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

The I.FAST superconducting magnet prototypes

WP8 - Innovative Superconducting Magnets (Tasks 8.1 – 8.5)

Ernesto De Matteis, INFN of Milan (Italy) – LASA laboratory

and all WP8 collaborators

I.FAST – 5th and Final Annual Meeting

21.October.2025 – CERN, Geneva, Switzerland

I.FAST WP8 – Innovative superconducting magnets

Scope

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;

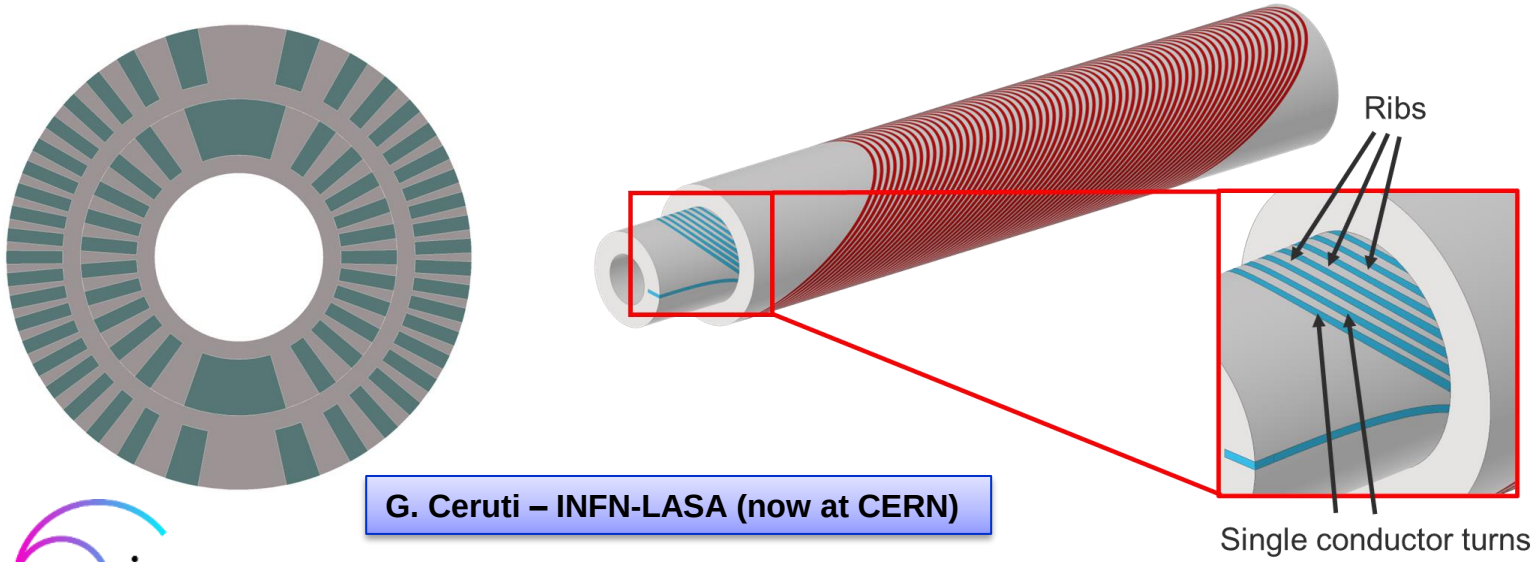
Exploring **Canted Cosine Theta with HTS superconductor (main goal),** preceded by a **combined function CCT based on LTS** → involving the industries that want to learn about the CCT magnets;

Construction of the two demonstrators: winding and magnet assembly, magnet test and validation

Magnet Members of Task 8.1 – 8.5

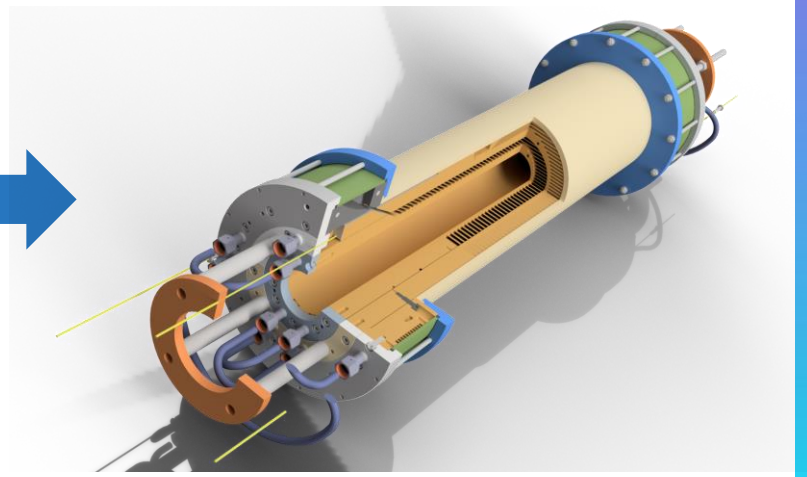
cea, CERN, Ciemat, Wigner, INFN Istituto Nazionale di Fisica Nucleare, Paul Scherrer Institut PSI, Uppsala Universitet, Université de Genève, Elytt Energy, Bilfinger Noell GmbH, Scanditronix

Canted Cosine Theta schematics



G. Ceruti – INFN-LASA (now at CERN)

Final HTS CCT magnet demonstrator

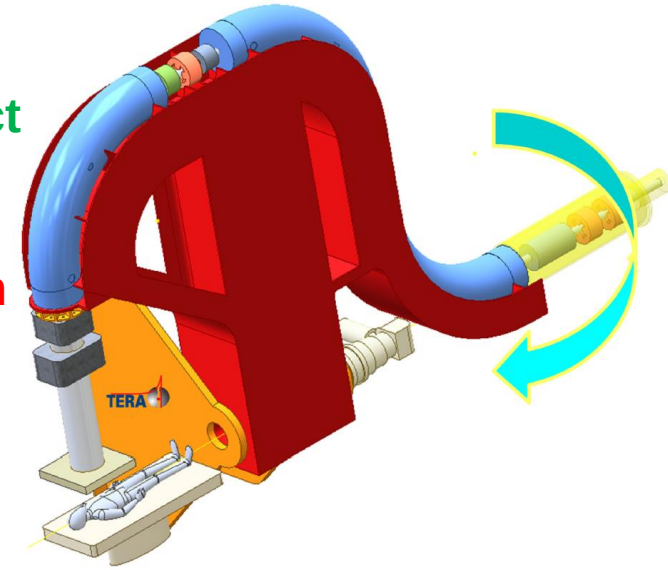


Parameters of demonstrator magnets

Parameters	Values		unit
Magnet type	CCTs		-
	LTS	**HTS**	
Geometry	**Straight**		-
Central magnetic field B_0	**4**		**T**
Magnetic and physical length	0.8, 1		m
Bore diameter	**80**		mm
dB/dt	**0.4**		**T/s**
Operation temperature	**4.7(4.2)**	**20**	**K**
Loadline margin (@4.7 K) static	25		%
Superconductor	**NbTi**	**RebCo tape**	-

Superconducting Rotating Gantry

Light and compact
weight<100 ton
Cost reduction
Cryogenic system

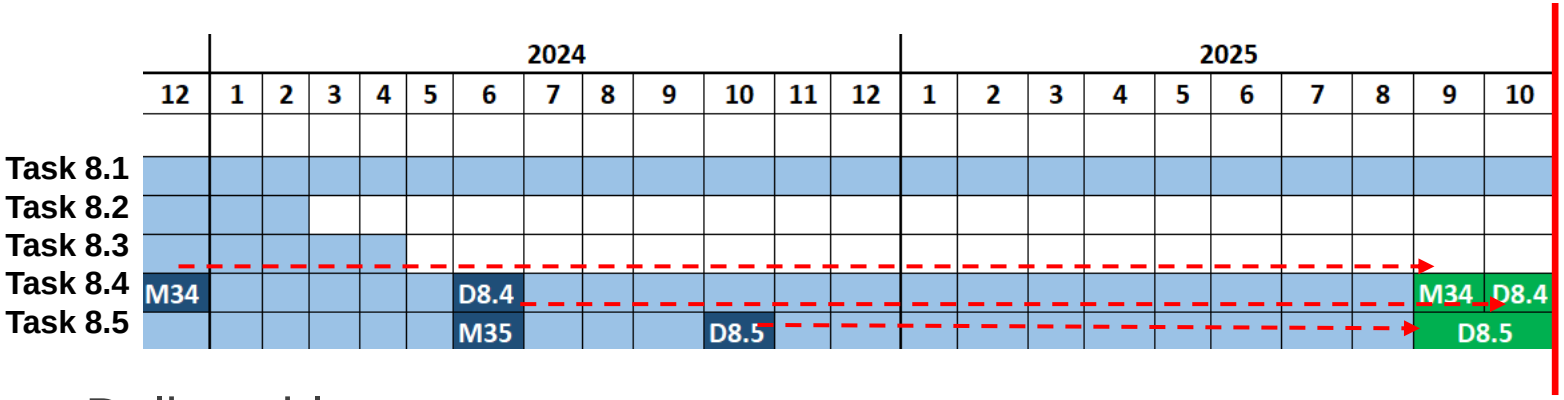


Carbon Ions beam rigidity

Magnet parameters as HITRIplus and EUROSIG programs (Hadron Therapy magnet)
Straight geometry →HTS is already difficult enough!

