Hands-on session experiments: Electrical Transport

Critical current, quench propagation, and resistive transition

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CERN TE-MSC-HSD and University of Southampton

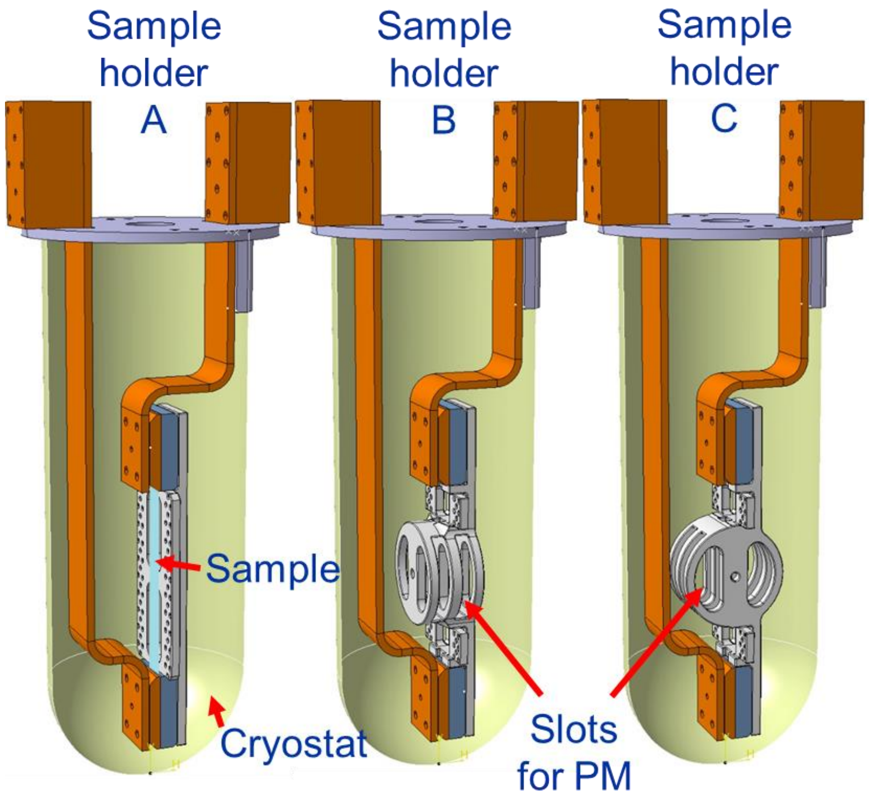
2023-10-21

Experiment 1A

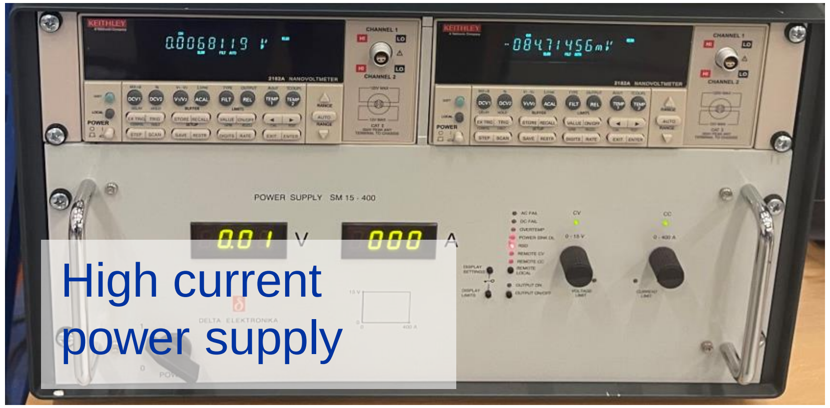
Critical Current Measurement

The experiment will demonstrate:

- How critical current is measured;
- Effect of applied magnetic field using purpose-built sample holders with permanent magnets (PMs):
  - Perpendicular applied field;
  - Parallel applied field;
- Explore the effect of copper stabilization in REBCO;
- Simple data analysis to determine the power-law fit to the collected voltage-current data to determine I_c and the *n*-value.



Nanovoltmeters

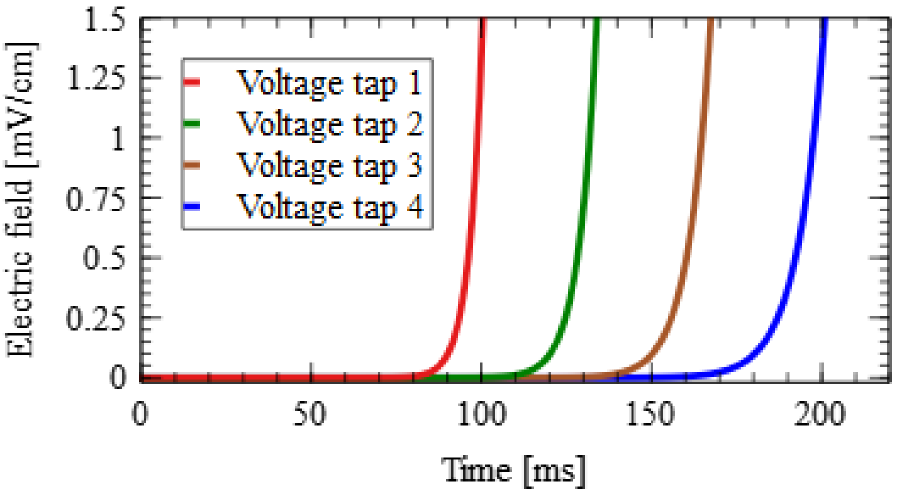


Experiment 1B

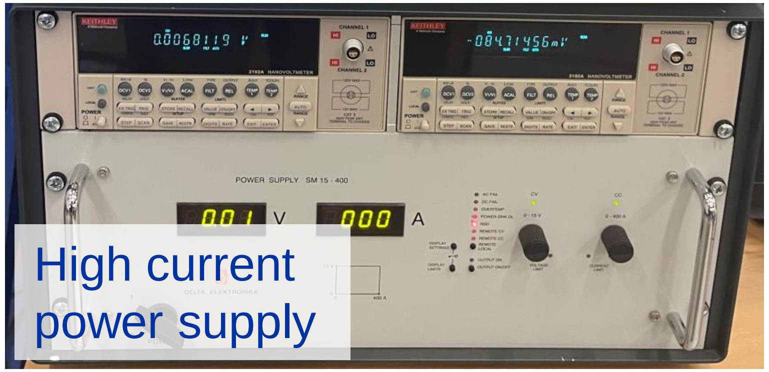
Normal Zone Propagation Velocity

During the experiment, you will initiate a localised quench to observe the spread of the normal zone by:

- Introducing a defect in REBCO tape;
- Measuring the voltage across segments of REBCO tape during a current pulse using high-speed data acquisition device;
- Perform data analysis to calculate the normal zone propagation velocity;
- Determine how the NZPV varies with operating current and why.



