Universität Konstanz

FIB nanotomography examination of superconducting wires

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Motivation

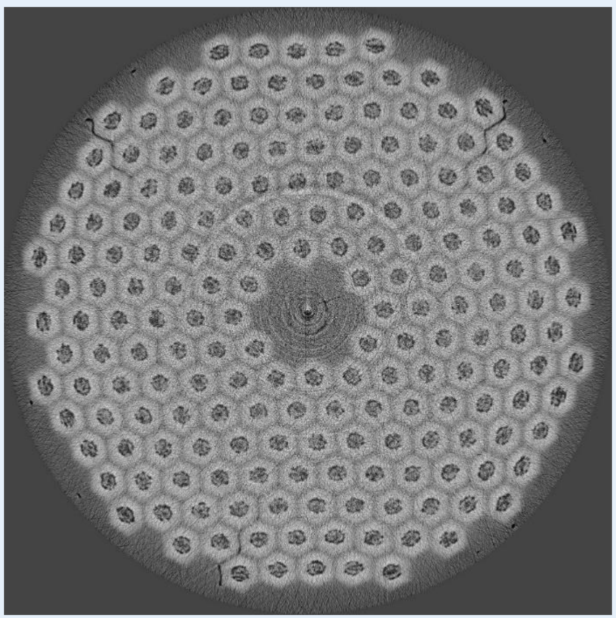
- The presence of porosity in superconductors produced by powder-in-tube (PIT) technology is unavoidable
- Porosity generally reduces the useful superconductor volume in the composite
- If porosity is distributed inside the superconducting phase, like in Bi-2223, Bi-2212 and MgB_2, it can block the supercurrent.

A better understanding of the porosity formation and redistribution can help to optimise the processing procedures in order to increase the critical current density.

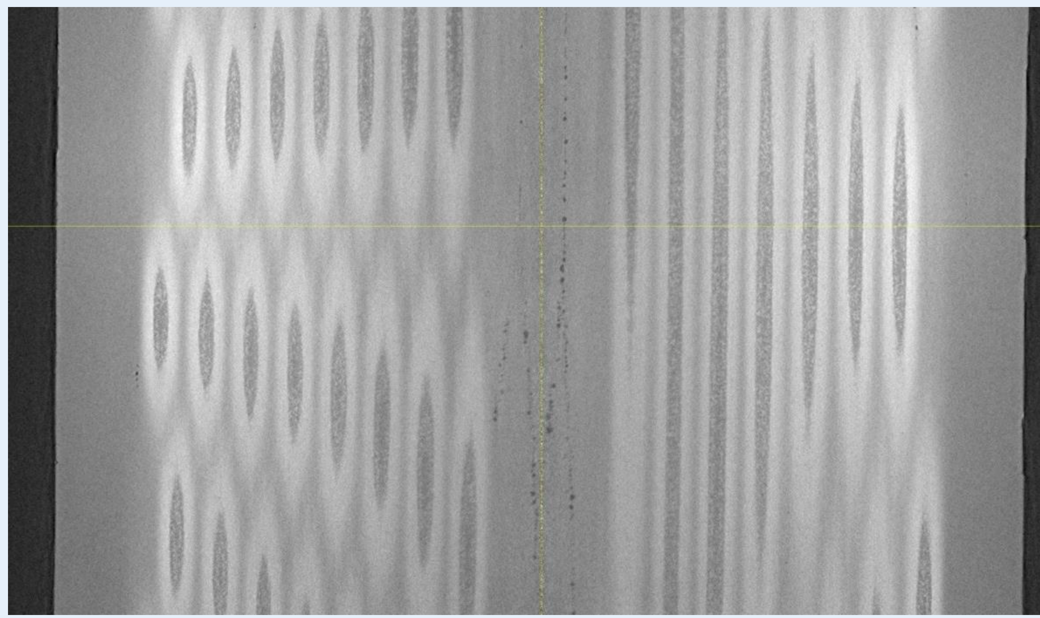
μ-CT of a PIT-type Nb_3Sn wire

The spatial resolution of μ-CT is not sufficient to resolve the porosity in a PIT-type Nb_3Sn wire

(a)

