Ernesto De Matteis, INFN of Milan (Italy) – LASA laboratory
and all WP8 collaborators

I.FAST – 2nd Annual Meeting

19.April.2023 – Trieste, Italy

# WP8 – magnets members

## (WP8 comprise also Task 8.6 on special SC cable for fast ramping led by GSI)

**HITRI & I.FAST**

**I.FAST**

**See the next talk by Tiemo Winkler (GSI)**

| | Coordination | Tasks | Task leader | Deputy-task leader |
|---|---|---|---|---|
| **WP8 Innovative superconducting magnets** | E. De Matteis (INFN)<br>T. Lecrevisse (CEA)<br>C. Roux (GSI) | 8.1 - Coordination and HTS Strategy Group | E. De Matteis (INFN) | A. Ballarino (CERN) |
| | | 8.2 – Preliminary Engineering design of combined CCT magnet | E. De Matteis (INFN) | D. Barna (Wigner Inst.) |
| | | 8.3 – Preliminary Engineering design of HTS CCT | S. Sorti (INFN) | A. Ballarino (CERN) |
| | | 8.4 - Construction of combined CCT magnet demonstrator | **J. Munilla (CIEMAT)** | **D. Barna (Wigner Inst.)** |
| | | 8.5 – Construction of HTS CCT magnet demonstrator | A. Echeandia (Elytt) | **S. Sorti (INFN)** |
| | | 8.6 – Development of ReBCO HTS nuclotron cable | T. Winkler (GSI) | C. Roux (GSI) |

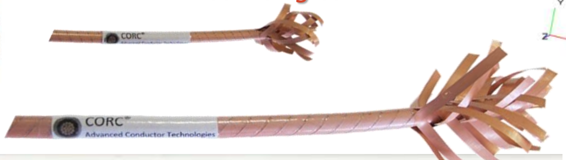
# WP8 – Scope

- *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;*

BERKELEY LAB

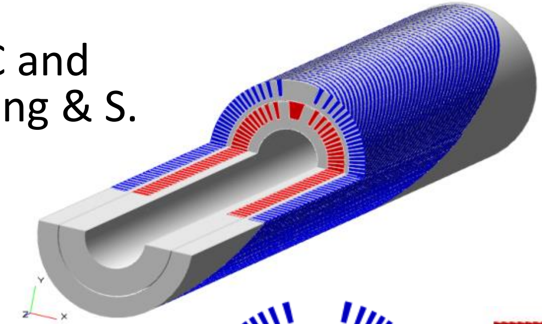
- Program based on CORC and CCT layout led by X. Wang & S. Prestemon

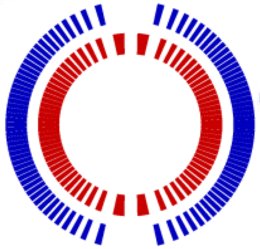
CORC® By Advanced Conductor Technologies




Outer layer

**Courtesy of Xiaorong Wang**





**Courtesy of Tengming Shen**

**CCT dipole**
4 T target
Ø =80 mm;
L <= 1000 mm


# Relevance of objectives and impact

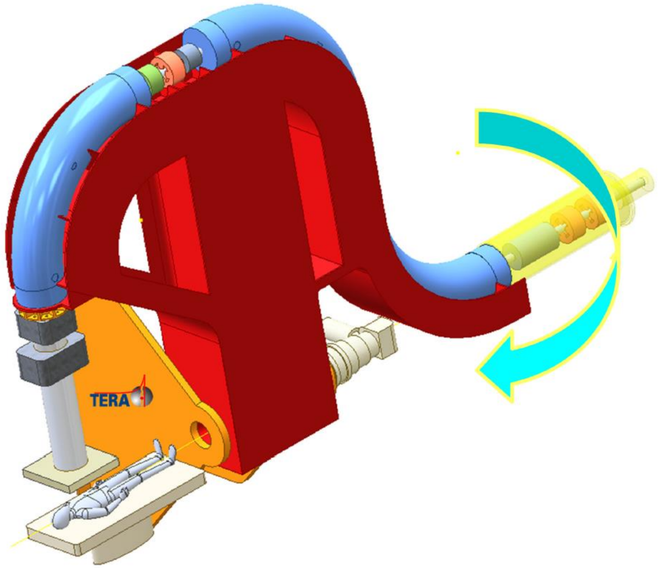
- Coordinate and foster initiatives towards High-Temperature superconductivity (HTS) for accelerators:
  - HTS is the new frontier for superconductivity, promising higher magnetic fields and smaller cryogenics systems, but has still to face challenges in terms of cable production schemes, magnet design, and cost.
  - The Strategy group will collect data, identify promising directions, and propose future R&D plans.
- Design a new magnet for medical applications in both classic superconductor and HTS, and build and test a demonstrator:
  - Reduce dimensions and cost of synchrotrons and gantries for research and for cancer therapy.
  - *WP8 will construct prototypes of advanced components to be used, among others, for medical accelerators.*

# 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** | **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 SIG/SIGRUM programs (Hadron Therapy magnet)**
**Straight geometry → HTS is already difficult enough!**

# First decision: change in the layout of the first CCT (in LTS)

- We devised to design a **curved CCT in LTS** as precursor of the HTS straight CCT.
- However, a **curved CCT is already foreseen in HITRIplus** (that is more oriented to design for gantry and less to technology R&D.
- All community thinks that a **combined function** (dipole + quadrupole winding, superimposed) is maybe **more interesting step**. Demonstrated in CosTheta but not in CCT, yet.
- In addition, we may use low losses SC wire to address the ramp rate;
- So **straight, combined function, with low losses design** (wires + former) is better that a simple curved CCT
- Change in DLV scope has been accepted by Project Coordination and GB.

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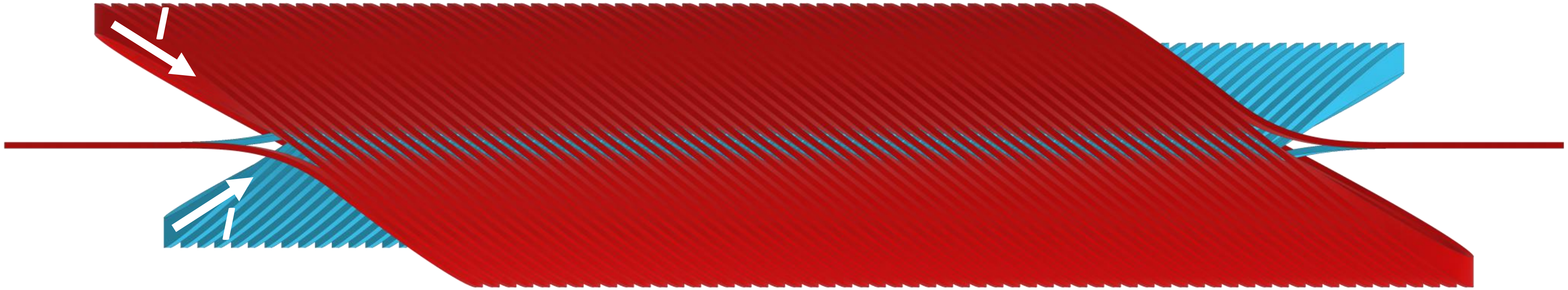
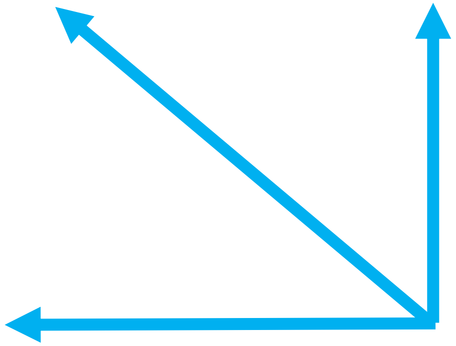
# Canted-Cosine-Theta (CCT) Magnet

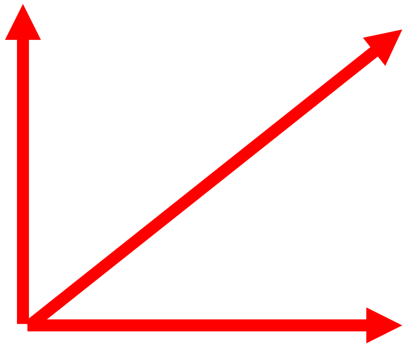



- **Current *I* flows in the two conductors so that the transverse magnetic field components add up and axial field components cancel each other out.**

