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PIANO NAZIONALE DI RIPRESA E RESILIENZA

INFN

Steady HTS magnets
The example of the PNRR-IRIS dipole

L. Balconi, L. Rossi,
S. Sorti, M. Statera
Università di Milano
& INFN – sezione di Milano
Laboratorio LASA

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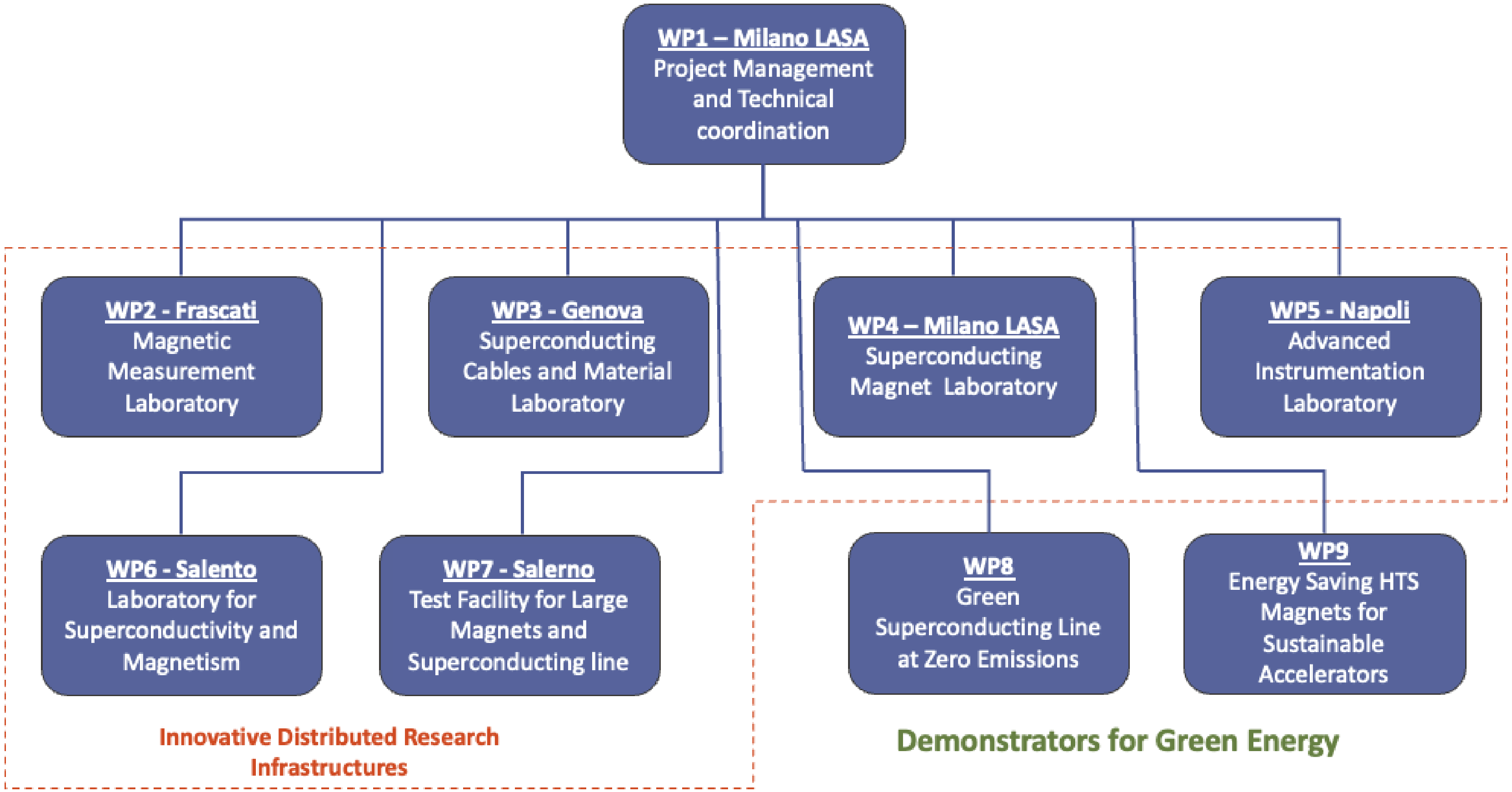
Innovative Research Infrastructure on applied Superconductivity

