UNIVERSITÀ DEGLI STUDI FIRENZE
DIEF DIPARTIMENTO DI INGEGNERIA INDUSTRIALE

ADDITIVE 4 BIOMEDICAL

October 17th–18th, 2022

LASER POWDER BED FUSION TO PRODUCE ADDITIVE MANUFACTURED TANTALUM COMPONENTS: FROM BIOMEDICAL TO NUCLEAR PHYSICS APPLICATIONS

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SC 09/A3 CoCo AM Additive Manufacturing

ASSOCIAZIONE NAZIONALE DISEGNO E METODI

COMET

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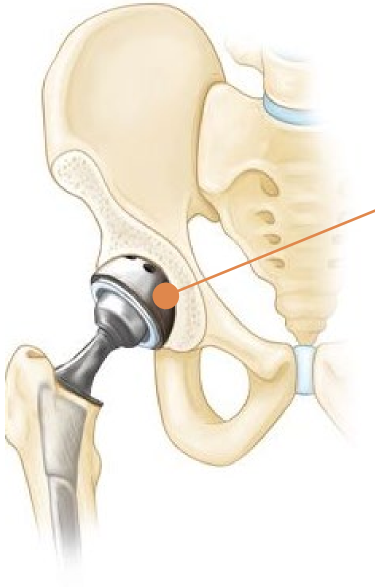
Outlook

- **Tantalum as a biomaterial**
- **Laser Powder Bed Fusion (LPBF) to produce tantalum components**
- **Case study: LPBF to optimize tantalum structural components at LNL SPES ISOL facility**
  - Design optimization and FEM analysis
  - LPBF process feasibility
  - LPBF production and post-processing
  - CMM verification
  - Preliminary High Temperature (HT) test
- **Conclusion and perspectives**

TANTALUM AS A BIOMATERIAL

- **1802** – Discovery
- **1940s** – First reported use as a component of surgical sutures by Burke
- **1950s** – Brånemark osseointegration research
- **1990s** – First trabecular metal implants



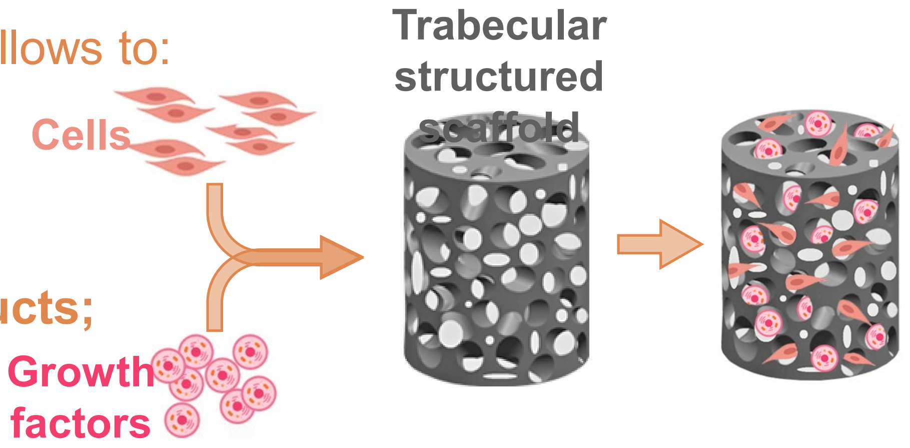
Tantalum characteristics as a **biomaterial**:

- exceptional **biocompatibility**;
- excellent **corrosion resistance**;
- favorable **mechanical ductility**;
- **osteoconductivity, osteoinductivity, and angioinductivity**;
- easily forms a **self-passivating** surface oxide layer (Ta_2O_5) that facilitates the **formation of bone-like apatite coatings**

TANTALUM BIOMEDICAL APPLICATIONS AND TRACEBECULAR STRUCTURES

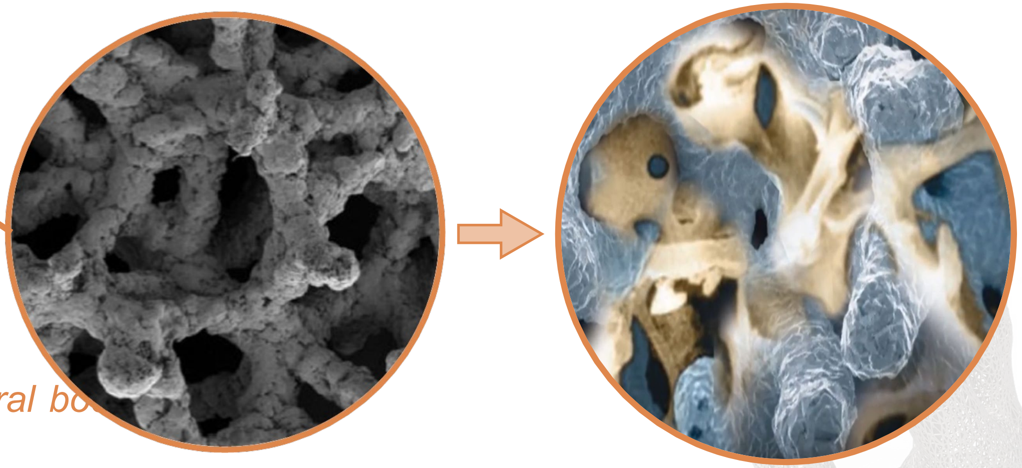
The **interconnected porosity** of **trabecular metal structures** allows to:

- promote **cell adhesion** and **migration**;
- enhance **vascularization;**
- facilitate **diffusion** of **vital cell nutrients** and **secreted products;**
- support **mechanical** and **biological functions.**



a)

b)

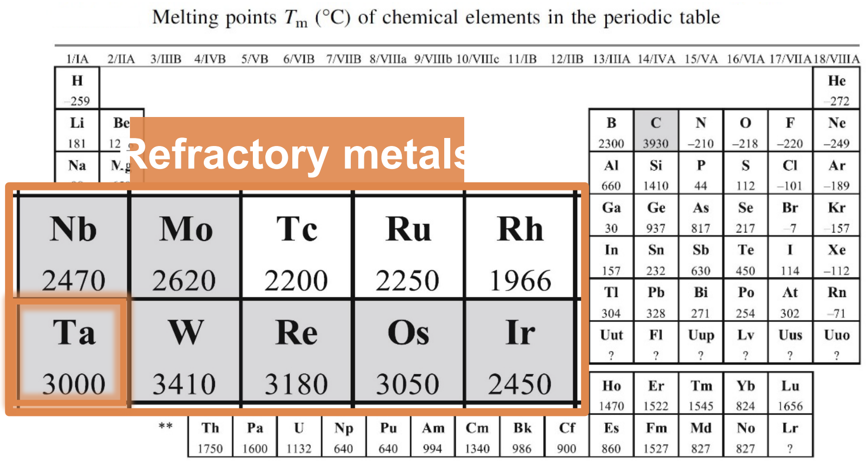


Tantalum medical devices:
a) Porous tantalum devices for use in cervical and lumbar fusion and vertebral body replacement
b) Porous tantalum shell with a cementable polyethylene liner for use in revision acetabular surgery
Source: courtesy of Zimmer Biomet.

