This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

R&D for HTS and MgB_2 Superconducting magnets for beam lines, ion gantries and the IRIS research infrastructure

@ INFN-LASA (Milan)

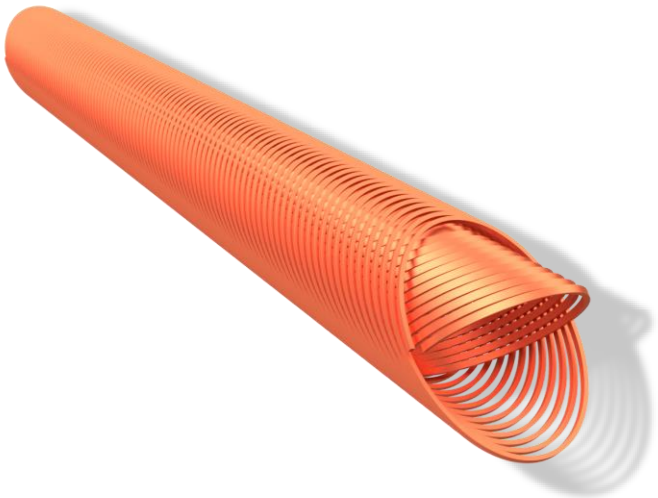
Industry Workshop on HTS developments and applications

Stefano Sorti, on behalf of LASA team

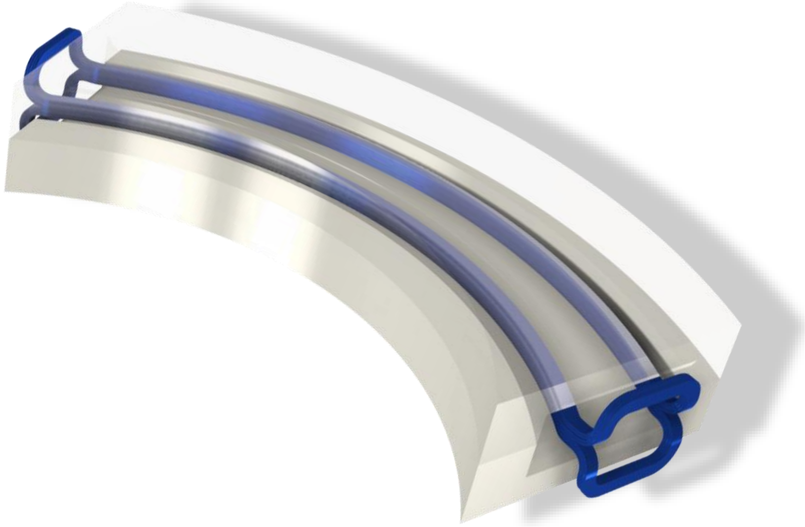
iFAST

Contents

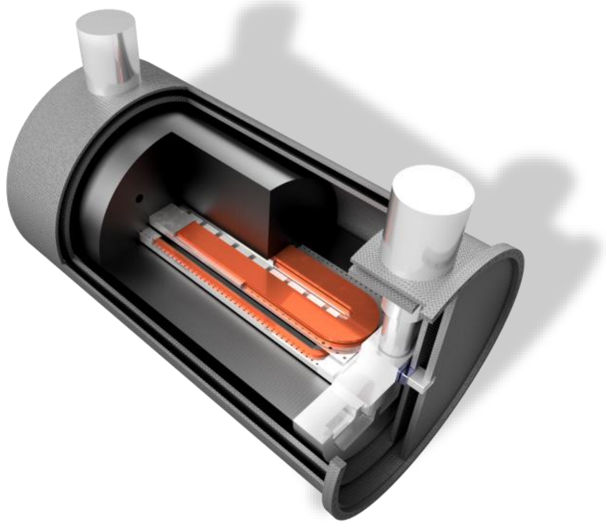
I.FAST WP8, Innovative superconducting magnets (tasks on CCT in HTS)



ESABLiM project, Energy Saving Accelerator and Beam Line Magnets



IRIS project, an Innovative Research Infrastructure on applied Superconductivity



IFAST WP8: main overview

SCOPES:
Exploring **Canted Cosine Theta (CCT) with HTS** superconductor (main goal), proceeded by a combined function CCT based on LTS, involving the industries that want to learn about the CCT magnets
Form a permanent **European Strategy Group**, open to worldwide partners, to discuss the European strategy for HTS magnets for accelerators, and to improve Industry involvement in this technology

TASKS:	
8.1 - Coordination and HTS Strategy Group	
8.2 – Preliminary Engineering design of comb. CCT magnet	
8.3 – Preliminary Engineering design of HTS CCT	← Institutes
8.4 - Construction of combined CCT magnet demonstrator	
8.5 – Construction of HTS CCT magnet demonstrator	← Industries
8.6 – Development of ReBCO HTS nuclotron cable	

	2021								
	4	5	6	7	8	9	10	11	12
Start 1st May									
8.1									
8.2							M32		
8.3									
8.4									
8.5									

	2022											
	1	2	3	4	5	6	7	8	9	10	11	12
8.1				D8.1								M31
8.2		D8.2										
8.3		M33								D8.3		
8.4												
8.5												

