Nb_3Sn High Field Magnet (HFM) activities at Saclay

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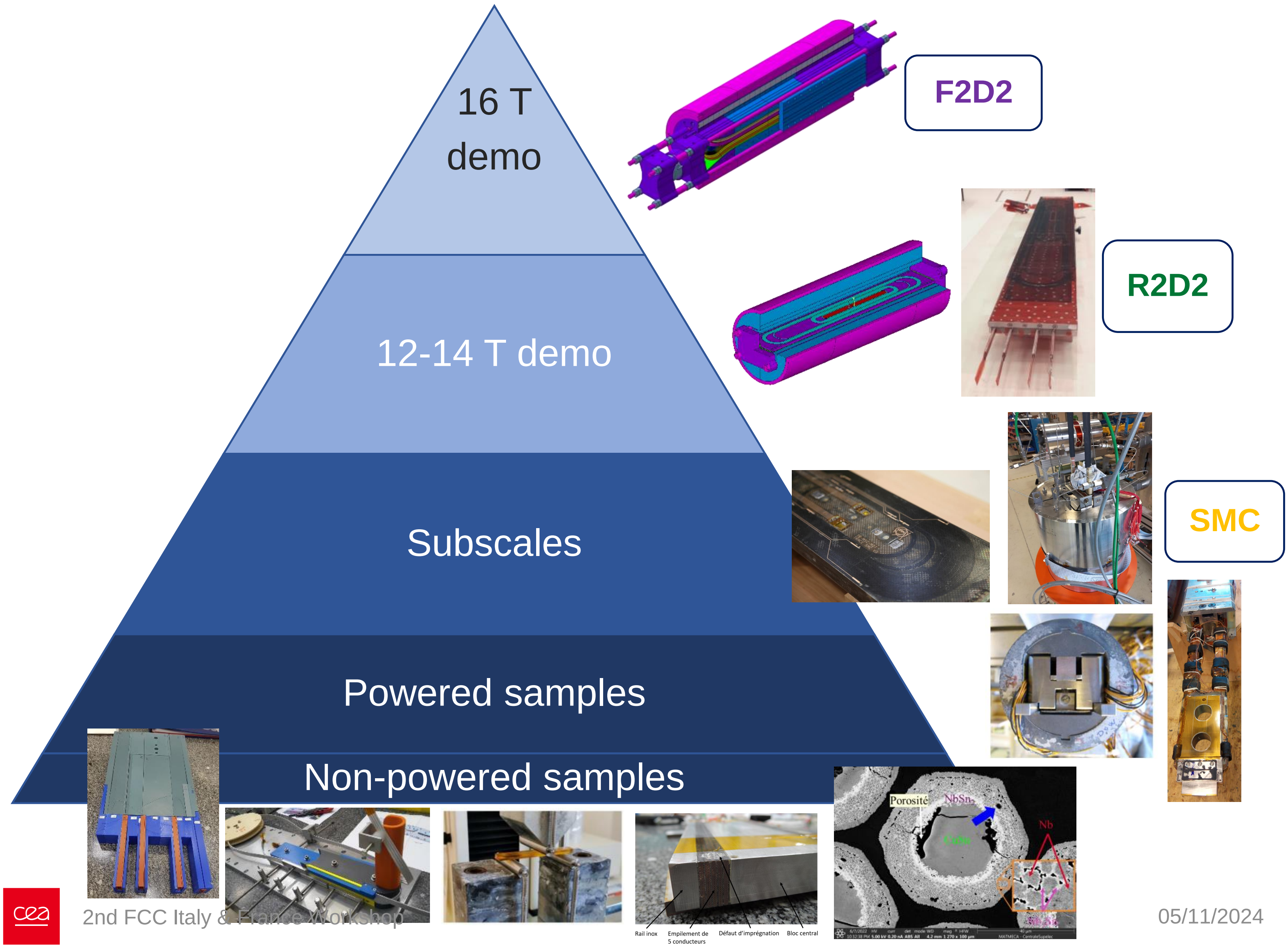
J.C. Perez - CERN

2nd FCC Italy & France Workshop

Development Plan towards 16 T Nb_3Sn Dipoles



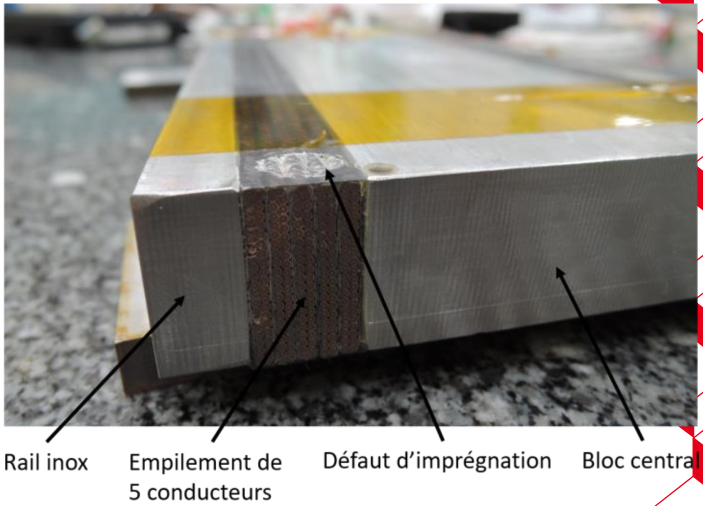
0. Non-Powered samples

Magnet scale - Subscale dipole

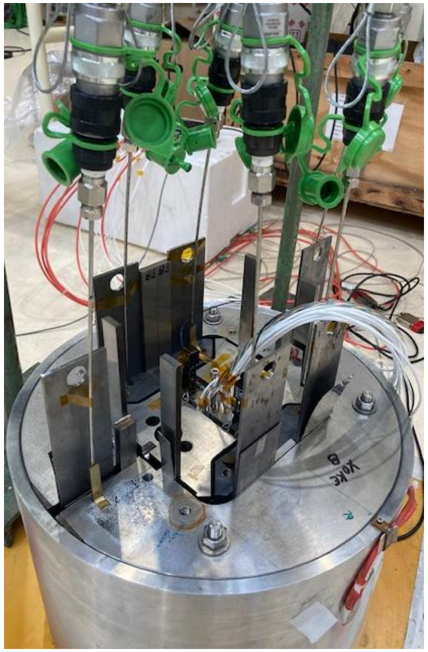
Courtesy of E. Rochepault and G. Campagna

