TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

TU Wien Contribution during FCC Study (2016-2021)

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J. Bernardi – USTEM / TU Wien

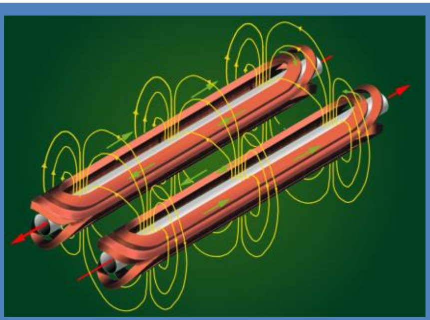
Low Temperature Physics and Superconductivity

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

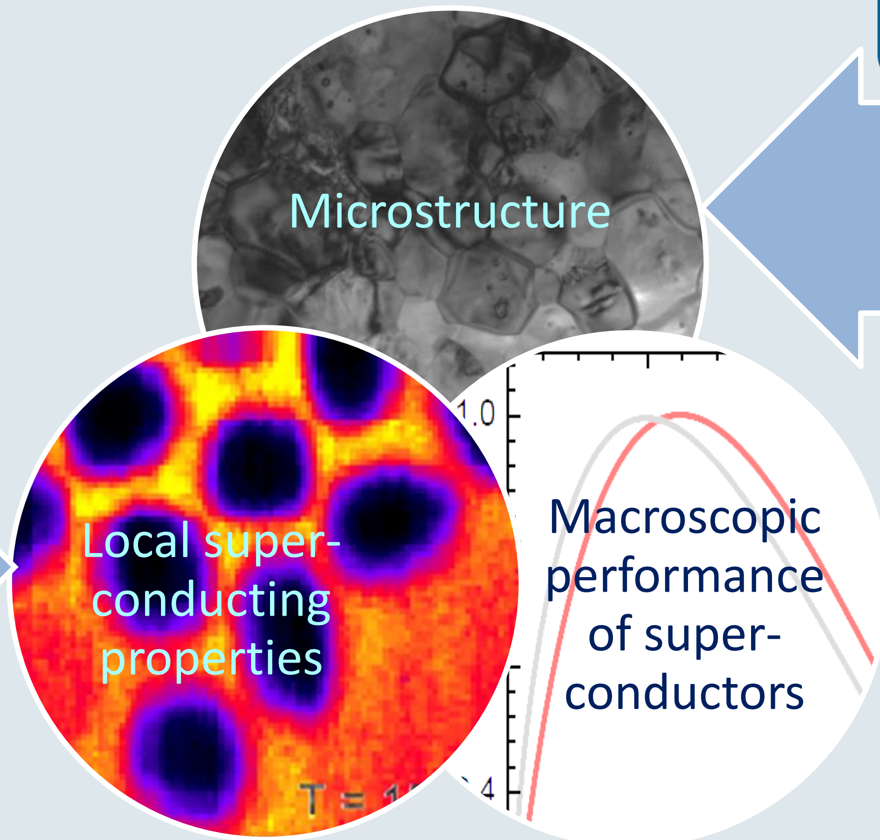
Beam Screen Development (HTS)

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

Goal of the investigation

SEM, TEM
EDX

SHPM, SQUID-
magnetometry
Irradiation

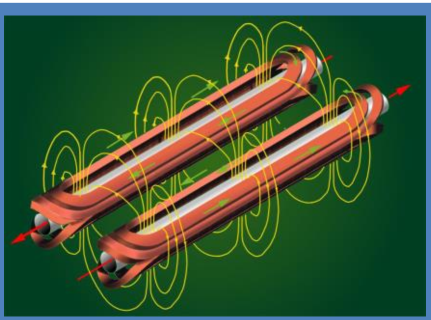


Investigations at ATI

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

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Introduction

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

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

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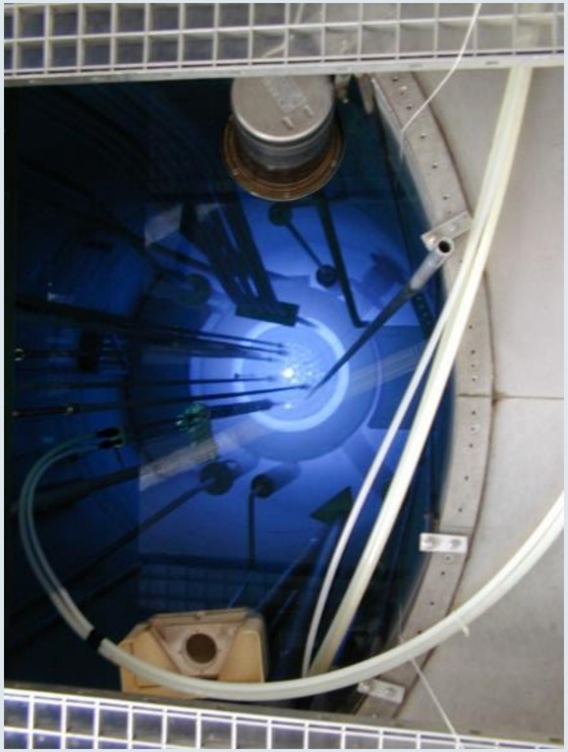
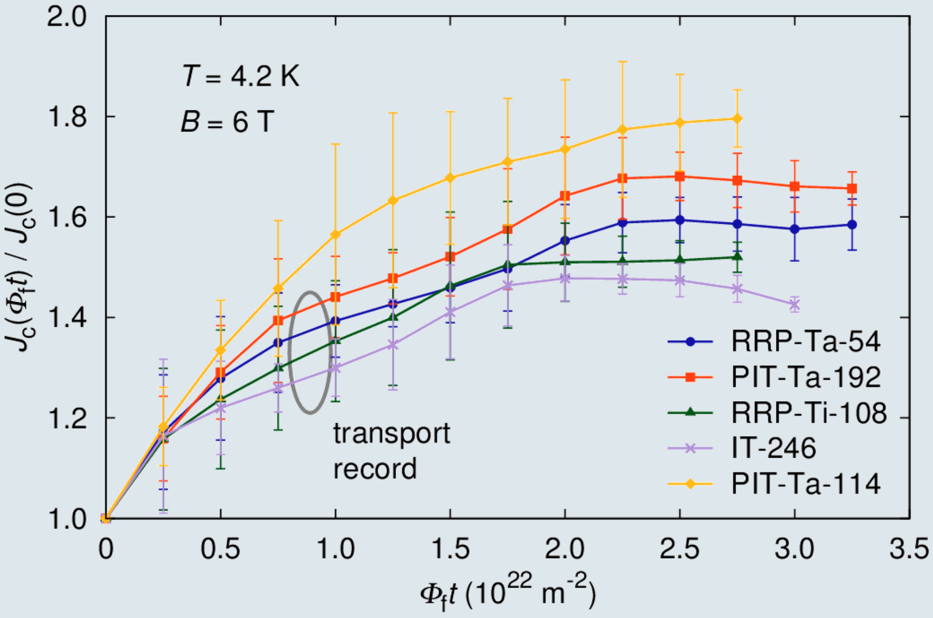
Irradiation experiments



