



Participation in Accelerator Projects

Andris Ratkus

Accelerator Technology Group Leader

11.10.2023

Accelerator Technology Team



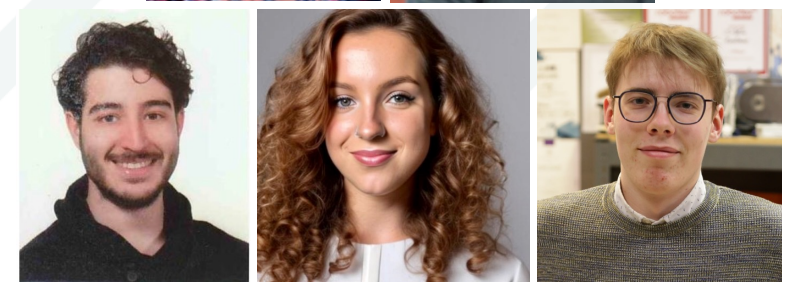
Institute of Particle Physics and
Accelerator Technologies

Accelerator Technology Team

- Prof. Toms Torims
- Guntis Pikurs PhD student
- Dr. Andris Ratkus

- Luca Piacentini PhD student*
- Lazar Nikitović PhD student*
- Kristaps Paļskis PhD student*
- Tobia Romano (PoliMi/ RTU) PhD student*

- Vincenzo Alberto Sansipersico PhD student*
- Aurēlija Viņķe Bachelor student
- Dairis Rihards Irbe Bachelor student



Accelerator Technology Team

Graduates

– Ekaterina Tskhay MSc student 2021



– Dagnija Kroģere MSc student 2022



– Viesturs Lācis MSc student 2023



Accelerator projects



Innovation Fostering in Accelerator Science and Technology (I.FAST)



- **WP1: Management, coordination and dissemination**
 - Task 1.2: Information Flow Management and Cross-coordination (Task Leader RTU)
- **WP10: Advanced Accelerator Technologies (Coordinator RTU)**
 - Task 10.1: Coordination and Communication (Task Leader RTU)
 - Task 10.2: Additive Manufacturing - Survey of applications and potential developments
 - Task 10.3: Refurbishment of accelerator components by AM technologies (Task Leader RTU)
- **WP12: Societal Applications**
 - Task 12.1 sub task 3: Environmental applications of electron beam

Innovation Fostering in Accelerator Science and Technology (I.FAST)



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 - Task 10.3: Refurbishment of accelerator components by AM technologies (Task Leader RTU)
- **WP12: Societal Applications**
 - Task 12.1 sub task 3: Environmental applications of electron beam

Student theses



- **Guntis Pikurs PhD thesis:** **Follow his talk @11:30 ([link](#))**

Research on performance improvement of accelerator and detector components by additive manufacturing

- **Tobia Romano PhD thesis:** **Follow his talk @12:15 ([link](#))**

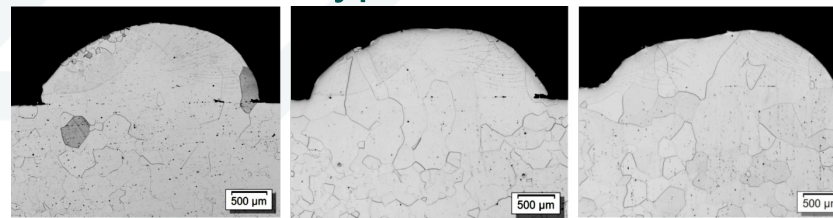
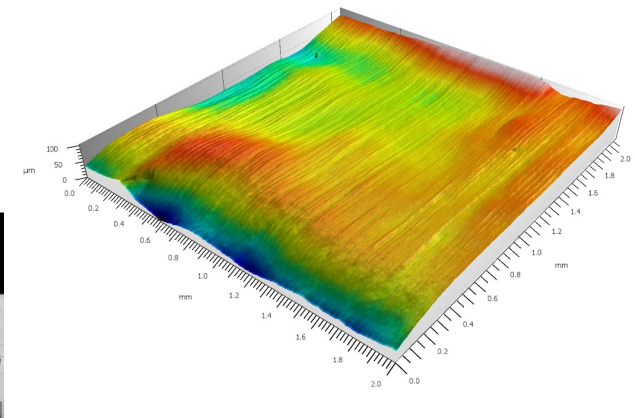
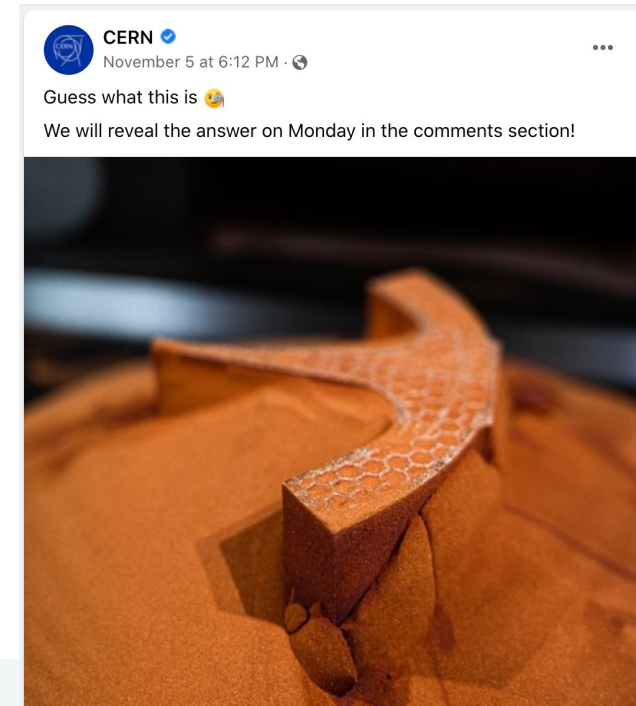
Investigation on the sintering behaviour of pure copper processed via additive manufacturing

- **Dagnija Krogere MSc thesis (Defended):**

Research of additive manufacturing applications and strategies for repairing particle accelerator components

- **Viesturs Lacis MSc thesis (Defended):** **Was @poster Session**

Laser Polishing of Additively Manufactured RFQ Prototype



Results so far

- Task 10.3 Deliverable was submitted and approved
Reported about:
 - AM state of the art in the accelerator community
 - Possible AM repair strategies for accelerators



I.FAST

Innovation Fostering in Accelerator Science and Technology
Horizon 2020 Research Infrastructures GA n° 101004730

DELIVERABLE REPORT

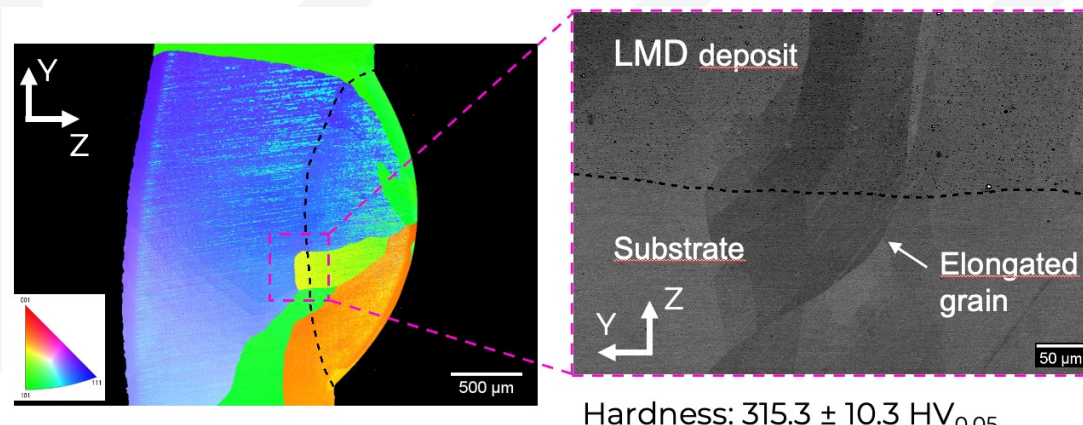
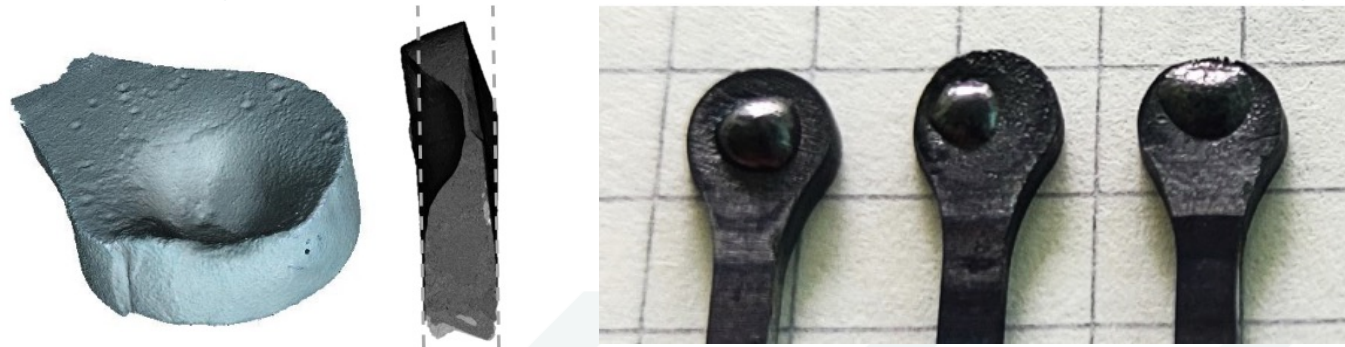
Survey of AM applications and strategies for repairing components by AM

DELIVERABLE: D10.2



Results so far

- Task 10.3 Deliverable was submitted and approved
Reported about:
 - AM state of the art in the accelerator community
 - Possible AM repair strategies for accelerators
 - Case study: Ta cathodes repair by two AM technologies



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Innovation Fostering in Accelerator Science and Technology
Horizon 2020 Research Infrastructures GA n° 101004730

DELIVERABLE REPORT

Survey of AM applications and strategies for repairing components by AM

DELIVERABLE: D10.2



POLITECNICO MILANO 1863	Fraunhofer IWS
TANI OBIS inspiring metal evolution	1862 RIGA TECHNICAL UNIVERSITY
GOBIERNO DE ESPAÑA	MINISTERIO DE CIENCIA, INNOVACIÓN Y UNIVERSIDADES
Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas	

Results so far

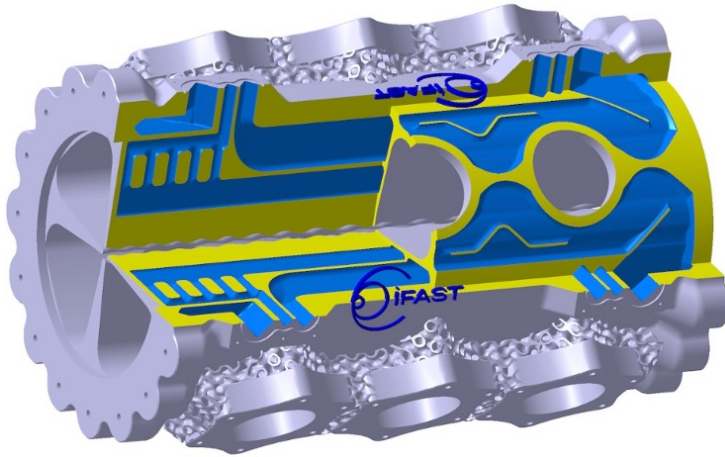
- Pure Cu (Cu-ETP) RFQ prototypes manufactured by AM

¼ RFQ L= 95 mm



Results so far

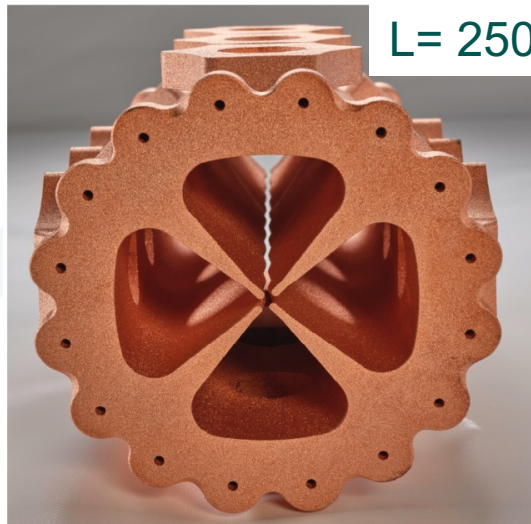
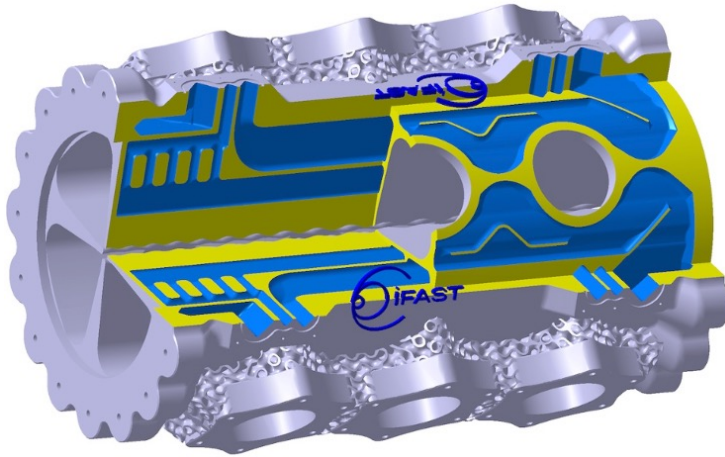
- Pure Cu (Cu-ETP) RFQ prototypes manufactured by AM



L= 250 mm

Results so far

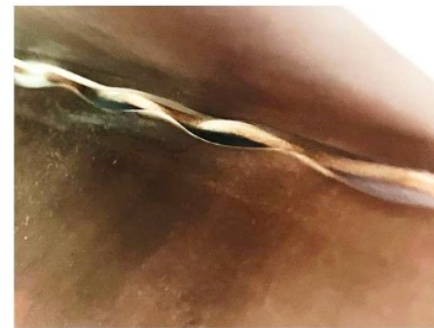
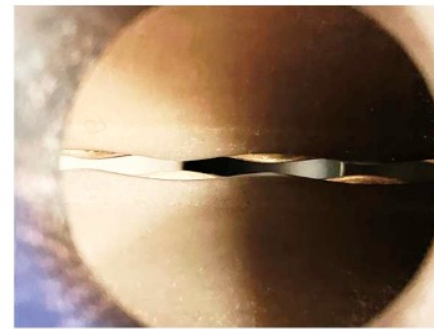
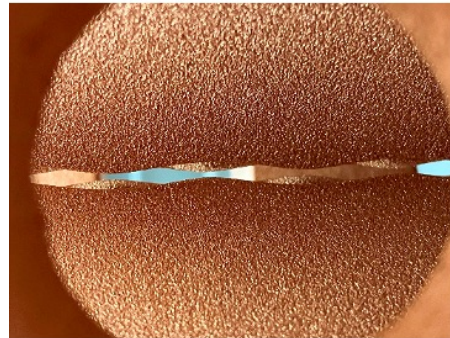
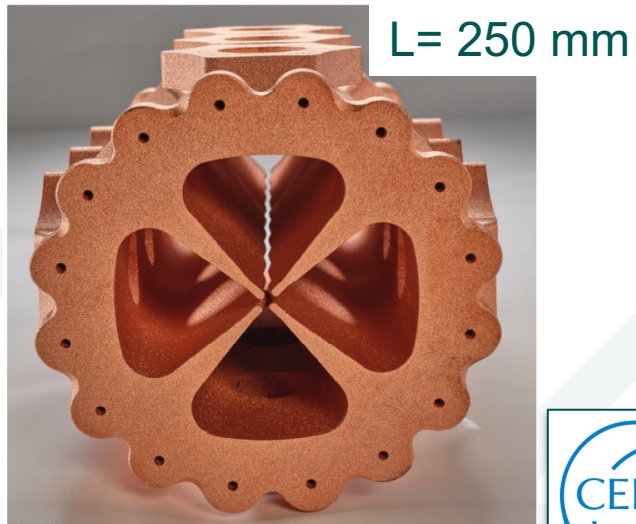
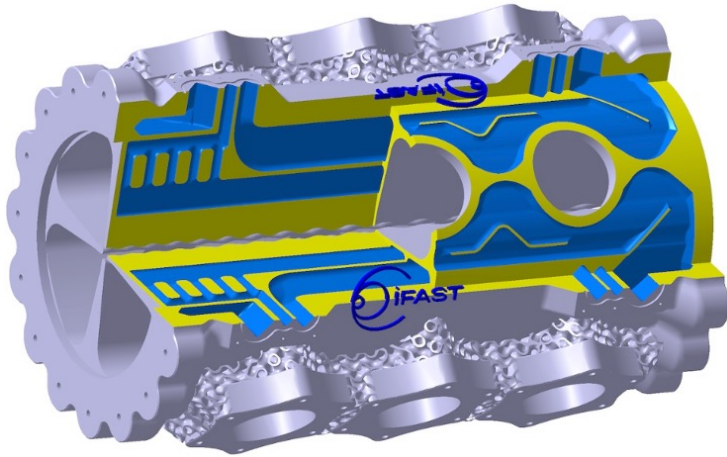
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L= 250 mm

