Nb_3Sn HFM activities at CEA
WP3.6 R2D2 and WP3.12 F2D2

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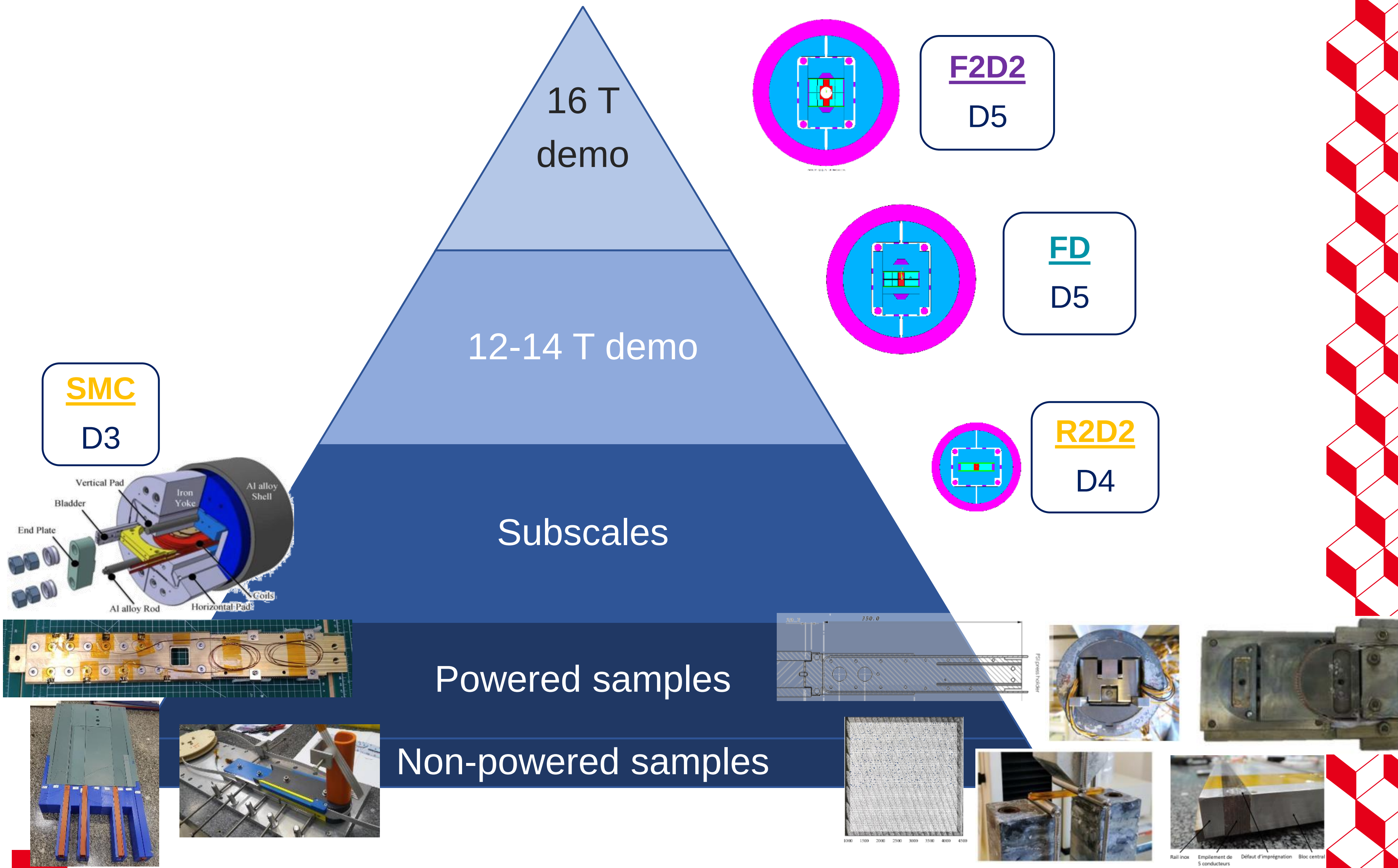
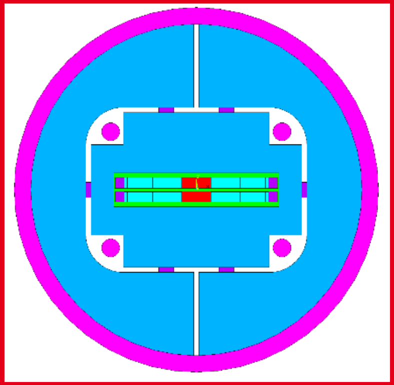
J. C. Perez. - CERN

HFM Annual meeting – 1st November 2023

Development Plan towards 16 T Nb_3Sn Dipoles



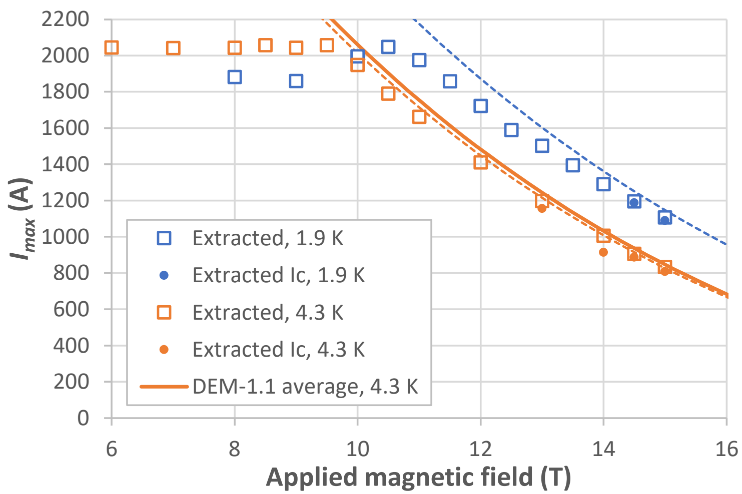


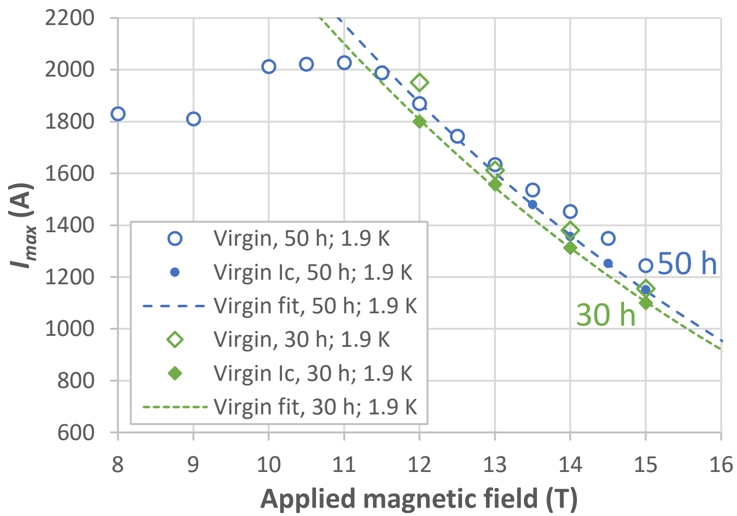
1. Activities linked to R2D2 (WP3.6)