- 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

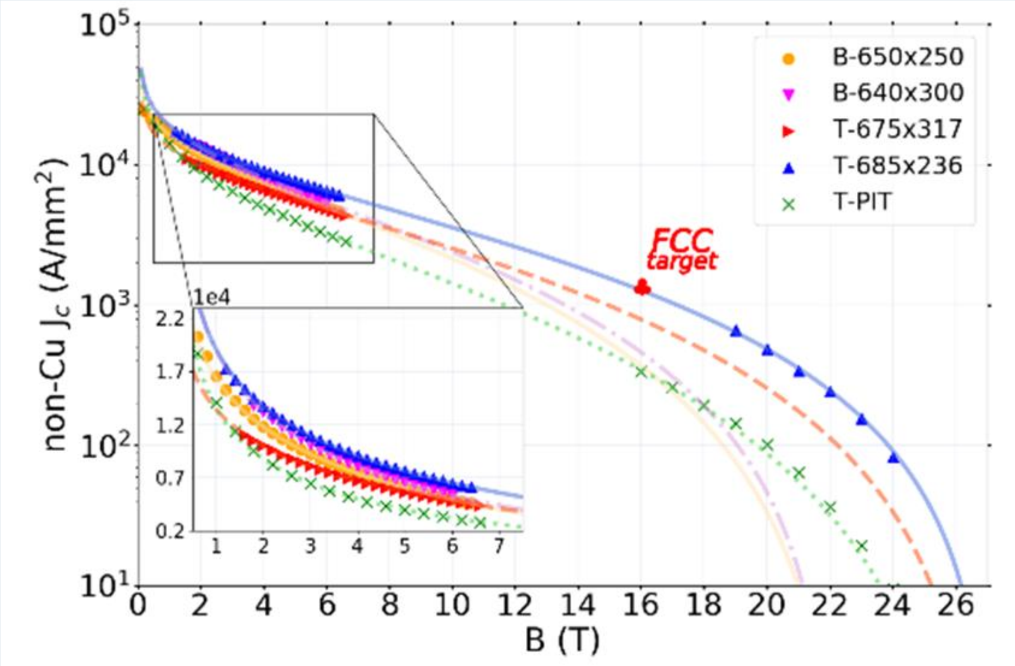
Irradiation experiments



- 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

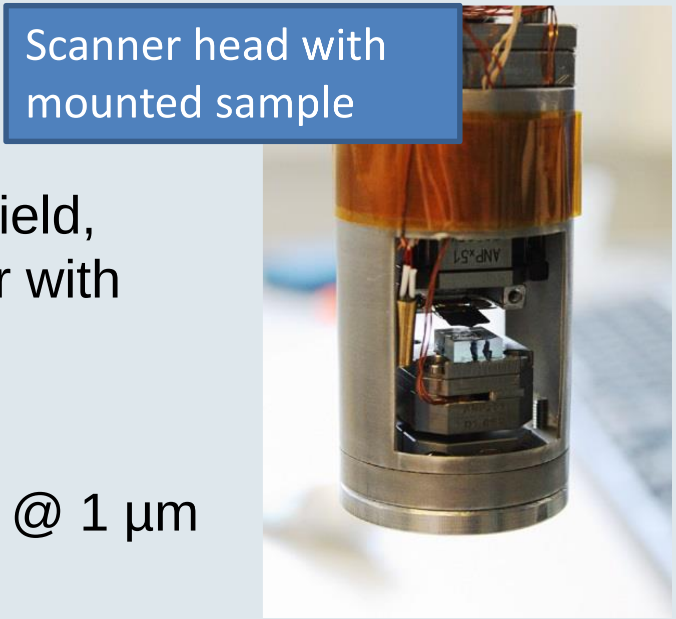
Micro Hall Scanner

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

Experiment

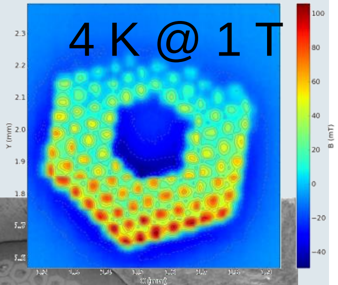
  - Field up to 8 T, range: 3 x 3 mm^2 @ 1 µm

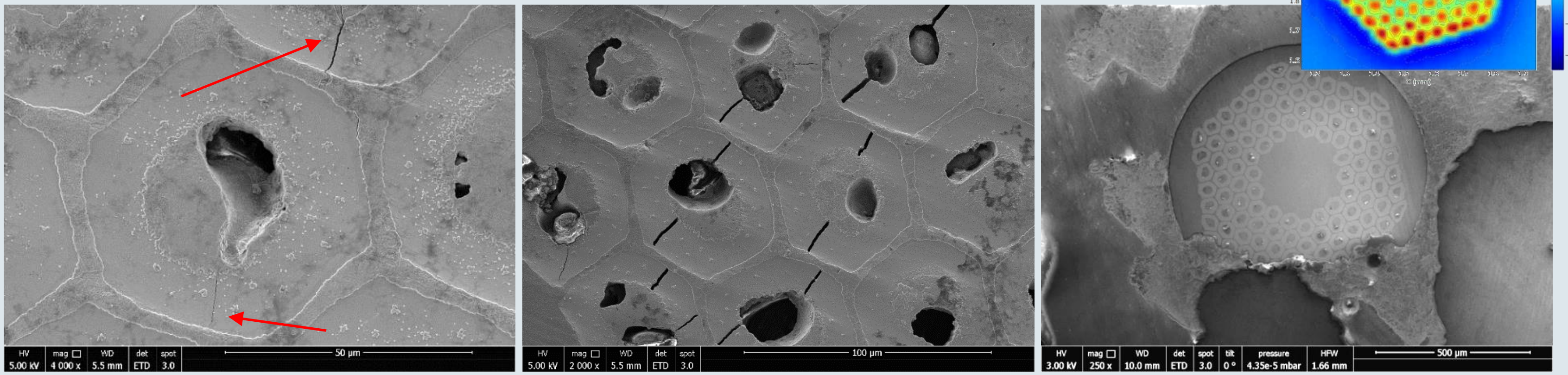
- Goal
  - Evaluating T_C gradients by scanning in the Meißner state at different temperatures
  - Assessing inhomogeneities in J_c by inversion of the Biot-Savart law



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





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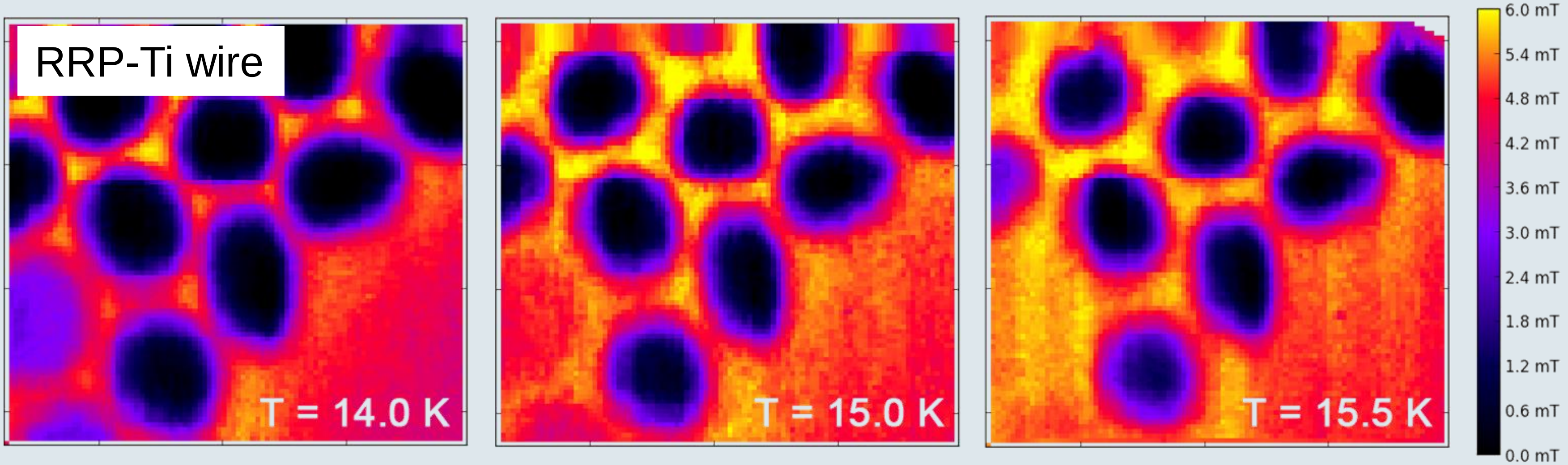
Magnetic Inhomogeneities