Results so far

- Pure Cu (Cu-ETP) RFQ prototypes manufactured by AM



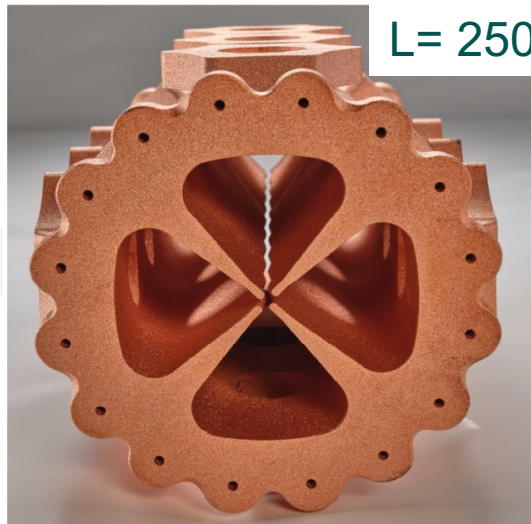
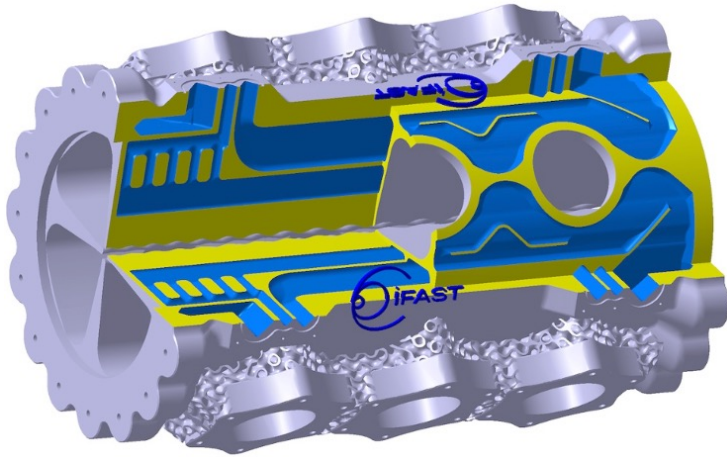
Before

After

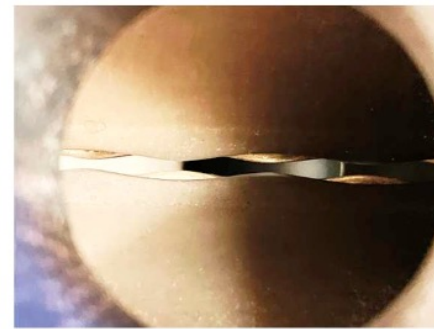
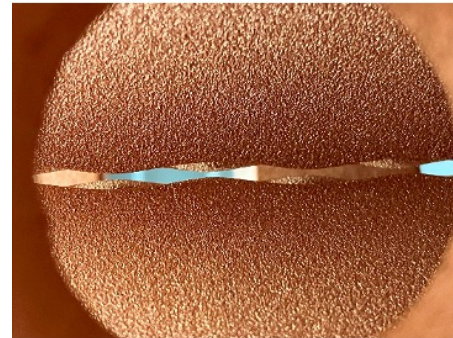
Post-processing

Results so far

- Pure Cu (Cu-ETP) RFQ prototypes manufactured by AM



L = 250 mm



Before

After

Post-processing

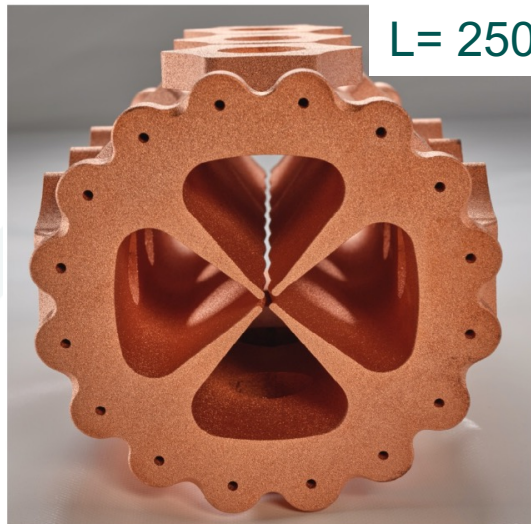
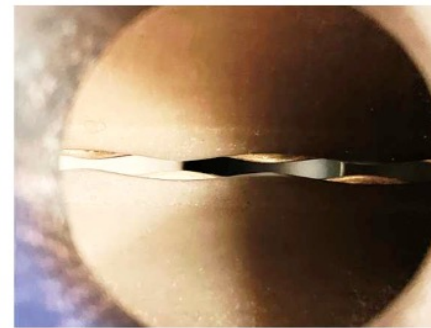
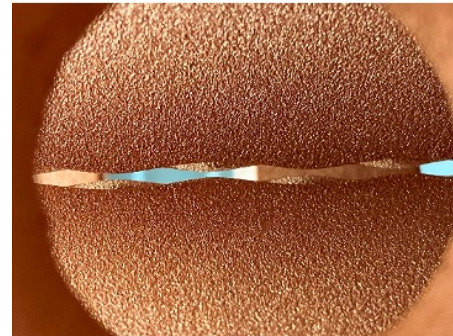
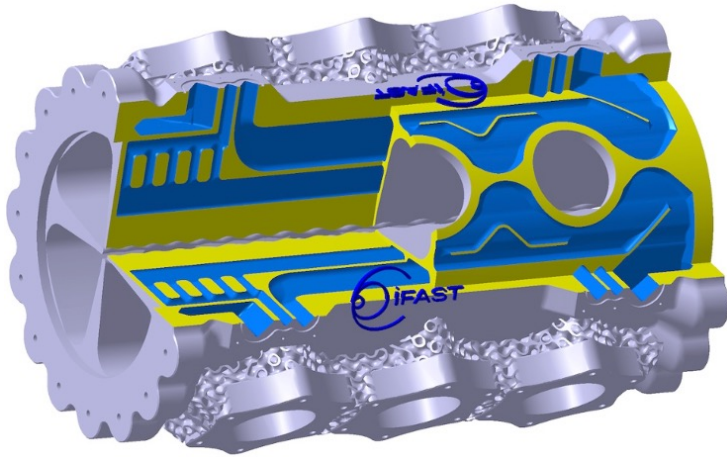


Post-processed and machined

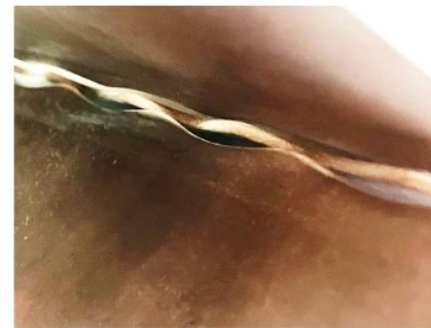
Results so far



- Pure Cu (Cu-ETP) RFQ prototypes manufactured by AM



L = 250 mm



Before

After

Post-processing

Post-processed and machined



Vacuum tests at IJCLab (currently)

RF tests at CERN will follow



POLITECNICO
MILANO 1863



Accelerator projects

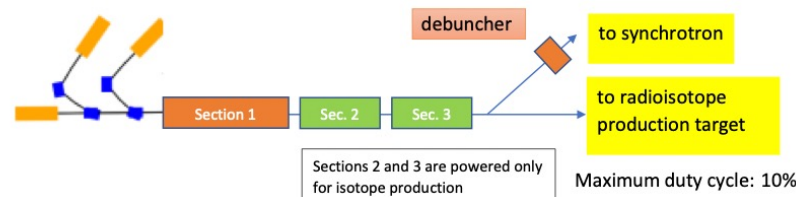
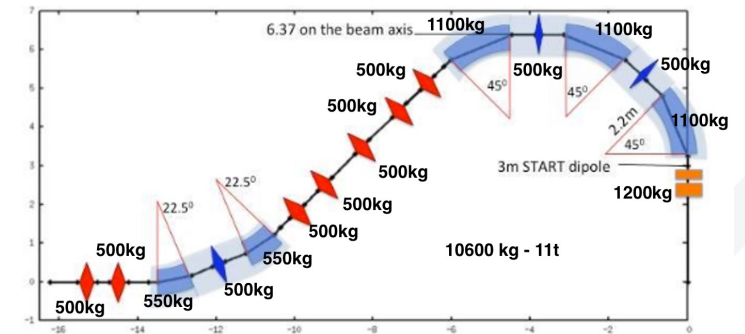
HITRI
plus
Heavy Ion Therapy Research Integration

Heavy Ion Therapy Research Integration



WP 7: Advanced accelerator and gantry design

- Task 7.4: Injector Linac Design
- Task 7.5: Integration of an innovative superconducting gantry: optics, mechanics, beam delivery



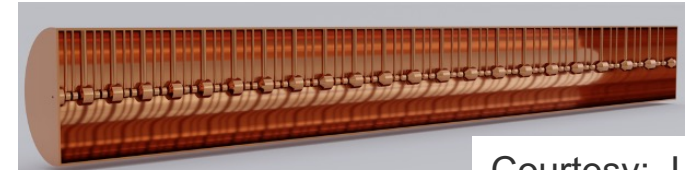
<p>3 ion sources</p> <p>$^{12}\text{C}^{4+}$, 600 μA, 0.25 π mm mrad, 45 kV</p> <p>$^4\text{He}^{2+}$, 0.5 mA, 0.3 π mm mrad</p> <p>p or H_2^+, 5 mA, 0.2-0.3 π mm mrad</p>	<p>Linac section1</p> <p>q/m=1/3</p> <p>$W_{\text{in}} = 15$ keV/u</p> <p>$W_{\text{out}} = 5$ MeV/u</p>	<p>Linac section2</p> <p>q/m=1/2</p> <p>$W_{\text{in}} = 5$ MeV/u</p> <p>$W_{\text{out}} = 7.1$ MeV/u</p>	<p>Linac section3</p> <p>q/m=1/2 or 1</p> <p>$W_{\text{in}} = 7.1$ MeV/u</p> <p>$W_{\text{out}} = 10$ MeV/u</p>
<p>Sections 2 and 3 are powered only for isotope production</p> <p>Maximum duty cycle: 10%</p>			
<p>baseline : 217 MHz</p> <p>alternative : 352 MHz</p>			



Student theses

- **Lazar Nikitovics PhD thesis:** Was @poster Session

Design study of a high-frequency linear accelerator for the purposes of injection into a therapy synchrotron and parallel production radioisotopes



Courtesy: L. Nikitovic

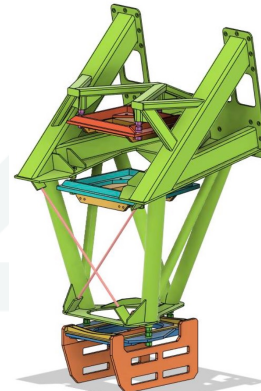


- **Luca Piacentini PhD thesis:** Was @poster Session

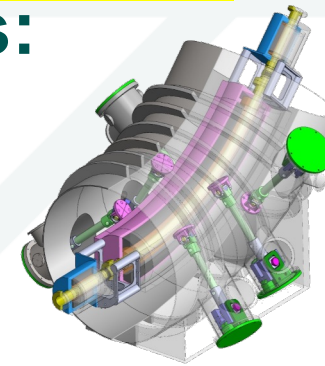
Mechanical integration of systems, instruments and components of a carbon ion rotating gantry for medical treatments

- **Dairis Rihards Irbe Bachelor thesis:** Was @poster Session

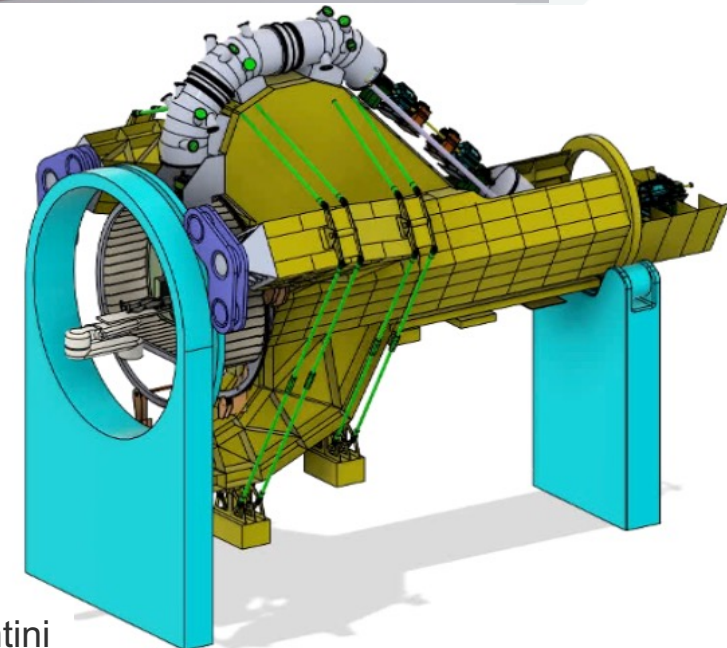
Designing of gantry mechanical components



Courtesy: D. Irbe



Courtesy: L. Piacentini



Results so far

1 Posters

2 Publications

IPAC'23 Proceedings:

<https://www.ipac23.org/preproc/index.html>

MDPI Journal Machines:

<https://www.mdpi.com/2075-1702/11/10/929>

HITRIplus Deliverables:

- Task 7.4 (submitted)
- Task 7.5 (work in progress)



COMPARISON OF 352 MHz LINAC STRUCTURES FOR INJECTION INTO AN ION THERAPY ACCELERATOR

L. Nikitovic^{1,2}, T. Torims¹, M. Vretenar²

¹Riga Technical University, Riga, Latvia
²CERN, Geneva, Switzerland

AIMS OF STUDY

- RF design and beam optics studies for comparison of various accelerating structures at 352 MHz for the HITRIplus LINAC:
- Quasi-Alvarez Drift Tube LINAC (QA-DTL);
- Inter-digital H-mode Drift Tube LINAC (IH-DTL);
- Separated Inter-digital H-mode Drift Tube LINAC (S-IH-DTL).

WHY DO WE NEED A NEW DESIGN?

- Lower operational costs of accelerators - hence more affordable to society;
- Improved beam optics with high transmission and optimum beam quality, achieving better performance for cancer treatment.

3 Ion Sources:

- ¹²C⁺: 0.6 mA, 45 kV, 0.25 mrad
- ¹⁶O⁺: 0.5 mA, 0.3 mrad
- ¹⁸O⁺: 0.4 mA, 0.2-0.3 mrad

LINAC sec. 1: ¹²C⁺: 15 MeV, W_{max} = 5 MeV

LINAC sec. 2: ¹⁶O⁺: 7.5 MeV, W_{max} = 7.5 MeV

LINAC sec. 3: ¹⁸O⁺: 10 MeV, W_{max} = 10 MeV

Baseline: 217 MHz
Alternative: 352 MHz

Maximum duty cycle: 10%

RESULTS

C⁺ in QA-DTL

QA-DTL

PROS:

- Higher effective shunt impedance in comparison to a standard DTL;
- Strong beam focusing in transversal plane;
- Klystron can be used as RF power source, at a lower cost per watt than a solid state amplifier.

CONS:

- Higher power dissipation in comparison to a conventional IH-DTL.

S-IH-DTL

PROS:

- Clean FODO beam optics, without the need for KONUS optics;
- Optimised effective shunt impedance - different radius for every tank;
- Different focusing systems can be used (e.g. doublets and triplets);

CONS:

- Higher power dissipation in comparison to a conventional IH-DTL;

S-IH-DTL

DTL

- Standard Alvarez DTL structure has been designed only for the acceleration of He³⁺ and H⁺ ions;
- DTL has been designed as the second and third tank of HITRIplus LINAC.

CONCLUSIONS

STRUCTURES	QA-DTL		S-IH-DTL (doublets)		DTL	
	C ⁺	C ⁺	He ³⁺	H ⁺	Cav.1	Cav.2
L _{total} [m]	5.1	5.9	1.5	1.1		
P _{dissipation} [kW]	626	614	181	147		
E _{input} [MeV/u]	0.7	0.7	5	7		
E _{output} [MeV/u]	5	5	7	10		

WHICH LINAC STRUCTURE IS THE "BEST"?

- QA-DTL, designed as the first tank of HITRIplus LINAC, has shown to be a good alternative to conventional IH-DTL for acceleration of C⁺ ions;
- Standard Alvarez DTL, designed as the second and third tank of HITRIplus LINAC, indicated to be a good choice for acceleration of H⁺ and He³⁺ ions;
- S-IH-DTL showed to be a viable option for acceleration of C⁺ ions, but not as effective as QA-DTL in terms of both production and operational costs.



