HFM

High Field Magnets

Introduction to RD Line 1
Nb_3Sn Conductor

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R&D strategy on Nb_3Sn conductor

- The first of the two main objectives, identified by the update of the European strategy for Particle Physics and LDG Accelerator R&D Roadmap for the HFM programme, is to **demonstrate Nb_3Sn magnet technology for large-scale deployment**
- In terms of **conductor development**, this involves:
  - **Overcoming the present limitations** linked to **stress/strain** sensitivity and degradation
  - **Pushing the Nb_3Sn performance to its ultimate limits**, towards the 16 T target required for the FCC-hh dipoles
  - **Driving the industrialization** of improved superconductors.

Nb_3Sn wire requirements

- **Performance targets** for **Nb_3Sn** conductor **development** for future accelerator magnets were initially defined in 2015 as:

1. non-Cu **$J_c \geq 1500$ A/mm²** (16 T and 4.2 K);
2. $\mu_0 \Delta M \leq 150$ mT (1 T, 4.2 K);
3. $d_{eff} \leq 20$ µm;
4. RRR ≥ 150.

- **Considering the disparity in manufacturers' capabilities** at the start of the programme, it was decided (circa 2018) to:

1. **Prioritise J_c** increase over **d_{eff} decrease**;
2. Set **intermediate** objectives comparable to specification of HL-LHC procurement:

- non-Cu **$J_c \geq 1000$ A/mm²** (16 T and 4.2 K), target: 1200 A/mm²;
- $d_{eff} \leq 60$ µm.

Nb_3Sn conductor: Roadmap for HFM (1)

- Following the gradual approach already mentioned, the HFM program is divided in two sub-programs: the 12 T value-engineered dipole and the 14+ T dipole.
- For 12 T value-engineered sub-program, the baseline is MQXF cable made of 40 108/127 RRP® wires (0.85 mm in diameter). The Roadmap is:

1. Continue strategic partnership with Bruker OST (in synergy with HL-LHC);
2. Procure and characterize strands for HFM needs at CERN and collaborators **(~400 km** of wire altogether);
3. Manufacture and characterize cables for HFM needs at CERN and collaborators (more than **8 km** of cables altogether);
4. To continue efforts to qualify additional suppliers on top of Bruker OST for the production at industrial scale of wires starting with MQXF-type requirements (e.g., non-Cu **$J_c \geq 1000$ A/mm^2,**16 T and 4.2 K). Technical requirements could be reviewed in due time.

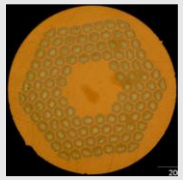
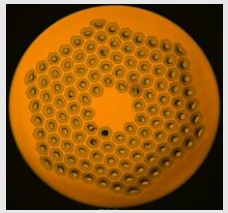
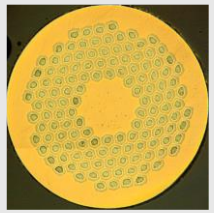
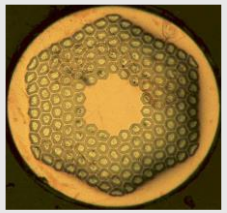
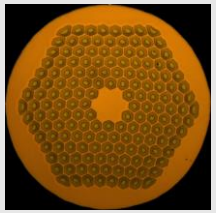
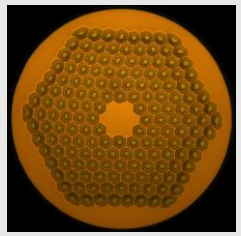
Nb_3Sn conductor: Roadmap for HFM (2)

- The non-copper critical current density target for **14+T** is at least **1500 A/mm²** at 16 T and 4.2 K, which constitutes a **salient** technological **breakthrough** as compared to ~ 1100-1200 A/mm² for current wire designs.
- This target will **not** be **achievable** within **1-2 years**, therefore there is need to select wire and cable designs for **14+T medium** term based on **known designs**.
- The idea is to **review different** strand/cable **designs** and see if one could be more promising as **14+T wire** for **medium term** (see next slides for more details).
- In parallel:

1. Continue ongoing **optimization** of Bruker OST strands (e.g., stability);
2. Develop/update technical requirements, procure and characterize wires (>**200 km**) and manufacture and characterize cables (>**7 km**) for HFM needs at CERN and collaborators;
3. Continue ongoing R&D efforts to achieve non-Cu J_c of **1500 A/mm²** at 16 T and 4.2 K, e.g. by **internal oxidation** process (plan to be assessed).

