This project has received funding from the European Union's Horizon 2020 Research and Innovation programme under GA No 101004730.

3D printing (additive manufacturing) applied to accelerator components

T. Torims, Riga Technical University

On behalf of I.FAST WP10 Task 10.2 partners

iFAST

HIAT 2022

AM technology

Additive Manufacturing is a primary shaping process

“Fabrication of a solid body from a shapeless material through cohesion”

… or simply…

“…a process in which 3D bodies are manufactured in a layer-wise fashion”

Lukas Stepien @ I.FAST AM workshop ‘22

AM technology

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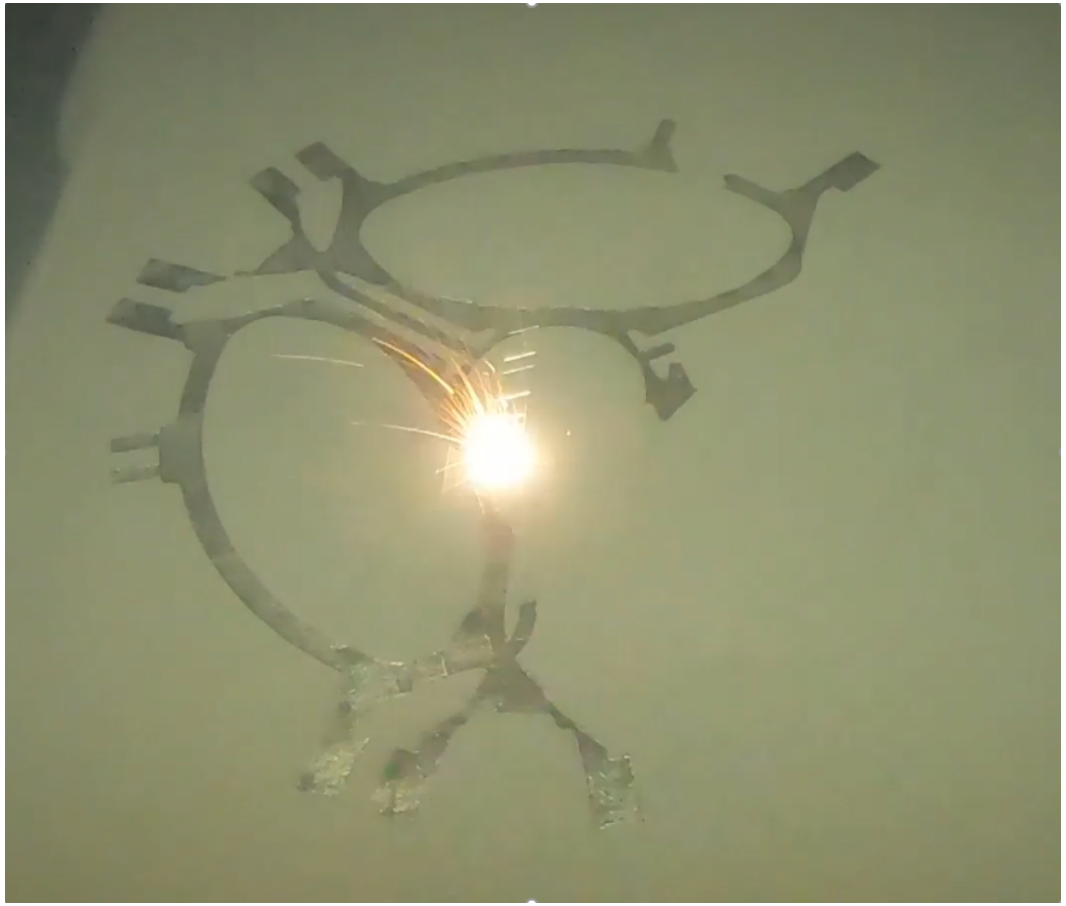

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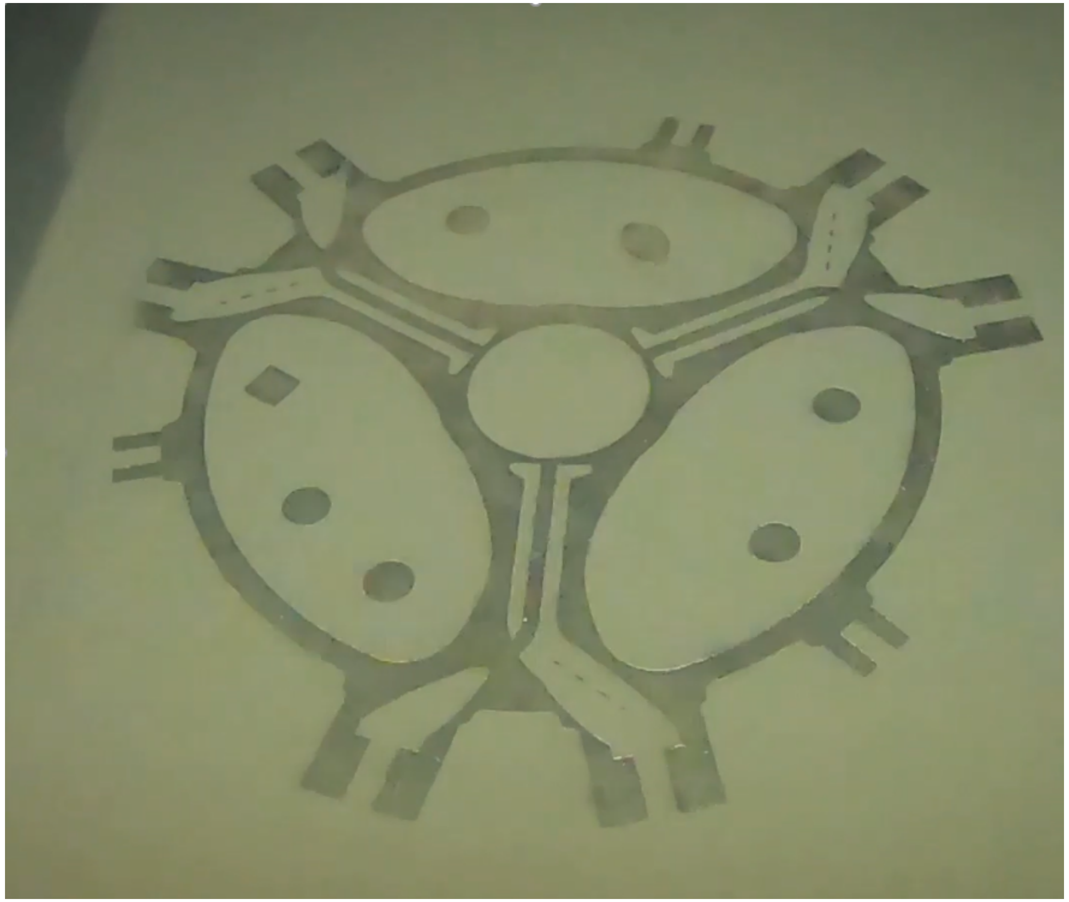

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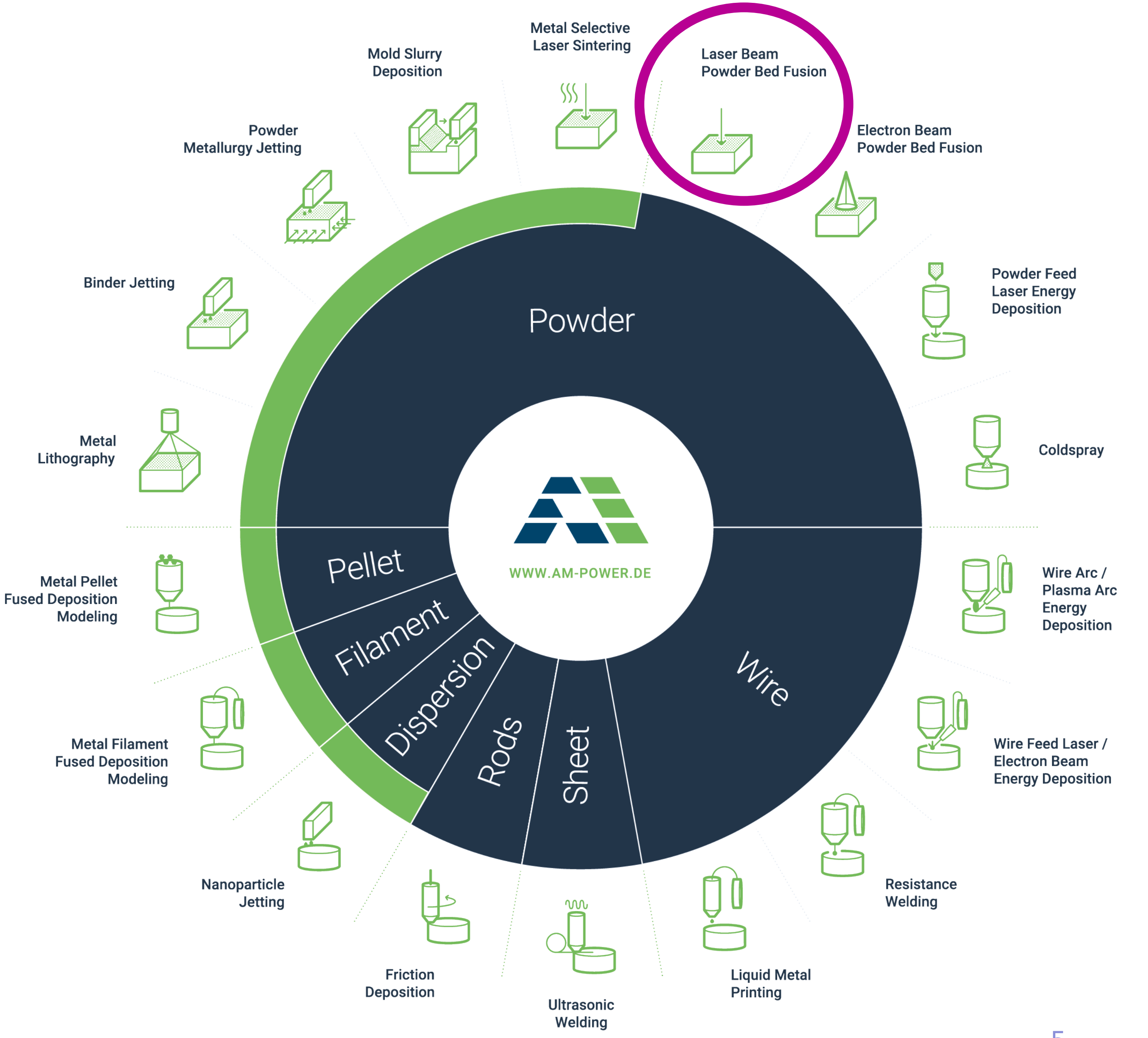
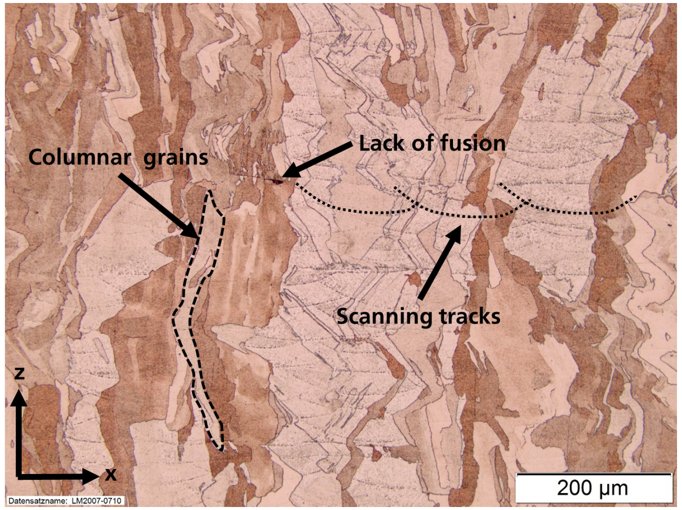


