

PhD Research Progress: Nb₃Sn Characterization and 10-Stack Studies

Joep Van den Eijnden^{1,2}, Juerg Leuthold¹, Jasmin Smajic¹,
Xiang Kong³, Theo Tervoort³, Douglas Araujo², Bernhard
Auchmann^{2,4} and André Brem².

¹Institute of Electromagnetic Fields, ETH Zurich

²Paul Scherrer Institute;

³Department of Materials, ETH Zurich;

⁴CERN, European Organization for Nuclear Research.

Work supported by the Swiss State Secretariat for Education, Research and Innovation SERI.

This work was performed under the auspices and with support from the Swiss Accelerator Research and Technology (CHART) program

Development of geometric cabling model

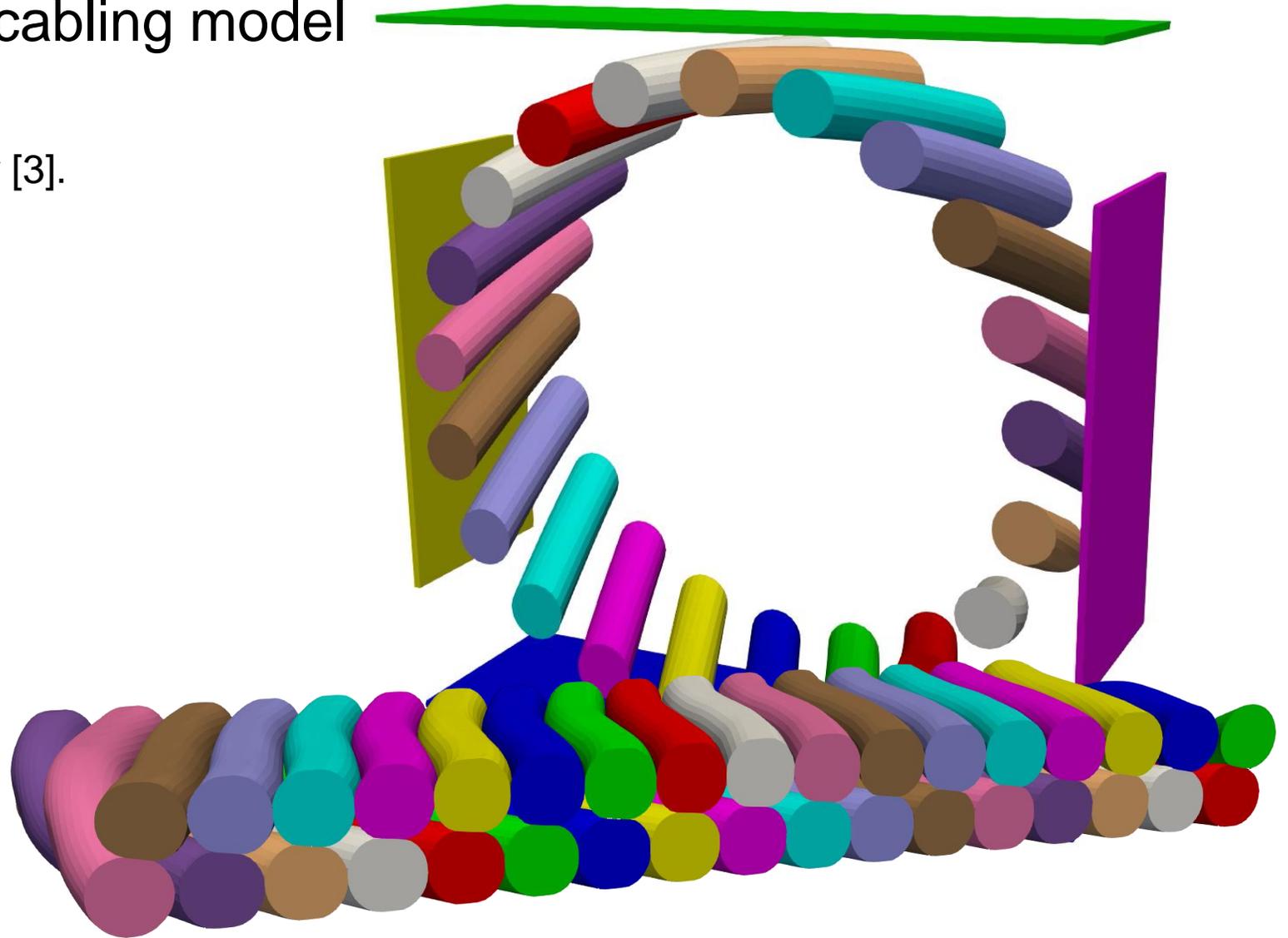
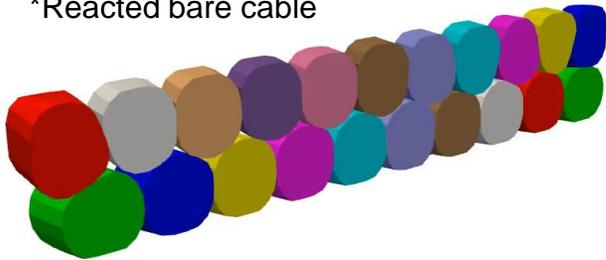
LS-DYNA – generating a RVE.

