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

I.FAST Period 1 Review, 09.02.2023

Istituto Nazionale di Fisica Nucleare

WP8 – magnets members

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

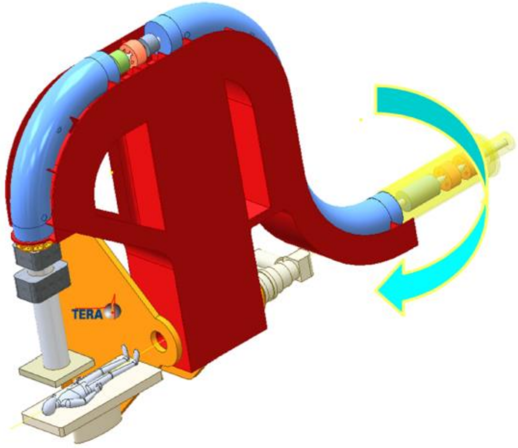
HITRI & I.FAST

I.FAST

	Coordination	Tasks	Task leader	Deputy-task leader
WP8 Innovative superconducting magnets	E. De Matteis (INFN) T. Lecrevisse (CEA) 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 maagnet	E. De Matteis (INFN)	D. Barna (Wigner Inst.)
		8.3 – Preliminary Engineering design of HTS CCT	T. Lecrevisse (CEA) **S. Sorti (INFN)**	A. Ballarino (CERN)
		8.4 - Construction of combined CCT magnet demonstrator	M. Gehring (BNG) **?(CIEMAT)**	M. Vieweg (Scanditronix)
		8.5 – Construction of HTS CCT magnet demonstrator	A. Echeandia (Elytt)	M. Gehring (BNG)
		8.6 – Development of ReBCO HTS nuclotron cable	T. Winkler (GSI)	C. Roux (GSI)

WP8 – Scope

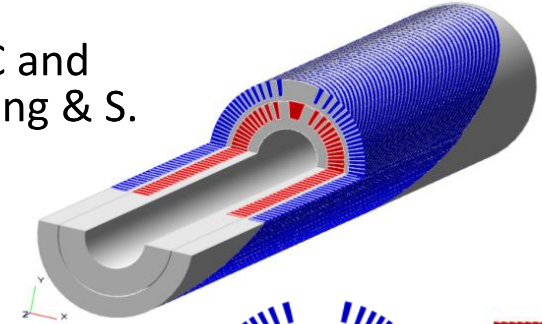
- *Form a permanent **European Strategy Group**, open to worldwide partners, to discuss the European strategy for HTS magnets for accelerators, and to improve Industry involvement in this technology;*
- *Exploring **Canted Cosine Theta with HTS superconductor (main goal),** proceeded by a **combined function CCT based on LTS** → involving the industries that want to learn about the CCT magnets;*
  - *Magnet parameters as HITRIplus program (Hadron Therapy magnet);*
  - *Straight geometry → HTS is already difficult enough!;*
- ***Construction of the two demonstrators**: winding and magnet assembly, magnet test and validation;*

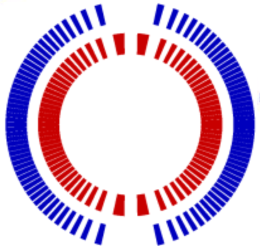


- Program based on CORC and CCT layout led by X. Wang & S. Prestemon

Outer layer

Courtesy of Xiaorong Wang





Courtesy of Tengming Shen

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

12 mm HTS REBCO tape

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.*

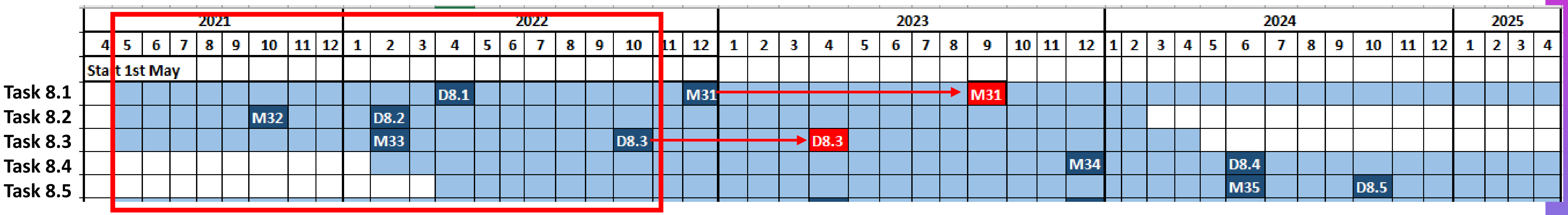
First decision: change in the layout of the first CCT (in LTS)

- 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.