State of the art

Laser Powder Bed Fusion

Process

- Due to layer-wise build-up defects can occur (e.g. lack of fusion, keyhole, gas porosity)
- Density up to 99.99 %
- Process leads to a fine crystalline microstructure
- Microstructure is often anisotropic (to build direction)
- Productivity ~ 20 - 170 cm³/ h (multiple Laser possible)
- Resolution 20 – 200 Ra µm
- Surface roughness typically ~ 5-15 µm



Fraunhofer IWS

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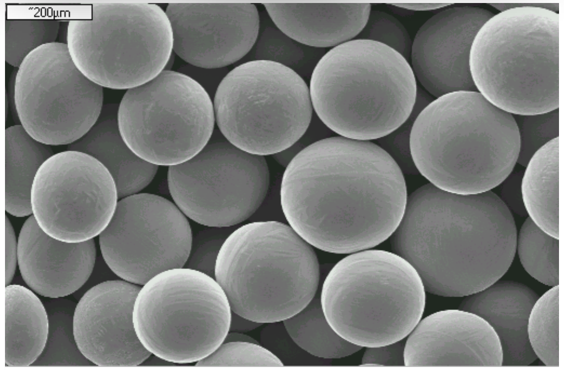
State of the Art

Laser Powder Bed Fusion

Materials

- Spherical powder with good flowability needed
- Powder size distribution D_{10} = 15 … D_{90} = 50 µm
- Wide range of common validated materials (Ni-base, Ti-base, Al-base, Fe-base, stainless steel, magnetic, refractory material, …)
- Composites (Ceramic-Metal-Composites)



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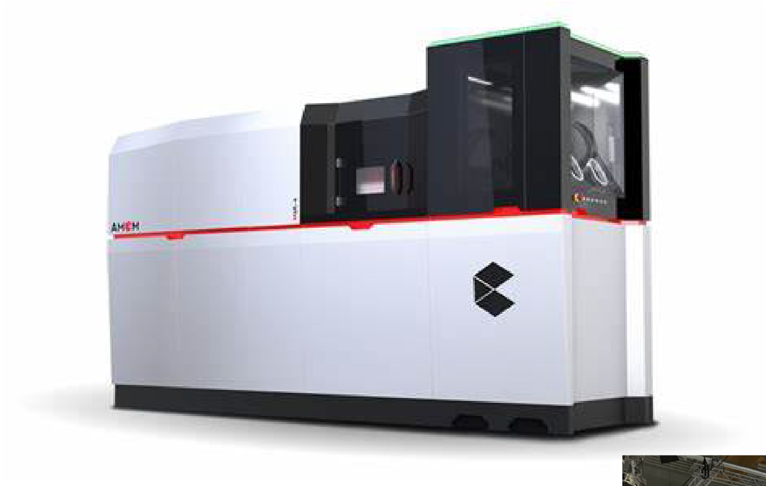
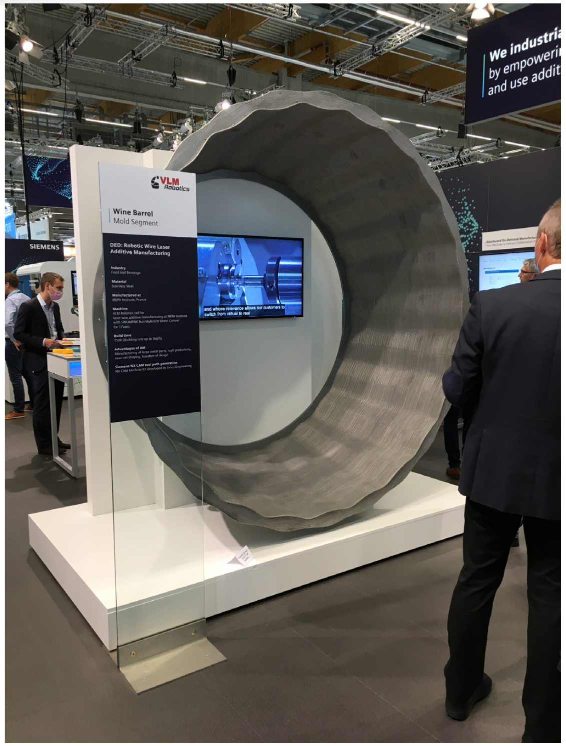
Latest trends

Laser Powder Bed Fusion



- Higher productivity through:
  - Multiple lasers
  - Increased laser power > 1 kW
  - Automated powder and part handling within machine -> costs >> 1 Mio.€
- Introduction of blue laser sources (65 % absorption, ~ 150 W needed)
- Increase in build-size ~ 1000 x 1000 x 1000 mm³ -> still R&D
- Copper and Copper alloys
- Large parts…



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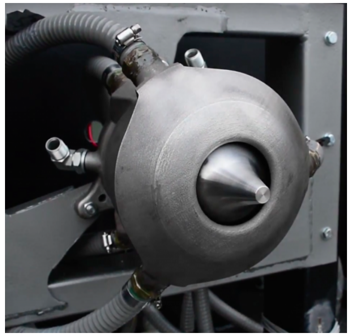
AM applications - latest trends

Automotive, medical, mining, maritime, aerospace – e.g. thrusters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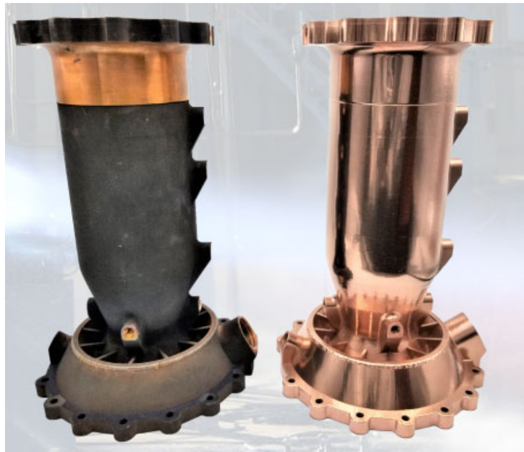
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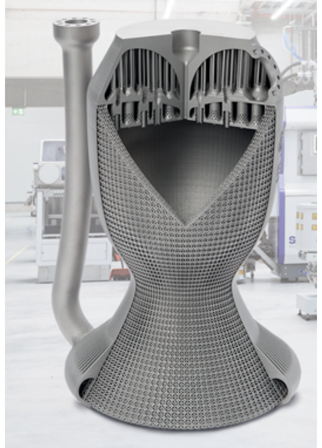
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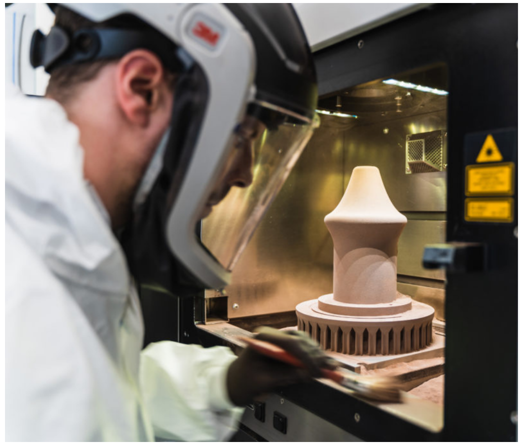
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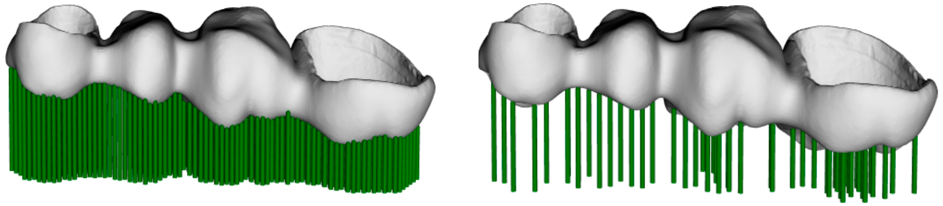
Supportless printing

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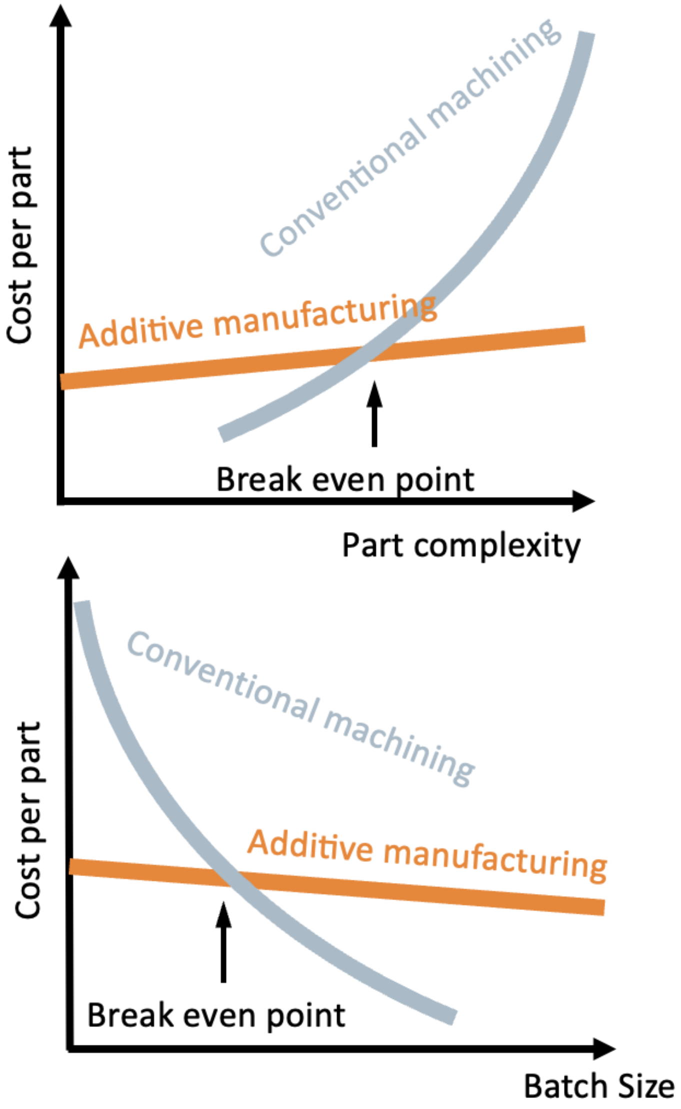
AM technology solutions