Characterize the mechanical behavior of Nb_3Sn coils in their structure

Instrumented coil segment



coil segment



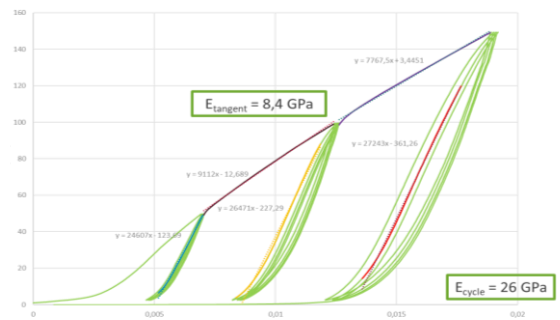
Mechanical loading in a structure

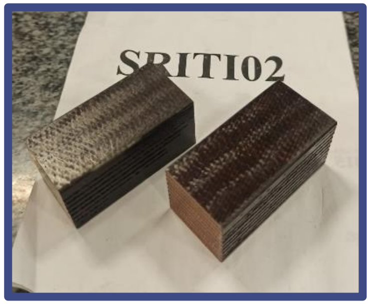
Cool-down to 77K

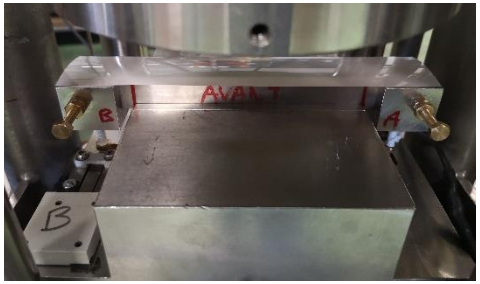
Cable scale - 10-stack campain

Adapted from S. Perraud

- Campain performed by M. Durante in 2000
- Restarted in 2022
- Objective
  - Independent test
  - Validated on old conductor (FRESCA2)
  - Test of all new conductor for HFM program
- R&D investigation
  - Characterization of mechanical behavior (strain rate, hold, unloadings and cyclic behavior)
  - Investigation of damage (impregnation matrix and conductors)
  - Validation of mechanical models

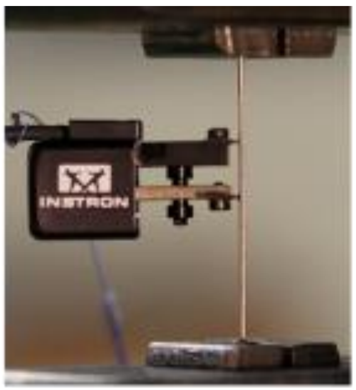




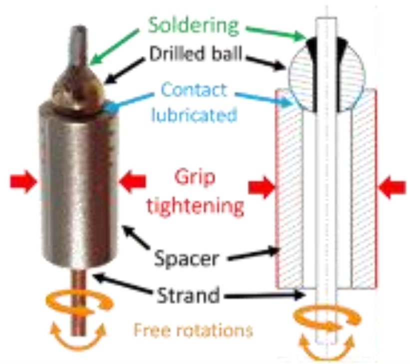


Strand and sub-element characterization

- Tensile test on strands at RT and 77 K
  - Data for the identification and the validation of mechanical models
  - Investigation of mechanical behavior of strands (strain rate, hold, cyclic behavior)



Test of a Nb_3Sn strand



Clamping setup

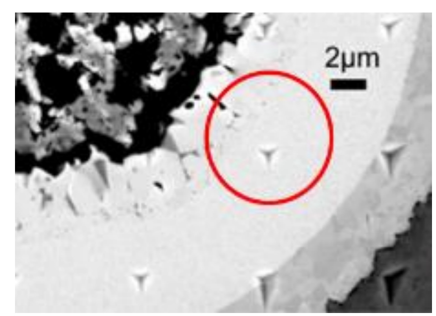
Outer part cryostat

Inner part cryostat

@CEA Paris-Saclay

- Nano-indentation at RT
  - Local elastic modulus and nano-hardness

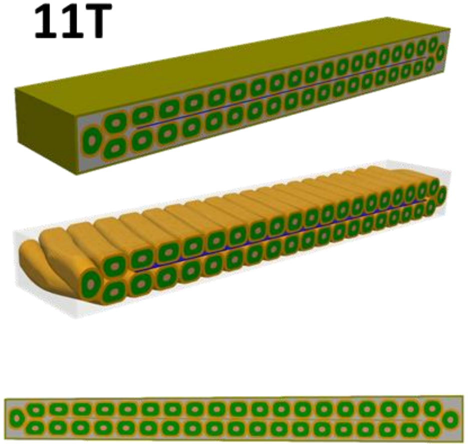
- Perspectives
  - Transverse tests on strands
  - Nano-indentation at cryogenic temperatures
  - Micro and nano-mechanical testing



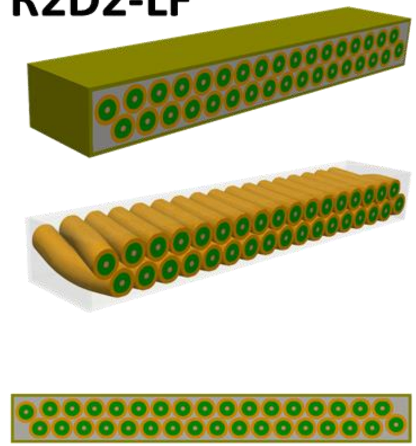
Nano-indentation in Nb_3Sn phase of a PIT strand [Lenoir 17]

