TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

# TU Wien Contribution during FCC Study (2016-2021)

M. Eisterer – Atominstitut / TU Wien
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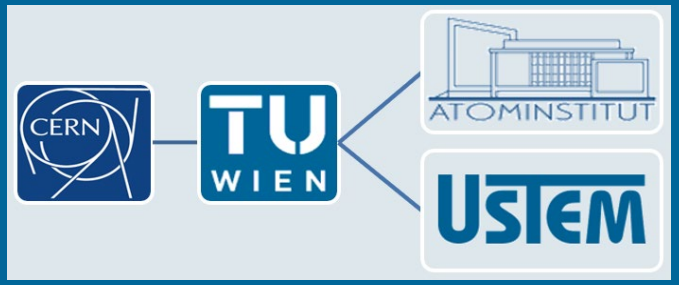


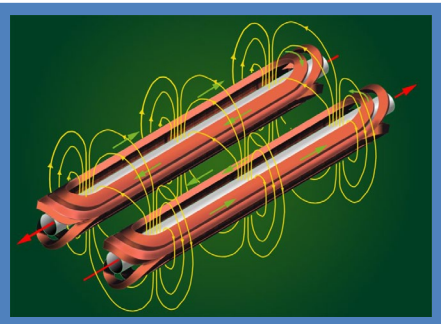

Low Temperature Physics
and Superconductivity

# Research Projects

$Nb_3Sn$ Conductor R&D

Beam Screen Development (HTS)

Marie Skodowska-Curie
ITN EASITrain



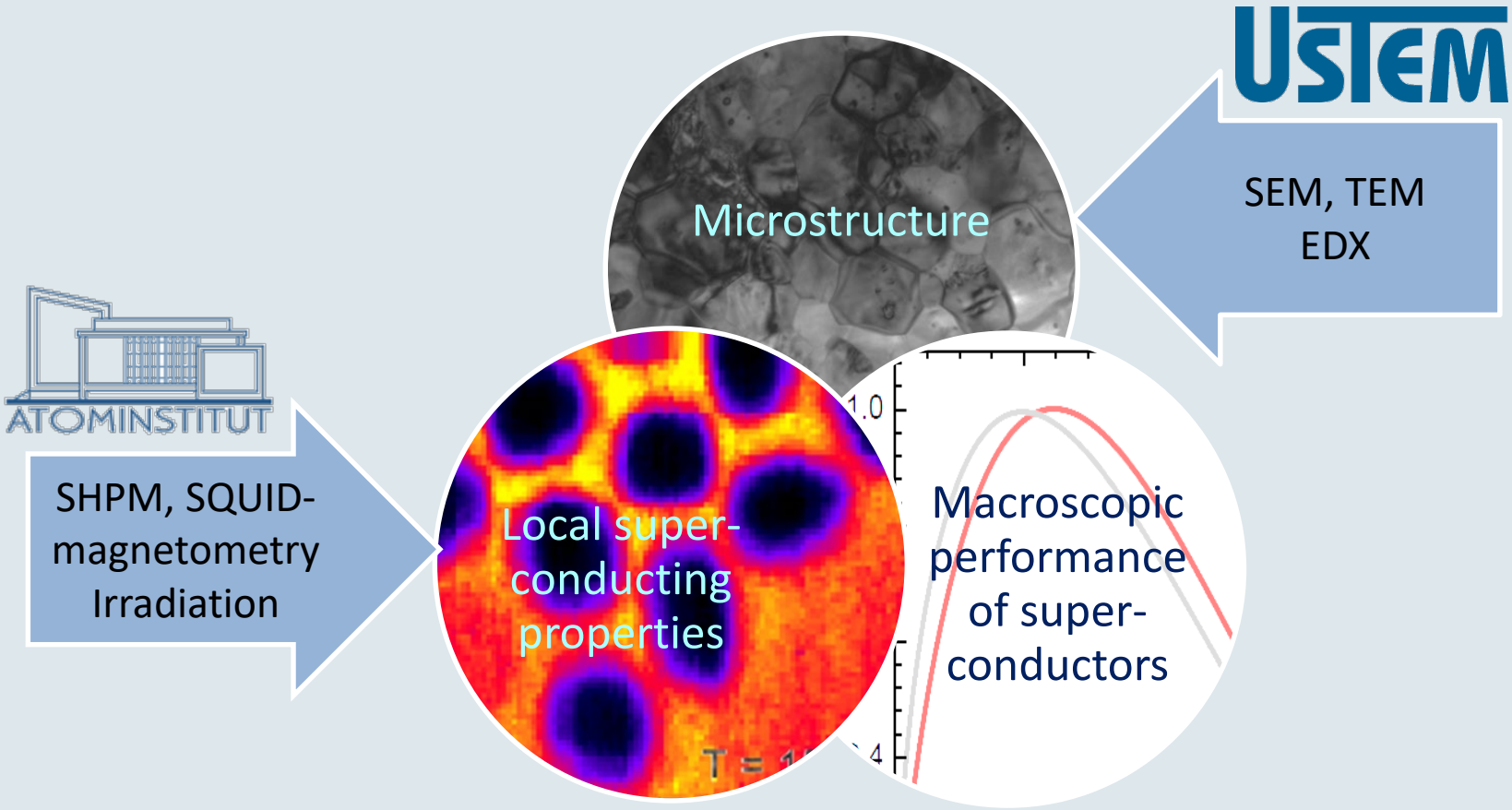
## $Nb_3Sn$ Conductor R&D

- 16 T dipole magnets
- 1500 A/mm$^2$
- 4.2 K

## Beam Screen Development (HTS)

- Low impedance coating for reduction of beam-induced RF image currents
- Operation at 50 K for reduced cryogenic power consumption

# Goal of the investigation

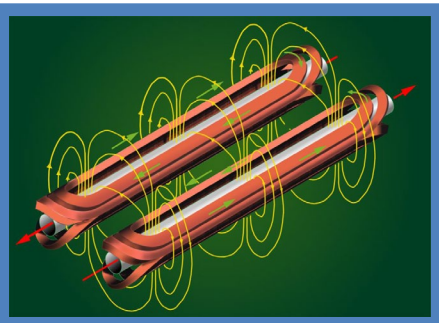


# Investigations at ATI

Low Temperature Physics
and Superconductivity

- Measurements of the critical currents
- Irradiation experiments of superconducting materials
- Magnetic field mapping
- Search for material inhomogeneities
- Finding the relationship between microstructure and superconducting properties

# How to achieve $J_c$=1500 A/mm$^2$?



**$Nb_3Sn$ Conductor R&D**

- 16 T dipole magnets
- 1500 A/mm$^2$
- 4.2 K

Two main concepts:

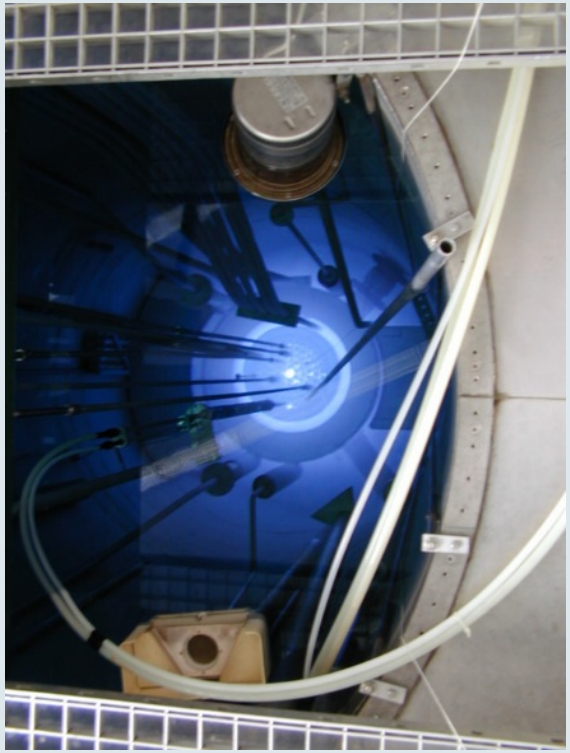
- Artificial pinning
- Reduction of inhomogeneities

# Introduction

Superconducting properties (e.g. $T_C$, $B_{C2}$, $J_C$) in $Nb_3Sn$ wires are influenced by:

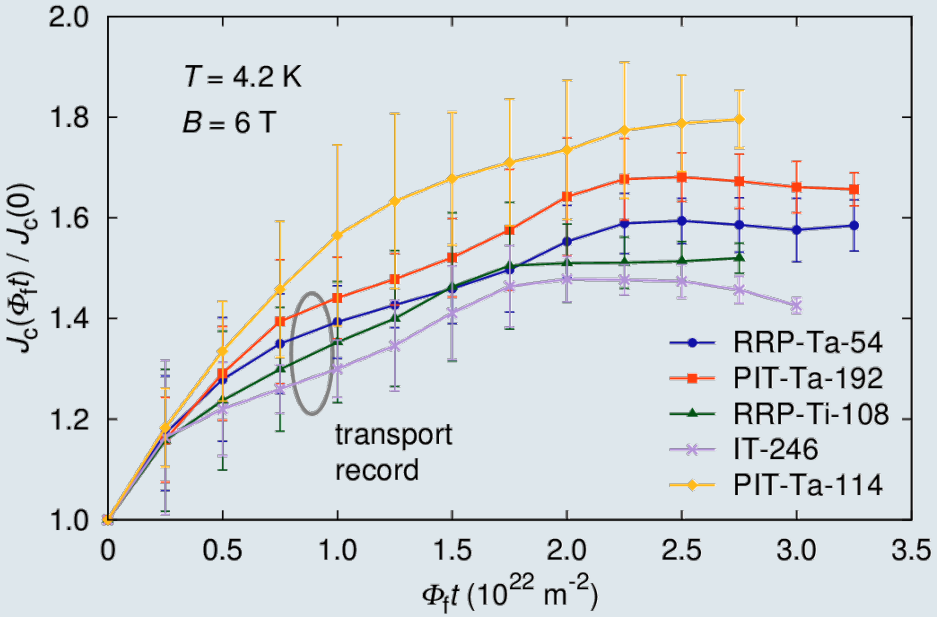
| Composition | Morphology | Composition gradients |
| --- | --- | --- |
| • Sn: $Nb_{1-\beta}Sn_\beta$<br>• Additives: Ti, Ta<br>• → $T_C$, $B_{C2}$ | • grain size (grain boundaries)<br>• Defects (APC)<br>• → $J_C$ | • → spatial $T_C$ distribution |

# Irradiation experiments



- Irradiation of short wire samples in the TRIGA Mark-II reactor at Atominstitut
- Sequential irradiation in relatively small steps in order to assess fluence dependence of superconducting properties
- Very important also for nuclear fusion

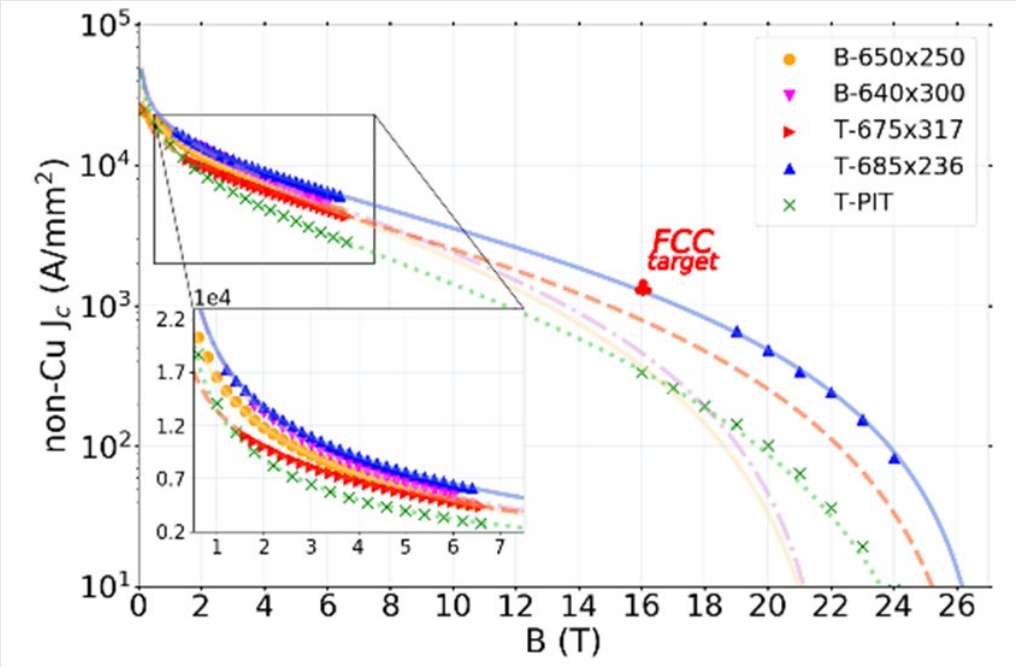
# Irradiation experiments




- Critical current density increases significantly in irradiated wires because of nano-sized defects.
- FCC target was obtained in industrial $Nb_3Sn$ wire!
- Only model system. Later realized by oxide nano-particles in prototype wires.

Baumgartner, T. *et al.*, *Sci. Rep.* ***5, 10236; doi: 10.1038/srep10236*** (2015).

# Artificial pinning centers




- “Addition” of Zr-O nanoparticles
- Collaboration with USA: Ohio State University, Hypertech, Fermilab

Ortino, M. *et al.*, *Supercond. Sci. Technol.* ***34, 035028; doi: 10.1088/1361-6668/abd5f4*** (2015).

# Magnetometry - SHPM

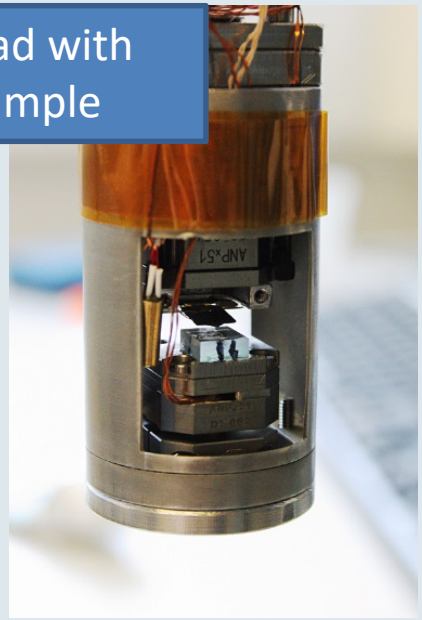
Micro Hall Scanner

- Principle:
  - Measurement of local magnetic field, either in applied magnetic field or with remnant magnetization

Experiment

  - Field up to 8 T, range: 3 x 3 $mm^2$ @ 1 µm

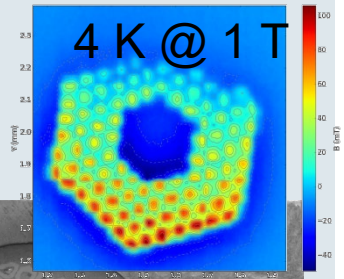
- Goal
  - Evaluating $T_C$ gradients by scanning in the Meißner state at different temperatures
  - Assessing inhomogeneities in $J_c$ by inversion of the Biot-Savart law

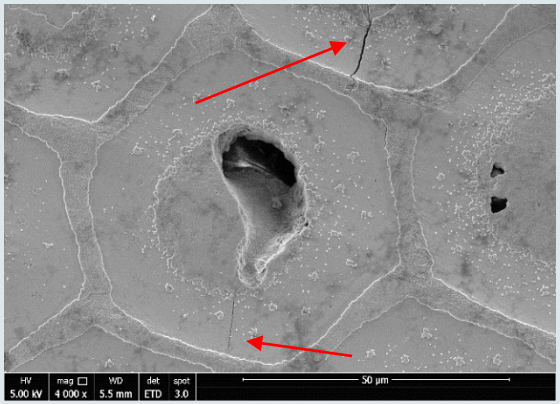


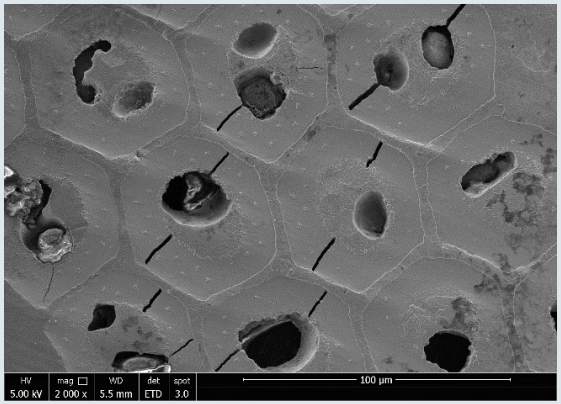
Scanner head with mounted sample

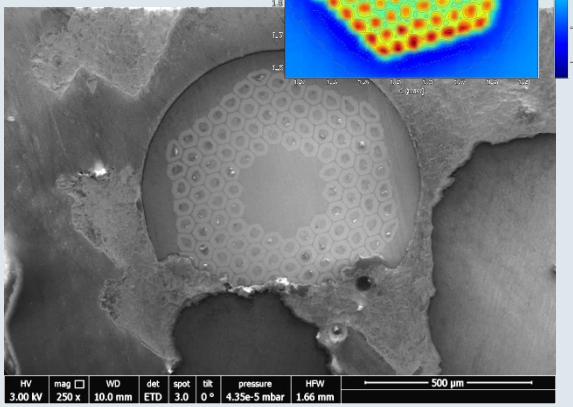
# Sample preparation for Micro Hall Scanner

- Thin slice of less than 10 µm prepared by mechanical polishing with diamond disks
- Parallel and even surfaces essential
- Polishing induces damage on the sample

