NEW 4 T MULTIPURPOSE SUPERCONDUCTING MAGNET FACILITY BTTB10

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INTRODUCTION & MOTIVATIONS

- European Committee for Future Accelerators has developed a global Detector Research & Development Roadmap, published in 2021, following recommendations of the 2020 Update of the European Strategy for Particle Physics.
- That roadmap aims to define the backbone of detector R&D required to deploy the community's vision for both the near- and longer-term. The mandate is to focus on the technical aspects to realise the research facilities in a timely fashion, and to provide strategic guidance for detector development at large, in synergy with neighbouring fields and industrial applications.

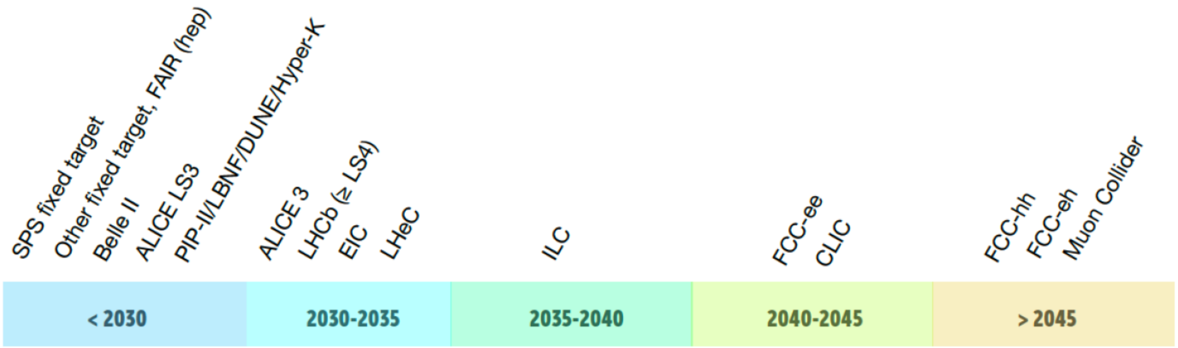


Figure 3: Large Accelerator Based Facility/Experiment Earliest Feasible Start Dates.

A lot of work ahead of us!

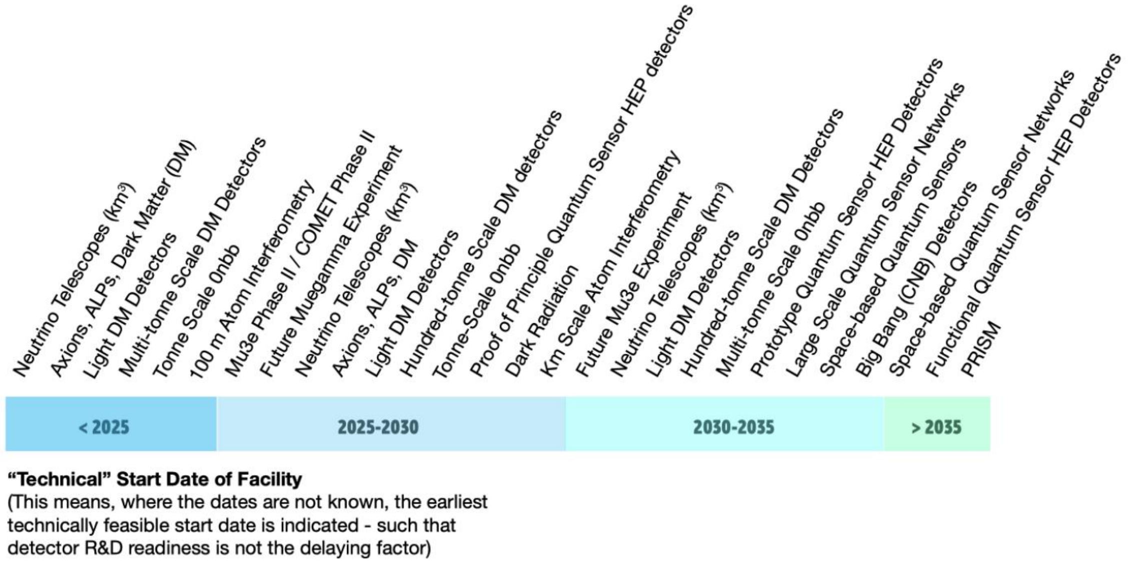


Figure 4: (Representative) Smaller Accelerator and Non-Accelerator Based Experiments Start Dates (*not intended to be at all an exhaustive list*).

INTRODUCTION & MOTIVATIONS

Some examples of future superconducting magnet systems listed in ECFA roadmap that represent the spectrum of engineering challenges and R&D needs for this topic :

- 4-T or higher field superconducting solenoids or dipoles,
- Placed either in front or behind the electromagnetic or hadronic calorimeters
- Large volumes
- Specific reinforced aluminium stabilized Nb-Ti superconductors
- High Temperature Superconductors (HTS) included as long term development

⇒ need for a high-field large-volume multi-purpose superconducting magnet as a test beam facility for the physics user community.

	Accelerator	Detector	B [T]	R[m]	L[m]	I [kA]	E [GJ]	comment
reference	LHC	CMS	4	3	13	20	2.7	scaling up
reference	LHC	ATLAS solenoid	2	1.2	5.3	7.8	0.04	scaling up
	FCC-ee [Ch8-1]	CLD	2	3.7	7.4	20-30	0.5	scaling up
		IDEA	2	2.1	6	20	0.2	ultra light
	CLIC [Ch8-2]	CLIC-detector	4	3.5	7.8	20	2.5	scaling up
	FCC-hh [Ch8-3]	main solenoid	4	5	19	30	12.5	new scaling up
		forward solenoid	4	2.6	3.4	30	0.4	scaling up
	IAXO [Ch8-4]	8 coil toroid	2.5	8x0.6	22	10	0.7	new toroid
	MadMax [Ch8-5]	dipole	9	1.3	6.9	25	0.6	large volume

Table 8.1: Examples of magnets for future experiments that represent the engineering and R&D challenges. The dimensions and fields refer to the free bore. The magnets for ATLAS and CMS are given for reference.

MOTIVATION FOR NEW TEST BEAM MAGNET

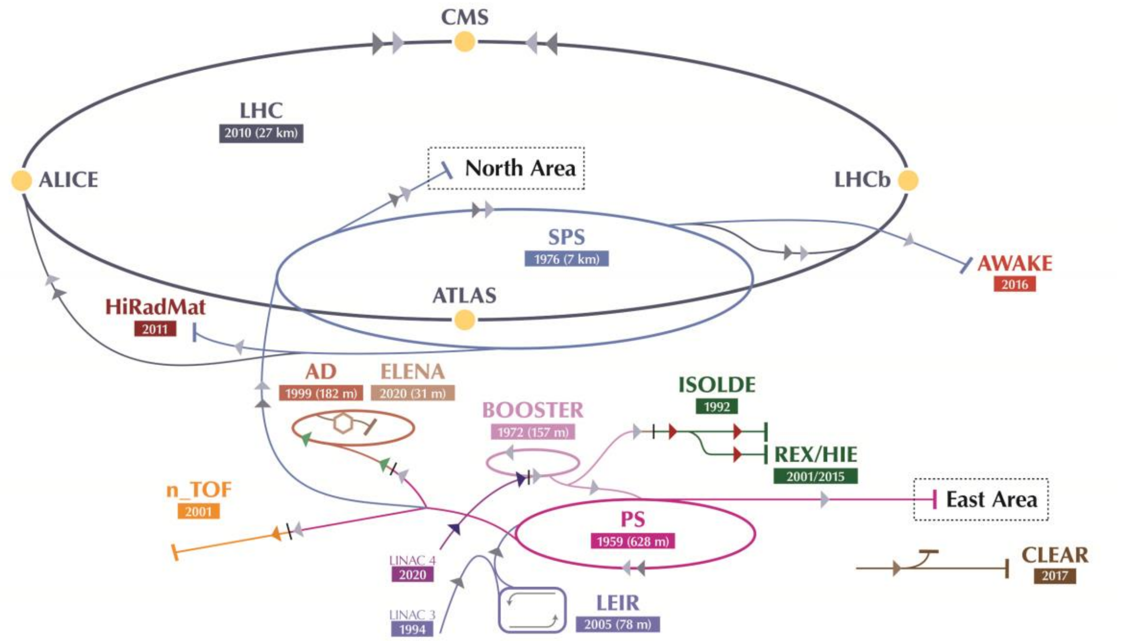
At CERN:

EP department has launched an R&D programme on new Detector Technologies.

This initiative, which spans a 5-years period from 2020 onwards (with a possible extension by another 5 years), covers detector hardware, electronics and software for new experiments and detector upgrades beyond LHC phase II.

WP	Work Packages	WP leaders & deputies
1.1	Novel hybrid Silicon detectors	Victor Coco, Paula Collins
1.2	Monolithic depleted Silicon sensors	Walter Snoeys, Michael Campbell
1.3	Silicon Modules	Petra Riedler, Dominik Dannheim
1.4	Silicon simulation and characterisation	Michael Moll, Dominik Dannheim
2	Gas detectors	Eraldo Oliveri, Christoph Rembser
3	Calorimetry and light based detectors	Martin Aleksa, Carmelo d'Ambrosio
4	Detector Mechanics	Corrado Gargiulo, Paolo Petagna
5	IC technologies	Kostas Kloukinas, Davide Ceresa
6	High Speed Links	Paolo Moreira, Jan Troska
7	Software	Graeme Stewart, Jakob Blomer
8	Detector Magnets	Benoit Cure, Matthias Mentink

CERN EXPERIMENTAL AREAS WITH TEST BEAM FACILITIES



The CERN accelerator complex

Beam lines at PS and SPS

Location	Beam line	Experiments & Users
East hall	T8	IRRAD & CHARM
East hall	T9	n.a.
East hall	T10	n.a.
East hall	T11	CLOUD
EHN1	H2	NA61 - SHINE & CERN NP
EHN1	H4	GIF++ & CERN NP
EHN1	H6	n.a.
EHN1	H8	n.a.
EHN2	M2	NA58 (COMPASS)
ECN3	P42/K12	NA62
TAG41	TT41	AWAKE
SPS	TT60	HiRadMat

MOTIVATION FOR NEW TEST BEAM MAGNET

- Existing test magnets on beam facilities at CERN (full list at http://ep-dep-dt.web.cern.ch/b-field-mapping/ep-spectrometer-magnets-inventory)

Name	Field [T]	Current [A]	Power / Energy	Weight [Tons]	Location/Use
SM1/SM2	1.65	2500	1250 kW	120	EHN2/COMPASS NA58
MNP 33/mod	0.8	2500	900 kW	125	ECN3/NA48/2, NA62
Goliath	1.5	Up coil 3600 Low coil 5350	550 kW 950 kW		EHN1/H4 beam NA57, RD51, (ShiP)
Superconducting COMPASS magnet	2.5				EHN2/COMPASS NA58
Superconducting Vertex magnet 1	1.5	5000	L = 1.68 Hy	380	EHN1/NA49 H2 beam
Superconducting Vertex magnet 2	1.5	5000	L = 1.68 Hy		EHN1/NA49 H2 beam
Superconducting Morpurgo	1.6	6000	20 MJ	230	EHN1/ATLAS H8 beam
Superconducting M1	3	4000	55 MJ	150	EHN1/CMS H2 beam