Cable scale - Mesh Generator

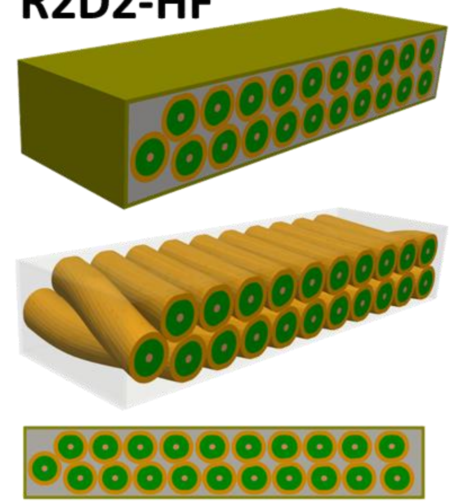
11T



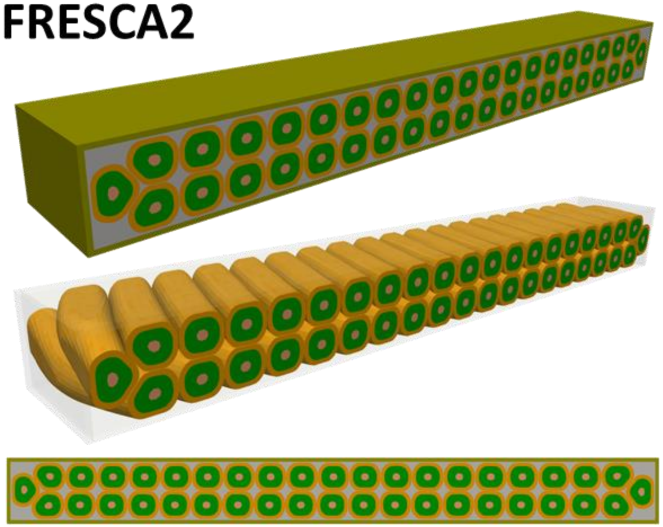
R2D2-LF



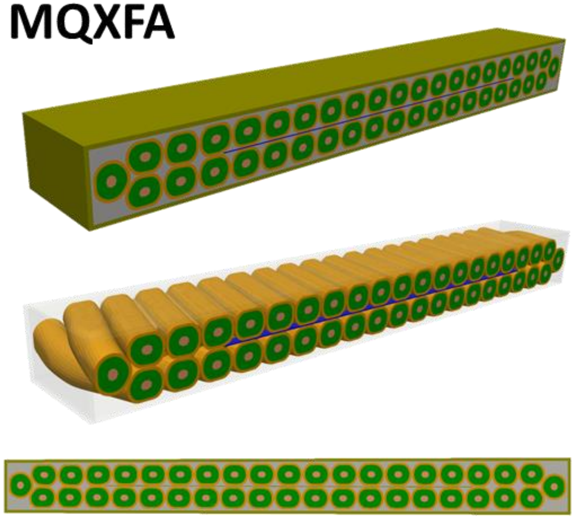
R2D2-HF



FRESCA2

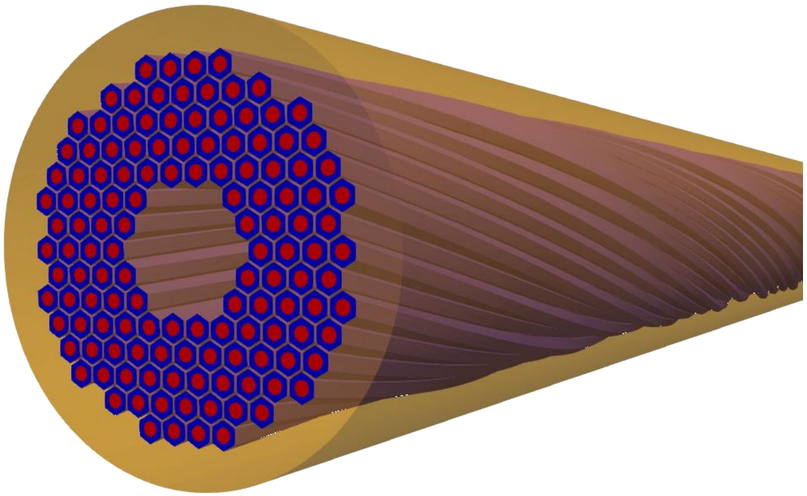


