Development and Innovation on Additive Manufacturing

AM for Accelerators

INFN-ACCELERATORI

Eng. Adriano Pepato

INFN PD - DIAM

Outline

- The Additive Manufacturing technology (for metals): history, benefits and limits, the DIAM Lab activity.
- The materials characterisation, the Projects and the Collaborations.
- Materials, technologies, software analysis.
- The surface finishing of parts.
- Applications for the accelerators community.
- Other applications.
- INFN activity on AM: the internal and the international network.

History of additive manufacturing

1983 – Invention of stereolitography (SL) by Charles Hull

1986 – Invention of Selective Laser Sintering (SLS) by J. Beaman and C. Deckard

1987 – Stereolitography (SL) from 3D Systems

1992 – Selective Laser Sintering (SLS) from DTM (part of 3D Systems)

1994 – Direct Metal Laser Sintering (DMLS) by EOS

1995 – Fraunhofer Institute develope the SLM

2002 – EBM technology by Arcam

2003 – SLM by EOS,
CONCEP LASER ,TRUMPF

NOW

Future ...

Now	Future

- **Wide variety of Material can be used for AM**
  → Polymers, metals, ceramics, composite.
- **Different forms of Materials:**
  → Powder, liquid, wire, ink ...
- **Many technologies are available:**
  → SLS, SLM, EBM, DIW, ...
- **Limited number of Machine and Powder supplier**
- **Main use:**
  → Prototyping; customized productions;

- **Development on "new" processable materials**
  → Alloys designed for AM
- **Continuous optimization of raw materials**
  → According to the process studied
- **360° Development of the process**
  → AI; M&C; Topology optimization; safety; …
- **increase in the number of available suppliers**
  → with relative reduction of market costs
- **Standards for design/production (ISO – ASTM)**
  → Regulation for mass production (?)

The BENEFITS of AM technology

Metal Additive Manufacturing technologies offer many key benefits:

- Increased **design freedom** versus conventional casting and machining.
- The net shape capability helps **creating complex parts** in one step only thus **reducing the number of assembly operations** such as welding, brazing.
- **Light weight structures**, made possible either by the use of lattice design or by designing parts where material is only where it needs to be, without other constraints.
- New functions such as **complex internal channels** or several parts built in one.

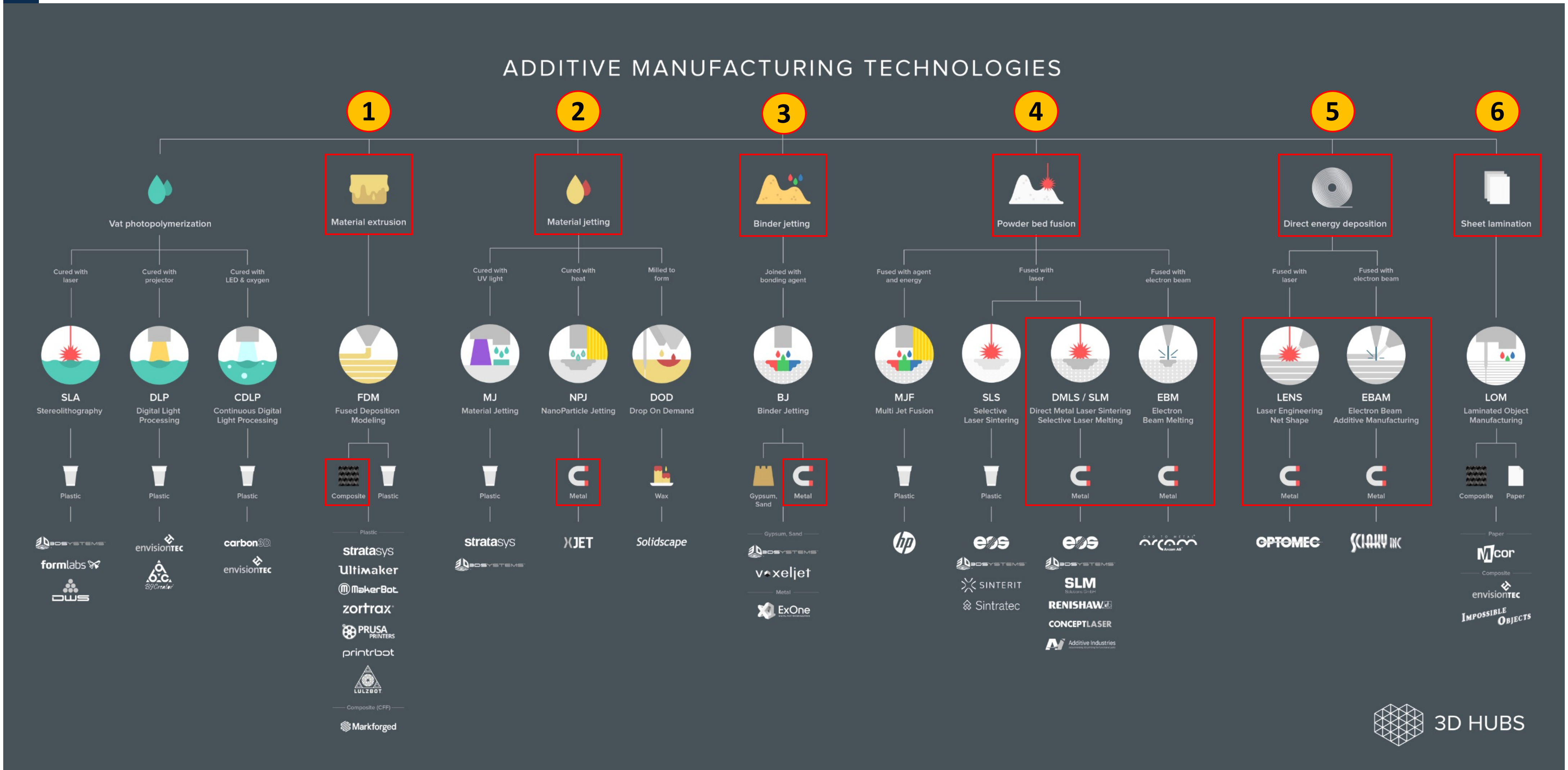
- Net shape process meaning **less raw material consumption**, up to 25 times less versus machining, important in the case of expensive or difficult to machine alloys.
- **No tools needed**, unlike other conventional metallurgy processes which require molds and metal forming or removal tools.

- **Short production cycle time**: complex parts can be produced layer by layer in a few hours in additive machines. The total cycle time including post processing usually amounts to a few days or weeks and it is usually much shorter than conventional metallurgy processes which often require production cycles of several months.

The LIMITS of AM technology

Metal Additive Manufacturing technologies offer also some limitations:

- **Slow build rates** (function of: building high; building area; materials & process parameters)
- High initial investment **cost**
- **Limited component size** and **small build volume**
- **Limited amount of processable materials** – (ex. For SLM - only weldable materials can be used)
- **Requires post-processing** in order to improve the surface finish and quality
- Product and material properties are **machine and process dependent**
- **Residual stresses** and **properties anisotropy** – thermal treatments are needed
- **Lack of standards** for materials, products, characterization and validation



ADDITIVE MANUFACTURING TECHNOLOGIES
1
2
3
4
5
6
Vat photopolymerization
Material extrusion
Material jetting
Binder jetting
Powder bed fusion
Direct energy deposition
Sheet lamination
Cured with laser
Cured with projector
Cured with LED & oxygen
Cured with UV light
Cured with heat
Milled to form
Joined with bonding agent
Fused with agent and energy
Fused with laser
Fused with electron beam
Fused with laser
Fused with electron beam
SLA Stereolithography
DLP Digital Light Processing
CDLP Continuous Digital Light Processing
FDM Fused Deposition Modeling
MJ Material Jetting
NPJ NanoParticle Jetting
DOD Drop On Demand
BJ Binder Jetting
MJF Multi Jet Fusion
SLS Selective Laser Sintering
DMLS / SLM Direct Metal Laser Sintering Selective Laser Melting
EBM Electron Beam Melting
LENS Laser Engineering Net Shape
EBAM Electron Beam Additive Manufacturing
LOM Laminated Object Manufacturing
Plastic
Composite
Metal
Wax
Gypsum, Sand
Paper
3D HUBS

Additive Manufacturing Technologies

1. **Material Extrusion (MEX)** = Ink/Wire is selectively dispensed through a nozzle/orifice.
   - DIW = Direct Ink Writing; ADAM = Atomic Diffusion Additive Manufacturing

2. **Material Jetting (MJT)** = droplets of feedstock material are selectively deposited.
   - NPJ = NanoParticle Jetting

3. **Binder Jetting (BJT)** = a liquid bonding agent is selectively deposited to join powder materials.

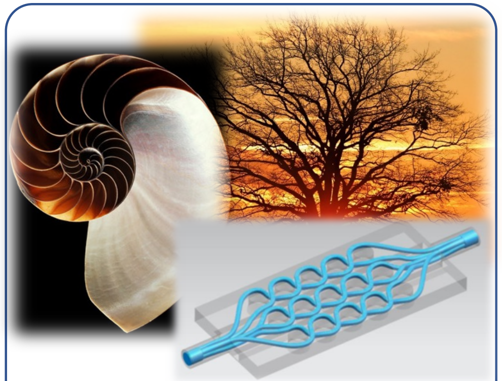
4. **Powder Bed Fusion (PBF)** = thermal energy selectively fuses regions of a powder bed.
   - DMLS/SLM = Selective Laser Melting; EBM = Electron Beam Melting

5. **Direct Energy Deposition (DED)** = focused thermal energy to melt the materials as they're being deposited.
   - LENS = Laser Engineered Net Shape; EBF3 = Electron Beam Freeform Fabrication

6. **Sheet Lamination (SHL)** = sheets of material are bonded to form a part.

4 Powder Bed Fusion (PBF) = thermal energy selectively fuses regions of a powder bed.

L-PBD = Laser Powder Bed Fusion



A NEW WAY TO DESIGN

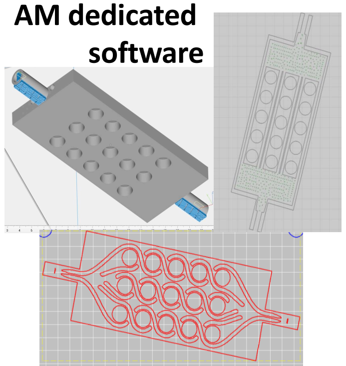
Design with more freedom:

- Complex Geometry
- Light Weight structures
- Internal cooling channels
- Using Topological Optimization software

STL file

ASTM standard F2792-10:
"Process of joining materials to make objects from **3D model data**, usually **layer upon layer** as opposed to **subtractive manufacturing process.**

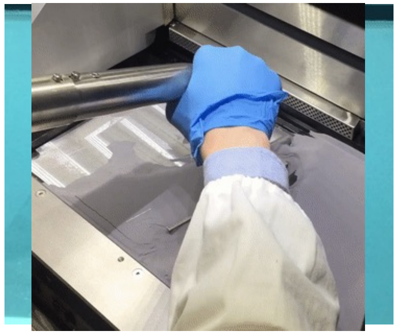
AM dedicated software



DATA PREPARATION

- Part orientation
- Support generation
- Slicing (CLI → SLI)
- Assignment of process parameters

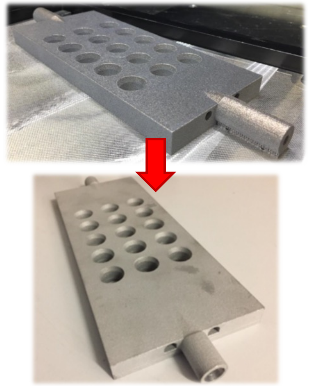
SLI file



MACHINE TOOLING & PRODUCTION PROCESS

- Chamber preparation before the process
- L-PBF production process
- Removal of Platform with parts and cleaning

PART



POST PROCESSING

- Stress Relief
- Removal of parts from the Platform
- Removal of Supports
- Surface refinement

