European Laboratory Directors Group Meeting and Accelerator R&D Workshop

June 6-7 2024
Brookhaven National Laboratory

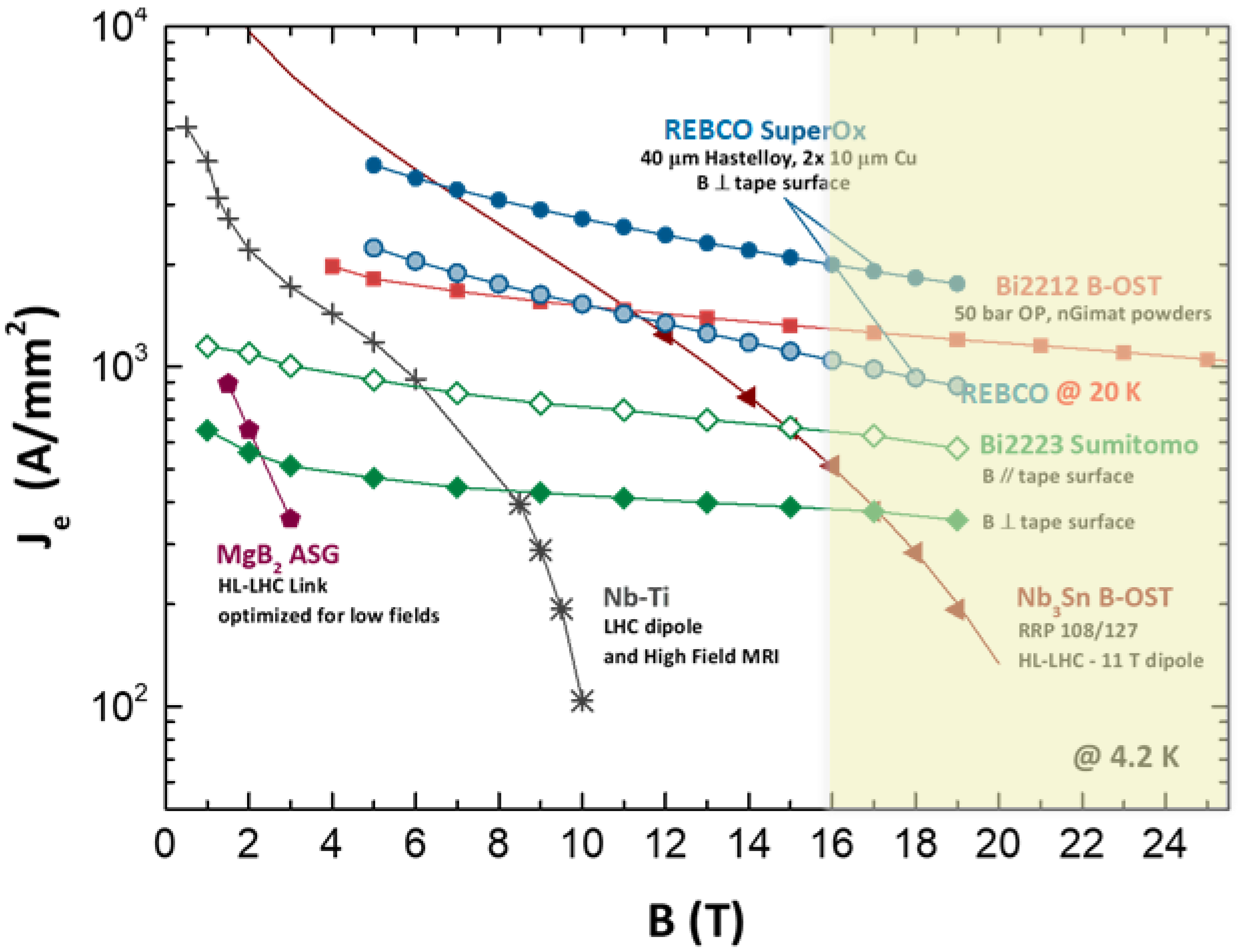
High Temperature Superconductors Status and Plan in Europe

A. Ballarino, CERN

With input from A. Malagoli (SPIN), A. Kario (Un. Twente), B. Holzapfel (KIT), Th. Lecrevisse (CEA), B. Auchmann (PSI), C. Senatore (Un. Geneva)

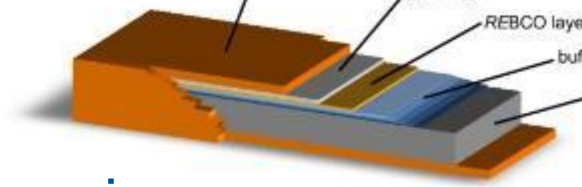
HTS for High Field Magnets

- HTS: an **enabling technology** for high fields (> ~16 T). A **sustainable technology** for future accelerators
- **Advantages**: high current, high field, higher operating temperature, no training, thermal stability,…
- To exploit potentials and bridge the technological gap wrt LTS, rigorous **R&D** and **innovation** are required, both on conductor and magnets
- Focus in **Europe** is on **REBCO**. Recently, work on **Iron Based Superconductors** has also started



Challenges

REBCO Tape



- **Conductor**
  - Understanding and improving performance of **REBCO tapes** – in collaboration with industry
  - Development of **high-current cables** that meet requirements for use in accelerator magnets (field quality, protection, …). Rutherford is not feasible, Roebel is not affordable/mature, stacks of tape does not meet field quality requirements
- **Magnets**
  - Develop **HTS magnet technology**, including dealing with **high mechanical forces** in compact high field magnet structures and solving **quench detection/protection issues**

Important synergy with other applications for society (fusion, medical applications, electrical applications including power transmission, aircraft and marine use)

HL-LHC Cold Powering System
93.4 kA DC, MgB_2 and REBCO
HTS in GHe at up to 60 K

HFM HTS Collaborating Institutes

Superconductor

KIT
Karlsruher Institut für Technologie

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

CERN

Consiglio Nazionale delle Ricerche
SPIN

UNIVERSITY OF TWENTE.

Magnets/Magnet Technology

cea

CERN

UNIVERSITY OF Southampton

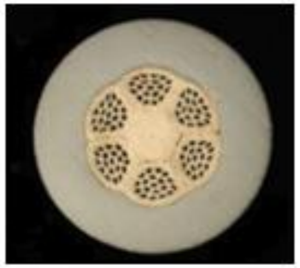
PAUL SCHERRER INSTITUT
PSI

Iron Based Superconductors

Iron Based Superconductors

- **China** is the only country that today **invests significantly in IBS** for high field applications
- **Ba122 potentials**
  - High upper critical field (> **70 T @ 20 K**)
  - Tc ~ **38 K**
  - **Low anisotropy**
  - **Multi-filamentary wire** or tape via **Powder In Tube technology** – industrialized for BSCCO 2223, BSCCO 2212, MgB_2 and Nb_3Sn. Potentially low cost

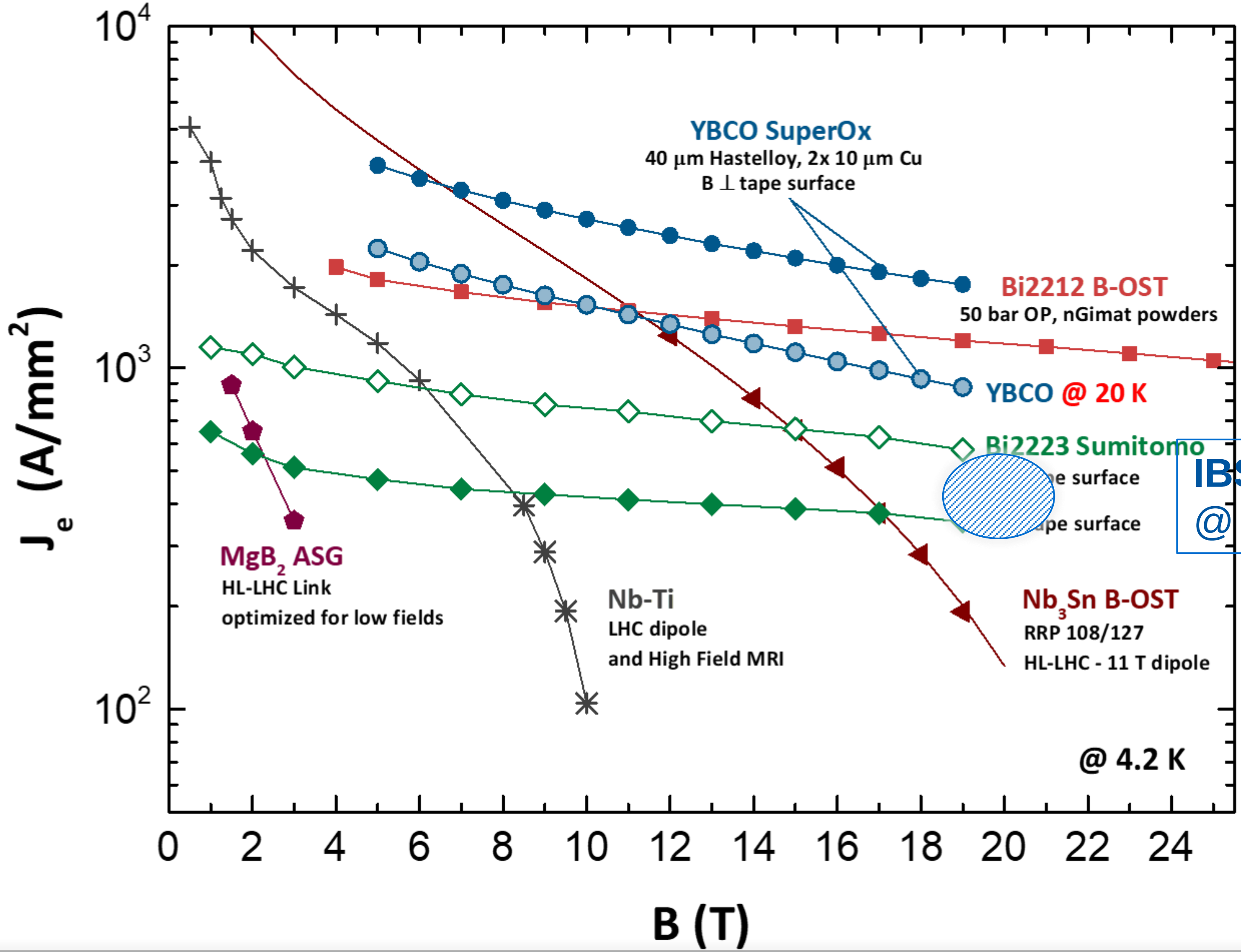
Φ ~ 1 mm



IBS 122, Institute of Electrical Engineering, Beijing

- R&D to **answer the driving question**: can 122 IBS become a viable high field conductor (preferentially in the form of round wire) ?
- **Activity at SPIN, Genova**, in the framework of a HFM collaboration agreement with CERN: **laboratory to develop Ba122 wire**

