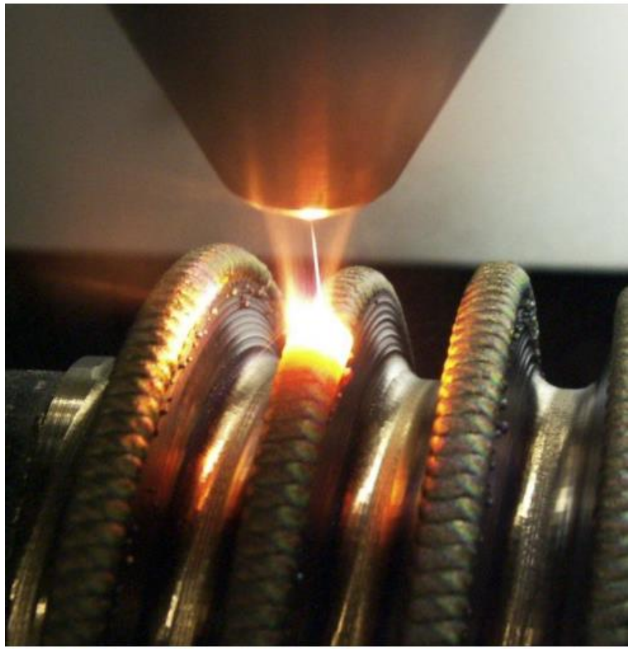
Prof. Toms TORIMS
Dr. Andris RATKUS, Riga Technical University
Prof. Maurizio VEDANI, PoliMi

On behalf of the great AM collaboration of Task 10.2 and Task 10.3

I.FAST 2nd Annual Meeting, Trieste, 20.04.2023

Recap – what is AM?



Source: joanneum.at

Source: https://www.twi-global.com

- Laser Powder Bed Fusion
- Direct Energy Deposition
- Cold spray

Courtesy of Lukas Stepien (Fraunhofer IWS)

Fraunhofer IWS

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Objectives
[Motivation]
set for AM team within WP10

- To **promote AM** [as a technology which is capable] to improve performance of particle accelerators
- To **communicate** opportunities offered by AM for accelerators

- *In other words: show me, **prove it to me**, convince me … … … and then [maybe] I will believe you!*

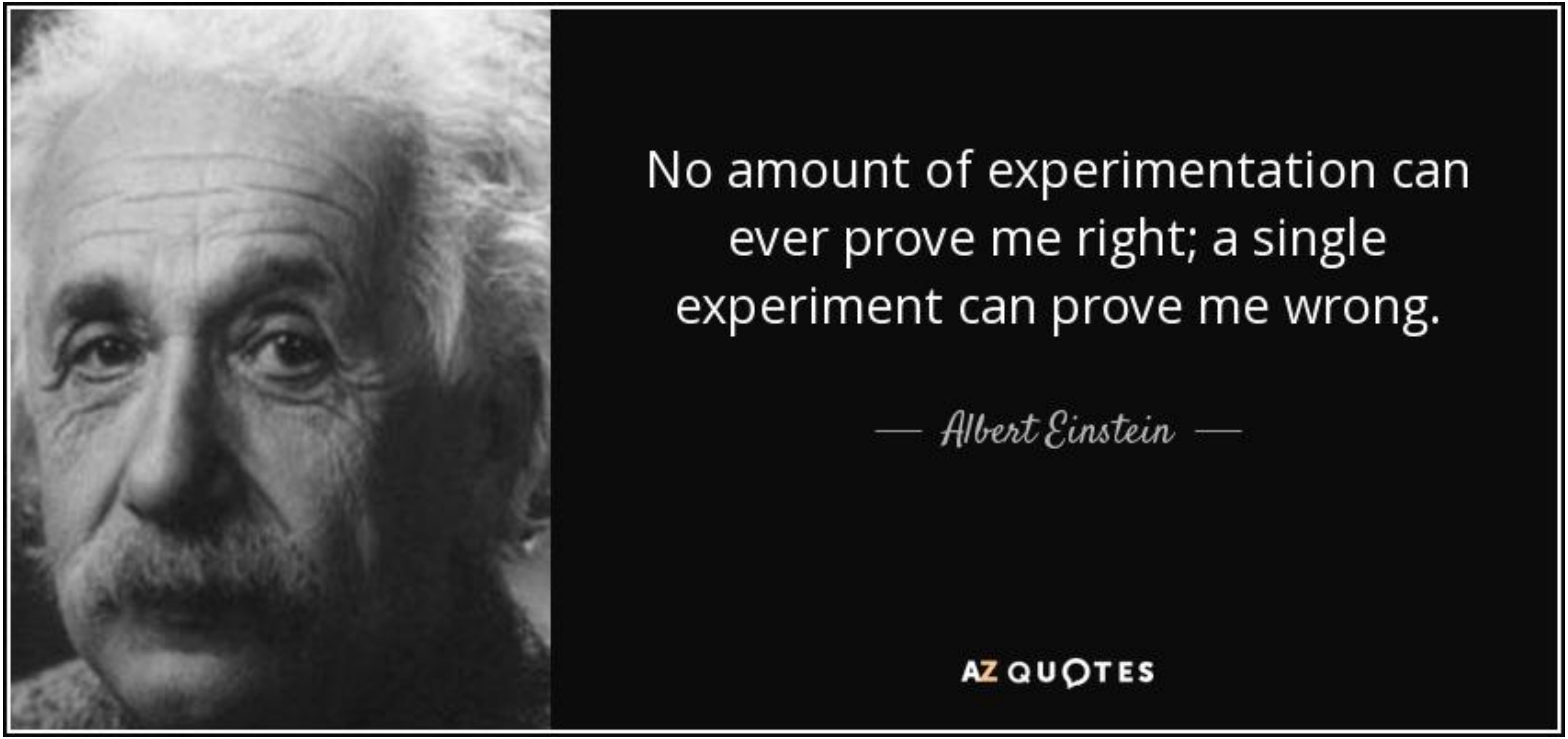
Task 10.2 & 10.3
Milestones and Deliverables

MS44	Survey on current AM applications in accelerators and expected new developments	10.2	30	Report Ongoing – no difficulties noted
MS45	Survey on current AM repair technologies for accelerator and list of possible applications	10.3	24	Report In draft stage

Deliverables related to WP10	
D10.1: Potential AM applications in accelerators. *Report on output of the survey on AM applications, further needs for the accelerator community, and perspective developments.*	30 Ongoing – no difficulties noted
D10.2: Survey of AM applications and strategies for repairing accelerator components by AM. *Report listing possible strategies and technologies for repairing of parts.*	24 In draft stage

Specific requirements within accelerators - challenges for AM

- Vacuum $<10^{-7}$mbar
- Electrical conductivity >90 % IACS
- High Voltage holding ~40 MV/m
- **Geometrical accuracy** **20μm**
- **Surface roughness (Ra)** **0.4 μm**
- Ultra-low temperatures 2 K
- Outgassing rate
- Material purity
- Minimised defects microstructure analysis
- RF properties



https://www.azquotes.com/quotes/topics/prove-me-wrong.html

Collaboration and [public] results

- *21 + meetings and events https://indico.cern.ch/category/13515/*
- *Dedicated **Workshop on Additive Manufacturing** applications at CERN globe during I.FAST annual meeting https://indico.cern.ch/event/1133254/sessions/439997/#20220505*

External dissemination of results:

- *Contribution and participation in the major **conferences** (IPAC, HIAT etc)*
- *Several **scientific papers**, and more are in the pipeline*
- *Presence and **visibility** in the major AM exhibition "Formnext 2022"*
- ***New** European industrial **partner** is engaged*

TRUMPF 100 1923–2023

- It is **great collaboration** which goes far beyond pre-set I.FAST goals
- AM manufactured RFQ provoked a **significant interest** of our community

Survey of AM applications and potential developments

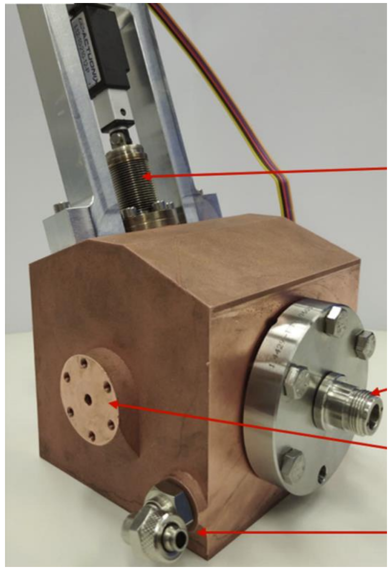
AM in the accelerator community - survey

State-of-play **one year ago**

Courtesy of Guntis Pikurs (RTU/CERN)

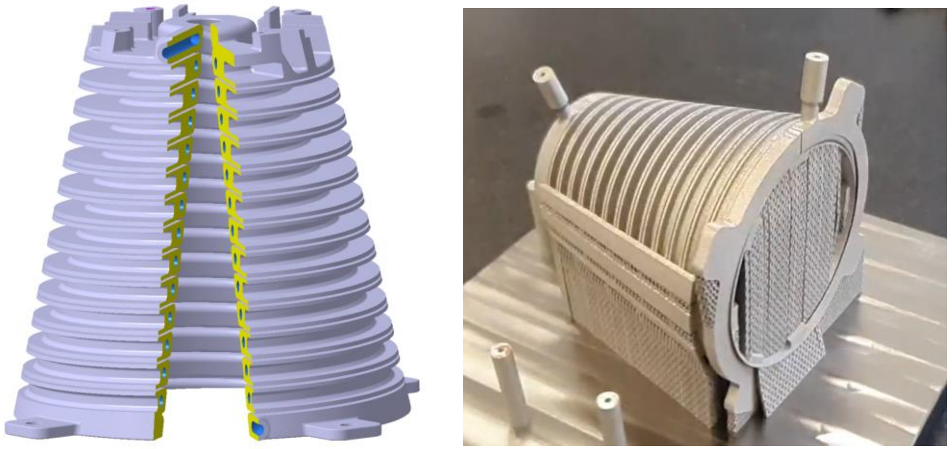
Latest additions

IN2P3 Grenoble

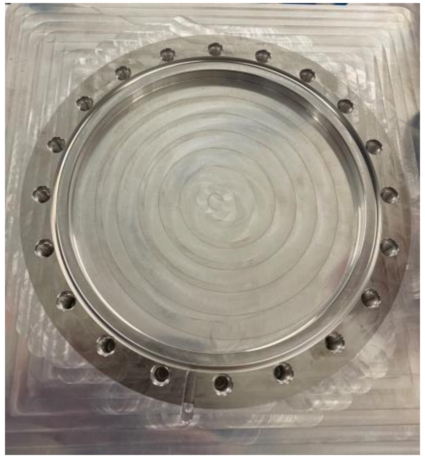


M.Mayerhofer

Institut für Angewandte Physik Goethe Universität Frankfurt



CERN SY-RF-MKS



PSI

Courtesy of Guntis Pikurs (RTU/CERN)

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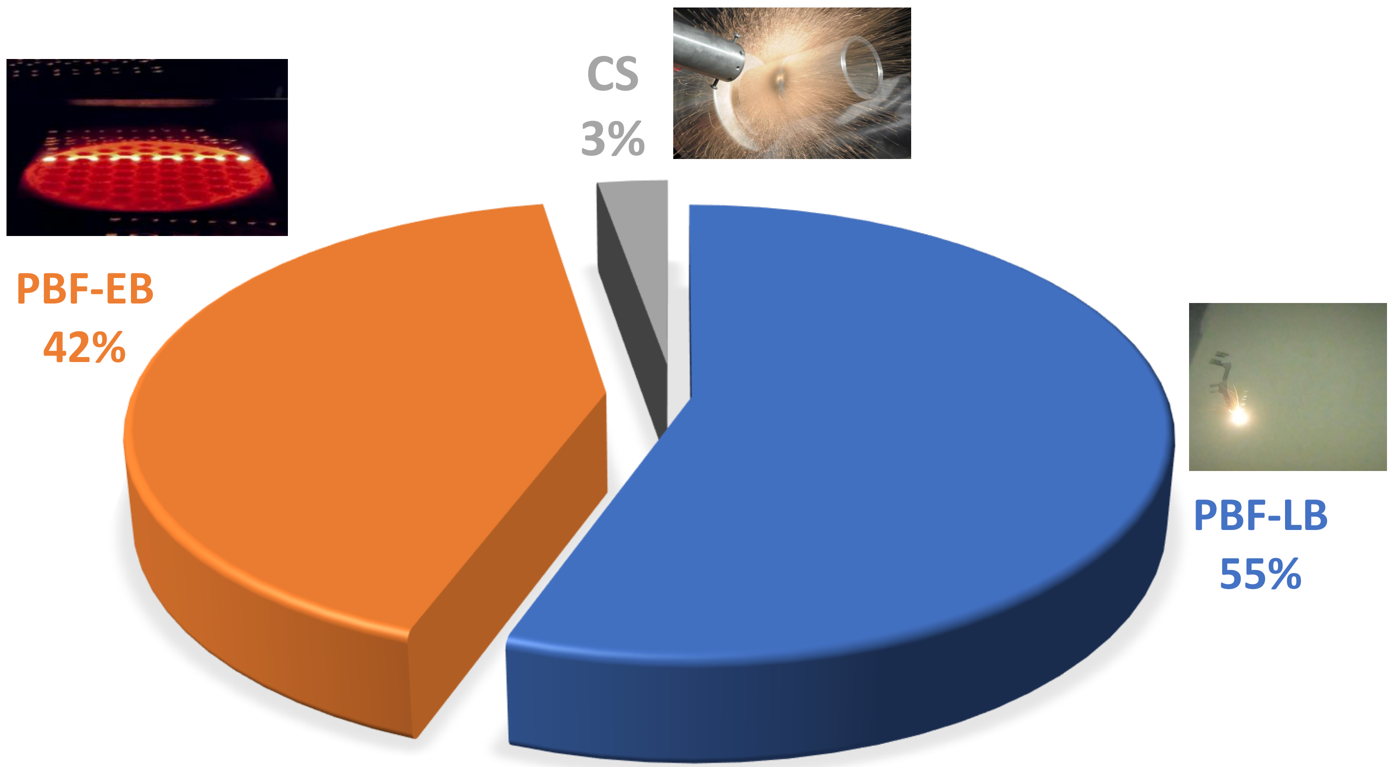
… in addition to these there are many confidential AM developments…

