T. Lécrevisse

C. Genot

# Demonstrator of the metal-insulated REBCO high field magnet coils

E. Benoist

G. Lenoir

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A. Blondelle

CEA-CERN HFM collaboration agreement on HTS developments (KE5647)

Thibault Lécrevisse (CEA)

Amalia Ballarino (CERN)

+ Technical support and DACM experts

# Overview

## 1. Program roadmap

Development main phases

Why Metal Insulated (MI) windings ?

Detail on Phase 1 program (2023-2025)

## 2. Activities Overview

Modelling

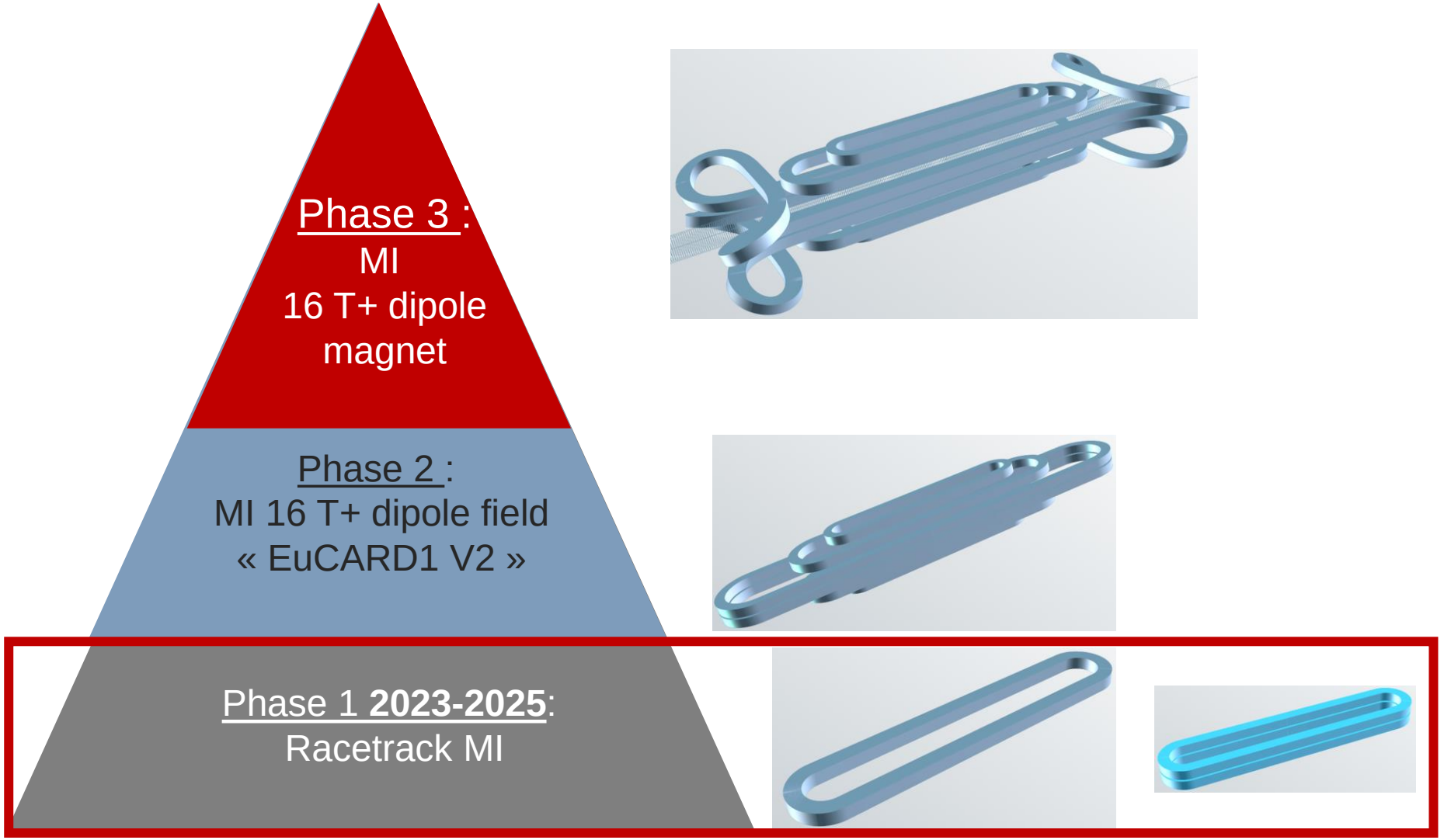
Characterization

Winding

Coil model conception

# 1. Program roadmap

# 1. Program roadmap: Development main phases









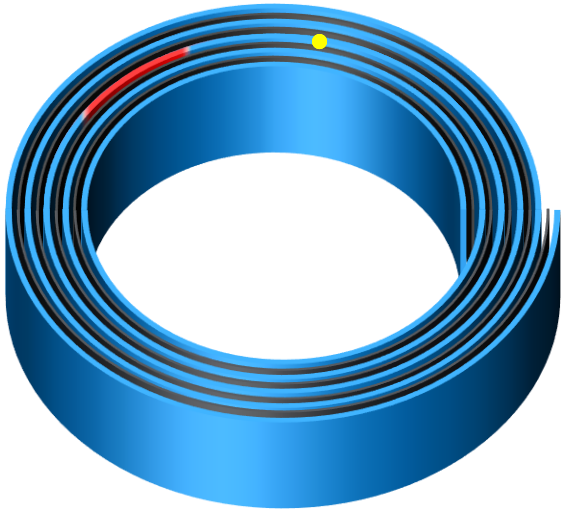



KE5647

Start: 01/04/2023
End: 31/03/2025

# 1. Program roadmap : Why Metal Insulated (MI) windings ?

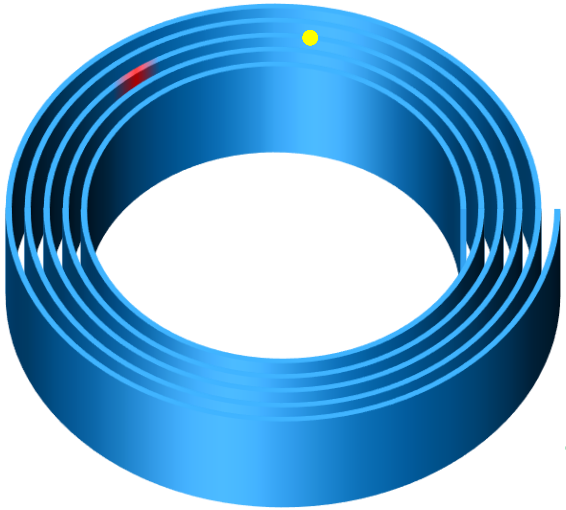
What is MI winding ? **Why to use it for those magnets ?**



Insulated HTS coil
Quench : ↗ local temperature

- ↘ Thermal risk during quench
- Design limits evaluation
- High current density
- Higher mechanics

- Radial currents effects ?
- Working for bigger coils ?
- High stored Energy ?
- What suitable $R_{ct}$ value ?