	2023											
	1	2	3	4	5	6	7	8	9	10	11	12
8.1									M31			
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	2025			
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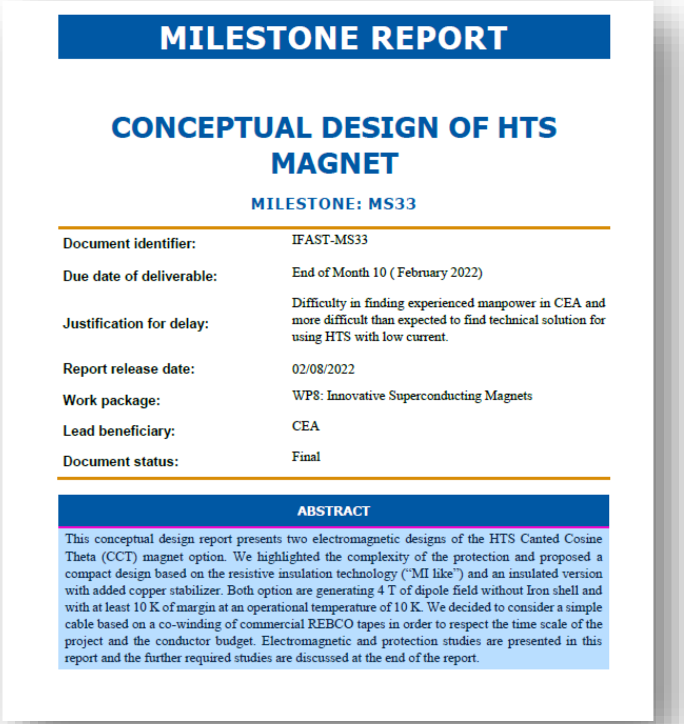
IFAST WP8.3: Defining the parameters


MILESTONE REPORT

CONCEPTUAL DESIGN OF HTS MAGNET

MILESTONE: MS33

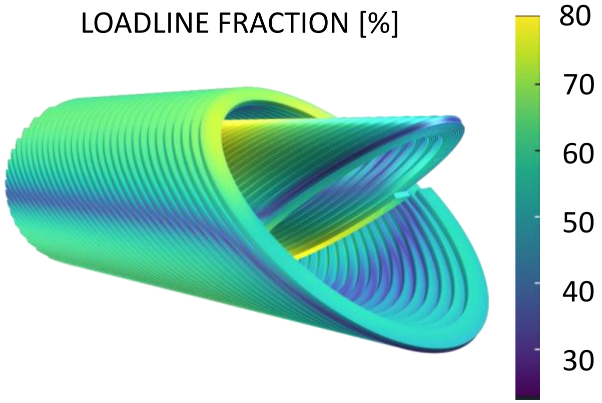
Document identifier:	IFAST-MS33
Due date of deliverable:	End of Month 10 (February 2022)
Justification for delay:	Difficulty in finding experienced manpower in CEA and more difficult than expected to find technical solution for using HTS with low current.
Report release date:	02/08/2022
Work package:	WP8: Innovative Superconducting Magnets
Lead beneficiary:	CEA
Document status:	Final

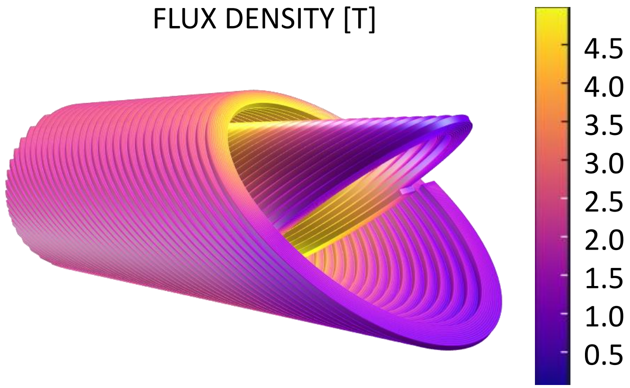
ABSTRACT

This conceptual design report presents two electromagnetic designs of the HTS Canted Cosine Theta (CCT) magnet option. We highlighted the complexity of the protection and proposed a compact design based on the resistive insulation technology ("MI like") and an insulated version with added copper stabilizer. Both option are generating 4 T of dipole field without Iron shell and with at least 10 K of margin at an operational temperature of 10 K. We decided to consider a simple cable based on a co-winding of commercial REBCO tapes in order to respect the time scale of the project and the conductor budget. Electromagnetic and protection studies are presented in this report and the further required studies are discussed at the end of the report.

Parameter	Unit	MI	Insulated
Inductance	mH	117.9	139.8
Stored Energy	kJ	71.0	82.9
Cable current	A	1100	1090
Groove current density	**A/mm²**	**1698**	**618**
B_0	T	4	
Turns per layer	-	85	88
Cable per groove	-	18	19
Cable path section	**mm x mm**	**4 x 2.9**	**4 x 8.4**
Frame length (In / out)	m	36.3 / 39.3	38.3 / 43.2
Total Length (cable / Tape)	km	1.5 / **3.0**	1.7 / **3.4**