**Total magnetic field of the inner layer**

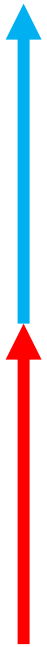


+

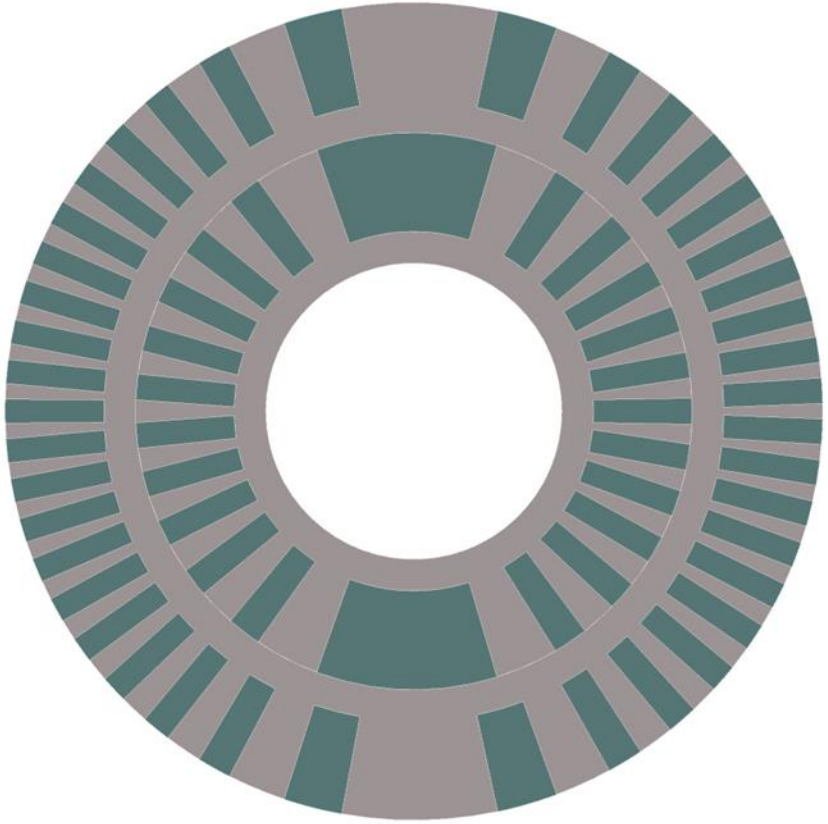


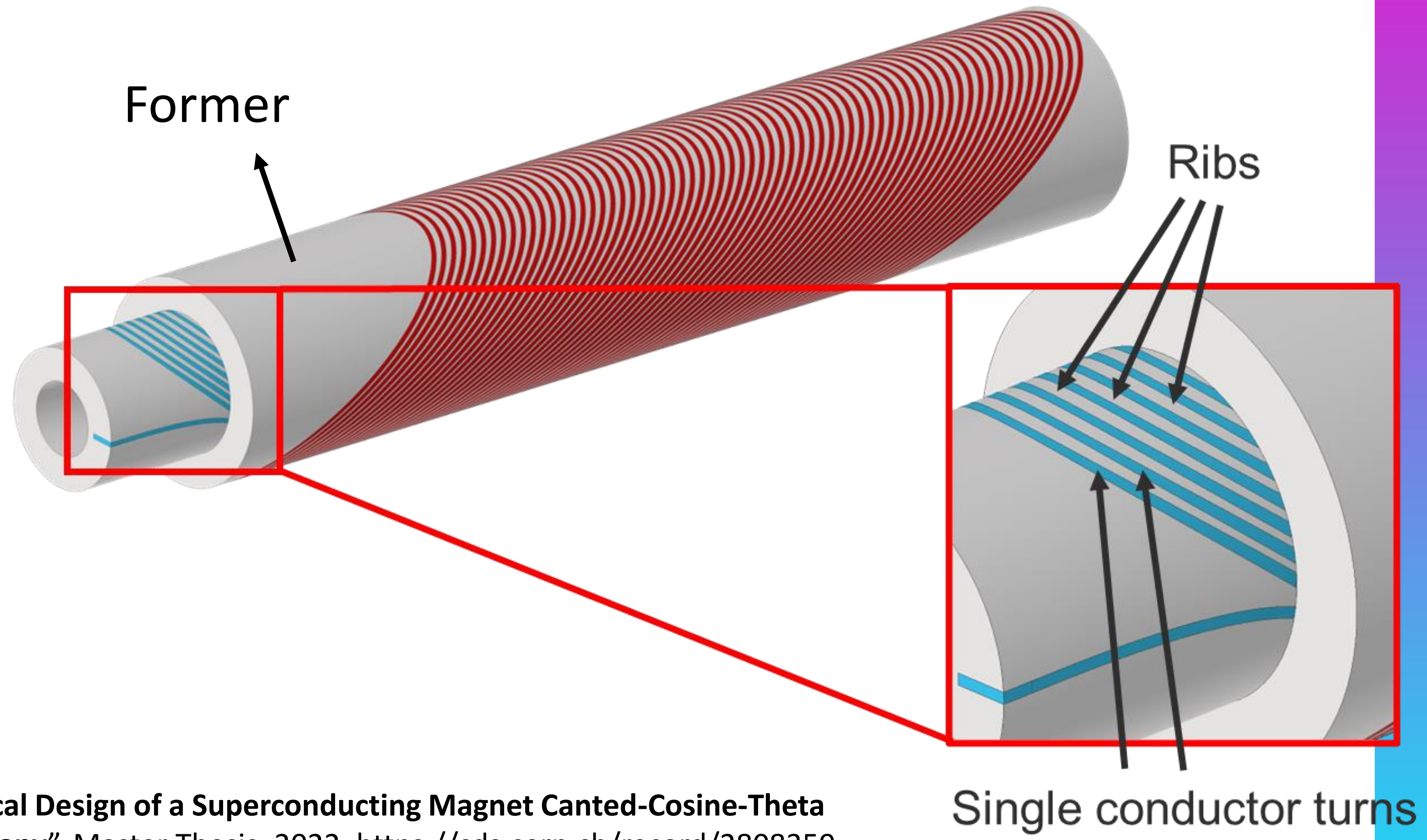
**Total magnetic field of the external layer**

=



# CCT schematics[1]



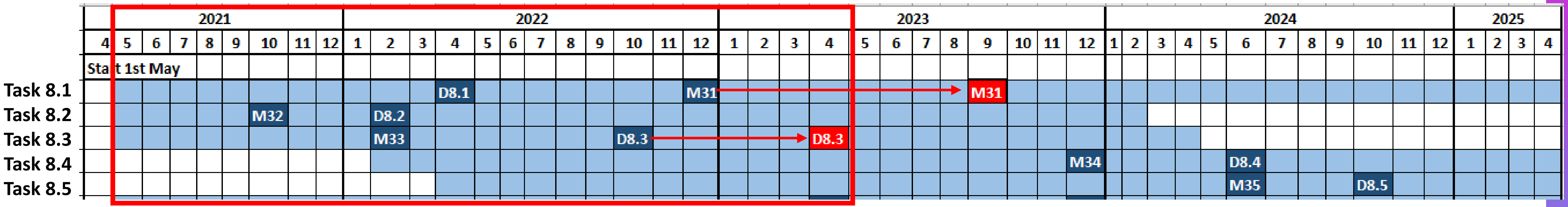



[1]Gabriele Ceruti, "**Preliminary Mechanical Design of a Superconducting Magnet Canted-Cosine-Theta (CCT) for a New Gantry for Hadron Therapy**", Master Thesis, 2022. https://cds.cern.ch/record/2808359

# WP8 – Timeline, Milestones and Deliverables

24 months activities

| 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 |




## Deliverables

- D8.1 (04/2022): HTS European Strategy Group (**ACHIEVED**) (CERN and INFN)
- D8.2 (02/2022): Conceptual Design of combined CCT in LTS (**ACHIEVED**) (INFN);
- D8.3 (10/2022 →04/2023): First Engineering design of HTS demonstrator (Submitted) (CEA→INFN)
  - Difficulty of CEA in finding people to hire and change of responsibility from CEA (T. Lecrevisse) to INFN (S. Sorti) of Task 8.3.

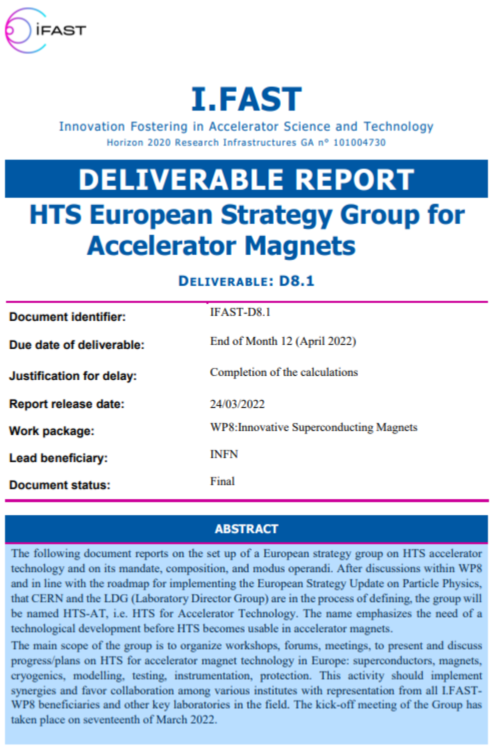
## Milestones:

- M32 (10/2021): Characterization of the first length of superconductor for low losses (**ACHIEVED**) (INFN, Univ. Geneva, and CERN)
- M33 (02/2022→06/2022): Conceptual design of HTS magnet (**ACHIEVED**) (CEA)
- M31 (12/2022 → 09/2023): Construction readiness of combined CCT demonstrator (Postponed) (INFN/CIEMAT)
  - Delay due to the withdrawal of the companies from the Task 8.4

# I.FAST WP8 meetings and two years activities

- Kick-off meeting : 20 April 2021
- From the 23th of June 2021 we had n.15 meetings (each third Thursday of each MONTH at 9h00);
- First Decision: change in the layout of the first CCT (curved → combined straight);
  - Change of the related Tasks (8.2 and 8.4), milestones and deliverables;
- Set up HTS European Strategy Group (Task 8.1 – CERN, INFN):
  - kick-off meeting of the Group was 17th of March 2022 – **D8.1 DLV**;
  - 1st High Temperature superconductor Accelerator Technology (HiTAT) workshop had in March 9-10, 2023, hosted by CERN (A. Ballarino chair).
- Conceptual Design of combined CCT in LTS (Task 8.2 - INFN):
  - Demonstrator based on NbTi (low losses strand – **M32 MLS**) and conductor (rope 6+1 strands) – **D8.2 DLV.**
- Conceptual design of HTS magnet (Task 8.3 - CEA):
  - Two preliminary designs based on ReBCo tapes, magnetic, and protection aspects – **M33 MLS**
- First engineering design of HTS demonstrator (Task 8.3 – INFN):
  - Two and four tapes solutions, quench protection study and AC losses – **D8.3 DLV**
- Construction of combined (Task 8.4) and HTS (Task 8.5) CCT demonstrators:
  - Facing the withdrawal of the two companies (BNG and Scanditronix) from Tasks 8.4 and 8.5 (**solved!**).

# Deliverable 8.1 : HTS European Strategy Group for Accelerator Magnets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Horizon 2020 Research Infrastructures GA n° 101004730

**DELIVERABLE REPORT**

**HTS European Strategy Group for Accelerator Magnets**

**DELIVERABLE: D8.1**

| | |
|---|---|
| **Document identifier:** | IFAST-D8.1 |
| **Due date of deliverable:** | End of Month 12 (April 2022) |
| **Justification for delay:** | Completion of the calculations |
| **Report release date:** | 24/03/2022 |
| **Work package:** | WP8:Innovative Superconducting Magnets |
| **Lead beneficiary:** | INFN |
| **Document status:** | Final |


**ABSTRACT**

The following document reports on the set up of a European strategy group on HTS accelerator technology and on its mandate, composition, and modus operandi. After discussions within WP8 and in line with the roadmap for implementing the European Strategy Update on Particle Physics, that CERN and the LDG (Laboratory Director Group) are in the process of defining, the group will be named HTS-AT, i.e. HTS for Accelerator Technology. The name emphasizes the need of a technological development before HTS becomes usable in accelerator magnets.

The main scope of the group is to organize workshops, forums, meetings, to present and discuss progress/plans on HTS for accelerator magnet technology in Europe: superconductors, magnets, cryogenics, modelling, testing, instrumentation, protection. This activity should implement synergies and favor collaboration among various institutes with representation from all I.FAST-WP8 beneficiaries and other key laboratories in the field. The kick-off meeting of the Group has taken place on seventeenth of March 2022.


## Task 8.1 – A. Ballarino (CERN), L. Rossi (INFN)

Set up of a European strategy group on HTS accelerator technology and on its mandate, composition, and modus operandi.

- Roadmap for implementing the European Strategy Update on Particle Physics;
- Group name : HTS-AT (HTS for Accelerator Technology);
- Main scope of the group is to organize workshops, forums, meetings, to present and discuss progress/plans on HTS for accelerator magnet technology in Europe: superconductors, magnets, cryogenics, modelling, testing, instrumentation, protection;
- Favoring synergies and collaboration among various institutes;
- kick-off meeting of the Group was 17th of March 2022.