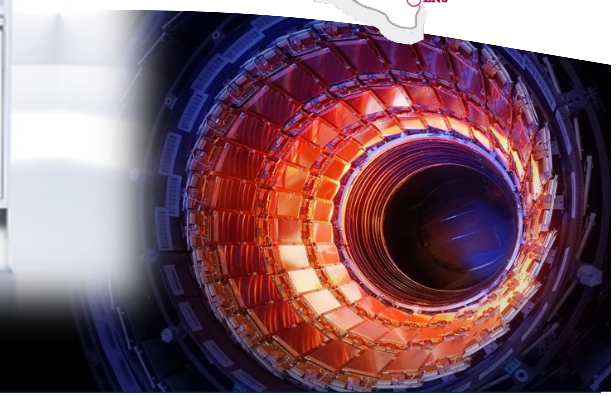
Project Phases

Production Phases

INFN – *National Institute for Nuclear Physics*

INFN PADOVA **DIAM**

***D**evelopment and **I**nnovation on **A**dditive **M**anufacturing*



DIAM workgroup

Head of the DIAM workgroup

Dirigente Tecnologo
Eng. ADRIANO PEPATO

Primo Tecnologo
Eng. RAZVAN DIMA

Post-doctoral Research Fellows

Eng. MASSIMILIANO BONESSO

Eng. PIETRO REBESAN

PhD Candidates

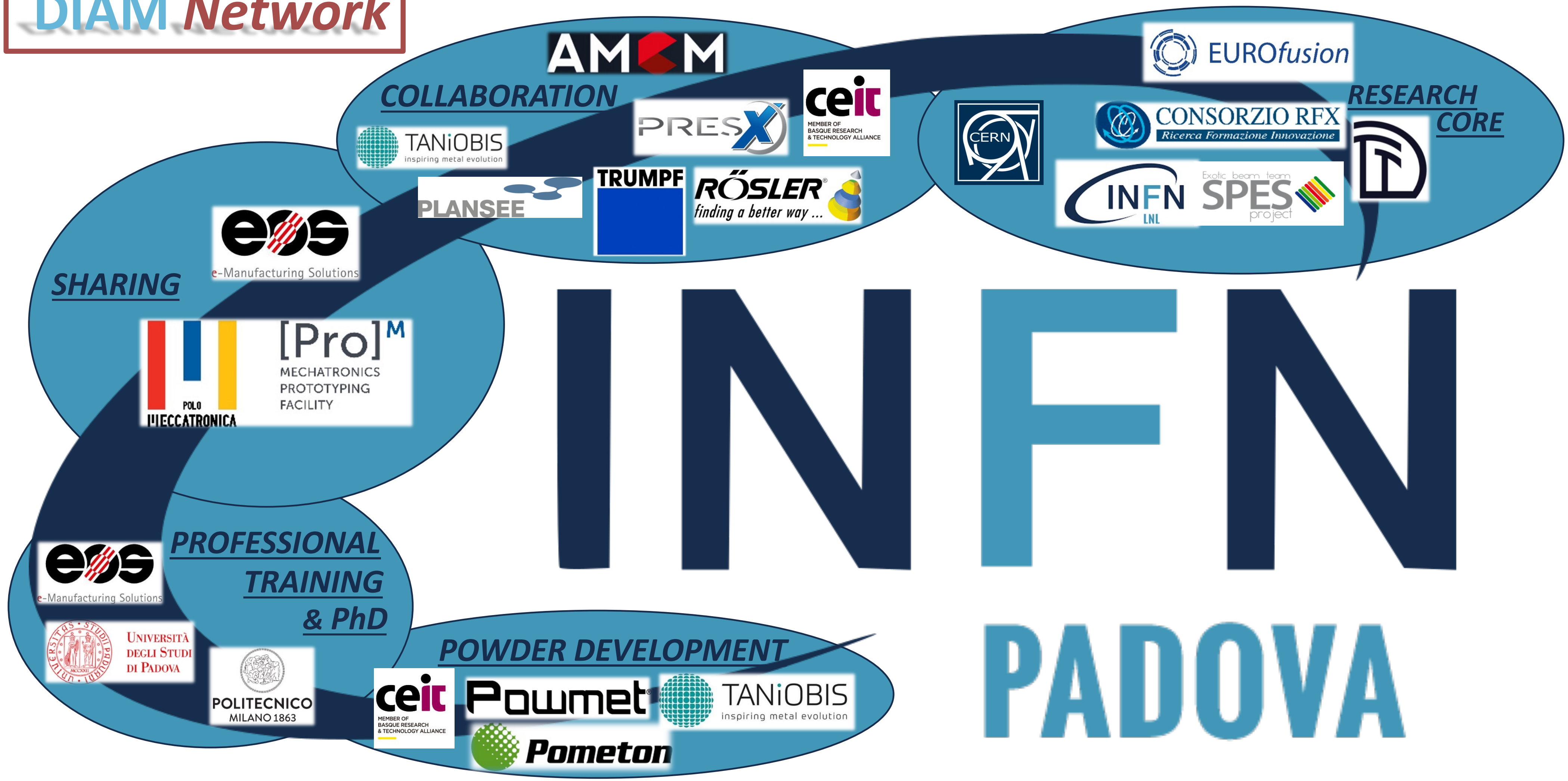
Eng. GIACOMO FAVERO

Eng. VALENTINA CANDELA

Eng. SILVIA CANDELA

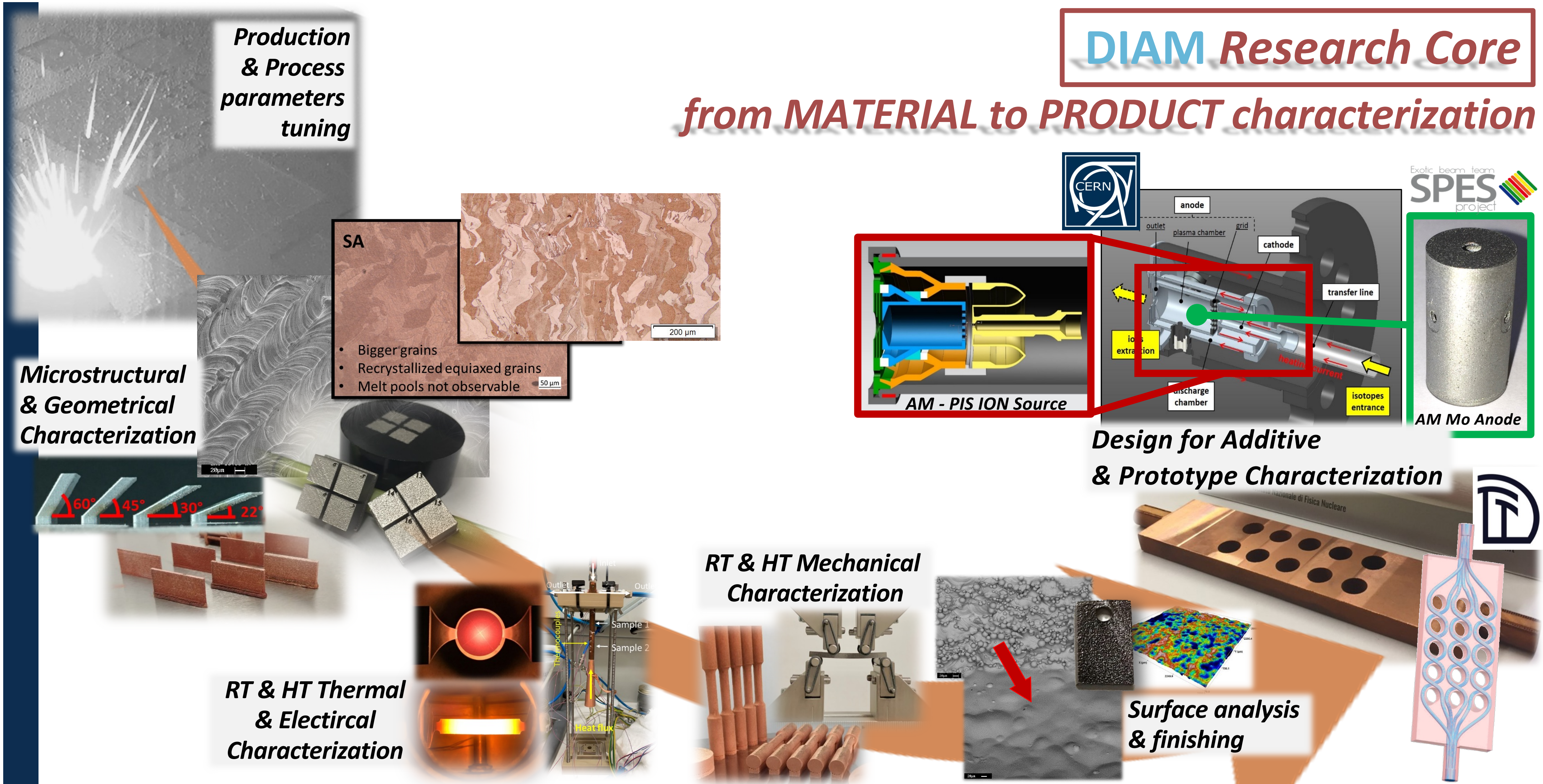
… Other 3 potential PhD Candidates for the A.Y. 2023/24

DIAM Network



DIAM Research Core

from MATERIAL to PRODUCT characterization



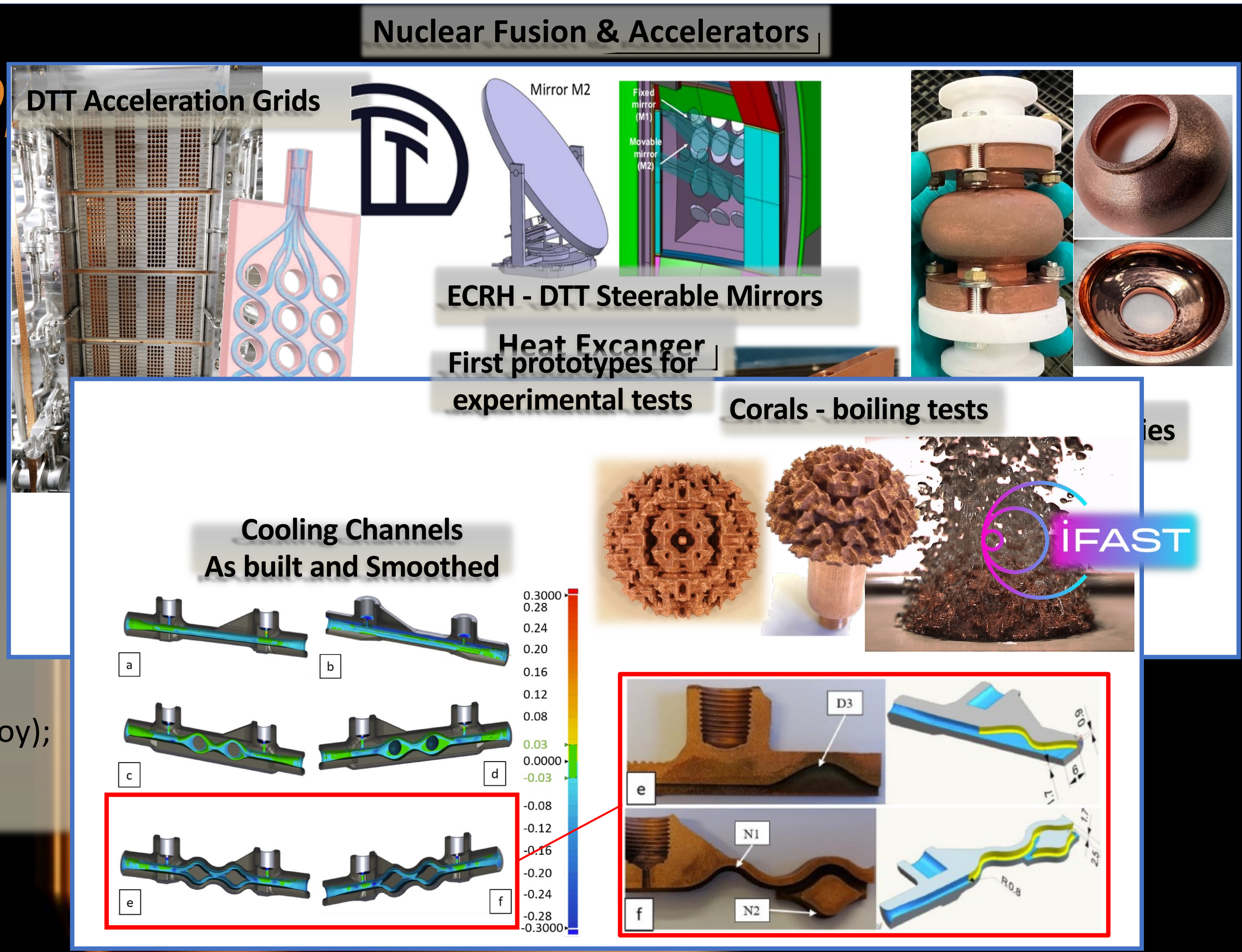
COP

@ DIAM lab:

- ✓ Pure Copper
- ✓ CuCrZr

Physical and Chemical properties:

- ➢ Excellent thermal conductivity;
- ➢ Excellent electrical properties;
- ➢ Good mechanical properties (alloy);
- ➢ Good corrosion resistance;



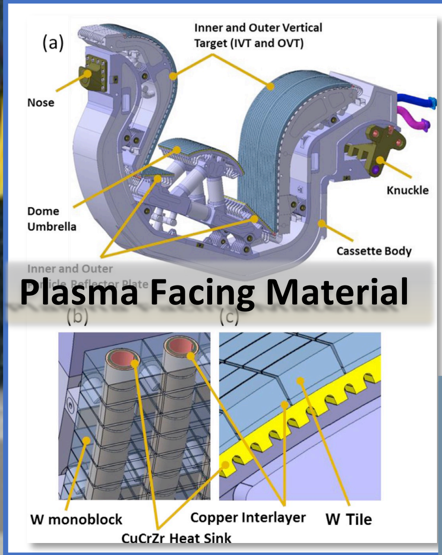
@ DIAM lab:

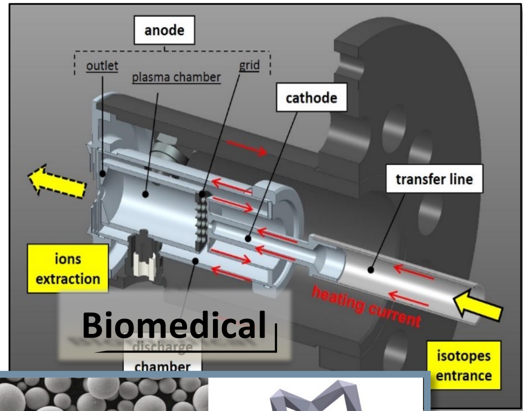
- ✓ Tungsten
- ✓ Molybdenum
- ✓ Tantalum
- ✓ Niobium

Physical and Chemical properties:

- Ultra-high melting point
- High density;
- Excellent corrosion resistance;
- Good thermal conductivity;
- Low thermal expansion;
- Good strength and hardness.

Nuclear Fusion & Accelerators

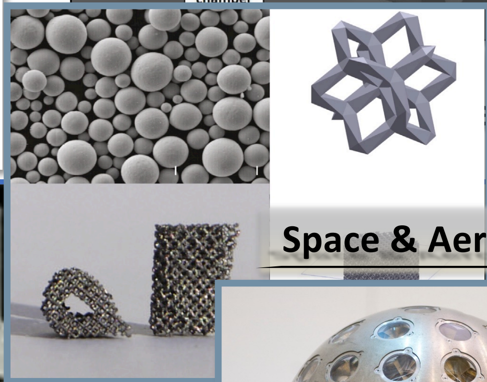




beams

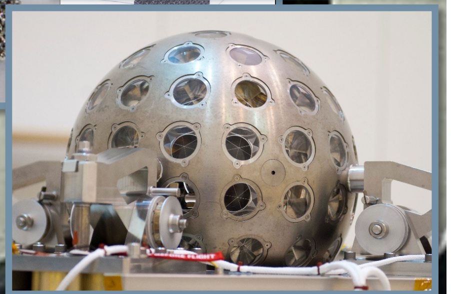
6 GHz Cavities

Prototypes manufactured in Nb
Romain Gerard (CERN)



2015. Research paper. R. Wauthle et al.. "Additively manufactured porous tantalum implants

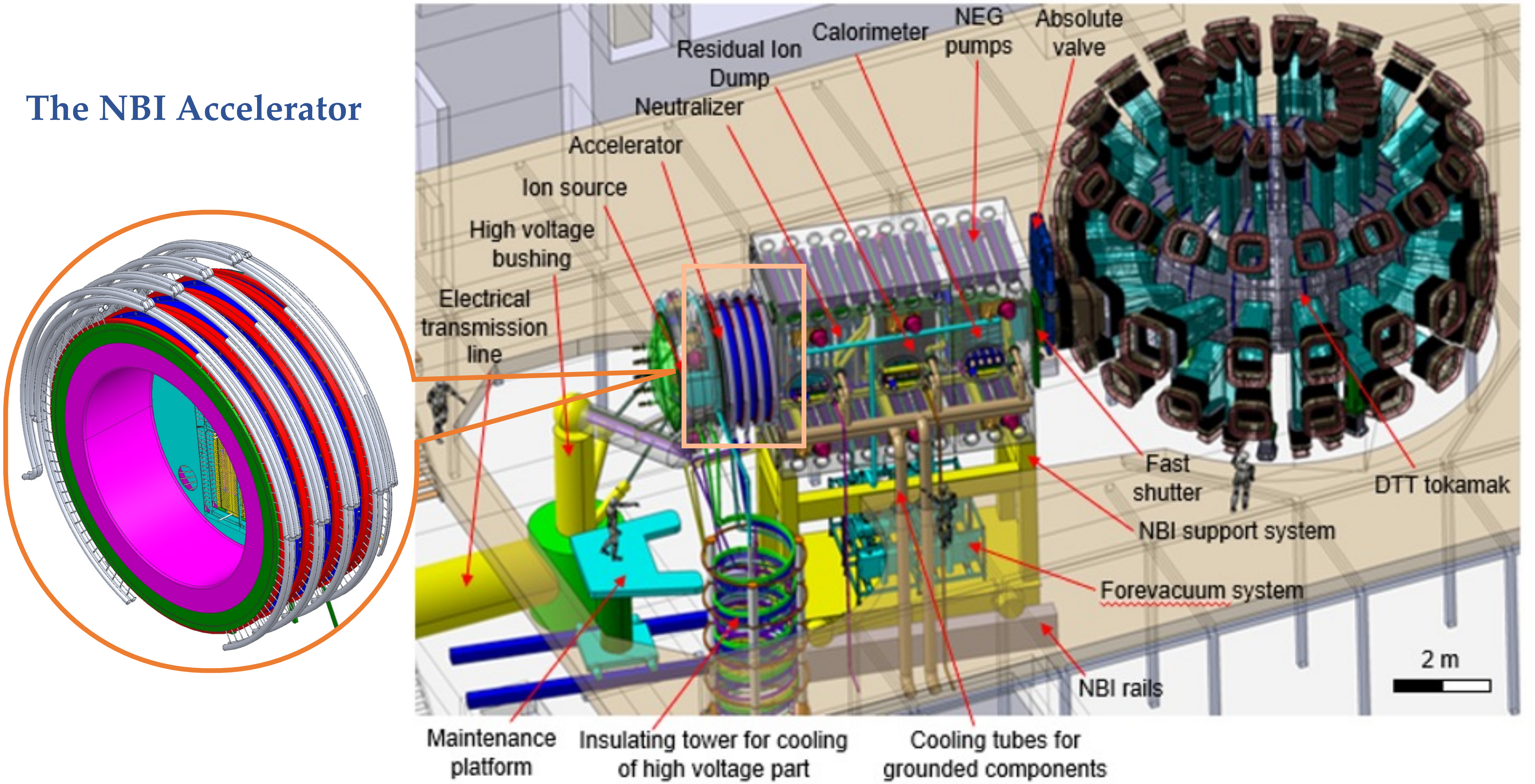
Space & Aerospace



Lares Satellite. Courtesy of LARES Team. Produced in Tungsten

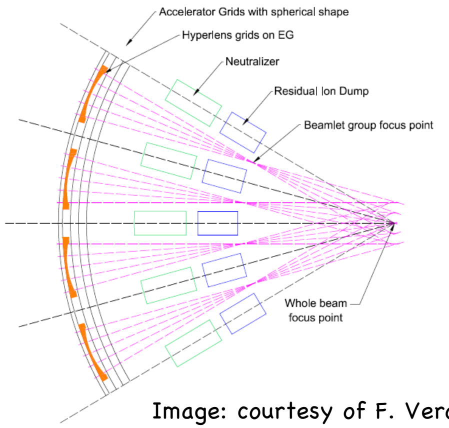
NASA MSFC AM C103 Green Propulsion Thruster and Stand-off

