# MQXFA13 – AUP227 metallographical inspection

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CERN, EN-MME-MM

07. 02. 2024

EDMS nr. 3014651

# Metallographical analysis of MQXFA13 – AUP227 coil

**Context of the study:** Coil AUP227 from magnet MQXFA13 experienced several quenches below nominal current during training. The details of the coil's history can be found in the link: https://indico.fnal.gov/event/61571/. The interface between end spacer and wedge in the AUP227 coil was identified as a suspected zone and the metallographic inspection was conducted in that area. Zones of interest were extracted by diamond wire saw cutting and the surface was polished up to 1 µm diamond paste.

**Samples:** MQXFA13 – AUP227 coil slice

**Client:** Giorgio Ambrosio

**Experimental work and reporting by:** Aleksandra Bartkowska (CERN EN-MME-MM)

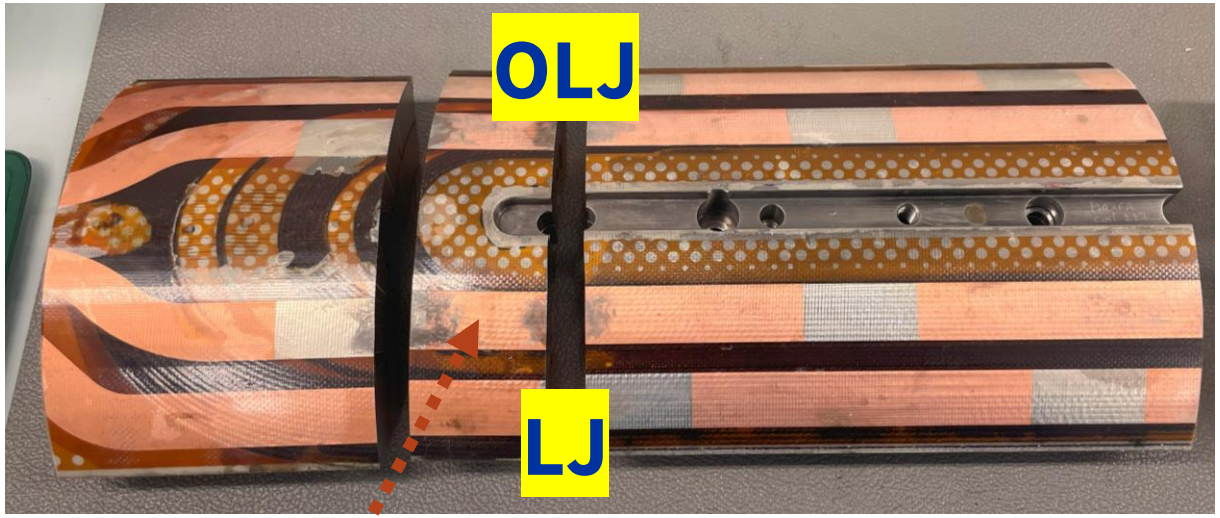
**Equipment:**
- Diamond wire saw
- Keyence VHX7000 digital microscope

# Volumes of interest (VOIs)

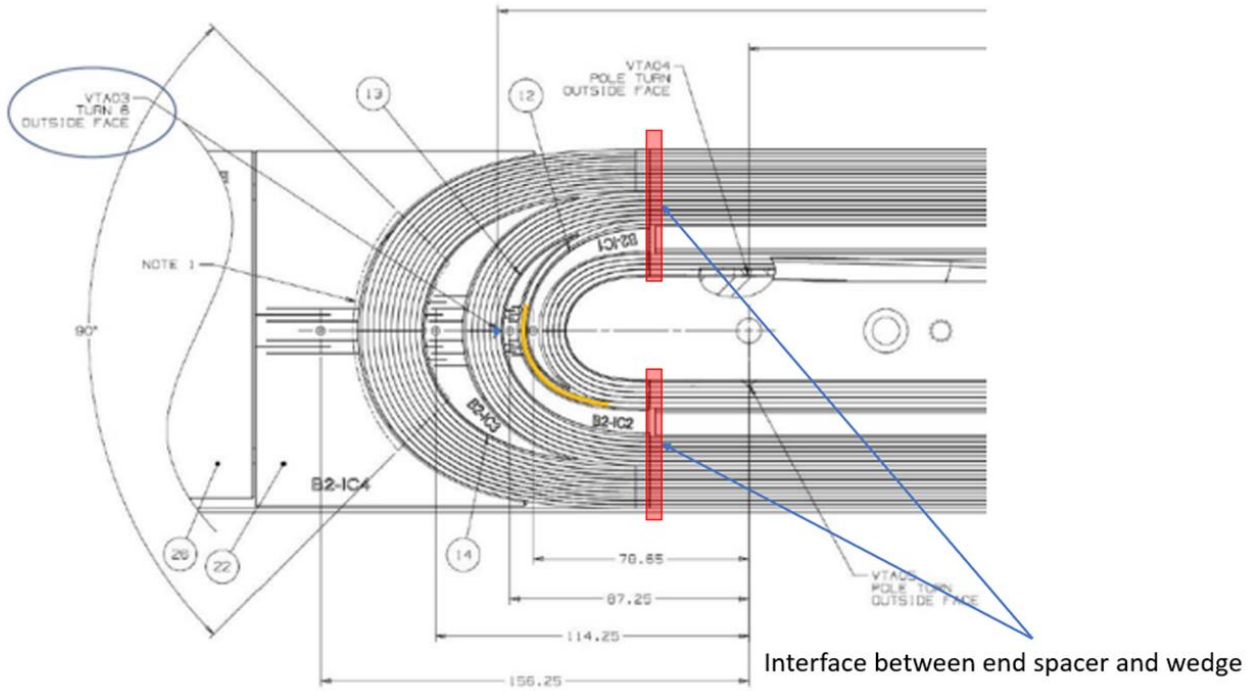
Transition between end spacer and wedge

## MQXFA13 – AUP227

43 mm thick slice including the transition between end spacer and wedge was extracted as illustrated below.

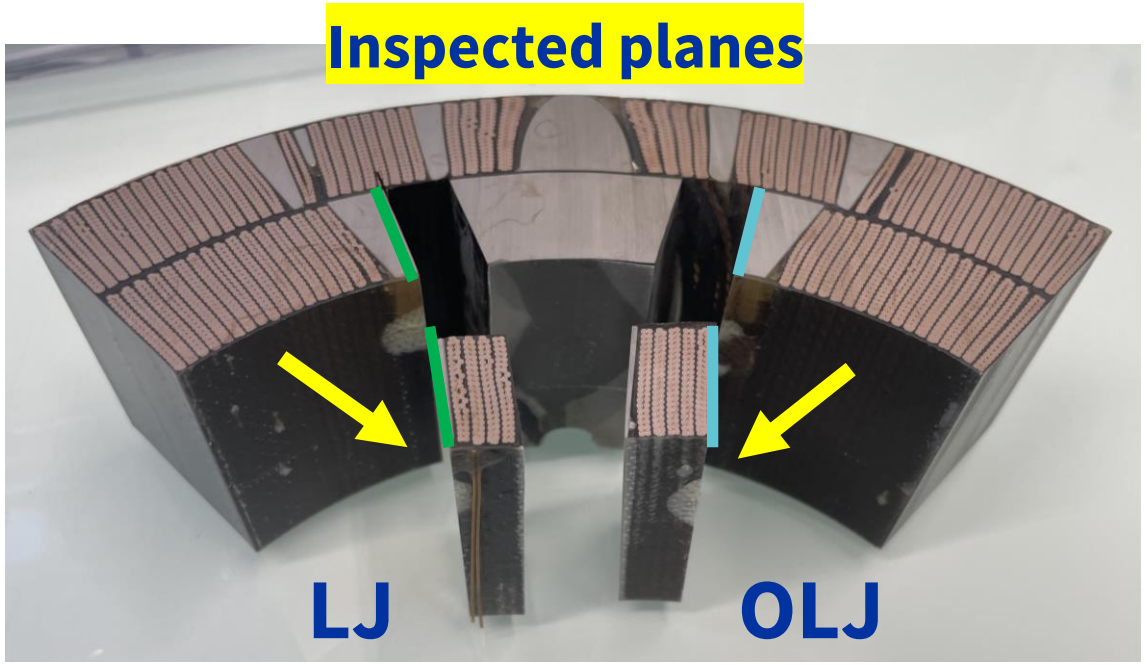



**Extracted part**

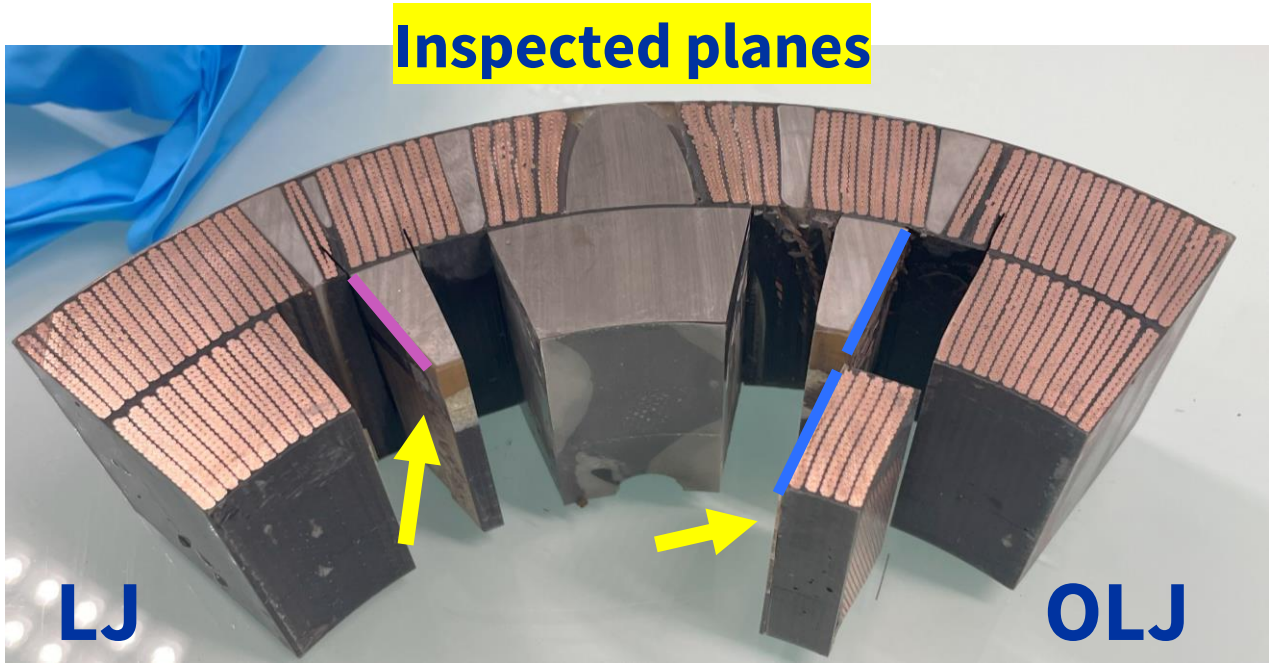


# Volumes of interest (VOIs)

VOIs have been then extracted from the slice accordingly to schema below.