**1st High Temperature superconductor Accelerator Technology (HiTAT) workshop planned in March 9-10, 2023, hosted by CERN**
**https://indico.cern.ch/event/1220254/**

[1]A. Ballarino and L. Rossi, '' **HTS European Strategy Group for Accelerator Magnets**'', IFAST WP8 Deliverable 8.1, Zenodo, **https://doi.org/10.5281/zenodo.6384239**

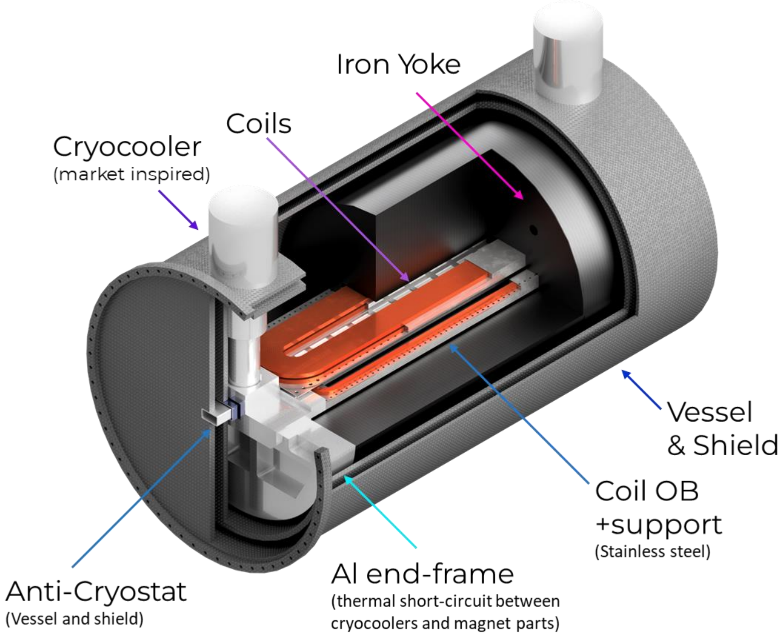
# Task 8.1 – 1st High Temperature superconductor Accelerator Technology (HiTAT)

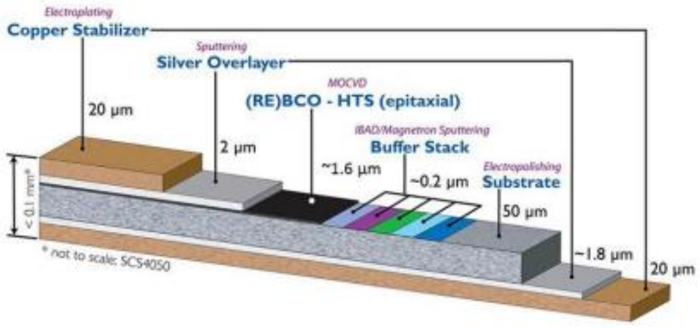
**Workshop in March 9-10, 2023, hosted by CERN - Chaired by A. Ballarino (CERN) and L. Rossi (INFN)**

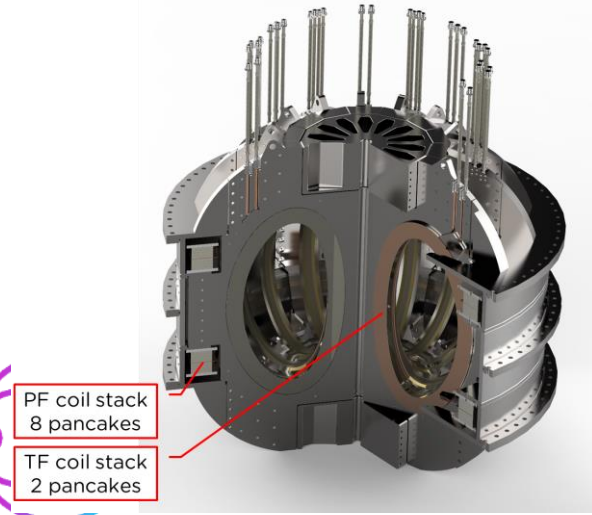
The focus of the program is on REBCO coated conductor for use in Hadron Therapy accelerator magnets, including post HL-LHC high energy colliders and beam lines.

**4 Sessions about REBCO: Conductor, Cables, Magnets and Technology.**

Program Committee:
Amalia Ballarino, CERN
Lucio Rossi, INFN & University of Milano
Bernhard Auchmann, PSI & CERN
Anna Kario, University of Twente
Thibault Lecrevisse, CEA
Carmine Senatore, University of Geneva
Yifeng Yang, University of Southampton
Valerie Brunner, CERN (administrative support)




https://indico.cern.ch/event/1220254/

# HiTAT – Group photo (CERN 30/7-018 - Kjell Johnsen Auditorium)

# Milestone MS32: Characterization of the first length of superconductor for low losses **Task 8.2 – E. De Matteis (INFN)**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MILESTONE REPORT

**Characterization of the first length of superconductor for low losses**

MILESTONE: MS32

| | |
|---|---|
| Document identifier: | IFAST-MS32 |
| Due date of milestone: | End of Month 6 (October 2021) |
| Justification for delay: | Completion of the measures |
| Report release date: | 19/01/2022 |
| Work package: | WP8: [Innovative Superconducting Magnets] |
| Lead beneficiary: | INFN |
| Document status: | Final |

ABSTRACT

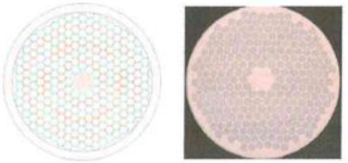
The document is a measurement report concerning the characterization of the NbTi low losses superconductor wire.

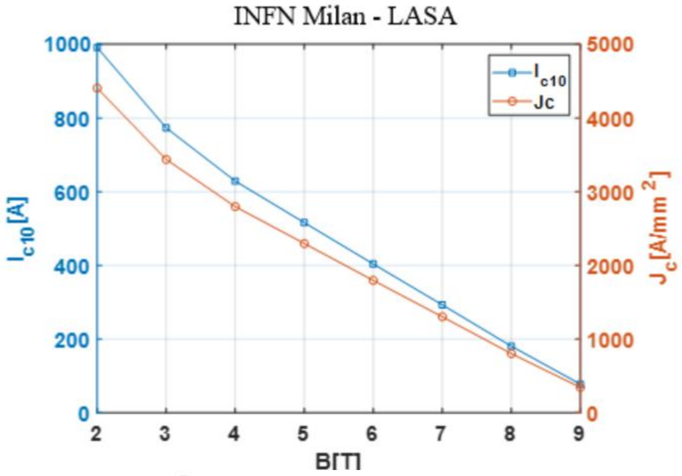
The measurement report collects the following measurements: critical current, RRR and magnetization measurements. The critical current and RRR measurements have been performed at LASA laboratory of INFN (Milan, Italy). A crosscheck measurement for the critical current has been done by CERN. The magnetization measurements have been performed by the Group of Applied Superconductivity of the Faculty of Sciences of the University of Geneva (Unige, Switzerland).

Grant Agreement 101004730 PUBLIC 1 / 14

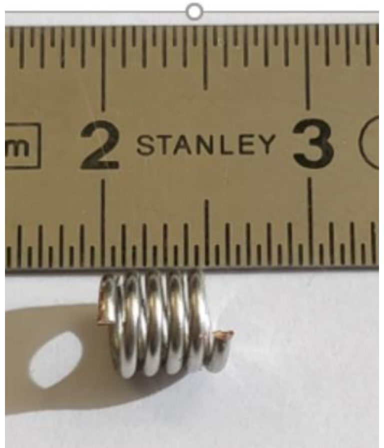
NbTi superconductor wire (originally designed according to the specifications for the DISCORAP project), produced by Bruker

- Strand Typ LF = F58464
- SnAg5 coated strand Ø ≈ 0.821 mm
- Cu / CuMn0.5 : NbTi ≈ 1.36
- Twist length ≈ 6.6 mm






- Critical current measurements (**INFN and CERN**):
  - (Jc= 2297 A/mm2 @ 5T, 4.2 K), about 20% less LHC02 outer layer strand;
- RRR measurements (**INFN**):
  - RRR>130 as expected;
- Magnetization measurements (**Univ. of Geneva**):
  - Nb-Ti filaments of the order of 3.1 µm

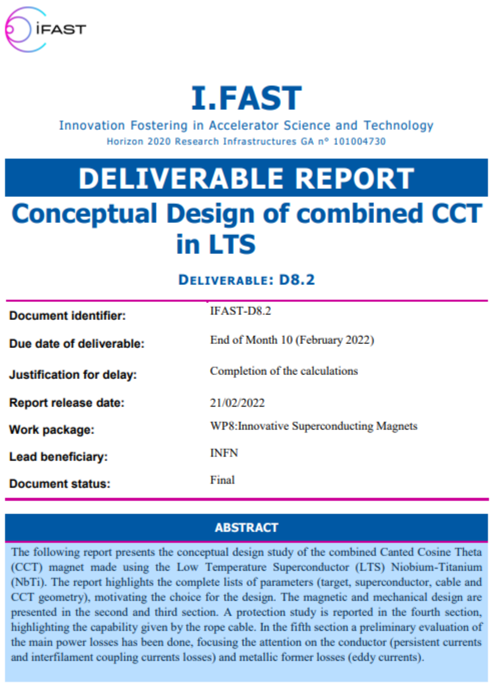



Minicoil for Magnetization meas.

[1]E. De Matteis, '' **Characterization of the first length of superconductor for low losses** '', IFAST WP8 Milestones 32, Zenodo, **https://doi.org/10.5281/zenodo.5901601**.

