Towards a Nb_3Sn conductor for FCC

Material development and electromechanical studies

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EuroCirCol

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Outline

Florin BUTA

Investigations on the enhancement of J_c in $(Nb,X)_3Sn$ superconductors by internally oxidized ZrO_2 particles

Addendum FCC-GOV-CC-0112 (KE3545/ATS)

@ CERN : Simon HOPKINS, Bernardo BORDINI, Amalia BALLARINO

Electromechanical studies – effects of the transverse stress

H2020 EuroCirCol WP5 Task 5: Conductor studies

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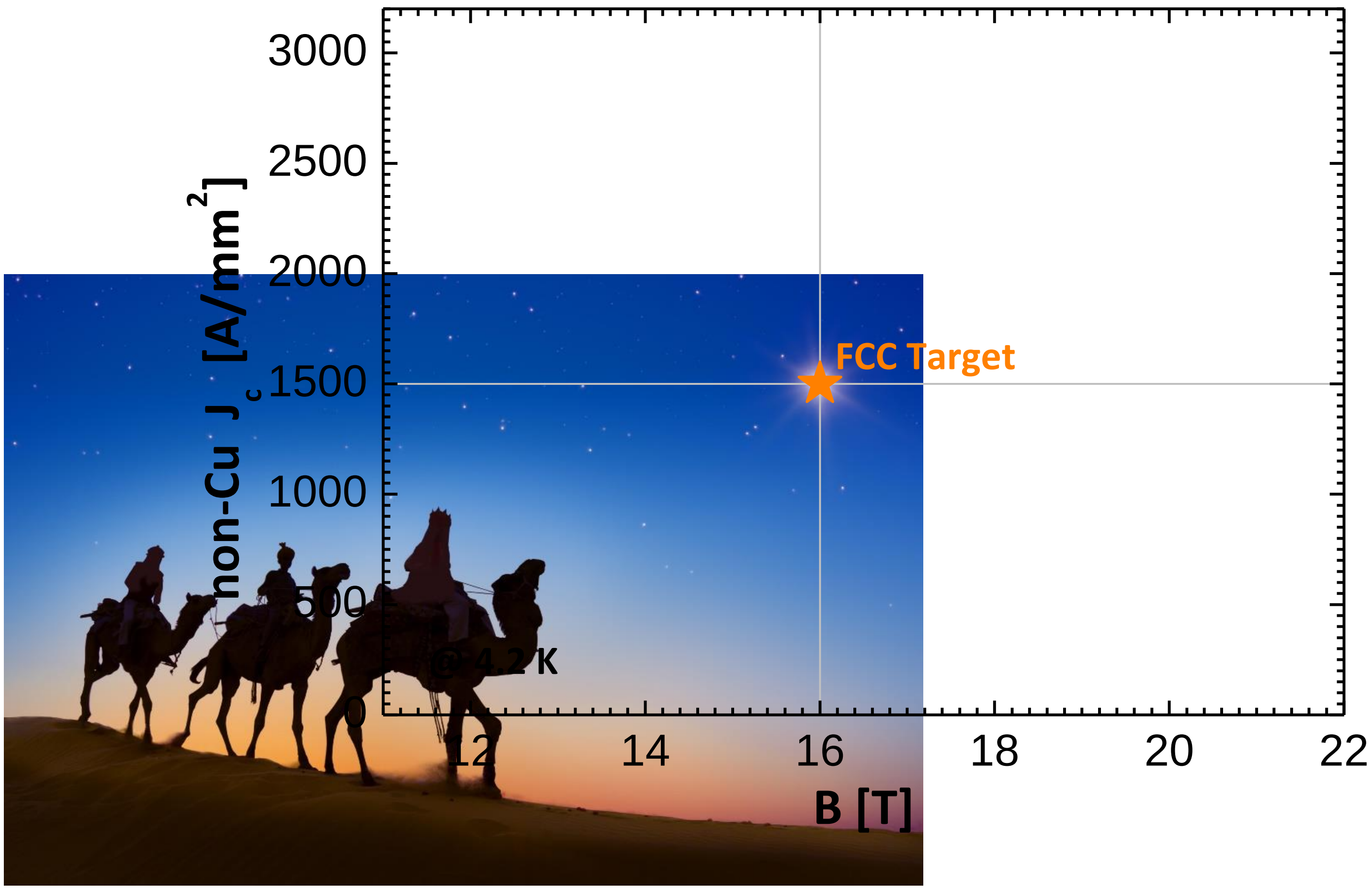
Performance target non-Cu J_c(4.2K,16 T) = 1500 A/mm²



Mt 2;10 When they saw the star, they rejoiced exceedingly with great joy

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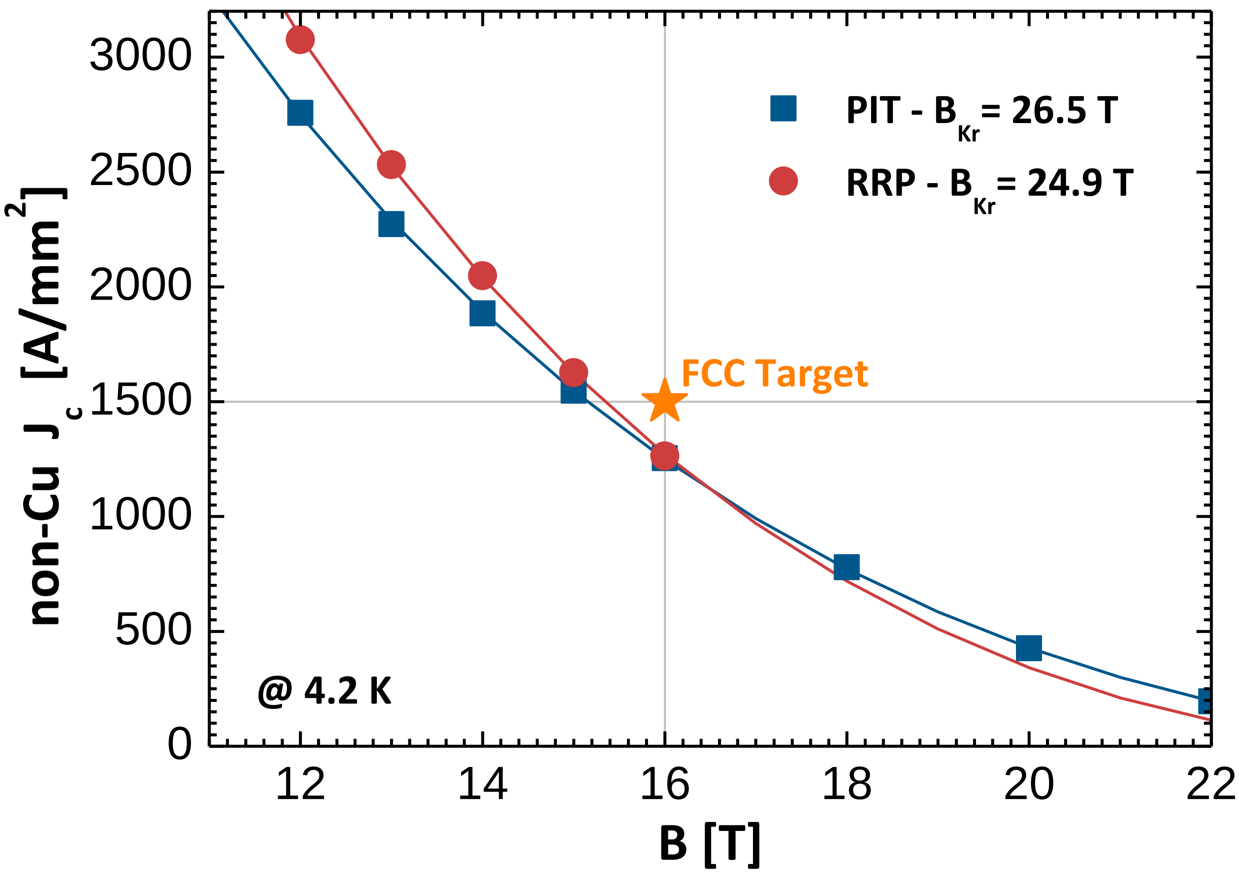