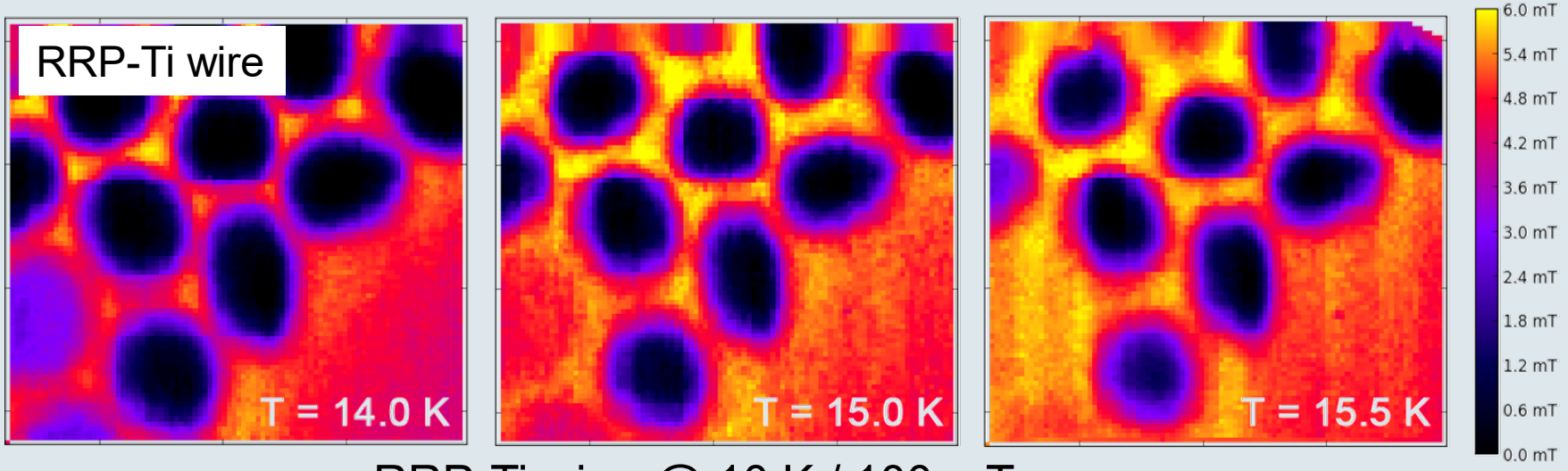


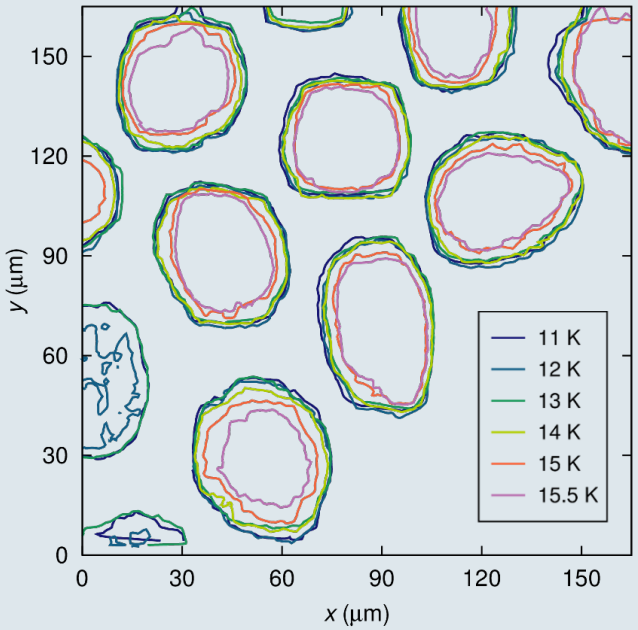
# Magnetic Inhomogeneities

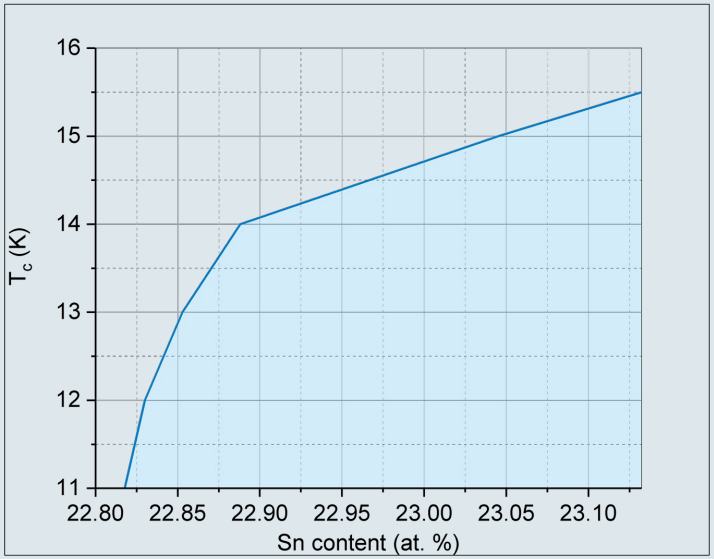



RRP-Ti wire @ 10 K / 100 mT

- RRP-Ti wire, scanned in the Meißner state at different temperatures
- Change in screened area reveals $T_C$ gradient in the sub-elements
- For finding inhomogeneities in $J_C$, scans at fields of several Tesla will be performed

# Meißner scans of RRP-Ti wire

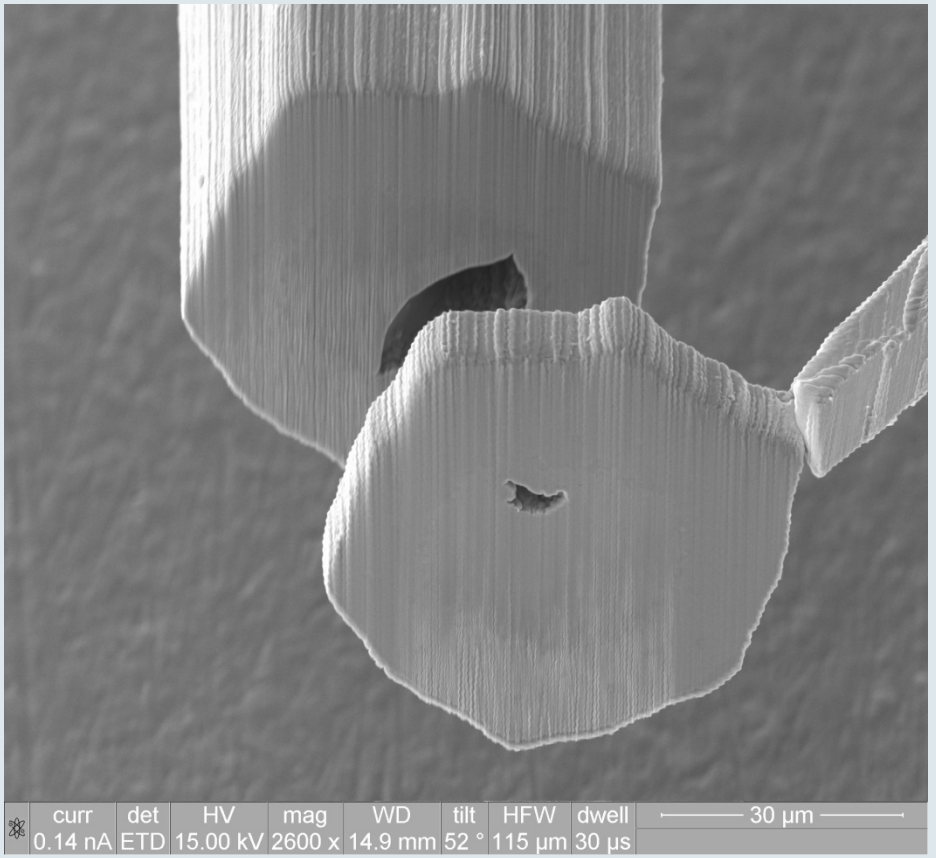



- Meißner Scans on 10 µm thin slice of RRP-Ti wire
- Screening radius depends on temperature due to gradient in Sn content
- Dependency of $T_C$ from the Sn content
- Small change in Sn content heavily impacts $T_C$

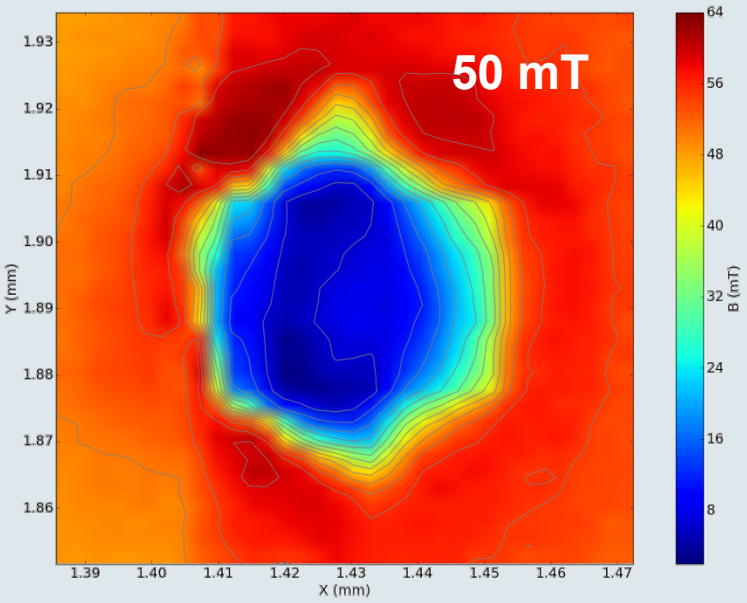
# Sample Preparation of subelement

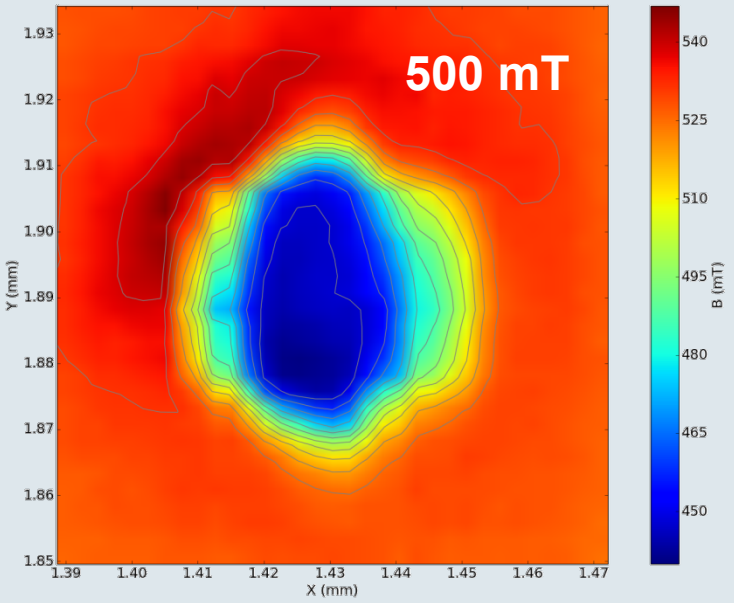
Preparing thin slices of etched subelements using FIB for SHPM measurements