# Deliverable 8.2 : Conceptual Design of combined CCT in LTS

## Task 8.2 – E. De Matteis (INFN)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**DELIVERABLE REPORT**
**Conceptual Design of combined CCT in LTS**
**DELIVERABLE: D8.2**

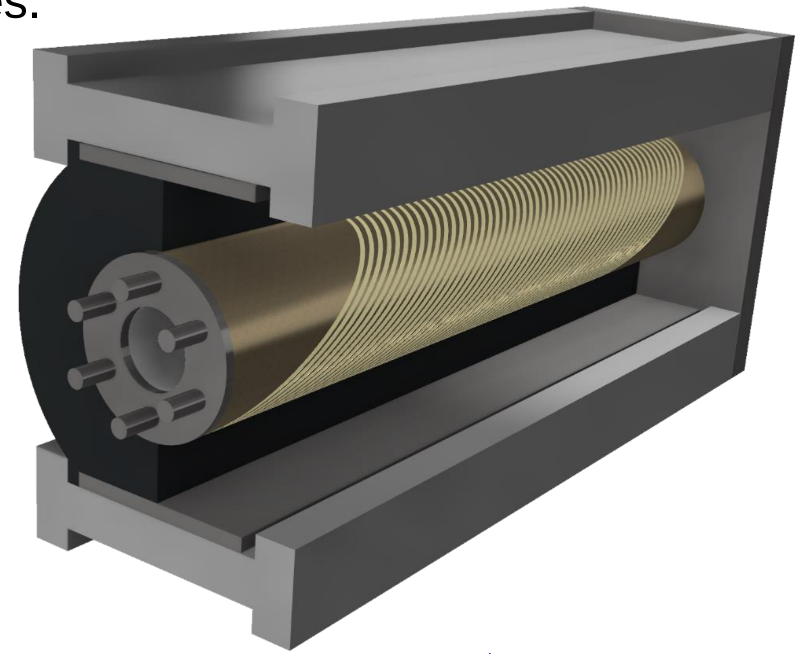
| | |
|---|---|
| Document identifier: | IFAST-D8.2 |
| Due date of deliverable: | End of Month 10 (February 2022) |
| Justification for delay: | Completion of the calculations |
| Report release date: | 21/02/2022 |
| Work package: | WP8:Innovative Superconducting Magnets |
| Lead beneficiary: | INFN |
| Document status: | Final |

**ABSTRACT**

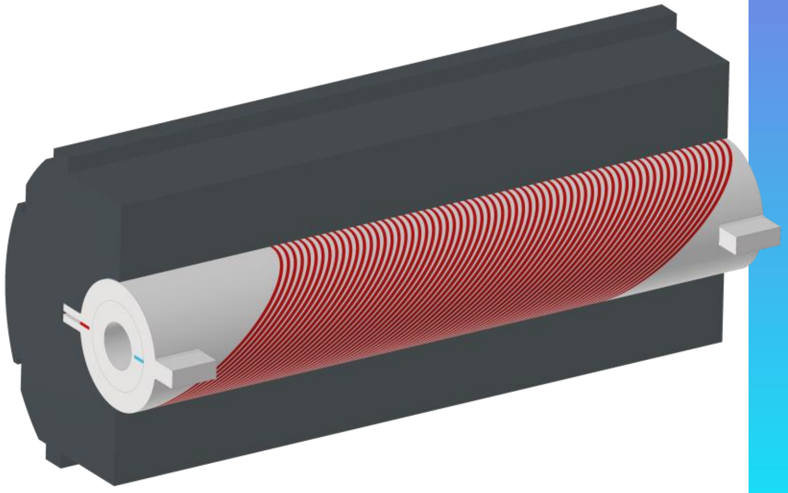
The following report presents the conceptual design study of the combined Canted Cosine Theta (CCT) magnet made using the Low Temperature Superconductor (LTS) Niobium-Titanium (NbTi). The report highlights the complete lists of parameters (target, superconductor, cable and CCT geometry), motivating the choice for the design. The magnetic and mechanical design are presented in the second and third section. A protection study is reported in the fourth section, highlighting the capability given by the rope cable. In the fifth section a preliminary evaluation of the main power losses has been done, focusing the attention on the conductor (persistent currents and interfilament coupling currents losses) and metallic former losses (eddy currents).

Report on the conceptual design study of the combined Canted Cosine Theta (CCT) magnet made using the Low Temperature Superconductor (LTS) Niobium-Titanium (NbTi).

- Complete lists of parameters (target, superconductor, cable and CCT geometry)
- 4 T dipole + 5 T/m gradient
- Magnetic and mechanical design, protection study, evaluation of the main power losses.



CCT magnet based on NbTi



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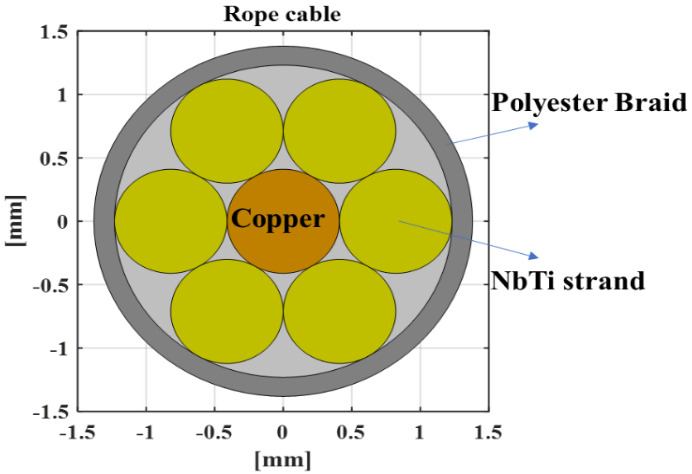
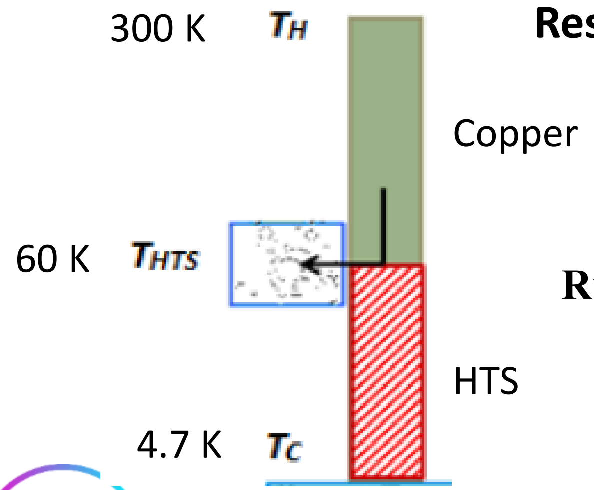
# HITRIplus & IFAST WP8 – Cable decision : Rope 6 + 1 NbTi + copper

Definition of the conductor:

- Comparison between Rutherford & Rope (6+1) of NbTi strands;
- Computation heat losses Current Leads (conduction cooled by **cryocooler**);
- Decision for **Rope cable NbTi** (as for **HITRIplus**) less expensive, cheaper power converter (2 kA, 150 A/s), winding is easier.




**Resistive part between 300 K and 60 K:**

$$\frac{Q_{c,min}}{I} = 46 \left[\frac{W}{kA}\right]$$

For each CL

| | |
|---|---|
| **Rutherford cable(I ~10 kA)** | $Q_{c,min}$~460 $W$ |
| **Ropes (I ~1.5 kA)** | $Q_{c,min}$~70 $W$ |

Test rope made of 7 NbTi strands and a single **polyester braid**

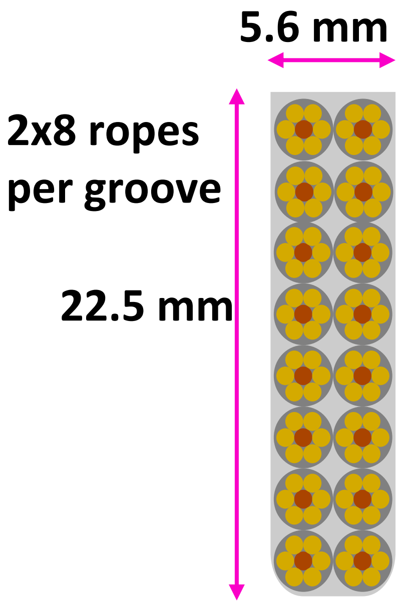
**Made by Texcavi srl (Inzago, Milan, Italy)**

# Deliverable D8.2 – Combined CCT magnet based on NbTi[1]

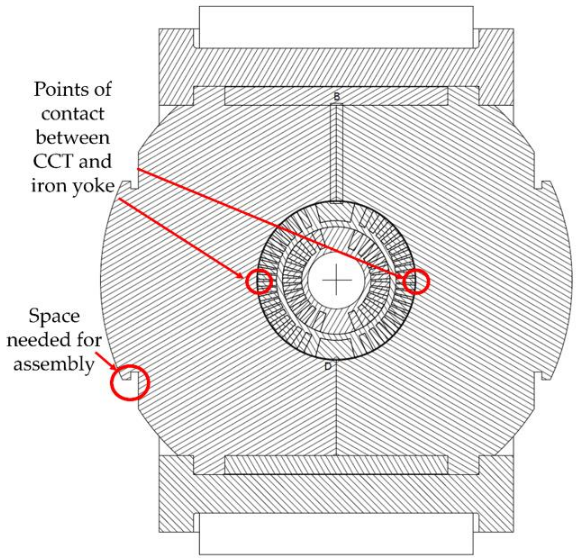
Conceptual design of the **Combined CCT magnet based on NbTi**:

- **Magnetic design:**
  - Combined fields (**4 T dipole + 5 T/m of quad. @4.7 K,** 28.7% LL margin, magnetic length of 0.73 m; **2 x 8 ropes** (1300 A each)
- **Mechanical design**:
  - **Full mechanical structure** (Former+ Iron yoke+ Assembly);
  - Materials for the former (Al-Br and PEEK);
- **Stability and Protection**:
  - Large time margin of **0.325** s for a rope 6 NbTi+1 copper strands.
- **Power Losses:**
  - Conductor Losses and eddy current losses for metal formers (0.4 T/s of ramped field) → St Steel good but difficult to machine, AlBronze good but sufficient for 0.25-0.3 T/s → solution PEEK (or polymer former);
- **Best solution for procurement and cost is the AlBr**
  - First demonstrator in preparation of the HTS one
  - Important test for losses study

**See next talk by Stefano Sorti**



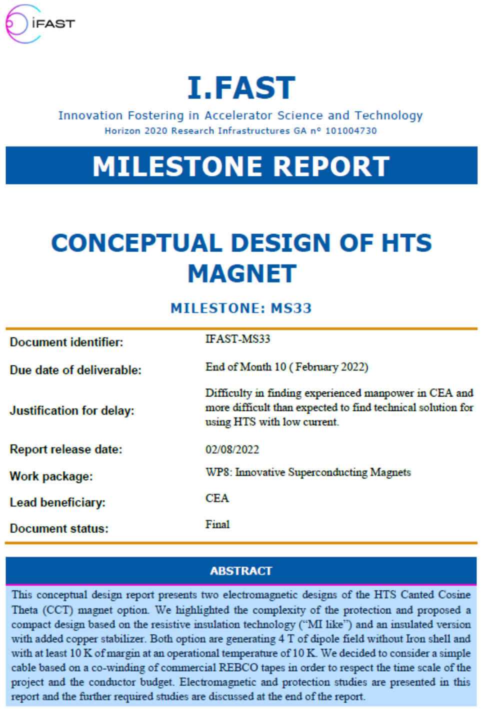

Iron yoke as shield and collar




[1]E. De Matteis, G. Ceruti, S. Mariotto, M. Prioli, S. Sorti, ''**Conceptual Design of combined CCT in LTS**'', IFAST WP8 Deliverable 8.2, Zenodo, https://doi.org/10.5281/zenodo.6389851

# Milestone MS33 : Conceptual Design of HTS Magnet

**Task 8.3 – T. Lecrevisse (CEA), lead by S. Sorti (INFN)**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**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.