Conductor production and qualification

- Strand characterization (CERN):
  - I_c measurement of HF strands done
  - I_c measurement of LF strands ongoing
  - Heat treatment optimization ongoing

- Cable production (CERN):
  - Cu prototype UL (HF+LF) received at Saclay and qualified
  - Nb_3Sn short prototype cables (HF+LF) received at Saclay and qualified
  - Nb_3Sn UL (HF+LF) produced
  - Insulation of UL ongoing (Thickness measurement at CERN)





Fabrication of SMC coils

- SMC-CEA #1 fabricated at Saclay in 2021
- Assembled and tested at CERN in 2022

→ **95 % of the Ic limit at 4.5 K !**

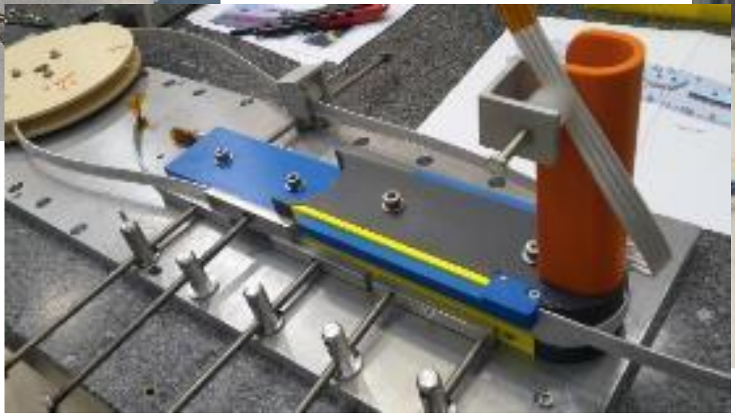
→ No sign of degradation, no loss of pre-stress

- SMC-CEA #2: ongoing fabrication at Saclay

Mockups to validate the technologies

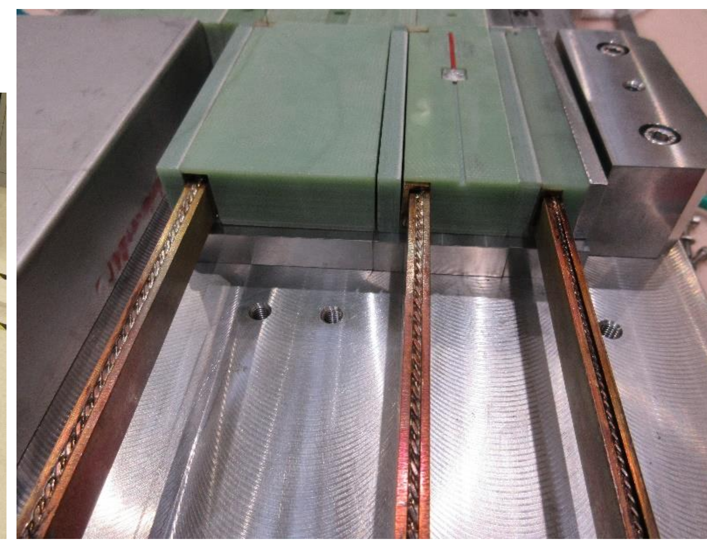
- ✓ Cable bending tests
- ✓ Layer jumps/exit jumps
- ✓ Junction mockups
- ✓ Dimensional changes during heat treatment

→ see MT28 poster+paper



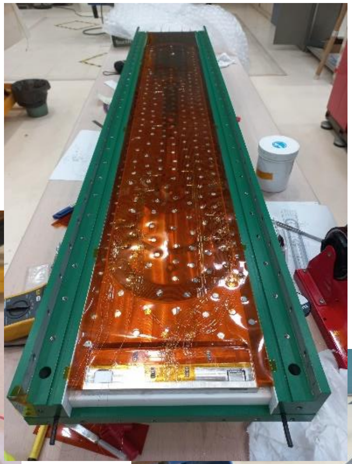
Qualification of the R2D2 tooling

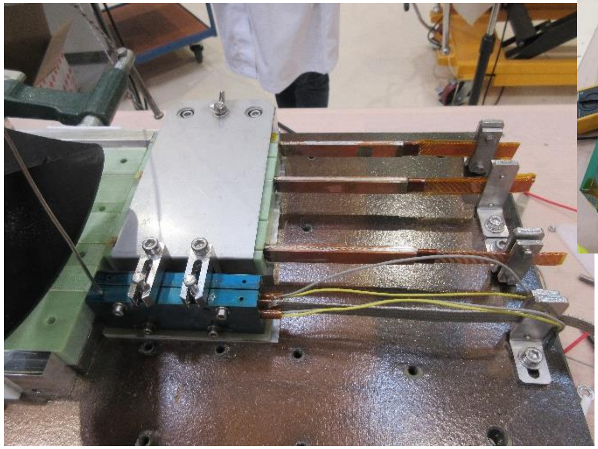
- ✓ Blank assembly of the Winding tooling
- ✓ Heat treatment of the reaction tooling and calibration of the oven
- ✓ Junction mockup with tooling and components
- ✓ Validation of the impregnation mold with an aluminum block

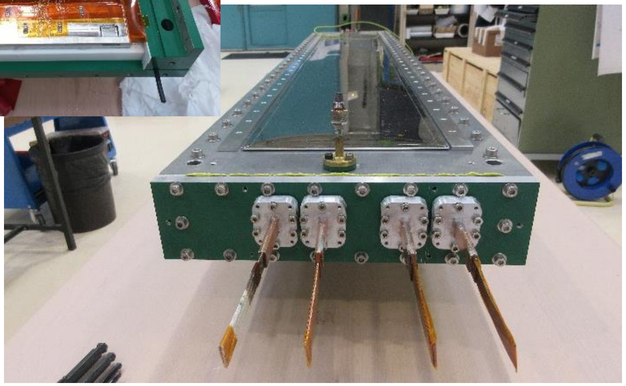


R2D2 Cu prototype coil fabrication

- ✓ Winding / heat treatment
- ✓ Junctions and operations pre-impregnation
- ✓ Impregnation
- ✓ Operations post-impregnation
- ✓ Qualification tests