WP8 – Timeline, Milestones and Deliverables

IFAST WP8: Innovative Superconducting Magnets
Task 8.1 - Coordination and High-Temperature Superconductor (HTS) Strategy Group
Task 8.2 - Preliminary Engineering design of combined Canted Cosine Theta (CCT) magnet
Task 8.3 - Preliminary Engineering design of HTS CCT
Task 8.4 - Construction of combined CCT magnet demonstrator
Task 8.5 - Construction of the HTS CCT magnet demonstrator



End of I.FAST!!

Deliverables

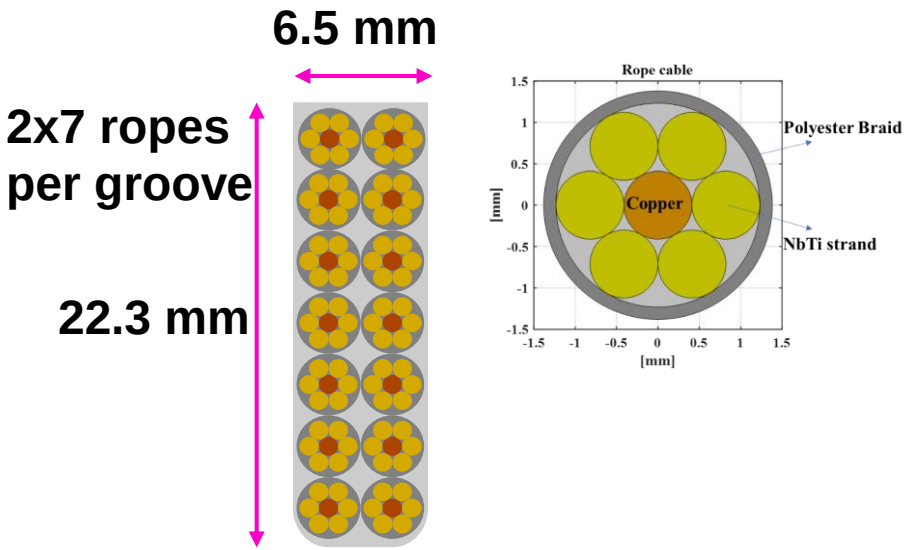
- **D8.4 (06/2024→ 10/2025) Construction of combined CCT demonstrator (ACHIEVED) (CIEMAT)→ report is on going (submitted by one week).**
- **D8.5 (10/2024→10/2025): Construction of HTS CCT magnet demonstrator (ACHIEVED) (ELYTT ENERGY)→ first draft of the report ready (it will be submitted soon).**

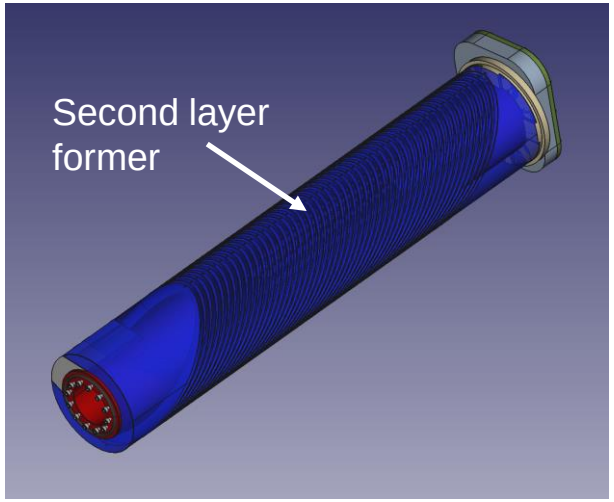
Milestones:

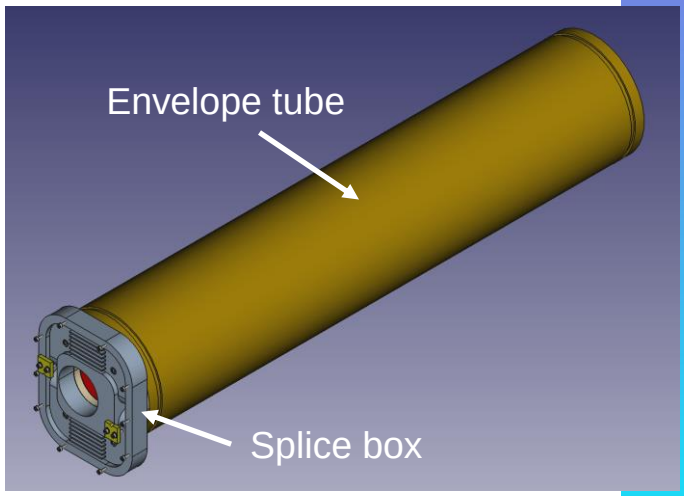
- **M34(12/2023→09/2025): Construction of the formers for combined CCT winding (ACHIEVED)(CIEMAT)→ Report published. https://zenodo.org/records/17135550**

Task 8.4 - Construction of combined CCT magnet demonstrator

- **Combined CCT based on LTS** (rope 6 NbTi + 1 copper strand):
- **4 T dipole + 5 T/m quadrupole (important feature to test it for CCT);**
- **Ramped at 0.2- 0.4 T/s** → challenge is the heat extraction generated by superconductor, and former;
- Straight geometry, Top of 4.2 K, nominal current of 1.5 kA;
- **Demonstrator for testing the combined feature of CCT and thermal study of AC losses;**
- Former made in Al-Br, wax impregnation;
- No iron yoke on the final demonstrator;







MS34 – Construction of combined formers for CCT winding[1] (CIEMAT)

iFAST

CONSTRUCTION OF THE COMBINED FORMERS FOR CCT WINDING

Milestone: MS34

Date: 12/09/2025

IFAST

Innovation Fostering in Accelerator Science and Technology

Horizon 2020 Research Infrastructures GA n° 101004730

MILESTONE REPORT

Construction of the combined formers for CCT winding

MILESTONE: MS34

Document identifier:	IFAST-MS34
Due date of milestone:	End of Month 32 (December 2023)
Justification for delay:	Change of beneficiary
Report release date:	12/09/2025
Work package:	WP8 - Innovative Superconducting Magnets
Lead beneficiary:	CIEMAT
Document status:	Draft

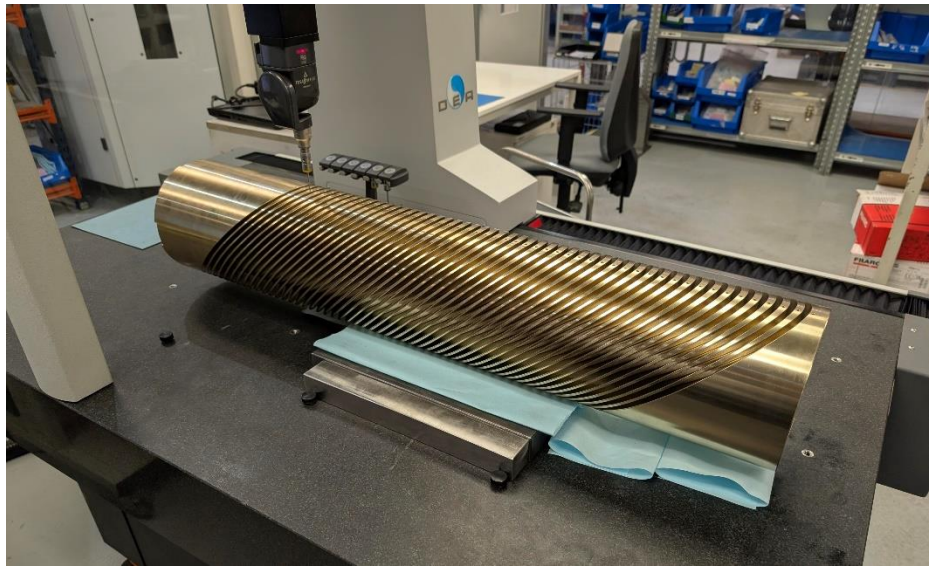
ABSTRACT

This milestone (MS34) confirms the successful construction of the combined formers for the Canted-Cosine-Theta (CCT) winding in I.FAST WP8. The formers, produced within Task 8.4, ensure precise conductor placement and mechanical stability for the magnet demonstrator. The conformity certificate verifies compliance with specifications. This achievement marks a key step towards Deliverable D8.4 and the upcoming winding and assembly of the CCT demonstrator magnet.