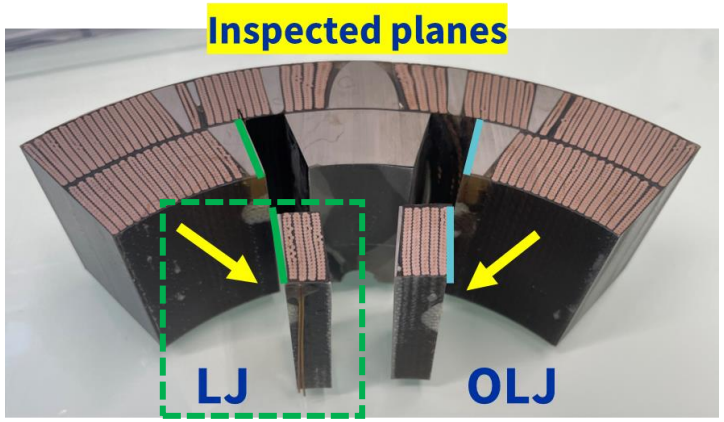

Pole blocks




Midplane blocks

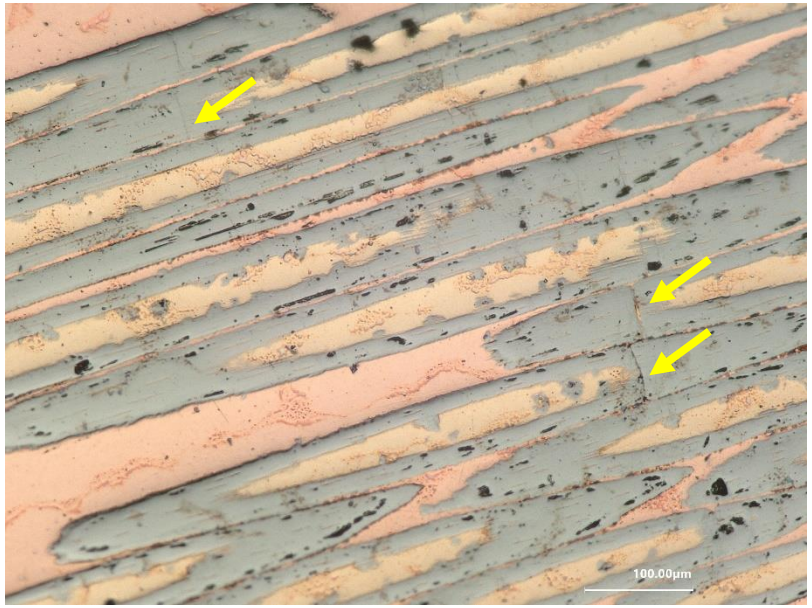
All 4 blocks were analysed from the connection side plane

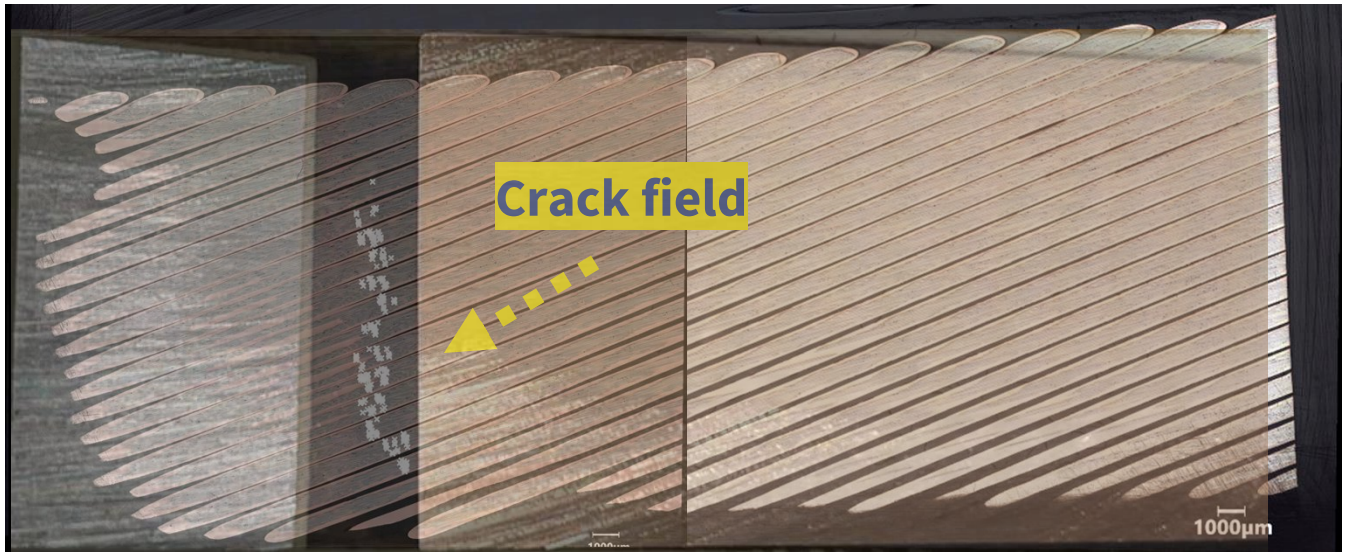
# Pole blocks – connection side (LJ)

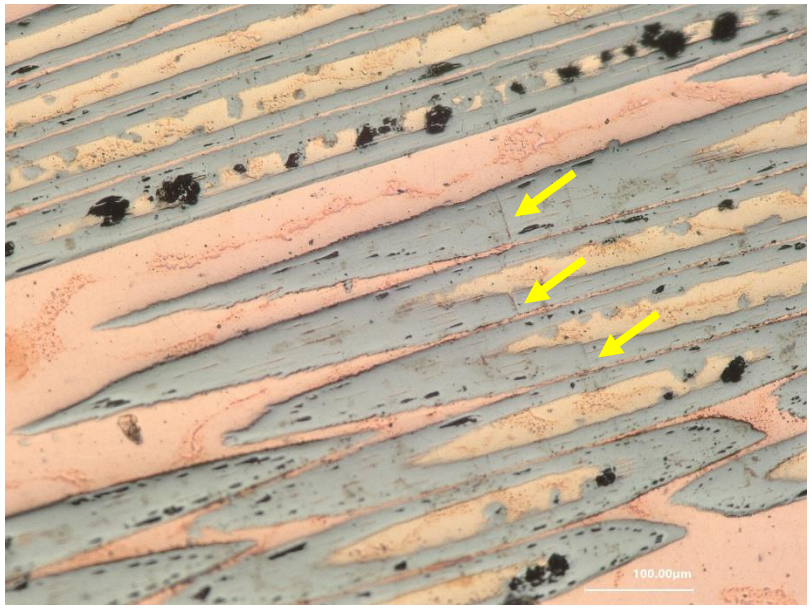



Pole blocks

- Transversal microcracks seem to follow the end spacer – wedge transition.
- The thickness of a resin is higher than in the previously analysed samples (AUP coils #213 and #214) – 3.6 mm compared to approx. 1.5 mm in AUP214

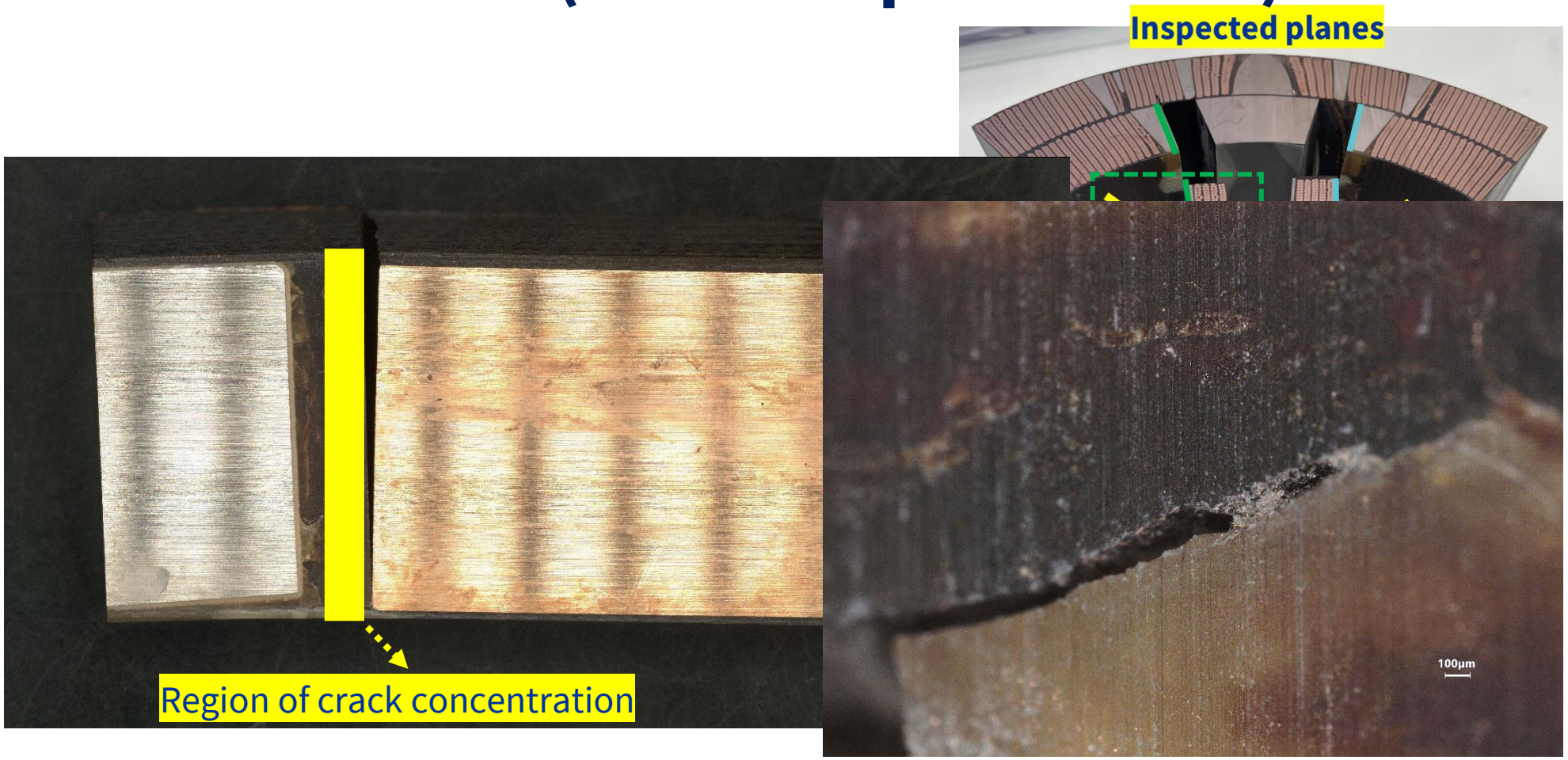



Calculated number of cracks - 180

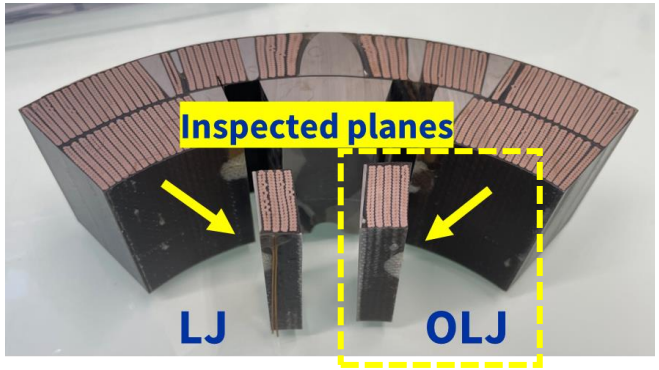
# Resin evaluation (LJ side – pole blocks)



