I.FAST – 1st Annual Meeting
04 .May.2022 – Globe conference room

Lucio Rossi, Ernesto De Matteis, **– INFN-MILANO-LASA**

and all WP8 collaborators

I.FAST WP8 -magnets members

(WP8 comprise also a task on special SC cable for fast ramping led by GSI)

cea

CERN

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Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

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UNIVERSITÉ DE GENÈVE

ELYTT ENERGY

SCANDITRONIX

WP8 Listing

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Innovative superconducting magnets	E. De Matteis (INFN), T. Lecrevisse (CEA), C. Roux (GSI)	Task 8.1	Coordination and HTS Strategy Group	E. de Matteis(INFN)	A. Ballarino (CERN)
		Task 8.2	Preliminary Engineering design of curved CCT magnet	E. De Matteis (INFN)	D. Barna (Wigner)
		Task 8.3	Preliminary Engineering design of HTS CCT	T. Lecrevisse (CEA)	A. Ballarino (CERN)
		Task 8.4	Construction of curved CCT magnet demonstrator	M. Gehring (BNG)	M. Vieweg (Scanditronix)
		Task 8.5	Construction of HTS CCT magnet demonstrator	A. Echeandia (Elytt)	M. Gehring (BNG)
		Task 8.6	Development of ReBCO HTS nuclotron cable	T. Winkler (GSI)	C. Roux (GSI)

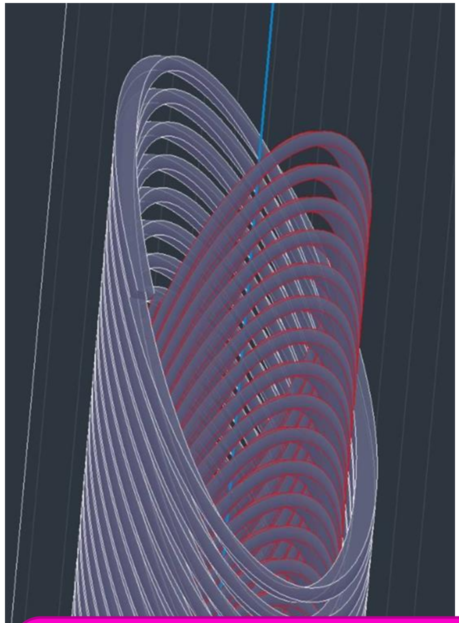
WP8 duration: from M1 to M48 !!
Scope of our WP8

- Here we want to develop technologies supporting the EU Industry that wish to learn about the CCT developed by CERN.
- We aim to verify if CCT and HTS can be the way to go for advanced HadronTherapy (CNAO, MedAustron,…SEEIIST), in particular for SC Gantry and – possibly- for SC synchrotrons.
- The big picture → talk **Ernesto De Matteis Thursday h14.45**
- Transpose HEP collider technology for medical accelerators…
  - Trying to fill the gap with Japan that has a strong leadership in SC Gantry…
  - A companion program based on classical costheta NbTi **– but curved!** – is going on (CERN-CNAO-INFN-MedAustron)
  - A twin program HITRIplus has a WP dedicated to **CCT curved in Nb-Ti**
- **Here the SC technology advance and the direct involvement of 3 important accelerator industries in EU.**

Nb-Ti CCT: p-gantry and HiLumi LHC

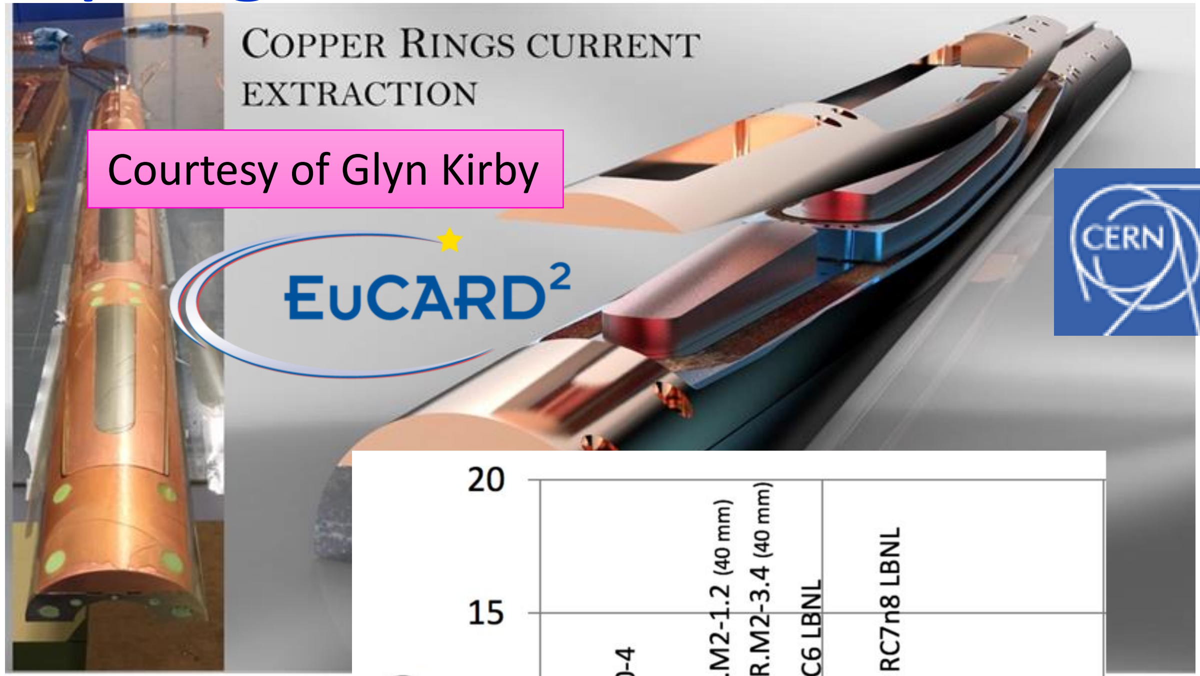
LBNL: CCT coil prototype for large acceptance proton gantry ∅ = 400 mm: Successfully tested to 3.5 T stady state; segmented former.

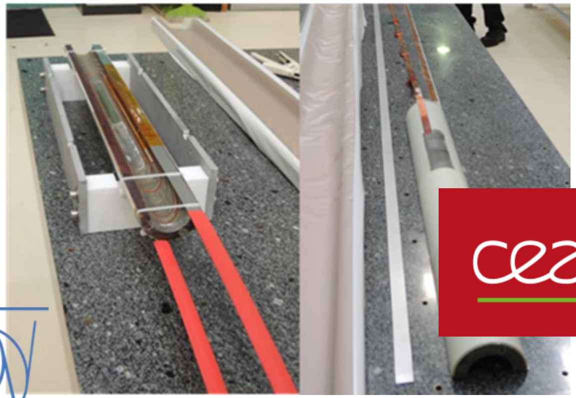
HiLumi LHC: CERN has designed, built and tested a dual 3 T, 2 m long - ∅ = 105 mm, straight CCT. Now IHEP Beijing producing 2x13 units

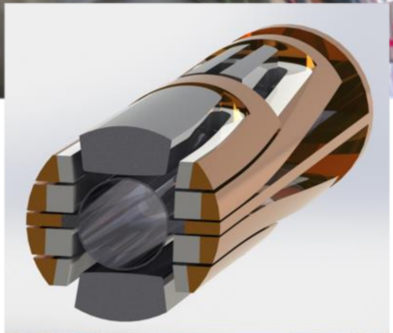


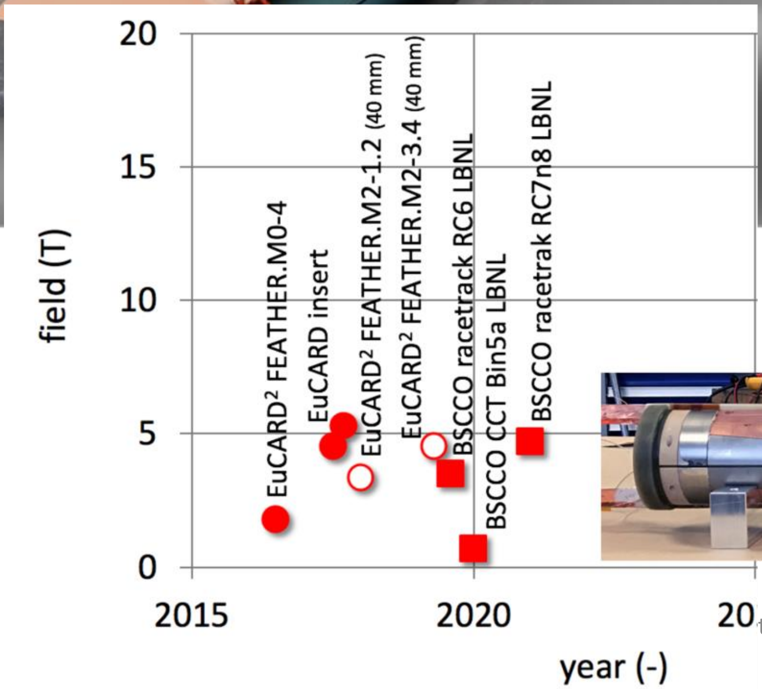
Proto 2m 2.9 T 105 mm very successful at CERN.
However, learning and transfer not easy (China…, SE…)

We build on HTS in FP7-Eucard2 – H2020-ARIES programs

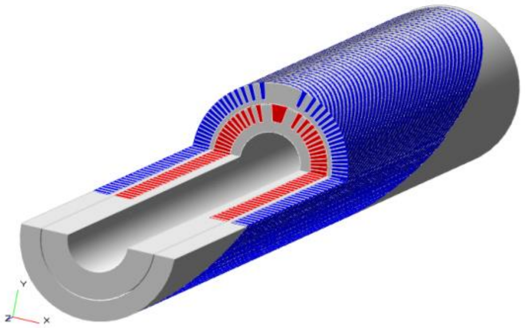








Scope of our WP8 – cont.