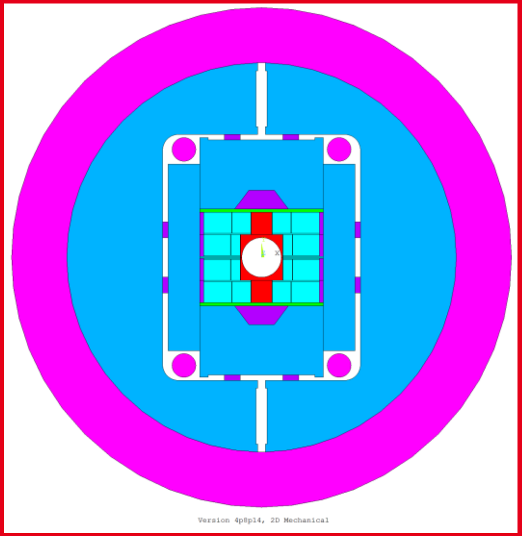


Future plans for R2D2 coil production

- Further tests planned on the Cu coil:
  - Instrumentation ongoing (connection of wires, strain gauges...)
  - Geometrical measurements ongoing (Faro arm)
  - Cuts for final inspections: cable arrangement, quality of the insulation, quality of the joints

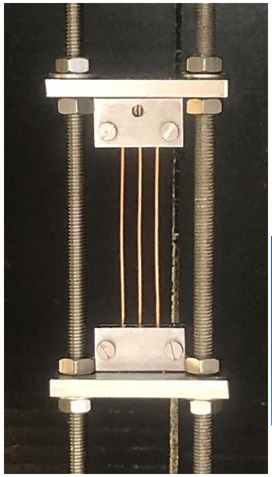
- Fabrication of 2 sets of components ongoing
  - Order sent to the company
  - Shipment foreseen for November
  - 1 set of spare components with minor modifications to be machined
  - Conductor UL to be insulated by CERN

- Production of 4 Nb_3Sn coils foreseen:
  - 1 practice → pending reception of components and cable
  - 2 series + 1 spare → production planned in 2024

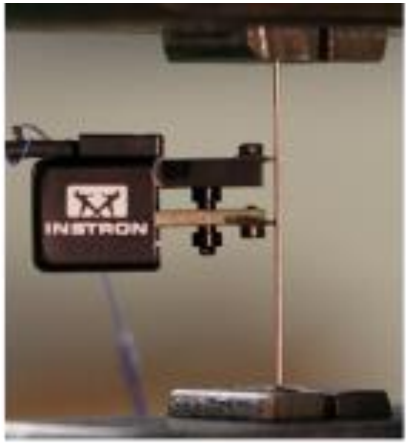


2. Activities linked to F2D2 (WP3.6)

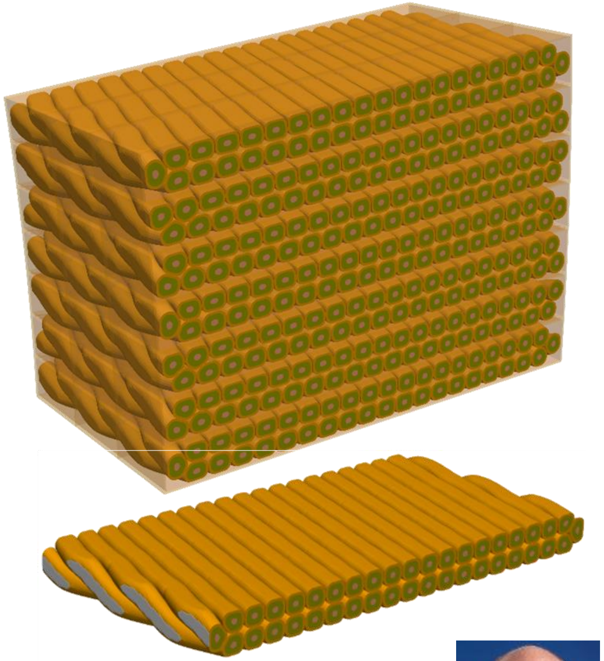
Characterization and modeling of conductors



Thermo-Mechanical characterization of Nb_3Sn strands during HT



Mechanical characterization of Nb_3Sn strands at ambient/nitrogen



Mechanical modelling of bi-metallic Nb_3Sn cables

The cable FEMs are now available to the community !

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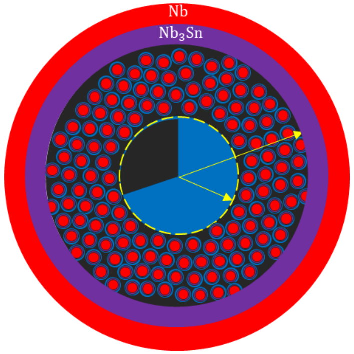
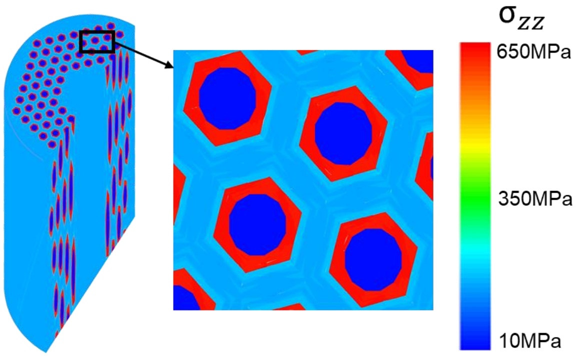
François.nunio@cea.fr