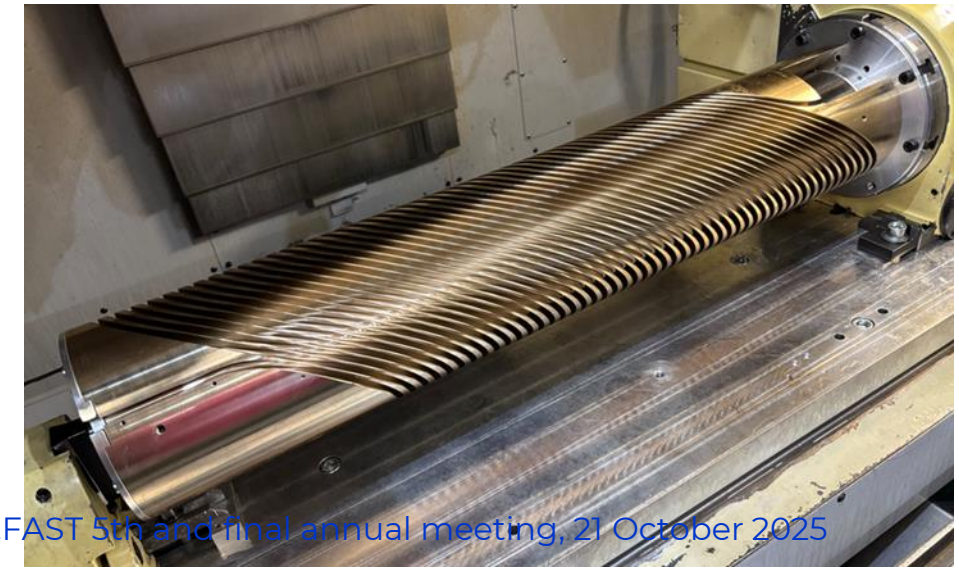
- Design, manufacturing, and inspection of CCT combined formers completed;
- Formers define conductor path and ensure mechanical stability;
- Dimensional checks and conformity certificate issued by Arquimea (Spain);
- Minor, non-critical deviations within acceptable limits;
- Components validated and ready for demonstrator winding and integration.

[1] E. De Matteis, F. Toral «Construction of the combined formers for CCT winding», Zenodo, set. 2025. doi: 10.5281/zenodo.17135550.

Inner former produced and measured



Outer former during machining

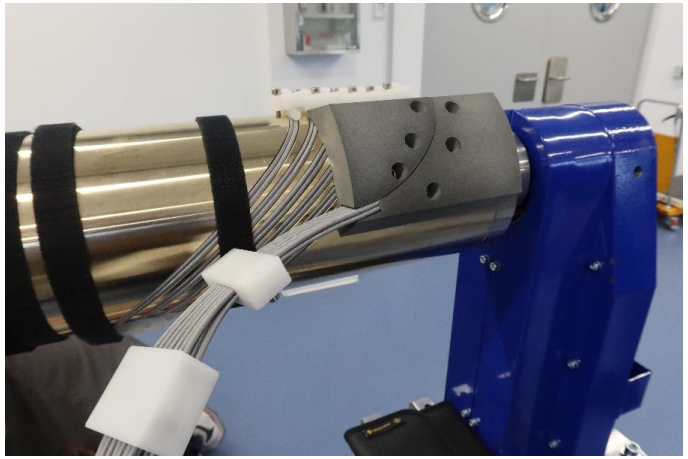


D8.4 – Preliminary activities

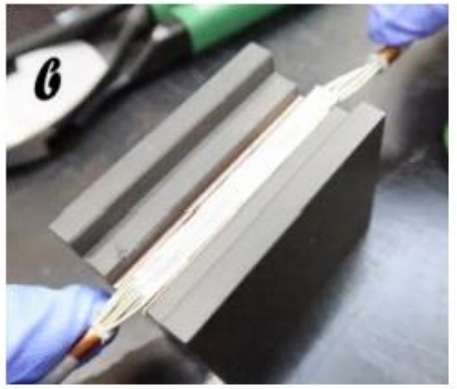
- The winding test was successful
- The electrical tests were succesful at low voltage.
- New splice procedure (LHC – like);
- Impregnation tooling ready;

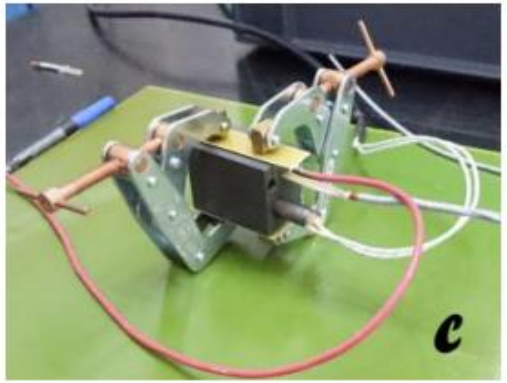
Test former on the winding machine

Inner former with layer jump



New splice procedure (LHC –like)



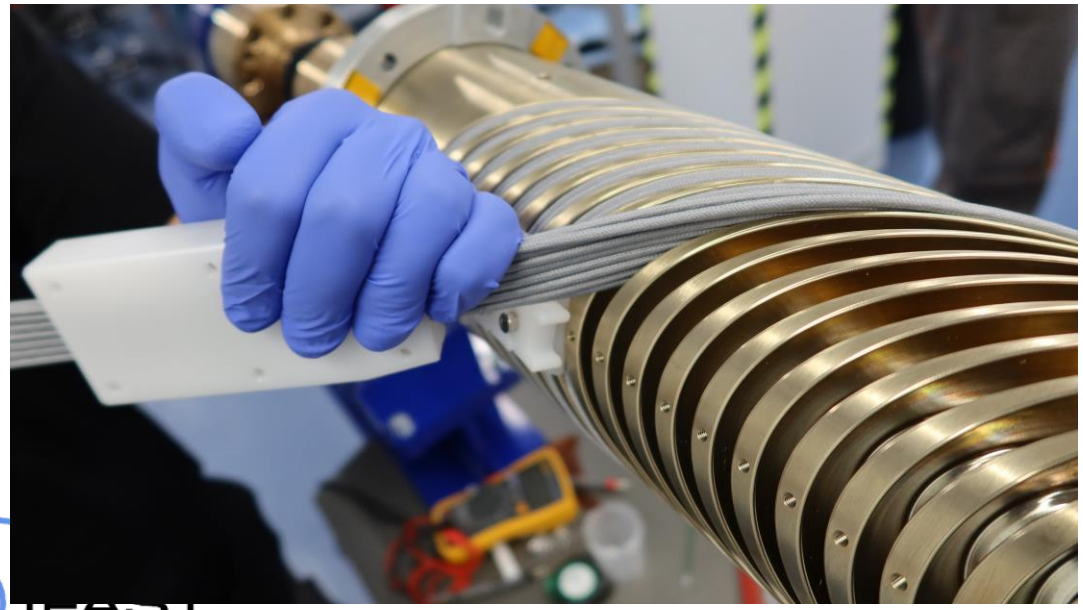


J. Munilla et al. "Fabrication of a straight canted cosine-theta prototype magnet for hadron therapy", submitted for publication on IEEE TAS, 2025.

D8.4 – Winding and impregnation activities (CIEMAT)

- **Inner and outer formers delivered in September 2025** (after significant delay).
- **Winding activities** initiated in October 2025.
- **Splice box** delivered at the **end of September** 2025.
- **Splices implementation** carried out immediately after delivery.
- **Wax impregnation** successfully performed and finalized in the last week.