J. Parrell et al., AIP Conf. Proc. 711 (2004) 369

T. Boutboul et al., IEEE TASC 19 (2009) 2564

An (almost) unique equipment

Laboratory for the development of superconducting wires @

UNIVERSITÉ DE GENÈVE
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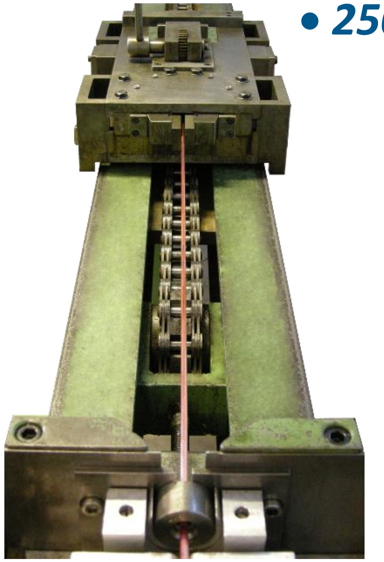
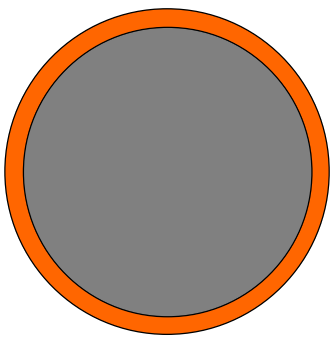
- Wire drawing bench 1.5t
- Wire drawing bull-block 0.3t
- Wire drawing dies from ∅15 to ∅0.2 mm
- Hot-rolling mill and hot-rolling groove roller
- Rolling mill with tungsten carbide rollers
- Powered turks head machine
- Two swaging machines
- 250t hydrostatic hot extrusion machine

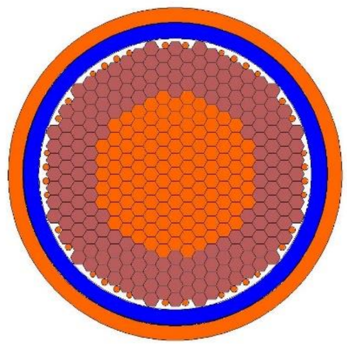


R&D of internal Sn Nb_3Sn conductors

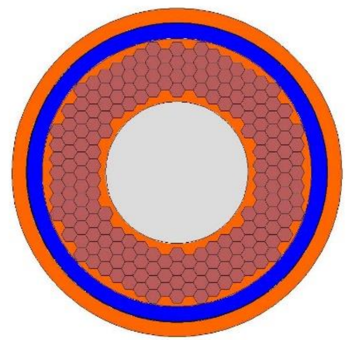
A collaboration between UNIGE and Bruker BioSpin funded by KTI/CTI (2007-2010)



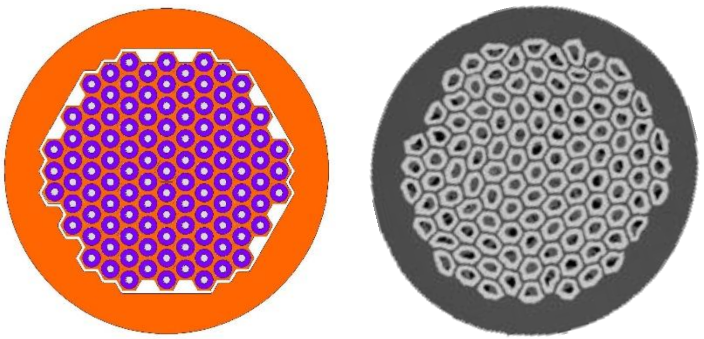
Cu/Nb-Ta rod



Sub-element bundle

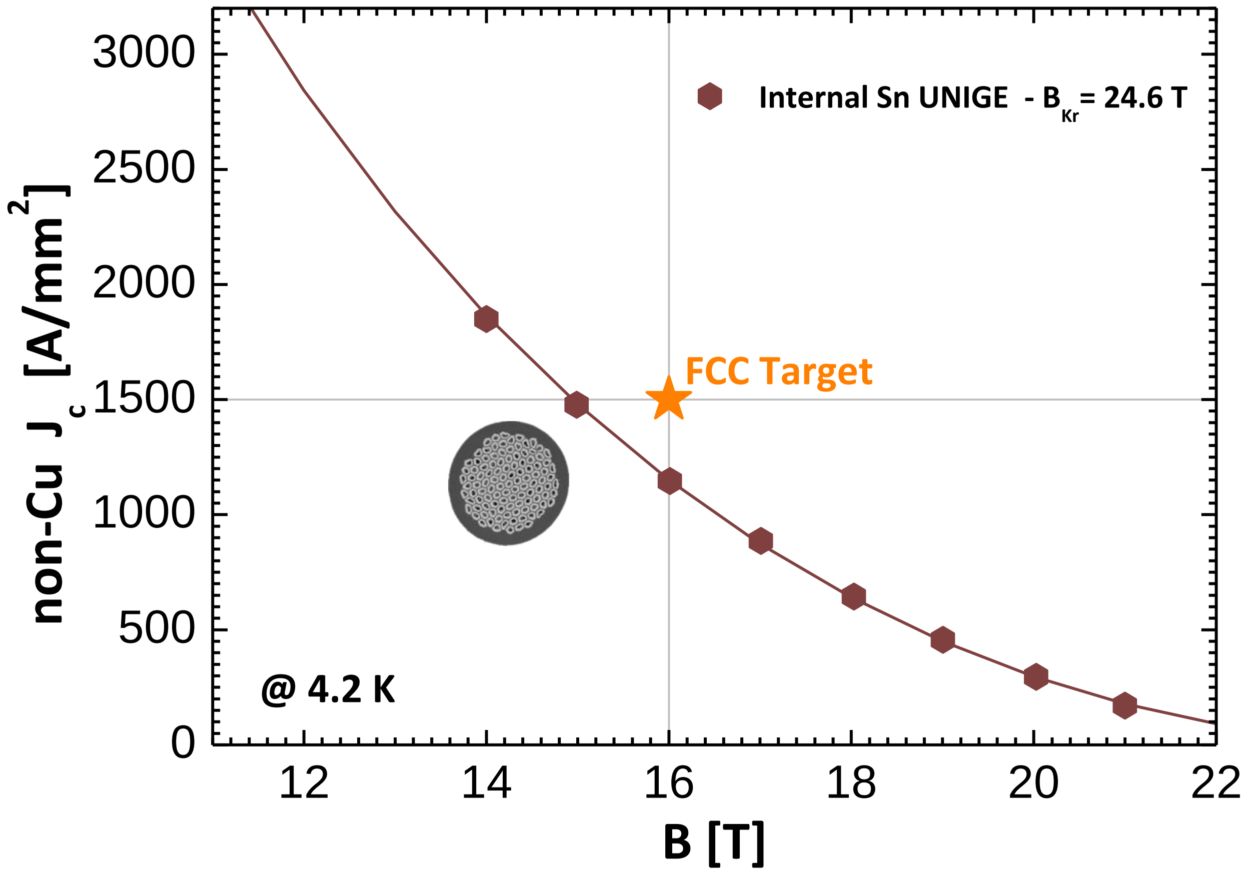


Sub-element with pure Sn core



Final wire 109 sub-elements

Performance target non-Cu J_c(4.2K,16 T) = 1500 A/mm²



F. Buta, R. Flükiger, CTI 9049.1 PFIW-IW final report, 2011

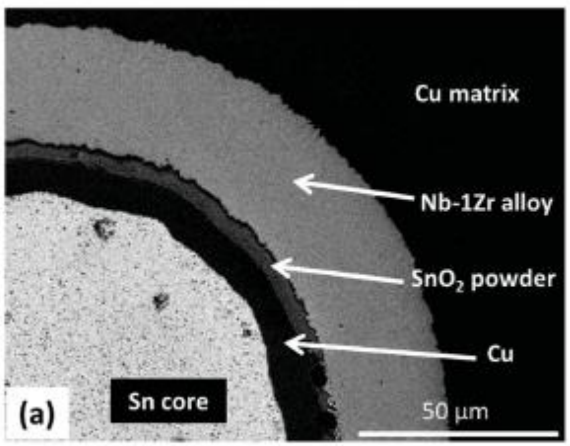
Internal oxidation and grain refinement in Nb_3Sn

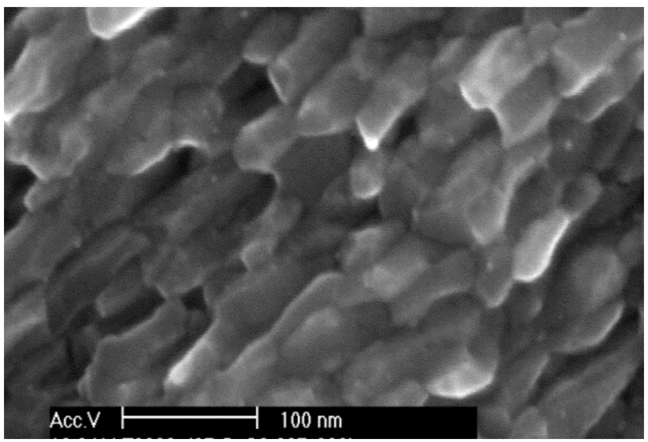
@ Ohio State University

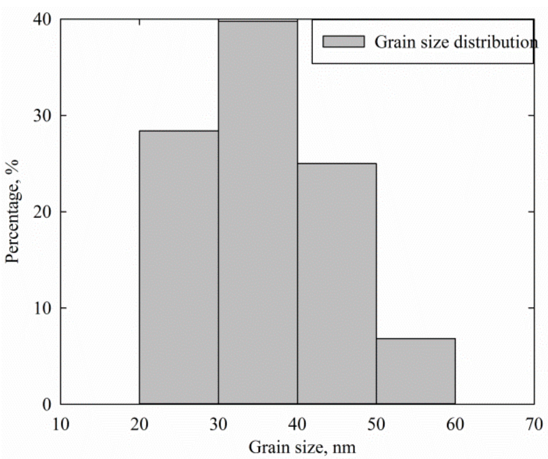
Idea from Benz (1968) to form fine precipitates in Nb to impede the A15 grain growth