The NBI Accelerator



Accelerator grids' design evolution

Horizontal aiming



Vertical aiming

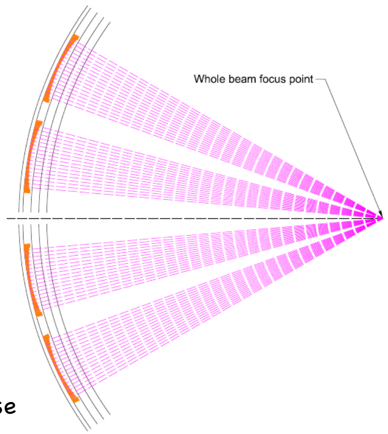
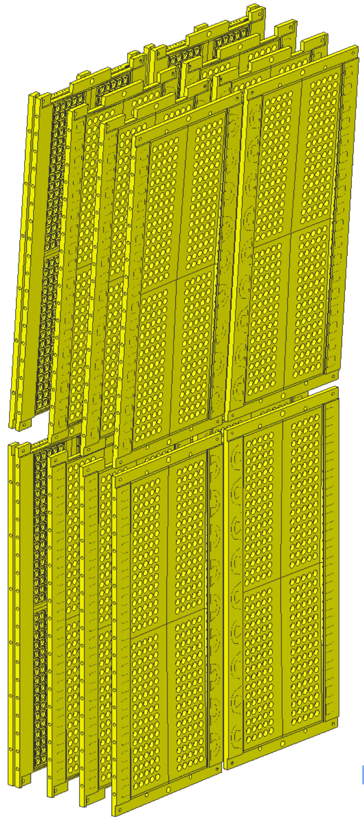


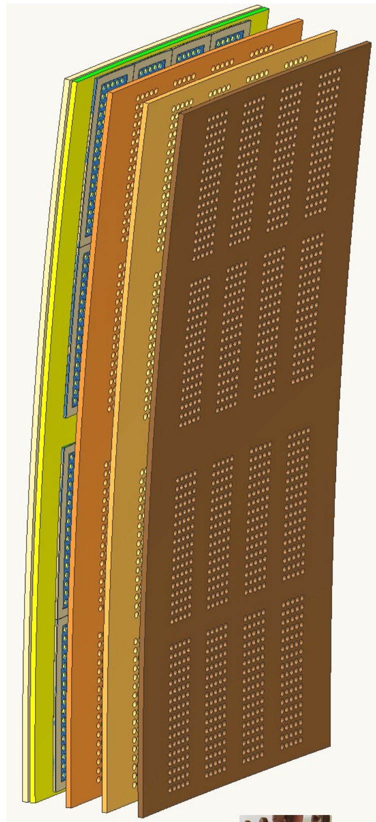
Image: courtesy of F. Veronese

Original multi plane grid design



Acceleration Grids (5 layers)
Plasma Grid (PG)
Extraction Grid (EG)
Acceleration Grid 1 (AG 1)
Acceleration Grid 2 (AG 2)
Grounding Grid (GG)

New spherical grid design



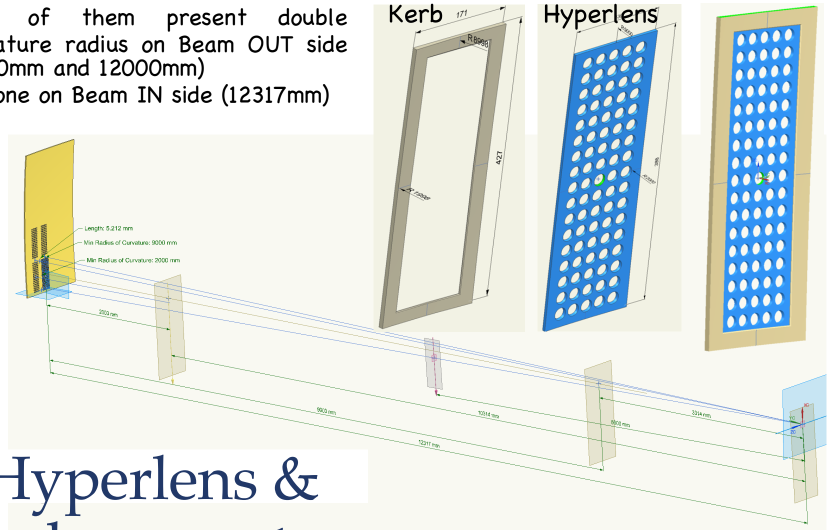
Main MODIFICATIONS:

1. **TECHNOLOGY: Additive Manufacturing**
2. SHAPE: **SPHERICAL**
3. grids' THICKNESS: **11mm -> 14mm**
4. cooling channels' GEOMETRY: **optimized**

Additive Manufacturing advantages:

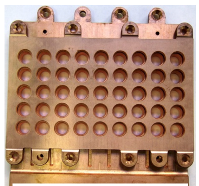
- Manufacturing process: less time, less complicated -> better reliability
- Possibility of printing (raw production) of 5 quarter-grid in a single batch
- Flexibility of design (especially of the cooling channels)

Both of them present double curvature radius on Beam OUT side (9000mm and 12000mm) and one on Beam IN side (12317mm)



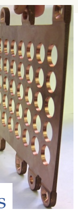
Hyperlens & Kerb geometry

5Axis Milling centre OKUMA



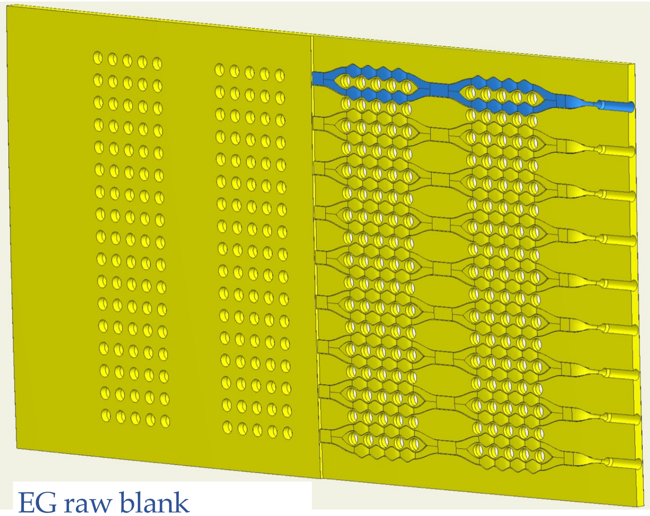
EG & Hyperlens

Kerb

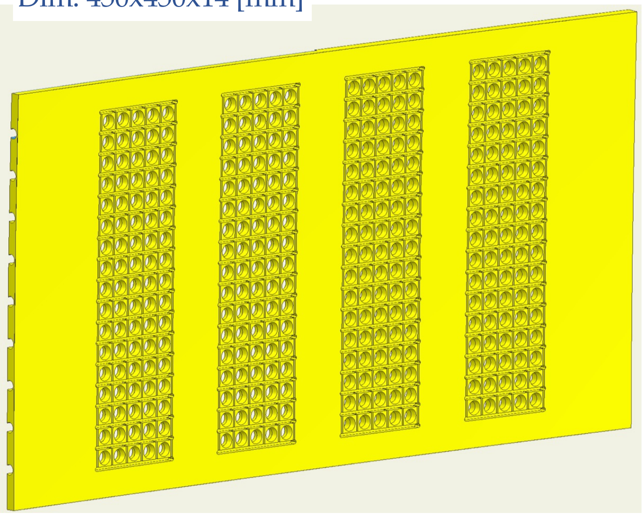


Hyperlens

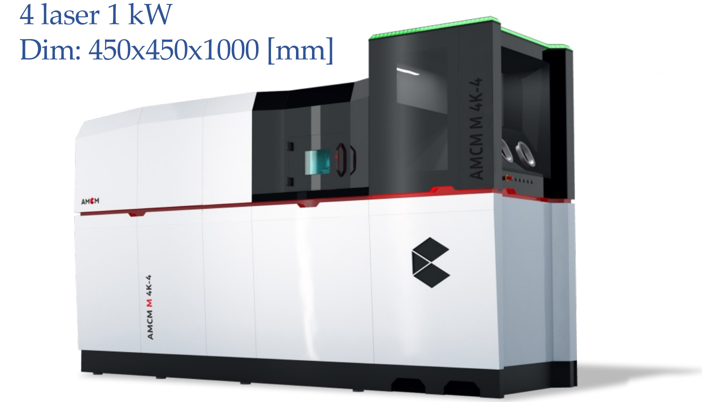
The Grid Planes FULL-SCALE Production



EG raw blank
Dim: 450x450x14 [mm]



AMCM M4K:
- 4 laser 1 kW
- Dim: 450x450x1000 [mm]



Page 2 / 5 Quote No: 20575_01
Istituto Nazionale di Fisica Nucleare (INFN)

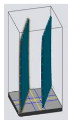
AMCM
Additive Manufacturing
Customized Machines

Quotation Benchmark Parts

1 Benchmark Part

1.1 Part Description

Material:	CuCrZr
System:	M4K-4 1kW
Parameter:	CuCrZr with 80µm layer thickness
Design:	According to the agreed file
Weight/part:	~31,5 kg
Post Processing:	Depowdered with Solukon System. No shot peening, no heat treatment
Delivery:	Part on build plate*.
Picture:	

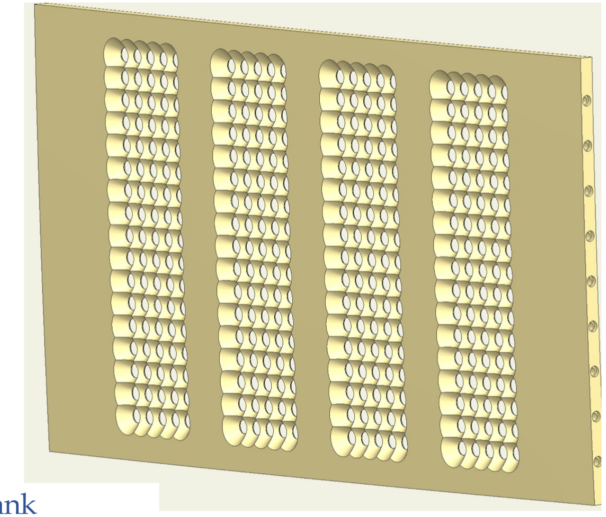


1.2 Price

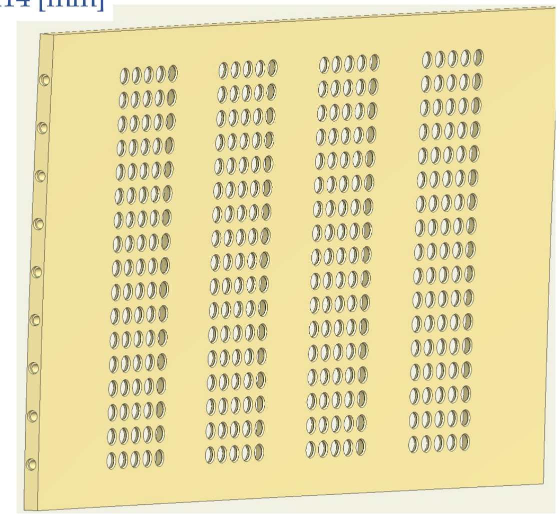
	Quantity	Total [€]
Production of Benchmark Part	2	39.300,-
Shipping Costs		700,-
	Total	**40.000,-**

*Please return the building platform to:

AMCM GmbH
Petersbrunner Str. 1B
82319 Starnberg
Germany

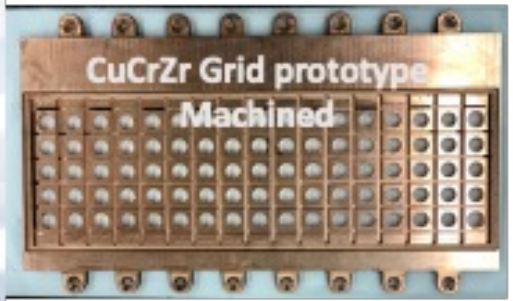


PG raw blank
Dim: 450x450x14 [mm]

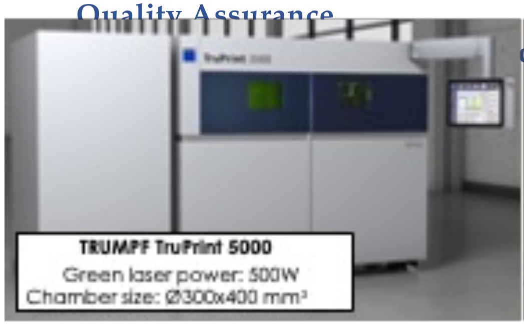


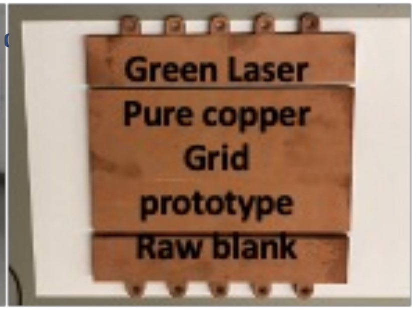
R&D Phase on AM approach Y2022: Small Size Prototypes (Cu & CuCrZr)

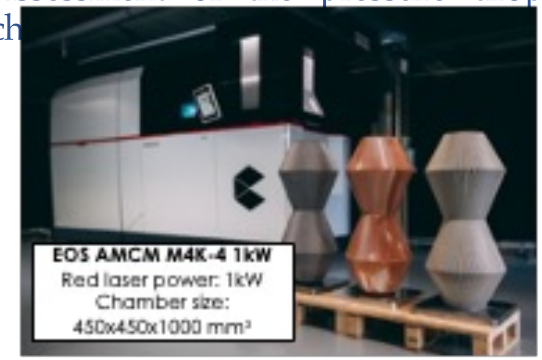
mmodate a modular
set of beamlets and relative Hyperlens;
•Capability to perform the main steps of the
Quality Assurance