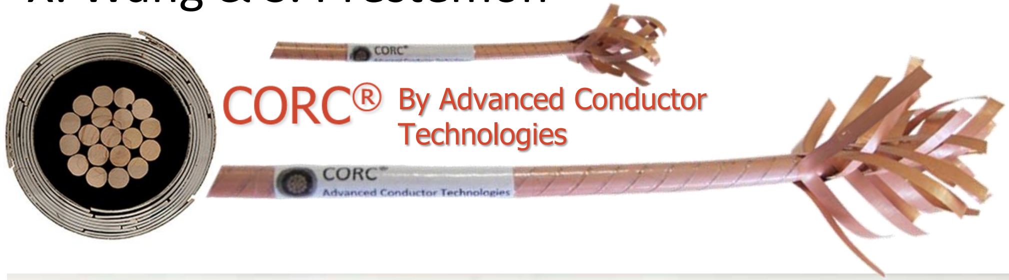


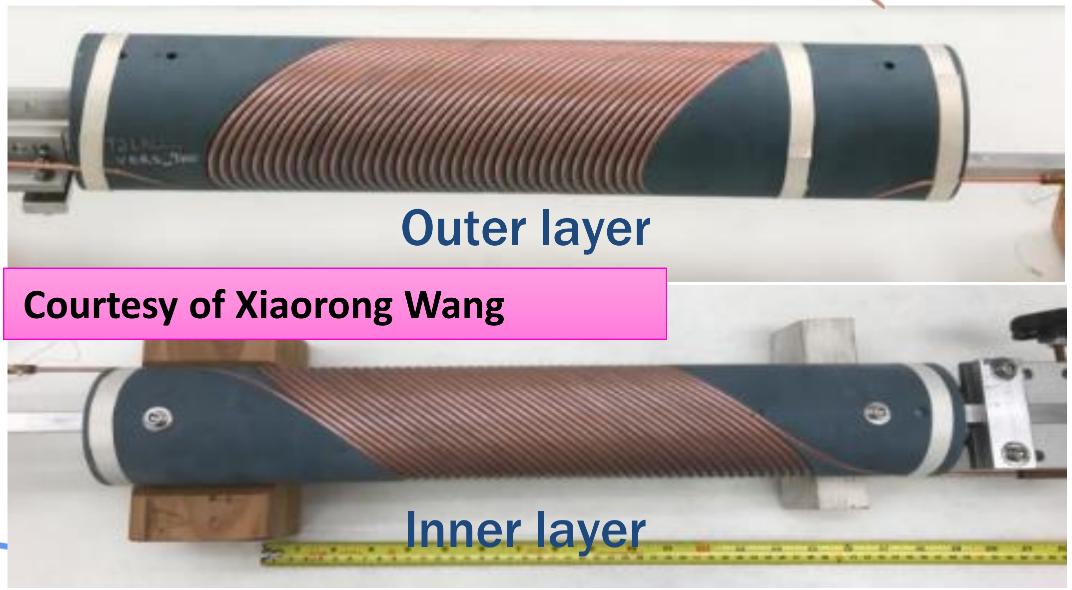
- Additional difficulty: **the magnets is RAMPED : 0.4 T/s**
- The field quality has not yet demonstrated in HTS
- CCT seems a technology suitable for 3-5 T:
  - Simple tooling
  - Little number of pieces
- → **1 HTS CCT** preceeded by 1 Nb-Ti of same dimension as "gauge"
  - 2 HTS CCT ideal: need additional effort for budget (HTS tapes -> CERN; or MgB2, but conductor procurement is also a cost issue… apart for field low)
- We would like to stay "near" the parameter of HITRI+
- Straight! We consider that HTS is already difficult enough!

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

LBNL effort on HTS accelerator magnets mainly based on CCT

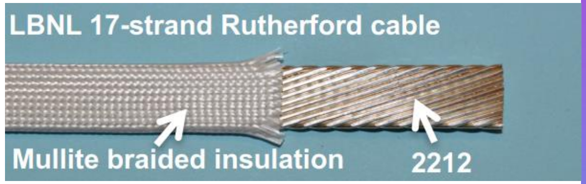
Program based on CORC and CCT layout led by X. Wang & S. Prestemon

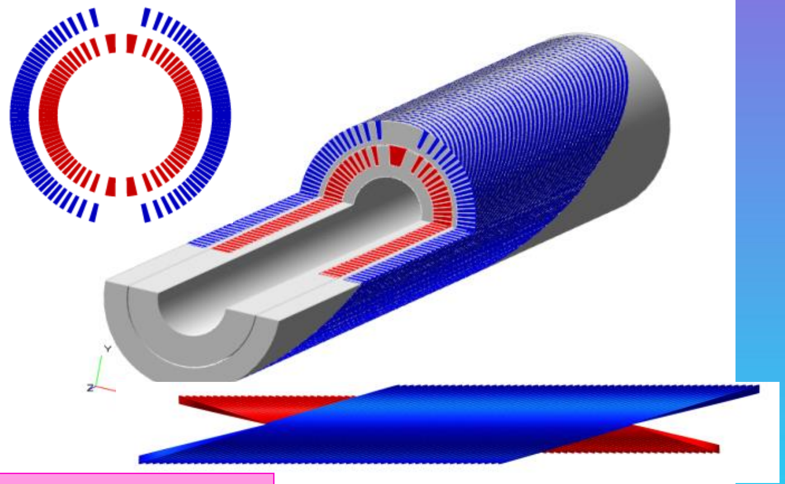




Courtesy of Xiaorong Wang

Program on use of Bi-2212 Rutherford cable with race track and CCT layout led by T. Shen and S. Prestemon

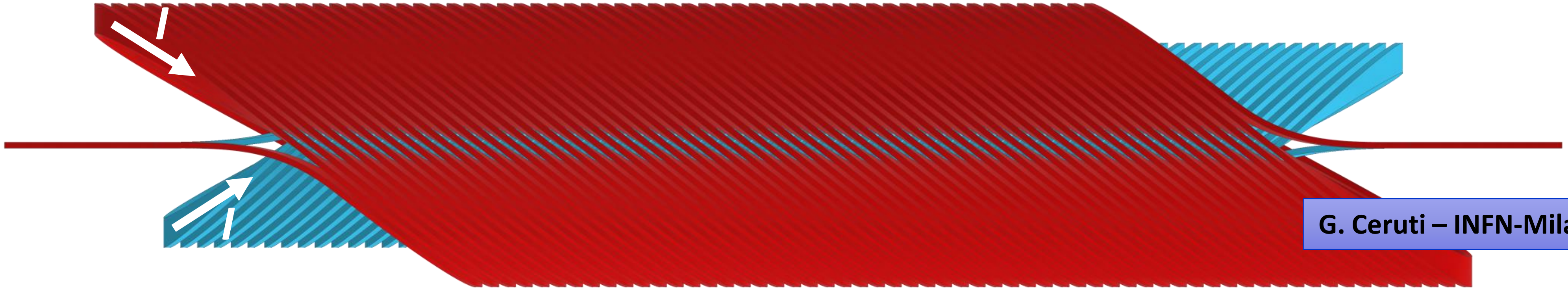




Courtesy of Tengming Shen

Canted-Cosine-Theta (CCT) Magnet (1)

- The CCT design is based on pairs of canted conductor layers:



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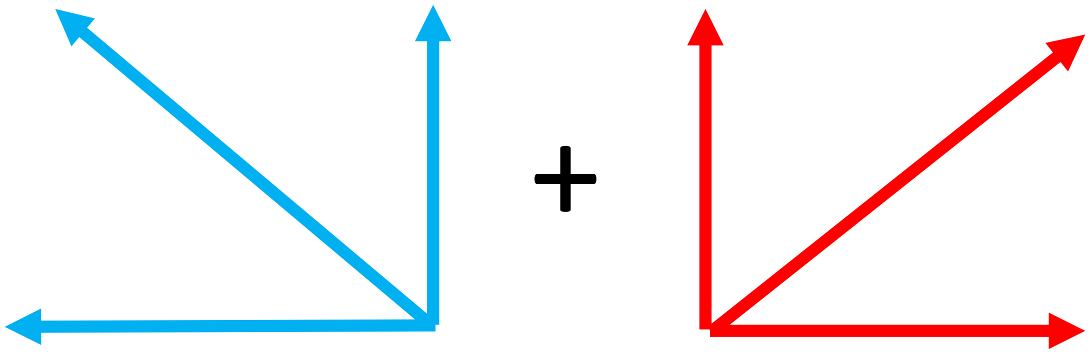
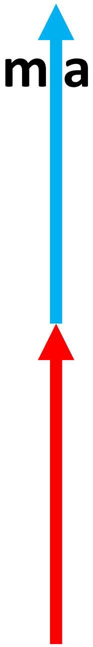
- **Current *I* flows in the two conductors so that the transverse magnetic field components sum and axial field components cancel each other.**