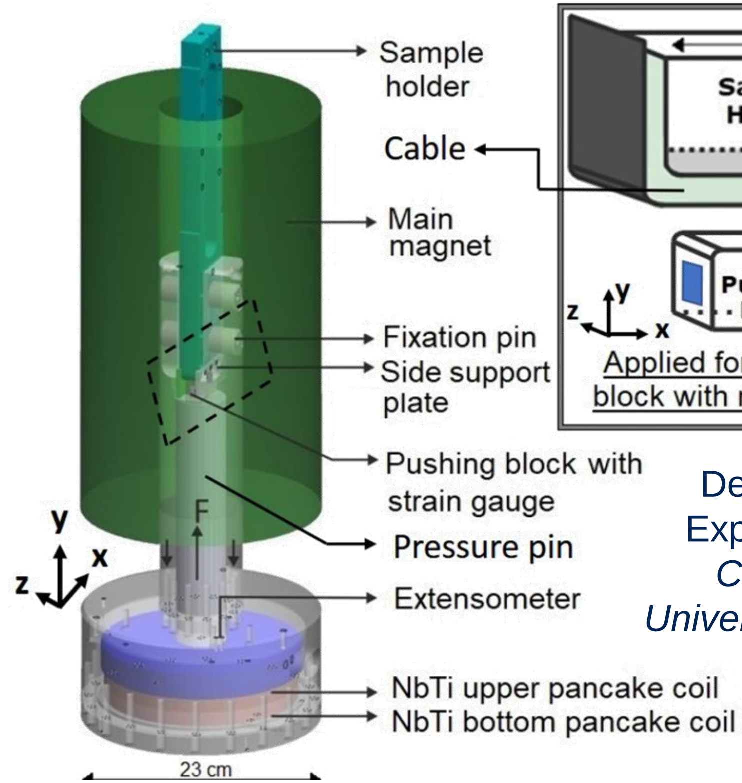


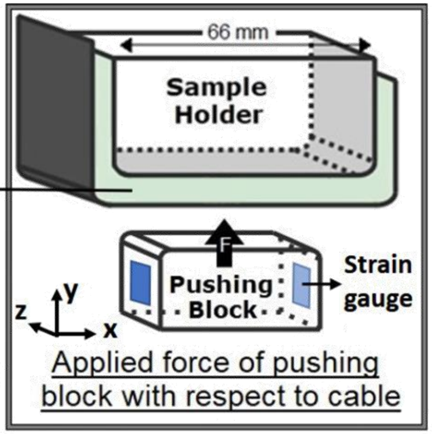
Thermo-Mechanical modeling of RRP sub-elements during HT



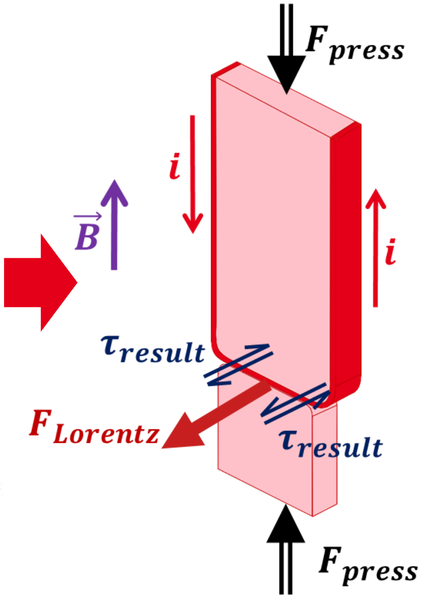
Mechanical modeling of detailed RRP strands

Debonding at the interface coil/components

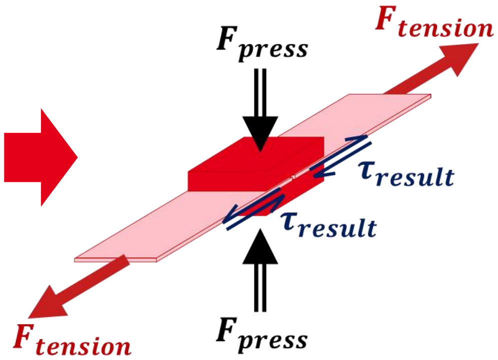




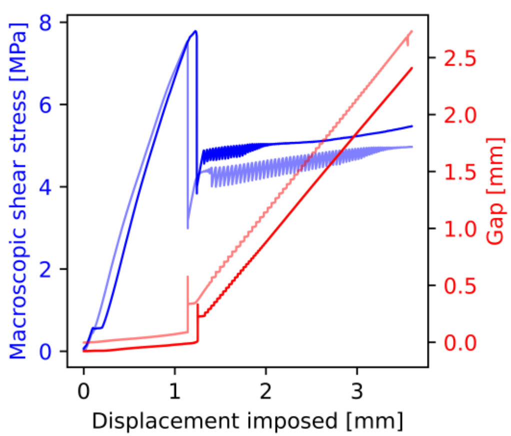
Debonding Experiment - *Courtesy University Twente*



Cable under debonding



Shear tests



Goal: Training of cables at high field, high current, under debonding, at 4.2 K → PhD G. Campagna

- Preliminary shear tests (see poster MT28)
- I_c measurements planned for the end of 2023

Future activities within Nb_3Sn HFM

- Mechanical characterization of R2D2 conductors:
  → Using the next available samples
- Modelling activities: strand → cable → coil
  → Activities ongoing, pending experimental validation at each step
- Debonding at the interface:
  → Collaboration agreement signed with University of Twente
  → 1st test planned for the end of 2023
- I_c Vs Stress of R2D2 cables:
  → Conceptual design of the sample holder ongoing

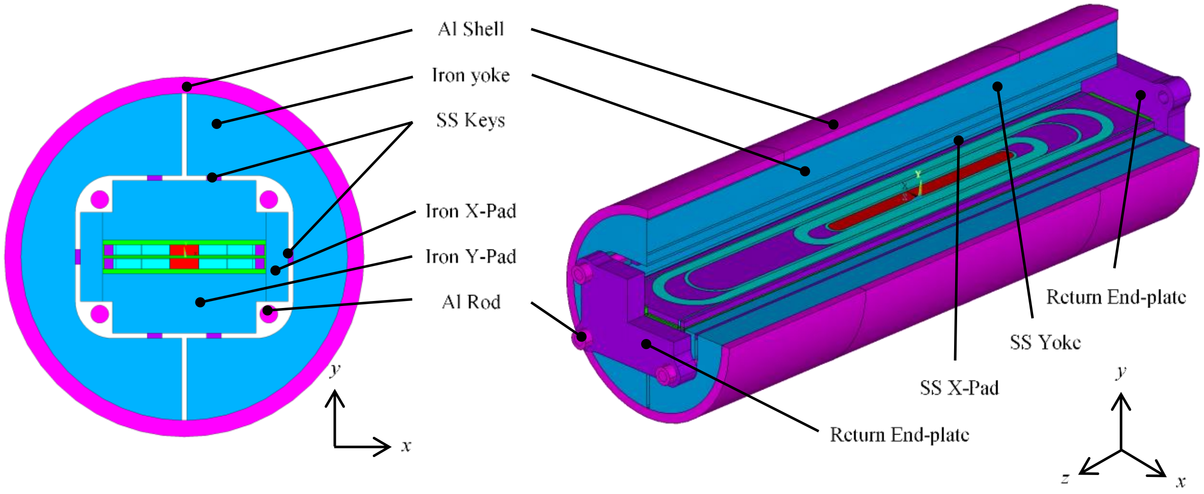
Merci !
Thank you !