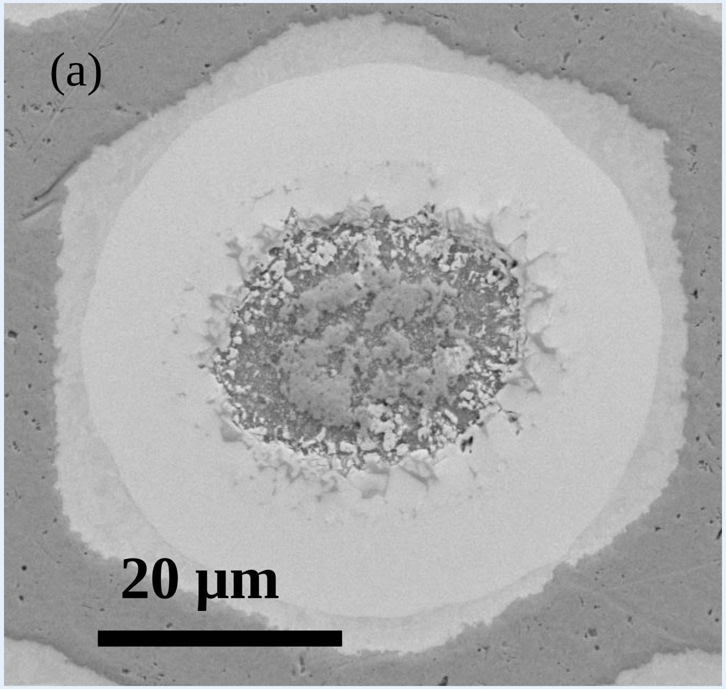


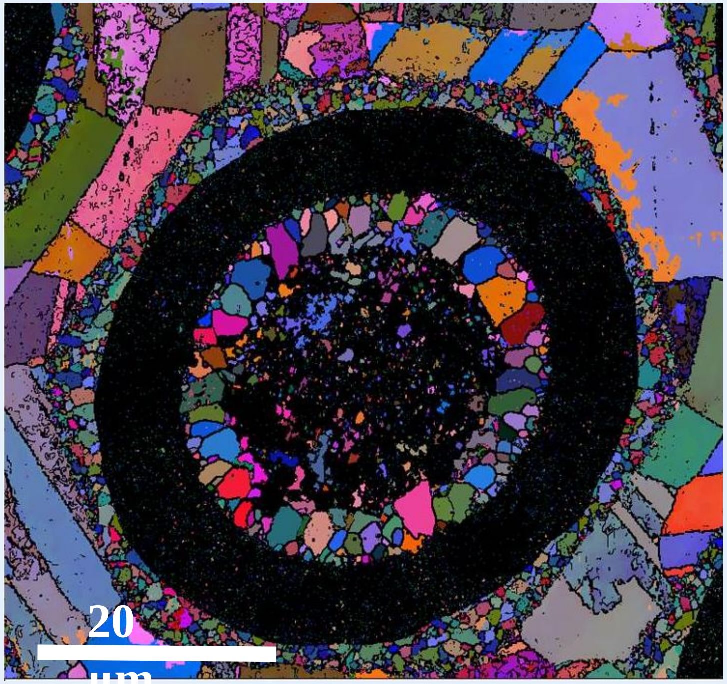
(b)



(a) Transverse and (b) longitudinal μ-CT cross section of an entire PIT Nb_3Sn wire (Ø=1.25 mm). Courtesy A. Rack, ESRF ID19.

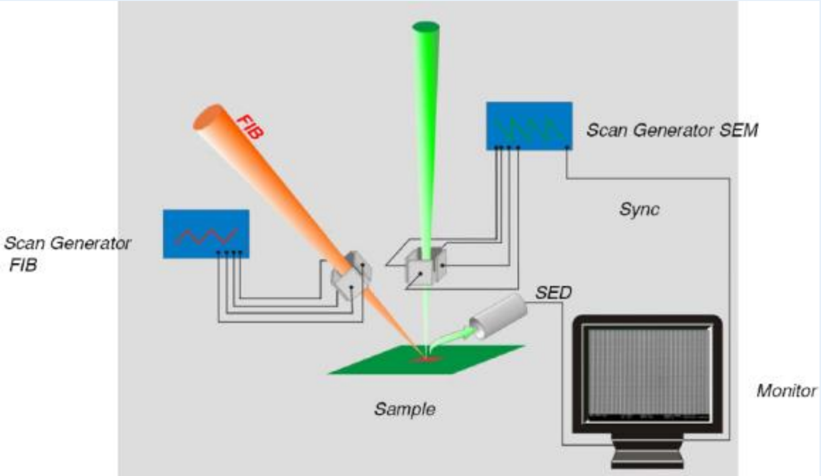
Conventional metallographic cross sections





Metallographic cross sections of a Nb_3Sn filament prepared by mechanical grinding and polishing. (a) Backscatter electron (BE) and (b) Electron Backscatter Diffraction (EBSD) contrast. Courtesy P. Alknes, CERN.

Focused Ion Beam



Zeiss Company

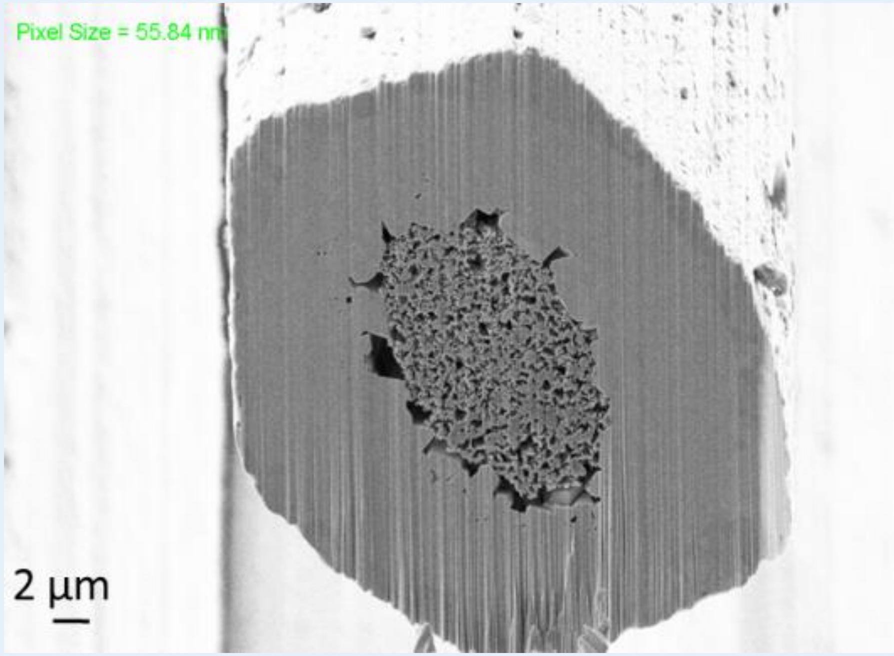
Zeiss Neon EsB

Incorporates:

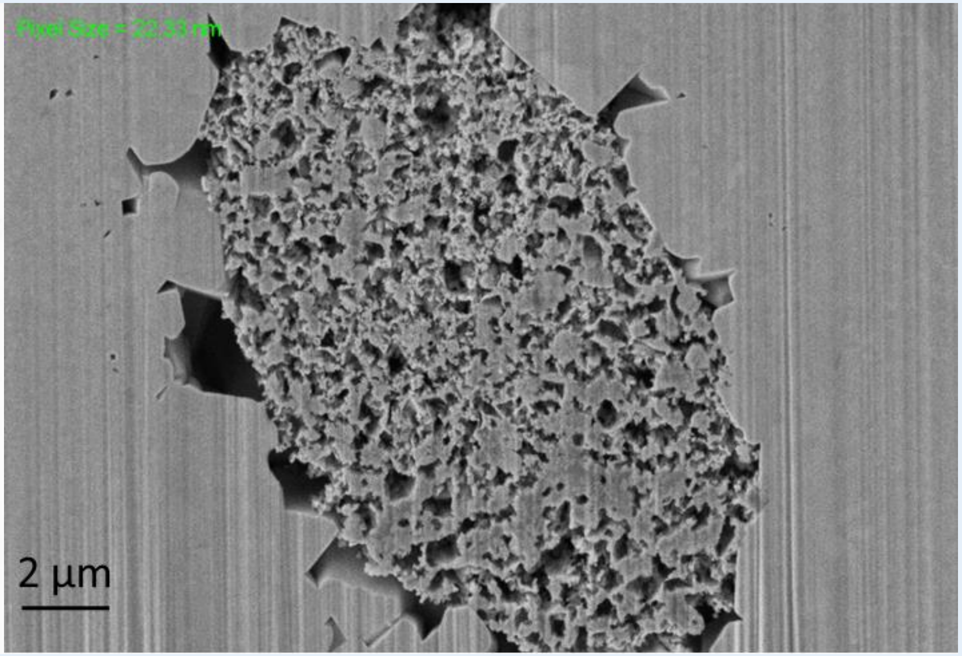
- SEM for non destructive imaging
- FIB for sight specific material removal

FIB Cross-Section

(a)

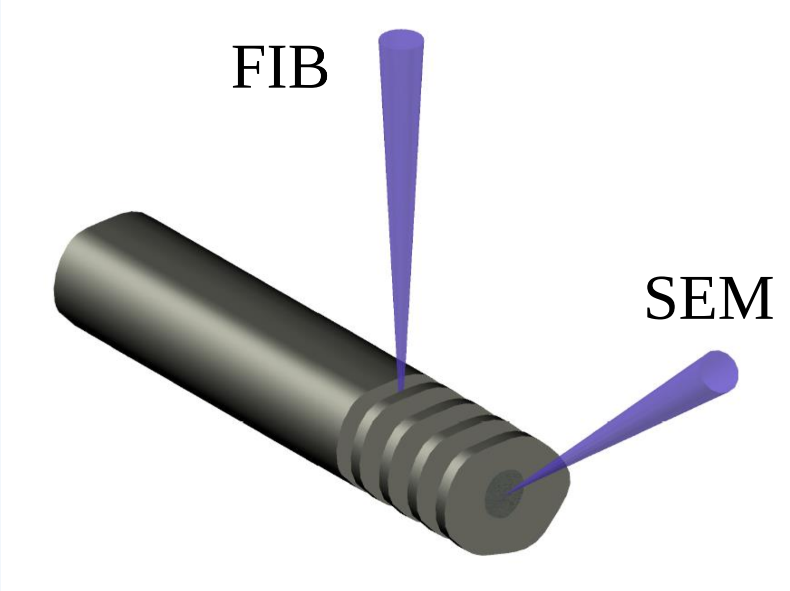


(b)



Secondary electron image of the cross section of an extracted Nb_3Sn filament prepared by Focused-Ion-Beam milling. The porosity between the coarse grains and inside the filament core is clearly visualised.