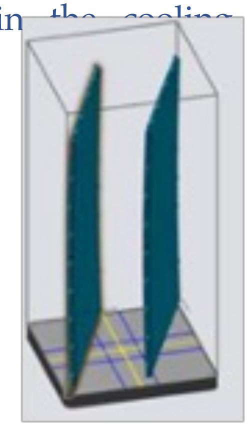


–Channel geometry.
Assessment of the pressure drops in the cooling
ch



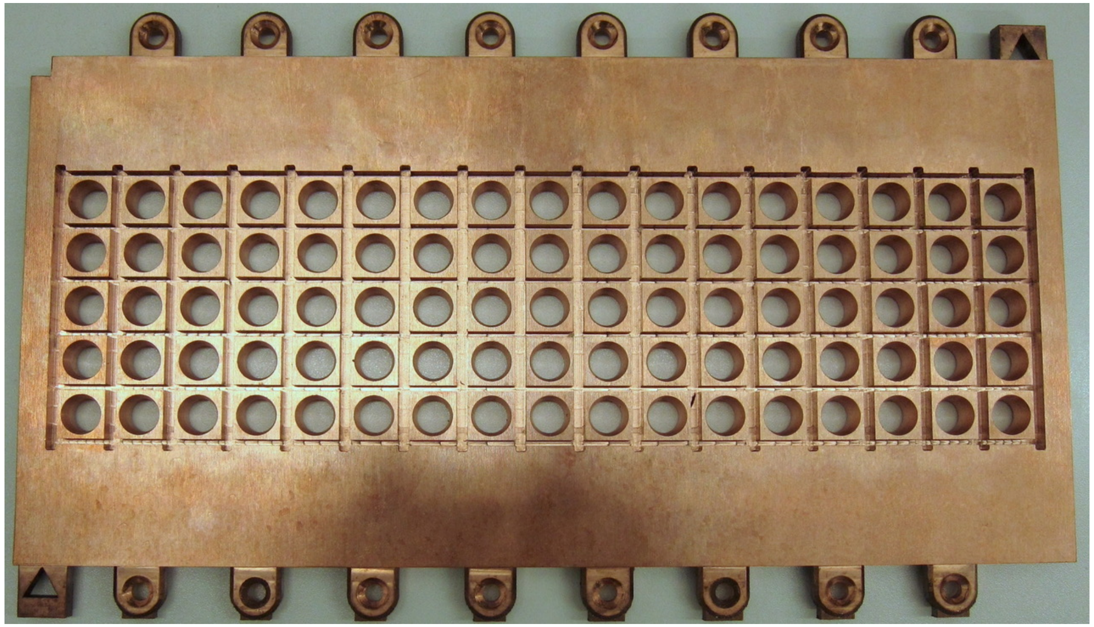




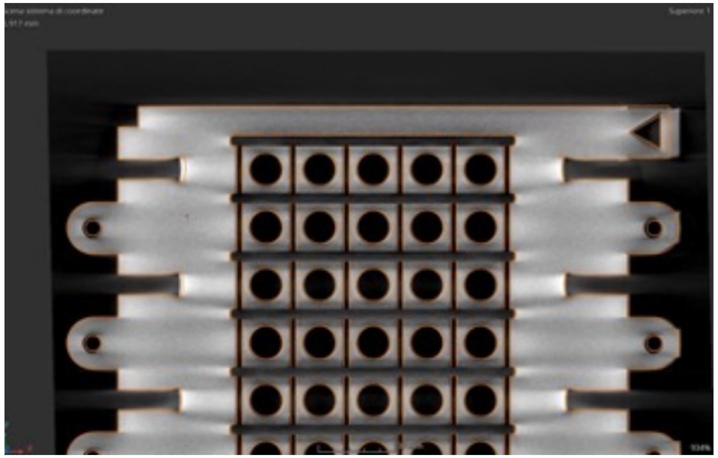


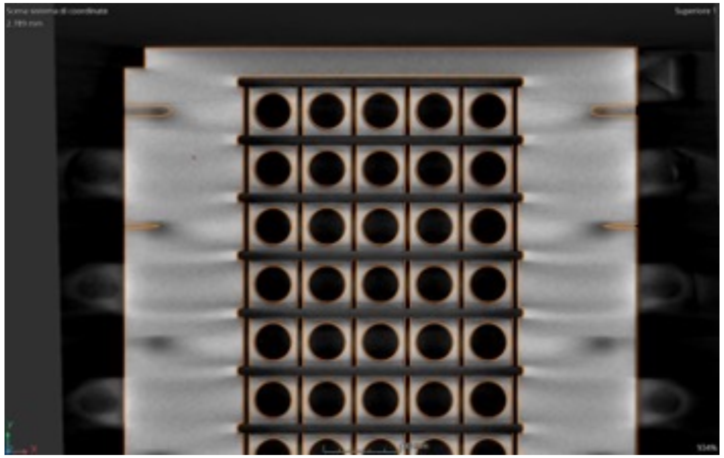
WIP CuCrZr Full Grid Prototypes

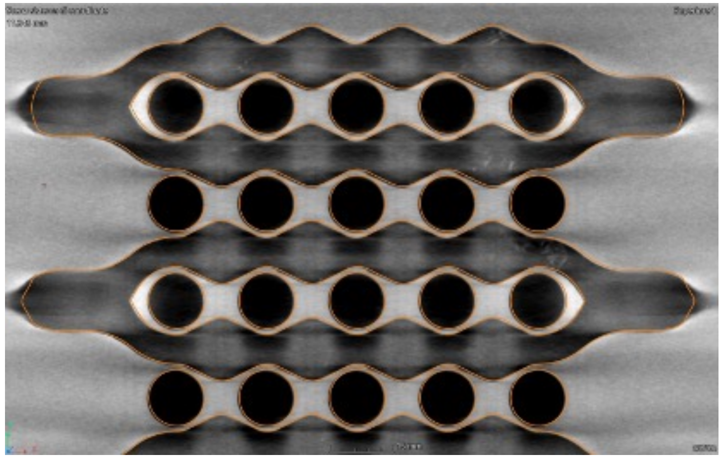
X Ray Tomographic Scan



EG prototype
CuCrZr
Dim: 400x2300x14 [mm]







Characterization of Additive Manufacturing (AM) copper parts

	EOS M290 1kW		TRUMPF TruPrint 5000		EOS M 400
	1 kW Infrared Laser Building Chamber: 250x250x325 mm Pure copper		1 kW Green Laser Building Chamber: Ø 300 x H 400 mm Pure copper		1 kW Infrared Laser Building Chamber: 250x250x325 mm CuCrZr
	FIRST BATCH	**SECOND BATCH**	**FIRST BATCH**	**SECOND BATCH**	
Porosity Archimede	0.64 %	0.38 %	1.04 %	1.02 %	0.63 %
Porosity Optical	0.16 %	0.18 %	0.13%	0.29%	0.29 %
Thermal conductivity [W/mK]	H 374 ± 19 V 389 ± 19	H 375 ± 19 V 376 ± 19	H 381 ± 19 V 380 ± 19	H 370 ± 19 V 374 ± 19	H 300 ± 15 V 323 ± 16
Yield Strength [MPa]	H 160.0 ±2.8 V 165.3 ± 4.6	H 159.3 ± 0.6 V 161.7 ± 1.2	H 139.7 ± 0.6 V 137.3 ± 2.1	H 140.3 ± 1.5 V 142.3 ± 3.8	H 199.3 ± 4.7 V 169.3 ± 27.0
Ultimate Tensile Strength [MPA]	H 224.9 ± 1.8 V 223.7 ± 0.5	H 225.9 ± 0.1 V 224.9 ± 0.6	H 221.2 ± 1.4 V 200.4 ± 0.1	H 211.6 ± 4.1 V 192.7 ± 4.8	H 340.9 ± 3.0 V 283.3 ± 20.5
Young Module [GPa]	H 125 ±4 V 124 ± 3	H 117 ± 7 V 127 ± 4	H 136 ± 3 V 124 ± 5	H 113 ± 5 V 112 ± 6	H 128 ± 1 V 106 ± 4
Elongation at Break	H 53 ± 1% V Over 50%	H 51 ± 1% V Over 50%	H Over 50% V Over 50%	H 49 ± 1% V 31 ± 2%	H 35 ± 1% H 36 ± 1%

- EOS samples show constant results
- TRUMPF's second Batch shows similar result, with the exception of the optical porosity and the elongation at break.

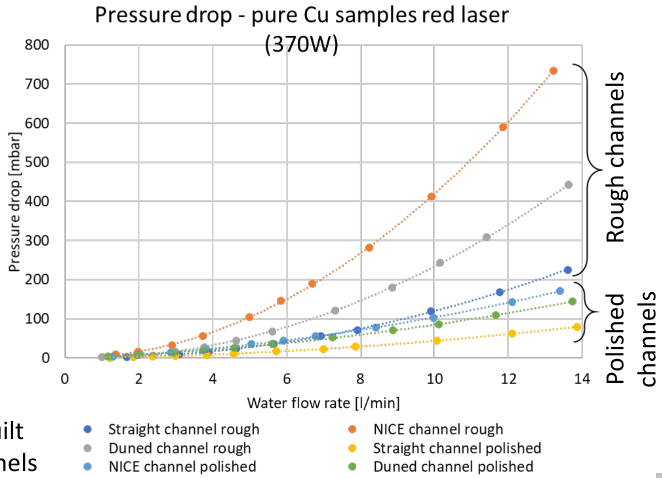
Laser Powder Bed Fusion of Copper and Copper alloys

Pressure drop tests & Roughness analysis – Surface Finishing

Cu samples

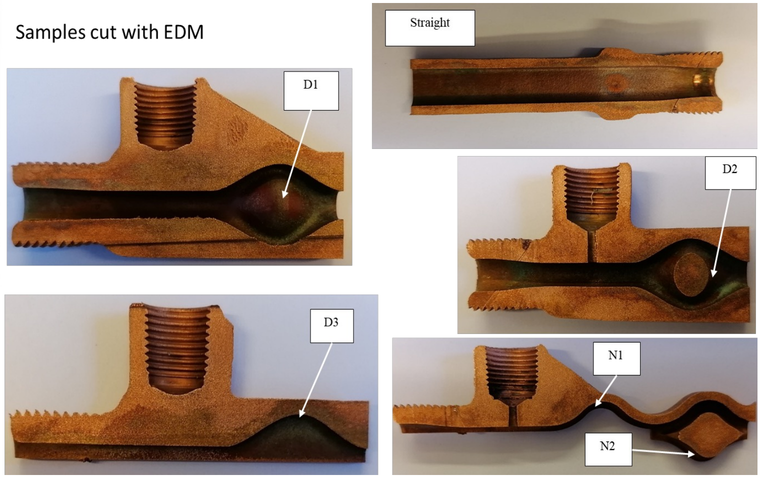
AM samples M280 LPBF machine

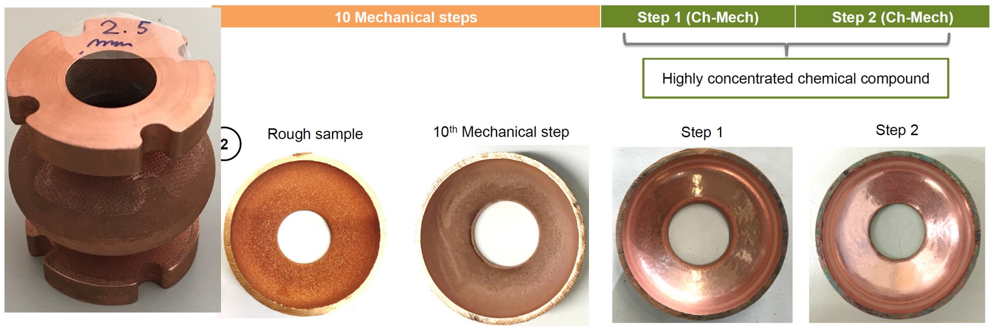
- Hydraulic tests in channels as built
- Hydraulic tests in polished channels

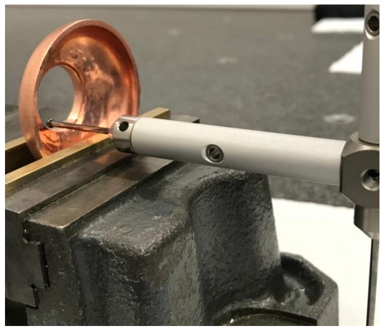


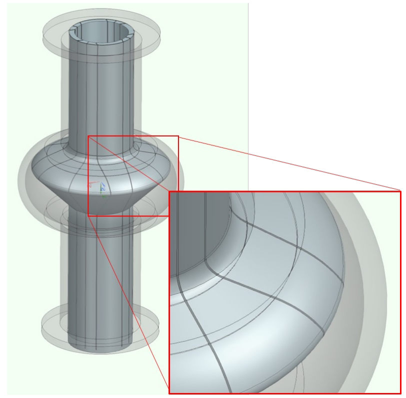
- 3D Non-Contact Profilometry
- Step size 2-5 µm

Samples cut with EDM







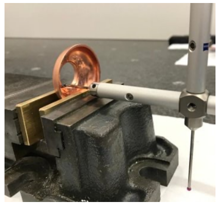


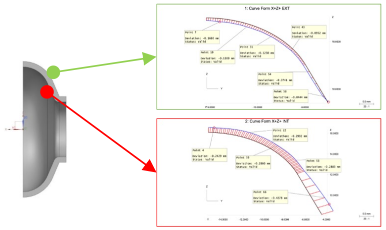
Cavities produced by LPBF

Cu cavities

First prototypes:

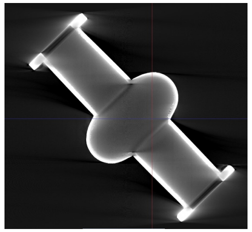
- Geometry verifications





6 GHz seamless cavities:

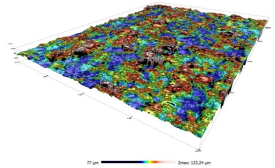
- Red laser
- Green laser



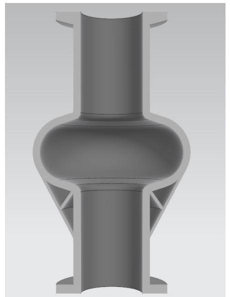
Nb cavities

Material characterization and process parameters optimization:

- Density
- Critical angle
- Down-skin
- Contour



6 GHz seamless cavities production



Surface treatments by Rösler

Cavities
P-shape →
L-shape
T-shape

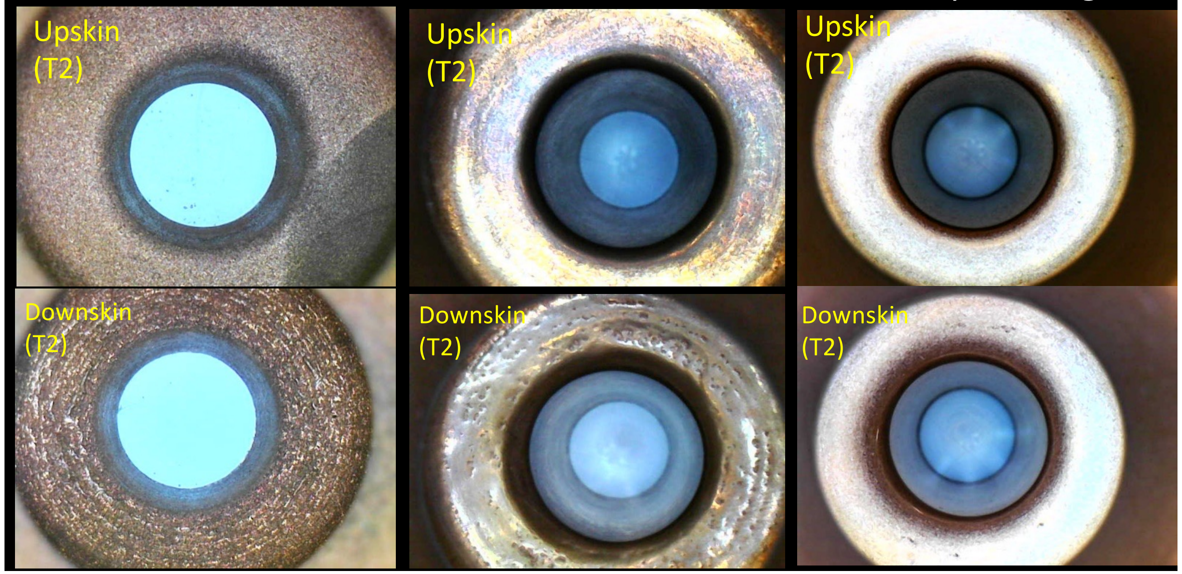
Scrap parts for preliminary test

Samples to be treated

GOAL: Ra ≤ 1,0 µm

Treatments			
Type	**Mechanical treatment**	**Chemically-assisted treatment**	**Extra polishing step**
# of steps	10	5	2
media and compounds	*Rösler* media: Cu needles + synthetic diamond powder	*Rösler* ceramic media: ***RMBD1 05 G*** *Rösler* compound: ***CMP 03/21 L***	*Rösler* plastic media: ***RKH/4***
GOAL	Roughness reduction R_a from about 30 µm to 4 µm	Roughness reduction **R_a ≤ 1,0 µm**	Last defects removal Final cleaning **R_a ≤ 1,0 µm**

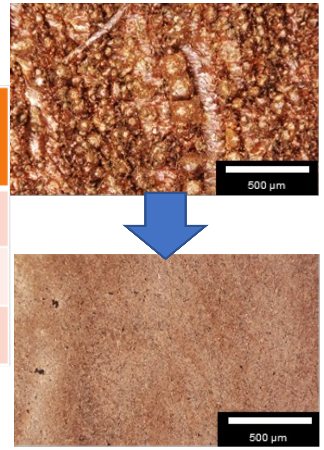
Rough | Chemically-assisted | Extra polishing



Average roughness at the end:

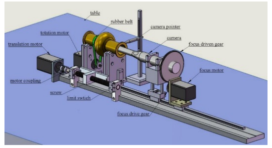
CAVITY	R_a µm	R_z µm
L2	0,48	2,32
L3	0,54	3,34
T2	0,48	3,39

Morphology



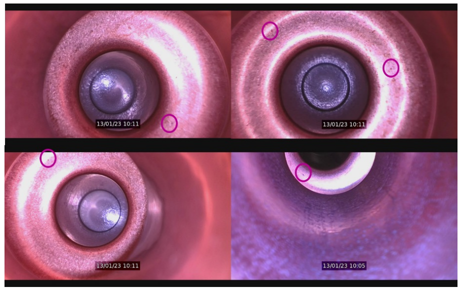
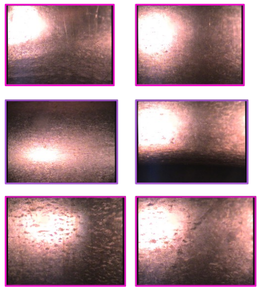
Surface treatments – Rösler Italiana

