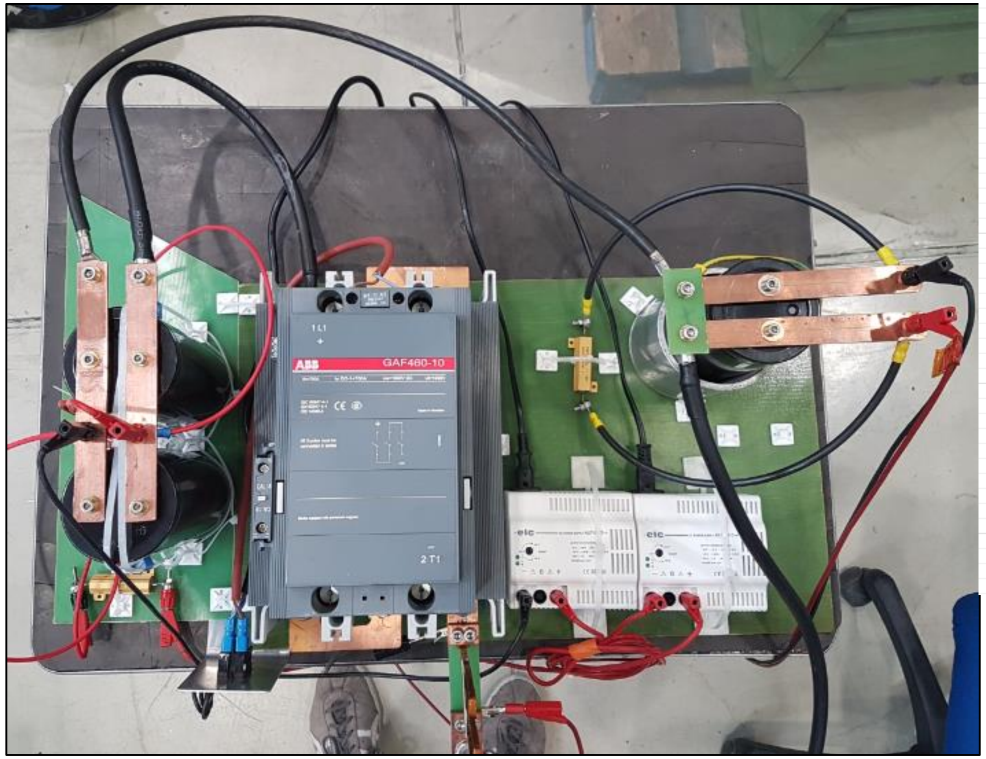
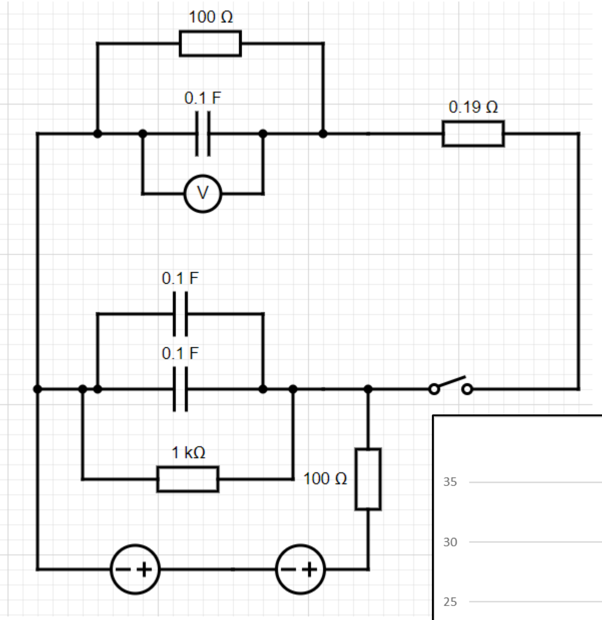
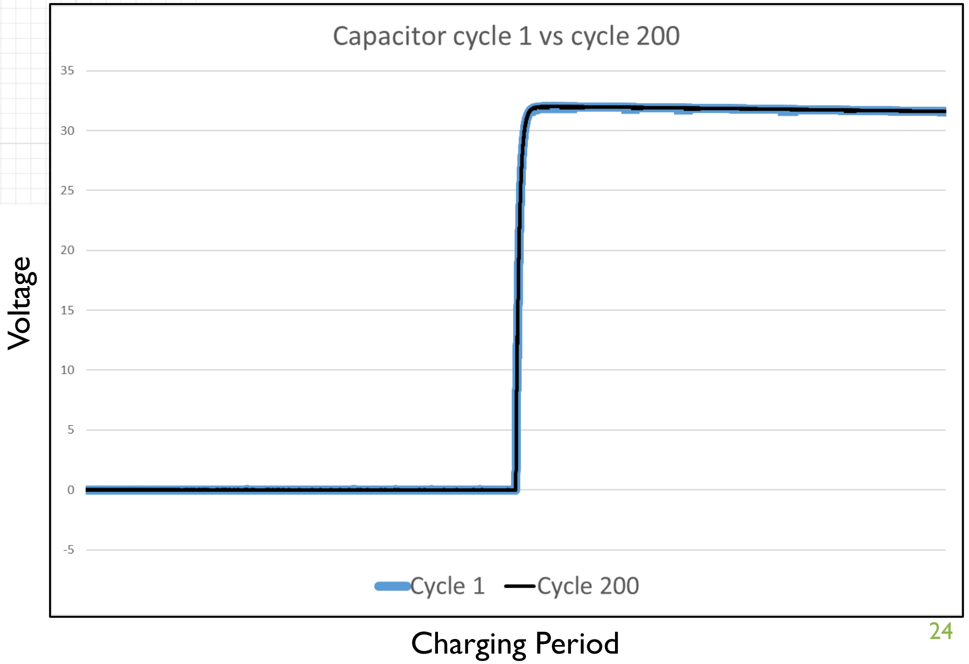
DETECTOR MAGNET SNUBBER CAPACITOR ENDURANCE TESTING

