# Status of HFM development at CEA - LTS and HTS

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FCC week 2025 – 22/05/2025

# $Nb_3Sn$ magnet program - R2D2 and F2D2 (Part I)

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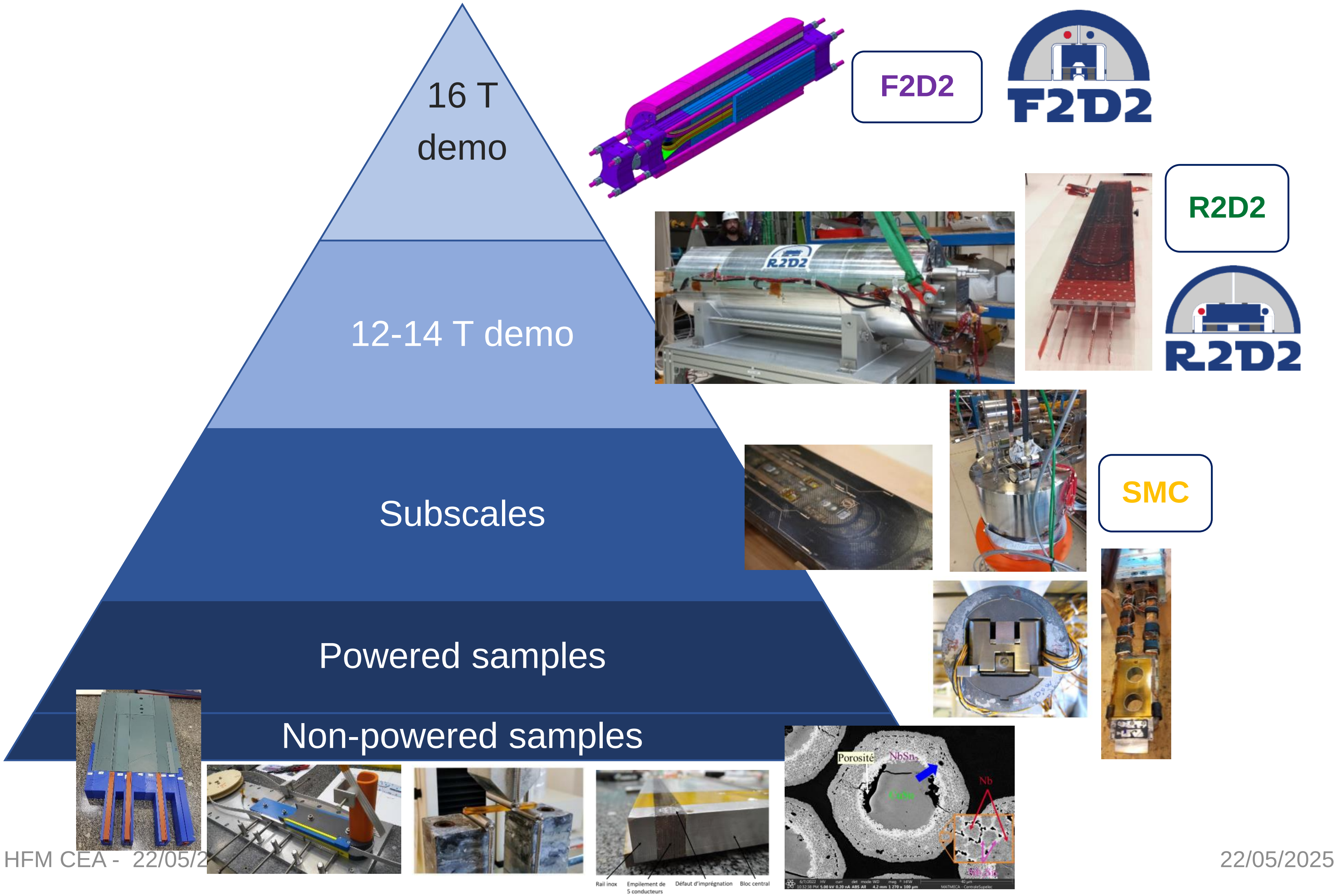
J.C. Perez - CERN