WP8 – Timeline, Milestones and Deliverables

First 18 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 (Postponed) (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:

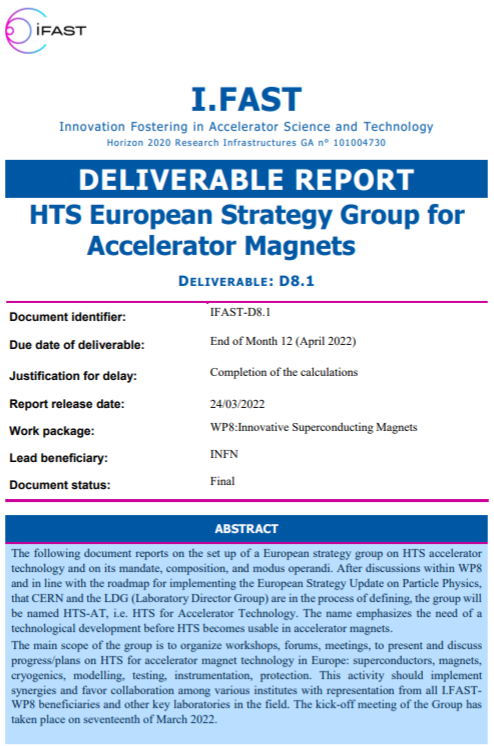
- M32 (10/2021): Characterization of the first length of superconductor for low losses (**ACHIEVED**) (INFN, Univ. Geneva, and CERN)
- M33 (02/2022→06/2022): Conceptual design of HTS magnet (**ACHIEVED**) (CEA)

I.FAST WP8 meetings and first 18 months activities

- Kick-off meeting : 20 April 2021
- From the 23th of June 2021 we had n.12 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 planned 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**
- 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

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



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Innovation Fostering in Accelerator Science and Technology

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.

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**

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

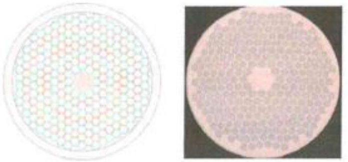
ABSTRACT

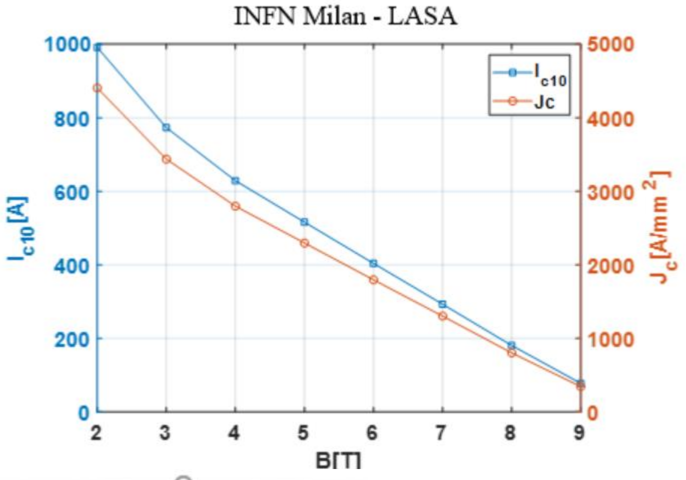
The document is a measurement report concerning the characterization of the NbTi low losses superconductor wire.
The measurement report collects the following measurements: critical current, RRR and magnetization measurements. The critical current and RRR measurements have been performed at LASA laboratory 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

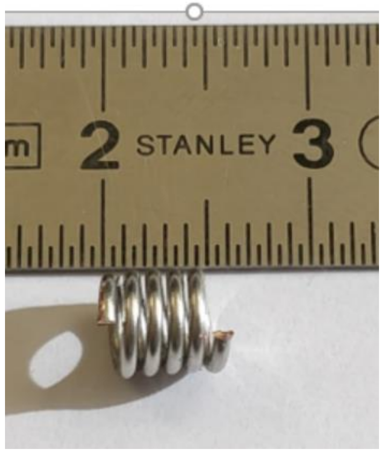
NbTi superconductor wire (originally designed according to the specifications for the DISCORAP project), produced by Bruker

- 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

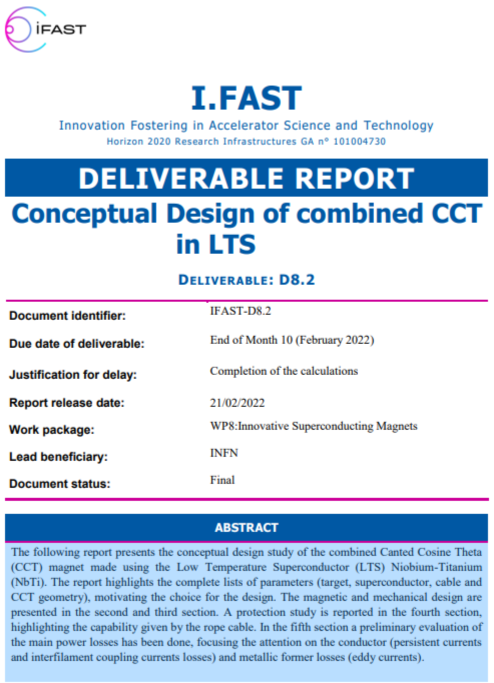


Minicoil for Magnetization meas.