# Magnetic Inhomogeneities

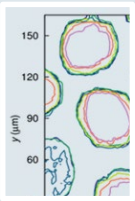
Hall scans of subelement at 5 K



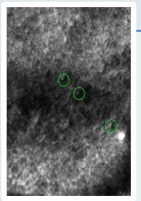




- FIB preparation of individual single subelements is feasible
- For detection of inhomogeneities of $J_C$ Hall scans at higher applied fields will be performed

# Investigations at USTEM

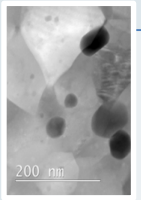



Composition gradients in $Nb_3Sn$ wires

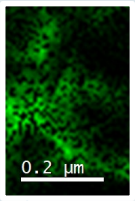


Irradiation Effects

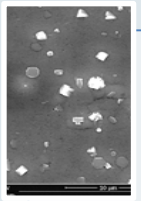
Tl1223 for beam screens




Artificial pinning centers (APC)

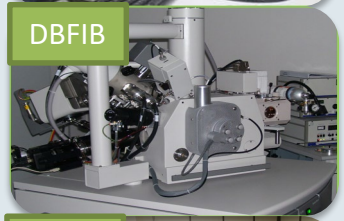



Carbon-Cluster in $MgB_2$

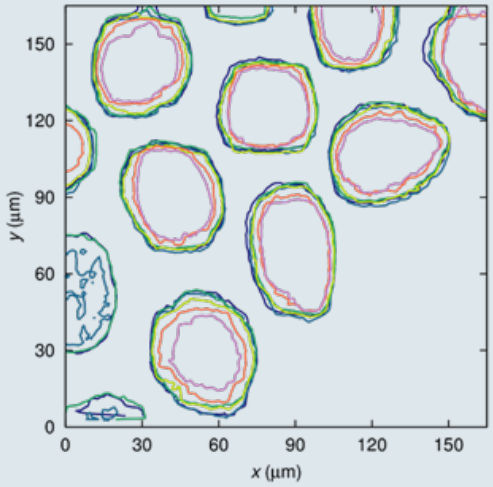


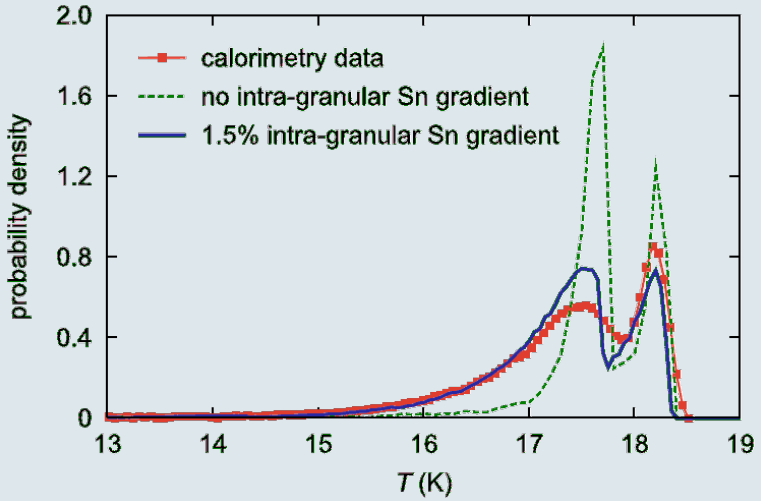
Coated conductors YBCO




# Composition Gradients

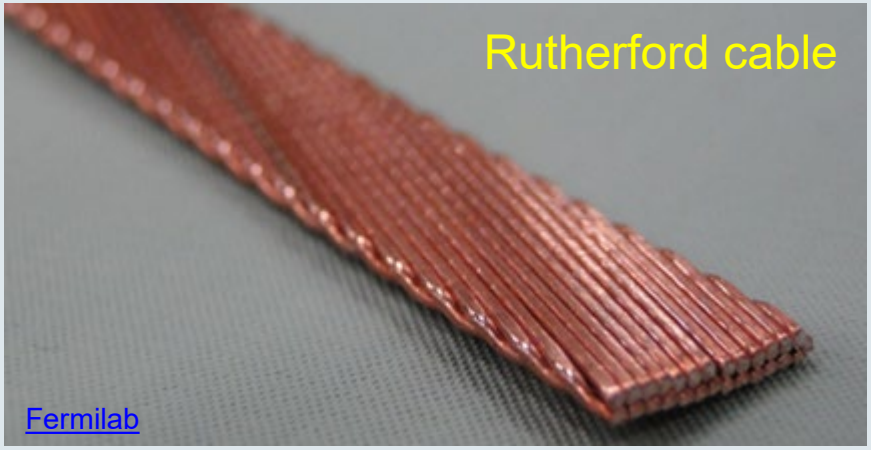


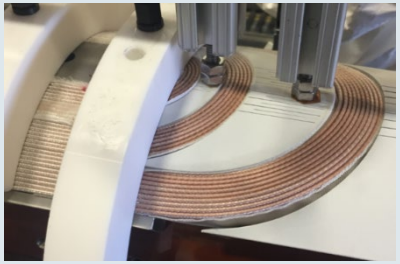



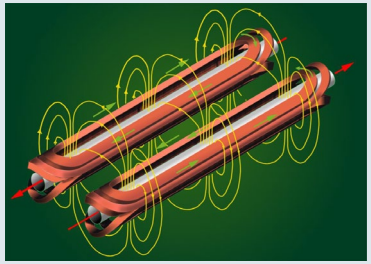

Thomas Baumgartner et al, SUST 30, (2017)

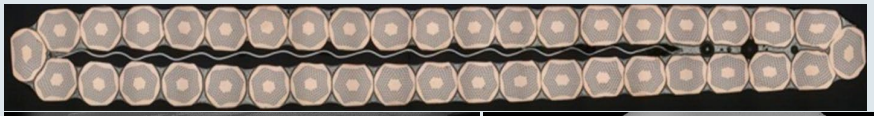
- Magnetometry and calorimetry lead to different distribution functions
- Caused by Sn distribution within individual grains