IRIS

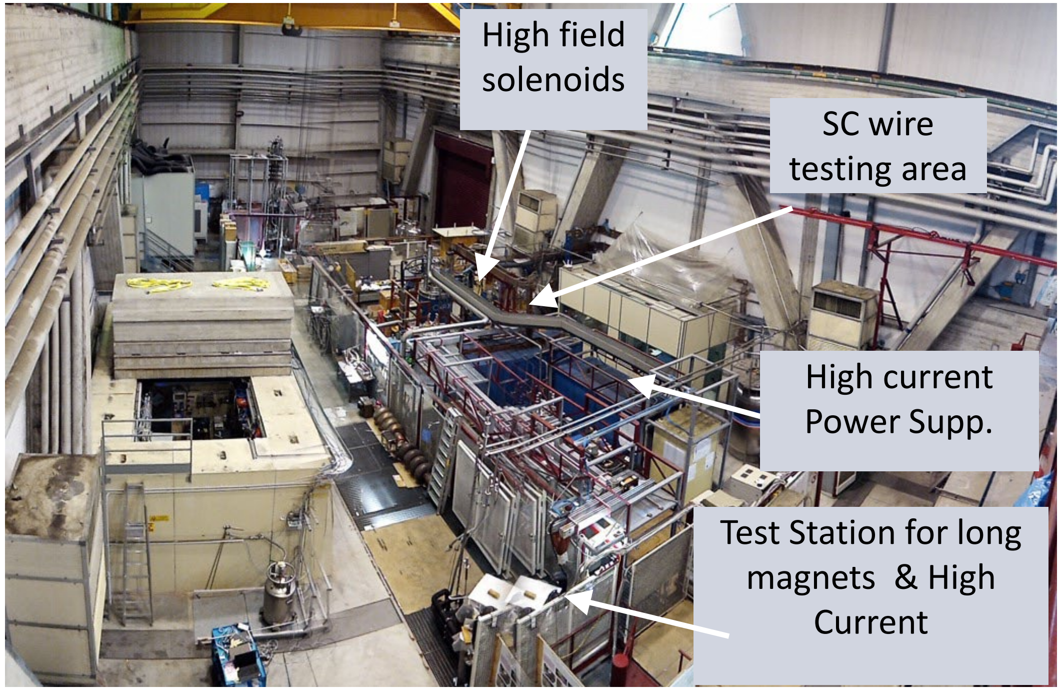
OUTLINE

- IRIS Project
- Magnet layout and parameters
- Insulated & Non-Insulated coils
- Concepts and Approaches for Quench Protections

IRIS Structure

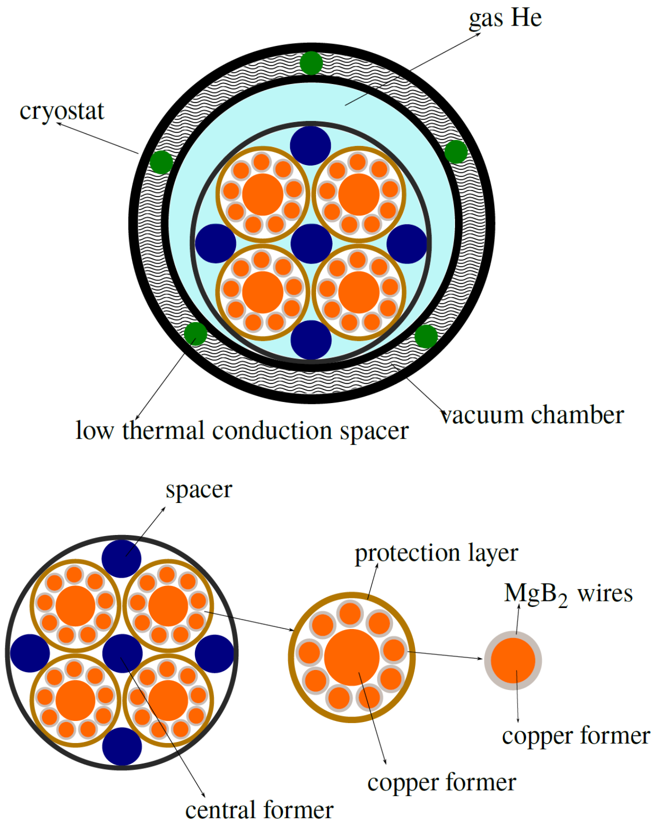


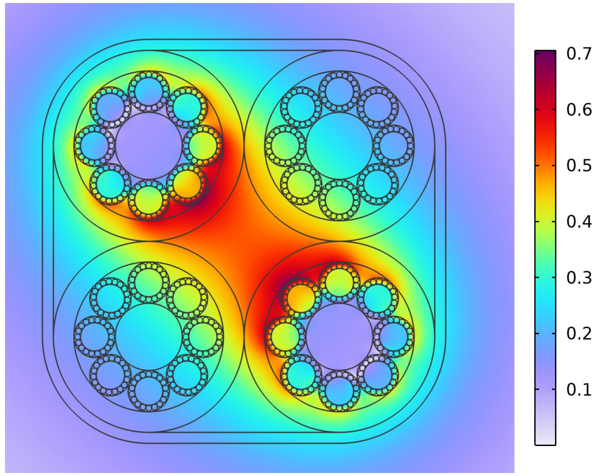
WP4 – Superconducting Magnets Laboratory



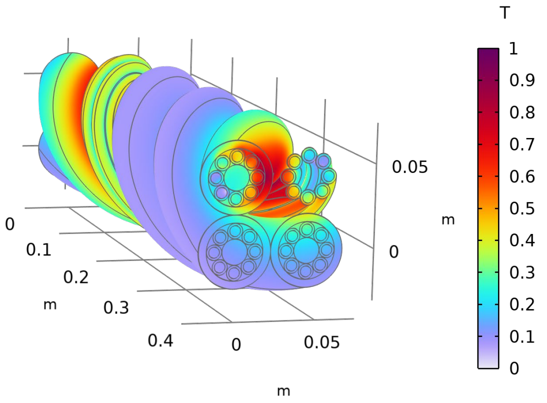
WP8 - Green Superconducting Line

Line characteristics	
Power transport	1 GW
Voltage	25 kV
Current	40 kA
Operating temperature	20 K
Line length	130 m
Expected losses	2.5 W/m at 20 K
Overall cable diamater	105 mm