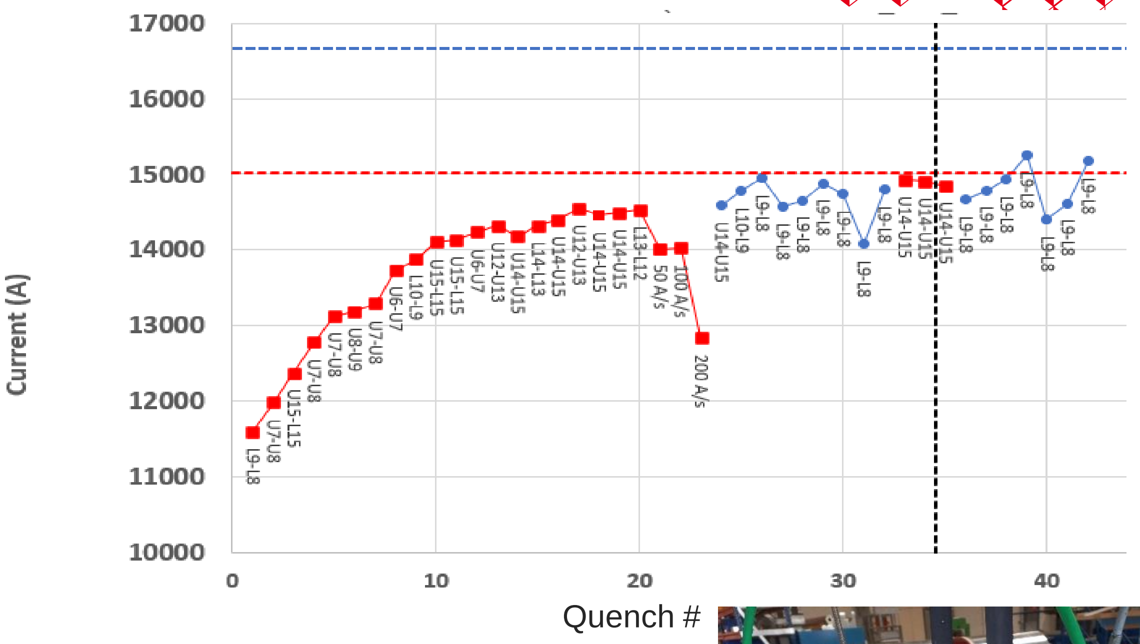
HFM
High Field Magnets
Programme

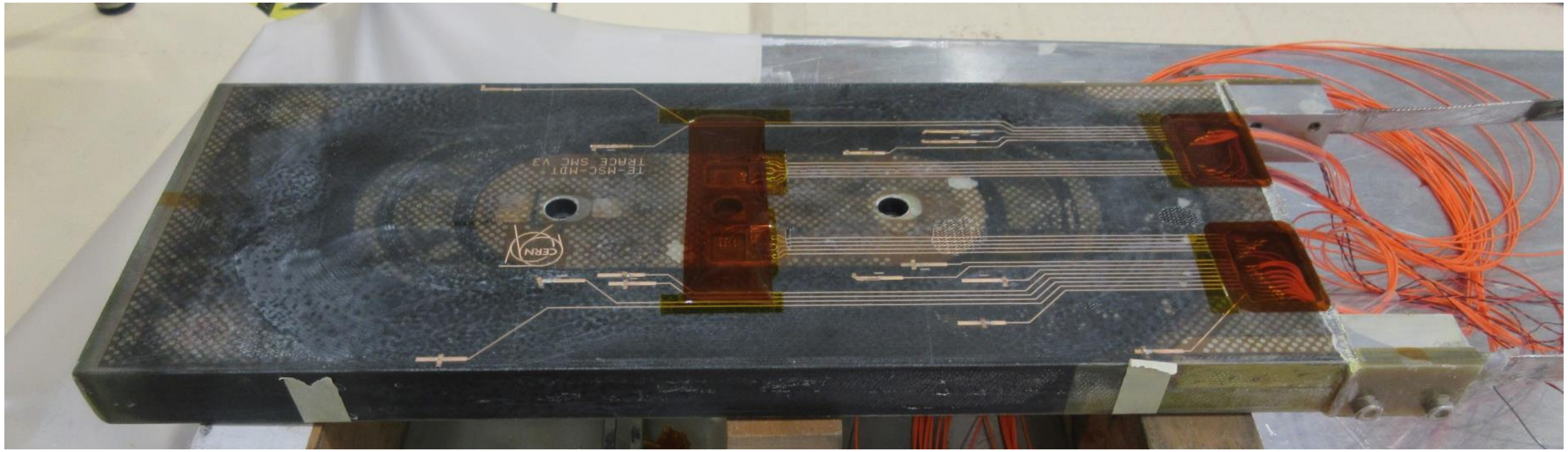
# Development Plan towards 16 T $Nb_3Sn$ Dipoles



# 2 SMC-CEA coils tested

- Coil #102 delivered to CERN in may 2024
- Assembled and pre-stressed in summer 2024
- **Test at CERN in sept-Oct 2024:**
    - **→ 99% of the limit at 4.5 K**
    - **→ 13.3 T peak field on the conductor**
- **$Nb_3Sn$ coil fabrication experience validated for CEA on 2 SMC coils**



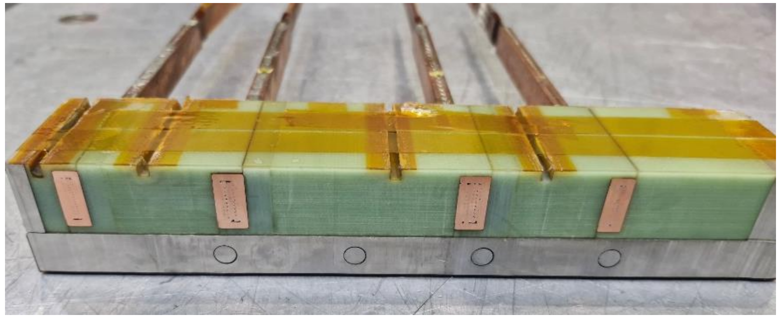
# Fabrication of R2D2 coils

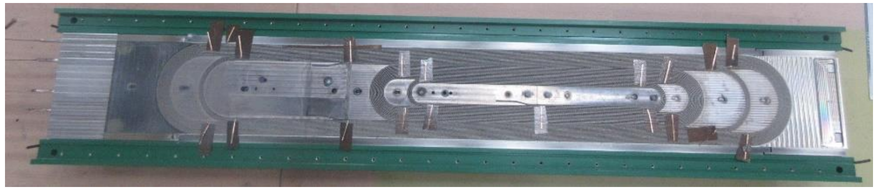
1. CC01: Cu Practice coil
   - Cuts for inspection
   - **Validation of the process**