Nanovoltmeters



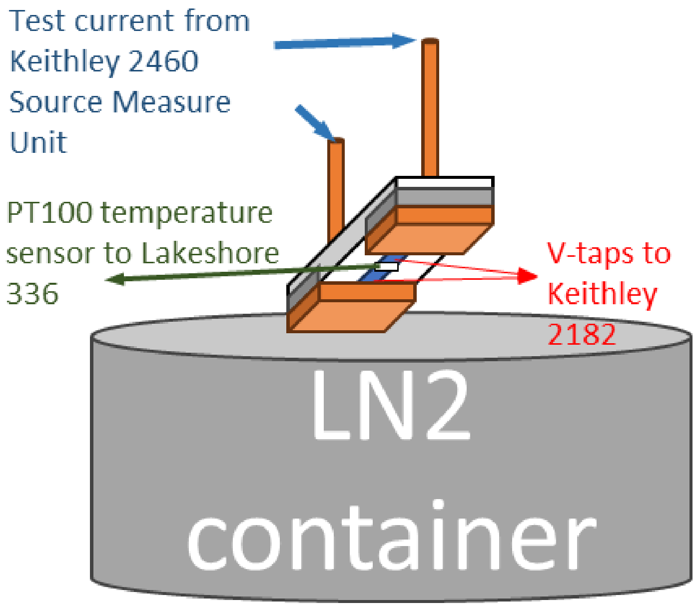
Multichannel data acquisition device DAQ

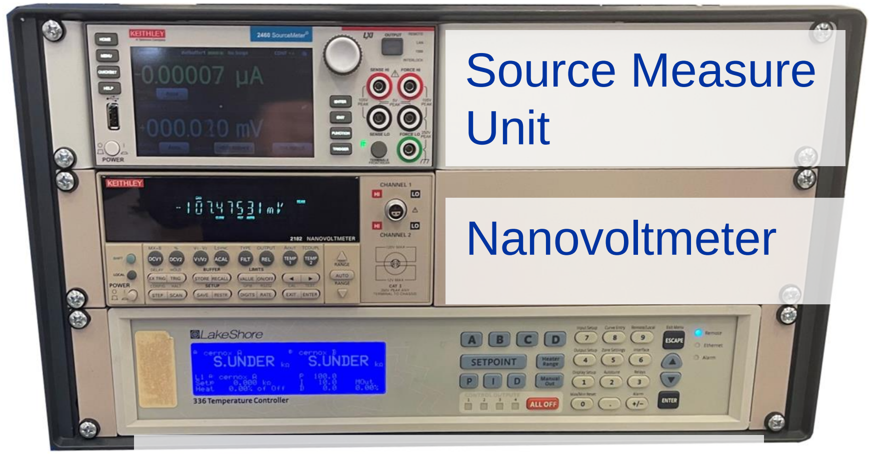
Experiment 2A

Critical Temperature Measurement

During this experiment, you will:

- Learn about four-terminal sensing technique;
- Measure sample resistance as a function of temperature;
- Determine the temperature at which the sample loses electrical resistance, T_c;
- Determine the identity of the *mystery* material;
- Learn about measuring small signals, the effect of thermal EMFs and how to counter them.



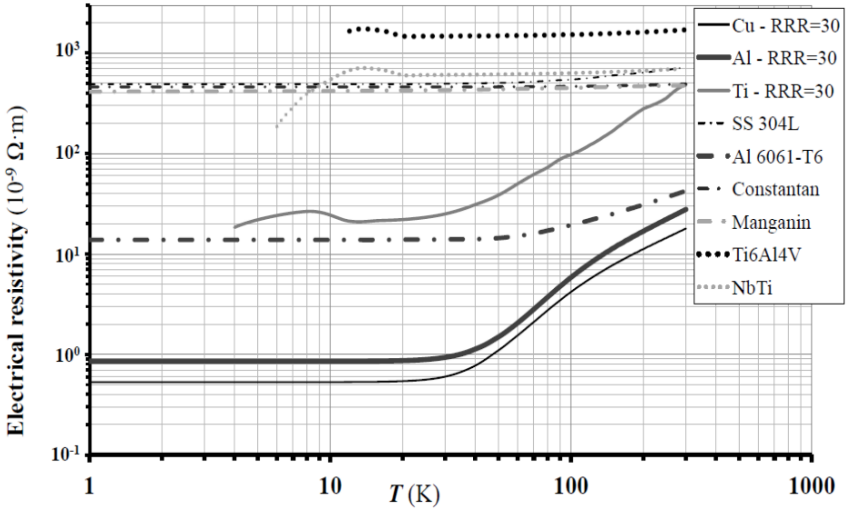


Experiment 2B

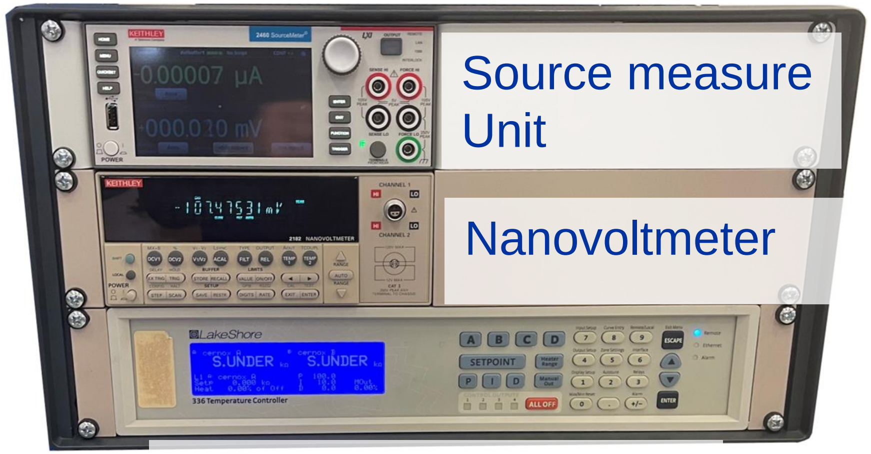
Low-temperature electrical resistivity of metals

You will have the chance to reinforce theoretical knowledge about material low-temperature resistivity by:

- Measuring electrical resistivity of REBCO tape components – Hastelloy and copper as a function of temperature;
- Learn about Residual Resistance Ratio;
- Compare electrical resistivity temperature dependence of pure metals and alloys;
- Reinforce knowledge about thermal EMF compensation.