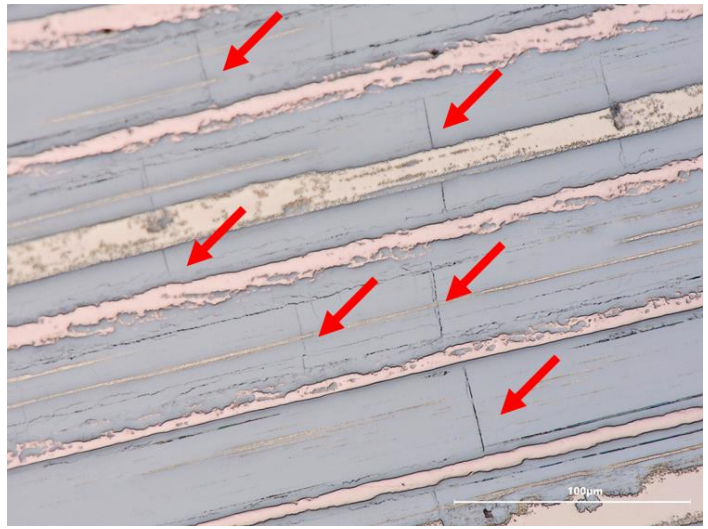


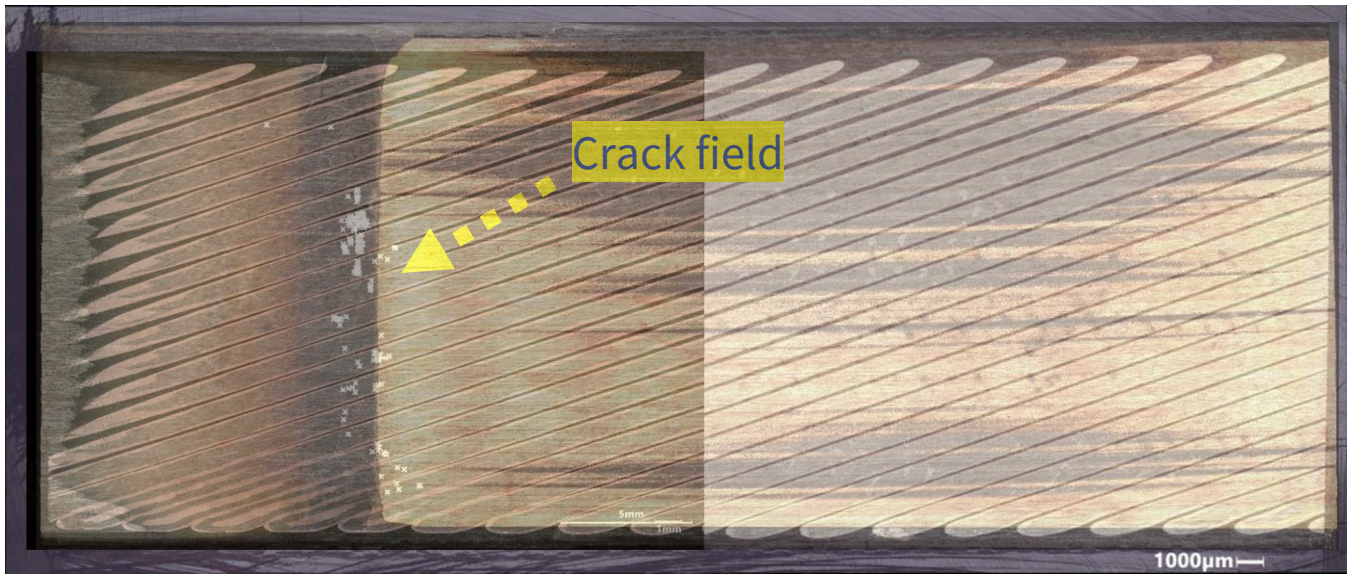
- The resin experienced decohesion after cutting, indicating its poor adhesion to copper block
- Cracks were present in the resin

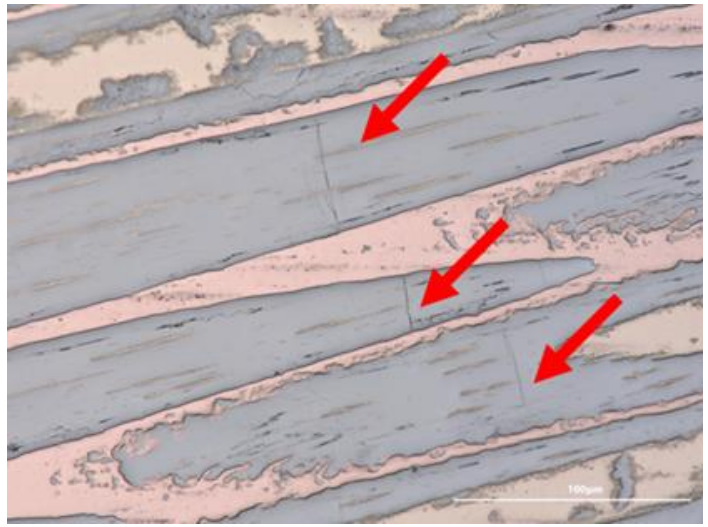
# Pole blocks – connection side (OLJ)




- Microcracks seem to follow the end spacer – wedge transition.
- The thickness of a resin is higher than in the previously analysed samples – 2.8 mm compared to approx. 2 mm in AUP214

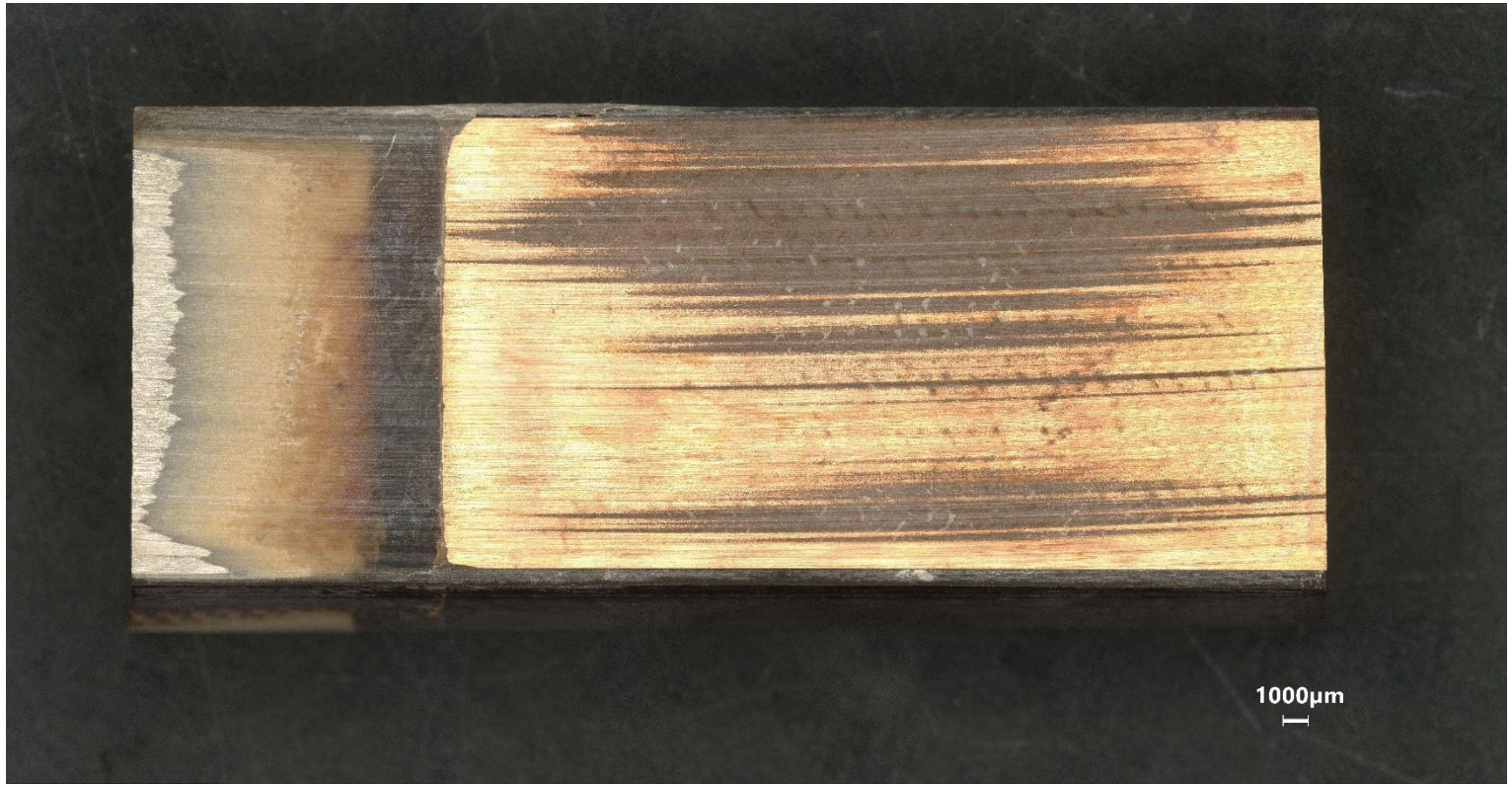




Calculated number of cracks - 210

# Resin evaluation (OLJ side – pole blocks)

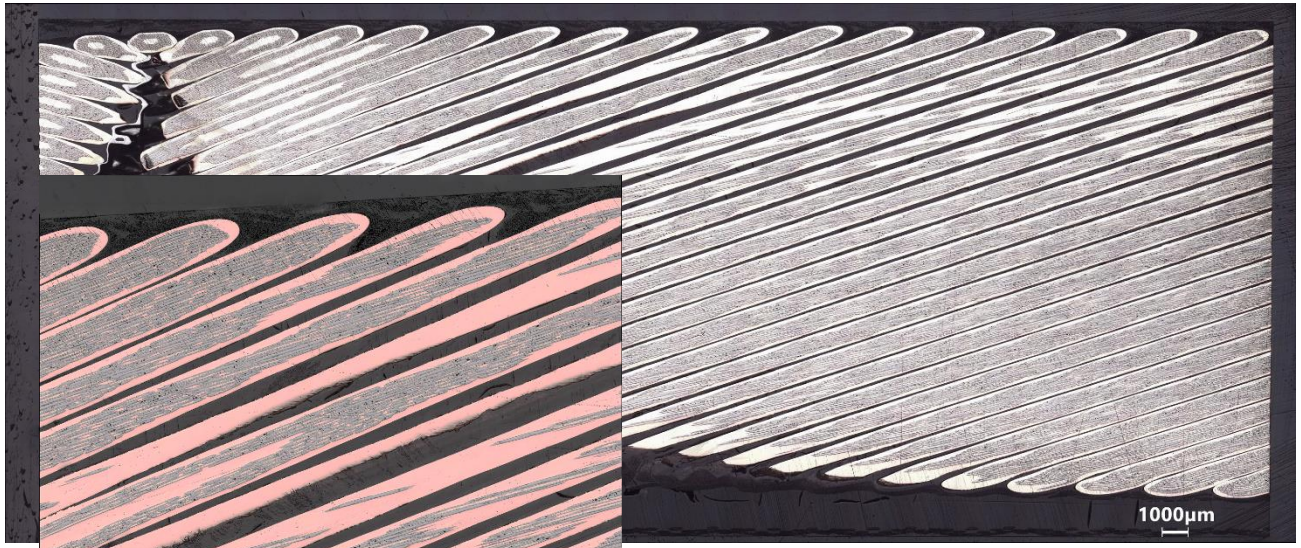


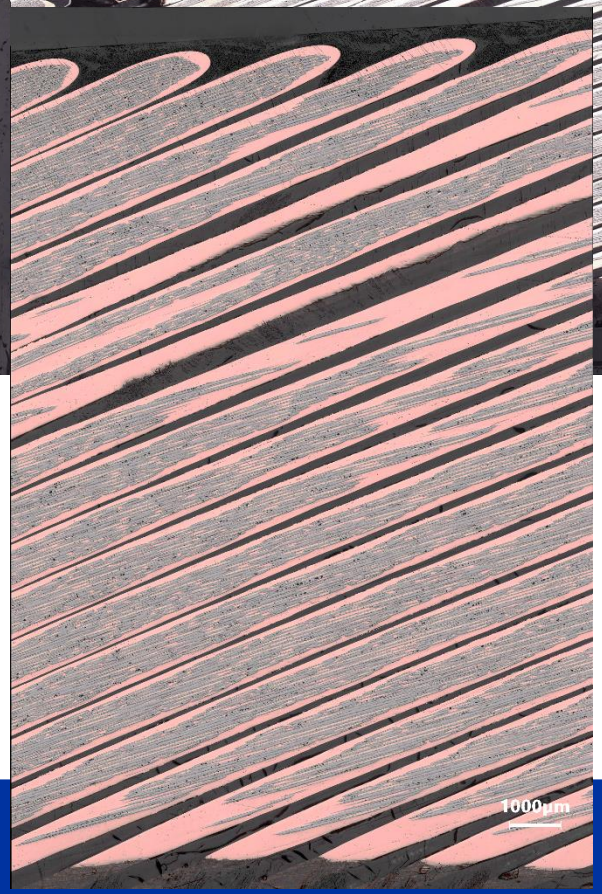


- Microcracks were observed in the resin, but less numerous than in the LJ side
- Resin thickness is higher than in the previously analyzed coils (for both LJ and OLJ blocks)