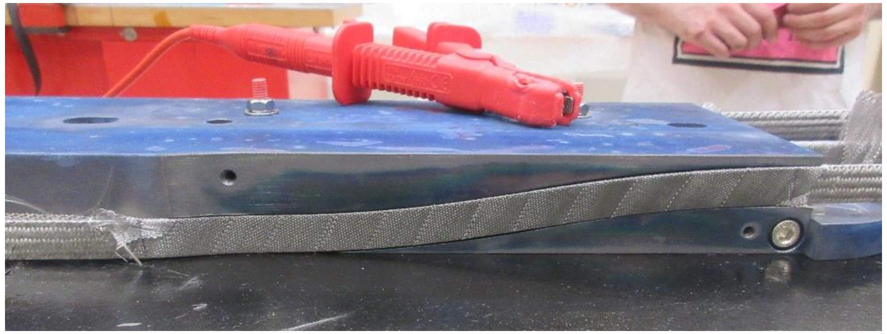
2. CR01: $Nb_3Sn$ Practice coil
   - **Electrical shorts in the exit jumps**
   - **Issue identified: composition of the fiber used**

3. CR02: final $Nb_3Sn$ coil
   - **Wound and unwound**
   - **Fiber replaced**
   - **Manufacturing validated**

4. CR03: final $Nb_3Sn$ series coil
   - **Wound and reacted**
   - **Manufacturing ongoing**

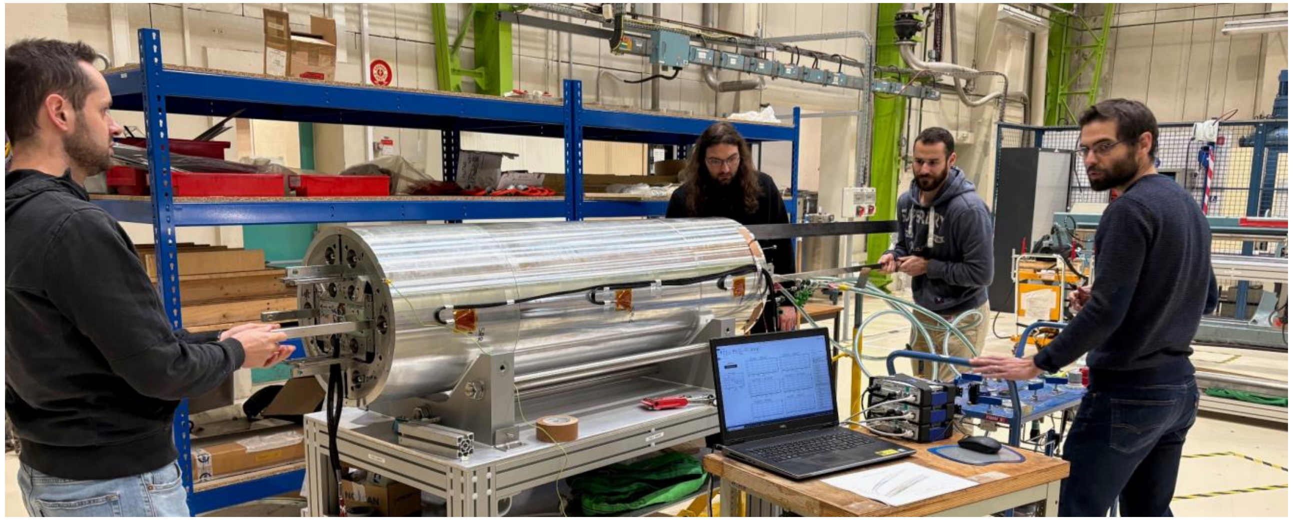






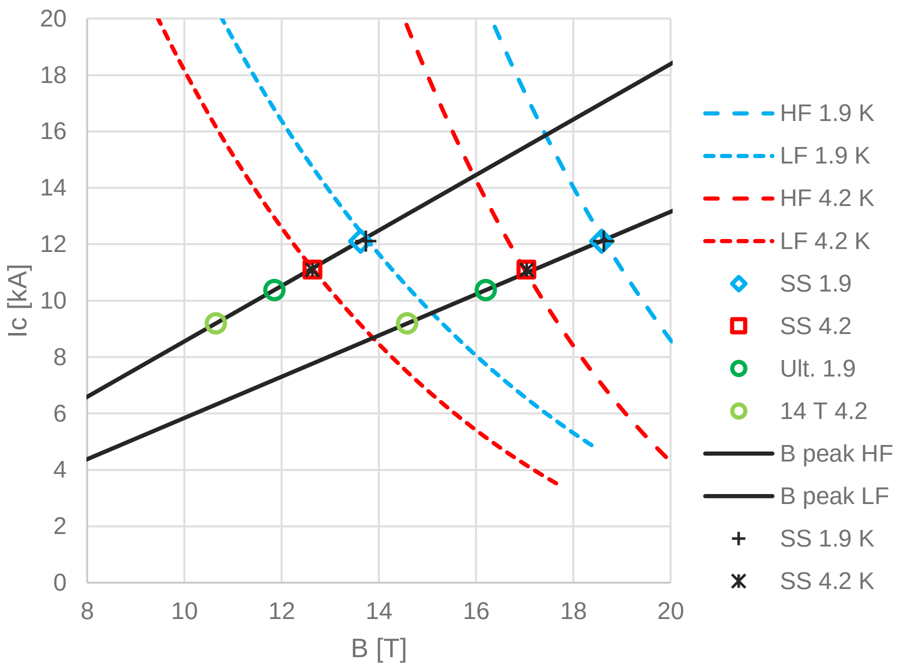
# Assembly of the R2D2 mechanical structure