Volume: Magnetic flux density norm (T)



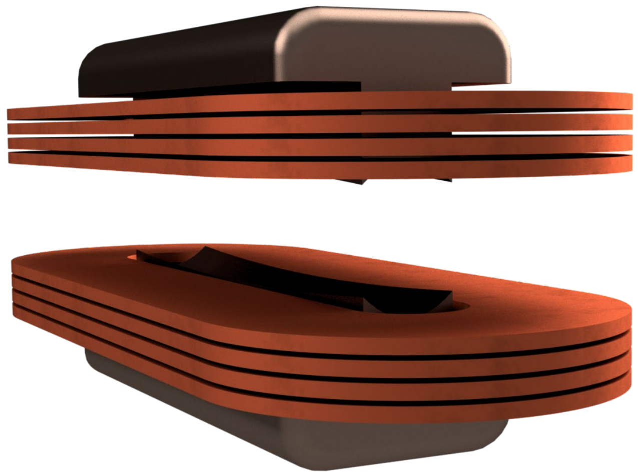
MAGNET LAYOUT AND PARAMETERS

Central field B_0	tesla	10
Minimum central field B_{0min}	tesla	8
Free bore and aperture (both sides) at 300 K, minimum.	mm	H80 x V50
Good field region uniformity	DB/B	1.5%
Good field region extension	mm	H50xV30xL400
Operating temperature	K	20
Minimum op. temper. for test	K	10
Range of field for uniformity	tesla	2-10
Reference ramping rate 0-10T and 10-0 T	A/s	0.1
Maximum feeding current-voltage	A-V	2,000-5
Maximum voltage to ground in any condition	kV	1.5
Maximum temperature difference inside coils following a quench	K	100
Maximum coil temperature following a quench	K	250

Additional plausible features:

- physical length <= 1 m
- cryocoolers at the two ends
- Iron insert for field enhancement

Simplified schematics:

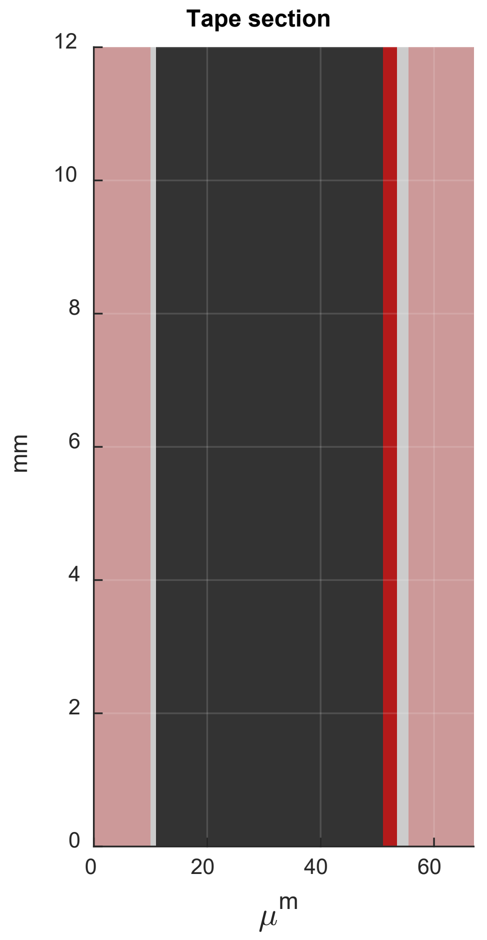


HTS CONDUCTOR

- The HTS conductor will be a 12 mm REBCO tape, matching the following requirements:

Parameter	Specification
Width	12 mm (optional 4 mm, up to 4 km total length)
Substrate material	Non-magnetic stainless steel or equivalent high resistance alloy
Substrate thickness	40 µm
Copper RRR	
Total copper thickness	20 (2x10) µm
Coated conductor thickness	

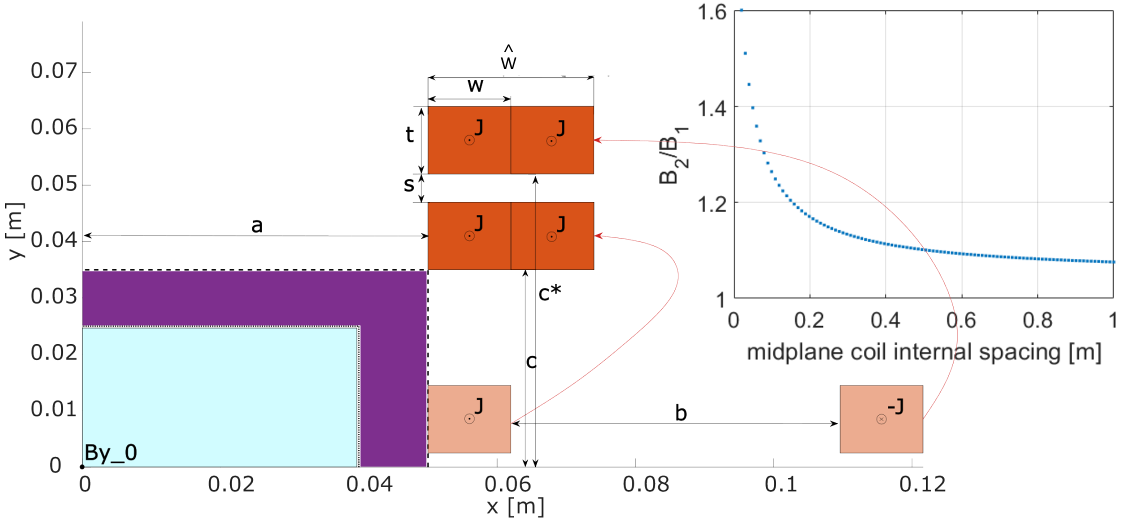
Parameter	Specification	Target
Minimum critical current (20 K, 15 T) over an entire Unit Length (UL)	500	> 600 A
Benchmark current (4.2 K, 5 T)		> 2400 A
Benchmark current (4.2 K, 10 T)		> 1500 A
Minimum length of a Unit Length (UL)	> 200 m	> 500 m
Minimum bending radius (easy axis)	15 mm	10 mm
Allowable non-Cu $\sigma_{longitudinal\ non\text{-}Cu}$ (4.2 K)	800 MPa	1000 MPa
Allowable compressive $\sigma_{transverse}$ (4.2 K)		200 MPa
Allowable tensile $\sigma_{transverse}$ (4.2 K)		25 MPa
Allowable shear $\tau_{transverse}$ (4.2 K)		20 MPa
Range of allowable $\varepsilon_{longitudinal}$		-0.4…+0.3%