Report on the conceptual design study of the HTS CCT magnet (main goal of the WP8)

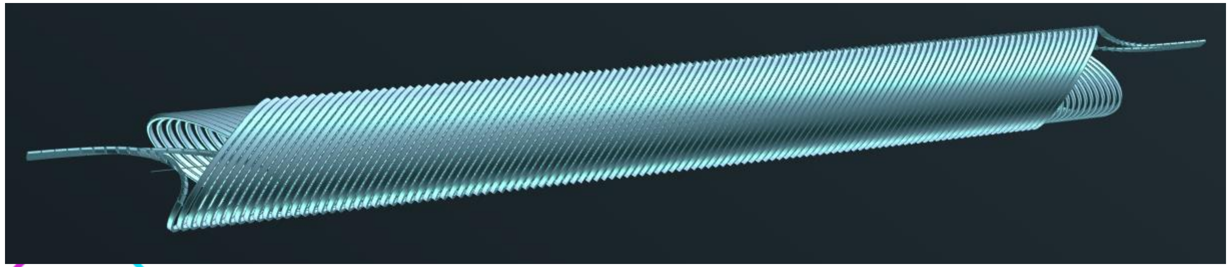
- Baseline (4 T dipole @ 10 K, > 15 K of margin);
- Superconductor ReBCO (Tapes);

Two preliminary designs (No iron):

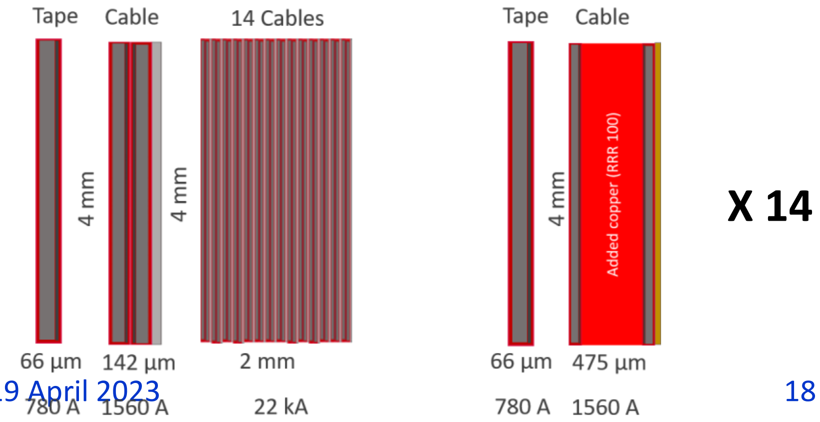
- "**Metal Insulation-like**" design with 2 layers cable (780 A x 2 tapes x 14 cables)
- "**Insulated-like**" design (added copper to the conductor);

Protection aspect is the critical point for both:

- No classical protection for the MI-like;
- Use of cable like for EuCard2: too big current → high losses in the Current Leads;
- 10-50 µV threshold and 10 ms delay (Insulated-like) adding more than 320 µm of copper;

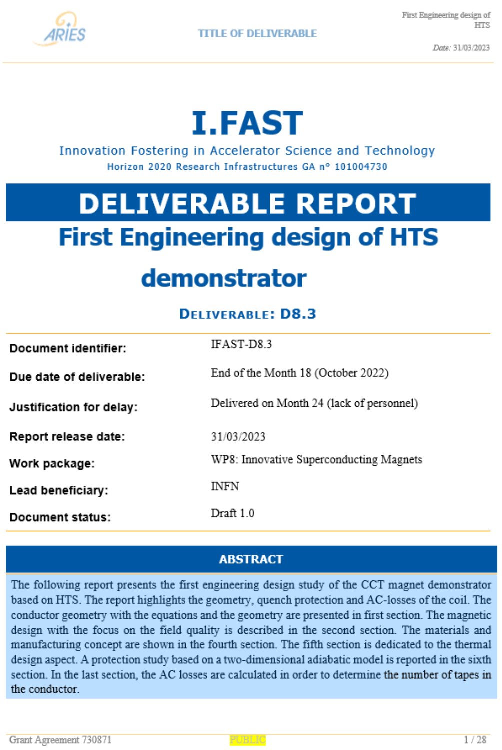


**"MI-like" design** **Insulated-like**




[1]T. Lecrevisse, "**Conceptual Design of HTS Magnet**", IFAST WP8.3 Milestone 33, Zenodo, https://doi.org/10.5281/zenodo.6979877

# Deliverable D8.3 : First Engineering design of HTS demonstrator[1] (1/3)


ARIES | TITLE OF DELIVERABLE | First Engineering design of HTS

Date: 31/03/2023

**I.FAST**

Innovation Fostering in Accelerator Science and Technology

Horizon 2020 Research Infrastructures GA n° 101004730

**DELIVERABLE REPORT**

**First Engineering design of HTS demonstrator**

**DELIVERABLE: D8.3**

| | |
|---|---|
| Document identifier: | IFAST-D8.3 |
| Due date of deliverable: | End of the Month 18 (October 2022) |
| Justification for delay: | Delivered on Month 24 (lack of personnel) |
| Report release date: | 31/03/2023 |
| Work package: | WP8: Innovative Superconducting Magnets |
| Lead beneficiary: | INFN |
| Document status: | Draft 1.0 |


ABSTRACT

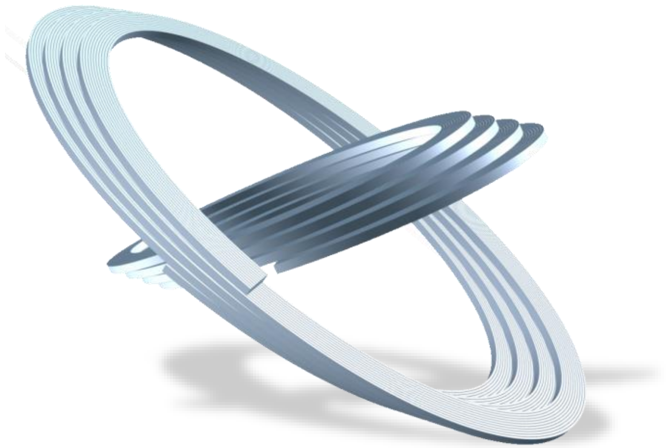
The following report presents the first engineering design study of the CCT magnet demonstrator based on HTS. The report highlights the geometry, quench protection and AC-losses of the coil. The conductor geometry with the equations and the geometry are presented in first section. The magnetic design with the focus on the field quality is described in the second section. The materials and manufacturing concept are shown in the fourth section. The fifth section is dedicated to the thermal design aspect. A protection study based on a two-dimensional adiabatic model is reported in the sixth section. In the last section, the AC losses are calculated in order to determine the number of tapes in the conductor.


Grant Agreement 730871 PUBLIC 1 / 28

## Task 8.3 – S. Sorti (INFN)

Report on the first engineering design study of the CCT magnet demonstrator based on HTS from the conductor, magnetic, manufacturing, thermal, protection and power losses point of view.

- 4 T dipole @ **20 K (>10 K of margin)**;
- Superconductor ReBCO (Tapes);
- Frenet-Serret frame used for the conductor geometry.

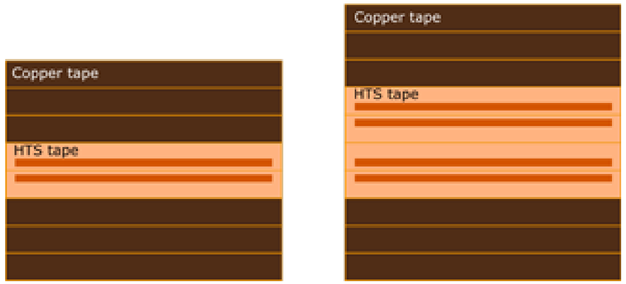


**Insulation option** for the conductor with Cu stabilizer is pursued.

**Two further design options:**

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

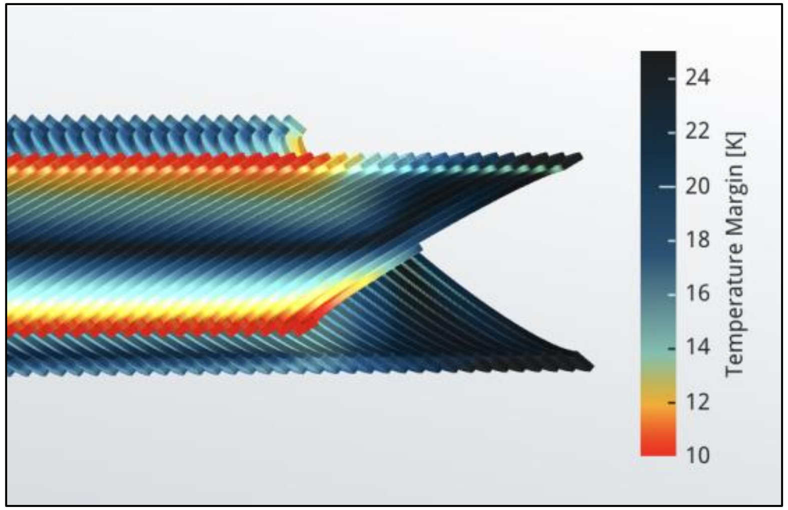
Soldering all tapes inside the cable under consideration;




**Collaboration with Jeroen van Nugteren (Little Beast Engineering)**

[1]S. Sorti, E. De Matteis, ‘’ **First Engineering design of HTS demonstrator** ’’, IFAST WP8 Deliverable 8.3, submitted (**soon on Zenodo**).