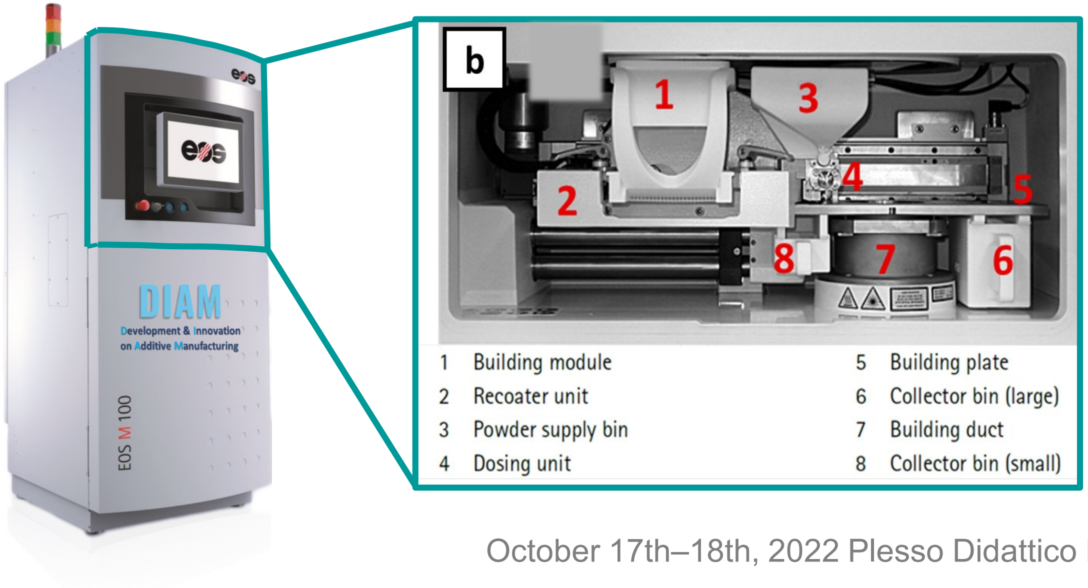
WHY LASER POWDER BED FUSION?

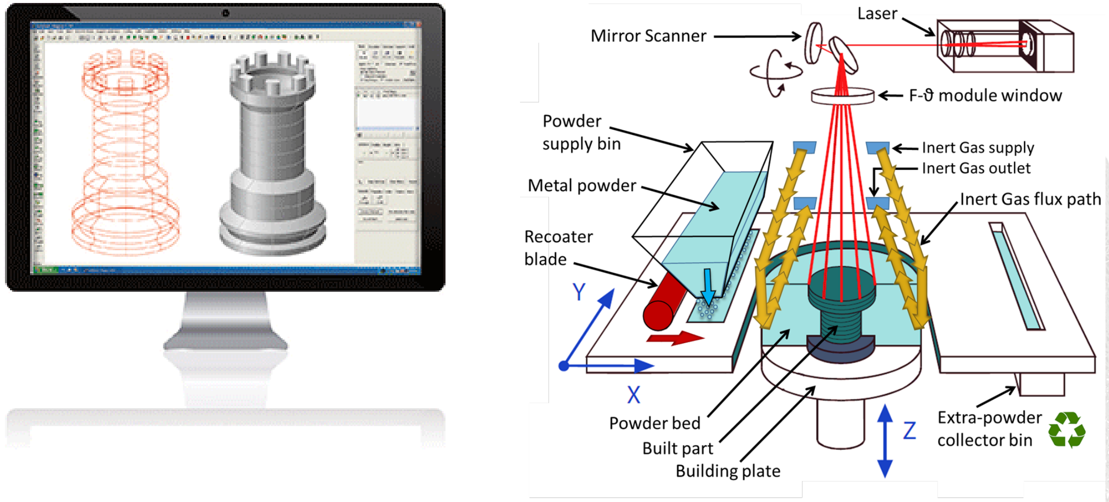
Tantalum structures are **complicated** to **process** via conventional methods because of:

- Tantalum very **high melting temperature** (≈3000 °C);
- Tantalum extreme **affinity** towards **oxygen**.



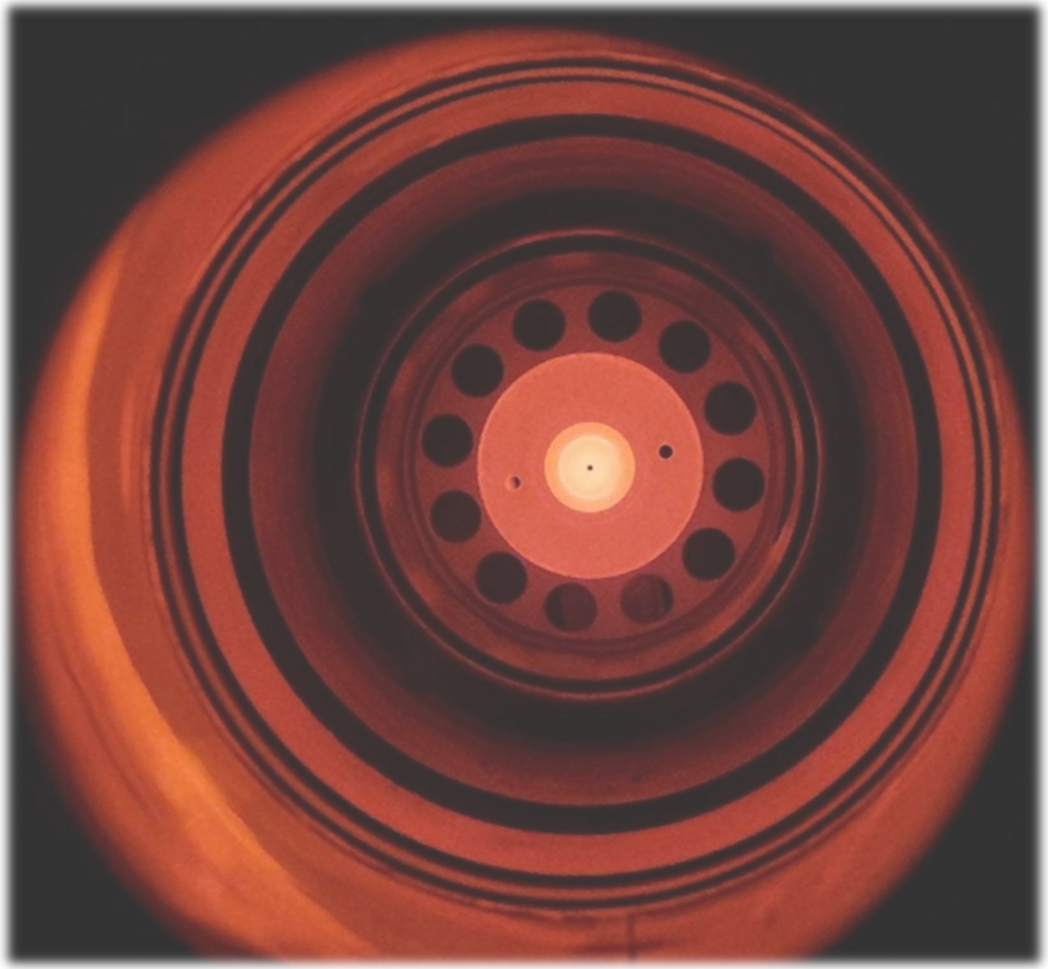
The **Laser Powder Bed Fusion (LPBF)** is an AM technology suitable to fabricate **porous tantalum components** with **well designed and highly controlled architectures**.





CASE STUDY: TANTALUM AND LPBF IN NUCLEAR PHYSICS

Tantalum is a refractory metal, therefore it is suitable for high temperature applications.