NI or MI
Quench : ↗ local temperature limited

- Quench at 32.5 T (18 + **14.5**)
- Still working
- Good training magnet
- Feedback on key issues

# 1. Program roadmap : Detail on Phase 1 program (2 years, 2023-2025)

## How to answer to the questions ?

**4 axes**

| Modelling | Characterization | Winding | Conception |
|---|---|---|---|
| Partial Element Equivalent Circuit (PEEC) **MatLab** | Turn to turn thermal conductivity | Analytical and Ansys model + ongoing developments | Structure for single or multi-racetracks |
| 3D FEM Thermal and mechanical model **CAST3M** | Integrated electrical connection | Winding of mockup coils | |

# 2. Activities Overview

# 2. Activities overview

**Modelling**

Partial Element Equivalent Circuit (PEEC) **MatLab**

3D FEM Thermal and mechanical model **CAST3M**

**Characterization**

Turn to turn thermal conductivity

Integrated electrical connection

**Winding**

Analytical and Ansys model + ongoing developments

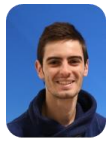
Winding of mockup coils

**Conception**

Structure for single or multi-racetracks

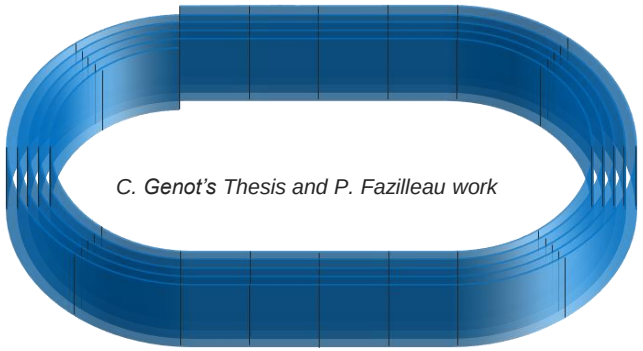
# 2. Activities overview : Partial Element Equivalent Circuit model