Collaboration Agreement CERN/SPIN



IBS Target: Je > 400 A/mm^2 @ **20 T** and ~ **10 K**

Explore **React&Wind** Technology (unlike Nb_3Sn and like Nb-Ti)

Activity at SPIN, Genova - IBS

CERN-SPIN HFM Agreement. Activity started in November 2023

Consiglio Nazionale delle Ricerche

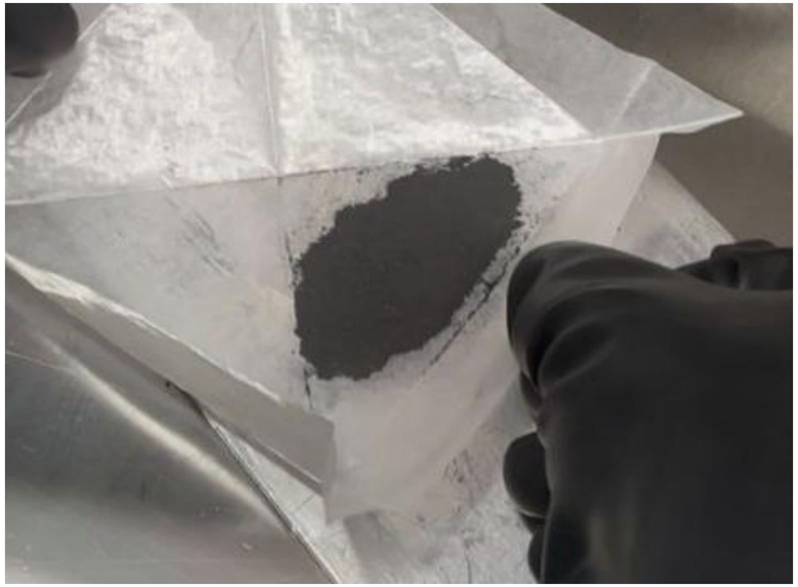
SPIN

Activity at SPIN, Genova - IBS

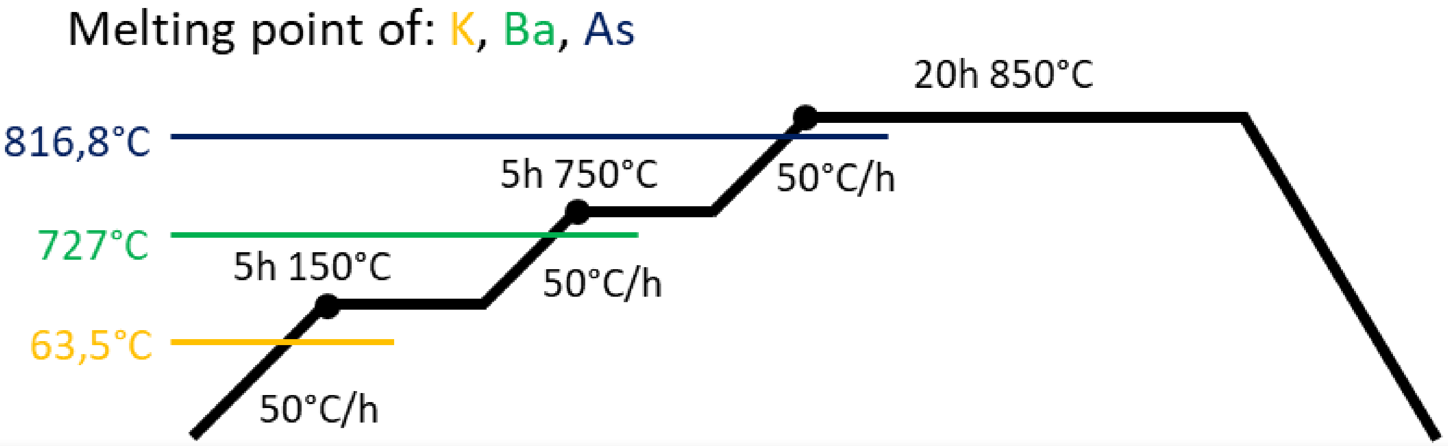
Precursors mixing and Ba-122 powder synthesis

Consiglio Nazionale delle Ricerche

SPIN



- Pure elements mixed by milling
- Stoichiometric ratio + ~20% wt of K
- High performance glove-box to control the Oxygen contamination
- **<u>1 step heat treatment</u>**



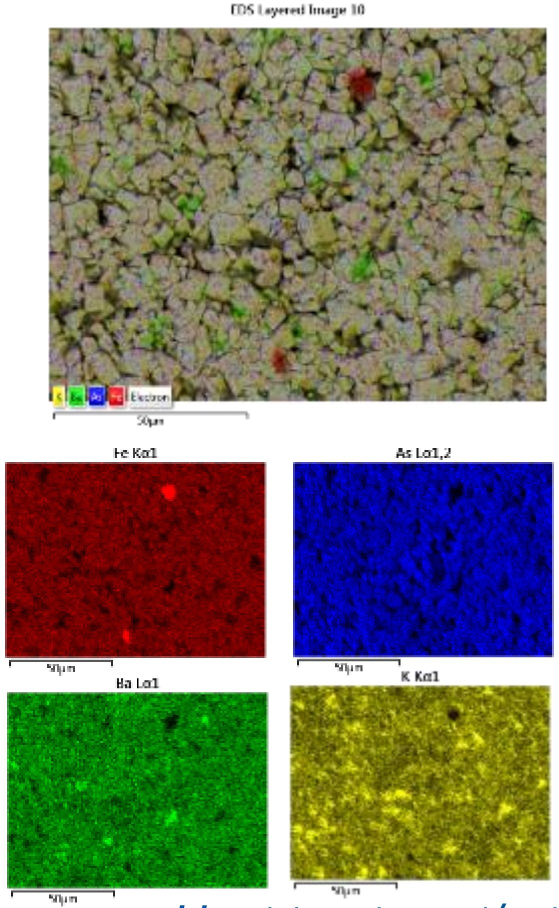
Activity at SPIN, Genova - IBS

Consiglio Nazionale
delle Ricerche

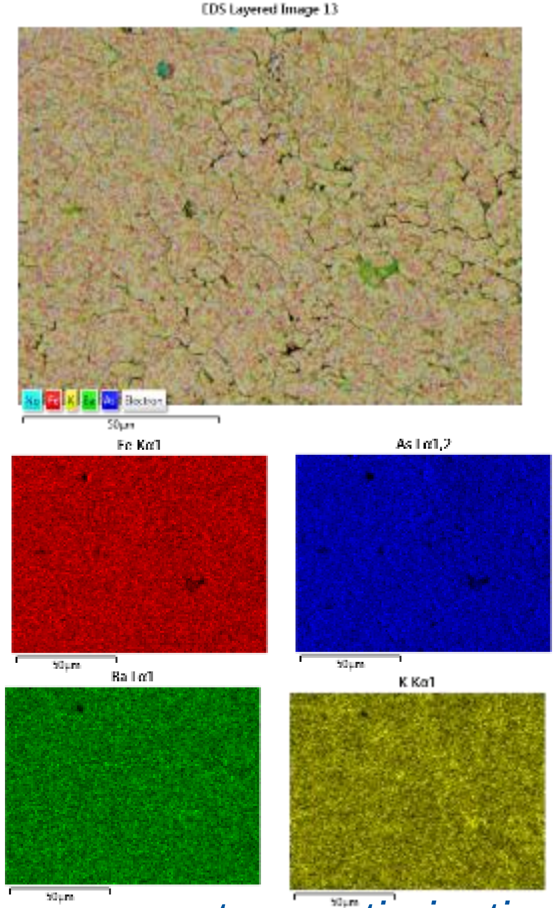
SPIN

Innovative rotating furnace

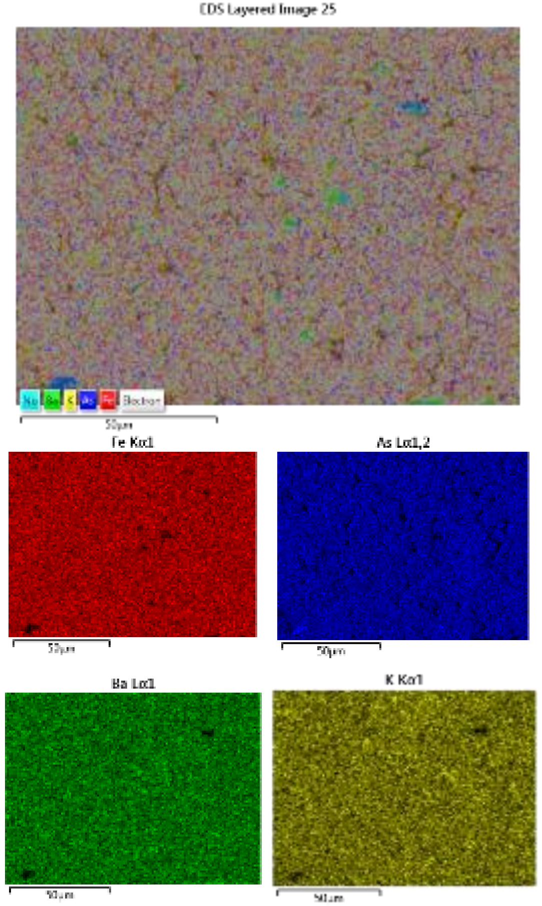
PWD – II 4 gr



PWD – V 6 gr



PWD – XXI 12 gr



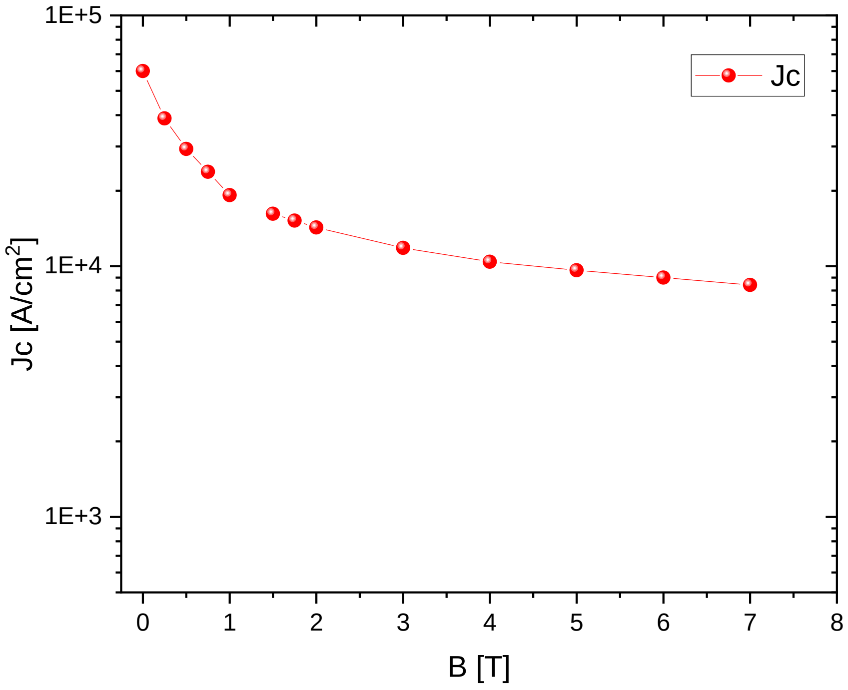
Heat treatment/rotation parameters optimization