[1]E. De Matteis, ʻʻ **Characterization of the first length of superconductor for low losses** ʼʼ, 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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Horizon 2020 Research Infrastructures GA n° 101004730

DELIVERABLE REPORT

Conceptual Design of combined CCT in LTS

DELIVERABLE: D8.2

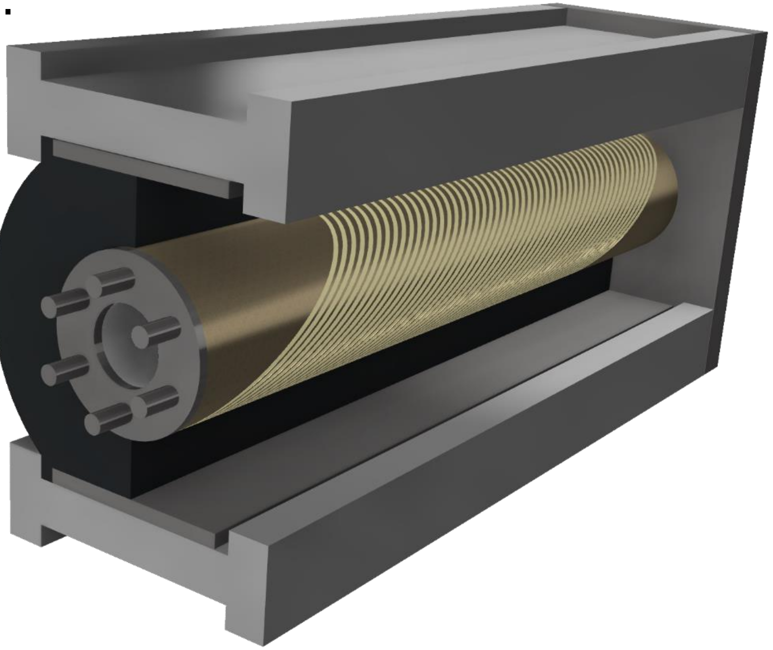
Document identifier:	IFAST-D8.2
Due date of deliverable:	End of Month 10 (February 2022)
Justification for delay:	Completion of the calculations
Report release date:	21/02/2022
Work package:	WP8:Innovative Superconducting Magnets
Lead beneficiary:	INFN
Document status:	Final

ABSTRACT

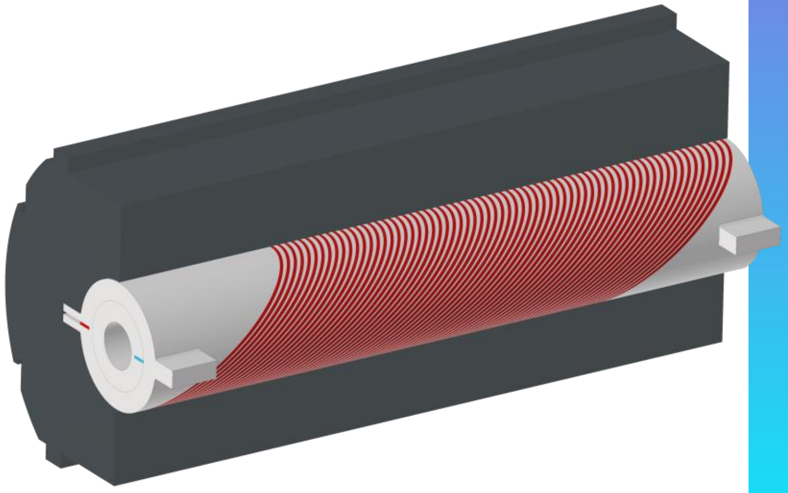
The following report presents the conceptual design study of the combined Canted Cosine Theta (CCT) magnet made using the Low Temperature Superconductor (LTS) Niobium-Titanium (NbTi). The report highlights the complete lists of parameters (target, superconductor, cable and CCT geometry), motivating the 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