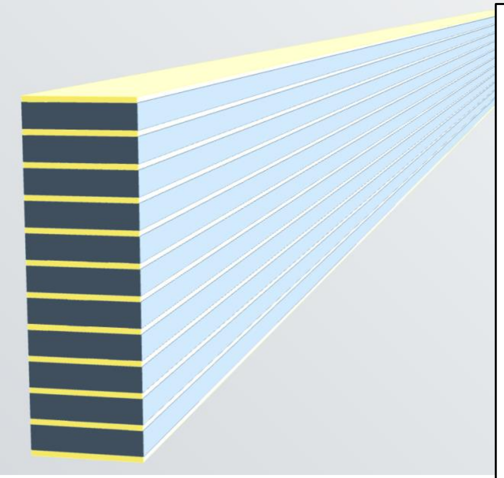
# Deliverable D8.3 : First Engineering design of HTS demonstrator[1] (2/3)

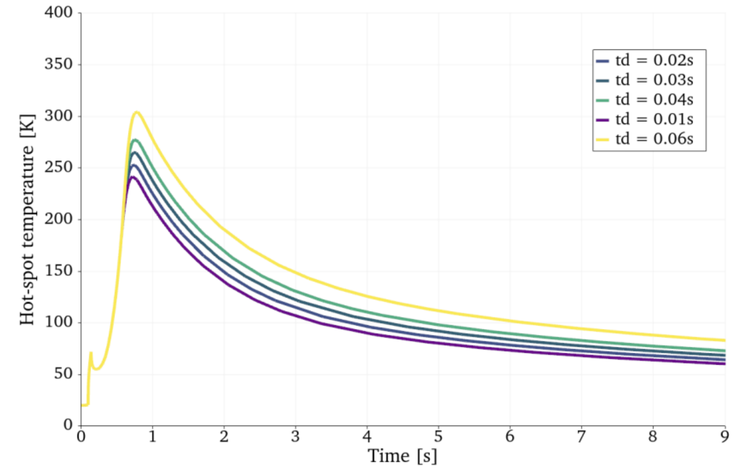



| | Two HTS tapes | Four HTS tapes | |
|---|---|---|---|
| | 350 μm | 600 μm | 700 μm |
| $V_{Th}$ | 0.2 V | 0.2 V | 0.3 V |
| $t_d$ [s] | $T_{hot\text{-}spot}$ [K] | $T_{hot\text{-}spot}$ [K] | $T_{hot\text{-}spot}$ [K] |
| **0.01** | 224 | 224 | 241 |
| **0.02** | 235 | 238 | 252 |
| **0.03** | 242 | 252 | 264 |
| **0.04** | 253 | 268 | 277 |
| **0.05** | 263 | 284 | 290 |
| **0.06** | 275 | 302 | 304 |

- Accelerator-level **field-quality** (integral below-unit), no iron yoke (shielding open problem);
- **Loadline margin** expectably 20-25% (reference tape has 660 A at 20 K, 5 T with a current-per-tape in cable of 500 A);
- Temperature **margin of 10 K** but most of the conductor with even higher margin;
- **Quench protection** system is being demanded for better performances:
  1. Inductive signal to be compensated;
  2. Higher $V_d$, above AC losses voltage (which is ~50 mV);
  3. Push the detection time to the lowest limit possible.
  4. Varistor unit?

# Deliverable D8.3 : First Engineering design of HTS demonstrator (3/3)



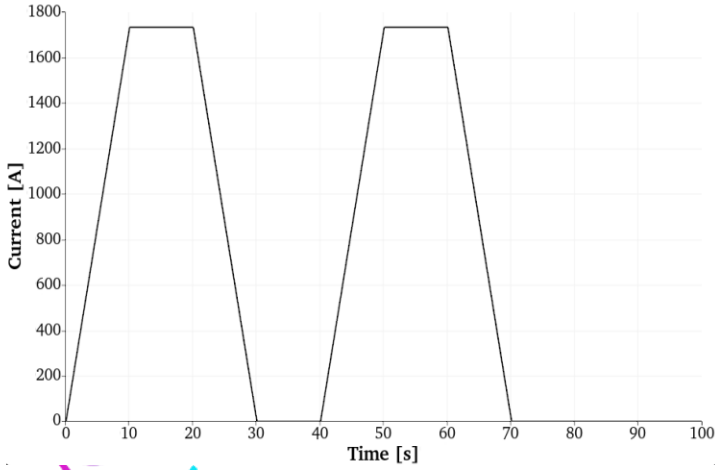


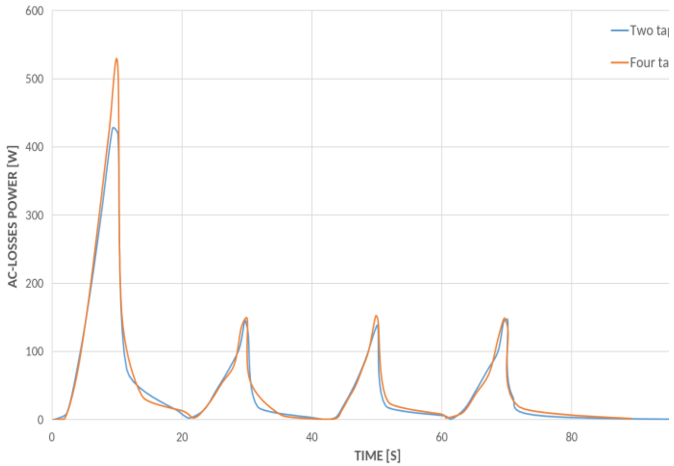

*(a) Hot-spot temperature.*

**Adiabatic quench analysis:**

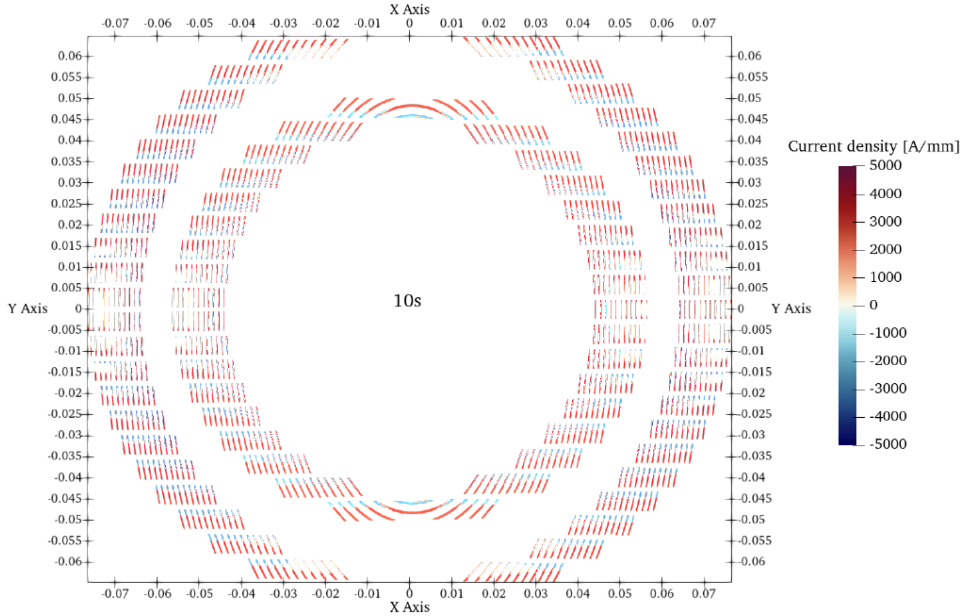
- quench detection voltage threshold of 0.3 V, a protection delay of 20 ms and a protection voltage of 500 V using a varistor unit,
- 350 μm and 700 μm of Cu stabilizer for the two-tape and four-tape designs, (peak temperature within **250 K**).

The **AC-losses** during operating for both designs are on average **50 W.** This is compatible with a conduction cooling system at 20 K.




**Current density in four tapes design**

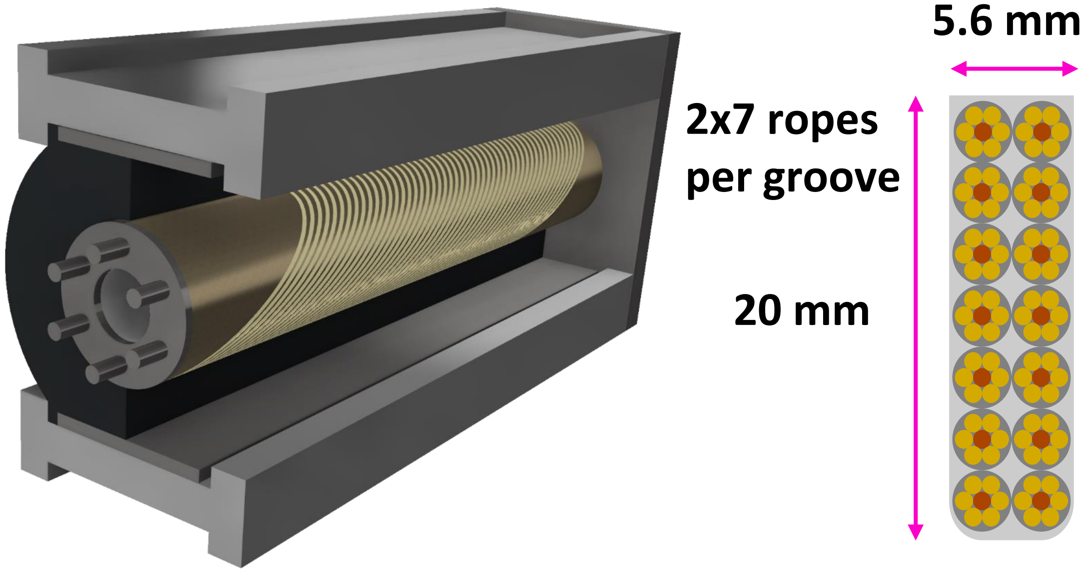


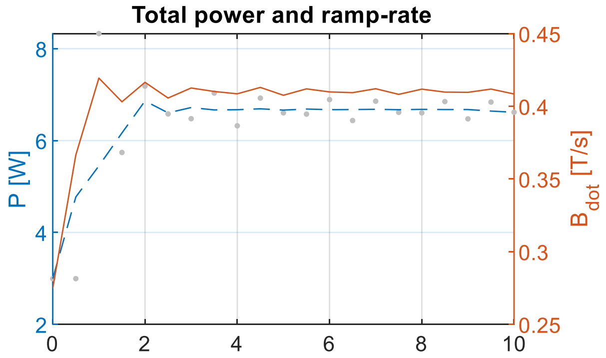
# Task 8.4/8.5 - Construction of combined and HTS CCT magnet demonstrators

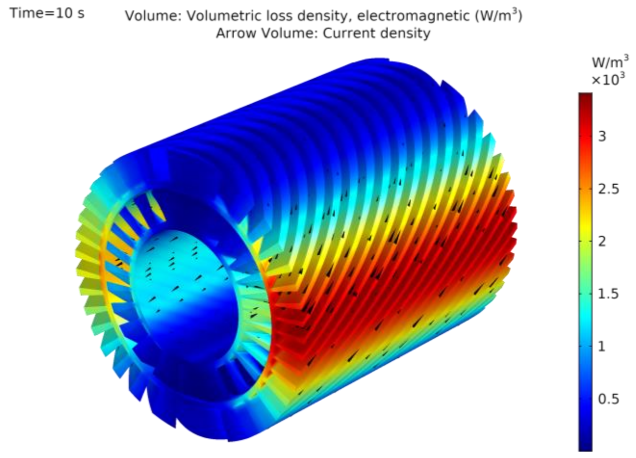
- Magnet demonstrator design and construction of coil former and assembly parts;
- Winding and magnet assembly, magnet test, and validation;
- Withdrawal of the two companies (BNG and Scanditronix) from Task 8.4;
  - Increase of the costs (international situation) and lack of matching funds;
  - After investigation among other institutes partners → CIEMAT is ready to take care of the Task at the same conditions as the withdrawing partners;
- Withdrawal of BNG from Task 8.5:
  - Other company involved, ELYTT, is ready to take care of 100% of the Task;