Applied AM technologies for accelerators



Guntis Pikurs @ I.FAST AM workshop ‘22

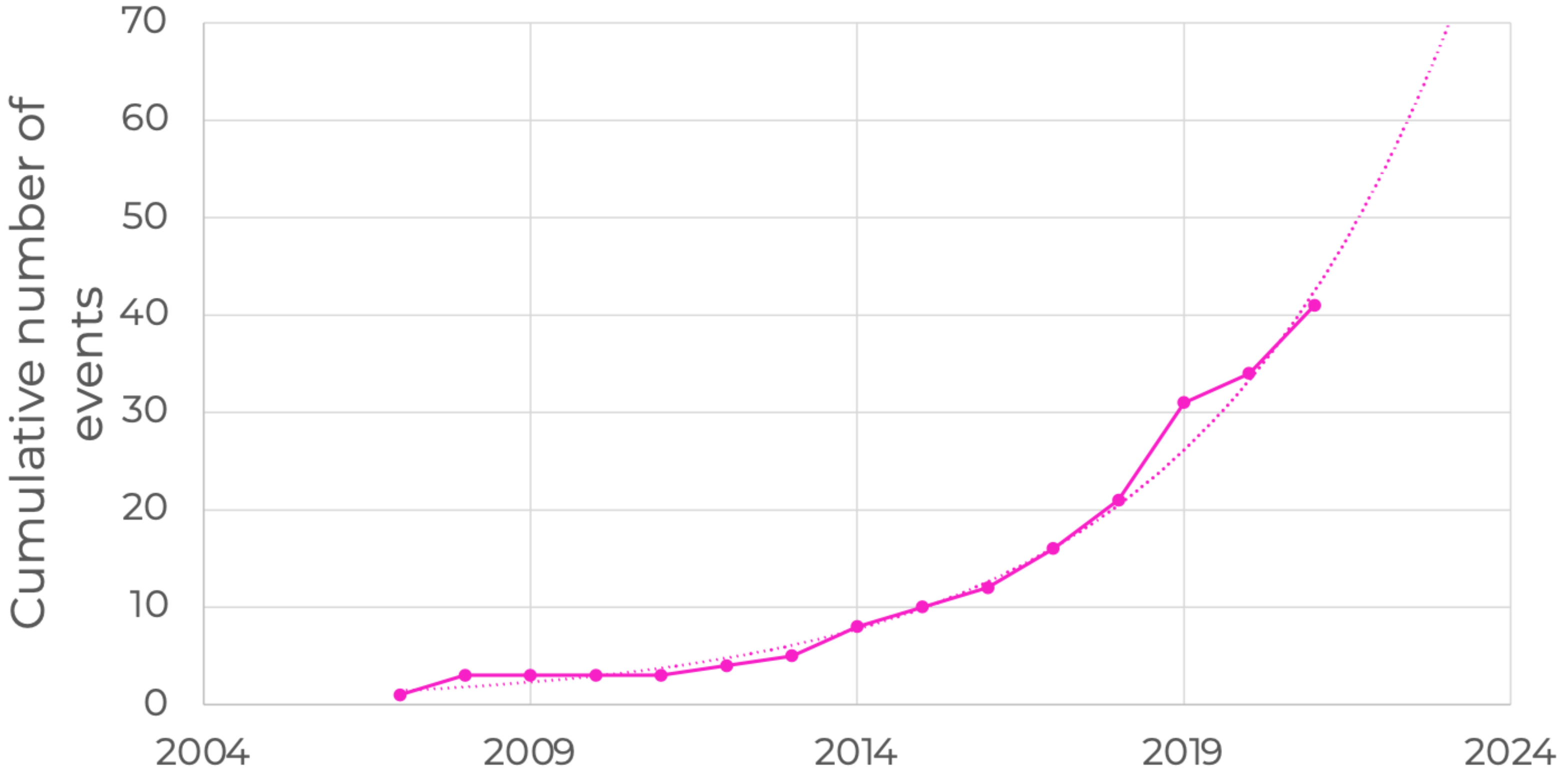
Applied metal AM technologies

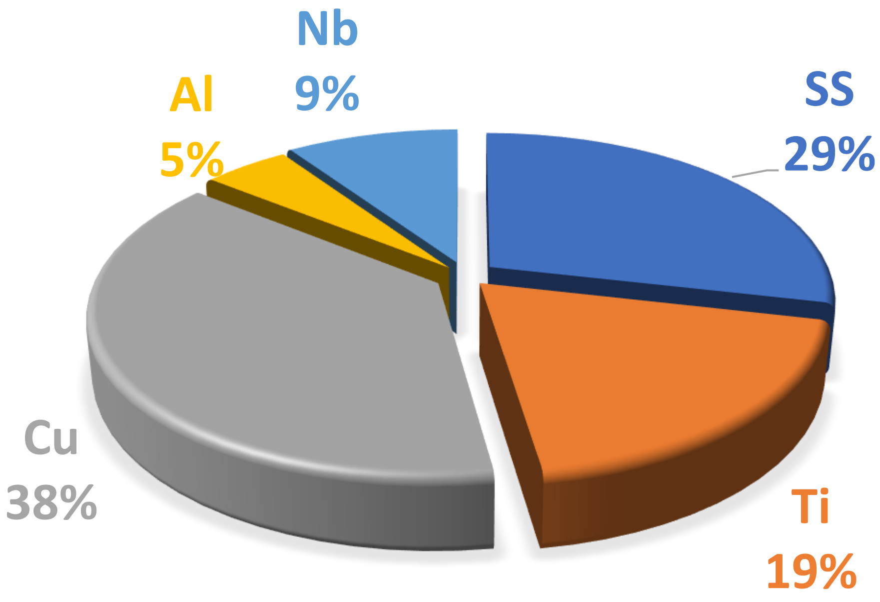
- Powder Bed Fusion -LB
- Powder Bed Fusion -EB
- Cold spray

Most often used AM machines

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

Known metal AM activities within accelerator community

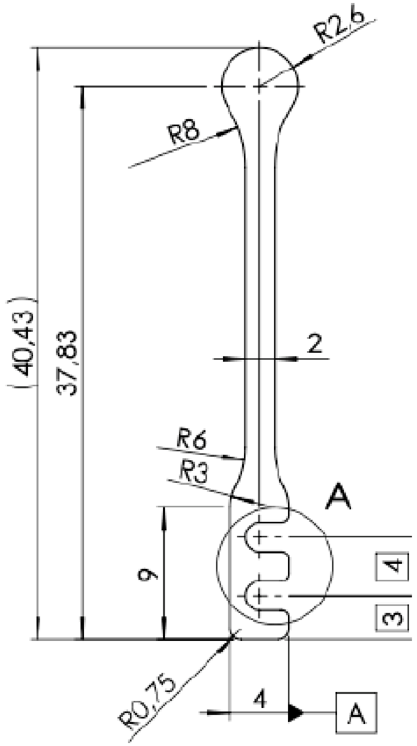


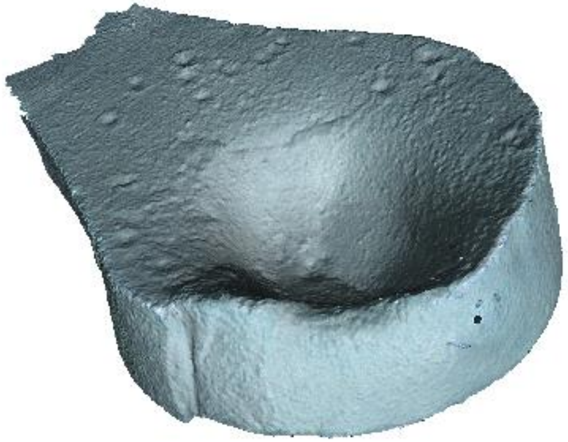


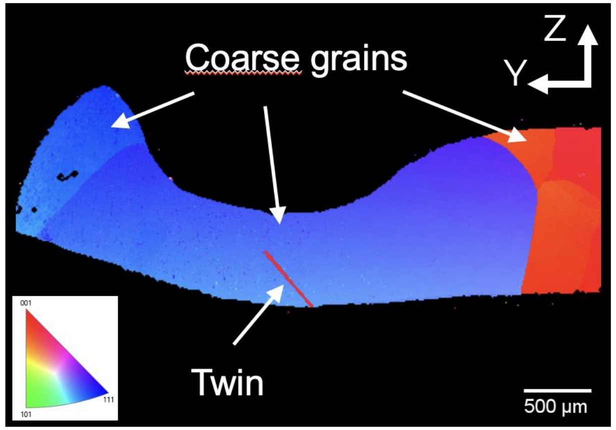
Guntis Pikurs @ I.FAST AM workshop '22

Accelerator component repairs with AM

Damaged cold cathode Penning Ionization Gauge (PIG) ion source



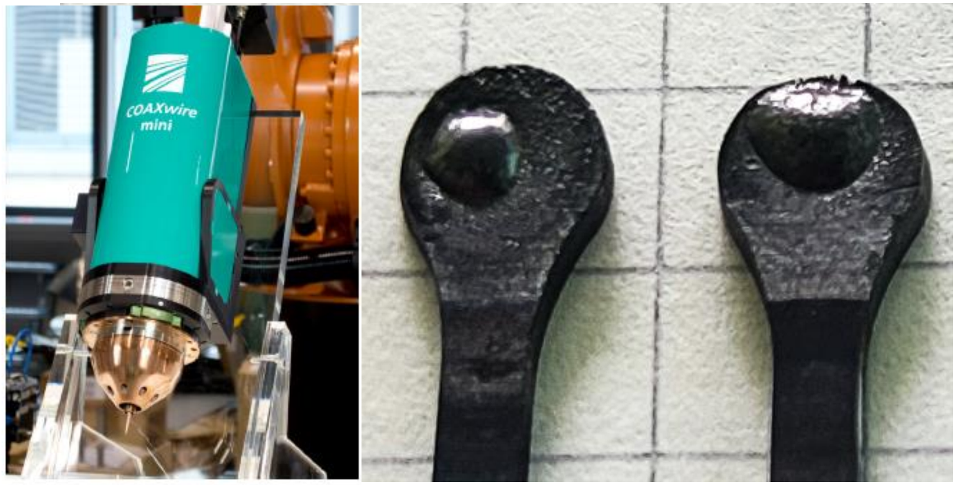




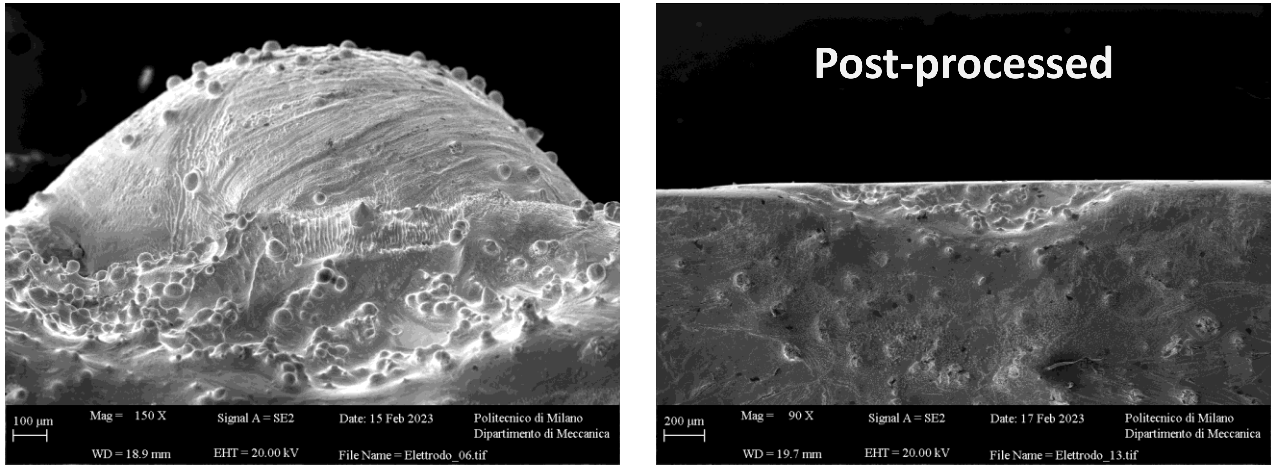
The cathodes sputtering by ions form the discharge which produces a crater

AM repairs are possible

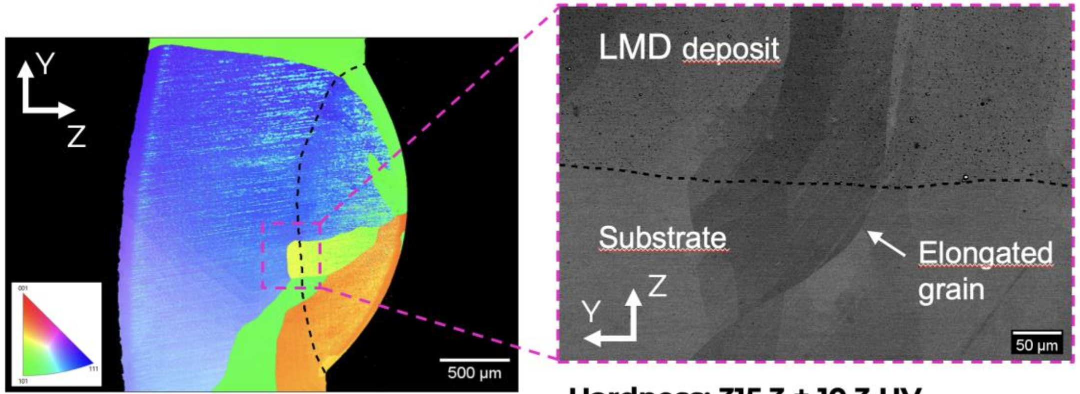
- **Demonstrated AM abilities** with Tantalum
- 2 Direct Energy Deposition AM technologies used
- Parameters diapasons were determined
- Several **repair strategies** successfully tested



Courtesy of Andris Ratkus (RTU/CERN)



Courtesy of Tobia Romano (PoliMi/RTU)



Hardness: 315.3 ± 10.3 $HV_{0.05}$

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1862 RIGA TECHNICAL UNIVERSITY

POLITECNICO MILANO 1863

Fraunhofer IWS

TANiOBIS inspiring metal evolution

Ciemat


Preform
RFQ Particle Accelerator
Innovation Fostering in Accelerator Science and Technology
IFAST
High-Frequency RFQ Prototype
.World Premiere

AM RFQ – step-by-step

Can one make RFQ by AM?

this is … *show me, **prove it to me**, convince me … … … and then [maybe] I will believe you! Or box of the best Prosecco…*