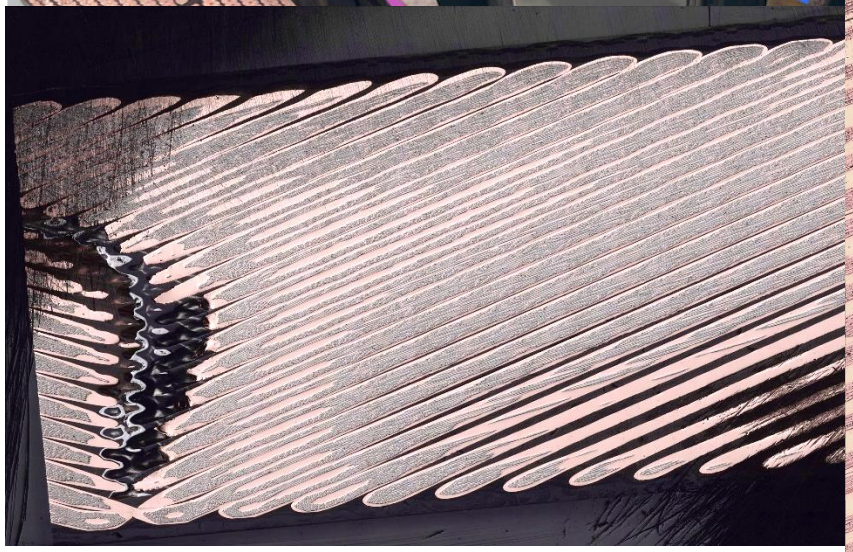
# Midplane blocks (LJ and OLJ)

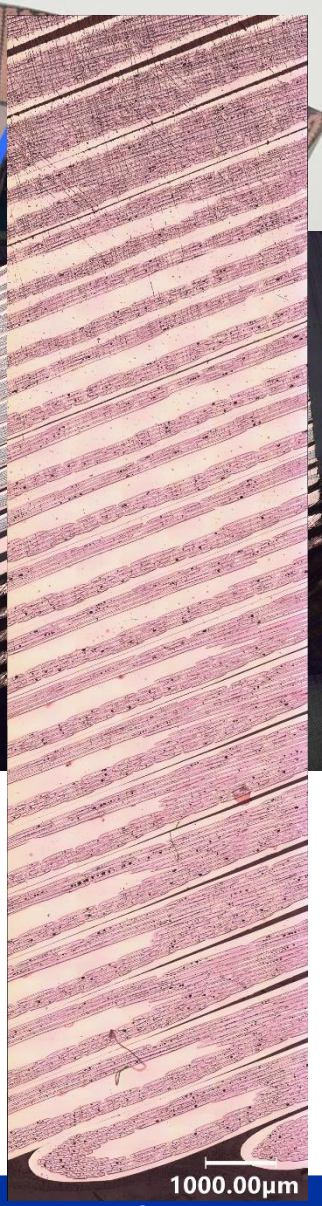

## Midplane block (LJ side)




## Midplane block (OLJ side)






Cracks were not observed in the midplane blocks (neither in LJ and OLJ sides).
Progressive polishing was made and examined up to the presented level and no cracks were observed.

# Summary and conclusions

Metallurgical inspection of the longitudinal cuts (LJ and OLJ side) involving the first row of Rutherford cables adjacent to the end spacer/copper wedge transition revealed :

- The presence of a localized field of cracks at first row's midplane in the pole blocks,
- The field of cracks is in correspondence to the transition between resin and copper wedge,
- Microcracks are transverse with respect to the longitudinal axis of strands,
- The cracks were not observed in the midplane blocks,
- Thickness of resin area is higher than in previously analysed coils, cracks are present in the resin

The present results are in accordance with previous results obtained from the metallurgical inspection of MQXFA07 – AUP214 (EDMS nr. 2739504) and MQXFA08 - AUP213 (EDMS nr. 2777506).

# MQXFA13 – AUP227
# metallographical inspection – pole turn

**Aleksandra Bartkowska**

**CERN, EN-MME-MM**

**07.05.2024**

**EDMS nr. 3083949**

# Metallographical analysis of MQXFA13 – AUP227 coil

**Context of the study:** Coil AUP227 from magnet MQXFA13 experienced several quenches below nominal current during training. The details of the coil's history can be found in the link: https://indico.fnal.gov/event/61571/. The pole turn area in the AUP227 coil was identified as a suspected zone and the metallographic inspection was conducted in that area. Zones of interest were extracted by diamond wire saw cutting and the surface was polished up to 1 µm diamond paste. Gradual polishing and light microscopy observations were conducted to reveal potential defects and cracks in the components.

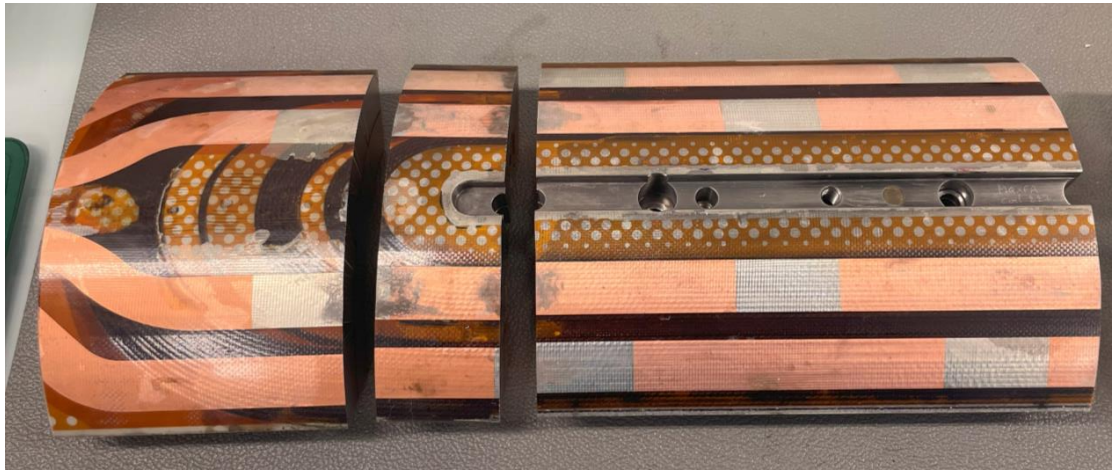
**Samples:** MQXFA13 – AUP227 coil slice

**Client:** Giorgio Ambrosio

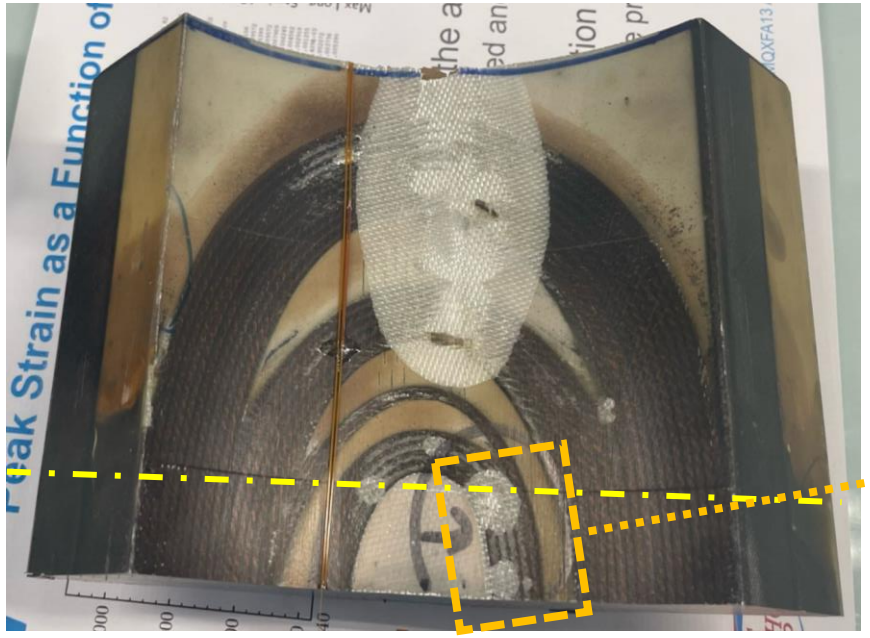
**Experimental work and reporting by:** Aleksandra Bartkowska (CERN EN-MME-MM)

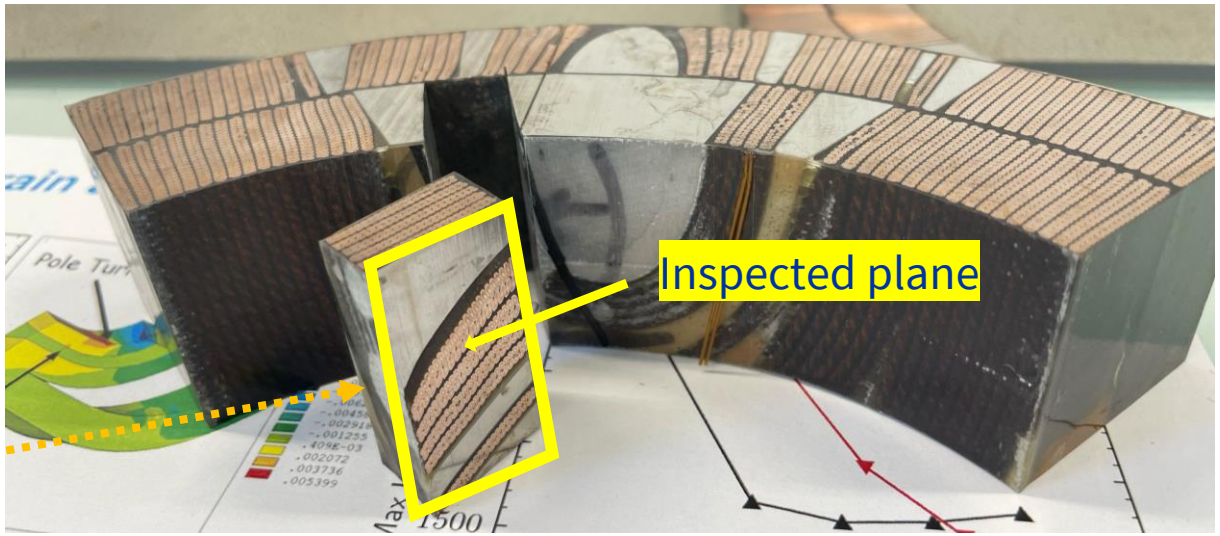
**Equipment:**
- Diamond wire saw
- Keyence VHX7000 digital microscope