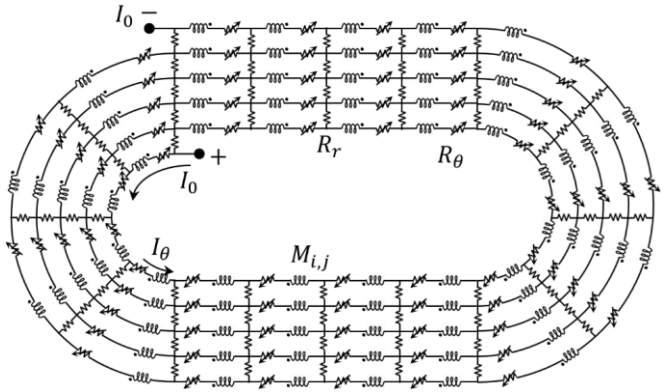
*A. Blondelle*

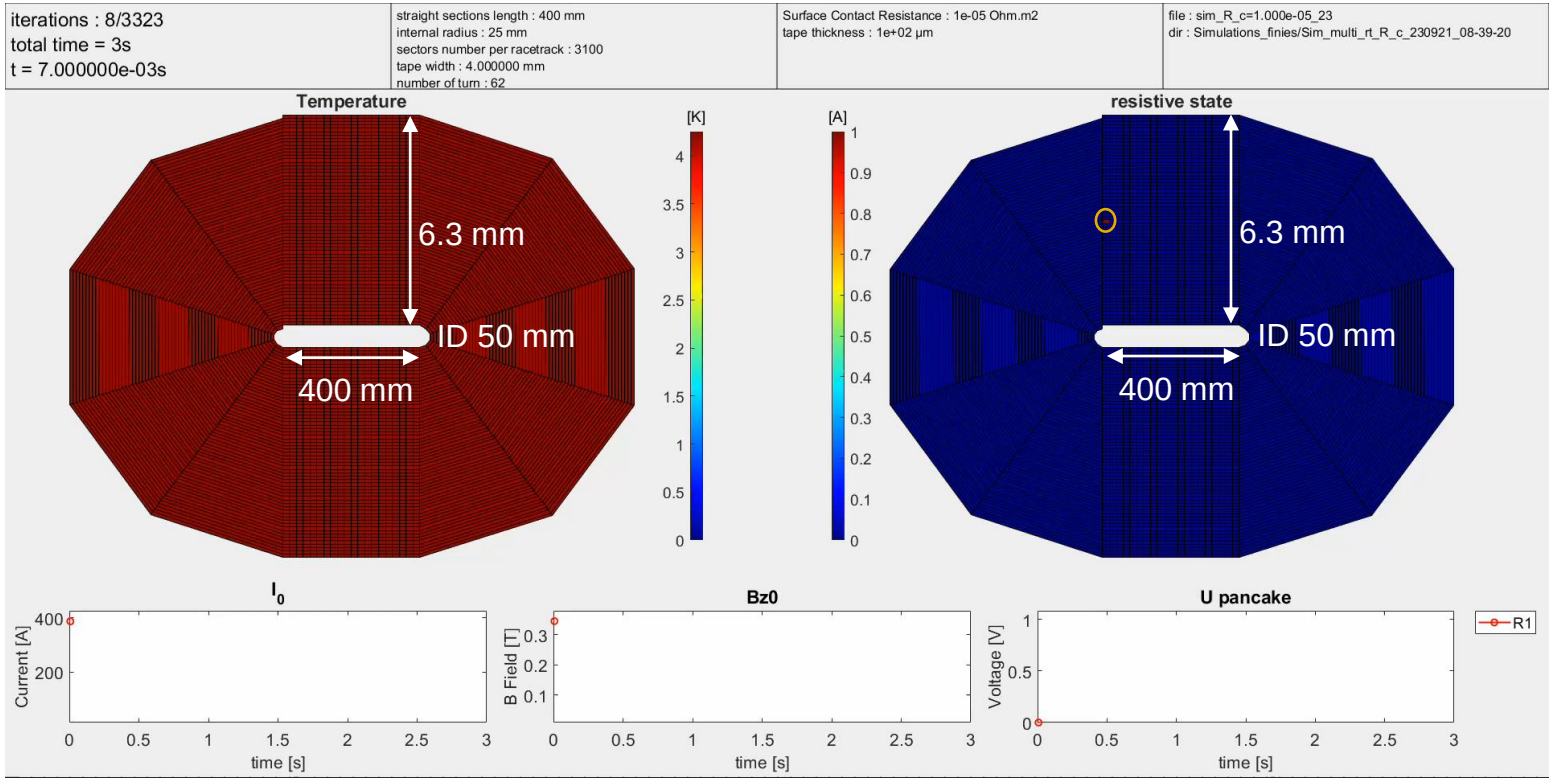


*C. Genot*

*P. Fazilleau*




62 turns / 60 m of tape / ID = 50 mm /$L_d$ = 400 mm

**3D electromagnetic**
**2D finite difference thermal** → **Implemented in MatLab**

MT 28 Poster

# 2. Activities overview : Partial Element Equivalent Circuit model

A. Blondelle

C. Genot

P. Fazilleau

## Racetrack model

### Optimization

- Code simplification
- Model Homogenization
- Model Simplification
- GPU / FMM

### Features

- Parametrization: Geometrical (size / sectors), Material (elect. And Thermal properties)
- Multi-racetracks model
- Magnetization / AC losses (feasibility under evaluation)

***Subject of A. Blondelle PhD***

### Cases implementation

- Over current
- Ramp up or down
- Quench by Local heat deposition
- Quench by Local degradation
- Voltage limitation

### Benchmark / validation

- **S**ingle **R**acetrack Parametrical study
- **M**ulti **R**acetrack Parametrical study
- Choice racetrack geometries and cases/signal

### Integration in multi-physics model

- Coupling with 3D thermal and mechanical models (see dedicated part)
- Time dependent heat sources / current distribution extraction