Normal conducting magnets

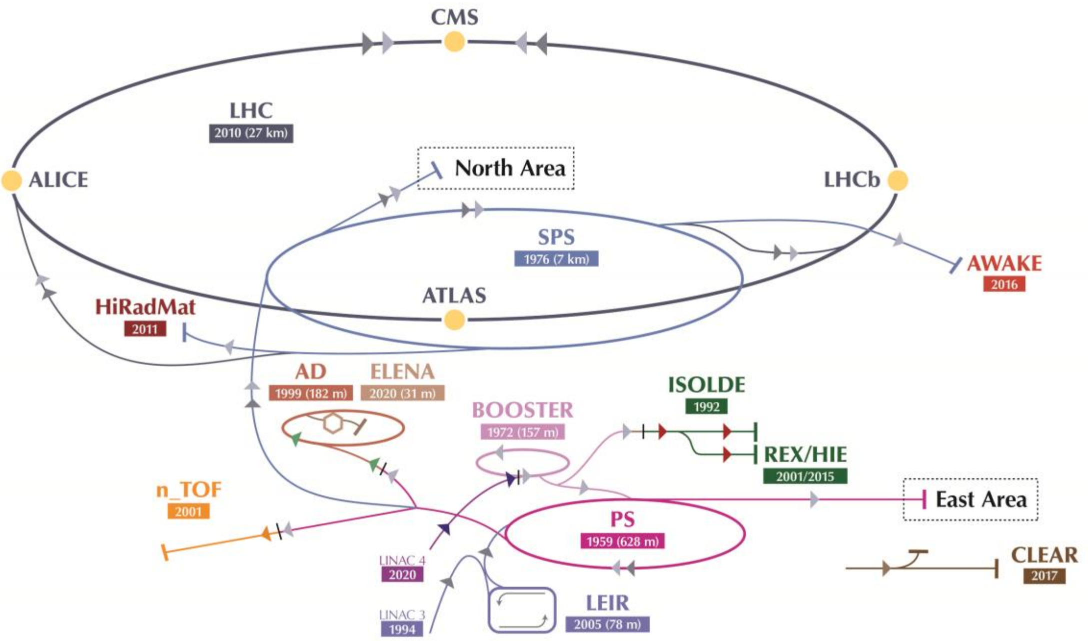
Superconducting magnets

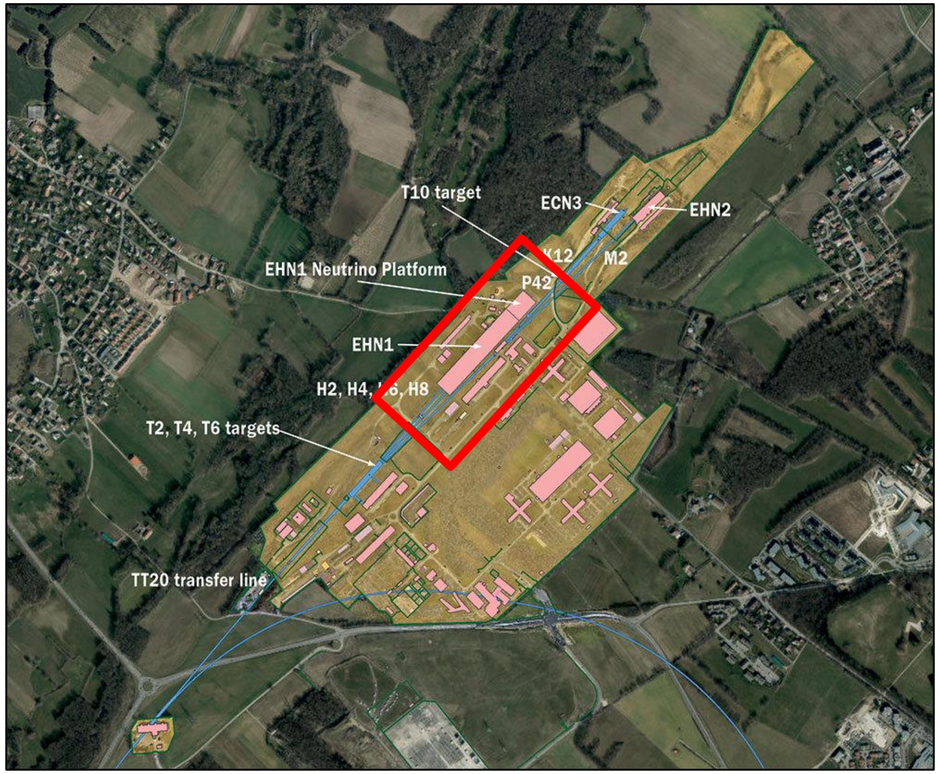
No 4-T magnet (with useful volume) for detector prototype tests

MOTIVATION FOR NEW TEST BEAM MAGNET

- The new cutting-edge high-energy particle detectors of the future accelerators have to work in **4-T magnetic field**
- For testing detector units and performing calibration with magnetic field, **a general purpose 4 T test facility is proposed** and will replace or complement the existing CERN general-purpose systems
- The magnet shall be installed on a beam line and the facility shared among collaborations to which CERN is contributing
- **The concept of a new 4-T beam test facility is studied in the context of the EP R&D work package 8**
- It is noted that the magnet construction itself, commissioning and installation on the beam line **is not included in the frame of this EP R&D program**
- **EP and CERN are encouraging institutes with needs in test beam** at high field to join and collaborate and in order to find a way to fund such a facility

THE SUPER PROTON SYNCHROTRON (SPS) AND EXPERIMENTAL NORTH AREA (EHN1)





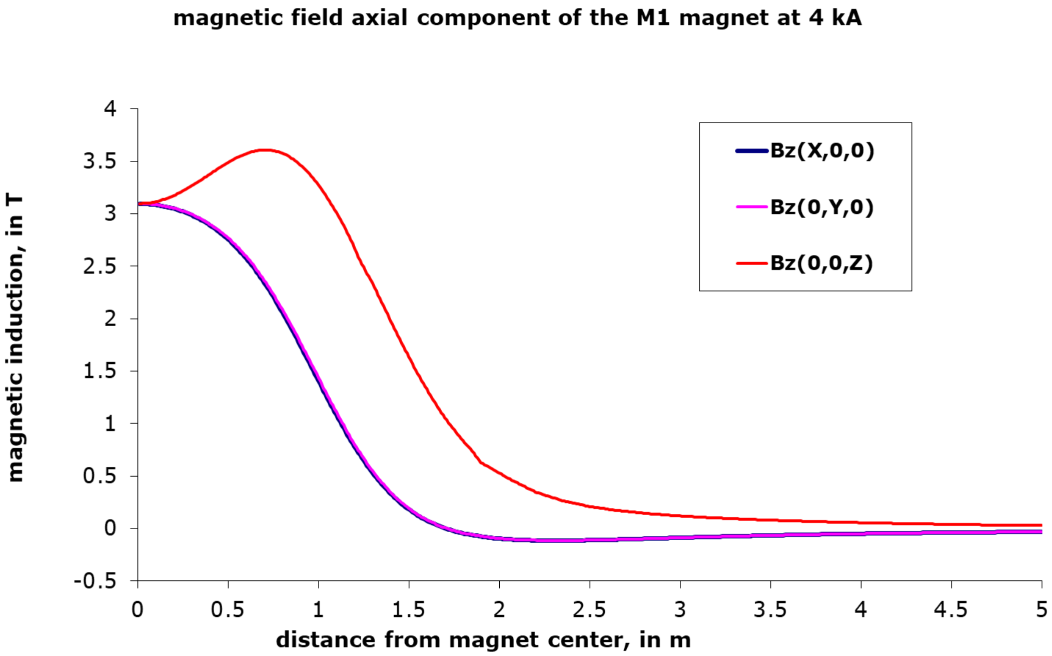
EHN1:

- H2, H4, H6, H8 beam lines
- **High-energy, high-resolution secondary beam lines.** The maximum momentum that can be transported in the experiments is 400 GeV/c protons (primary SPS beam) or secondary mixed hadron beams within the range **10-400 GeV/c**

EXISTING GENERAL-PURPOSE MAGNETS IN NORTH AREA

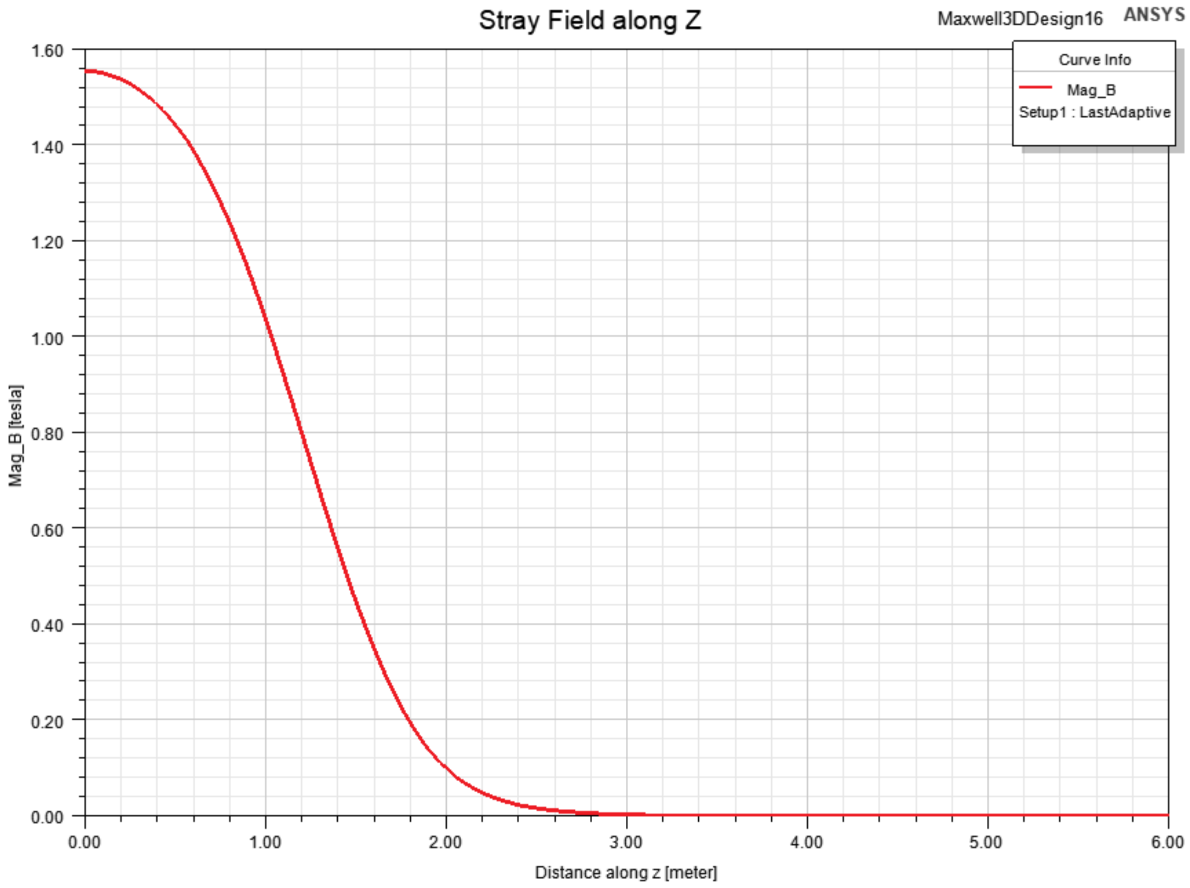
The starting point of the study is the two general purpose facilities available as test beam facilities: Morpurgo and M1 facilities.