- Mechanical structure assembled with a dummy coil block
- Mechanical tests to validate the behavior:
  - Different room temperature preloads
  - Cool-down to 77 K
  - Analysis ongoing
- Goal: get ready for the final assembly with the $Nb_3Sn$ coils

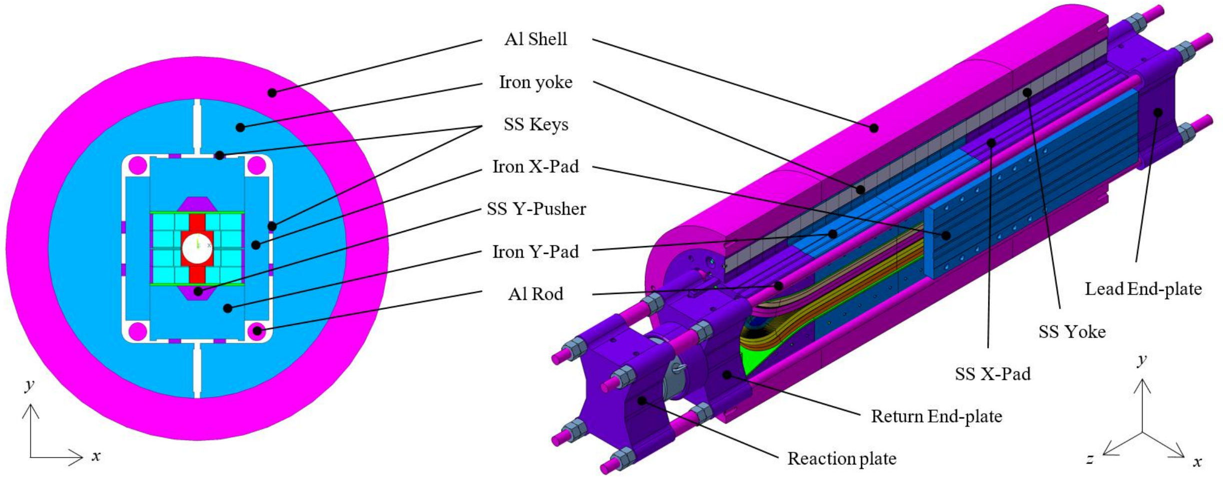


# Overview of the F2D2 design

- **Conceptual design done, detailed engineering ongoing**
- Fabrication, assembly and pre-stress at Saclay
- Tests at cold at CERN
- **Main goal: demonstrate all technologies**
  - Representative of high field magnets: grading, joints, flared-ends, high field and high stress
  - Representative of accelerator magnets: 50 mm bore, field quality




**F2D2** = **F**uture **F**lared **D**ipole **D**emonstrator

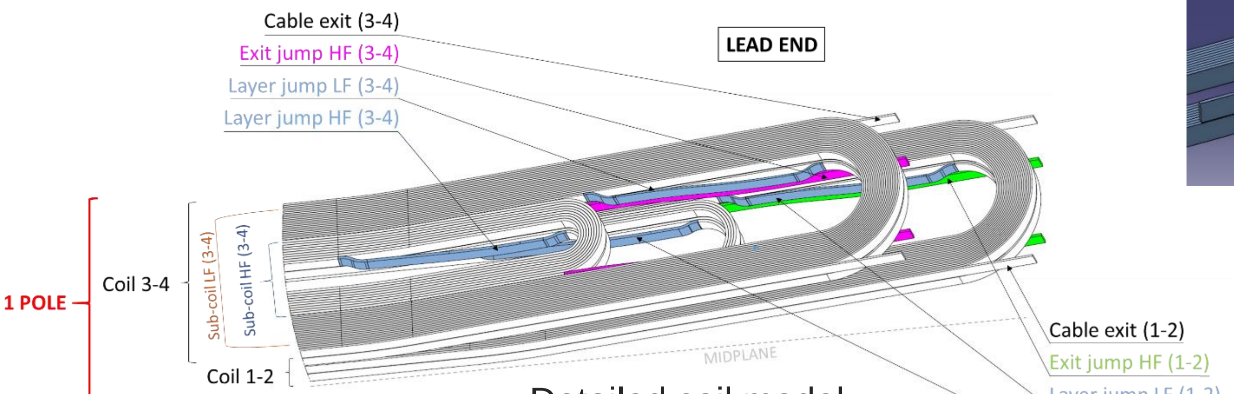



| | |
|---|---|
| Aperture | 50 mm |
| Outer diameter | 650 mm |
| Total length | 2.0 m |
| Central field @76% LL | 14.0 T |
| SS central field | 17.8 T |