Geometric – moving planes – inspired by [3].

Parametrisation under development

Cable	CD1 [1]
Strand diameter [mm]	0.85
#Strands	21
Dimensions* [mm]	9.55 x 1.62
Pitch [mm]	64

*Reacted bare cable



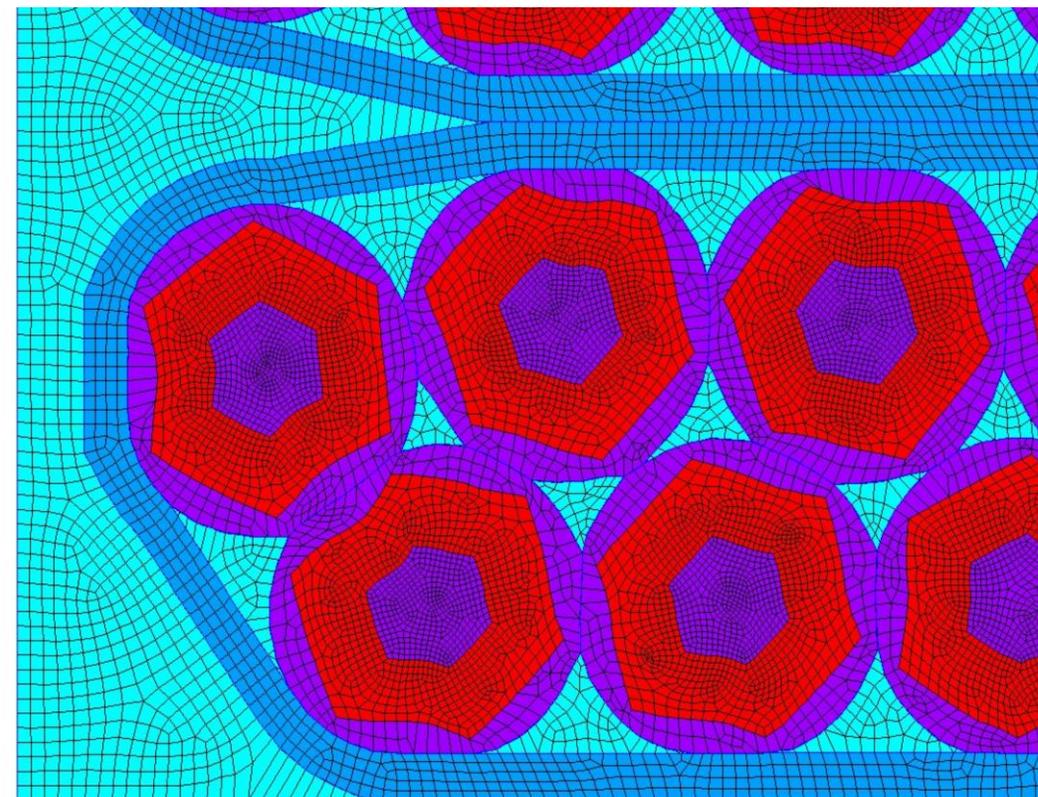
[1] B. Auchmann *et al.*, "Test Results From CD1 Short CCT Nb₃Sn Dipole Demonstrator and Considerations About CCT Technology for the FCC-Hh Main Dipole," in *IEEE Transactions on Applied Superconductivity*, vol. 34, no. 5, pp. 1-6, Aug. 2024

[2] D. Araujo *et al.*, "Electromechanical Design of Nb₃Sn Stress Managed Asymmetric Common-Coils," in *IEEE Transactions on Applied Superconductivity*, vol. 35, no. 5, pp. 1-5, Aug. 2025