HITRI*plus* Annual meeting and Workshop



www.hitriplus.eu

26 – 28 June 2023
Riga Technical university, Latvia
Domus auditorialis,
Zunda krastmala 8, Riga
107. auditorium, 1st floor

<https://indico.cern.ch/event/1246177/>

HITRI
Heavy Ion Therapy Research Integration

CNAO
The National Center for Oncological Hadrontherapy

RIGA TECHNICAL UNIVERSITY
1862

Workshop: Clinics and research: considerations to create a novel particle therapy center (within HITRIplus Event)

Wednesday 28 Jun 2023, 10:00 → 15:45 Europe/Riga

Domus auditorialis, Zunda krastmala 8

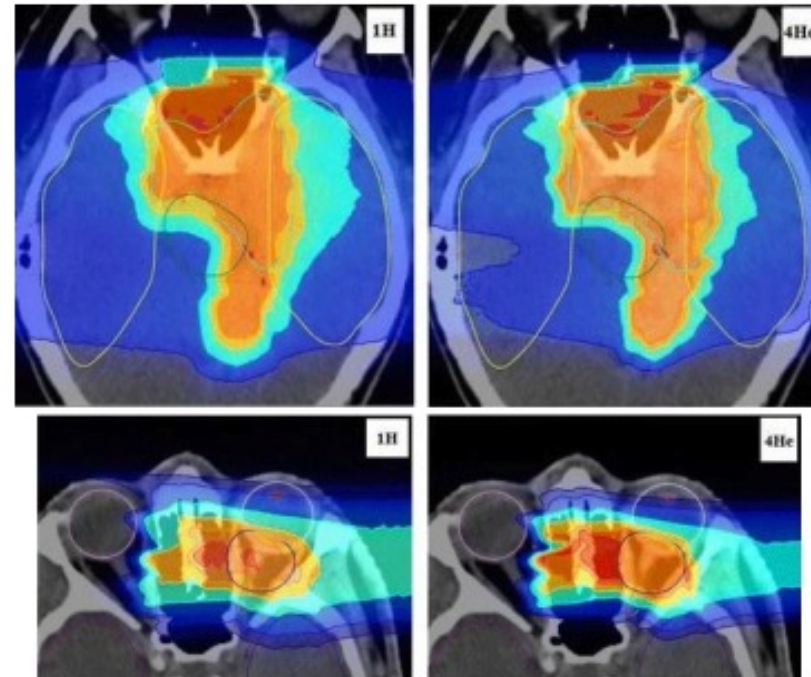
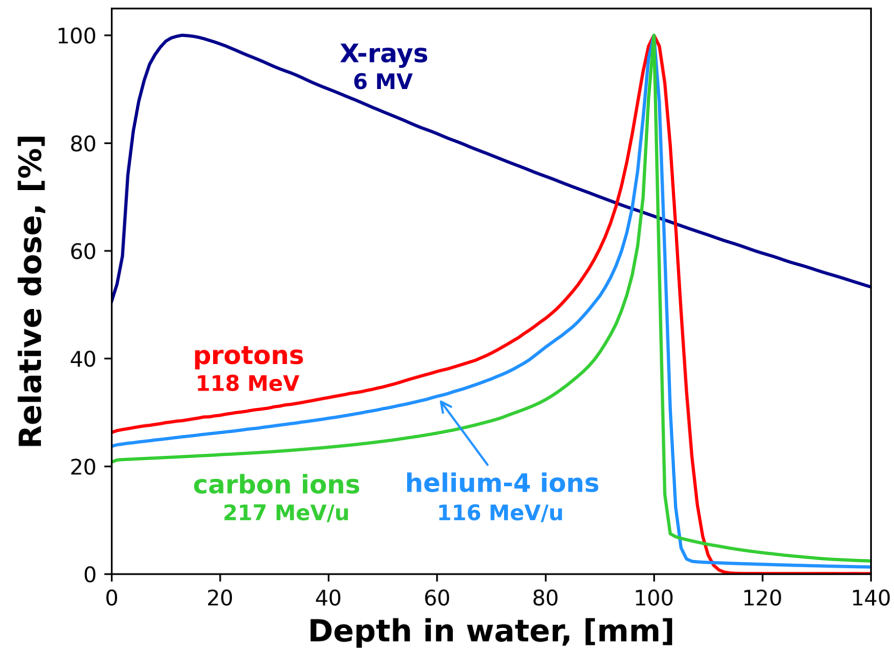
<https://indico.cern.ch/event/1256528/>

Accelerator projects



Next Ion Medical Machine Study

- Developing new technologies for the future generation of accelerators for cancer therapy



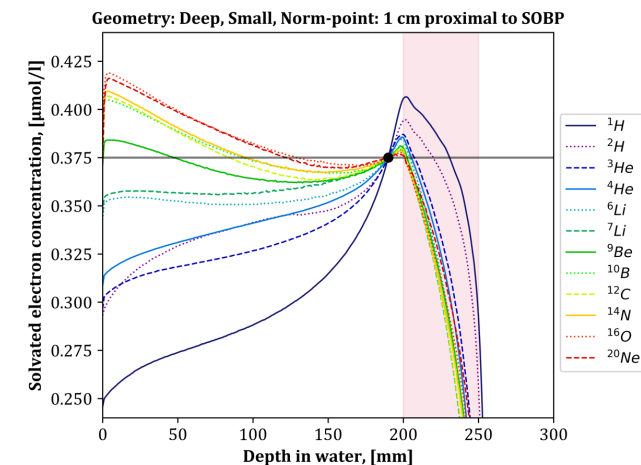
Student theses

- Kristaps Paļskis PhD thesis:** Studies of different ion types and their use for radiation therapy, *FLASH* therapy aspects. Optimization of ion beam parameters for very high dose rate (FLASH) radiotherapy

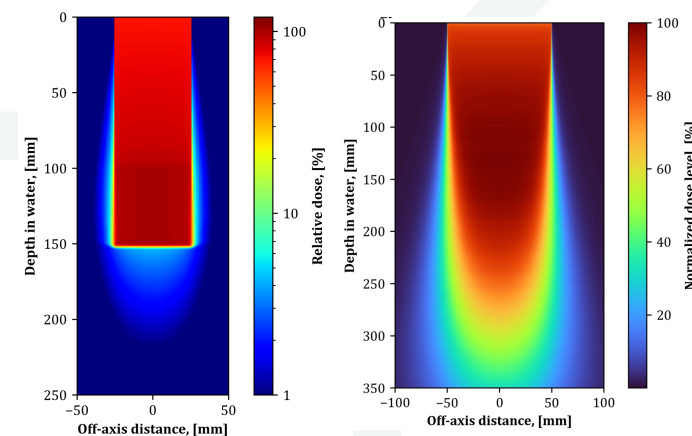
Presented @9:55 ([link](#))

- Vincenzo Alberto Sansipersico PhD thesis:** Optimization and Integration of a $^4\text{He}^{2+}$ Synchrotron for Cancer Therapy

- Aurēlija Viņķe Bachelour thesis:** Studies of proton radiography



FLASH effect modeling for Ions



SFUD field

VHEE field

Results so far

2 Posters 1 Publications

Madrid, Spain
10 - 16 June
2023
61st Annual PTCOG Conference



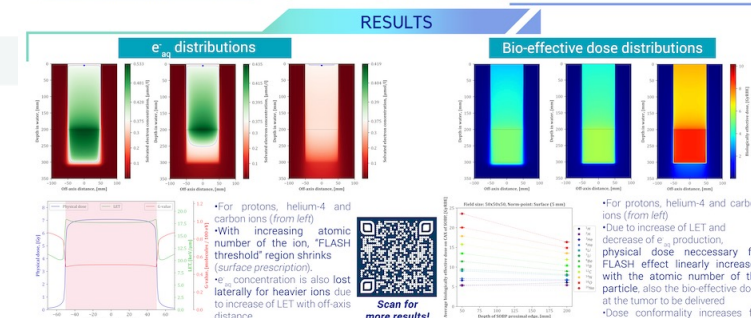
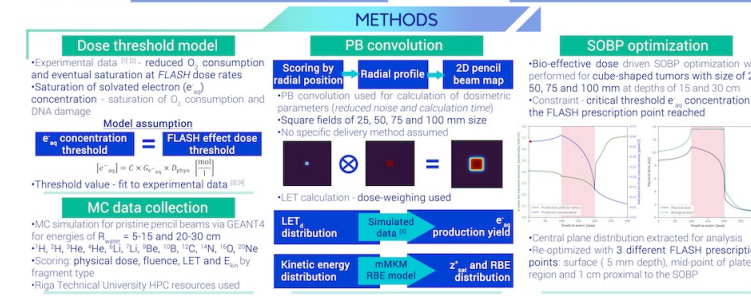
FLASH-RT DOSE THRESHOLD EFFECT ESTIMATION FOR PARTICLE BEAMS BY MODELLING SOLVATE ELECTRON PRODUCTION DEPENDENCY ON PARTICLE LET 3D DISTRIBUTION

K. Palskis^{1,2}, M. Sapinski³, T. Torims¹, M. Vretenar², J. Seco⁴

¹Riga Technical University, Riga, Latvia; ²CERN, Geneva, Switzerland; ³PSI, Villigen, Switzerland; ⁴DKFZ, Heidelberg, Germany

BACKGROUND
• FLASH-RT - growing clinical interest and emerging technological developments for delivery
• Majority of experimental evidence - electron, photon and proton beams
• Investigations of heavy ion FLASH-RT feasibility - necessary

AIMS OF THE STUDY
• Investigate FLASH effect dose threshold for 12 different ion types
• Off-axis dependency of the dose threshold - spatial variations
• Impact of SOBP geometry and FLASH prescription point
• "What would be the most efficient ion for FLASH-RT?"



CONCLUSIONS
• FLASH dose threshold modelling framework has been established by using produced e_{aq}^- concentration and dependency on LET as surrogate
• Due to e_{aq}^- distribution, FLASH conditions would be reached in larger volumes with lighter ions. e_{aq}^- concentration is lost at large off-axis distances for heavy ions
• Higher dose levels are needed to reach FLASH conditions with heavier ions - for example for ¹²C: 18 to 27% and for ¹⁶O: 88% to 155% higher physical dose at prescription point compared to proton beams (depending on SOBP geometry and prescription point depth)
• A compromise between FLASH dose level and conformity - helium, lithium and VHIE to be included in further studies, as well - studies of impact of ion beam delivery method and delivery parameter optimization

Prescription point
• For light ions: FLASH prescription point closer to tumor volume decreases the bio-effective dose at tumor to be delivered to reach FLASH effect
• FLASH prescription near the tumor would be more beneficial also clinically

[1] Iwanaga T, Furukawa T, Kase Y, et al. Treatment planning for a scanned carbon beam with a modified microdosimetric kinetic model. Phys Med Biol. 2010;55(22):6721-6737.
[2] Kase Y, Kanai T, Matsufuji N, Furusawa Y, Eladassi T, Scholz M. Biophysical calculation of cell survival probabilities using amorphous track-structure models for heavy-ion irradiation. Phys Med Biol. 2008;53(1):37-59.
[3] Boscolo D, Kramer M, Fuss MC, Durante M, Sofroni E. Impact of Target Oxygenation on the Chemical Track Evolution of Ion and Electron Radiation. Int J Mol Sci. 2020;21(2):424.
[4] Liu M, Zengshu, Bingxin Chen, Fum Yokobayashi, J. Clare Wren. A combined experimental and model analysis on the effect of pH and O₂(aq) on γ-radiolysis produced H₂ and H₂O₂. Rad Phys Chem. 2008;77(9):1009-1020.
[5] Tessonnier T, Mein S, Walsh DWM, et al. FLASH Dose Rate Helium Ion Beams: First In Vitro Investigations. Int J Radiat Oncol Biol Phys. 2021;111(4):1011-1022

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For questions contact: kristaps.palskis@cern.ch
Logos of partner institutions: Riga Technical University, CERN, Knowledge Transfer, dkfz.



Courtesy: K. Palskis

Other activities





FUTURE
CIRCULAR
COLLIDER

CERN TE-VSC

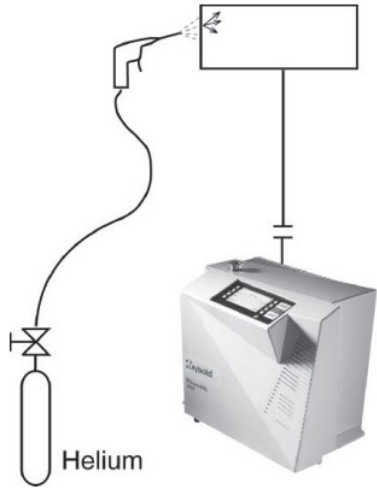


Primarily concerned with two Additive Manufacturing (AM) technologies



FUTURE
CIRCULAR
COLLIDER

CERN TE-VSC



Cold-Spray (CS)



Laser Powder Bed Fusion
(L-PBF)

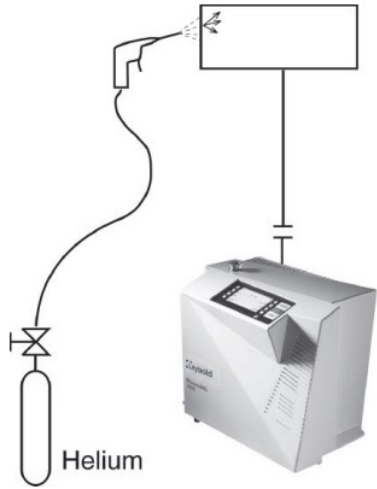
Primarily concerned with two Additive Manufacturing (AM) technologies





FUTURE
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CERN TE-VSC

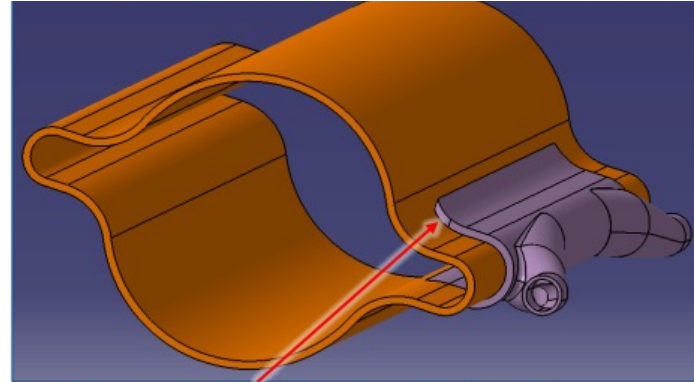


Cold-Spray (CS)



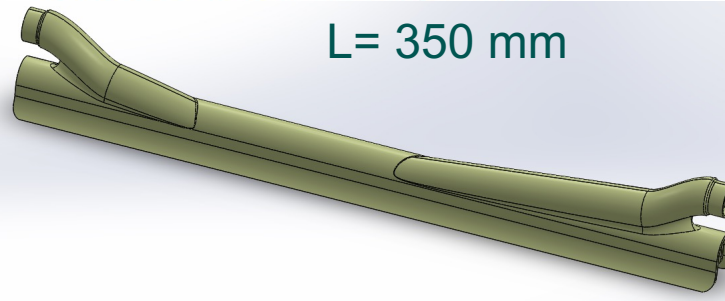
Laser Powder Bed Fusion
(L-PBF)

Primarily concerned with two Additive Manufacturing (AM) technologies



SR Absorber to be laser welded along outer profile

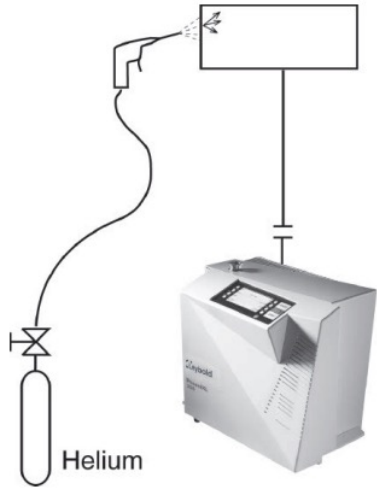
L= 350 mm





FUTURE
CIRCULAR
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CERN TE-VSC

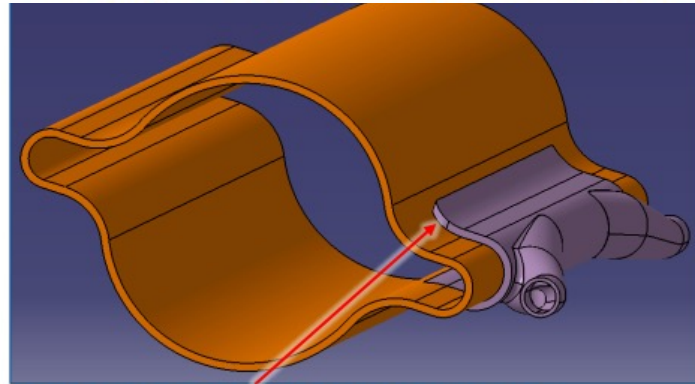


Cold-Spray (CS)



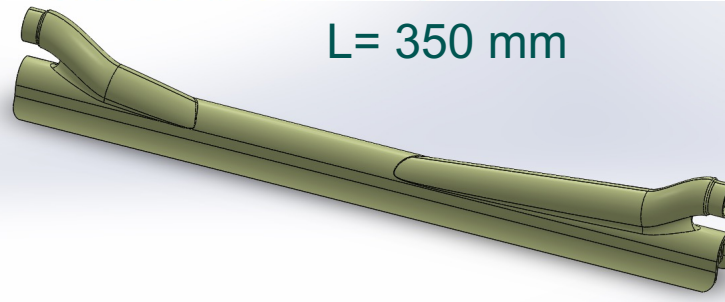
Laser Powder Bed Fusion
(L-PBF)