Use of a Nb-Zr alloy: Zr has stronger affinity to oxygen than Nb

Oxygen supply added to the composite: oxidation of Zr and formation of nano-ZrO_2







X. Xu et al., APL 104 (2014) 082602

X. Xu et al., Adv. Mat. 27 (2015) 1346

Average grain size is reduced down to < 50 nm

Greatly enhanced pinning in binary Nb_3Sn

M.G. Benz, Trans. Metall. Soc. AIME, 242 (1968) 1067-1070

R&D on internal oxidation in Nb_3Sn @ UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

- *Explore routes leading to the increase of the critical current densities in Nb_3Sn by reducing the grain sizes and increasing the upper critical field*

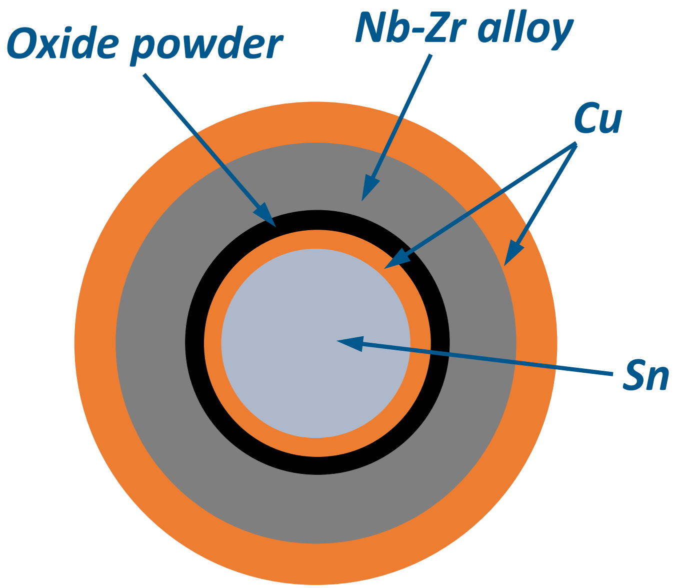
- *Evaluate different oxygen sources for the internal oxidation of Zr atoms present in the Nb filaments*

- *Addition of suitable dopants to enhance the upper critical field*

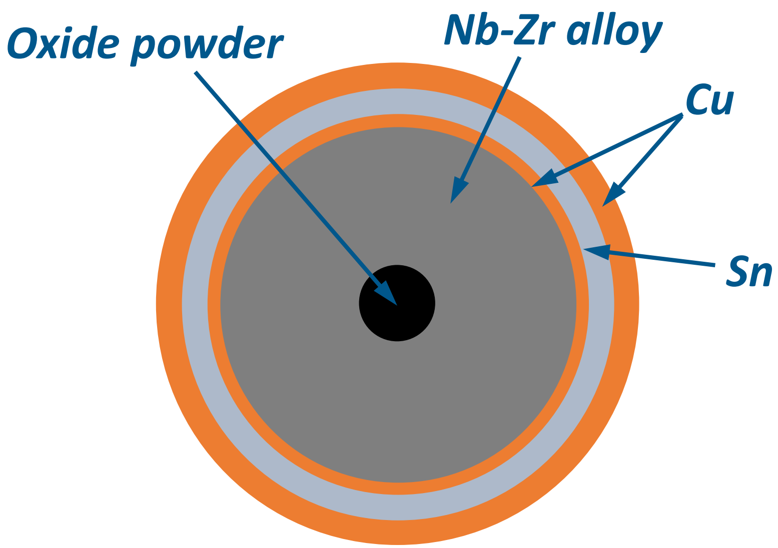
- *Optimize wire configurations and heat treatments*

R&D on internal oxidation in Nb_3Sn @ UNIVERSITÉ DE GENÈVE FACULTÉ DES SCIENCES

Ohio State Univ. Configuration



UNIGE configuration



Filament material - oxygen source combinations

Nb alloy	Metal oxide	Status
Nb-7.5wt%Ta	none	
Nb-7.5wt%Ta	MoO_3	
Nb-7.5wt%Ta	SnO_2	planned
Nb-1wt%Zr	MoO_3	
Nb-1wt%Zr	SnO_2	
Nb-1wt%Zr	CuO	being drawn
Nb-7.5wt%Ta-1wt%Zr	SnO_2	being drawn
Nb-7.5wt%Ta-2wt%Zr	SnO_2	being drawn

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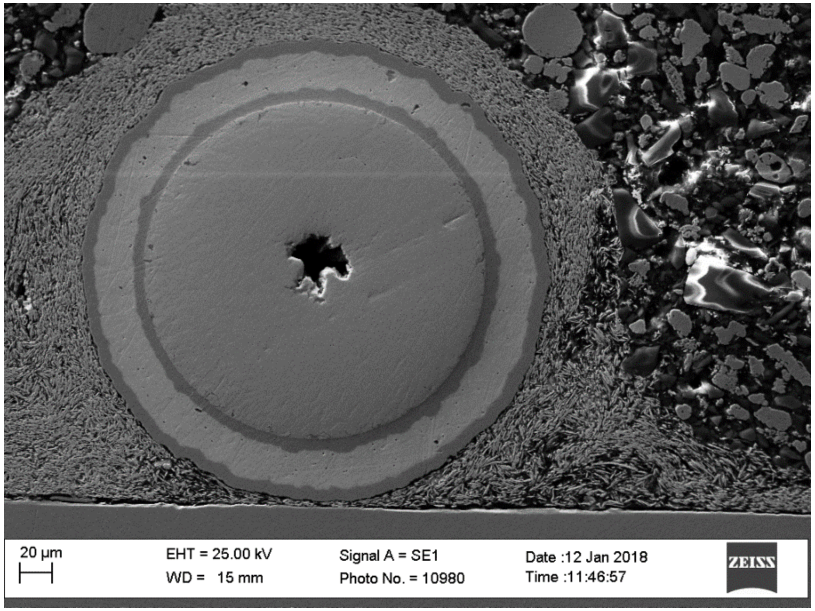
Nb-1wt%Zr	SnO_2	
Nb-1wt%Zr	*CuO*	*being drawn*
Nb-7.5wt%Ta-1wt%Zr	SnO_2	*being drawn*
Nb-7.5wt%Ta-2wt%Zr	SnO_2	*being drawn*

How to select the oxygen source ?

- *high Gibbs free energy of formation*
- *low hardness that would make it compatible with wire fabrication*
- *the metal resulting from the reduction has not to affect superconductivity*