FIB nanotomography

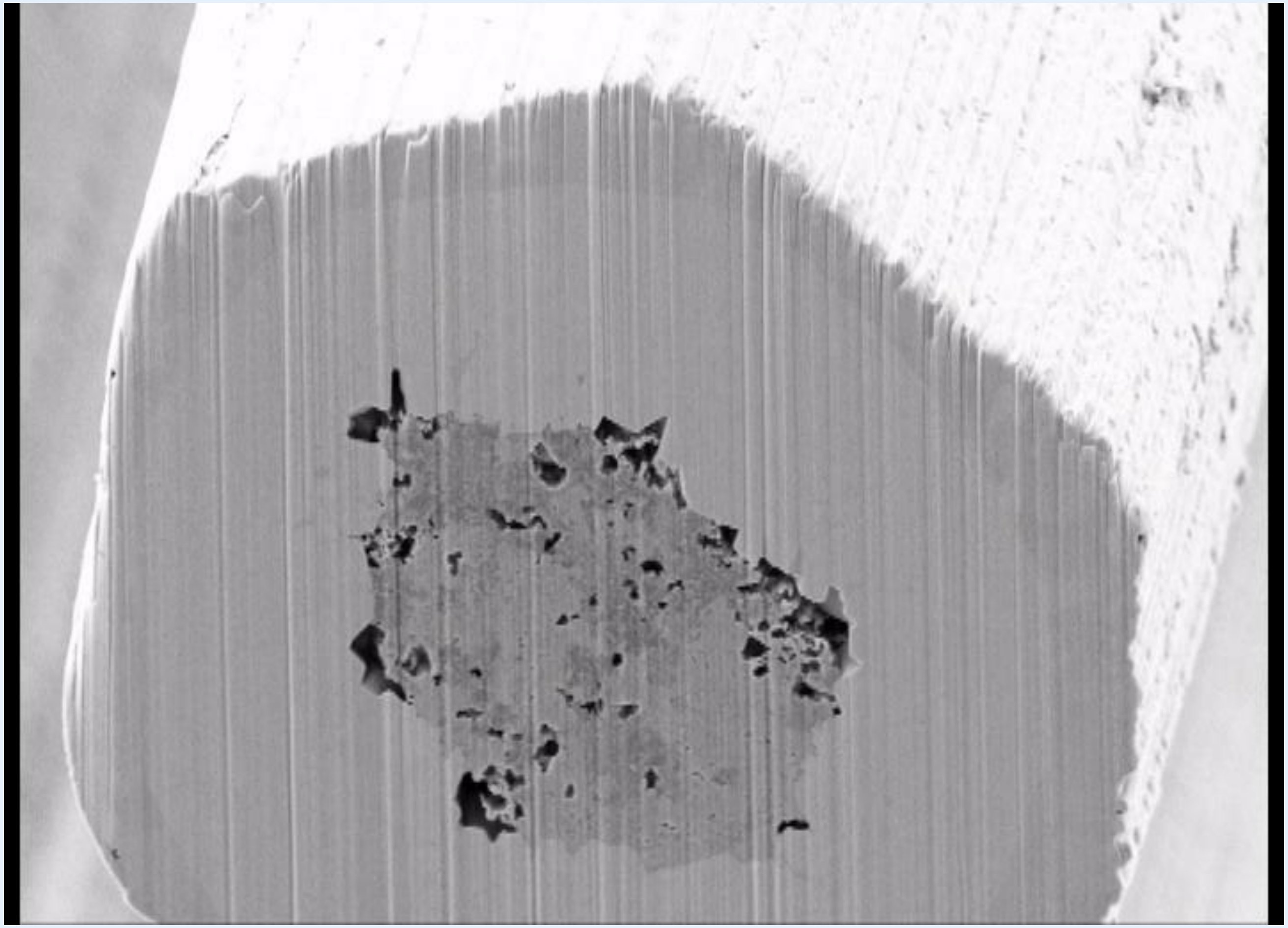


3D sturcural analysis

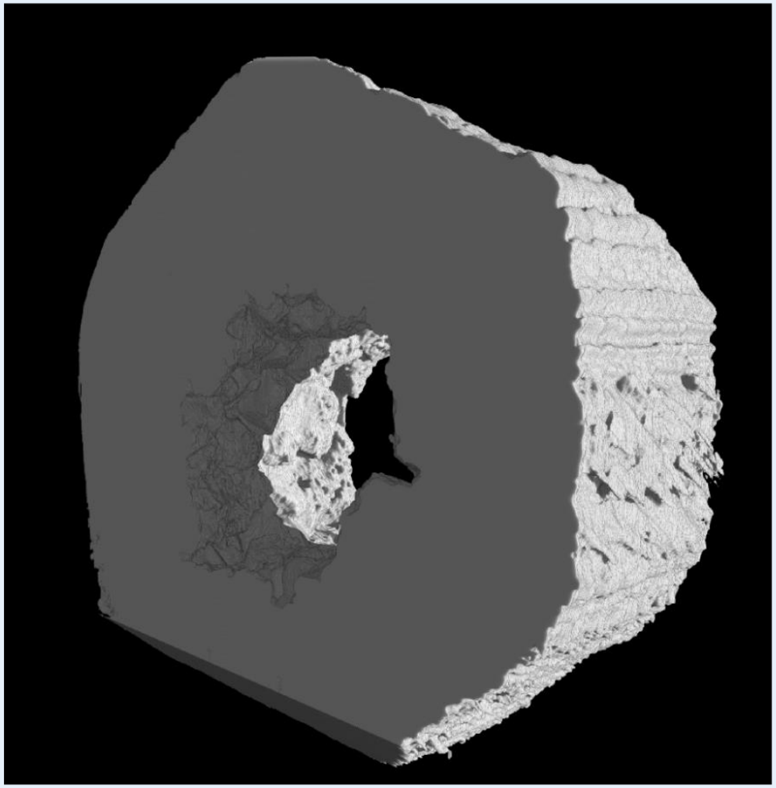
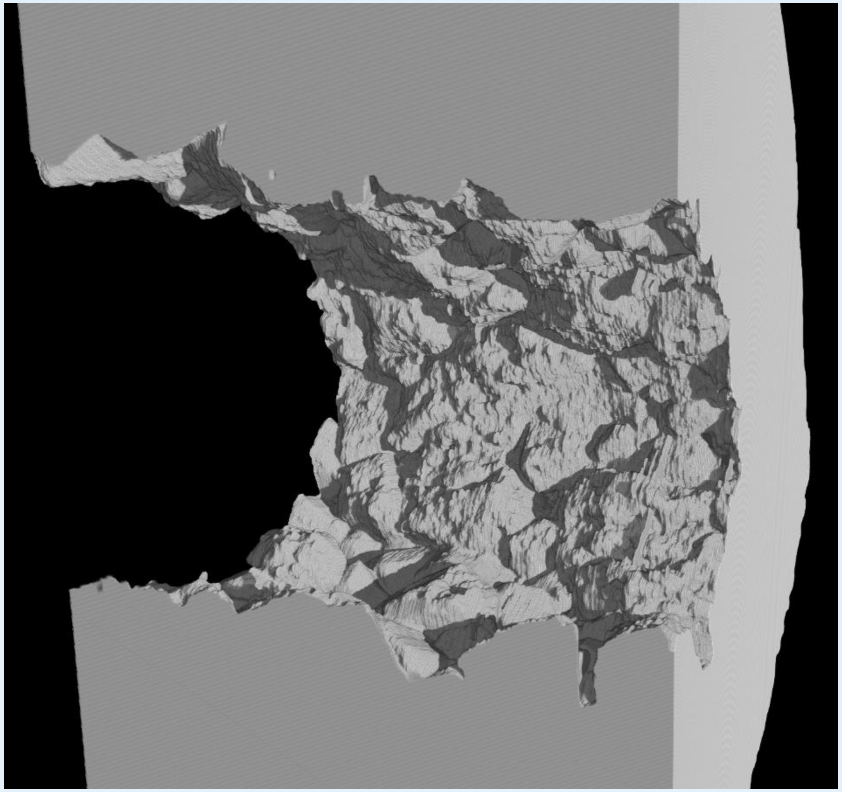
- voxel size down to 10 nm
- higher resolution than X-ray
- larger volume than TEM