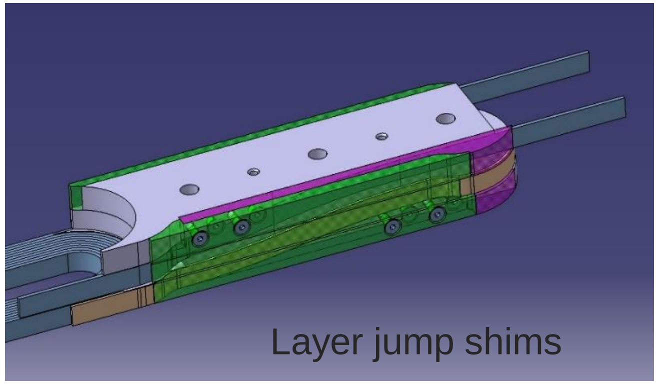
@1.9 K

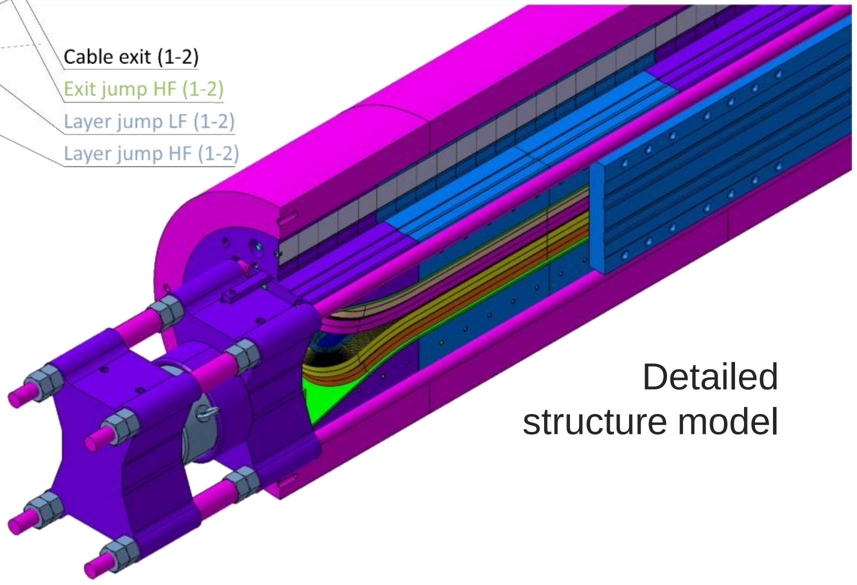
# F2D2 conceptual engineering design

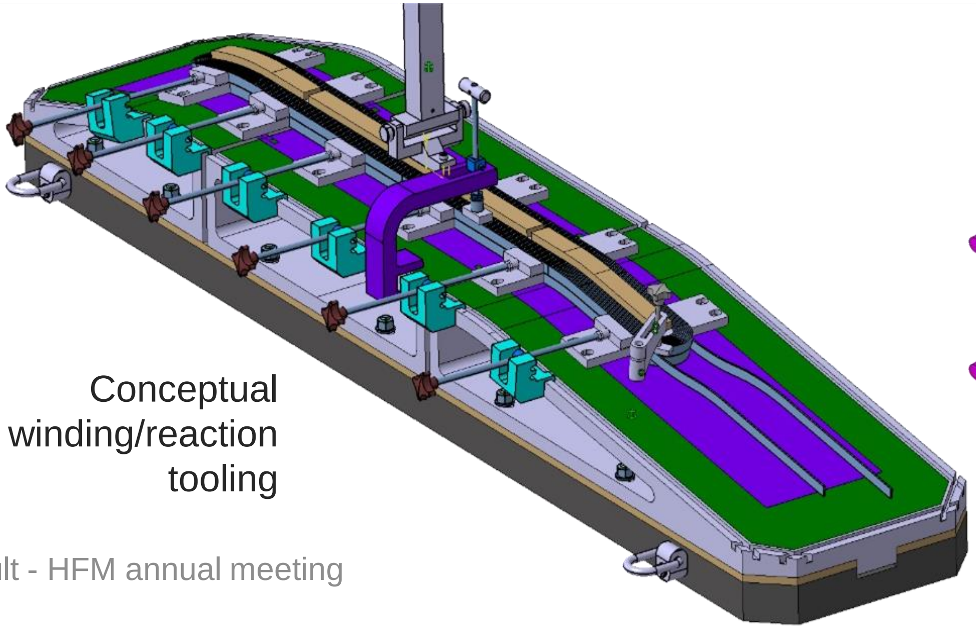
- **Conceptual design finalized**
- **Detailed design ongoing**



Detailed coil model


Layer jump shims


Detailed structure model


Conceptual winding/reaction tooling

# Conclusion: plan towards ultimate-field $Nb_3Sn$

- SMC coils as a learning tool
  - **$Nb_3Sn$ coil fabrication experience acquired at CEA Saclay**
- R2D2 as a 1st demonstrator
  - Demonstrator for **grading in block-coils**
  - Simplified design → **single-layer, flat racetracks, no bore**
  - ~12 T @1.9 K with 20 % margin on the load-line
  - **Fabrication of the coils ongoing**
  - **Structure validation ongoing**
- F2D2: the final goal
  - Demonstrator for **accelerator magnets**
  - **double-layers coils with layer jumps, grading, 50 mm bore, field quality**
  - 14 T @1.9 K with 25 % margin on the load-line
  - 15.5 T @1.9 K with 15 % margin on the load-line
  - **Detailed design ongoing**