SPES FACILITY AT INFN - LNL

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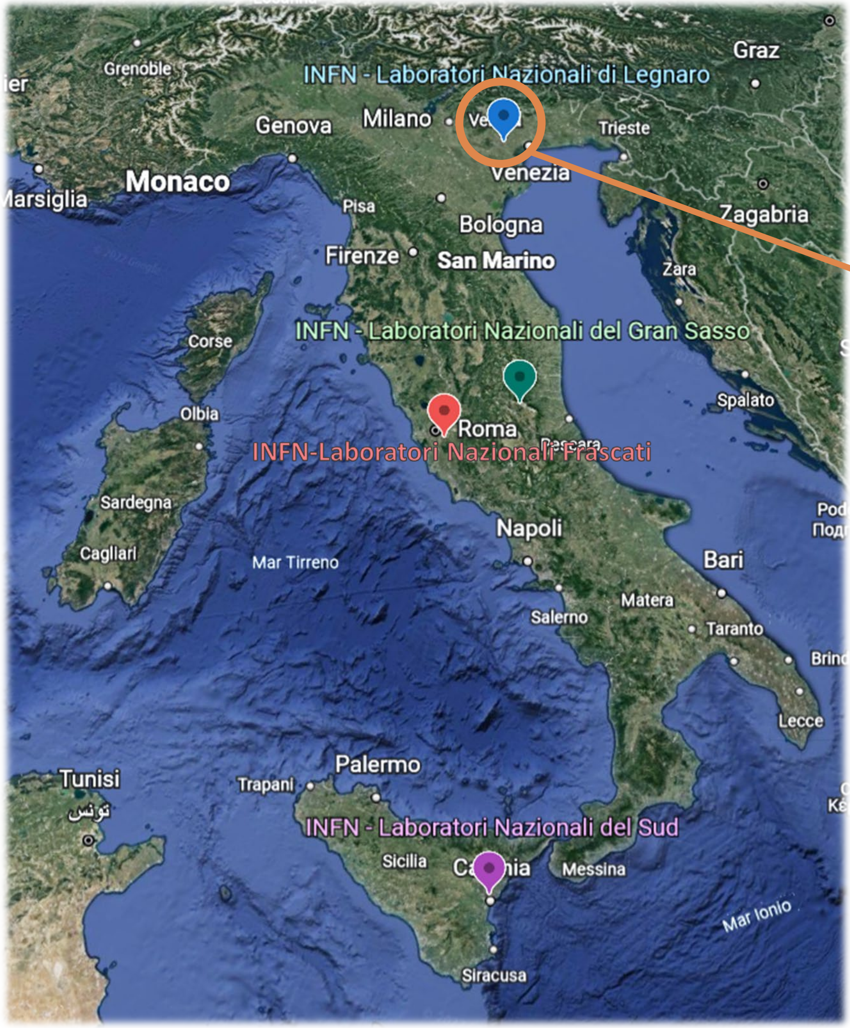
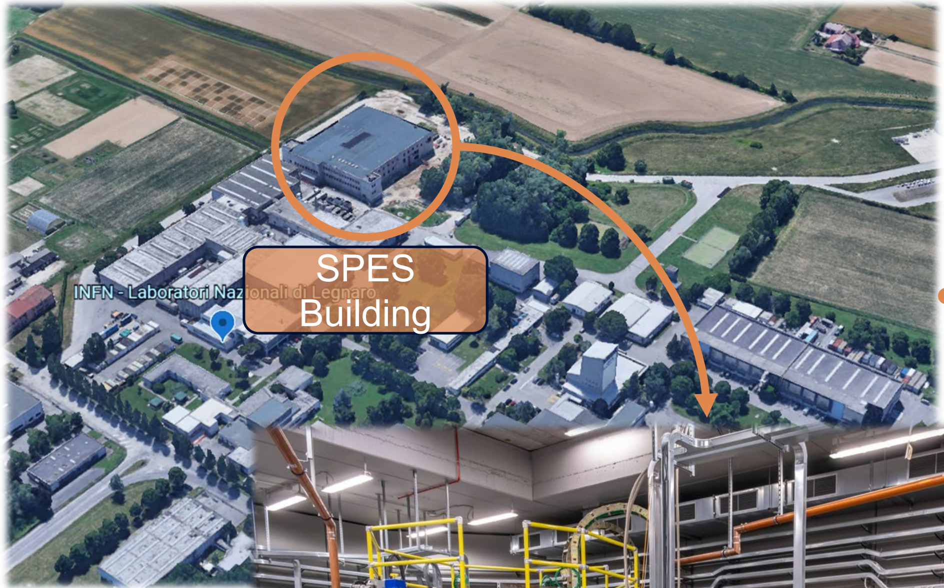
INFN national laboratories





INFN
LABORATORI NAZIONALI DI LEGNARO

Cyclotron SPES building

SPES project

October 17th–18th, 2022 Plesso Didattico Morgagni, Viale Morgagni, 44-48, 50134 Firenze

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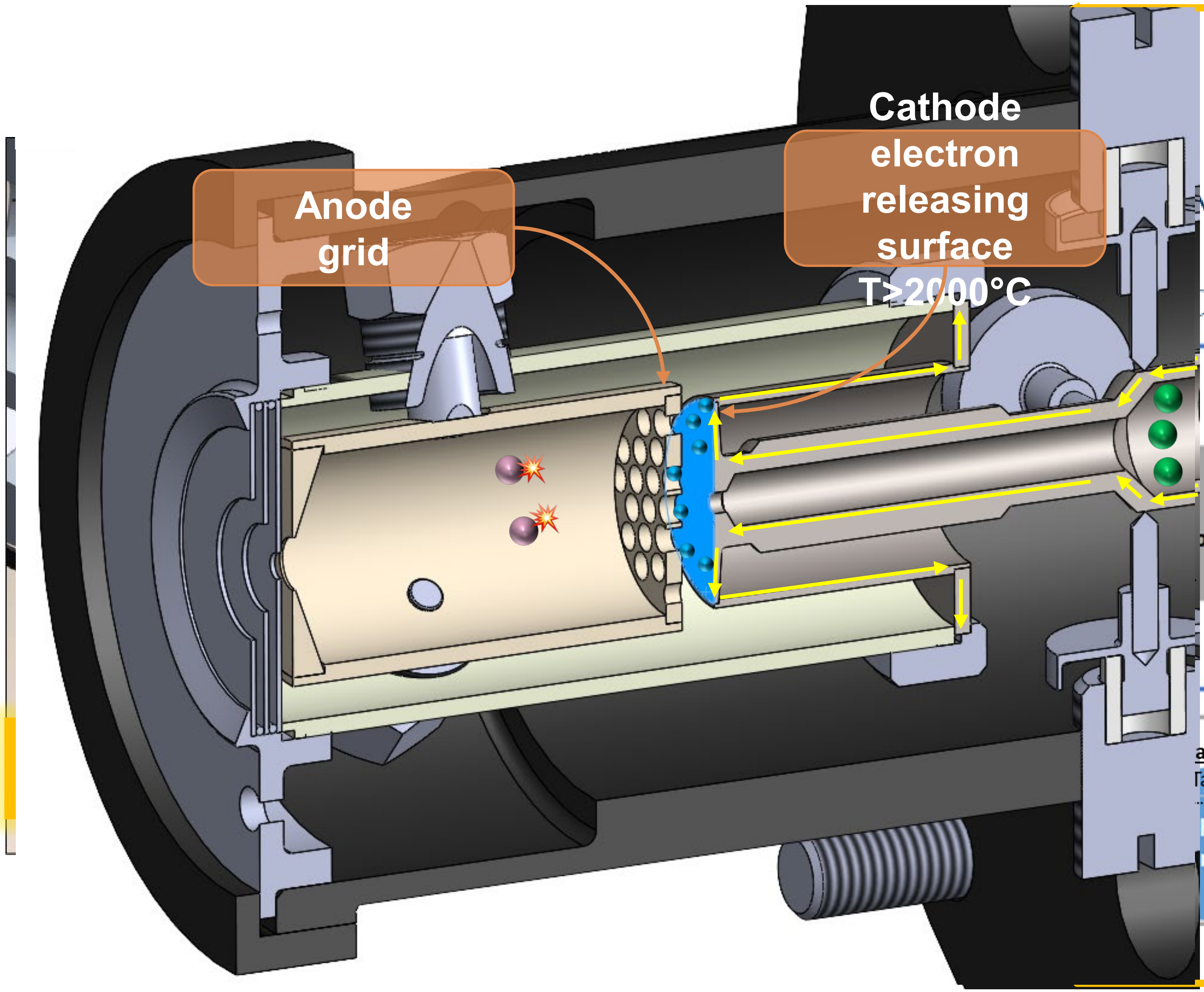
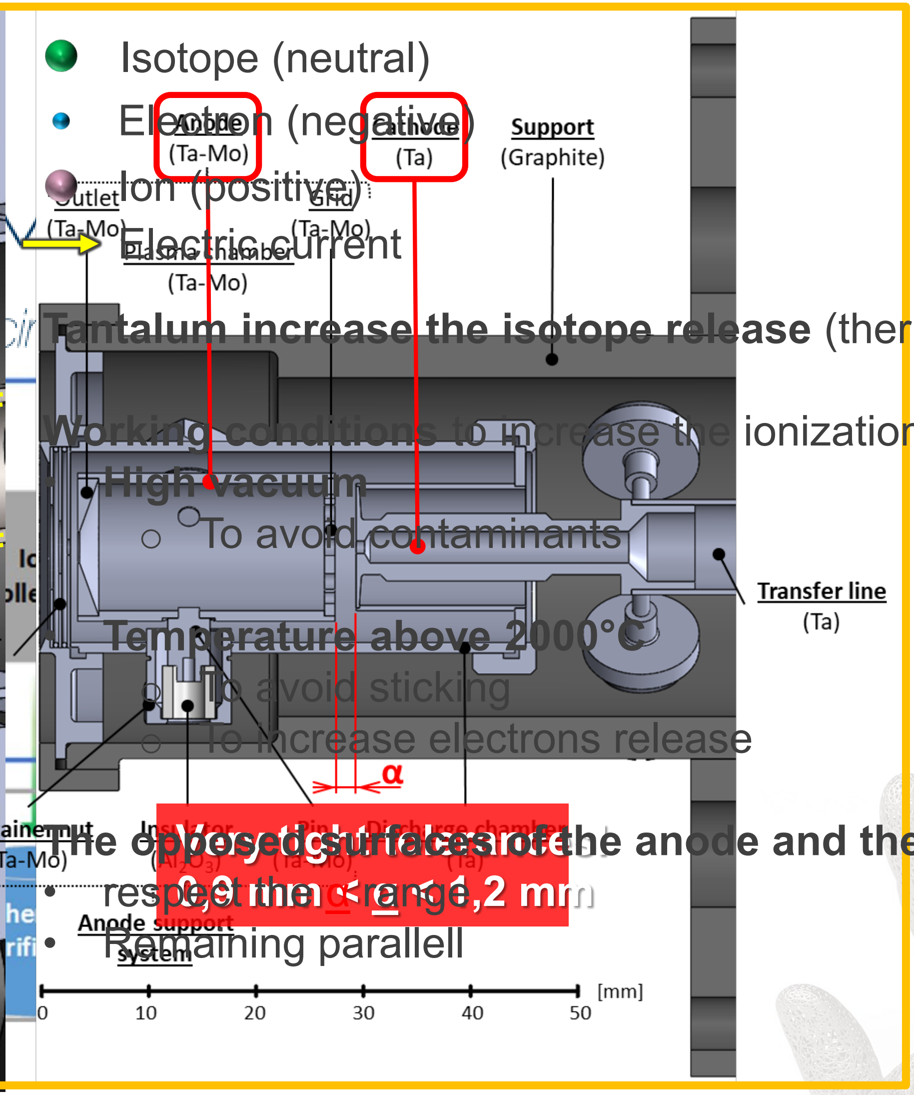
ISOTOPE SEPARATION ON-LINE FOR NUCLEAR MEDICINE