Primarily concerned with two Additive Manufacturing (AM) technologies



SR Absorber to be laser welded along outer profile

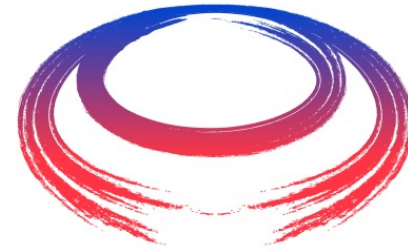
L= 350 mm





FUTURE
CIRCULAR
COLLIDER

TE-VSC



International
UON Collider
Collaboration

The Memorandum of Understanding
has been signed by RTU

SR Absorber to be laser welded along outer profile

L= 350 mm



Laser Powder Bed Fusion
(LPBF)



3D Manufacturing (AM) technologies



CERN Summer Student Programm

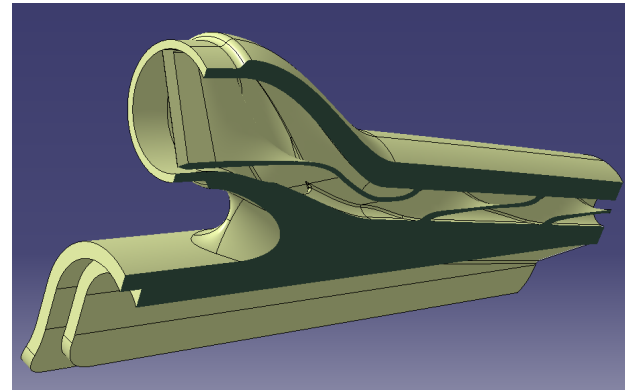


CERN Summer Student Programm



Student: Kristupa Seskauskaite (KTU) tasks:

- AM component and surface characterisation
- Measurements
- Design evaluation
- Continuation with Bachelor thesis



SR Absorber test sample (95 mm)

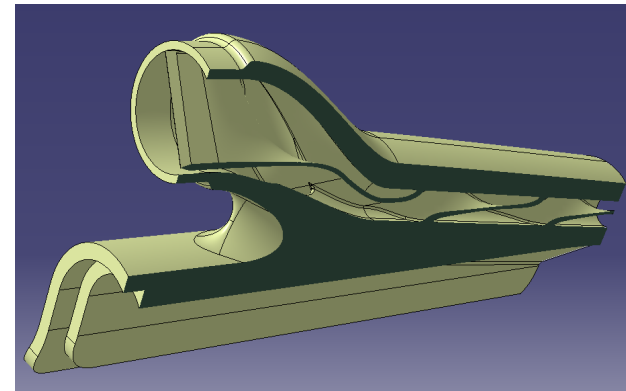
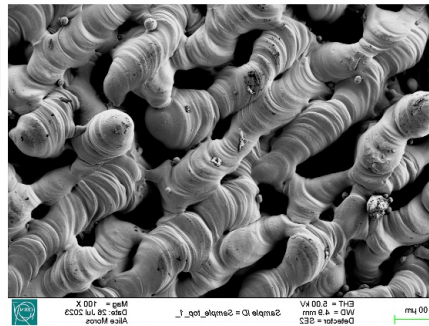
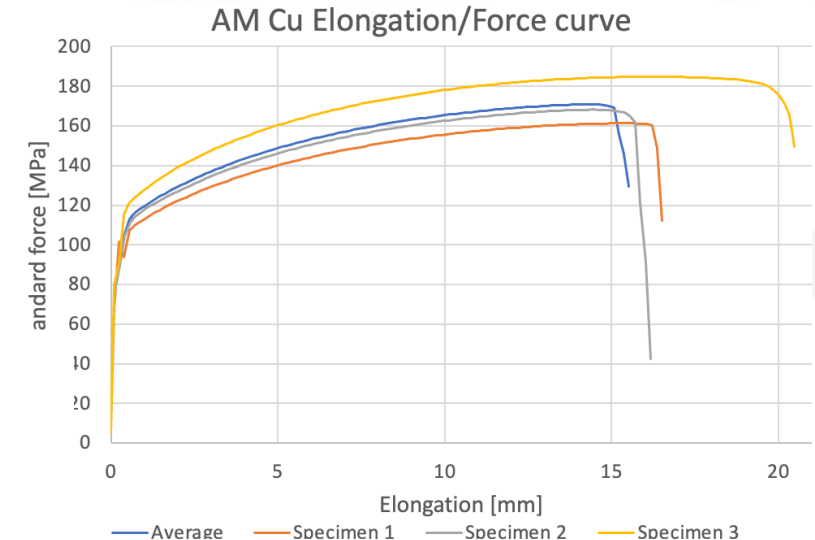
CERN Summer Student Programm



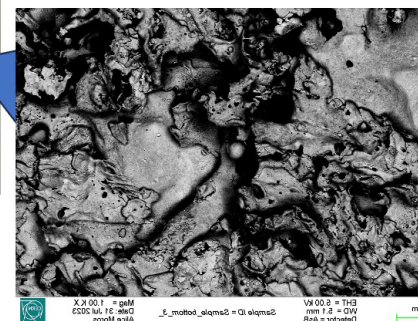
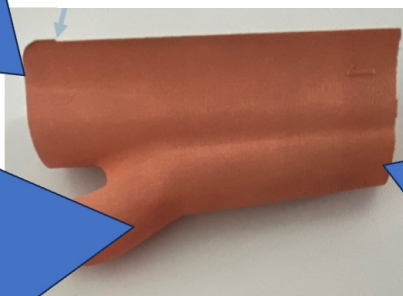
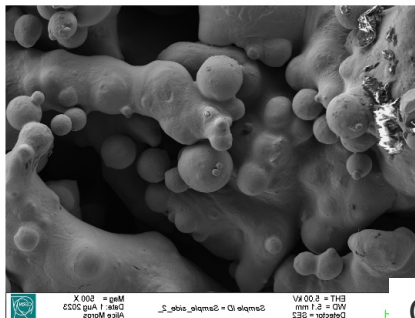
Was @poster Session

Student: Kristupa Seskauskaite (KTU) tasks:

- AM component and surface characterisation
- Measurements
- Design evaluation
- Continuation with Bachelor thesis



SR Absorber test sample (95 mm)



Material/Property	AM Cu	AM CuCrZr [1-3]	Cu10100 [4]
Yield strength, MPa	100	204-361	69-360
Young's modulus, GPa	137,6	114	115
Hardness, HV	71,2-73,8	88,185	51-127
Density, %	96-99	90-99	100
Roughness, μm	18,01	8-18	N/A

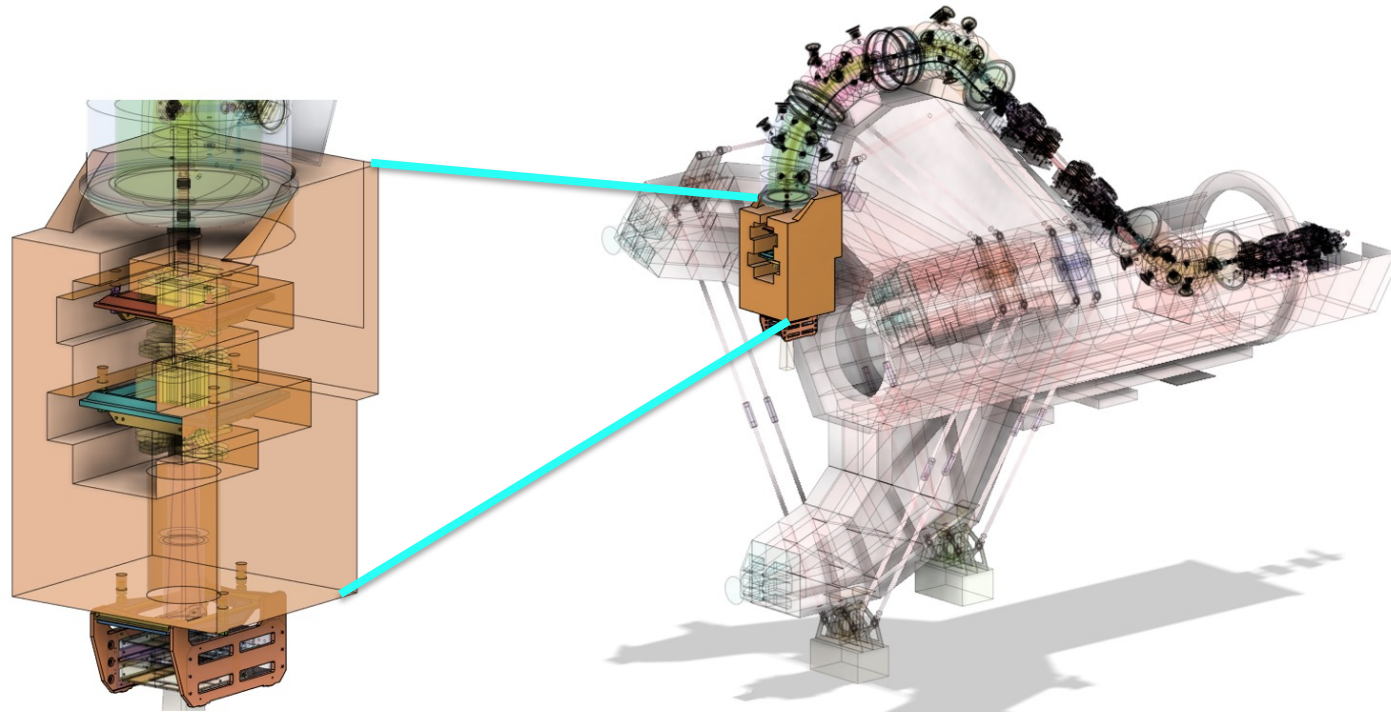
Courtesy: K. Seskauskaite



CERN Summer Student Programm

Student: Dairis Irbe (RTU) tasks:

- Design of support structure for nozzle components
- Evaluation of design
- Continuation with Bachelor thesis



CERN Summer Student Programm

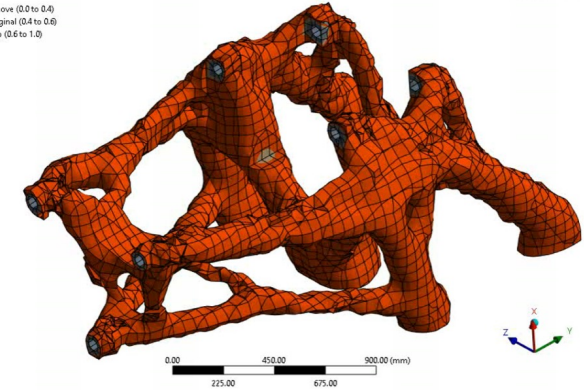
Was @poster Session

Student: Dairis Irbe (RTU) tasks:

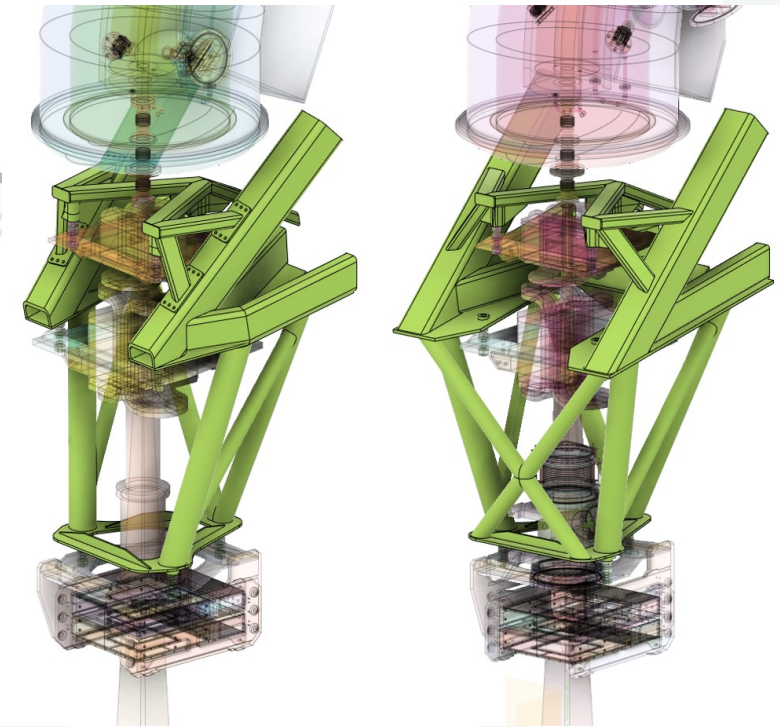
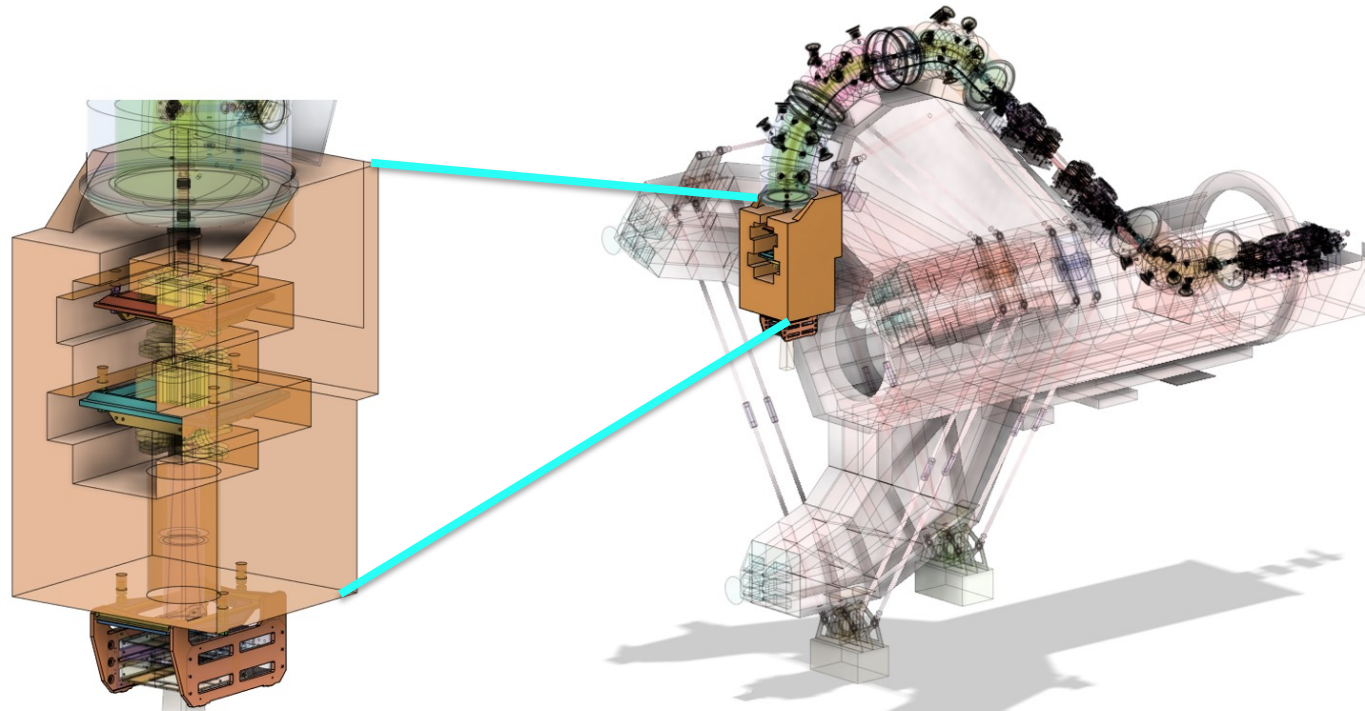
- Design of support structure for nozzle components
- Evaluation of design
- Continuation with Bachelor thesis

1-Structural Optimization
Topology Density
Type: Topology Density
Iteration Number: 45
04/09/2023 12:56

Remove (0.0 to 0.4)
Marginal (0.4 to 0.6)
Keep (0.6 to 1.0)



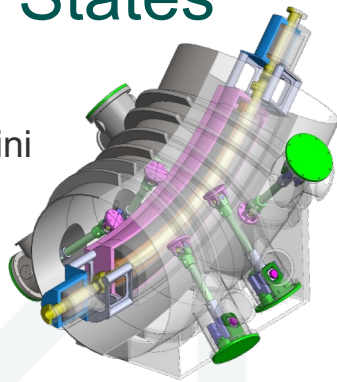
Ansys
2023 R1
STUDENT



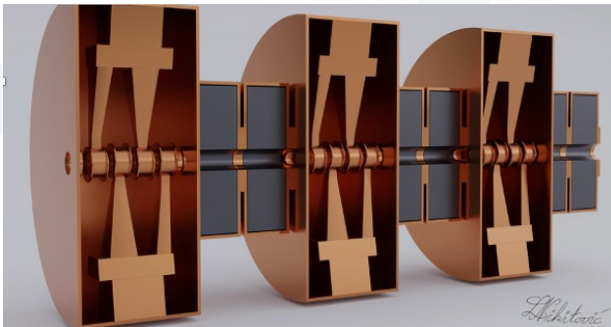
Building the expertise in Accelerator Technologies