Winding activities

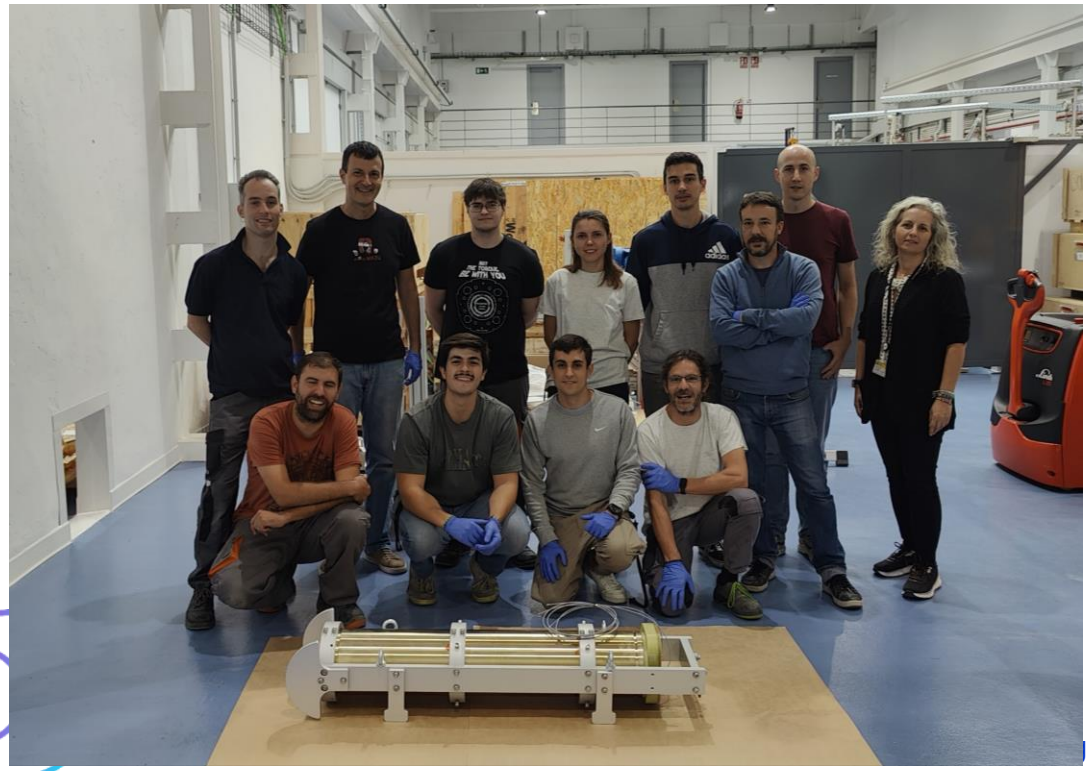


Wax-impregnation tooling

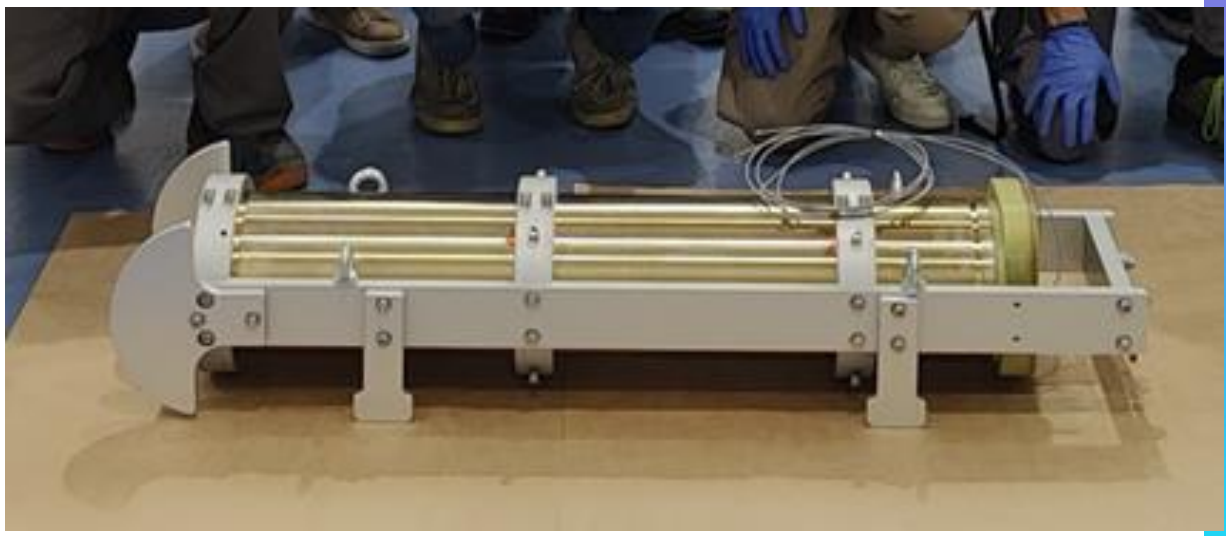
D8.4 – Demonstrator magnet (CIEMAT)

- **Breaking news (as of yesterday): Demonstrator completed!**
- **The combined-function CCT magnet (LTS) is now ready for cryogenic qualification tests at Uppsala.**
- **After cold tests, the magnet will reach TRL 5, validating the design and industrial scalability.**
- **Extraordinary effort and results from the CIEMAT team!**

Final **TRL 5** → Technology validated in (industrially) relevant environment (as CIEMAT facility) but tested in laboratory (Uppsala).



Combined CCT magnet demonstrator



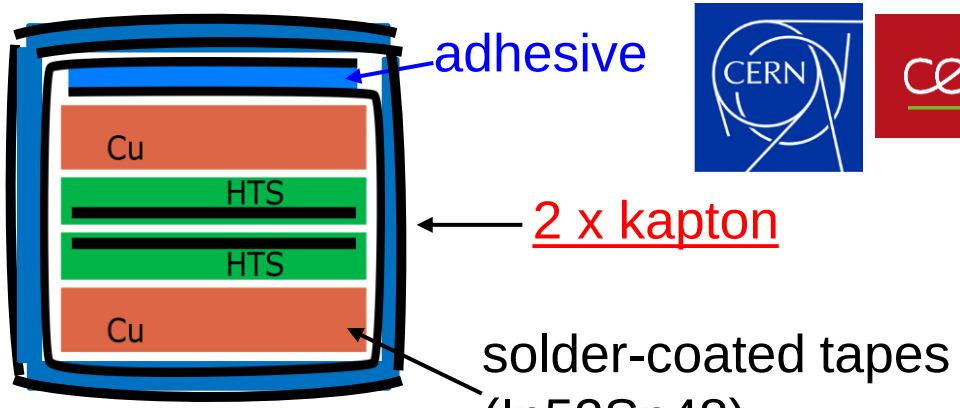
Task 8.5 - Construction of HTS CCT magnet demonstrator

CCT based on HTS (REBCO tape 4 mm wide):

- **4 T dipole** with a new Top of **20 K** (> 10 K of margin);
- Frenet-Serret frame used for the conductor (avoid hard way bending);
- **Straight geometry** just to start the study (HTS is already difficult enough);
- **Design option:** 2-tapes cable (980 A) → **New layout**
- Quench protection is demanded (Cu stabilizer added for this);

Company Elytt Energy (Spain) in charge of the construction of demo;

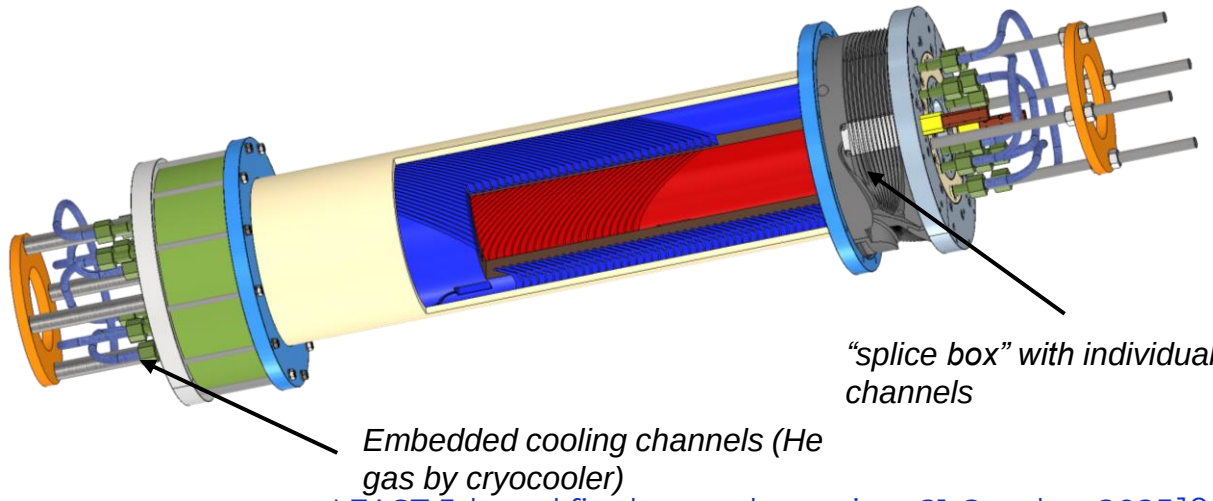
New Cable layout



The **AC-losses (ramping at 0.4 T/s)** during operating for both designs are on average **50 W.** This is compatible with a **conduction cooling system at 20 K.**