■ Backup slides

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

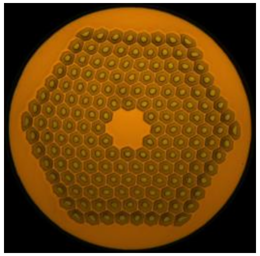


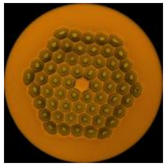
Aperture	None
Outer diameter	480 mm
Structure length	2.0 m
Nominal central field	11.1 T
Ultimate central field	12.0 T
Nominal peak field	12.7 T
Ultimate peak field	13.7 T

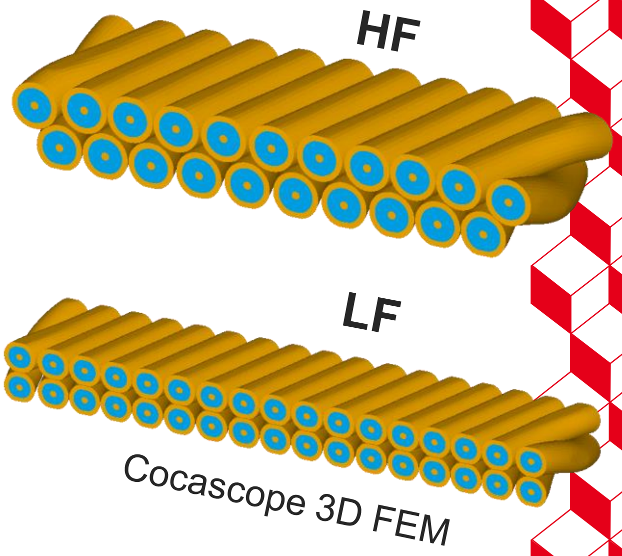
Conductor definition

- State-of-the-art strands (CERN):
  - HF “High-Field” 1.1 mm,
    475 A @ 12 T, 4.2 K
  - LF “Low-Field” 0.7 mm,
    315 A @ 12 T, 4.2 K

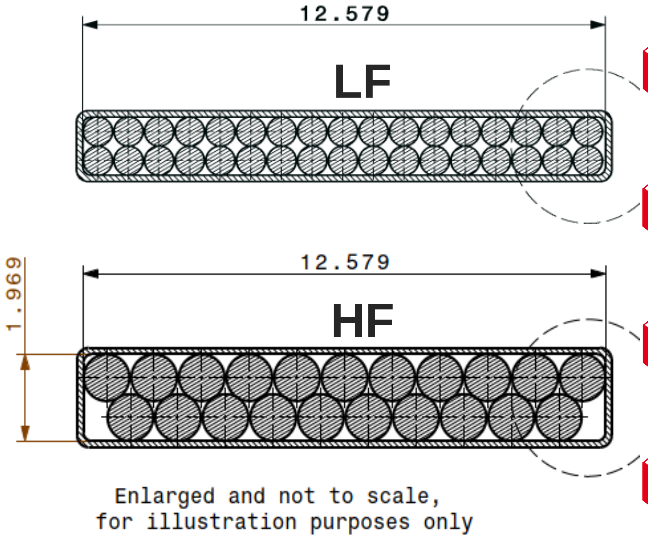
- Cables (CERN):
  - HF 21 strands
  - LF 34 strands
  - Same width







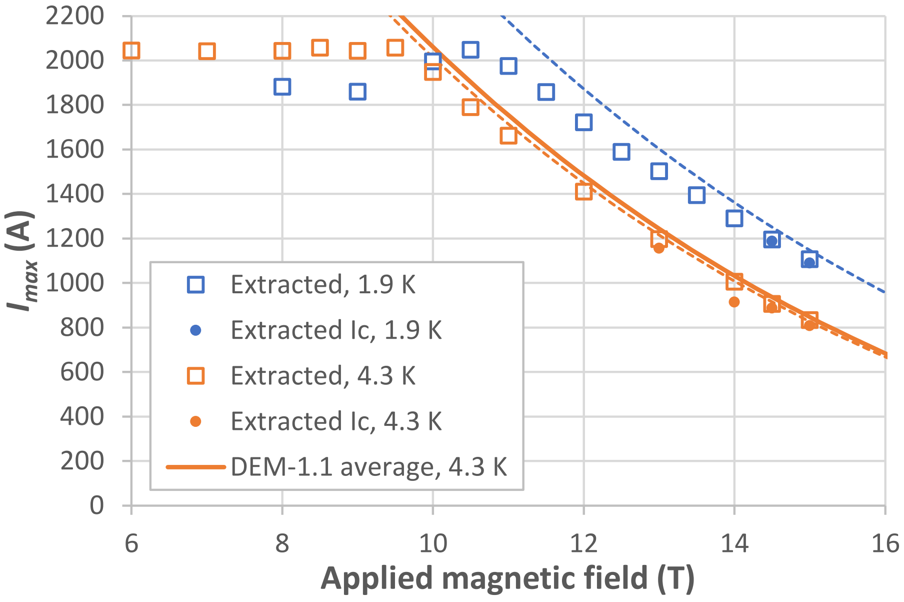
Parameter	Unit	HF cable	LF cable
Strand type		DEM-1.1	DEM-0.7
Strand layout		RRP® 162/169	RRP® 60/91
Strand diameter	mm	1.1	0.7
Number of strands		21	34
Cable mid-thickness	mm	1.969 ± 0.010	1.253 ± 0.010
Cable width	mm	12.579 ± 0.050	12.579 ± 0.050
Pitch	mm	84 ± 3	79 ± 3
Core		No core	No core



Technical drawings, CERN

Stability of DEM-1.1: Extracted Strand

- For a DEM-1.1 strand extracted from a trial cable for R2D2, after the standard heat treatment cycle (final step 665 °C 50 h)
  - I_c shows some cabling degradation relative to virgin wire
  - But unlike the extracted strands of ERMC-1, stability behaviour is **almost identical** to the virgin wire