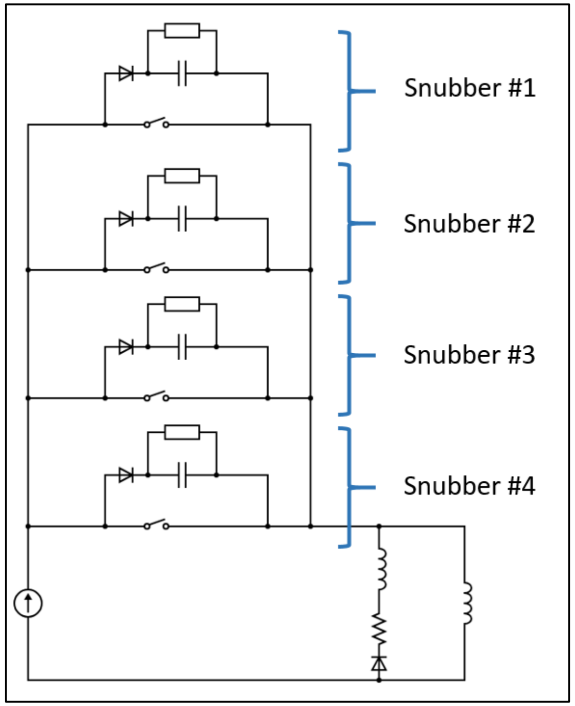


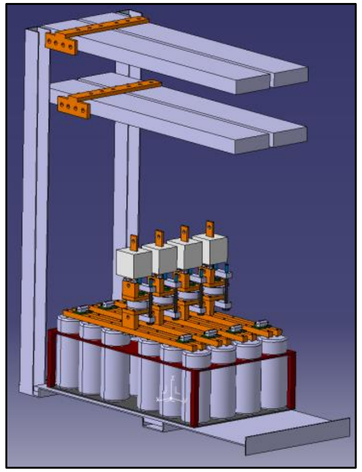




- Capacitor charging and discharging endurance tests to ensure capacitors would be suitable for an equivalent of 20 years in worst case scenario conditions.
- Zero degradation experienced