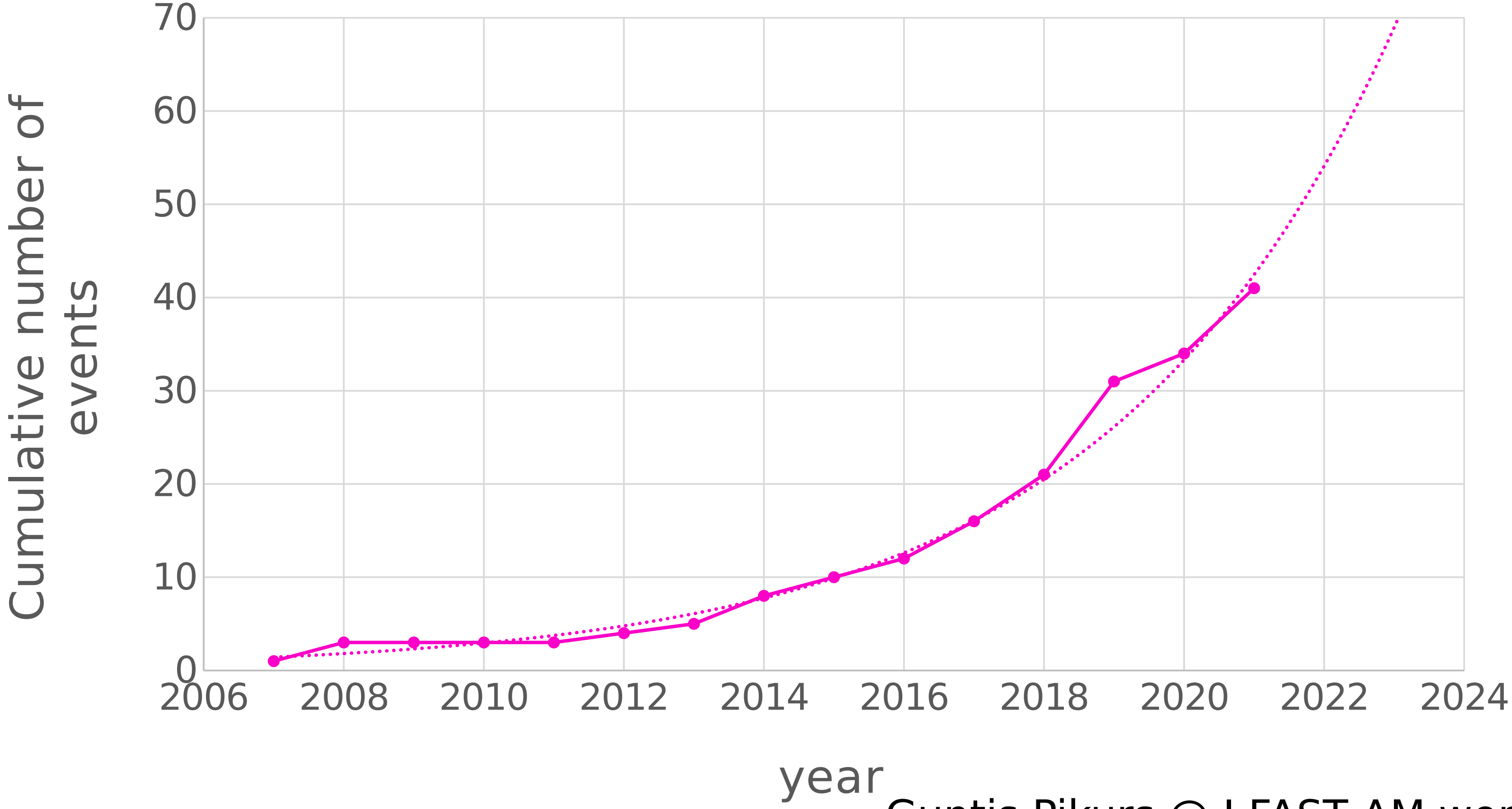
- + From micro to macro
- + Multilaterals
- + Economic production of complex parts
- + High material utilization
- + Individualization
- + Optimization and redesign
- + In-situ monitoring
- + Density up to 99.99 %

- – **Geometrical accuracy** - close to net-shape
- – **Surface roughness**
- – Sensitive process chain
- – Anisotropic material properties
- – Support structures needed
- – Fabrication speed is comparatively low - productivity ~ 20 - 170 cm^3/ h
- – Build size 800 x 400 x 500 mm^3 (l x w x h)



Accelerator Community ?

Recognized metal additive manufacturing activities within accelerator community



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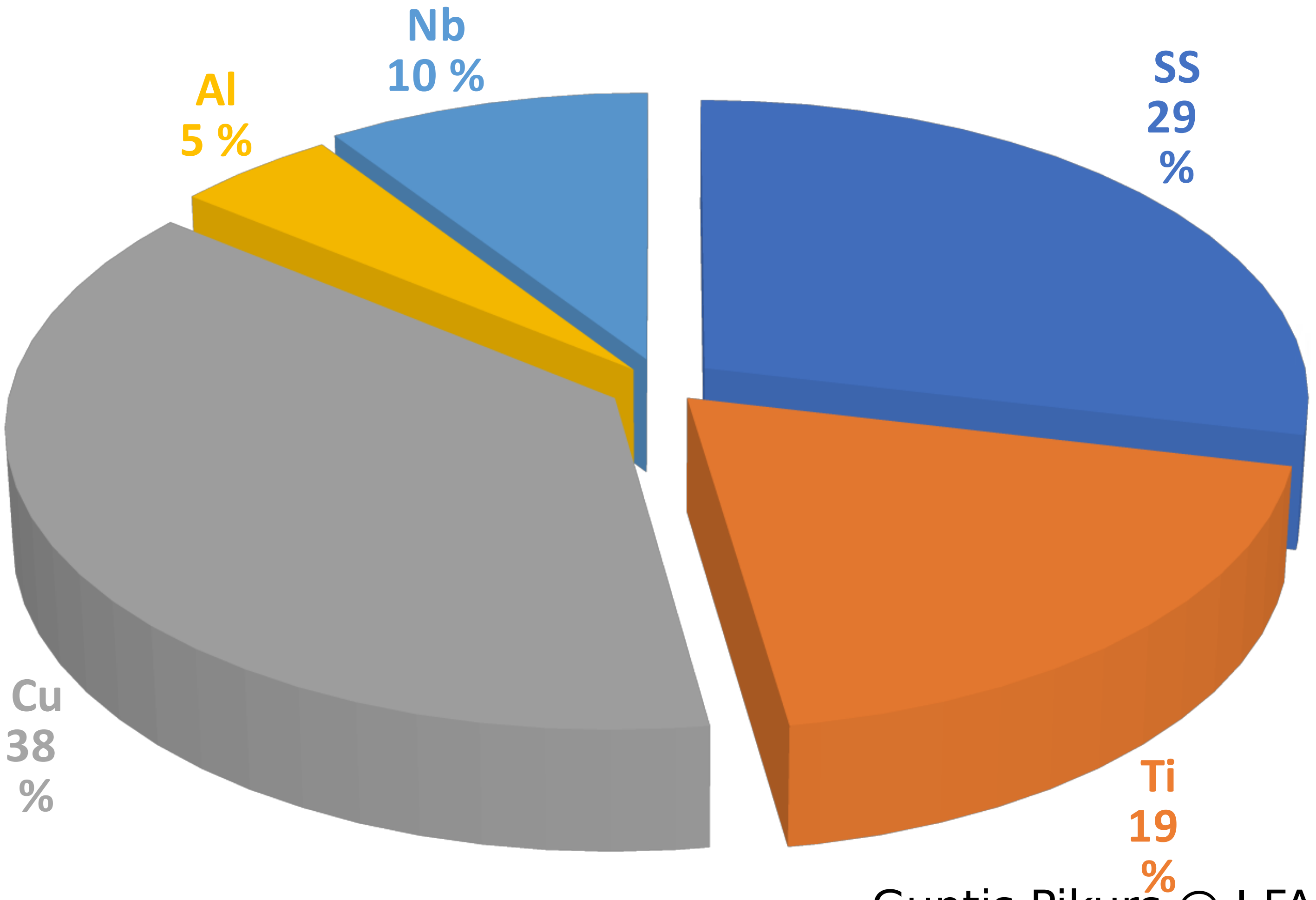
Materials used for accelerator parts



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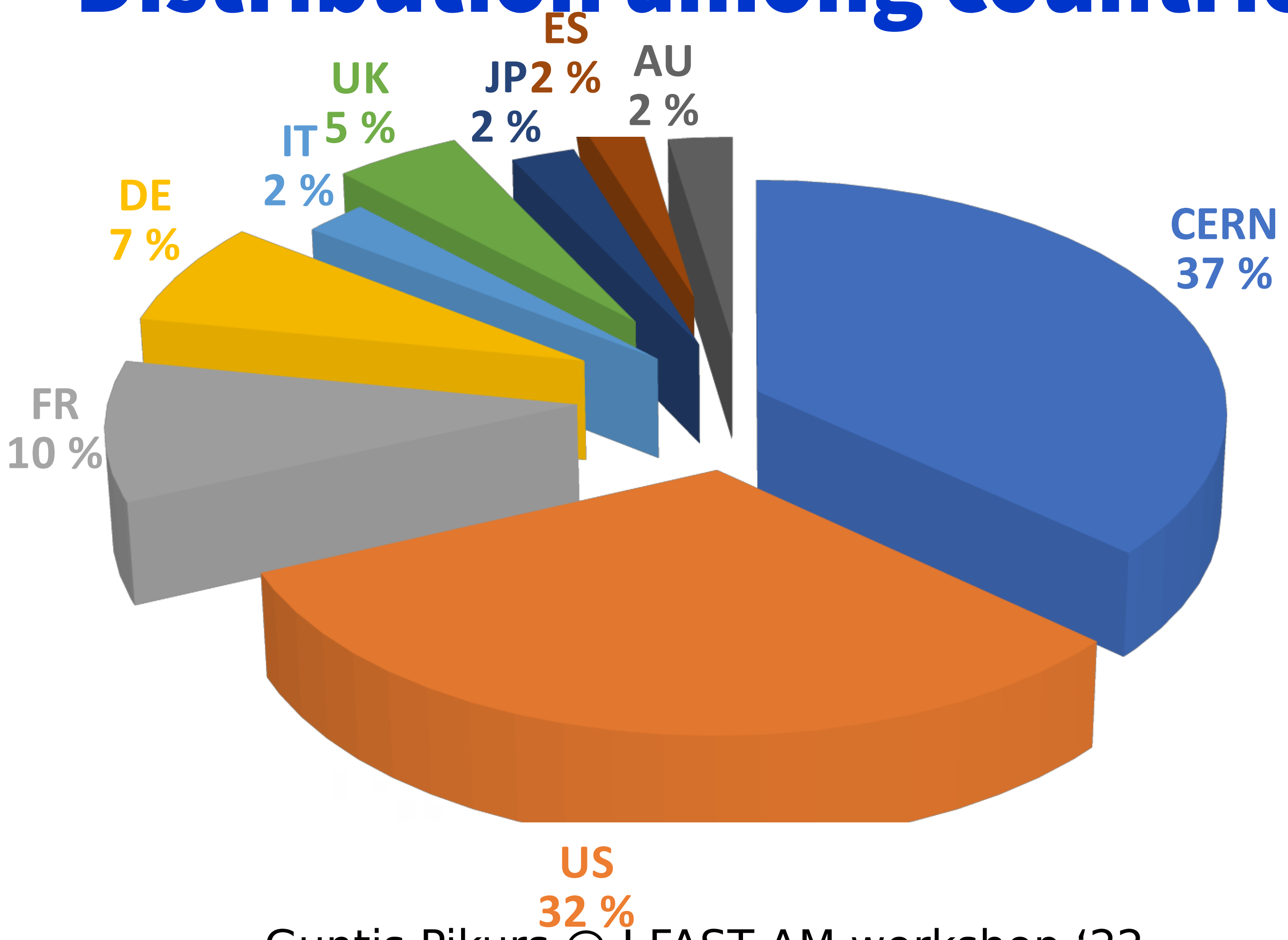
Distribution among countries



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Europe:

CERN(CH)

LAL, CNRS/IN2P3(FR)

INFN(IT)

University of Nottingham(UK)

FAU(DE)

US:

SLAC

NCSU

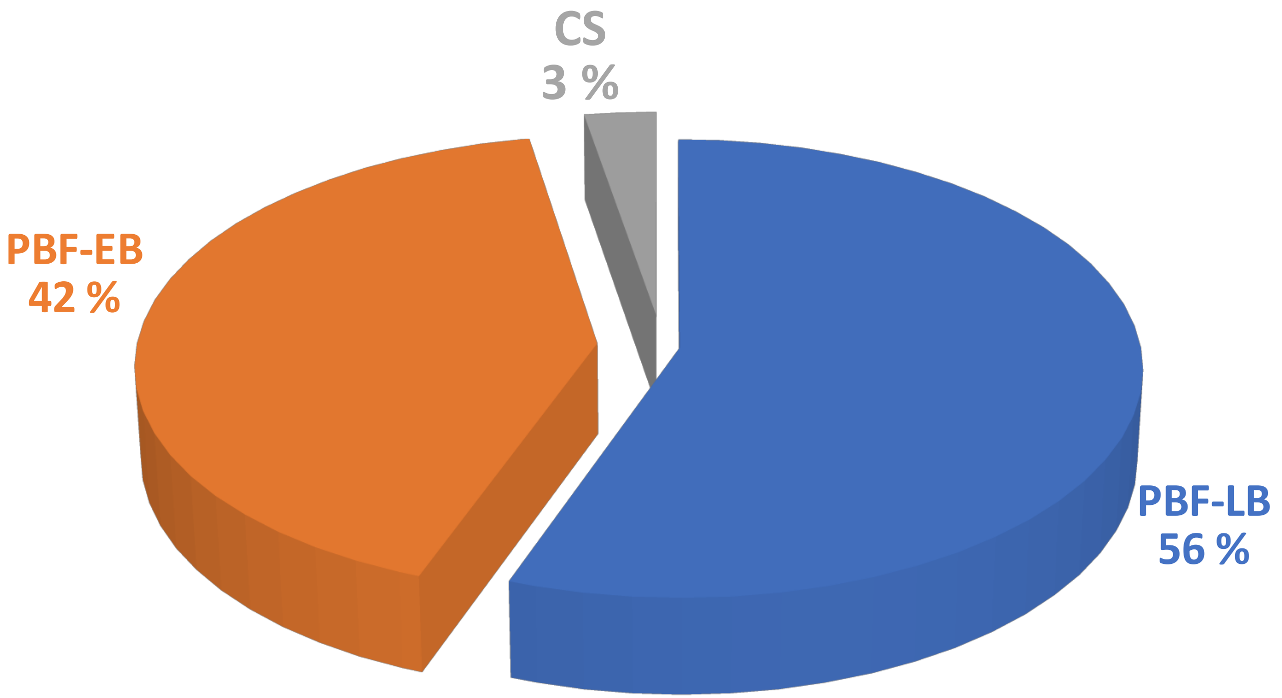
LLNL

RadiaBeam

Asia:

JEOL

Applied AM technologies for accelerators



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Applied metal AM technologies:

- PBF-LB
- PBF-EB
- Cold spray

Most often used AM machines:

- GE Arcam
- EOS
- SLM
- Renishaw
- Trumpf
- GE Concept Laser

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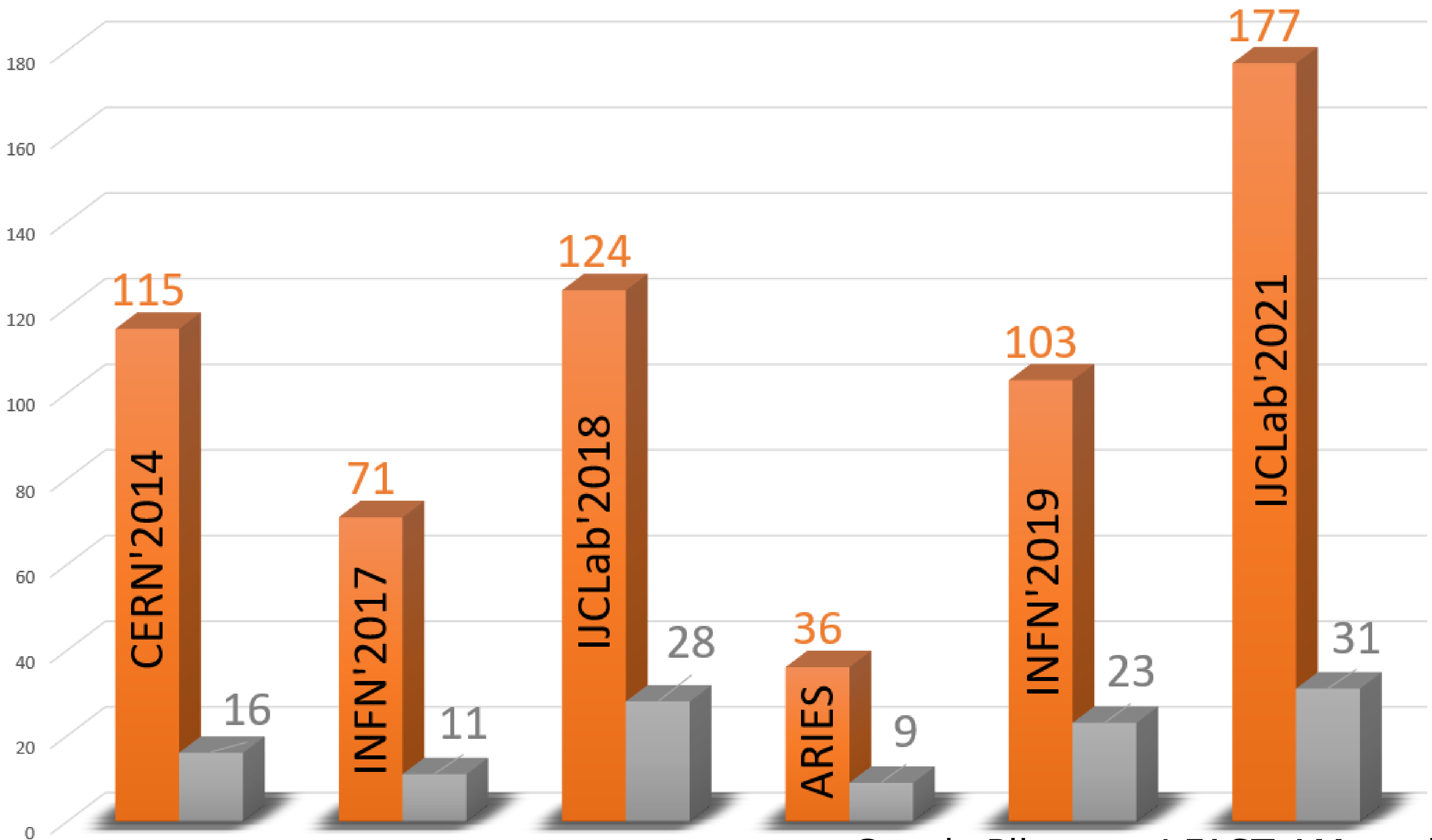
AM Workshops dedicated to HEP

(registred participants/contributions)



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AM in accelerator community

Guntis Pikurs @ I.FAST AM workshop '22

AM in accelerator community

In HIAT ‘22 please see:

- "Beam Instrumentation, Challenging Tools for Demanding Projects -ca Snapshot from the French Assigned Network” - TU3I2, F.Poirier et al.
- “Innovation Aspects in future Accelerators for Hadron Therapy” – invited talk by Elena Benedetto

Challenges within accelerators

Vacuum, cryo, RF: leak tightness, outgassing rate, porosity, electrical conductivity

Size limitations of machines and available simulation tools

Materials: ultra-clean, chemical purity – still limited avaliability, flow properties

Accuracy: surface roughness, tolerances, geometry precision

Radiation impact and activation

AM technological specificities an optimisation to end requirments (RF, cryo, etc.)

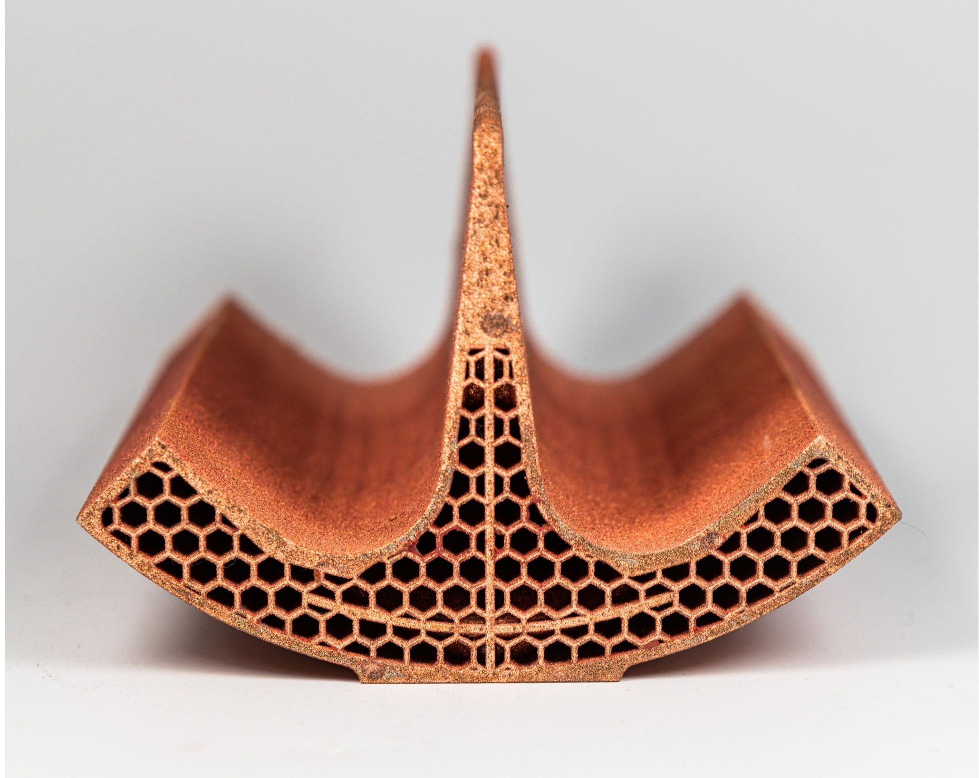
Microstructure uniformity, residual stresses, inclusions, voltage holding

Potential post-processing and eventual hybrid-machining

Yet most importantly: **traditionalism, lack of knowledge, and scepticism on AM compliance with the stringent accelerator requirements**

¼ RFQ prototype

The first prototype by AM pure-copper RFQ



- AM design and optimisation
- Manufacturing – July 2021
- Measurements:
  - ⇨ geometrical precision
  - ⇨ surface roughness
- Results published – Nov 2021
- Post-processing – Mar/Apr 2022
- measurements after post-processing – Apr 2022

Fraunhofer IWS · CERN · EN · EN/MME MATERIALS & METROLOGY · BINC INDUSTRIES SUPER PRECISION SURFACE FINISHES · RÖSLER finding a better way ...

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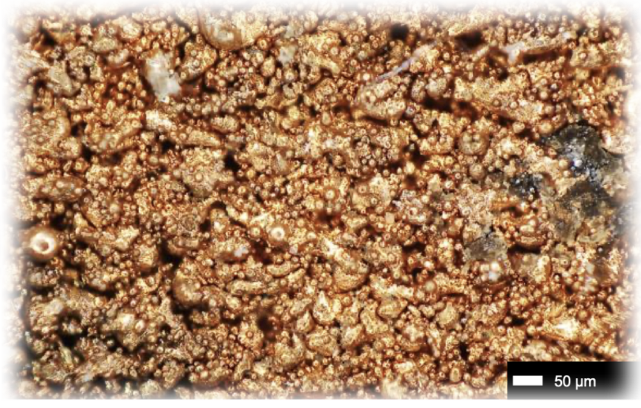
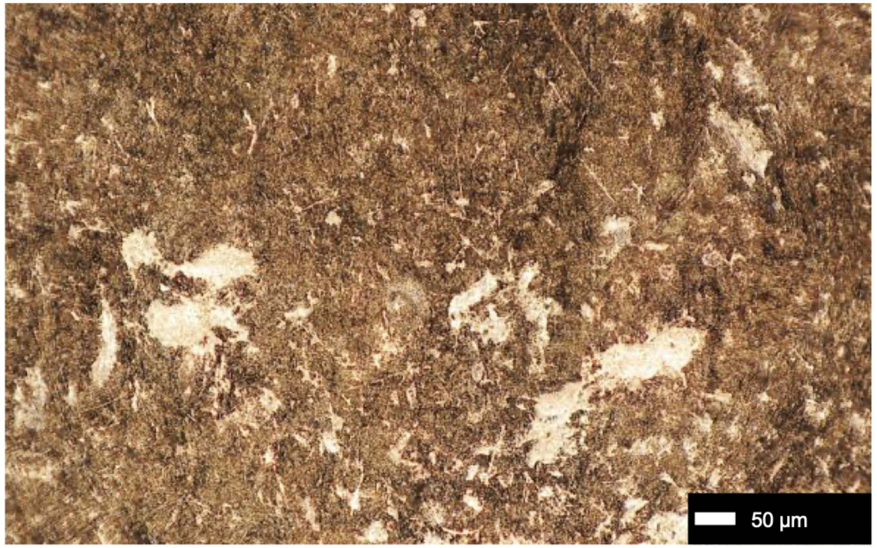
Post-processing of ¼ RFQ