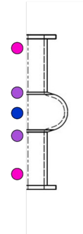
1 inspection




- ✓ Vacuum leak detection
- ✓ Frequency measurement

T 1 T2

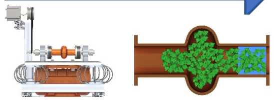





2 Treatment workflow

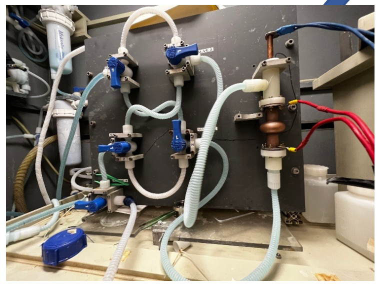
T 1

1Vibro-Tumbling at LNL



T 2

1Vibro finishing @Rösler

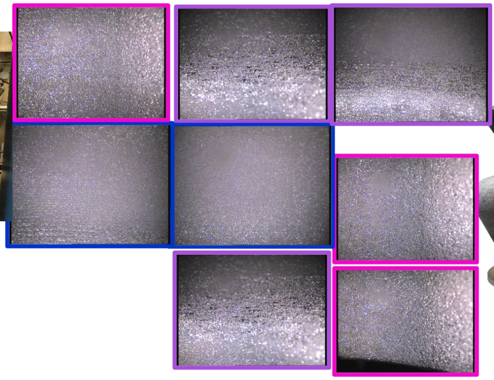
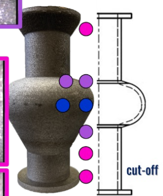


2 Electropolishing

3. Chemical polishing (SUBU)
4. Inspection
5. High Pressure Rinsing
6. Physical Vapour Deposition of Nb
7. SC measurements

- ✓ Vacuum leak detection
- ✓ Frequency measurement

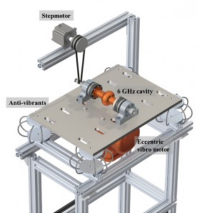
Nb

Cavities frequency and optical inspection - INFN-LNL

Nb

1Vibro-Tumbling at LNL



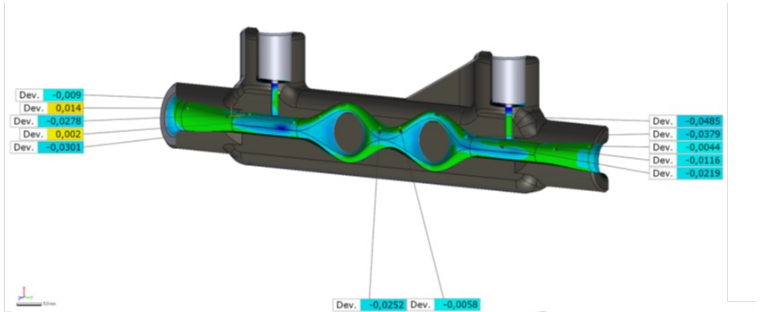
2 Electropolishing

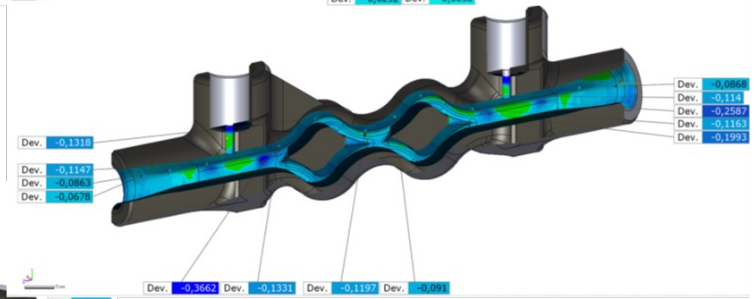
3. Inspection
4. High Pressure Rinsing
5. SC measurements

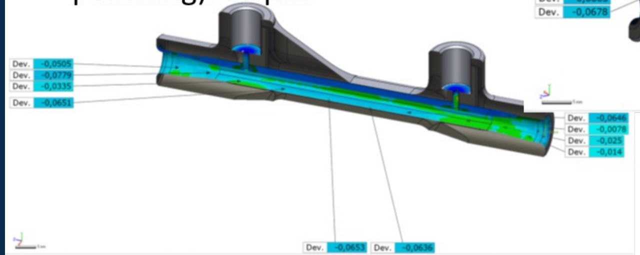
Laser Powder Bed Fusion of Copper and Copper alloys

Cu cooling channels samples – CT dimensions & Prototype production

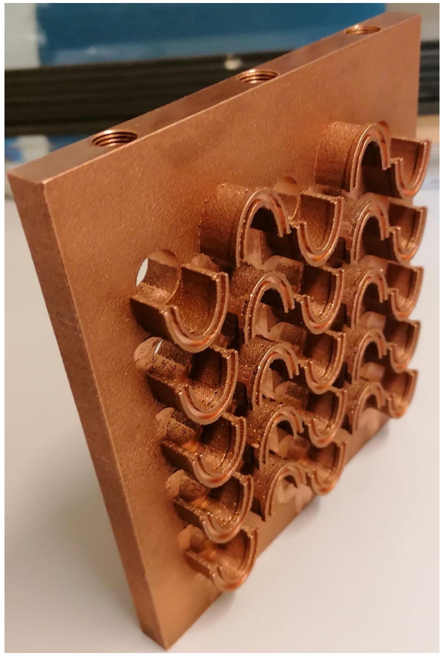
- Zeiss Metrotom 1500
- Voxel size: 55 µm
- Accuracy: ±25 µm
- Wall mean offset (CAD theoretical-samples after polishing): 50 µm



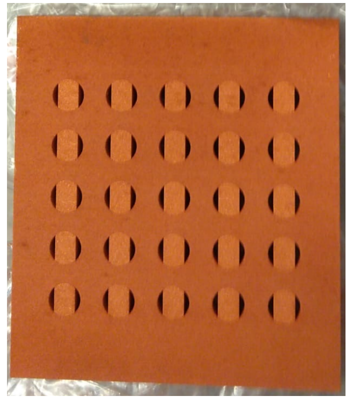




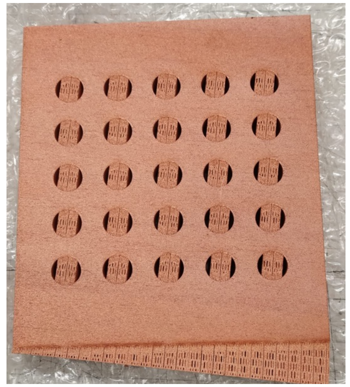
EOS 1 kW Red Laser (CuCrZr)



Trumpf Green Laser (Pure Cu)

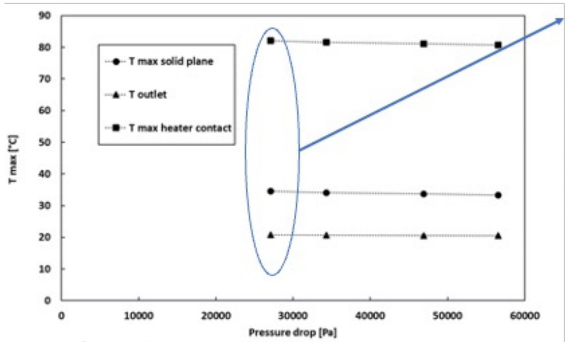


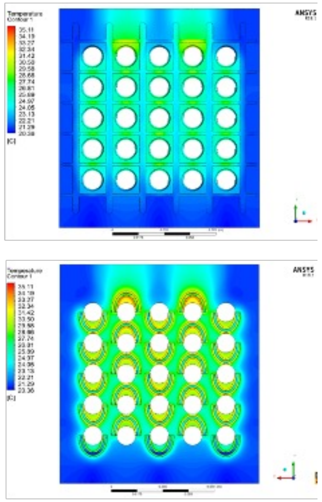
EOS 1 kW Red Laser (Pure Cu)



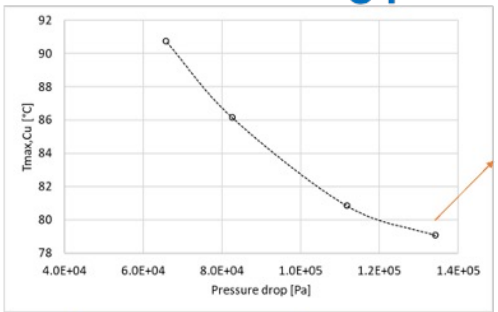
Numerical simulation EG prototype

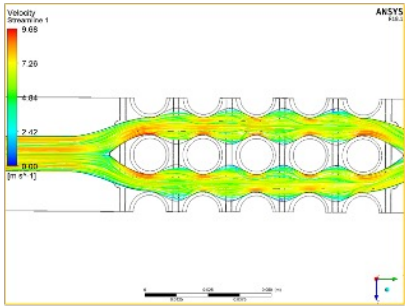
- P=80W per beamlet
- T inlet=20°C
- Adiabatic condition in insulated surfaces Turbulence model: Standard k-epsilon
- Wall function: Enhanced Wall Treatment (smooth channels)





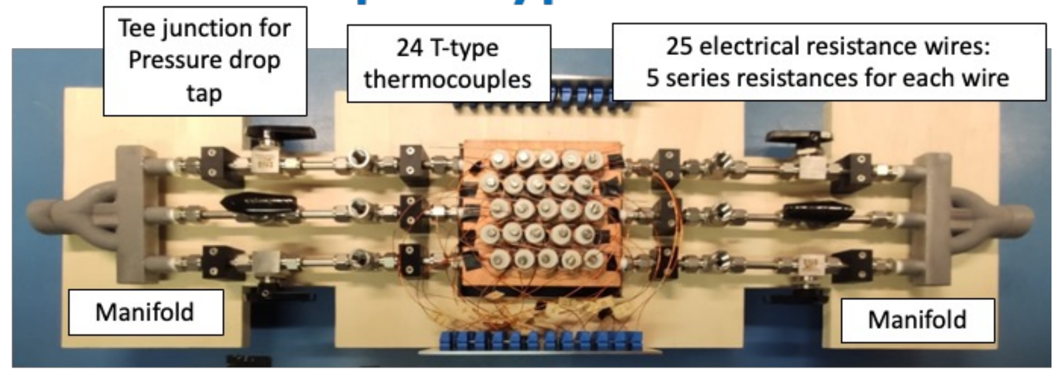
Numerical results EG segment grid – cooling performance

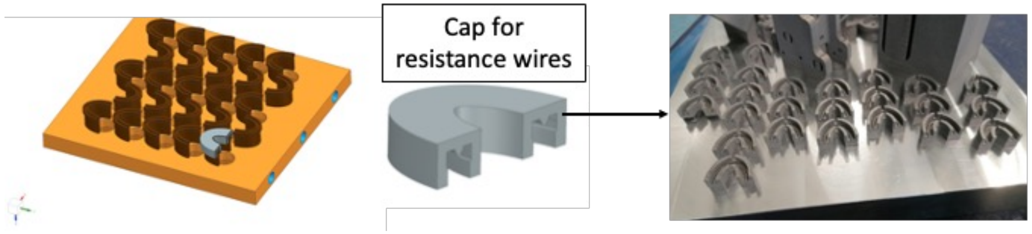


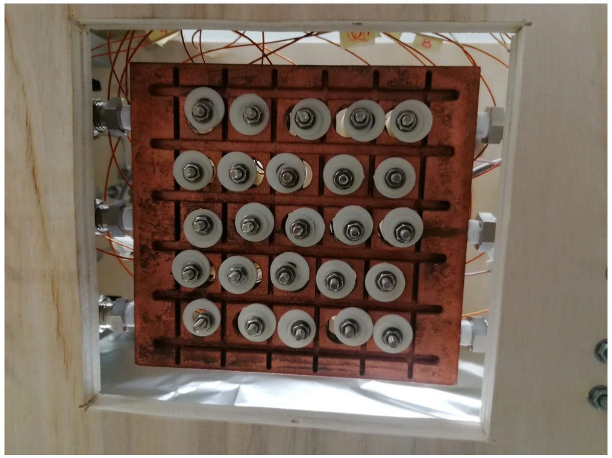


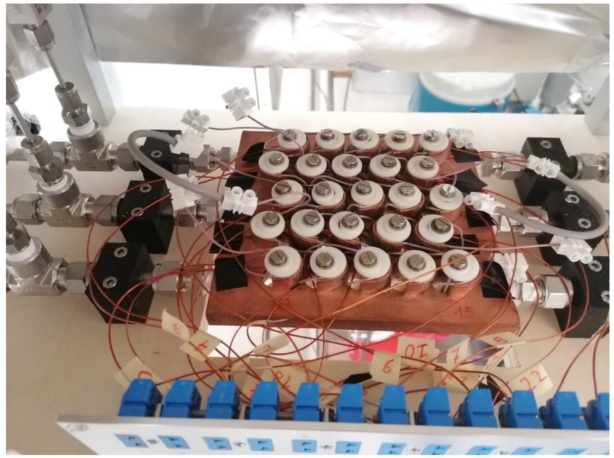
Mass flow rate [kg/s]	Pressure drop [bar]	$V_{max,water}$ [m/s]	$T_{max,Cu}$ [°C]
0,306	1,34	9,79	79,06
0,275	1,12	8,75	80,85
0,229	0,824	7,26	86,15
0,200	0,658	6,31	90,75

Experimental setup of the EG prototype



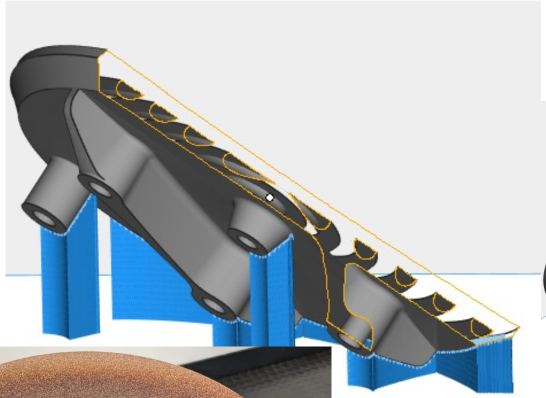


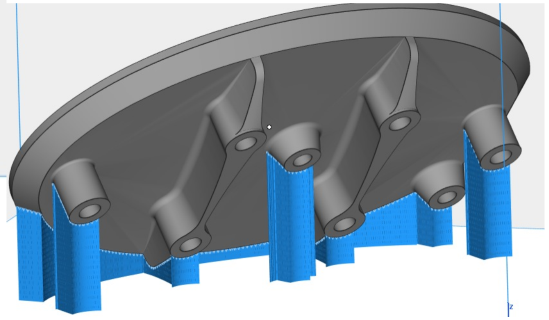


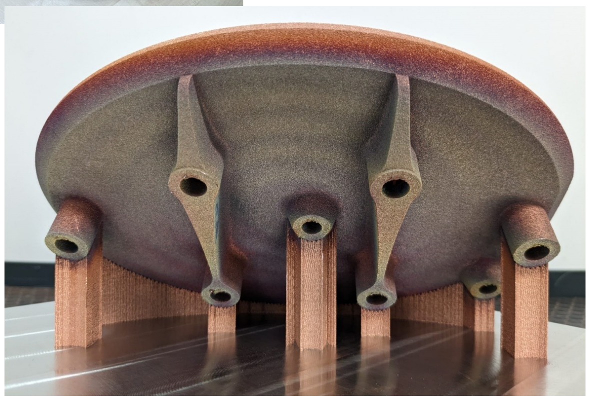


Laser Powder Bed Fusion of Copper alloys

CuCrZr ECRH - DTT Steerable Mirrors

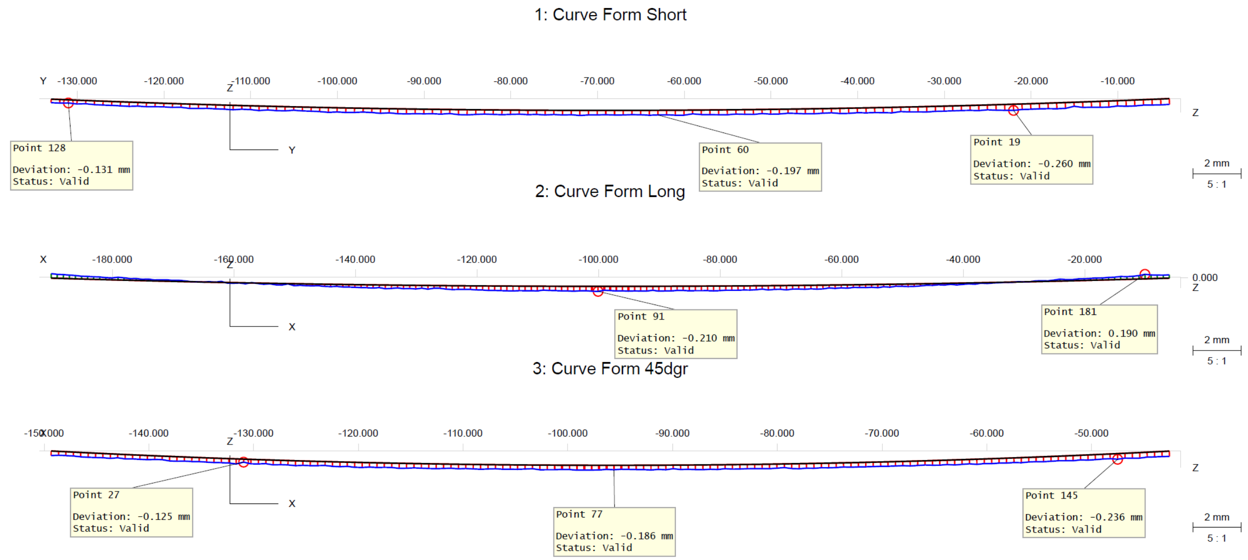






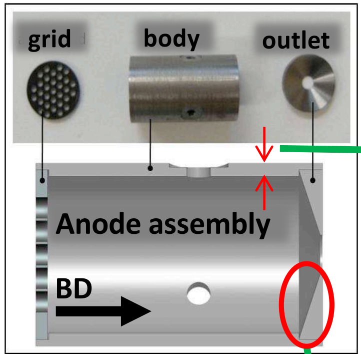
Black line = theoretical
Blue line = real