These magnets have been in operation since the late 70s, for experiments, then later as test beam facilities.



- 3-T **M1** H2 Superconducting Magnet
- Dipole and Solenoidal function (split solenoid)
- 1.4 m free bore diameter
- 800 mm free gap

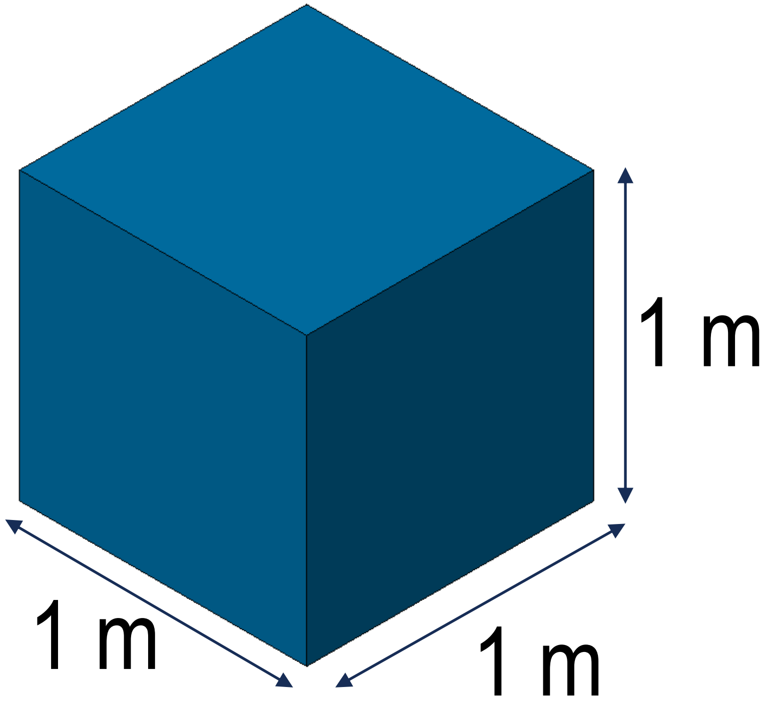
EXISTING GENERAL-PURPOSE MAGNETS IN NORTH AREA



- 1.6 -T **Morpurgo** H8 Superconducting Magnet
- Dipole function (saddle)
- 1.6 m free bore diameter

NEW NORTH AREA TEST BEAM MAGNET PARAMETERS

1) 4-T central field
2) 1 m^3 free volume target
3) Stray field must be minimised due to proximity of other experiments



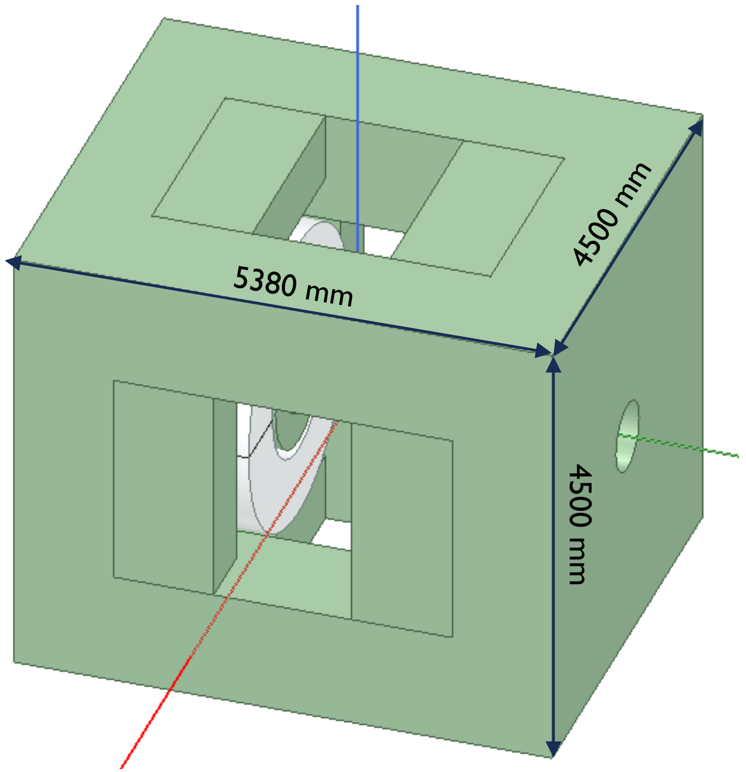
This facility will allow to perform tests with the **full range of magnetic conditions** in a detector:

- constant field value up to 4-T,
- variable field conditions similar to magnet ramps or discharges.

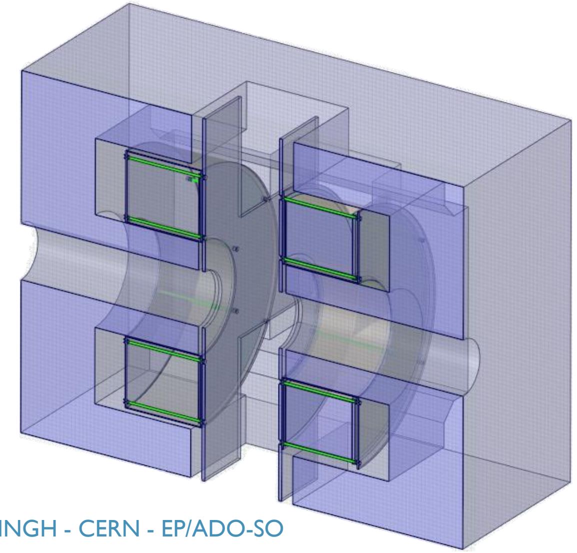
The **field homogeneity** within the duty volume shall be specified based on the requests of the potential users from the test-beam community.

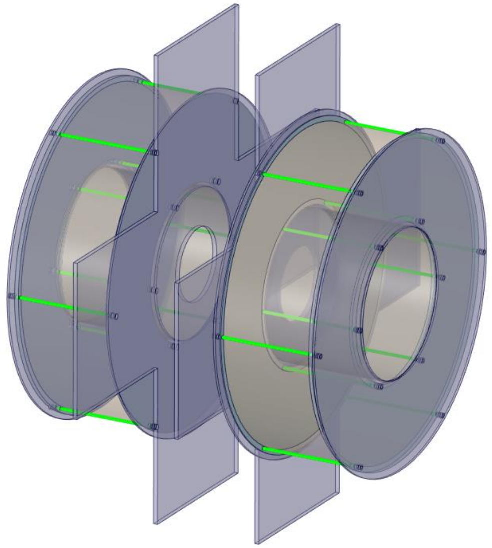
Please contact us if you are interested in such a facility and let us know your requests

SPLIT COIL SOLENOID MAGNET



Specifications	
Field at Center	4 T
Free gap	1000 mm
Free bore diameter	700 mm
Total Stored Energy	106 MJ
Axial coil length	600 mm
Peak field in conductor	5.7 T
Stray field at 5 m	15 mT

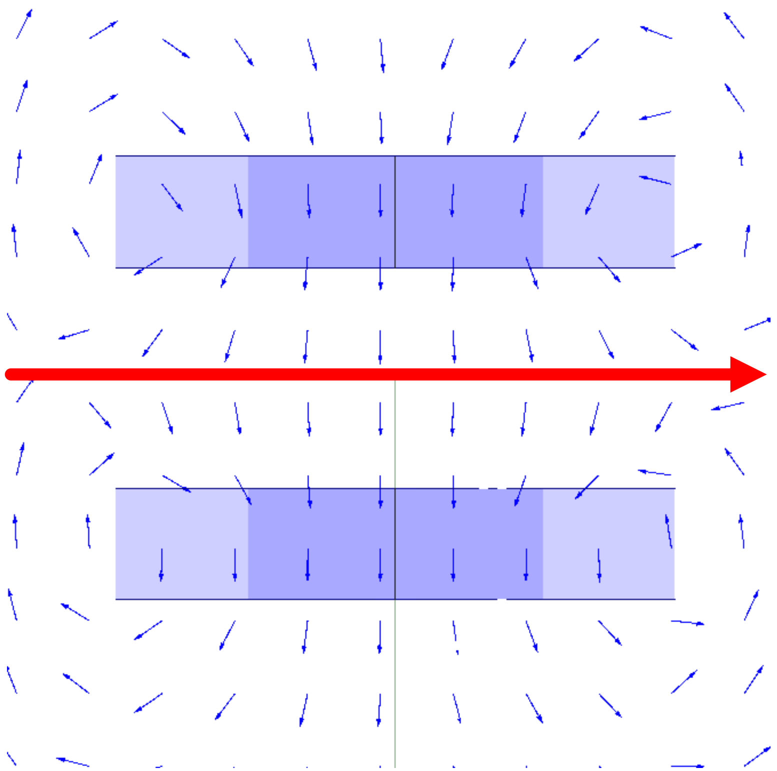




- Split Coil Solenoid (SCS) similar in design and functionality of M1
- Iron yoke allows for beam in 2 directions
- Coils supported by titanium tie-rods

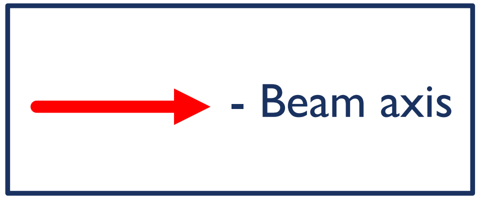
BENEFITS OF A SPLIT COIL SOLENOID MAGNET