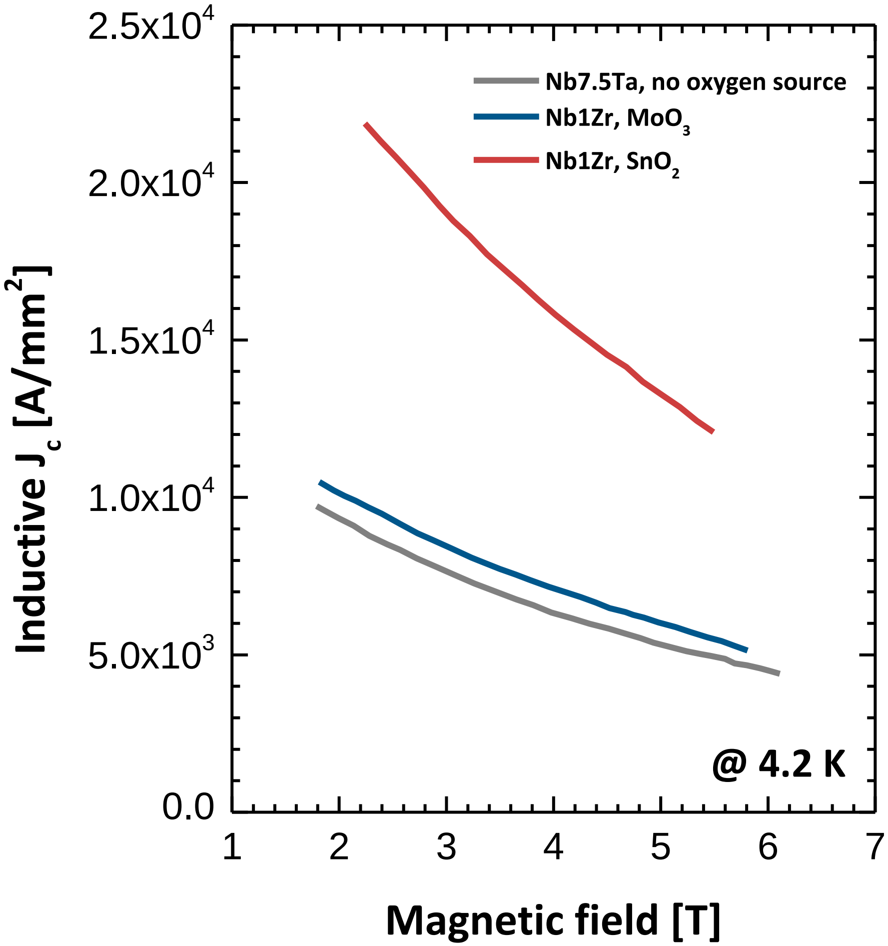
Sample fabrication

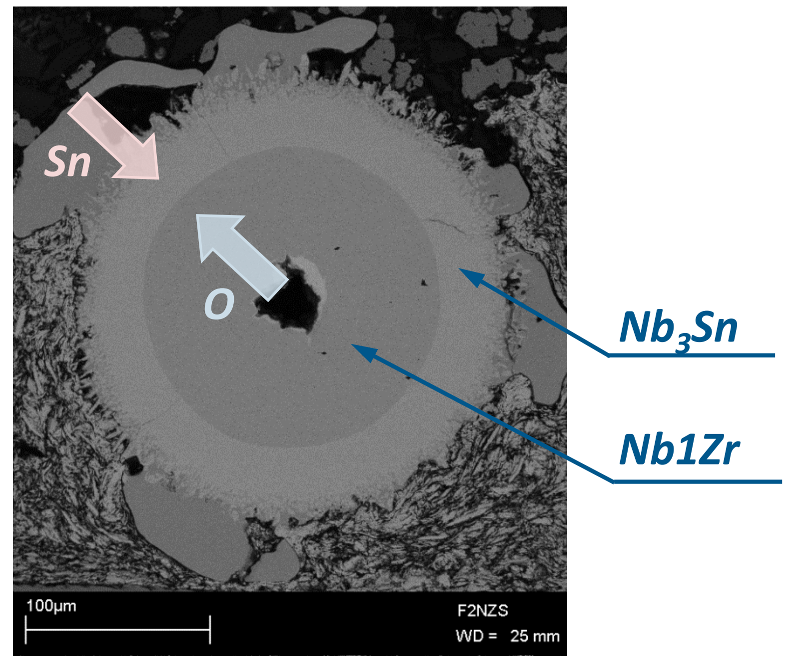


0.22 mm diameter wires of Nb alloy were prepared by cold deformation of a 12 mm diameter rod with nano-sized powders compacted in a central hole

- *The Nb alloy wire was then electroplated successively with: Cu, Sn, Cu*
- *The deposit thicknesses were varied to achieve different Cu/Sn and Nb/Sn ratios*
- *Oxygenation treatment was performed on the Nb alloy wire prior to the electroplating or on the full wire prior to the A15 formation*