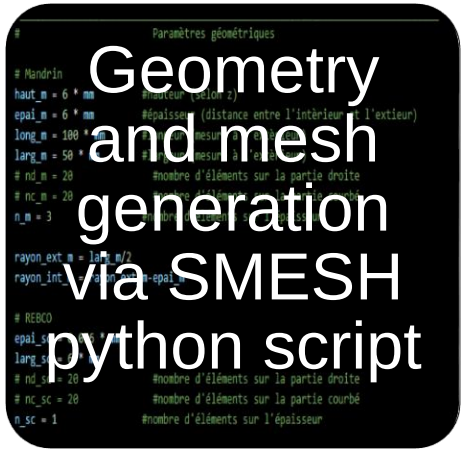
Done | Ongoing | Not started

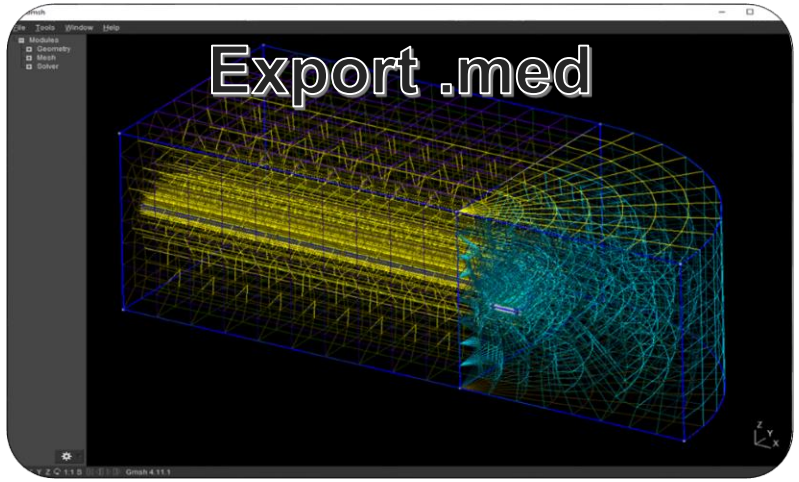
# 2. Activities overview : CAST3M / SALOME