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

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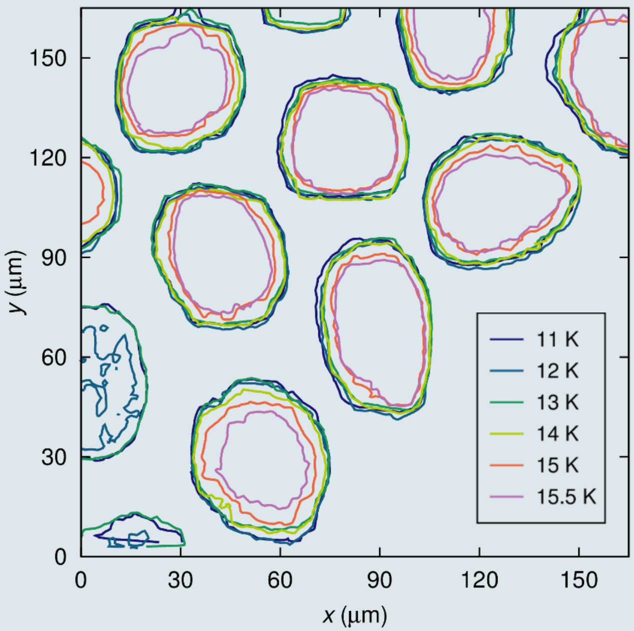
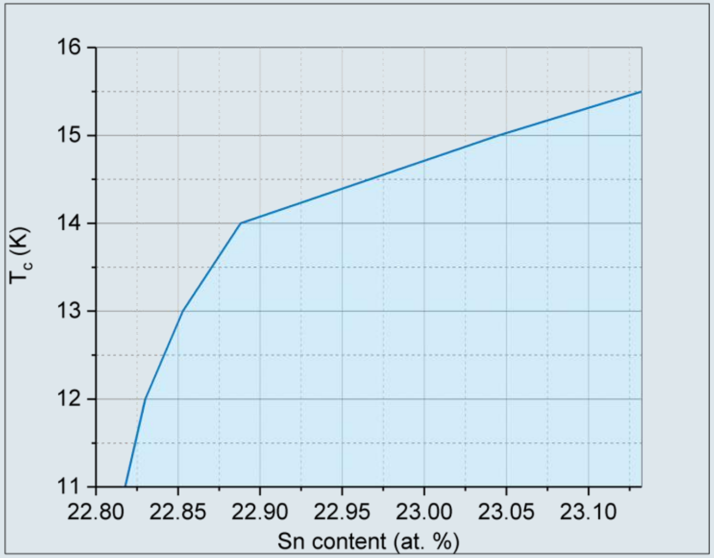
Meißner scans of RRP-Ti wire

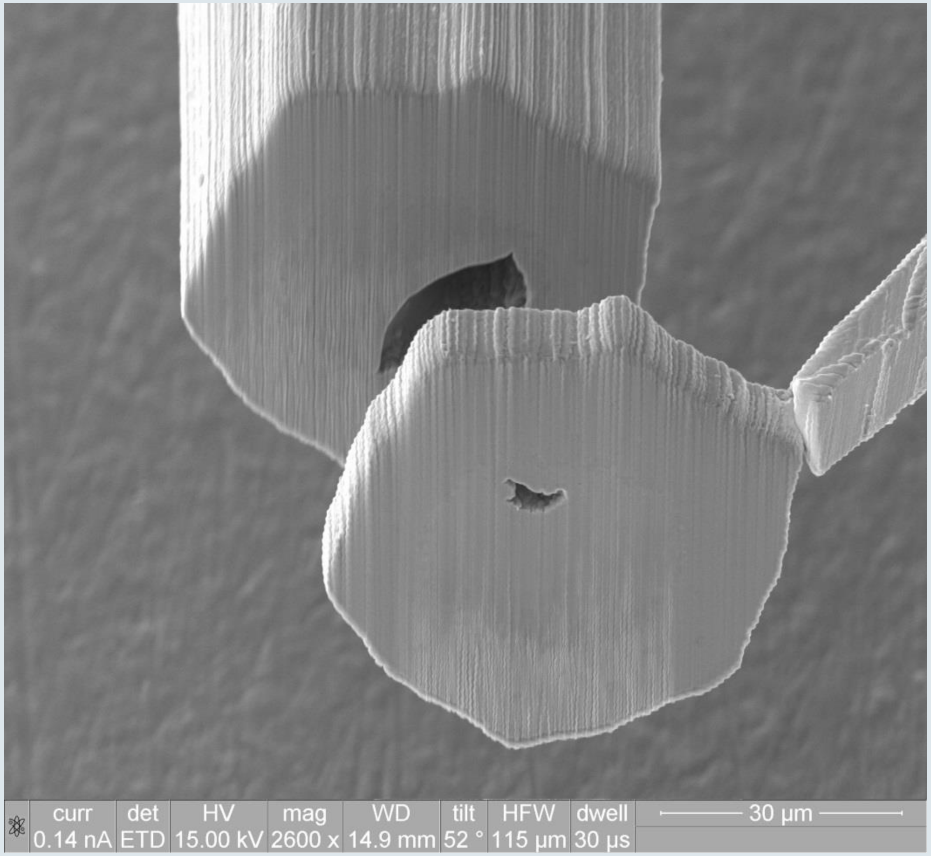




- Meißner Scans on 10 µm thin slice of RRP-Ti wire
- Screening radius depends on temperature due to gradient in Sn content
- Dependency of T_C from the Sn content
- Small change in Sn content heavily impacts T_C

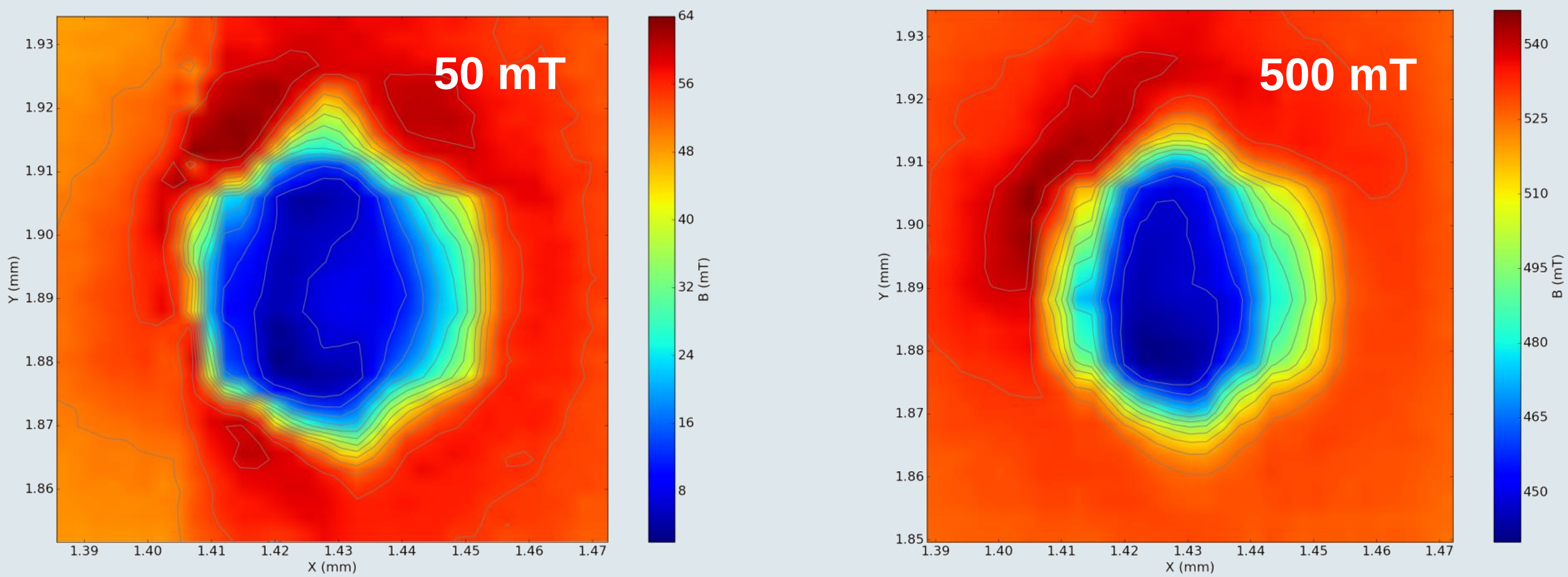
Sample Preparation of subelement

Preparing thin slices of etched subelements using FIB for SHPM measurements



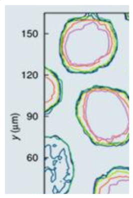
Magnetic Inhomogeneities

Hall scans of subelement at 5 K

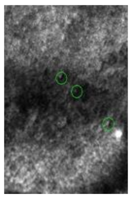


- FIB preparation of individual single subelements is feasible
- For detection of inhomogeneities of J_C Hall scans at higher applied fields will be performed

Investigations at USTEM

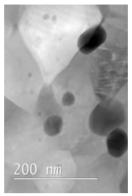


Composition gradients in Nb_3Sn wires

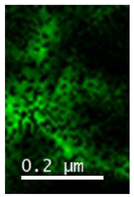


Irradiation Effects

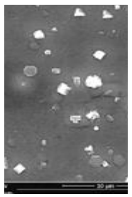
Tl1223 for beam screens



Artificial pinning centers (APC)