P. Duhil, Material Properties at Low Temperature, 2013



Temperature controller

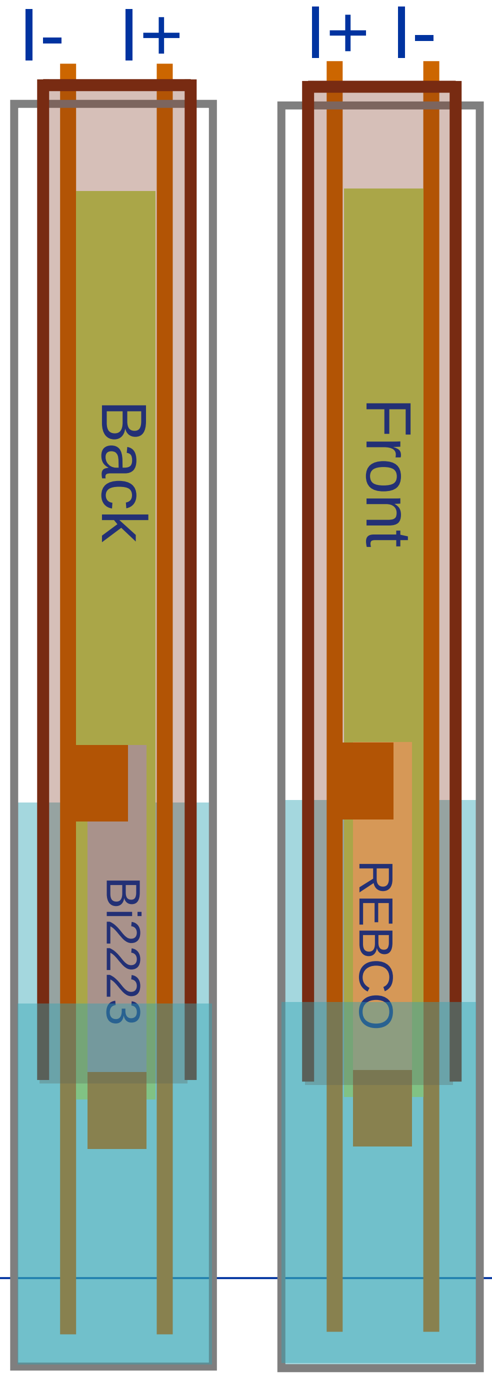
Experiment 3

Resistance vs Temperature

As a more visual and low-tech variant of 2A, this experiment allows resistance measurements on REBCO and Bi2223 tapes over a wider temperature range.

You can

- See the differences in their Tc;
- And ponder on the simple techniques used
    - Glass dewar to see the setup inside LN2
    - Smoother temperature change using “cold fingers”
    - Better temperature homogeneity using cooling by self-boil off
    - Temperature measurement with thermocouples

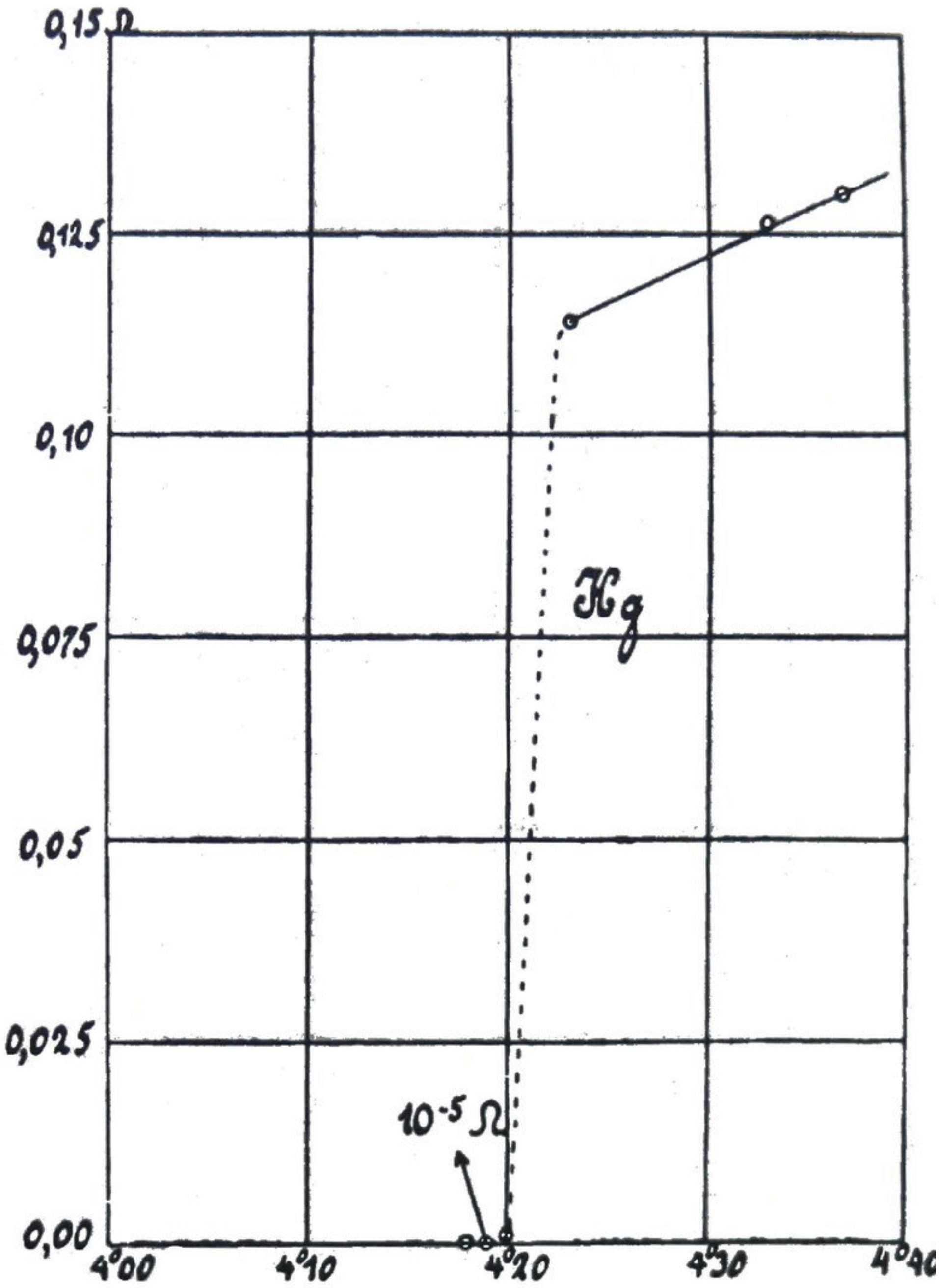


Experiment 3

Resistance vs Temperature

Think about the follow questions as you wait for the transitions to happen:

- How will the temperature indicated by the thermal couple vary as LN2 boils off?
- What will be the shape of the resistive transition?
- What are the errors and how to reduce them and how to work with them?
- Do you know the figure on the right?
  - Marvel at the extraordinary “luck” to discover the first superconductor with an Tc happened to be less than 0.1K above the saturation temperature of liquid helium which you just liquefied?
  - How was 10^(-5) ohms (or 0.01%) be determined? What was our hand-on’s equivalent?