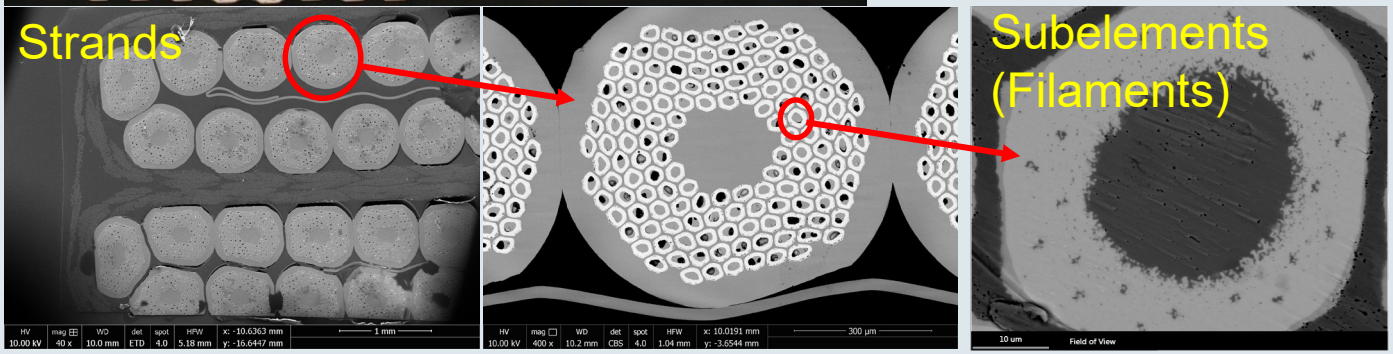
# $Nb_3Sn$ Conductor R&D



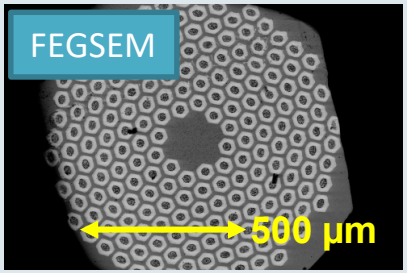



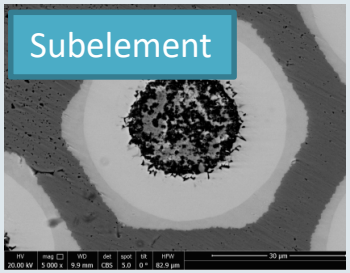


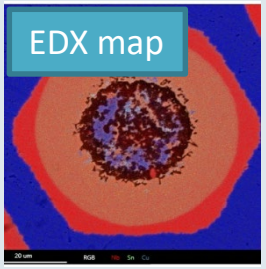


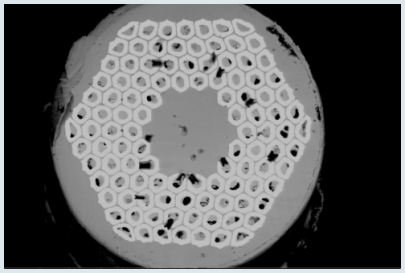


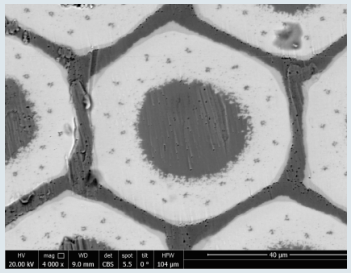
# Investigated $Nb_3Sn$ wires

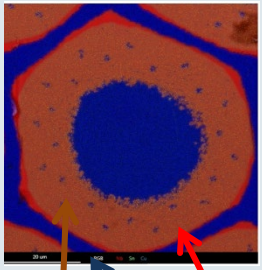


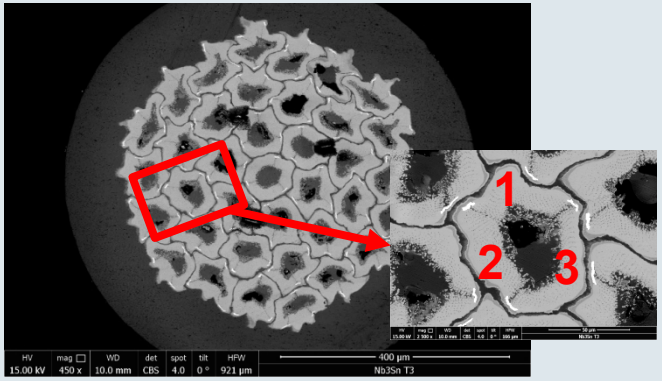







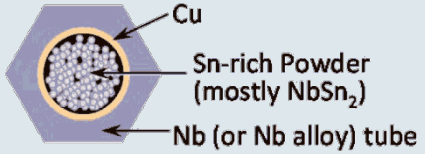



$Nb_3Sn$ Cu Nb

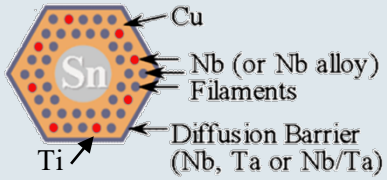
Distributed Nb + Ta

**Clustered layout**

**PIT-Ta**

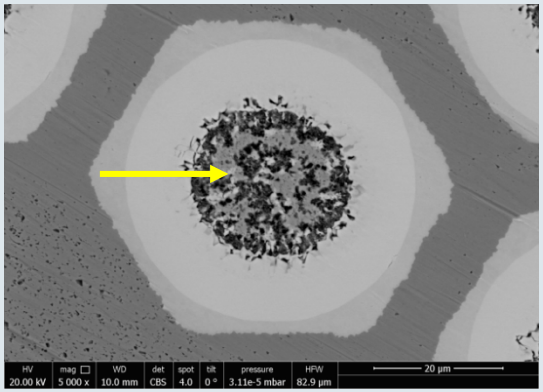


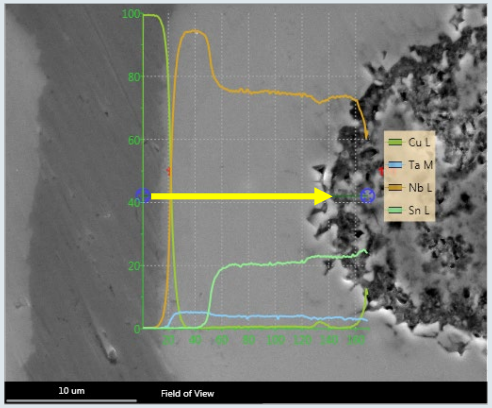

**Internal Sn–Ti RRP**

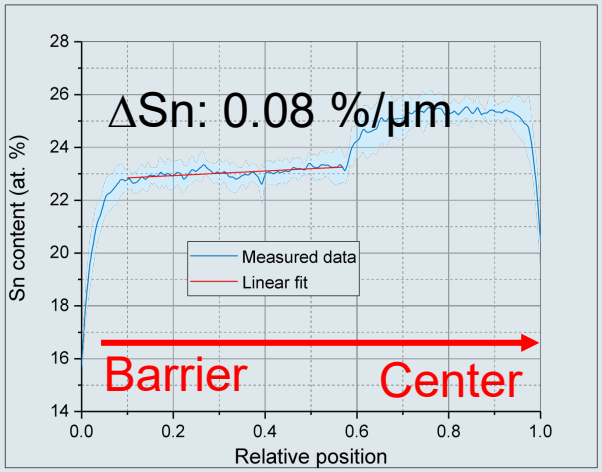


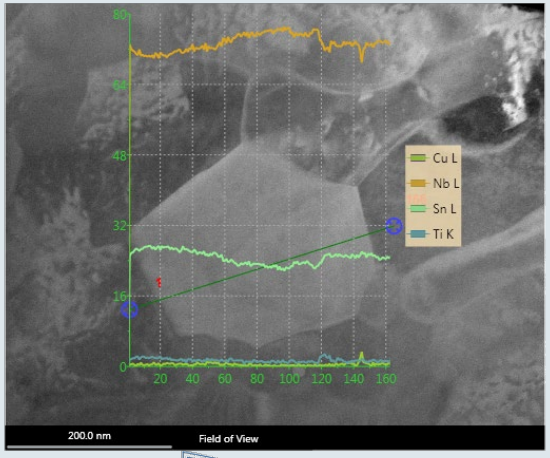