1st iteration

¼ RFQ – 95 mm

Fraunhofer IWS

2nd iteration

250 mm

TRUMPF 100 1923–2023

3rd iteration

390 mm

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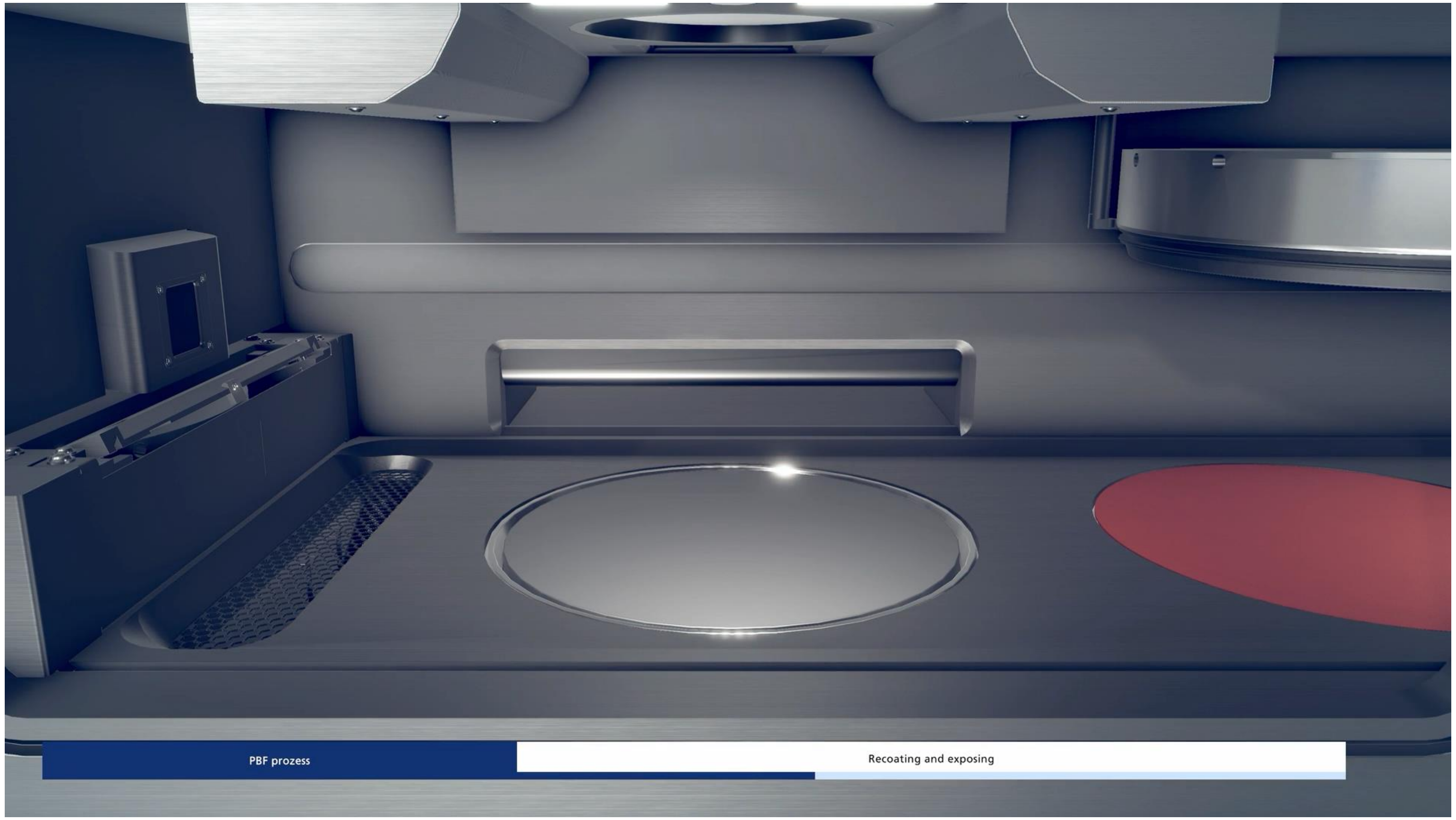
OK, you made it, but what about all these…

Specific requirements
- within accelerators

- Vacuum $<10^{-7}$mbar
- Electrical conductivity >90 % IACS
- High Voltage holding ~40 MV/m
- **Geometrical accuracy** **20μm**
- **Surface roughness (Ra)** **0.4 μm**
- Ultra-low temperatures 2 K
- Outgassing rate
- Material purity
- Minimised defects microstructure analysis
- RF properties

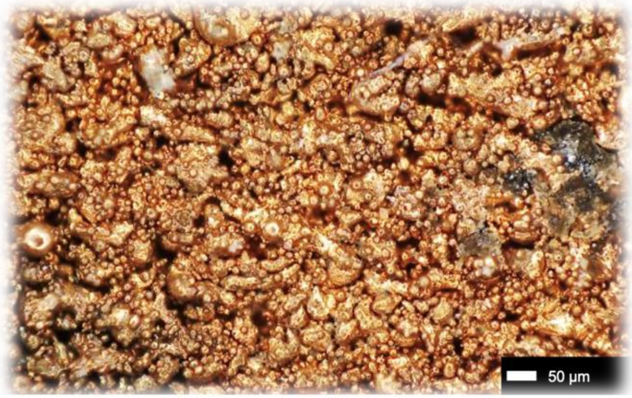
The first prototype by AM pure-copper RFQ

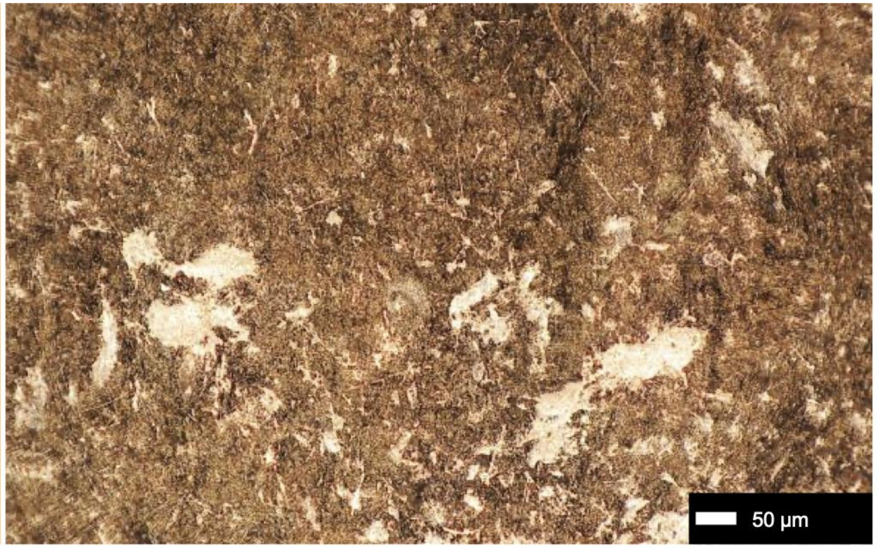
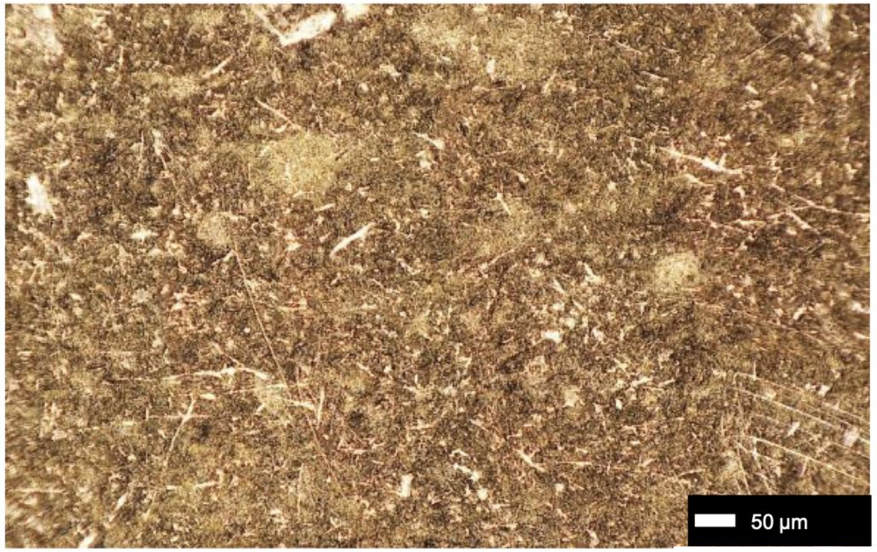


- AM design and optimisation
- Manufacturing
- Measurements:
  - ⇨ geometrical precision
  - ⇨ surface roughness
- Results published
- Post-processing
- measurements after post-processing
- Repeat for 3 iterations

Post-processing of ¼ RFQ

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



		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

Mass finishing applied to AM components for particles accelerators

Step 1: Chemically-assisted mass finishing

- No holder needed
- Chemical compounds

R.Ecoshape abrasive media: PET-based media patented by Rösler

- No chemicals
- Sample holder needed

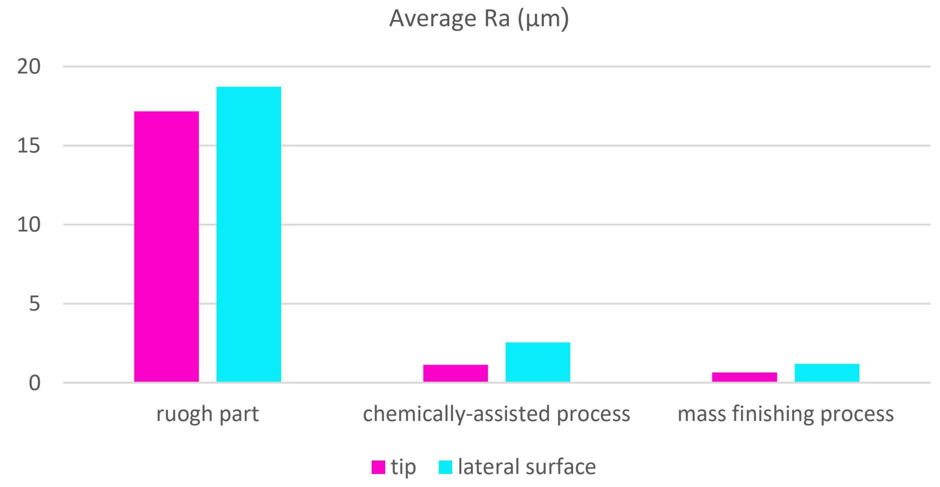
Step 2: Mass finishing

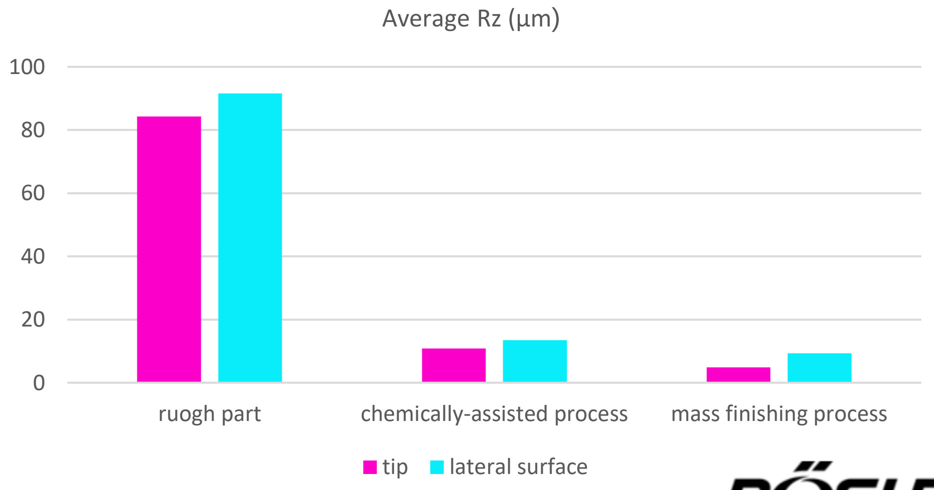
Courtesy of Matteo Pozzi (RÖSLER)

Surface roughness - comliance

Some results

	Tip		Lateral surface		Mass loss	
	Ra (µm)	Rz (µm)	Ra (µm)	Rz (µm)	Δm (g)	Δm%
Rough part	17,16 ± 2,84	84,30 ± 16,20	18,73 ± 3,59	91,59 ± 11,28		
Chemically assisted process	1,14 ± 0,43	10,87 ± 5,71	2,55 ± 0,77	13,49 ± 3,77	278	2,05
Mass finishing process	**0,65 ± 0,08**	**4,85 ± 0,57**	**1,19 ± 0,39**	**9,33 ± 2,74**	**448**	**3,30**





Mass finishing applied to AM components for particles accelerators

Improvement possibilities

Pre-treatment: blasting technology

- most surfaces are accessible with blasting nozzle
  → precision
- ↑ Surface homogenization
- ↓ initial surface roughness

STEP 1: Chemically-assisted mass finishing

STEP 2: mass finishing

STEP 3: fine polishing – mass finishing

- Further roughness reduction
- Sticking problems (because of media shape and dimensions)!!

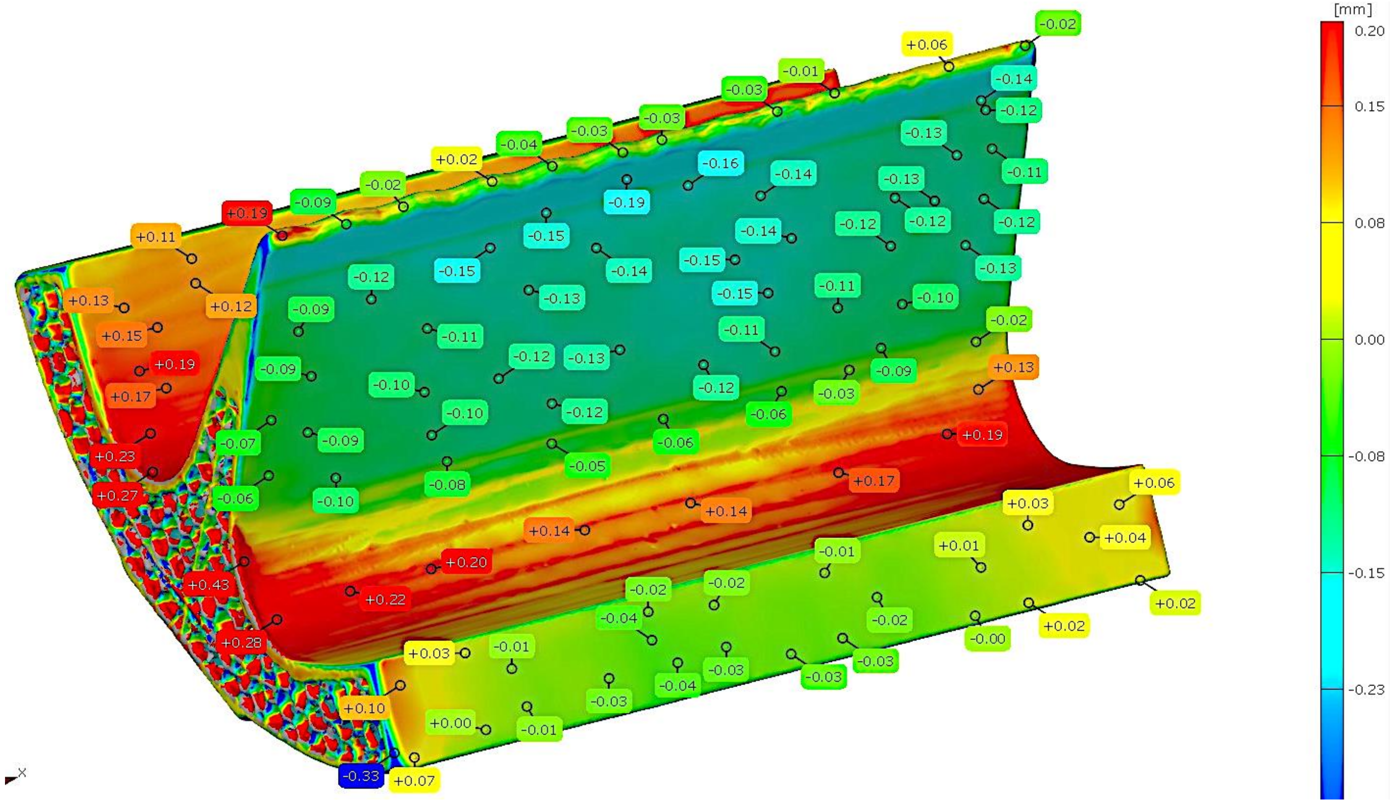
Sample holder

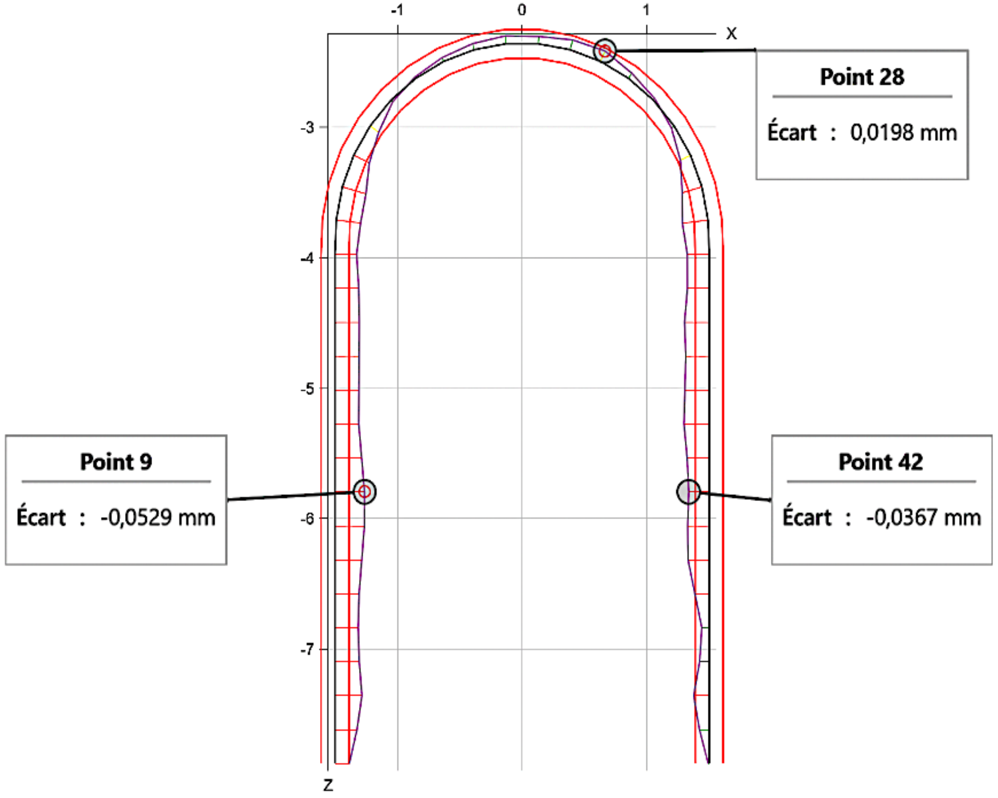
Courtesy of Matteo Pozzi (RÖSLER)