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# Metal-insulated REBCO Racetracks last results (part II)

CEA-CERN HFM collaboration W2-11 agreement on HTS MI racetracks developments

Thibault Lécrevisse (CEA) on behalf of CEA team

Amalia Ballarino, Algirdas Baskys (CERN)

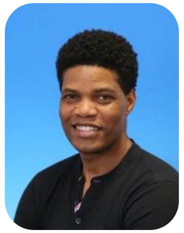
HFM High Field Magnets Programme

+ Many thanks to CNRS Néel Institute for helping in 4.2 K tests (A. Badel, J. Vialle & P. Tixador)

S. Somson

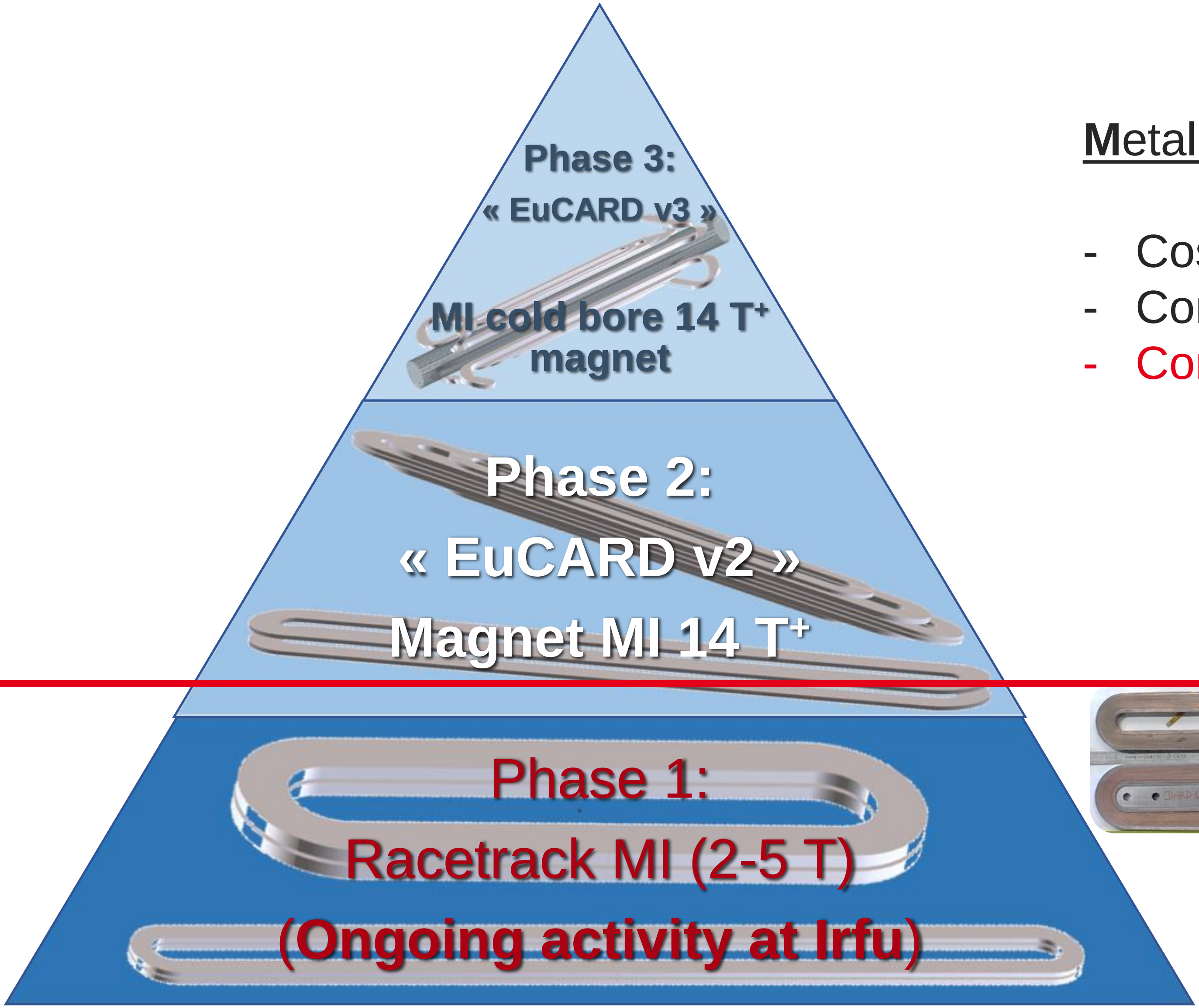
B. Maloeuvre

T. Barabe



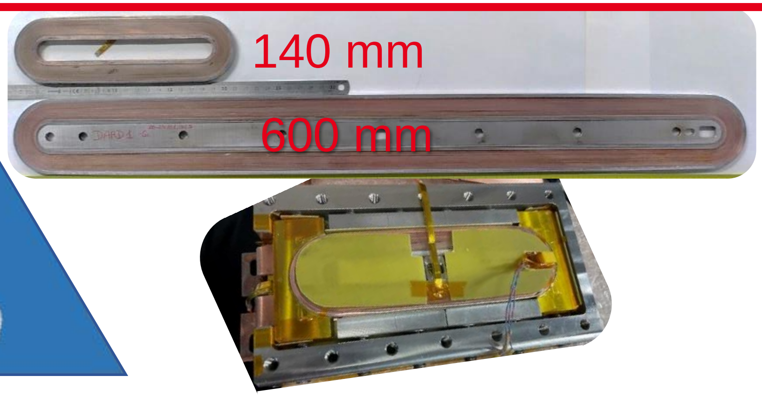
E. Pepinter

# 1. Agreement Status : Development main phases




<u>**M**etal **I**nsulated (NI steel co-winding) for</u> :