Total magnetic field of the inner layer

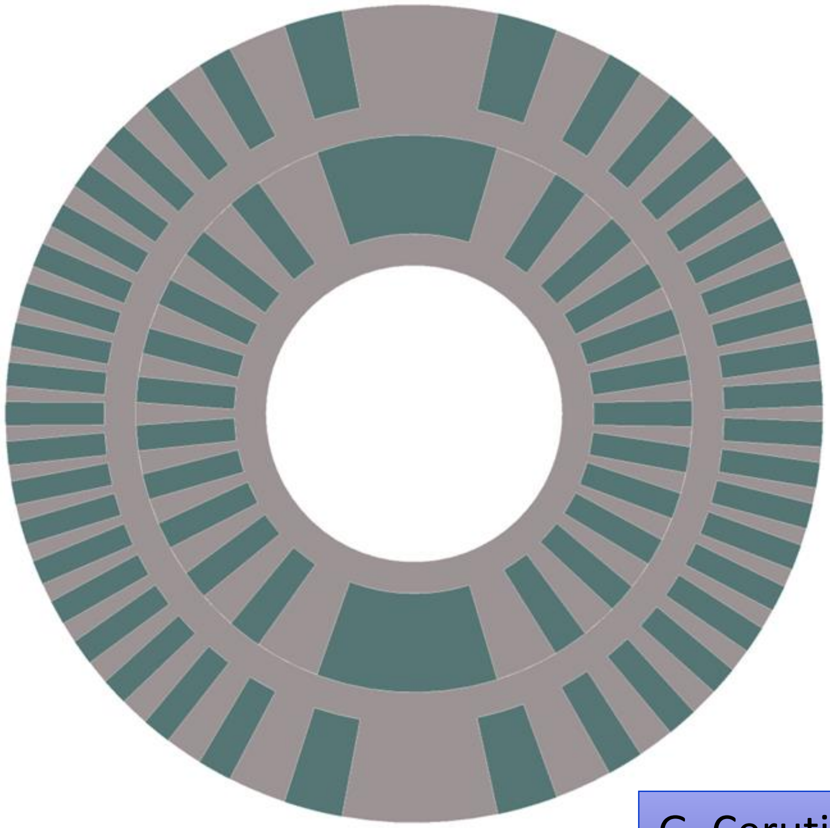


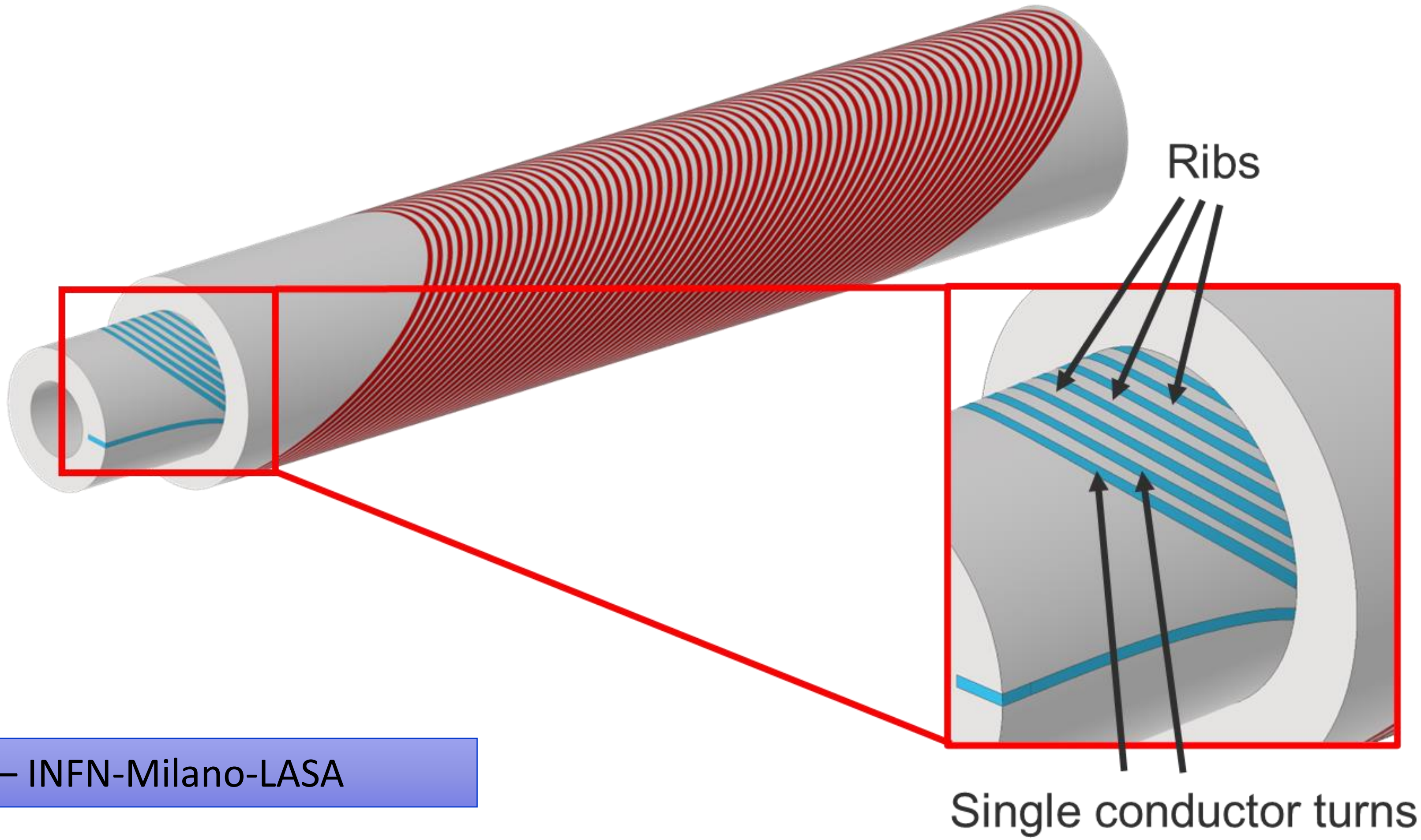
Total magnetic field of the external layer

=



CCT schematics





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IFAST-WP8 (CCT magnets part) meetings

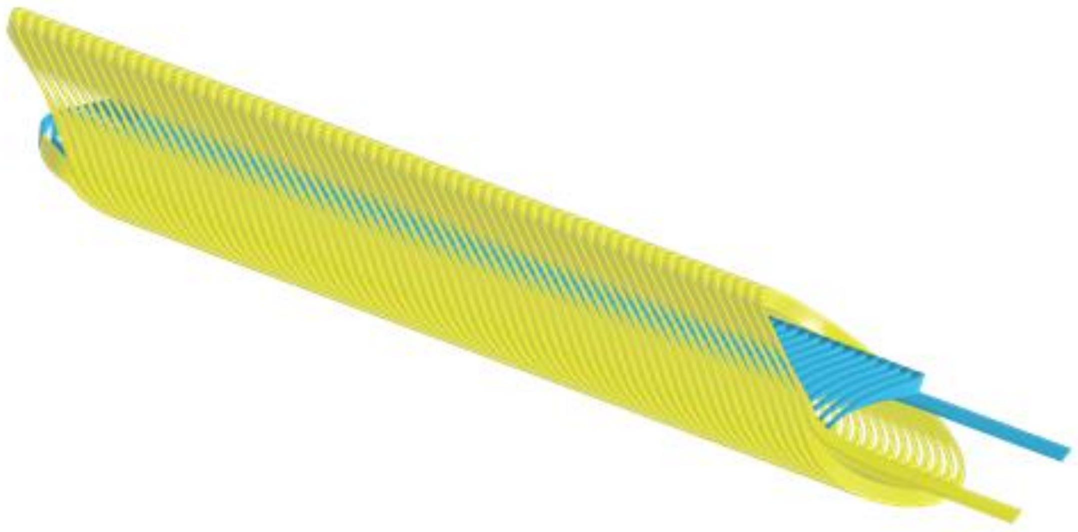
- **Kick off meeting : 29 April 2021**
- We had n.9 meetings (Last meeting : 21 April 2022)
- Regular meeting each third Thursday of each MONTH at 9h00.
- (we invite also HITRI*plus* members as observer)
- First Decision: change in the layout of the first CCT
  - We have proceeded mainly with design work in this 1st year
- Set up HTS European Strategy Group:
  - deliverable 8.1 deadline shift to 04/2022 to synchronize with LDG roadmap implementation for Accelerator R&D (ESUPP 2020)
- MLS and DLVs updates
- CCT Computation and Design Workshop