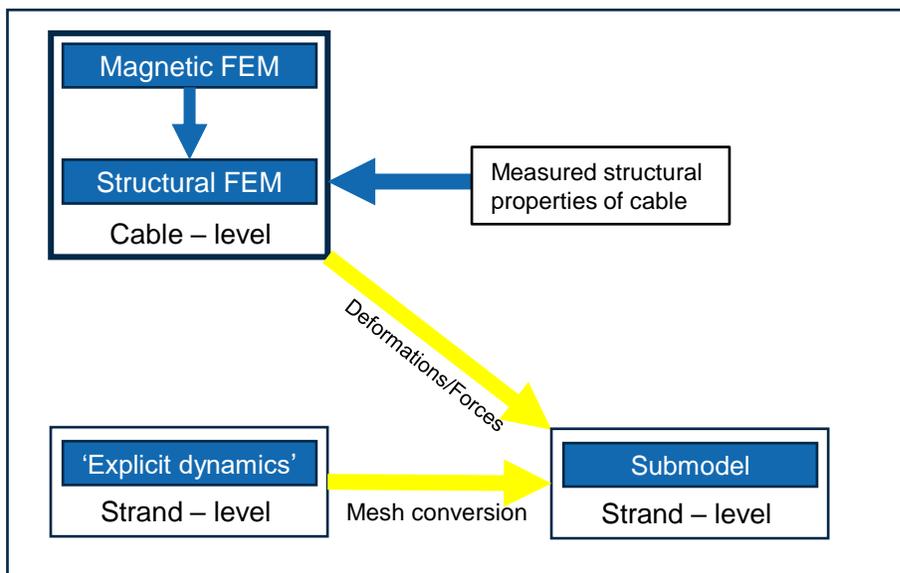
[3] F. Nunio *et al.*, "CoCaSCOPE-Mesh Generator: A Tool to Generate 3D Numerical Models of Rutherford Cables," in *IEEE Transactions on Applied Superconductivity*, vol. 34, no. 5, pp. 1-5, Aug. 2024

Downscaling procedure

1. Write deformation of cable model to file
2. Mesh conversion
 1. Reading mesh from LS-DYNA
 2. Interpolate LS-DYNA mesh to create 2D cross-section
 3. Map deformation of outside nodes
 4. Create watertight geometry for strands
 5. Mesh 'impregnation' area



- Nb₃Sn in copper matrix
- Copper
- Impregnation
- Insulation



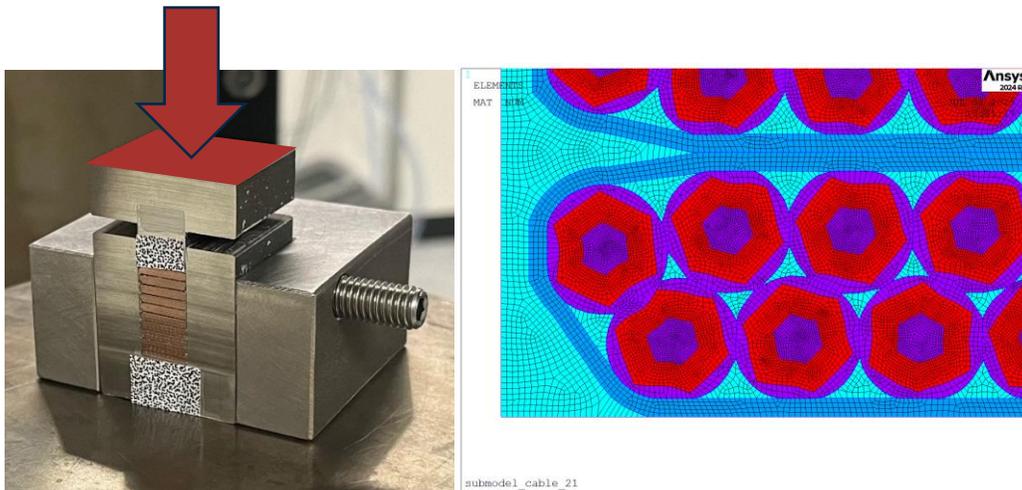
Filled wax impregnated 10-stacks - measurements and simulations.