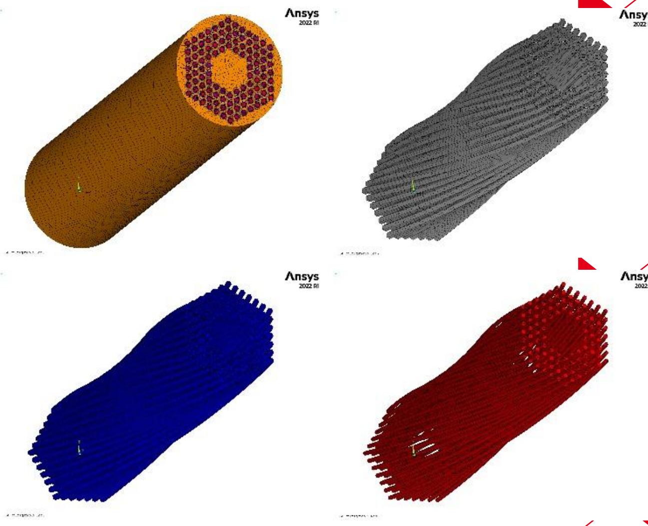
MQXFA

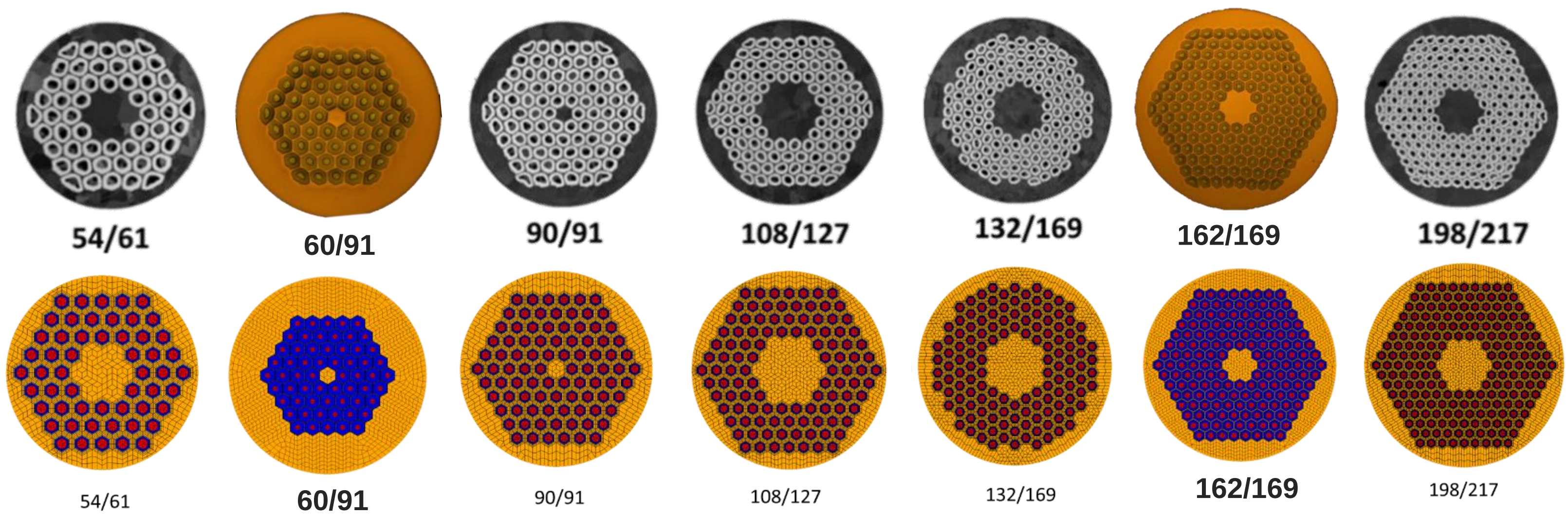


Strand scale - Mesh Generator

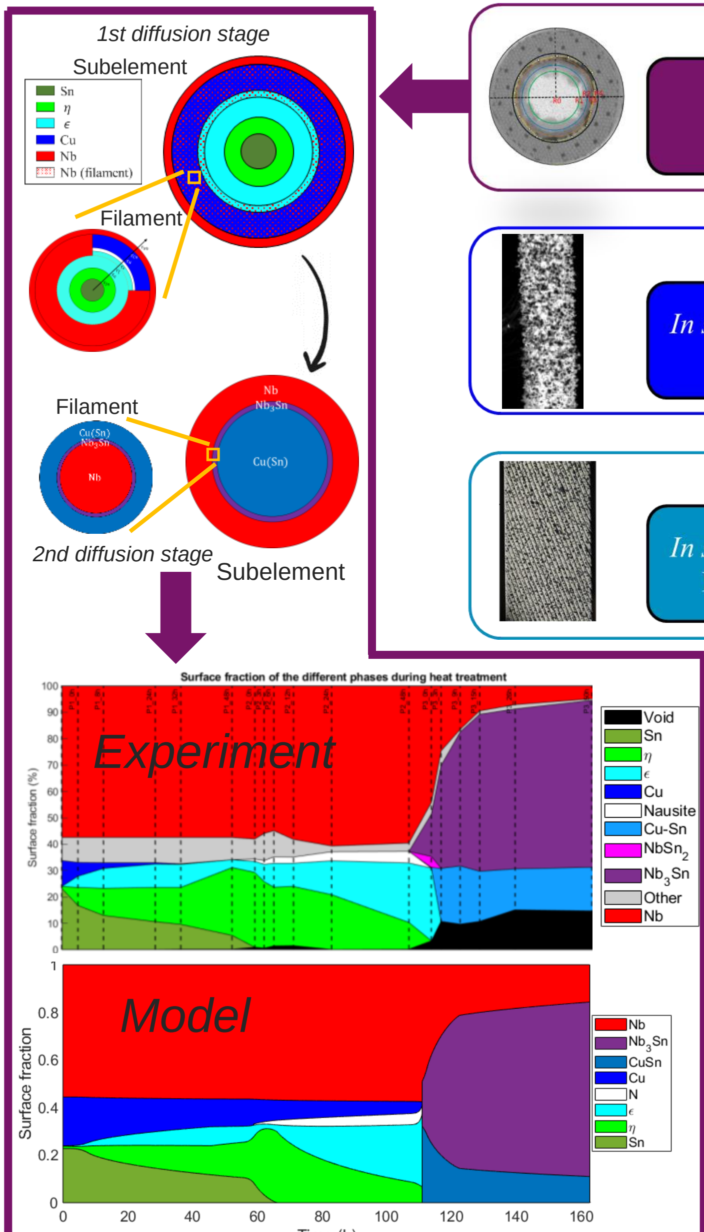
Numerical models from Y. Perron
Micrographies from S. Hopkins and C. Sanabria