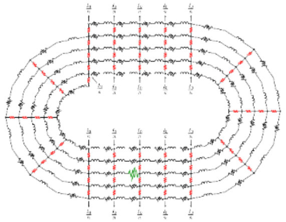
- Costs / risks reduction
- Conductor and design **limit exploration**
- Compact 14 T+ REBCO mock-ups



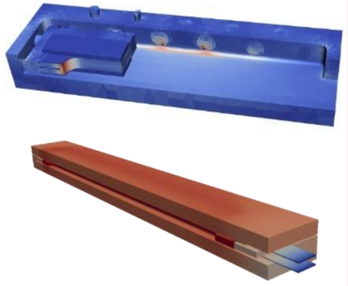

**2023-2025**

## 2. Development blocks

### Modeling



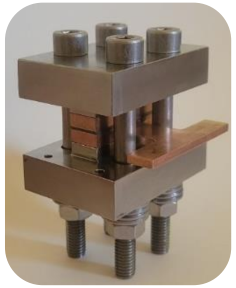
PEEC-R



3D FEM

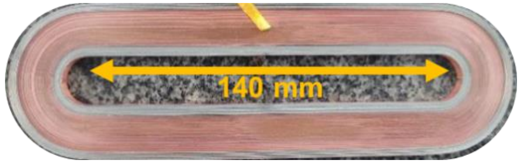
### R&D / Characterization

*Electrical connections*

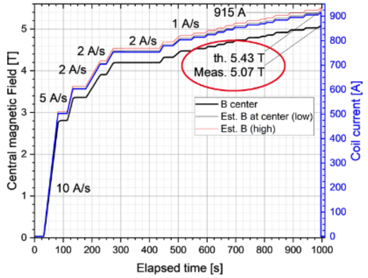


*Radial thermal conductivity*

### MI Racetrack fabrication, assembly and tests



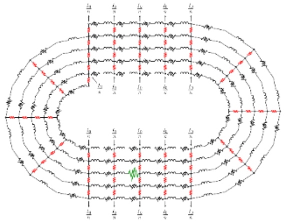

Winding & assembly



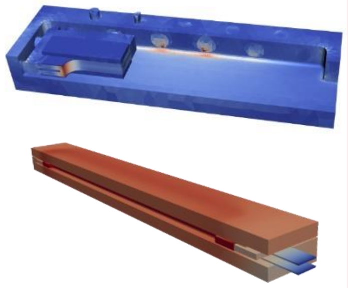

Test and analysis

# 3. Modeling and small R&D

## Modeling



*PEEC-R*



*3D FEM*

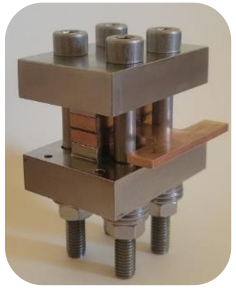
- Magnetic model (RAT-GUI, OPERA, CASTEM)
- Transient PEEC-R without magnetization (MATLAB)
- Thermo-mechanical model (CASTEM / ANSYS)

→ **Need to be compared to measurements**

- PEEC-R with magnetization : started

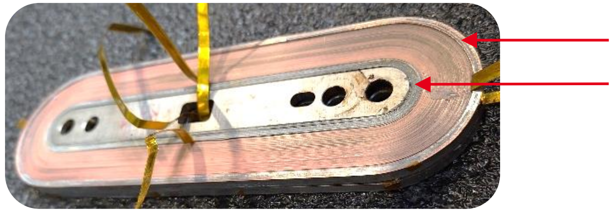
## R&D / Characterization

*Electrical connections*



*Radial thermal conductivity*

- Study on copper to copper electrical contacts resistance
  - For contacts between racetracks and/or leads




- Study on turn to turn thermal conductivity in MI windings

# 4. Racetrack coils : Samples overview

- **26 mm** inner width, **140 mm** straight part
- Shanghai Superconductor Technology (SST), **4 mm wide** and **73-75 µm thick**
- Co-winding of :**1 REBCO tape** with a **30 µm thick Durnomag®**
- ~**54-59 m of single 4 mm tape** per Racetrack