CHART collaboration with D-MATL of ETHZ: dr. Xiang Kong and Prof. Theo Tervoort

Mechanical testing from 77 K to RT

- Materials: filled wax, epoxy, copper, filaments
- Impregnated conductor stacks

1. Input for structural model
 - a) Material properties
 - b) Composite properties
2. Validation of detailed modelling



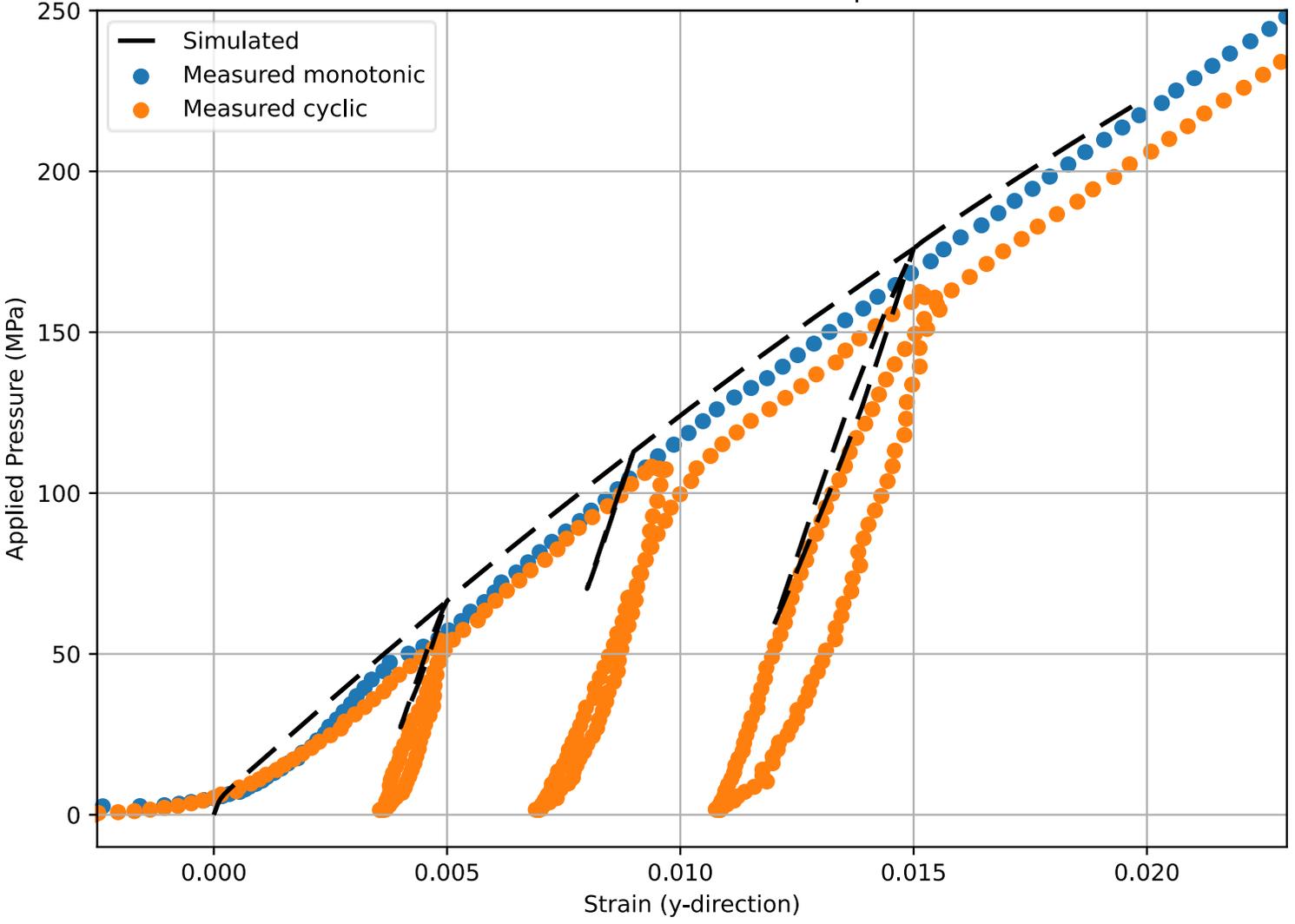
10-stack sample prepared at PSI

Cables currently under test

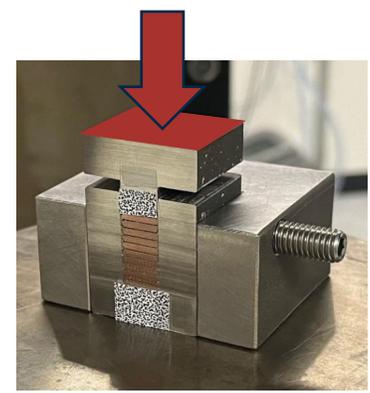
Cable	Uniaxial	Constrained	
		Transverse	Radial
CD1	Transverse LN2 RT	LN2 -80°C RT	LN2 -80°C RT
SMACC-LF	--	LN2 -80°C	LN2 -80°C
SMACC-HF	--	LN2 -80°C	LN2 -80°C