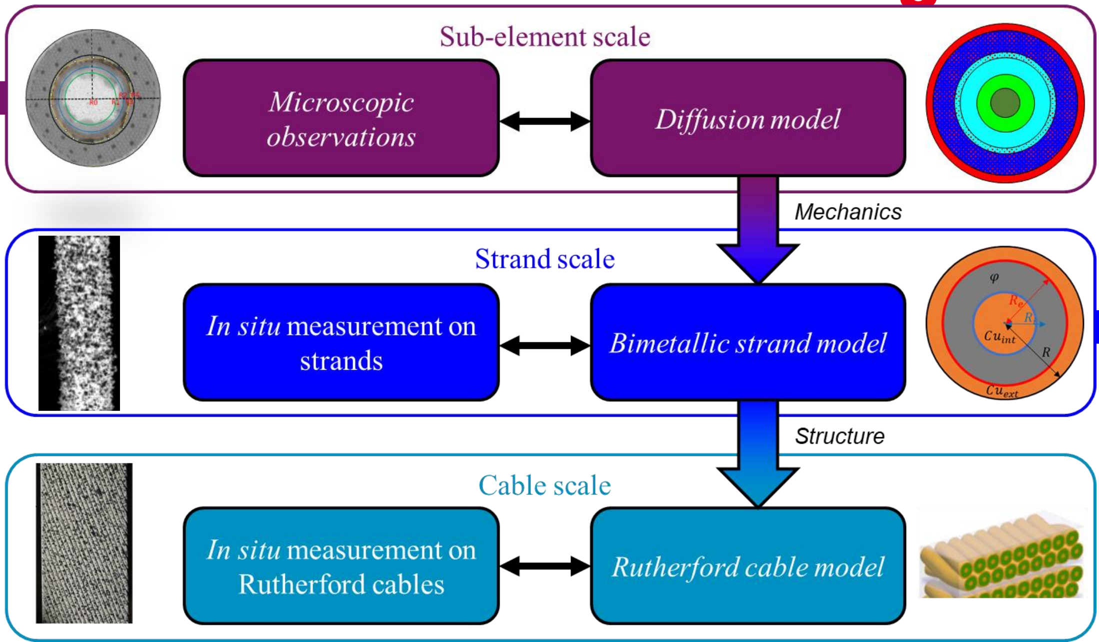




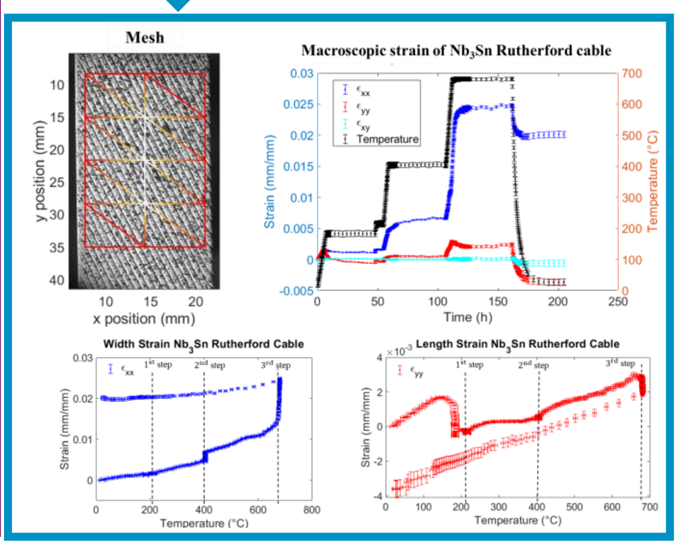


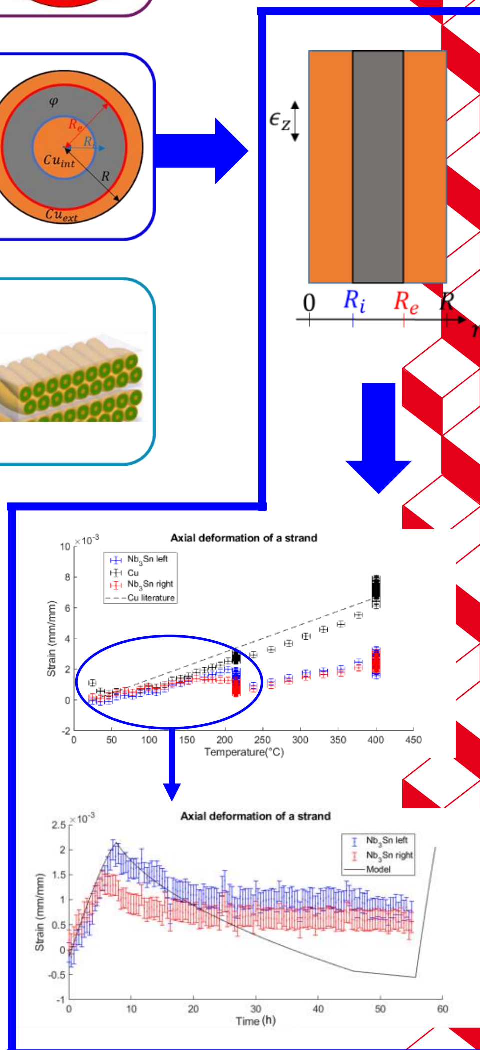
Thermomechanical behavior during HT





Work performed during PhD of M. Abdel-Hafiz @ CEA/LMPS, Univ. Paris-Saclay

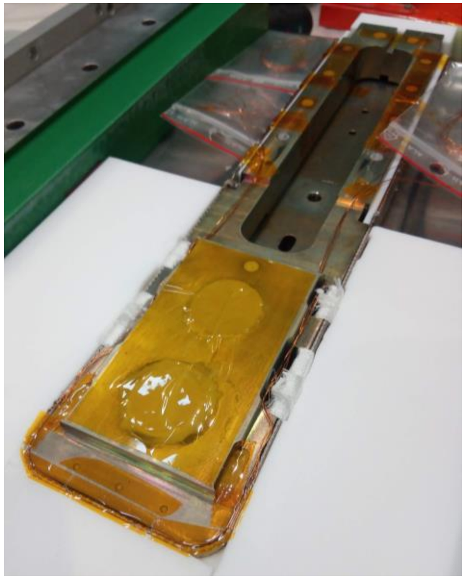


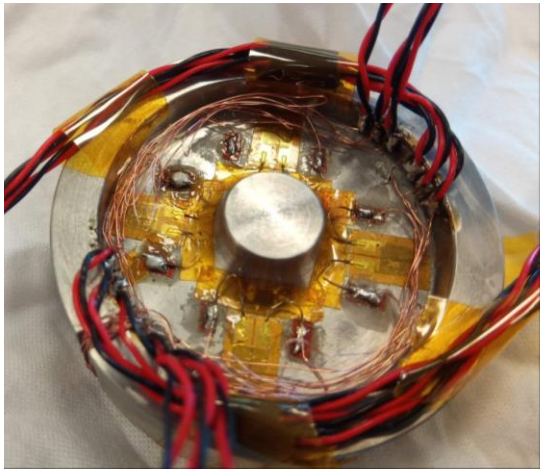


1. Powered samples

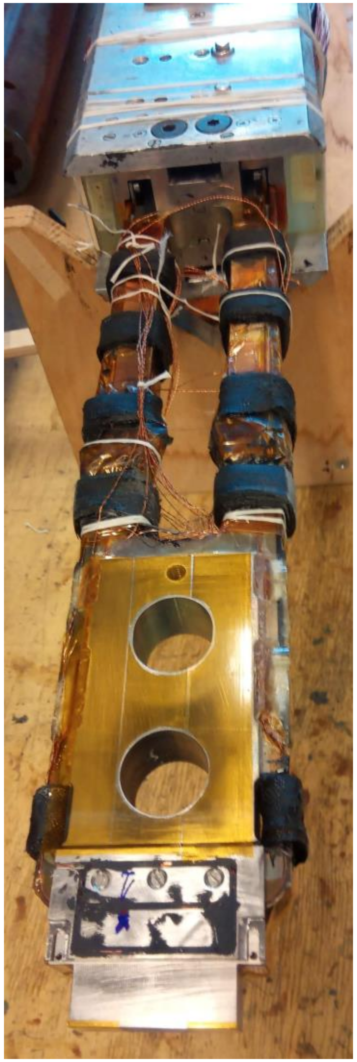
deBOnding eXperiment n°1 - deBOX1

[PhD Thesis Guillaume Campagna]





New instrumentation: two pick-up coils and a 7 kN load cell for cryogenic use



Twente sample holder : 11 T background, 100 kA transformer, up to 200 MPa compression

2. SMC-11T

SMC-CEA#101

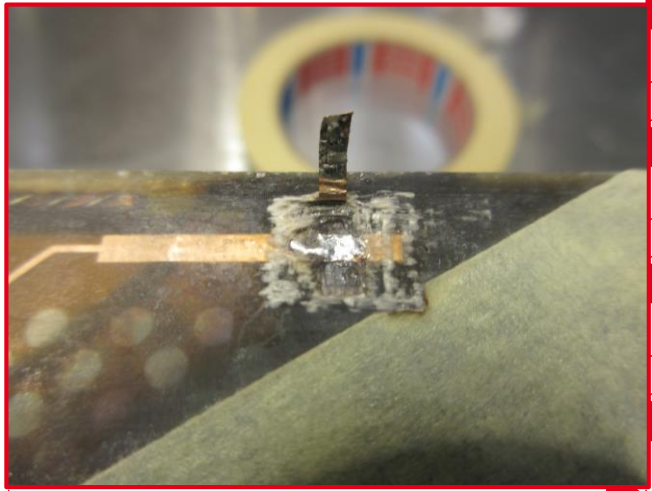
- SMC-CEA #101 fabricated at Saclay in 2021
- Assembled and tested at CERN in 2022
- **95 % SS @ 4.2 K**
- **No sign of mechanical degradation or loss of pre-stress**