Holders might be partially implemented in the design phase before printing process

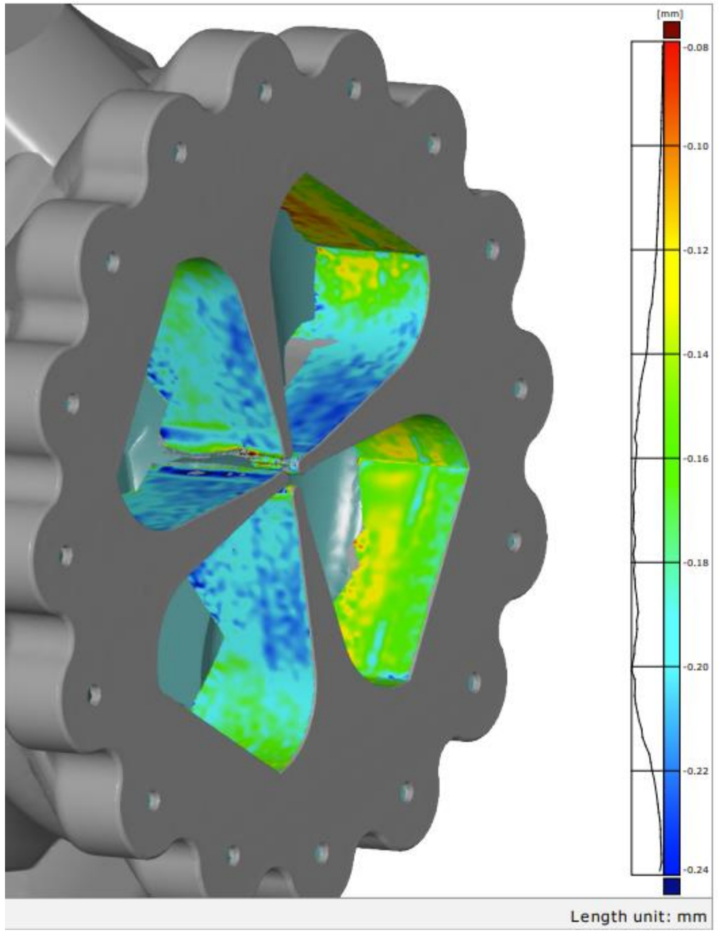
Geometrical accuracy - compliance

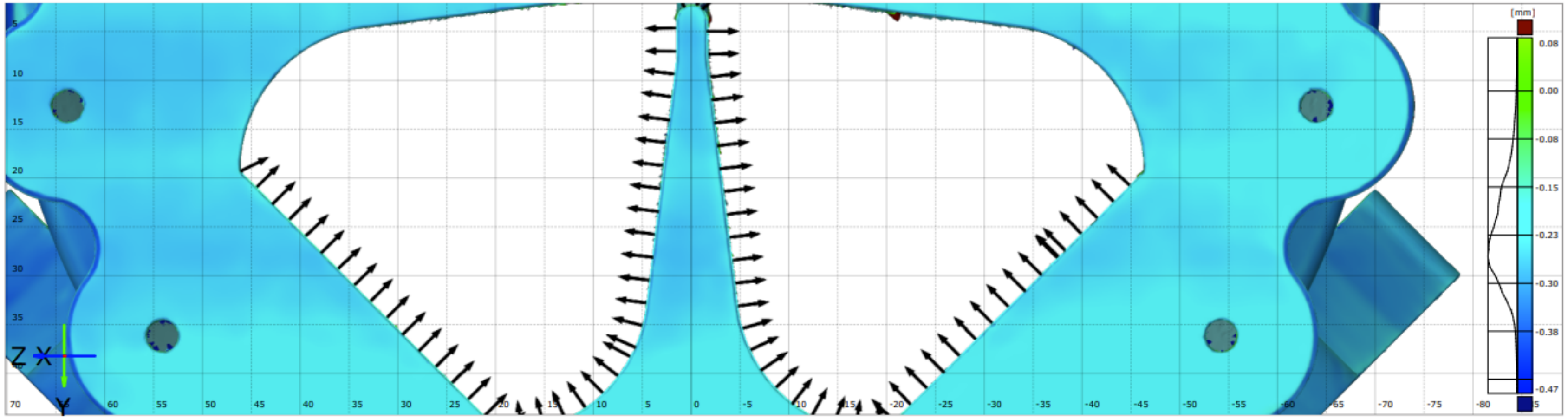
Target values: 20 µm on vane-tip / 100 µm elsewhere

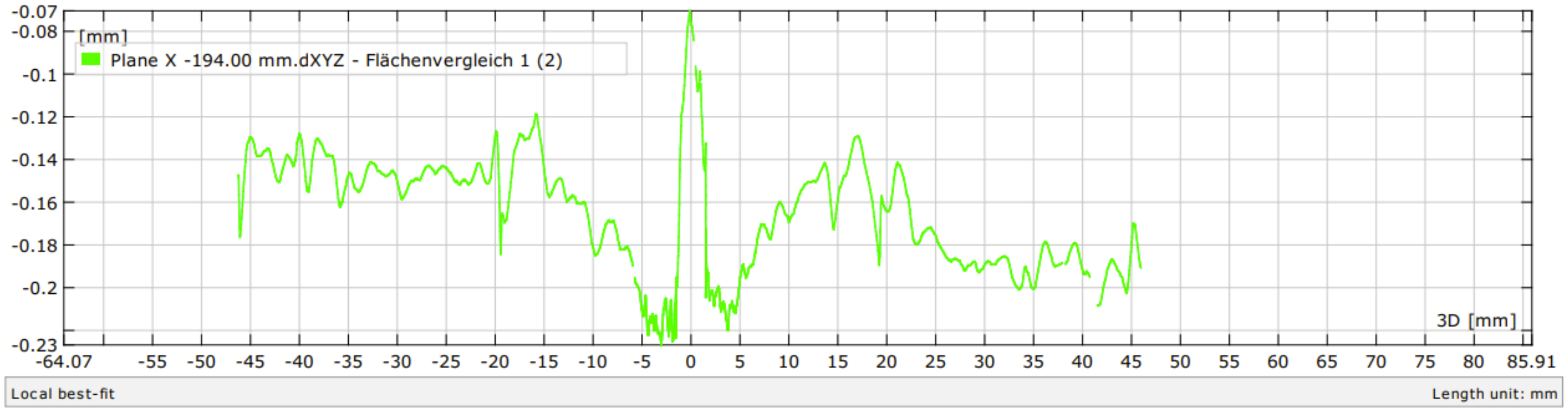




RFQ390 cavity crossection deviation diagram

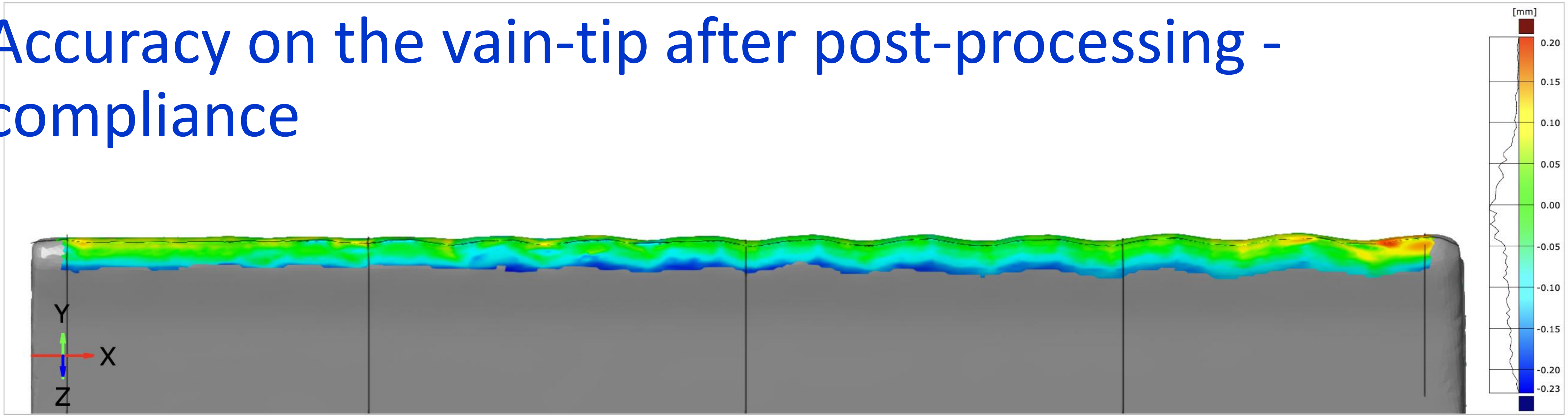


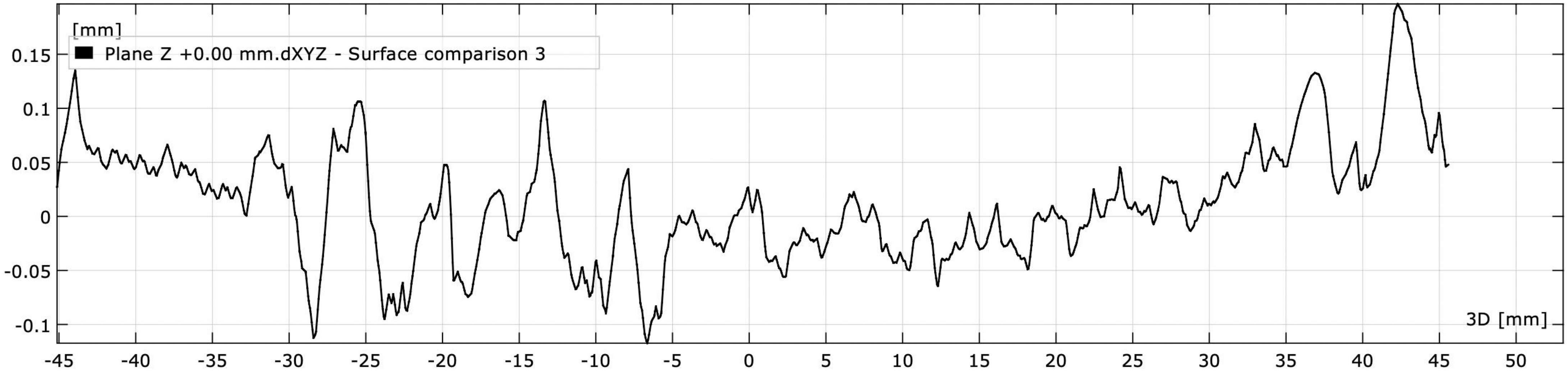




Courtesy of Guntis Pikurs (RTU/CERN)

Accuracy on the vain-tip after post-processing - compliance

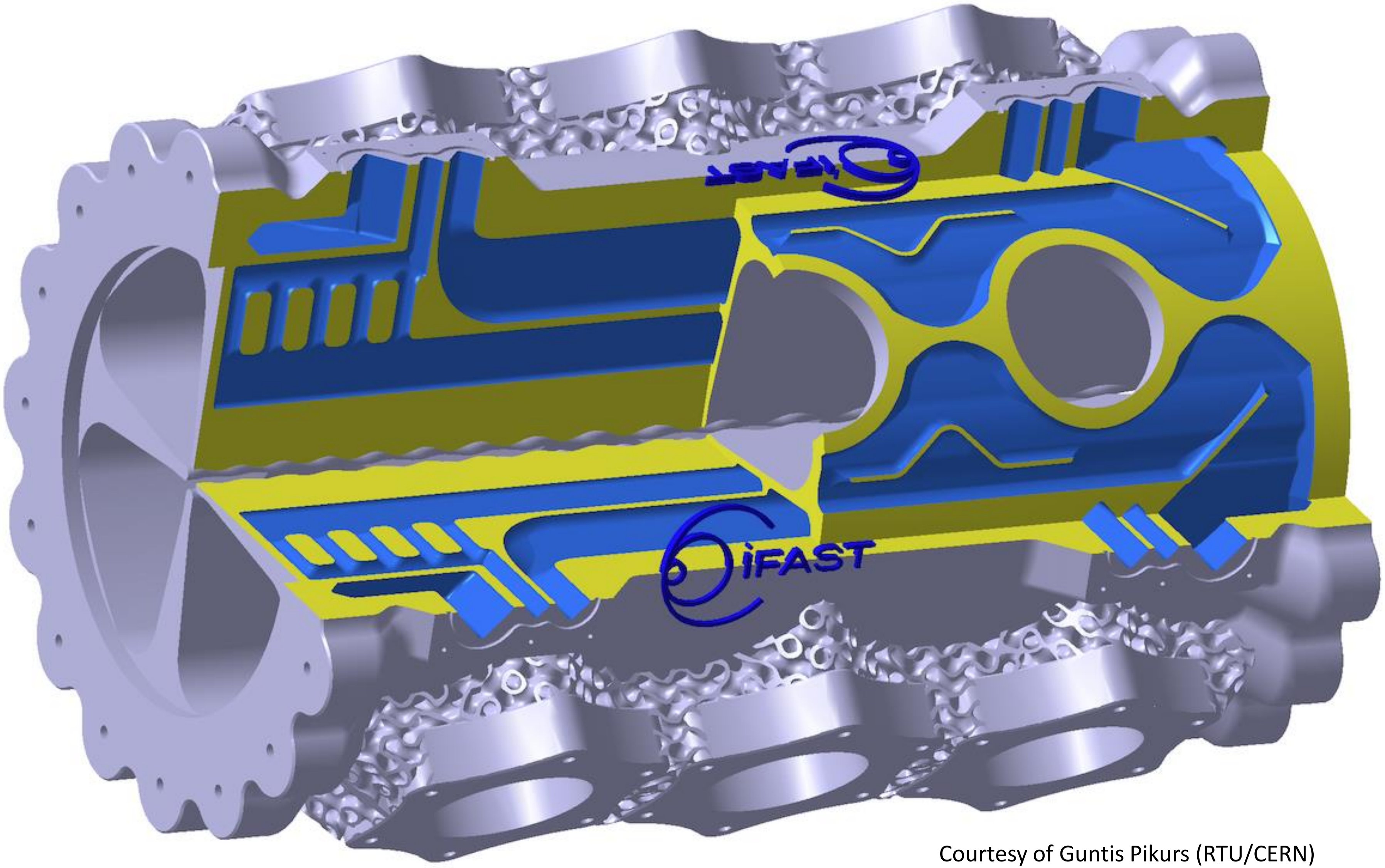




Courtesy of Guntis Pikurs (RTU/CERN)