# Volumes of interest (VOI)

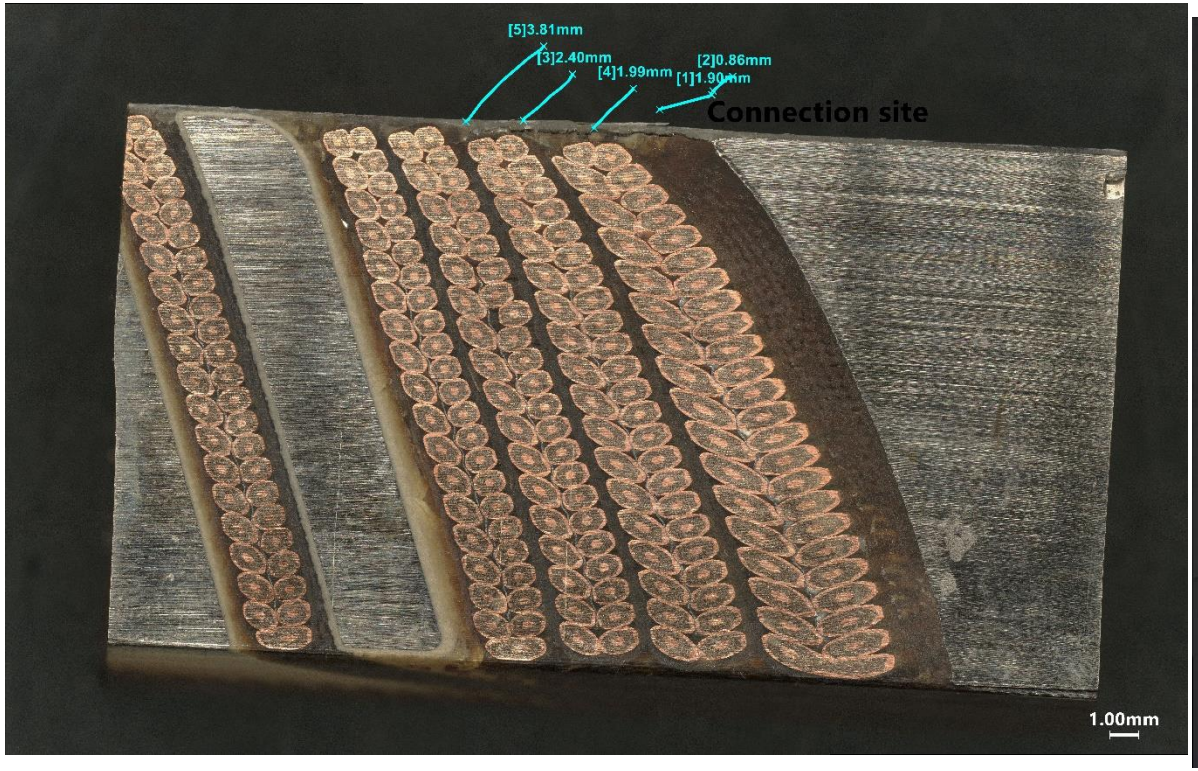


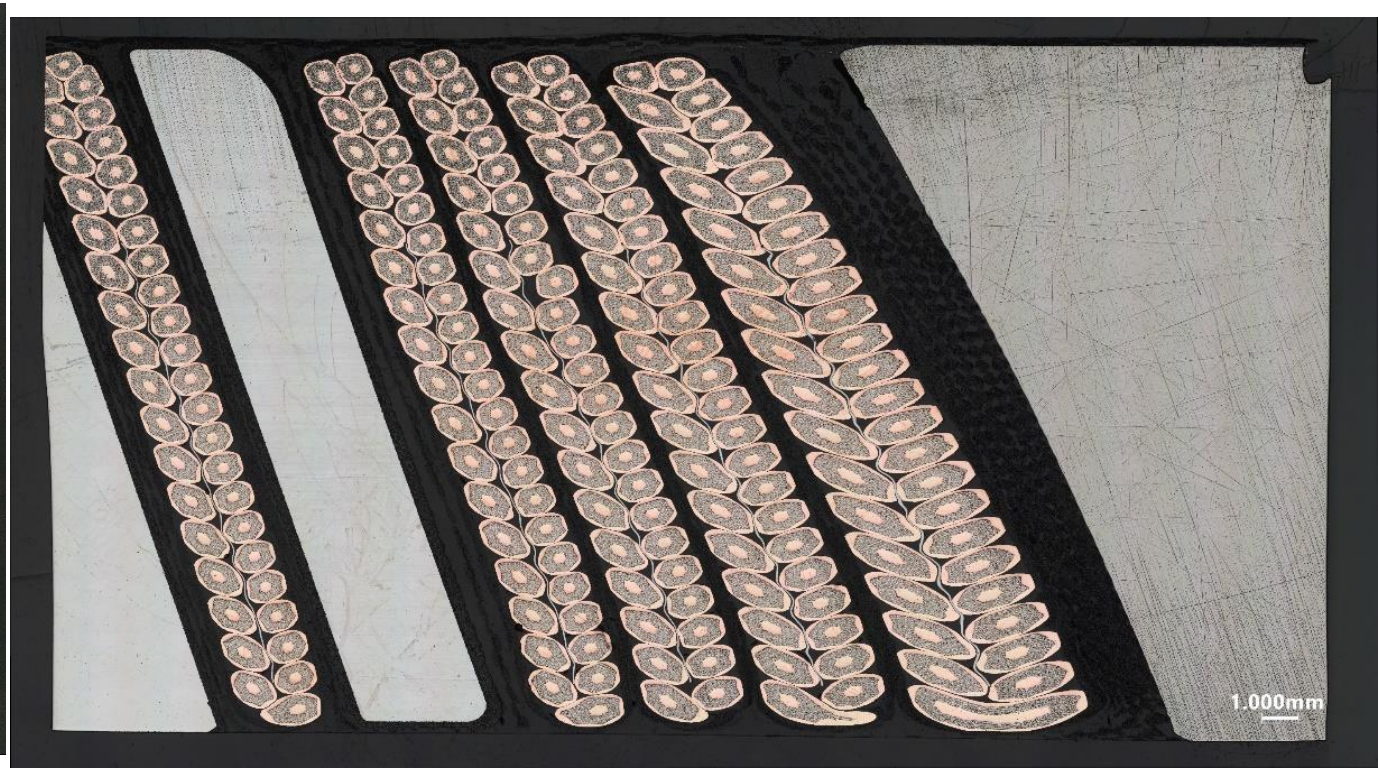
VOI have been then extracted from the slice accordingly to schema below.





# As-cut surface and 1st step polishing

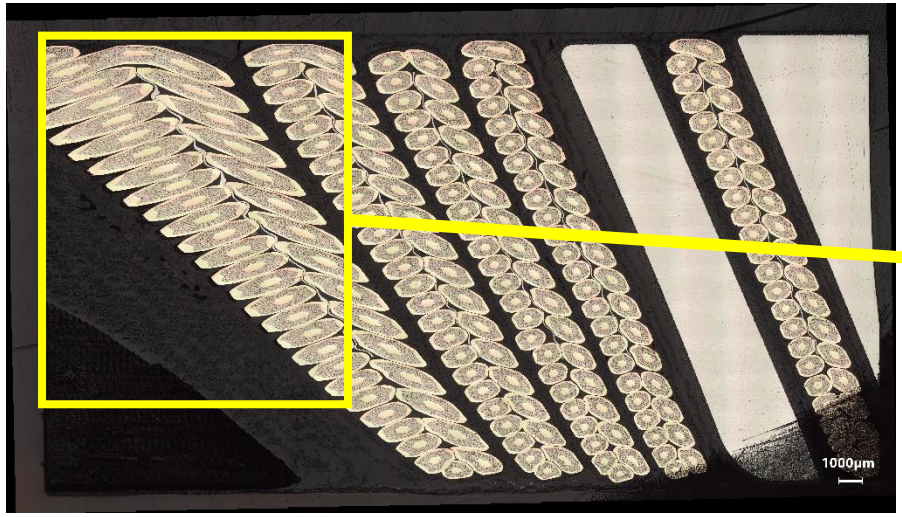


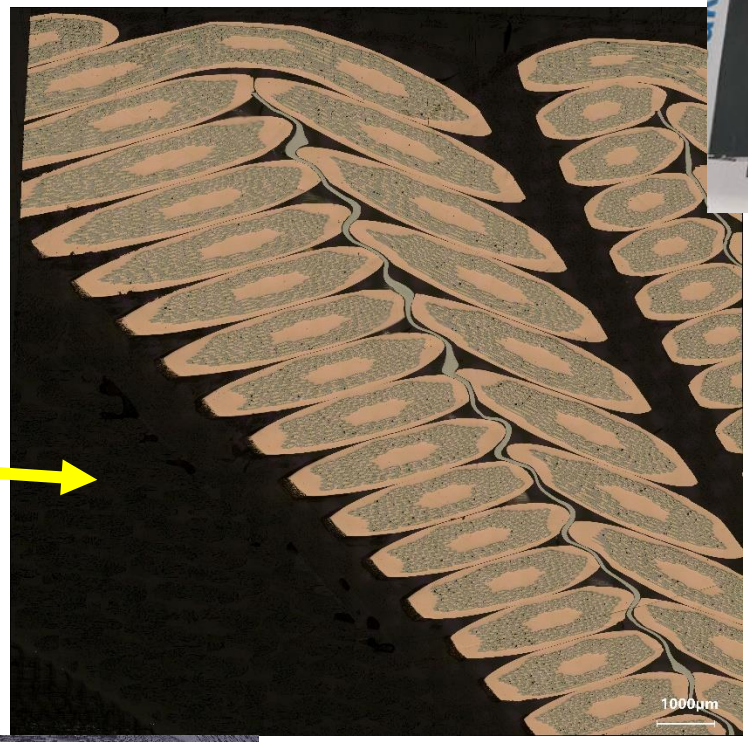



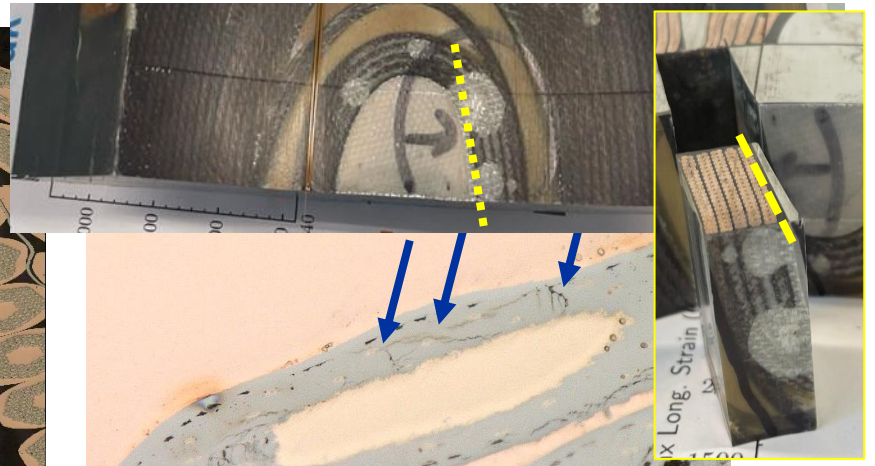

Observations of the as-cut surface revealed only discontinuities in the part of the resin corresponding to the connection side.

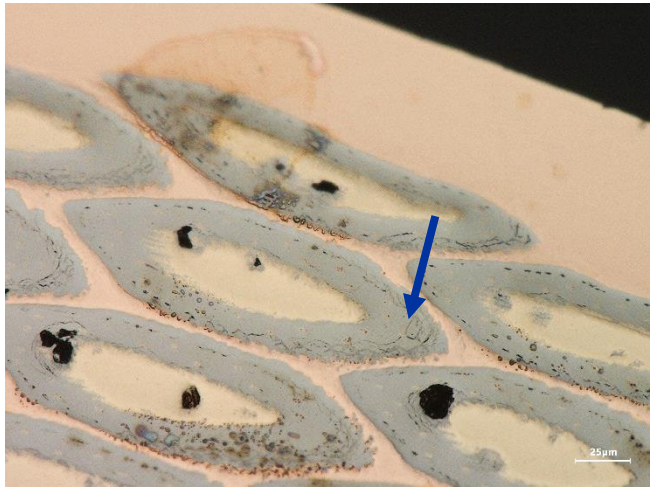
Rough polishing step after cutting, followed by optical inspection showed good state of the resin, no major discontinuities were observed.