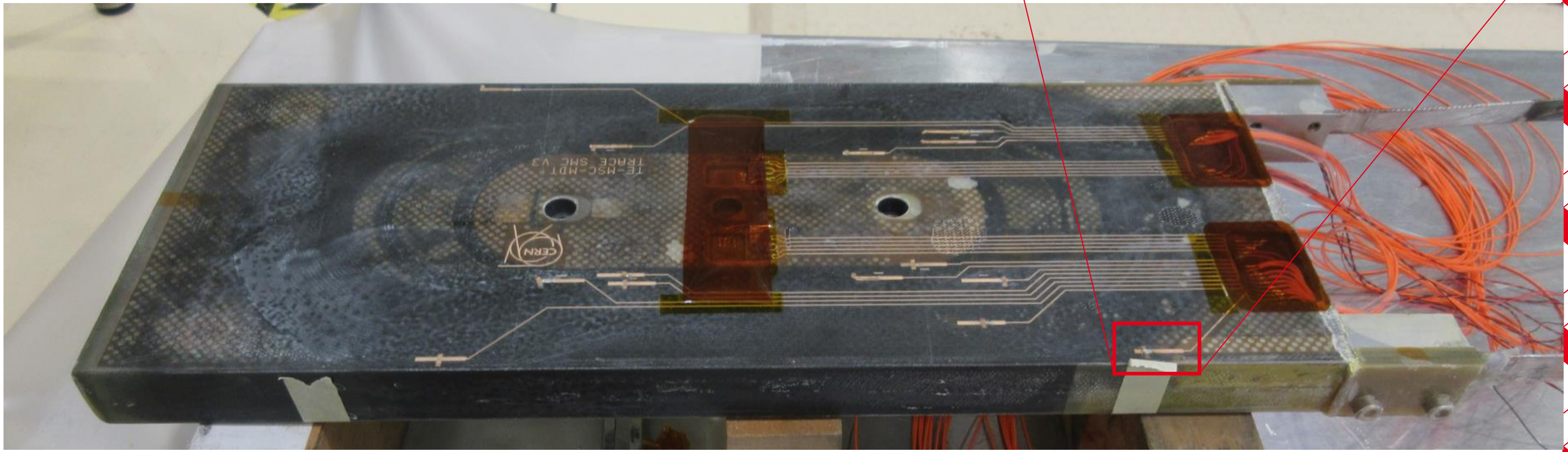
SMC-CEA#102

- Introduction of the CTD flexibilizer
- **2 shortcuts detected after impregnation**

→ **repaired, electrical tests passed !**

- Assembled and tested at CERN in 2024
- **99 % SS @ 4.2 K**
- **No sign of mechanical degradation or loss of pre-stress**

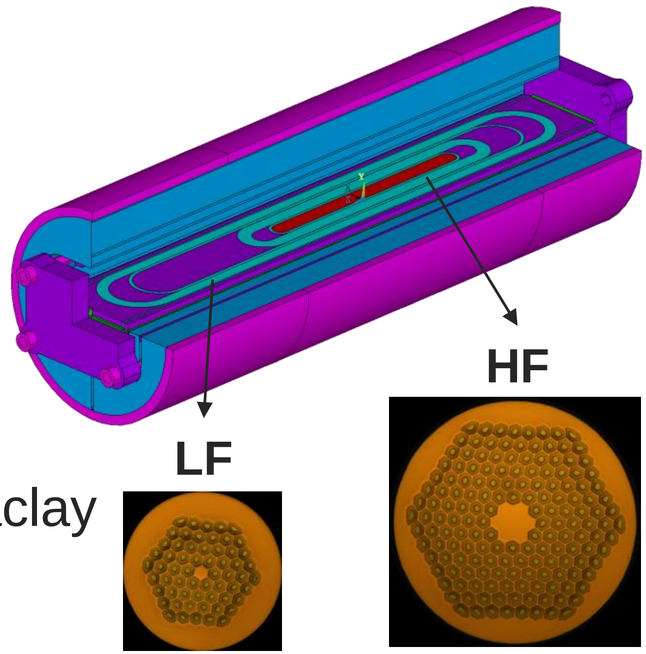




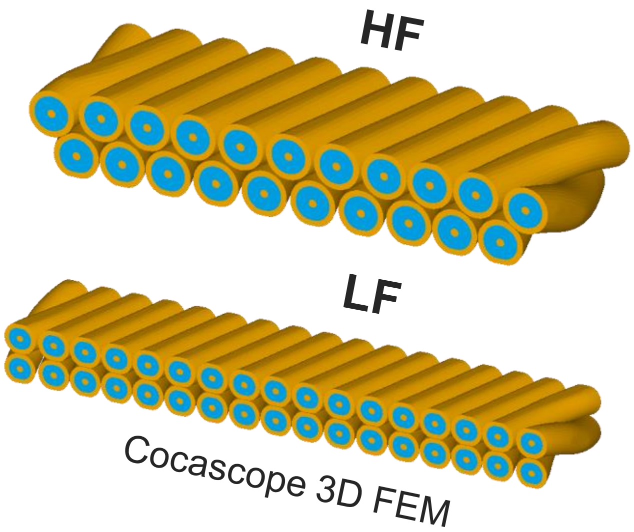
3. R2D2

Conductor production and qualification

- 2 Nb_3Sn RRP conductors for grading
- Same cables for all magnets
- Strand characterization @ CERN
- Cable production @ CERN
- Cable and strand characterization @ Saclay



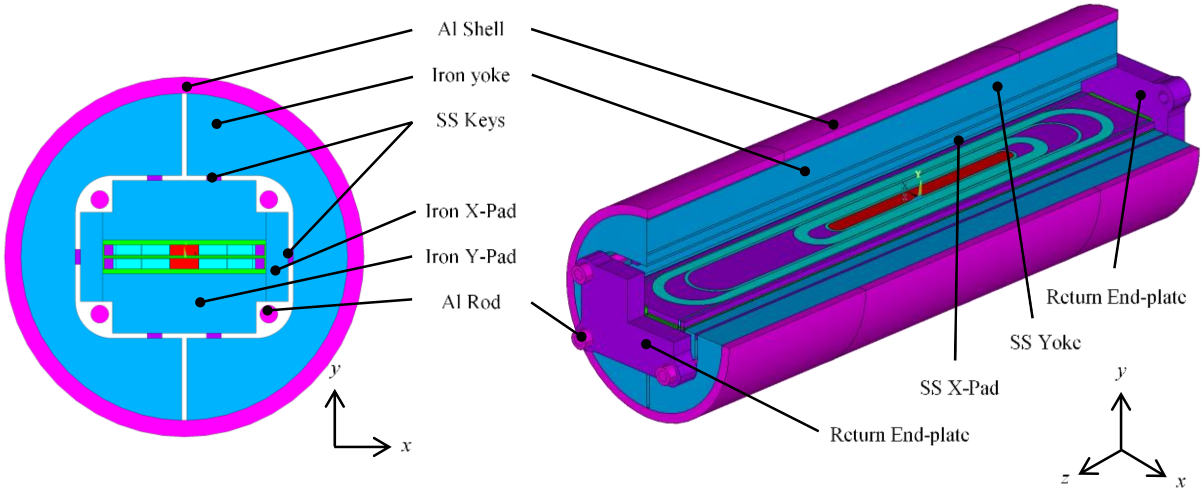
Parameter	Unit	HF cable	LF cable
Strand type		DEM-1.1	DEM-0.7
Strand layout		RRP® 162/169	RRP® 60/91
Strand diameter	mm	1.1	0.7
Number of strands		21	34
Cable mid-thickness	mm	1.969 ± 0.010	1.253 ± 0.010
Cable width	mm	12.579 ± 0.050	12.579 ± 0.050
Pitch	mm	84 ± 3	79 ± 3
Core		No core	No core