- Isotope (neutral)
- Electron (negative)
- Ion (positive)
- Electric current

Tantalum increase the isotope release (thermionic e

Working conditions to increase the ionization efficien

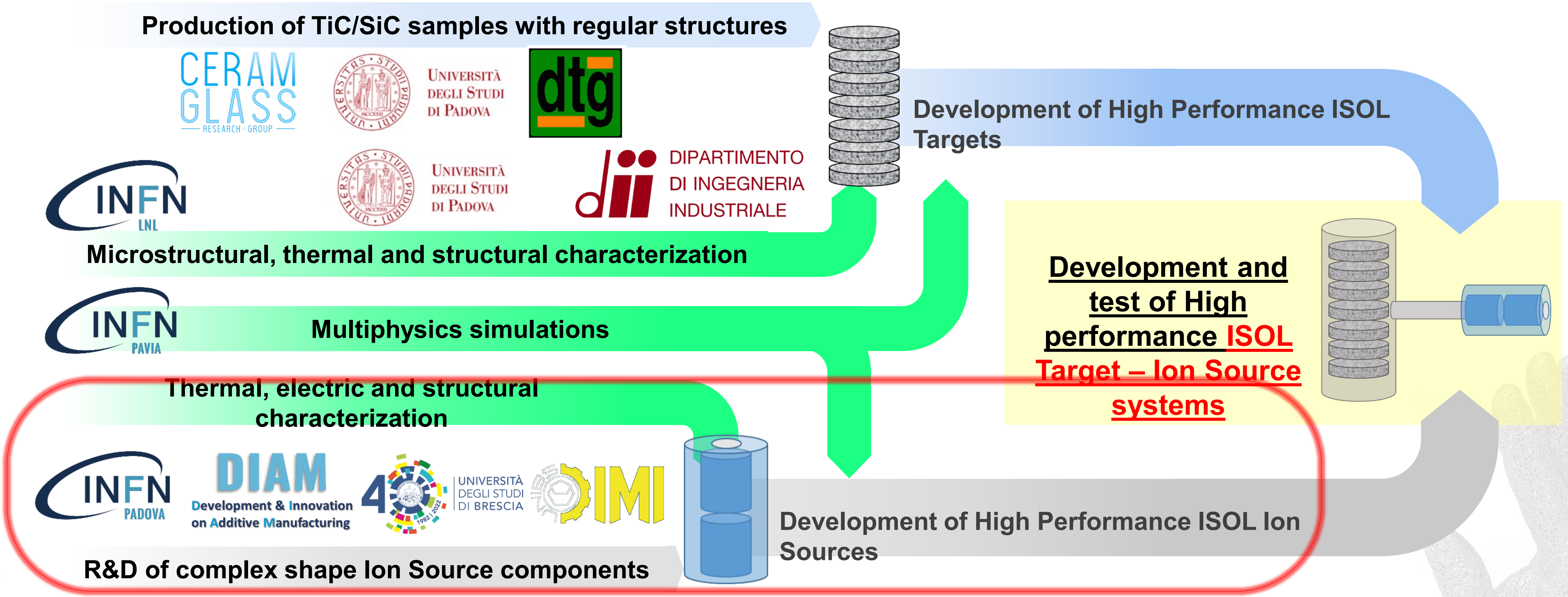
- **High vacuum**
  - To avoid contaminants
- **Temperature above 2000°C**
  - To avoid sticking
  - To increase electrons release

The opposed surfaces of the anode and the cathod

- respect the range
- Remaining parallell

HISOL RESEARCH CONTEXT

HISOL → **H**igh performance **ISOL** systems for the production of radioactive ion beams



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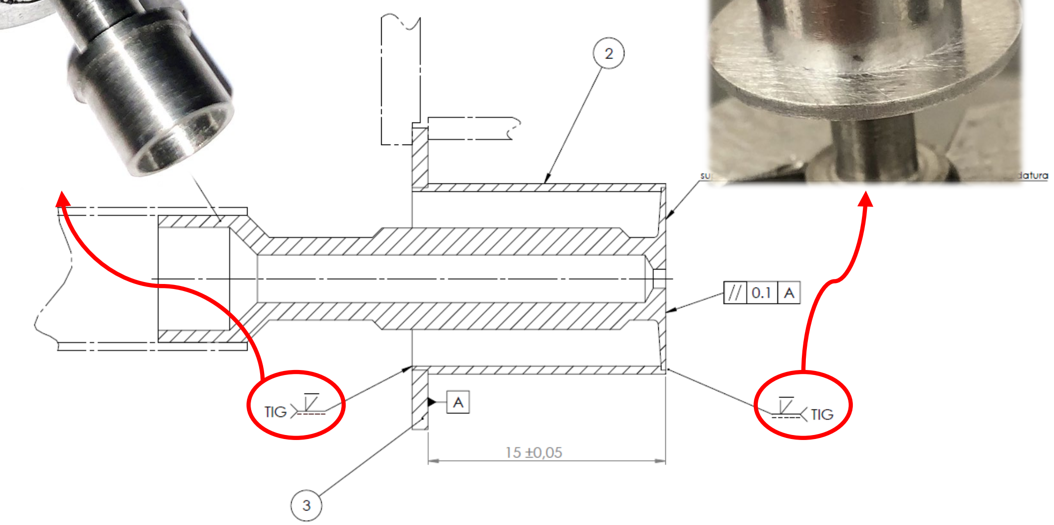
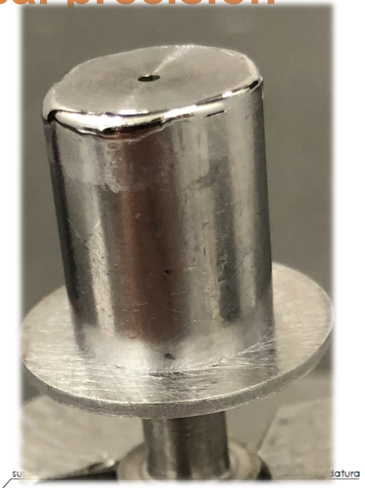
Design optimization and FEM analysis