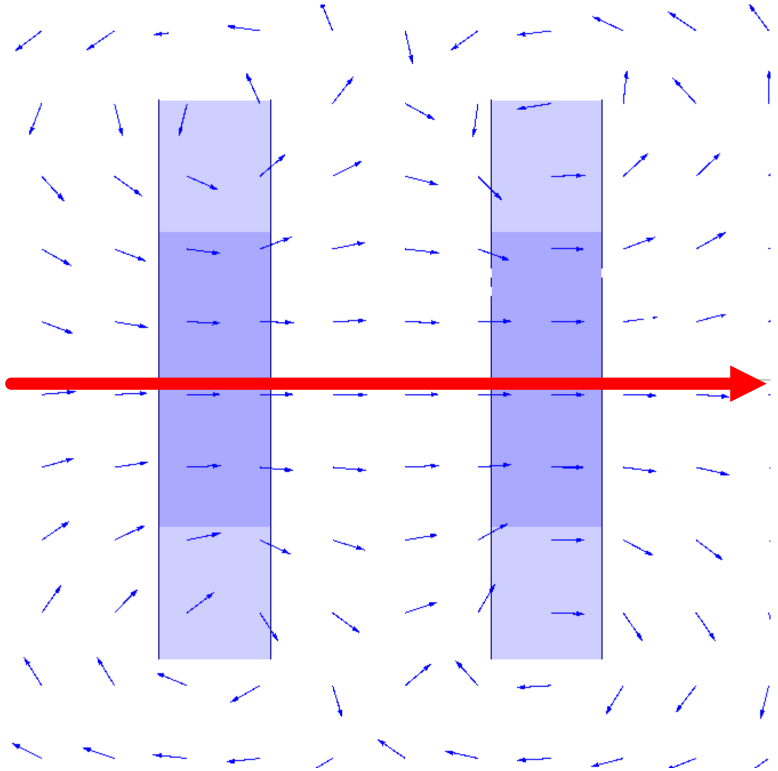
Top view of magnet



Dipole function

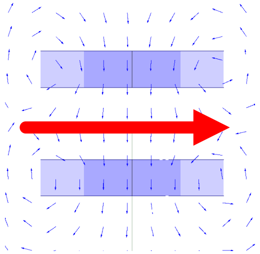
- Two different testing orientations are possible relative to beam axis
- Dual functionality similar to M1