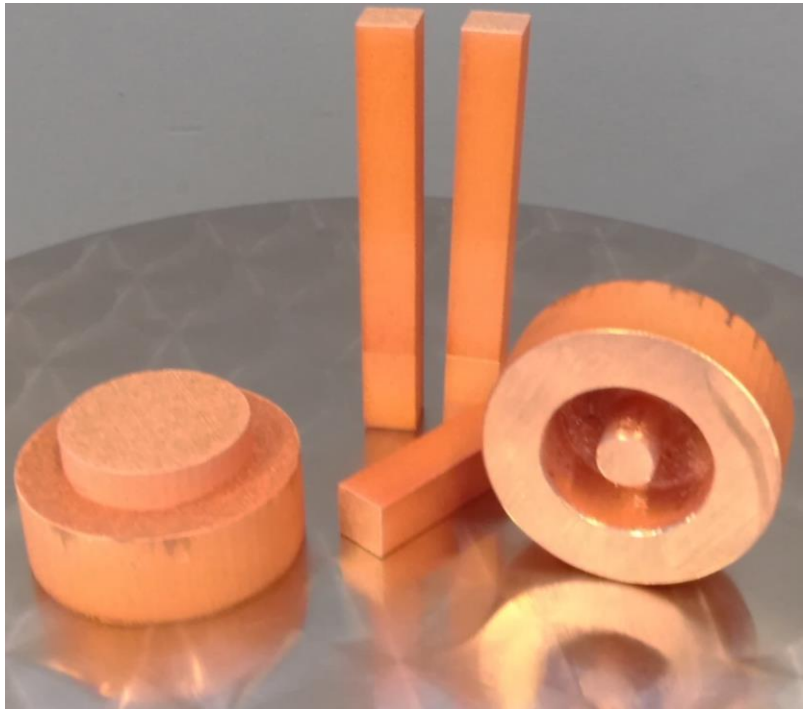
*AM **as a tool** to improve performance of particle accelerators*

Optimisation of design - thanks to AM



Courtesy of Guntis Pikurs (RTU/CERN)

Voltage holding tests of AM samples



Testing for **high-voltage behaviour**

- RF breakdown behaviour – how much it could hold?
- High geometrical precision is required for these tests
- Electrodes are built **as the RFQ**, to investigate the same material structure
- Samples for other tests (finishing, conductivity, microstructure) will be manufactured

First results expected @ IPAC '23

POLITECNICO MILANO 1863

In collaboration with: CLIC group of CERN

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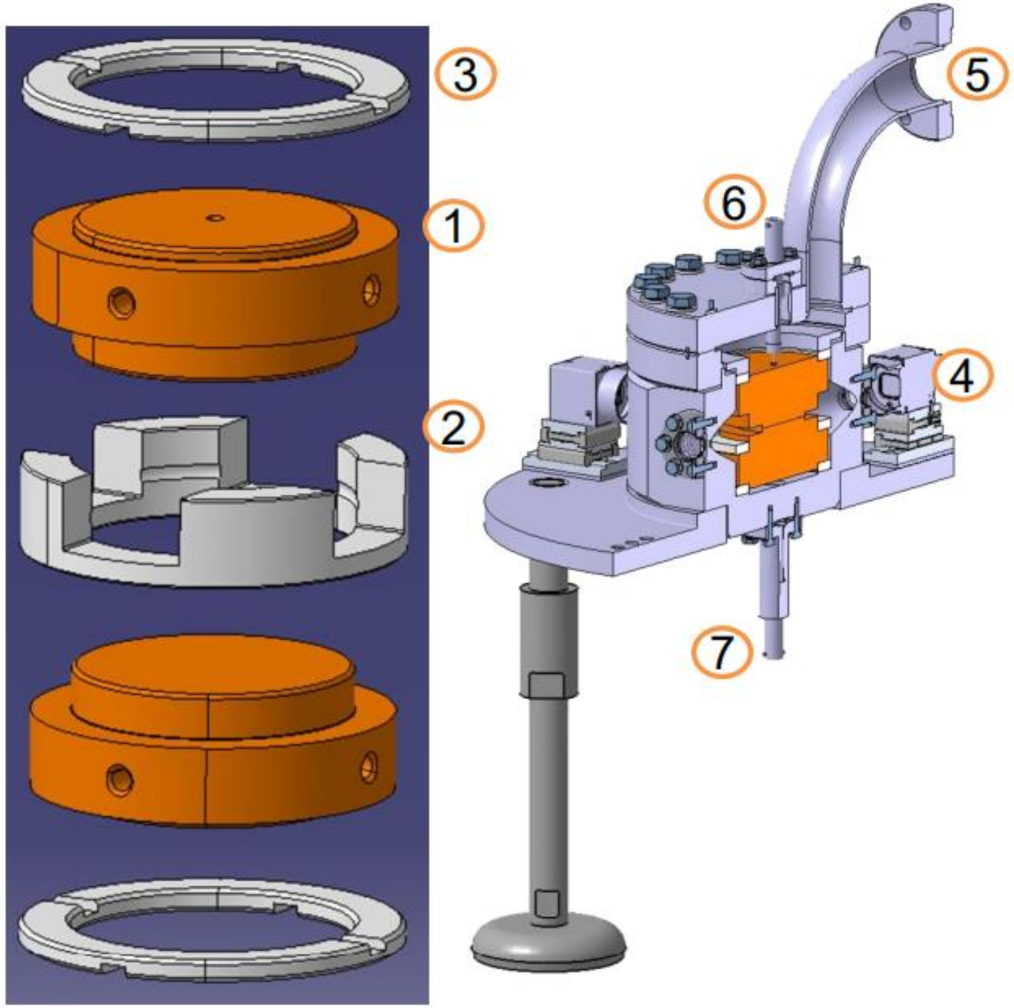
Testing for high-voltage behaviour of AM Copper

Testing for high-voltage behaviour

- The RF breakdown behaviour of smooth surfaces is measured under high voltage
- High geometrical precision is needed for testing (diamond machining)
- Need for electrodes to be built as the RFQ, to investigate the same material structure (PoliMi in charge)
- Samples for other tests (finishing, conductivity, microstructure) will be manufactured

Pulsed DC Large Electrode System



ref. Ruth Peacock, Recent Test - CERN Pulsed DC Large Electrode System (2021)

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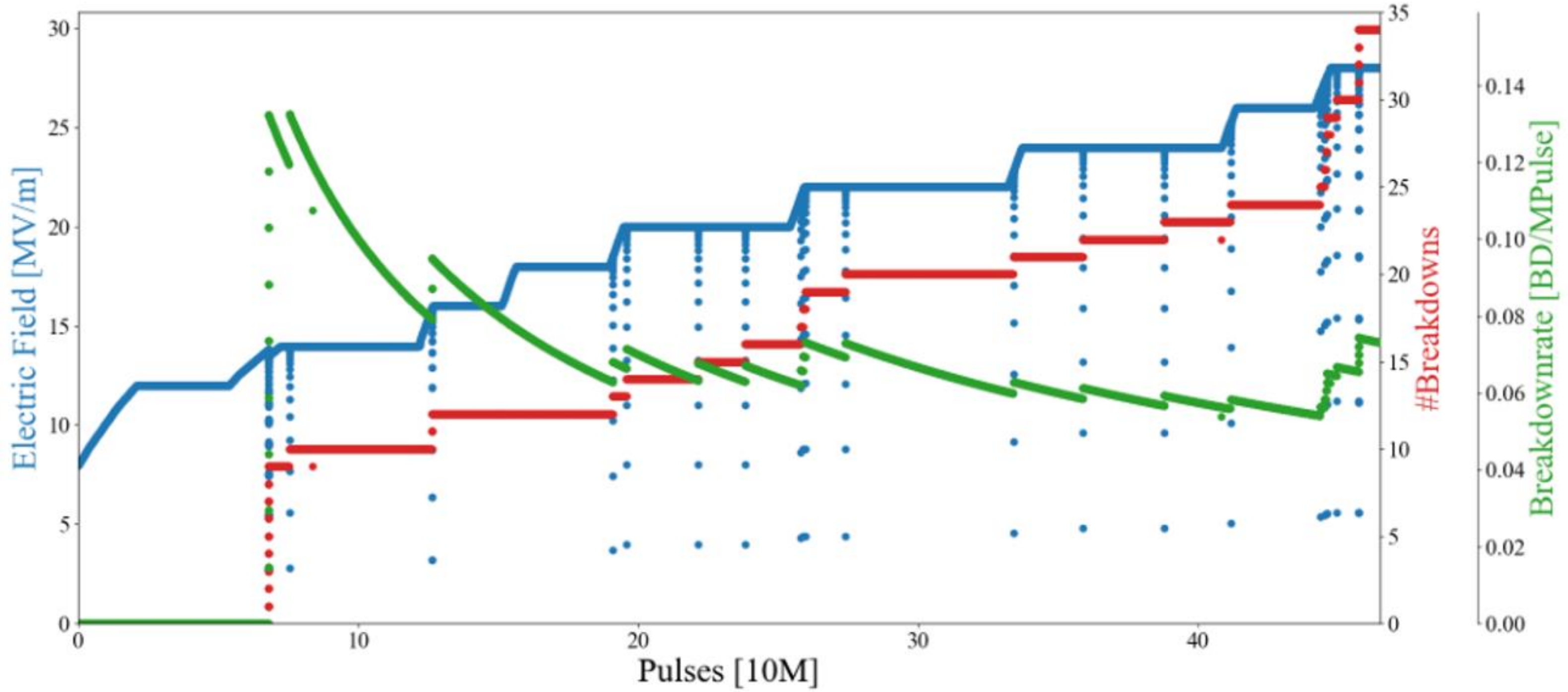
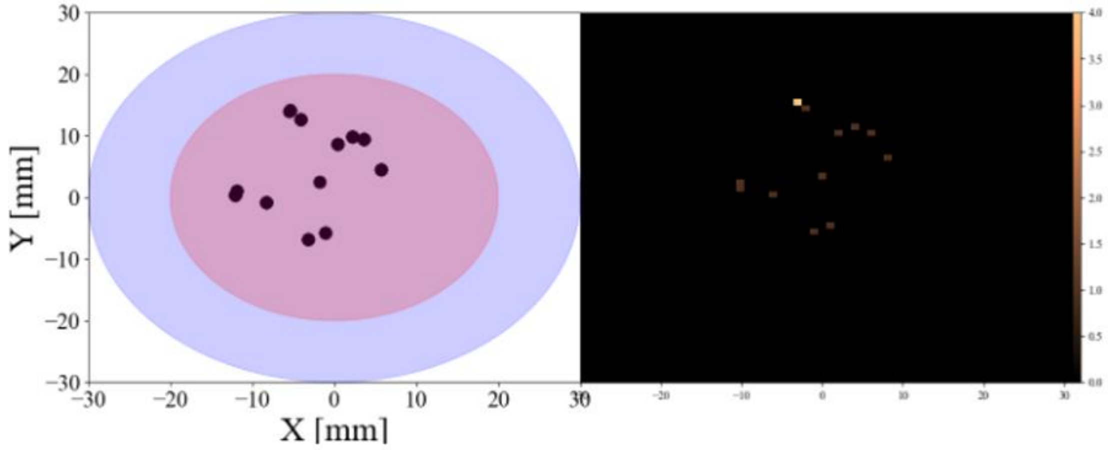
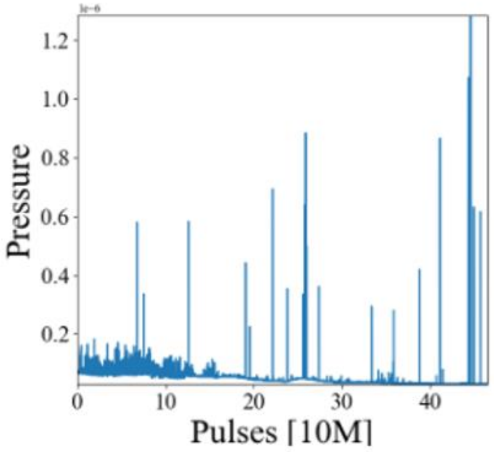
HV tests
first results

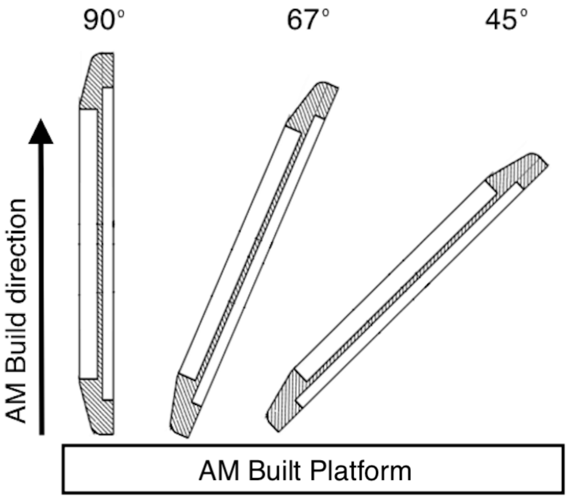




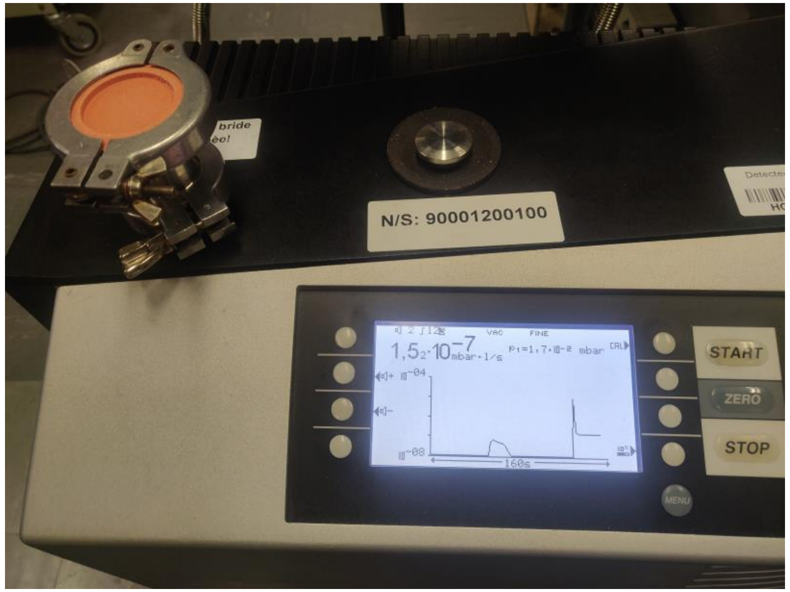


Vacuum tests of AM samples

- Leakage tight
- Vacuum 10^{-3} mbar



Vacuum <10^{-7}mbar



First results expected @ IPAC '23

Courtesy of Sam Rorison
CERN-TE-VSC-DLM

RIGA TECHNICAL UNIVERSITY

Fraunhofer IWS

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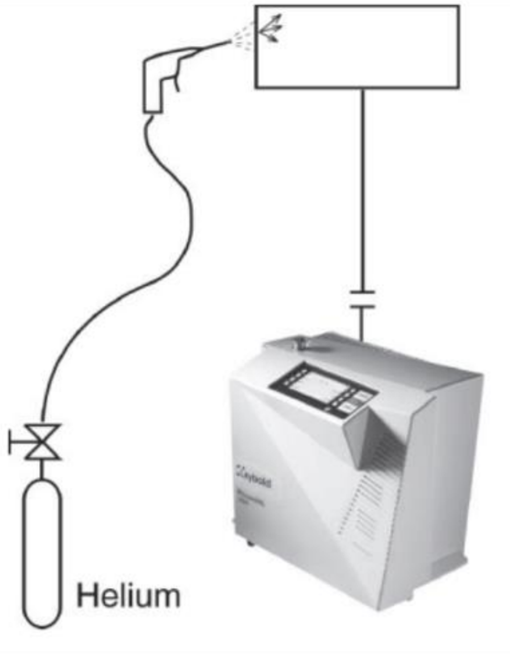
Vacuum test results