# Task 8.4 - Construction of combined demonstrator (1/3)

- The decision on Aluminium Bronze as former material after D8.2 lead to a refined design with 6 mm spar;
- Conductor: 2 x 7 ropes (1350 A per rope current, 0.4 mm of min rib thickness);
- Eddy-Currents Losses in the former by 3D FEM estimation brings unfavorable results (> 6 W) for the cryocooler application;
- Simplified design without the iron yoke:
  - Additional complication at this stage;



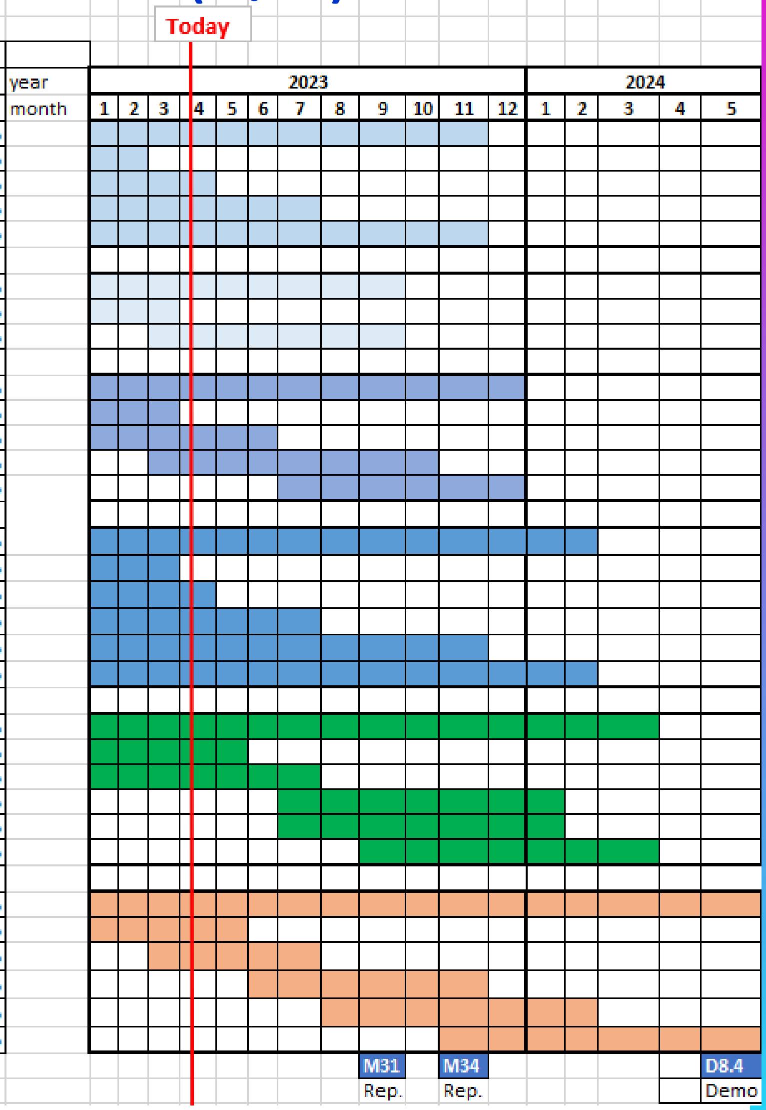
# Task 8.4 - Construction of combined demonstrator (2/3)

- **Workplan of the activities** (with CIEMAT, Wigner, INFN-LASA and Univ. Uppsala):
  - Definition of 6 subtasks;
- **Respect of the same deadline for the demonstrator D8.4** (06/2024) and the milestone report **MS34** (11/2023):
  - Simplified model without iron yoke to save time and money;
- **Postponement of the milestone MS31** (from 12/2022 to 09/2023)

Deliverable 8.4 IFAST WP8

| D8.4 | 8.4 | INFN | Demo | 36 |
|---|---|---|---|---|
| Completion of the Combined CCT demonstrator | | | | |

| Task | % |
|---|---|
| **8.4- 1 Cable and splices (INFN - LASA)** | 84% |
| 1.1 Preliminary tests | 100% |
| 1.2 Cable definition (6+1 rope + polyester) | 95% |
| 1.3 Cable production | 90% |
| 1.4 Splices definition and tests | 50% |
| **8.4 - 2 Formers (CIEMAT/Wigner)** | 50% |
| 2.1 Straight former tests (AlBr) | 100% |
| 2.2 formers construction | 0% |
| **8.4- 3 Winding (CIEMAT)** | 43% |
| 3.1 Tests (procedure) | 70% |
| 3.2 Definition for straight former | 100% |
| 3.3 Setup for straight former | 0% |
| 3.4 Winding of the final formers | 0% |
| **8.4 - 4 Impregnation (CIEMAT/Wigner)** | 48% |
| 4.1 Tests (Wax) | 100% |
| 4.2 Impregnation material (Wax or Std resin) | 90% |
| 4.3 Setup definition for straight former | 50% |
| 4.3 Final setup for straight former | 0% |
| 4.4 Impregnation of the two wound formers | 0% |
| **8.4 - 5 Magnet assembly (CIEMAT)** | 26% |
| 5.1 Mechanical structure definition | 80% |
| 5.2 Tooling for assembly definition | 50% |
| 5.3 Mechanical structure production | 0% |
| 5.4 Tooling production | 0% |
| 5.5 Final assembly | 0% |
| **8.4 - 6 Magnet test (Univ. of Uppsala)** | 10% |
| 6.1 Test facility definition | 50% |
| 6.2 Magnetic meas. System definition (cold) | 0% |
| 6.3 Test facility preparation | 0% |
| 6.4 Magnetic measurement system production | 0% |
| 6.4 Tests (magnetic meas. + training ) | 0% |



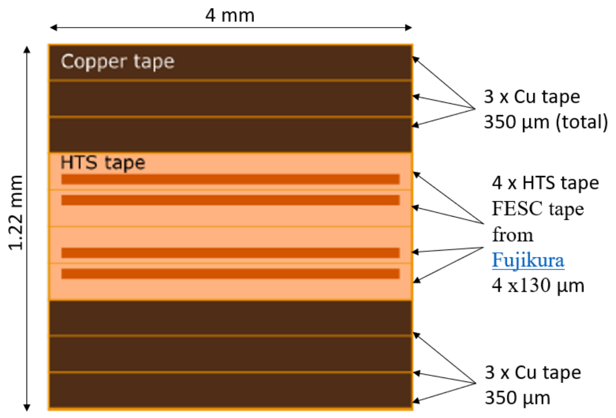

| | | | |
|---|---|---|---|
| M31 | Review Report | 01/09/23 | Construction readiness of combined CCT demonstrator |
| M34 | Rep. Conformity Cert. | 01/11/23 | Construction of the formers for combined CCT winding |
| D8.4 | Demo | 01/06/24 | Construction of combined CCT demonstrator |

# Task 8.4 - Construction of combined demonstrator (3/3)

- Conductor: final production of the rope 6+1 with double braid of polyester (99% of covering factor) almost ready made by TexCavi srl (Inzago, Milan, Italy)→ followed by INFN (LASA);
- CAD drawings of the two formers + layer jump to be adjusted with respect to the final rope size→ done by Wigner RCP;
- CIEMAT will be ready to start ordering materials (waiting for the official transfer of the EU funds).
- Open points: winding and impregnation setup to be done (CIEMAT), rope-to-rope joints/splices to be tested (INFN-LASA).

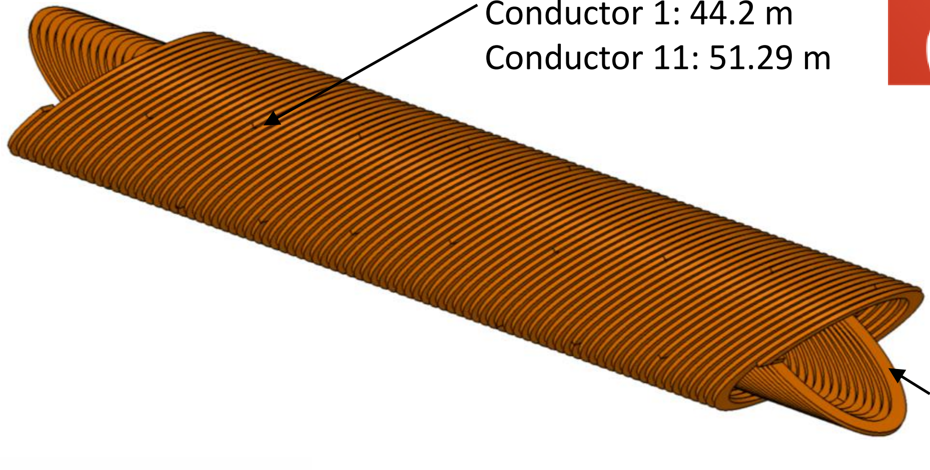
# Task 8.5 - Construction of the HTS CCT magnet demonstrator (1/2)

- Elytt has started the activity on the definition of the former, cabling and winding




ELYTT ENERGY

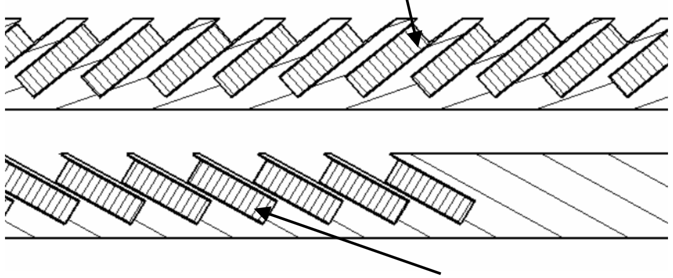
Outer layer
Conductor 1: 44.2 m
Conductor 11: 51.29 m



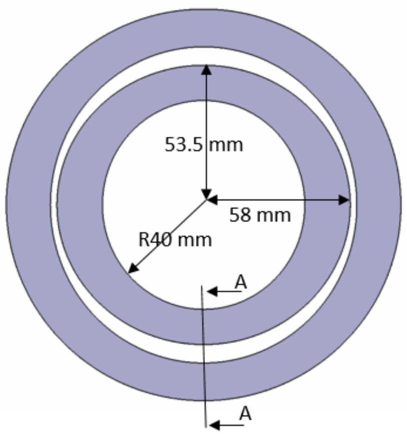
Inner layer
Conductor 1: 36.33 m
Conductor 11: 43.4 m

Cut A-A

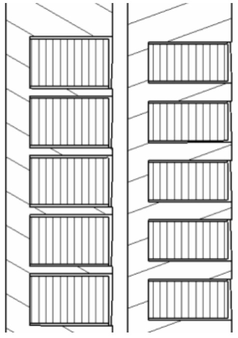
Stacking of conductors in the outer layer

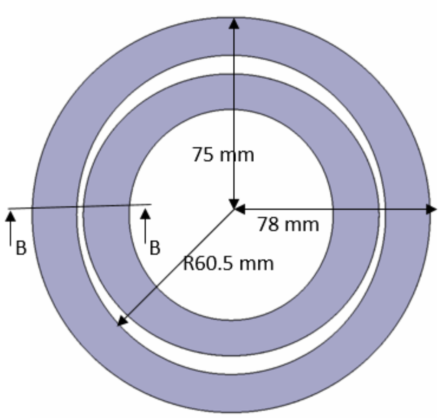


Stacking of conductors in the inner layer




Cut B-B



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**Courtesy of Julio Lucas (Elytt)**

# Task 8.5 - Construction of the HTS CCT magnet demonstrator (2/2)

Initial phase of the manufacturing R&D (ELYTT) is to identify the main challenges for the construction of the magnet. As a first proposal, it should be investigated:

- The conductor manufacturing. A short length of conductor should be manufactured and processed (soldered)  (Use of dummy tape to save money);
- A short length of mandrel should be manufactured (100 mm or 10 pitches) - using the same route that we plan for the final prototype;

INFN will support the activities by FEM simulation (e.g. mechanical part);

CERN is in charge for the procurement of the HTS tape (dummy tape?).