# 2nd step polishing



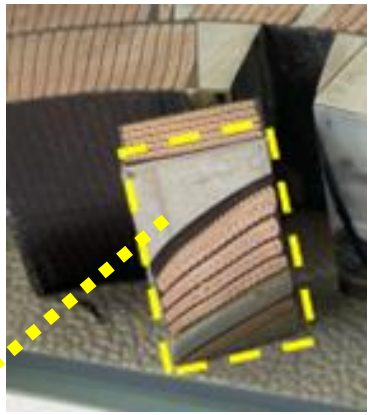



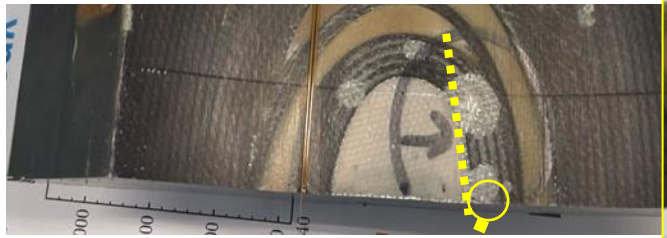


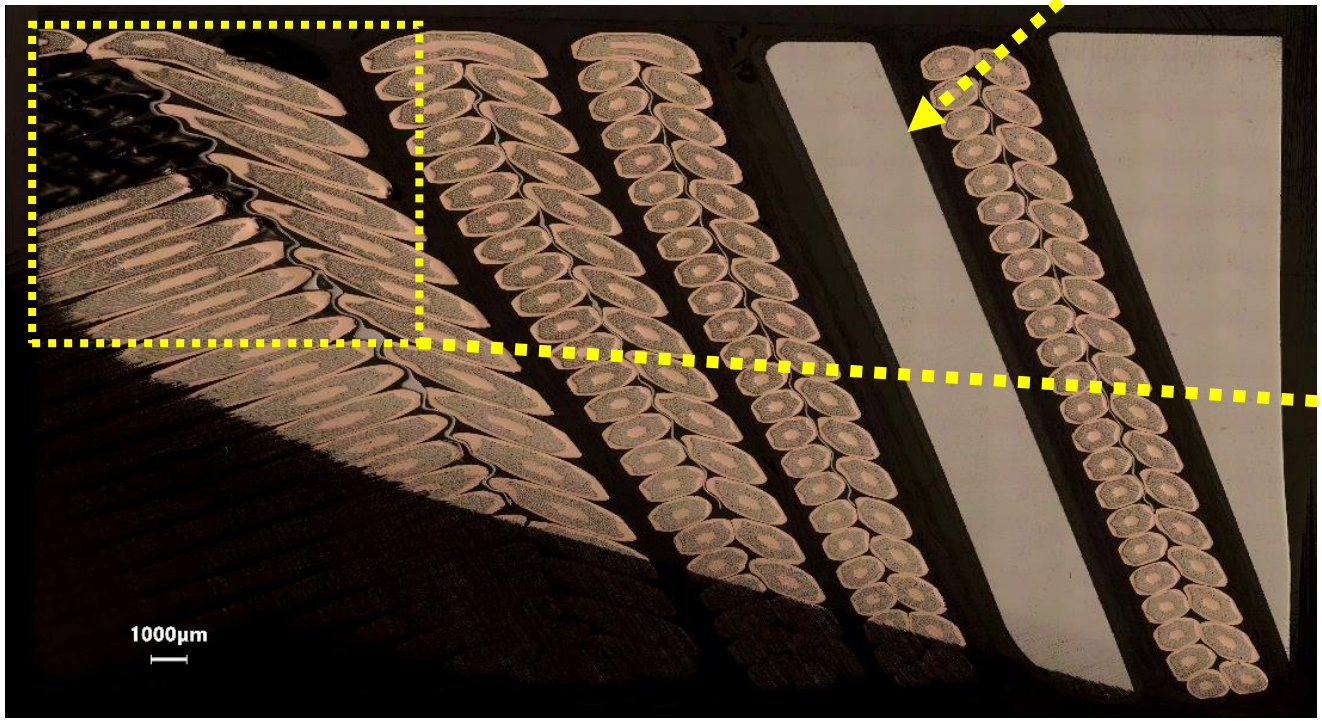

2nd polishing step (to reveal the resin state below Ti), did not show cracks in resin. The $Nb_3Sn$ filaments possess a minor amount of radial cracks, as indicated by blue arrows.

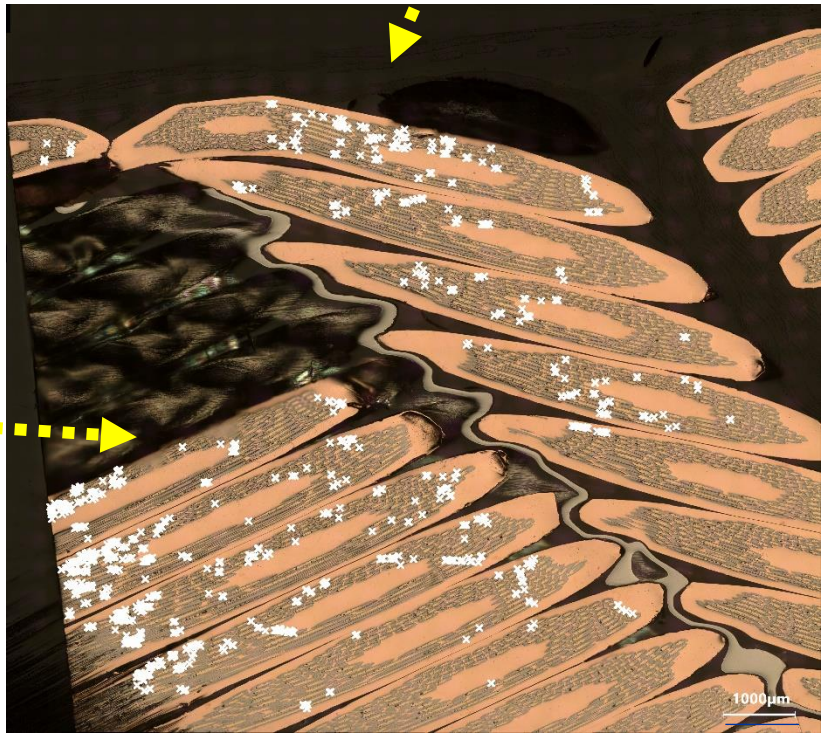
# 3rd polishing step (mid plane of Rutheford cable)

Numerous transversal cracks present, up to $10^3$ cracks in the highlighted region

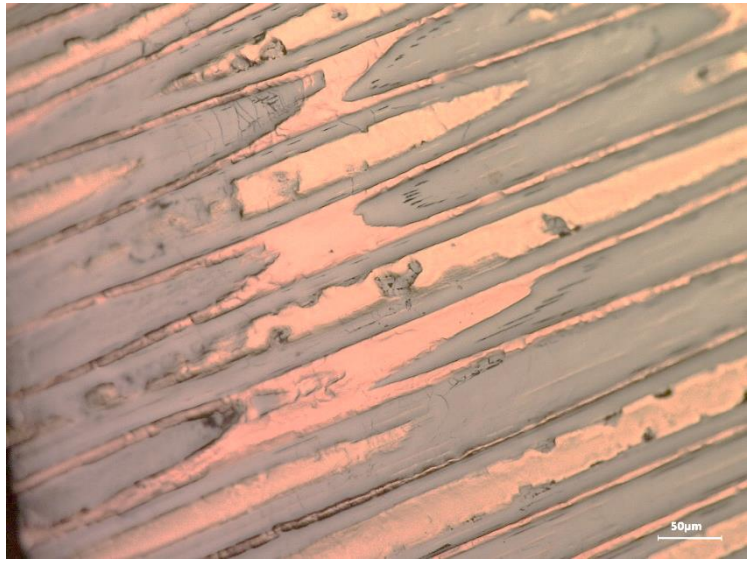


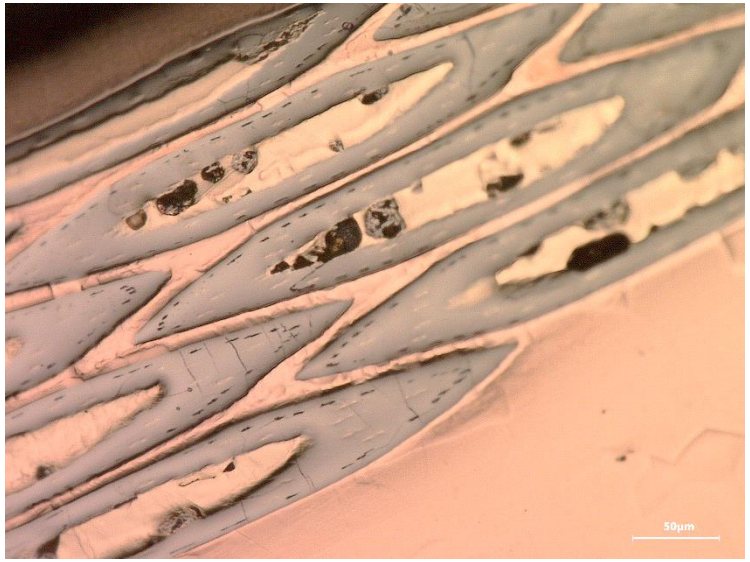


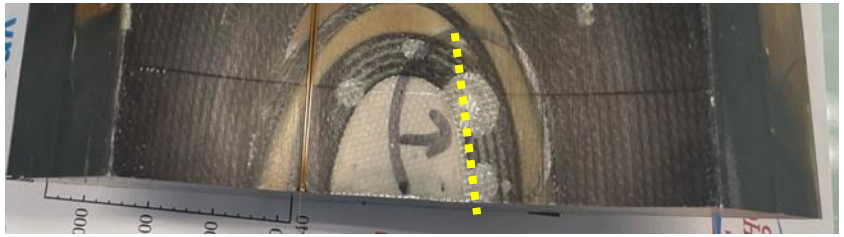


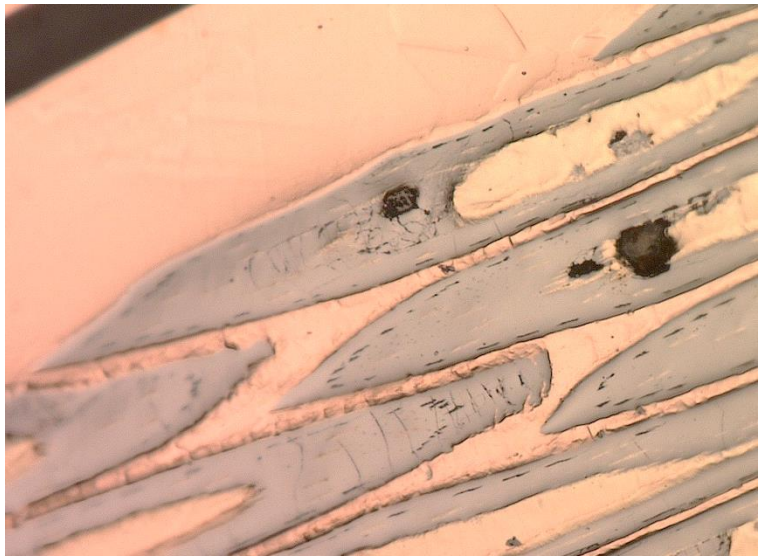



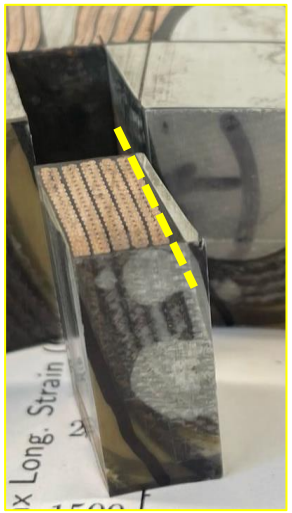
# 3rd polishing step (midplane of the Rutheford cable)

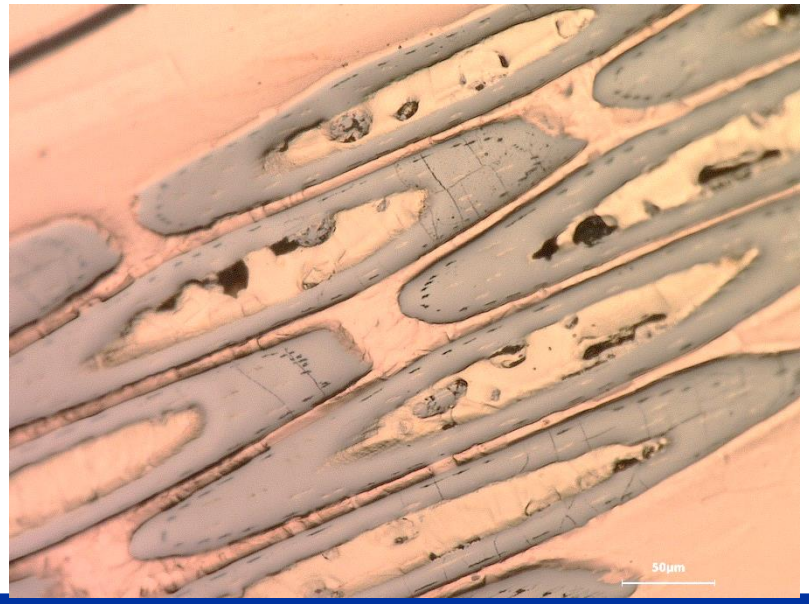









Numerous transversal cracks present, up to $10^3$ cracks in the highlighted region – high resolution images can be found in the EDMS report.