Critical current density

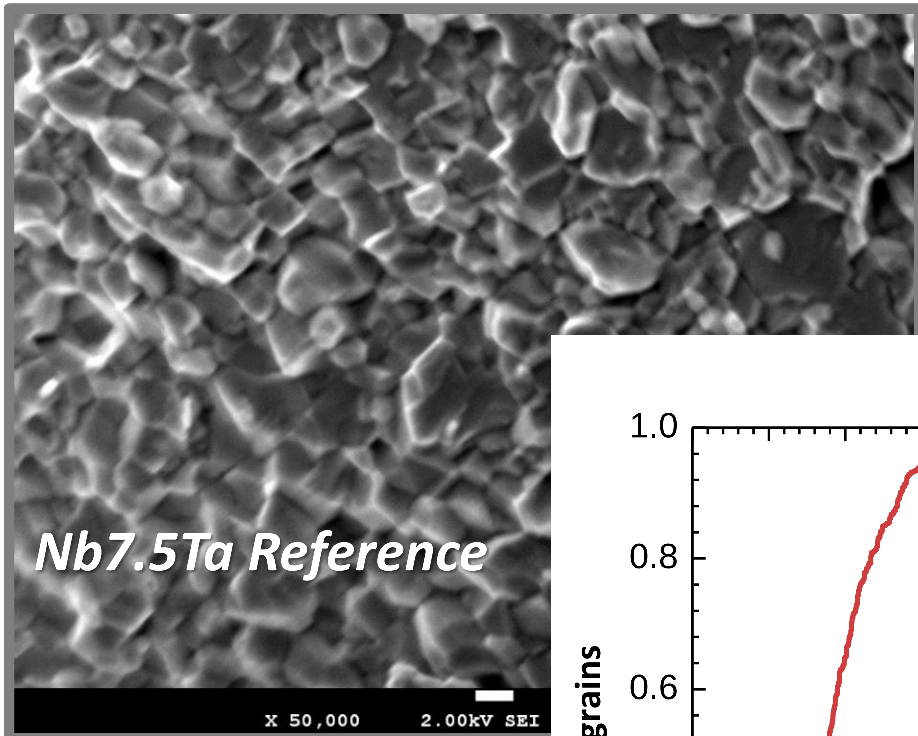


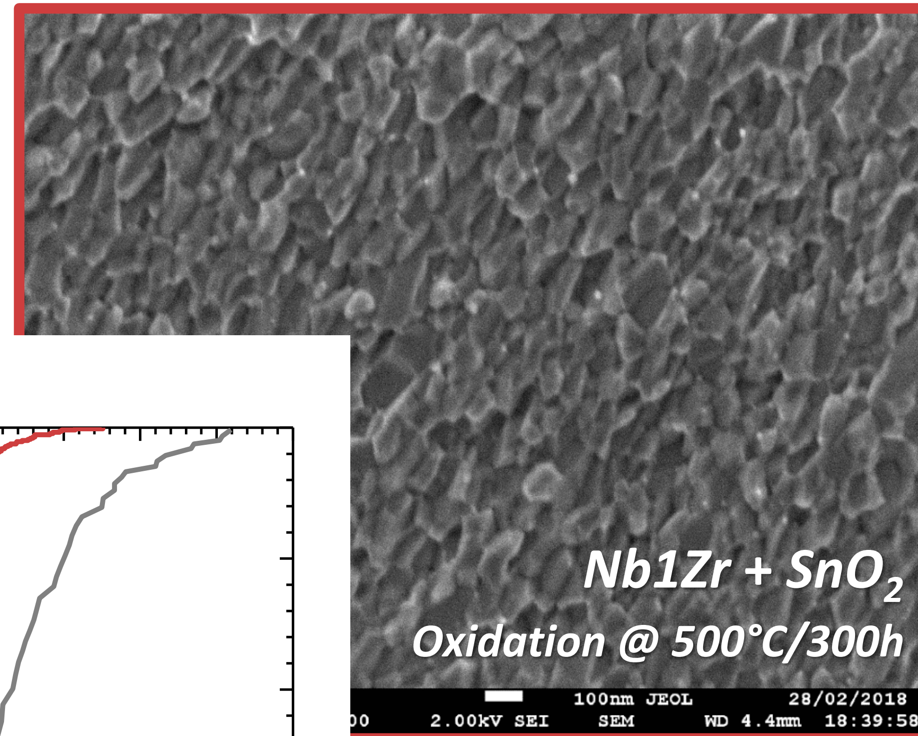


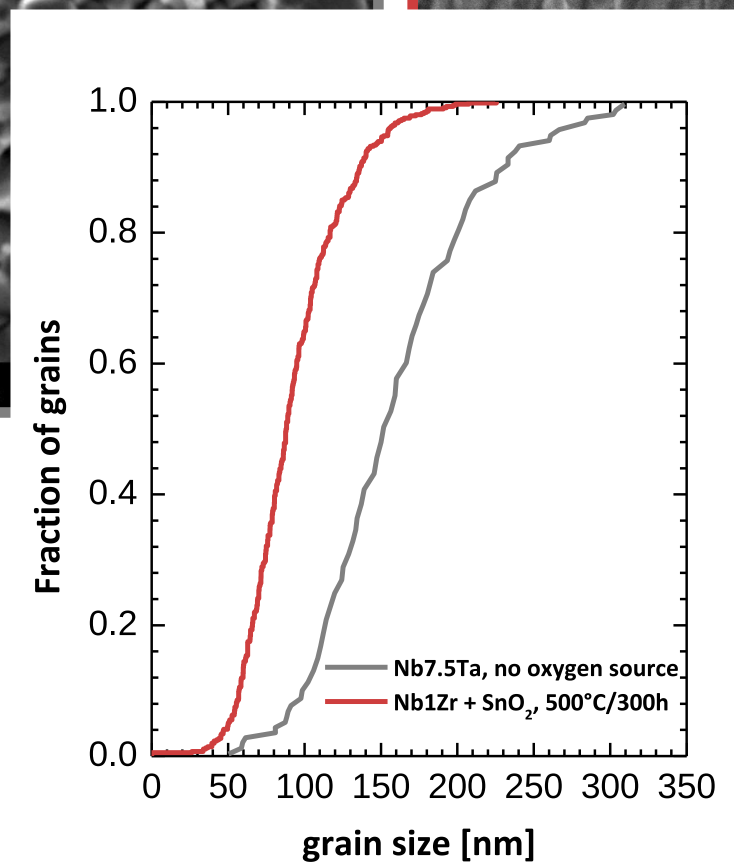
	Nb7.5Ta	Nb1Zr + SnO_2
F_p^{MAX}(4.2 K)	28.3 GN/m³	62.4 GN/m³
B_{Kramer}(4.2 K)	27 T	23.4 T