Hand on Experiments
TU Wien

Morteza Asiyaban, Alexander Bodenseher, Florian Semper
Raphael Unterrainer, <u>Michael Eisterer</u>

Atominstitut, TU Wien, Vienna, Austria

CAS, St. Pölten, November 21st 2023

Experiment 4A
Superconducting Coil

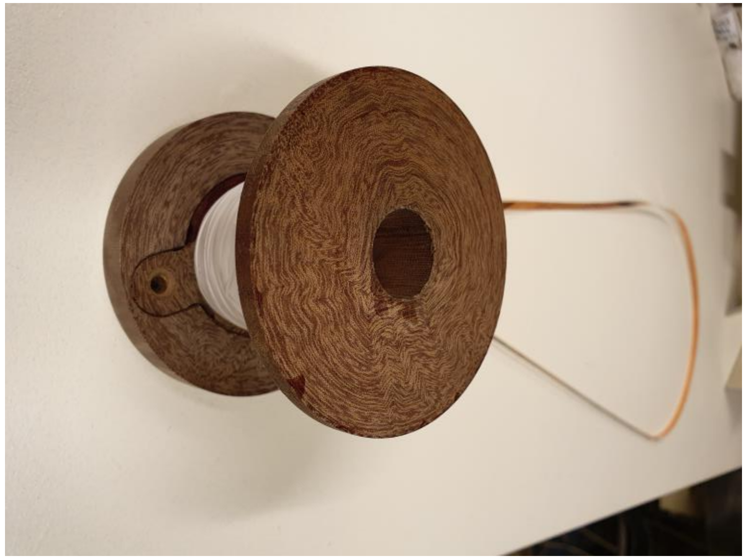
Special thanks to Alexander Bodenseher, Morteza Asiyaban, Florian Semper, Raphael Unterrainer!

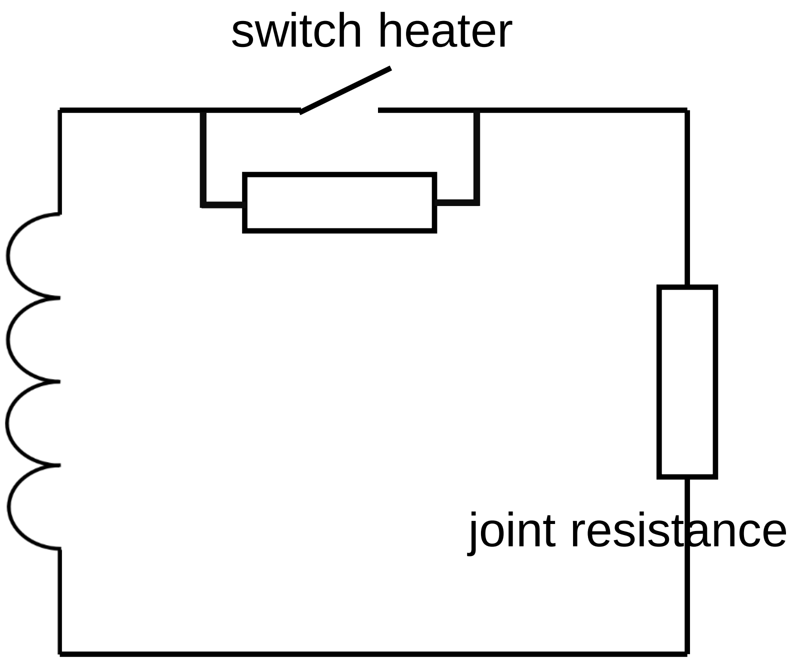
Experience basics of superconducting magnets:

- Forces in a superconducting coil
- Persistent currents
- Switch heater
- Flux transformer
- Flux pump
- (AC losses)

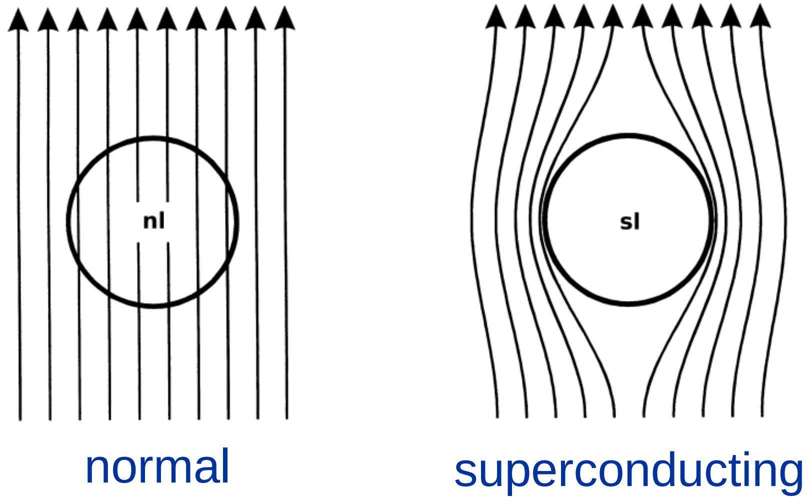
Experiment 4A
Superconducting Coil

- Forces of a superconducting coil on magnet
- “Persistent” currents
  - Finite joint resistance: $B = B(t=0)e^{-\frac{R}{L}t}$
  - Monitored by Hall probe
- Switch heater
- Flux transformer
  - Flux inside a closed superconducting loop remains constant (not always!)
- Flux pump
  - Increasing the flux in the sc loop.
- (AC losses)
  - De-magnetize the magnet by an ac-field