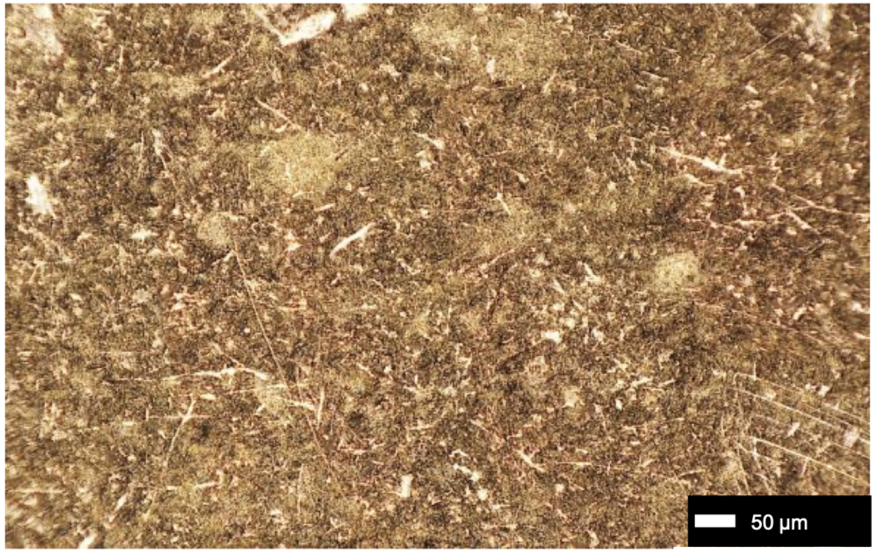
1. Conventional surface mass finishing
2. Chemically assisted surface finishing
3. High precision surface finishing with MMP TECHNOLOGY®



#1: mechanical treatment

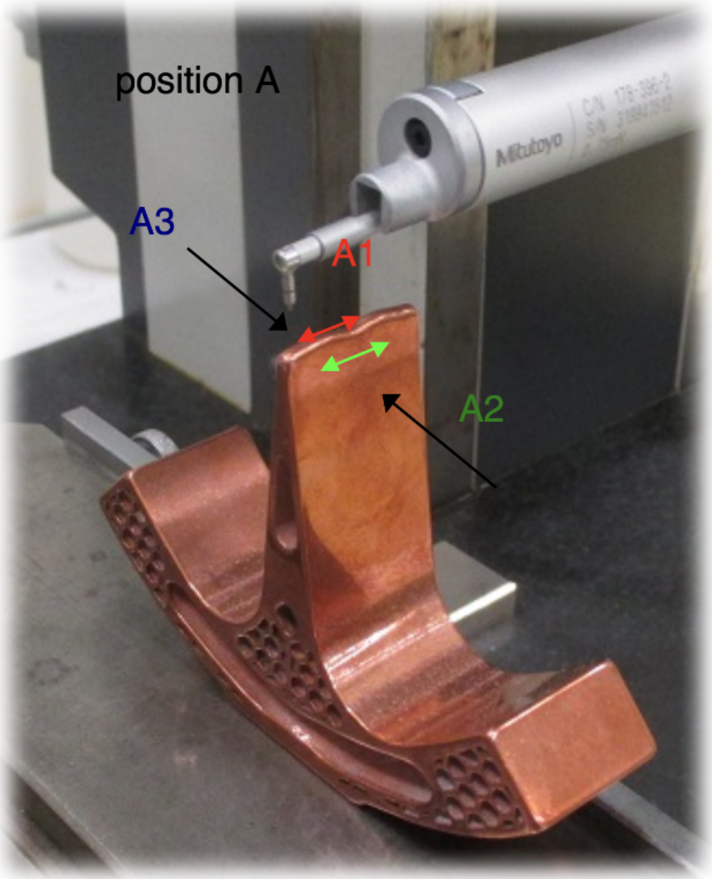


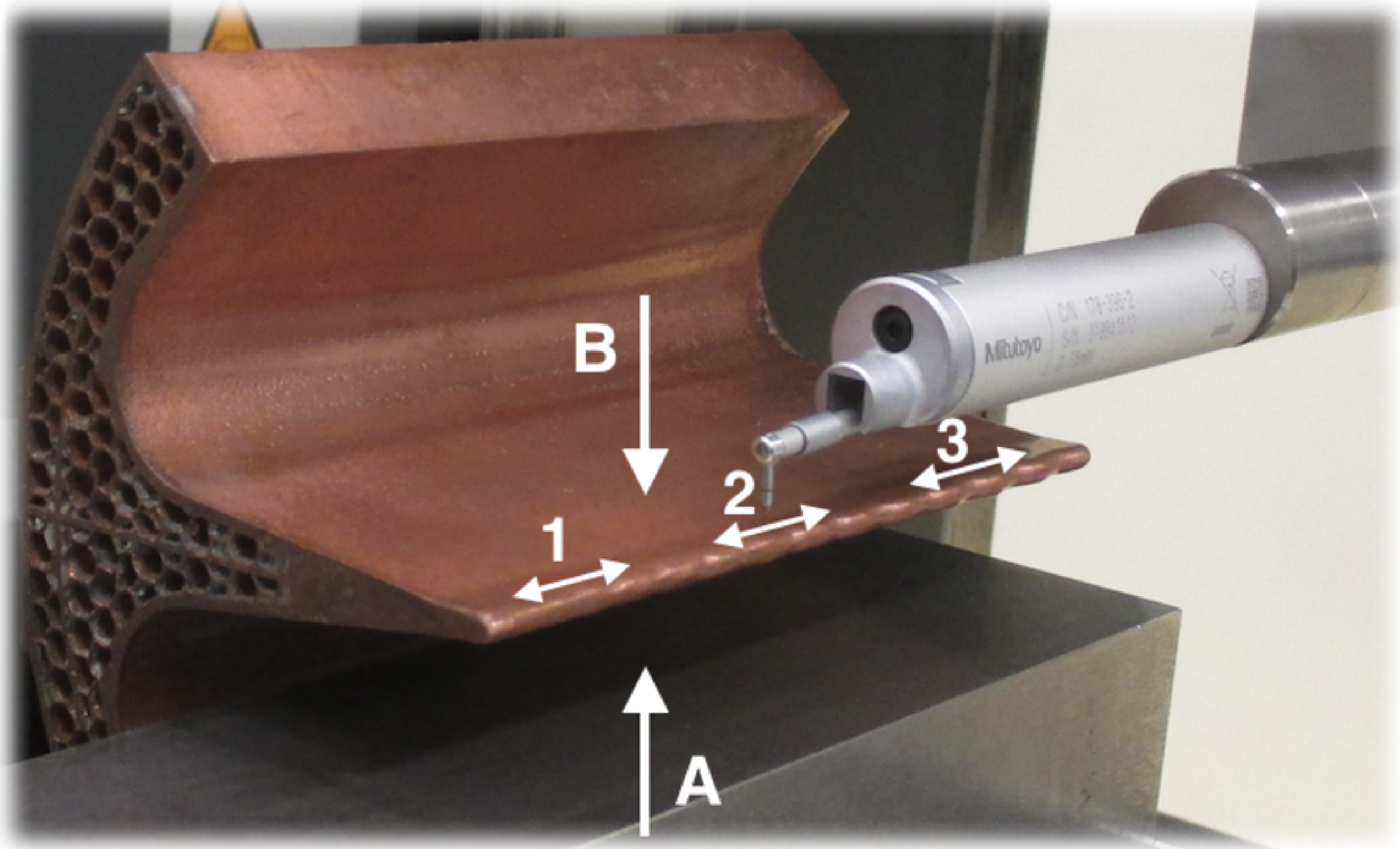
#2: chemically assisted process



Process	Ra (µm)	Rz (µm)
#1: mechanical treatment	0,28 ± 0,12	2,09 ± 0,89
#2: chemically assisted process	0,28 ± 0,09	1,56 ± 0,50

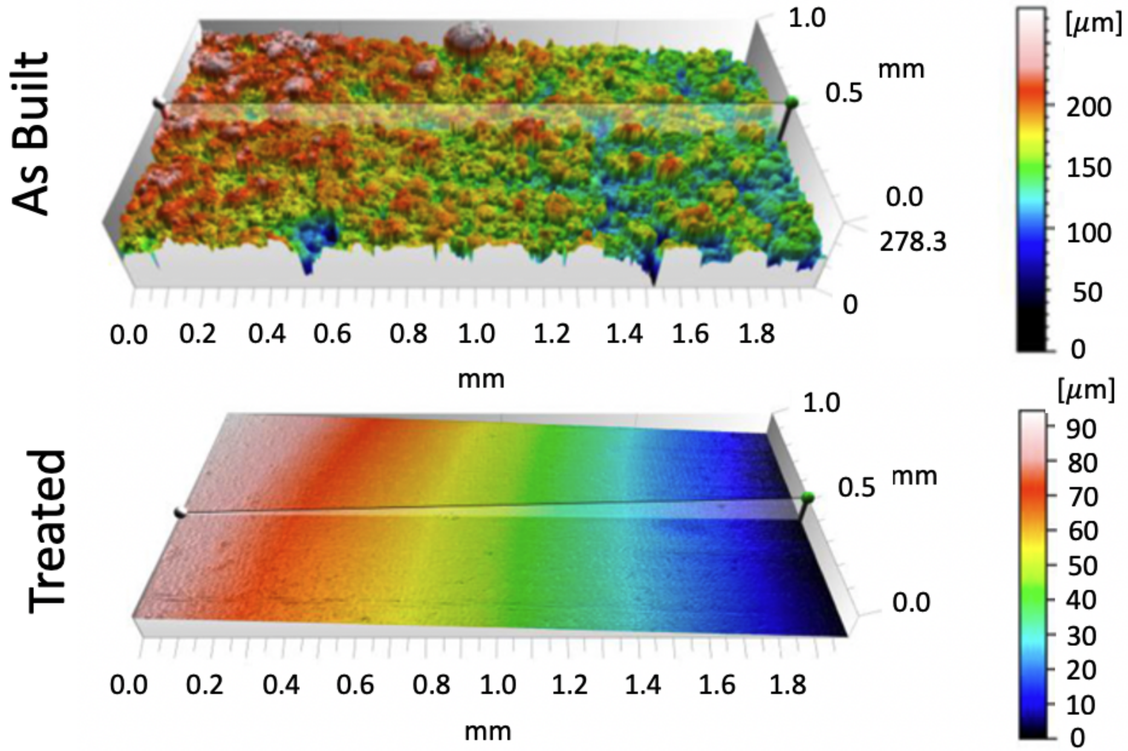
Surface roughness measurements





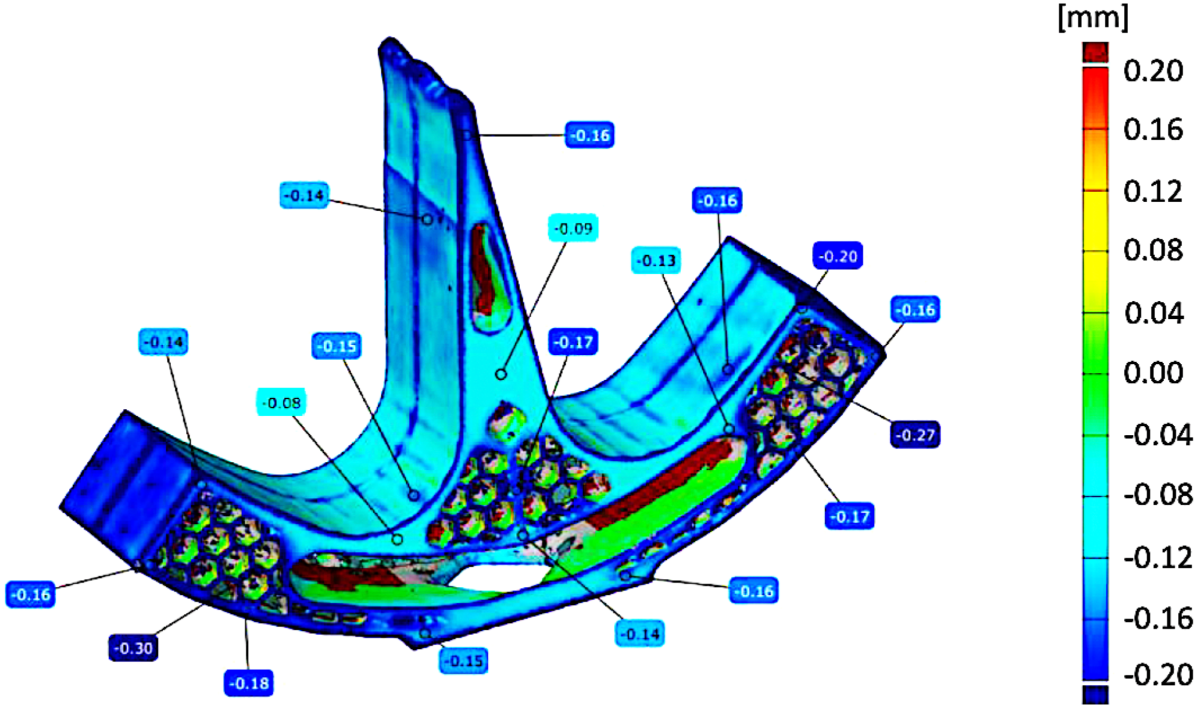
Surface roughness before and after post-processing