FIB tomography fills the gap between classical tomography methods (e.g. X-ray) and high resolution TEM tomography

Image acquisition

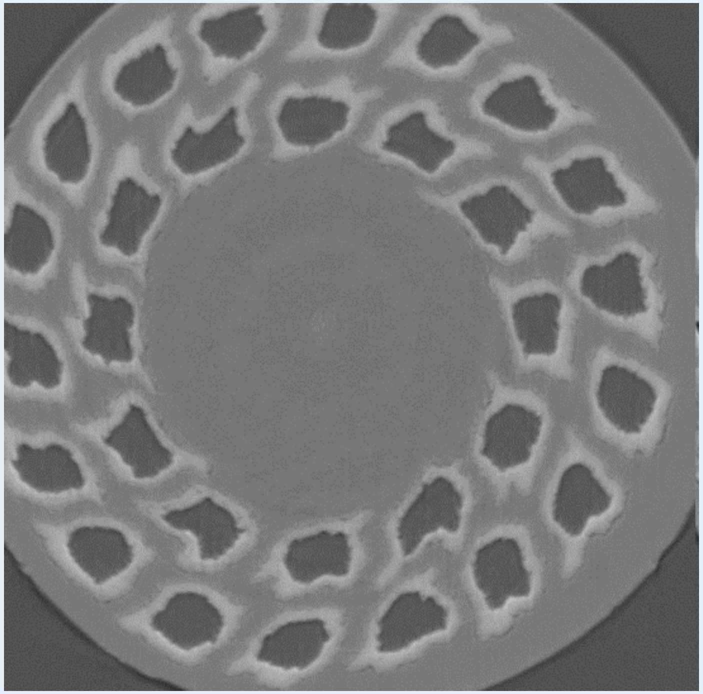


3D rendering of the coarse Nb_3Sn grains

3D rendering of a 30µm long Nb_3Sn PIT filament. The inner core has been removed in order to expose the coarse Nb_3Sn grain surface.