Oxidation treatment @ 500°C/50h

Grain morphology





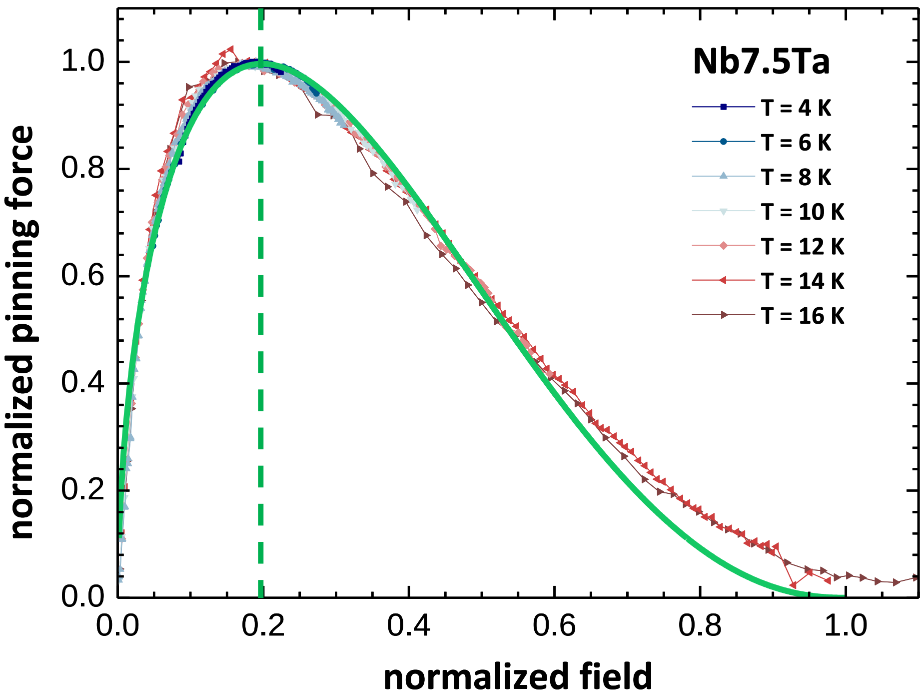


Median grain size
153 nm

Median grain size
88 nm

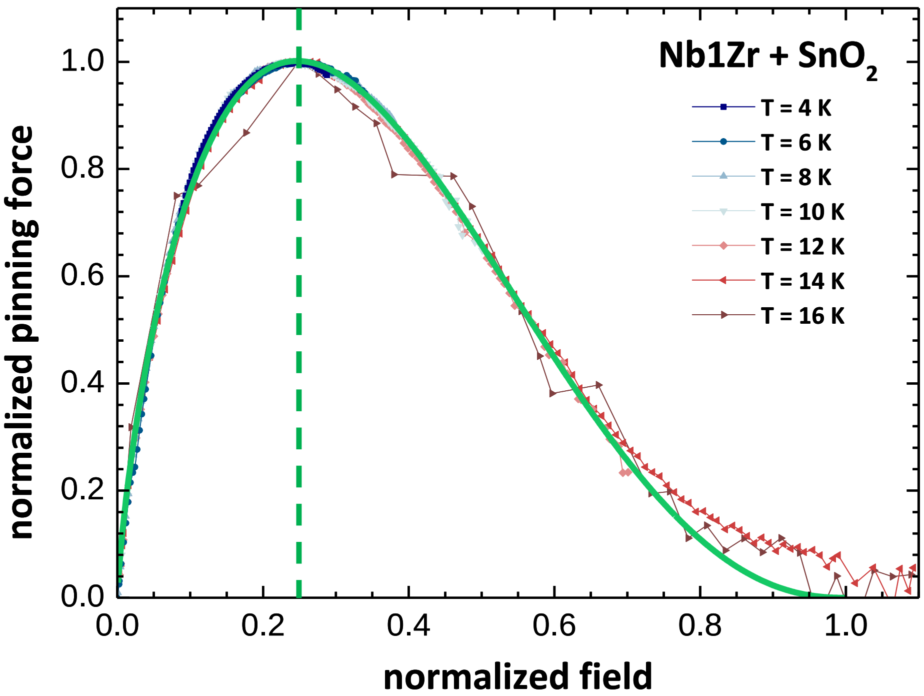
Pinning force

Nb7.5Ta Reference

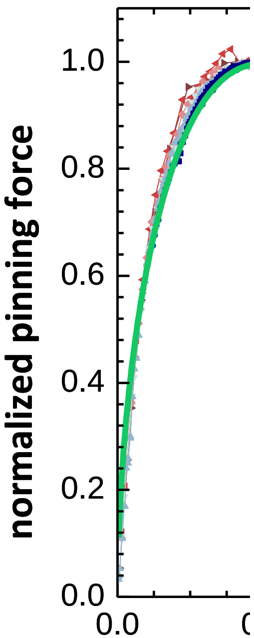


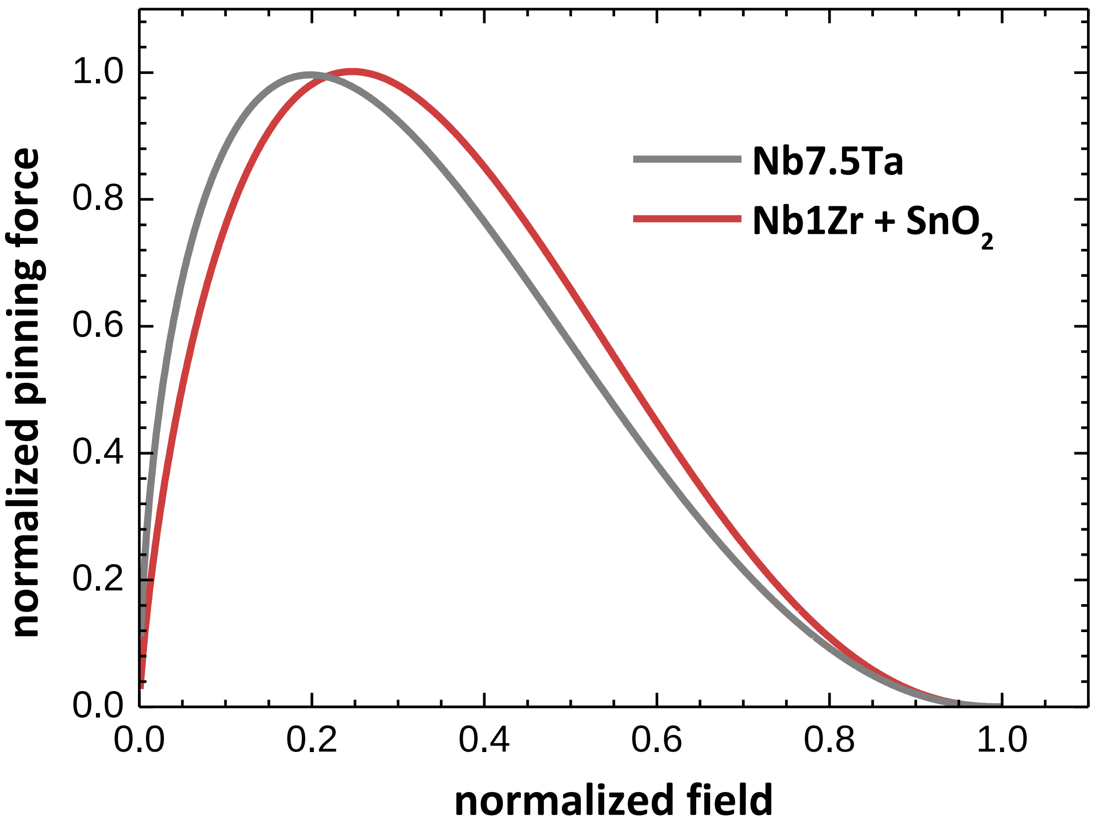
$Nb1Zr + SnO_2$

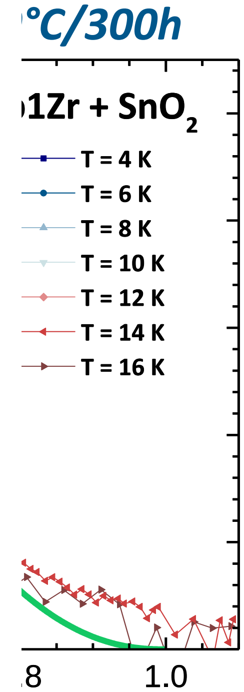
Oxidation treatment @ 500°C/300h



Pinning force







GB pinning ⇒ max @ b = 0.2
point pinning ⇒ max @ b = 0.33

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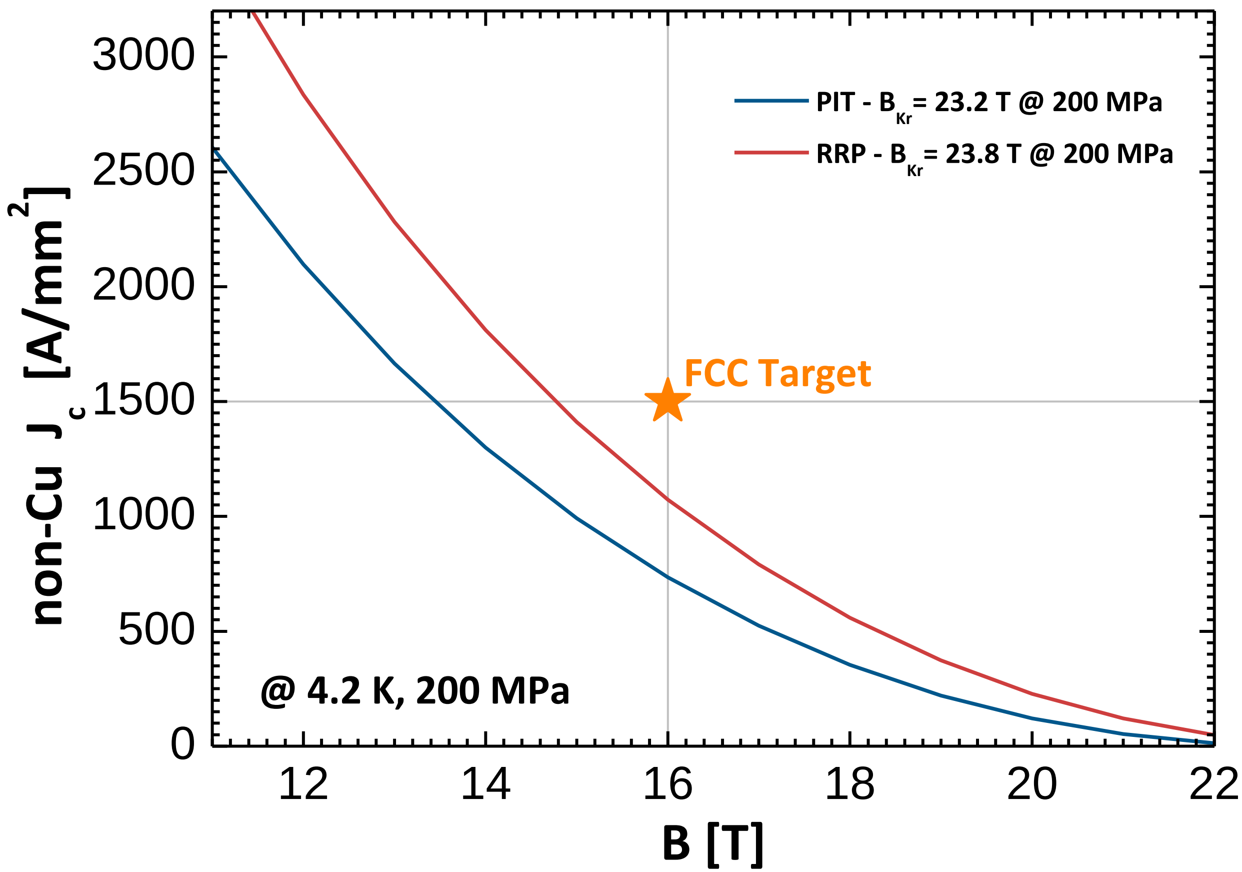


J. Parrell et al., AIP Conf. Proc. 711 (2004) 369

T. Boutboul et al., IEEE TASC 19 (2009) 2564

Degradation upon transverse loads

The 16 T FCC dipoles are being designed with a peak stress of 200 MPa at operation

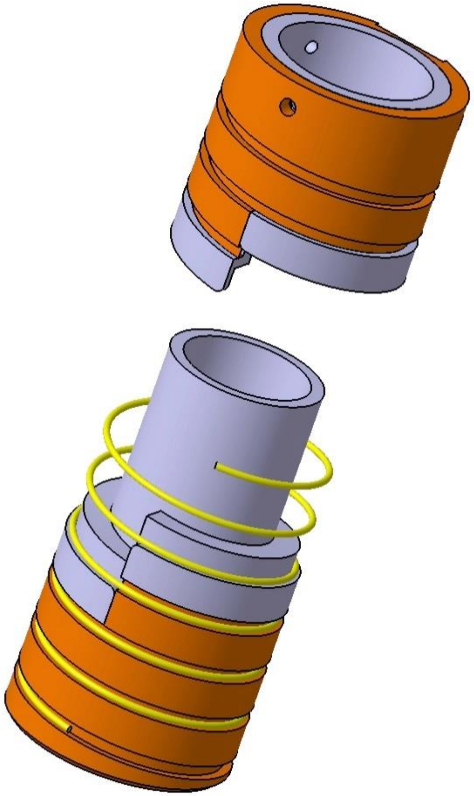
Are the Nb_3Sn wires in the cable able to withstand such a high stress level? Which degradation is tolerable?

Nb_3Sn Rutherford cable for HL-LHC, 40 strands

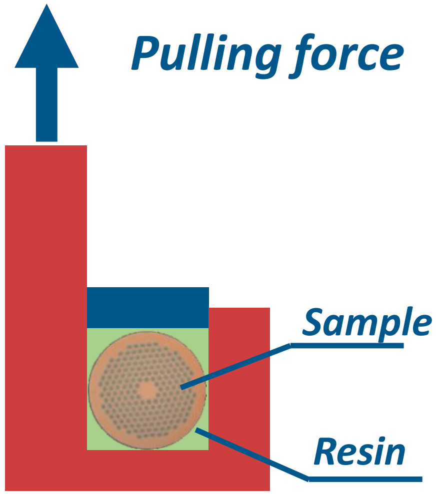
- Nb_3Sn wires are deformed during cabling
- Cables are braided with glass fiber
- The winding is impregnated with resin

Is it possible to extrapolate the behaviour of the cable from a single wire experiment?