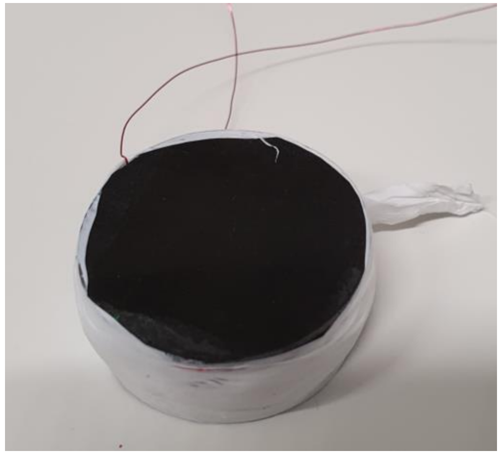


Experiment 4B
AC susceptibility

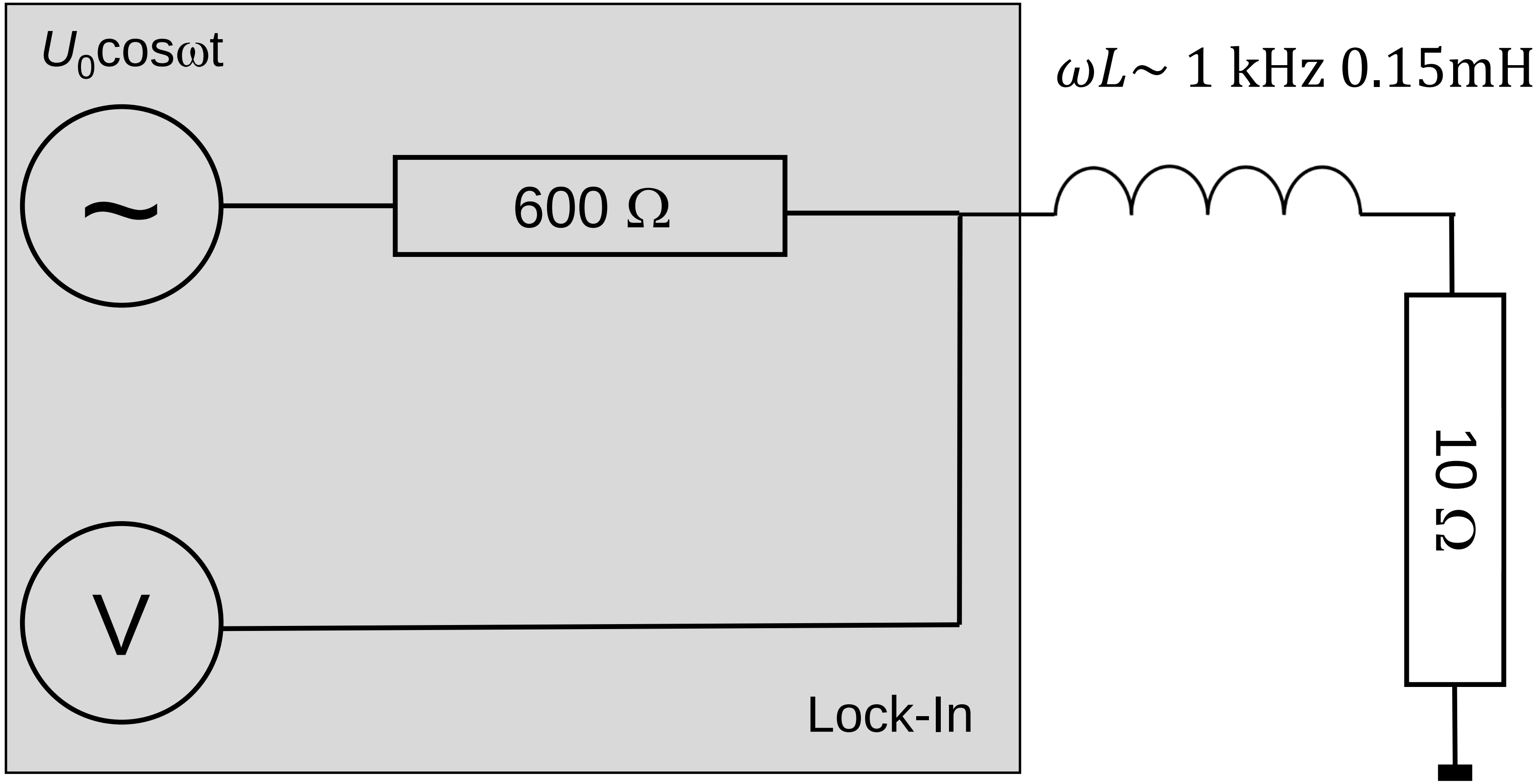


Perform a magnetic measurement

- Demonstration of flux expulsion (Meissner effect)
- Measurement of superconducting transition temperature (T_c)
- Hands-on!
  - Wrap a coil around the superconductor
  - Excite the coil
  - Measure the inductivity (voltage)
    - $U = -\frac{d\phi}{dt} = -L\frac{dI}{dt}$
    - $L = \frac{d\phi}{dI}$
    - Inside superconductor: $B = 0 \rightarrow \phi = 0 \rightarrow L = 0$ (or $L \downarrow$)



Experiment 4B
AC susceptibility



$\omega L \sim 1\,\mathrm{kHz}\; 0.15\mathrm{mH} = 0.15\,\Omega$

$$I = I_0 \cos(\omega t + \varphi)$$

$$\approx I_0 \cos(\omega t)$$

$$U_{coil} = -L\frac{dI}{dt}$$

$$\approx L\omega \sin(\omega t)$$

Impedance: $Z = \sqrt{(600+10)^2 + (\omega L)^2} \rightarrow I_0 = \frac{U_0}{Z} \sim \frac{U_0}{600\,\Omega}$

Experiment 5
THE DEVELOPMENT PROCESS OF A HTS MAGNET: Design, Fabrication and Testing

Luis García-Taba Carlos Gil, Carlos Hernando, Kamil Etxagibel, J. Munilla

1983 —2023 years
The CERN Accelerator School

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CERN

SCOPE OF THE HANDS-ON LESSON

GOAL: To understand the principles of the design, building and testing of a HTS solenoid magnet

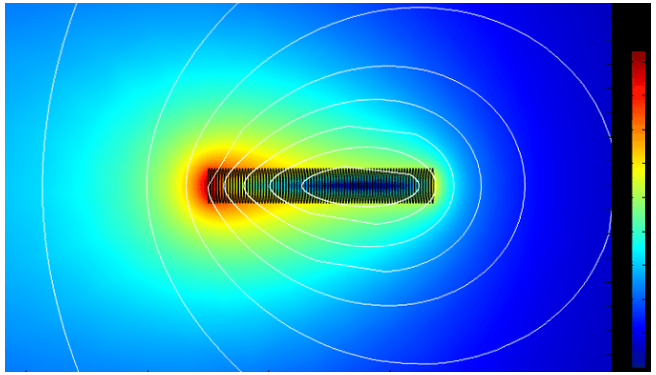
MATERIAL:

1) A presentation on the design process of a magnet (basically magnetic)
2) A video describing how the magnet has been made and tested
3) An experimental set-up to measure the Voltage-Current curve of the magnet