Localisation and quantification of stress/strain in CD1 cable at 77 K

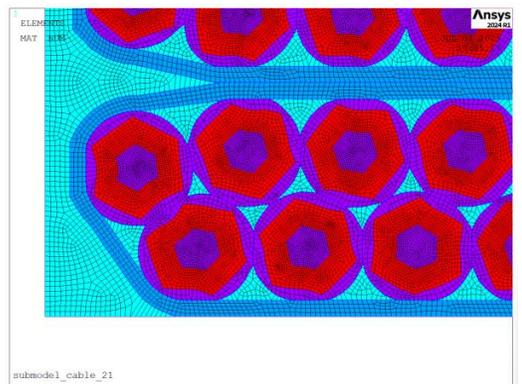
Stress-Strain Curves of 10-stacks Comparison at 77 K



- Measured and simulated stress–strain curves of the 10-stack at 77 K show similar behaviour.
- Reload stiffening is linked to copper hardening; the reloading slope is mainly governed by the insulation and impregnation elasticity.
- Simulation material properties are based directly on experimental measurements.
- Can be used as constitutive model for magnet design.

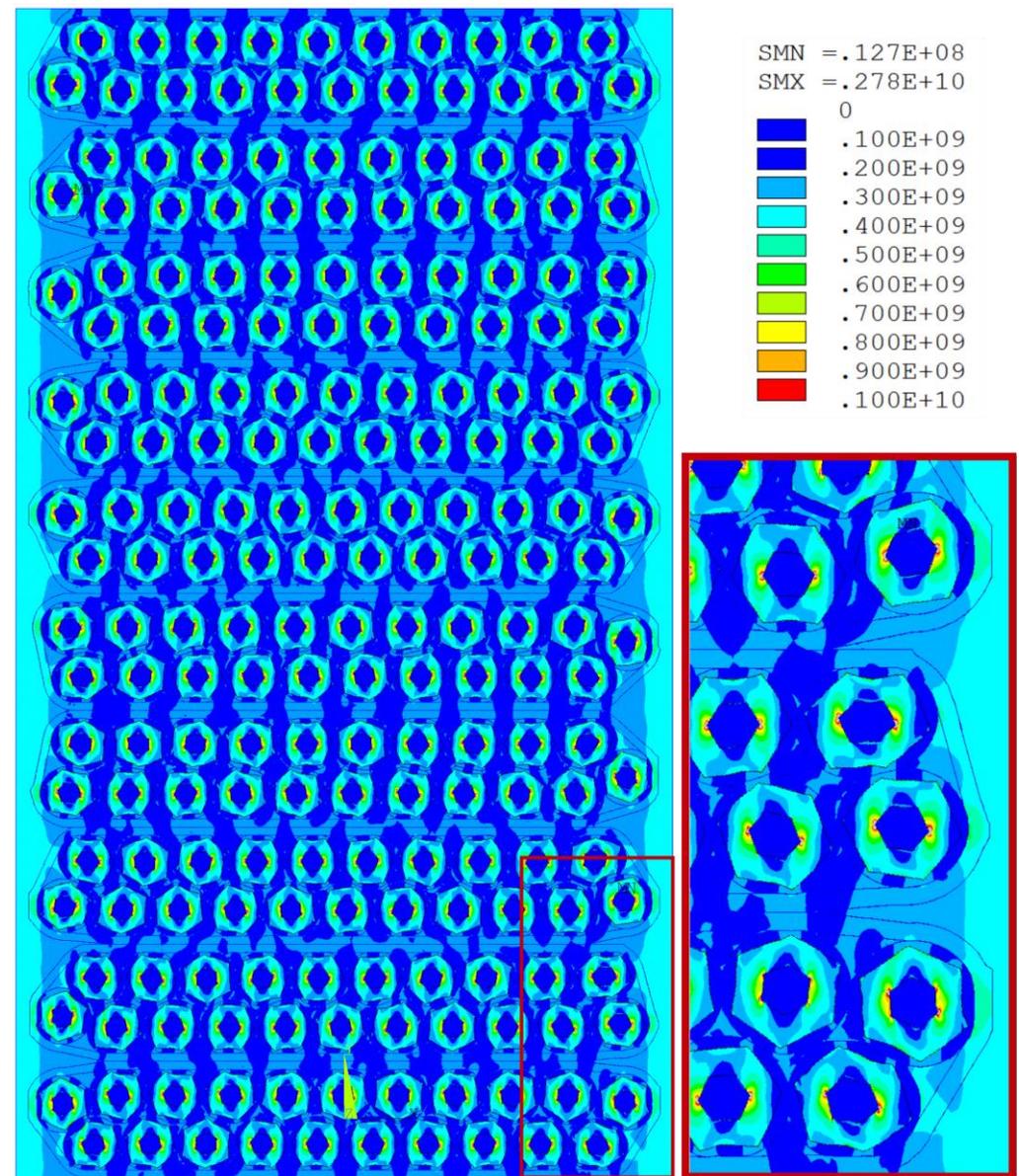