DETECTOR MAGNET SNUBBER BOX LAYOUT





- Final snubber layout would comprise 4 boxes, one for each parallel breaker
- Each snubber, 2.4 F, would comprise 4 branches of 6 capacitors, 0.6 F
- Each branch would include a diode and fuse to protect against capacitor damage/shorts
- Installation requested in 2021

DETECTOR MAGNET SNUBBER BOX INSTALLATION

- Snubber installation completed in November 2021
- Commissioning ongoing

CMS FWT COMMISSIONING

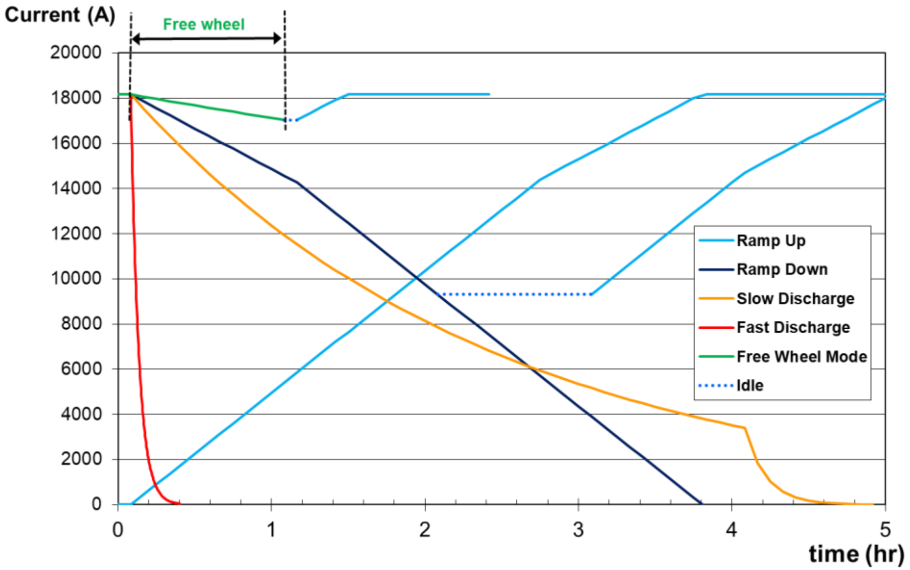
CMS Free Wheel Thyristor

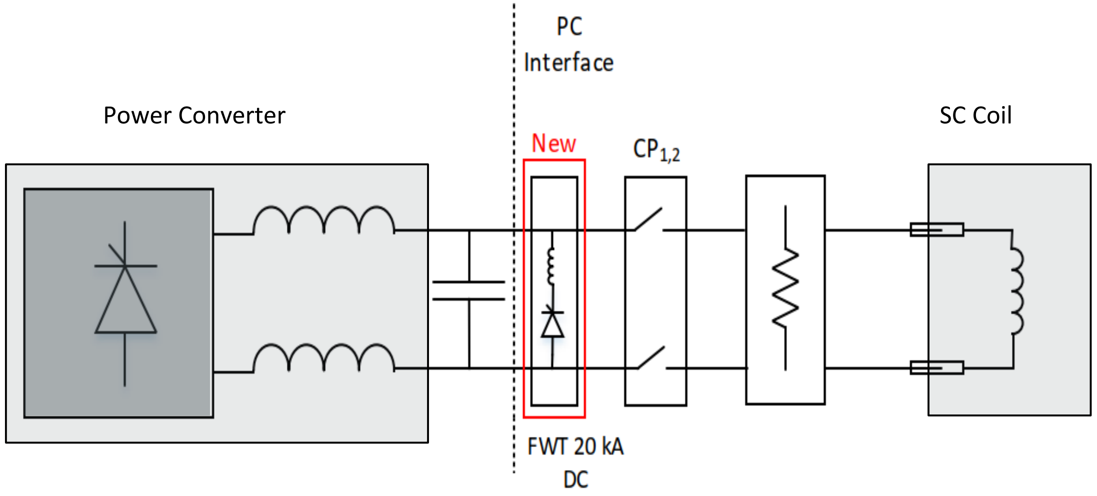
Magnet upgrade Phase-2 project, planned for LS2