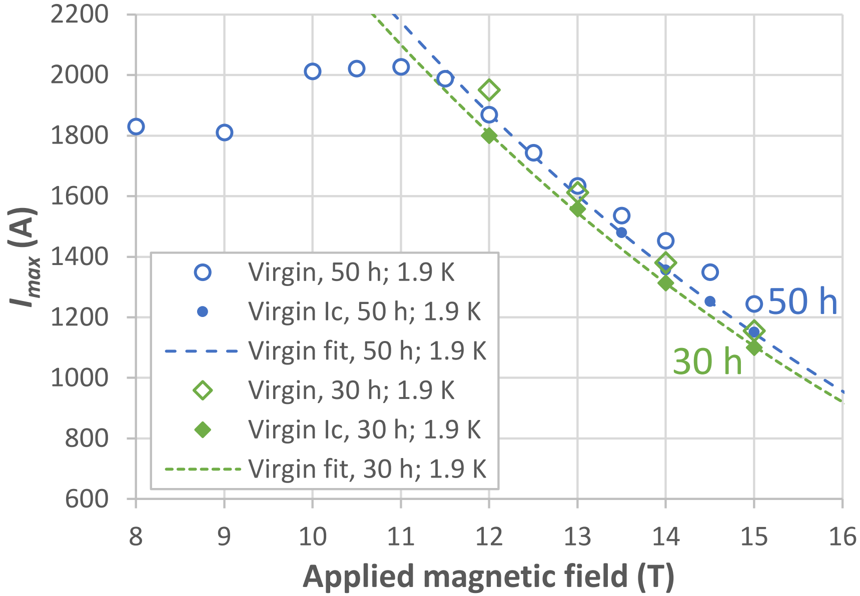


Measured $I_{max}(B)$ for extracted strand from R2D2 trial cable after the standard heat treatment (665 °C 50 h). The lines show the virgin DEM-1.1 wire I_c for comparison.

Courtesy of S. Hopkins: “Design Optimisation, Cabling and Stability of Large-Diameter High Jc Nb3Sn Wires”, ASC2022, Honolulu

Effect of 650 °C 30 h HT: DEM-1.1

- The same alternative heat treatment as for ERMC-1 was assessed: 650 °C 30 h
- As before for ERMC-1, I_c was then measurable at 1.9 K down to a lower field: in this case, the lowest measured (12 T)
  - Note measurements were performed only until a current of 2000 A was reached for this tests
- The reduction in I_c due to the change in heat treatment was only **4 %**
  - Much lower than for ERMC-1, despite also reducing the temperature
  - B_{c2} reduced by ~0.5 T
- As expected from the previous slides, for the measured range this does not increase quench currents: further testing needed over the full field range, to currents > 2000 A



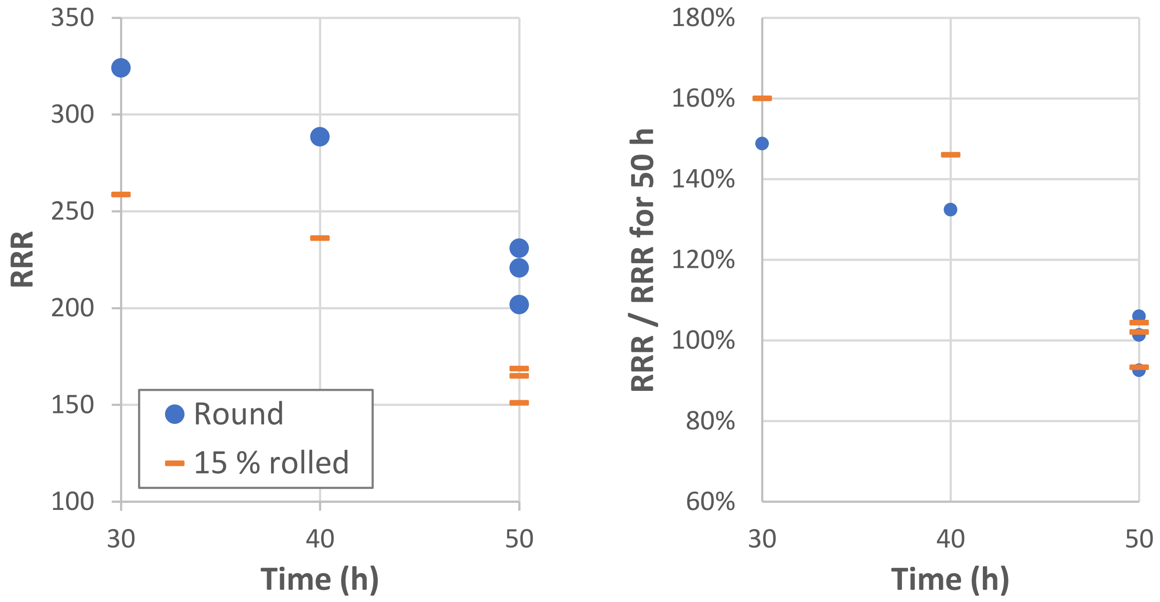
Measured $I_{max}(B)$ for virgin DEM-1.1 wire at 1.9 K for final heat treatment step durations of 50 h and 30 h

Courtesy of S. Hopkins: “Design Optimisation, Cabling and Stability of Large-Diameter High Jc Nb3Sn Wires”, ASC2022, Honolulu

Shorter HT: Effect on RRR

- Reducing the heat treatment duration increases RRR substantially both for rolled and round samples
  - ~50 % for 30 h
  - ~40 % for 40 h