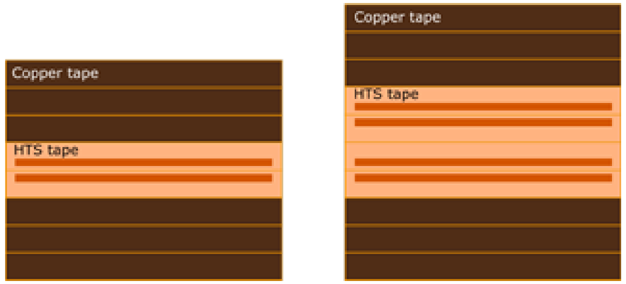
IFAST WP8.3: Redacting Deliverable D8.3



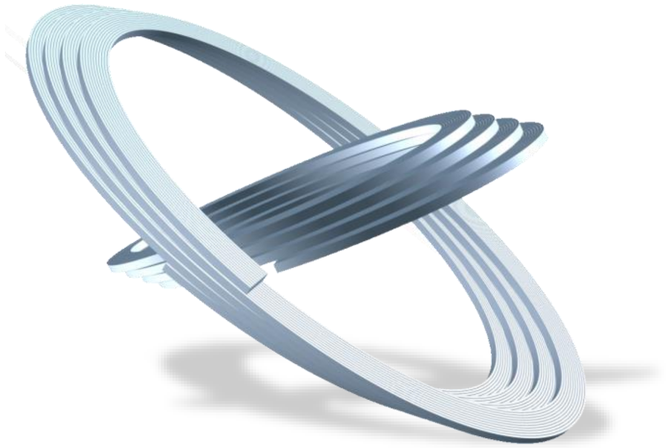


- **INS option** with Cu stabilizer is pursued. **Final T_{op} is 20 K**, Two further design options:

  1. 2-tapes cable (980 A)
  2. 4-tapes cable (1990 A)



- **Soldering** all tapes inside the cable under consideration;
- **Hard-way bending** must be avoided or minimized.
- Accelerator-level **field-quality** (integral below-unit), no iron yoke (shielding open problem);



- **Quench analysis** was used to determine the required thickness of copper stabilizer tapes in the cable.

IFAST WP8: from 8.3 to 8.5

ELYTT ENERGY

- **Scientific partners** leading the conceptual design of the magnet (Deliverable 8.3).
- **Industry partner Elytt SL** is transforming scientific design *into a construction project for a real operating magnet demonstrator including drawings, description of the construction process, design and construction of the tooling and magnet components*.
- Finally, the demonstrator will be tested and qualified in conditions near to the operative ones by cold test at scientific partners' facilities.

Active and proactive role in developing ideas, approaches and processes in the technological challenges of building an operative magnet

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Energy Saving Accelerator and Beam Line Magnets (ESABLiM)

- Study of new cryogen-free superferric magnets in MgB_2 (and HTS) to **substitute** resistive magnet for heavy particles beam lines;
- **Reduce** the peak power loss from 10 to 50 times, by working @ T= 8-20 K with solid conduction cooling.

- Different apporaches, the ones we are focusing on are:
  1. Revamping: reuse the same iron yoke and magnet interfaces. Substitute copper coil, only, with MgB2 (or HTS conductors)
  2. Develop superferric magnets for accelerators and beamlines suitable designed and optimized for low power consumption

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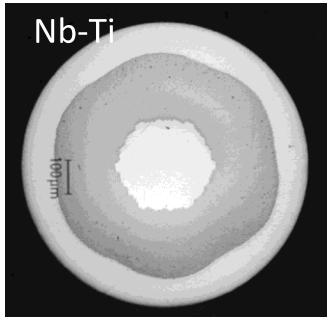
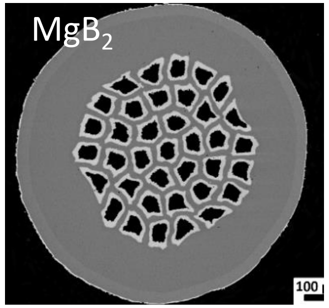
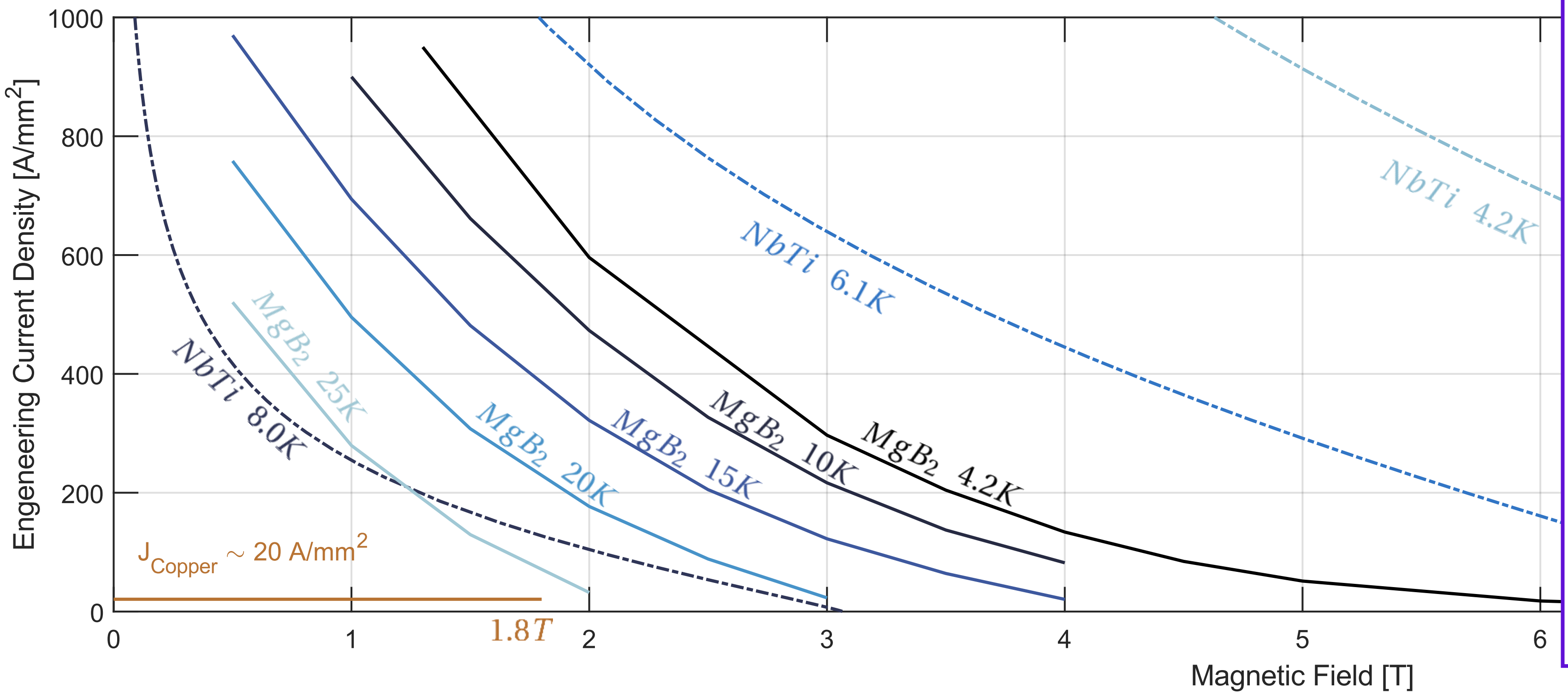
ESABLiM: conductors choice