The **traditional process route** foresees the joining of three different components through a TIG welding causing:

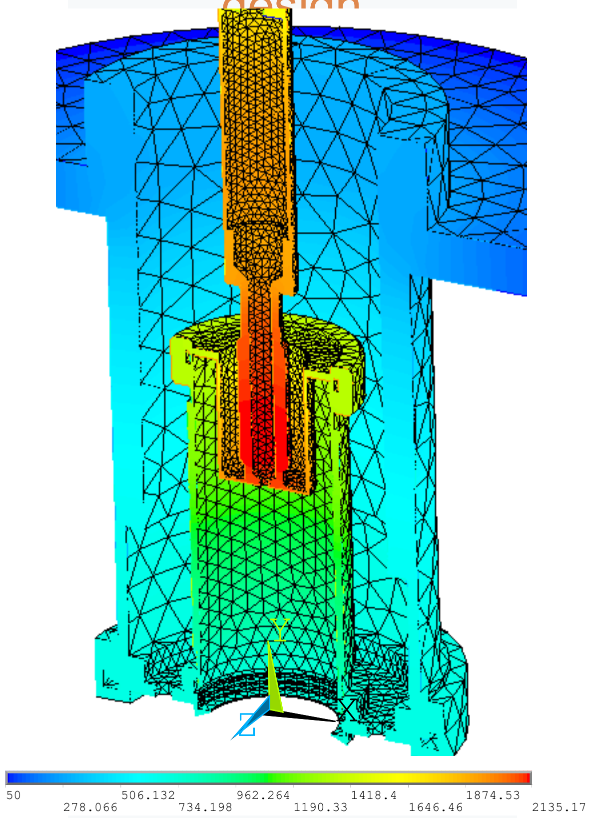
- **Distorsions**;
- **Lack dimensional / geometrical precision**

Reliability ✗
Repeatability ✗

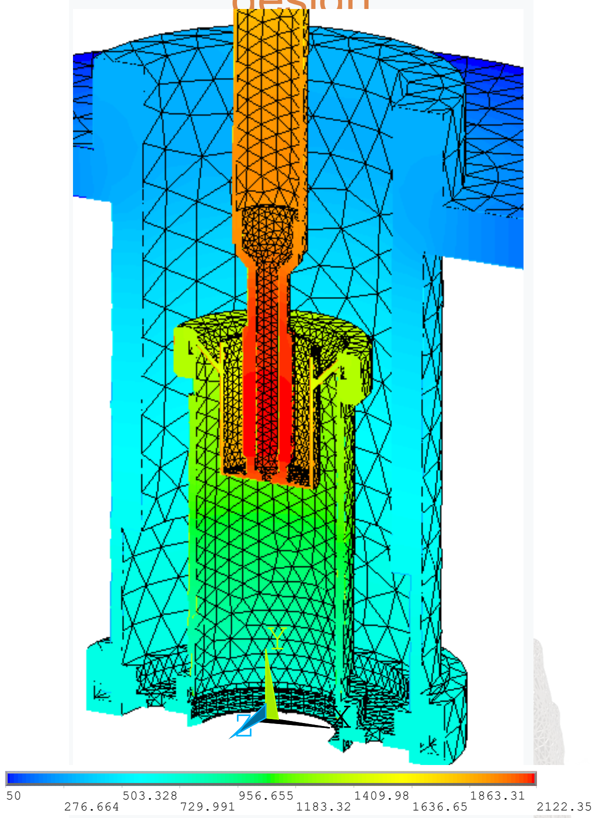




Current design



Proposed AM design

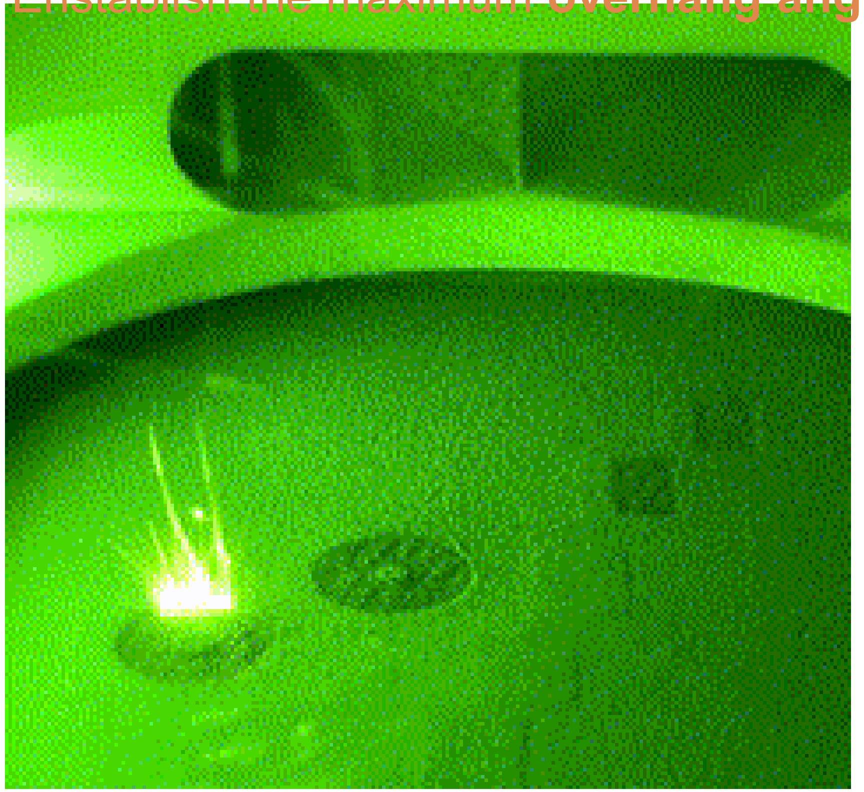


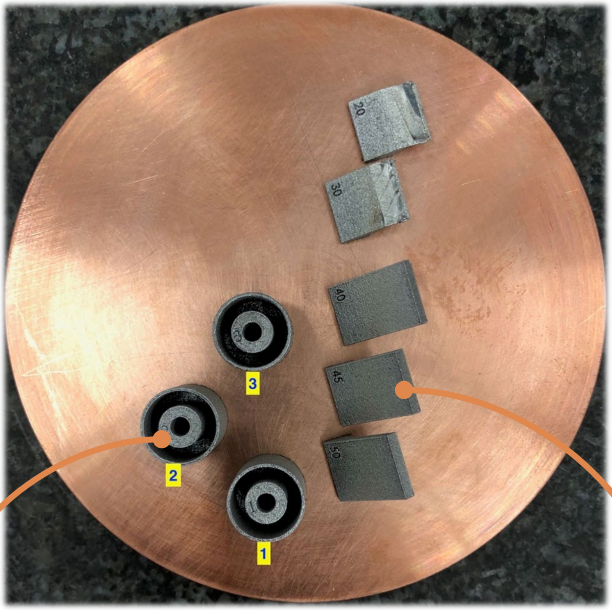
The **Additive Manufacturing** allows to overcome the intrinsic limits of the current design making **more repitible and reliable** the FEBIAD ion source **performance**.

LPBF PROCESS FEASIBILITY

The aim was to set the **process parameters** in order to:

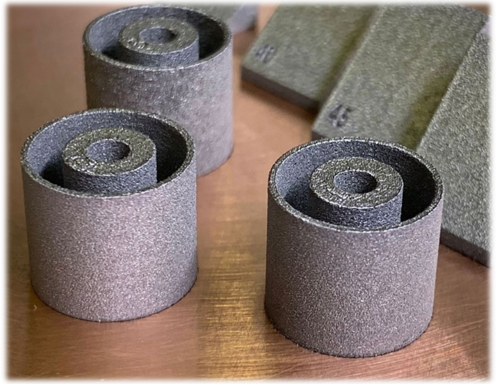
- Reduce the **surface roughness**;
- Obtain the **dimensions** as close as possible to the nominal ones;
- Enstablish the maximum **overhang angle**.