FWT racks developed by CERN/SY-EPC

- Avoids an 8 hour magnet Slow Dump discharge in the event of a power convertor stoppage
- Preserves lifetime of the solenoid (3.8 T @ 18 kA)
- Extends operational time at nominal field

The FWT leaves the possibility to reconnect the converter at any magnet current, **or** to open the breakers to safely discharge the magnet on Rdump.



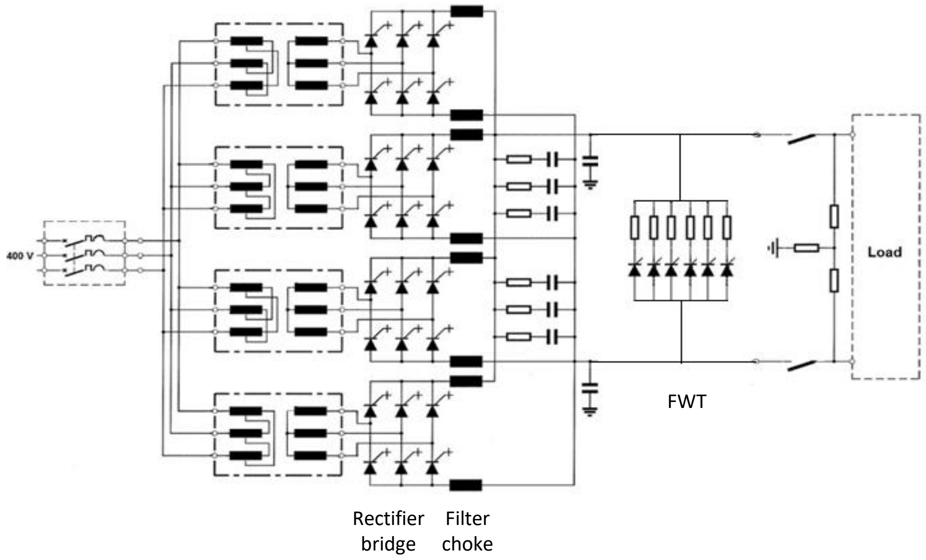


CMS FWT COMMISSIONING

- 6 thyristors in parallel inside a new cabinet, installed and connected in USC55 next to the existing power converter

The FWT discharge mode was successfully validated during the commissioning in October 2021 before LHC pilot beam:

- Very slow current decrease with FWT
- Converter reconnection possible at any current value



SUMMARY AND ONGOING TASKS FOR WP 8.1 AND 8.4

- A 4-T Split Coil Solenoid has been developed and further studies will continue to mature the design
- Snubber has been installed for ATLAS toroidal magnets and commissioning is ongoing
- Free Wheel Thyristor has been installed for CMS solenoid and successfully commissioned

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REFERENCES

1. S. Singh et al, "Strategic R&D Programme on Technologies for Future Experiments - Annual Report 2020",

   CDS number CERN-EP-RDET-2021-001

2. F. Malinowski et al., "A Quench Analysis for the New North Area Magnet", EDMS note 2508348 (2020)

3. M. Mentink, "ATLAS Circuit Breakers Update", 18/05/2020

4. S. Singh et al, "ATLAS Toroidal Snubber Demonstrator", EDMS note 2466567 (2021)