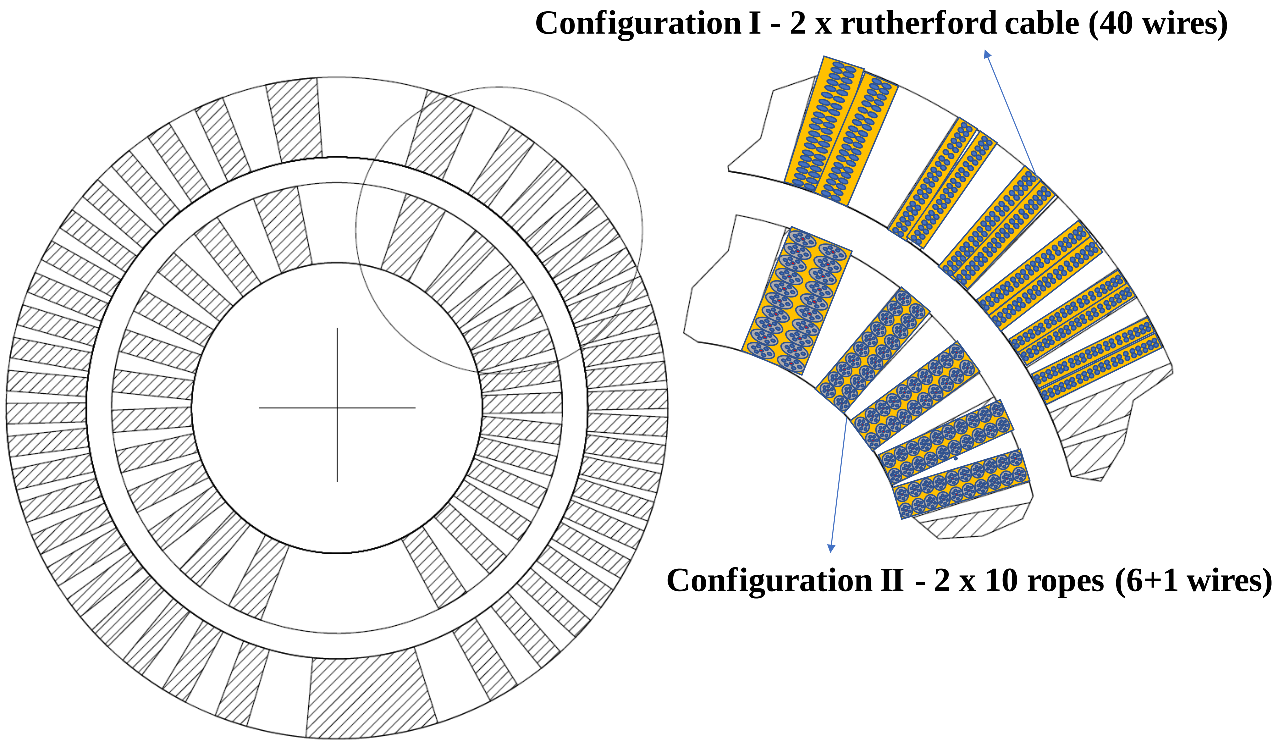
First decision: change in the layout of the first CCT (in LTS)

- We devised to design a curved CCT in LTS as precursor of the HTS straight CCT.
- However, a curved CCT **is already foreseen in HITRI*plus*** (that is more oriented to design for gantry and less to technology R&D.
- All community thinks a that a **combined function (dipole + quadrupole winding, superimposed)** is maybe more interesting step. Demonstrated in Cosϑ 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 (and of preceeding MS) has been accepted by Project Coordination and GB.

Preliminary design combined function

Considered two options:
High current (two Rutherford cables in //)
Low current : 2x10 ropes (6+1)
Other possibility is to go toward 4 layers, i.e., → 4 formers design





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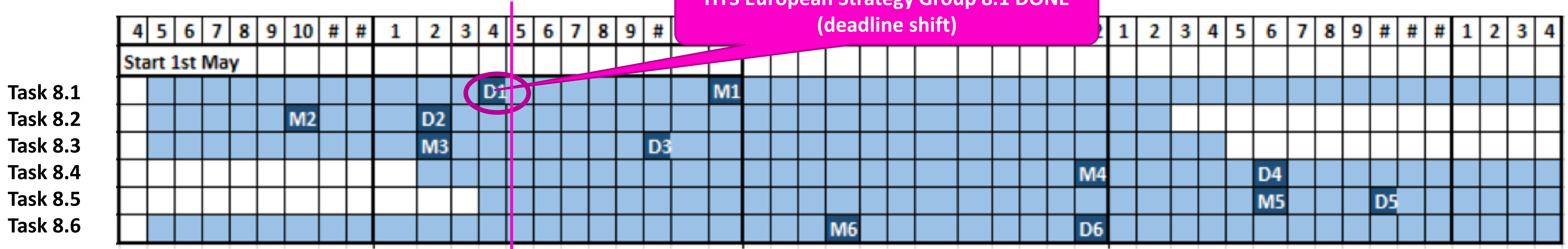
Timeline

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
Task 8.6 - Development of ReBCO HTS nuclotron cable

Change: design of a straight combined function, low loss CCT magnet

HTS European Strategy Group 8.1 DONE (deadline shift)



IFAST Deliverables

	Task	Resp.	Type	Del. In Months	Name	
D1	8.1	CERN	Report	12	HTS European Strategy Group	Set up of the [illegible] kick off meeting with approval of program, scope, and modus operandi.
D2	8.2	INFN	Report	10	Conceptual Design of combined CCT in LTS	Report with complete list of parameters motivating the choice for the design.
D3	8.3	CEA	Report	18	First Engineering design of HTS demonstrator	Report with a set of coherent parameters of the near-to-final design
D4	8.4	BNG	Demo	38	Construction of combined CCT demonstrator	Magnet demonstrator complete with electrical termination and transport constrains
D5	8.5	Ellytt	Demo	42	Construction of HTS CCT demonstrator	Magnet Demonstrator with electrical terminations and transport constrains.
D6	8.6	GSI	Report	32	Fast-cycling Nuclotron HTS cable design	Design parameters of the HTS Nuclotron cable aiming at 6 T magnetic field cooled by two phase forced flow Helium, AC loss measurements.

Milestone Report done by INFN

IFAST Milestones

	Task	Type	Deliv. In Months	Name
M1	8.1	Review Report	20	Construction readiness of combined CCT demonstrator
M2	8.2	Measurement Report	6	Charac. of the first length of superconductor for low losses
M3	8.3	Design Report	10	Conceptual design of HTS magnet
M4	8.4	Rep. Conformity Cert.	32	Construction of the formers for combined CCT winding
M5	8.5	Rep. Test and Ass.	38	Test of mock up coils with dummy cable
M6	8.6	Lab. Test of Sample	24	HTS Nuclotron cable produced

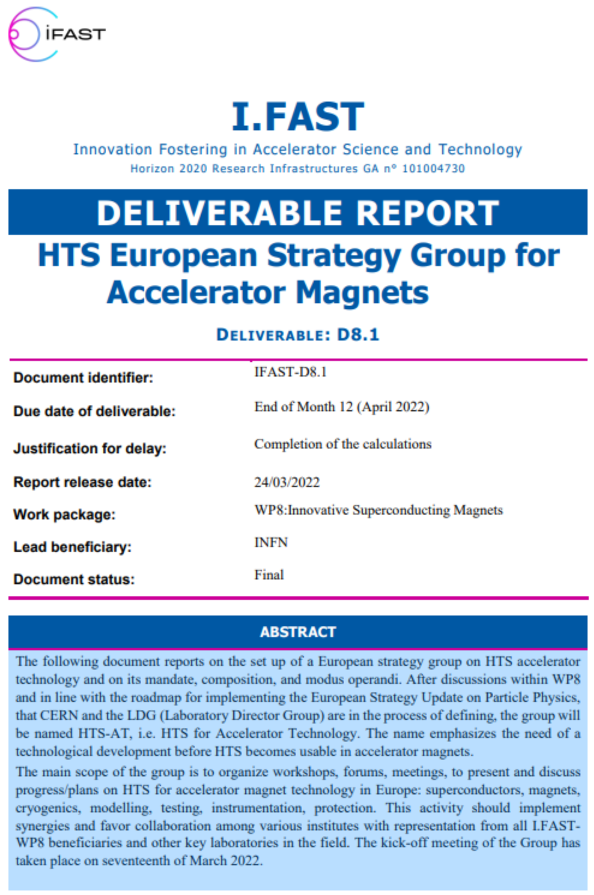
Milestone Report done by INFN CERN, and UNIGE

IFAST WP8 – MLS and DLVs

	2021													
	4	5	6	7	8	9	10	11	12	1	2	3	4	5
IFAST WP8: Innovative Superconducting Magnets	Start 1st May													
Task 8.1 - Coordination and High-Temperature Superconductor (HTS) Strategy Group													D8.1	
Task 8.2 - Preliminary Engineering design of combined Canted Cosine Theta (CCT) magnet							M32				D8.2			
Task 8.3 - Preliminary Engineering design of HTS CCT											M33			

- Deliverables
  - D8.1 (04/2022): HTS European Strategy Group (DONE) https://zenodo.org/record/6384239#.Ym-95NpBw2y
  - D8.2 (02/2022): Conceptual Design of combined CCT in LTS (DONE) https://zenodo.org/record/6389851#.YmwhA9pByUl
- Milestones:
  - M32 (10/2021) : Charac. of the first length of superconductor for low losses (DONE) https://zenodo.org/record/5901601#.YmrIvNpByUl
  - M33 (02/2022) : Conceptual design of HTS magnet **(work in progress- delay 3-4 months)**
  - → will entail a delay of at least 2 months on D5 (engineering design), hopefully not on the construction of the magnet **(however procurement of materials is a hurdle these days…)**

Deliverable 8.1 : HTS European Strategy Group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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, L. Rossi

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.

https://zenodo.org/record/6384239#.Ym-95NpBw2y

Deliverable 8.2 : Conceptual Design of combined CCT in LTS

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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