Diagrams redrawn from: M.Jewell, Thesis, (2008), UW-Madison

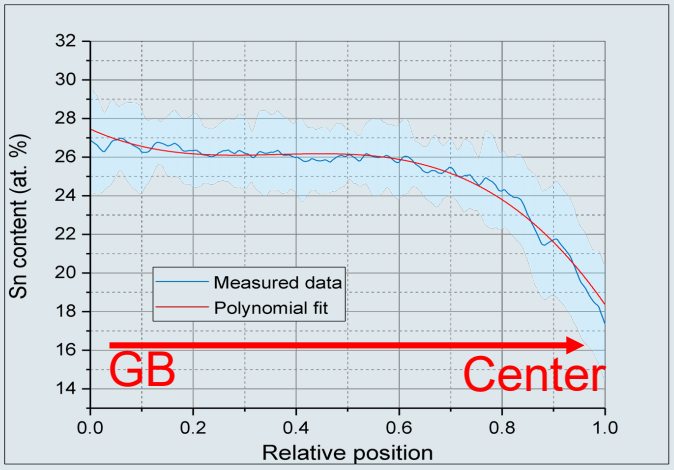
# Sn distribution within PIT-Ta

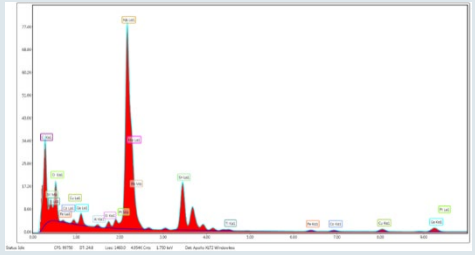


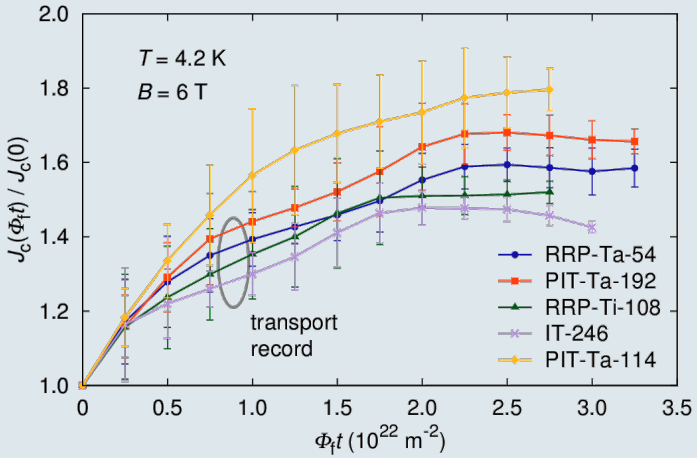



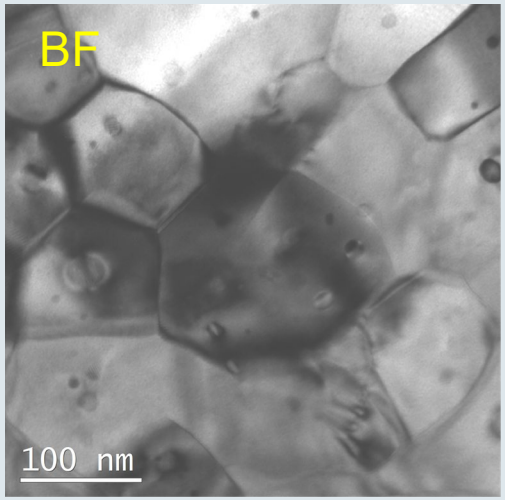



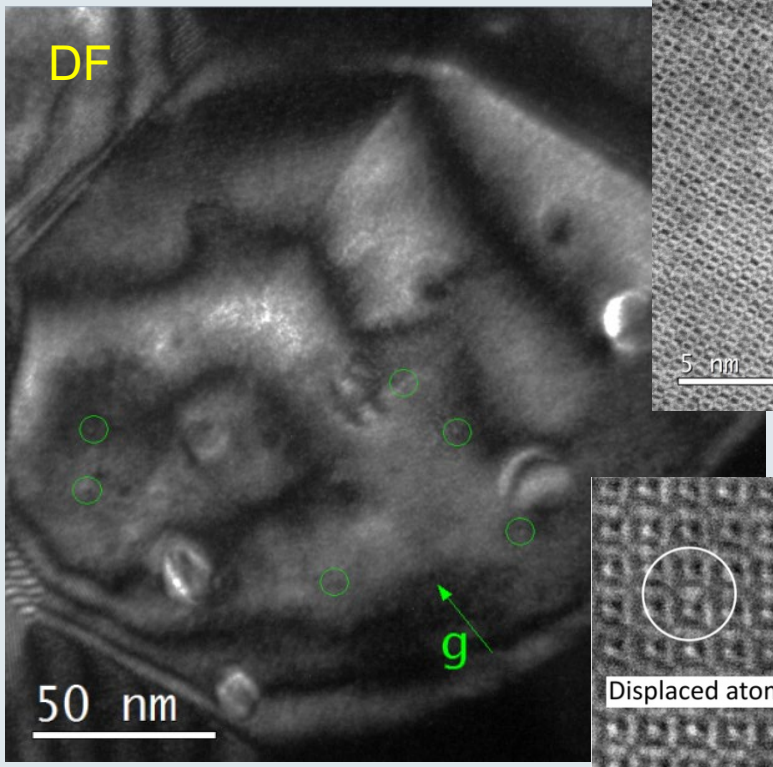



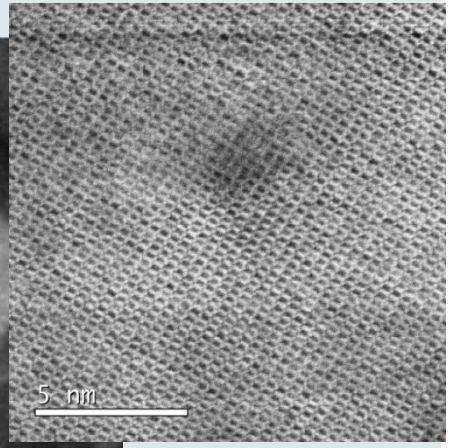
# Irradiated RRP-Ti wire

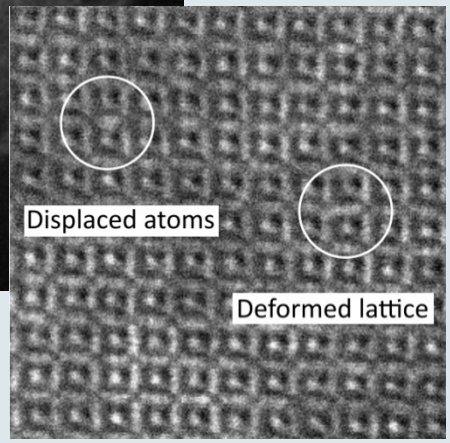
# Irradiation experiments




Formation of nanosized defects

# TI1223 for Beam Screens

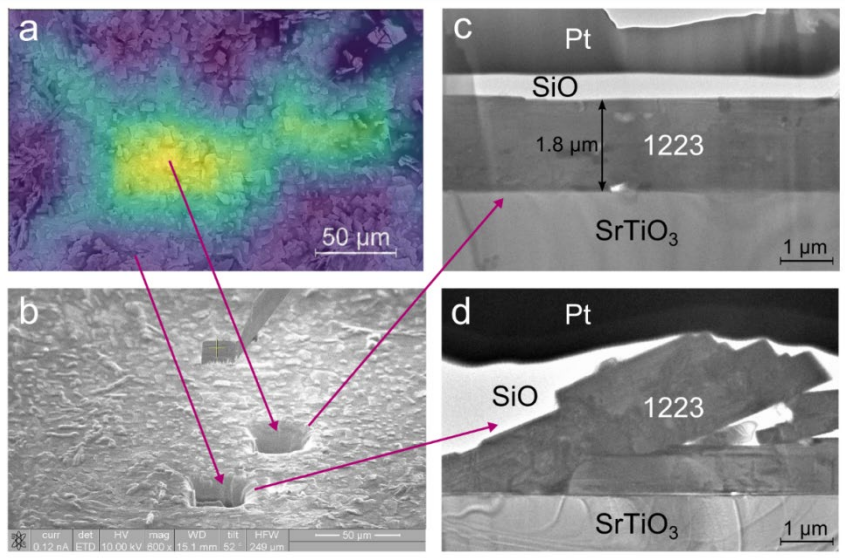
Synchrotron radiation must be absorbed at 50 K

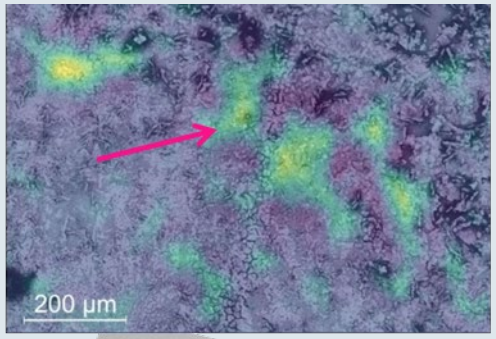
- Vacuum requirements
- Cryogenic efficiency
- Power consumption

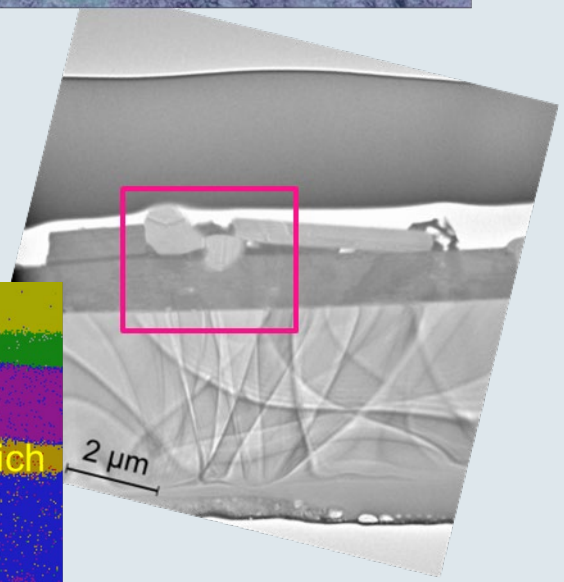
- Cu is not sufficient
- YBCo or TI based HTS are an option