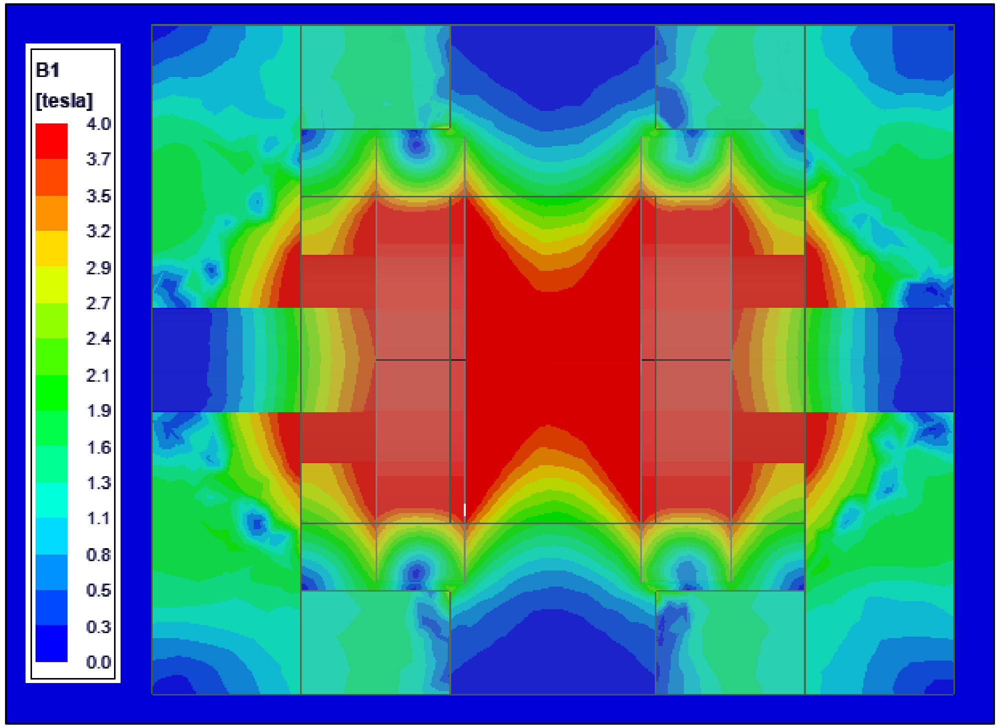


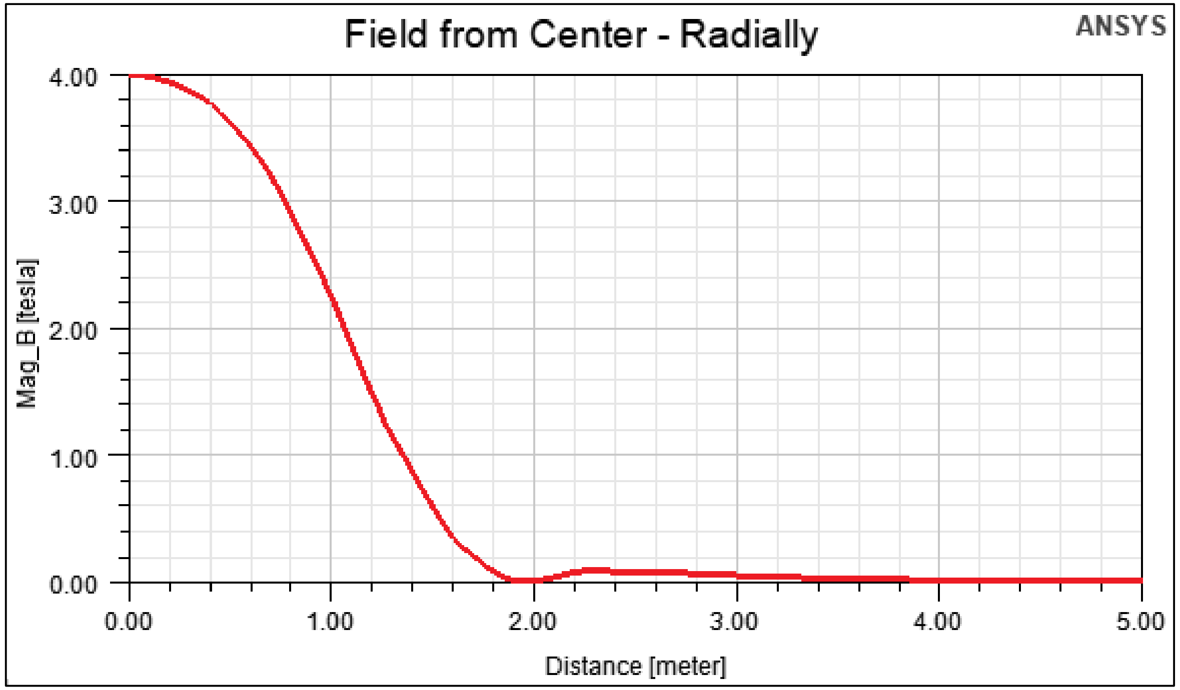


Solenoidal function

SPLIT COIL SOLENOID MAGNETIC FIELD PLOTS

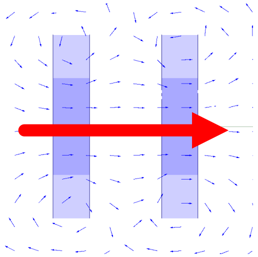


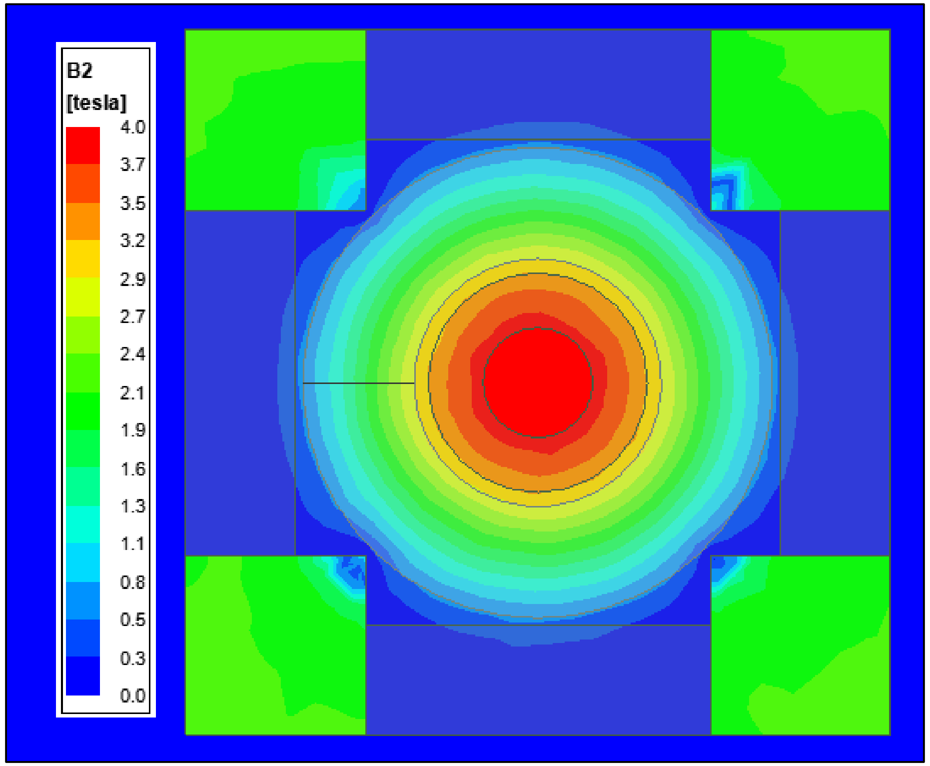


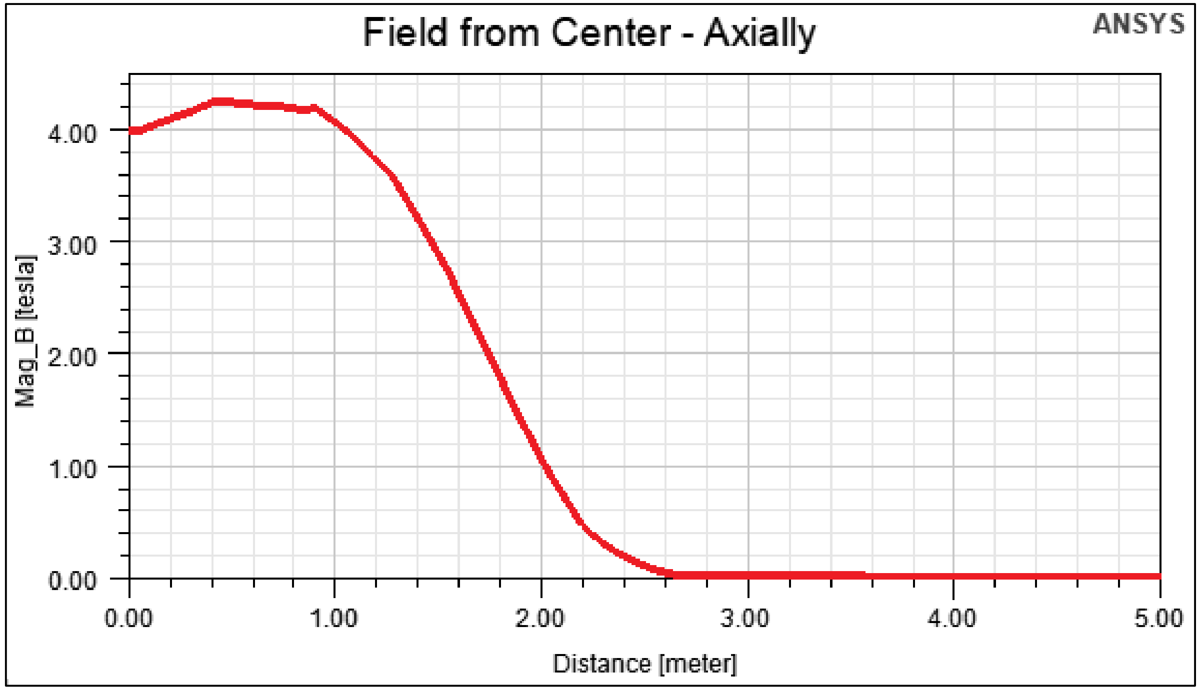


Sections through central plane

SCS FIELD ALONG AXIAL AND RADIAL DIRECTION



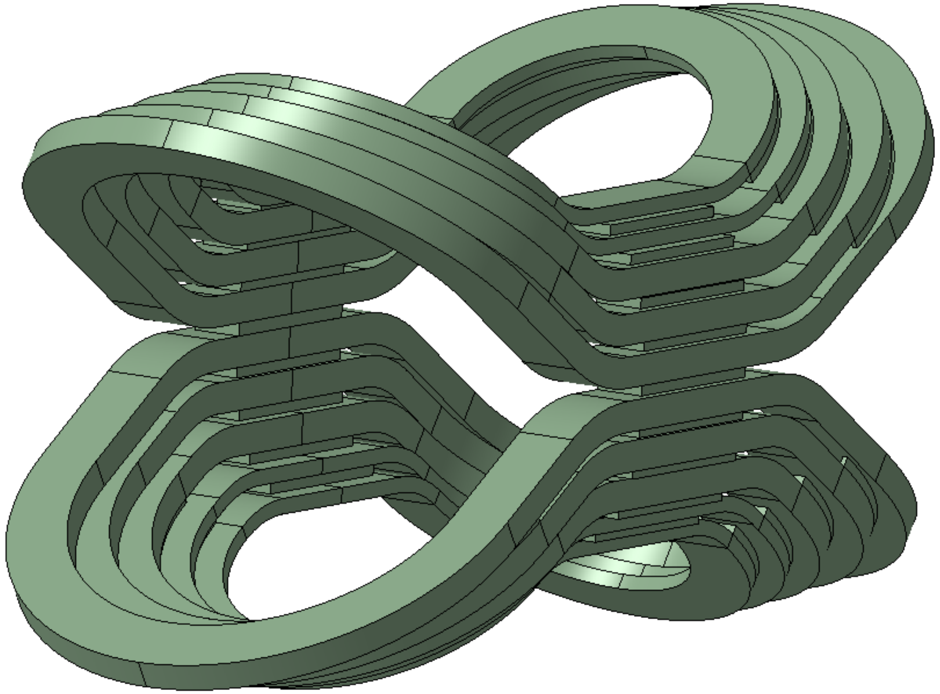




THE MAGNADON

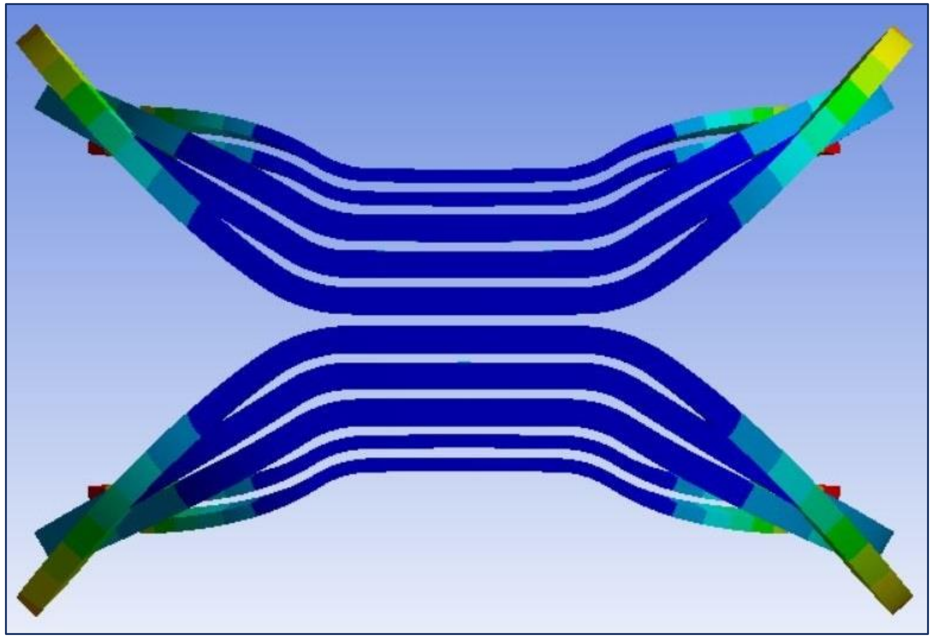
- **MAG**net for **N**orth **A**rea with a **D**ipole **CON**cept

~ 2 m bite radius / outer bore like the extinct Megalodon shark

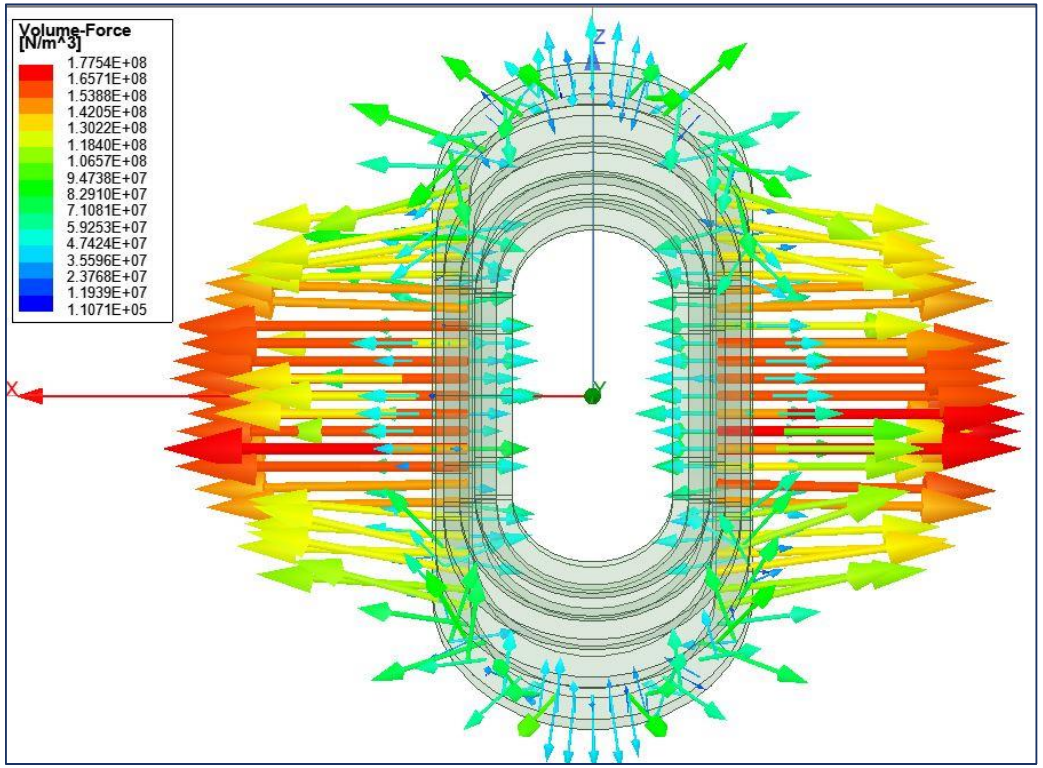


- Like the MADMAX magnet design
- Special thanks to CEA - IRFU Saclay for fruitful discussions

MAGNADON MAGNET LORENTZ FORCES AND DEFLECTION



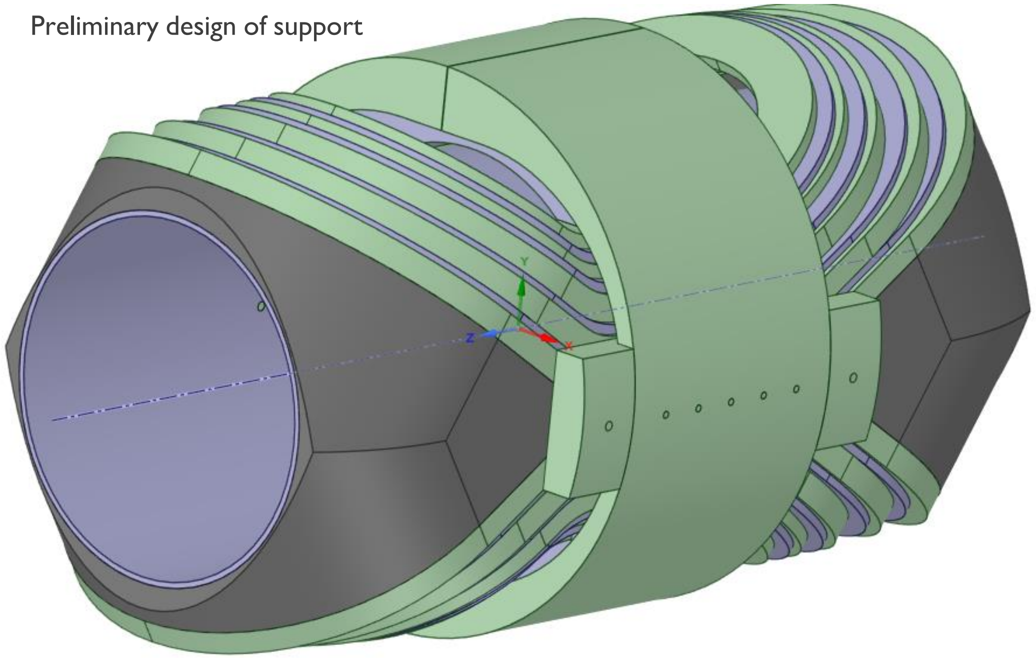
- Coils attempt to “open” and “close” during current ramp up requiring a robust and complex mechanical support structure