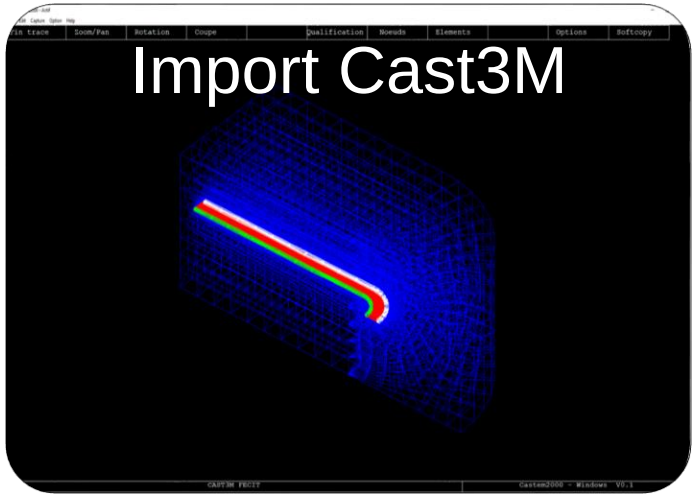
A. Caunes

G. Lenoir

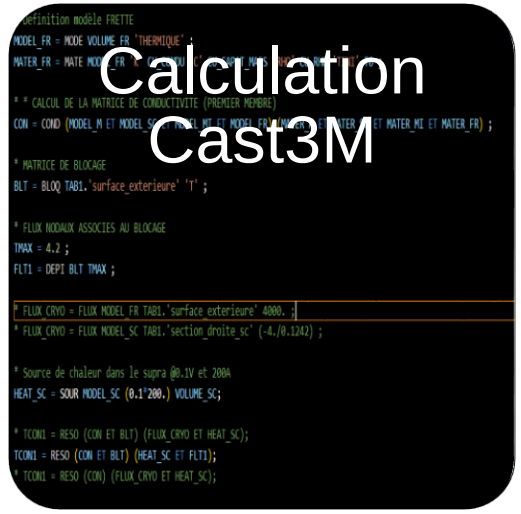
E. Benoist

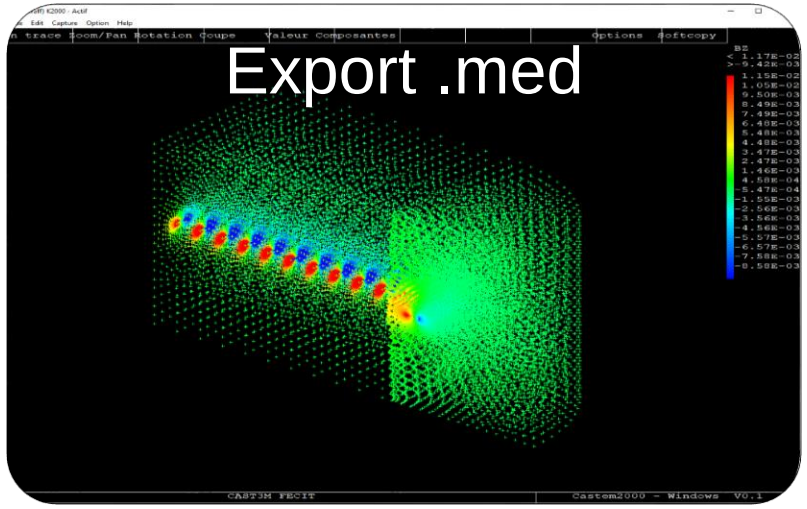


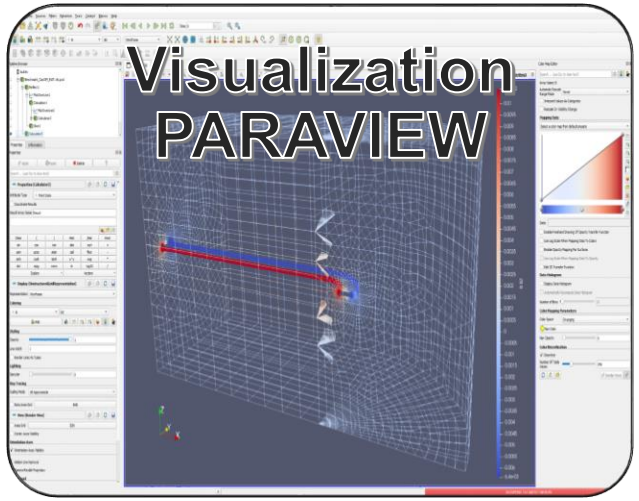




OPEN SOURCE



# 2. Activities overview : CAST3M / SALOME

## Batch

- Definition of variables in an external file
- Call of geometry and mesh generation Python script
- Call of Cast3M
- Call of Salome for optimization loop

## Salome Python

- Fine 3D Geometry and mesh generation
- PEEC model data importation
- PEEC model sectors Association with 3D mesh
- Mesh exportation in MED file
- PEEC model fields on mesh sectors exportation in MED file
- Optimization loop with Persalys/Uranie

## Cast3M

- MED file data and mesh import
- Thermal material properties recovery for thermal model
- Definition of model limit conditions
- Application of volume heat sources on thermal model for each time step
- Modification of the geometry for cooling system integration
- Magnetic field calculation in magneto static
- Load line estimation
- Importation of other Sc fits
- Forces calculation
- Stress calculation
- Loop on field calculation

A. Caunes

G. Lenoir

E. Benoist

Done | Started | Not started

# 2. Activities overview

**Modelling**

Partial Element Equivalent Circuit (PEEC) **MatLab**

3D FEM Thermal and mechanical model **CAST3M**

**Characterization**

Turn to turn thermal conductivity

Integrated electrical connection

**Winding**

Analytical and Ansys model + ongoing developments

Winding of mockup coils

**Conception**

Structure for single or multi-racetracks

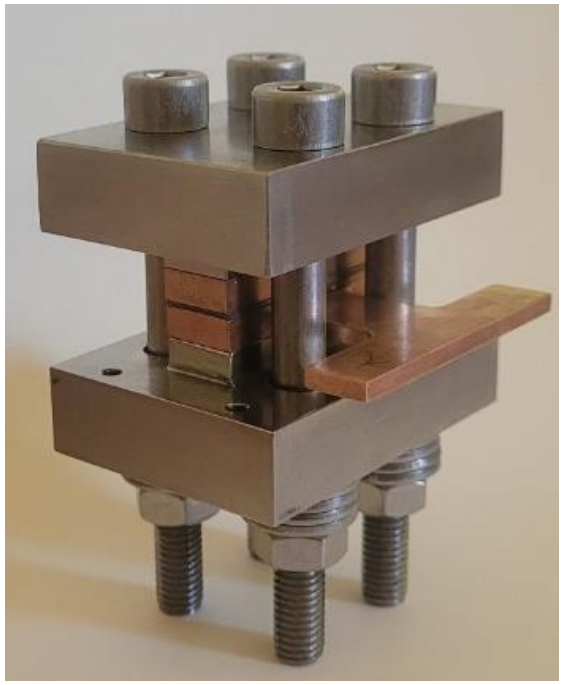
# 2. Activities overview : Turn to turn thermal conductivity

E. Benoist

B. Maloeuvre

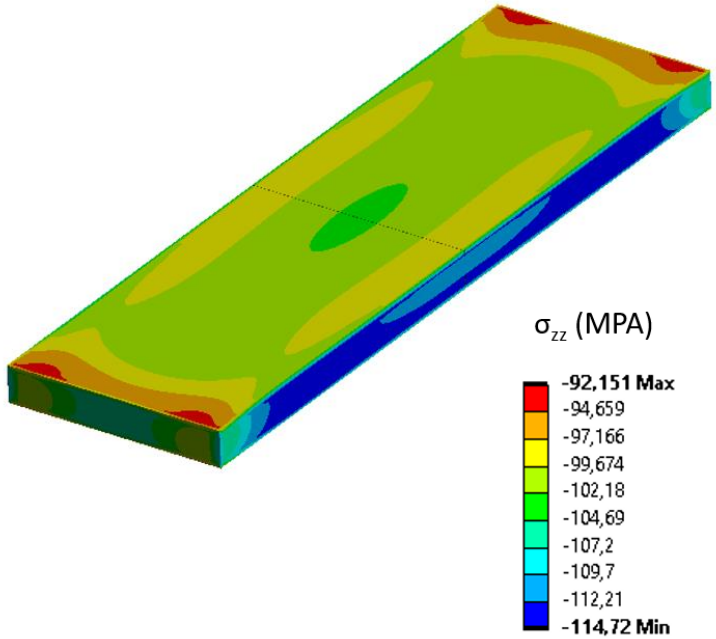
S. Somson

- **Turn to turn thermal conductivity study → to be tested inside Mectix(*) facility**