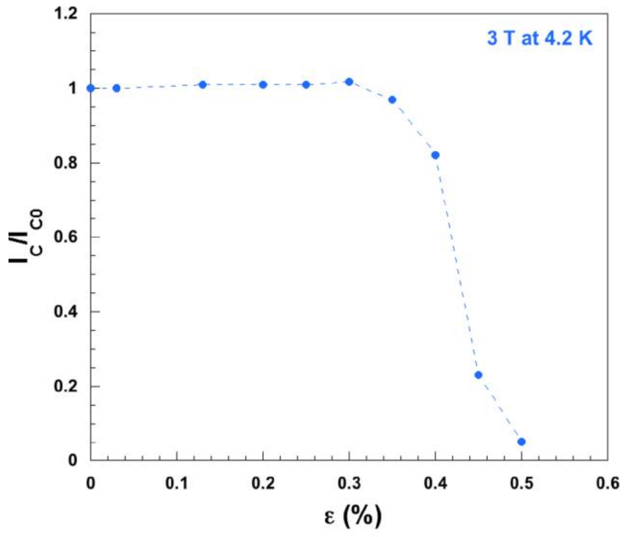




- Round strands: MgB_2 at 20 K > Nb-Ti at 8 K, but higher T means more efficient cooling.
- Tapes: HTS on the table. Need to re-think layout for tapes.