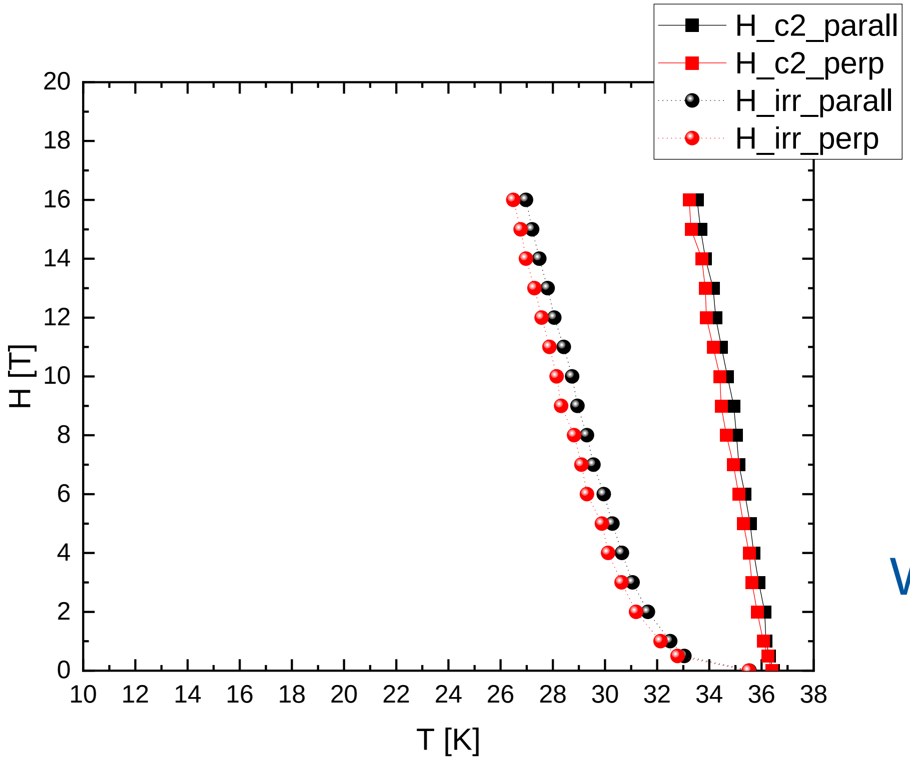
High purity
High homogeneity

Activity at SPIN, Genova - IBS

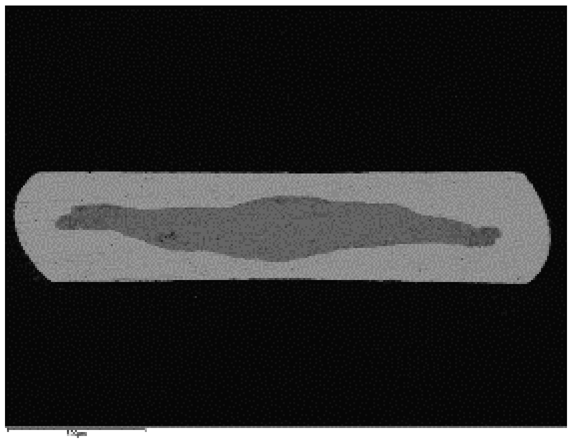
Consiglio Nazionale delle Ricerche | SPIN

- **First preliminary results on simple mono-filamentary Ag-sheathed tape**
- **A step towards the isotropic multifilamentary wire development**





Ba-122 tape



Width~2 mm, Thickness~0.4 mm
Short samples (~ 2 m long)