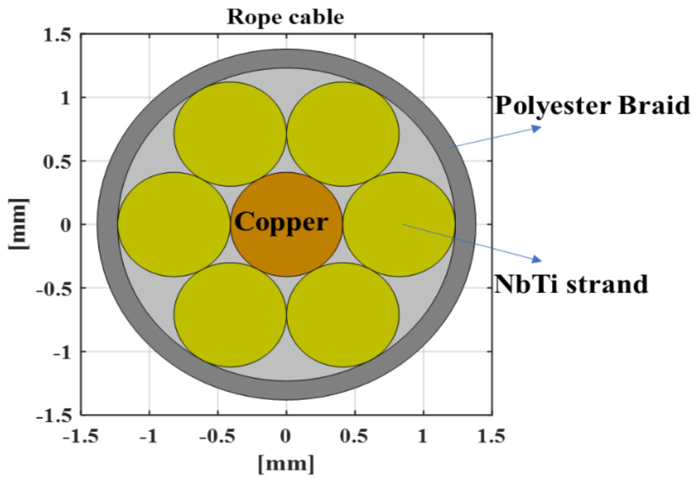


Deliverable D8.2 – Combined CCT magnet based on NbTi

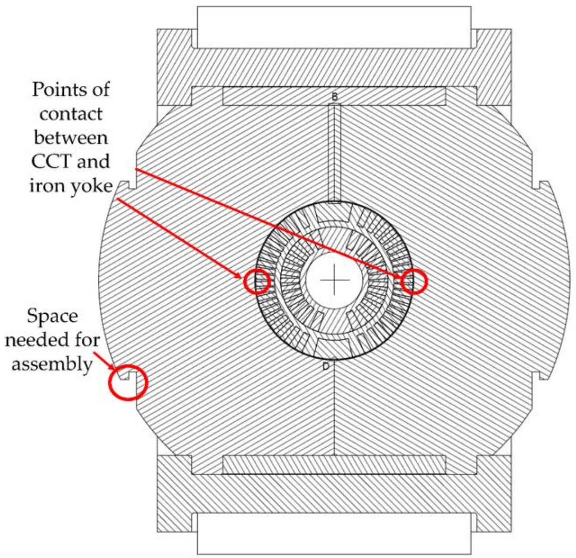
Conceptual design of the **Combined CCT magnet based on NbTi**:

- **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

[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



Iron yoke as shield and collar



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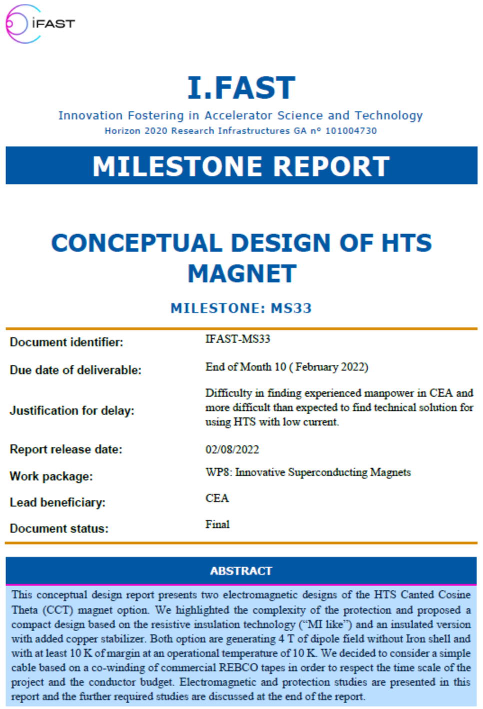
Milestone MS33 : Conceptual Design of HTS Magnet

Task 8.3 – T. Lecrevisse (CEA), lead by S. Sorti (INFN)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Horizon 2020 Research Infrastructures GA nº 101004730

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)

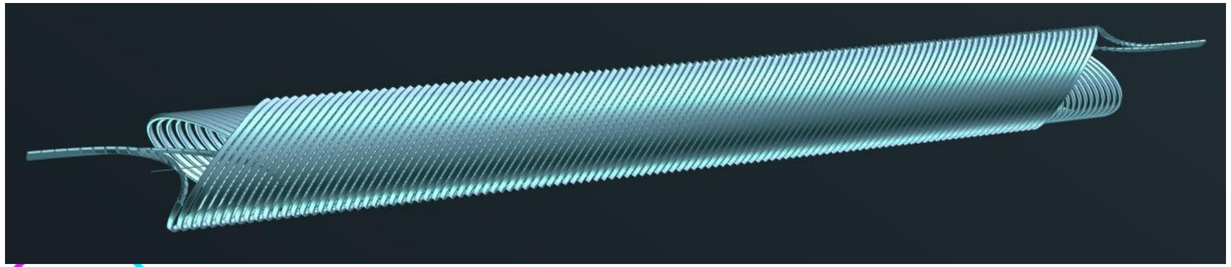
- Baseline (4 T dipole @ 10 K, > 15 K of margin);
- Superconductor ReBCO (Tapes);

Two preliminary designs (No iron):

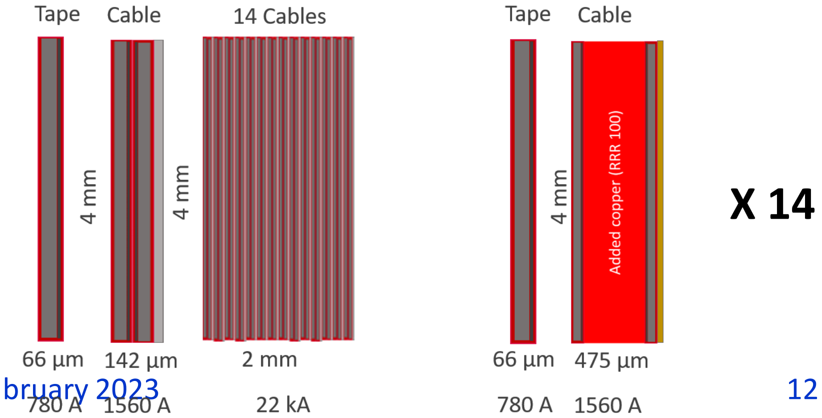
- "**Metal Insulation-like**" design with 2 layers cable (780 A x 2 tapes x 14 cables)
- "**Insulated-like**" design (added copper to the conductor);

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

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;