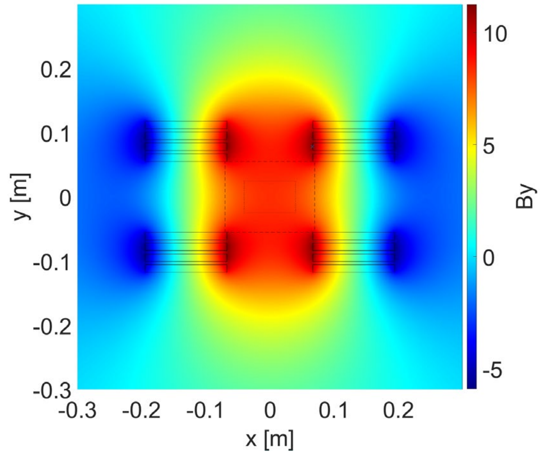


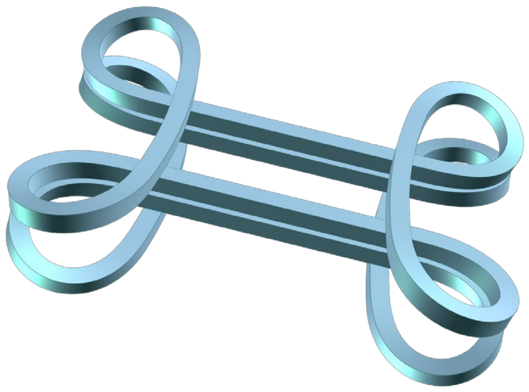
MAGNET LAYOUT AND PARAMETERS

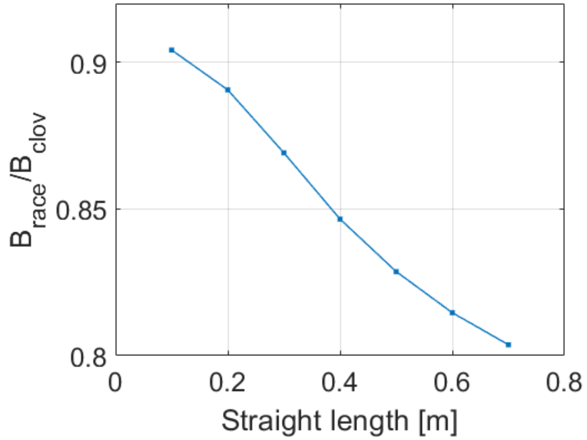
- Different magnet layouts are investigated, among all: extra-midplane coils and cloverleaf.

- Conclusion is that flat racetracks are a good trade-off between magnetic efficiency and manufacturability.









THE INSULATION TECHNOLOGY

Insulation

- Control over current and field, and forces
- Repeatable magnet properties

- Demanding protection system
- Lower overall current density

Non-Insulation

- Easier to protect
- Easy to wind
- High overall current density

- High screening currents →high forces at quench
- Variability of properties in time

Controlled-Insulation

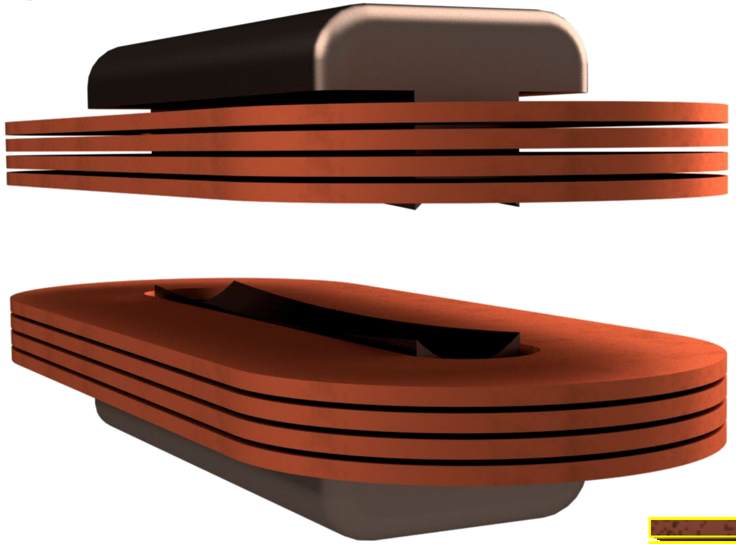
- Possible to tune PROS/CONS of other solutions on the specific needs