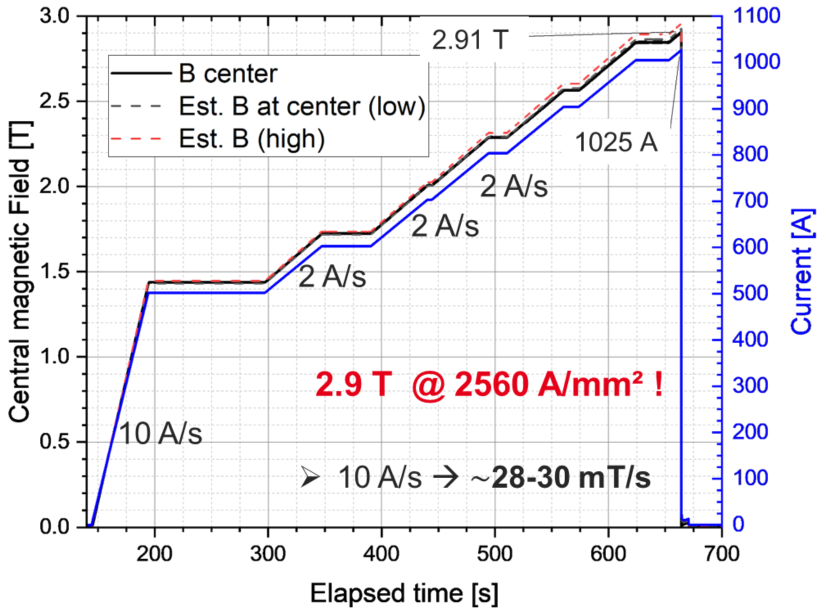
**REBCO tape provided by CERN**

- Dummy winding (copper stainless steel)
- **11 RaceTracks** (RT) with copper rings built (RT1, …, RT9, RT10 & RT11)
- **3 Double RaceTrack** (DRT) assemblies (DRT78, DRT75 & DRT10-11)
- 77 K tests (LN2 bath)
- 4.2 K tests (LHe bath)

2 tests campaigns : November 2024 (DRT78 and DRT75) → learning
March 2025 (RT9 and DRT10-11) → Promising results (HFM forum: metal insulated HTS coil)

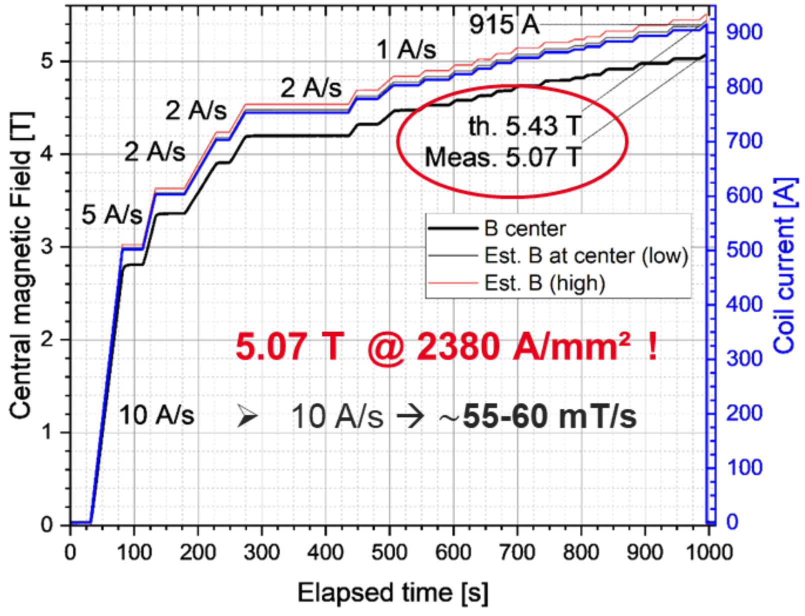
## 5. RT and DRT promising results

RT9 tests




- High current density ($j_{overall}$> 2500 A/mm²)
- Peak field on REBCO tape > 8 T
- 2.9 T at center (at quench current)
- 20-30 mT/s reached
- Survived to quench… BUT damaged

DRT10-11 tests

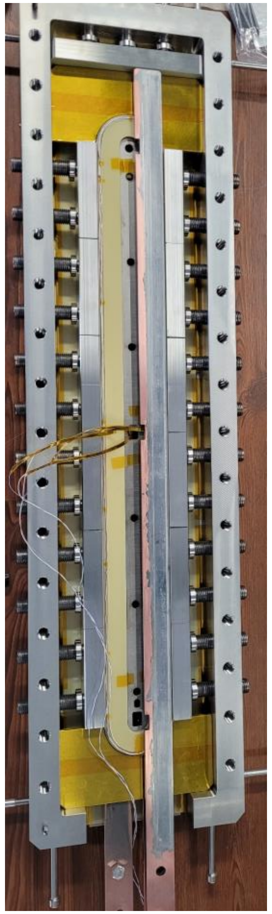



- High current density ($j_{overall}$> 2300 A/mm²)
- Peak field on REBCO tape > 12 T
- > 5 T at center (at quench current)
- 55-60 mT/s reached
- Survived to quench without visible damaged (2 quenches above 2100 A/mm²)

# 6. NARSIL toward 14 T dipole magnet

- ➢ Many open question and lot of data to try to answer them
- ➢ Nice setup to test different king of windings
- ➢ Possibility to compare measures to models

<u>And now </u>: reproduce the results on 600 mm **NARSIL*** DRT

Est. current limit @ 4.2 K : 1000 A → **4.5-5 T at center and >10 T peak field**

* **N**ext generation of **A**ccelerator HTS **R**acetrack**S** with metal **I**nsulation at **L**ab-scale

# Thank you for your attention !