Overview of the R2D2 design

- CEA conceptual design validated by an external committee
- Fabrication, assembly and pre-stress at Saclay
- Tests at cold at CERN
- **Main goal: demonstrate feasibility of grading**
  - Winding two cables on top of each other
  - Heat treating two different cables together
  - Jonctions of the 2 cables → 1st option: external Nb_3Sn-NbTi joints

R2D2 = **R**esearch **R**acetrack **D**ipole **D**emonstrator

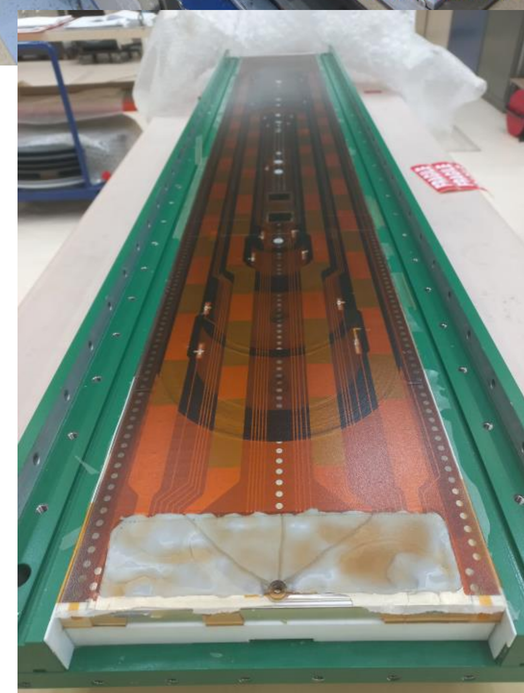


Aperture	None
Outer diameter	480 mm
Structure length	2.0 m
Nominal central field	11.1 T
Ultimate central field	12.0 T
Nominal peak field	12.7 T
Ultimate peak field	13.7 T

Fabrication of R2D2 Nb_3Sn coil CR01

<u>CR01</u>:

- ✓ Winding
- ✓ Heat treatment
- ✓ Junctions
- ✓ Impregnation
- × Electrical shortcut, identified

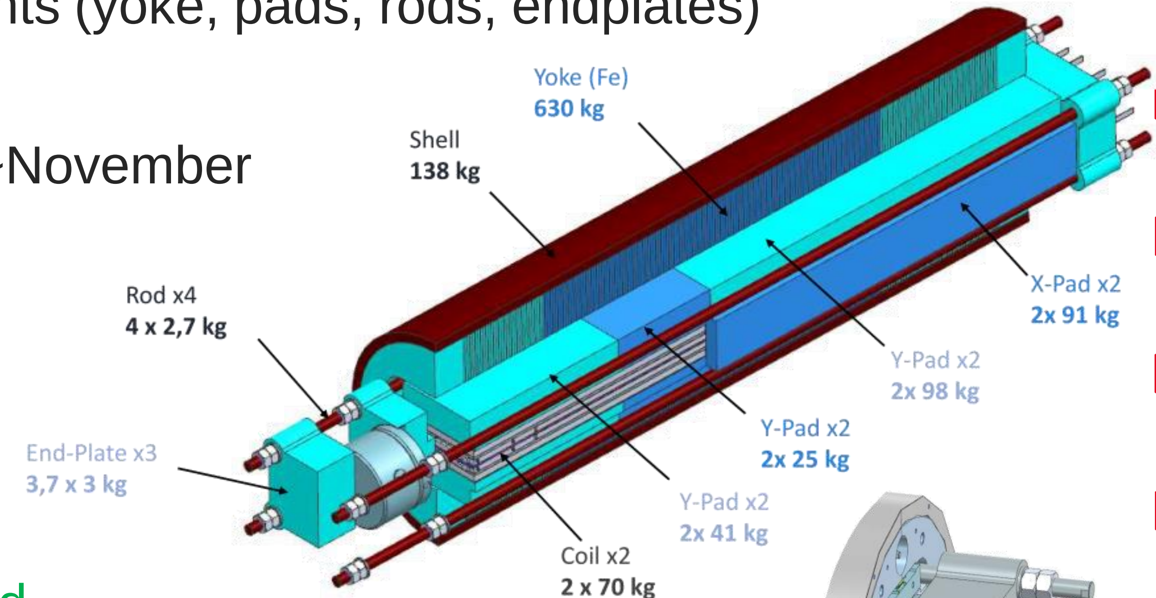


<u>CR02</u>:

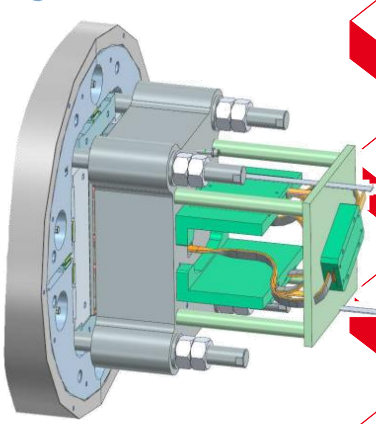
- ✓ Winding
- ➢ Heat treatment pending

R2D2 structure procurement

- ✓ Shell segments received at CERN
- Structure components (yoke, pads, rods, endplates)
  - ➢ Machining ongoing
  - ➢ Delivery expected ~November



