Finanziato dall'Unione europea
NextGenerationEU

Italiadomani
PIANO NAZIONALE DI RIPRESA E RESILIENZA

MUR
Ministero dell'Università e della Ricerca

IRIS

Innovative **R**esearch **I**nfrastructure on applied **S**uperconductivity

PNRR program (**Next Generation Europe** in Italy)

12 October 2022-Muon Collider Meeting@CERN

Lucio Rossi

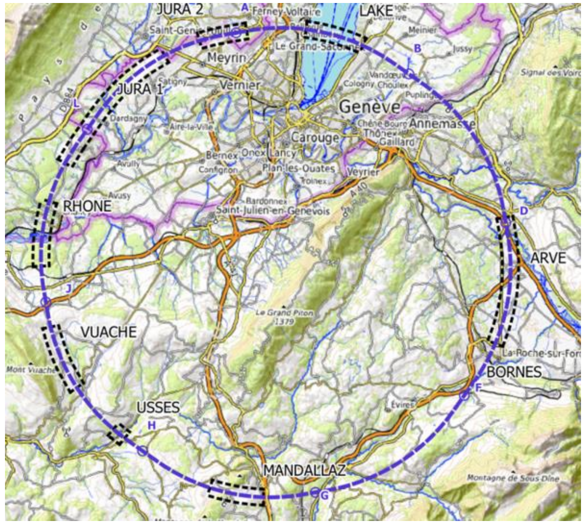
University of Milan – Physics Department
& INFN- Milan LASA laboratory

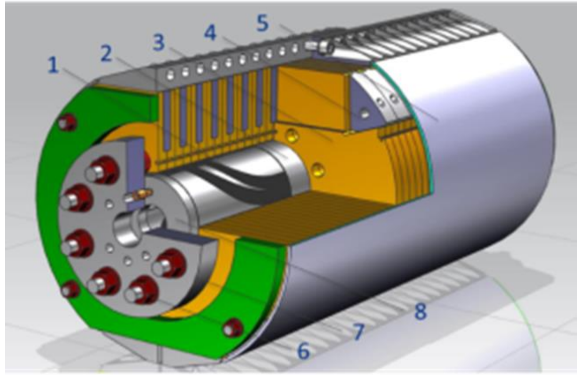
IRIS project - scope

- Response to a call by the Ministry for Research in the frame of the PNRR, Italian Next Generation Europe (or *Recovery Funds*)
- Form a new distributed infrastructure for applied superconductivity in Italy, mutualizing existing infrastructures, competences, skills and by expanding with new laboratories
- → ultimate goal: contribute to Fundamental Physics instrumentation (particle accelerators for post-LHC era) and to **Societal Applications for green energy and medicine**.

IRIS project scope -1
Fundamental Physics instrumentation

Superconductivity has been instrumental for the discovery of the Higgs boson and its development will be critical for future accelerators and we need of adequate infrastructure to sustain this.





LHC dipoles (8 T) in the tunnel

HiLumi MQXF quad (12 T)

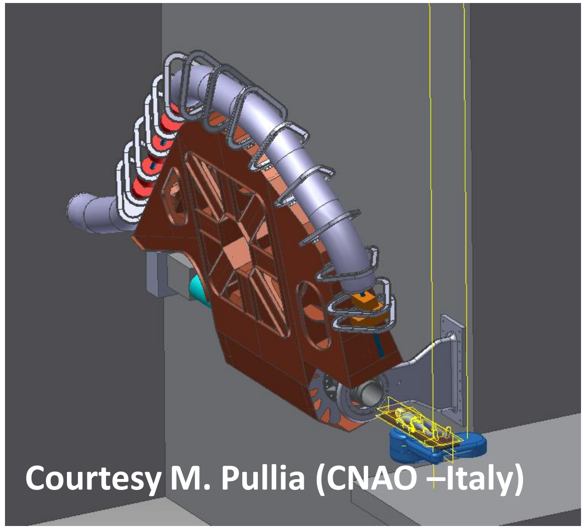
FCC (12-16 T)

IRIS project scope -2
Societal Applications

- **Green Energy** and **Medical**
- Green : energy transport at zero emission and energy saving magnets.
  - important for society but also for the sustainability of our research infrastructure

- Medical: Superconductivity could play a key role in heavy ion therapy by enabling a rotatable gantry

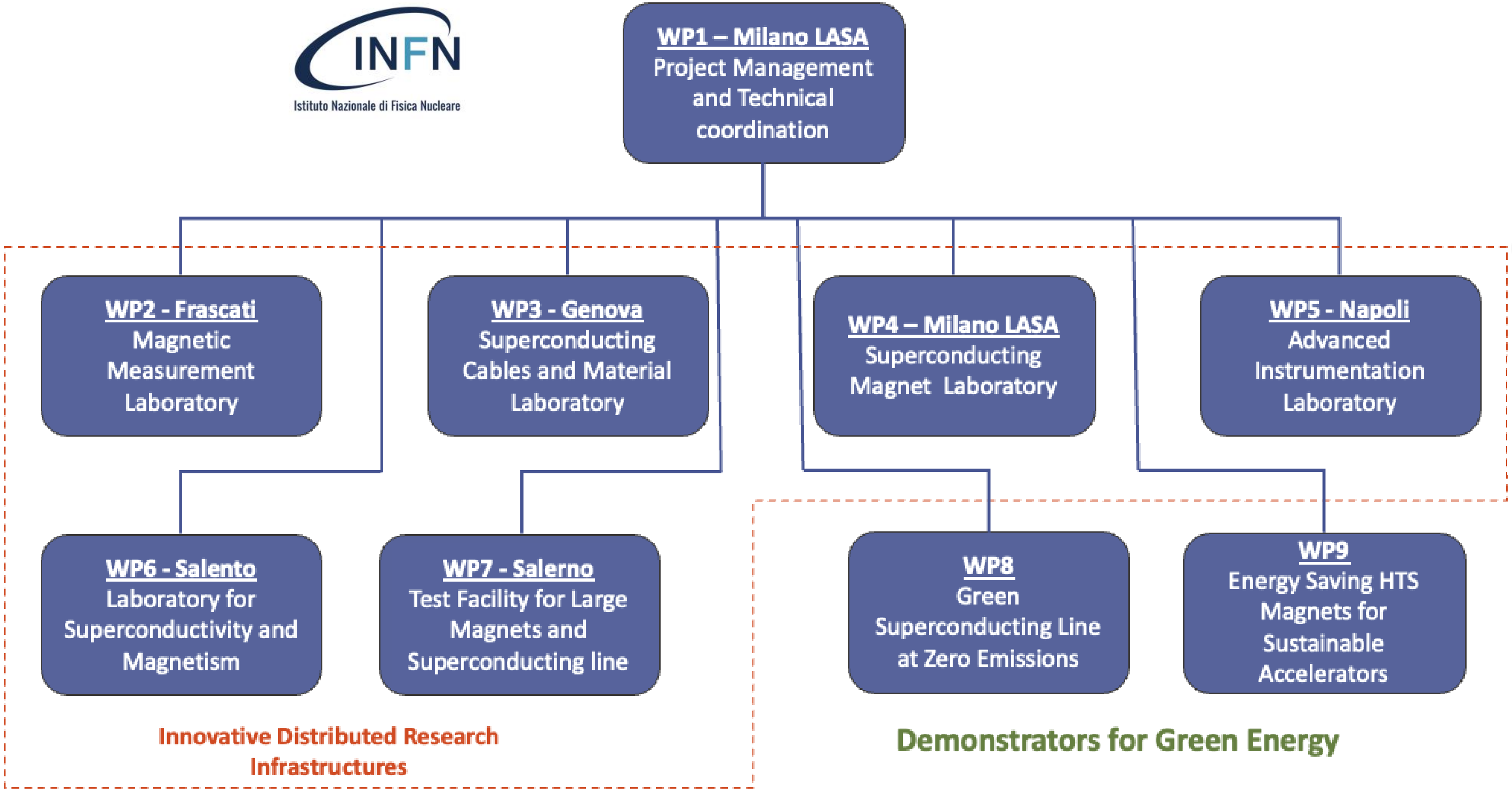
Medical: dismiss from these project
But pursued in part with other projects



IRIS - Time line

- ***Avviso MUR n. 3264 del 28-12-20221***
- Application on 25 February 2022
- Negotiation phase with MUR: 10 June 2022 (resubmission new proposal : 17 June 2022)
- Decree of approval: 24 June 2022
- **Start date of the project: 1 November 2022**
- End of project: 28 February 2025
  → 6-month extension, to **30 October 2025** is possible (mentioned in the call)

Organization and Project structure



Structure and Organigram (by Project and by Institution)

IRIS

		Scientific Coordinator (P. Campana, INFN), Project Coordinator (L. Rossi, Unimi & INFN)								
		Infrastructure Manager, Administration Chief Officer (A.Sequi, INFN), Financial Officer (M. Canale Parola, INFN)								
		WP1	**WP2**	**WP3**	**WP4**	**WP5**	**WP6**	**WP7**	**WP8**	**WP9**
		P. Campana,	**L. Sabbatini,**	**R. Musenich**	**M.Sorbi**	**P. Arpaia**	**G. Maruccio**	**U. Gambardella**	**L. Rossi**	**L. Rossi**
		L. Rossi	**A. Vannozzi**	**A. Bersani**	**M. Statera**	**G. Fiorillo**	**A.G. Monteduro**	**D. D'Agostino**	**M. Statera**	**M. Sorbi**
INFN	*L. Rossi*	*L. Rossi*	*L. Sabbatini*	*R. Musenich*	*M. Statera*			*U. Gambardella*	*L. Rossi*	*L. Rossi*
PNRR_IRIS	*(IM)*	*T. Benson*	*A. Vannozzi*	*A. Bersani*	*E. De Matteis*			*D. D'Agostino*	*M. Statera*	*M. Prioli*
CNR-SPIN	*F. Miletto*			*A. Malagoli*		*F. Miletto*		*M. Cuoco,*		
	A. Malagoli			*E. Bellingeri*		*E. Sarnelli*		*C. Cirillo*		
Unige	*M. Putti*			*M. Putti*						
	D. Marré			*D. Marré*						
Unimi	*M. Sorbi*				*M. Sorbi*					*L. Rossi*
	S. Mariotto				*S. Mariotto*					*S. Mariotto*
Unina	*P. Arpaia*					*P. Arpaia*				
	G. Fiorillo					*G. Fiorillo*				
UniSalento	*G. Maruccio*						*G. Maruccio*			
	A.G. Monteduro						*A.G. Monteduro*			
Unisa	*S. De Pasquale*							*S. De Pasquale*		
	C. Attanasio							*C. Attanasio*		

WP2 – Frascati
INFN-LNF

Magnetic Measurements Laboratory @ LNF

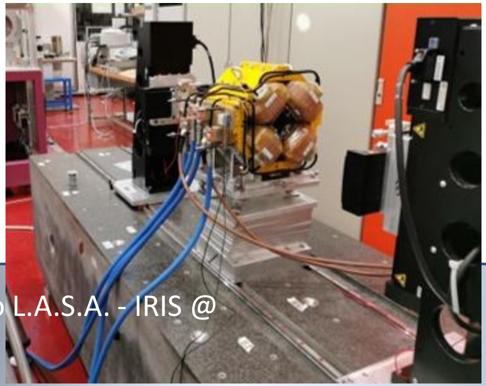
The INFN-LNF magnetic measurements laboratory, about 200 m^2, with 15 T crane has already :

- a Hall effect digital teslameter with a 5-axes movement device on a granite bench;
- a stretched wire bench for integral measurements of fields and mechanical fiducialization;
- a rotating coil multipole measurement system; an NMR teslameter.