Carbon-Cluster in MgB_2



Coated conductors YBCO

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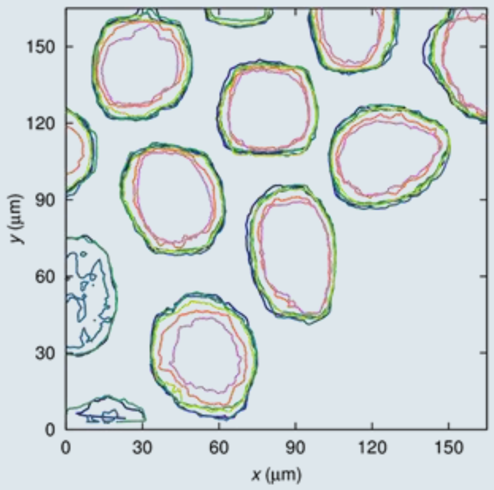
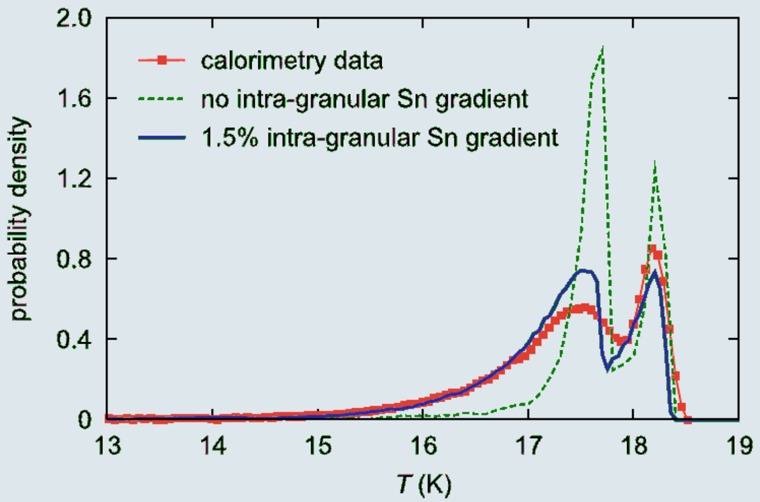
Composition Gradients

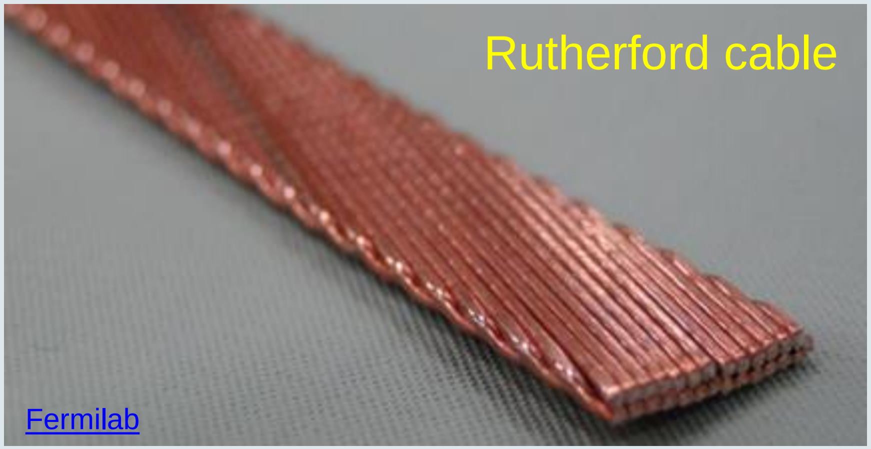


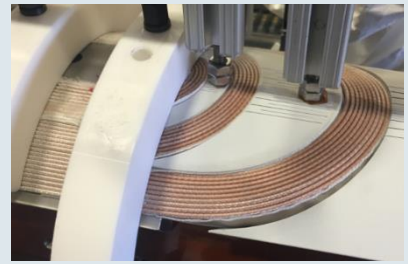


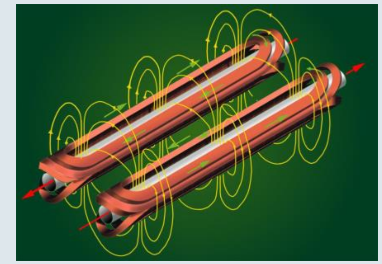
Thomas Baumgartner et al, SUST 30, (2017)

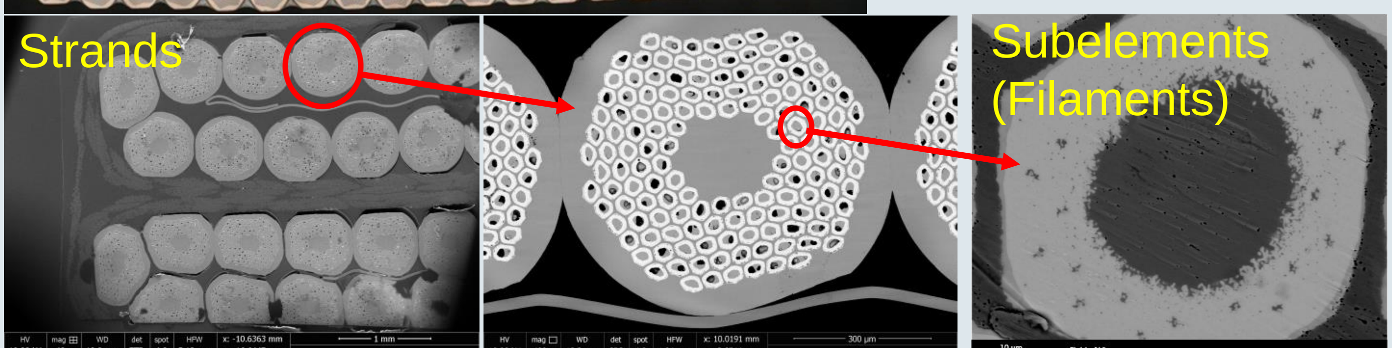
- Magnetometry and calorimetry lead to different distribution functions
- Caused by Sn distribution within individual grains