- Project initiative: Advanced Particle Therapy center in the Baltic States

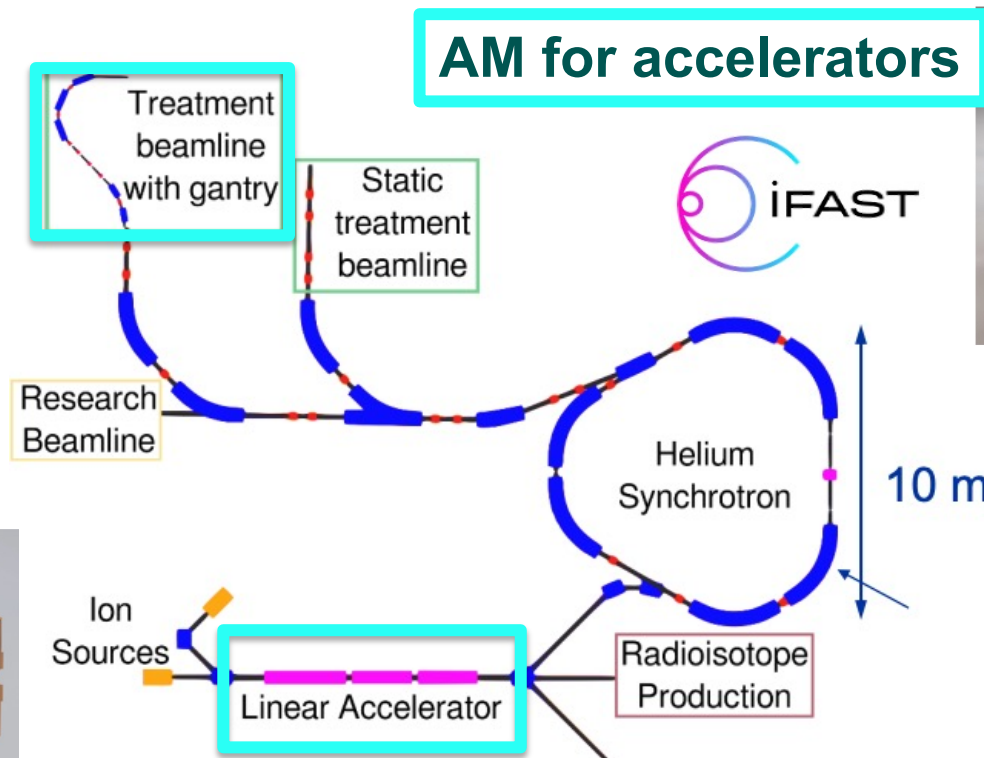
Courtesy: L. Piacentini



Courtesy: L. Nikitovic

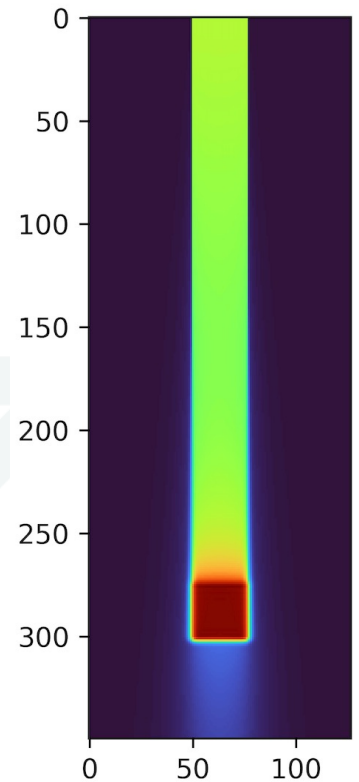
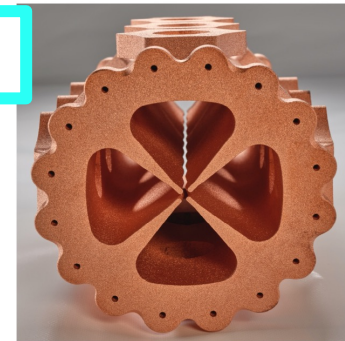


Riga Technical University



Source: M. Vretenar et al., IPAC2022

AM for accelerators



FLASH therapy



Courtesy: K. Palskis



RIGA TECHNICAL
UNIVERSITY



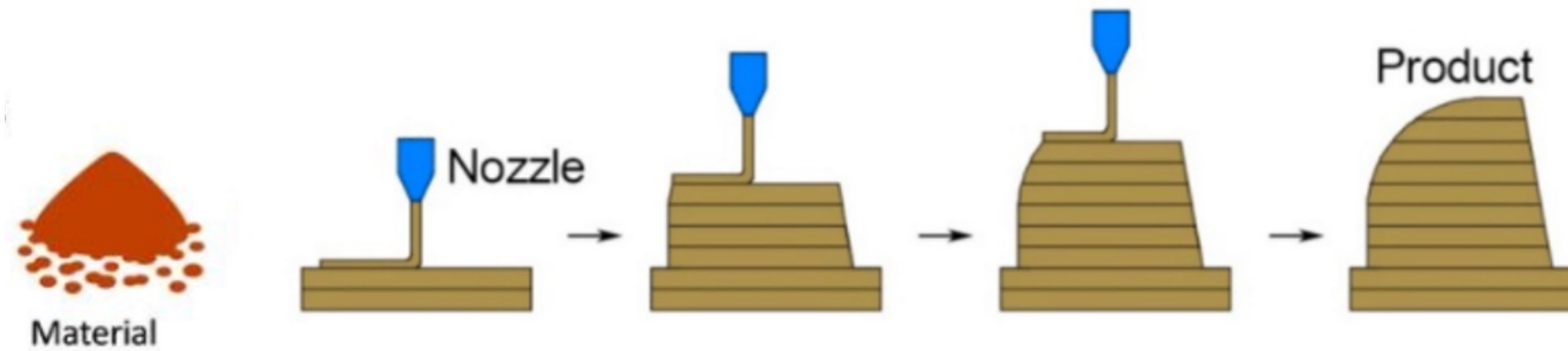
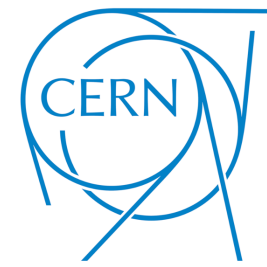
Examination of AM for accelerator applications

Andris Ratkus

Accelerator Technology Group Leader

11.10.2023

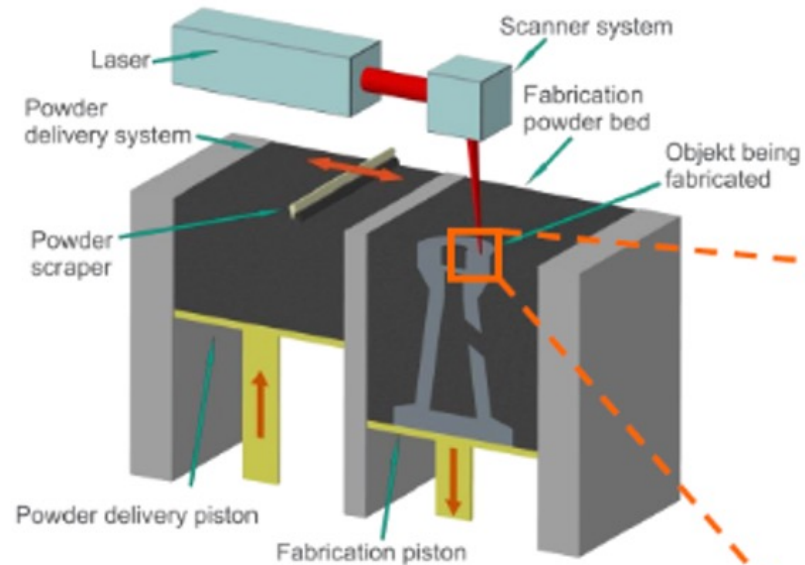
AM Technology



AM Technology

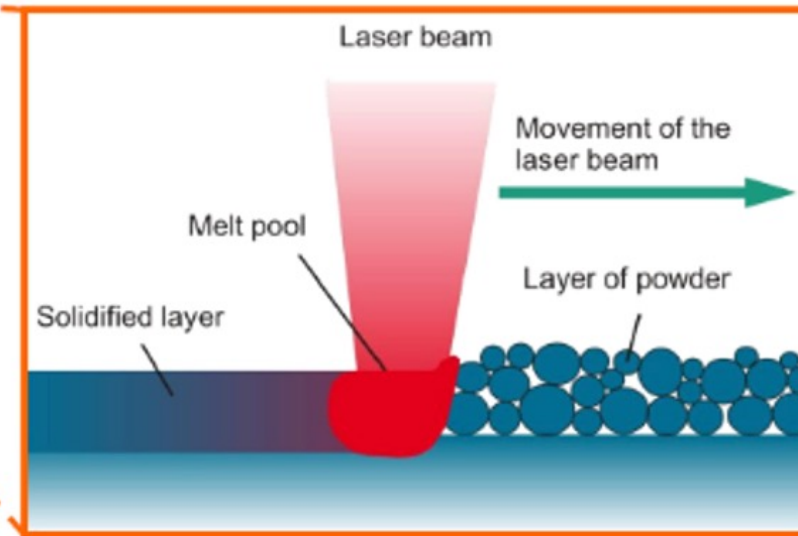


Powder Bed Fusion



Principle sketch of a laser melting machine

Source: Fraunhofer IWU



Schematic diagram of laser beam melting

Accelerator Requirements



Requirement	Target value
Geometrical accuracy	20 μm on vane tip, 100 μm elsewhere
Surface roughness	Ra = 0,4 μm for all inner surfaces
Vacuum	10^{-7} mbar
Electrical conductivity	90% IACS
Peak electric field on surface	≈ 40 MV/m

**RFQ Requirements*

Accelerator Requirements



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P (Torr)	λ	Regime
760	70 nm	Atmosphere
1	50 μm	Rough vacuum
10^{-3}	5 cm	Medium vacuum
10^{-7}	500 m	High Vacuum
10^{-10}	500 km	Ultra High Vacuum
10^{-12}	50,000 km	Extreme High Vacuum

**RFQ Requirements*

Accelerator Requirements

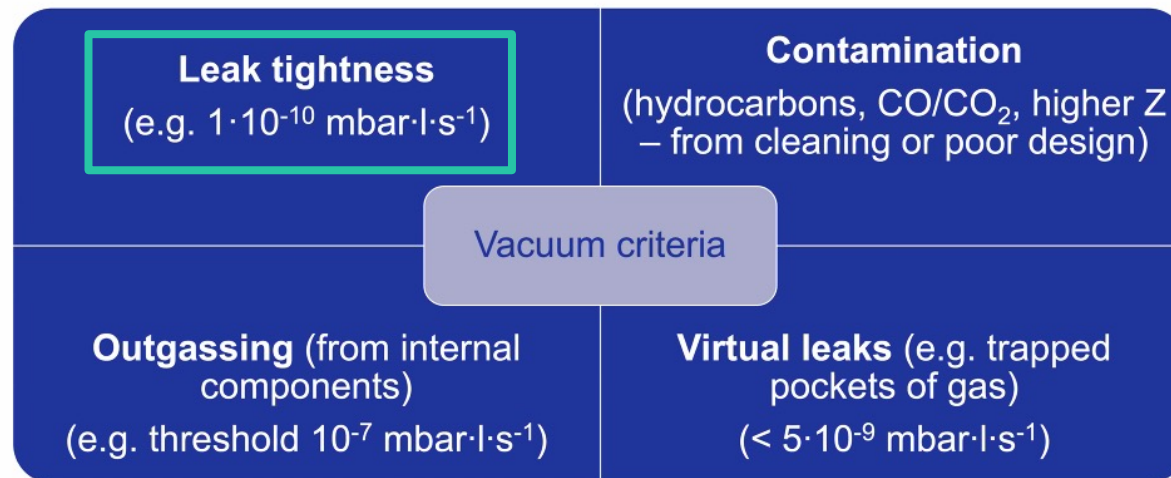


Requirement	Target value
Geometrical accuracy	20 μm on vane tip, 100 μm elsewhere
Surface roughness	$R_a = 0,4 \mu\text{m}$ for all inner surfaces
<u>Vacuum</u>	10^{-7} mbar
Electrical conductivity	90% IACS
<u>Peak electric field on surface</u>	$\approx 40 \text{ MV/m}$

P (Torr)	λ	Regime
760	70 nm	Atmosphere
1	50 μm	Rough vacuum
10^{-3}	5 cm	Medium vacuum
10^{-7}	500 m	High Vacuum
10^{-10}	500 km	Ultra High Vacuum
10^{-12}	50,000 km	Extreme High Vacuum

*RFQ Requirements

Ultra High Vacuum design for BIDs

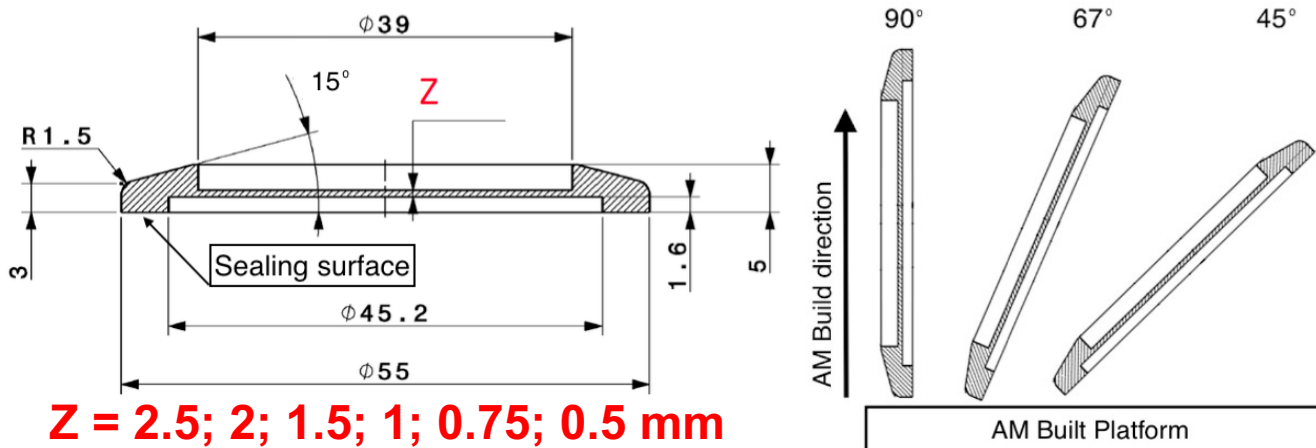


He leakage test



First test for Ultra High Vacuum applications

The aim of this research is **to find the minimum pure copper AM wall thickness limits applicable for UHV** by using **specially designed test membranes**

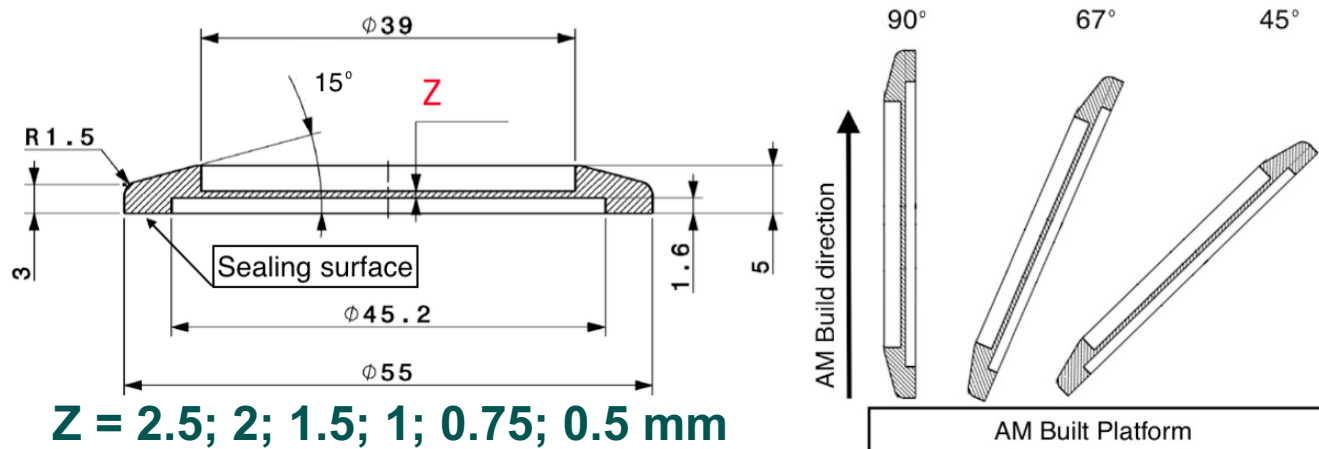


He leakage test



First test for Ultra High Vacuum applications

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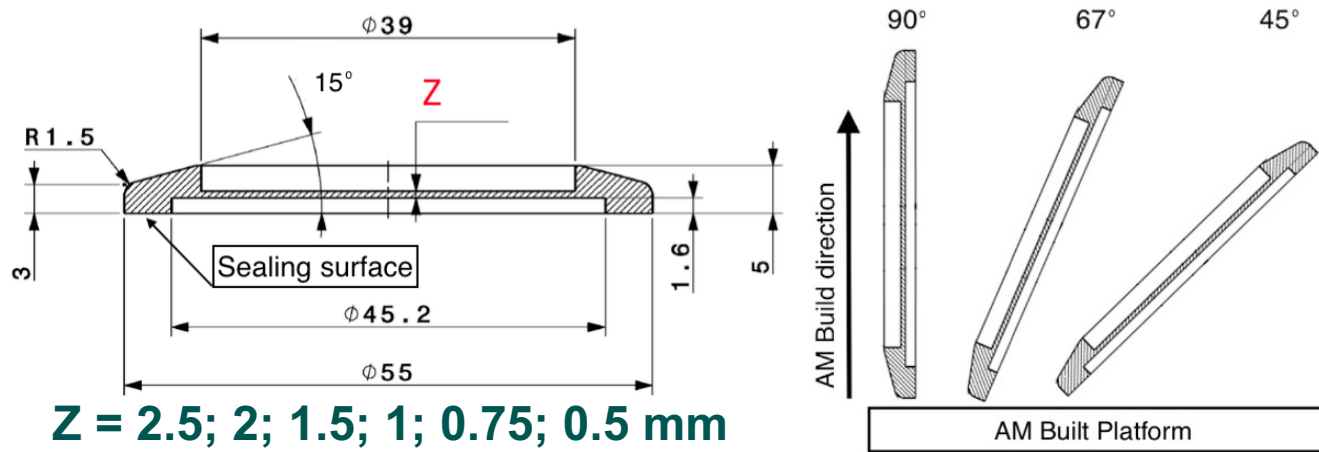