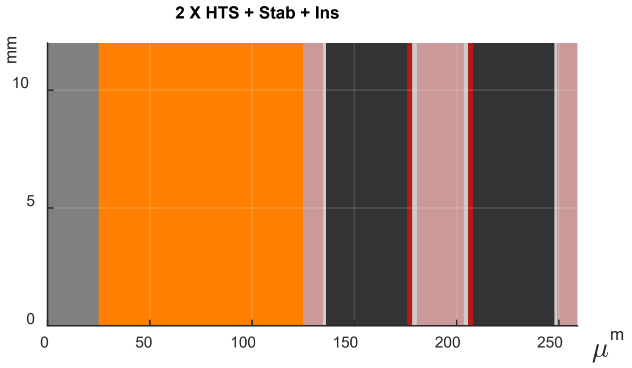
- High effort for research, test, manufacturing
- Need to account for worst scenarios from both cases

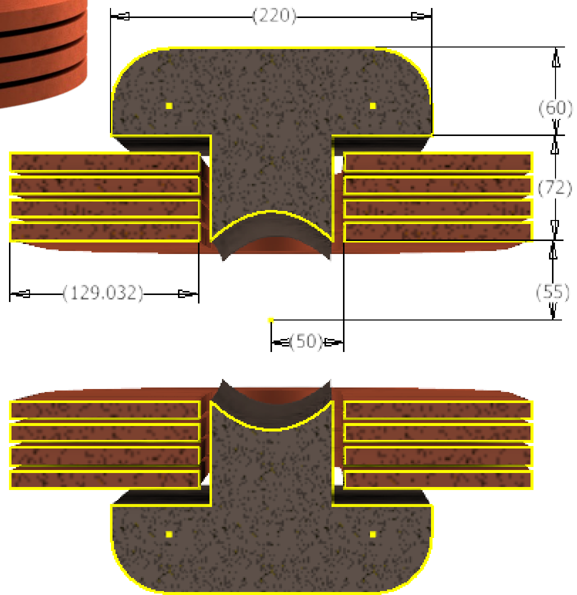
PRELIMINARY DESIGN - INSULATED COIL

- This is intended to be the starting point to evaluate different options.
- In order to match the 10 T requirements, a maximum of **30 mm** bore-frame and **1 kA** are required.
- Other parameters are:

Number coils		8
Cable layout		2 X HTS
Add. Cu in cable	µm	100
Ins. between cables	µm	25
Space between coils	mm	4
L straight part	mm	550
Cable consumption	km	14
Iron insert material		ARMCO