The WASP concept for I_c vs. transverse stress



4-WALL + impregnation

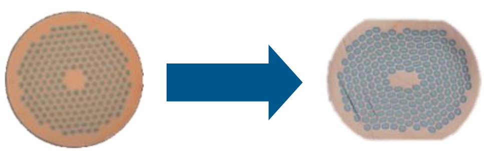


3 groove widths
- 1.30 mm
- 1.15 mm
- 1.00 mm

CERN-UNIGE collaboration agreement K1629/TE (2009-2012)

The irreversible limit of the wire under transverse stress is influenced by several parameters

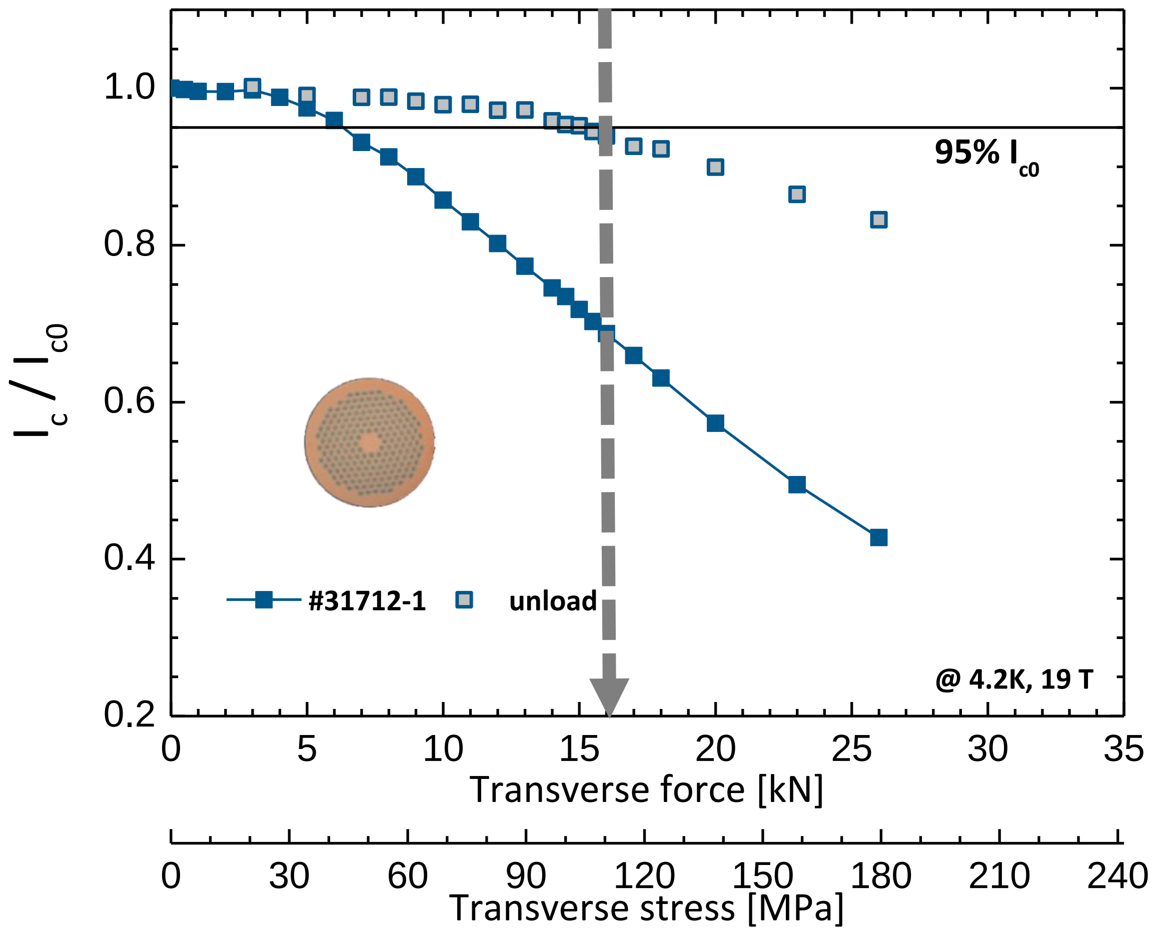
- *the type of impregnation (the elastic modulus of the resin)*
- *the redistribution of the applied stress on the wire*

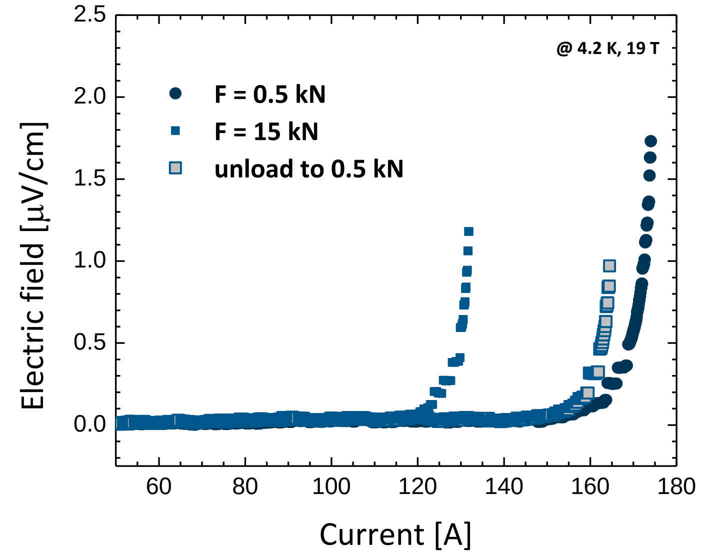


Rolled wire to simulate the deformation during cabling

- *the type of wire*

I_c vs. transverse stress
PIT 192 + epoxy L





The irreversible limit is defined at the force level leading to a 95% recovery of the initial I_c after unload

Here

$$F_{irr} = 16\ kN$$

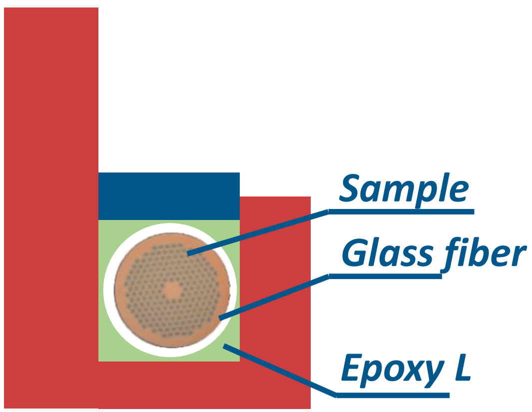
The corresponding irreversible stress limit is