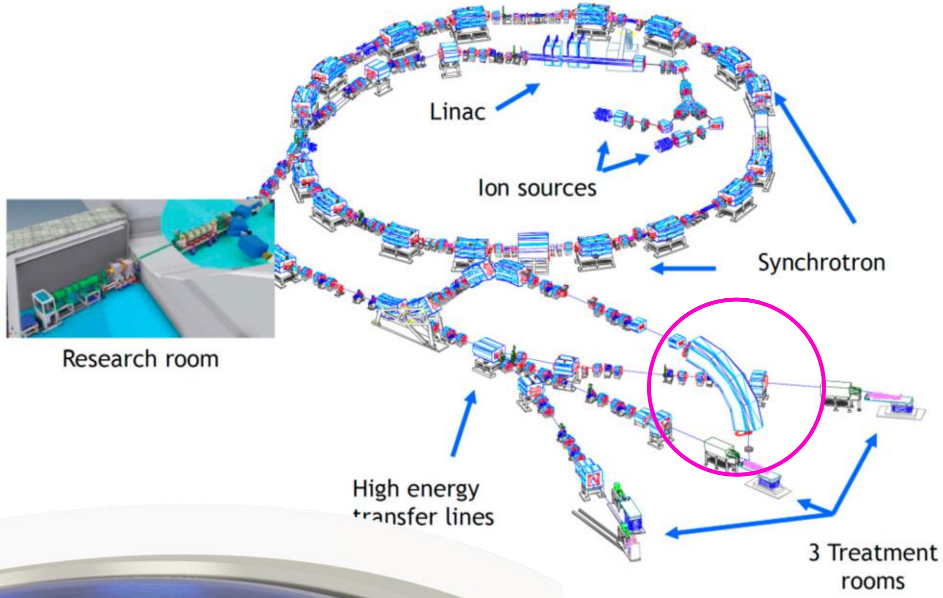


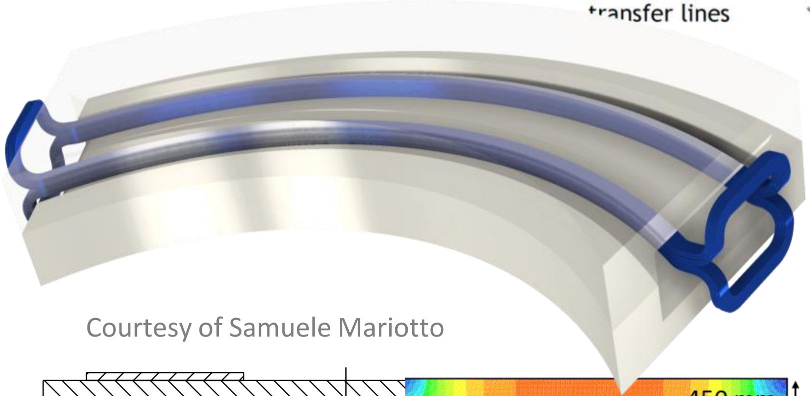
Issue of MgB_2 : strain sensitivity



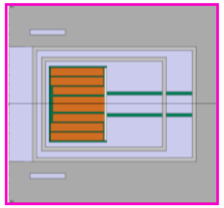
ESABLiM: first case study

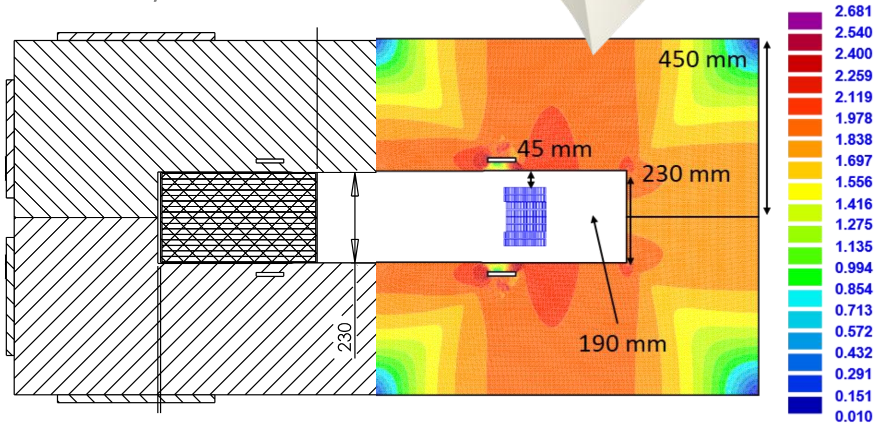
- Ramped Window-frame Bending Magnets, installed at CNAO (IT); Coil compatible with minimum bending radius required for MgB_2;
- Actual coil: 80 channels each carrying 2.28 kA.
  S.C: coil: 630 ropes (3 SC + 4 Cu); each one carries 276 A (low current for heat losses).
- Empty space by new coil for mechanical supports and cryogenic systems.
- Actual consumption 30 kW DC (equiv.); The case study set-up prescribes 6 cryocoolers for a total of 7.4 kW DC at 10 K, with an incoming 20 K case expected to consume the half. Gain factor **>4**.