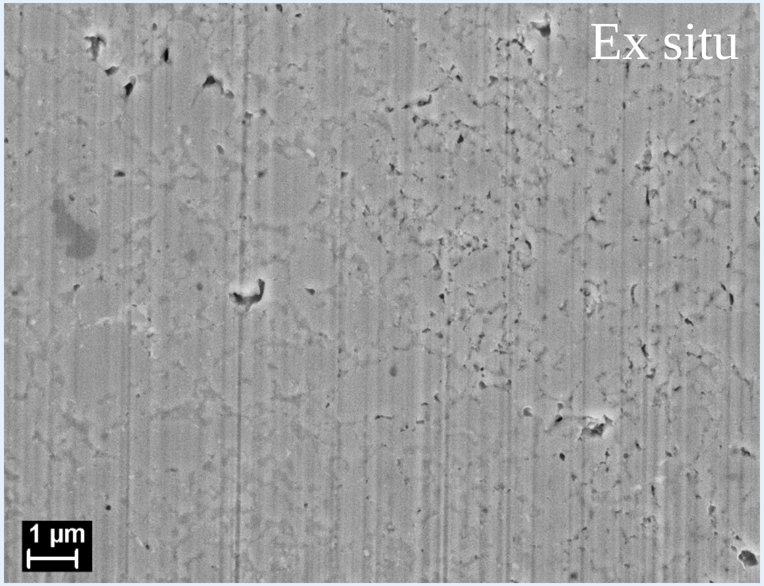
µ-CT of a MgB_2 wire

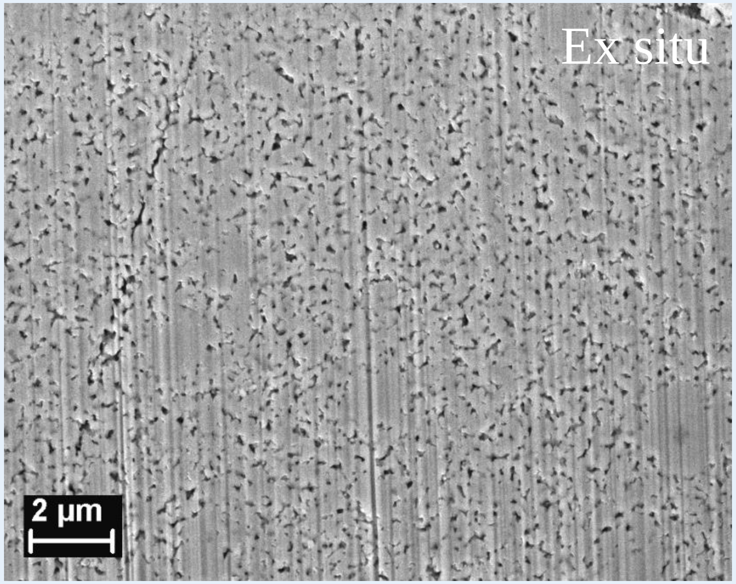


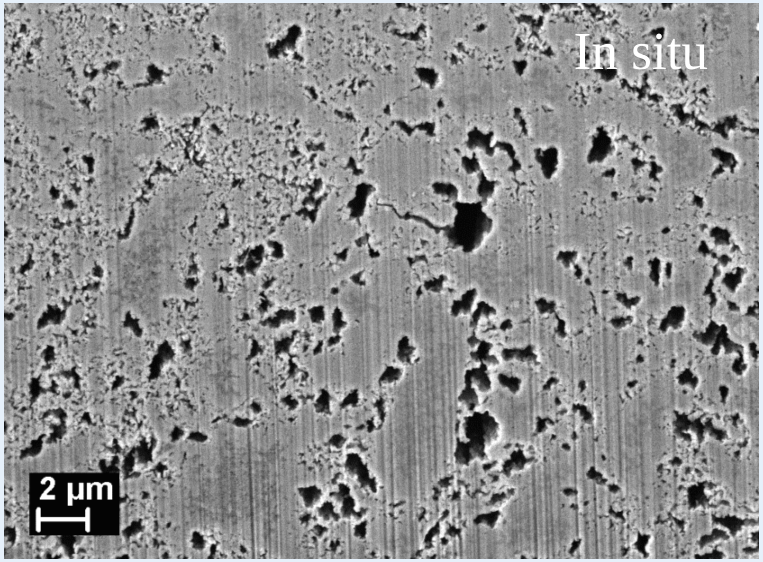
µ-CT cross sections of an ex situ MgB2 wire.

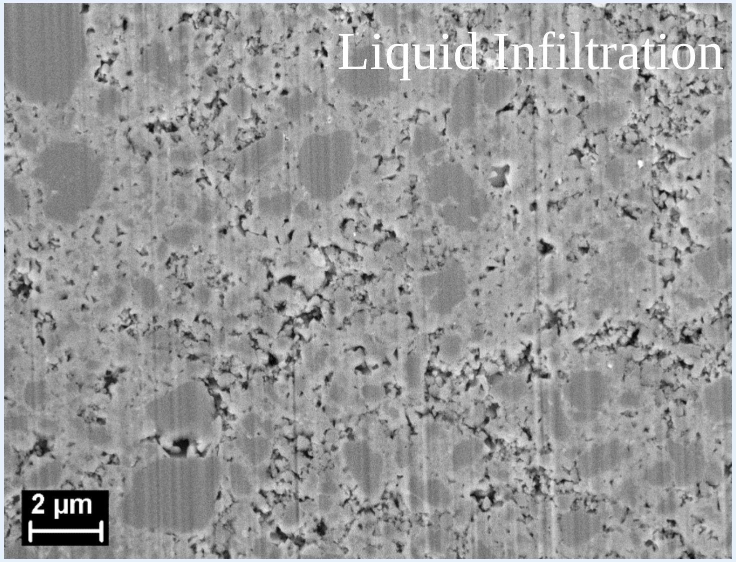
Main problems in µ-CT of MgB2 wires are the very low x-ray attenuation by the weekly absorbing B and Mg inside a strongly absorbing matrix, and the small size of the porosity inside the MgB2 filaments.