Conclusions and next steps

- *First demo - Combined function CCT based on NbTi:*
  - *Complete the engineering design and schedule the activities for the construction (Task 8.2 and 8.4) with CIEMAT as responsible for **DLV 8.4**;*
  - *Milestone 31: construction readiness of combined CCT demo (delayed – 09/2023);*
  - *Milestone 34: Construction of the combined formers for CCT winding (12/2023)*
- *Second demo – CCT dipole based on HTS:*
  - *Complete the preliminary engineering design (**DLV 8.3** of Task 8.3 - INFN);*
  - *Launch the procurement of the HTS tape (CERN);*
  - *Schedule the activities for tests and construction with ELYTT (**DLV 8.5** - Task 8.5);*
    - *Former and winding tests.*
- *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'', submitted for publication on IEEE Transactions on Applied Superconductivity, 2022. ***(HITRIplus and IFAST WP8)***

HITRI plus

Heavy Ion Therapy Research Integration

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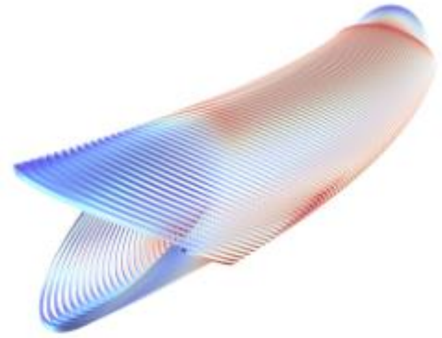

CCT-CDW - 1

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.

Milestone MS33– Conceptual Design of HTS CCT magnet

The main goal of the WP8

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

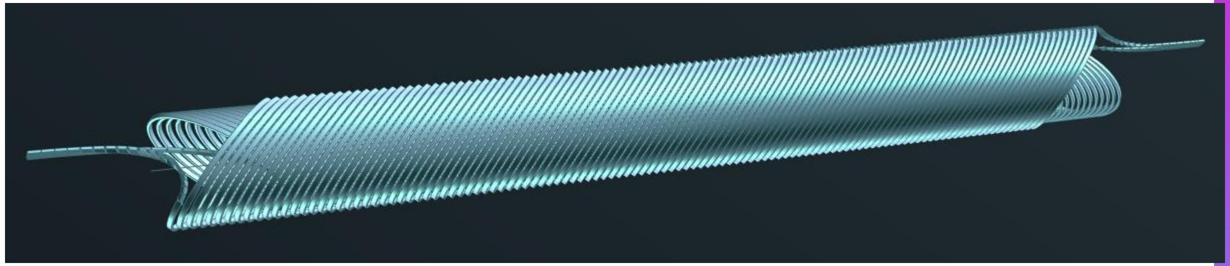
Two preliminary designs (No iron):

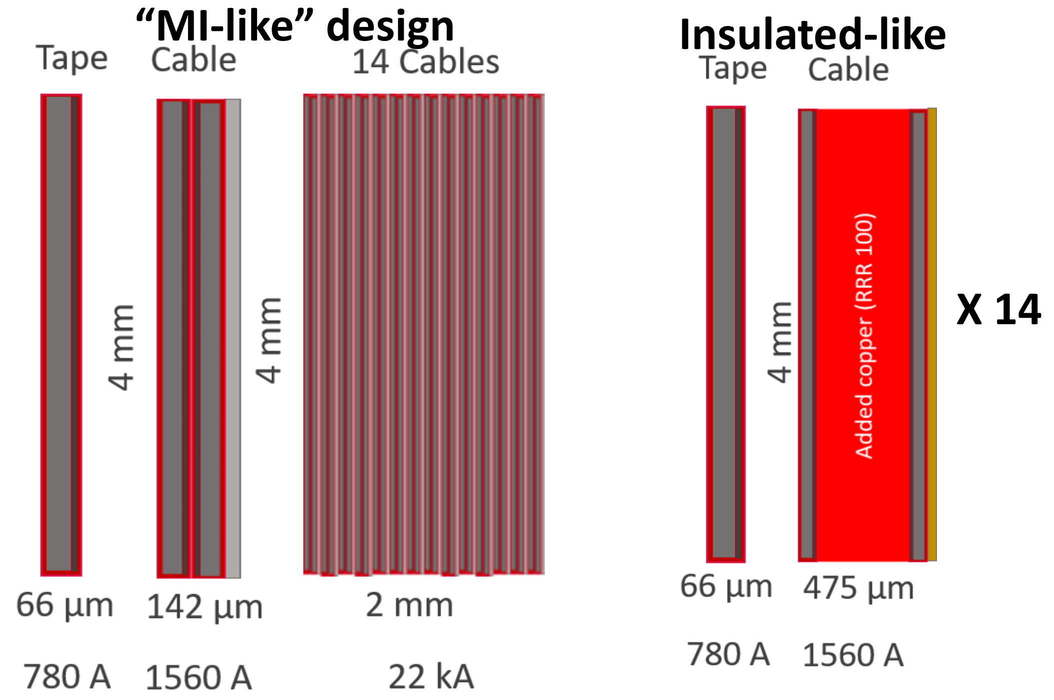
- "**Metal Insulation-like**" design with 2 layers cable (780 A x 2 tapes x 14 cables)
- "**Insulated-like**" design (added copper to conductor);

Protection aspect is the critical point for both:

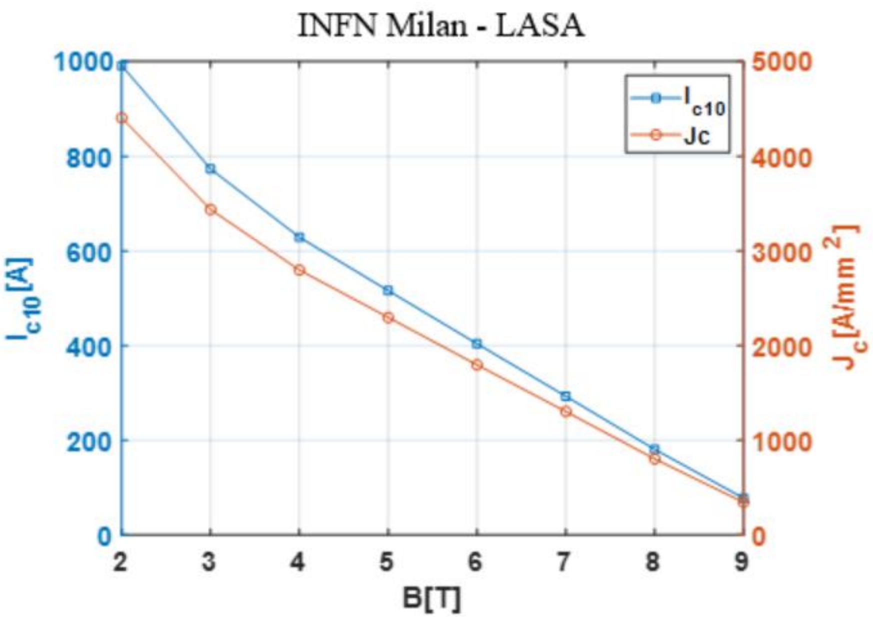
- No classical protection for the MI-like;
- Use fo cable like for EuCard2: too big current → high losses in th Current Leads
- 10-50 µV threshold and 10 ms delay (Insulated-like) adding more than 320 µm of copper;

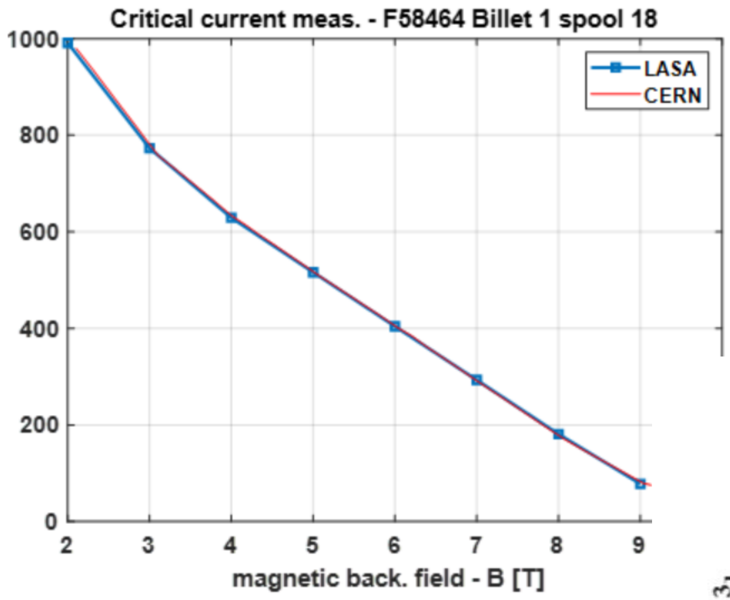
[1]T. Lecrevisse, ''**Conceptual Design of HTS Magnet**'', IFAST WP8.3 Milestone 33, Zenodo, https://doi.org/10.5281/zenodo.6979877



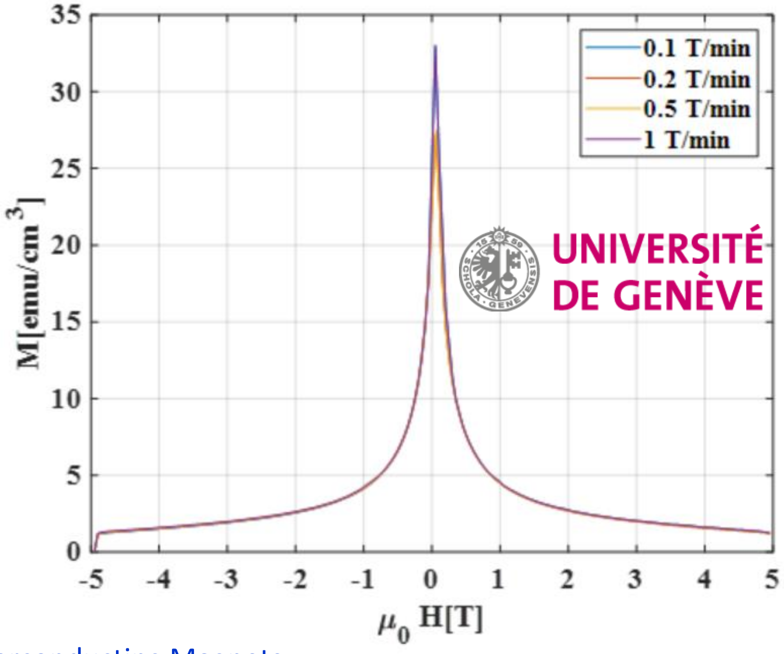


Milestone MS32: Characterization of the first length of superconductor for low losses





Minicoil for Magnetization meas.