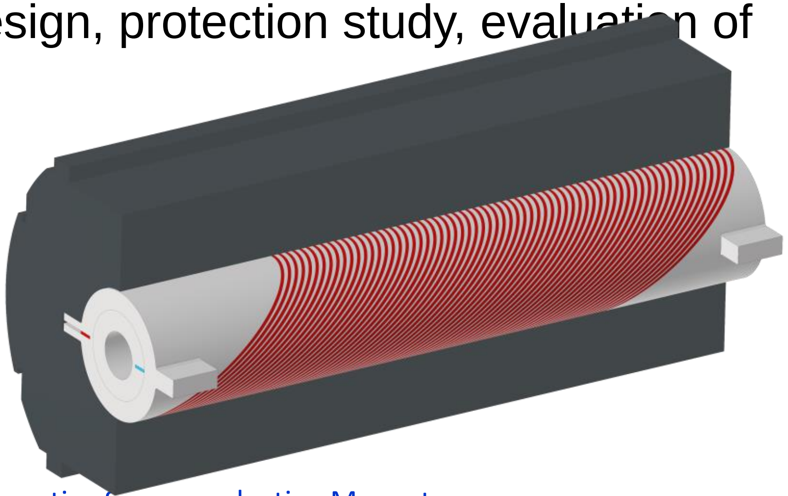
The following report presents the conceptual design study of the combined Canted Cosine Theta (CCT) magnet made using the Low Temperature Superconductor (LTS) Niobium-Titanium (NbTi). The report highlights the complete lists of parameters (target, superconductor, cable and CCT geometry), motivating the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

Task 8.2 – E. De Matteis, task leader

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

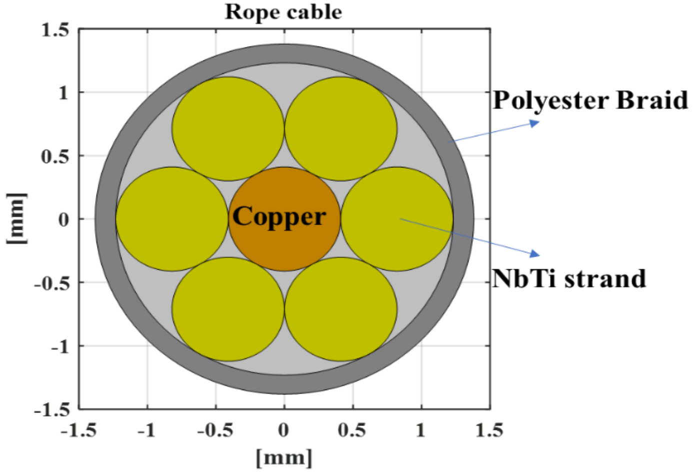


Deliverable D8.2 – Combined CCT magnet based on NbTi

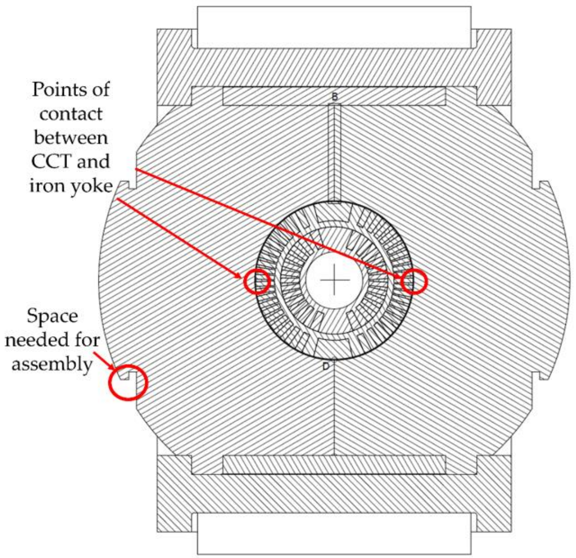
Conceptual design of the **Combined CCT magnet based on NbTi**:

- **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 and difficult to rpocure
  - → solution **PEEK (or polymer former);**

Deliverable 8.2 https://zenodo.org/record/6389851#.YmwhA9pByUl



Iron yoke as shield and collar



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

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Horizon 2020 Research Infrastructures GA n° 101004730

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:	12/11/2021
Work package:	WP8: [Innovative Superconducting Magnets]
Lead beneficiary:	INFN
Document status:	Draft 1.0

ABSTRACT

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

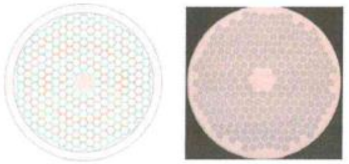
The measurement report collects the following measurements: critical current, RRR and magnetization measurements. The critical current and RRR measurements have been performed at LASA laboratory of INFN (Milan, Italy). A crosscheck measurement for the critical current has been done by CERN. The magnetization 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

Task 8.2 – E. De Matteis, task leader

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

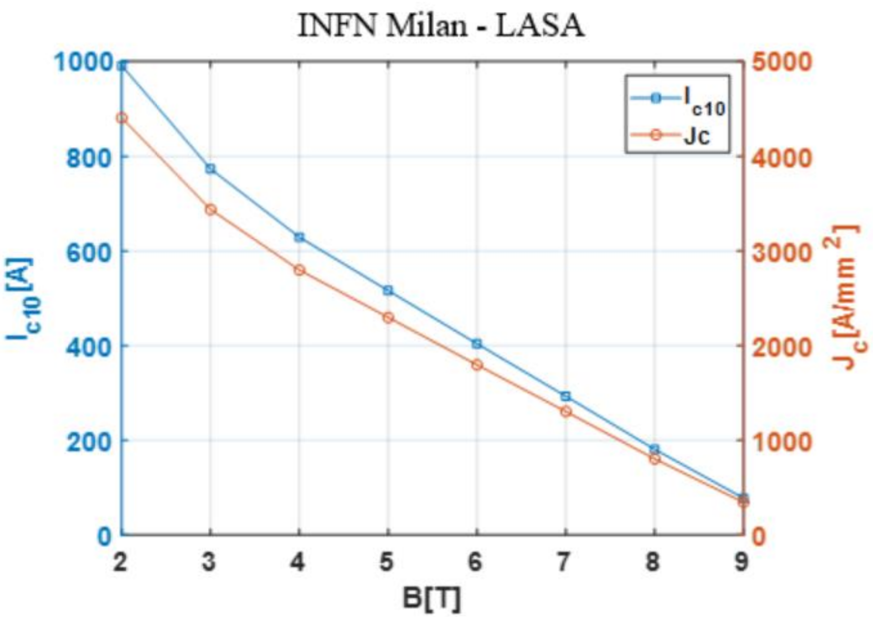
- Strand Typ LF = F58464
- SnAg5 coated strand Ø ≈ 0.821 mm
- Cu / CuMn0.5 : NbTi ≈ 1.36
- Twist length ≈ 6.6 mm

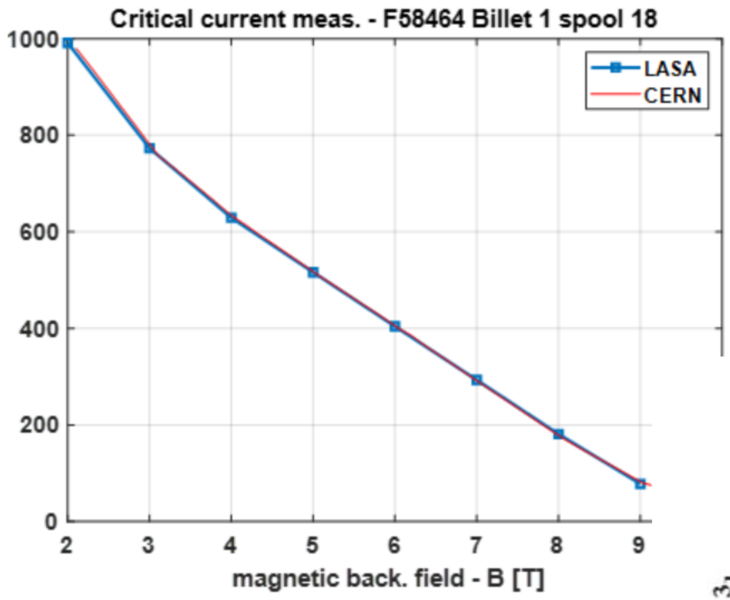


- Critical current measurements (INFN and CERN)
- RRR measurements (INFN)
- Magnetization measurements (Univ, of Geneva)

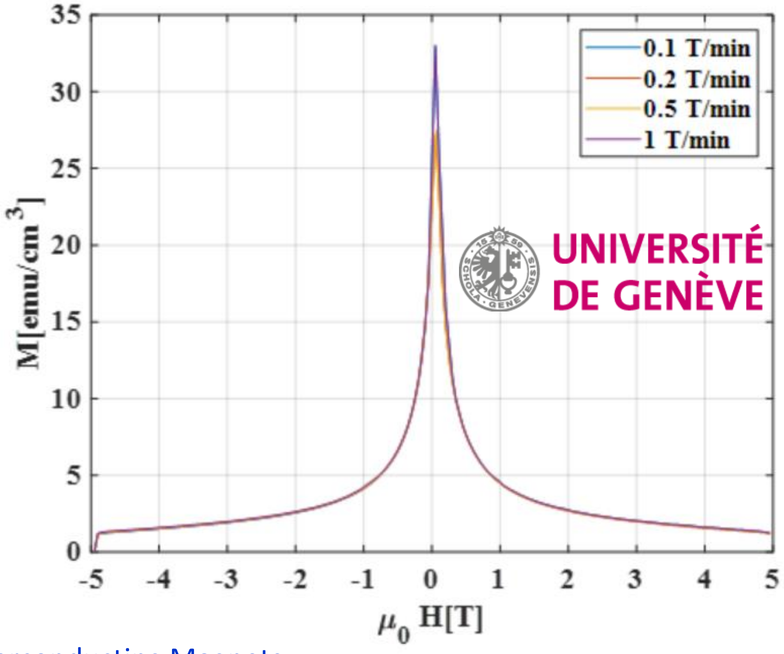
https://zenodo.org/record/5901601#.YmrIvNpByUl