Several other ancillary instruments are available, such as gaussmeters, integrators, etc…

Hall probe mounted on the coordinatometer

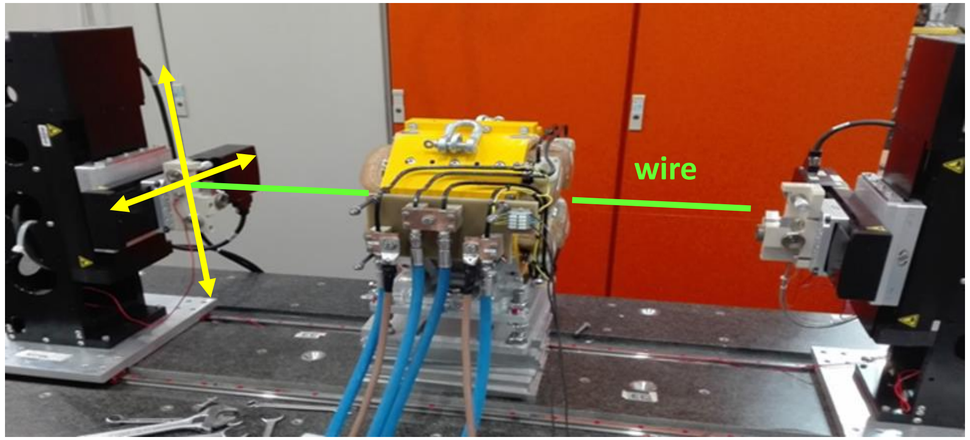
Stretched wire bench



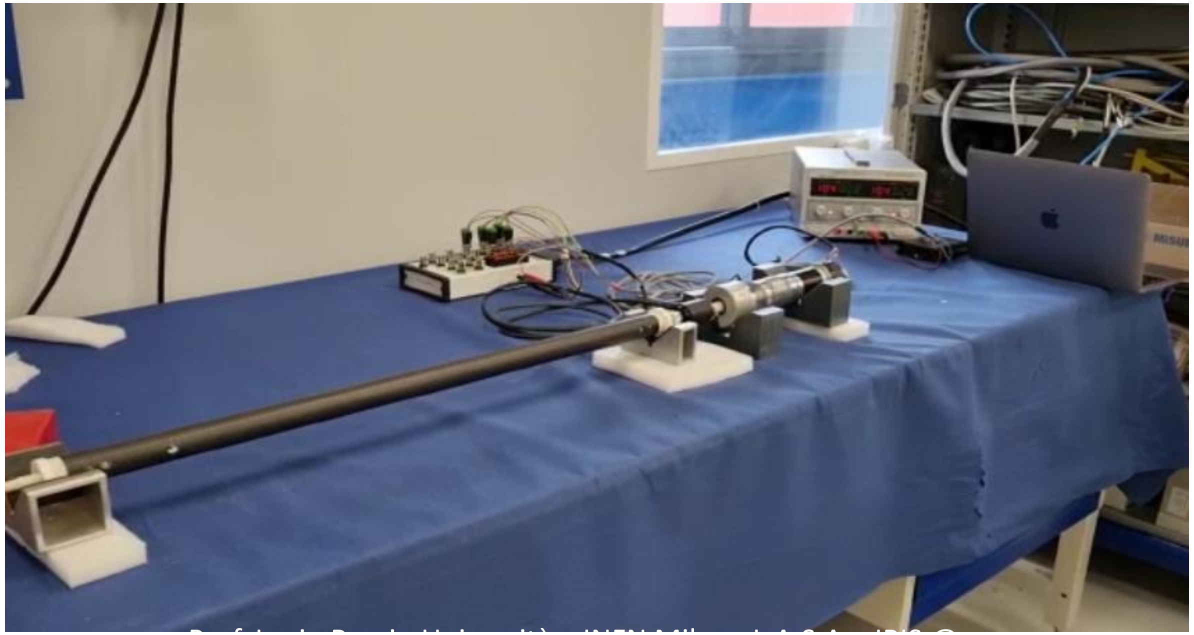
Rotating coil bench

LNF Magnetic Measurements Facility

5-axes digital Movement device equipped with Hall Probe

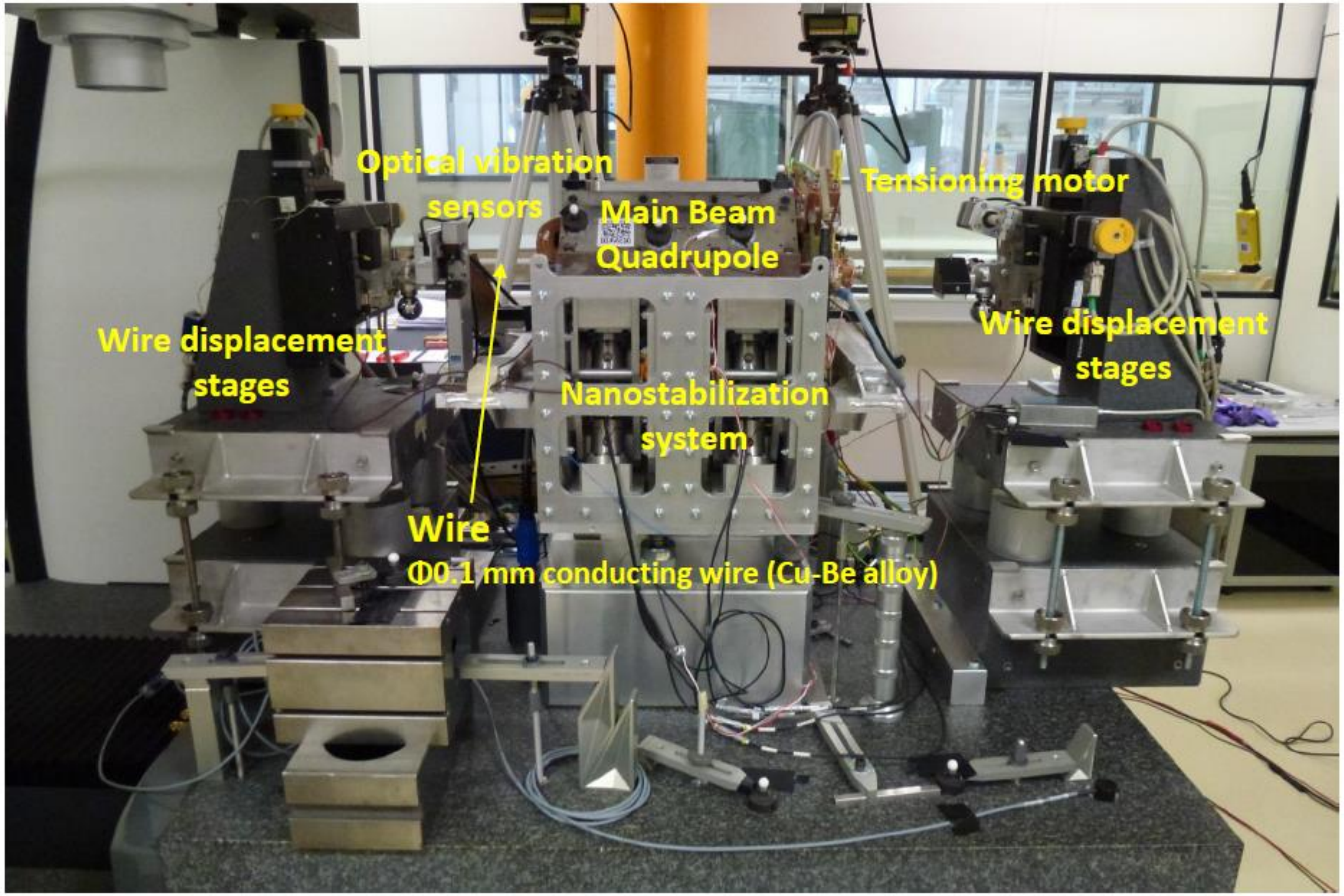


Stretched Wire Measurement Bench



Rotating Coil under test at CERN

New instruments: Vibrating Wire



New instruments: Hall probe Mole and Modular PS

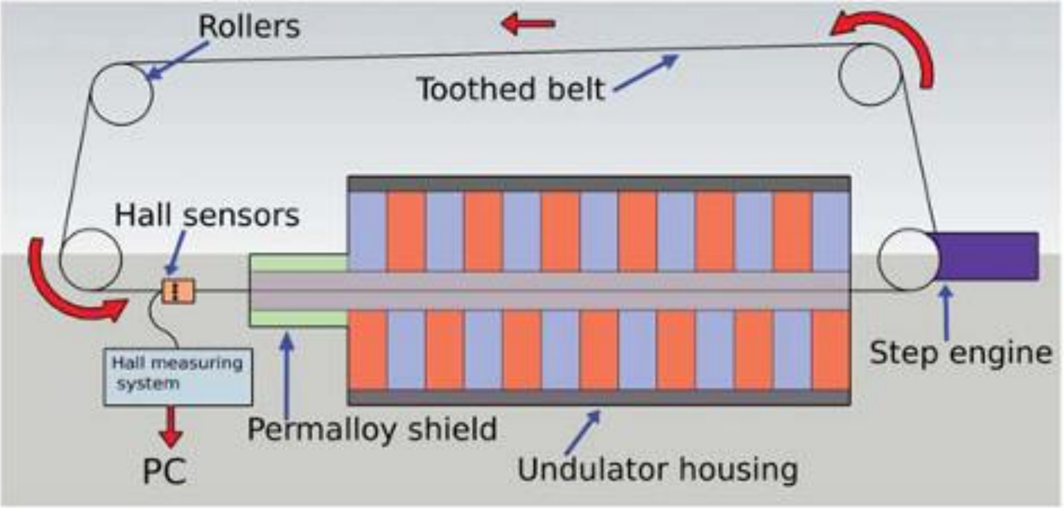
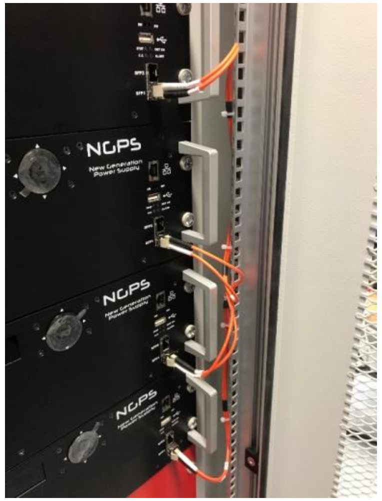