1) No need of helium gas;
2) Power efficiency higher at 20 K wrt 4.5 K (**factor 5**)

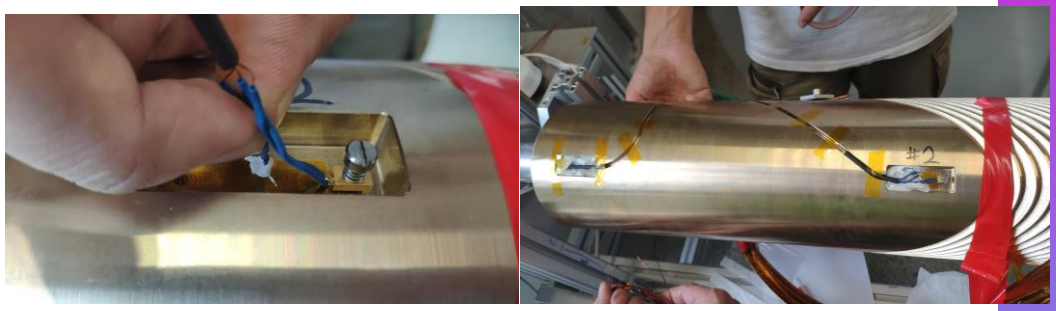
Final magnet with impregnation tooling and cooling channels



D8.5 - Assembly activities (Wigner RCP)

- Delivery of the **Inner and outer formers** in middle June 2025 (with a delay of more than 3 months);
- **Assembly verification** of the formers;
- **Installation of the temperature sensors** (2 pockets for each former):
  - One PT100 + one CERNOX (monitoring and cryogenic cooldown);
- **Splice boxes** arrived in July 2025:
  - Tefloned and mechanical verification (at INFN-LASA);

Temperature sensors installation



Inner and outer formers delivered

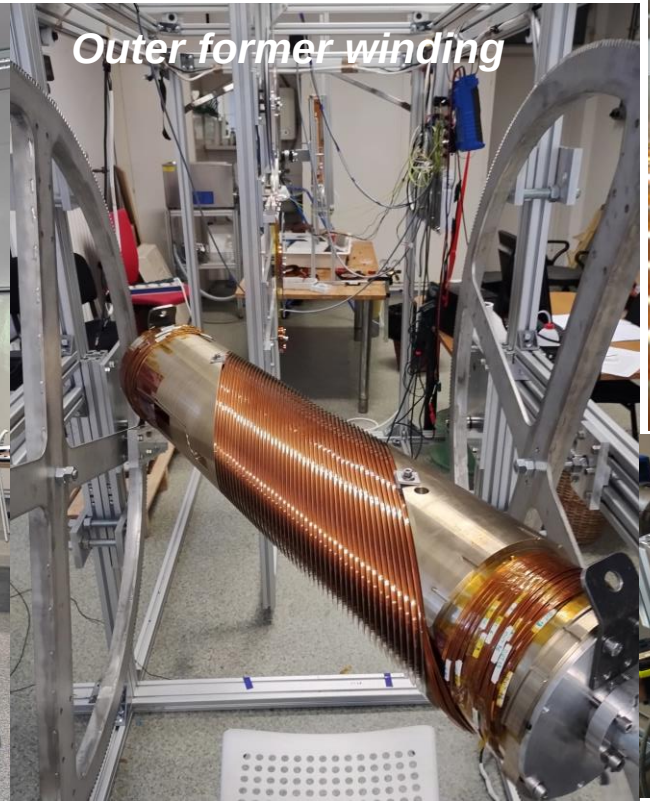
Assembly verification

Splices boxes tefloned

D8.5 - Winding activities (Wigner RCP)

- **July 2025**: 4-week “epic” winding campaign
- **Teams**: Elytt, INFN-LASA & Wigner in coordinated shifts;
- **Custom winding machine** ensured precise tape handling;
- **20 HTS cables wound** (reduced from 23 due to thicker Kapton insulation);
- Inner & outer formers wrapped with fiberglass and Kapton for insulation integrity;
- **Insertion of wound formers** into envelope tube — **assembly shipped to Elytt** for next integration phase.