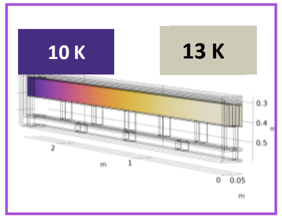


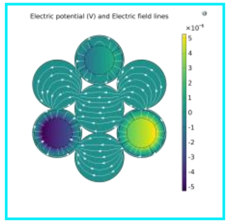


Courtesy of Samuele Mariotto



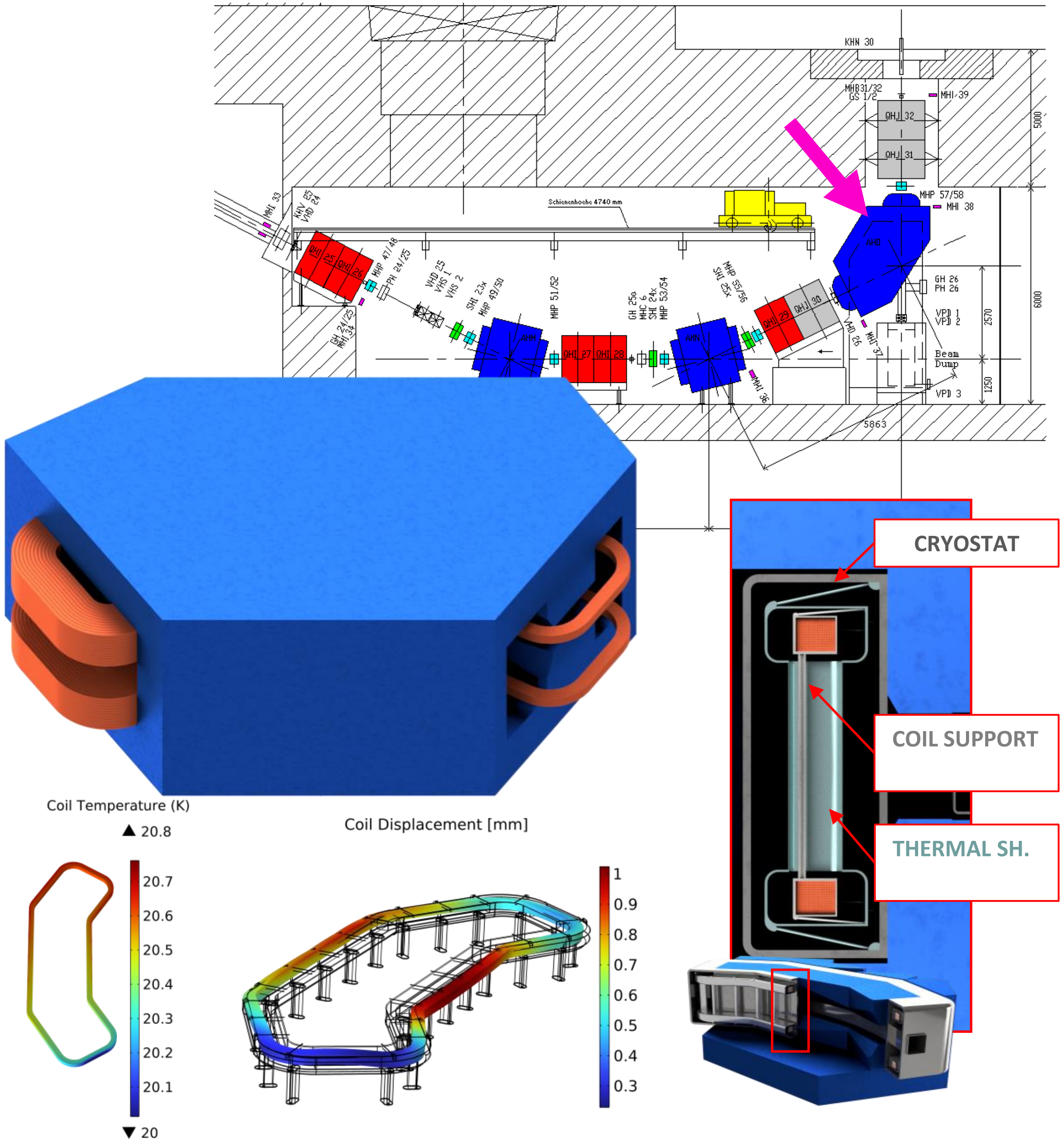






ESABLiM: second case study

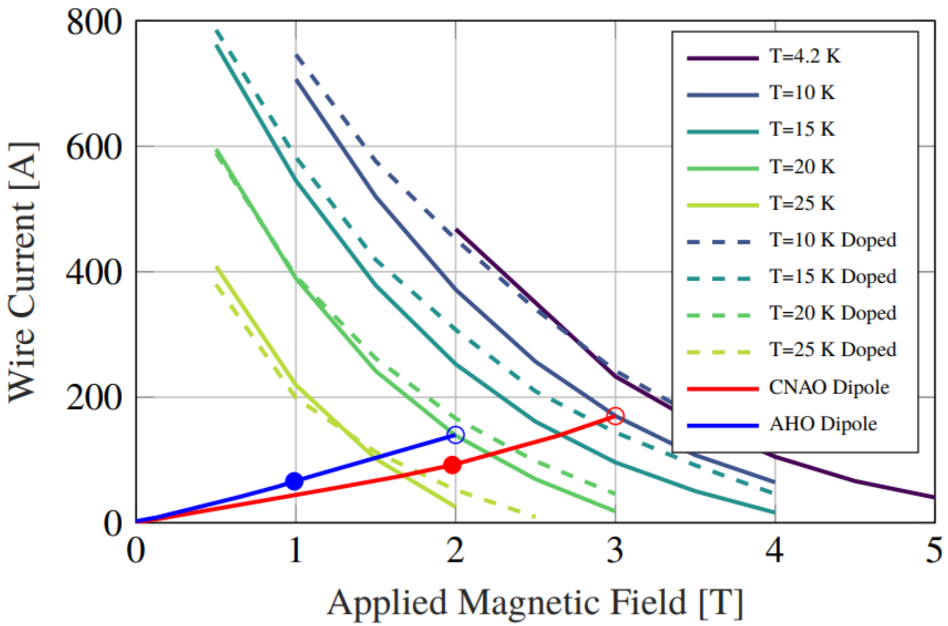
- DC Bending Magnets, installed at Spallation Source, PSI (CH); flat racetrack coil.
- 1.45 T largely given by yoke, coil far from it: safe operation of S.C. at 20 K (50% L.L. margin and 8 K T. margin).
- Actual coil: 144 channels each carrying 1 kA.
  S.C: coil: 484 ropes (4 SC + 3 Cu); each one carries 300 A (low current for heat losses).
- Empty space by new coil for mechanical supports and cryogenic systems.
- Actual consumption 190 kW DC (May-Dec); The case study set-up prescribes 2 cryocoolers for a total of 5 kW DC at 20 K. Gain factor **40**.



ESABLiM, industry partnership:

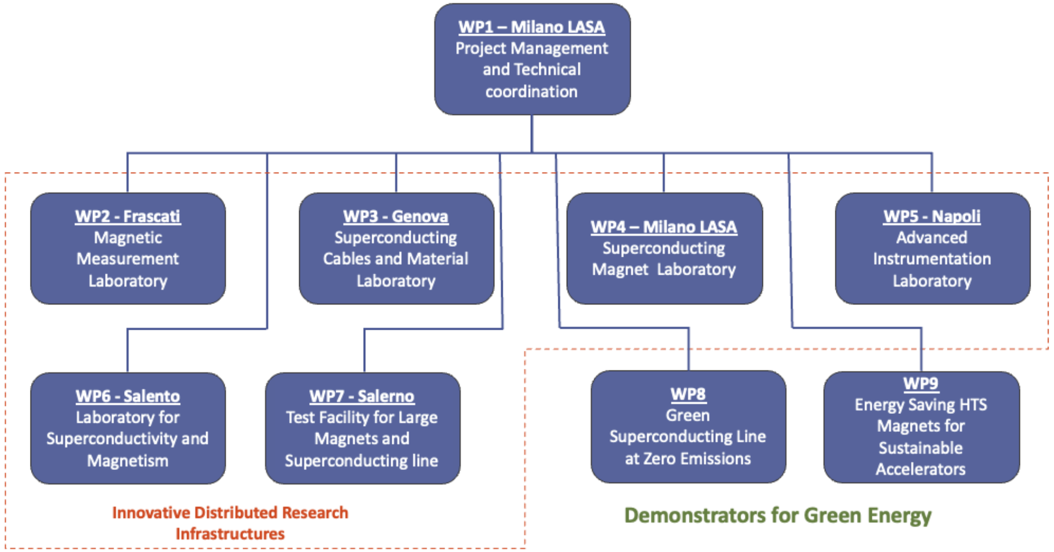
ASG and ASG Columbus

- Direct involvement of ASG for the choice of case studies and investigating incoming demonstrator magnets. Fundings for research personnel at university.
- Interest form ASG Columbus in contributing with their MgB_2 conductors.
- Common interest in developing a “magnet portfolio” about the revamping of magnets.



IRIS project

A distributed research infrastructure

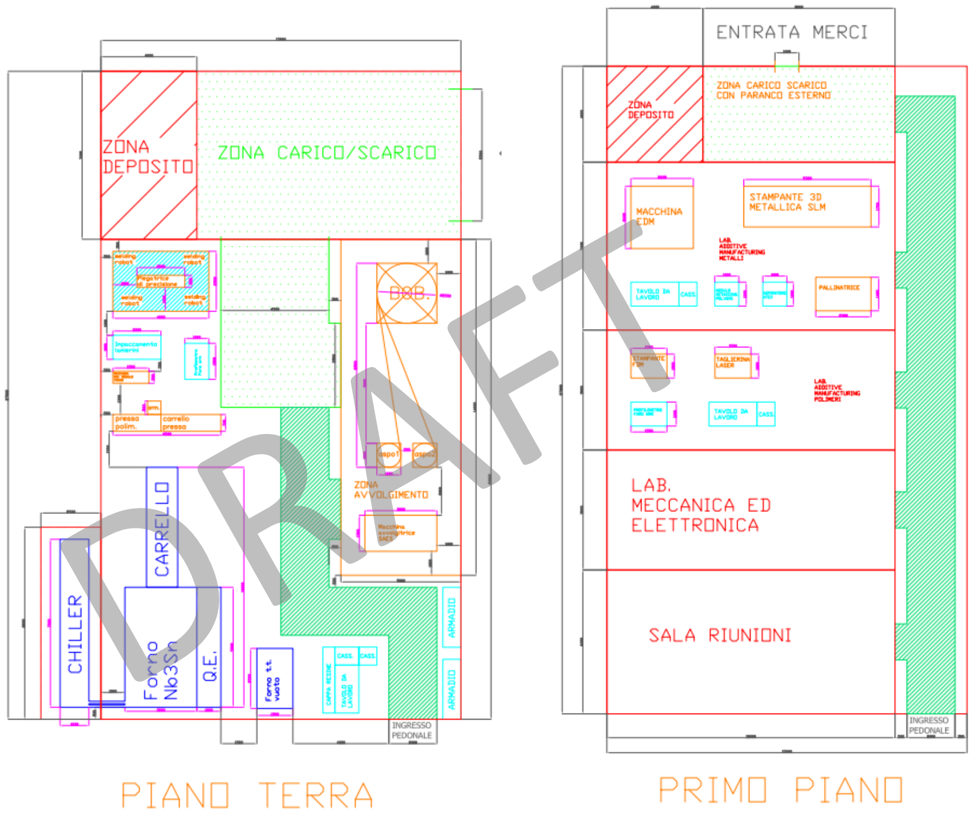


A wide range of objectives

1. Fundamental Physics instrumentation
2. Societal Applications
   - Green: energy transport at zero emission and energy saving magnets;
   - Medical: Superconductivity could play a key role in heavy ion therapy by enabling a rotatable gantry;
3. Two full-scale demonstrators.
4. Final deadline is 30 October 2025.

Infrastructures in WP4

4.1 Civil Engineer with technical services for Magnet Laboratory
4.2 QA bare magnet test stand
4.3. Winding machines
4.4. Instruments and large equipment for superconducting winding and magnet assemby laboratory
4.5 3D Additive Manufacturing for Metal and Polymers for rapid protyping



Demonstrators (WP8, WP9)

Green Superconducting Line

- Energy transport at 0[3] emission:
    1. **Zero** (almost) **emission** of C02 :
       consumption will be 1% over 1000 km
    2. **Zero emission** of e.m. radiation (DC)
    3. **Zero** (almost) **land consumption**: a 50 cm underground pipe can carry the 5 GW power of 30 m X 50 m overhead line.
- 25 kV - 40kA, at 20 K (50+ kV testing)
- Round MgB_2 strands, cooled with He gas;
  after IRIS, investigation on LH cooling.

Energy Saving HTS magnet

- Main goal: **8 T – 20 K**, 10 K margin, **conduction cooled**.
- Aperture 80 mm X 50 mm, with 700 mm straight section, for **cable test** (at INFN-Genova).
- Additionally, **technology driver** for 15 T – 20 K magnets for FCC or Muon-C.
- Around 10 km of 12 mm wide ReBCO tape. Stack cable with controlled-insulation.
  Charging time in the range of (a few) hours.