All part of the system have been **received**

Bolts are being **calibrated**, **pressure homogeneity** on the stack need to be evaluate before the first measurement



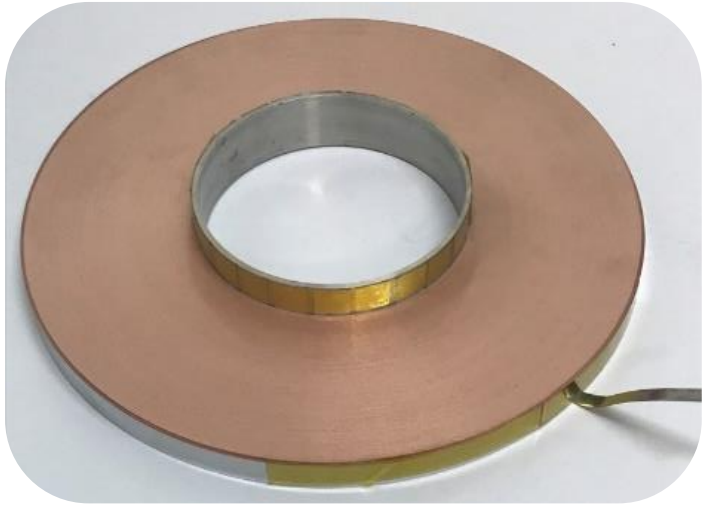

**Simulated compressive stress on the stack**

MT28 poster

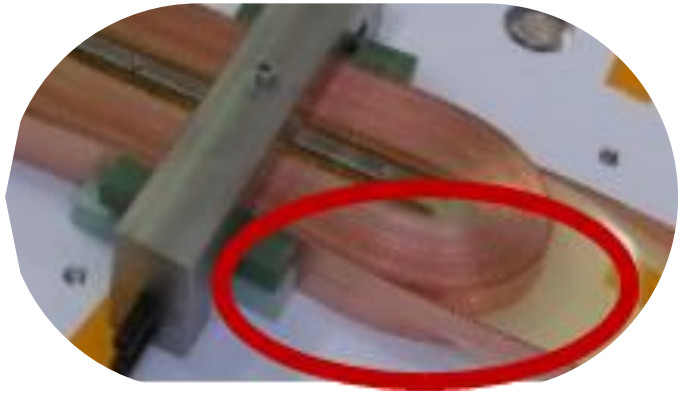
**(*)** isoperibolic cell developed for Nb3Sn stack conductivity measurements

# 2. Activities overview : Integrated electrical connection

➢ **Integrated electrical connections**



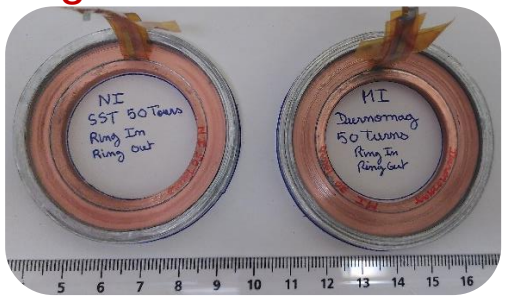
HTS strips



Avoid such leads out

Integrated electrical connection

Rings tests on NI and MI



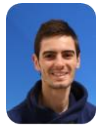

## Connections material and design

- Rings / Blocs
- Manufacturing process
- Composition and surface

G. Lenoir

## Test plan

- Parameters and aimed values for the final object (pressures, temperature, current, cycles, etc.)
- Samples definition



C. Genot

E. Benoist

## Test apparatus & station

- Setup design
- Integration in existing test stations
- Interfaces number & modularity
- Instrumentation

A. Caunes

T. Barabe

S. Somson

B. Maloeuvre

E. Pepinter

# 2. Activities overview

| Modelling | Characterization | Winding | Conception |
| --- | --- | --- | --- |
| Partial Element Equivalent Circuit (PEEC) **MatLab** | Turn to turn thermal conductivity | Analytical and Ansys model + ongoing developments | Structure for single or multi-racetracks |
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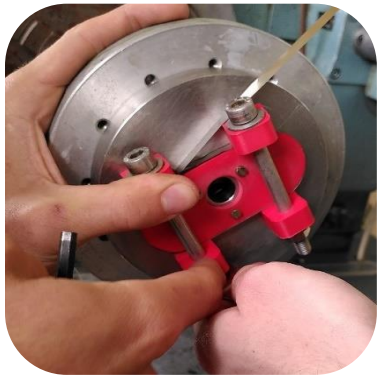
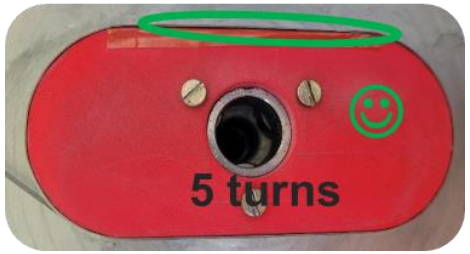
# 2. Activities overview : Winding