He leakage test

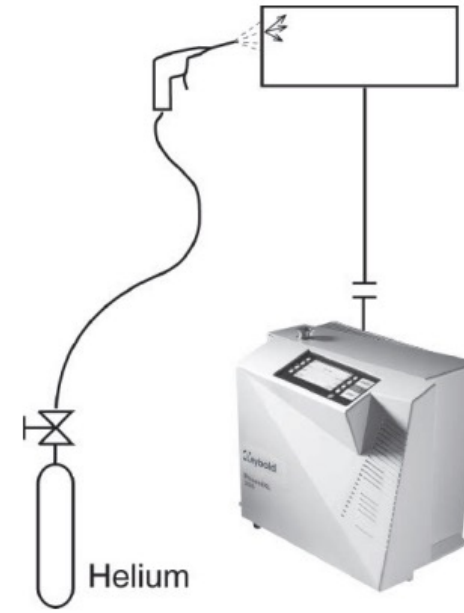


First test for Ultra High Vacuum applications

The aim of this research is **to find the minimum pure copper AM wall thickness limits applicable for UHV** by using **specially designed test membranes**



Z = 2.5; 2; 1.5; 1; 0.75; 0.5 mm



During the test vacuum level of 10^{-3} mbar was provided

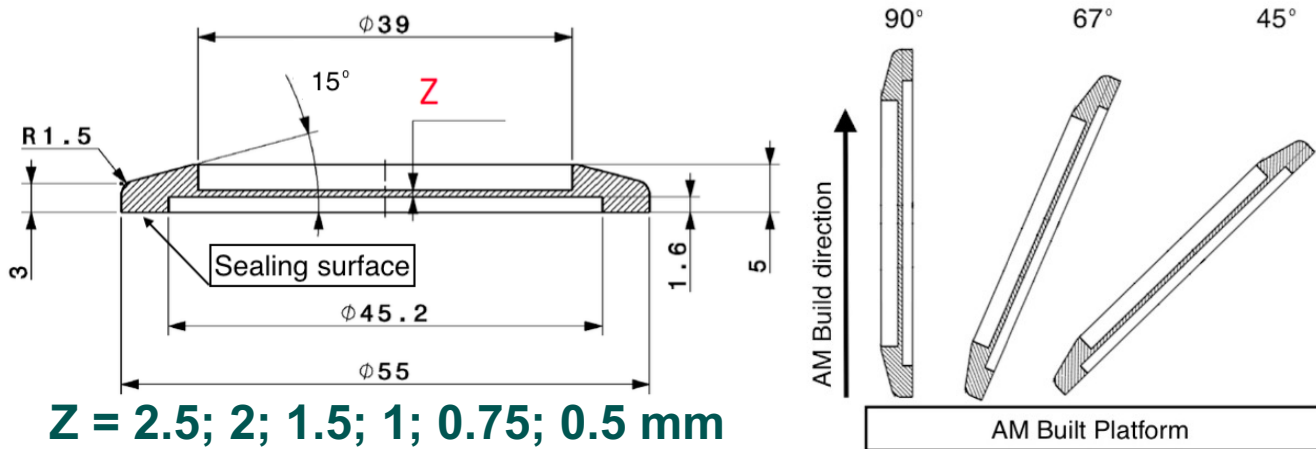
Thanks to CERN TE-VSC and Cedric GARION

He leakage test



First test for Ultra High Vacuum applications

The aim of this research is to find the minimum pure copper AM wall thickness limits applicable for UHV by using specially designed test membranes



Results

The leak detector threshold value is set at $1 \cdot 10^{-10} \text{ mbar} \cdot \text{l} \cdot \text{s}^{-1}$

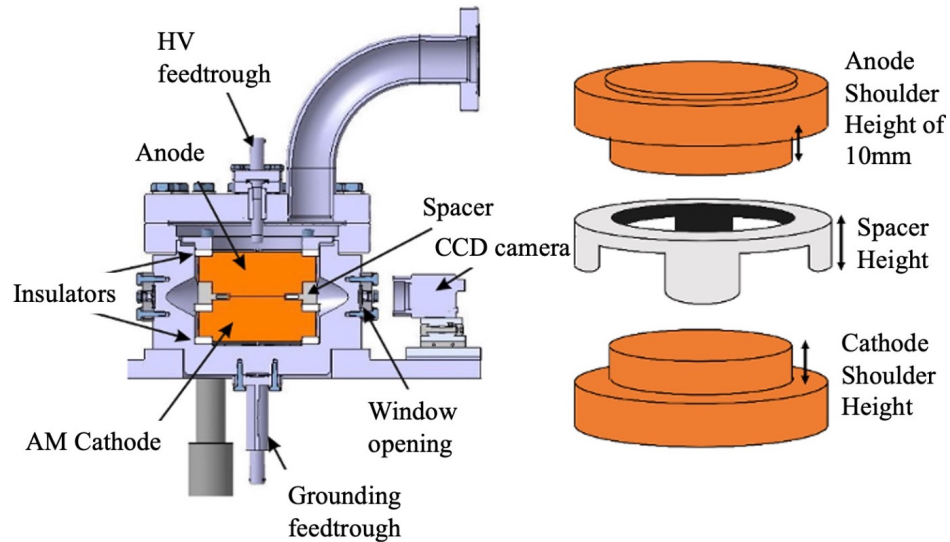
Thickness Z (mm)	Angle/Result (mbar/l/s ⁻¹)		
	45°	67°	90°
2.5	PASS	PASS	PASS
2	PASS	PASS	PASS
1.5	PASS	PASS	PASS
1	PASS	PASS	PASS
0.75	PASS	PASS	$1 \cdot 10^{-6}$
0.5	PASS	$2.5 \cdot 10^{-3}$	$5 \cdot 10^{-2}$

High voltage holding test



CERN's pulsed high-voltage

a) DC system b)



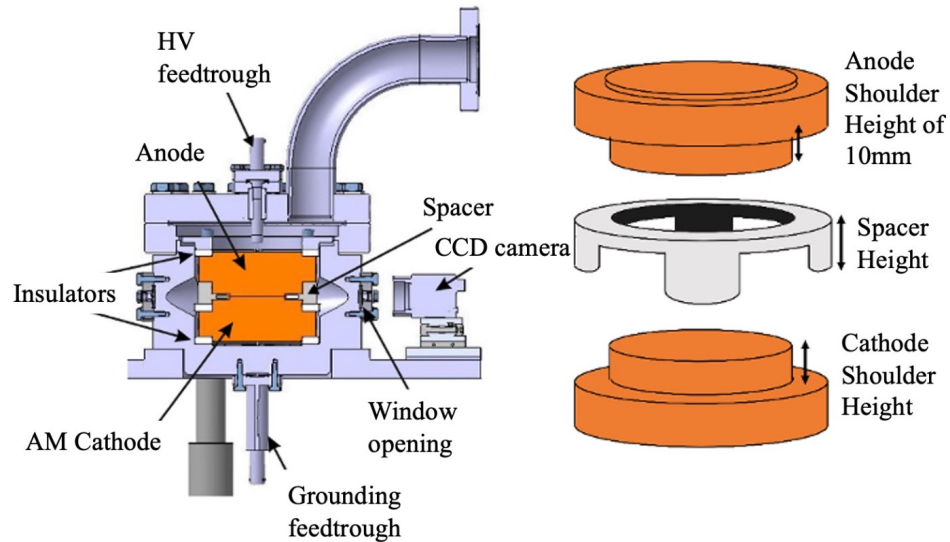
High voltage holding test



HV characteristics are related to surface roughness values and chosen material, therefore, the aim is to clarify AM pure copper **surfaces performances in as-built conditions.**

CERN's pulsed high-voltage

a) DC system b)



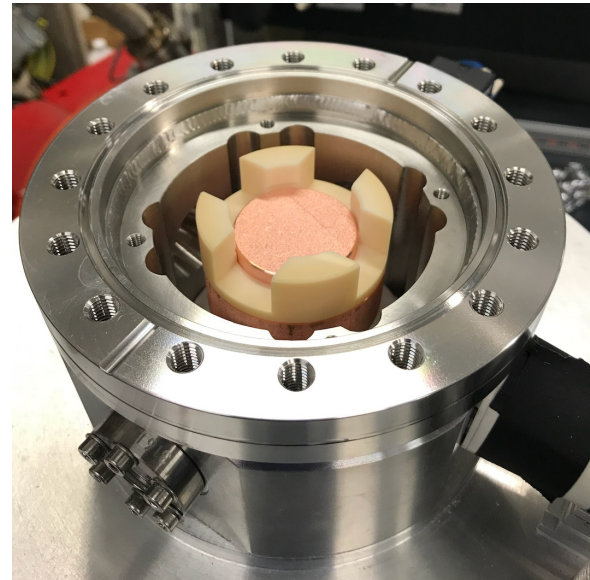
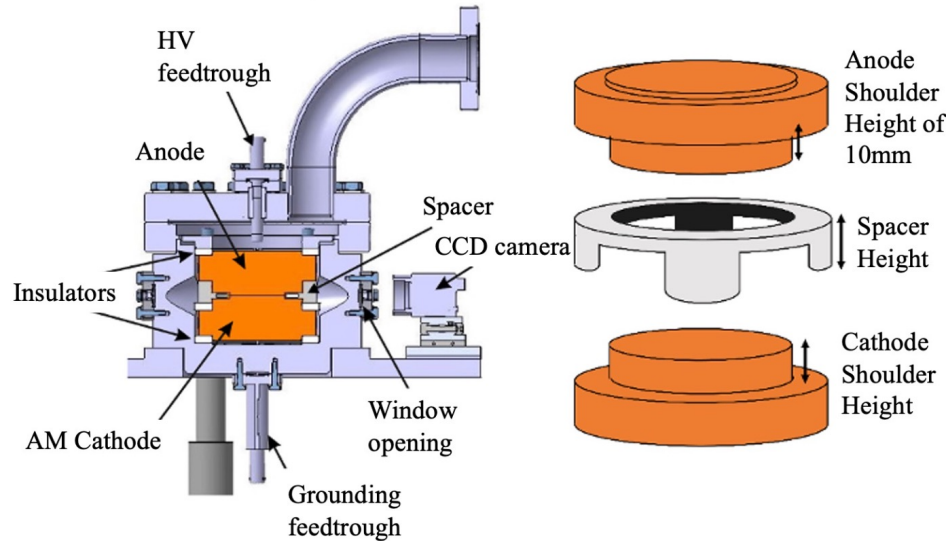
High voltage holding test



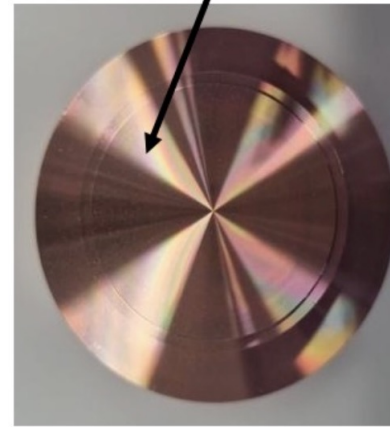
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CERN's pulsed high-voltage

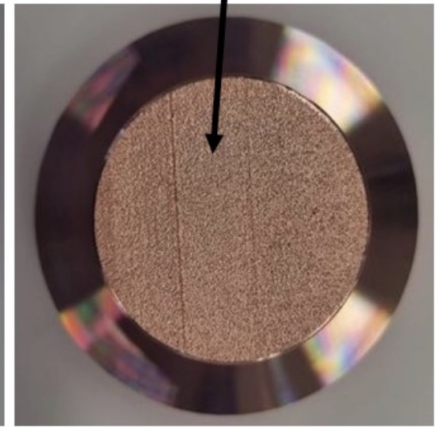
a) DC system b)



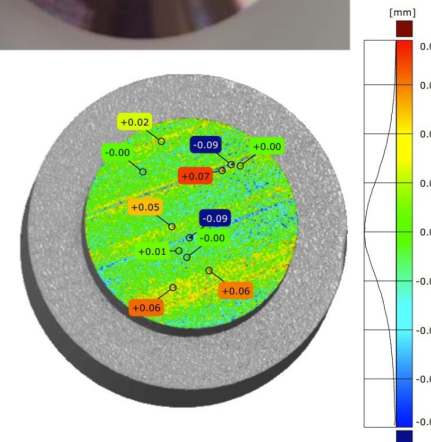
The Anode's test surface
 $R_a = 0.4\mu\text{m}$



The Cathode's test surface
 $R_a \sim 10\mu\text{m}$



$R_a = 8.28 \pm 0.89$ and $10.67 \pm 1.16 \mu\text{m}$
 $R_z = 42.10 \pm 5.33$ and $52.76 \pm 7.56 \mu\text{m}$
(two perpendicular measurements)

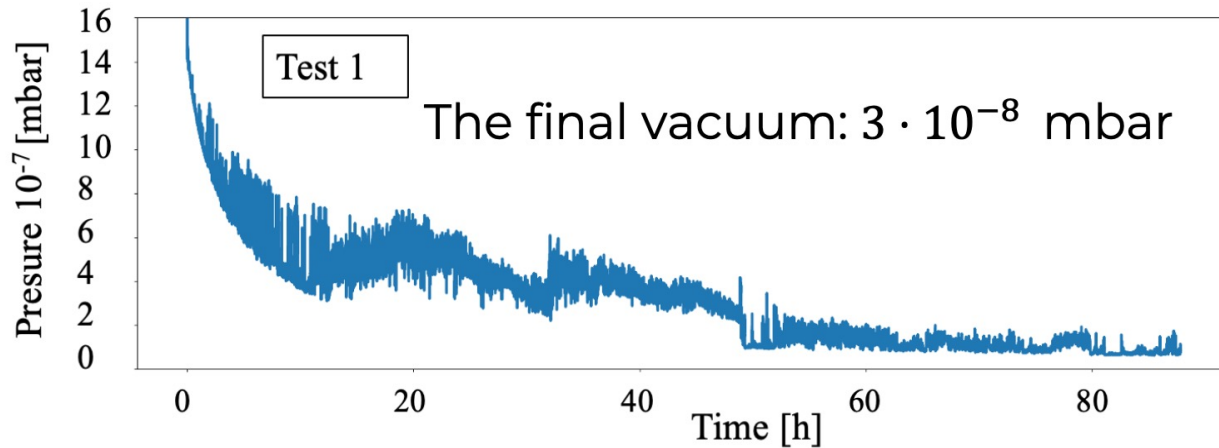


High voltage holding test

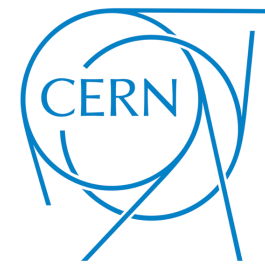


Initial results: Test 1 (Gap $270\mu\text{m}$)