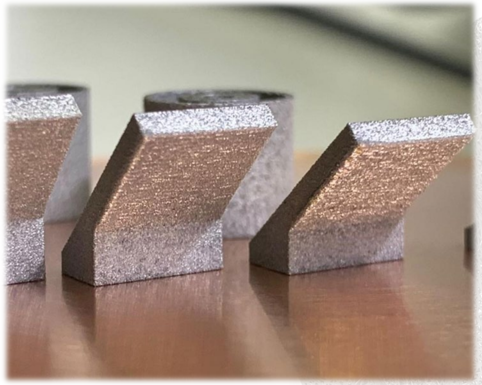




Three concentric cylinders were fabricated with **different process parameters**

Inclined walls were produced with different angles



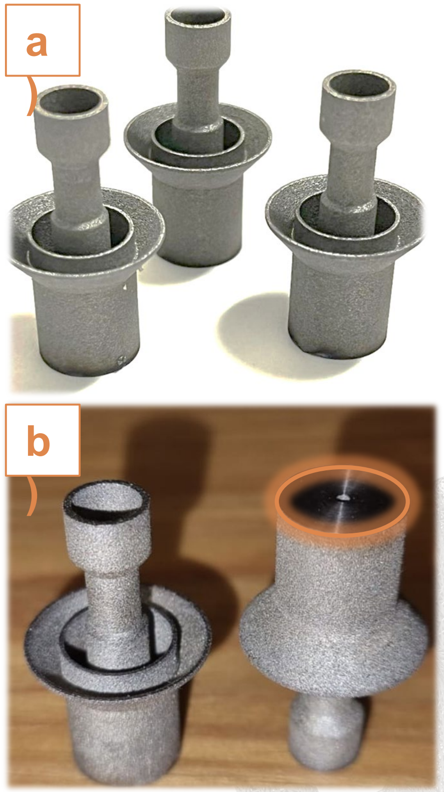


LPBF PRODUCTION AND POST-PROCESSING

The **excess Ta powder** was removed, sieved and finally **recycled**

Post-processing:

a) the samples were removed from the copper platform by EDM
b) the HT surfaces of the cathode were machined by a lathe



CMM DIMENSIONAL/GEOMETRICAL VERIFICATION

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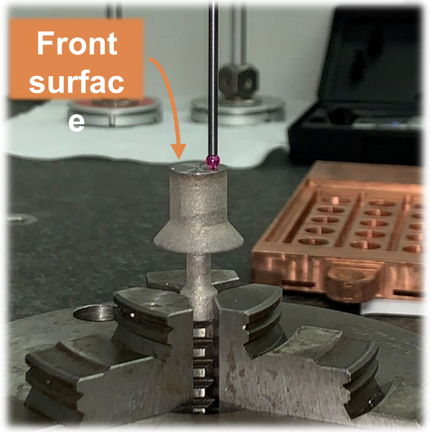
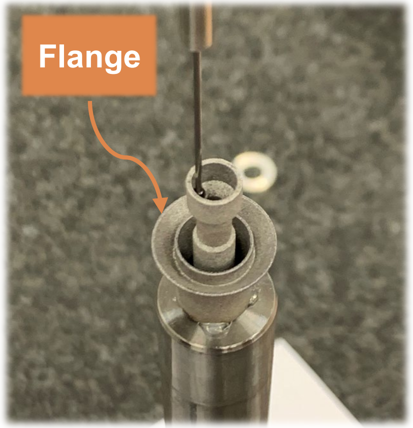




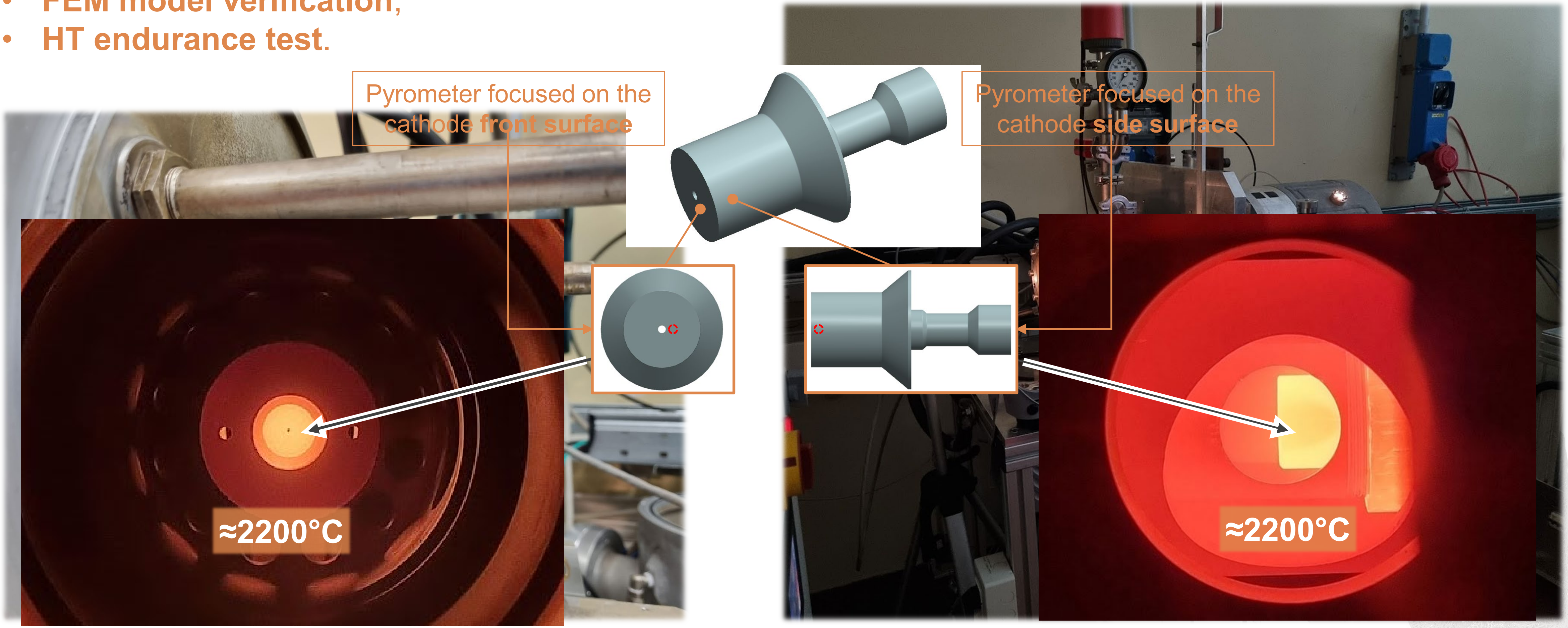
The **geometrical/dimensional features** of the AM cathodes are **comparable** with respect to traditional ones, except for the **perpendicularity of the front surface with respect to the cathode axis**: this feature presents **lower values** for the AM cathodes.

	External diameter	Cone angle	Front surface flatness	Flange flatness	External surface cylindicity	Perpendicularity ext surf - cyl axis
Nominal	12,000	80	-	-	-	-
LPBF technology	12,018	79,549	0,003	0,035	0,04	**0,021**
Traditional technology	12,023	-	0,0759	0,0432	0,0363	**0,145**

Preliminary High Temperature test

The **experimental setup** at LNL allows to replicate the **real working condition** of the component. (T > 2000°C and under high vacuum)

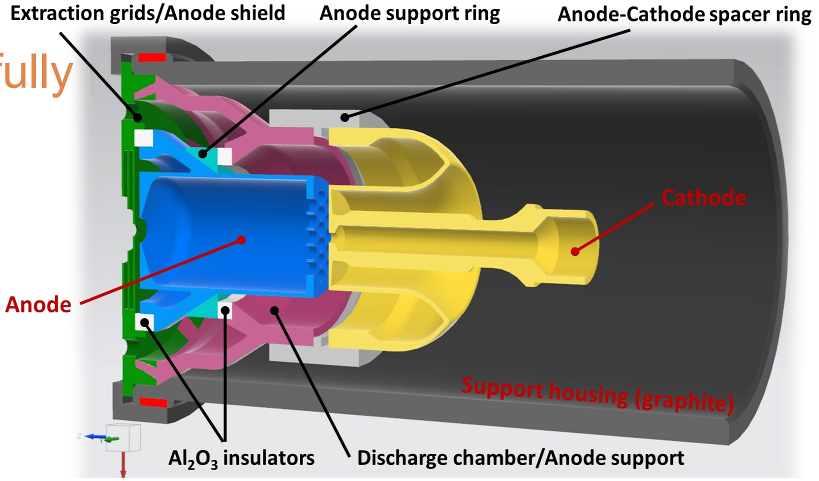
- **FEM model verification**;
- **HT endurance test**.