REBCO

Activity at KIT – REBCO Conductor

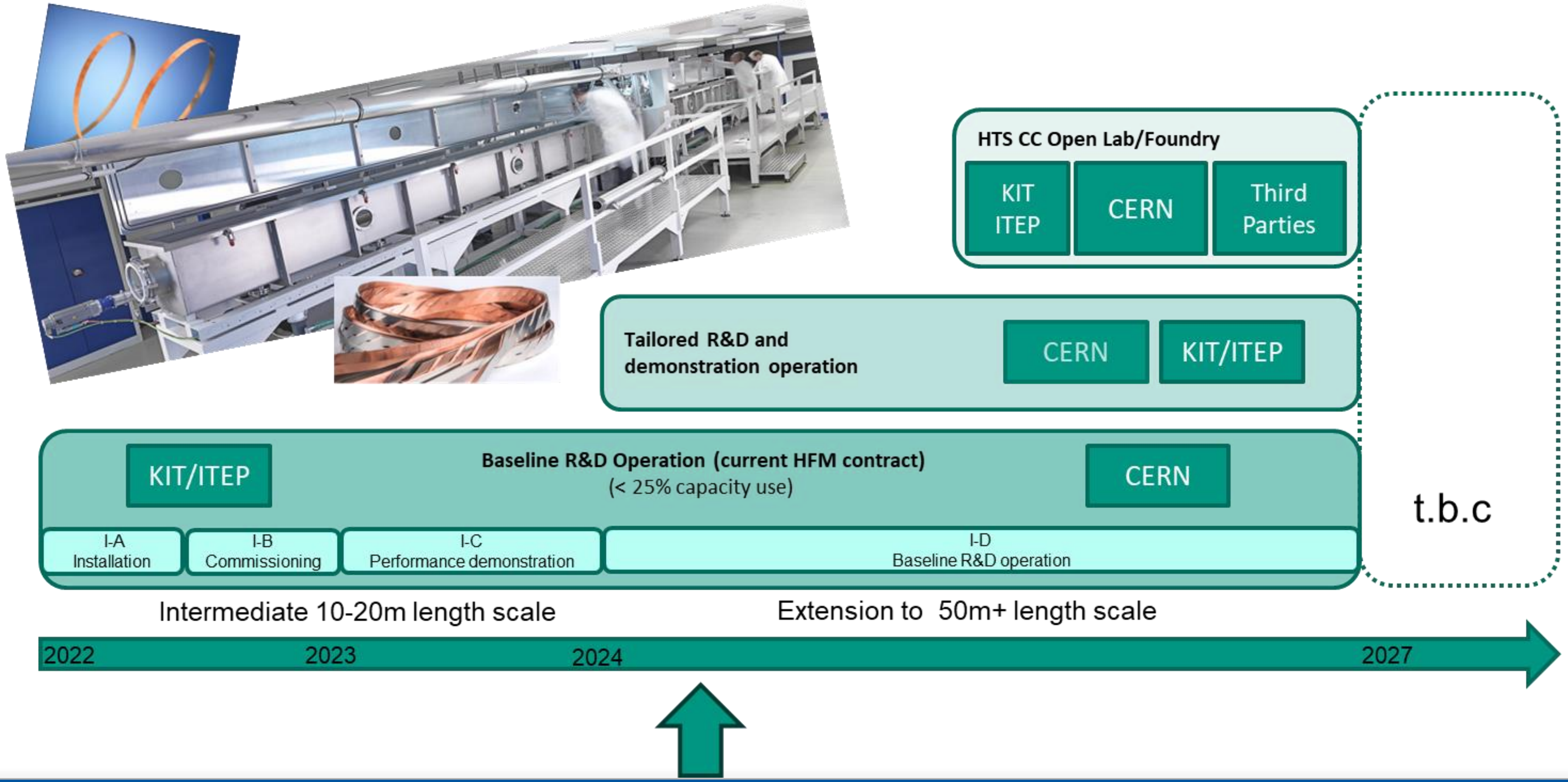
KIT-CERN Collaboration on CC

KIT-CERN Collaboration on Coated Conductors

Program and Timeline

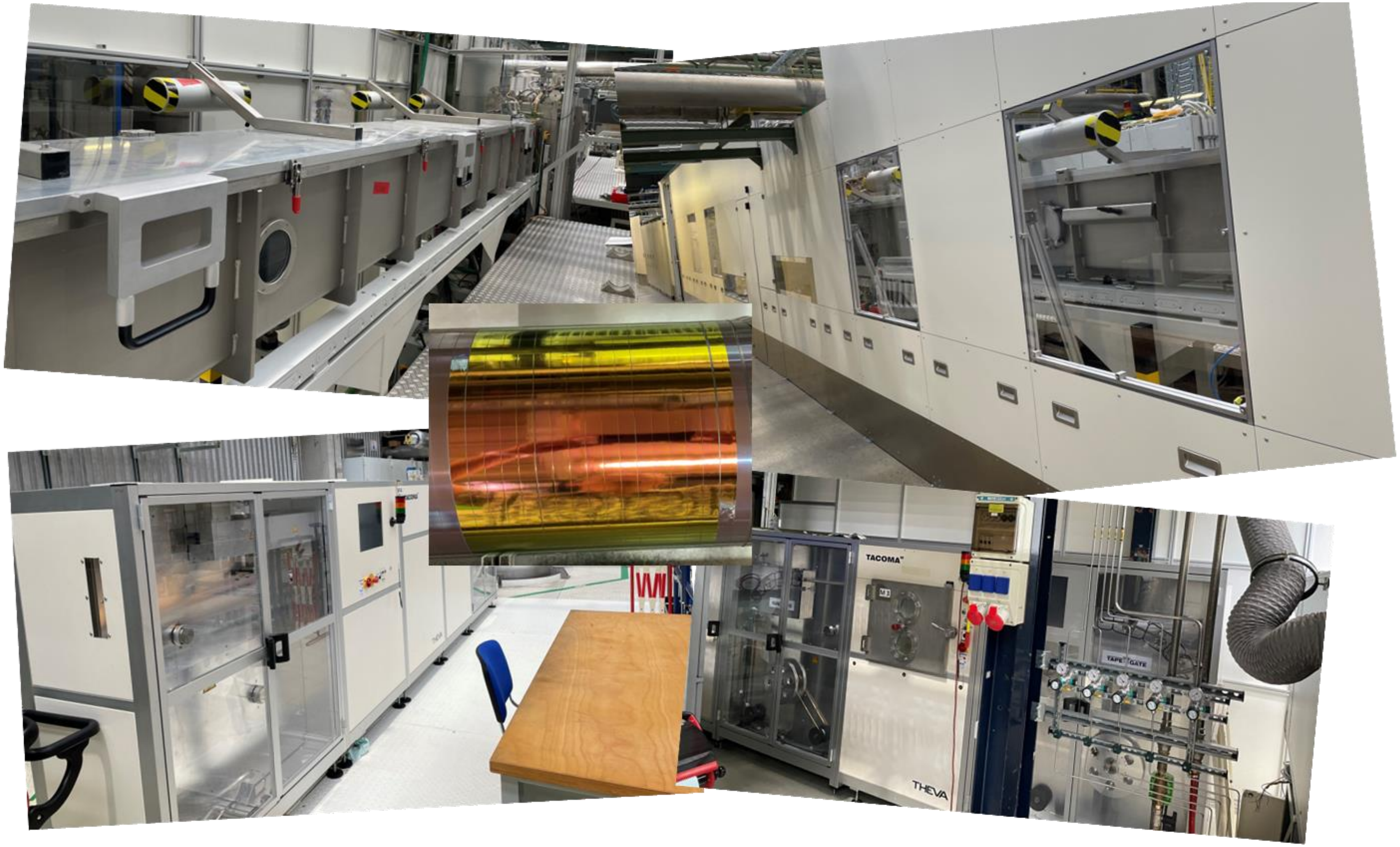
Karlsruhe Institute of Technology

CERN



Activity at KIT – REBCO Conductor

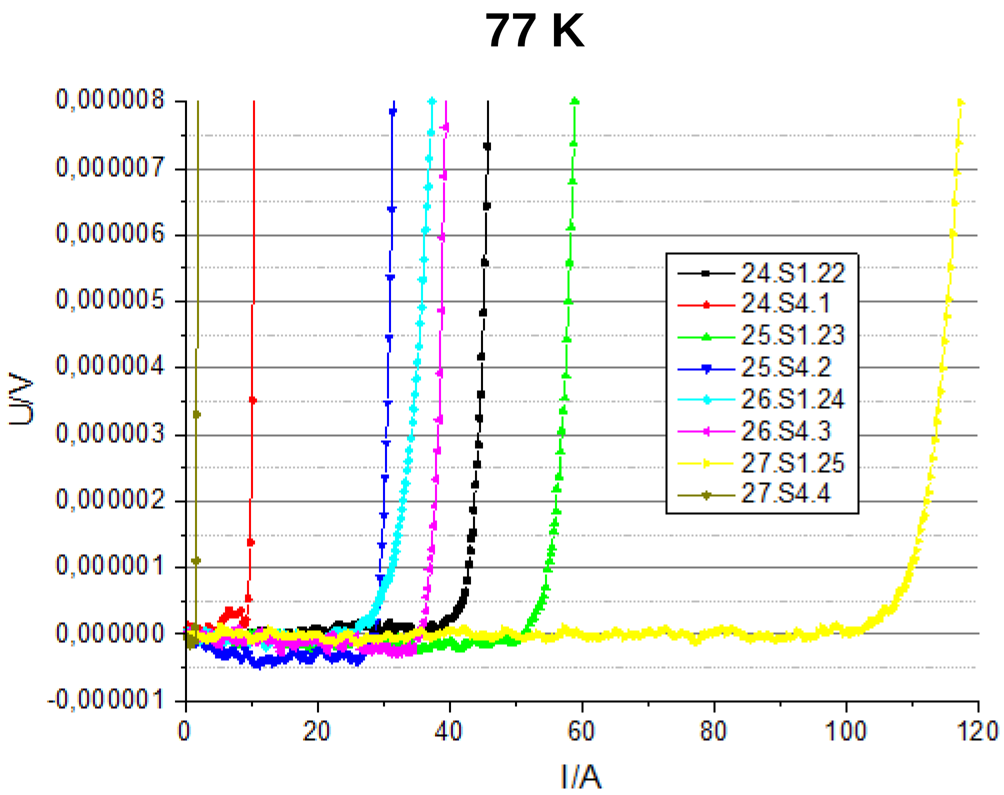
KIT-CERN Collaboration on CC

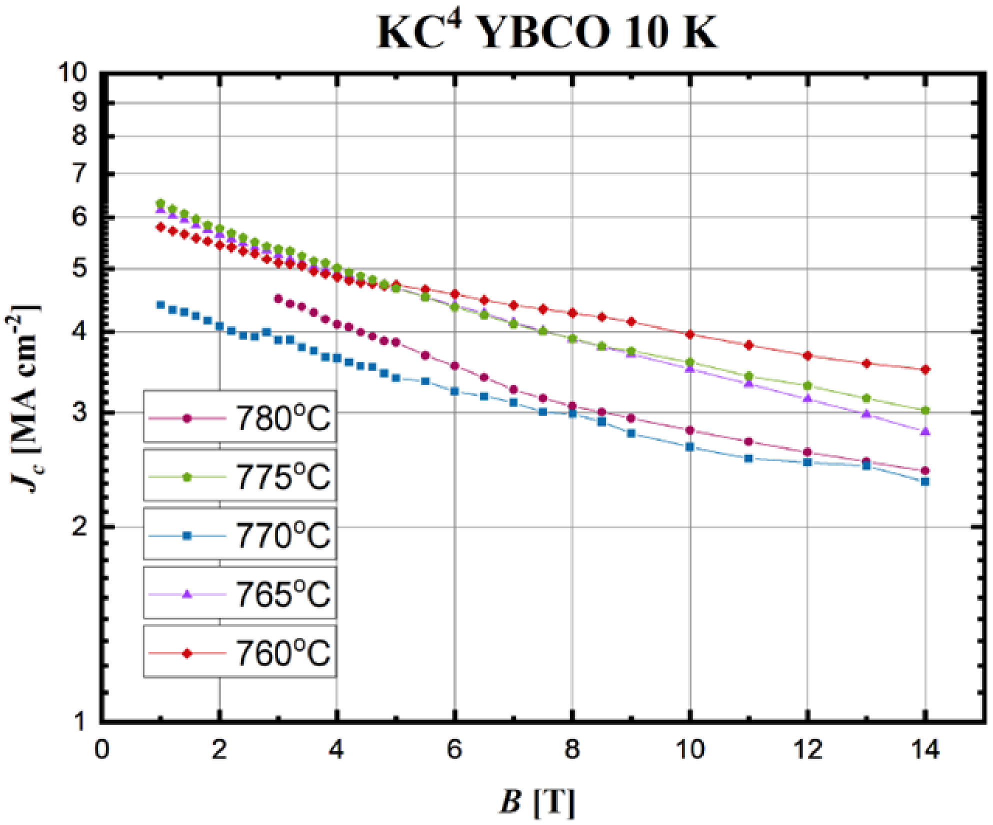


Activity at KIT – REBCO Conductor

- KC4 Baseline **R&D operation** (10 m long samples) within the HFM program **since March 2024**
- Experiments to optimize/check deposition conditions for regular Y123 coatings
- IBAD MgO tapes from Faraday, SUNAM, HTS and Shanghai SC under investigation- LMO and CeO buffer layer termination of IBAD MgO tapes
- So far **61 full deposition runs** (each run inclides 1 day for PLD, 1 day for silver coating, 1 day for oxygenation)
- In total **92 tape pieces** prepared
- Launched **tailored research program** for understanding and improving **internal resistance in tapes**

Activity at KIT – REBCO Conductor



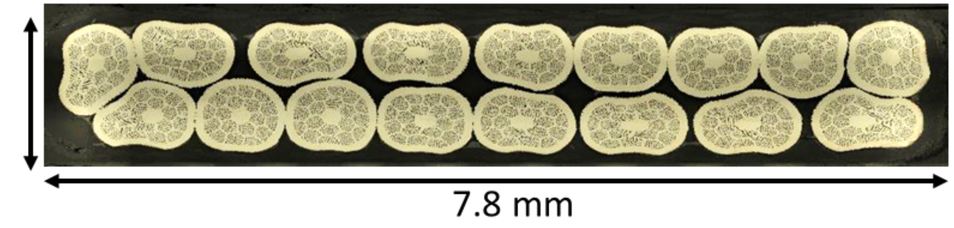


J_c(77K, self field) > 1MA/cm^2
Good homogeneity demonstrated

High field J_c values meet expectations
More characterization needed

Activity at Twente University

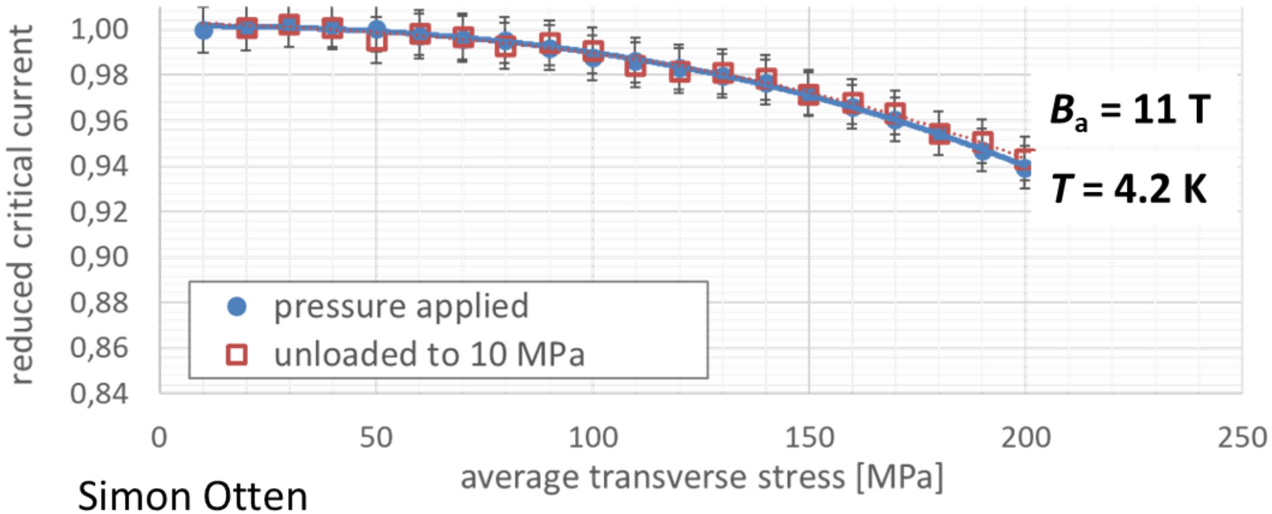
BSCCO-2212 Rutherford cable: critical current versus transverse stress