ERMC 1 mm wire

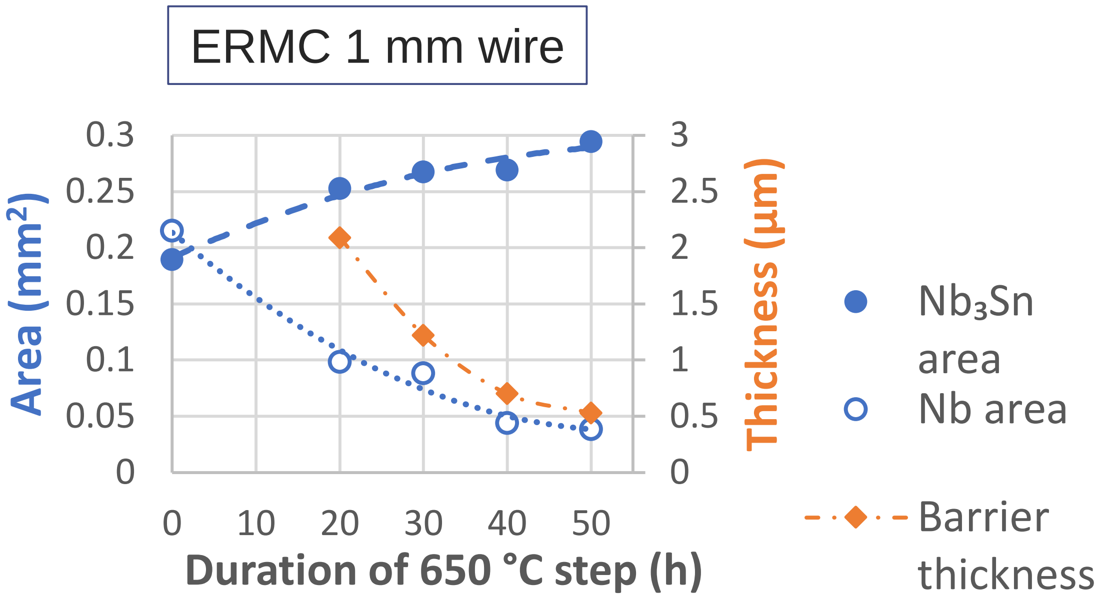


RRR of round and rolled wire after heat treatments with a final plateau of 30 h, 40 h and 50 h at 650 °C

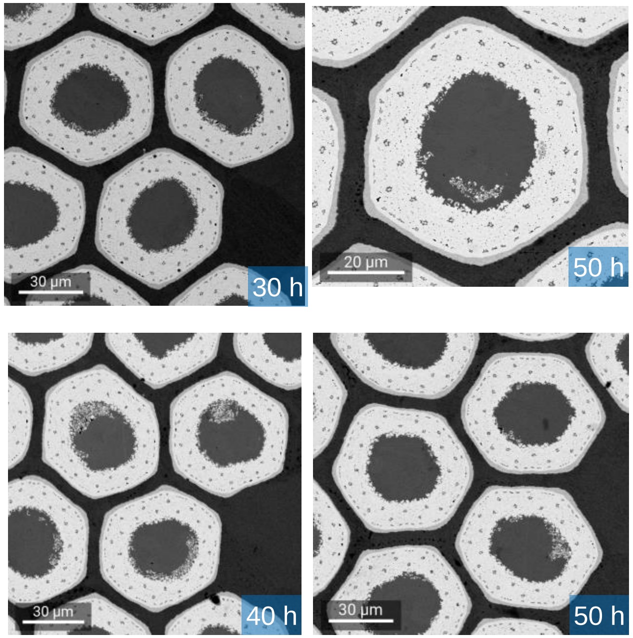
Courtesy of S. Hopkins: "Design Optimisation, Cabling and Stability of Large-Diameter High Jc Nb3Sn Wires", ASC2022, Honolulu

Shorter HT: Micrographs

- Image analysis of electron micrographs shows:
  - The thickness of unreacted barrier decreases sharply from 20–40 h
  - Overall Nb and Nb_3Sn areas change relatively slowly from 30 h onwards
  - The optimum compromise between I_c and RRR is likely to lie in the 30–40 h range



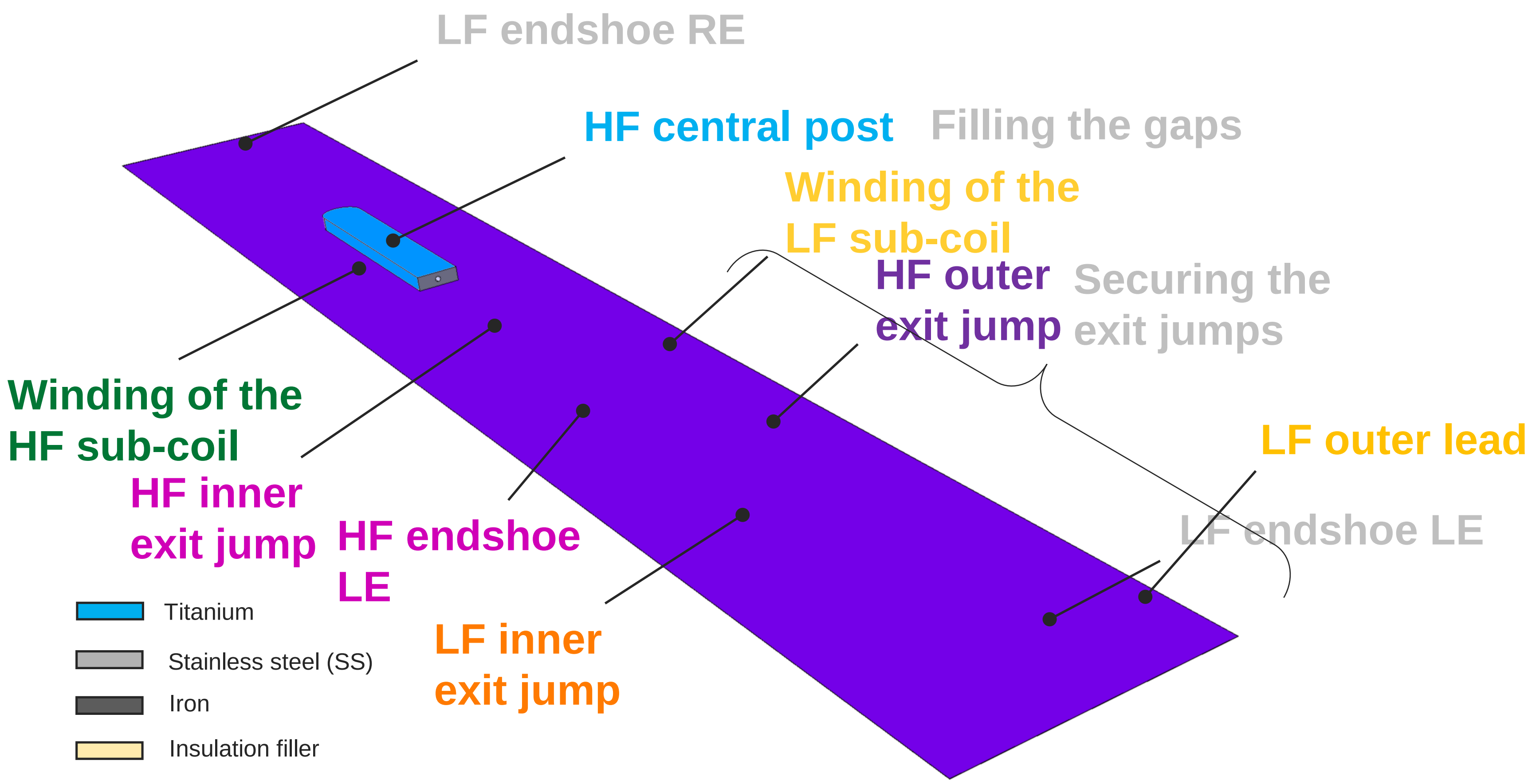
Dependence of Nb_3Sn and Nb area, and average barrier thickness, on duration of 650 °C plateau