CONCLUSION AND PERSPECTIVES

Tantalum components were sucessfully produced by LPBF and tested:

- The cathode was designed for the LPBF process
- The LPBF process feasibility allowed to choose the best process parameters;
- CMM verification allowed to measure the dimensional/geometrical features;
- HT measurements were performed;
- The endurance HT test was successfully



Future perspectives:

- Design development;
- Accurate assembly verifications;
- Off-line and On-line ionization tests.

BIBLIOGRAPHY

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Porous tantalum scaffolds: Fabrication, structure, properties, and orthopedic applications

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Hairui Gao [a,1], Jingzhou Yang [a,e,f,*,1], Xia Jin [a,d,1], Xinhua Qu [b], Faqiang Zhang [a], Dachen Zhang [e,f], Haishen Chen [e,f], Huiling Wei [e,f], Shupei Zhang [e,f], Weitao Jia [c,*], Bing Yue [b,*], Xiaopeng Li [g,*]

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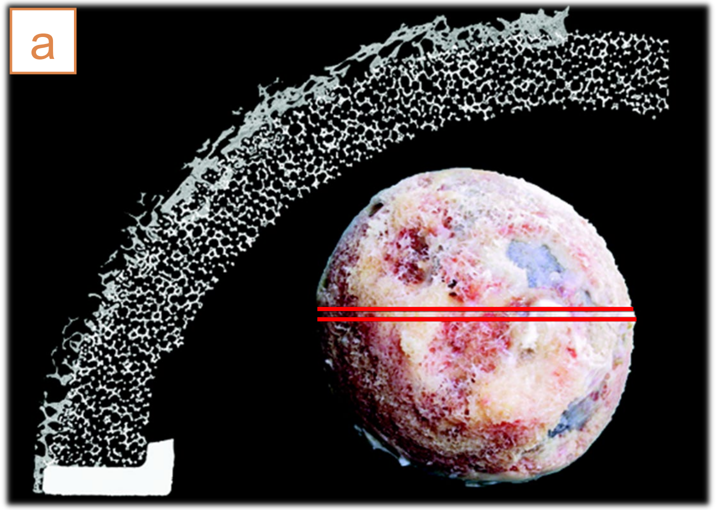
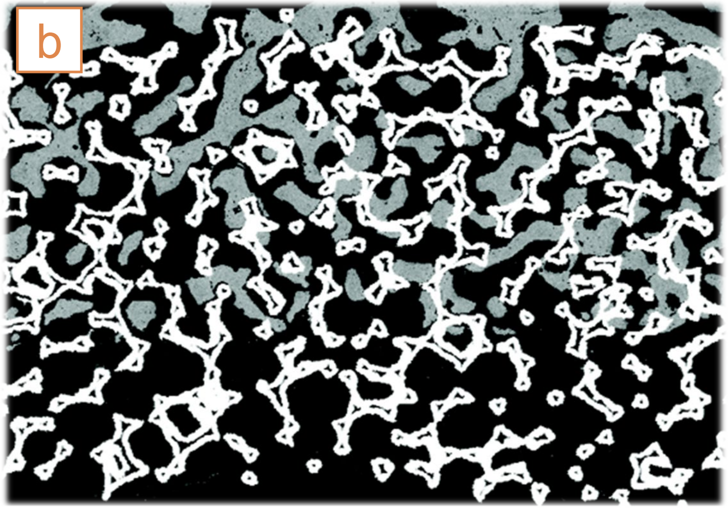
Thank you for your kind attention!

EXTRA SLIDES



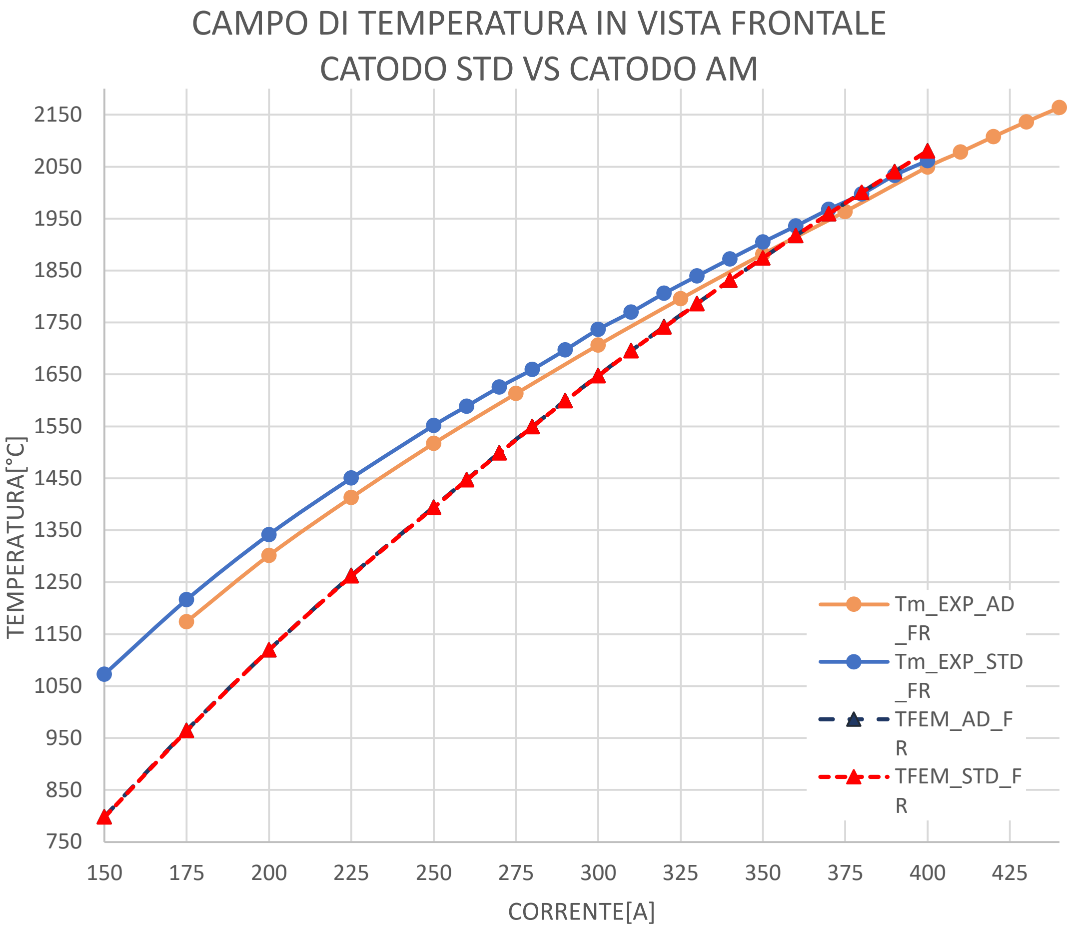


a) Backscattered scanning electron photomicrograph of a coronal histologic section of the monoblock tantalum cup taken through the region indicated by the parallel red line. There is a uniform, although mostly shallow, bone ingrowth along the porous tantalum interface and an absence of calcified tissue in the dome region.

b) Backscattered scanning electron photomicrograph of a region from a different histologic section, illustrating extensive new-bone formation within the tantalum pores.