- Bursting force along X-Axis : 2.5 MN

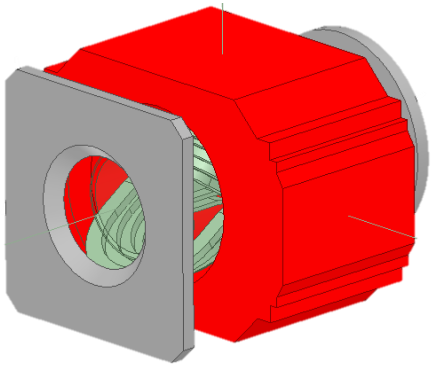
MAGNADON MAGNET SPECIFICATIONS

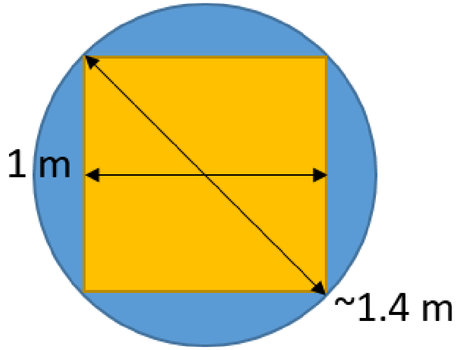
Preliminary design of support



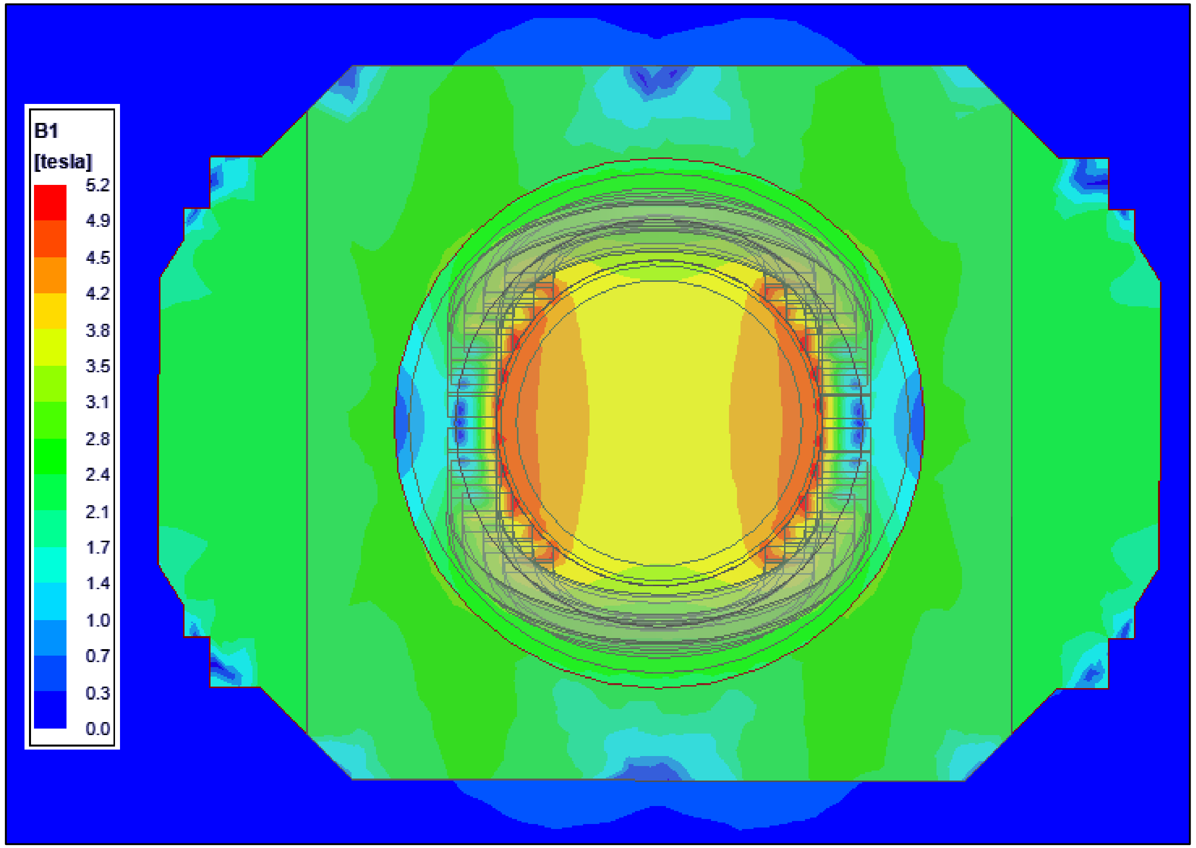
- New design used a tilted racetrack "skateboard" design
- Compatible with Morpurgo iron yoke

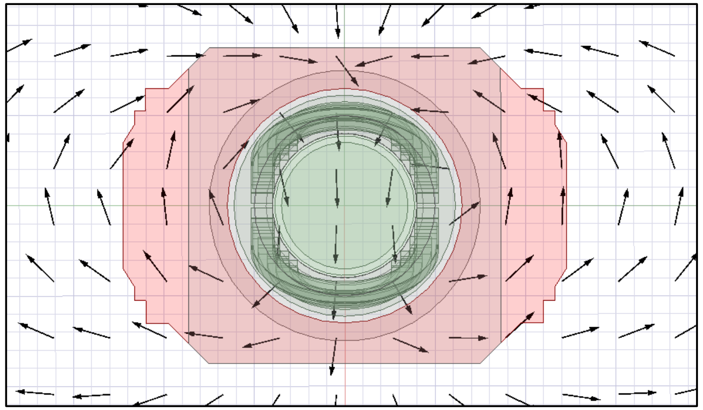
Specifications	
Field at Center	4 T
Free warm bore diameter	1400 mm
Total Stored Energy	80 MJ
Peak field in conductor	5.5 T
Stray field at 5 m	11 mT