- **TI-HTS produced at CNR Spin / Genova**

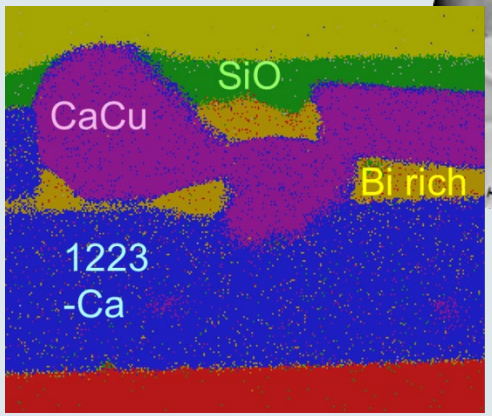
# What influences sc properties



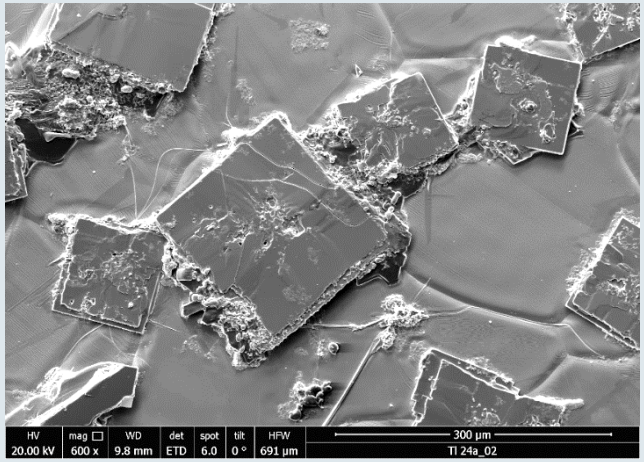



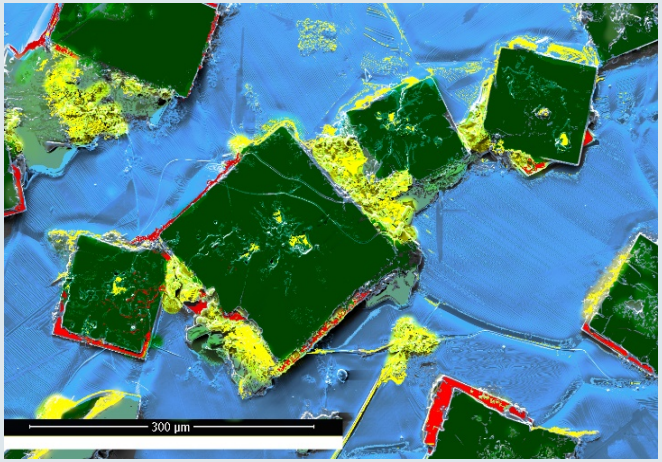




- Misagligned 1223 grains
- Impurities

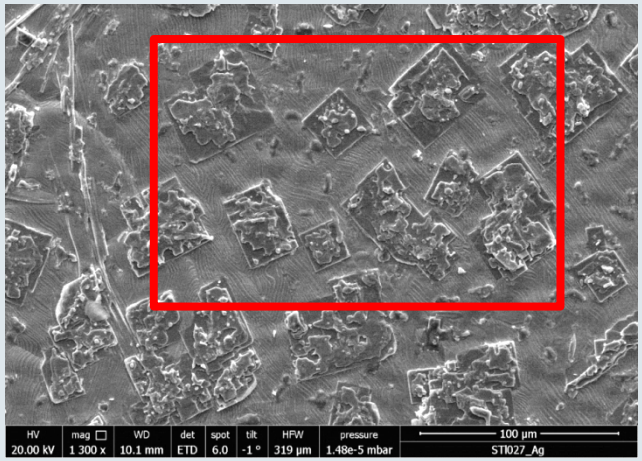


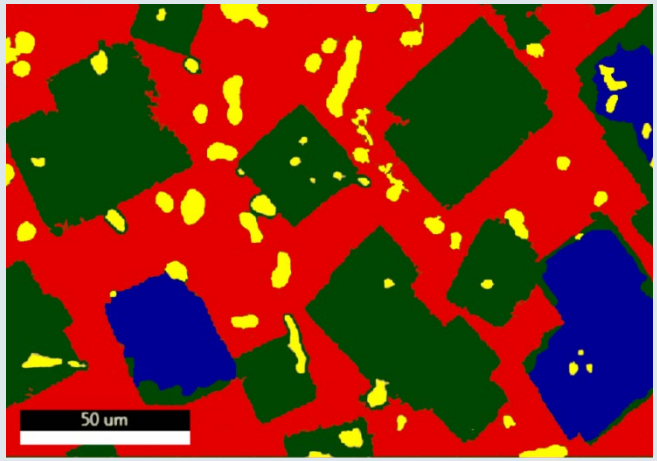
# Beam Screen Development (HTS)




Ag
Tl-1223
Tl-1212
O, Ca rich
O, Ca, Sr rich

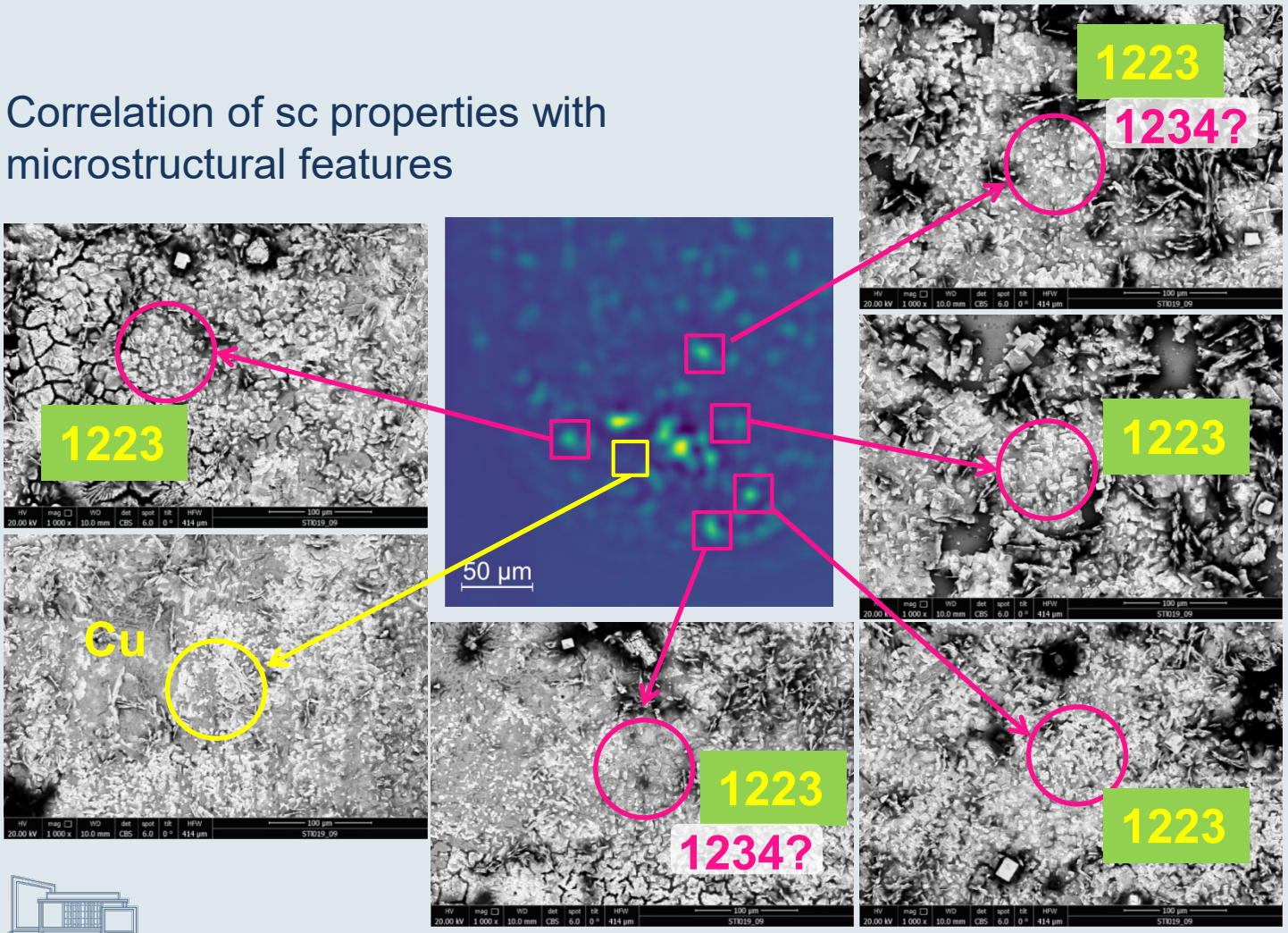



Ag
Tl-1223
O, Ca, Pb rich
Tl-1212

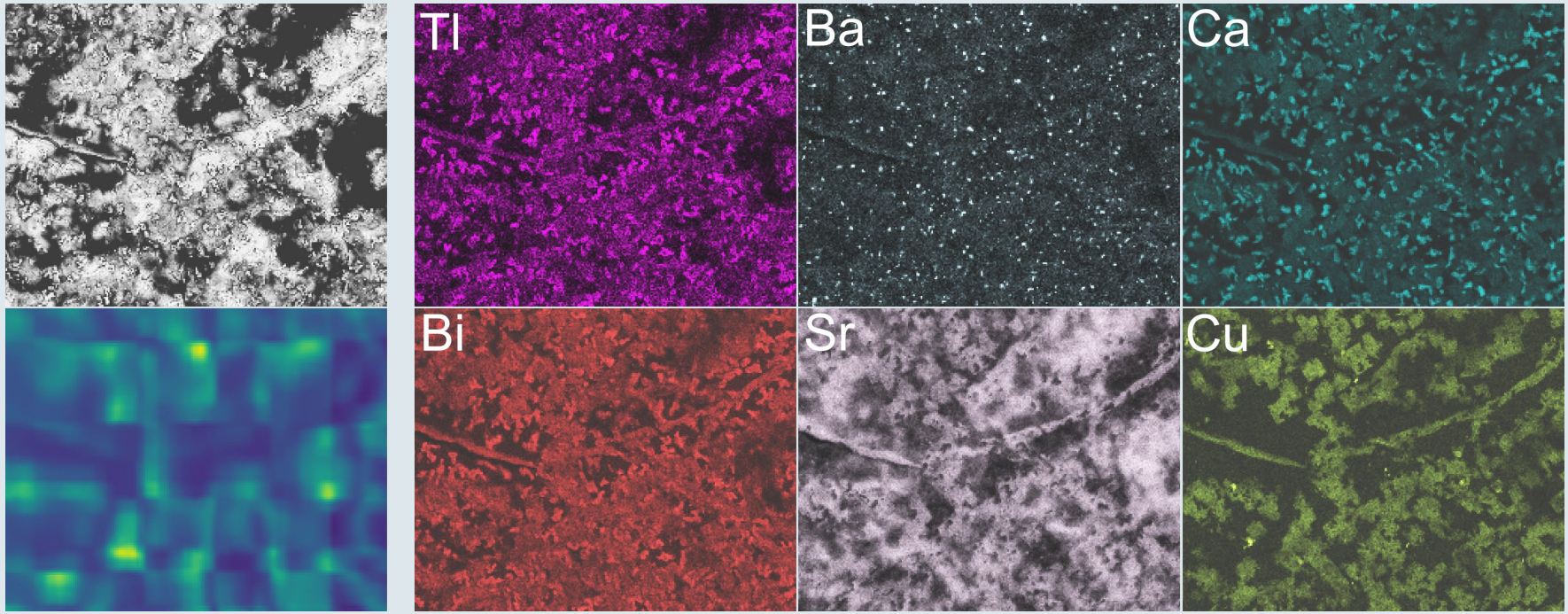
# Beam Screen Development (HTS)