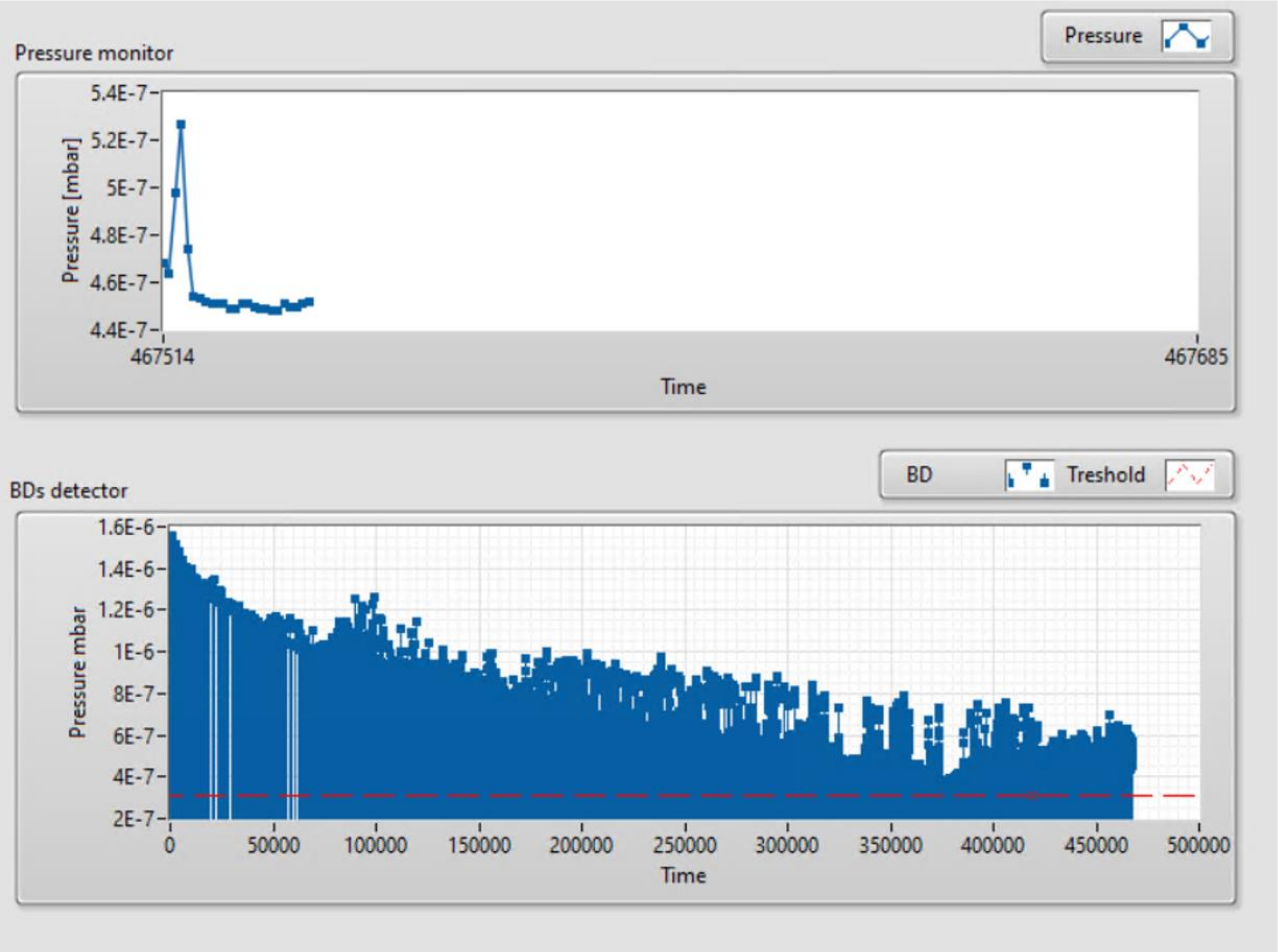


Vacuum is provided into the system at 10^{-3} mbar. When the background value is below the detection limit (10^{-10} mbar·l·s^{-1}), helium is sprayed for 10 to 30 seconds in an enclosure on top of the upper surface of the pure Cu disk to reach He concentration close to 100%.

Table 1: Helium tightness results

Thickness Z (mm)	Angle/Result (mbar/l/s^{-1})		
	45°	67°	90°
2.5	PASS	PASS	PASS
2	PASS	PASS	PASS
1.5	PASS	PASS	PASS
1	PASS	PASS	PASS
0.75	PASS	PASS	$1\cdot10^{-6}$
0.5	PASS	$2.5\cdot10^{-3}$	$5\cdot10^{-2}$

Outgassing tests of AM samples



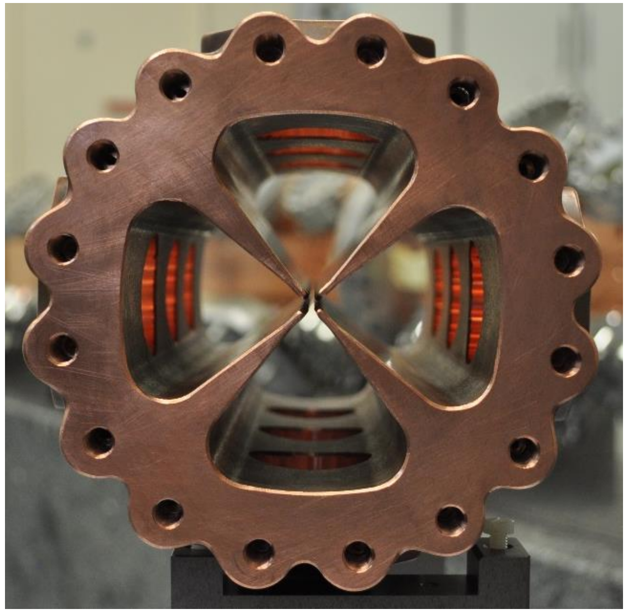
In preparation for the HV tests at CERN

In collaboration with: CLIC group of CERN

Vacuum tests of RFQ

- RFQ – purpose designed - target - 10^{-7} mbar
- Viton seals, then Aluminium seals

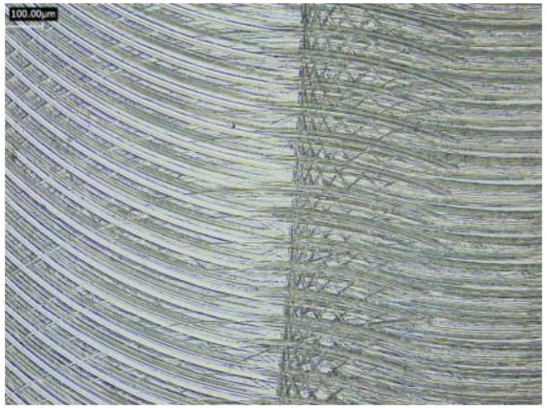
Seal plan DN40



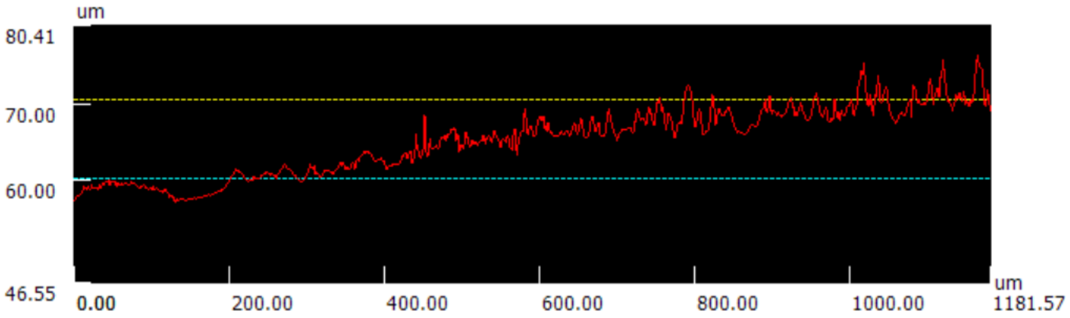
Seal plan DN100

Vacuum tests - work in progress

- AM is not a problem, some damages occurred during post-machining and handling = lessons learned
- To date 13 out of 15 flanges are vacuum tight
- Manual polish of several seal plans required
- Re-machining of the plane at micro-level



Bottom plan of seal groove DN40



Profil of bottom plan of seal groove DN40

Courtesy of Alexandre Gonnin (IJCLab)

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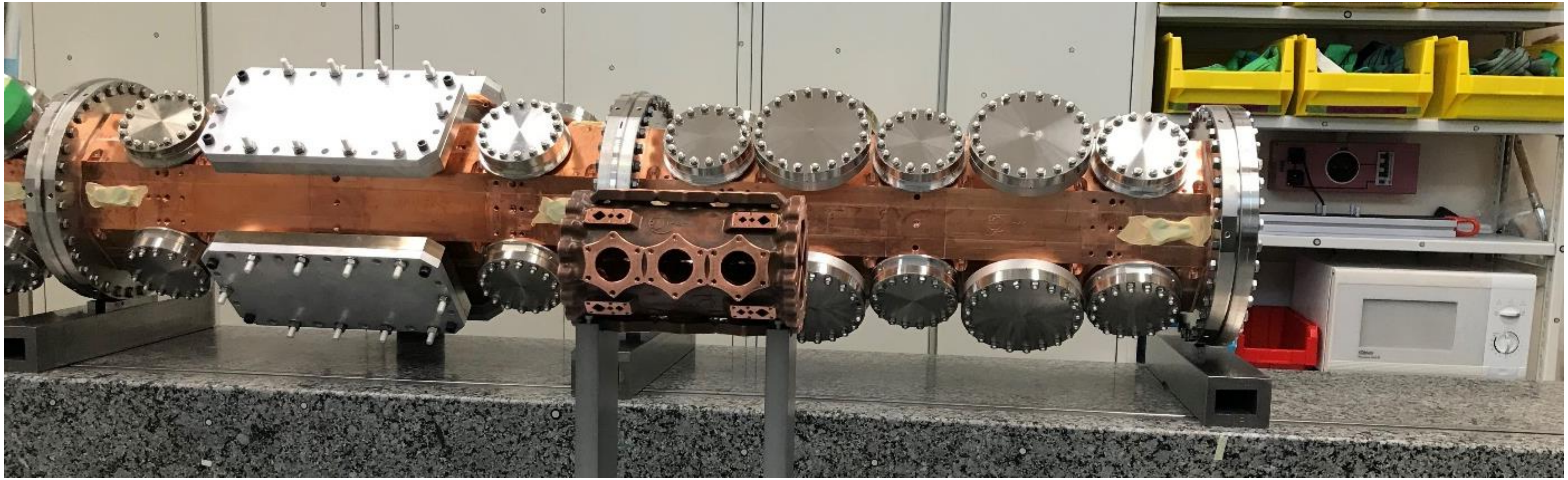
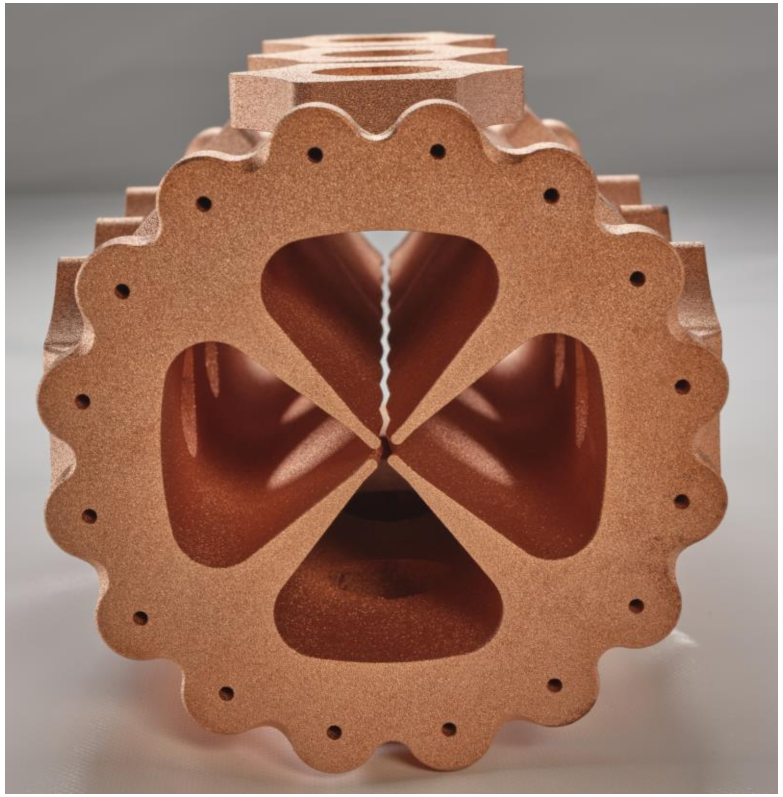
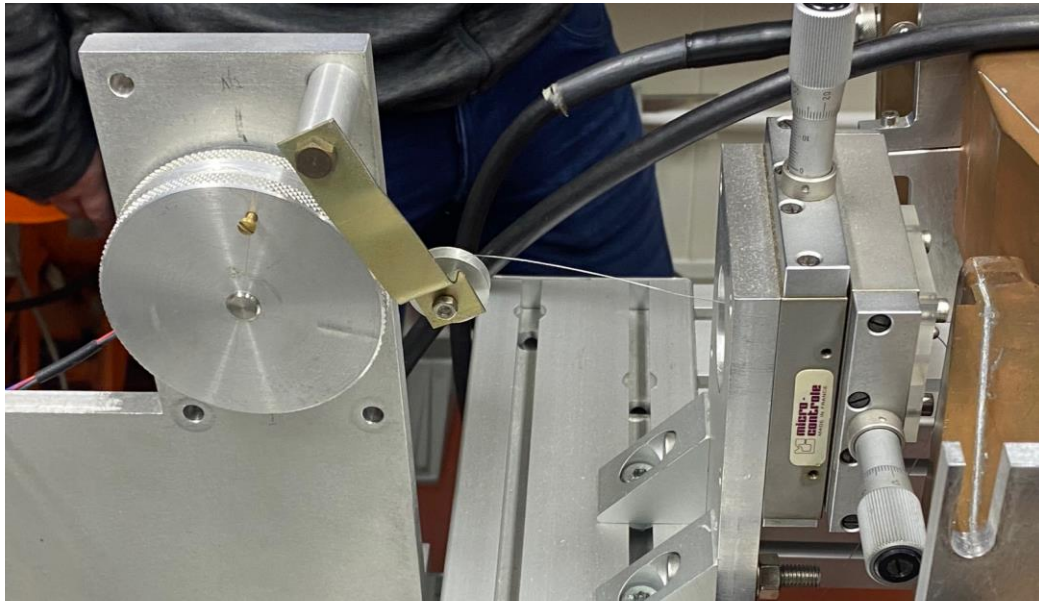
Further plans and visions