Vacuum pumdown

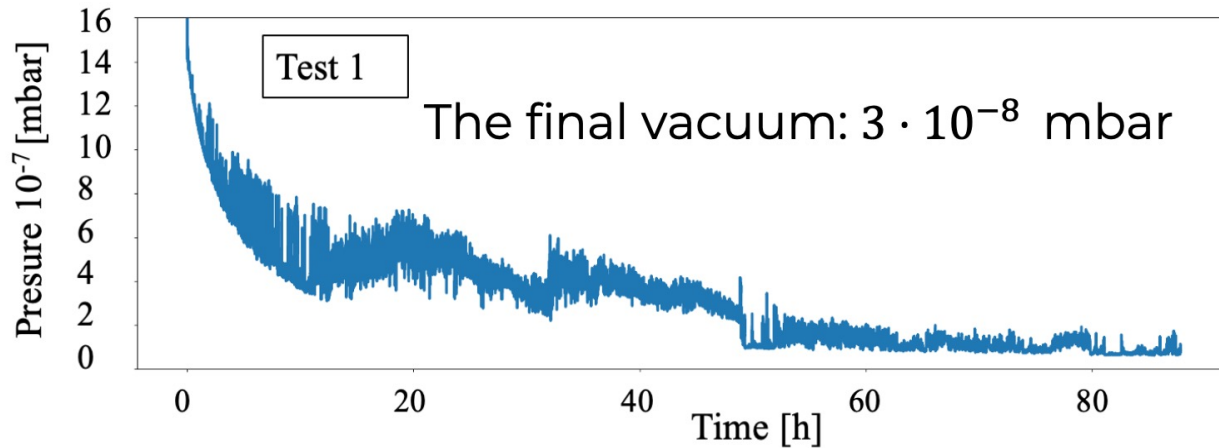


High voltage holding test



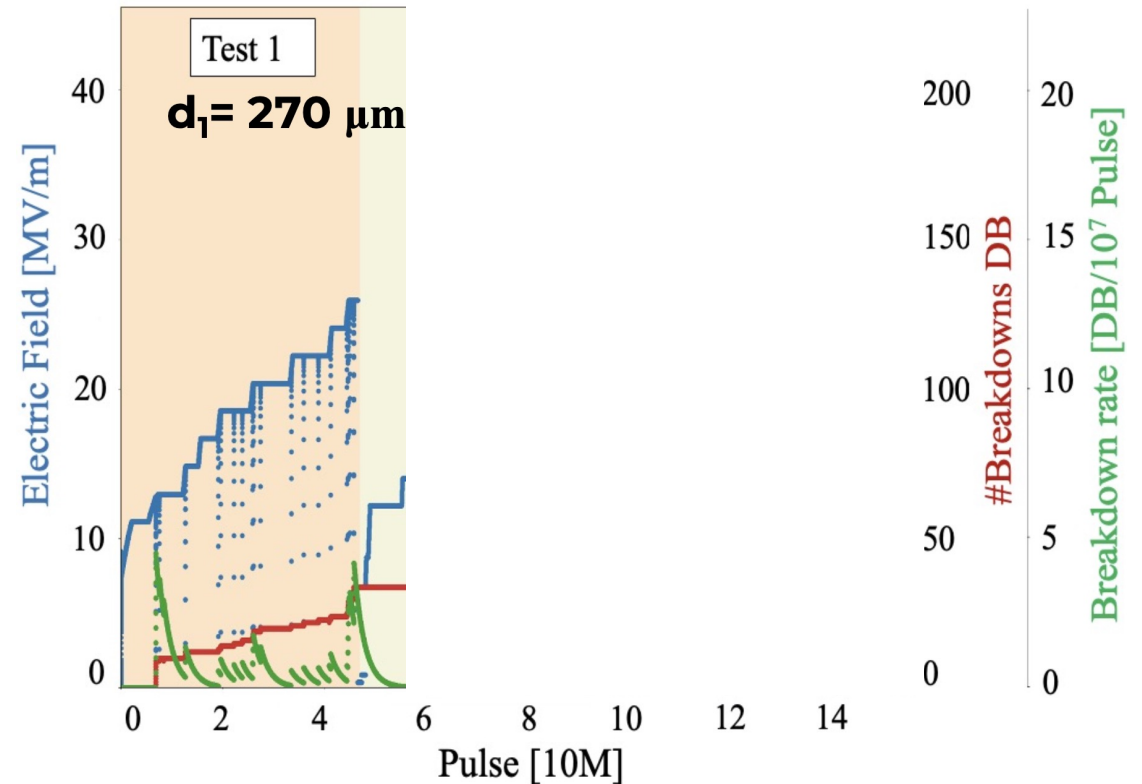
Initial results: Test 1 (Gap $270\mu\text{m}$)

Vacuum pumdown



Test 1 reached a stable **26 MV/m** (equivalent to the system maximum voltage of 7 kV)

HV holding test

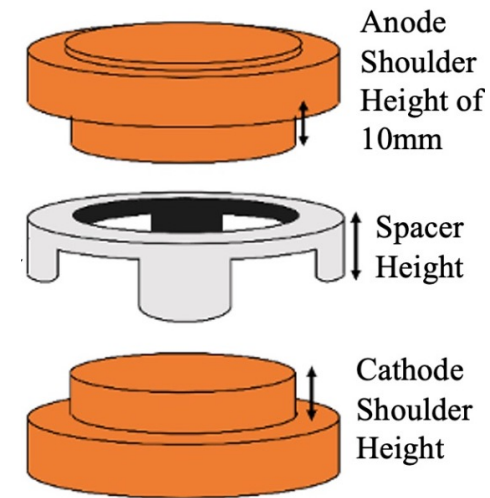
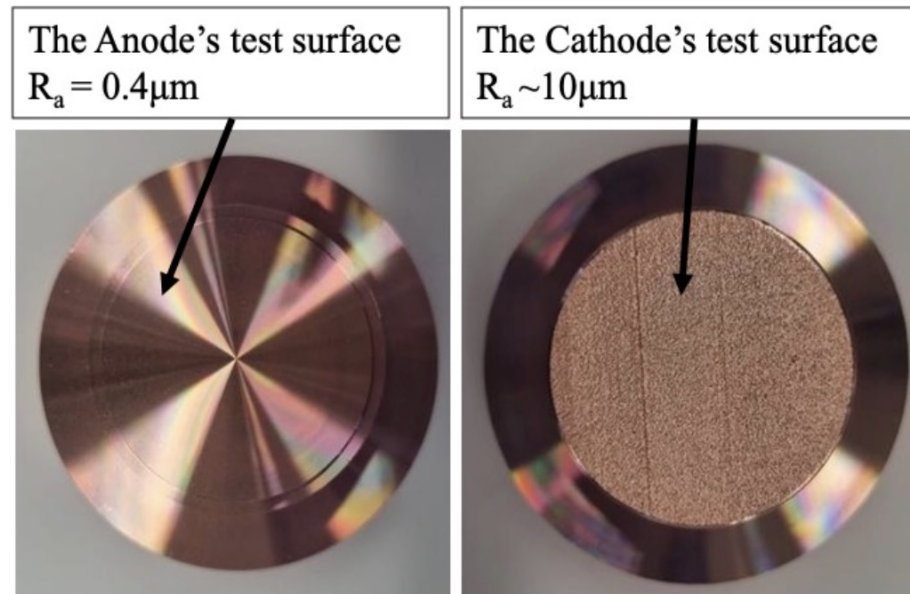


High voltage holding test



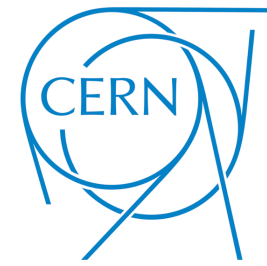
Initial results: Test 2 (Gap $115\mu\text{m}$)

Gap reduction by remachining shoulder height



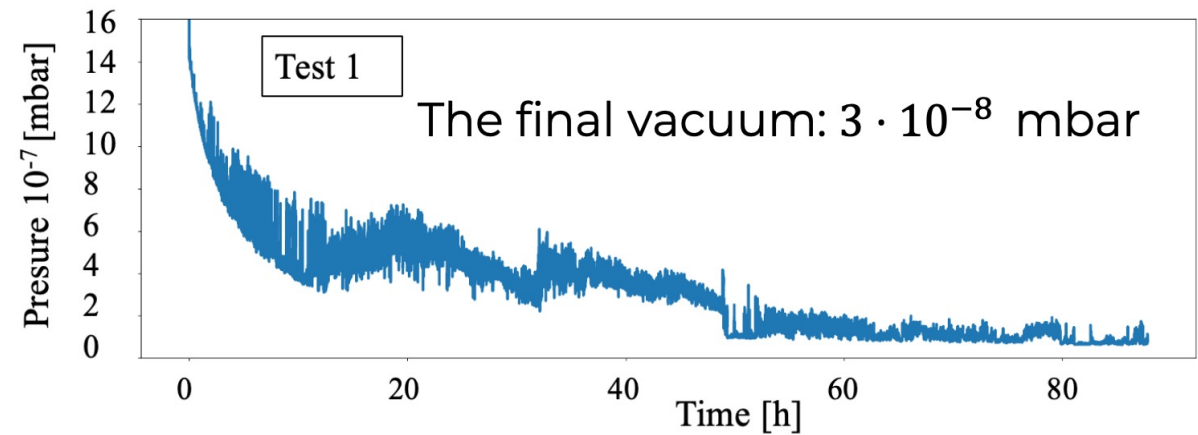
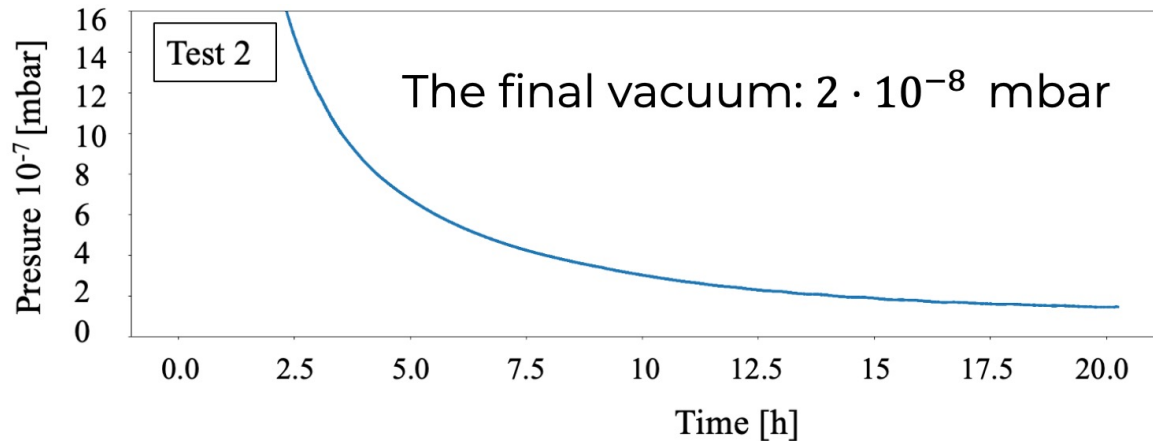
The same preconditioned cathode and anode were used for test 2

High voltage holding test

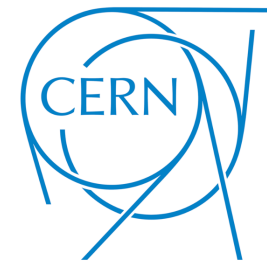


Initial results: Test 2 (Gap $115\mu\text{m}$)

Vacuum pumdown

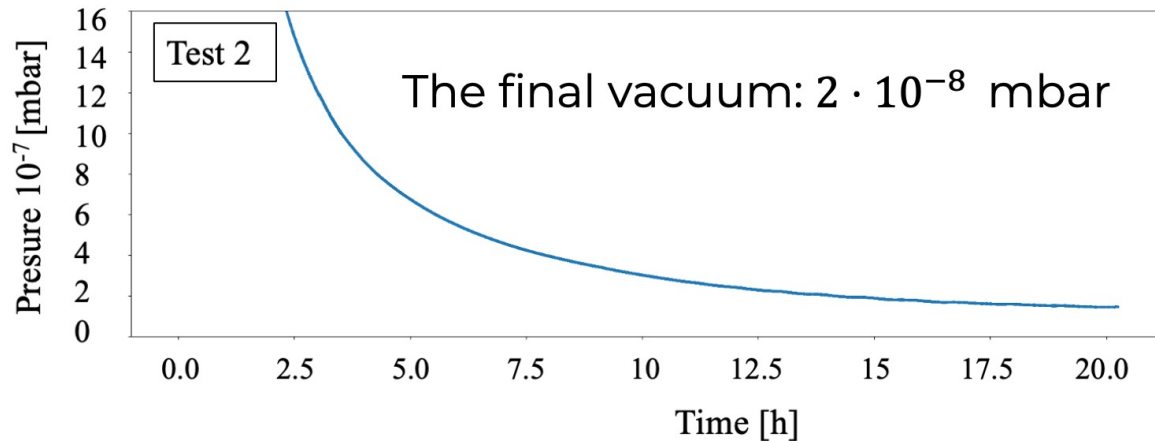


High voltage holding test



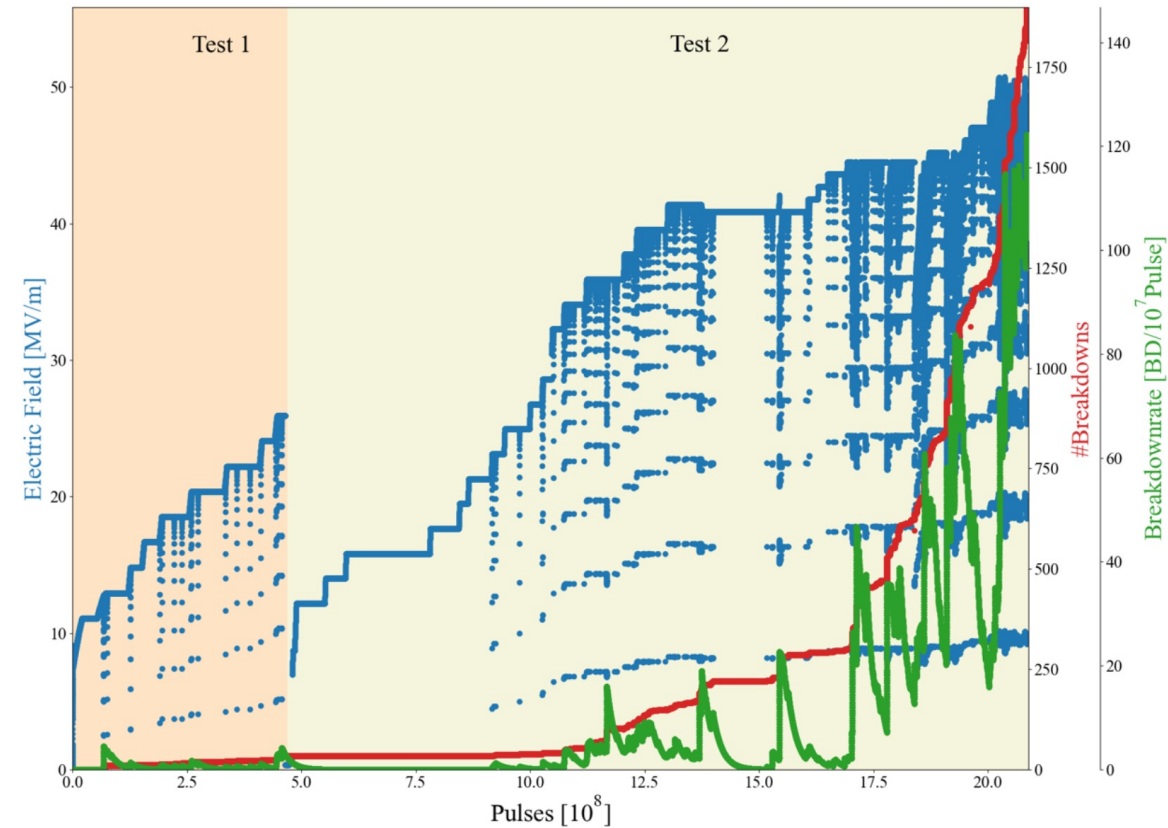
Initial results: Test 2 (Gap $115\mu\text{m}$)