# Summary and conclusions

Metallurgical inspection of the longitudinal cuts involving the first row of Rutherford cables adjacent to the pole turn region revealed:

- The presence of a localized field of cracks (above 1k) at first row's midplane in the pole blocks, mostly underneath the Ti;
- Microcracks are transverse with respect to the longitudinal axis of strands,
- No major defects in the resin observed in any of the polishing steps.

# MQXFA13 – AUP227
# Extended inspection of pole turn region by deep copper etching and CT analysis

**Aleksandra Bartkowska, Michal Dalemir Celuch**

**CERN, EN-MME-MM**

**13.09.2024**

**EDMS nr. 3160866**

# Metallographical analysis of MQXFA13 – AUP227 coil

**Context of the study:** Coil AUP227 from magnet MQXFA13 experienced several quenches below nominal current during training. The details of the coil's history can be found in the link: https://indico.fnal.gov/event/61571/. The pole turn area in the AUP227 coil was identified as a suspected zone and the metallographic inspection was conducted in that area, documented in EDMS 3083949. This report is complementary to EDMS 3083949 and describes an additional analysis by deep copper etching and computed tomography.

**Samples:** MQXFA13 – AUP227 coil slice

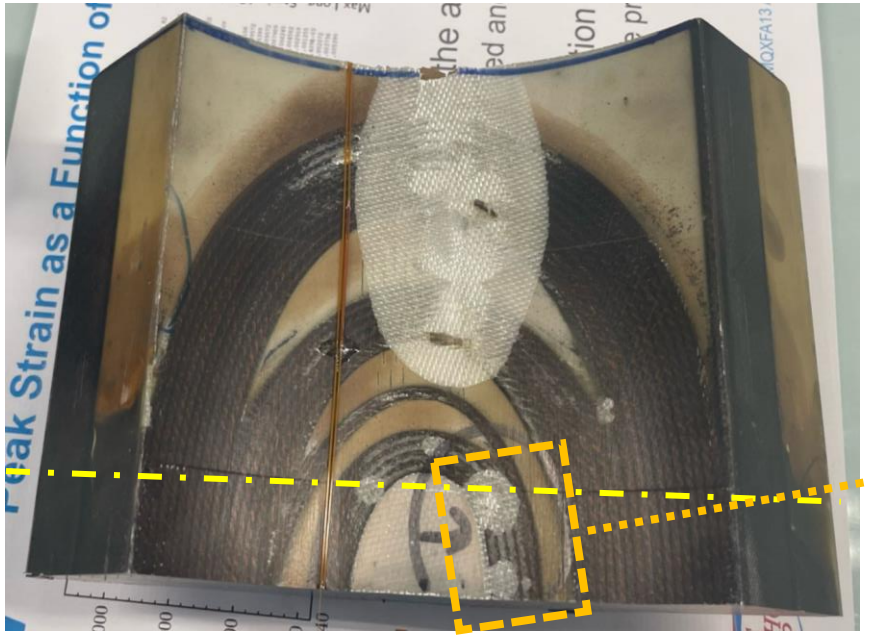
**Client:** Giorgio Ambrosio

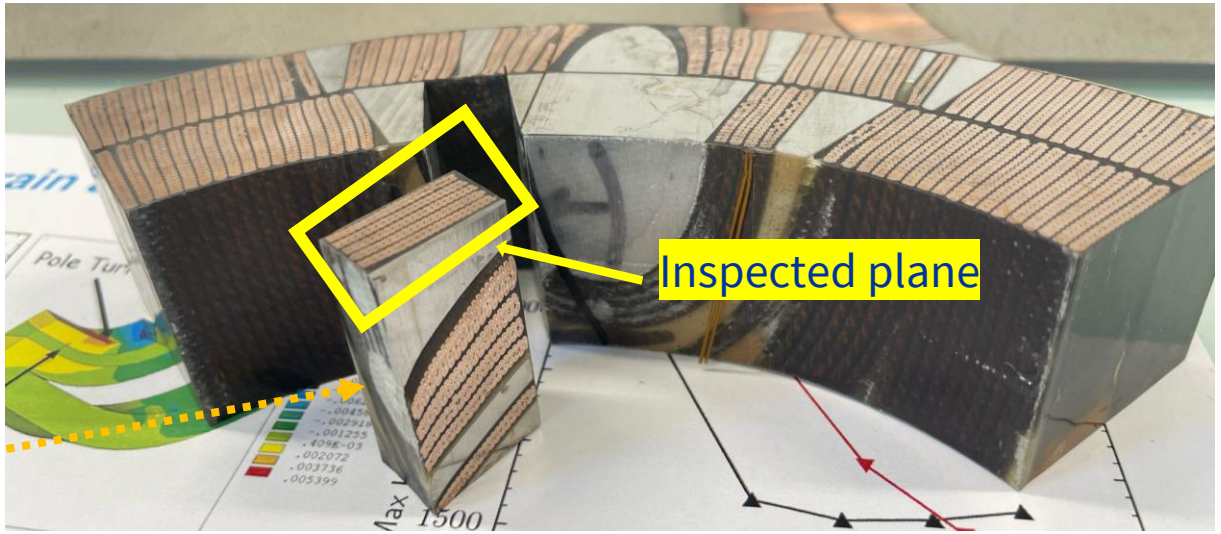
**Experimental work and reporting by:** Aleksandra Bartkowska, Michal Dalemir Celuch (CERN EN-MME-MM)

**Equipment:**
- Keyence Keyence VHX7000
- Zeiss METROTOM 1500 CT scanner

# Volumes of interest (VOI)

VOI have been then extracted from the slice accordingly to schema below.