Inner former winding with Elytt and LASA teams


Outer former winding

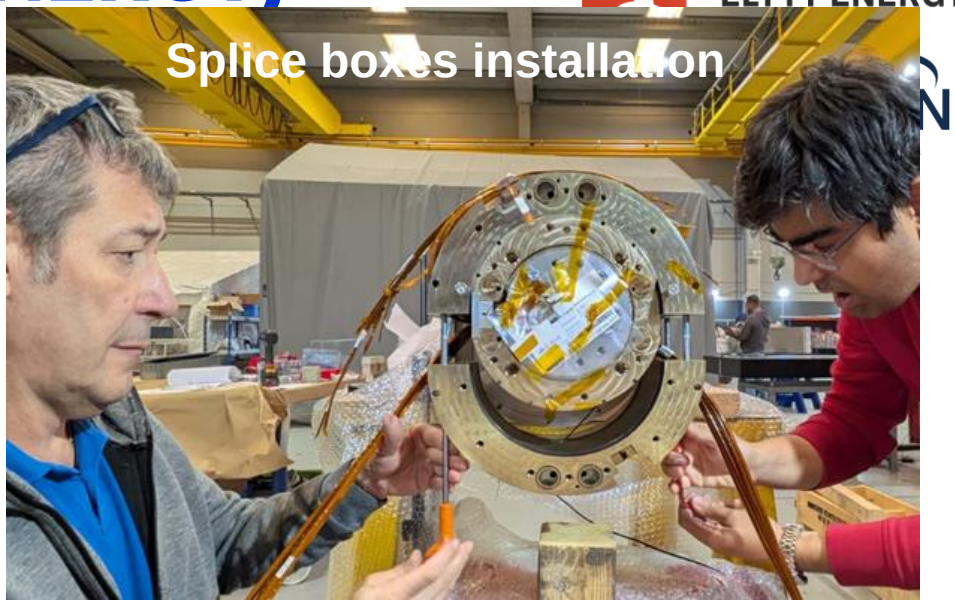
Cables Exit detail

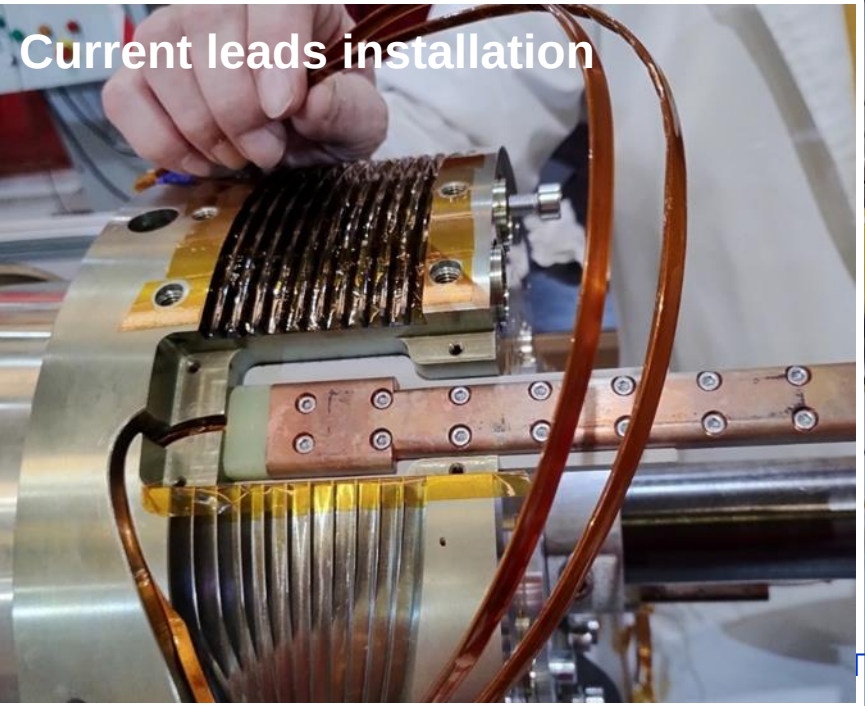
Wrapping intralayers

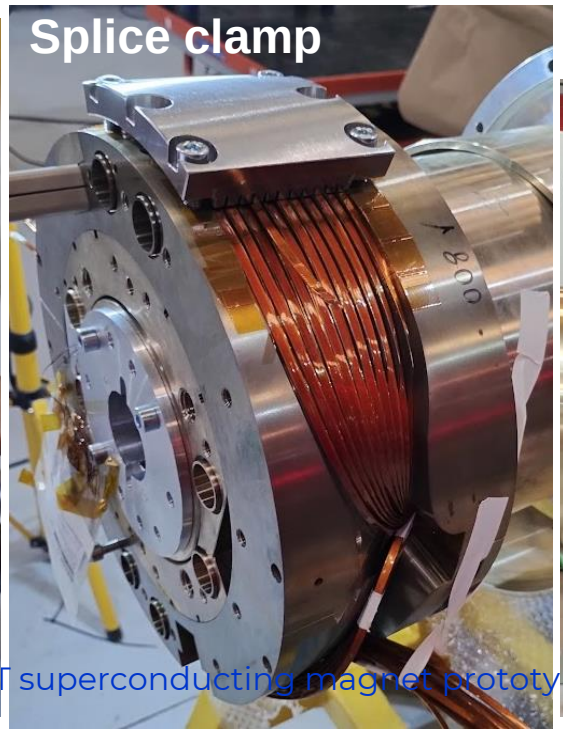
Envelope tube insertion

D8.5 - Assembly activities (ELYTT ENERGY)

- **September 2025**: Activities carried out at **Elytt Energy (Arteia, Spain)** with **INFN-LASA** support
- **Splice boxes installation**: challenging phase — retouched to ensure full insulation integrity
- **Current leads soldered** to copper blocks with precise alignment
- **Cable coupling** and "**crocodile**" **splice configuration** prepared for all joints
- **In-situ soldering** performed at **up to 140 °C** for full cable and splice consolidation – just before of **wax impregnation**
- **HV tests (up to 1 kV)** conducted after each stage to verify insulation and electrical integrity



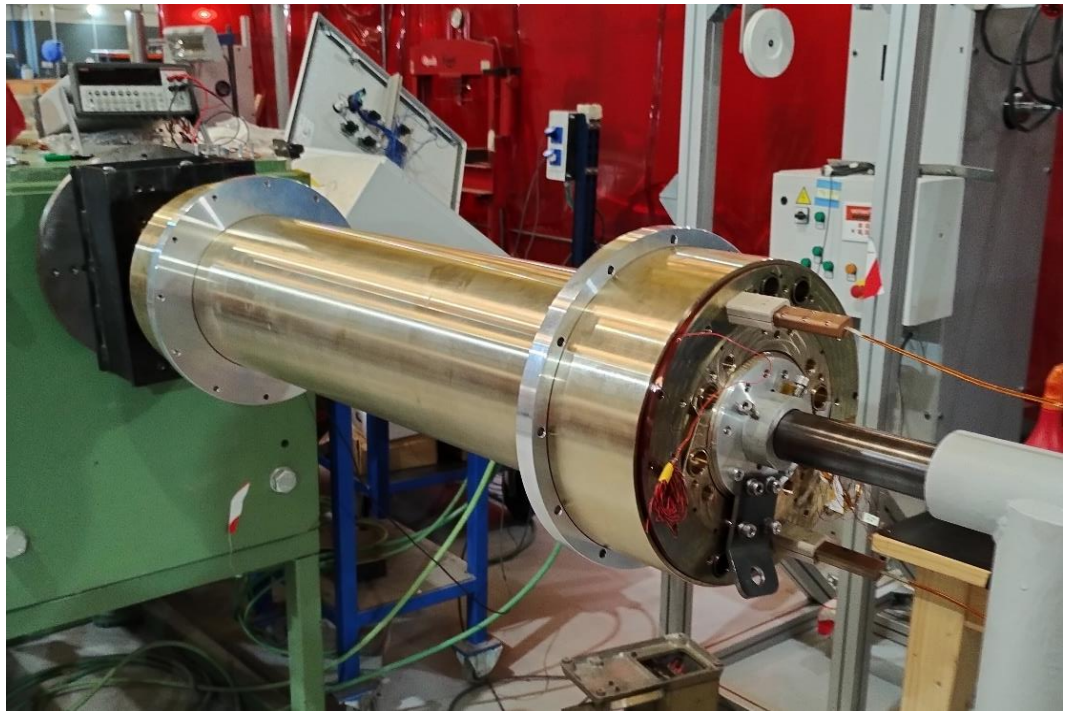




D8.5 – Demonstrator Magnet (ELYTT ENERGY)

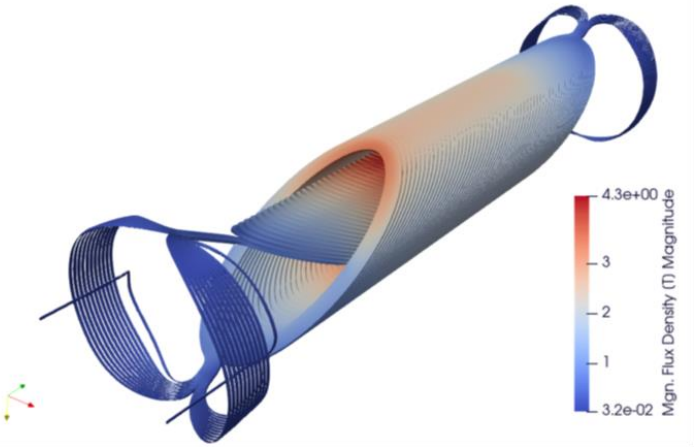
- **Beginning of October 2025:** the **HTS CCT magnet demonstrator successfully finalized!**
- **A remarkable achievement through close collaboration between Elytt Energy, Wigner RCP, and INFN-LASA;**
- **The HTS CCT magnet is now ready for cryogenic qualification tests at INFN-LASA (after cold tests it will reach TRL5 validating design and industrial scalability).**
- **GREAT TEAMWORK – GREAT RESULT!**

Final **TRL 5** →Technology validated in (Industry- ELYTT) relevant environment but tested in laboratory (INFN-LASA)

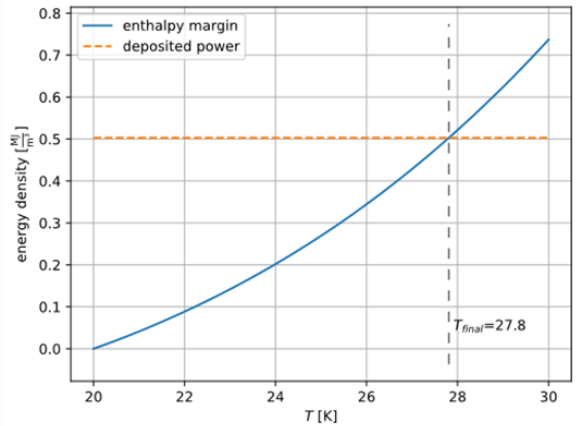


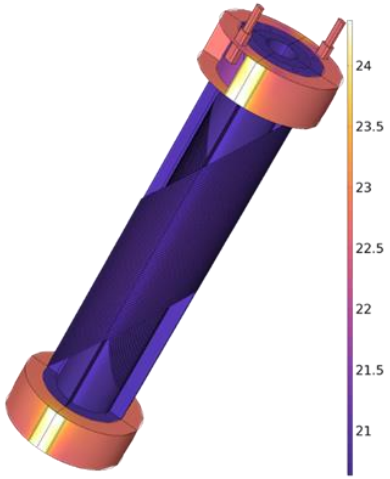
IFAST WP8 – Preparation for the cold tests