Nb_3Sn Conductor R&D

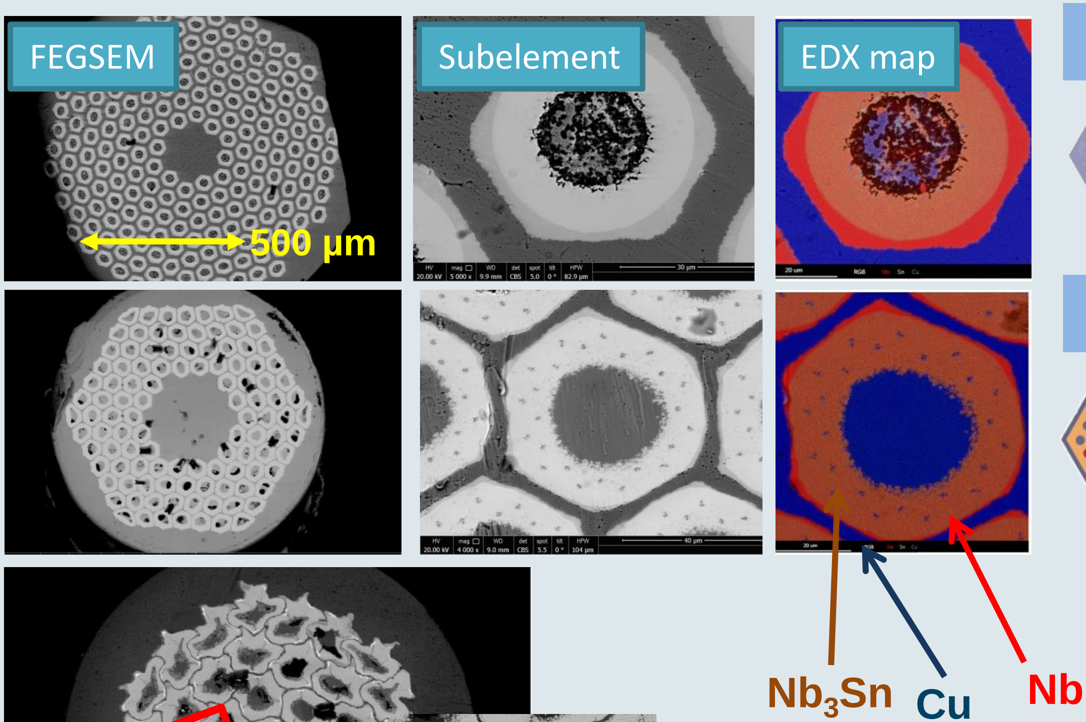


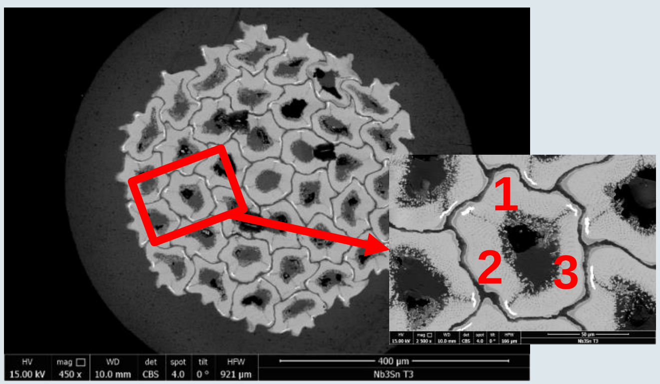






Investigated Nb_3Sn wires

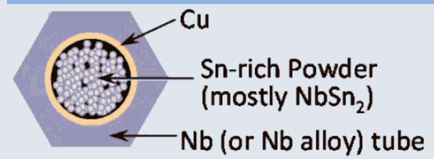




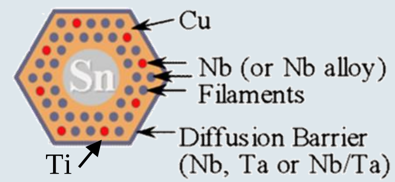
Distributed Nb + Ta

Clustered layout

PIT-Ta

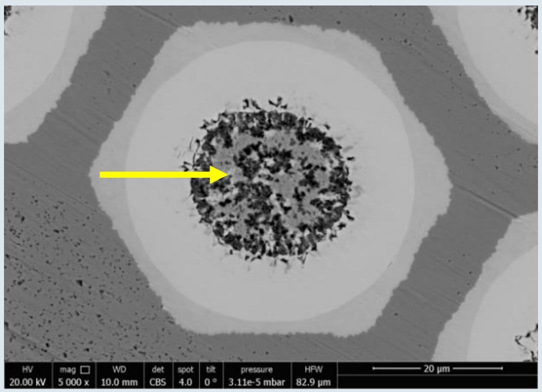


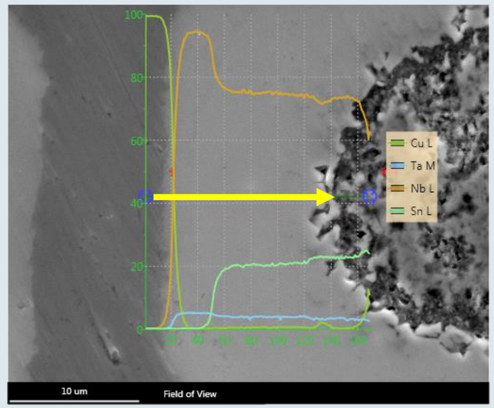
Internal Sn–Ti RRP

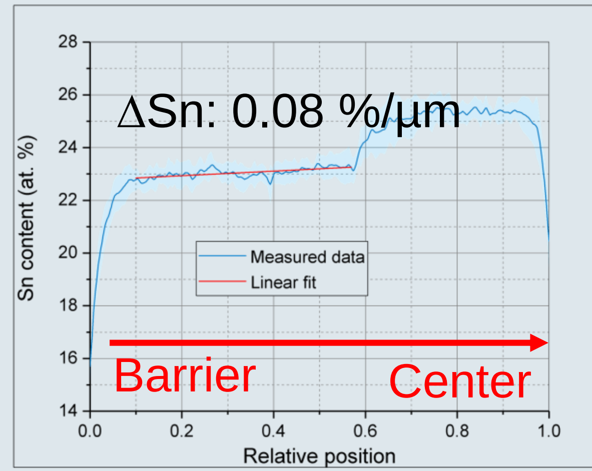


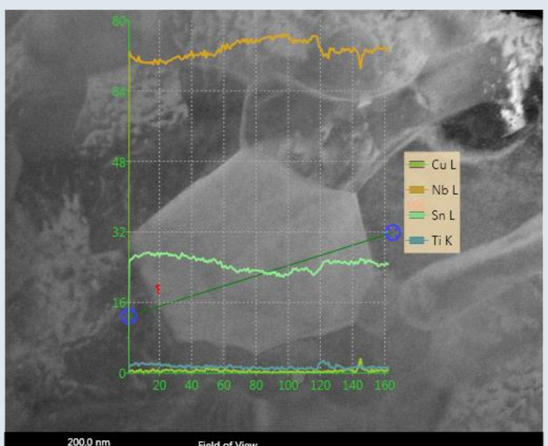
Diagrams redrawn from: M.Jewell, Thesis, (2008), UW-Madison