RRP® Strand Characteristics

- BOST (NJ, USA) can produce Nb_3Sn wire by RRP® (Restacked Rod Process) with different designs.
- Various designs of interest are given, showing the various important parameters, in the following table.

	Comparisons				HFM	
	MQXF	**ERMC#101**	**FRESCA 2**	**ERMC#102**	**ERMC-1**	**DEM-1.1**
						
***d* (mm)**	0.85	1.0	1.0	1.0	1.0	1.1
Layout	108/127	120/127	132/169	150/169	162/169	162/169
d_s (µm)	54	64	58	57	58	64
Cu/non-Cu	1.2 ± 0.1	1.06 ± 0.1	1.25 ± 0.1	1.08 ± 0.1	0.9 ± 0.2	
Nb:Sn	3.6 (red. Sn)	*	3.4 (std. Sn)	*	3.4 (std. Sn)	
Heat treat.	665 °C 50 h	665 °C 50 h	650 °C 50 h	665 °C 50 h	650 °C 50 h	665 °C 50 h

HFM medium working plan for 14+ T conductor

- Wire/strand designs mentioned in previous slides will be tested for:
- ➢ V-I stability measurements made on strands extracted from existing cables,
- ➢ Virgin strands measured under compressive stress at UNIGE for a semi-quantitative comparison,
- ➢ Heat treated and impregnated cable samples will be submitted to various levels of compressive stress and cable cross-sections examined for defects/broken sub-elements.
- ➢ This combined study will allow to select an adequate strand/cable design before confirmation at FRESCA/FRESCA 2 station.

Current partners and WPs of RD Line 1

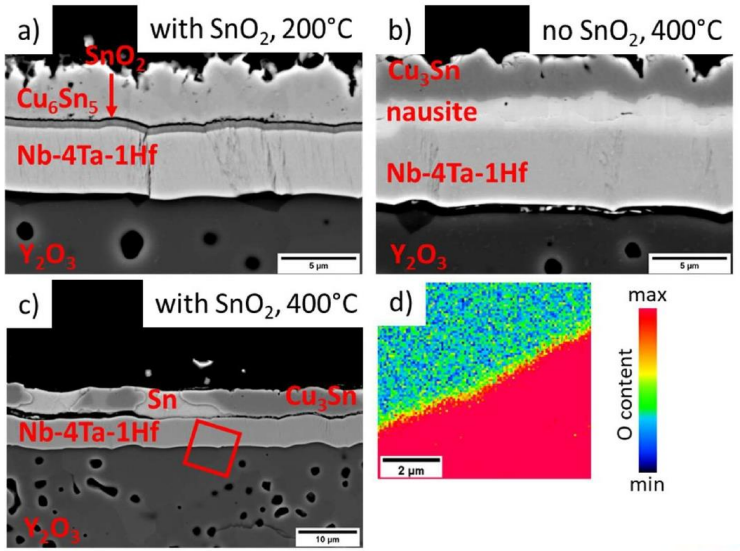
WP1.1 Nb_3Sn conductors for high field magnets (see talk by Simon Hopkins)

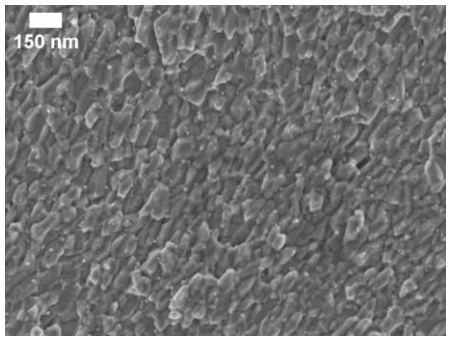
WP1.2 R&D on optimization of Nb_3Sn microstructure and pinning (see presentation by Andreas Leineweber)

WP1.3 Nb_3Sn conductor J_c performance and electromechanical properties beyond state of the art (see presentation by Gianmarco Bovone)