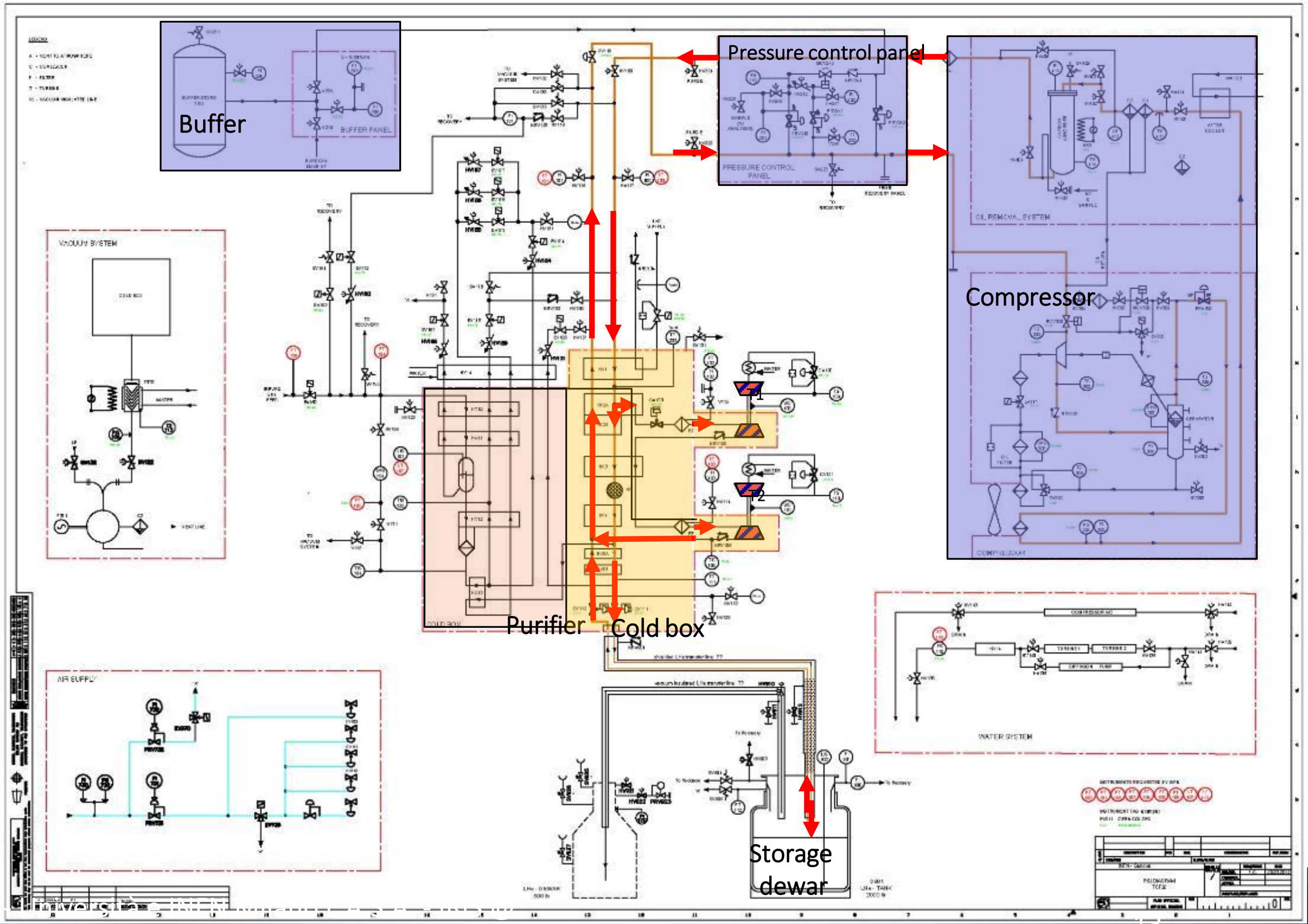
FIGURE 7. Layout of magnetic measurement setup.



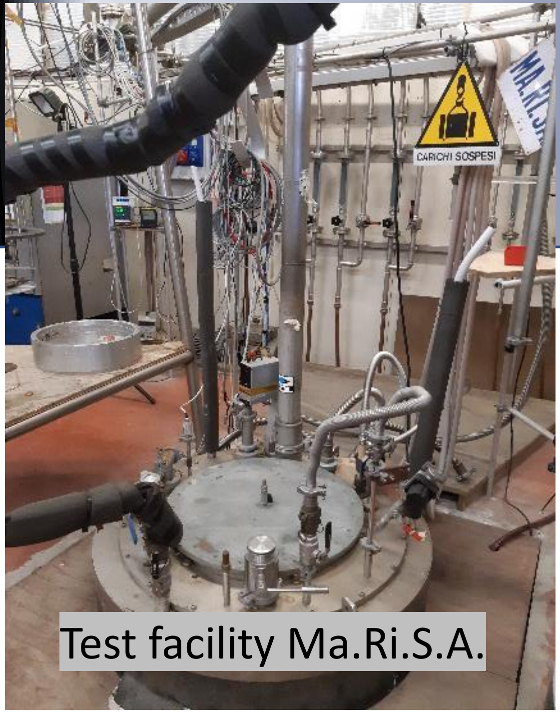
WP3 – Genova
INFN, CNR-SPIN, UNIGE-DIFI

- Collaboration among the three Insitutes has been formalized with a new Joint Research Lab : LabCoR
- INFN
  - Characterization of very high current cable
  - Design of SC magest for accelerators and Detectors
  - Industrial Folow-ip of the SC magnets Construction
  - R&D on future Magnets
- CNR-SPIN
  - Study of Sc material for application
  - Development of SC wires
- UniGe – Physics Dept.
  - Research on SC material

INFN: LINDE TCF20 Helium Liquefier (1989) + recovery and storage plant. It serves all three Institutes, must be revamped with better effciency, less losses and less manpower for its operation



INFN-Ge lab



Test facility Ma.Ri.S.A.

INFN-Ge lab is one of the few where very high current cables can be tested for particle physics.

Upgrade with better safety and energy efficiency, new Power Supplies, new test station at high field, new instrumentation

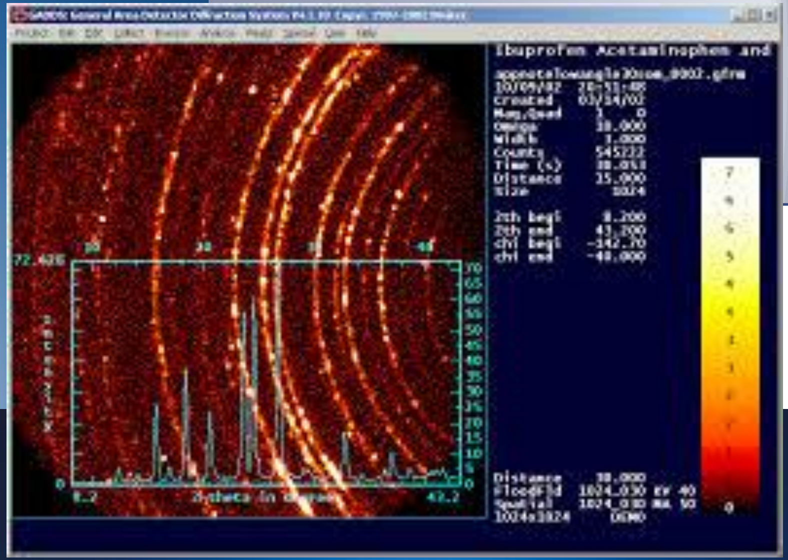
High field test station

Power supply for superconducting magnets (1000 A, 10 V)

CNR-SPIN lab is used for new superconducting material development and new wires for future applications. It will be revamped with new instrumentation to improve competitiveness at international level.

Scanning Electron Microscope

Morphological and compositional analysis of superconducting meterials



X-Ray diffractometer

Structural analysis of
Superconducting materials

Unige - DIFI

The Physics Department will also contribute, with INFN, to the improvement of the cryogenic plant, (He recovery and LN distribution). A new test station with high magnetic field for thermal capacity and magnetization will increase competitivness of the resarch in superconducting material science.

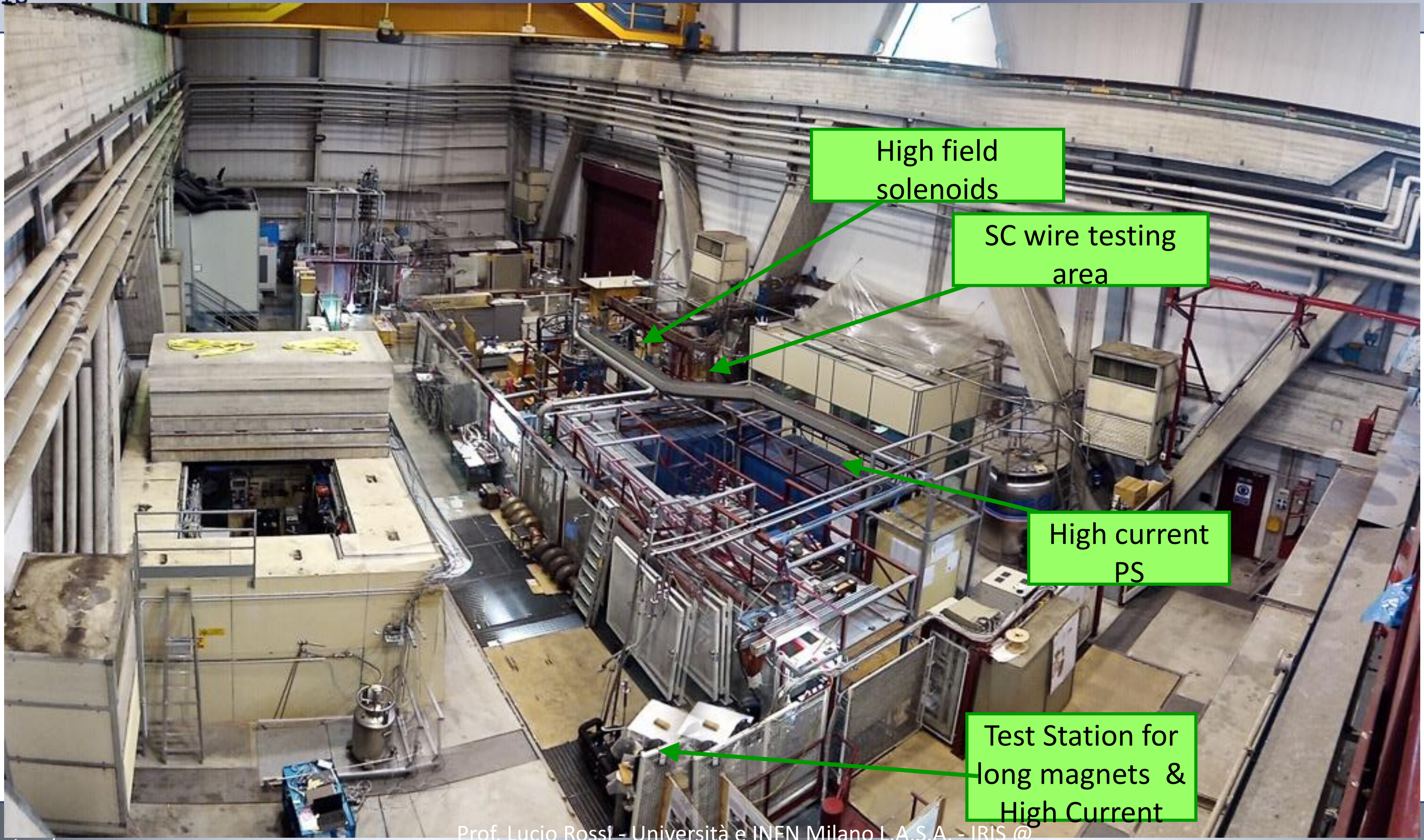
WP4 – Milano LASA
INFN-Milano, UNIMI-DIFI