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

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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):

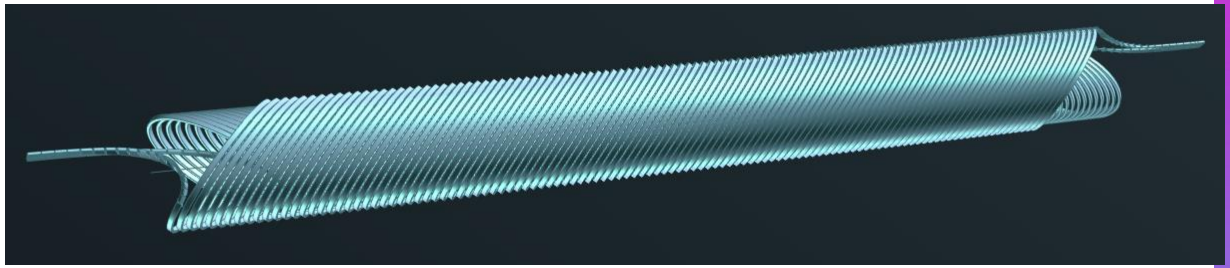
- "**Metal Insulation-like**" design with 2 layers cable (780 A x 2 tapes x 14 cables)
- "**Insulated-like**" design (added copper to conductor);

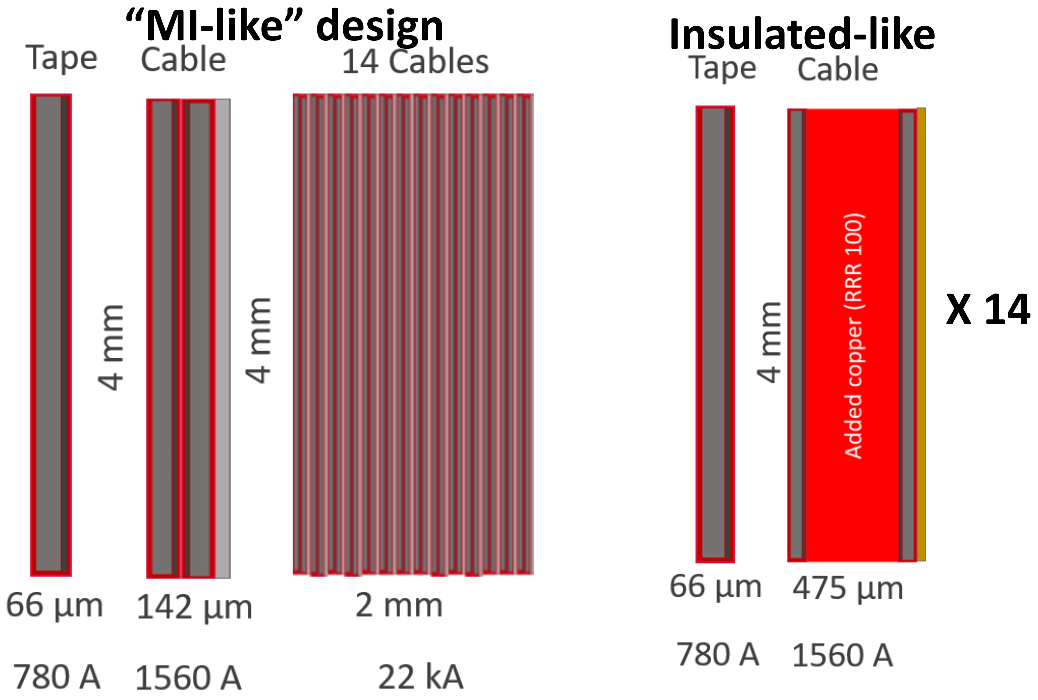
Protection aspect is the critical point for both:

- 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;

<u>Working in progress (MS Report in preparation)</u>

Task 8.3 - T. Lecrevisse (CEA) Task leader





CCT Computation Design Workshop:

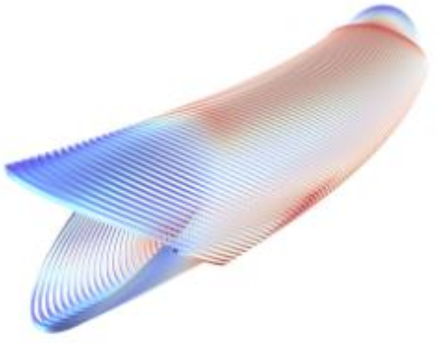
Scope: the strong interest of magnet design according to the Canted Cosine Theta (CCT) concept, pursued in both European H2020-HITRIPlus and H2020-I.FAST programs, HITRIPlus-WP8 (Superconducting Magnet Design) and H2020-I.FAST-WP8 (Innovative Superconducting Magnet)

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

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

Chair: Lucio Rossi, INFN-Milano LASA lab (HITRIPlus-W8 and IFAST-WP8 coordinator), lucio.rossi@cern.ch
Scientific Program Committee:
- Berhard Auchmann, PSI/CERN, Bernhard.Auchmann@cern.ch
- Thibaut Lecrevisse, CEA, thibault.lecrevisse@cea.fr
- Soren Prestemon, LBNL, soprestemon@lbl.gov
- Davide Tommasini, CERN, Davide.Tommasini@cern.ch

Workshop Scientific Secretary: Ernesto De Matteis (INFN-LASA Milano), ernesto.dematteis@mi.infn.it
Workshop Assistant: Sara Sabatini (INFN-Milano), sara.sabatini@mi.infn.it