DOI: 10.2106/00004623-200412002-00017

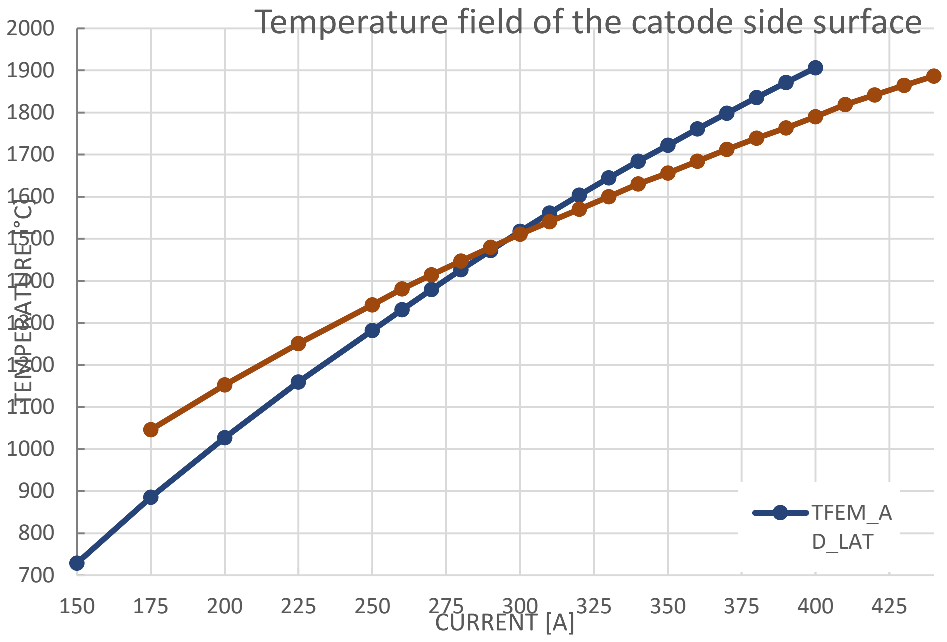
EXTRA SLIDES

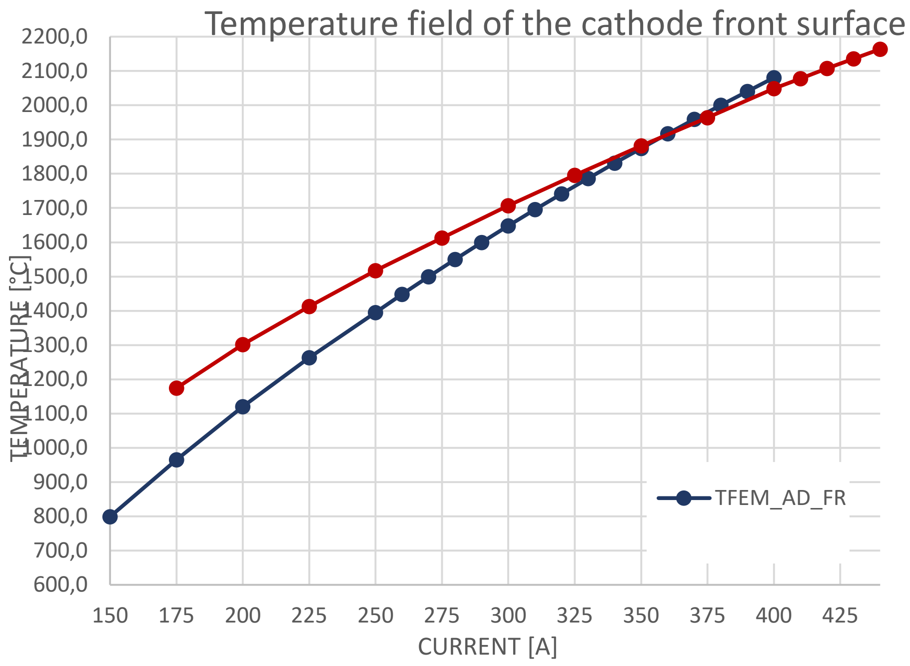


EXTRA SLIDES

Cathode	Diameter ext cylinder (Ø12 nominal)	Cilindricity ext cylinder	Flange flatness	Top flatness	Perpendicularity Top surf-cyl axis
Std 1	12,0160	0,0395	0,154	0,0208	0,2103
Std 2	12,0358	0,0303	0,0305	0,0339	0,1684
Std 3	12,0158	0,0391	0,0432	0,0177	0,0573
AM 1	12,021	0,0290	0,0340	0,004	0,0360
AM 2	12,014	0,0200	0,0350	0,002	0,005

EXTRA SLIDES





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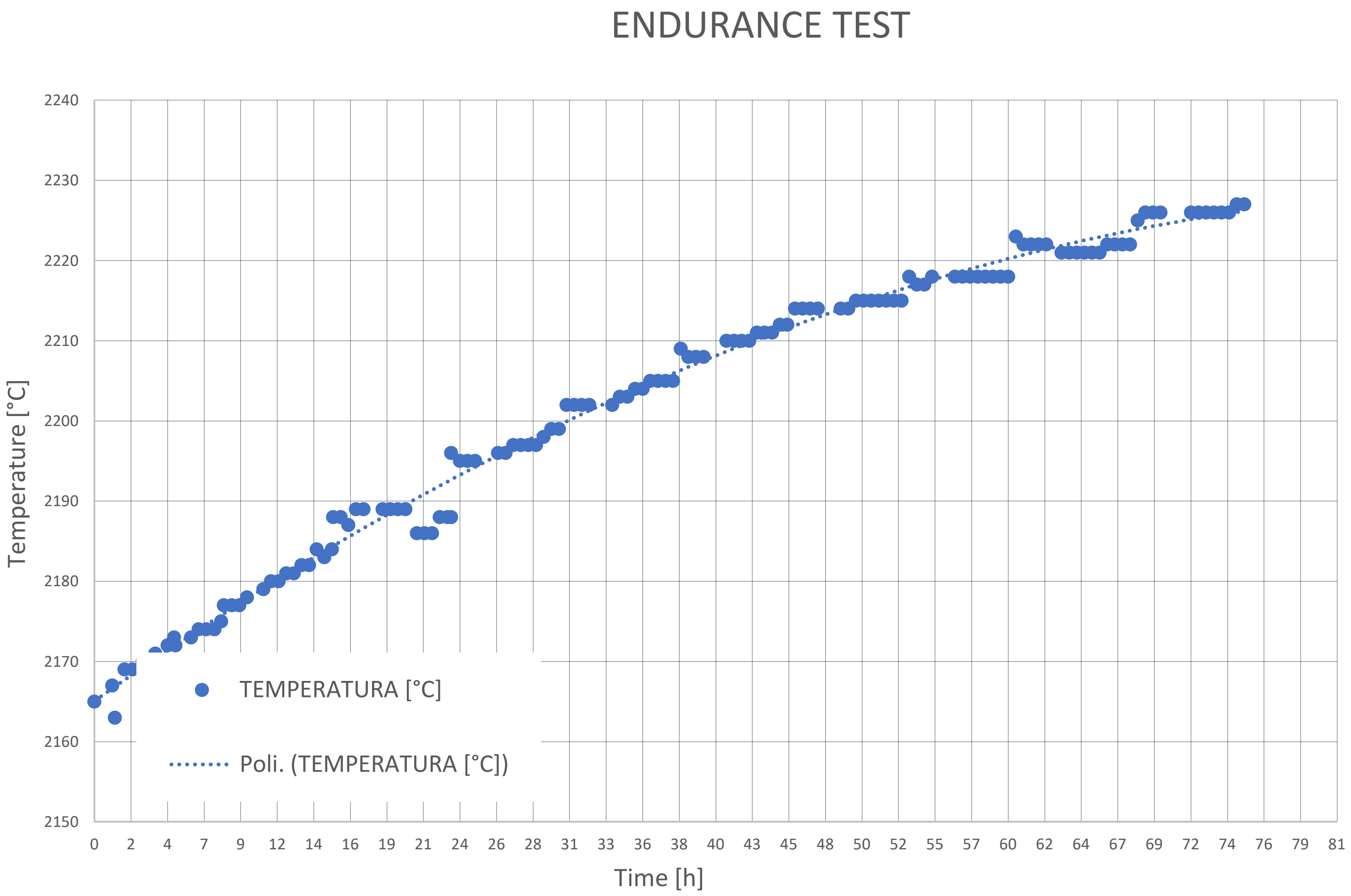

EXTRA SLIDES

Scanning strategies