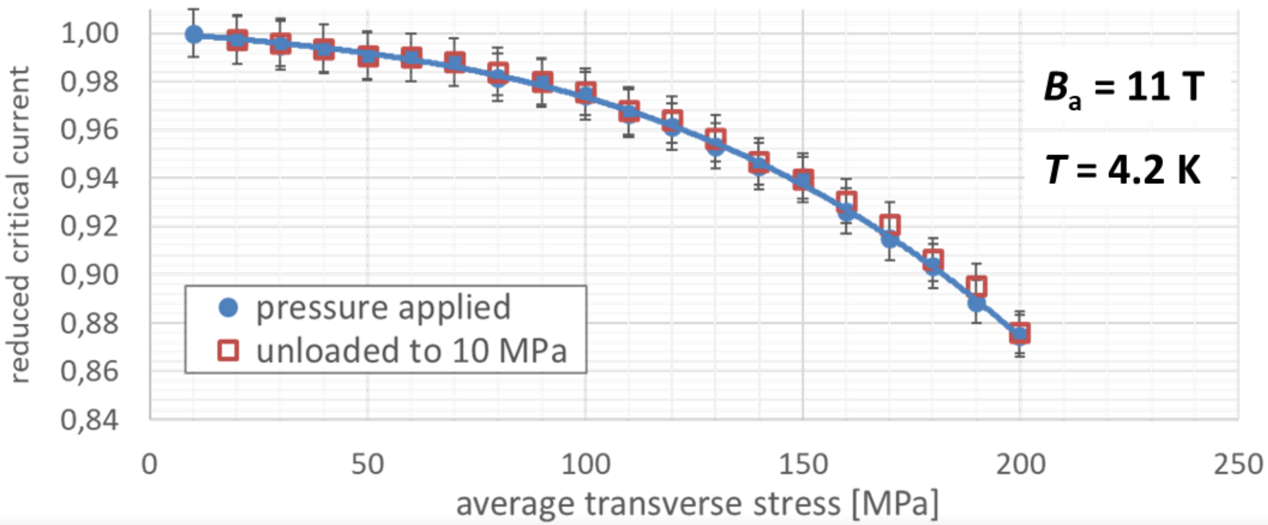
Applied magnetic field 11 T, normalized to initial I_c of 2.70 kA (sample 3), and 4.07 kA (sample 4)

- Measurement sequence:
  10, 20, 10, 30, 10, 40 MPa, etc.

- **5% irreversible degradation reached at:**
  170 - 200 MPa in sample 3 and
  120 - 150 MPa in sample 4



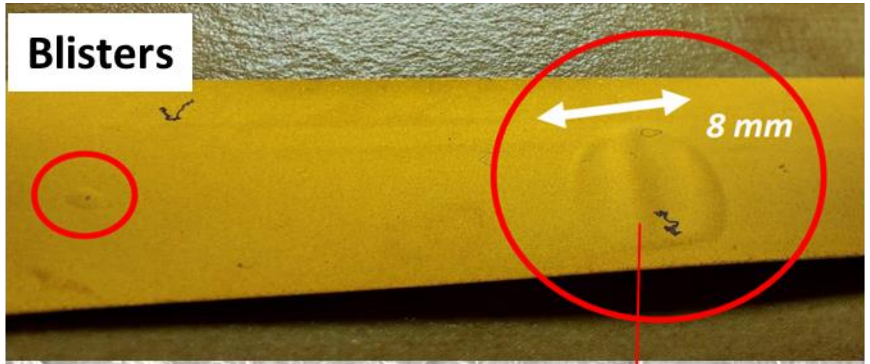
Simon Otten

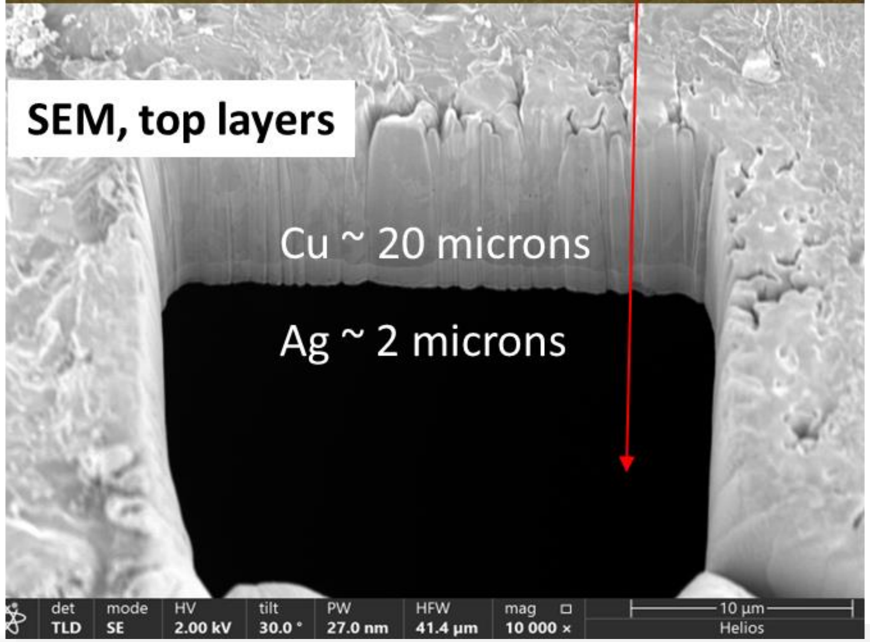


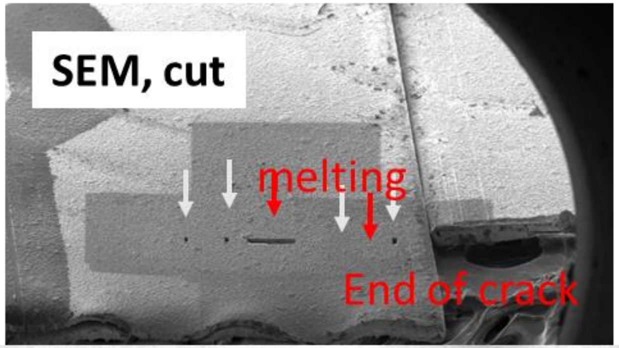
Activity at Twente University

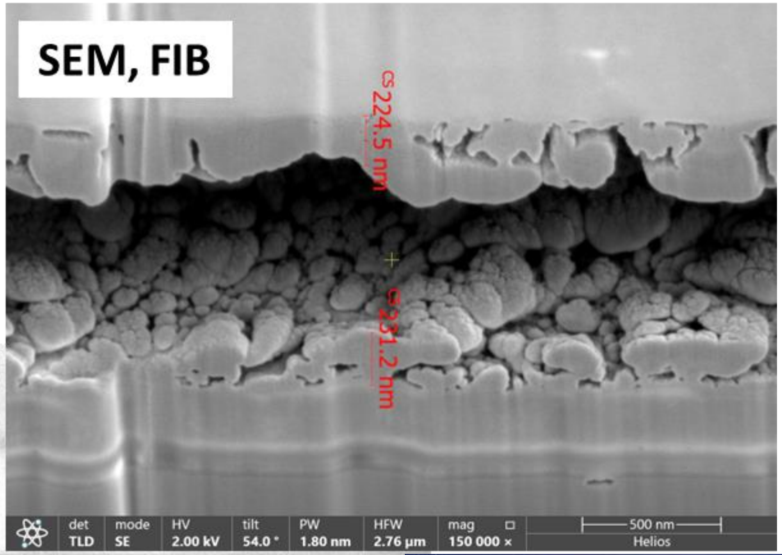
*Re*BCO pancake coils: NI dry double-tape coil degraded at LHe, postmortem analysis - Microstructure

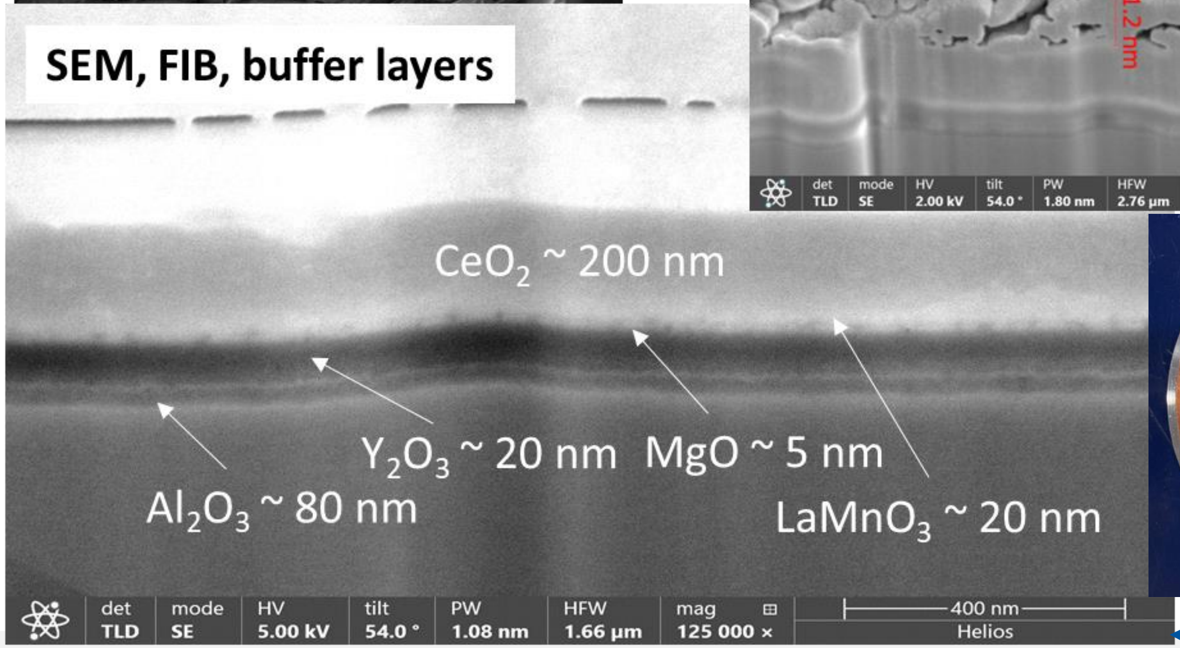
Melissa Goodwin

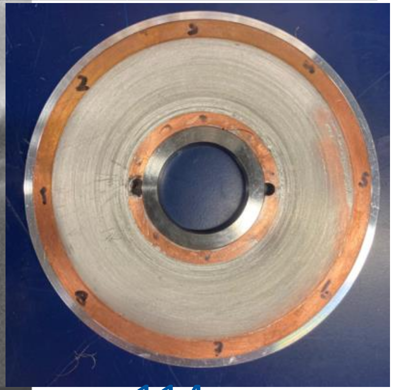










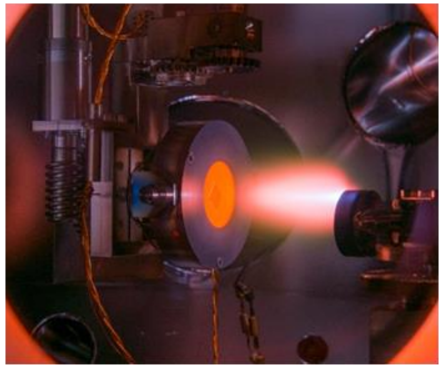


114 mm

Irreversible degradation of the tape, most probably due to local defects inducing quench with temperatures reaching several hundreds Celsius