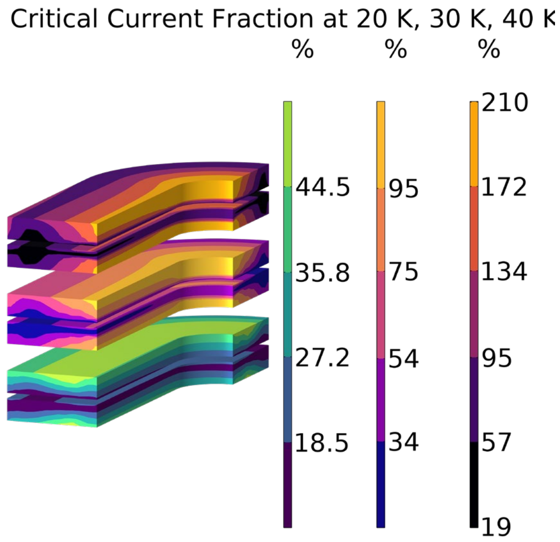


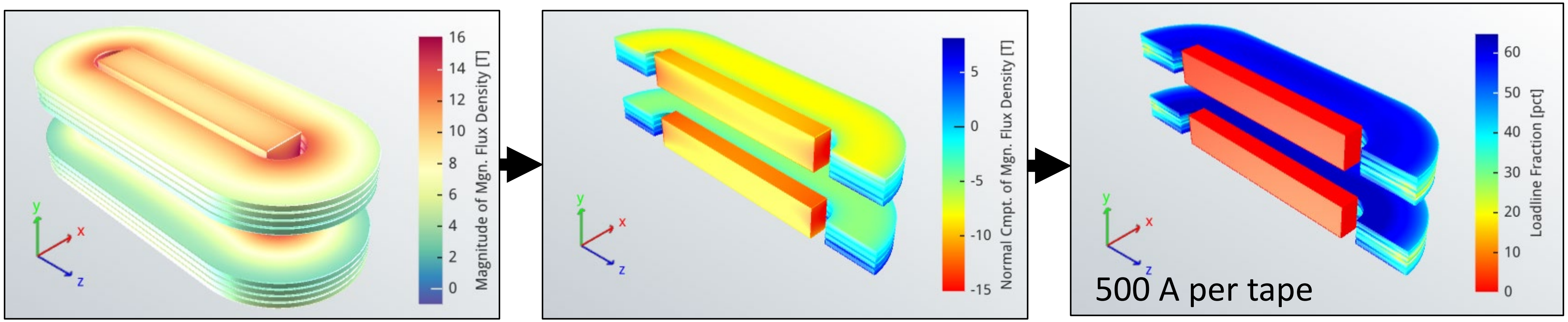




PRELIMINARY DESIGN - INSULATED COIL

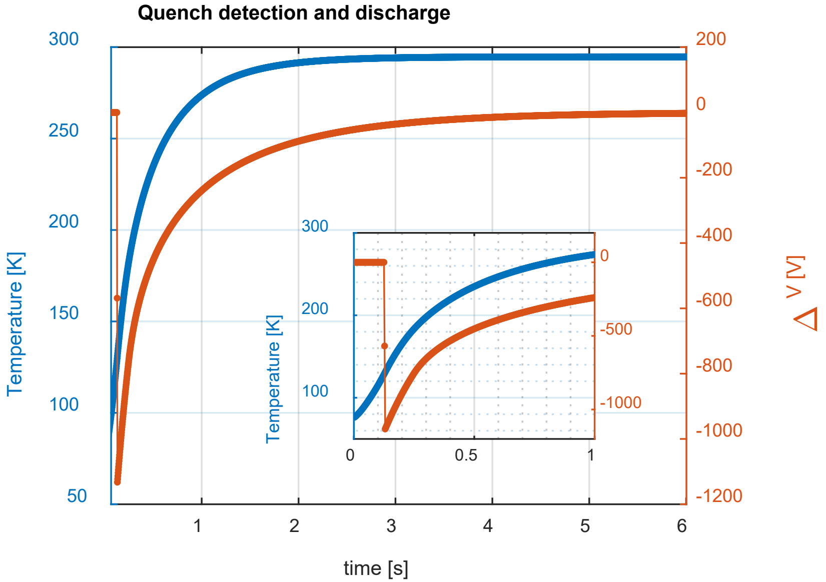
- In the design, the tape should have a local lowest Ic around 700 A (as 500 A is for 15 T worst-angle).
- The target margins are >20% on the load-line and a 10 K temperature margin.

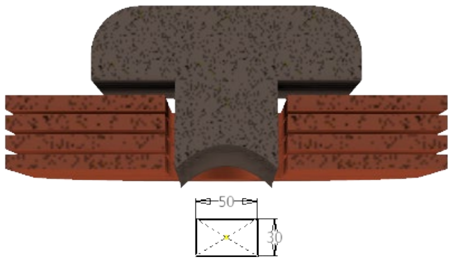


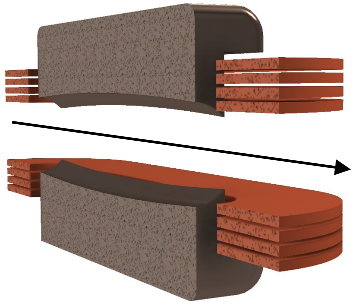


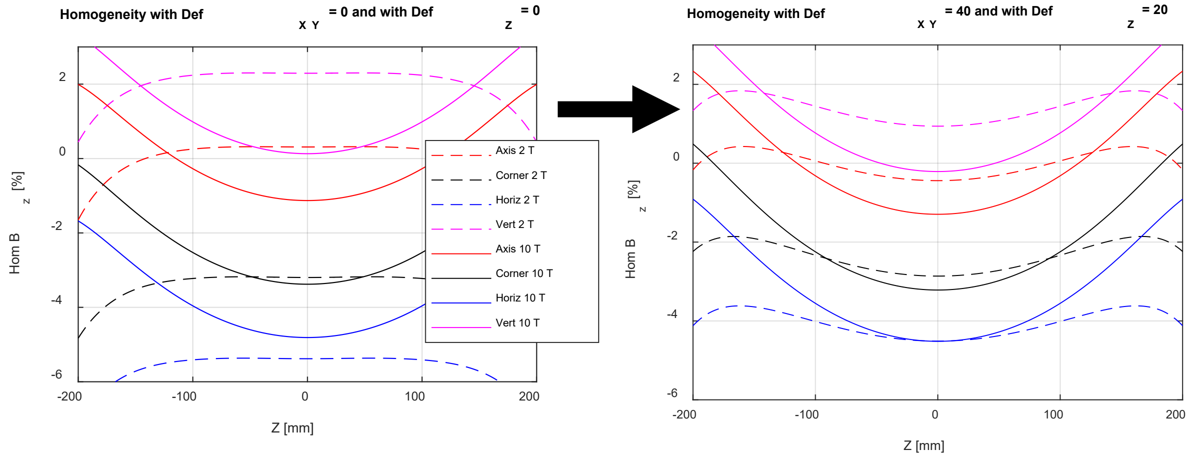
PRELIMINARY DESIGN - INSULATED COIL

- Stray field < 0.5 mT @ 7 m
- Protection remains challenging. Most critical aspect is discharge due to the large inductance of the magnet (~ 6H)
- Homogeneity is still under investigation and will be improved by shaping the iron insert.
  1st attempt at pole shaping:





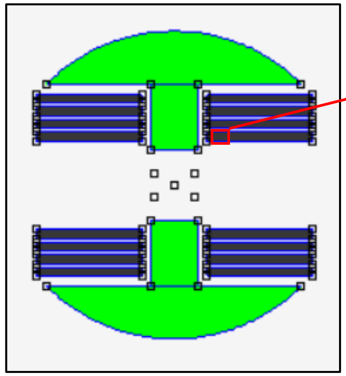


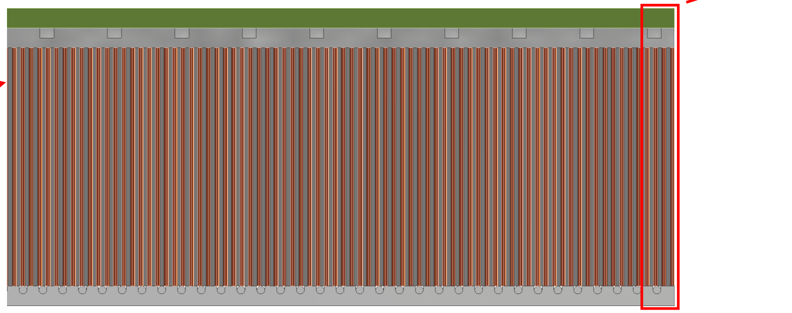


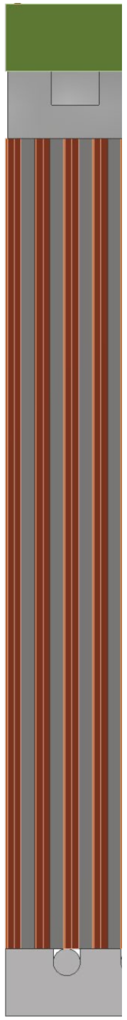
QUENCH PROTECTION, ADDITIONS

- Due to the difficulties in protecting HTS magnets by voltage detection, different techniques are studied world-wide, as:

1. Optical fibres (temperature);
2. LTS co-wind (temperature);
3. Distributed sensors network (temperature, field, strain).







PCB copying winding shape, compensation of inductive voltage for QDS based on coil-wide taps

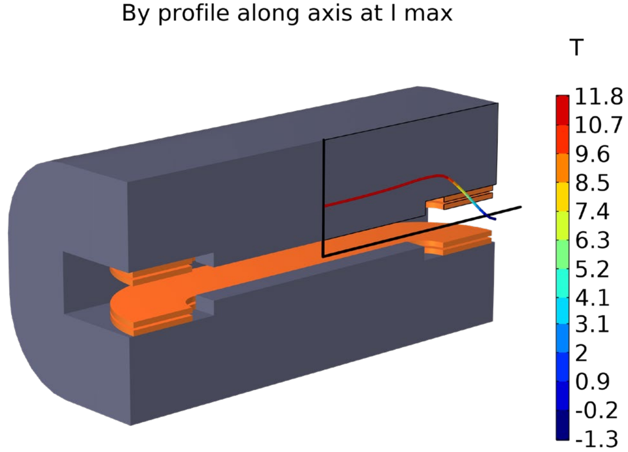
Voltage taps every n-turns, for a finer voltage detection, here with a plate to guide exiting wires

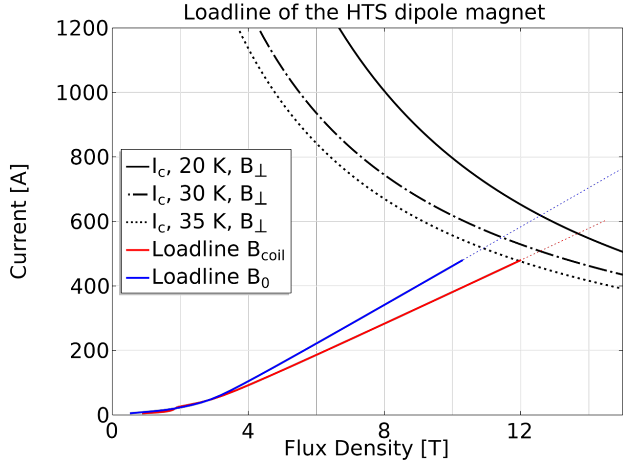
Optical fibres (Ø200 μm) for local temperature measurements, supported by a non-continuous Al plate for thermal contact

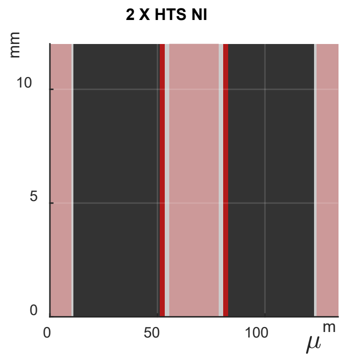
And/or: S.C. strand (MgB_2 main candidate) to sense T threshold by quenching it