10-stack sample prepared at PSI



Localisation and quantification of stress/strain

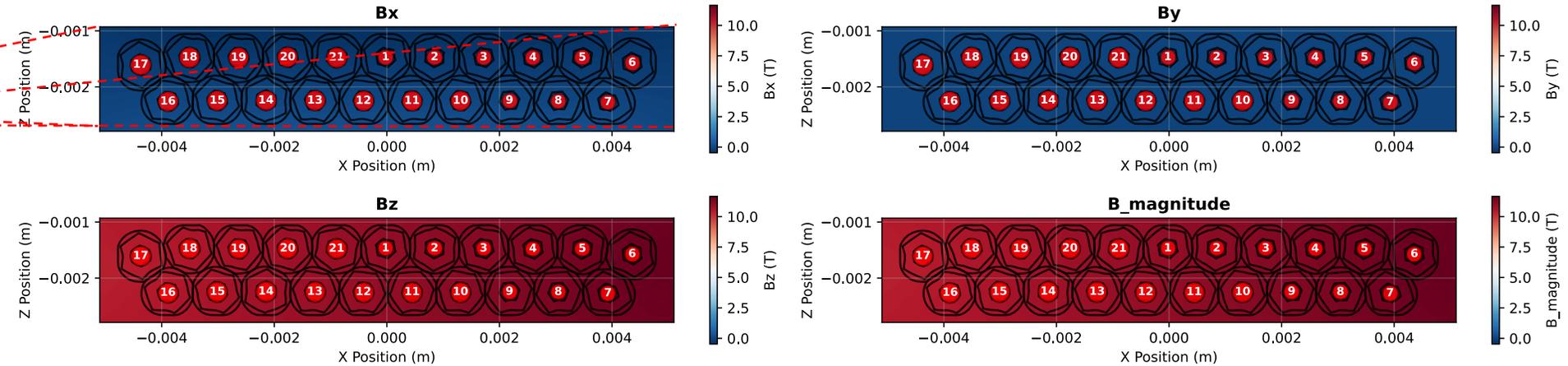
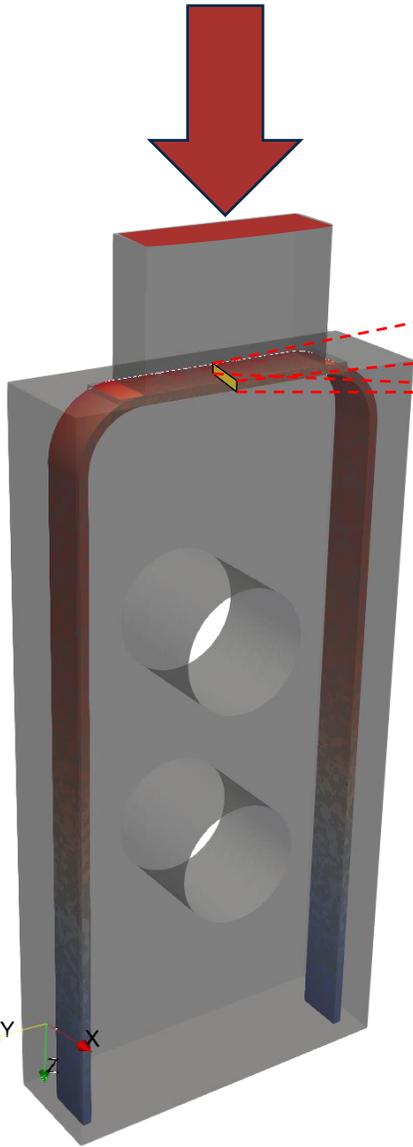
- Simulated von Mises stress shows that load is channelled through the stiffer Nb₃Sn regions.
- Imperfect wire alignment in the model leads to curved stress “pillars”.
- Highest stress concentrations in simulation occur at sharp corners of the interfilamentary region, especially at vertical midpoints.
- An X-shaped stress pattern appears within the strand, consistent with previous single-strand and image-based studies.