# Conclusions and next steps

- *First demo - Combined function CCT based on NbTi:*
  - *Complete the engineering design (Wigner-INFN) and schedule the activities for the construction with CIEMAT (Task 8.4), as responsible for **DLV 8.4**;*
  - *DLV 8.4 – respect of the actual deadline (06/2024);*
  - *Milestone **MS31**: Construction readiness of combined CCT demo (delayed – 09/2023);*
  - *Milestone **MS34**: Construction of the combined formers for CCT winding (12/2023).*
- *Second demo – CCT dipole based on HTS:*
  - *The first engineering design completed (**DLV 8.3** of Task 8.3, **<u>submitted by INFN</u>**);*
  - *Launch the procurement of the HTS tape (CERN) and of the dummy tape;*
  - *Schedule the activities for tests and construction with ELYTT (**DLV 8.5** - Task 8.5);*
    - *Former, cabling and winding tests (Elytt already started!);*
  - *We will try to respect the actual deadlines of the **MS35** (06/2024) and **DLV 8.5** (10/2024).*
- *Priority is to transfer the funds from the outgoing companies to CIEMAT (Task 8.4) and ELYTT (Task 8.5).*

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# Other activities of WP8

***CCT Computation and Design Workshop (Chair L. Rossi)***

*Scope: the strong interest of Canted Cosine Theta (CCT) magnet design according to the, pursued in both European H2020-HITRIPlus and H2020-I.FAST programs, HITRIPlus-WP8 (Superconducting Magnet Design), and H2020-I.FAST-WP8 (Innovative Superconducting Magnet)*

*The workshop was held in remote and on 21 and 22 September 2021 afternoon (3.00 pm - 7.00 pm)*

*Attendees: I-FAST and HITRIplus partners but also other groups, as LBNL and CERN*

***Papers published***

*L. Rossi et al., "A European Collaboration to Investigate Superconducting Magnets for Next Generation Heavy Ion Therapy," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 4, pp. 1-7, June 2022, Art no. 4400207, doi: 10.1109/TASC.2022.3147433.* ***(HITRIplus and IFAST WP8)***

*E. De Matteis et al., "Straight and Curved Canted Cosine Theta Superconducting Dipoles for Ion Therapy: Comparison Between Various Design Options and Technologies for Ramping Operation," in IEEE Transactions on Applied Superconductivity, vol. 33, no. 5, pp. 1-5, Aug. 2023, Art no. 4401205, doi: 10.1109/TASC.2023.3259330.* ***(HITRIplus and IFAST WP8)***

HITRI plus
Heavy Ion Therapy Research Integration

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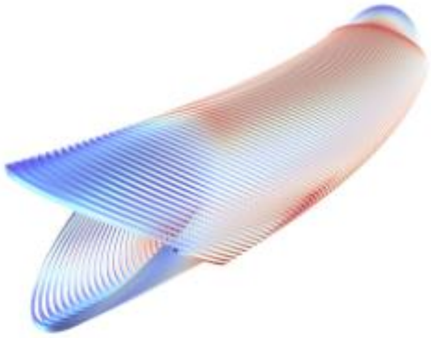

CCT-CDW - 1

https://indico.cern.ch/event/1065779/

**IFAST WP8 Meetings indico page:**

https://indico.cern.ch/category/13096/

**Big list of outreach talks**

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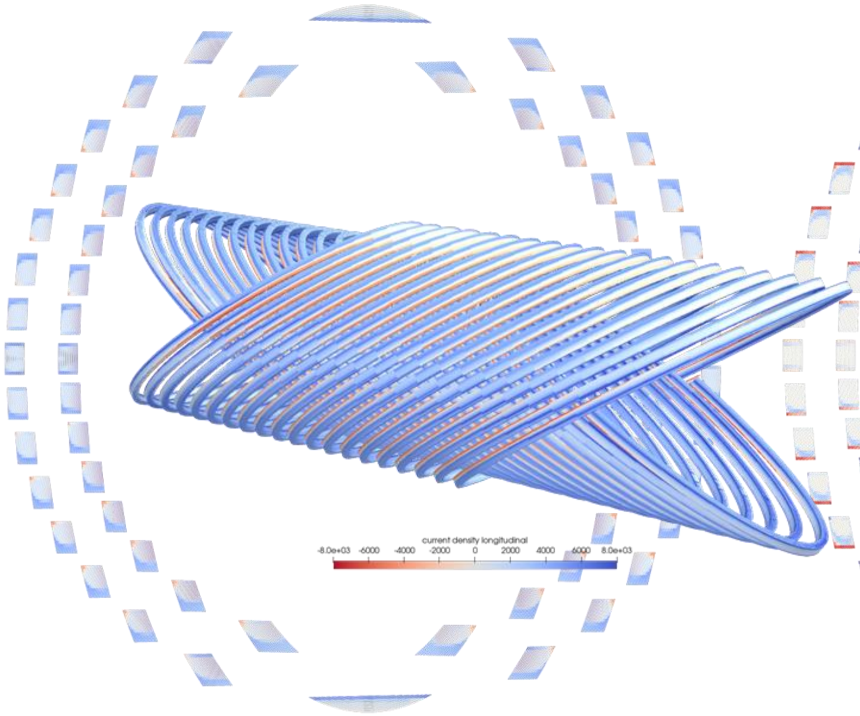
# Thank you for your attention!

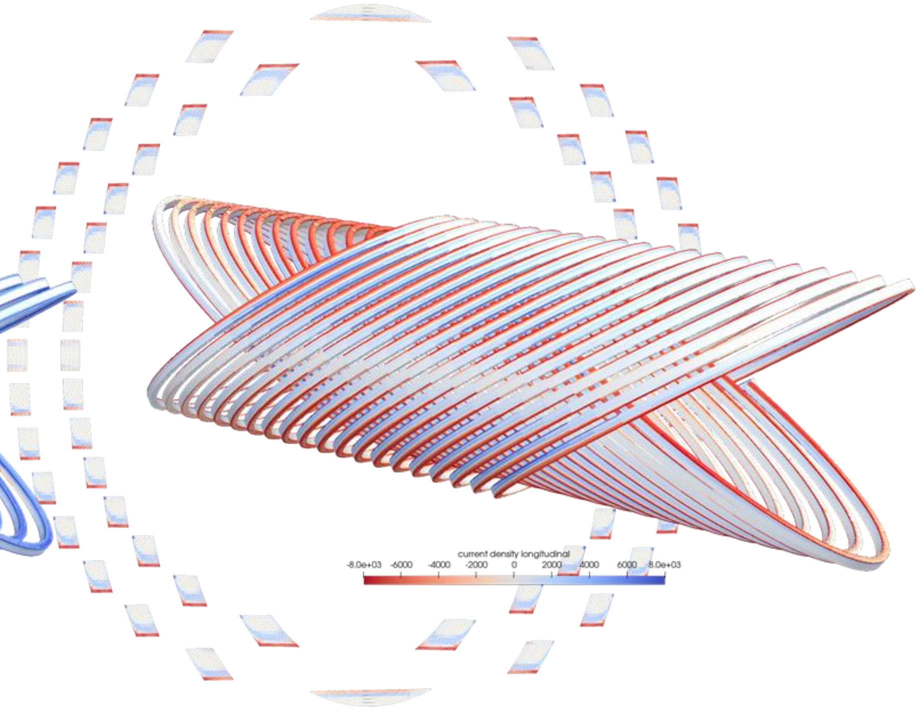
This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under GA No 101004730.

# Deliverable D8.3 : First Engineering design of HTS demonstrator[1] (2/3)

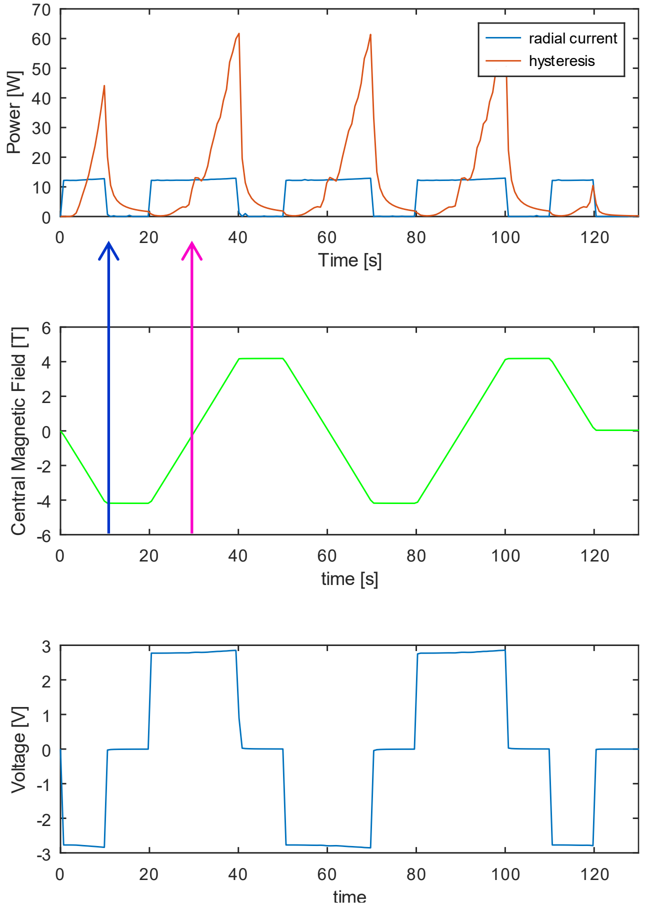
**current distribution in subscale model (20 turns) for a ±4 T cycle**




**End of 1° ramp ($t_1$)**




**Passing at 0 A ($t_2$)**




[1]S. Sorti, E. De Matteis, ‘’ **First Engineering design of HTS demonstrator** ’’, IFAST WP8 Deliverable 8.3, submitted (soon on Zenodo).