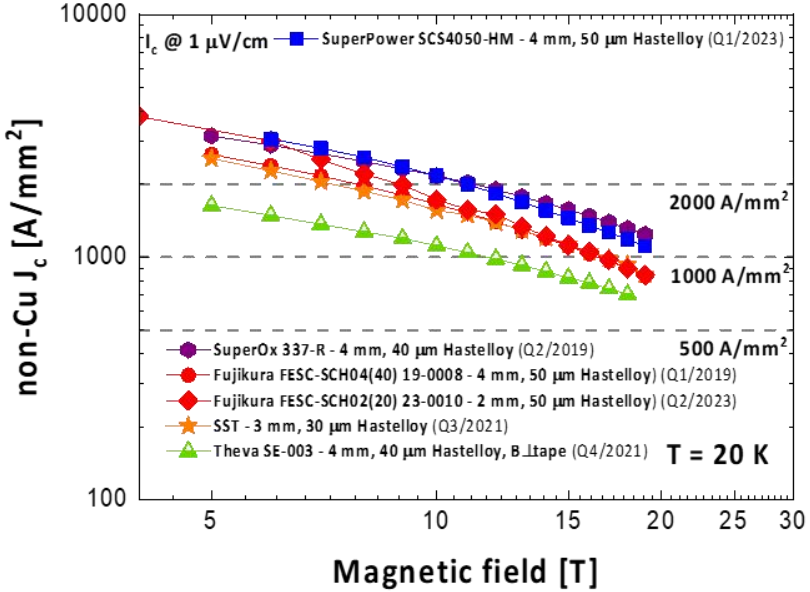
Activity at University of Geneva

UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES

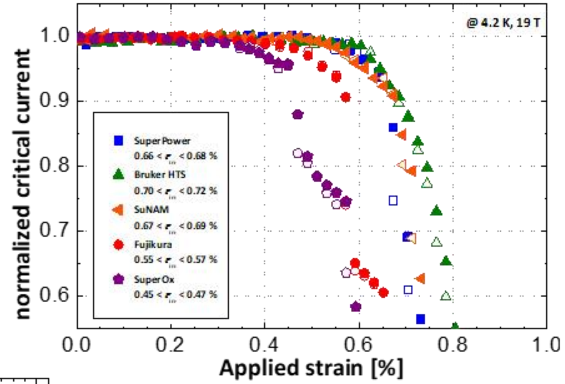


R&D on materials

HTS film deposition by physical and chemical routes

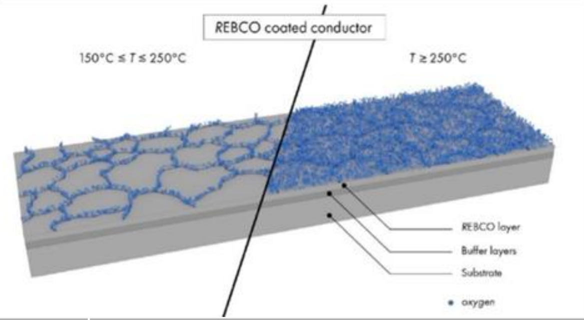


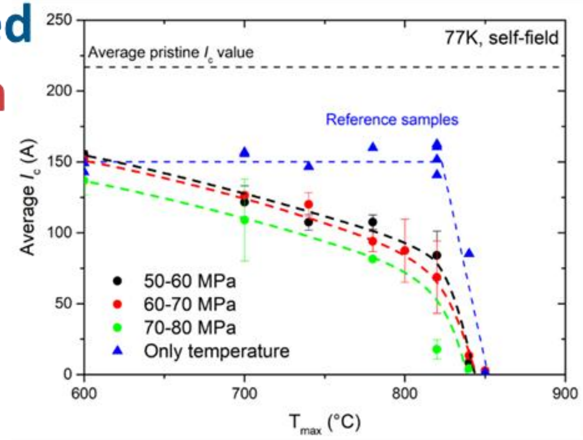
High-field/Low-temperature characterization of the critical current surface up to 20 T

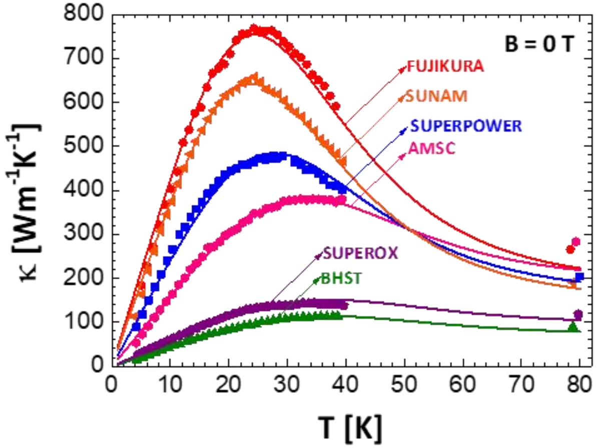


Thermo-mechanical studies

Heat and pressure induced performance degradation







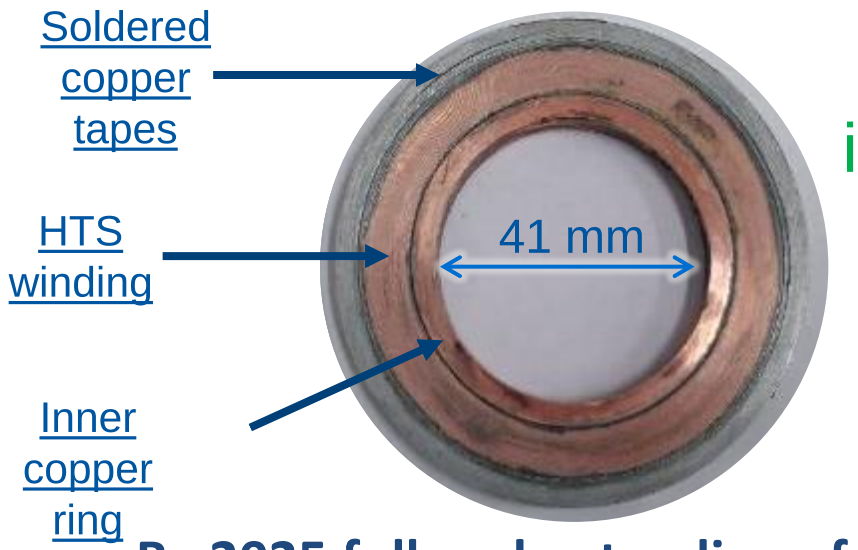
Electromechanical and Thermophysical properties to support magnet design

Activity at CEA

HTS Metal-Insulated technology development at CEA towards 20 T dipole magnets: pancakes and racetracks

First windings completed

Inner ring : 3 mm thick, OD 41 mm
Outer ring : 3 mm thick (100 µm copper tape)
HTS Winding : 50 turns

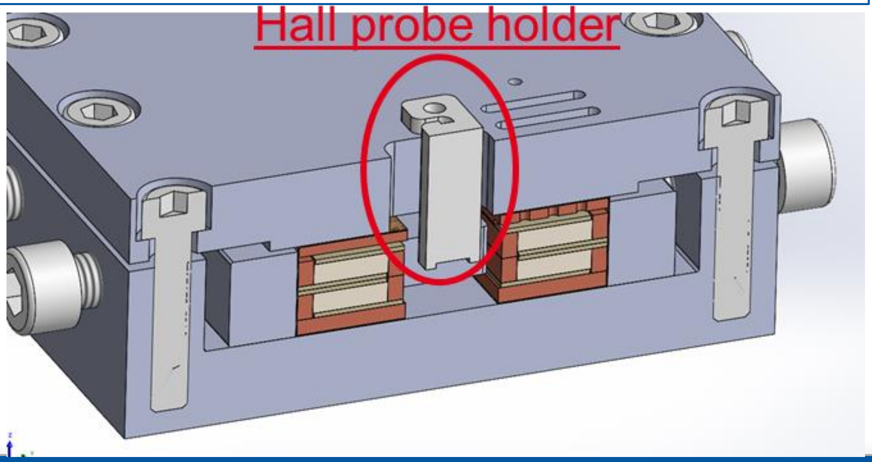


Metal-insulated coils

PEEC — SALOME (python) — CAST3M

Modelling
Electrical
Thermal
Mechanical

Stacks of racetracks (up to 4)



By 2025 full understanding of MI racetrack technology, 4 T

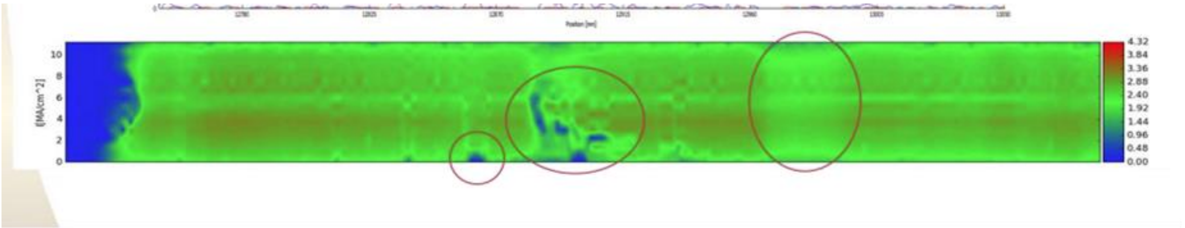
Tests to be done in the next months

Activity at CERN – REBCO Conductor

- **Procurement of tape** (for CERN and for HFM collaborators)
  - IT with specific requirements and QA
  - Ic @ 20 T, 4.2 K and 20 K
  - Unit length ≥ 100 m
  - **33 km**, **width: 2-4-12 mm**, **four suppliers**, full quantity to be delivered in 2024