WP1.4 R&D on mechanical properties of Nb_3Sn wires and cables

From material studies…
… to wire and cable development/testing





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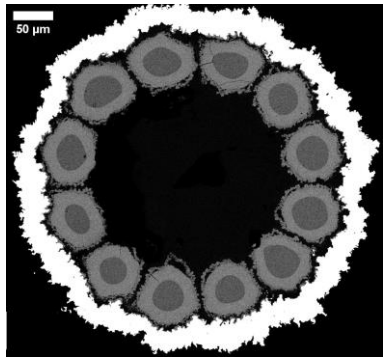
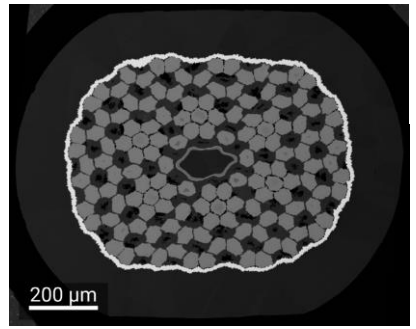
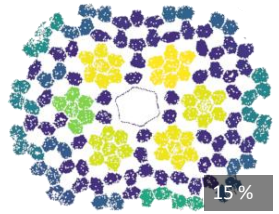
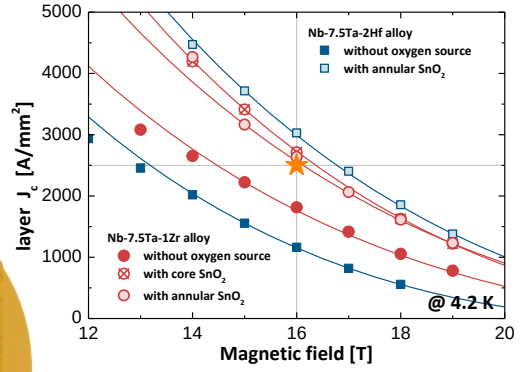
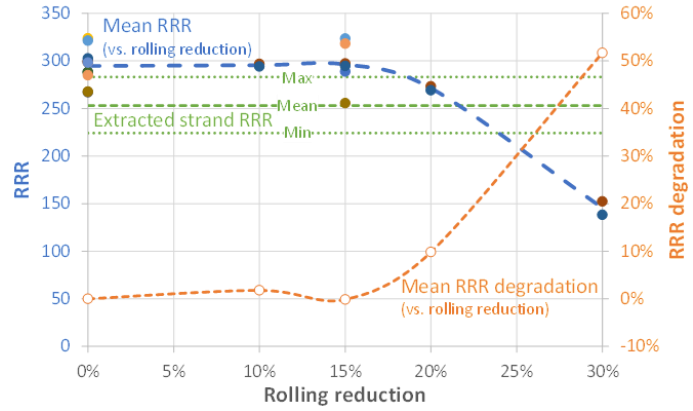




CERN







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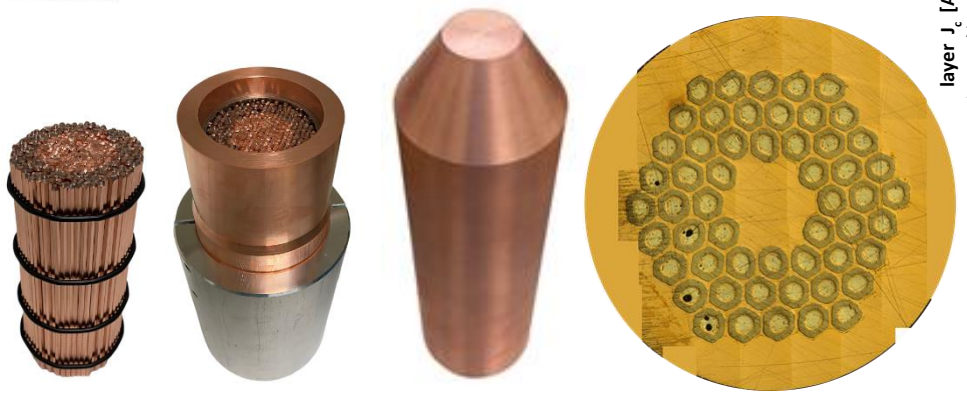

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