Simulated von Mises stress distribution (Pa) in the 10-stack under 2% applied vertical strain, showing stress concentrations in the Nb₃Sn regions and an X-shaped stress-pattern in the interfilamentary region of the strands.

Modelling reduction of I_c as function of transverse pressure.

Rutherford cable overlaid on field Magnetic Field Components Heatmaps (Case 1, Loadstep 0)



Simulated B-field overlaid on the Rutherford cable, used to calculate Lorentz forces in the mechanical model. The strands are numbered.

Lorentz forces computed using simulated field, and current from experiment.
Pressure on pusher from experiment.

Filled wax impregnation

Contacts:

Strand – strand, strand – insulation, strand – impregnation

Insulation – impregnation

Impregnation – steel former

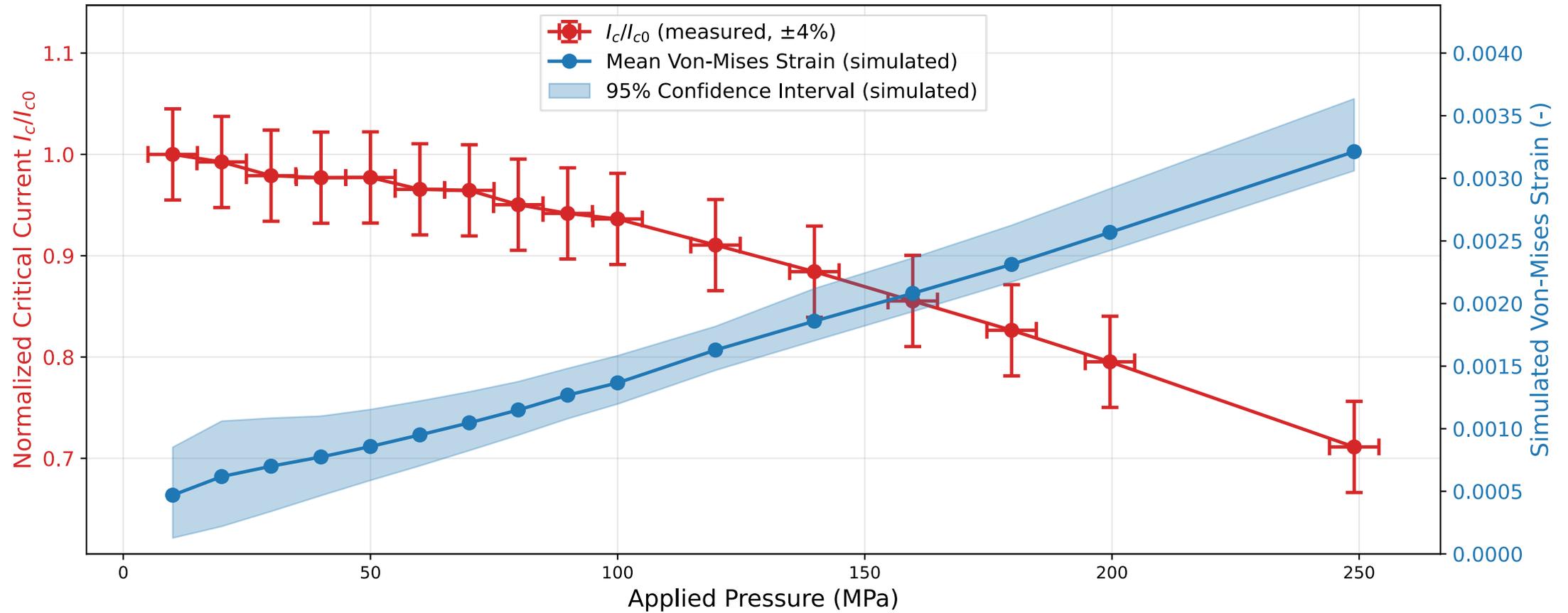
2 – no separation (sliding permitted)