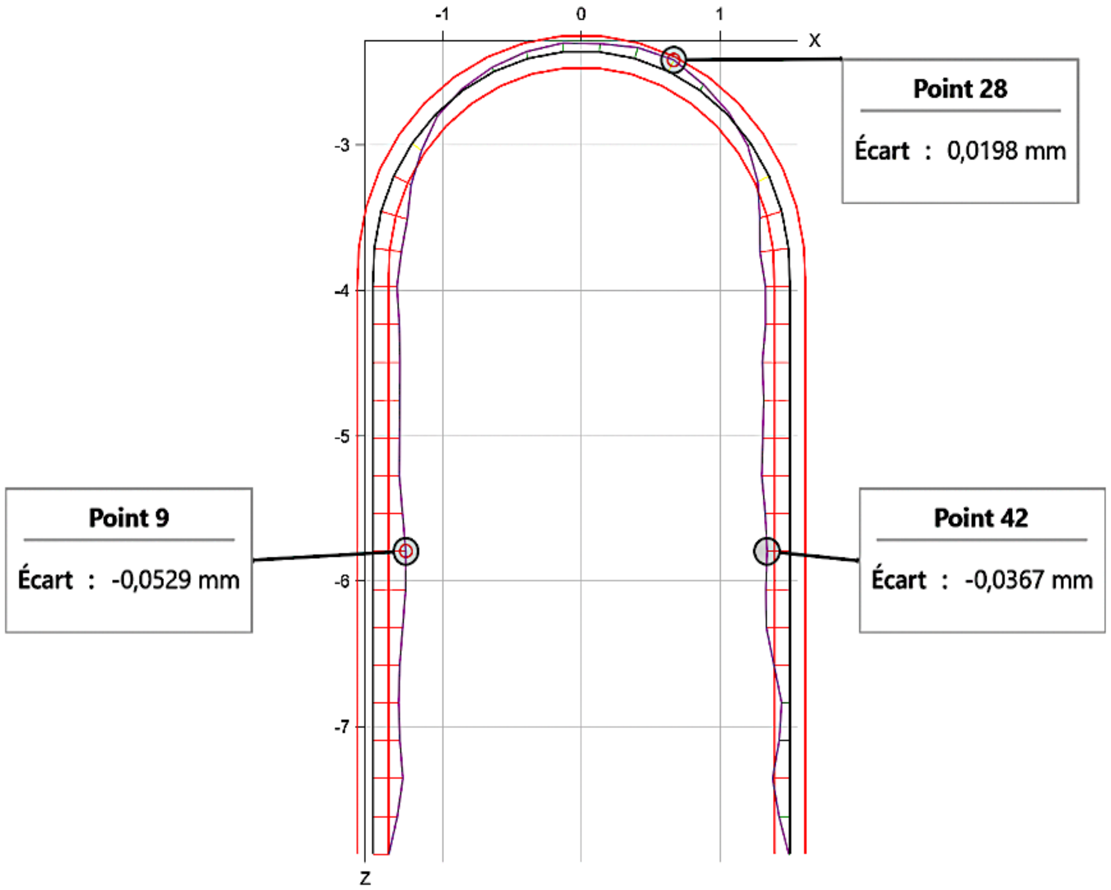
Post processing method	Side	R_a, µm	R_z, µm
Before post-processing		13.82	48.86
Trad. mass finishing	A	0.09	0.83
	B	0.07	0.58
Chemically assisted	A	0.07	0.67
	B	0.12	0.97
MMP TECHNOLOGY®	A	0.30	3.24
	B	0.11	1.03
Target roughness		0.4	not set



Attained geometrical accuracy

Target values:
- 20 µm on vane-tip
- 100 µm elsewhere





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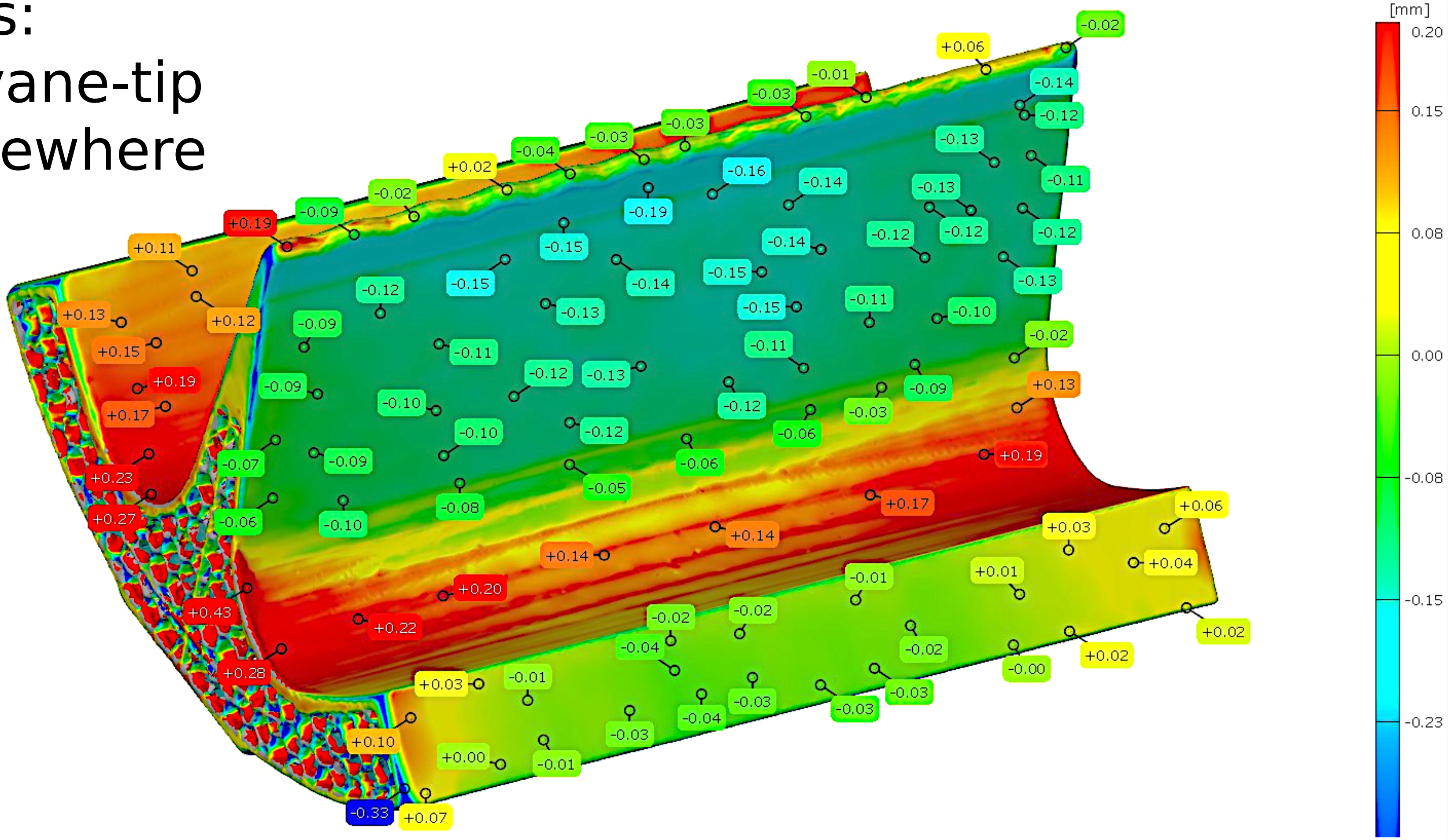
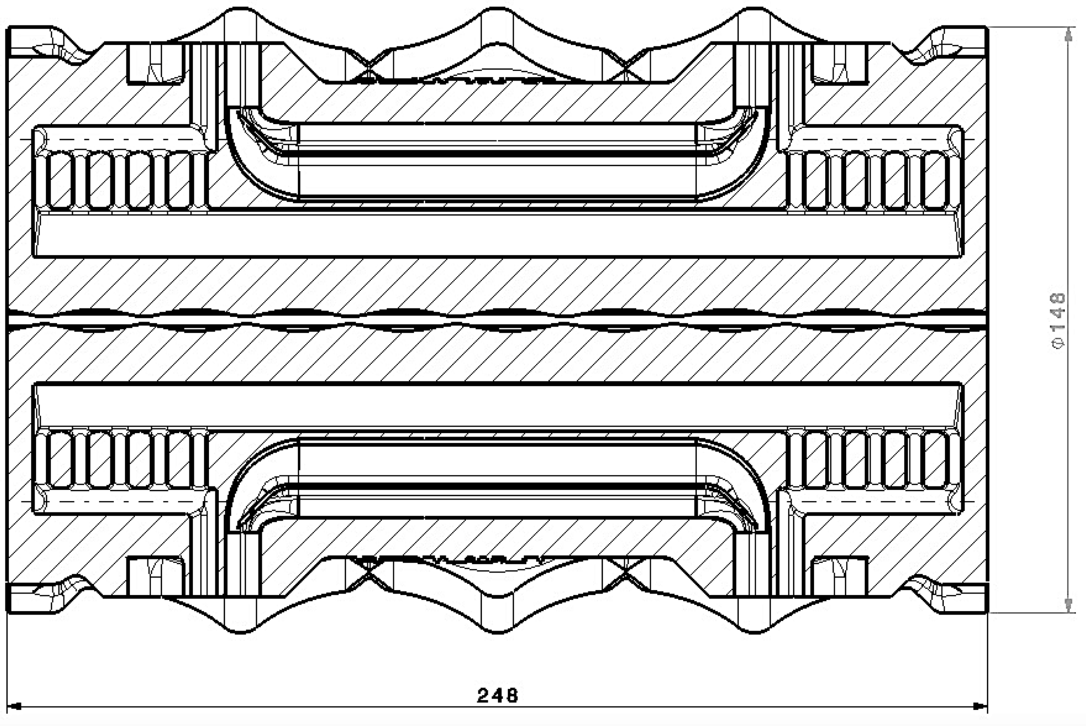
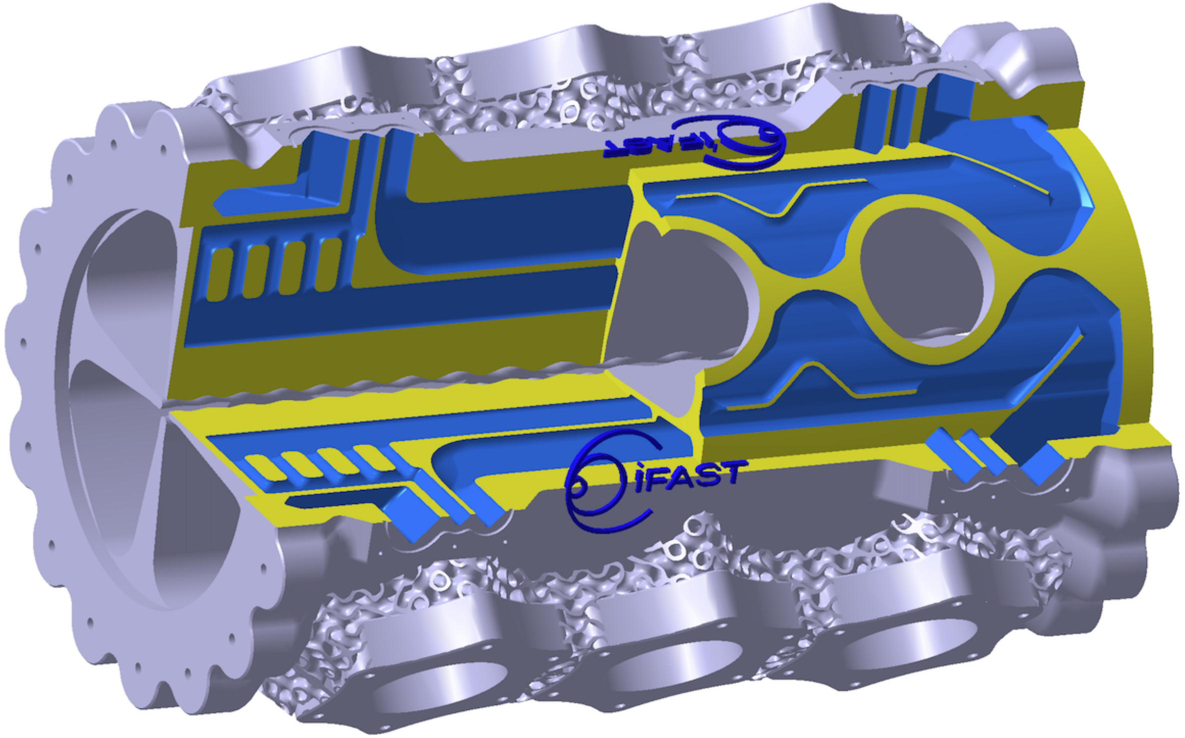