RESULTS: Understanding the Design & Fabrication process of an HTS magnet

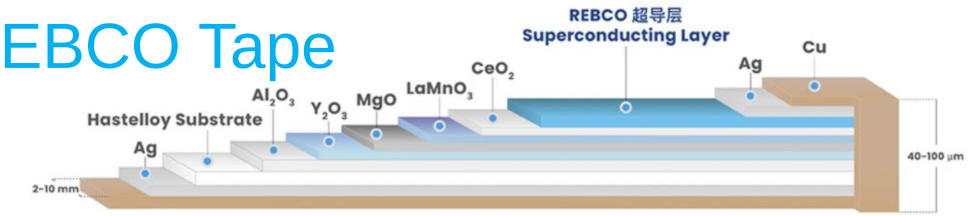
Measurement & discussion of the Voltage-Current curve of the magnet @ 77K (to be done by the students)

ABOUT THE MAGNET(s) TO BE DEVELOPED



TYPE OF MAGNET (s): Flat Solenoidal Magnet with Iron Bore

TYPE OF SC MATERIAL: > Shanghai Superconductor REBCO Tape



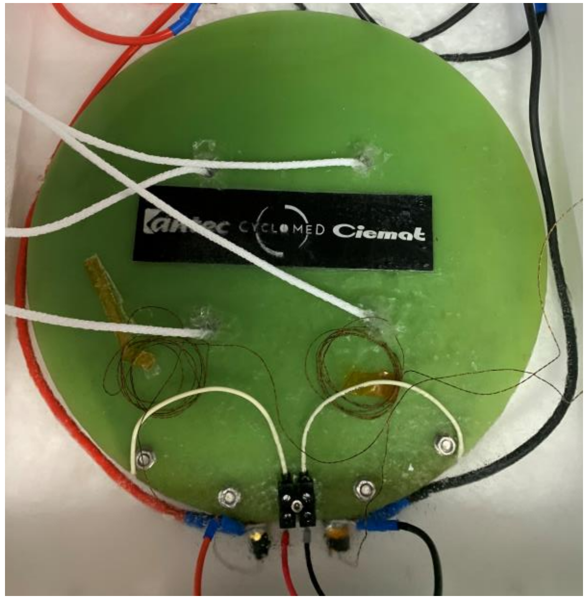
> THEVA REBCO Tape

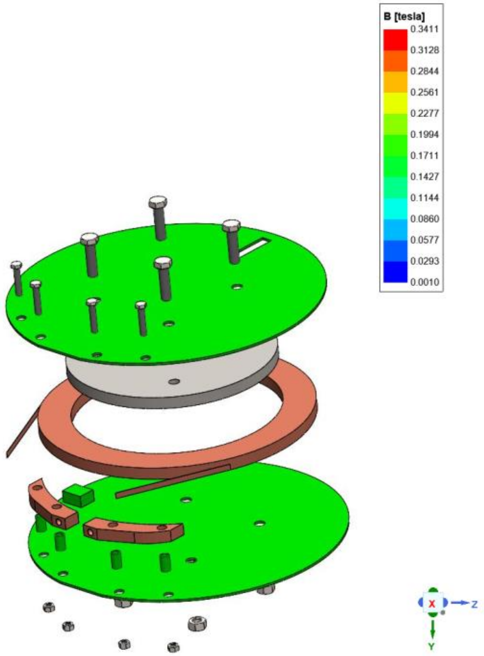
TYPE OF SC WINDING: Double Pancake Winding

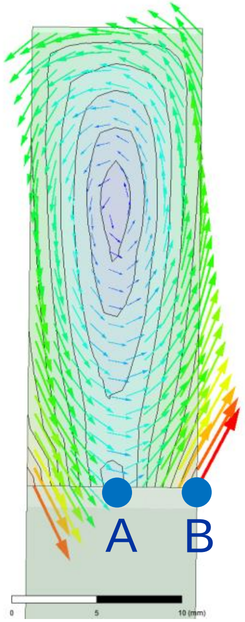
DESIGN CONSTRAINS: Working temperature , Tape length & Minimum bending radius

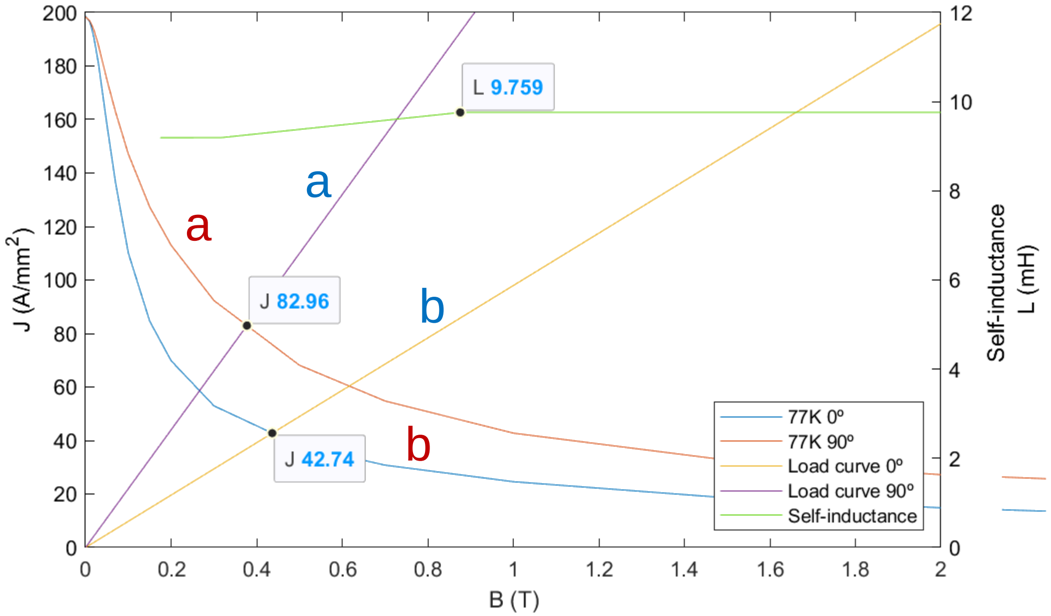
SCOPE OF THE HANDS-ON LESSON ON A HTS MAGNET (1)

PART I: The Design of a HTS Magnet (Presentation)