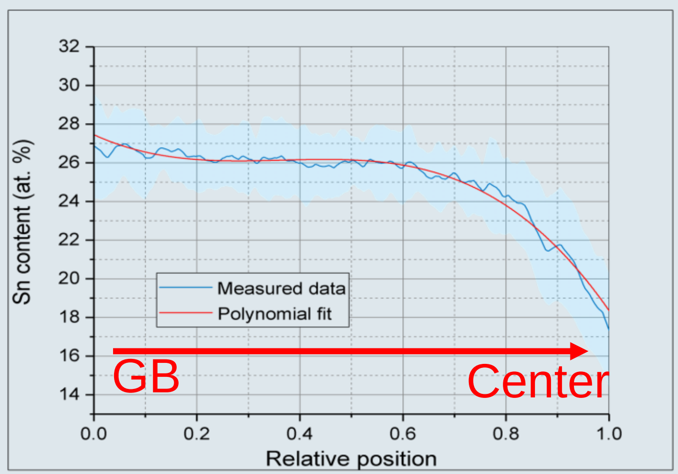
Sn distribution within PIT-Ta

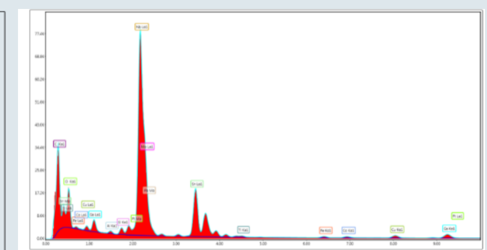






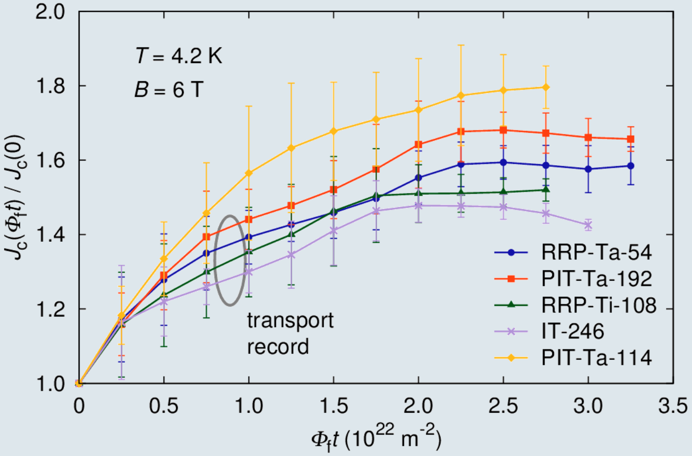


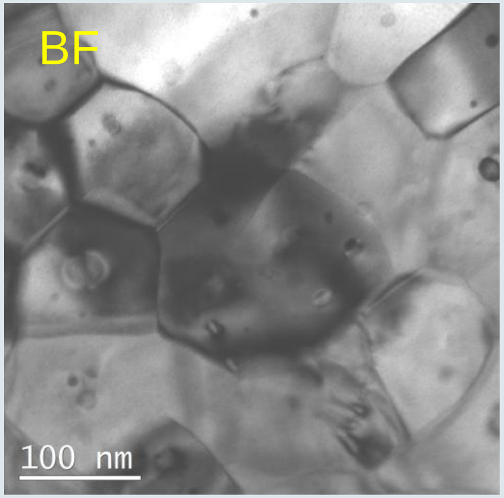


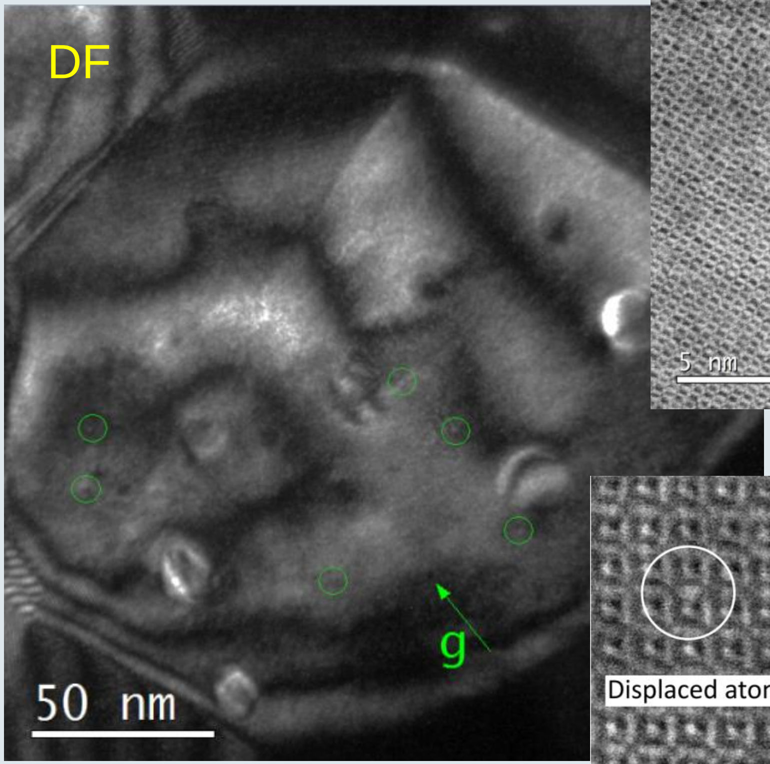


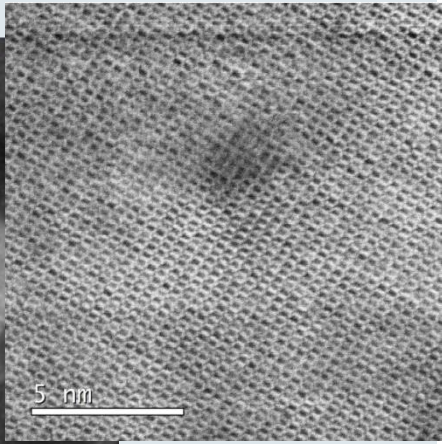
Irradiated RRP-Ti wire

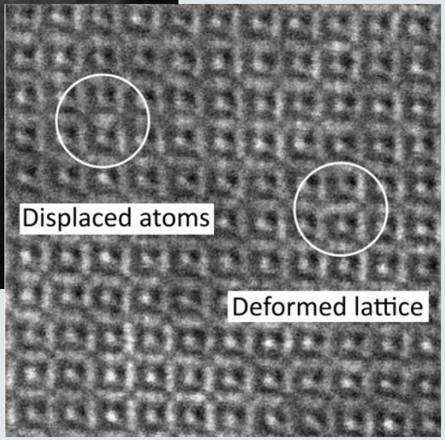
Irradiation experiments











Formation of nanosized defects

Tl1223 for Beam Screens

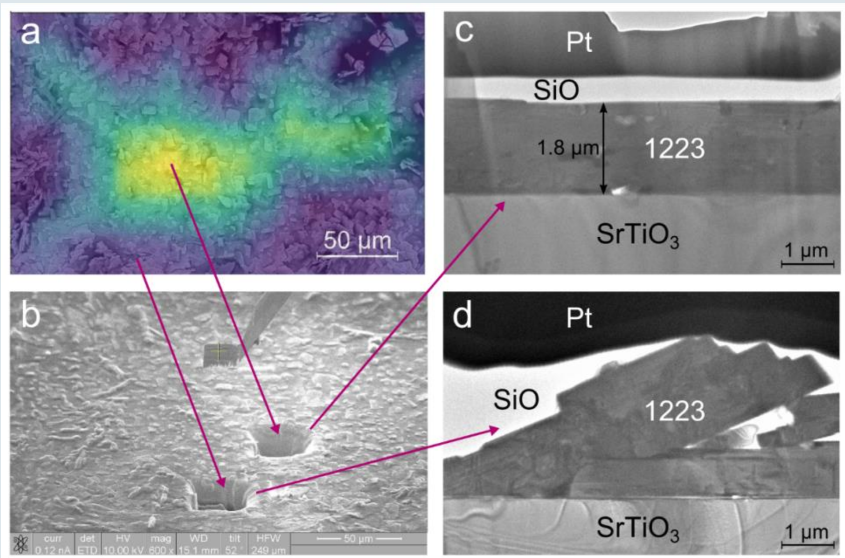
Synchrotron radiation must be absorbed at 50 K

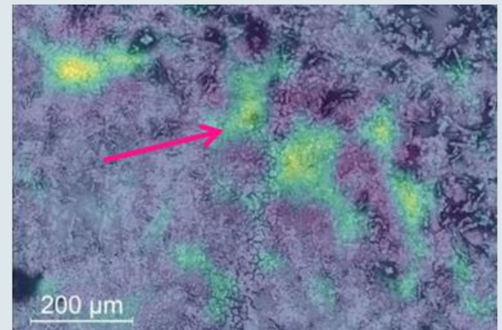
- Vacuum requirements
- Cryogenic efficiency
- Power consumption

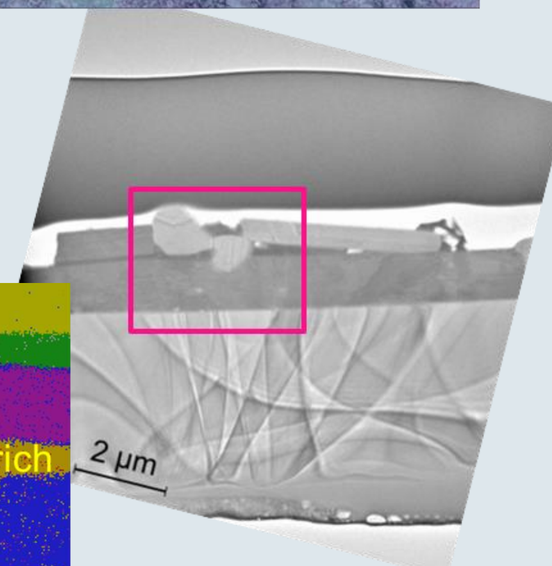
- Cu is not sufficient
- YBCo or Tl based HTS are an option