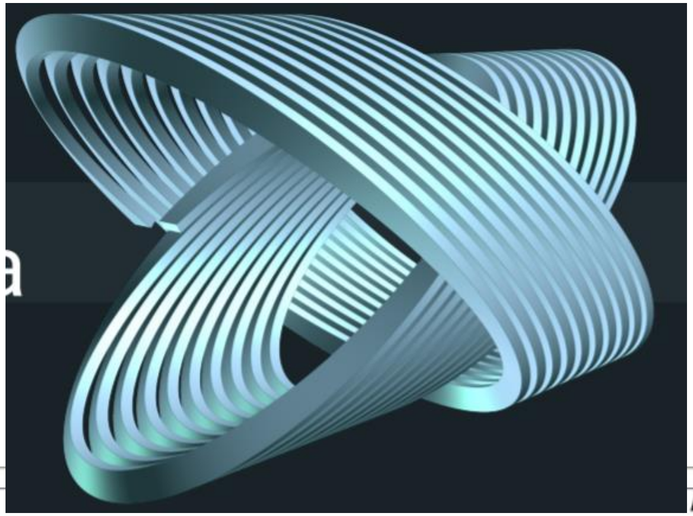


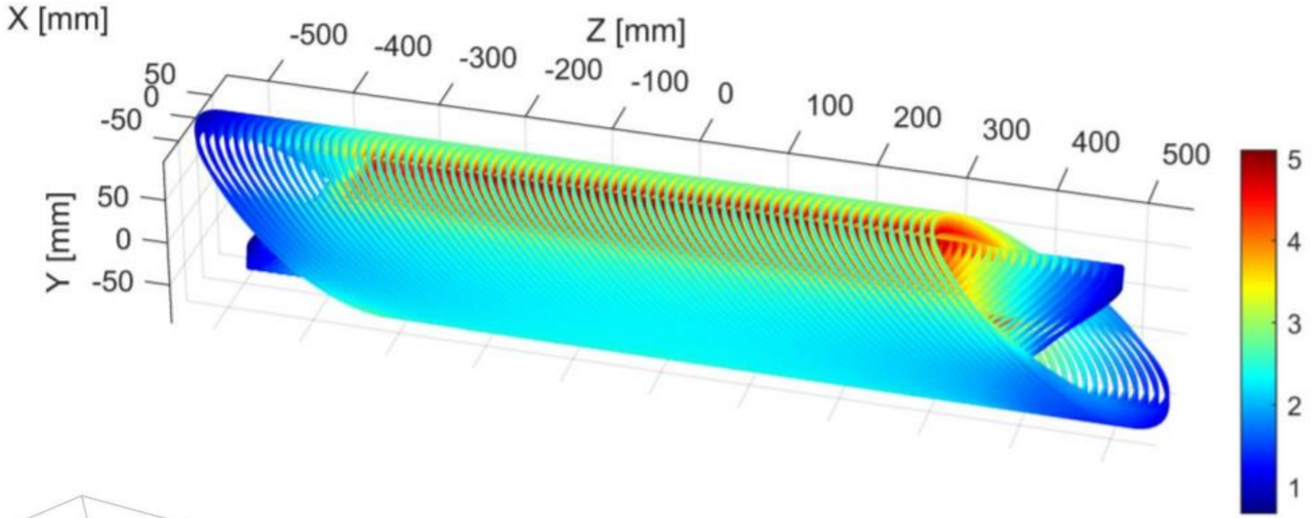
CCT-CDW - 1

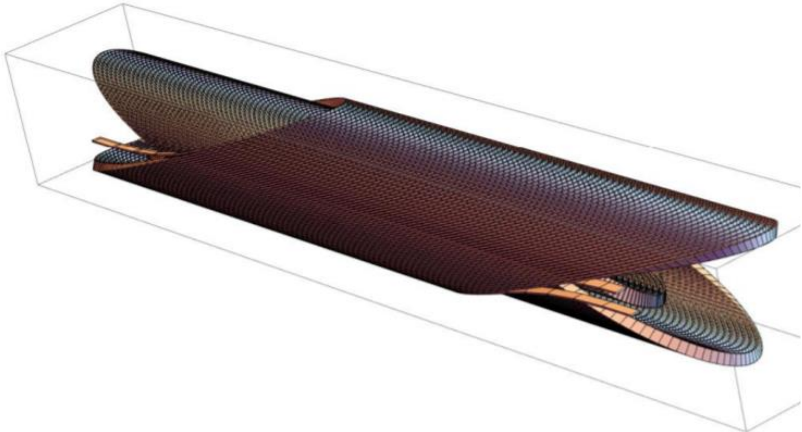
https://indico.cern.ch/event/1065779/

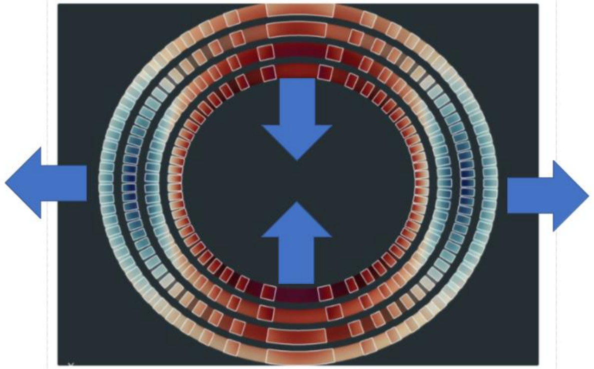
CCT-CD Workshop: Outcomes

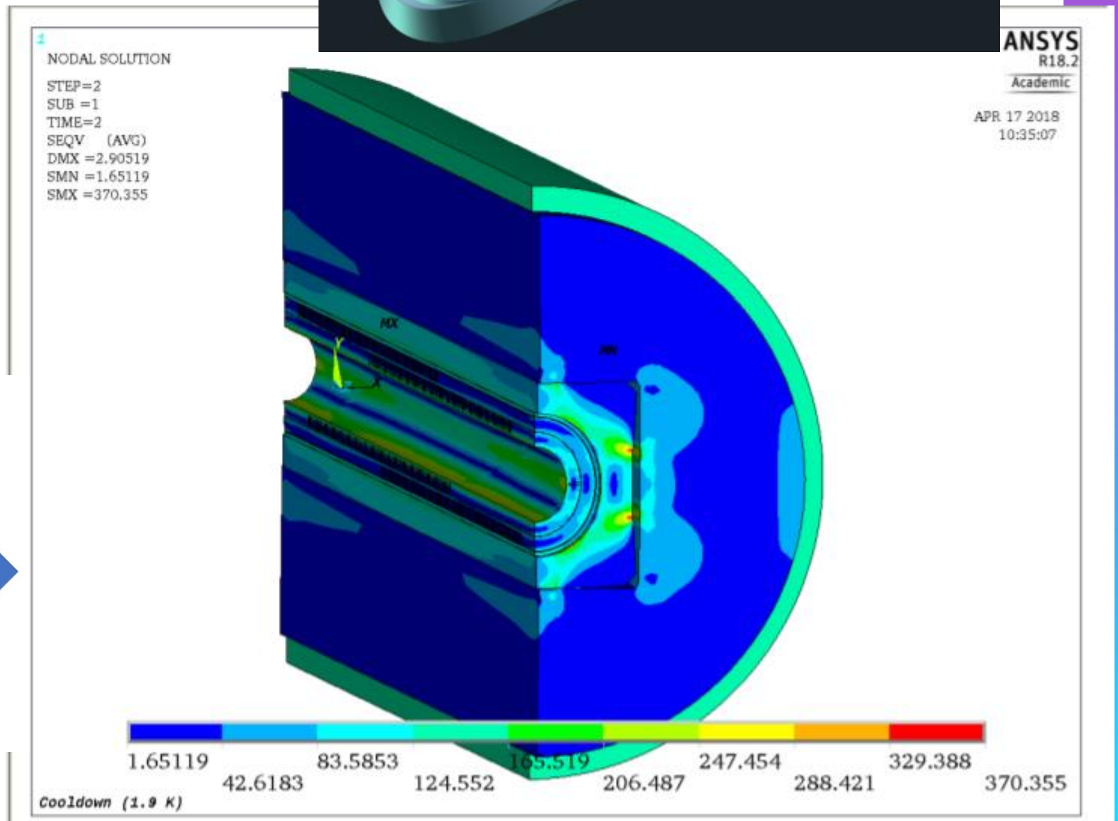
- Design and Computation Tools





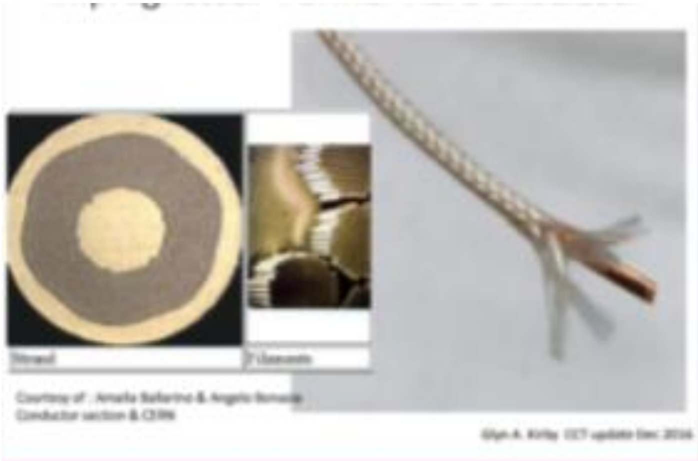


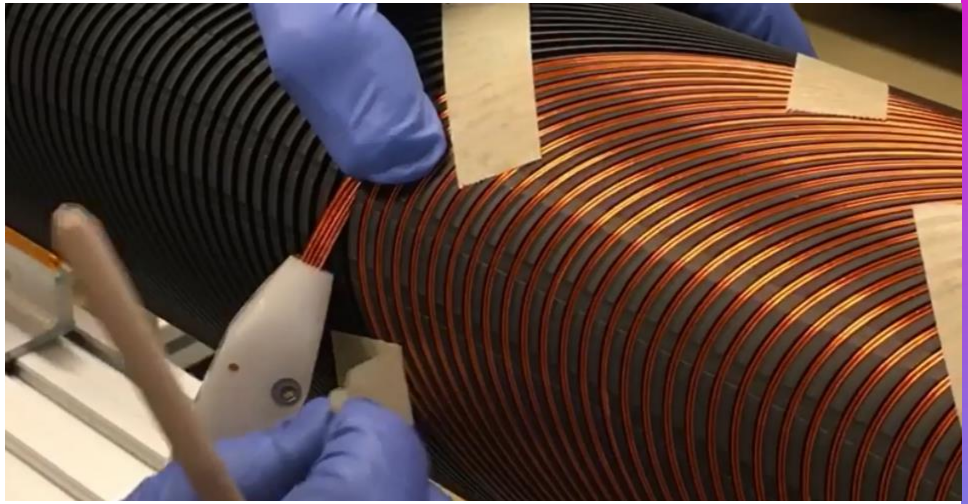


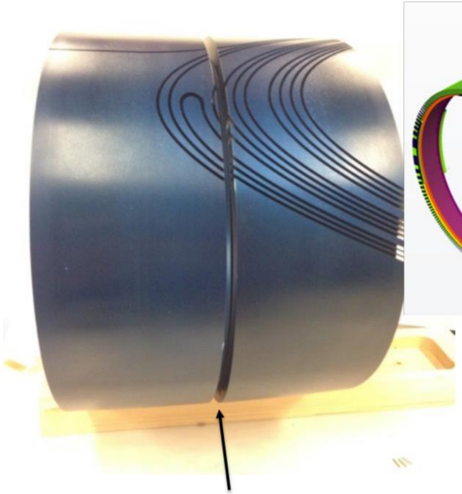


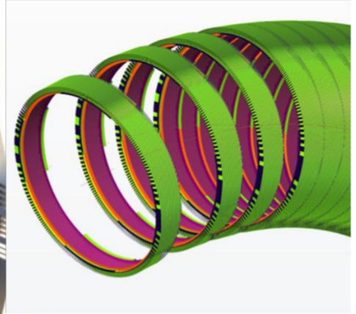
CCT-CD Workshop: Outcomes

- Technology for CCT

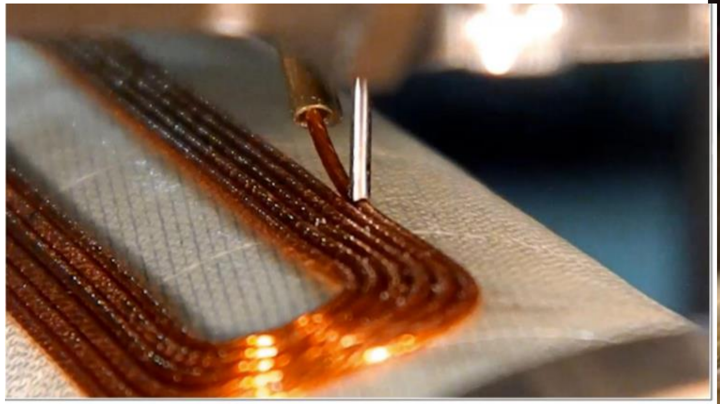


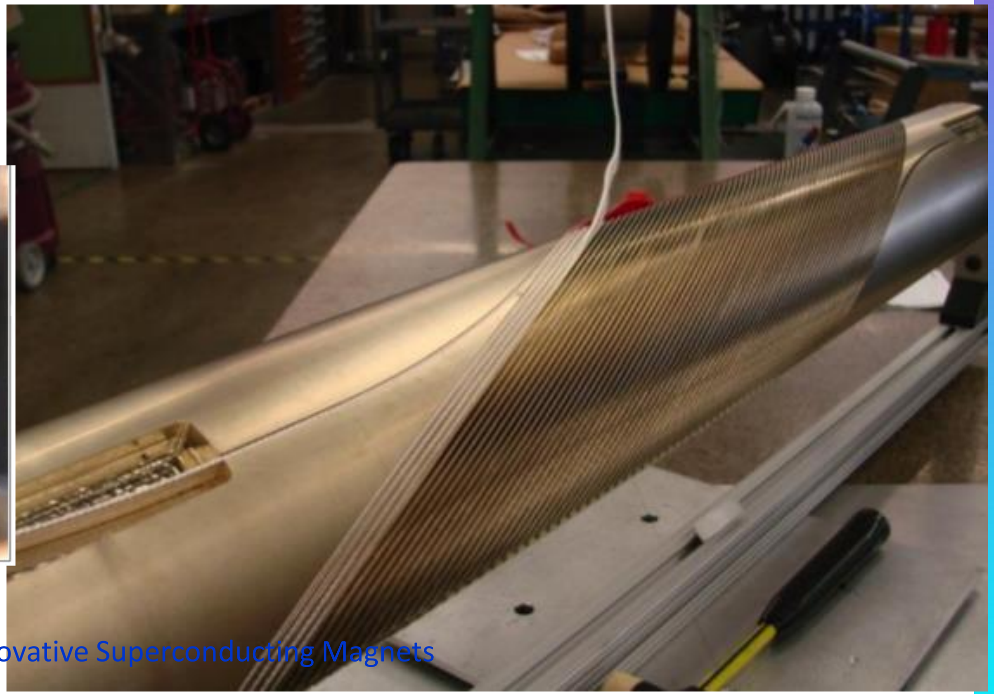






Matching parts





Next steps

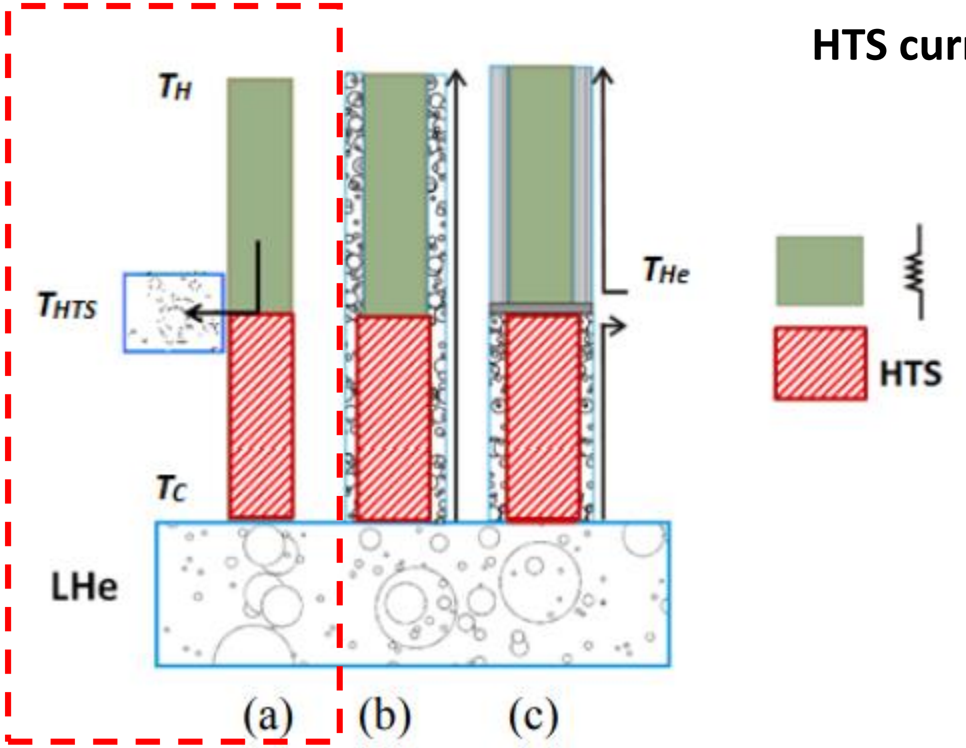
- **HTS workshop planned in February 6-10, 2023, hosted by CERN (A. Ballarino chair).**
- Finalization of the Conceptual Design of HTS CCT magnet.
  - **CEA → INFN**
  - **Define conductor and protection**;
  - Prepare the Engineering Design (Deliverable 8.3 – 10/2022 → **12/2022??).**

- Engineering Design of the Combined CCT magnet based on NbTi:
  - Former tests: polymer or metal – Aluminum Bronze materials;
    → keep an eye on the WP10 on Additive manufacturing…
  - Winding tests: dummy rope and tools for tests;
  - Industries will be more involved and slowly take the lead of the construction.

iFAST

Thanks for the attention!!!