Vacuum pumdown

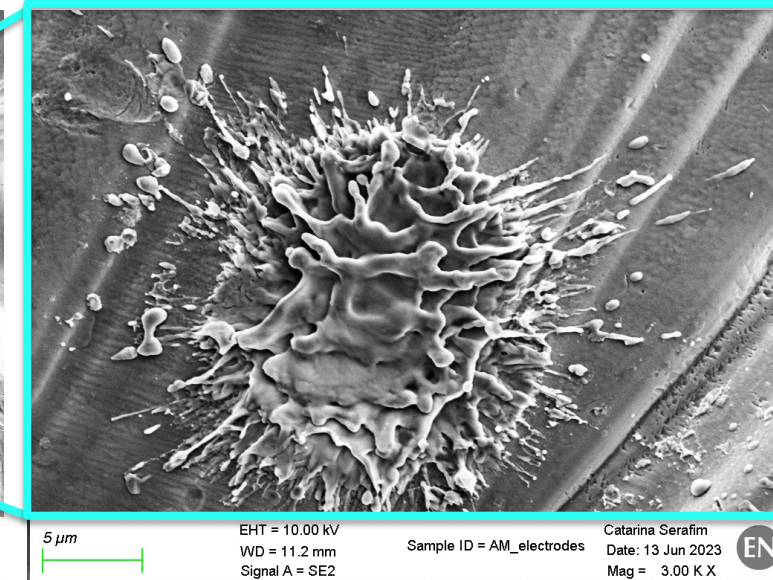
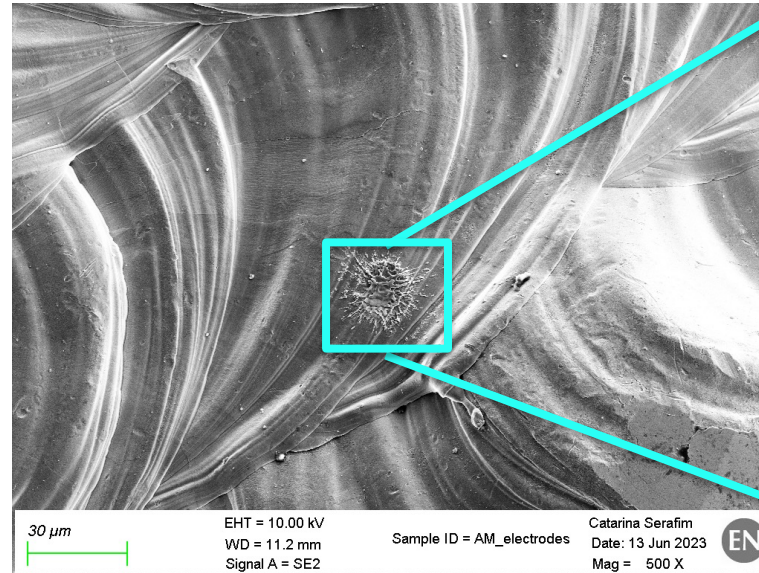
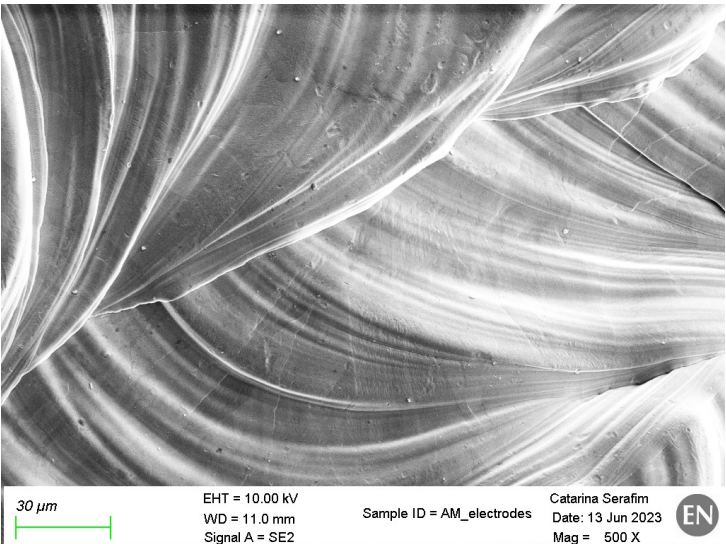
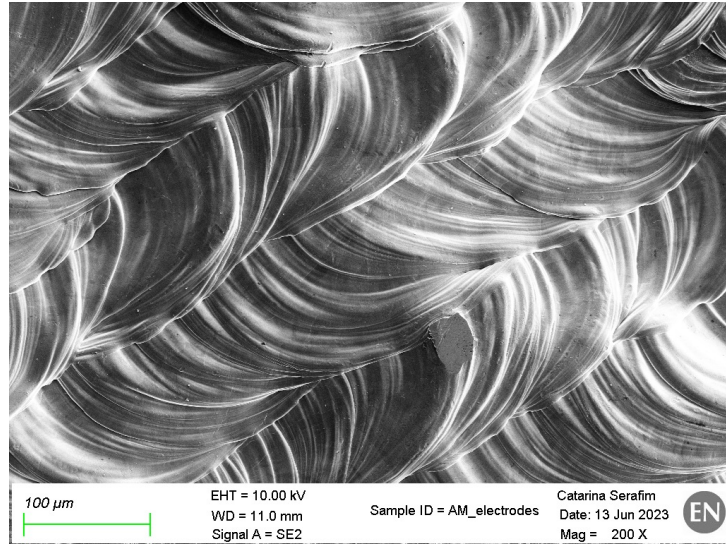


Electrical Field reached a stable **50 MV/m**;
(**40 MV/m** corresponds to the operating conditions
of the compact **750 MHz RFQ** design of CERN)

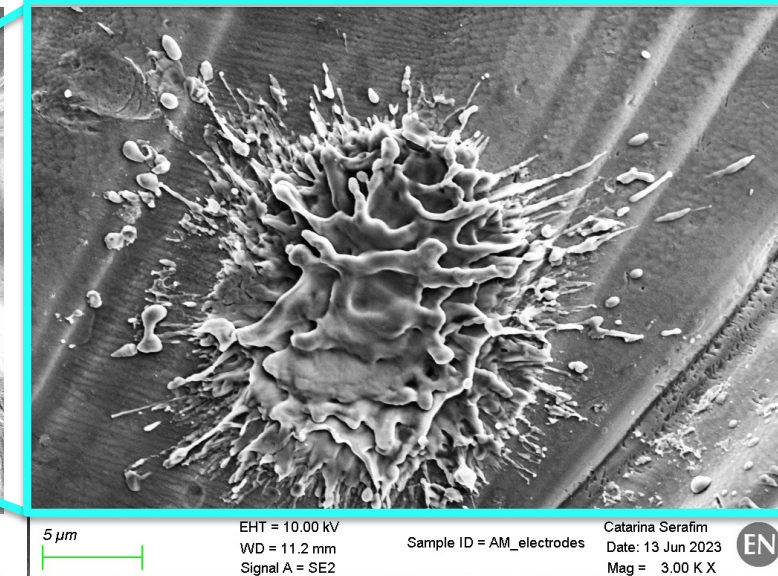
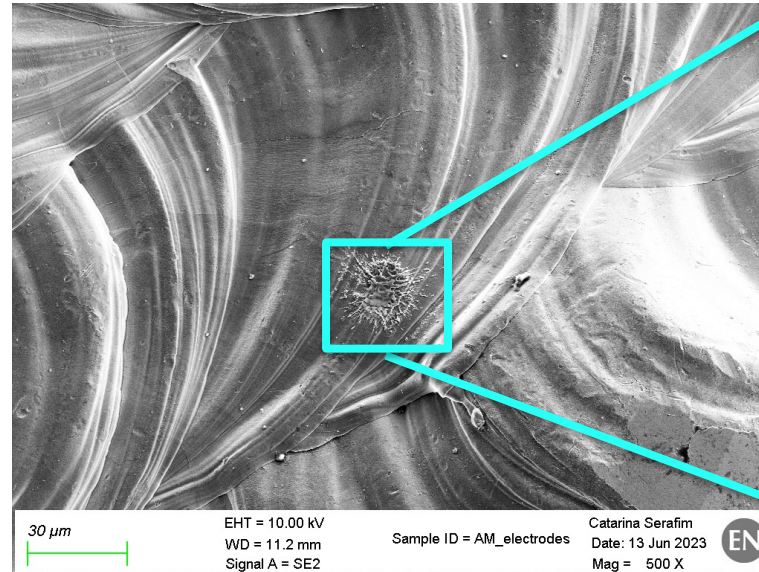
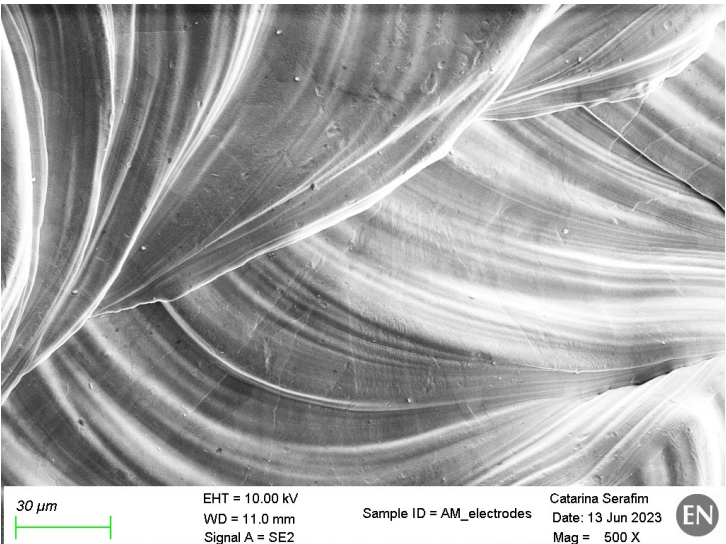
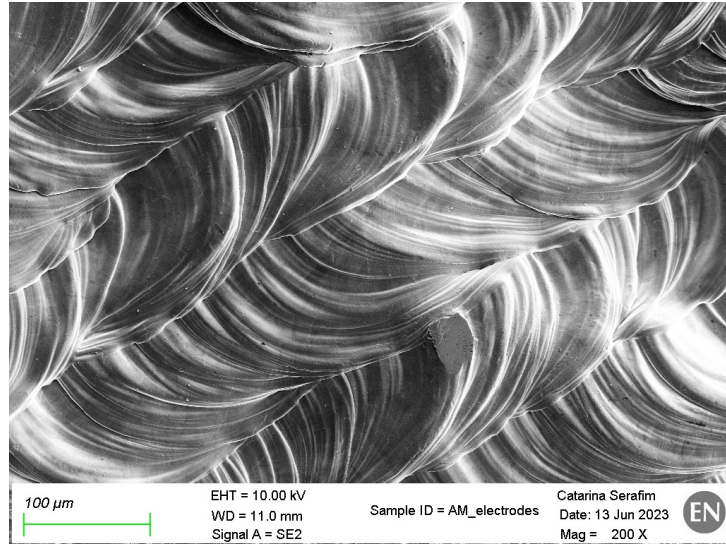
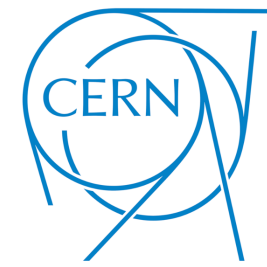
HV holding test



High voltage holding test



High voltage holding test



Further tests with:

- Smaller gap height – $60\mu\text{m}$;
- HV Tests after surface post-processing;
- Test of built direction and laser source influence

Results

3 Posters
2 Publications



DEVELOPMENT AND TESTS OF A FULL-SIZE ADDITIVE MANUFACTURED RADIO FREQUENCY QUADRUPOLE MODULE

T. Torims, A. Ratkus, G. Pikurs, V. Lācis, Rīga Technical University, Latvia
M. Vretenar, A. Cherif, CERN, Switzerland
S. Gruber, E. Lopez, L. Stepien, Fraunhofer IWS, Germany
M. Pozzi, M. Foppa Pedretti, Rösler Italian, Italy
P. Wegenblast, M. Thielmann, TRUMPF, Germany
M. Vedani, T. Romano, Politecnico di Milano, Italy
N. Delerue, A. Gonnin, P. Laperca, E. Mistretta, IJCLab, France

Outline

- A full-size single-piece pure-copper RFQ prototype was designed and additively manufactured
- Produced by the state-of-art AM technology with significant RFQ design improvements made
- Based on the CERN high-frequency 750 MHz RFQ
- Geometrical accuracy and surface roughness measurements were performed - before and after surface treatment operations

Goals

- Geometrical accuracy <math><20 \mu\text{m}</math> on vane tip **attained**
- Surface roughness (Ra) <math><0.4 \mu\text{m}</math> **attained**
- Vacuum tests <math><10^{-7}</math> mbar see THPM031
- Electrical conductivity >90% IACS **attained**
- High Voltage holding ~ 40 MV/m see THPM030
- Ultra-low temperatures 2 K **envisaged**
- RF properties tests >90% of Q_0 **envisaged**

1st iteration

95 mm

2nd iteration

Ø148 x 250 mm

3rd iteration

390 mm

Full-size optimised RFQ made by **13C** TruPrint 5000 Green Edition

Optimised design

- Smart cooling channels
- Integrated connection flanges
- Improved Q factor
- Honeycomb structures
- Better functionality and thermal behaviour

Surface treatment

Average Ra, μm

van tip | lateral surface

Required: 0.39

Actual: 0.14

mass finishing

Geometrical accuracy on a vane tip

<math><20 \mu\text{m}</math> | <math><100 \mu\text{m}</math>

Conclusions

- Achieved surface roughness and geometry fully in line with stringent requirements of RFQ.
- RFQ geometry can be improved based solely on accelerator physics and functional requirements without considering technological limiting factors (e.g. tolerances, shape, size and configuration) imposed by the conventional manufacturing techniques. **This is change of paradigm.**
- AM technology unlocks great potential for the optimisation of complex accelerator components.
- Vacuum, RF and water tightness tests are being performed on the full prototype.

toms.torims@rtu.lv

INITIAL HIGH ELECTRIC FIELD - VACUUM ARC BREAKDOWN TEST RESULTS FOR ADDITIVELY MANUFACTURED PURE COPPER ELECTRODES

A. Ratkus¹, T. Torims², G. Pikurs¹, V. Bjelland³, S. Catron⁴, R. Peacock², C. Serafini², M. Vretenar², W. Wuensch², M. Vedani⁵, T. Romano^{1,3}, M. Pozzi⁴, M. Foppa Pedretti⁴

¹Rīga Technical University, Rīga, Latvia; ²CERN, Geneva, Switzerland; ³Politecnico di Milano, Italy; ⁴Rösler, Milan, Italy

Motivation and Objectives

Additive manufacturing (AM) is a good candidate to be used for complex accelerator component production like Radio Frequency Quadrupole (RFQ) manufacturing. Several accelerator component prototypes have been developed by AM using pure copper, however, high electrical field holding (HV) behaviour is unknown. Moreover, it is known that HV characteristics are related to surface roughness values and chosen material, therefore to see AM pure copper surfaces performances in as-built conditions, the first experiment with rough surface performance was executed.

Motivation and Objectives

- AM applications with pure copper for accelerator component production potentially can offer several benefits such as design freedom, functionality improvements etc.
- Pure copper AM (green laser source) characterization under UHV requirements are needed.
- The aim of this research is to find the **minimum pure copper AM wall thickness limits applicable for UHV** by using specially designed test membranes.

Methods

CERN's pulsed high-voltage DC system

Methods

Conventionally built anode and AM built cathode

Methods

AM cathode test surface characterisation

$R_a = 8.28 \pm 0.89$ and $10.67 \pm 1.16 \mu\text{m}$
 $R_z = 42.10 \pm 5.33$ and $52.76 \pm 7.56 \mu\text{m}$ (two perpendicular measurements)

Experiment with careful gap (d) reduction by machining cathodes shoulder height and changing the insulator spacers

Results

The Vacuum Pump Down

The final vacuum: $3 \cdot 10^{-8}$ mbar
The final vacuum: $2 \cdot 10^{-8}$ mbar

Electric Field Breakdown

Test 1: $d_1 = 270 \mu\text{m}$, $d_2 = 115 \mu\text{m}$

Test 1 reached a stable 26 MV/m; equivalent to the system maximum voltage of 11 kV
Test 2 an electric field of 40 MV/m;
Slower conditioning was applied compared to the reference, using approximately twice as many pulses;

Conclusions

Initial tests show the capability of AM electrodes to hold high vacuum levels and high electric fields with low breakdown rates, approving AM to be a valid candidate for accelerator component manufacturing.

The number of breakdowns and breakdown rate are found to be even lower than for a reference of a standard, oxygen-free, heat-treated copper electrodes. A stable electric field of 40 MV/m was reached with the smaller gap height of 115 μm and that corresponds to the operating conditions of the compact 750 MHz RFQ design of CERN.

Further tests with:

- Smaller gap height;
- AM cathodes produced in different build directions;
- AM cathodes after surface finishing processes

EVALUATION OF GREEN LASER SOURCE ADDITIVE MANUFACTURING TECHNOLOGY FOR ACCELERATOR APPLICATIONS WITH ULTRA-HIGH VACUUM REQUIREMENTS

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Motivation and Objectives

- AM applications with pure copper for accelerator component production potentially can offer several benefits such as design freedom, functionality improvements etc.
- Pure copper AM (green laser source) characterization under UHV requirements are needed.
- The aim of this research is to find the **minimum pure copper AM wall thickness limits applicable for UHV** by using specially designed test membranes.

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Methods

Membrane production with AM

- The membranes were specially designed to assess two factors:
 - Membrane wall thickness (d) 2.5, 2.15, 1.075, 0.5 mm
 - AM build angle 30°, 45° and 60°

Methods

Membrane leak tightness test

- The helium leak test method is used:
 - Leak down to 10^{-7} mbar-h² can be detected.
 - The background level of helium is very low.
 - Helium is an inert gas and it is non-flammable and harmless.
 - Helium is non-condensable and it is lighter than air.
 - The gas is widely available at affordable prices.

Leibold Phoenix 300i equipment

AM Equipment and parameters

A. TruPrint5000 Green Edition
LSPR with a green TruGreen200 gas-atomized spherical shaped powder. The powder particle size distribution is between 19.5 and 34.9 μm .
The laser spot size of 200 μm .

Results

All pure copper membranes were successfully built and sealing surfaces were additionally machined for testing

Thickness Z (mm)	Angle/Result (mbar-h ²)
2.5	PASS PASS PASS
1.5	PASS PASS PASS
1	PASS PASS PASS
0.75	PASS PASS 1 10 ⁻⁷
0.5	PASS 2.5 10 ⁻⁷ 5 10 ⁻⁷

However, the samples that did not pass leak tightness test can be classified accordingly:
• 5 10⁻⁷ mbar-h² water tight;
• 2.5 10⁻⁷ mbar-h² vapour tight;
• 1 10⁻⁷ mbar-h² oil tight.

The leak detector threshold value is set at $1 \cdot 10^{-7}$ mbar-h².

Conclusions

According to these results, the following can be concluded:

- Membranes with wall thicknesses down to 0.5 mm can built with the green laser source;
- The green laser source is applicable for thin wall UHV applications;
- 1 mm wall thicknesses can provide UHV leak tightness requirements in all studied build angles (30°, 45° and 60°);
- 0.5 mm wall thickness samples need more accurate investigations before drawing final conclusions.

Achieved results clearly indicate the **possibility of AM applications for accelerator and vacuum system component production** that are operating at room temperatures, such as LINACs, beam transfer lines and injectors with larger design flexibility.



Thank you!