3 – bonded

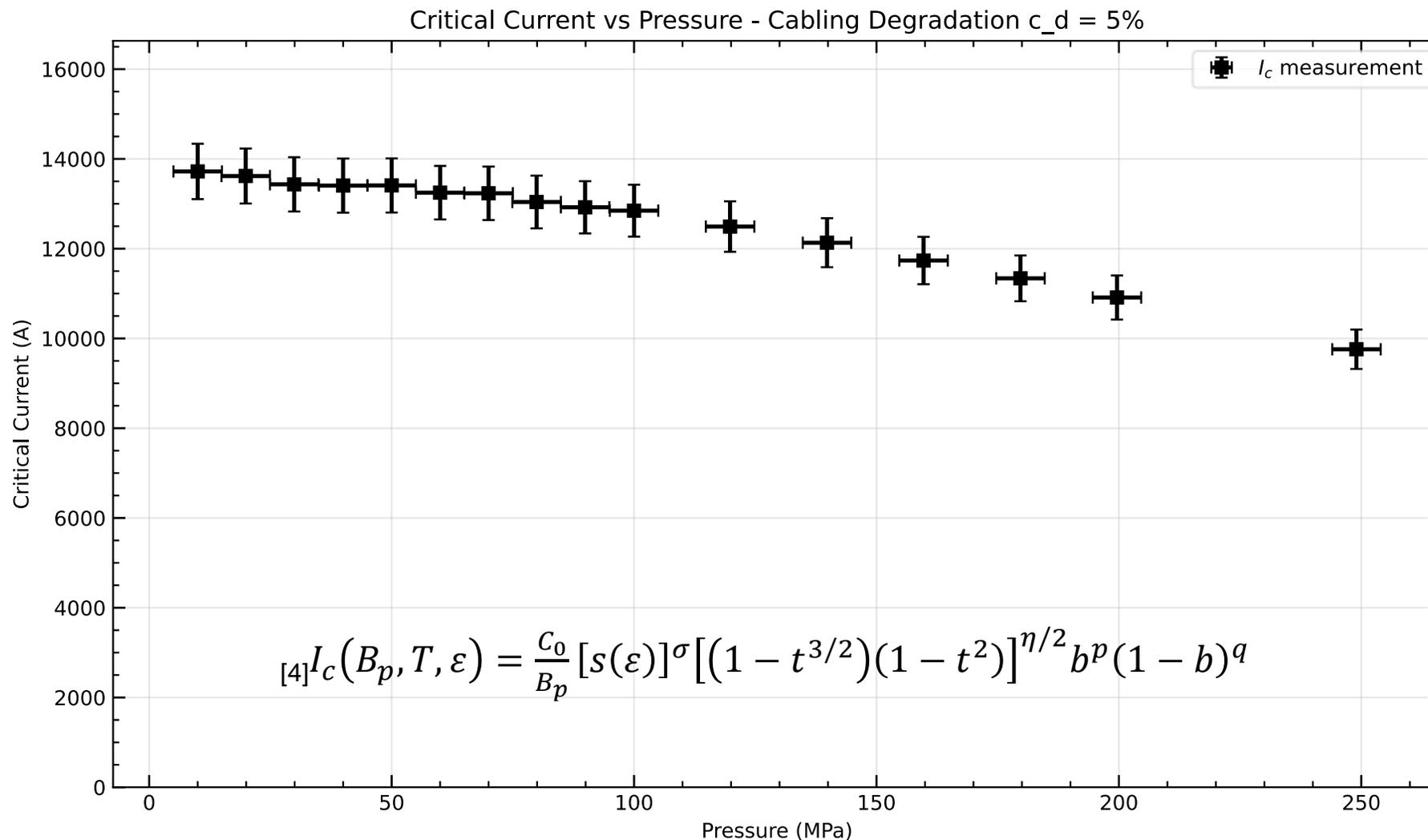
0 – standard

Normalised reduction of I_c and simulated strain

Normalised I_c and simulated Von-Mises Strain
on Nb₃Sn interfilamentary area as function of transverse pressure



Measured and simulated reduction of critical current as function of transverse pressure, in 11 T background field.



[4] G. De Marzi et al., "Magnetic and Electromechanical Characterization of a High-JC RRP Wire for the HL-LHC MQXF Cable," in IEEE Transactions on Applied Superconductivity, vol. 32, no. 6, pp. 1-5, Sept. 2022, Art no. 6001505