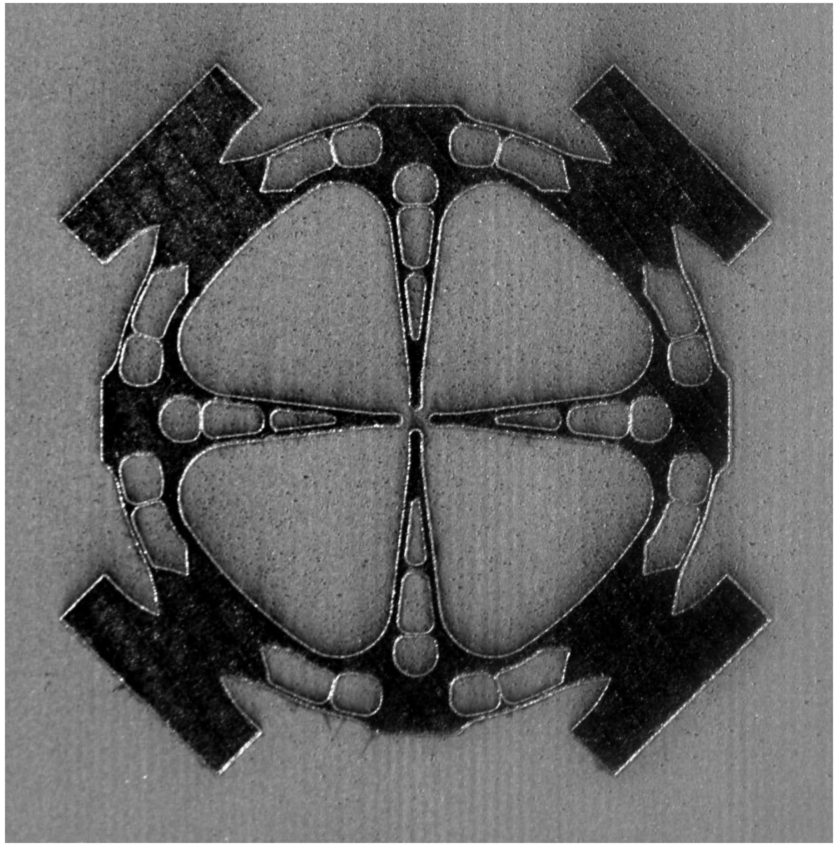
AM produced full-size RFQ module

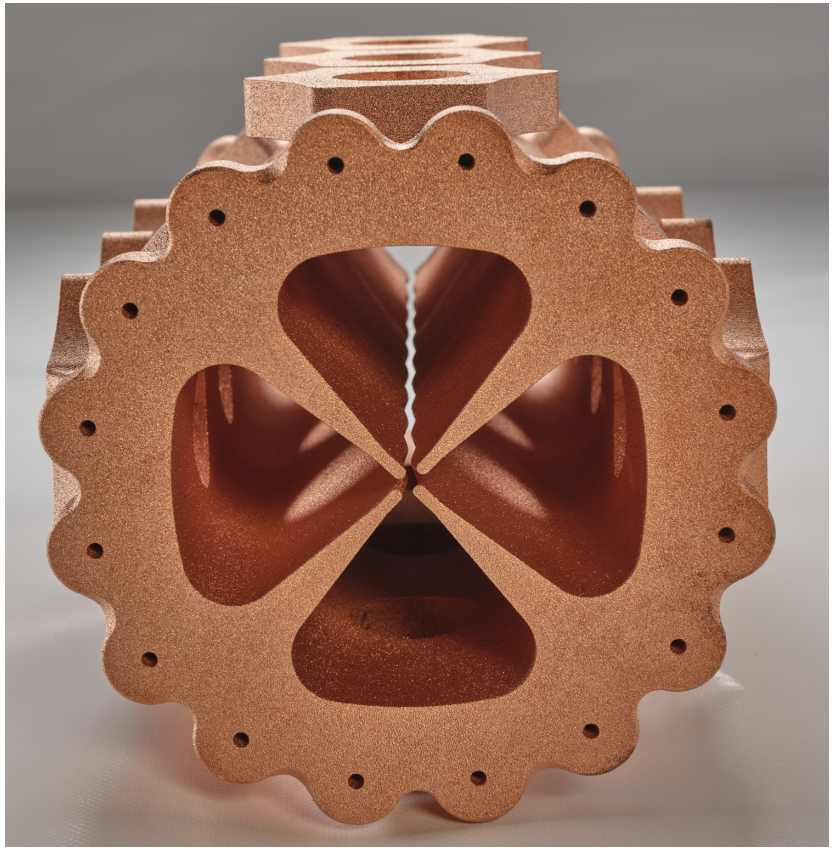
Optimisation of design - thanks to AM





Enabling complex designs





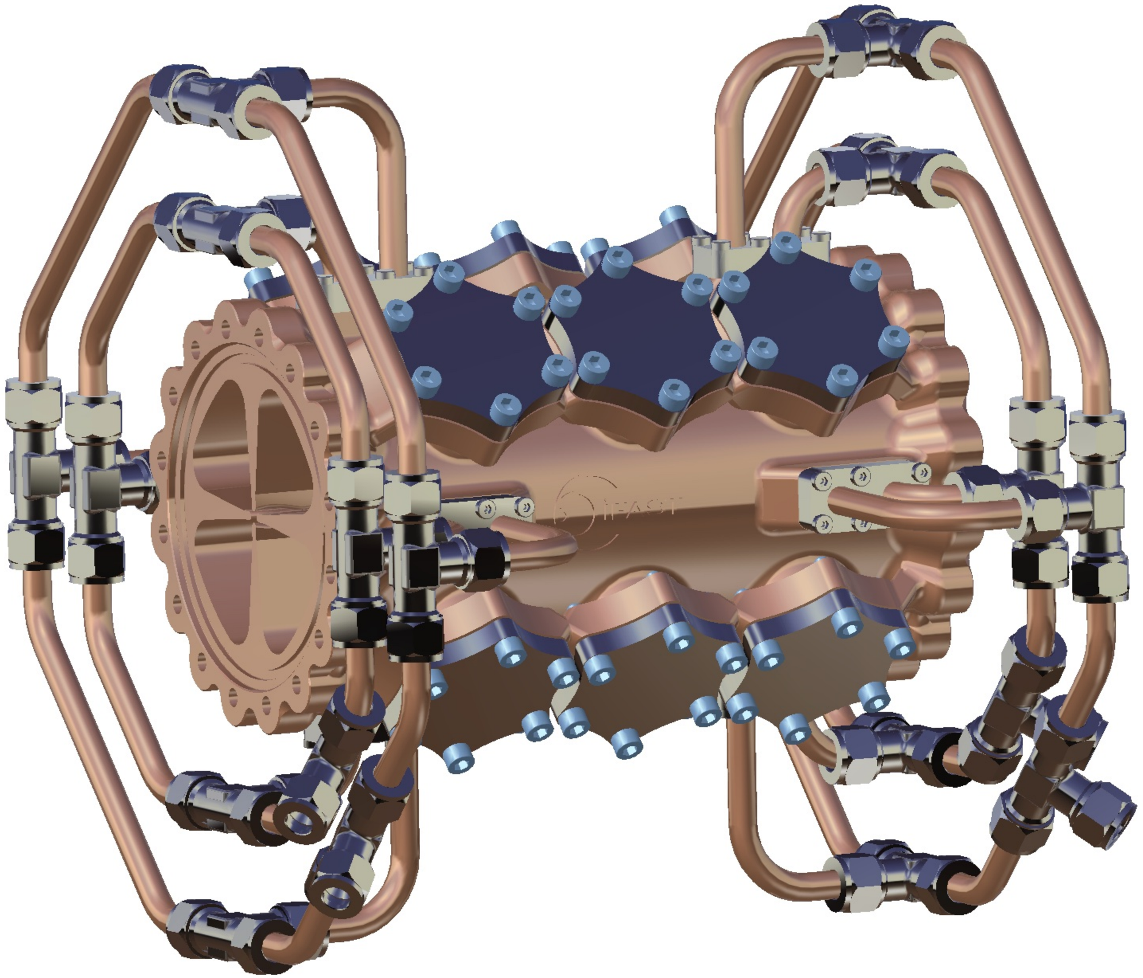
AM produced full-size RFQ module

- Manufacturing – May 2022
- Measurements – June 2022

Next steps

Tests of the full RFQ module

- Comprehensive geometrical accuracy and surface roughness measurements @ CERN
- Vacuum, watertightness, and RF tests at IJCLab
- RFQ module has been designed and equipped with the flanges and orifices enabling these tests