M1 RAW



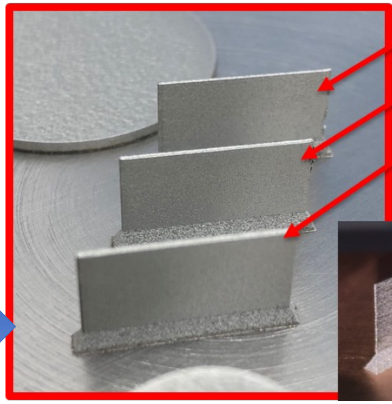
Mo Anode PRODUCTION - FEBIAD Ion Source - INFN SPES facility

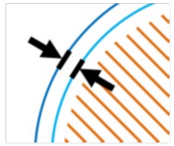
TRADITIONAL Anode



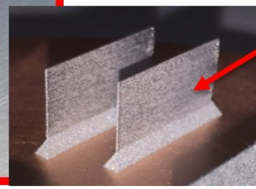
STEP 1 Verification of the possibility to manufacture the part

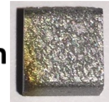
1. Thickness of the component
→ 0.5 mm (body)
→ 0.3 mm (grid)

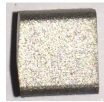




Double contour strategy

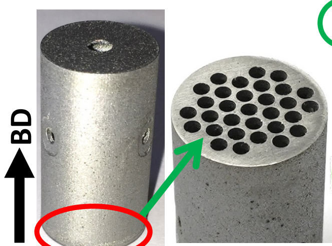






With contour
→ Ra = 1.5 ÷ 1.8 µm

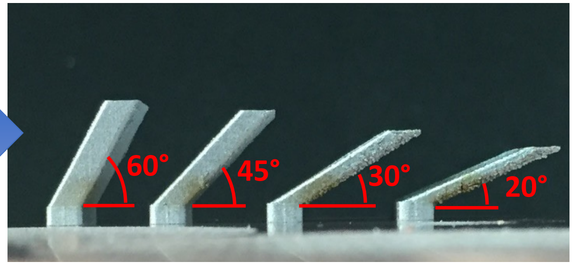
AM Anode



Unique body – high quality of the grid

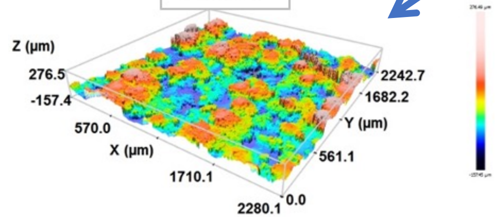
2. Overhang angle
→ 22°

Down Skin parameters tuning



Inclined walls surface roughness measurement

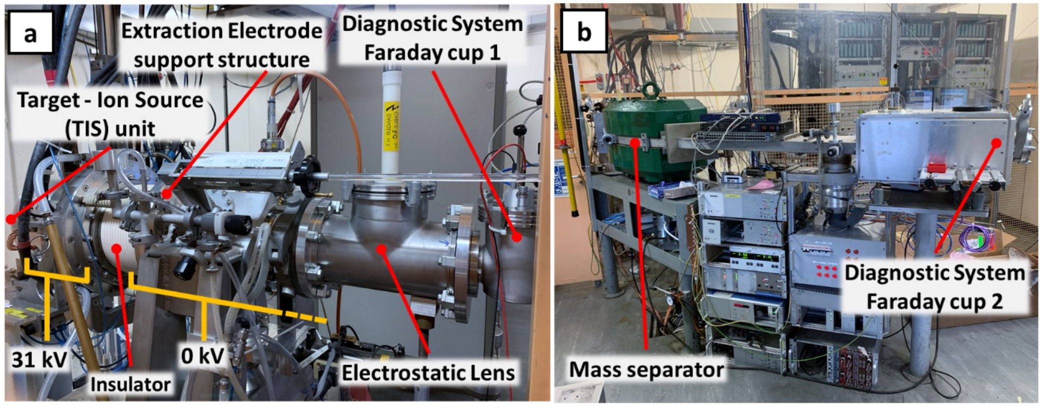
Parameter	Mo-60°	Mo-45°	Mo-30°	Mo-20°
Sa	6.2	19.8	55.8	60.4
Sq				74.4
Ssk				0.653
Sku				2.928
Sz				423.3
Sp				259.3
Sv	26.8	56.4	125.7	164.0



Mo Anode TEST - FEBIAD Ion Source - INFN SPES facility

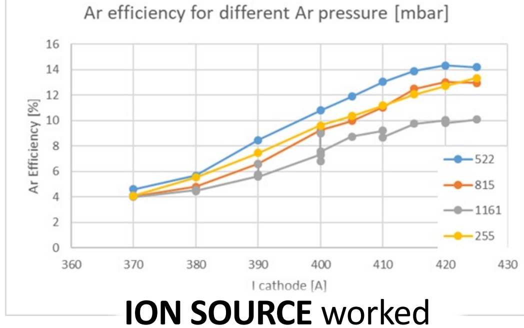
STEP 2 OFF-LINE test - ION SOURCE @ CERN - ISOLDE

The first step → ionization of 100% Ar
The second step → ionization of 20% of each noble gas (Ar,Ne,El,Xe,Kr)



2 main RESULTS of this PROOF-of-CONCEPT test

1. Ionization Efficiency Estimation



ION SOURCE worked properly for **2 weeks**

2. Contaminants Measurement

Mo and MoO_x

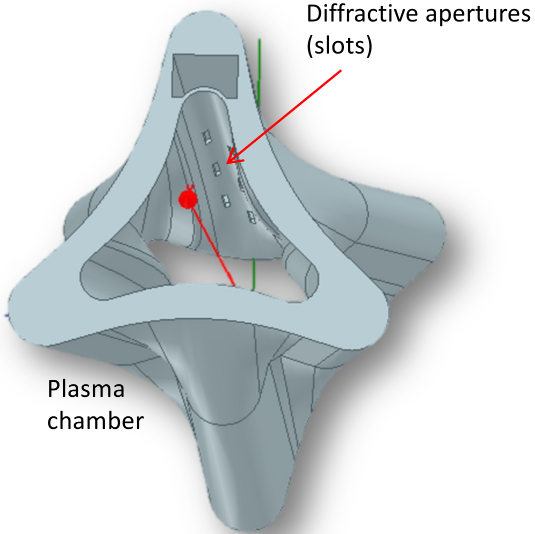
decreases drastically after reaching the **exercise conditions**

What is important for AM research activity ?

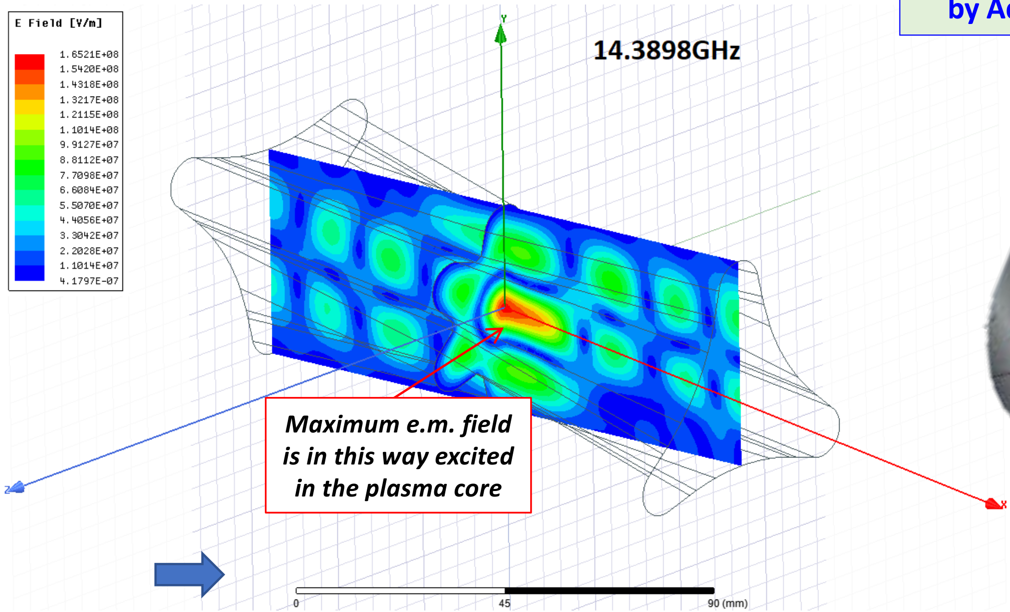
1. *Plasma Ion Source components can be produced by LPBF*
2. opening up the possibility of fully exploiting its technological advantages. First of all, the new design for assembly

Innovative Resonator Ion Source (IRIS) (Prototype)

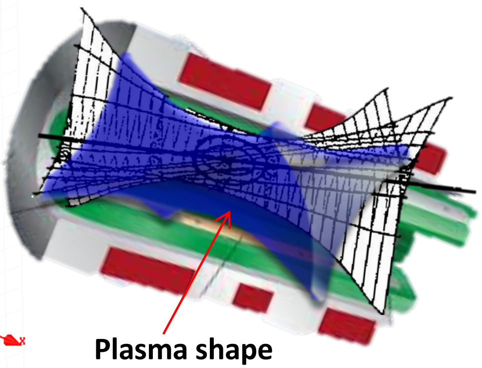
Non conventional resonators and RF launchers for Ion Sources will be fabricated by Additive Manufacturing Technology

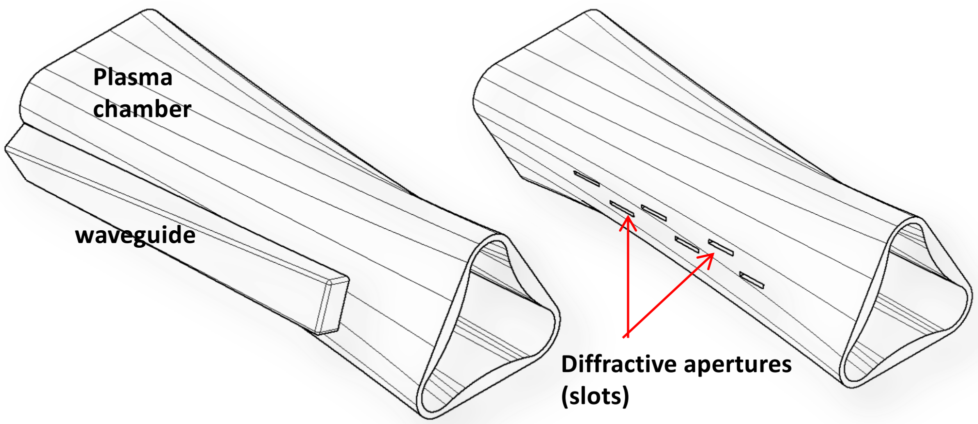


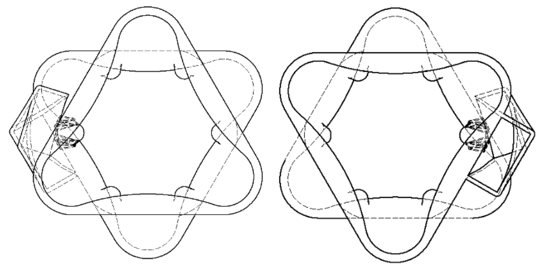
Typical IRIS size is 10x20 cm



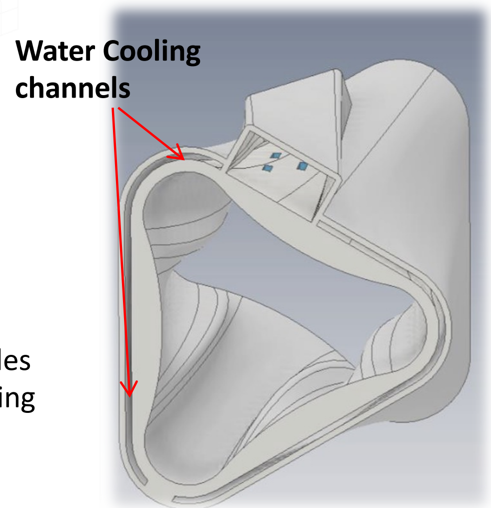
$B_{minimum}$ magnetic field structure





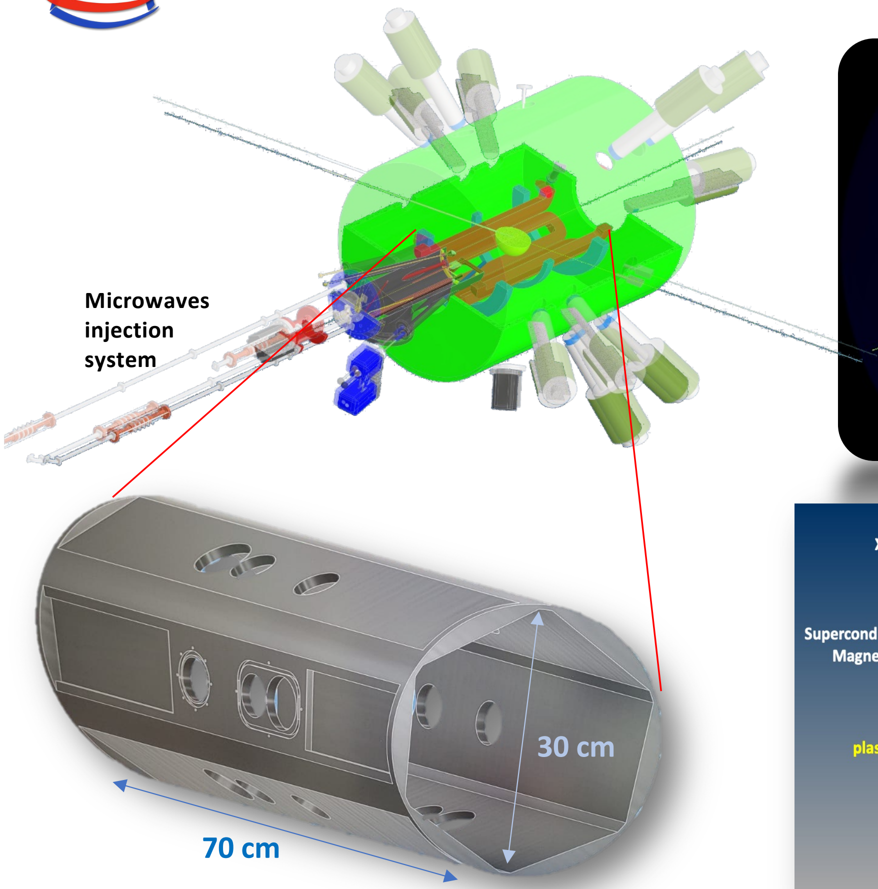


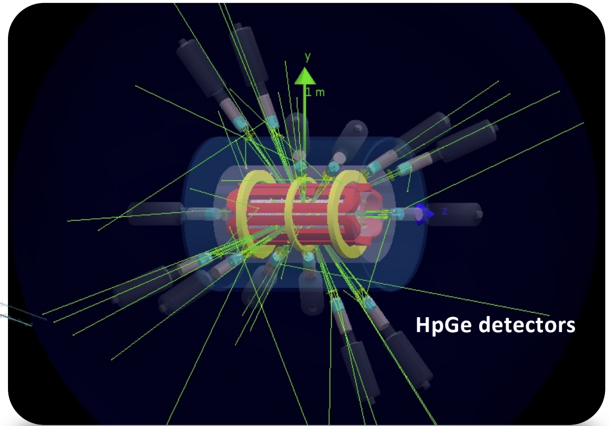
The cross-section of the IRIS cavity resembles the shape of the magnetostatic field confining plasmas in ECR Ion Sources.