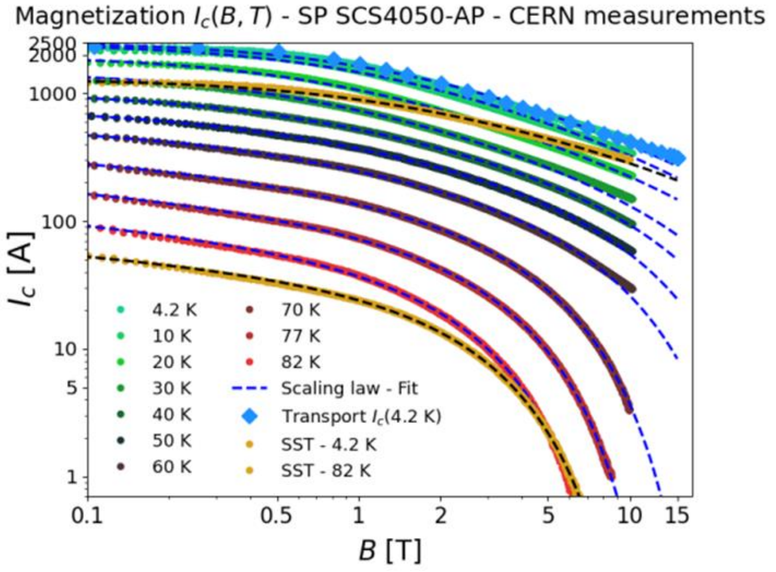
- Procured THEVA Tapestar™ XL-HF. High throughput (200 m/h). Reel-to-reel

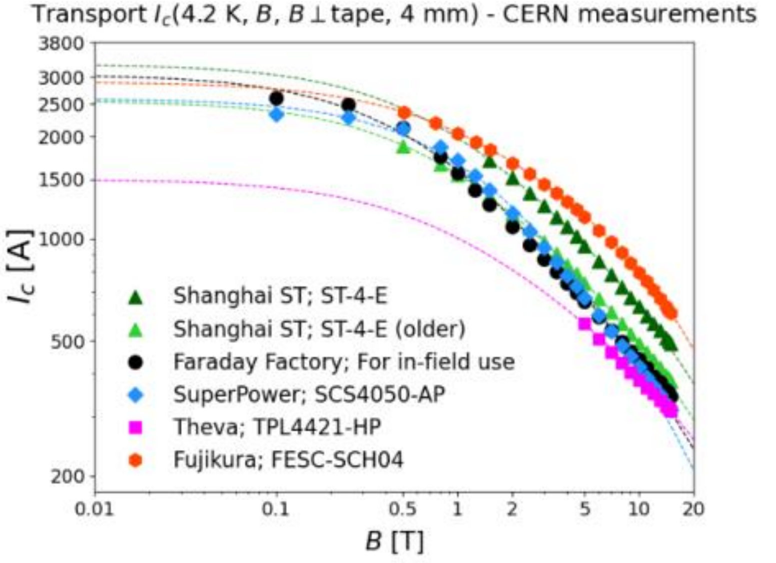
- Critical current and critical current homogeneity
- Identification and localization of defects



Defects and their location

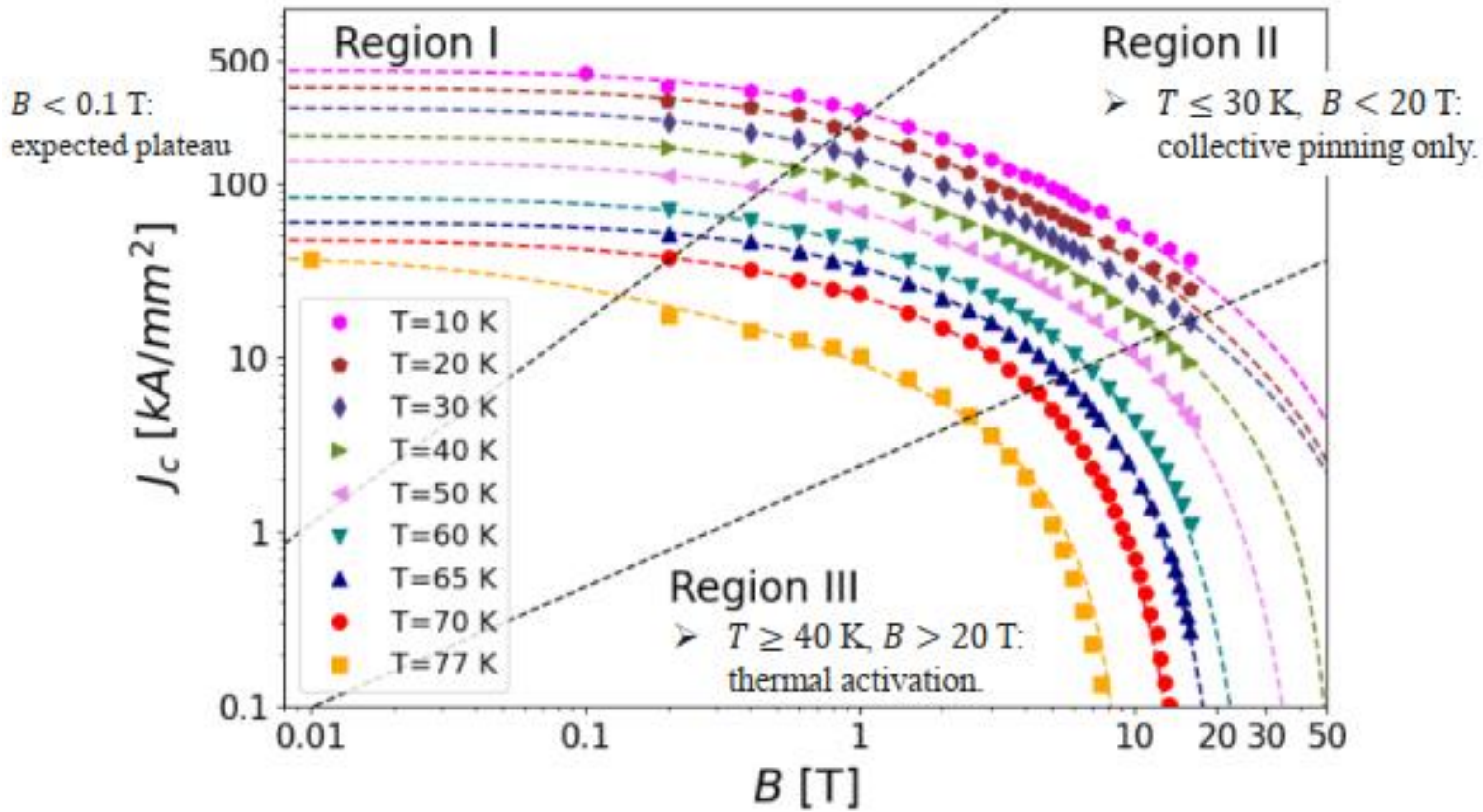
Activity at CERN – REBCO Conductor





From measurements to Scaling Laws

$$I_c(B, T = T^*, \theta = \theta^*) = I_{c,0}^* \cdot \left(1 + \frac{B}{B_0^*}\right)^{-\alpha^*} \cdot \left(1 - \frac{B}{B_{irr}^*}\right)^{q^*}$$



Activity at CERN – REBCO Coils

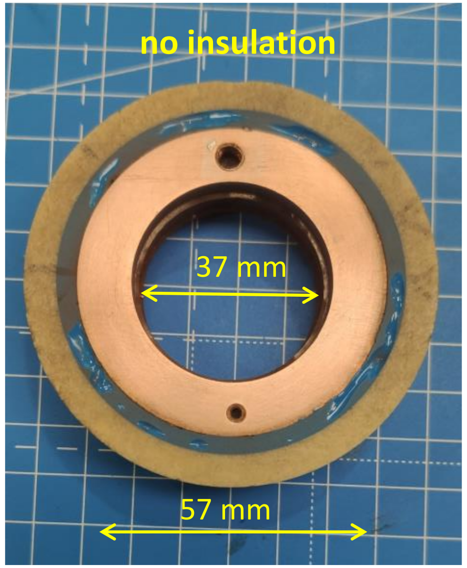
Racetrack coil program

- **Racetrack coils** with straight section of about 10 cm
- Kapton® **insulated cable** in a stack of tapes configuration being used now. Other cables under development
- **Modular approach** allowing for intermediate milestones of 3 T and 5 T

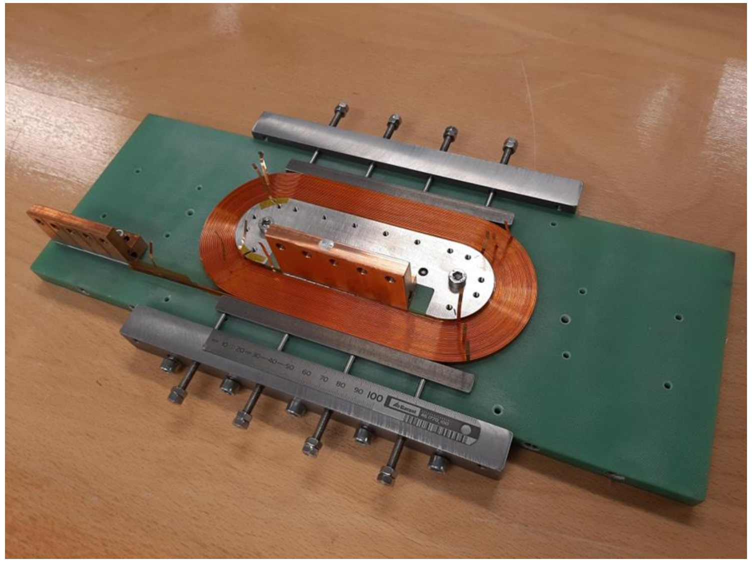
Goal: 10 T @ 4.2 K (8.7 T @ 10 K, 7.2 T @ 20 K, 1.14 T @ 77)

Parameter	Value
HTS tape	4 mm wide from SST
Required I_c @ 12.5 T	> 550 A
Number of HTS tapes	4
Additional copper	2 x 100 μm
Insulation thickness	50 - 100 μm Kapton

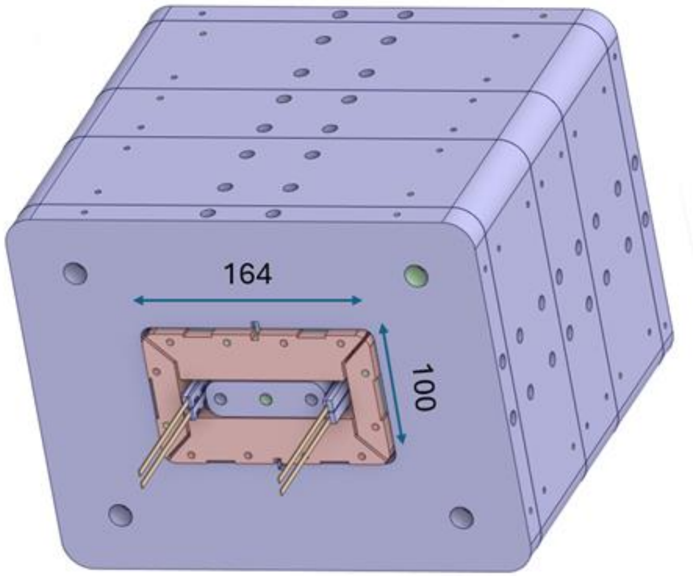
Double pancakes
2x 7.35 meters of tape
3.93 T @ 4.2 K, 1500 A