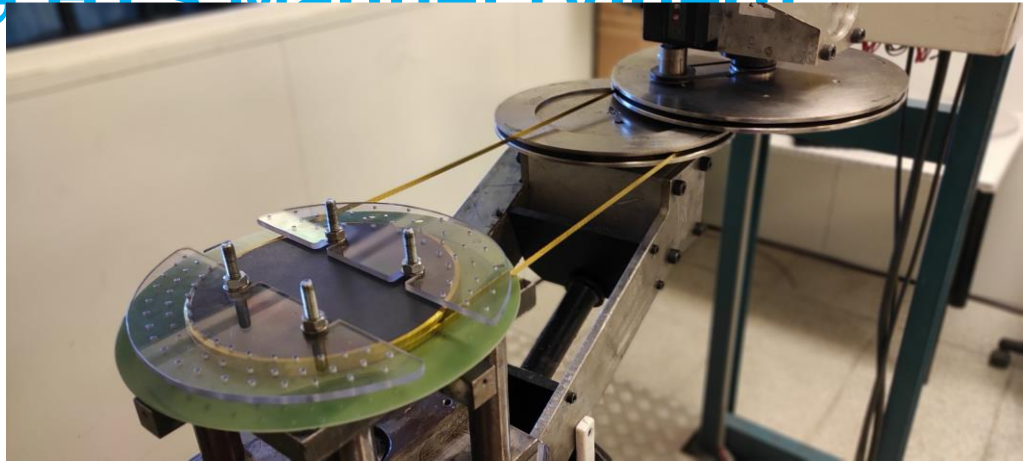


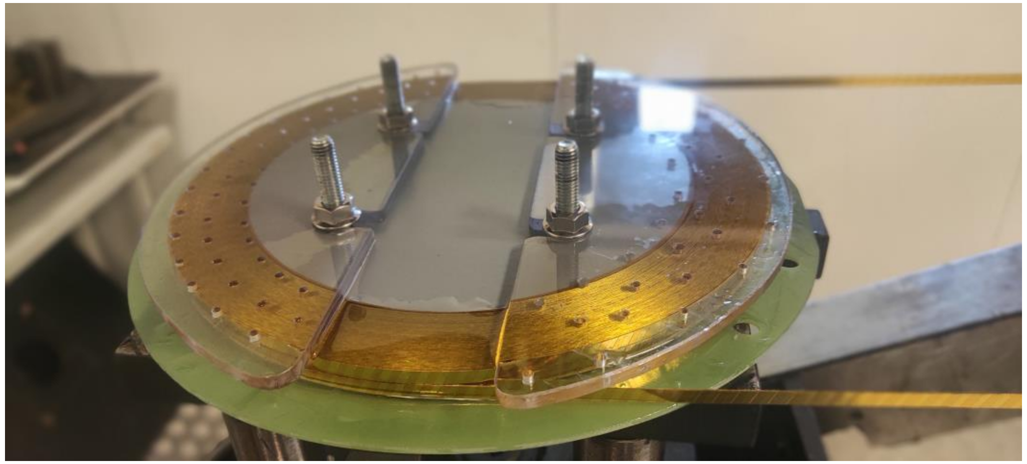




SCOPE OF THE HANDS-ON LESSON ON A HTS MAGNET (2)

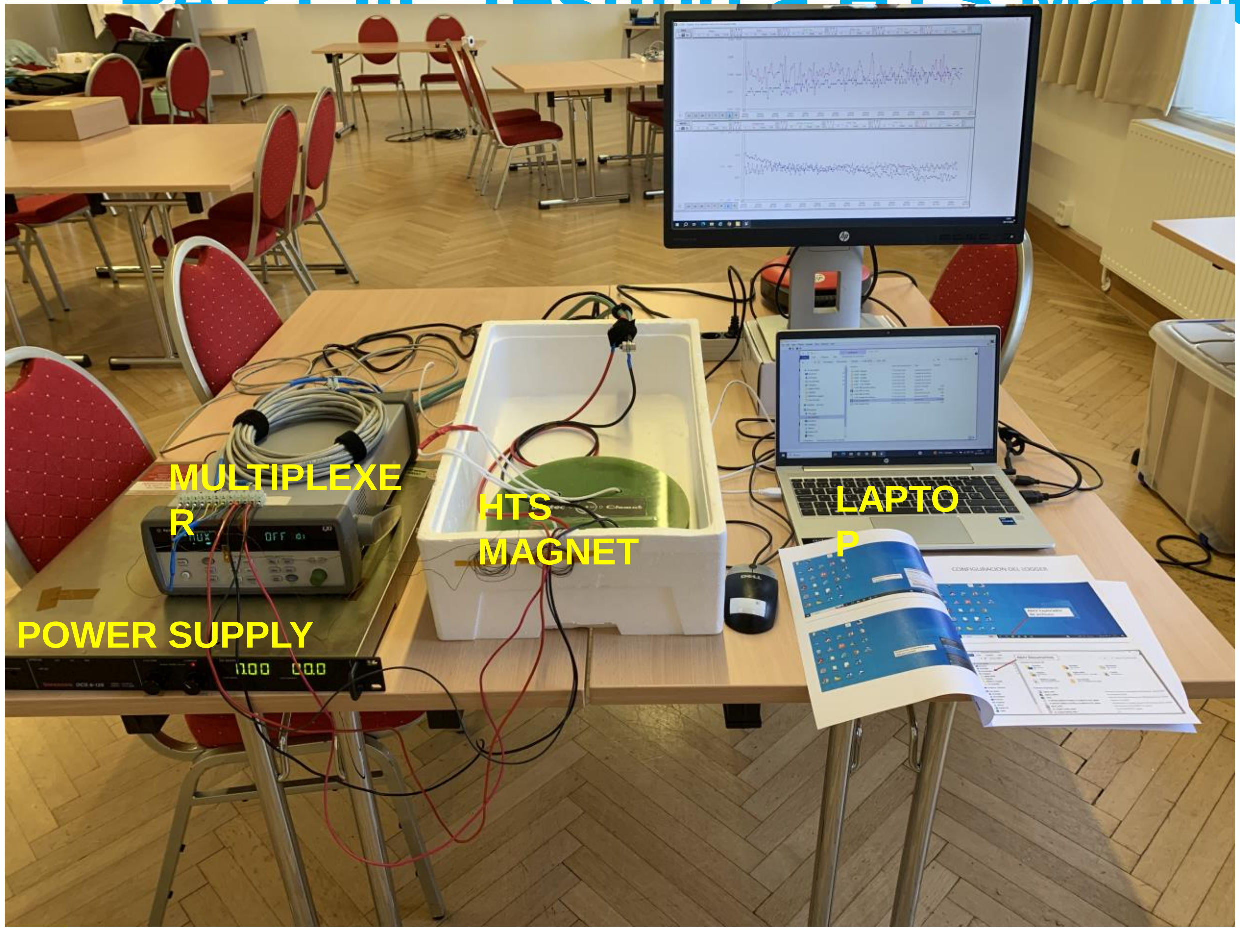
PART II: The Fabrication of a HTS Magnet (Video)