- Laboratorio Acceleratori & Superconduttività Applicata
  - **SC magnets and SRF cavities**
- Also photocathodes and other activities (BriXino, radionuclides studies)
- (old) LHe plant to be renewed in the next 2 years
- About 25 people active in applied superconductivity
- Belong to Unimi, co-managed by INFN-Milano and Unimi-DIFI
- It is National R.I. as INFN infrastructure (in the list of PNIR as medium priority)

Main activity WP4

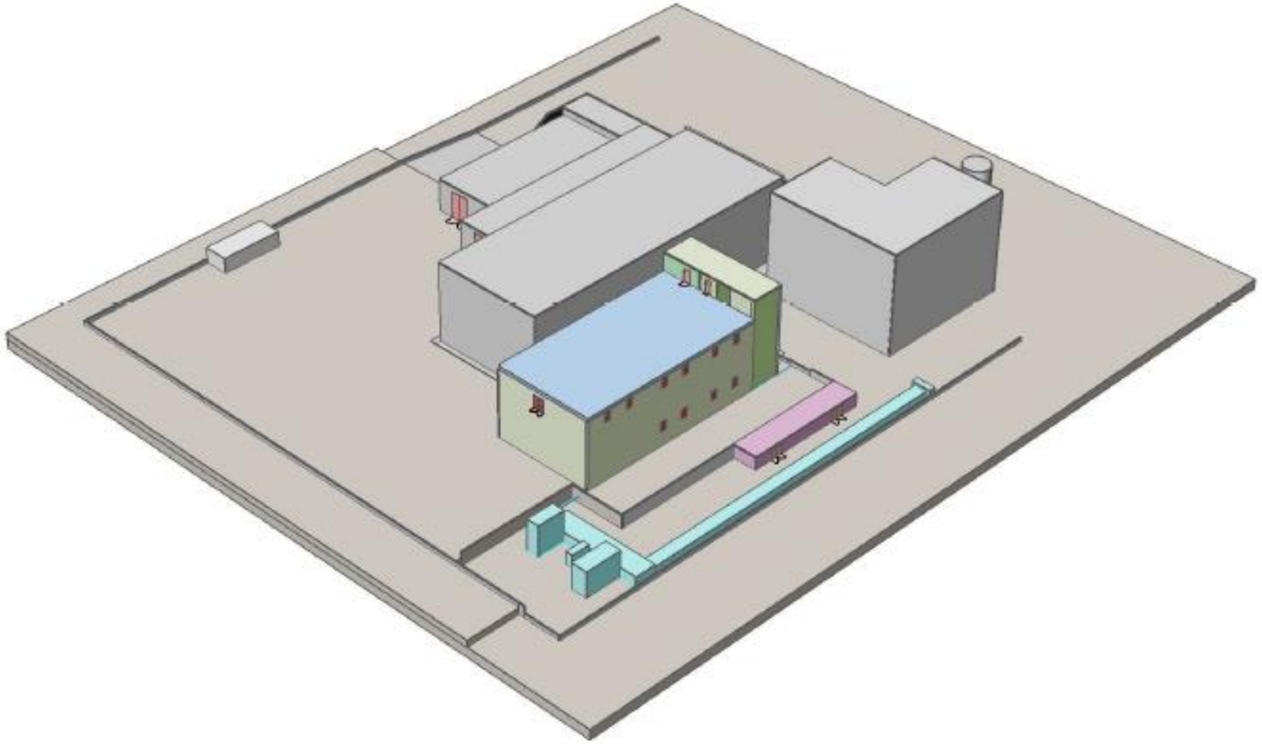
- Re-vamping of the exiting equipment in the main hall for SC magnet test
  - (INFN) Revamping of the existing SC magnet test facility (for bare magnets) up to 30 kA
  - (INFN) Addition of VTI for magnet tests at variable temperature, new feeding lines, etc…
- (DIFI) New building for a **Superconducting Magnet Laboratory** open to other labs and Industry to support new projects (FCC, **MuCol**, other) and novel ideas
- (DIFI) Metal AD equipment to support prototypal activity
- (INFN) A complete set of new equipment for manufacturing small/medium size SC magnets

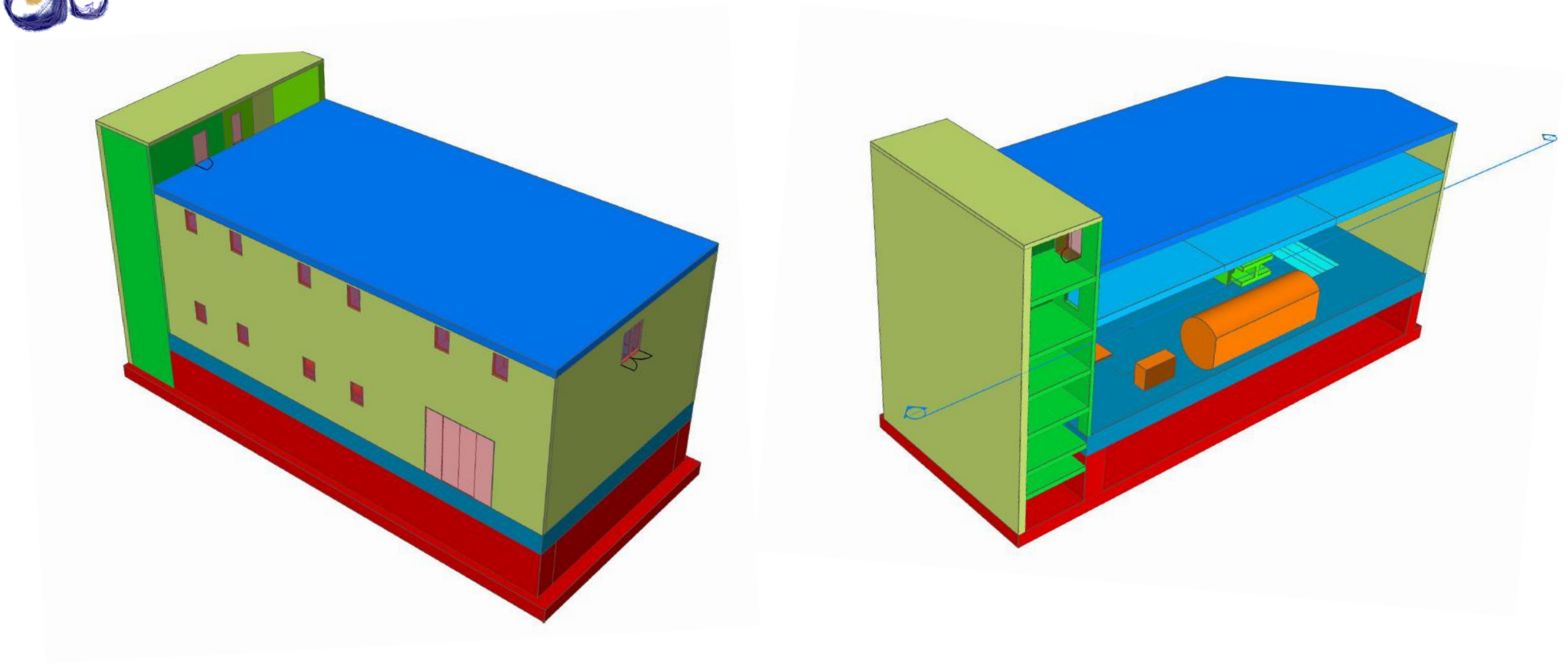
LASA Hall



High field solenoids
SC wire testing area
High current PS
Test Station for long magnets & High Current

300-400 m2 surface building
2 floors + underground bunker





WP5 – Napoli - CIRMIS IMPALAB expertise

- Magnetic measurements
  - Improved digital integrator for magnetic measurements.
  - High rotation coil system.
  - Measurements of field harmonics, gradients and magnetic centres in small aperture magnets.
  - Vibrating wire for longitudinal field measurements
  - Monitoring of accelerator magnets during operation
  - Multi-purpose magnetic field mappers
  - Characterisation of magnets

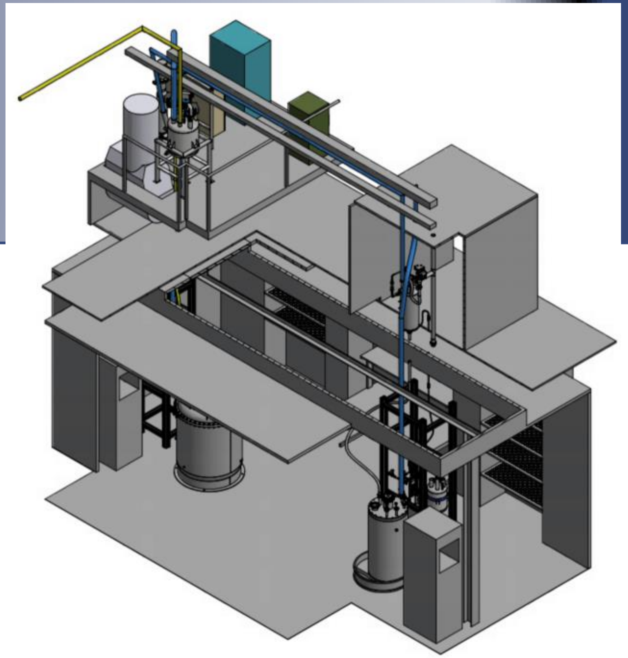
- Measurements on superconducting cables
  - Test station for superconducting cables with superconducting transformers
  - Intelligent test controller for superconducting cables

- Cryogenics
  - Helium flow monitoring
  - Failure detection for compressors
  - Decentralisation diagnostics for refrigerated cryogenic systems
  - Predictive maintenance for helium storage systems
  - Virtual helium monitoring

2x IEEE Transactions on Instrumentation and Measurement
3x Nuclear Instruments & Methods in Physics Research
2x Sensors and Actuators A
3x Journal of Physics Conference Series
7x JINST
13x AIP Review of Scientific Instruments

Napoli:
DIFI CRYOLAB

Dipartimento di Fisica
"Ettore Pancini"