Low-level RF tests





IJCLab
Irène Joliot-Curie
Laboratoire de Physique des 2 Infinis

iFAST

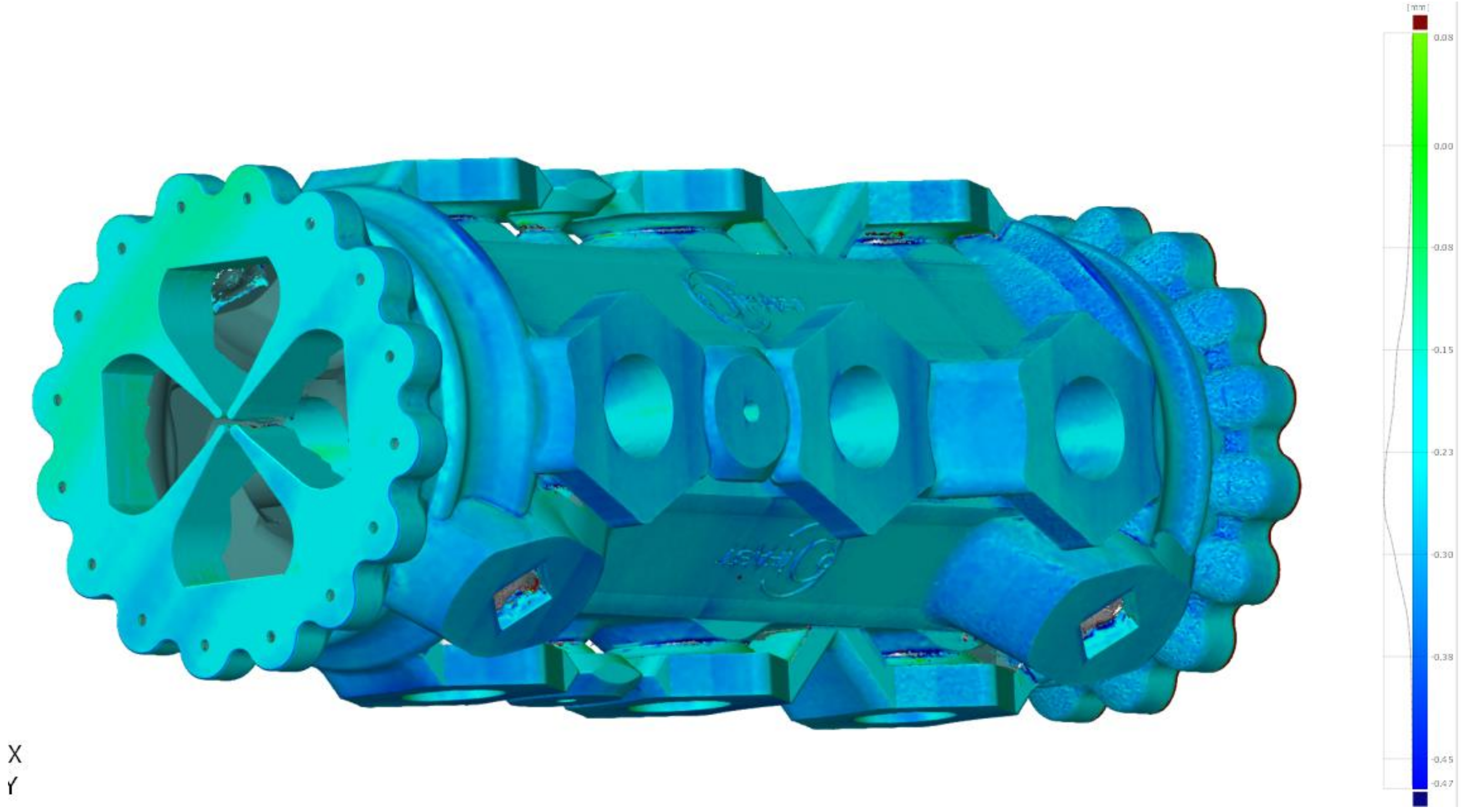
4^{th} generation of RFQ

Improved design

Will be made for tests

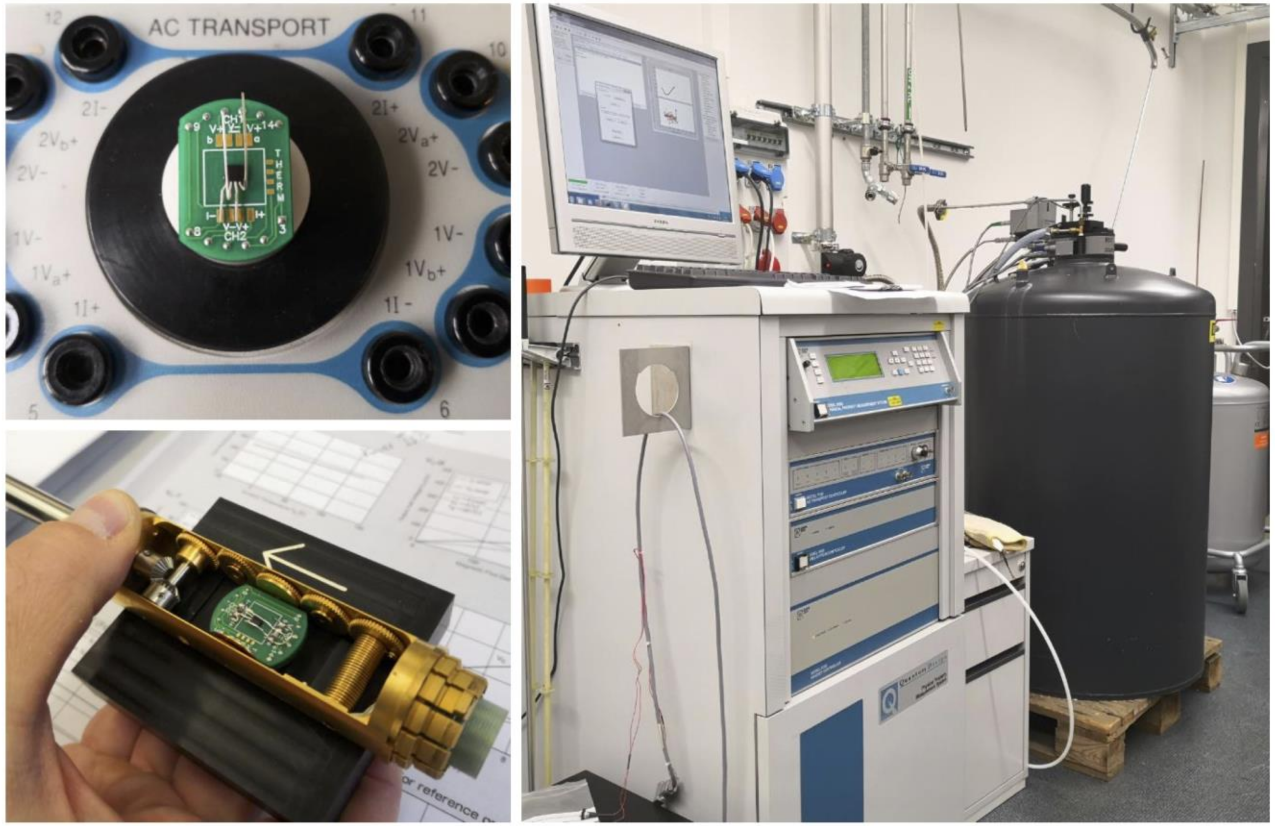
Lessons learned to be applied

Improved process parameters



Wider collaboration engaging with community

Cryogenic tests of pure-copper AM



Physical Property Measurement System (PPMS)

Up to 9T and down to 2K

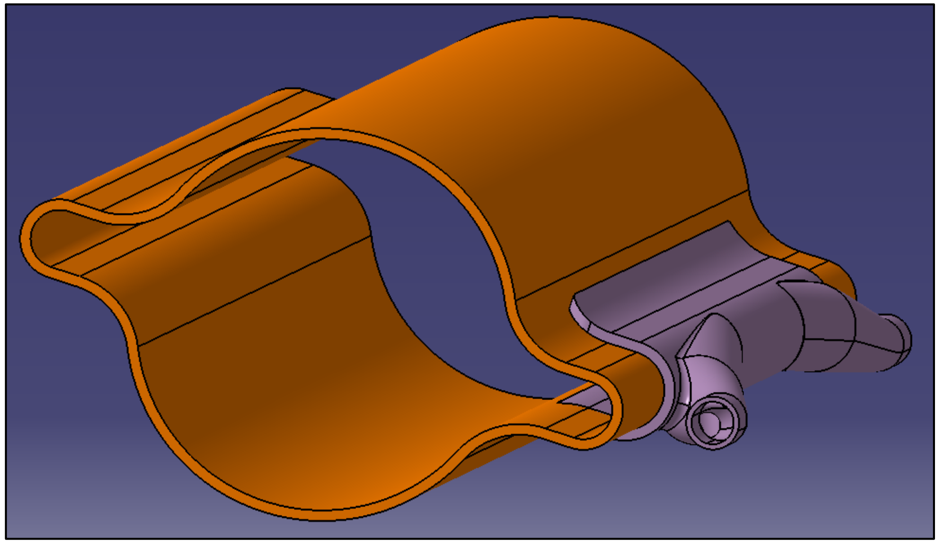
On picture: calibration instrument for hall probes

PAUL SCHERRER INSTITUT

PSI

In collaboration with:
Insertion Device Group, Photon Science Division of PSI

FCC – ee: Additive Manufacturing
Synchrotron Radiation Absorber



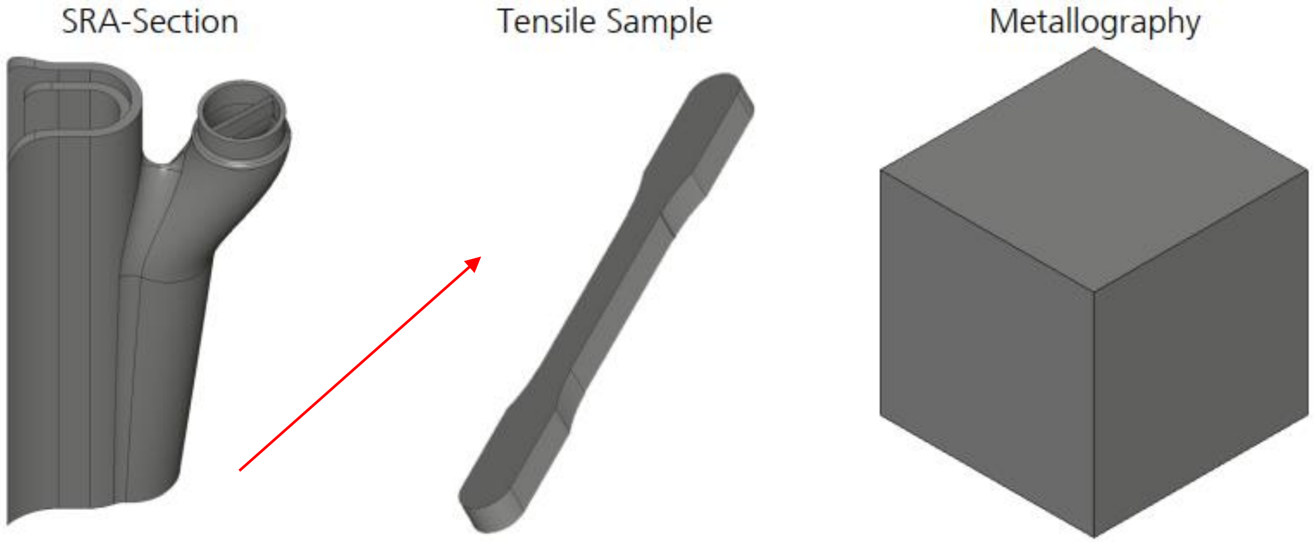
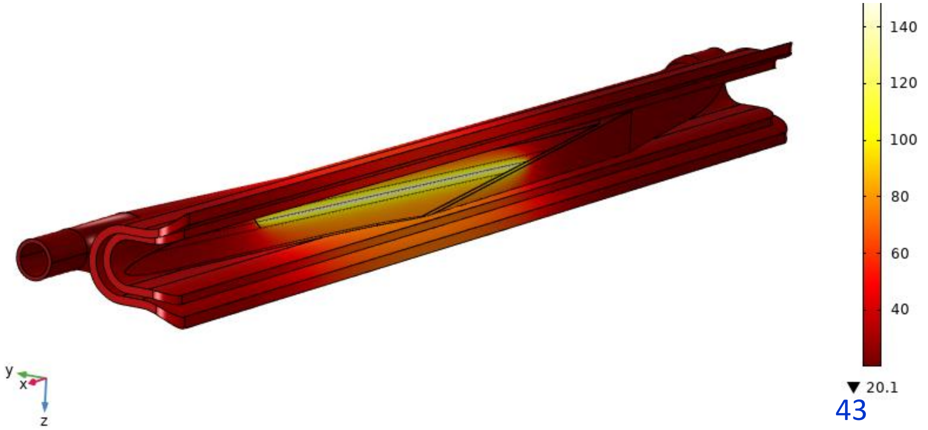
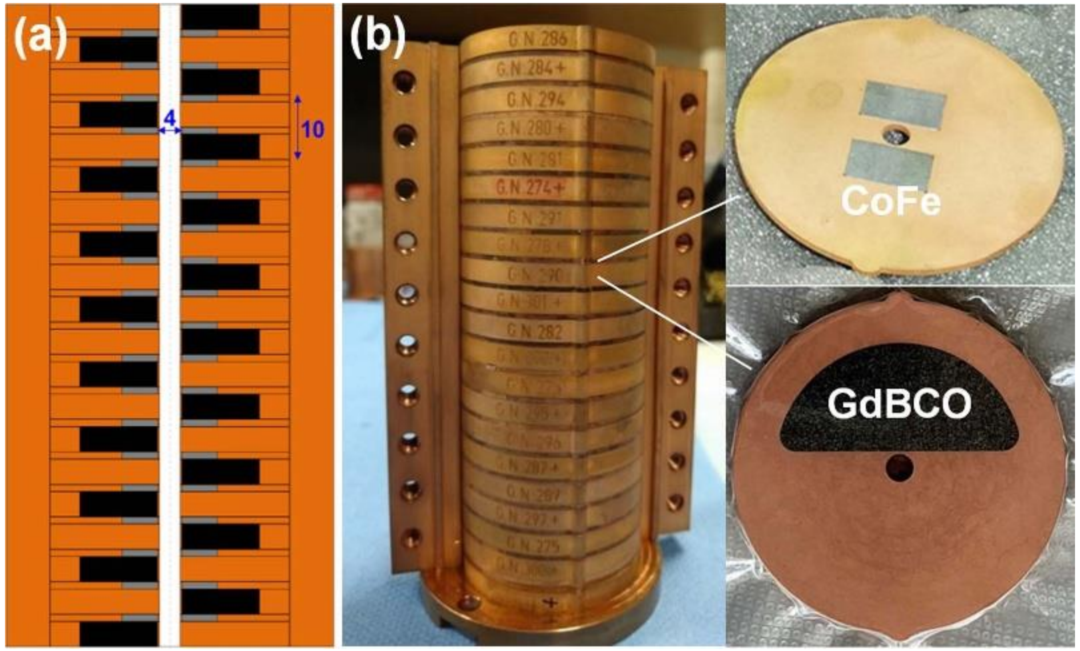