FIB nanotomography MgB_2

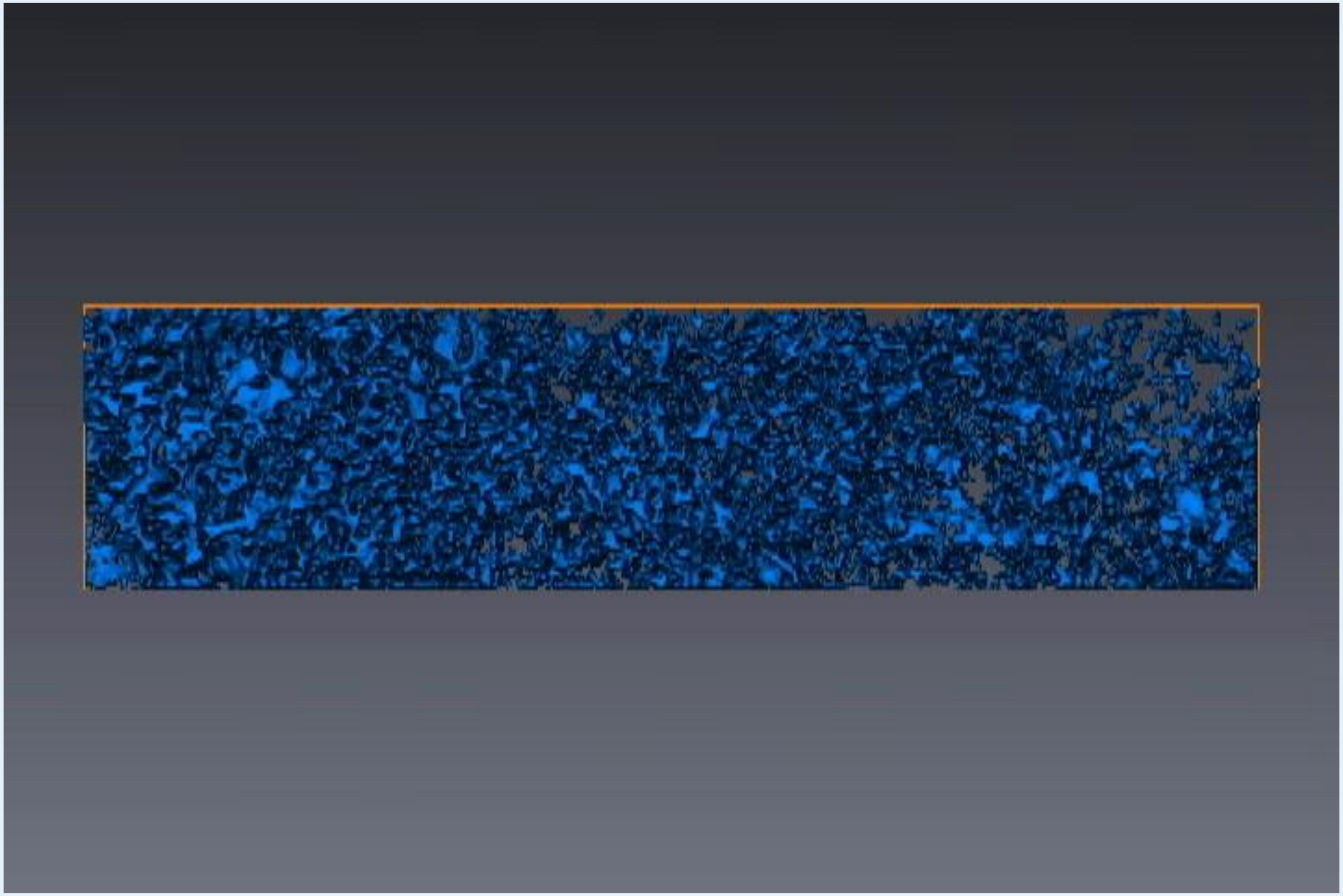






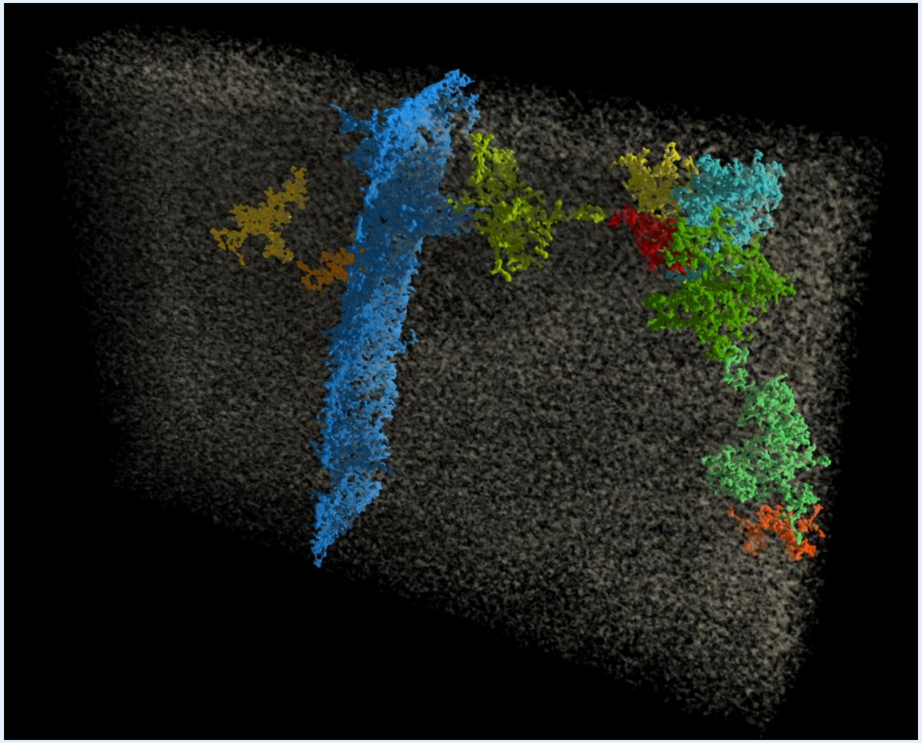


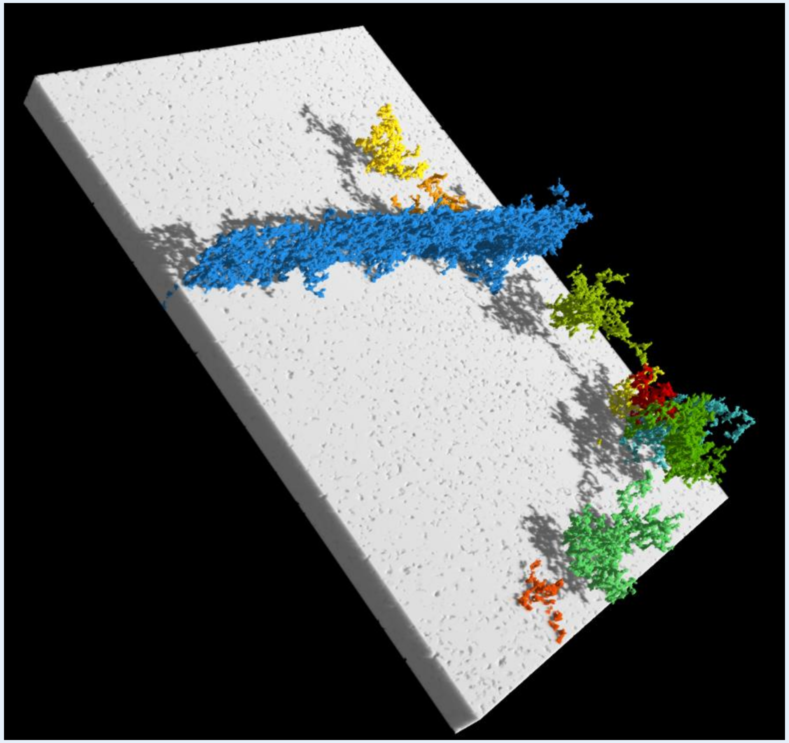
FIB nanotomography MgB_2



FIB nanotomography MgB_2

Pore connectivity





The 10 largest connected pore-networks are highlighted in colour

Conclusion & Outlook

Conclusion:

- ✓ Porosity is clearly visualised with SEM after FIB preparation