Finanziato dall'Unione europea
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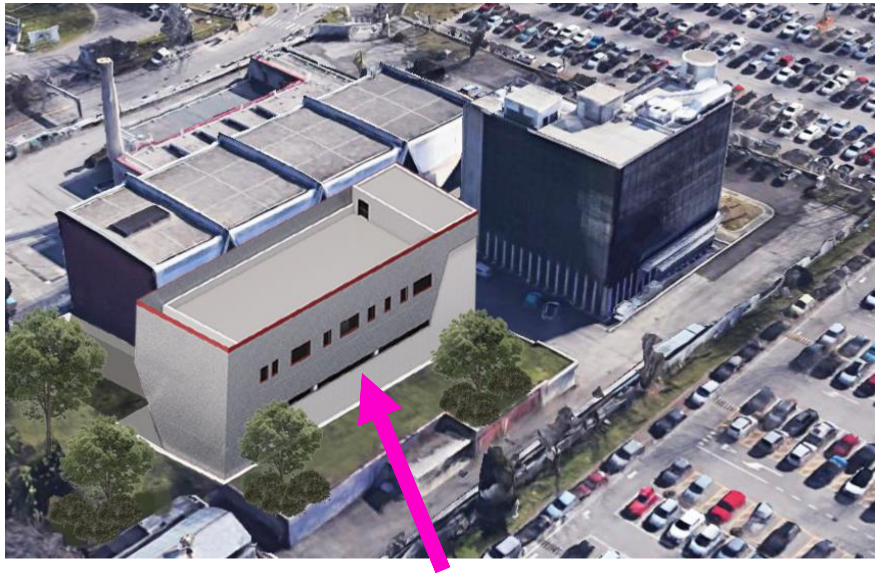
Industrial partners in WP4, WP8 WP9

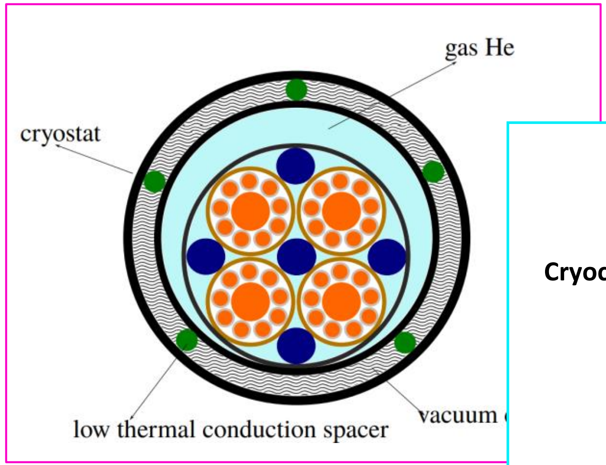
Calls for infrastructures

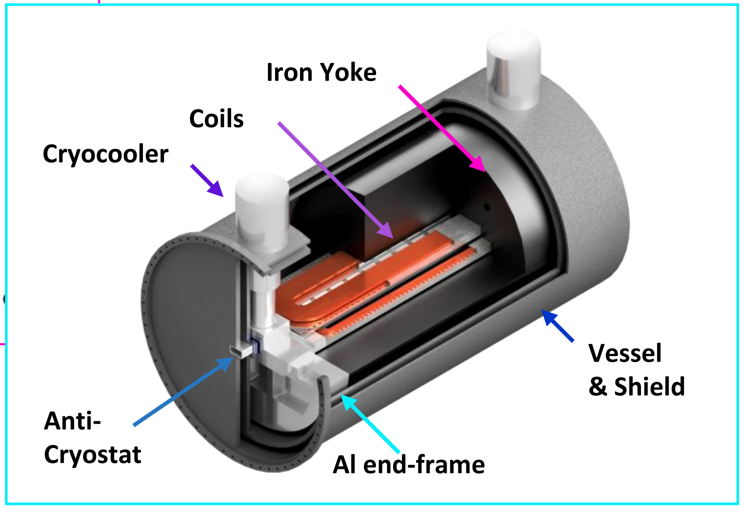
- Bids under scrutiny for large equipment
- Incoming for building and procuring



Call for both demonstrators

- Bids under scrutiny
- Manufacturing of both demonstrators



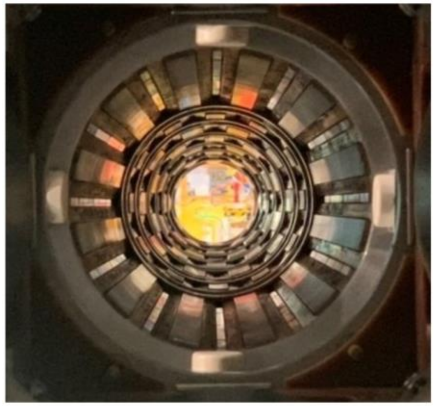


Special Mention: HOCM for HL-LHC

- INFN-LASA recently concluded the program for the design and construction of 54 High-Order Corrector Magnets for the Hi-Lumi upgrade of LHC at CERN;

- The project was concluded successfully and in time. A key ingredient was a **strong partnership** with the companies SAES RIAL Vacuum and SAES Getters;

- SAES RIAL Vacuum was responsible for manu-facturing of all the production magnets and it was actively involved in many steps from prototyping to testing.



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Istituto Nazionale di Fisica Nucleare
Laboratorio Acceleratori e Superconduttività Applicata
HiLumi HL-LHC PROJECT

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THANKS FOR THE ATTENTION!

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