SEM micrographs of sub-elements after heat treatments with a final plateau of 30 h, 40 h and 50 h at 650 °C

Courtesy of S. Hopkins: “Design Optimisation, Cabling and Stability of Large-Diameter High Jc Nb3Sn Wires”, ASC2022, Honolulu

R2D2 coil winding concepts

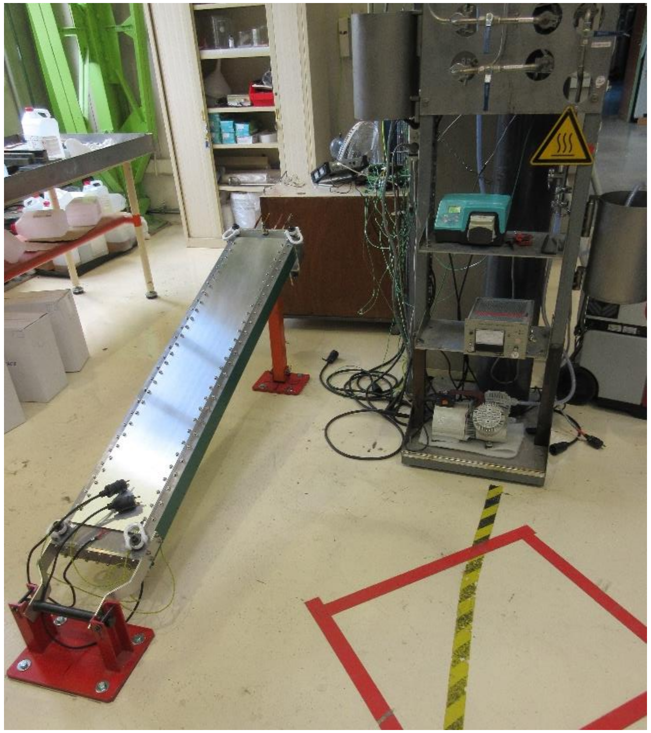


Infrastructure

1. Winding table
2. Heat treatment oven
3. Impregnation bay
4. Qualification tests







Quality assessment

1. Operating procedures
2. Travelers
3. Documentation with CERN

	INSTITUT DE RECHERCHE sur les LOIS FONDAMENTALES de l'UNIVERS Département des Accélérateurs, de Cryogénie et de Magnétisme **Procédure de fabrication de la bobine R2D2** **Partie 1 : bobinage**	B
Auteur	F.Rondeaux	
Découpage technique	*610 Procédures*	Nb pages 59

Cette version s'appuie sur la nomenclature des composants et outillages
71 T141 DM- 2203 RB - Ergonomic winding tooling
71 T141 DM- 3100 RA - Assembly
71 T141 DM- 3102 RB - Coil components
71 T141 DM- 4101 RA - Winding machine interface
71 T141 DM- 4102 RB - Coil winding tooling
71 T141 DM- 4103 RA - Straight section tooling
71 2519 DMB 7109 000 AD FRESCA2 -implantation Saclay

Autres documents :
xxx (plan d'ensemble échelle 1 : 1 avec Vtapes)
Vtaps location xxx (position prises de potentiel)
« *R2D2-dimensions isolations.xlsx* » (description des différentes isolations)

Index	**Action**	**Auteur**	**Vérificateur**	**Approbateur**
B	Mise à jour	F.Rondeaux le 18/01/2023		
A	Création	F.Rondeaux, le 06/01/2022		

INSTITUT DE RECHERCHE sur les LOIS FONDAMENTALES de l'UNIVERS
Service des Accélérateurs, de Cryogénie et de Magnétisme

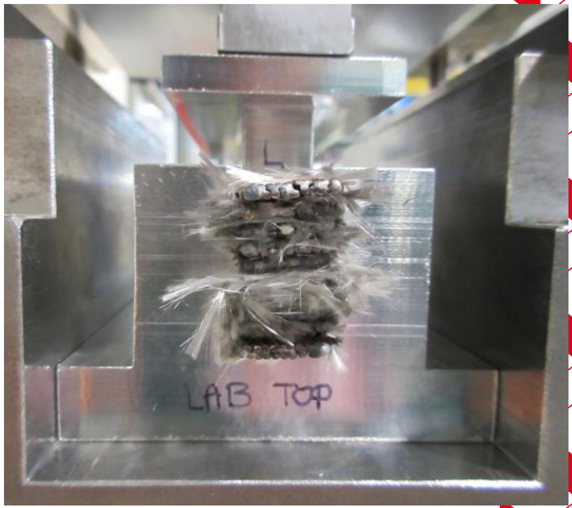
FICHE DE SUIVI ouverture moule de réaction - jonction R2D2 Cu

	Remarques	Date/opérateur
Sortie du four		
Mise en place des butées?		
Déplacement sur un établi		
Observations diverses :		
Préparation		
Découpe des isolations :		
Préparation des câbles NbTi : - 2 LF - 2 HF		

Dimensional changes during Heat Treatment

Goals:

- **quantify the dimensional changes of coils during the heat treatment**
- **Define the room for expansion/contraction in the heat treatment toolings**

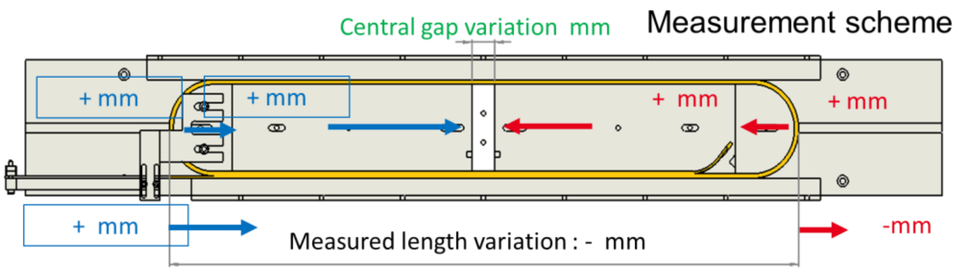


Measurement of cable thickness at CERN

Ongoing activities :

- Transverse expansion → measurement of 10-stacks before/after HT
- Longitudinal contraction → measurement of length changes of short coils before/after HT

Measurement scheme



Measurement of coil length at CEA