Correlation of sc properties with microstructural features



# μHall: Magnetic field mapping

Comparison between remnant magnetic field and local composition of the superconductor

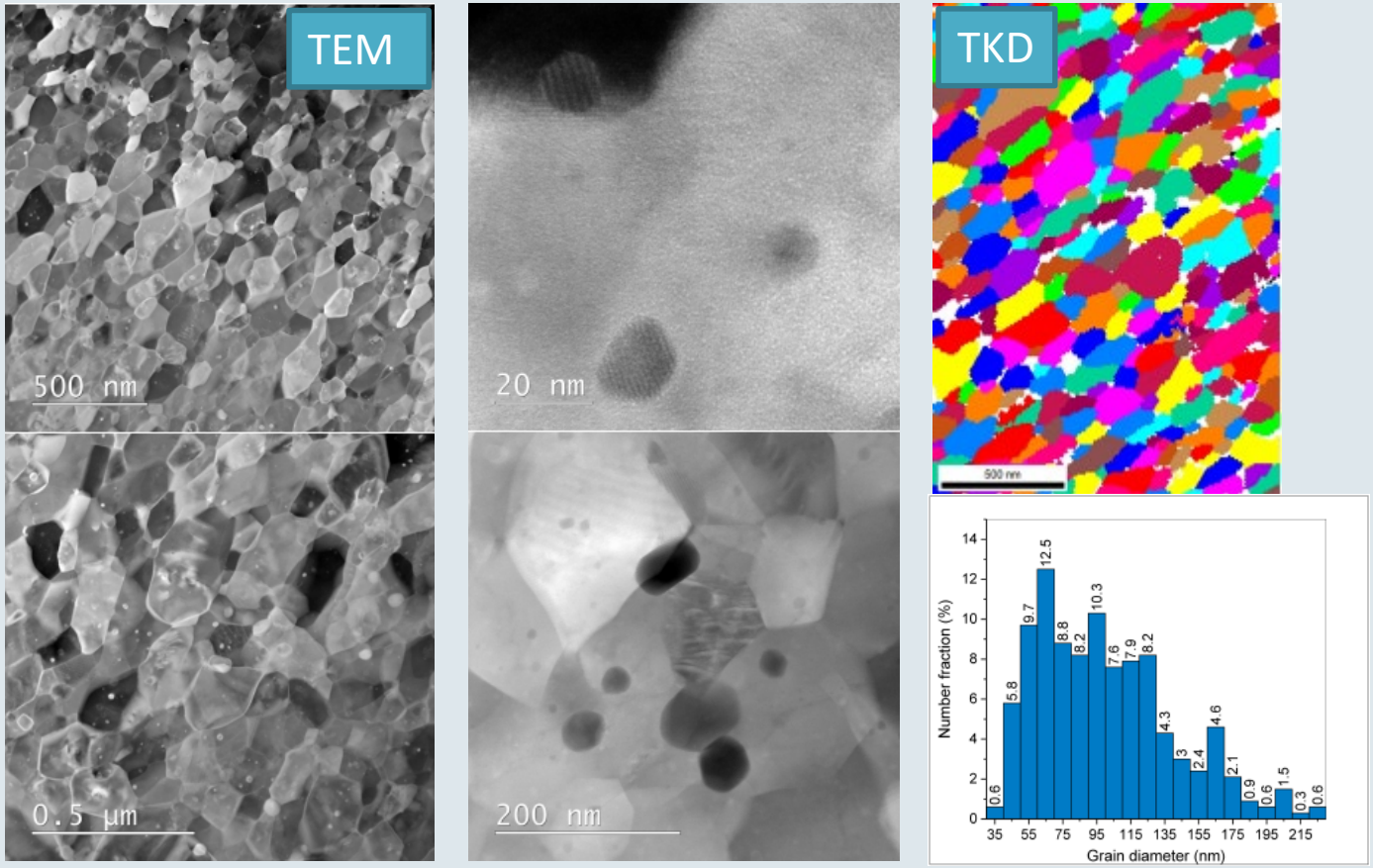


# $Nb_3Sn$ with artificial pinning

Formation of $ZrO_2$ or $HfO_2$ precipitates

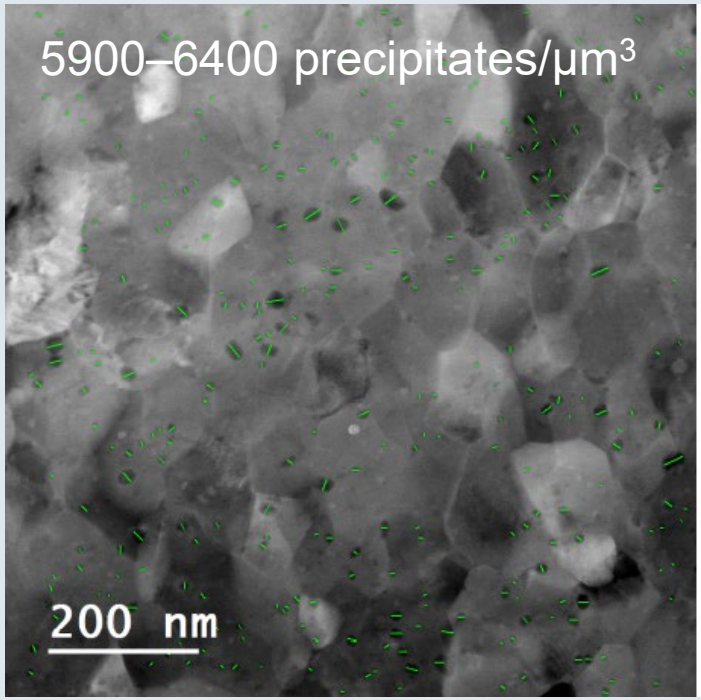
- Grain size refinement  (more grain boundaries)
- Additional pinning centers

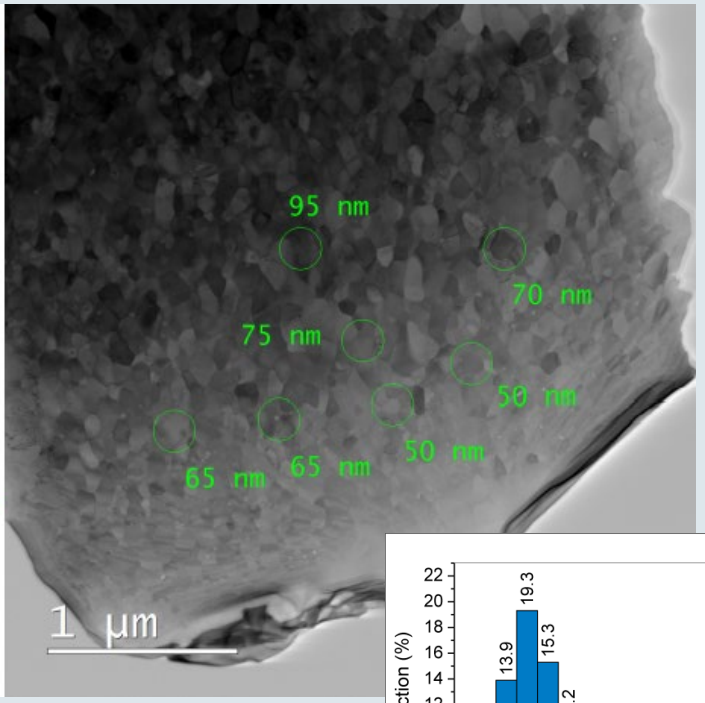
# $Nb_3Sn$ with APC

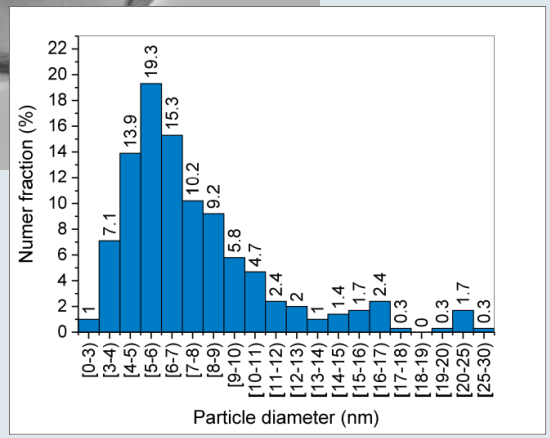



Grain refinement determined by TKD

# $Nb_3Sn$ with APC




Sample thickness determined by EELS
Estimation of APC density

# Scientific Output FCC related

2016 – 2021

- 14 Publications in Journals
- 11 Poster Presentations
- 20 Talks

- 3 PhD and 2 PhD