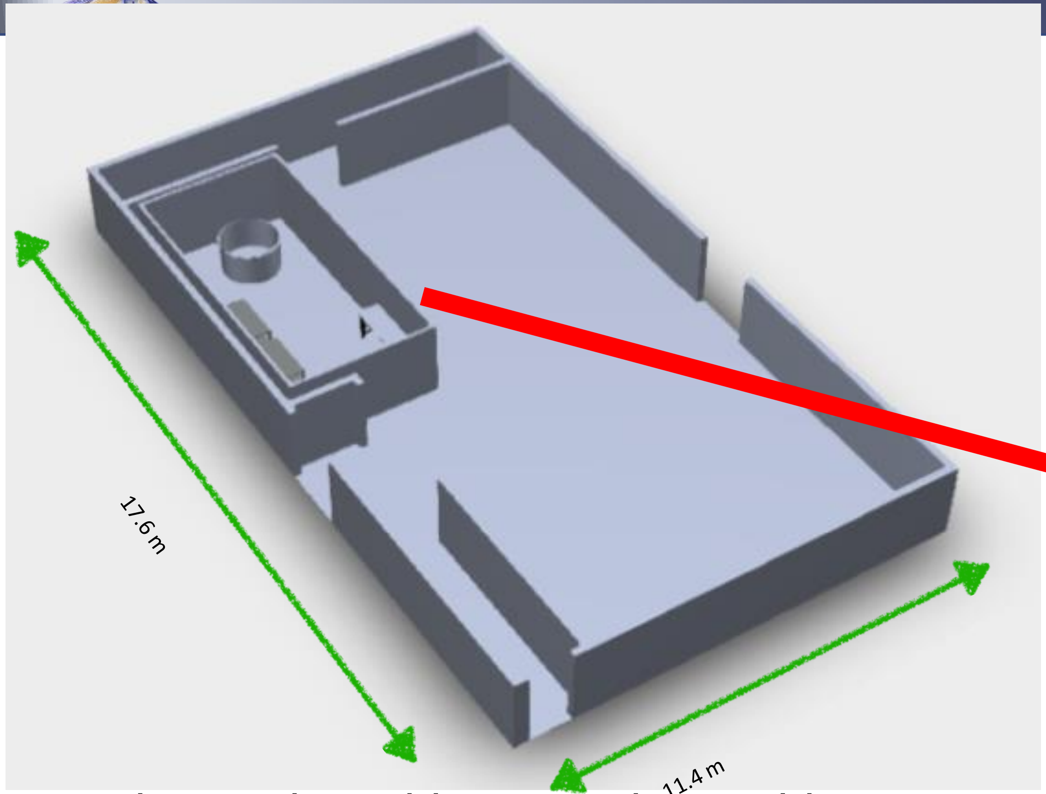


- Light Detectors Test
- Stand alone cryo system
- Vacuum and cryogenic equipment

New facility: IRIS ACME laboratory

Aims:

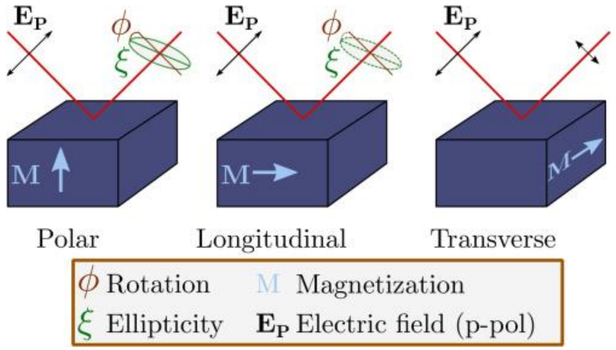
- Extend the current instrumentation and measurement procedure for superconducting magnets and cable
- Improve the metrological feature of the measure
- Develop new procedures for facing the state of the hard challenge for LTS and HTS

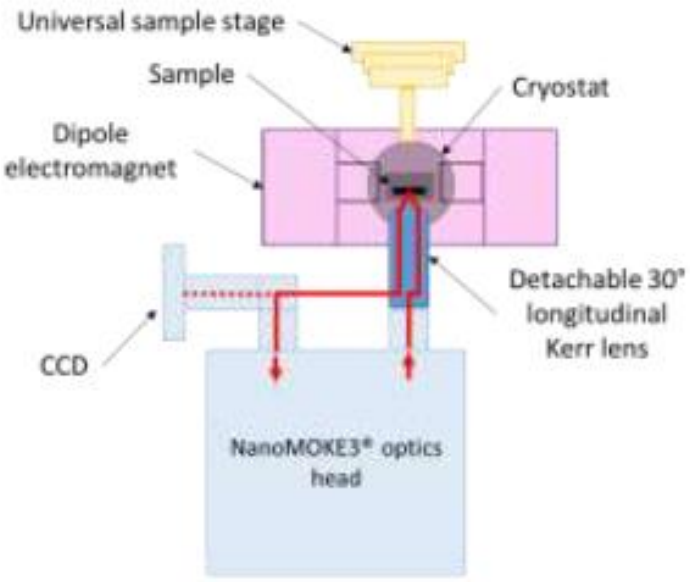


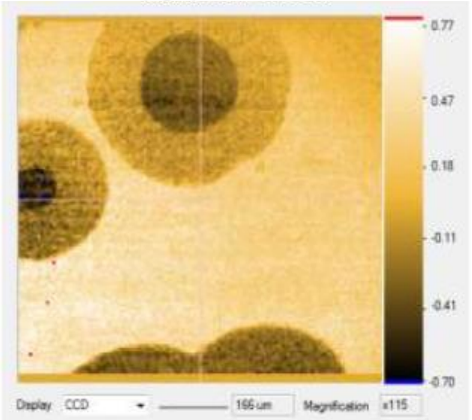
- Advanced Machine Learning Architecture System
- Measurement stations :
- Machine for superconducting cables instrumentation

Napoli CNR-SPIN MOKE

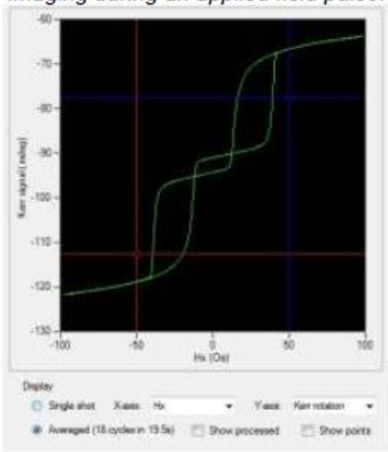
- Instrumentation for studying material properties relying on magneto-optic Kerr effect (Moke)







Domain imaging at 10 frames per second, out-of-plane magnetization in a continous film, imaging during an applied field pulse.



Hysteresis loop from bilayer CoFeB (3nm) synthetic ferrimagnet.

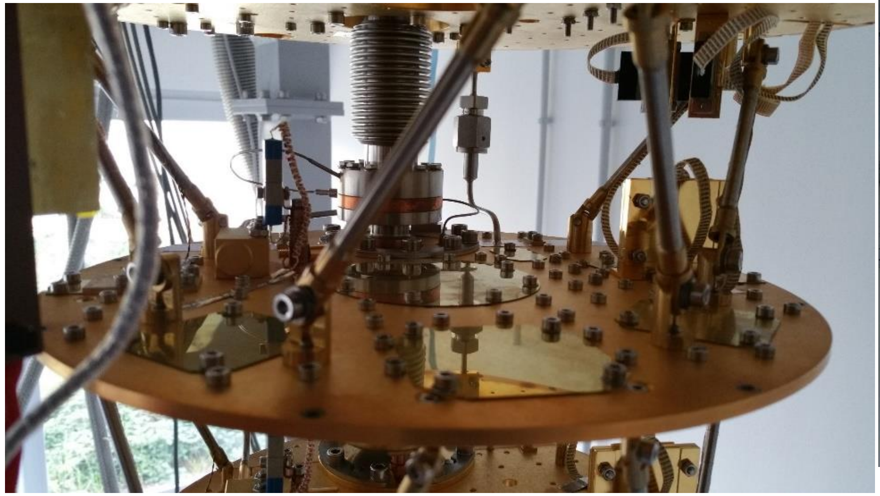
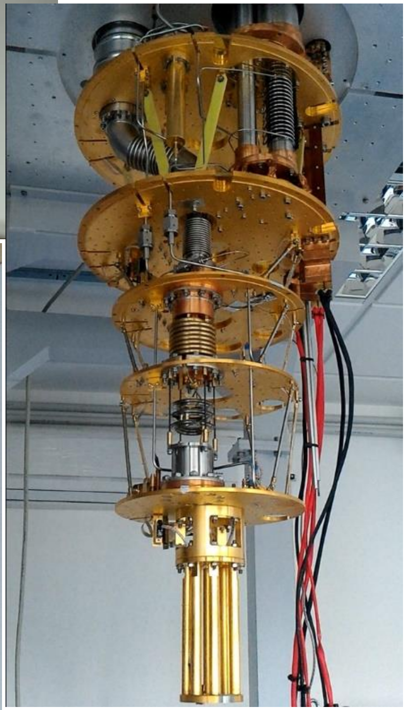
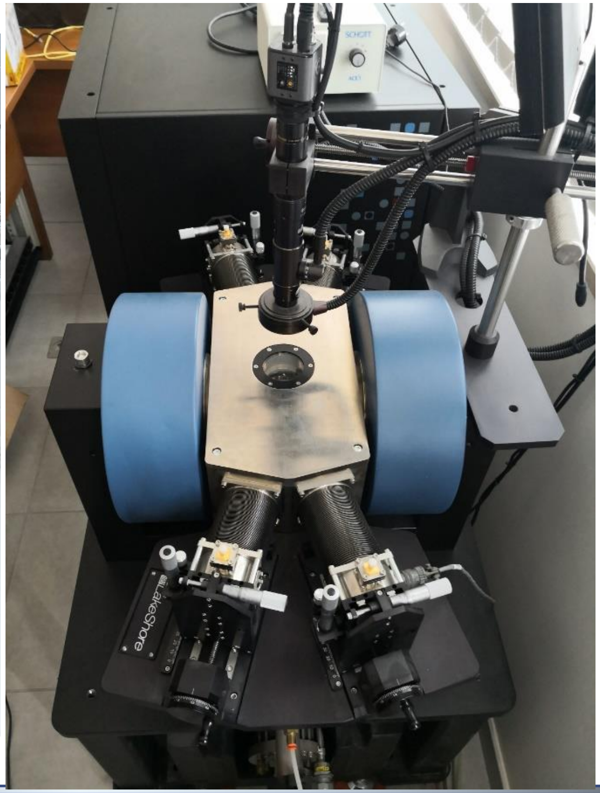
SALENTO (Lecde)
Laboratory for Superconductivity and Magnetism

IRIS

Italian node of the European Infrastructure on Magnetism EMFL-ISABEL (funded within ISABEL project, H2020-INFRADEV-2018-2020, Grant No. 871106).

- Cryogenic superconducting magnet (10.5 T, 0.3-300 K)
- Oxford dilution refrigerator (down to 10 mK, vector magnet 6T/1T/1T)
- Lakeshore Cryogenic RF probe station (down to 8 K and up to 0.5 T and 70 GHz).