Last Design updates[1] concerning the field quality and Thermal Design



Order	b_n [units]	a_n [units]
2	4.6	-0.2
3	-4.8	-0.1
4	-1.0	0.0
5	1.3	0.0





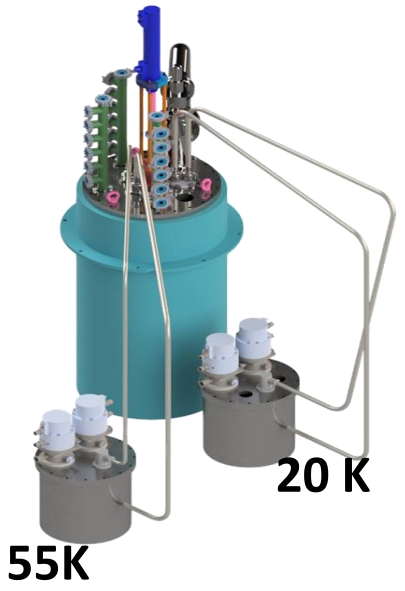
Insert and Variable Temperature Cooling Plant

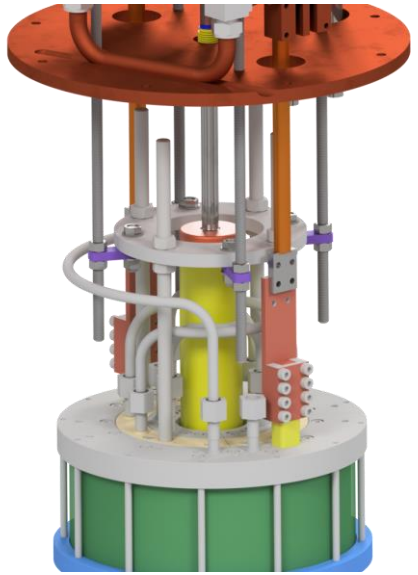
Closed loop G-Helium cooling 20 K – 50 K;

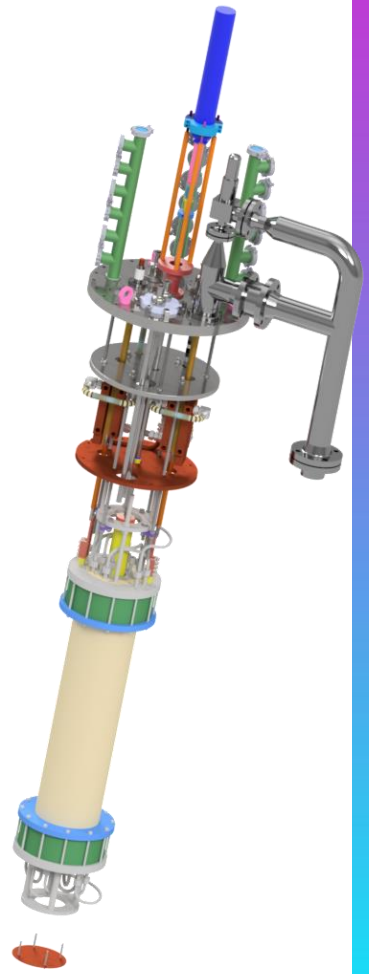
55K – Shield + Current Leads (1kA);

Dedicated Rotating coil shaft (field quality);

Delivery in December 2025.







[1]E. De Matteis et al., "Design and Development of a High-Temperature Superconductor CCT Magnet for Research and Hadron Therapy Applications," in IEEE Transactions on Applied Superconductivity, doi: 10.1109/TASC.2025.3622552.

Results, Outcomes, and Impacts

Results	Outcomes (1-3 years)	Impacts (4-5 years)
European coordination through **ESG-HTS** and **HiTAT workshops**	• Established a European roadmap for **HTS magnet R&D** • Strengthened **collaboration** among **labs** and **industries** • Regular technical and strategic exchanges **(EPITA)**	• Consolidated European leadership in HTS magnet development • Long-term alignment with the **European Strategy for Particle Physics (EPITA)**
CCT demonstrator design and **construction** (**LTS + HTS)**	• Achieved **key advances in HTS technology** (optimized cables, low-resistance joints, integrated cooling, validated mechanical support)→**EPITA** • Demonstrators fabricated and prepared for testing **(READY to collect results!!)**	• Provided **enabling technologies for next-generation, compact, and energy-efficient accelerator magnets (EPITA)** • Strengthened industrial know-how and European capability in CCT fabrication • Supported applications in research and medical accelerators
Energy efficiency and sustainability gains	• Demonstrated **conduction-cooled HTS operation (EPITA)** • **Reduced cryogenic power** and complexity • Improved system sustainability	• Lower facility life-cycle costs • **Reduced environmental** footprint • Alignment with EU green-transition goals (EPITA)

Lessons learned

Industry Engagement:

- Engagement was **partially unsuccessful**, strongly **affected by the geopolitical situation** (war and rising costs);
- **Two out of three companies withdrew**, causing **major delays** in the D8.4 demonstrator schedule;
  - Industrial partners faced **difficulty providing matching funds**, leading to a **shift in strategy** toward short-term, production-oriented projects rather than R&D;
- For future initiatives (e.g., **EPITA**), **industry involvement should be encouraged**, with engagement models tailored to company capabilities and priorities.

Recruitment of Skilled Personnel:

- Recruiting **qualified staff in superconducting magnet R&D** remains **challenging**, especially for **HTS magnet design;**
- **CEA** faced significant delays due to the **lack of specialized personnel**, impacting the D8.5 schedule;
- Future project planning should **account for personnel availability (internal resources→EPITA).**

Other activities

- **HiTAT-2 Workshop** @ CERN (23–24 Oct 2025) - 30/7-018 (Kjell Johnsen Auditorium).
  - **Organized within I.FAST WP8** – Innovative SC Magnets (**A. Ballarino & L. Rossi**)
  - Focus on HTS conductors & cables, magnet design, and dedicated R&D
  - **Continuation of the series** foreseen in the upcoming **EPITA** proposal.
  - https://indico.cern.ch/event/1455509/
- WP8 Dissemination
  - Several papers and outreach activities completed — see task reports for details

Final Conclusions

- **WP8 successfully completed** its mission, delivering the **two magnet demonstrators (last three months very exciting)**:
- **Task 8.4 – Combined CCT (LTS)**:
  - **D8.4 COMPLETED** – magnet ready for cold tests …GREAT JOB from CIEMAT!!
  - **MS34 report** on former construction submitted and **published**.
  - **Final report under preparation** – submission within the week.
  - Cryogenic tests planned at **Uppsala** (FREIA) in **2026**.
- **Task 8.5 – HTS CCT Demonstrator**:
  - **D8.5 COMPLETED** – fully assembled and instrumented magnet ready for tests.
  - **Excellent collaborative work between Elytt Energy, INFN-LASA, and Wigner RCP.**
  - **Cryogenic tests** in preparation at **LASA** for 2026.
- **Outcome & Impact**:
- WP8 established a **solid technological and collaborative foundation** for future **HTS magnet R&D** in Europe.
- The **results and partnerships** directly support the objectives of the **EPITA proposal**, ensuring continuity in advanced superconducting magnet development.

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INFN LASA

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INFN Istituto Nazionale di Fisica Nucleare