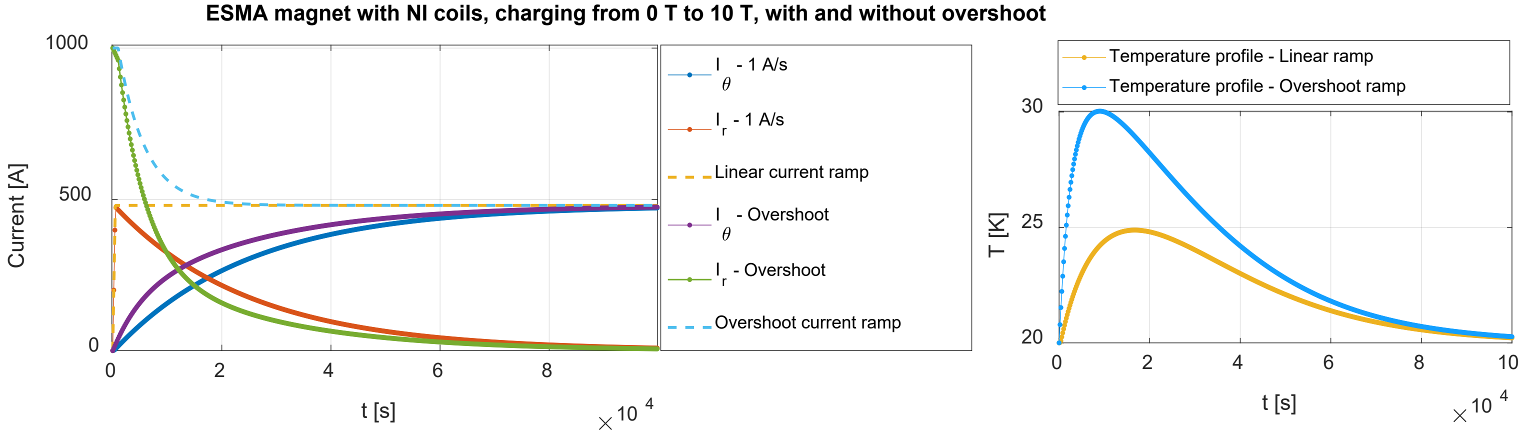
NON-INSULATED COILS FOR IRIS ESMA

- Designed with conservative approach (margins with $B_\perp$) suitable for MI and further improvable for pure NI.
- Charging time for pure NI is 24 h; overshoots possible but limited by heating.



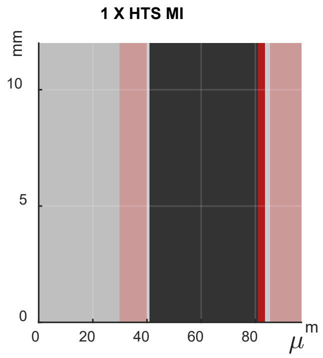




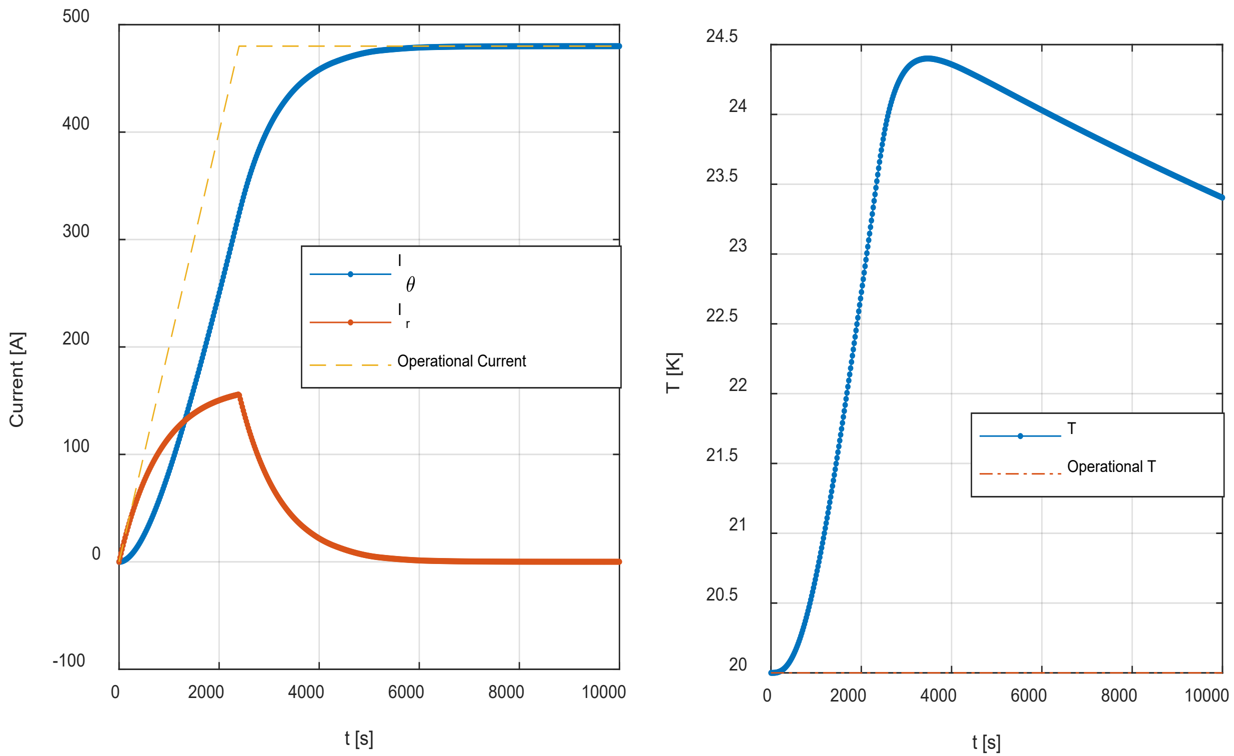


STEP ZERO DESIGN, VARIANTS, CI

- We are further investigating Metal-Insulation, both with 1-tape and 2-tape cases + 30 µm steel.
- Proper load-cycle may work, if we get slightly faster, we can ignore charging-uncertainty issue.



Charging of a MI variant of IRIS magnet



Thank you for the attention!