Figure 1: test sample geometries

In collaboration with: CERN-TE-VSC-DLM and Fraunhofer IWS

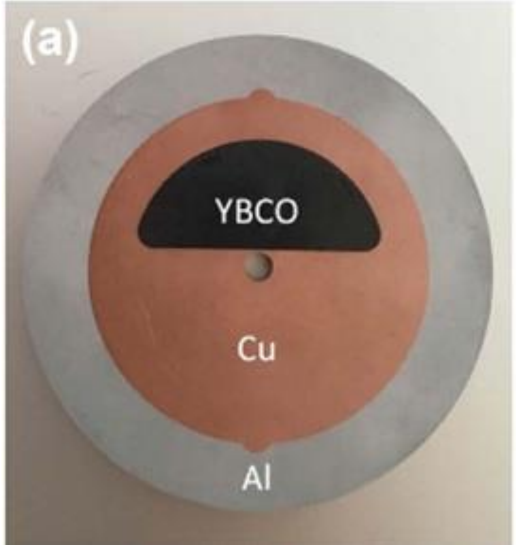


Pure cupper printing on YBCO disk?



https://doi.org/10.1088/1361-6668/acc1a8

In collaboration with:
Insertion Device Group, Photon Science Division of PSI



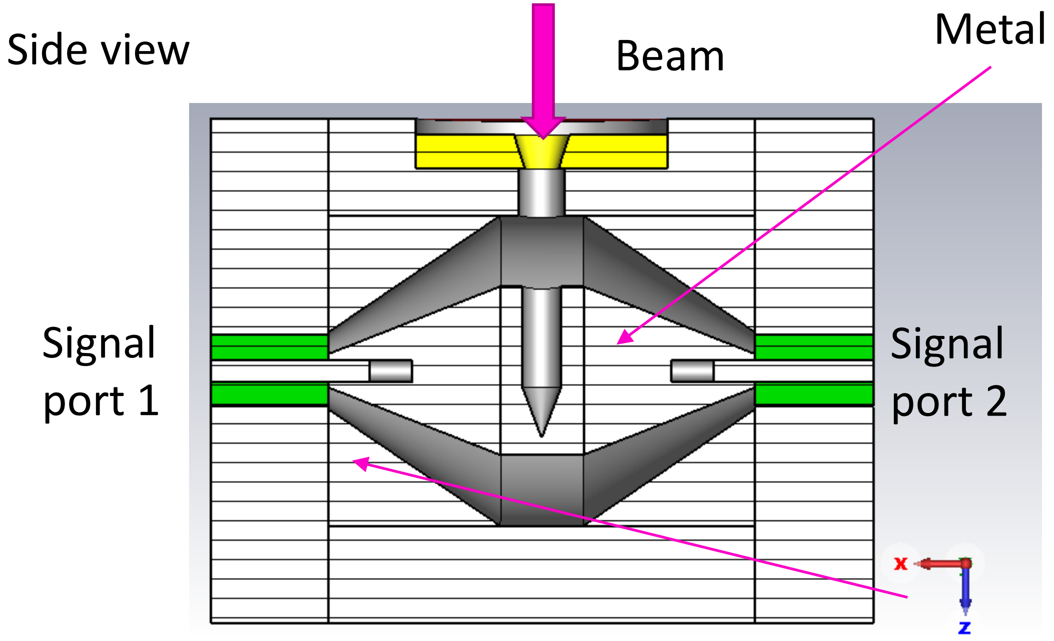
High-temperature superconducting undulator

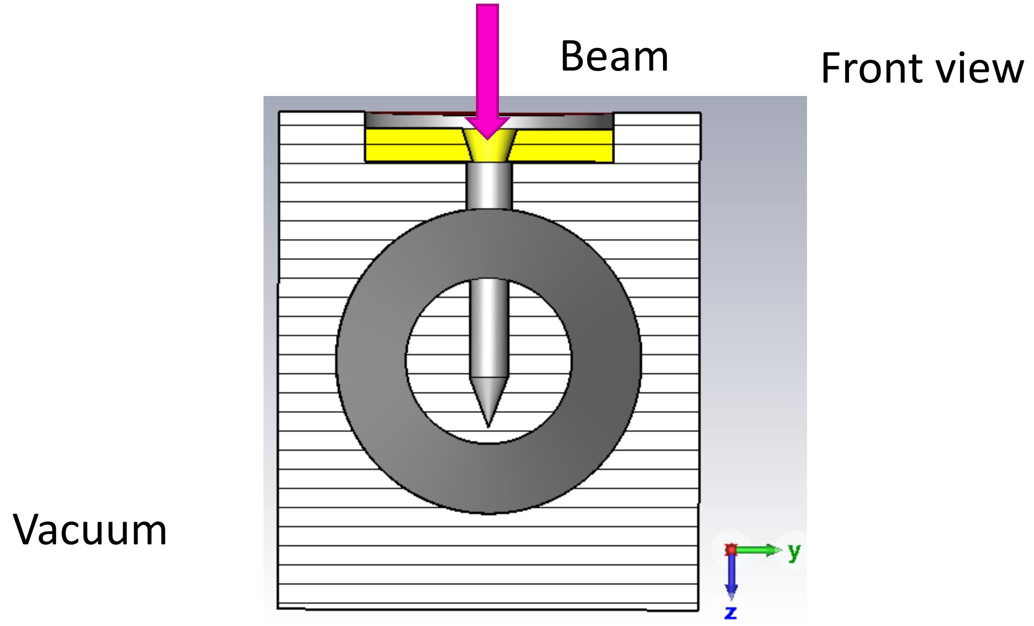
Half-moon shaped YBCO disk

Cryogenic tests of pure-copper AM made samples are planned **at PSI**

Fast Faraday Cup for AM

Unpublished design
S. Klaproth, R. Singh





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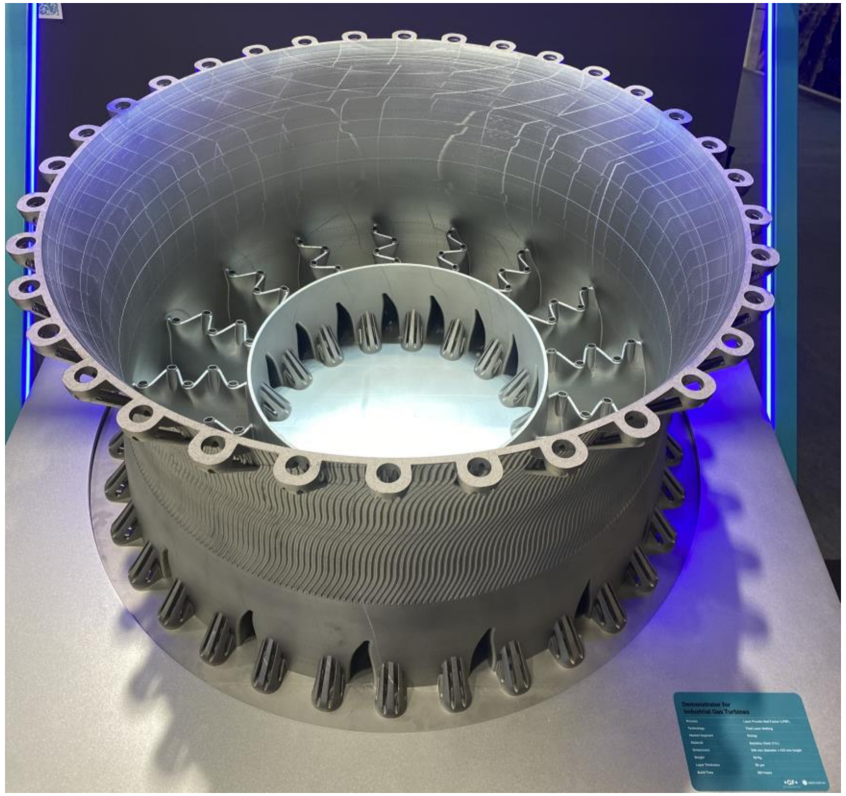
- These are used to measure bunch shape of non-relativistic beams
- Evaluation of the RF properties of additively manufactured RF beam diagnostic devices
- Conical hole allows reduction of secondary electron emission and profile distortion due to ion beam interaction with FFC

AM change of paradigm

- Our community is having new design opportunities
- We can do designs based on accelerator physics and not mechanical engineering needs
- 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

Latest trends (Formnext 2022)

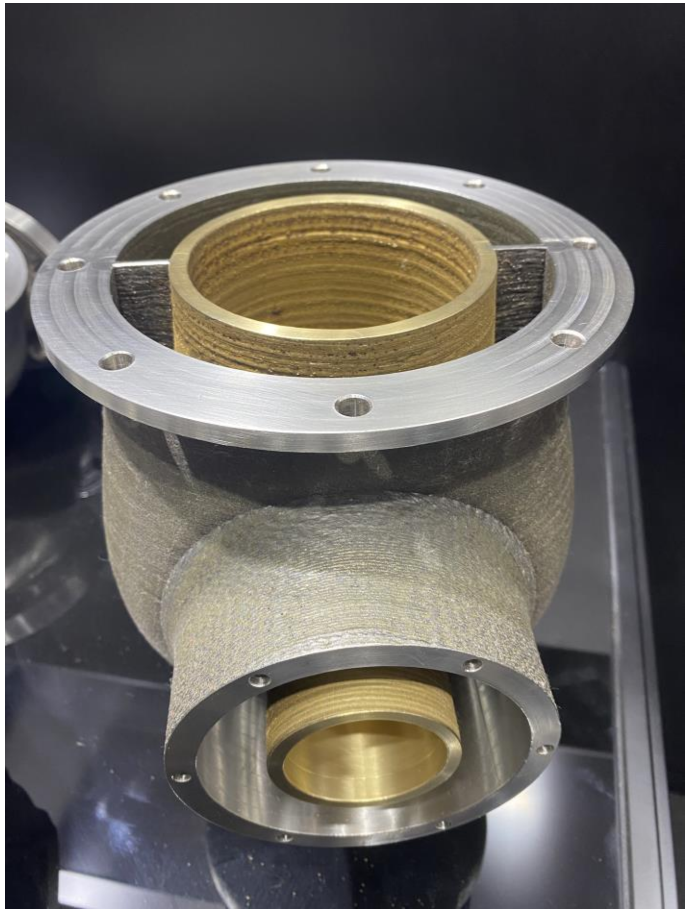
- Building sizes goes up



- Artificial Intelligence designs

hyperganic

- Multi-materials
- Hybrid processes



DMG MORI

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T10.2 achievments during P1
- *addressing 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 avalibility, 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**	

- *Define **strategic directions** for future AM technologies and foster their impact on accelerator applications (inc. societal), identifying technology barrier and challenges.*

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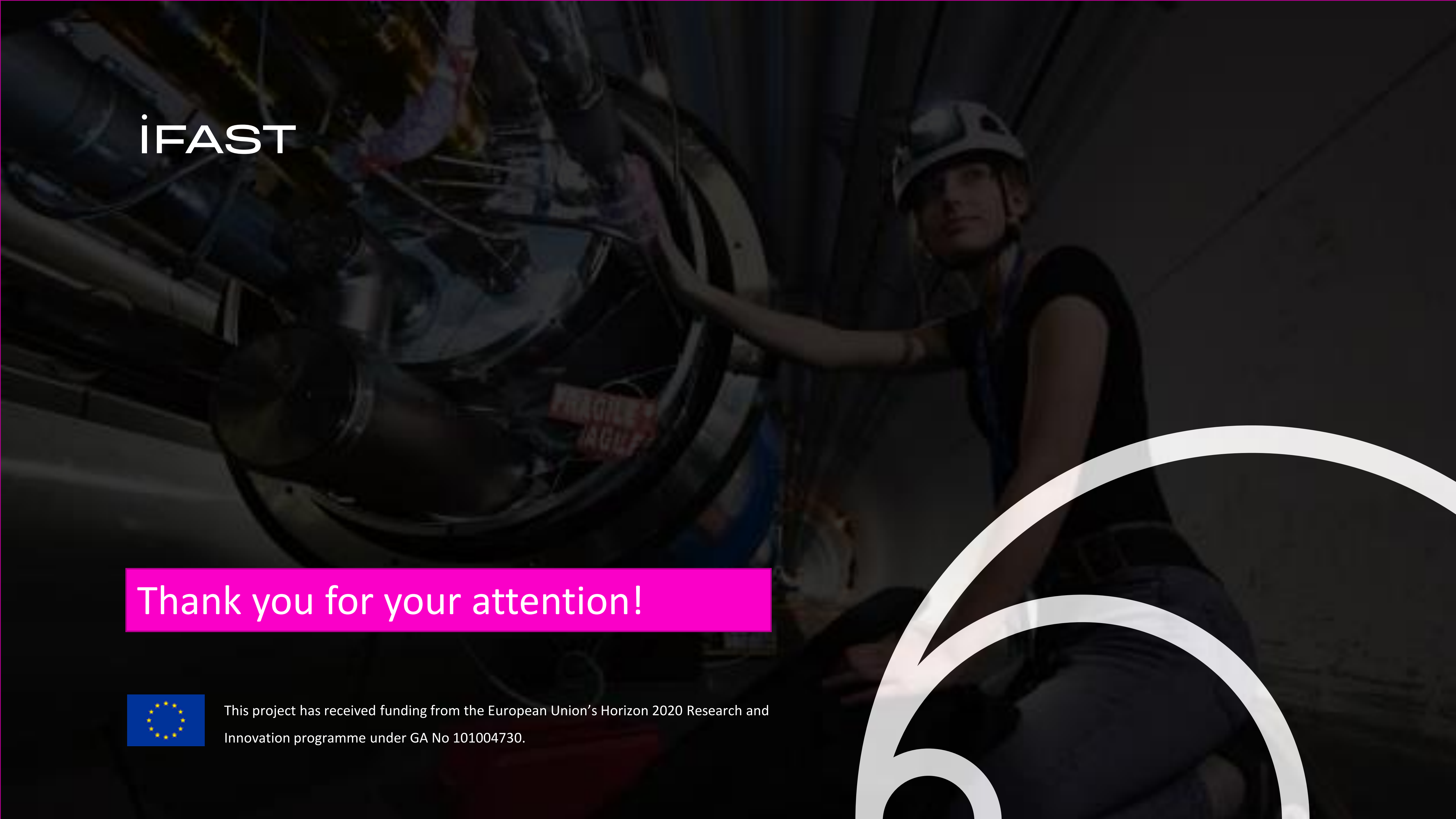
Work is going-on!



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Thank you for your attention!

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