*result of the simplified winding model*

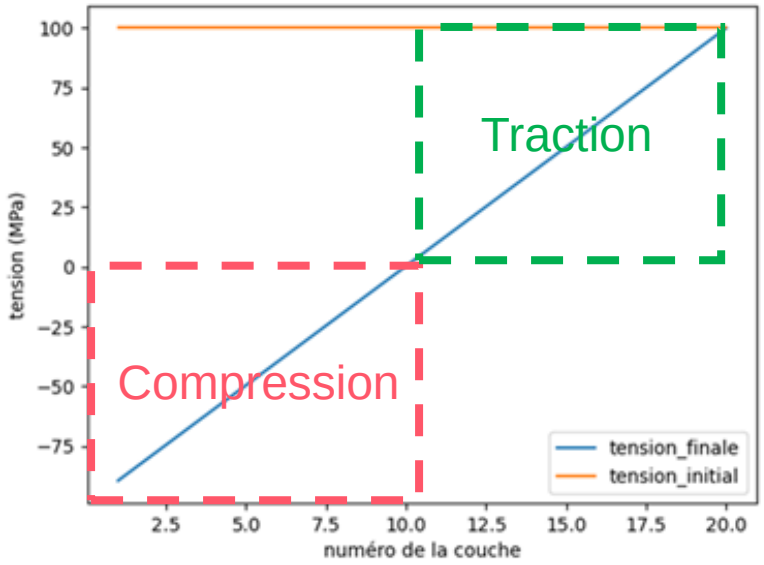


*3D printed tests*

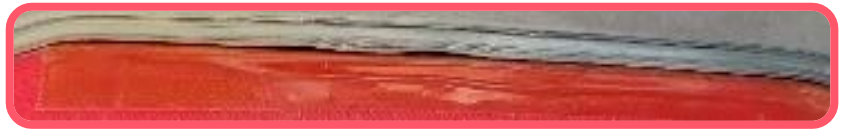
Traction




Compression

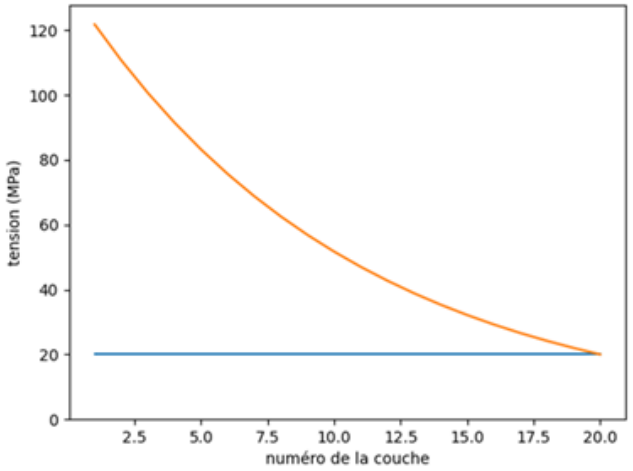


**Traction**



**compression**

*Study on small racetrack with dedicated mandrels*



*E. Benoist*

*G. Lenoir*

*C. Genot*

*A. Caunes*

*A. Blondelle*

*T. Barabe*

*S. Somson*

*B. Maloeuvre*

*E. Pepinter*

- **Validate** Analytical / ANSYS winding model
- Find the **bests winding parameters**
- Training on **Racetrack winding**