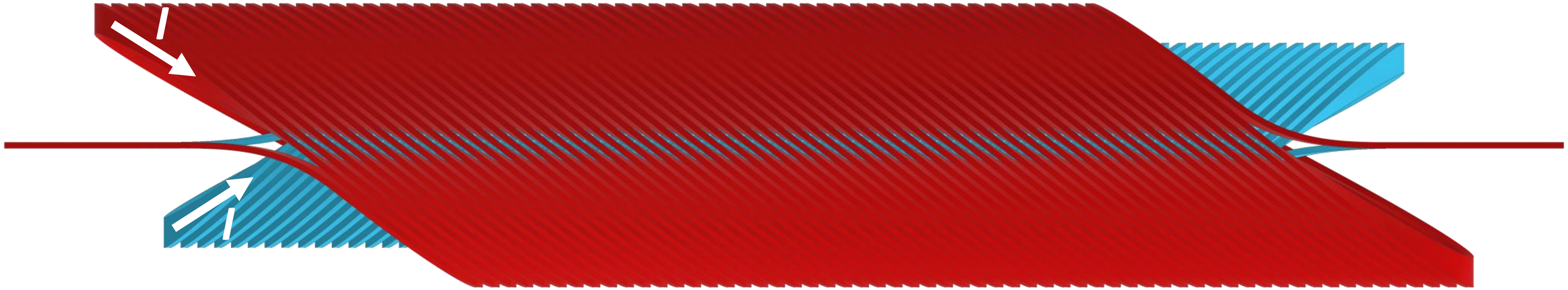


1. Critical current (Jc= 2297 A/mm2 @ 5T, 4.2 K), about 20% less LHC02 outer layer strand.

2. Nb-Ti filaments of the order of 2.6 µm

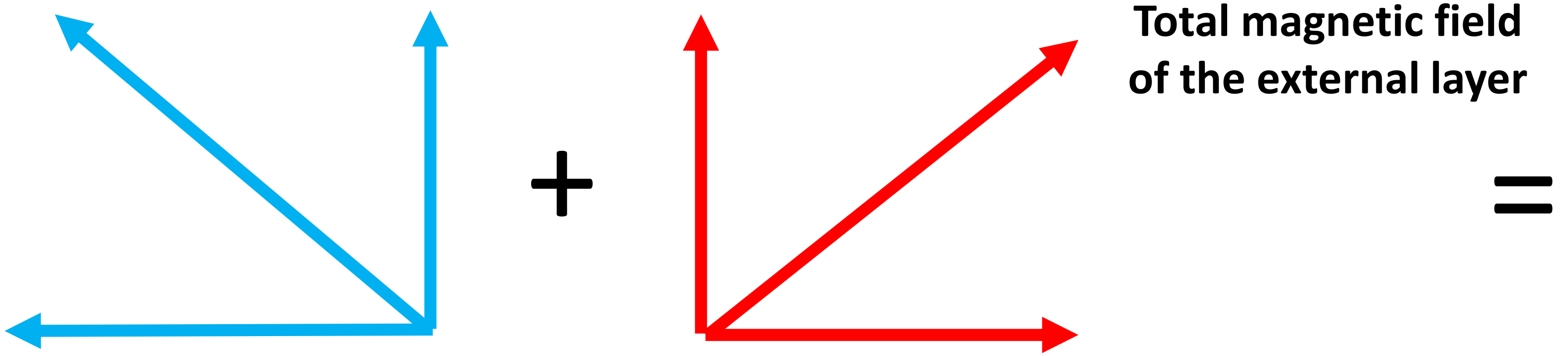
3. RRR>130 as expected

Canted-Cosine-Theta (CCT) Magnet



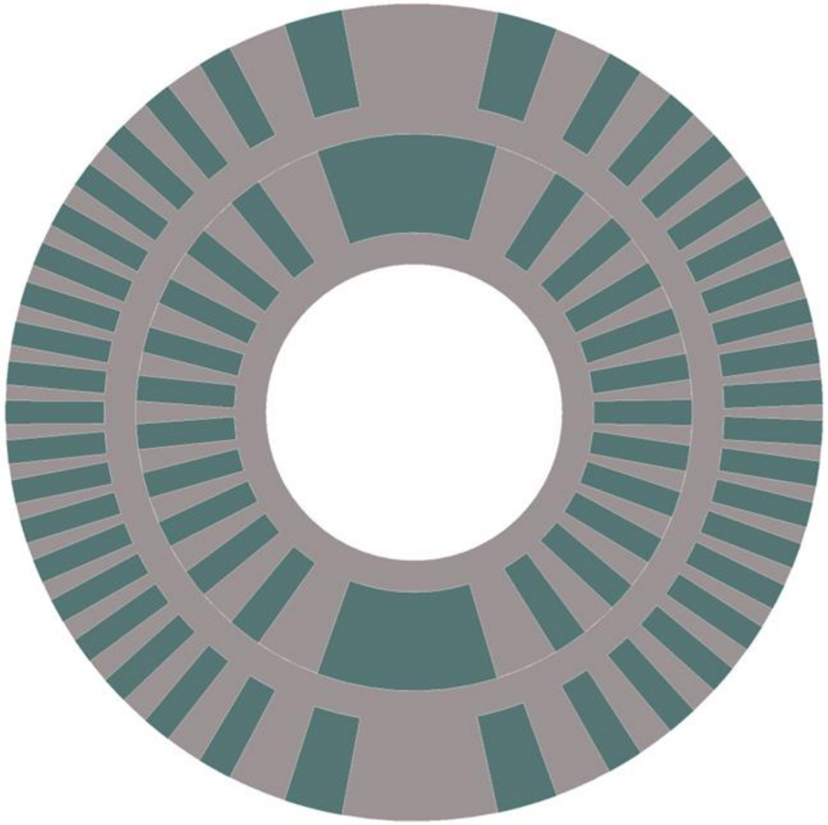