- Connection box:
  - ✓ 3D design finalized
  - ➢ Mockup ongoing



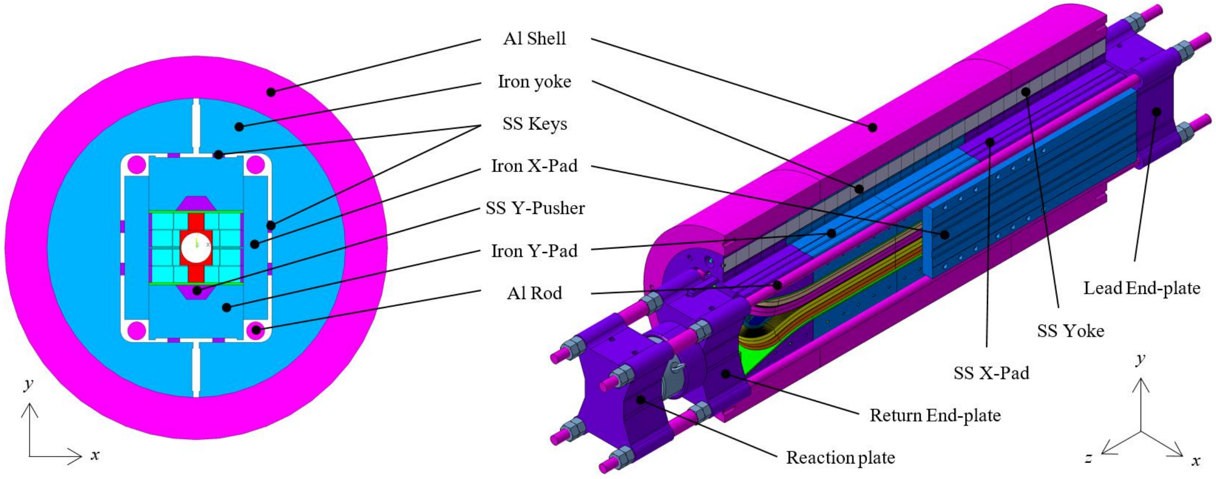
- Magnet schedule :
  - ➢ Dummy assembly at Saclay to validate the mechanical behavior of the structure → Q4 2024
  - ➢ Selection of the 2 best coils for assembly → Q1 2025
  - ➢ Delivery at CERN for cold tests → mid-2025

4. FD/F2D2

F2D2 16T demonstrator magnet

- **Conceptual design stage**
- 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

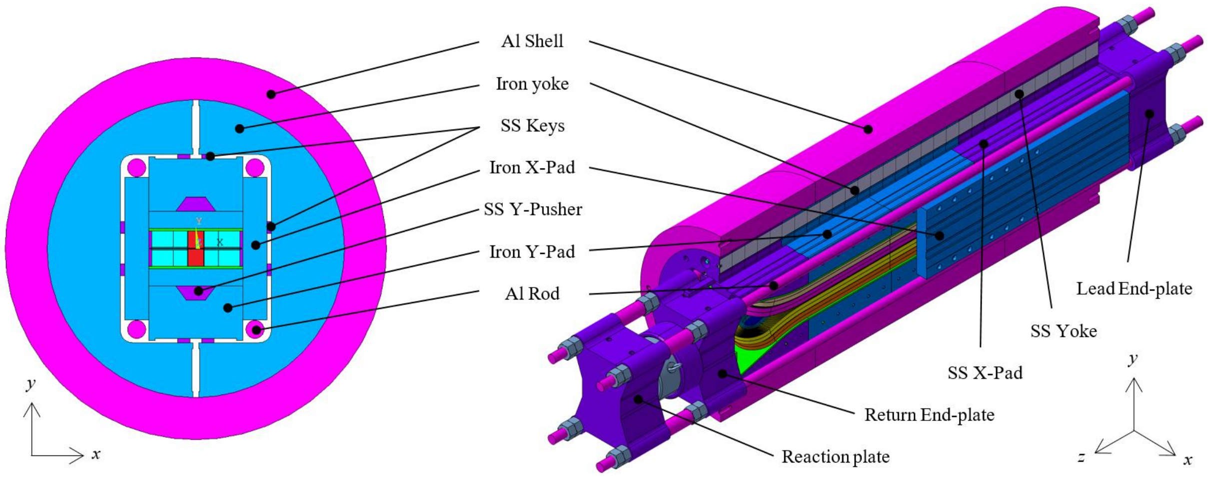


Aperture	50 mm
Outer diameter	650 mm
Structure length	2.0 m
Nominal central field	15.5 T
SS central field	17.8 T
Nominal peak field	16.2 T
SS peak field	18.6 T

FD 14T demonstrator magnet

- **Conceptual design stage**
- Fabrication, assembly and pre-stress at Saclay
- Tests at cold at CERN
- **Main goal: demonstrate key technologies**
  - Representative of high field magnets: grading, joints, flared-ends, high field and high stress
  - Some simplifications: 1 type of coils, no bore

FD = **F**lared **D**ipole



Aperture	None
Outer diameter	650 mm
Structure length	2.0 m
Nominal central field	14.0 T
SS central field	17.2 T
Nominal peak field	14.7 T
SS peak field	17.9 T

Conclusion

❑ **Non-powered samples**
- Characterization of materials
- Modelling activities

❑ **Powered samples**
- Behavior of Nb_3Sn cables at low or no pre-stress
- Behavior of HFM Nb_3Sn cables under stress

❑ **Short Model coil SMC** :
- **2 coils manufactured at Saclay: successful tests!**
- **Development of fabrication processes, infrastructure, experience**

❑ **Demonstrator magnet R2D2**
- → **Proof of concept** of the grading technologies
- **Coil fabrication ongoing**
- **Structure components being machined**

❑ **Demonstrator magnet F2D2**
- → **Design of a 14+ T** accelerator-type magnet
- **FD: 14+ T dipole** as an intermediate assembly to validate the concepts

Merci !

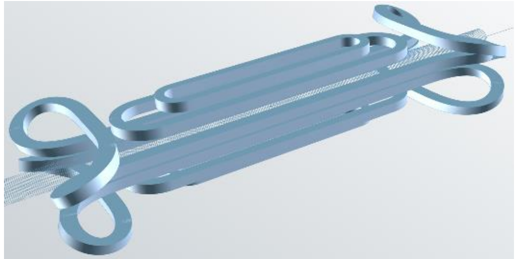
Thank you !

▪ Backup slides

CEA plan towards 20 T HTS dipoles

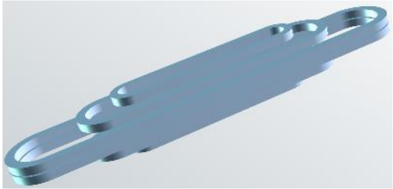
Phase 3 :

« EuCARD V3 »
MI cold bore 16 T+ magnet

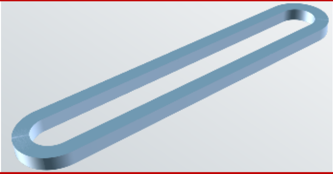


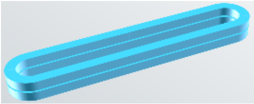
Courtesy T. Lécrevisse

Phase 2 :
magnet MI 16 T+
« EuCARD V2 »



Phase 1 **2023-2025**:
Racetrack MI





Ongoing Project

Phase one objectives :

- **Adapt and validate** the numerical tools for electromagnetic + thermal + quench models
- **Characterize** specific parameters of MI windings (Turn-to-turn thermal conduction…)
- **Develop** the technologies from winding to assembly including electrical connections
- **Evaluate** the options of **conduction cooled** dipole
- **Fabricate** and **test** one racetrack coil for models benchmark