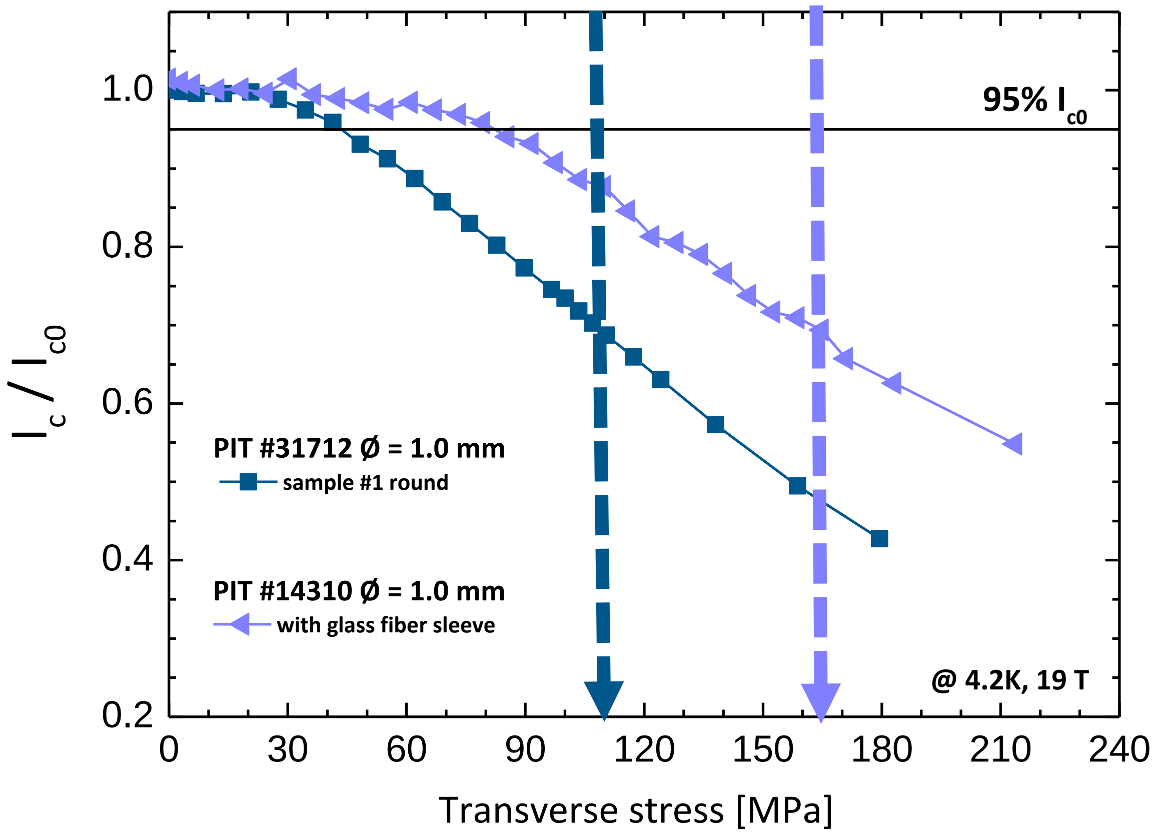
$$\sigma_{irr} = 110\ MPa$$

where

$$Stress = \frac{Force}{groove\ length \times groove\ width}$$

I_c vs. transverse stress: wire in a glass fiber sleeve

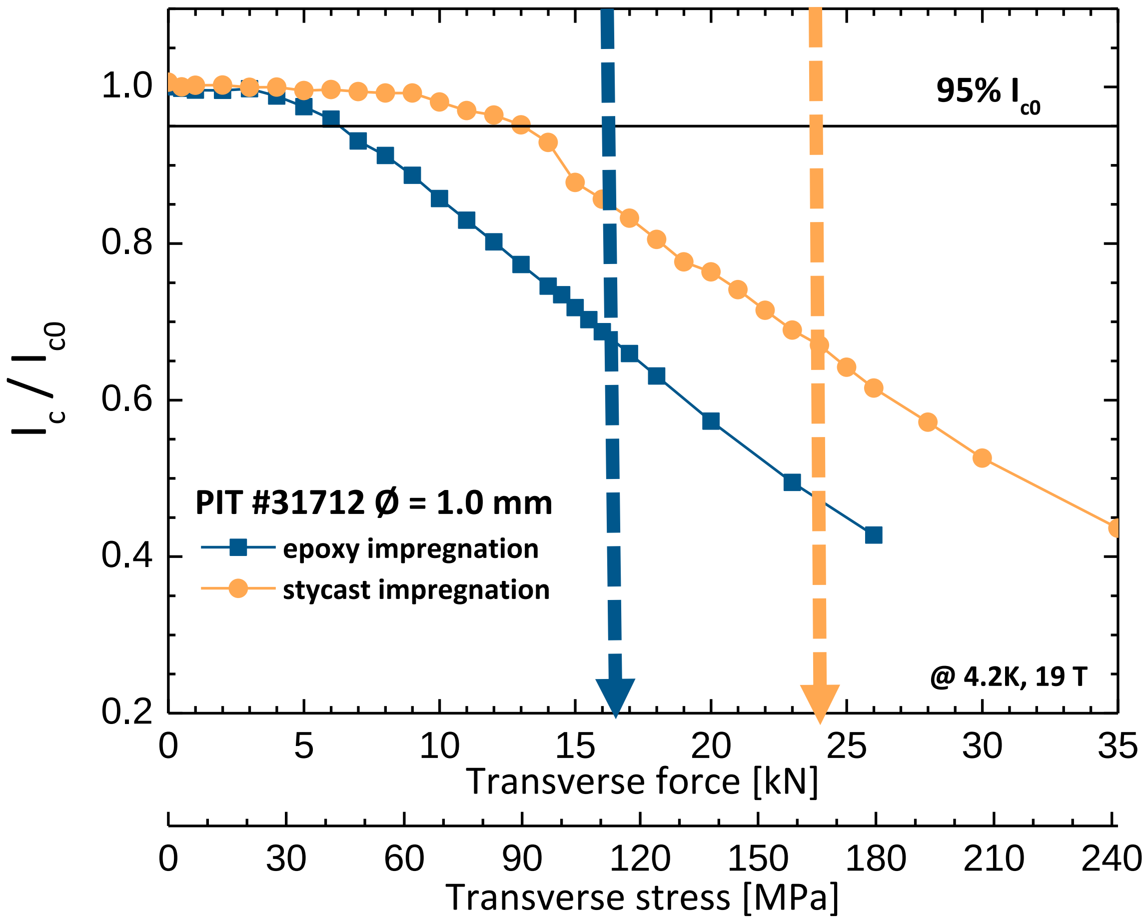




Shift of σ_{irr} by > 50 MPa

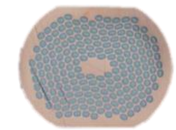
The wire with glass fiber sleeve was measured in a larger groove (1.30 mm vs 1.15 mm)

I_c vs. transverse stress: epoxy L vs. stycast

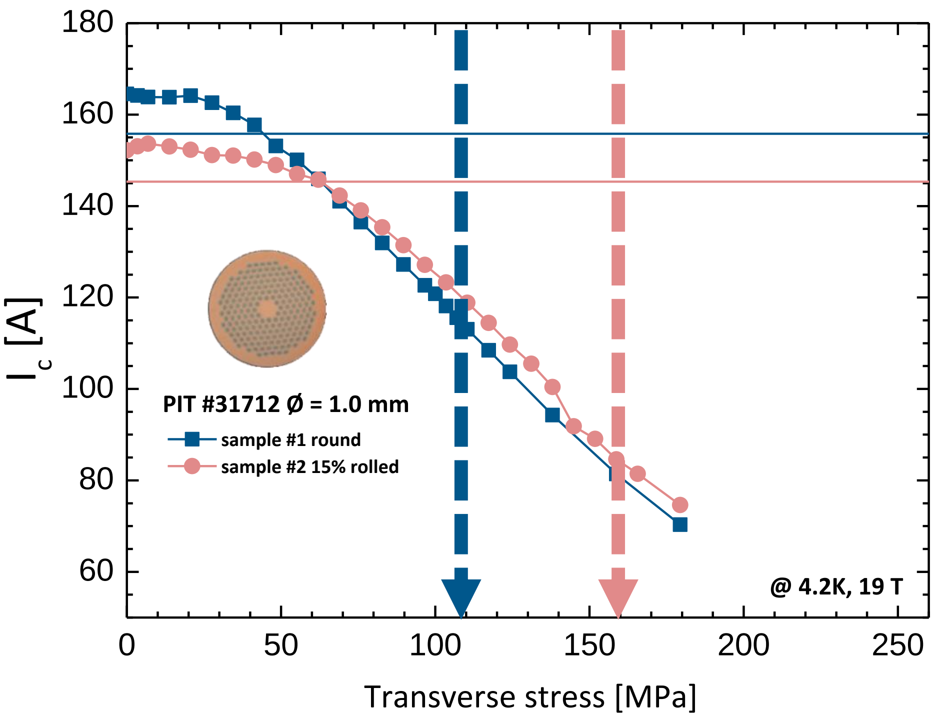


The change of resin, from epoxy to stycast, leads to an increase of σ_{irr} by > 50 MPa
The result is comparable to the value found with epoxy + glass fiber sleeve

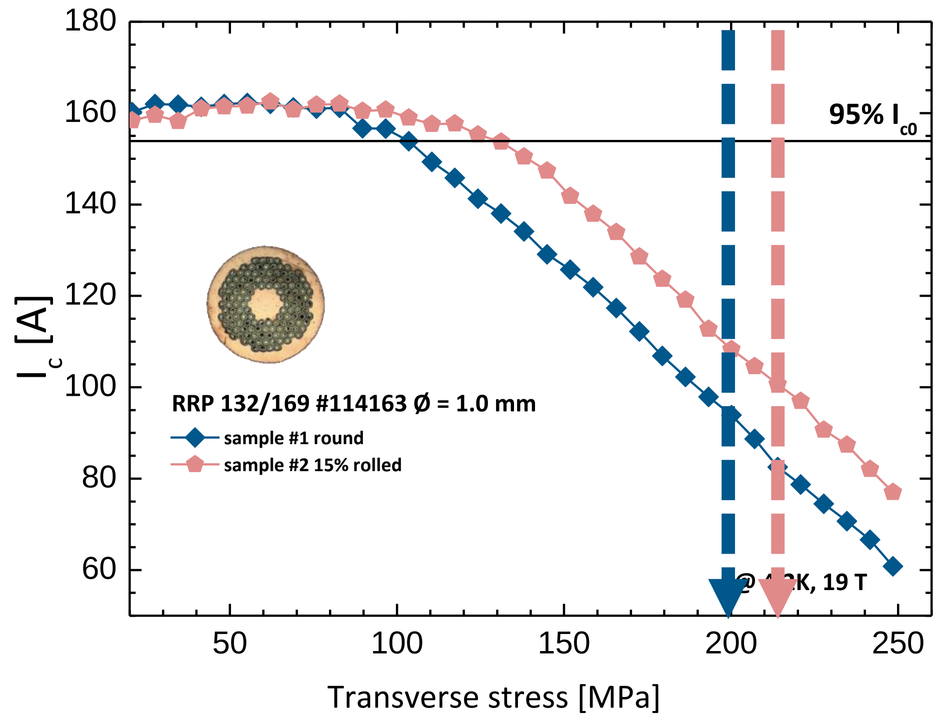
I_c vs. transverse stress on 15% rolled wires



PIT 192



RRP 132/169



~7.5% I_c reduction by rolling

Shift of σ_{irr} by ~ 40 MPa

NO I_c reduction by rolling

Shift of σ_{irr} by ~ 15 MPa

…more details in the poster (#256) of José FERRADAS

Summary

- *Observed a refinement of the Nb_3Sn grains but the process is still under optimization*
- *NbTaZr alloys: The goal is to produce material with refined grains (ZrO_2 dispersion) and enhanced B_{c2} (Ta-doping)*
- *Explored the irreversible stress limit of PIT and RRP wires in different load conditions*

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Thank you for the attention !

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