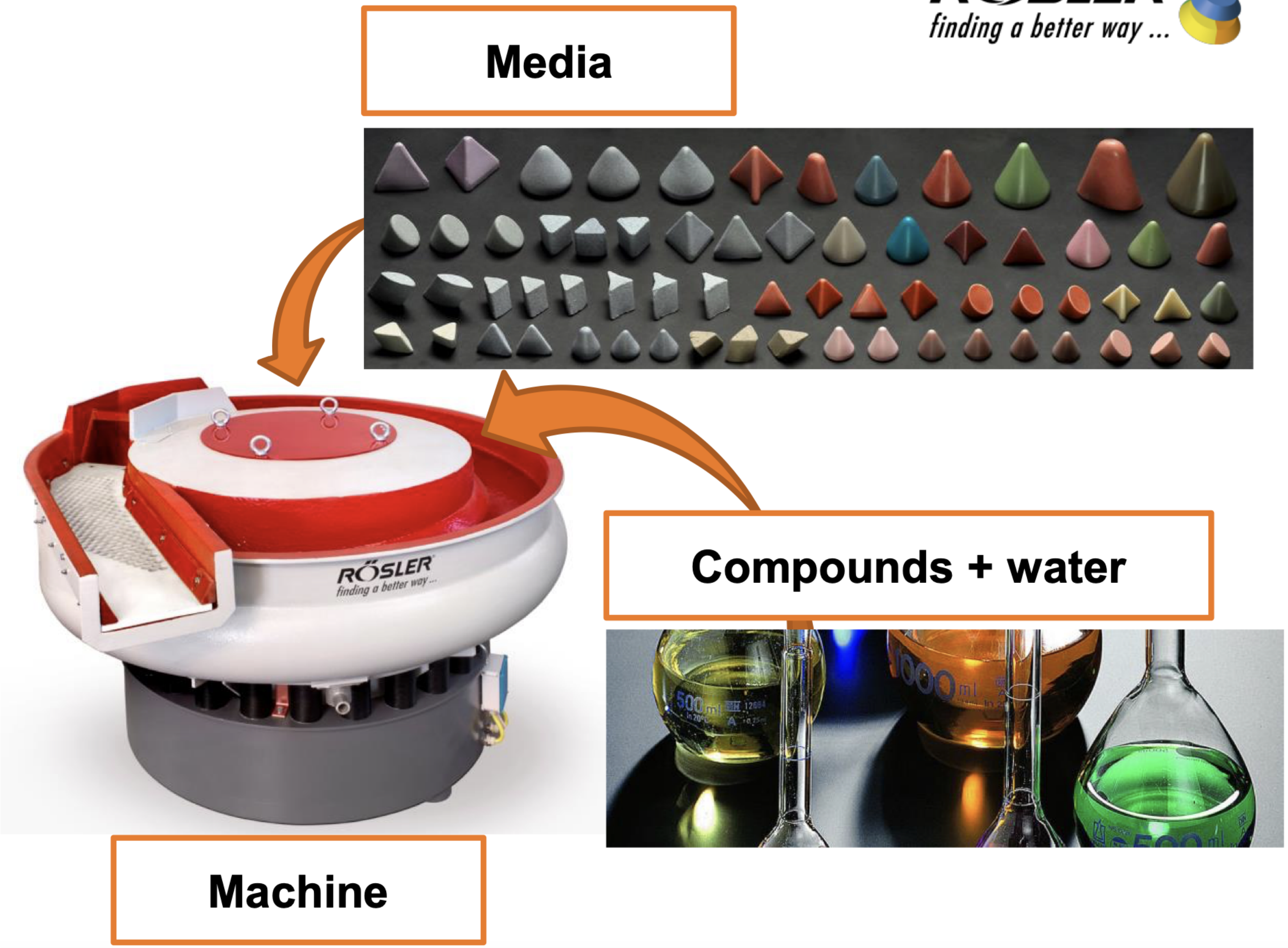


Post-processing of full RFQ

Surface engineering:

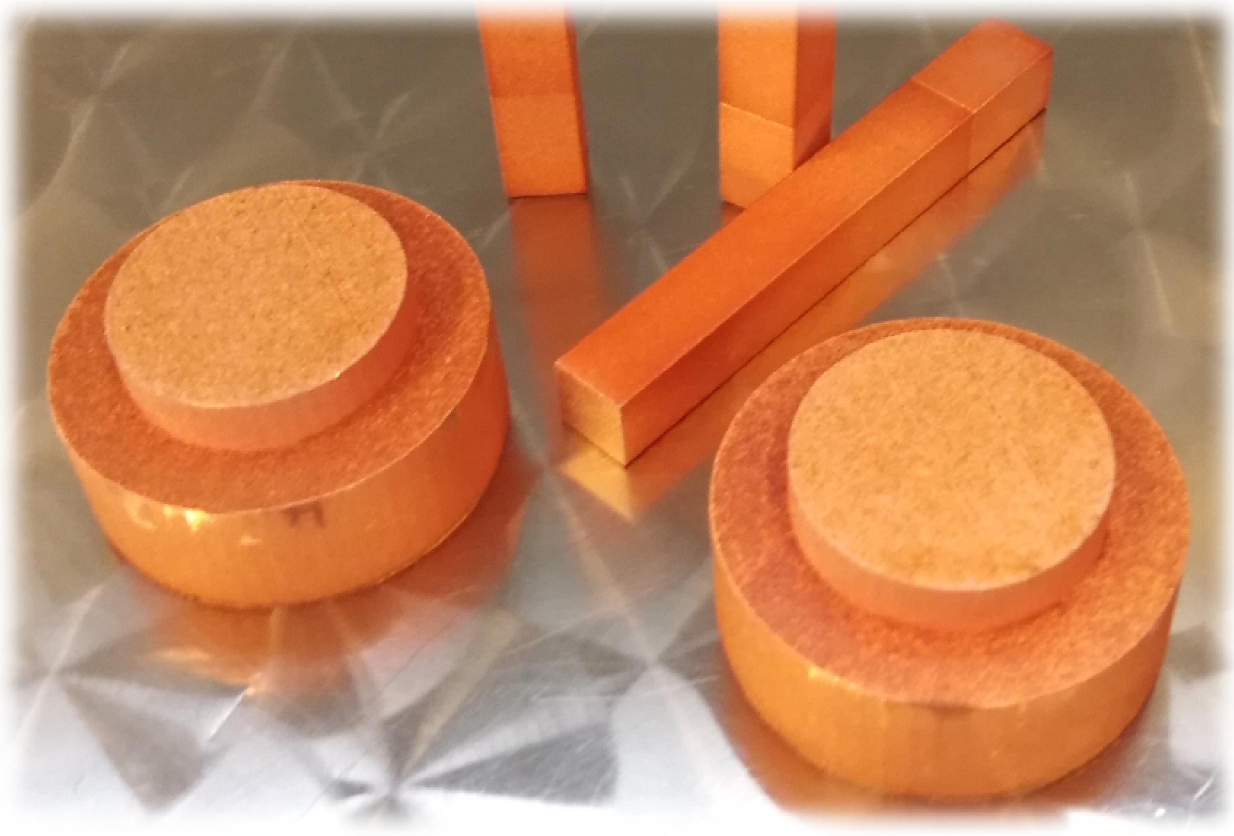
1. Conventional surface mass finishing
2. Chemically assisted surface finishing
3. High precision surface finishing

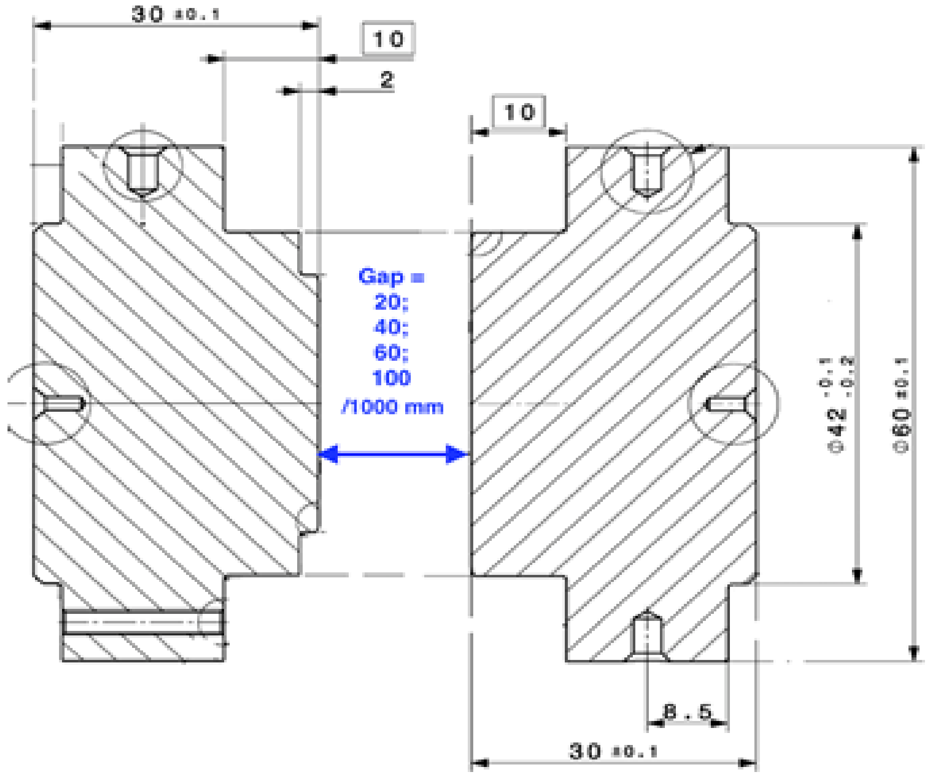
With subsequent full set of measurements



RÖSLER finding a better way ...

High Voltage Holding tests @ CERN





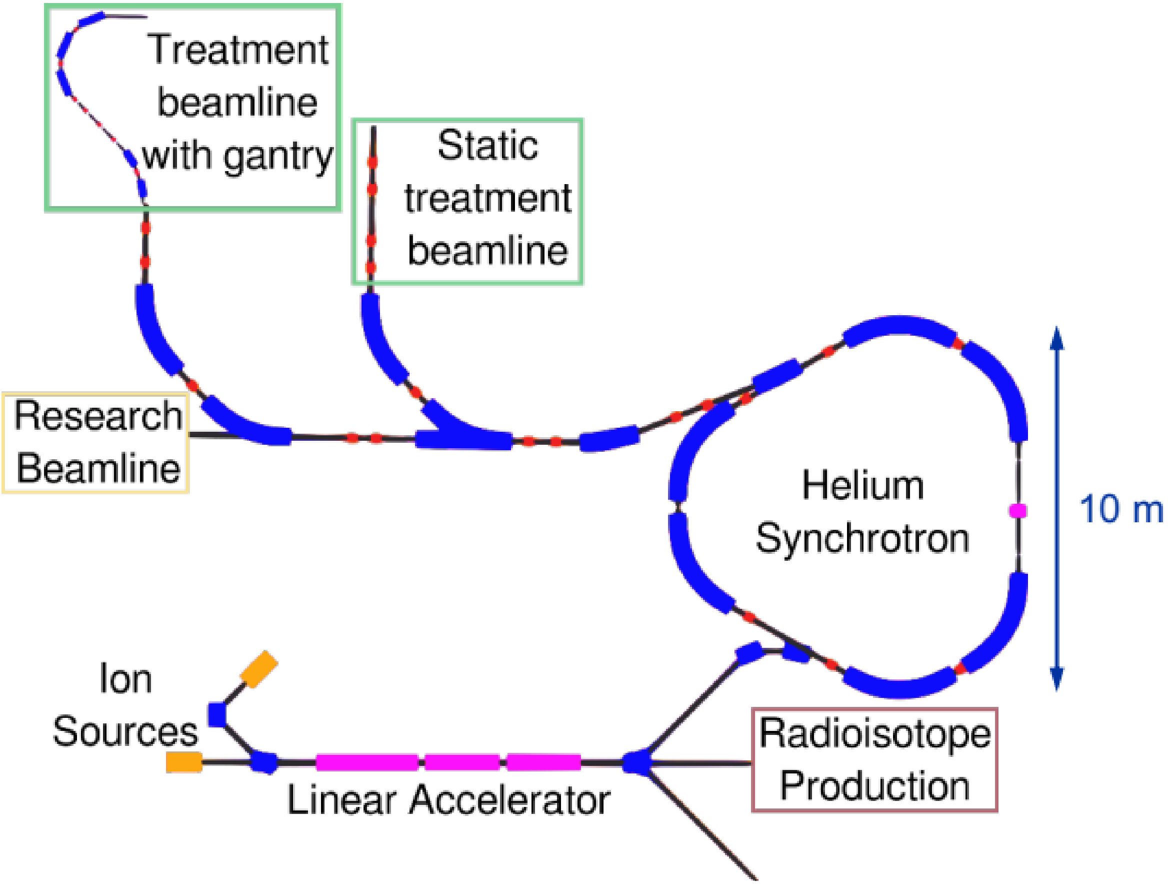
Anode Cathode

Future ideas – AM-RFQ for medical applications

- Production of radioisotopes for cancer imaging and treatment with compact linear accelerators
- To use a 750 MHz linac as injector for the He-synchrotron
- To use a 750 MHz linac to produce isotopes
- 750 MHz RFQ, this can be done in AM?

Maurizio Vretenar @ IPAC ‘22

https://ipac2022.vrws.de/html/author.htm



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AM change of paradigm

- Our community is having new design opportunities
- e.g. RFQ braze-less manufacturing
- Multi-materials are possible
- Hybrid machining options
- Is vastly used by other communities and industries
- Ideal for small quantities high complexity and precision
- Technology is developing rapidly and is accessible

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This project has received funding from the European Union’s Horizon 2020 Research and Innovation programme under GA No 101004730.