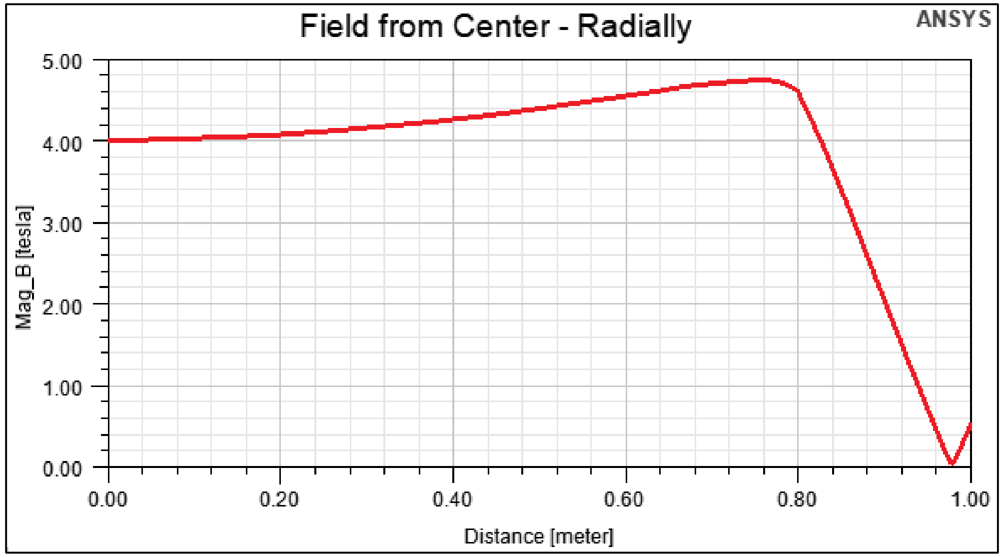




MAGNADON MAGNETIC FIELD PLOTS

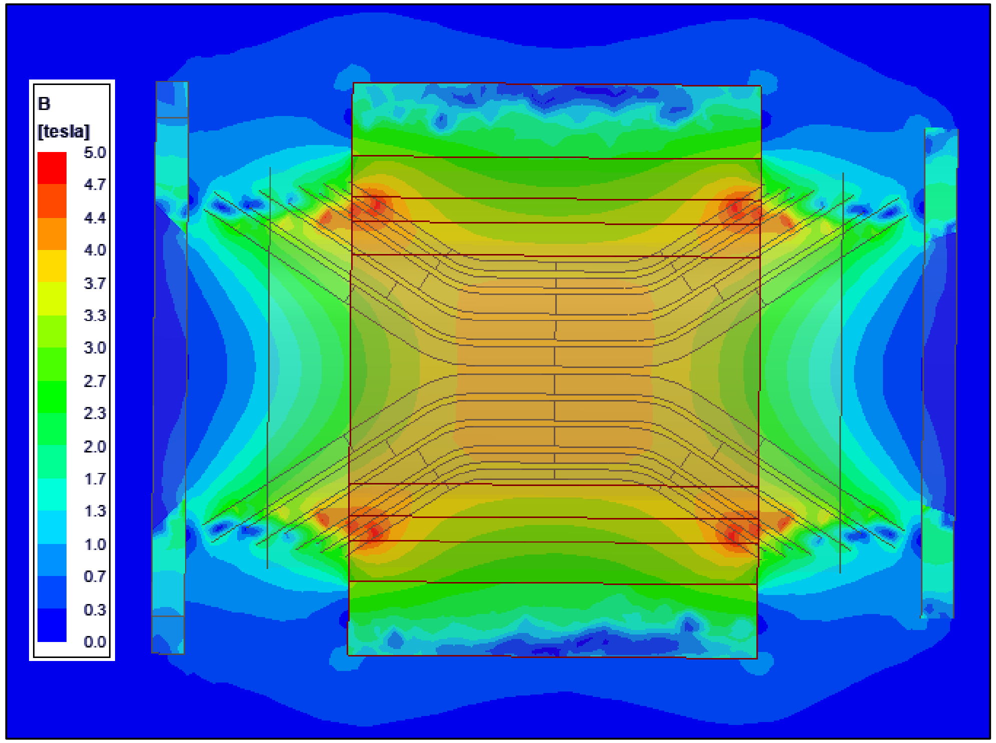




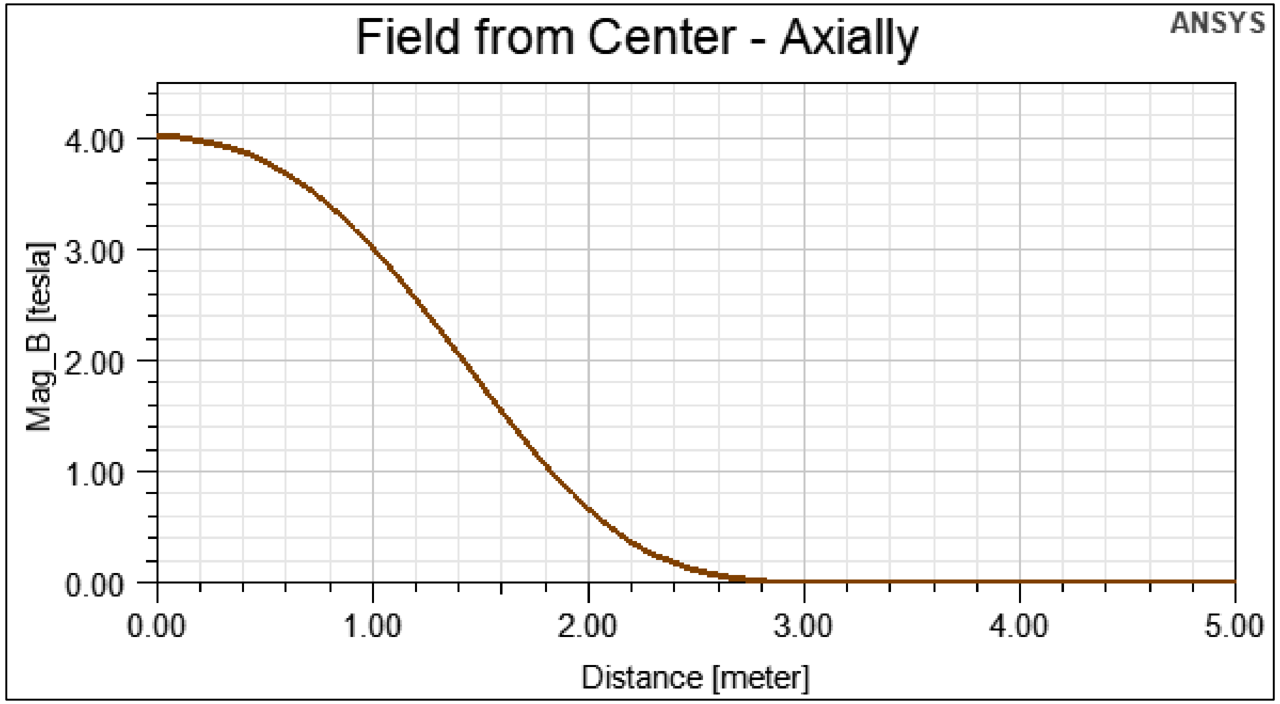


The field drops off radially at 1 m due to the iron yoke

MAGNADON FIELD ALONG AXIAL AND RADIAL DIRECTION



Sections through central plane



NORTH AREA MAGNETS SUMMARY AND BENEFIT COMPARISON

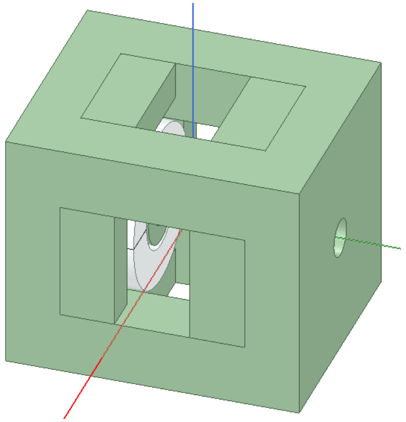
- Both magnets have a **4 -T central field**
- A minimum of **1 m^3 free volume**

Split Solenoid Coil	**The Magnadon**
▪ Dual orientation of testing ▪ Simpler mechanics and manufacture	▪ Better field homogeneity ▪ Larger aperture of 1.4 m

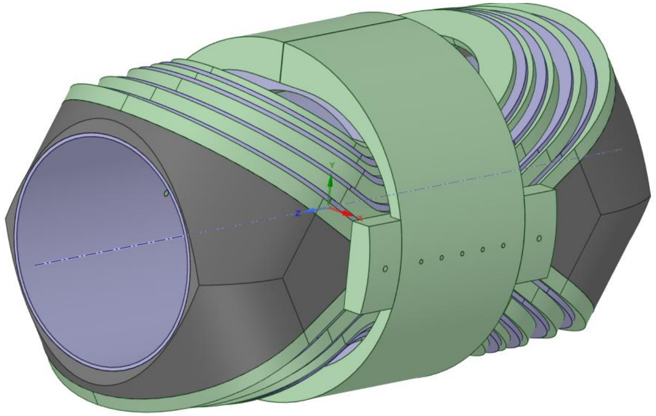
- **Magnadon has a more complex winding process and mechanical structure** to be further developed, so priority has been given **the Split Coil Solenoid at this stage**

PROJECT OUTLOOK

- Split Coil Solenoid 1-T demonstrator to be built
- Looking towards future user community for feedback and possible collaborations



Is a **4 -T** superconducting magnet facility with **1 m^3 free volume** appropriate for the user community?



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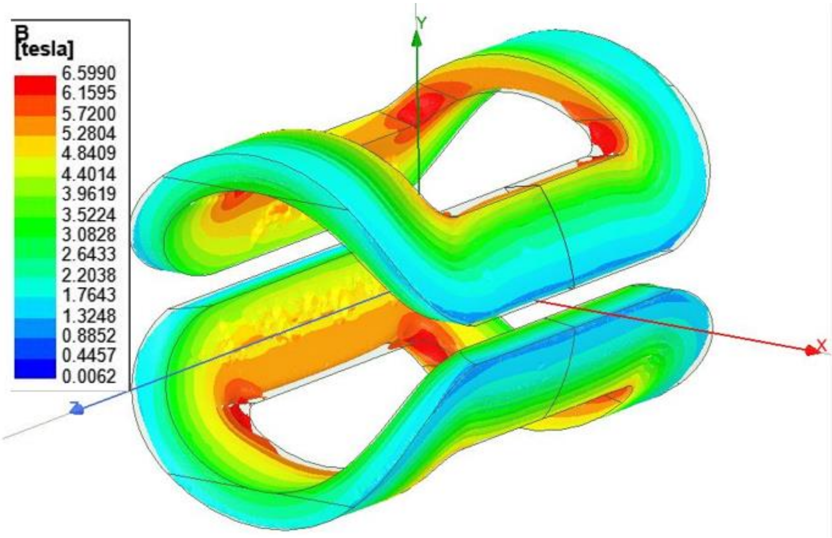
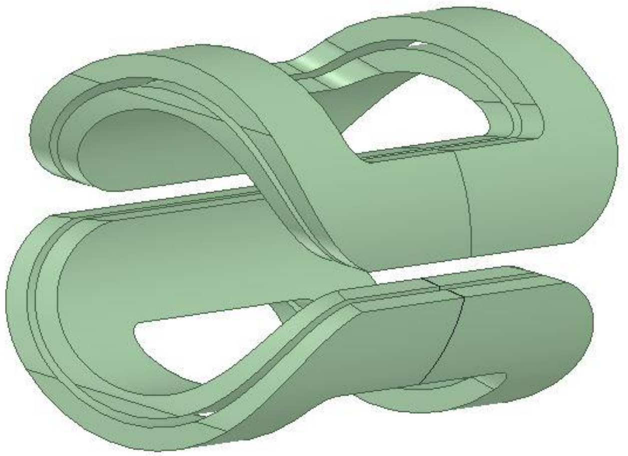
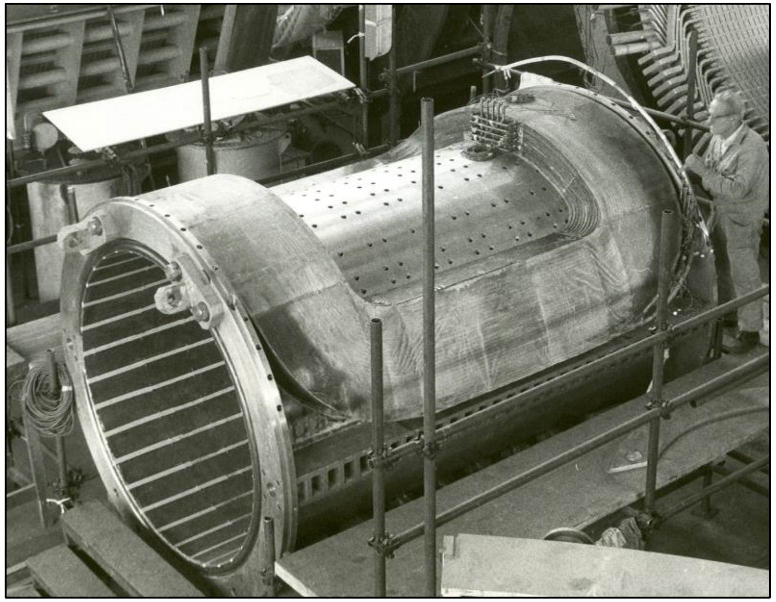
SUPPORTING SLIDES