Focus on Power consumption of Current leads (Last IFAST/HITRIplus meetings)



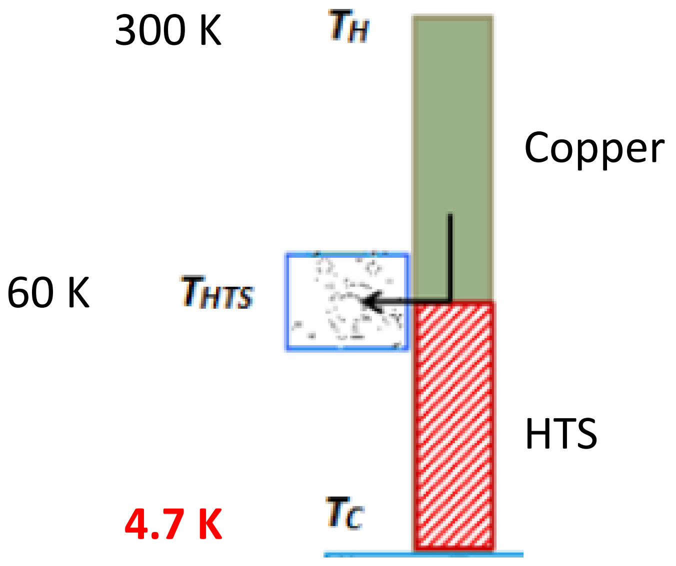
HTS current leads : cooling scheme[1]

(a) HTS conduction-cooled current lead;
(b) HTS self-cooled current lead;
(c) HTS gas-cooled current lead.

T_{HTS} is the temperature at the top end of the HTS part

[1]Amalia Ballarino, ''Current Leads, Links and Buses'', CAS-CERN Accelerator School: Superconductivity for Accelerators, Erice, Italy, 24 April - 4 May 2013

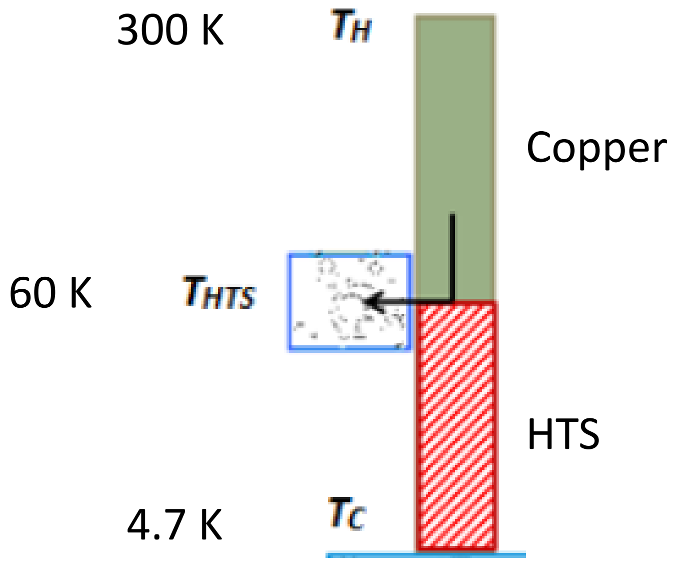
CCT configuration: HTS conduction-cooled current lead



The CLs consist of a copper resistive part between room temperature and 60 K, and an HTS part between 60 K and 4.7 K.

The 60 K temperature should be provided by a cryo-cooler, which acts as heat-sink for the upper resistive part of the leads

CCT configurations: current leads power consumption



Resistive part between 300 K and 60 K:

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

2 x Rutherford cables (I ~10 kA) → $Q_{c,min} \sim 460\ W$

2 x 10 ropes (I ~1.5 kA) → $Q_{c,min} \sim 70\ W$

For each CL

Are there available cryocoolers?

Current Limitations for NbTi and Nb3Sn supercondutors

The same CL at zero current absorbs the 50% of the nominal power (nominal current) if made by phosphorus deoxidized copper (much more if made by pure copper).