Activity at CERN – REBCO Coils



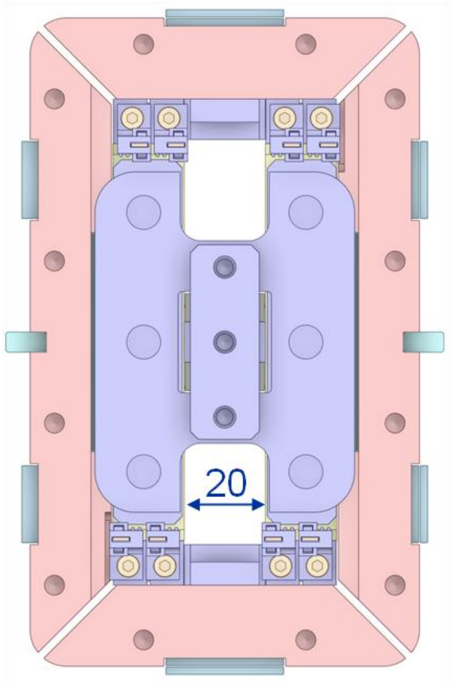
Stage 1: Single pancake



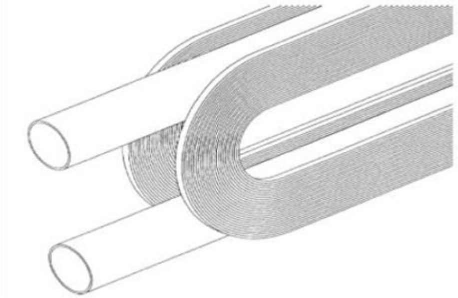
Stage 2: Four double pancakes (**5 T**)

Stage 3: Up to six double pancakes (**10 T**)

Front view

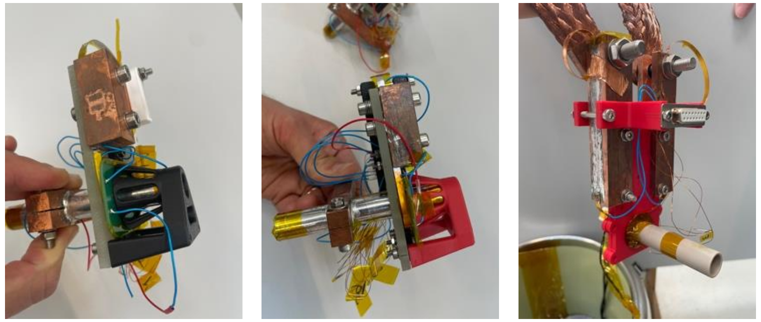


Common Coil double aperture **demonstrator**

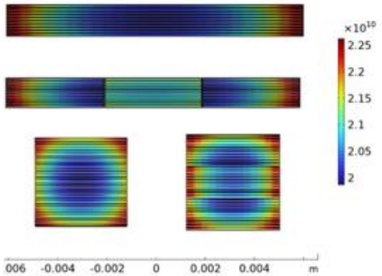


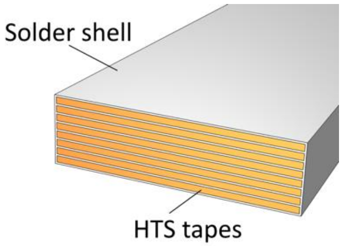
Activity at PSI – REBCO Coils

- Small-scale coil development for model validation and cable testing

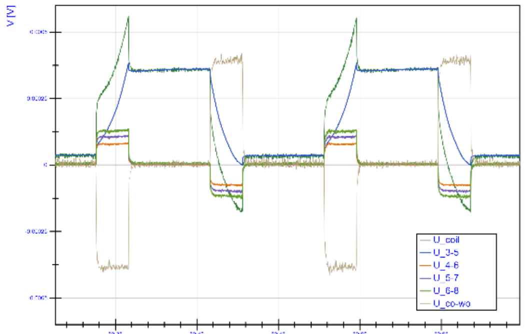


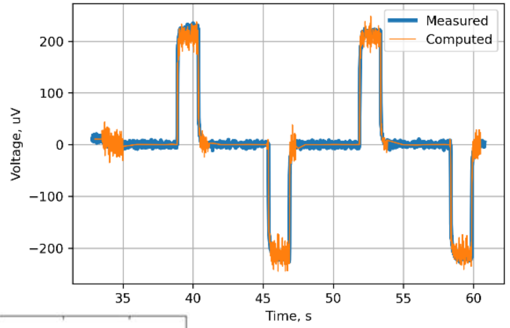
“Baby-HTS” Coils (1-3) with 2-stack single-pancake (1,2) and 1-stack double-pancake (3) geometry.



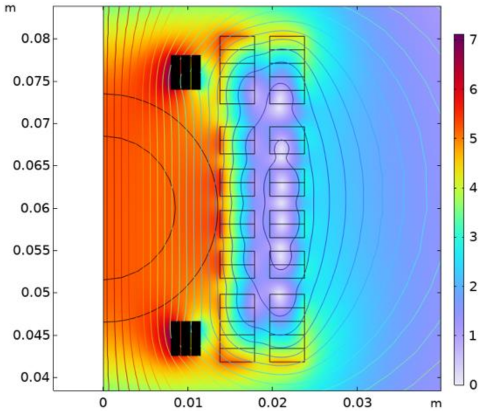


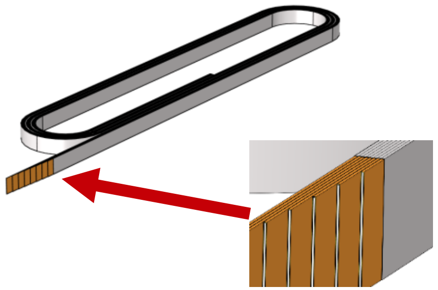
Measured signal from Coil 2

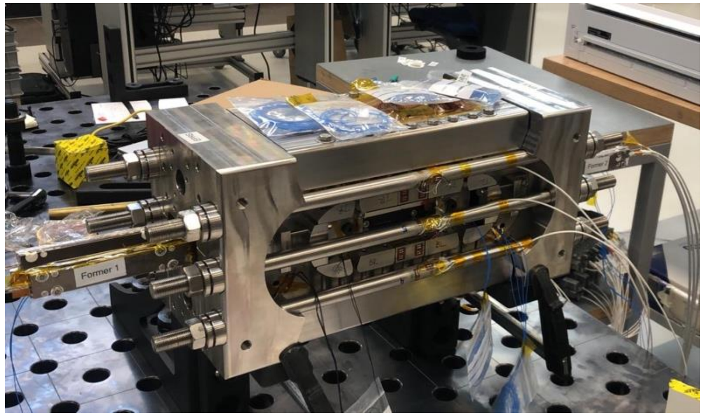




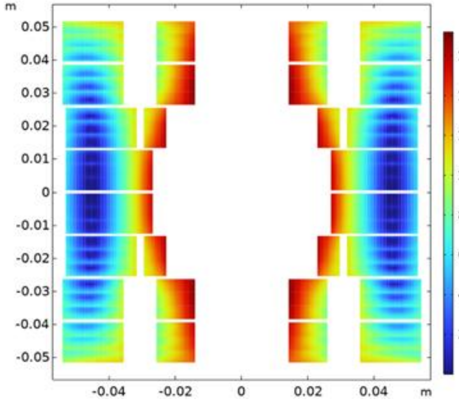
- Design of Racetrack coils to operate in background field of Nb_3Sn 5-T subscale stress-managed common coil







Nb_3Sn subSMCC1



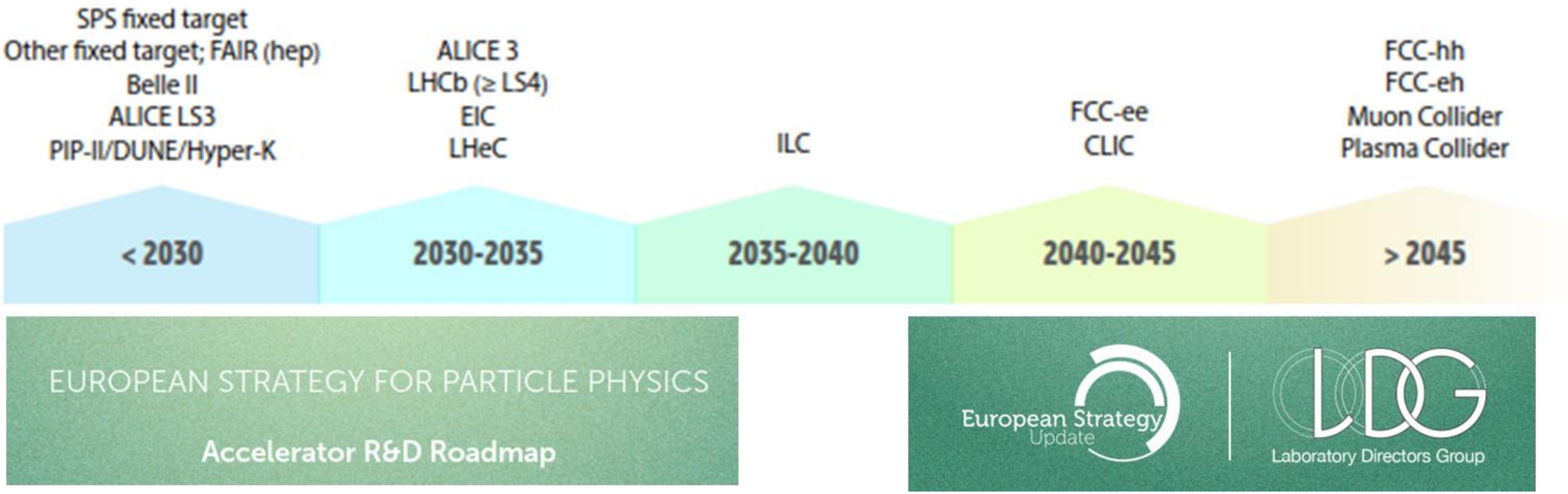
16-T coil, from 4-mm soldered tape-stack cable

AC Losses with different cable layouts

Conclusions (1/2)

- **HTS** activities for **High Field Magnets** are progressing at several EU institutes
- Accelerator technology has challenging and specific requirements. We need to continue to develop an intense and dedicated **R&D program** to prove **feasibility of HTS in future accelerator magnets** - and fully exploit its unique potentials

Conclusions (2/2)



LHC Timeline

22 years

1984 → **2006**

Short Model Magnets — Magnet Series Production Completed

Next 5 to 10 years to fill the technological gap of HTS wrt LTS – for a large machine > 2055

Thanks for you attention !