Laboratorio di Superconduttività e Magnetismo

development plan

close-cycle SQUID magnetometer

close-cycle superconducting magnet for physical properties measurement

scanning probe microscope for material characterization

split pair cryogen-free magnet system for combined magneto-optical and FMR measurements

WP6 – Salento (Lecce) UNISALENTO- DMF

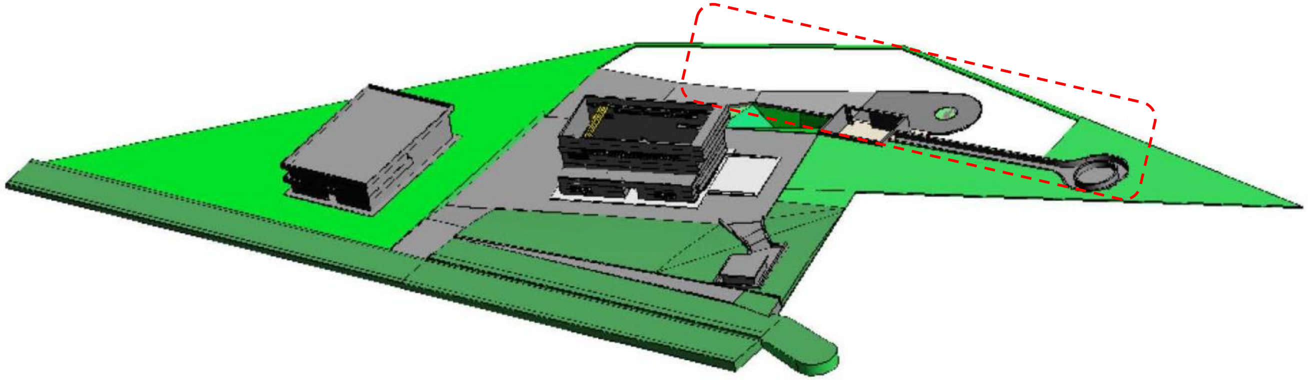
- Magnetometry measurements under external stimuli such as light irradiation and electric fields for the characterization of innovative materials [novel setup expected to attract users working in the fields of advanced magnetic materials with controllable bistable states and investigating the interplay among magnetism and superconductivity] +50% users
- Measurements of physical properties of materials (e.g. magnetotransport and measurements of critical currents) in a wide range of temperatures and magnetic fields [novel setup expected to attract users working on spintronics, superconductive devices, sensors/detectors and quantum computation] +50% users
- Combined magneto-optical and ferromagnetic resonance measurements [novel setup expected to attract users working in the fields of magneto-optics, magnonics and quantum computation] +30% users
- AFM, MFM and PFM microscopy measurements for the characterization of superconducting, magnetic and multifunctional materials novel setup expected to attract users working in the field of advanced functional materials, spintronics and applied superconductivity] + 30% users

WP7 – Salerno
INFN-NA-G.C.Salerno, CNR-SPIN- UNISA

- INFN-Salerno with UNISA has built and commissioned a new SC Magnet test facility in the last 5 year, THOR
- It is used at present for testing GSI – SIS100 SC multiplets
- With IRIS the INFN/Unisa facility will evolve by:
  - *Increasing the cryogenic power for SC magnets*
  - *Ability to test magnets not only at Supercritical He flow and ability to test magnets of LHC/Hilumi/FCC size (however, no HEII at te moment)*
  - *Adding a new test facility for Green SC Lines : up to 25 kV – 40 kA (1 GW),20 K He gas, with a dugout for cable as long as 140 m*

WP7 – Salerno THOR Lab

THOR: present and IRIS extension



WP7 – Salerno CNR-SPIN

- The SPIN Salerno Unit aims to acquire and setting up a magneto-transport measurement system including the application of strain and stress.
- The equipment for magneto-transport (e.g. Quantum Design PPMS) consists of a variable temperature (1.9 to 300 K)-field (up to ±9 T) system, designed to perform a variety of automated measurements.
- Additional elements to be acquired within IRIS are cryogenic strain and stress cells (e.g. Razorbill Instruments), which are fully compatible with the PPMS probe.
- The main goal is to strengthen the capacity for investigating the role of strain/stress on the transport properties of superconducting materials.

WP8 – Demonstrator
Green SC LINE at zero emission


(courtesy of A. Ballarino, CERN, archive)

Left: Superconducting Line, in its flexible cryostat, 60 m , 100 kA – 3 kV, during successful test in 2020 at CERN for the High Luminosity LHC Project

Right: cabling a subelement of a MgB_2 cable for High Luminosity LHC Project


(courtesy of A. Ballarino, CERN)

Scope: Manufacturing a demonstrator capable of 1 GW DC, operated at 20 K and test it in "operative" conditions in a test facility that will then be available for other projects. 40 kA-25 kV, 20 K; use of round wire MgB_2

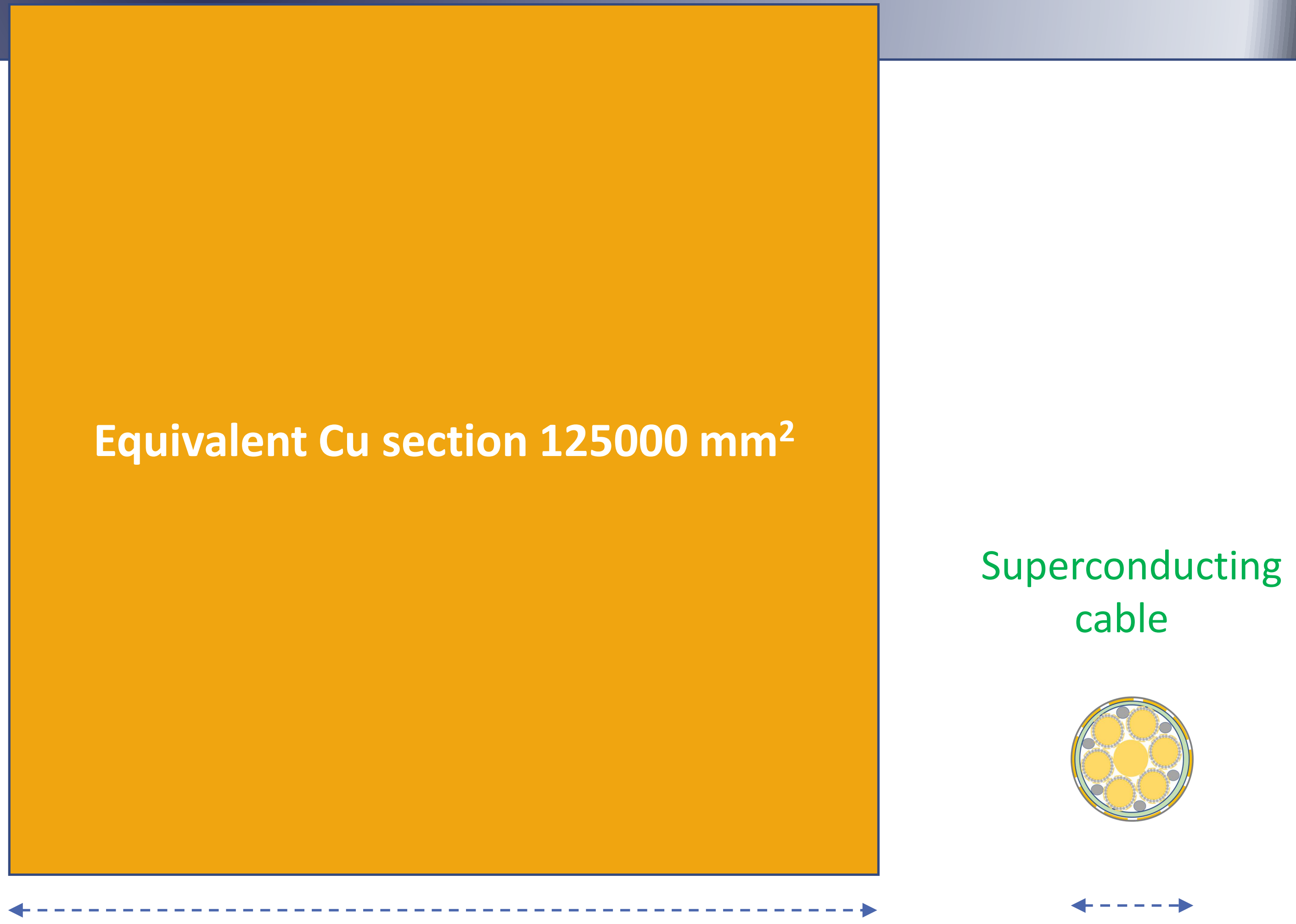
Use: beside long-distance large electrical power transmission, significant place in the electric system for HVDC back-to-back system (study for placing the demonstrator in an Italian facility after the PNRR).

We will design the facility and this demo for cooling with He gas; **however, in second stage compatibility with LH cooling will be investigated, too**.

IRIS 1GW DC *25 kV-40 kA power cable*

A very compact environmental friendly unrivalled solution !!!

- Easier to install due to a large reduction of cross section
- Large saving of raw materials and CO_2 emissions
- No thermal impact



Resistive Copper bus bar

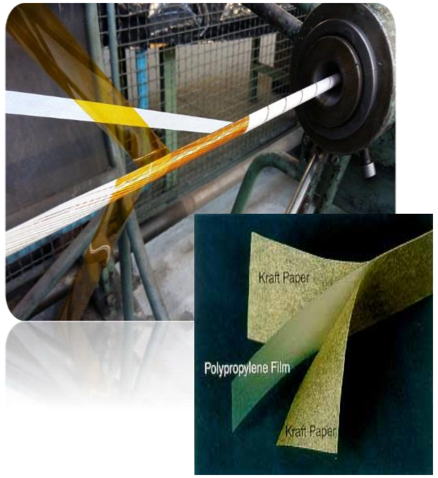
Iris solution

IRIS 1GW DC 25 *kV-40 kA power cable*

Manufactured with industrial cabling processes

Planetary cabling machine for the petal

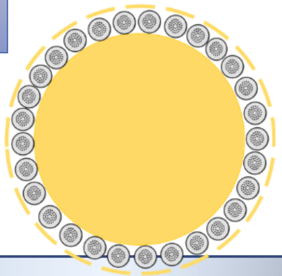
Planetary assembling machine
for the final conductor



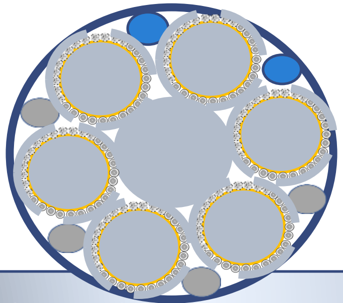
Lapping line for the HV insulation
and protection

Courtesy of E. Bruzek , ASG Itlay

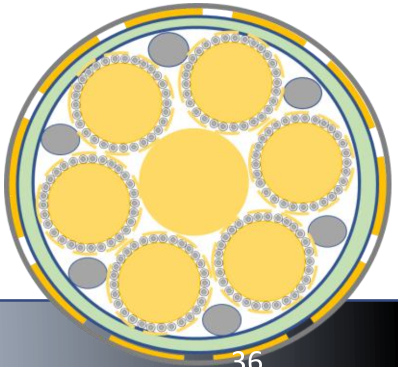
d =1,33 mm



d =14,4 mm



d =43,2 mm

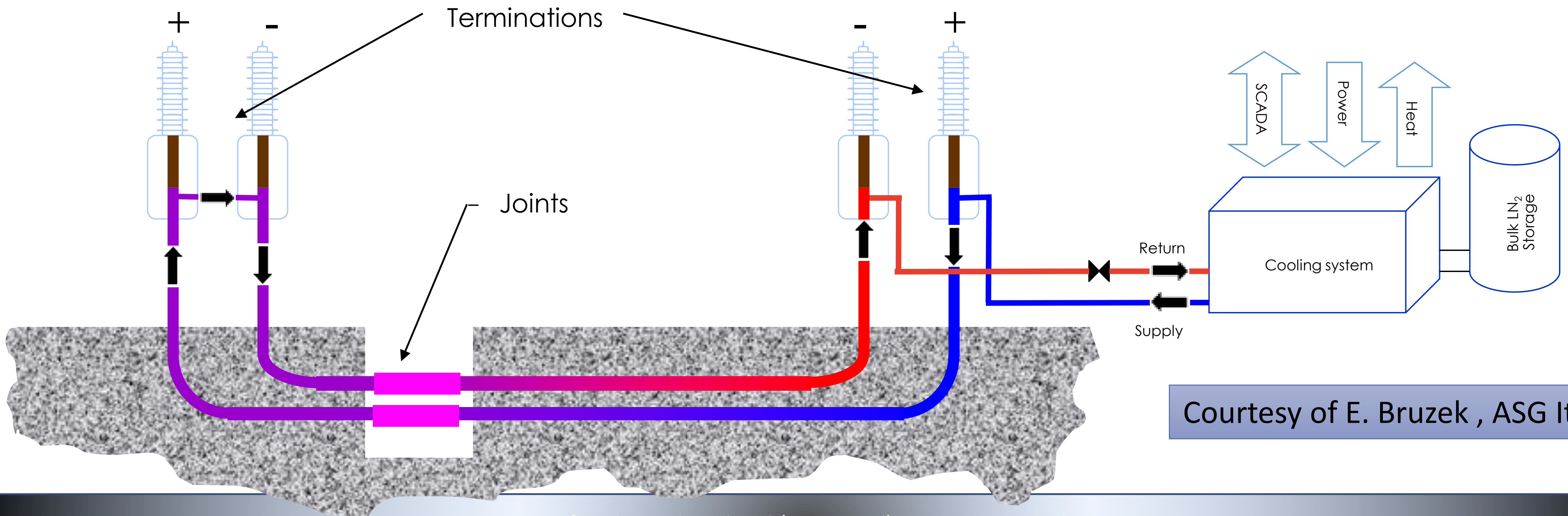


d =49 mm

IRIS 1GW DC *25 kV-40 kA power cable*

Its integration within the grid needs:

1. A cooling machine
2. Two terminations and when necessary joints for long cables
3. Cable control systems connected to the grid mgt



Courtesy of E. Bruzek , ASG Itlay

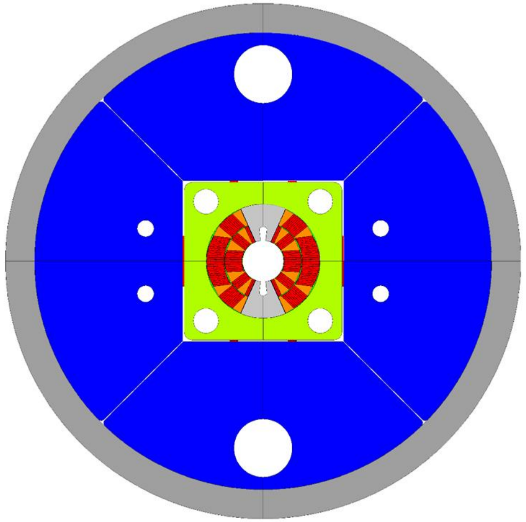
WP9 – Demonstrator
Energy Saver Superconducting Magnet in HTS

Cable in HTS for da 10 kA, developed in the EU collaboration **FP7-Eucard2 GA 312453**

The record field for HTS dipole (with some accelerator quality) is Eucard2, only 4.5 T… it is time to try to see if HTS can really be useful for accelerators.
Scope : a dipole rated for:
10 T – 150 mm bore – 10-20 K operation as background field for cable test.
As technology driver for 15 T – 20 K operation for FCC…

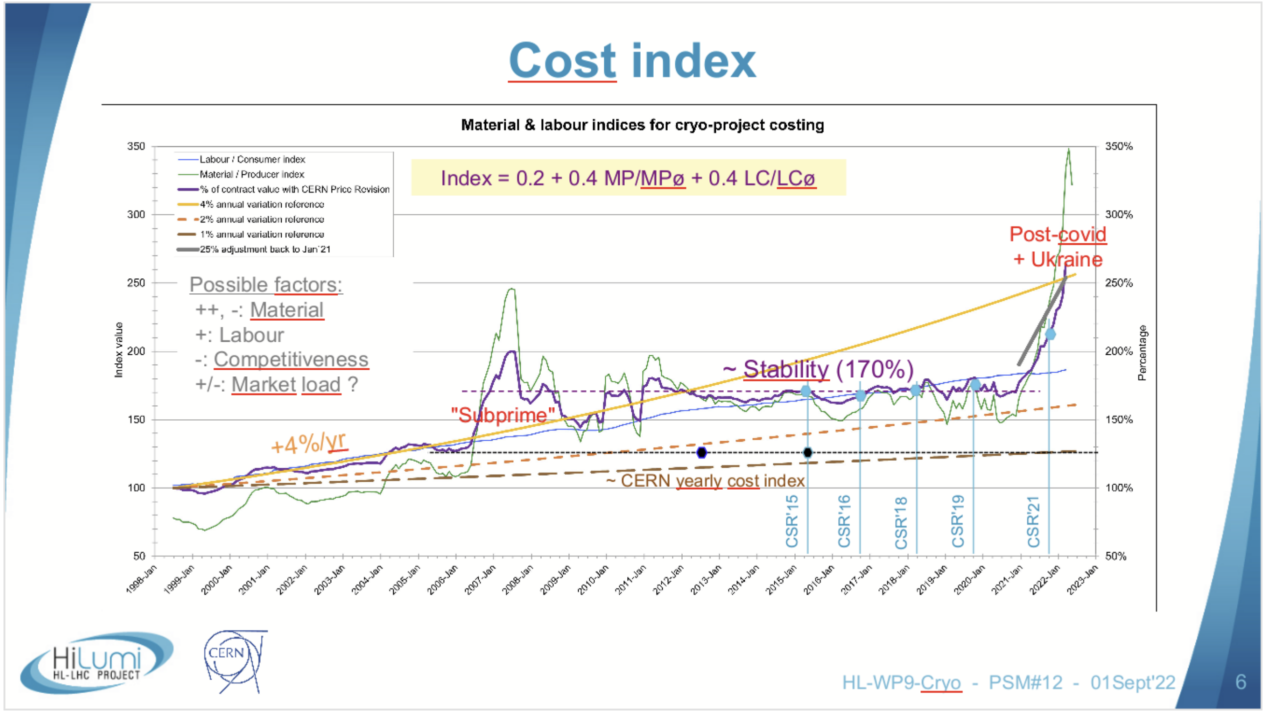
Post HiLumi LHC SC Magnets

- Nb_3Sn : fields in excess of the 12 T of Hilumi seems very difficult. Now in Hilumi big success with 3 magnets in a raw that did work.
  - However a lot of work will be needed just to consolidate the 12 T region (INFN Falcon D project, and all HFM program (CERN, CEA, PSI, etc…).
  - The zone of 14-16 T si not impossible but training and degradations will be a severe obstacle. In addition B=16 T needs HeII (baseline in FCC-hh). **300 MW cryo!**



HTS should be explored for next hadron collider design

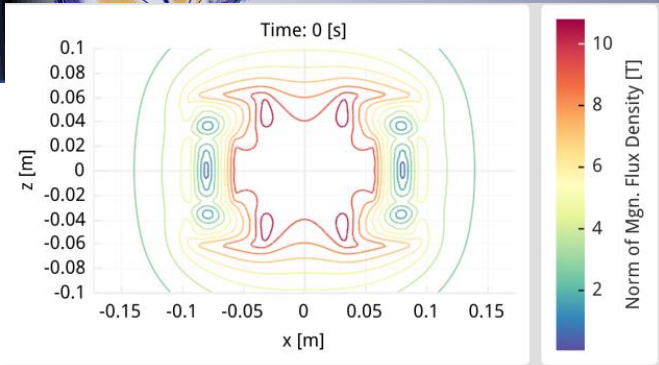
Cost of Cryogenics evolution over 30 years
(source: **Serge Claudet, CERN, Hilumi LHC project**

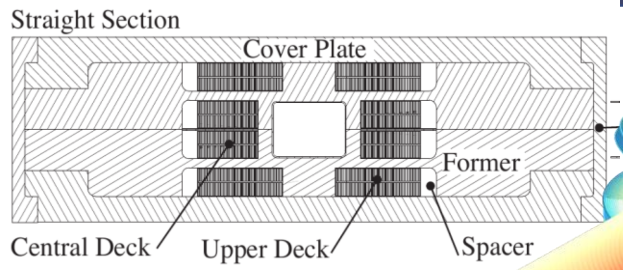


- HTS : today record for dipole is 4.5 T but very little effort
  - Solenoids are at 30-40 T!
  - Cost of HTS is still vey high but is steadily (however slowly) decreasing in $/kA-m
- So far HTS dipole design more for 20+T regime @ 2-4 K.
- Now we think that could 12-16 T @ 10-20 K: Electric bill 5-10 limes less!
- Towards colliders with HTS magnets: *State-of-the-art of the main objectives and challenges* by Lucio Rossi (CERN), ECFA Newsletter #4, Winter 2019, Following the Plenary ECFA meeting, 14-15 November 2019, https://indico.cern.ch/event/847002/overview

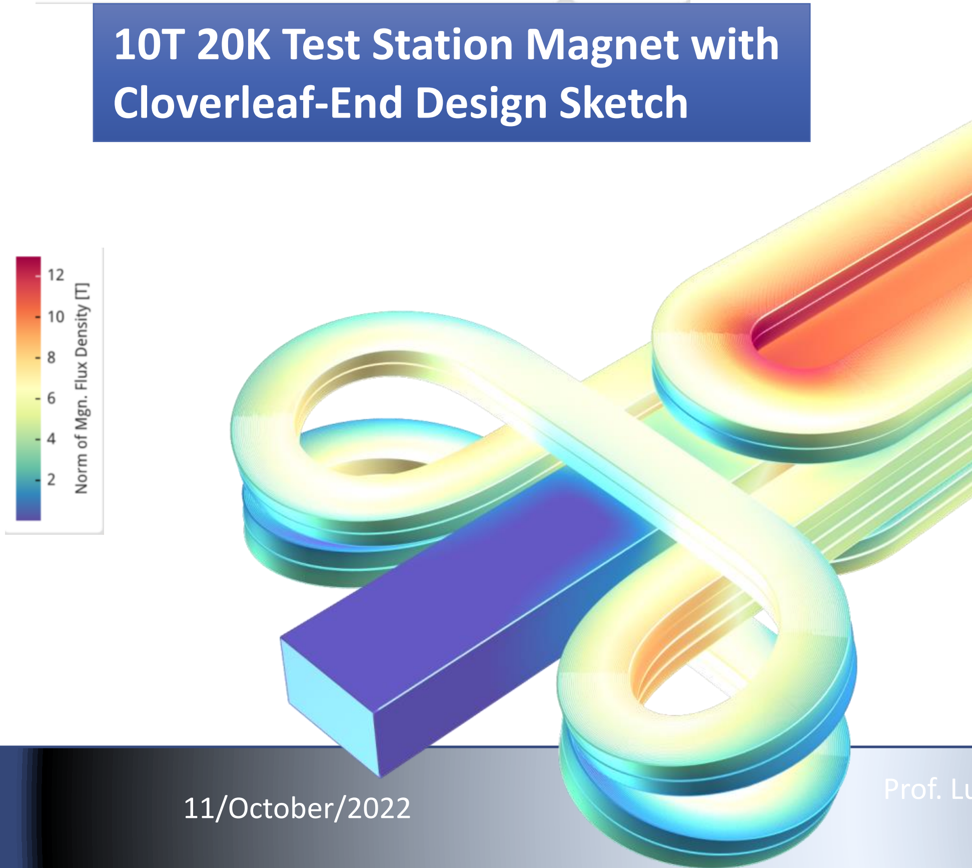
8 T- 10 K 810 T 20 K) DIPOLE steady state Cloverleaf desing