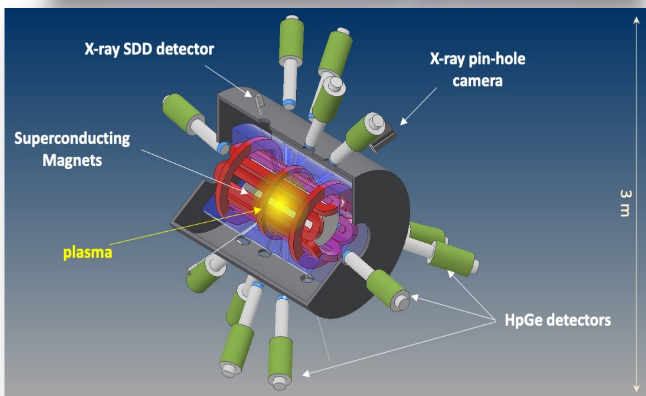


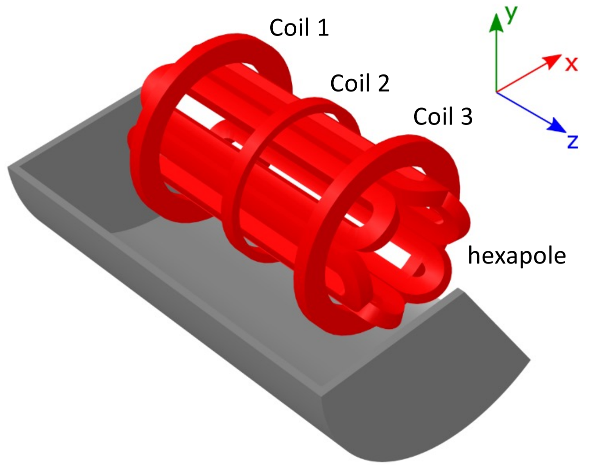
Plasmas for Astrophysics Nuclear Decay Observation and Radiation for Archaeometry

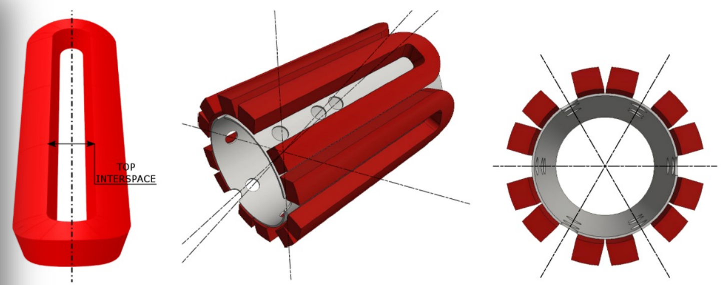
The *New ECRIT – ECR Ion Trap* **(the largest never built…)** *is made of fully superconductin magnets, allowing radial position of HpGe detectors*











PANDORA superconducting magnetic system

An advanced (Stain. Steel) plasma chamber design is needed to operate at 10^{-8} mbar supporting a 10 kW plasma power and radial "holes" for measuring γ-ray emission

New alloy development

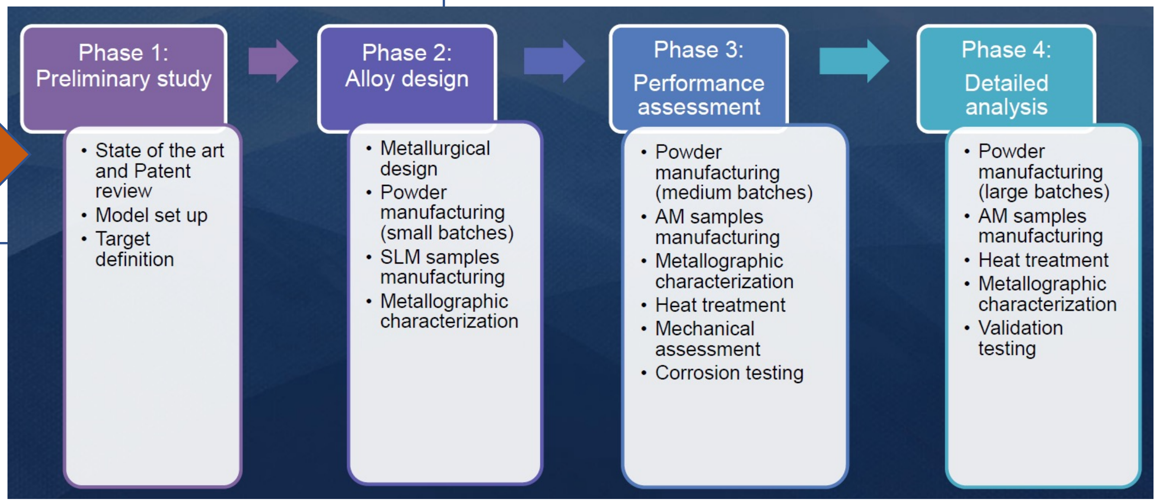
Collaboration network for new alloy development

Metal powder and composite material atomization. Powders for use in additive manufacturing and magnetic materials

MEMBER OF BASQUE RESEARCH & TECHNOLOGY ALLIANCE

Rina Consulting – ***Centro Sviluppo Materiali S.p.A. (CSM)*** can provide to support clients on Additive Manufacturing topics, mainly for:

- Development of materials,
- powder manufacturing and qualification,
- component design,
- post process conditioning,
- performances assessment.



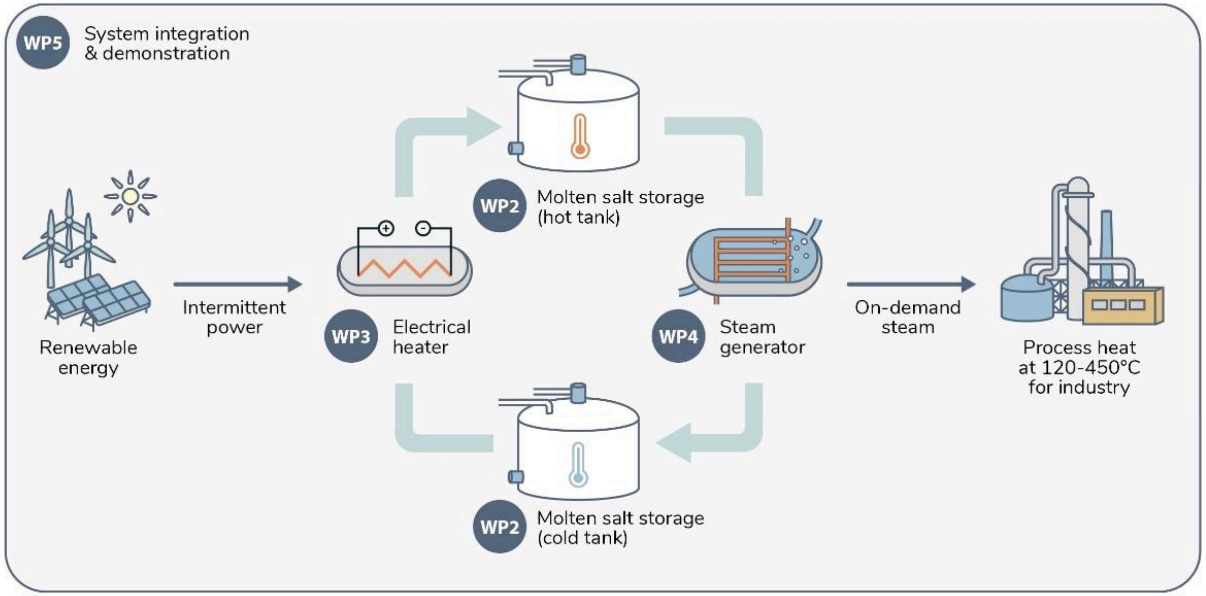
PometonPlus – Think it, Print it

new development in the powder production technologies to obtain

Cu Chemical purity > 99,95 %

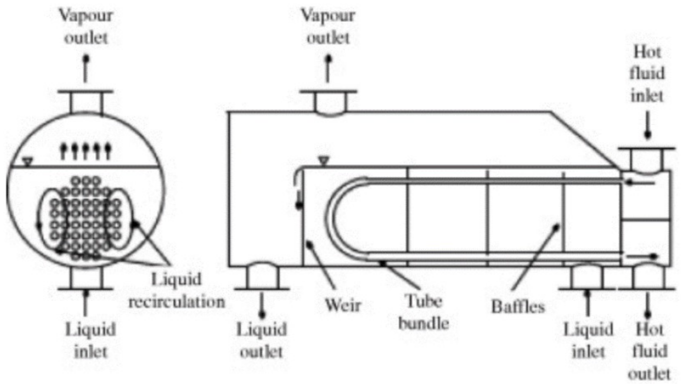
Examples:

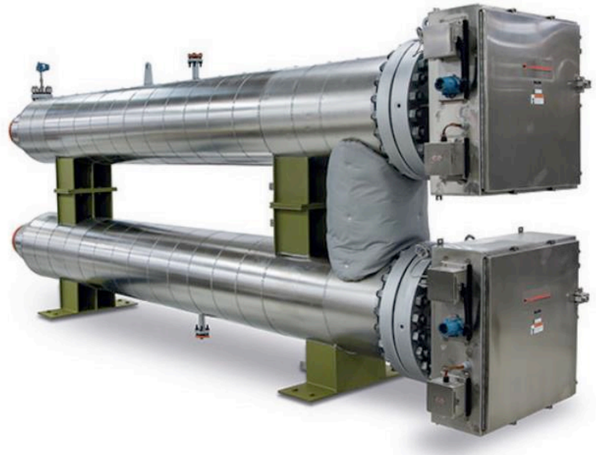
- CuCrNb21
- Cu-Al2O3
- Cu-W
- Cu-Mo
- Nb-Si alloys
- HEAs
- W-Re alloys
- …



Thermal Storage

LoCoMoSa aims to demonstrate a cost-reduced medium- to long-duration thermal energy storage system based on molten salt to deliver industrial heat at 120-450 °C.

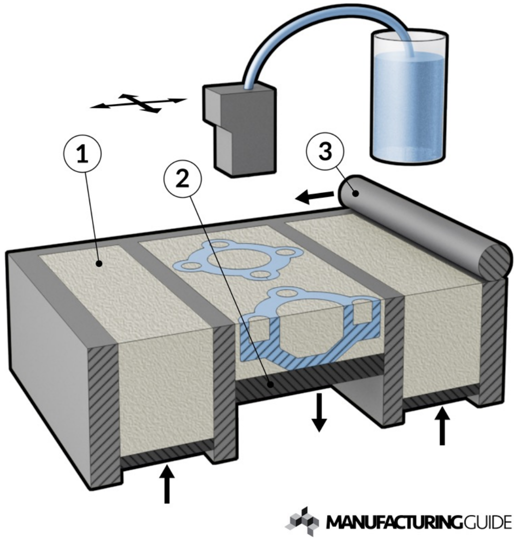




- **Binder Jetting (BJT)** = a liquid bonding agent is selectively deposited to join powder materials.

BJT = Binder Jetting

The process begins by spreading a thin layer of powder (1) on a building platform (2) using a roller (3), with printheads strategically depositing droplets of binder into the powder bed. The printing plate then lowers and another layer of powder is spread. …



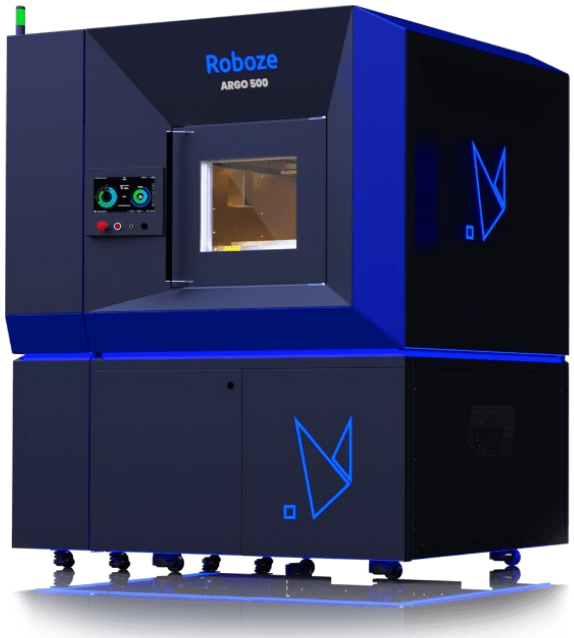
Process sequence:

- 3D shape creation
- Curing of 3D shape → «green»
- Debinding → «brown»
- Sintering → Metal components

- best surface finishing in comparison to SLM e EBM
- Complex shape and geometrical precision
- **No supports are needed** !!!
- Density also greater than 99.5%

	Test method	Values
PEEK MECHANICAL PROPERTIES		
Tensile Strength (Ultimate)	ASTM D638	XY 86 MPa - XZ 89 MPa
Tensile Modulus	ASTM D638	XY 3.3 GPa - XZ 3.4 GPa
Flexural Strength	ASTM D790	120 MPa
Flexural Modulus	ASTM D790	3.5 GPa
PEEK THERMAL PROPERTIES		
Continuous Use Temperature	ASTM D3045	250°c
Melting Point	ASTM D3418	343°c
HDT @1.82 MPa	ASTM D648	150°c
Glass Transition Temperature	ASTM D3418	143°c
Thermal conductivity		0.43 W/m*K
Lowest temperature		-70°c
PEEK PHYSICAL PROPERTIES		
Density	ASTM D570	1.29 g/cm3
Water Absorption	ASTM D792	<0.45°c
Moisture Absorption	ASTM D570	<0.10°c
UL 94 Flame Class Rating	UL 94	V0 (@1.5 mm, @1.3 mm)
Volume Resistivity @23°C	ASTM D257	1016 Ohm*cm
Hardness	ISO 868	87 Shore D

PEEK production



Technology developed by ***ROBOZE*** guarantees maximum material management; from hygroscopic control to drying and preheating, up to the phase of gradual cooling of the produced part, **maximizing the crystallinity of the PEEK printed**.