PAUL SCHERRER INSTITUT PSI

UPPSALA UNIVERSITET

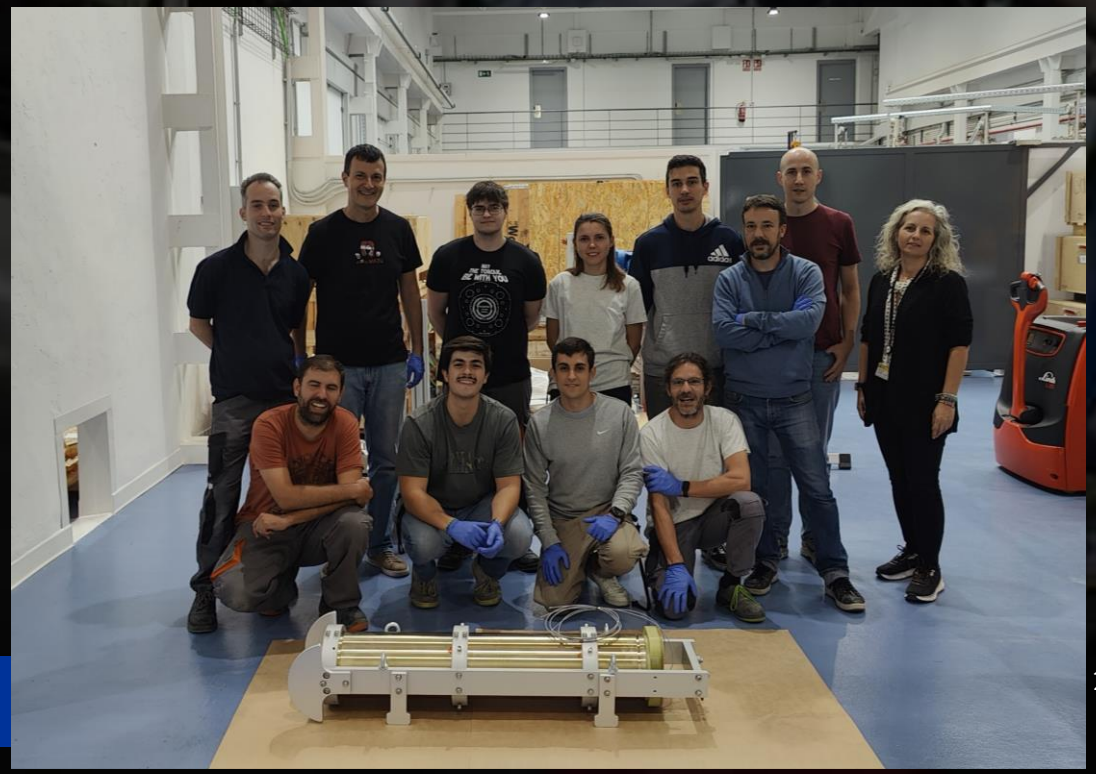
UNIVERSITÉ DE GENÈVE

ELYTT ENERGY

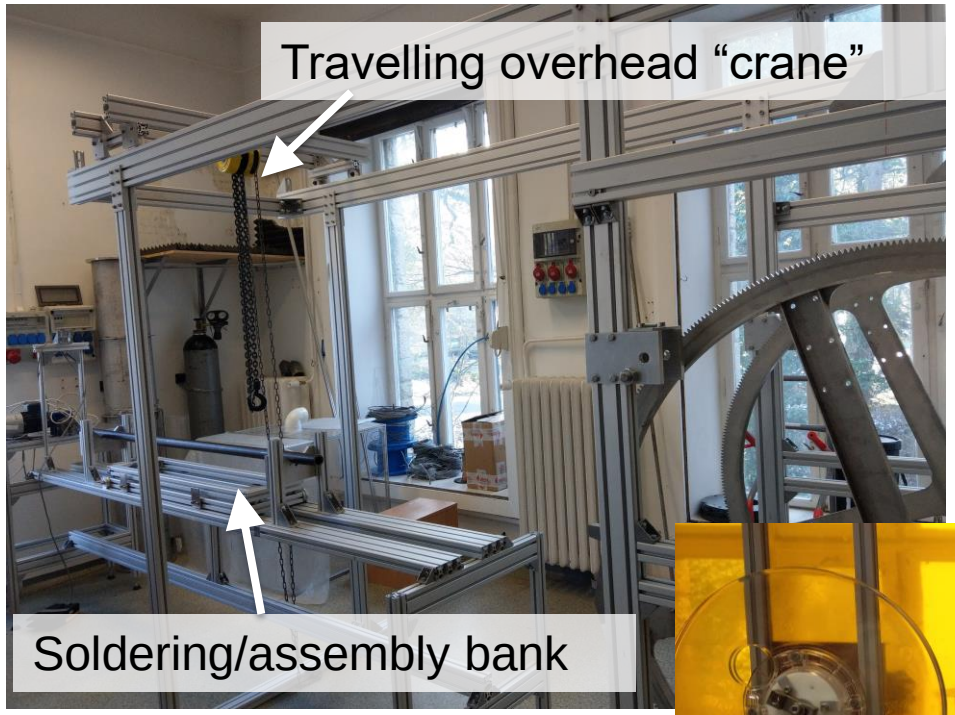
BILFINGER Bilfinger Noell GmbH

SCANDITRONIX

Thank you for your attention!



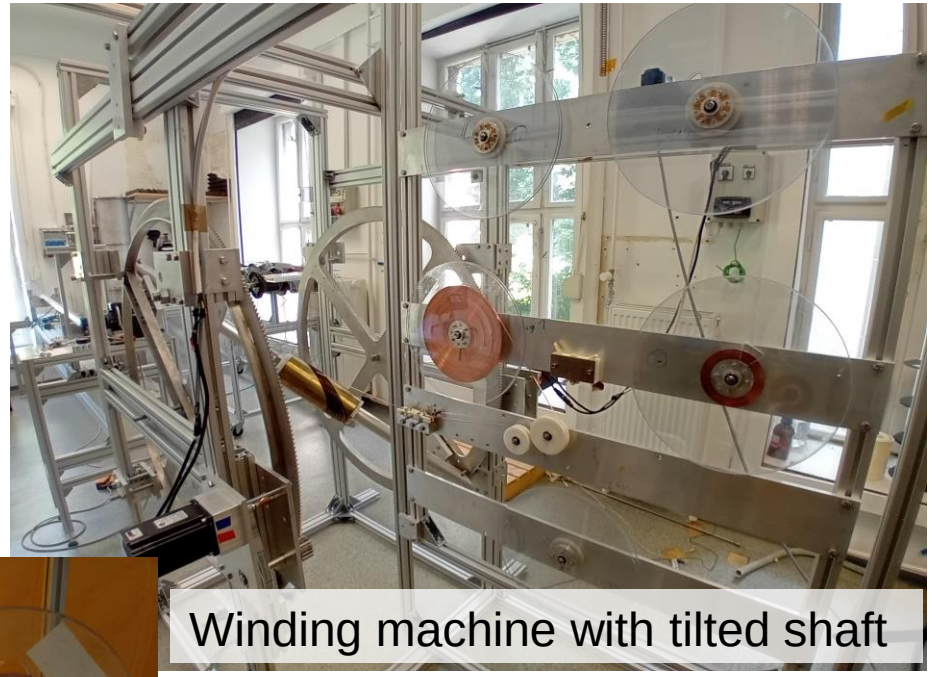
D8.5 – HTS CCT Demonstrator: Infrastructure ready

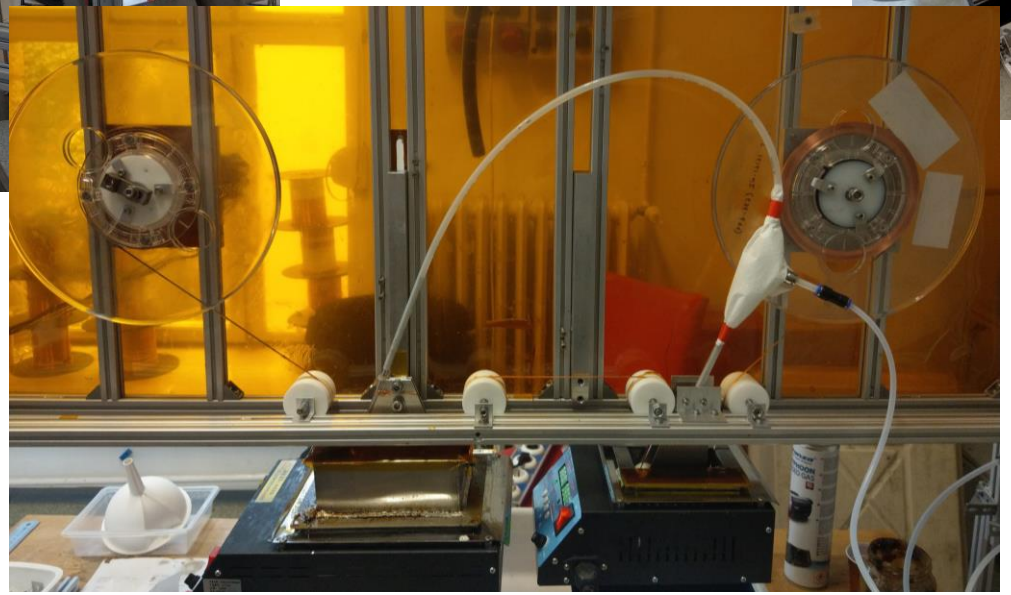


ELYTT ENERGY

WIGNER

INFN LASA


Winding machine with tilted shaft



Solder coating:

1. (Cleaning of Cu tapes)
2. Hot flux (rosin) bath
3. In52/Sn48 bath

iFAST