Courtesy : J. van Nugteren
Little Beast Engineering

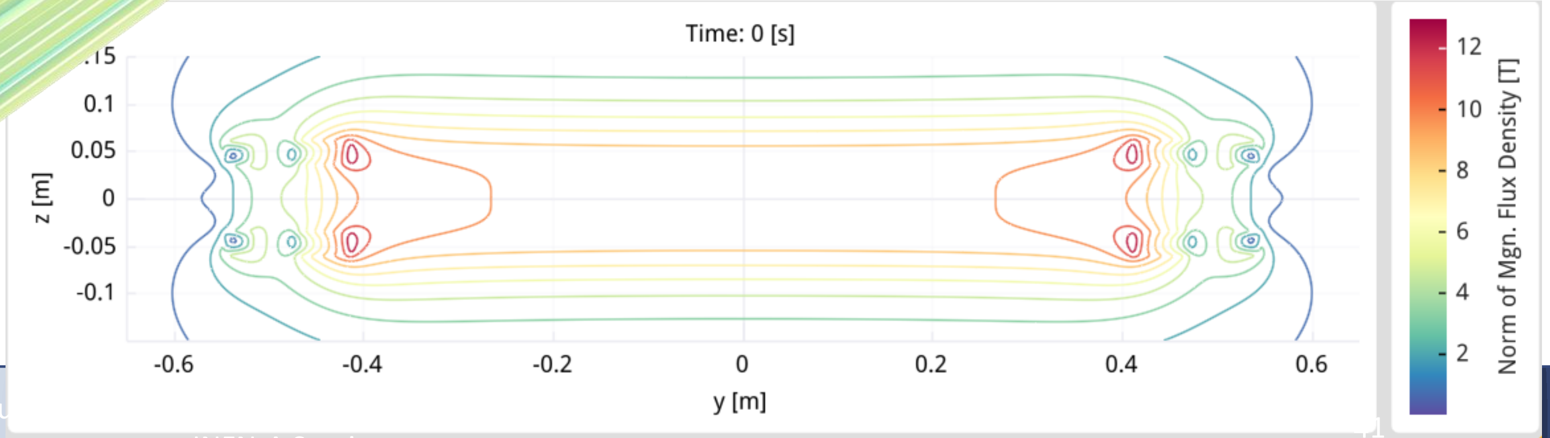




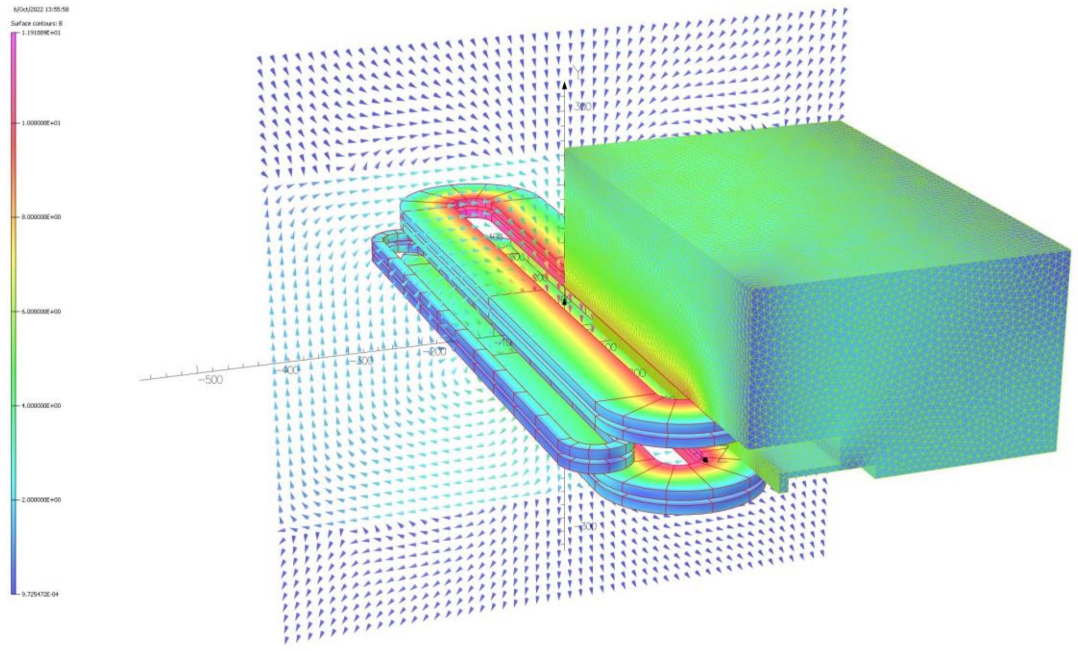
10T 20K Test Station Magnet with Cloverleaf-End Design Sketch

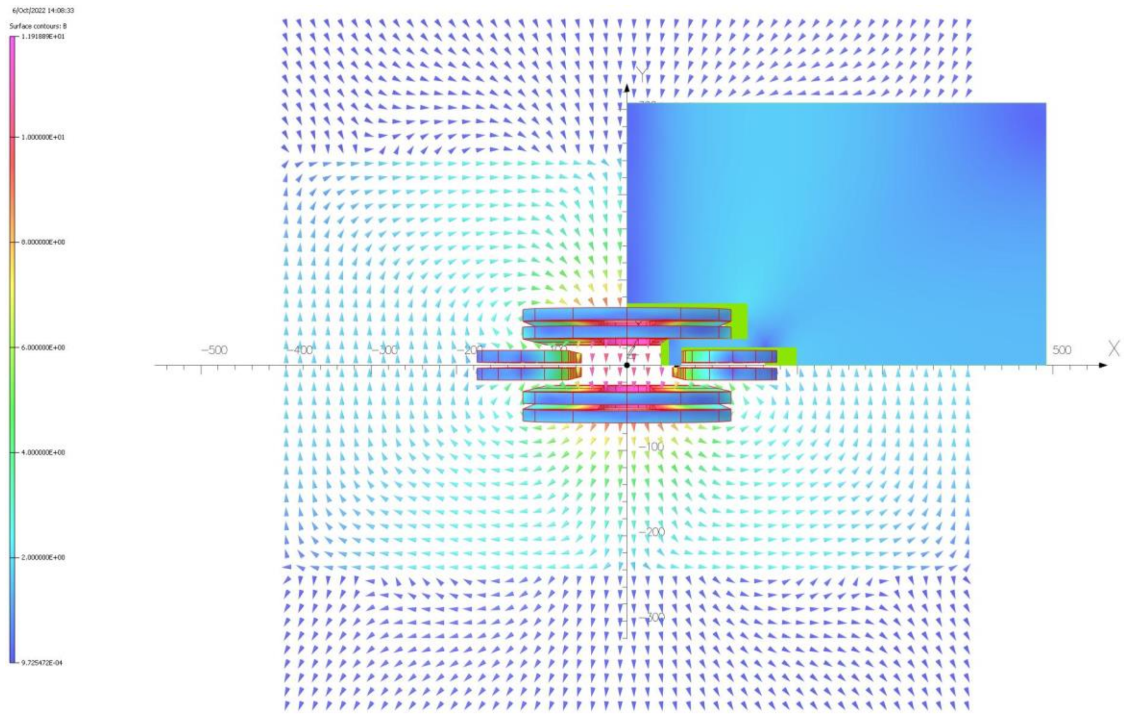


- Aperture 80X50 mm
- 700 mm straight section
- B3 B5 geometric field quality
- 12 mm wide REBCO tape (stack)
- 1.2 MJ stored energy
- 10 K temperature margin
- 11 km of HTS tape (~1 M$)
- 550 A/mm^2 cable current density



Alternative Dipole design: flat race track (with return flux coils)





Pictures from Magnus Dam, INFN-LASA

Leader	WP	description	Reported	Indirect costs	Total grant
P. Campana	1	Project Management and Technical Coordination	4,300,009.70 €	301,000.68 €	4,601,010.38 €
L. Rossi	1	INFN-Milano	4,300,009.70 €	301,000.68 €	4,601,010.38 €
L. Sabbatini	2	Innovative distributed R.I. POLO FRASCATI	1,046,760.00 €	73,273.20 €	1,120,033.20 €
L. Sabbatini	2	INFN-LNF	1,046,760.00 €	73,273.20 €	1,120,033.20 €
R. Musenich	3	Innovative distributed R.I. POLO GENOVA	5,407,000.26 €	378,490.02 €	5,785,490.28 €
R. Musenich	3	INFN- Sez. GE	3,211,899.80 €	224,832.99 €	3,436,732.79 €
A. Malagoli	3	SPIN-GE	1,090,099.58 €	76,306.97 €	1,166,406.55 €
M. Putti	3	UNIGE-DIFI	1,105,000.88 €	77,350.06 €	1,182,350.94 €
M. Sorbi	4	Innovative distributed R.I. POLO MILANO (LASA)	8,227,151.08 €	575,900.58 €	8,803,051.65 €
M. Statera	4	INFN-Milano	3,722,000.55 €	260,540.04 €	3,982,540.59 €
M. Sorbi	4	UNIMI-DIFI	4,505,150.53 €	315,360.54 €	4,820,511.07 €
P. Arpaia	5	Innovative distributed R.I. POLO NAPOLI	2,390,670.00 €	167,346.90 €	2,558,016.90 €
F. Miletto	5	SPIN-NA	480,020.00 €	33,601.40 €	513,621.40 €
P. Arpaia	5	UNINA (Federico II) - CIRMIS	1,410,650.00 €	98,745.50 €	1,509,395.50 €
G. Fiorillo	5	UNINA (Federico II) - DIFI	500,000.00 €	35,000.00 €	535,000.00 €
G. Maruccio	6	Innovative distributed R.I. POLO SALENTO	3,370,000.00 €	235,900.00 €	3,605,900.00 €
G. Maruccio	6	UNISALENTO-DMF	3,370,000.00 €	235,900.00 €	3,605,900.00 €
U. Gambardell	7	Innovative distributed R.I. POLO SALERNO	13,285,441.52 €	929,980.91 €	14,215,422.43 €
U. Gambardell	7	INFN-Napoli-GC Salerno	7,322,830.20 €	512,598.11 €	7,835,428.31 €
M. Cuoco	7	SPIN-SA	687,850.00 €	48,149.50 €	735,999.50 €
S. De Pasquale	7	UNISA-DIFI	5,274,761.32 €	369,233.29 €	5,643,994.61 €
L. Rossi	8	Green Superconducting Line at zero emission	11,968,400.10 €	837,788.01 €	12,806,188.10 €
L. Rossi	8	INFN-Milano	11,968,400.10 €	837,788.01 €	12,806,188.10 €
L. Rossi	9	Energy Saving HTS Magnet for Sustainable Accelerator	6,076,500.22 €	425,355.02 €	6,501,855.24 €
L. Rossi	9	INFN-Milano	5,411,500.00 €	378,805.00 €	5,790,305.00 €
L. Rossi	9	UNIMI-DIFI	665,000.22 €	46,550.02 €	711,550.24 €
		TOTAL PROGRAM	56,071,932.87 €	3,925,035.30 €	59,996,968.17 €

Thee figure includes VAT and other duties)

-18 days to the start!
3 years to build

Thanks for your attention