- **Current *I* flows in the two conductors so that the transverse magnetic field components add up and axial field components cancel each other out.**

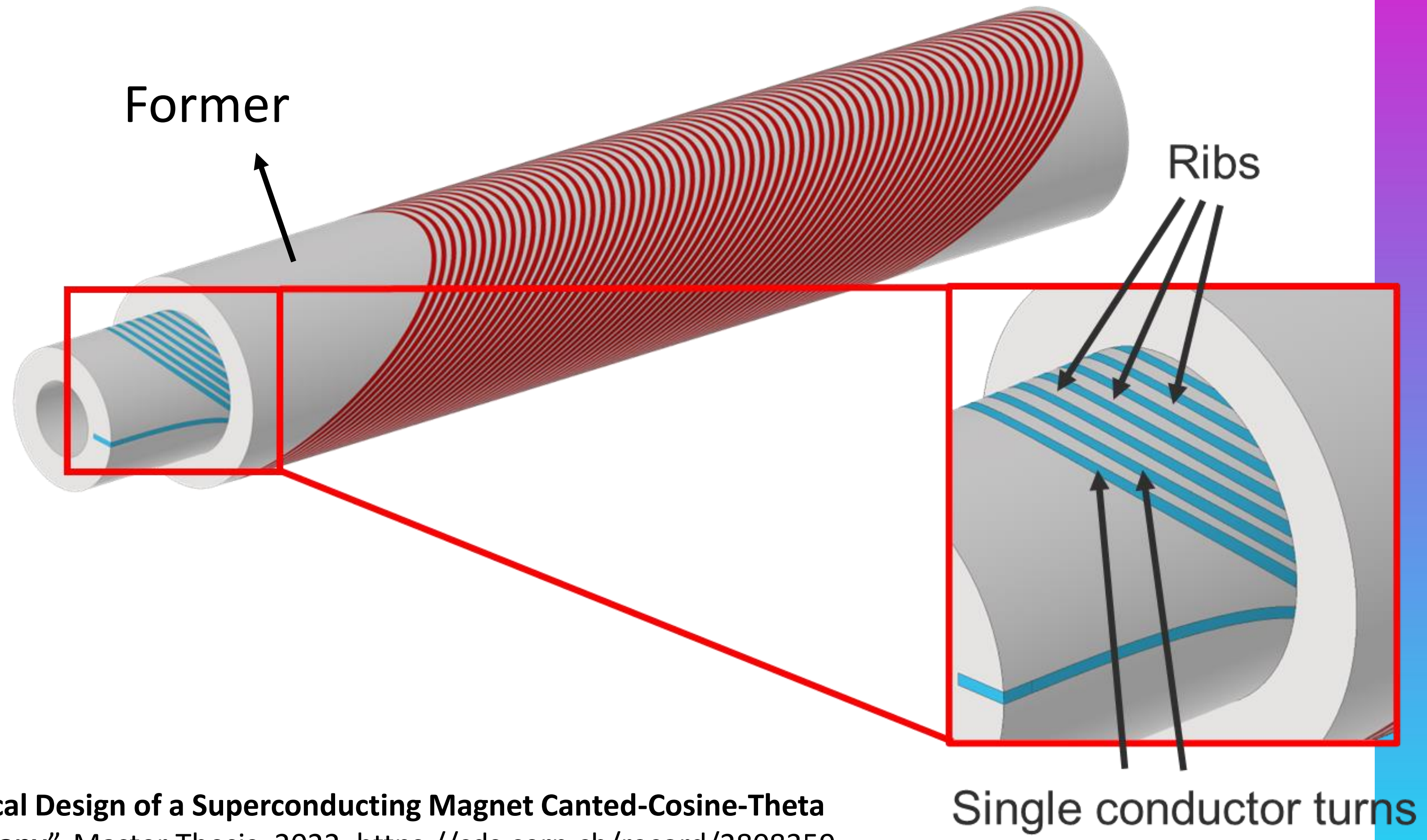
Total magnetic field of the inner layer



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