- ✓ Large volumes can be studied with high resolution

Outlook:

- ➢ Quantitative analysis of pore size and distribution
- ➢ Comparison with experimental data about superconducting and mechanical properties

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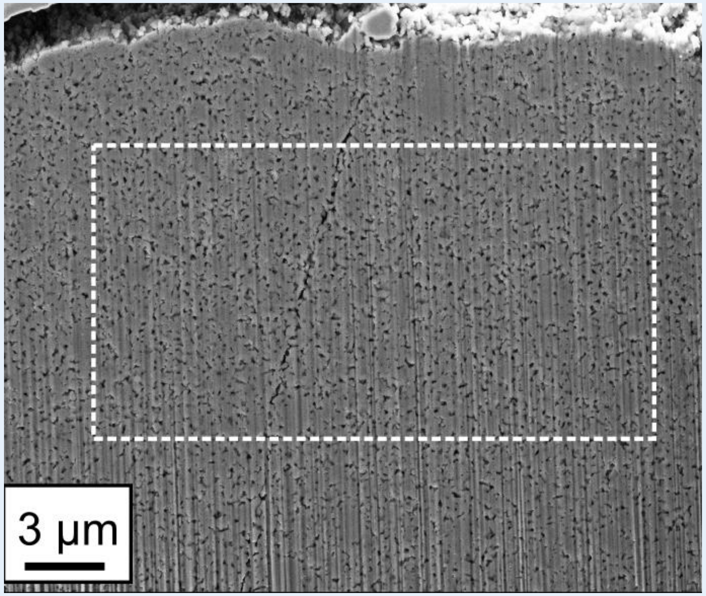
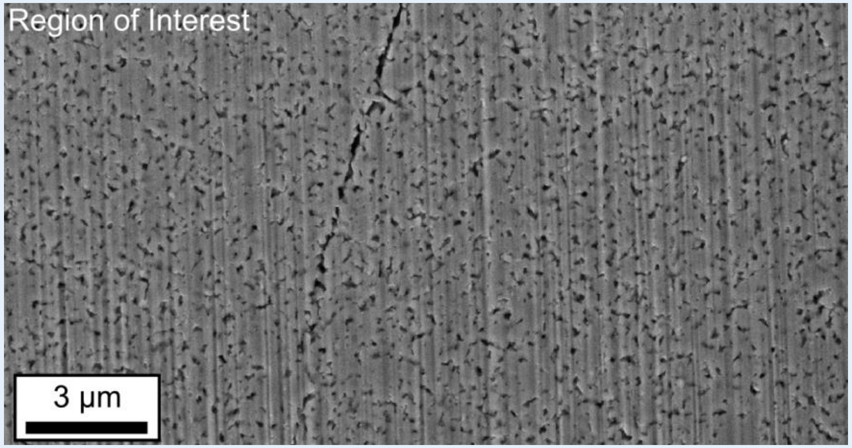
Bernardo Bordini
Amalia Ballarino

Workflow of the Reconstruction

1.



2.



3.