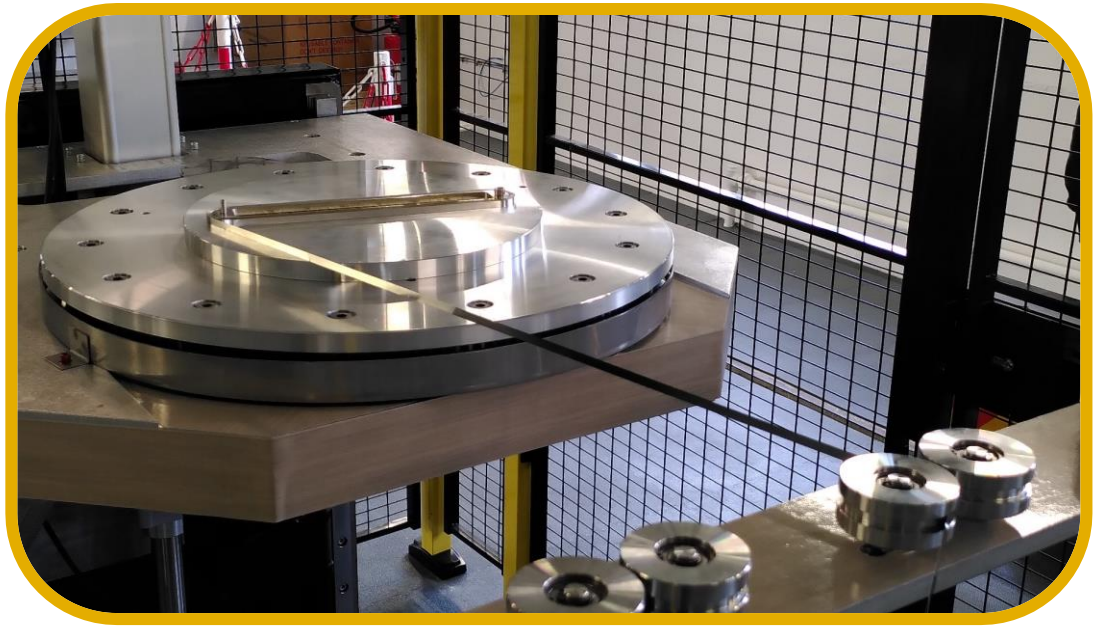
# Hall Building 392

Control bay

- Coil up to **1 m in diameter**, **500 mm in high**
- Up to **6 co-wound tapes** (later 10)
- Tension **up to 230 N per tape** (individually controlled)
- All winding **parameters recorded** for analysis

Tape spools tension management

Winding part



# 2. Activities overview

| Modelling | Characterization | Winding | Conception |
| --- | --- | --- | --- |
| Partial Element Equivalent Circuit (PEEC) **MatLab** | Turn to turn thermal conductivity | Analytical and Ansys model + ongoing developments | Structure for single or multi-racetracks |
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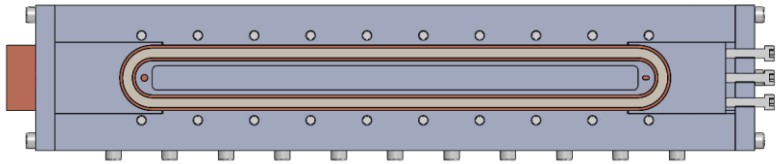
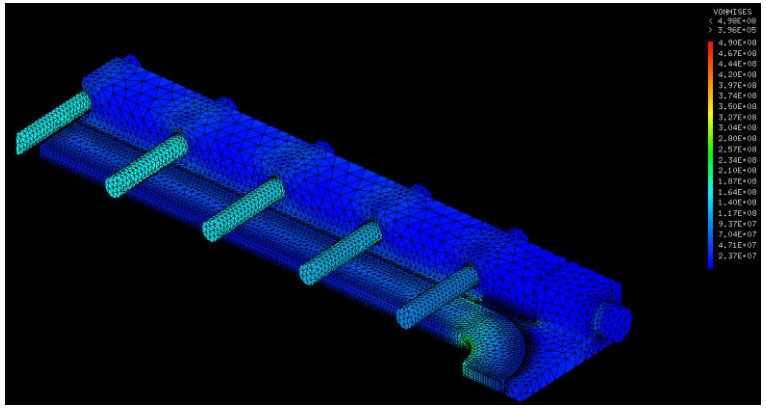
# 2. Activities overview : Coil model conception

- **Ongoing pre-design of racetrack mechanical structure**





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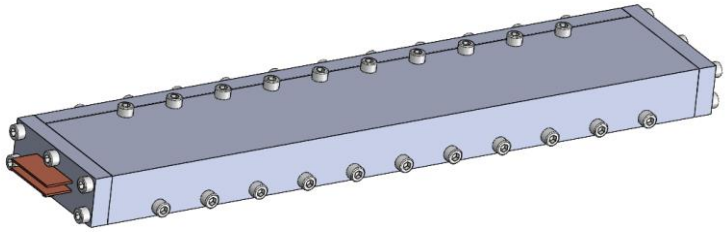
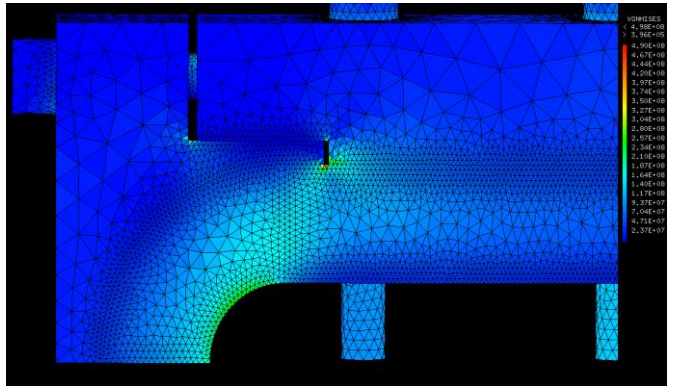
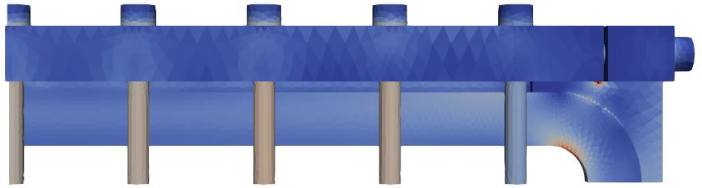


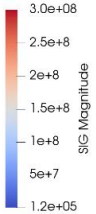
- For one or multi pancakes
- Include current leads
- Include conduction cooling

…



G. Lenoir





# Thank you

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