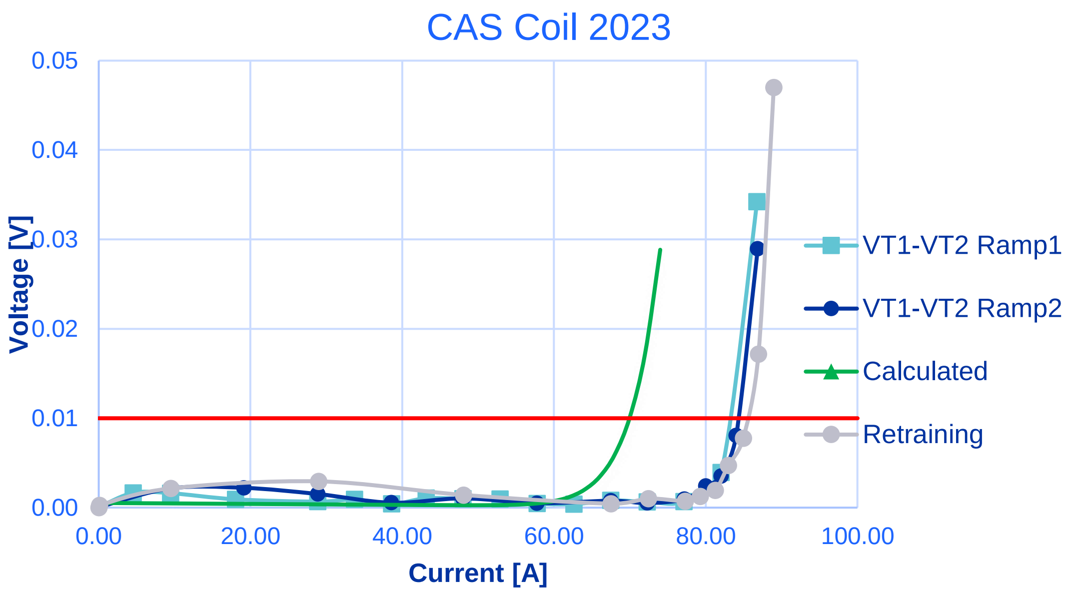




SCOPE OF THE HANDS-ON LESSON ON A HTS MAGNET (2)

PART III: Testing a HTS Magnet (Video & Table Set-up)





¡¡¡ Thank you very much and enjoy the Lesson ¡¡¡

Hand on Safety: Familiarise with the Document

Event Safety

CERN Accelerator School
Course on Superconductivity
in St. Pölten (AT) (19.11.-30.11.23):
Safety of Experiments

RÉSUMÉ :

The CERN Accelerator School Course on Superconductivity includes two laboratories in which students perform experiments on normalconducting and superconducting magnets. Associated hazards are cryogenic fluids and electricity.
This Safety File describes the hazards, risks and mitigation measures to be adopted.

Hand on Safety: Things to Remember

- Please let the instructors know if you are carrying any medical devices (implants or wearables) before starting your session
- Please do not wear metallic jewelries and accessories during the hands-on
- Ware protective items (visor and gloves) when handling LN2 or when LN2 is being dispensed in your vicinity
- Do not touch naked electric connections even if they are at low voltages for supplying superconductors
- Keep your mobile devices away from the superconducting coils and permanent magnets
- Beware of the warning beeps from the oxygen monitors

Hand on Safety: Experiments in a Glance

	Table 1 (Prepared by CERN) Properties of Superconductors	Table 2 (Prepared by SOTON)	Table 3 (Prepared by CIEMAT)	Table 4 (Prepared by Un. of Vienna)
Magnets and cryostatic equipment	- REBCO Tape - REBCO Bulk - Permanent magnet - Permanent magnet in U-shaped configuration - LN2 4 containers 2.5 l each, total of 10 l. - Glass cryostat with vacuum insulation - Liquid nitrogen open cryostat (2 units)	- REBCO Tape - No magnets - LN2 containers 1 container 2.5 l and 1 container 1.0 l - Glass cryostat with vacuum insulation (from CERN) - Liquid nitrogen open cryostat (1 units from CERN)	- Laptop Computer - Software Quick Field Student version - 2 *HTS coils (manufactured & provided by CIEMAT) - 3* Polystyrene Boxes (Cryostat provided by CIEMAT) - 2* LN2 Dewar for filling the cryostat (8 & 4 litre, respectively) - Demonstration magnetic bearing kit (manufacturing & provided by CIEMAT)	- LN2 containers: 1 container of 10 l. To be refilled regularly. At least 20 l are needed each day. - REBCO bulk - Styrofoam box - HTS coil - Various permanent magnets - Varnish insulated copper wire -Teflon tape
Electrical Instrumentation	- Safety extra-low voltage (SELV) power supply (2 units): Delta Electronica SM15-400, 15 V, 400 A - Keithley 2460, 100 V, 1.05 A, the voltage will be limited to below 48 V and front panel locked Needed: 2 outlets 16 A three-phase - Cryogenic Pt sensors - Hall probe - Four minicomputers for DAQ Needed: 2 outlets 10 A monophase - Multimeters with shunt (2 units) - Nanovoltmeter (4 units) - Source measure unit (2 units) - Lakeshore 224 (2 units	- Agilent E3632A Power Supply, 30 V, 4A - Agilent 34970A Data Logger, no power output - A laptop computer Needed: 3 outlets 10 A monophase - Datalogger (1 unit) - Power supply (1 units) - laptop (1 unit)	- DC power supply (8V- 125 A) **Needed:** 1 socket 10A single-phase - Millivoltmeter - DC Amperemeter up to 125A - Thermometer (77K-300K) - Data logger - Laptop with Labview - Screen **Needed:** up to 3 sockets 5A single-phase	- Two miliampere current sources (Lakeshore 120 precision current sources: max 100 mA, max 14 V) - Lock-In-Amplifier - Voltmeter - Hall probe - Temperature sensor - Computer with USB ADC converter -Heating cartridge
Exercises and Measurements (Summary)	-**critical current of REBCO tape** at 77 K and in self-field - **anisotropy of critical current** of REBCO tape: use of U-shaped magnet at 77 K - **critical temperature** of REBCO tape - **Resistive transition** of REBCO tape and quench propagation - **Field-cooled** and **zero field-cooled** experiment with REBCO bulk and permanent magnet - **electrical resistivity** of selected materials (copper, stainless steel and REBCO tape) at room temperature and at 77 K	- **Resistive transition as a function of temperature** of REBCO tape and Bi2223 tape	- **The process of designing a HTS magnet** (pptx presentation) - **HTS Coil fabrication** (video presentation) - **Cooling down process** of the HTS coil controlled by thermometer - **V-I curve measuring** of the HTS coil at 77 K using voltage taps placed in the coils - **Optional: Operating a magnetic bearing demonstrator** based on a Field-cooled process*	- Inductive measurement of superconducting transition temperature - Flux transformer - Persistent mode operation, influence of joint resistance - Flux trapping in magnet - Flux pumping