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

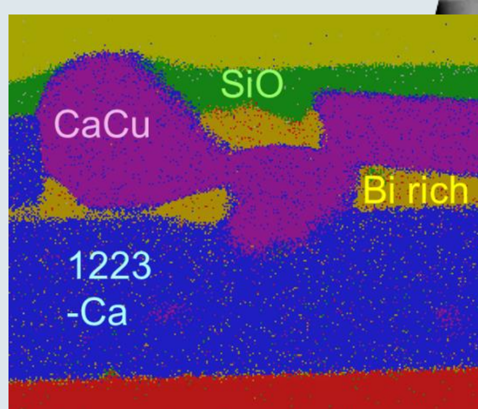
What influences sc properties



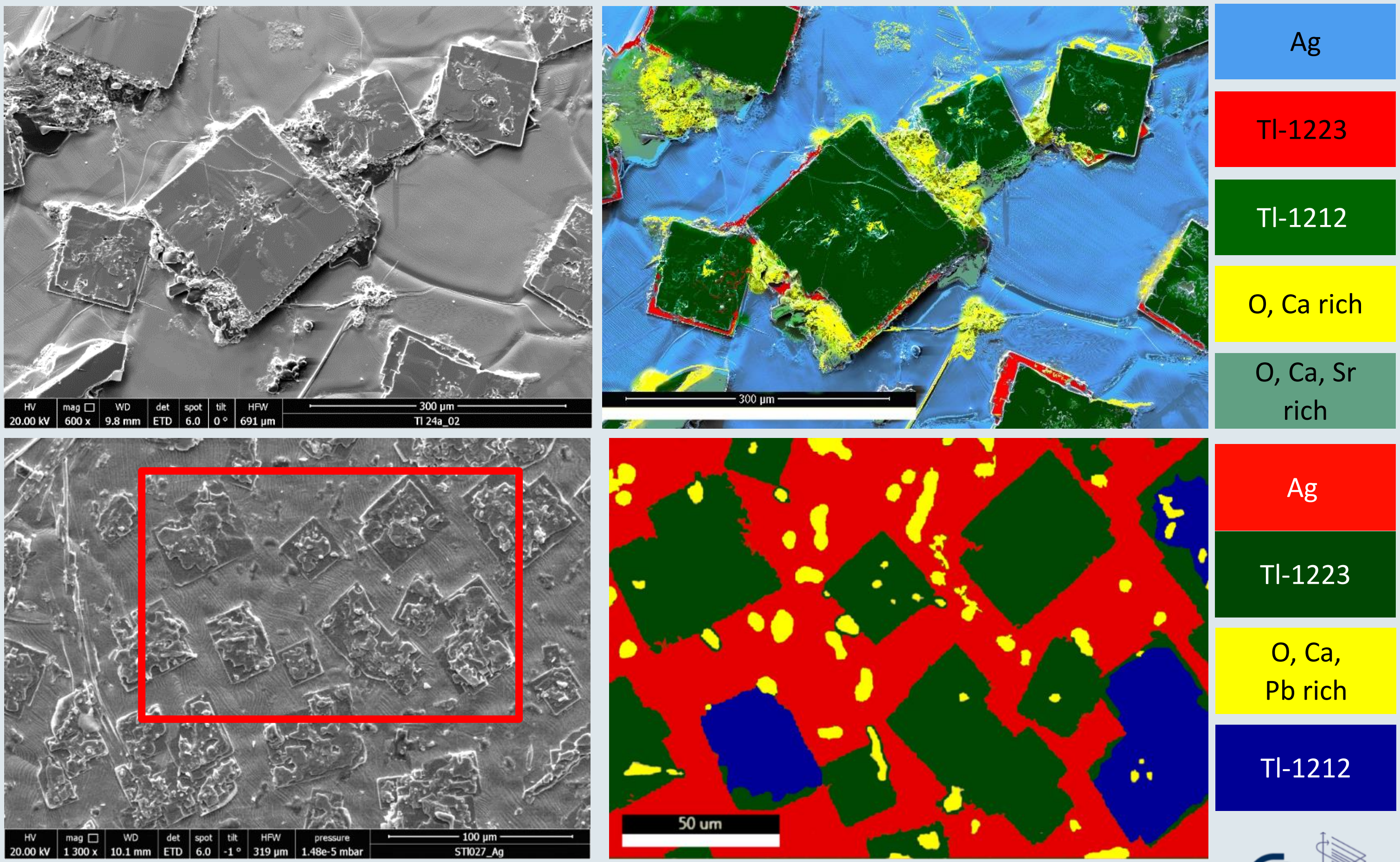




- Misagligned 1223 grains
- Impurities

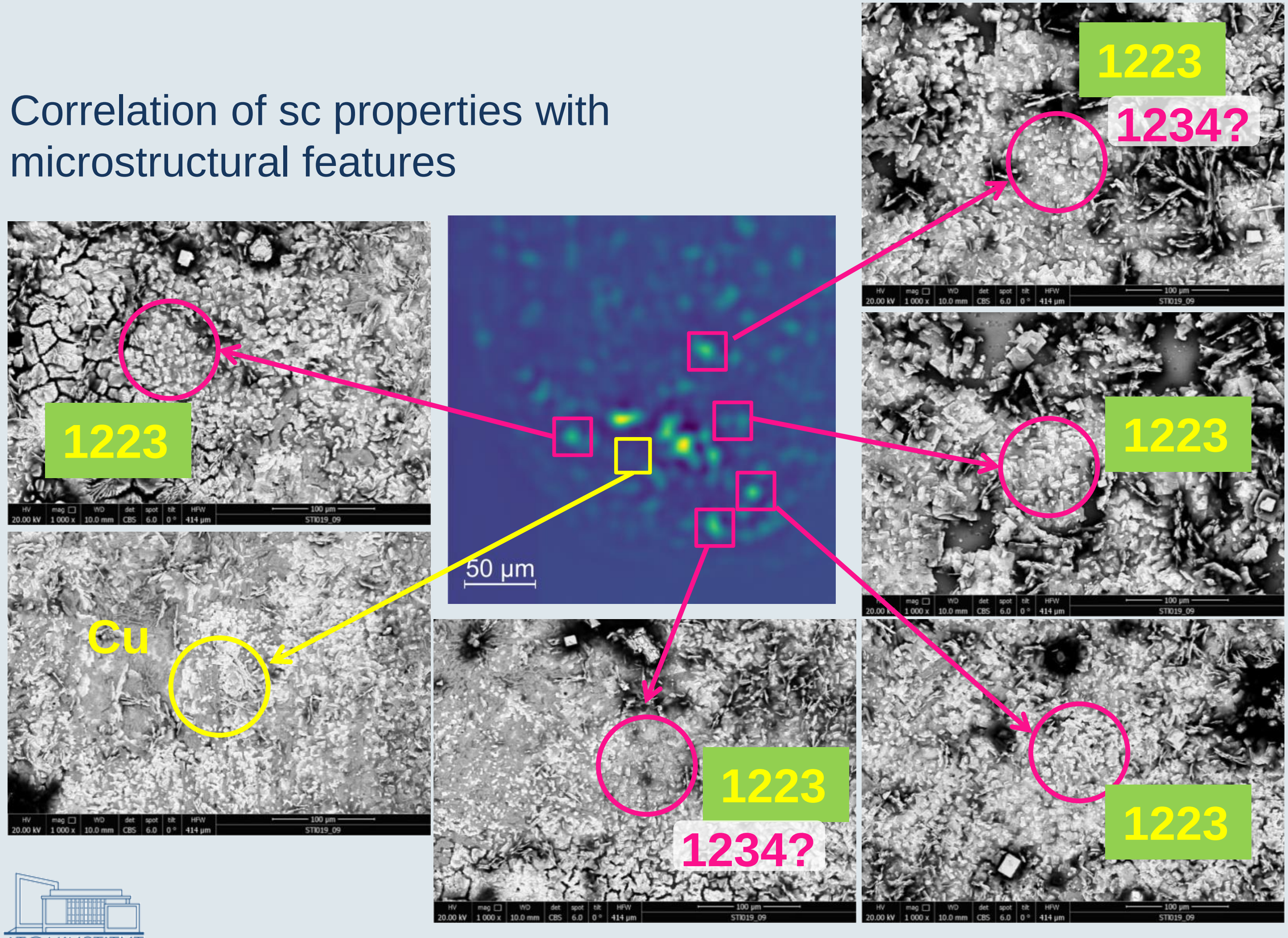


Beam Screen Development (HTS)



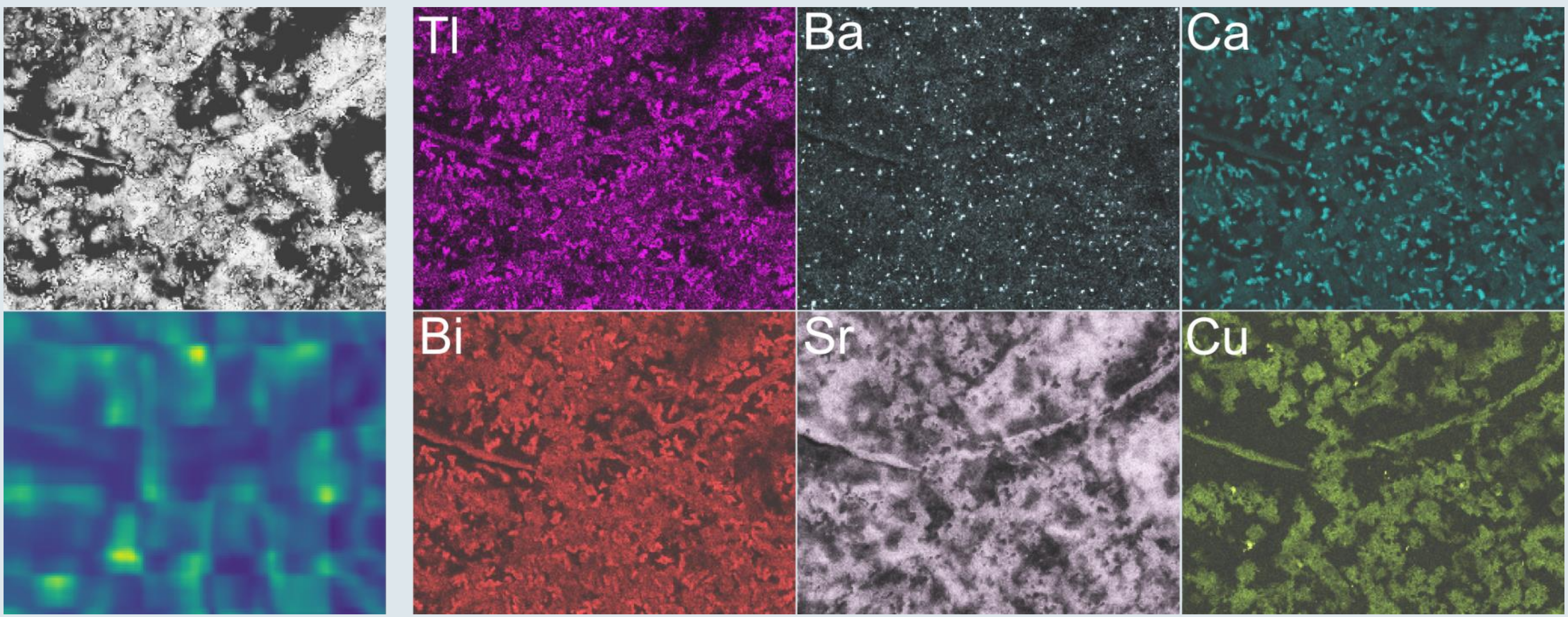
Beam Screen Development (HTS)