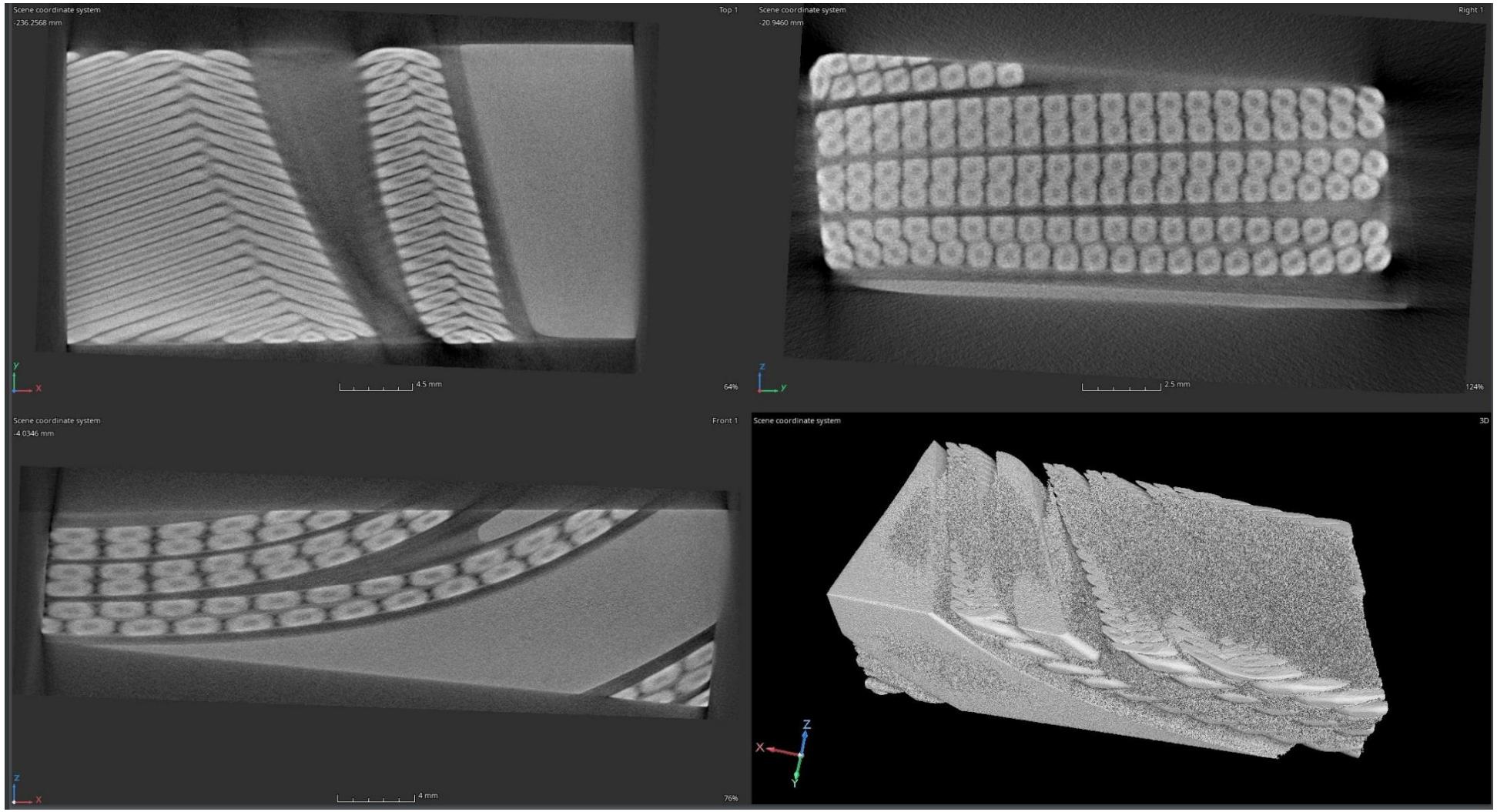




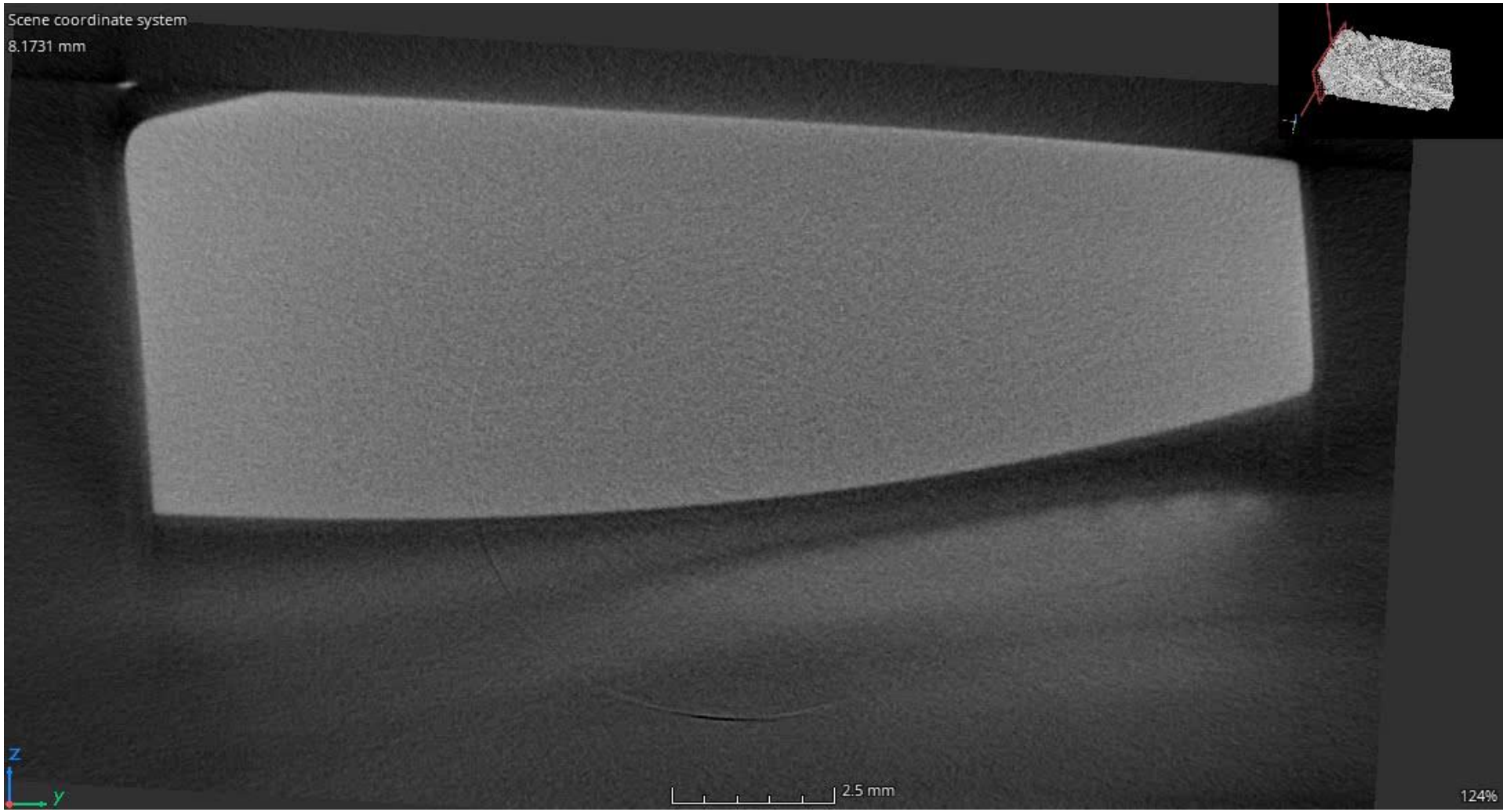

PLEASE NOTE that two lines of the cables were partially removed during the previous polishing thus we are only observing the remaining parts.

# Computed tomography (CT)

- No events observed during the CT analysis
- Videos in 3 different orientations added to the EDMS document

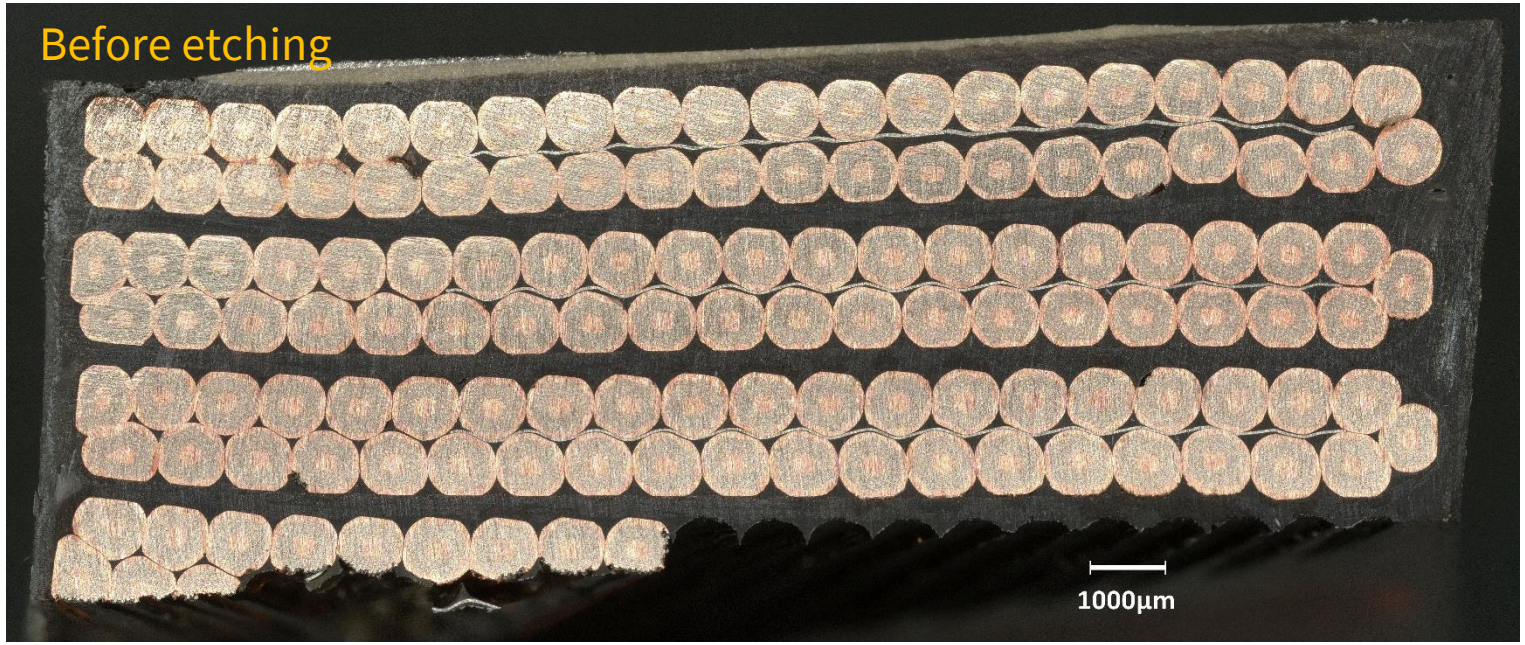


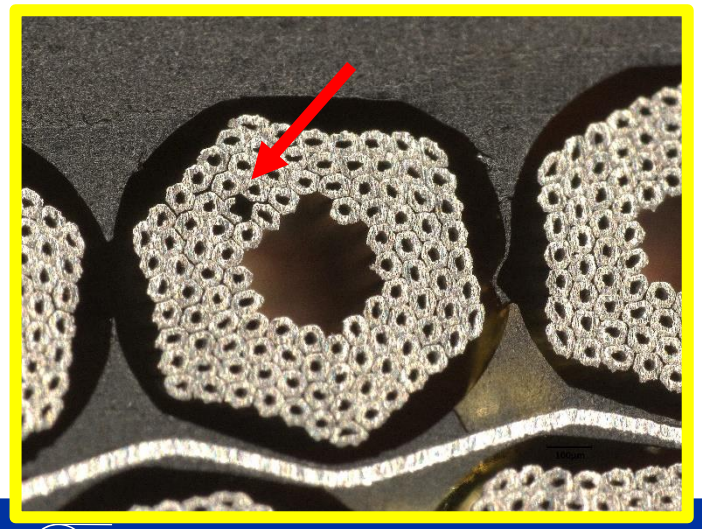
# Computed tomography (CT)

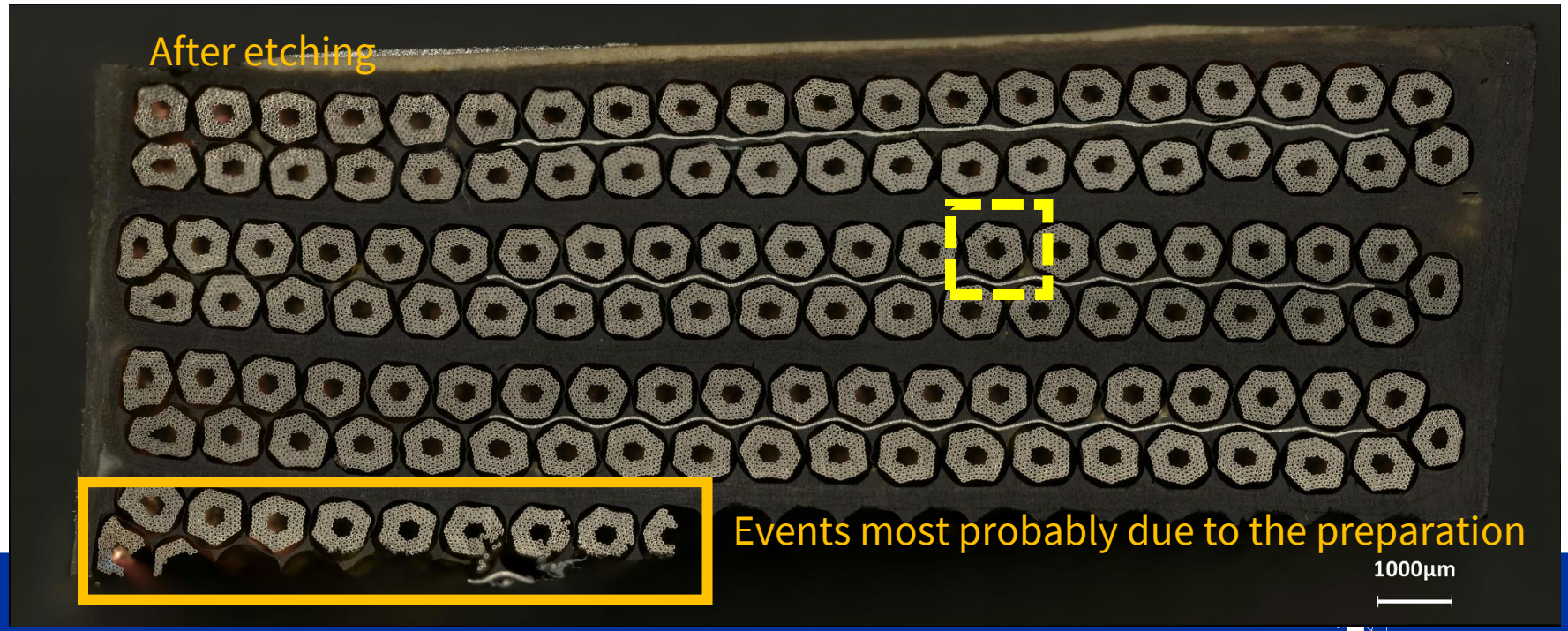


# Deep copper etching

- Around 400 µm of copper has been dissolved
- Events observed in the orange-highlighted zone were considered as a residual of the preparation
- In the remaining rows just one event observed – partially collapsed filament (highlighted by yellow frame and red arrow)



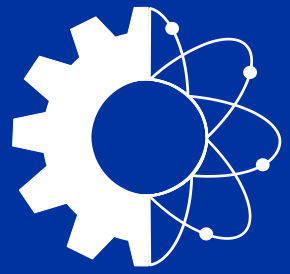





# Conclusions

- Extended analysis of the pole turn region in MQXFA13 – AUP227 coil was performed by deep copper etching and computed tomography
- The computed tomography analysis haven’t shown the presence of any defects
- Deep copper etching analysis revealed just one, partially collapsed filament

**NOTE – more events might have occurred in the analysed area, but due to the previous analysis, where the sample was ground, two first rows were partially removed.**



# Engineering Department