Helios™PEEK 2005

Carbon PEEK

PEEK

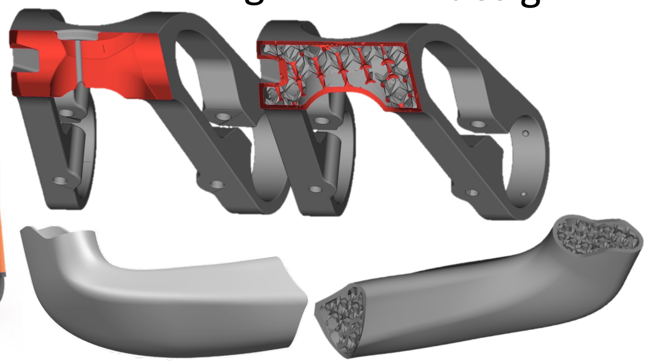
Extra Activities & Other materials

- **Ti & Ti alloy & Al alloy**

Biomedical sector

POR FESR / REGIONE DEL VENETO 2014/2020

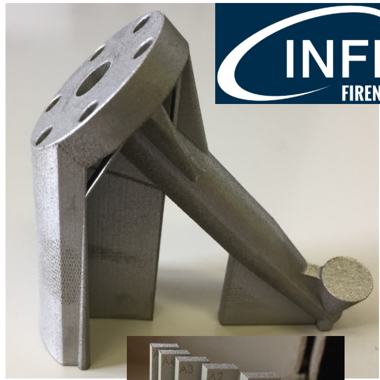
Traditional design | AM design

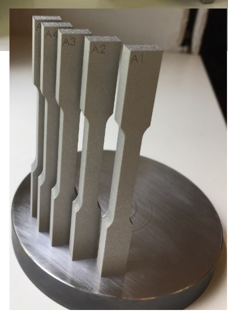


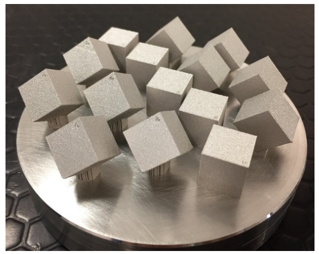
Fashion & Design

Trasferimento Tecnlogico

- **Stainless Steel 316L**

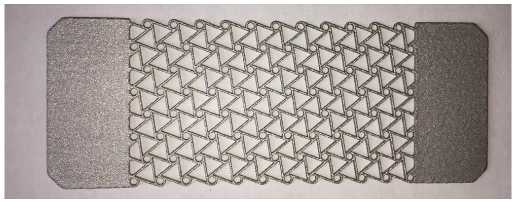






- **Auxetic material**

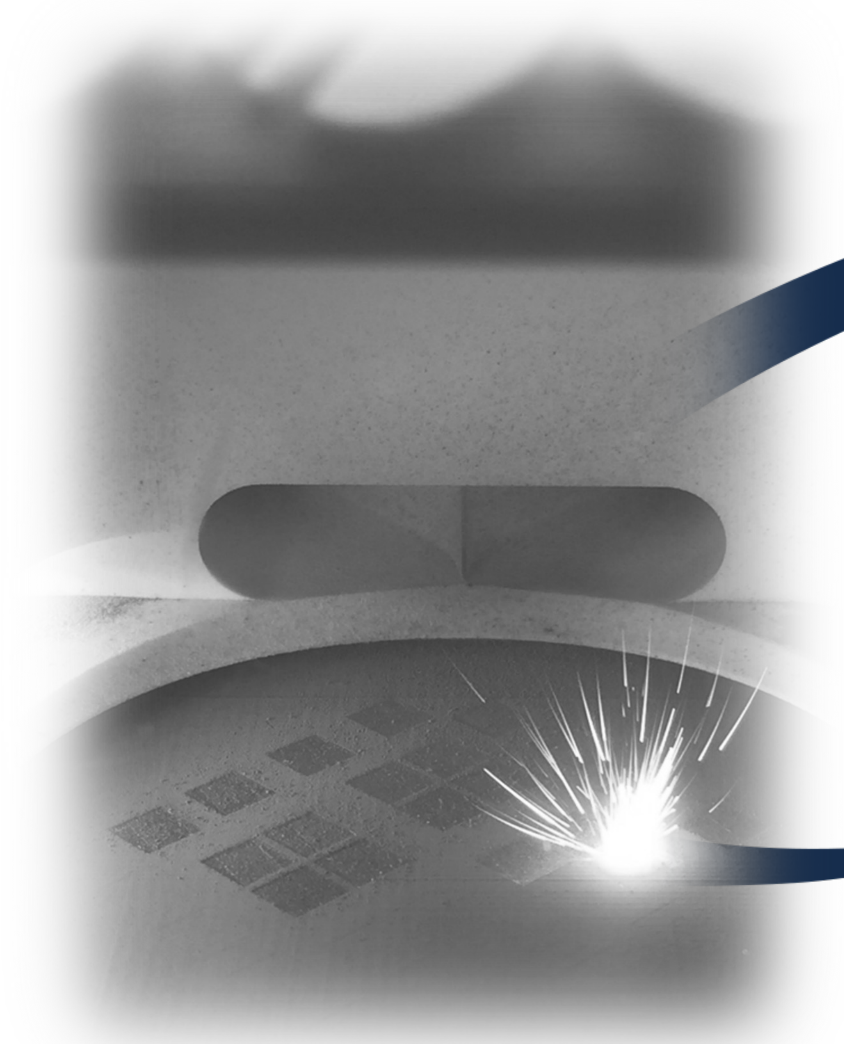
→ 316L; AlSi10Mg; CuCrZr



- **Nb alloys – HEA**

→ Baker Hugues

Baker Hughes



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GRAZIE

Thank you for your attention

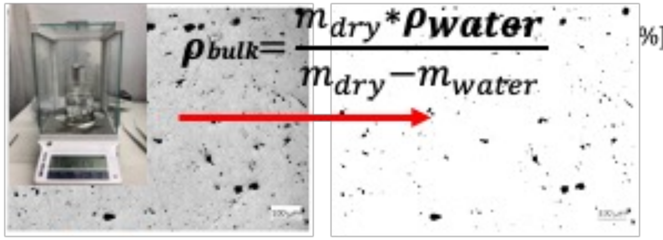
Backup Slides

Material Properties Characterisation.

Density measurements

- Archimedes method
- Optical density method

ρ_{ref} = 8.89 g/cm^3 measured on an CuC2 (C10100) Pure Copper sample

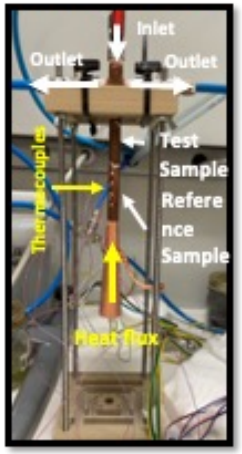


$$\rho_{bulk} = \frac{m_{dry} * \rho_{water}}{m_{dry} - m_{water}}$$

$$\%] = \rho_{bulk} / \rho_{Ref}$$

Analysis of the cross section

Thermal conductivity measurements



- Measurements based on the physical principle of **Fourier law**
- Two samples are connected: one is a reference (Cu-OFE) and one is the sample
- The samples are heated from one side and cooled from the other
- Once in stationary condition, the gradients are measured and the conductivity is measured
- The ASTM E1225-20 standard was followed
- Samples manufactured in both vertical and horizontal direction of printing

$$|\overline{q}| = k \cdot \frac{dT}{dx}$$

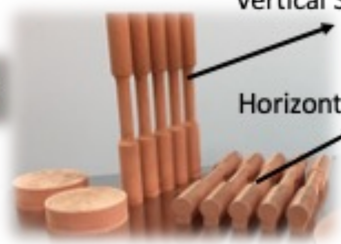
$$k_{TOP} = \frac{k_{ref} \cdot \left(\frac{dT}{dx}\right)_{ref}}{\left(\frac{dT}{dx}\right)_{TOP}}$$

k_{ref} = 396 w/mK

Measured with Hot Disk Method

Tensile tests

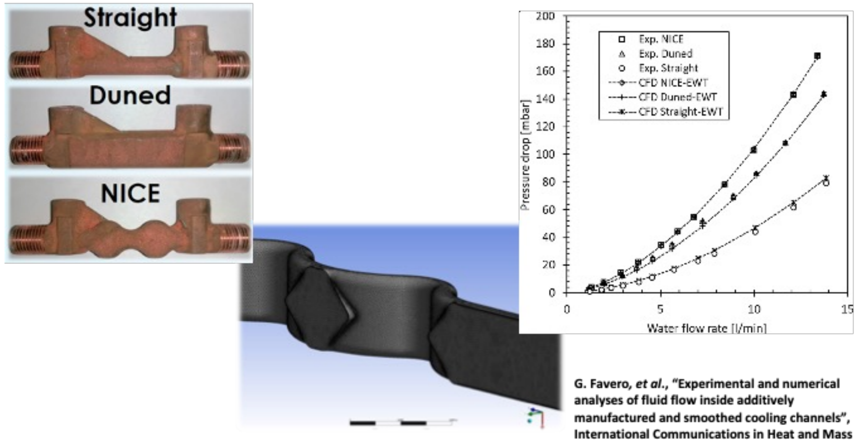
Tensile test performed on samples manufactured in both horizontal and vertical direction of printing Standard ASTM E8 was followed



Vertical Samples

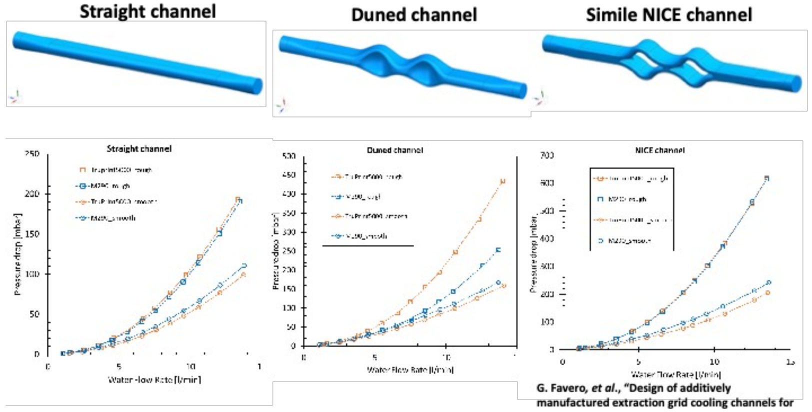
Horizontal Samples

Smoothed single channels



G. Favero, *et al.*, "Experimental and numerical analyses of fluid flow inside additively manufactured and smoothed cooling channels", International Communications in Heat and Mass Transfer, 135, 106128, (2022)

Pressure drop results in single channels

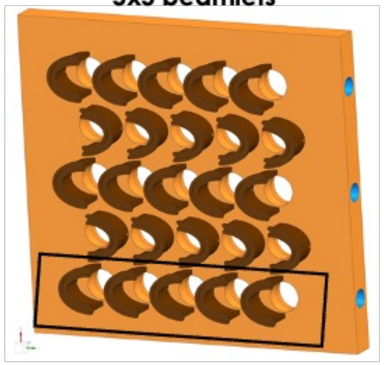


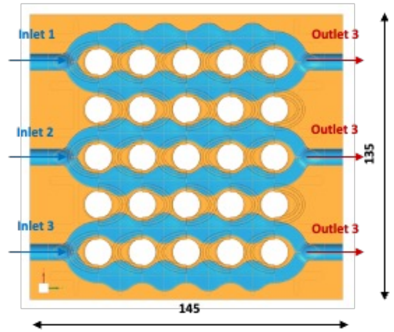
G. Favero, *et al.*, "Design of additively manufactured extraction grid cooling channels for the DTT Neutral Beam Injector", Poster SOFT 2022

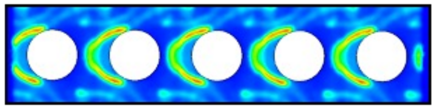
EG prototype

The integrated cooling system upgrade

5x5 beamlets





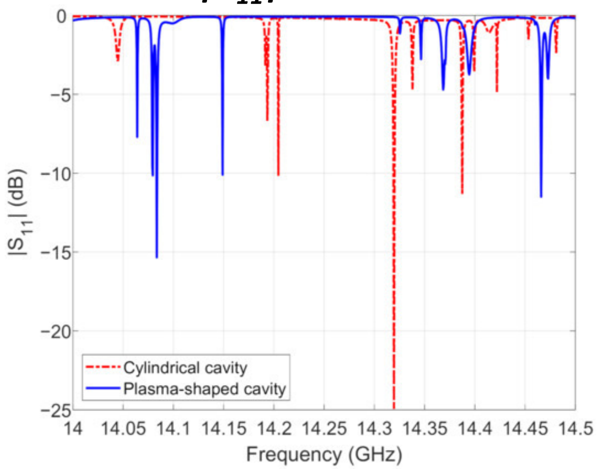


Heat flux map (from optical simulations carried out by F. Veronese RFX)

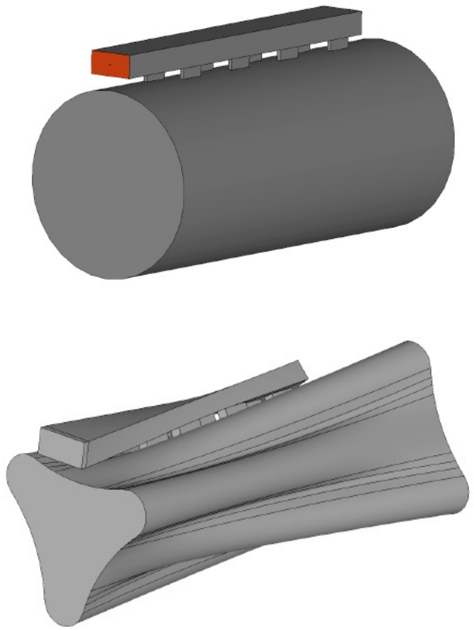
CuCrZr prototype after heat treatment

Slotted Waveguide Injection Simulations

$|S_{11}|$ curves

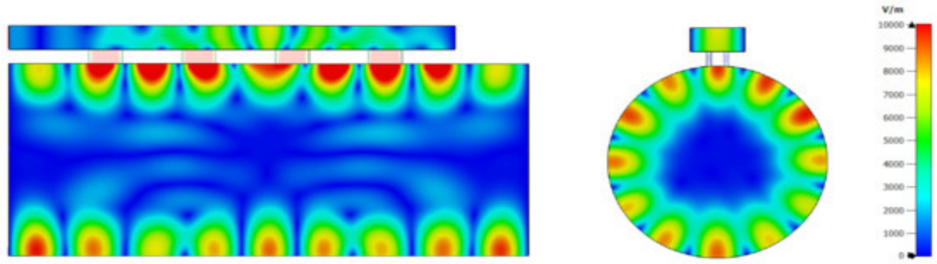


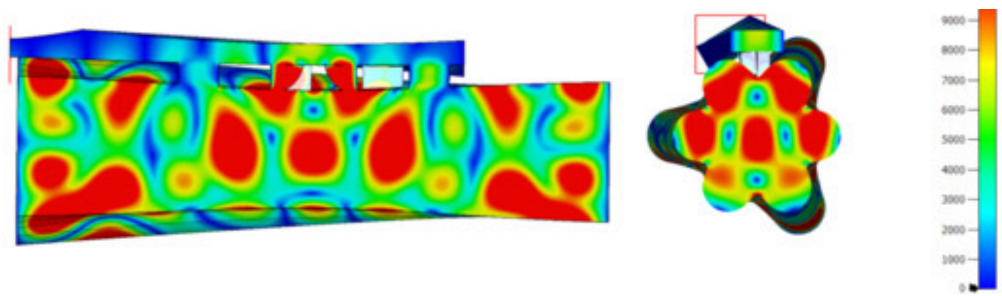
- Better microwave and power coupling to the plasma
- E-field presents a maximum around the cavity axis



Electric field module plot on side and front slices employing the side-coupled slotted waveguide injection system

off-axis electric field component.



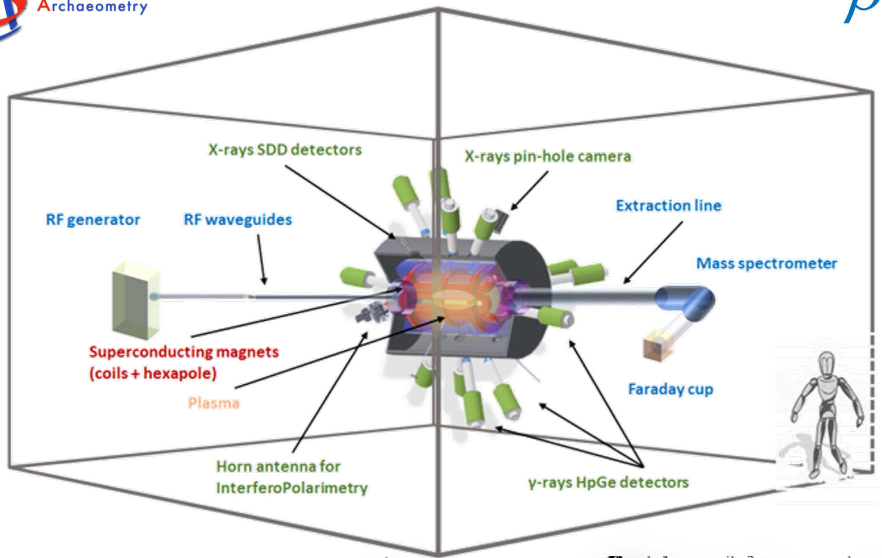


IRIS: *D. Mascali, G. Torrisi, G. Mauro, O. Leonardi, italian patent pending n. 102020000001756, International patent pending N. PCT/IB2021/050696 // (E0130645) BRE-sz*

More modes coupled inside the cavity and better wave-to-cavity match PLUS possibility to obtain modes with predominant axial field component.

PANDORA main goal: *A New ECRIT – ECR Ion Trap for investigating β-radioactivity in a «stellar» environment*

Plasmas for Astrophysics Nuclear Decay Observation and Radiation for Archaeometry



PANDORA consists of:

1) **Superconducting Magnetic Plasma Trap:** it contains a plasma made of multiply charged radioisotopes
2) **HpGe Array**: it consists of 14 detectors to measure the γ rays emitted after β-decays
3) **Plasma Diagnostics System:** it consists of RF, optical and X ray spectrometers allowing direct correlation of β-decay rate to plasma density and temperature

It could *"add unique research capability"* [CVI-report 2019] in Astrophysics and Nuclear Astrophysics in laboratory

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Contribution (official sites with budget and local responsible)

PANDORA is supported by INFN-CSN3 as a facility to be realized at LNS, involving 45 people in Italy (including Researchers and Technologists)+25 abroad