THE MAGNADON

- Alternative saddle shape first considered and studied



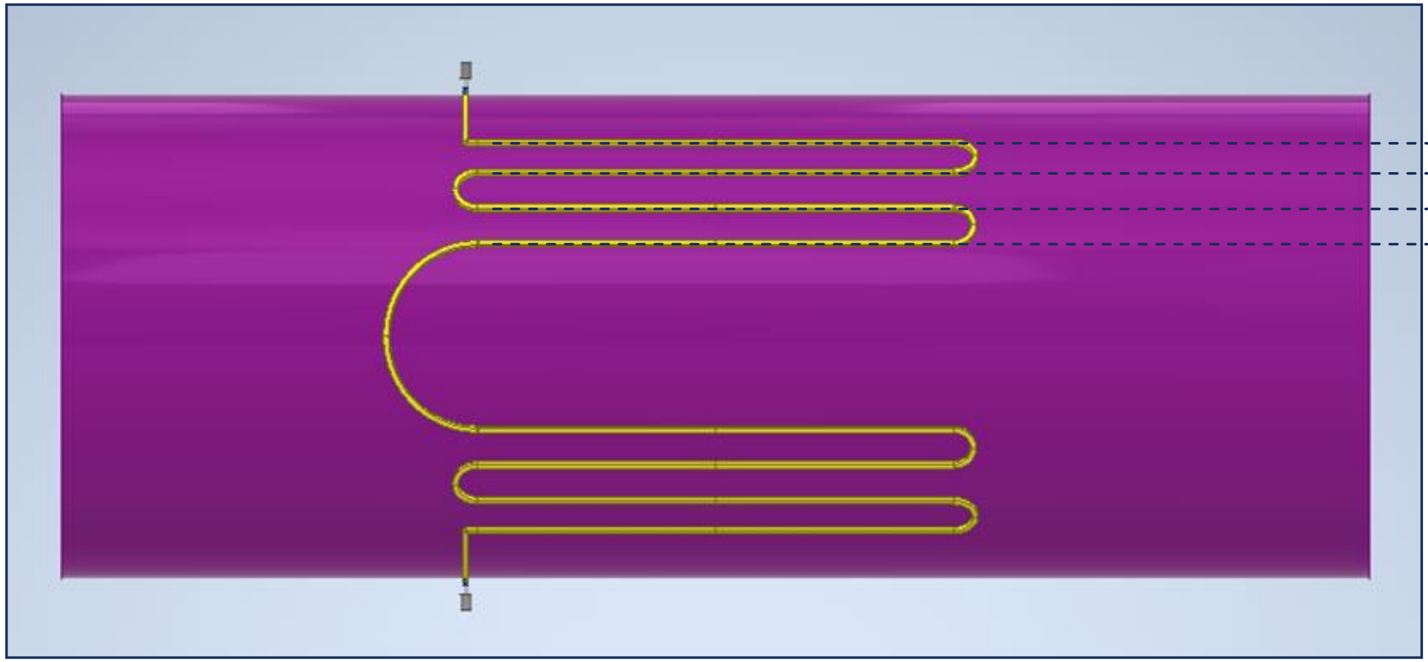


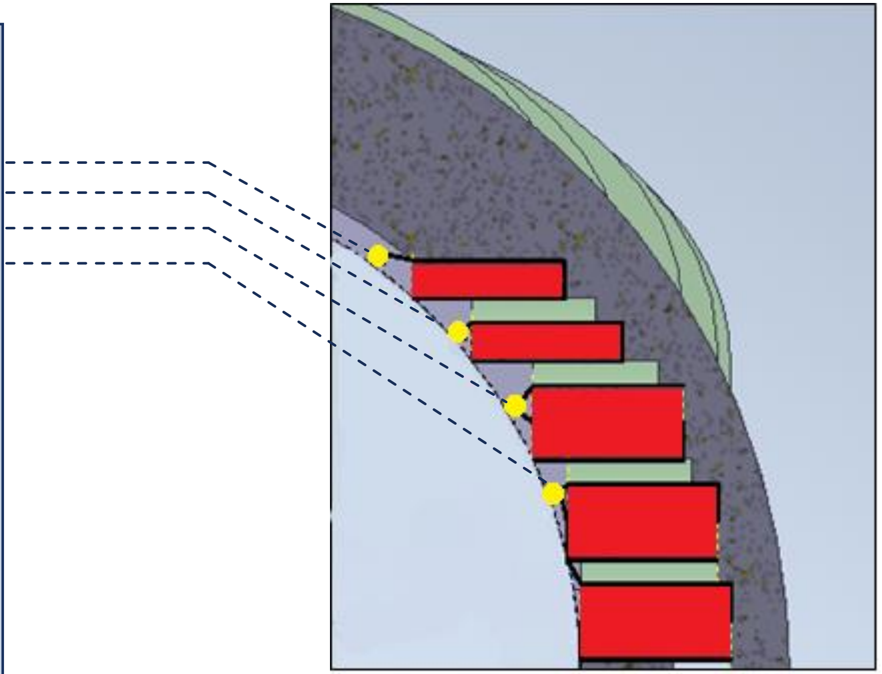


Construction of Morpurgo magnet

- Like the H8 Morpurgo magnet
- Peak field concerns lead focus to Magnadon

MAGNADON MAGNET THERMOSIPHON CONCEPT

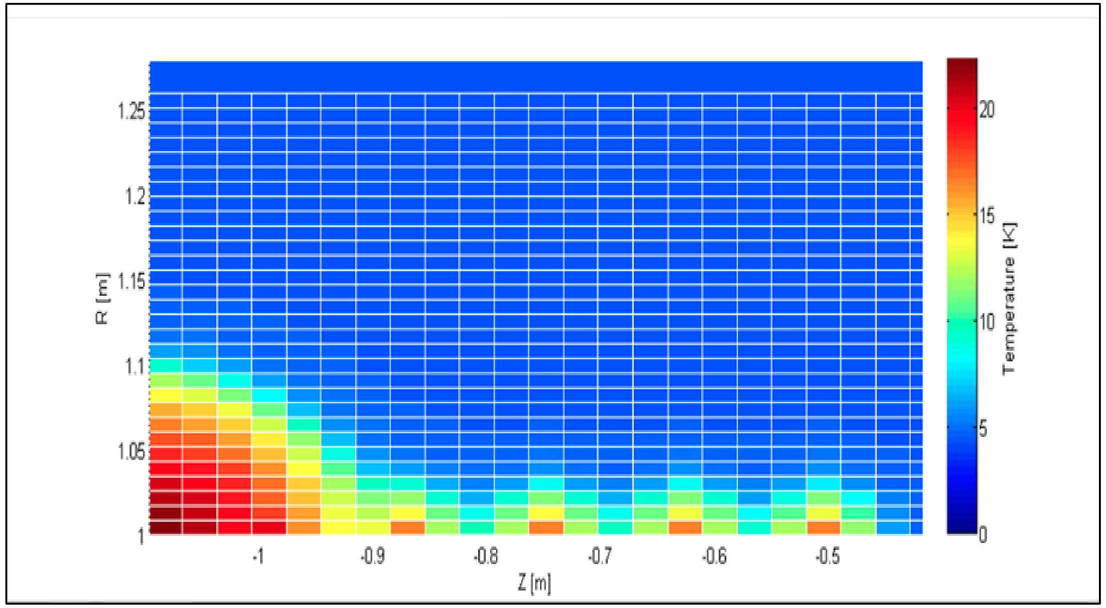




Cross-section of Magnadon assembly

- 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

SPLIT COIL SOLENOID MAGNET QUENCH BEHAVIOUR

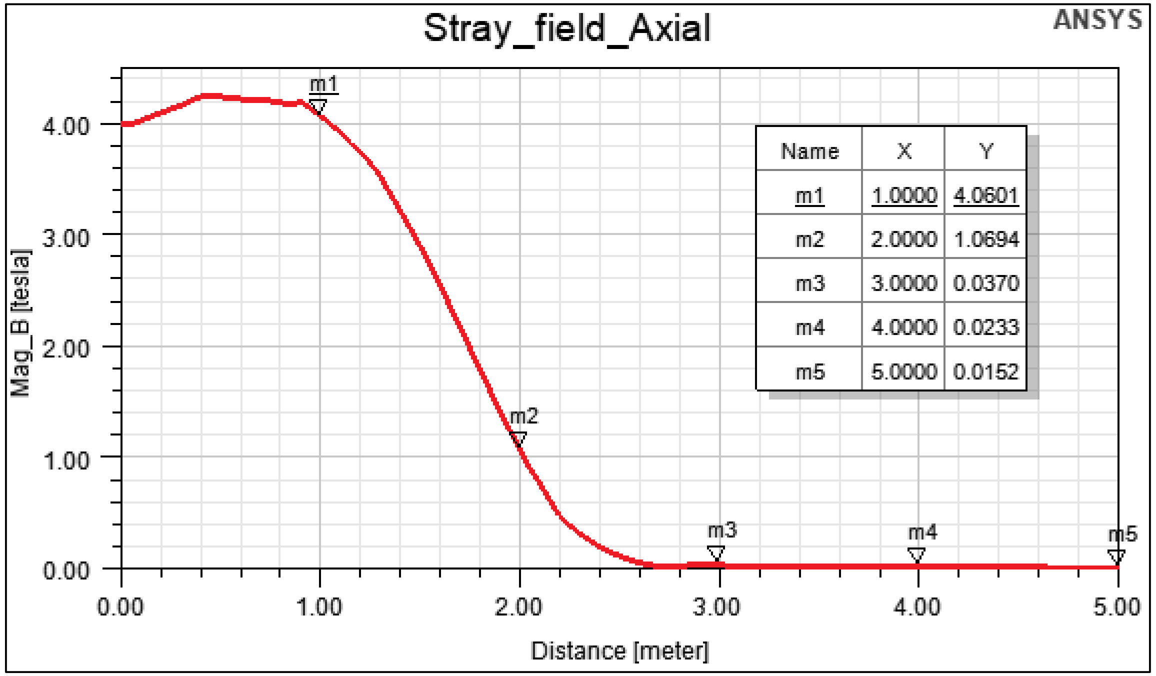


- Preliminary split coil simulations done with updated "**Quench 2.7**"
- Quench heater concept showed satisfactory results with a good safety margin
- With the quench heater variant the coil reaches a temperature of approximately **100 K**, but with a relatively small temperature gradient below **25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

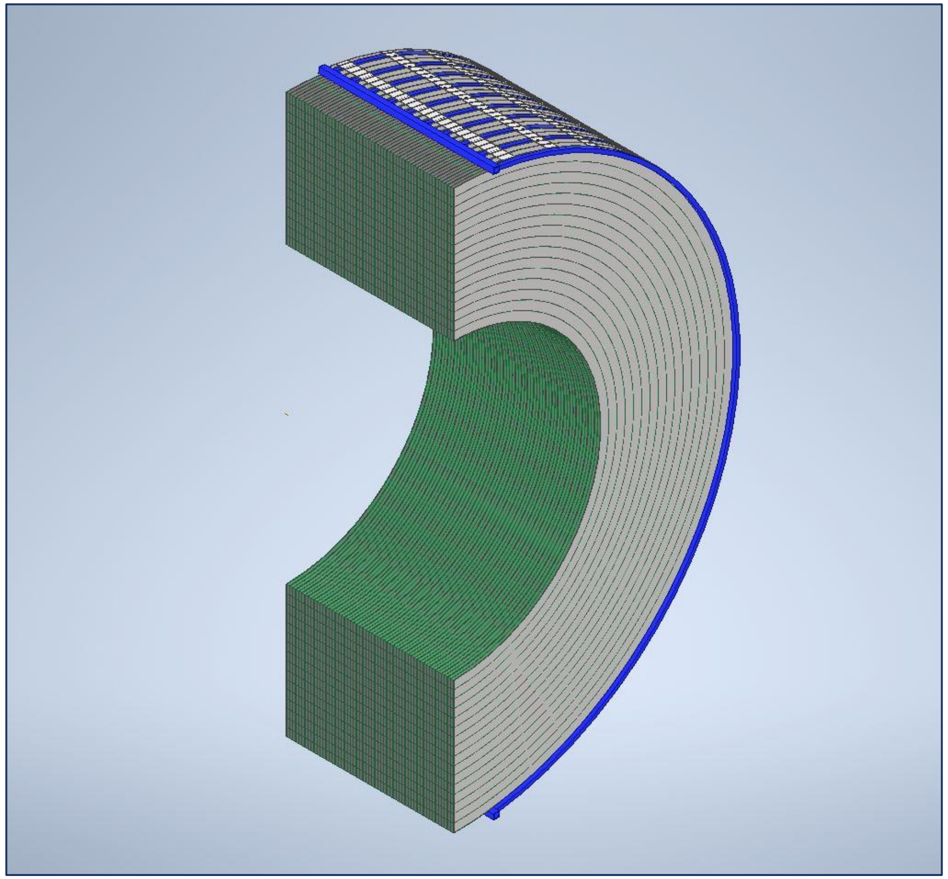
[2]

SPLIT COIL SOLENOID STRAY FIELD AND CRYOGENICS

- Current stray at 5 m is 15 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**



Name	X	Y
m1	1.0000	4.0601
m2	2.0000	1.0694
m3	3.0000	0.0370
m4	4.0000	0.0233
m5	5.0000	0.0152



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