Correlation of sc properties with microstructural features



µHall: Magnetic field mapping

Comparison between remnant magnetic field and local composition of the superconductor

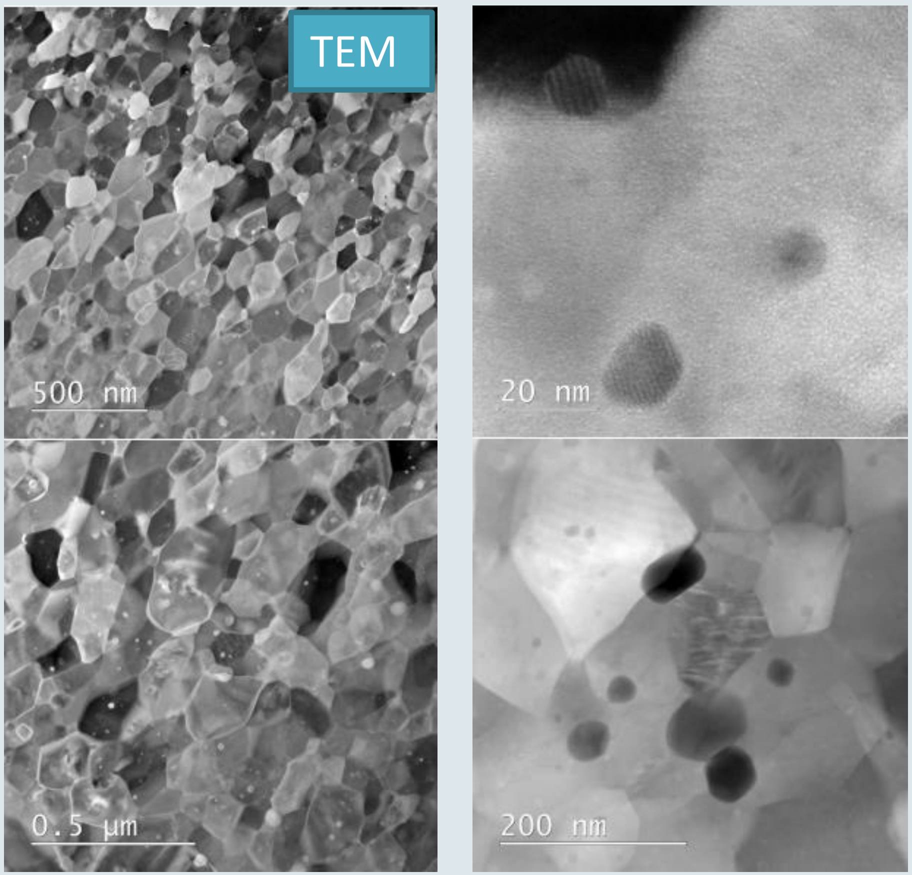


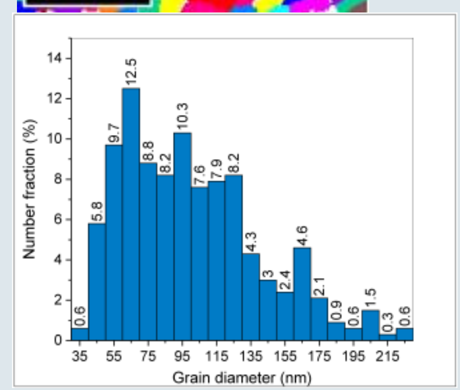
Nb_3Sn with artificial pinning

Formation of ZrO_2 or HfO_2 precipitates

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

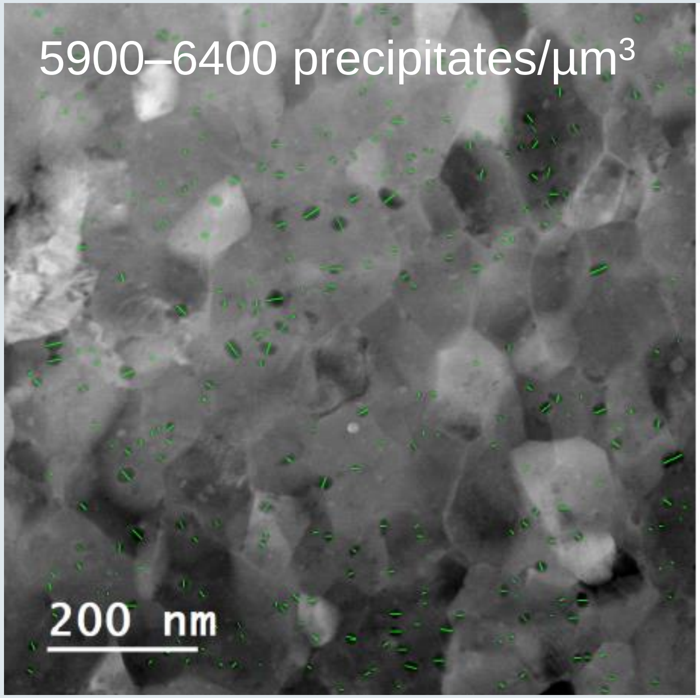
Nb_3Sn with APC

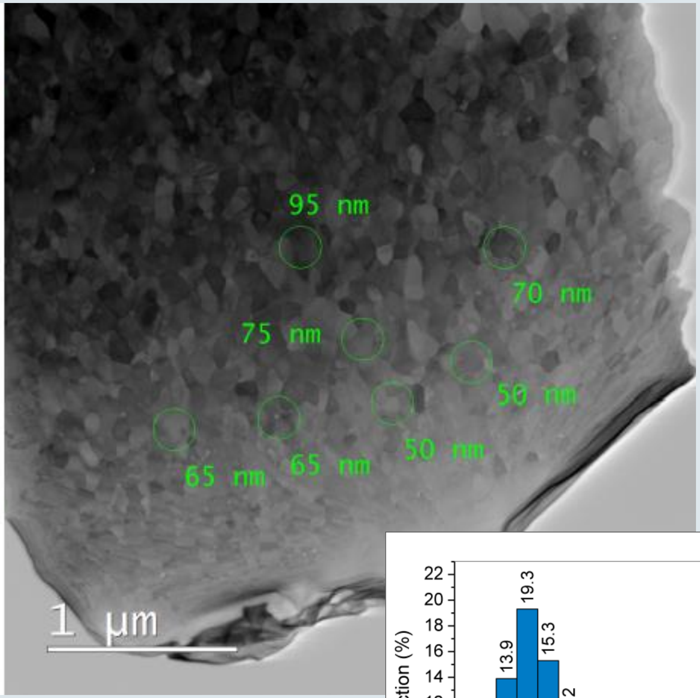


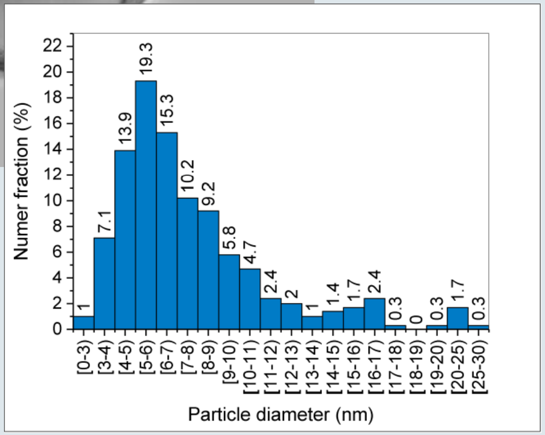


Grain refinement determined by TKD

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 EASITrain